FINAL AGENDA

4th EASN Association International Workshop

on Flight Physics & Aircraft Design

Time		Monday 27.10.2014
Room:		**Generali**
9:00	12:00	**BoD Meeting**
12:00	14:00	**EASN General Assembly**
13:00	14:00	**Registration**
14:00	**14:30**	**Welcome and Introduction** ***E. Stumpf*** *RWTH Aachen University*, ***Prof. Schmachtenberg*** *Rector of RWTH Aachen University*, ***Sp. Pantelakis*** *EASN Chairman*, ***W. Schröder*** *RWTH Aachen University*
14:30	**15:00**	**Keynote Lecture:** **"Aeronautics Research & Innovation at European Level - Achievements and Future Perspectives"**, *Dr.-Ing. Dietrich Knoerzer, European Commission, DG Research-H.3 Aeronautics*
15:00	**15:30**	**Keynote Lecture:** **"EREA Future Sky"**, *Prof. Rolf Henke, Executive Board Aeronautics, DLR*
15:30	**16:00**	**Coffee**

Time		Monday 27.10.2014 (afternoon)		
Room:		**Ford**	**Generali**	**Junkers**
Session		**#1** Aircraft Structure Concepts & Design	**#2** Aircraft Design Methodologies I	**#3** Flow and Load Control & Atmosph. Turbulence
Session Chair(s)		**C. Huehne**	**B. Nagel**	**F. Scarano**
16:00	**16:25**	**PoLarBEAR Project:** **Anisogrid Structures in EU-Projects ALaSCA and PoLaRBEAR,** *C. Hühne, S. Niemann*	**Towards Deployment of the Lattice Boltzmann Approach into the Aircraft Design Process,** *E. Fares*	**Optical Inspection Tool for Micro-structured, Fuel -Conserving Surfaces,** *H. Brüning, K. Brune, Y. Wilke, G. Patzelt, M. Imlau, J. Tschentscher, S. Hochheim*
16:25	**16:50**	**PoLarBEAR Project:** **Development of lattice concept for robust composite fuselage structures,** *V. Vassiliev, A. Shanygin, A. Razin, I. Kondakov*	**Recent Developments in the CEASIOM Framework Using the Common Language CPACS,** *A. Da Ronch, J. Vos, A. Rizzi*	**PEL-SKIN Project:** **A Novel Kind of Surface Coatings in Aeronautics - Overall Presentation,** *C. Brücker*
16:50	**17:15**	**PoLarBEAR Project:** **Efficient modelling and analysis of anisogrid fuselage structures,** *T. Ludwig, R. Wagner*	**Overview of the Versatile Options to Define Fuselage Structures within the CPACS Data Format,** *J. Scherer, D. Kohlgruber*	**Future Wings Project:** **Study of Passive and Active Deformation Behaviors of Hybrid Specimens Made of Composite Substrates and MFC Piezoelectric Patches,** *M. Chiarelli, V. Binante, M. Cagnoni, A. Massai, J. Kunzmann, A. Cortebaldo, D. Romano*
17:15	**17:40**	**PoLarBEAR Project:** ***Energy Approach for Analysis of Delamination of Lattice Ribs,*** *E. Dubovikov, V. Fomin*	**PyPAD:** **A Multidisciplinary Framework for Preliminary Airframe Design,** *L. Travaglini, S. Ricci, G. Bindolino*	**Transonic Wind-tunnel Investigation for Active Load Control Using a Winglet – Rudder – Configuration and for Passive Load Control Integrating Vortex Generators on the Wing Surface,** *S. Schlupkothen, A. Dafnis*
17:40	**18:05**	**Parametric Model Generation and Automated Sizing Process for the Analysis of Aircraft Structures,** T. Führer, S. Freund, F. Heinecke, C. Willberg	**Impact of Certification Constraints in a Multi-disciplinary Design Process,** *P. Schmollgruber, N. Bartoli, Y. Gourinat*	**STARLET Project:** **Wing-load Control via Fluidic Devices,** *J. Sznajder, W. Stalewski*
18:05	**18:30**	**Automated Sizing of a Composite Wing for the Usage within a Multidisciplinary Design Process,** *T. Bach, T. Führer, S. Freund, C. Willberg, S. Dähne*	**Multi-Fidelity Mass Estimation of a Strut-braced Wing Configuration,** *D. Böhnke, F. Dorbath, B. Nagel*	**Aeronautics Lidar applications - Airborne LIDAR detection of Clear Air Turbulence (CAT) within the FP7 DELICAT project,** *P. Vrancken, G. Ehret, M. Wirth, H. Barny, H. Veerman, L. Lombard*
18:30	**19:30**		**Aircraft Design Forum**	
19:00	**21:00**	**Reception in Exhibition Area**		
END OF DAY 1				

Time		Tuesday 28.10.2014		
Room:		**Generali**		
8:00	8:30	**Registration**		
8:30	**9:00**	**Keynote Lecture: Simplified Hybrid Laminar Flow Control,** *Dr. –Ing. Geza Schrauf, Airbus Operations GmbH*		
9:00	**9:30**	**Keynote Lecture: The present and the perspective of aerodynamic experimentation – the view of an operator of wind tunnels,** *Prof. Dr.-Ing. Georg Eitelberg, Director of the German-Dutch Wind Tunnels*		
9:30	**9:45**	**EASN AWARD introduction and presentation,** *Prof. Dr. –Ing. Spiros Pantelakis*		
9:45	**10:15**	**(Award) Lecture: The Air Transport System as Basis for Aircraft Design,** *Prof. Dr. –Ing. Dieter Schmitt*		
10:15	**10:30**	**Coffee**		
Room:		**Ford**	**Generali**	**Junkers**
Session		**#4** Morphing Aircraft Concepts	**#5** Innovative AC Propulsion Concepts	**#6** Wake Vortex
Session Chair(s)		**S. Ricci /A. Suleman**	**M. Hornung**	**E. Coustols**
10:30	**10:55**	**NOVEMOR Project:** **Application of Morphing Camber Concept to a Regional Aircraft,** *A. De Gaspari, S. Ricci, A. Antunes, F. Odaguil, G. Lima, M. Morelli*	**Multi-disciplinary design investigations of propulsive fuselage aircraft concepts,** *J. Bijewitz, A. Seitz, M. Hornung*	**Enhanced Wake Vortex Decay in Ground Proximity Triggered by Plate Lines,** *F. Holzäpfel, A. Stephan, T. Heel, S. Körner*
10:55	**11:20**	**NOVEMOR Project:** **Design and Experimental Validation of Morphing Wings,** *J.E. Cooper, R. Cheung, C. Wales, L. Lambert, A. Dale, J. Yang*	**Hybrid Propulsion and Future Configurations,** *L. Jörgensen, P. Rostek*	**Multi-Model Ensemble Wake Vortex Prediction,** *S. Körner, F. Holzäpfel, N. Ahmad, F. Proctor*
11:20	**11:45**	**NOVEMOR Project:** **Multidisciplinary Design Optimization of Novel and Morphing Aircraft Configurations: Computational Studies and Experimental Validation,** *J. Vale, F. Afonso, F. Lau, A. Suleman, A. Antunes, F. Odaguil, J. Parizi, J.E. Cooper*	**Novel Air-Breathing Plasma Jet Propulsion for High Altitude Flight Platforms,** *B. Göksel, I. Mashek, H. Klefenz*	**Revisiting Wake Vortex Mitigation by Means of Passive Devices: Demonstration and Validation of a Novel Device,** R.M. Buffo, E. Stumpf
11:45	**12:10**	**NOVEMOR Project:** **Geometry Modeling, Parametrization and Meshing of Conventional and Joined-Wing Aircraft,** *M. Zhang, A. Rizzi, R. Nangia*	**Plasma Flyer - The World's First Plasma Flow Controlled Flying Wing,** *B. Göksel, H. Klefenz*	**Numerical Simulation of Vortex Roll-Up Processes at Elliptical Wings Using Reynolds-Stress-Models,** *A. Pongs, S. Braun, E. Stumpf*
12:10	**12:35**	**NOVEMOR Project:** **Morphing Leading Edges for a Wing and Wingtip Based on Compliant Structures,** *S. Vasista, H.P. Monner, A. De Gaspari, S. Ricci*	**ANULOID Project:** **CFD Analysis and Optimization of Novel VTOL Aircraft "Anuloid" in Relation to Vertical Flight,** *Z. Janda*	**Co-Rotating Vortex Interaction,** *A. Romeos, A. Giannadakis, K. Perrakis, Th. Panidis*
12:35	**13:30**	**Lunch**		

Time		Tuesday 28.10.2014 (afternoon)		
Room:		**Ford**	**Generali**	**Junkers**
Session		**#7** Innovative AC Configurations	**#8** Aircraft Design Methodologies II	**#9** Transition & **#10** Advanced CFD I
Session Chair(s)		**M. Meussen**	**E. Costa / P. Arbez**	**P. Doeffer / D. Drikakis**
13:30	**13:55**	**Three Surface Aircraft (TSA) Configuration – Profits and Problems,** *T. Goetzendorf-Grabowski, T. Antoniewski*	**RBF4AERO Project:** **Reshaping the future of aircraft design,** *E. Costa, M.E. Biancolini*	**TFAST Project:** **Transition Location Effect on Shock Wave Boundary Layer Interaction– Project overview,** *P. Doeffer*
13:55	**14:20**	**New Small Aircraft Concepts and Required Technologies Following FlightPath 2050 and Single European Transport Area,** *K. Piwek, W. Wisniowski*	**RBF4AERO Project:** **Morphing Technique: Mesh quality verification** *G. D'Agostini*	**TFAST Project:** **Numerical Simulations of Transitional Shock Boundary Layer Interaction and Buffeting Control,** *G. Barakos*
14:20	**14:45**	**Evaluation of Variable Camber Concept for Aircraft in Formation Flight,** Y. Liu, F. Peter, E. Stumpf	**RBF4AERO Project:** **Explorative studies** *E. Costa, M. Andrejasic*	**TFAST Project:** **Physical and Experimental Challenges,** *J. P. Dussauge*
14:45	**15:10**	**Design Challenges for Novel Concept of Highly Maneuverable Flying Target,** *Z. Goraj, A. Frydrychewicz*	**TOICA Project:** **Thermal Overall Integrated Conception of Aircraft - Overall Presentation (Part A),** *P. Arbez*	**Azure: High-Order CFD Software for Aerospace Applications,** *D. Drikakis, A. Antoniadis, P. Tsoutsanis*
15:10	**15:35**	**MAAT Project:** **Cruiser-Feeder Airship Optimization and Modular Design,** *M. Trancossi, M. Madonia*	**TOICA Project:** **Thermal Overall Integrated Conception of Aircraft - Overall Presentation (Part B),** *P. Arbez*	**Ground Testing: Driving Forward Innovation in Fluid Dynamics,** *K. Kontis*
15:35	**16:00**	**SOAR Project:** **An Analysis of FanWing Flight Physics and Potential Business Cases,** *J. Gibbs, G. Seyfang, P. Peebles, L. Villafane, B.H. Saracoglu, G. Paniagua, C. May, B. Nagel, A. Bachmann*		**Go4Hybrid Project:** **Improved methods for turbulence-resolving CFD: The Go4Hybrid Project** *C. Mockett, W. Haase, F. Thiele*
16:00	**16:30**	**Coffee**		

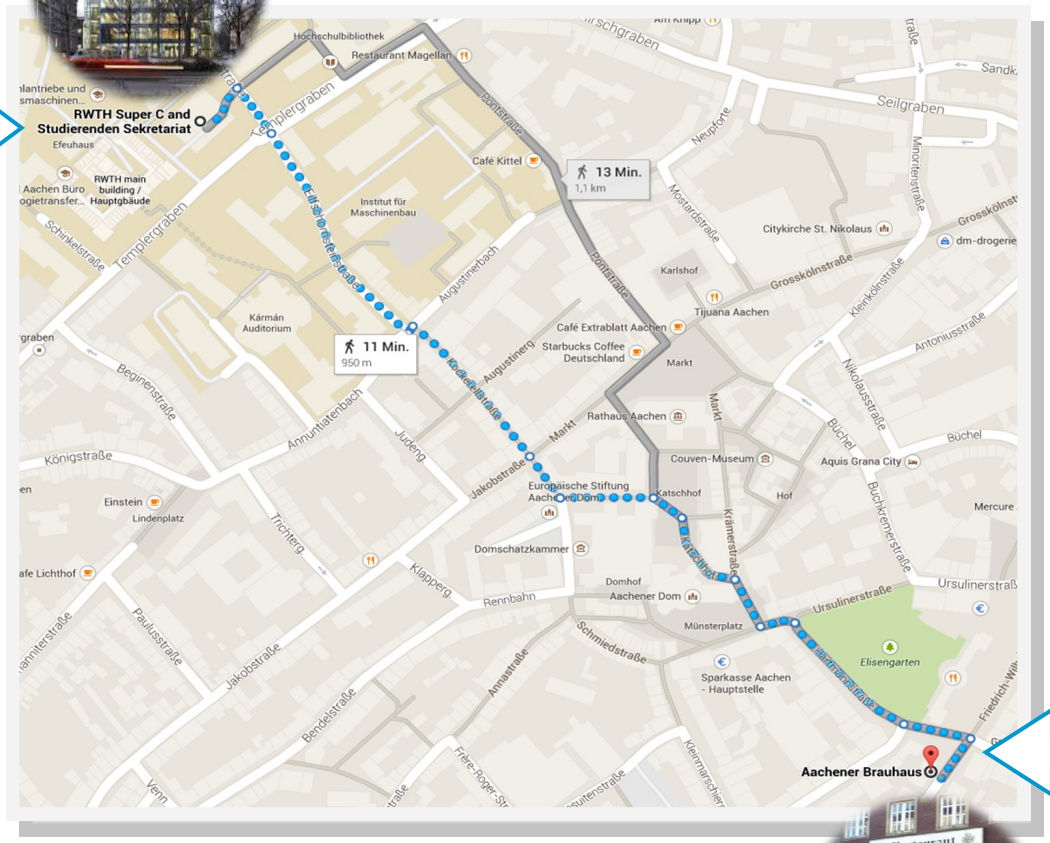
Time		Tuesday 28.10.2014 (afternoon)		
Room:		**Ford**	**Generali**	**Junkers**
Session		**#11** Aeroelasticity & **#12** Flight Dynamics	**#13** Aerodynamic Wing Concepts & Design	**#14** Innovative Cockpit Design & **#15** Personal Air Vehicle
Session Chair(s)		**A. Dafnis / T. Panidis**	**A. Rizzi / A. Seifert**	**R. Habig / F. Nieuwenhuizen**
16:30	**16:55**	**Investigation on Nonlinear Transonic Aeroelasticity using a Harmonic Balance Method,** *S. Marques, R. Hayes, W. Yao*	**The Intelligent Wing - enabled by advanced moveables,** *D. Reckzeh, S. Bauß*	**i-VISION Project:** **i-VISION** (Immersive Semantics-based Virtual Environments for the Design and Validation of Human-centred Aircraft Cockpits) **– Overall Presentation** *L. Rentzos*
16:55	**17:20**	**Dynamics Properties Of Light Turboprop Aircraft Including Weak And Strong Gyroscopic Effects,** *E. Cichocka, Z. Goraj*	**DESIREH Project:** **Low Speed Design of Laminar Wings,** *A. Eberle, H. Strüber*	**i-VISION Project:** **i-VISION – the Future of Human-centric Cockpit Design,** *R. Habig, L. Rentzos*
17:20	**17:45**	**Preliminary Flyability Analysis of Novel VTOL Aircraft "Lenscopter",** Z. Janda	**Preliminary Design of Hybrid Laminar Flow Wings for Optimum Cruise Conditions,** *K. Risse*	**MYCOPTER Project:** **MYCOPTER: Enabling Technologies for Personal Aerial Transportation Systems,** *F. Nieuwenhuizen, H. Bülthoff*
17:45	**18:10**	**Small UAV Autopilot System Synthesis, Tests and Results,** *S. Levin, A. Ledovskiy, R. Murzagalin, N. Ageev, V. Kobtsev*	**AFLONEXT Project:** **2nd Generation Active Wing Active Flow- Loads & Noise control on Next Generation Wing - Overall Presentation,** *A. Seifert*	**MYCOPTER Project:** **Vision Based Control And Navigation For Personal Aerial Vehicles,** *M. Achtelik, S. Lynen, S. Weiss, M. Chli, R. Siegwart*
18:10	**18:35**	**CESAR Project:** **Model Updating of Small Aircraft Dynamic Finite Element Model Using Standard Finite Element Software,** *B. Prananta, T. Kanakis, J. Vankan*	**UMRIDA Project:** **Uncertainty Management for Robust Industrial Design in Aeronautics - Overall Presentation** *D. Wunsch, C. Hirsch*	**MYCOPTER Project:** **Handling Qualities and Training Requirements for Personal Aerial Vehicles,** *M. Jump, P. Perfect, L. Lu, M. White*
END OF DAY 2				
20:00	**22:00**	**Facultative Dinner ***		

**** Optional Facultative Dinner will take place at 'Aachener Brauhaus' . Participants should register at the registration desk during Day 1.***

Facultative Dinner : Map

Restaurant Aachener Brauhaus, Kapuzinergraben 4

We are here



Restaurant
Aachener Brauhaus
Kapuzinergraben 4

Aachener Brauhaus

Time		Wednesday 29.10.2014		
Room:		Generali		
8:30	9:00	Registration		
9:00	9:30	**Keynote Lecture:** **The Stratosphere challenges to Aeronautics & Space R&T,** *Dr. Giovanni Bertolone, Chairman of the Italian Cluster for Aerospace Technology (CTNA)*		
9:30	10:00	**Keynote Lecture:** **Clean Sky projects on Aircraft Design and Flight Physics,** *Giuseppe Pagnano, Coordinating Project officer – Clean Sky Joint Undertaking*		
10:00	10:30	**Coffee**		
Room:		Ford	Generali	Junkers
Session		**#16** Collaborative Support Actions I	**#17** Cycloidal Rotor Configurations	**#18** Air Transport Innovation & Policy
Session Chair(s)		D. Knoerzer	J.C. Páscoa / M. Schwaiger	E. Blanvillain / C. Galinsky
10:30	10:55	**CAPPADOCIA Project:** **Coordination Action Pro 'Production, Avionics, Design' on Cost-efficiency in Aeronautics - Overall Presentation,** *F. Marty*	**CROP Project:** **Multi-Dielectric Barrier Discharge Plasma Actuators for Cycloidal Rotor Active Flow Control** *C.M. Xisto, J.C. Páscoa, J.A. Leger, A. Gerlach,*	**HIKARI Project:** **HIKARI: Joining Efforts to Pave the Way Towards High Speed Transport,** *E. Blanvillain*
10:55	11:20	**CATER Project:** **Coordinating Air transport Time Efficiency Research - Overall Presentation,** *A. Napolitano*	**CROP Project:** **Cycloidal Rotor Aerodynamic and Aeroelastic Analysis,** *L. Gagon, G. Quaranta, M. Morandini, P. Masarati*	**HIKARI Project:** **Thermal management activities and overall technical excellence in the frame of HIKARI** *F. Falempin, S. Balland*
11:20	11:45	**OPTICS Project:** **Observation Platform for Technological and Institutional Consolidation of research in Safety - Overall Presentation** *B. Kirwan*	**CROP Project:** **D-Dalus - a Revolutionary VTOL Aircraft,** *M. Schwaiger, S. Elflein, D. Wills*	**TERESA Project:** **IATA'S Technology Roadmap and its Connection to Current Aviation Research and Innovation,** *P. Nolte, T. Rötger*
11:45	12:10	**FORUM AE Project:** **Forum on Aviation and Emissions,** *O. Penanhoat*	**CROP Project:** **Optimized Pitching Schedules for a Cycloidal Rotor in Hovering,** *D. Angeli, A. Andrisani, A. Dumas*	**Aircraft Design for Future Operations,** *V. Gollnick*
12:10	12:35	**Coordinating research and innovation in the field of Aeronautics and Air Transport: Overview and latest achievements of running CSAs** Discussion & Feedback	**CROP Project:** **Aerodynamic Optimization of Cyclorotors,** *J.A.L. Monteiro, J.C. Páscoa, C.M. Xisto*	**Responsiveness of European Airline Business Stakeholders Regarding the Inclusion of Aviation in the ETS,** *M. Naumow, P. Nolte*
12:35	13:30	**Lunch**		

Time		Wednesday 29.10.2014 (afternoon)		
Room:		**Ford**	**Generali**	**Junkers**
Session		**#19** Collaborative Support Actions II & **#20** Noise	**#21** Aerodynamic Optimization	**#22** Technology Innovation
Session Chair(s)		**G. Bugeda /E. Stumpf**	**W. Schröder**	**G. Cabañero / Z. Goraj**
13:30	**13:55**	**PROMOAIR Project:** **Promoting Aeronautics Innovation and Research - Overall Presentation,** *A. Chamos*	**ESPOSA project:** **MDO Approach for a Light Turboprop Aircraft - Engine Integration and Improvement,** *A. Iwaniuk, W. Wisniowski*	**IN-LIGHT Project:** **Innovative bifunctional aircraft window for lighting control to enhance passenger comfort,** *G. Cabañero, A. Viñuales*
13:55	**14:20**	**GRAIN2 Project:** **GReener Aeronautics International Networking-2 - Overall Presentation,** *G. Bugeda*	**ESPOSA project:** **Aerodynamic Design of Engine Intake Duct Shape of a General Aviation TurboProp Aircraft,** *B. Soemarwoto, O. Boelens, T. Kanakis*	**Airport based air stream assistance for aircraft take off and landing,** *P. Nikolakopoulos, D. Bompos, D. Drikakis*
14:20	**14:45**	**X-NOISE Project:** **Aviation Noise Research Network and Coordination,** *D. Collin*	**Can Constructal Theory Help in Overcoming the Intrinsic Limits and Simplifying the Processes by MDO?,** *M. Trancossi*	**One Method of Spatial Flight Path Optimization for Non-Stationary Aircraft Flight Regimes,** *S. Levin*
14:45	**15:10**	**Discussion & Feedback**	**Investigations on Drag Reduction for a Light Class Utility Helicopter,** *C. Breitsamter, M. Grawunder, R. Reß*	**REPAIR Project:** **Future RepAIR and Maintenance for Aerospace industry - Overall Presentation,** *J. Pottebaum*
15:10	**15:35**	**Assessment of Aircraft Noise Annoyance during Conceptual Aircraft Design,** *A. Sahai, E. Stumpf*	**Aerodynamic Optimisation Using CAD Parameterisations in SU2,** *S. Marques, P. Hewit, T. Robinson*	
15:35	**16:00**	**Long-Range Noise Propagation of Aircraft Noise,** *A. Filippone*	**Minimization of Body of Revolution Aerodynamic Drag at Supersonic Speeds in the Framework of RANS,** *N. Ageev, A. Pavlenko*	
END OF DAY 3				

16:30 - 18:00: Optional guided Aachen City Tour or RWTH faculty tour. Participants should register at the registration desk during Day 1.

Sponsors

Platinum

AIRBUS

ELECTROFLUID SYSTEMS

rtm

Resources Technologies Management

Gold

ALTHOM

THE OFFSHORING COMPANY

Agilent Technologies

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4th EASN Workshop

Aachen, 27th – 29th October 2014

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RWTH AACHEN UNIVERSITY

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Technology Innovation Services

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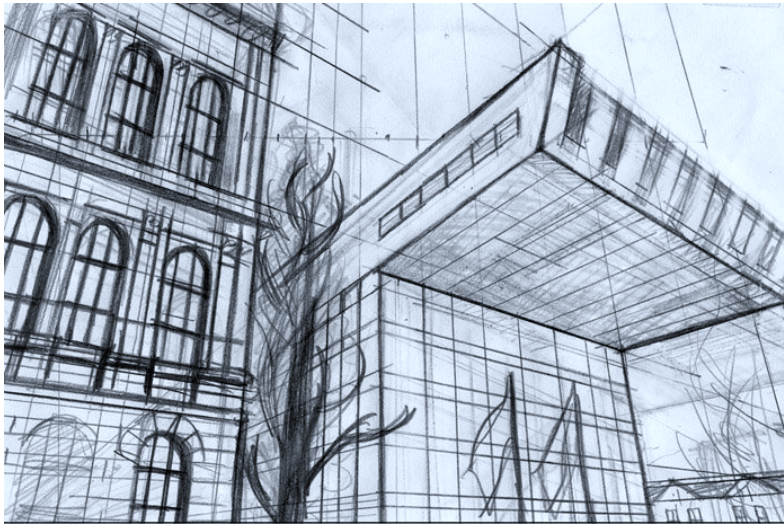
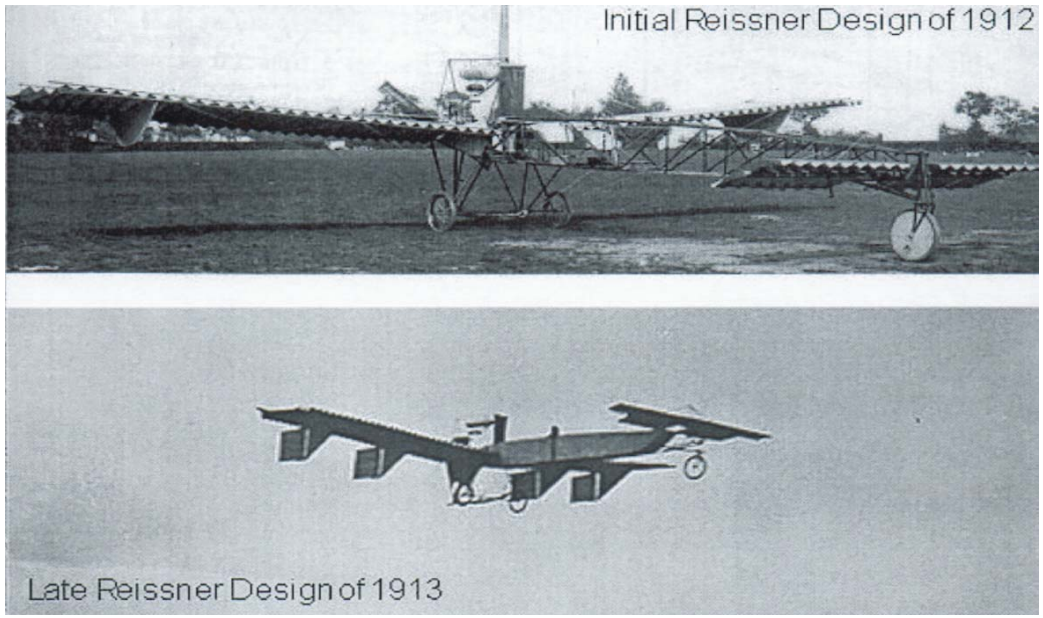


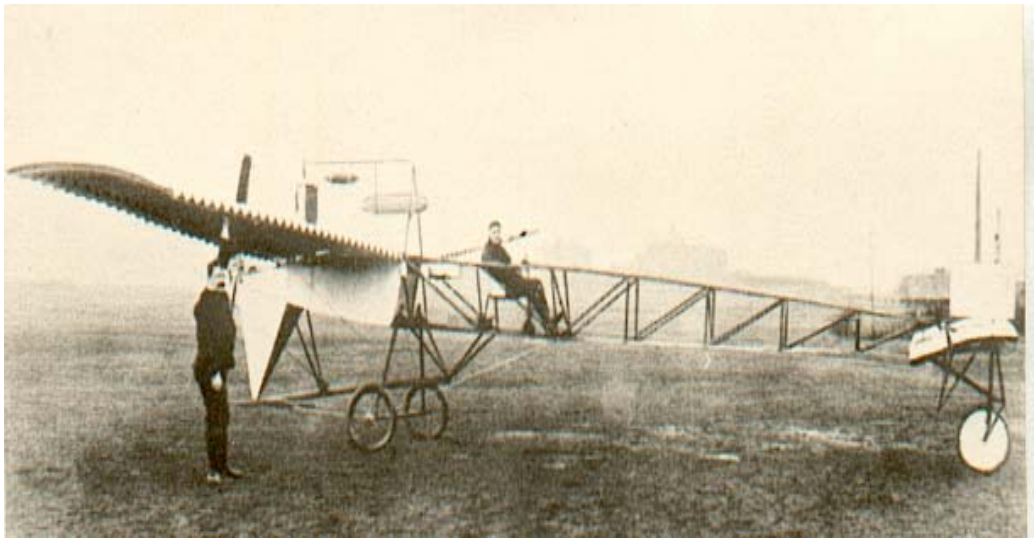
RWTH AACHEN UNIVERSITY

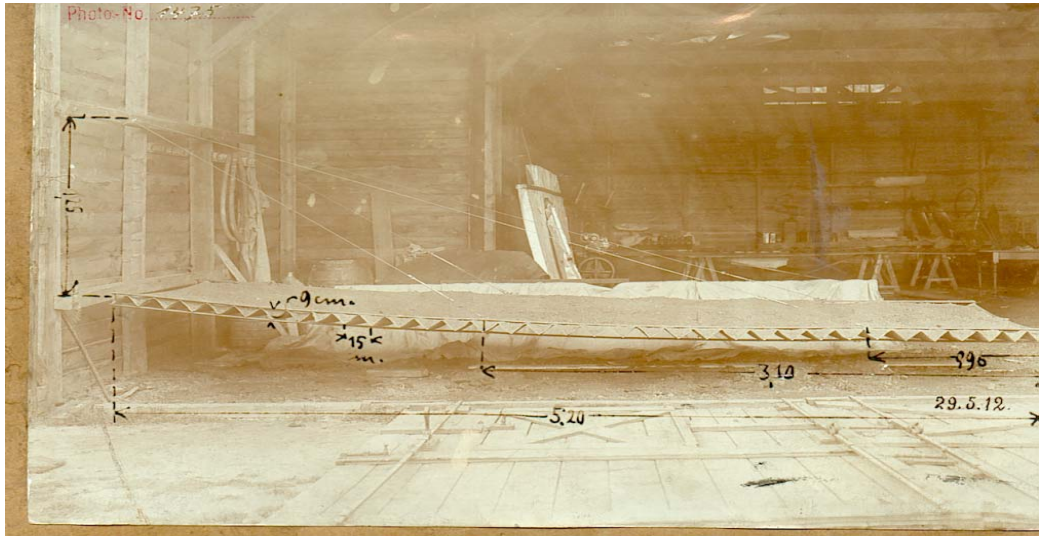
Early Days of Aerospace at RWT Aachen University

Early Days of Aerospace at RWTH

RWTH AACHEN UNIVERSITY

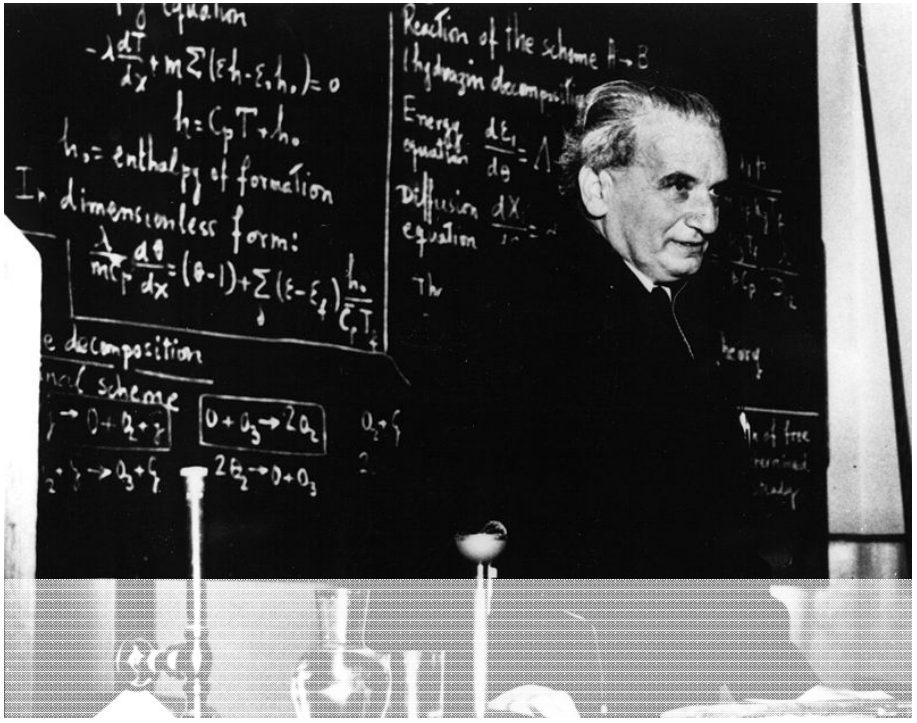


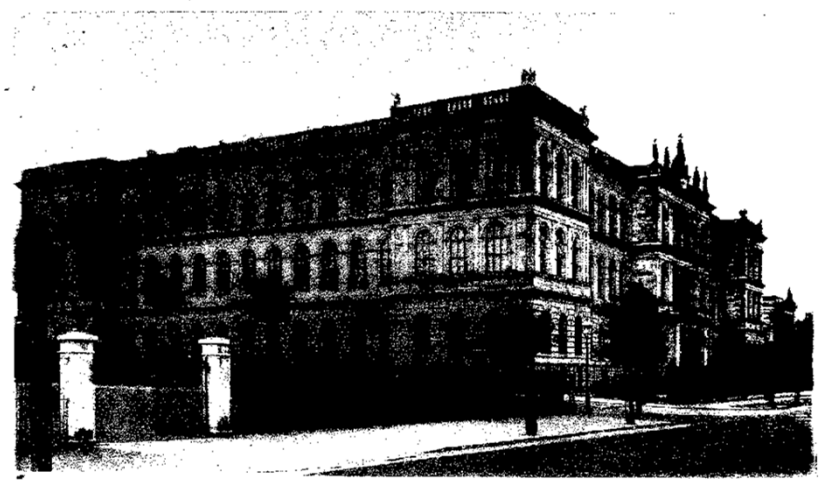




Early Days of Aerospace at RWTH

RWTH AACHEN UNIVERSITY





AACHEN. Polytechnikum.

4th EASN Workshop

Aachen, 27th – 29th October 2014

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RWTH AACHEN UNIVERSITY

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Technology Innovation Services

Aeronautics Research and Innovation on European Level

- *Achievements and Future Perspectives*

Dietrich Knoerzer

DG RTD-H.3 Aviation

Aachen, 27 October 2014

Dornier DoX (1929)

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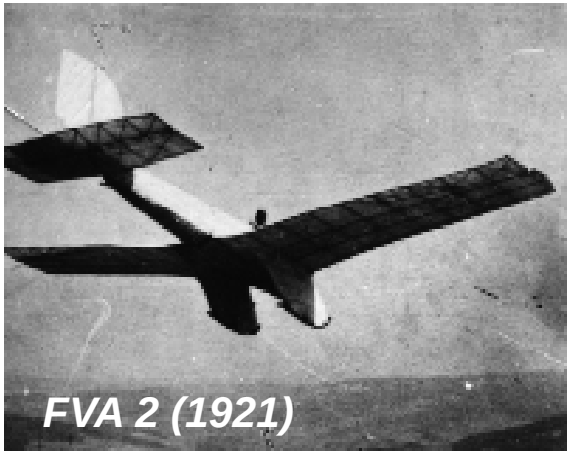
Airbus A380 (2006)



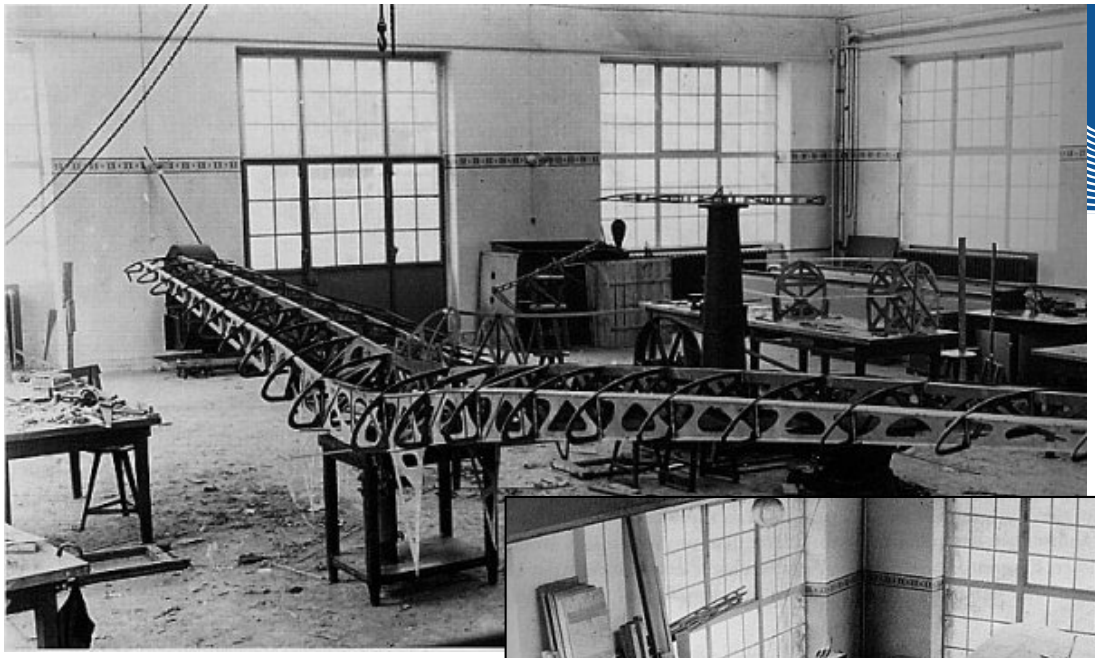
FVA 2 (1921)

Eta - L/D = 70 (2001)

Aeronautics has to prepare the technologies for a quantum leap in aircraft efficiency

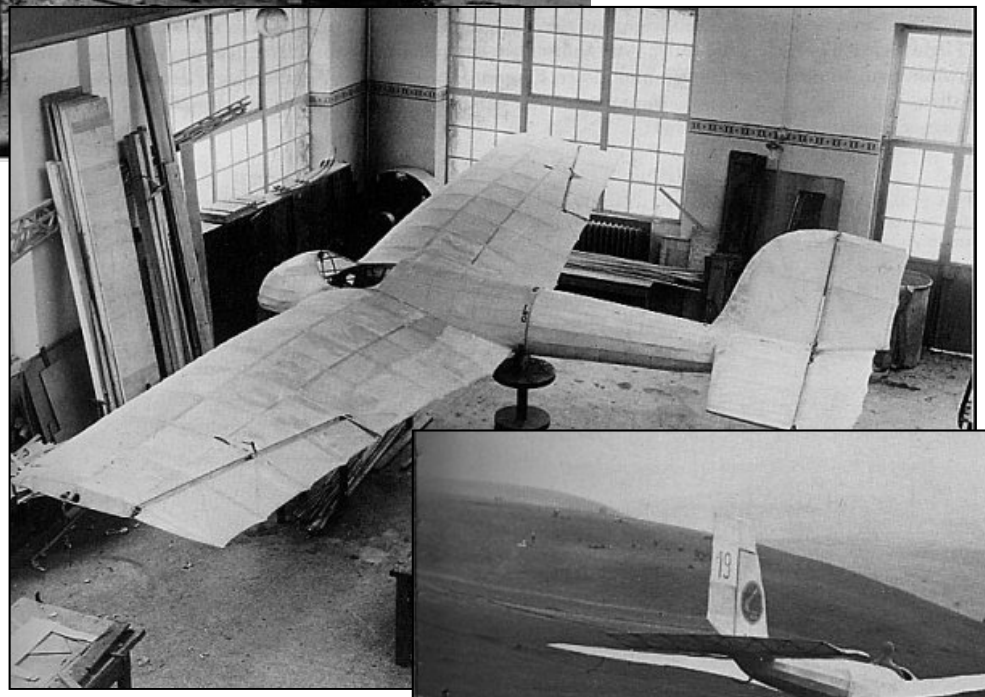
European Commission

Glider Flying Started in Aachen



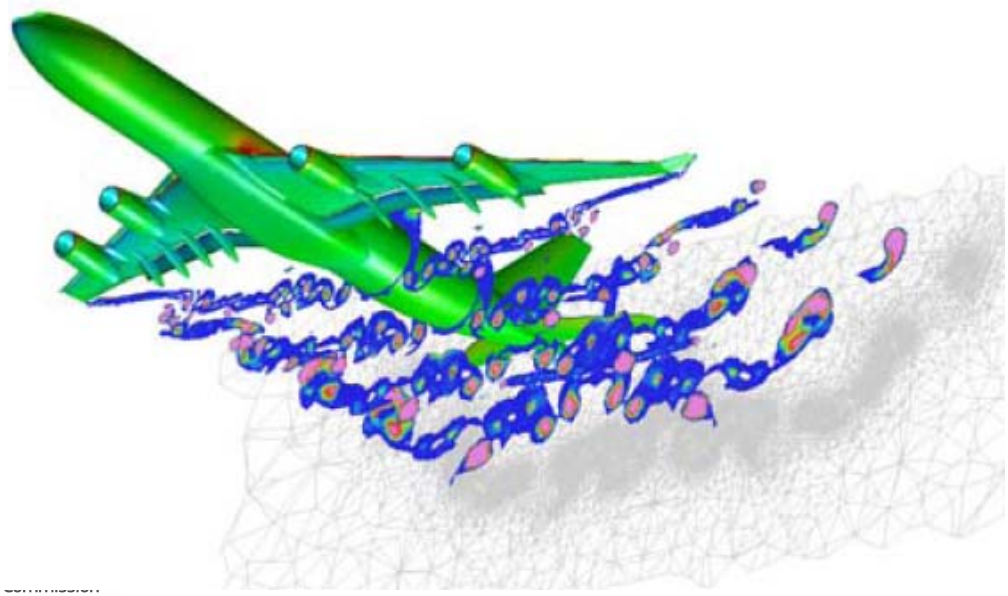
The Aerodynamic Institute of the RWTH Aachen University under Theodor von Karman was the origin of glider flying in 1920/ 1921

The construction of FVA-1 'Black Devel' and FVA-2 'Blaue Maus' In the shop of the Aerodynamic Inst. in 1920/ 1921



Content

- The European Union
- The Challenges for Aviation
- Aviation in the Framework Programmes
- Horizon 2020 – Opportunities for Aviation



The European Union

European Commission proposes

Annual Budget
(~120 billions €)

(e. g. Horizon 2020)

President
J.-C.Juncker

Amendments

Treaties

Amendments

Council of the European Union decides

Presidency changes every 6 months (now Italy)

Co-decision procedure

European Parliament is consulted, co-decides

751 representatives elected directly by citizens in May 2014

Court of Auditors
advises

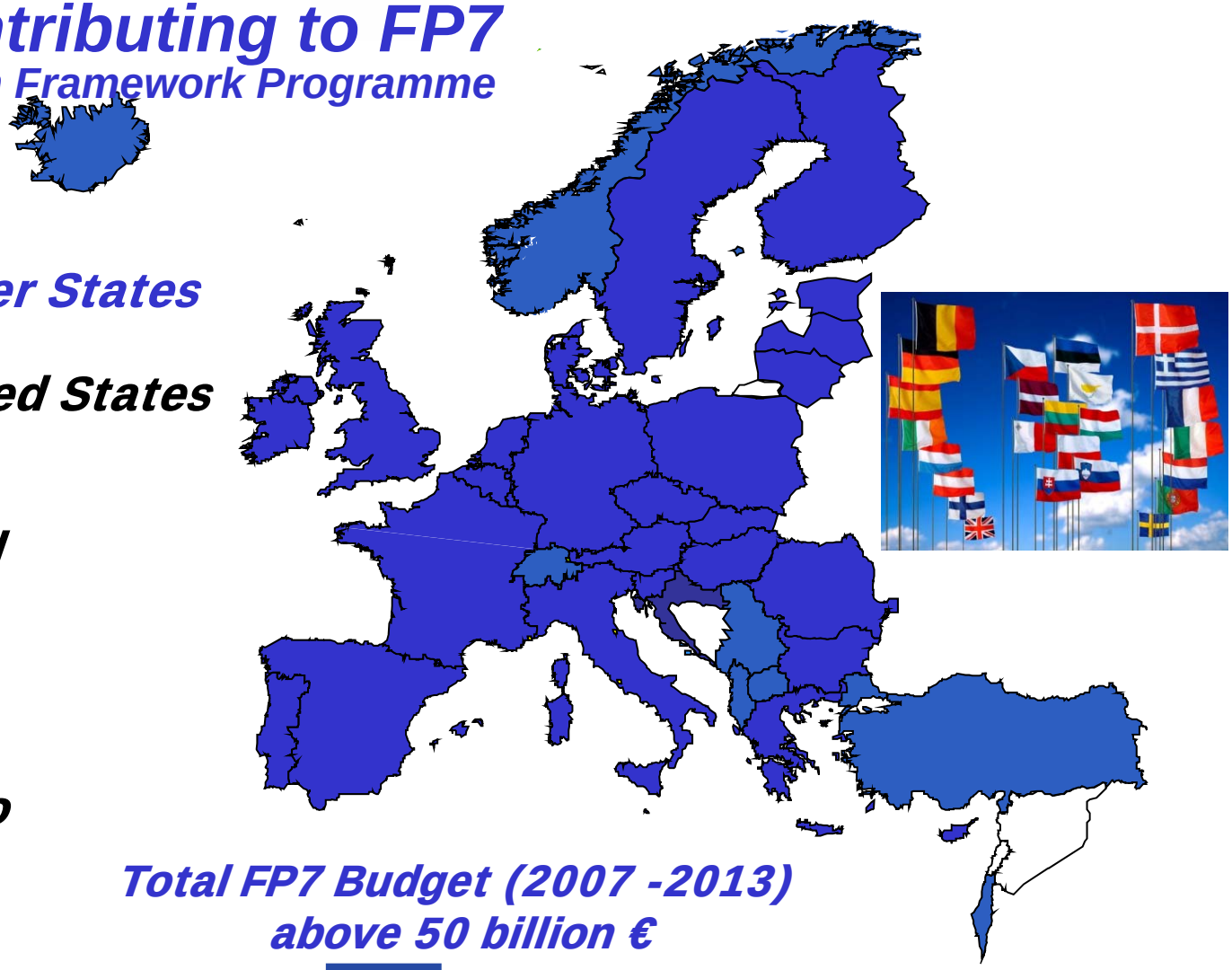
Committee of the Regions
advises

European Economic and Social Committee - European Investment Bank -
European Central Bank - European Ombudsman - European Data Protection Supervisor - ...

The Research Framework Programme of the EU

States Contributing to FP7

7th EU Research Framework Programme

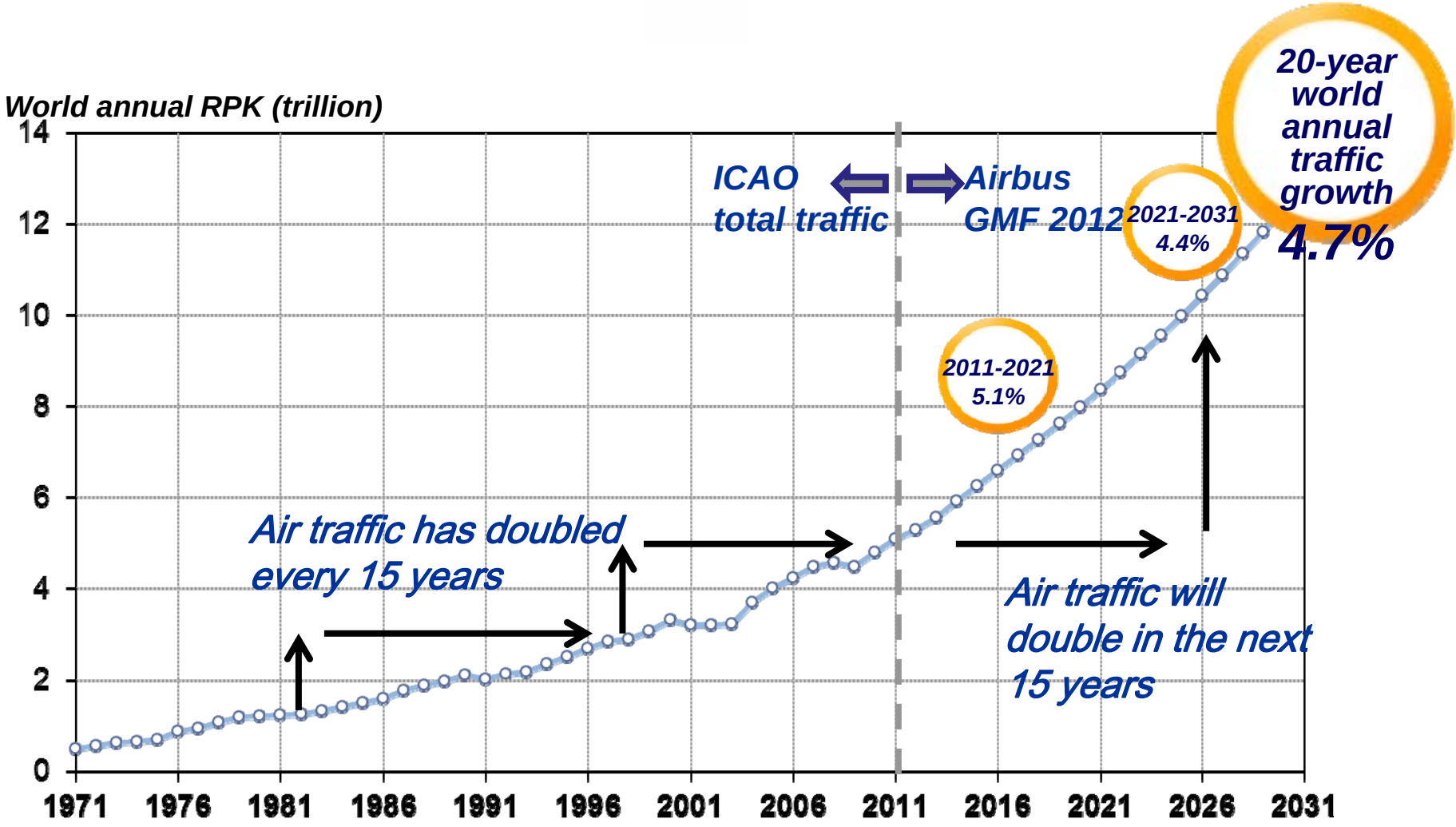


- ***28 EU Member States***
- ***FP7 Associated States***
  - ***Iceland***
  - ***Norway***
  - ***Switzerland***
  - ***Turkey***
  - ***Albania***
  - ***Israel***
  - ***Macedonia***
  - ***Montenegro***
  - ***Serbia***

Total FP7 Budget (2007 -2013) above 50 billion €

European Commission

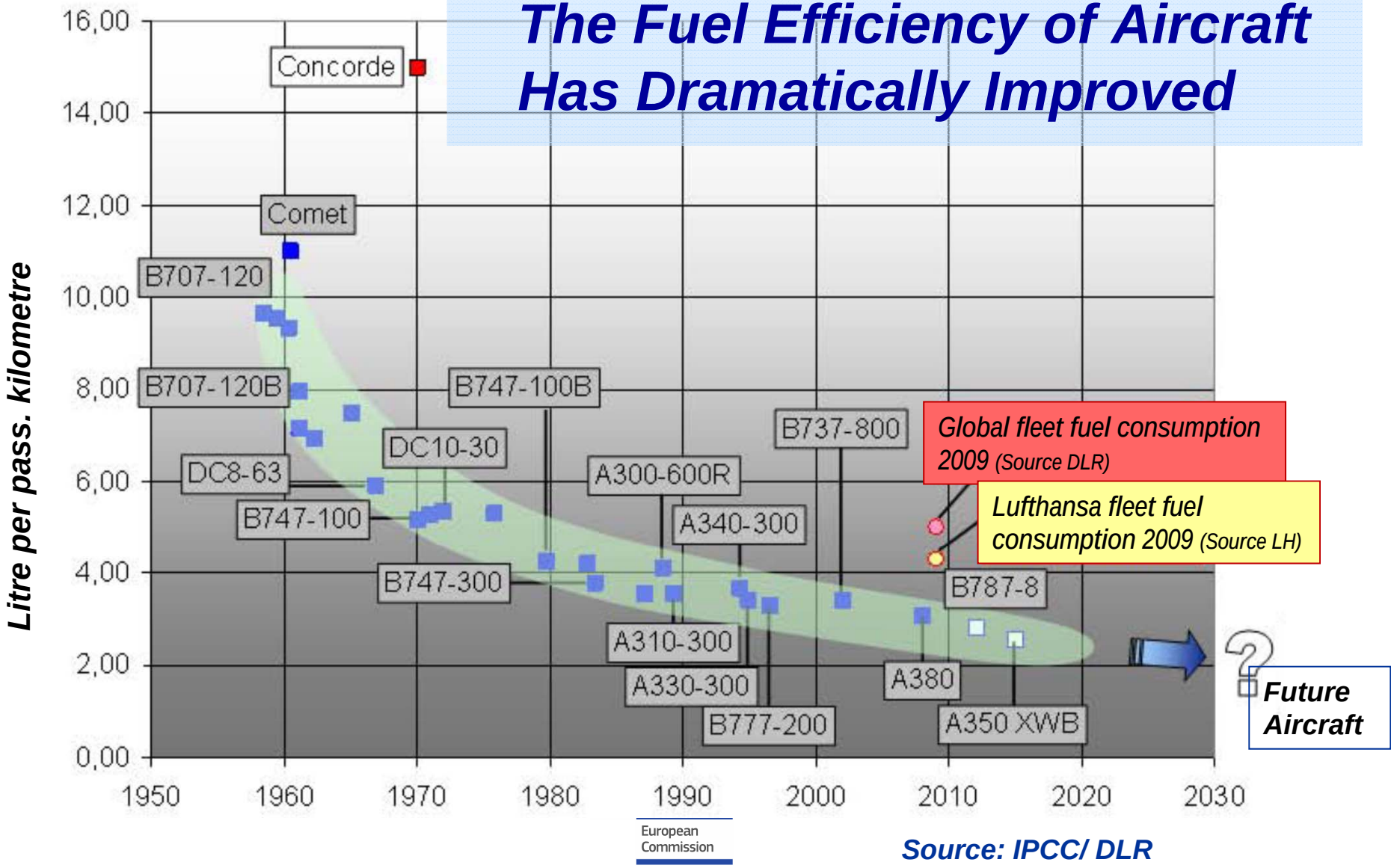
Air Travel Development
(only Passengers)



Source: ICAO, Airbus

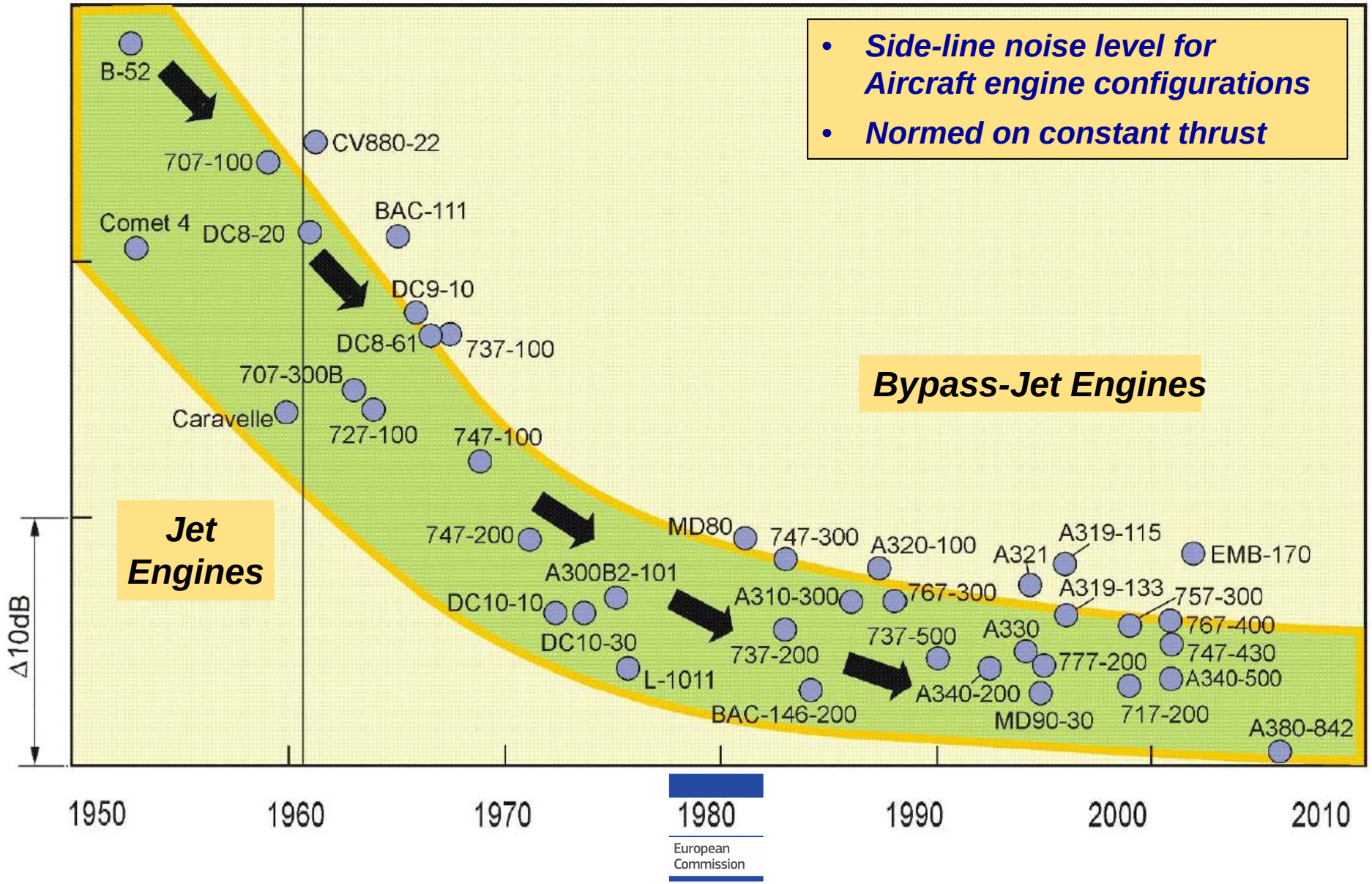
European Commission

The Fuel Efficiency of Aircraft Has Dramatically Improved



Source: IPCC/ DLR

Development of Civil Aircraft Noise Emission



Global Market Forecast (GMF): 20-year New Deliveries of PAX and Freight Aircraft

19,520 *single-aisle aircraft*

6,970 *twin-aisle aircraft*

1,710 *very large aircraft*

28,200 *new aircraft*

+443 aircraft over GMF 2011

Passenger aircraft (≥ 100 seats)
Jet freight aircraft (>10 tons)

Market value of $4 trillion

Source: Airbus GMF – Global Market Forecast

European Commission

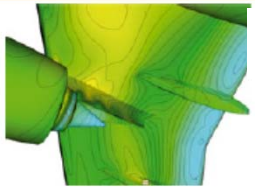
ACARE* and Europe's "Vision 2020"

Key Goals

- 50% cut in CO2 emissions per passenger/km
- 80% cut in NOx emissions
- Halving perceived aircraft noise
- Five-fold reduction in accidents
- ATS capable of handling 16 mio. flights a year
- 99% of all flights within 15 min. of timetable

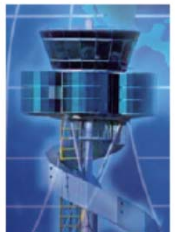
How is the 50% CO_2 Reduction Achieved ?

Airframe 20-25%



Engines 15-20%

Operations 5-10%



ACARE

*) Advisory Council for Aeronautics Research in Europe

European Commission

In the Year 2010: Europe's Vision for Aviation 'Flightpath 2050'

Responding to society's needs

Securing global leadership for Europe

Meeting Societal and Market Needs

Maintaining and Extending Industrial Leadership

Protecting the Environment and the Energy Supply

Ensuring Safety and Security

Prioritising Research, Testing Capabilities & Education

European Commission

Flightpath 2050

Protecting the Environment and the Energy Supply

In 2050 technologies and procedures available allow

- *75% reduction in CO2 emissions per passenger kilometre,*
- *90% reduction in NOx emissions, and*
- *65% reduction in perceived noise emission of flying aircraft*

relative to the capabilities in 2000.

Aircraft movements are emission-free when taxiing.

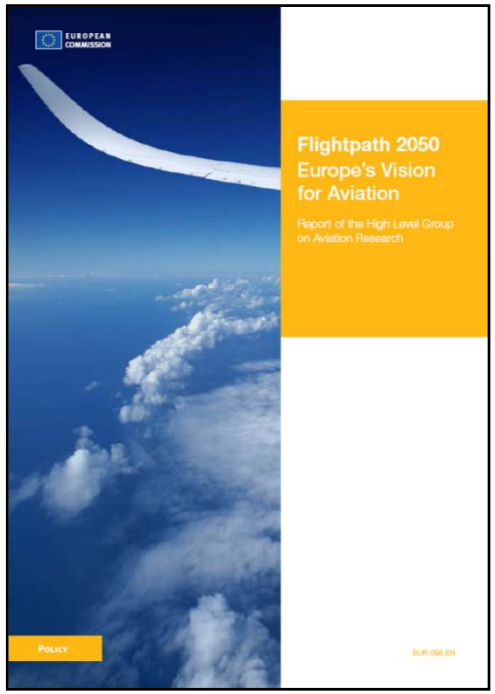
Air vehicles are designed and manufactured to be recyclable.

Europe is established as a centre of excellence on alternative fuels

Europe is at the forefront of atmospheric research

From Vision to Strategy

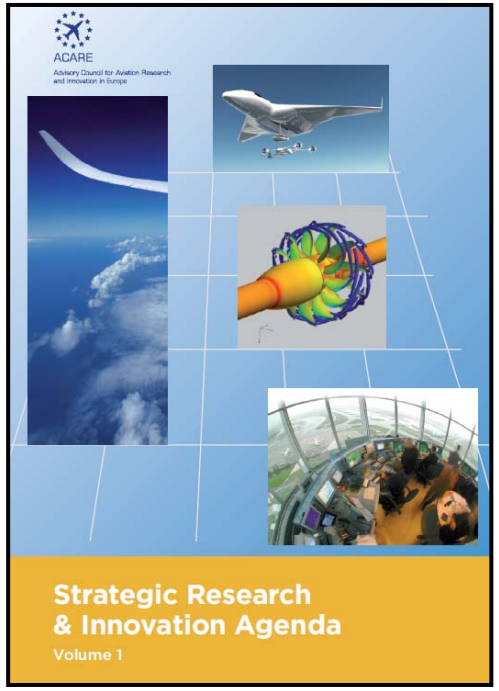
Flightpath 2050



March 2011
Aerodays

Sept. 2012
ILA

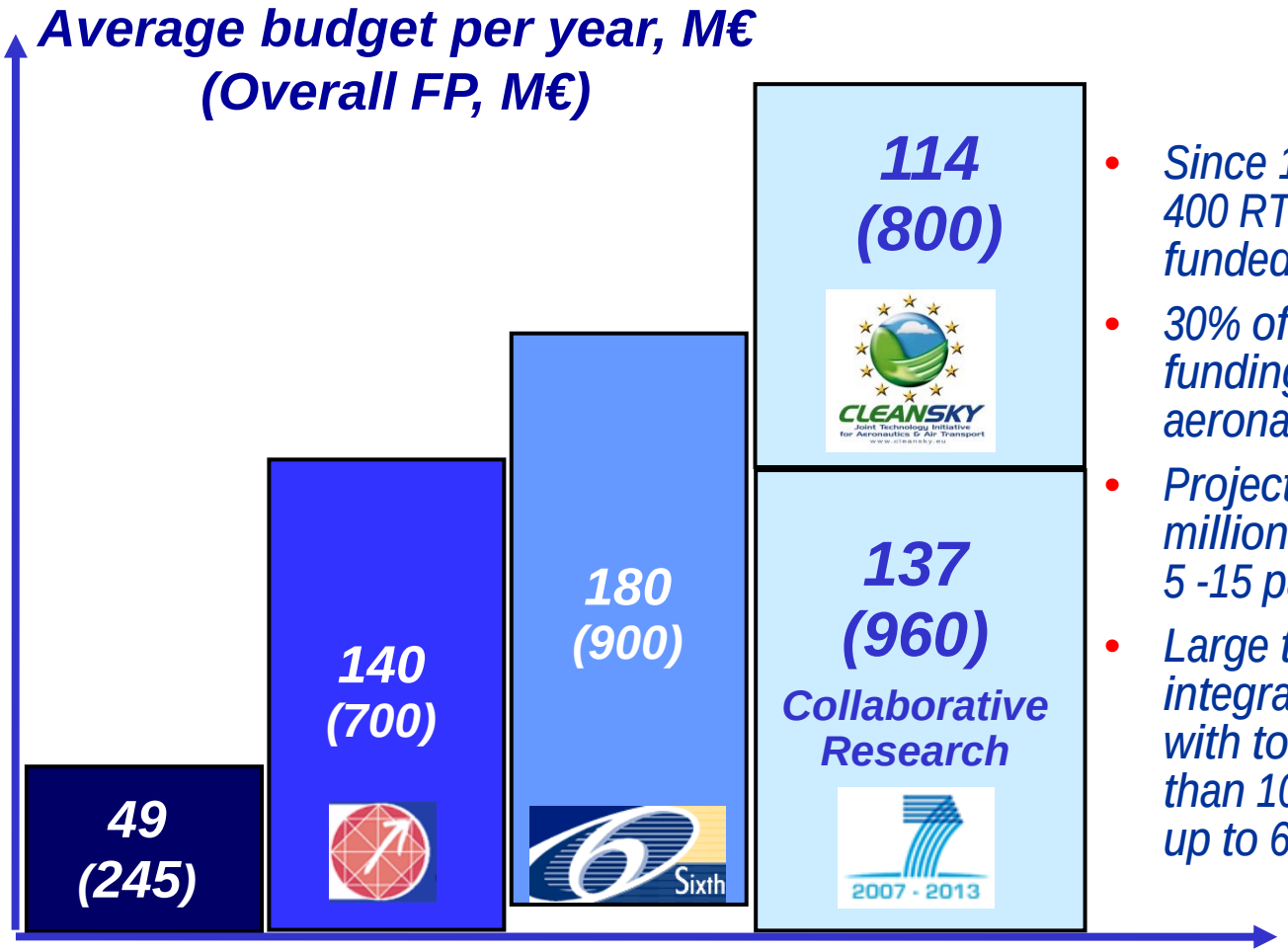
SRIA



www.acare4europe.org

Short (2020), medium (2035) and long term (2050)
Research and Innovation actions enabling to reach 2050 goals

Aeronautics Research in Framework Programmes



- *Since 1990 more than 400 RTD projects funded with 3 billion €*
- *30% of EU public funding in civil aeronautics RTD*
- *Project size 2 - 8 million € with typically 5 -15 partners*
- *Large technology integration projects with total budget more than 100 million € with up to 60 partners*

FP7: plus 350 M€ contribution to SESAR

European Commission

FP2

European Laminar Flow Investigations ELFIN

- First European large scale research project
- About 11 million € total costs
- 24 Partners
- 1989 – 1992

- Fokker 100 flight tests with natural laminar flow glove
- ONERA S1 Tests with Hybrid Laminar Flow using a 1:2 model of the ATTAS wing
- Numerical transition prediction methods

European Commission

FP2

Windtunnel tests of the ALVAST model with counter rotating TPS in the DNW-LLF

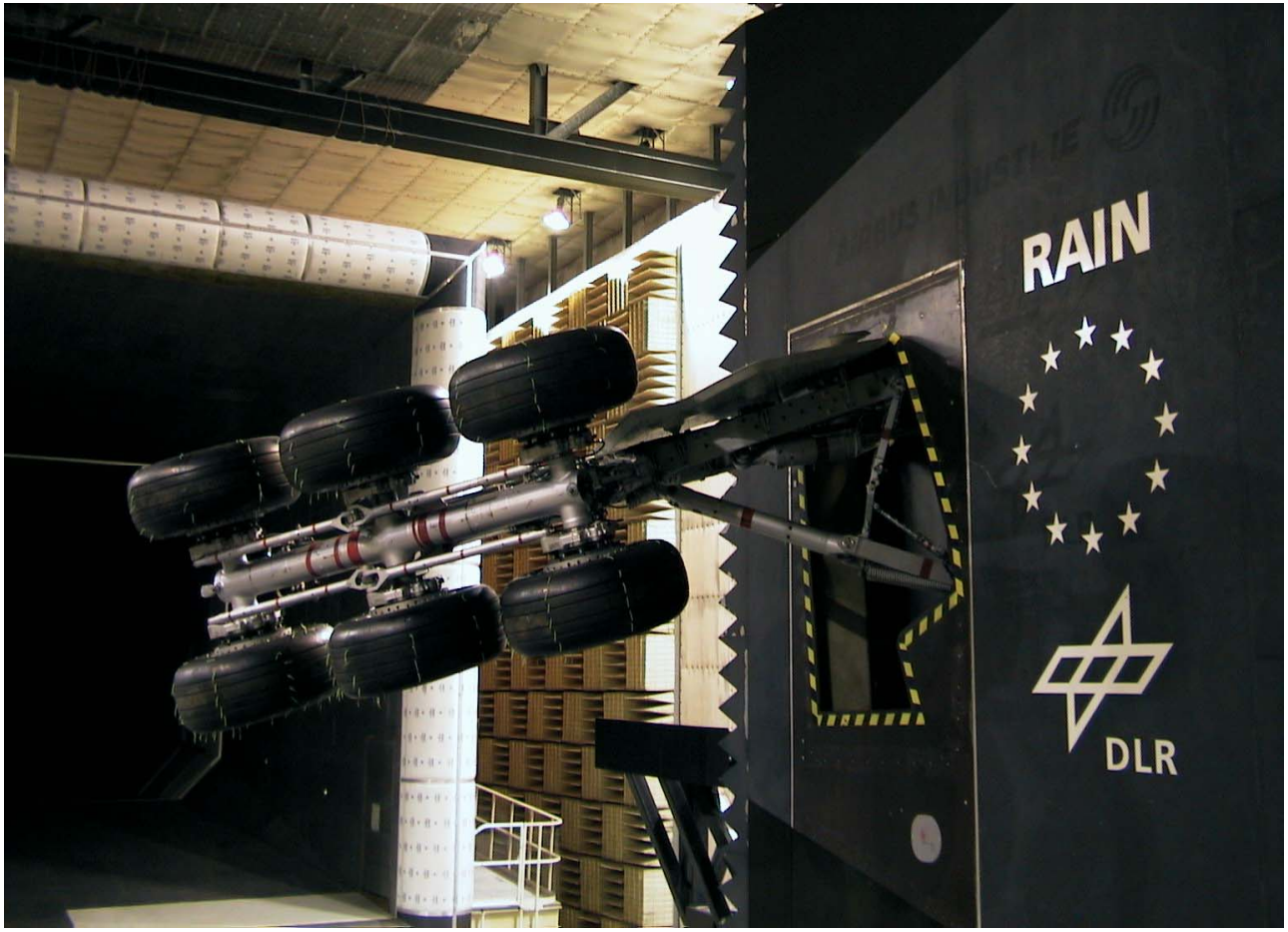
DUPRIN

Ducted Propfan Investigations

1990 – 1993
14 Partners

European Commission

FP4



Landing gear noise test in DNW-LLF

RAIN – Reduction of Airframe and Installation Noise

1998 - 2001

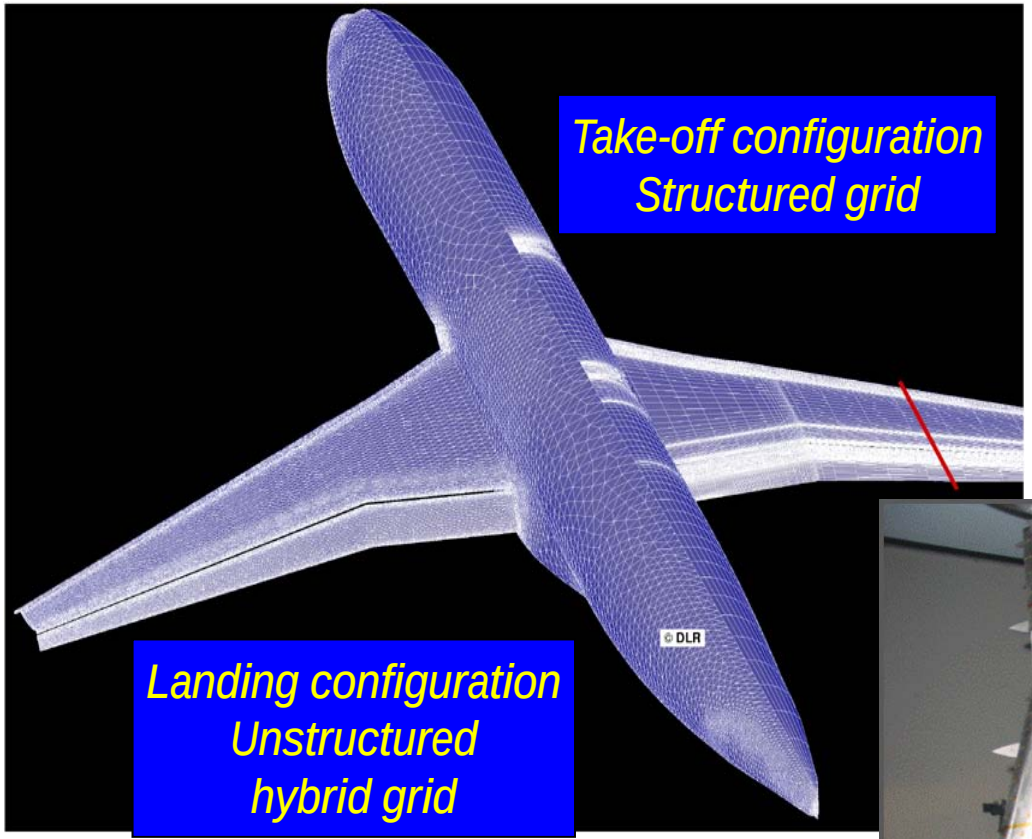
European Commission

FP4

HELIFLOW (Improved Tools for Helicopter Aeromechanic and Aeroacoustic Interaction) *1996 - 2001*

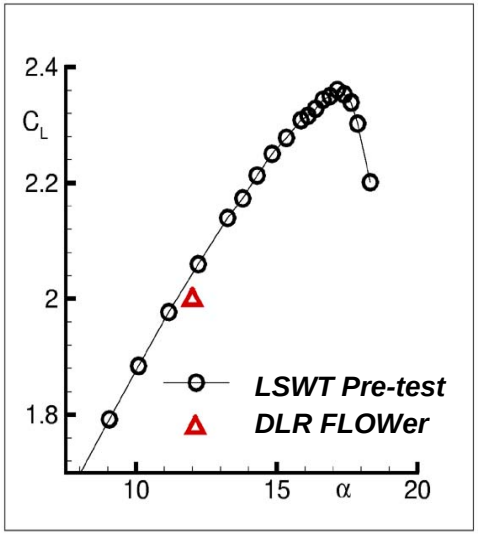
European Commission

Pre-test RANS Computations of Landung Configuration

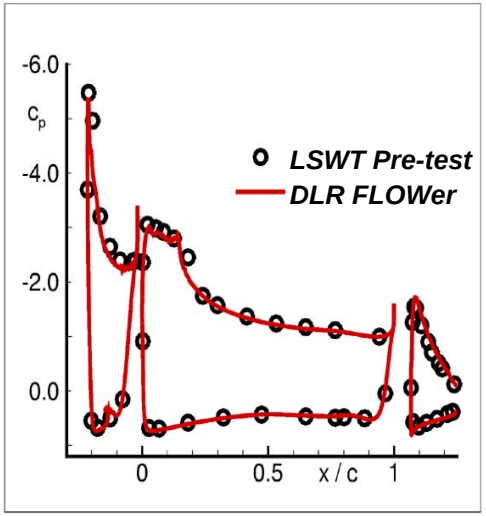


Surface grids of KH8Y configuration

Take-off configuration
Ma=0.18 R=1.4x106

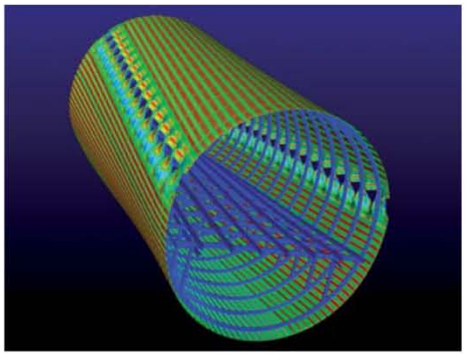


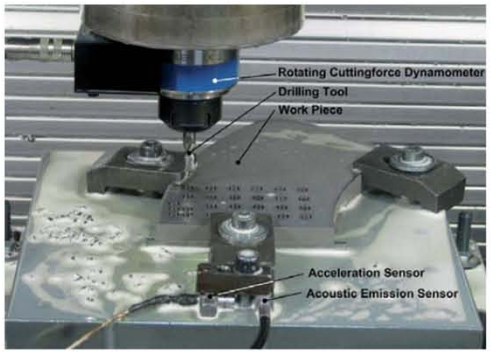
Pressure distribution
a=12° DV5



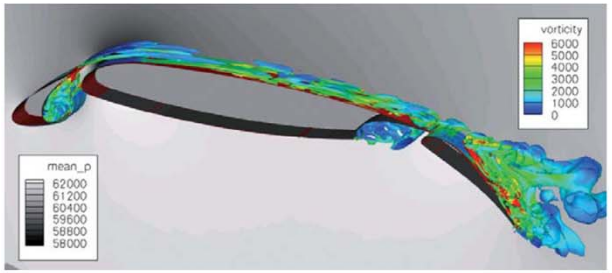
Cryogenic windtunnel model
in high-lift configuration

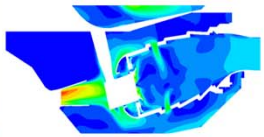
Examples of FP7 Projects in Aeronautics Technologies

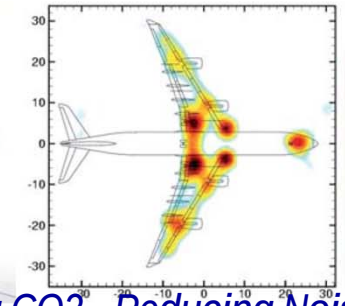




Carbon fibre profile manufacturing - Composite fuselage modelling - Adaptive manufacturing *Manufacturing of complex titanium sheets*







Reducing drag *- Reducing NOx - Reducing CO2 - Reducing Noise* ***- Towards 2050 ?***

Personal helicopter ***- Pulsar guided aircraft*** ***- Plasma controlled flow*** ***- Brussels-Tokyo in 3 hours***

Technologies of Airbus A380
Origins from EU Projects

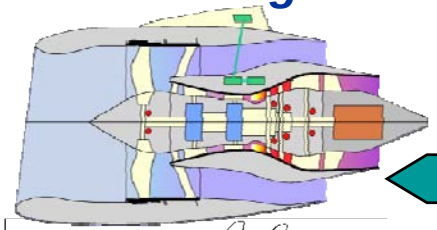
Clean Sky

Joint Technology Initiative **Clean Sky** 2008, 7 years,1600 M€, EC: 800 M€

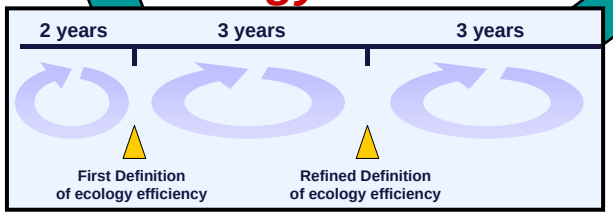
SMART Wing Aircraft

Regional Air Transport

Green Engines



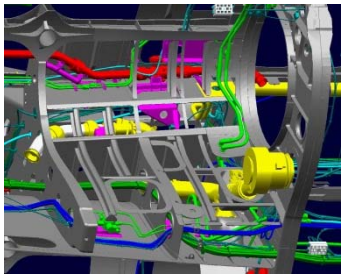
Technology Evaluator



Simulator Platform AC, ATM, AP (flight segment)

ATS Model

Green Rotorcraft



Eco-Design

Systems for Green Operation

More info: www.cleansky.eu

European Commission

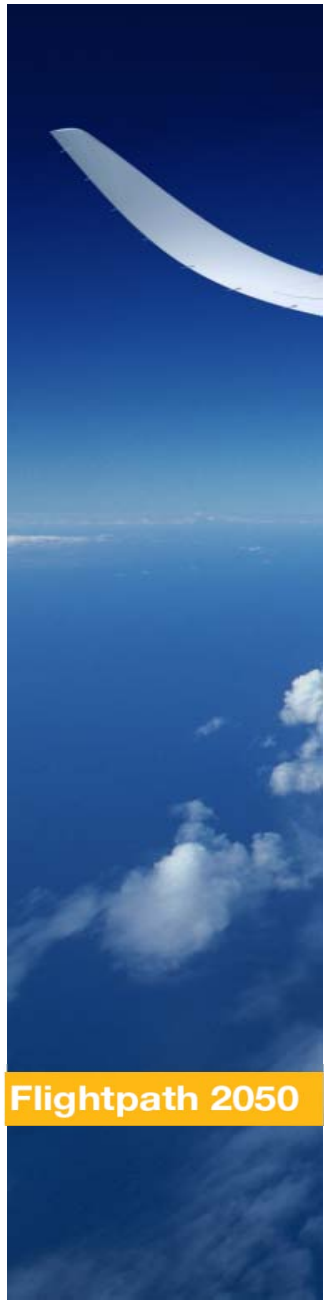
CLEANSKY
Joint Technology Initiative for Aeronautics & Air Transport
www.cleansky.eu

Europe's Vision for 2050 'Flightpath 2050'

Vision 2050:	Responding to society's needs
	Securing global leadership for Europe

Five Objectives of the Strategic Research & Innovation Agenda - SRIA

- Meeting Societal and Market Needs
- Maintaining and Extending Industrial Leadership
- Protecting the Environment and the Energy Supply
- Ensuring Safety and Security
- Prioritising Research, Testing Capabilities & Education



www.acare4europe.org

European Commission

The EU Framework Programme for Research and Innovation

'Horizon 2020'

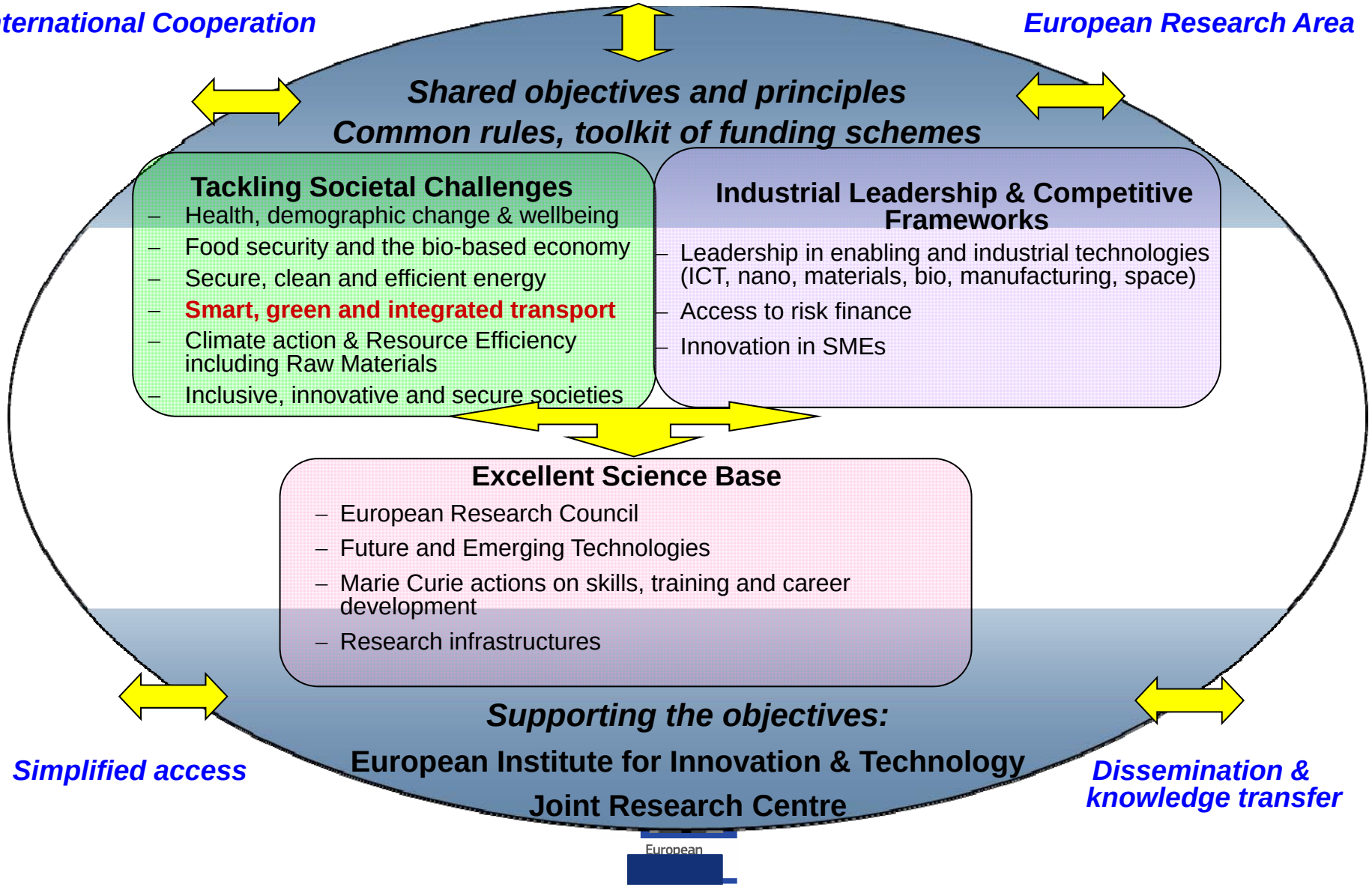
(2014 – 2020)

Three Priorities

1. Excellent Science 31.7 % (of Budget)
2. Industrial Leadership 22.1 %
3. Societal Challenges 38.5 %

Budget: 77 billion Euro

‘Horizon 2020’
Objectives & Structure



"Smart, Green and Integrated Transport"

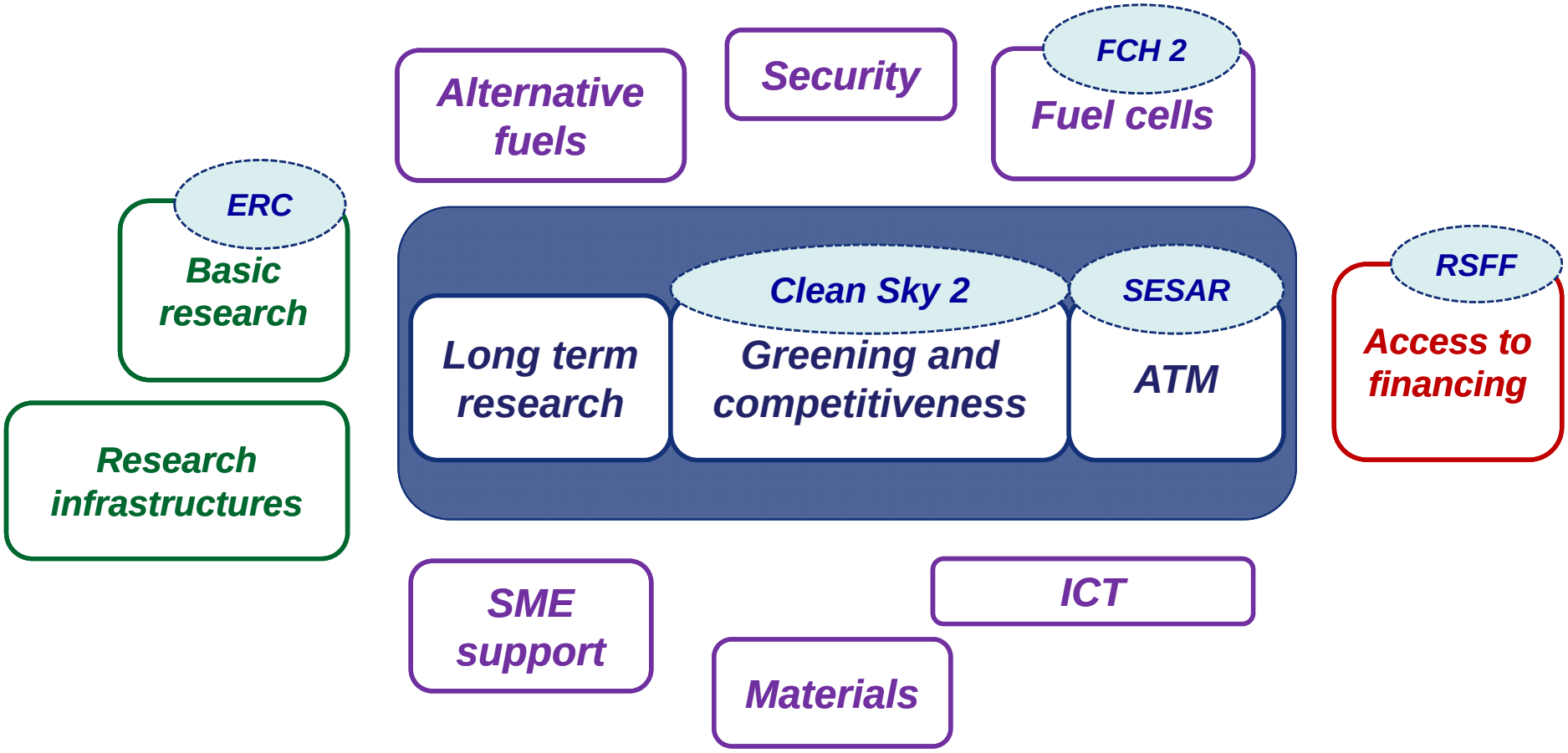
(budget of € 6 billion)

Focus on research that require trans-European cooperation to address today's most pressing transport challenges,

Aviation:

- **Making the European Aviation sector more competitive**
- **Decreasing its environmental impact**
- **Continuing to enhance the already very high levels of safety**
- **Contributing to seamless mobility when using air transport**

Aviation research and innovation in Horizon 2020



European Commission

What is new in 'Horizon 2020'

- Up to 100% research funding for all partners
- Single Stage and two stage evaluation procedures (mainly remotely)
- Large share of budget in Joint Technology Initiatives (JTI)
- Level 2 like activities in Clean Sky 2
- Bi-annual Workprogramme (with update for 2nd year)

Transport Workprogramme

European Commission

Aviation Topics 2014/ 2015

In line with the Strategic Research and Innovation Agenda (SRIA) of ACARE

- **Competitiveness of European aviation through cost efficiency and innovation**
- **Enhancing resource efficiency of aviation**
- **Seamless and customer oriented air mobility**
- **Coordinated research and innovation actions targeting the highest levels of safety for European aviation**
- **Breakthrough innovation for European aviation**
- **Improving skills and knowledge base in European aviation**
- **Support to European aviation research and innovation policy**
- **International cooperation in aeronautics**

European

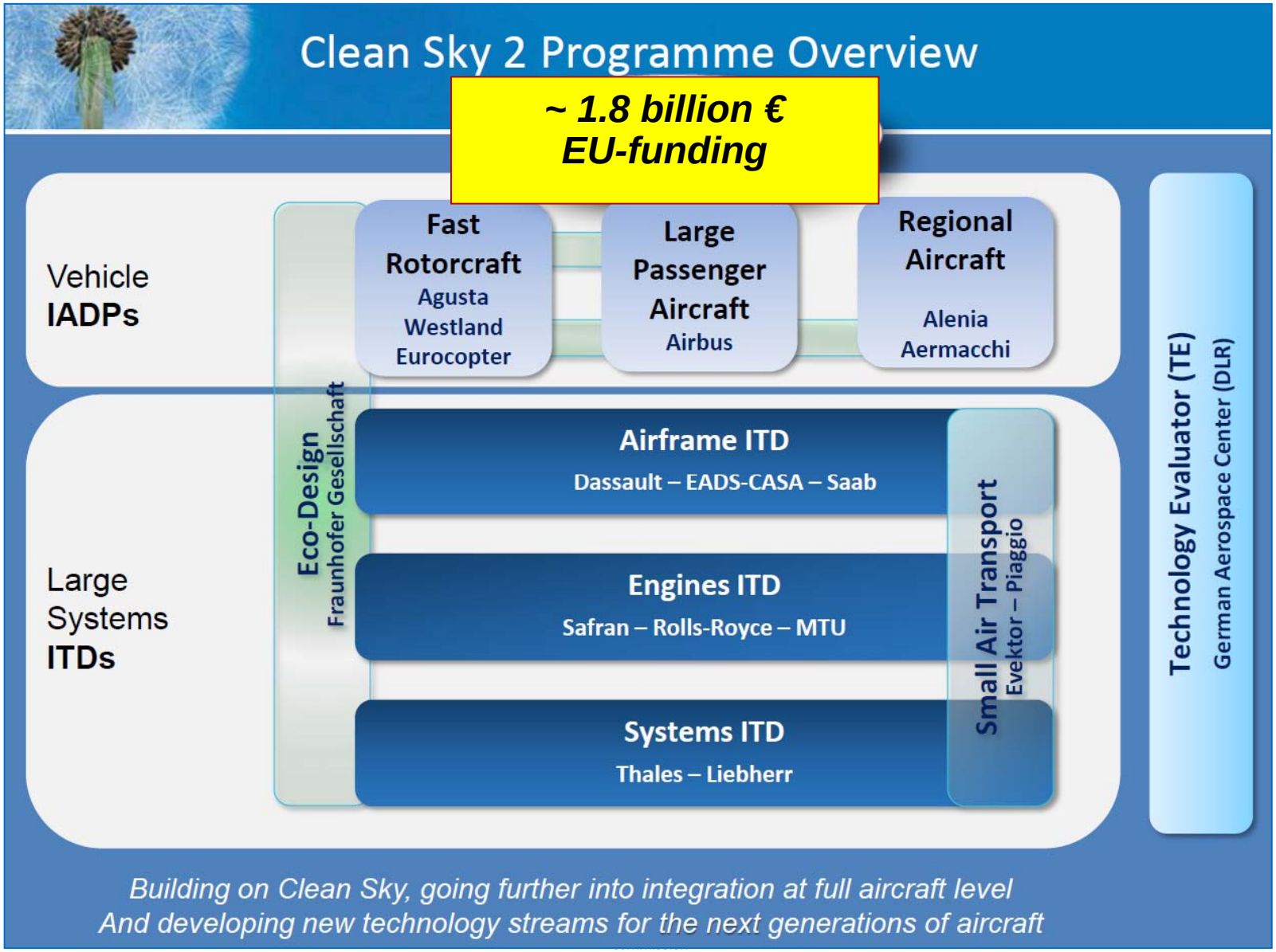
Clean Sky 2

New Frontiers beyond *Clean Sky*

1. **Bridging the gap**: FP7 & Clean Sky end well before 2020, the reference date for the "ACARE SRA1 Goals"
   - **Further demonstration required**: Some large systems from Clean Sky ITDs will still need further demonstration in order to achieve a full TRL6
   - **Further improvements will be needed to reach the 2020 Goals**, e.g. the 50% decrease of CO_2 (ACARE: 40% from Vehicle Technology – 10% from ATM & Operations)
2. **Growing competition** (including new entrants)
3. **New and ambitious goals** in ACARE SRIA

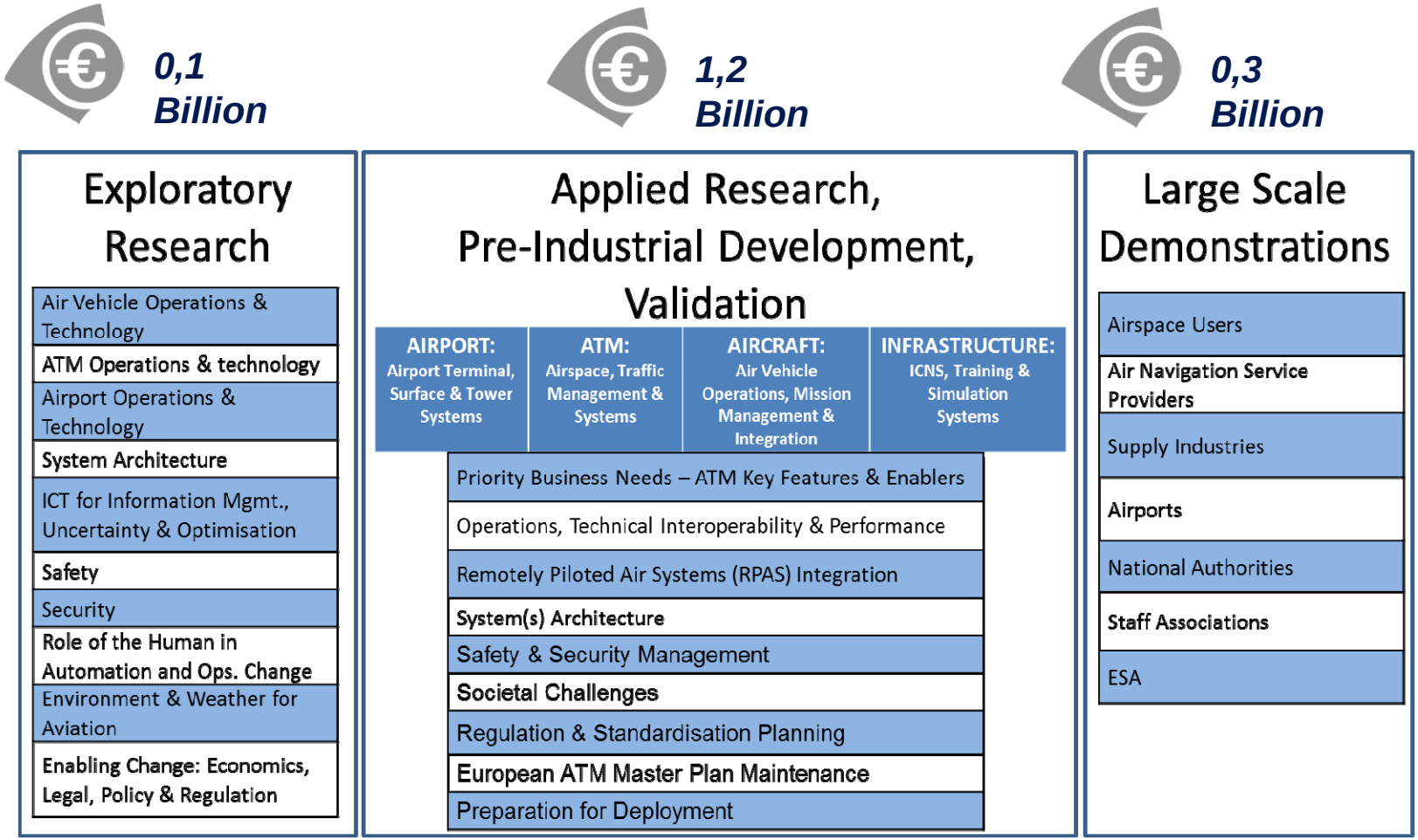
Not legally binding

JTI 'Clean Sky' is part of the Innovation Investment Package



Extension of SESAR Joint Undertaking

The High Level SESAR Programme Research and Innovation 2020 addressing remaining part of the European ATM Master Plan



Source: SESAR JU

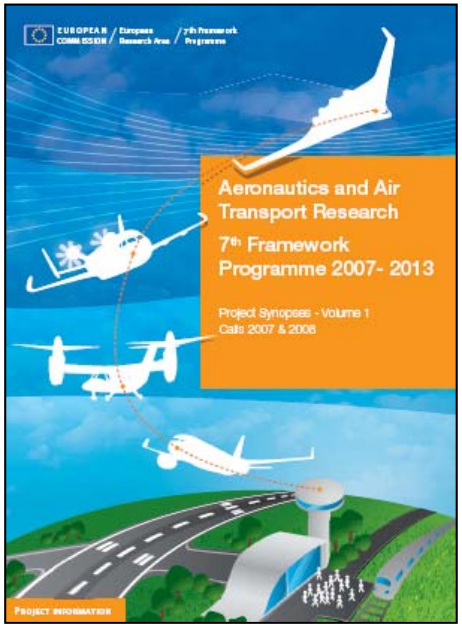
The Future

Where are we with Aviation?

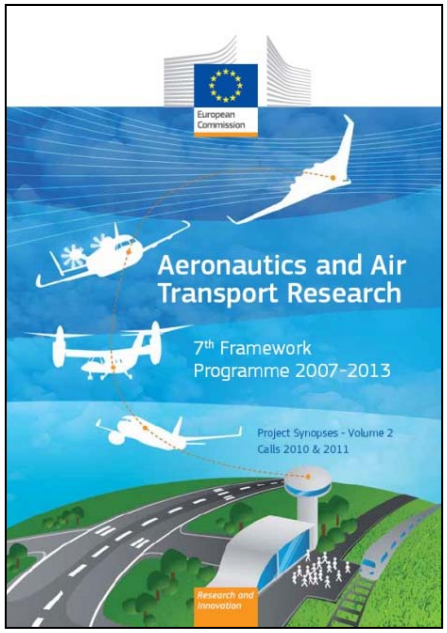
- Europe's Vision for Aviation and the SRIA of ACARE address the challenge of future needs
- Europe's new Framework Programme 'Horizon 2020' offers an opportunity and a multi-national platform for the needed technologies
- Most budget goes to Clean Sky 2 (1,8 billion €) and SESAR Extension (600 million €); little budget for the 'classical' RTD activities
- Council approved the Joint Undertakings (SESAR Extention, Clean Sky 2, etc.) in May 2014
- First Call closed in March and Commission launched the second Call in July 2014 (limited budget)

Project Synopses of 7th Framework Programme

FP7 Volume 1
Calls 2007 & 2008



FP7 Volume 2
Calls 2010 & 2011



FP7 Volume 3
Calls 2012 & 2013

PDF version for download:

http://bookshop.europa.eu/uri?target=EUB:NOTICE:KI3012536

European Commission

European Commission

The EU Framework Programme for Research and Innovation

2014 - 2020

Thank you for your attention!

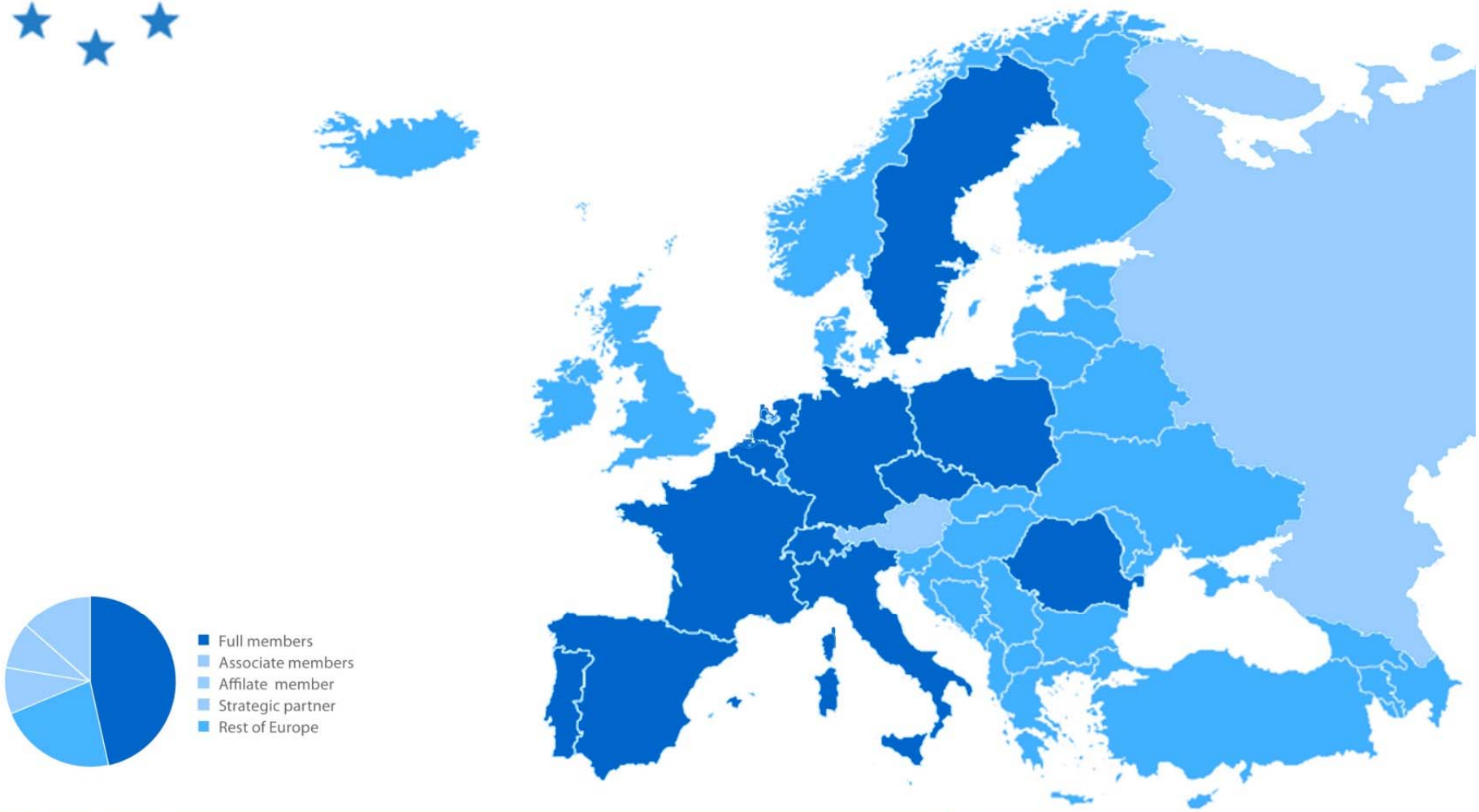
Association of
European Research Establishments in Aeronautics

Joint Research Initiative JRI “FutureSky”

Rolf Henke

EREA

Association of
European Research Establishments in Aeronautics



Full members:

CEIJA · CIRA · DLR · FOI · INCAS · INTA · NLR · ONERA · VON KARMAN INSTITUTE FOR FLUID DYNAMICS · :: csem

Associate members, Affilate member & Strategic partner

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY · CIAM

EREA in numbers

> 5.000

Employees in aeronautics

~ 180

Number of PhD Thesis

~ € 0,5 Bln

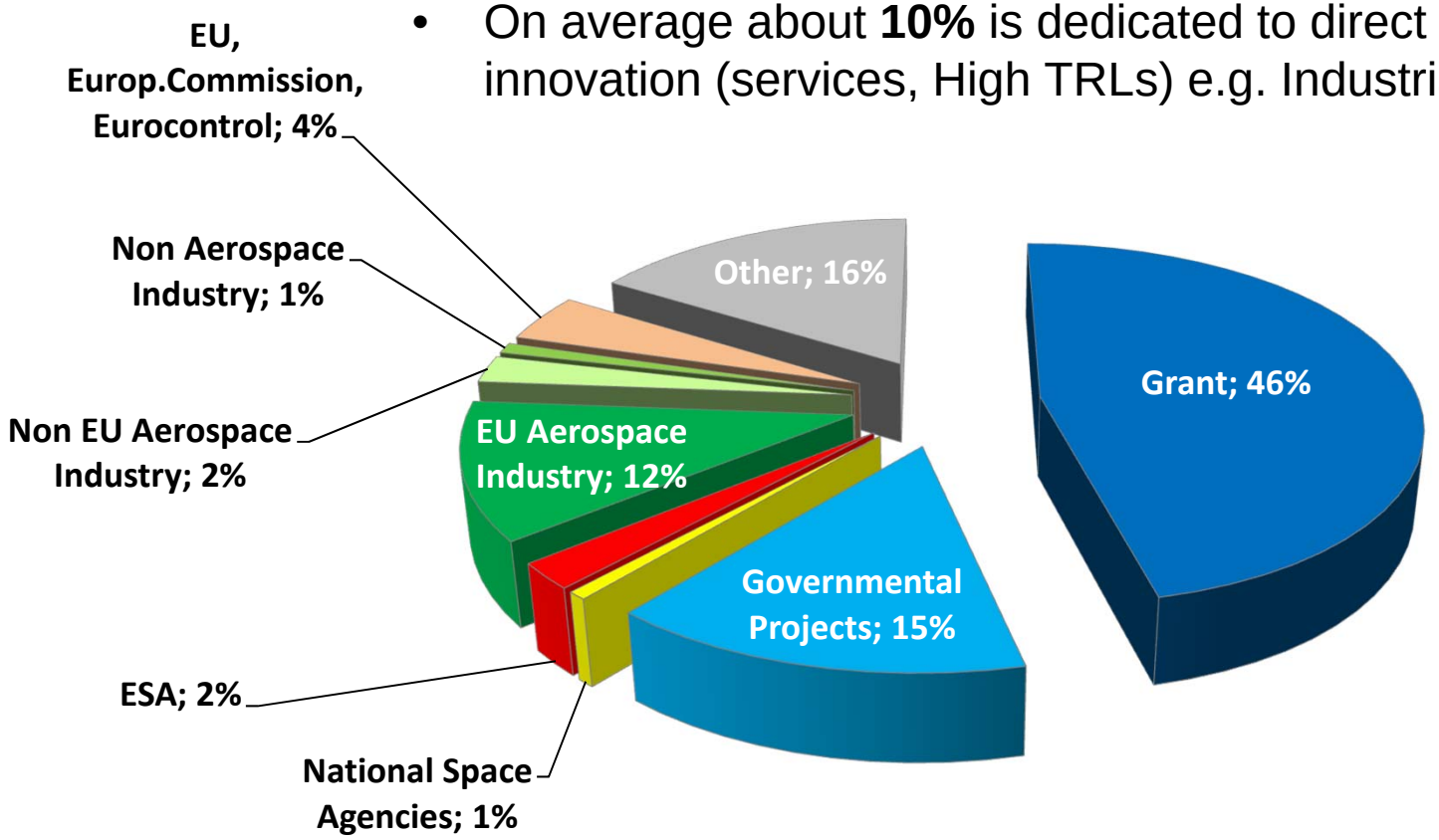
Annual spend on research in aeronautics

> 6.000

Number of Publications

Breakdown of EREA Revenues (2011)

- On average about **20%** of EREA work is used to build up new knowledge (Low TRLs 0-3)
- Technology development counts on average **70%** of EREA's work (TRLs 4-6), e.g. Collaborative Projects
- On average about **10%** is dedicated to direct support to industrial innovation (services, High TRLs) e.g. Industrial Contracts



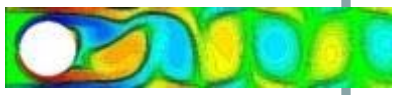
The Role of EREA

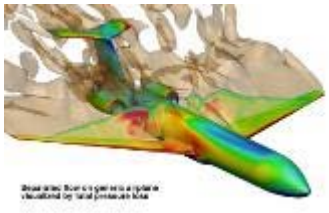
Development & Integration of technologies

Transfer to industry

Production & commercialisation

Research





Universities

Industrial partners, Spin-offs, Start-ups

Example of technology transfer

Eurocopter BlueEdge® Low Noise Blade

ONERA THE FRENCH AEROSPACE LAB

DLR

Development & Integration

EUROCOPTER AN EADS COMPANY

ONERA THE FRENCH AEROSPACE LAB

Transfer & Industrialisation

EUROCOPTER AN EADS COMPANY

ONERA THE FRENCH AEROSPACE LAB

2010: EC155

The Role of EREA: Applied Research and Research Infrastructure RI Provider

FP 2050 Goals

- „Next generation wide & narrow body aircraft“
- „Quiet short take-off & landing“
- „Night operations by quiet aircraft“

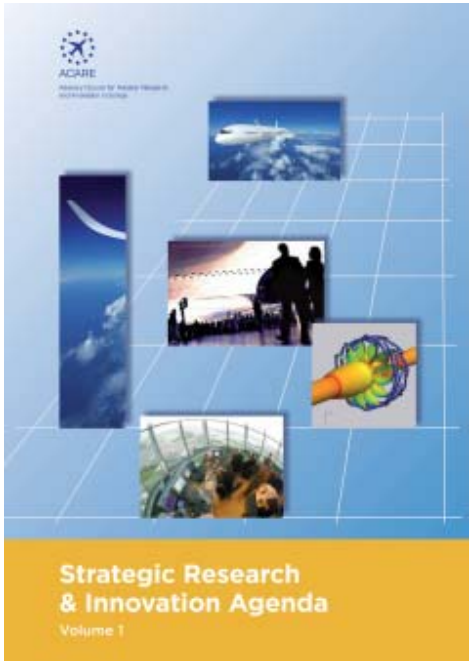
Requirements

- New TLAR (noise, intermodality, …)
- New methods (*design-to-noise*, source noise design)
- Massive flow control
- Mission adaption capabilities
- ATM design for 24/7 (incl. intermodality)

Infrastructures

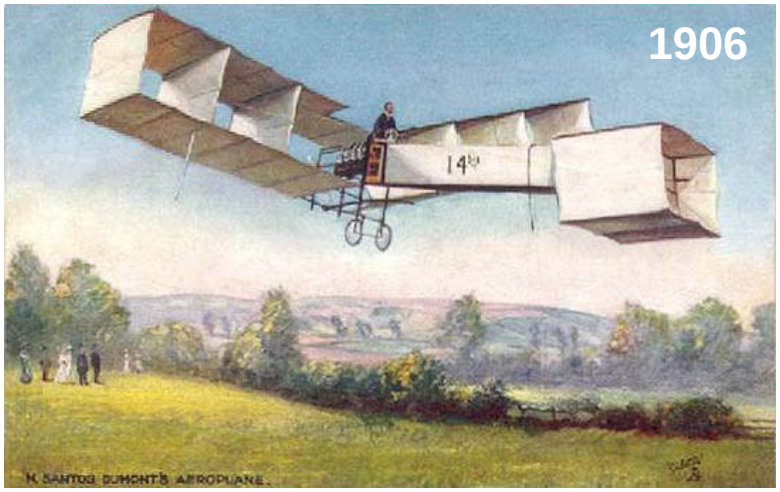
- Classic Aeronautics Infrastructure for aircraft design
  - HPC for CFD, CAA, CSM
  - Wind tunnels
  - Engine test beds
  - Structure test rigs, Iron Bird
- Aviation Infrastructure & Periphery
  - Labs for Noise Perceiption, Standardisation
  - Simulators for new ATM/ATS
  - Materials, Life Cycle, VR => Virtual Certification

Challenges



- Meeting Societal and Market Needs
- Maintaining and Extending Industrial Leadership
- Protecting the Environment and the Energy Supply
- Ensuring Safety and Security
- Prioritising Research, Testing Capabilities and Education

Looking Back to the Future



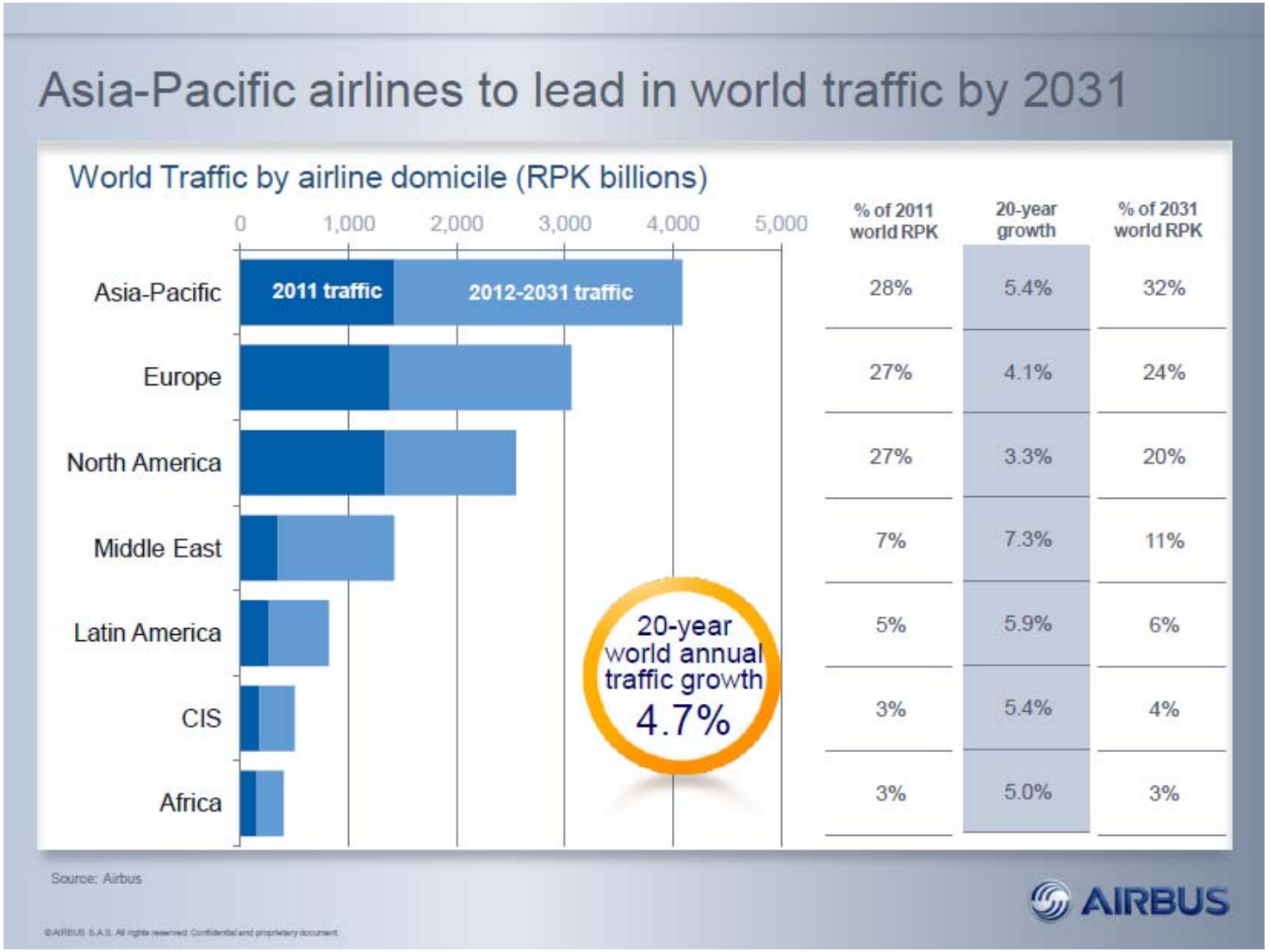
Convergence of Concepts

Looking Back to the Future

THF, Berlin-Tempelhof 1923

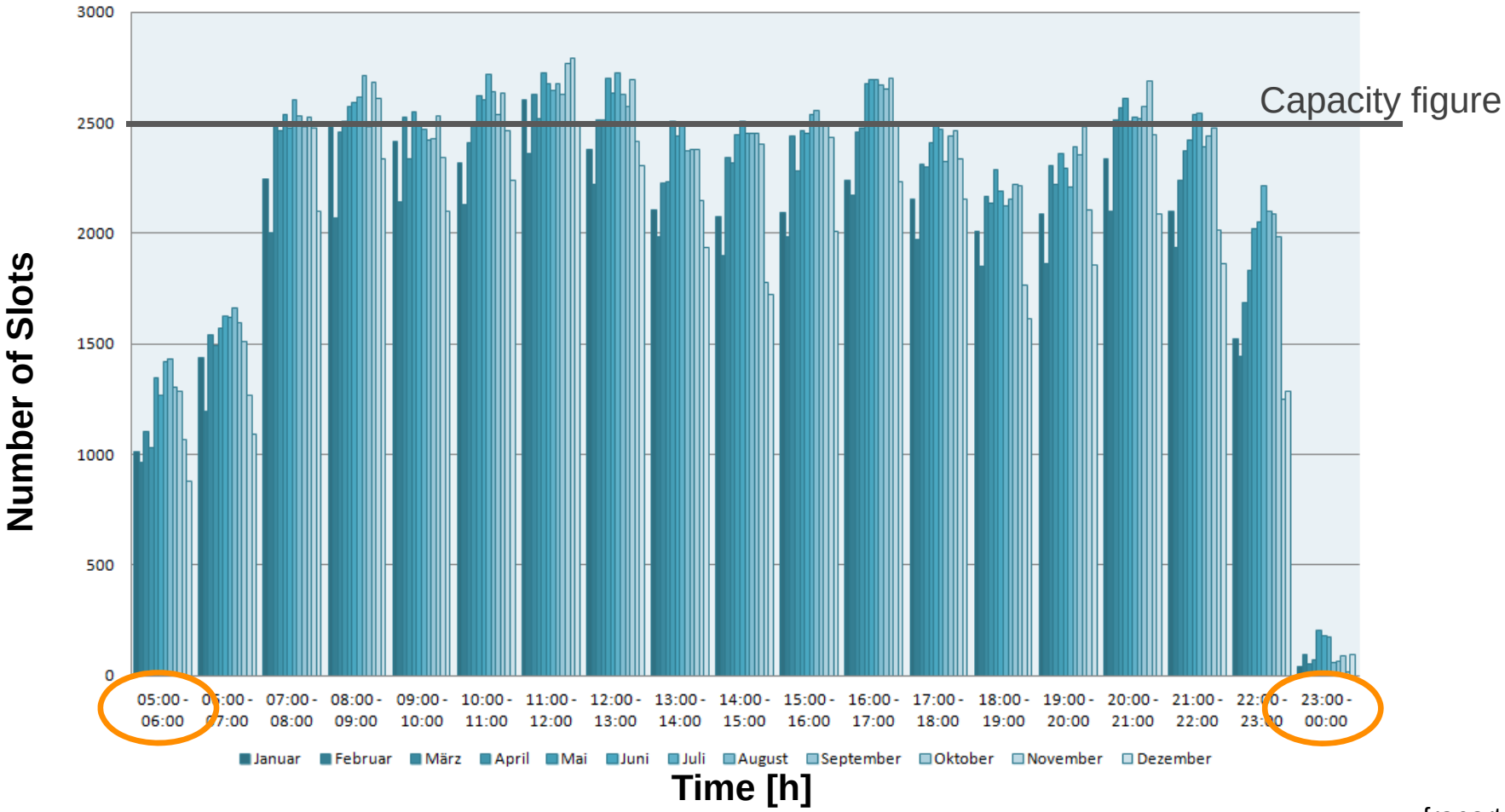
FRA, Frankfurt Airport 2006

Persistent Growth of Air Traffic

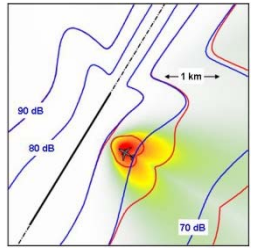


Only Little Room for Further Growth

Cumulative monthly slots at FRA per hour



24/7 Air Transport
Not With Today's Vehicles!



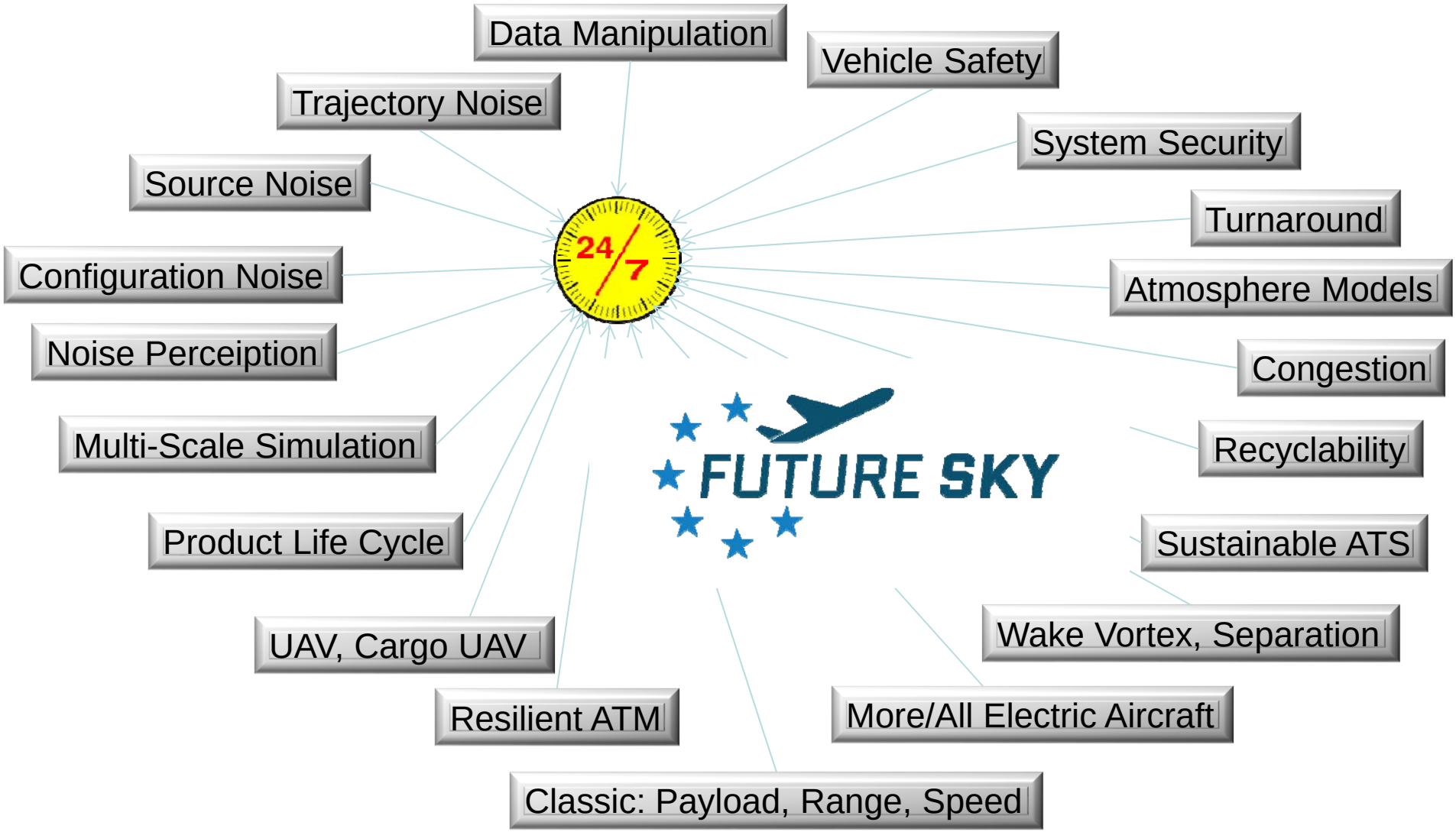
Noise

Wake Vortex / ATM

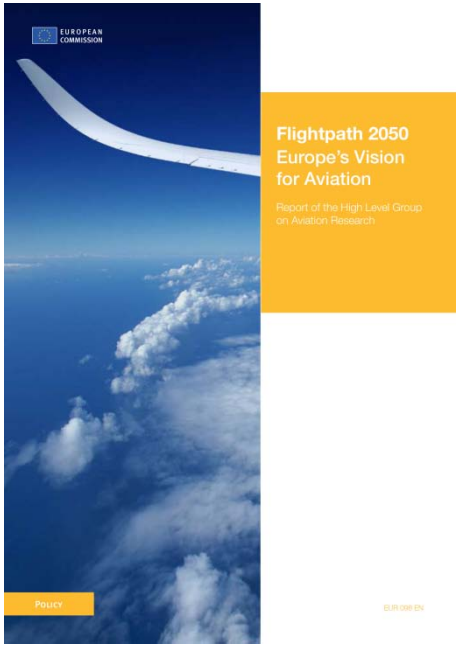
Emissions / Climate Impact

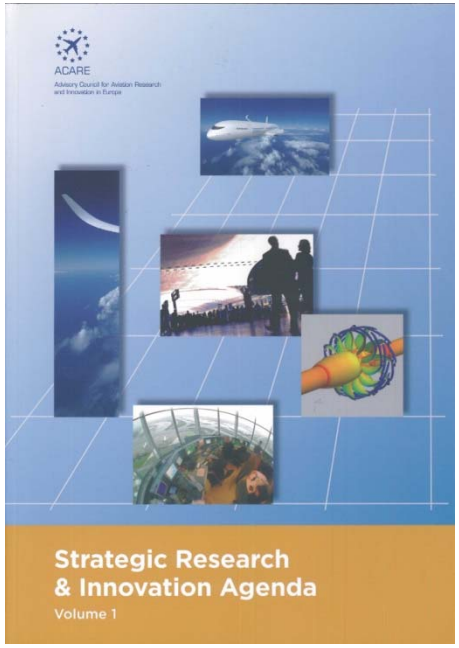
Ground Processes / Turnaround

Challenges linked to Aviation Growth



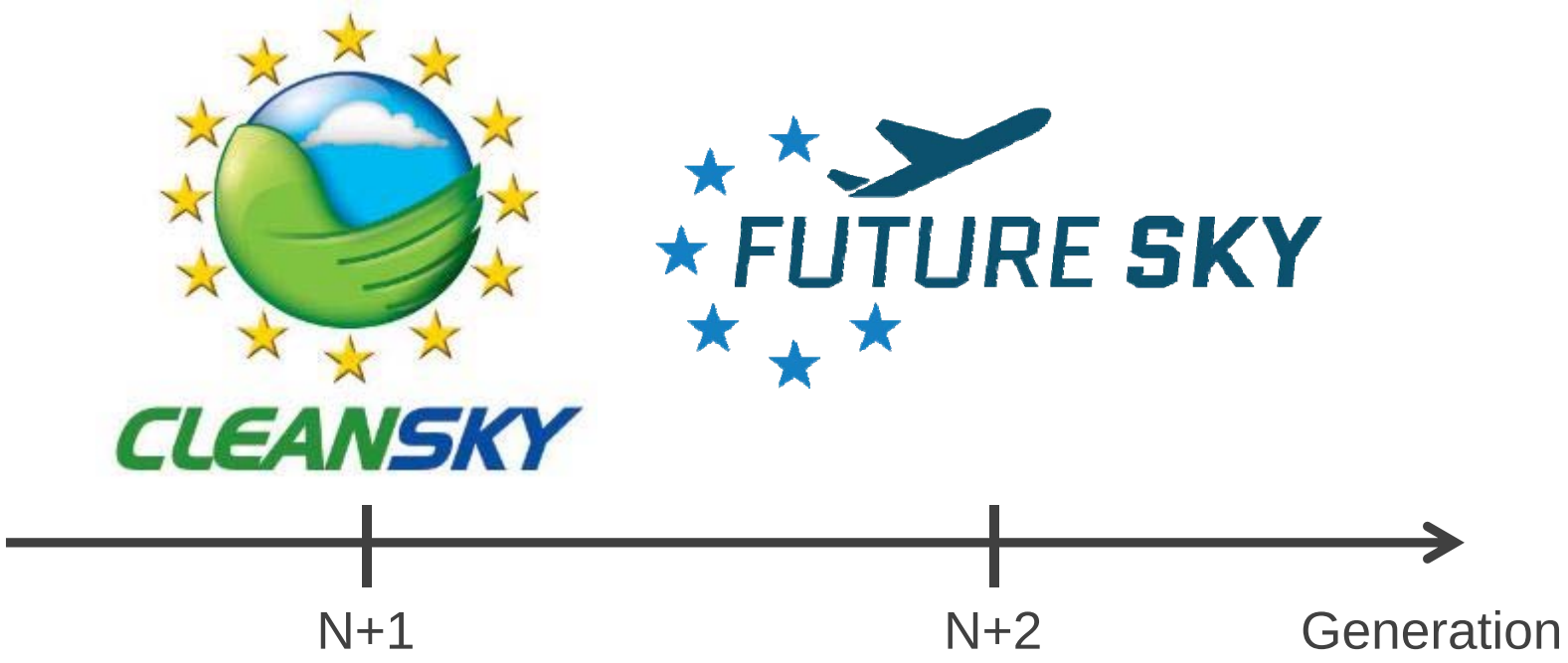
How to get there?





+ national aerospace strategies, e.g.:

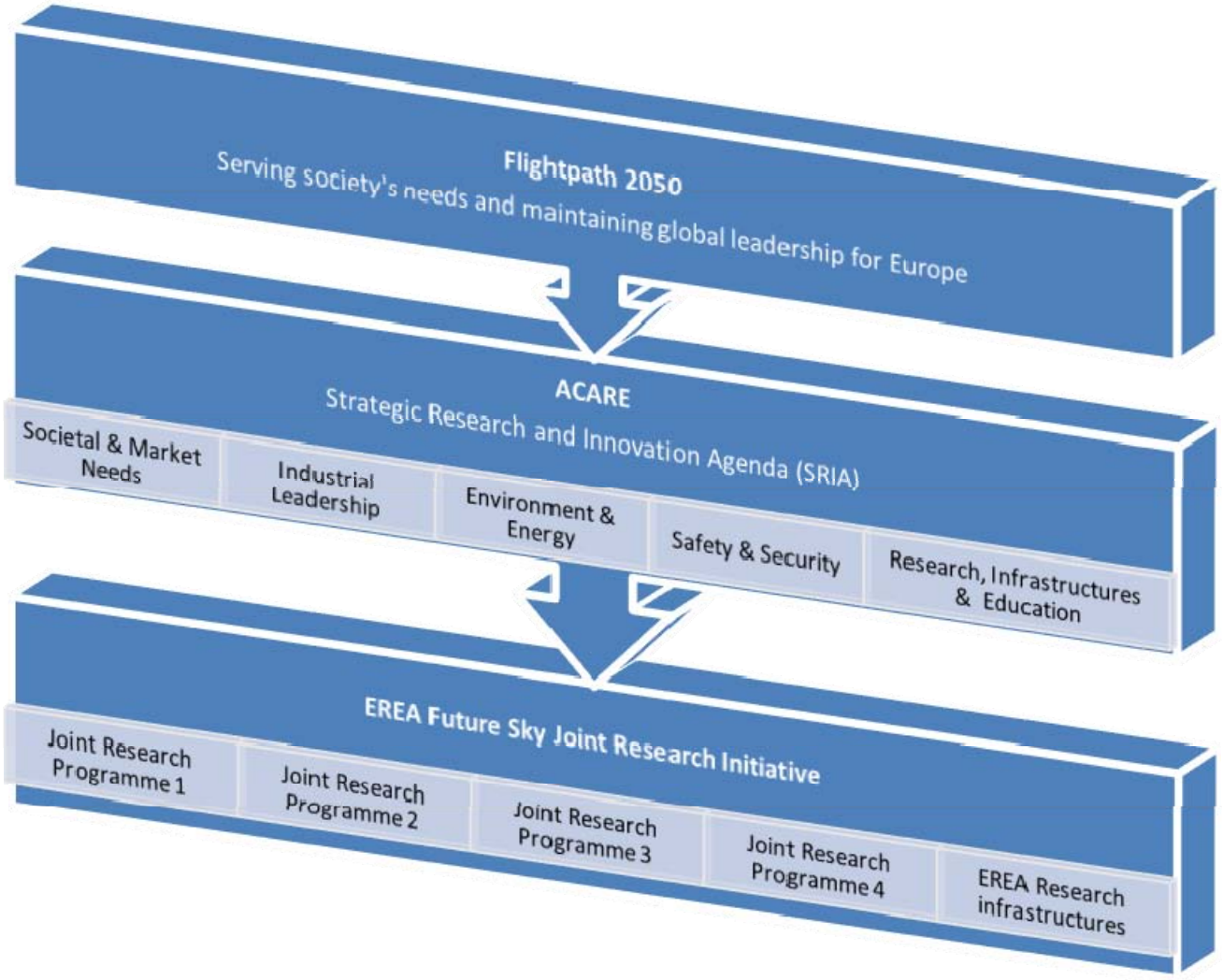
Open Up New Perspectives in Joint Research



Joint Untertaking JU

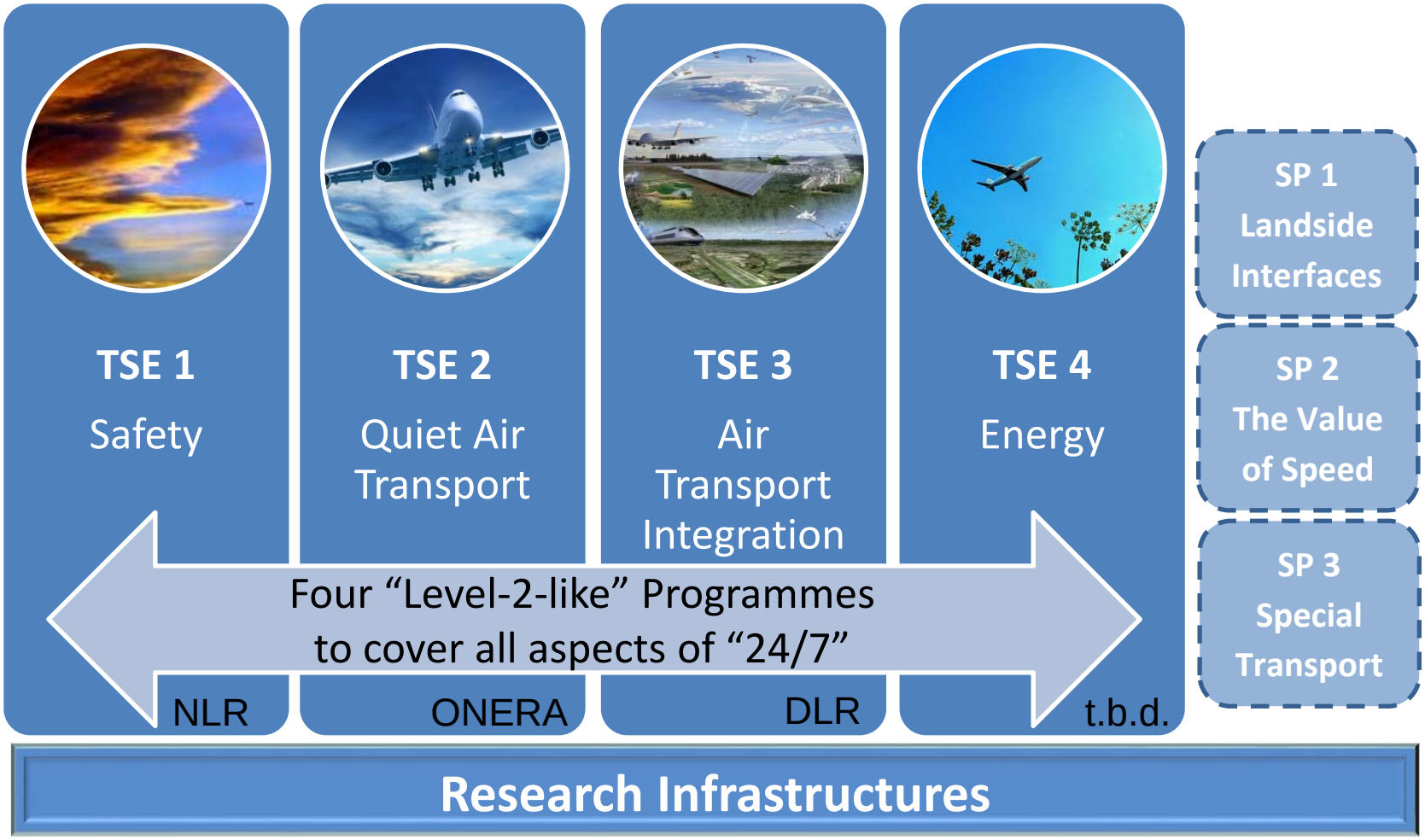
Joint Research Initiative JRI

Joint Research Initiative



Programmatic Outline

Enablers and Support Projects for 24/7 ATS



Overall FutureSky Management is at DLR

Future Sky Goals

Vision

Define technologies, systems and processes with regards to Flightpath 2050

Knowledge

Develop the knowledge for the next ATS generation including complex testing and validation capabilities

Contribute to the education of future engineers

24/7

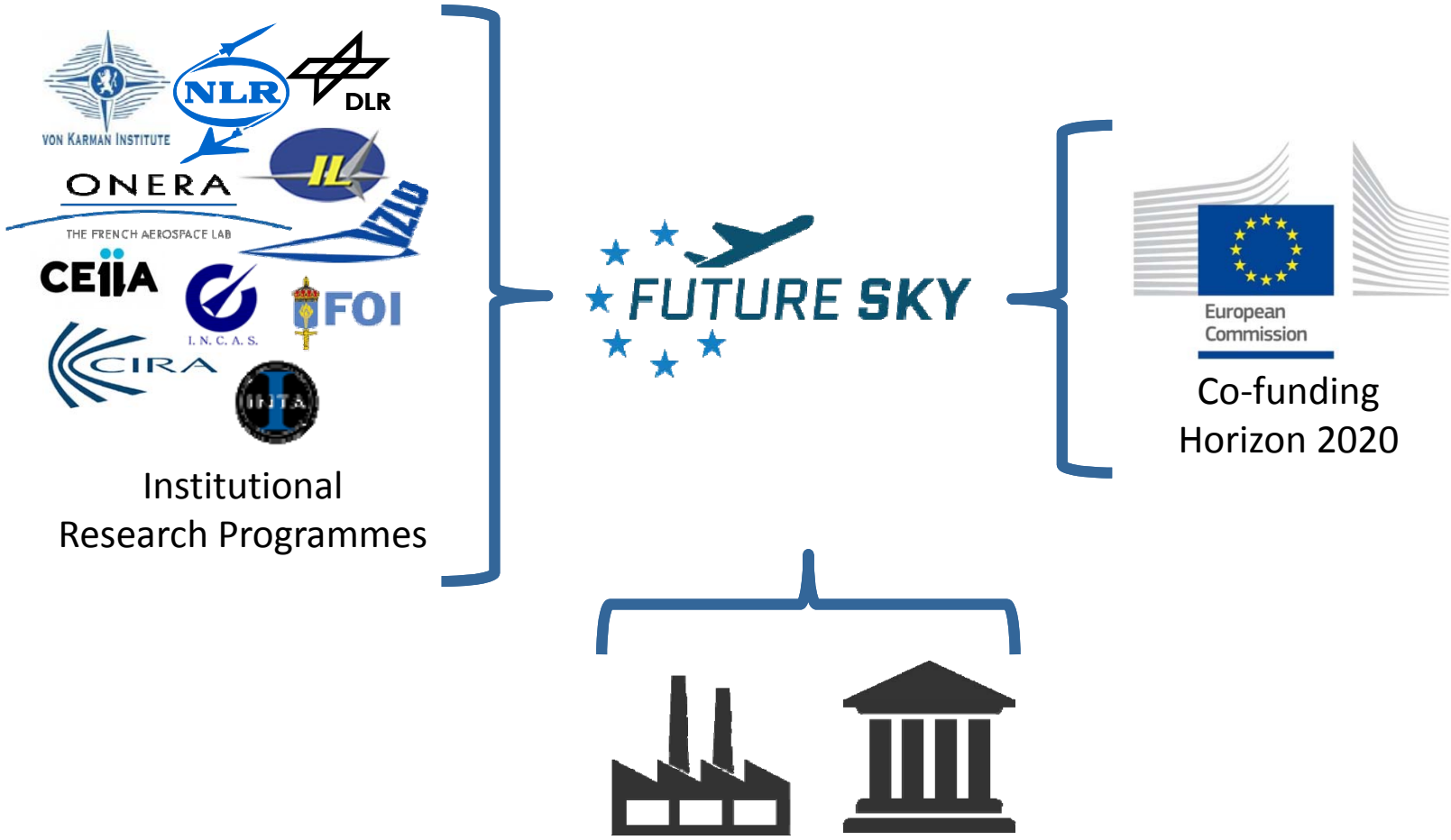
Attraction

Make aviation fascinating for the public and attract the young generation

Competetiveness

Analyse and prepare the scientific technological ground for future ATS beyond Clean Sky and SESAR

Funding & Participants



Whom to Call for European Aviation RTE*?

Henry Kissinger:

„Who do I call if I want to speak to Europe?“

*RTE: Research, Technology, Education

www.erea.org

www.futuresky.eu

Anisogrid Structures in EU-RU-Projects ALaSCA and PoLaRBEAR

Niemann, S., Hühne, C.

27th Oct. 2014, 4th EASN Workshop

DLR

SEVENTH FRAMEWORK PROGRAMME

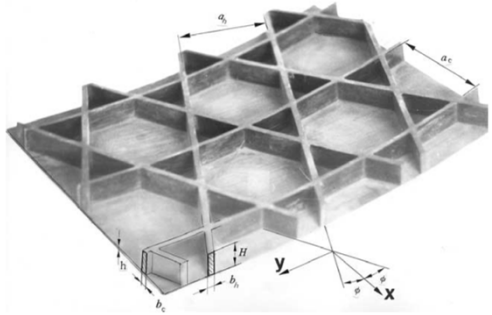
Motivation

- Anisogrid / Lattice structures in aerospace
  - Lightweight structure
  - Pro-Composite design
  - Cost-efficient fabrication

➢ Flying primary aero structures - interstage and adapter sections

Picture of launching Proton-M rocket (2009)

➢ *Anisogrid structures suitable for airframe structures?*



Source of Pictures: Prof. V.V. Vasiliev, CRISM

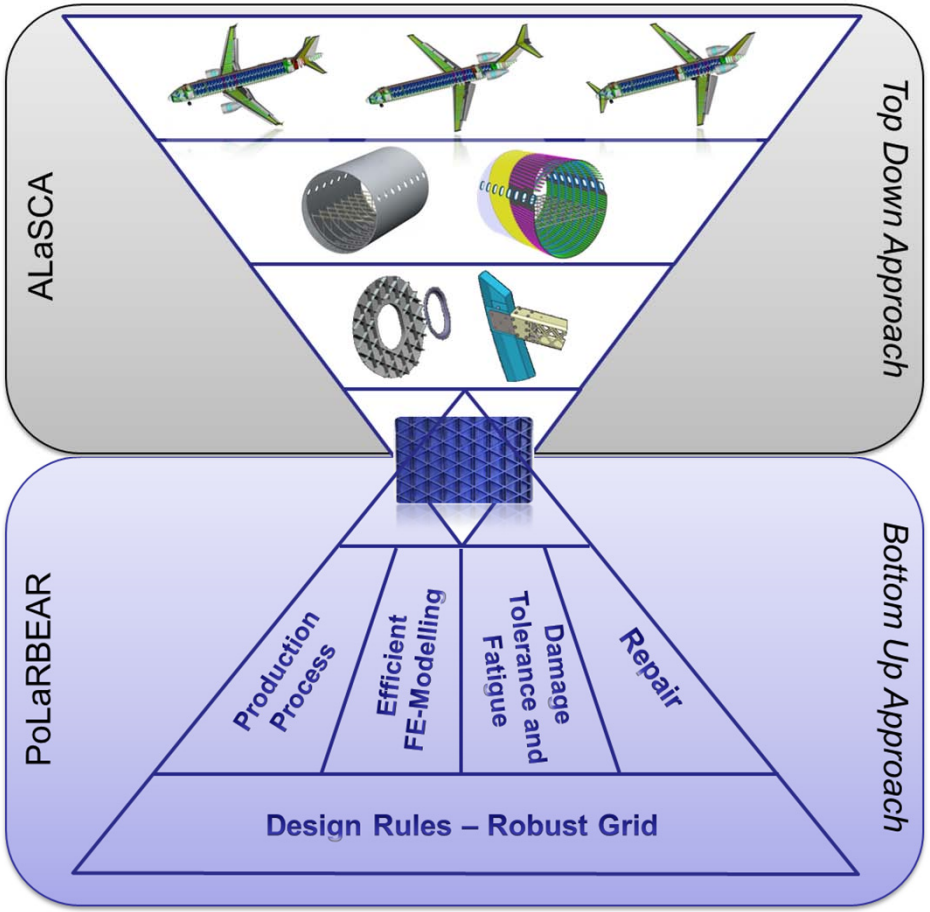
EU-projects - ALaSCA and PoLaRBEAR

➢**EU-RU-ALaSCA project**
- Dec. 2010 – Nov. 2013
- 6 EU and 6 RU partners

Goal: Technology Transferability

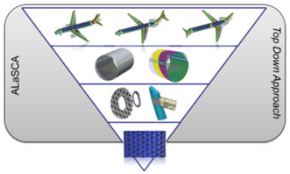
➢**EU-RU-PoLaRBEAR project**
- Dec. 2013 – Nov. 2016
- 6 EU and 6 RU partners

Goal: Increase of TRL



ALaSCA – Project

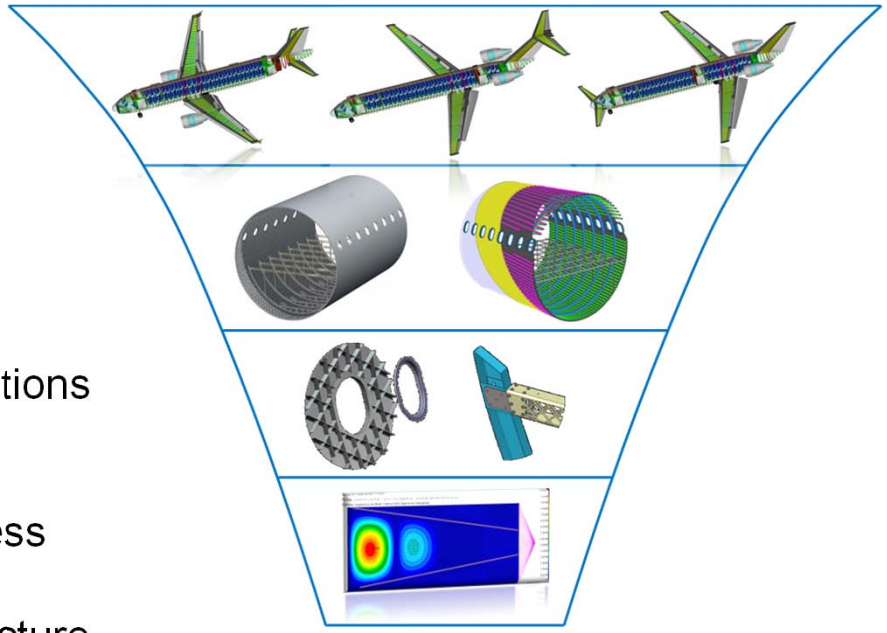
Advanced Lattice Structure for Composite Airframe



Idea: "*Is a lightweight Geodesic Structure,*
which is well-proven in space technology,
suitable for airframe structures?"

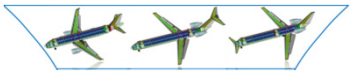
Methodology:

- Choice of airplane configuration suitable for composite fuselage
- Development and sizing of geodesic design
- Development of detailed design solutions (e.g. window belt)
- Developing methods for sizing process



Aim: Comparison of a geodesic fuselage structure with a conventional semi-monocoque structure

DLR PoLaR BEAR

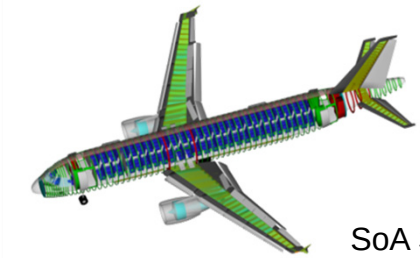


ALaSCA – Project

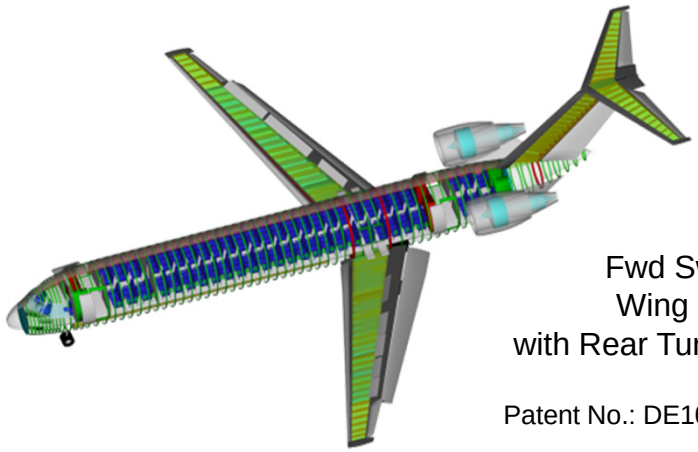
Configuration Investigation

- Investigation of three airplane configurations
- Overall airplane design analysis
- Forward swept wing with aerodynamic benefits and future engine concepts

- Determination of fuselage loads out of flight envelope

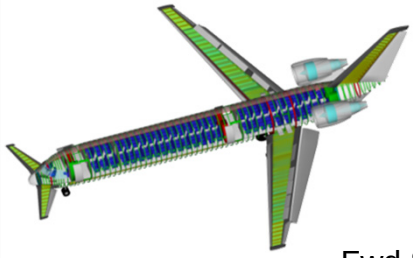


SoA Single Aisle
Aircraft Configuration



Fwd Swept Laminar
Wing Configuration
with Rear Turbine Engines

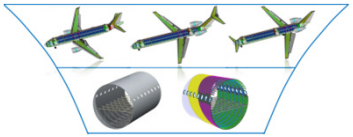
Patent No.: DE102012002352B4



Disruptive
Fwd Swept Wing
Canard Configuration

Aircraft configuration	m_{MTO}	L/D	$m_F/(R\ m_P)$	x_{CG}
Reference aircraft	72.6 t	16.4	2.50 l/(100 km 100kg)	15.5 m ... 17.2 m
ALaSCA configuration	74.0 t	19.4	2.27 l/(100 km 100kg)	19.8 m ... 21.8 m
Canard configuration	71.1 t	18.9	2.24 l/(100 km 100kg)	19.7 m ... 22.4 m

DLR PoLaR BEAR

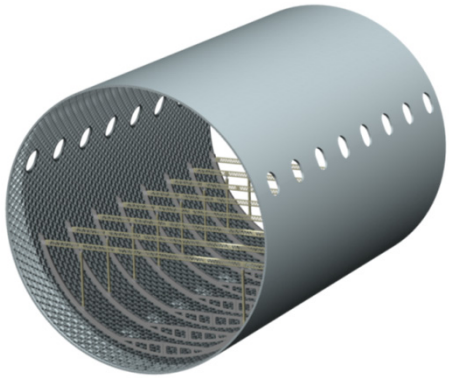


ALaSCA – Project

Barrel Design Concepts

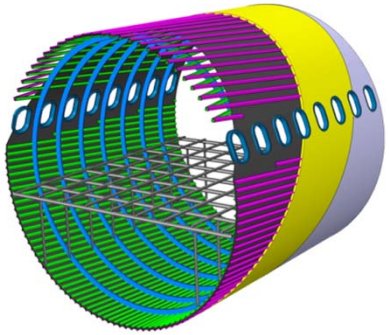
Integral Lattice Concept

- *Tailored lattice rib structure*
- *Skin for internal pressure loads*



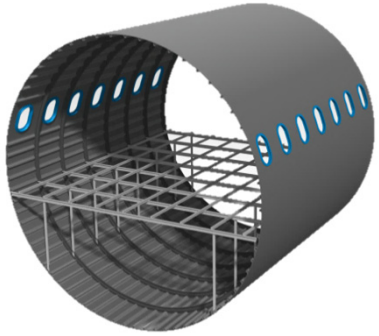
Differential Inner-Skin Concept

- *Load bearing skin*
- *Stiffeners on both sides of the skin*
- *Stiffeners with CFRP-Hybrid-Steel laminates*



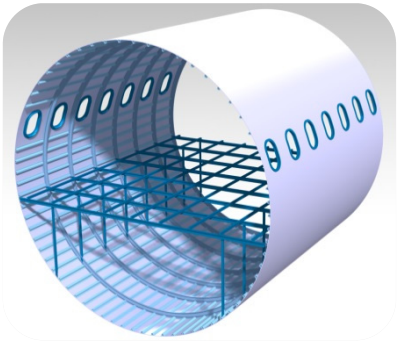
CFRP-Semi-Monocoque Concept

- *Skin-Stringer-Frame architecture*
- *Fully CFRP-Material concept*

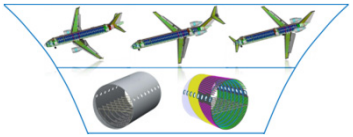


Al-Semi-Monocoque Concept

- *Skin-Stringer-Frame architecture*
- *Aluminium concept*



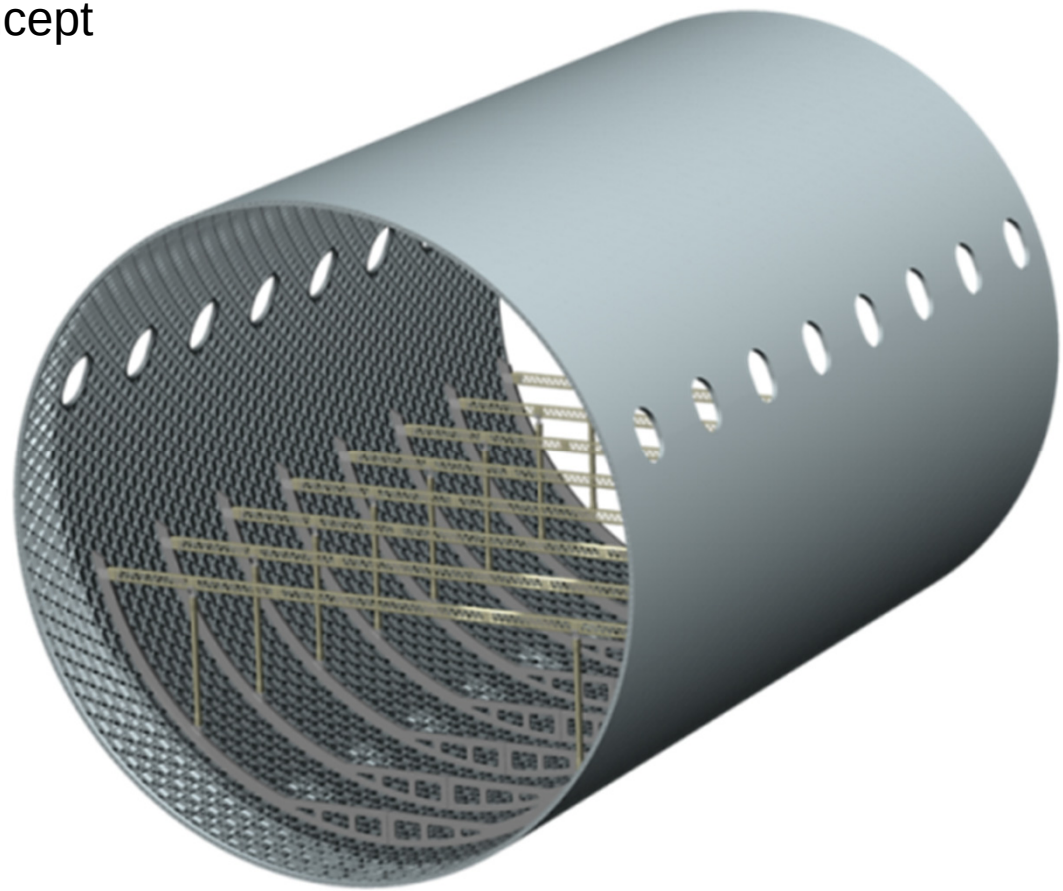
DLR PoLaR BEAR



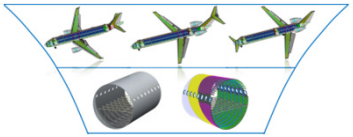
ALaSCA – Project

Integral Lattice Concept

- *Tailored lattice rib structure*
- *Skin for internal pressure loads*



Source: CRISM - Central Research Institute of Special Machinery



ALaSCA – Project

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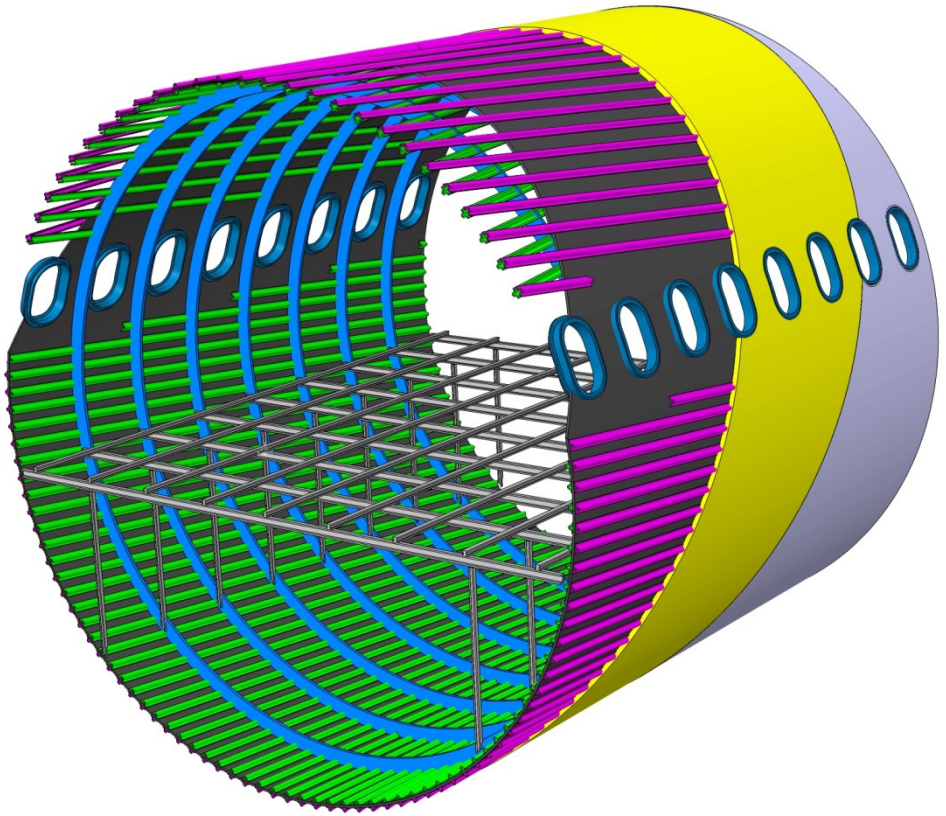
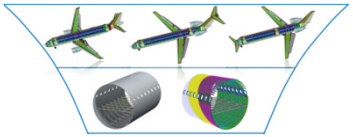


Patent Concept: DE102012019905B3
Patent Hybrid-Material: DE102010035324A1

DLR PoLaR BEAR

ALaSCA – Project



CFRP-Semi-Monocoque Concept

- *Skin-Stringer-Frame architecture*
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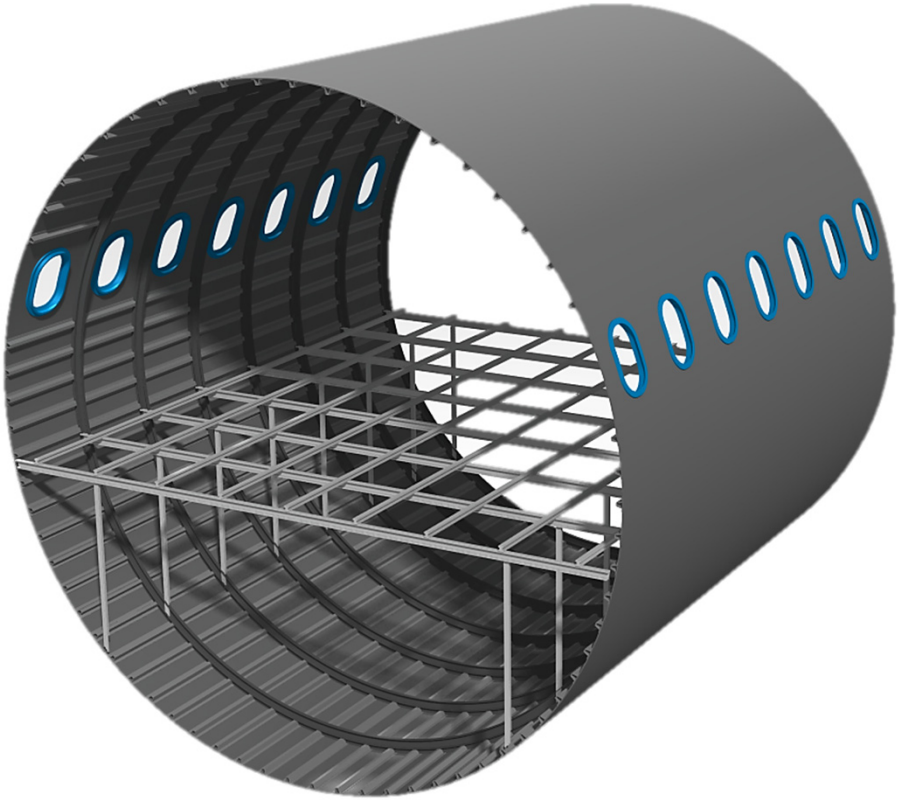
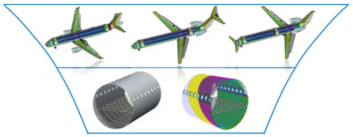
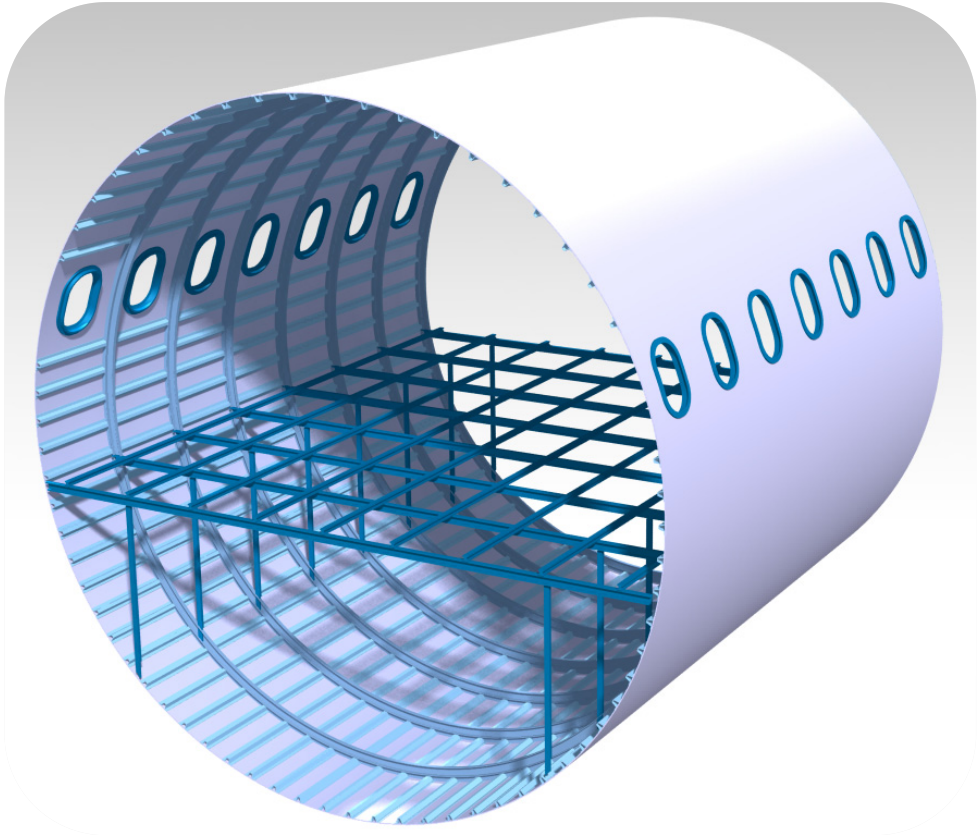


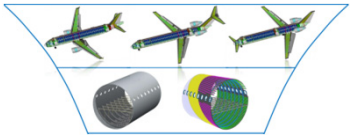


ALaSCA – Project

Al-Semi-Monocoque Concept

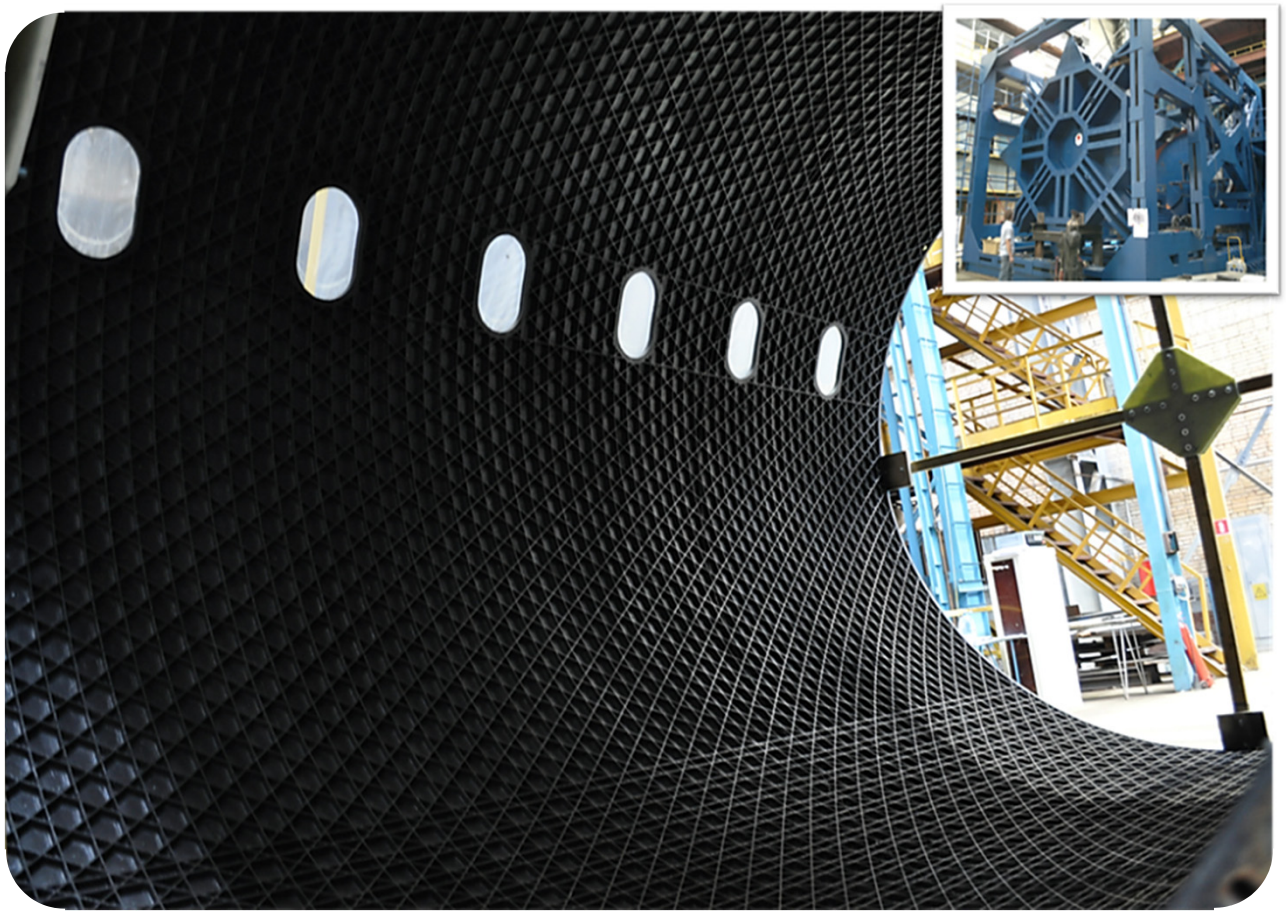
- *Skin-Stringer-Frame architecture*
- *Aluminium concept*





Tailored Integral Lattice Concept

Full-scale Demonstrator and Testing Barrel

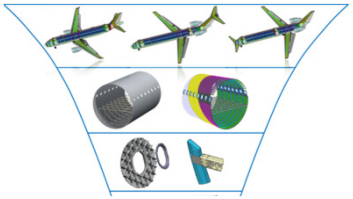


TsAGI Demonstrator and Testing Full-Size Barrel
manufactured by CRISM

TSNIISM

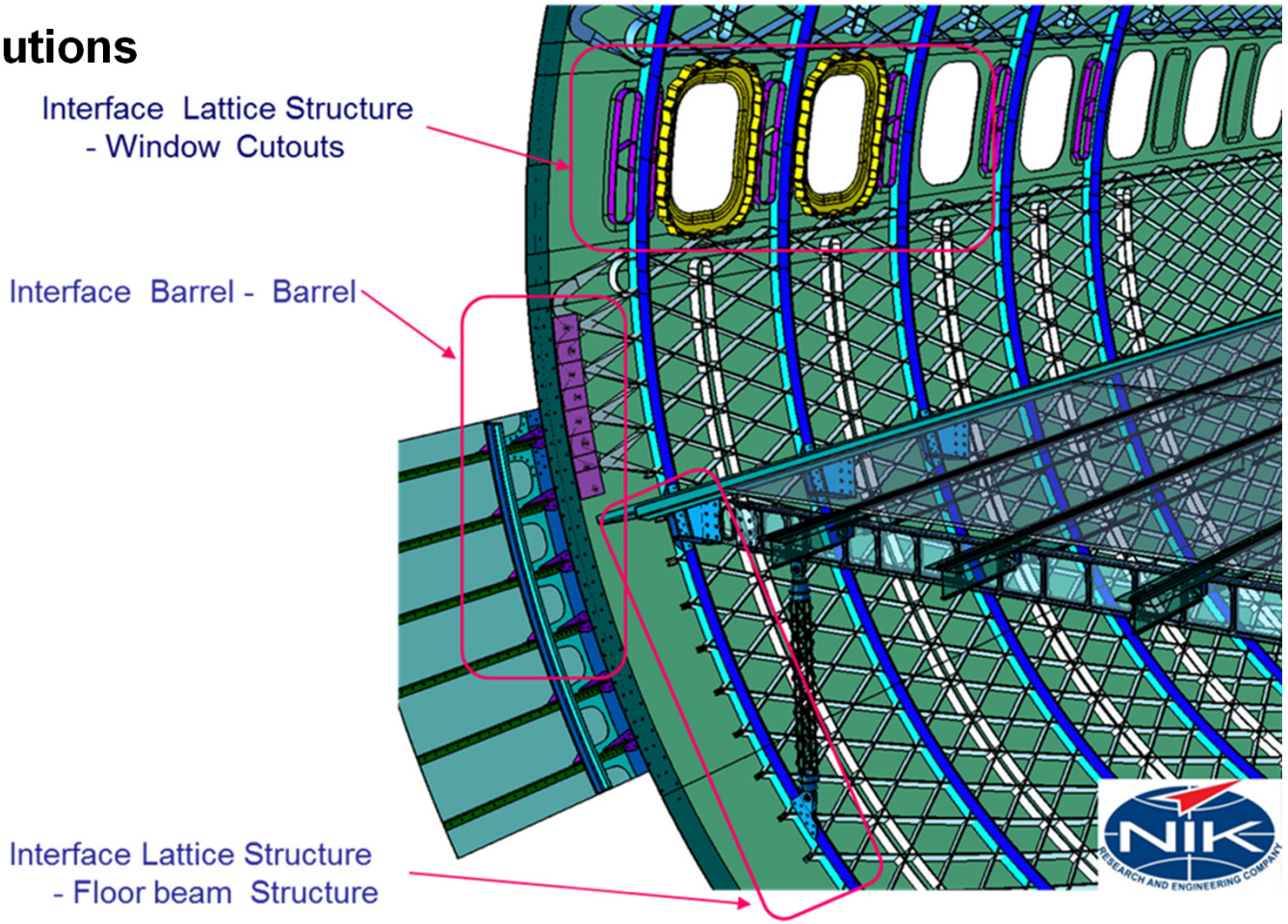
DLR

PoLaR BEAR



ALaSCA – Project

Detail Solutions



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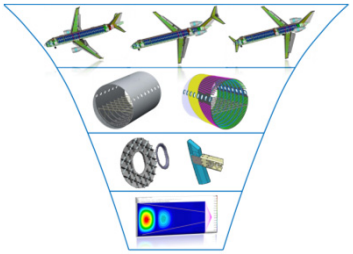
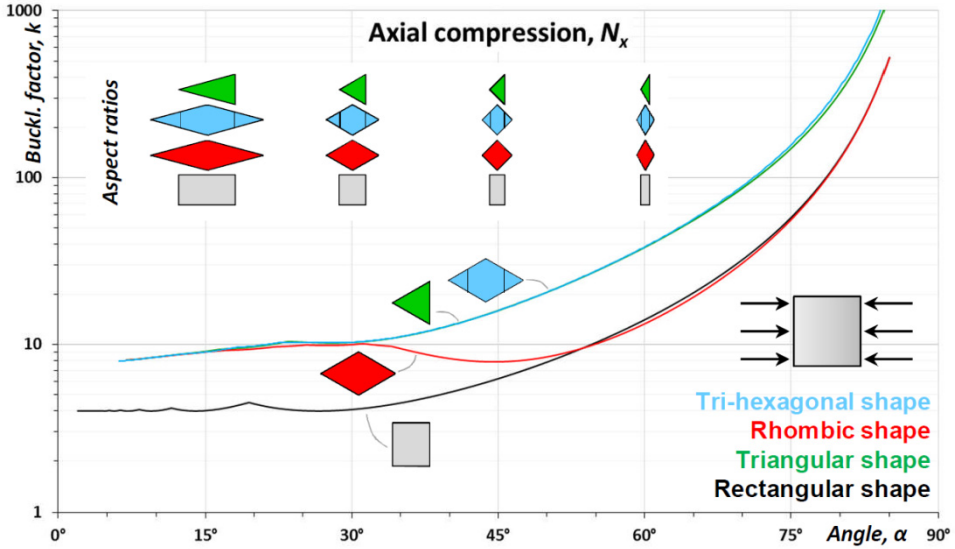


ALaSCA – Project

Methods:

- Method development
  - Semi-analytical buckling value determination method for orthotropic skin fields
- Algorithm development
  - Multi parameter optimisation algorithm with automated numerical model generator
  - Multi-level sizing algorithm for airframe barrel sections



Source: M. Weber – EADS-IW; Buckling Factor Diagramm

ALaSCA – Project

Conclusion

- Variety of possible structure designs (Patents, Publications)
- Method development for Structure Analysis
- 10% mass reduction for primary structure weight of barrel
- Resultant 1% overall fuel consumption reduction

Outlook

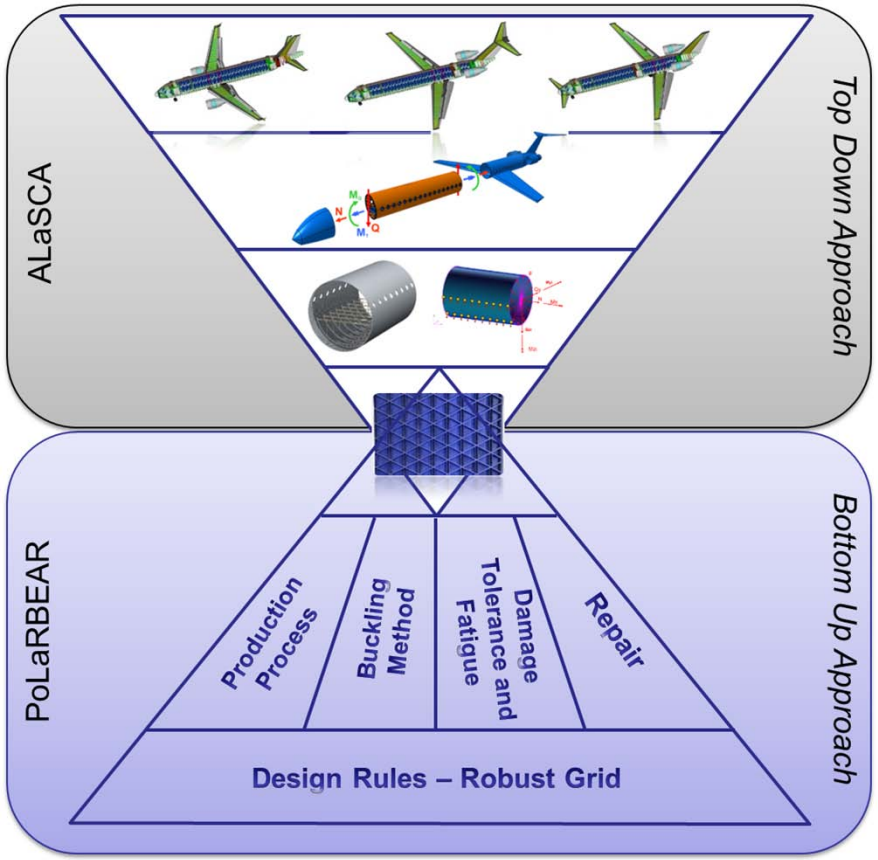
- Open questions especially on local level for highly integral structures

PoLaRBEAR - Project

Production and Analysis Evolution for Lattice Related Barrel Elements under Operations with Advanced Reliability

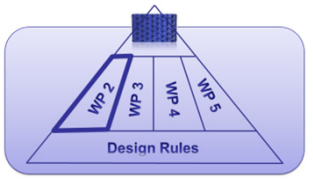
- **Approach**: Increase technology readiness level (TRL) of highly integral structures with analysis on local level

- **Main objectives** of this research programme are:
  - Industrial highly automated process for cost efficient barrel manufacturing
  - Advanced reliability of geodesic structures under operational loads
  - Design rules for robust grid structures



DLR

PoLaR BEAR

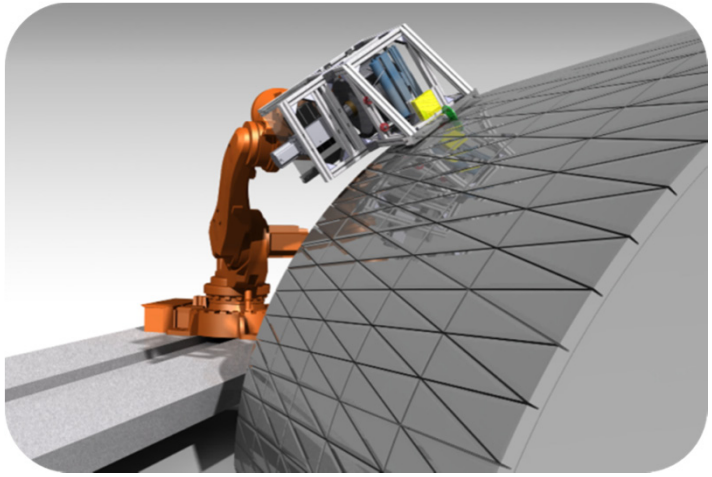


PoLaRBEAR - Project

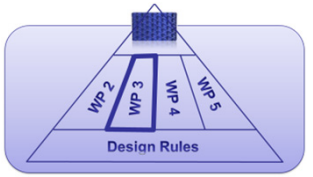
Manufacturing

- Investigation of Prepreg manufacturing process

- Winding Structures: Implementation of protection layer for highly unidirectional ribs



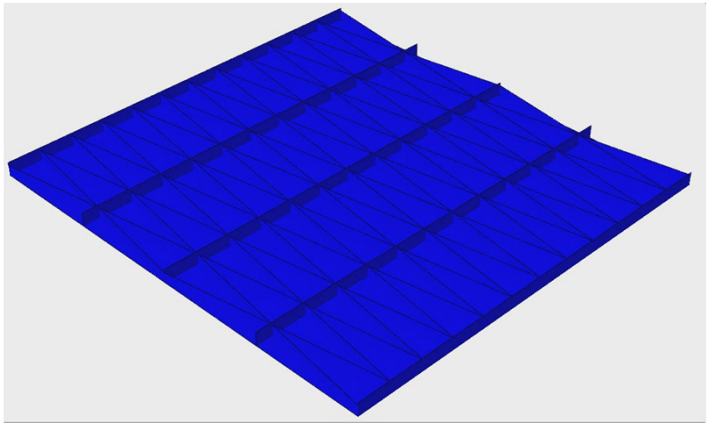
Source: TUBS – Technical University of Braunschweig

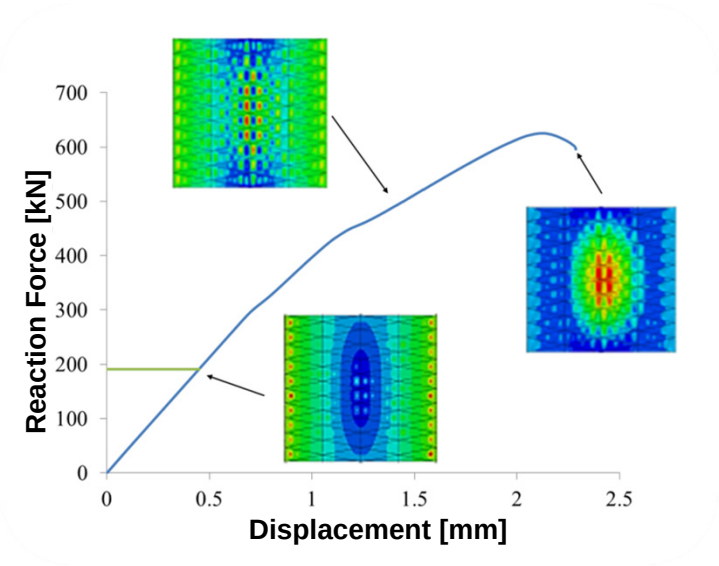


PoLaRBEAR - Project

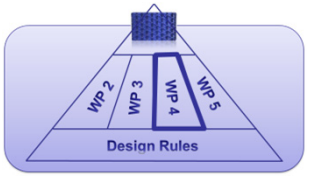
Efficient Numerical Analysis

- Modelling investigation for Anisogrid Structures
- Increase efficiency and robustness of numerical modelling process
- Buckling behaviour of delaminated ribs





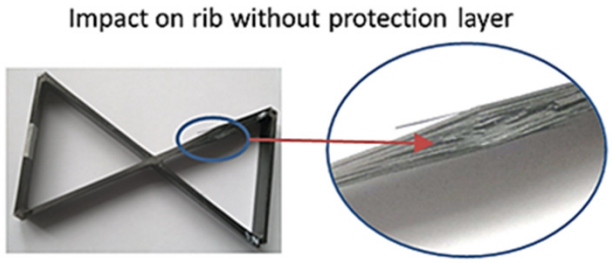
PoLaRBEAR - Project

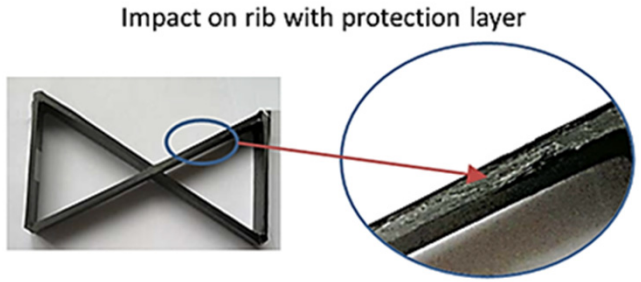


Damage Tolerance

- Impact tests on CFRP-Metal-Hybrid specimen
- Crack propagation analysis on CFRP-Hybrid-coupons
- Impact tests on highly unidirectional ribs with protection layer

Source: DLR – CAI Specimen

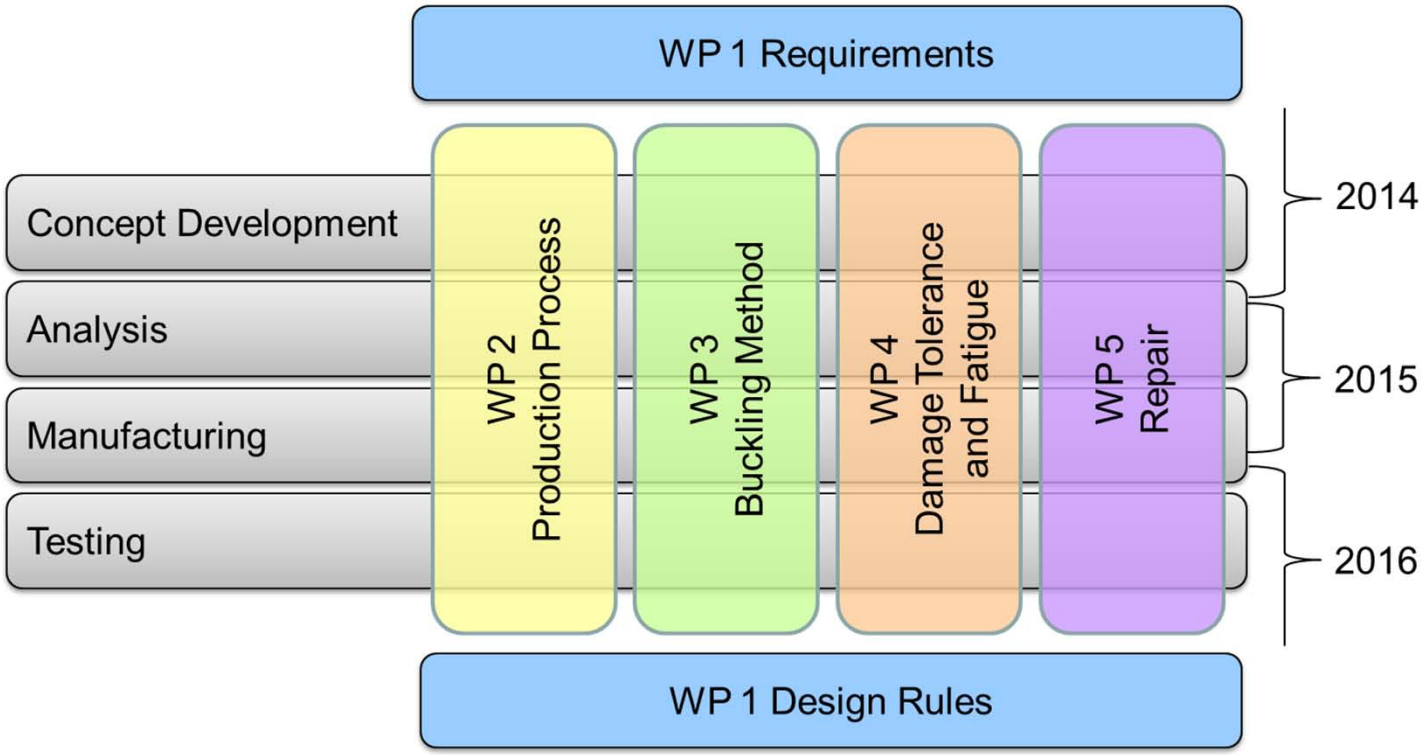




Source: TsAGI - Central Aerohydrodynamic Institute

PoLaRBEAR - Project

Outlook:



Thanks for your attention ..

Impressions …

DLR

PoLaR BEAR

4th EASN Association International Workshop
on Flight Physics & Aircraft Design

DEVELOPMENT OF LATTICE CONCEPT FOR ROBUST COMPOSITE FUSELAGE STRUCTURES

A.Shanygin, I.Kondakov (TsAGI, Russia)

V. Vassiliev, A.Razin (CRISM, Russia)

PoLaR BEAR

27th-29th October, Aachen, Germany

Main Stages of Development of Lattice Technology

1

Proton-M

Rocket concept

2

ALaSCA

Fuselage alternative concepts

3

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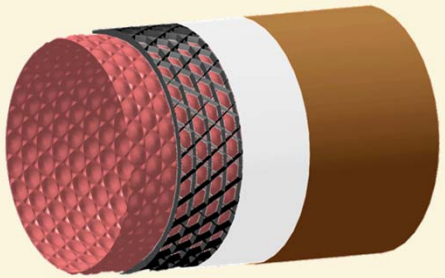
Fuselage rational concept



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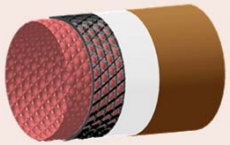
Concepts' Readiness Level
Taking Into Account the Main Requirements

FUSELAGE STRUCTURE CONCEPTS	GEOMETRICAL PARAMETERS	LOADS ON STRUCTURE	SAFETY AND ECOLOGY	LONG-TERM STRENGTH	MAINTENANCE AND REPAIR
Proton-M	– +	– +	– –	– –	– –
ALaSCA	+ +	+ +	+ –	– +	– –
 PoLaRBEAR	+ +	+ +	+ +	+ +	+ +

« – – » no investigations

« – + » preliminary level

« + – » conceptual level

« + + » detailed level

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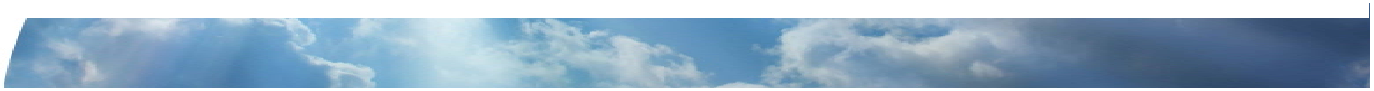
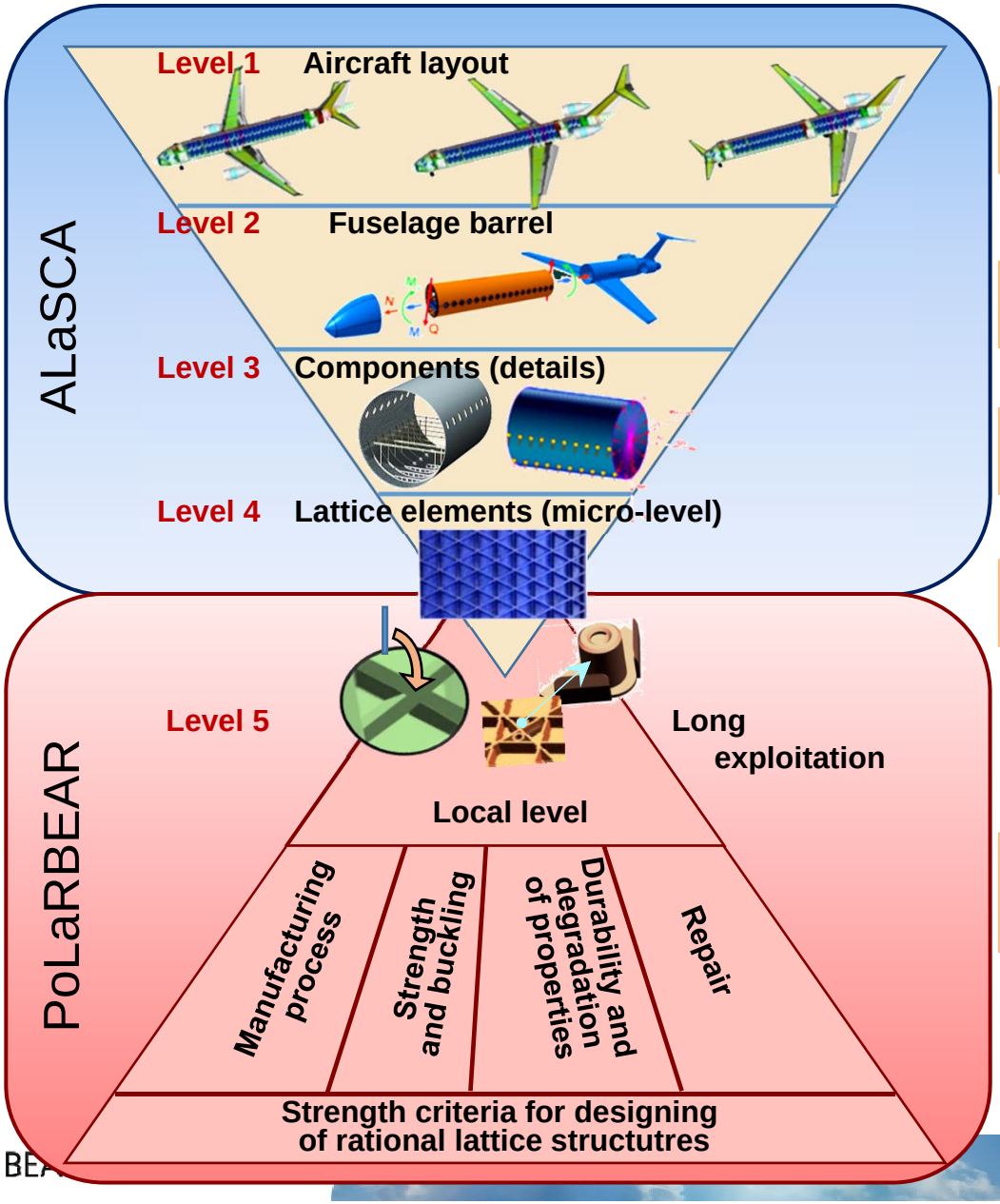


Evolution of Development of Lattice Composite Fuselage Structures



GEOMETRICAL PARAMETERS

LOADS ON STRUCTURE

SAFETY AND ECOLOGY

LONG-TERM STRENGTH

MANUFACTURING, MAINTENANCE AND REPAIR

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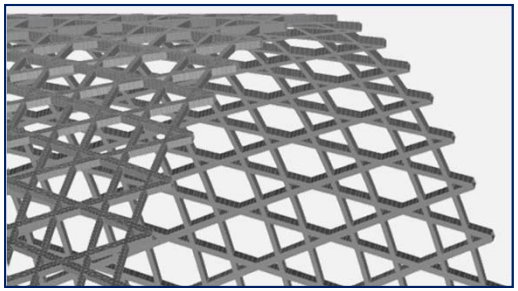
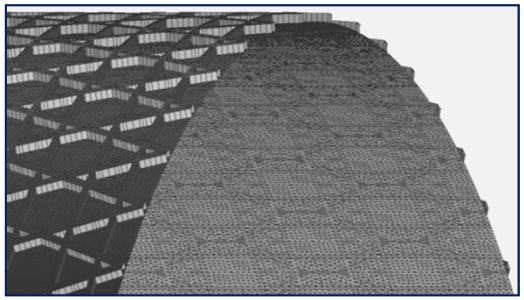
Evolution of Lattice Structure Concepts within ALaSCA Project

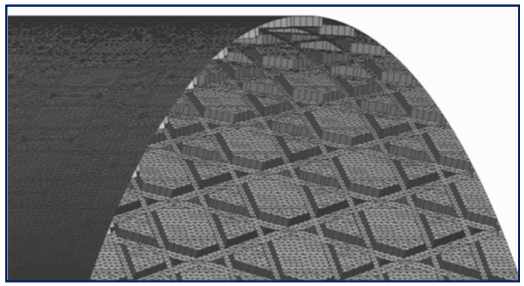
Without Skin



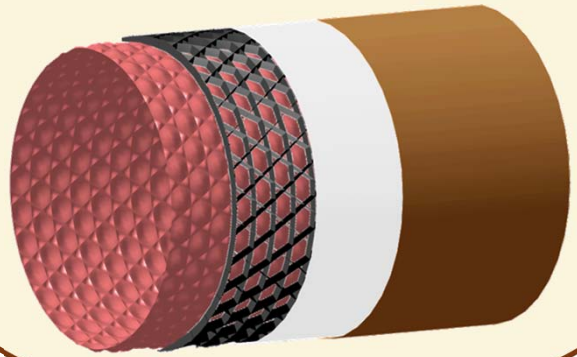
ALaSCA - Skin In



ALaSCA - Skin Out



Lattice concept with elastic skins



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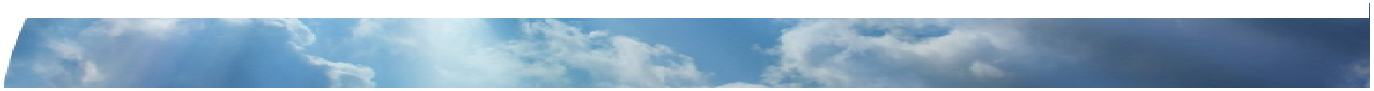
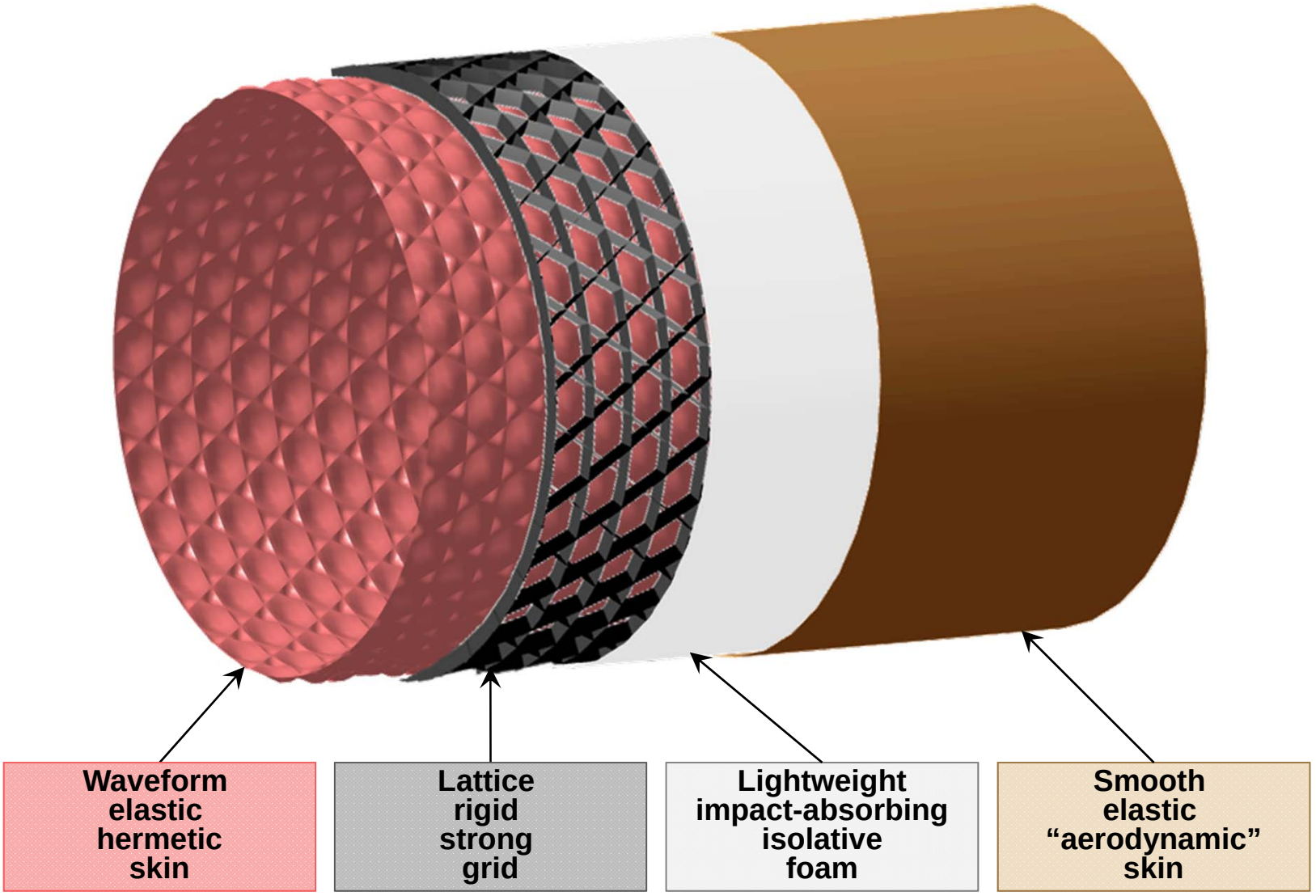


Novel Fuselage Structure Concept



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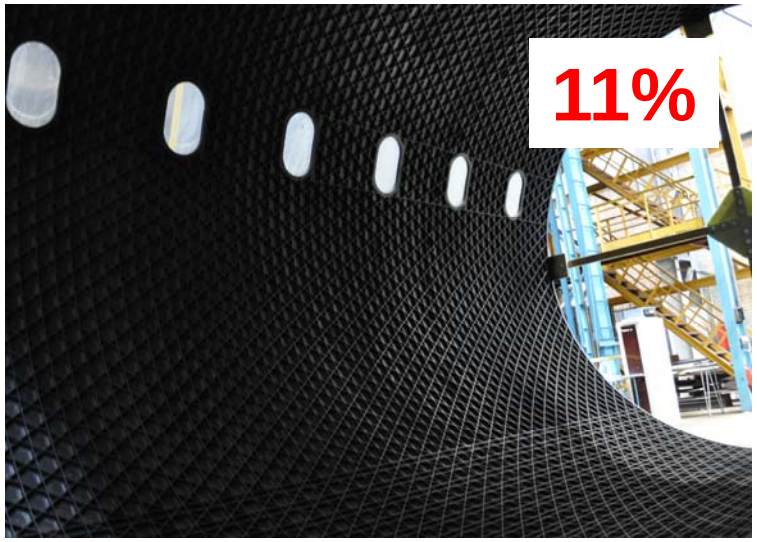
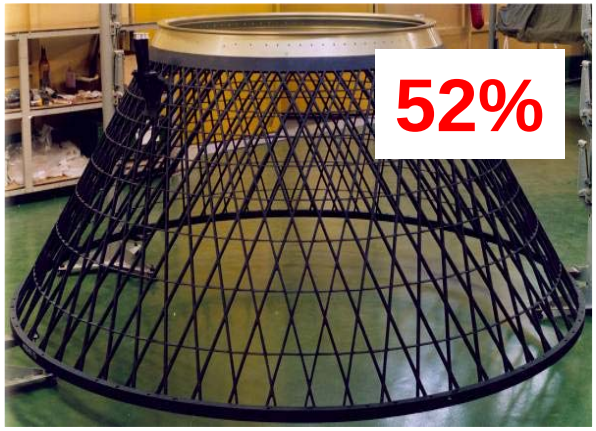
Weight Saving For Lattice Composite Primary Structures

Rocket adapter (rigid skin)

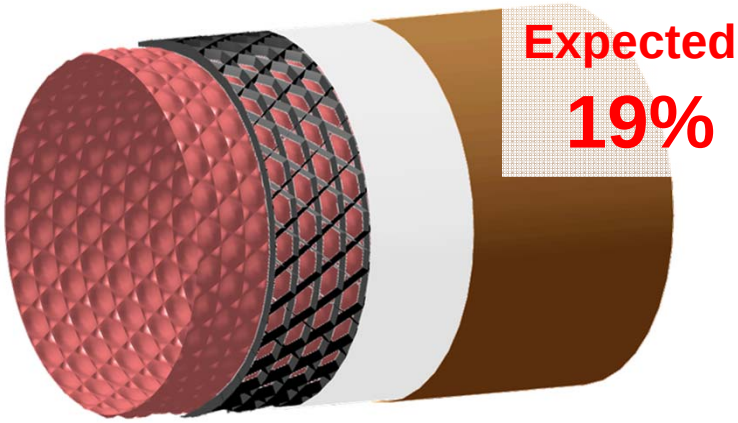
ALaSCA concept (rigid skin)



Rocket adapter (without skin)



PoLaRBEAR concept (elastic skins)



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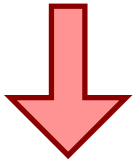
Development of Robust Lattice Structures

Main Ideas
to Enhance Robustness of Lattice Structures

- **Multilevel protection for composite primary structure**
- **Effective multilevel repair concepts**
- **Lattice composite panels**



Main Research Activities

- **Increase of lattice cell size**
- **Optimization of cross-section of ribs**
- **Development of lightweight strong joints**

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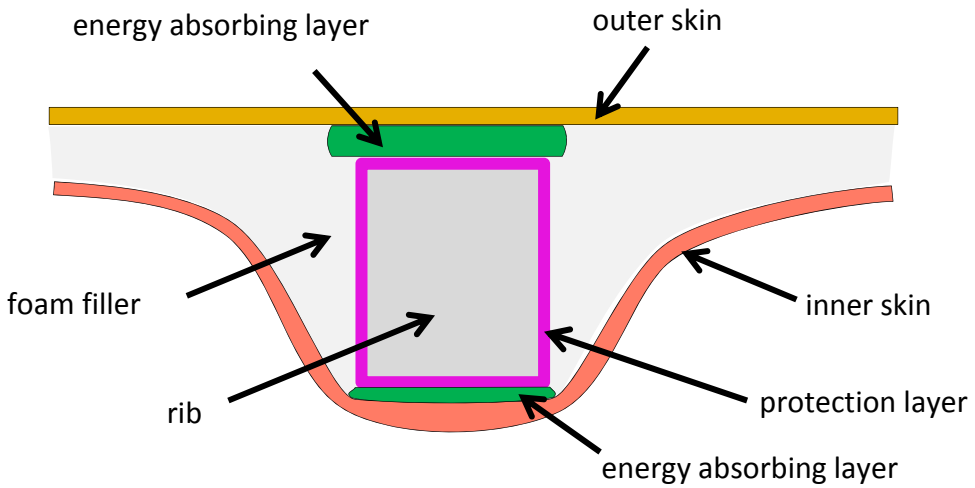
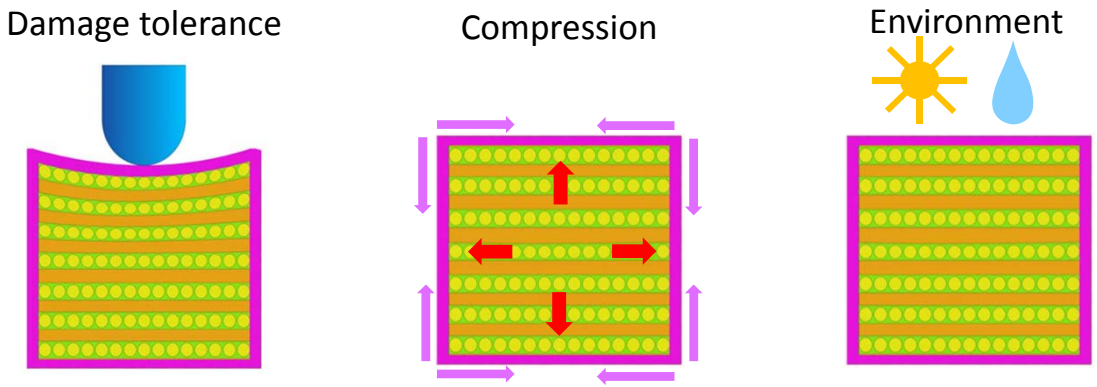
Protection of Lattice Composite Ribs Against External Factors

Concept of multilevel protection



Functions of protection layer: synergetic effects



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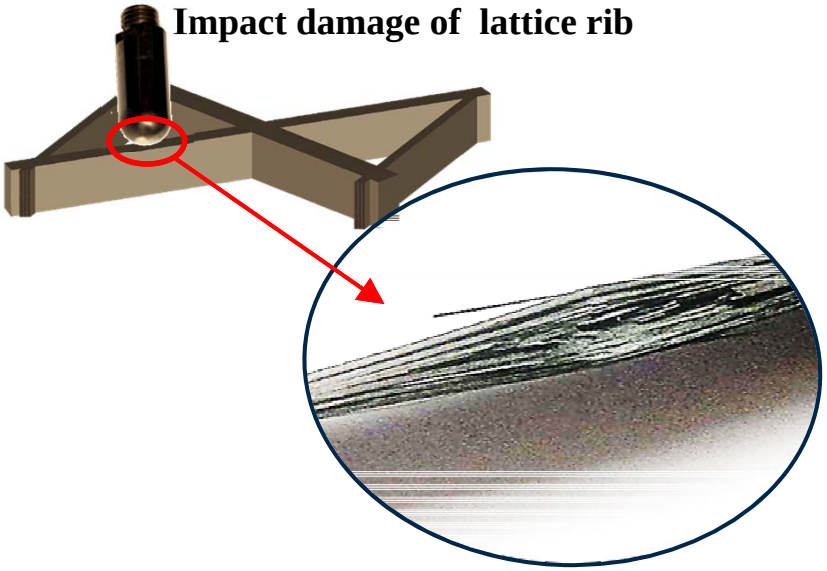
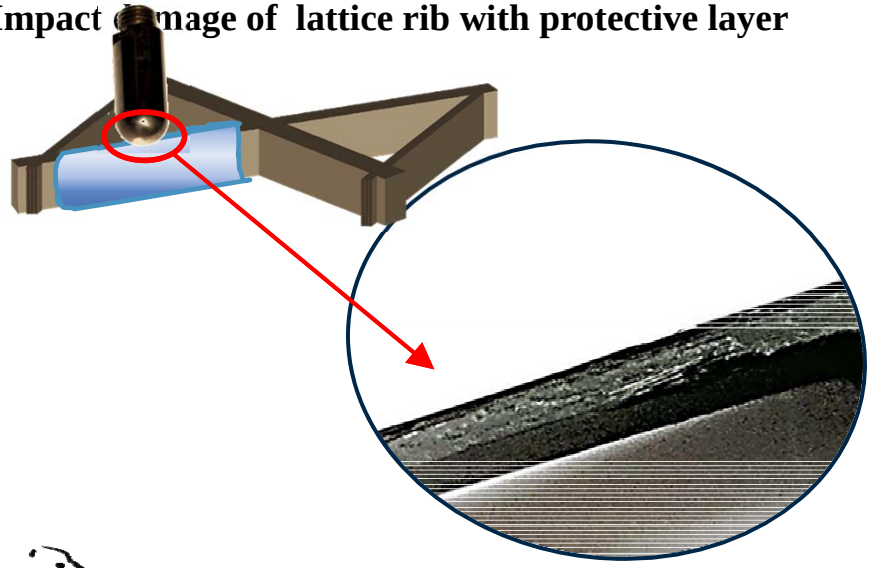
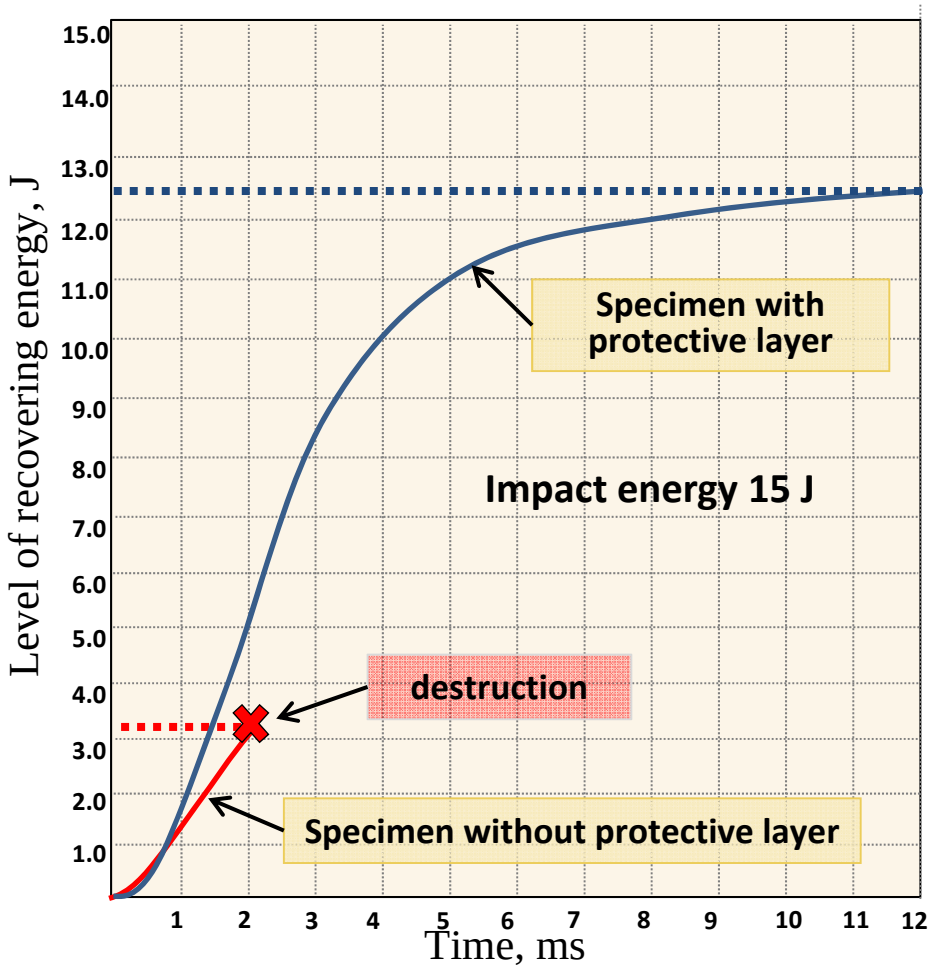
Results of First Experimental Tests

Impact damage of lattice rib



Impact damage of lattice rib with protective layer





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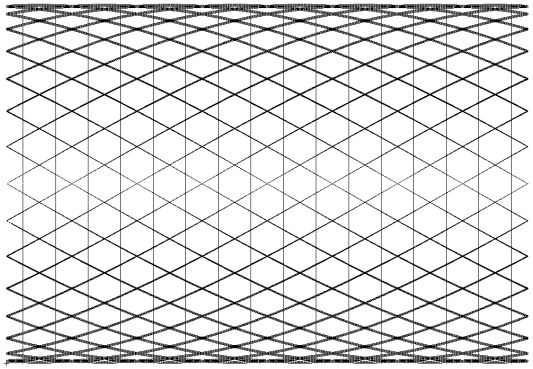
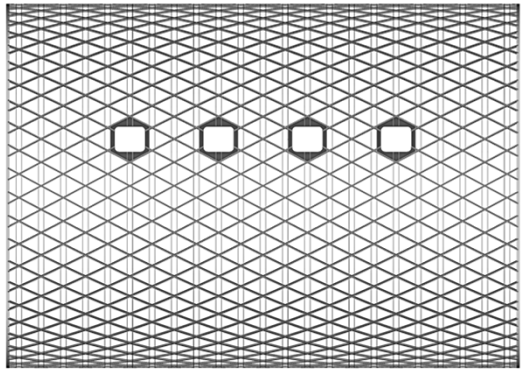
Evolution of Lattice Structure Concept

	G-0	G-1	G-2
Typical size of lattice grid cell	220 mm	440 mm	700 mm

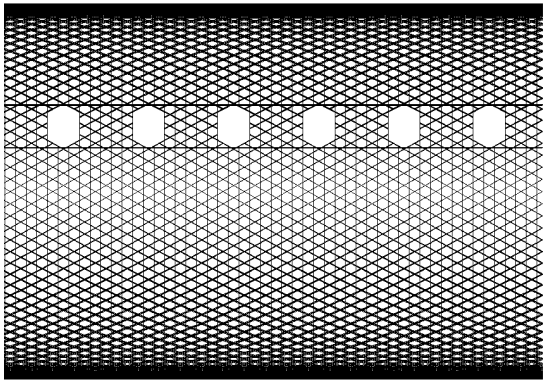
Future Lattice Concept (G-2)



PoLaRBEAR Prototype (G-1)



ALaSCA Prototype (G-0)



Weight of protection system

G-0	G-1	G-2
100%	75%	65%

Weight $_{\text{protection+skin}}$ ~ 0.4 Weight $_{\text{fuselage shell}}$

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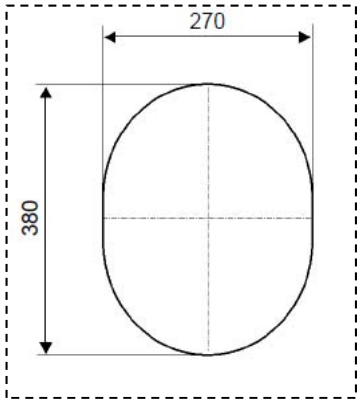
Evolution of Lattice Windows

Reference Windows



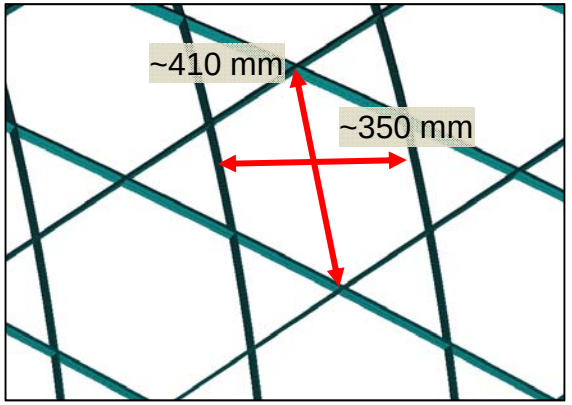
Window pitch: ~ 580 mm
22 windows*

Surface of all windows

Reference	G-0	G-1	G-2
100%	77%	101%	102%

Lattice Windows G-2

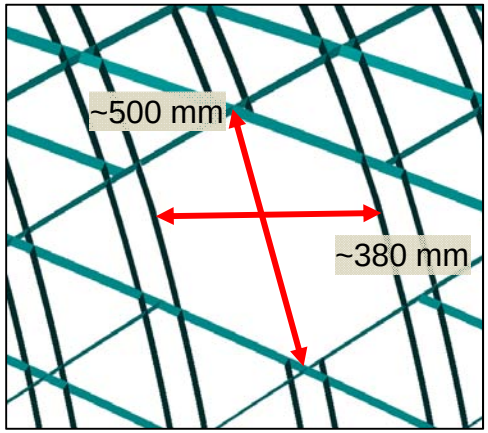
NO cut – undisturbed lattice!



Window pitch: ~710 mm
16 windows*

Lattice Windows G-1

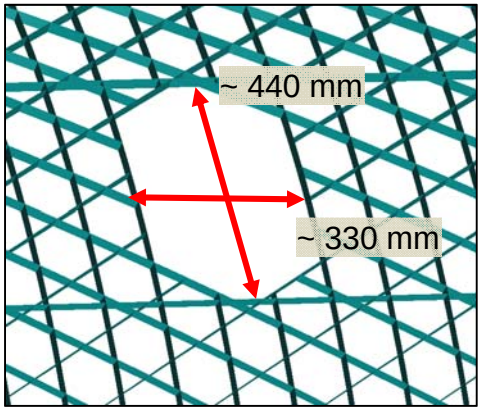
cut: 1 pair of helical ribs



Window pitch: ~900 mm
12 windows*

Lattice Windows G-0

cut: 3 pairs of helical ribs



Window pitch:~ 900 mm
12 windows*

*for 6m fuselage section

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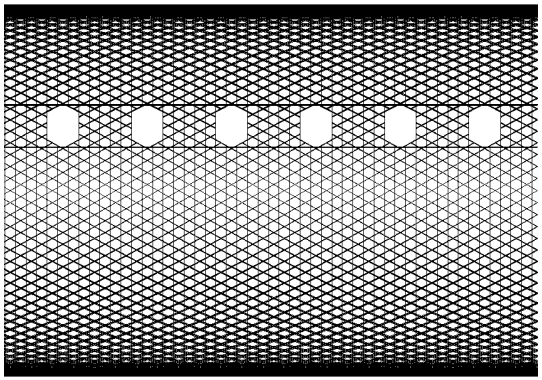
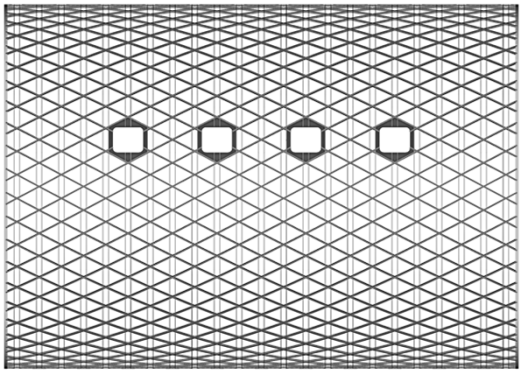
Weight Efficiency of Lattice Structure Concepts

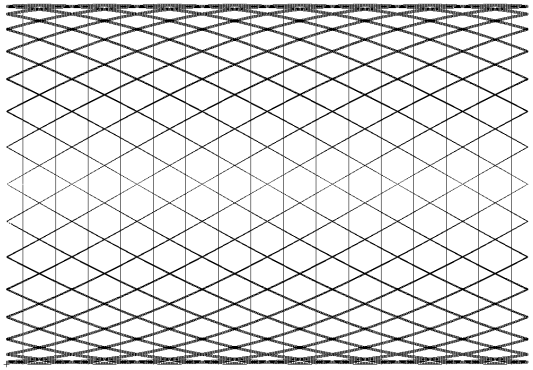
ALaSCA Prototype (G-0)



PoLaRBEAR Prototype (G-1)



Future Lattice Concept (G-2)



*Results of **preliminary** comparative **weight analysis***

	G-0	G-1	G-2
Lattice grid	60%	56%	53%
Skin and protective elements	40%	32%	28%
TOTAL	**100%**	**88%**	**81%**

EXPECTED

Weight protection+skin ~ 0.4 Weight fuselage shell

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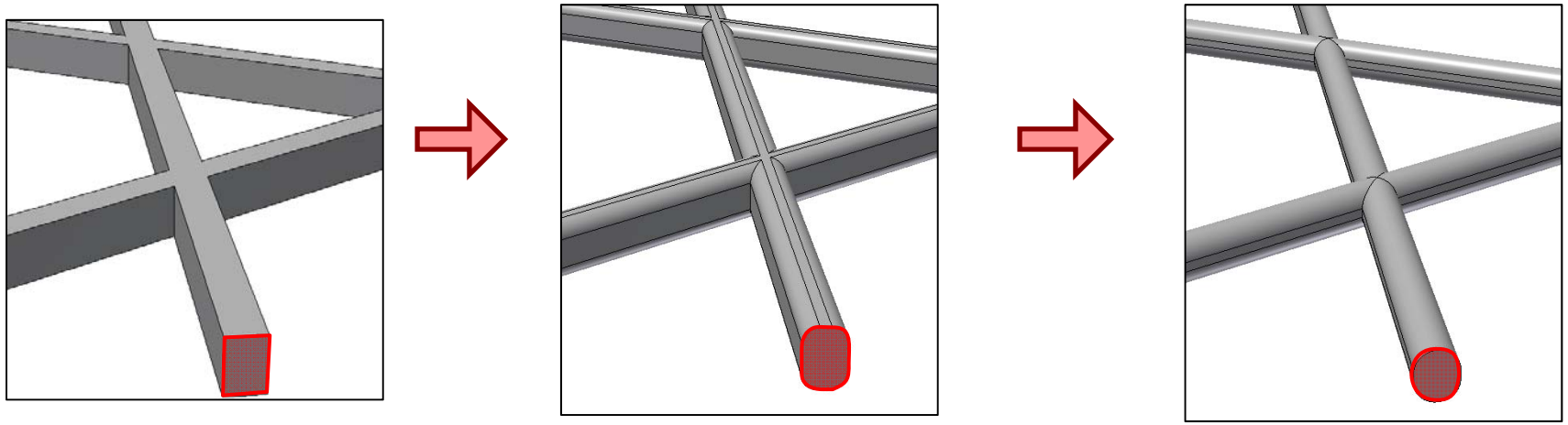
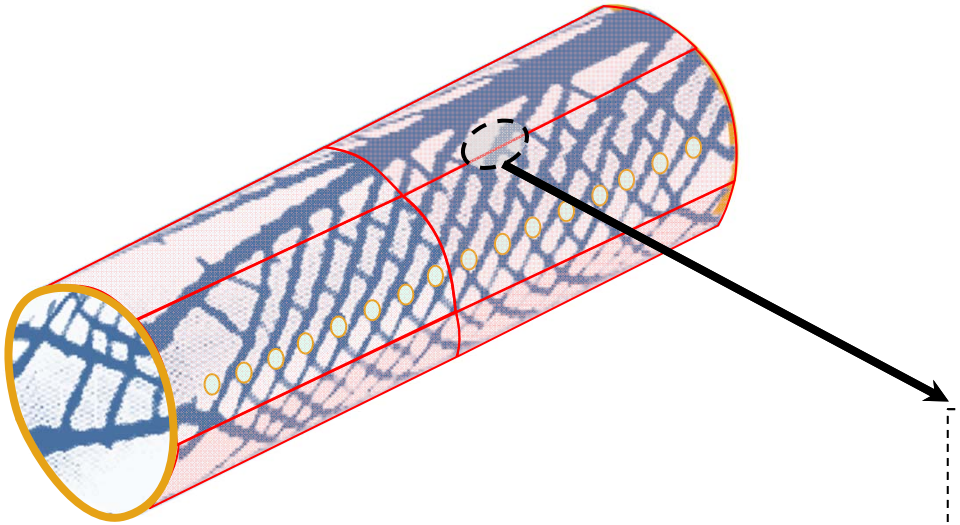
Optimization of Cross-Section of Ribs



- ✓ Increase of impact resistance
- ✓ Possibility to tighten protection layer to improve buckling characteristics
- ✓ Capability to organize robust clamp connection to join equipment, wires etc.

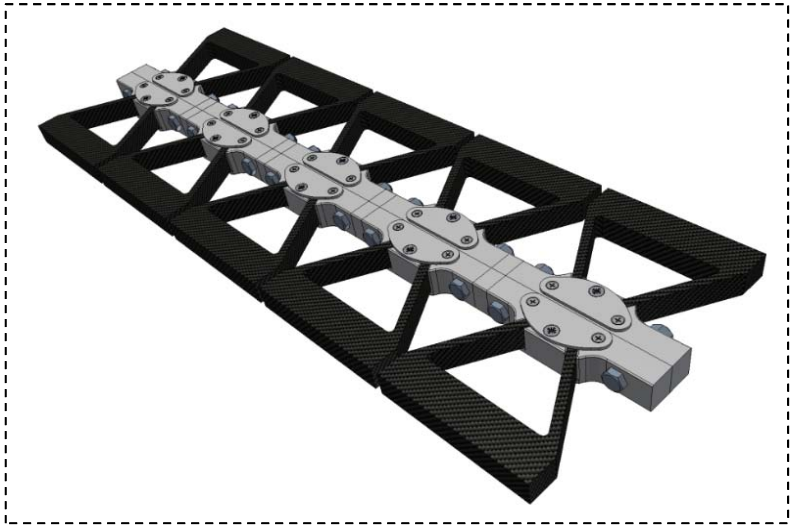
Directions for Future Researches

Lattice panels with lightweight robust joints



Optimal lattice structure: panels with different topology

(results of topology optimization - University of Leeds)



Perspective concept of flange joint

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PoLaR BEAR thanks you for your attention!

and is waiting for your questions.

PoLaR BEAR

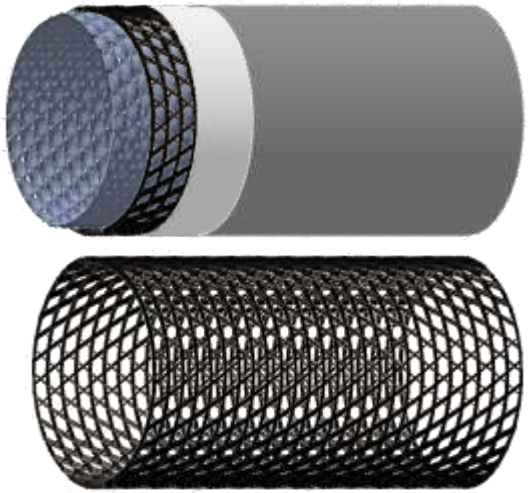
ENERGY APPROACH FOR ANALYSIS OF DELAMINATION OF LATTICE RIBS

V. Fomin, E. Dubovikov (TsAGI, Russia)

27th-29th October, Aachen, Germany

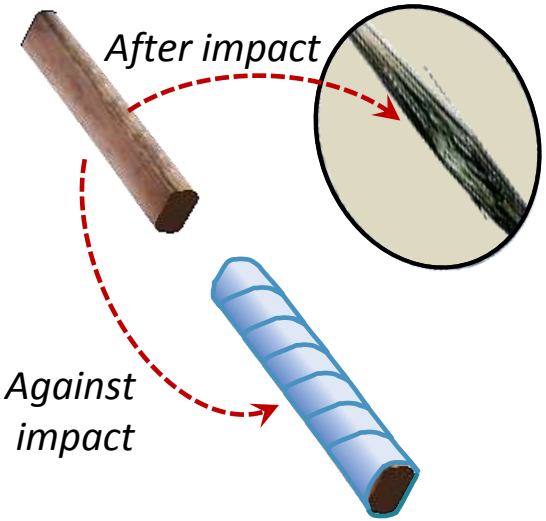
SEVENTH FRAMEWORK PROGRAMME

GENERAL PROBLEM: DEGRADATION OF STRENGTH PROPERTIES IN LATTICE STRUCTURES



Lattice structure of composite fuselage section with two elastic skins.

Lattice grid with **UD composite ribs** – the basic load-bearing part of the structure.



Long-term strength of lattice ribs

↓

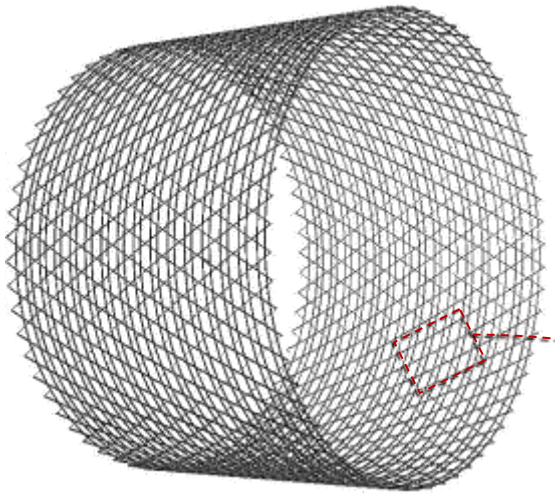
Development of protection for lattice ribs against impact, environment and ***delamination***

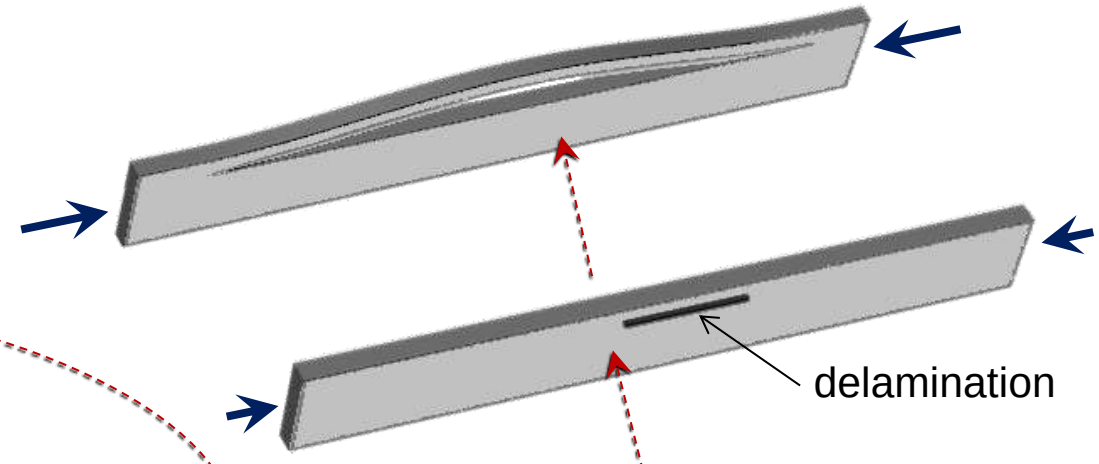
↓

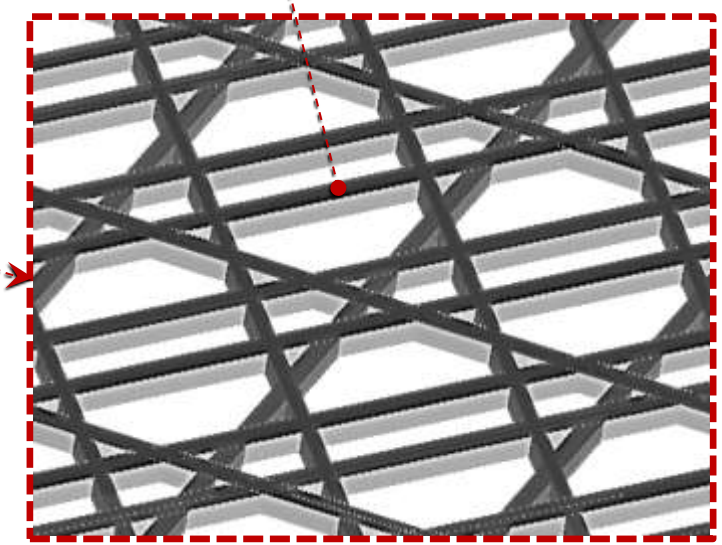
Investigation of possible ***degradation of lattice grid*** and protection system

TECHNIQUE: INFLUENCE OF DELAMINATION ON STRENGTH CHARACTERISTICS OF LATTICE RIB AT COMPRESSION

Regular lattice rib with delamination



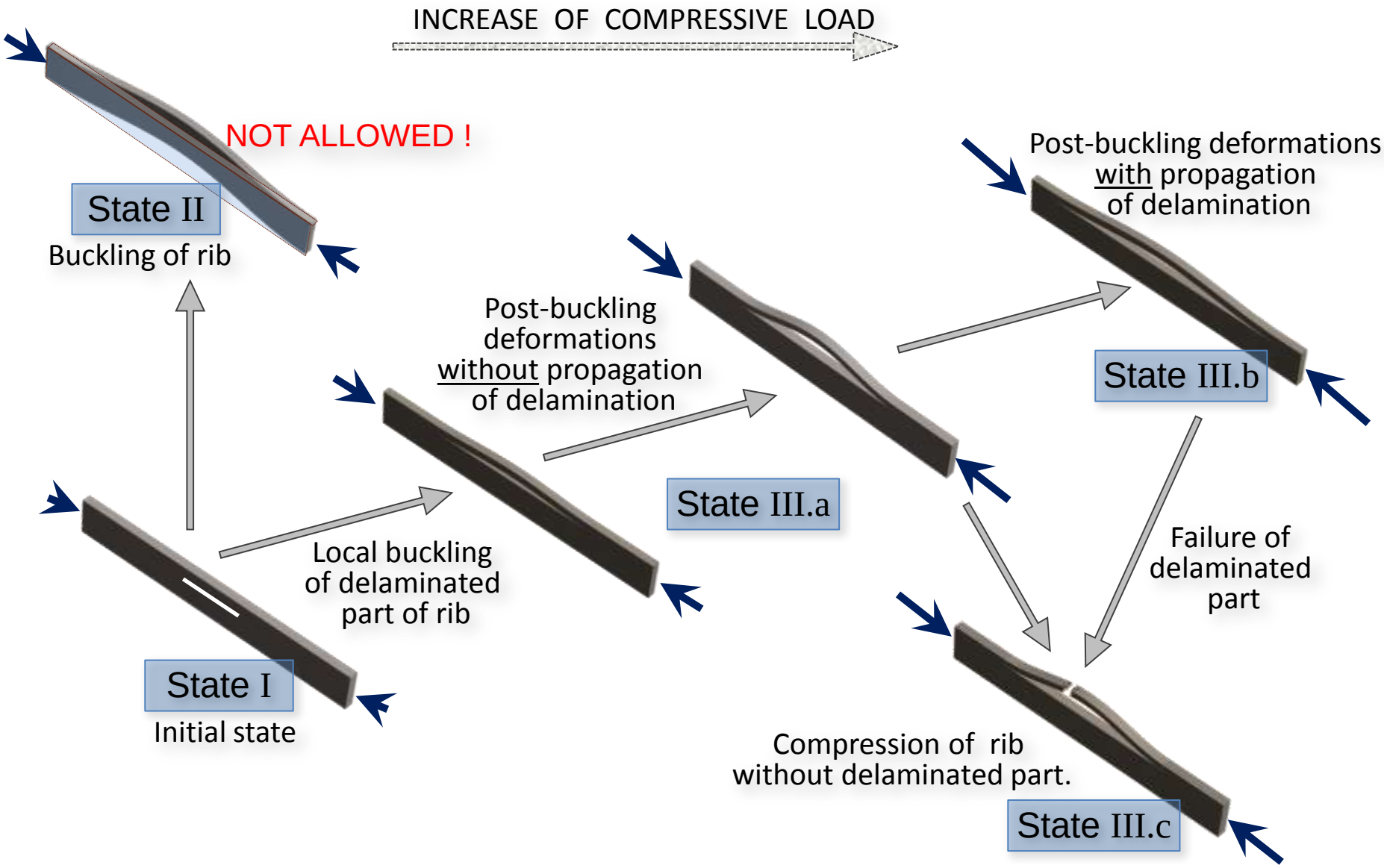




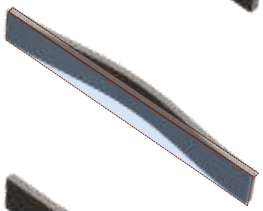
Tasks:

- Determination of current state of rib with delamination at compression
- Non-linear (post-buckling) behaviour of delaminated part of rib
- Propagation of delamination in regular part of lattice rib

POSSIBLE STATES OF LATTICE RIB WITH DELAMINATION AT COMPRESSION

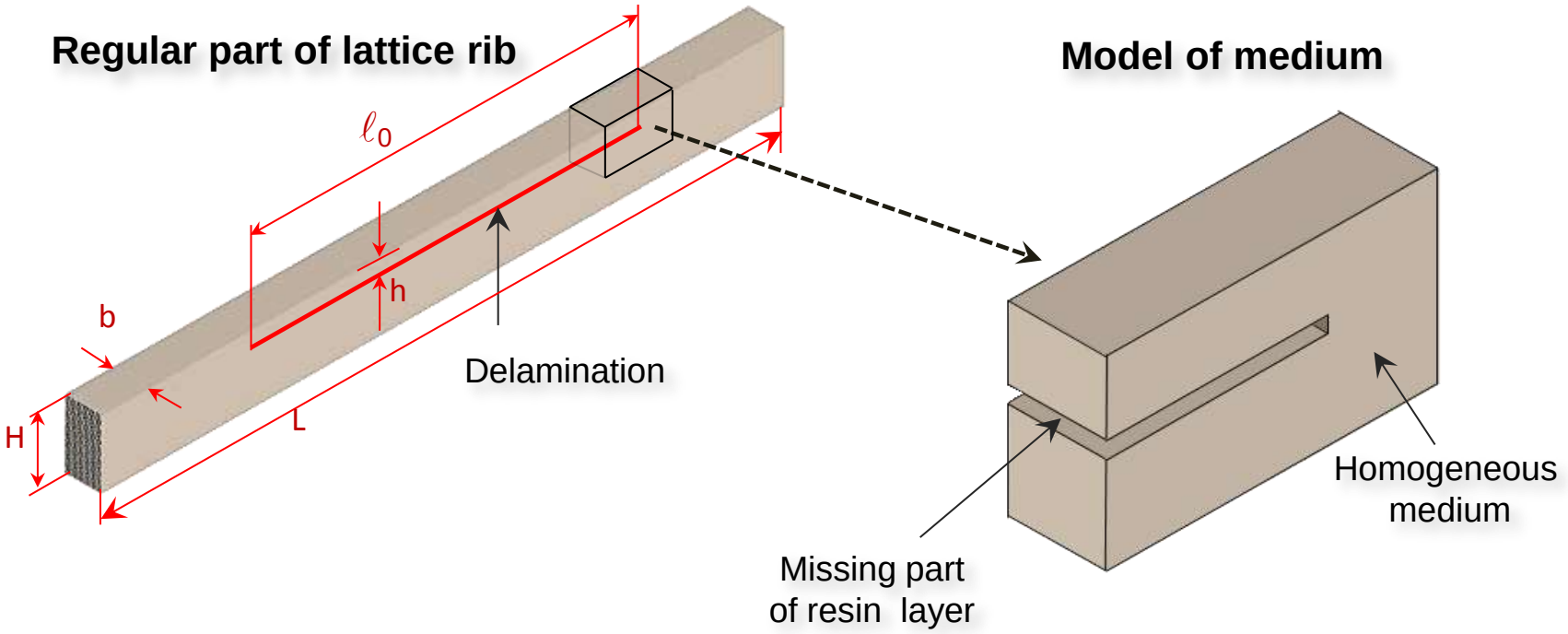


ENERGY APPROACH TO DETERMINATION OF CURRENT STATE OF LATTICE RIB WITH DELAMINATION

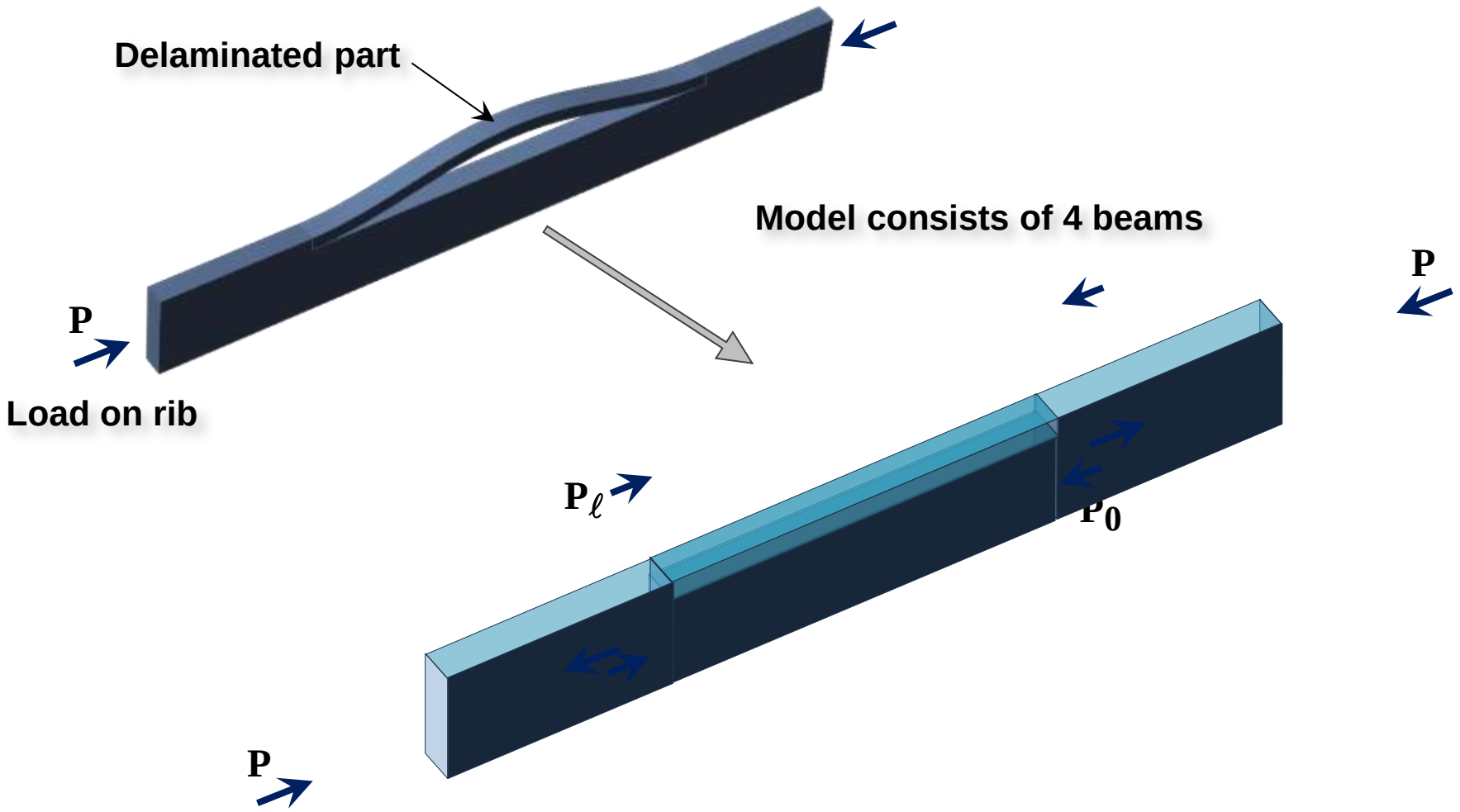
STATE		ENERGY
State I	Initial state	U_I
State II	 Buckling of rib	U_{II}
State III.a	Post-buckling deformations	$U_{III.a}$
State III.b	Propagation of delamination	$U_{III.b}+R_\ell$
State III.c	Rib with destroyed delaminated part	$U_{III.c}$

ENERGY APPROACH: CURRENT STATE OF LATTICE RIB WITH DELAMINATION AT COMPRESSION IS THE STATE WITH MINIMAL ENERGY

MODEL OF DELAMINATION IN LATTICE RIB

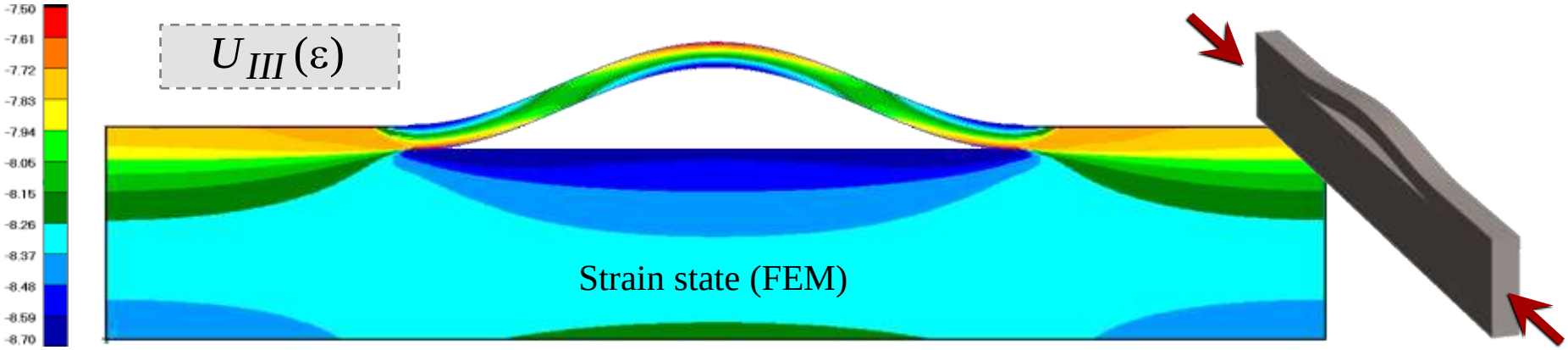


MODEL OF LATTICE RIB WITH DELAMINATION UNDER COMPRESSION



ENERGY OF LATTICE RIB WITH DELAMINATION

"ACCURATE" NON-LINEAR SOLUTION FOR POTENTIAL ENERGY OF DEFORMATIONS

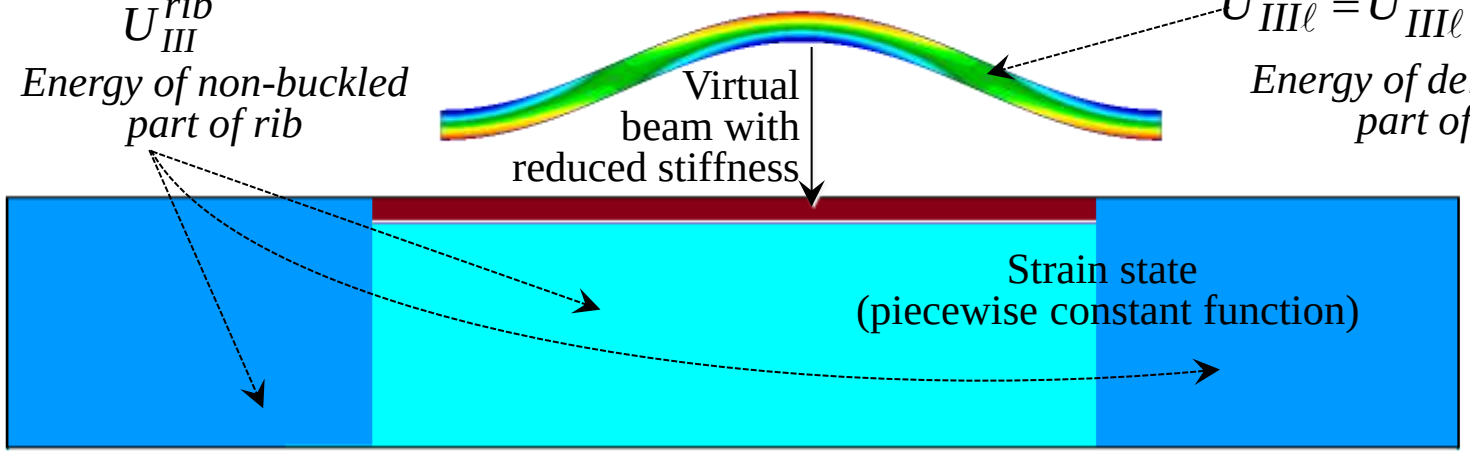


APPROXIMATE NON-LINEAR ANALYTICAL SOLUTION

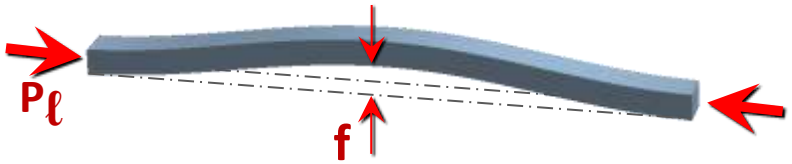
$$U_{III} = U_{III}^{rib} + U_{III\ell}$$

U_{III}^{rib}
Energy of non-buckled part of rib

$U_{III\ell} = U_{III\ell}^{comp} + U_{III\ell}^{bend}$
Energy of delaminated part of rib



MODELING OF POST-BUCKLING BEHAVIOUR OF DELAMINATED PART OF RIB

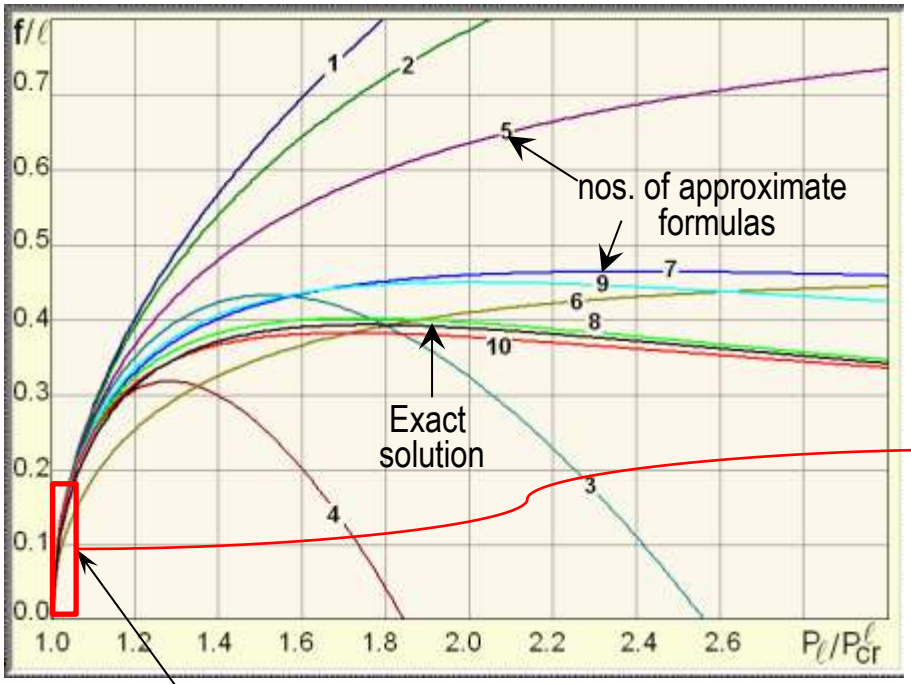


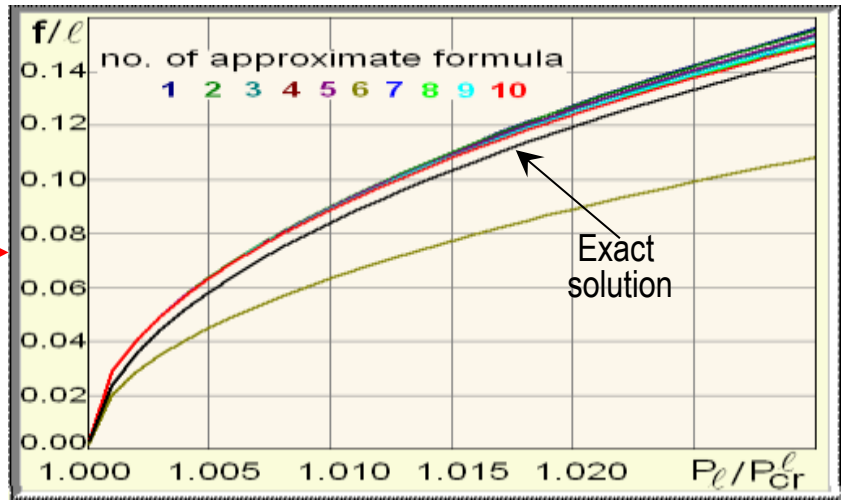
APPROXIMATE SOLUTION f(Pℓ) FOR POST-BUCKLING COMPRESSION

Variant for post-buckling analysis

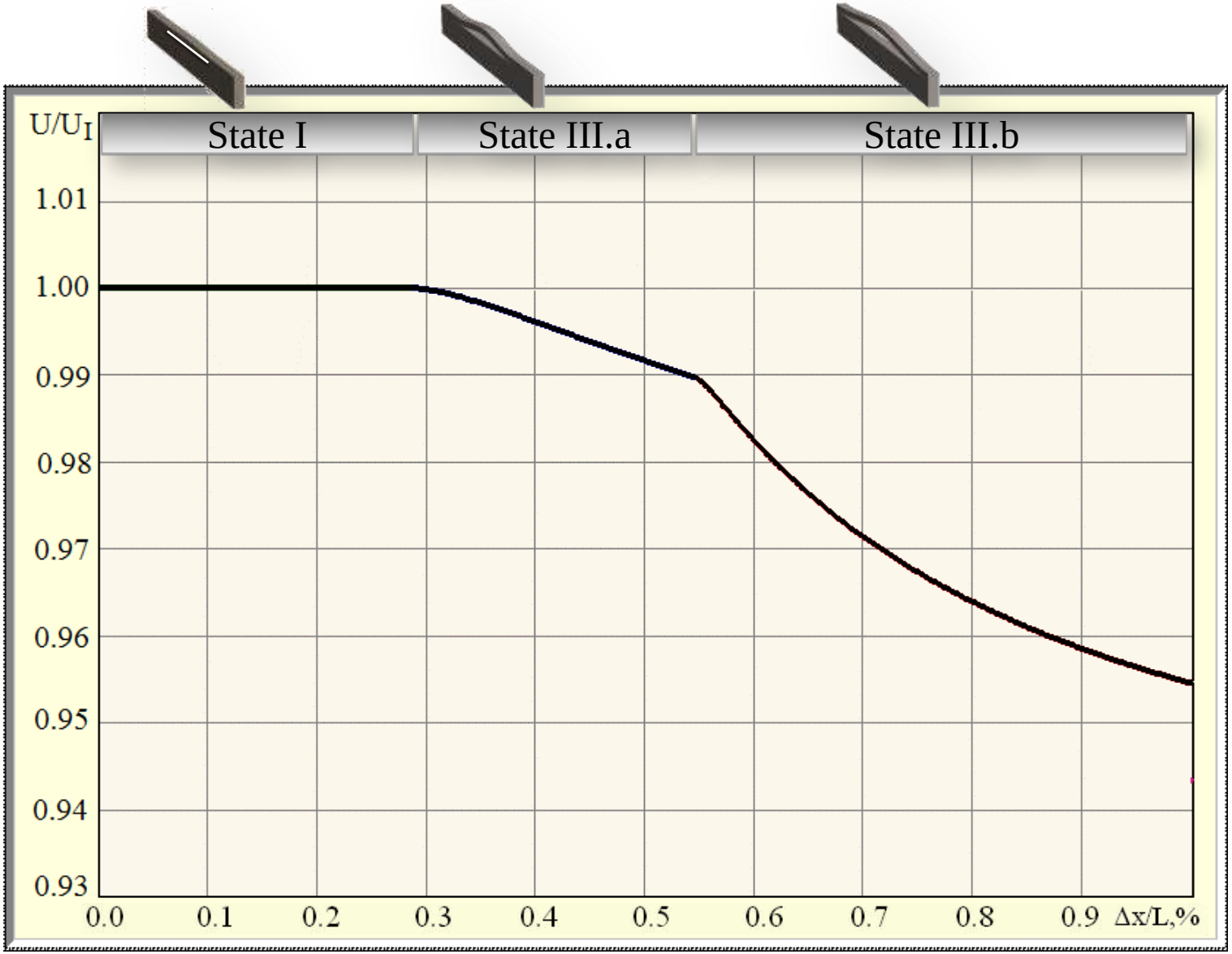
Approximate formula:

$$\frac{f}{\ell} = \frac{2\sqrt{2}}{\pi}\sqrt{P_\ell / P_{cr}^{\ell} - 1}$$





DETERMINATION OF CURRENT STATE OF RIB WITH DELAMINATION AT COMPRESSION (example)



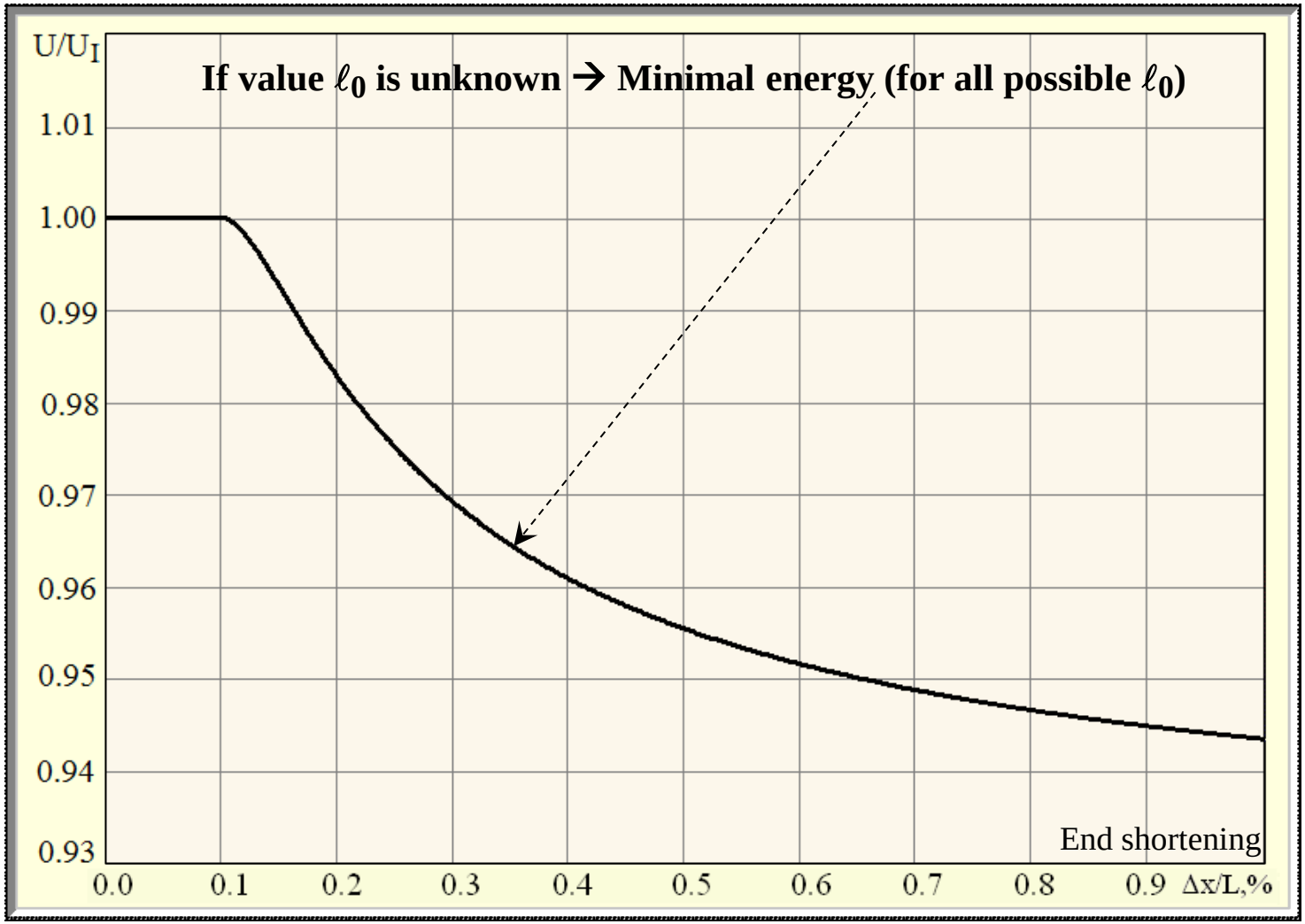
Rib:

ℓ_0/L=0.6

h/b=0.28

L/H=4

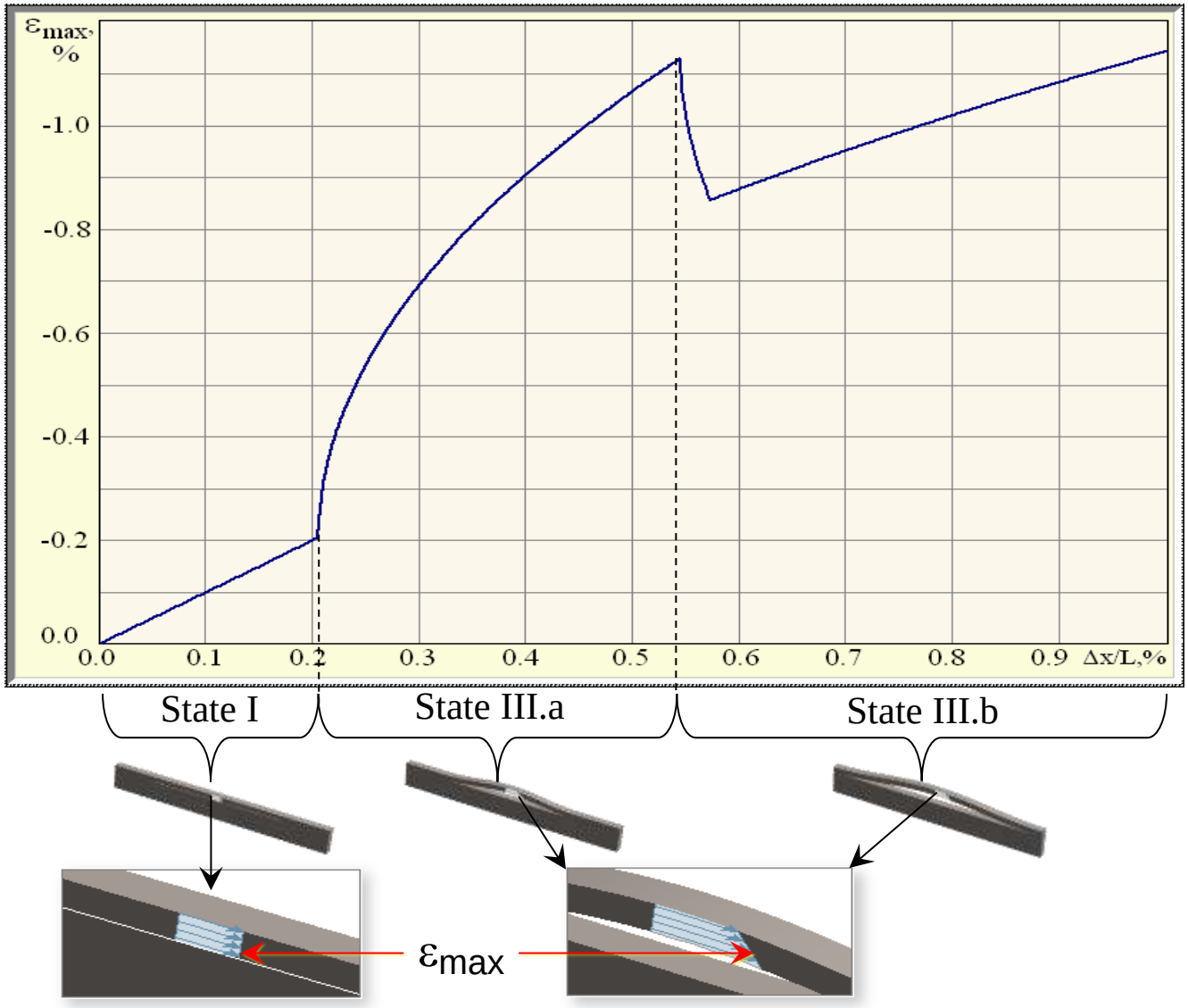
ENERGY FOR CURRENT STATE OF RIB FOR DIFFERENT DELAMINATION LENGTH (example)



Variation of $\Delta\ell_0$

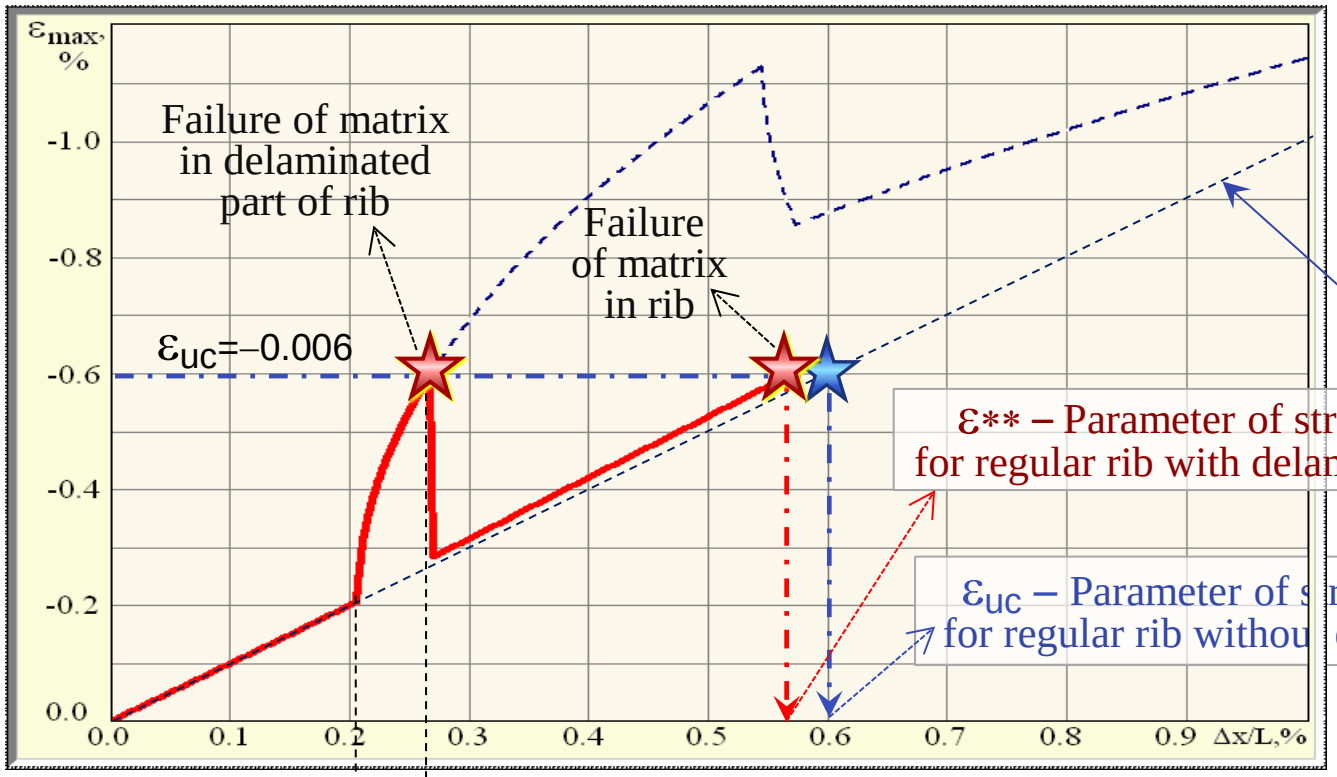
Minimal energy for $\ell_0/L=0.6$

DETERMINATION OF MAXIMAL STRAINS IN RIB WITH DELAMINATION AT COMPRESSION (example)



ESTIMATION OF STRENGTH DEGRADATION FOR RIB WITH DELAMINATION AT COMPRESSION (example)

Rib:
ℓ_0/L=0.7
h/b=0.28
L/H=4

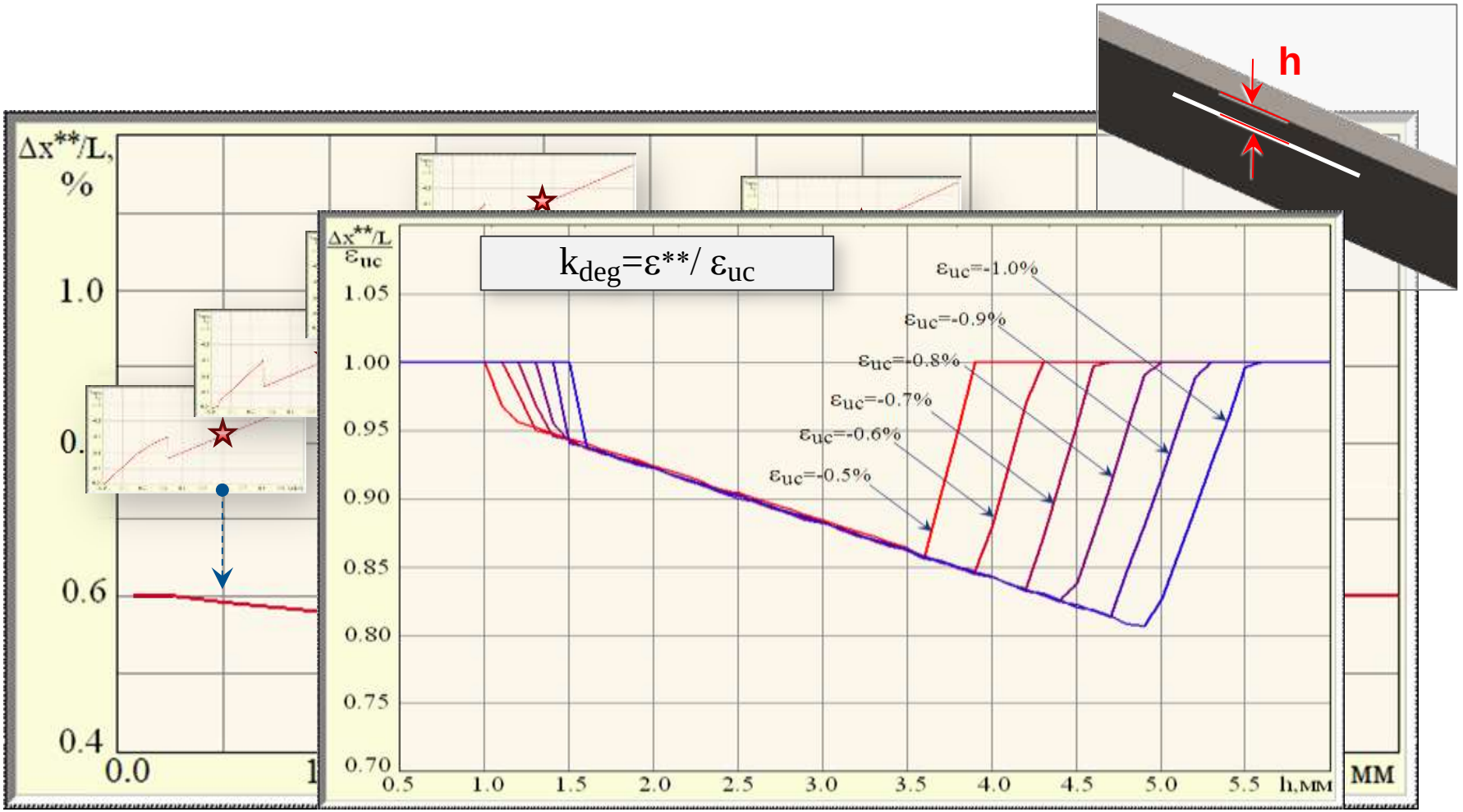


$k_{deg} = \varepsilon^{**} / \varepsilon_{uc}$

Parameter of strength degradation for regular rib with delamination

DEGRADATION OF STRENGTH FOR RIB WITH DELAMINATION (example)

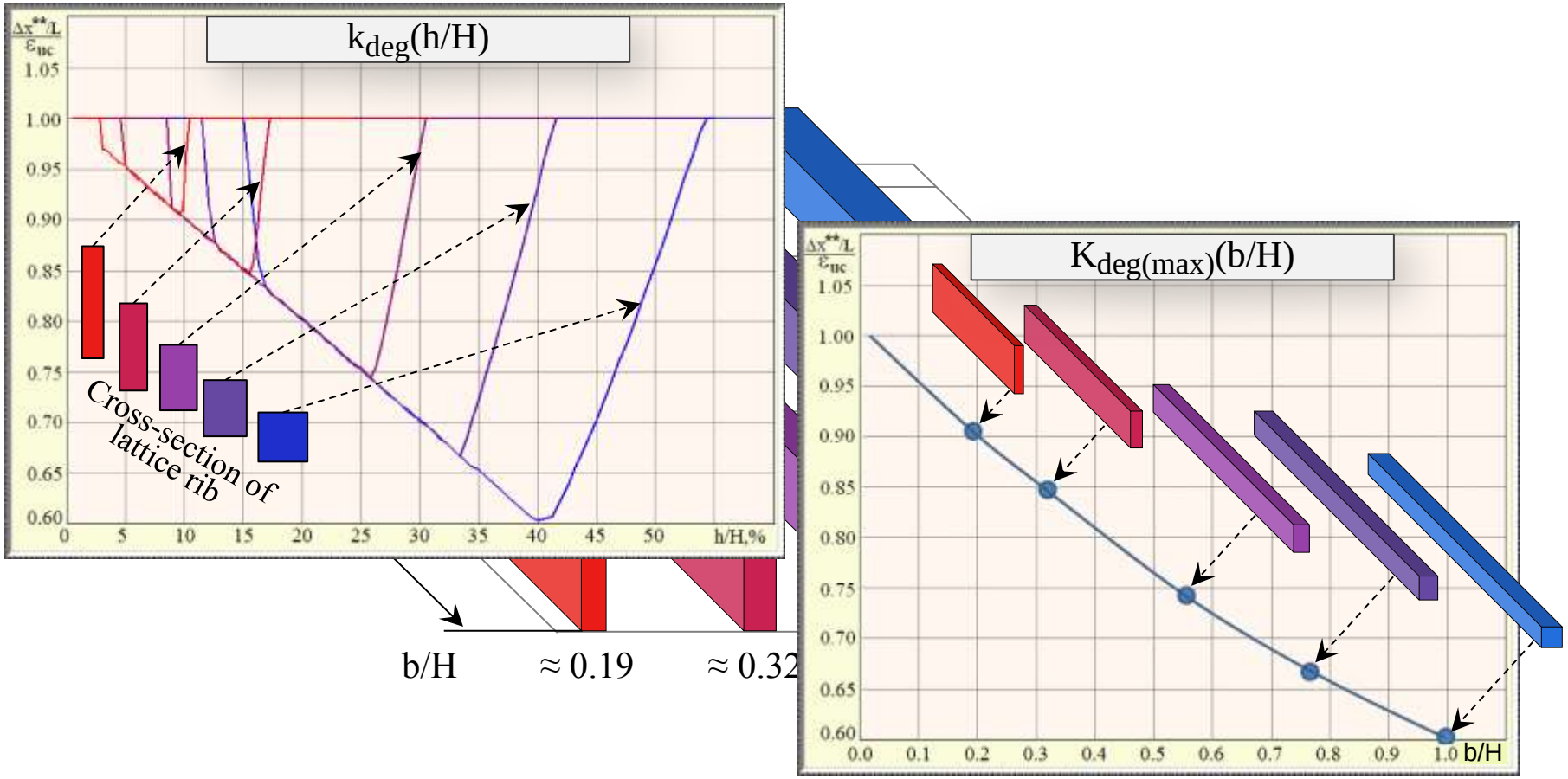
RELATIVE ULTIMATE STRAINS DEPENDING ON LOCATION OF DELAMINATION



DEGRADATION OF RIB STRENGTH FOR DIFFERENT SHAPE OF CROSS SECTION (example)

CONSTANT: CROSS-SECTION AREA, CRITICAL DEFORMATION OF BUCKLING

$F=b\times H=const \quad L/b=const\ (\approx 12.7) \rightarrow \varepsilon_{cr}=const\ (\approx 1\%)$

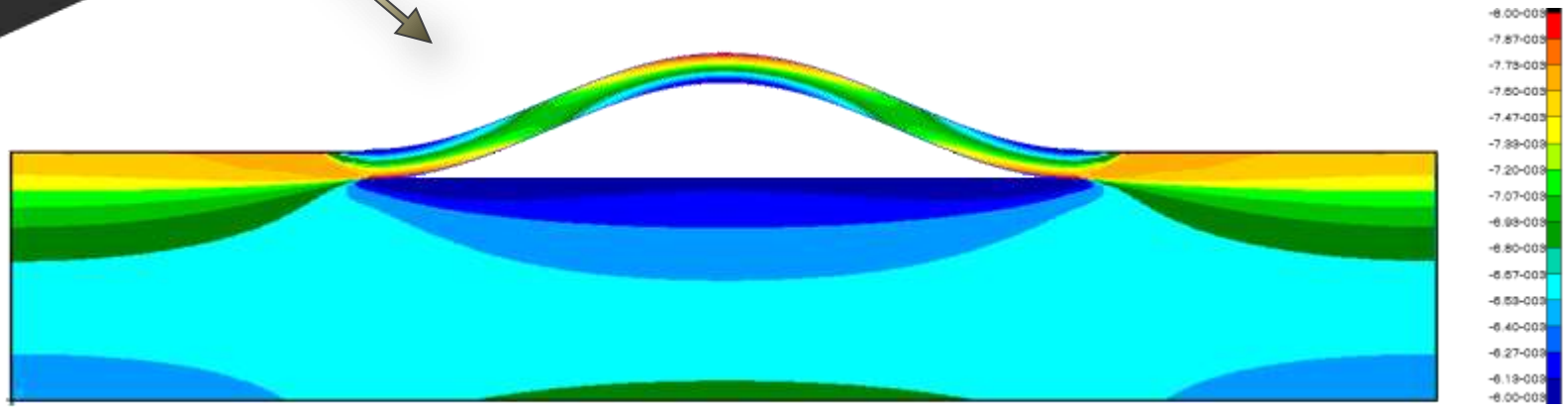


VALIDATION

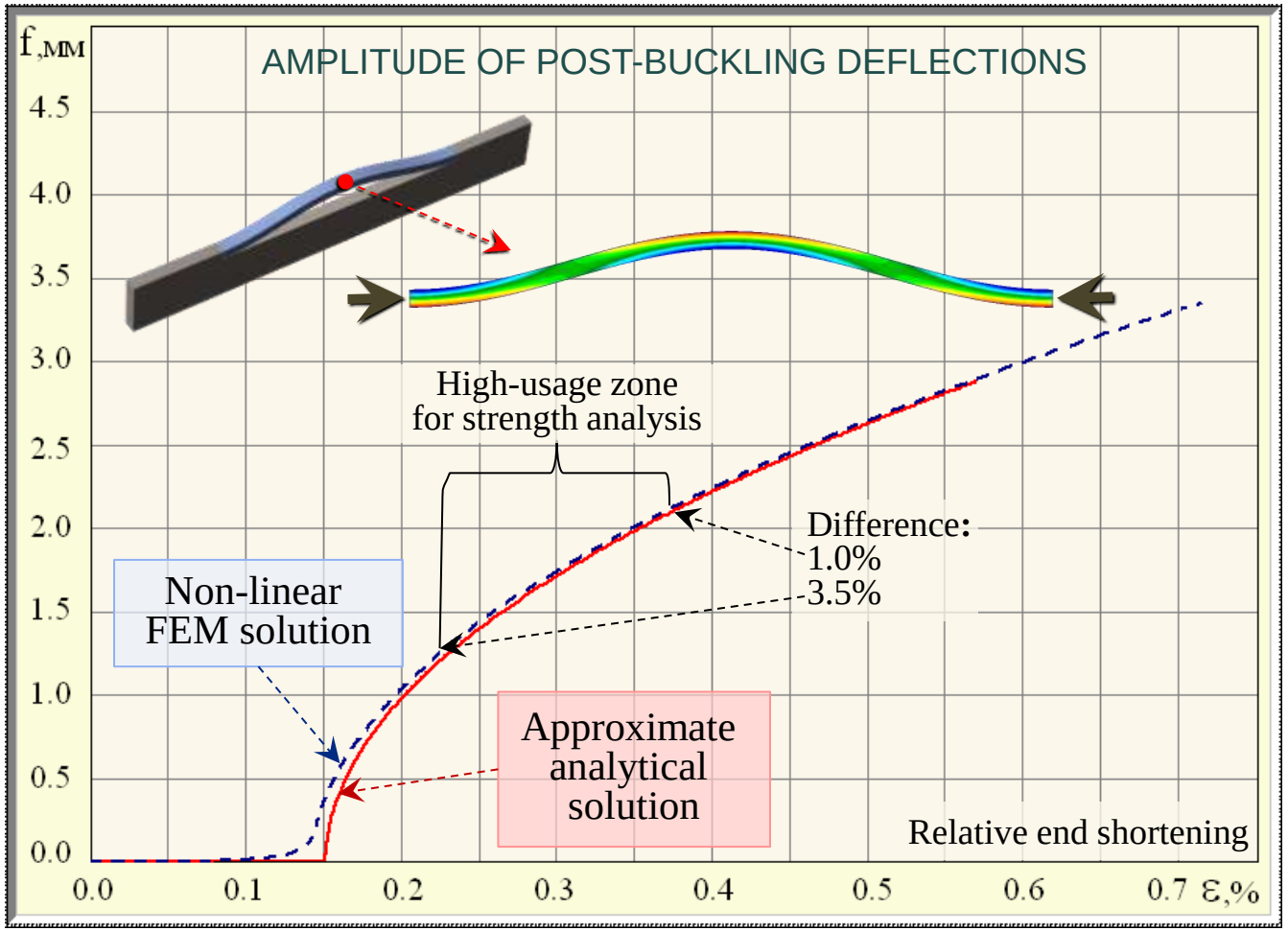
APPROXIMATE SOLUTIONS USED IN THE ALGORITHM

- ✓ Post-buckling deflection of delaminated part of lattice rib
- ✓ Potential energy of deformations for lattice rib with delamination

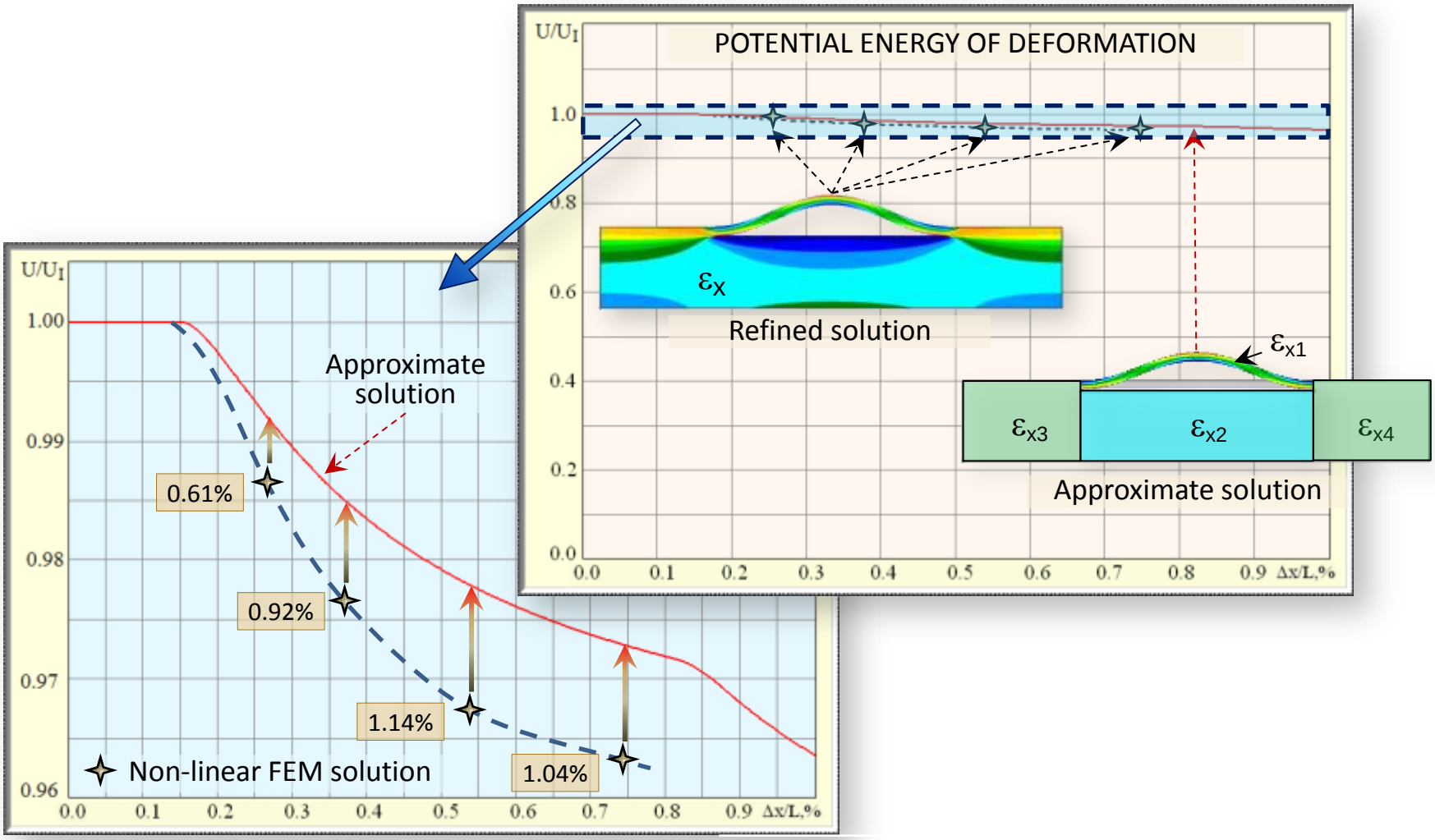
Technique for refined solutions:
Non-linear FEM (NASTRAN)



VALIDATION: POST-BUCKLING DEFORMATION OF DELAMINATED PART OF LATTICE RIB



VALIDATION: POTENTIAL ENERGY OF DEFORMATION FOR LATTICE RIB WITH DELAMINATION



CONCLUSIONS:

- The strength models of lattice composite ribs with typical damage (initial longitudinal delamination) have been developed.
- The method for estimation of strength degradation for the lattice ribs with delamination at compression has been developed.
- Parametrical investigations of influence of typical damage on strength characteristics of the lattice rib for different geometry parameters have been carried out.
- Validation of the method with use of results of the refined technique based on nonlinear FEM has shown sufficient level of accuracy for the analytical models and the basic procedures of the approximate nonlinear analytical technique.

Next step:

- Validation of the method with use of experimental investigation of behaviour of lattice ribs with delamination at compression.
- Analysis of influence of strength degradation of lattice ribs on the strength parameters of the fuselage section.

THANK YOU
FOR YOUR ATTENTION!

Parametric model generation and automated sizing process for the analysis of aircraft structures using the design environment DELiS

T. Führer, C. Willberg, S. Freund, F. Heinecke

EASN
Aachen, 27.10.2014

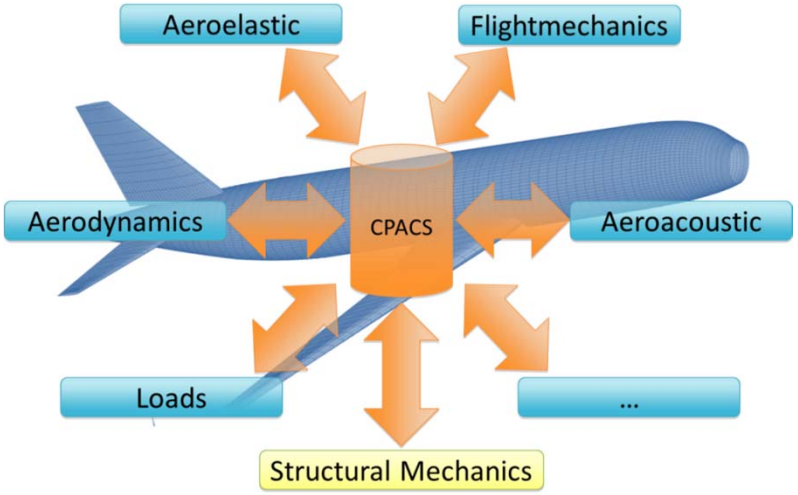
DLR

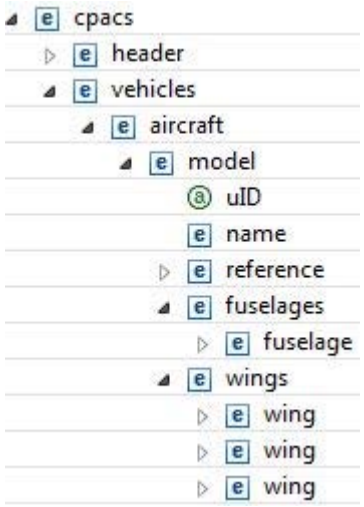
Content

- Introduction
- Design process
- Model generation
- Sizing process
- Application within MDO process
- Summary

Introduction

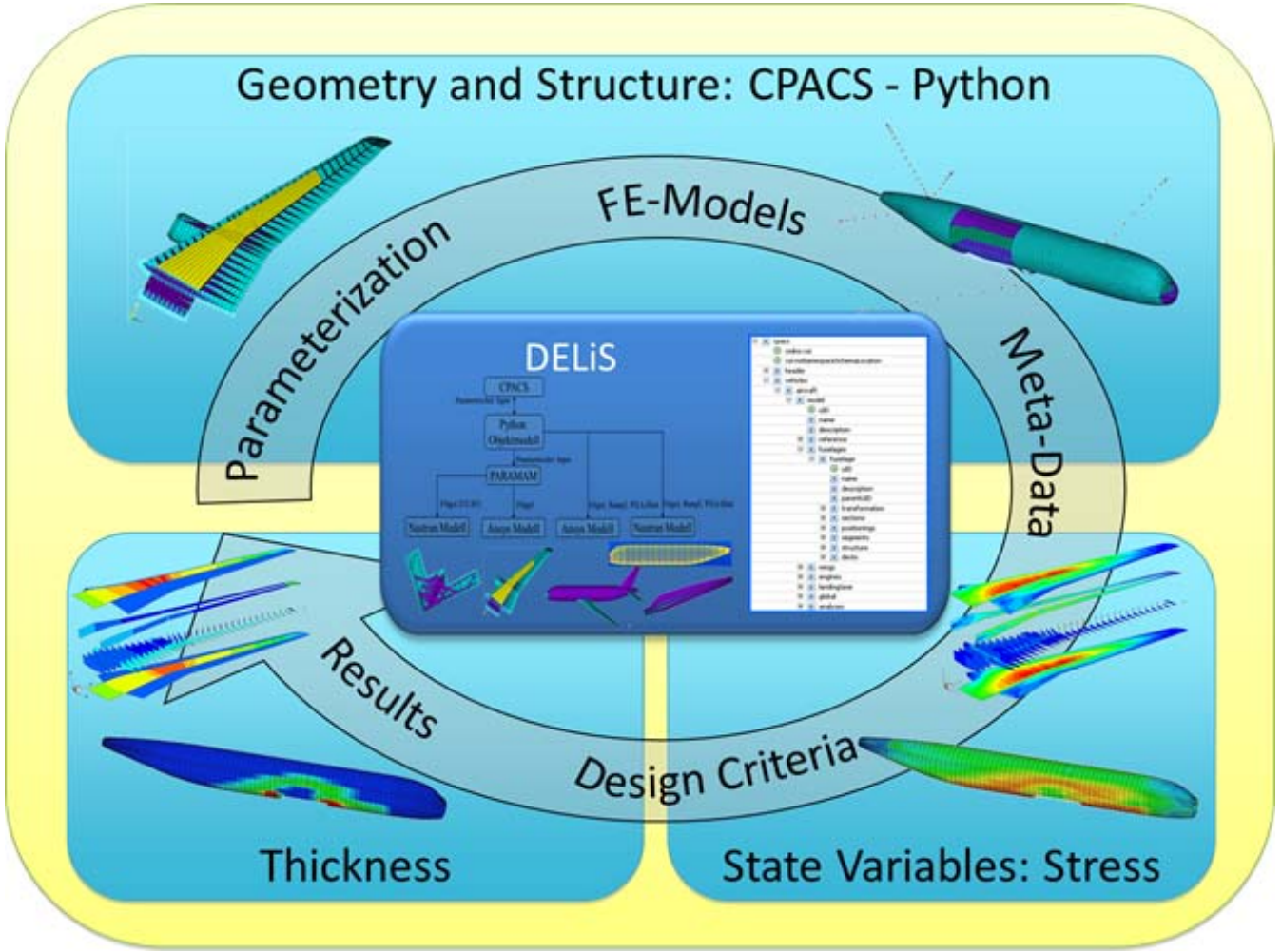
- Consideration of various designs in the early design process to obtain suitable pre-designs
- Low fidelity tools used for first starting design
- New materials or designs → higher fidelity methods
- CPACS:
  - abstract data base
  - exchange the description of aircraft configurations between several disciplines





CPACS (Common Parametric Aircraft Configuration Schema)

Design process



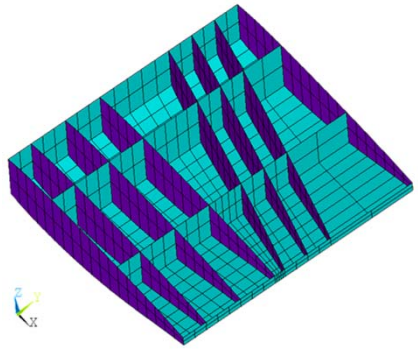
DELiS
Design
Environment of
Lightweight
Structures

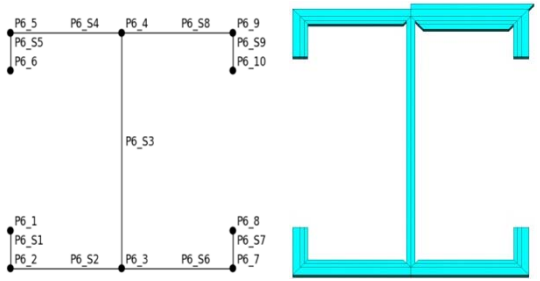
SBOT
(**S**izing ro**BOT**)

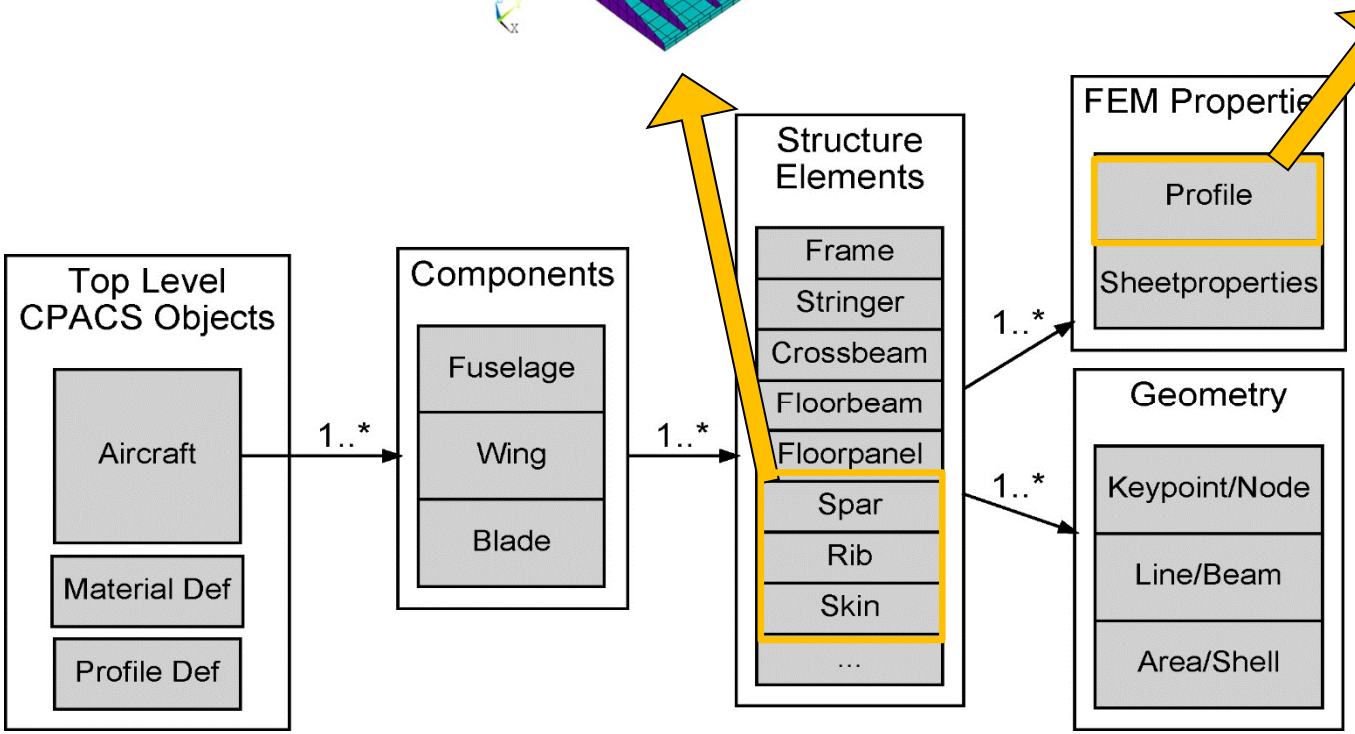
Structural design process

DLR

Model generation





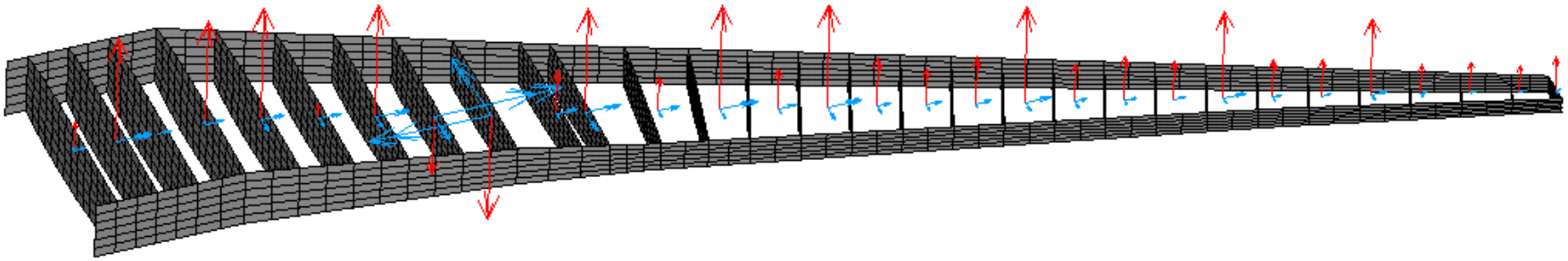


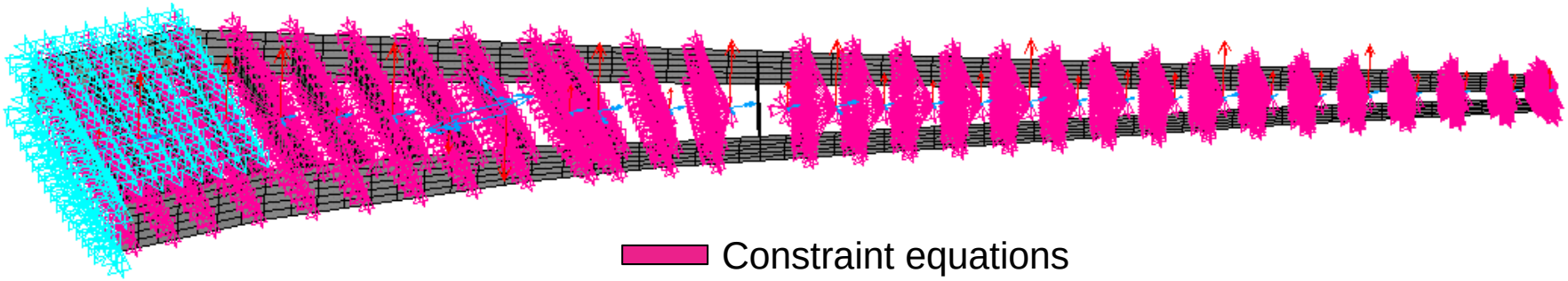
DELiS object model

CPACS ⟷ Structural model

Model generation

- Application of loads
  - Loads on the load reference axis from low fidelity tools
  - Loads on nodes of the wing box from high fidelity aerodynamic simulations

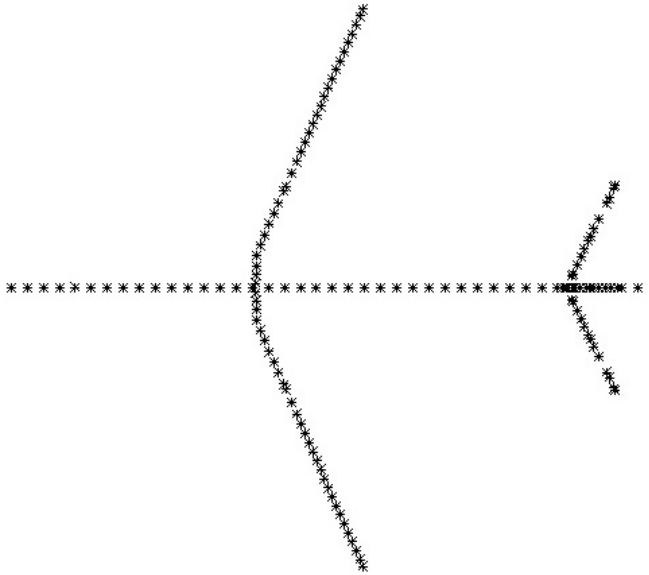




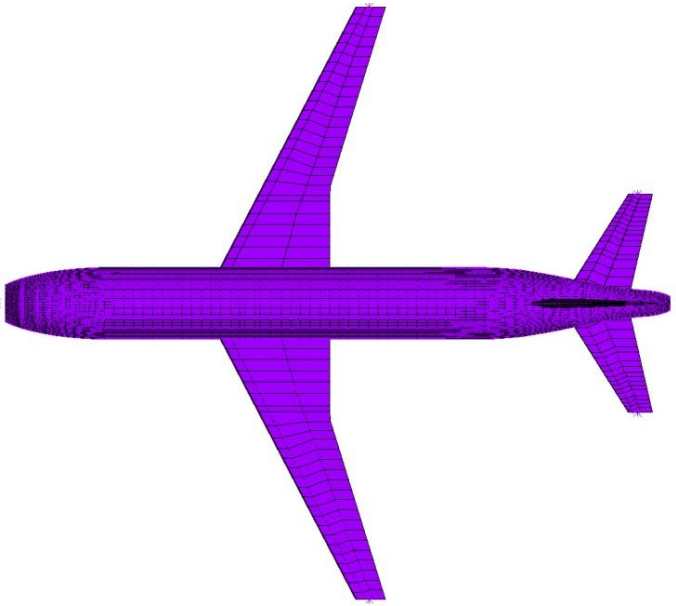
DLR

Model generation

- Abstract definition of the object oriented model allows different modelling approaches for wings and fuselages
  - Finite beam models
  - Finite shell models

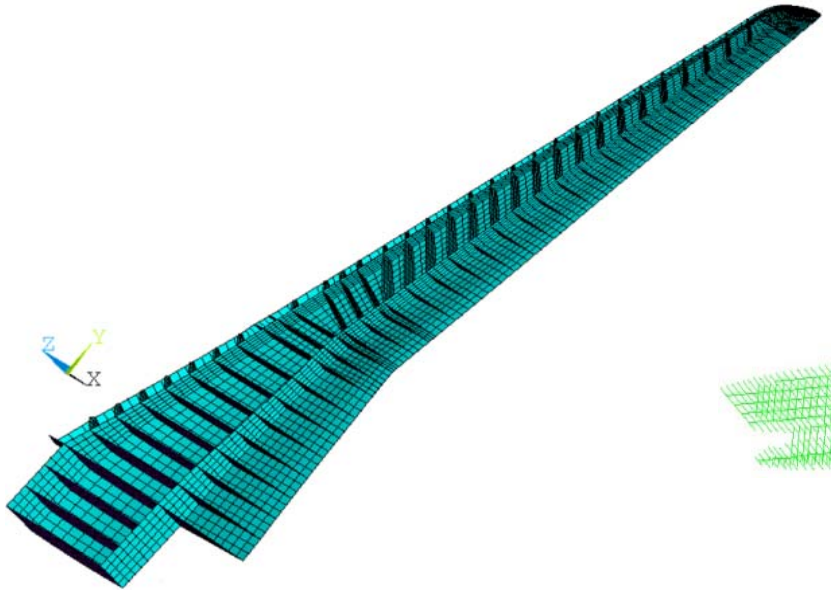


Aircraft beam model

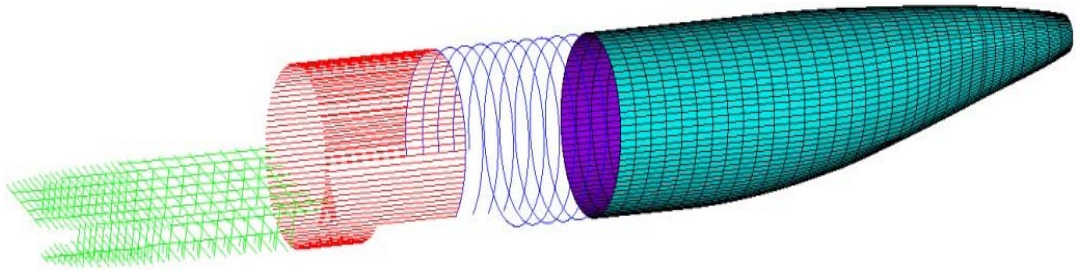


Aircraft shell model

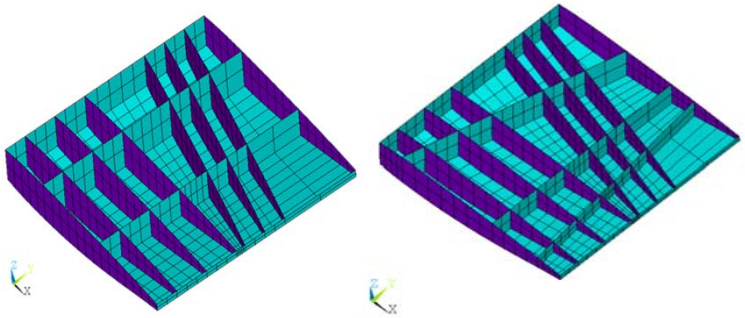
Model generation



Wing model

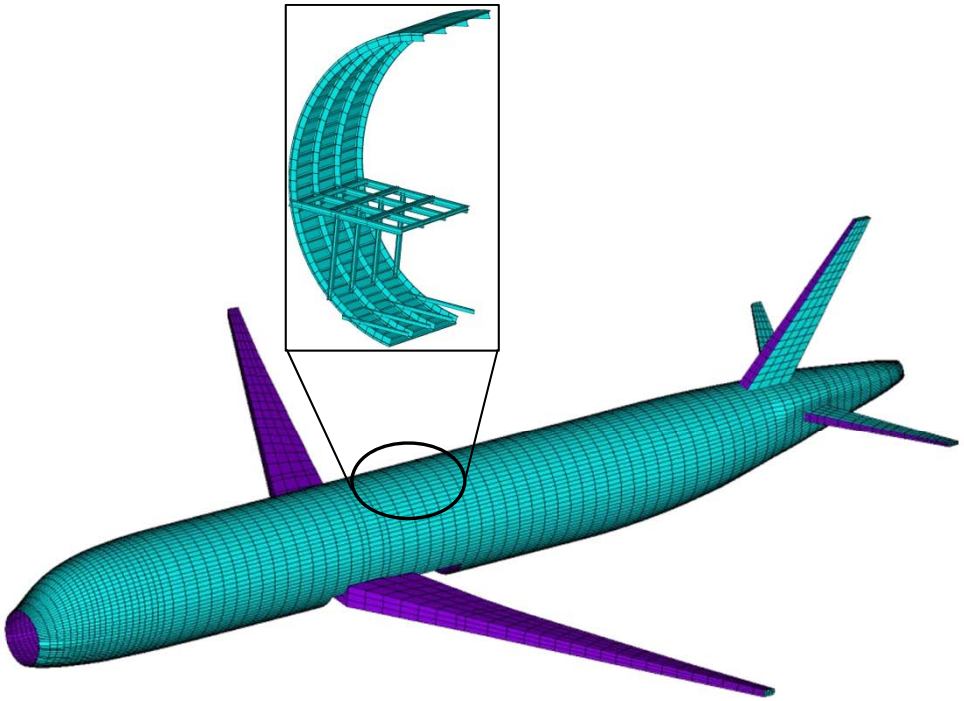


Fuselage model

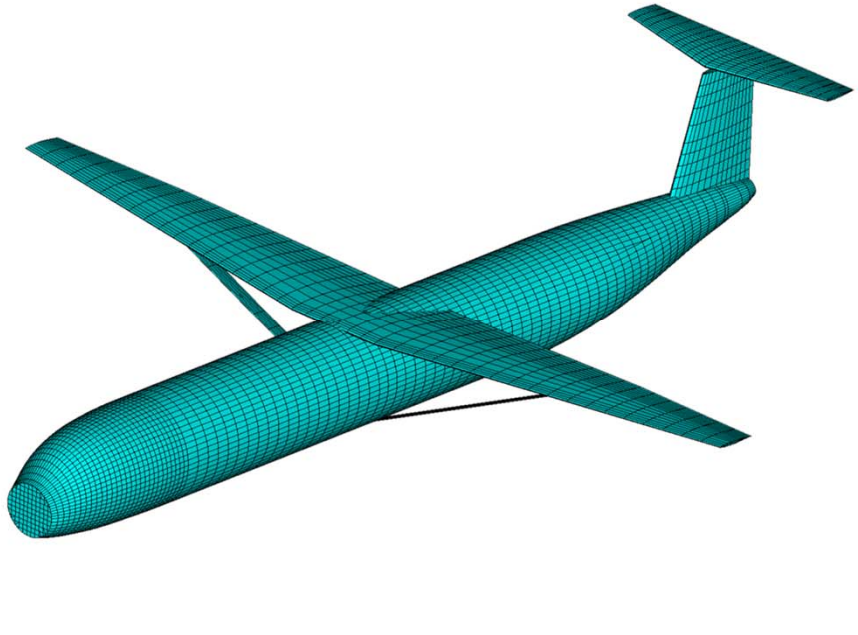


Wing segments with different number of spars and different rib rotations

Model generation



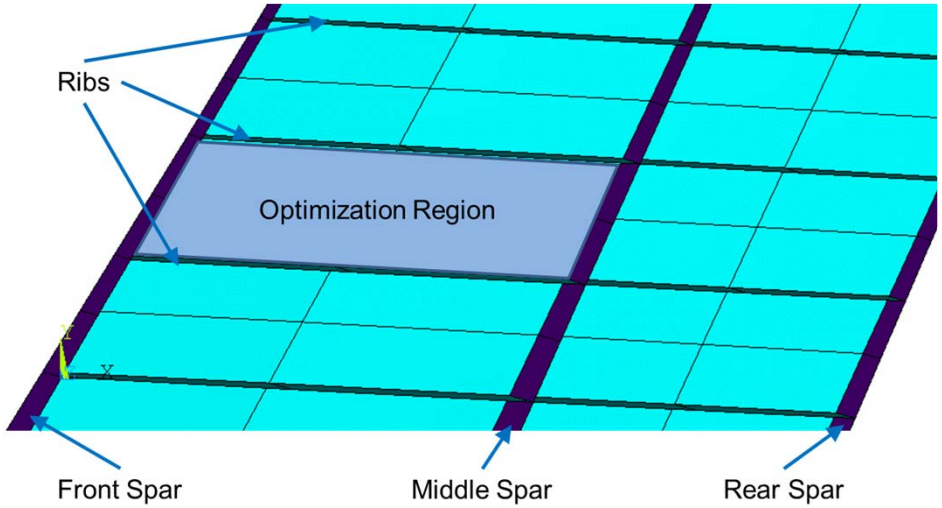
Typical aircraft configuration



Aircraft configuration with strut braced wing

Sizing process in SBOT

- Calculation of structural response in Ansys
- Computation of residuals
  - Application of various strength criteria (max. stress) and stability criteria (considering shear, compression, combination of both)



Sizing process in SBOT

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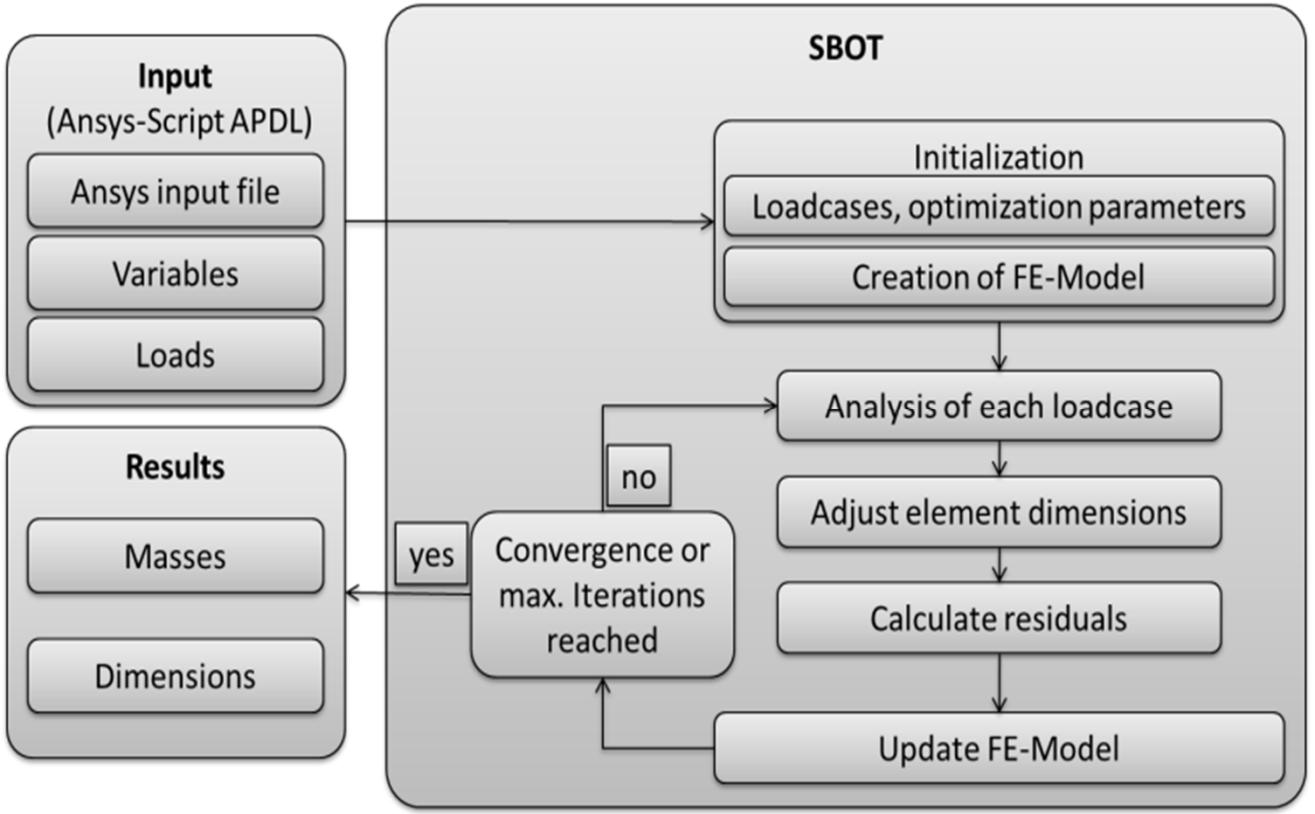
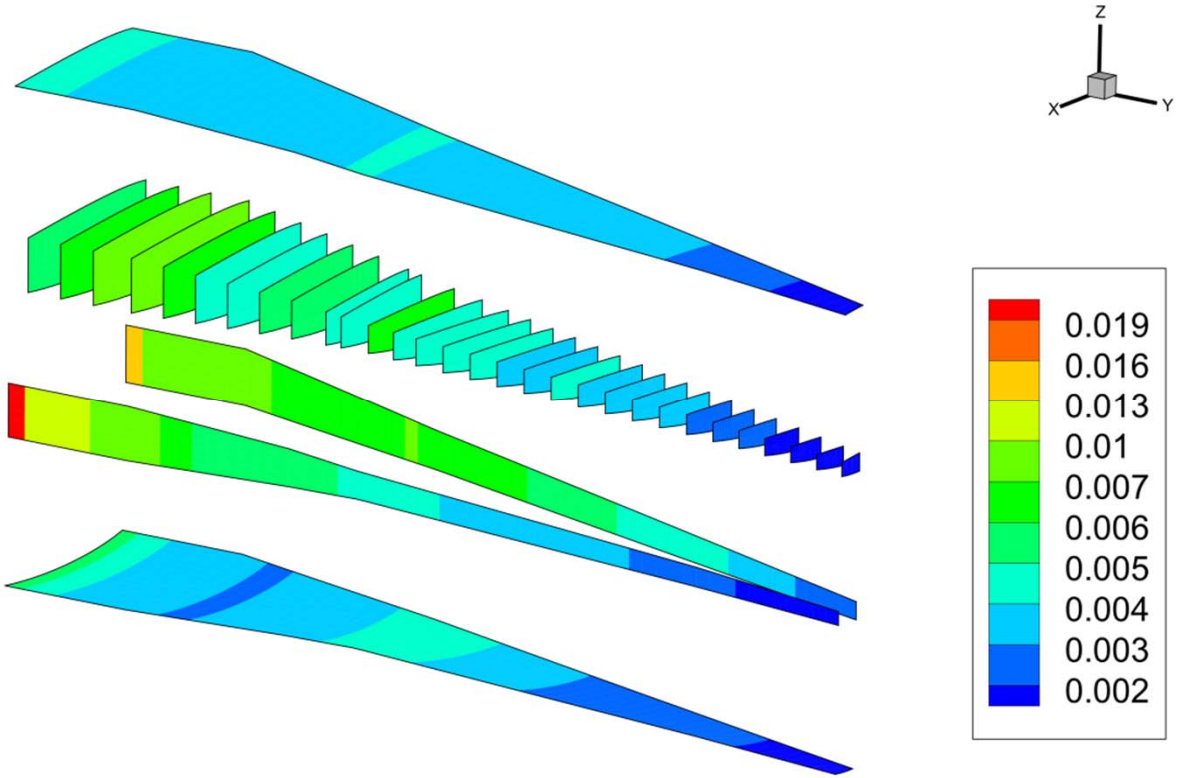


SBOT workflow

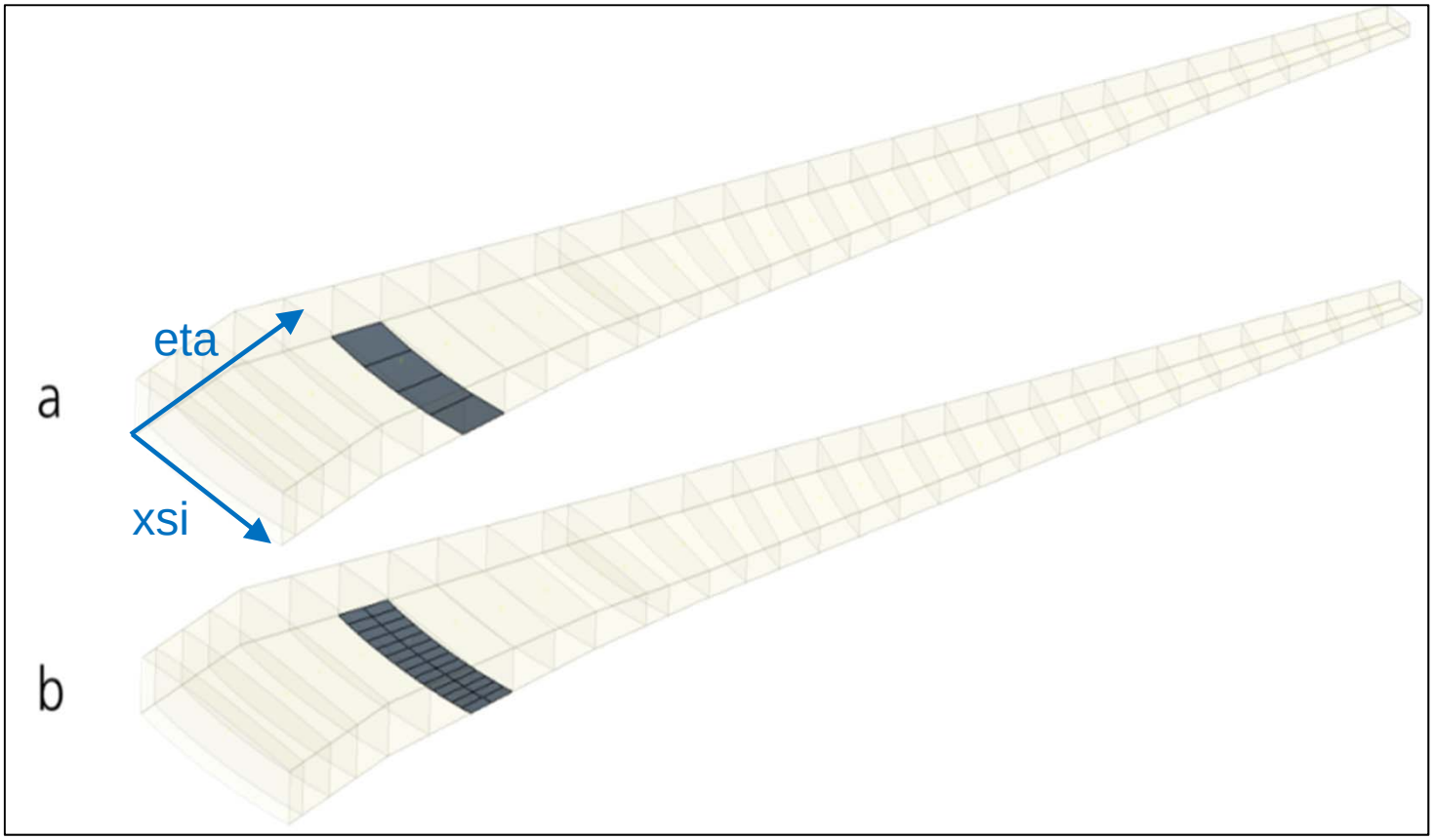
Sizing process in SBOT

- Calculation of structural response in Ansys
- Computation of residuals
  - Application of various strength and stability criteria
- After convergence thicknesses are written back to CPACS



Resulting thickness distribution [mm]

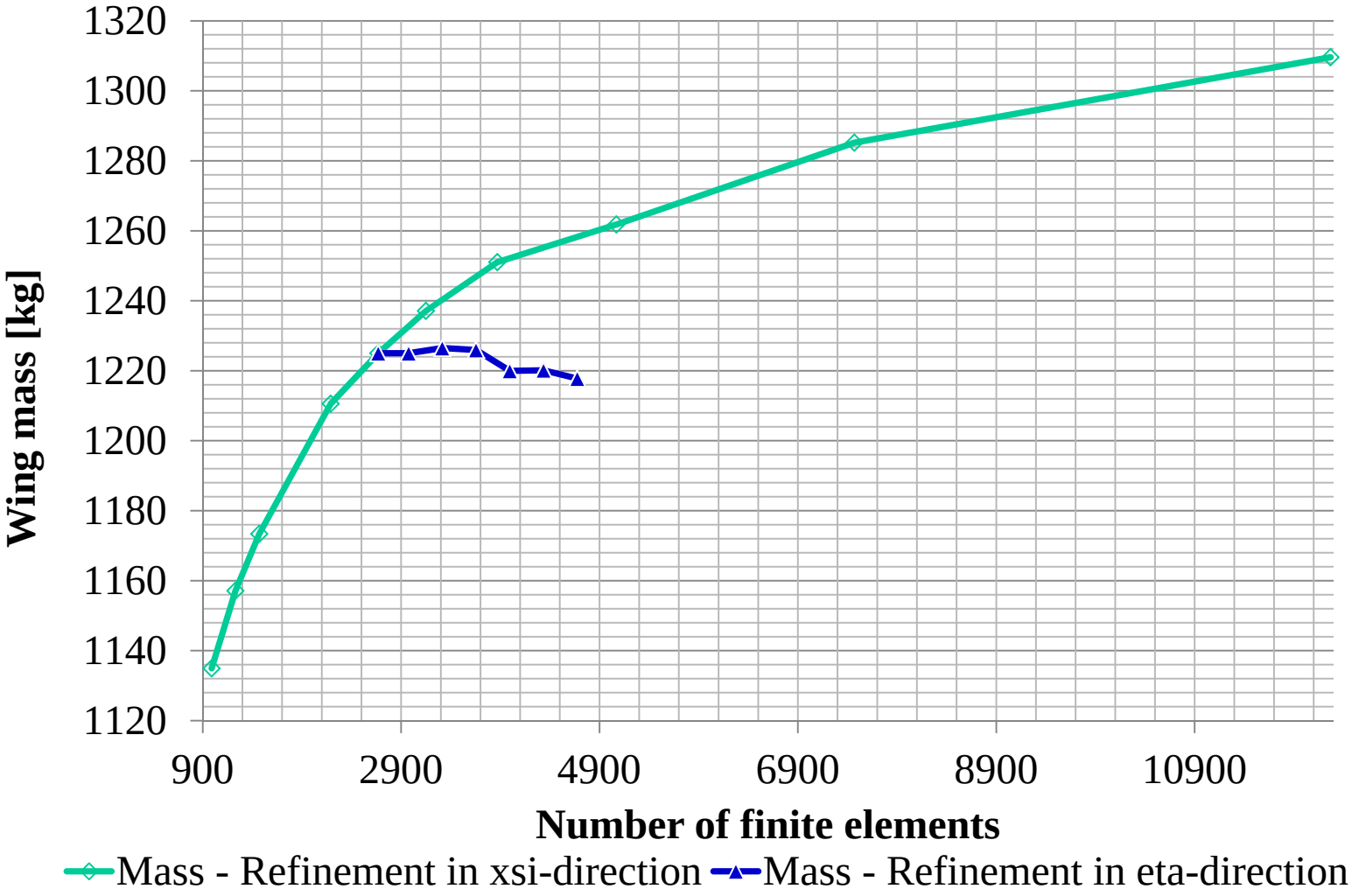
Sizing process
Convergence study of mesh density: Wing



Different wing box mesh seeds

Sizing process

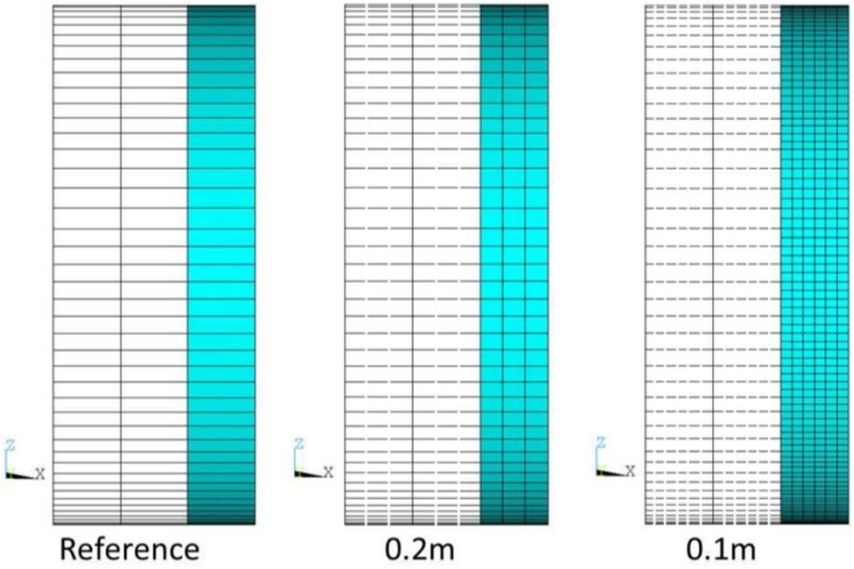
Convergence study of mesh density: Wing



DLR

Sizing process

Convergence study of mesh density: Fuselage



Sizing components and mesh refinement

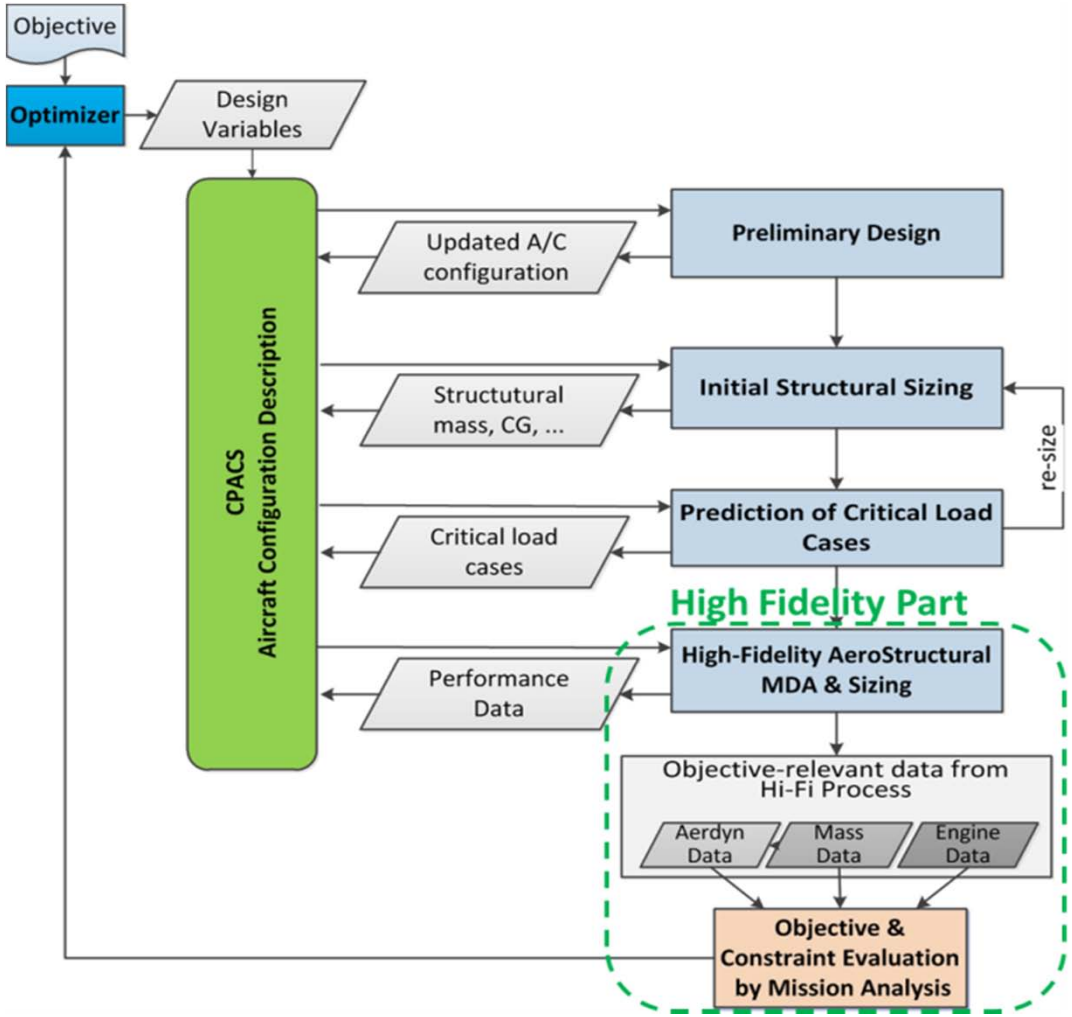
→ Not necessary to refine mesh density of the fuselage in the early design phase

Elements per bay	1	3	6
Skin mass [kg]	1447.05	1457.59	1466.89

Resulting skin masses per bay in [kg]

Application within MDO process

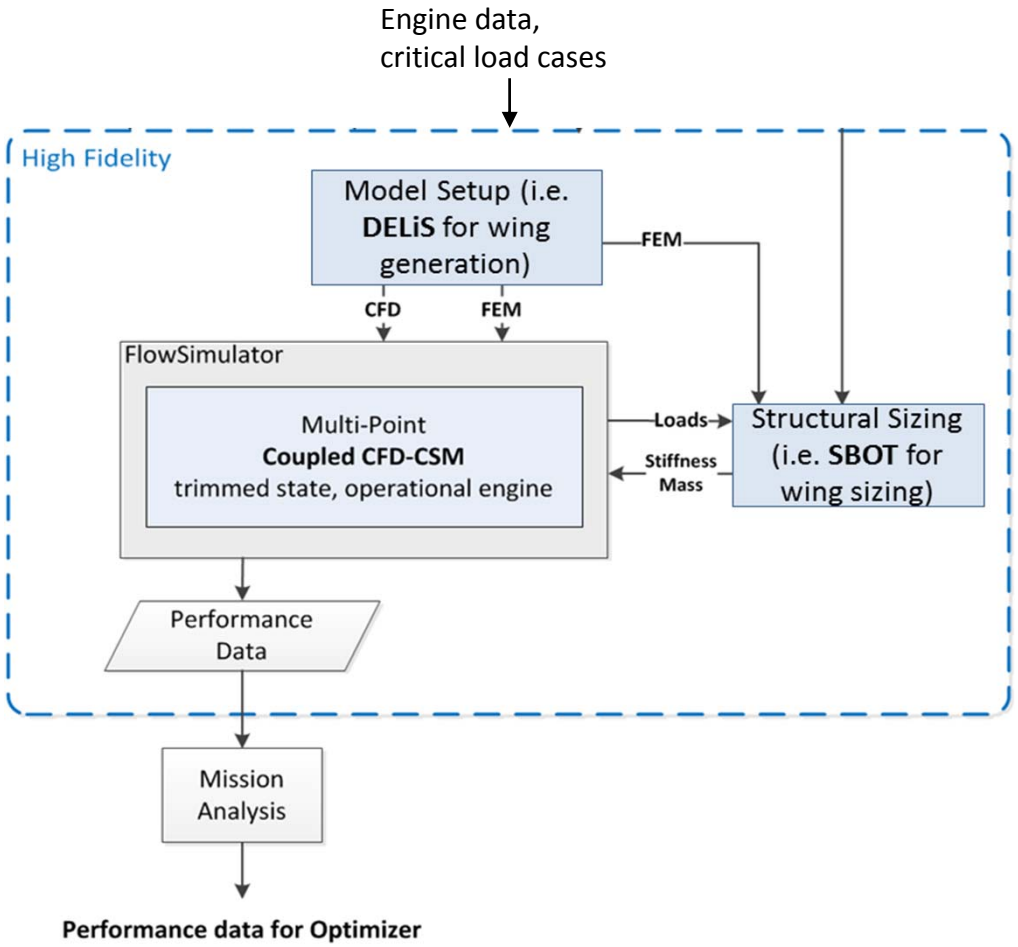
- A multi-disciplinary optimization (MDO) process includes several disciplines to study a wide range of suitable designs
- First fast tools perform a preliminary structural sizing and predict critical loads



MDO (multi-disciplinary optimization) chain

Application within MDO process

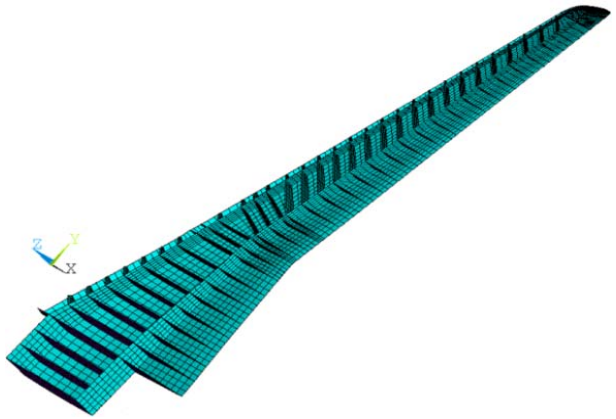
- High Fidelity part
  - More detailed sizing of structural model
  - Aero-structural coupling analysis
- Generation and sizing of structural model
- Recalculation of critical load cases

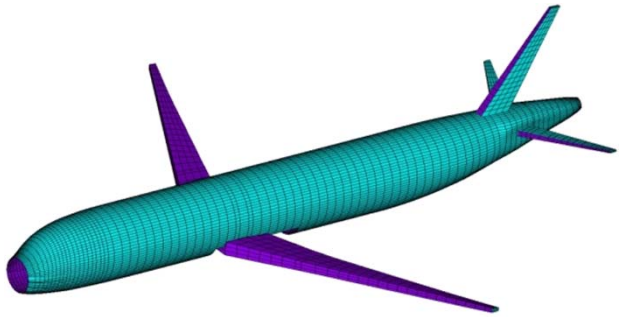


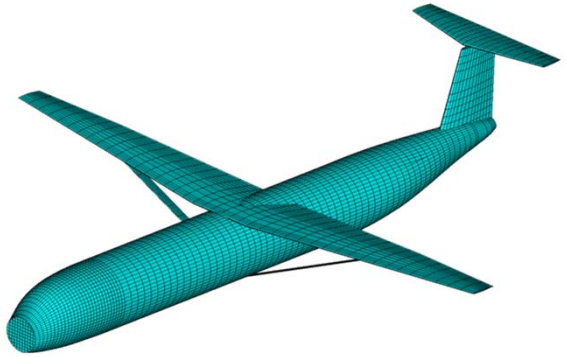
High Fidelity part of the MDO chain

Summary

- DELiS enables
  - To model various aircraft configurations (different mesh densities, levels of detail)
    - Fully parametrized
    - Based on the CPACS data set
  - To analyze the finite element models (interfaces to Ansys, Nastran)
  - To size the aircraft configurations (interfaces to SBOT, HyperSizer)
- Automatic model generation and sizing
- DELiS is already used within a MDO chain







- Next Steps:
  - Further investigation of unconventional configurations
  - Consideration of additional stability criteria

DLR

Recent developments in the CEASIOM framework using the common language CPACS

Marco Cristofaro
Da Ronch A., Rizzi A., Vos J.

Master thesis
University of Southampton and Politecnico di Torino

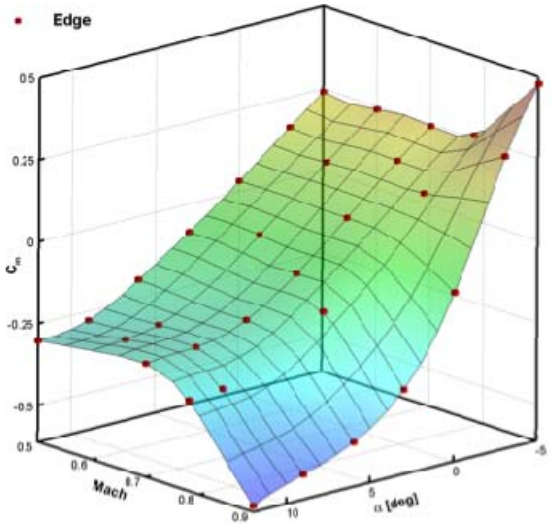
4th EASN Workshop on Flight Physics and Aircraft Design
Aachen (DE) - 15 October 2014

University of Southampton

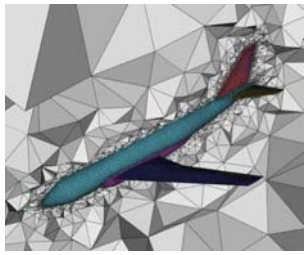
Work objective

Efficient flight dynamics analysis

Nonlinear aerodynamic → CFD fidelity → S&C during conceptual aircraft design phase (limited budget)



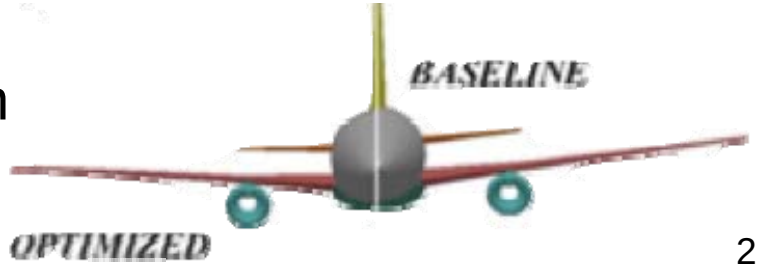
Aerodynamic table (~1million flight points) at reduced cost



Automatic mesh generation

Traditional flight simulators

Geometry optimization for flight dynamics



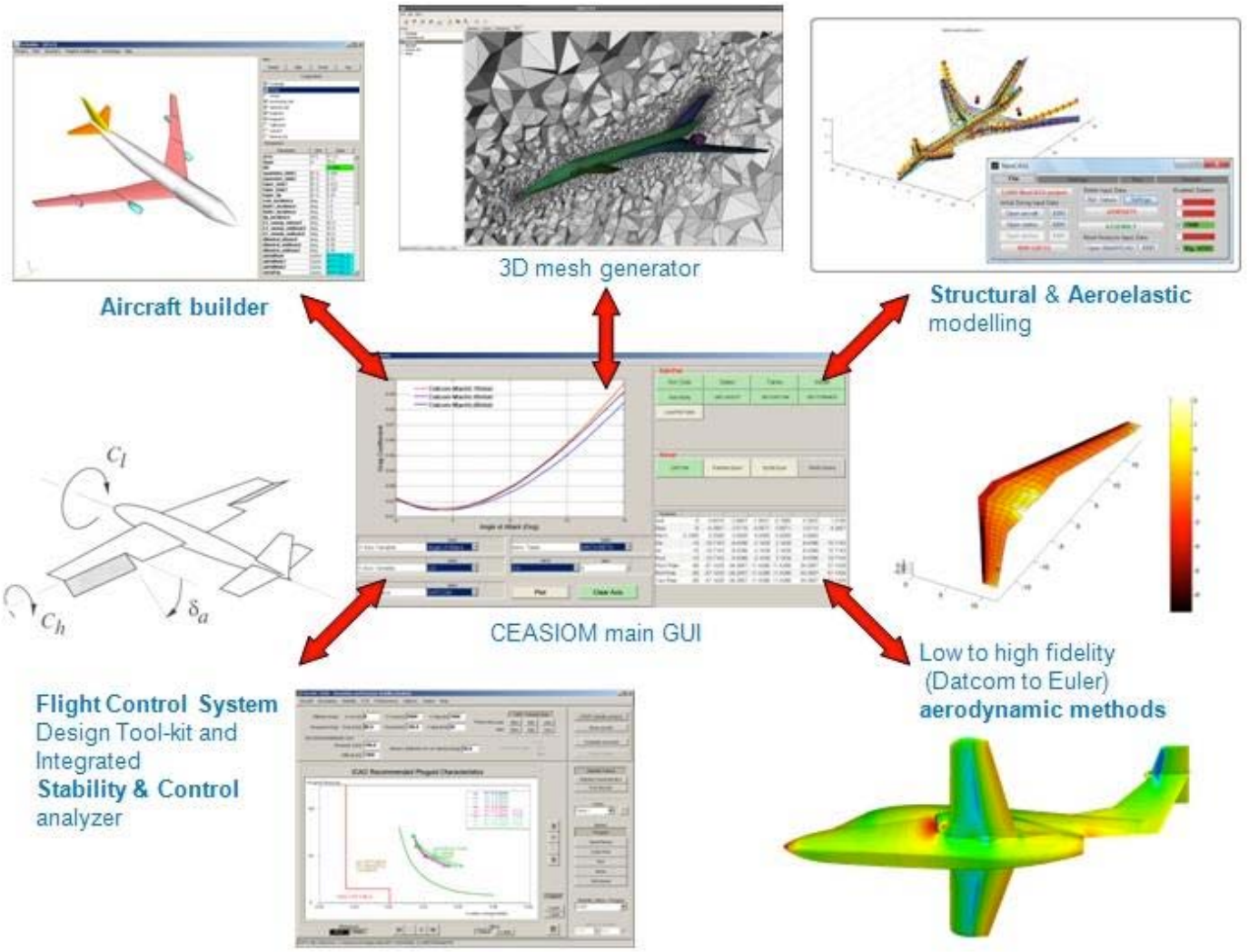
CPACS based CEASIOM

1. Work objective
2. Aircraft conceptual design and CEASIOM
    - 2.1 New file scheme
    - 2.2 Aerodynamic module upgrade
3. Cognitive sampling development
    - 3.1Validation
4. Regional Jet test case
    - 4.1 Aerodynamic data validation
    - 4.2 Stability analysis
    - 4.3 Geometry variations
5. Geometry optimization considering aircraft stability
    - 5.1 Loop definition
6. Alternative aircraft configurations
    - 6.1 Strut-braced wing aircraft
    - 6.2 Blended wing body aircraft
7. Conclusions

Aircraft conceptual design and CEASIOM

Conceptual design:

- Today
  - Handbook method
  - Linear mechanics hypothesis
- Future
  - High fidelity
  - Virtual flight simulation



Scharl, J., Mavris, D.N., Burdun, I.Y., "Use of Flight Simulation in Early Design: Formulation and Application of the Virtual Testing and Evaluation Methodology ," *2000 World Aviation Conference, San Diego, CA*

www.ceasiom.com

CPACS based CEASIOM

1. Work objective
2. Aircraft conceptual design and CEASIOM
    - 2.1 New file scheme
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    - 3.1Validation
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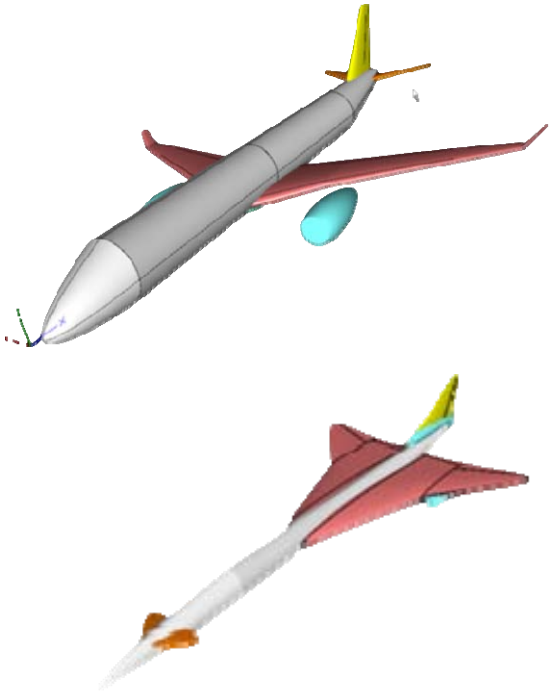
    - 6.2 Blended wing body aircraft
7. Conclusions

Geometry definition

Old CEASIOM

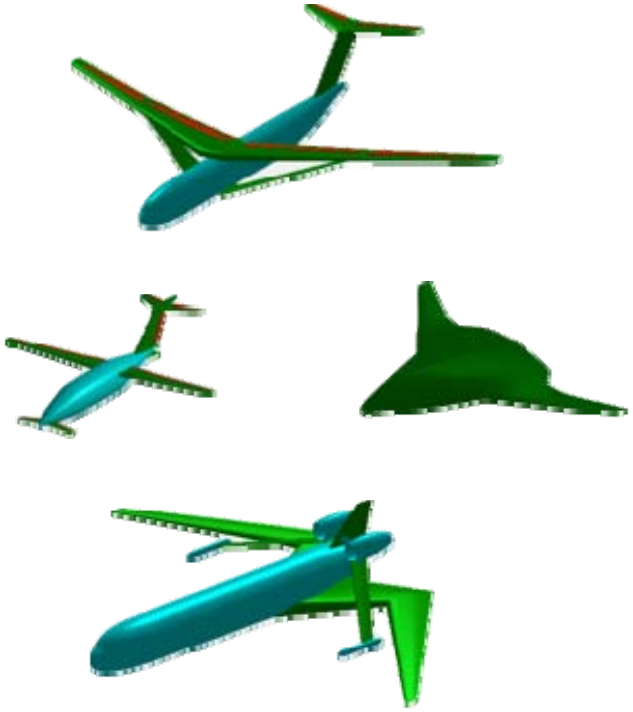
~100 parameters



vs

CPACS

unlimited parameters



Rizzi, A., Zhang, M., Nagel, B., Boehnke, D., and Saquet, P., “Towards a Unified Framework using CPACS for Geometry Management in Aircraft Design,” *50th AIAA Aerospace Sciences Meeting, Nashville, Tennessee, USA,* January 2012.

CPACS based CEASIOM

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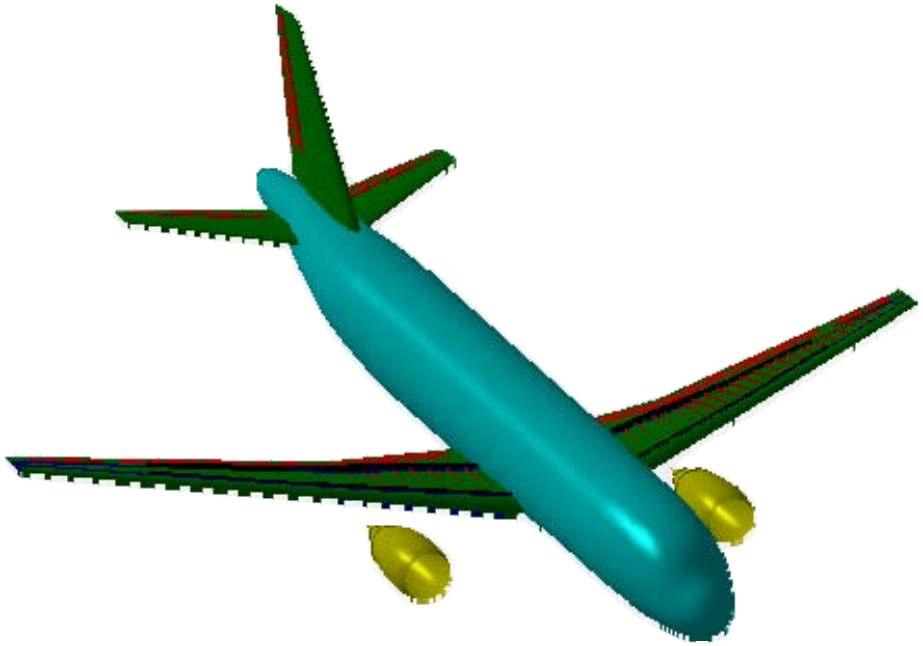
    - 6.2 Blended wing body aircraft
7. Conclusions

DATCOM

USAF S&C Digital Compendium

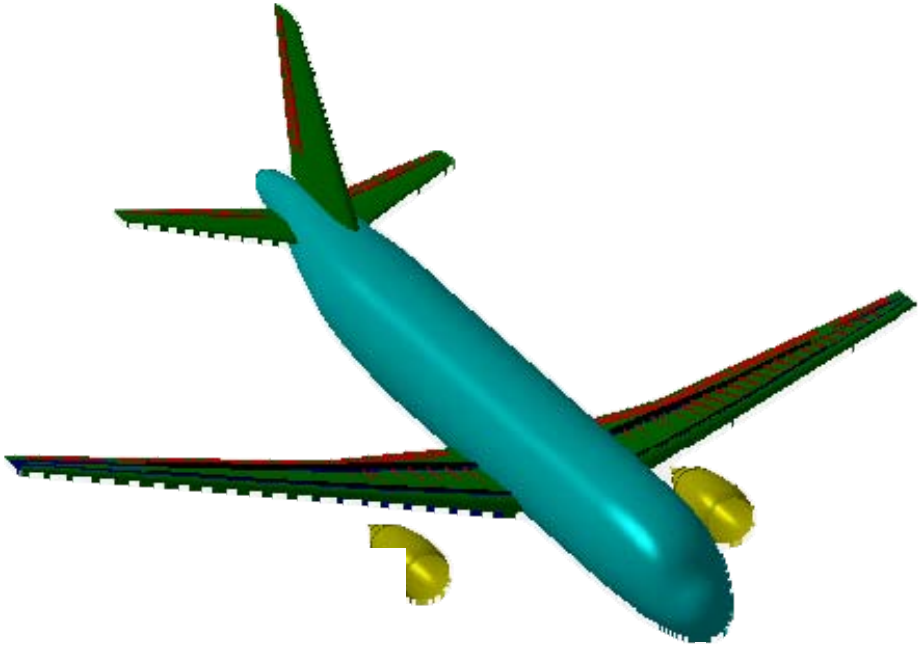
complex geometry
parameters



Edge

FOI unstructured CFD solver

defined external geometry



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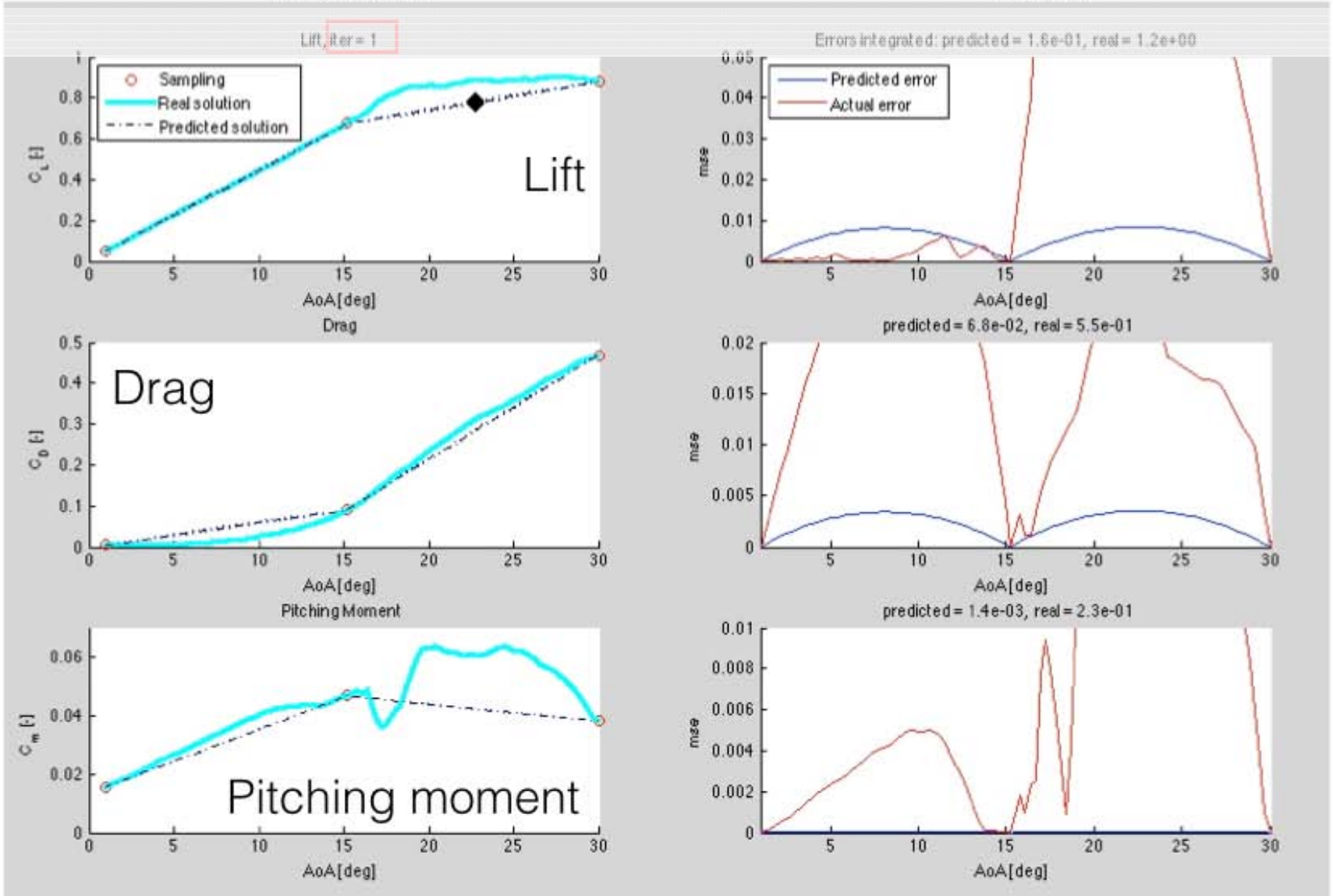
Sampling procedure

Kriging interpolation model

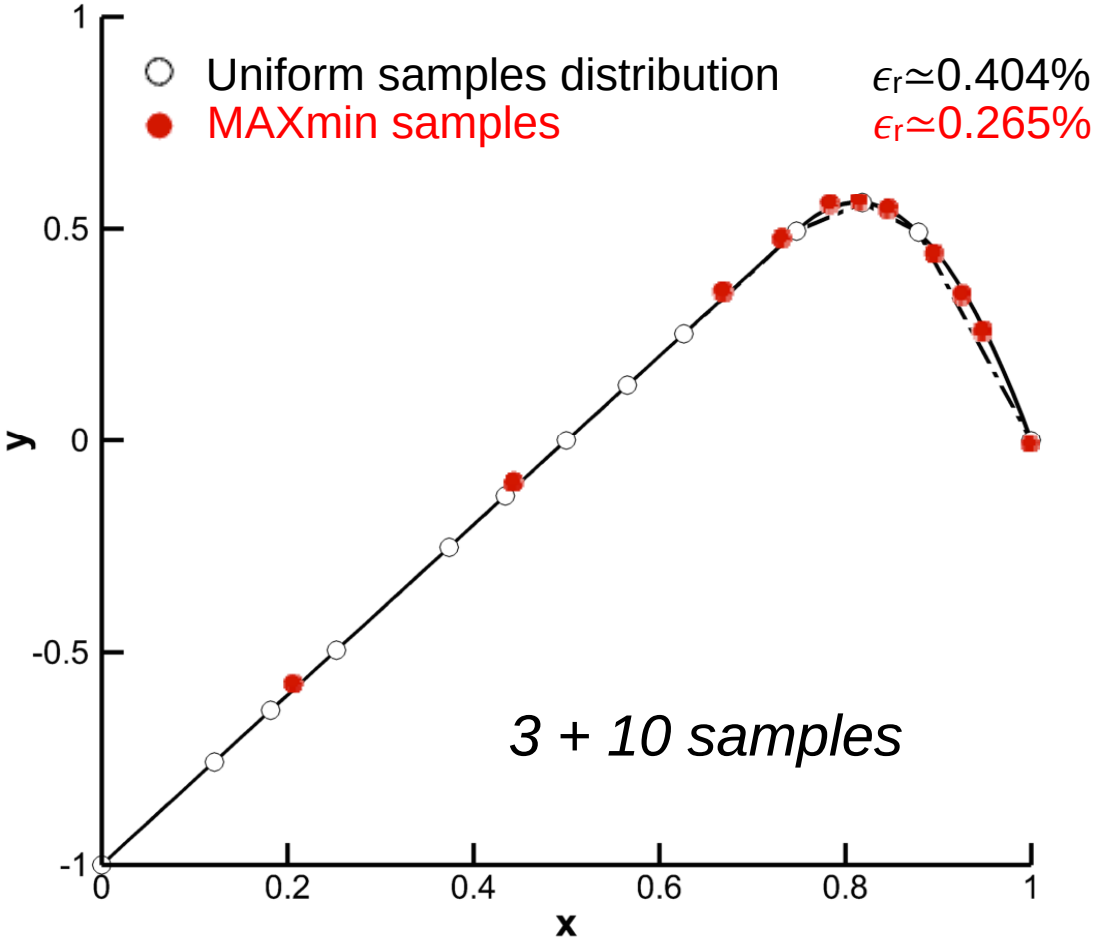
target & predicted functions

predicted & real errors



Cognitive sampling methods

lift like function



Off-the-shelf methods *(max EIF)*:

- Inability to capture local nonlinearities
- Large number of samples for convergence

Developed methods:

Local maxima and minima of the function prediction search

Second derivative (Hessian matrix) of the function prediction estimation

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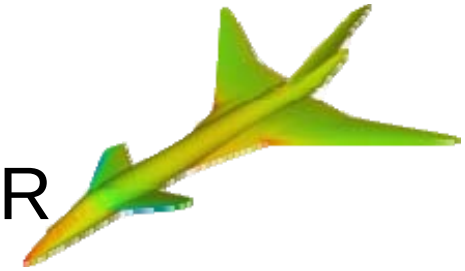
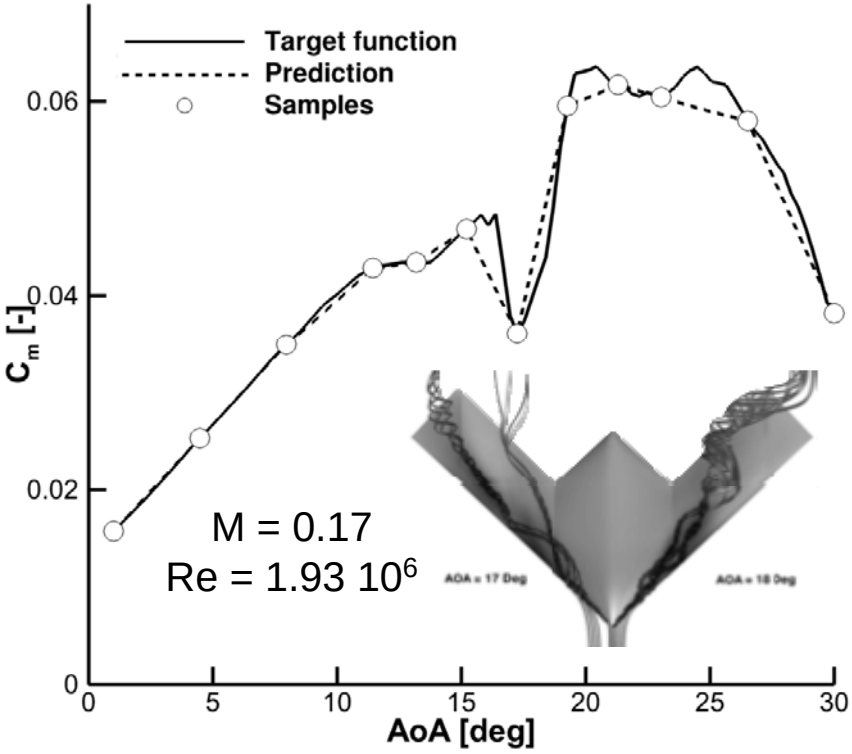
Cognitive sampling validation

UCAV

TCR

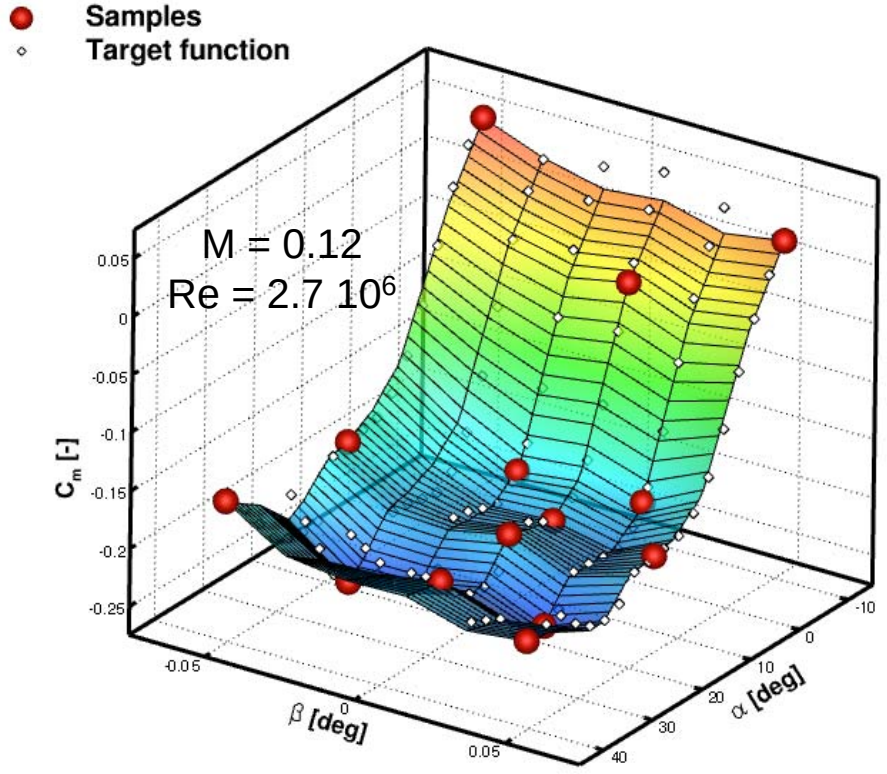


MAXmin based $\epsilon_r \simeq 2.40\%$



Vallespin, D., Da Ronch, A., Badcock, K. J., and Boelens, O.,
"Vortical Flow Prediction Validation for an Unmanned Combat Air Vehicle Model,"
Journal of Aircraft, Vol. 48, No. 6, 2011, pp. 1948–1959.

Hessian based $\epsilon_r \simeq 13.12\%$



Rizzi, A., Eliasson, P., Goetzendorf-Grabowski, T., Vos, J. B.,
Mengmeng, Z., and Richardson, T. S.,
"Design of a canard configured TransCruiser using CEASIOM,"
Progress in Aerospace Sciences, Vol. 47, No. 8, 2011, pp. 695–705.

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Regional Jet

Design requirements:

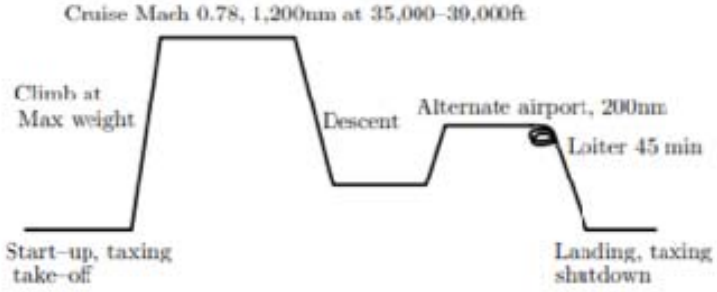
Parameter	Value
Range	2,600 km
Cruise Mach	0.78
Cruise altitude	10,668–11,887 m
Number of engines	2
Number of passengers	110
Landing field length	1,450 m
Take off field length	1,550 m
Long. ref. length	3.6 m
Lat. ref. length	30 m
Wing area	105 m^2

Geometrical model:

Mass and inertia Howe's evaluations:

Parameter	Value
MTOW	$4.97 \cdot 10^4$ kg
CG location	(16.13, 0, 0.0236) m
Ixx	$1.11 \cdot 10^6$ kg·m^2
Iyy	$1.90 \cdot 10^6$ kg·m^2
Izz	$2.87 \cdot 10^6$ kg·m^2
Ixz	$6.72 \cdot 10^4$ kg·m^2
Ixy, Iyz	0 kg·m^2

Mission specifications:



Cristofaro, M., Wang, Y., and Da Ronch, A., "Towards computational flight dynamics of a passenger jet aircraft," *ICAS International Council of Aeronautical Sciences Conference, St Petersburg, Russia,* Vol. 0462, September 2014, DOI: 10.13140/2.1.4988.5445.

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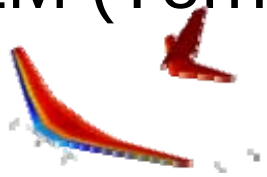
Aerodynamic data validation

- WT

Reynold 4 10^6

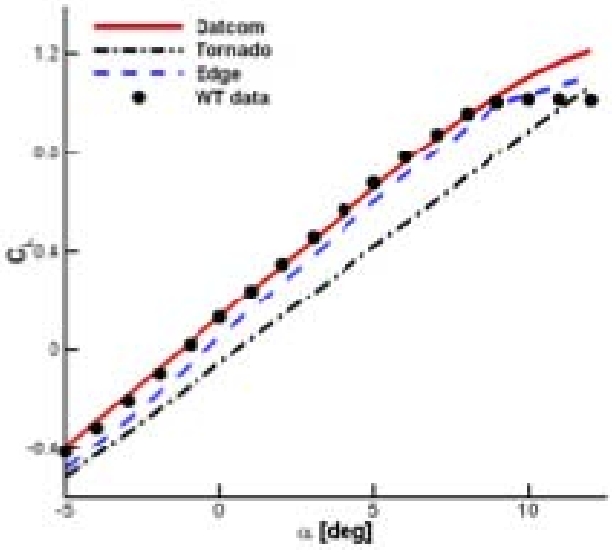
- DATCOM

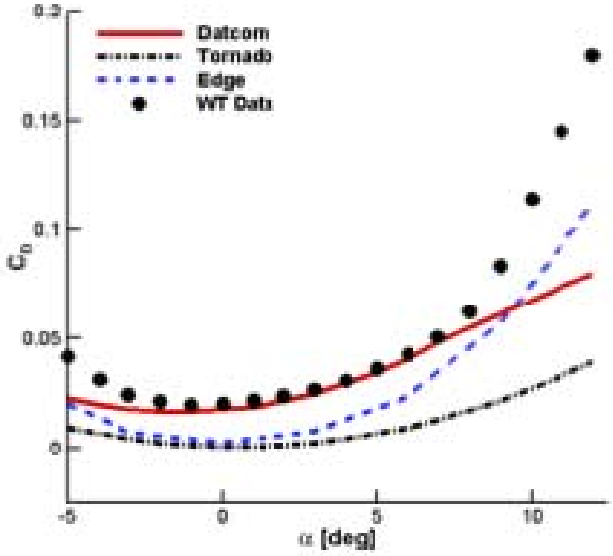
- VLM (Tornado)

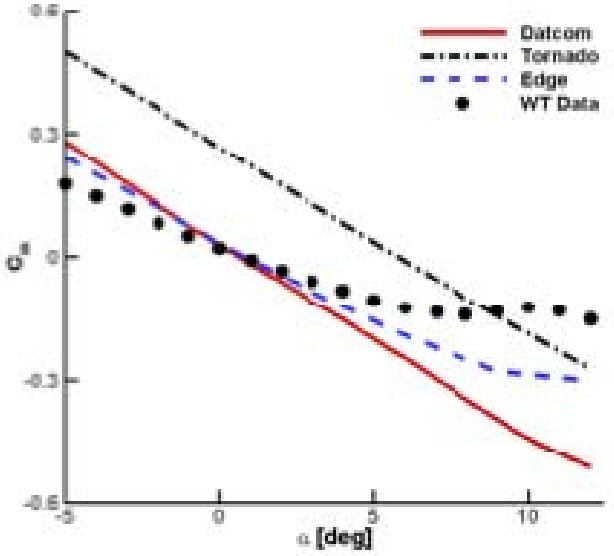


- CFD (Edge)

(non viscous)







Mach 0.5 at 39,000 ft (147 m/s wrt ISA)

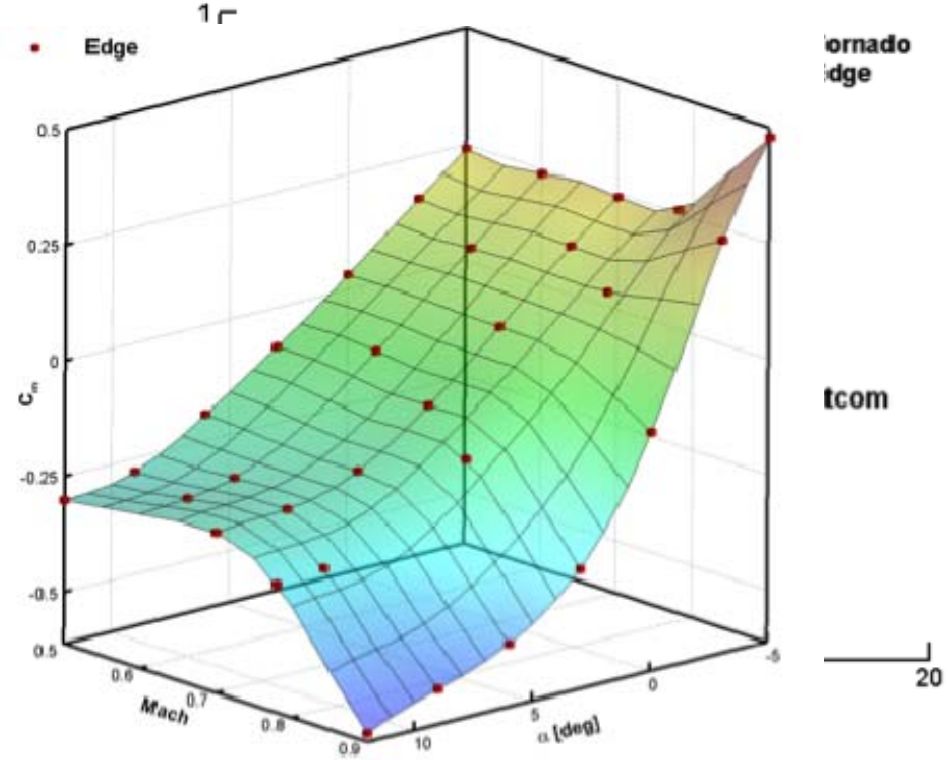
ROM for aero-tables generation

Kriging interpolation of the CFD solutions

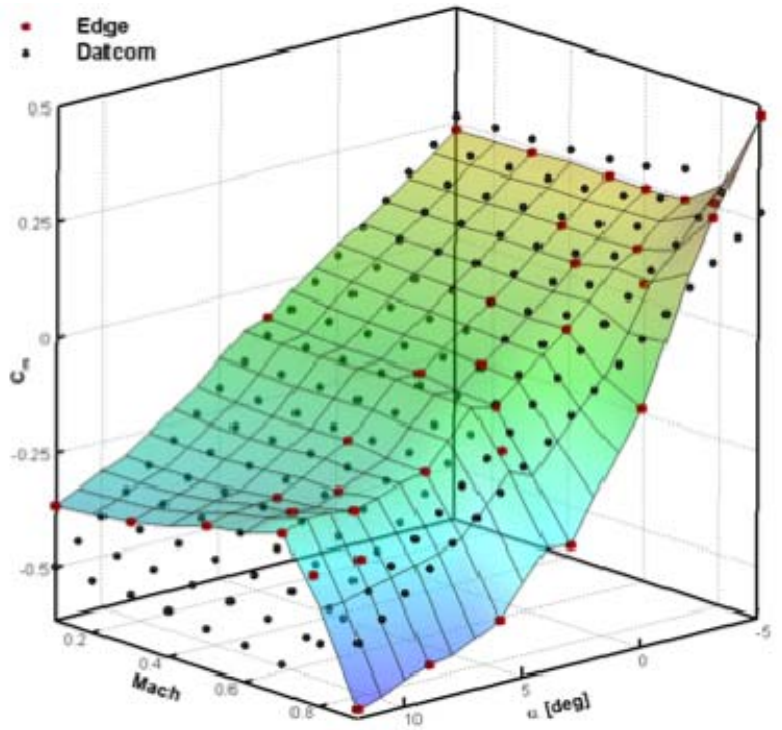
Computations distribution

Data fusion of DATCOM and CFD

Aerodynamic tables:



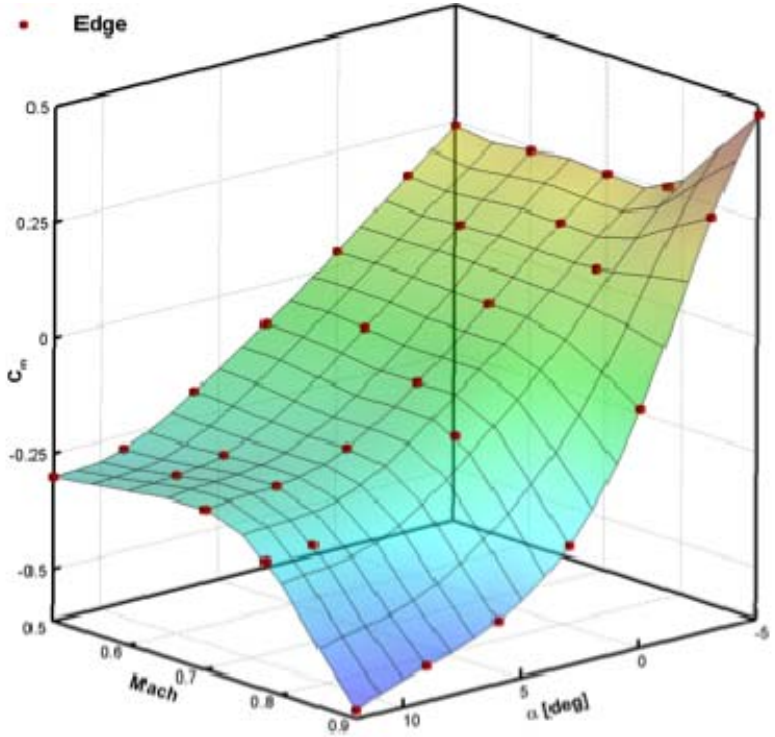
α	M
x	x
x	x
x	x
x	x
x	x
x	x
x	x
x	x



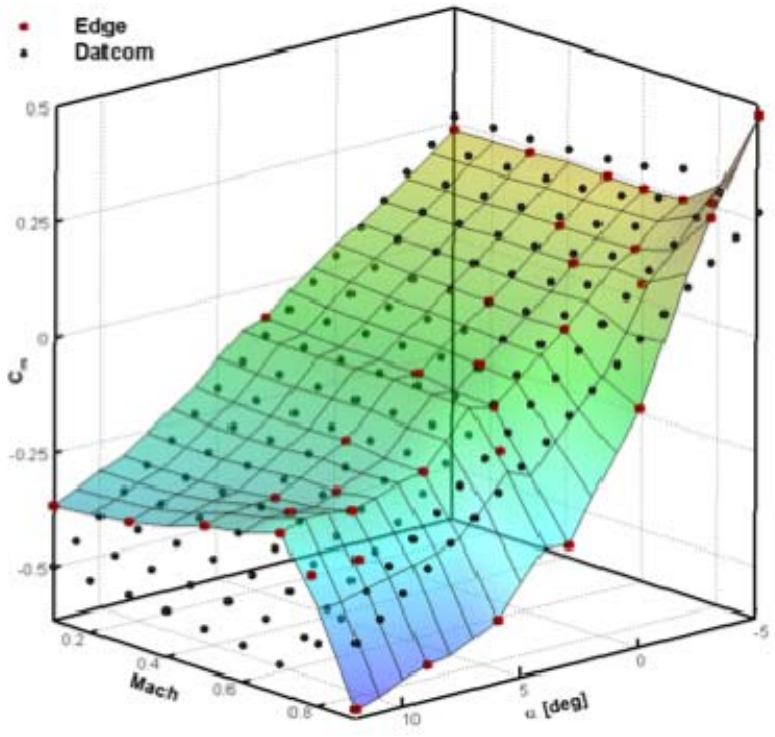
97 CFD computations → data density: 5% of (α, M, β)

ROM for aero-tables generation

Kriging interpolation of the CFD solutions



Data fusion of DATCOM and CFD



97 CFD computations → data density: 5% of (α, M, β)

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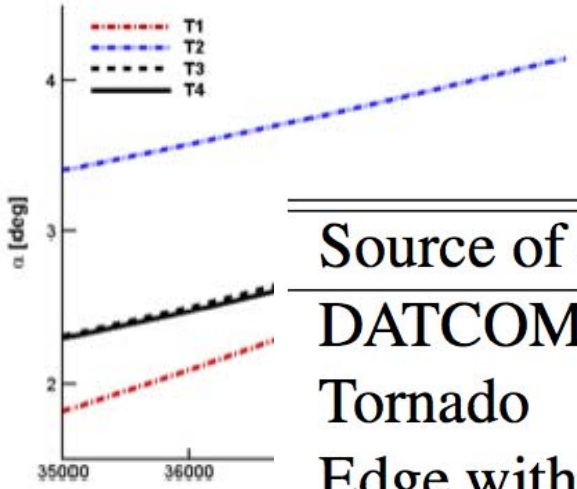
Longitudinal stability

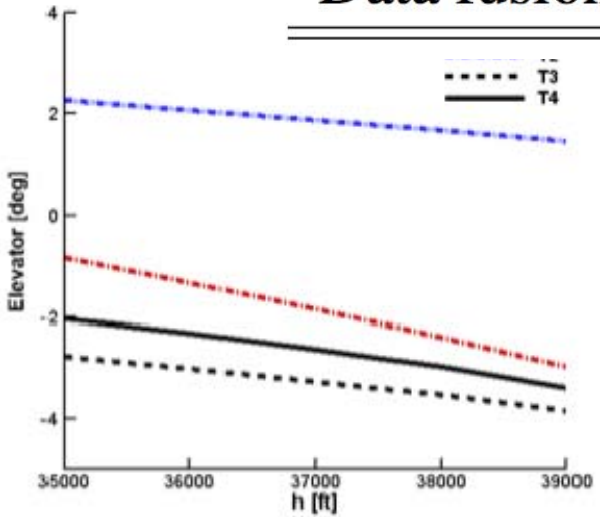
Trim analysis

Angle of attack



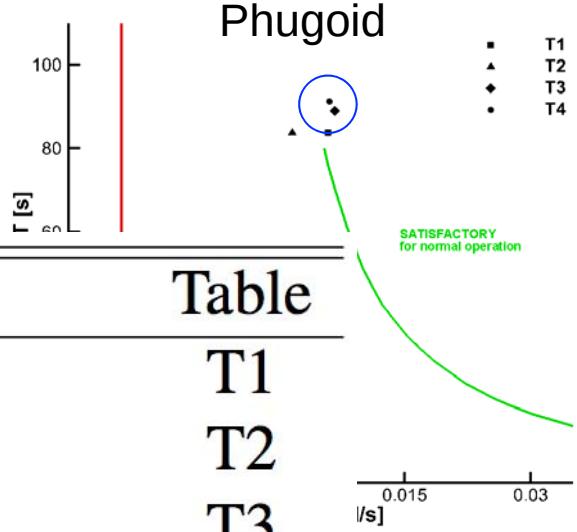
Source of data	Table
DATCOM	T1
Tornado	T2
Edge with Kriging interpolation	T3
Data fusion of T3 and wind tunnel data	T4

Eleva

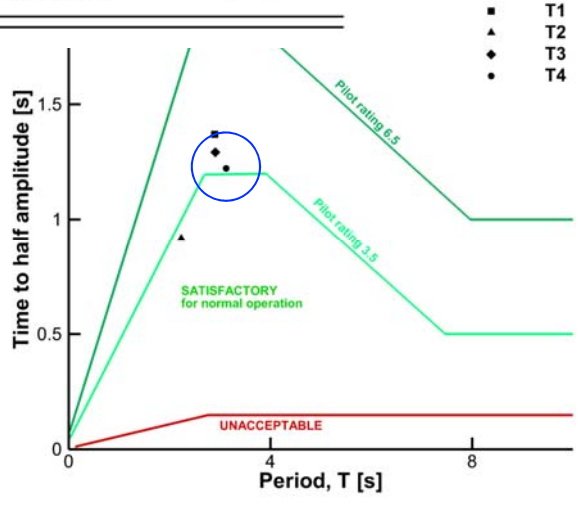


Dynamic stability

Phugoid



eriod



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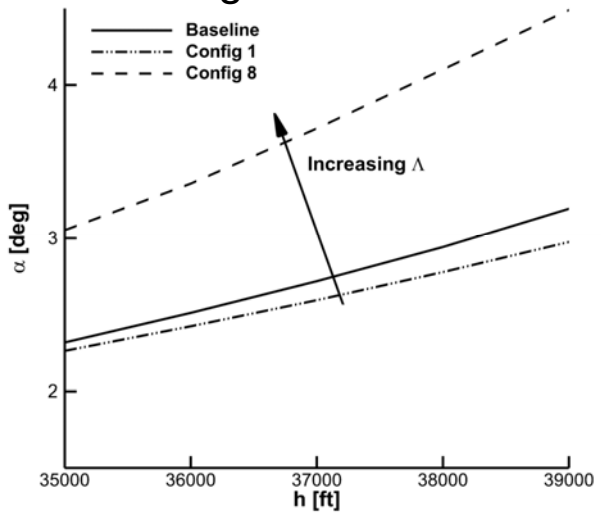
Geometry variations stability effect

Trim analysis

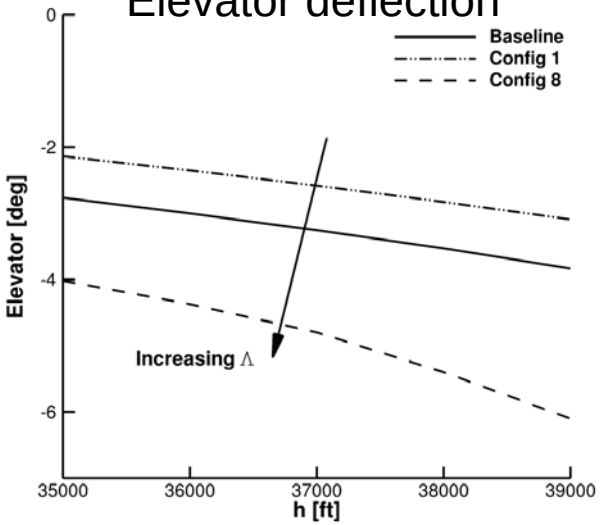
W&B estimation: handbook methods

Aerodynamic tables: data fusion + 18 CFD computations per configuration

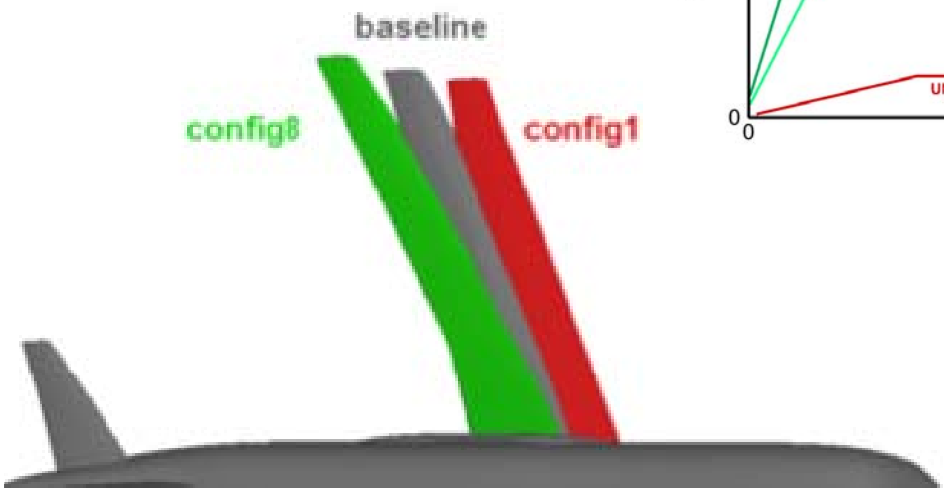
Angle of attack



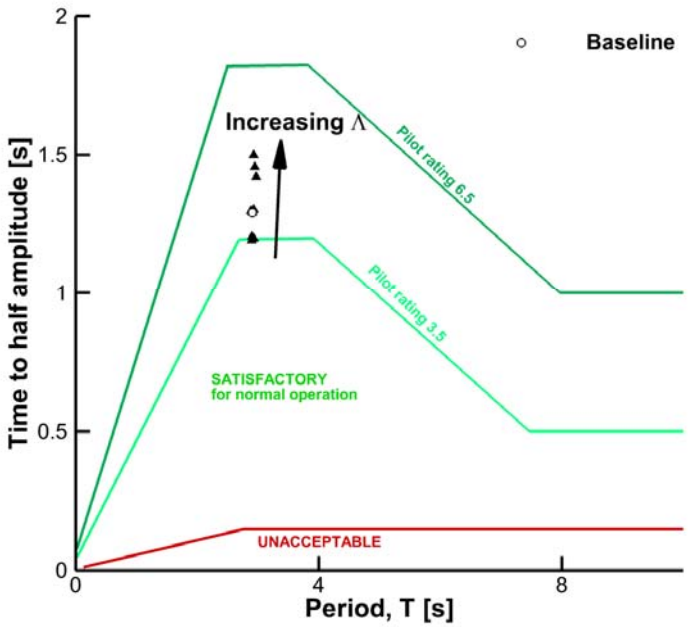
Elevator deflection



Configuration	Λ_{LE} [deg]	AR [–]
Baseline	27	9.4
Configuration 1	20	9.0
Configuration 2	20	9.4
Configuration 3	20	10.0
Configuration 4	27	9.0
Configuration 5	27	10.0
Configuration 6	33	9.0
Configuration 7	33	9.4
Configuration 8	33	10.0



Short period longitudinal mode



Computational Flight Dynamic

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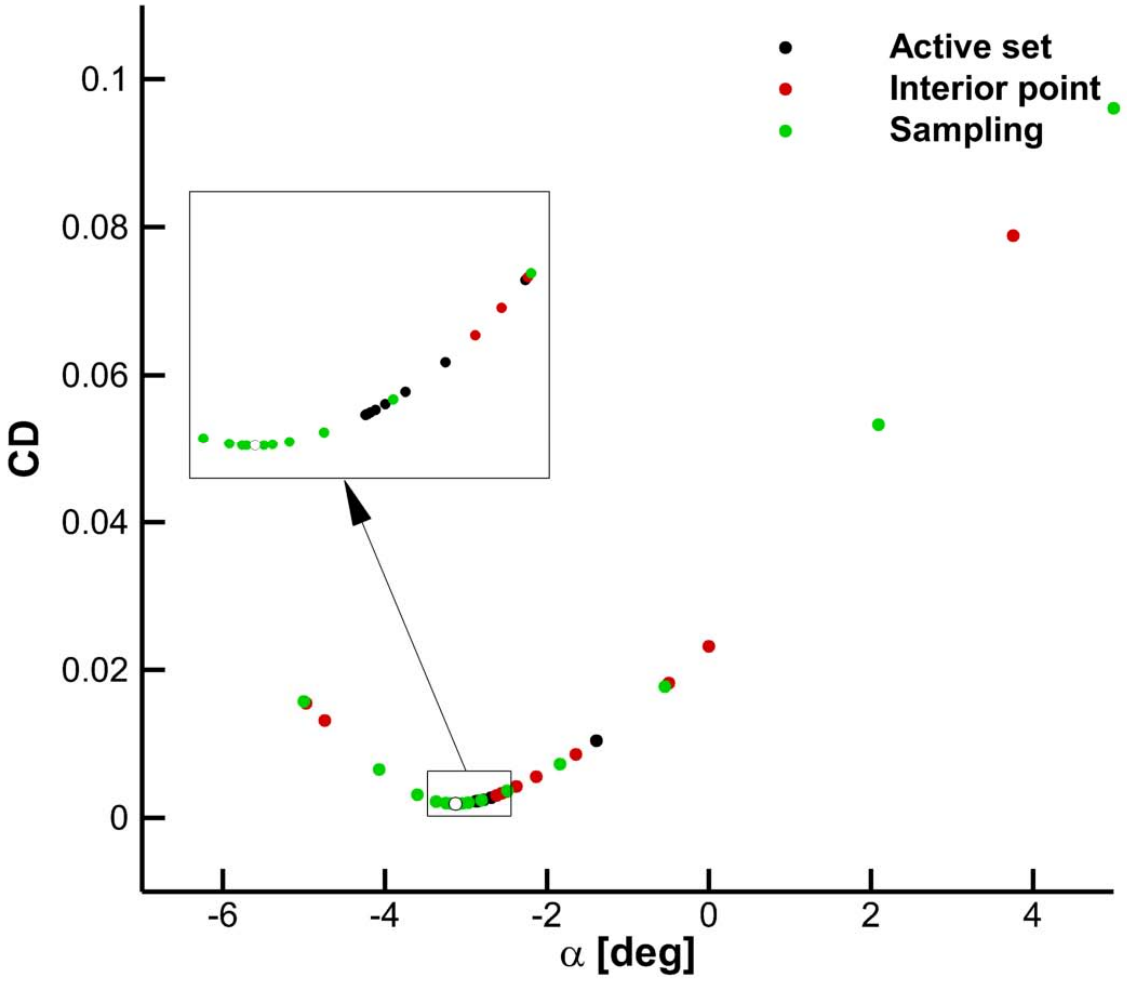
Rae2822 drag minimization

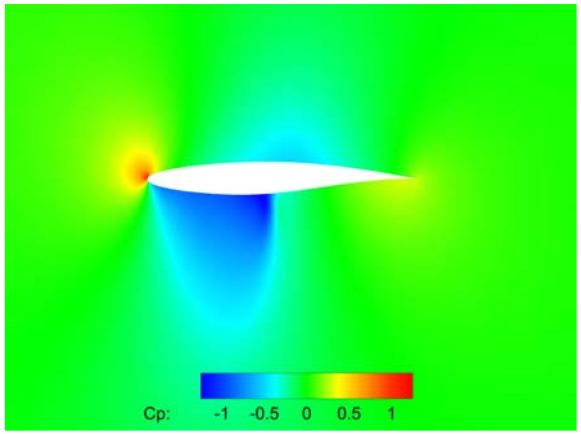
minimize C_D

α

Mach 0.75
(V_∞=225 m/s at s.l. wrt ISA)



Result:
α=-2.87°



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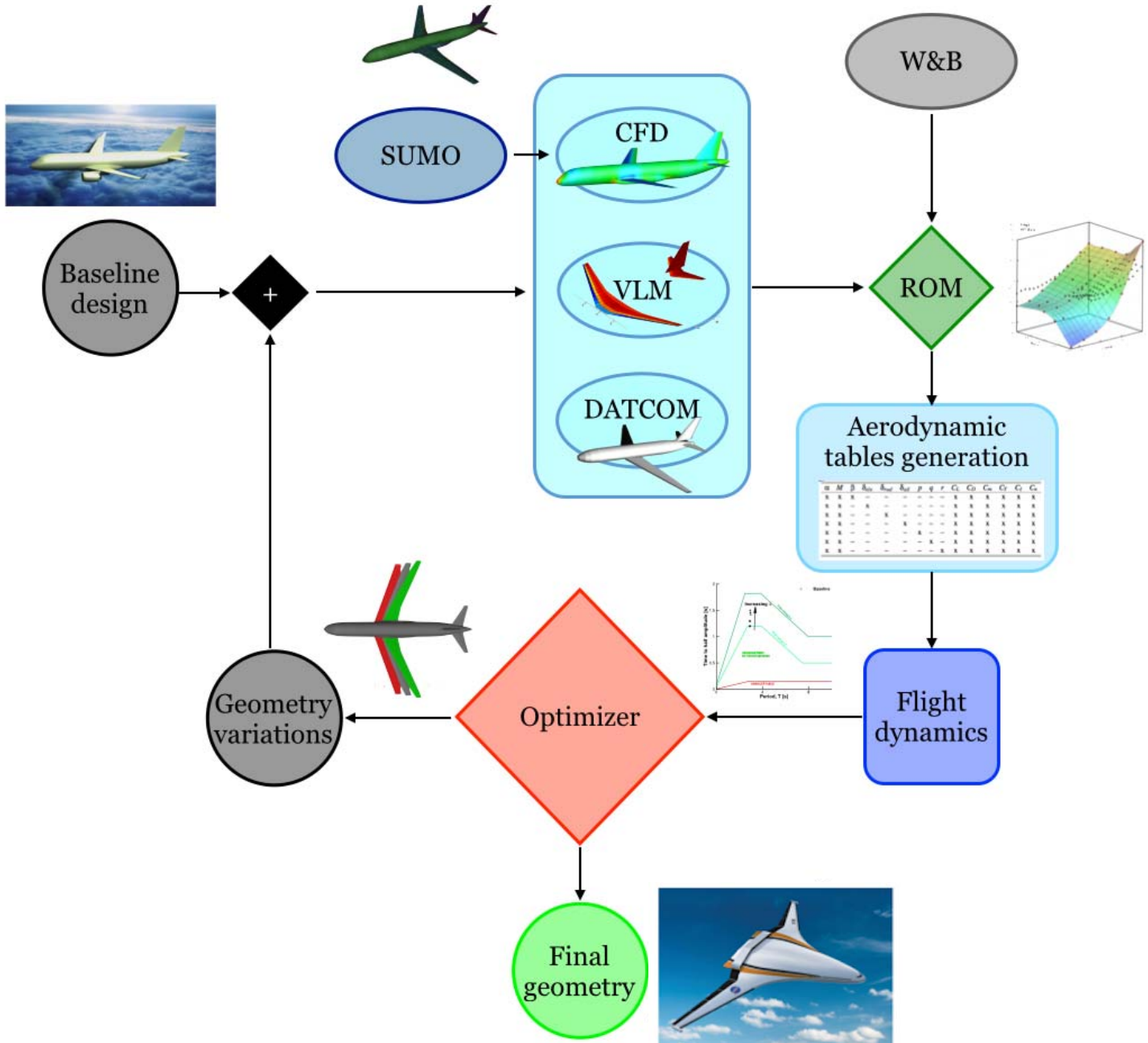
Geometry optimization loop

optimize *stability*
geometry

subject to *feasible geometry*

e.g.
minimize CD_{TRIM}
Λ
subject to $-90° \leq \Lambda \leq 90°$



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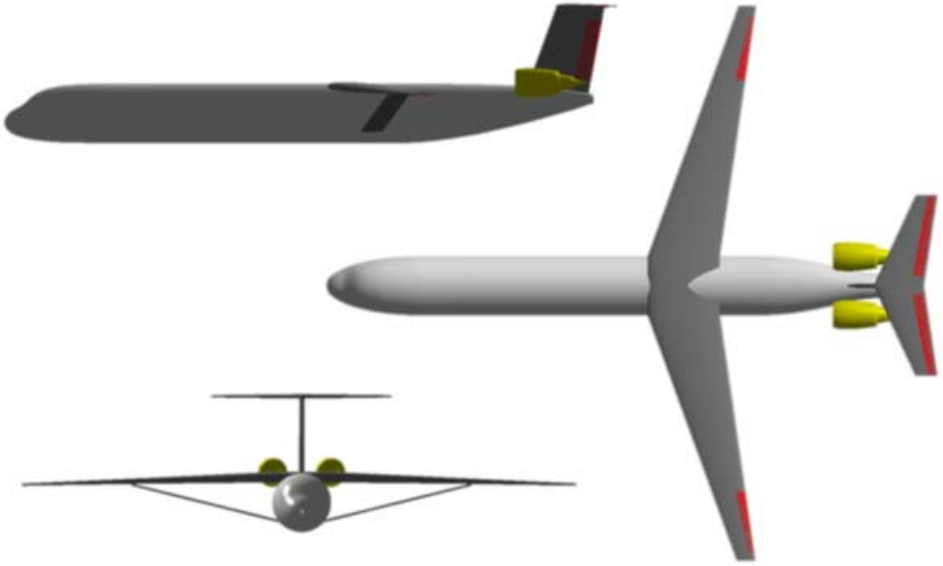
Strut-braced wing aircraft

Jungo A., CFSE under Vos J.



Jungo, A., *Development of the CEASIOM aircraft design enviroment for novel aircraft configurations*, Master's thesis, Ecole polytechnique federale de Lausanne, 2014.

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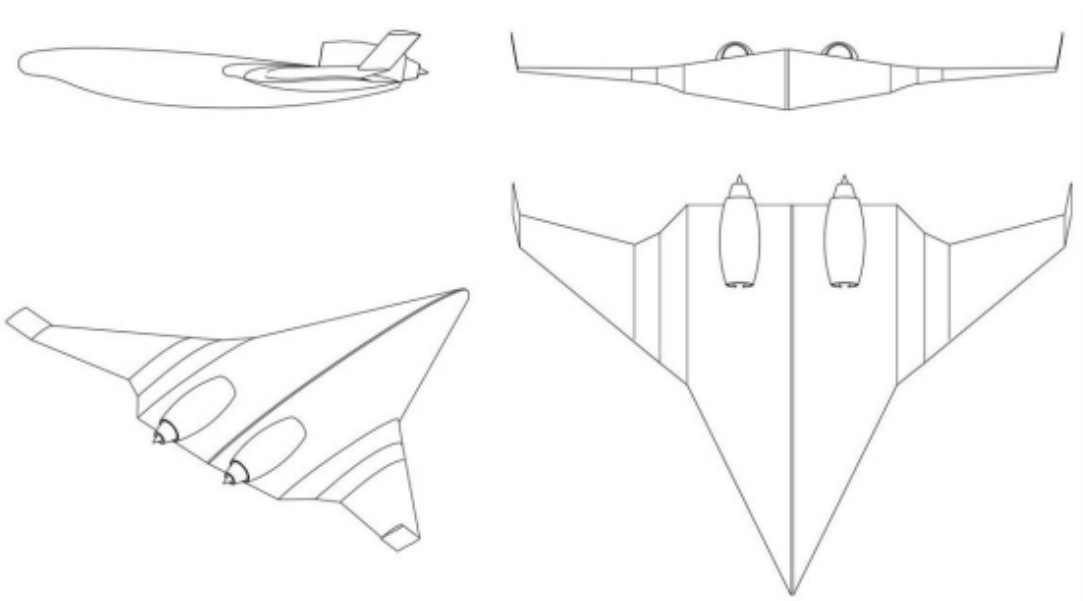
Blended wing body aircraft

Martinez R. M., KTH under Rizzi A.



Roberto, M. M., *Design and Analysis of the Control and Stability of a Blended Wing Body Aircraft*, Master's thesis, Royal Institute of Technology, Stockholm, 2014.

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Conclusions and future work

- CEASIOM upgrade for CPACS format.
- Cognitive sampling methods.
- Geometry optimization considering aircraft S&C.

Overview of the Versatile Options to Define Fuselage Structures within the CPACS Data Format

J. Scherer*, D. Kohlgrüber*

German Aerospace Center (DLR)
**Institute of Structures and Design (BT)*

4th EASN Association International Workshop on Flight Physics & Aircraft Design

27th – 29th October 2014

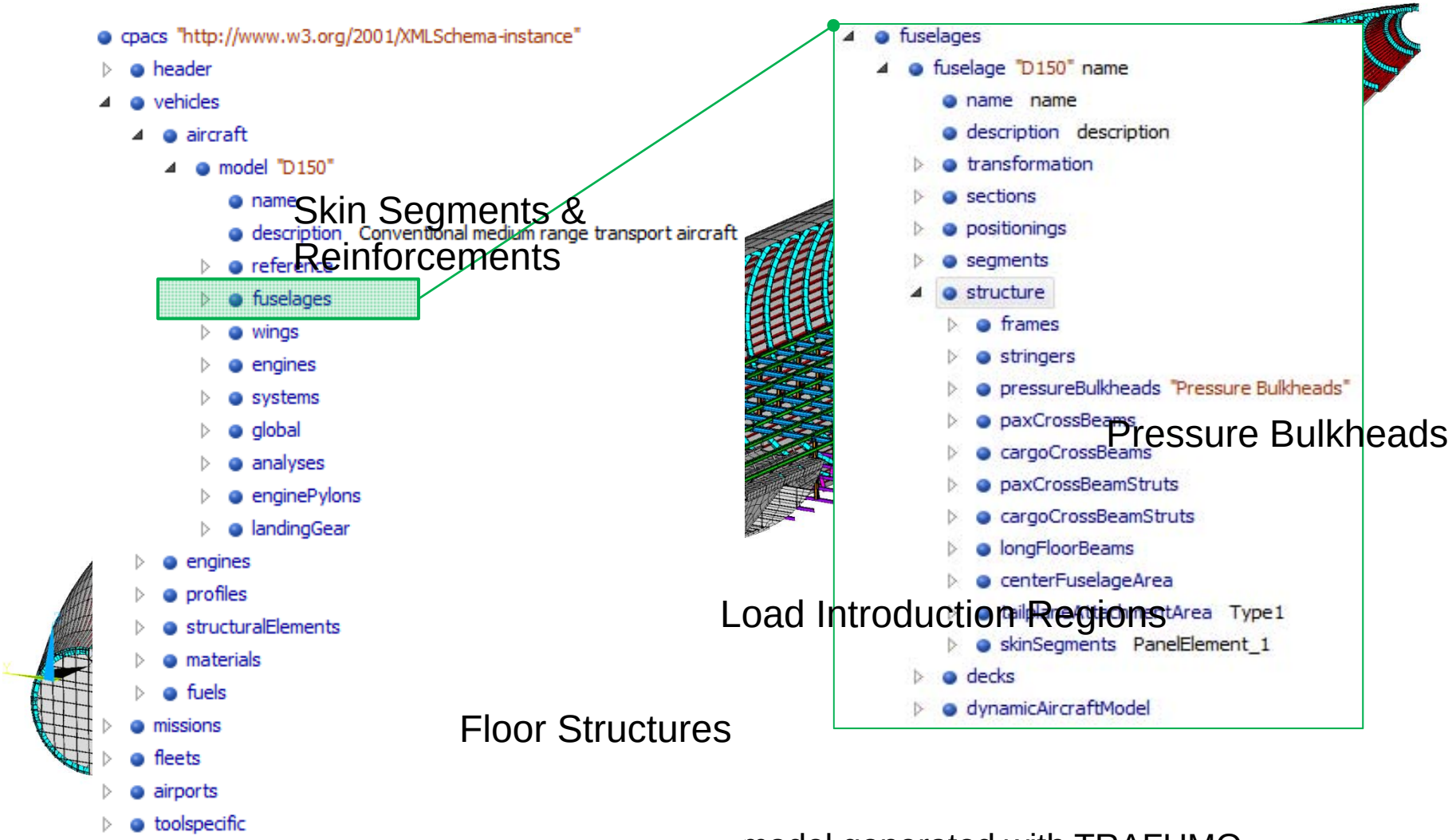
Aachen, Germany

Introduction

Introduction

- CPACS (Common Parametric Aircraft Configuration Scheme)
- XML-based
- Support tools: TIXI and TIGL libraries
- Open Source
- Parametric description of complete aircraft
- Significant reduction of interfaces in multidisciplinary design environments

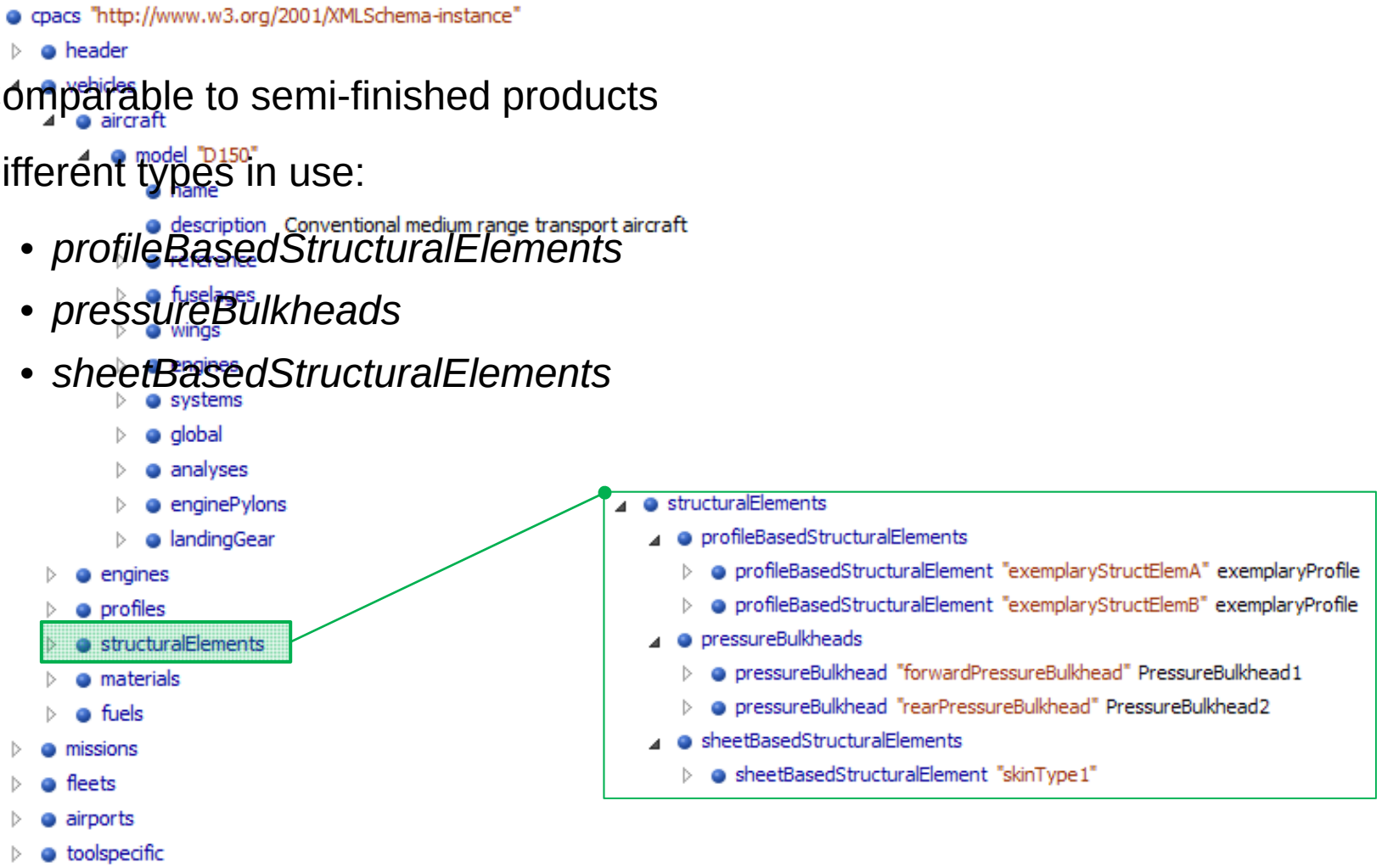
Fuselage Structures within CPACS



D150 (medium range) fuselage half model generated with TRAFUMO

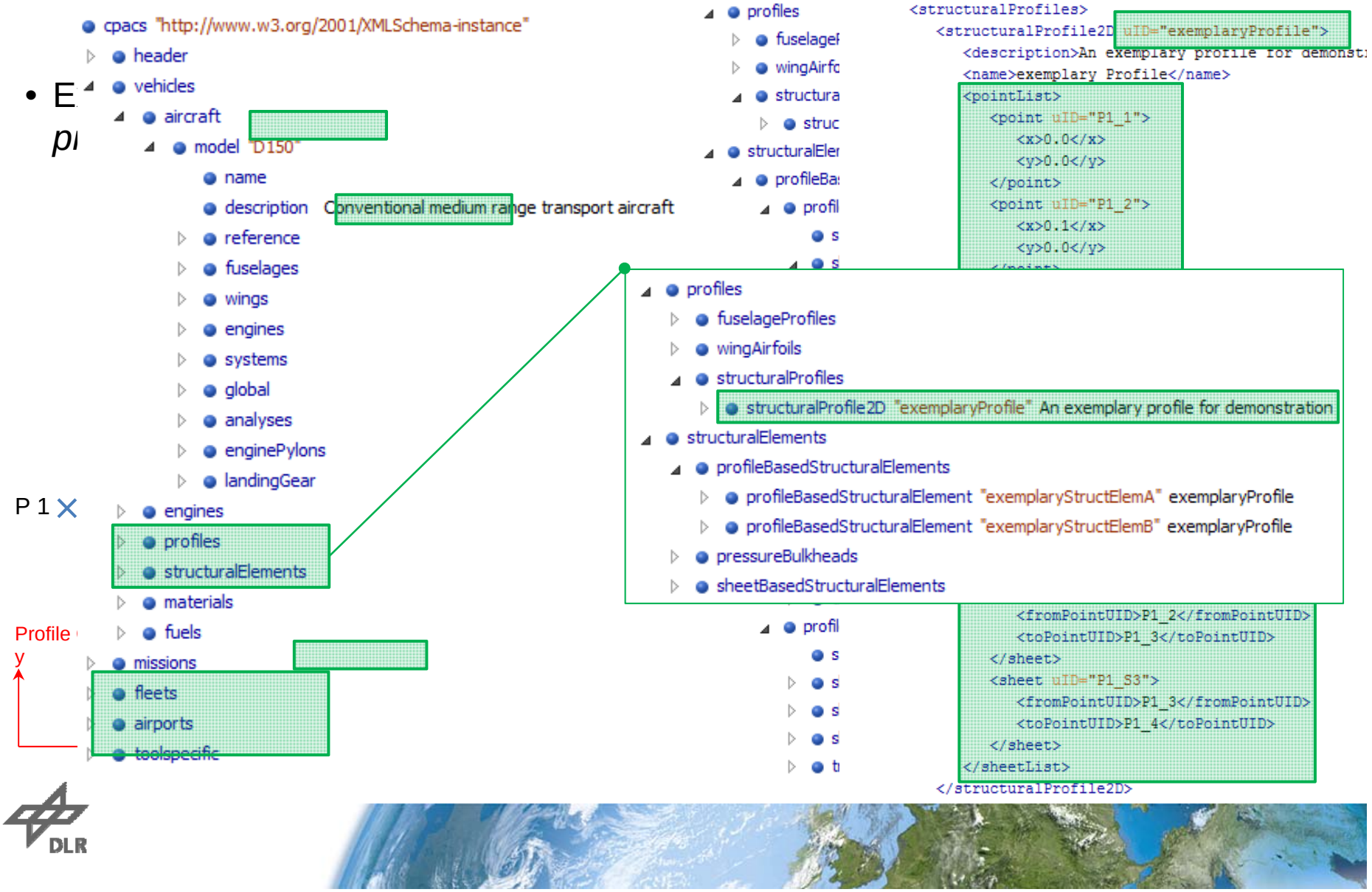
Fuselage Structures within CPACS: Structural Elements

- Comparable to semi-finished products
- Different types in use:
  - *profileBasedStructuralElements*
  - *pressureBulkheads*
  - *sheetBasedStructuralElements*



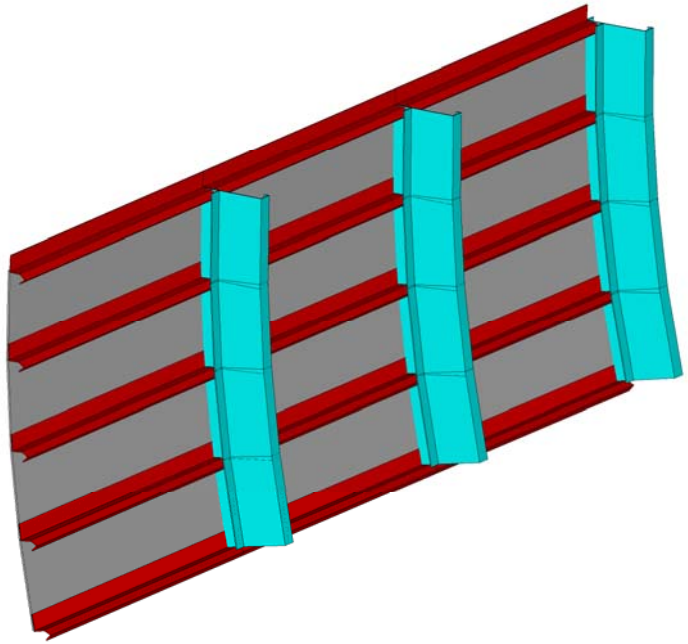
Fuselage Structures within CPACS: Structural Elements

- E
  pl



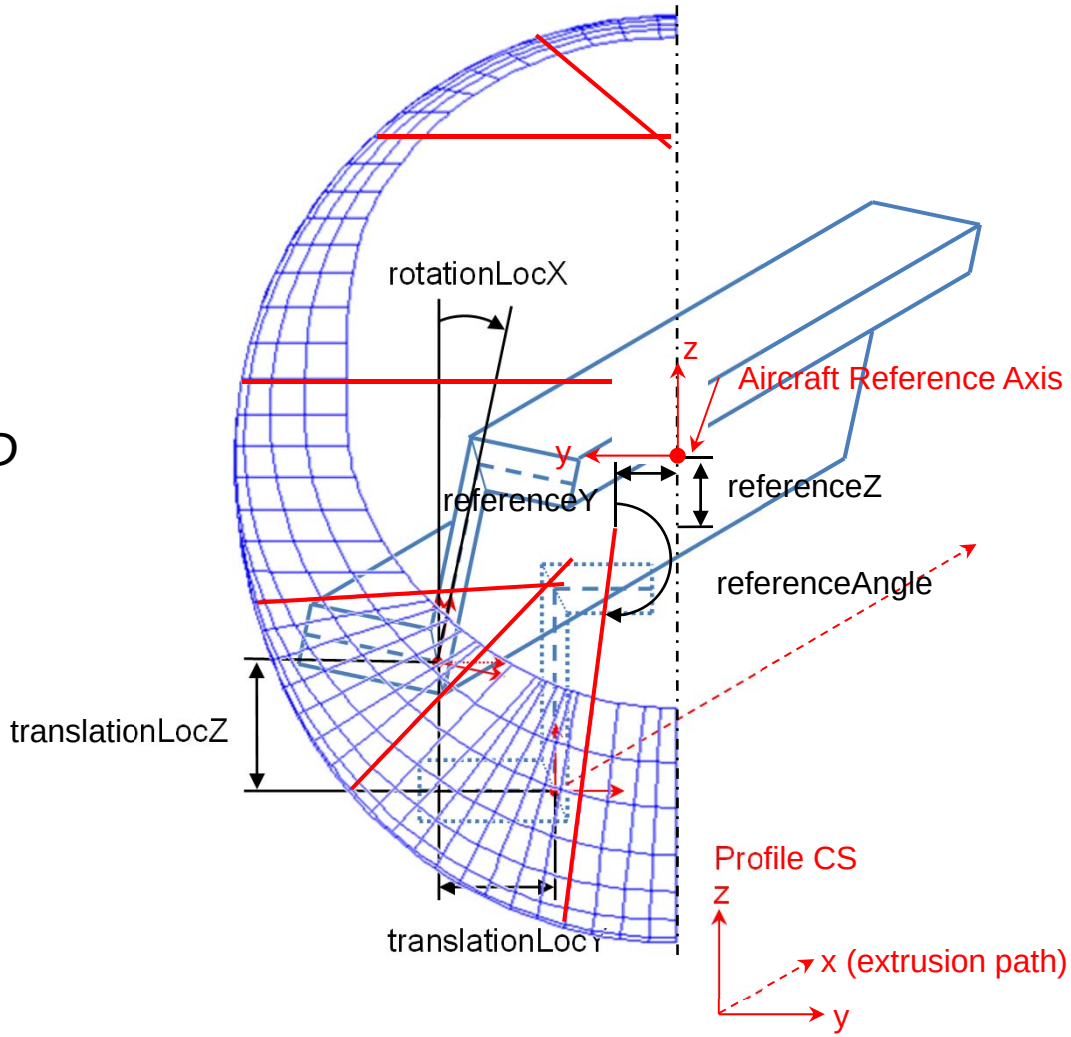
Fuselage Structures within CPACS: Reinforced Skin

- Skin panels typically reinforced with stringers and frames
- *skinSegment*: region (panel) between defined frame and stringer UIDs
- Skin properties: *sheetBasedStructuralElement*
- Frame and stringer properties: *profileBasedStructuralElement*



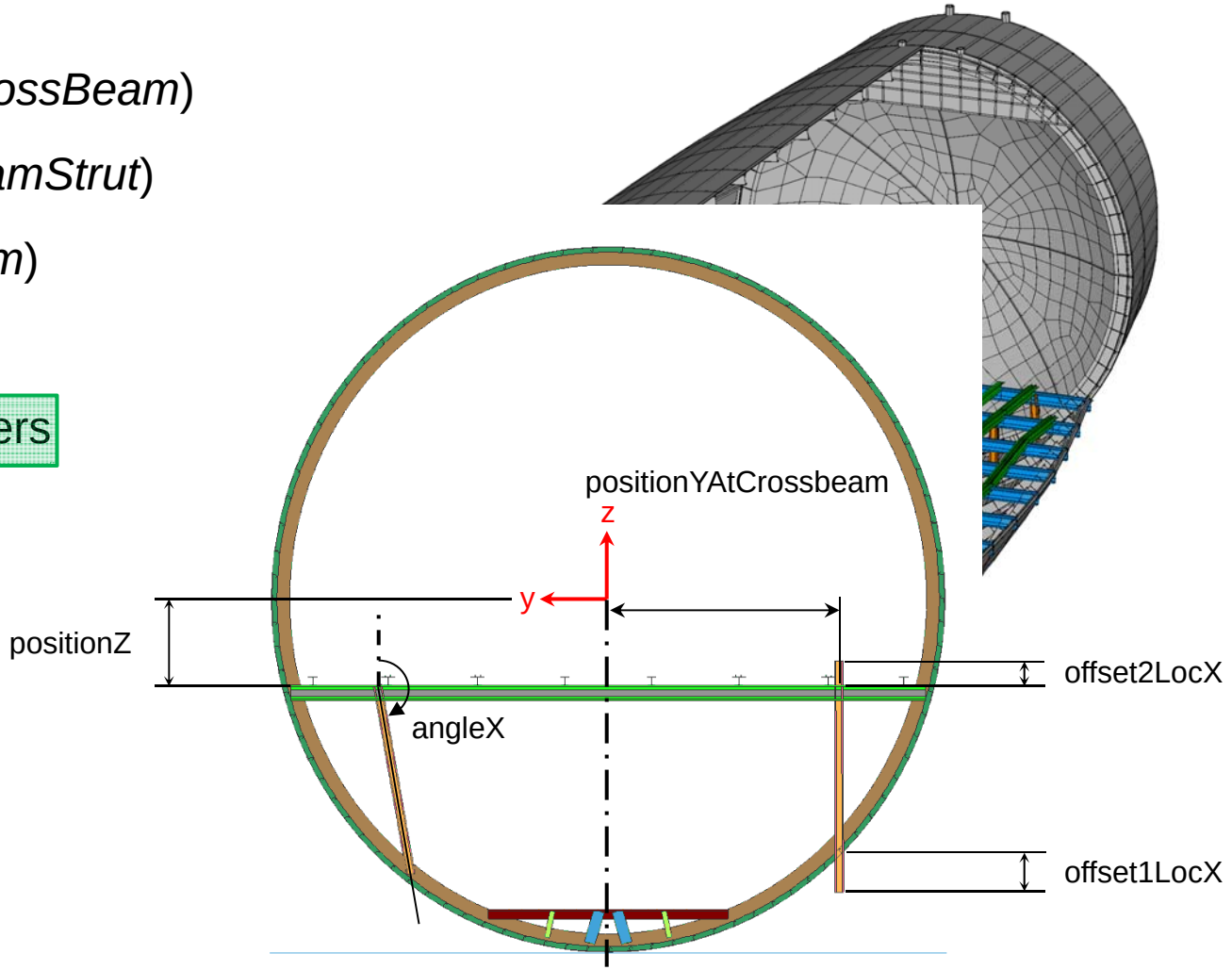
Fuselage Structures within CPACS: Reinforced Skin

- Stringers & frames: extrusions of *structuralElements* on paths on fuselage loft
- Pointer to define cutting planes: *stringerPosition*
- Link path to *structuralElementUID*
- Optional parameters
  - *continuity* (of extrusion path)
  - *interpolation* (between two *stringerPosition* definitions)
  - *alignment* (of stringer profile/*structuralElement*)



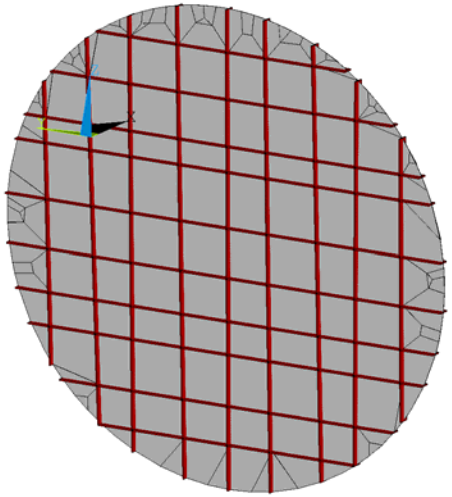
Fuselage Structures within CPACS: Floor Structures

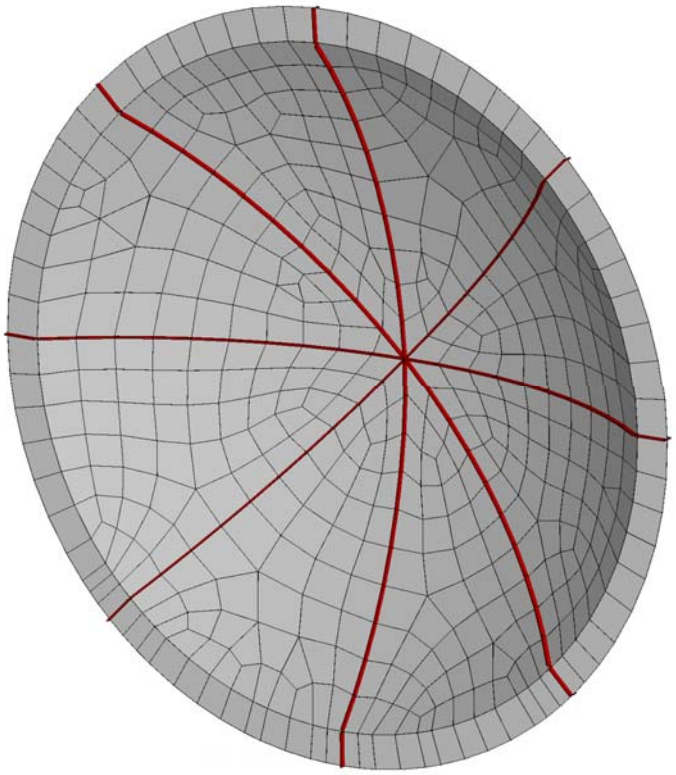
- Crossbeams (*paxCrossBeam*)
- Struts (*paxCrossBeamStrut*)
- Rails (*longFloorBeam*)
- Link to UIDs
- Positioning parameters



Fuselage Structures within CPACS: Pressure Bulkheads

- Linked to frame UID
- “flat” or “dome-shaped”
- Type, reinforcements, shape defined in structural element *pressureBulkhead*





Fuselage Structures within CPACS: Load Introduction Regions

- Center
- Comple
- CPACS
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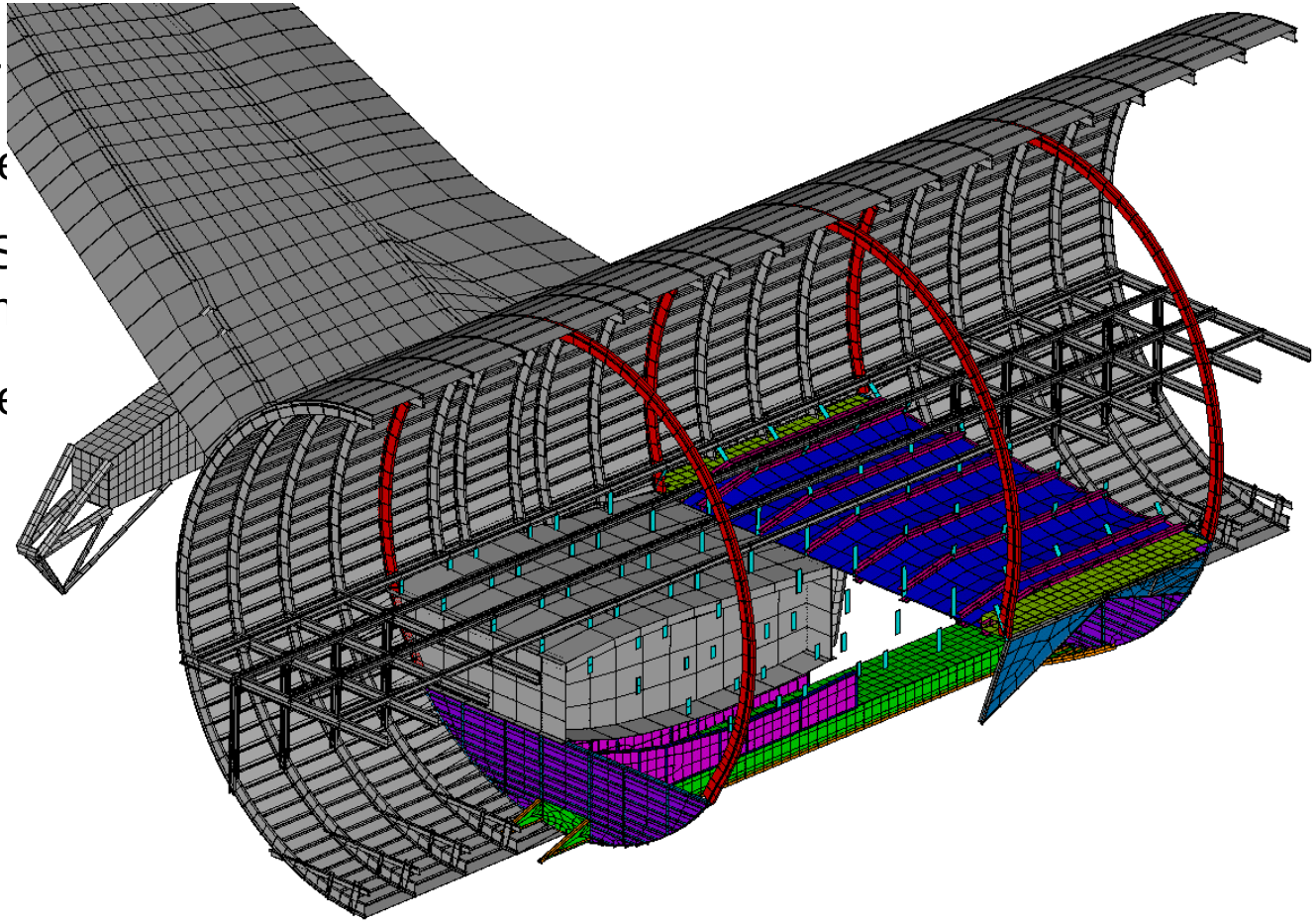
- High de



Main structural components of the center fuselage area

Fuselage Structures within CPACS: Load Introduction Regions

- Tailplane attachment area
- Cc
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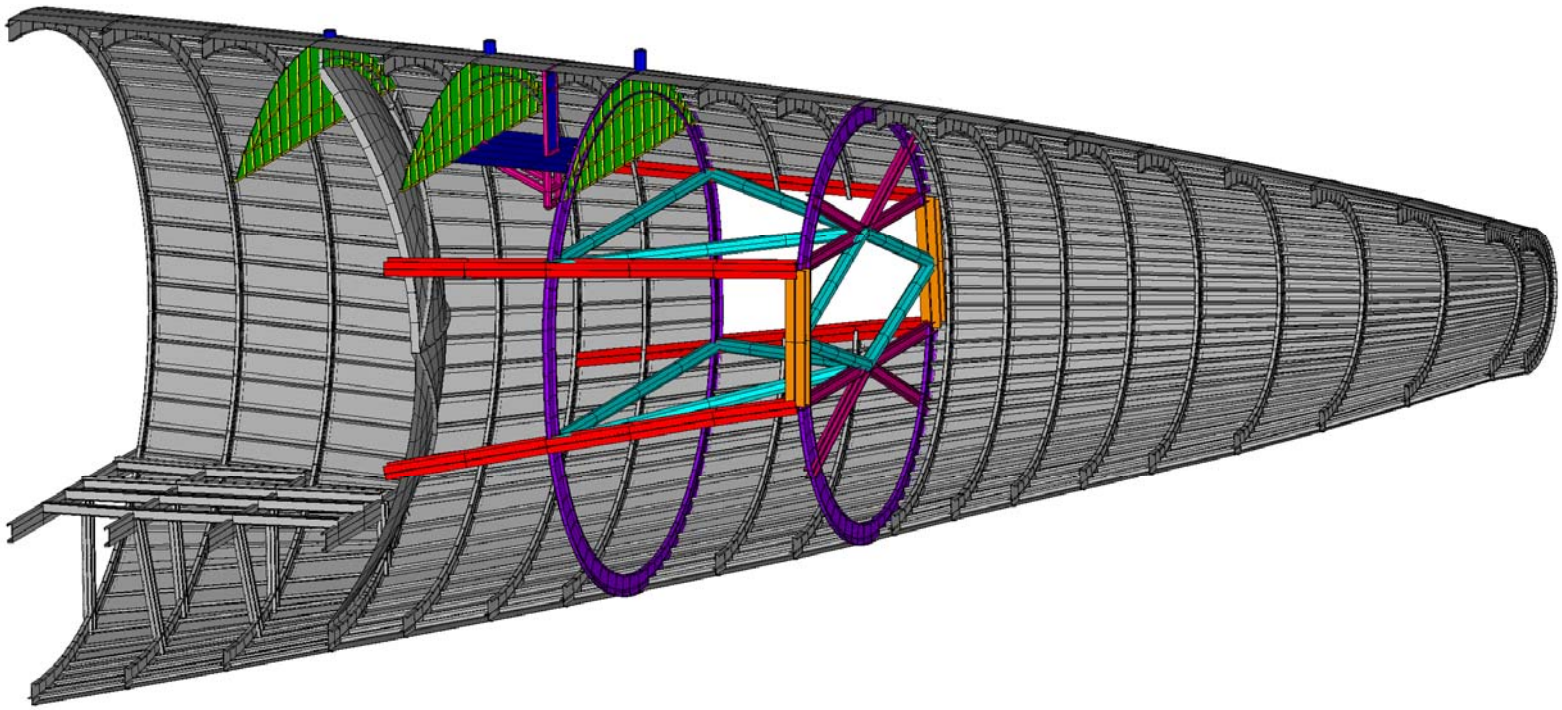
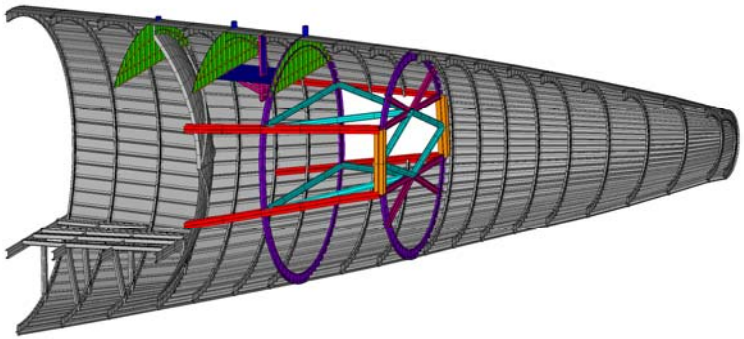


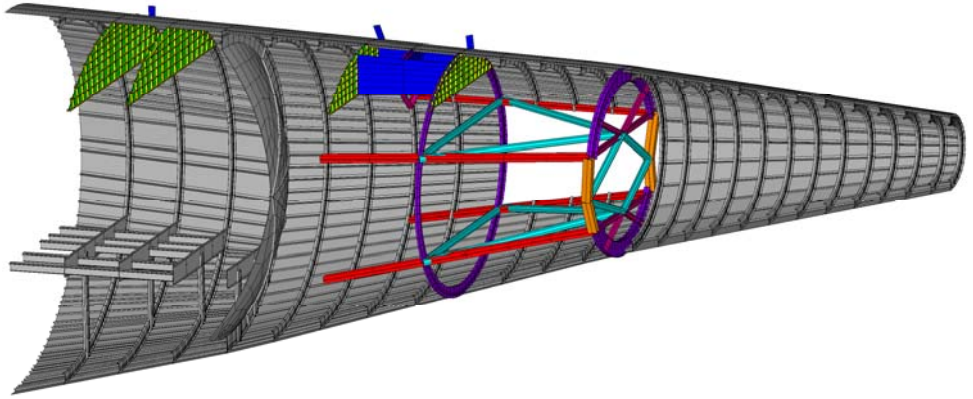
Main structural components of the tailplane attachment area

Fuselage Structures within CPACS: Load Introduction Regions

Type „Short/Medium Range“



Type „Long Range“



Applications: Static and Dynamic Analysis

TRAFUMO (TRansport Aircraft FUselage MOdel)

- Generate FE fuselage models for static analysis/sizing
- Python/APDL* based
- Fully automated
- CPACS - controlled

AC-CRASH (AirCraft-CRASH)

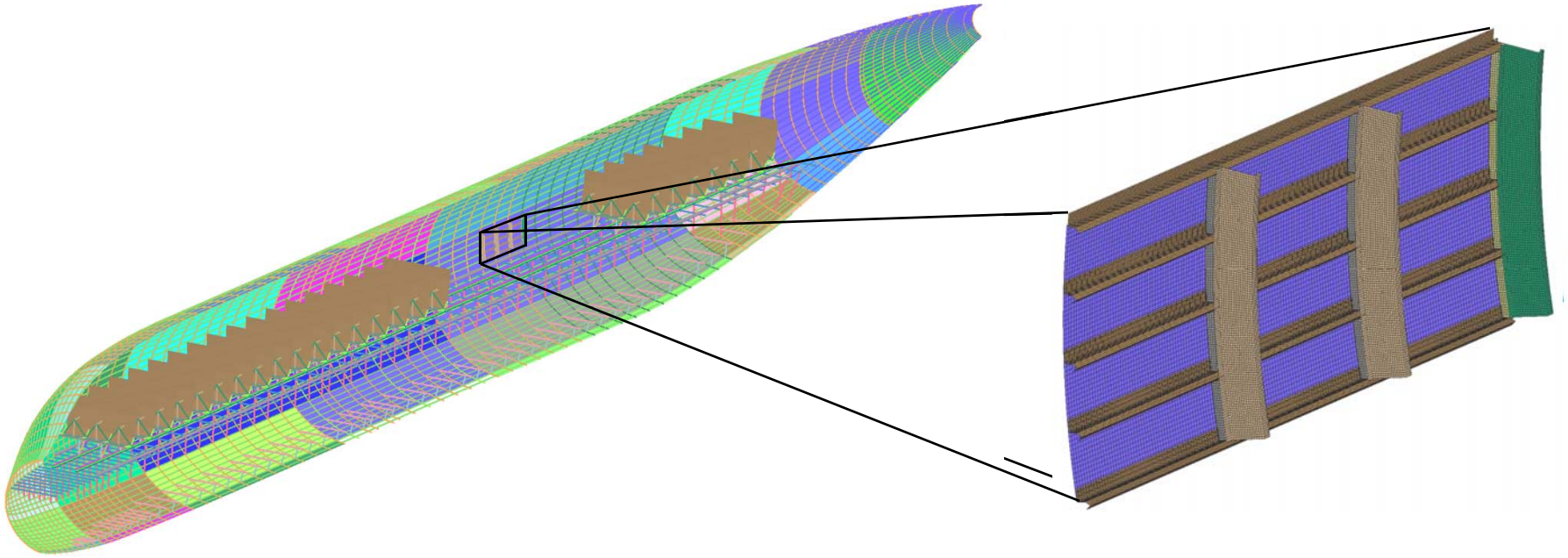
- Generate FE fuselage models for crash load scenarios
- Python/APDL* based
- Fully automated
- CPACS - controlled
- Large deformations
- Fine meshes
- Explicit dynamic analysis (PAM-CRASH v2011)

***) APDL** - ANSYS Parametric Design Language

Applications: Static and Dynamic Analysis

TRAFUMO (TRansport Aircraft FUselage MOdel)

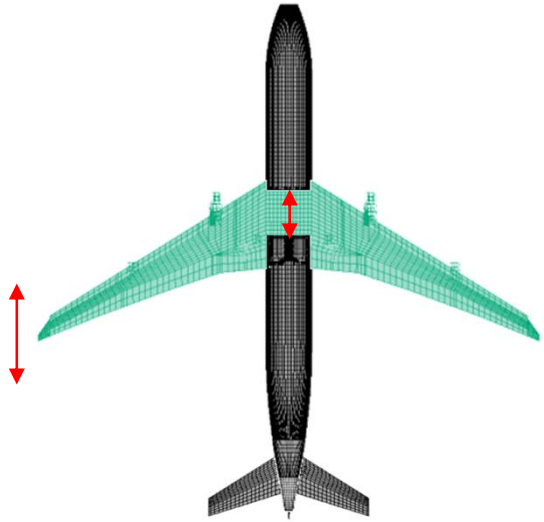
AC-CRASH (AirCraft-CRASH)

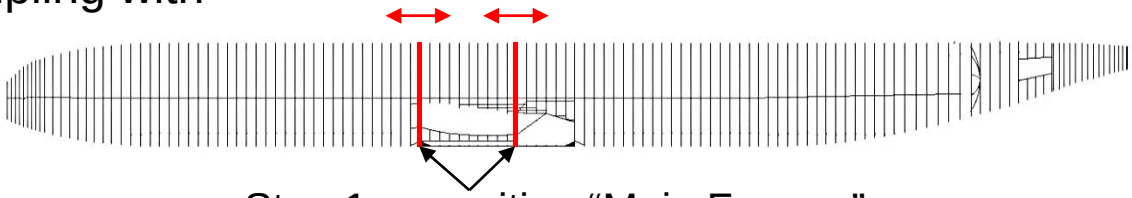


Applications: Automatic Generation and Modification of CPACS Fuselage Structure Definition

F-DESIGN (Fuselage-DESIGN)

- Numerical tools in MDO applications require a CPACS fuselage definition
- Different scenarios
    1. Adapt positions of reinforcements
    2. Create structural start design in outer geometry
- F-DESIGN “Step1” operative
    - Reposition “Main Frames” according to optimized wing position/size
    - Guarantee structural coupling with wing



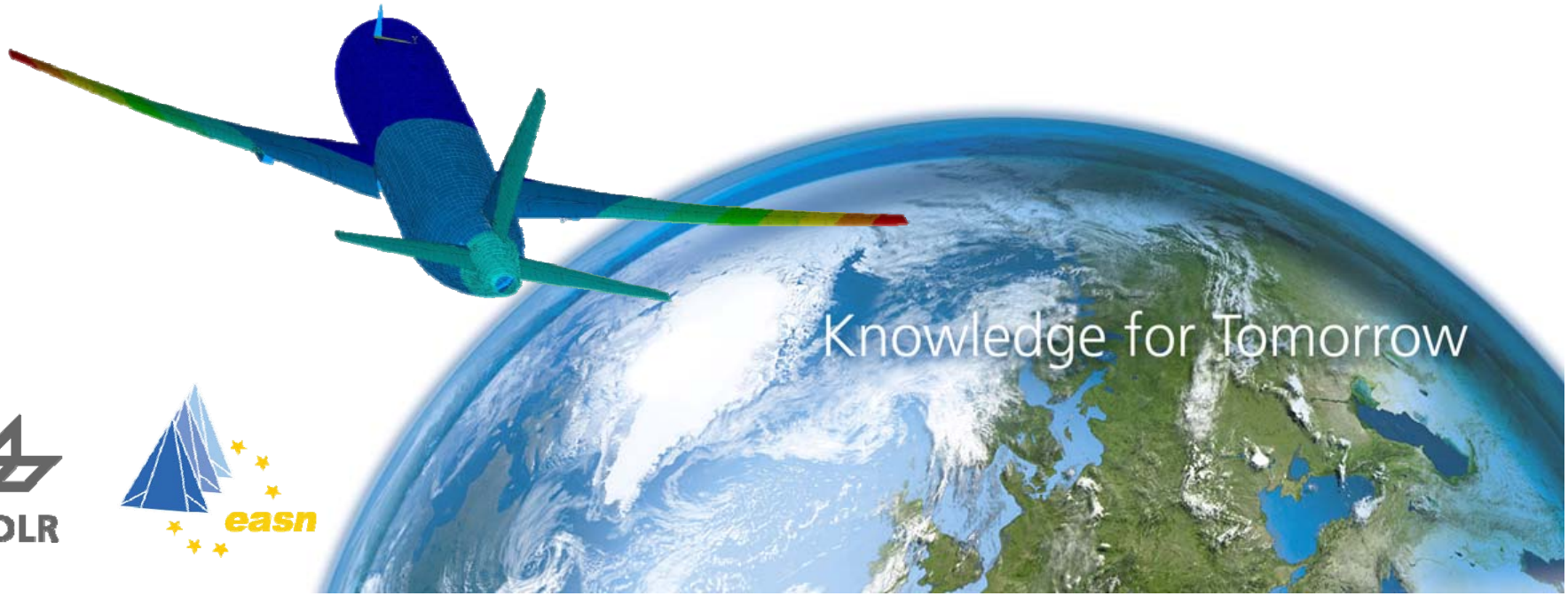


Step 1: reposition “Main Frames”

Conclusion and Outlook

- CPACS
  - *structuralElement* definition
  - Structural members (stringers, frames, floors, etc.)
  - Load introduction regions
- Initial applications
- Automated CPACS fuselage description generation
- **NEXT:**
  - Enhance load introduction regions description → other AC configurations
  - Add/Improve definitions for forward landing gear bay, windows, doors, etc.

Thank you for your attention.



Politecnico Di Milano
Dipartimento di Ingegneria Aerospaziale

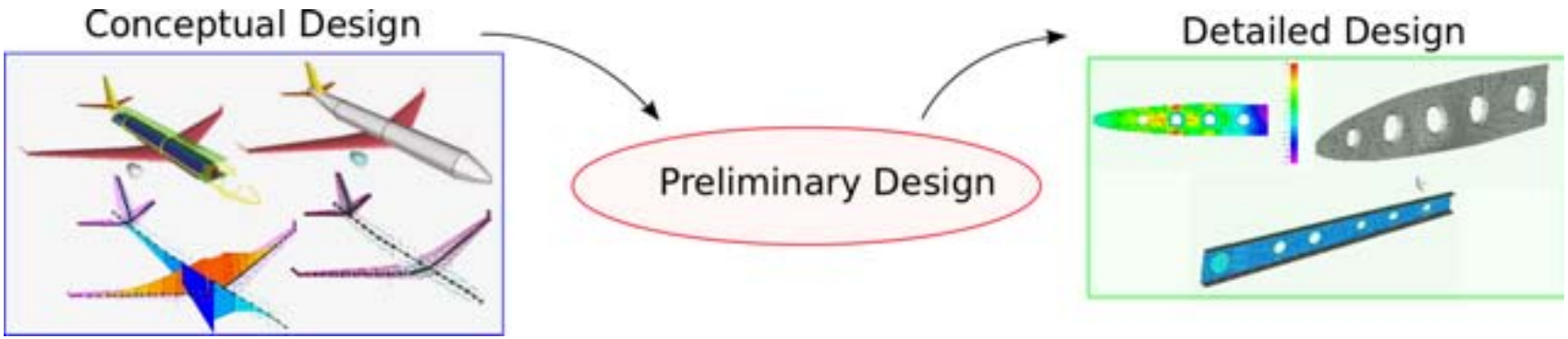
PyPAD: a Multidisciplinary Framework for Preliminary Airframe Design

Lorenzo Travaglini, Sergio Ricci, Giampiero Bindolino

4th EASN Association International Workshop on Flight Physics and Aircraft Design

27-29/10/2014

Preliminary Design



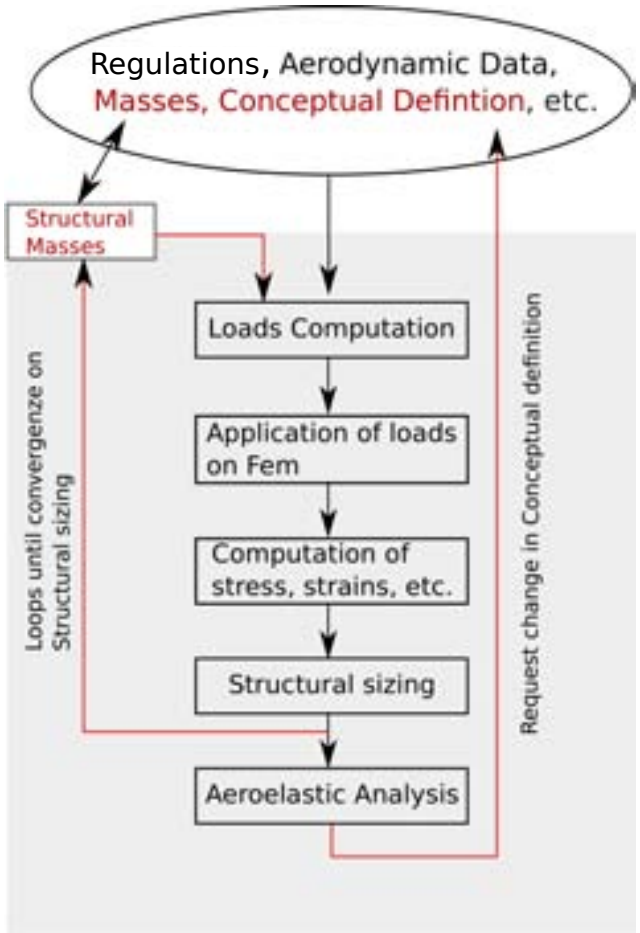
Preliminary Design:

- Starts when one or more conceptual designs are available;
- Changes in this project level are still not much expensive;
- The goal is to develop the project until it is possible to freeze the design and to focus on detailed analysis.

Multidisciplinary problem:

The problem is strongly interdisciplinary, the present work focus on loads, dynamics and airframe sizing.

Design Process (1/2)



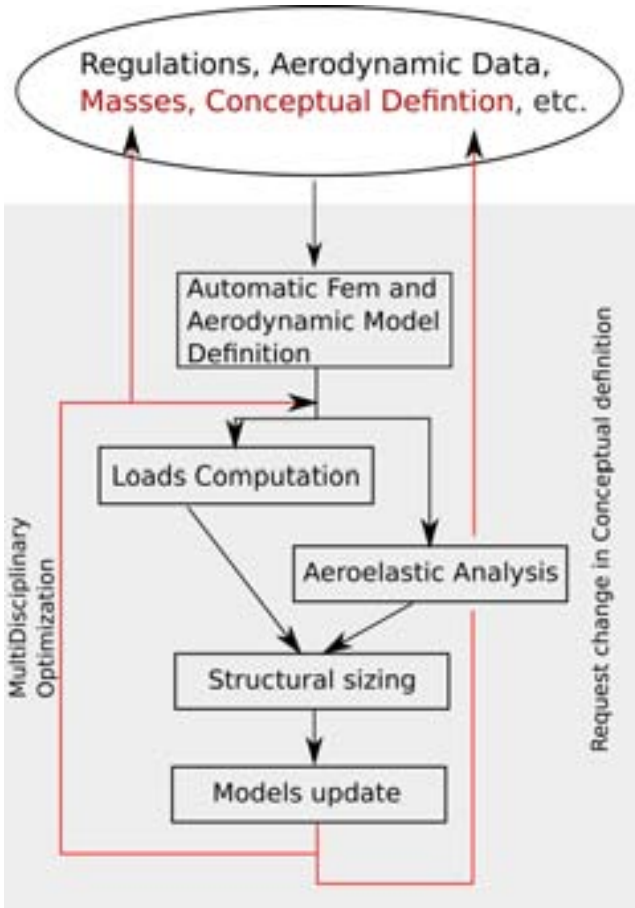
Typical Approach: Main Disadvantages

- All the steps are performed manually, and by different departments. Engineers deal with repetitive work and the processes are error prone;
- Aeroelastic analysis are used to check the solution, not to drive it. Airframe are always lighter and aeroelastic effect must be taken in consideration during the sizing process;
- A change in the conceptual design (due to aeroelastic behaviour or other requests) is very expensive. In this way is very hard to investigate different conceptual designs considering all the aspect of the problem, and the solution found could not be the best one.

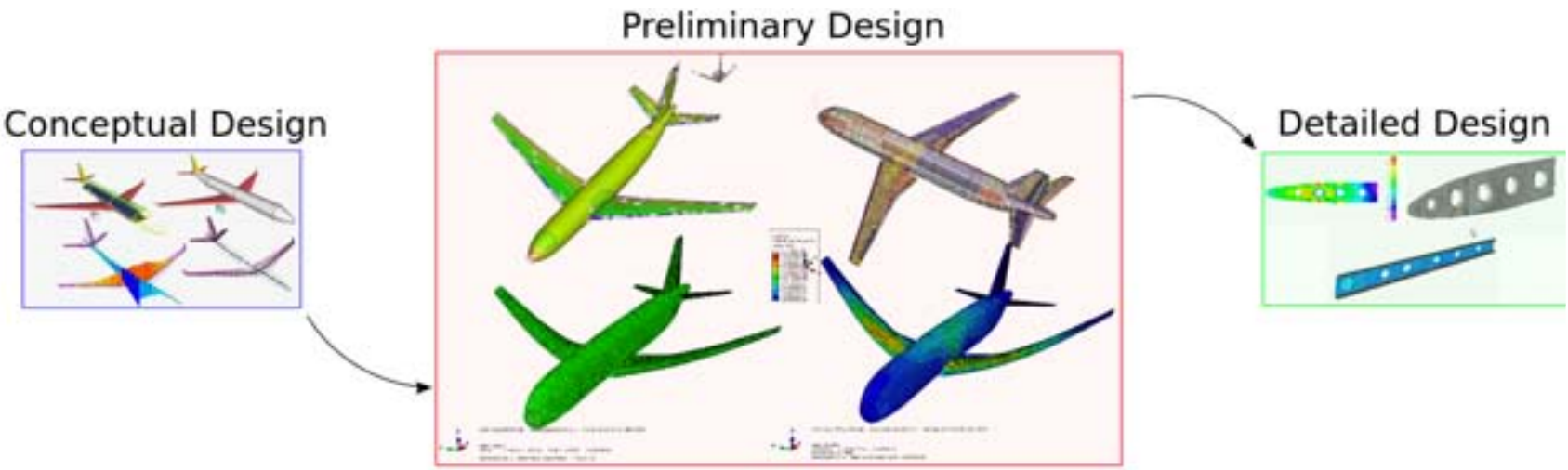
Design Process (2/2)

Proposed Approach: Main Advantages

- The FE models and the aerodynamic models for loads and aeroelasticity analysis are defined automatically. In this way a change in the conceptual design can be simple investigated and different conceptual design can be studied in a easily way;
- The structural sizing is driven by different sizing criteria, aeroelastic criteria included, moreover using directly the FE models, ad-hoc analysis can be simply considered in the process;
- All the process can be highly automated using multidisciplinary optimization algorithms. Once procedures are verified the problem is error free.



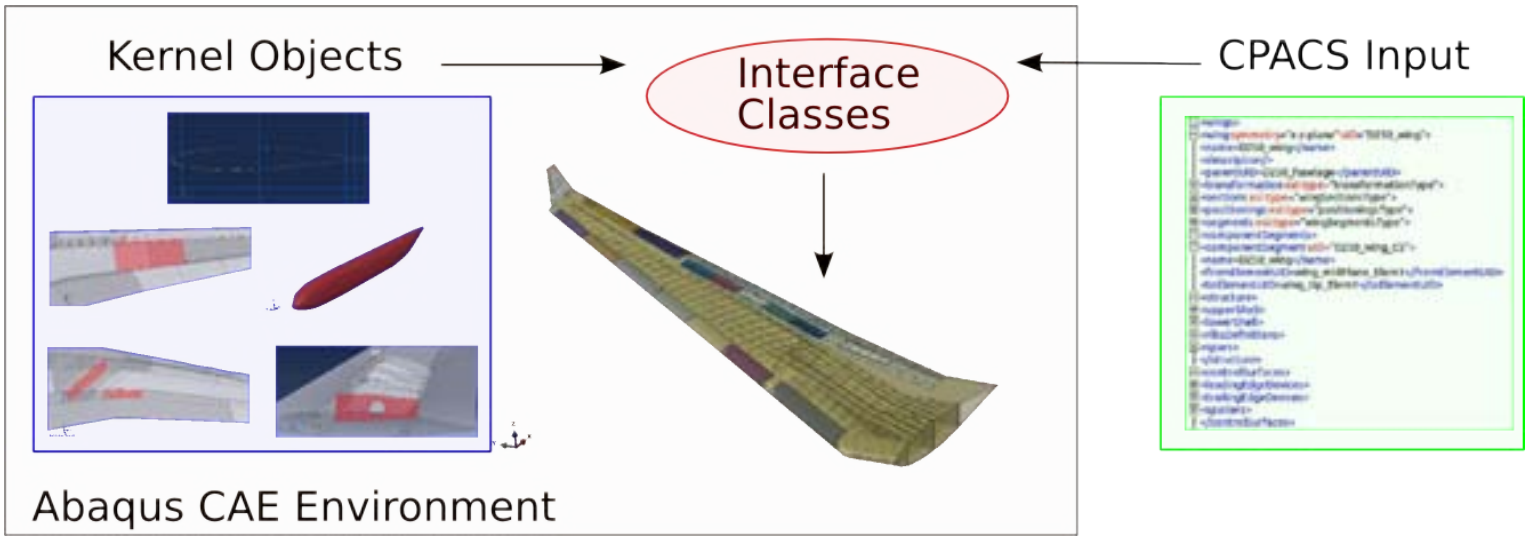
PyPAD: Python module for Preliminary Airframe Design



PyPAD sub-components:

1. PyGFEM: a models generator (in Abaqus-CAE environment), able to define FE and aerodynamic models starting from a fully parametric aircraft description based on CPACS;
2. PyAERO: a package for loads computation and aeroelastic analysis;
3. PySIZE: a package for the structural sizing, able to deal with different sizing criteria.

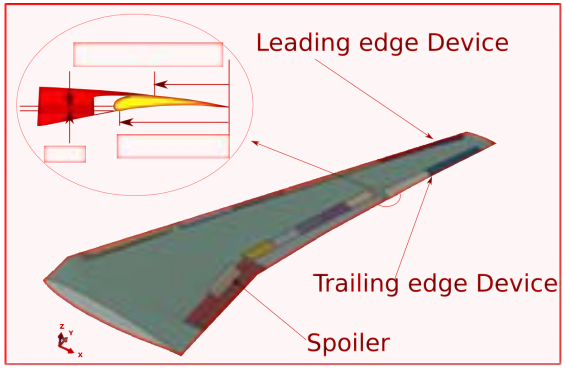
PyGFEM: Python modules for the Generation of Finite Element Models

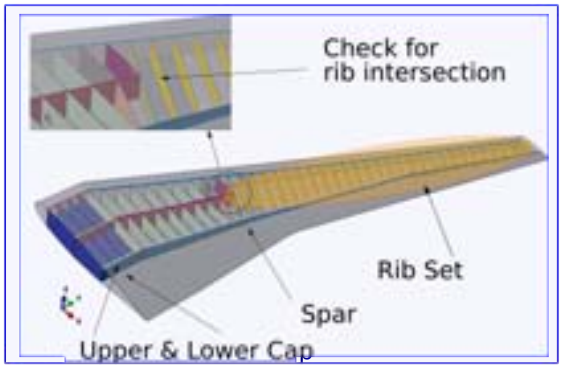


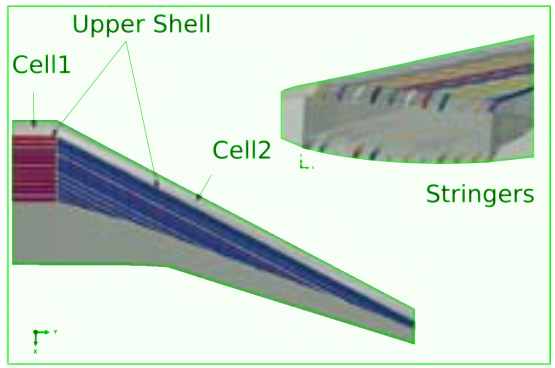
PyGFEM:

- Abaqus CAE environment allows to use all the CAD/CAE functionality by Python scripts;
- The core classes providing the definition of basic objects, like edges, airfoils, planes, cuts, lofts, materials, properties, etc.;
- The interfaces classes providing the coupling between CPACS input and core objects.

PyGFEM: Wings definition



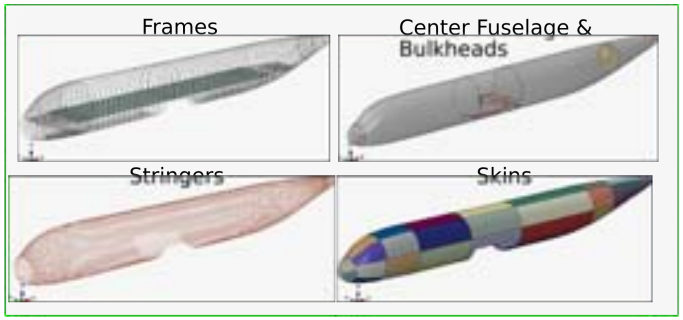


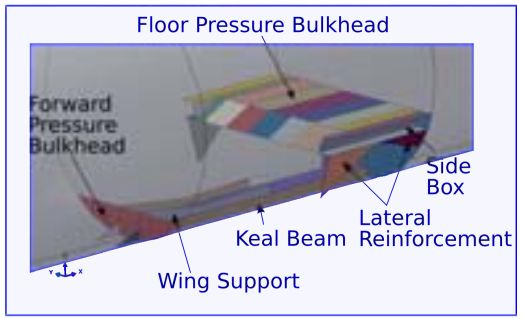


Wings definition steps:

- Once the loft is obtained (starting from airfoils definitions) PyGFEM defines the movable surfaces;
- All the spars and rib sets are defined;
- The skins (both using parametric positions and rib/spar edges) can be defined with the proper stringers.

PyGFEM: Fuselages definition

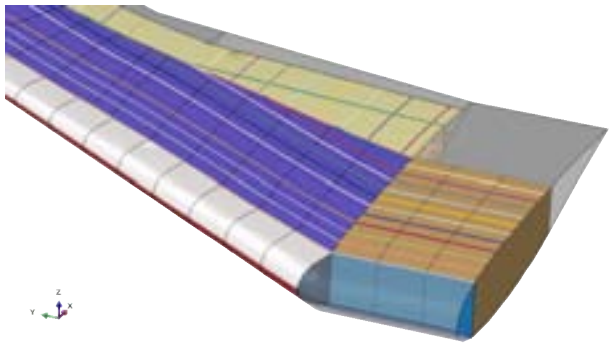


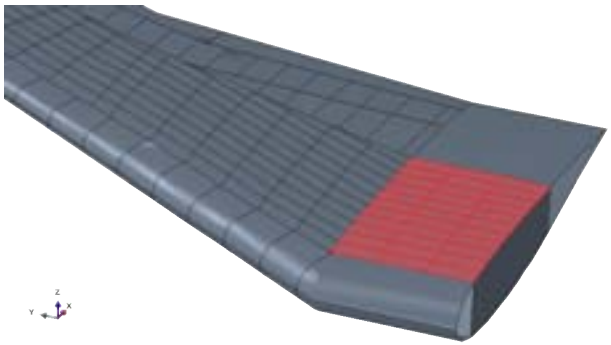


Fuselages definition steps:

- Once the loft is obtained, stringers, frames, skins and central fuselage are defined;
- All the components are defined in different parts;
- The different parts are then merged together in the assembly.

PyGFEM: Properties & Sets



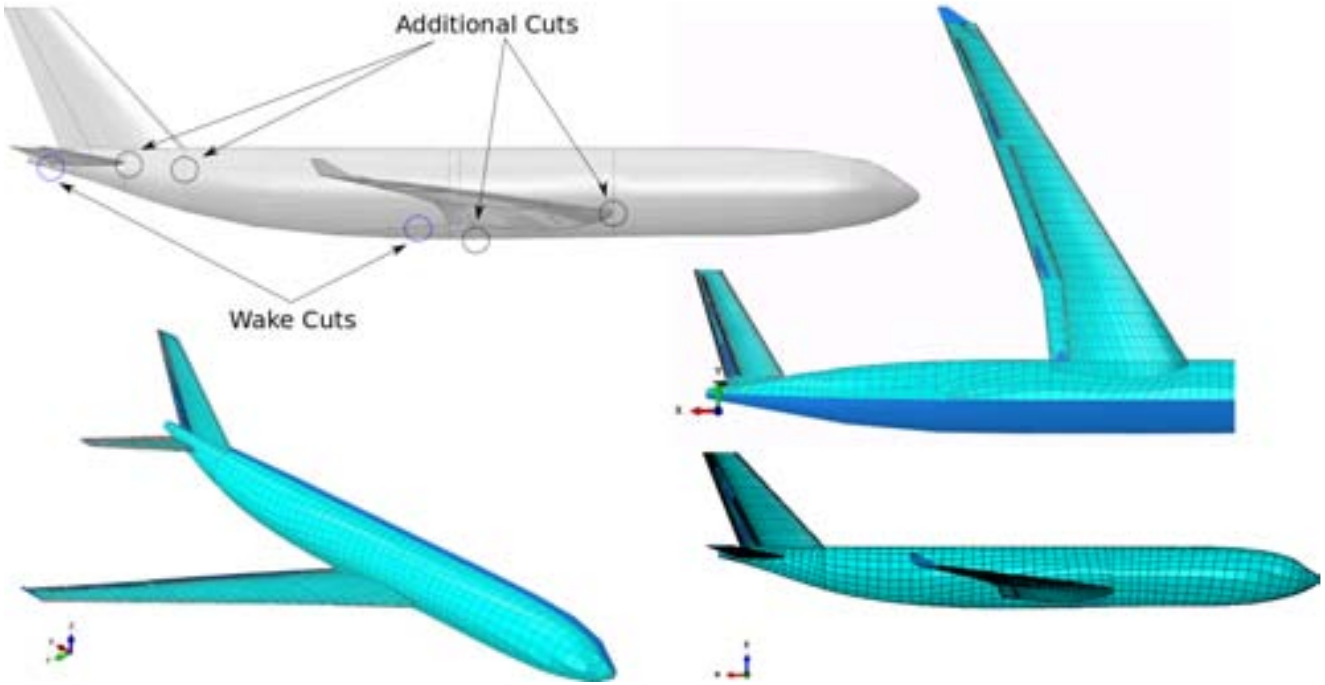


Internal database:

- The objects are able to handle all the properties of the model;
- All the objects hold information about their geometry and mesh using different set definitions;

This will be very helpful during optimization and to run analysis on local objects like buckling using ad-hoc solutions.

PyGFEM: Aerodynamic models

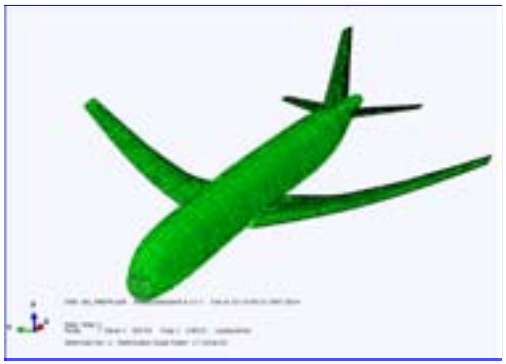


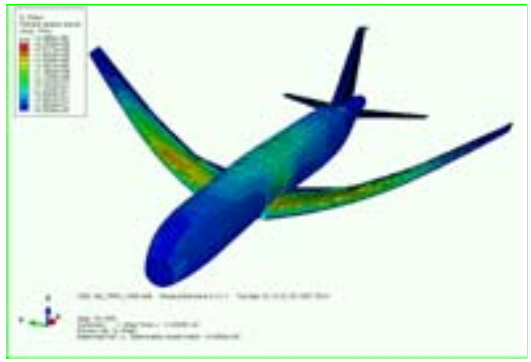
Structured Mesh:

PyGFEM merges all the component finding each intersection, then checks all the different couple of intersecting parts, adding construction cuts to simplify the geometry, or to define the projections of wing wake on the other part involved in the intersection.

PyAERO: Python module for Aeroelastic responses

- Different aeroelastic solvers: Trim, Flutter, Dynamic Response (Both frequency and time domain);
- Core functions written in Fortran and taking advantages of modern libraries (OpenBLAS, Lapack, Plasma, OpenMP, FFTW).

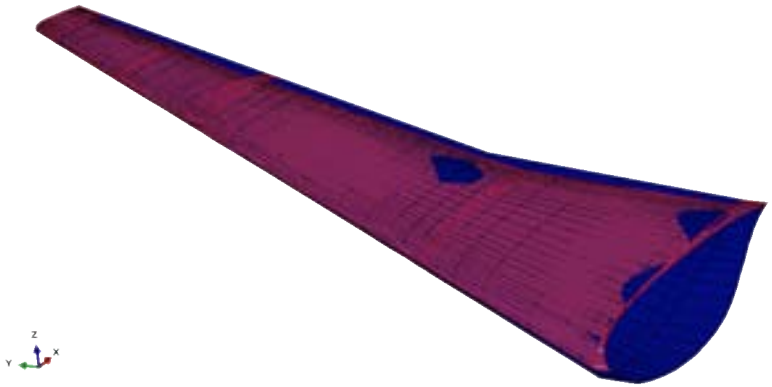


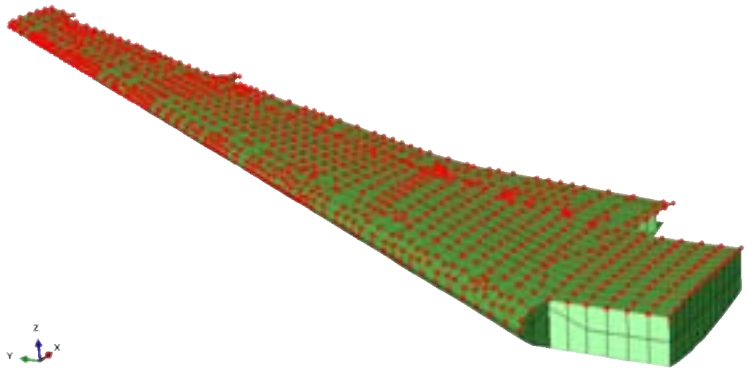


Aeroelastic models:

The models are defined starting from the aerodynamic meshes and the `.inp` & `.dat` files of Abaqus, the input and the output file of a modal analysis.

Aero-structural coupling



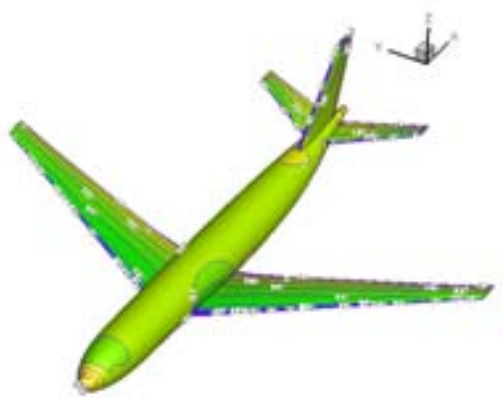


Aero-structural coupling:

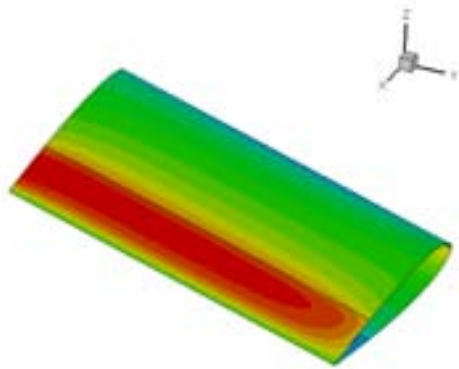
The aeroelastic coupling between structural and aerodynamic models are provided by RBF (Radial Basis Functions) interpolations. The definition of the "interpolation object" is very simple, because the aerodynamic and the structural models share the same aerodynamic set descriptions.

SUnPaM: Subsonic Unsteady Panel Method

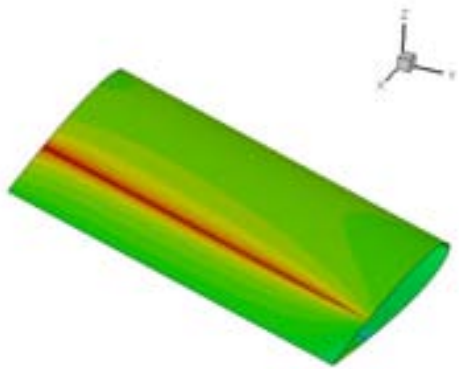
It is a panel aerodynamic solver, based on the Morino method, developed in the Department of Aerospace Science and Technology of Politecnico di Milano. The tool solves linearized subsonic compressible flow both in steady and unsteady conditions



(a) Steady Solution

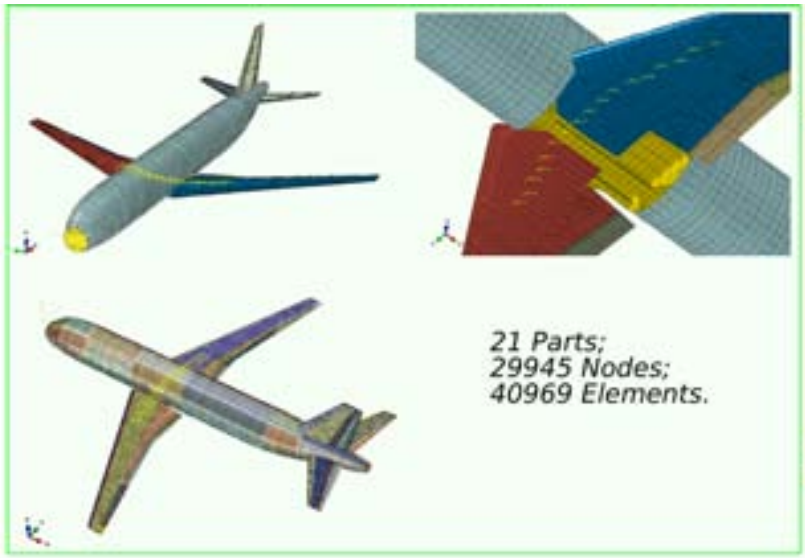


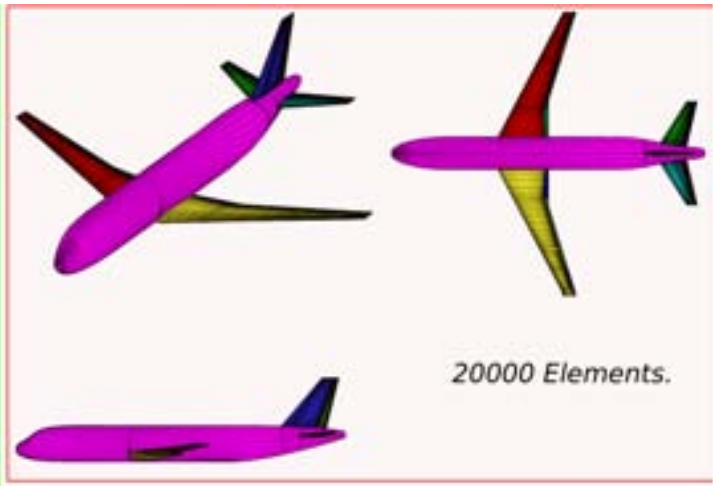
(b) Oscillating Flap, Imag



(c) Oscillating Flap, Real

CPACS D150-v21: by DLR (Dieter Kohlgrueber)





Analysis:

- Six trim conditions;
- Flutter analysis;
- Two dynamic responses.

(a) mass properties about the center of mass

m $[kg]$	I_{xx} $[kgm^2]$	I_{yy} $[kgm^2]$	I_{zz} $[kgm^2]$	I_{xz} $[kgm^2]$
30323	419202	1722204	2089803	-81064.59

(b) geometry properties

S $[m^2]$	c $[m]$	b m
122.4	4.2	16

Eigenvalues: 25 modes used for the aeroelastic model.

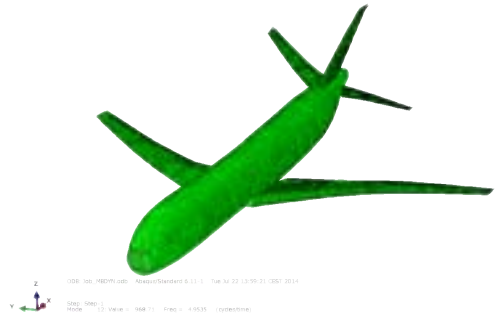
(a) Mode 1: 2.89 Hz

(b) Mode 2: 3.06 Hz

(c) Mode 3: 3.57 Hz

(d) Mode 4: 4.44 Hz

(e) Mode 5: 4.79 Hz



(f) Mode 6: 4.95 Hz

Trim conditions

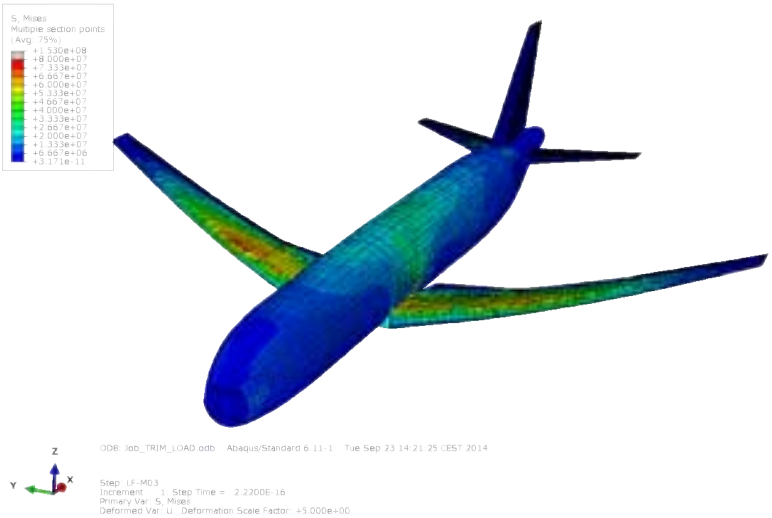
Six conditions:

- 2 Level flight conditions at Mach 0.3 and Mach 0.5,
- 2 Pull-up conditions ($n_z = 2.5$) at Mach 0.3 and Mach 0.5,
- 2 Sideslip conditions with $\beta = 10deg$ at Mach 0.3 and Mach 0.5.

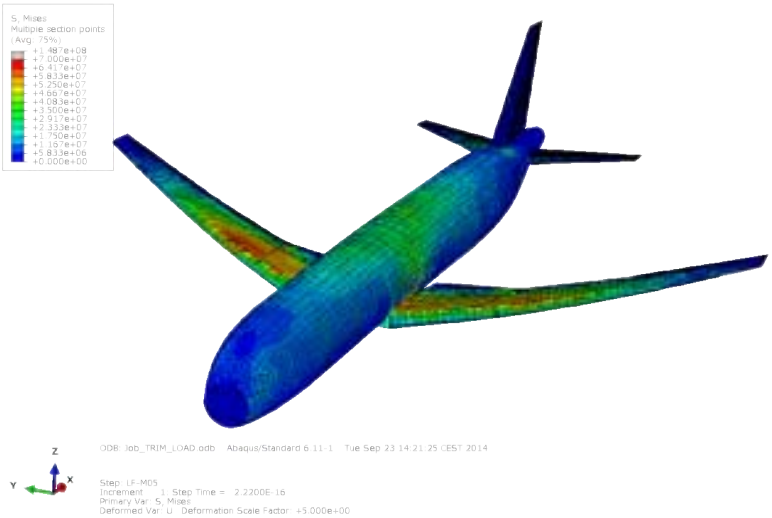
Loads

For all the conditions the nodal loads are computed and exported in Abaqus format. These loads are then used to perform a static analysis in Abaqus to get the stress solution

Trim results: Level Flight

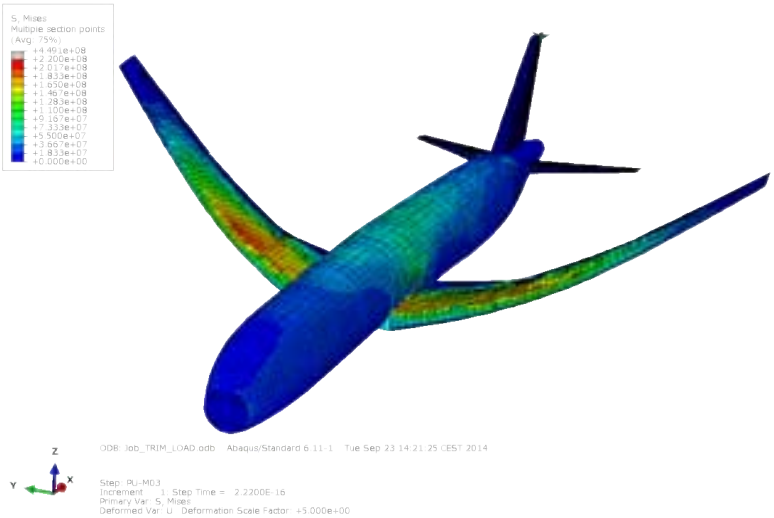


M= 0.3	α	δ_e
Rigid	2.033	-5.05
Elastic	2.490	-5.82

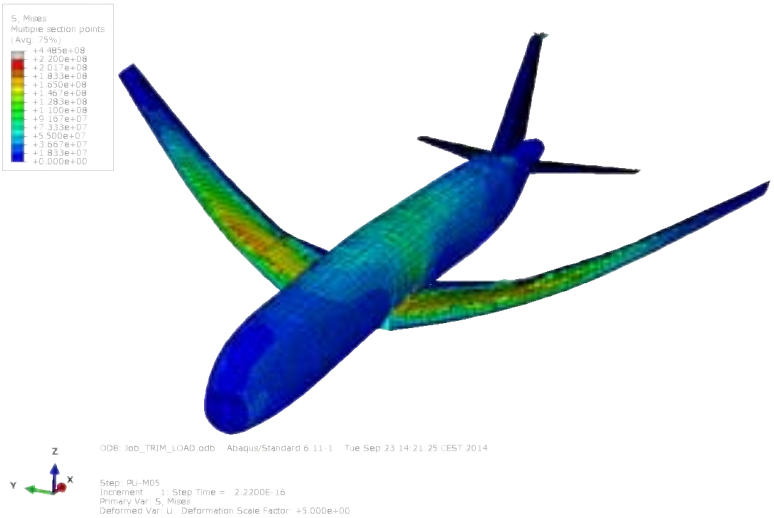


M= 0.5	α	δ_e
Rigid	-0.244	-1.47
Elastic	0.223	-2.45

Trim results: Pull Up

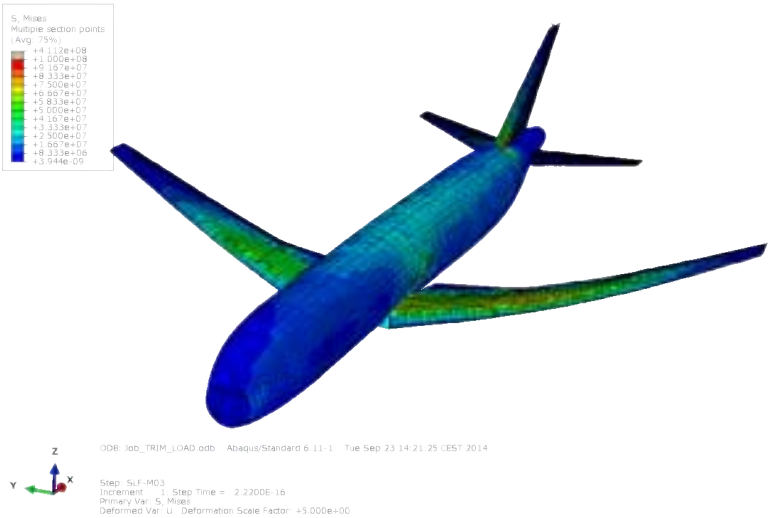


M= 0.3	α	δ_e
Rigid	9.69	-17.35
Elastic	10.99	-19.32

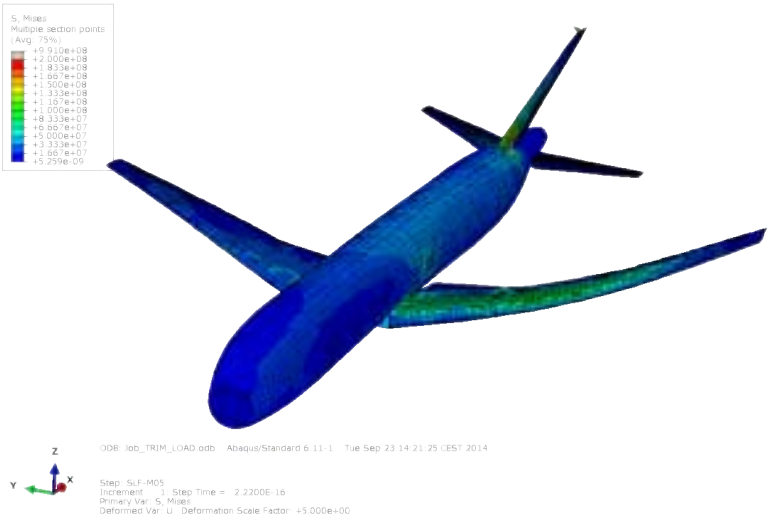


M= 0.5	α	δ_e
Rigid	2.82	-6.44
Elastic	4.06	-8.52

Trim results: Sideslip

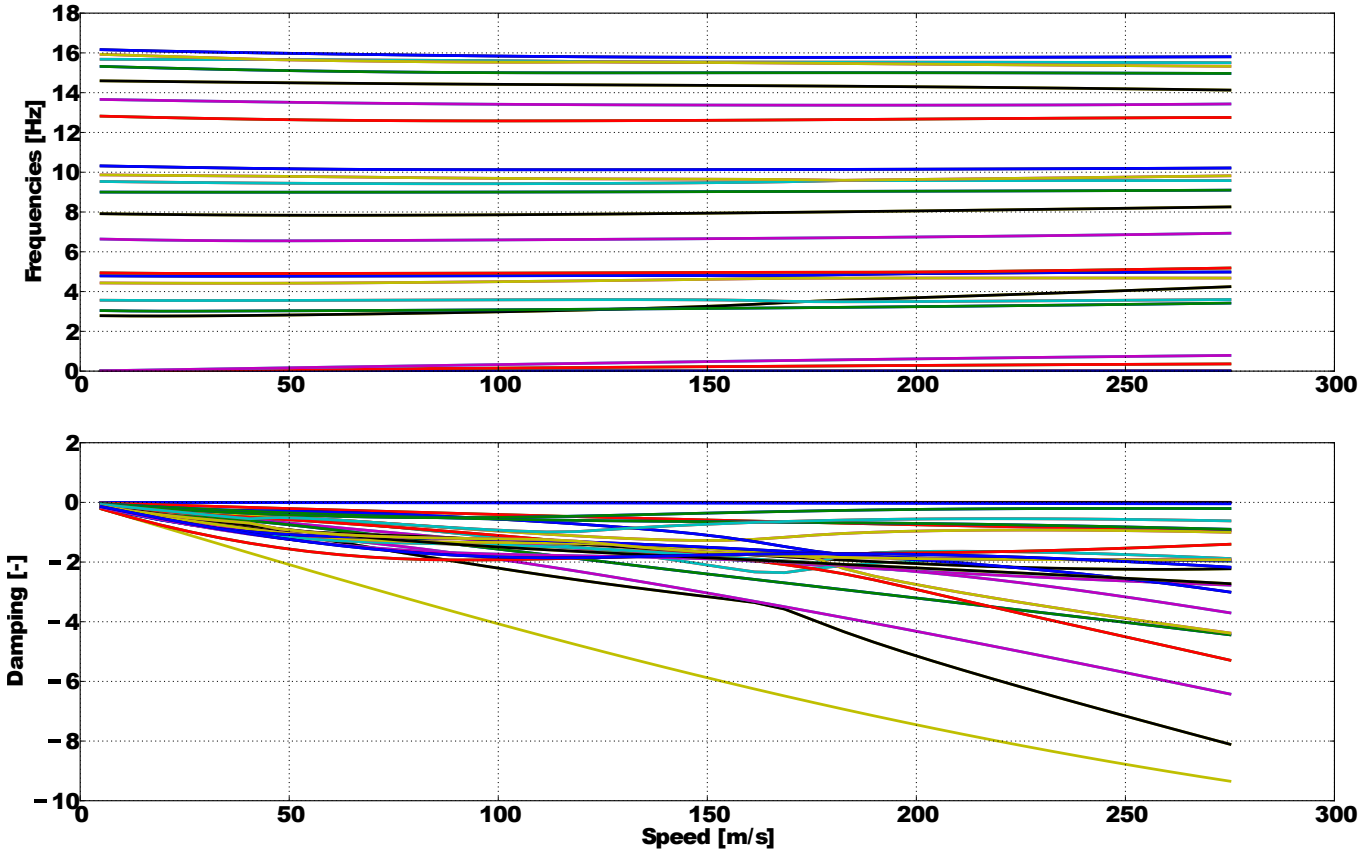


M = 0.3	α	δ_e	δ_{a2}	δ_r	$\ddot{y}$
Rigid	2.03	-5.04	-11.7	-8.32	-2.066
Elastic	2.49	-5.85	-12.93	-8.14	-2.05



M= 0.5	α	δ_e	δ_{a2}	δ_r	$\ddot{y}$
Rigid	-0.243	-1.46	-10.77	-8.47	-5
Elastic	0.22	-2.53	-14.36	-8.02	-4.91

Flutter: Mach=0.5



Flutter (movable surfaces fixed):

There are not instabilities in the flight envelope.

Dynamic Analysis

Two conditions (solved in frequency domain):

1. Discrete gust condition, $v_g = 15(1 - \cos(3\pi\ t))\ m/s$, Mach=0.5;
2. Elevator rotation, $\delta_e = -15 \sin(4\pi\ t)\ deg$, Mach=0.5.

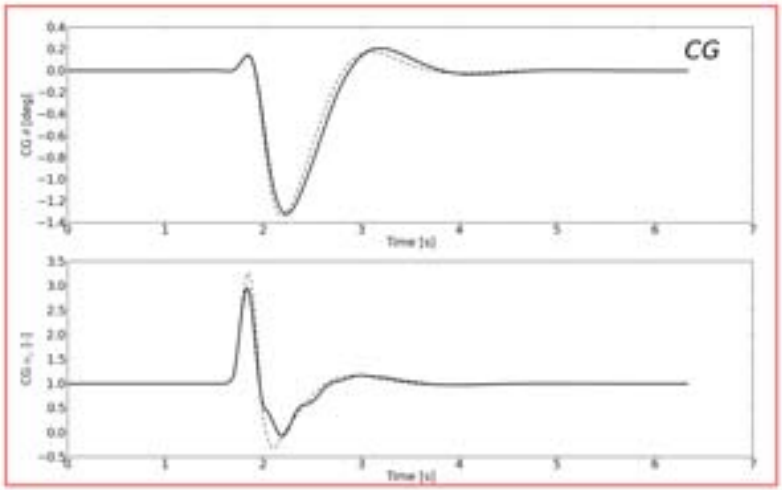
The output request are:

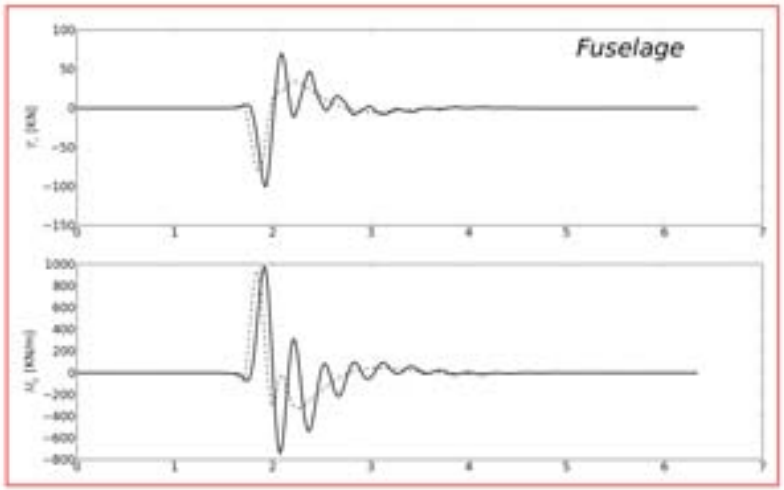
- The wing root internal loads,
- The horizontal tail root internal loads,
- The internal loads of the fuselage section after the wing.

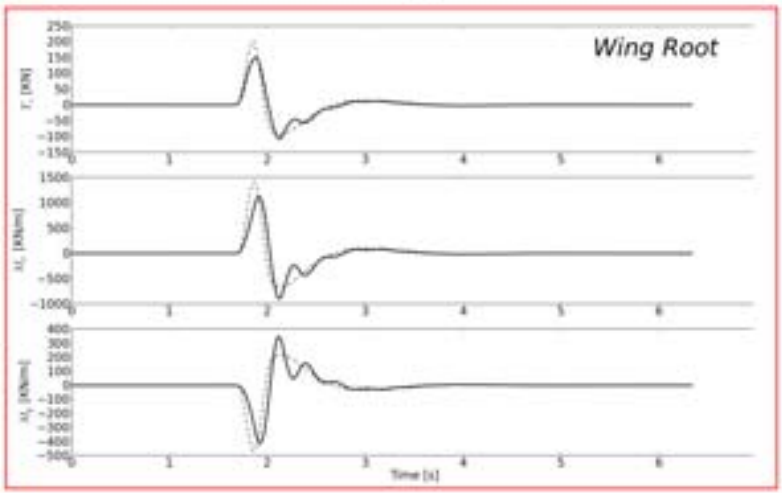
Loads:

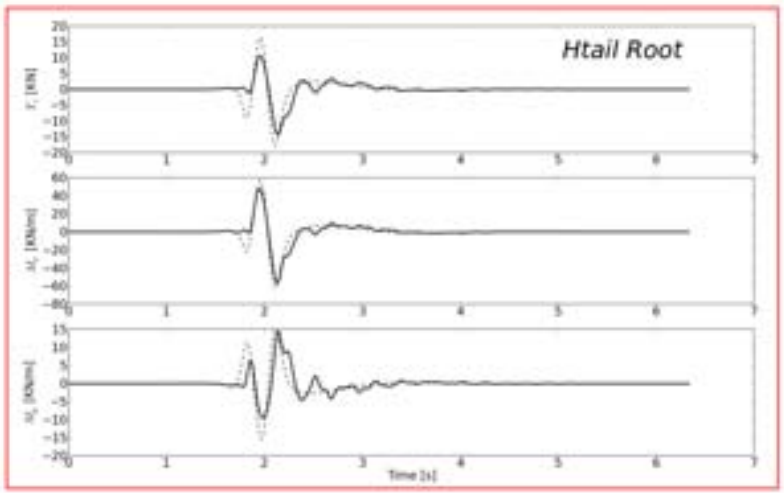
All the internal loads are computed trough the summation of forces technique.
Two time steps are selected; the first one corresponding to the maximum load factor, the second one corresponding to the maximum wing bending moment. In these time steps the nodal loads, both aerodynamic and inertial ones of the whole aircraft are exported and an Abaqus steady solution is executed.

Dynamic Analysis: Gust (1/2)

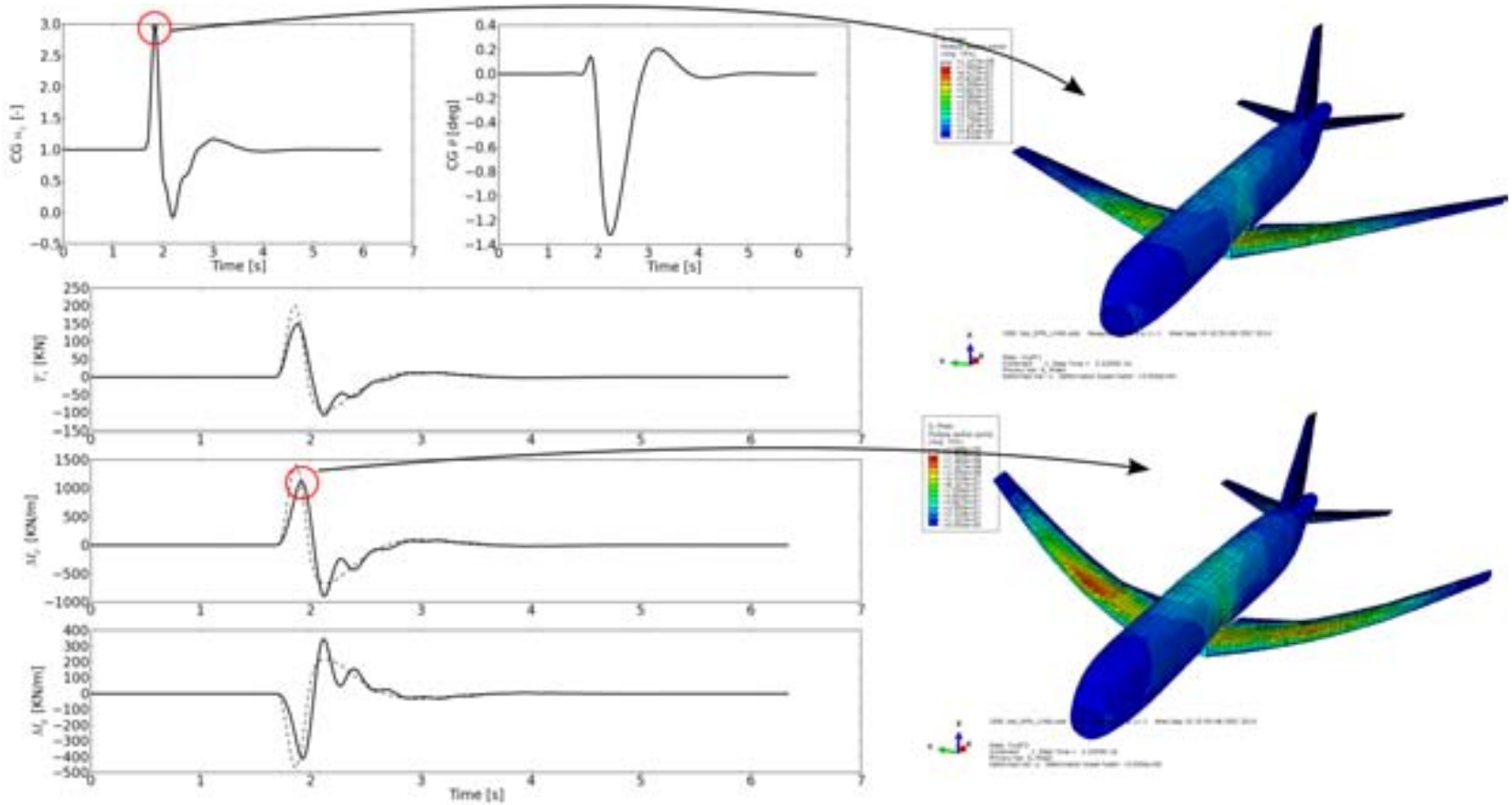




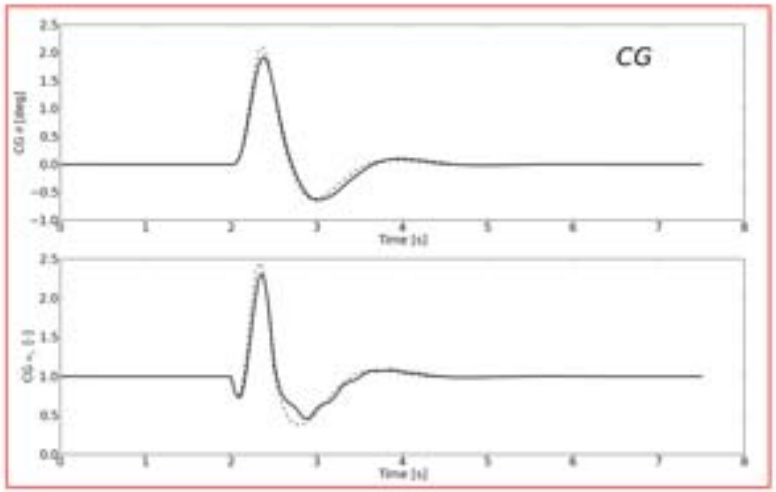


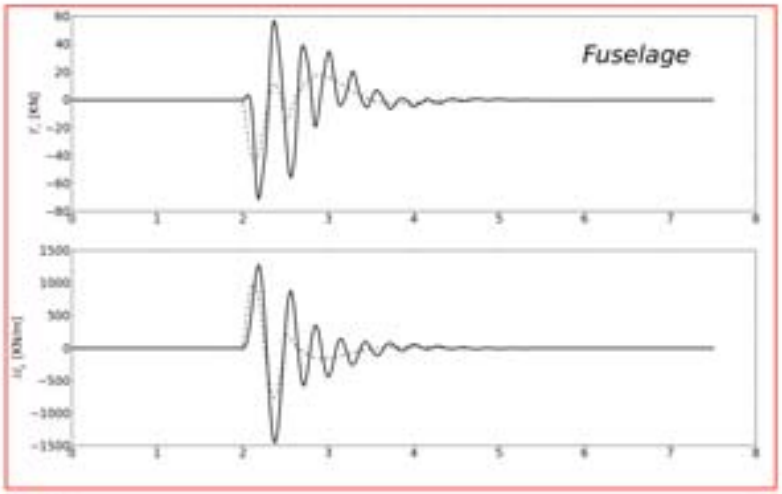


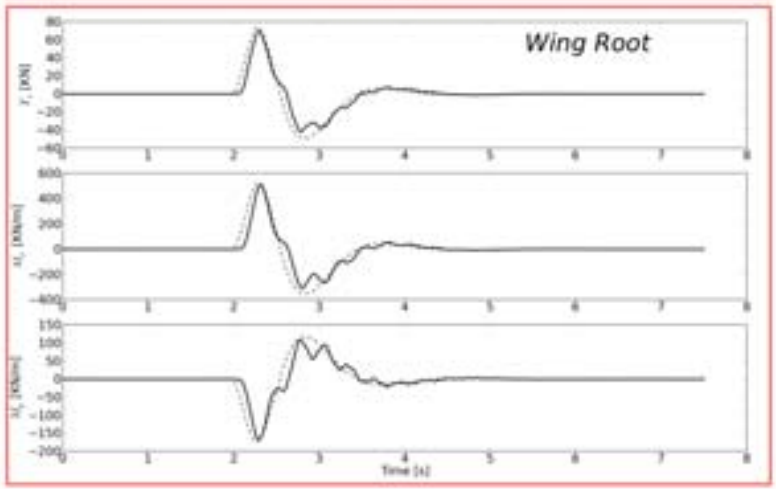
Dynamic Analysis: Gust (2/2)

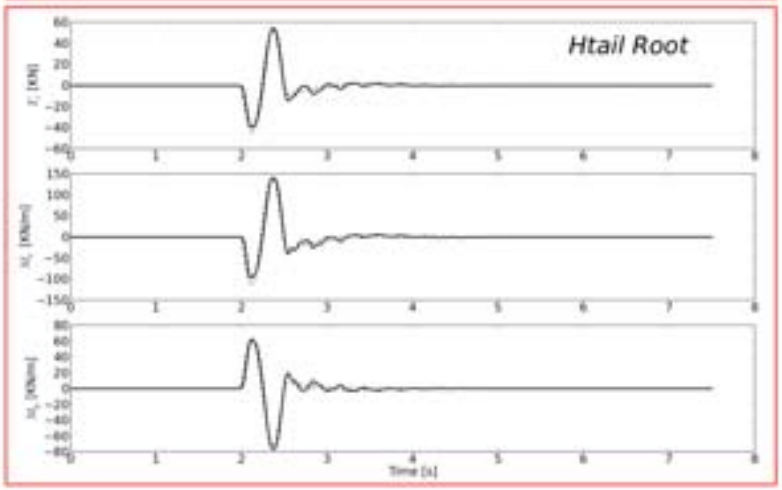


Dynamic Analysis: Elevator manoeuvre (1/2)

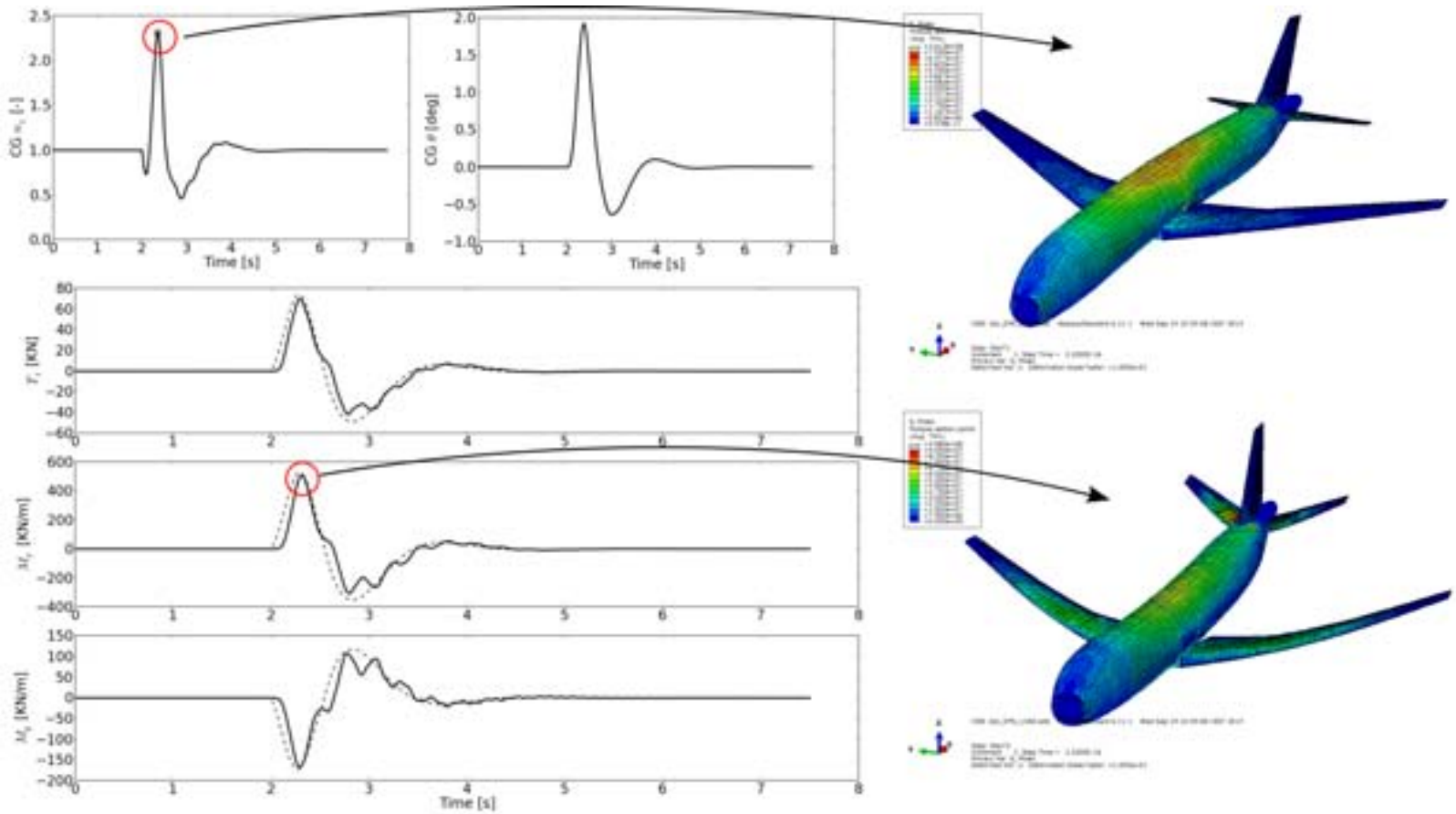








Dynamic Analysis: Elevator manoeuvre (2/2)



Conclusion

Conclusion:

This work shows the definition of a new framework designed to be able to perform all the different analyse of the preliminary design managing quite big databases both for structural and for aerodynamic models. The tool is able to communicate with Abaqus in a very easily why, in order to take advantage of one of the most powerful CAD/CAE software.

Future Developments:

Mid-Term developments:

- At the moment is under development the coupling of the aeroelastic state space model with the multi-body solver MBDyn, in order to be able to compute landing conditions and landing loads;
- Definition of a smart tool able to define all the load cases and analysis requested by the regulations (EASA-CS23 and EASA-CS25) starting from few inputs;

Long-Term developments:

- A tool able to identify the critical load cases for the different structures once all the load cases are computed;
- Knowing the design load cases the sizing process can be defined trough an optimization problem. Different optimization tools are under study to identify the best solution and approach.

Stability Derivatives

(a) Stability Derivatives Rigid

Mach	c_{l_α}	c_{M_α}	c_{y_β}	c_{L_β}	c_{N_β}
0.3	5.65	-2.71	-0.66	0.20	-0.248
0.5	5.90	-2.84	-0.68	0.205	-0.26

(b) Stability Derivatives Elastic

Mach	c_{l_α}	c_{M_α}	c_{y_β}	c_{L_β}	c_{N_β}
0.3	5.17	-2.613	-0.65	0.20	0.244
0.5	4.84	-2.38	-0.65	0.205	-0.24

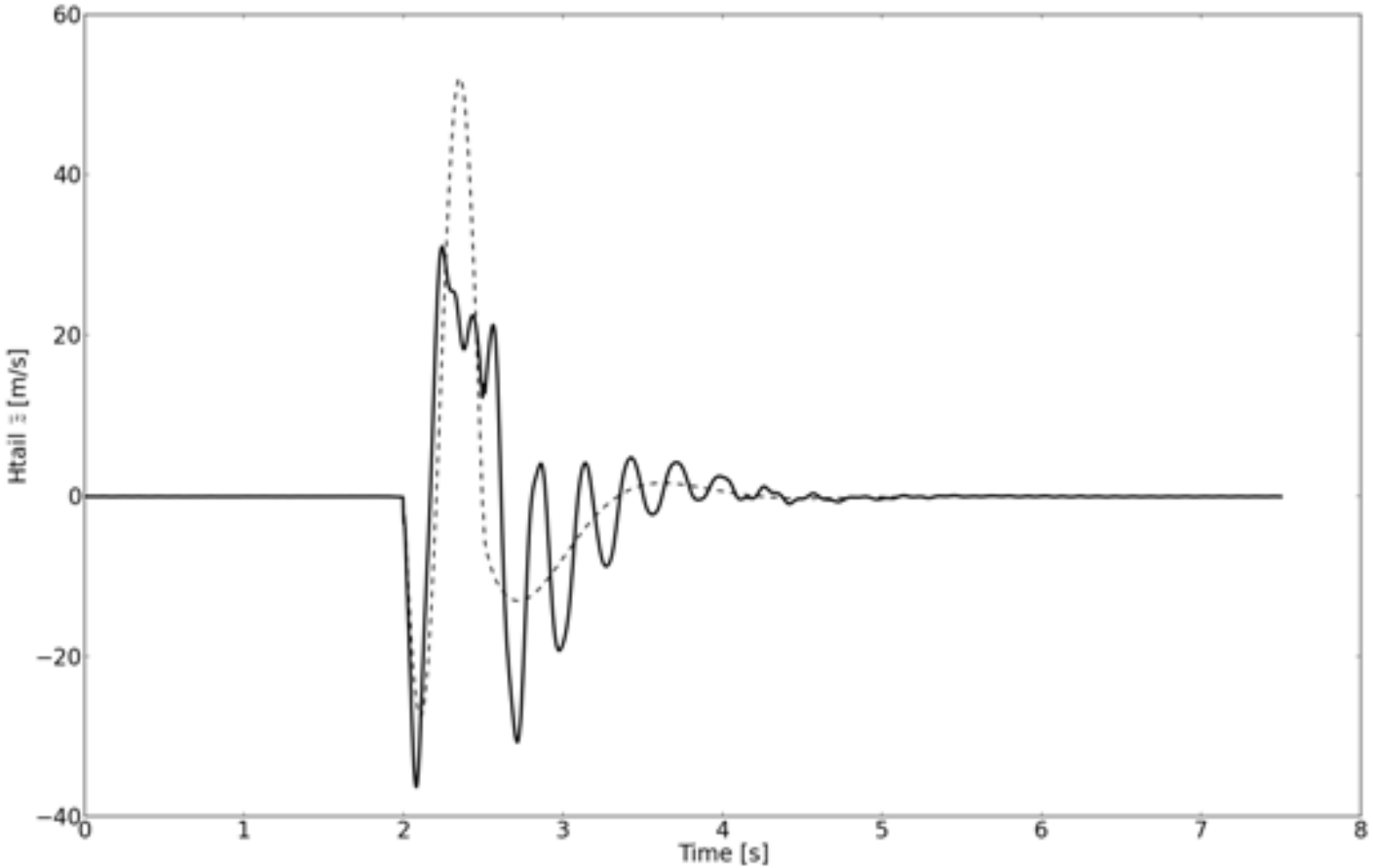
(c) Control Derivatives Rigid

Mach	$c_{l_{\delta_e}}$	$c_{M_{\delta_e}}$	$c_{y_{\delta_r}}$	$c_{L_{\delta_r}}$	$c_{N_{\delta_r}}$	$c_{L_{\delta_a^2}}$
0.3	0.45	-1.76	-0.30	0.064	-0.298	0.14
0.5	0.47	-1.84	-0.31	0.066	-0.309	0.145

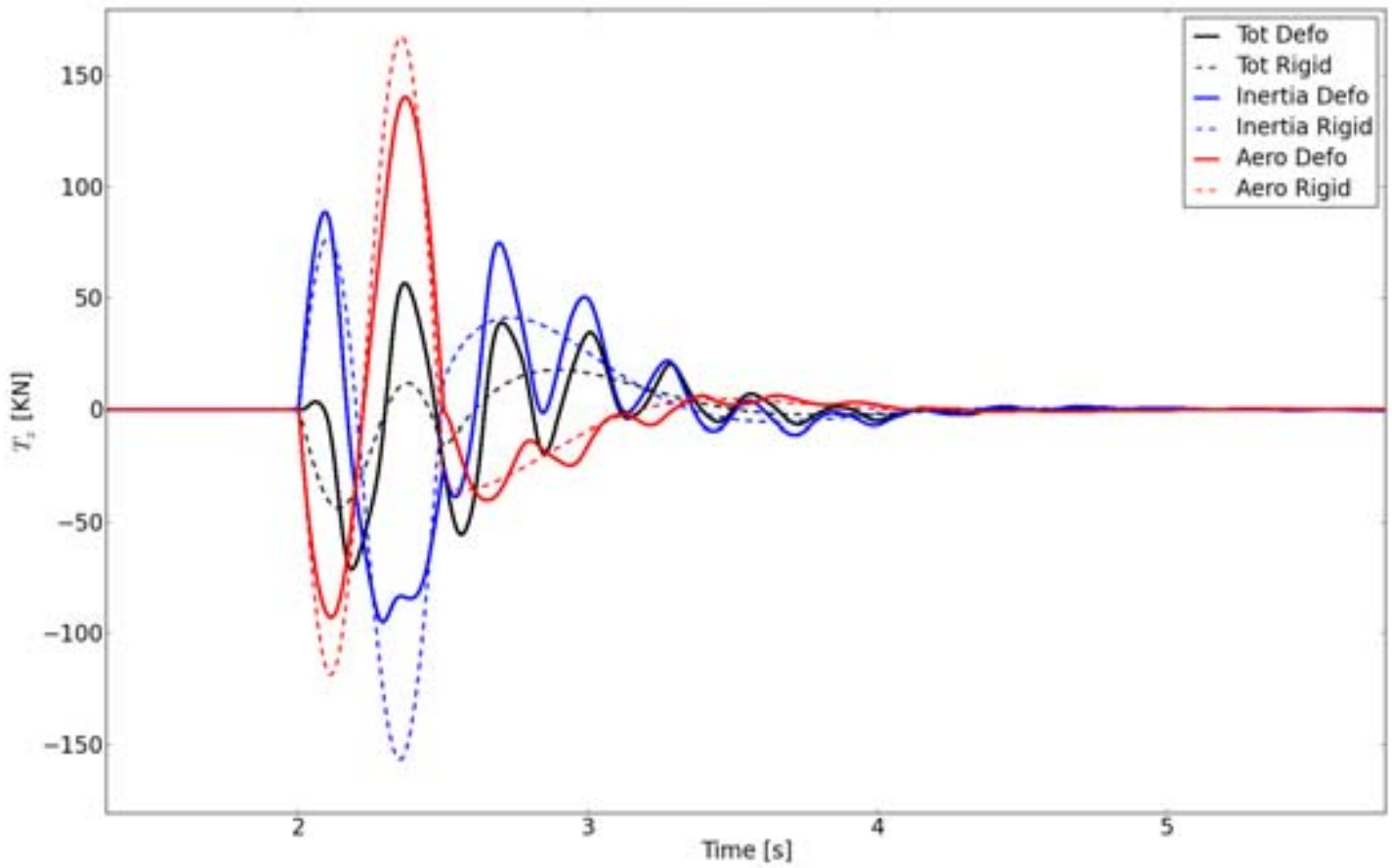
(d) Control Derivatives Elastic

Mach	$c_{l_{\delta_e}}$	$c_{M_{\delta_e}}$	$c_{y_{\delta_r}}$	$c_{L_{\delta_r}}$	$c_{N_{\delta_r}}$	$c_{L_{\delta_a^2}}$
0.3	0.46	-1.71	-0.29	0.066	-0.294	0.131
0.5	0.47	-1.58	-0.29	0.076	-0.292	0.103

Elevator: Htail Acceleration



Elevator: Fuselage Shear



Impact of Certification Constraints in a Multi-Disciplinary Design Process

Peter Schmollgruber (Onera / DCPS),
N. Bartoli (Onera / DCPS) and Y. Gourinat (ISAE)

Aachen, 27/10/2014

ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

Introduction

- Optimization of new configurations
  - Aerodynamics
  - Structure
  - Aeroelasticity
  - Controls

- Operational aspects and certification must be taken into account

- Impact of certification on final design and optimization process definition
  - Optimization results considering certification
  - New requirements on the Multi Disciplinary Analysis
  - Changes to an open-source simulator

Optimization results considering certification (1/7)

- FP7 EU Project GABRIEL (2011-2014)

- Assisted take-off and landing
- Landing gear removal

- Performance improvement
- Environmental benefits

- Control laws validation

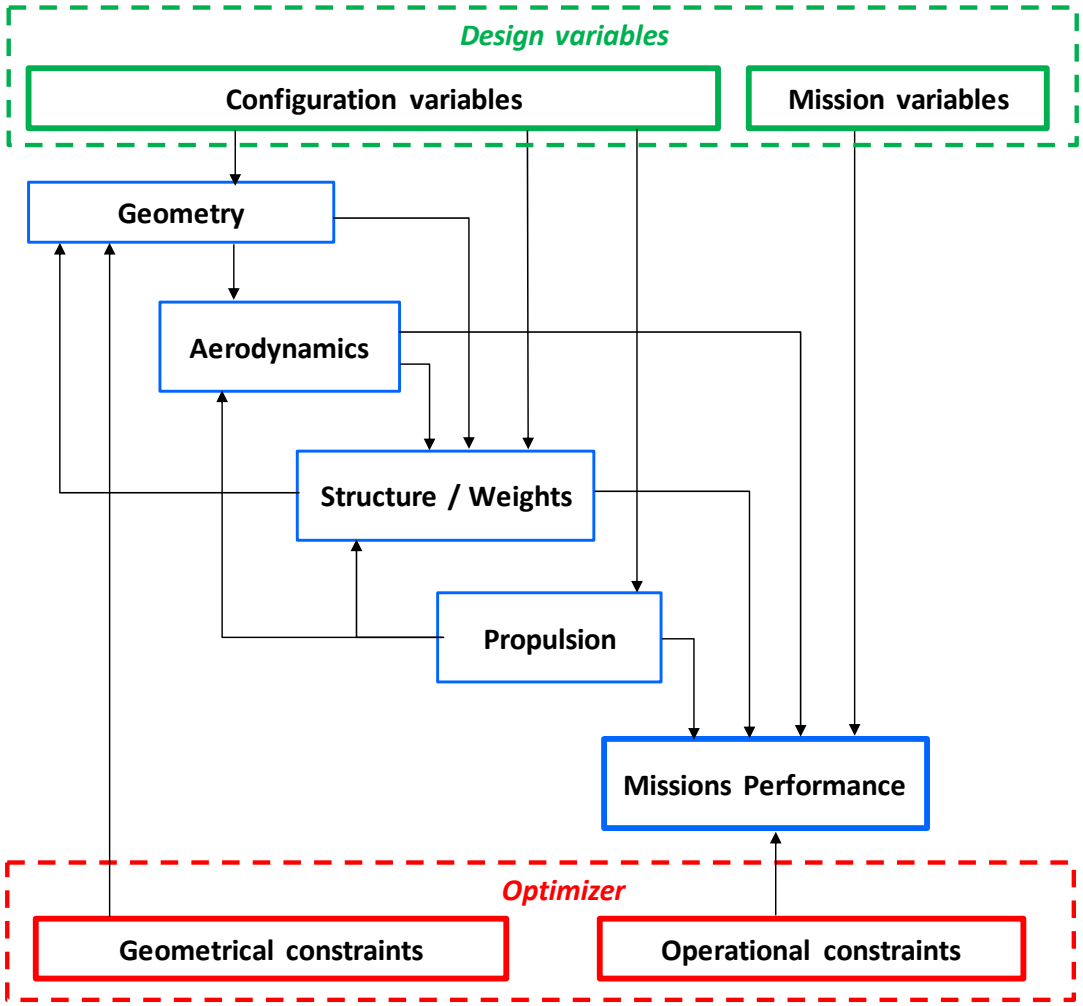
Optimization results considering certification (2/7)

- Sizing and optimization of the GABRIEL aircraft

  - Assisted take-off phase
  - New aerodynamics
  - Fixing system

  - Rubber engine
  - New wing planform

  - Multi-objectives optimization



Optimization results considering certification (3/7)

- Certification constraints to limit the engine size reduction

- For given Weight and Aerodynamic configuration:
  - CS 25-119 Landing climb: all-engines operating
    - Minimum climb gradient : 3.2%

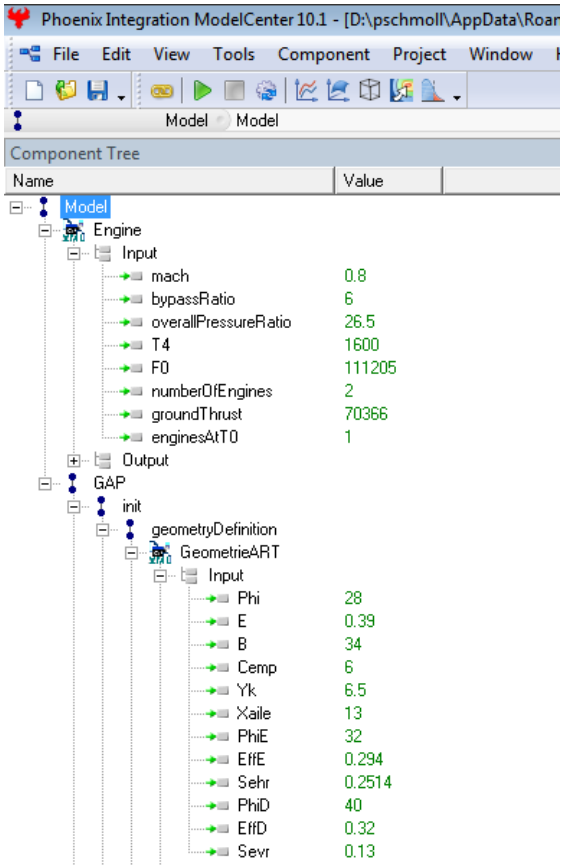
  - CS 25-121 (b) Climb: one-engine inoperative (for 2 engines aircraft)
    - Minimum climb gradient : 2.4%

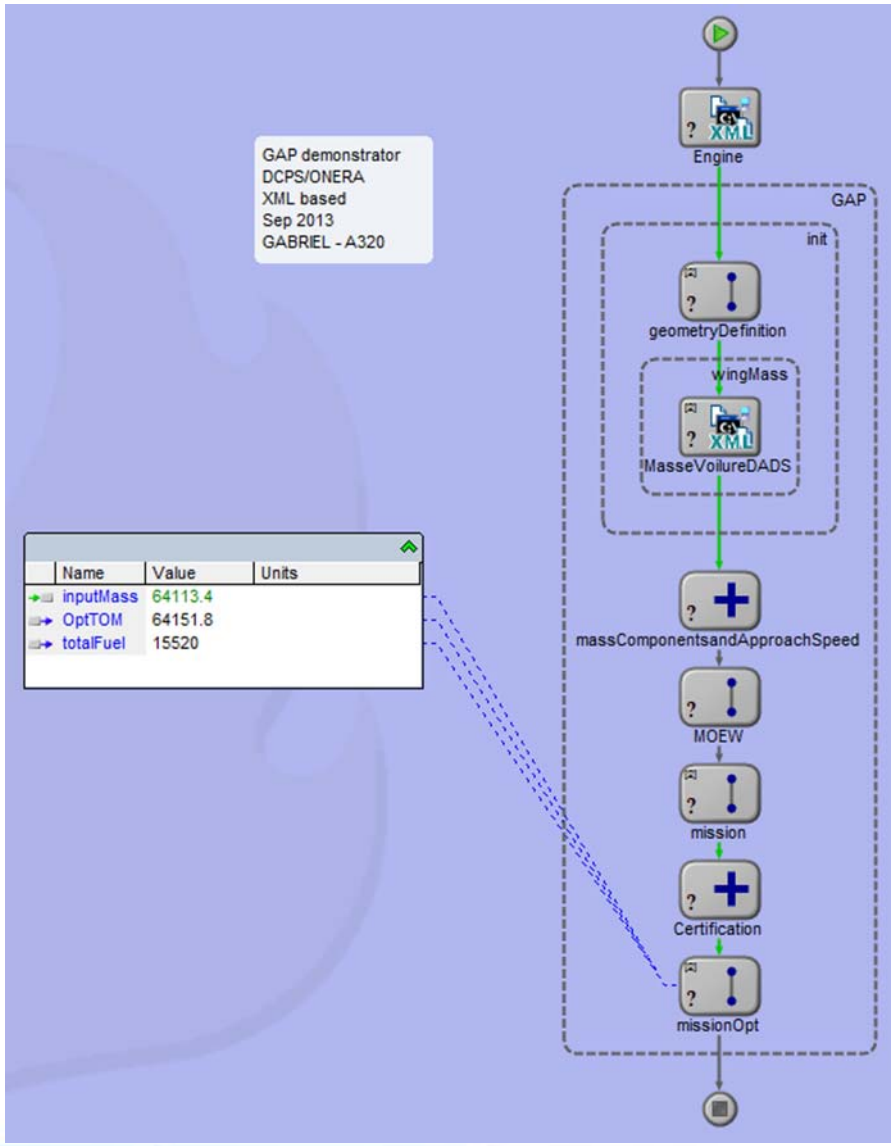
  - CS 25-121 (d) Climb: one-engine inoperative (for 2 engines aircraft)
    - Minimum climb gradient : 2.1 %

- Service ceiling verification (500 ft/min)

Optimization results considering certification (4/7)

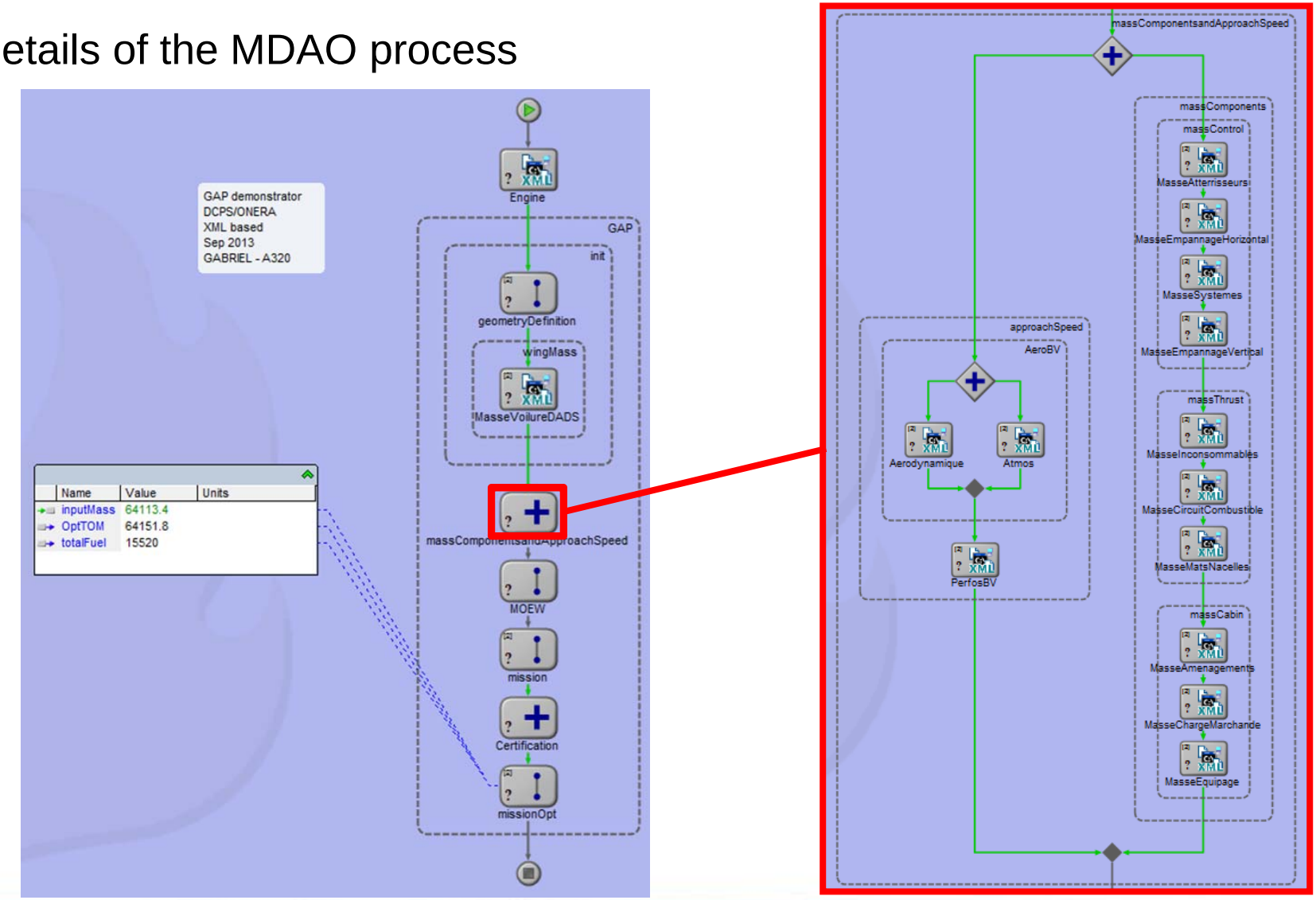
- Implementation of the MDAO process in ModelCenter





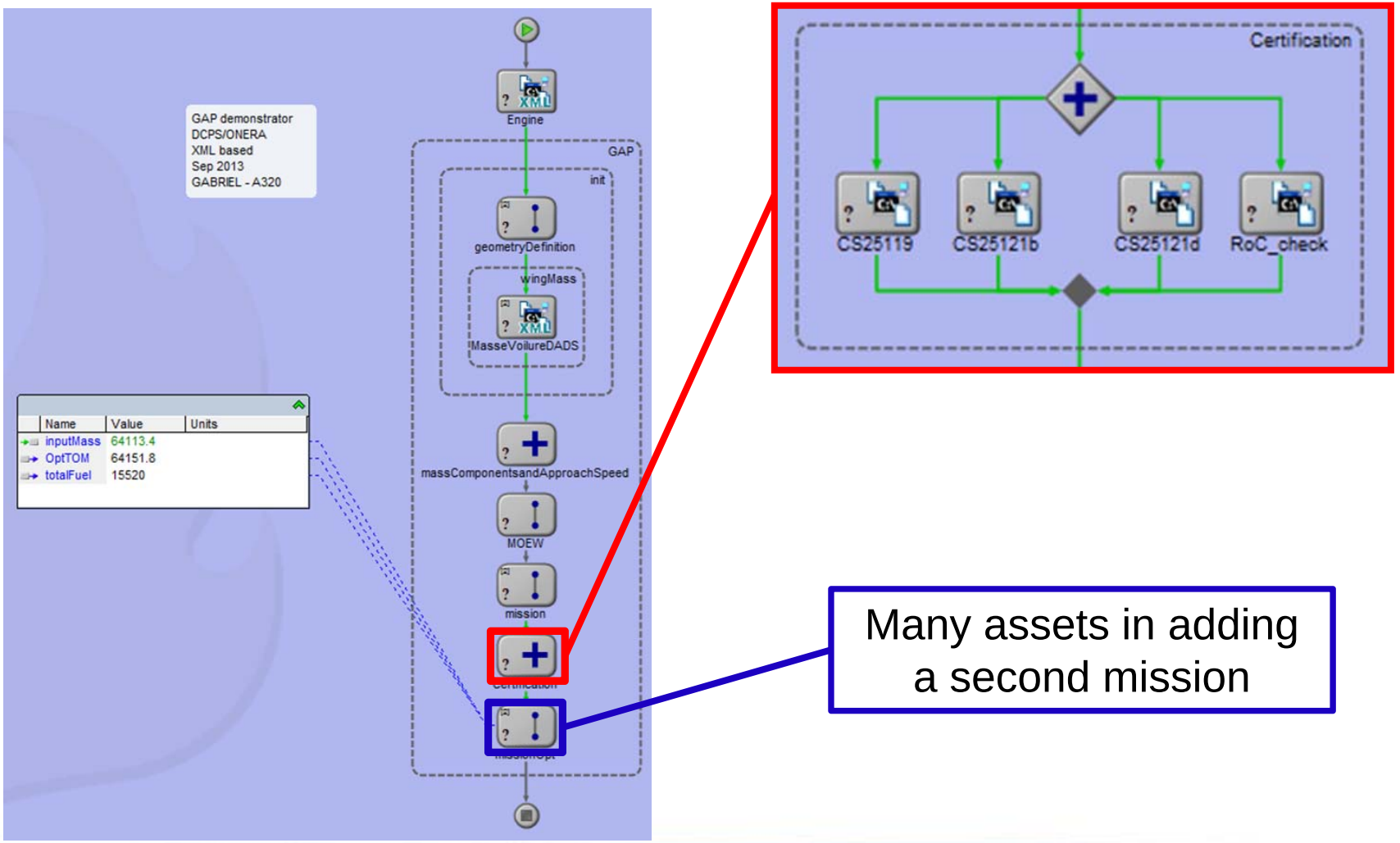
Optimization results considering certification (5/7)

- Details of the MDAO process



Optimization results considering certification (6/7)

- Details of the MDAO process

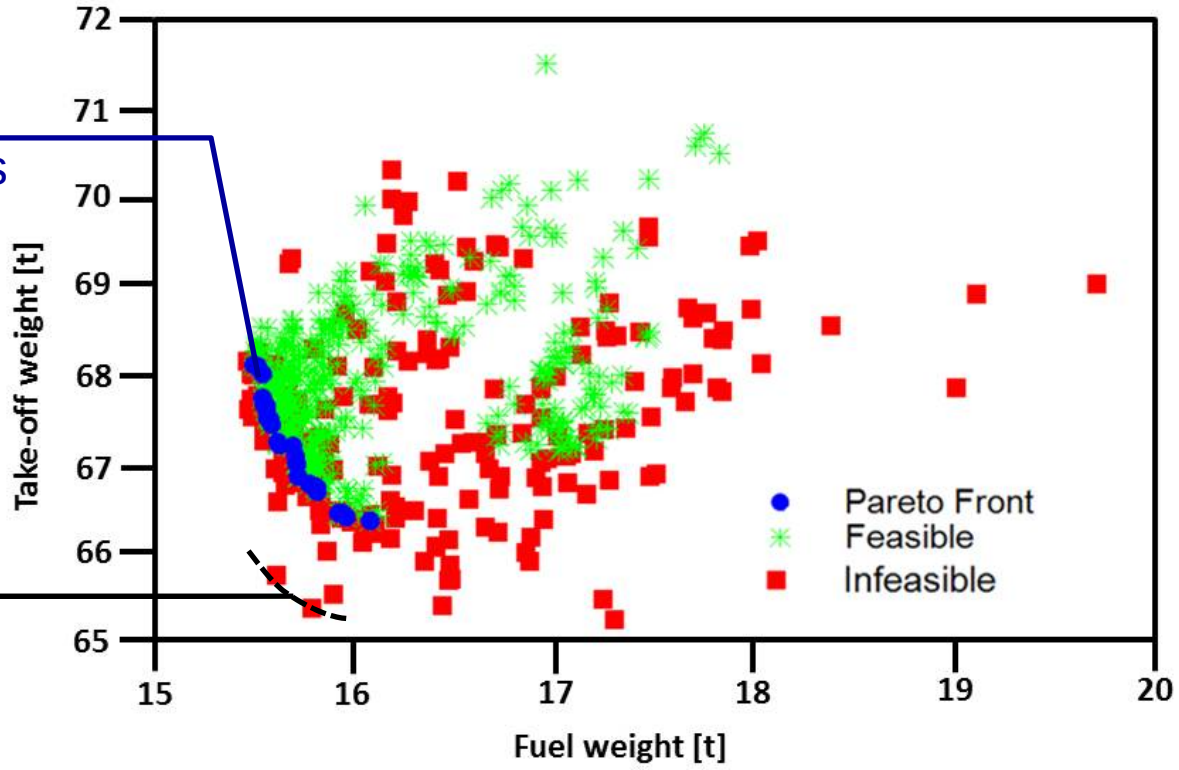


Optimization results considering certification (7/7)

- Results of the optimization process

Pareto front with certification constraints

Pareto front without certification constraints



- Important shift in the pareto front defining the best family of aircraft

New requirements on the Multi Disciplinary Analysis

- Review of CS-25

SUBPART B FLIGHT

GENERAL	CS 25.	20
	CS 25.	33
PERFORMANCE	CS 25.	101
	CS 25.	125
CONTOLLABILITY AND	CS 25.	143
MANOEUVRABILITY	CS 25.	149
TRIM	CS 25.	161
STABILITY	CS 25.	171
STALLS	CS 25.	201
	CS 25.	207
GROUND HANDLING	CS 25.	231
CHARACTERISTICS	CS 25.	237
MISCELLANEOUS FLIGHT	CS 25.	251
REQUIREMENTS	CS 25.	255

CS 25.147 Directional and lateral control

(a) *Directional control; general.* (See AMC 25.147(a).) It must be possible, with the wings level, to yaw into the operative engine and to safely make a reasonably sudden change in heading of up to 15° in the direction of the critical inoperative engine. This must be shown at 1·3 V_{SR1}, for heading changes up to 15° (except that the heading change at which the rudder pedal force is 667 N (150 lbf) need not be exceeded), and with –

(1) The critical engine inoperative and its propeller in the minimum drag position;

(2) The power required for level flight at 1.3 V_{SR1}, but not more than maximum continuous power;

(3) The most unfavourable centre of gravity;

(4) Landing gear retracted;

(5) Wing-flaps in the approach position; and

(6) Maximum landing weight.

New requirements on the Multi Disciplinary Analysis

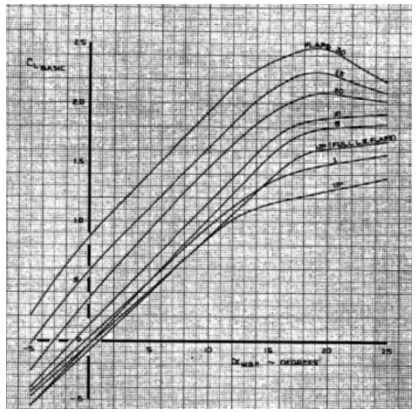
- A 6 DOF model must be integrated within the Missions Performance module

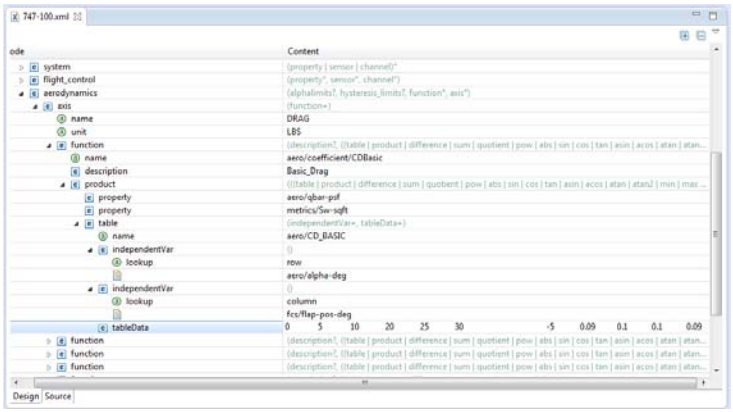
- Additional requirements
  - To facilitate collaboration between entities
  - To be flexible enough to explore various configurations
  - To be used in an automated process for optimization
  - To be able to include new subsystems

- Selection of JSBSim
  - Open source simulator
  - Flight dynamics model of FlightGear

New requirements on the Multi Disciplinary Analysis

- Quick view on JSBSim





Node	Content
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bypassratio	5.2
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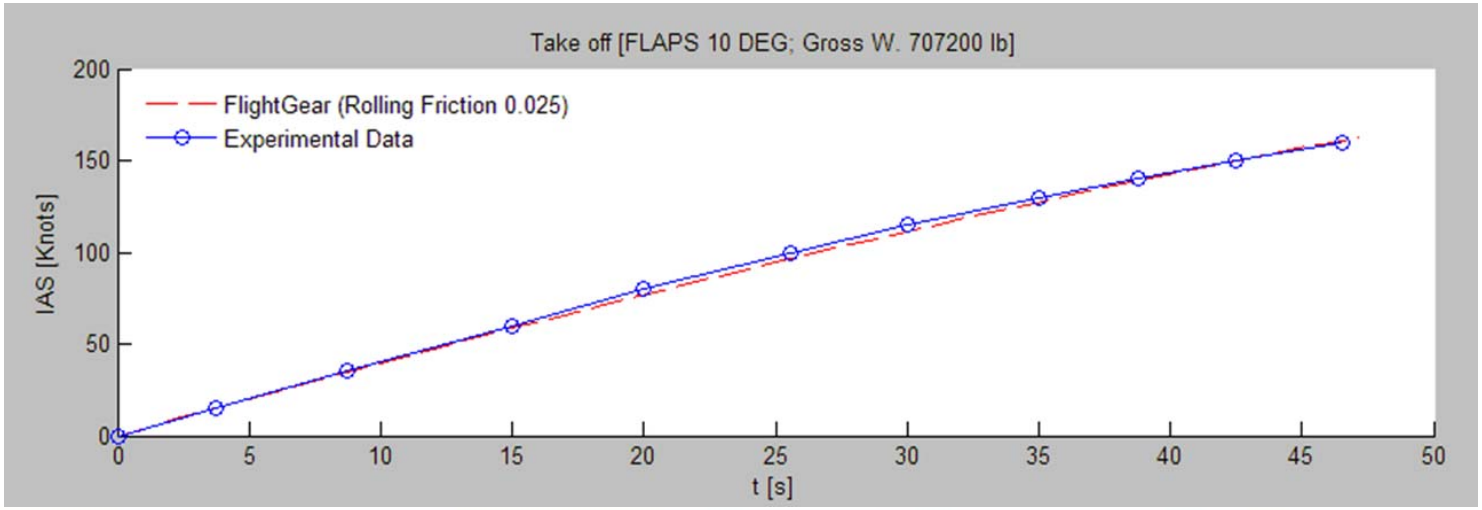
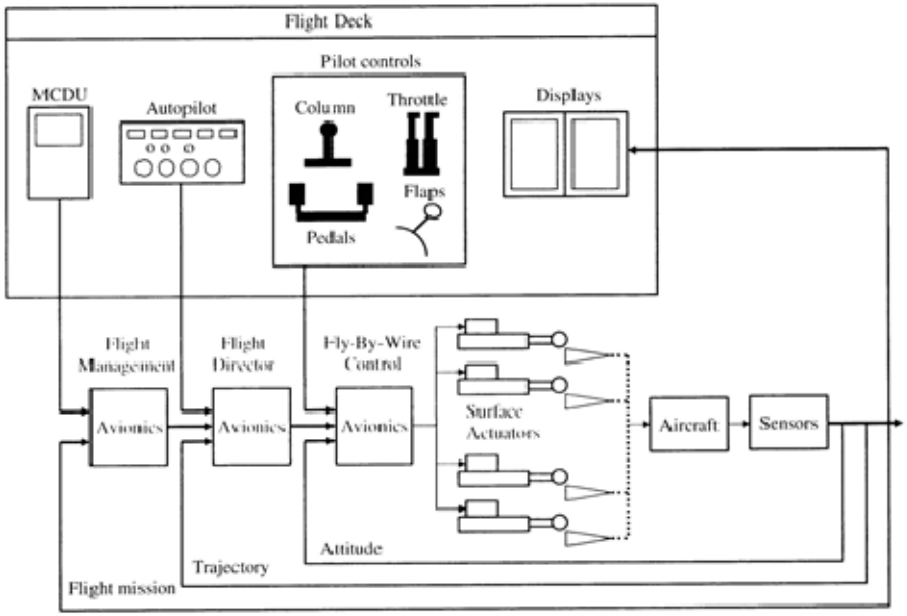
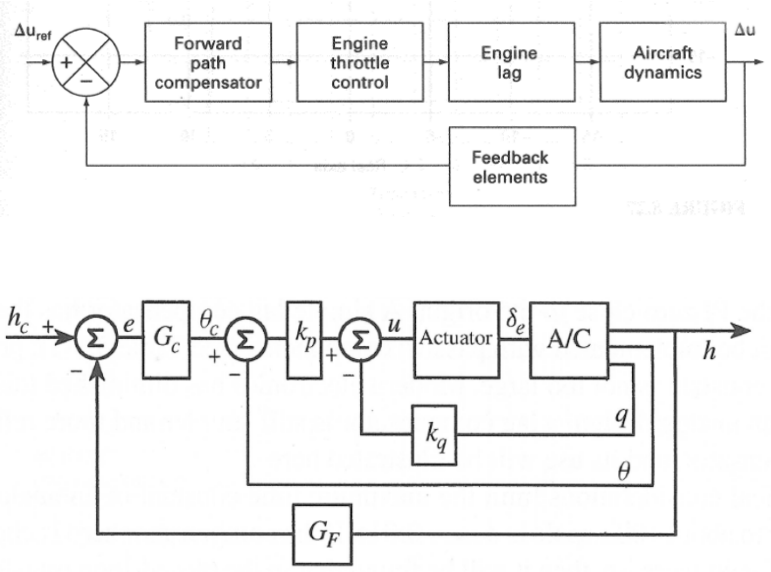
idlen2	60.0
maxn1	100.0
maxn2	100.0
augmented	0
augmethod	1
injected	0



Changes to an open-source simulator

- The main role of the Performance module is to assess the energy consumption for a given mission
- Definition of an automated mission based on high level orders





Aircraft Control and Simulation, B. L. Stevens, F. L. Lewis, Wiley, 2003
Flight Stability and Automatic Control, R. Nelson, McGraw-Hill, 1997
Stability and Control of Aircraft Systems, R. Langton, Aerospace Series, Wiley, 2006

Changes to an open-source simulator

- Mission script .xml

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<property value="0.40"> fcs/cruise-mach-target </property>
<property value="20000.0"> fcs/cruise-altitude-target </property>
<property value="0.3"> fcs/climb-mach-target </property>
<property value="10.0"> fcs/descent-vdown-target </property>

<event name="climb mach hold">
  <condition> simulation/sim-time-sec ge 1.0 </condition>
  <set name="fcs/wing-leveler" value="1.0"/>
  <set name="fcs/climbMH" value="1.0"/>
  <set name="fcs/throttle-cmd-norm[0]" value="0.9"/>
  <set name="fcs/throttle-cmd-norm[1]" value="0.9"/>
</event>

<event name="cruise phase">
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  <set name="fcs/climbMH" value="0.0"/>
  <set name="fcs/PAH" value="1.0"/>
  <set name="fcs/CAH" value="1.0"/>
  <set name="fcs/CMH" value="1.0"/>
  <set name="fcs/throttle-cmd-norm[0]" value="0.0"/>
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</event>

<event name="Descent">
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  <set name="fcs/PAH" value="0.0"/>
  <set name="fcs/CAH" value="0.0"/>
  <set name="fcs/CMH" value="0.0"/>
  <set name="fcs/descentVDH" value="1.0"/>
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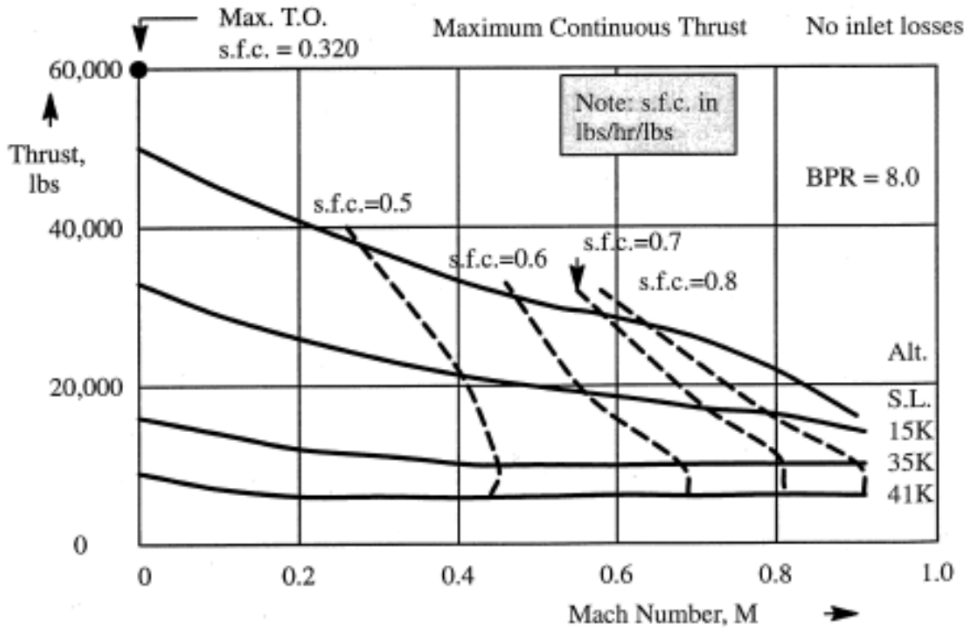
</event>
```

- Fuel consumption correction



Airplane Aerodynamics and Performance, J. Roskam, C.T. Lan, Darcorporation, 2000

Changes to an open-source simulator

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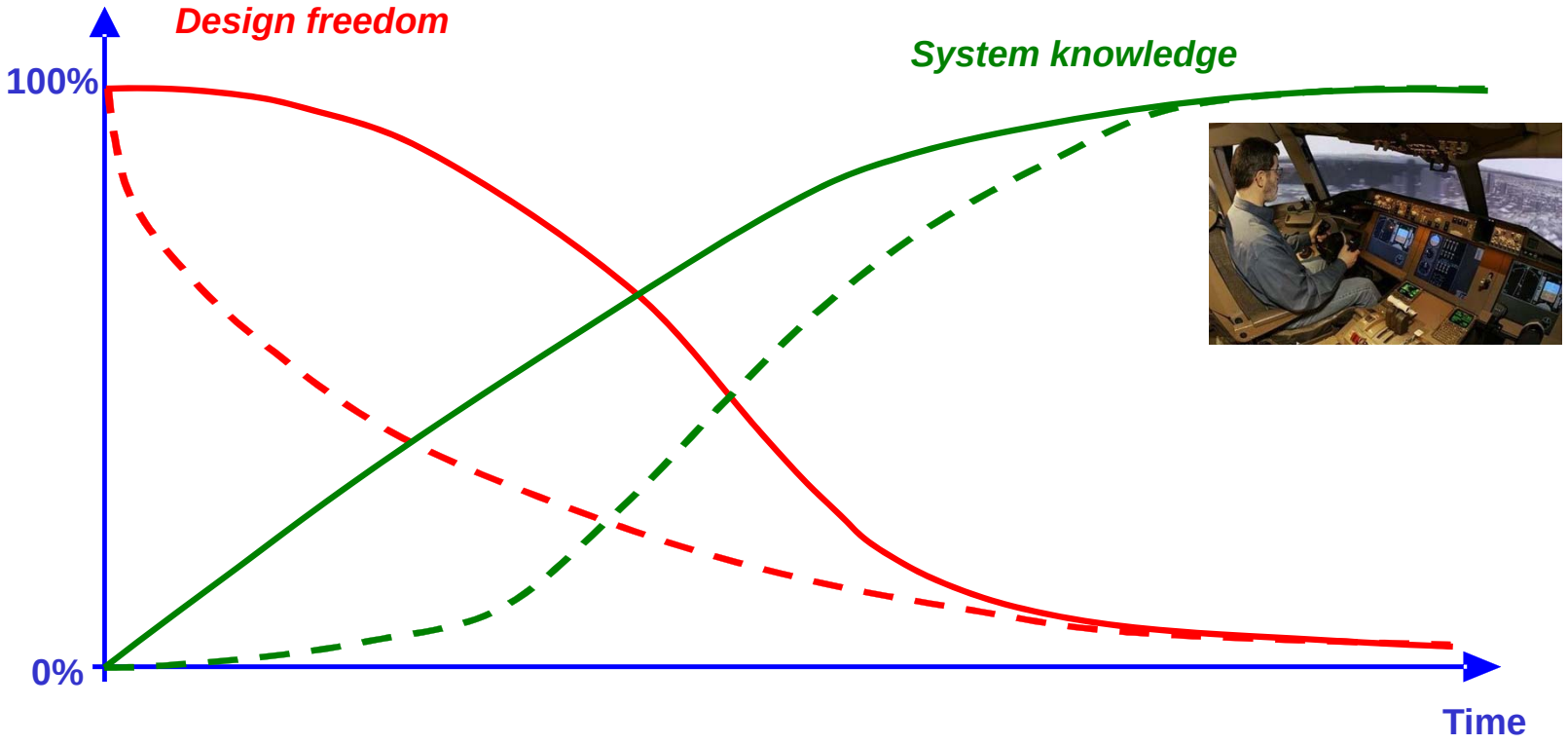
Conclusions

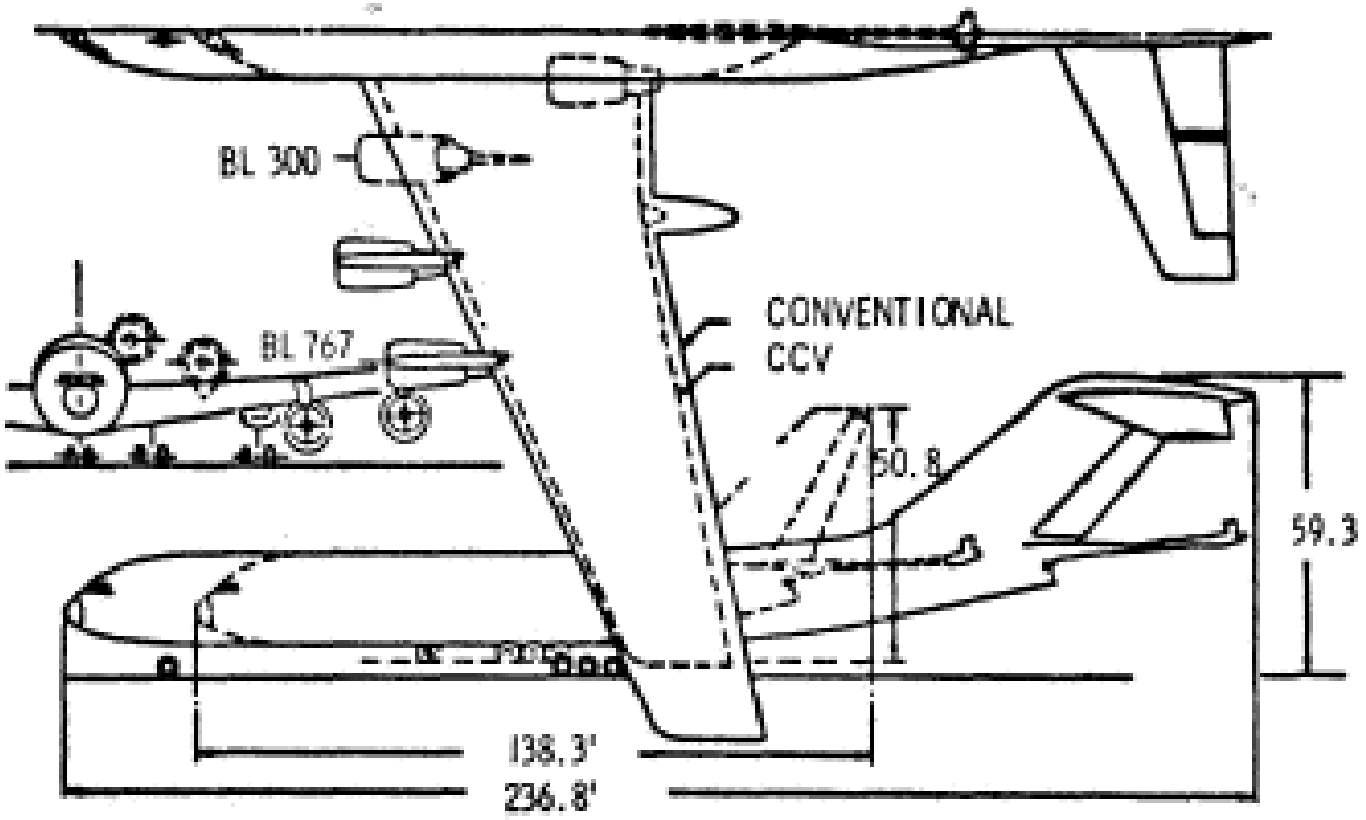
- Modification of the classical approach



"Methodology for examining the simultaneous impact of requirements, vehicle characteristics, and technologies on military aircraft design, Dimitri N. Mavris, Dan DeLaurentis, ICAS Congress, 2000

Conclusions

- Control configured vehicle



"Design of a control configured tanker aircraft", S. A. Walker, NASA 76N31158, 1976

Conclusions

- Impact of certification cannot be neglected during the definition of innovative configurations
- The use of a simulator earlier in the design and optimization process allows:
  - An extension of the design space
  - More detailed analyses that are in some cases mandatory
- The new process aims at helping in the definition of certifications rules
- Next step consists in carrying out a complete optimization loop based on the new Multi Disciplinary Analysis

Thank you

Questions?

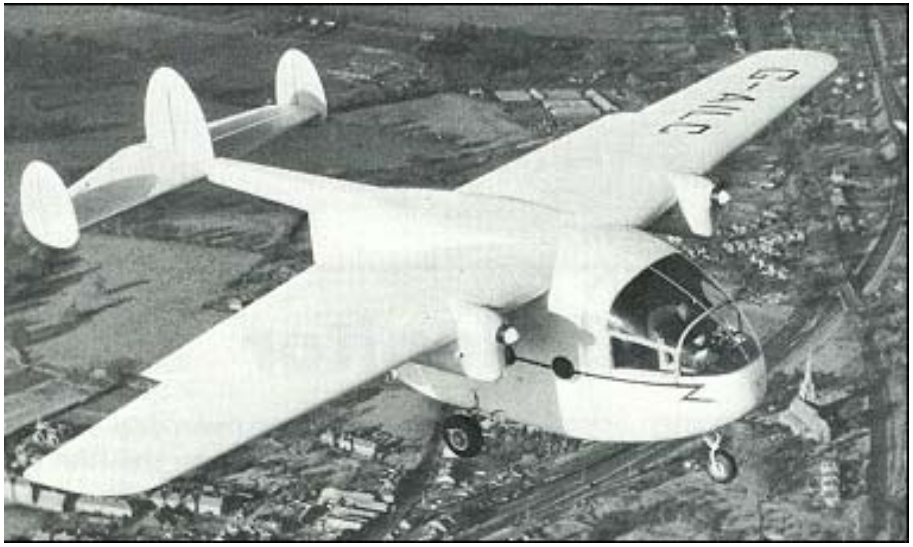
Multi-Fidelity Mass Estimation of a Strut-Braced Wing Configuration

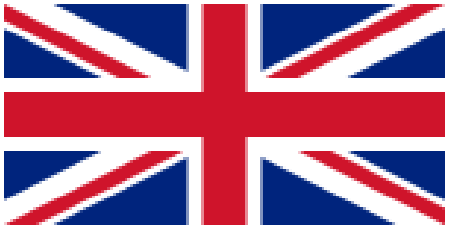
D. Böhnke, F. Dorbath, B. Nagel

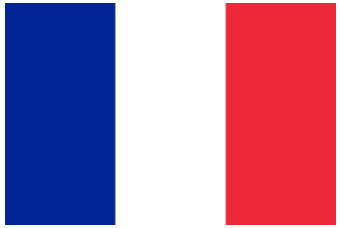
Integrated Aircraft Design

Air Transportation Systems, DLR e.V.

DLR

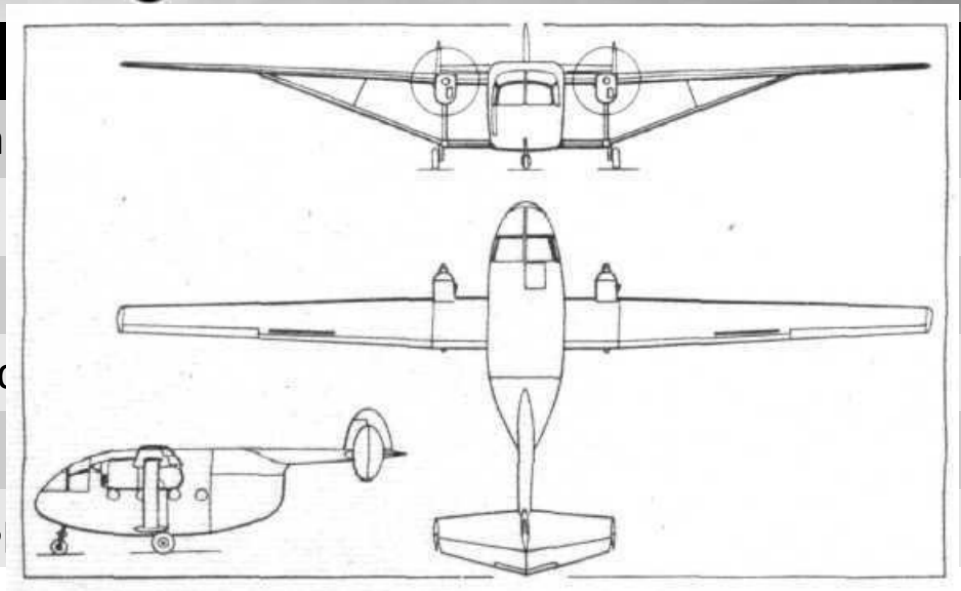






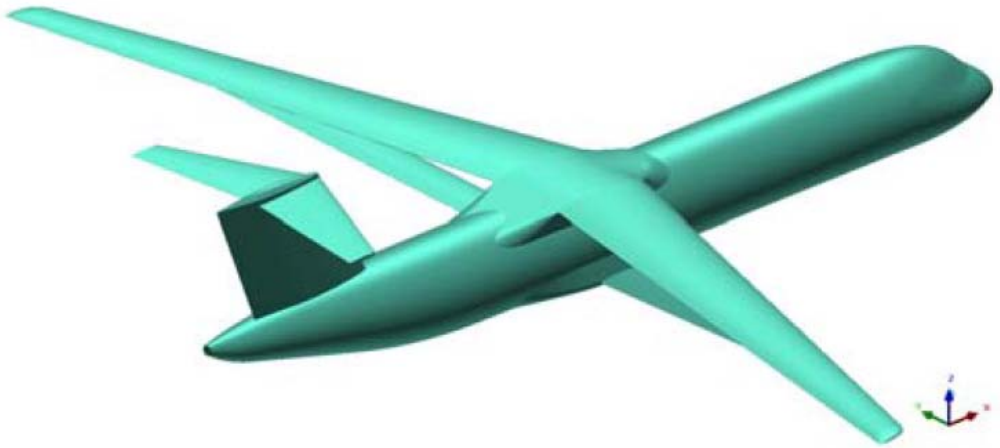
aviastar.org, 1000aircraftphotos.com, wikipedia.de

Wing a	
Aspect	
OEM	
Payloa	
TOFL	
Level S	

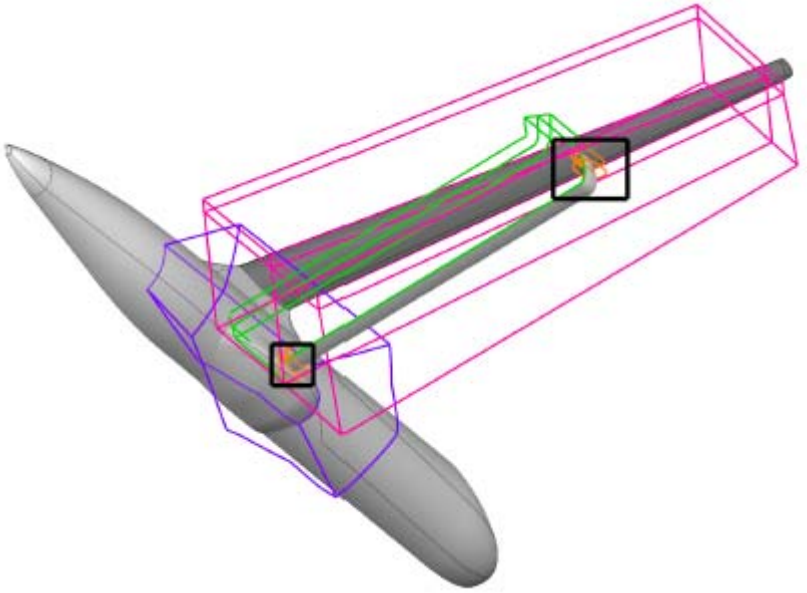


Flight, 1955

ONERA – ALBATROS



- A320/B737 Successor
  - 180pax
  - 3000Nm
  - Ma = .75
  - TOFL 2400m



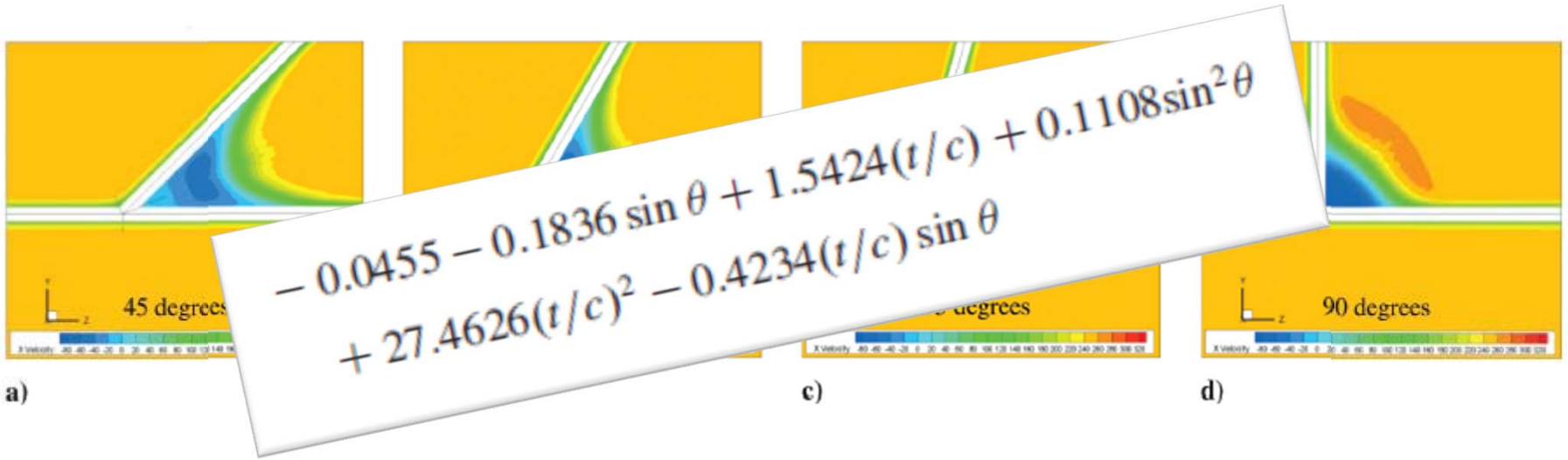
- Laminar wing design
  - 3D RANS
  - Detailed geometry

- Weight estimation
  - Beam model
  - Empiric estimation of secondary structures

G. Carrier et al., Investigation of a Strut-braced Wing Configuration for Future Commercial Transport

Virgina Tech – Strut/Truss Braced Wing

- SBW research since at least 1998
- Several design frameworks for either strut or truss braced wing designs
- Transsonic interference drag of strut-wing intersection

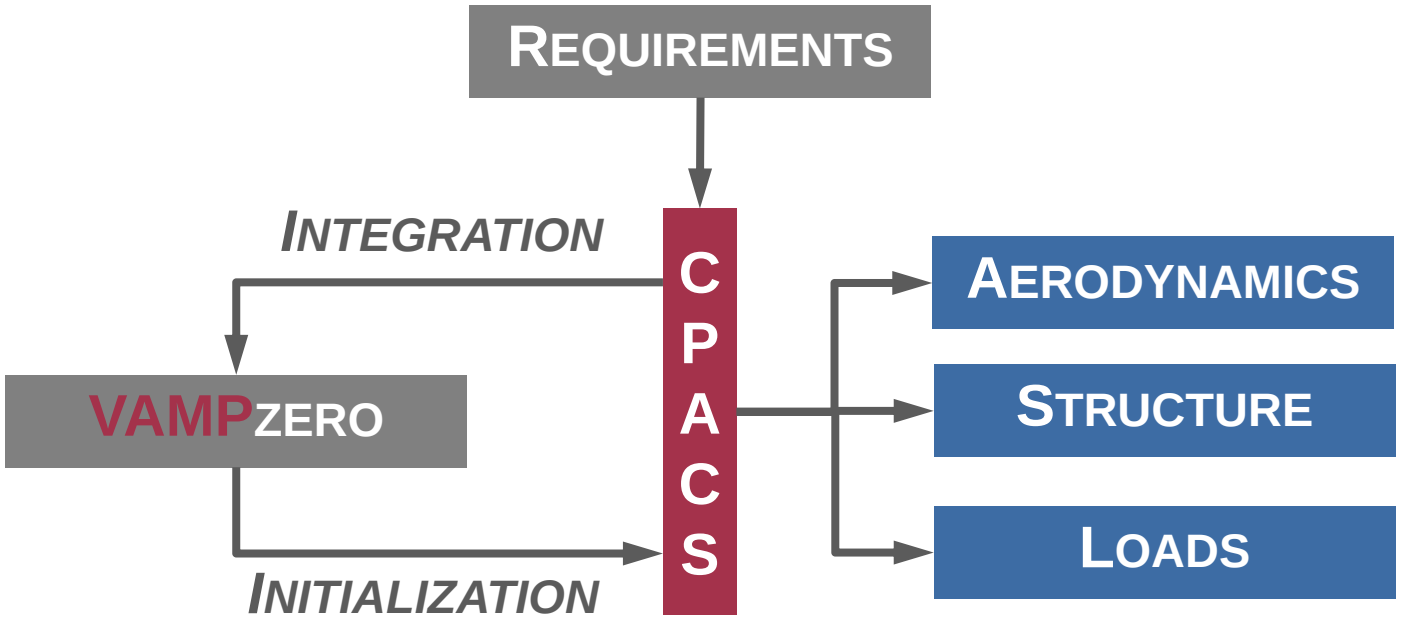


$$-0.0455-0.1836\sin\theta+1.5424(t/c)+0.1108\sin^2\theta$$
$$+27.4626(t/c)^2-0.4234(t/c)\sin\theta$$

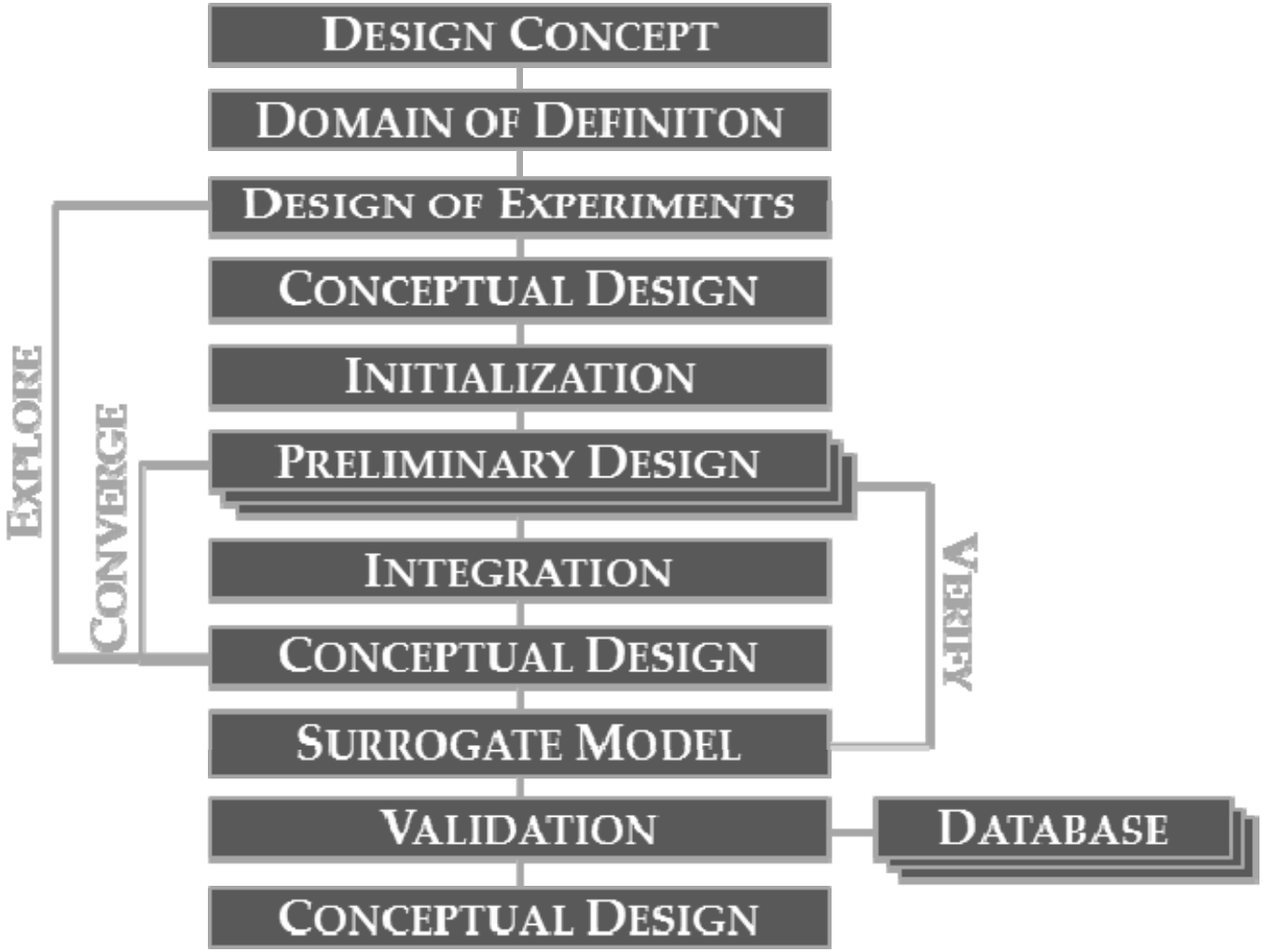
R. K. Duggirala et al. Analysis of Interference Drag for Strut-Strut Interaction in Transonic Flow

Physics-based conceptual design methods are necessary for the design of new aircraft configurations!

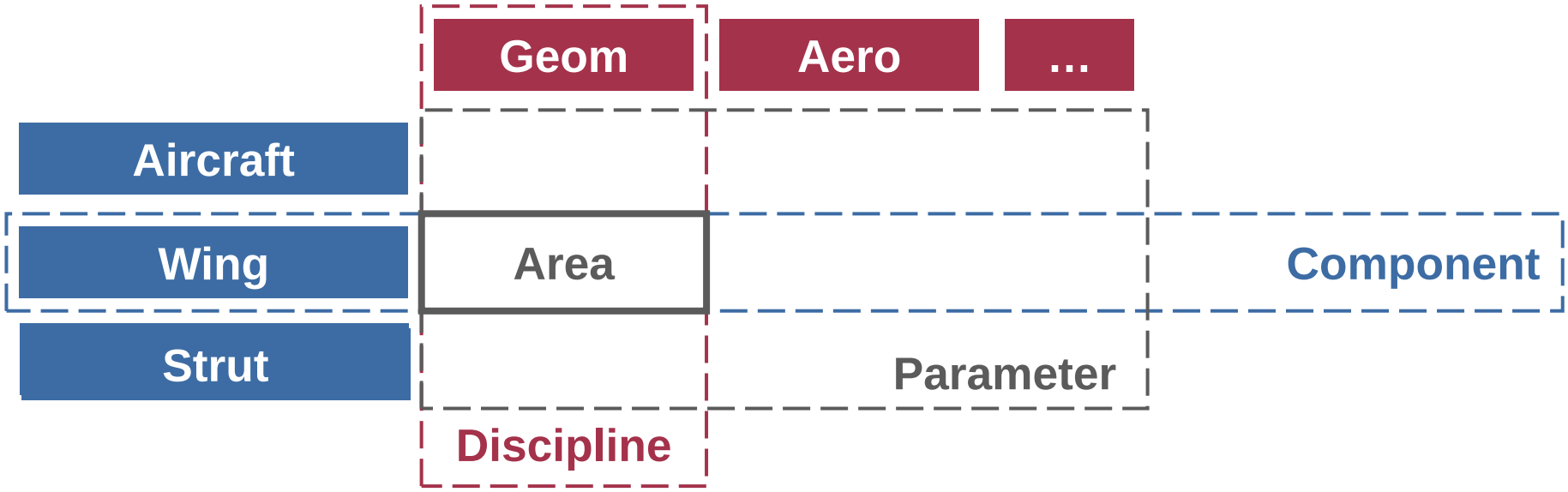
Multi-Fidelity Loop



Multi-Fidelity Workflow



VAMPzero – Conceptual Aircraft Design



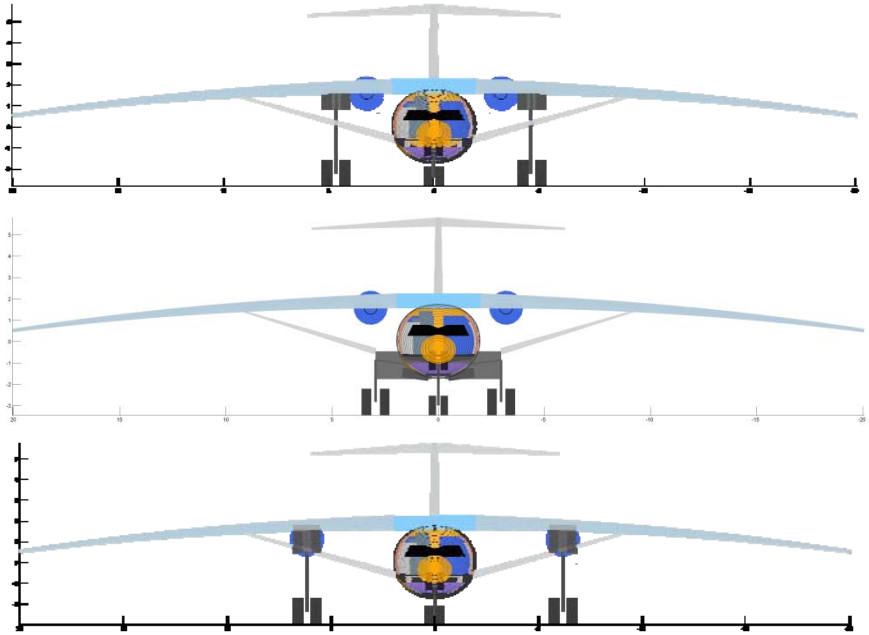
Conceptual Design Strut-Braced Wing

An **incomplete** list…

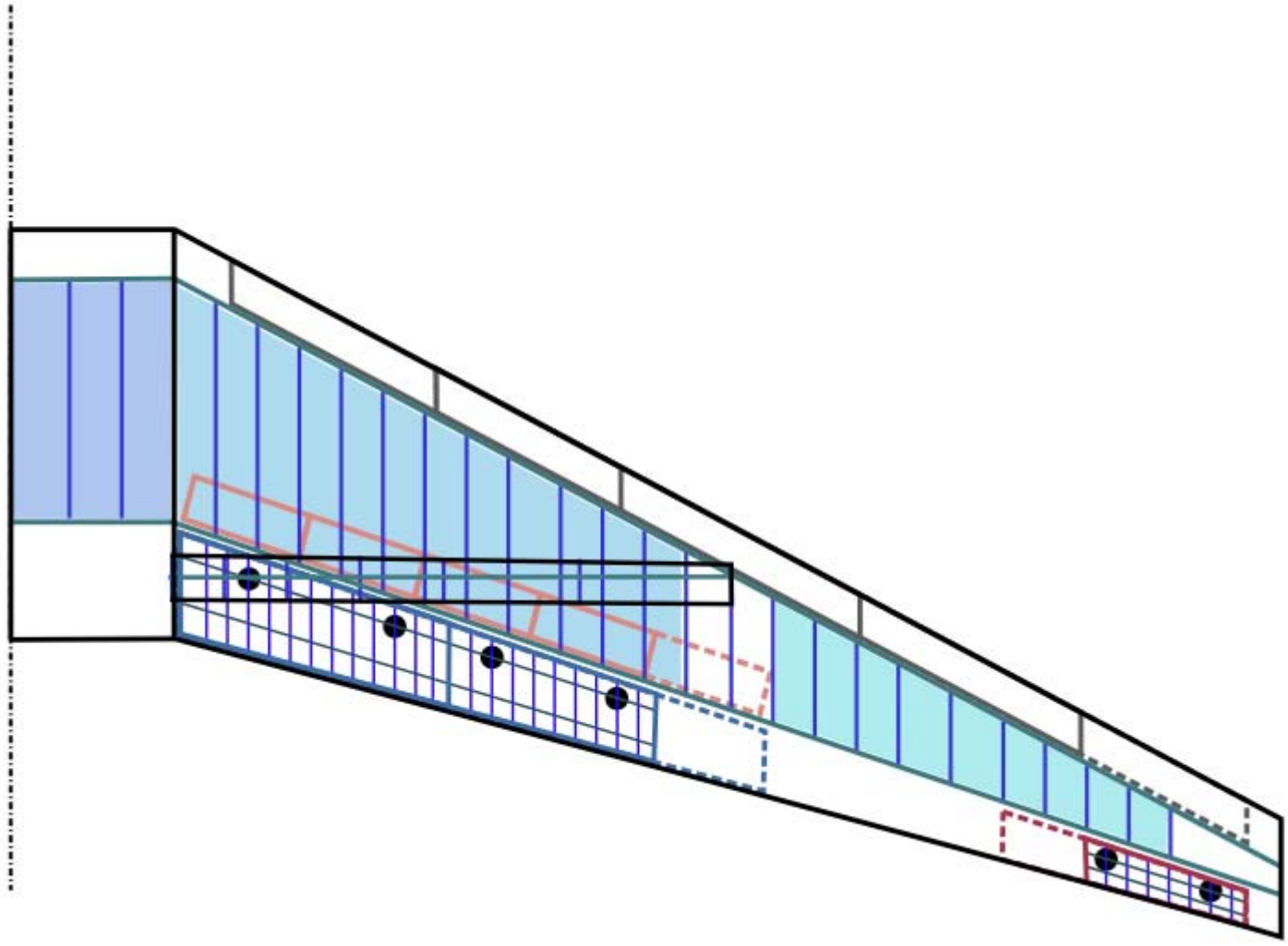
- High wing
- (Rear) engine placement
- T-Tail
- Landing gear integration

- Strut-Braced
  - Additional drag
  - Additional lift?
  - Lower bending moments
    - Less thickness
    - Less sweep
    - More aspect ratio
    - More/less weight

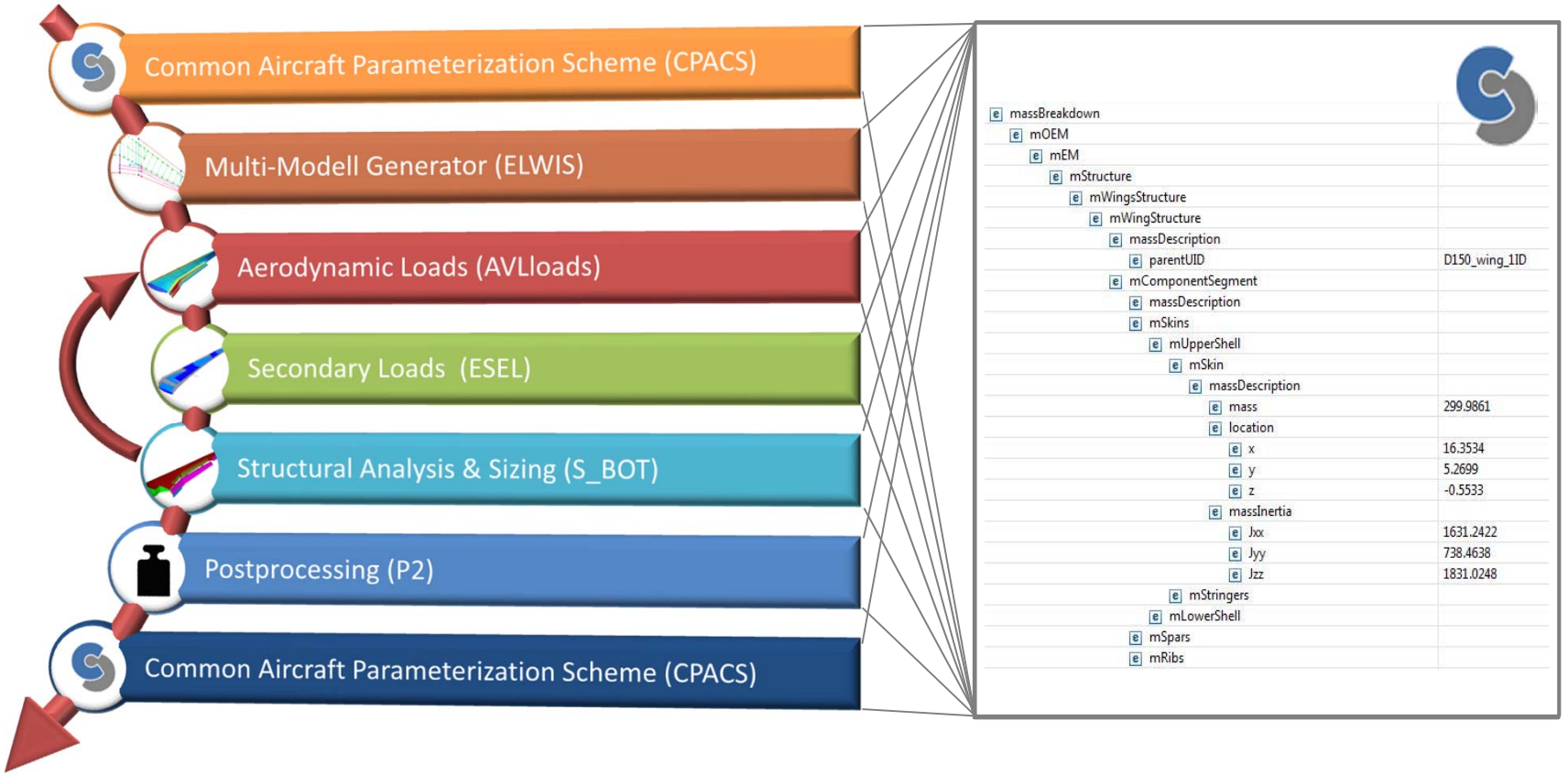
- etc. etc.

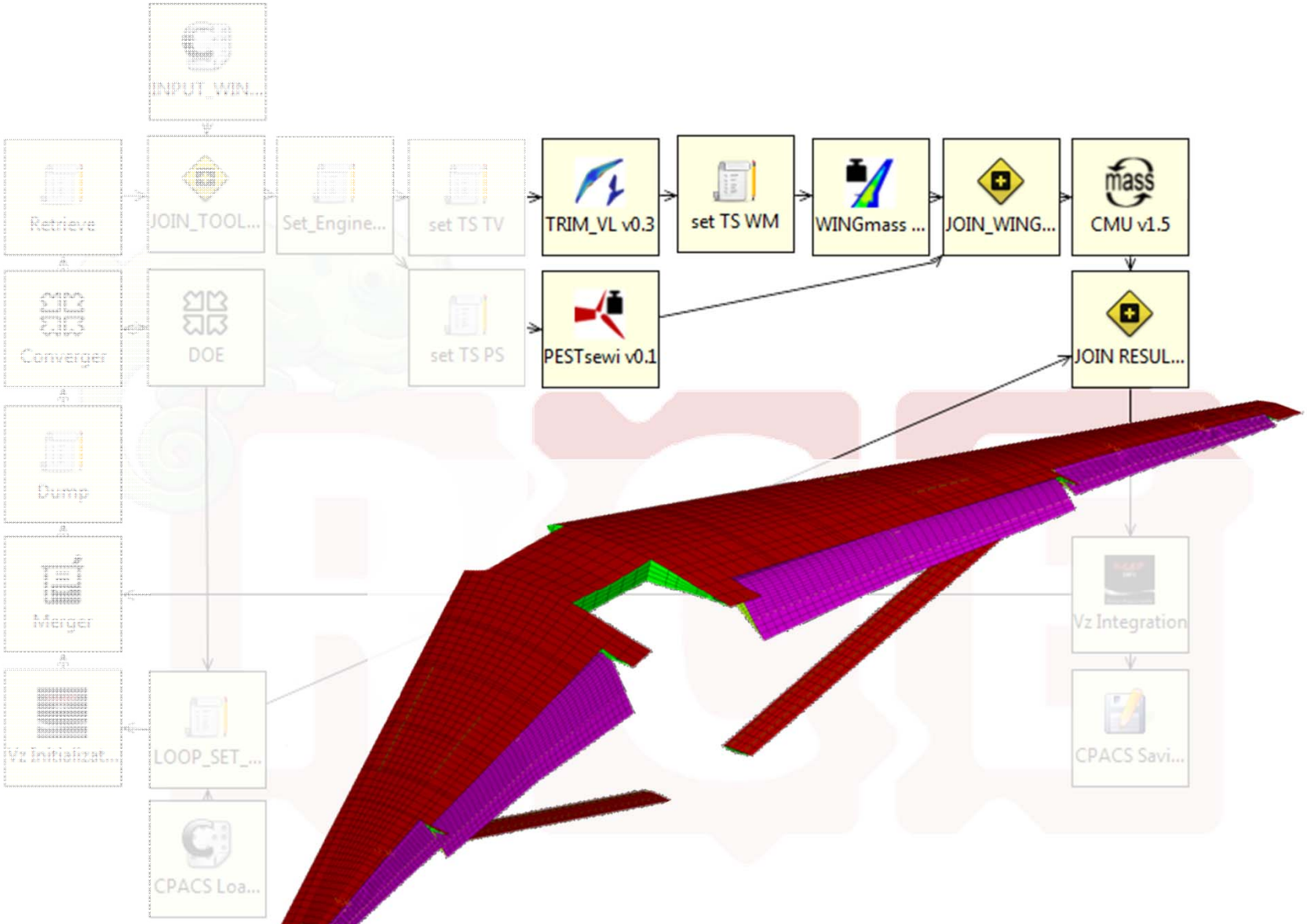


Initialization Strut-Braced Wing



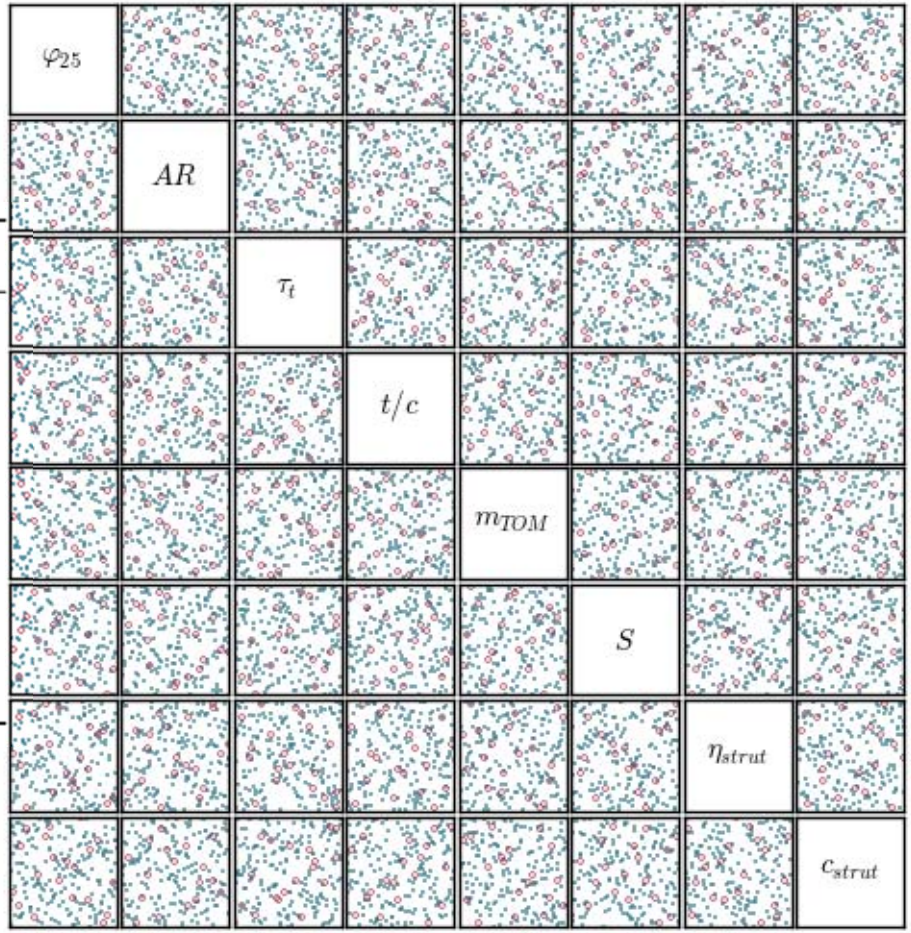
ElWIS


Common Aircraft Parameterization Scheme (CPACS)
Multi-Modell Generator (ELWIS)
Aerodynamic Loads (AVLloads)
Secondary Loads (ESEL)
Structural Analysis & Sizing (S_BOT)
Postprocessing (P2)
Common Aircraft Parameterization Scheme (CPACS)
massBreakdown
mOEM
mEM
mStructure
mWingsStructure
mWingStructure
massDescription
parentUID D150_wing_1ID
mComponentSegment
massDescription
mSkins
mUpperShell
mSkin
massDescription
mass 299.9861
location
x 16.3534
y 5.2699
z -0.5533
massInertia
Jxx 1631.2422
Jyy 738.4638
Jzz 1831.0248
mStringers
mLowerShell
mSpars
mRibs


INPUT_WING...
Retrieve
JOIN_TOOL...
Set_Engine...
set TS TV
TRIM_VL v0.3
set TS WM
WINGmass ...
JOIN_WING...
CMU v1.5
Converger
DOE
set TS PS
PESTsewi v0.1
JOIN RESUL...
Dump
Merger
Vz Integration
Vz Initialisat...
LOOP_SET_...
CPACS Savi...
CPACS Loa...

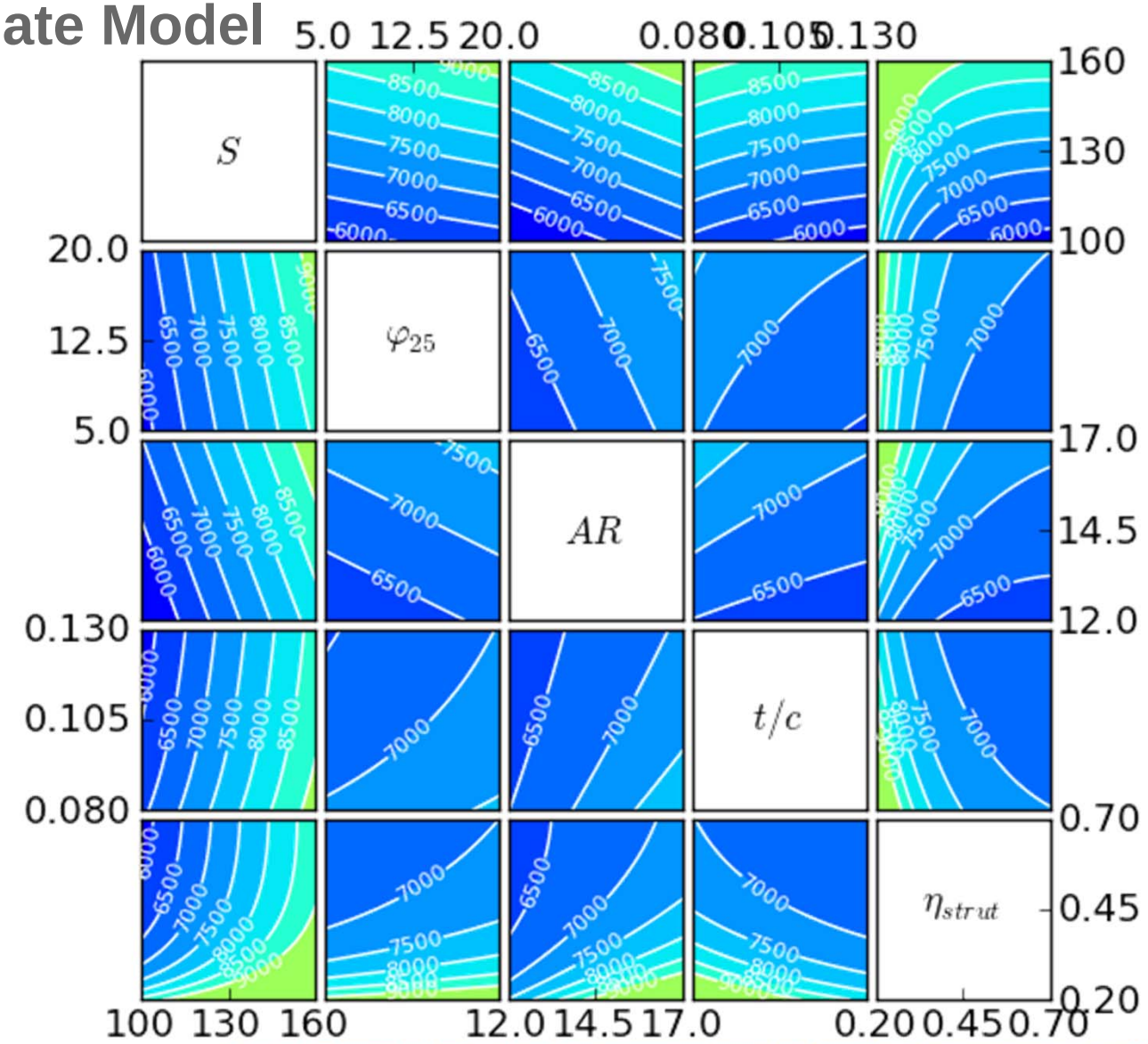
Design Space and DOE

Variable	Symbol	Range	Unit
Reference area	S	100. - 160.	[m²]
max. take-off mass	m_{TOM}	60.0 - 90.0	[t]
Sweep angle	φ_{25}	5.0 - 20.0	[ ]
Aspect ratio	AR	12.0 - 17.0	[ ]
Tip twist	τ_t	-6.0 - 0.0	[ ]
Thickness ratio	t/c	0.08 - 0.13	[ ]
Strut position	η_{strut}	0.2 - 0.7	[ ]
Strut chord	c_{strut}	0.1 - 0.2	[ ]



Sample Points Validation Points

Surrogate Model

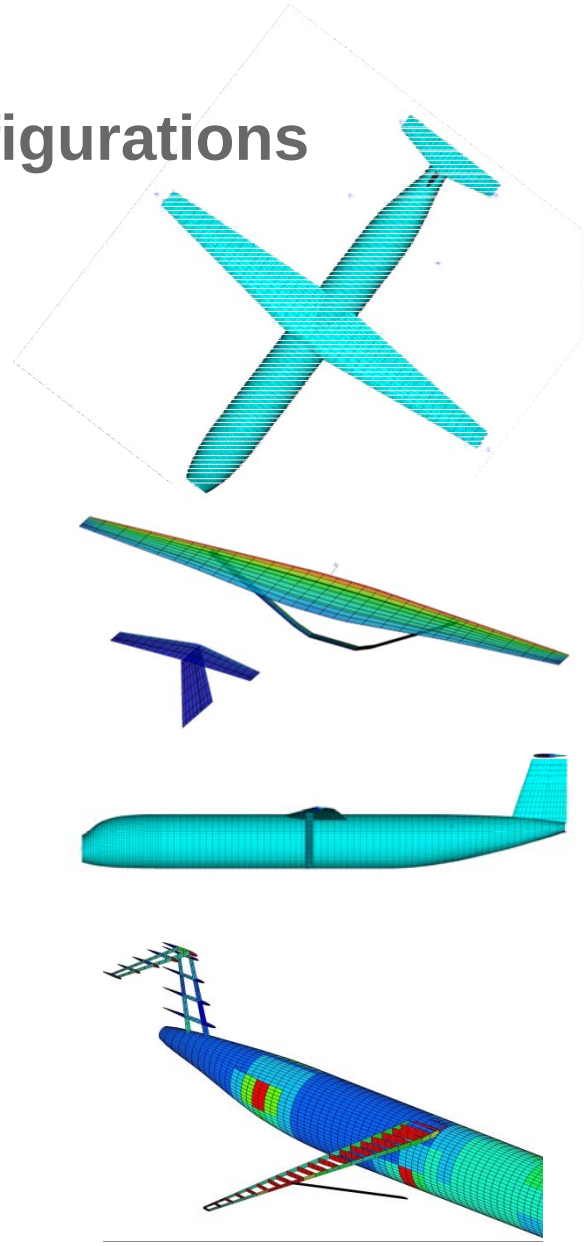


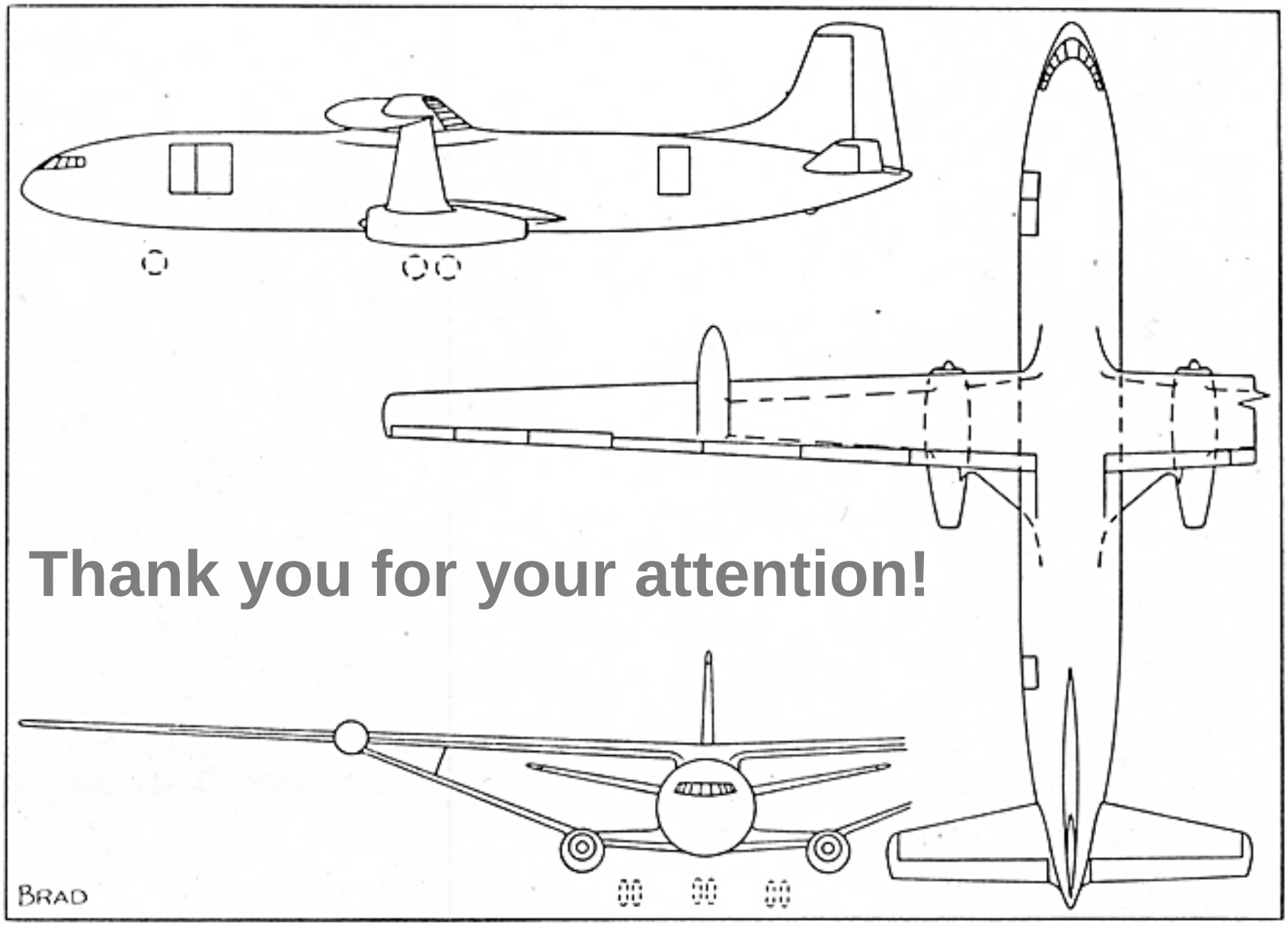
FrEACs – Future Enhanced Aircraft Configurations

- Quantification of uncertainties in the design of unconventional aircraft configurations

- Strut-braced wing
  - A320/B737 successor
  - EIS 2035
  - Focus on structures, loads and aeroelastics

- DLR internal project
  - 4/14 Kick-off
  - 6/14 TLAR
  - 8/14 Initial design camp
  - 12/14 Conceptual design freeze





Jane's all the world's aircraft 1953-1954, p.138

Optical Inspection Tool for Micro-structured, Fuel-Conserving Surfaces

H. Brüning, K. Brune, Y. Wilke, G. Patzelt

Fraunhofer IFAM

M. Imlau, J. Tschentscher, S. Hochheim

University Osnabrück

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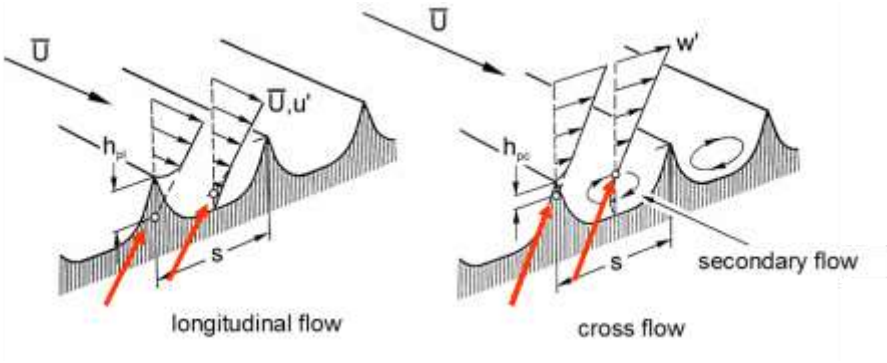
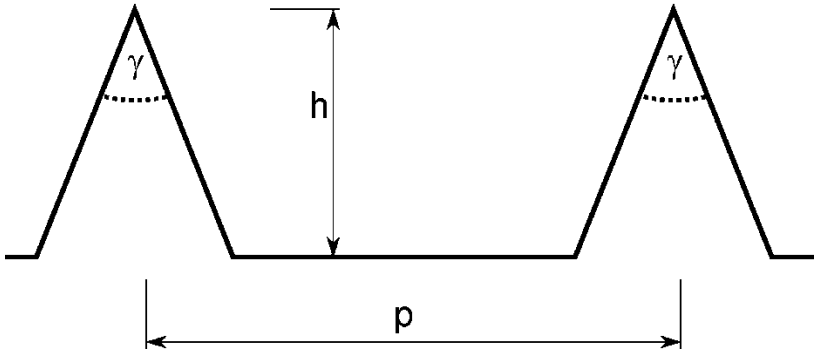
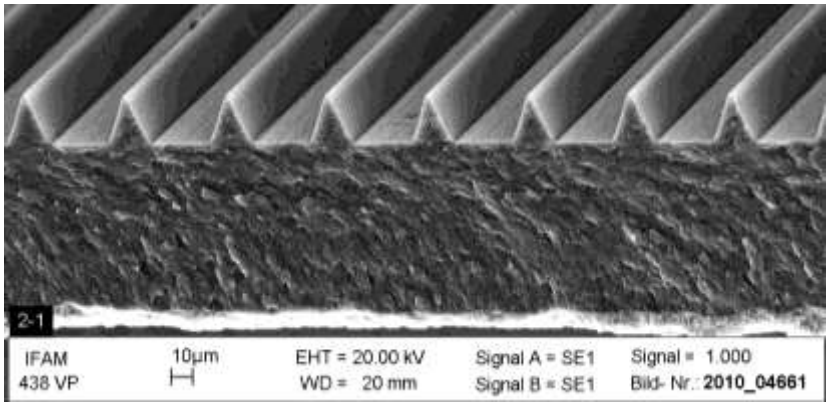
Why to use riblet-structured surfaces

- Riblet-structured surfaces can reduce drag
- High potential to reduce fuel consumption



- Geometry used at the moment:
  periodicity p = 96 µm, height h = 48 µm, opening angle γ = 45°





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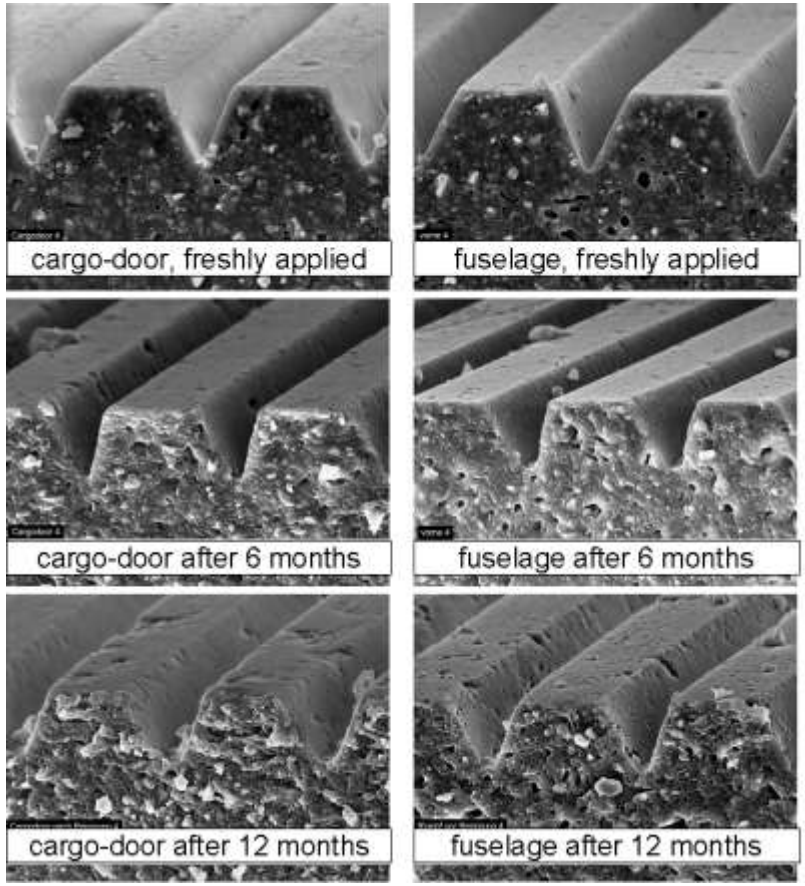
Degradation of riblet-structured surfaces

- Performance strongly depends on the quality of the riblet coating, especially of the riblet tip
- Quality is decreased by:
  - Application problems
  - Erosion from air, sand, water, ice… during flight operation
  - Contamination with insects, …
  - Cleaning procedures
- Degradation is studied by SEM images of negative molds



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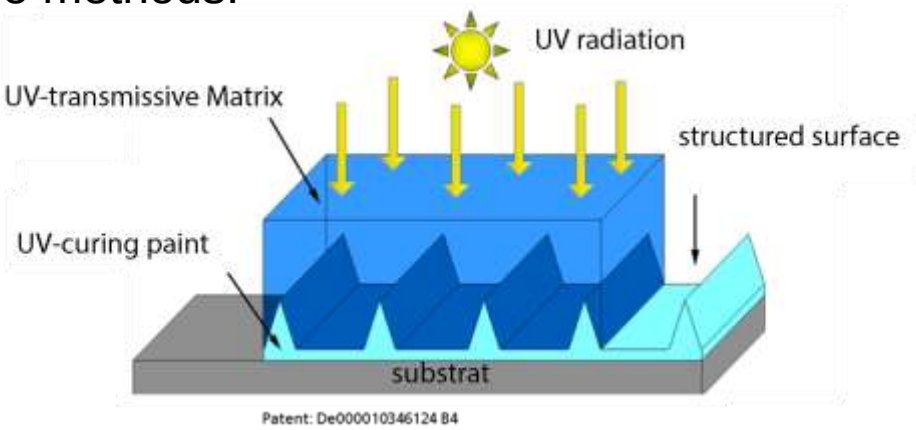
Quality assurance of riblet-structured surfaces

Two main applications for quality assurance methods:

1. Monitoring during application of riblet-structures:
   - Deviation of parallelism, direction, …
   - Missing, damaged structures



2. Monitoring during maintenance (In-Service):
   - Degradation of structures, especially erosion of riblet -tips
   - Local defects

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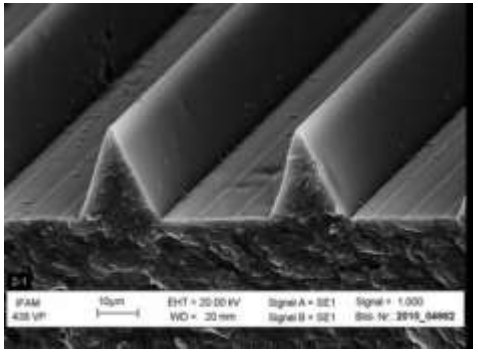
Problems of used techniques

- Geometry can be detected in principle by:
  - Laser scanning confocal microscopy
  - (White light) interferometry
  - Scanning electron microscopy



- General and specific problems:
  - Techniques are mostly time-consuming, sensitive to vibrations, destructive,…
  - Steepness of flanks, transparency of surface

➢ Techniques are not suited for in-service use and monitoring of quality during lacquer application

➢ Fast, robust technique is needed

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Overview

- Basic principles of light scattering on riblet-surfaces

  Reflection or diffraction phenomena?

- Detection of different kinds of riblet degradation

  Wearing and structural deviation

- Development of sensor device

  Handheld sensor concept

- Computer simulations

  Ray-tracing and wave calculations

- Summary

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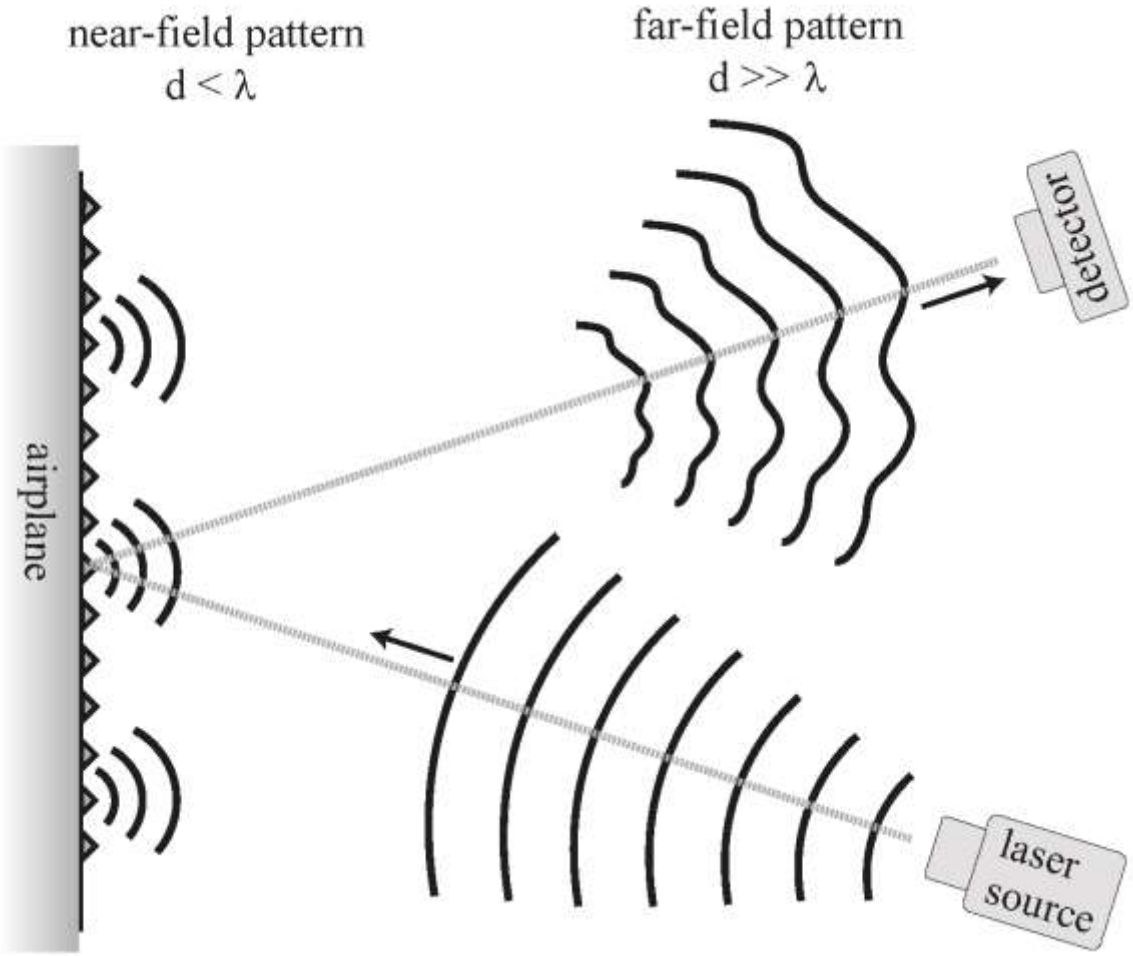
Basic principle of measurement



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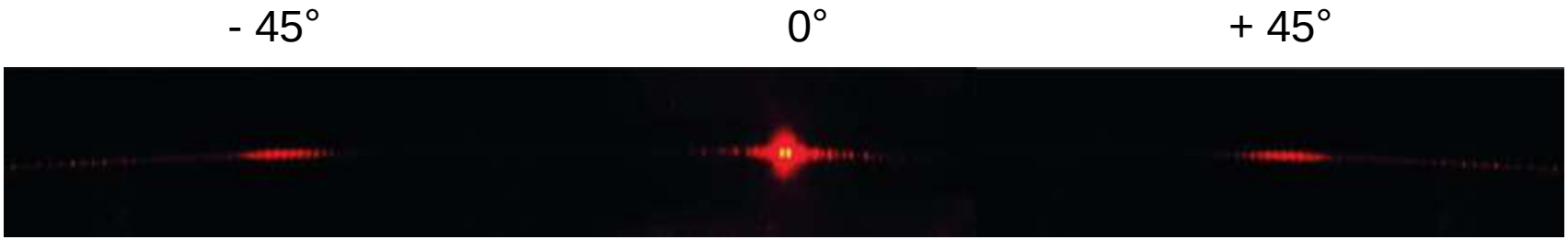
Scattered light distribution

- Intensity pattern from an intact riblet structure
- 0°-pattern much brighter than ± 45°-pattern
- Symmetrical distribution



- Two levels of information:
  - Overall intensity can be used to determine degree of degradation
  - Fine structure from interference contains geometrical information

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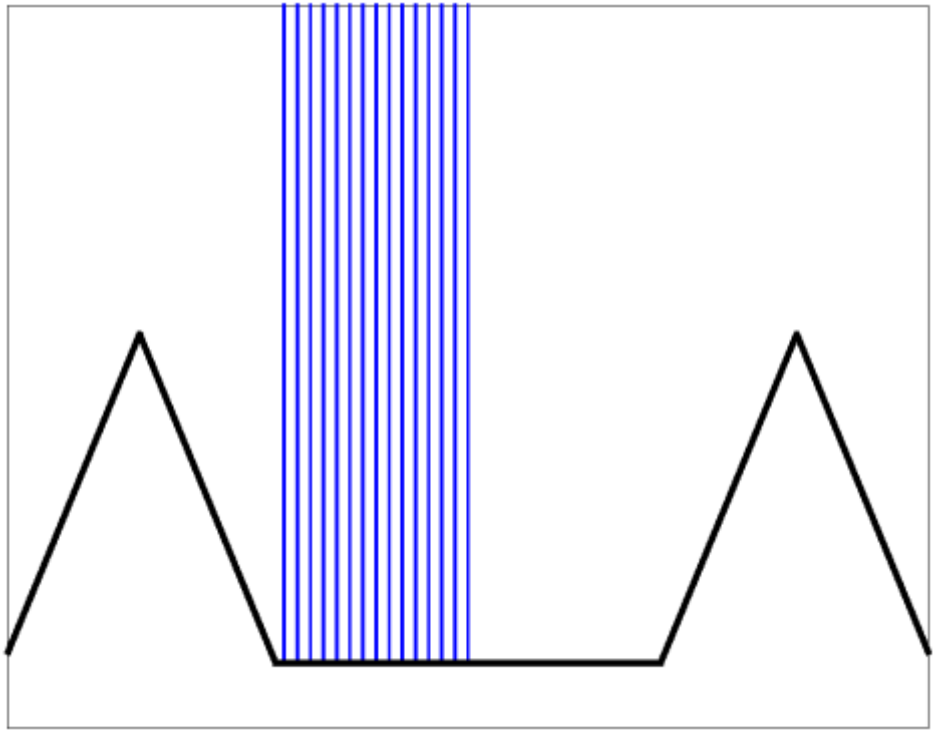
Origin of scattered light distribution

Ray tracing, geometrically tracing of beam paths,

illumination perpendicular to surface



- 0°-pattern caused by single reflection on plane between riblets

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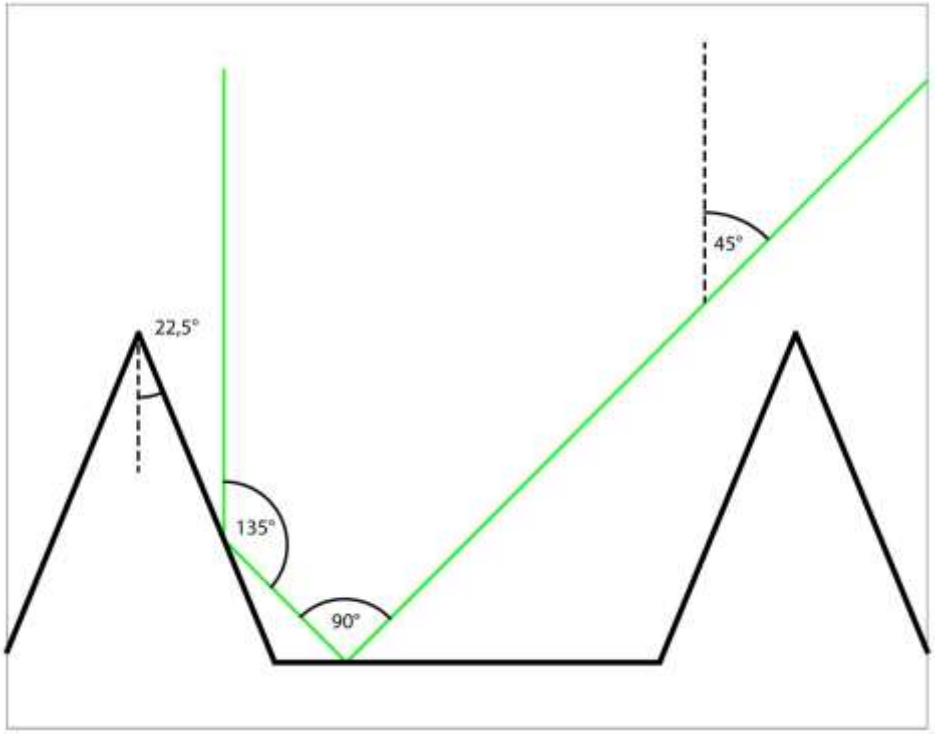
Origin of scattered light distribution

Ray tracing, geometrically tracing of beam paths,

illumination perpendicular to surface



- 0°-pattern caused by single reflection on plane between riblets
- Double reflection on flank and plane leads to additional pattern at ± 45°

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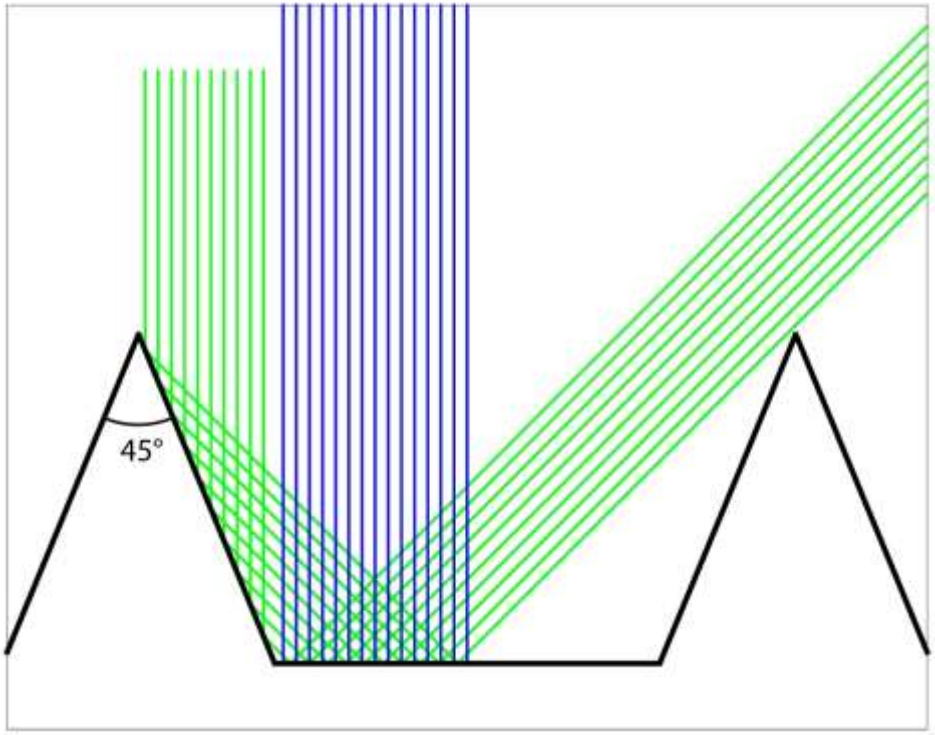
Origin of scattered light distribution

Ray tracing, geometrically tracing of beam paths,

illumination perpendicular to surface



- 0°-pattern caused by single reflection on plane between riblets
- Double reflection on flank and plane leads to additional pattern at ± 45°
- No shadowing effects due to riblet geometry
- Signal of flanks (± 45°) is lower as signal of plains (0°)

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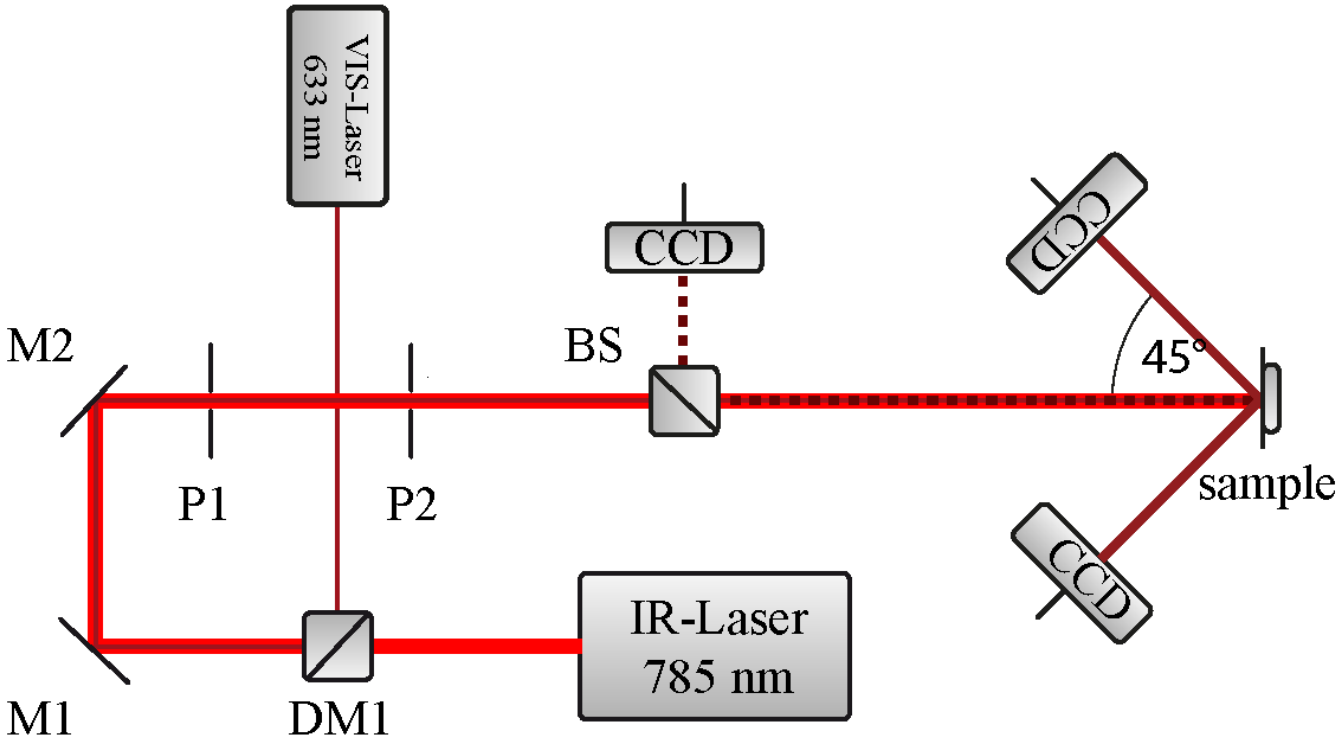
Riblet sensor: experimental setup



- Use of two laser systems; alignment and measurement
- Detection of all 3 characteristic patterns at 0° and ±45°
- Acquisition of pattern with ccd-lines or movable photodiodes

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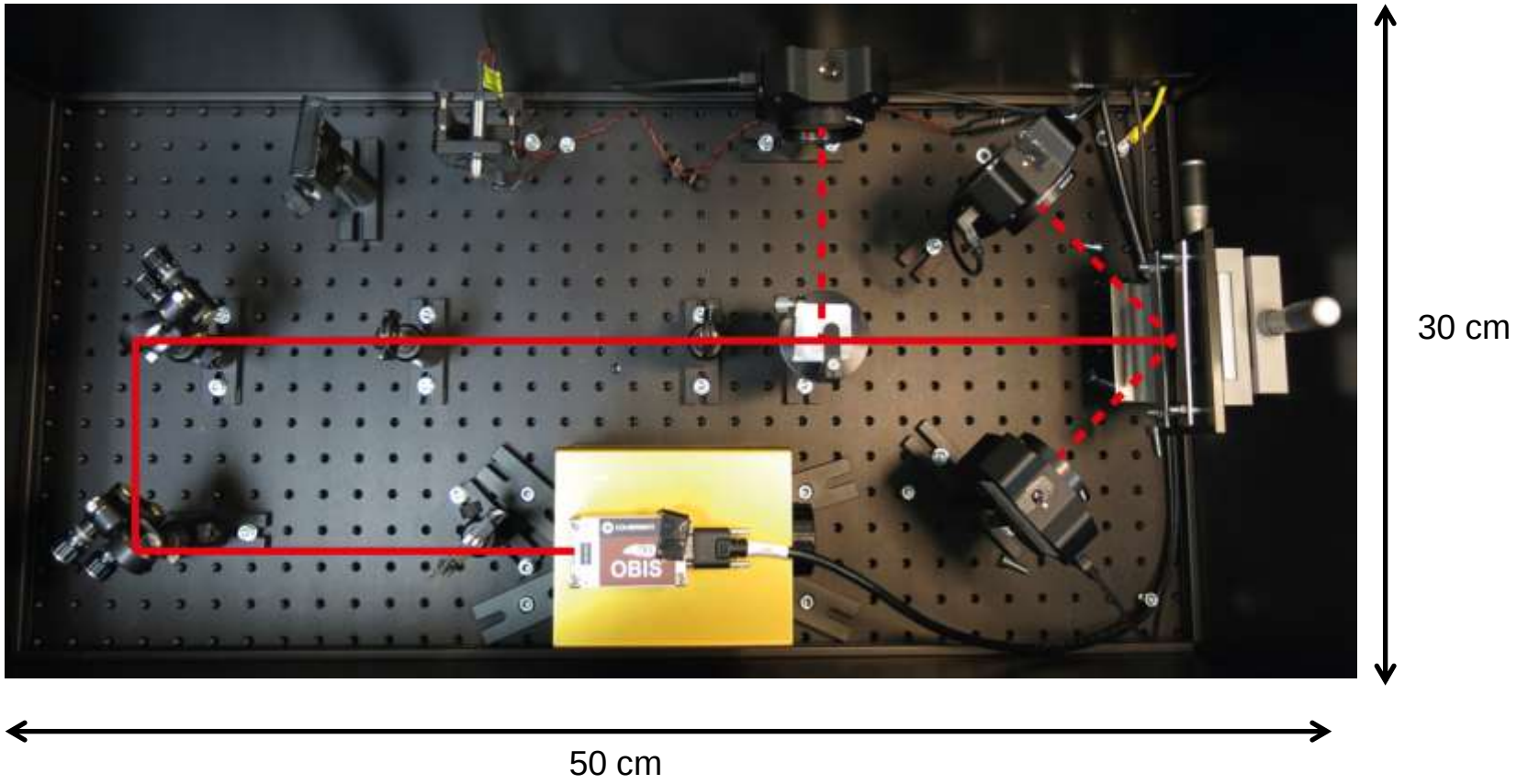
Riblet sensor: experimental setup



- Experimental setup in the lab at IFAM

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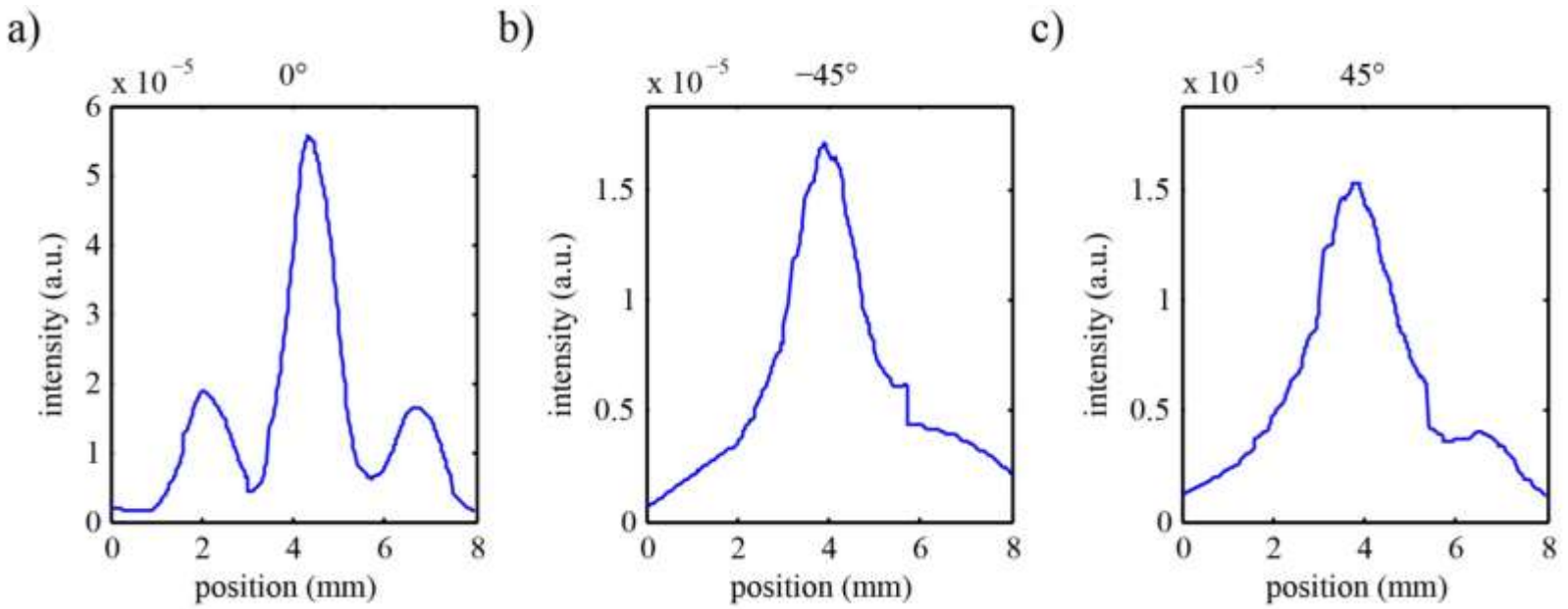
Results of non-degraded riblet



- Simultaneous acquisition of all three patterns
- Characteristic distribution is found
- Symmetric patterns at ±45°

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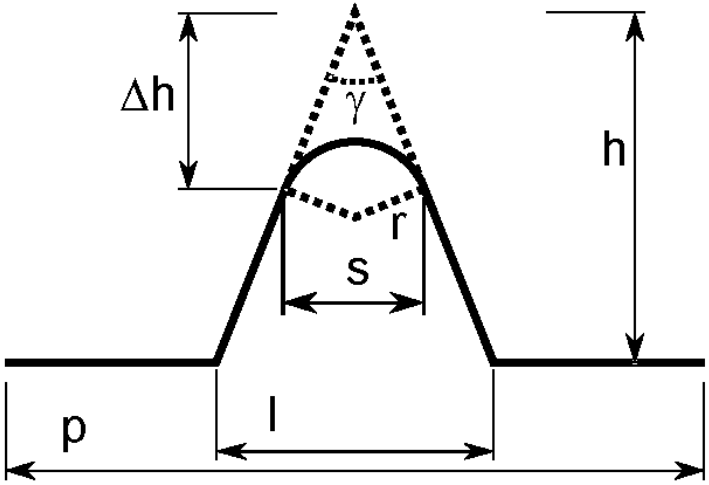
Definition of degraded riblets

- Degradation of riblets by removal and rounding of tip
- No change of reflectivity, angles, …



Parameters of riblets:
- Periodicity p = 96 µm
- Riblet-high h = 48 µm
- Opening angle γ = 45°

Degree of degradation:

$$d = \frac{s}{l} = 2\frac{r\cos(22{,}5°)}{l} = \Delta h/h, \quad 0 \leq d \leq 1$$

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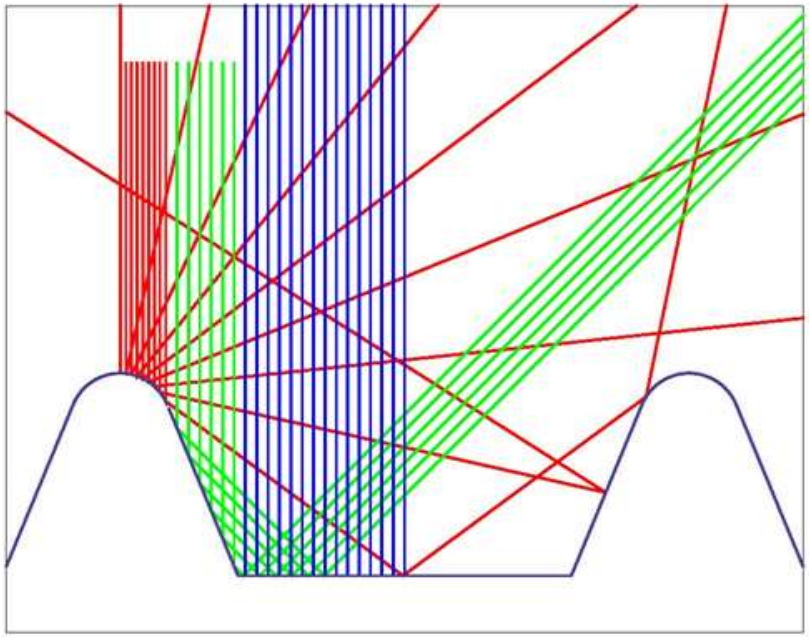
Degradation of riblets



- Scattering on rounded tips of riblets in broad angular range (red)
- Light is scattered diffuse in all directions
- Decrease of intensity reflected by the flanks (green)
- Degree of degradation is calculated from intensity measurements

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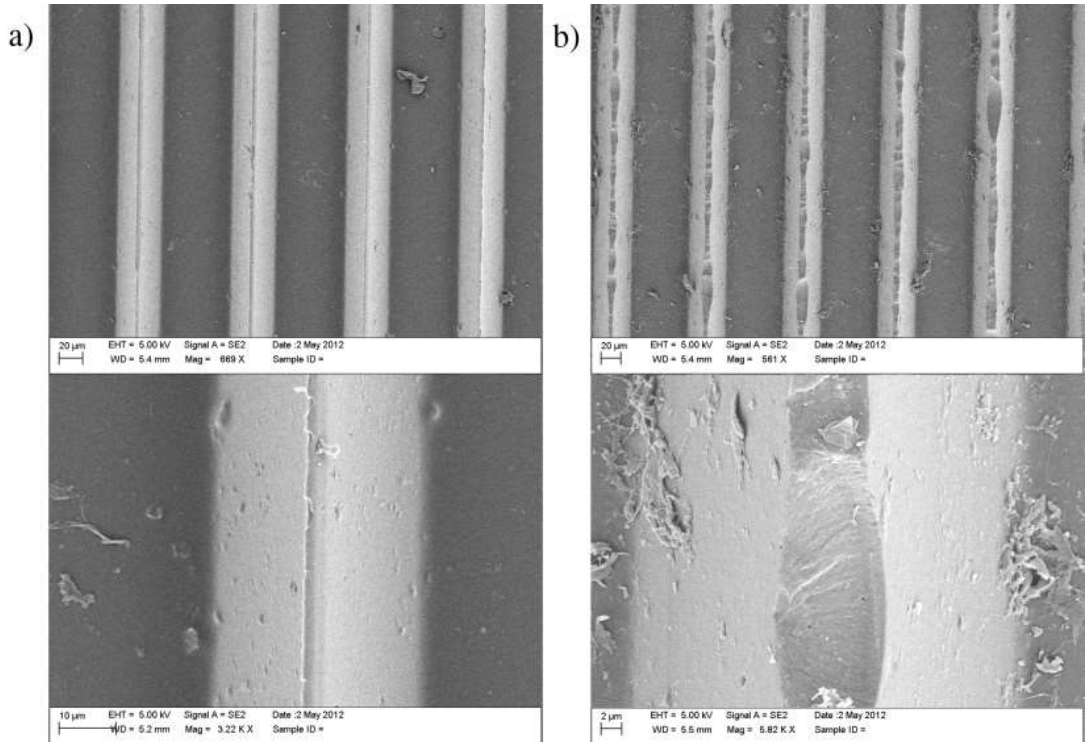
Degradation of riblets



- Artificial degradation by removal of riblet-tip
- Flanks and plains are preserved
- No change of reflectivity

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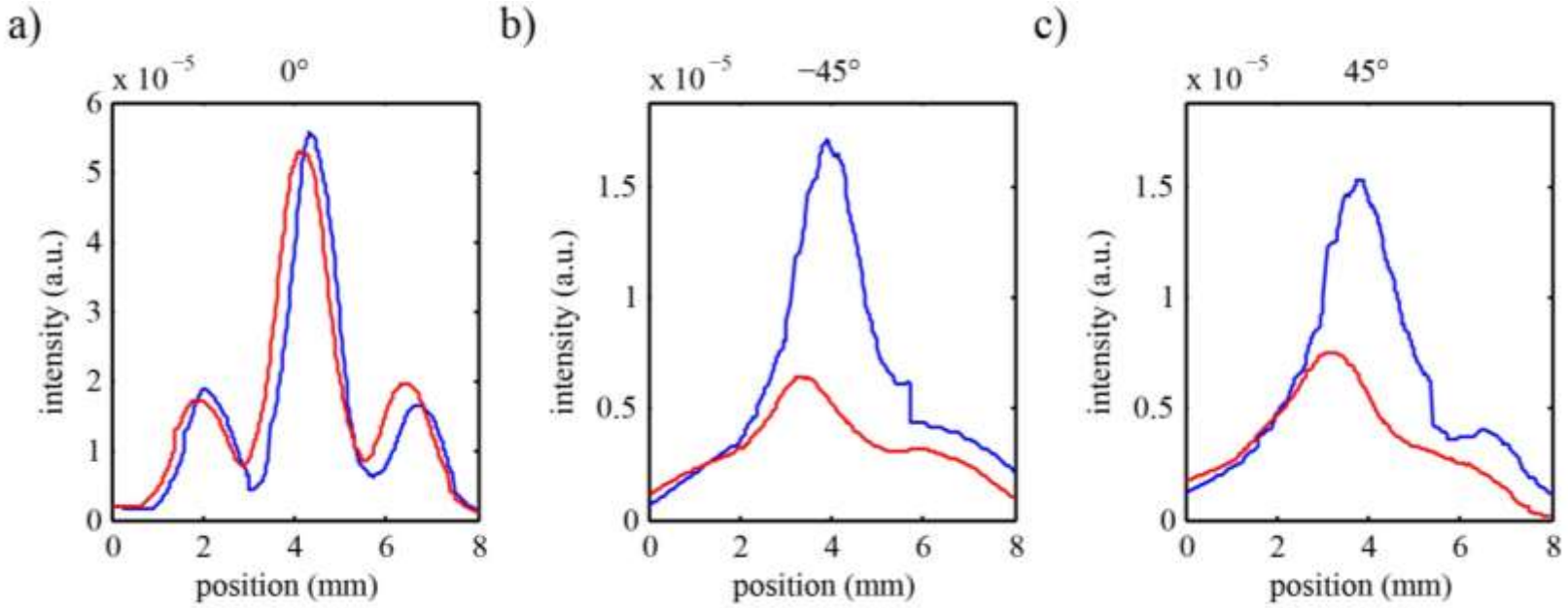
Influence on scattered light distribution

Degradation by mechanical removal of riblet-tip



- No change of 0°-pattern
- Significant changes of both ±45°-pattern
- Linear correlation between degradation and reflected intensity

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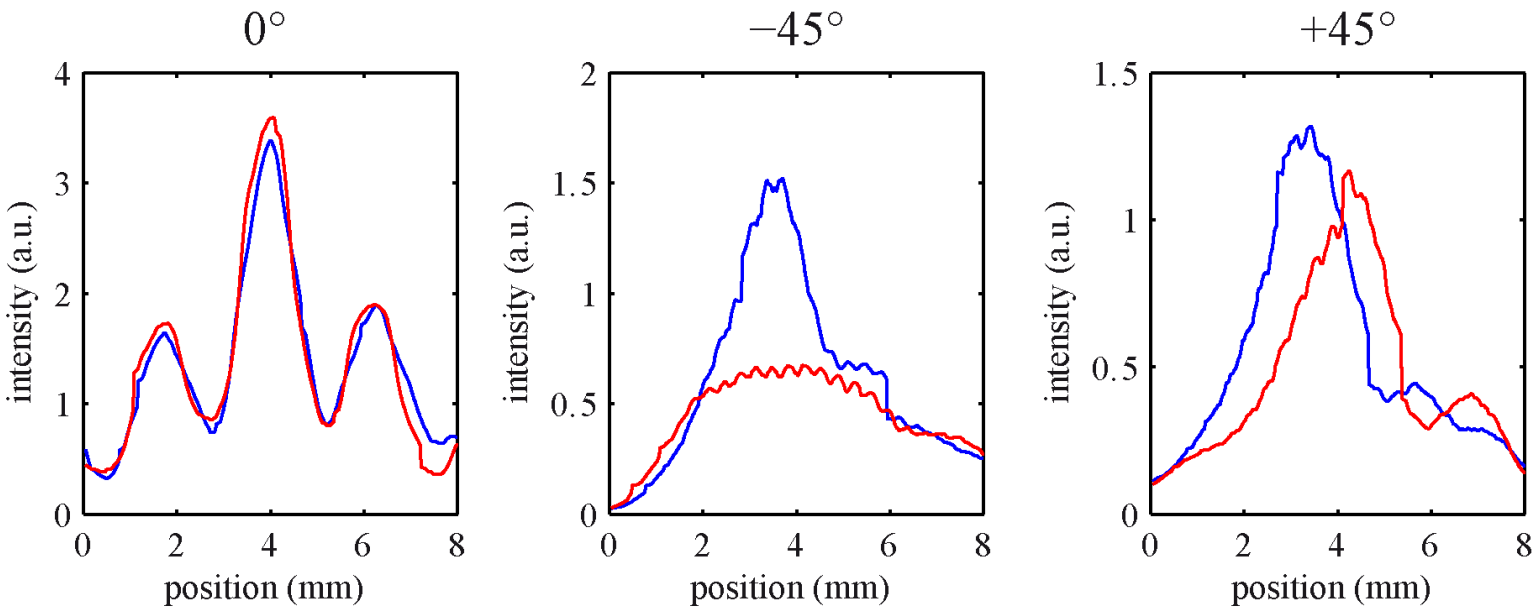
Different kinds of degradation

Asymmetric damage by mechanical pressure on the surface



- 0°-pattern unchanged ⇒ no change of reflectivity
- Asymmetry of ±45°-pattern ⇒ asymmetric degradation

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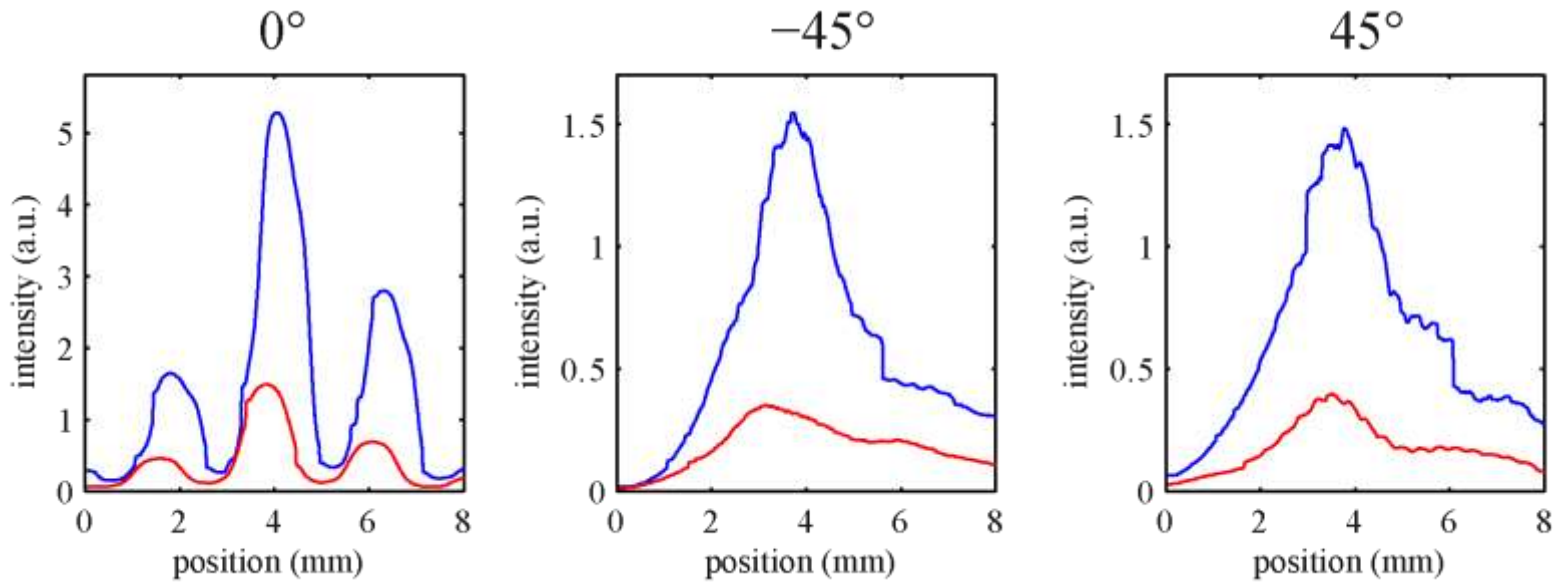
Different kinds of degradation

Chemical change of surface reflectivity



- 0°-pattern and ± 45°-pattern changed
- Change of reflectivity
- Intensity loss shows that riblet-structure remains intact

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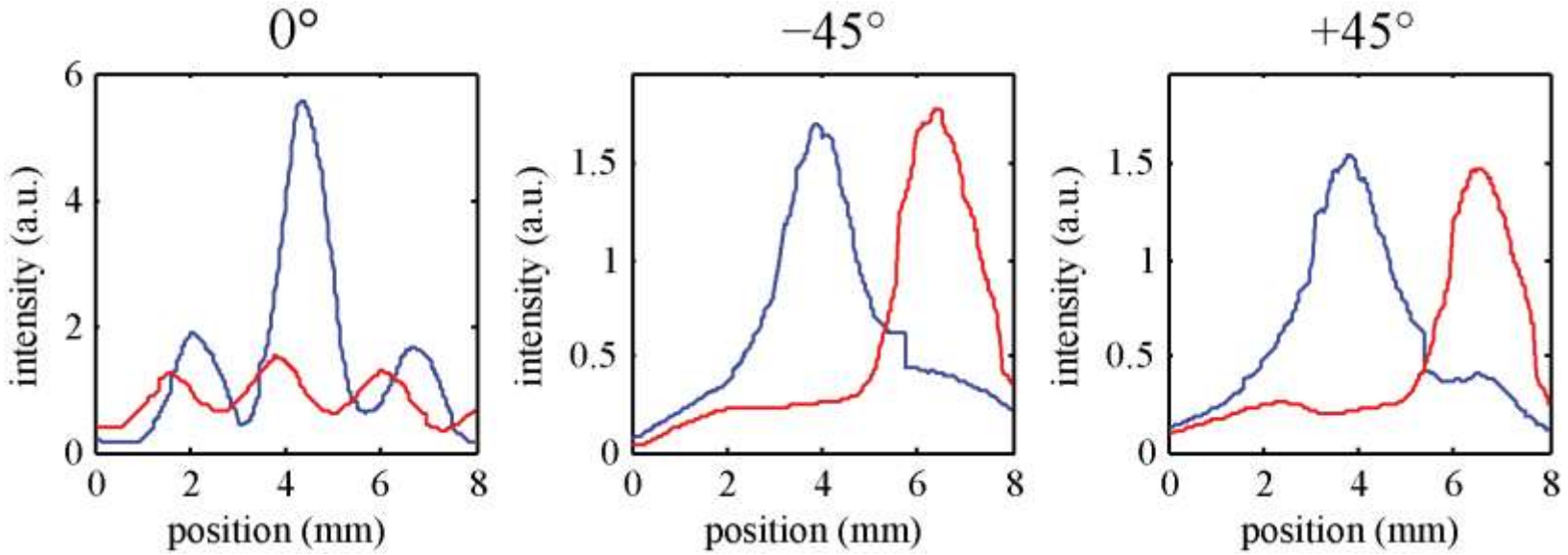
Different kinds of degradation

UV-induced shrinkage



- 0°-pattern shows changed reflectivity
- ± 45°-pattern show a symmetric change in position
- Angles are increased

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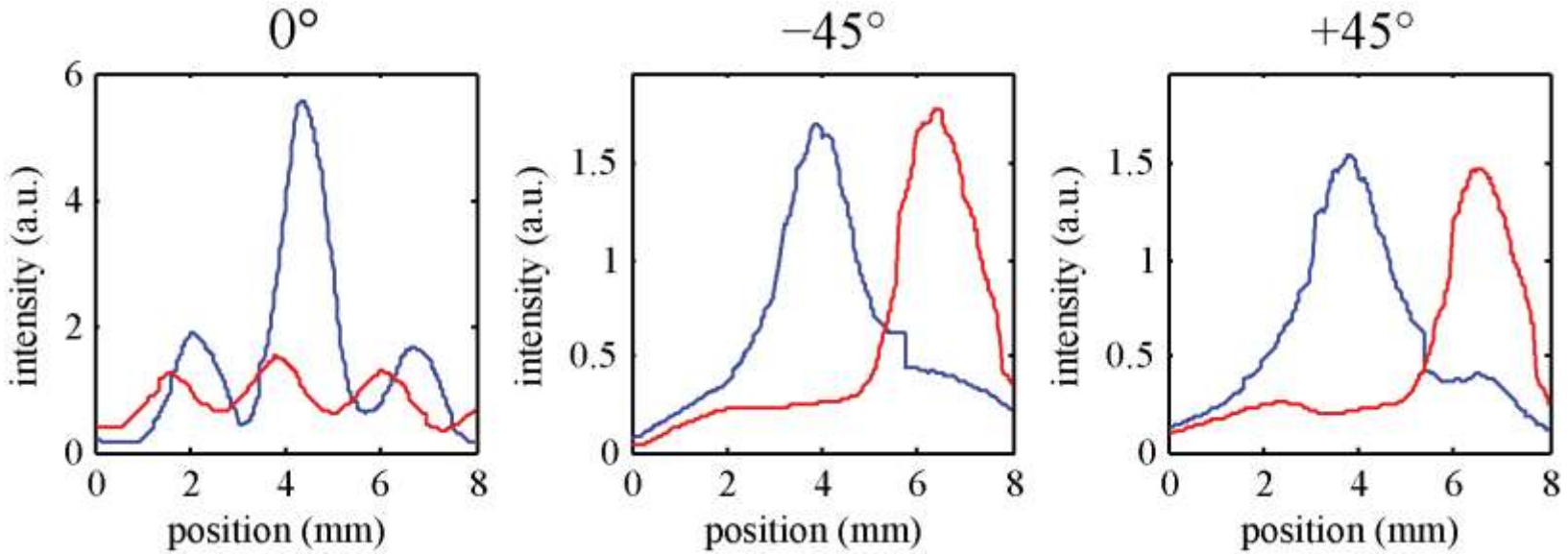
Different kinds of degradation

UV-induced shrinkage



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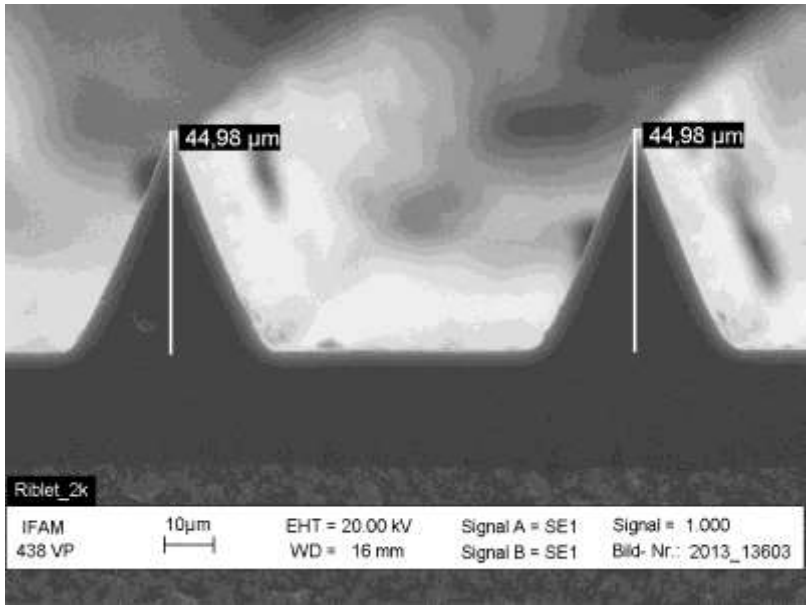
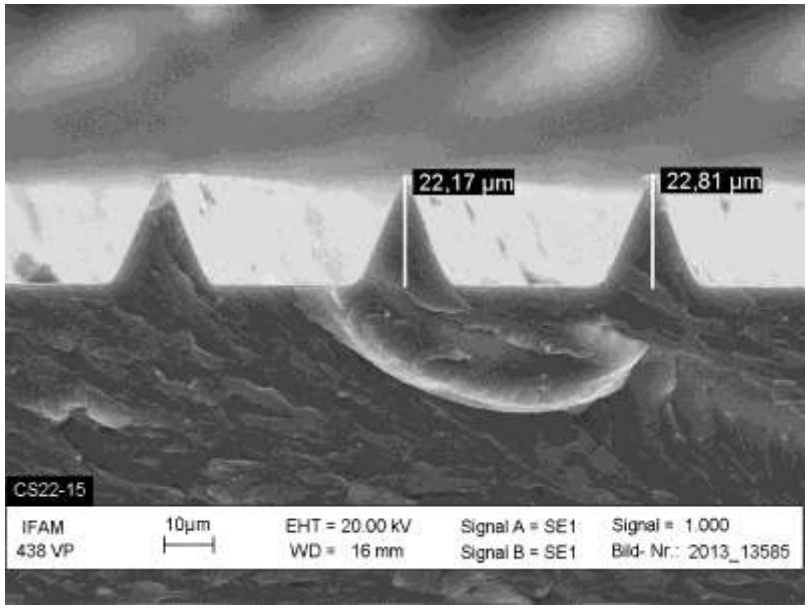
Influence of riblet geometry





- SEM results of 48 µm and 25 µm riblets
- Angle and ratio of distances and height are the same

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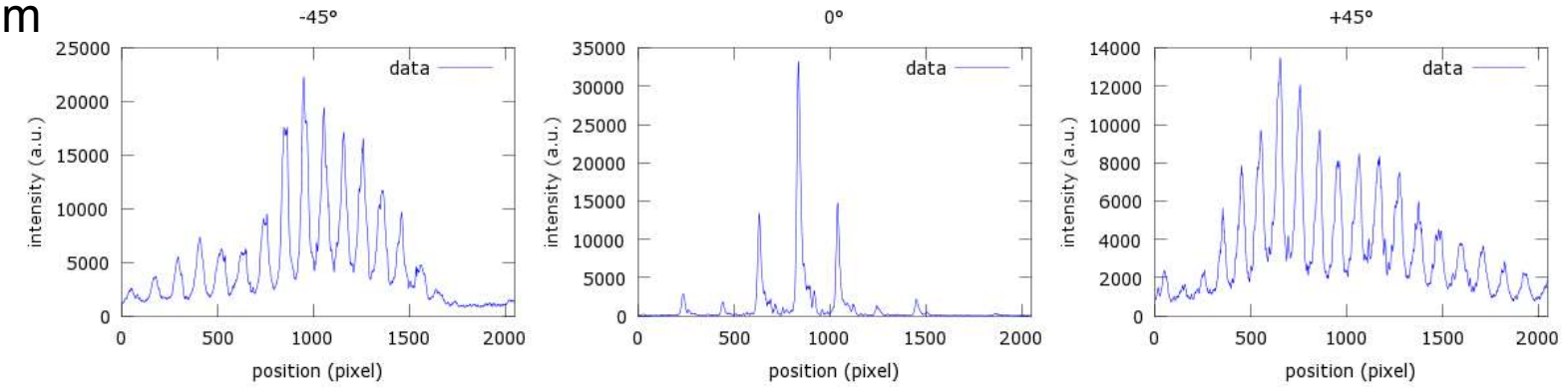
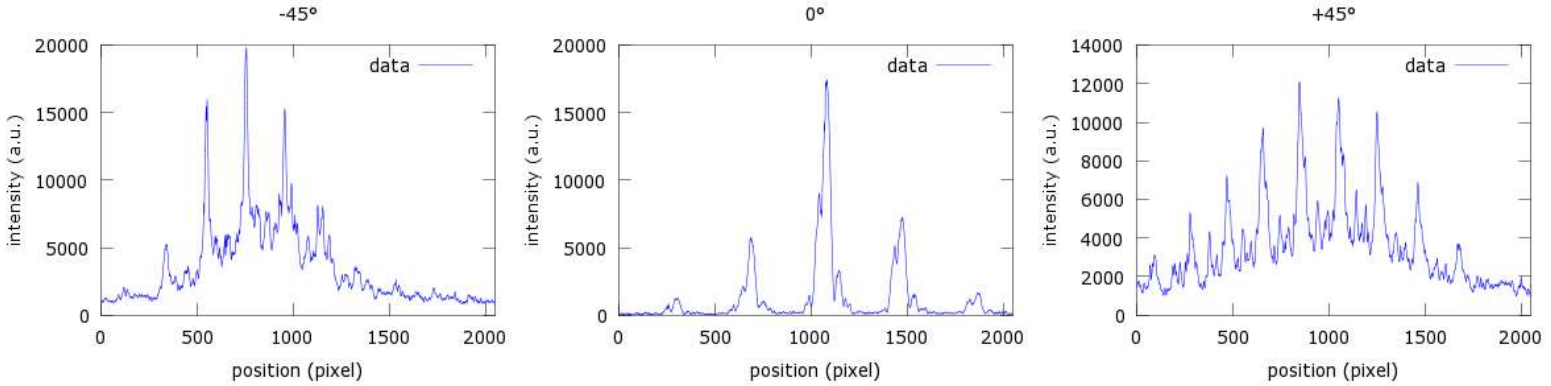
Detection of riblet geometry

48 µm



25 µm



- Comparable integral intensity
- Fine structure is different, diffraction phenomena

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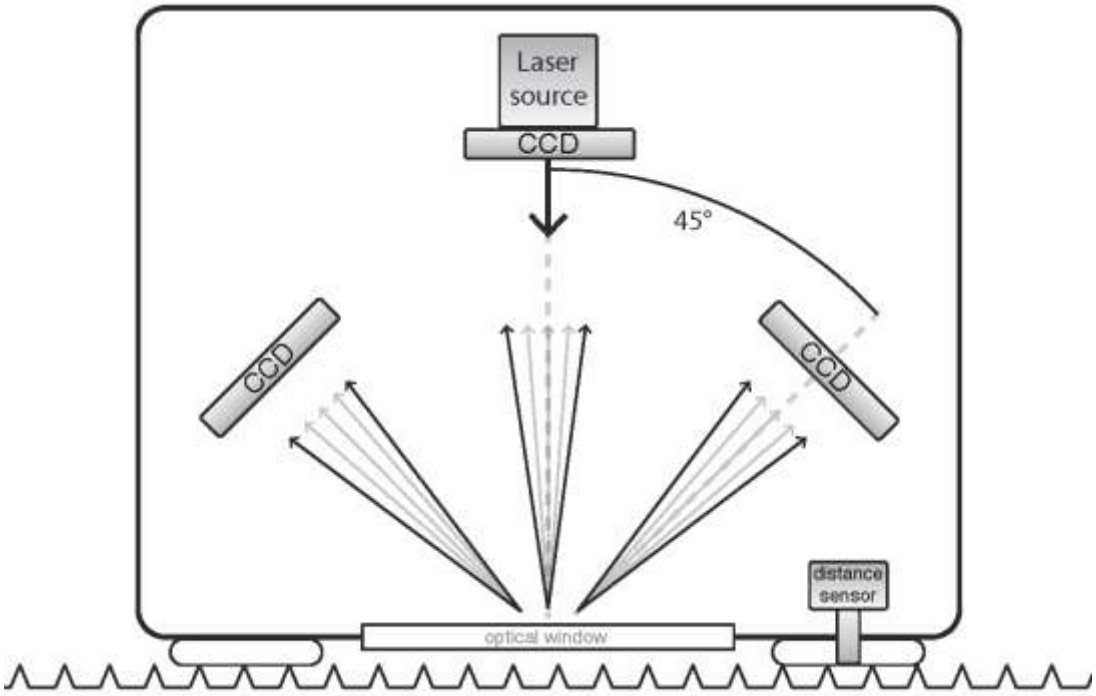
Sensor development

Preliminary device configuration:



- Detection and evaluation of all 3 characteristic patterns
- Mechanical stability, no use of movable components
- Sensor system and method are patented

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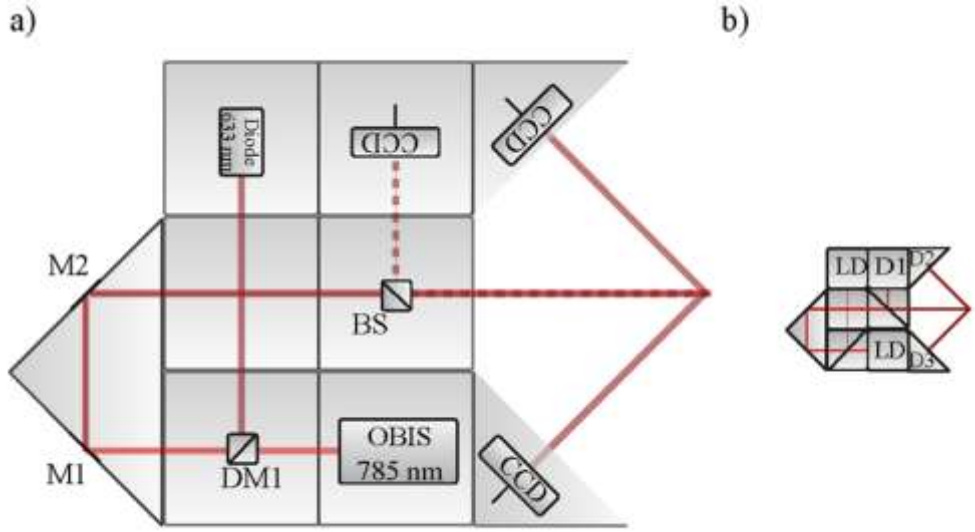
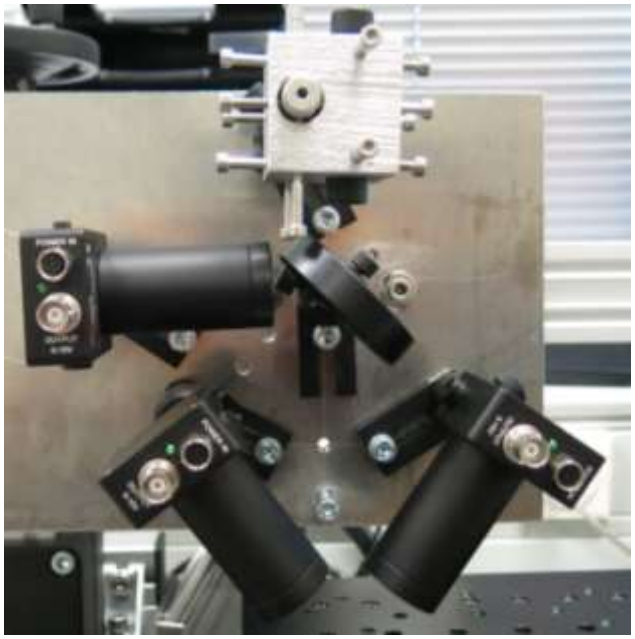
Sensor development

- Several designs for possible handheld devices available
  - Directly bonded optical components





- Cooperation with Optosurf in framework of LuFo-V
  - Expertise in stray light measurement
  - Optical roughness determination

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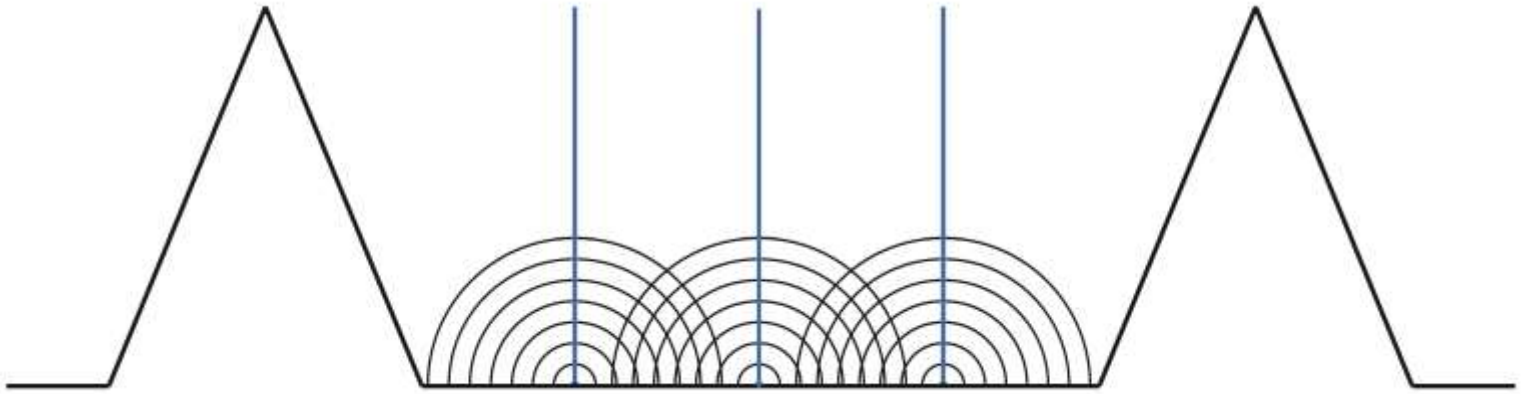
Computer simulations

- Based on Huygens' Principle
- Each point is origin of spherical wave
- Numerical calculations by superposition of many waves
- Only plains between riblets are considered



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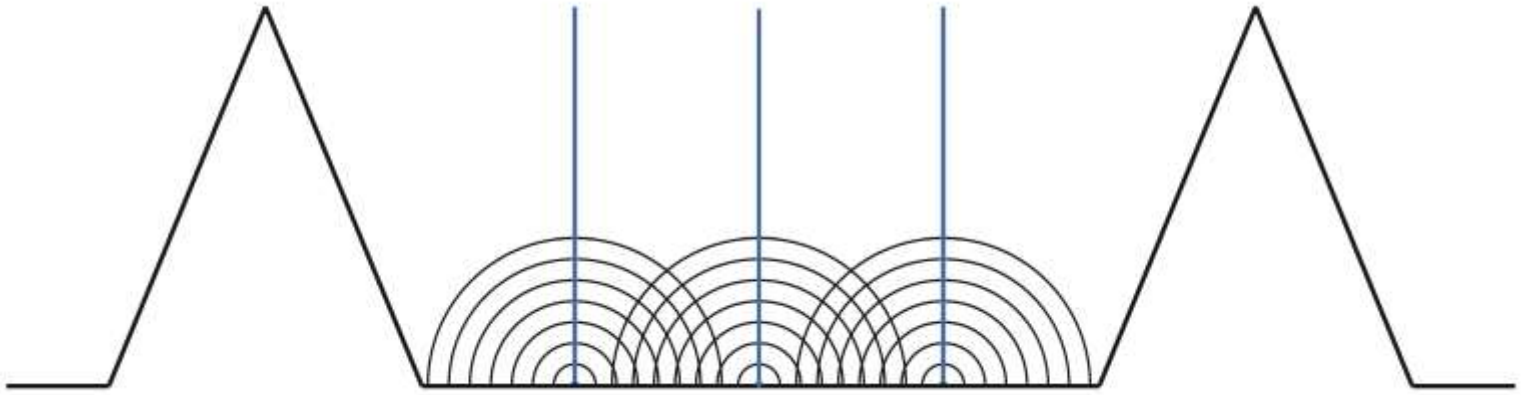
Computer simulations

0°-pattern:

- In-phase generation of all spherical waves on the plain
- Simulation of experimental losses by changed reflectivity

➢ Direct reflection back in 0° direction



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Computer simulations

45°-patterns:

- Reflection from flanks is modeled by phase shift
- Only plains are considered
- Influence of degradation by reduction of number of waves

➢ Aligned reflection in 45° direction

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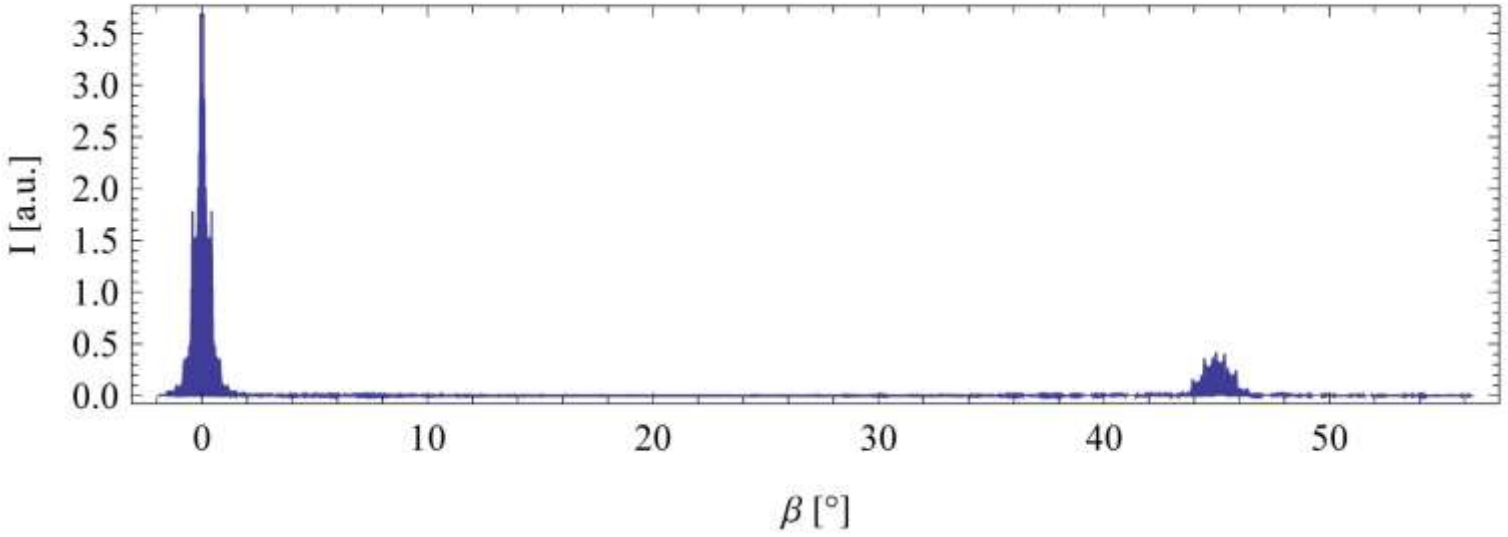
Computer simulations: results

- Verification of ray tracing results:
  - 0°-pattern caused by reflection of planes
  - ±45°-patterns result from waves reflected of flanks
  - Diffuse scattering of degraded riblet tip can be neglected



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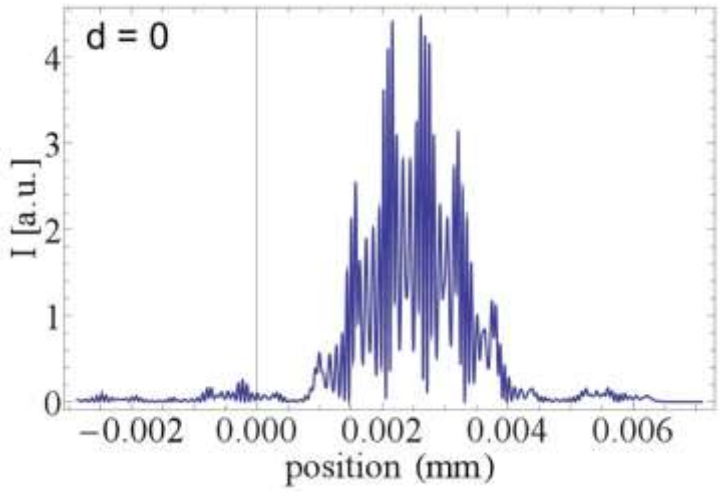
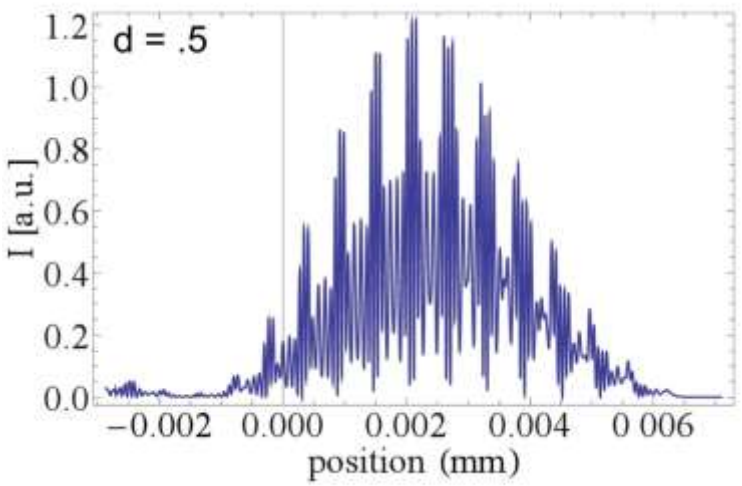
Influence of degradation

- Results comparable to experiment:
  - No change of 0°-pattern
  - Significant change of ±45°-patterns
  - Loss of integral intensity
  - Increase of FWHM (full width half maximum)

±45°



±45°



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Summary

- Experimental results
  - Riblets show distinct intensity patterns

  - Different types of riblet degradation can be classified and quantified
  - Technique is highly sensitive for small deviations

- Sensor development
  - Minimal need for optical components
  - System capable for use in rough environment

- Computer simulations
  - Calculate intensity patterns of different types of degradation
  - Possible use is the reconstruction of riblet geometry

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Thank you for your attention !

Kai Brune

Stefan Dieckhoff

Christian Tornow

Johannes Derksen

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Study of Passive and Active Deformation Behaviors of Hybrid Specimens Made of Composite Substrates and MFC Piezoelectric Patches

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4th International Workshop on Flight Physics & Aircraft Design
Aachen, Germany, 27 – 29 October, 2014

Outline

- Introduction
  - About the FutureWings project and its objectives
  - Some notes on hybrid specimens
- Numerical studies of bending and torsion of hybrid specimens
  - Finite element analyses of piezoelectricity
- Experimantal tests on hybrid specimens
  - Test equipment
  - Bending tests
  - Torsion tests
- Comparison between Numerical and Experimental Results

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Wings of the Future

"Think of an airplane as a great body with its end structures (wings, horizontal tail surfaces, vertical tail surfaces) that could have the possibility to change their shape as they had internal nerve endings and muscles ..."

"FutureWings" is an International Project co-financed by the European Union under the 7th Framework Program (1st June 2013 – 31th May 2015)

Wings of the Future

The FutureWings project focuses on the development of a wing structure having the capability of changing its aerodynamic shape (“self-shaping wing”) through the use of a new type of hybrid materials, made up of piezoelectric fibers drowned into composite materials.

For such a morphing wing, traditional control surfaces (such as ailerons, flaps, slats and so on) are no longer required; that allows us to save weight in wing structures and reduce the sources of vibrations.

The deformed shape of a wing required by a given flight maneuver will be obtained as a result of medium/high voltages applied to the active piezo-electric layers.

Low electric power level and very small current intensity values should be require to deform the FutureWings structure.

Wings of the Future

The final goal of the FutureWings project is to manufacture a small scale model of the Future Wing.

This requires a proper design of the hybrid active composite laminate (composite layup, ply stacking sequence, piezo electric fibers orientation and so on), supported by testing activities and finite element non-linear analyses.

Mechanical tests on the Future Wing model will be carried out to verify the technical feasibilty of the FutureWings concept.

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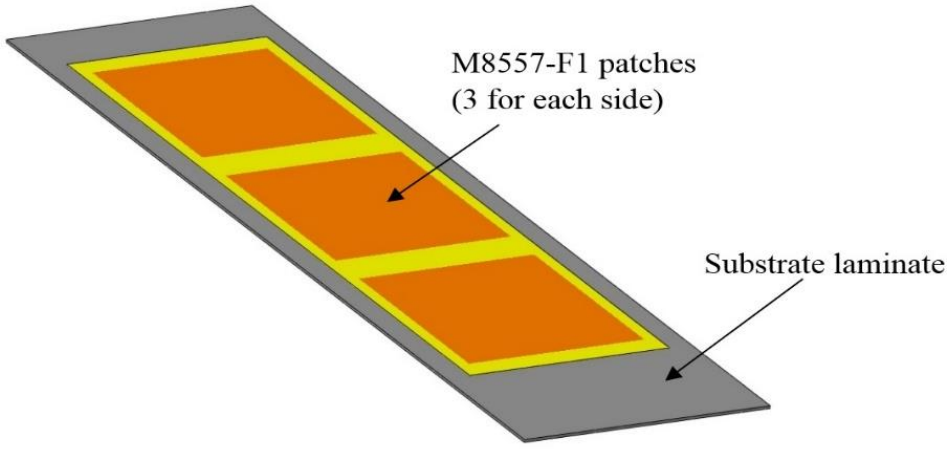
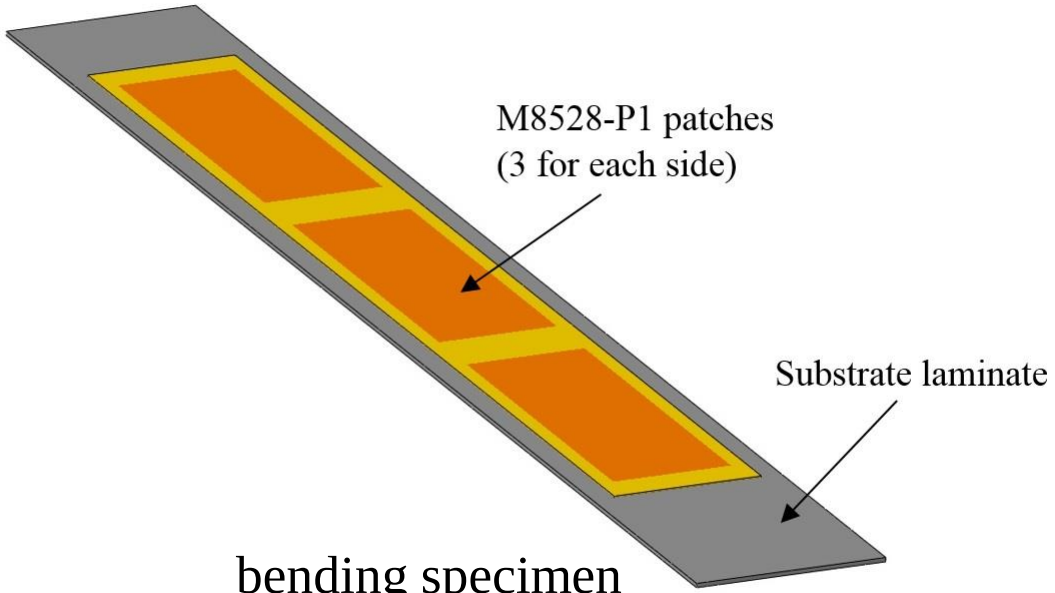
Hybrid Specimens

Until now, much effort into the project has been made at studying deformation behaviors of realistic hybrid specimens made of composite materials and Macro Fiber Composite (MFC) piezoelectric patches.

Two kinds of hybrid specimens have been considered



torsion specimen



bending specimen

Hybrid Specimens: Laminated substrate

For each kind of hybrid specimens, two types of laminated substrate have been considered:

- 4-ply Graphite/Epoxy laminate made of KGBX2508 0°/90° fabrics
- 4-ply Glass/Epoxy laminate made of GGBX2808 0°/90° fabrics

Two ply stacking sequences have been chosen for the testing activities:

Ply Id	Sequence 1	Sequence 2
1	+45/-45	0/90
2	0/90	+45/-45
3	0/90	+45/-45
4	+45/-45	0/90

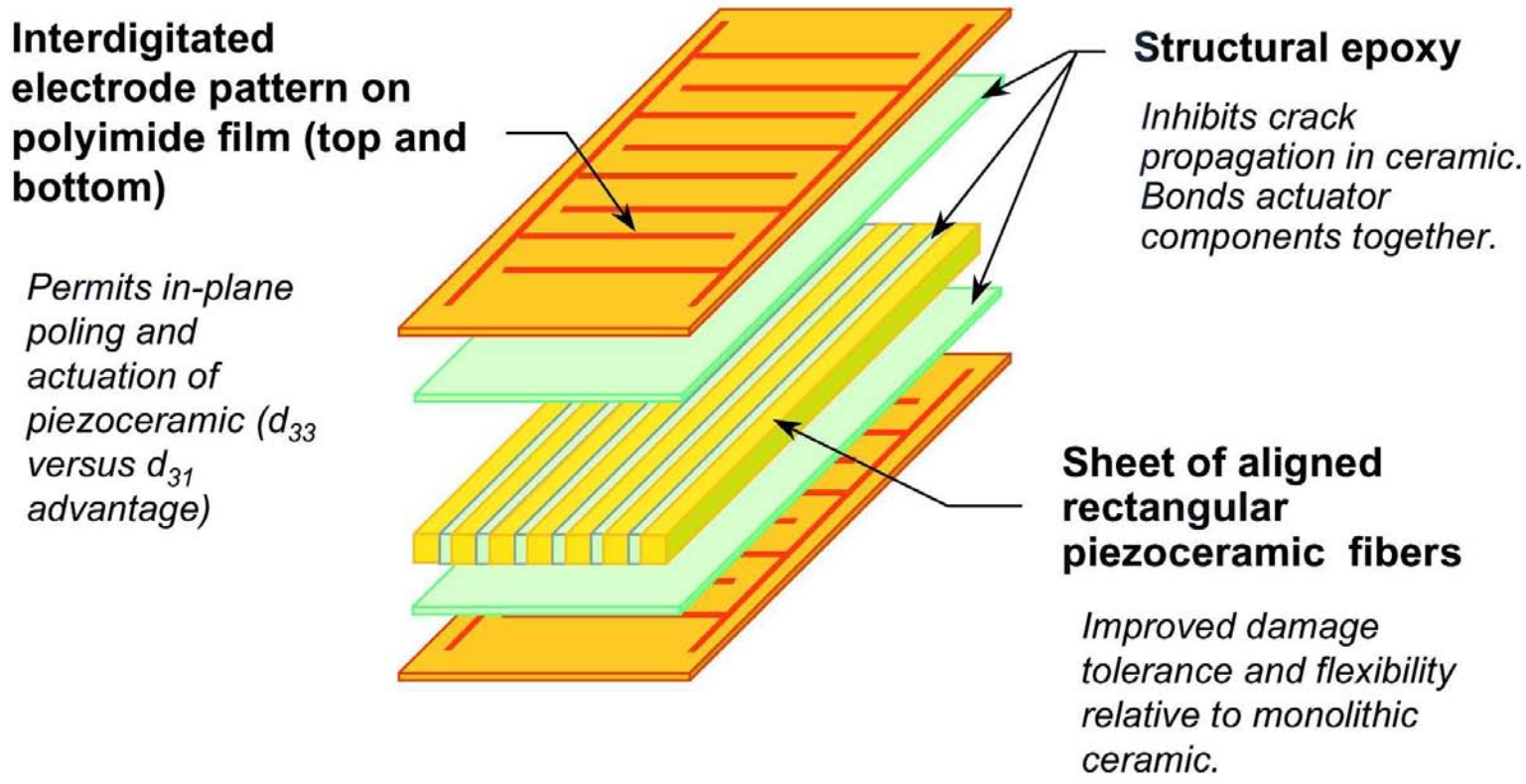
Mechanical properties of KGBX2508 and GGBX2808 fabrics have been obtained by means of specific material characterization tests.

Hybrid Specimens: Macro Fiber Composite (MFC)

What is a Macro Fiber Composite (MFC)?

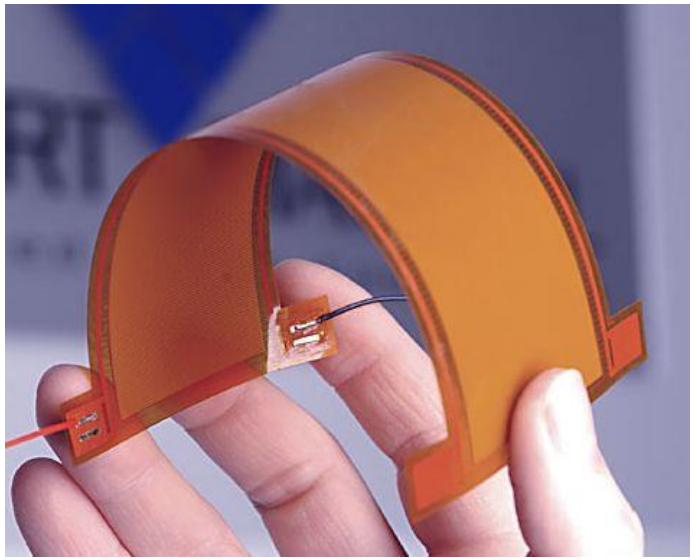
MFC benefits

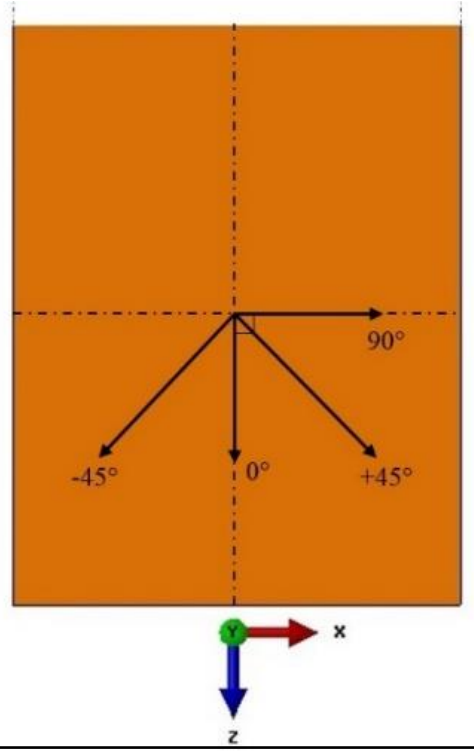
- Flexible and durable
- Increased strain actuator efficiency
- Directional actuation/sensing
- Damage tolerant
- Available as elongator (d33 mode) and contractor (d31 mode)
- Conforms to surfaces
- Readily embeddable
- Environmentally sealed package
- Demonstrated performance
- Different piezo ceramic materials available

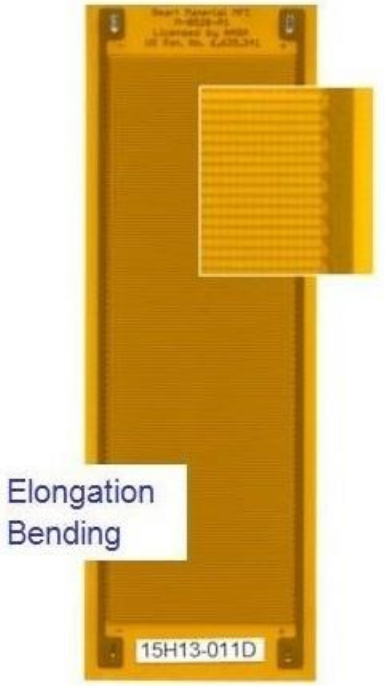


Hybrid Specimens: Macro Fiber Composite

MFC types and piezoelectric fiber orientation

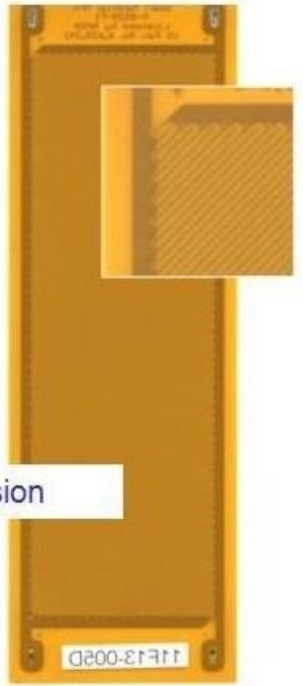






M8528-P1

- high strain (d33)
- -500V … 1500V
- 0° fiber orientation



M8528-F1 / M8557-F1

- high strain (d33)
- -500V … 1500V
- 45° fiber orientation

units in mm

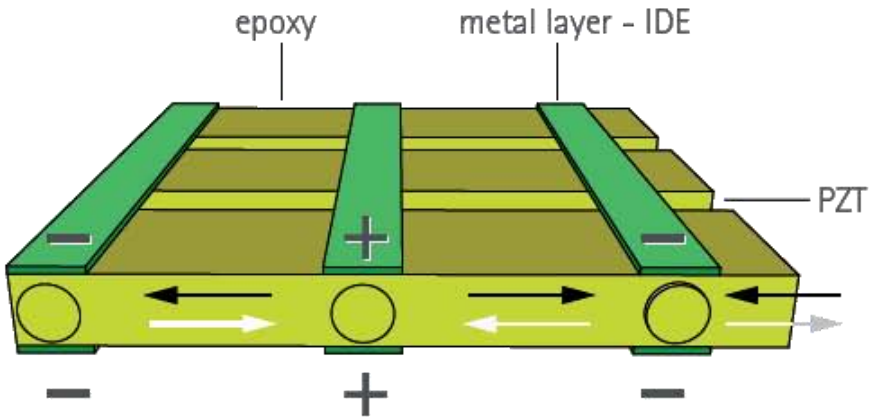
	Length	Width	Active length	Active width	thickness
MFC M8528-P1	103	35	85	28	0.3
MFC M8557-F1	105	65	85	57	

Hybrid Specimens: How a MFC works

Two operational modes:

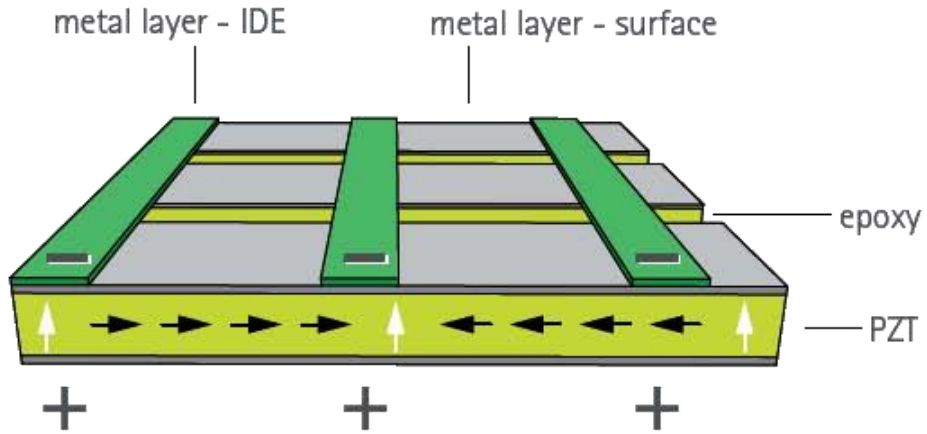
MFC P1 Type (d_{33} effect)

Elongator
- powerful actuator
- sensitive sensor



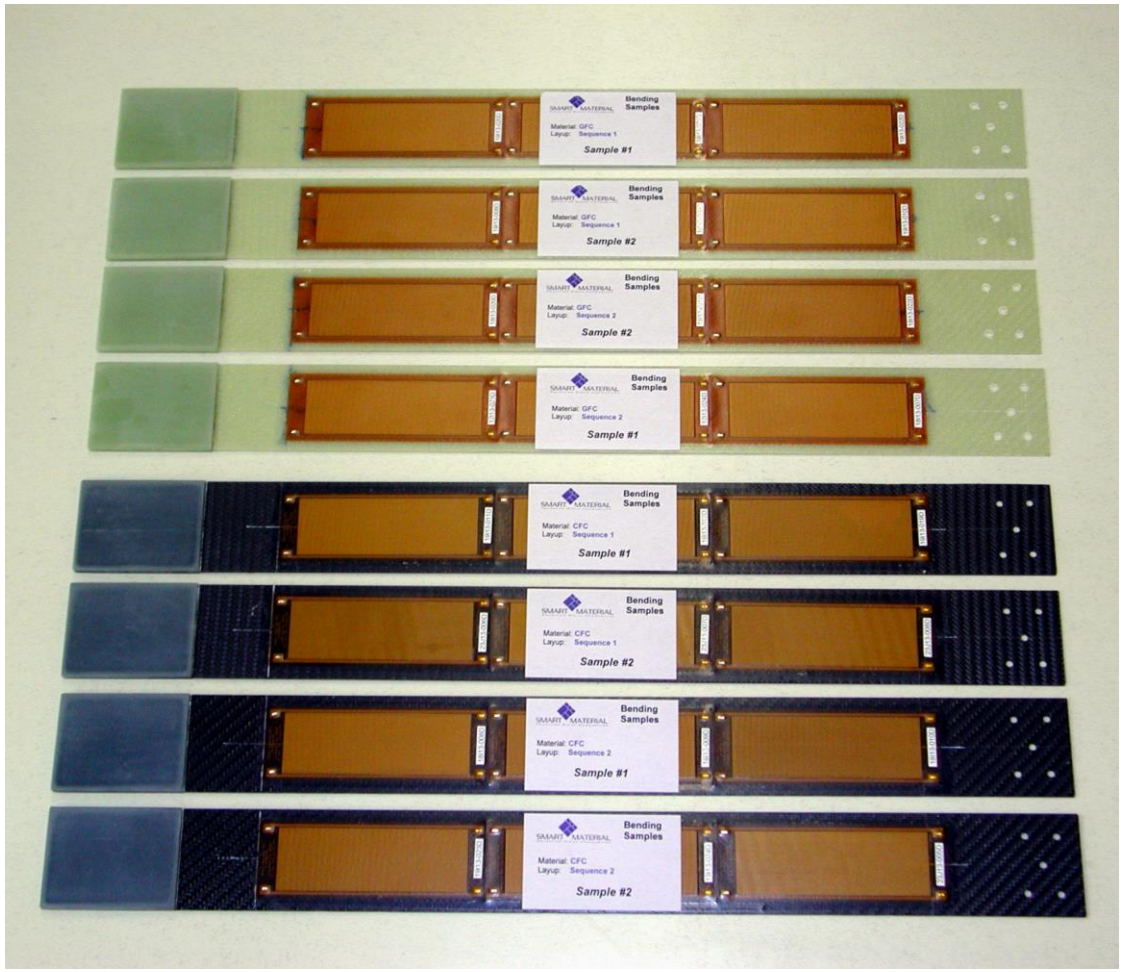
MFC P2 Type (d_{31} effect)

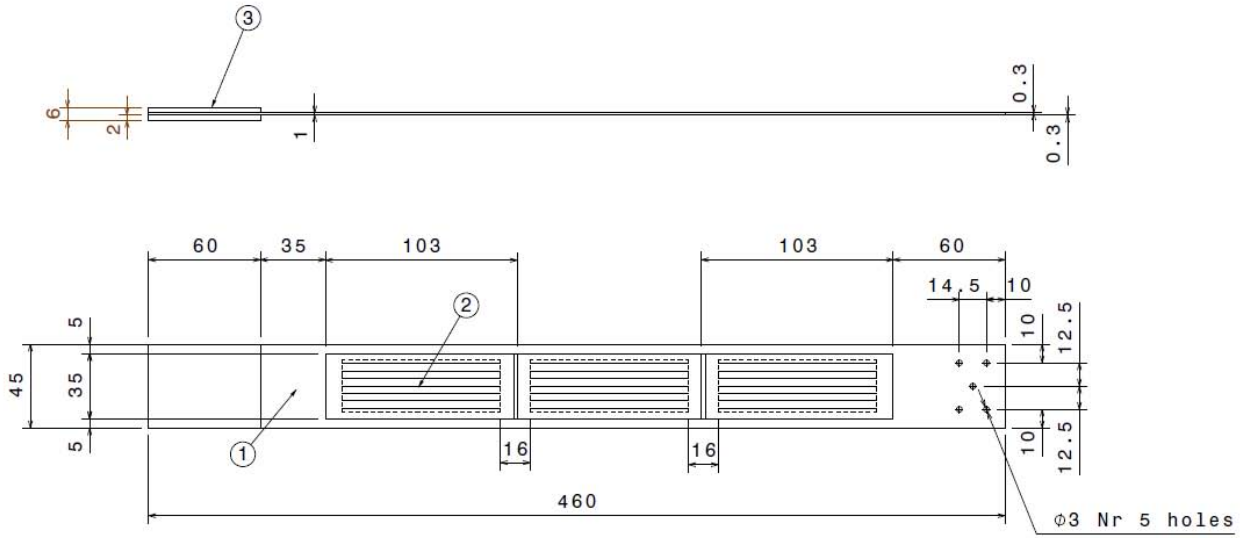
Contractor
- Low Impedance sensor
- energy generator



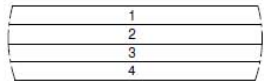
Hybrid Specimens: Manufacturing

Bending specimens





ply stacking sequence



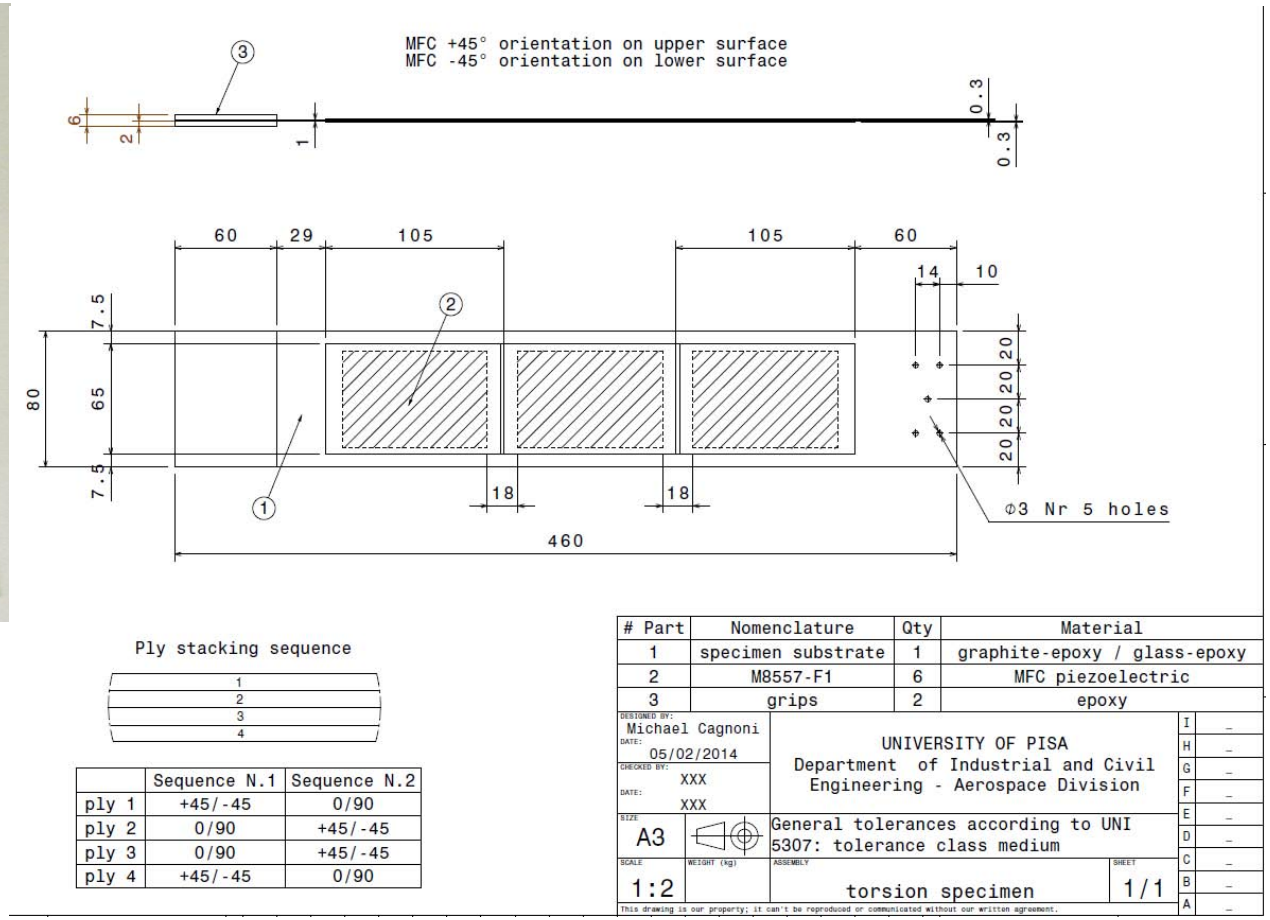
	Sequence N.1	Sequence N.2
ply 1	+45/-45	0/90
ply 2	0/90	+45/-45
ply 3	0/90	+45/-45
ply 4	+45/-45	0/90

# Part	Nomenclature	Qty	Material
1	specimen substrate	1	graphite-epoxy / glass-epoxy
2	M8528-P1	6	MFC piezoelectric
3	grips	2	epoxy

DESIGNED BY: Michael Cagnoni
DATE: 11/02/2014
CHECKED BY: XXX
DATE: XXX
UNIVERSITY OF PISA
Department of Industrial and Civil Engineering - Aerospace Division
SIZE A3
General tolerances according to UNI 5307: tolerance class medium
SCALE 1:2
WEIGHT (kg)
ASSEMBLY bending specimen
SHEET 1/1

Hybrid Specimens: Manufacturing

Torsion specimens



	Sample weigth [g]	
	Graphite/Epoxy laminate	Glass/Epoxy laminate
Bending sample	74	78
Torsion sample	137	147

	Sequence N.1	Sequence N.2
ply 1	+45/-45	0/90
ply 2	0/90	+45/-45
ply 3	0/90	+45/-45
ply 4	+45/-45	0/90

Hybrid Specimens: Mechanical properties

Engineering constants	Graphite/Epoxy substrate	Glass/Epoxy substrate	Bonding resin	Kapton	MFC active area
E_1 [GPa]	67	25.3	4	2.5	30.34
E_2 [GPa]	67	25.3			15.86
E_3 [GPa]	67	25.3			15.86
ν_{12}	0.042	0.119	0.4	0.34	0.31
ν_{13}	0.042	0.119			0.16
ν_{23}	0.042	0.119			0.16
G_{12} [GPa]	4.78	4.83			5.51
G_{13} [GPa]	4.78	4.83			5.51
G_{23} [GPa]	4.78	4.83			5.51
Density [kg/m^3]	1852	2273	833.4	1320	5440
Dielectric [F/m]					ϵ_{ii} = 1.64E-08
Piezoelectric [m/V]					d_{31} = 4.6E-10

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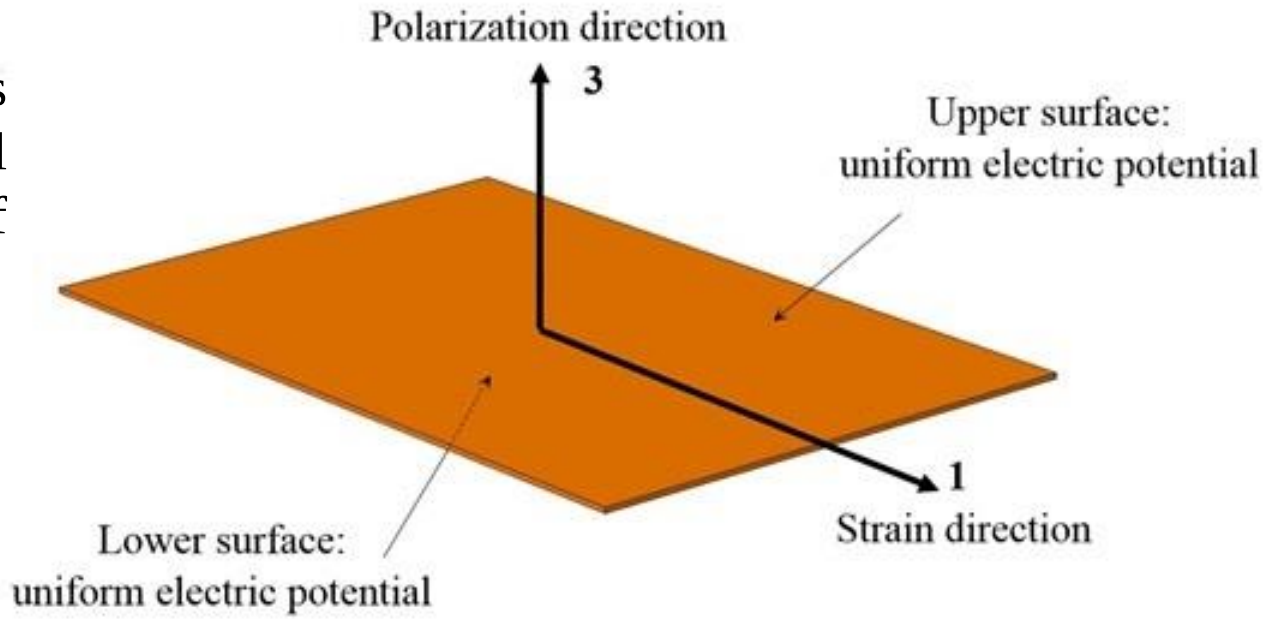
Finite Element Analyses: General Assumptions

General Assumptions

- The FEM model of a hybrid sample does not account for the grips for constraining the specimen to the test equipment.
- A very thin layer of resin has been considered as glue between the substrate and the MFC patches. The layer is 0.075 mm thick.
- A 0.3mm thick layer accounts for the passive area of each MFC patch; an isotropic elastic material has been used to describe the mechanical behavior of the Kapton
- Each ply of the laminated substrate is 0.25 mm thick; thus, the substrate is 1mm thick
- The FE mesh of a sample is made up of 20-node quadratic brick elements with full integration; 20-node quadratic brick elements with the additional electric potential d.o.f have been used for the active area of the MFC

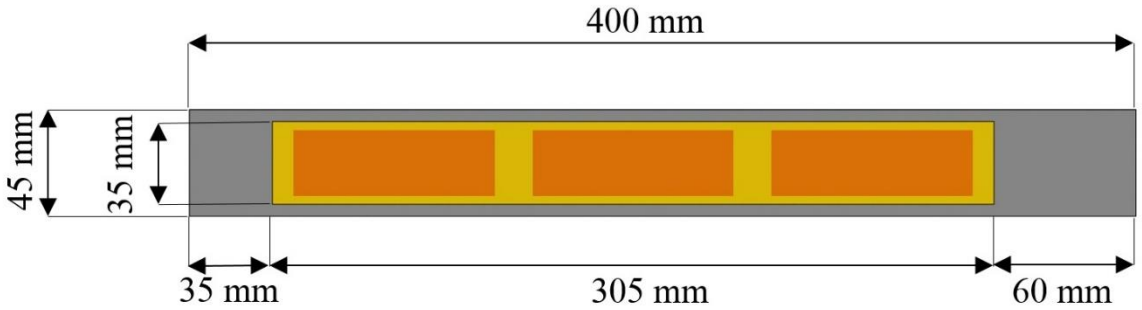
Finite Element Analyses: General Assumptions

- Large displacement formulation has been considered for all analyses.
- The d_{33} operational mode of the MFC P1/F1 types has been modeled as the d_{31} mode; in so doing, an electric potential gradient through the thickness (direction 3) produces strain in the fiber direction (direction 1). This allows us to apply a uniform electric potential on the upper and lower surface of a MFC.
- A clamped boundary condition has been used to constrain the nodal displacements of the root section of the specimen.

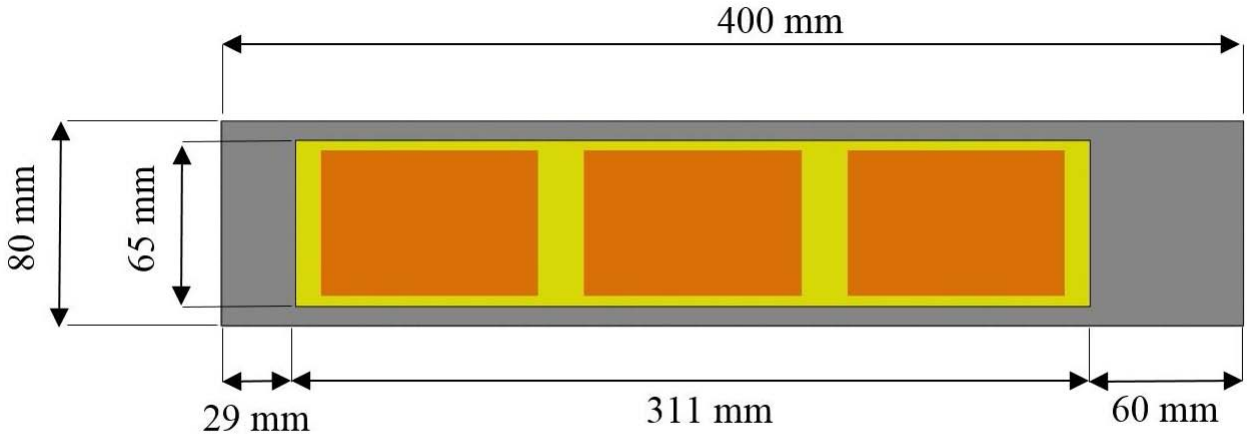


Finite Element Models

bending specimen



torsion specimen



cross-section of a specimen

Finite Element Analyses: Ply stacking sequences

Ply stacking sequences of hybrid specimens

Ply Id	Sequence 1	Sequence 2	Sequence 3	Sequence 4
1	+45/-45	0/90	+45/-45	+45/-45
2	0/90	+45/-45	0/90	0/90
3	0/90	+45/-45	0/90	0/90
4	+45/-45	0/90	+45/-45	+45/-45

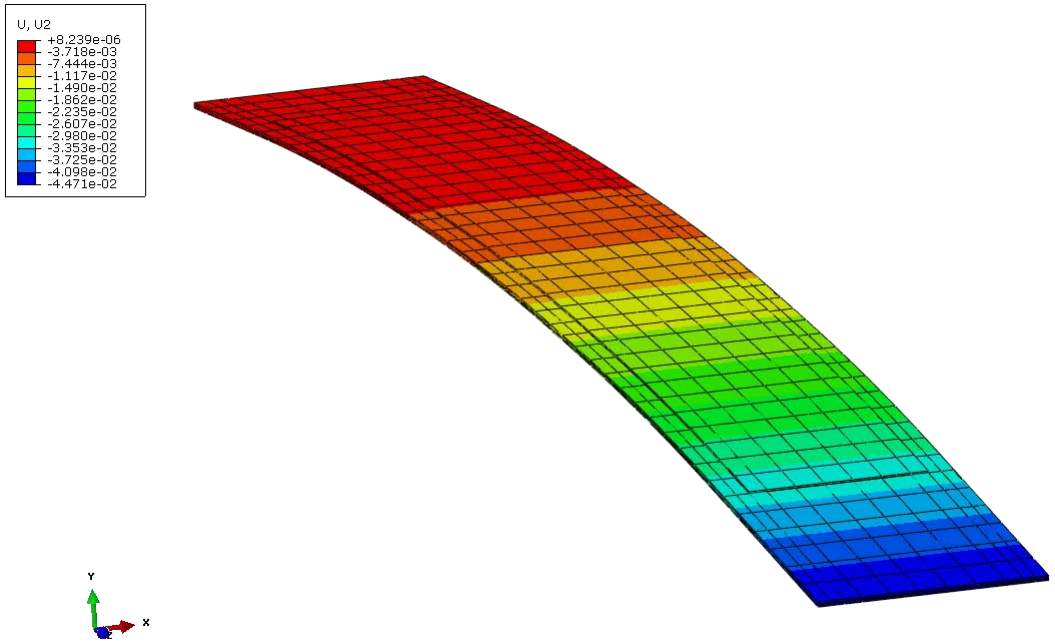
Finite Element Analyses: Bending

Graphite/Epoxy laminated substrate

	Vertical displacement at the free end of the sample [mm]	
Stack. Seq. Id	Voltage +500V/-500V	Voltage +1500V/-500V
1	22.82	44.71
2	17.25	34.36
3	16.76	33.42
4	24.82	48.71

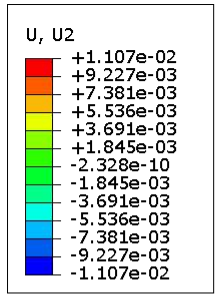
Glass/Epoxy laminated substrate

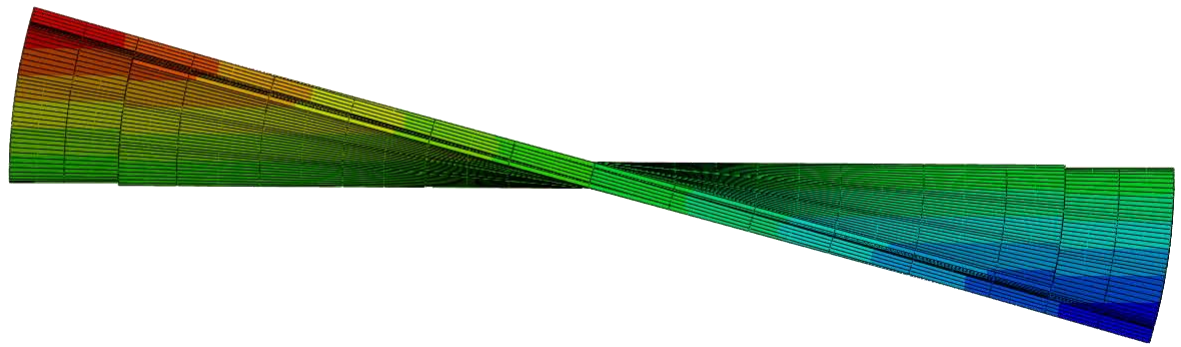
	Vertical displacement at the free end of the sample [mm]	
Stack. Seq. Id	Voltage +500V/-500V	Voltage +1500V/-500V
1	25.82	50.90
2	23.78	47.14
3	23.52	46.63
4	26.27	51.81



Finite Element Analyses: Torsion

Graphite/Epoxy laminated substrate





Data at the free end of the sample		
Stack. Seq. Id	Vertical displacement [mm]	Torsion angle [deg]
1	8.18	11.56
2	11.07	15.47
3	10.96	15.32
4	8.68	12.24

Results obtained by supplying the maximum operating voltage (equal to +1500V)

Finite Element Analyses: Torsion

Glass/Epoxy laminated substrate

	Data at the free end of the sample	
Stack. Seq. Id	Vertical displacement [mm]	Torsion angle [deg]
1	11.28	15.75
2	12.52	17.38
3	12.26	17.04
4	11.67	16.26

Results obtained by supplying the maximum operating voltage (equal to +1500V)

Outline

- Introduction
  - About the FutureWings project and its objectives
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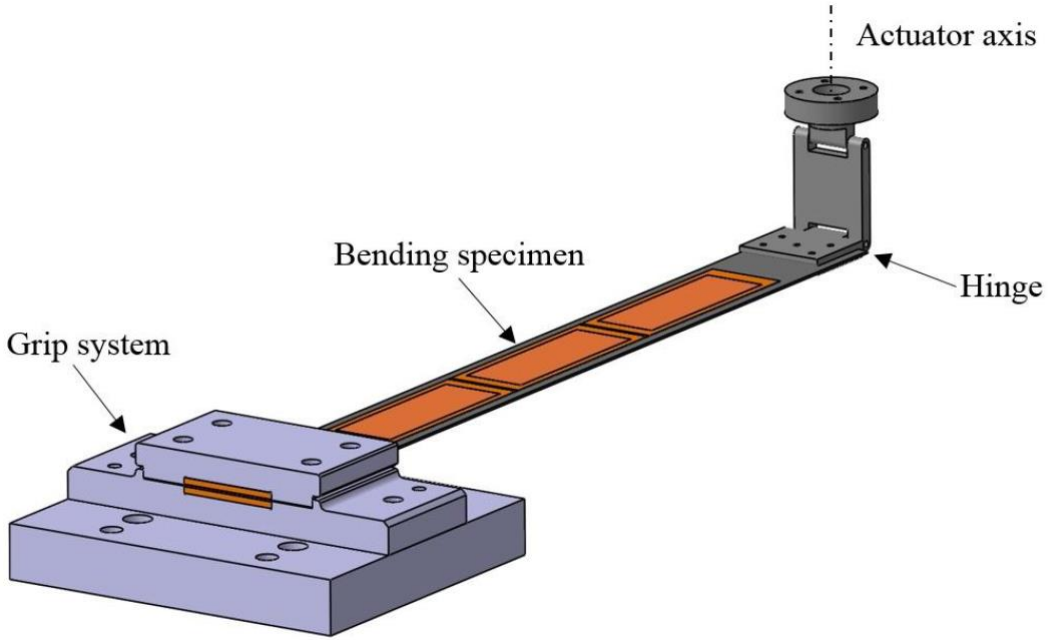
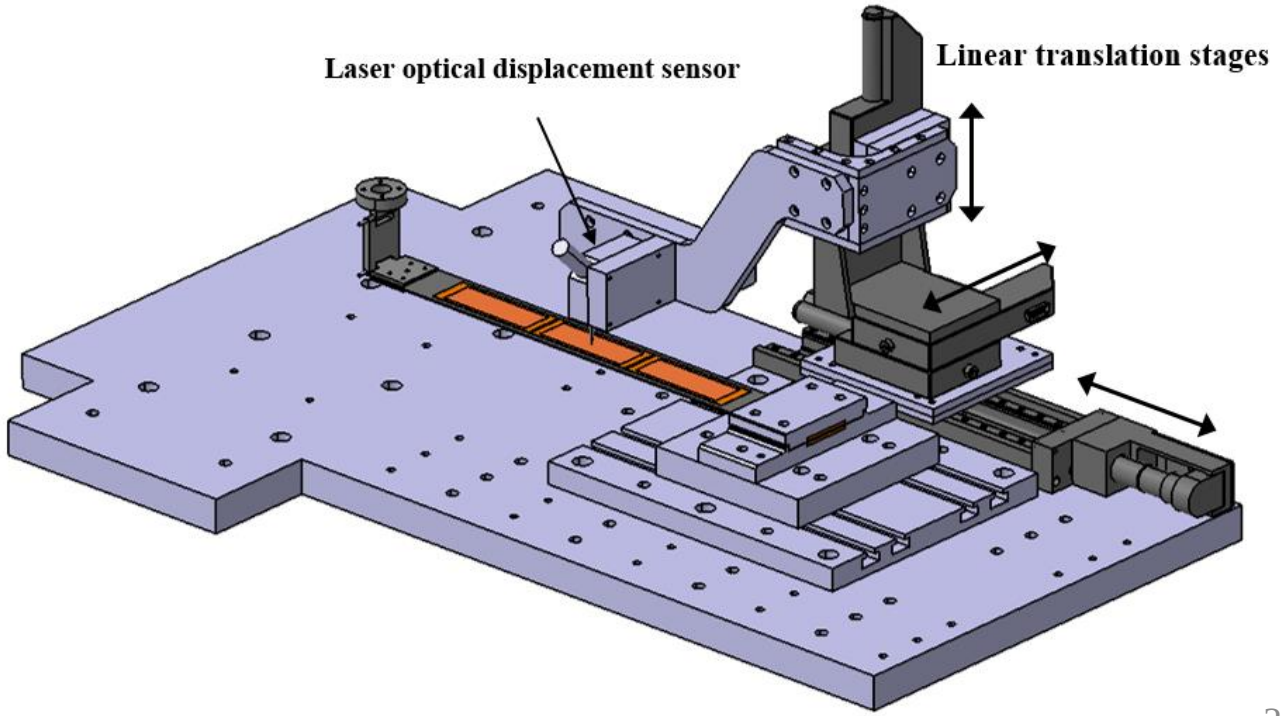
  - Bending tests
  - Torsion tests
- Comparison between Numerical and Experimental Results

Test Equipment: Bending specimen

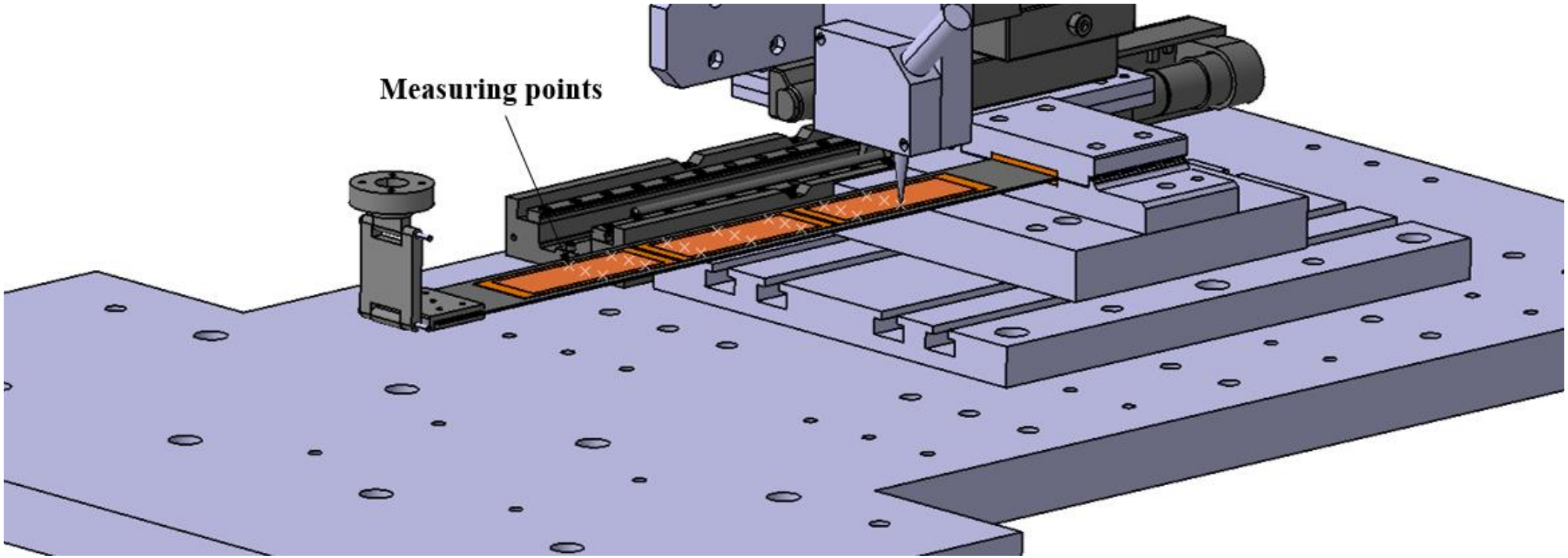
- 3 linear stage allow a laser optical displacemen sensor to measure the deformed shape of a specimen in several points
- The displacement measuring range of the sensor is about 10 mm; measurements range from 20 mm to 30 mm, with respect to the specimen surface





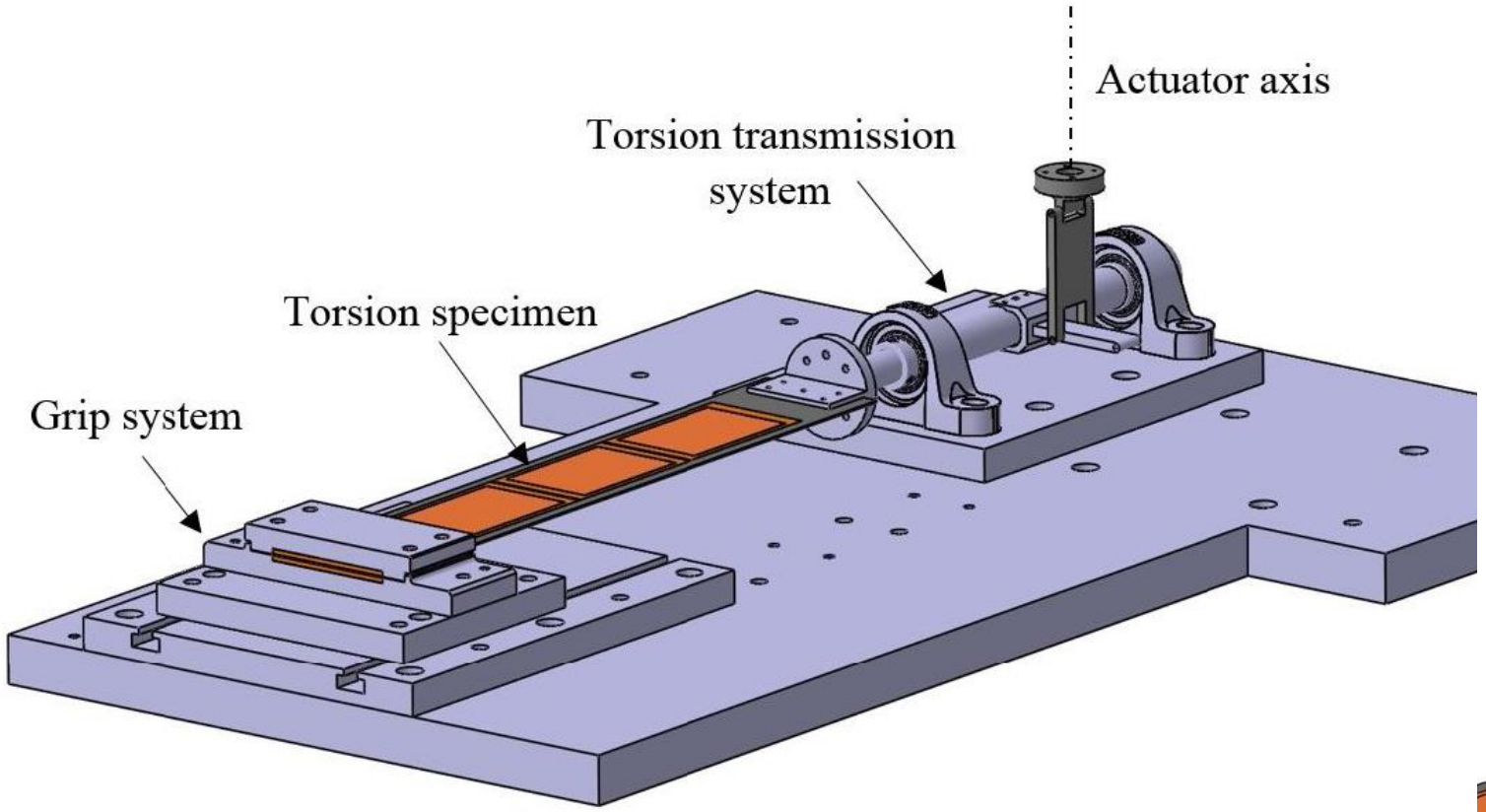
Test Equipment: Bending specimen

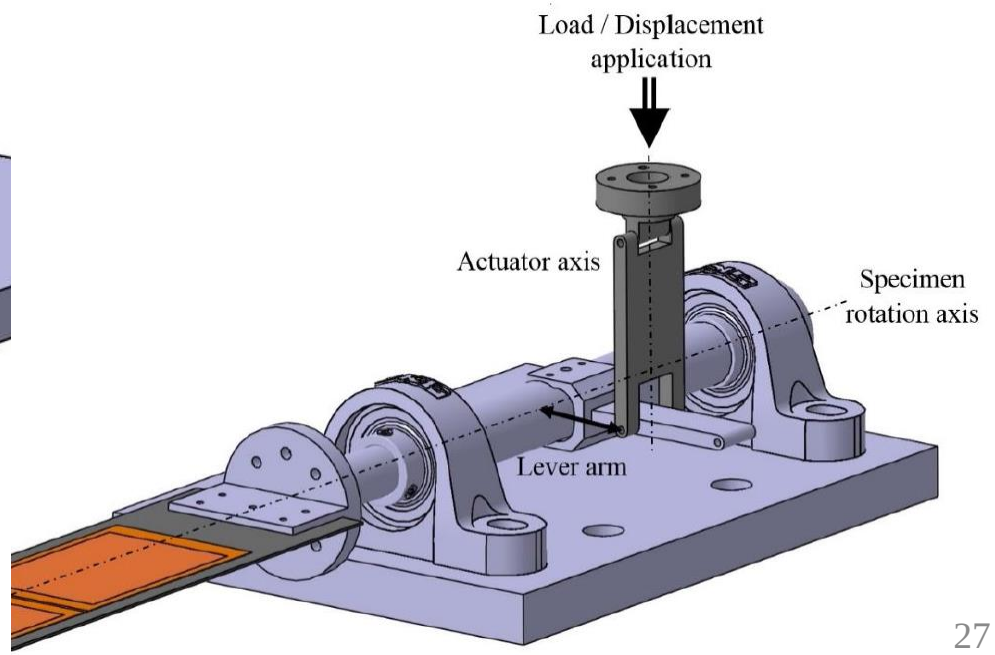
- for bending samples a matrix of 21 measuring points have been used



Test Equipment: Torsion specimen

- Frame for transferring torque moment

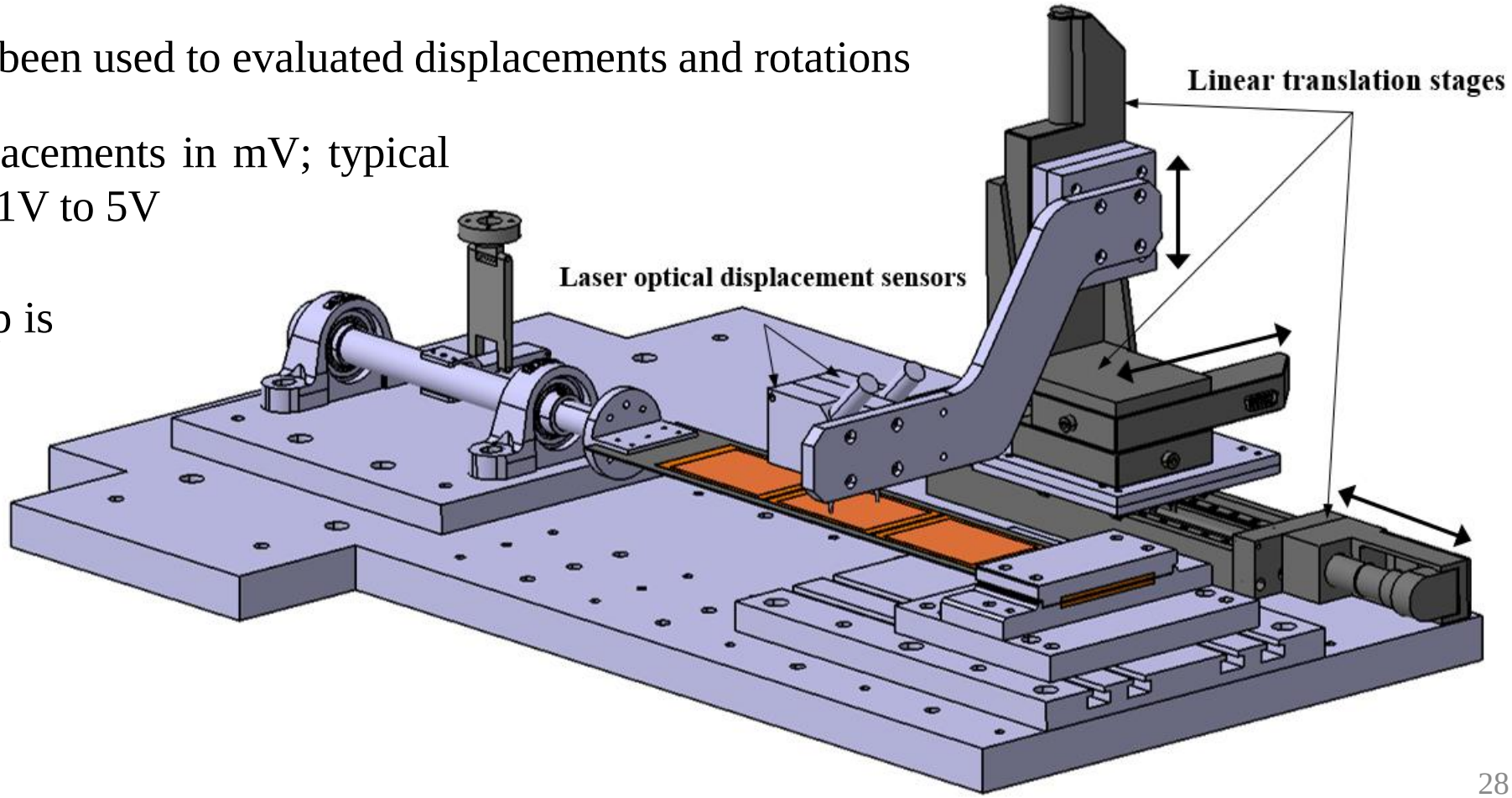




Test Equipment: Torsion specimen

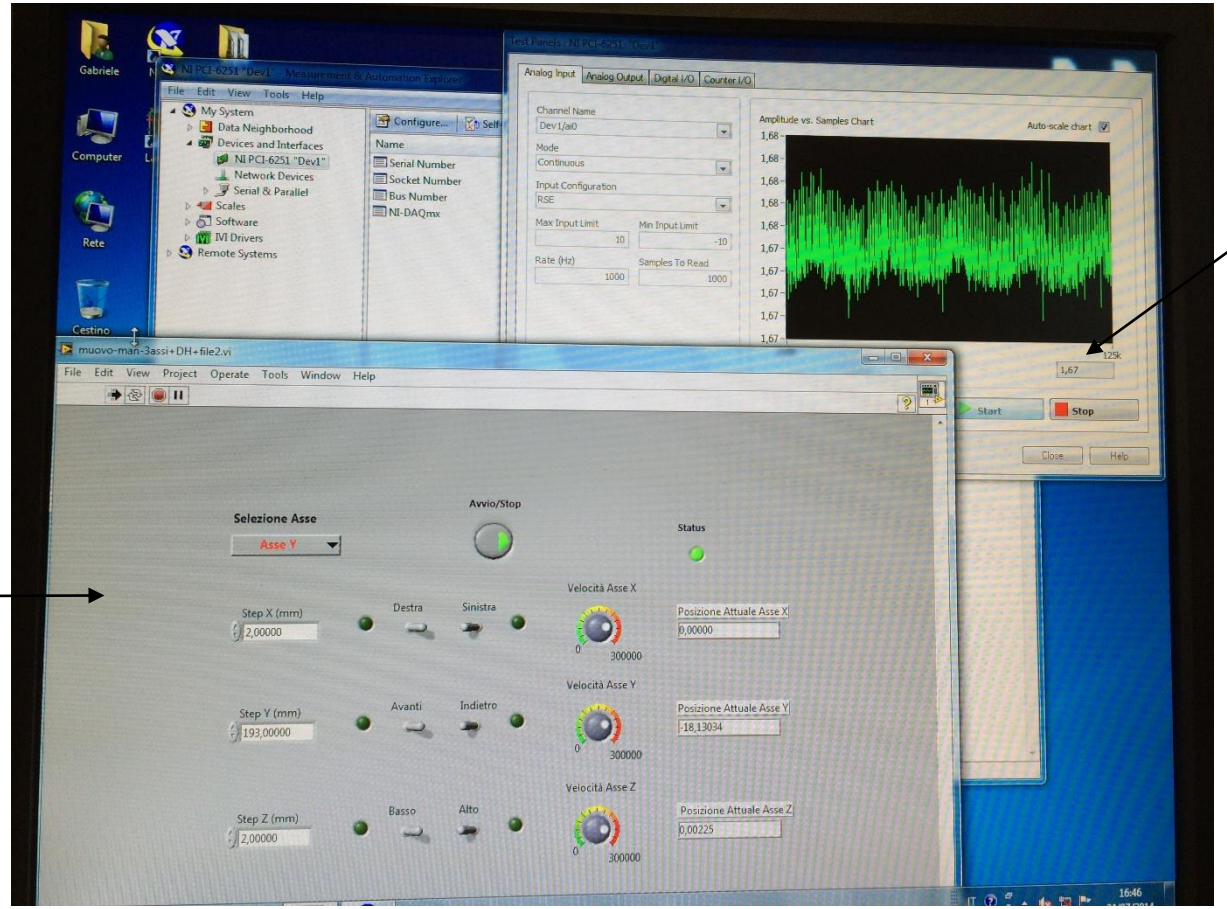
- 2 laser optical displacement sensors have been used for torsion specimens
- 14 measuring points have been used to evaluated displacements and rotations
- the sensors measure displacements in mV; typical measurements range from 1V to 5V
- The following relationship is valid:

$$1\text{mm} \equiv 400\text{mV}$$



Test Equipment: LabView

- A LabView user program has been developed to move the linear stages along the three directions

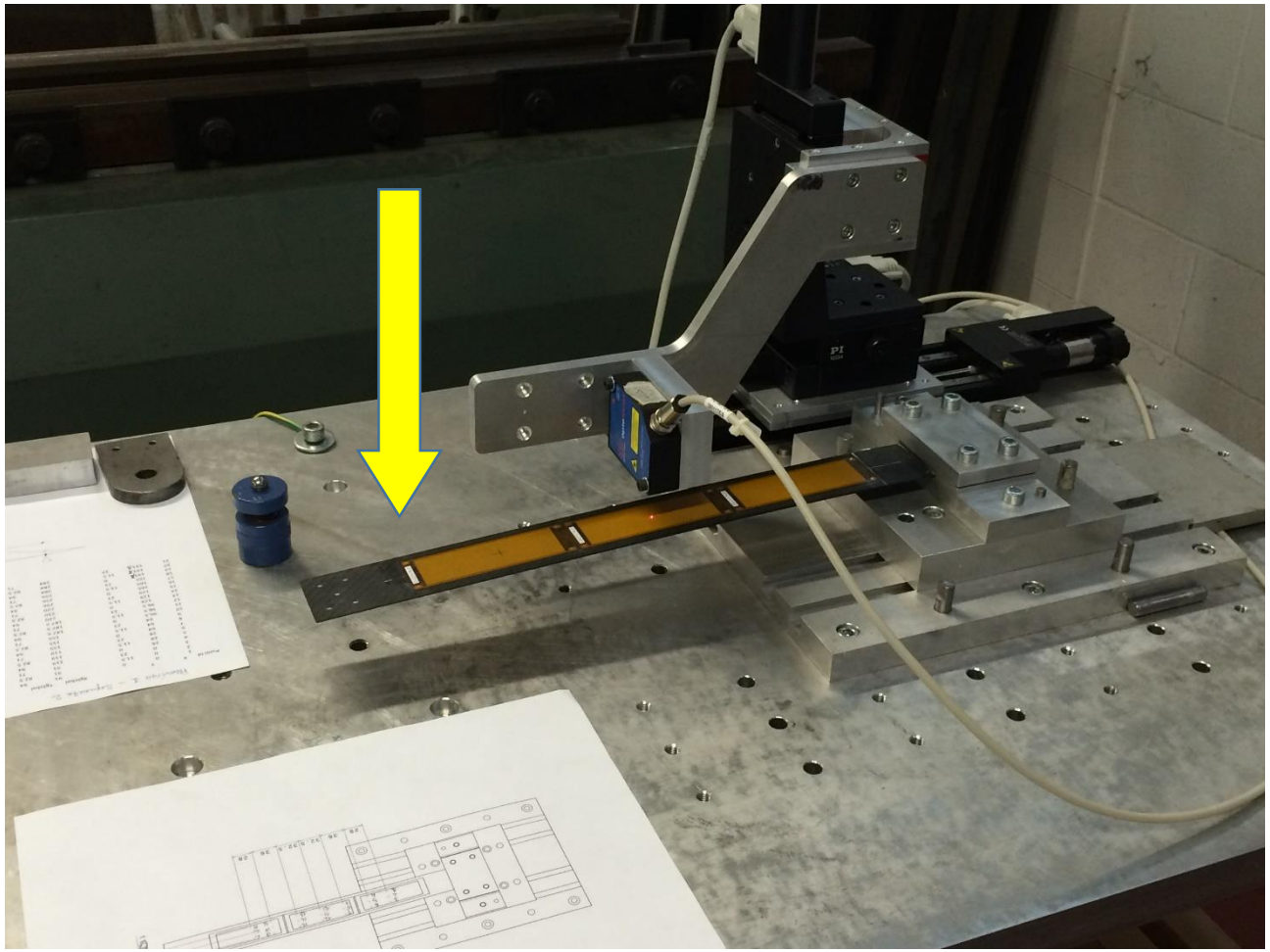


Test panel showing the measurements

Interactive GUI used for moving the linear stages

Test Equipment

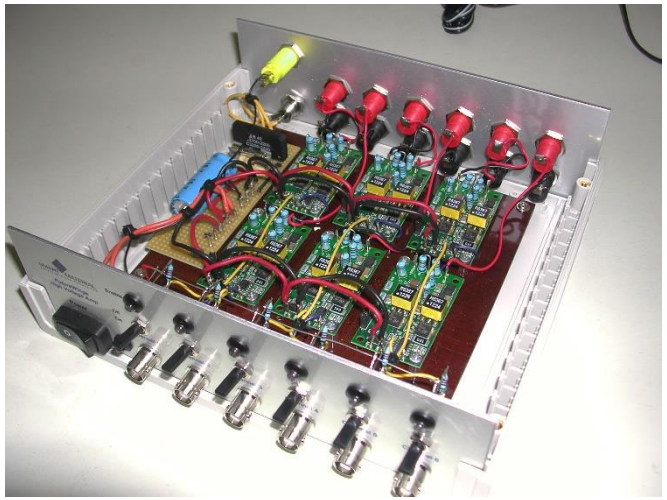
High voltage six-channel amplifier; one channel is used to give a positive voltage to the lower MFC patch close to the clamped section of a bending specimen



A typical measurement of the deformed shape of a bending specimen due to its weight

Test Equipment: High Voltage six-channel Amplifier

- Electric potential gradients have been applied on MFC piezoelectric patches, by means of a high voltage six-channel amplifier
- The basic idea behind the development of a six-channel amplifier is that to be able to control each MFC patch separately
- Input voltages range from 0V to 5V correspond to output voltages ranging from -500V to 1500V; more precisely, the input voltage range from 0V to 2.5V is equivalent to an output voltage ranging from -500V to 0V, that ranging from 2.5V to 5V corresponds to a voltage ranging from 0V to 1500V.



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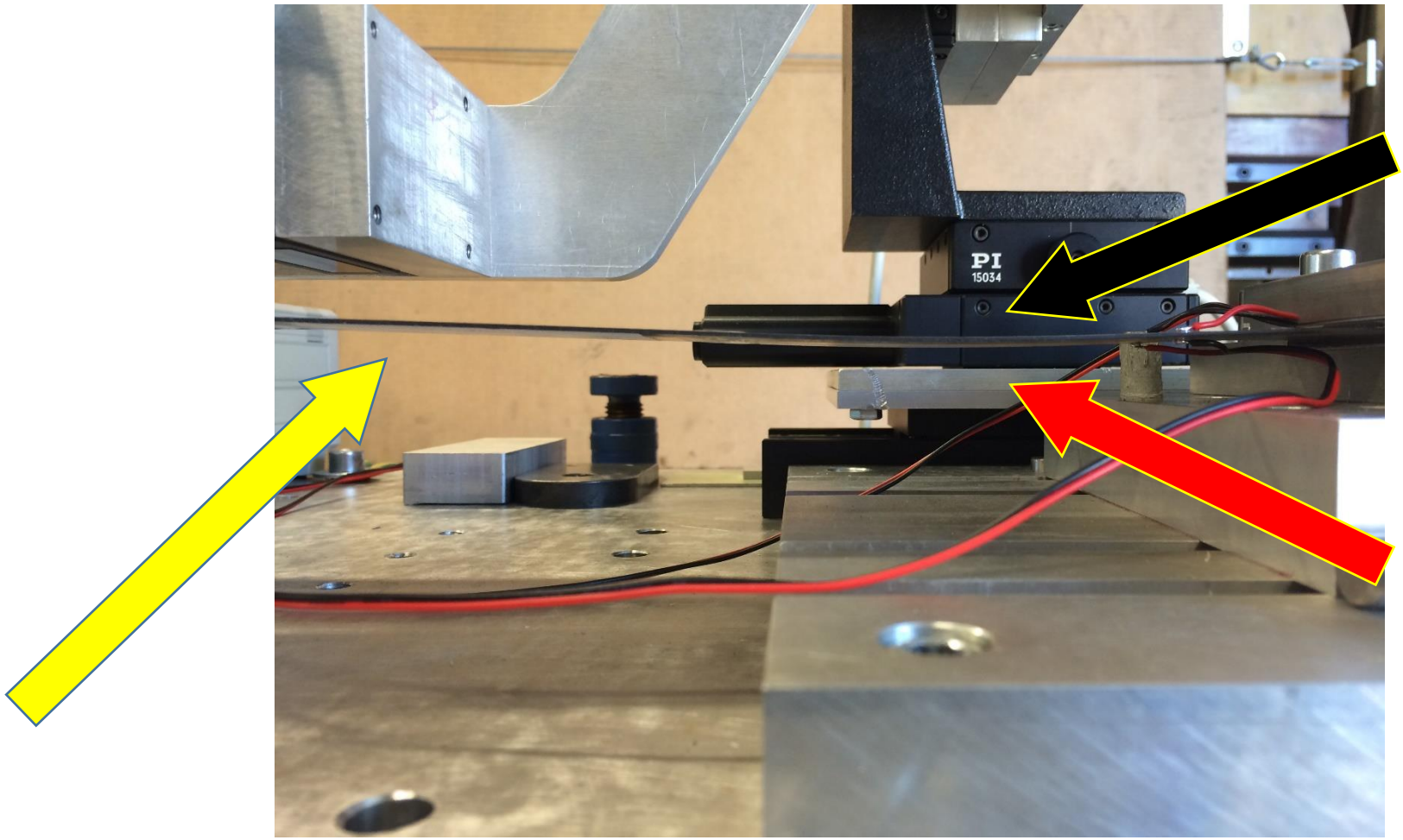
Bending tests

- As a “mechanical load”, all testing specimens are subjected to their weight; thus, they undergo bending
- In addition, due to manufacturing process, specimens are characterized by an initial deformed shape, which is different from the ideal one; thus, the resulting deformed shape is assumed as the reference one
- In contrast to the reference deformed shape, MFC patches have been activated in order to promote an opposite bending deformation; this has been done by supplying positive voltages to lower MFC patches and negative ones to the upper MFC patches.
- Thus, an input voltage range from 0V to 2.5V (equivalent to -500V to 0V as output of the HV amplifier) has been applied to the MFC patches which behave as contractors, whereas the voltage range from 2.5V to 5V has been used for MFC elongating actuators.

Bending tests

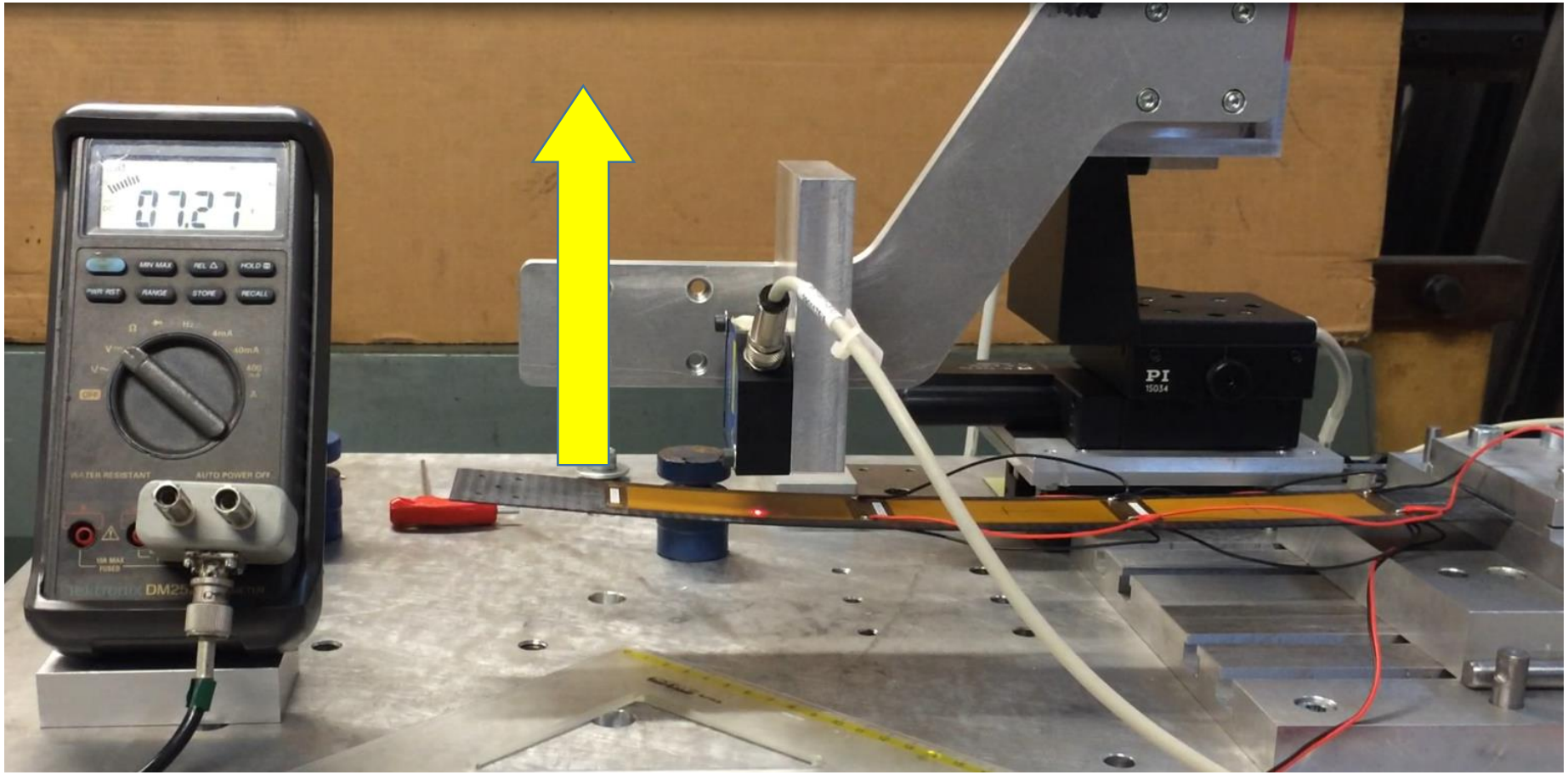


Negative voltage applied to the upper MFC

Positive voltage applied to the lower MFC

A local deformation of a sample due to the behavior of the MFC patches close to the clamped section

Bending tests

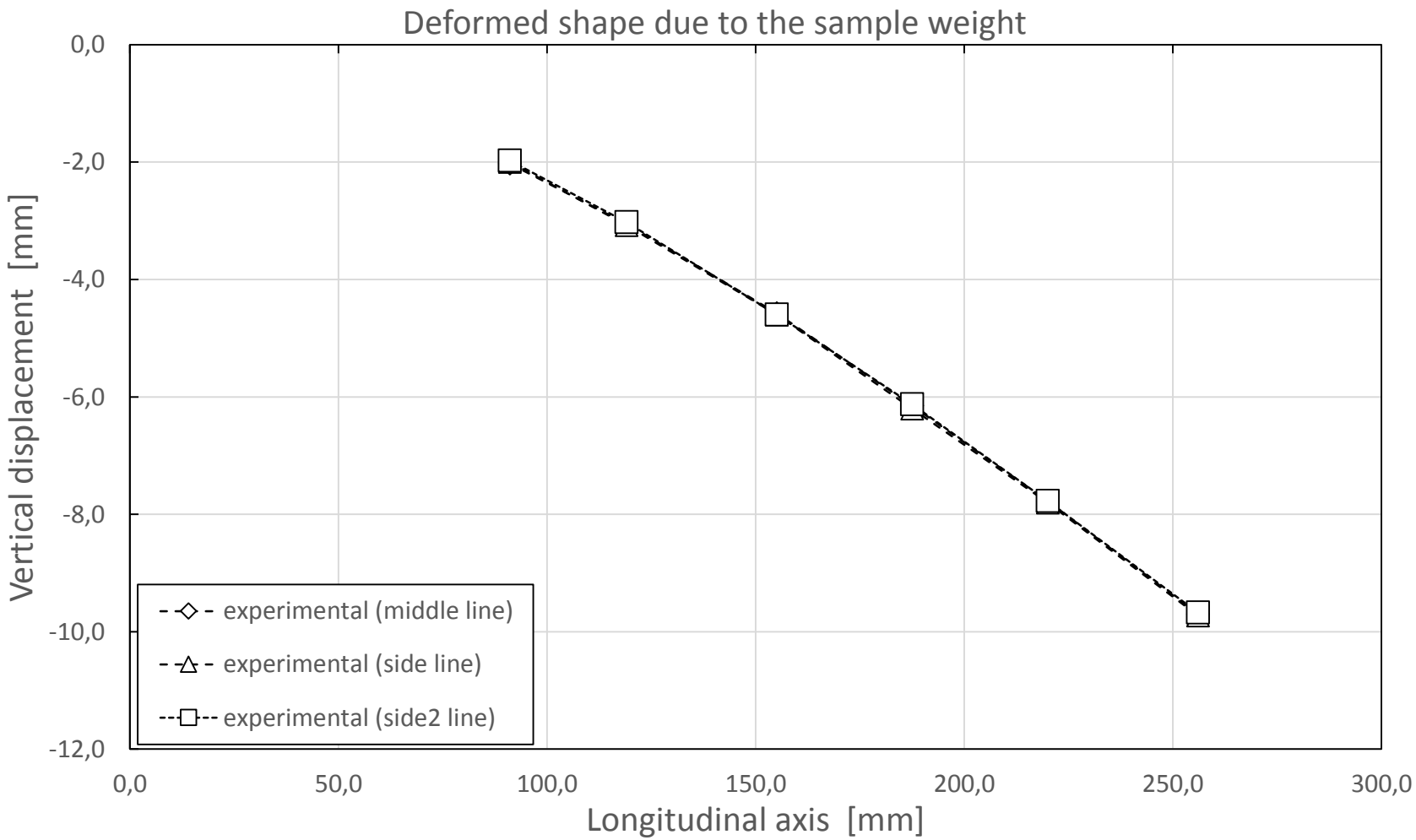


(see graph page 38)

Lower MFC patches connected in parallel at a channel of the HV amplifier

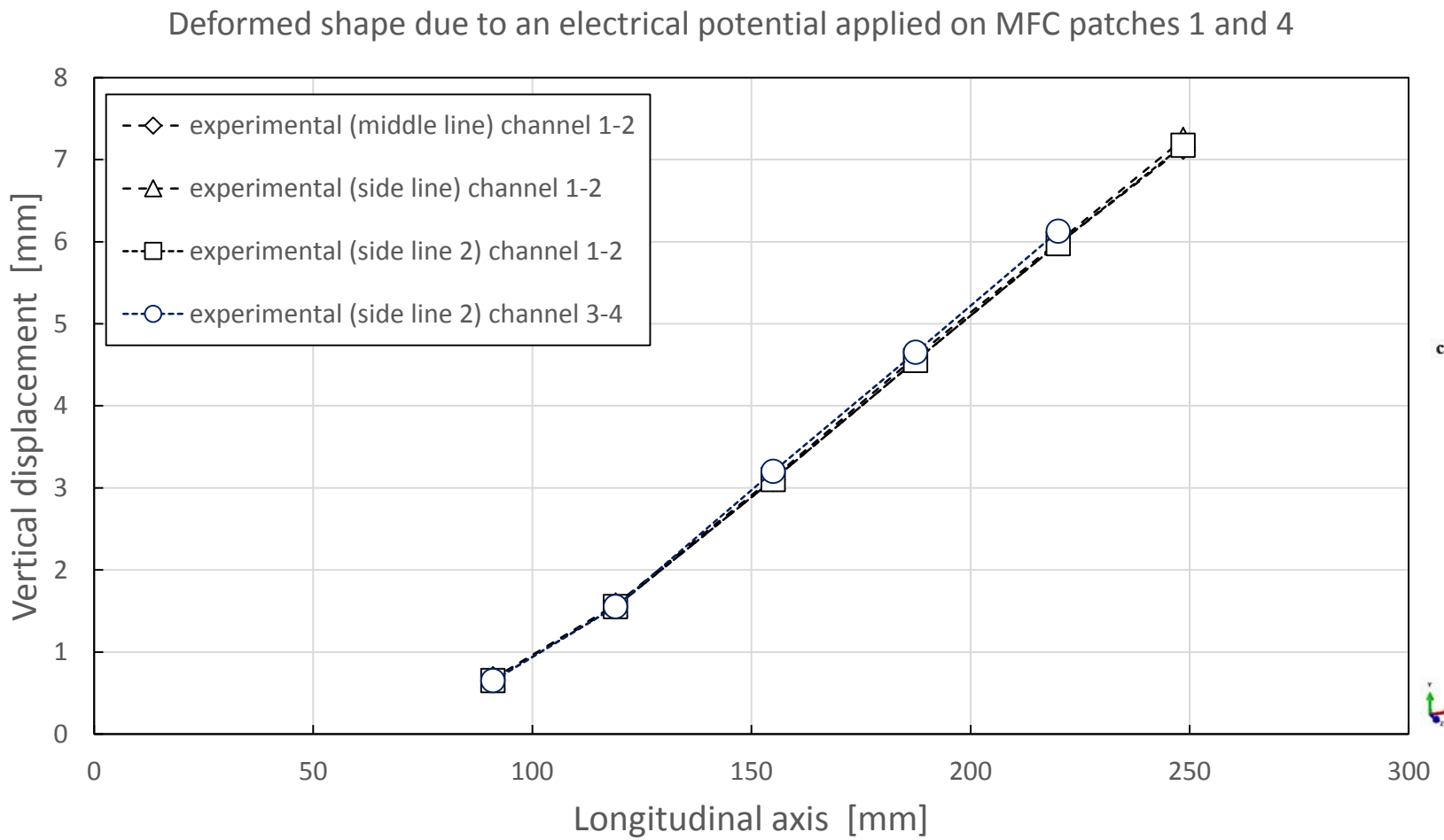
A deformed shape of a sample due to a voltage of +1450V applied to the lower MFC patches

Bending tests: the weight effects



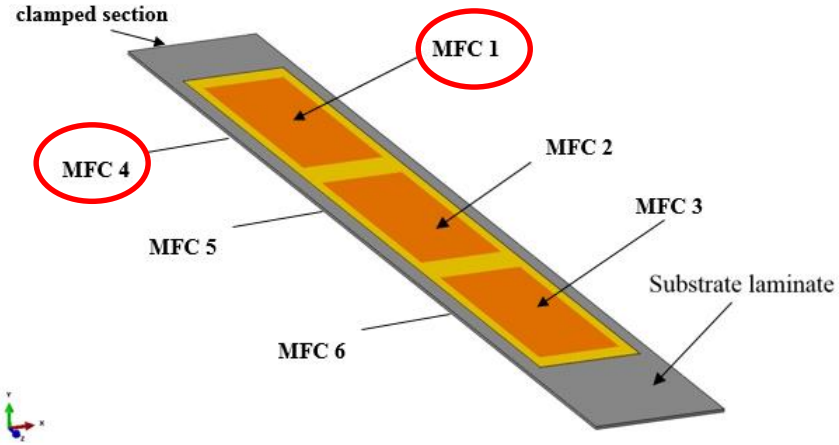
Bending tests: the voltage effects

Grahite/Epoxy sample 1 with ply stacking sequence 1



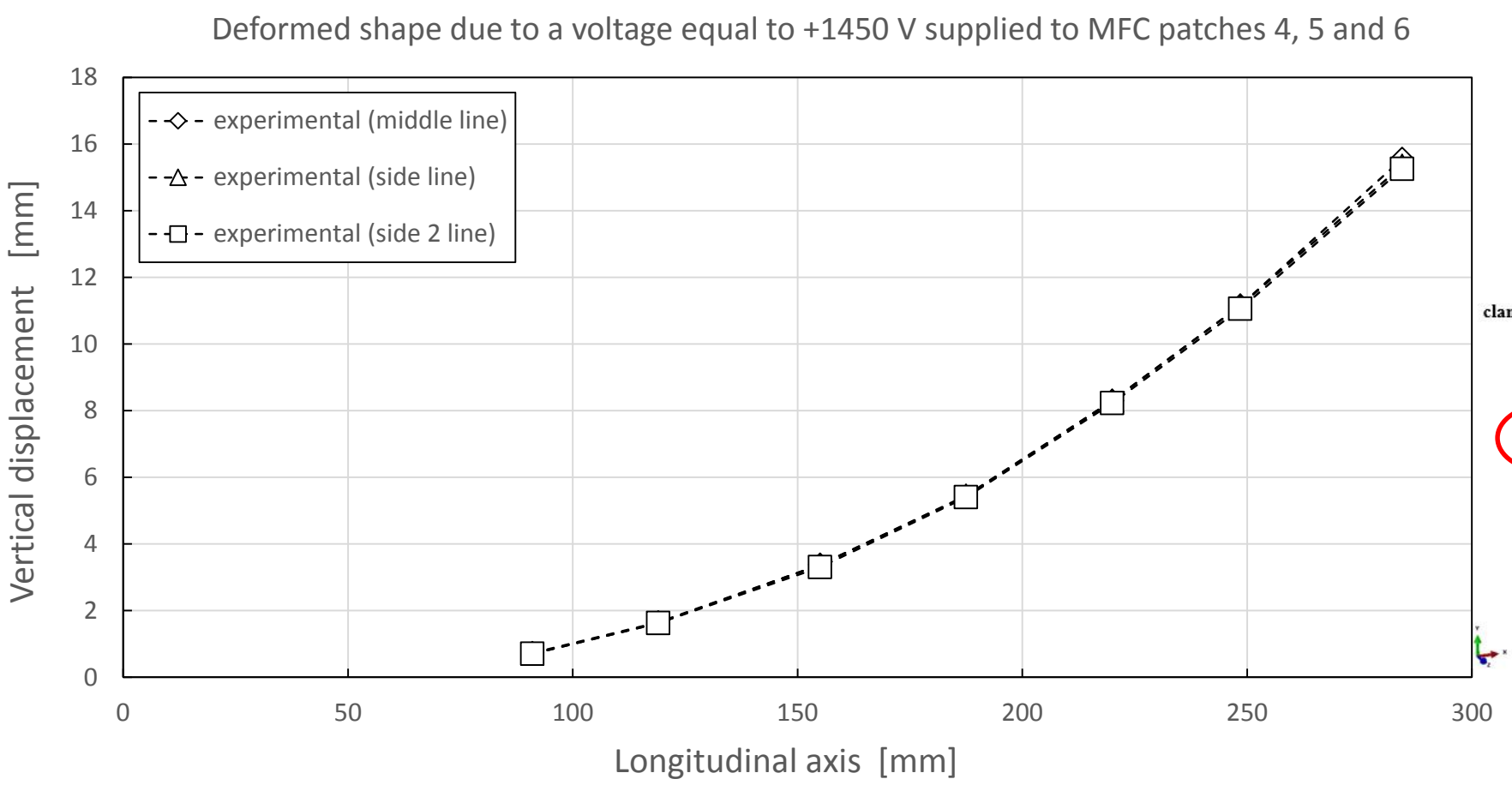
MFC 1: -400 V

MFC 4: +1200 V



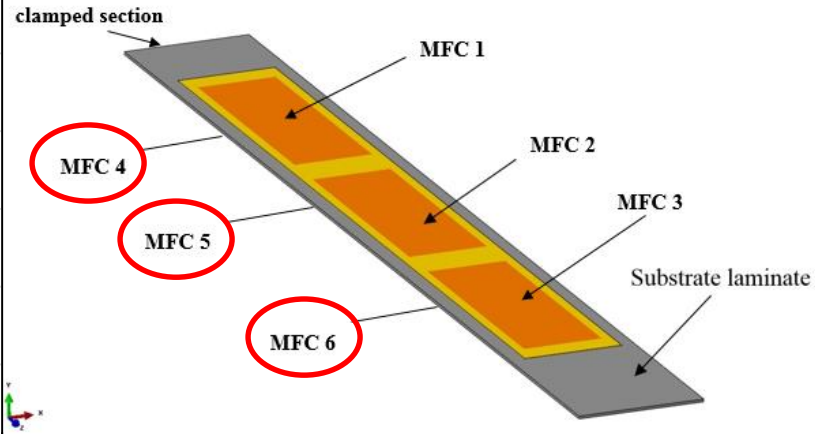
Bending tests: the voltage effects

Grahite/epoxy sample 1 with ply stacking sequence 1



(see picture page 35)

MFCs 4, 5, 6: +1450 V



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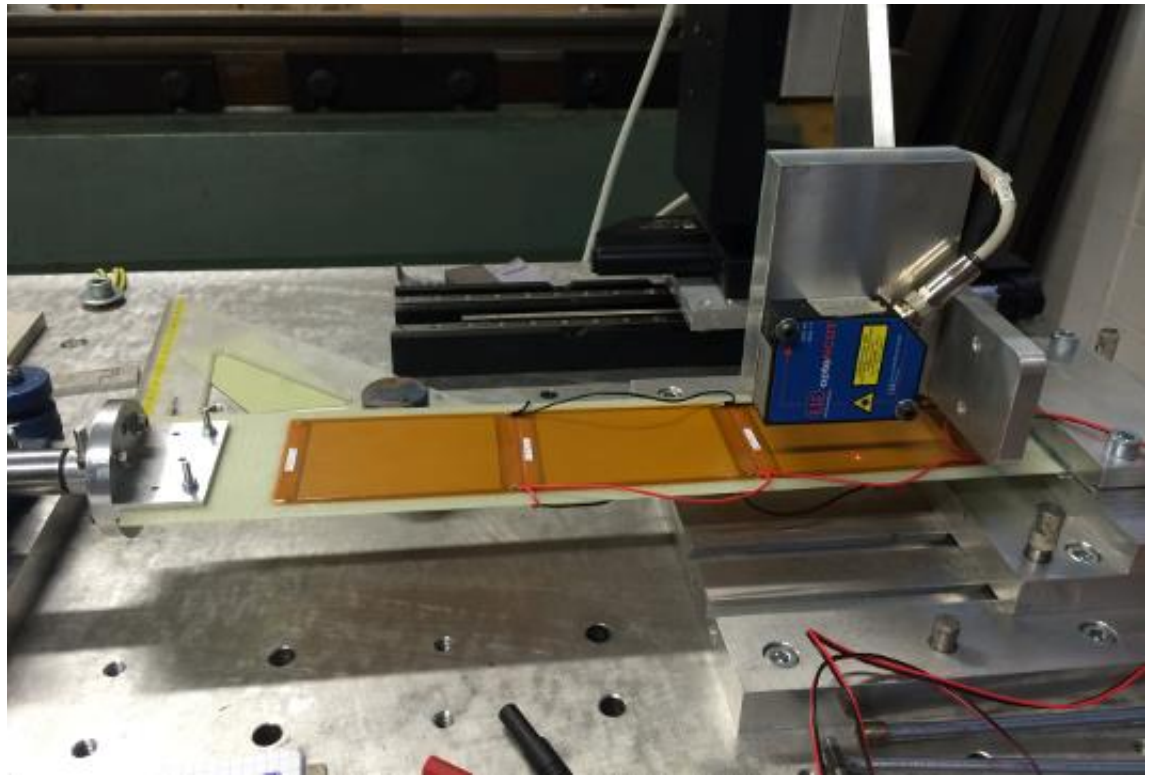
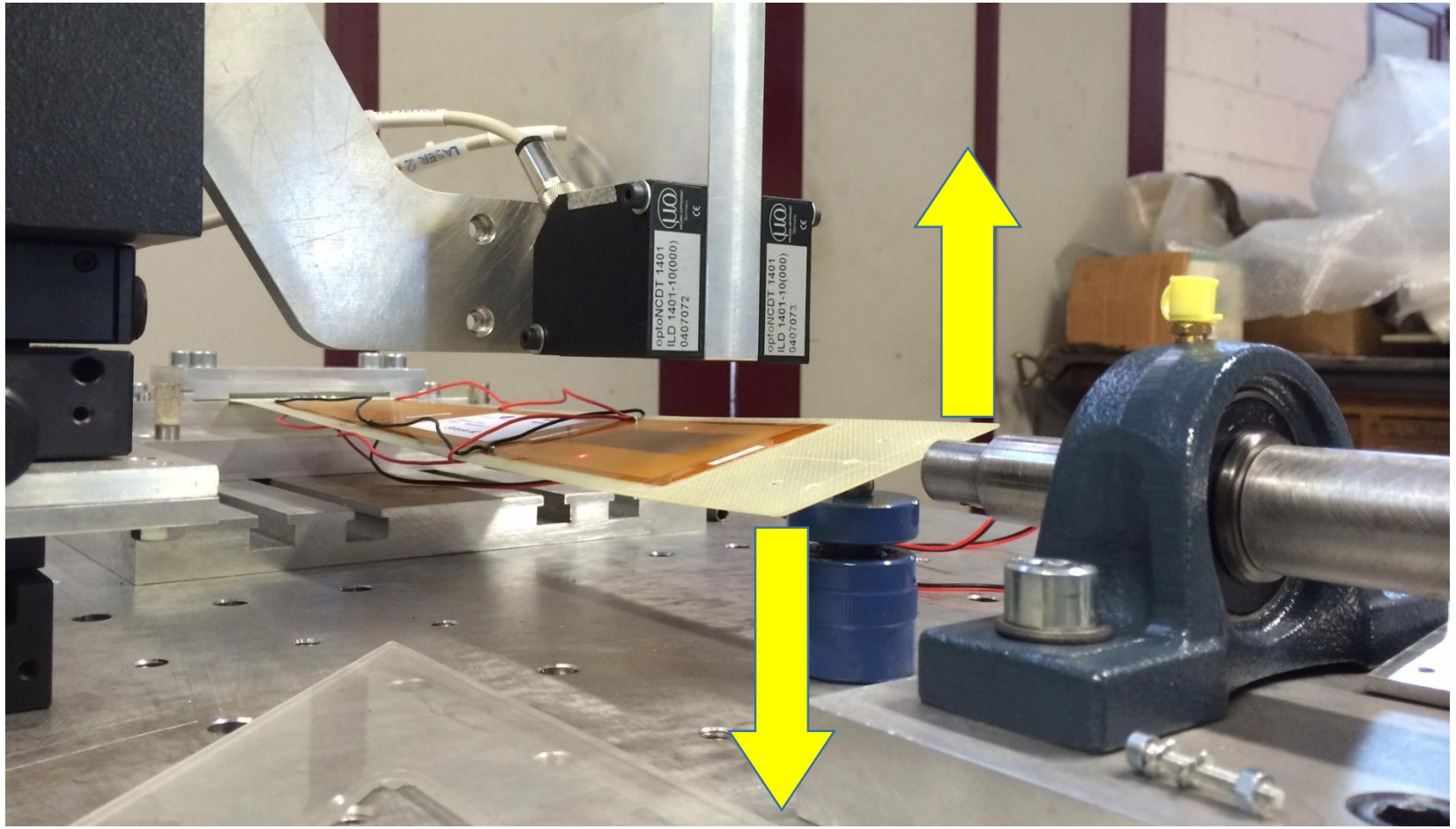
Torsion tests

- Torsion tests have been carried out by constraining both root and tip sections of the samples; a pin constraint applied to the tip section allows the sample to rotate around its axis
- All the six MFC patches have been connected in parallel to the first channel of the HV amplifier
- Three voltages have been supplied: -400V, +700V and +1400V



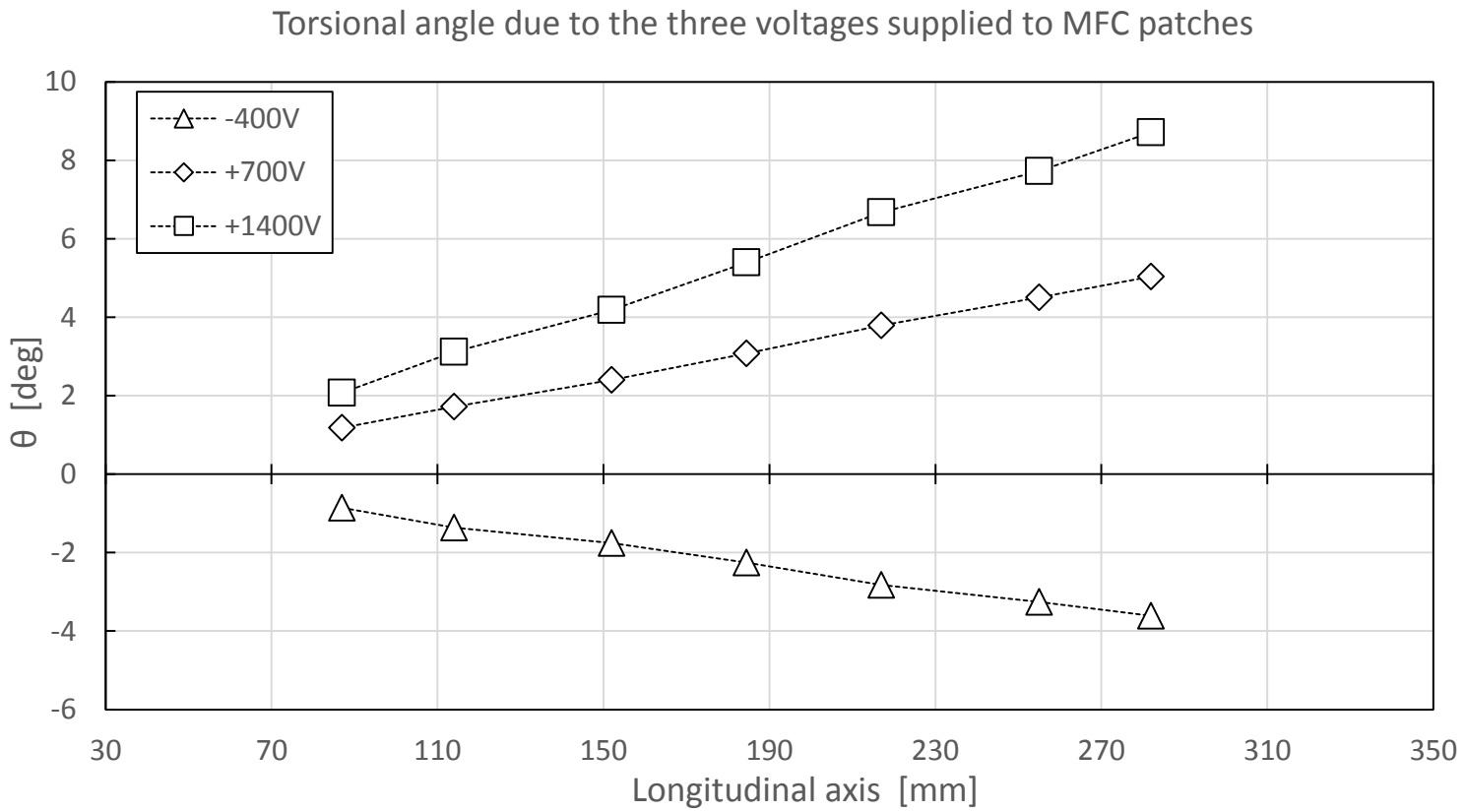
Torsion tests



A typical torsional deformation of a specimen

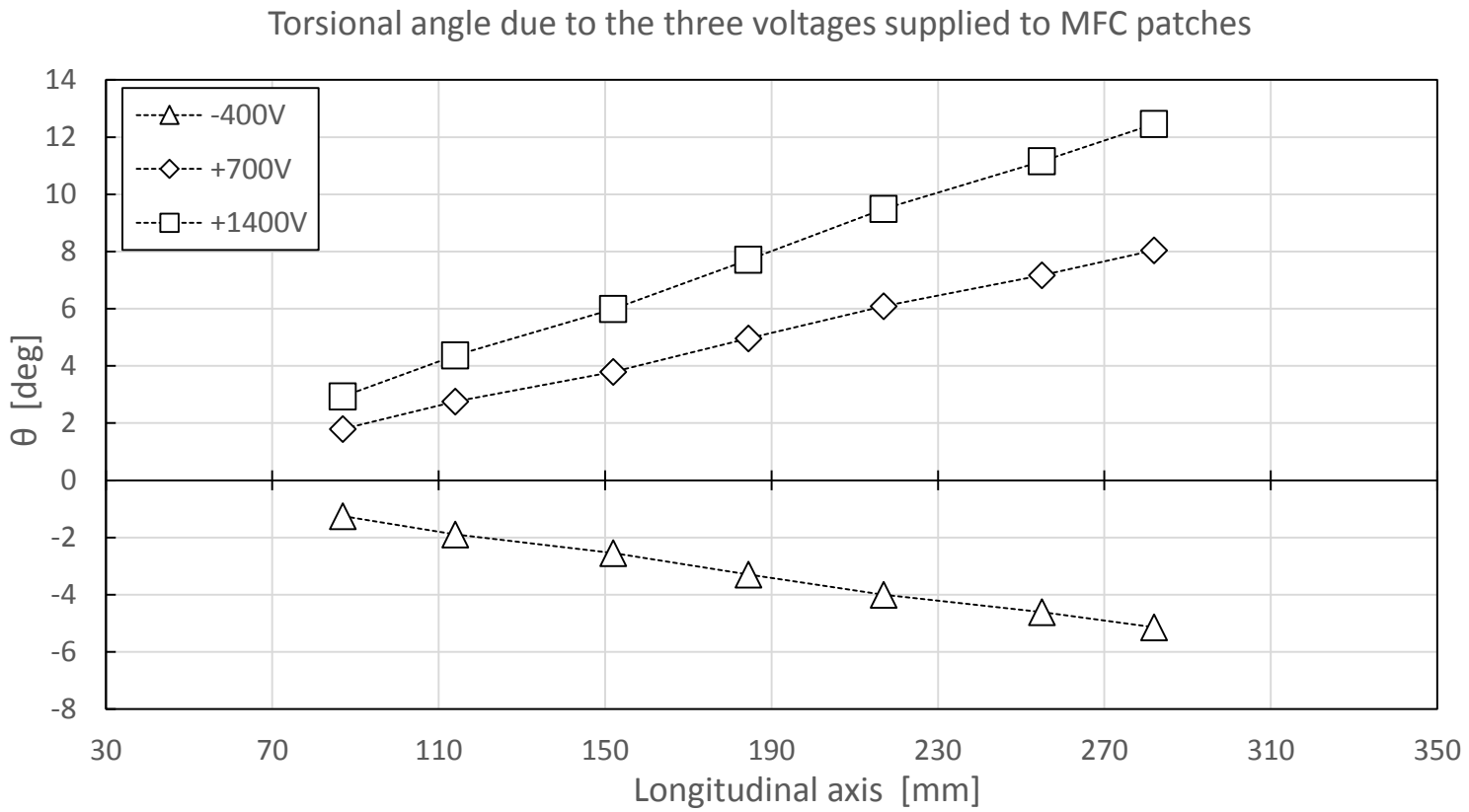
Torsion tests

Graphite/Epoxy Sample 3 with ply stacking sequence 1 (stiffer sequence)



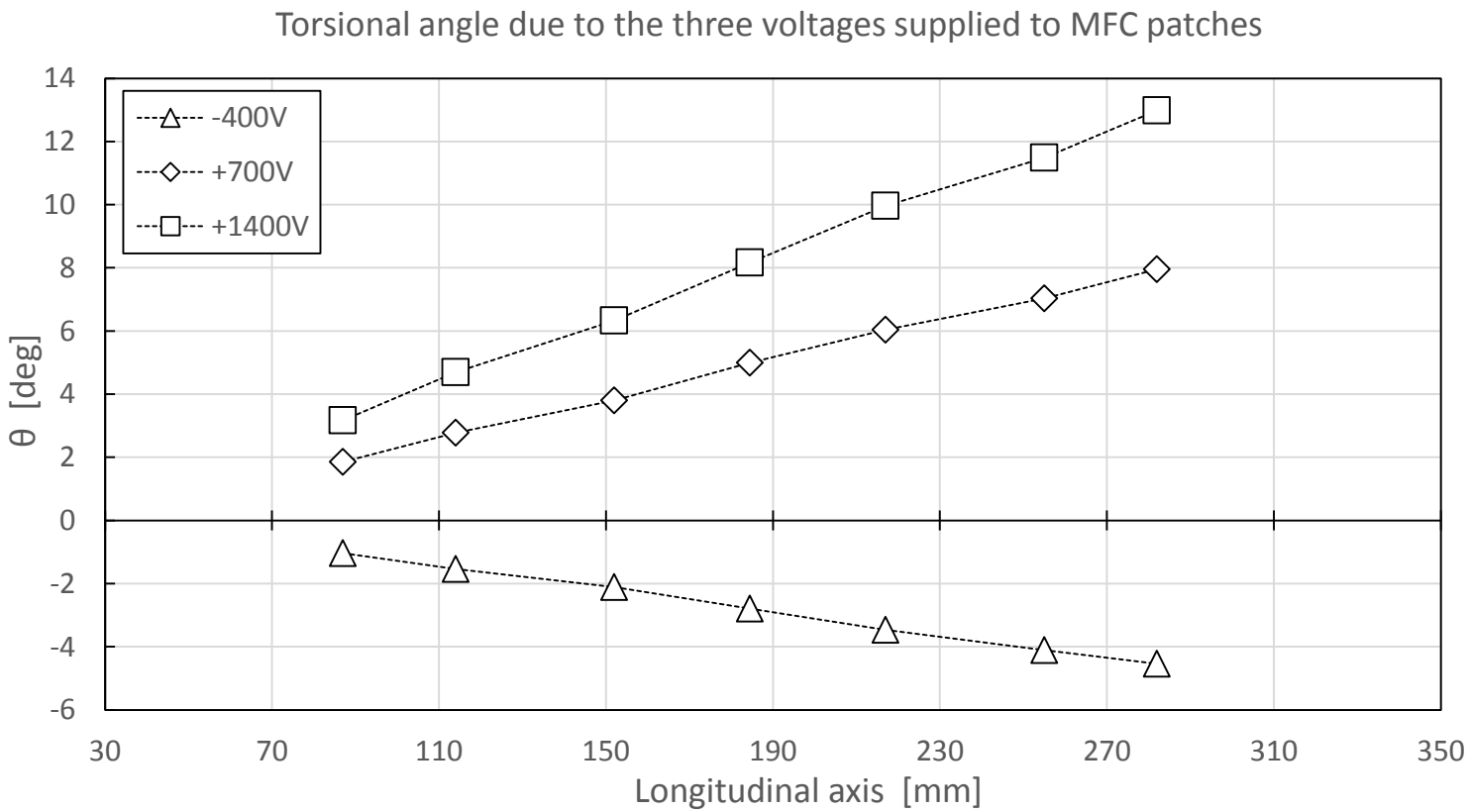
Torsion tests

Graphite/Epoxy Sample 2 with ply stacking sequence 2



Torsion tests

Glass/Epoxy Sample 2 with ply stacking sequence 1



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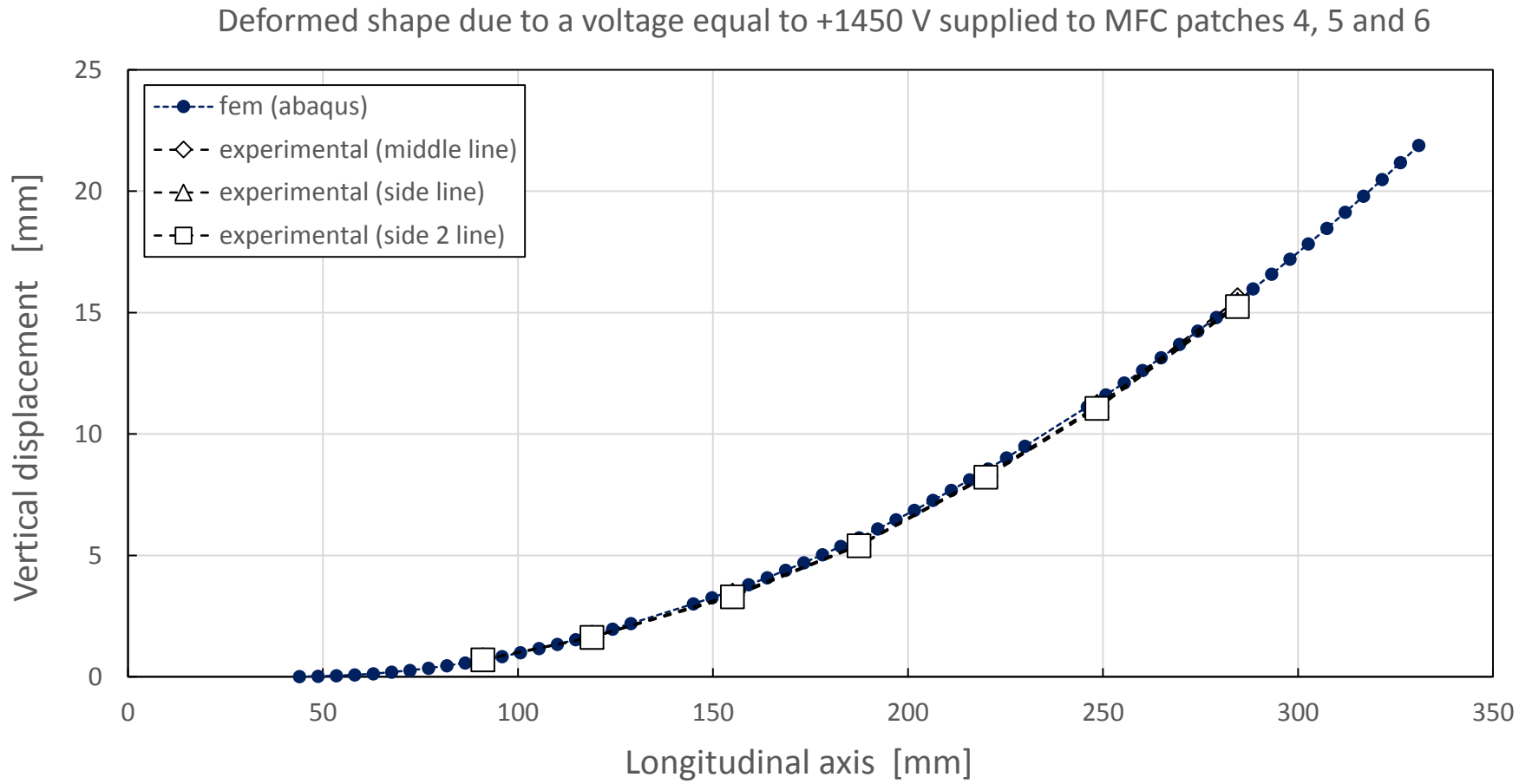
Comparison between Numerical and Experimental Results

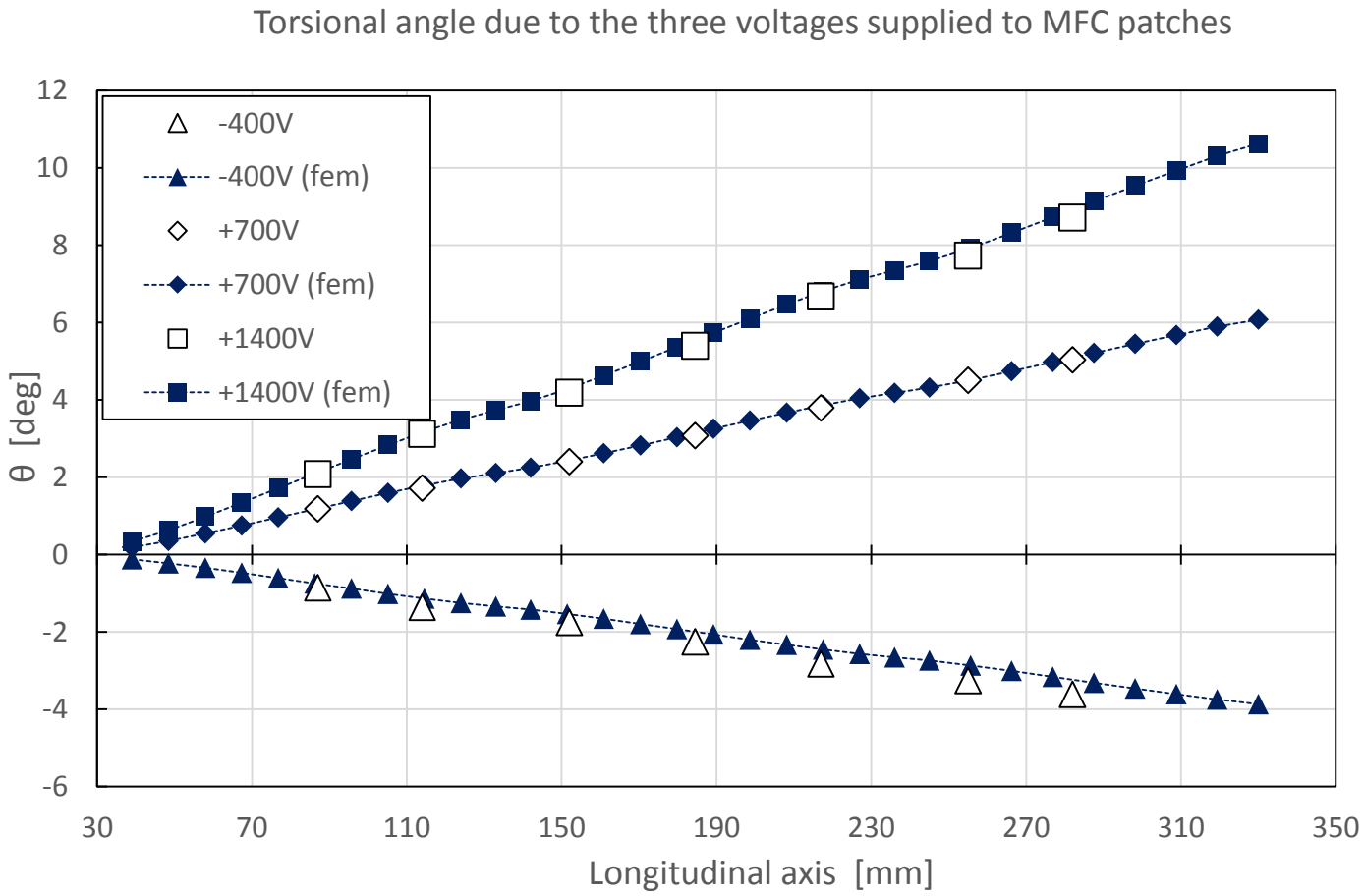
Bending of Graphite/Epoxy Sample 1 – Ply Sequence 1



(Test of picture page 35)

Comparison between Numerical and Experimental Results

Torsion of Graphite/Epoxy Sample 3 – Ply Sequence 1



Summary

- Within the FutureWings project of the FP7 program a study of hybrid specimens has been carried out
- The hybrid specimens have been designed, manufactured and preliminarly tested
- Test equipment has been designed and manufactured
- Two types of materials (Glass/Epoxy and Graphite/Epoxy) have been used for the specimens substrate
- Deep numerical analyses have been performed within the project activities and detailed FE-models have been realized
- Numerical and Experimental results show a good agreement; so the numerical procedures have been validated

Future Works

- Modeling, design and manufacturing of small scale model of the FutureWings Unit
- Development of aeroelastic model of FutureWings aircraft
- Preliminary definition of a semi-automatic technique to describe the deformed shape of a morphing profile
- Implementation of the aeromechanical model of the FutureWings aircraft inside an available flight simulator (preliminary implementation of a rolling maneuver)

SEVENTH FRAMEWORK PROGRAMME

Wings of the Future

www.futurewings.eu

Thank you for your attention

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Transonic Wind-tunnel Investigation for Active Load Control Using a Winglet-Rudder-Configuration and for Passive Load Control Integrating Vortex Generators on the Wing Surface

4th EASN Association International Workshop on Flight Physics and Aircraft Design
Aachen, Germany

Johanna Schlupkothen, Athanasios Dafnis

Institute of Structural Mechanics and Lightweight Design, RWTH Aachen University

27th October 2014

Active Load Control Using a Winglet-Rudder-Configuration

Project Motivation

Research project LARC

“PETW Tests for Loads, Aeroelastics and their Robust Control”

→ Prospective motivation:
Active control of structural responses and aerodynamic behavior of flexible wings with winglets at cruise speed

- Test model: Winglet with a piezo-electrical actuated rudder as active control surface

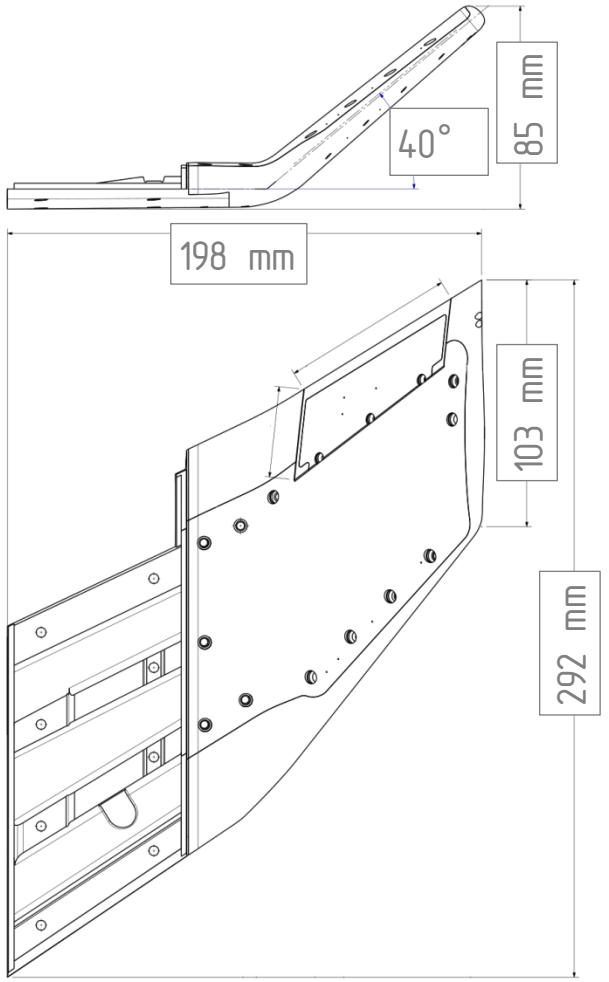
- Transonic test conditions in the cryogenic transonic wind-tunnel PETW (Pilot-ETW, Cologne)

Outline – Active Load Control

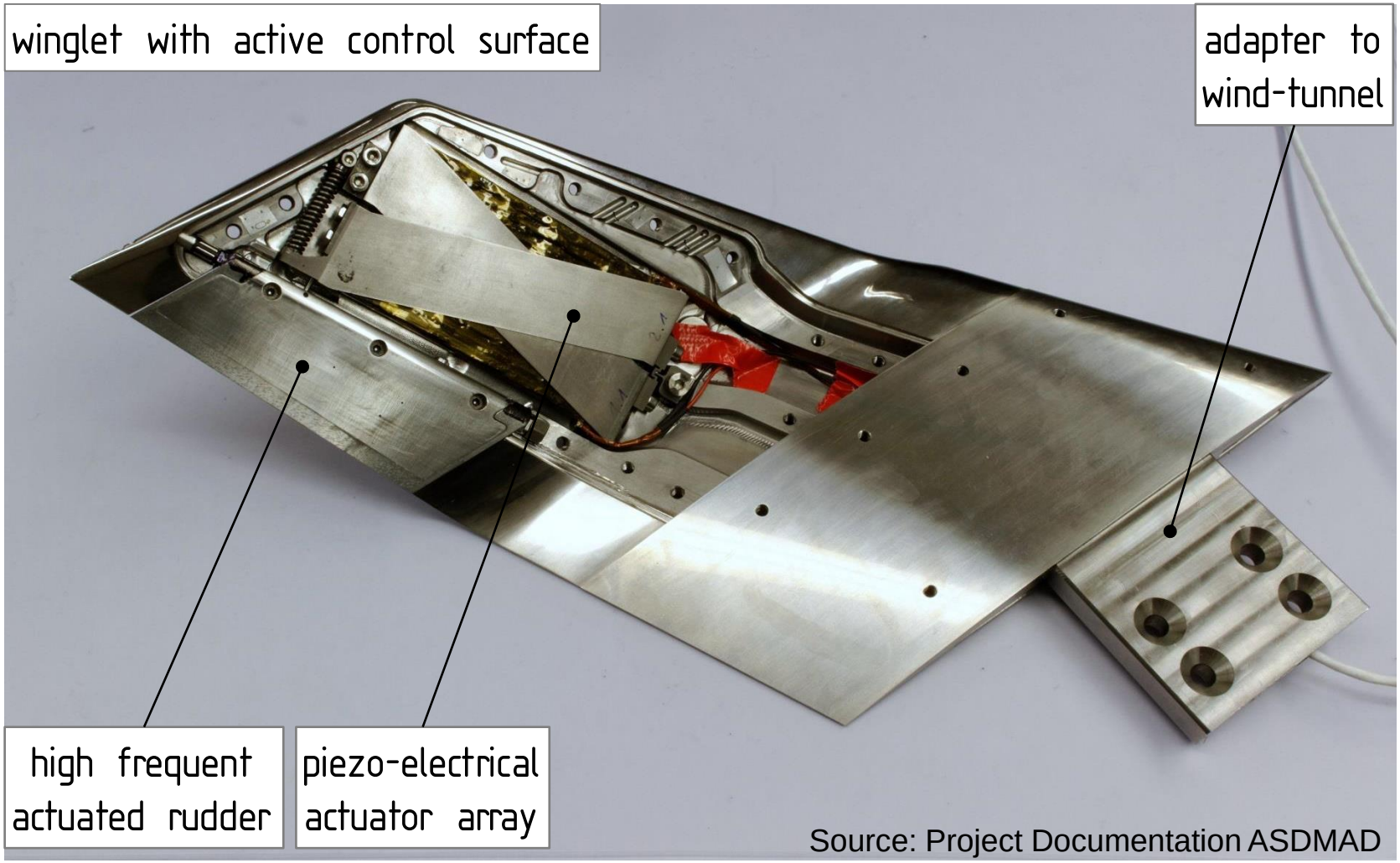
- The Wind-tunnel Model
- The Active Control System
- The Experimental Set-up
- Summary and Next Steps

The Wind-tunnel Model

- Rigid winglet with a rudder
- Rudder actuation by a mechanism with two piezo-stacs
- Max. actuation frequency: 30 Hz
- Max. rudder deflection: +/- 5°
- Mass of the winglet: 2.5 kg

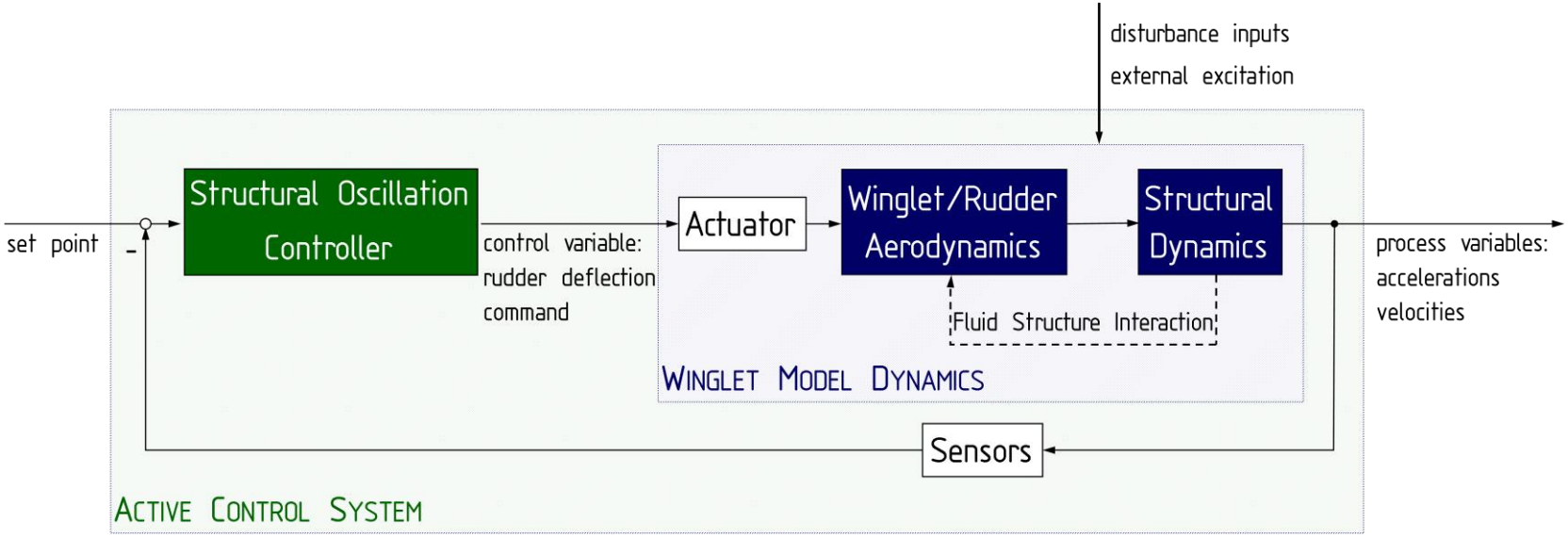


The Wind-tunnel Model



The Active Control System

- Control of unsteady aerodynamic-structural behavior



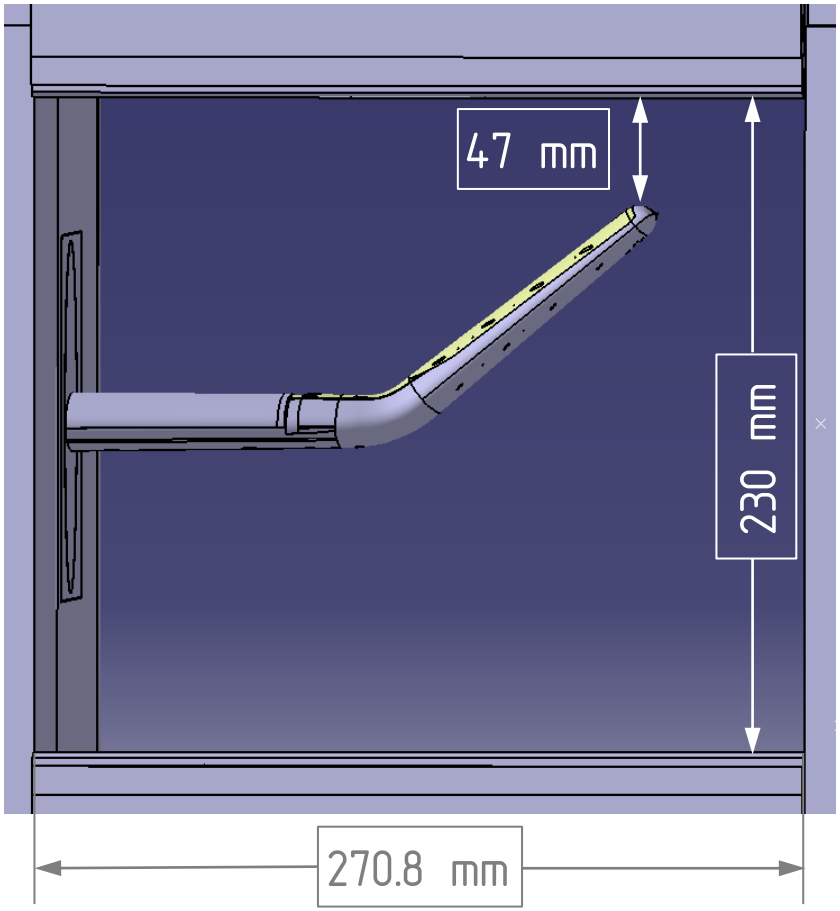
→ Flexible wind-tunnel model that allows for relevant reduced frequencies ($k = \omega b/V_\infty = 0.15 \ldots 0.25$)

→ External excitation

The Experimental Set-up

- Rigid winglet
- Additional flexible structural behavior needed
- Limited space in PETW

→ Elastic support outside the test section



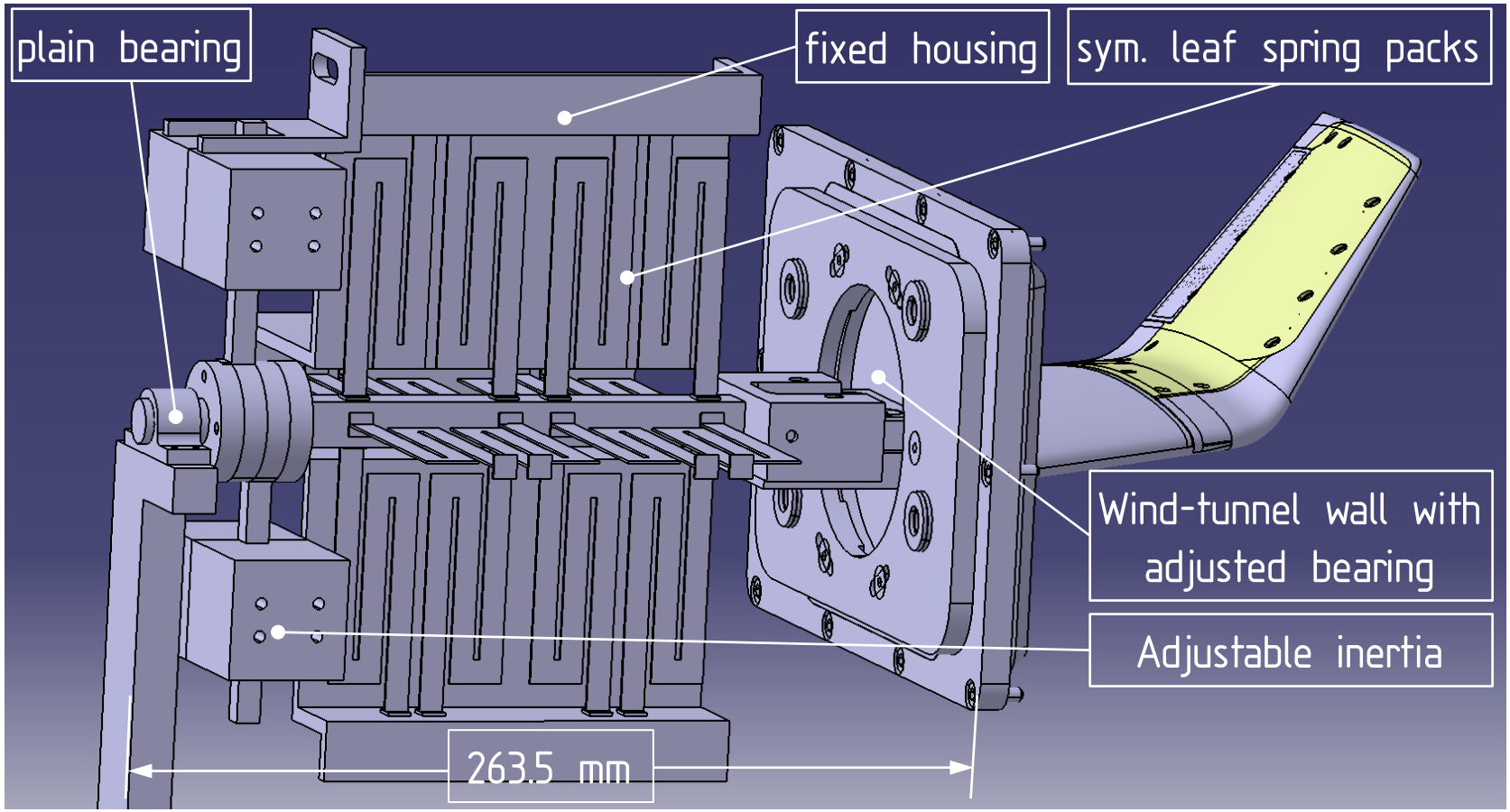
The Experimental Set-up

- Elastic support of the rigid winglet to model a controllable flexible structural behavior

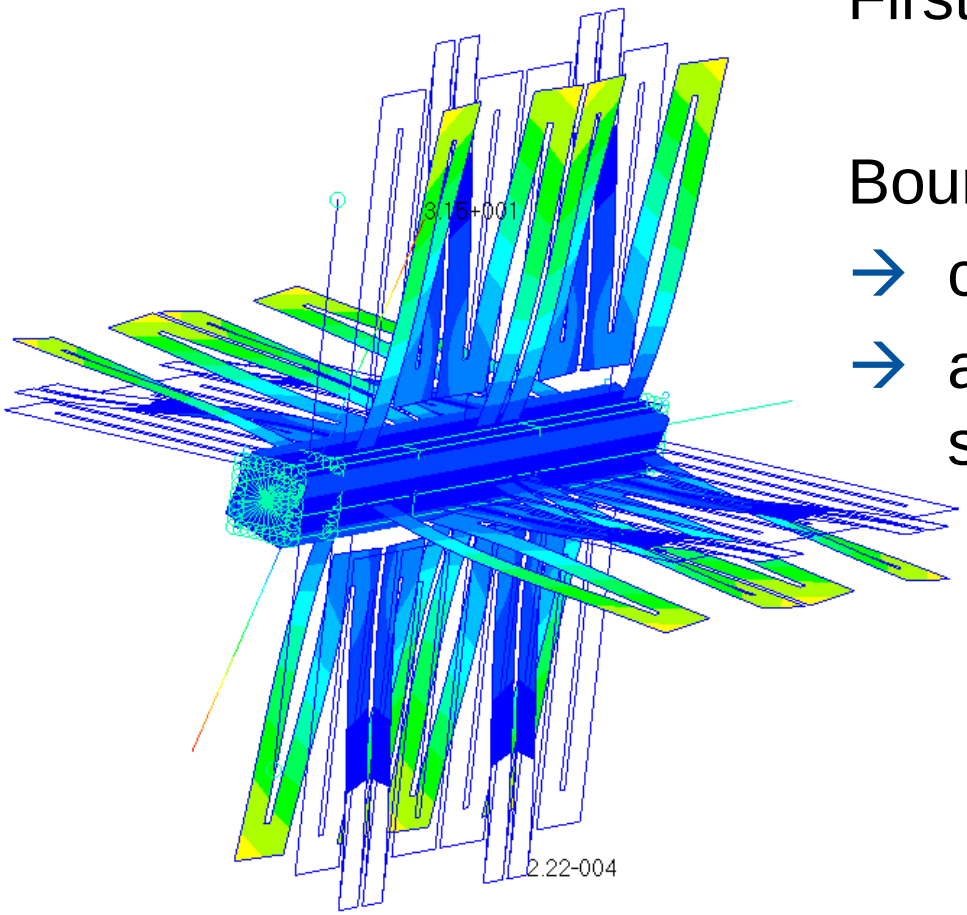
  → One degree of freedom: α-oscillation
  → One mass-spring-oscillator
  → Aeroelastic stable behavior
  → Adjustable natural frequency: 8 Hz – 15 Hz
  → High modal isolation to next structural modes

  1. Mode: 8.2 Hz
  2. Mode: 94.2 Hz

The Experimental Set-up



The Experimental Set-up



First mode at 8.2 Hz

Boundary conditions:

→ clamped on the housing

→ adjusted and floating support on the shaft ends

Experimental Set-up

- General test procedure:
  - → External excitation of aeroelastic stable α-oscillation
  - → Record of structural response decay time histories

	TEST SERIES:	a. without ACS	b. with ACS
AERODYNAMIC STATES:	↳	Comparison of structural responses with/ without ACS	
1. Transonic quasi-steady flow	→	Investigation of control at nonlinear aerodynamic behavior	
2. Unsteady flow	→	Investigation of control at unsteady aerodynamic-structural behavior	

Summary and Next Steps

- Test set-up to investigate active control of unsteady aerodynamic-structural behavior in transonic flow for an α-oscillation

→ Qualification of test assembly
  - ➢ structural, functional, environmental

→ Implementation of modal parameters in the state-space model

→ Design of a control law for a range of parameters

→ Testing and evaluation

Passive Load Control Integrating Vortex Generators on the Wing Surface

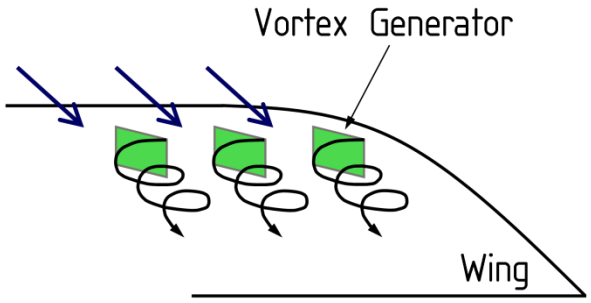
Load alleviation of deformed flexible wings by influencing the boundary layer condition with vortex generators

Outline – Passive Load Control

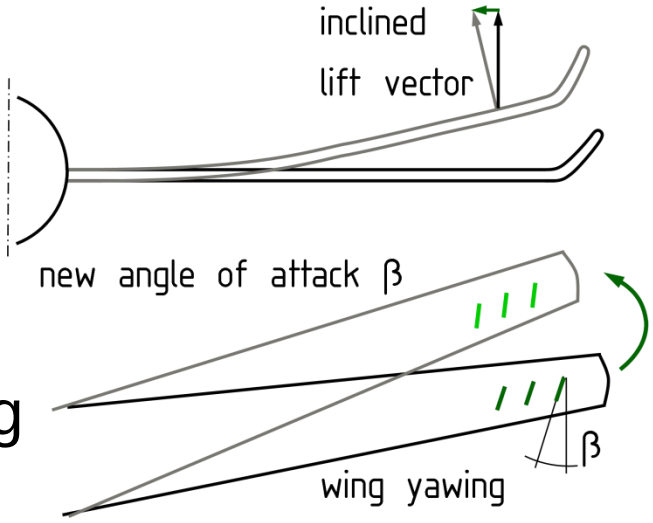
- The Reversed Effect of Vortex Generators
- Preliminary Experiments
- Next Steps and Open Issues

The Reversed Effect of Vortex Generators

- Vortex generators (VGs) energize the boundary layer to increase its resistance to flow separation
  - → VGs mounted with an angle of attack β to the air flow



- Inclined lift vector on a deformed swept wing
  - → Angle of attack β of the VGs reduces

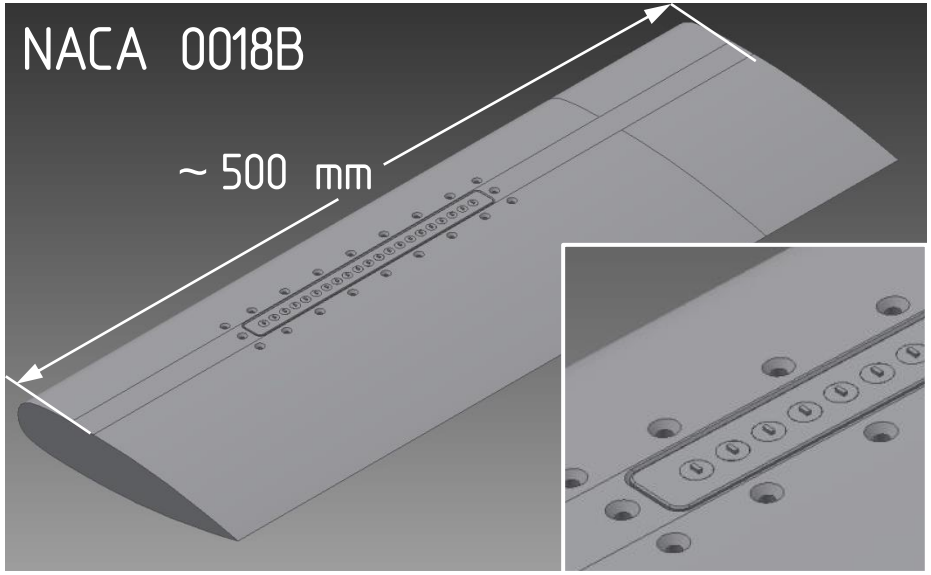


- Flow separation on the outer wing leads to load alleviation

Preliminary Experiments

- Set-up for preliminary water-tunnel experiments

→ Study local aerodynamic influence of vortex generators and record corresponding aerodynamic loads



Test parameters:

- → adjustable angle β
- → varying angle α
- → steady flow condition
- → measurement of velocity fields and loads

Next Steps and Open Issues

- Water-tunnel experiments: Testing and evaluation
- Conclusions about effectiveness
- Adjusted integration on the winglet
- Transonic wind-tunnel testing:
  - → Effectiveness in transonic flow
  - → Unsteady aerodynamic-structural interaction

Thank you for your kind attention!

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4-th EASN Assciation International Workshop on Flight Physics and Aircraft Design
RWTH Aachen University, 27-29 October 2014

WING-LOAD CONTROL VIA FLUIDIC DEVICES

*Janusz Sznajder
Wieńczysław Stalewski

instituteofaviation
warsaw, since 1926

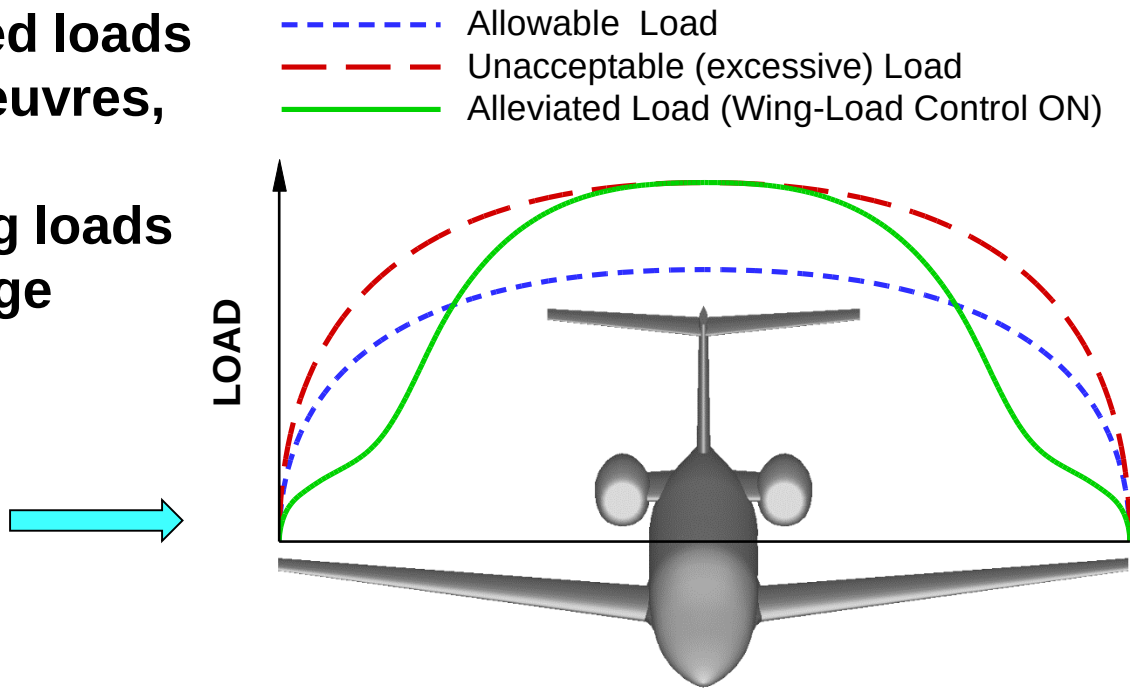
Outline

1. Research Background
2. Research Methodology
3. Results of CFD Simulations
4. Comparison of predicted effectiveness of fluidic devices with results of wind-tunnel tests
5. Summary and Conclusions

Research Background

Wing-Load-Control Systems

- **Developed as means to stabilise flight parameters or mitigate excessive loads acting on a wing structure**
- **Intended for use in flight conditions characterized by increased loads due to accelerated manoeuvres, sudden gusts, etc. in which the growing wing loads may lead to fatigue damage of the wing structure**
- **Reduce bending loads through redistribution of aerodynamic loads along wing span**



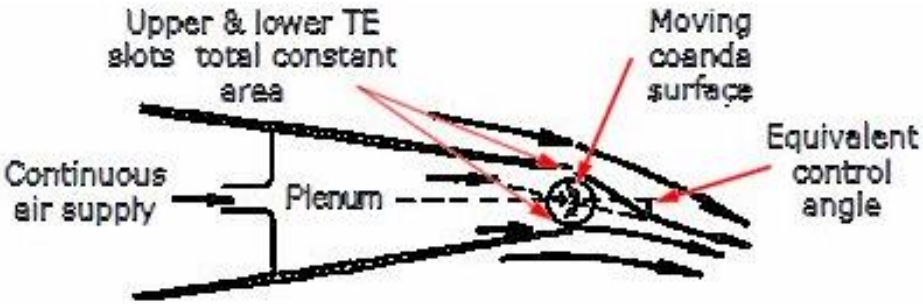
General idea of wing-load-control system used to alleviate unacceptable aerodynamic loads acting on aircraft-wing structure

Research Background

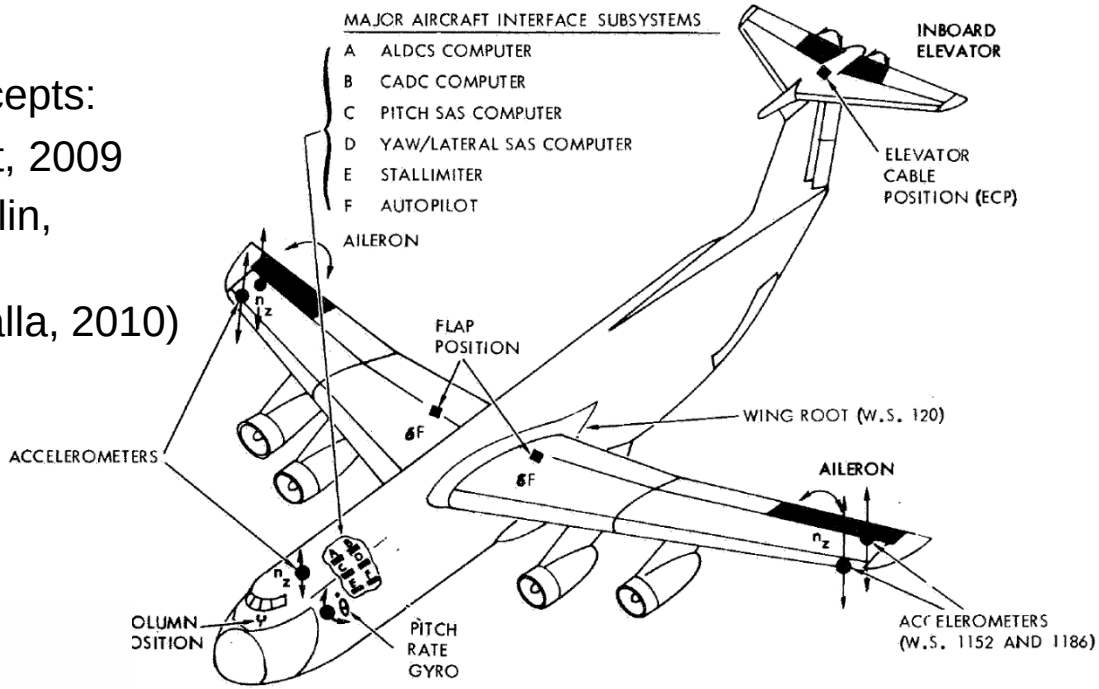
Wing-Load-Control Systems

- Classic: Deflection of Control Surfaces (e.g. ALDCS - Lockheed C-5 Galaxy)
- Innovative Mechanical / Structural Concepts:
  - Mechanical Spoiler – Airbus patent, 2009
  - Additional Control Surfaces, (Moulin, Karpel, 2007)
  - Morphing wing (Vos, Gürdall, Abdalla, 2010)
- Flight / Load Control via Fluidic Devices

(e.g. Cranfiel University, Demon UAV)



source for the picture:
Dr A. SAVVARIS
Department Aerospace Science, Cranfield University
"FLAVIIR UAV Operations and Technology Integration", 2007



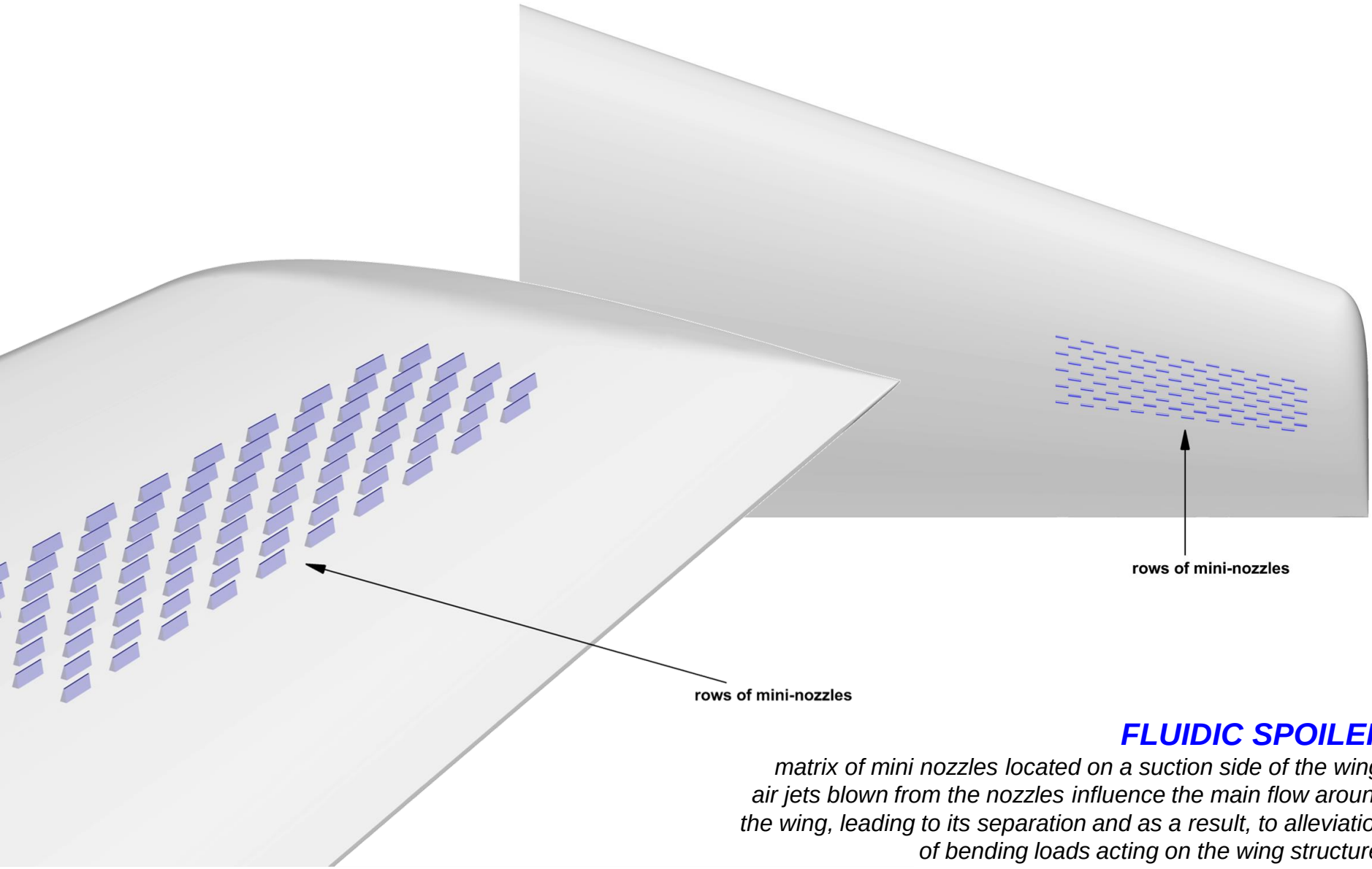
The Lockheed C-5 Galaxy
Active Lift Distribution Control System (ALDCS)

source for the picture: Wiliam J. Hargrove
„The C5A Active Wing Load Control System", NASA-TM X-3409, 1976

Flow/Load-Control Concepts

- **European Project STARLET**
- **Conducted by Institute of Aviation, Warsaw, co-Financed by:**
  - Clean Sky Joint Undertaking,
  - Institute of Aviation,
  - Ministry of Science of Poland
- **Focused on application of fluidic devices for active control of loads acting on an aircraft wing**
- **Within the Project three Concepts of Fluidic Devices dedicated to Wing-Load Control have been developed:**
  - FLUIDIC SPOILER
  - Double Trailing-Edge Nozzle (DTEN) System
  - LEAKY WING

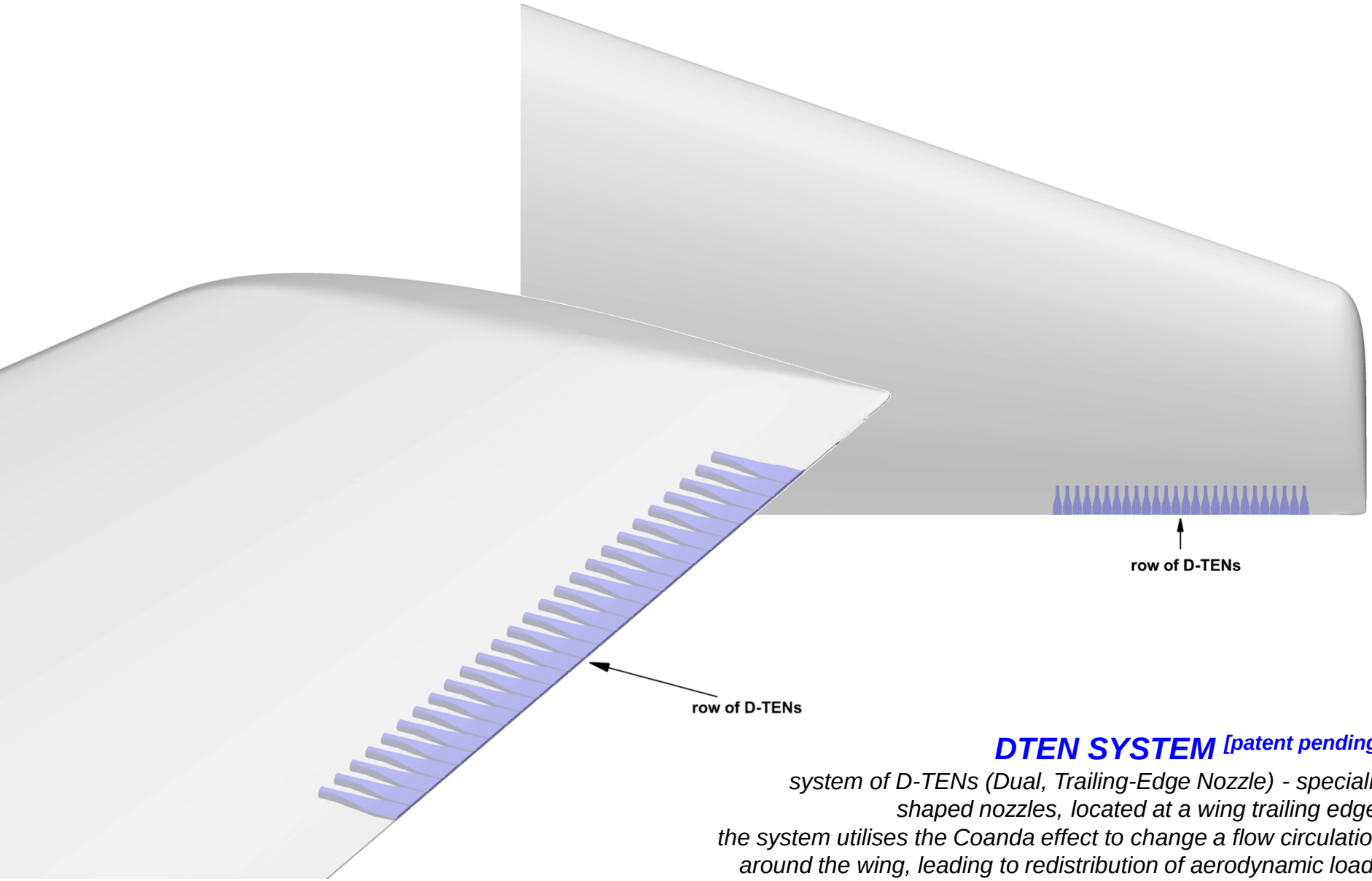
Flow/Load-Control Concepts – FLUIDIC SPOILER



FLUIDIC SPOILER

matrix of mini nozzles located on a suction side of the wing; air jets blown from the nozzles influence the main flow around the wing, leading to its separation and as a result, to alleviation of bending loads acting on the wing structure.

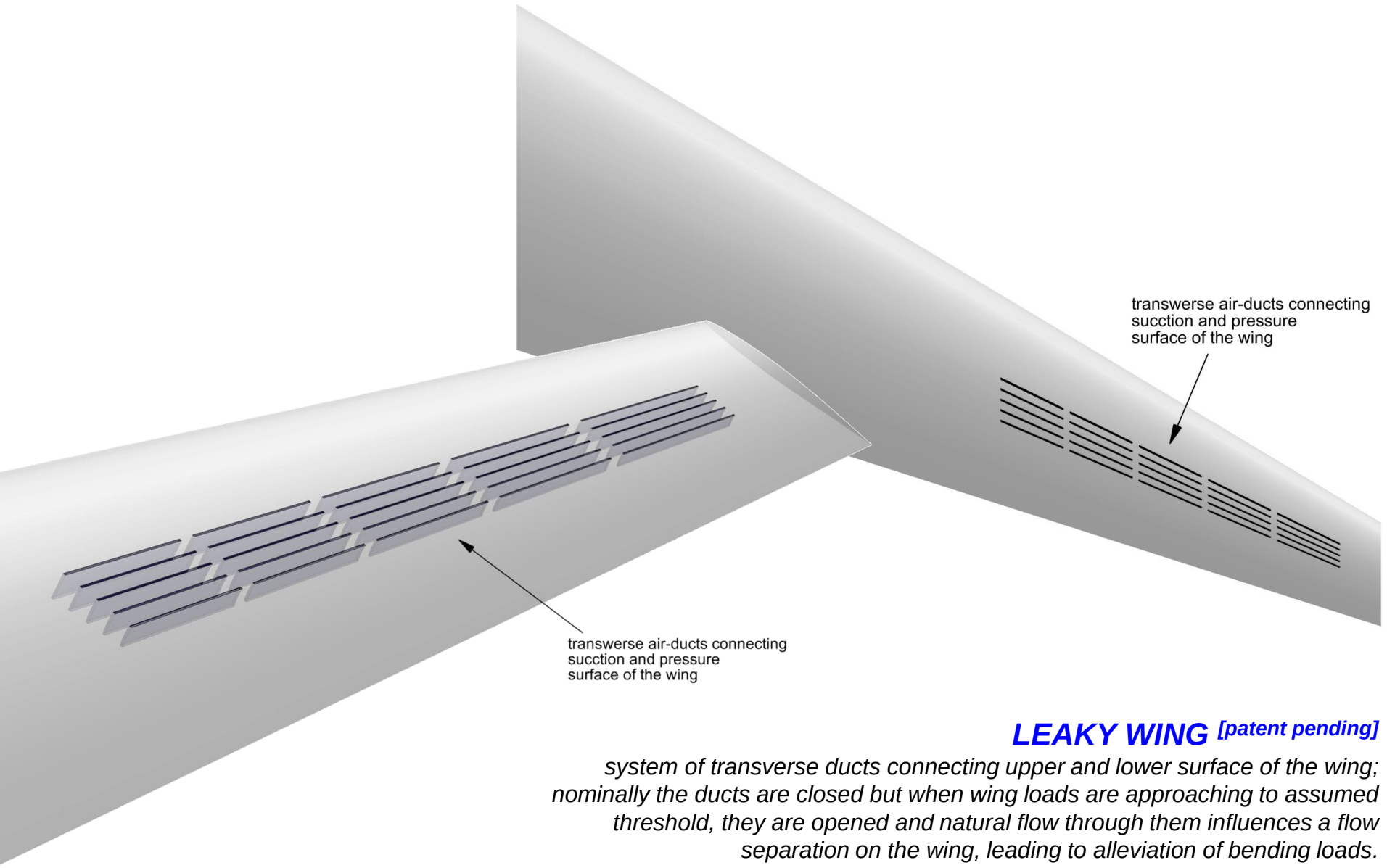
Flow/Load-Control Concepts – DTEN System



DTEN SYSTEM ***[patent pending]***

system of D-TENs (Dual, Trailing-Edge Nozzle) - specially shaped nozzles, located at a wing trailing edge; the system utilises the Coanda effect to change a flow circulation around the wing, leading to redistribution of aerodynamic loads

Flow/Load-Control Concepts – LEAKY WING



LEAKY WING ***[patent pending]***

system of transverse ducts connecting upper and lower surface of the wing; nominally the ducts are closed but when wing loads are approaching to assumed threshold, they are opened and natural flow through them influences a flow separation on the wing, leading to alleviation of bending loads.

Research Subject and Methodology

Scope of the Research

Investigations of the effectiveness of load alleviation using the proposed concepts of fluidic flow control in simulated gust conditions

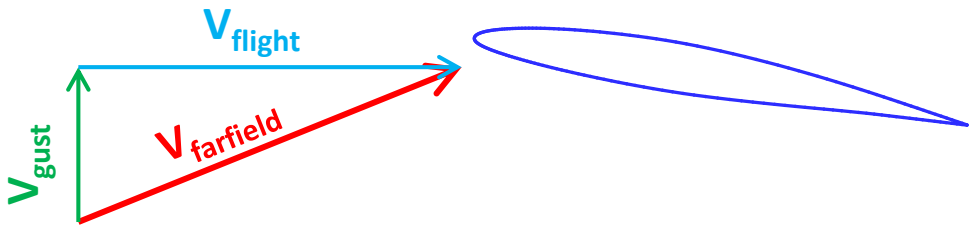
Methodology

- **3D CFD simulations: URANS solver ANSYS FLUENT**
- **Flow Model : URANS**
  - unsteady
  - compressible
  - viscous
  - model of turbulence: k-ω SST
- **Computational Mesh:**
  high quality and resolution (y^+ <= 1), especially within the regions of boundary layers, aerodynamic wakes and in proximity of fluidic devices
- **Investigated Configurations**
  - Active Wing-Load-Control System
  - Clean Wing (reference)

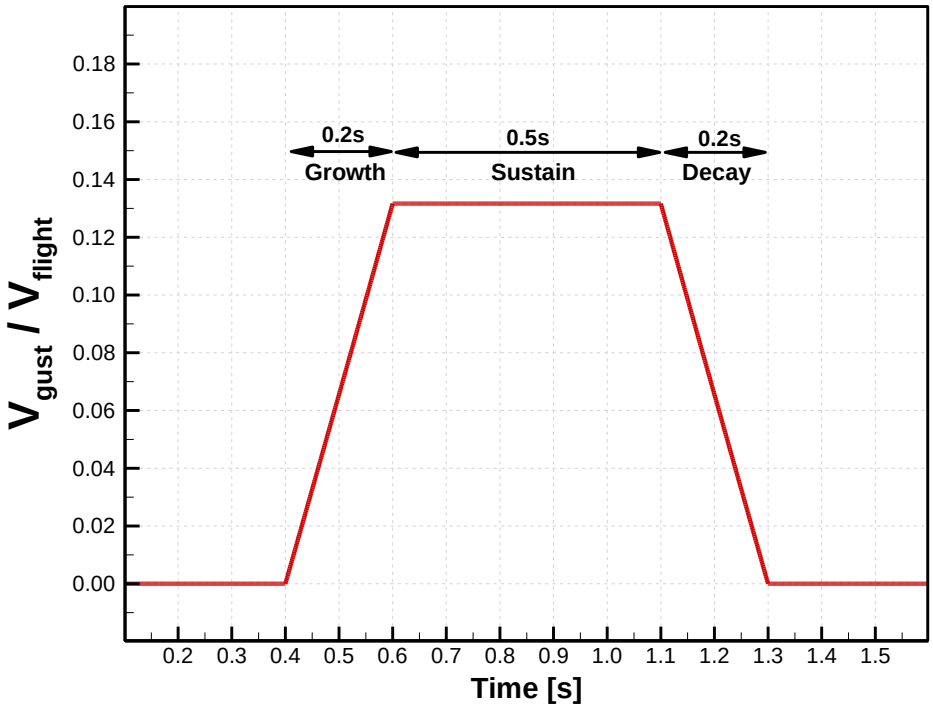
Methodology - CFD Simulations

- CFD study on efficiency and rate of load-alleviation of the developed concepts in sudden-gust conditions
- 3D URANS simulations
- Gust simulation

$$\vec{V}_{farfield} = \vec{V}_{flight} + \vec{V}_{gust}$$



- Gust profile



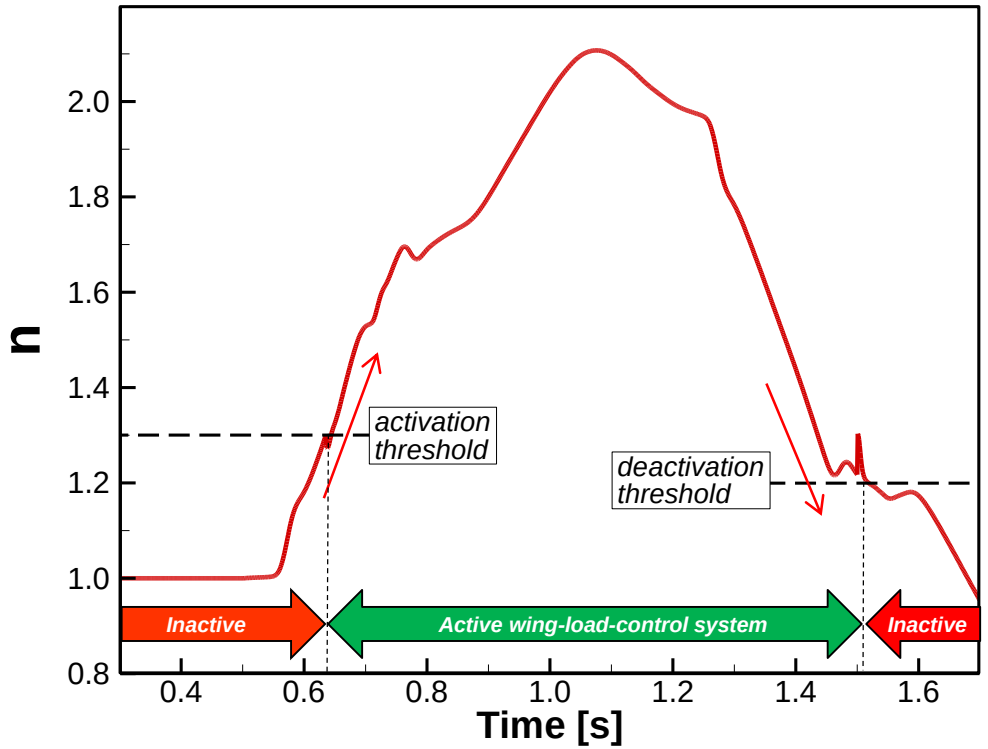
CFD Simulations – Closed Loop Control

Simple Closed-Loop-Control (CLC) system:

- Monitored: **n - load factor**

$$n = \frac{LIFT\ FORCE}{AIRCRAFT\ WEIGHT}$$

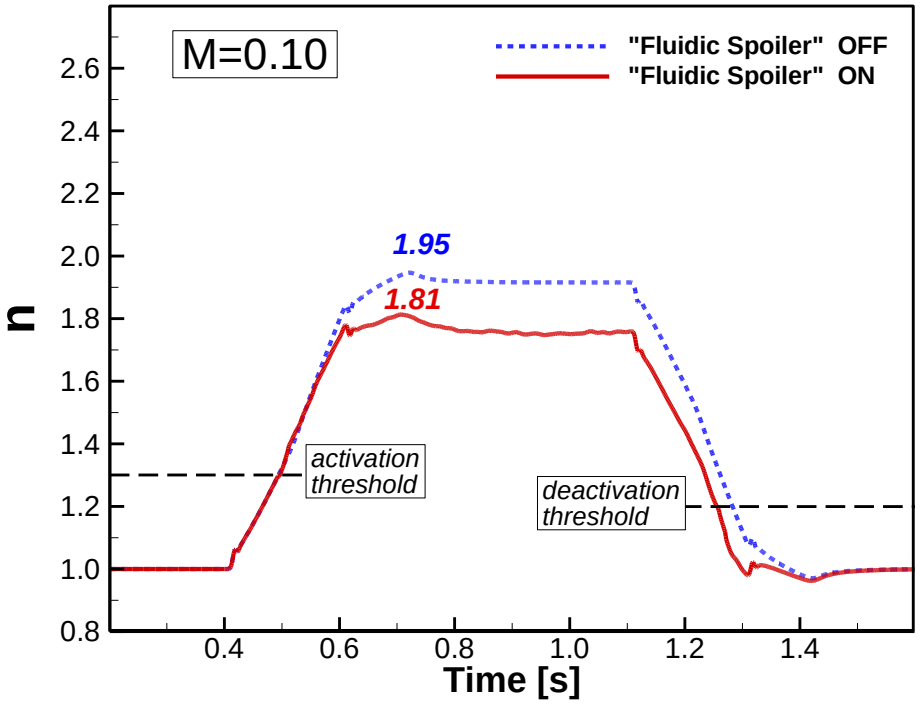
- CLC Algorithm
  - Load Control **ACTIVE**, **if** { **n** is increasing **and** **n** > 1.3 }
  - Load Control **INACTIVE**, **if** { **n** is decreasing **and** **n** < 1.2 }



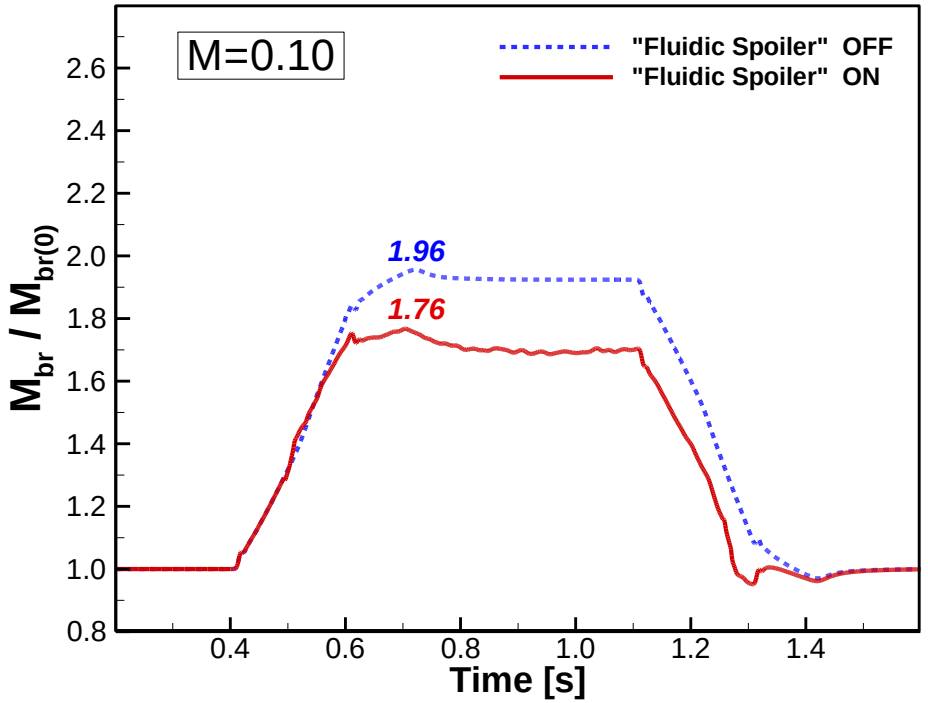
CFD Simulations – FLUIDIC SPOILER , M=0.10

reduction of maximum value of Load Factor
≈7%

alleviation of maximum Wing-Root Bending Moment
≈10%



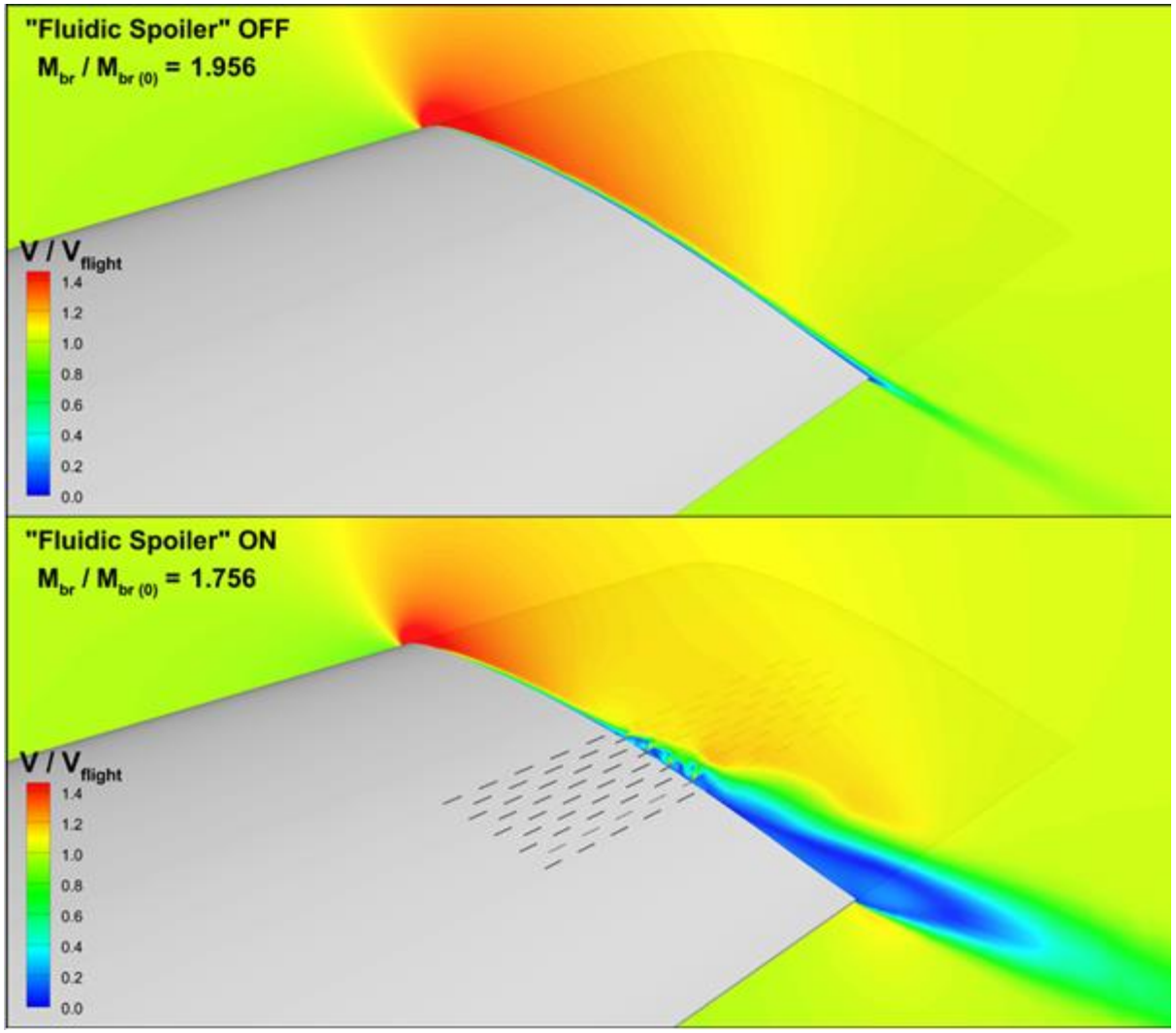
Comparison of time histories of LOAD FACTOR, for the "Fluidic Spoiler" OFF and ON.



Comparison of time histories of WING-ROOT BENDING MOMENT, for the "Fluidic Spoiler" OFF and ON.

n - *load factor : n = Lift / Weight*
M_{br} - *wing-root bending moment*
$M_{br(0)}$ - *wing-root bending moment in normal, cruise-flight conditions*

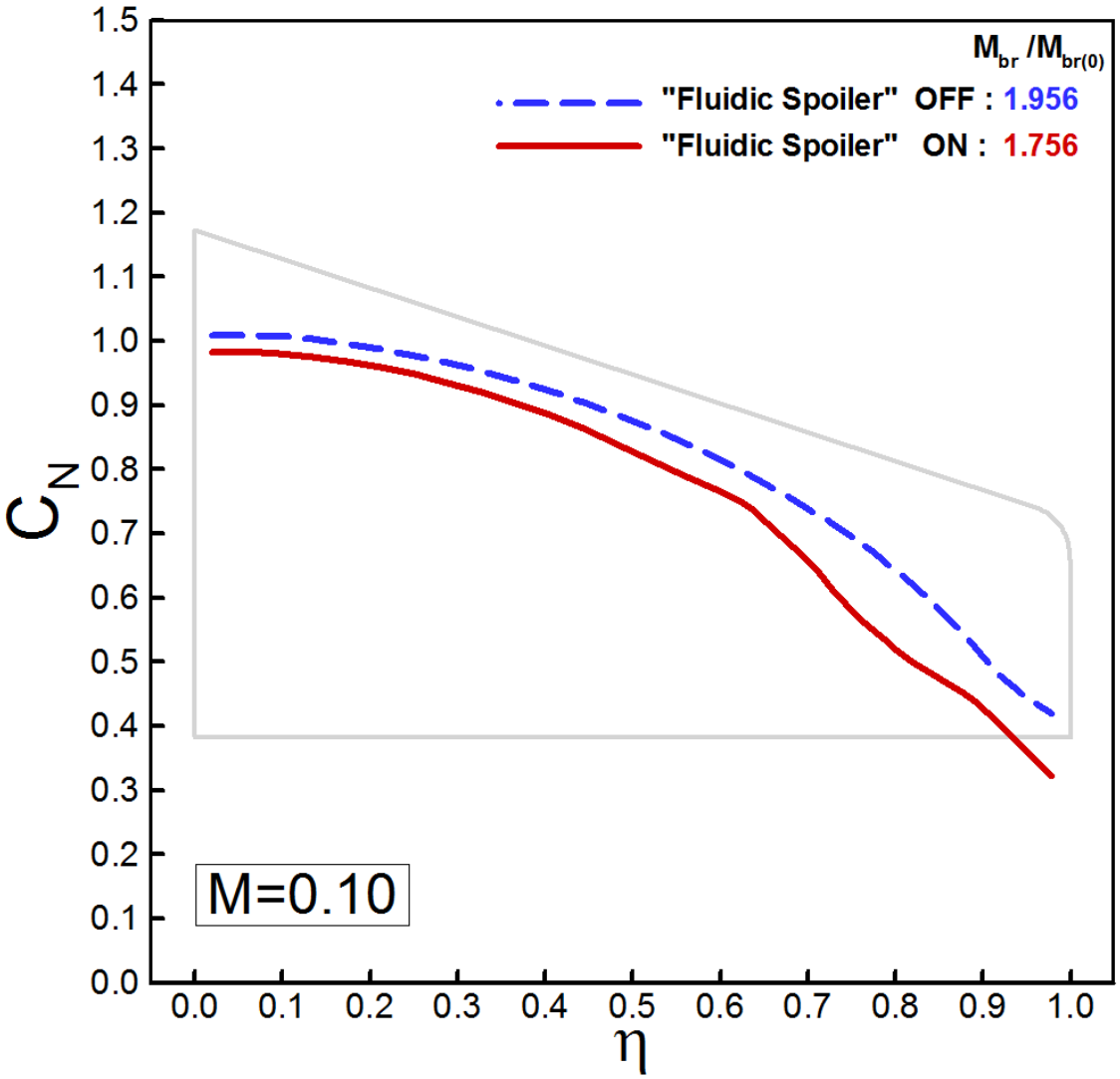
CFD Simulations – FLUIDIC SPOILER , M=0.10



Comparison of Velocity Magnitude Contours for the "Fluidic Spoiler" OFF and ON.

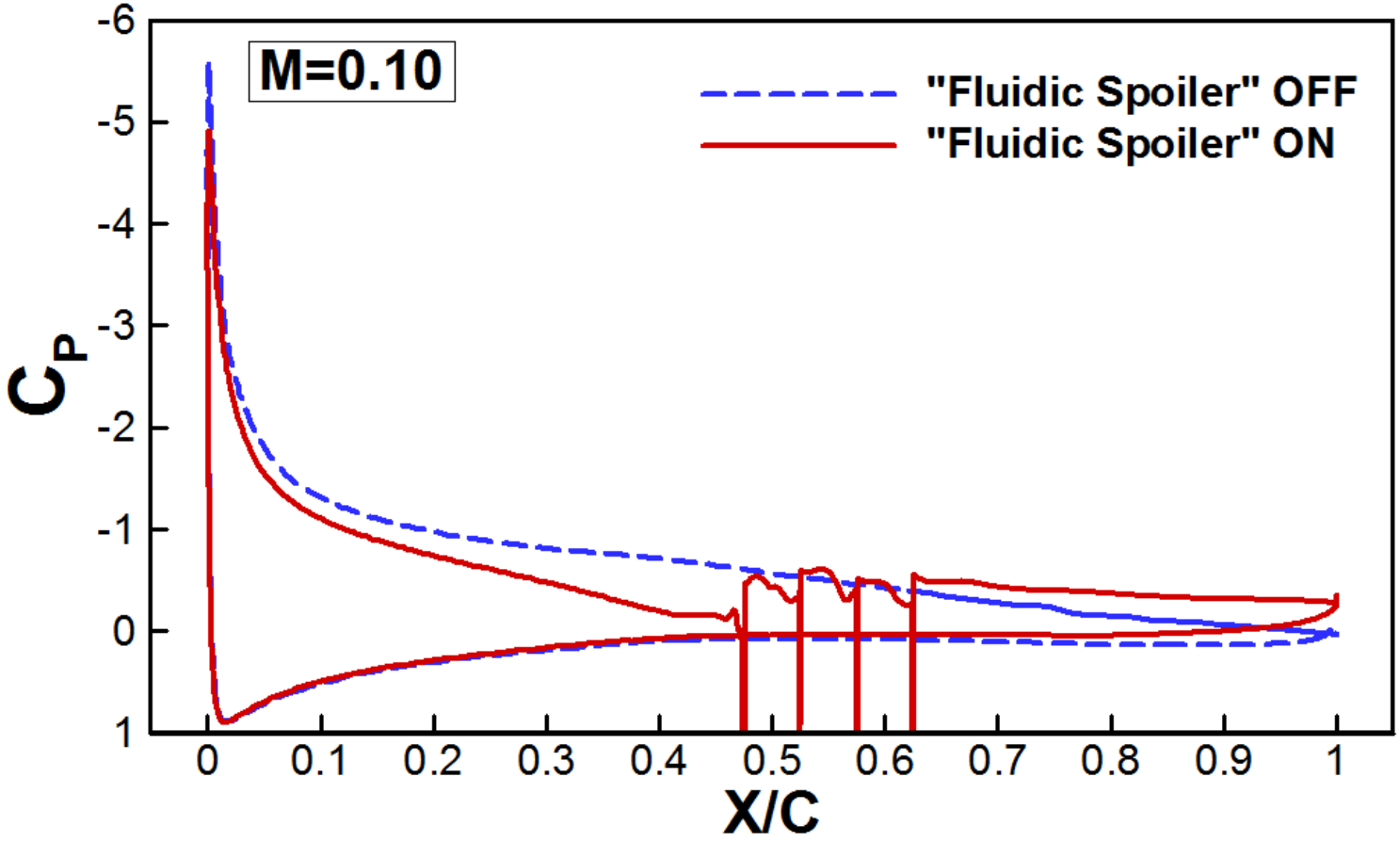
The case of the highest values of Wing-Root Bending Moment.

CFD Simulations – FLUIDIC SPOILER , M=0.10



Comparison of spanwise distribution of aerodynamic bending-load coefficient (C_N), for the "Fluidic Spoiler" system OFF and ON. The case of the highest values of measured wing-root bending moment at flight speed M=0.1.

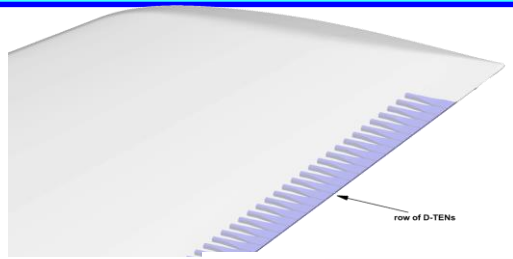
CFD Simulations – FLUIDIC SPOILER , M=0.10



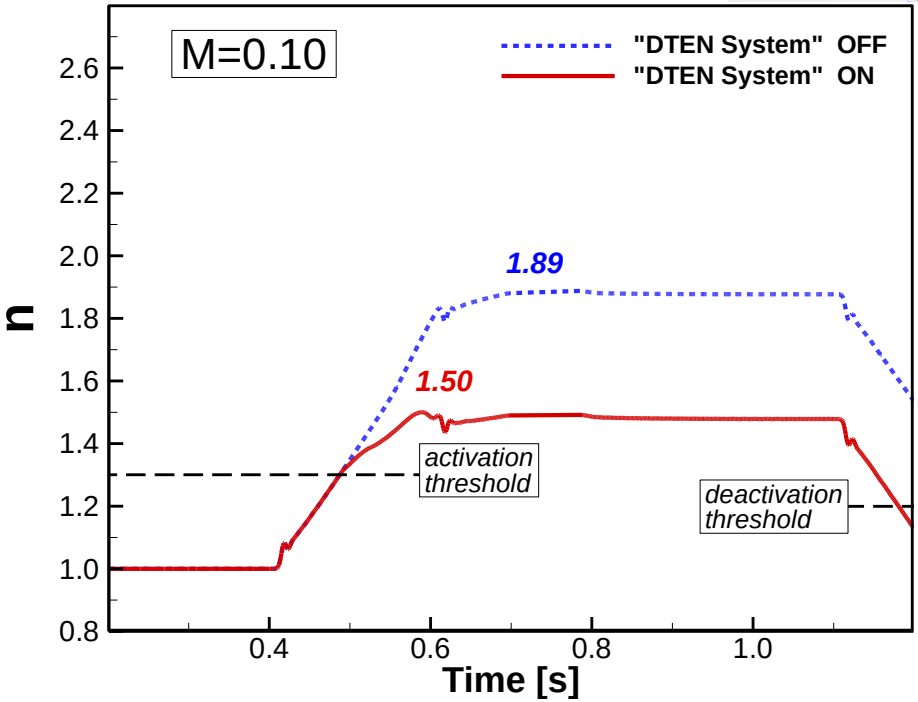
Comparison of chordwise distribution of pressure coefficient (C_P), for the "Fluidic Spoiler" system OFF and ON. .
The case of the highest values of measured wing-root bending moment at flight speed M=0.10.

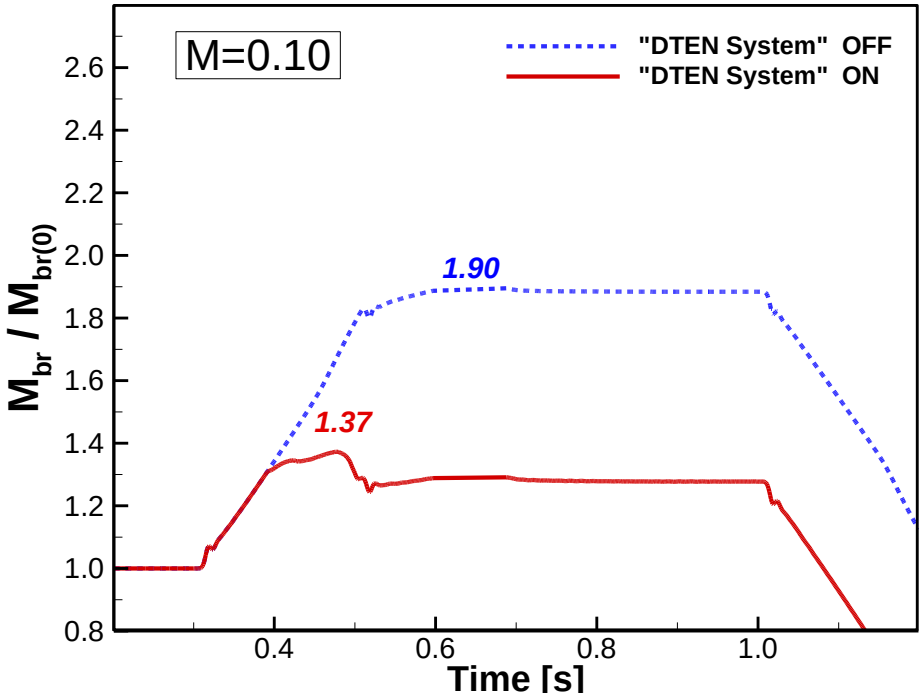
CFD Simulations – DTEN System, M=0.10

reduction of maximum value of Load Factor ***≈22%***



alleviation of maximum Wing-Root Bending Moment ***≈29%***





Comparison of time histories of LOAD FACTOR, for the "DTEN System" OFF and ON.

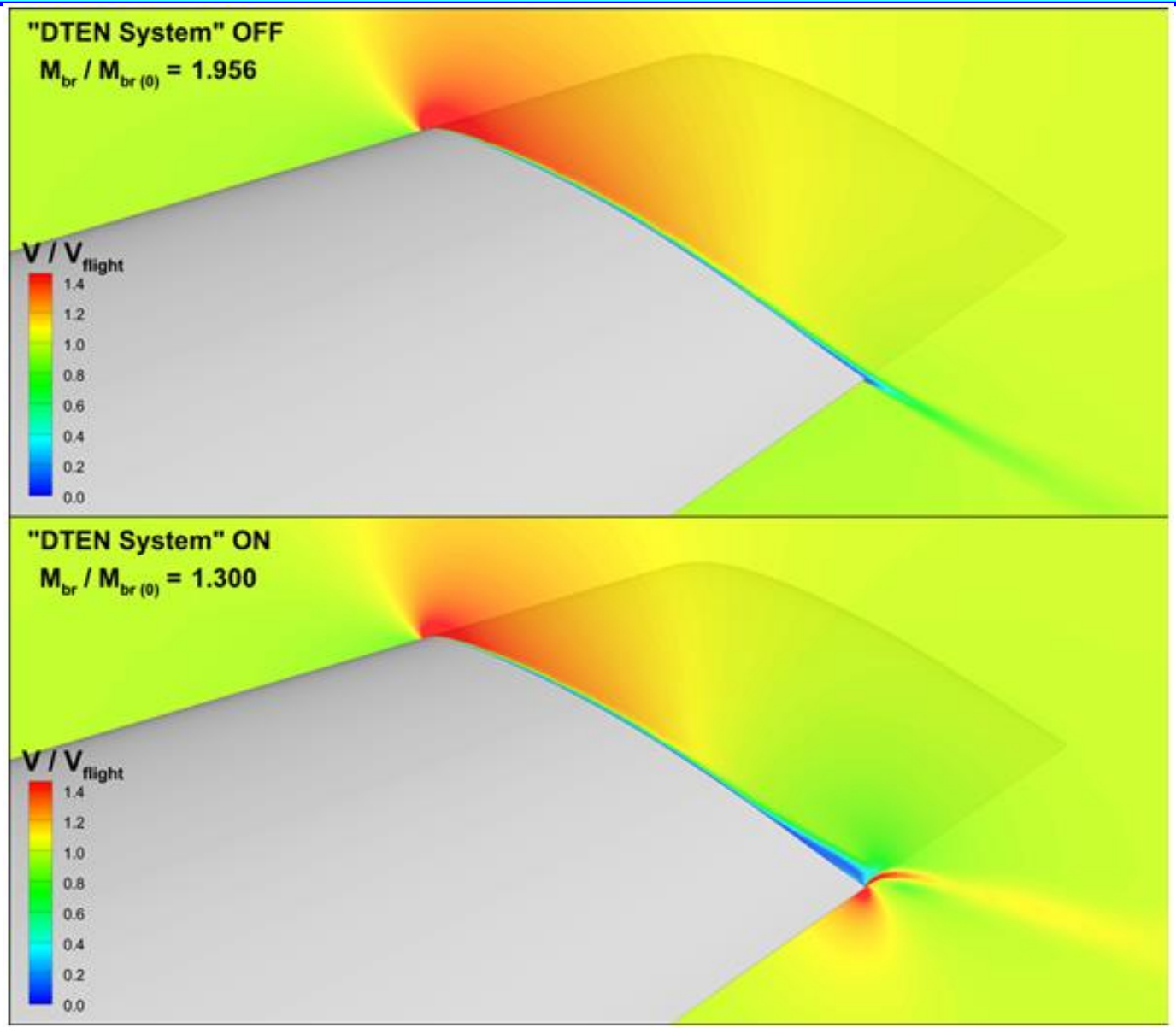
Comparison of time histories of WING-ROOT BENDING MOMENT, for the " DTEN System" OFF and ON.

n - load factor : n = Lift / Weight

M_{br} - wing-root bending moment

$M_{br(0)}$ - wing-root bending moment in normal, cruise-flight conditions

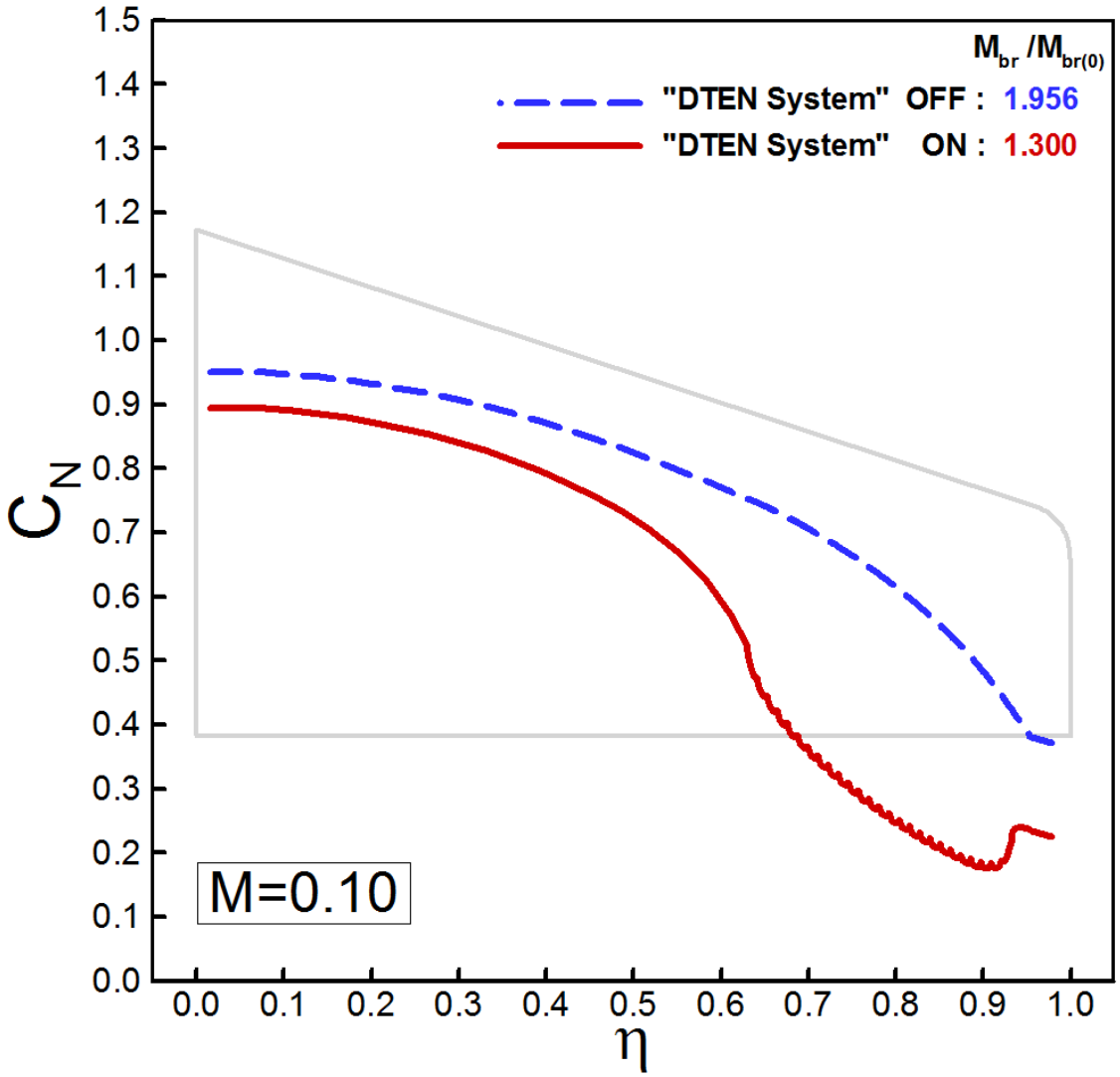
CFD Simulations – DTEN System, M=0.10



Comparison of Velocity Magnitude Contours for the "DTEN System" OFF and ON.

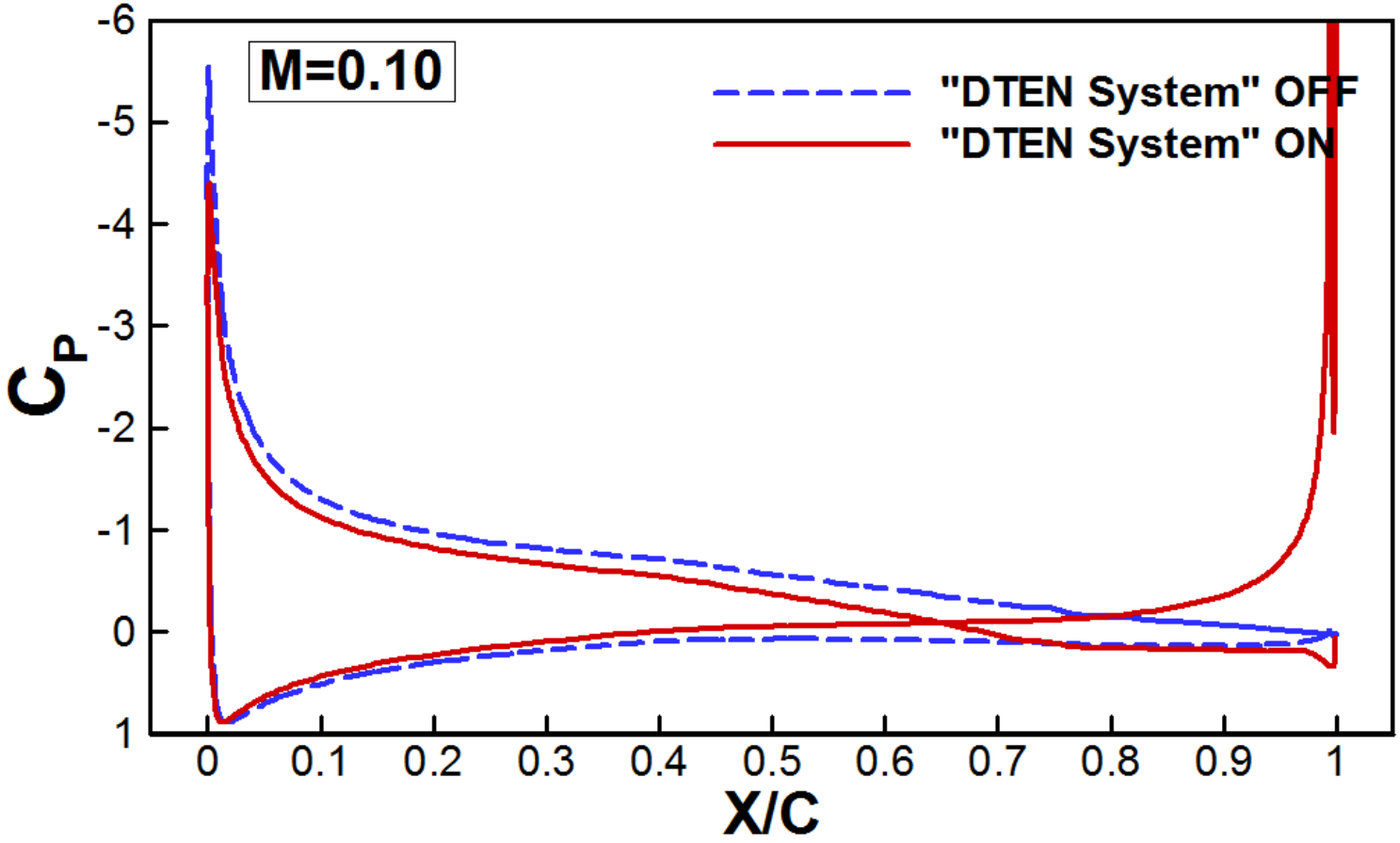
The case of the highest values of Wing-Root Bending Moment.

CFD Simulations – DTEN System, M=0.10



Comparison of spanwise distribution of aerodynamic bending-load coefficient (C_N), for the "DTEN System" system OFF and ON. The case of the highest values of measured wing-root bending moment at flight speed M=0.1.

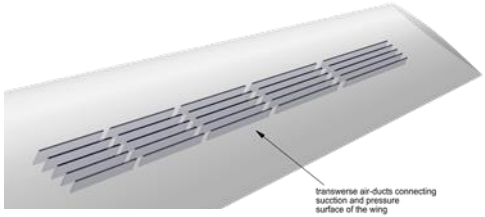
CFD Simulations – DTEN System, M=0.10



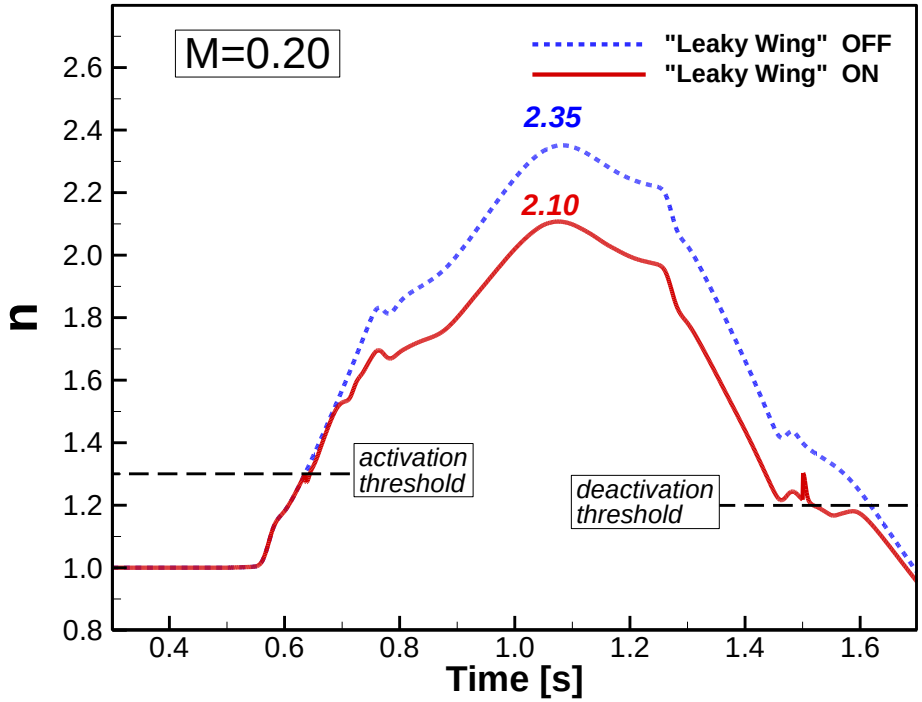
Comparison of chordwise distribution of pressure coefficient (C_P), for the " DTEN System" system OFF and ON. .
The case of the highest values of measured wing-root bending moment at flight speed M=0.10.

CFD Simulations – LEAKY WING , M=0.20

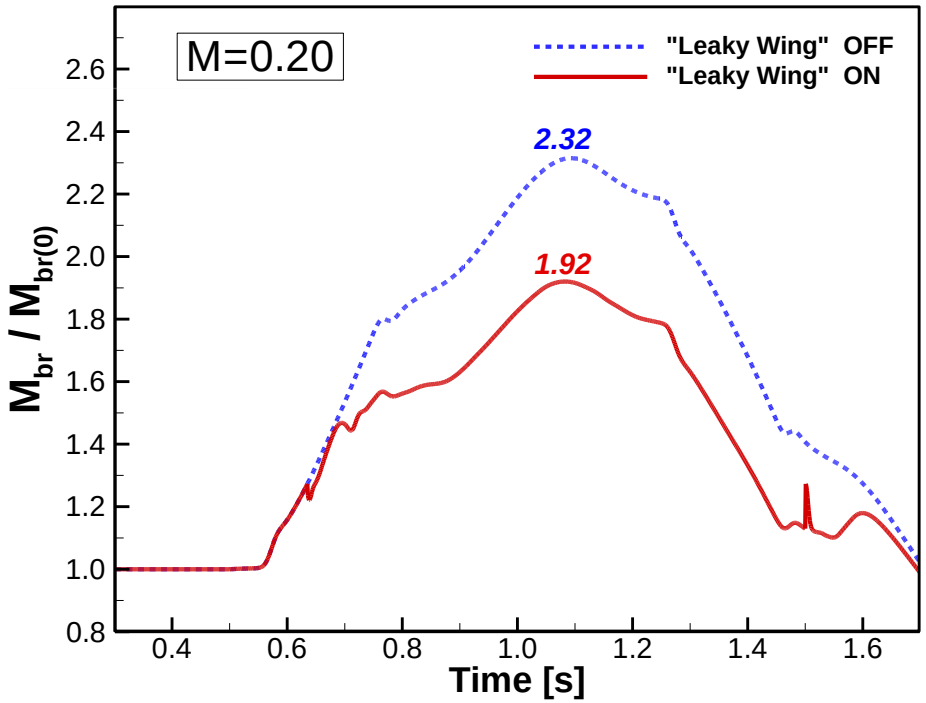
reduction of maximum value of Load Factor ***≈11%***



alleviation of maximum Wing-Root Bending Moment ***≈17%***



Comparison of time histories of LOAD FACTOR, for the "Leaky Wing" System OFF and ON.



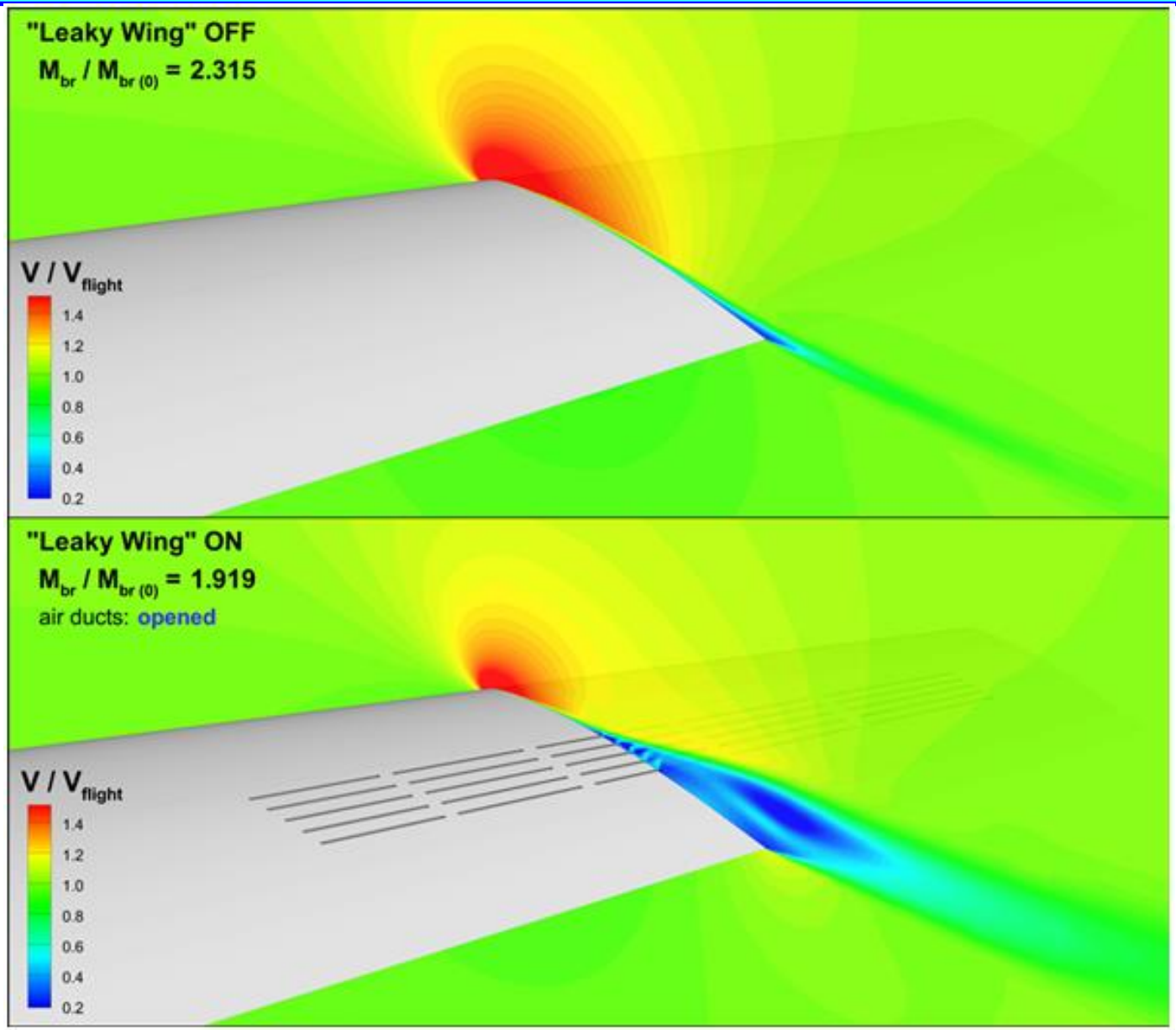
Comparison of time histories of WING-ROOT BENDING MOMENT, for the "Leaky Wing" System OFF and ON.

n - *load factor : n = Lift / Weight*

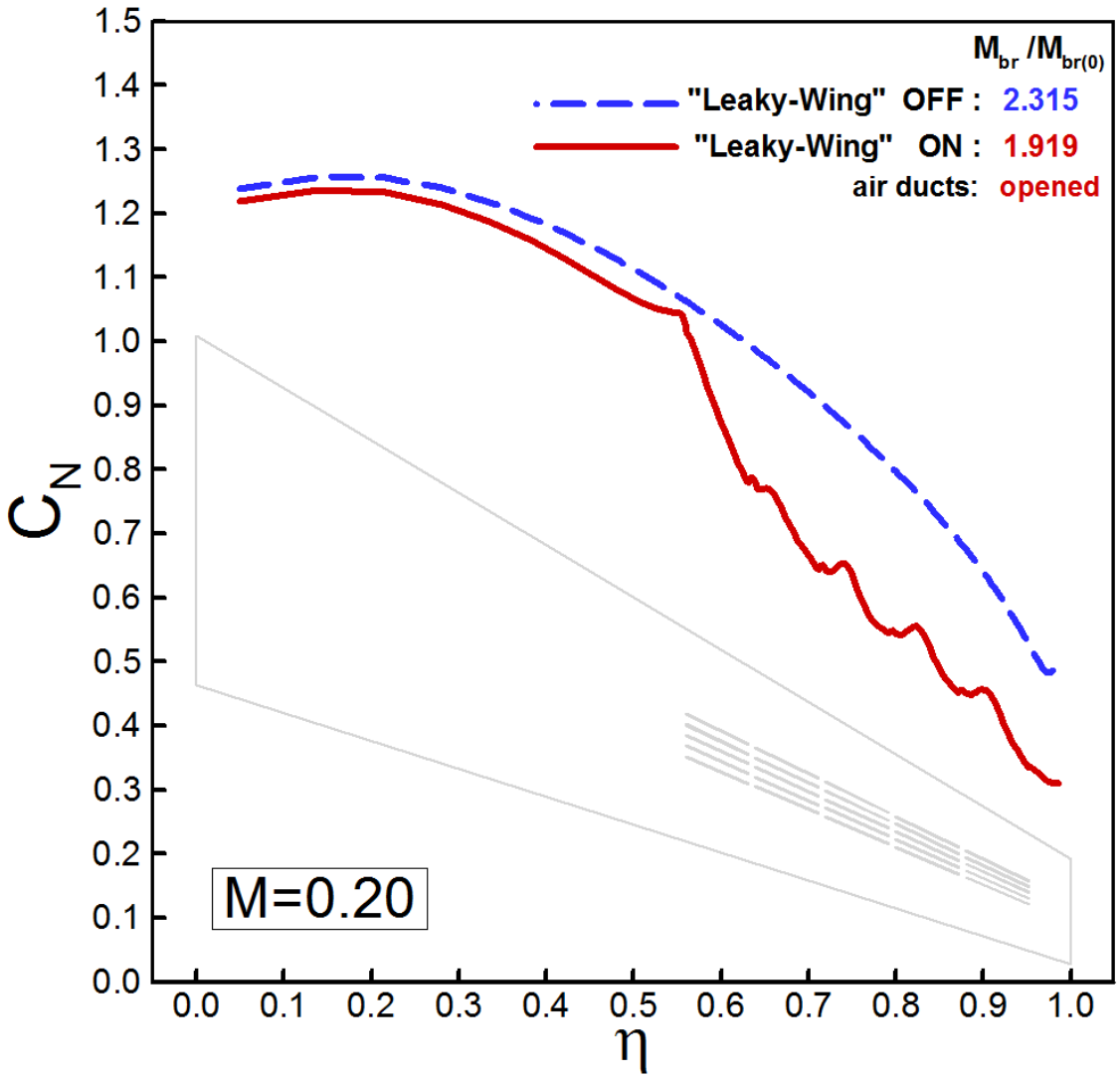
M_{br} - *wing-root bending moment*

$M_{br(0)}$ - *wing-root bending moment in normal, cruise-flight conditions*

CFD Simulations – LEAKY WING , M=0.20

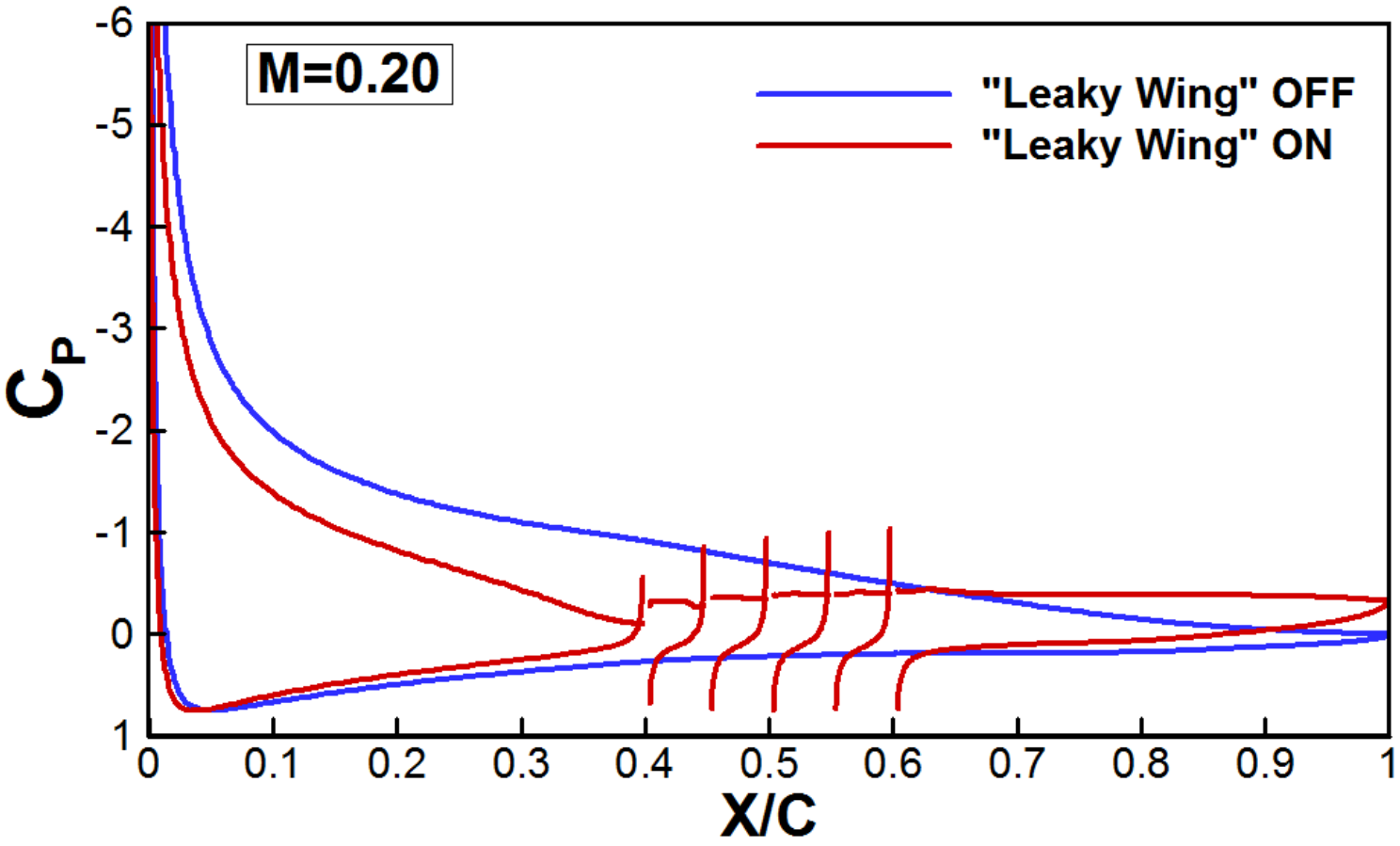


CFD Simulations – LEAKY WING , M=0.20



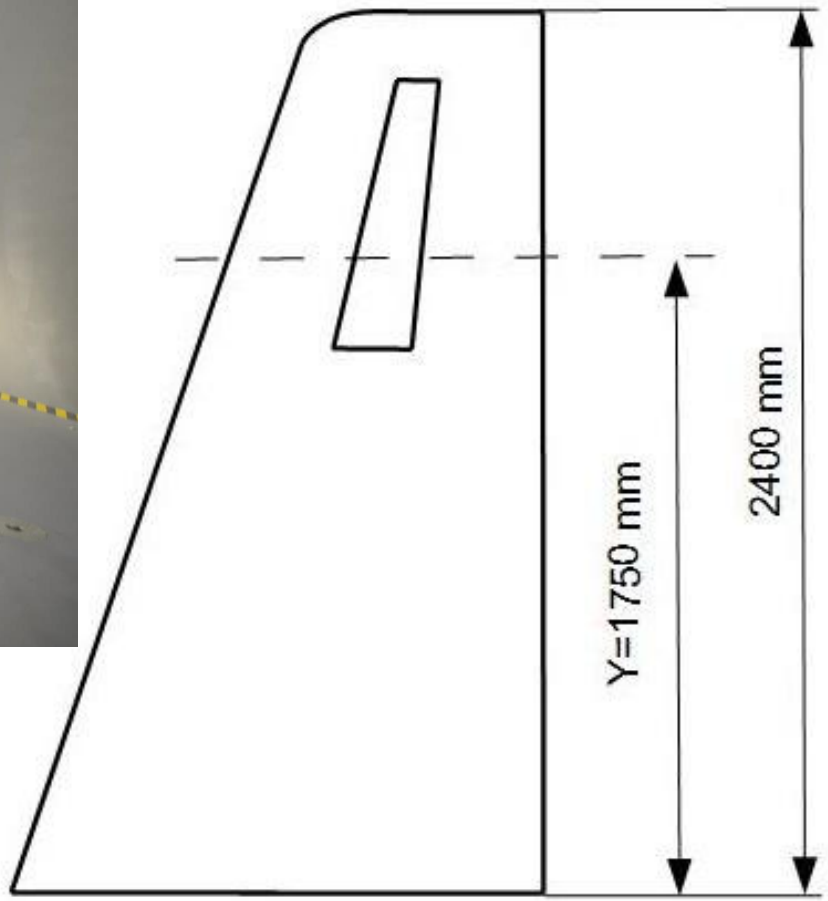
Comparison of spanwise distribution of aerodynamic bending-load coefficient (C_N), for the "Leaky Wing" system OFF and ON. The case of the highest values of measured wing-root bending moment at flight speed M=0.20.

CFD Simulations – LEAKY WING , M=0.20



Comparison of chordwise distribution of pressure coefficient (C_P), for the "Leaky Wing" system OFF and ON. .
The case of the highest values of measured wing-root bending moment at flight speed M=0.20.

CFD Results vs. WTT Results



Test conditions: M=0.1, Re=2.4 mln, α= 0 - 12°

Wing model in 5-meter-diameter WTT section, location of pressure-test cross-section.

CFD Results vs. WTT Results

Measure of effectiveness of fluidic devices:

Wing-root bending moment alleviation coefficient,

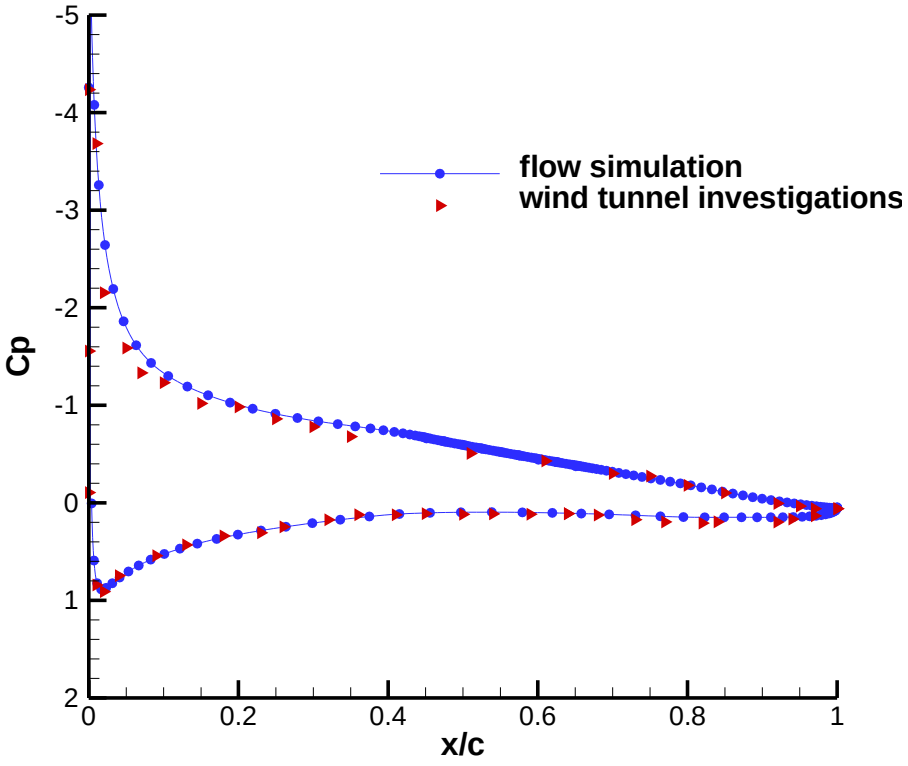
$$C_{BMA} = \frac{M_{B\,ref} - M_{B\,alleviated}}{M_{B\,ref}}$$

$M_{B\,ref}$ – reference wing-root bending moment with fluidic devices inactive

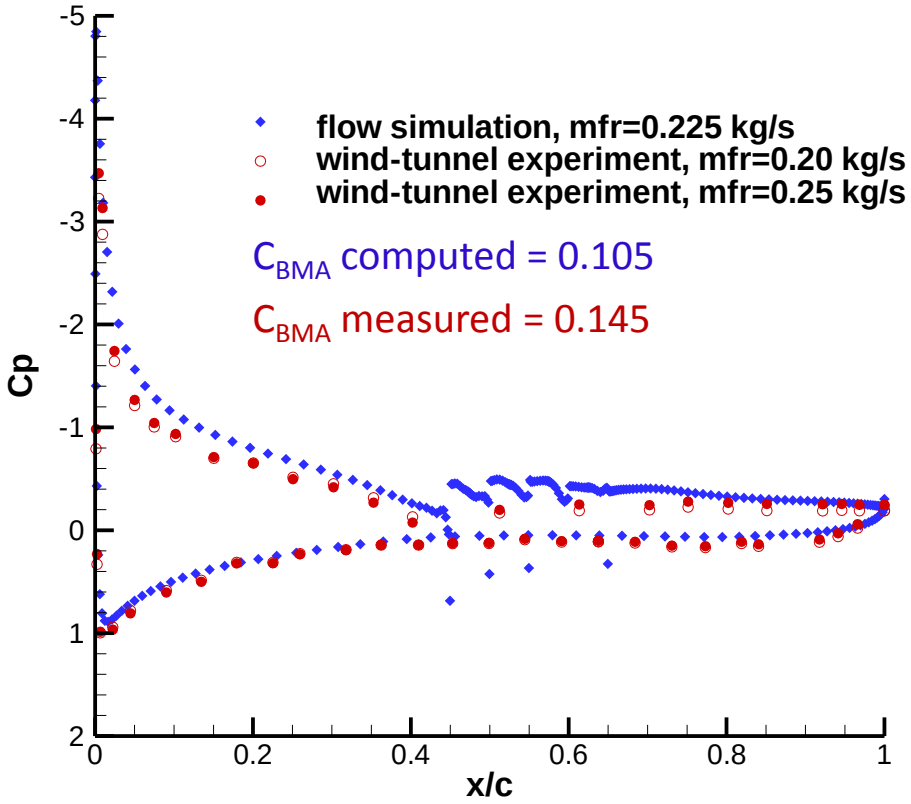
$M_{B\,alleviated}$ – wing-root bending moment with fluidic devices activated

CFD Results vs. WTT Results

fluidic devices inactive



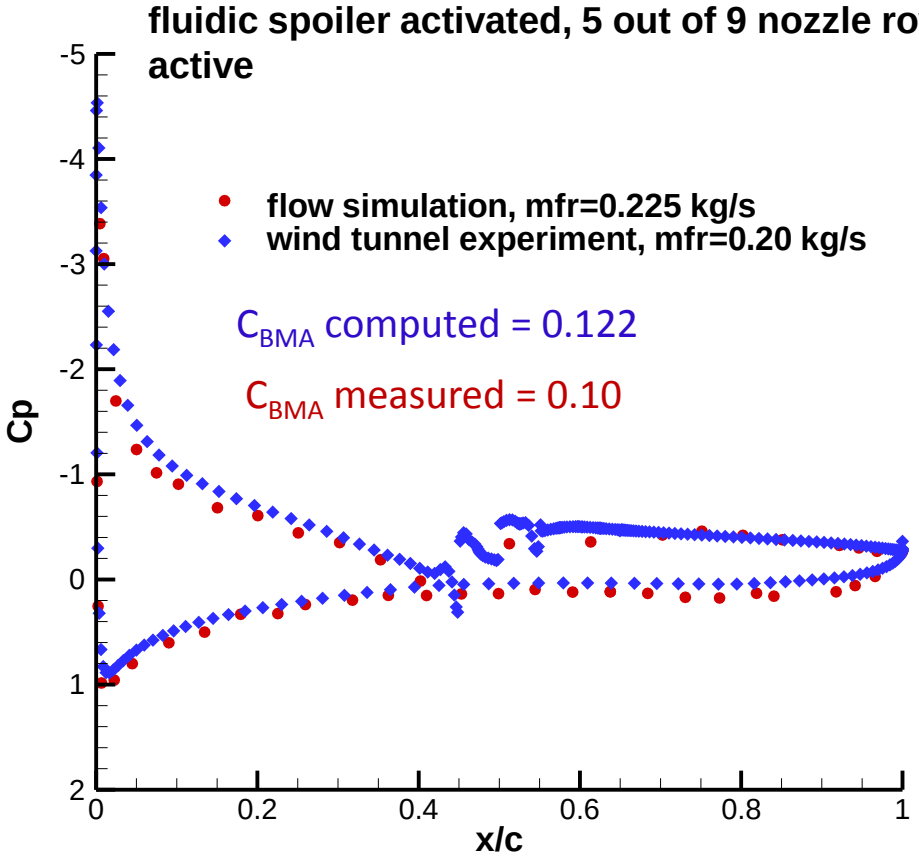
fluidic spoiler activated, 9 nozzle rows active

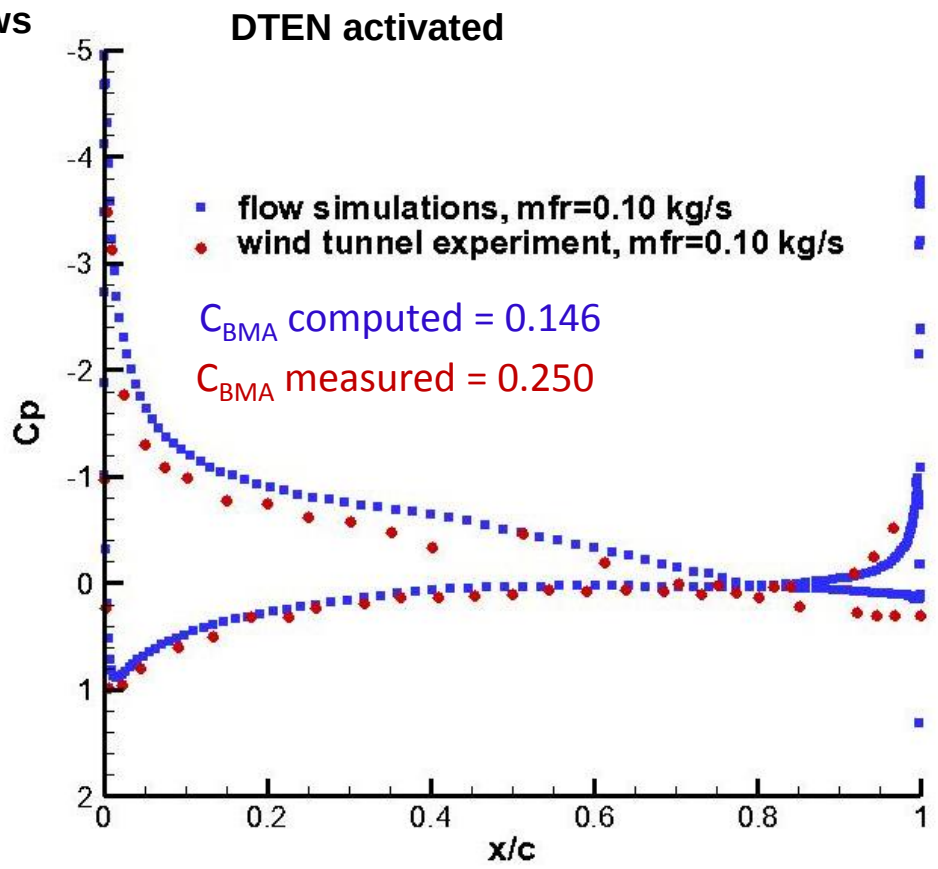


Distribution of pressure coefficient in control test sections, M=0.1, Re=2.4 mln, α=10°

Source of experimental data: dr Andrzej Krzysiak & staff of Laboratory of Aerodynamic Investigations, Institute of Aviation

CFD Results vs. WTT Results





Distribution of pressure coefficient in control test sections, M=0.1, Re=2.4 mln, α=10°

Source of experimental data: dr Andrzej Krzysiak & staff of Laboratory of Aerodynamic Investigations, Institute of Aviation

Summary and Conclusions

- **The developed concepts of fluidic load control were investigated by 3D URANS simulations, conducted in conditions of sudden gust and in static tests both computational and experimental.**
- **Based on results of the simulations, it may concluded that:**
  - All investigated concepts alleviated harmful effects of sudden gust fast enough to achieve significant reduction of root-bending moment and load factor in gust.
  - The wing-root-bending-moment-alleviation effectiveness was approximately:
    - **10%** for the Fluidic Spoiler
    - **30%** for the DTEN System
    - **17%** for the Leaky Wing

Summary and Conclusions

- **The efficiency of the developed concept depends on several factors, both geometric and fluidic. It is expected that the efficiency could be increased through a thorough optimisation, which could be subject of future research.**
- **All three presented concepts seem to be feasible to adapt and implement in the real aircraft. However, safety, reliability and influence of the concepts on aircraft stability and controllability need further investigations.**
- **The concepts may be naturally adapted to cases of other lifting surfaces exposed to excessive aerodynamic loads, for example to rotor blades of wind turbines. Such application seems to be especially reasonable in the case of Leaky Wing concept.**

Acknowledgements

The resulted presented here were obtained in the project „Basic Wind Tunnel Investigations to Explore the Use of Active Flow Control Technology for Aerodynamic Load Control”, acronym "STARLET" conducted by Institute of Aviation, Warsaw,

co-financed by the Clean Sky Joint Undertaking, Grant Agreement No. CS-GA-2011-01-296345 and by

Ministry of Science of Republic of Poland by funds allocated for supporting scientific research in international, co-financed projects in 2012-2014 , Agreement No 2370/CLEAN SKY/2012/2

and by Institute of Aviation.

Thank You
for Your Attention

4th EASN Association
International Workshop
on Flight Physics and
Aircraft Design

Aeronautics LIDAR applications

Airborne LIDAR Detection of Clear Air Turbulence (CAT)

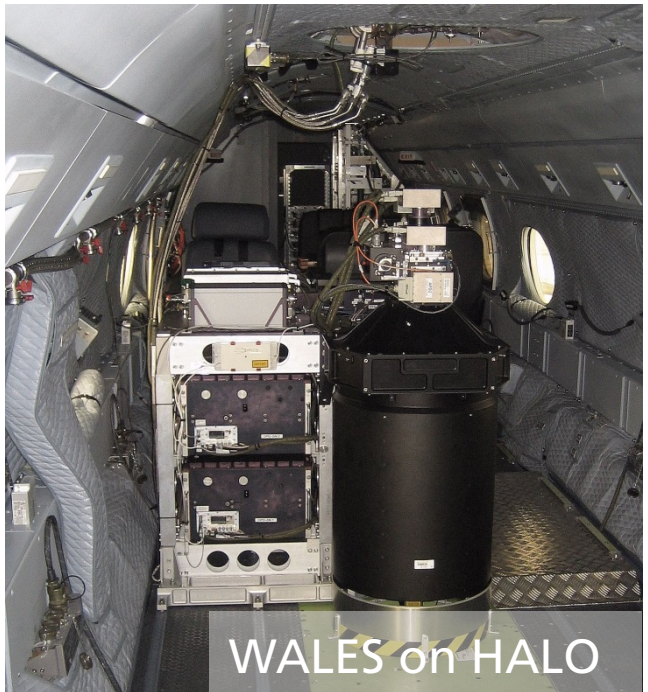
>> The DELICAT FP7 project

Patrick Vrancken
DLR - German Aerospace Center
Institute of Atmospheric Physics
Oberpfaffenhofen

Introduction:
DLR – Institute of Atmospheric Physics – LIDAR group

Head: G. Ehret

- LIDAR group – developing and operating lidar instruments for atmospheric research
  - Trace gases (O_3, CH_4, CO_2, H_2O): CHARM-F, MERLIN, WALES
  - Aerosols: WALES
  - Wind: 2µm & 1.6µm coherent systems (LM), ADM demonstrator (A2D)
- Operating on DLR's research aircraft: HALO G550, Falcon 20, Do228



Introduction:
LIDAR – LIght Detection And Ranging

- Emission of laser pulse into atmosphere

- Backscatter by:
  - Molecules (Rayleigh process)
  - Aerosols (Mie process)

- Collection of backscattered radiation with telescope and detector

- Range-resolved analysis of signal w.r.t. intensity / polarisation / spectrum
  - Aerosols (Backscatter/HSRL/Depol)
  - Trace gases (DIAL)
  - Wind speed (Doppler heterodyne / HSRL)

LIDAR for aeronautics applications
Safety

- ACARE: **Strategic Research and Innovation Agenda** (*SRIA*)
- ACARE / EC: **Flightpath 2050**

Strategic Research & Innovation Agenda

1. Overall, the European ATS has **less than one accident per ten million commercial aircraft flights**. For specific operations, such as search and rescue, the aim is to reduce the number of accidents by 80% compared to 2000 taking into account increasing traffic.
2. Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated.

Flightpath 2050 Europe's Vision for Aviation

Goals:

1. **Overall, the European air transport system has less than one accident per ten million commercial aircraft flights. For specific operations, such as search and rescue, the aim is to reduce the number of accidents by 80% compared to 2000 taking into account increasing traffic.**
2. **Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated.**

stipulating:

- Increase safety
- On-board sensor technology
- Situational awareness w.r.t.
- Atmospheric hazards

4.5 Air vehicle operations and traffic management

The airspace in the year 2050 has evolved considerably. Apart from the continuous growth of the number of aircraft and an increased demand for air travel, there are **new forms of flying vehicles and aerial applications**. These are integrated seamlessly into the air traffic scheme. New technologies and applications introduce new safety challenges. In addition, airspace is ever more crowded. Consequently, air traffic management concepts evolve along with the growing demand to achieve safety and security goals. Instead of a number of mostly isolated aircraft moving through airspace, there is a multitude of different co-operative and uncooperative elements in the all-encompassing data space incorporating aircraft movements, trajectories, live performance, vehicle status information as well as copious other kinds of data. This leads to - and requires - increased situational awareness and innovative mechanisms to

4.5.1 SAFETY RADAR

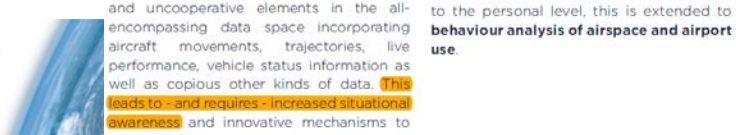
The safety radar comprises innovative methods, processes and services to ensure the identification and detection of safety hazards. It is enabled by the proactive **identification of atmospheric and other external hazards**. Models are developed that enable the identification of hazard probability, impact and mitigation. The safety radar is also underpinned by **behaviour analysis of passengers, staff and personnel** to identify in real-time abnormal behaviour, mobility patterns, etc. to identify hazards to safety. Similar to the personal level, this is extended to **behaviour analysis of airspace and airport use**.

4.5.3 OPERATIONAL MISSION MANAGEMENT SYSTEMS AND PROCEDURES

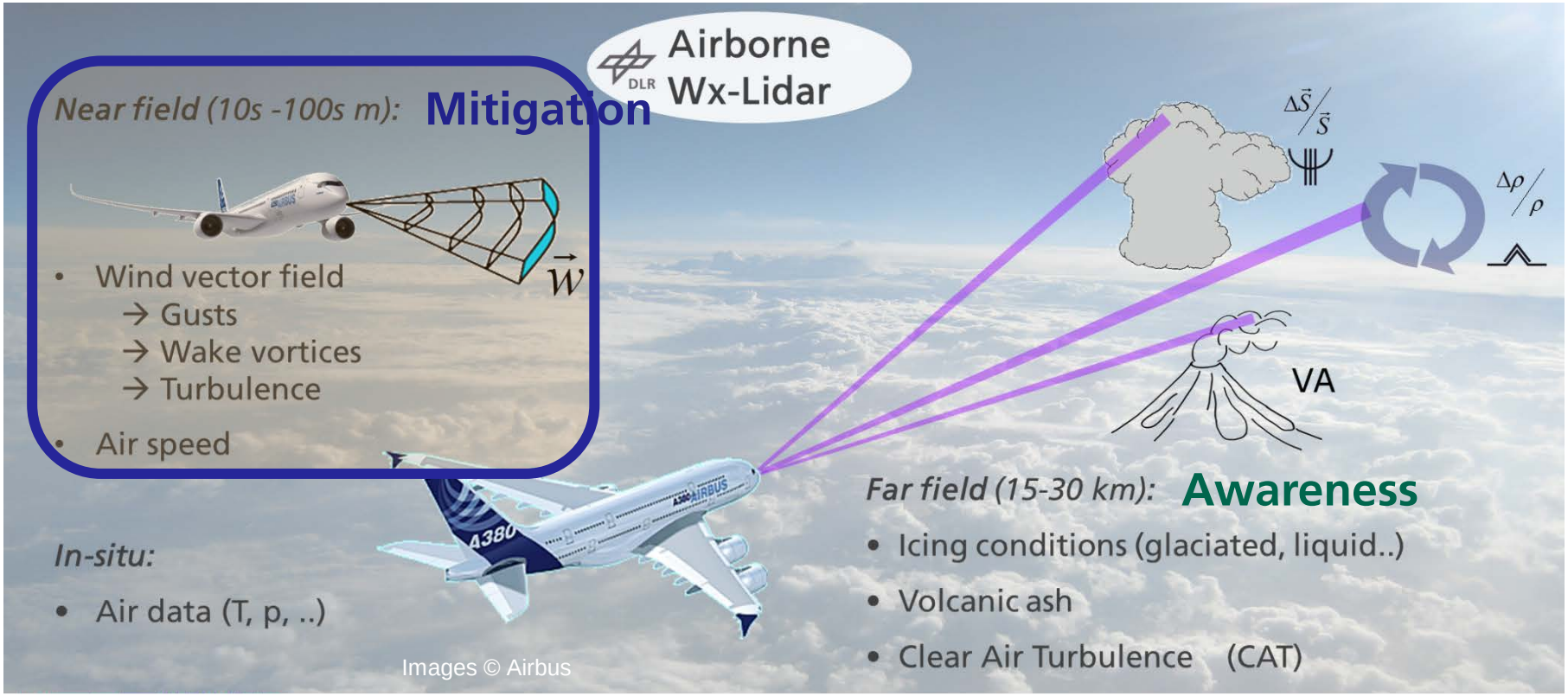
Operational mission management systems and procedures are concerned with protection and responses that facilitate hazard risk management through use of the appropriate tools, including atmospheric models. They enable the optimisation of trajectories to ensure hazard and collision avoidance throughout all flight phases and with the earth's surface. They also enable the **safe access and integration of non-commercial flights, personal air vehicles and UAV** within airspace and airports and ensure that **commercial space operations** are merged safely with traditional atmospheric flight operations and airspace structures. **Innovative usage concepts** are used to maximise the utilisation of scarce resources such as airspace, runways and parking.

To **support accurate mission planning**, a complexity assessment modelling capability is available together with models to identify and predict meteorological and other environmental hazards affecting flights.

In order to ensure hazard avoidance while in-flight and on the ground, systems and new traffic services are coupled with on-board sensor technology that **monitor atmospheric conditions, airspace environment, traffic proximity and flight data**. This is supported by **intelligent**



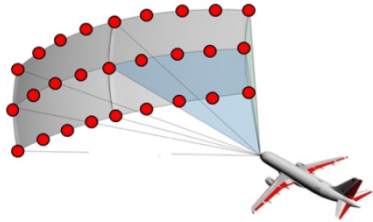
LIDAR for Aeronautics
Applications: Atmospheric / weather hazards



→Vision: One instrumentation for multiple targets (Wx hazards)

→ Research implementation: Separate tracks

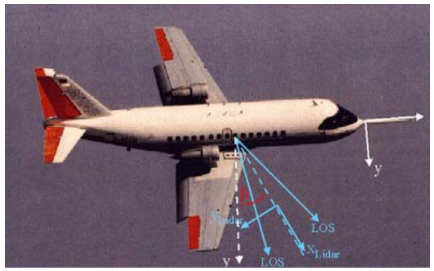
LIDAR for Aeronautics
Near field applications: Gust & WakeVortex mitigation



- Short range scanning LIDAR for wind field estimation
- Direct detection UV LIDAR OR coherent heterodyne LIDAR
- Wind speed determination by Doppler frequency shift

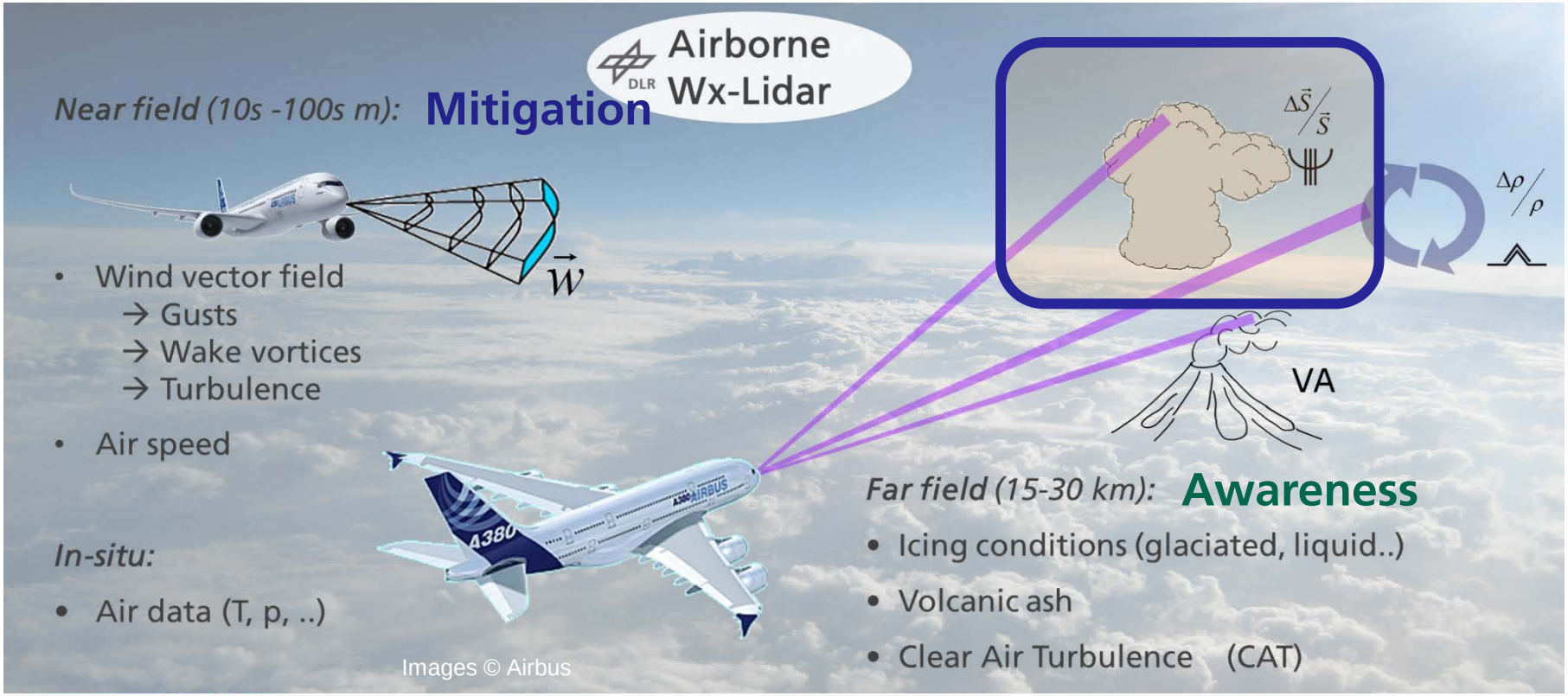
Concept demonstrated in EC FP6 AWIATOR project (Airbus)

- Instrument tested on DLR ATTAS and Airbus A340



DLR IPA continuing from 2014 on (instrumental developments in L-bows)

LIDAR for Aeronautics
Applications: Atmospheric / weather hazards

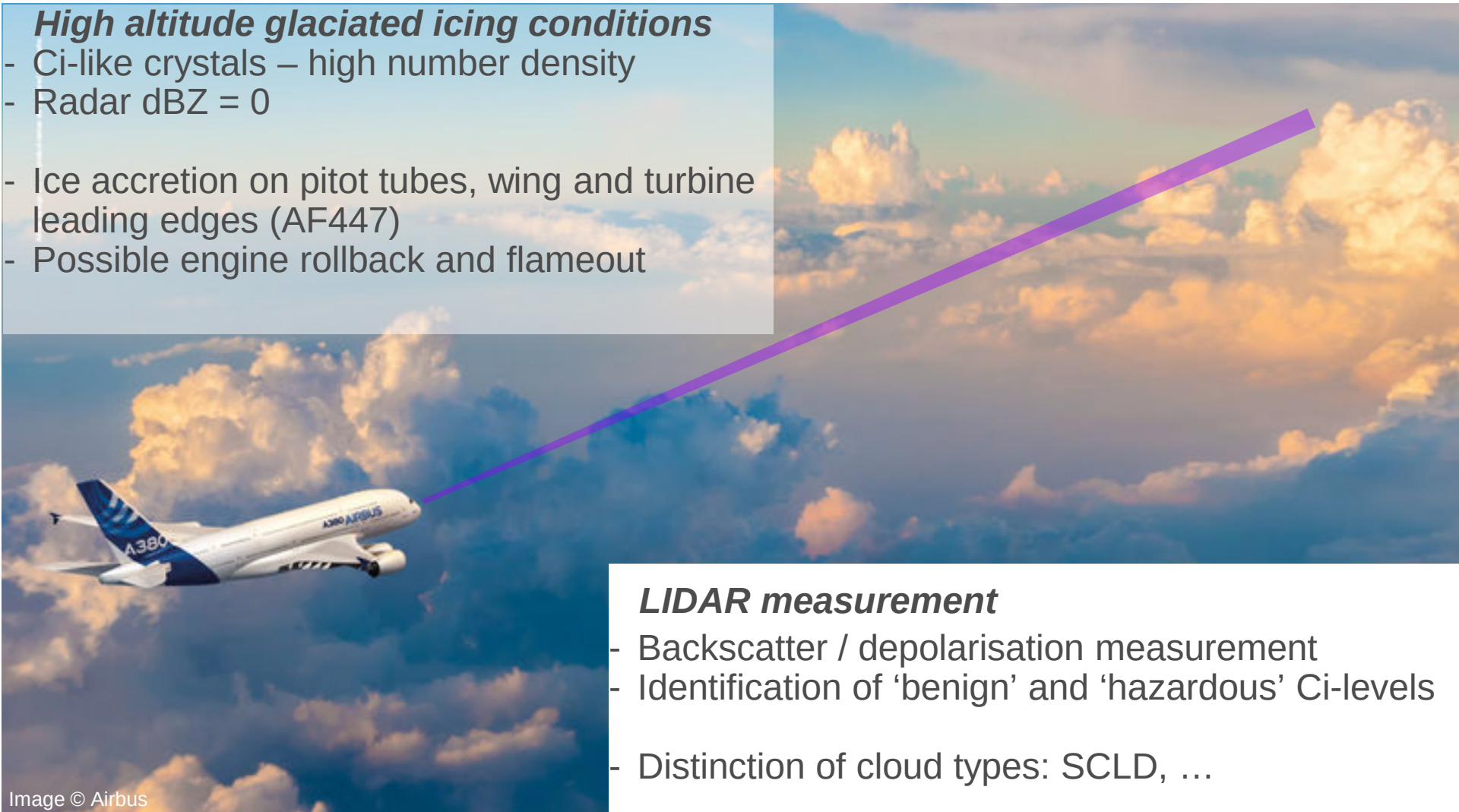


LIDAR for Aeronautics
Far field application: Hazardous icing conditions

High altitude glaciated icing conditions

- Ci-like crystals – high number density
- Radar dBZ = 0

- Ice accretion on pitot tubes, wing and turbine leading edges (AF447)
- Possible engine rollback and flameout



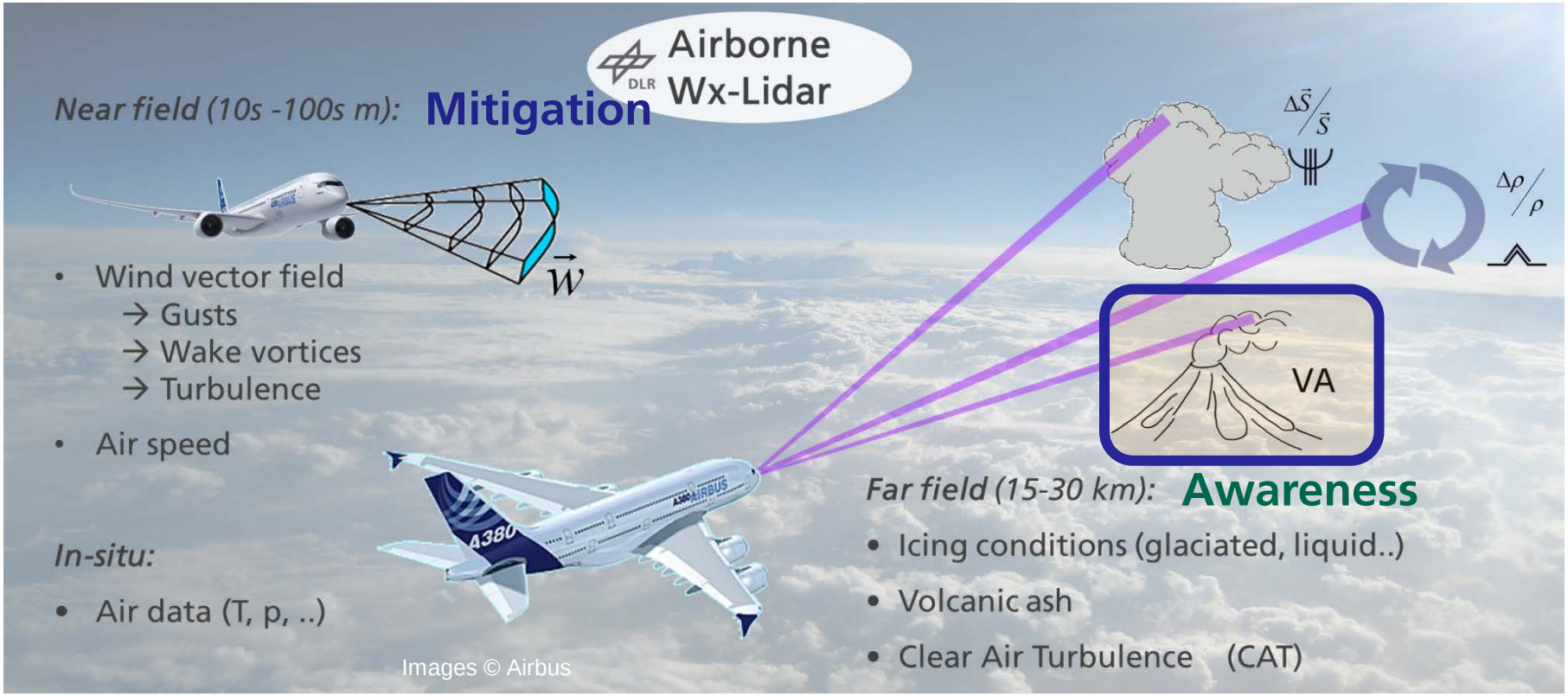
LIDAR measurement

- Backscatter / depolarisation measurement
- Identification of ‘benign’ and ‘hazardous’ Ci-levels

- Distinction of cloud types: SCLD, …

Image © Airbus

LIDAR for Aeronautics
Applications: Atmospheric / weather hazards



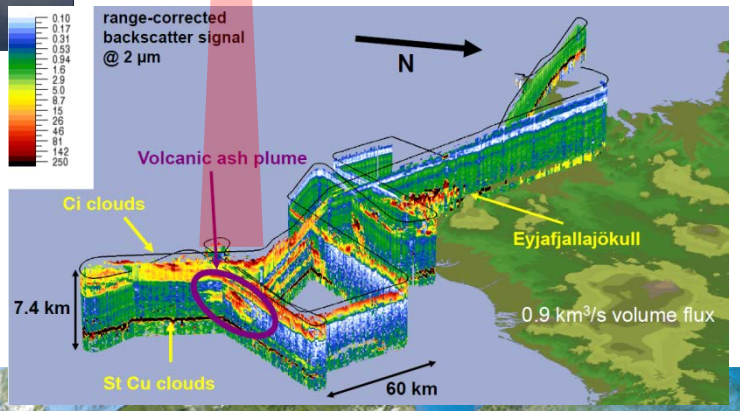
LIDAR for Aeronautics
Far field application: Volcanic ash & Mineral dust

Eyjafalla 2010:
- Lidar measurements with 2µm-wind lidar on DLR Falcon

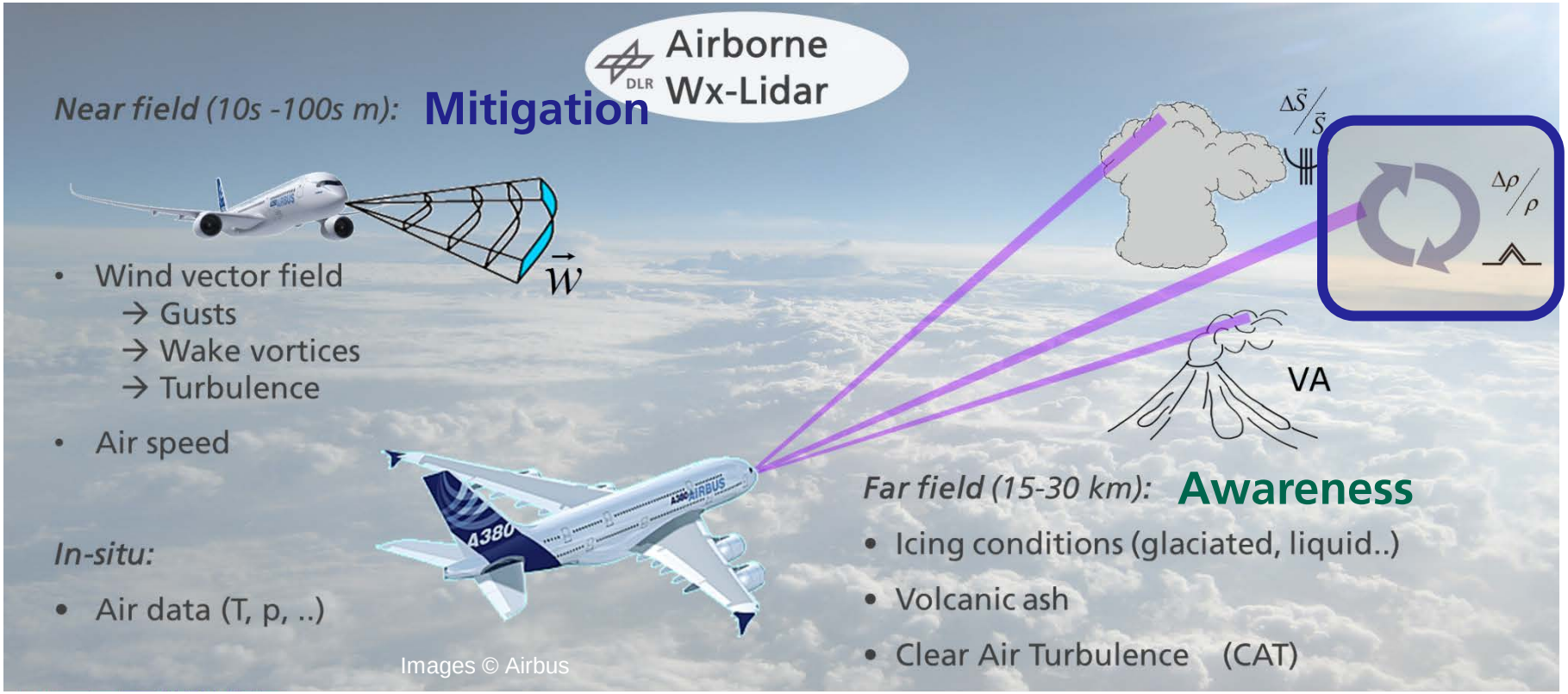
Future:
- LIDAR-based determination of ash concentration (mg/m³)

- VADAS project in H2020

+ Mineral dust



LIDAR for Aeronautics
Applications: Atmospheric / weather hazards

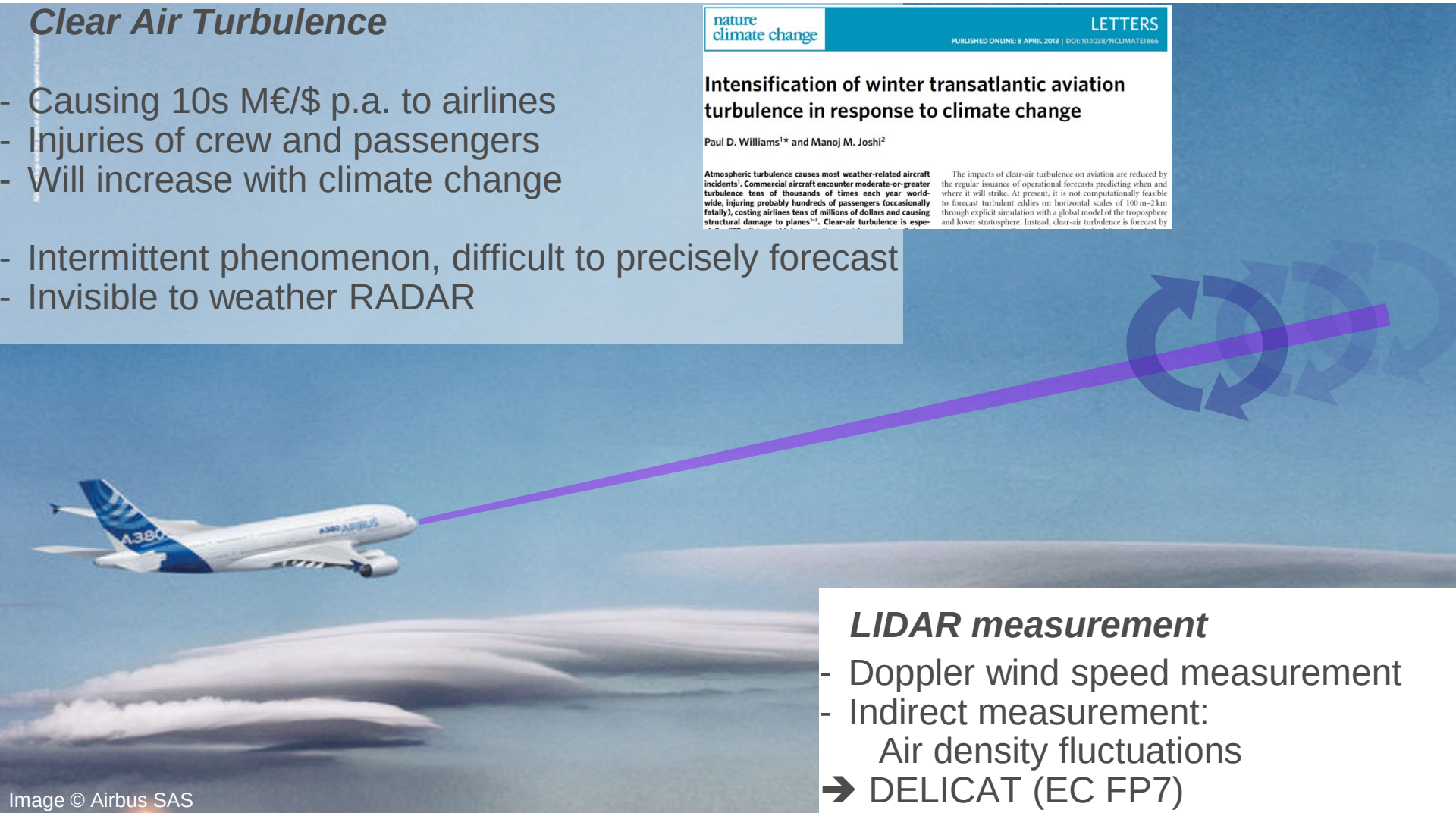


LIDAR for Aeronautics
Far field application: Clear Air Turbulence (CAT) & WV

Clear Air Turbulence

- Causing 10s M€/$ p.a. to airlines
- Injuries of crew and passengers
- Will increase with climate change

- Intermittent phenomenon, difficult to precisely forecast
- Invisible to weather RADAR



nature climate change
LETTERS
PUBLISHED ONLINE: 8 APRIL 2013 | DOI: 10.1038/NCLIMATE1866

Intensification of winter transatlantic aviation turbulence in response to climate change

Paul D. Williams[1]* and Manoj M. Joshi[2]

Atmospheric turbulence causes most weather-related aircraft incidents[1]. Commercial aircraft encounter moderate-or-greater turbulence tens of thousands of times each year worldwide, injuring probably hundreds of passengers (occasionally fatally), costing airlines tens of millions of dollars and causing structural damage to planes[2,3]. Clear-air turbulence is espe-

The impacts of clear-air turbulence on aviation are reduced by the regular issuance of operational forecasts predicting when and where it will strike. At present, it is not computationally feasible to forecast turbulent eddies on horizontal scales of 100 m–2 km through explicit simulation with a global model of the troposphere and lower stratosphere. Instead, clear-air turbulence is forecast by

LIDAR measurement

- Doppler wind speed measurement
- Indirect measurement:
  Air density fluctuations

➔ DELICAT (EC FP7)

Image © Airbus SAS

SEVENTH FRAMEWORK PROGRAMME

DELICAT

Demonstration of **Li**dar-Based **CAT** (Clear Air Turbulence) detection

P. Vrancken, M. Wirth, G. Ehret
DLR - German Aerospace Center
Institute of Atmospheric Physics
Oberpfaffenhofen

H. Barny THALES AVIONICS
H. Veerman NLR
L. Lombard ONERA
D. Nicolae INOE
…

DLR

DELICAT
EC Aeronautics Research FP7 project

- Goal: Demonstration of technology - Detection of **Clear Air Turbulence** (CAT) by LIDAR during cruise in far field (15-30 km)

- **Consortium of twelve European partners**: Thales (lead), DLR, CNRS/LATMOS, ONERA, Météo France, NLR, RAS/Inst. of Atm.Ph., Hovemere Inc., INOE (Romania), Laser Diagnostics Instruments, Warsaw University/ICM, Airbus (EADS/IW).

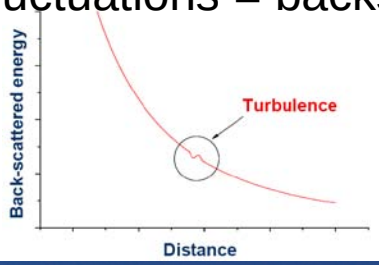
- Envelope: 5.6 M€, grant by EC: 3.8 M€
  Start: 01/04/2009, end 31/03/2014

DELICAT
Lidar-based CAT detection: Basic concept

w ⊥ LOS && insufficient aerosols at cruise altitude
→ Coherent Doppler lidar not usable

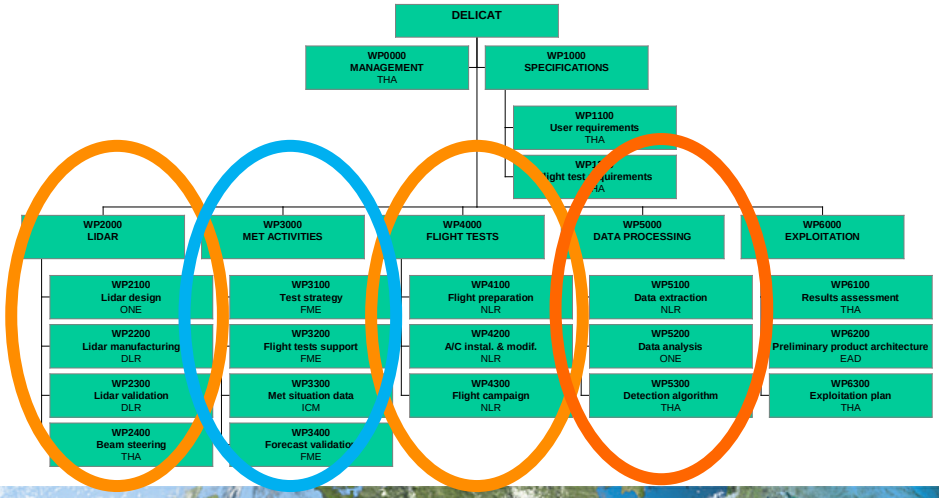
➔ Indirect measurement:
Air temperature / density fluctuations = backscatter fluctuations (molecular)

$$\frac{\Delta\rho}{\rho} = -\frac{\Delta T}{T} = w\frac{N}{g}$$



DELICAT
Lidar-based CAT detection: Main project goals

- Design and build **lidar** system
- Perform **flight test** campaign of lidar system
- Assess CAT **meteorology** and provide campaign support
- Retrieve CAT signature from lidar **data** and develop detection algorithms



DELICAT
Test aircraft PH-LAB (NLR – Dutch Aerospace Lab)

- Cessna Citation 2
- Ceiling 43,000 ft, max. payload 1300 kg, max. 5.5 h endurance

- Front looking fairing
  for directing laser beam on trajectory

DELICAT
Lidar system synopsis

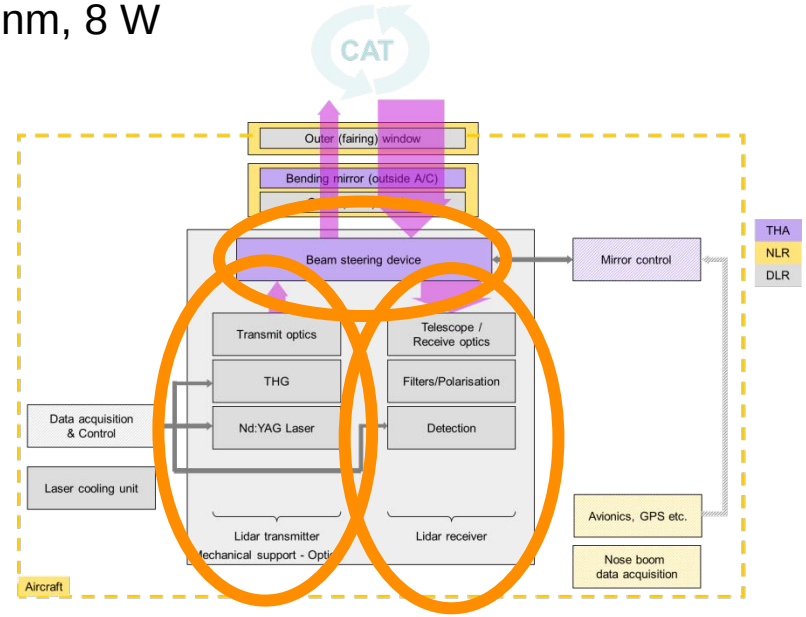
- Laser transmitter (DLR):
  - Nd:YAG, 100 Hz, 40 W, 7 ns, 200 µrad (based on DLR-lidar WALES)
  - Third Harmonic Generation → UV 355 nm, 8 W

- Beam steering system (Thales):
  - Two 2-axis-movable mirrors
  - External front-pointing mirror

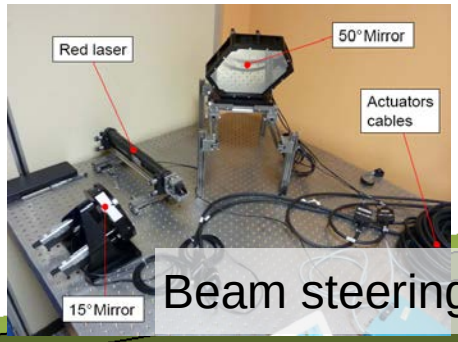
- Receiver I (DLR):
  - 6” f/5 telescope
  - Front optics, polarisation optics
  - PMT detection: ∥ (molec.) and ⊥

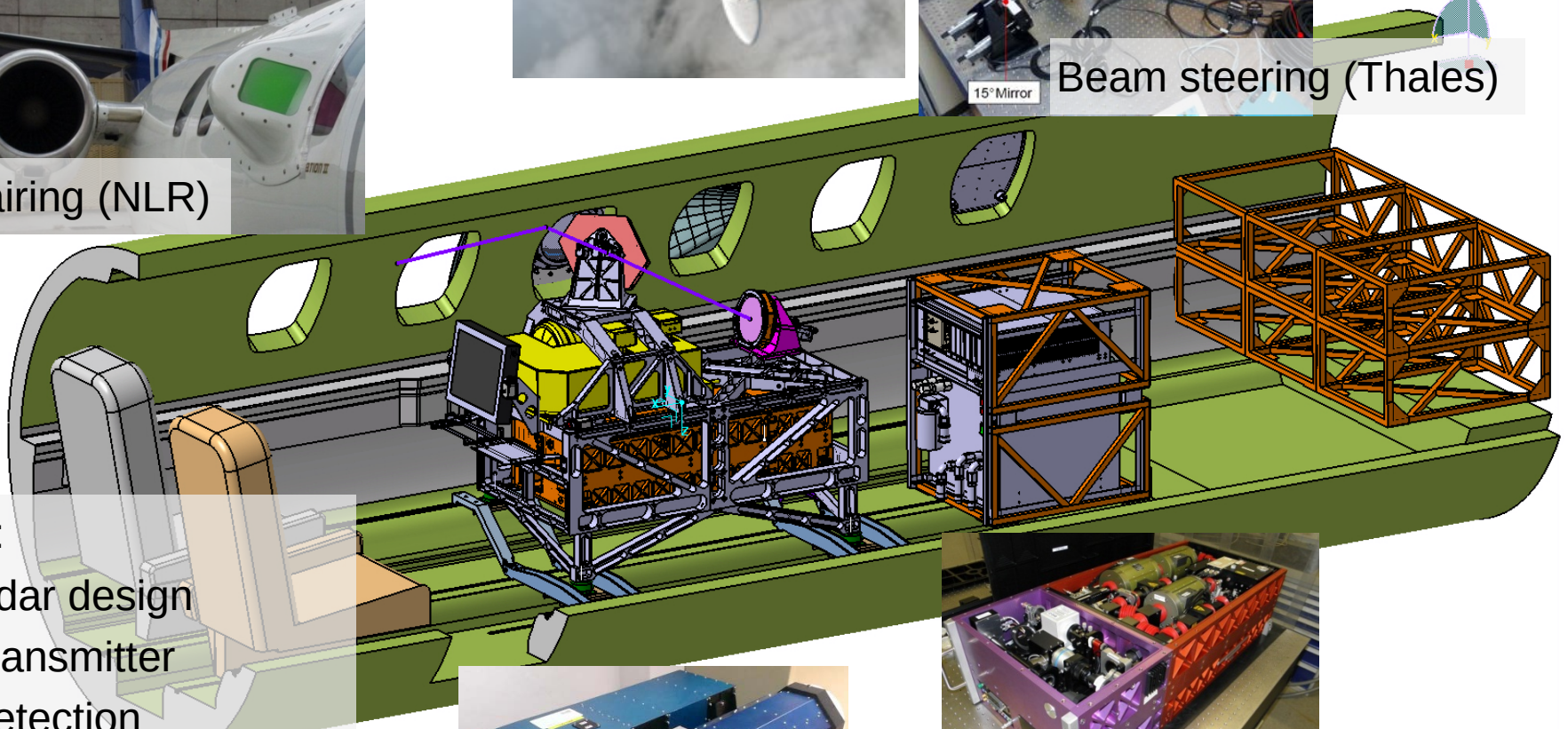
- Receiver II (Hovemere):
  - idem I
  - high spectral resolution filtering (aerosol backscatter filtering)
  - for ground tests only

- Aircraft integration (NLR+DLR)



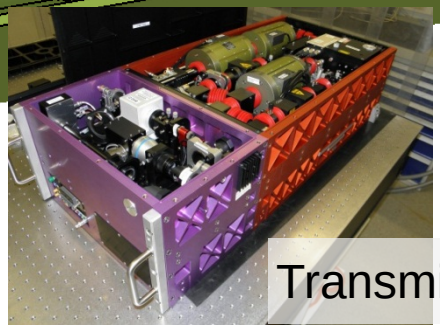
DELICAT

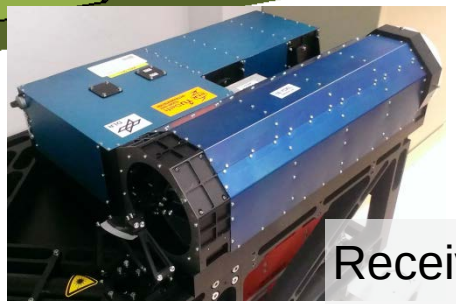




DLR:

- Lidar design
- Transmitter
- Detection
- Aircraft integration
- Validation tests
- Flight tests





DELICAT
Lidar on PH-LAB

- Installation and calibrations in June 2013

- STC on 16/07/2013

Ministry of Infrastructure and the Environment
Civil Aviation Authority - Netherlands

SUPPLEMENTAL TYPE CERTIFICATE

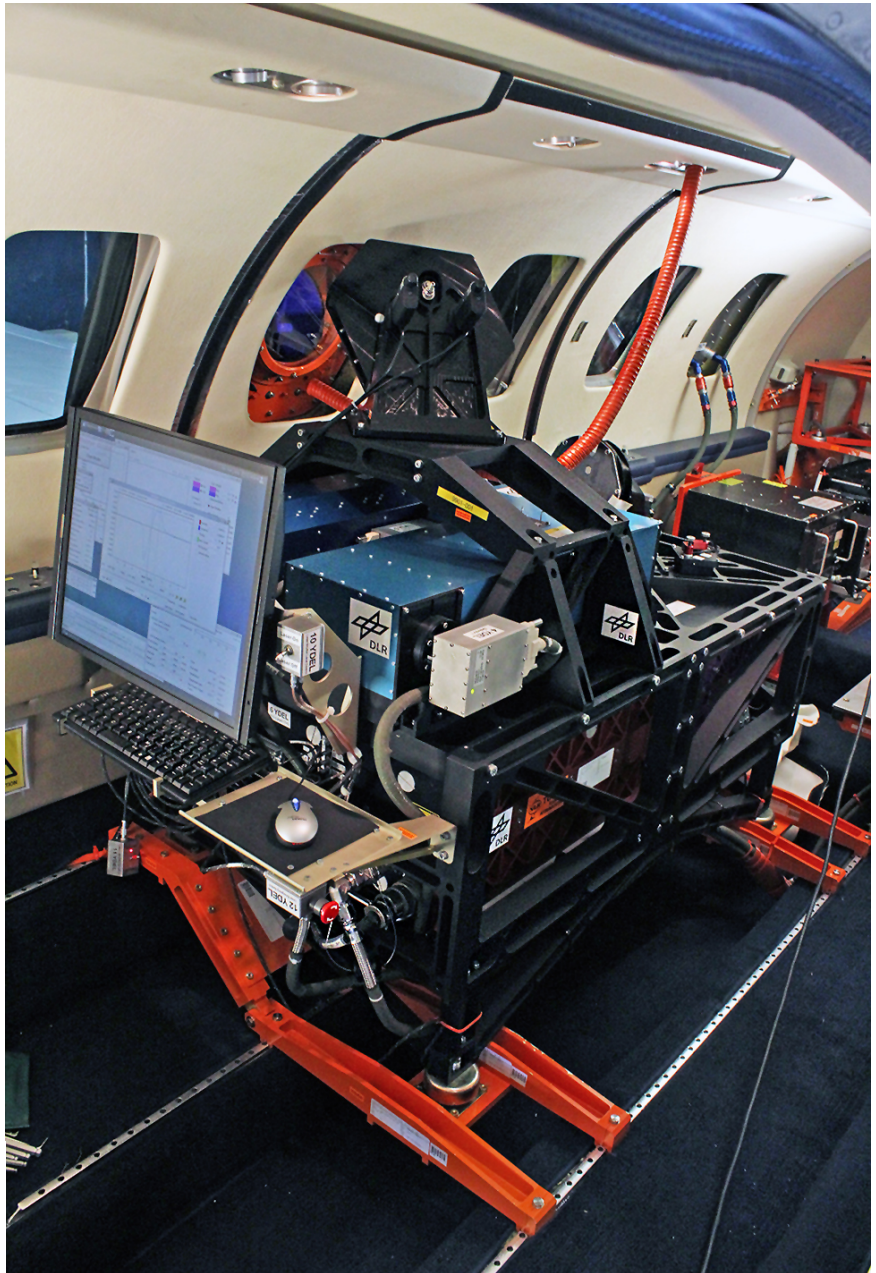
This approval is issued to:	Nationaal Lucht- en Ruimtevaartlaboratorium NLR Anthony Fokkerweg 2 1059 CM Amsterdam The Netherlands
Number:	SA1301NL
Date of application:	25 April 2012
Issue Date of application:	16 July 2013
Aircraft and Type:	Cessna 550 s/n 0550-0712
CAA-NL Type Certificate:	T-0056-1991
Type Certificate country of origin:	A22CE -USA
Certification basis:	See associated technical documentation
Description of the Change:	The DELICAT modification consists of the installation of a nose boom, an additional Total Air Temperature sensor, flight test instrumentation in the cabin and a LIDAR (laser) system: with several equipment items in the cabin, an optical window panel assembly, an optical mirror assembly on the outside, protected by a fairing, and a cooler window panel assembly.

This is to certify that the change in the type design as defined above meets the airworthiness requirements of the certification basis identified above.
This approval is subject to the conditions and limitations on the following page(s).

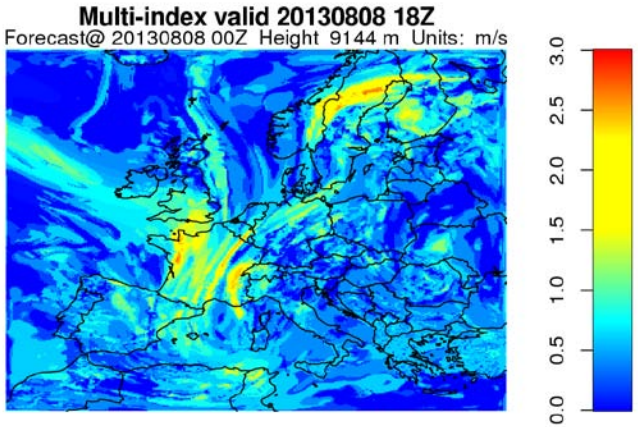
THE MINISTER OF INFRASTRUCTURE AND THE ENVIRONMENT,
on his behalf,
MANAGING DIRECTOR CIVIL AVIATION AUTHORITY THE NETHERLANDS,

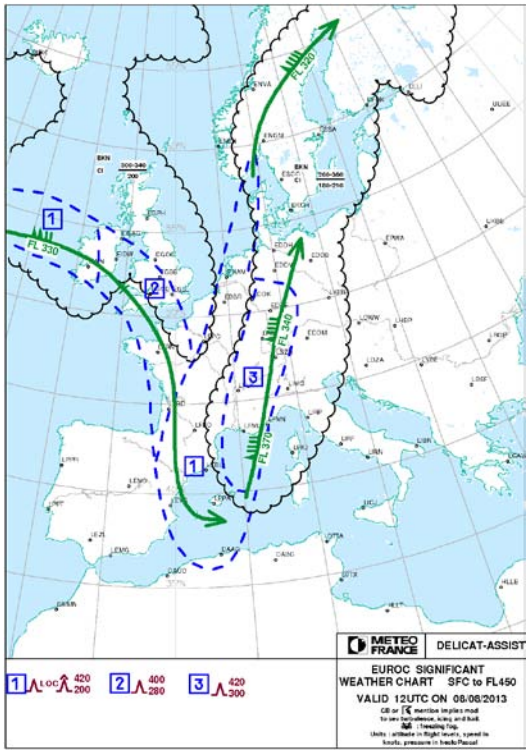
Edwin Griffioen.

Page 1 of 2 pages



DELICAT
Flight campaign 17/07 – 12/08/2013 from Schiphol





Met support:

- Used NWPs:
  - ARPEGE (MF)
  - COAMPS (UW-ICM)
- Turbulence indices
- Combined index analysis (ICM)

- Aeronautics forecaster (MF): Synoptical situation analysis

DELICAT
Flight campaign 17/07 – 12/08/2013 from Schiphol

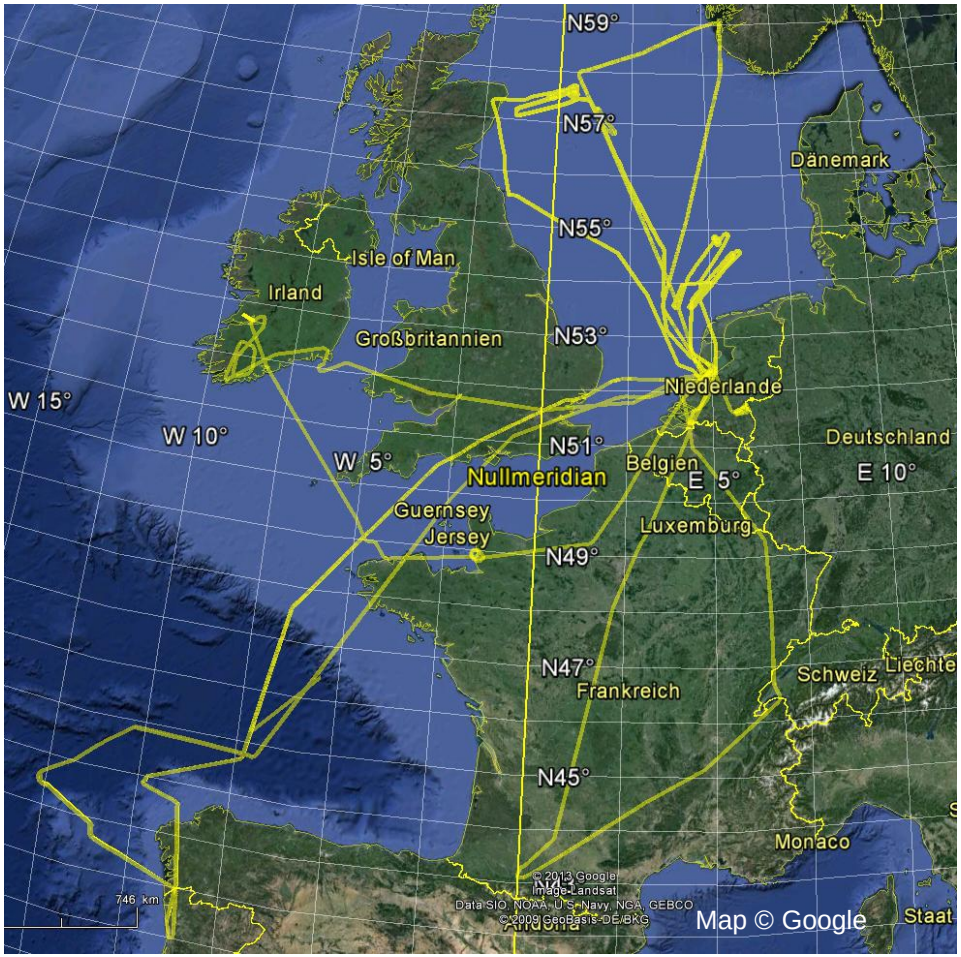
- 11 Flights, 33 h

- Calibrations

- Systems verification
  - Lidar
  - Beam steering
  - Aircraft experimental system

→ All systems performed exceedingly well

→ CAT very localised, light and difficult to find



DELICAT
Data analysis: LIDAR system evaluation

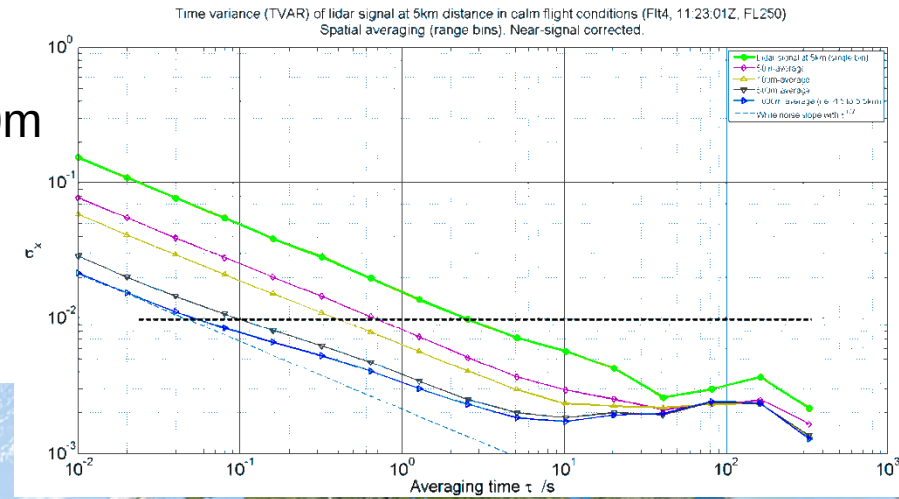
- Fundamental lidar sensitivity:
  - Goal: Detect light-moderate CAT detection
    Necessary density (backscatter) measurement sensitivity $\sigma \leq 1\%$
  - Averaging: $\sigma_M \propto {}^{1}/_{\sqrt{N_{Shots}}}$

  - Prereq: White noise (detection system)

  - Detection noise evaluation by 'time variance' analysis
    → Over time: Averaging over lidar shots
    → Spatially: Averaging over range

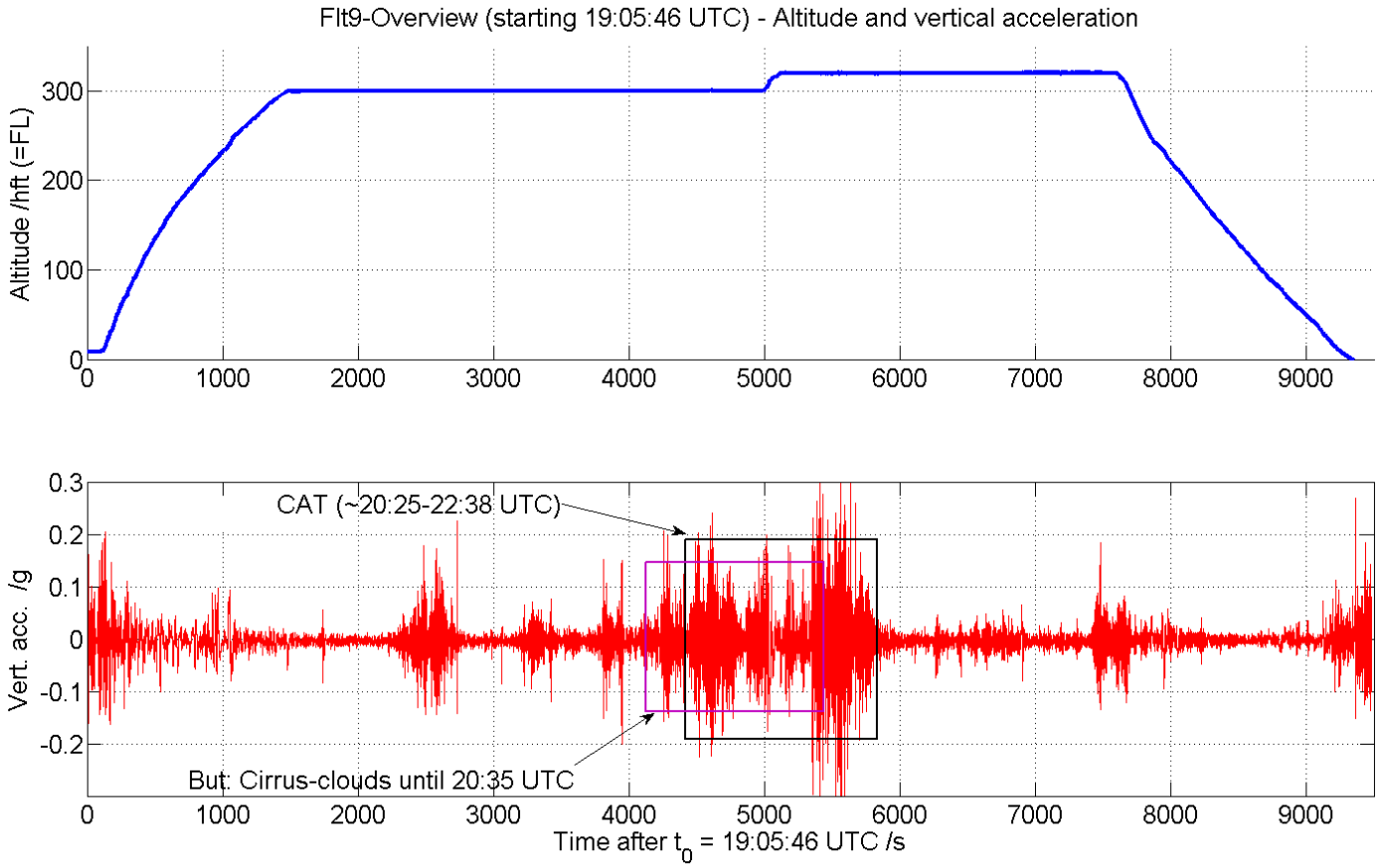
➔ Sub-% domain attainable by integrating over ~1s and ~100m

➔ **DELICAT lidar apt for measuring ≥ light-mod CAT**
(by analysing signal variance)



DELICAT
Data analysis: CAT signature retrieval

- Challenge: Few, isolated and weak (< light-mod) CAT events
- Simple signal variance analysis insufficient



DELICAT
Conclusion

- Challenging project:
  - Complexity (LIDAR ↔ aircraft)
  - Delicate (sensitive) systems / instruments
  - Airworthiness certification
  - Scarce and weak CAT yield

➔ DELICAT project carried out successfully!

- Instrumental development continued within DLR
- Further validation by flight tests necessary

- LIDAR system ‘upgradable’ for other research topics (icing, VA, MD…)

- Thanks to the EC for the support!

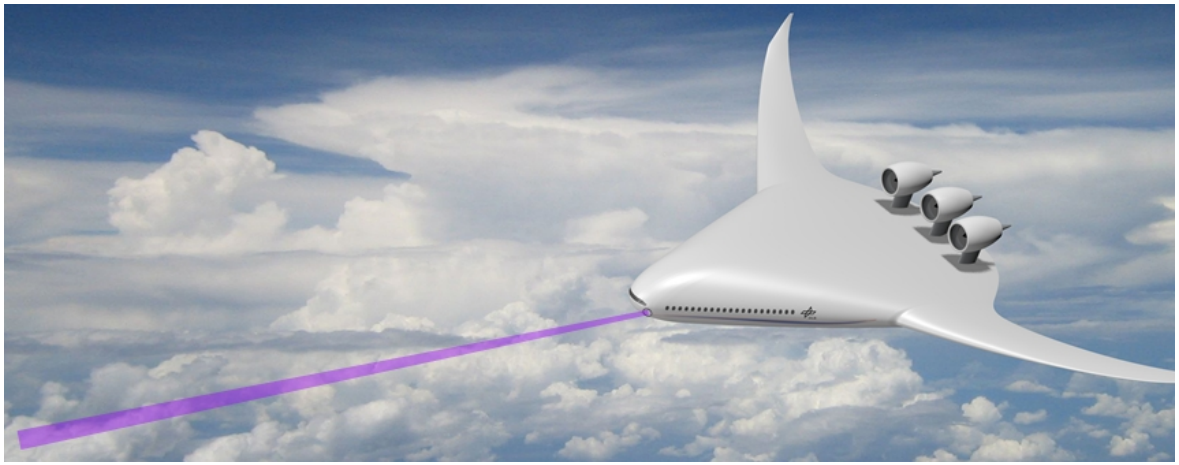
The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 233801

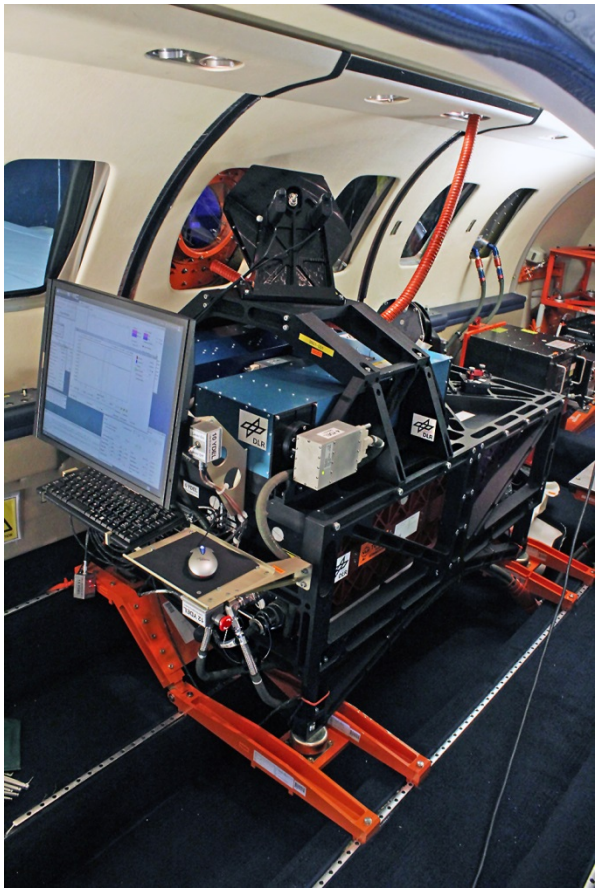
LIDAR for Aeronautics - DELICAT

- Thank you for your attention!

- Questions:
  patrick.vrancken@dlr.de

- Website:
  http://delicat-fp7.org/





4th EASN Workshop on Flight Physics and Aircraft Desgn
Aachen, Germany, 27-29 October 2014

Simplified Hybrid Laminar Flow Control

Geza Schrauf
Airbus
Bremen, Germany

AIRBUS

Content

- **Introduction – Previous Complex HLFC Systems**
- **Simplified Suction: Review of the ALTTA System**
- **Further Simplification: HIGHER-LE / VER²SUS System**
- **Wind Tunnel Validation of Simplified HLFC**
- **Next Steps**

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Introduction

Introduction
Previous Complex HLFC Systems

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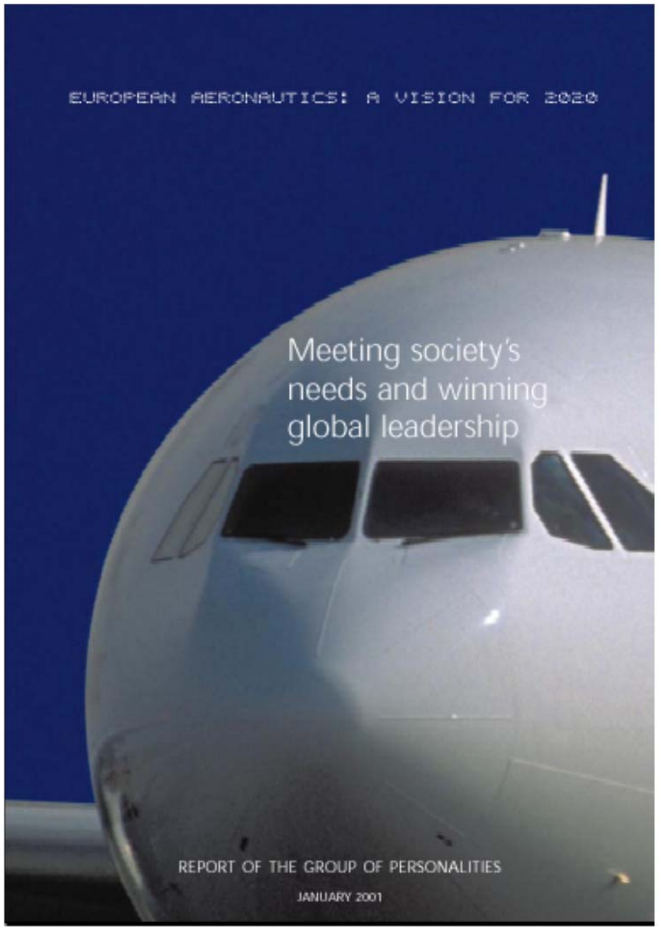
Drivers for Performance Improvement

Environment => VISION 2020

- **50% reduction of fuel consumption**
- **80% reduction of NO_X**



Economics => reduction of fuel cost

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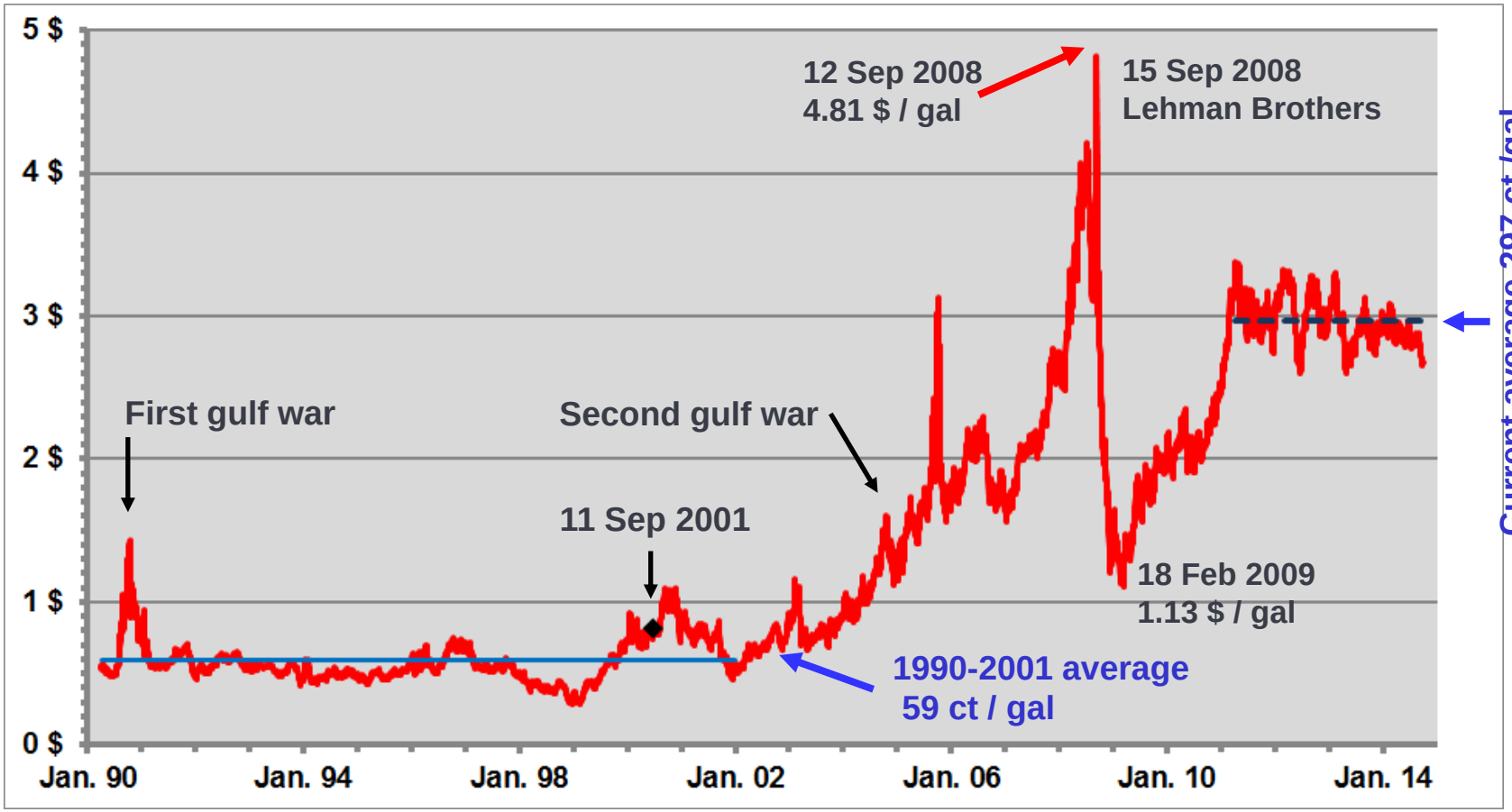
Drivers for Performance Improvement

US Gulf Coast kerosene fuel spot price



Source: US Energy Information Administration, 4 October 2014

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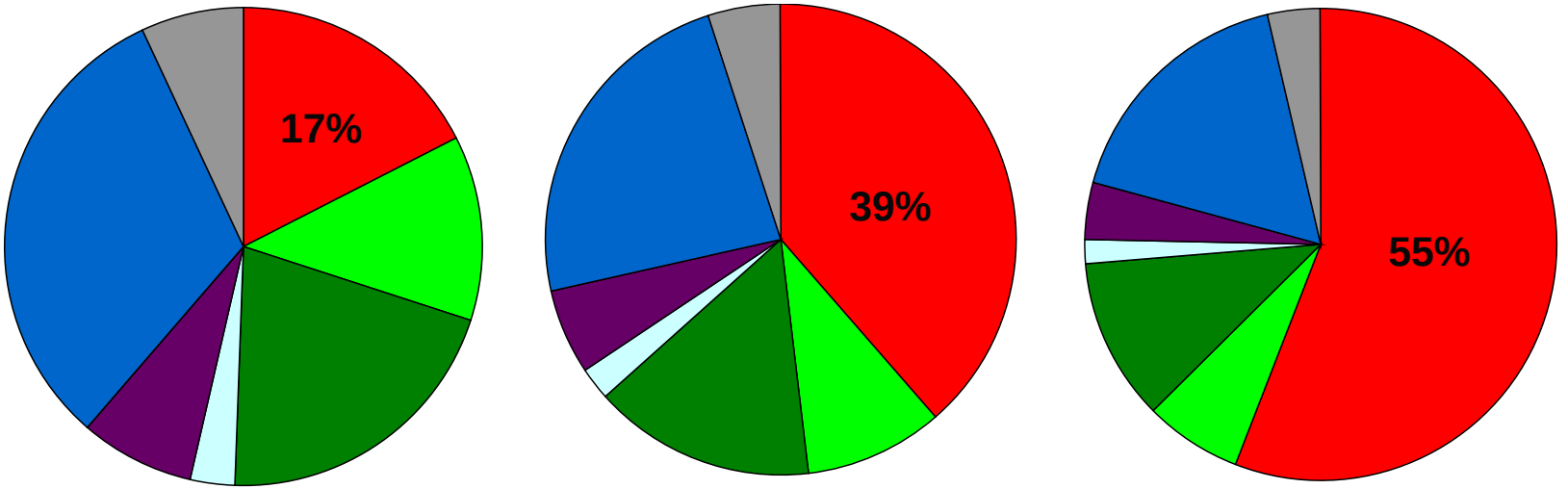
DOC shares for 4000nm mission with A330-300



60 US-ct / US-gallon **180 US-ct / US-gallon** **360 US-ct / US-gallon**

- Fuel
- Maintenance
- Flight crew costs
- Landing fees
- Navigation charges
- Capital cost
- Insurance

Status: July 2008

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Specific Range as Performance Measure

Specific range *SR* measures performance of aircraft

Lift = Weight
Drag = Thrust

$$SR = \underbrace{1/TSFC}_{engine} \cdot \underbrace{V \cdot L/D}_{aerodynamics} \cdot \underbrace{1/W}_{structure}$$

more efficient engine => increase bypass ratio, intercooler, …

lighter structure => advanced materials

better aerodynamics => improve $M \cdot L/D$

=> reduce drag

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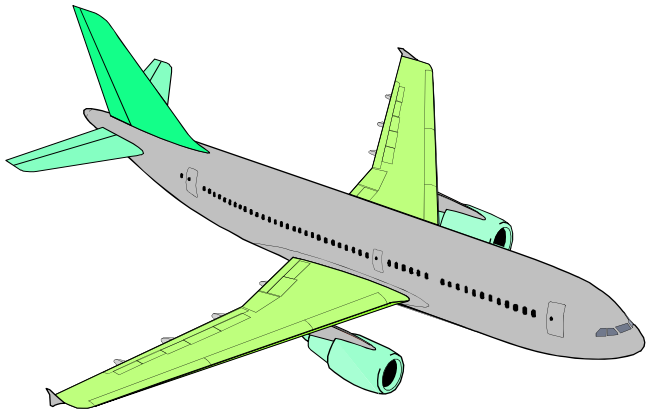
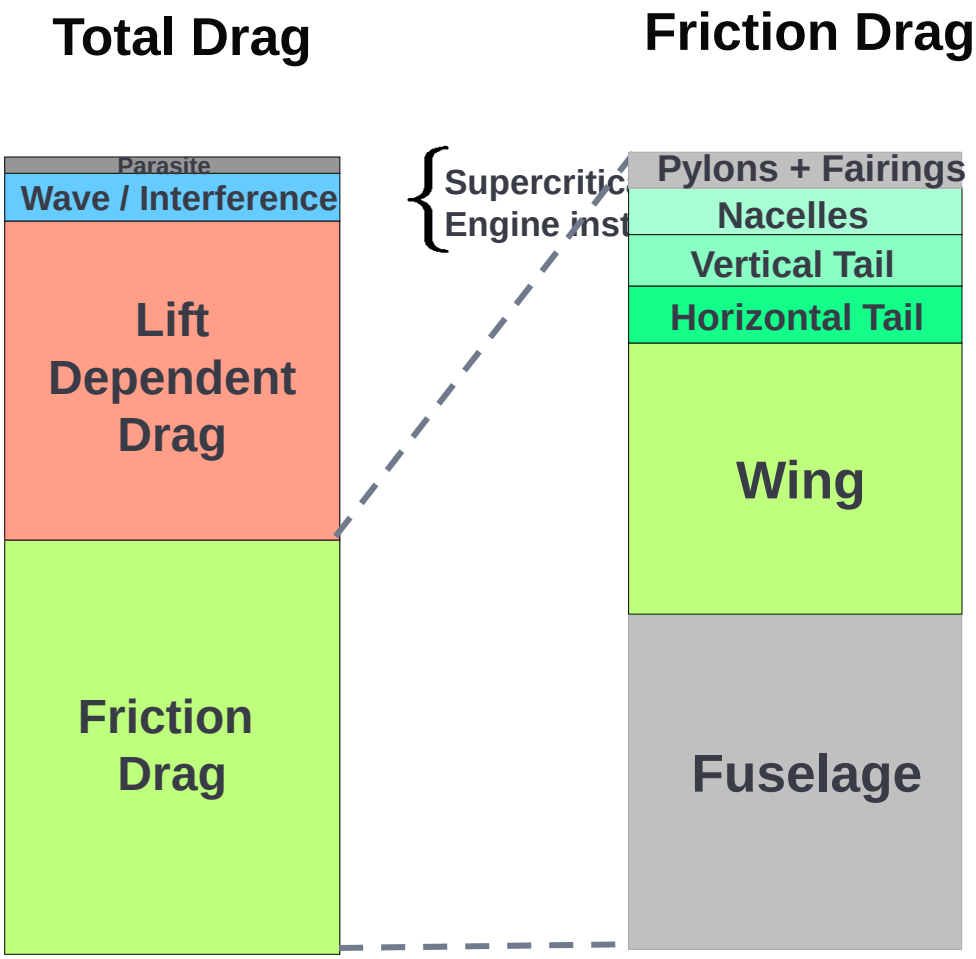
Drag Breakdown of a Typical Transport Aircraft





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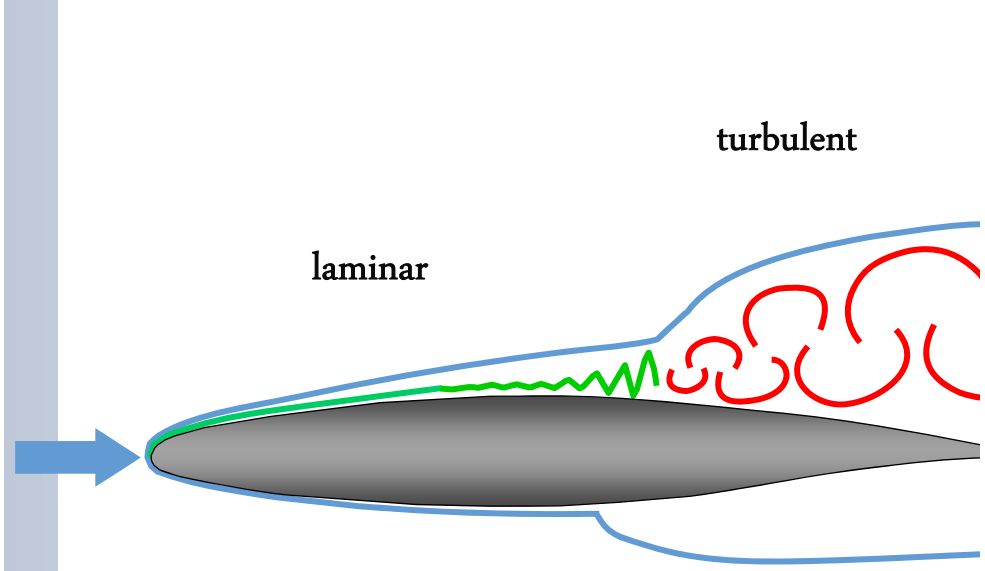
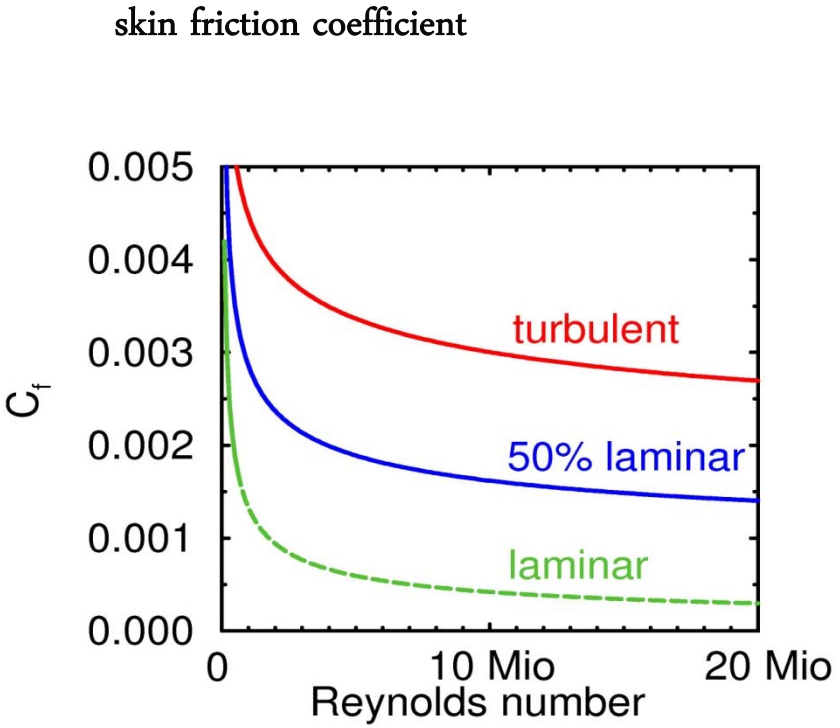
Laminar Flow

Laminar boundary layer has much lower friction drag





Large profile drag reduction, even if only part of the surface is laminar

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Previous Experimental HLFC System

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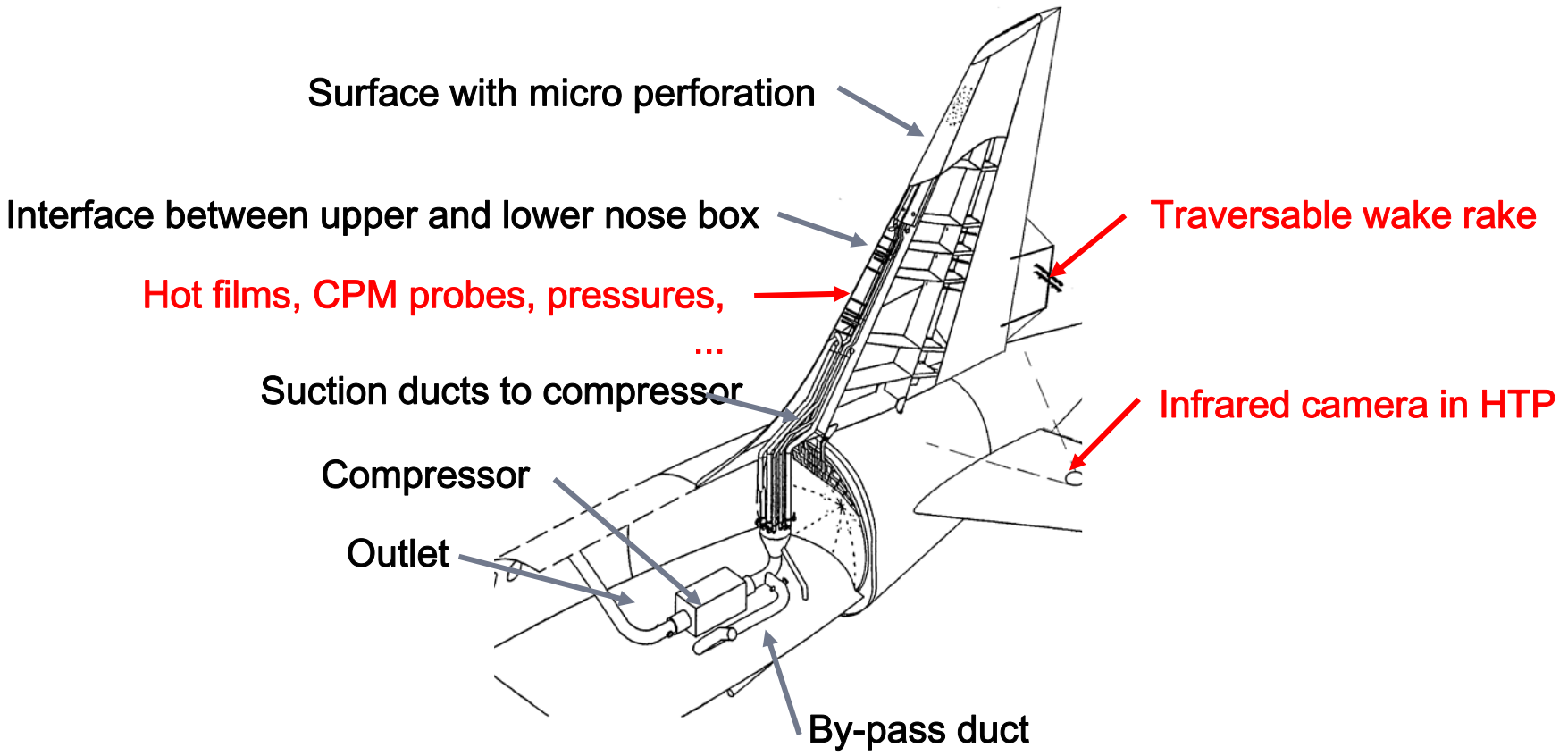
Previous Experimental HLFC System



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Previous Experimental HLFC System

Feasibility for the application of HLFC technology was proven by flight tests with HLFC fin (1998; LaTeC, HYLDA, 3E)

➔Simpler and lighter system needed to obtain overall benefit

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Simplified HLFC

Simplified HLFC: Review of the ALTTA System

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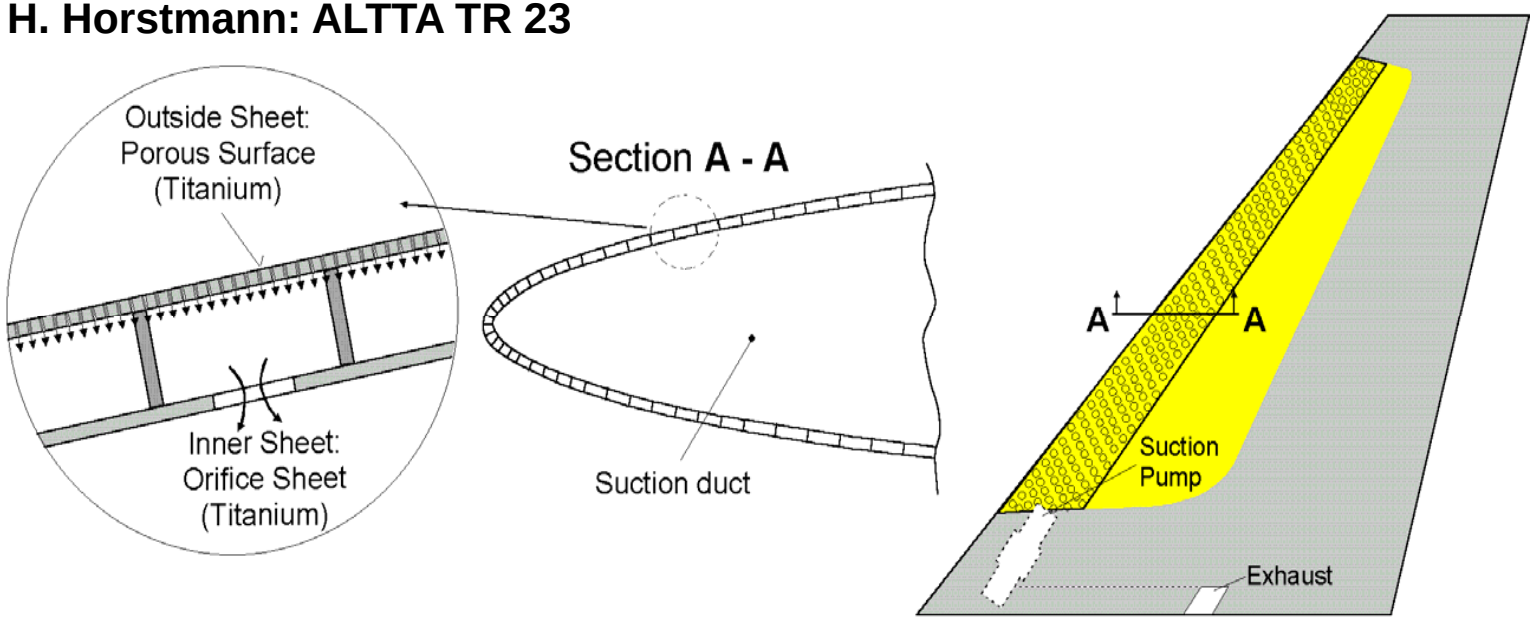
Simplified HLFC Systems – ALTTA System

K. H. Horstmann: ALTTA TR 23



Inner skin has two functions:

- **Support the micro-perforated outer skin**
- **Generate adequate pressure on the inside of the outer skin**

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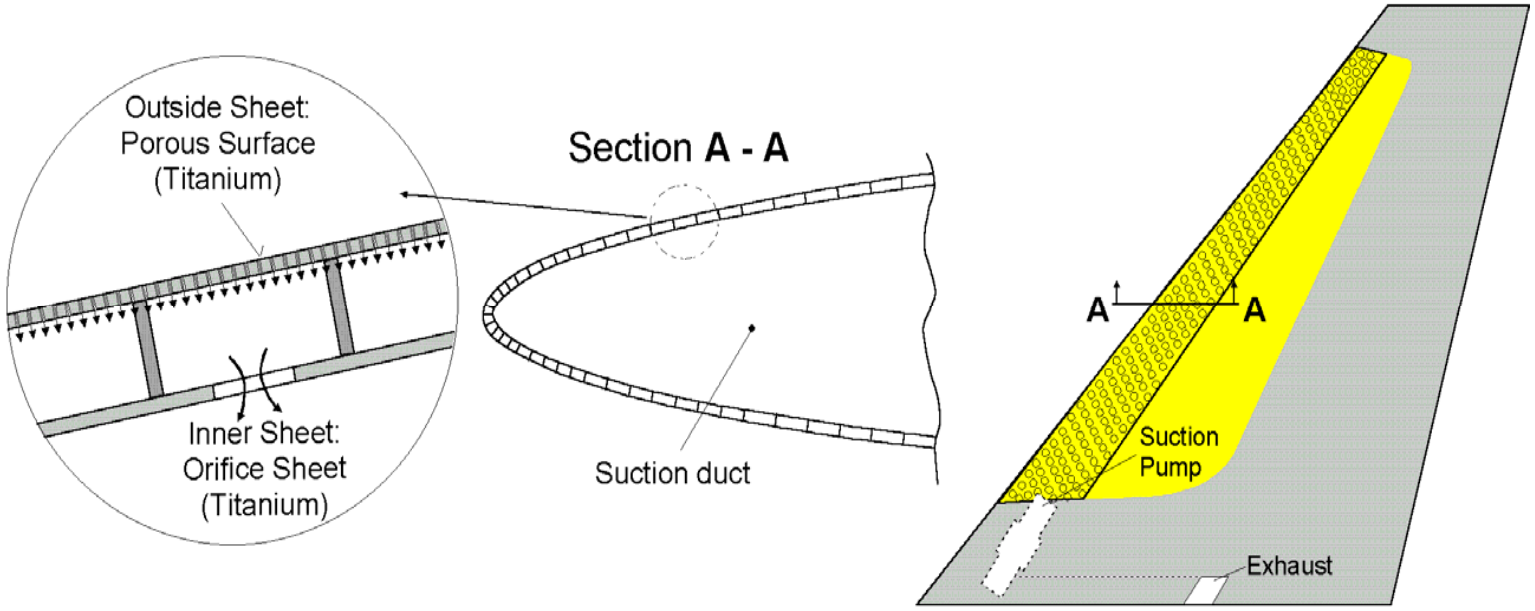
Simplified HLFC Systems – ALTTA System



- **No suction chambers below double skin** ➔ **weight reduction**
- **No ducting to collector** ➔ **weight reduction**
- **No vents in ducts to regulate mass flow** ➔ **weight reduction**
- **No mass flow control/regulation for each suction chamber**

➔The suction distribution must be adequate for the whole flight envelope

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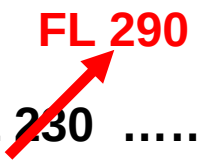
Simplified HLFC Systems – ALTTA System

ALTTA flight envelope

The suction system should provide laminar flow at the following flight conditions:



- **Range of flight levels:** **FL 230 …… 310 …... 390**
- **Range of Mach numbers:** **M = 0.76 ... 0.78 ..... 0.80**
- **Range of yaw angles:** **β = -2° …… 0° …… +2°**
- **Range of ruder deflections:** **δ = -2° …… 0° …… +2°**
- **Outflow velocity:** **M = 0.2**

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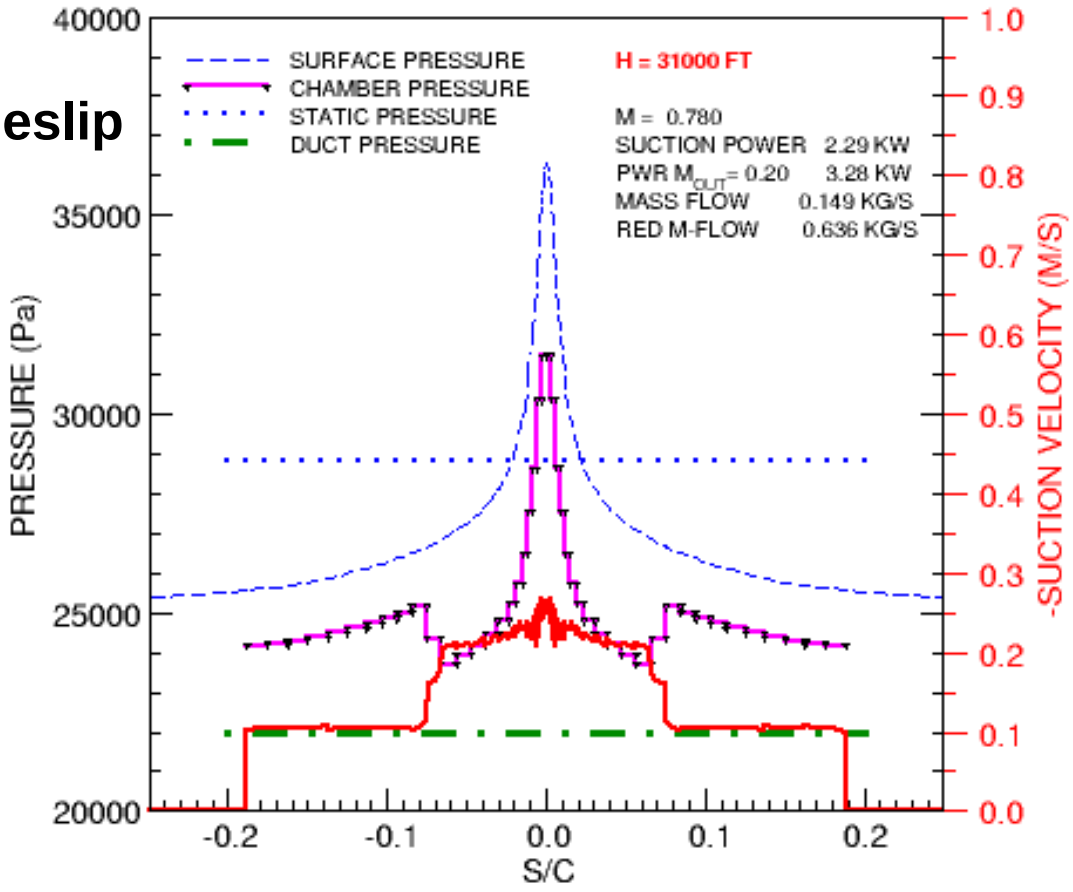
ALTTA Design: Pressures and Suction Velocities

Flight altitude 31000ft
Straight flight without sideslip
No rudder deflection



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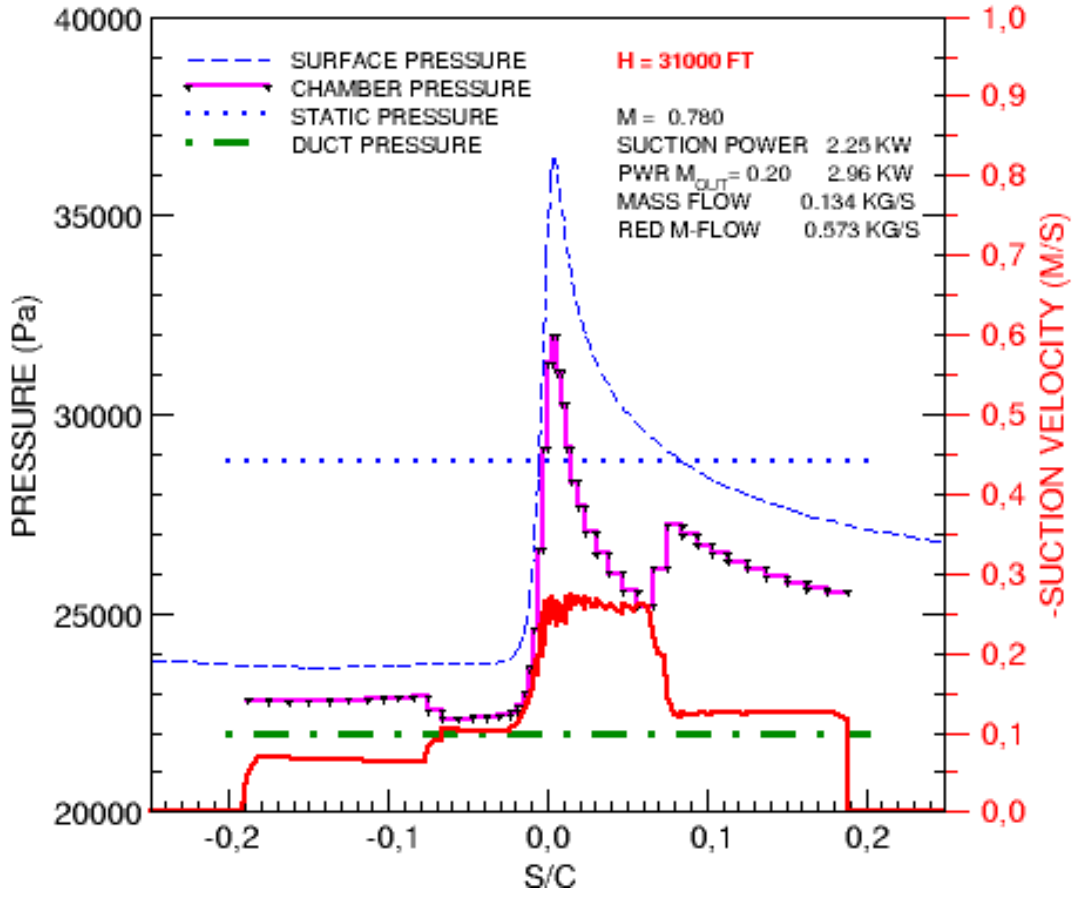
ALTTA Design: Pressures and Suction Velocities

Flight altitude 31000ft
Sideslip (yaw) 2^0
No rudder deflection



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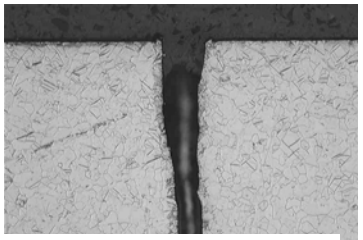
Simplified HLFC Systems

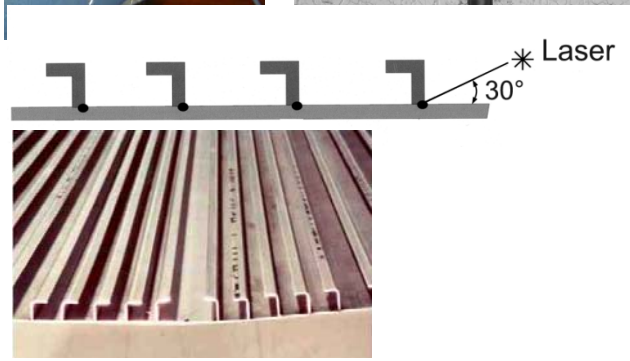
New manufacturing concept for improved surface quality: “Outside-first”

Drilling of the micro-perforation:

- **Hole diameter: 65 µm**
- **Distance between two holes in a row: 0.9 mm**
- **Row distance: 0.9mm**

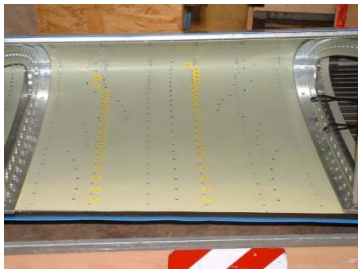


Attachment of the stringers by laser welding



Cold forming

Attach inner skin with metering holes to stringer



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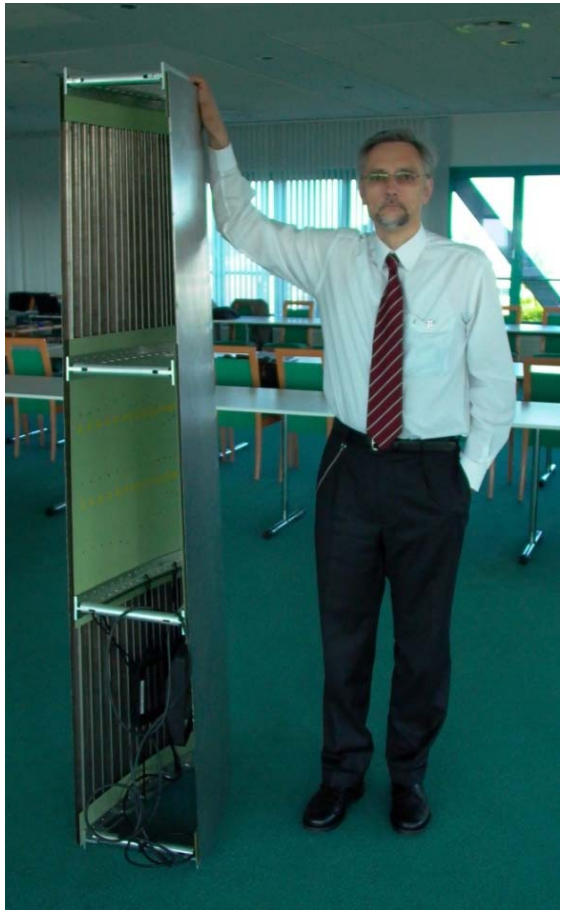
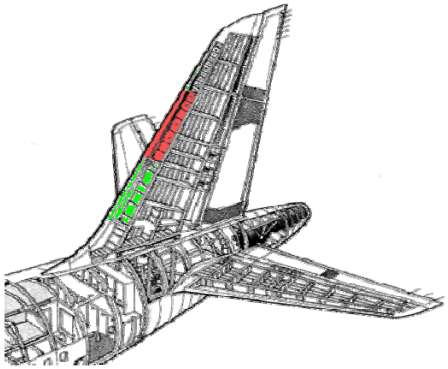
Simplified HLFC Systems





A manufacturing mock-up of the middle LE-box was built

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HIGHER-LE / VER²SUS Design

Further Simplification: HIGHER-LE / VER²SUS System

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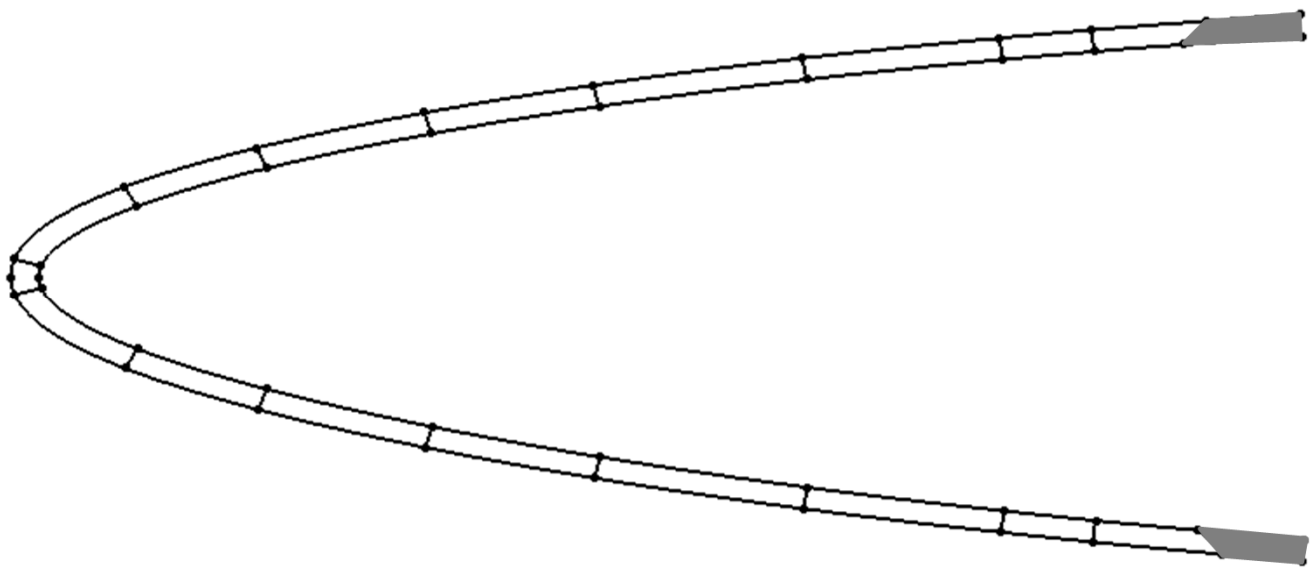
HIGHER-LE / VER²SUS (HV) Design



Reduction of the number of chambers

- ➔ **Structural requirements**
- ➔ **Ease of manufacturing**
- ➔ **Weight reduction**

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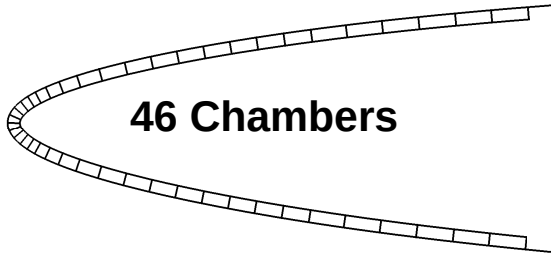
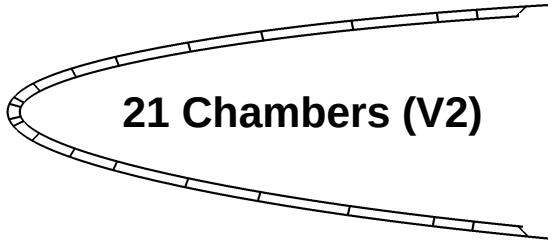
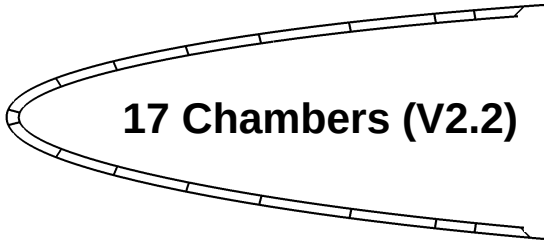
Development of suction chambers



ALTTA 2003



Reduced number of chambers (status 2010)



Chamber distribution used for ECCOMAS 2012

G. Schrauf, H. von Geyr: "Simplified Hybrid Laminar Flow Control for Transport Aircraft." ECCOMAS 2012, Vienna, Austria.

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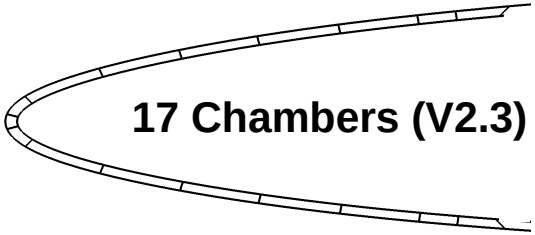
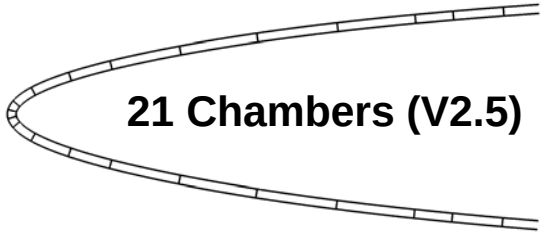
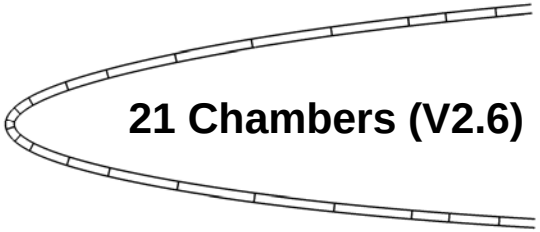
Development of suction chambers



Chamber distribution for final development



Additional stringers at leading edge to ease cold forming process



Shift of second stringer location for better contour reproduction during cold forming

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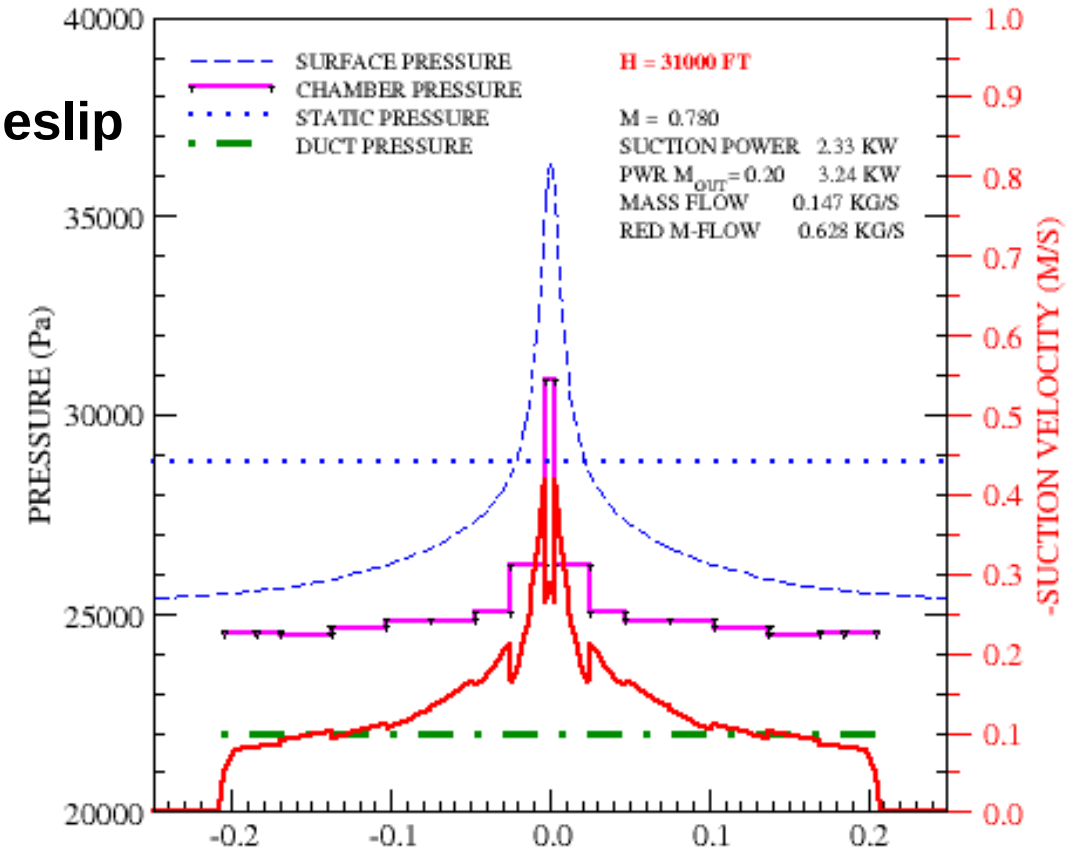
HV Design: Pressures and Suction Velocities (V2.2)

Flight altitude 31000 ft
Straight flight without sideslip
No rudder deflection



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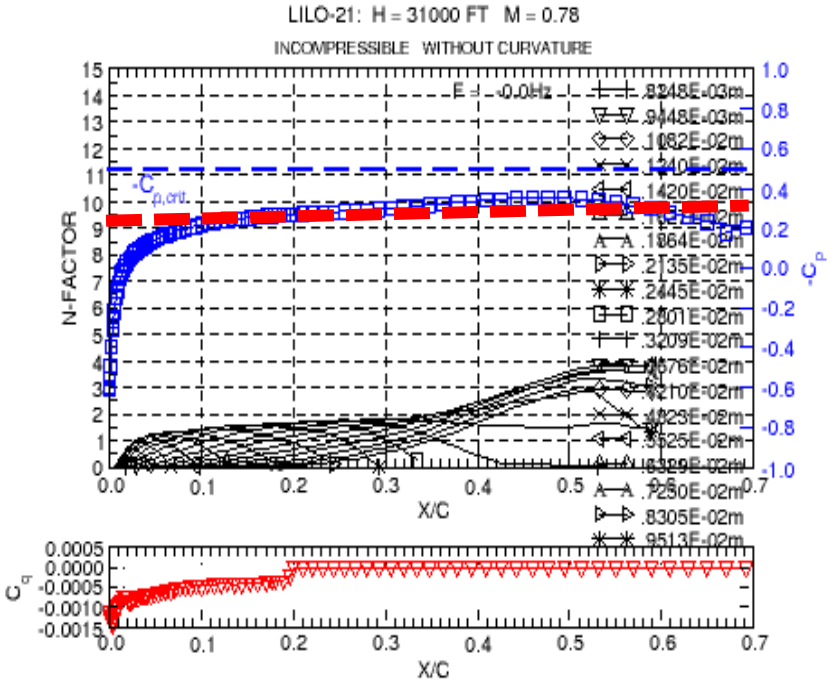
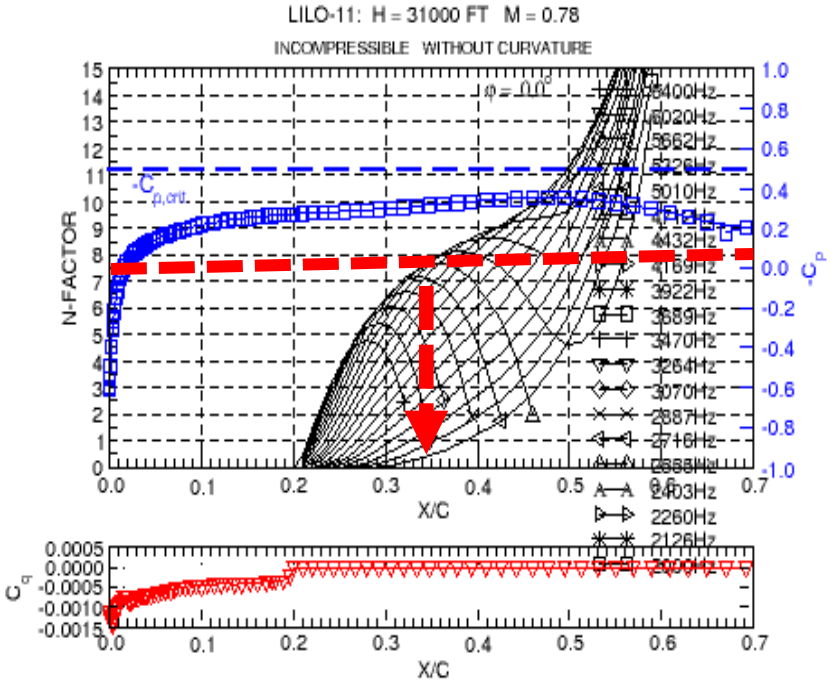
HV Design: N_{CF}- and N_{TS}-Factors (V2.2)





Tollmien Schlichting transition at 34%

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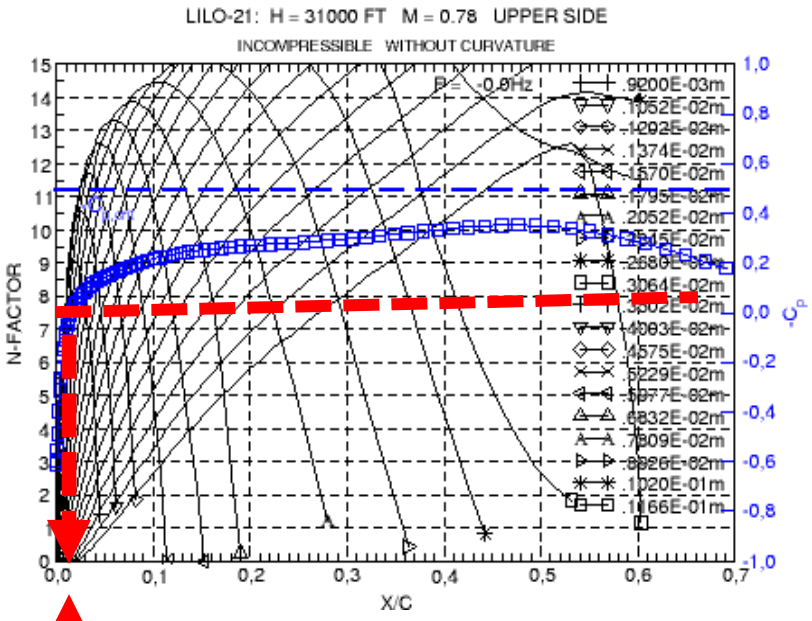
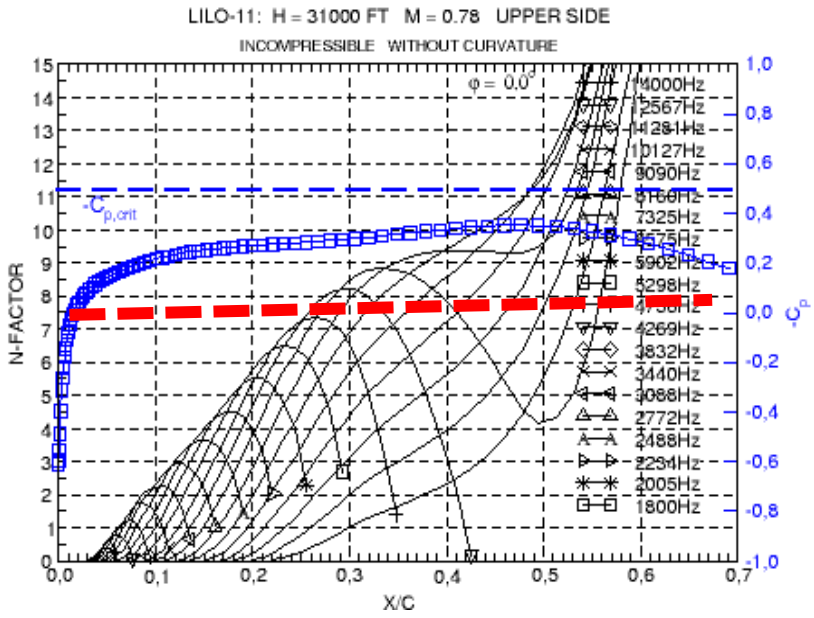
HV Design: N_{CF}- and N_{TS}-Factors without Suction





Crossflow transition at 0.2%

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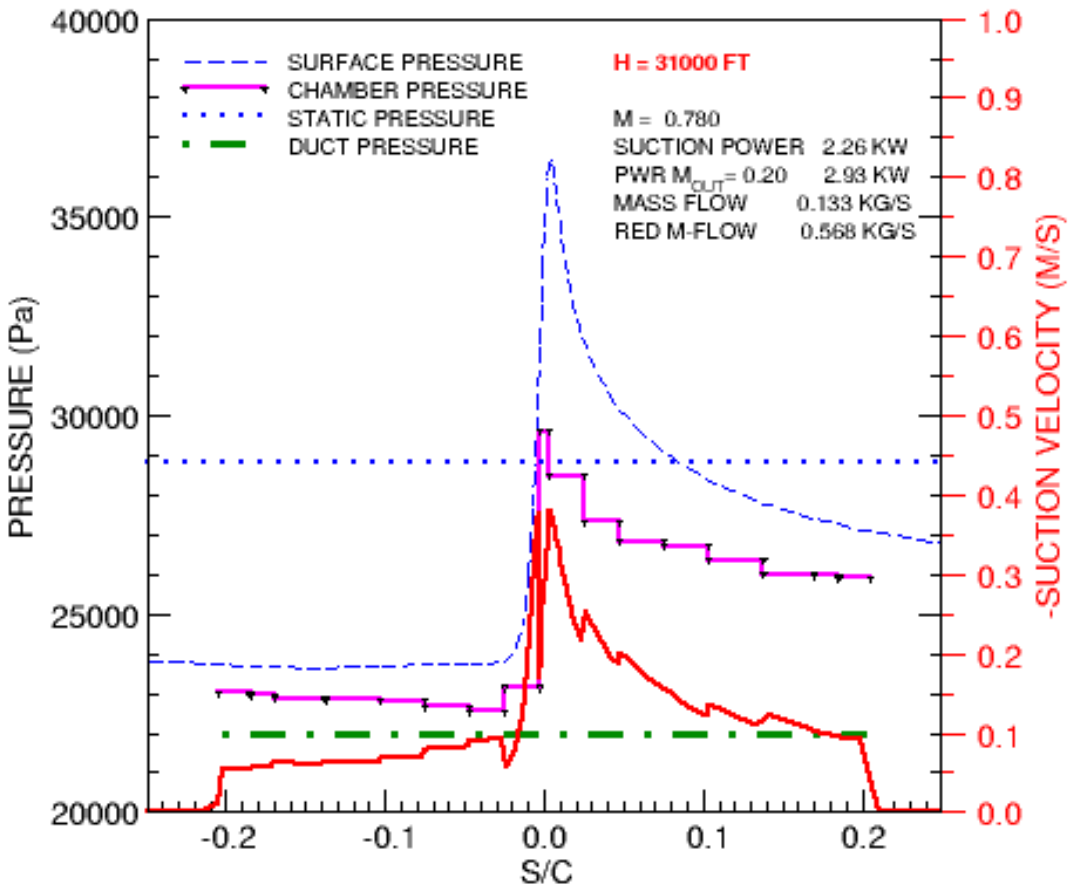
HV design: Pressures and Suction Velocities (V2.2)

Flight altitude 31000ft
Sideslip (yaw) 2^0
No rudder deflection



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HV Design: Conclusions

The HIGHER-LE / VER²SUS simplified design satisfies

Aerodynamic requirements for all (flight) conditions:

suction requirements:

- no outflow

- no choking in holes

- no transition by flow into holes (“oversuction”)

- smoothness conditions are satisfied

Structural & manufacturing requirements

loads

bird strike

manufacturing processes

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Wind Tunnel Validation of Simplified HLFC

Wind Tunnel Validation of Simplified HLFC

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Wind Tunnel Model for DNW-LLF Test

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Micro-perforation - Manufacturing Tolerances

It is impossible to drill a few million micro-holes with the exactly the same geometrical shape.

Therefore, the design of the simplified HLFC system, which has to function for the different flight conditions, must also take variations of the micro-perforation into account.

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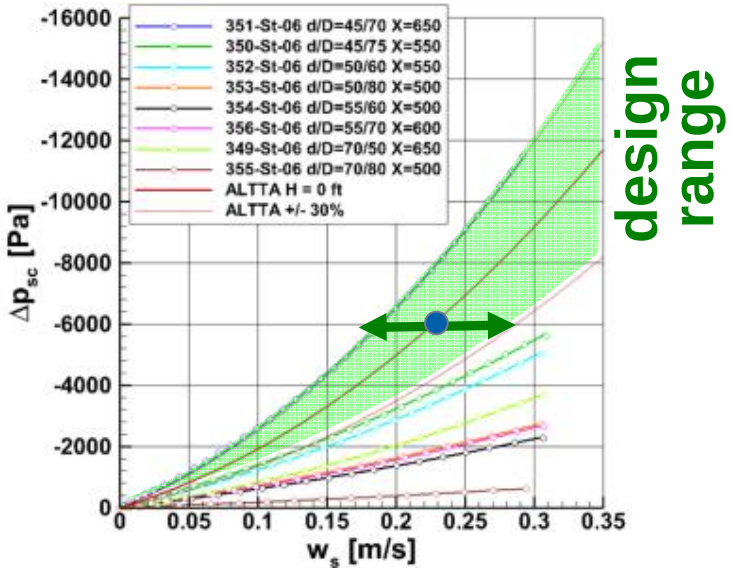
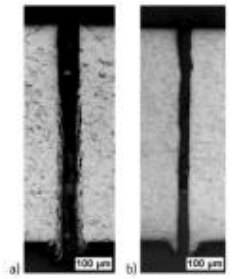
Micro-perforation - Manufacturing Tolerances

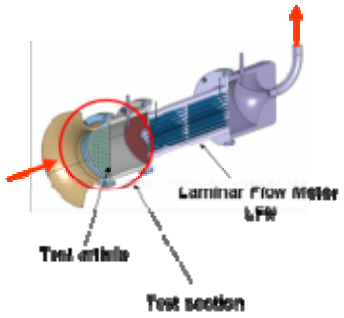
We define a design range for the micro-perforation and guide the manufacturer using flow measurements of test specimen in combination with analytical hole modelling



Determination of pressure loss characteristics



Test specimen with 15cm diameter



Measurements with DLR flow meter

Use analytical model to modify hole parameters

New parameters for laser drilling

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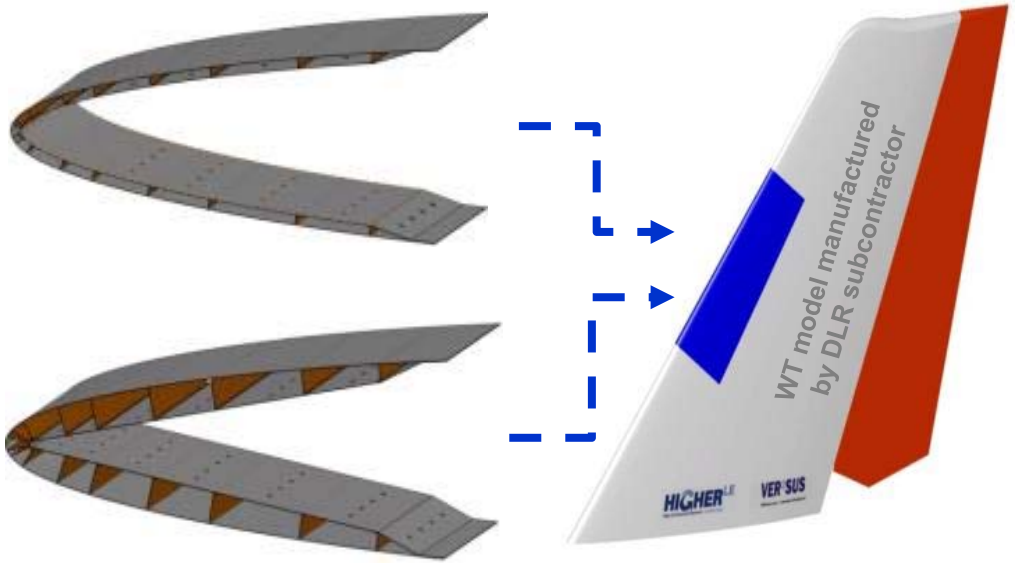
Two HLFC Structures Tested in DNW-LLF Tunnel

ALTTA concept

Splitter concept



DNW-LLF wind tunnel model with HLFC system

Two structural concepts for simplified suction for the A320 fin with the same chambering are being manufactured and will be tested in the DNW-LLF wind tunnel

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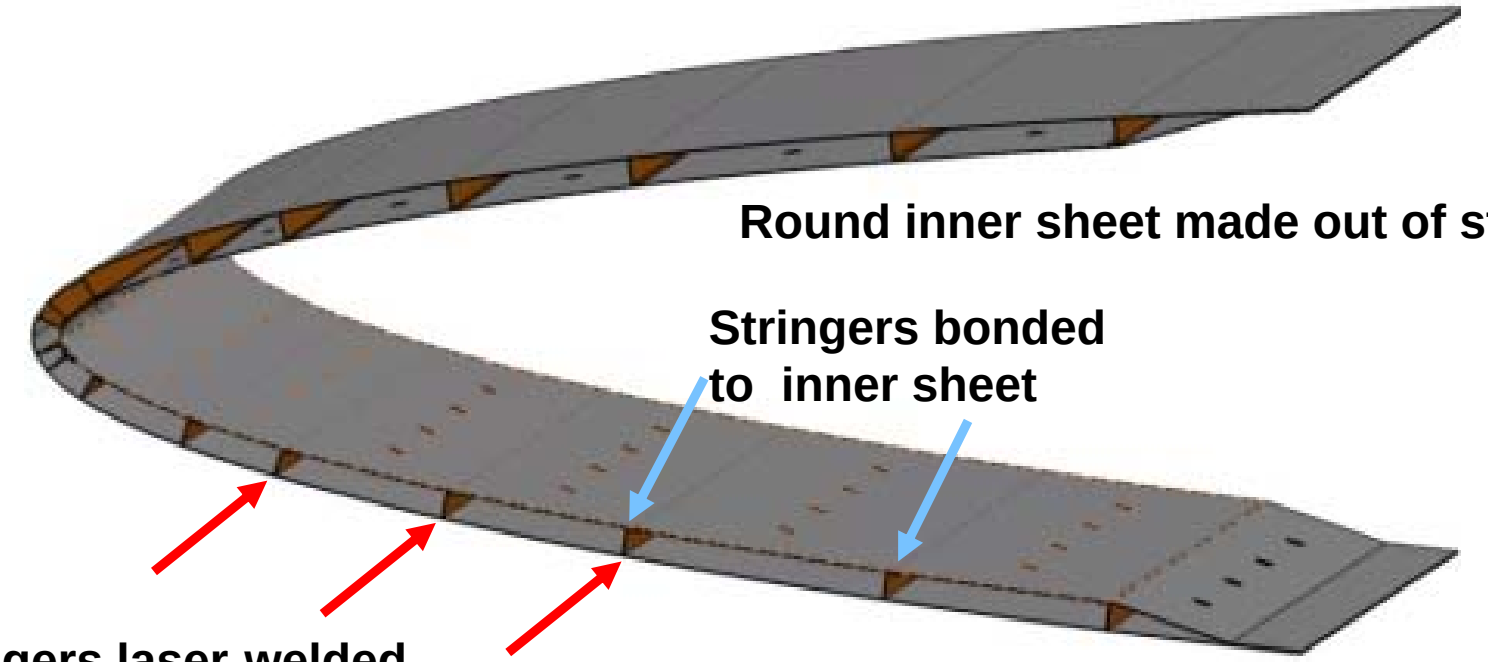
ALTTA Concept

Micro-perforated suction surface made out of steel



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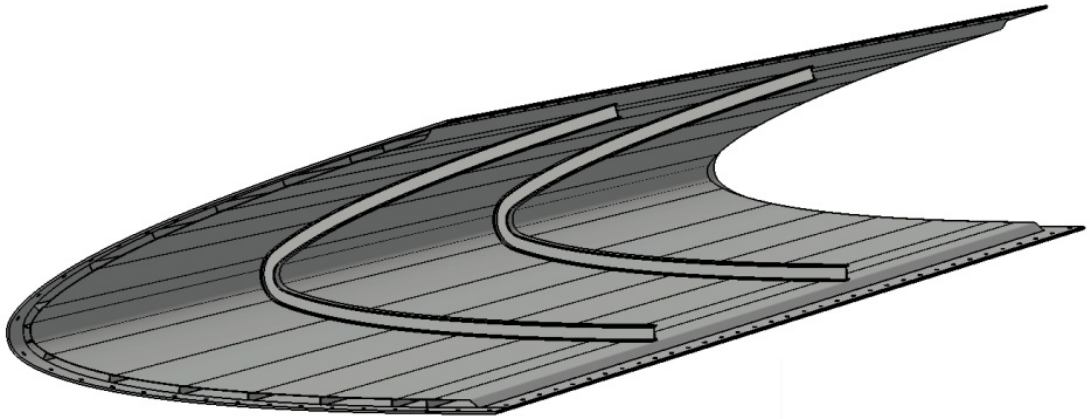
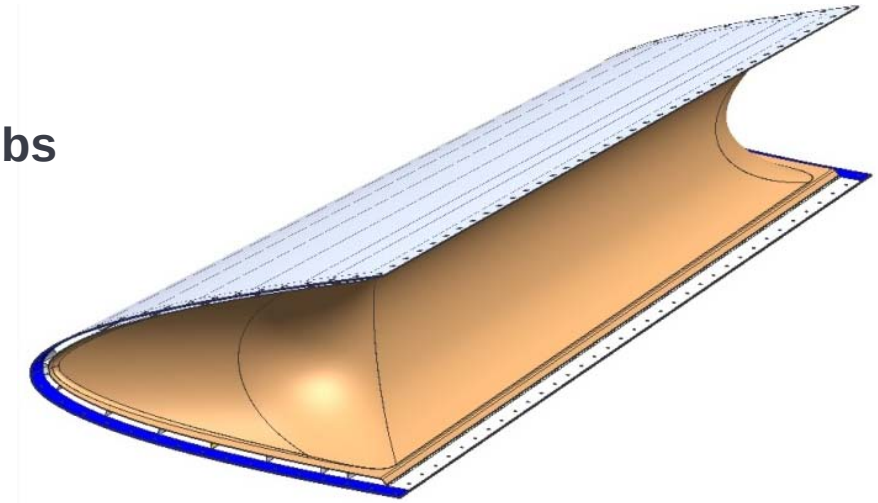
ALTTA Concept



ALTTA leading edge with two ribs



… and sealing membrane

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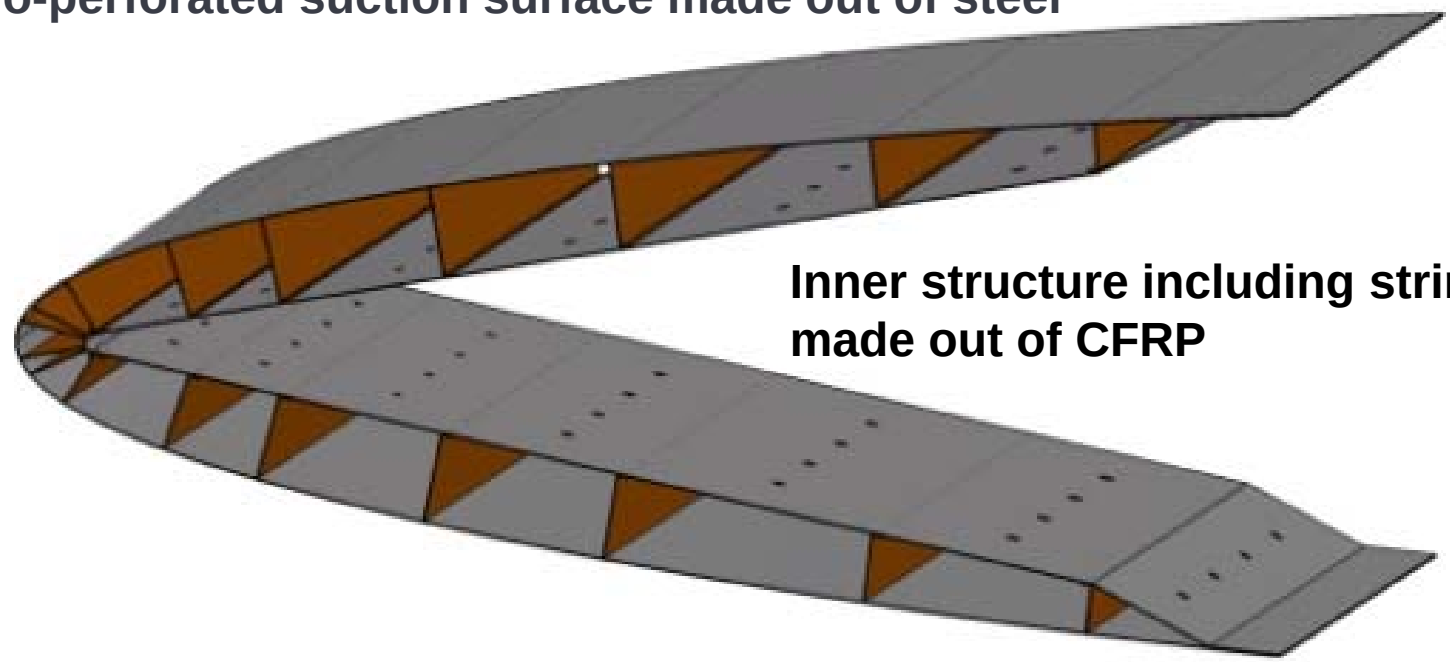
Splitter Concept

Micro-perforated suction surface made out of steel



Inner structure including stringers made out of CFRP

Inner structure bonded to micro-perforated outer sheet

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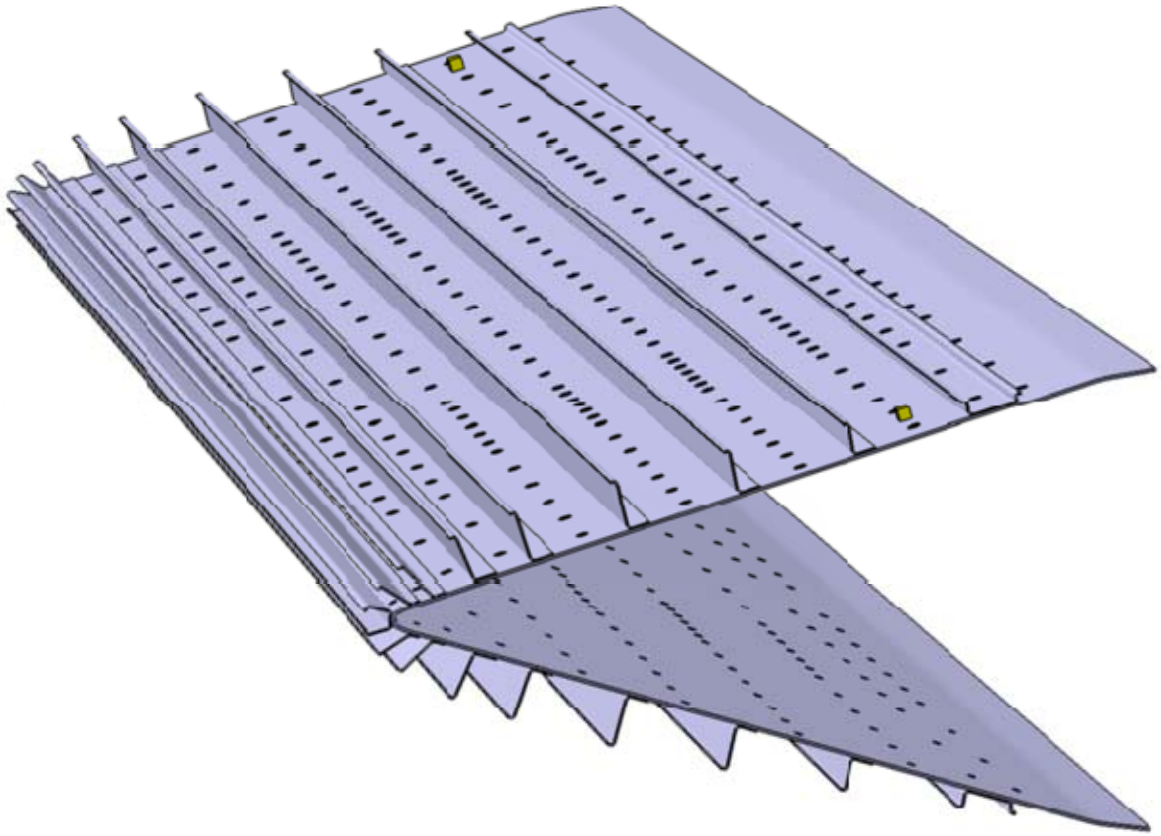
Splitter Concept



Inner CFRP structure with throttle holes
and orifices for pressure and temperature measurement devices

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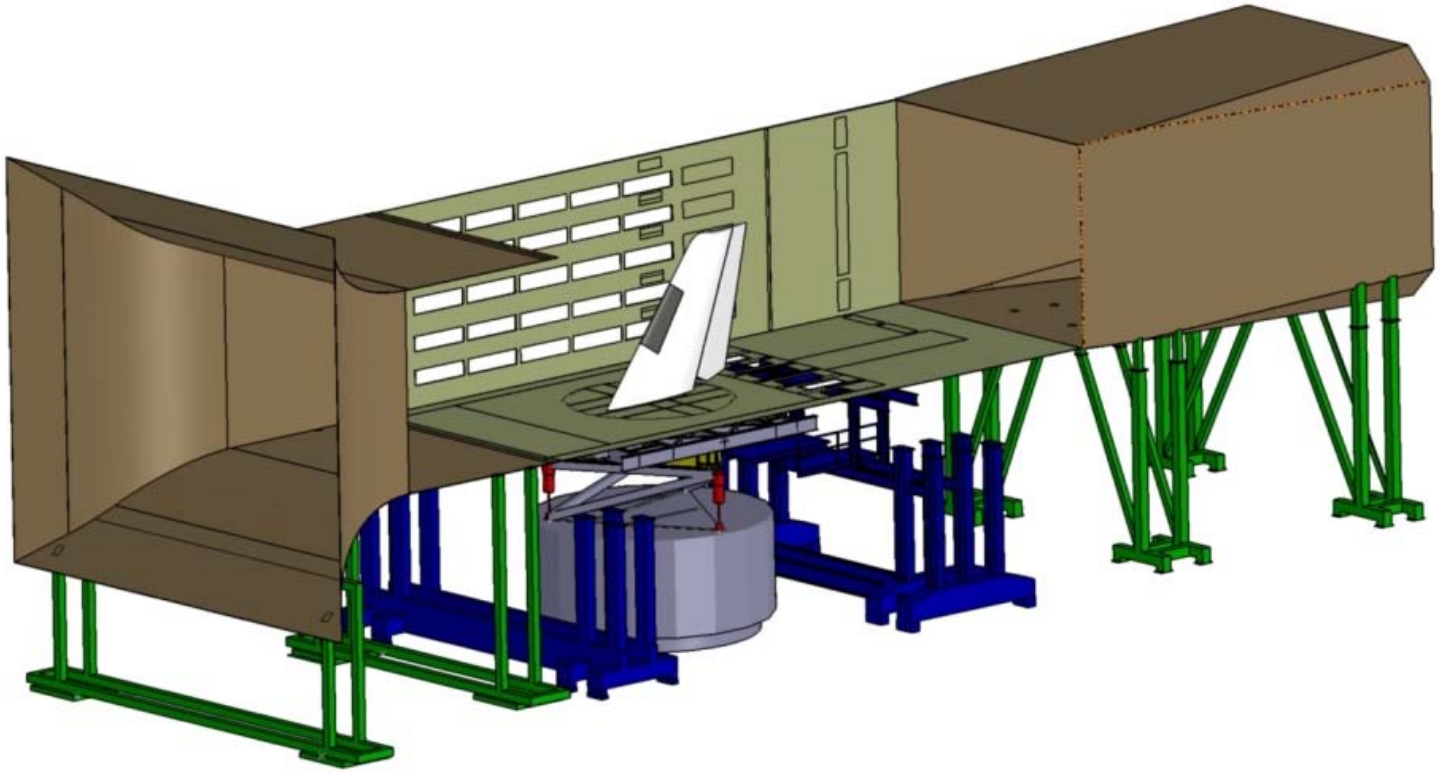
Design Validation

Wind tunnel test in DNW-LLF in November 2014



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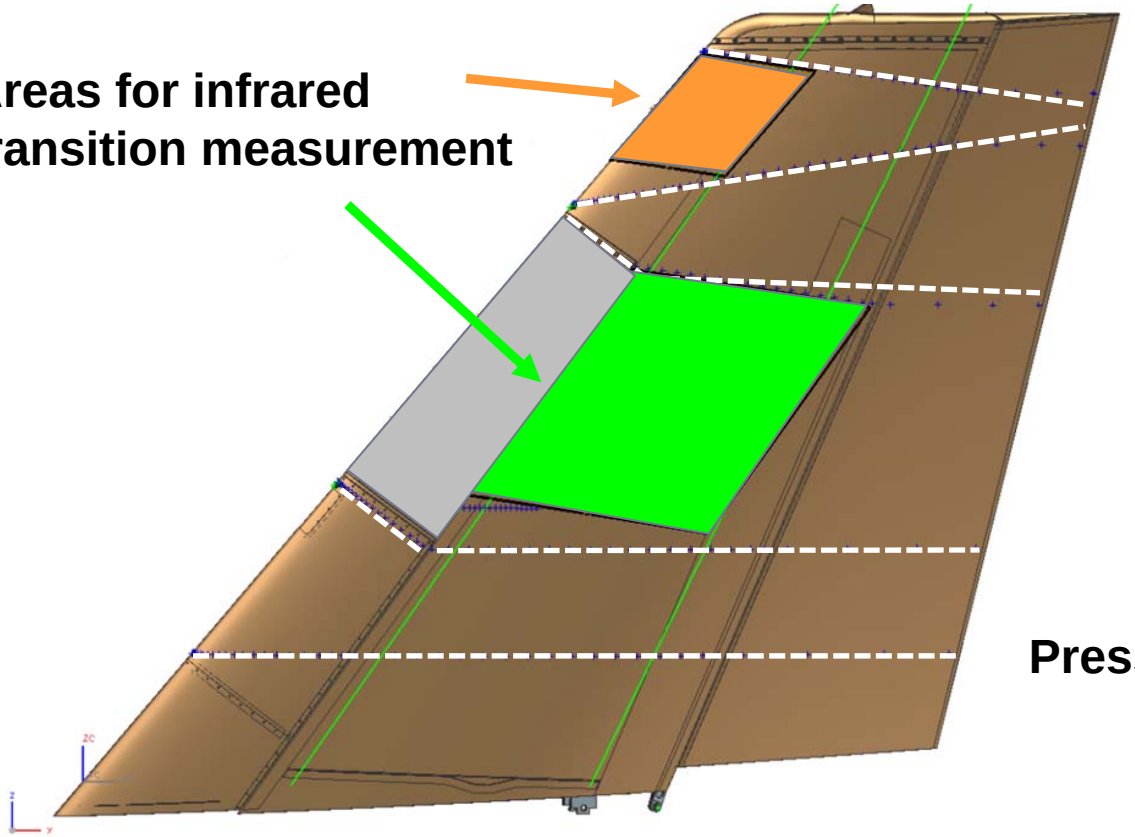
Instrumentation of Wind Tunnel Model



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DNW-LLF Test in November

ALTTA type leading edge mounted to WT model

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Next Steps in Europe – Status in US

Next Steps:
AFLoNext – Clean Sky 2

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AFLoNext – CleanSky 2

AFLoNext: Validation of simplified HLFC on the VTP of an A320 aircraft

CleanSky 2: Long-term in-service demonstration of simplified HLFC on commercial airliner

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Thank you

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Backup Material

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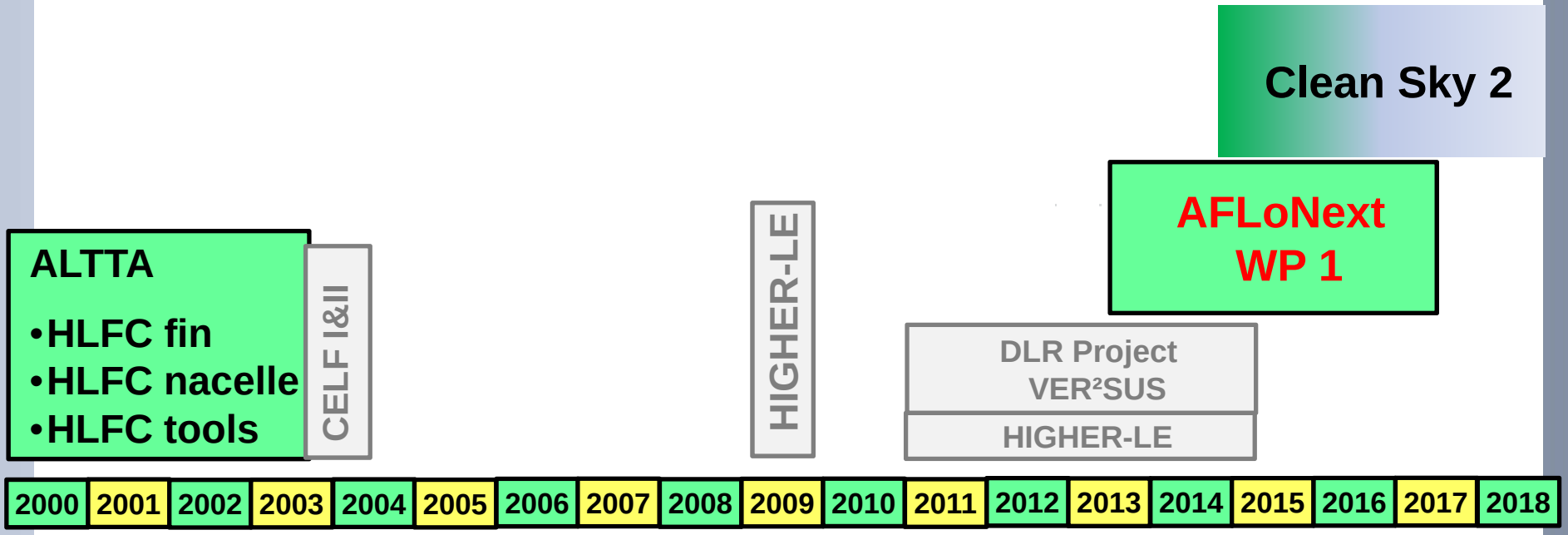
HLFC Activities in Europe



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The Air Transport System as Basis for Aircraft Design

by
Prof. Dr. Dieter Schmitt
Aeronautical Consultant

EASN Workshop on
Flight Physics and Aircraft Design
in Aachen from 27th – 29th Oct. 2014

Content

- Introduction
- Air transport as essential part of worldwide economy
- Air transport as input/requirement for aircraft design
- Aircraft manufacturer – the duopoly Airbus – Boeing
- Do market forces create new aircraft ??
- Will “TTIP” help the aircraft industry ?!?
- Air Transport – the second input for Aircraft Design
- Market aspects – globalisation strategies to overcome national constraints !!
- The new Arabic Challenge !! Fair markets ??
- Conclusions

Introduction

- **Finance** is dominating today‘s world!
  - Money is the new **Goodness**! but not really helpful to help to understand the complexity of the world.
- **Marketing** is the other dominating pillar!
  - Important is a proper marketing and not the quality of the product!
- **Engineering** is the 3rd important pillar, normally linked to quality!
  - Engineering thinking allows to have a wider perspective and an understanding of system and system behavior

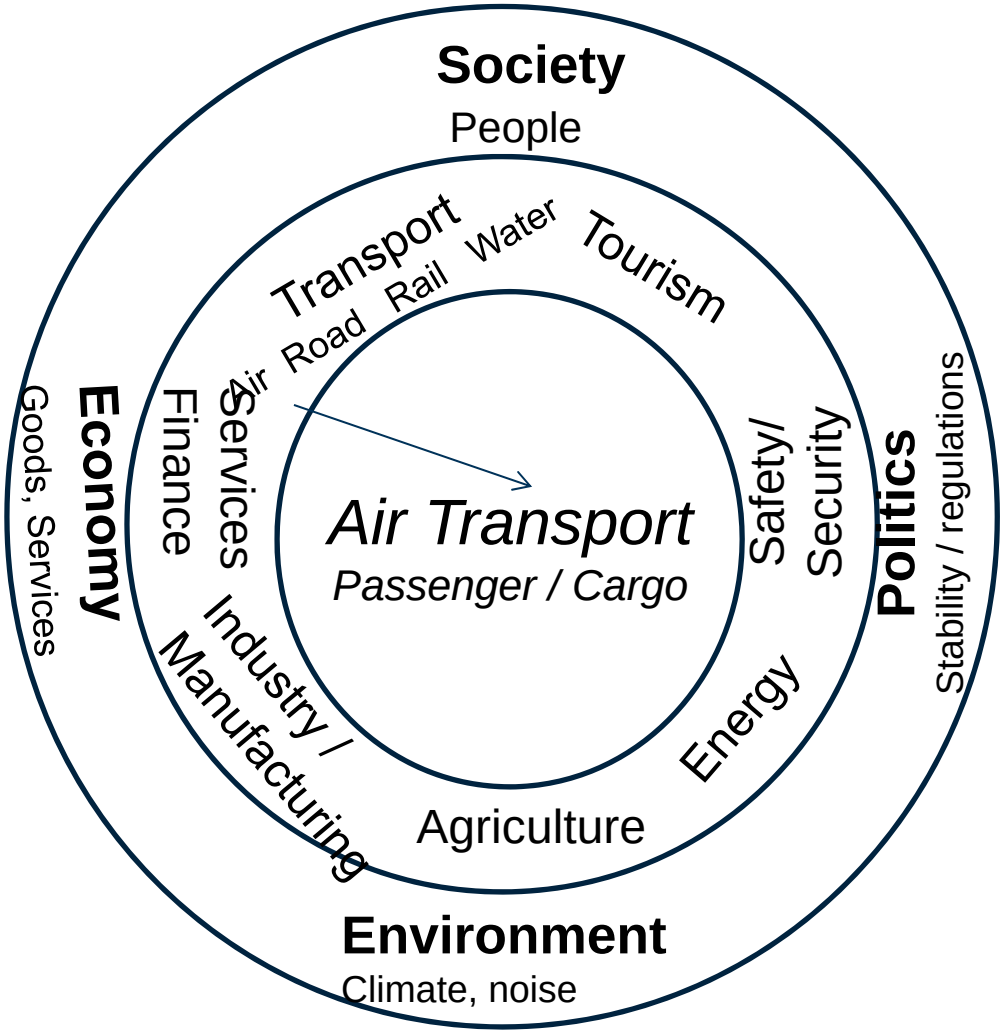
- Air transport is an important element in the industrial and commercial world and it is not only a subject for F and M

- Aircraft design is a major motivator for young engineering students! This is the motivation to fascinate them for engineering
- Air transport is the wider system approach to identify the task, the aircraft has to do and also understand the driving market forces!

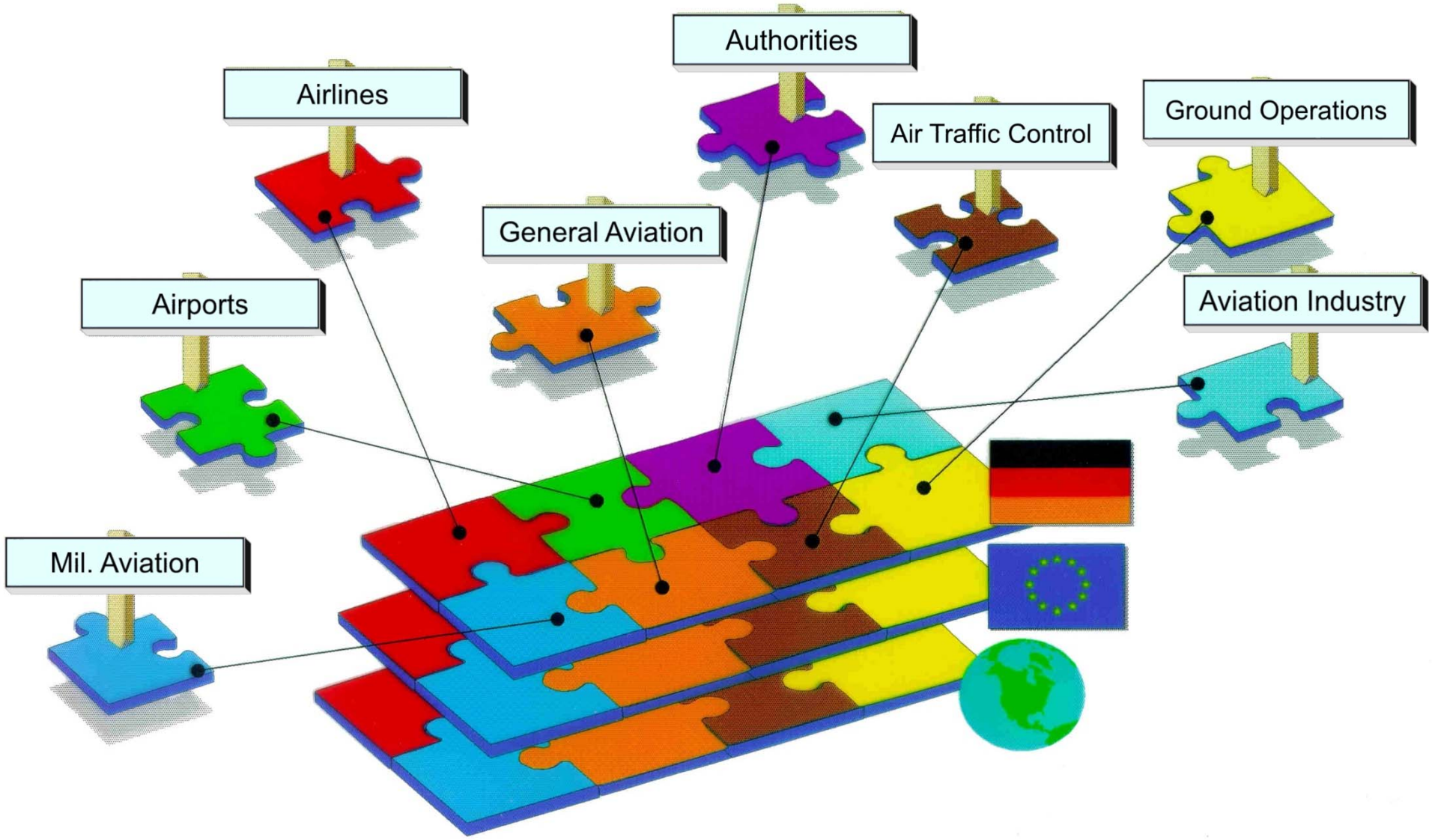
Who needs an aircraft to do what??-

Air Transport as part of worldwide Economy

ARTS-DS



Air Transport System



Bodies and Agencies in Air Transport System *ARTS-DS*

	Poland	***Germany***	***Europe***	***International***
General Transport Guidelines	Ministry of Transport	Ministry of Transport *Berlin*	European Union **(CEC)** DG Move *Brüssel*	International Civil Aviation Organization (**ICAO)** *Montreal*
Certification, Airworthiness and Personal	Ministery for Transport	Luftfahrt-Bundesamt (**LBA)** *Braunschweig*	Joint Airworthiness Authorities (**JAA)** →***EASA*** *Cologne*	Federal Aviation Administration (**FAA)** *USA*
Air Trafic Control	Ministry of Transport	Deutsche Flugsicherung (**DFS)**	Eurocontrol *Maastricht*	*Air Navigation Standards **(ICAO)***
Operator/Airline	LOT Polish Airlines	Lufthansa *Cologne/Frankfurt*	Association of European Airlines (**AEA)** *Brüssel*	International Air Transport Association (**IATA)** *Montreal*
Airport	Rzeszow Airport	Arbeitsgemeinschaft deutscher Verkehrsflughäfen (**ADV)** *Stuttgart*	Airports Council International – Europe (**ACI-Europe)** *Brussels*	Airports Council International (**ACI)** *Geneva*
A/C - Industry	??	Airbus Germany MTU, Liebherr	EADS	Boeing, Airbus, etc.

- 2 Examples to illustrate the complexity of the Air Transport System

1. The aircraft manufacturers dilemma to respond to market demand

   Product strategy as seen today

   Optimization of „financial engineering“

2. Airline strategies to overcome national constraints

   The airlines choices and competitive situation

   Globalization strategies

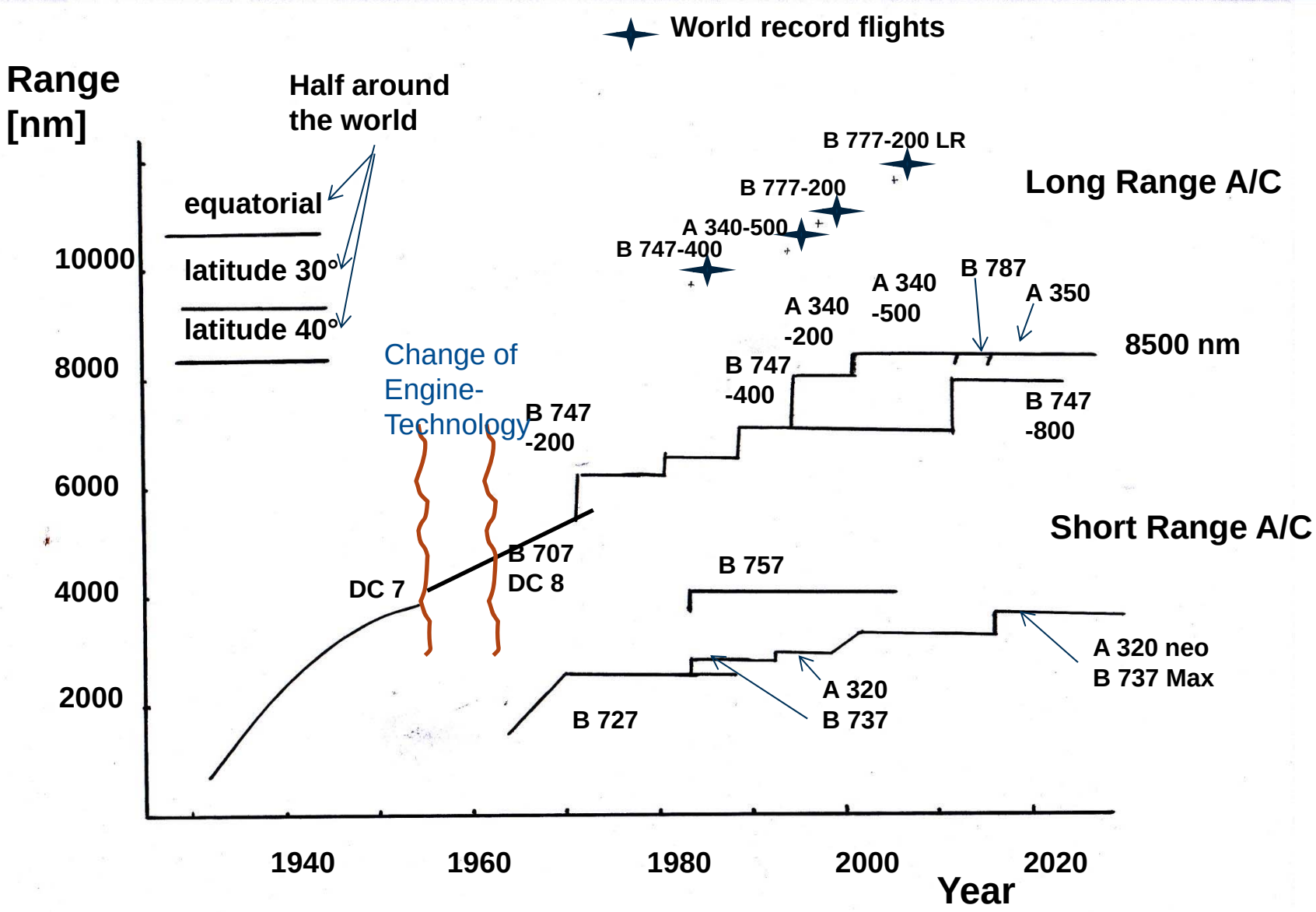
Aircraft manufacturers

- 1. The aircraft manufacturers dilemma to respond to market demand
- US manufacturers dominate the market in 1960 - 1970
- Europes approach to enter the market
  - Creation of Airbus in 1970
  - The product development from A300 » A310 » A300-600 » A320 ..
  - Technology as the driver

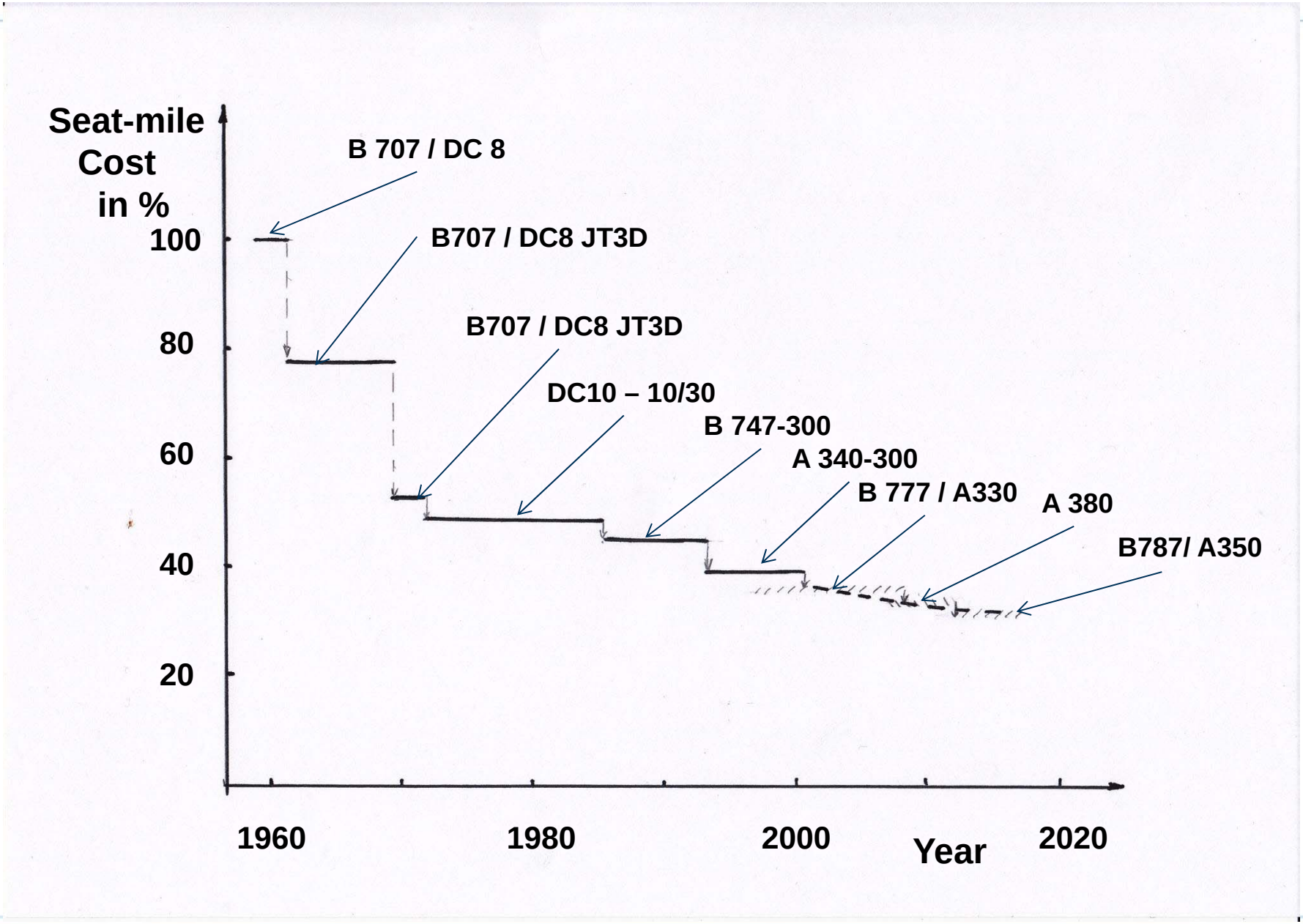
- The duopol – Boeing and Airbus

- What is their strategy??
  - Respond to market demand or looking for market share?

Range of civil aircraft

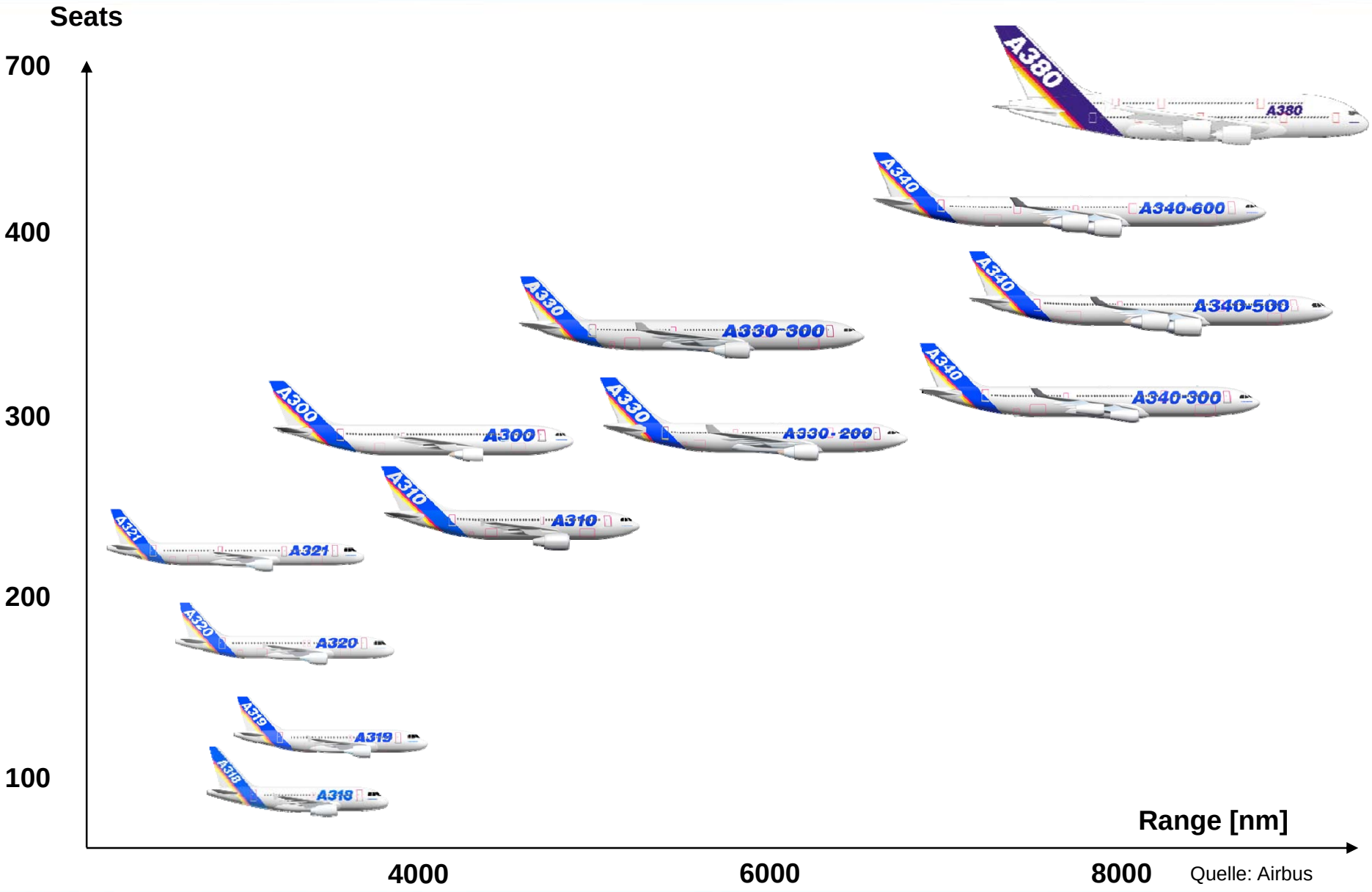


Seat-mile Cost versus time



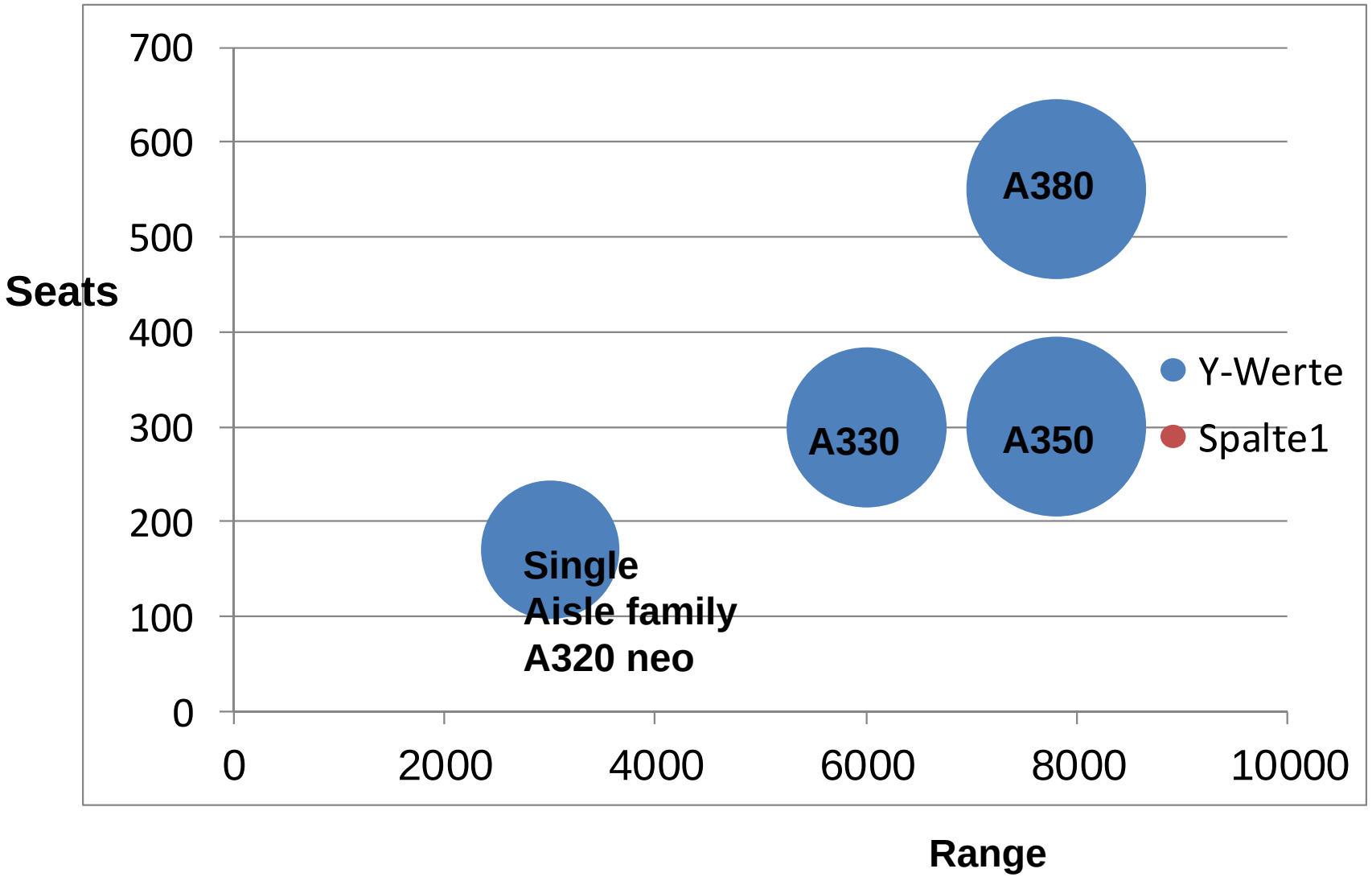
Family Concept for Airbus

ARTS-DS



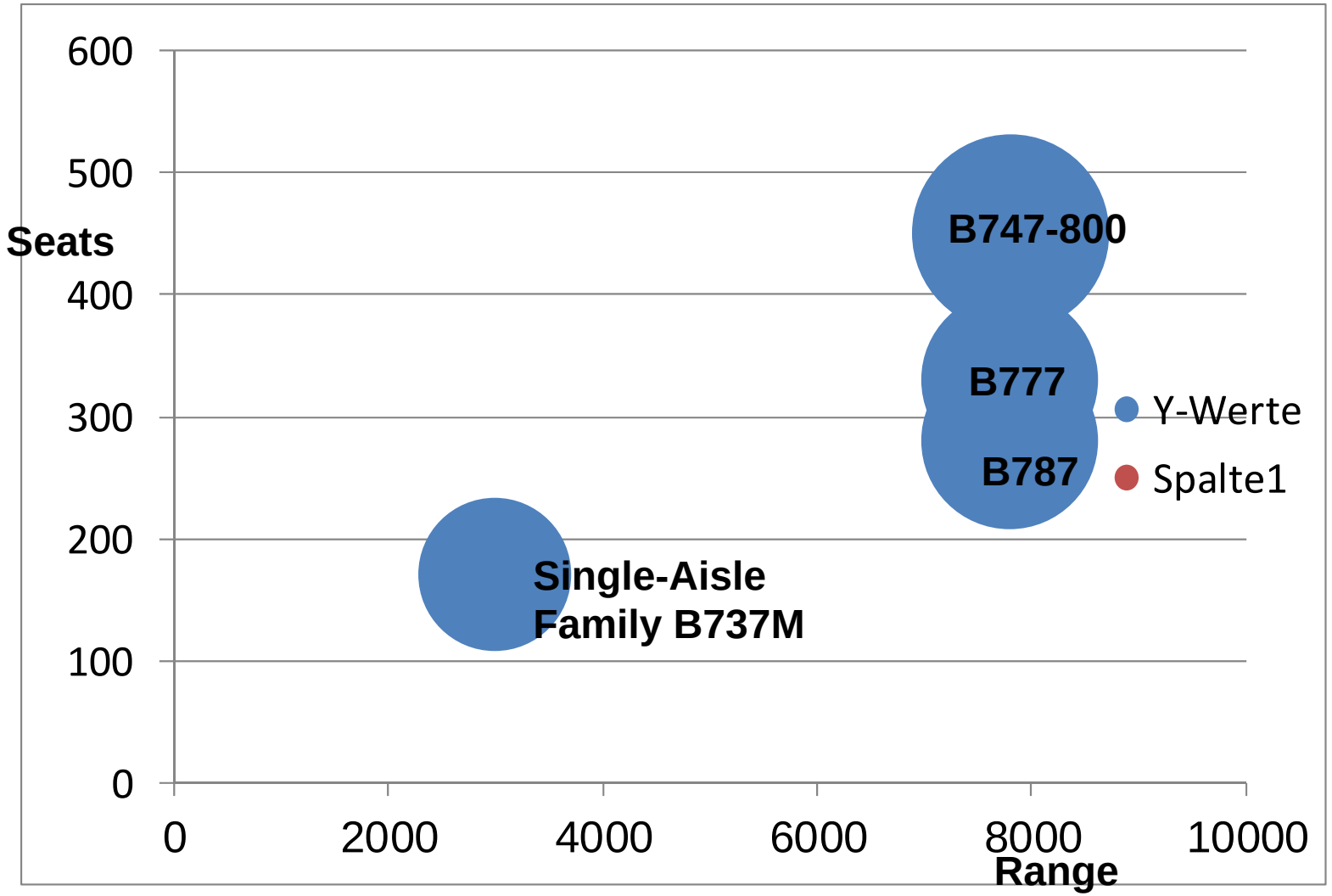
Quelle: Airbus

Airbus Family Concept



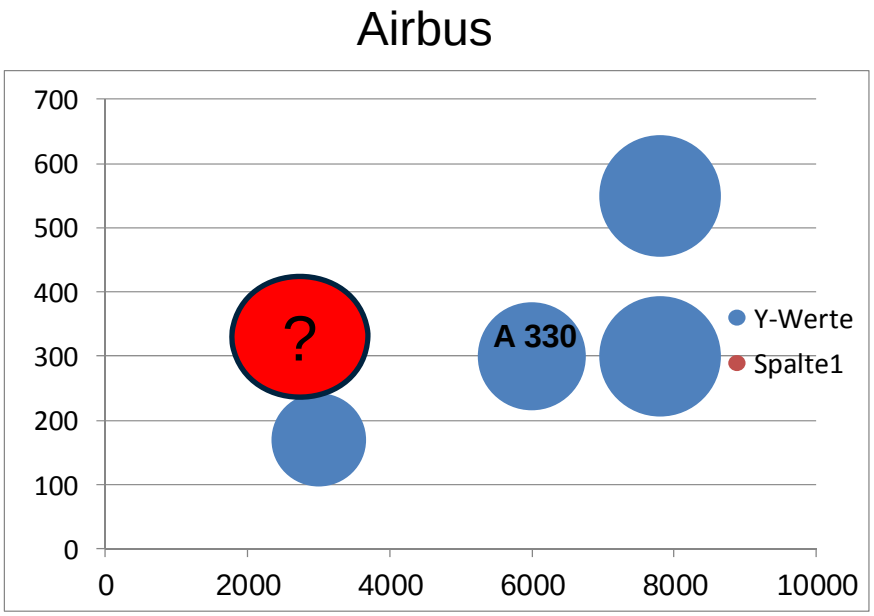
Boeing Family Concept

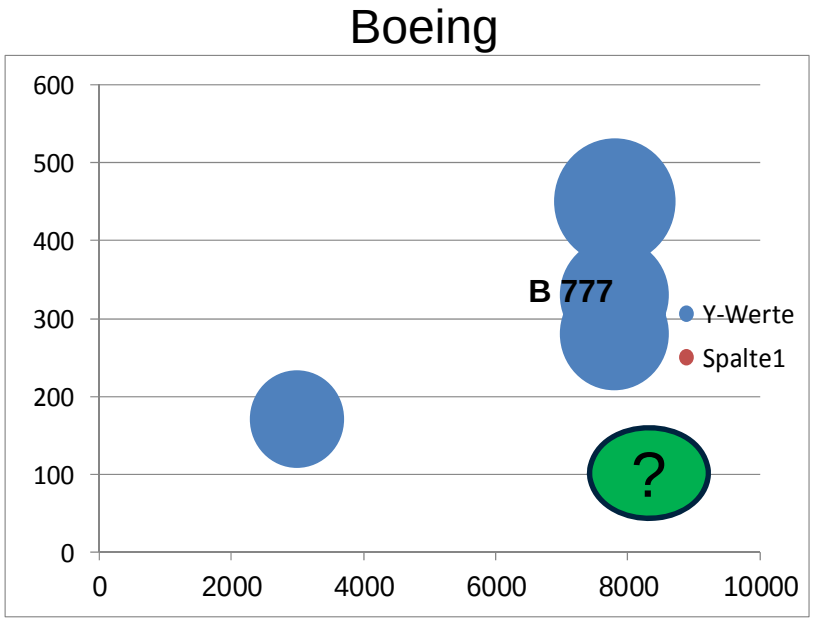
ARTS-DS



Comparison of Airbus and Boeing A/C families

ARTS-DS





- **Status:**
- Both cover the same market segments with SA and new TA (B787 vs. A350)
- Both have a similar product as Very Large A/C (A380 vs. B747-8)
- Both have still an old metallic TA-aircraft in production (B777 – A330)

- No product at low range and high capacity (people mover) !
- No product at long range and small capacity
- No environmentally friendly medium range aircraft!

GATT Agreement (General Agreement on Trade and Traffic)

GATT Agreement was established in 1992, regulating loans, financial conditions and research
Gatt Agreement from 1992 cancelled by Boeing and US
US military transport aircraft
US has the military budget for development which is out of any Gatt agreement;
Europe has no equivalent instrument

TTIP: This black hole is not defined , butbe careful!

What is with our ACARE strategy and the EC research budget?
Is now Boeing allowed to ask for funding from EC
Clean Sky etc.?? Can they attack Europe for unfair practices?
Is anybody aware, what this is all about?
The „lying club“ of bankers and politicians are seeing a lot of new jobs??
For whom??
Globalization is a must ??

Questions:

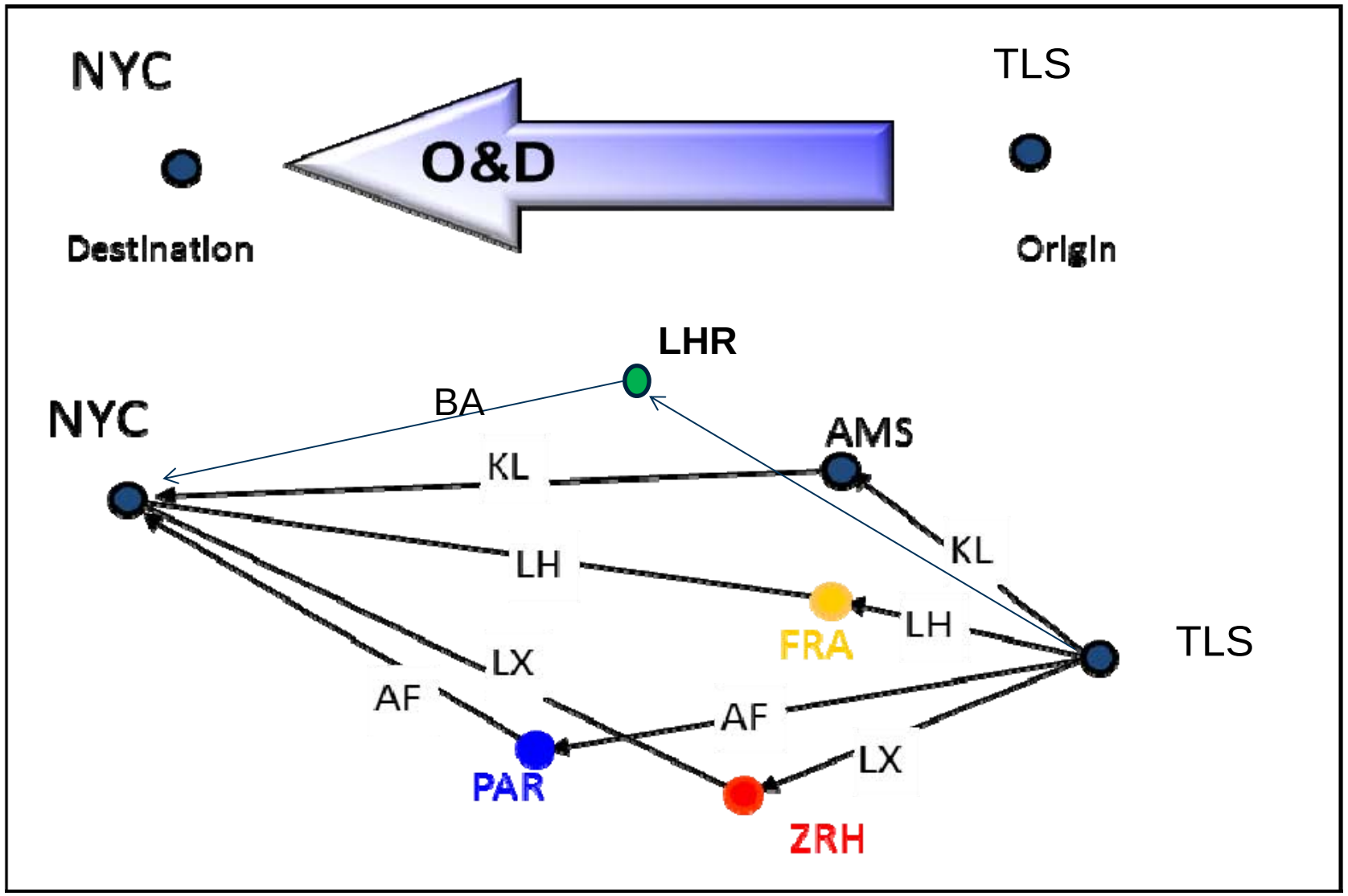
- Is there no market for:
  - the short range and big capacity aircraft (people mover) ??
  - The small long range aircraft (less than150 pax) ??
- Where is the dedicated **freighter aircraft**??
- If the **LCC airlines** are no longer using and selling the lower cargo compartment, why are they flying empty cargo capacity around?
- We need a new design for **LCC** with a new cabin design which includes passengers and luggage ???
- New engine technology will lead to low noise aircraft!
  - What is the minimum noise level, where aircraft will no longer disturb their airport environment ?? 24h operation, the dream of all airlines and manufacturers

Airline Market

- Airbus Global Market Forecast says, that GMF has analysed more than 900 airlines!
  - Airlines have spent in 2013 more than 200 billion for fuel! (IATA quote!)
  - Airlines are spending today more than 30% of their cost for fuel!
  - In 2000, this was only 14% of overall cost
  - Fuel cost have increased by a yearly average of 6.5% over last 14 years!
  - Other airline cost have decreased by a constant 2.5 %! productivity gain!

- There are too many airlines in the market today !
- This means there is no healthy competition !
- Airlines are created under national law!
  - So each country tries to support its national airline, which is understandable, but this may spoil fair competition between the airlines
- In Europe, Alitalia is a constant problem since 15 years, where national funding is required to keep Alitalia alive! AF, LH, BA are constantly demanding the EC to ensure fair competition!
- Do each country needs its national airline????

Different Airline Choices



Airline strategies

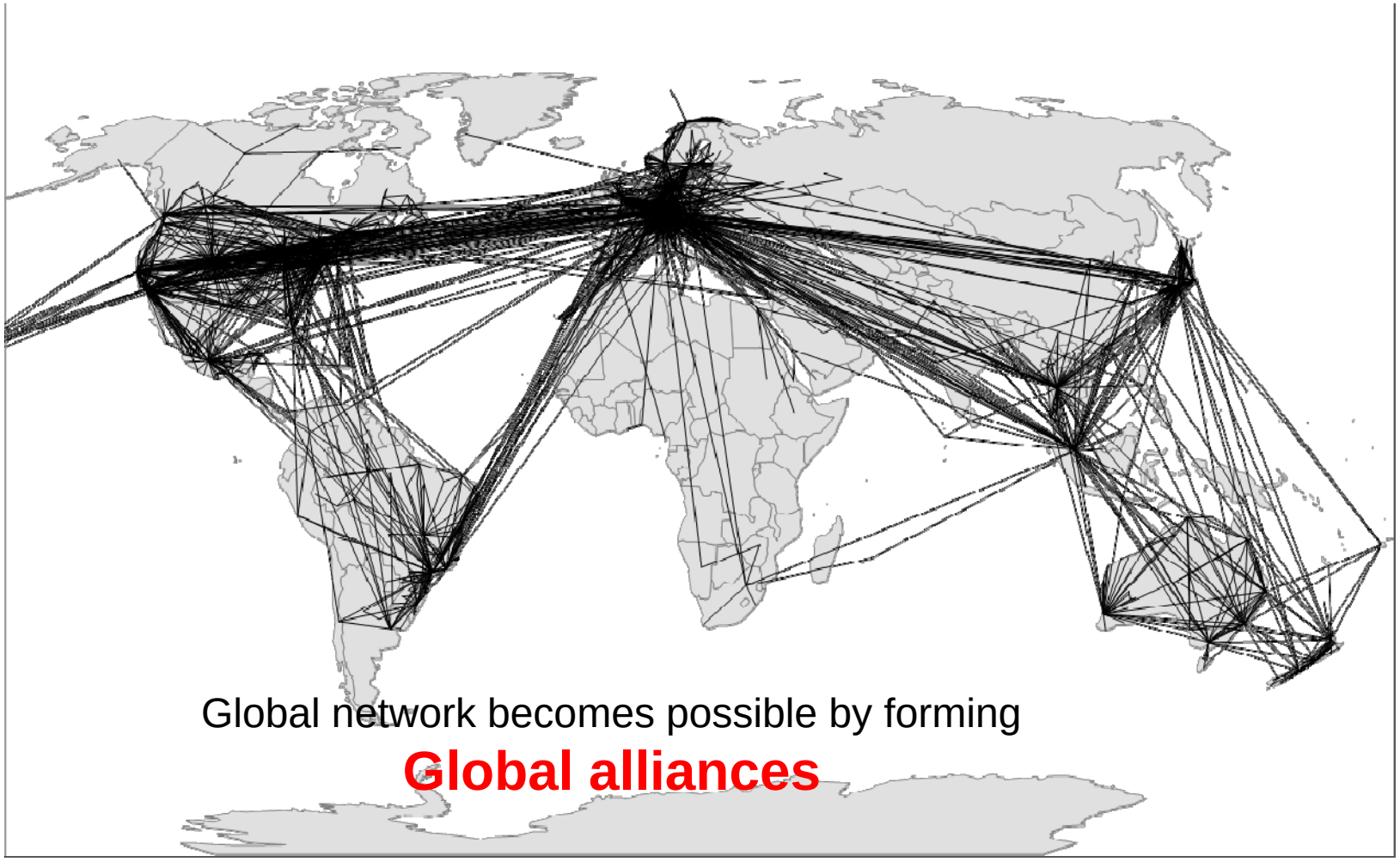
- Airlines are created under national law!
- Several trials, to buy another national airline, failed! » ex.: Alitalia
- Cooperation is the only way out to provide to the customer a worldwide network.

- Globalisation strategies started in the 90ies between USA and Europe
- 3 big US airlines were looking for European partner airlines.
  - American Airlines and British Airways started
  - Delta and Air France followed
  - United and Lufthansa formed the 3rd alliance

  The 2nd step was the search for partners in Asia, Australia and South America

  Important airlines like Singapore, Air India, Cathay Pacific, Thai Airways, Qantas were heavily sought after ..

Global network



International Cooperations – Example *Star Alliance* ARTS-DS

- In Global Cooperations like STAR ALLIANCE the airline members agree to accept the tickets of their partners, the so called „Code-Sharing“. This helps the passenger when booking a flight to have access to the whole alliance network of all partner airlines (2014: 27 airlines, connecting 1316 airports in 192 countries; 18500 daily departures).

- The partners agree to provide a common standard for passengers and harmonize flight plans.

- Frequent Flyers and business travellers can get additional mileage bonus from all partner airlines and have access to common business lounges at nearly all airports..

- Besides the attractivity for the customer the airlines can better manage their capacity by common and flexible use of aircrafts and also adjustment of slot availability at the airports.

Quelle: Star Alliance

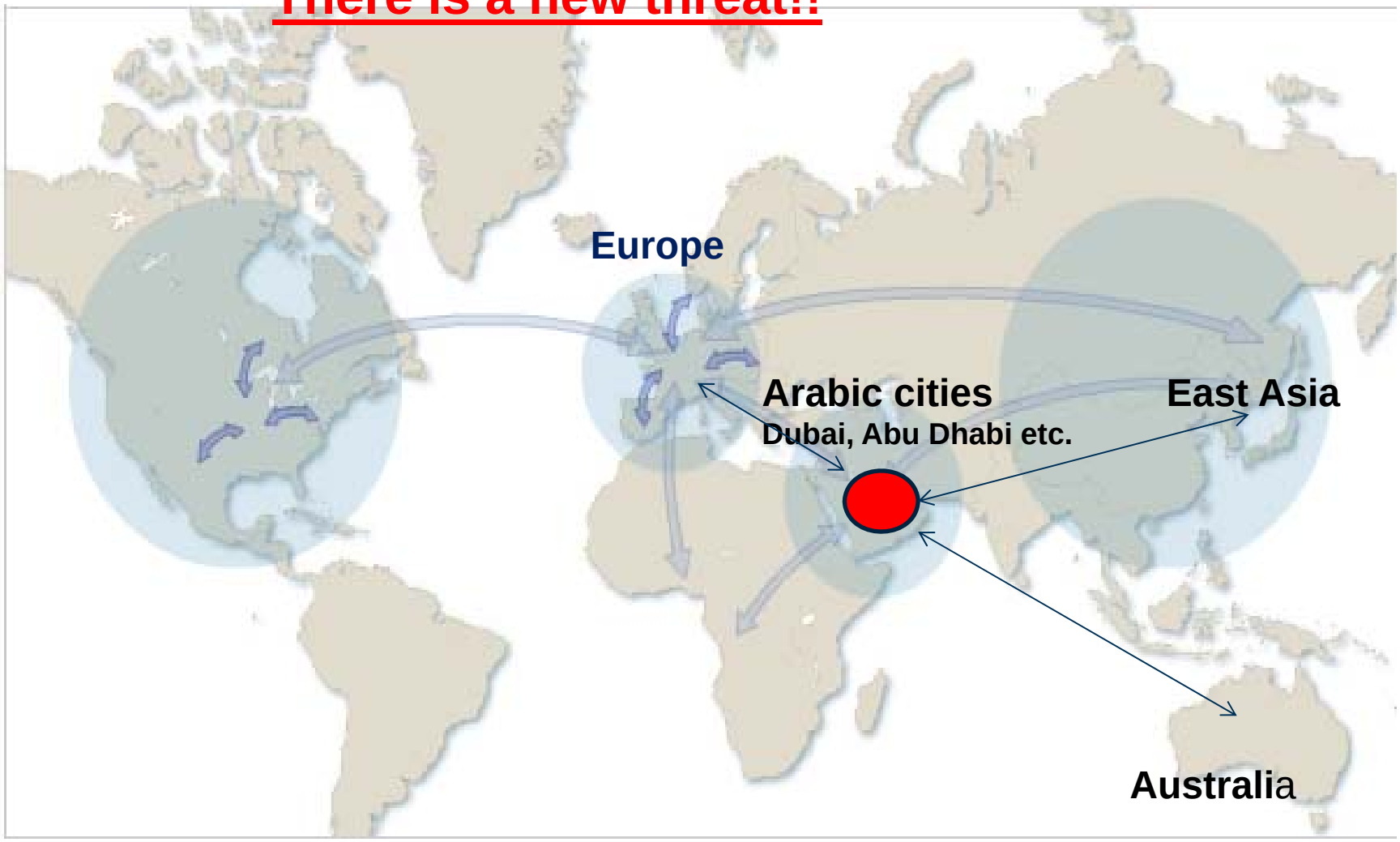
Global Airline-Alliances

Partners	19	28	13
Connected Countries:	178	195	151
Connected Airports :	1024	1328	883
Daily destinations (flights):	15.207	21.900	10.117
Number of aircraft:	2853	4701	
IATA-Market share:	22 %	29 %	16 %
transported Passengers:	569 Mio.	727 Mio.	353,5 Mio.
Tonne-kilometer:	32,3 (Mio., nur int. Verkehr, 2002)	89 (Mio., nur int. Verkehr, 2005)	43,7 (Mio., only int. traffic, 2002)
Employees in 1.000:	452	460,2	343

Source: OneWorld, Skyteam, Star Alliance 2013

Route Europe to Asia/Australia

There is a new threat!!



Fair competition in air transport ??

- The European airlines are in strong competition
- For the transatlantic market, 3 Global alliances are competing:
  - Sky Team, Star Alliance; One World
  - Good and „fair“ competition ?!?!!

- For the routes between Europe and Asia/Australia, new airlines have appeared on the market during the last 10 years
- Emirates is the largest customer for Airbus A380! Just to spend money and support Airbus?? Orders: **140 A380 !!**
- ETIHAD has taken over Air Berlin! Orders: **10 A380 + 62 A350**
- QATAR is the first customer for A350; Orders: **10 A380 + 80 A350**
- All these new airlines are not part of any alliances, but they are buying aircrafts like hell! Where do they get the money from??
- What is GATT doing?

Fair Market conditions ??

German Newspaper FAZ from 18.10.2014

ARTS-DS

- Heading in FAZ from 18th Oct. 2014:
- Lufthansa and Air Berlin are in strong conflict!!
  - Air Berlin has a new shareholder **ETIHAD**
  - The German Ministry of transport has allowed ETIHAD, to operate in Germany via Air Berlin flights within Germany under the code sharing label ETIHAD.
  - What does it mean?
  - Etihad can market flights from Arabia to whole Europe via Germany,
  - i.e. Abu Dhabi to Berlin and further (With the traffic rights from Air Berlin) to other European cities!
  - Lufthansa is opposing strongly!
  - The ex manager from Air Berlin – Hartmut Mehdorn – speaks about a conspiracy of Lufthansa and Airport Frankfurt against the city of Berlin!

Where has ETIHAD earned their money to grow so phantastically???

Fair market conditions??

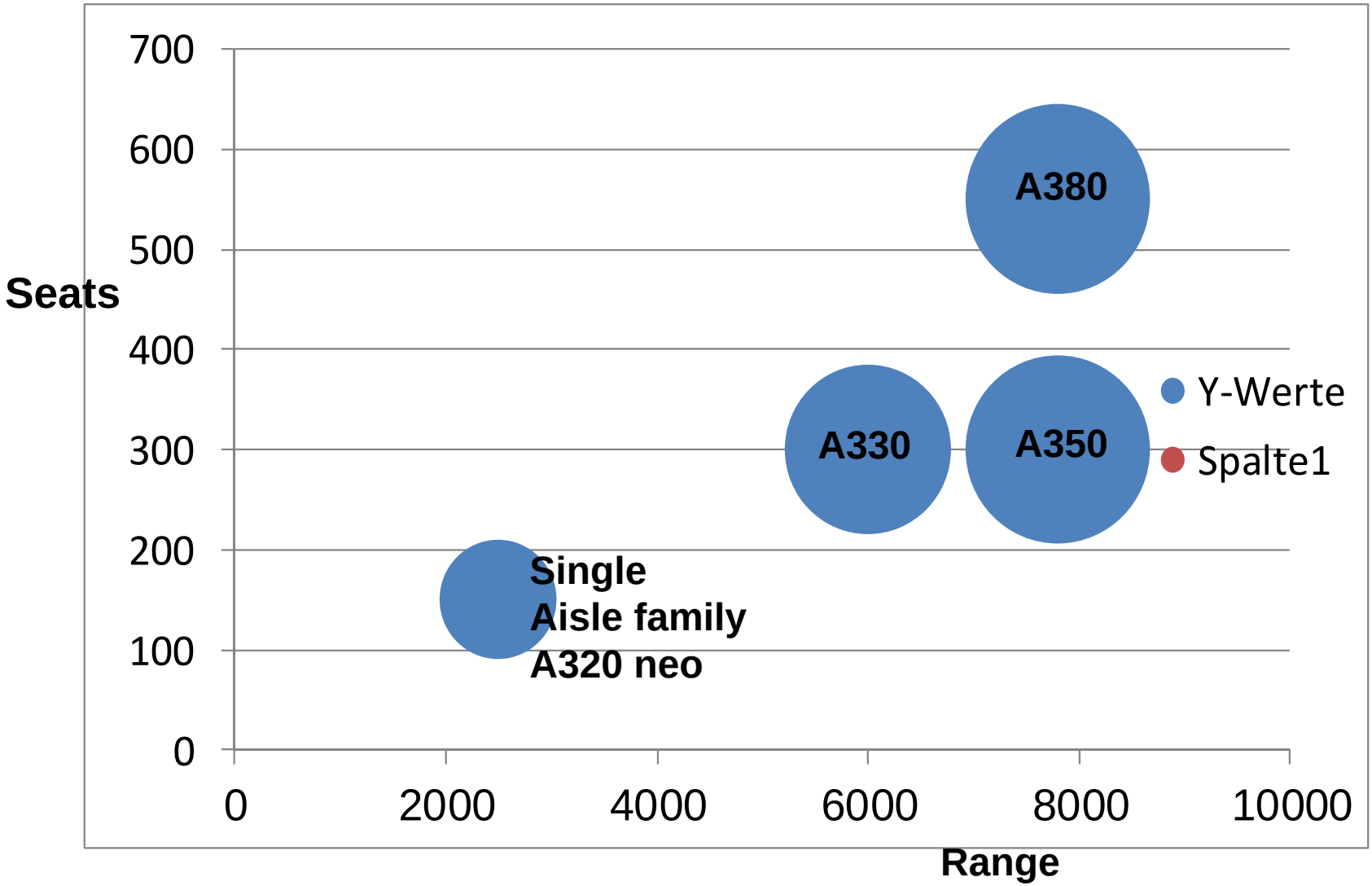
Globalization will help to create a lot of new jobs in Europe??

Conclusions

- Air Transport is not only a topic for
  - Civil Engineering
  - Marketing, business and transport people
  - **Engineering students** should be aware of trends and business background
- Aircraft design needs input from the market side (Requirements)
- Globalization is a **magic** word which is said to create a lot of new jobs! Where??
- Dominating rich countries like US, China and Saudi Arabia may profit from globalization!
  - Europe with its complex set-up and weak decision structure has little chances to be successful!
  - TTIP ?? who will be the winner?? Is it needed for Europe??

Thank you
for your attention!

Airbus Family Concept



- **Back - Up**

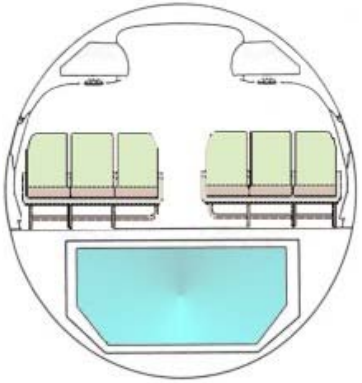
Cross Section

Systems have to be integrated and installed

Commuter

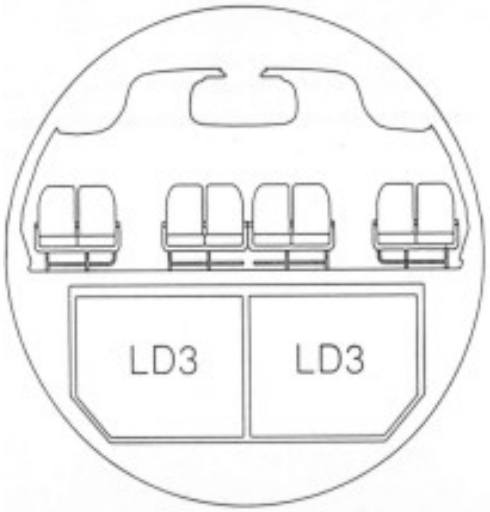
Single Aisle

Narrow- / Standardbody



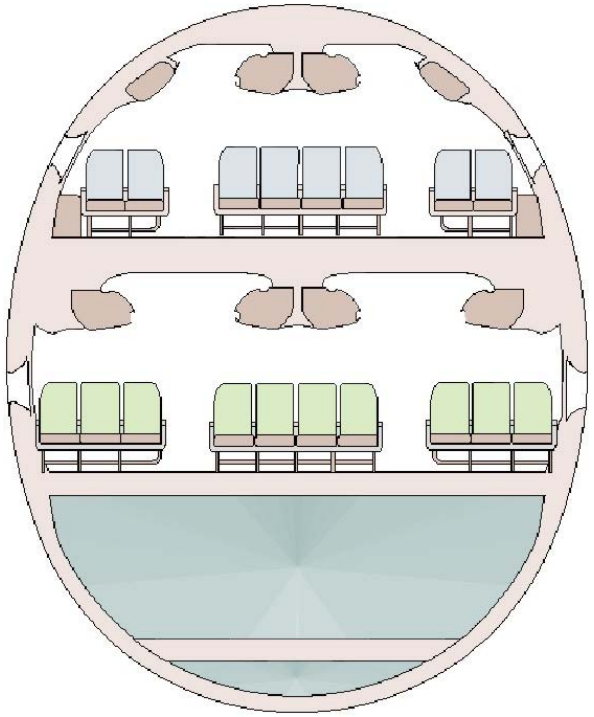
Single Aisle

Widebody



Twin Aisle

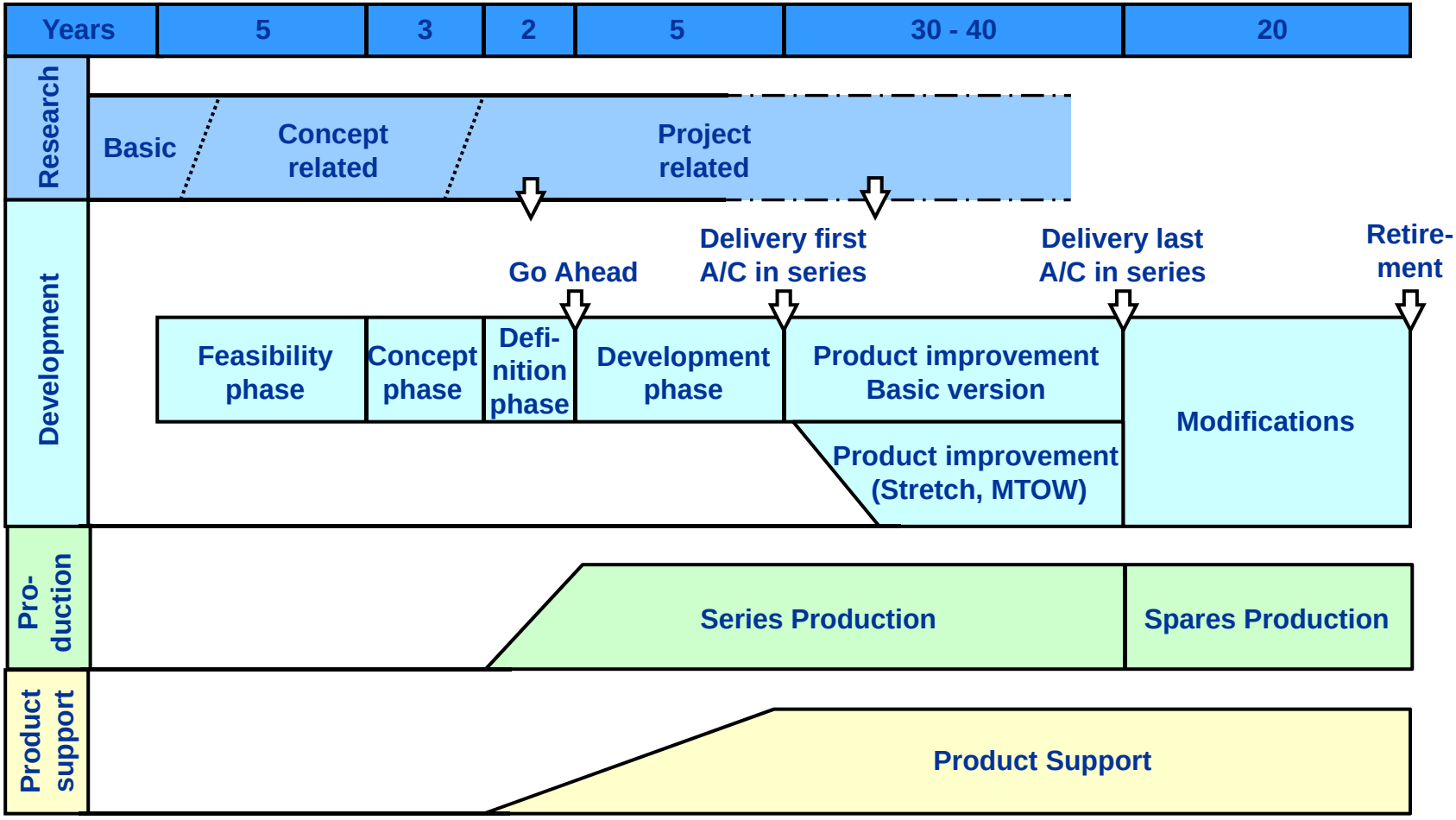
Macrobody



Double Deck

Typical life cycle of a civil program

ARTS-DS



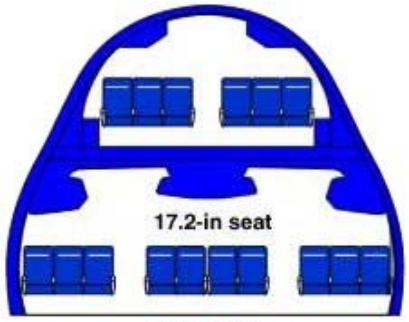
Konkurrenzanalyse - Rumpfquerschnitte

ARTS-DS

A380

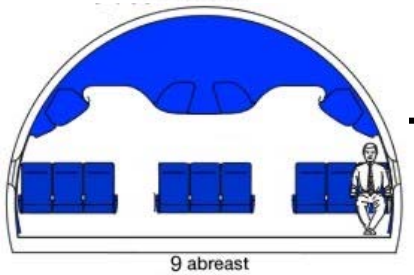
10+8

B747



10+6

B777

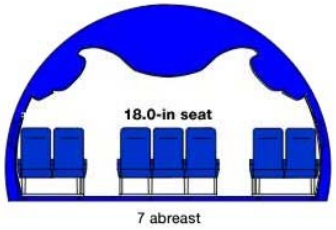


9

A300
A310
A330
A340

8

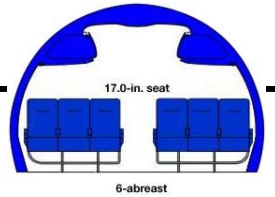
B767



7

A318
A319
A320
A321

B737
B757



6

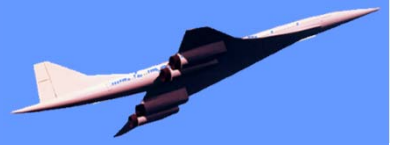
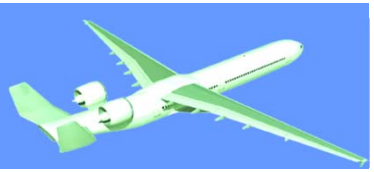
Quelle: Airbus; Boeing

W2 Früher: Folie_I.4.19b_12/97.doc
Wittmann; 2/9/2002

Drivers for aircraft design

Economy

Conventional, classical configuration

- further
- bigger
- faster 
- cheaper
- greener 

Situation Air Transport 2014

- **ACARE Vision 2020 established;**
  - **Update SRA2 in 2004**
  - **Flight**
- **Recent Changes have happened:**
  - New Airline Business Models, LCC, ??
  - Constant Pressure on Airlines (Financial crisis ??, Arabic countries)
  - Fuel prices ?? What will be the limit?
  - Many Airlines (esp. in USA + Europe) have financial problems:
    - ✈ Reduction/Concentration of number of Airlines/Alliances
    - ✈ Retirement of old aircraft
    - ✈ Cancellation of air routes?

Questioning of traditional practice

Till today the following marketing trends are visible:

- Maximum range/
- Very high cruise speed!
- Ma >=0,78 für SR; Ma = 0.85 für LR
- Family Concept is dominating the A/C Design
- Noise is an issue, but no design criteria for optimisation
- Emissions are treated by economic trend to reduce fuel, but this is no specific design criteria!
- Constant evolution, no step changes in order to reduce the development risk.
- Freighters are not worth a specific development. They are important as a conversion from elder passenger aircraft!

New Challenges

- Increasing fuel prices!
- More stringent night restrictions on major airports
- Increasing political pressure on air transport wrt climate change
- New „Business models“ for airlines
- No free airline market (national subsidising of state cariers!)
- Relaxing support from aircraft industry to push innovation!
- Industry is ruled by financial controllers, no engineering vision!
- Need for stronger role of scientists (Universities + Research Centers)

European Transport Development

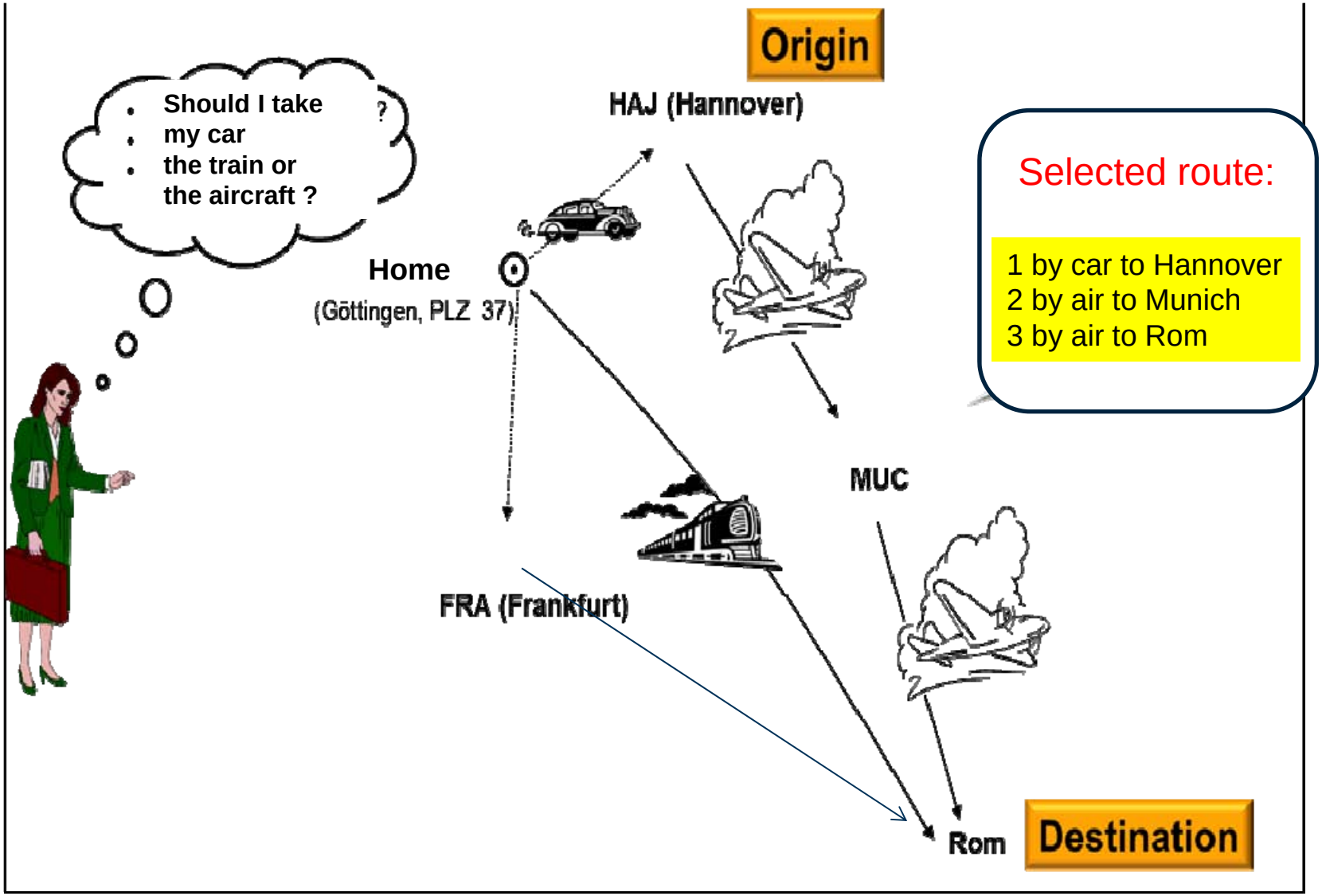
- Europe has still a fragmented Transport system
  - The Western part has a very good infrastructure in rail and road
  - The Eastern part has still a big deficit in infrastructure
  - There are several ideas to further develop the road and the rail infrastructure
  - Transport is normally investigated by specialists from Civil Engineering
    - This means a concentration on tracks, bridges, tunnels, etc.
    - but less of a global approach including the vehicle, including cost of transport, including flexibility of development
  - A global approach is still missing with clear criteria like:
    - Development of a flexible system
    - Comparing the key parameters cost, environmental impact (noise, land use, primary energy usr, infrastructure, flexibility for adaptation if transport streams may change, etc.

- Transport Situation in Western Europe
  - France and Germany have a well developed transport infrastructure
    - A good road system with many motorways, connecting all major cities via the motorway system
    - A Highspeed railway system, connecting also all major cities
    - A well developed normal railway system allowing trains to run at 160 km/h
    - All major cities, having an airport
    - A well established regional air transport system
  - International network
    - The Highspeed railway network is expanded to the neighbour countries (B,NL, UK,E, CH, A)
  - Conclusion:
    - There are several alternatives to go from City A to City B
    - Strong competition between rail and air transport!

- Transport Situation in Eastern Europe
  - Poland , Czech Rep., Hungary ,..
    - A good road system with motorways is needed, connecting all major cities via a motorway system (100 km distance max.)
    - A Highspeed railway system, connecting also all major cities!

      Is it really needed??
    - A well developed normal railway system allowing trains to run at 160 km/h
    - All major cities will have to develop an airport (airfields are available)
    - A well established regional air transport system to be developed
      - Very easy!
  - International network
    - All links are going to Brussels !!
    - The connection points are Berlin, Frankfurt, Munich or Vienna !
    - Main direction for highspeed roads and future rail is East - West
  - Conclusions:
    - There are several projects running for East – West routes
    - **Strong competition between road, rail and air transport!**
    - **However air transport needs only little new infrastructure!!**

Individual Travel Choice



Transport Modes – 5 Phases Model

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	Lowspeed	Transit	Highspeed	Transit	Lowspeed
Mode		Mode Change		Mode Change	
Speed in km/h	0 - 50	0 - (100)	100 :-: 900	0 - (100)	0 - 50
Road	City	National Road	Motorway	National Road	City
Rail	Car, Taxi, PT	Railway Station	Highspeed Train	Railway Station	Car, Taxi, PT
Air	Car, Taxi, PT	Airport	**Air Transport**	Airport	Car, Taxi, PT
Water	Car, Taxi, PT	Harbor	Ship Transport	Harbor	Car, Taxi, PT

PT = Public Transport (Metro, Tram, Bus, ..)

Conclusion

- Industry is no longer the big driver in innovation!
- The Research Centers and Universities have to become stronger and take a role as pioneers for innovation and new ideas!
- The strong aeronautical countries in Europe have to define their regional interests and have to promote their research proposals,
- The upcoming European countries have to engage themselves and define their national priorities.
- Who is taking the lead? (industry or a strong coordinator from Airbus or Rolls Royce? Or ??
- Universities network like EASN and Pegasus could play a strong role in this context and become a major organisational driver for technology.
- A strong and competent pesonality is required ffor this role and task!!

APPLICATION OF THE MORPHING CAMBER CONCEPT TO A REGIONAL AIRCRAFT

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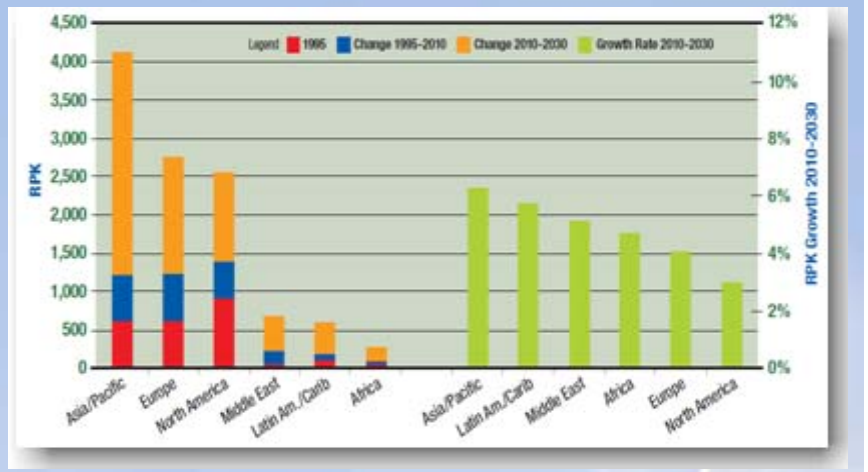
A.Antunes[2], F.Odaguil[2], G.Lima[2]
M.Morelli[3], S.Tuling[3]

[1]Dept. of Aerospace Science and Technology, Politecnico di Milano, Italy
[2]EMBRAER S.A., Sao Jose dos Campos, Brazil
[3]Council for Scientific and Industrial Research, Pretoria, South Africa

Motivations

- **Conflicting Challenges**
  - Air Traffic is growing:
  - Need to increase capacity;
  - Reduce travel time;
- **Environmental Impact reduction**
  - Noise Regulations
  - Emissions Regulations
- **Enabling Tools**
  - New aircraft technologies (innovative materials, morphing technologies, unconventional configurations, etc...)
  - Flight Operation Optimization



Air Travel Growth Forecast (Source: ICAO-Airbus)

Some lessons learned about Morphing

- **Old** or **new** technology?
- **Lights** and **shadows** resulting from available applications
- Very difficult to prove **the real benefits**
- Need for **reliable test case** data to perform accurate comparisons
- Morphing as a **mission-based concept** to be validated by in depth mission analysis
- Need for a **system level analysis** from the beginning of the project
- Still many **open issues**, such as maintenance costs, certification, fatigue, weight penalty…

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EU-FP7 NOVEMOR: Novel Air Vehicle Configurations, From Fluttering Wings to Morphing Flight

Outline

- Overview of FP7-NOVEMOR Project
- The Reference Aircraft
- Design tools for variable camber morphing wings
- Results for Reference Aircraft
- Experimental validation
- Aerodynamic validation at CSIR
- Functionality validation at POLIMI
- Conclusions

EU-FP7 NOVEMOR project

Aims

The aim of the NOVEMOR (NOvel Air VEhicle Configurations: From Fluttering Wings to MORphing Flight) research project is to investigate **novel air vehicle configurations** with new lifting concepts and **morphing wing solutions** to enable cost-effective air transportation.

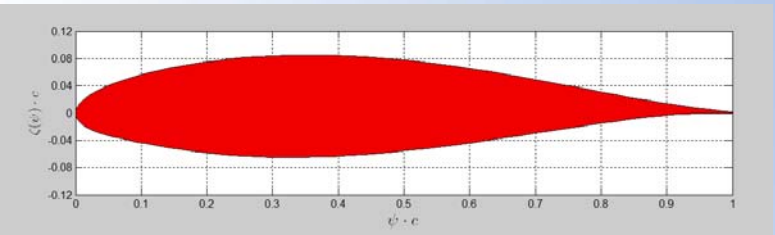
Partners

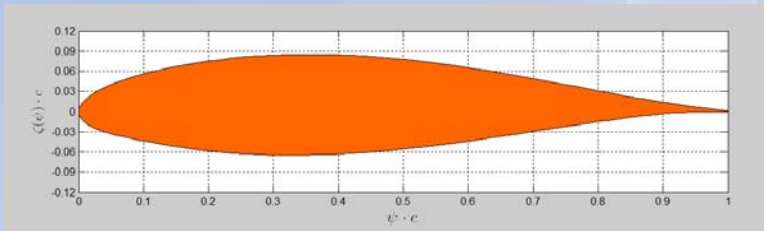
- **IST, Portugal**
- **Politecnico di Milano, Italy**
- **University of Bristol**
- **KTH, Sweden**
- **DLR, Germany**
- **CSIR, South Africa**
- **Embraer, Brazil**

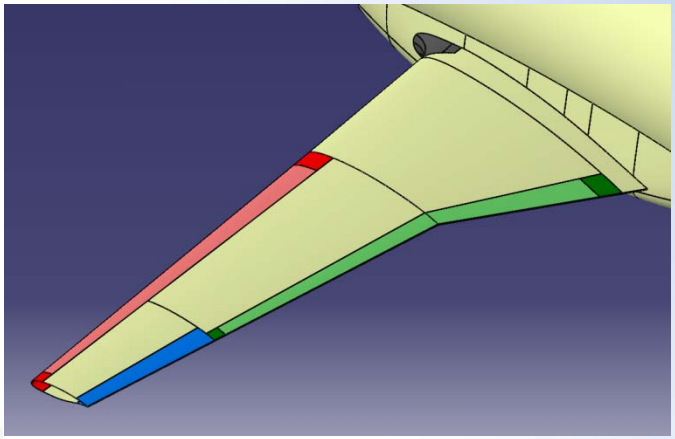
The morphing concept: Active Camber

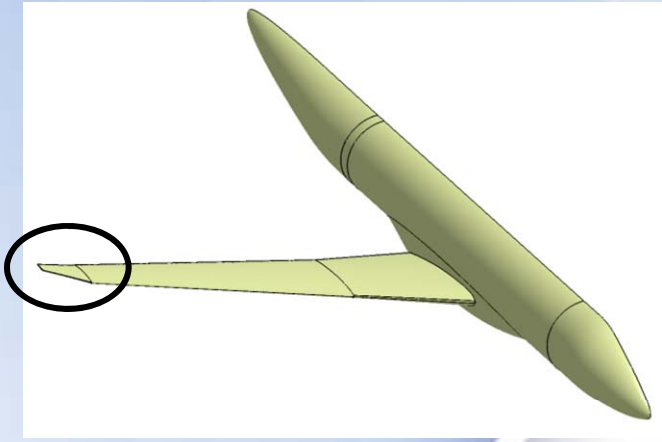
Why?

- Potential short term application
- Possibility of retrofit
- Wingbox untouched (previous experience in SADE and SARISTU Projects)









The needs...

To develop and validate the potential impact of the proposed morphing concept we need basically:

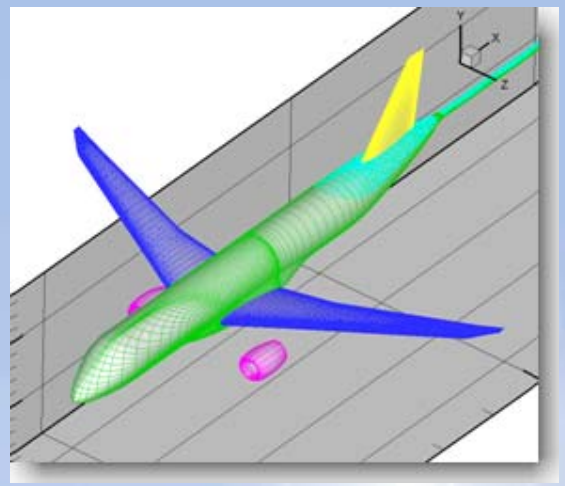
- A Reference Aircraft
- A set of tools to quickly create, manage and optimize aircraft models, to generate the optimal morphing shapes and the related morphing mechanisms
- A global mission based verification strategy
- An experimental validation

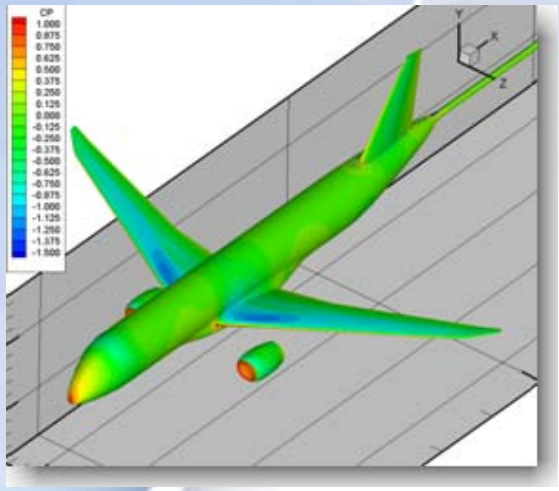
The Reference Aircraft (EMB9MOR)

Aims

To set up a consistent, reliable set of data to be used a reference in evaluating potential morphing benefits.

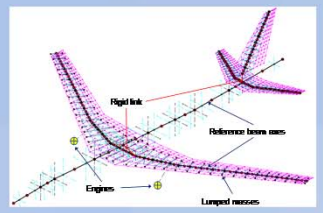
Reference Aircraft Main Characteristics	
Maximum Takeoff Weight	58,034 kg
Maximum Landing Weight	53,034 kg
Maximum Zero Fuel Weight	48,034 kg
Basic Operating Weight	34,034 kg
Maximum Payload	14,000 kg
Maximum Fuel(1)	18,000 kg
Maximum Operating Speed	Mach 0.82
Time to Climb to FL 350, TOW for 600 nm	17 min
Takeoff Field Length, ISA, SL, MTOW	1,490 m
Takeoff Field Length, ISA, SL, TOW to 600 nm	1,152 m
Landing Field Length, ISA, SL, MLW	1,626 m
Range 113 pax @ 220 lb (100 kg), LRC	4,387 km
Mean Aerodynamic Chord	3.86 m
Reference Wing Area	110 m2
Reference Wing Span	15.73 m

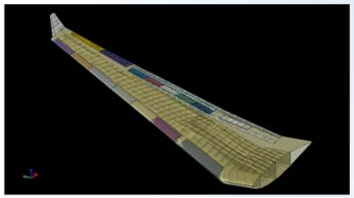


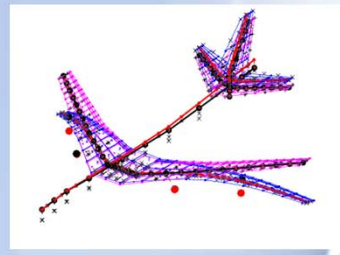


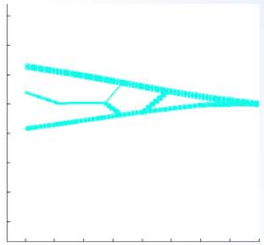
Tools for fast model generation

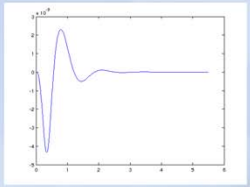
The family of tools for conceptual aircraft design and morphing evaluation developed @POLIMI during EU pojects like SimSAC, FFAST, NOVEMOR, SARISTU

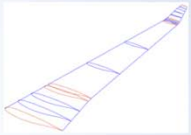


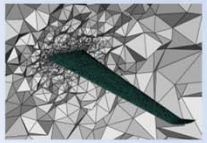












Tools for morphing shape generation

PHORMA (Parametrical sHapes for aerOdinamic and stRuctural Modeling of Aircraft) is a suite of object oriented tools with the following capabilities:

- Improved CAD export capabilities for CATIA and IGES compatibility;
- Automatic 3D CFD mesh generation for Euler computations based on CSTv3 parameterization;
- Automatic 3D FEM model generation (FVBeam/Beam/Plate/Shell elements) based on CSTv3 parameterization and new PFEM code;
- Embedded post-processing capabilities for CFD analyses;
- New shape-optimization procedure base on 2 nested loop to combine skin structural constraints and CFD analyses.

Tools for morphing shape generation

Airfoil shape description:

$$\zeta(\psi) = C_{N2}^{N1}(\psi)\, S(\psi) + \psi\zeta_{TE}$$

$$\zeta = \frac{z}{c} \quad \text{Non-dimensional coordinates w.r.t airfoil chord}$$

$$\psi = \frac{x}{c}$$

Class Function

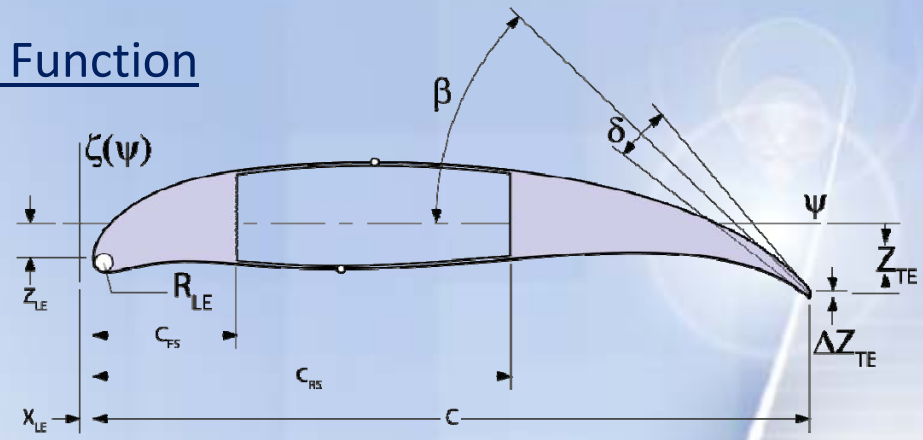
Shape Function

$$\zeta_{TE} = \frac{Z_{TE}}{c}$$

$$Z_{TE} = \zeta_{TE} \pm 0.5 \cdot \Delta Z_{TE}$$

Z_{TE} Vertical position of TE

ΔZ_{TE} Thickness of trailing TE

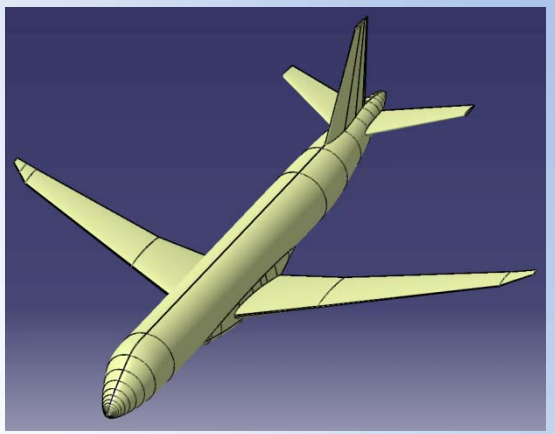


Fully analytic description of the airfoil based on few parameters

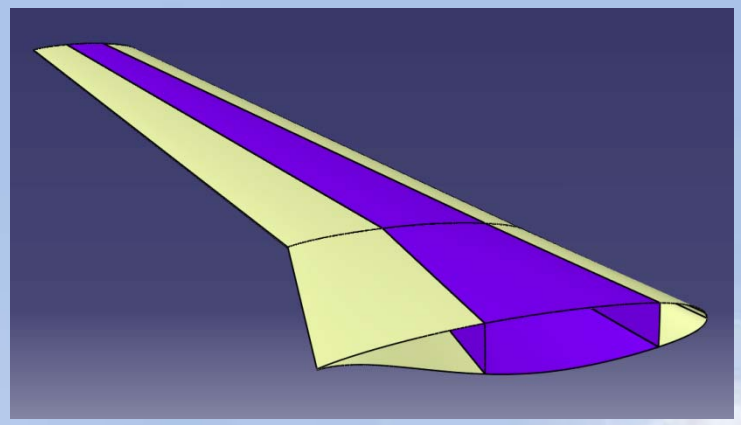
Easy to calculate length and curvature

Possibility to predict axial and bending stresses in the skin

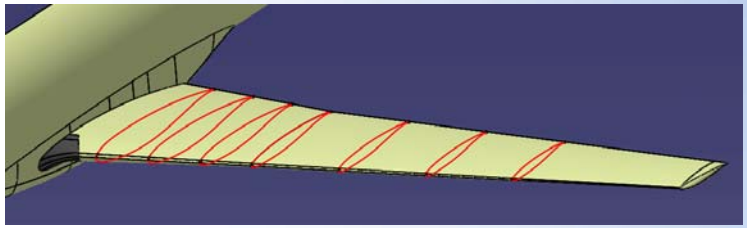
Typical models generated by PHORMA

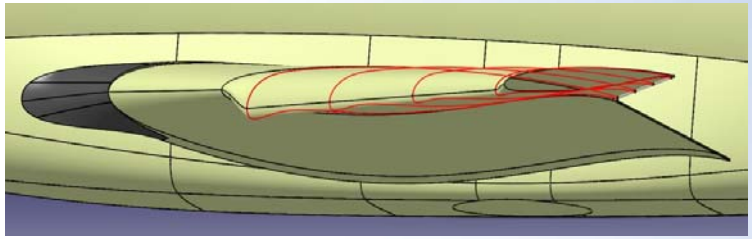


CAD geometry of Reference Aircraft

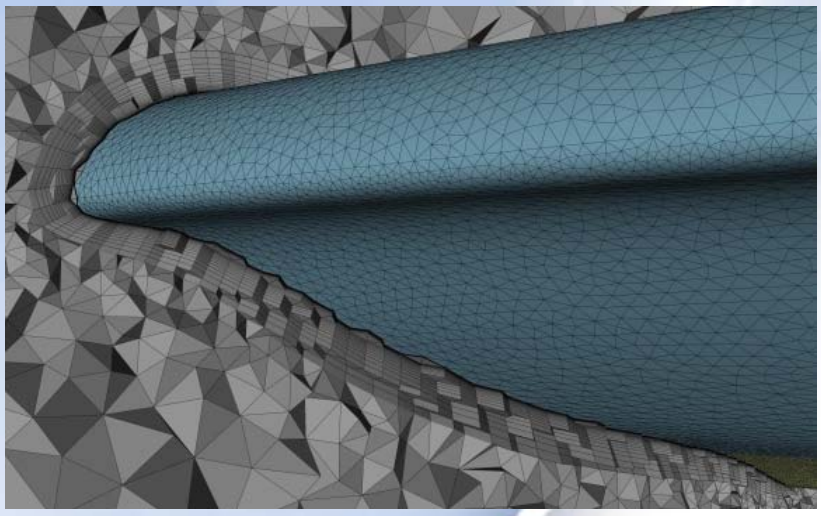


Wingbox extension





mTE and mLE morphing airfoils distribution

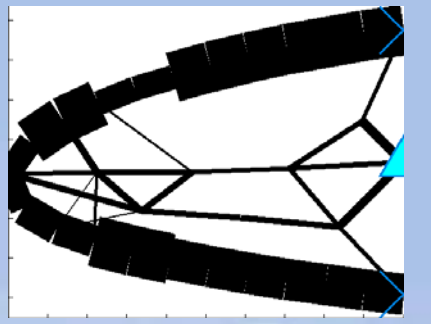


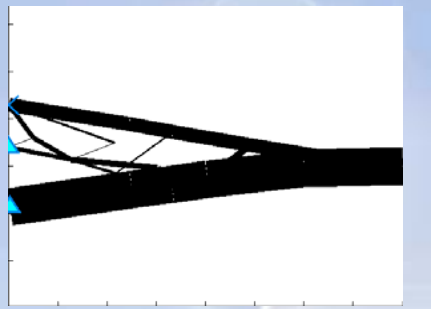
CFD mesh

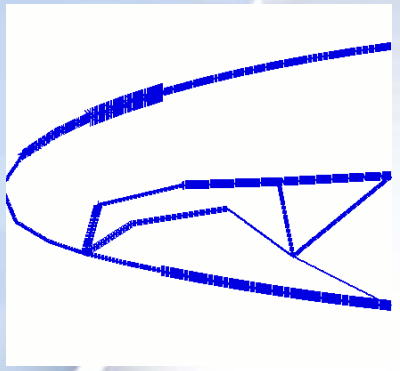
Tools for morphing mechanisms

SPHERA (Synthesis of comPliant mecHanisms for EngineeRing Applications) is the part of a more general tool for the synthesis of compliant mechanisms dedicated to the design of morphing airfoils. It is used to optimize the internal structure able to match the optimal shape generated by PHORMA and includes:

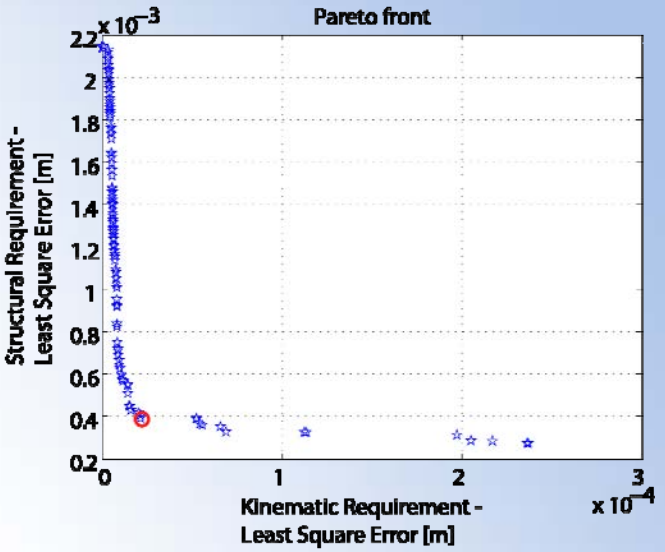
- Load path representation of internal structures
- A non linear beam solver
- A multi-objective genetic optimizer to solve both sizing and topological problem
- An FSI tool for aero loads transfer.

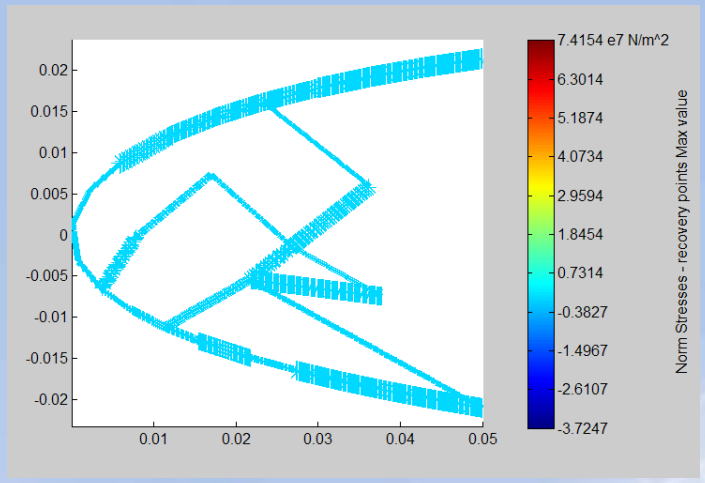






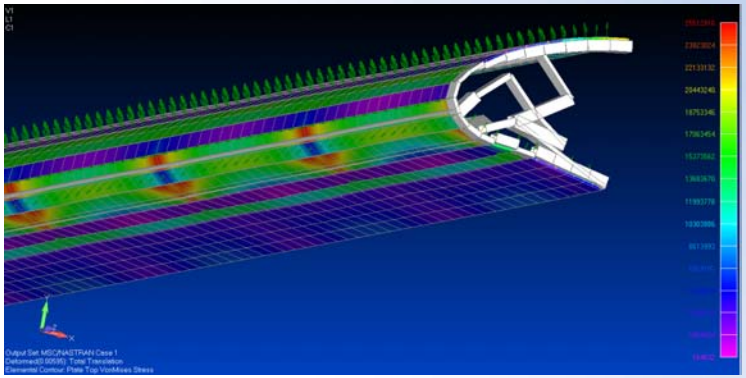
Tools for morphing mechanisms

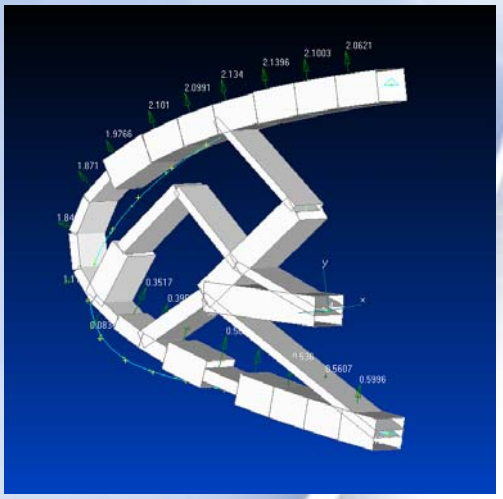




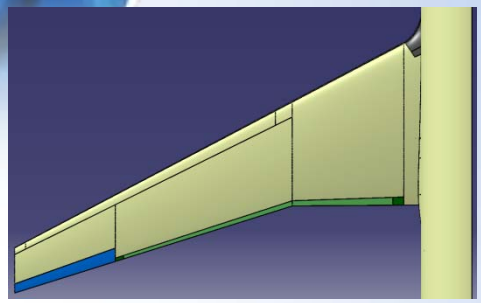
Selection of most promising configuration

Automatic generation of 3D models



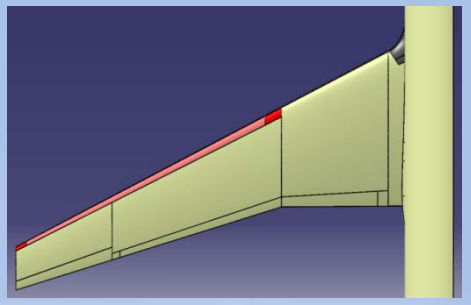


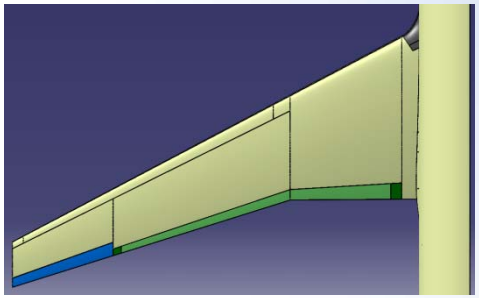
Morphing LE and TE configurations for RA

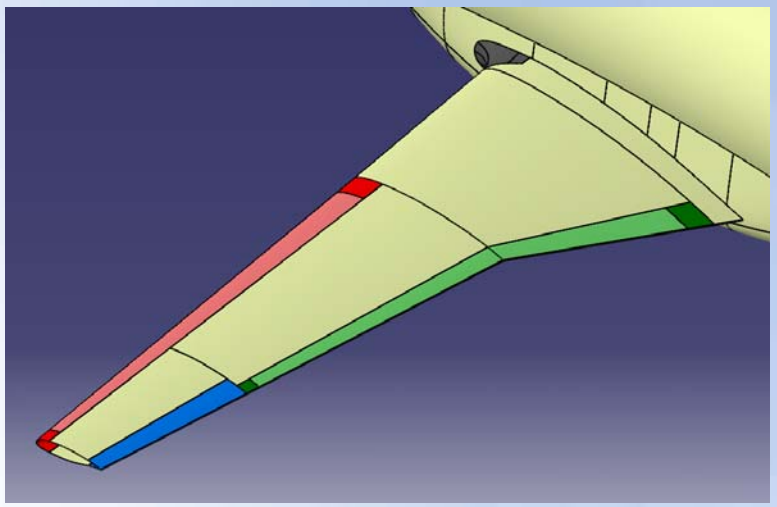


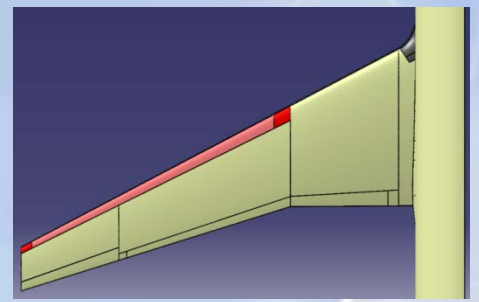
3 morphing devices:

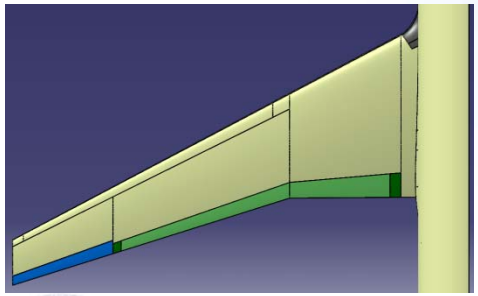
1. Morphing leading edge for low speed;
2. Morphing leading edge for high speed;
3. Morphing trailing edge for low speed;

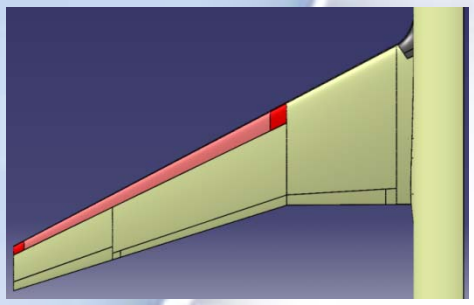












Optimization variables:

- Chordwise extensions;
- Morphing deflections;
- Size of the transition regions;

Global strategy adopted for full aircraft

2 flight conditions analyzed: low speed (Ma=0.15) and high speed (Ma=0.74 and 0.78)

- Generation of a family of 3D shapes (CAD) using PHORMA
- Preparation of a huge aerodynamic lookup table using a medium fidelity tool (full potential + boundary layer correction).
- Performance analysis during the complete flight mission to select, for each flight condition, the optimal morphing configuration.
- Validation of medium fidelity CFD results by means of high fidelity analysis (RANS).

De Gaspari A., Ricci S. *Application of the Active Camber Morphing Concept Based on Compliant Structures to a Regional Aircraft*, in: SPIE conference, San Diego, CA, USA, 9 Mar. 2014.

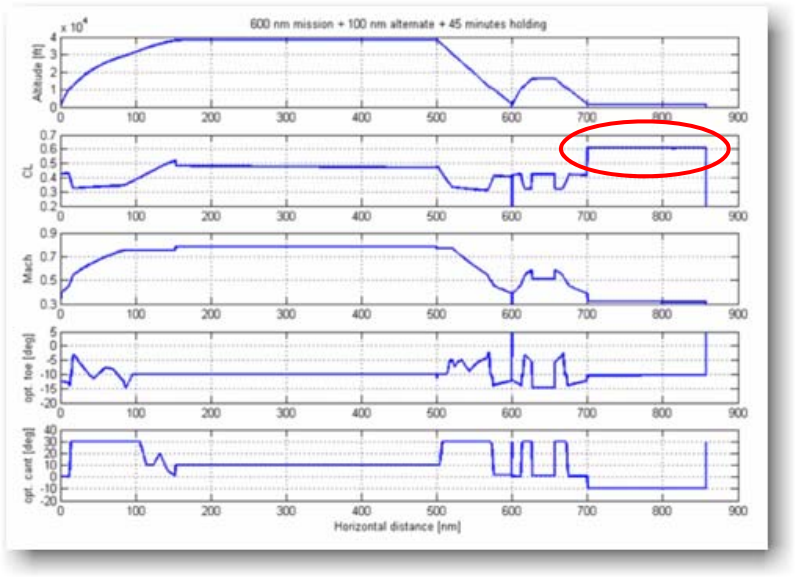
De Gaspari A., Ricci S. *Application of Active Camber Morphing Concept to a Regional Aircraft*, Paper presented at: 22nd AIAA/ASME/AHS Adaptive Structures Conference, National Harbor, MD, US, 13-17 Jan. 2014, p. 1-23, AIAA-2014-1259.

mLE Results

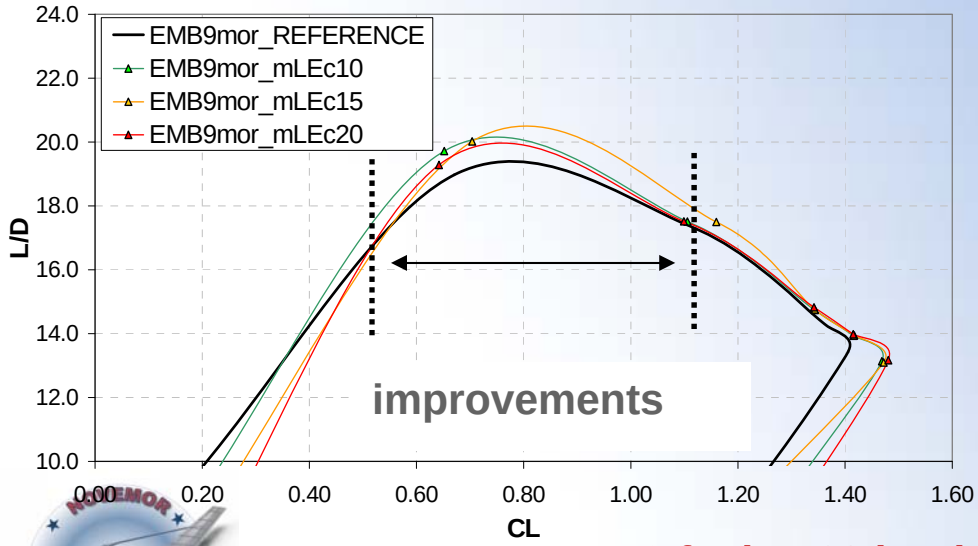
Typical mission + 100 nm alternate + 45 minutes holding

Payload	= 12000kg
Range	= 600nm
Mach Number	= 0.78
Cruise altitude	= 38000ft
TOW	= 51126kg

Holding 45 minutes @ CL = 0.6



L/D x CL
Rey = 13 Million , Mach = 0.15

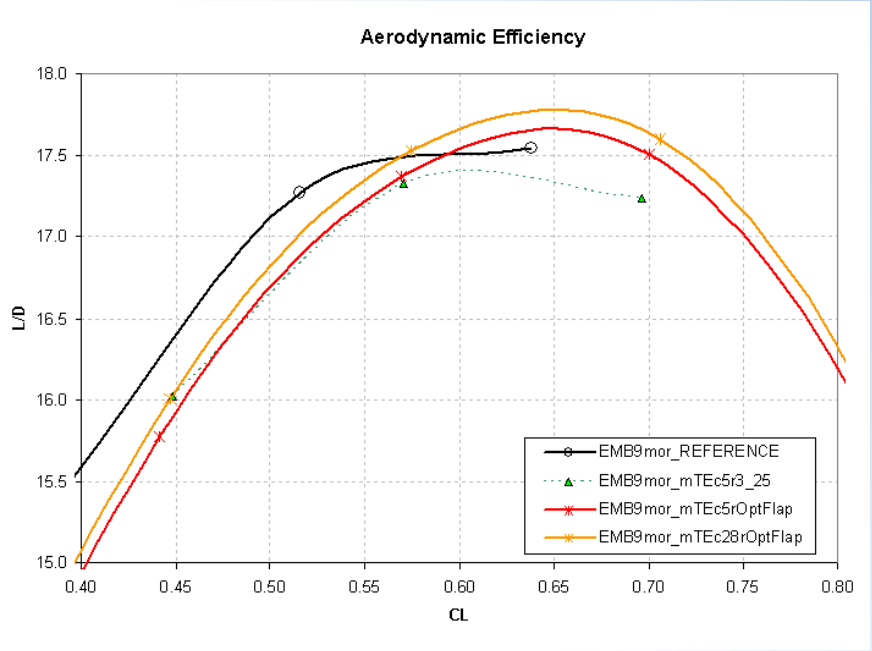


CL	mLE_c10	mLE_c15	mLE_C20
0.6	5%	0%	3%
0.7	3%	6%	1%
0.8	3%	5%	1%
1.0	1%	3%	1%

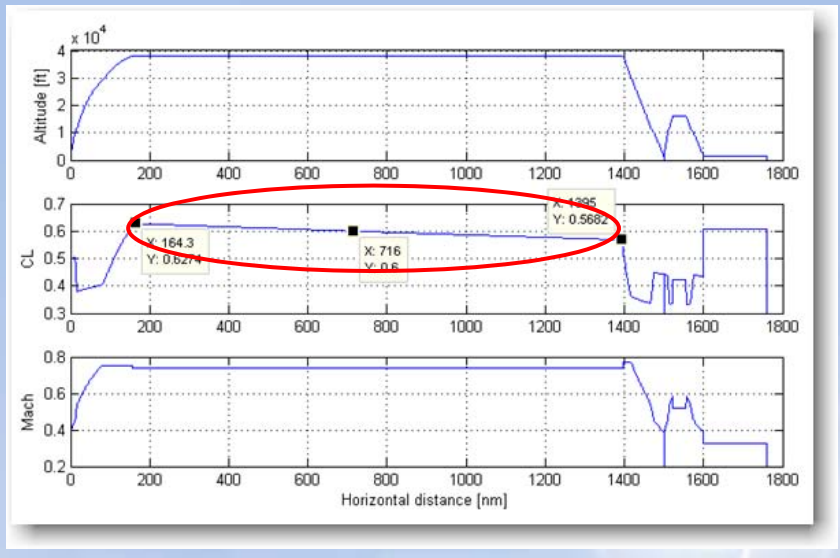
Δ fuel ≈ 62 kg (5% of 1236 Kg)

mTE Results

Payload	= 14000kg
Range	= 1500nm
Mach Number	= 0.74
Cruise altitude	= 38000ft
TOW	= 57252kg



Cruise @ Ma = 0.74



Fuel saving / Fuel required to accomplish the mission

Mach	RANGE		
	600 nM	1000 nM	1500 nM
0.74	0/ 3153	63/4881	75/7136
0.78	0/3064	0/4681	65/6771

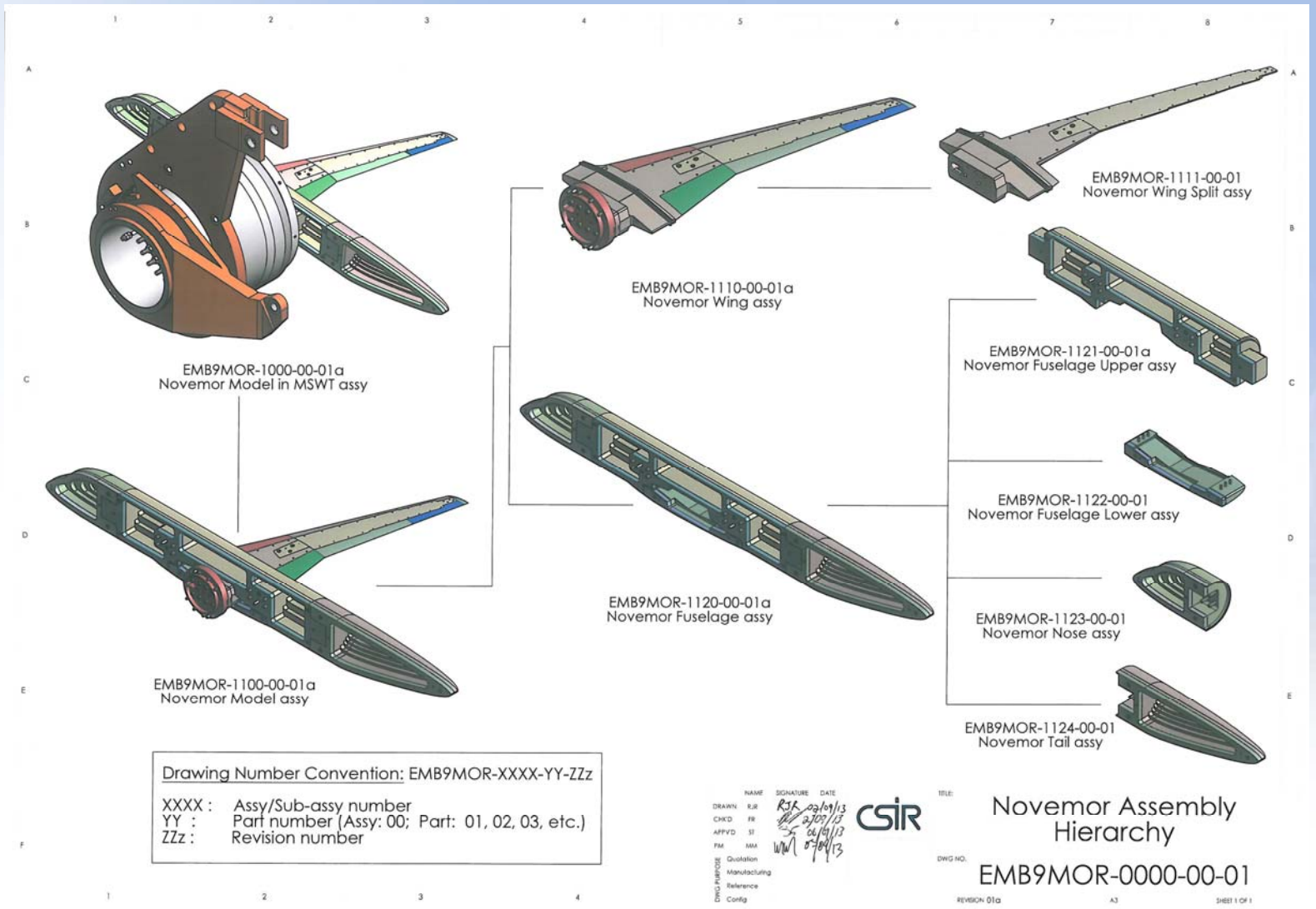
Δ fuel ≈ 75 kg (1.02% of 7136 kg)

Experimental validation

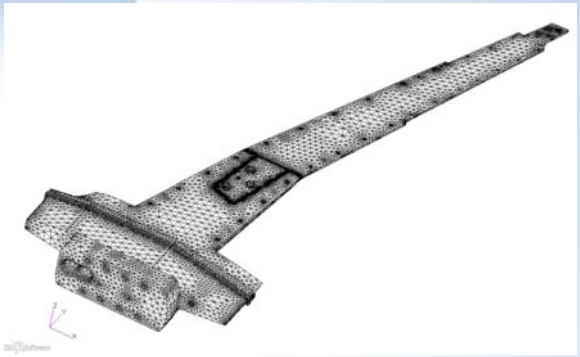
The experimental validation is based on a two steps approach:

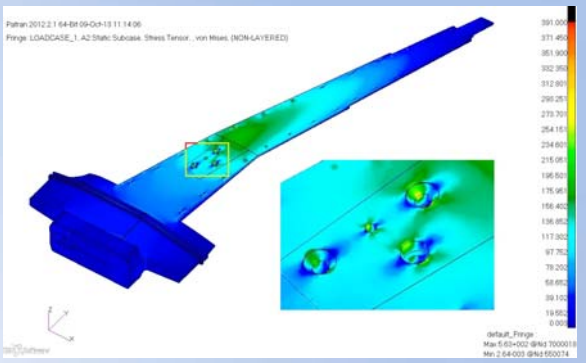
1. Aerodynamic validation of morphing benefits by means of transonic Wind Tunnel test @CSIR (Mach 0.15 and 0.74) on a rigid model
2. Validation of the aerostructural optimization of compliant morphing LE and TE on a low speed Wind Tunnel model @POLIMI

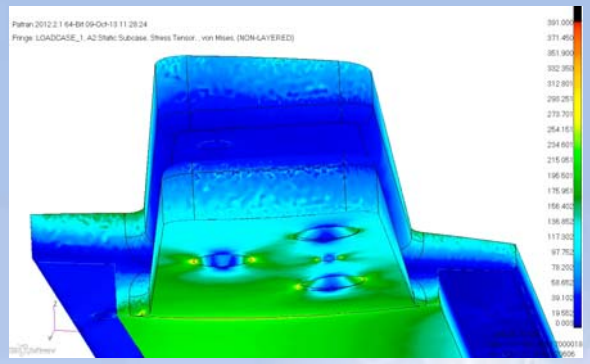
Transonic WT test at CSIR

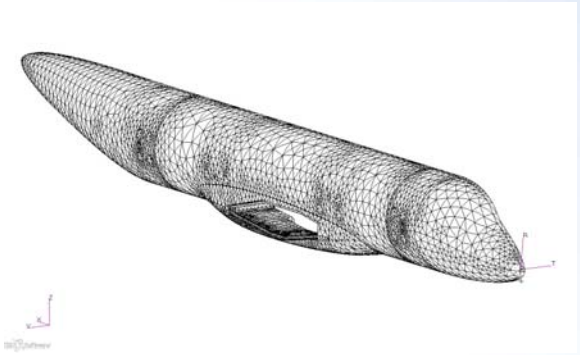


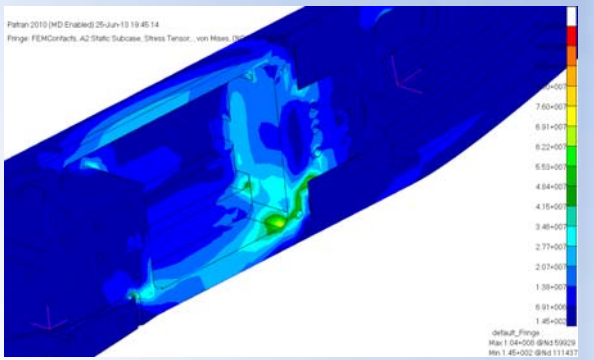
Transonic WT test at CSIR

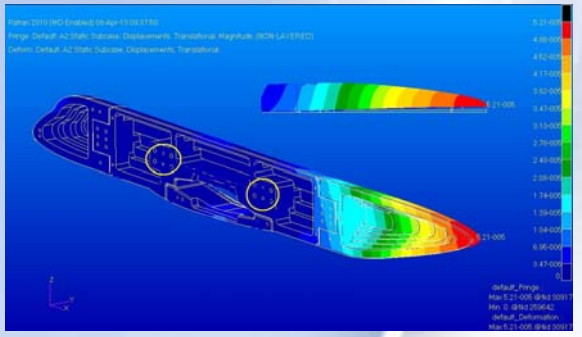












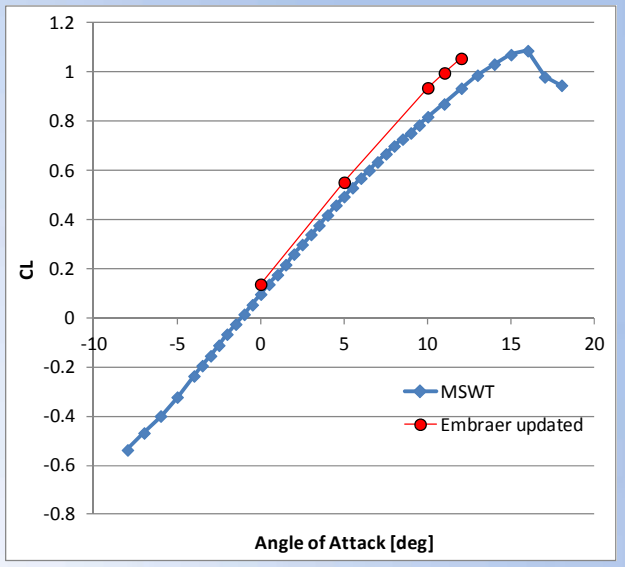
WT model verification

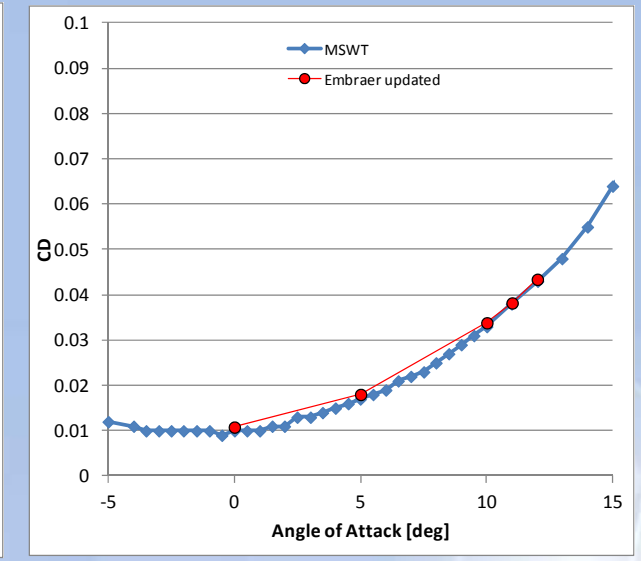
Transonic WT test at CSIR

Assembling of the model for WT testing at CSIR

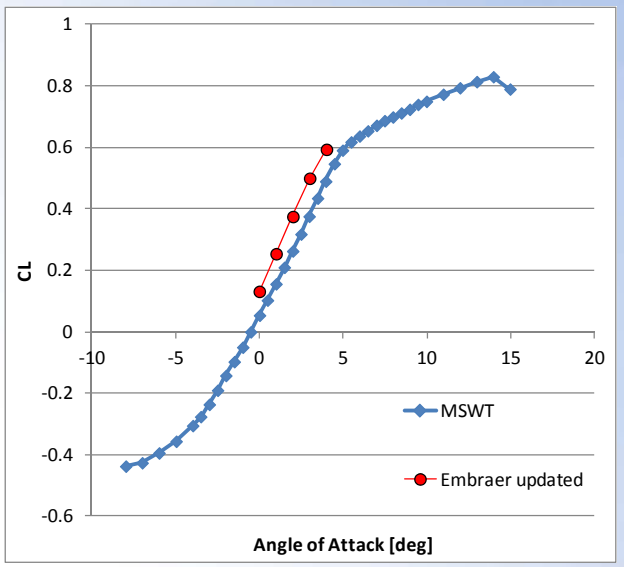
WT test at CSIR: preliminary results

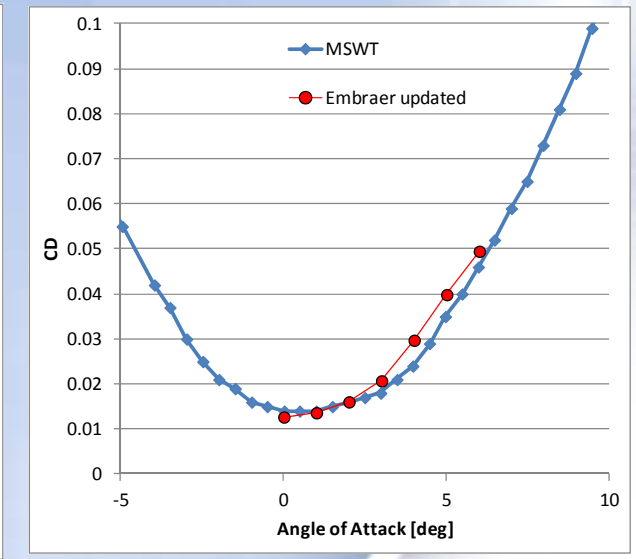
Low speed results comparison: Ma 0.15



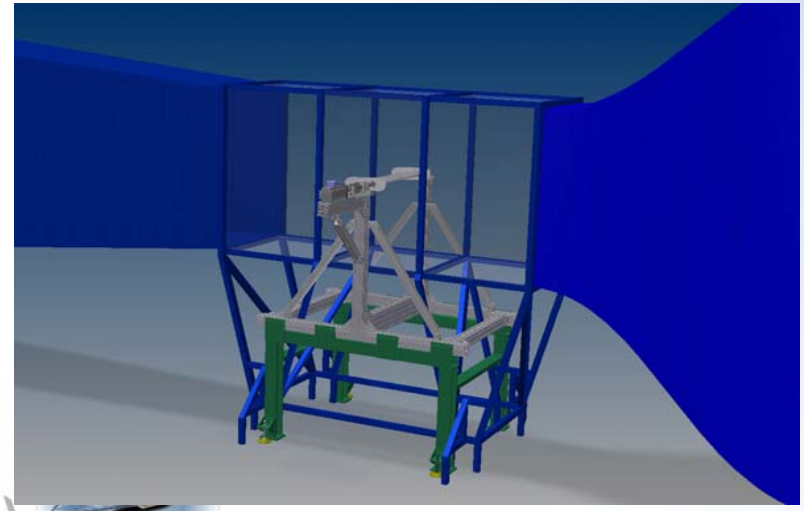


Cruise speed results comparison: Ma 0.74





Low Speed WT test at POLIMI



- 1:10 2D wing model (1m span) equipped with morphing LE and TE
- Low speed WT: 1 × 1.5m, 55 m/s

Aims:

- Measure the structural deformation (3D) of the wing under aerodynamic loads and compare with the target shapes
- Measure stress and strain levels in the skin and compliant mechanism under aerodynamic loads
- Measure the pressure distribution along one station and compare with CFD for the purpose of validating the aerodynamic load inputs used in the structural codes

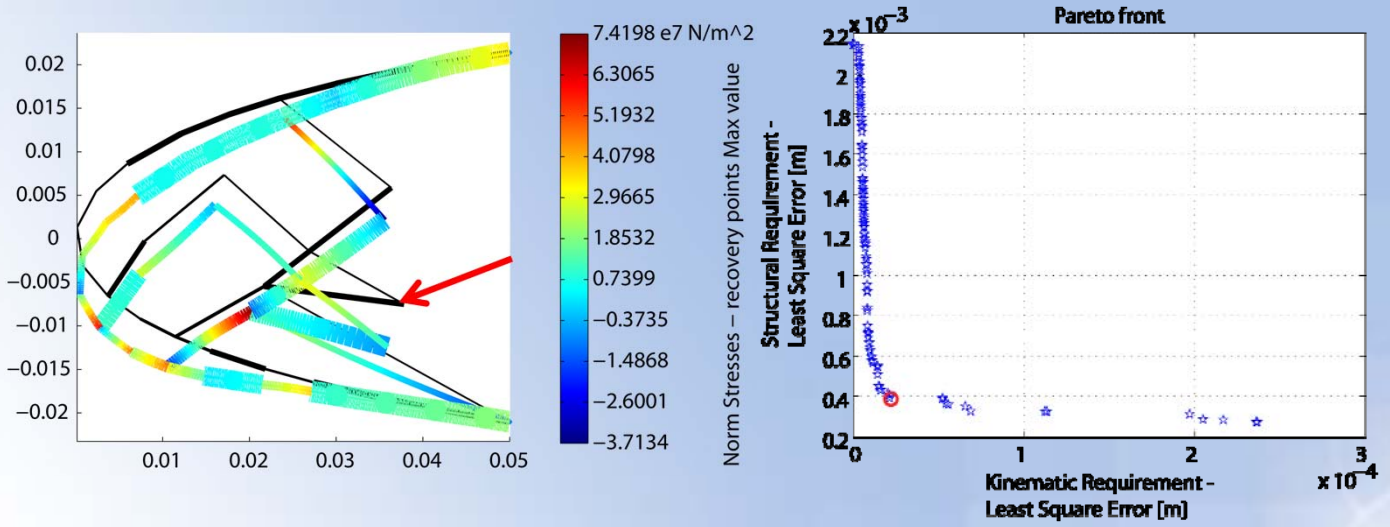
Low Speed WT test at POLIMI

Open issues on testing small scale morphing models based on compliant structures:

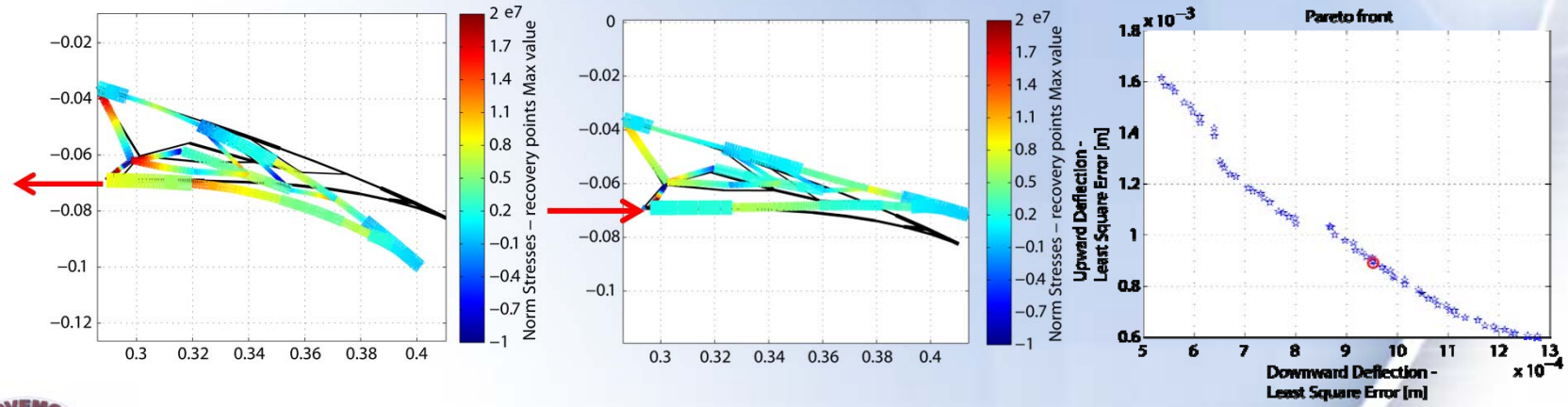
1. The down scaling of the compliant structure designed for full aircraft is not possible. A complete redesign is necessary.
2. The scale factor adopted for the wing models poses challenges about the manufacturing technologies (thickness distribution accuracy)

Morphing configurations for wing model to be tested for validation

Morphing LE and TE for wing model



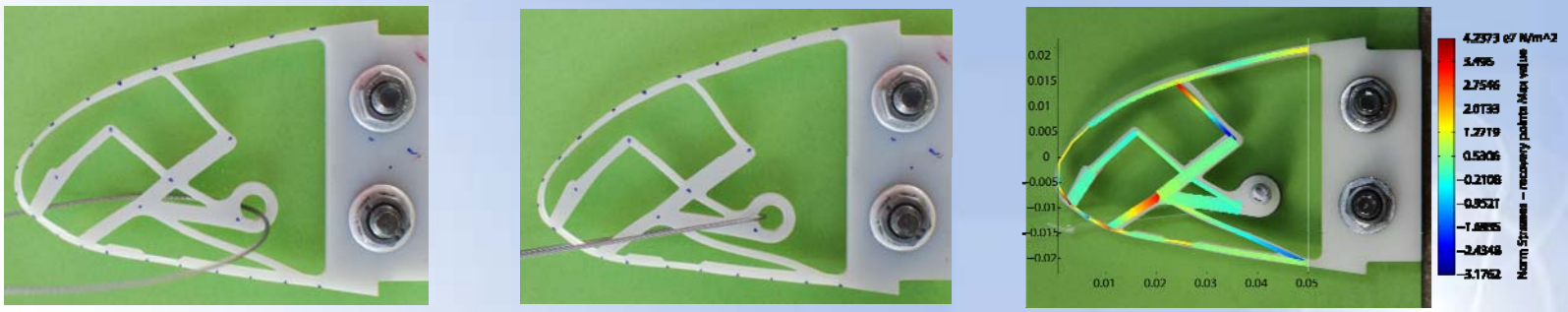
The optimal LE compliant structure in the deformed configuration and the Pareto front



The optimal TE compliant structure in the deformed configurations and the Pareto front

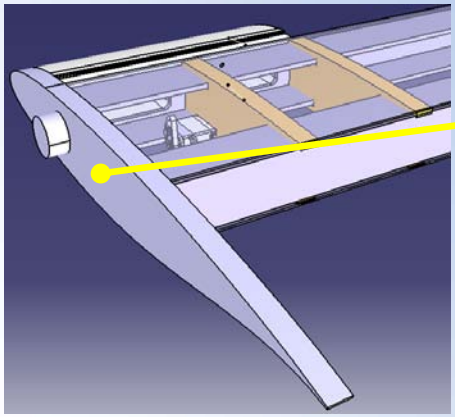
Manufacturing technologies evaluation

Different 3D printing technologies (FDM, STS, SLT, Polyjet) have been evaluated aiming at the manufacturing of the complete morphing LE and TE in one single piece.



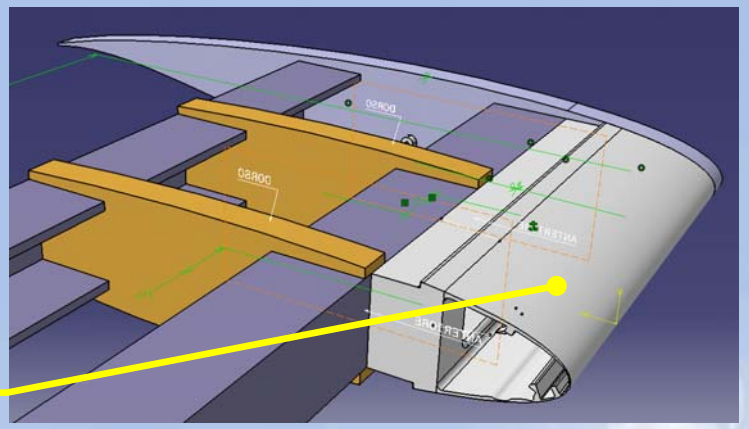
Preliminary static test on a morphing rib manufactured by Polyjet technology: unloaded structure (left), intermediate load (middle) and maximum load (right)

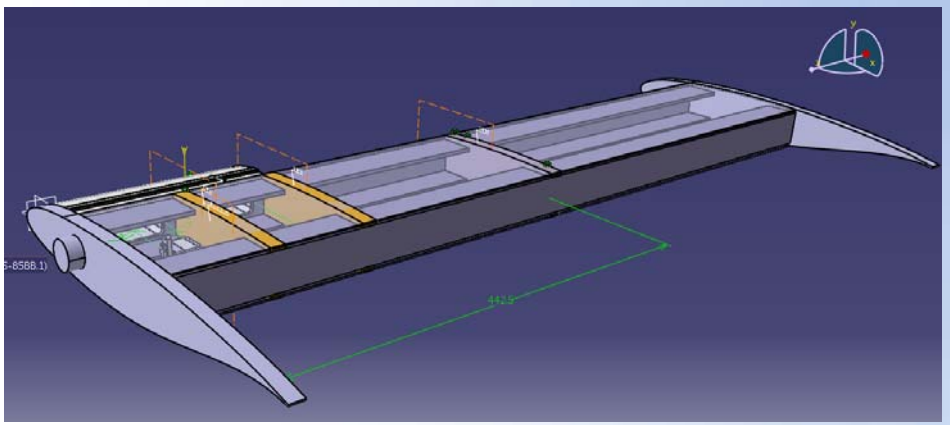
Wing model: final layout



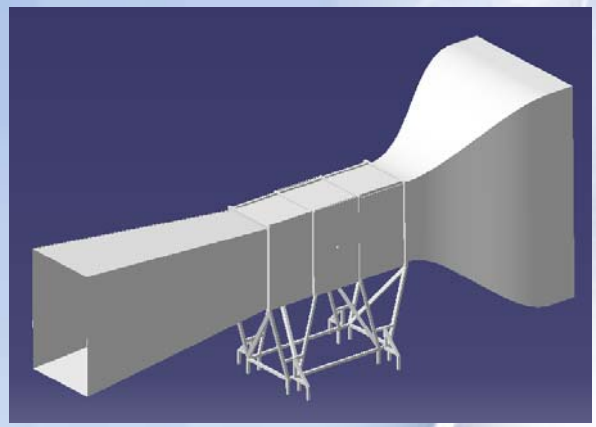
Left rib connected to the rig

Morphing LE attached to the front spar





Wing model overview



Low speed wind tunnel

Conclusions

A complete assessment about the potential benefits of using morphing devices is on the way in the framework of FP7EU-NOVEMOR project. It includes:

- Development of a Reference Aircraft representing a typical 130 pax regional aircraft
- Evaluation of the methodologies to design and implement the Active Camber concept
- A mission based evaluation of potential benefits in terms of fuel saving

✓ The preliminary WT results appear as promising, but only at the end of the assessment it will be possible to draw the final conclusions

Future activities

- Finalization of the experimental validation campaign in low speed WT @POLIMI
- Final evaluation of the concept tacking into account for the aeroelastic effects
- Final assessment

Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7 / 2007-2013) under a grant agreement number 285395. A special thanks to A.Antunes, F.Odaguil (EMBRAER), M.Morelli (CSIR), A.Faina, L.Cirocco (POLIMI).

…and finally…

Thanks for your attention

Any question?

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PRELIMINARY EXPERIMENTAL VALIDATION OF 0-υ HONEYCOMB ADAPTIVE MORPHING WING

Author: **Ashley Dale**, PhD Student, University of Bristol
Academic Supervisor: **Prof. Jonathan Cooper**, University of Bristol
Industrial Supervisor: **Anthony Mosquera**, Applied Computing & Engineering Ltd.

Speaker: **Raj Nangia, University of Bristol**

Sponsors: EPSRC Engineering and Physical Sciences Research Council ac&e

Ashley Dale:
a.s.dale@bristol.ac.uk

What will be talked about:

1.) Motivation

2.) Conception

3.) Results thus far

4.) Developments

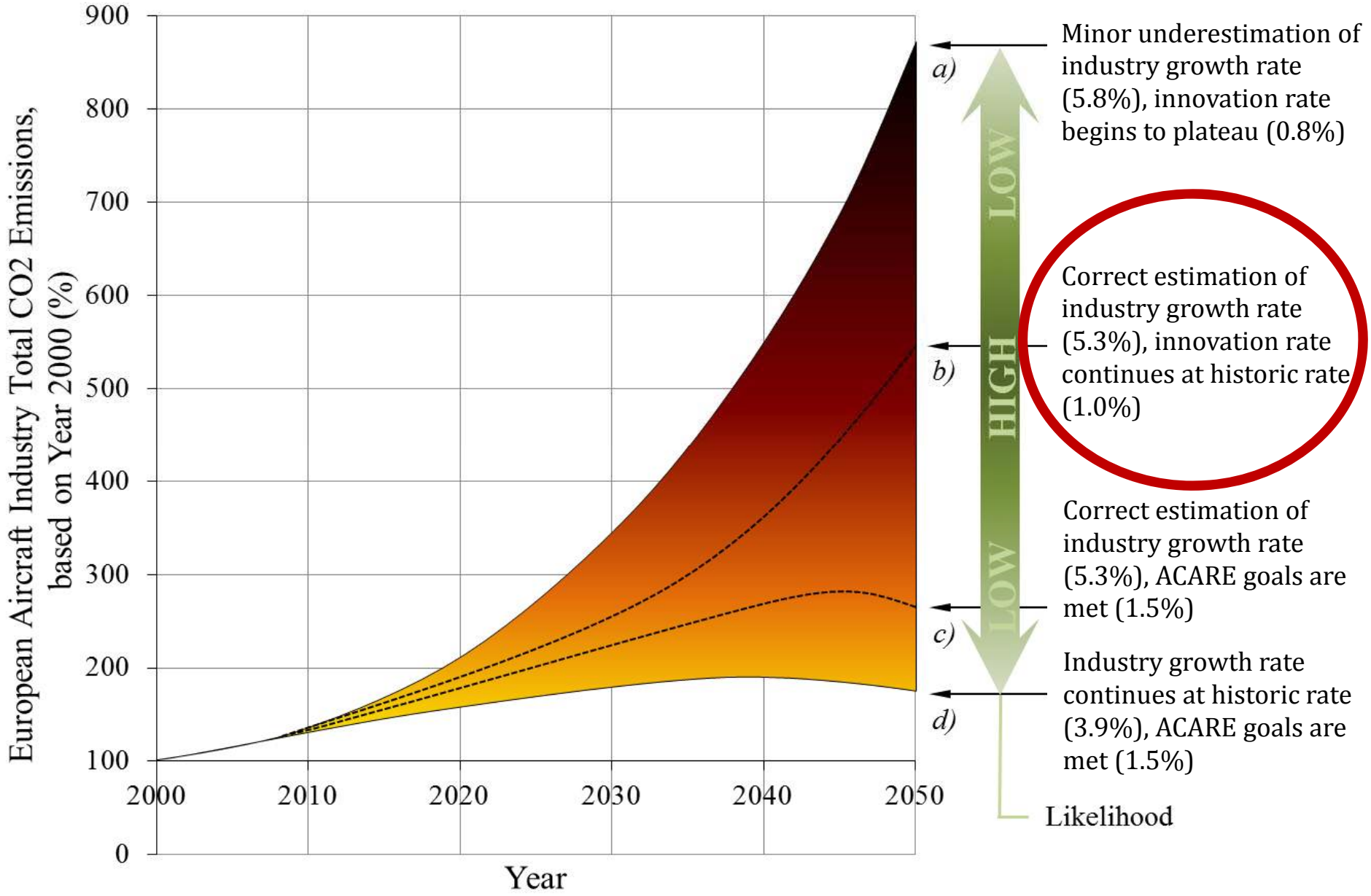
5.) Future Work

6.) Closing and Questions

Motivation

We have a problem… Air Travel Forecasts

Ashley Dale:
a.s.dale@bristol.ac.uk



Source: Ashley Dale, *Morphing is One Way to Make Aircraft More Efficient*, 2014 www.space.com

The Problem with Wings Control Surfaces

Ashley Dale:
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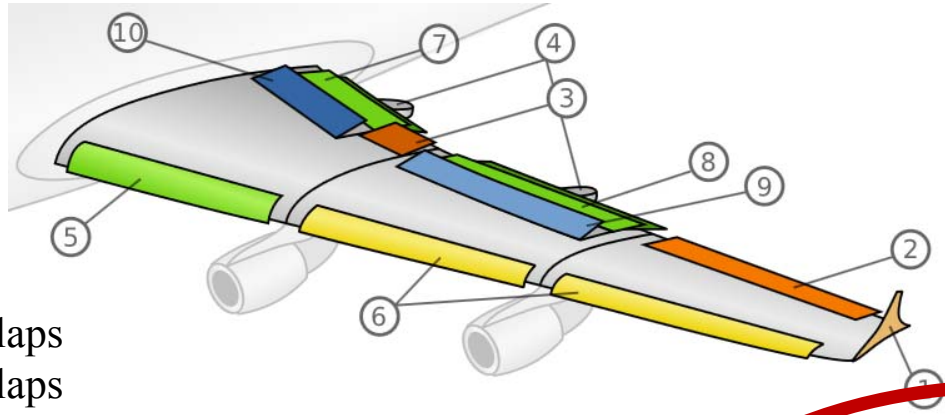
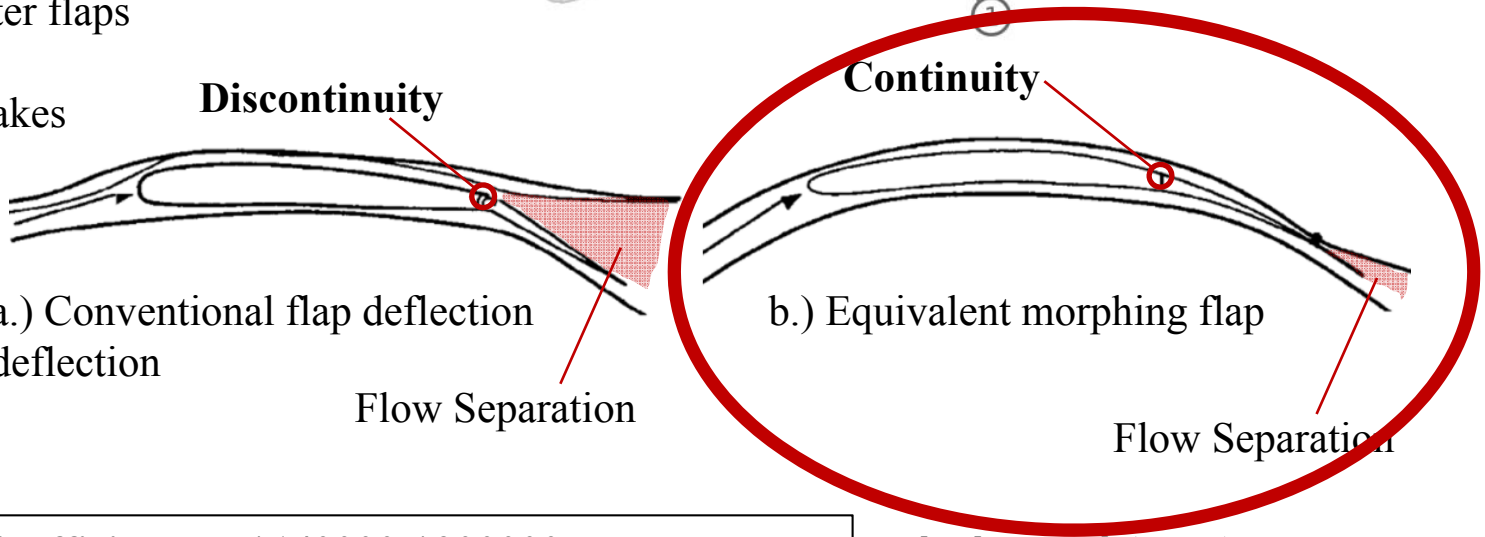
Replacing conventional control surfaces to improve aerodynamic/stealth performance:

Typical control surfaces configuration on a large transport aircraft:

1.) Winglet
2.) Low Speed Aileron
3.) High Speed Aileron
4.) Flap track fairing
5.) Krüger flaps
6.) Slats
7.) Three slotted inner flaps
8.) Three slotted outer flaps
9.) Spoilers
10.) Spoilers Air-brakes



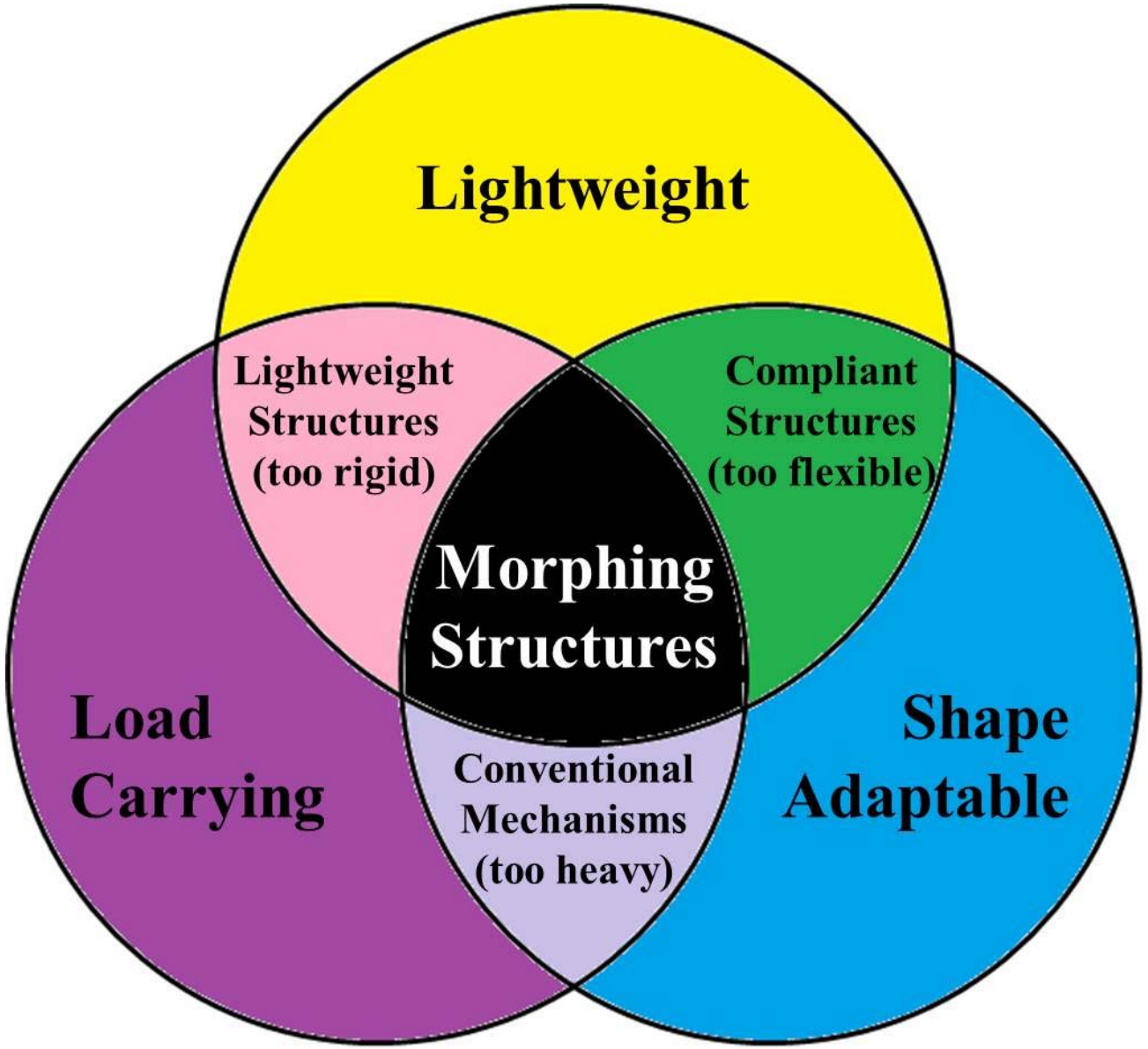


1% increase in airfoil efficiency = $140000-$200000 annual return on each large transport aircraft with regards to fuel-save

Bolonkin et al (1999), Gilyard et al (1999)

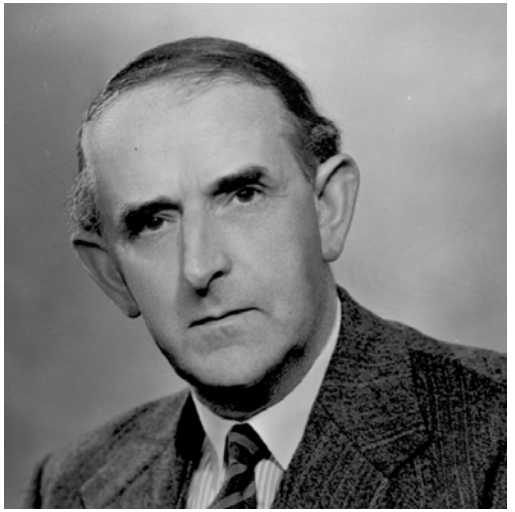
Concept Development

Ashley Dale:
a.s.dale@bristol.ac.uk



“All modern aircraft have four dimensions: span, length, height, and politics.”

- Sir Sydney Camm



The Inspiration

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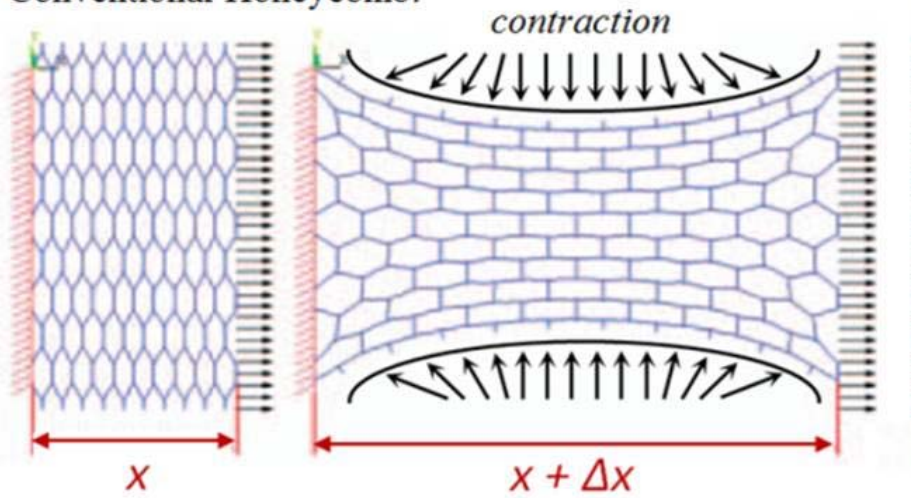
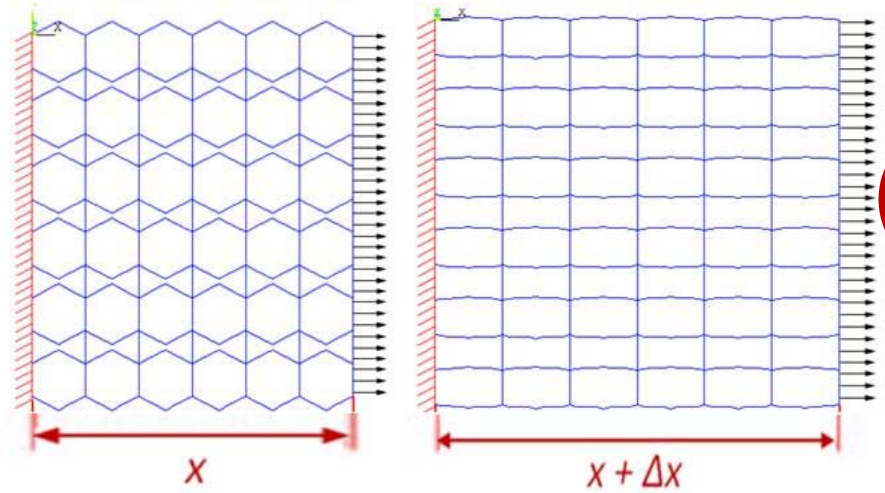
Conventional Honeycomb:



Poisson's Ratio, $\upsilon > 0$

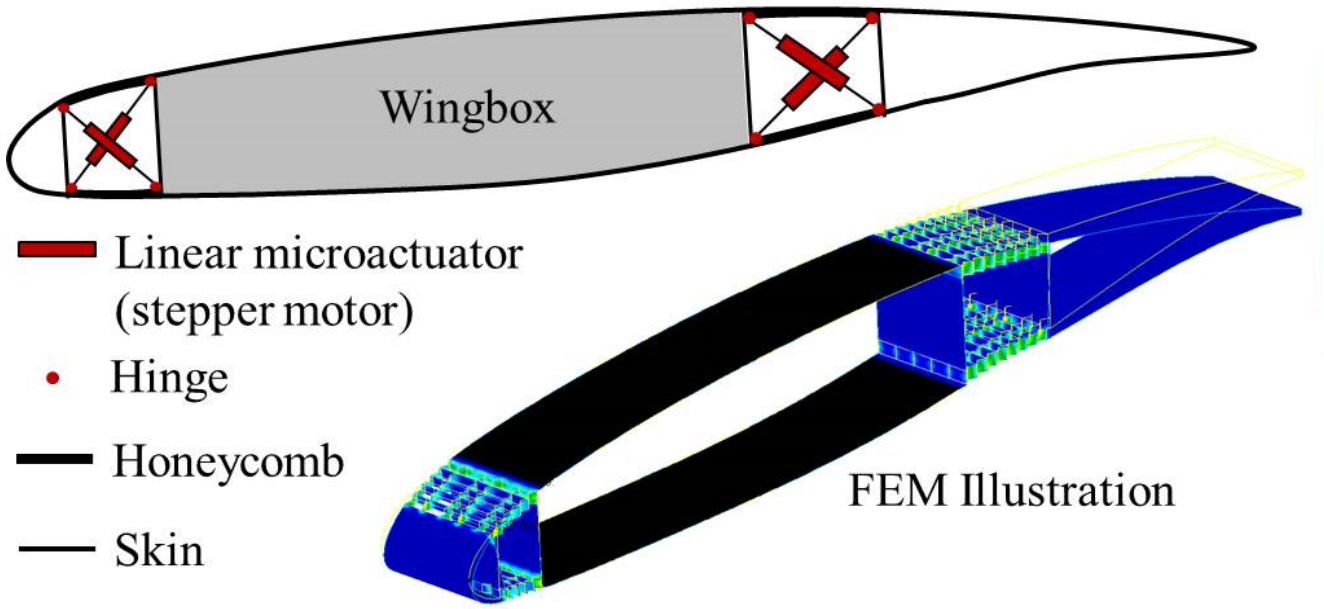
Accordion Honeycomb:



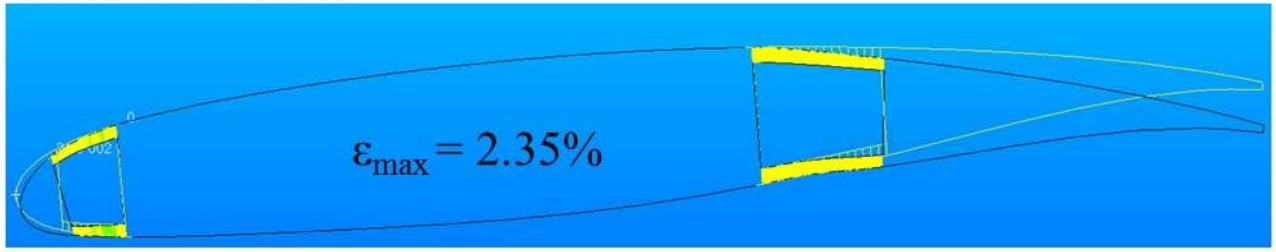
Poisson's Ratio, $\upsilon = 0$

(developed by Olympio & Gandhi, 2010)

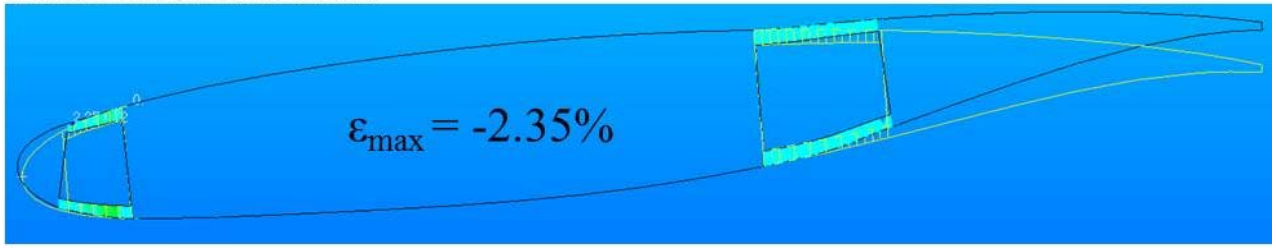
Original Concept

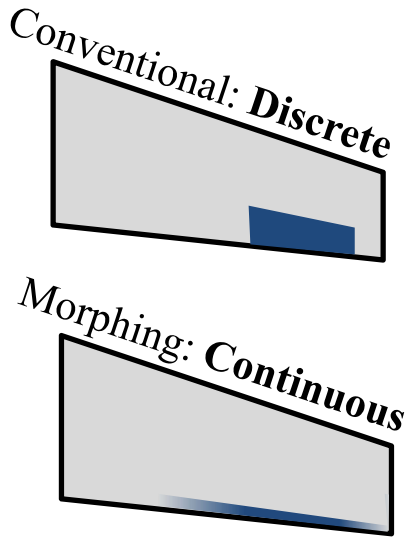


Camber Increase:



Camber Reduction:





Morphing Concept Advantages

Continuous structural transition between wing and control surfaces promotes reduction in vortex production.

So, lack of spanwise structural discontinuities reduces lift induced drag.

Therefore, for a given amount of lift, less effective camber is required.

And with a more global change in camber, chord-wise, through honeycomb system reduces pressure gradients.

So, with less camber required there is a reduction in pressure gradients over the wing control surface area.

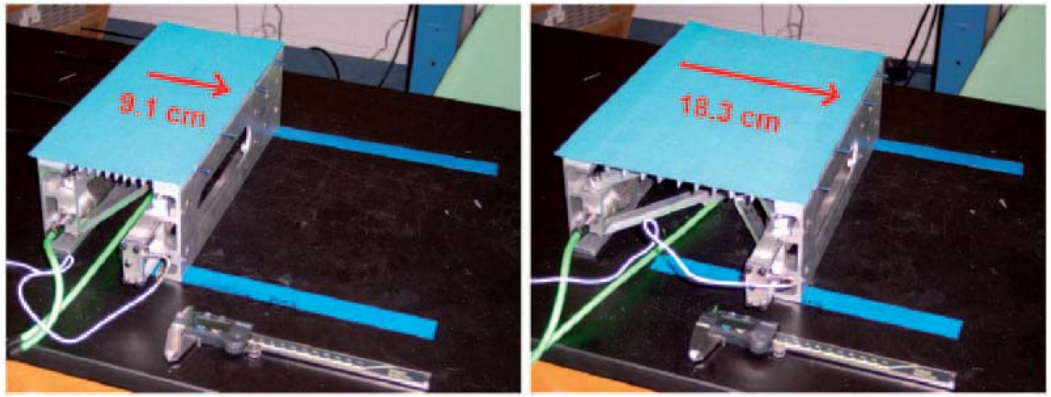
Less adverse pressure gradients promotes more attached flow.

Hence wing produces less drag

Manufacturing constraints - wingbox

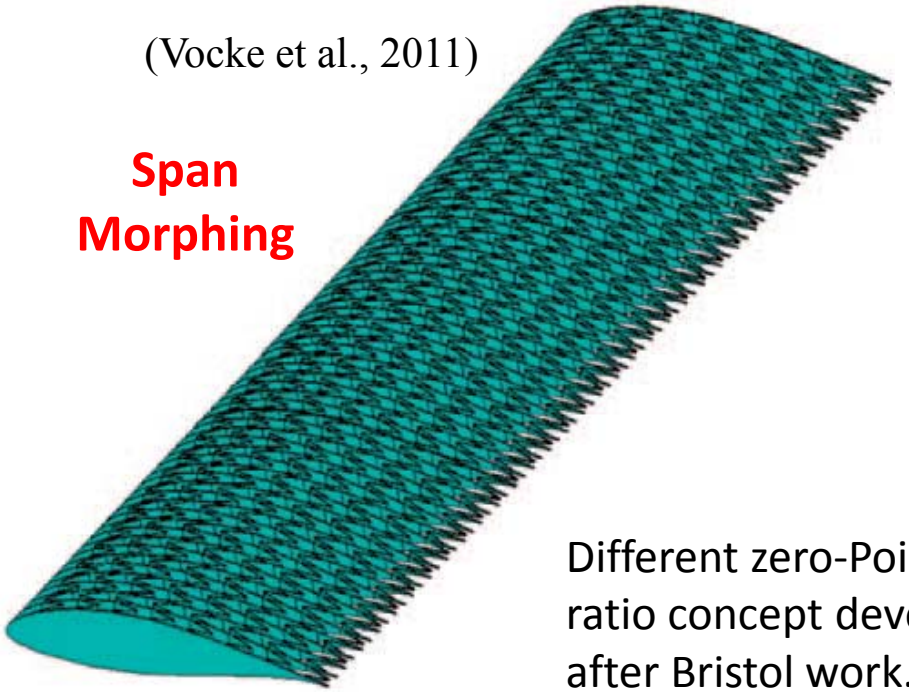
Current Work in Literature

(Bubert et al., 2010)



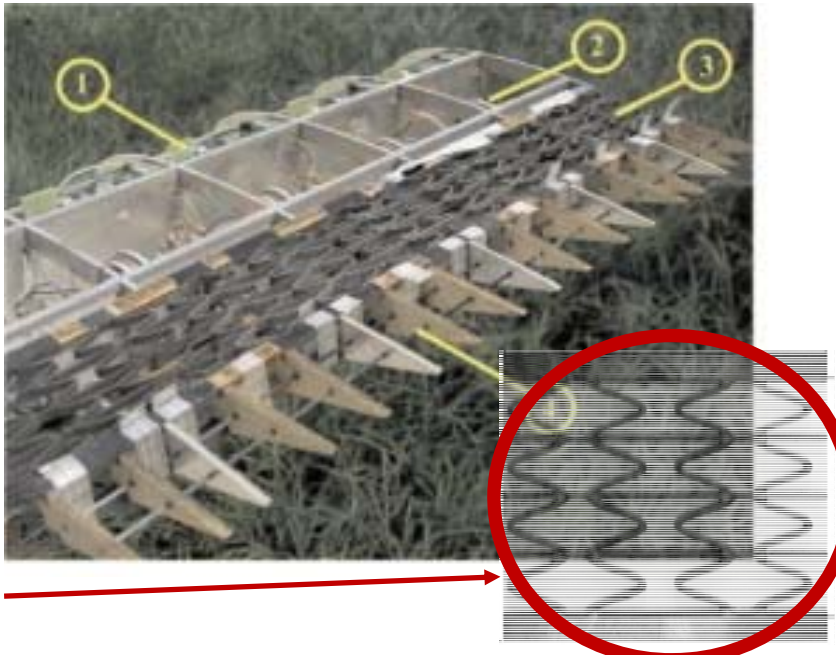
(Vocke et al., 2011)

Span Morphing



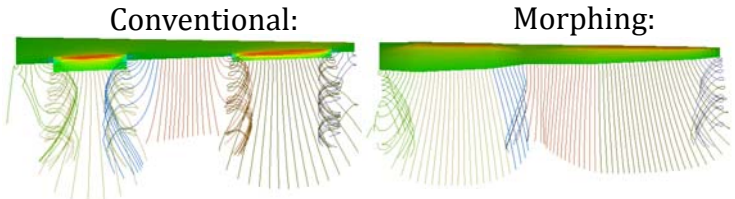
Different zero-Poisson's ratio concept developed after Bristol work.

(Liu et al., 2013)

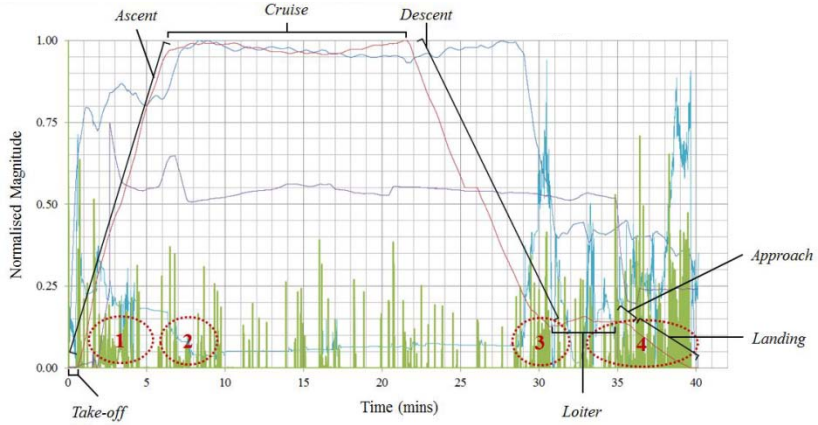


Previous Papers…

Adaptive Camber-Morphing Wing using Zero-Poisson's Ratio Honeycomb RAeS, 3rd Aircraft Structural Design Conference, Delft, NL, Oct '12



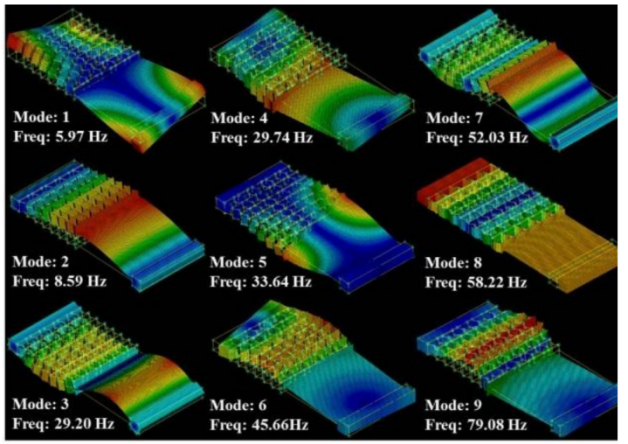
Aerodynamic Study of Adaptive Camber-Morphing Wing using 0-υ Honeycomb RAeS, IFASD Conference, Bristol, UK, June '13



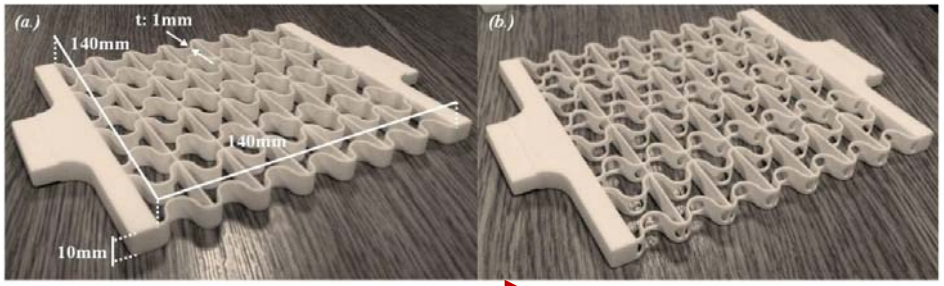
*With morphing outboard aileron, increase in aircraft range of between **0.8-0.9%***

Replacing the Conventional Wing Control Surface: The 0-ν Camber-Chord Morphing Wing Demonstrator, RAeS, Novel Concepts Design and Operation, UK, July 2014

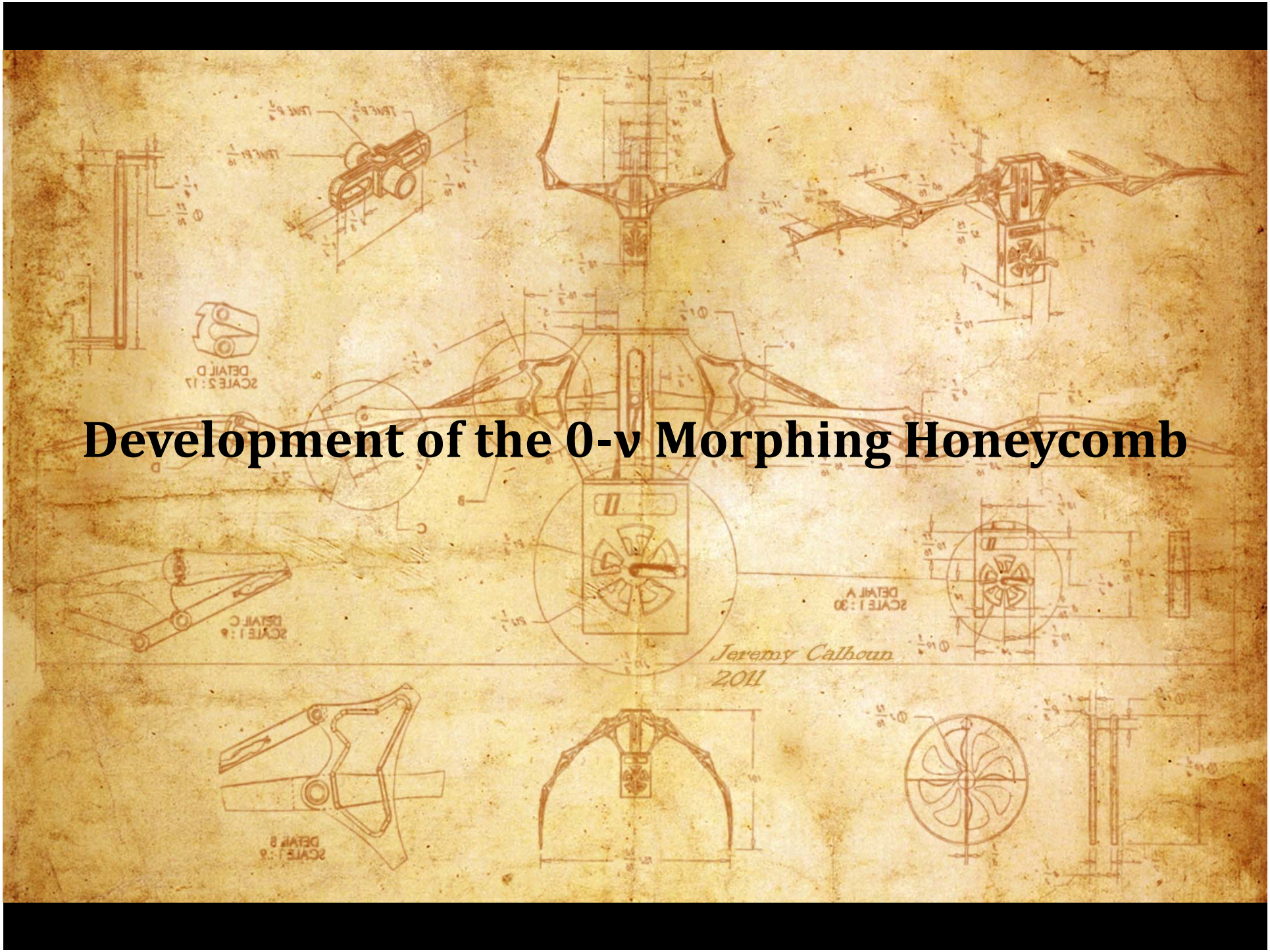
Adaptive Camber-Morphing Wing using 0-υ Honeycomb AIAA, SDM Conference, Boston, USA, Apr '13



Topology Optimization & Experimental Validation of 0-υ Honeycomb for Adaptive Morphing Wing AIAA, SCITECH Conference, Washington DC, USA, Jan '14



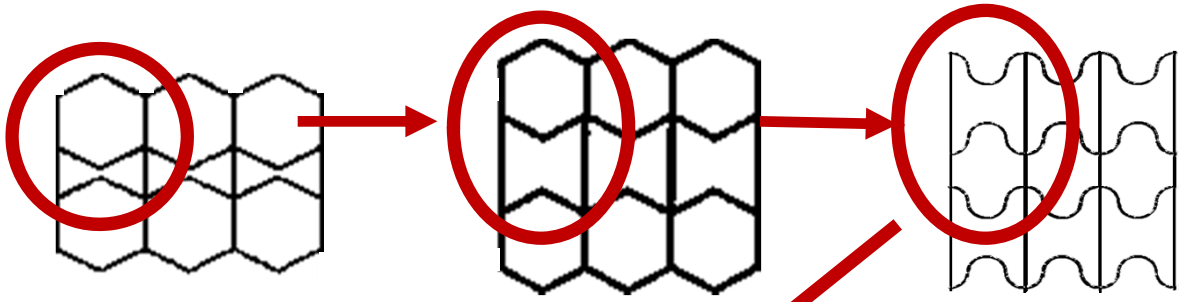
*Reduction in actuator loading requirements for morphing to between **42%-55%***



Development of the 0-ν Morphing Honeycomb

Topology Optimisation of Honeycomb

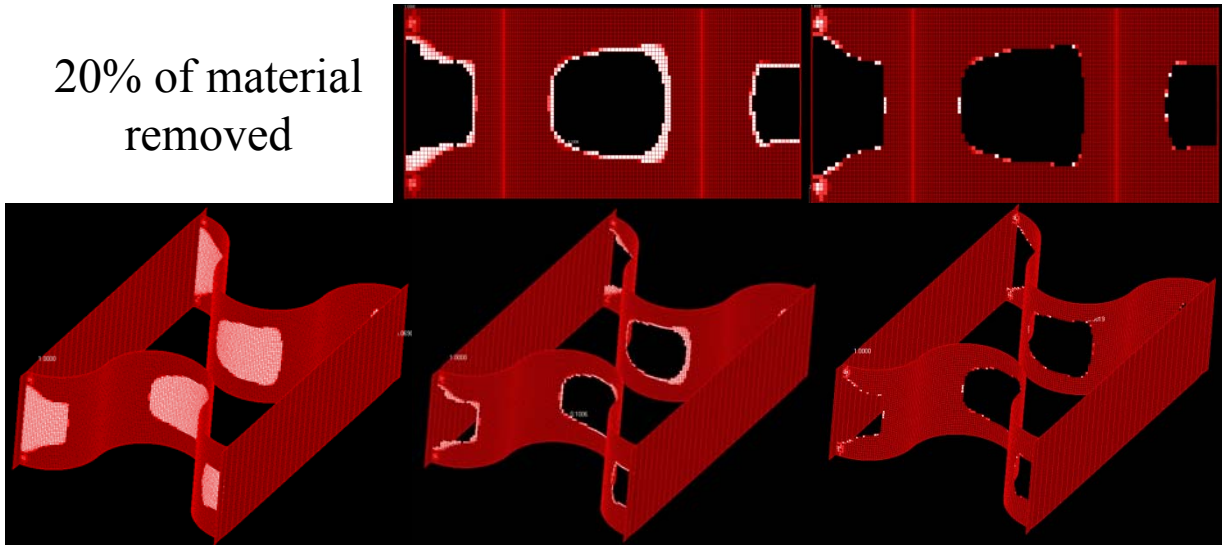
Development of Honeycomb:



Using NASTRAN in-built topology optimisation code:

Minimising Compliance in z-direction

20% of material removed



Cell Material Removed:

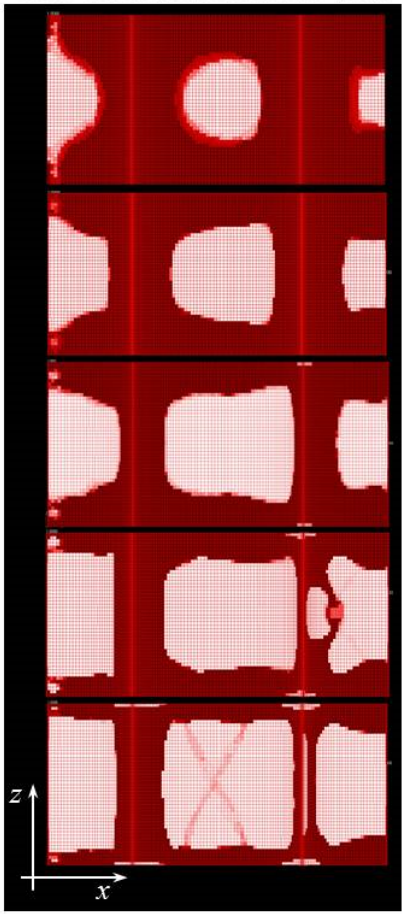
a.) 10%

b.) 20%

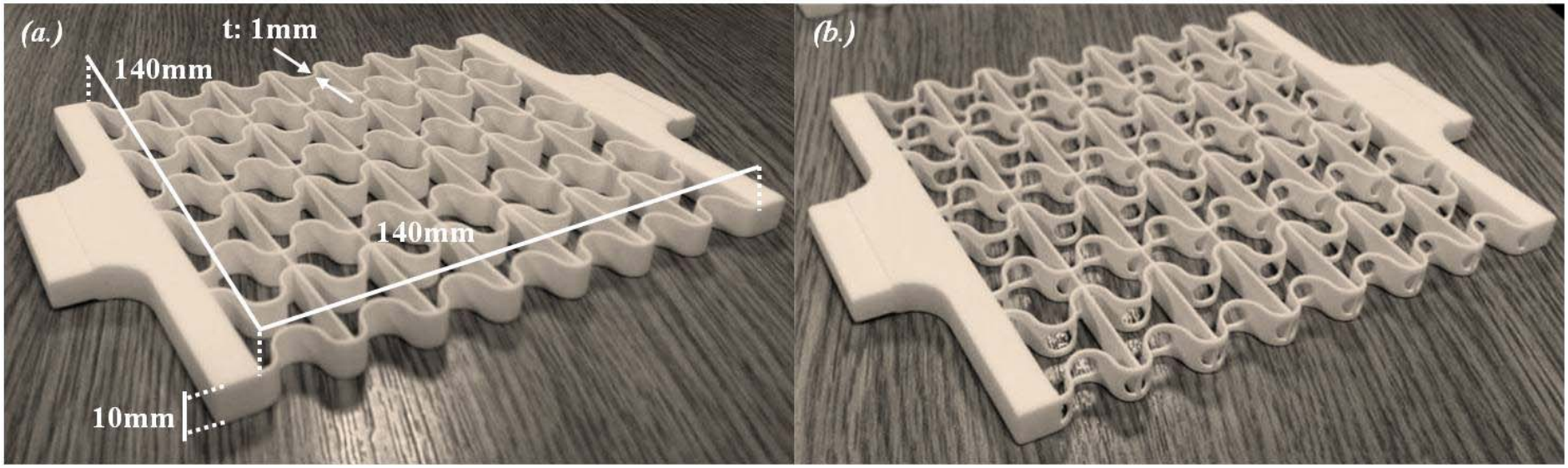
c.) 30%

d.) 40%

e.) 50%

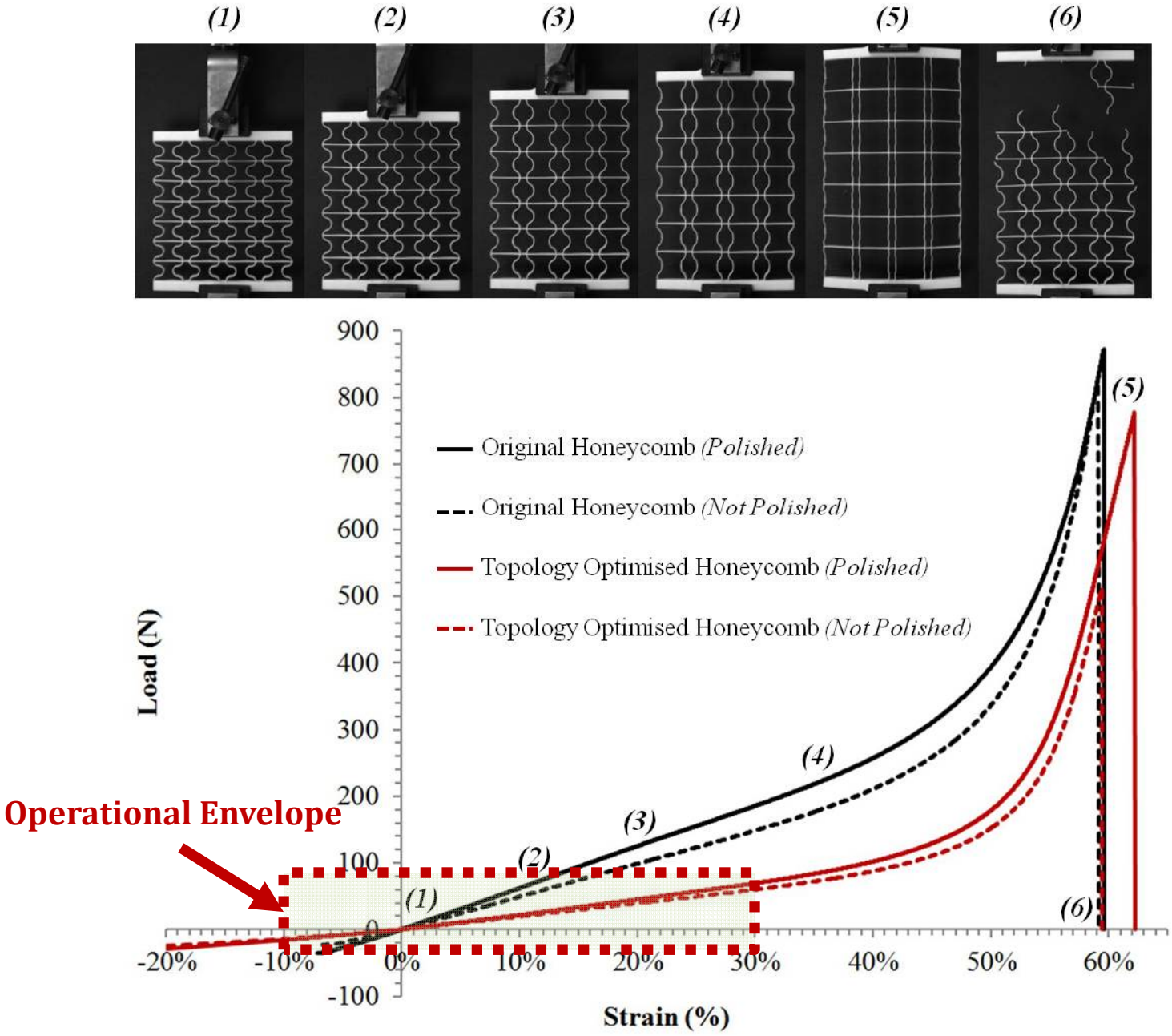


3D-Printed Honeycomb Coupons

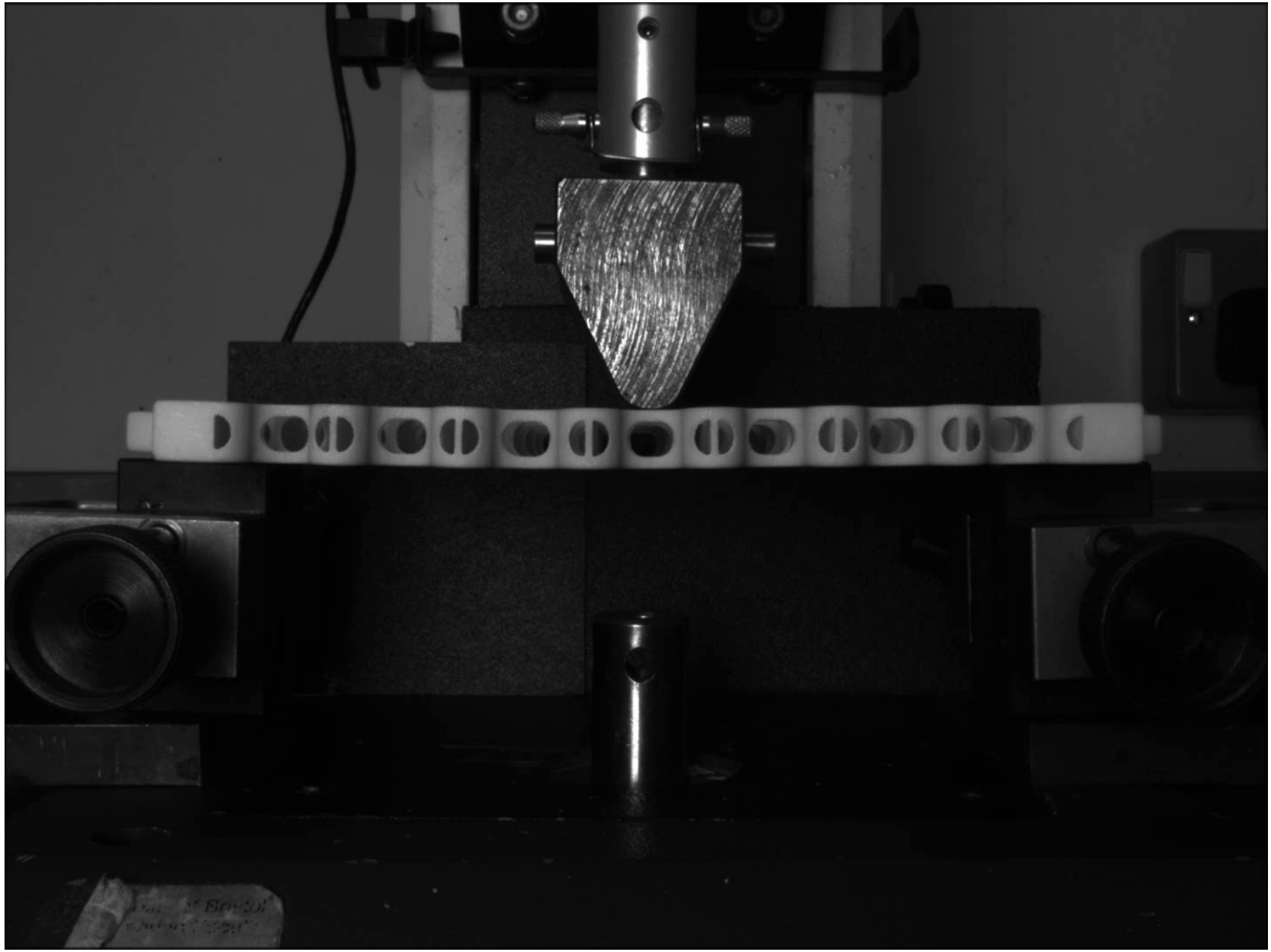


Tensile Tests – 90% extension, Poisson's = 0

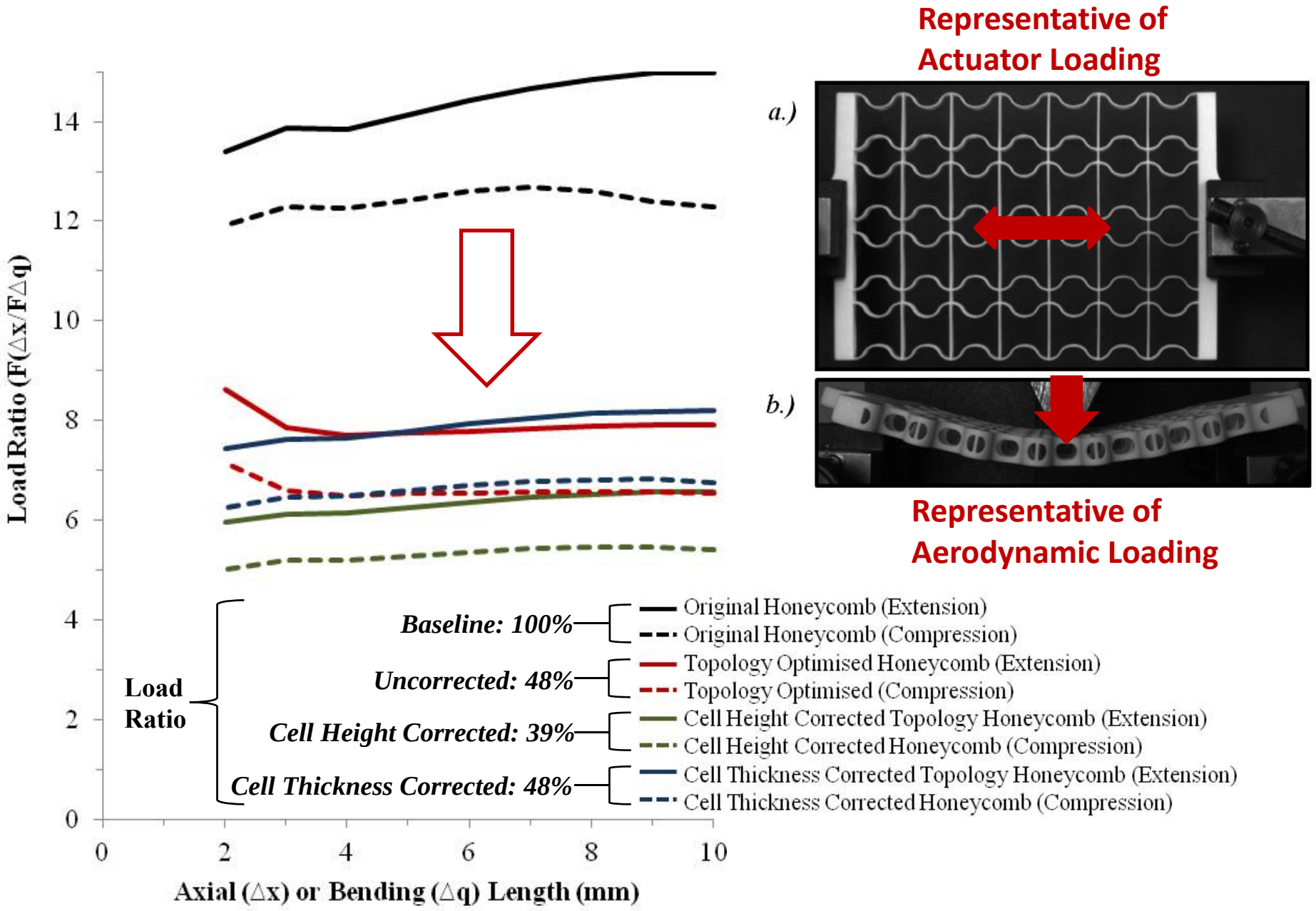
Strain to Failure – Linear to 40%



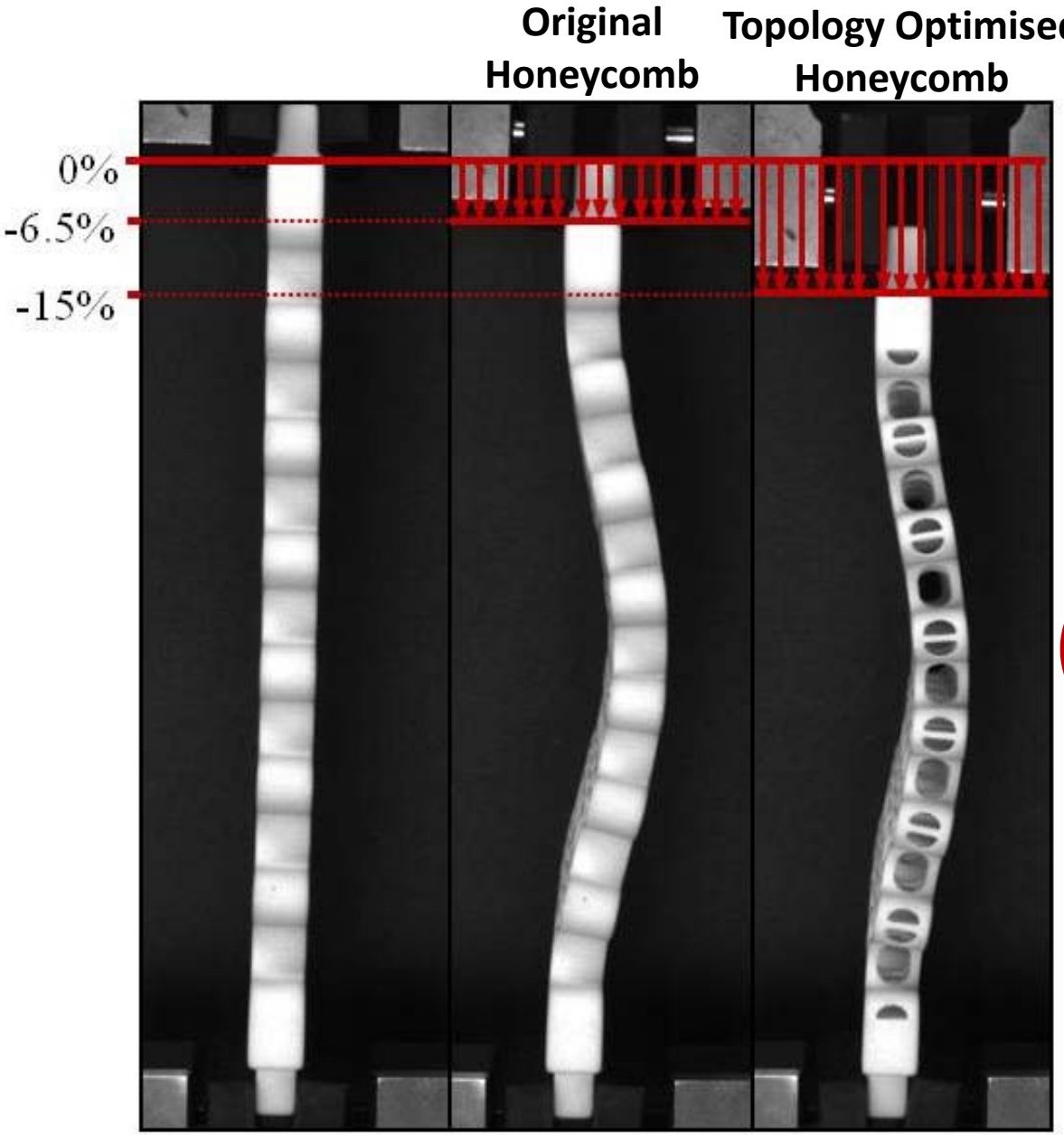
3-Point Bending Test



Topology Optimisation Result

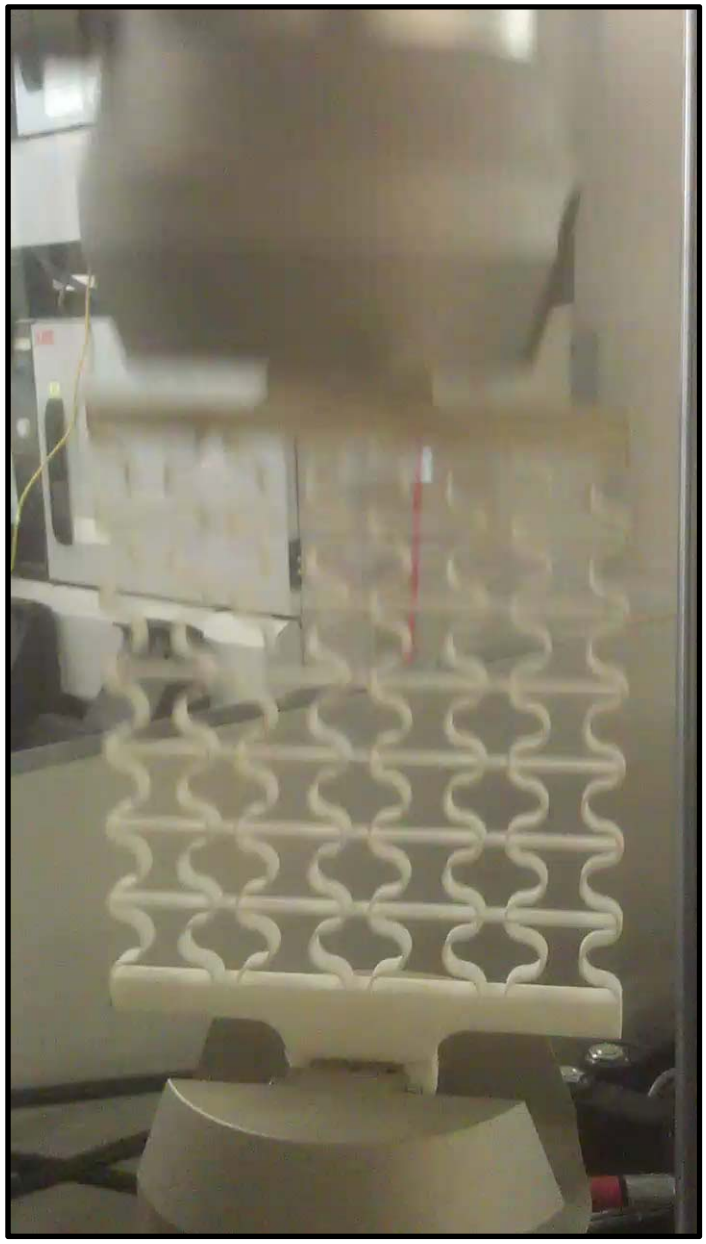


Comparative Buckling Characteristics

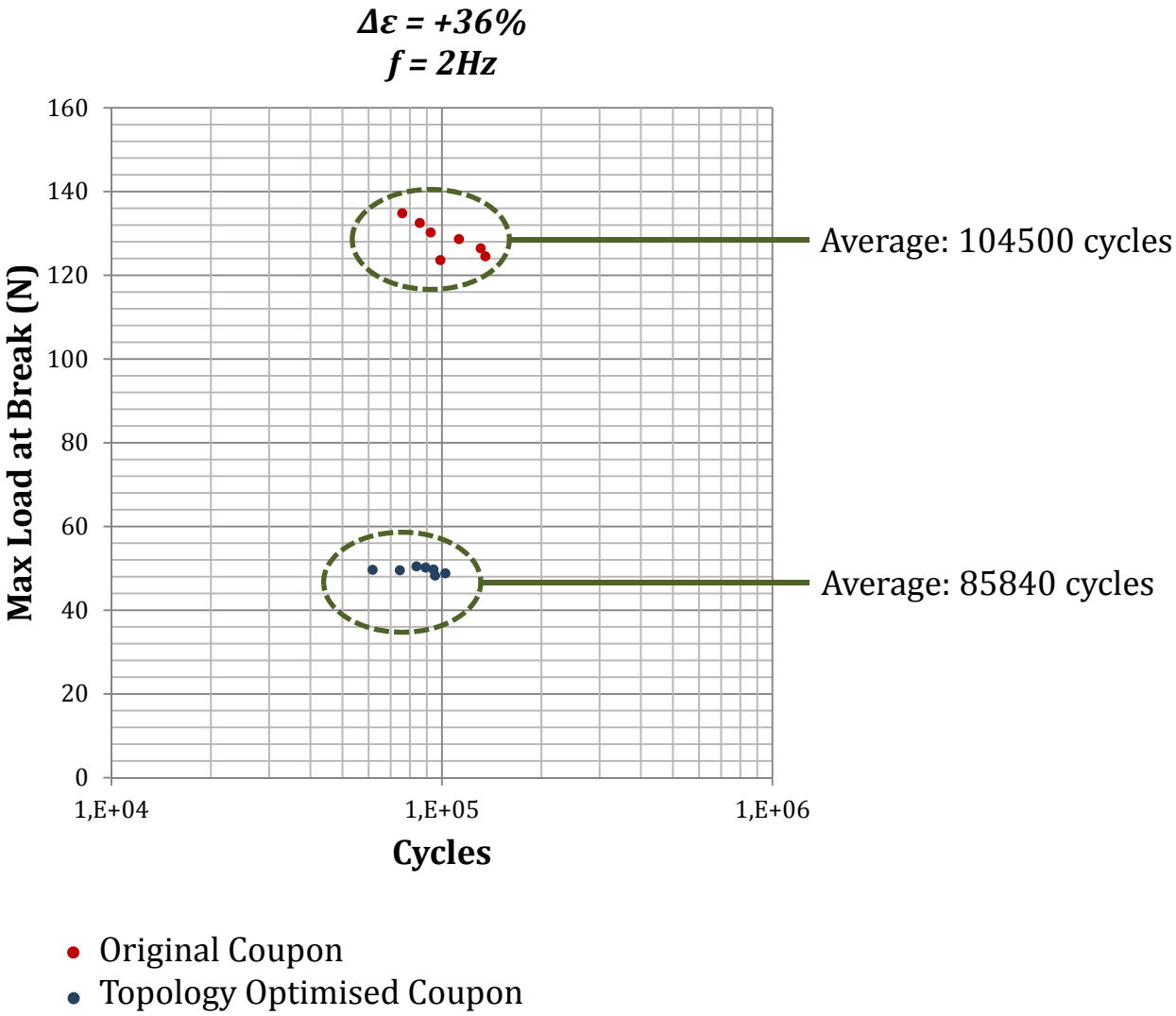


Significantly better buckling characteristics

Fatigue Study Video

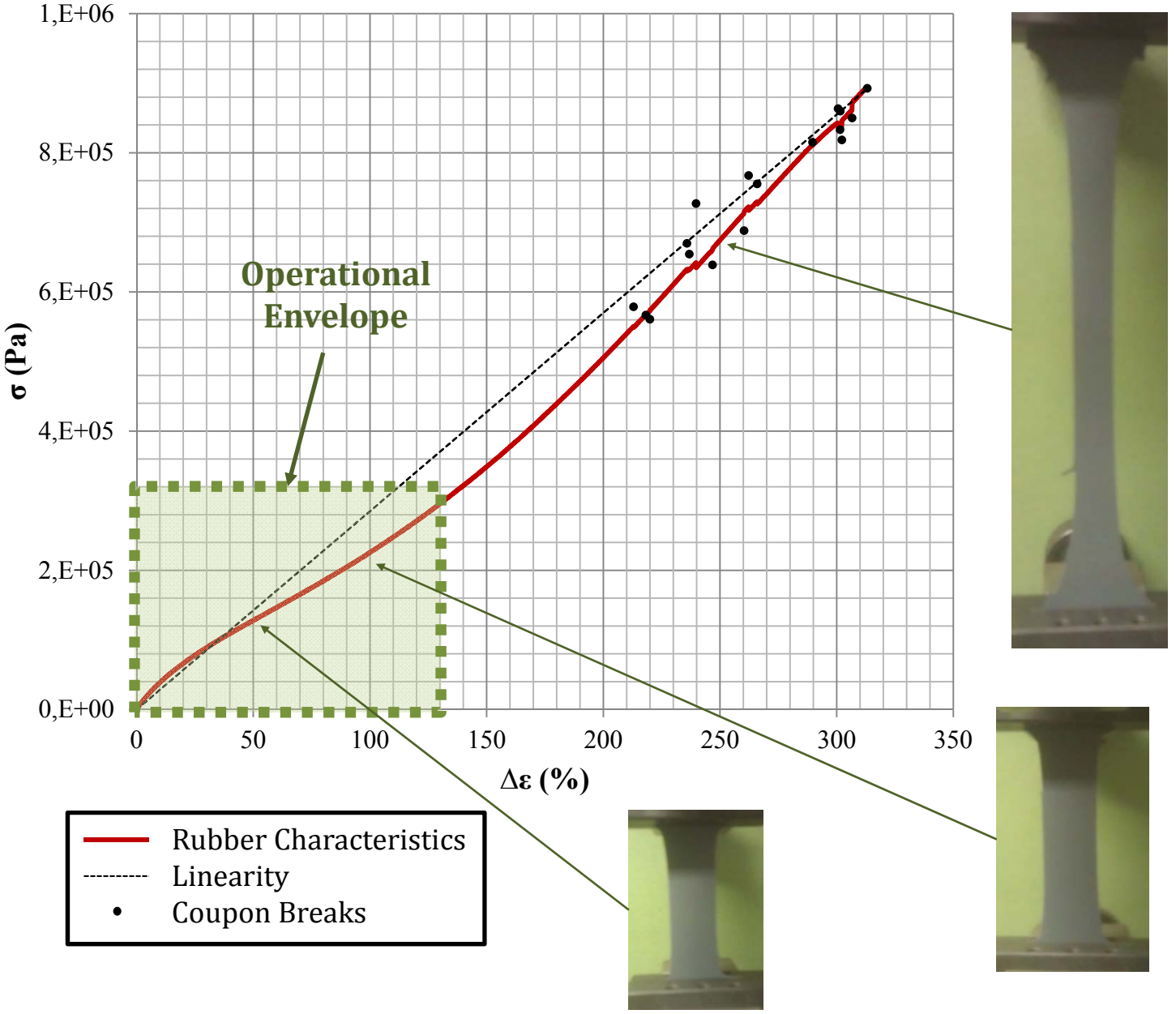


Comparative Fatigue Characteristics

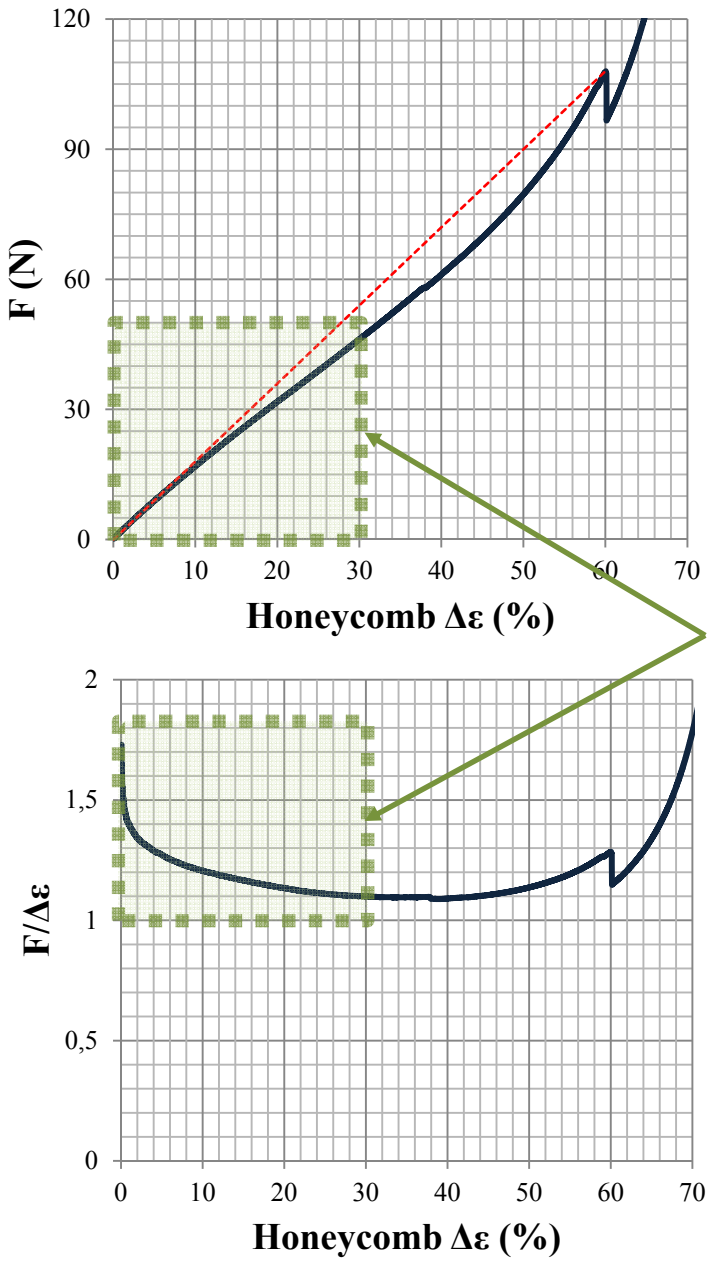


Integration of Hyper-Elastic Rubber Skin

Hyper-Elastomer Tensile Test

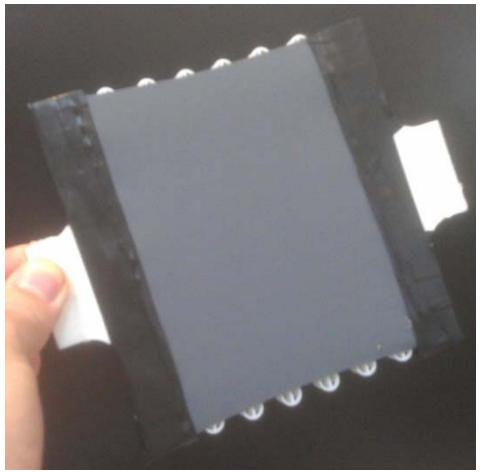


Honeycomb-Elastomer Coupled Tensile Test



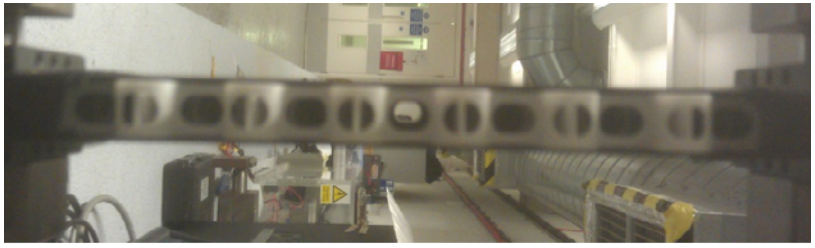
Operational Envelope

Coupled Coupon:

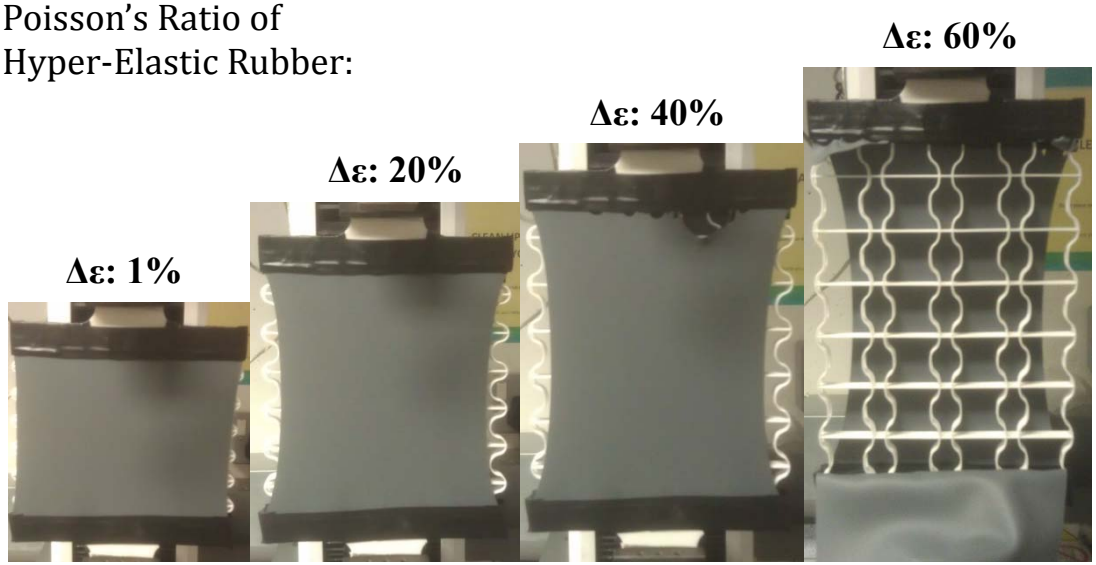


Rubber pre-stressed by Δε = 100%

Side View:



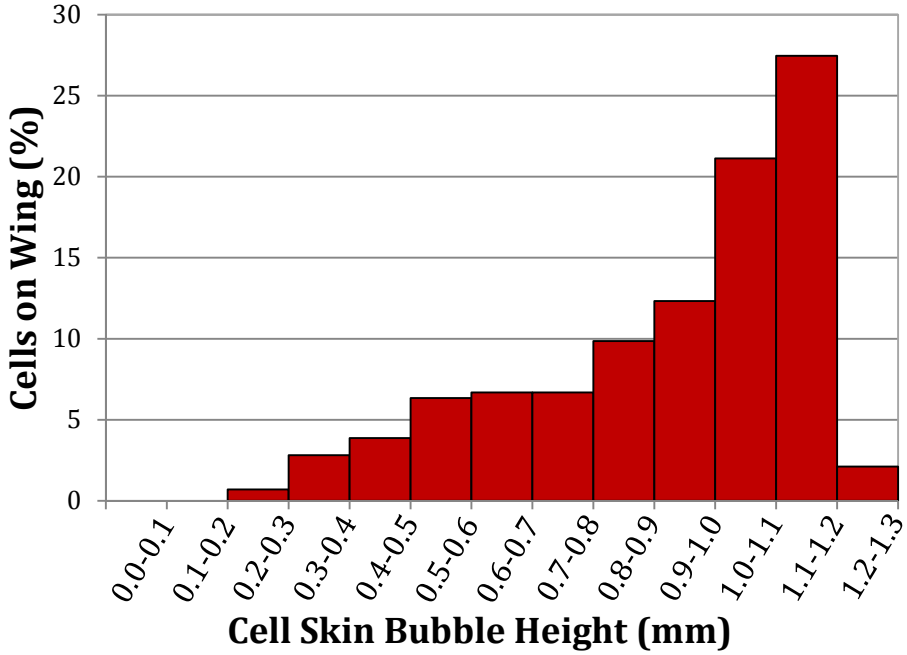
Poisson's Ratio of Hyper-Elastic Rubber:



Pre-Stressed Rubber Deformation due to Aerodynamics

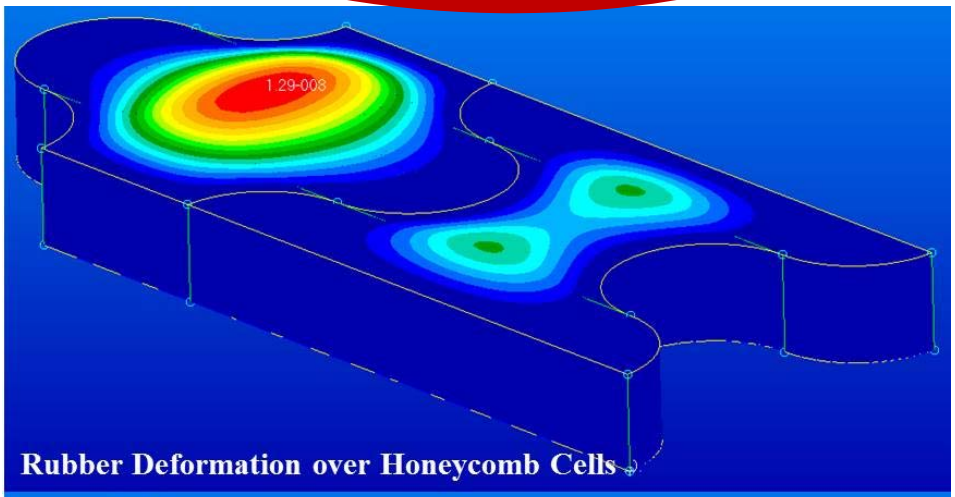
Worst Case Scenario: SF = 1.5 $\alpha = +5^0$ $\delta = +20^0$

Rubber is 0% pre-stressed →



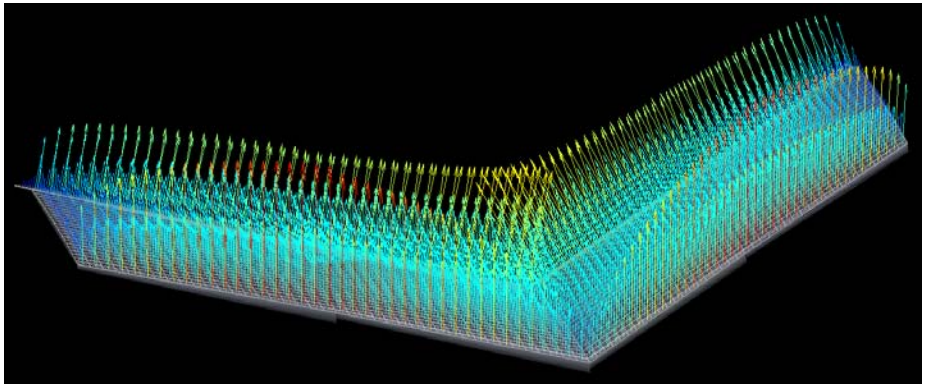
Pre-stress:
- 0% = 1.29mm
- 25% = 1.13mm
- 50% = 0.97mm
- 75% = 0.81mm
- 100% = 0.65mm

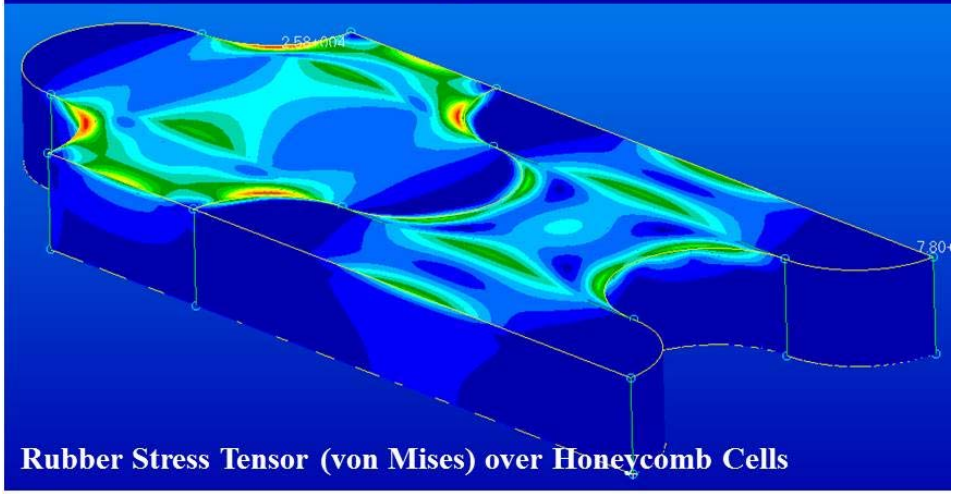
} Maximum rubber bubble height



Rubber Deformation over Honeycomb Cells

Aerodynamic Panel Loading:

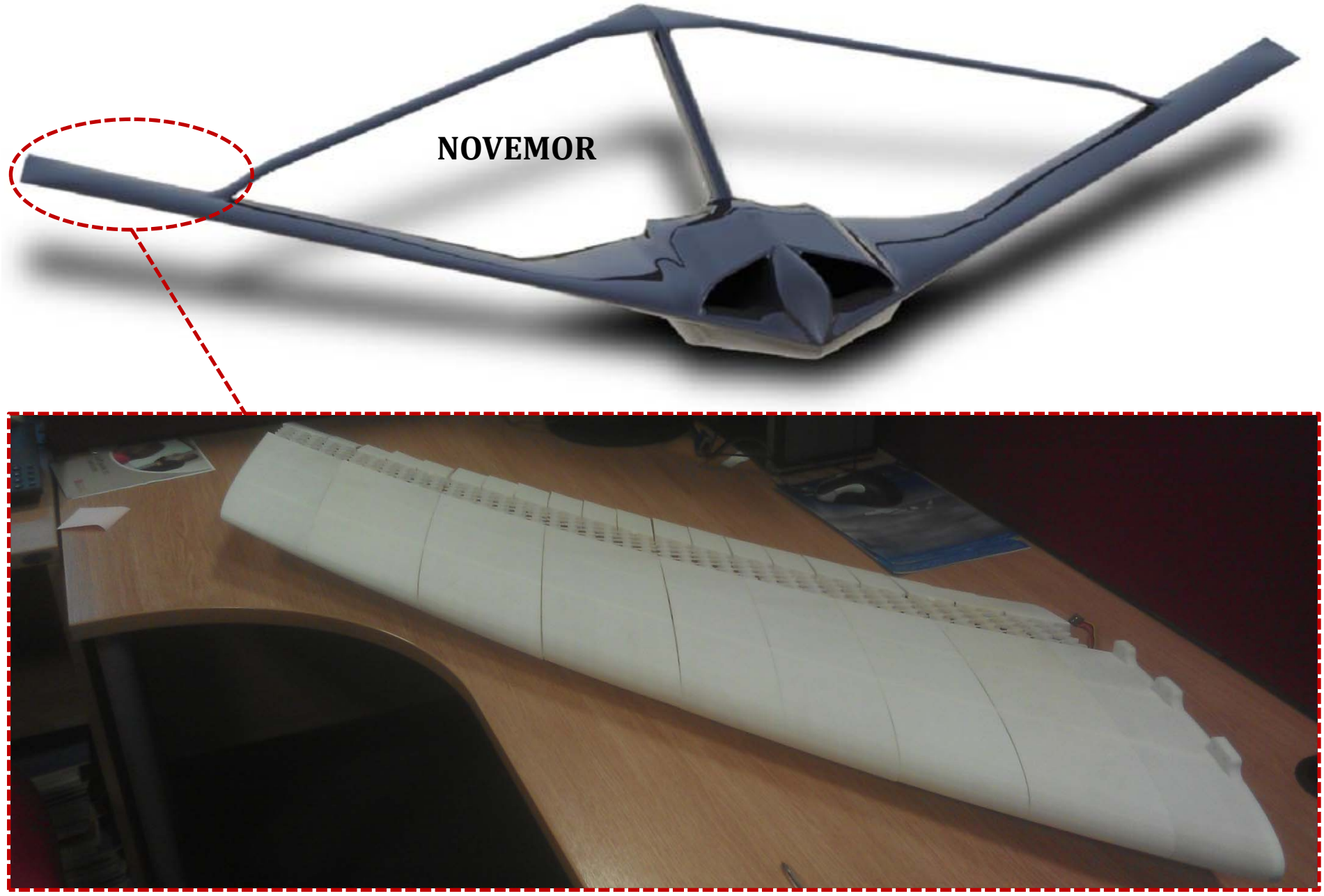



Rubber Stress Tensor (von Mises) over Honeycomb Cells

Otto Lilienthal 1894

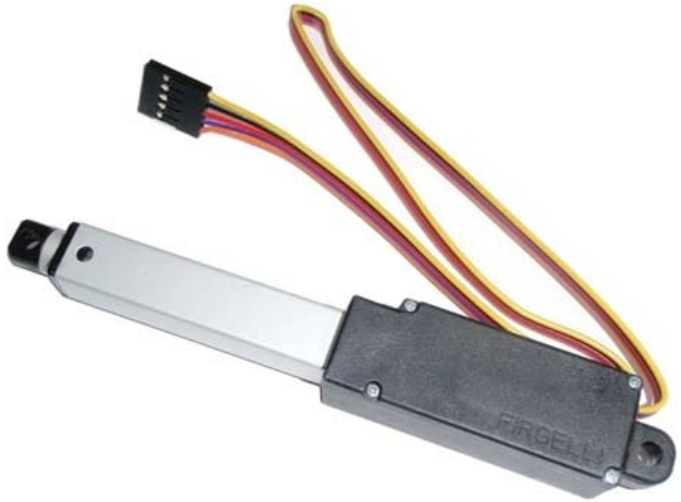
Wing Demonstrator

Context of Demonstrator



Micro-Linear Actuators

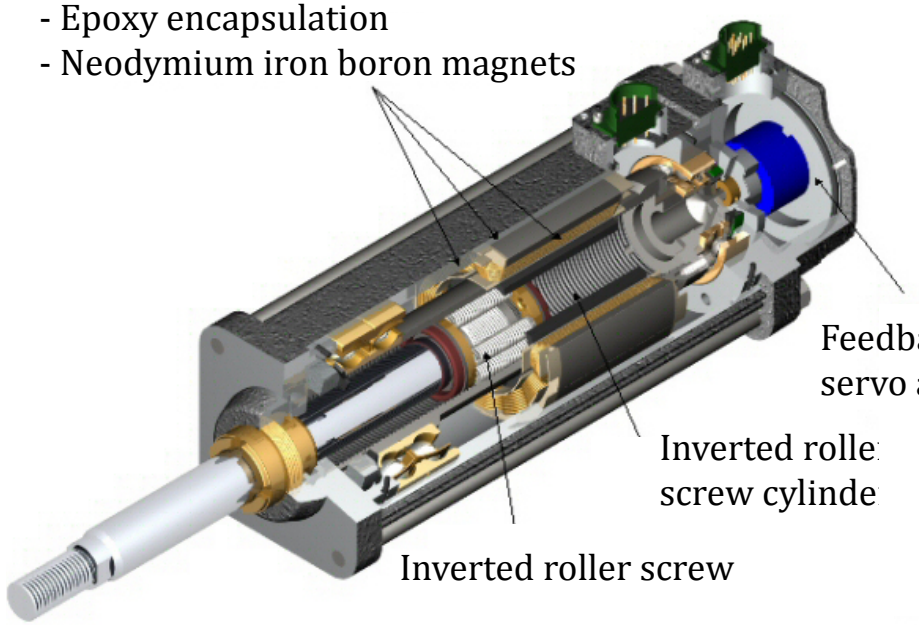
Firgelli: L16-P Linear Actuator



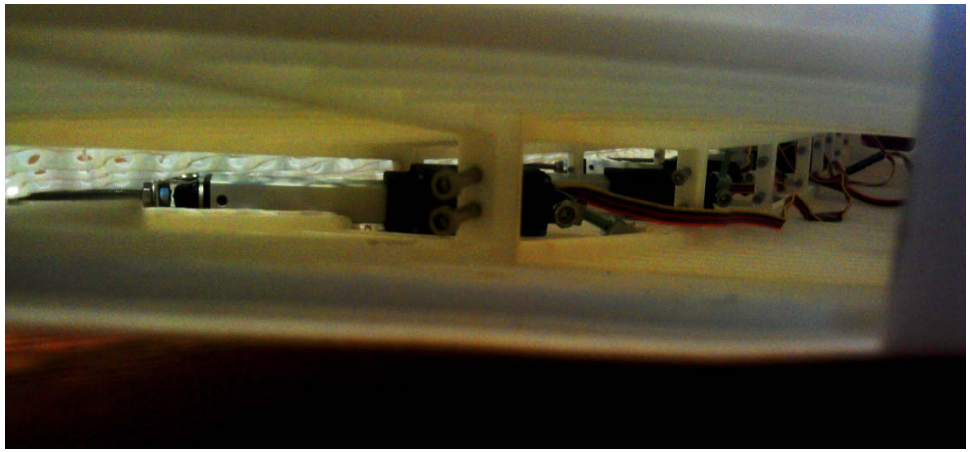
L16 Specifications

Gearing Option	35:1	63:1	150:1
Peak Power Point	50N @16mm/s	75N @10mm/s	175N @4mm/s
Peak Efficiency Point	24N @24mm/s	38N @15mm/s	75N @7mm/s
Max Speed (no load)	32mm/s	20mm/s	8mm/s
Max Force (lifted)	50N	100N	200N
Back Drive Force	31N	46N	102N
Stroke Option	**50mm**	**100mm**	**140mm**
Mass	56g	74g	84g
Positional Accuracy	0.3mm	0.4mm	0.5mm
Max Side Load (extended)	40N	30N	20N
Feedback Potentiometer	9kΩ±30%	18kΩ±30%	25kΩ±30%
Electrical Stroke	48mm	98mm	138mm
Input Voltage	0-15 VDC. Rated at 12VDC.		
Stall Current	650mA @ 12V		
Operating Temperature	-10°C to +50°C		
Audible Noise	60dB @ 45cm		
Ingress Protection	IP-54		
Mechanical Backlash	0.2mm		
Limit Switches	Max. Current Leakage: 8uA		

Integrated T-LAM Brushless Motor:
- Segmented lamination stator
- Epoxy encapsulation
- Neodymium iron boron magnets



Actuators fitted within wing demonstrator:

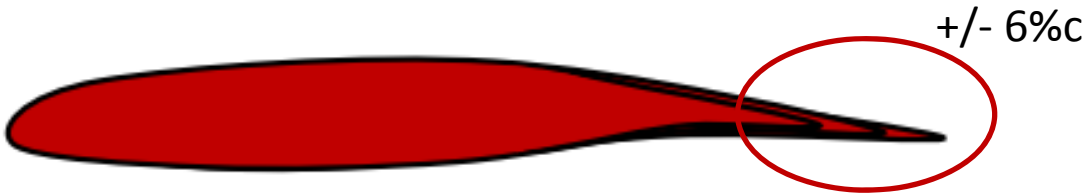


Load Requirements for Morphing Design Space

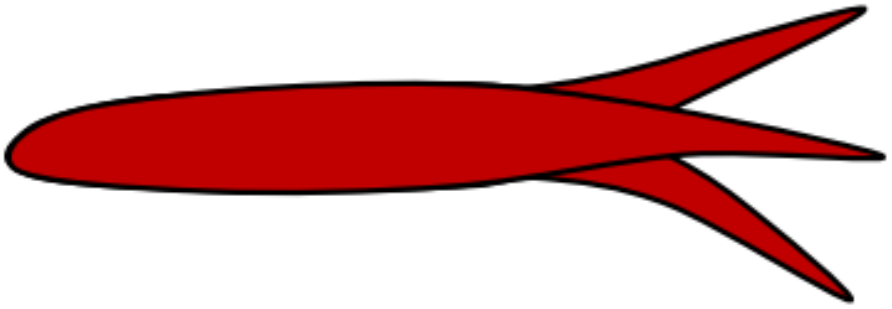
Actuator system max. potential:
- 1200N in extension
- 612N in retraction

Morphing load requirements **per 1%** / 10% / 100% span for:

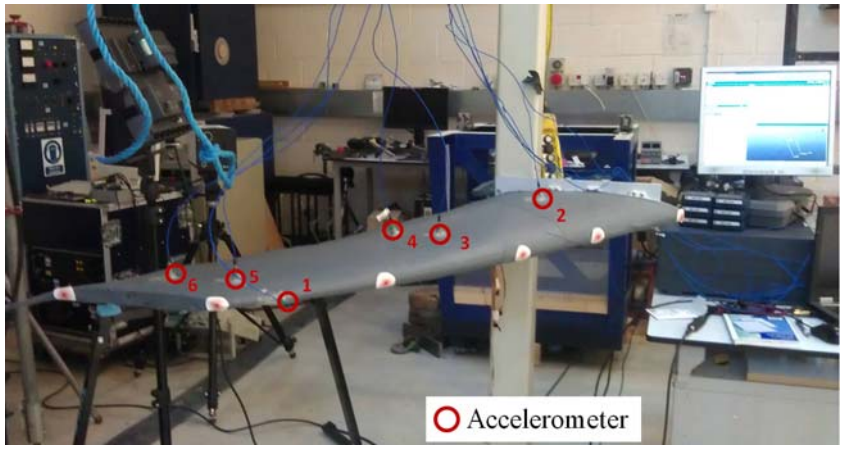
a.) 6% chord increase: **9.07N** / 90.7N / 907N
b.) 6% chord decrease: **8.35N** / 83.5N / 835N



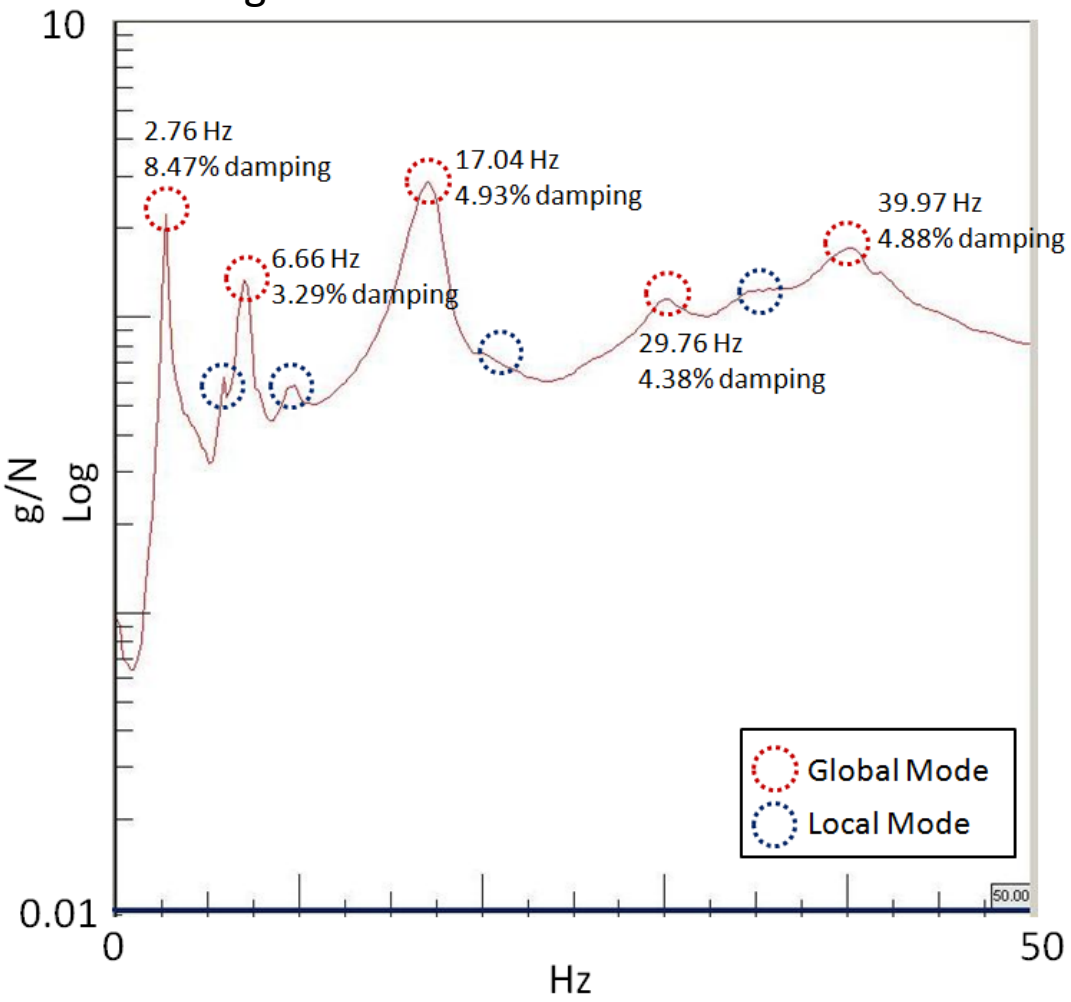
c.) ±30^0 control surface deflection: **3.66N** / 36.6N / 366N
(equivalent to 4.8% chord increase on one surface)



Modal Analysis of Wind-tunnel Geometry (Flutter / Divergence)

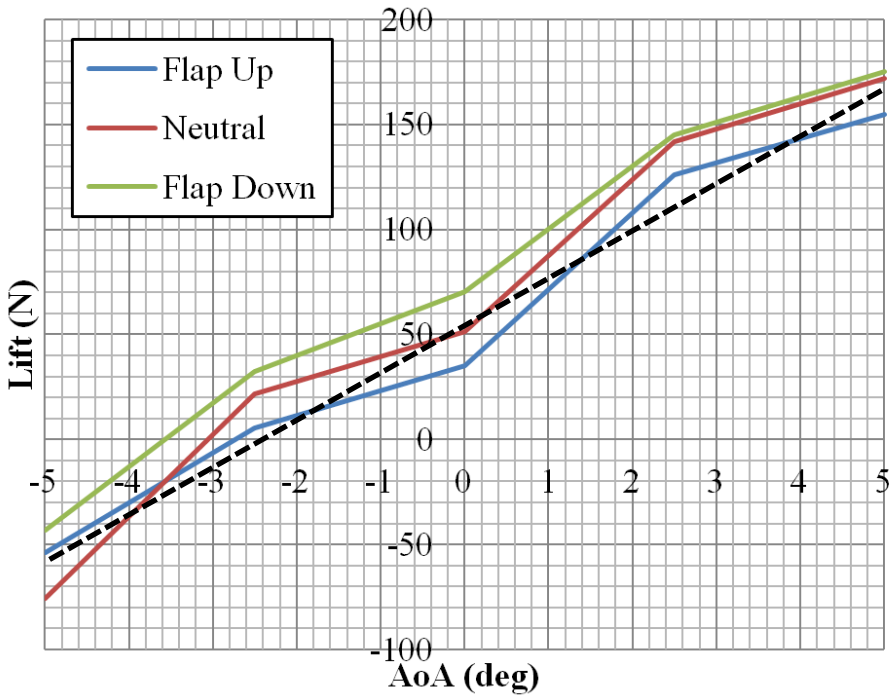


Average of all FRFs:

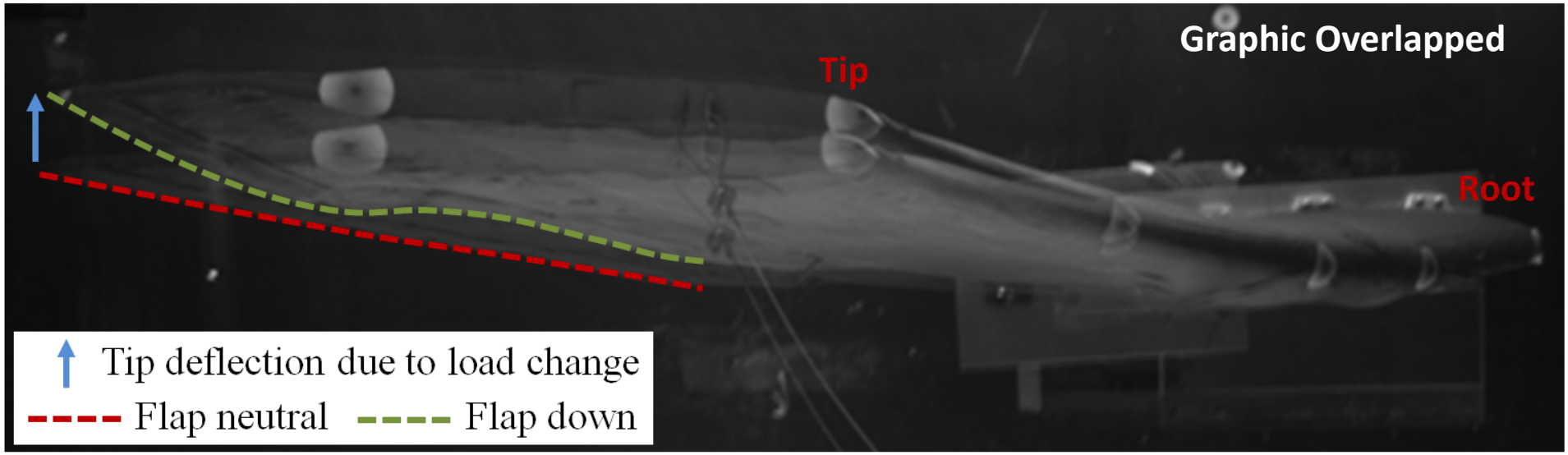


Initial Wind-tunnel Results

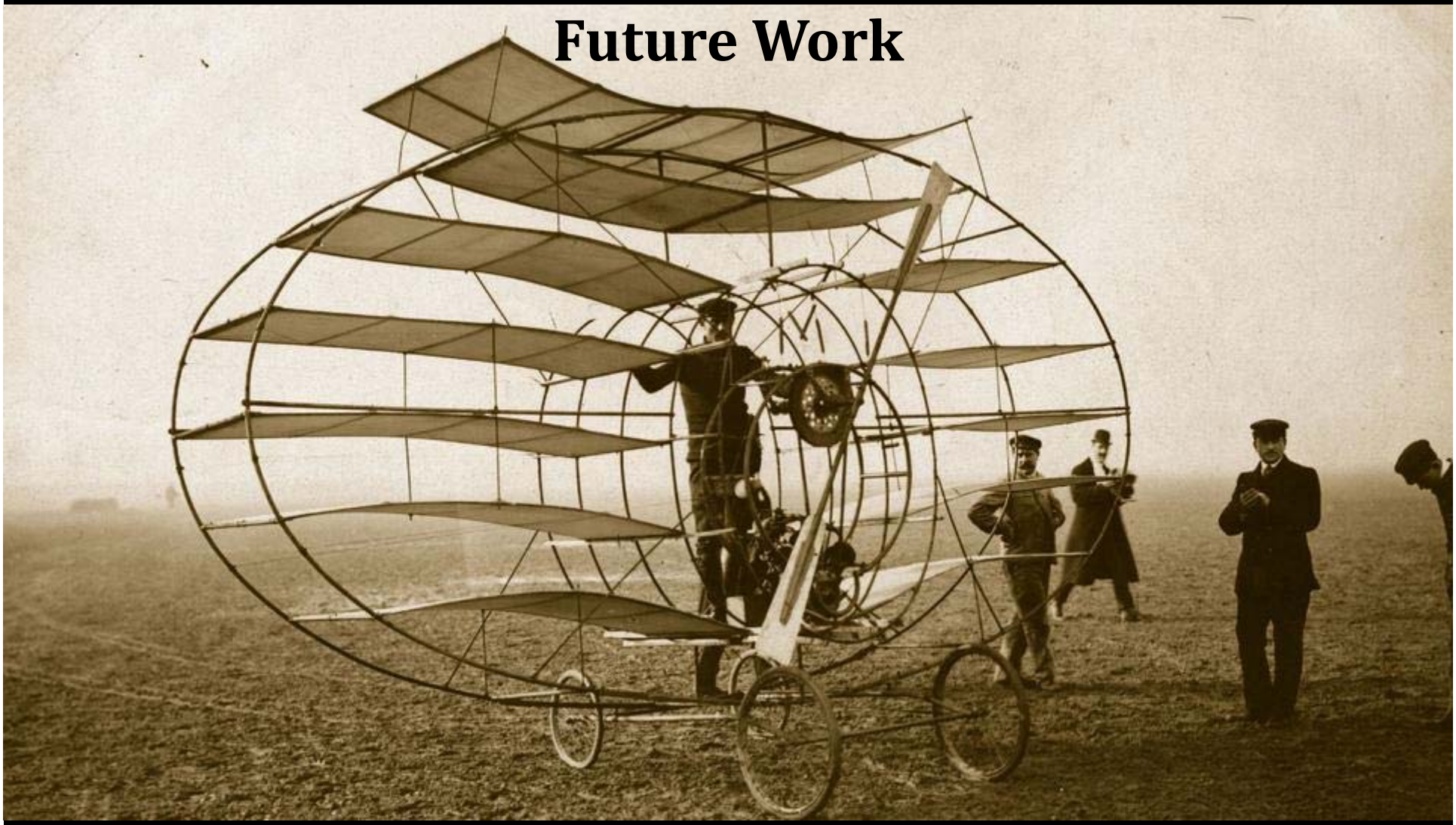
Wind-tunnel results for variation of outboard actuator



Increase in tip deflection due to flap down (increase in lift)

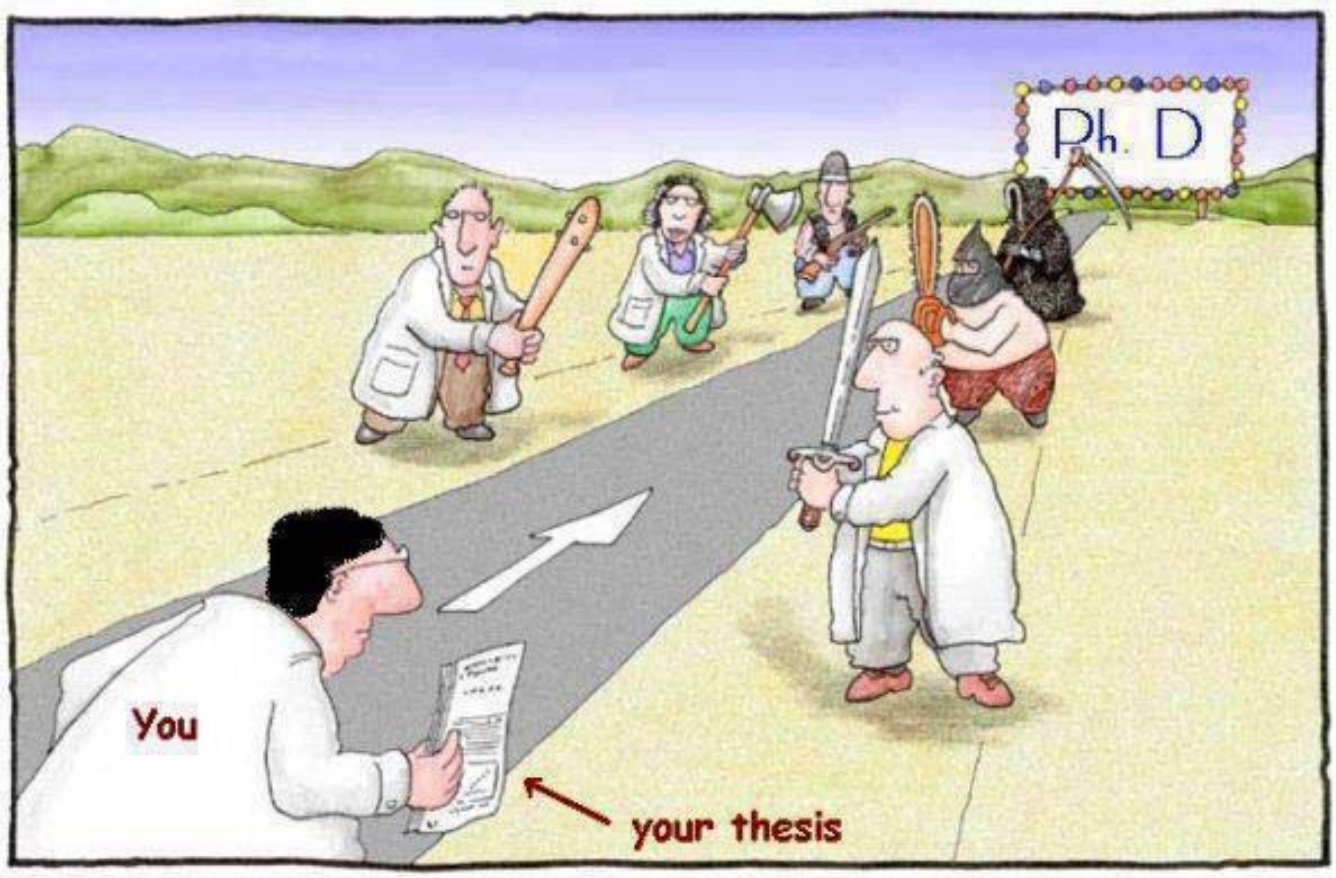


Future Work



Future Work…

Thesis Write-Up… Where is Ashley ….. Marks for Guessing



Further Thoughts

Morphing technologies may not be the sole solution to the problem we are facing, but they will play an important role. All-electric propulsion, energy harvesting systems, prolific use of light-weight composite materials, and formation flying will all go some way to resolving the issue.

"Nature's imagination is so much greater than man's, she's never going to let us relax."

- Richard Feynman

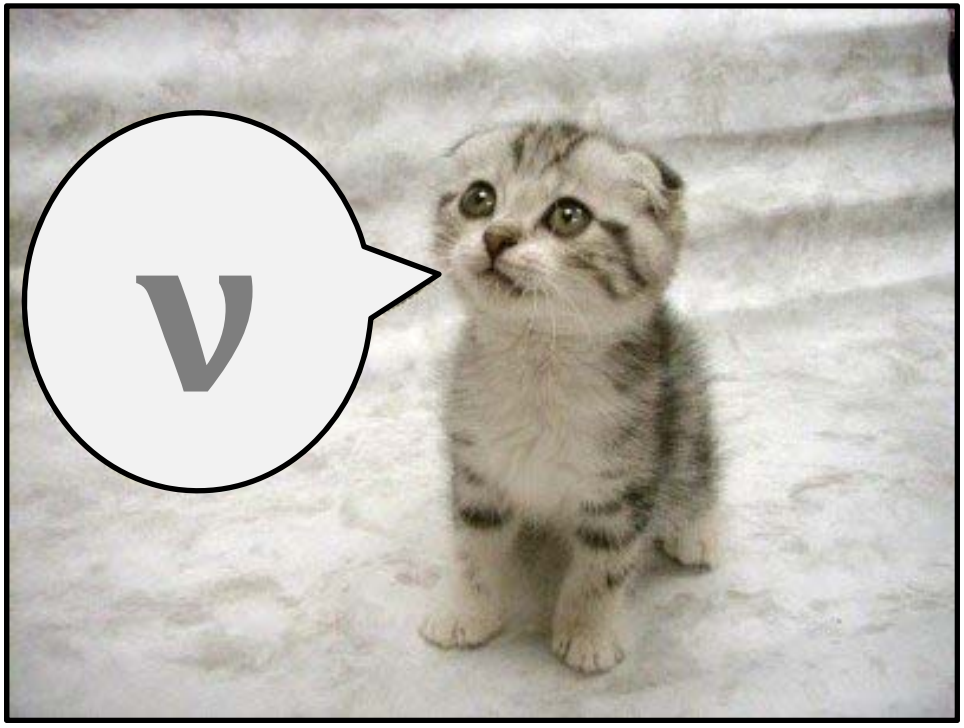
"Biology is becoming the new basis for technology."

- Mike Griffin

Replacing the Conventional Wing Control Surface:
The 0-ν Camber-Chord Morphing Wing Demonstrator

Ashley Dale – ***a.s.dale@bristol.ac.uk***

Comments / Questions?



Multidisciplinary Design Optimization of Novel and Morphing Aircraft Configurations: Computational Studies and Experimental Validation

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EMBRAER S.A., São José dos Campos, Brazil

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University of Bristol, Bristol, United Kingdom

4th EASN Association International Workshop on Flight Physics & Aircraft Design, 27 – 19 October 2014, Aachen, Germany

Outline

1. Motivation
2. Background
3. MDO Framework
4. Morphing Wingtip Applied to a Joined-Wing Conceptual Model
5. Optimization of a Joined-Wing Regional Transport Aircraft
6. Conclusions and Future Work

Motivation

- **Aircraft Design Challenges**:

  - Increase speed and capacity

    Air travelling is predicted to grow at a annual rate between 3 to 5%.

  - Reduce environmental impact

    Demanding requirements such as the stated in Flightpath 2050 vision for European Aviation.

- **Possible Solutions:**

  - Morphing Strategies

    Examples:

    LE/TE morphing devices

    Morphing wingtips

  - Novel Designs

    Examples:

    Blended Wing Aircraft

    Joined-Wing

    Strut-braced Wing

Background – Joined-Wing Configuration

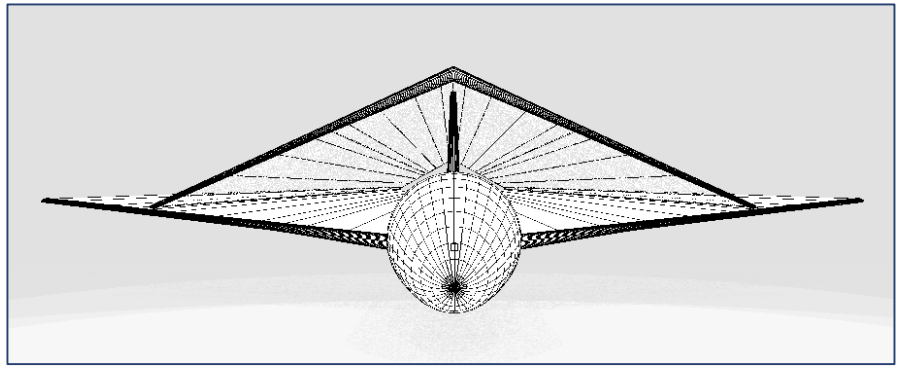
Pros	Cons
Lighter structure	Aft wing buckling
Higher stiffness	Pitch-down tendency
Low vortex drag	Design integration
Low wave drag	Main landing gear installation
Direct Lift	Propulsion integration
Side-force control capability	Costly to manufacture and maintain (at least at the beginning)
Higher Trimmed Maximum Lift	Difficult to change aircraft shape maintaining the gains to adapt for different payload configuration
Quieter in climb-out and landing	Reduced chord extension to install high lift devices
Higher flutter speed	
Higher aileron effectiveness	

MDO Framework

- A MDO framework is under development for preliminary design and analysis of novel configurations, including the capability to analyse morphing solutions.

- The main focus of this computational tool is **Performance-Based Multidisciplinary Aircraft Design Optimization**.

- List of Modules:
  - Geometry
  - Aerodynamic (Panel Method)
  - Structural (Equivalent Beam Model)
  - Propulsion (Ideal Turbofan Model)
  - Payload Distribution
  - Fuel Distribution
  - Performance
  - Optimization
  - Fluid-Structure Interaction



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MDO Framework

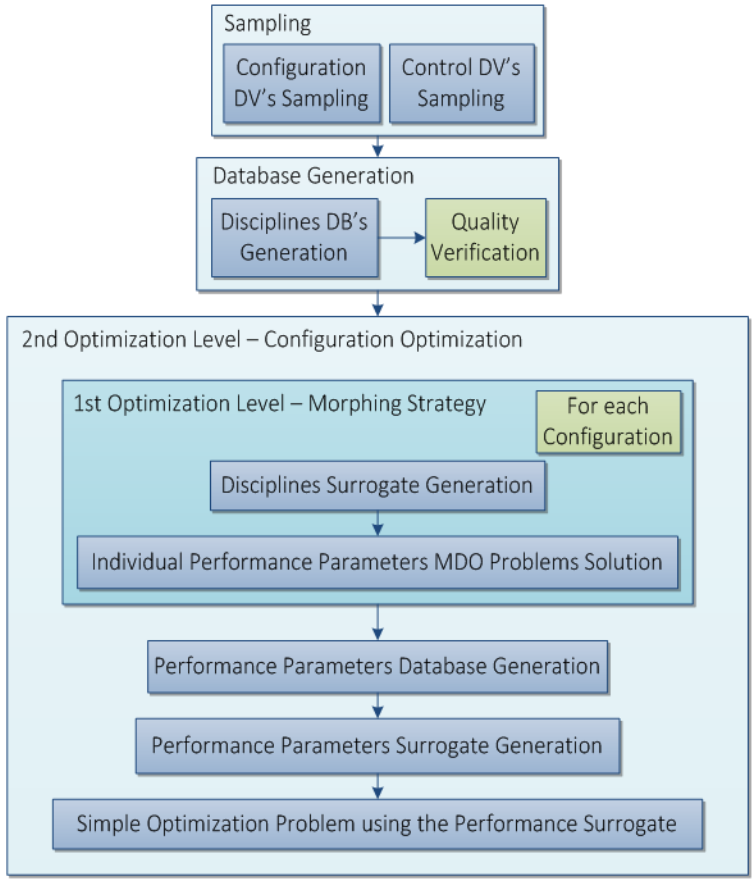
- A MDO architecture was especially designed to incorporate two levels of optimization:

1. Lower Level of Optimization:

   Where the multi-MDO performance optimization problems are defined and the controls able to change during flight optimized.

2. Upper Level of Optimization:

   In the upper level, the fixed components of the aircraft can be optimized.

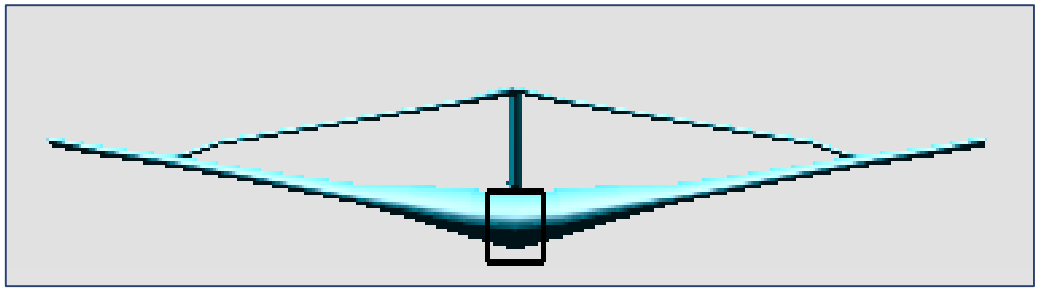


Morphing Wingtip Applied to a Joined-Wing Conceptual Model – Morphing Concept

- In project **NOVEMOR** a baseline joined-wing model is used to evaluate the application of morphing concepts on novel configurations.

- This particular configuration present poor lateral directional stability.

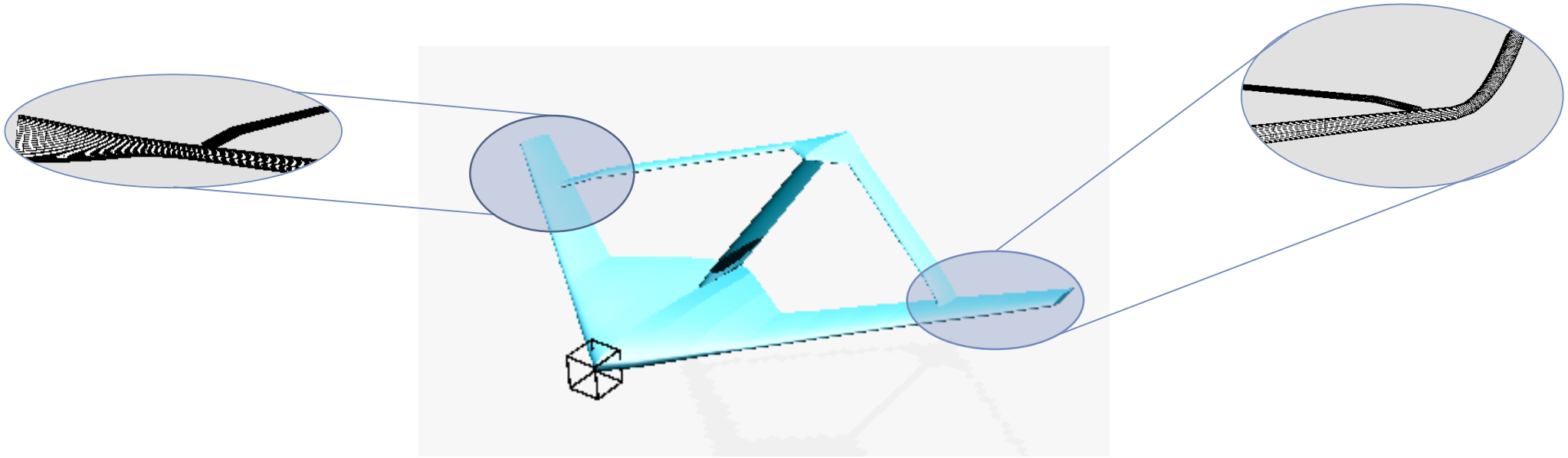
- So a morphing wingtip concept placed on the outboard part of the main wing was applied introduced to improve the lateral directional stability of the aircraft and replace the conventional controls for low speed and altitude condition.



Speed	Altitude
30 m/s	0 m (Sea Level)

Morphing Wingtip Applied to a Joined-Wing Conceptual Model – Morphing Concept

- Two morphing controls were introduced:
- Twist Morphing Control
- Bending Morphing Control



Morphing Wingtip Applied to a Joined-Wing Conceptual Model – Morphing Concept

▪ Two optimization problems were generated to preliminary evaluate the capabilities of the morphing wingtip:

- Roll Moment Coefficient Maximization
  Bending and Twist controls are used
  Level Flight Condition was imposed
  Side-slip angle fixed to 0 degrees

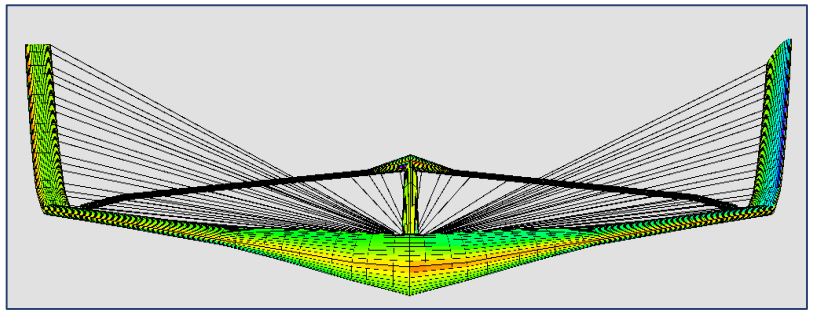
- Yaw Moment Coefficient Maximization
  Bending and Twist controls are used
  Level Flight Condition was imposed
  Side-slip angle fixed to 5 degrees

▪Just the 1st Optimization Level of the MDO framework is employed.

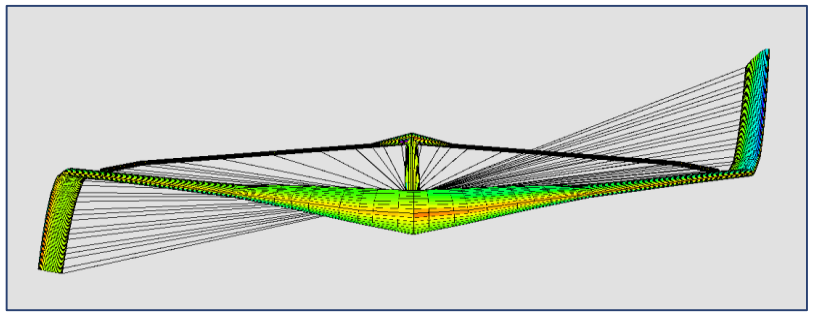
▪Only aerodynamics are considered and no multidisciplinarity was added.

Morphing Wingtip Applied to a Joined-Wing Conceptual Model – Morphing Concept

- Two configurations were used in order to prevent numerical instabilities:
- Symmetric Configuration



- Anti-Symmetric Configuration



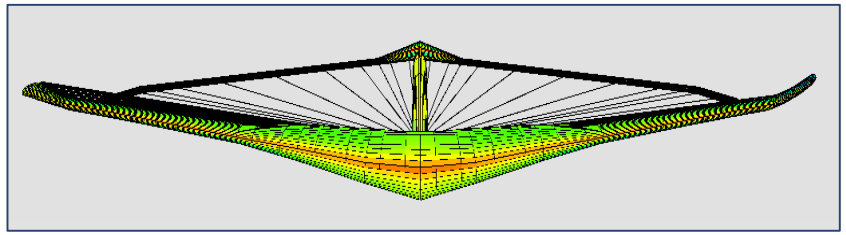
Morphing Wingtip Applied to a Joined-Wing Conceptual Model - Maximization of Roll Authority

Configuration	Angle of Attack [º]	Right Tip Height [m]	Left Tip Height [m]	Right Twist [º]	Left Twist [º]	C_l [-]	C_n [-]	T [s]
Clean with Ailerons	2.74	-	-	-35.00	25.00	0.0462	0.0018	0.47
Twist Only	2.60	-	Lower Boundary	-10.00	10.00	0.0150	0.0002	0.83
Symmetric	2.74	0.0516	0.0119	-10.00	10.00	0.0088	0.0005	1.08
Anti-Symmetric	2.74	-0.0145	0.0210	-10.00	10.00	0.0085	0.0001	1.10

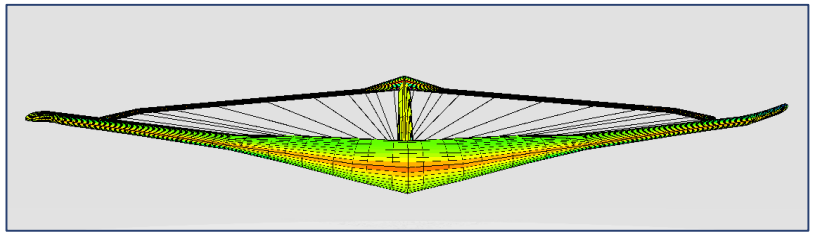
Near Lower Boundary

Lower Boundary

Upper Boundary



Symmetric Configuration



Anti-Symmetric Configuration

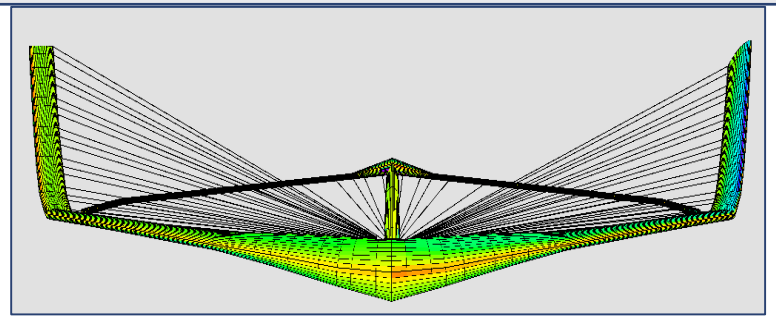
Morphing Wingtip Applied to a Joined-Wing Conceptual Model - Maximization of Yaw Authority

Configuration	Angle of Attack [º]	Right Tip Height [m]	Left Tip Height [m]	Right Twist [º]	Left Twist [º]	C_n [-]	C_l [-]	T [s]
Clean	2.74	-	-	-	-	0.0029	-0.0033	1.88
Symmetric 1	2.76	0.7	0.7	-10	10	0.0216	-0.0144	0.69
Anti-Symmetric 1	2.39	0.7	-0.7	10	10	0.0212	-0.0042	0.70
Symmetric 2	2.67	0.5	0.5	-10	10	0.0151	-0.0152	0.82
Anti-Symmetric 2	2.29	0.5	-0.5	10	10	0.0155	-0.0051	0.81

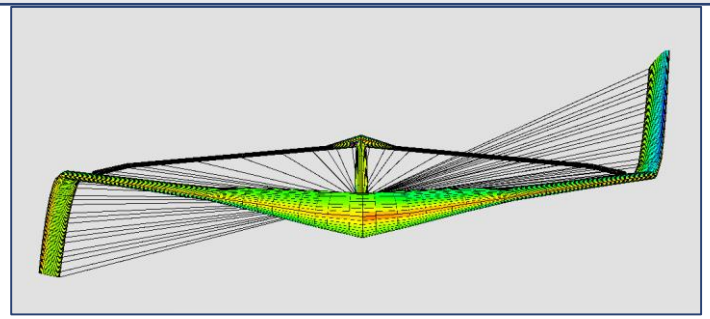
Upper Boundary

Upper Boundary

Lower Boundary



Symmetric Configuration (1)

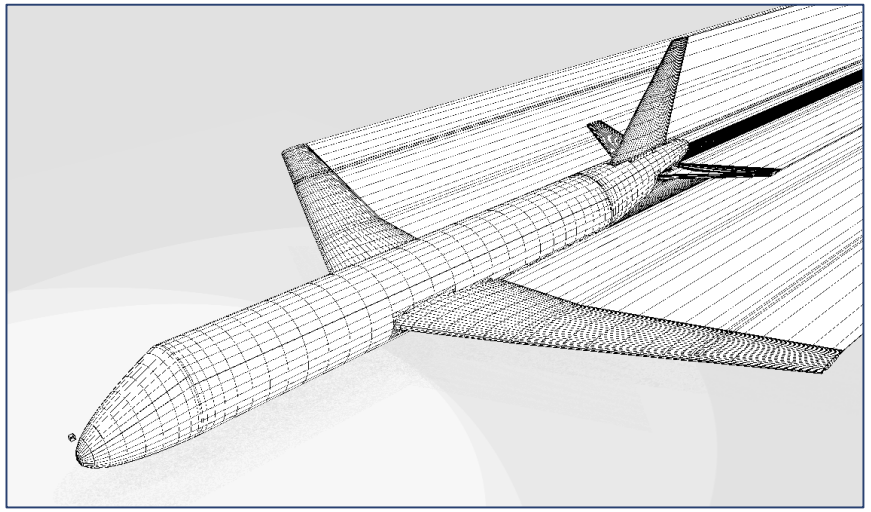


Anti-Symmetric Configuration (1)

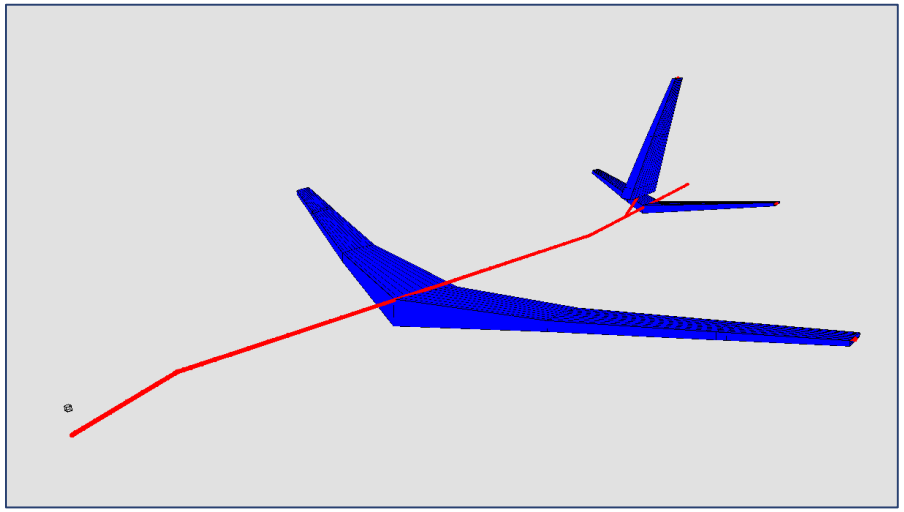
Optimization of a Joined-Wing Regional Transport Aircraft - Problem Definition

- In project **NOVEMOR** a baseline model was designed by EMBRAER to evaluate morphing concepts.

Aerodynamic Model



Structural Model



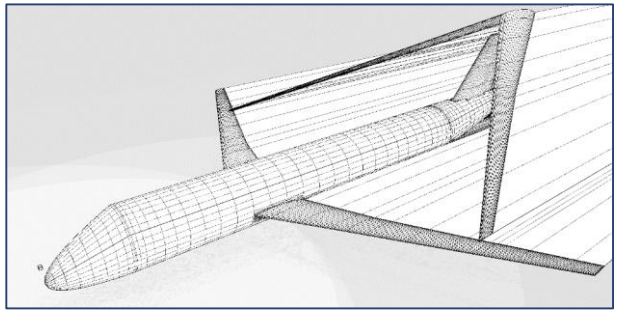
- This reference model was set as comparison for the Joined Wing configuration and was optimized as well for the same objectives.

Optimization of a Joined-Wing Regional Transport Aircraft - Problem Definition

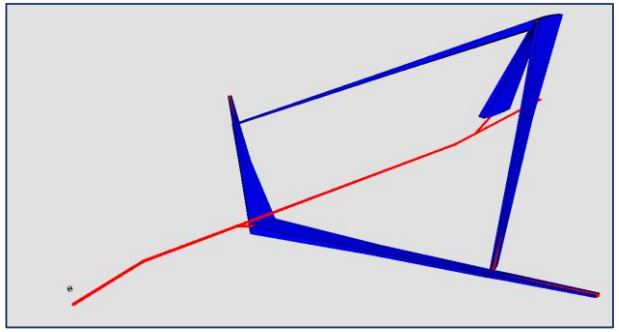
- To maintain the dimensionality of the joined-wing optimization relatively small, a few possible geometric parameters were down-selected:

- wings joined at around 70% span;
- aft wing was connected to the vertical tail at its top;
- no variation on the outboard sweep angle;
- the propulsion system is placed at the same location as in the reference model;
- the fuselage is exactly the same one employed in the baseline aircraft;
- the wing area of the joined-wing configuration was set equal to the wing area of the reference model.

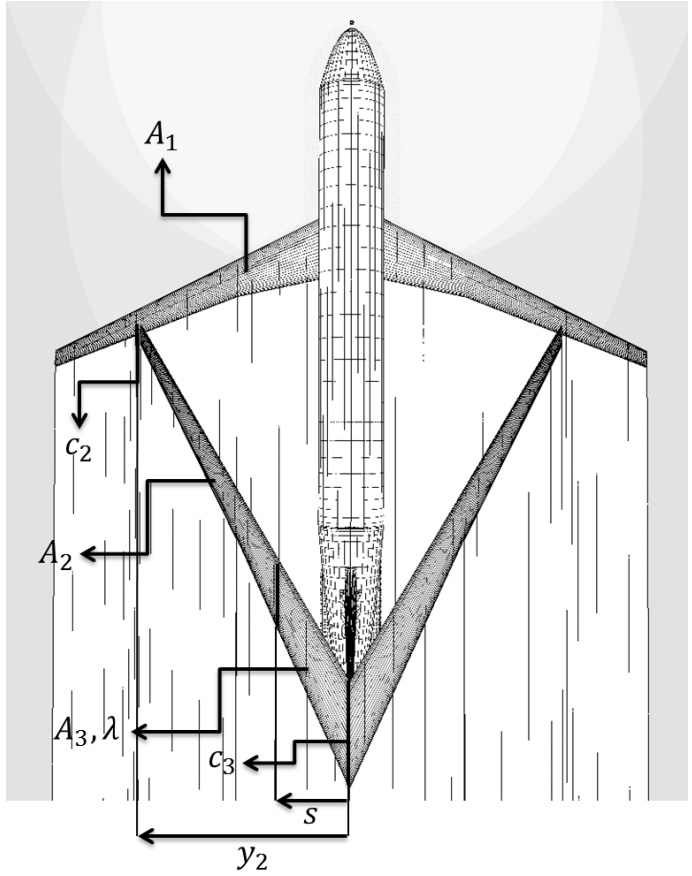
Aerodynamic Model



Structural Model



Optimization of a Joined-Wing Regional Transport Aircraft - Problem Definition



- Joined Wing configuration design parameters:
  - F_{FW} - the percentage of the reference model main wing area that is assigned to the joined-wing front wing;
  - F_{AW} - elevator actuation area.

$$F_{AW} = \frac{A_3}{A_1(1-F)}$$

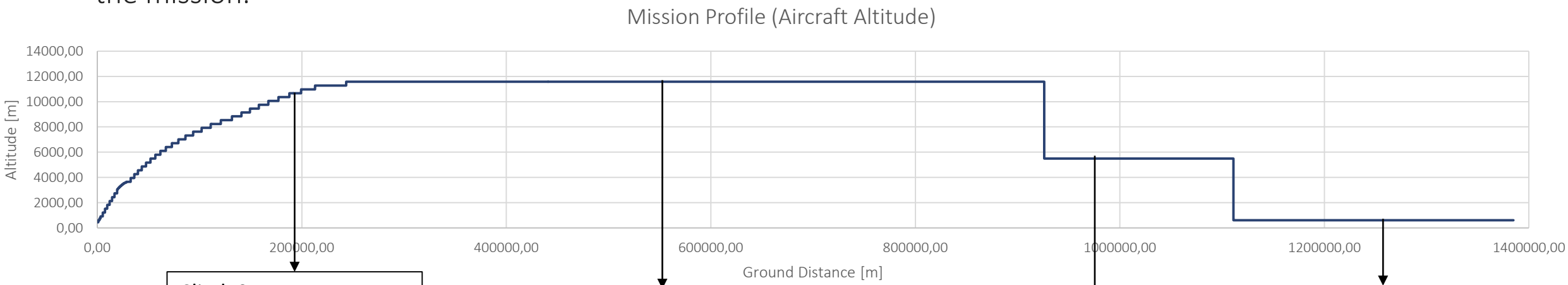
$$s = \left[(1-F)A_1 - \frac{c_3\lambda + c_2}{2} y_2\right] \Big/ \left[\frac{c_3 - c_2}{2}\right]$$

$$A_0 = \frac{(c_3\lambda + c_2)}{2}(y_2 - s)$$

Optimization of a Joined-Wing Regional Transport Aircraft - Problem Definition

- For this problem it was selected the climb, cruise, alternate and hold stages of the mission defined in the **NOVEMOR** consortium.

- The main goal selected for this application problem was the minimization of the block of fuel burned in the mission.



Climb Stage:
Initial Mach = 0.35
Initial Altitude = 1500 ft
Final Mach = 0.78
Final altitude = 38000 ft

Cruise Stages (Cruise and Alternate):
Cruise Mach = 0.78
Cruise Altitude = 38000 ft
Final Mach = 0.50
Final altitude = 18000 ft
Combined Range = 500 nm

Hold Stage:
Mach = 0.3
Altitude = 2000 ft
Time = 45 min

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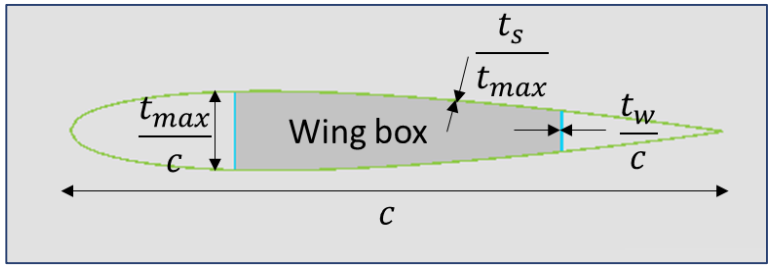
Optimization of a Joined-Wing Regional Transport Aircraft – Reference Model

Upper Level Optimizer (Configuration Level)

$$min: f = f_1 + f_2 + f_3 + f_4$$

$$w.r.t.: \frac{t_w}{c}, \frac{t_s}{t_{max}}$$

$$s.t.: (\sigma_{max} - \sigma_{yield})/\sigma_{yield} \leq 0$$



Lower Level Optimizers

Climb

$$min: f_1 = fuel\ burned$$

$$w.r.t.: throttle, \alpha, I_{HT}$$

$$s.t.: \begin{cases} \dfrac{L - W\cos\gamma + T\sin\alpha}{W/g} = 0 \\ \dfrac{D + W\sin\gamma - T\cos\alpha}{W/g} = a \\ C_m = 0 \end{cases}$$

Cruise, Alternate and Hold

$$min: f_2 = f_3 = f_4 = fuel\ burned$$

$$w.r.t.: throttle, \alpha, I_{HT}$$

$$s.t.: \begin{cases} \dfrac{L - W + T\sin\alpha}{W/g} = 0 \\ \dfrac{D - T\cos\alpha}{W/g} = 0 \\ C_m = 0 \end{cases}$$

DV	LB	UB
$\frac{t_w}{c}$	0.001	0.010
$\frac{t_s}{t_{max}}$	0.001	0.010
$throttle$	0.0	1.0
α	-10.0°	10.0°
I_{Ht}	-8.0°	8.0°

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Optimization of a Joined-Wing Regional Transport Aircraft - Joined Wing Model

Upper Level Optimizer (Configuration Level)

$$min: f = f_1 + f_2 + f_3 + f_4$$

$$w.r.t.: \frac{t_w}{c}, \frac{t_s}{t_{max}}. F_{FW}, F_{AW}$$

$$s.t.: (\sigma_{max} - \sigma_{yield})/\sigma_{yield} \leq 0$$

Lower Level Optimizers

Climb

$$min: f_1 = fuel\ burned$$

$$w.r.t.: throttle, \alpha, \delta_e$$

$$s.t.: \begin{cases} \dfrac{L - W\cos\gamma + T\sin\alpha}{W/g} = 0 \\ \dfrac{D + W\sin\gamma - T\cos\alpha}{W/g} = a \\ C_m = 0 \end{cases}$$

Cruise, Alternate and Hold

$$min: f_2 = f_3 = f_4 = fuel\ burned$$

$$w.r.t.: throttle, \alpha, \delta_e$$

$$s.t.: \begin{cases} \dfrac{L - W + T\sin\alpha}{W/g} = 0 \\ \dfrac{D - T\cos\alpha}{W/g} = 0 \\ C_m = 0 \end{cases}$$

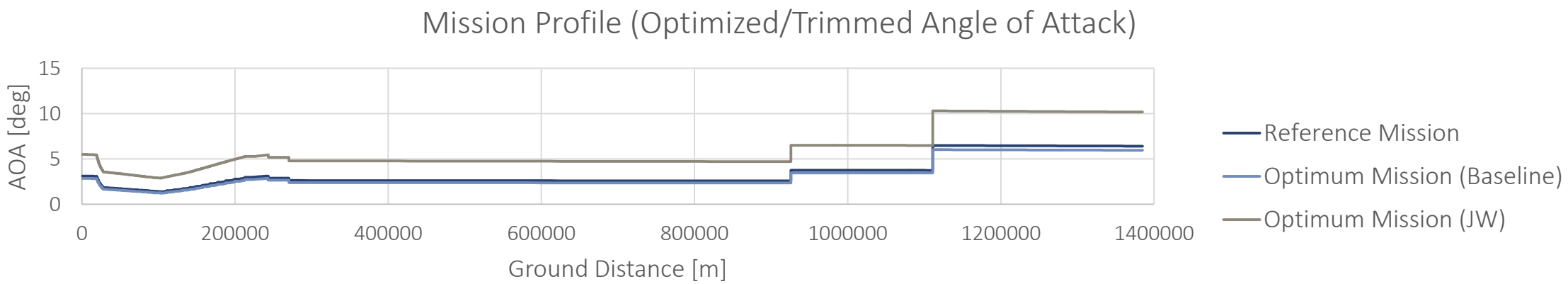
DV	LB	UB
$\frac{t_w}{c}$	0.001	0.010
$\frac{t_s}{t_{max}}$	0.001	0.010
F_{FW}	0.5	0.8
F_{AW}	0.275	0.925
$throttle$	0.0	1.0
α	-10.0°	10.0°
δ_e	-30.0°	30,0°

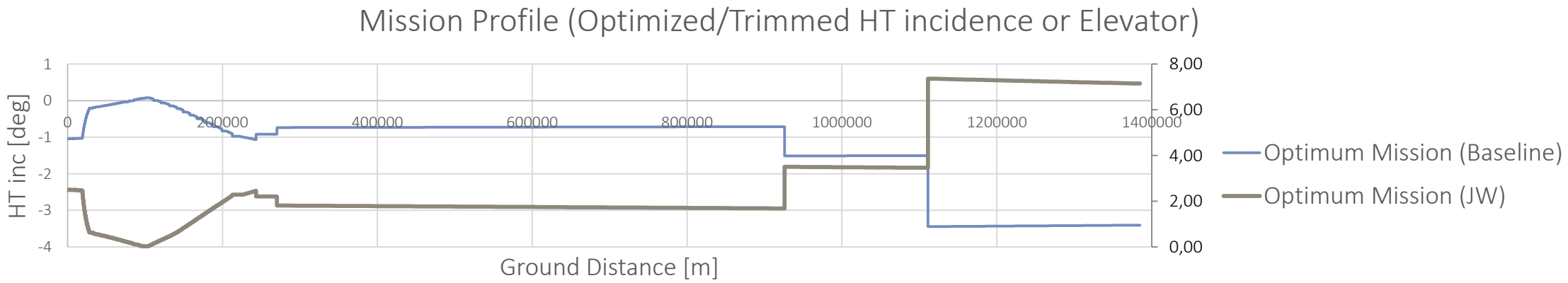
Optimization of a Joined-Wing Regional Transport Aircraft - Results

	Baseline Model	JW Model
$\frac{t_w}{c}$	0.0010	0.0100
$\frac{t_s}{t_{max}}$	0.0054	0.0100
F_{FW}	-	0.5000
F_{AW}	-	0.9250
$\frac{f}{f_{ref}}$	0.9288	0.7976
Feasible	Yes	Yes

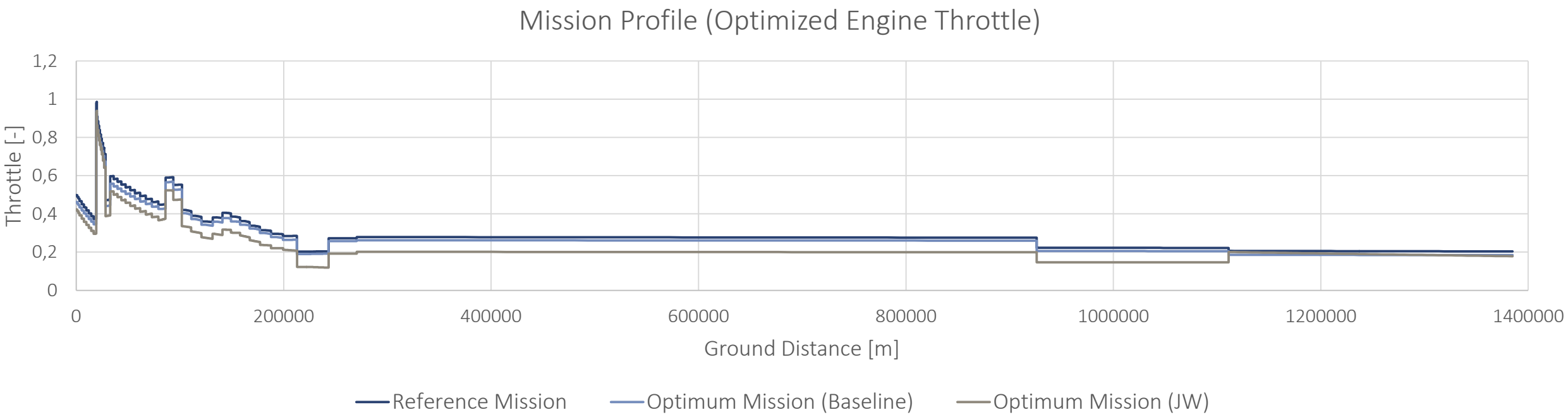
Segment	Baseline/Reference	JW/Reference	Reduction
Climb	0.94	0.85	9.54%
Cruise	0.94	0.73	22.75%
Alternate	0.92	0.66	28.09%
Hold	0.90	0.95	-5.81%
Overall	**0.93**	**0.80**	13.08%

Optimization of a Joined-Wing Regional Transport Aircraft - Results





Optimization of a Joined-Wing Regional Transport Aircraft - Results



Conclusions and Future Work

- A morphing wingtip was applied to a non-conventional joined-wing aircraft, to improve lateral-directional stability.

- For roll authority, the bending and twist morphing were not able to improve roll moment in comparison with ailerons.

- For yaw authority, a significant increase of yaw moment was achieved since this aircraft has no rudder.

- It is our intent to performance dynamic stability analyses to evaluate:

  - if the morphing wingtip in fact improve lateral stability;
  - if the lower roll authority is sufficient to control the aircraft.

Conclusions and Future Work

- A substantial fuel consumption reduction was obtained by employing a joined-wing configuration for several flight stages.
- Only in holding condition the baseline model presented a lower consumption than the joined-wing model.
- This results are in agreement with the claimed drag reduction benefit of this novel configuration.
- Several aircraft parameters were taken into account in calculations such as engines, fuel and payload distributions.
- In structural terms, higher stresses were found for the joined-wing model, for a comparable wing structural weight. As consequence the achieved JW optimum configuration weights 4 tons more than the optimum baseline configuration.

Conclusions and Future Work

- Introduction of new design variables, for example some of the parameters excluded in the down-selecting phase.

- A more complex structural model with a asymmetrical thickness distribution could reduce this weight increase.

- Further computations on the best design using higher fidelity tools.

Acknowledgments

- The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7 / 2007-2013) under a grant agreement number 285395.

- NOVEMOR (Novel Air Vehicle Configurations – From Fluttering Wings to Morphing Flight) is a collaborative research project aimed at developing, implementing and assessing a range of numerical simulation technologies to accelerate future aircraft design. Advances in morphing technologies will lead to more efficient and greener aerostructures. The partners in NOVEMOR are: IST Lisbon, Politecnico di Milano, University of Bristol, KTH, DLR, CSIR and Embraer.

Multidisciplinary Design Optimization of Novel and Morphing Aircraft Configurations: Computational Studies and Experimental Validation

J. Vale, F. Afonso, F. Lau and A. Suleman

Instituto Superior Técnico, Lisbon, Portugal

A. Antunes, F. Odaguil, G. Lima and J. Parizi

EMBRAER S.A., São José dos Campos, Brazil

J. Cooper

University of Bristol, Bristol, United Kingdom

4th EASN Association International Workshop on Flight Physics & Aircraft Design, 27 – 19 October 2014, Aachen, Germany

Geometry Modeling, Parametrization and Meshing of Conventional and Joined-Wing Aircraft

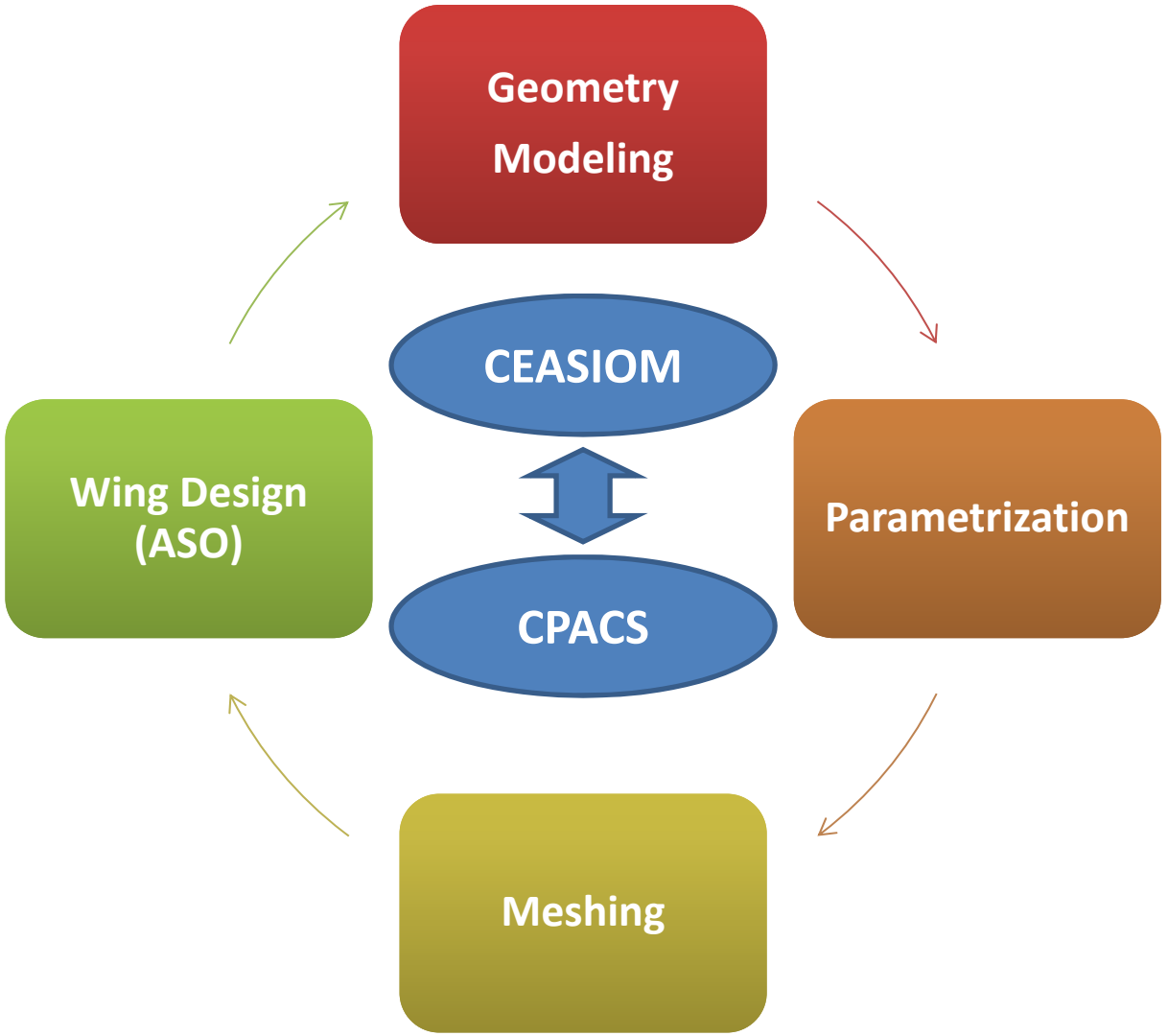
Mengmeng Zhang and Arthur Rizzi
Royal Institute of Technology (KTH), Sweden
Raj Nangia
University of Bristol, UK

4th EASN Association International Workshop
27-29 October 2014, Aachen, Germany

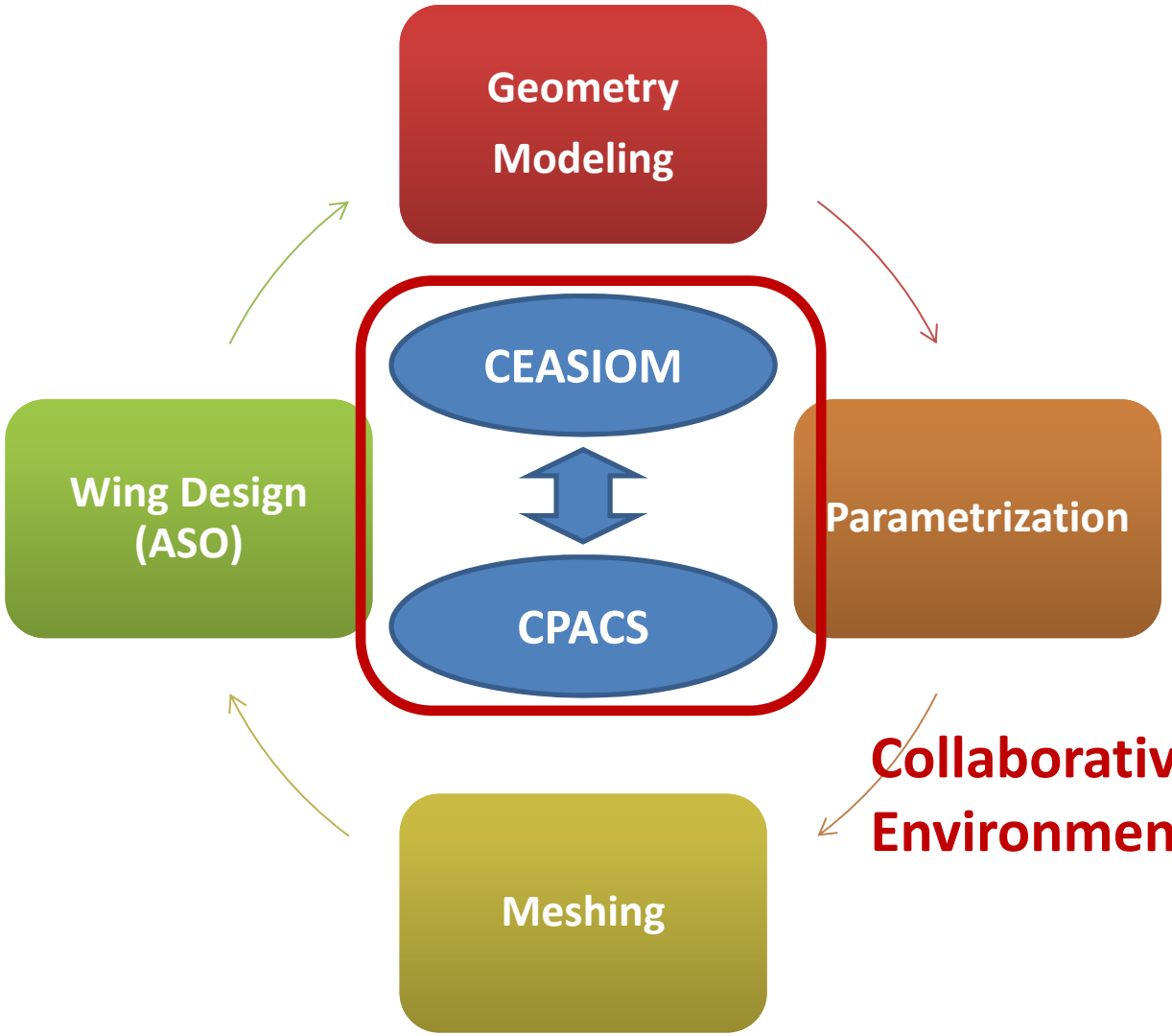
Overview

- Introduction
- Collaborative Design Environment
- Geometry Modeling
- Parametrization
- Wing Design
- Study Cases

Design Framework: CEASIOM with CPACS



Design Framework : CEASIOM with CPACS

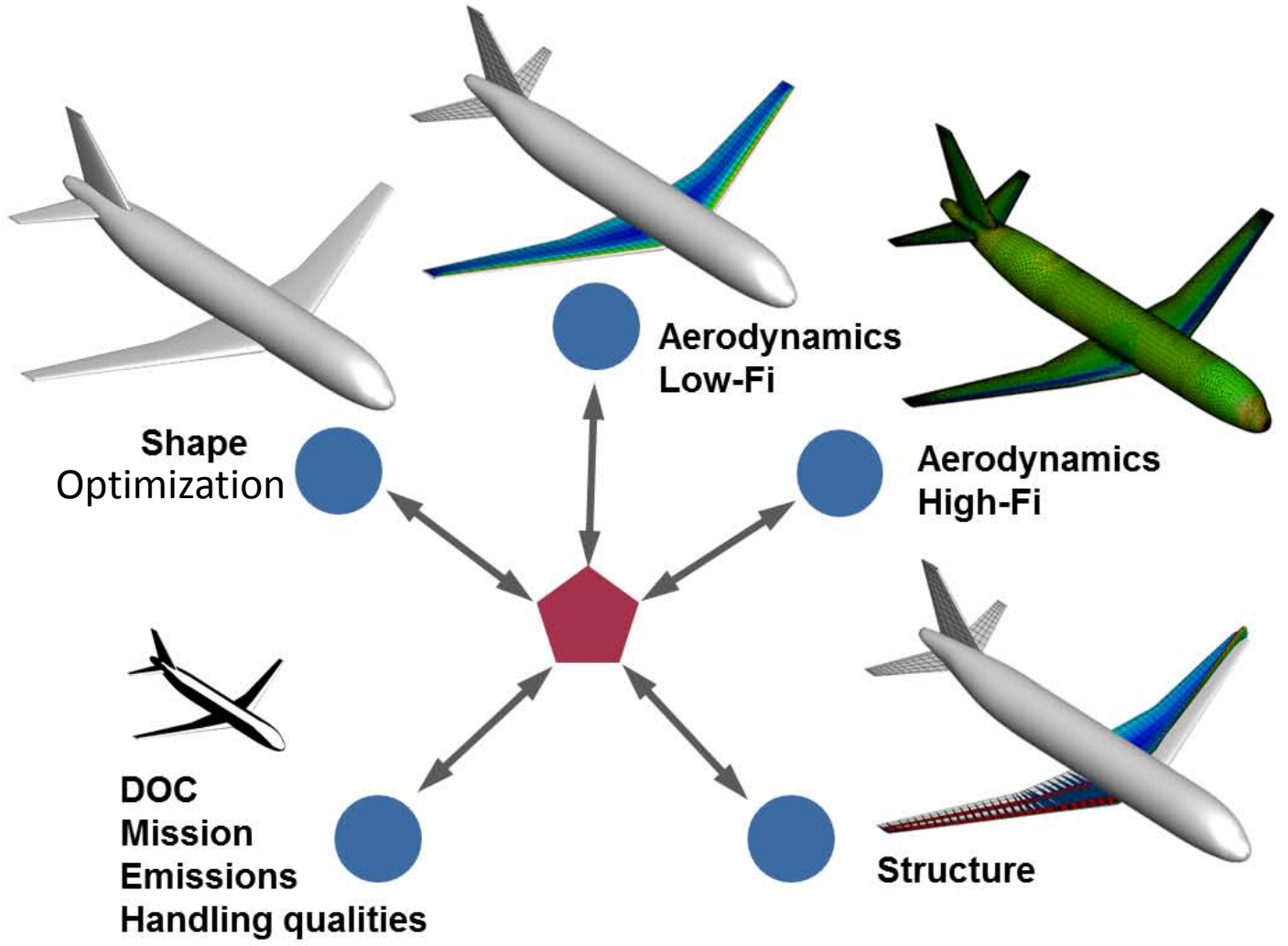


Collaborative Design Environment, I

• CPACS & • CEASIOM

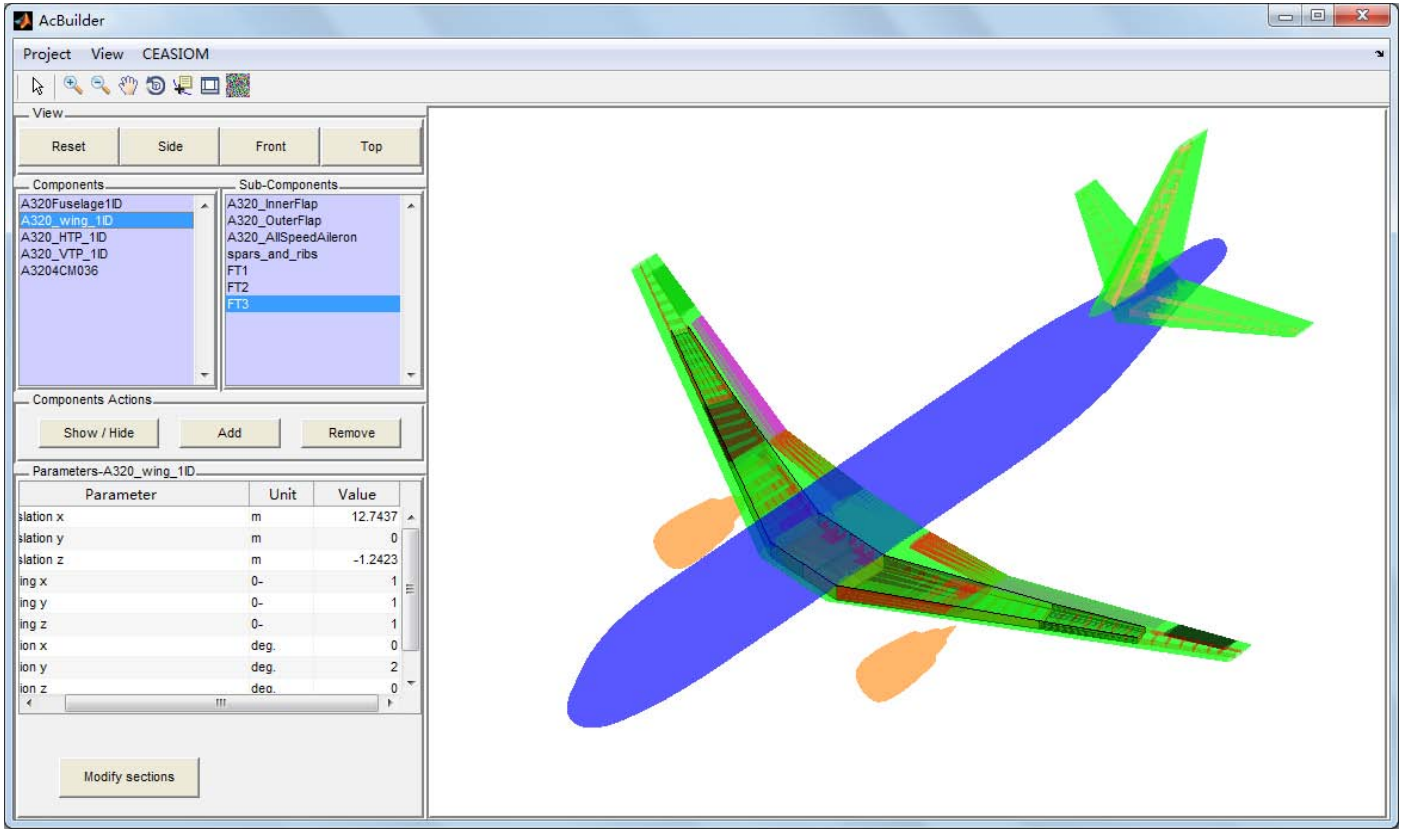
CPACS

- cpacs
  - header
  - vehicles
    - aircraft
      - model
        - uID
        - name
        - description
        - reference
        - fuselages
        - wings
        - engines
        - landingGear
        - global
        - analyses
    - engines
    - profiles
    - structuralElements
    - materials
    - composites
  - missions
  - airports
  - fleets
  - toolspecific



Create Aircraft Shape in CEASIOM

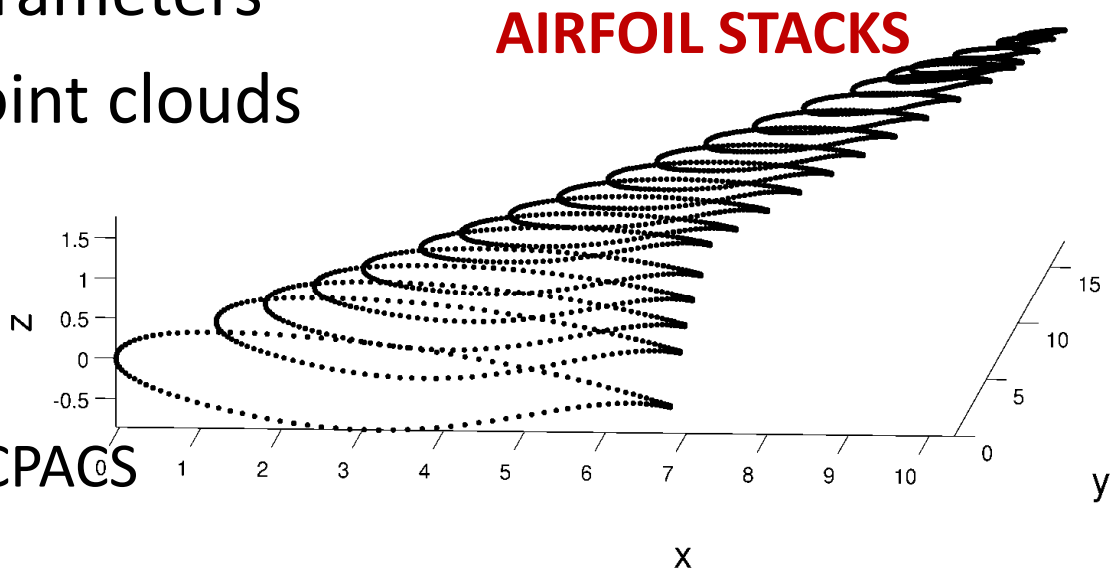
- **CEASIOM**
  - **-CPACSCreator**
    visual renderer and editor of CPACS XML file
  - **-SUMO**
    Surface Modeler, mesh generator

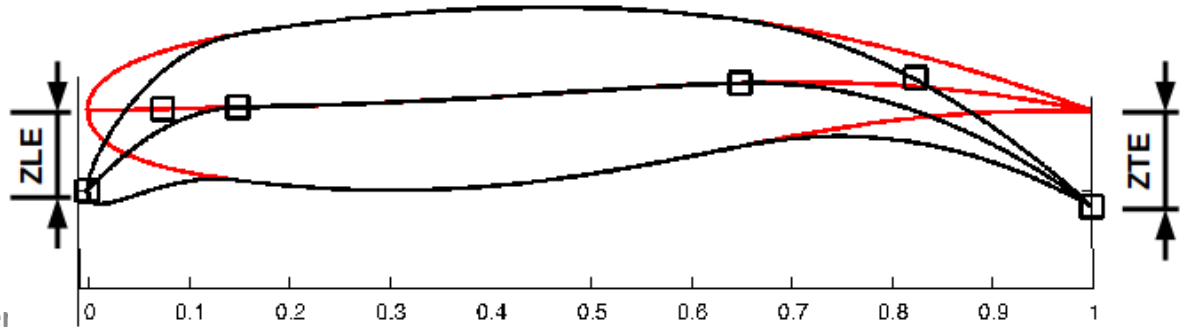


How make a wing **surface ?**
How make a fuselage **body ?**

Wing Parametrization – Spanwise

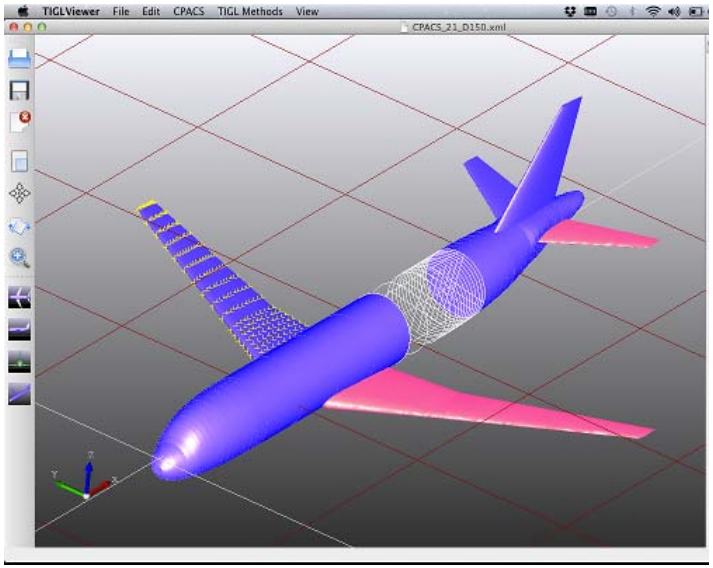
- Wing planform parameters
- Airfoil! – CPACS point clouds
  - Polynomials
    - Bezier curves, ...
  - CST
  - Output points to CPACS

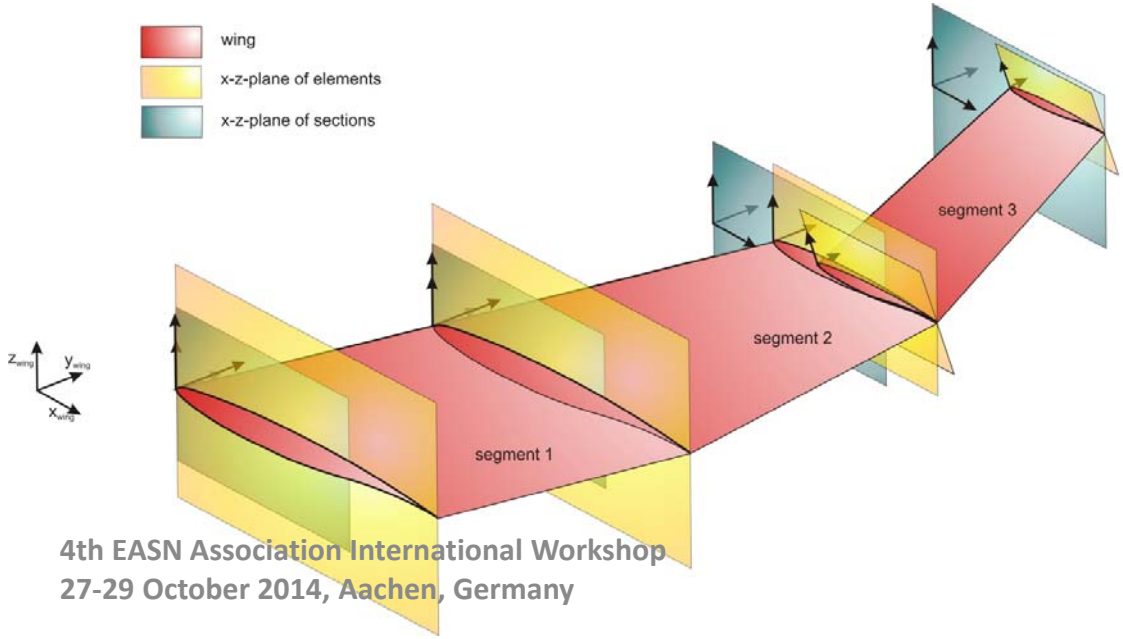


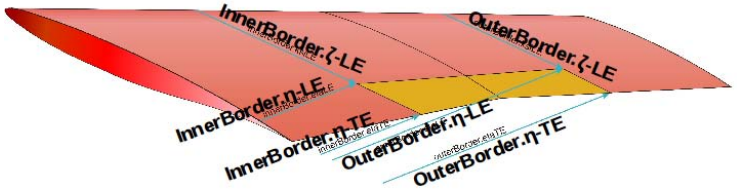


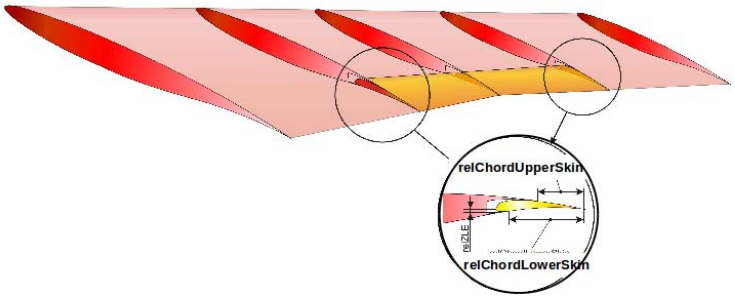
Stack Airfoils with CPACS Parameters

- Varied levels of simplification!
- Allow complexities:
  - unconventional a/c
  - Informative geometry for hi-fi analysis
  - control surfaces

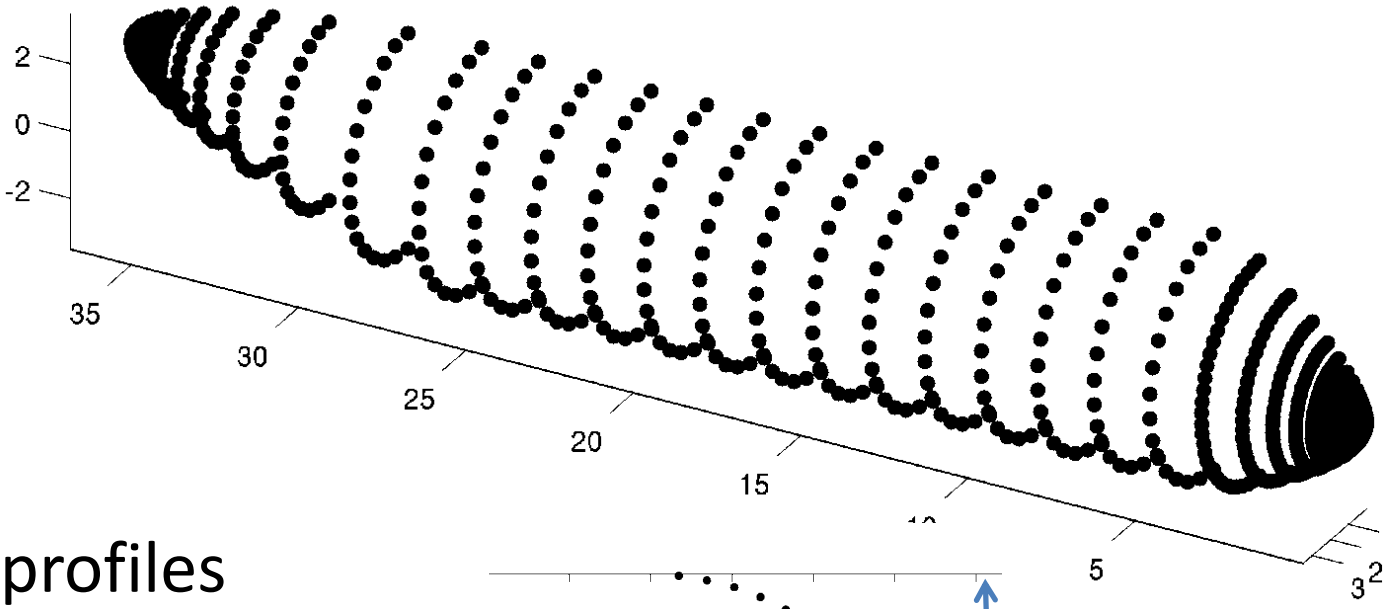




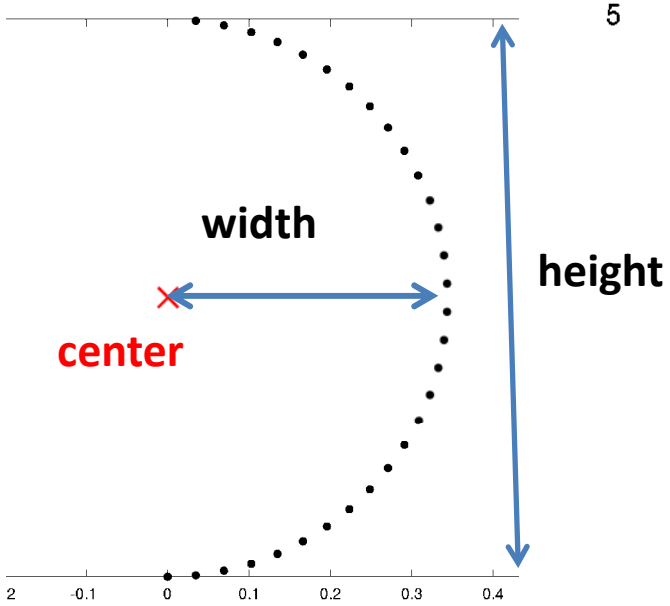




Fuselage Parametrization: Streamwise

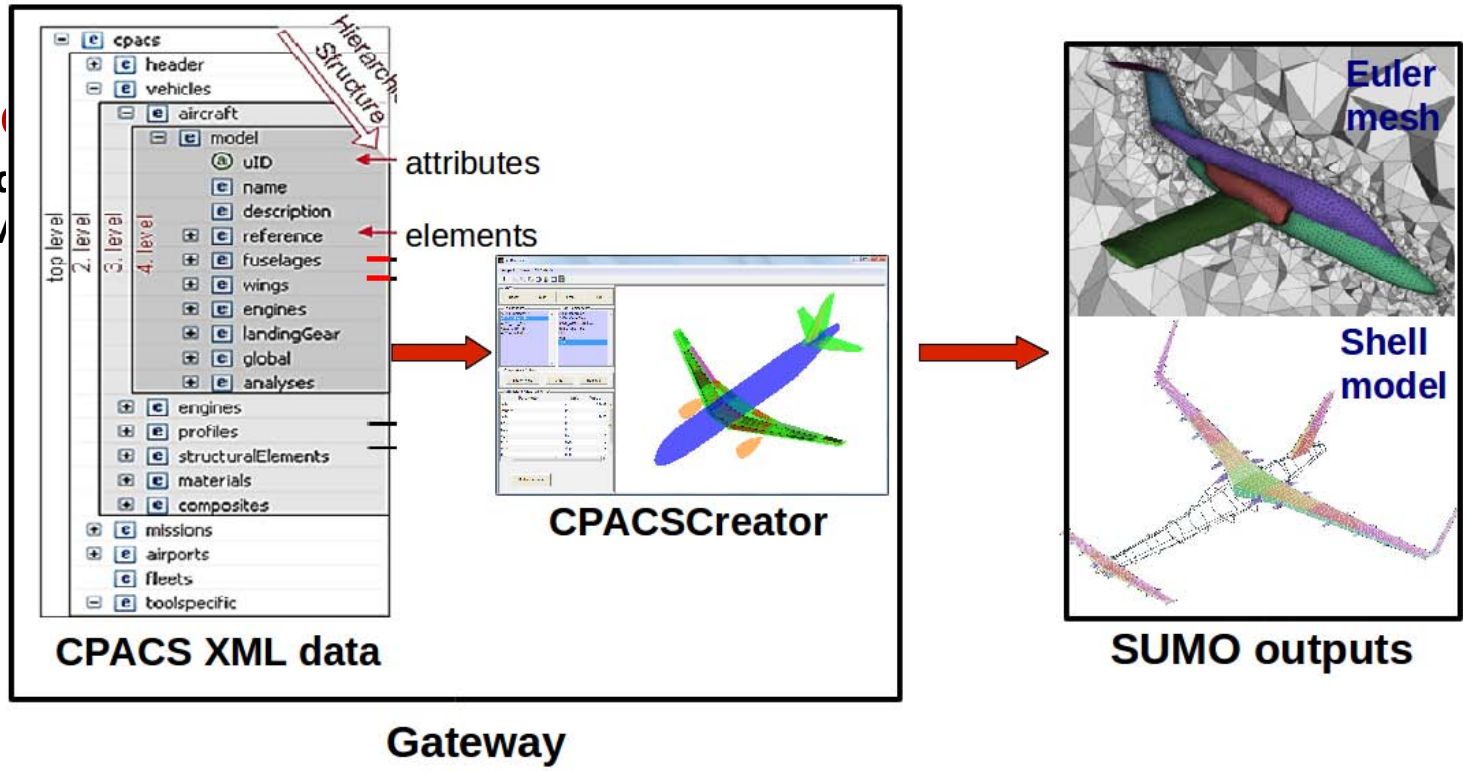


- Sectional profiles
- CPACS - point clouds!
  - Scaled to 0-1
  - Center, Height & width
  - Symm. On/Off
- Use **SUMO** B-spline curve to parameterize points



Assemble CPACS Components with **SUMO**

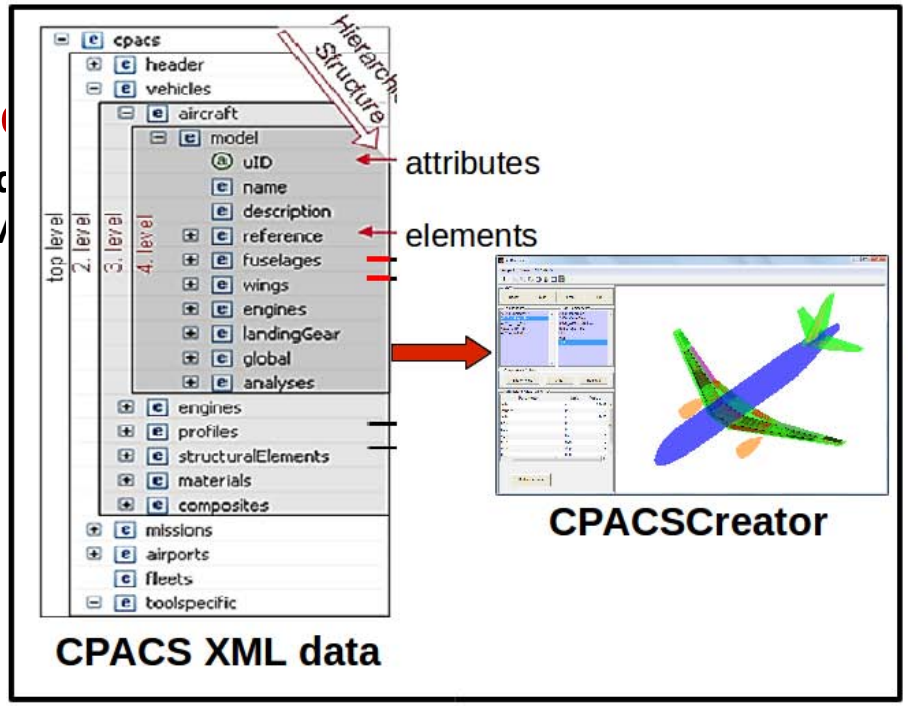
- **CEASIOM**
  - **-CPACSCreat**
    visual renderer and
    editor of CPACS XM
    file
  - **-SUMO**
    Surface Modeler,
    mesh generator

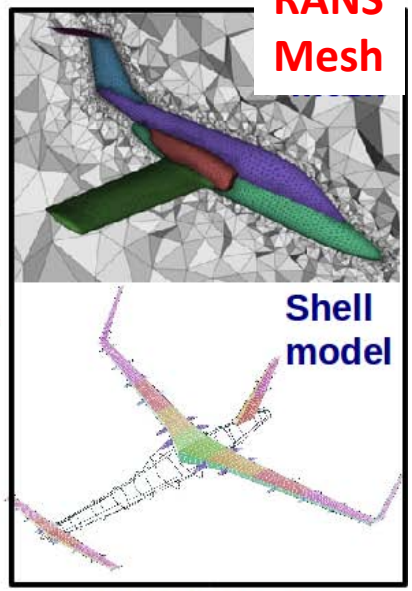


Assemble CPACS Components with **SUMO**

Lastest: Prismatic layer module!

- **CEASIOM**
  - **-CPACSCreat**
    visual renderer and editor of CPACS XM file
  - **-SUMO**
    Surface Modeler, mesh generator





Assemble CPACS Components with **SUMO**

Lastest: Prismatic layer module!

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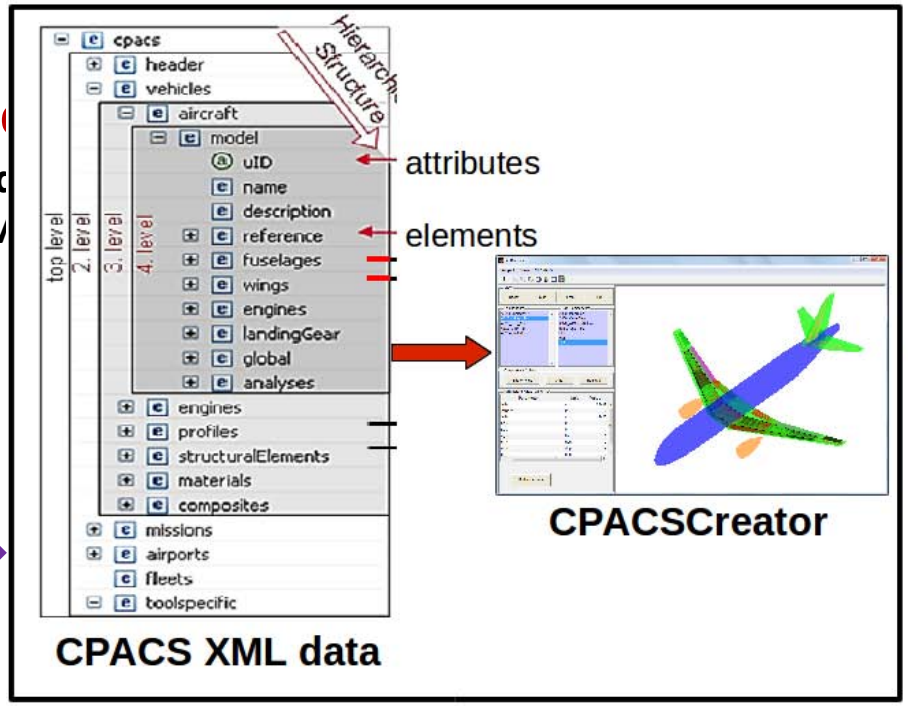
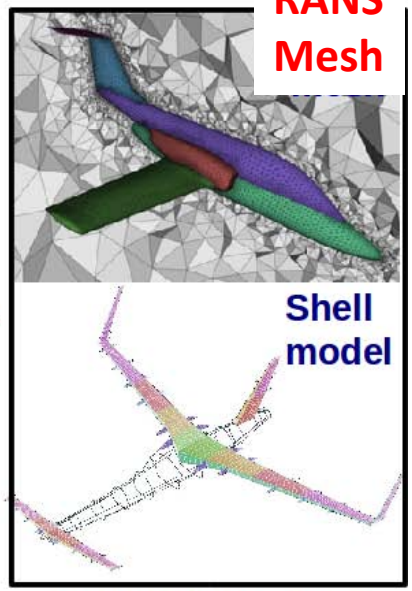


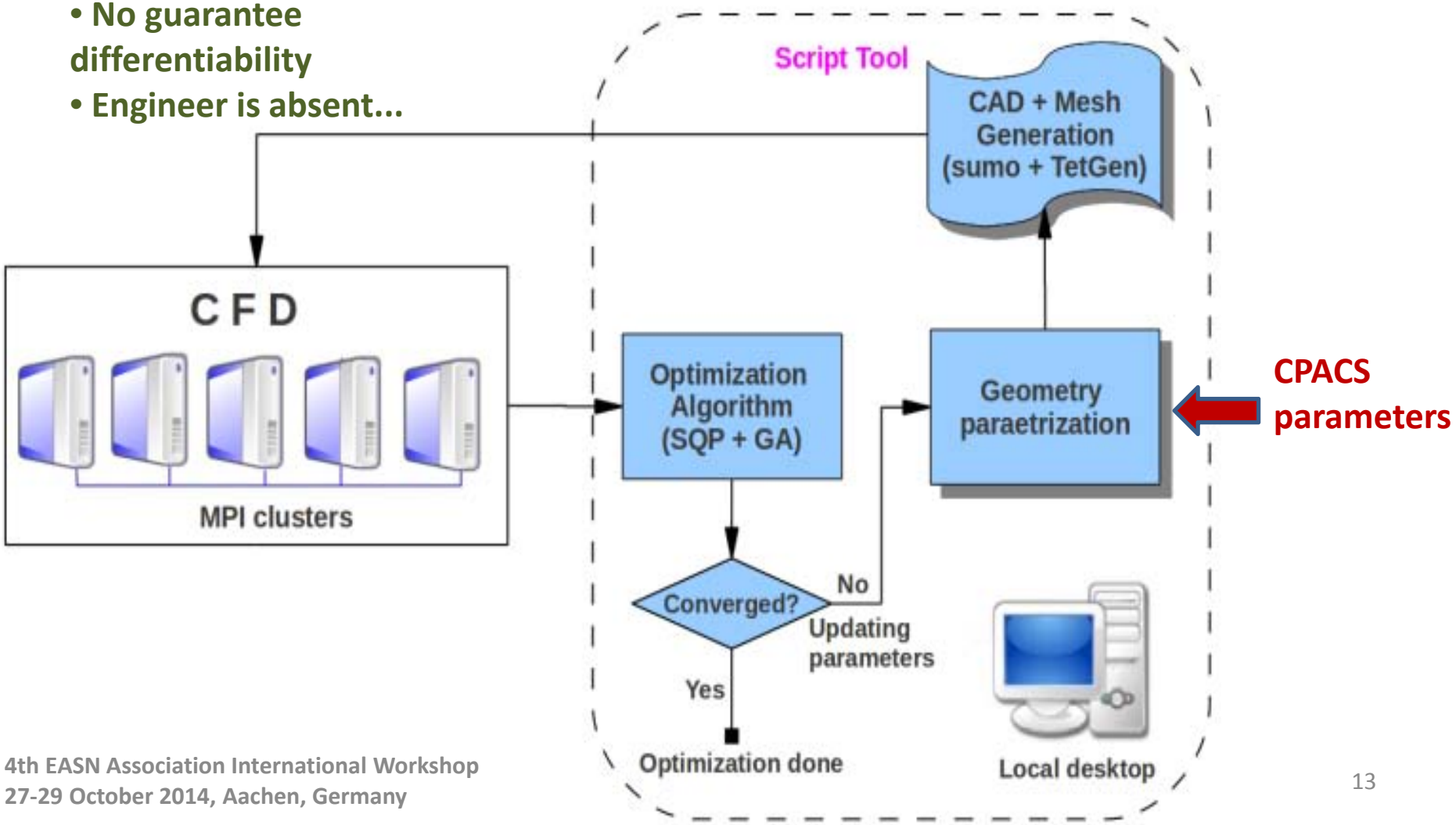


AAA, ADAS, VSP, RDS, ...

Wing Design – Optimize shape wing surface

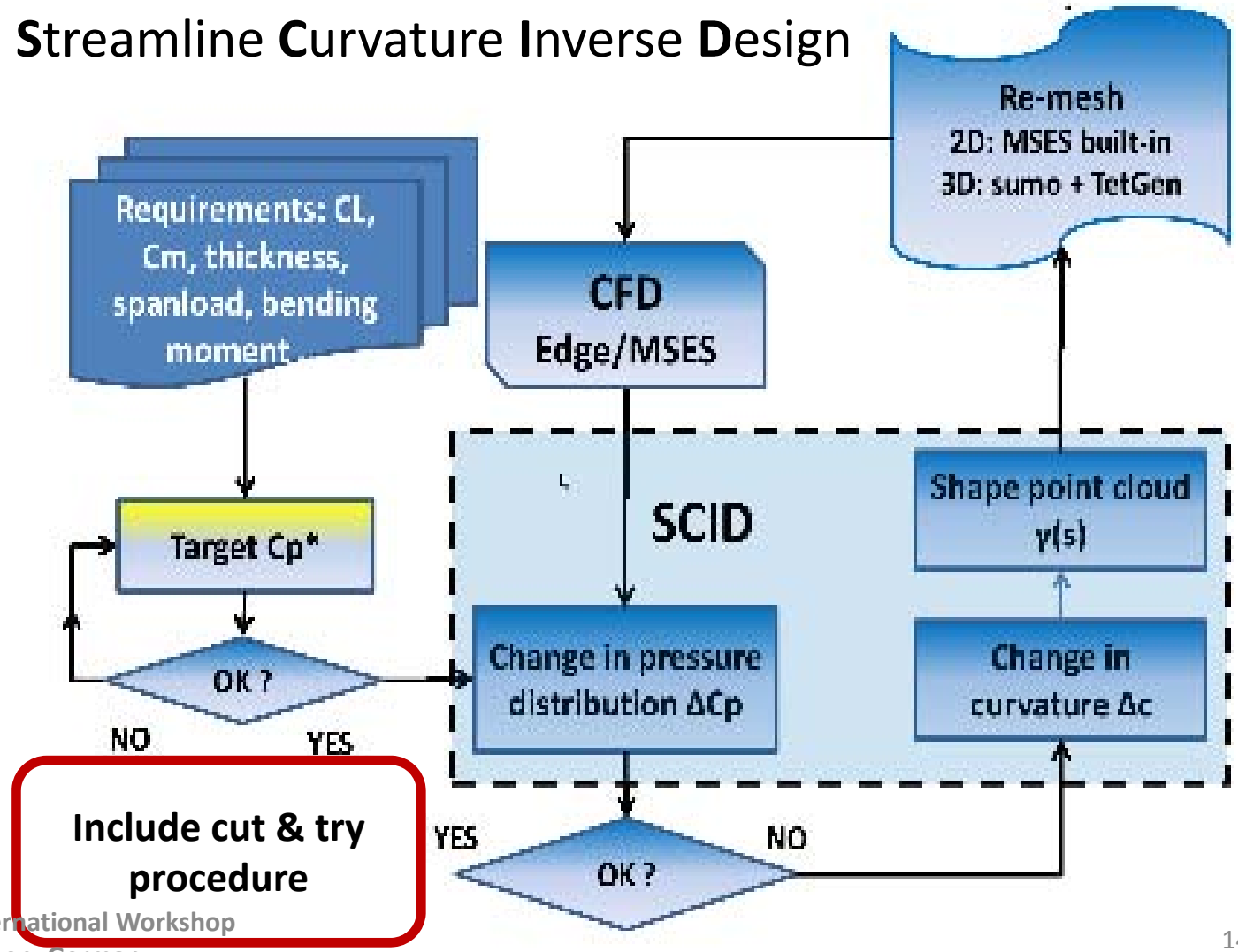
- Local minimum
- Unclear physics
- No guarantee differentiability
- Engineer is absent...

Aero-optimization Design Loop



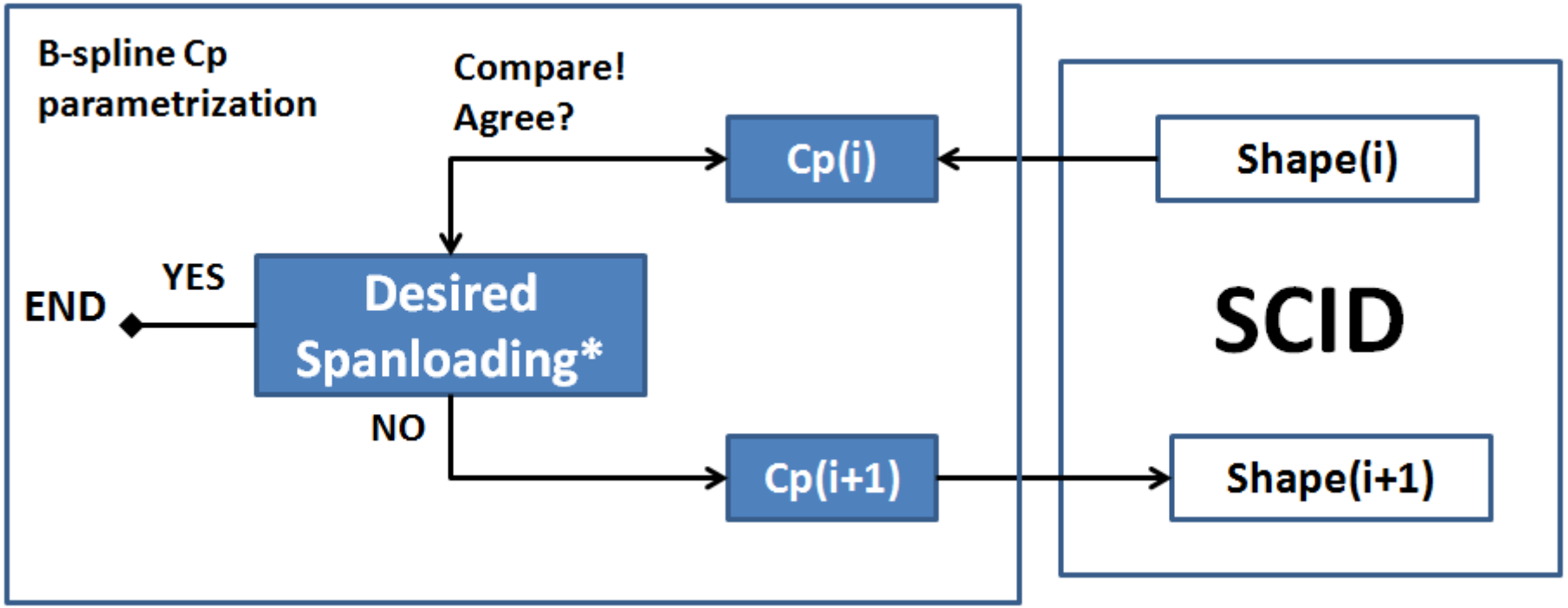
Inverse Wing Design, II-i

- Classical Inverse Design
  - Select target pressure, find corresponding shape
  - **S**treamline **C**urvature **I**nverse **D**esign



Inverse Wing Design, II-ii

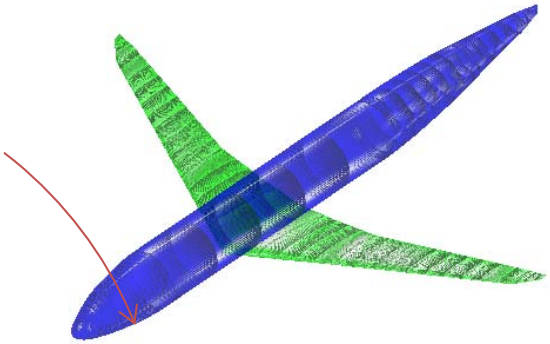
- **CUT & TRY**
- **ENGINEER IN LOOP**
- **INSTANT GRAPHIC FEEDBACK**



Study Case I: Novemor Wing

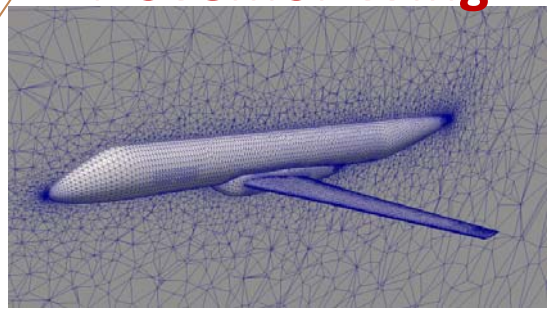
Inverse Design
Engineer-in-Loop

Geometry Modeling



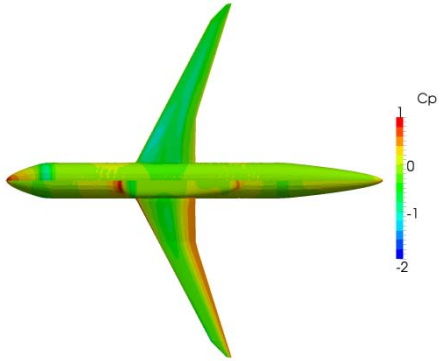
Parametrization

Novemor Wing

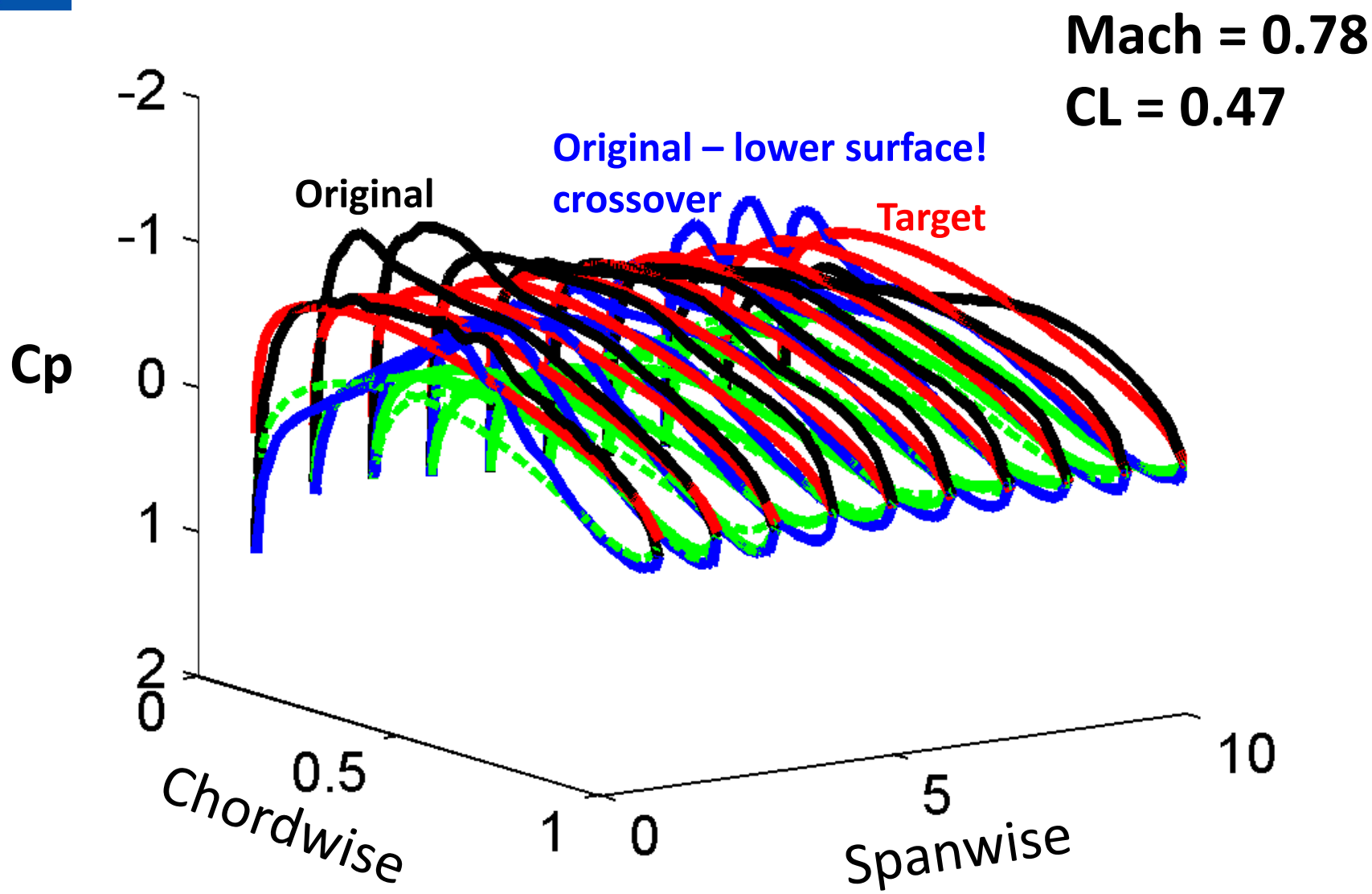


Meshing

Wing Design (ASO)

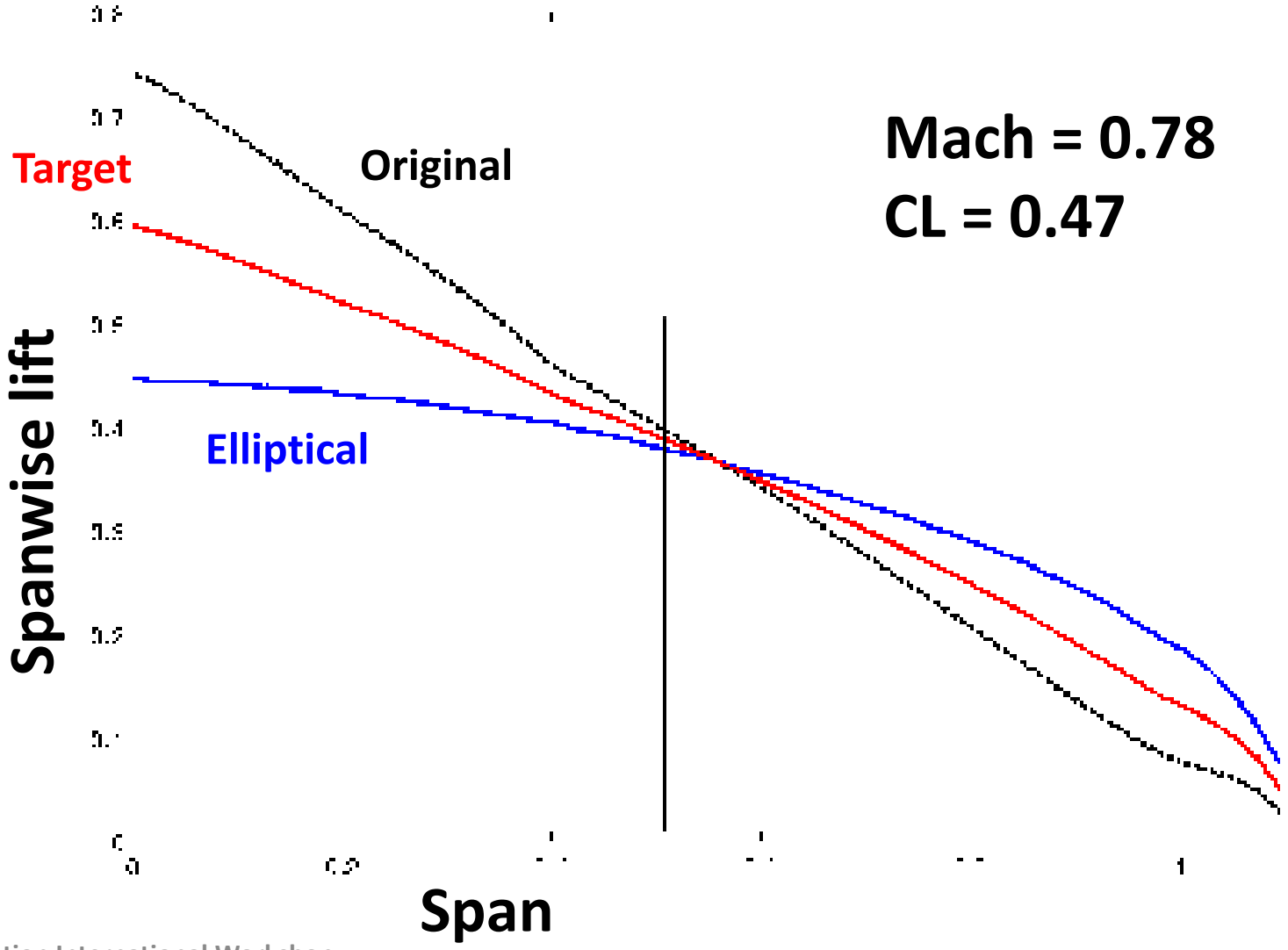


Inverse Design: Engineer-in-loop



How to choose Cp-distribution?

Spanwise Lift distribution

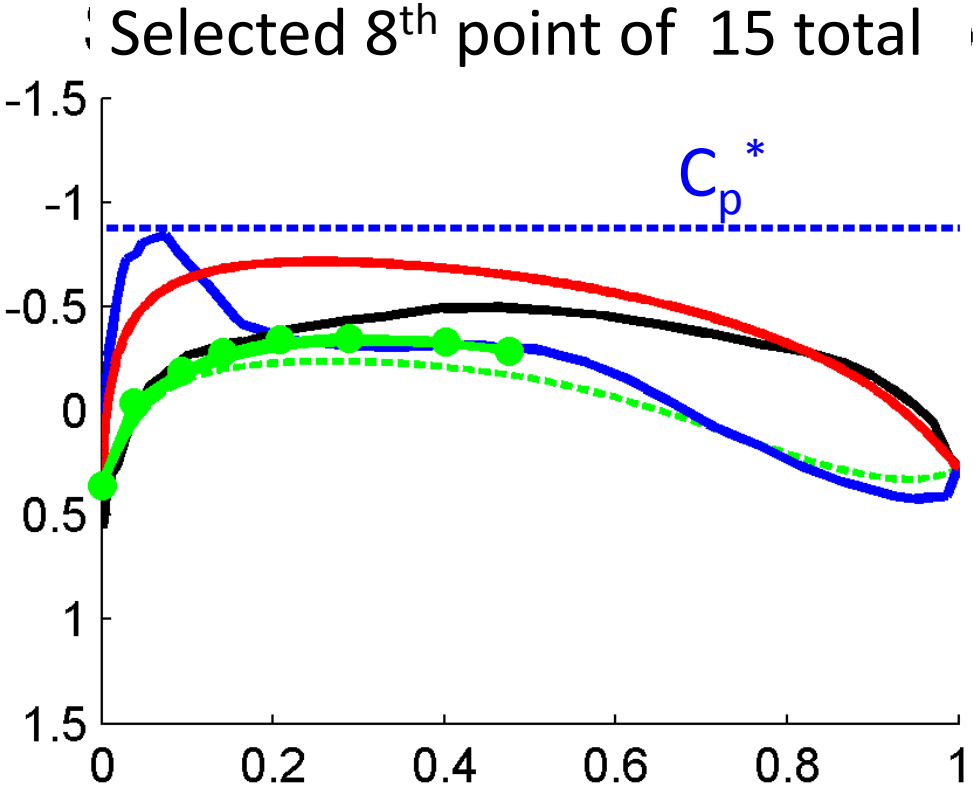


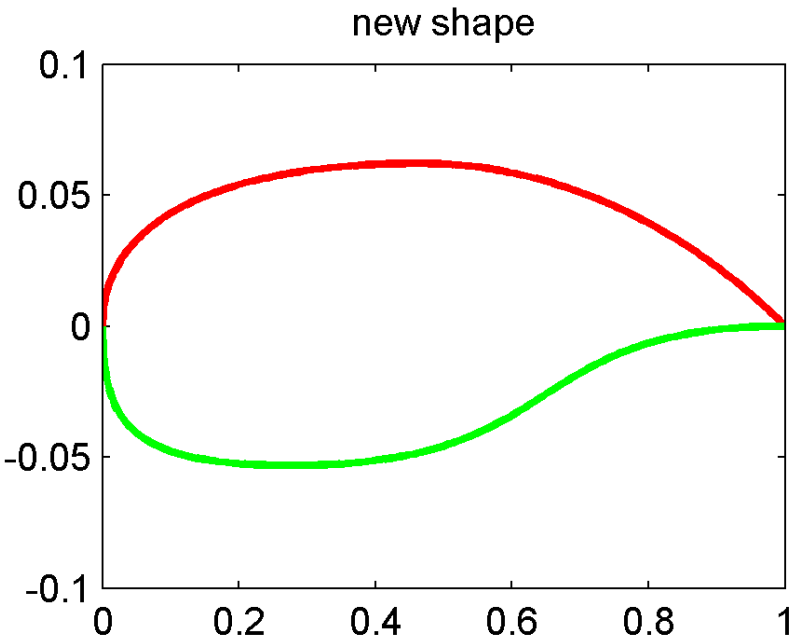
Optimize Section-by-Section → Surface
Example: section 7

```
----------Information for Section: 7 ----------
********** Set up Target Pressure **********
    Do you want to fix the leading edge? Y/N :Y
    Do you want to fix the trailing edge? Y/N :Y
    ---------------------------------
    Currect cL is :0.054323
    Updated cL with previous upper surface is :0.10746
    Target cL is :0.1316
    ---------------------------------
    Currect cD is :0.002471
    Updated cD with previous upper surface is :-0.019264
    ---------------------------------
    Do you want to use the previous upper surface? Y/N :Y
    ---------------------------------------------------
    ----------Upper surface confirmed!----------
    ---------------------------------------------------
    Target cL is :0.1316
    Updated cL with previous lower surface is :0.15393
    ---------------------------------
    Currect cD is :-0.014073
    ---------------------------------
    Do you want to use the previous the Lower surface?
    Y/N :N
```

```
---------- Set up Lower Surface Target Pressure ----------
    ---------------------------------
    Updated cL is 0.1442, Target cL is0.1316
    ---------------------------------
    Updated cD is -0.011605
    Do you confirm the lower surface? Y/N :N
    ---------- Set up Lower Surface Target Pressure ------
    Updated cL is 0.1444, Target cL is0.1316
    ---------------------------------
    Updated cD is -0.010634
    Do you confirm the lower surface? Y/N :Y
    Do you want to reset both surfaces? Y/N:N
    ---------------------------------------------------
    ----------converge criteria met!----------
    ---------------------------------------------------
    ------ all Cp are ready----------
    ----------end deltaCP----------
    ----------start to modify section----------
    **********smooth**********
    ---------start to modify section----------
    ----------modify section END ----------
    Do you confirm the shape of this section? Y/N: Y
```

Example: Optimize Section 7





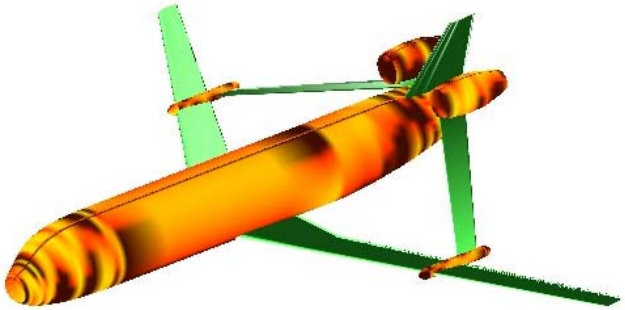
Find CL_target = 0.1316

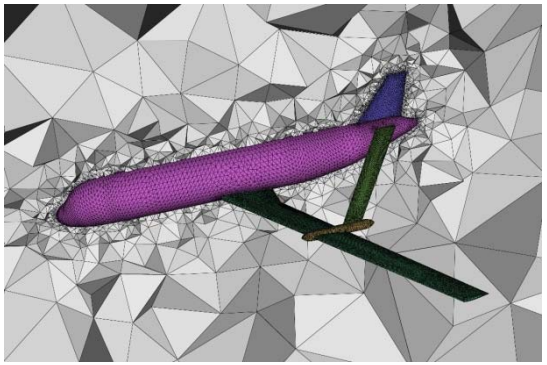
Before	**After**
CL = 0.054323	**CL = 0.1442**
CD = 0.002471	**CD = -0.010634**

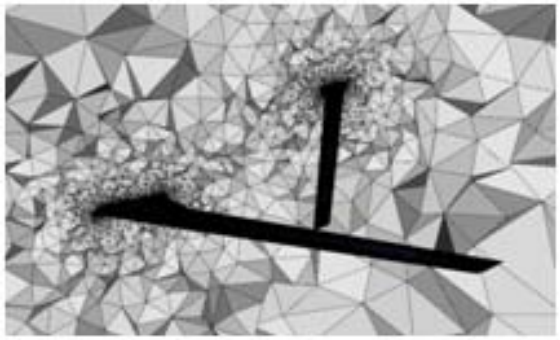
Study Case II: Joined-Wing

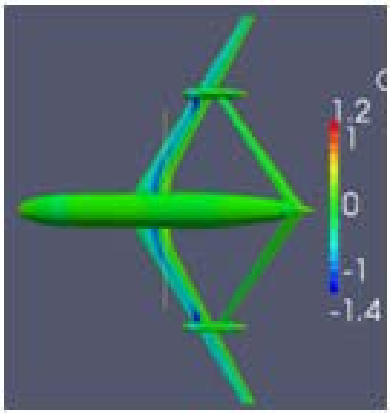
Focus: forward wing

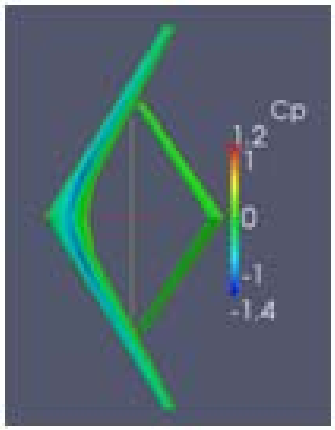
GEOMETRY SIMPLIFICATION









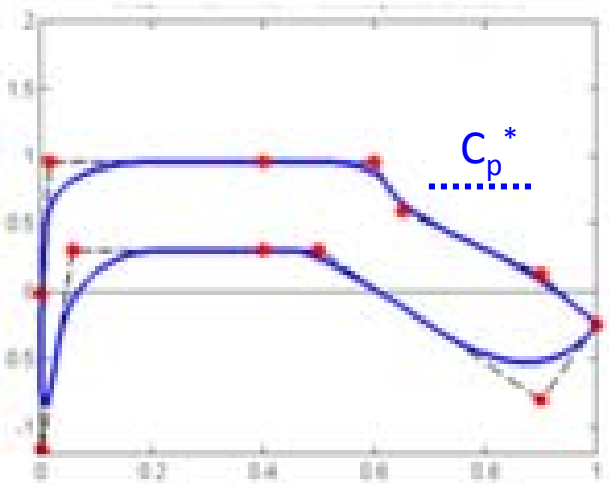


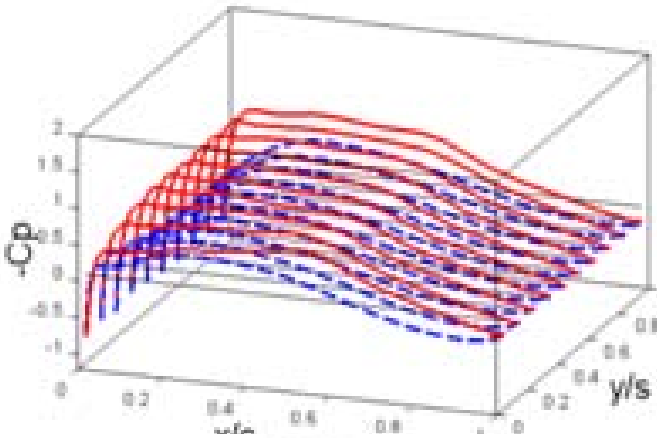
Mach = 0.78

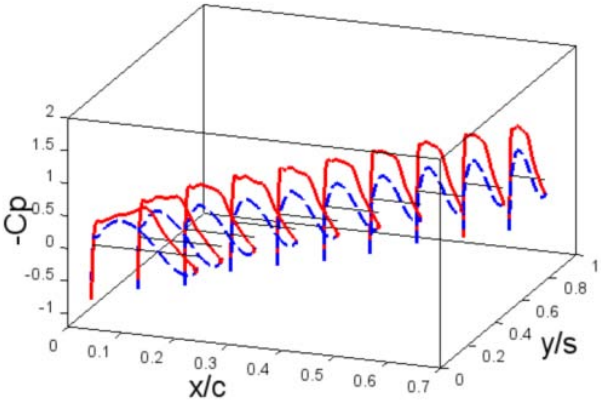
CL = 0.5

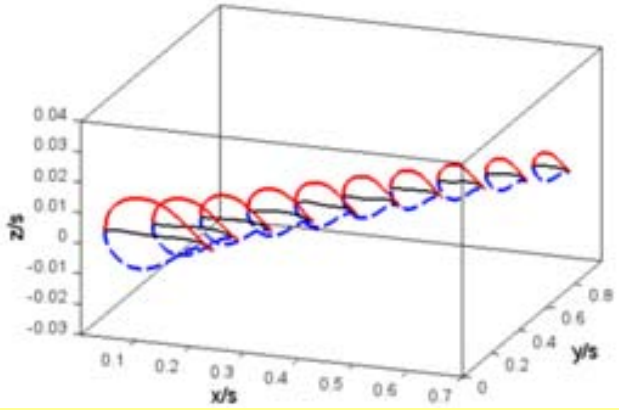
TOWARDS FORWARD WING DESIGN

Inverse design of Forward Wing



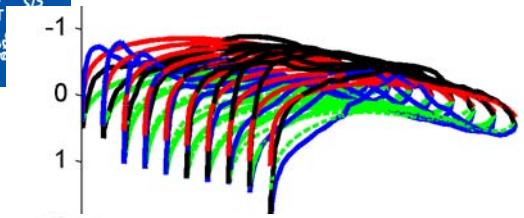


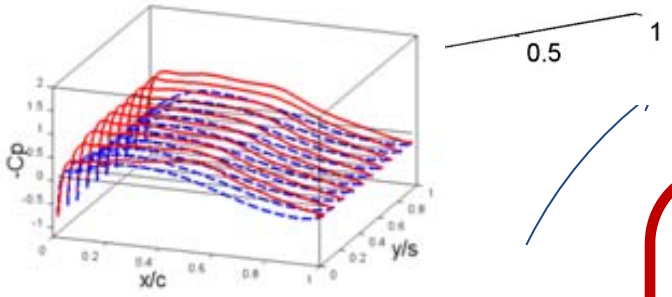


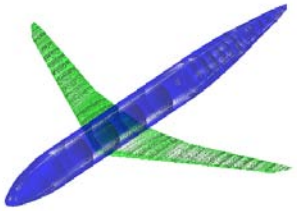


Progress with Inverse Design of JW Civil Configuration, Mach 0.78, CL 0.5

Conclusion







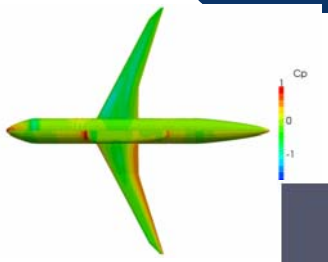
Geometry Modeling

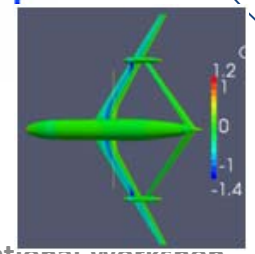
CEASIOM

Wing Design (ASO)

Parametrization

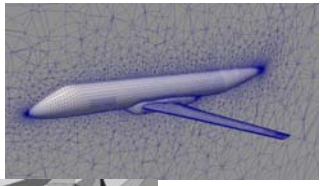
CPACS

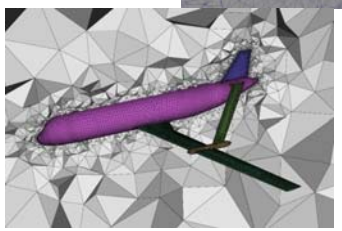




Collaborative Design Environment

Meshing





Morphing Devices for a Wing and Wingtip Based on Compliant Structures

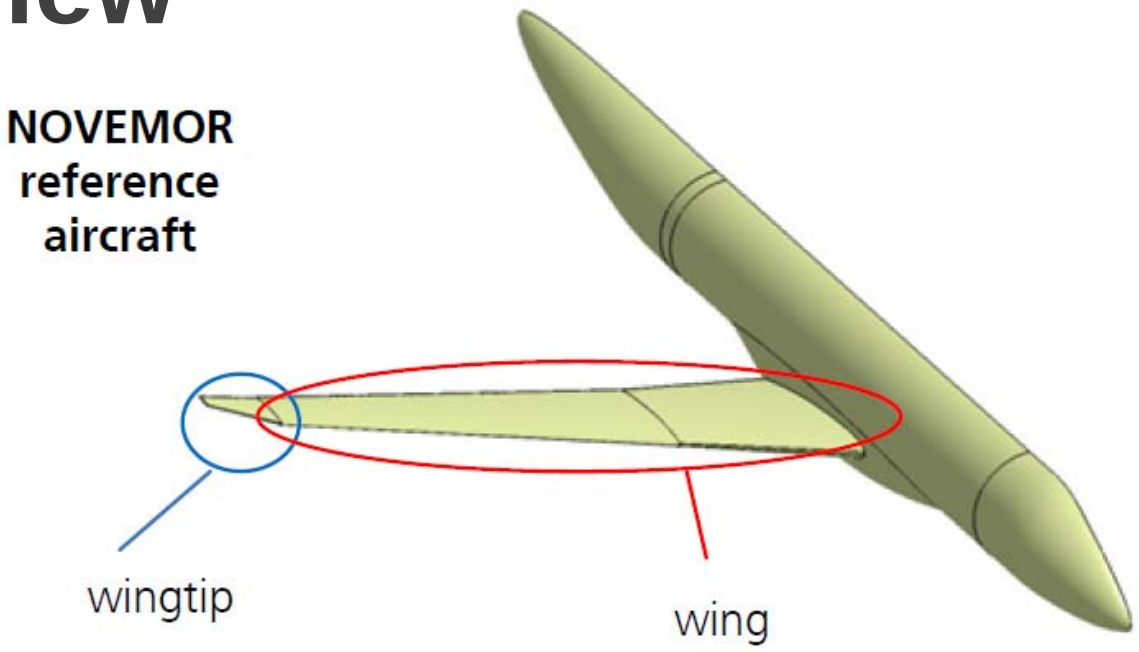
Srinivas Vasista, Hans Peter Monner
Institute of Composite Structures and Adaptive Systems
German Aerospace Center (DLR), Braunschweig, Germany

Alessandro de Gaspari & Sergio Ricci
Department of Aerospace Science and Technology
Politecnico di Milano, Milan, Italy

4th EASN Association International Workshop
on Flight Physics & Aircraft Design

28 October 2014, Aachen, Germany

Overview



DLR

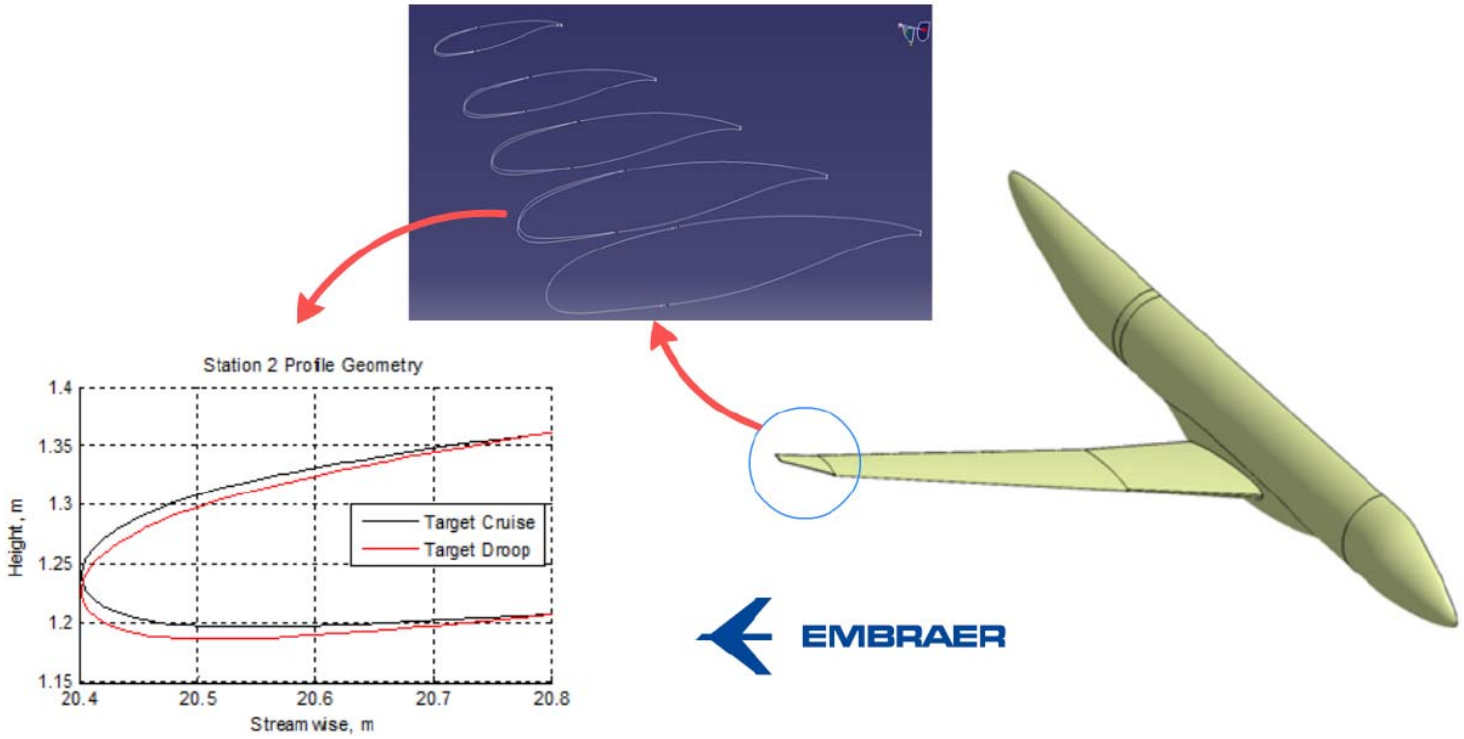
- **wingtip** droop-nose morphing LE
- composite skin with tailored stiffness
- compliant substructure via continuum-based topology optimization

POLIMI

- **wing** droop-nose morphing LE
- **wing** morphing TE devices
- parametric framework with CFD-FEA
- compliant substructure via load path-based topology optimization and GA

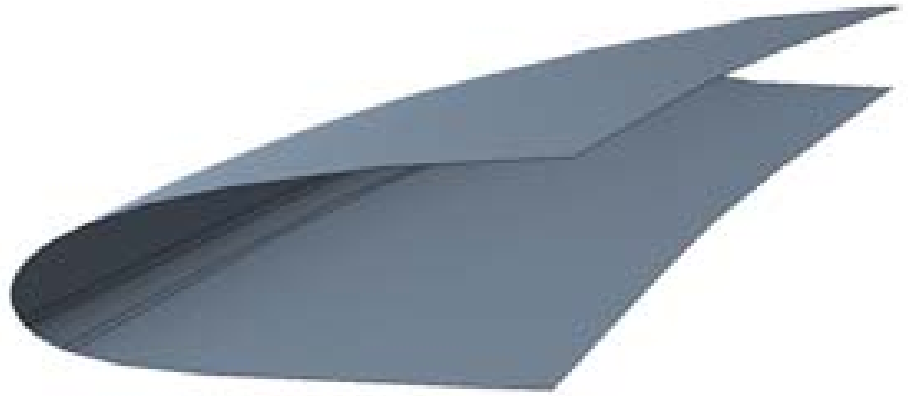
DLR
Droop-Nose
Morphing Wingtip

Application & Performance Benefits

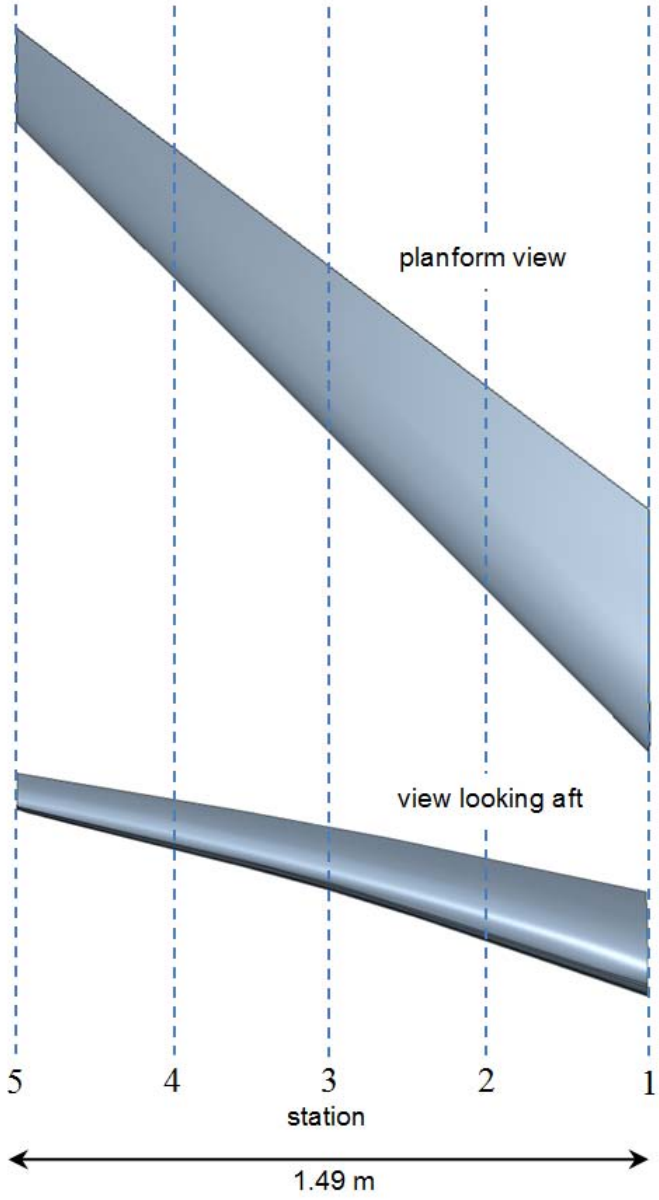


- Embraer narrow-bodied regional jetliner
- wingtip droop-nose morphing
- target deflection ~2°
- drag reduction, aeroelastic benefits

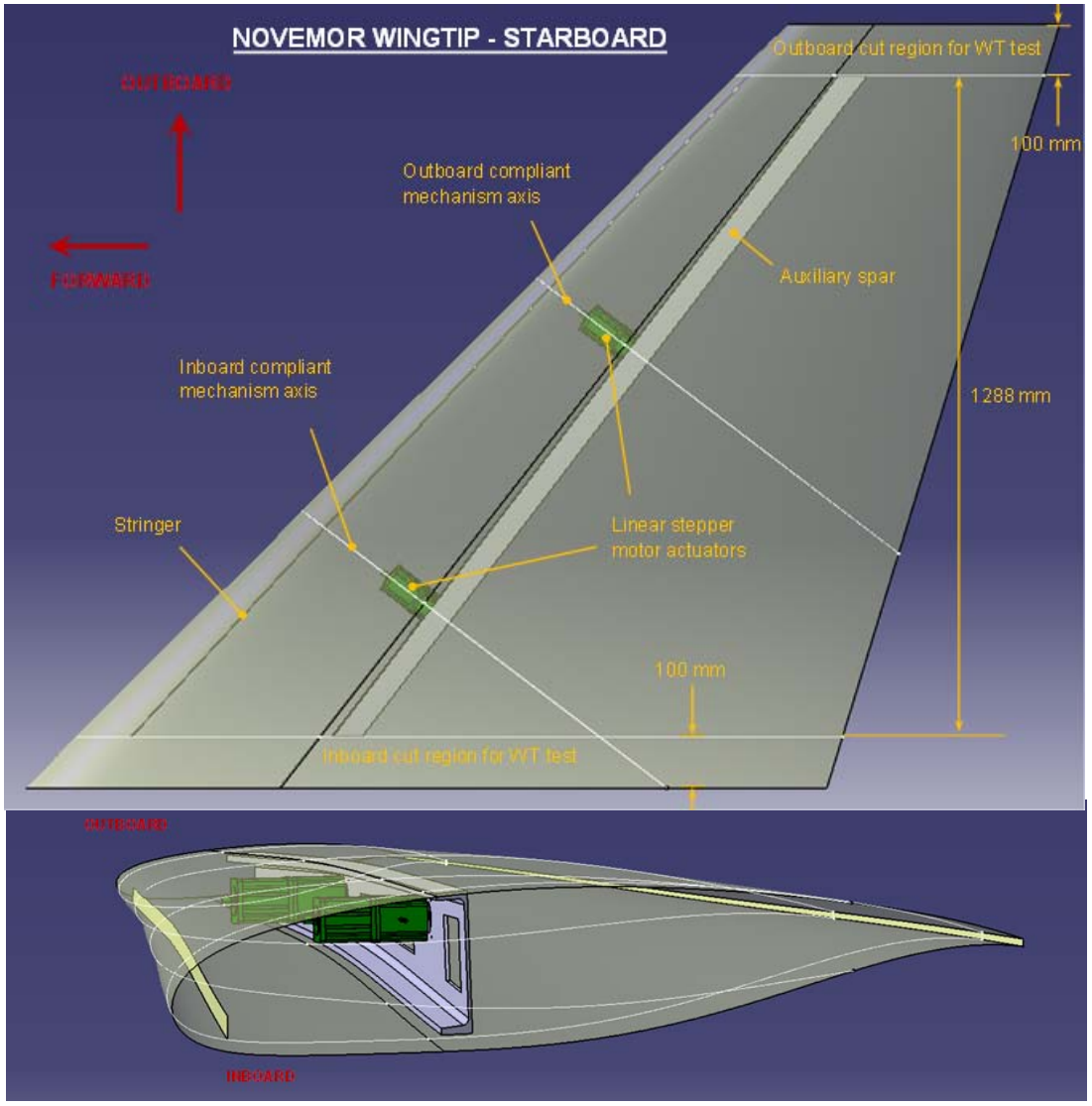
Highly 3D Geometry



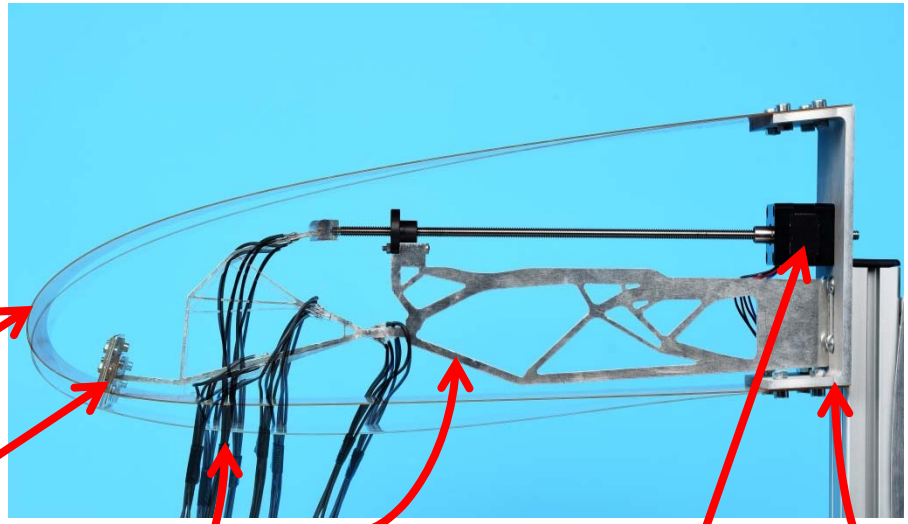
- sweep ~35°
- taper: chord and thickness
- dihedral
- double curvature
- streamwise morphing targets
- smooth spanwise morphing transition



Structural Architecture

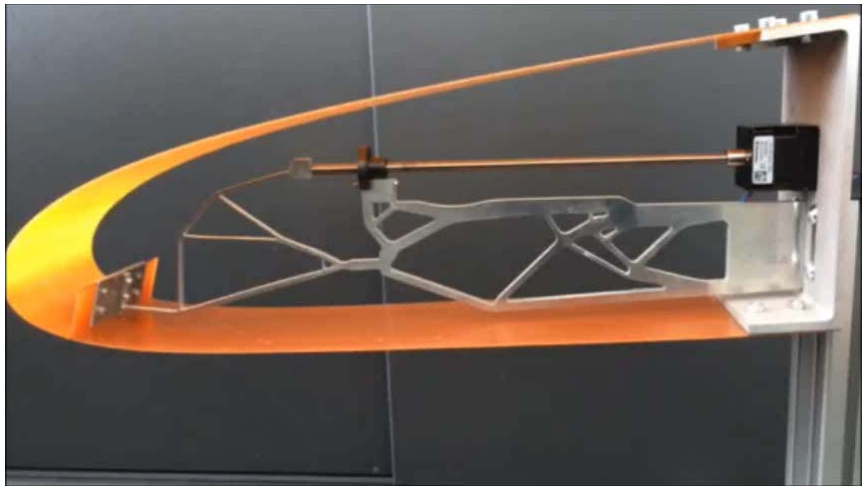


Concept in Demonstration



flexible optimized GFRP skin

skin – substructure interface



linear stepper actuator

monolithic optimized structure:
compliant mechanism and support

strain gauge cables

spar

Process

Design Chain:

Actuation

- Target geometries
- Aerodynamic loads
- Skin material properties
- Actuator properties

- Mechanism material properties
- Thickness
- Actuator properties
- Fixed support location

1. Composite Skin

3DSkinOpt

- Design domain
- Connection points
- Target displacements
- Resisting force, stiffness

2. Compliant Mechanism

Topology Optimisation

post-processing

post-processing

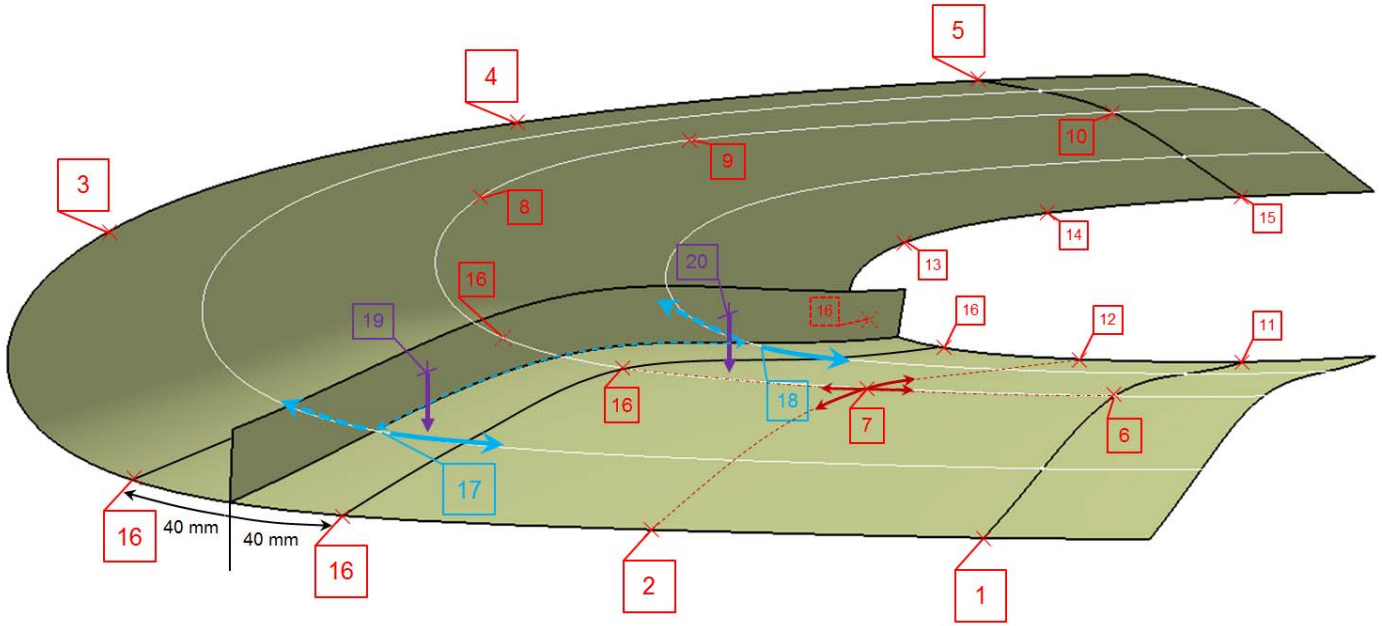
Manufacture

Assembly & Integration

Skin Concept

- tailored stiffness:
  optimized skin thickness distribution
- thickness achieved via appropriate ply stacking
- GFRP Hexcel HexPly® 913 prepreg plies
- skin – compliant substructure interface: **stringer**
  i.e. load introduction point

Skin Optimization Design Variables (DVs) x 20



DVs 1 – 16:

- skin thickness at 21 points
- [1 – 4] mm
- bilinear interpolation

DVs 17 – 18:

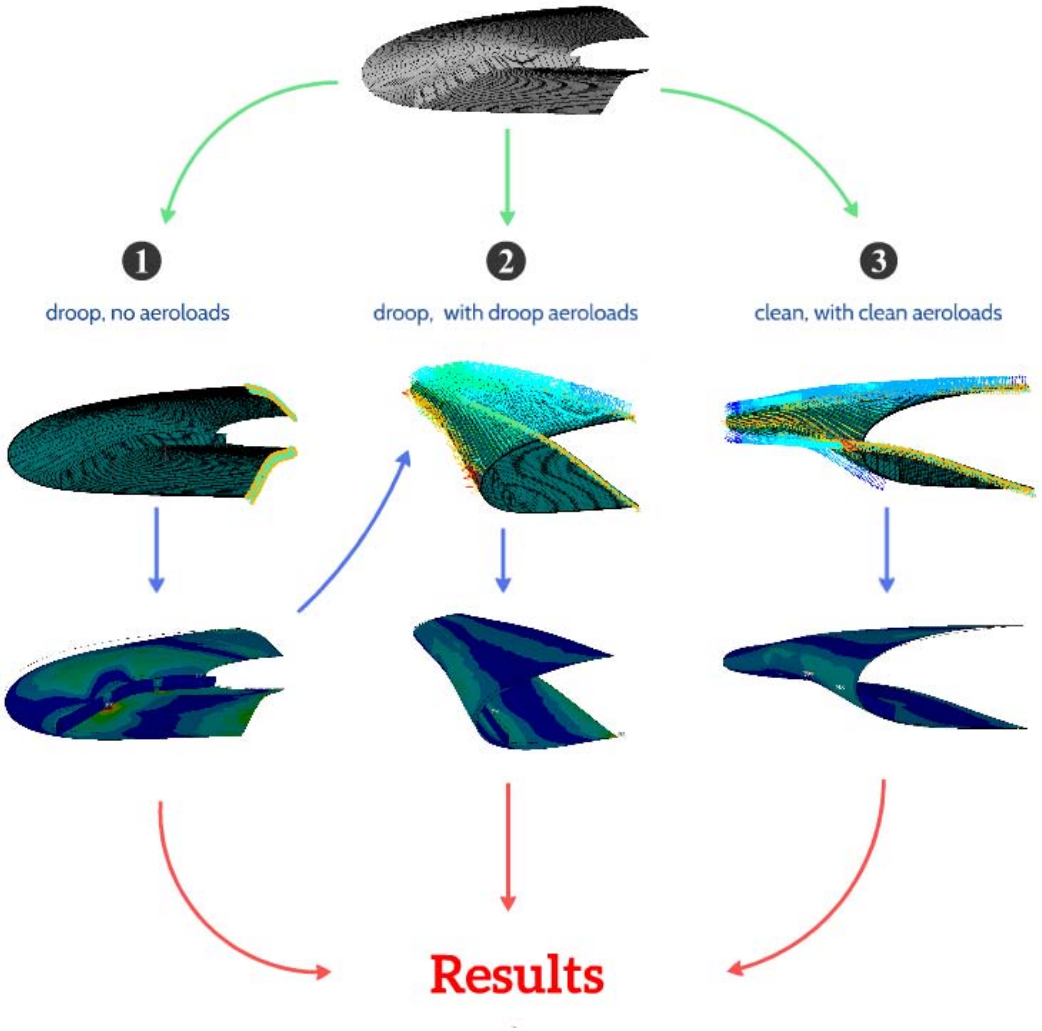
- stringer position at stations 2 and 4
- [35 – 55] % station perimeter length
- spline interp. and extrap.

DVs 19 – 20:

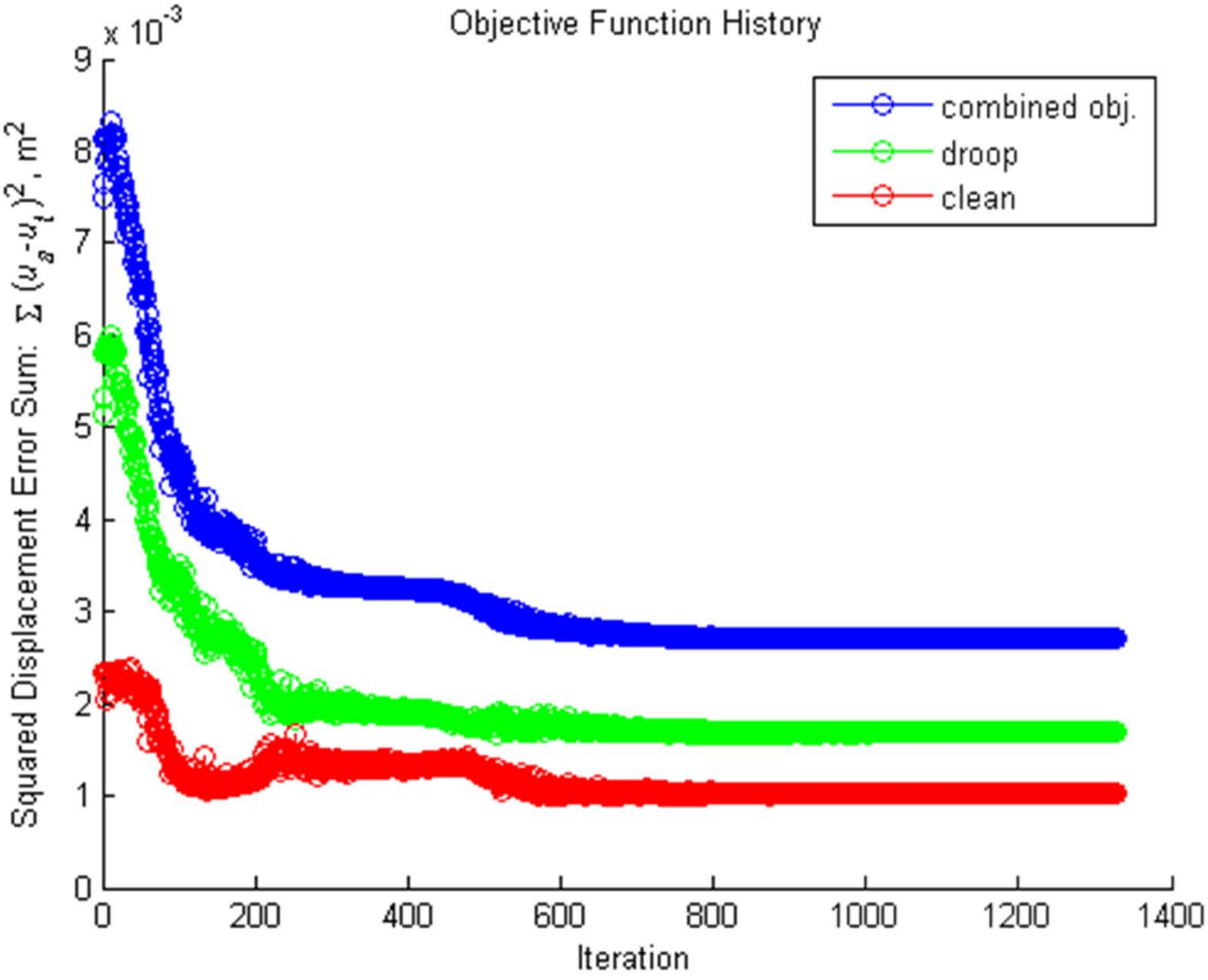
- force magnitude at CM stations
- [50 - 650] N

Skin Optimization Algorithm

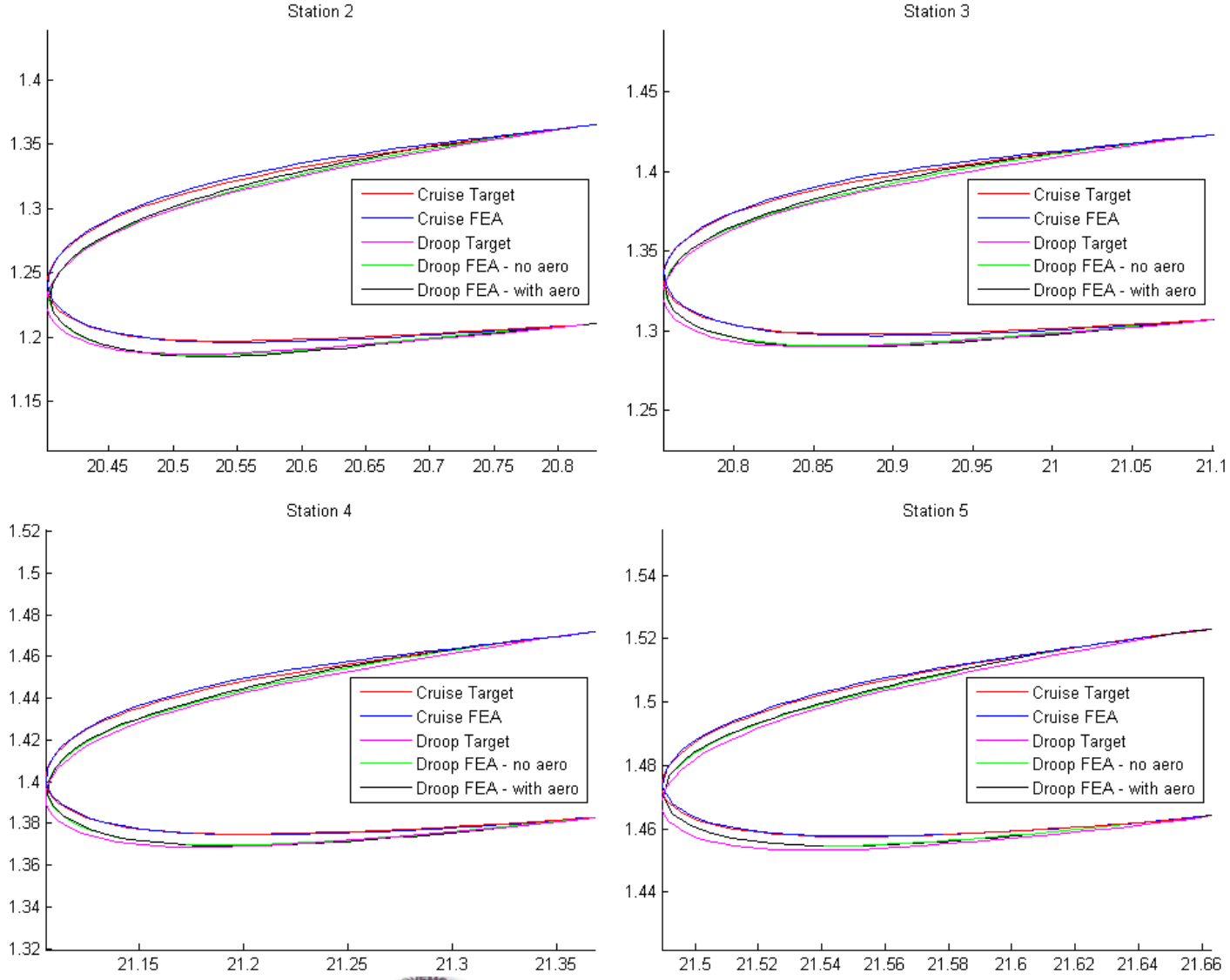
- concept follows Kintscher et al., SADE program
- this work: 3D
- Simplex algorithm
- automated and iterative
- objective function: LSE clean and droop configurations
- multiple FEA solutions via Ansys:
  - combined shape change and stiffness functionality



Results – Objective Function

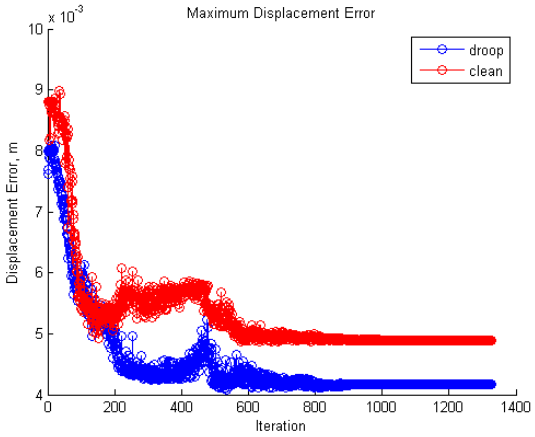


Results – Profile Shapes

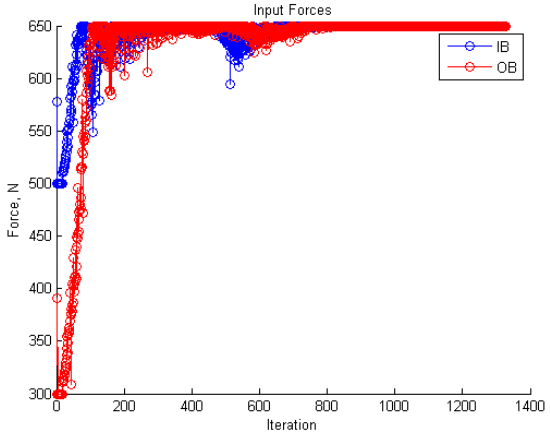


Additional Results – for Monitoring Purposes

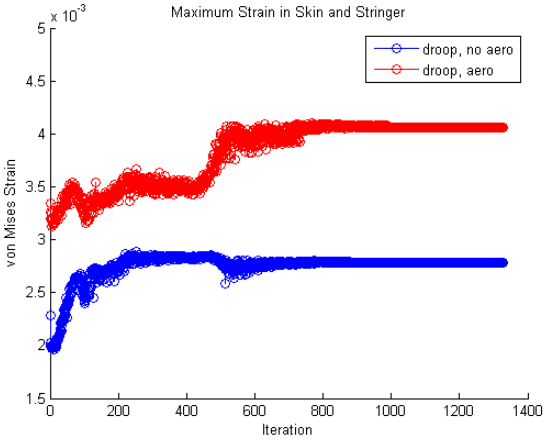
max displacement error



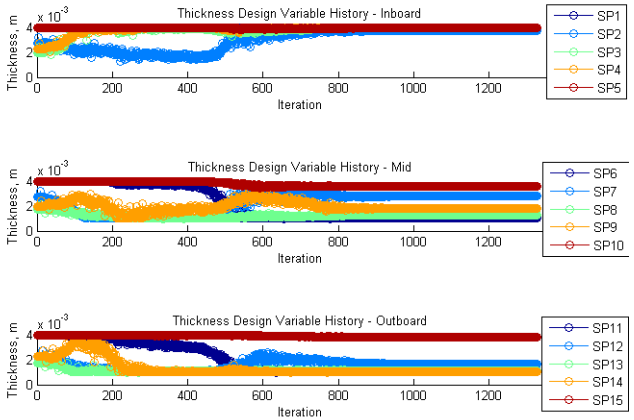
input forces



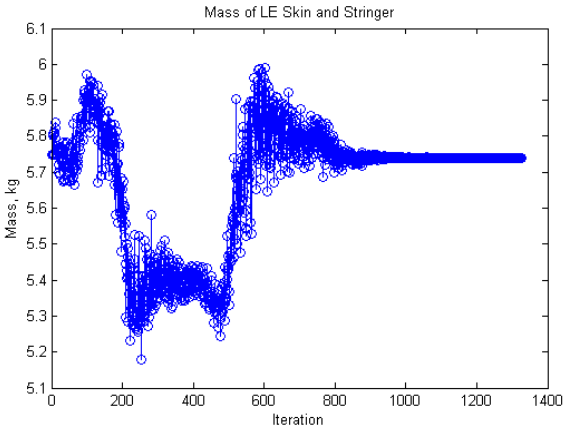
max strain



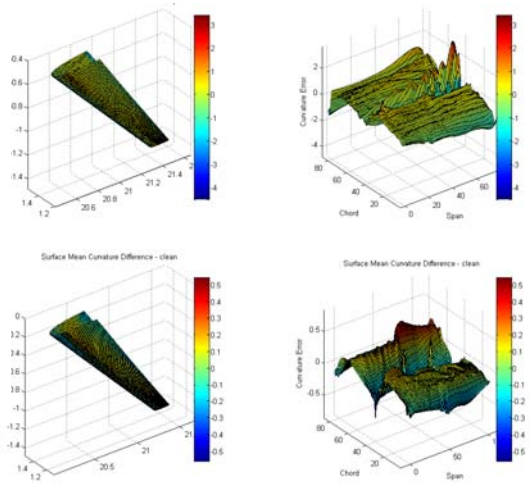
thickness DVs



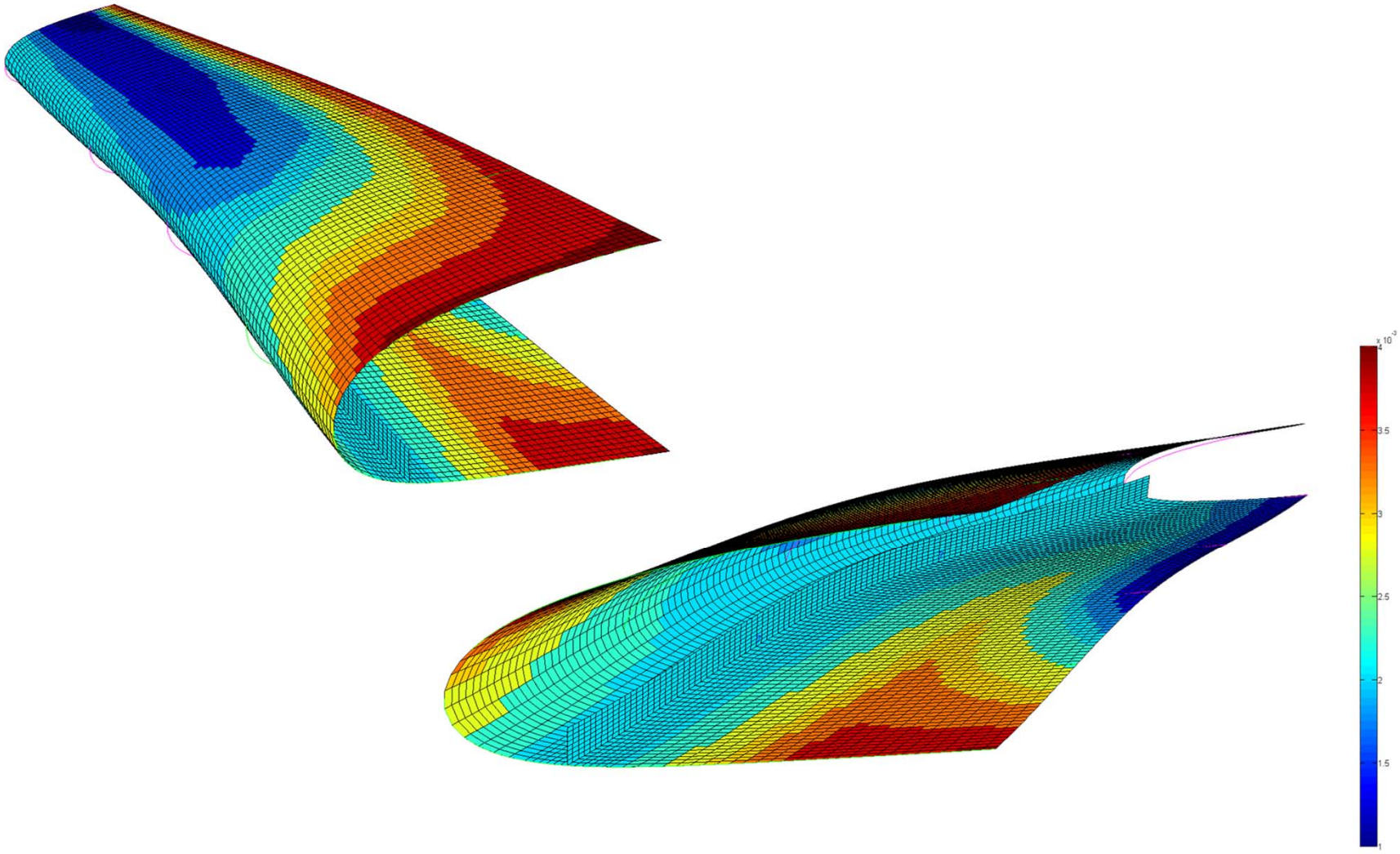
mass



3D surface mean curvature errors

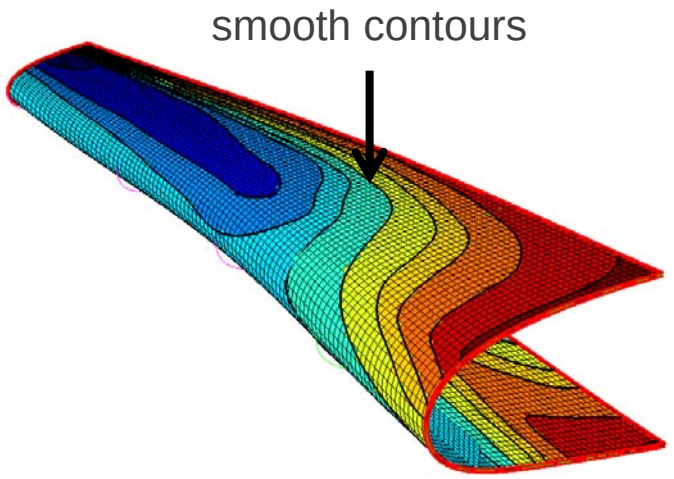


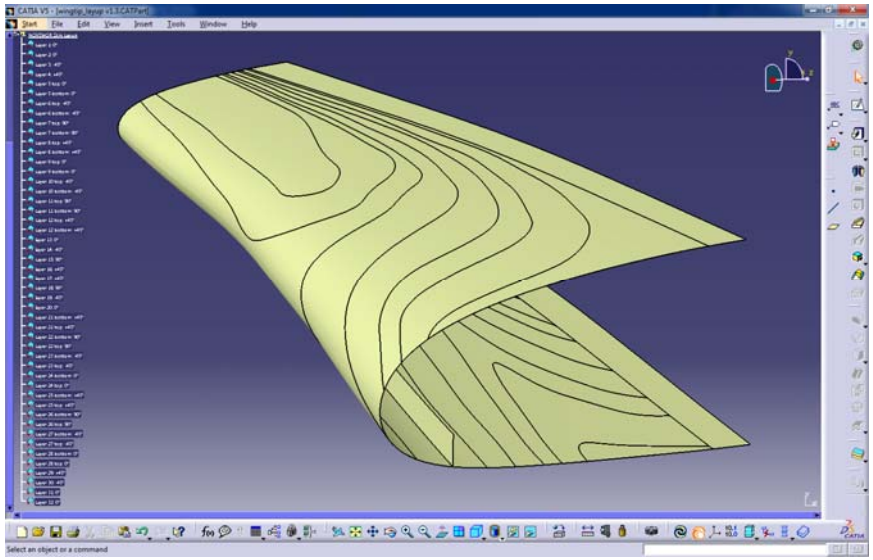
Final Thickness Distribution

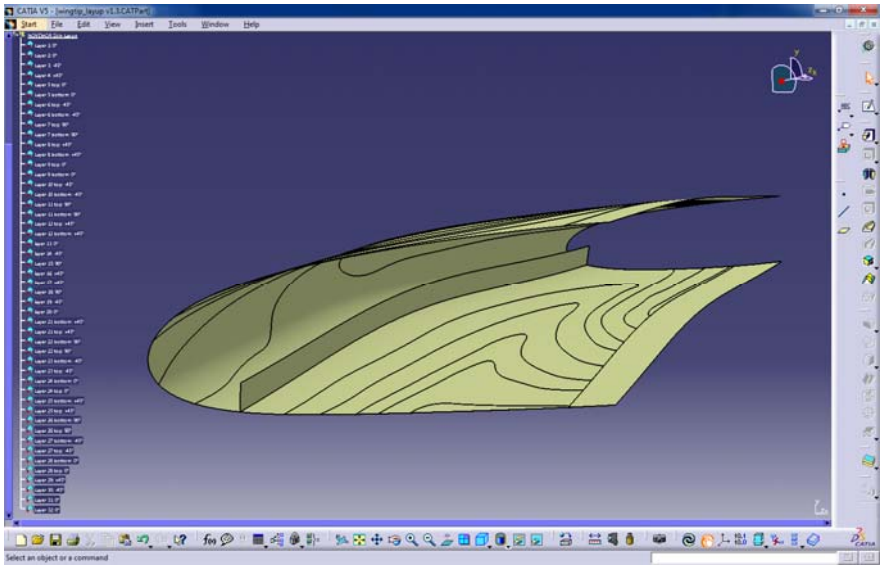


Post processing

- algorithm established for ordered edge detection
- LSE 3D spline-fit based on coordinate parameterization for smooth contour generation
- export files to CAD
- 32 plies (HexPly® 913) as per stacking sequence

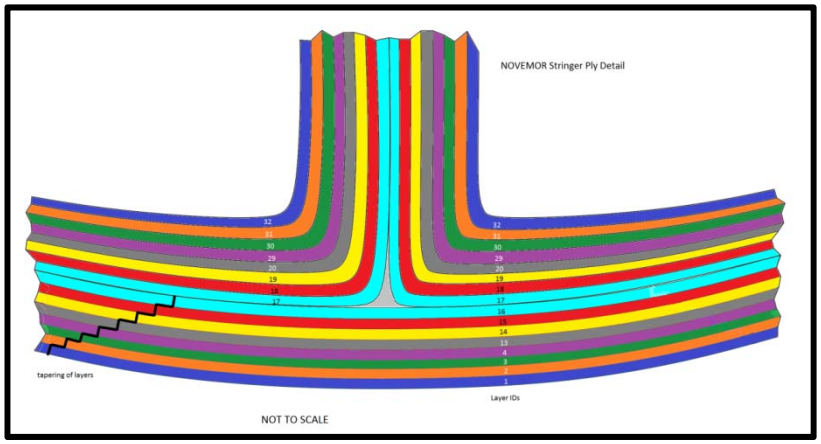


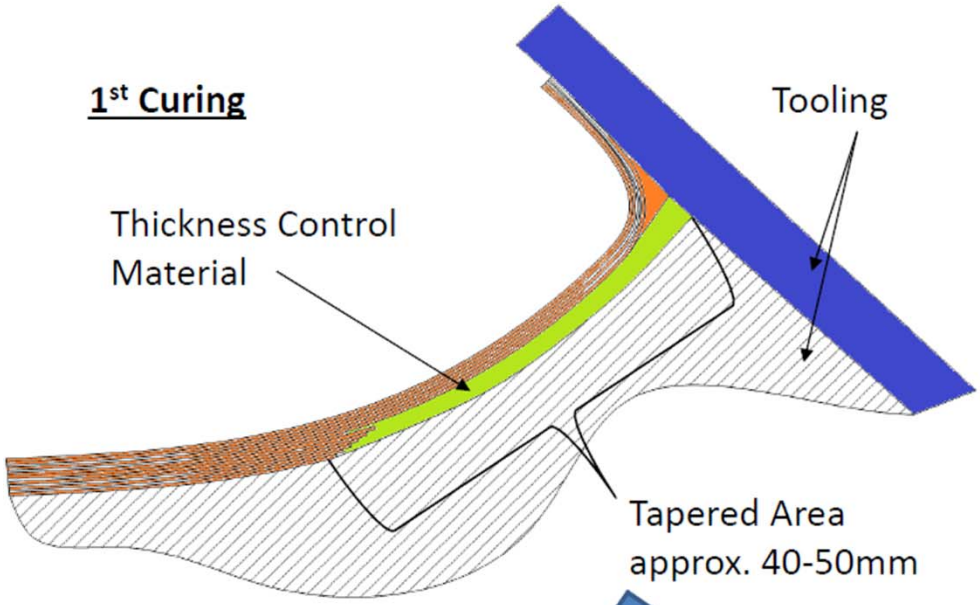




Manufacture

finished stringer detail





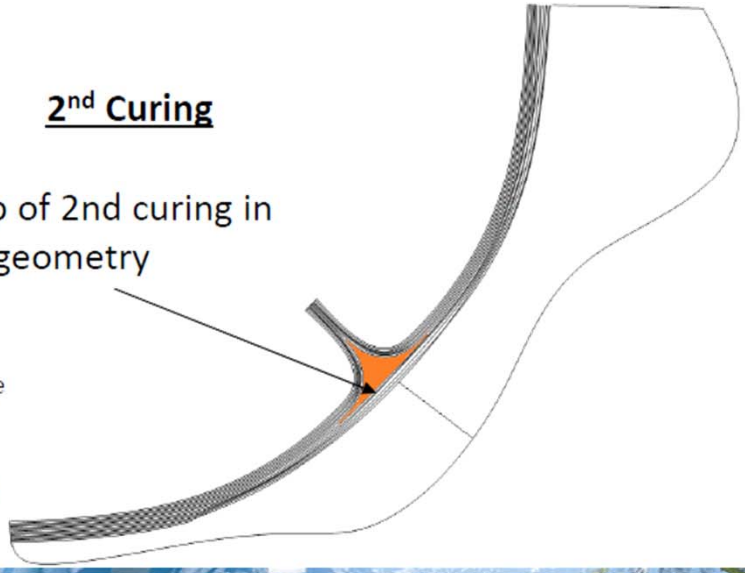
Manufacturing Concept

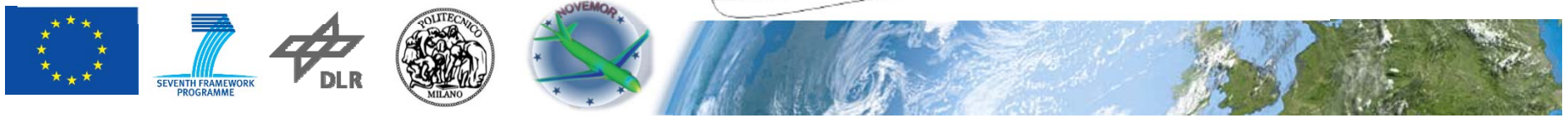
1st curing

- skin layers tapered
- Stringer layers placed completely until stringer head
- 5-6 layers tapered using a thickness control material (i.e. wax)
- ½ pedentive placed in 1st curing cycle

2nd curing

- Removal of thickness control material
- Placing of (adhesive if needed and) 2nd tapered skin layers running til the end of the part
- 2nd ½ pedentive placed
- Stringer layers placed from stringer head running to the end of the part





Compliant Mechanisms & Topology Optimization

Advantages of Compliant Mechanisms

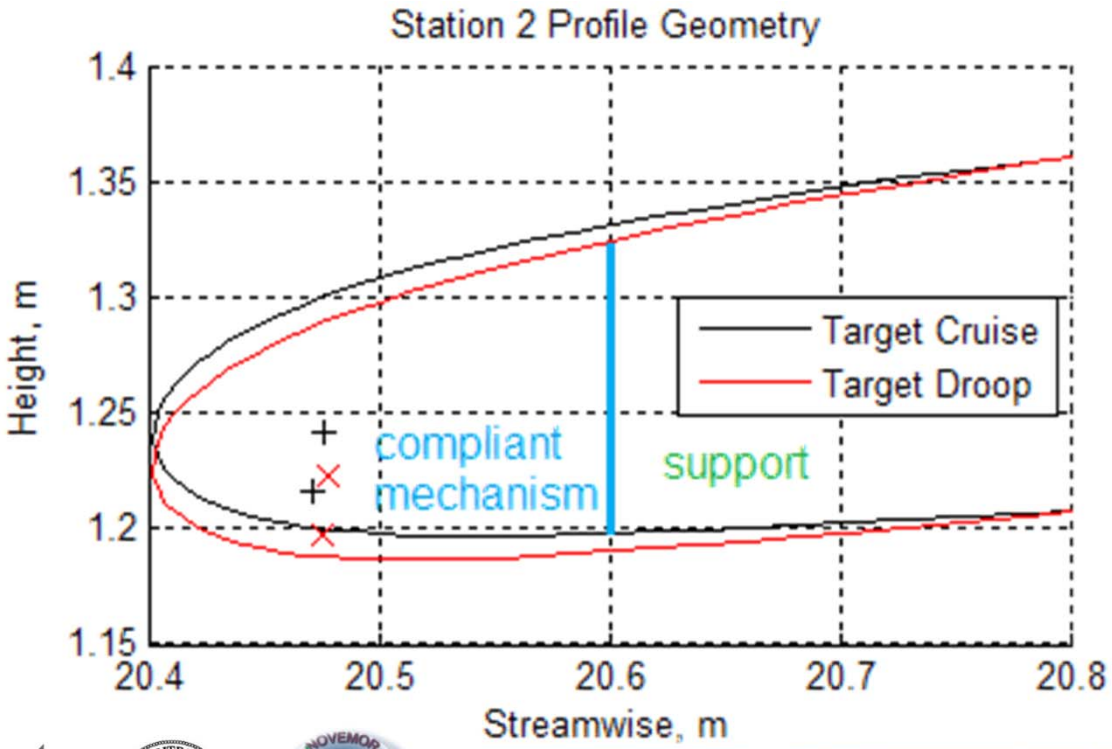
- lightweight structures
- reduced assembly complexity
- no backlash

Topology Optimization

- find best structural layout starting from a “blank canvas”
- continuum gradient based via SIMP, sensitivity analysis and MMA
- 2D plane stress
- linear FEA routine (small target deflections)

Demonstrator Design

- station 2 geometry
- LE space divided: compliant mechanism + support region
- monolithic
- aluminium 7075 plate (5 mm thick)
  E = 71 GPa, v = 0.334, yield strain ~ 0.6%



Compliant Mechanism Design

- shape control problem formulation for shape matching
- constraint on amount of material
- **design variables: topological densities (x) and actuator force** magnitude (α)

$$\min_{\mathbf{x},\alpha}: J(\mathbf{x},\alpha) = \sum_{r=1}^{p} (h_r(\mathbf{x},\alpha))^2$$

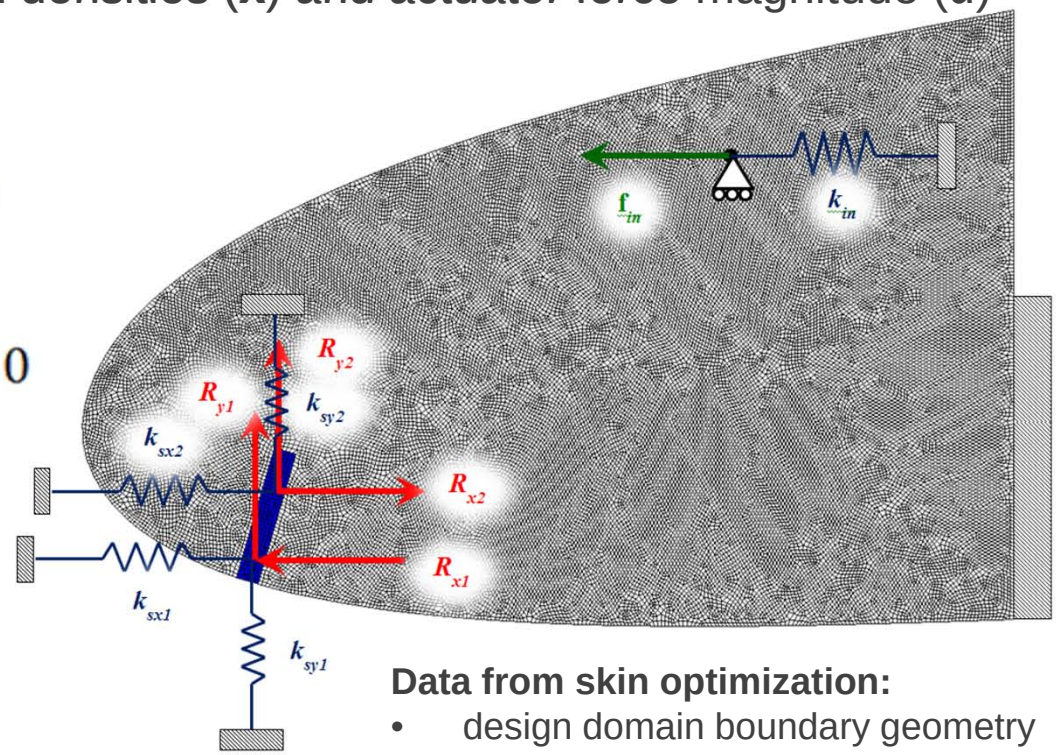
$$\text{s.t.}: g(\mathbf{x}) = \frac{\sum_{i=1}^{N} x_i A_i}{w \sum_{i=1}^{N} A_i} - 1 \leq 0$$

$$\mathbf{Ku} = \mathbf{f}$$

$$\mathbf{0} \leq \mathbf{x} \leq \mathbf{1}$$

$$0 < \alpha \leq 1$$

$$h_r(\mathbf{x},\alpha) = u_r(\mathbf{x},\alpha) - \bar{u}_r$$

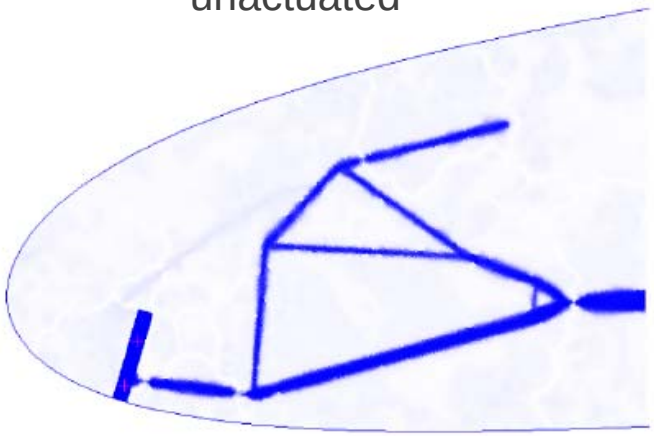


Data from skin optimization:

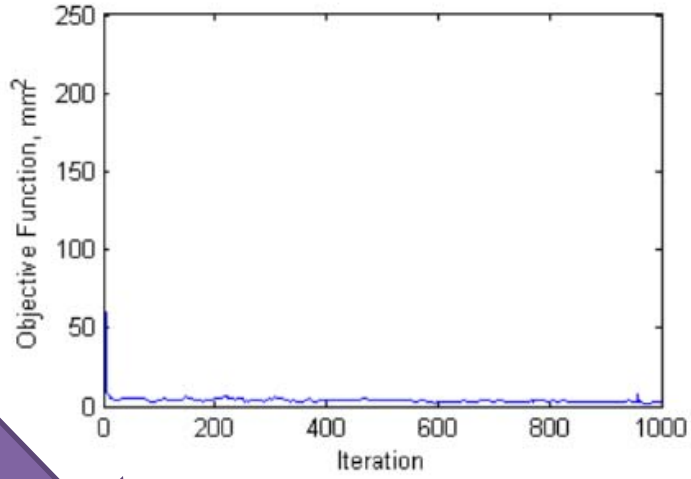
- design domain boundary geometry
- stringer location
- resisting forces and stiffnesses

Topology Optimization Results

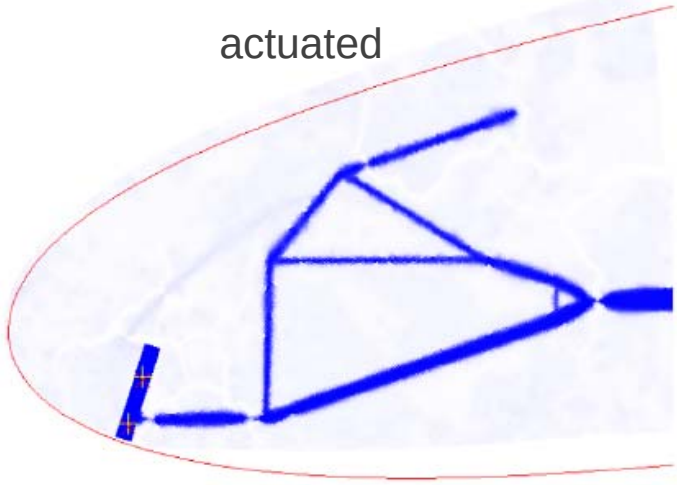
unactuated



shape error history



actuated



- postprocess geometry (CAD)
- laser cut manufacture
- displacement measurement via image analysis, strain measurement via strain gauges

Wind Tunnel Testing

- conducted at the University of Bristol (UBRIS)
- low speed WT: 2.1 x 1.5 m section, 55 m/s, -5 to +22 deg AOA
- DLR droop-nose LE + UBRIS wingbox

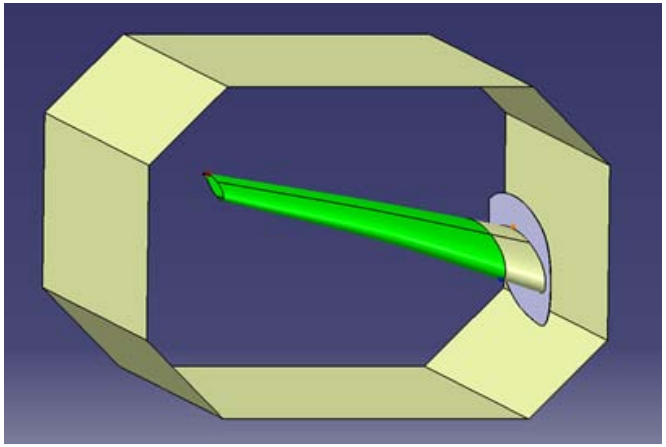
Aims:

- assessment of the feasibility of the DLR droop-nose under aerodynamic loads
- measure strain levels in the skin and compliant mechanism under aerodynamic loads
- validate skin and topology optimization structural codes
- measure pressure distribution along one station and compare with CFD simulations for analysis validation

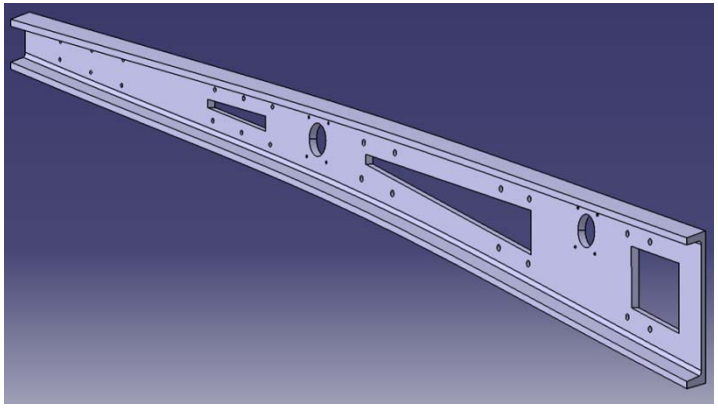
Wind Tunnel – Mounting and LE/Wingbox Interface

UBRIS wind tunnel

mounting configuration

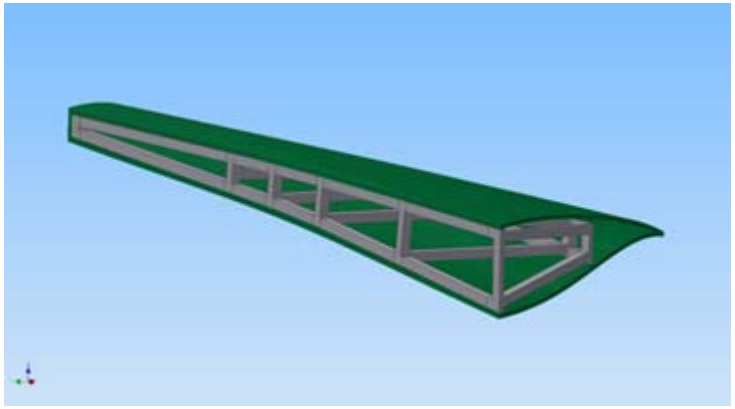


DLR auxiliary spar



milled single piece aluminium 5083 block

UBRIS wingbox and TE



milled plastic skins and steel frame substructure

POLIMI
LE and TE
Morphing Devices

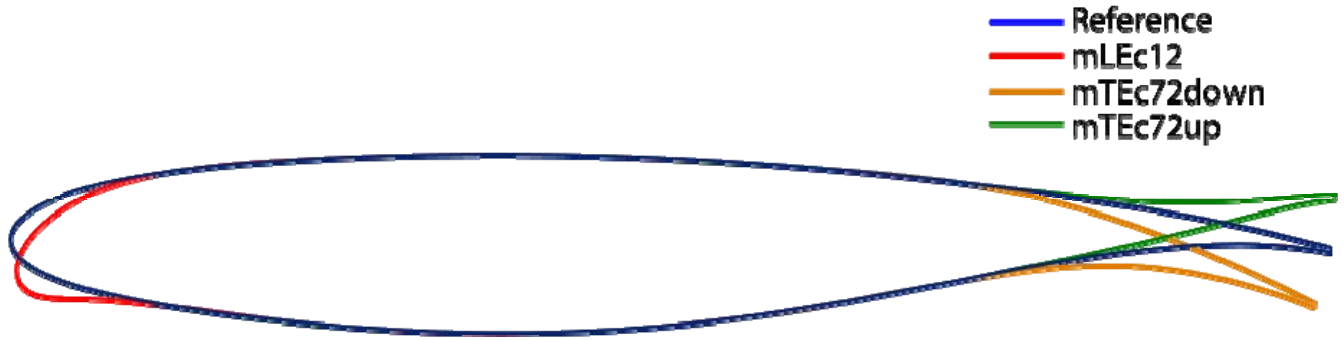
Overview

- Geometry parameterization via the CST method (Kulfan, 2008)
- 2 level optimization procedure
  1. **PHORMA – best airfoil shape:**

     most efficient aerodynamic shape whilst limiting energy required to deform the skin
  2. **SPHERA – best internal structural configuration:**

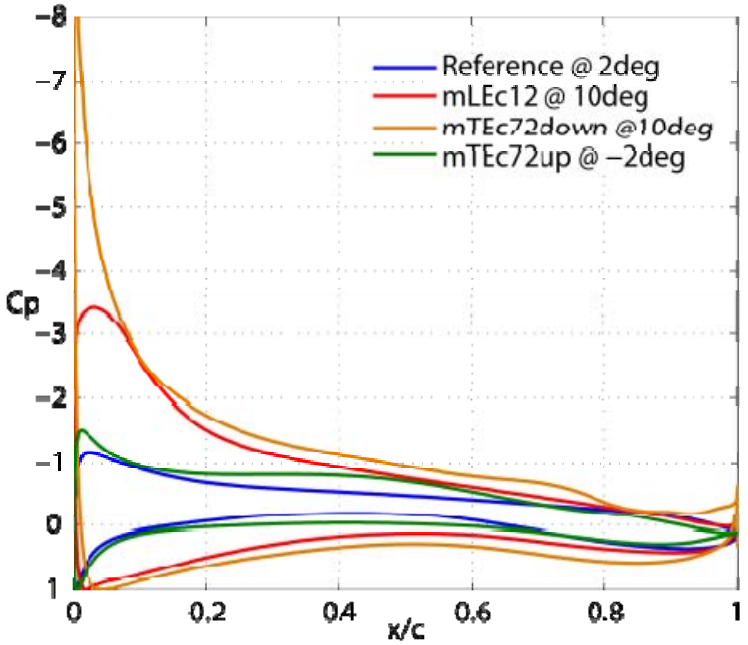
     load path topology optimization via GA → synthesis of compliant mechanism to best match shape in level 1
- Parametric framework
- Object oriented programming
- CFD – FEA analyses

Application to NOVEMOR Reference Aircraft



optimal aerodynamic shape obtained by PHORMA

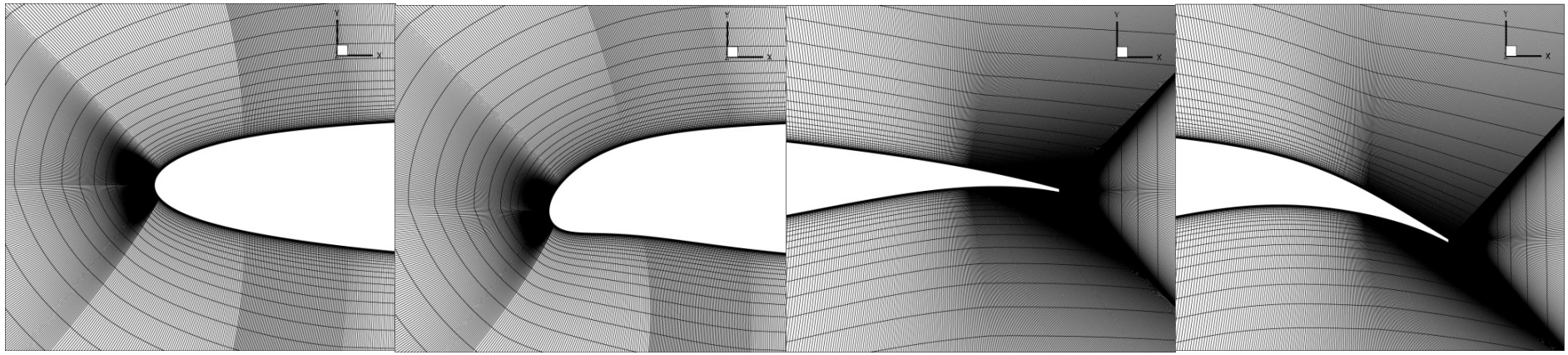
- applied to airfoil of the NOVEMOR reference aircraft
- scaled wind tunnel morphing model
- WT speed: 40 m/s
- **LE:**
  - maximum aerodynamic efficiency
  - skin null length variation constraint
- **TE:**
  - maximum C_L
  - limit on skin deformation



CFD Modelling – 2D

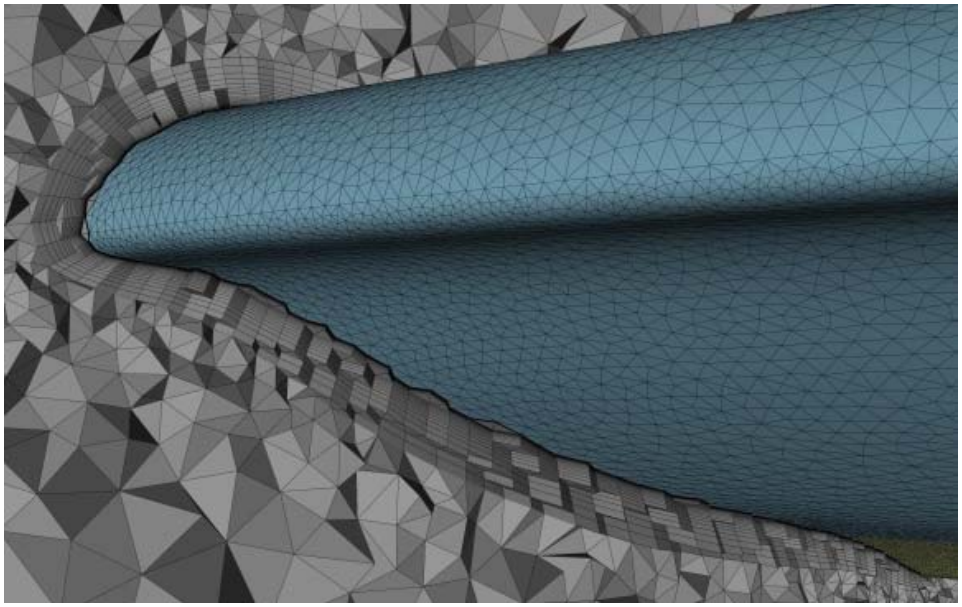
- structured mesh based on script for ANSYS ICEM CFD
- CFD: EDGE code
- CST: extract C_P distribution, spread along airfoil for compliant mechanism modelling

CFD 2D mesh adaptation to parametric shape changes around the LE and TE



CFD Modelling – 3D

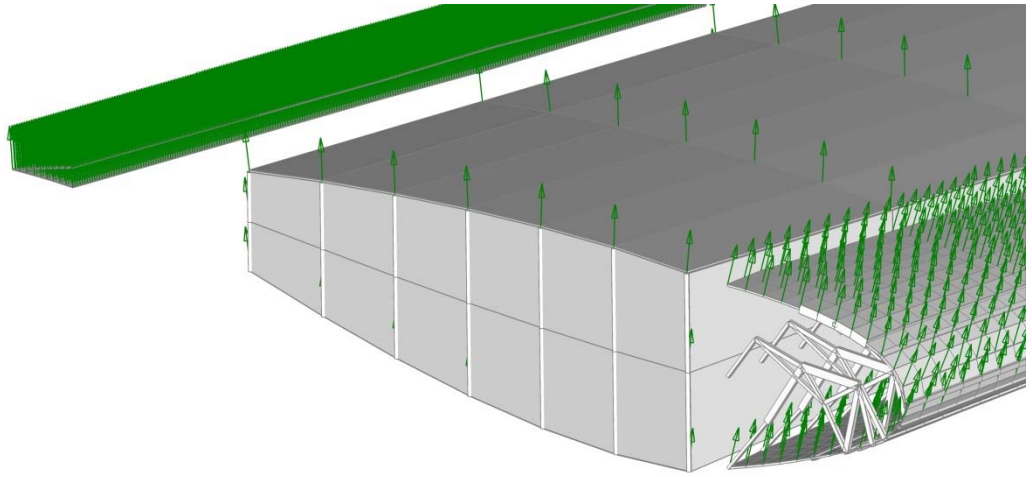
3D hybrid mesh for RANS computation



- aerodynamic loads extracted from 3D CFD
- **PHORMA:** extrapolates aerodynamic results around one or more arbitrarily positioned and oriented sections → match to CST parameterized shapes

FEM Modelling

FEM mesh generation with loads transferred from CFD



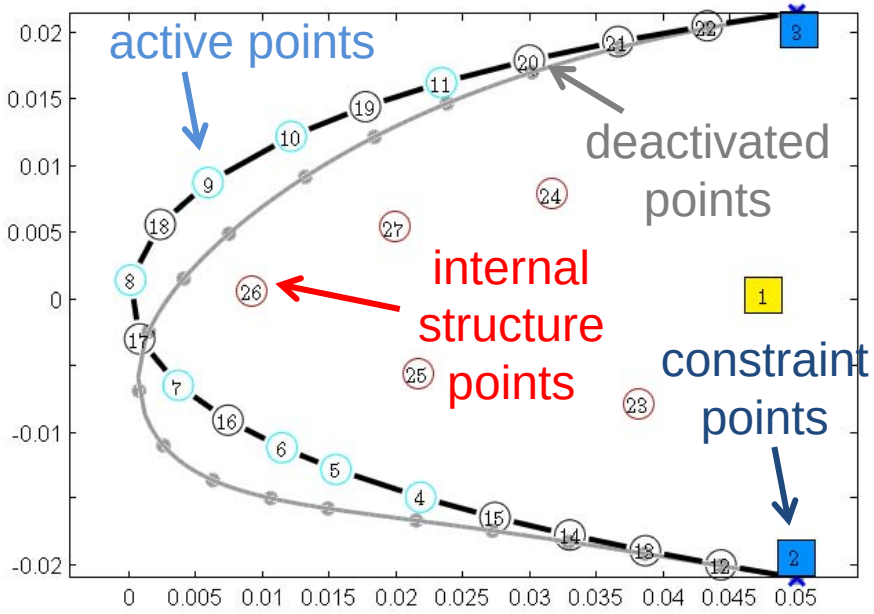
- **PHORMA** → interacts with **PFEM** methods to generate 3D aeronautical FEM models
- **PFEM** → incorporates modal, buckling, linear and non-linear static analyses, different element types
- **PHORMA** → coupled with **SPHERA** to add 3D FEM models of compliant mechanisms
- **FSI** → via radial basis function for conservation of energy between fluid and structure

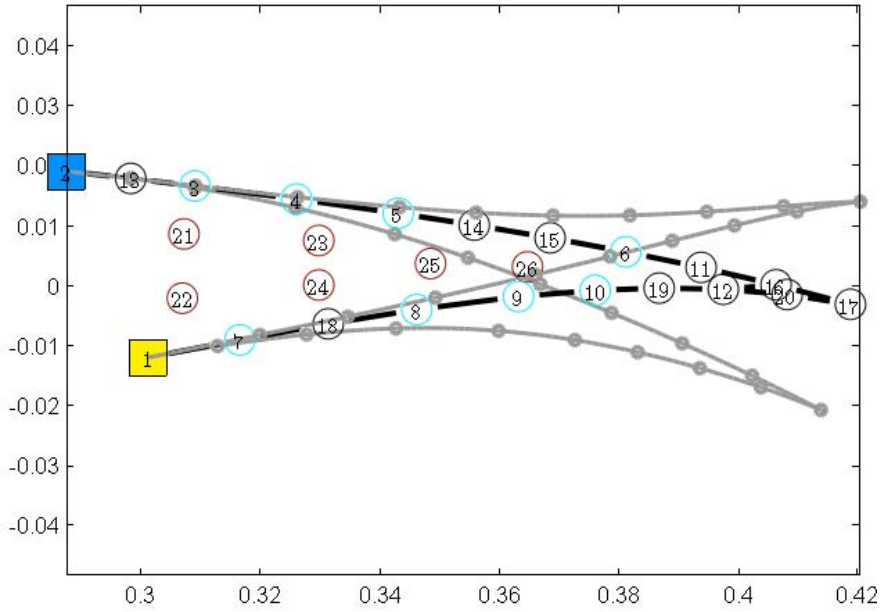
Synthesis of Compliant Mechanisms - SPHERA

SPHERA → load path representation

design parameterization of the stiffness tensor

- different structural topologies, cross-sectional beam areas, position of essential points for the shape control problem
- based on beam element models → distributed compliance
- SISO and SIMO





Problem Formulation and DV Update via GA

DVs:

- path sequence
- binary path existence
- internal point coordinates
- cross sectional load path sizes
- load path output destinations
- structure boundary sizes

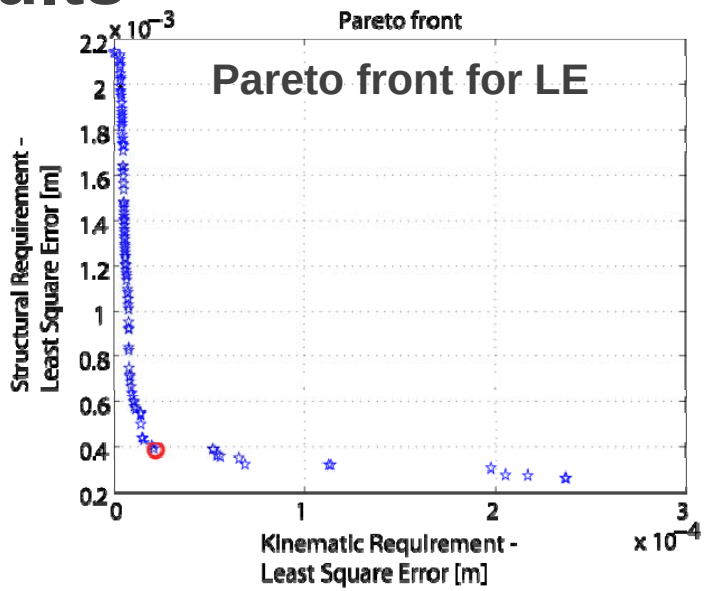
min: LSE between deformed and target shapes

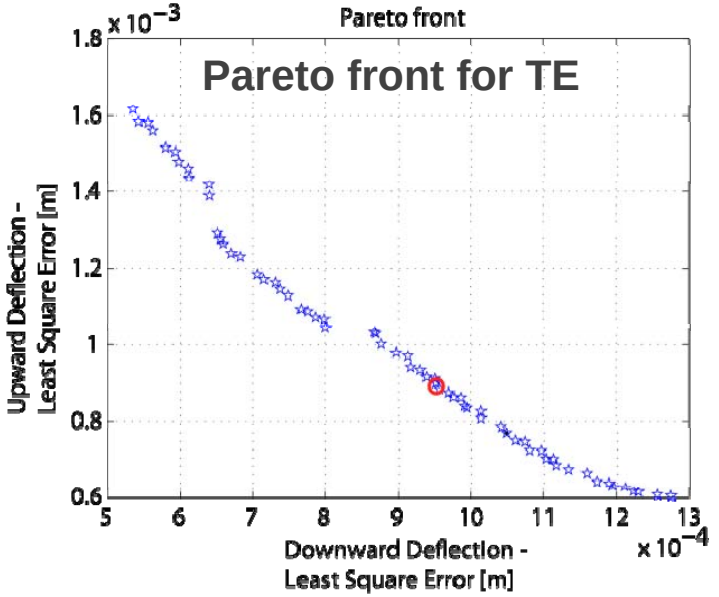
subject to:

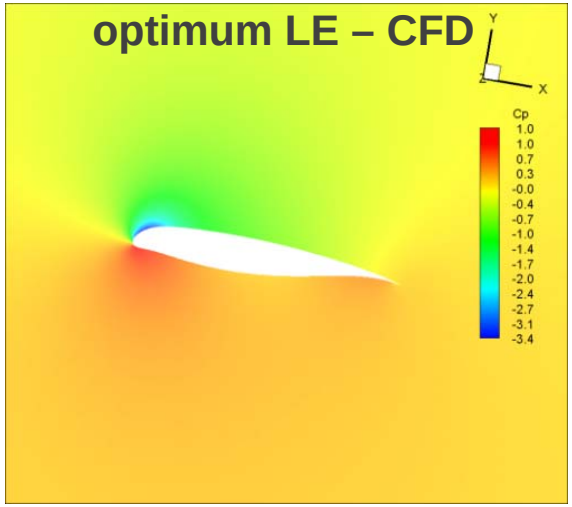
- size constraints for load path beam elements and structure boundary elements
- internal point boundaries
- 2 global connectivity equations
- stress and buckling constraints
- equilibrium equation

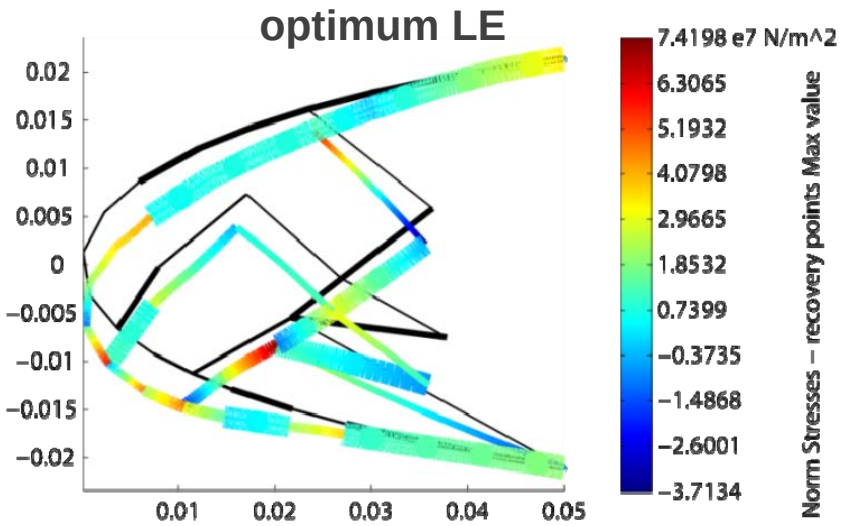
solved via an Elitist Non-Dominated Sorting Genetic Algorithm

Results

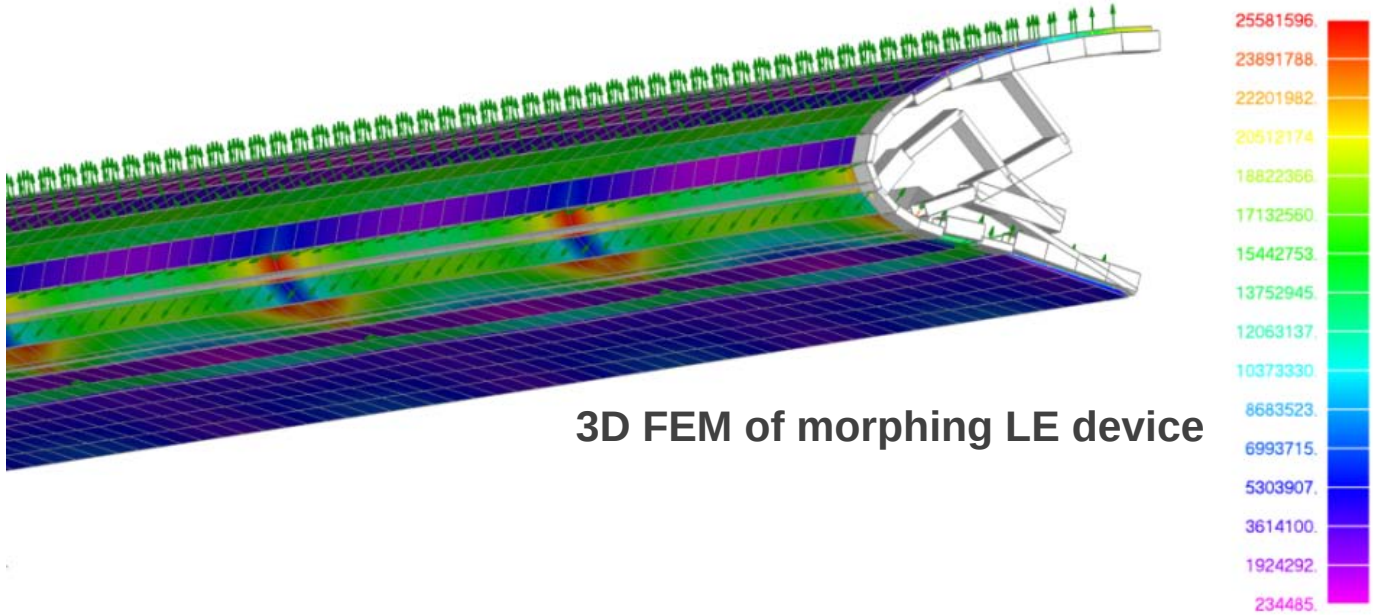

Pareto front for LE
Pareto front
x 10^-3
Structural Requirement - Least Square Error [m]
Kinematic Requirement - Least Square Error [m]
x 10^-4


Pareto front for TE
Pareto front
x 10^-3
Upward Deflection - Least Square Error [m]
Downward Deflection - Least Square Error [m]
x 10^-4


optimum LE – CFD
Cp

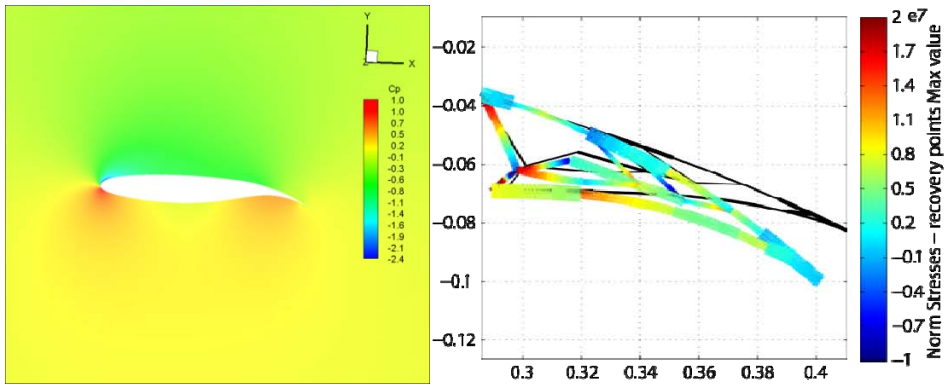

optimum LE
7.4198 e7 N/m^2
6.3065
5.1932
4.0798
2.9665
1.8532
0.7399
−0.3735
−1.4868
−2.6001
−3.7134
Norm Stresses – recovery points Max value

Results

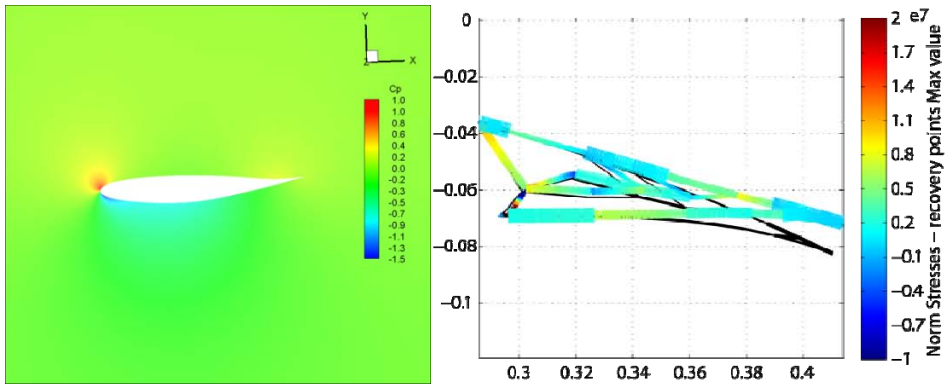


3D FEM of morphing LE device

morphing TE – maximum down deflection

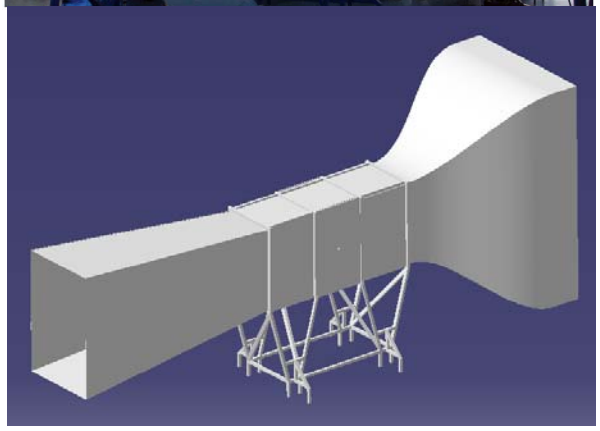


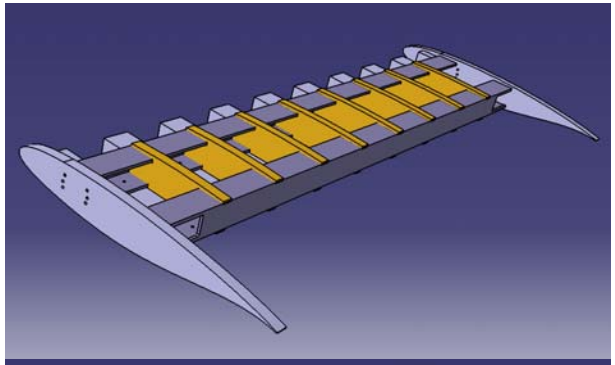
morphing TE – maximum up deflection

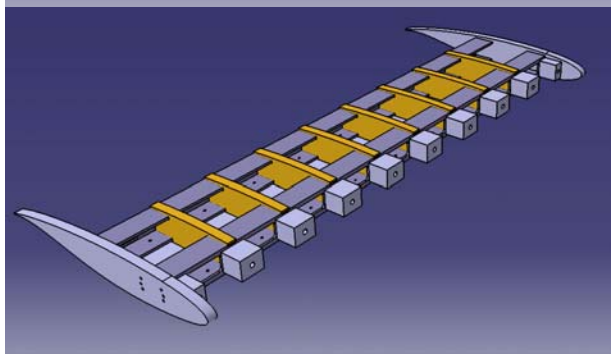


Experimental Testing

- wind tunnel testing at POLIMI
- 1 x 1.5 x 3 m working section
- wing model (untapered):
  1 m span, 0.4 m chord







- aluminium ribs, C spars (front and rear)
- 1 x 1.5 x 3 m working section
- wing model: 1m span, 0.4 m chord
- off-the-shelf servo actuators
- morphing LE and TE attach to front and rear spars

Summary

morphing devices from DLR and POLIMI for NOVEMOR

DLR

- droop-nose morphing wingtip
- composite skin, compliant aluminium substructure
- demonstrator tests show functionality
- full scale 3D design to be WT tested in January 2015

POLIMI

- morphing LE and TE devices
- compliant structures
- 2-level optimization procedure
- WT testing underway

Acknowledgments

- European Commission (Grant Agreement 285395)
- Alexander von Humboldt Foundation

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Neue Wege.

Multi-disciplinary Design Investigation of Propulsive Fuselage Aircraft Concepts

J. Bijewitz, A. Seitz and M. Hornung
Bauhaus Luftfahrt e.V.

4th EASN Association International Workshop on Flight Physics and Aircraft Design
Aachen, 27-29 October 2014

Overview

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- Introduction and Motivation
- Outline of Multi-disciplinary Design Investigation
- Propulsion System Sizing Investigation
- Implications of Fuselage Fan Power Plant Integration
- Integrated Performance Results
- Conclusion & Future Work

Introduction and Motivation

>> *Ambitious emission reduction targets (e.g. Flightpath 2050) stipulate significant efficiency improvements for aircraft and propulsion system*

> Exploration of unconventional aircraft and power plant options required

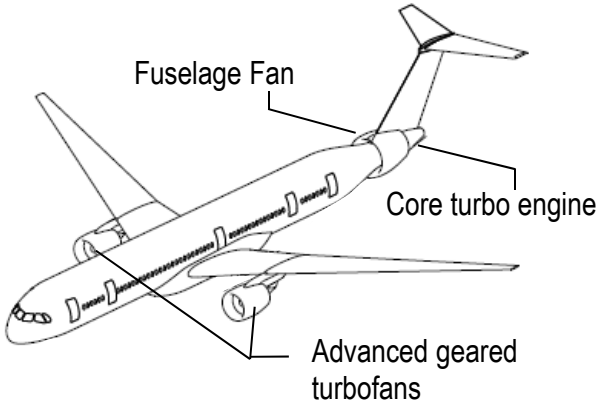
> Distributed Propulsion considered to allow for significant aircraft level benefits

>> *The DisPURSAL project*

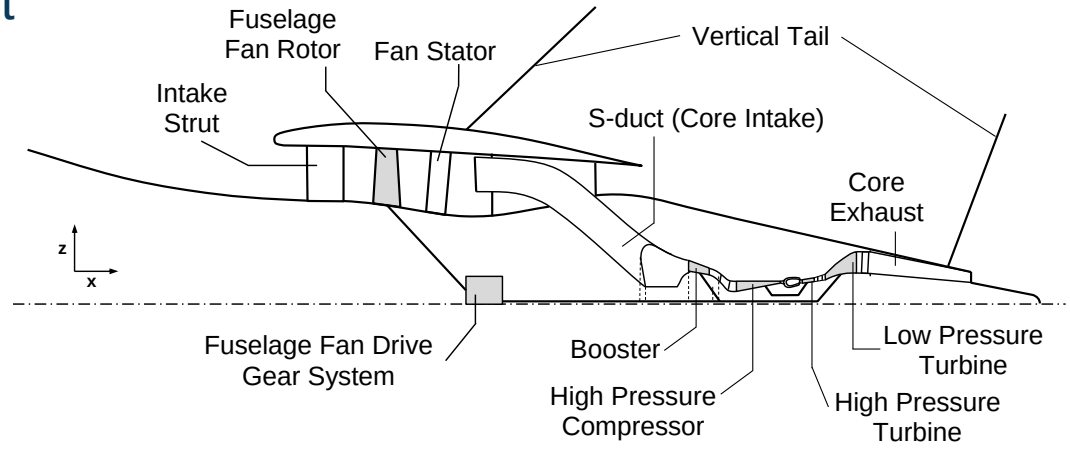
> Multi-disciplinary investigation of novel propulsion system integration solutions

> Key figures: 4800 nm design range, 340 passengers, potential EIS year of 2035

> Propulsive Fuselage (PF) Concept



Schematic view of Propulsive Fuselage concept



Schematic view of Fuselage Fan propulsion system

Outline of Multi-disciplinary Design Process

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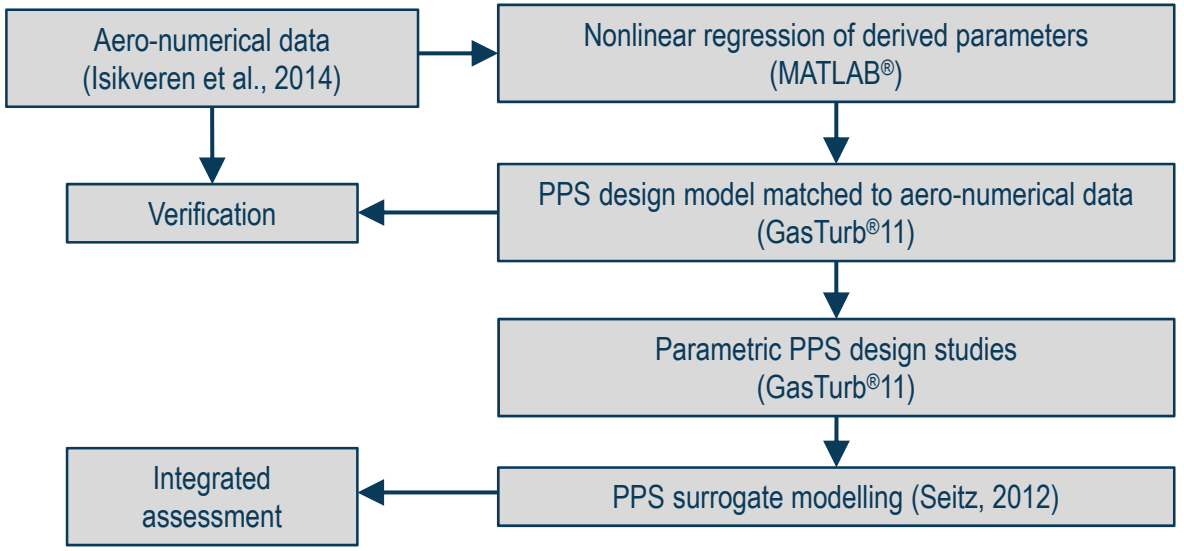
>> *Aerodynamic characteristics of PF assessed through 2D axisymmetric CFD calculations conducted by ONERA*

> Investigated configuration includes fuselage and Fuselage Fan propulsor

> Design space exploration through systematic variations of propulsor size parameters

>> *Numerical results used for derivation of propulsion system sizing and performance models suitable for integrated aircraft level assessment*

>> *Implemented CFD and power plant performance matching procedure:*



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Mapping of Intake Pressure Ratio

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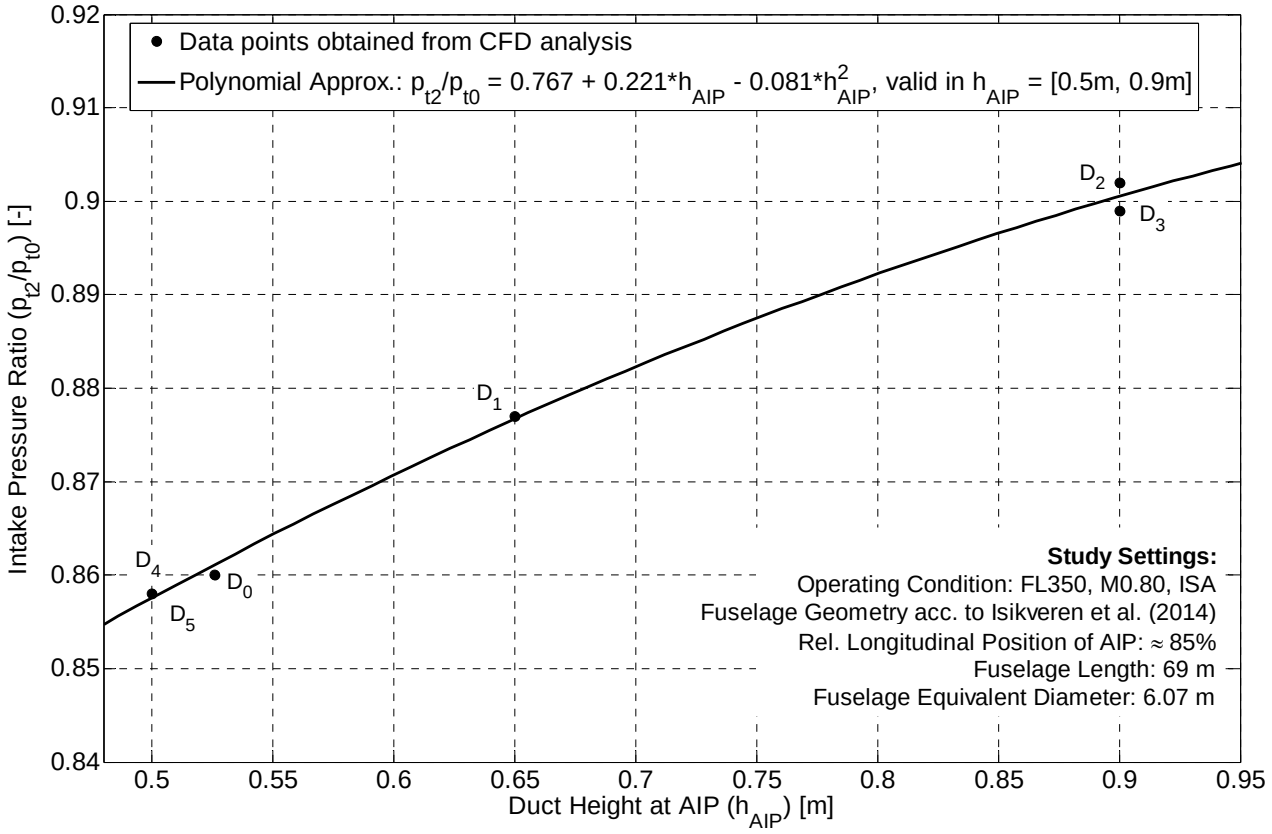
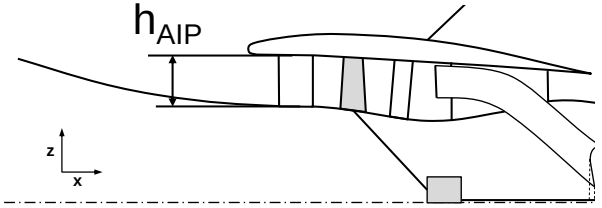
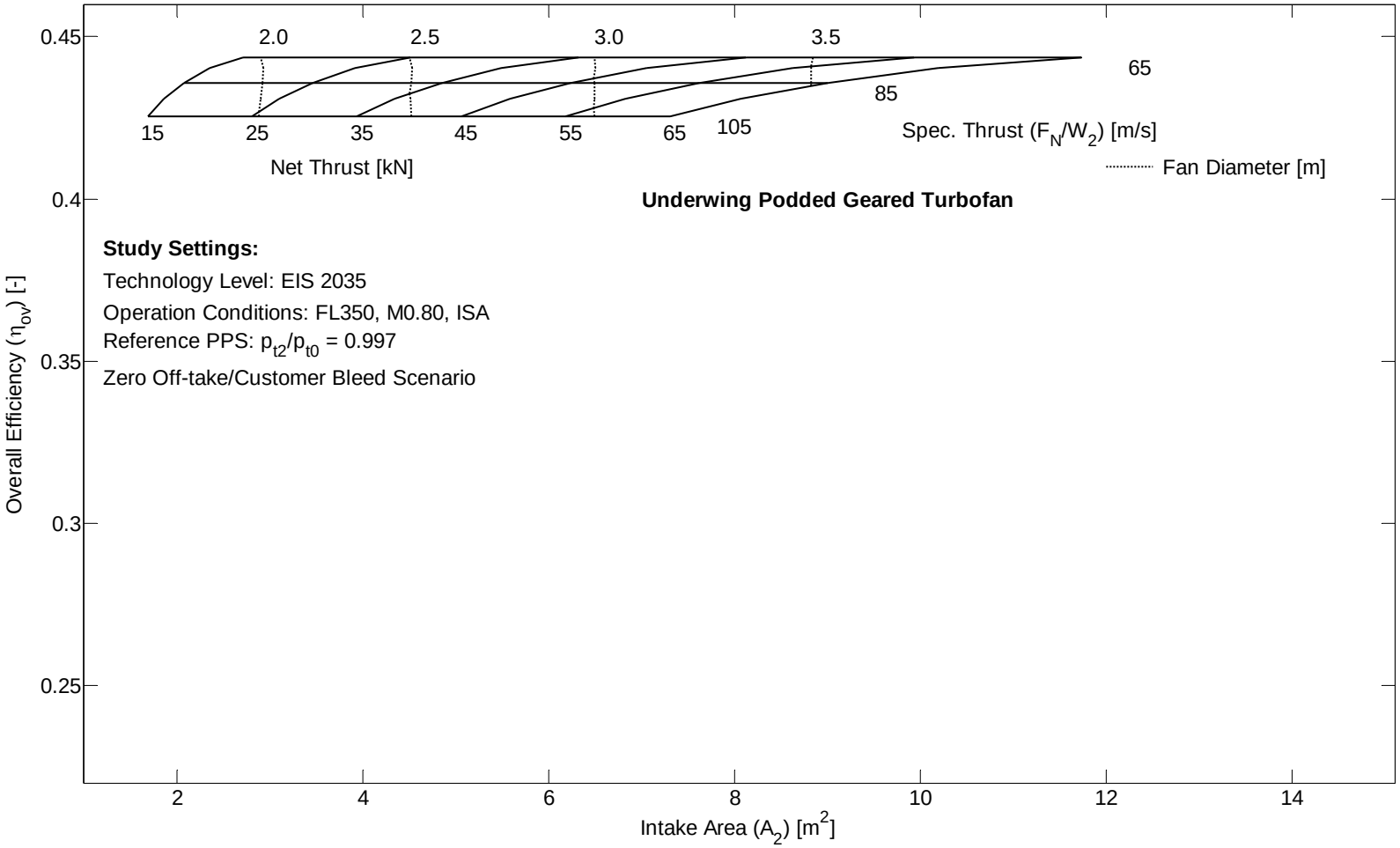
>> Strong impact of intake duct height at aerodynamic interface plane (AIP) on intake pressure ratio

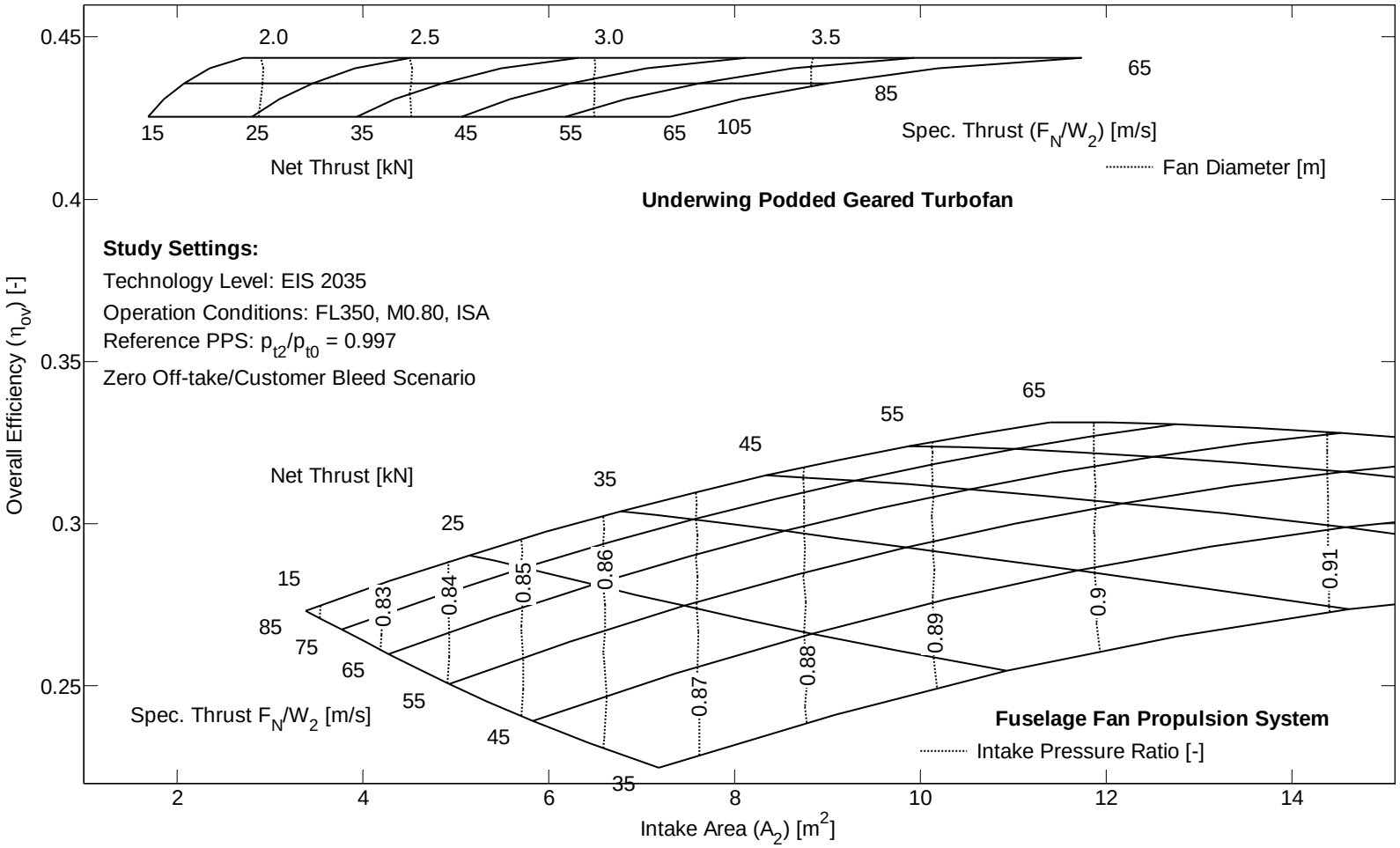




Propulsion System Sizing Investigation

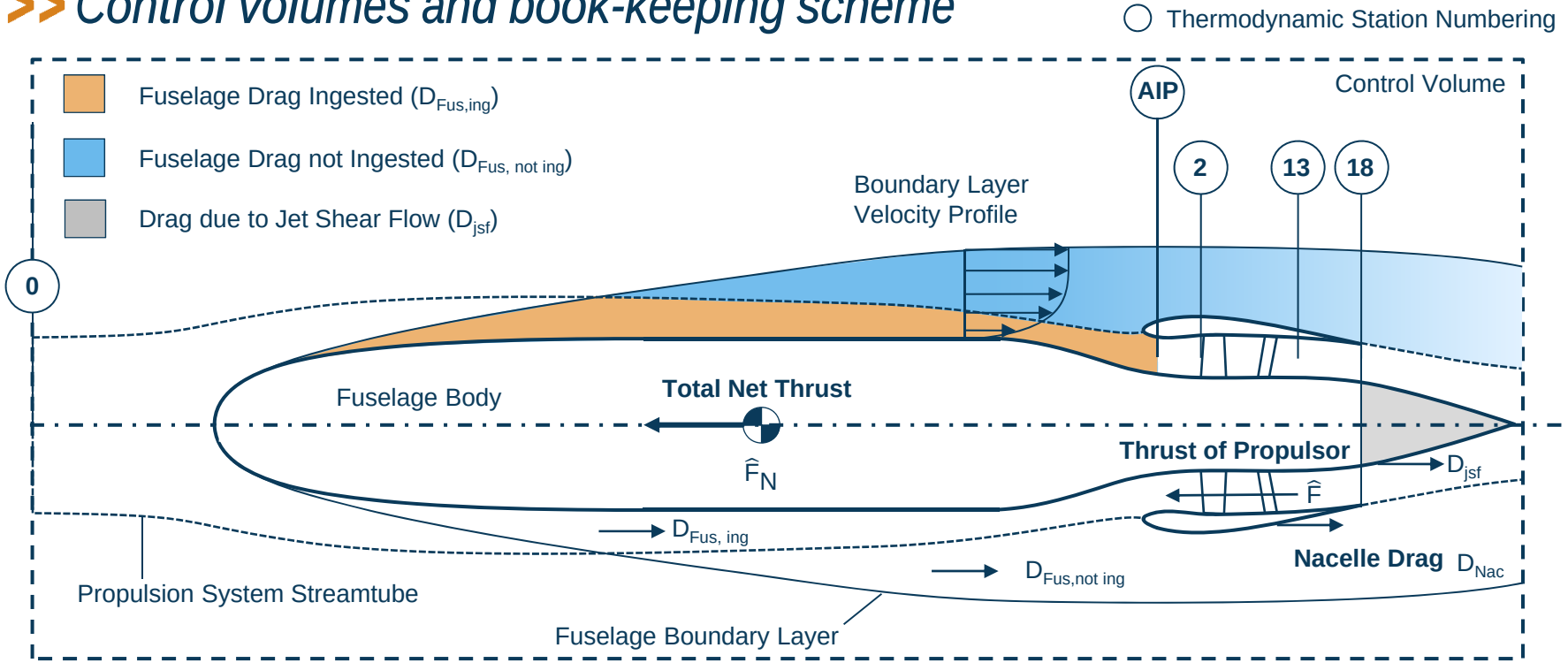


Propulsion System Sizing Investigation



CFD / Performance Matching

>> Control volumes and book-keeping scheme



>> Thrust / Drag Book-keeping:

$$\hat{F}_N = \hat{F} - \hat{D}$$

where $\hat{D}$ includes all drag shares occurring for the configuration

>> Integration Factor:

$$f_{int} = \frac{F_{N,calc}}{\hat{F}_N}$$

Implications of Fuselage Fan Propulsion System Integration

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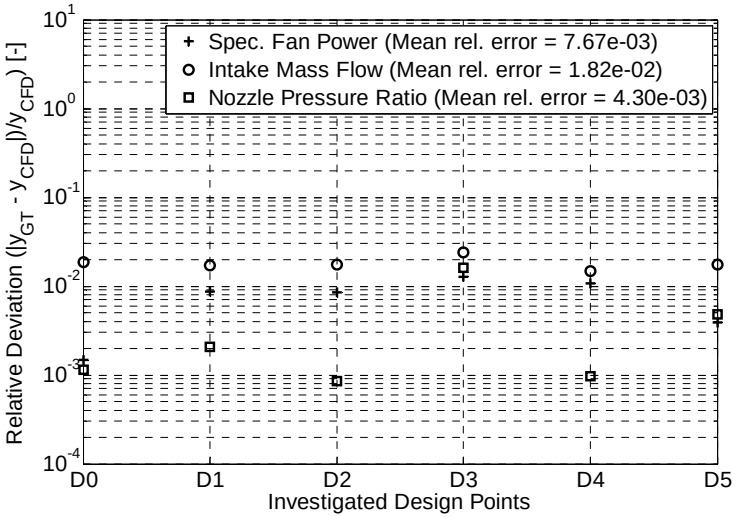
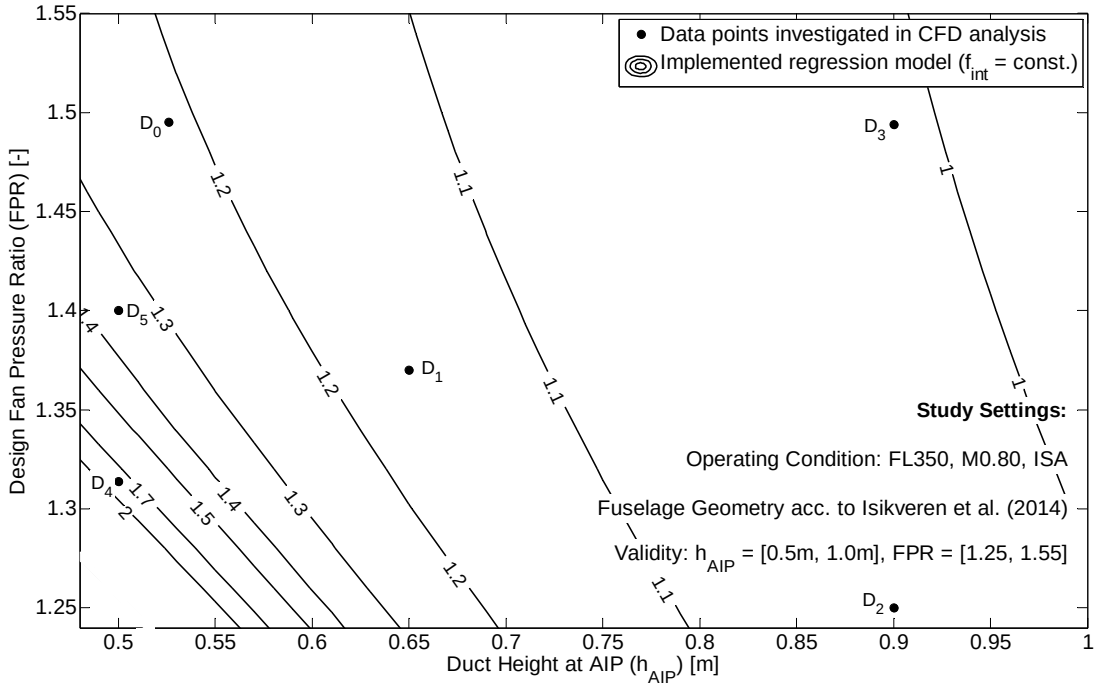
>> Nonlinear regression model of integration factor

>> Sensitivity to

- > Intake duct height at AIP
- > Design Fan Pressure Ratio





>> Verification Results:

- > Mean standard error: 1.2%

Integrated Performance Results

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Parameter	Unit	Semi-empirical methods (Seitz et al., 2014)	Present method	Delta [a] [%]
FF Inlet Duct Height	[m]	0.526	0.526	±0.0
FF Intake Pressure Ratio	[-]	0.909	0.861	-5.3
FF Core Intake Pressure Ratio	[-]	0.970	0.976	+0.6
FF Propulsion System Weight	[kg]	7811	8924	+14.2
Total TSFC at typical cruise [c]	[g/s/kN]	14.3	16.0	+11.9
Ingested Drag Ratio	[-]	0.21	0.29	+38.1
Delta OEW [d]	[%]	+3.5	+5.6	+2.1 [b]
Delta MTOW [d]	[%]	+0.1	+1.2	+1.1 [b]
Delta Block Fuel Burn [d]	[%]	-8.9	-9.4	-0.5 [b]
Delta ESAR [d]	[%]	+9.8%	+10.4	+0.6 [b]

[a] Results obtained from present method compared to semi-empirical methods
[b] Percentage points
[c] FL350, M0.80, ISA
[d] Relative to advanced reference aircraft (cf. Seitz et al., 2014)

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Conclusion & Future Work

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>> *Procedure for matching of aero-numerical characteristics with integrated performance simulation*

>> *Summary of important findings*

> Significant impact of propulsor size on Fuselage Fan integration effects

> Propulsion system overall efficiency degraded relative to podded power plant

> ESAR improvement for Propulsive Fuselage of 10.4% vs advanced reference aircraft

> Good agreement between presented approach and semi-empirical methods

>> *Focus of future work:*

> Detailed exploration of the design space feasible for PF concept

> Enhanced prediction of airframe-propulsion interaction and related propulsion system losses

> Investigation of hybrid electric power train options

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Backup

Investigated Design Space

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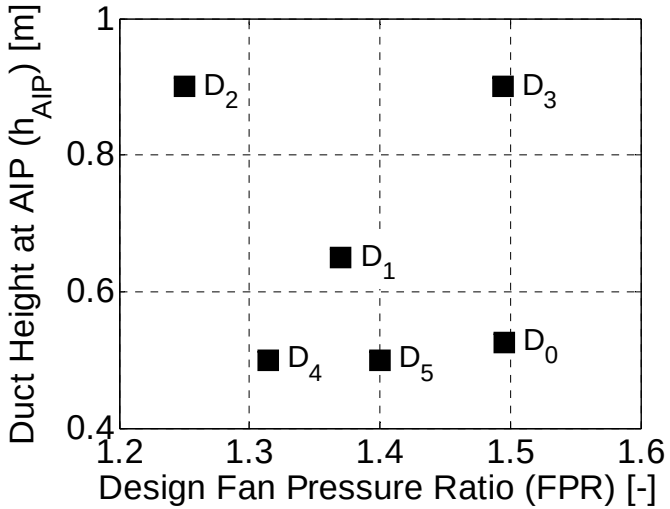
>> *Design points analyzed in multi-disciplinary investigation*

>> *Design parameters:*

> Duct height at aerodynamic interface plane → directly prescribed

> Design Fan Pressure Ratio → Adjusted via prescription of nozzle area ratio



Settings for Power Plant Design Studies

Parameter	Unit	Reference PPS	Fuselage Fan PPS
Turbine Entry Temperature (T_4) [a]	[K]	1750	1750
Overall Pressure Ratio (OPR) [a]	[-]	60.0	60.0
Axial Fan Inlet Mach number ($M_{ax,2}$)	[-]	0.70	0.56
Fan Inlet Hub/Tip Ratio (HTR_2)	[-]	0.29	Iterated acc. to intake duct height
Intake Pressure Ratio (p_{t2}/p_{t0})	[-]	0.997	Iterated acc. to present model
Core Intake Pressure Ratio (p_{t22}/p_{t21})	[-]	0.990	0.97
Fan polytropic efficiency (η_{Fan})	[-]	Base	-0.02

[a] Max. Climb at Top-of-Climb (FL350, M0.80, ISA)

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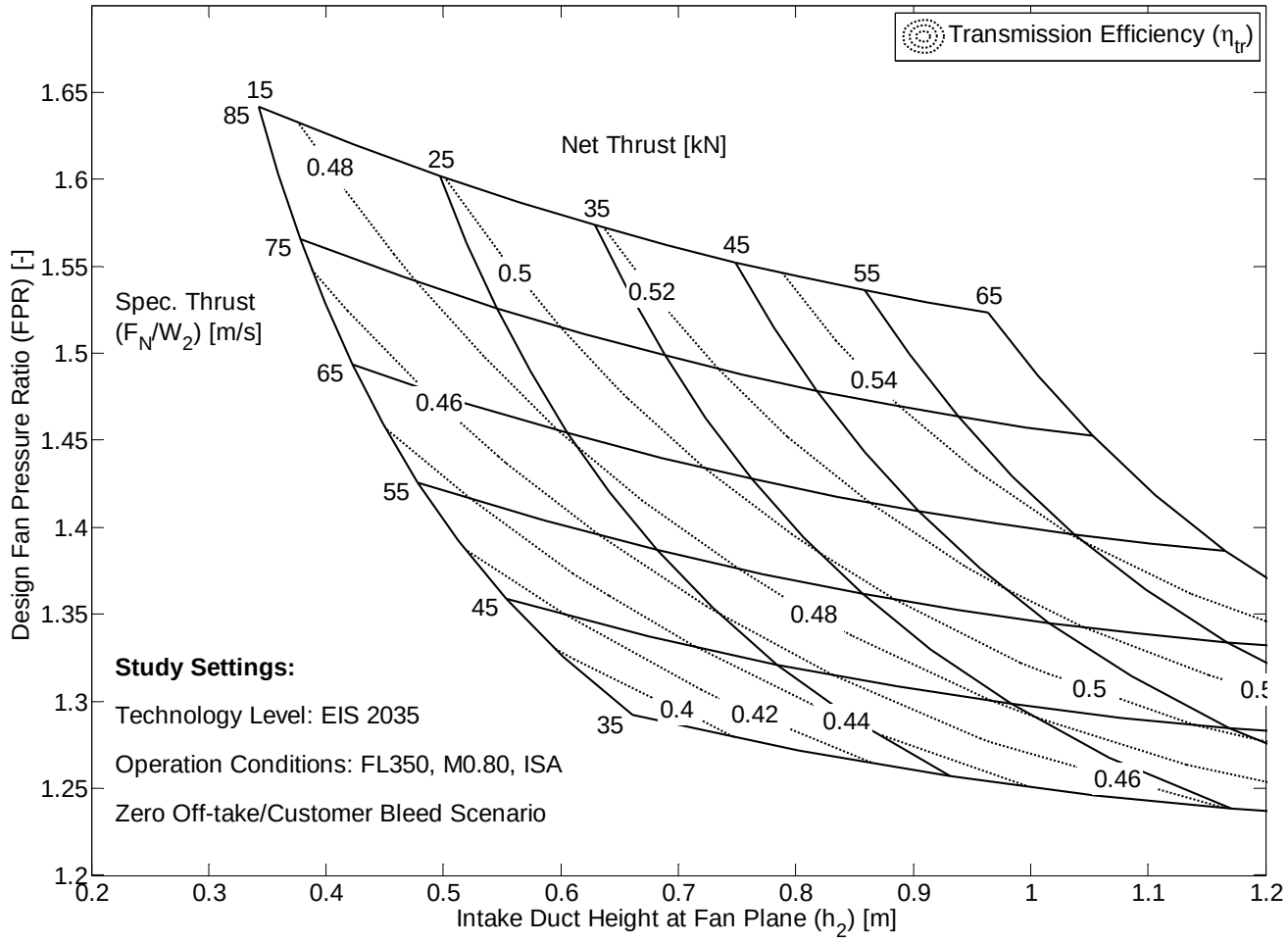
Details of Propulsion System Sizing Investigation

>> Characteristics of Transmission Efficiency



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Airbus
Lars Jørgensen, Peter Rostek

Hybrid electric propulsion and future configurations

EASN Aachen, 28-Oct-2014

Innovation

A long term future technology vision

Configuration and new power plant	Non-conventional aircraft concept New propulsion concepts
Flow control	Full active flow and load control
Airframe	Adaptive, intelligent structures
Value adding cabin	New passenger services full wireless
Mission management	Flight or ground based Mission management

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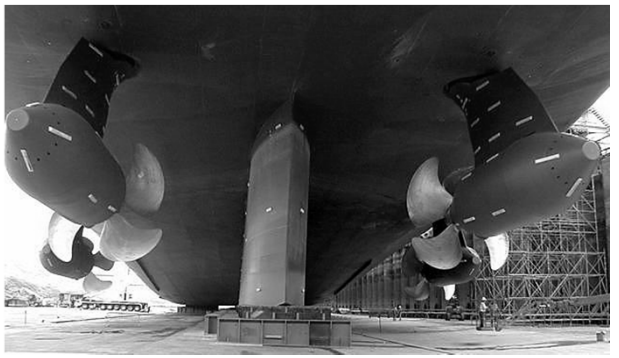
Hybrid Electric Propulsion

Nothing New for Other Markets

- Panamera Hybrid
- 0.07 MW / 5500 rpm
- 1 to 2 kW/kg

- Liebherr Mining Truck
- 3 MW
- 0.25 kW/kg



- Queen Mary 2
- 20 MW / 180 rpm
- 0.2 to 0.4 kW/kg

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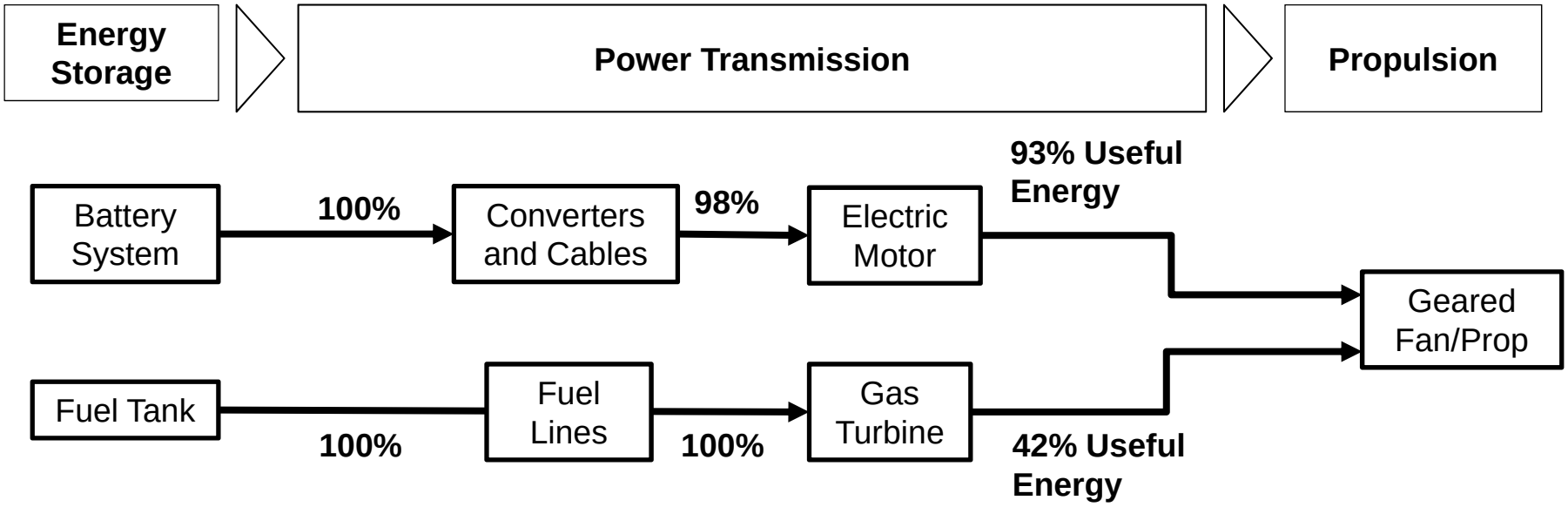
Overall Energy Architecture

Challenge: Battery weight

Opportunity: Open the design space

High efficiency of electric power chain to boost overall efficiency of hybrid architecture



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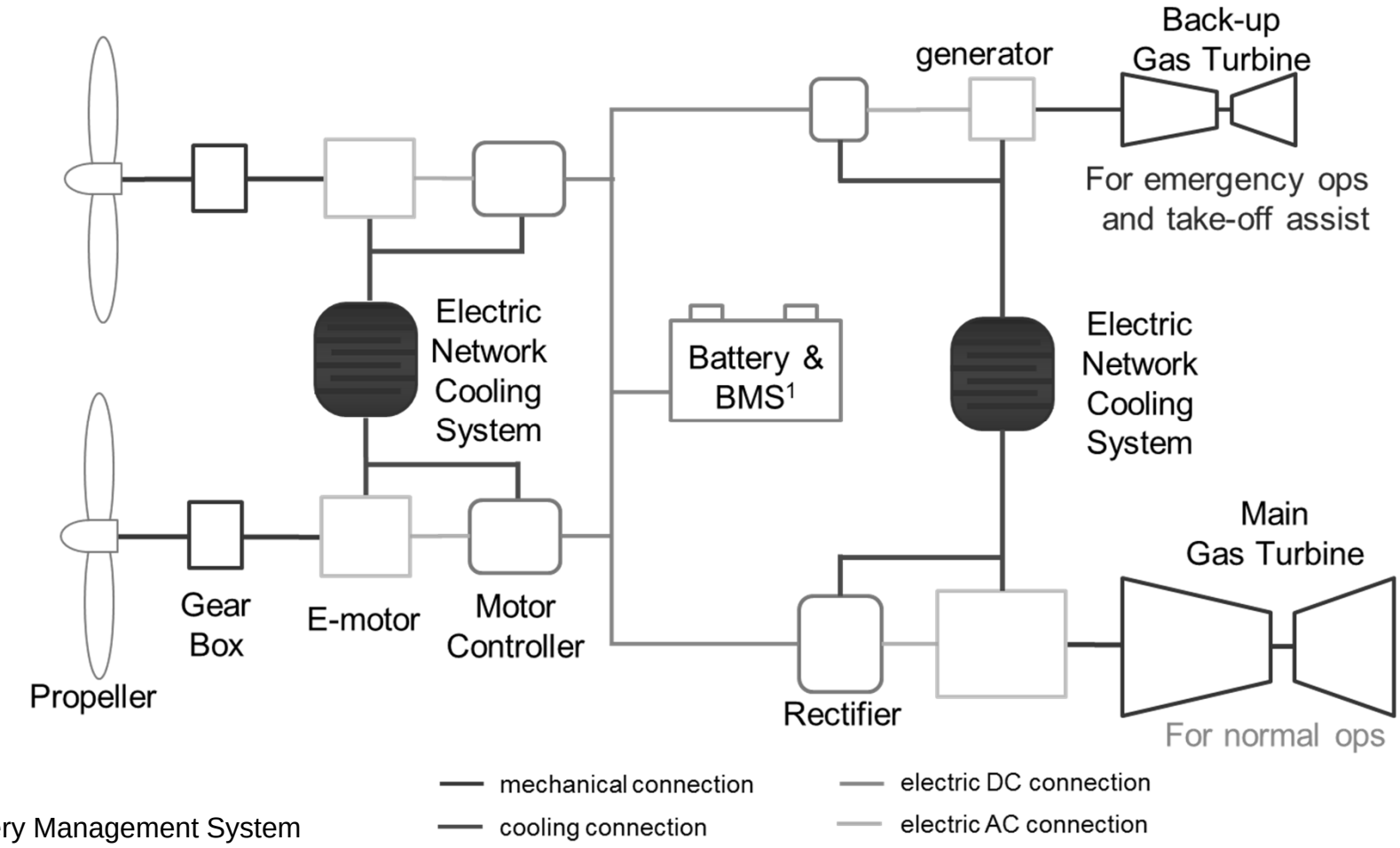
Baseline Propulsion Architecture



[1]: Battery Management System

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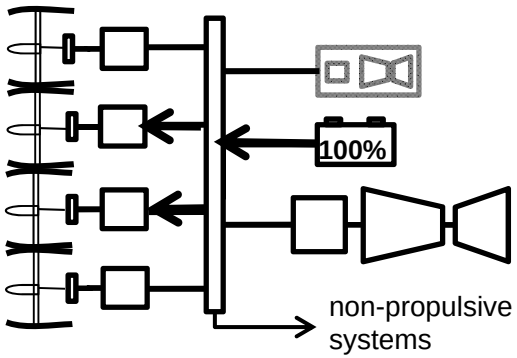
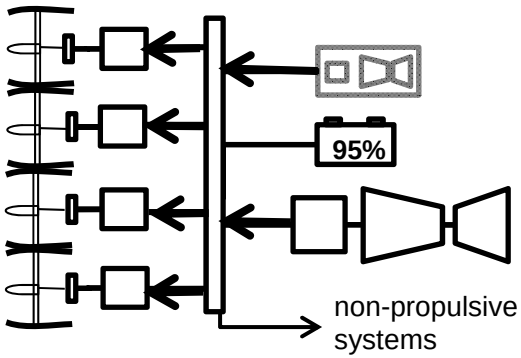
Energy Management Strategy

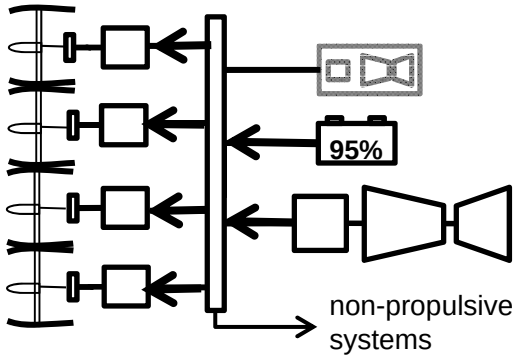
Energy and power management are key for efficient operation of hybrid architectures



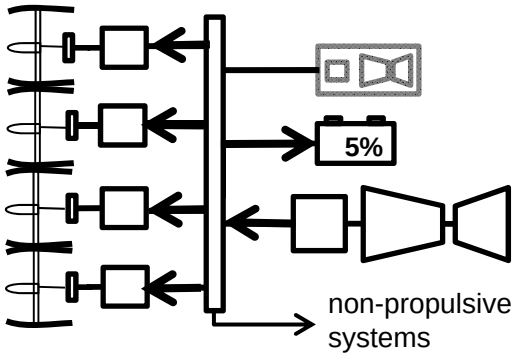
Taxi-Out



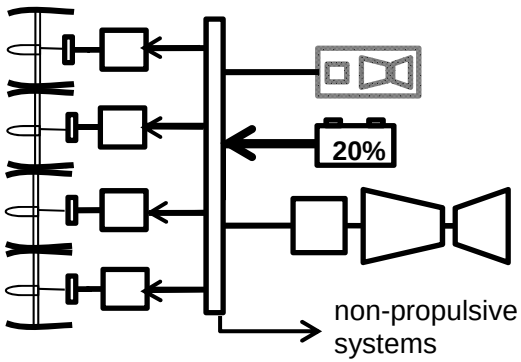
Take-Off



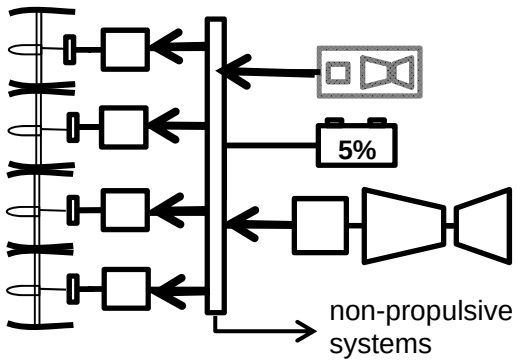
Climb



Cruise



Descent



Approach

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Airbus E-Fan

- Light training aircraft
- First flight: 11-Mar-2014
- Total power: 60KW, for about 30min of flight
- Electric taxiing
- To be manufactured by *VoltAir*, a wholly owned subsidiary of Airbus Group in Mérignac (France)
- To be developed into a family of aircraft, including larger models and hybrid propulsion

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e-Genius

- Test platform by University Stuttgart, with Airbus support
- First flight 25-May-2011
- Power 72kW
- Took second place in Green Flight Challenge 2011
  - Fuel consumption: 0.63 l/100km
- Development to be continued with new propulsion concepts (including hybrid)

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European research programs

CORAC (PIA-2)

LuFo5-2

ATI / TSB

NACRE

Components/
Configurations

Clean Sky 1

CleanSky2

WP 1.3 Scale Flight Testing

WP1.6 Radical A/C Conf.

Hybrid Electric Demonstrator

IEP
(Innovative Evaluation Platform)

Large Scale … Simulator

?

First flight 2022

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

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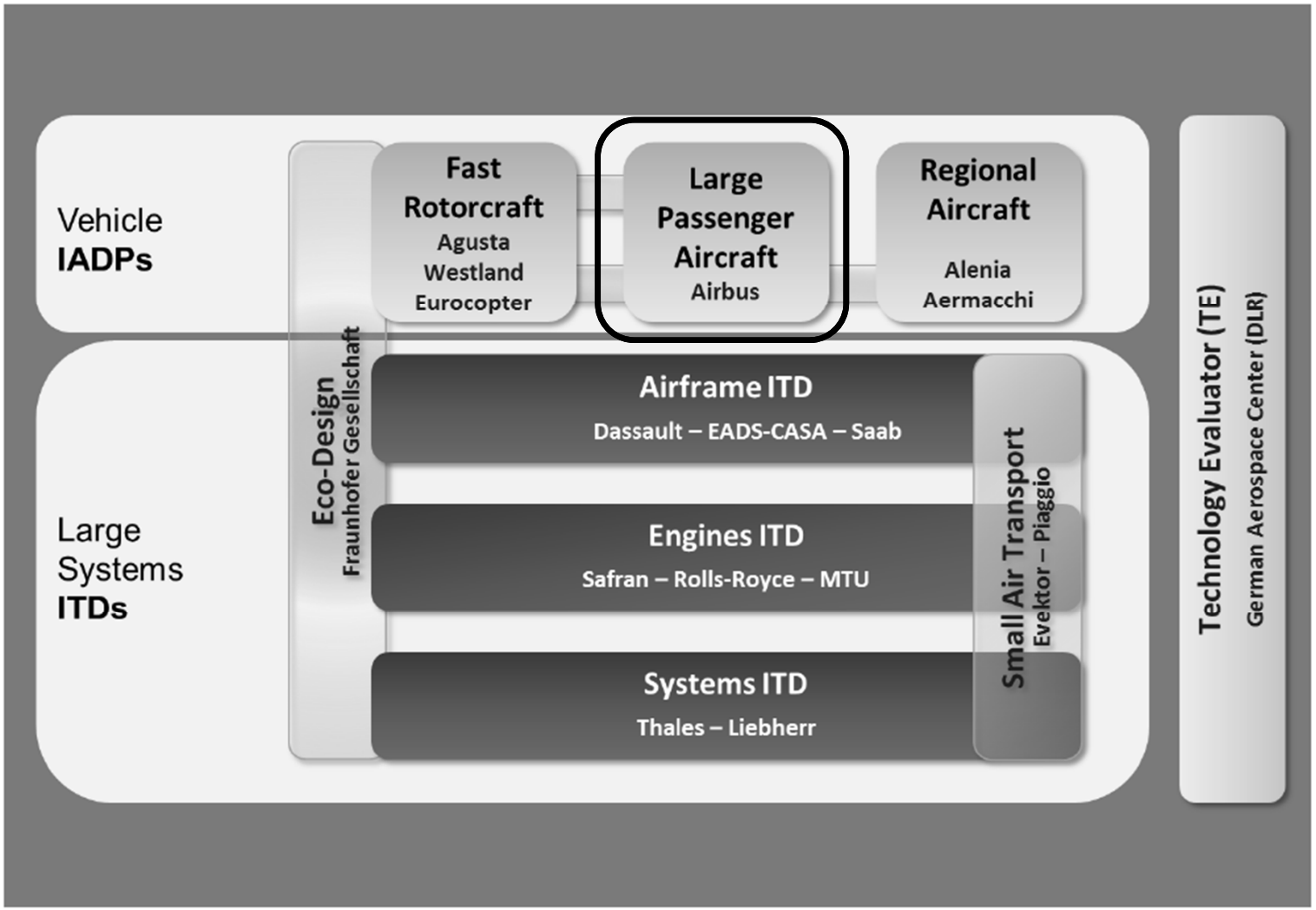
Overall Structure of Clean Sky 2 (2014 - 2023)



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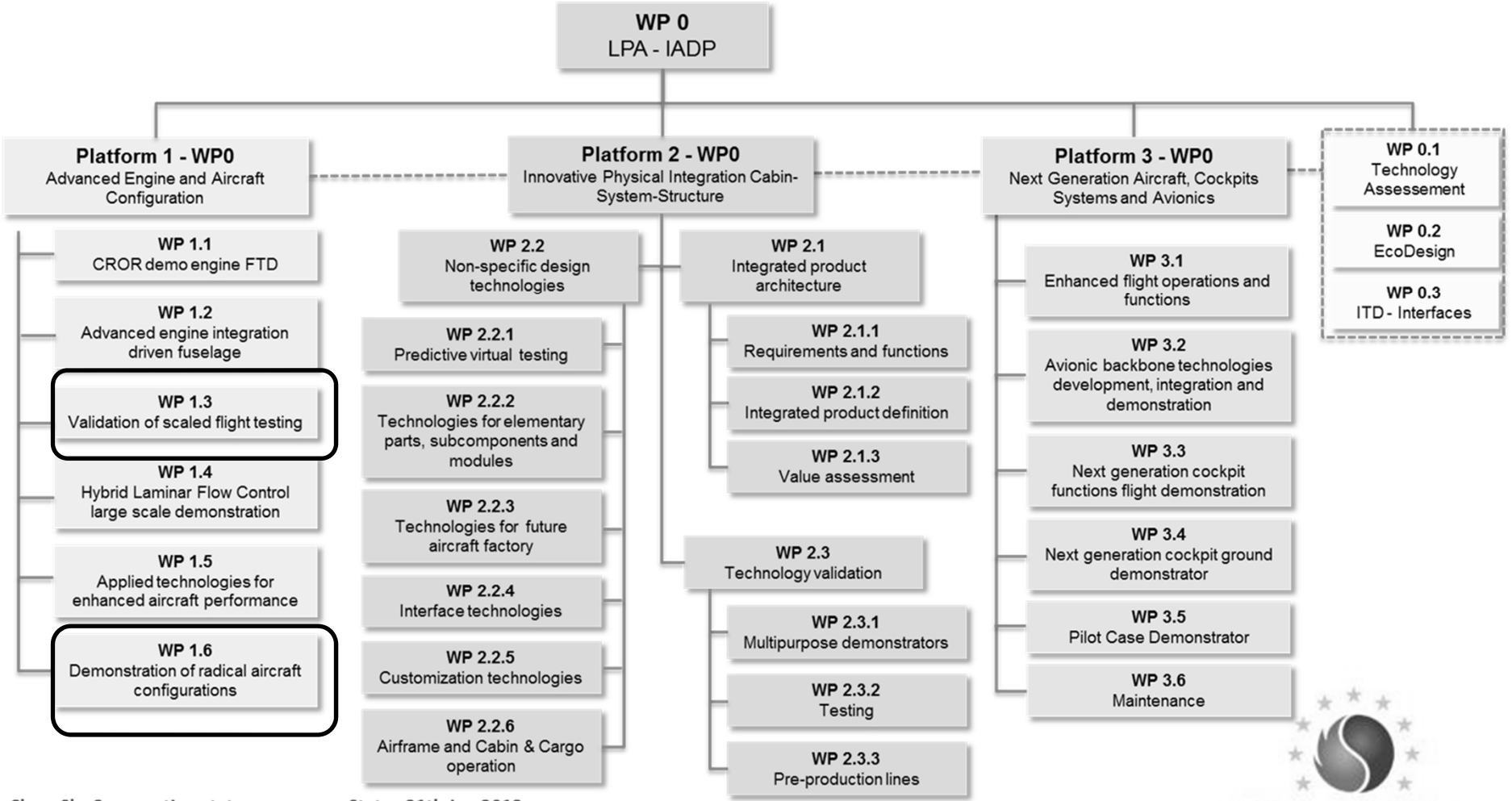
CleanSky2 – LPA-IADP Work Breakdown Structure



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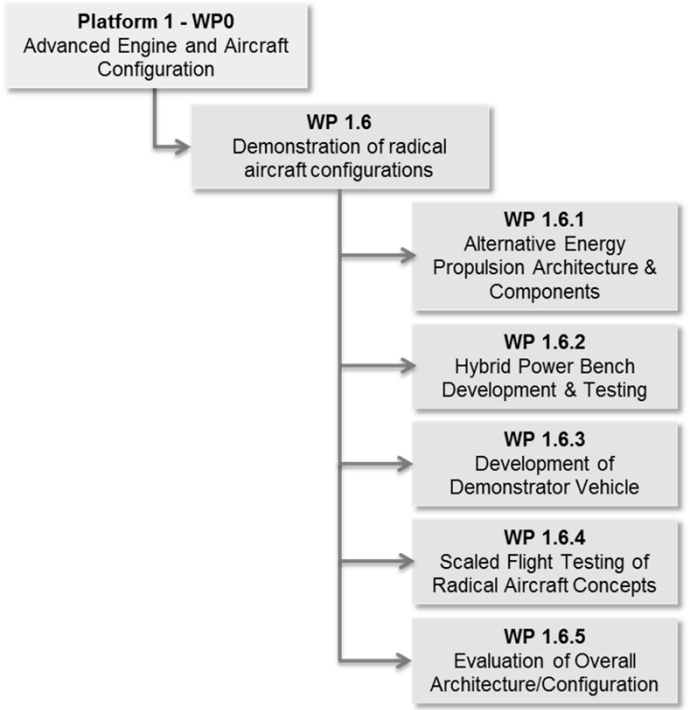
WP1.6 – Demonstration of Radical Aircraft Configurations



Gross budget: 98M€

Timescale: Q3 2015 – Q3 2024

Top objectives

- Development of advanced aircraft concepts (airframe, systems architecture, propulsion concept) with an integrated design approach.
- In particular development of hybrid propulsion concepts.
- Testing of developed technologies and airframe components by means of adaptable and rapid test means such as scaled flight testing.

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Conclusion

- **Hybrid electric propulsion is seen as a candidate technology for future large passenger aircraft by Airbus**
- **One of the benefits is seen in the opening of the design space, enabling new configurations**
- **For the development both studies and demonstrators are required**
- **The technology maturation will be supported through different funding frameworks**

eThrust concept 2013

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Enhanced Wake Vortex Decay in Ground Proximity Triggered by Plate Lines

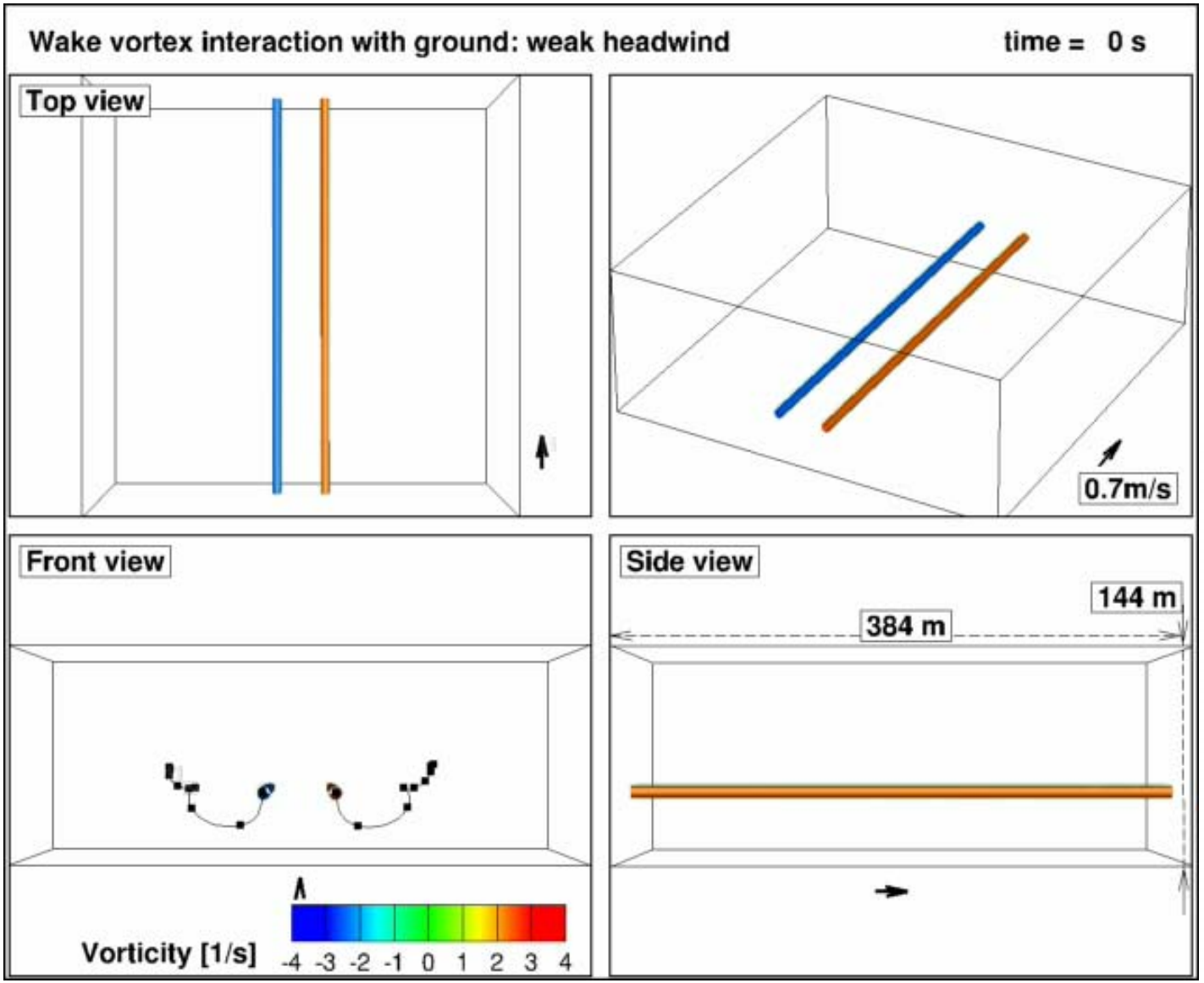
F. Holzäpfel, A. Stephan, T. Heel, S. Körner
[1]*Institut für Physik der Atmosphäre, DLR, Oberpfaffenhofen*

- wake vortex behavior in ground proximity – impact of wind, ground effect, end effects, plate line
- numerical simulation (hybrid RANS/LES)
- measurement campaigns WakeMUC & WakeOP
- outlook: plate lines at Munich airport

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

L-bows

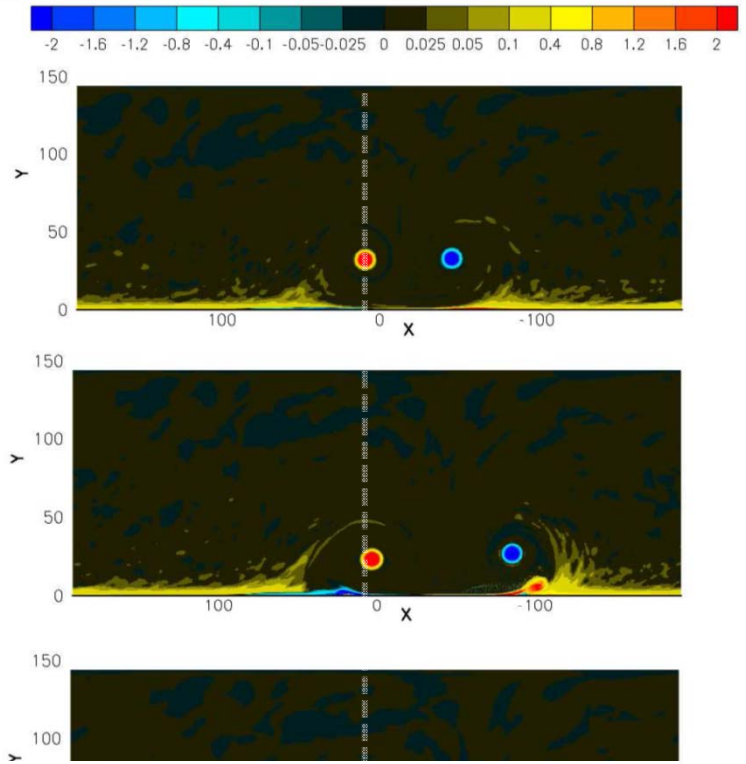
wake vortex evolution in ground proximity

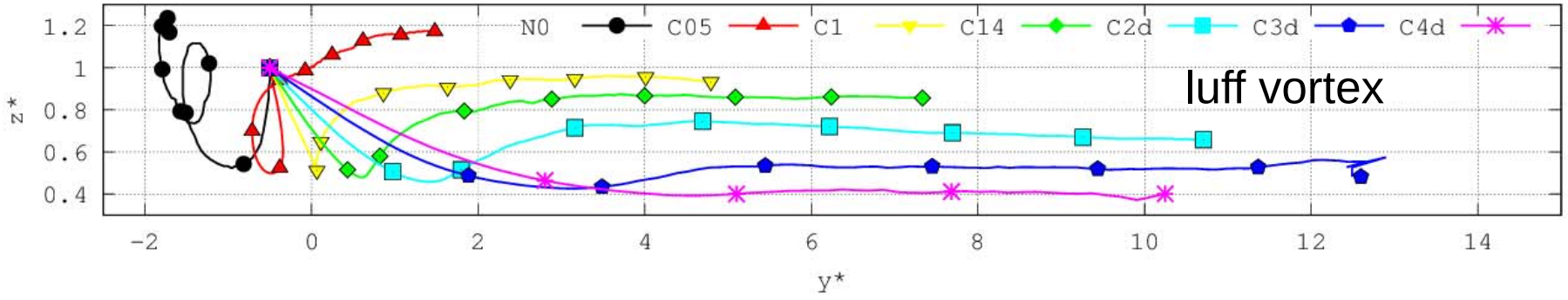


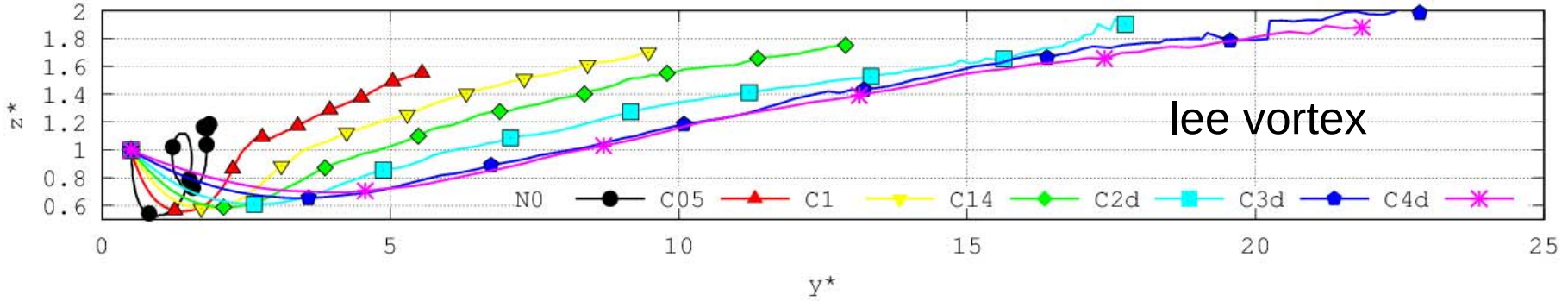
$z_0 = b_0$

ground effect with crosswind

($0.5\ w_0 - 4\ w_0$)







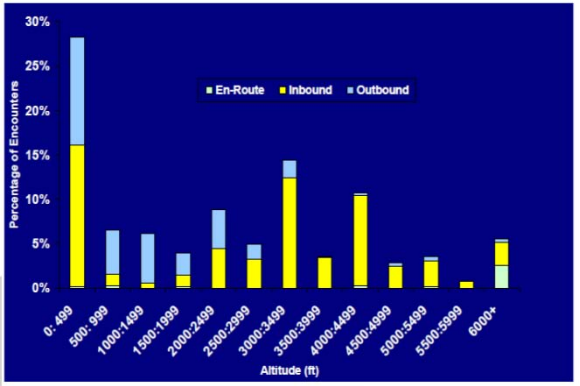
why consider approach & landing ?

- high risk to encounter WV in ground proximity:
  - physics: WV cannot descend below glide path ⇒ rebound
  - lidar, LES: WV may live much longer than 2 min (5 NM)
  - NATS incident reporting: most encounters in ground proximity
  - CDG airport: 3% WV closer than 25 m to follower a/c at threshold (V. Treve)
  - analysis of WSVBS: 57 – 70% of lowest gates impede reduced separations (AIAA Paper 2011-3037)
- possibilities to recover limited by low altitude ⇒ potentially critical situation

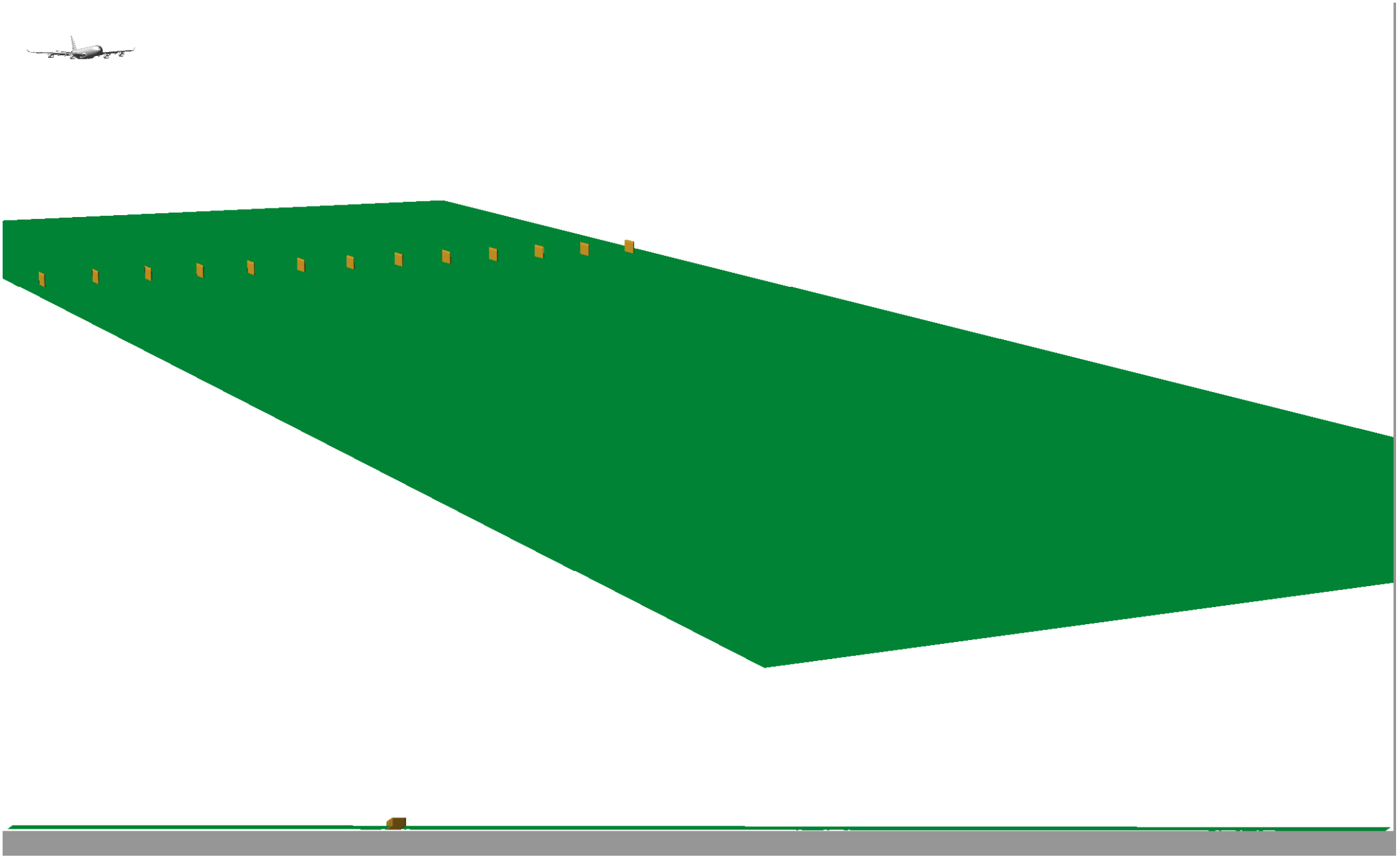
⇒ “Why is approach and landing safe under these conditions?”

⇒ “Can we actively promote WV decay in ground proximity?”

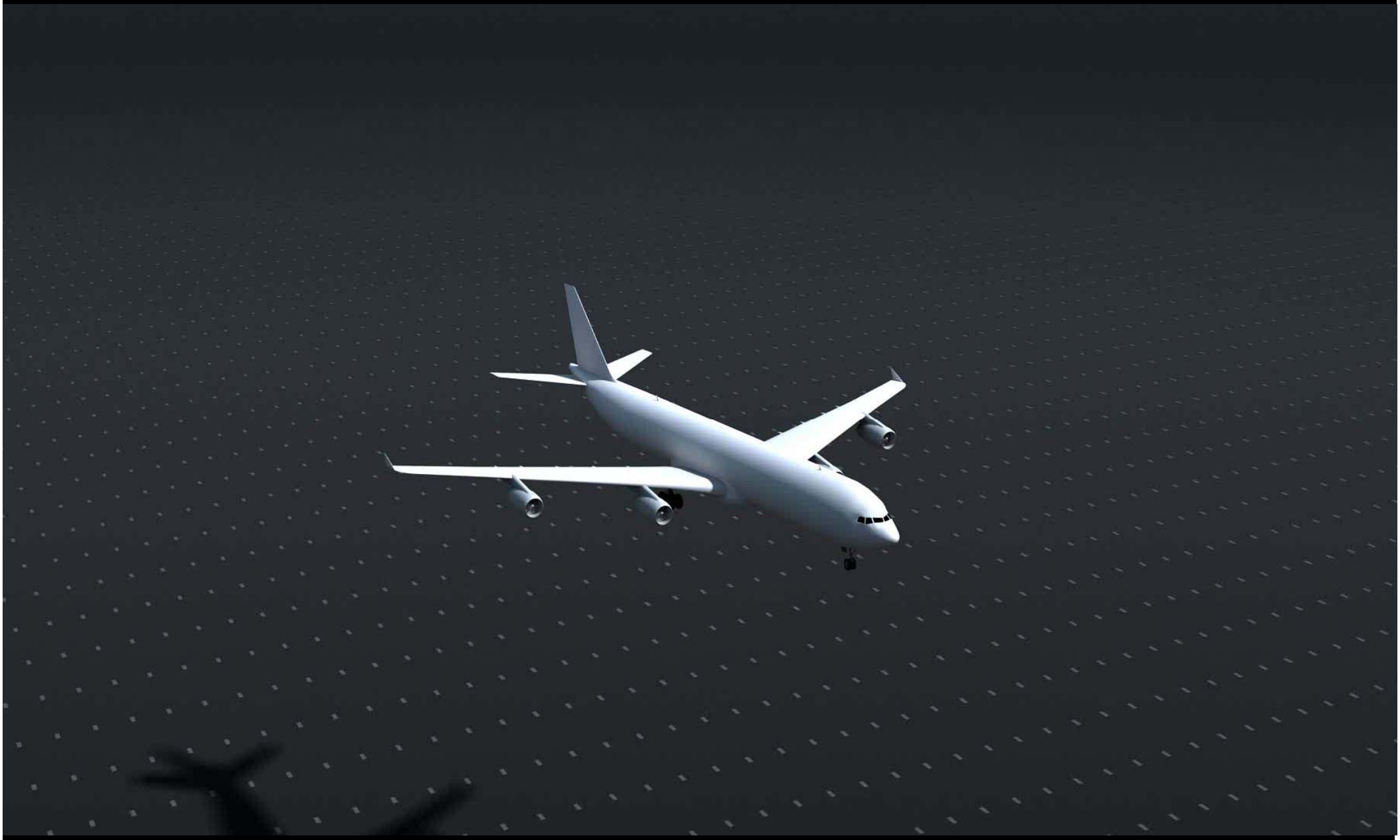
- answers crucial for design of optimal WVAS



LES – landing aircraft with end effect & plate line

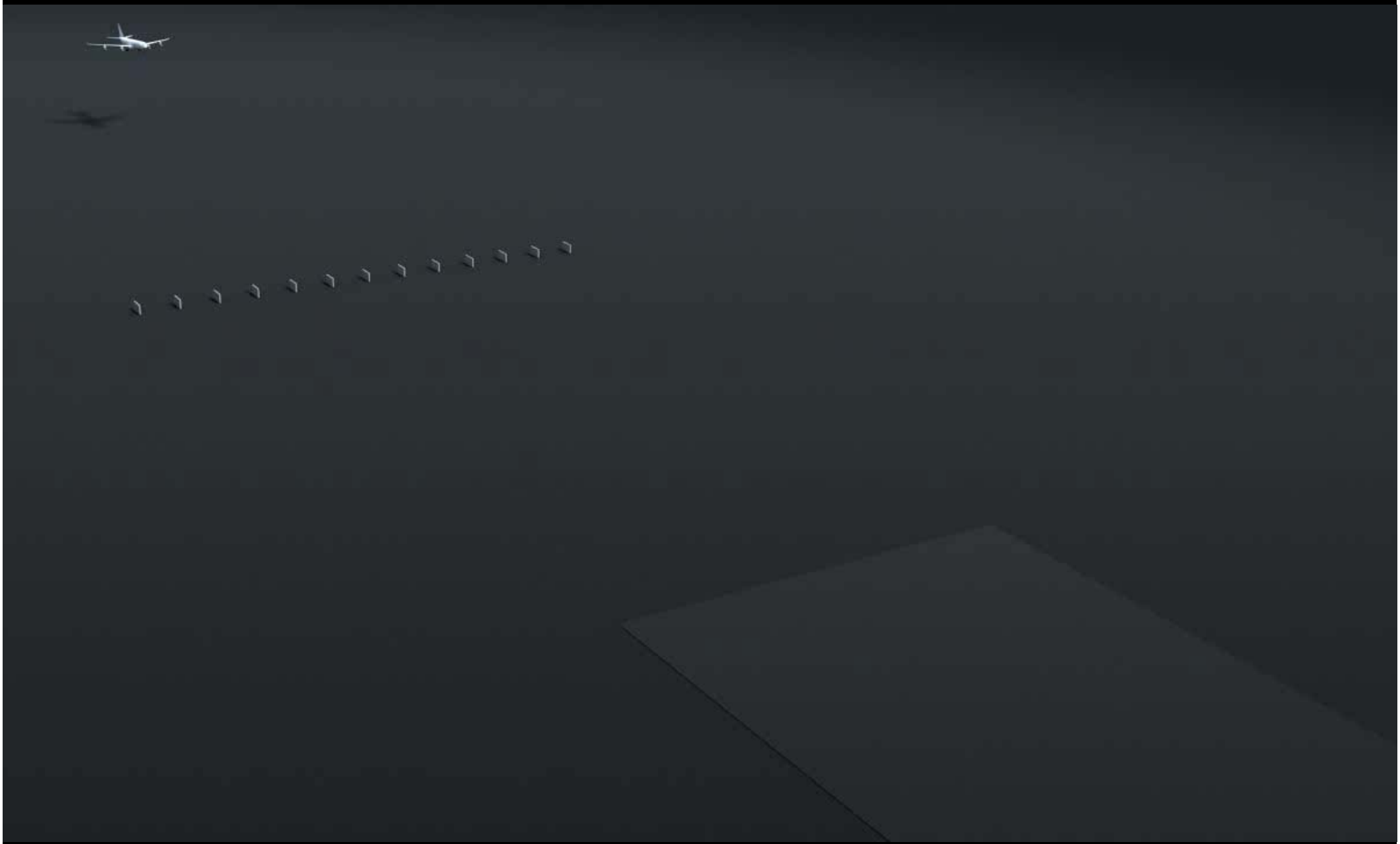


LES – landing aircraft with end effect & plate line

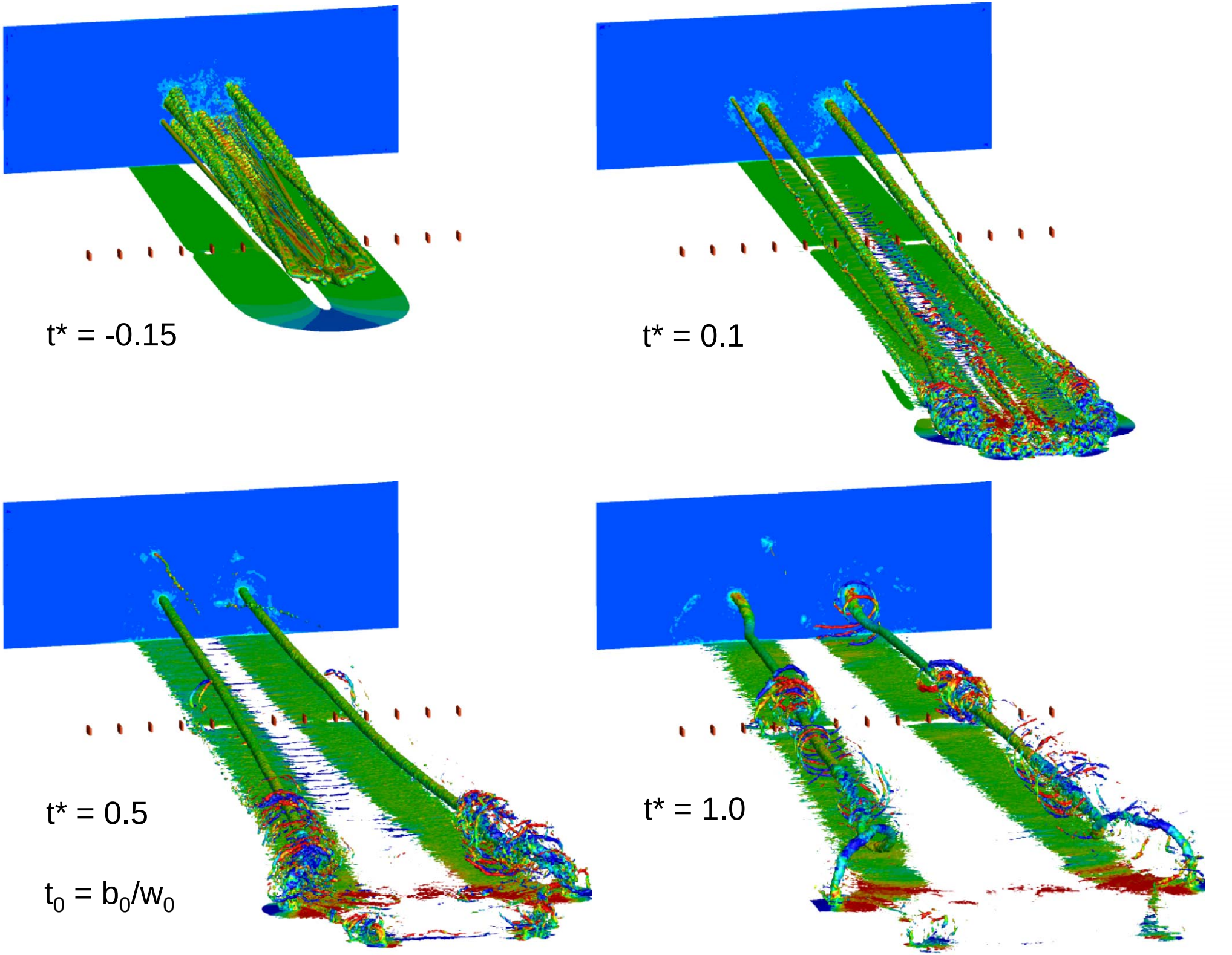


Animation Gregor Hochleitner, Thomas Ruppert, DFD

LES – landing aircraft with end effect & plate line



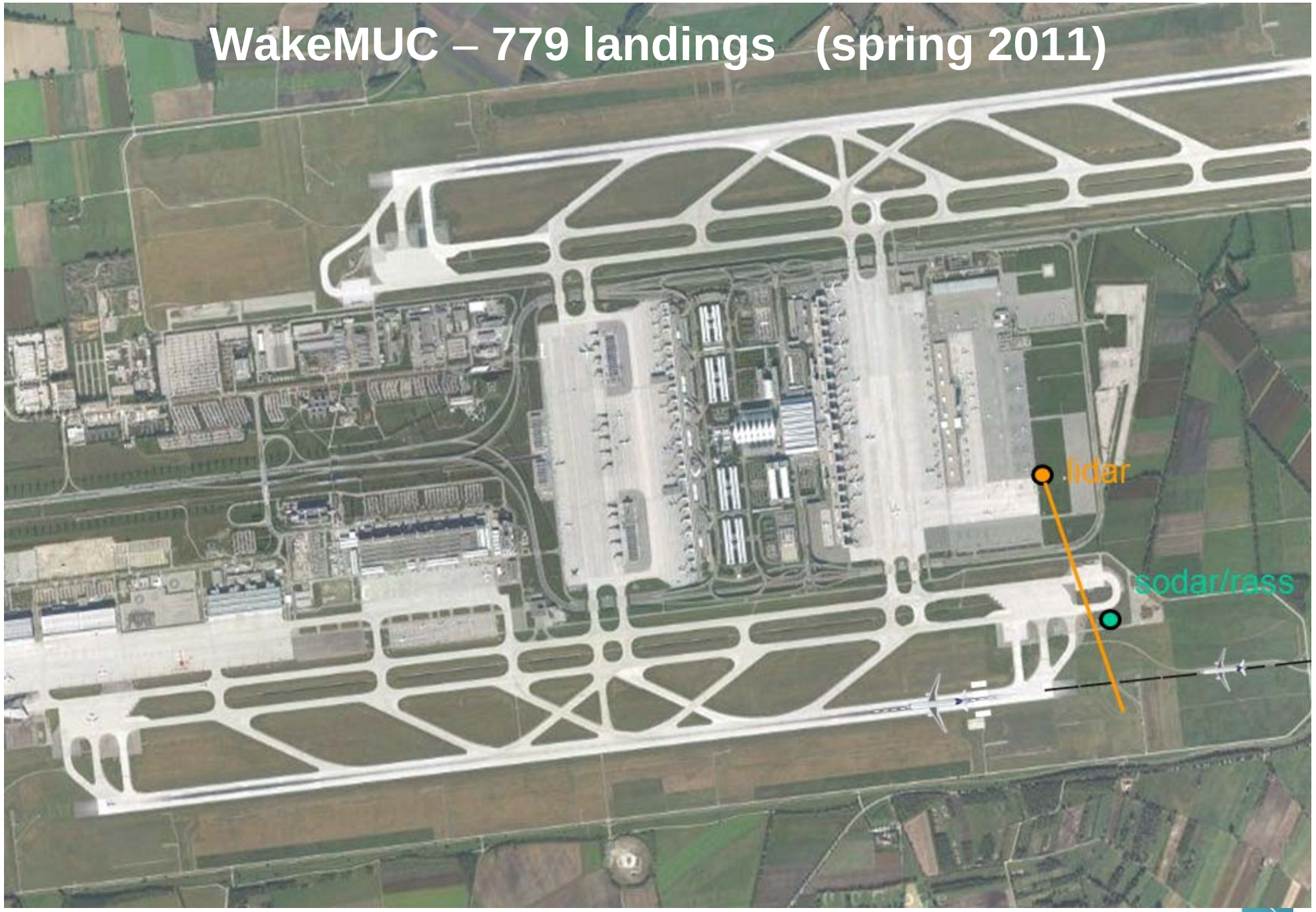
Animation Gregor Hochleitner, Thomas Ruppert, DFD

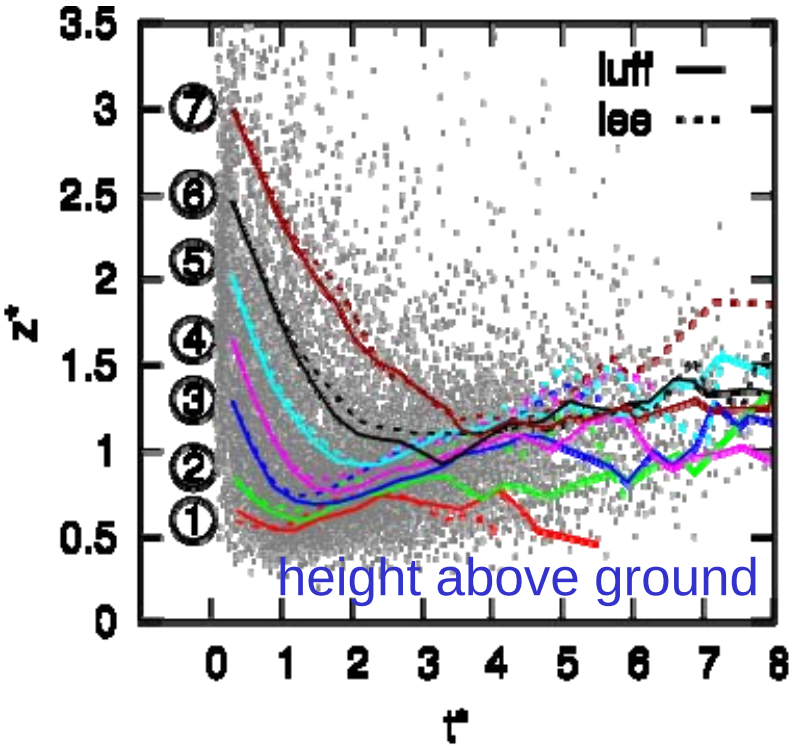

t* = -0.15
t* = 0.1
t* = 0.5
$t_0 = b_0/w_0$
t* = 1.0

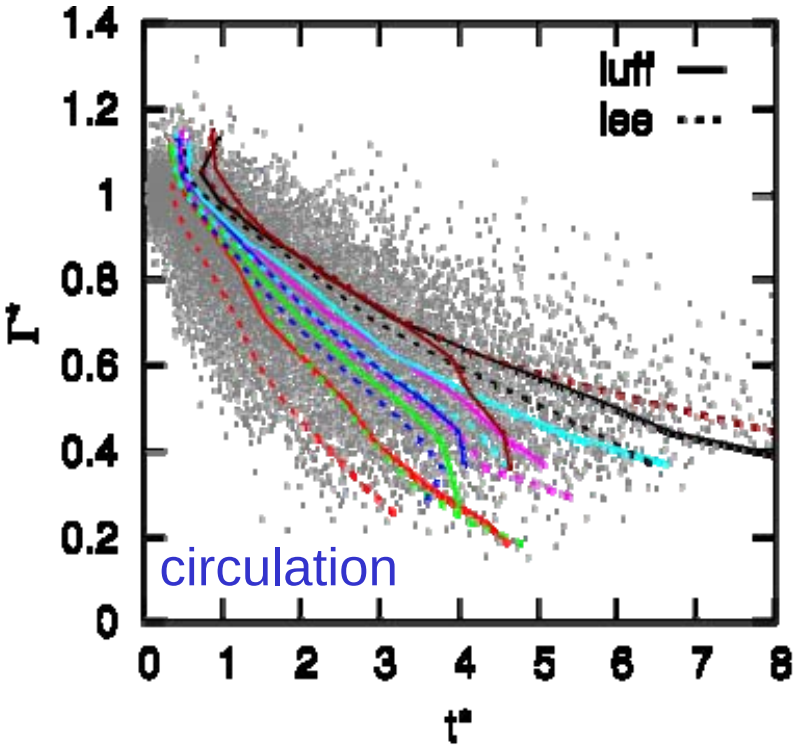
end effect
YouTube - a very wet arrival at Port Macquarie

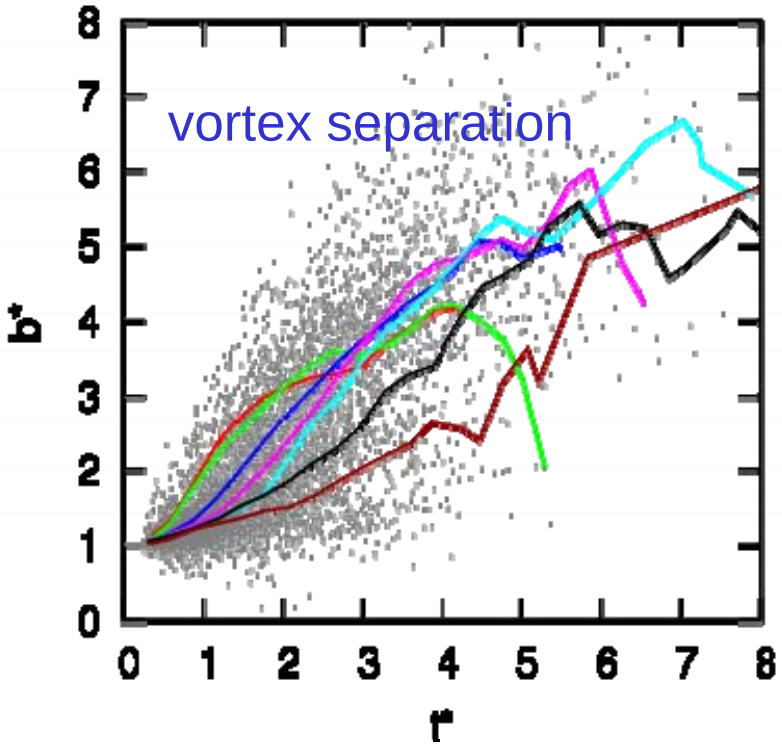
v_{prop} ~ 60 m/s (very rough estimate)

WakeMUC – 779 landings (spring 2011)









number	normalized height range
1	0.4 – 0.8
2	0.8 – 1.2
3	1.2 – 1.6
4	1.6 – 2.0
5	2.0 – 2.4
6	2.4 – 2.8
7	2.8 – 3.5

decay triggered by plate line ($z_0 = b_0$)

BUNDESREPUBLIK DEUTSCHLAND

URKUNDE

über die Erteilung des

Patents

Nr. 10 2011 010 147

IPC
B64F 1/36

Bezeichnung
Oberflächenstruktur einer Erdbodenoberfläche zur Beschleunigung des Zerfalls von Wirbelschleppen im Endteil eines Anflugs auf eine Landebahn

Patentinhaber
Deutsches Zentrum für Luft- und Raumfahrt e.V., 51147 Köln, DE

Erfinder
Holzäpfel, Frank, Dr., 86919 Utting, DE

Tag der Anmeldung
02.02.2011

München, den 05.07.2012

Die Präsidentin des Deutschen Patent- und Markenamts

Rudloff-Schäffer

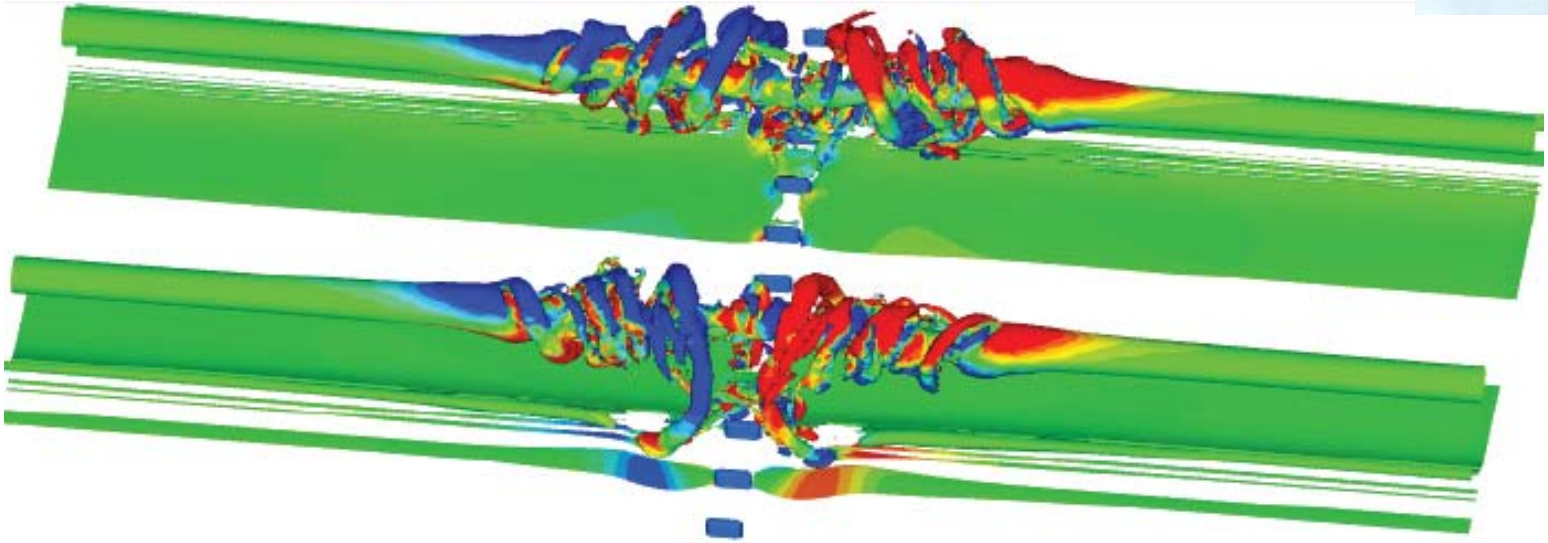
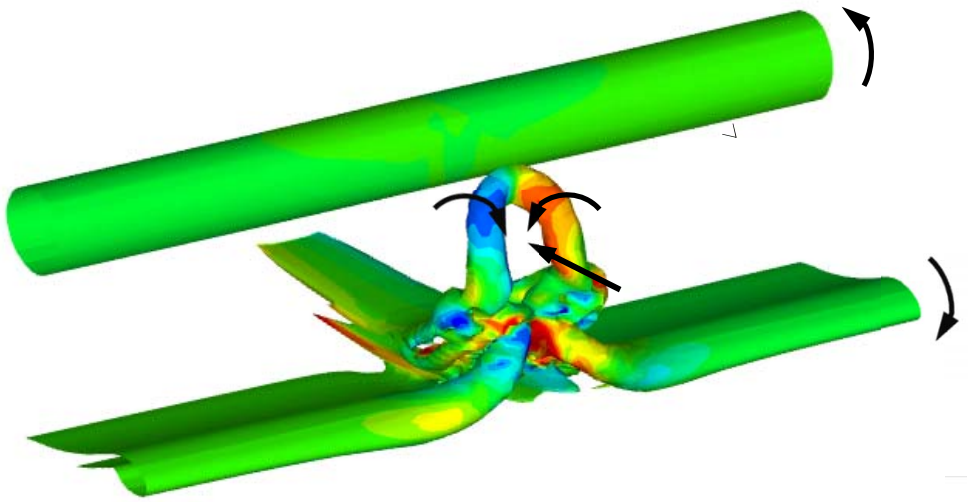


plate dimensions for e.g. A340:
length × height: 9 m × 4,5 m
spacing: 20 m

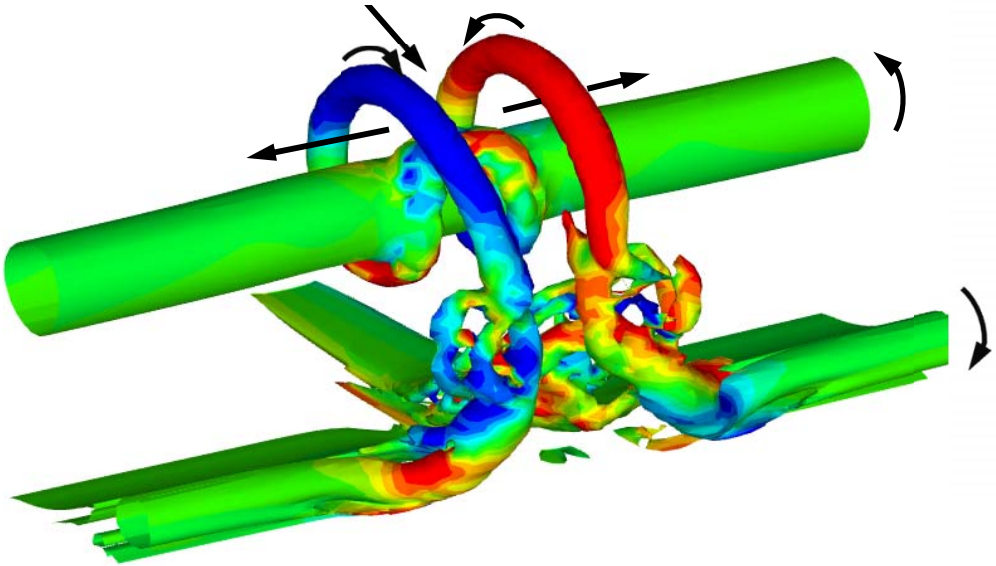
key mechanisms

(with and w/o obstacles)

2. Ω shape causes self-induced **fast approach** to primary vortex (PV)

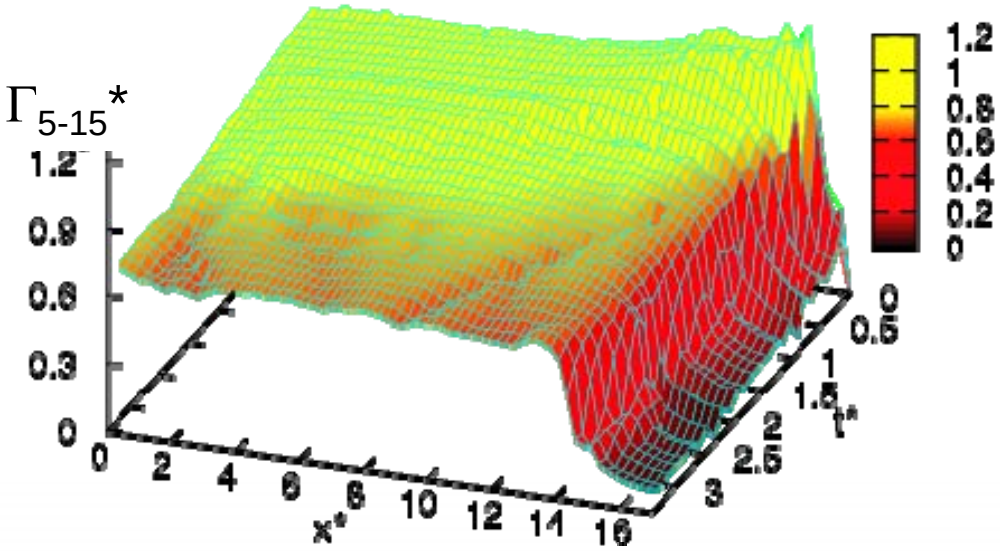


3. after SV has looped around PV it separates and **travels along the PV** (again driven by self induction)

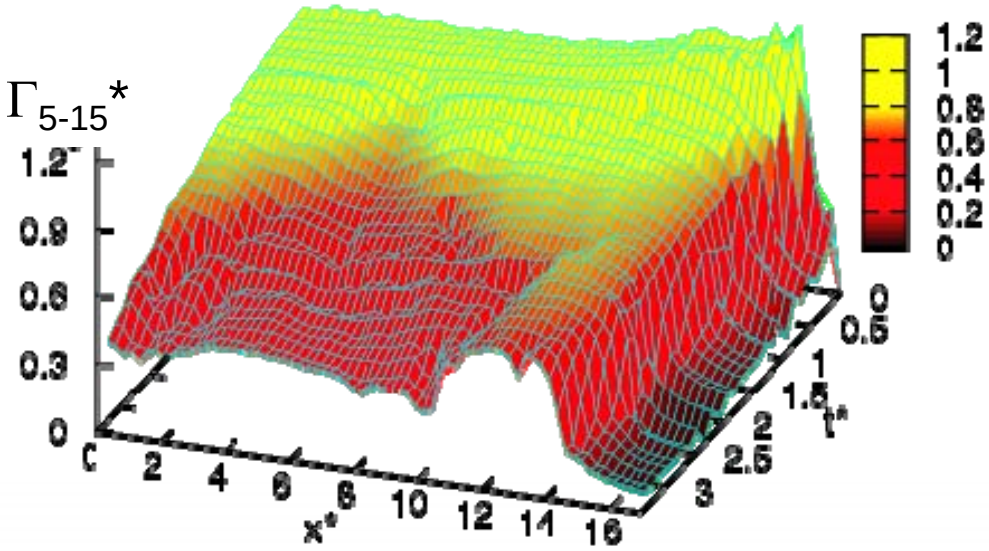


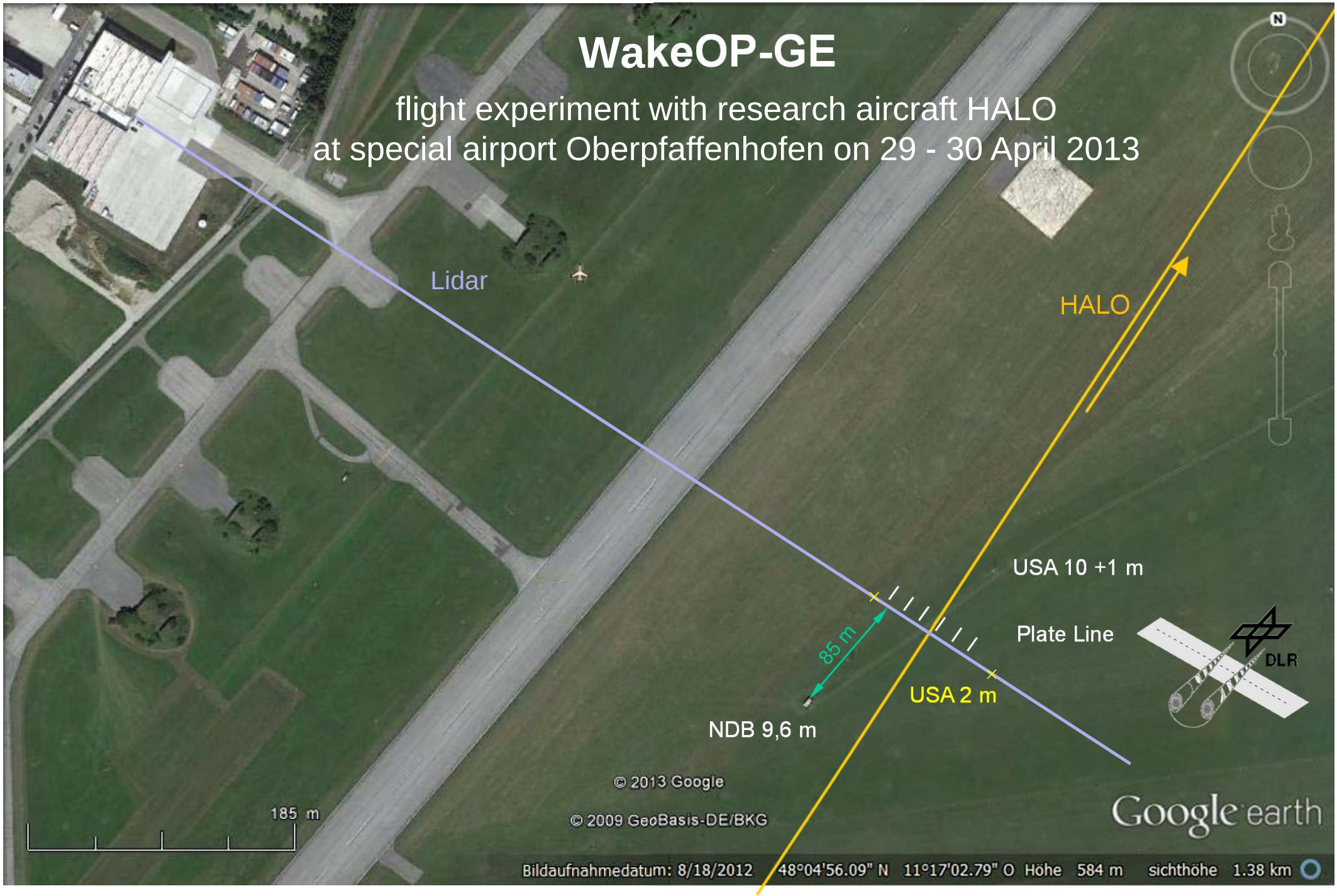
circulation decay with end effect

w/o plate line



with plate line




WakeOP-GE
flight experiment with research aircraft HALO
at special airport Oberpfaffenhofen on 29 - 30 April 2013
Lidar
HALO
USA 10 +1 m
Plate Line
85 m
USA 2 m
NDB 9,6 m
DLR
© 2013 Google
© 2009 GeoBasis-DE/BKG
185 m
Google earth
Bildaufnahmedatum: 8/18/2012
48°04'56.09" N 11°17'02.79" O Höhe 584 m
sichthöhe 1.38 km

WakeOP-GE – plate line

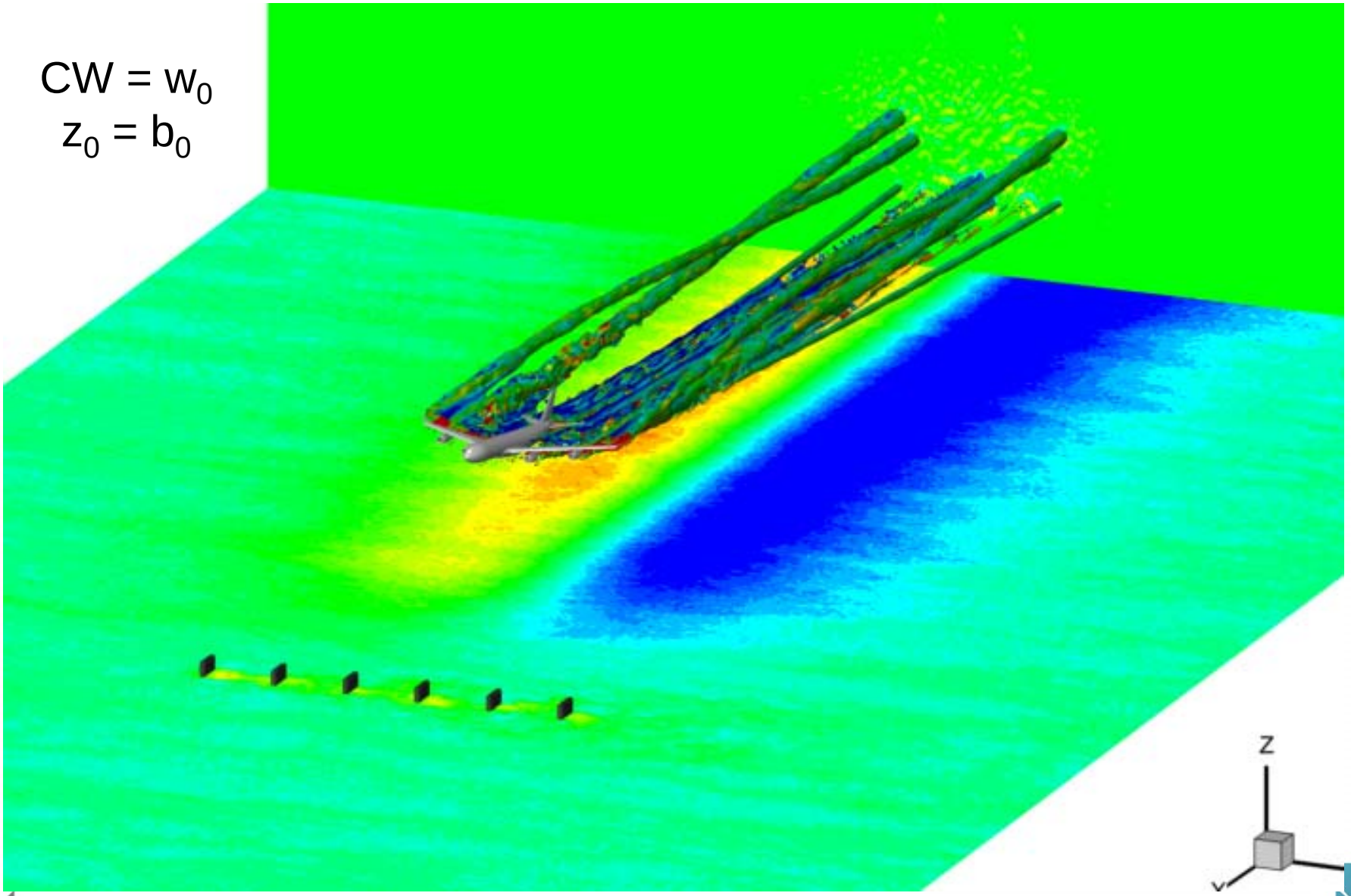
WakeOP-GE – impression

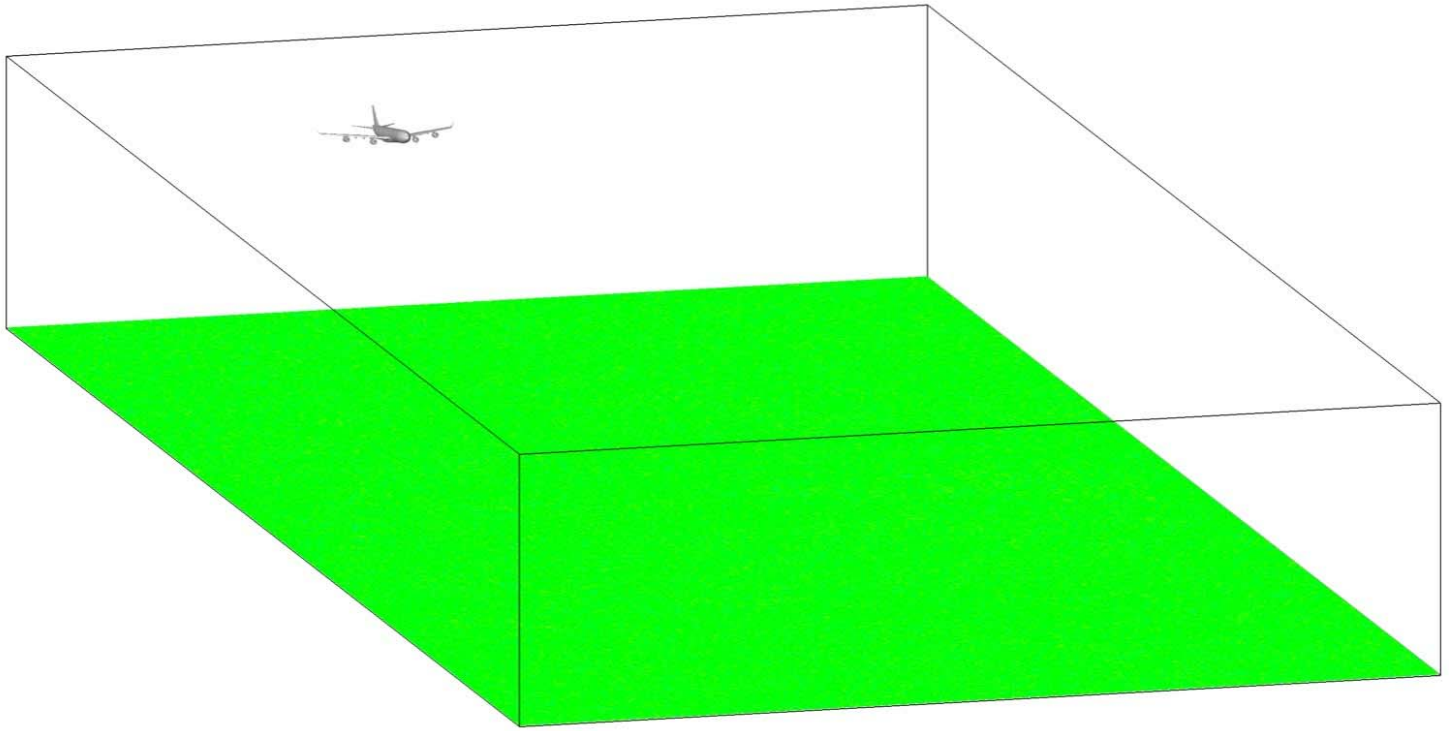
WakeOP-GE – smoky vortices

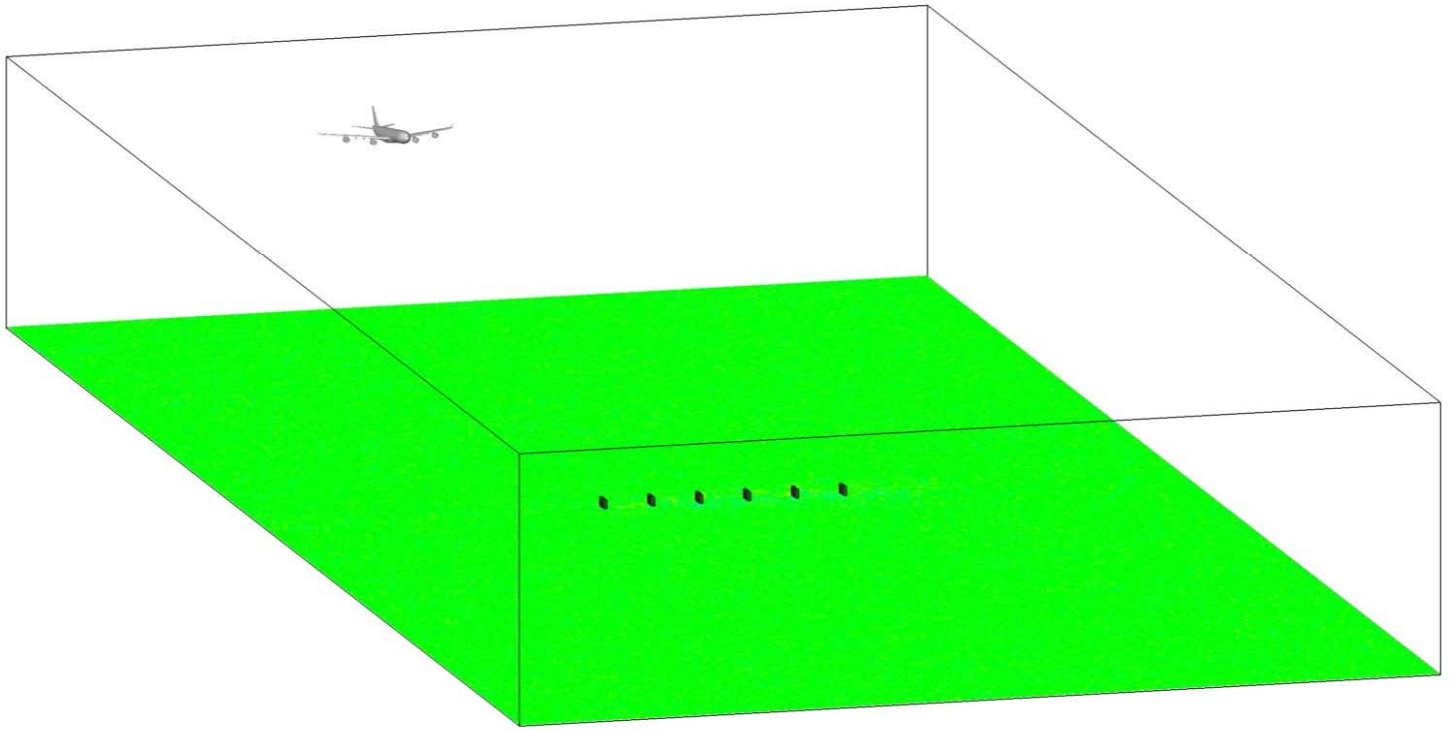
WakeOP-GE – LES

$CW = w_0$

$z_0 = b_0$





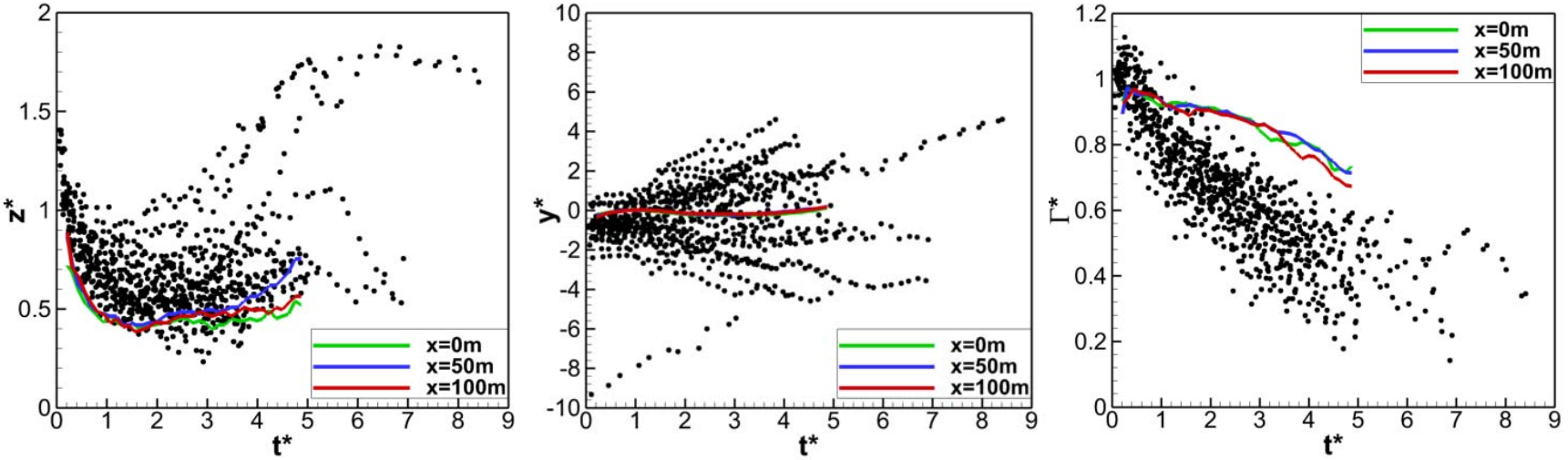


WakeOP-GE

$CW = w_0$

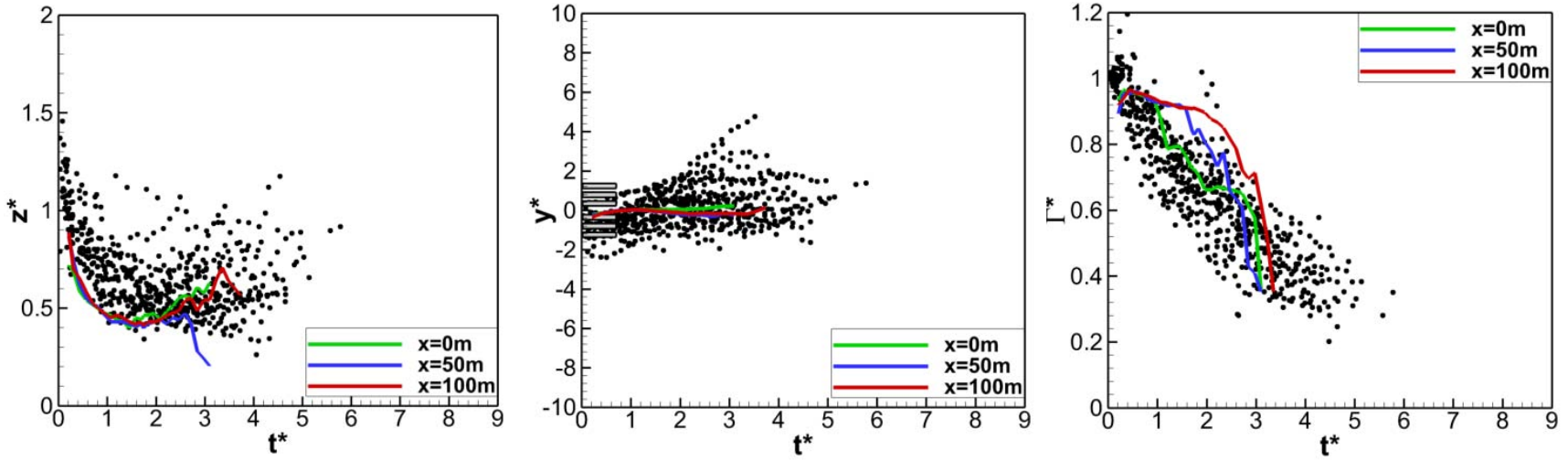
$z_0 = b_0$

WakeOP – measurement – simulation



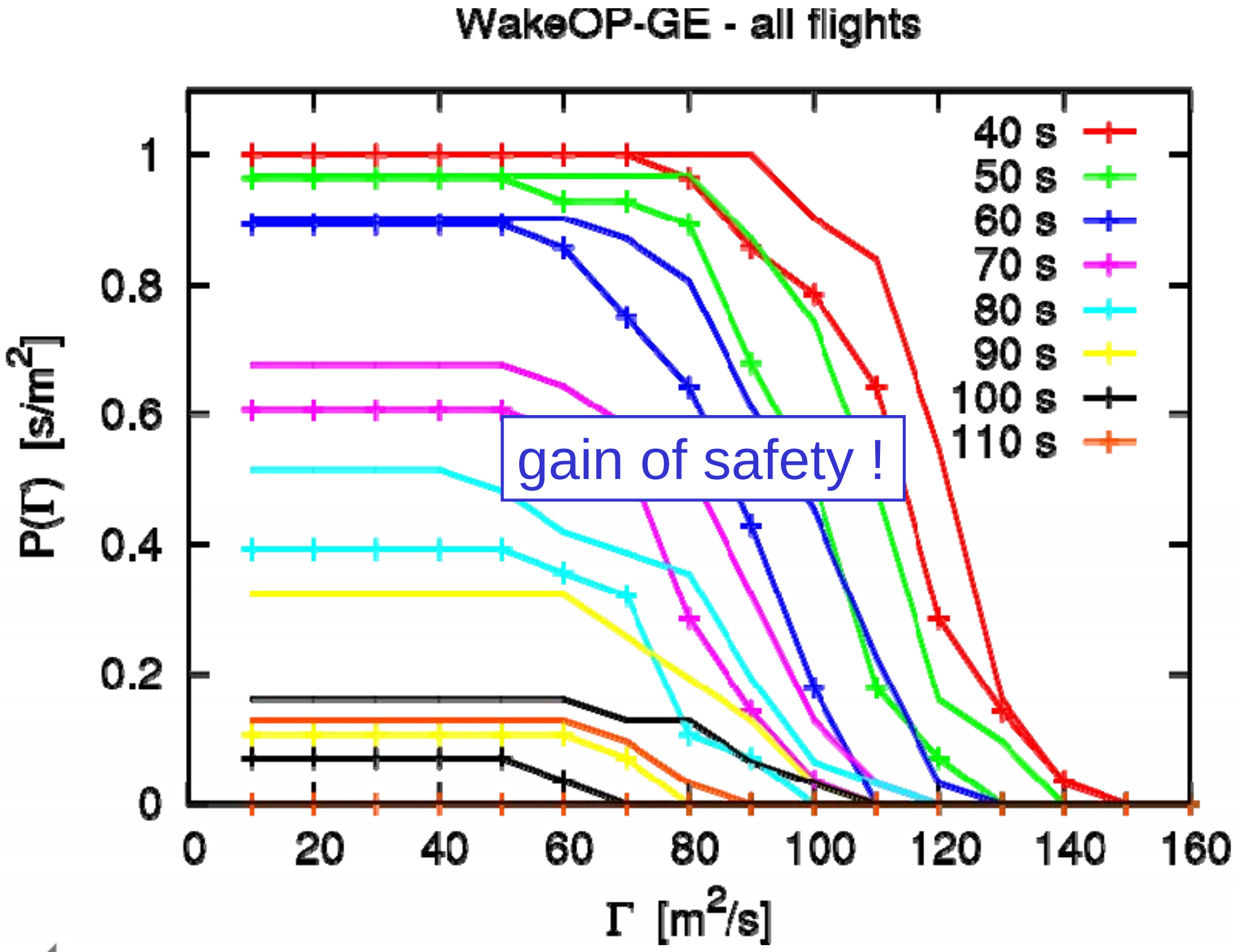
luff vortex

w/o plate line

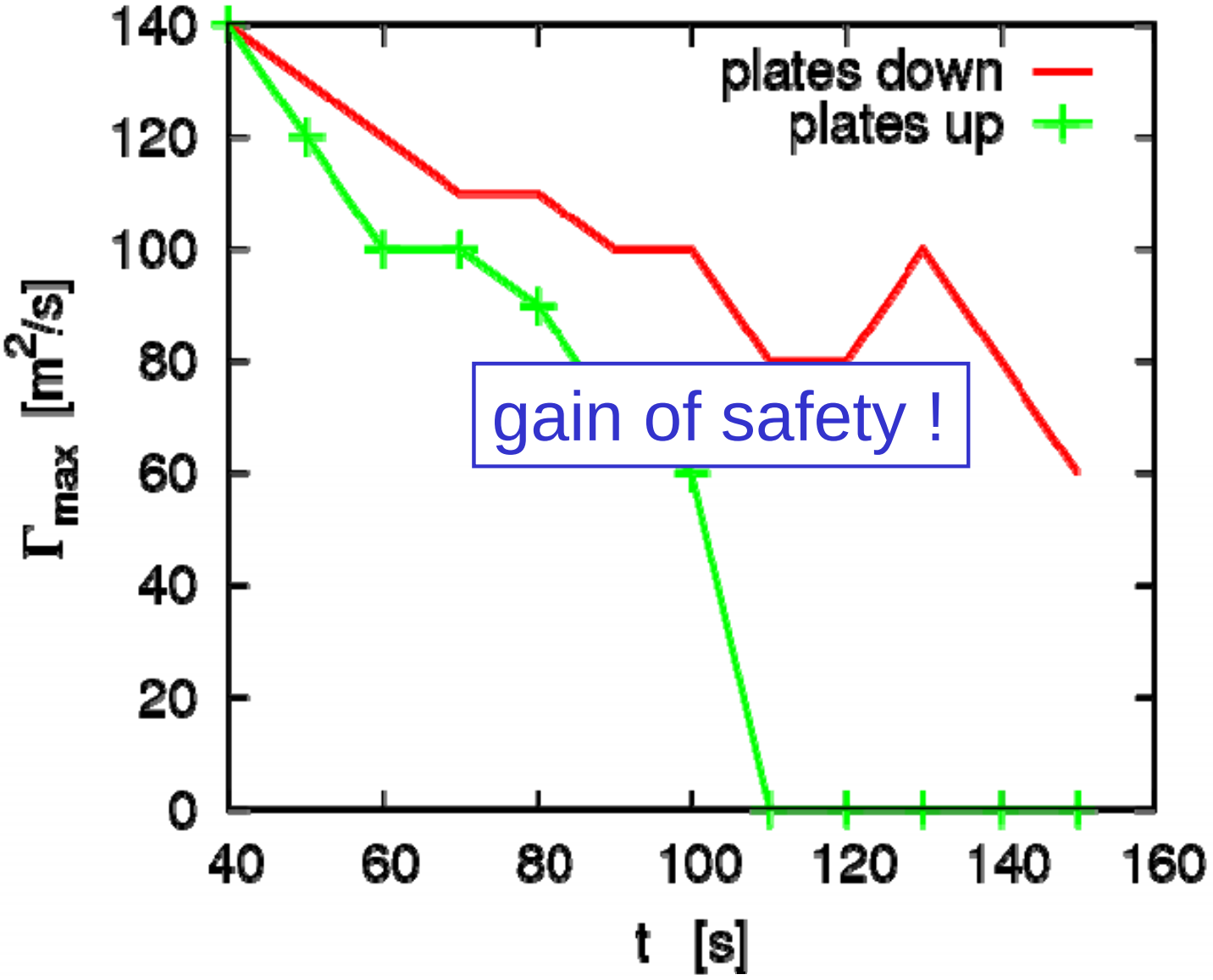


luff vortex

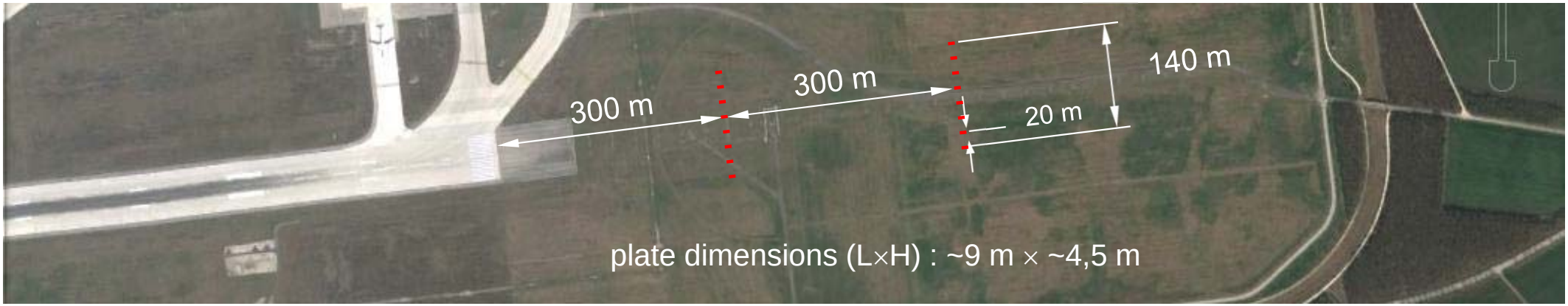
plate line


WakeOP-GE - all flights
40 s
50 s
60 s
70 s
80 s
90 s
100 s
110 s
gain of safety !
P(Γ) [s/m²]
Γ [m²/s]
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100
120
140
160

WakeOP – longest lived vortex (highest risk)



demonstration of plate lines at Munich airport



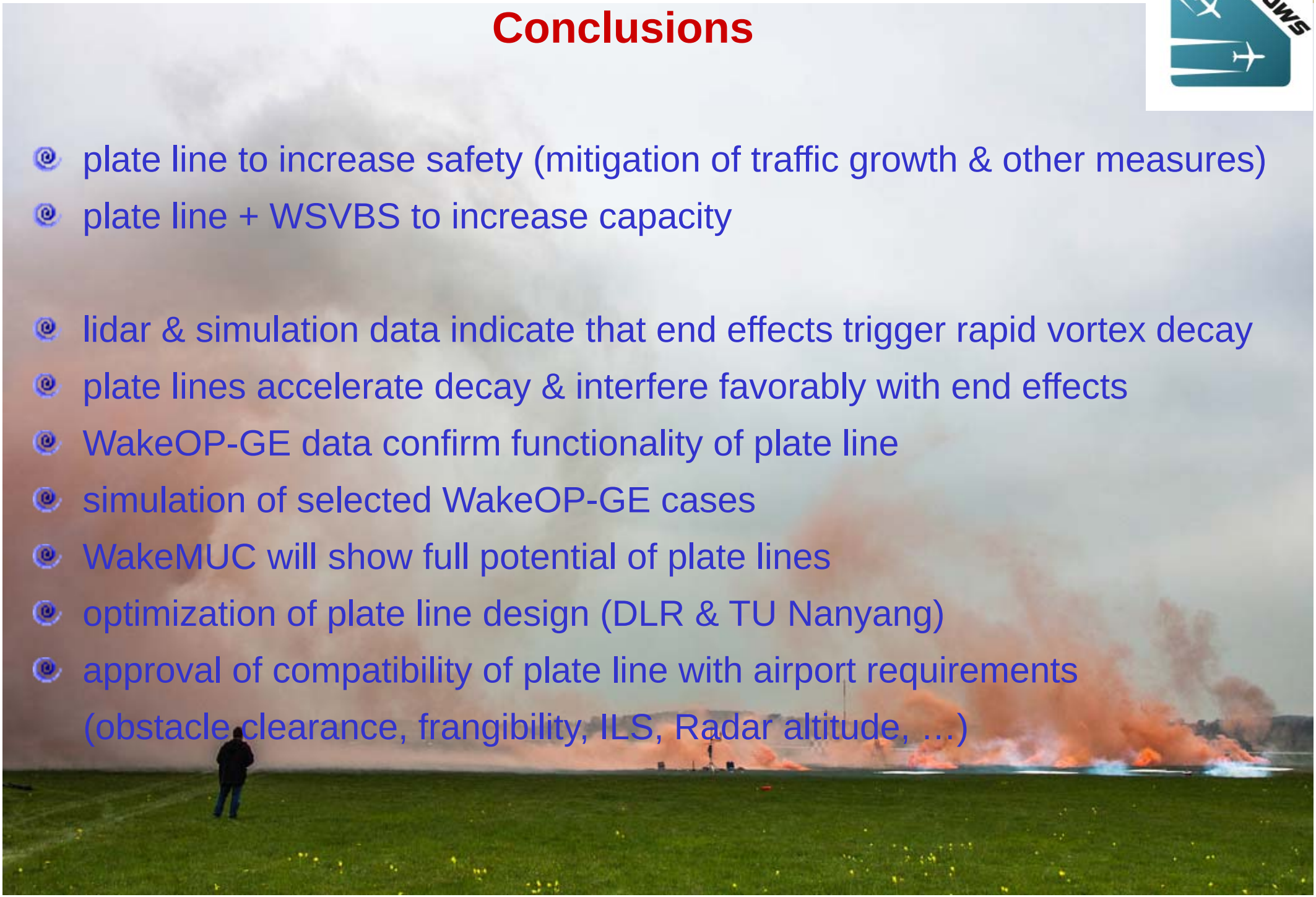
- DFS & FMG interested to test plate lines at Munich airport
- simultaneous lidar measurements at parallel runways with and w/o plate lines
- plates subject to approval by authorities (Luftamt Südbayern)
- criteria: obstacle clearance, stability, frangibility, localizer, wildlife, grounds maintenance

dist. from TDZ [m]	460	560	600	660	960	1260	1560	1860
dist. from THR [m]	160	260	300	360	660	960	1260	1560
flight altitude [m]	24	29	31	35	50	66	82	97
obstacle height [m]	2	4	4.4	6	>6	>6	>6	>6

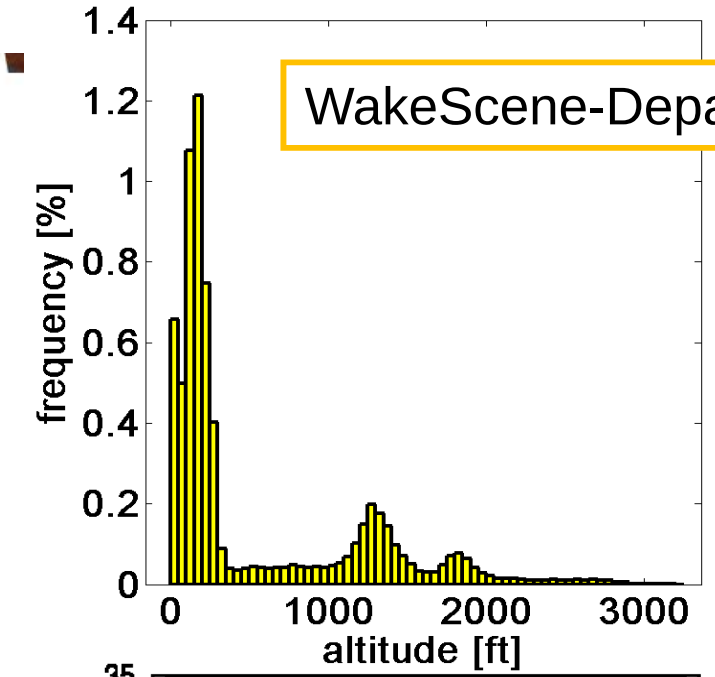
Conclusions

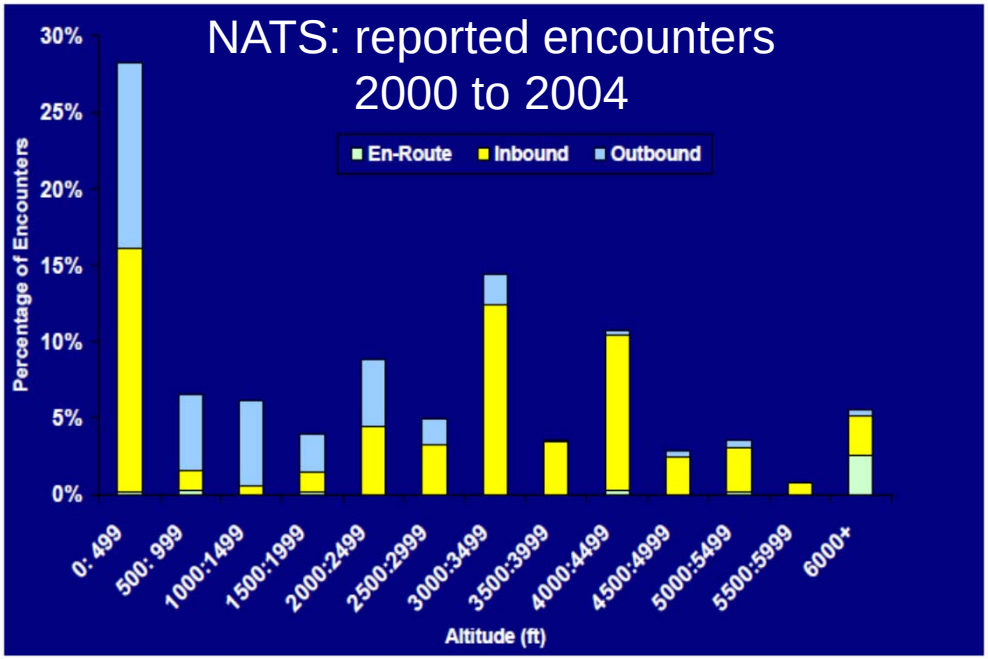
- plate line to increase safety (mitigation of traffic growth & other measures)
- plate line + WSVBS to increase capacity

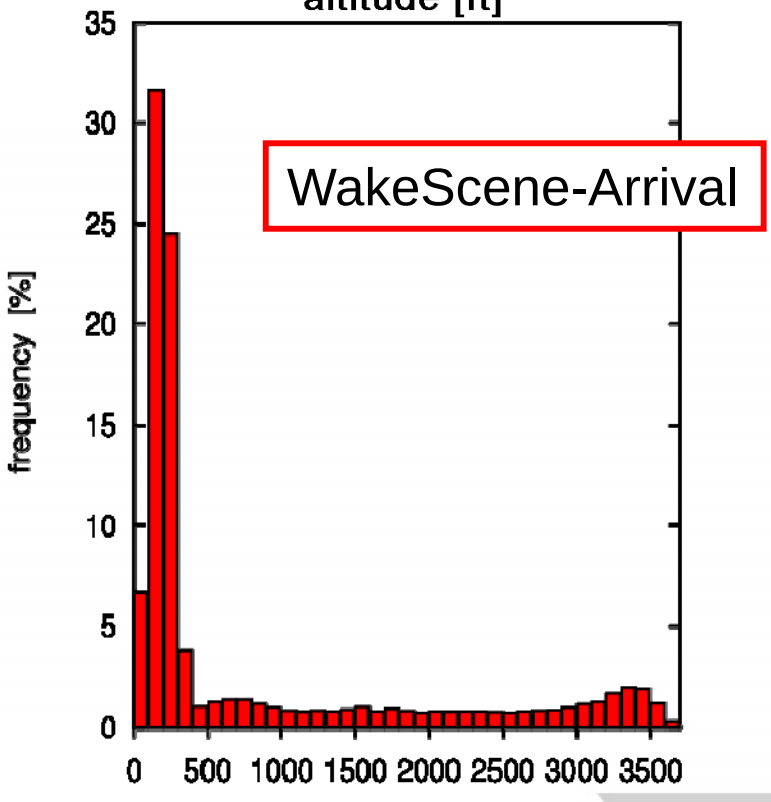
- lidar & simulation data indicate that end effects trigger rapid vortex decay
- plate lines accelerate decay & interfere favorably with end effects
- WakeOP-GE data confirm functionality of plate line
- simulation of selected WakeOP-GE cases
- WakeMUC will show full potential of plate lines
- optimization of plate line design (DLR & TU Nanyang)
- approval of compatibility of plate line with airport requirements (obstacle clearance, frangibility, ILS, Radar altitude, …)

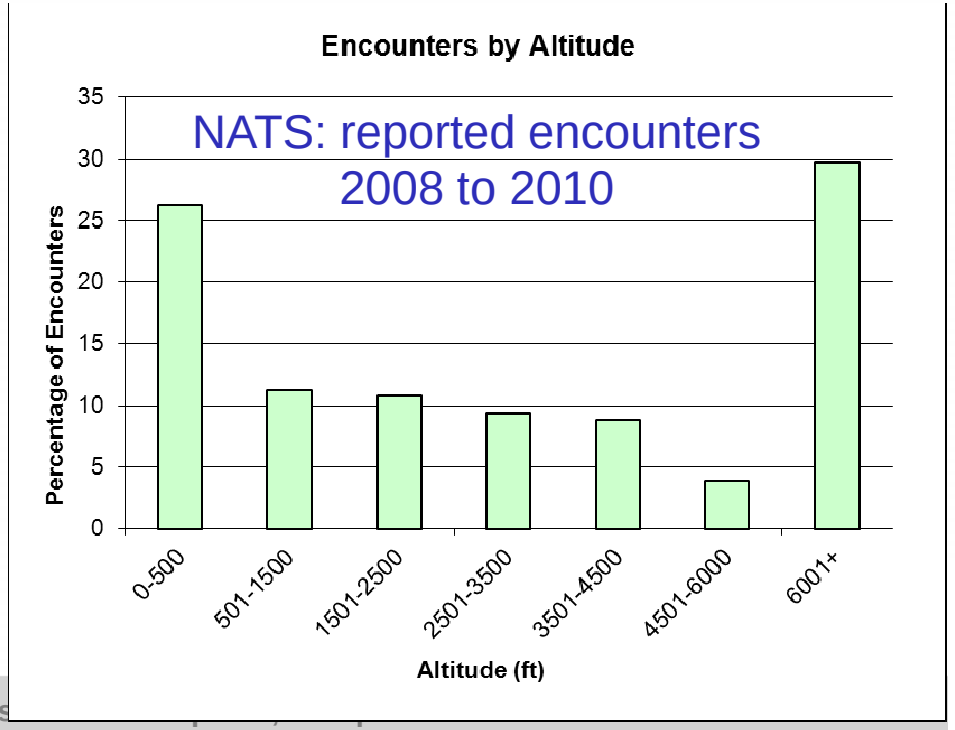


encounter statistics

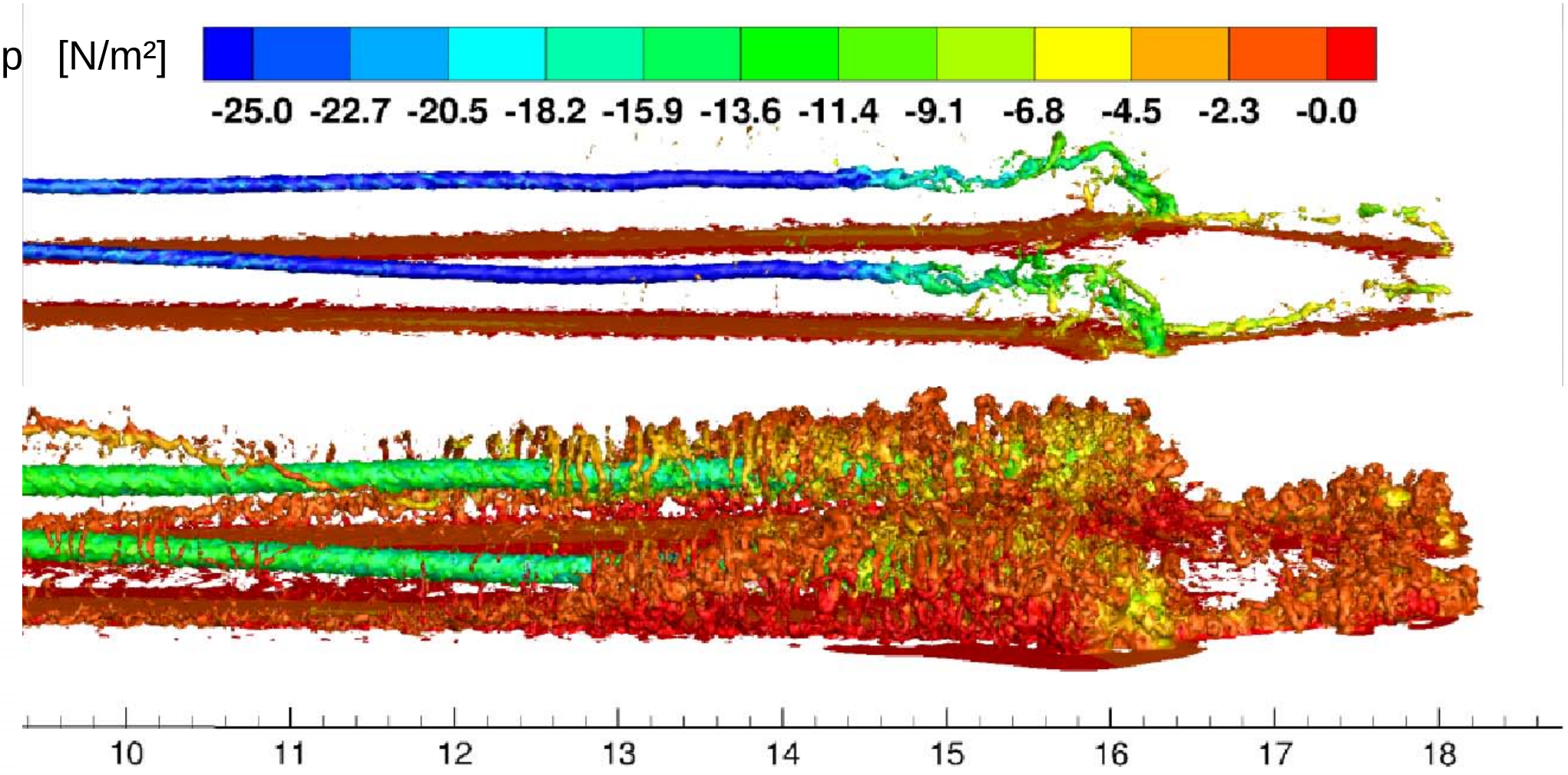








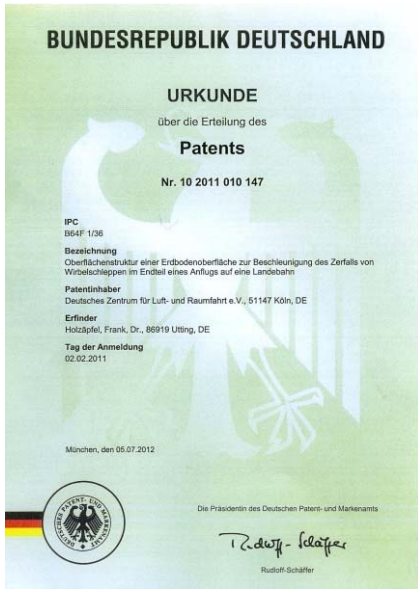
end effect versus ground effect



t* = 0.28

WakeOP-GE

flight experiment with research aircraft HALO
at special airport Oberpfaffenhofen on 29 - 30 April 2013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URKUNDE

über die Erteilung des

Patents

Nr. 10 2011 010 147

IPC
B64F 1/36

Bezeichnung
Oberflächenstruktur einer Erdbodenoberfläche zur Beschleunigung des Zerfalls von Wirbelschleppen im Endteil eines Anflugs auf eine Landebahn

Patentinhaber
Deutsches Zentrum für Luft- und Raumfahrt e.V., 51147 Köln, DE

Erfinder
Holzäpfel, Frank, Dr., 86919 Utting, DE

Tag der Anmeldung
02.02.2011

München, den 05.07.2012

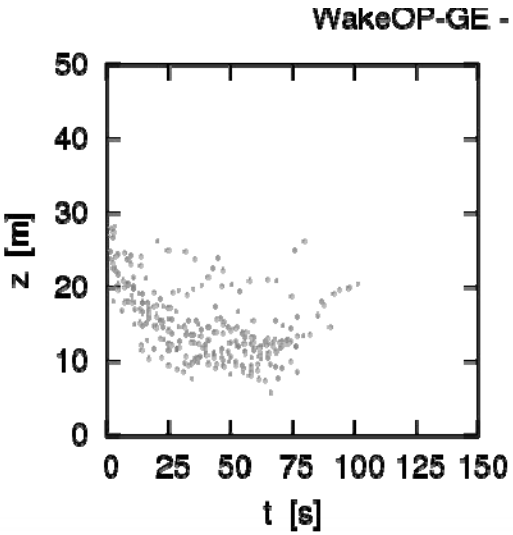
Die Präsidentin des Deutschen Patent- und Markenamts

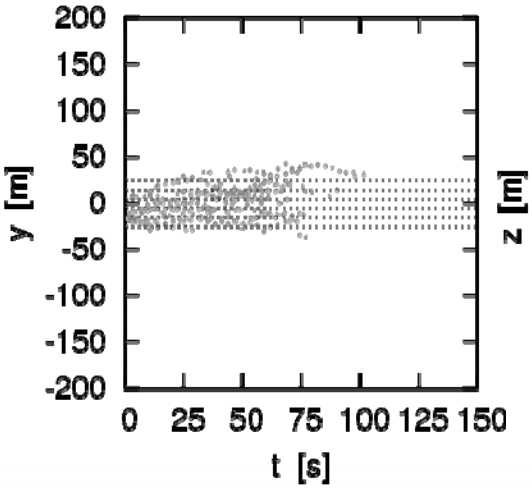
Rudloff-Schäffer

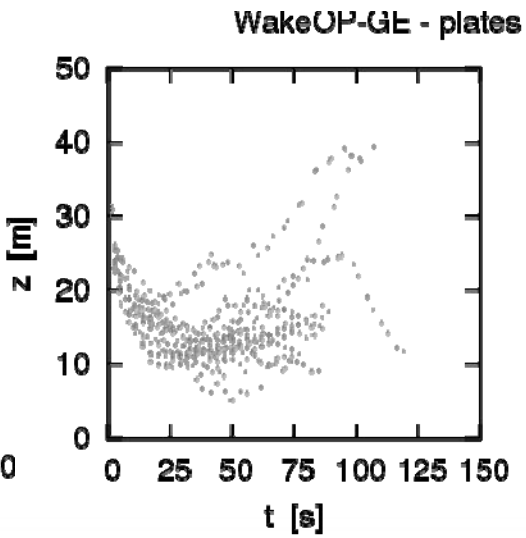
- purpose: demonstrate functionality of plate line
  patent DE 10 2011 010 147
- 74 overflights at airport Oberpfaffenhofen
- 4 flights each 1.5 h
- flight altitude $b_0 \approx 22$ m above ground
- HALO heavy and slow (landing with MLW) $\Rightarrow$ strong WV
- high-lift configuration, landing gear deployed
- HALO instrumentation: avionic data, nose boom, 4 cameras
- weather impact minimized by folding away plates alternatingly
- weak wind & turbulence, poor visibility

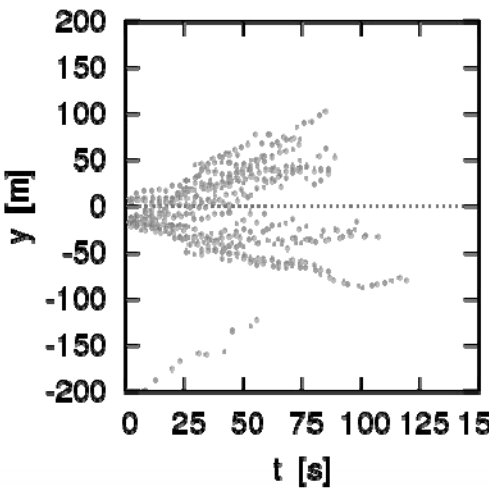
- Lidar measurements from Falcon hangar
- 2 ultrasonic anemometers with microphones
- smoke/fog visualization documented by video and photo

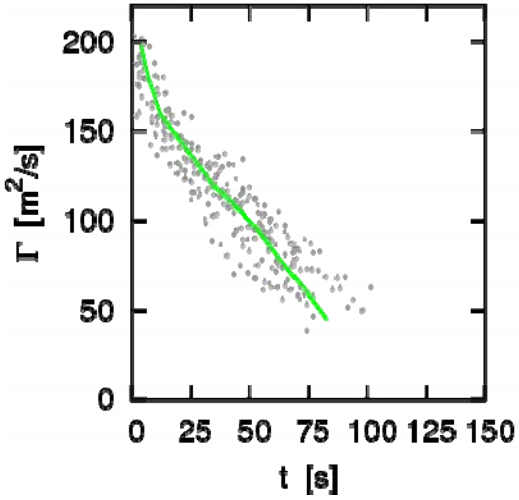
WakeOP – setup 1

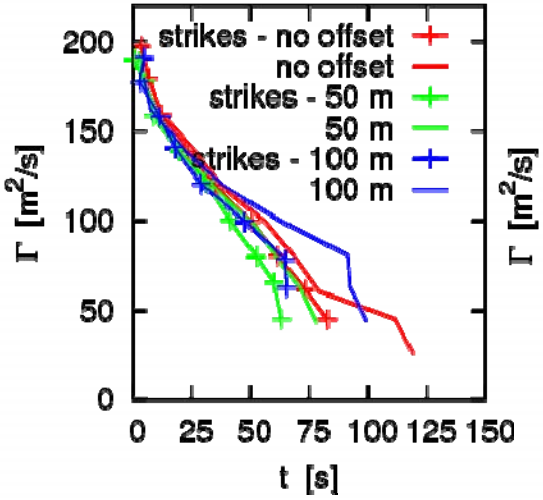


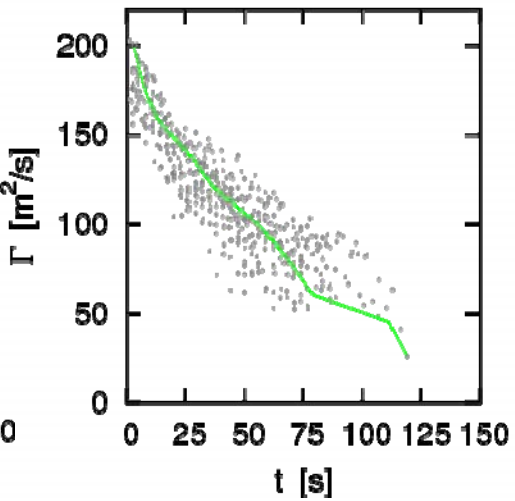


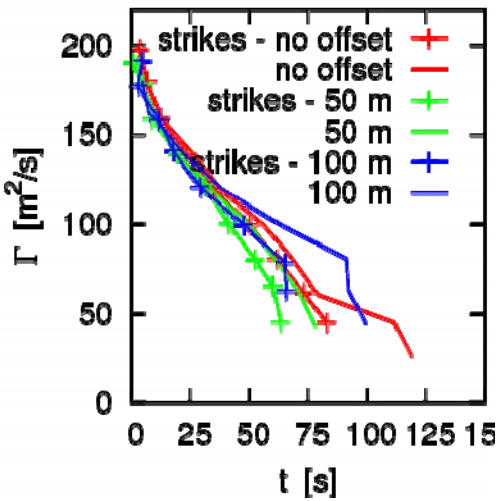




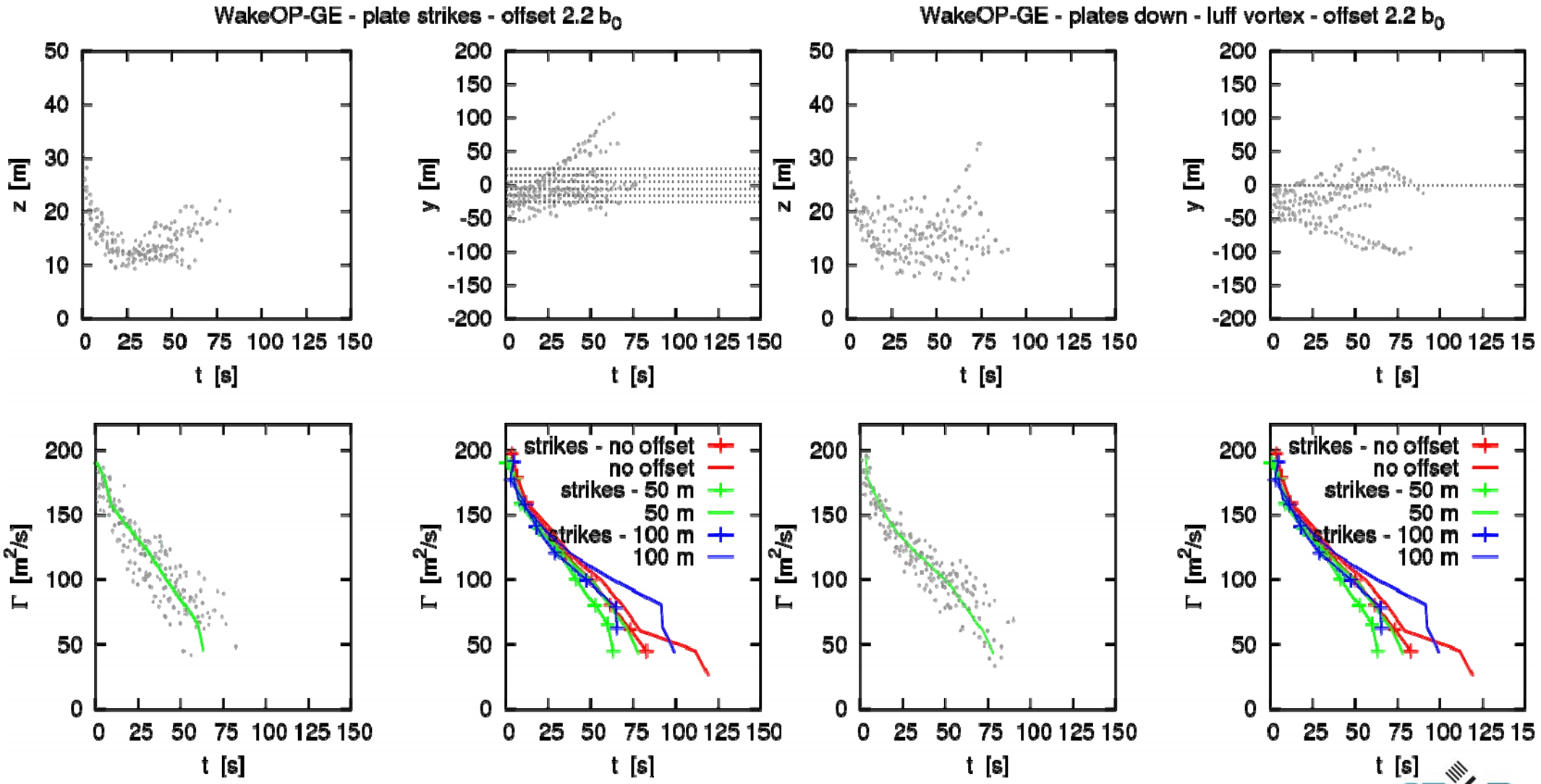




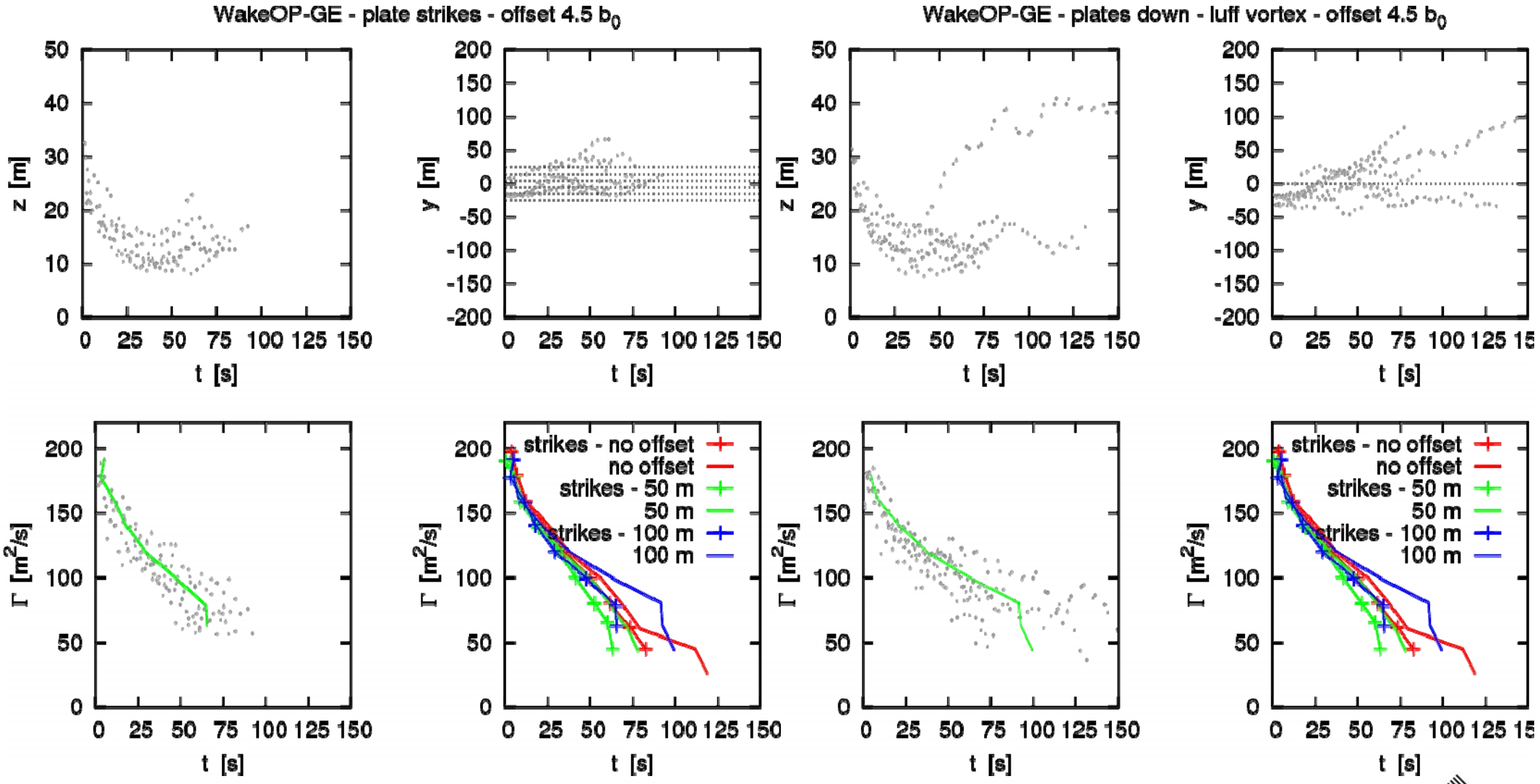




WakeOP – setup 2 (50 m offset)



WakeOP – setup 3 (100 m offset)



Multi-Model Ensemble Wake Vortex Prediction

Stephan Körner, Frank Holzäpfel

German Aerospace Center (DLR)
Institute of Atmospheric Physics

EASN workshop, RWTH Aachen
28.10.2014

DLR

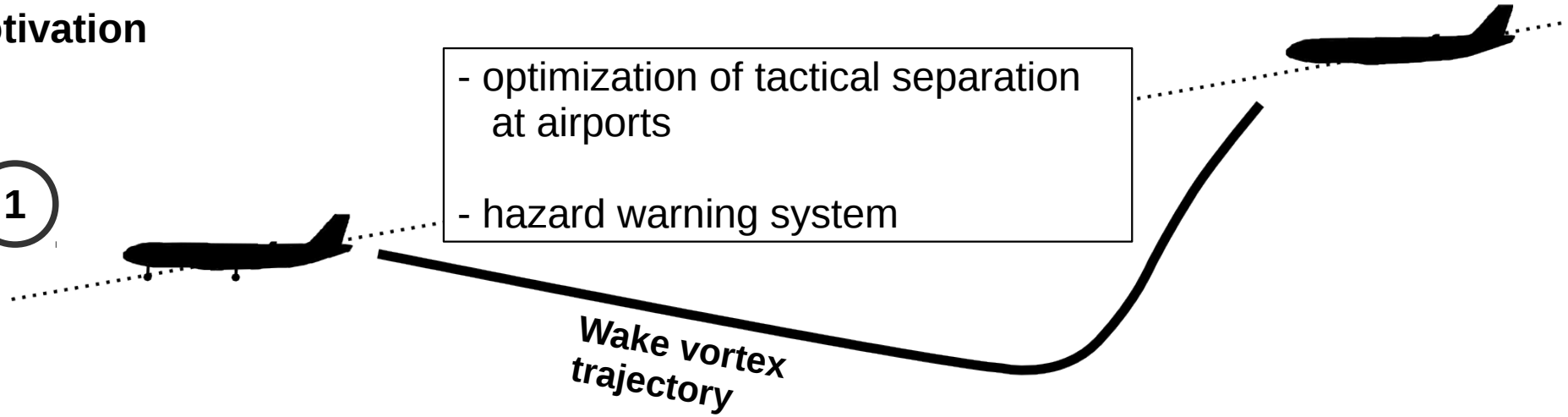
Wake Vortex Predictions

Motivation

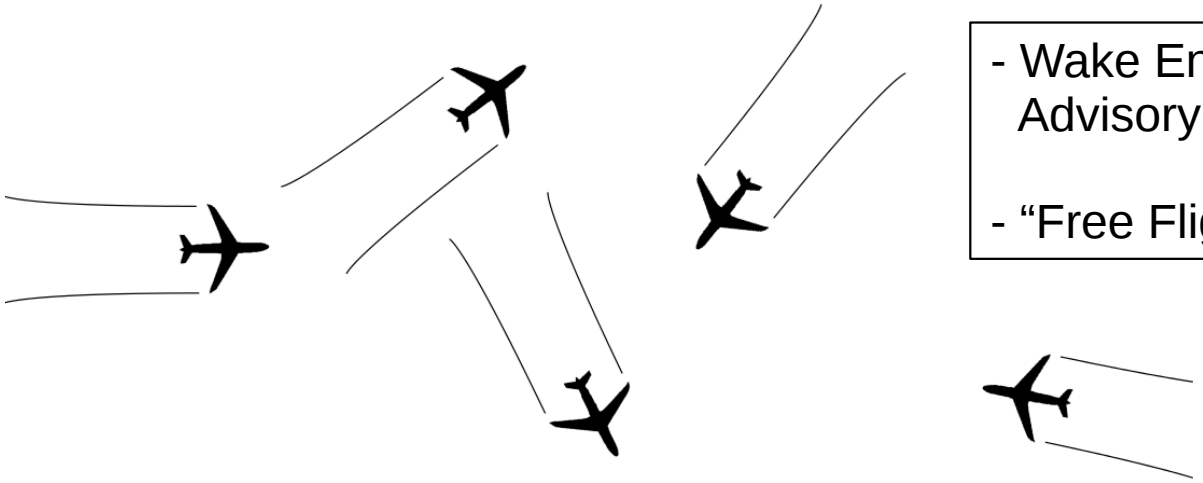
1

- optimization of tactical separation at airports

- hazard warning system



2



- Wake Encounter Avoidance & Advisory System (WEAA)

- “Free Flight”

Sugar

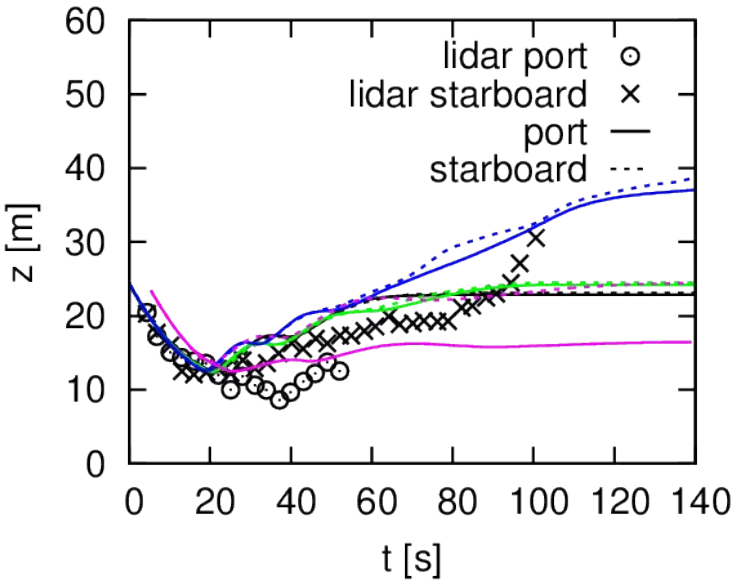
How to mix several good ingredients?

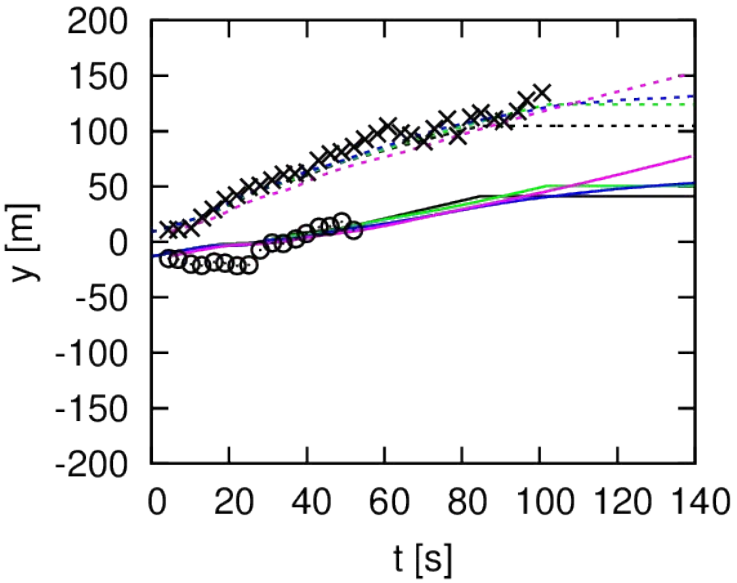
Water

Lemon Juice

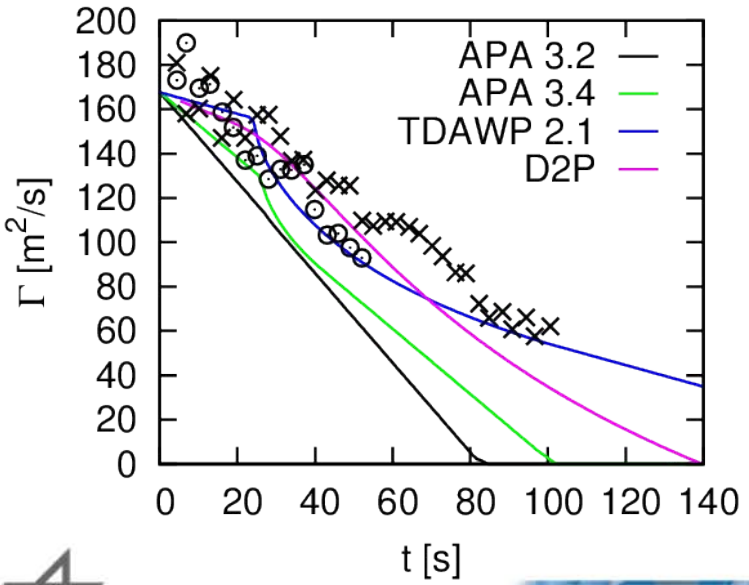
Lemonade

Multi-Model Ensemble





NASA-DLR cooperation



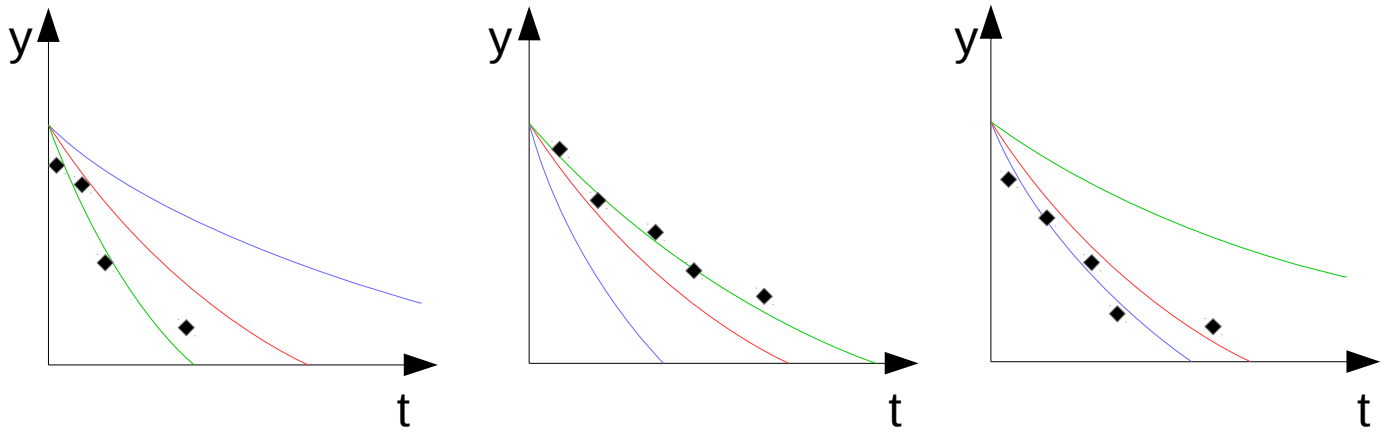
wake vortex models:

- **D2P:** based on Navier-Stokes, adapted to LES results (DLR)
- **APA 3.2:** decay and transport model according to Sarpkaya (NASA)
- **APA 3.4:** reduced effect of stratification (NASA)
- **TDAWP 2.1** :considers effect of crosswind shear on vortex descent (NASA)

Multi-Model Ensemble

Why not use the best ensemble member exclusively?

- which is the best member?
- in average best performing member can sometimes be the worst one



Can an ensemble outperform its best member?

- success of ensemble approach: error cancelation
- consistently low performing models → no increase of skill

Yes!

according to Hagedorn et al., 2005

Multi-Model Ensemble

Reliability Ensemble Averaging (REA)

$$\widetilde{f} = \tilde{A}(f) = \frac{\sum_i R_i f_i}{\sum_i R_i}$$

model performance (a-priori)

model convergence

iteration loop

according to Giorgi and Mearns, 2002

$$R_i = [(R_{B,i})^m \cdot (R_{D,i})^n]^{[1/(m \cdot n)]} = \left\{ \left[\frac{nv}{abs(B_i)} \right]^m \left[\frac{nv}{abs(D_i)} \right]^n \right\}^{[1/(m \cdot n)]}$$

f_i = forecast of model i

$\tilde{A}(f)$ = REA-forecast

R_i = reliability factor of model i

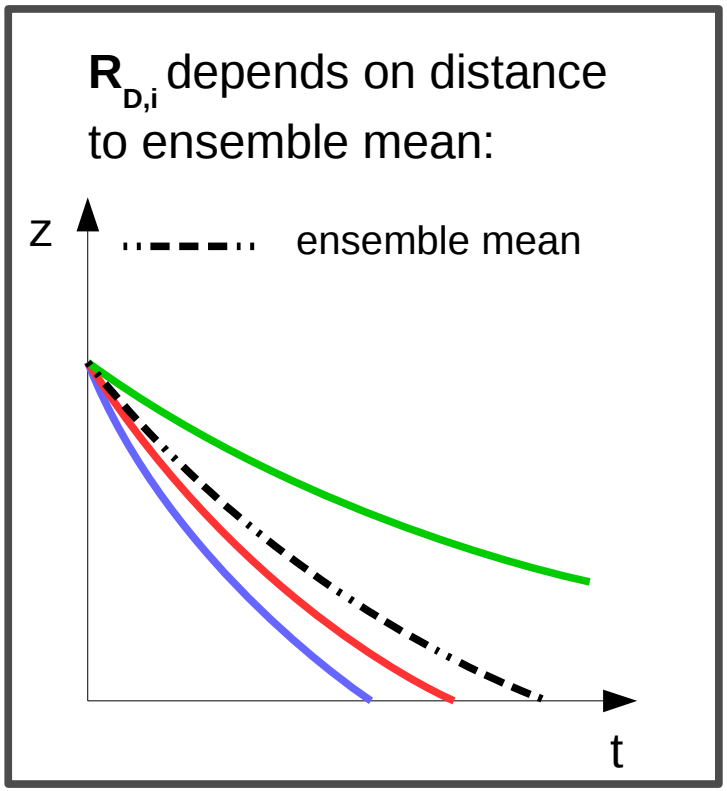
nv = natural variability

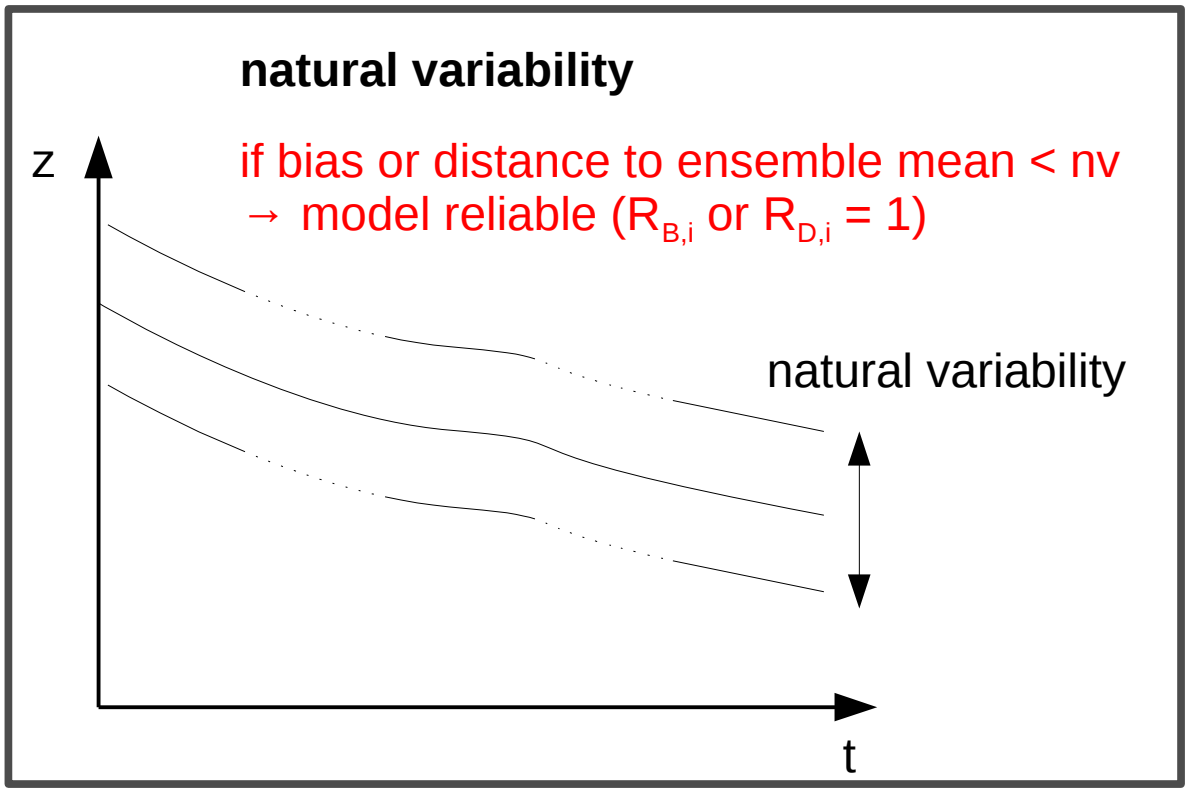
B_i = absolute bias of model i

D_i = absolute difference between forecast of model i and ensemble mean

Multi-Model Ensemble

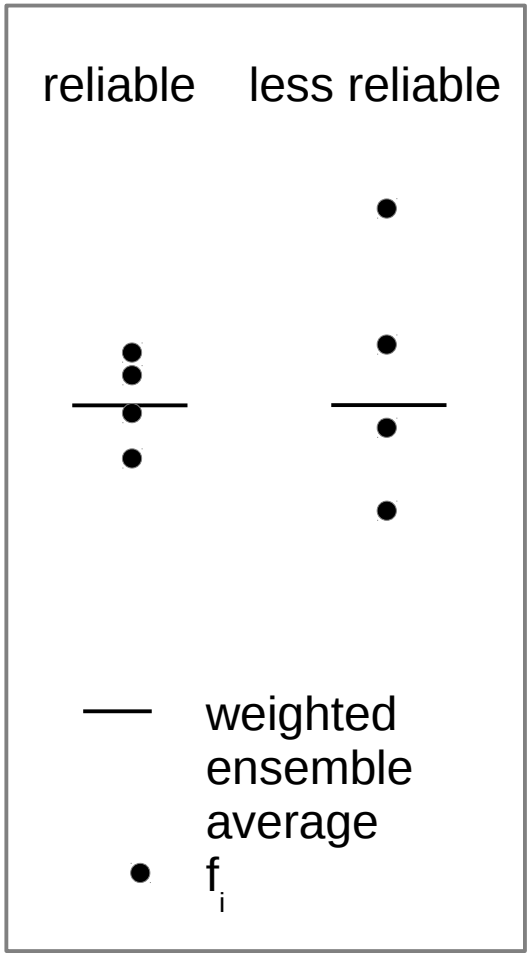
Reliability Ensemble Averaging





Multi-Model Ensemble

Reliability Ensemble Averaging uncertainty bounds:

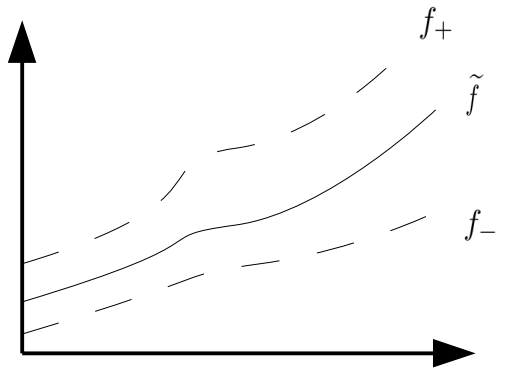


$$\tilde{\delta}_f = [\tilde{A}(f_i - \tilde{f})^2]^{1/2} = \left[\frac{\sum_i R_i (f_i - \tilde{f})^2}{\sum_i R_i}\right]^{1/2}$$

uncertainty bounds depend on ensemble spread

$$f_+ = \tilde{f} + \tilde{\delta}_f$$

$$f_- = \tilde{f} - \tilde{\delta}_f$$



according to Giorgi and Mearns, 2002

Application to Wake Vortex Models

Reliability Ensemble Averaging

Training

- WakeFRA (292 landings of heavy aircraft)
- good quality
- used for D2P training

$R_{B,i}$ and $R_{D,i}$

- $R_{B,z,i}(t)$, $R_{B,y,i}(t)$, $R_{B,\Gamma,i}(t)$, $R_{D,z,i}(t)$, $R_{D,y,i}(t)$, $R_{D,\Gamma,i}(t)$
- $\Delta t^*=2$ ($t^*=t/w_0$)
- separately for luff/lee vortices
- performance criterion($R_{B,z,i}$) stronger weighted (m=1,n=0.3)

Uncertainty bounds

- initial condition uncertainty not considered in original approach → limits too narrow
- measurement uncertainty added for wake vortex application:

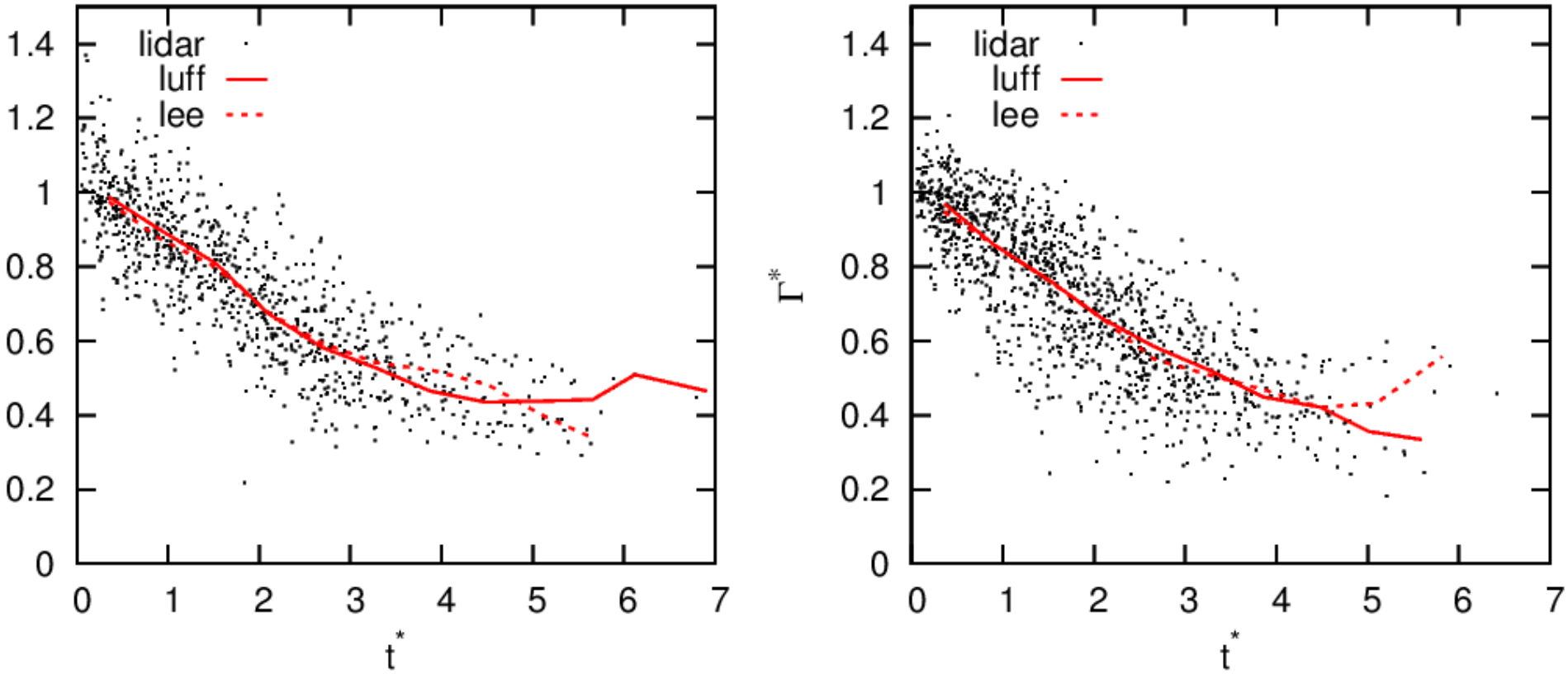
$\sigma_{err,z}$ = 9 m $\sigma_{err,y}$ = 13 m $\sigma_{err,\Gamma}$ = 13 m^2 /s.

Application to Wake Vortex Models

$\Gamma^*=\Gamma/\Gamma_0$, $z^*=z/b_0$, $y^*=y/b_0$, $t^*=t/w_0$
b_0 = initial vortex spacing
w_0 = vortex descent speed
* = non-dimensional
N* = Brunt-Väisälä frequency
ε* = eddy dissipation rate

REA natural variability

$$\sigma_{obs} = \sqrt{\sigma_{err}^2 + \sigma_{nv}^2}$$



observed variability for $1 < z_0^* < 2$ and a.) $N^* > 0.3$, $\varepsilon^* > 0.2$ and b.) $N^* < 0.3$, $\varepsilon^* < 0.2$

Application to Wake Vortex Models

*	= non-dimensional
N*	= Brunt-Väisälä frequency
ε*	= eddy dissipation rate
V*	= crosswind speed

REA natural variability

observed variability of Γ*

	$N^* > 0.3,\ \epsilon^* > 0.2$	$N^* < 0.3,\ \epsilon^* < 0.2$
σ_{obs,Γ^*} (for $z_0^* < 1$)	$0.090_{\ 759}$	$0.107_{\ 229}$
σ_{obs,Γ^*} (for $1 < z_0^* < 2$)	$0.101_{\ 999}$	$0.104_{\ 716}$

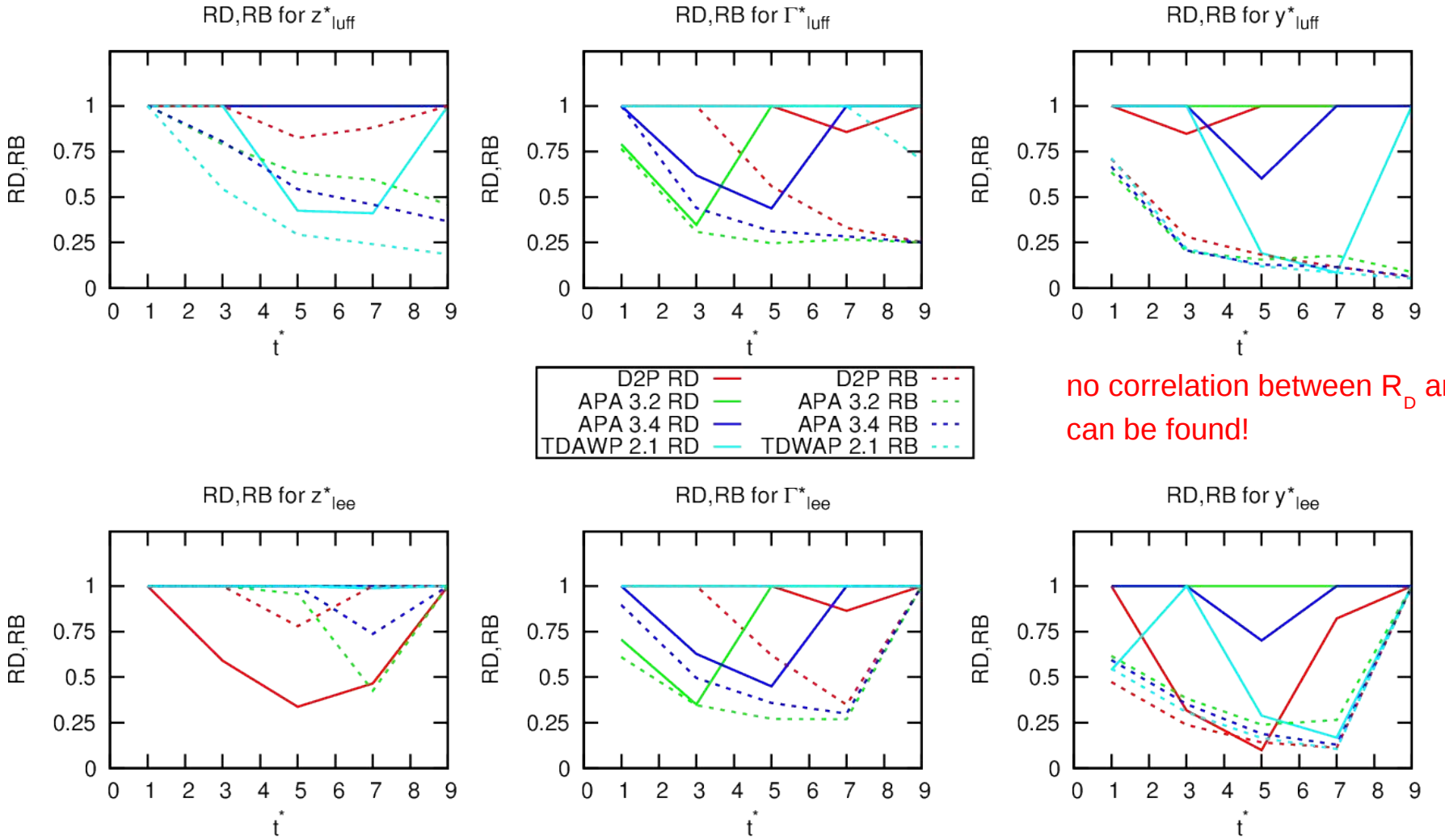
observed variability of z* for $1.0 < z_0^* < 1.2$

	$N^* > 0.3,\ \lvert v^* \rvert > 0.5$	$N^* < 0.3,\ \lvert v^* \rvert < 0.5$
$\sigma_{obs,z^*_{lee}}$	$0.259_{\ 577}$	$0.205_{\ 433}$
$\sigma_{obs,z^*_{luff}}$	$0.198_{\ 577}$	$0.198_{\ 433}$

Preliminary: $\sigma_{nv,z} = \sigma_{err,z}$ and $\sigma_{nv,y} = \sigma_{err,y}$

Results

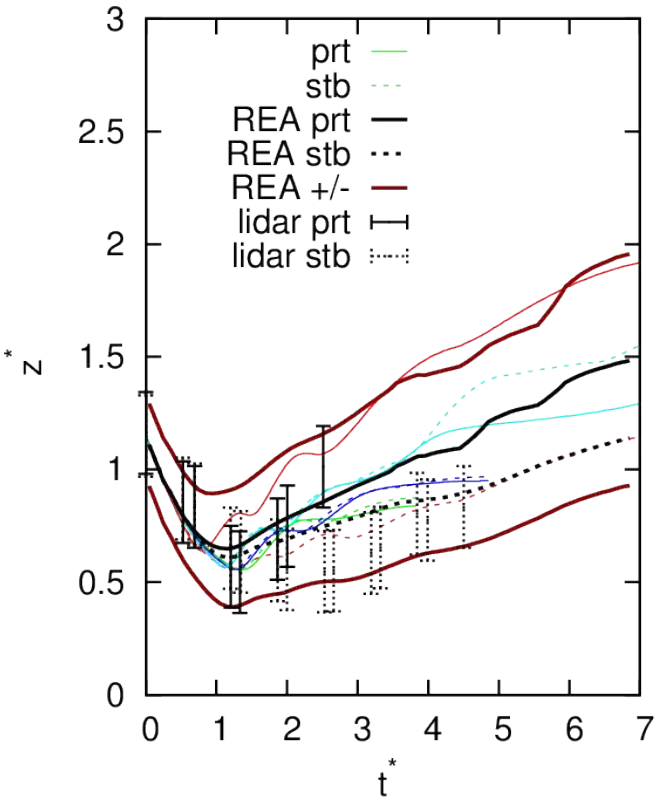
REA reliability factors (one single landing)

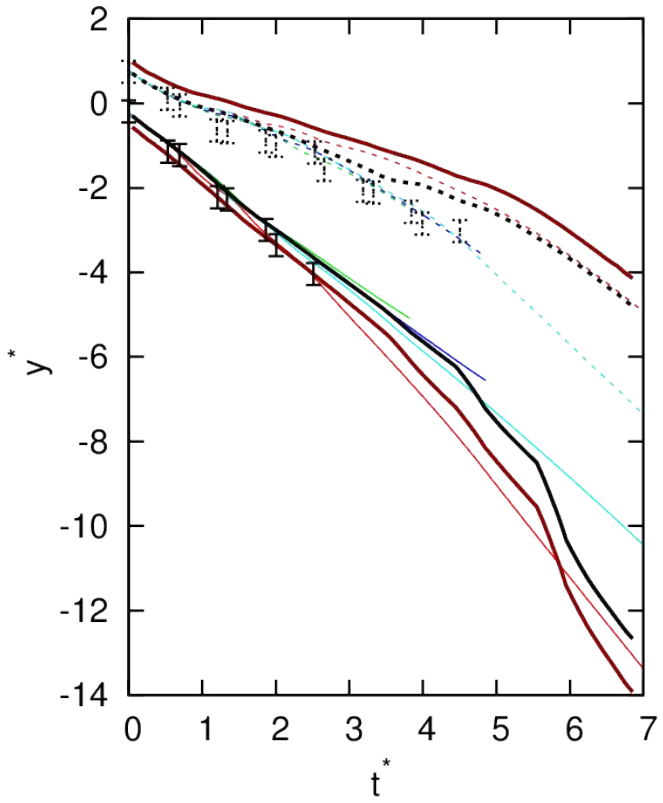


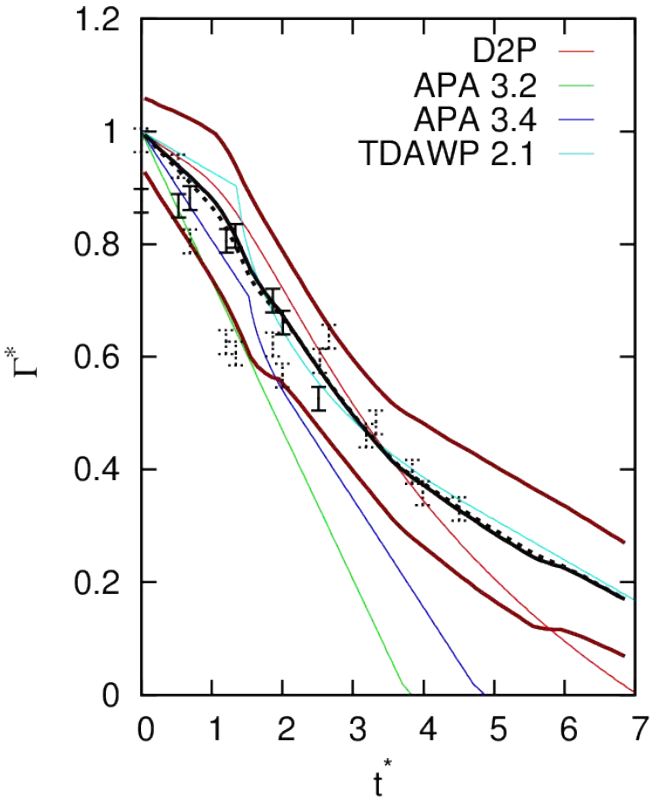
no correlation between R_D and R_B can be found!

Results

REA forecast (one single landing)







$\Gamma^*=\Gamma/\Gamma_0$, $z^*=z/b_0$, $y^*=y/b_0$, $t^*=t/w_0$

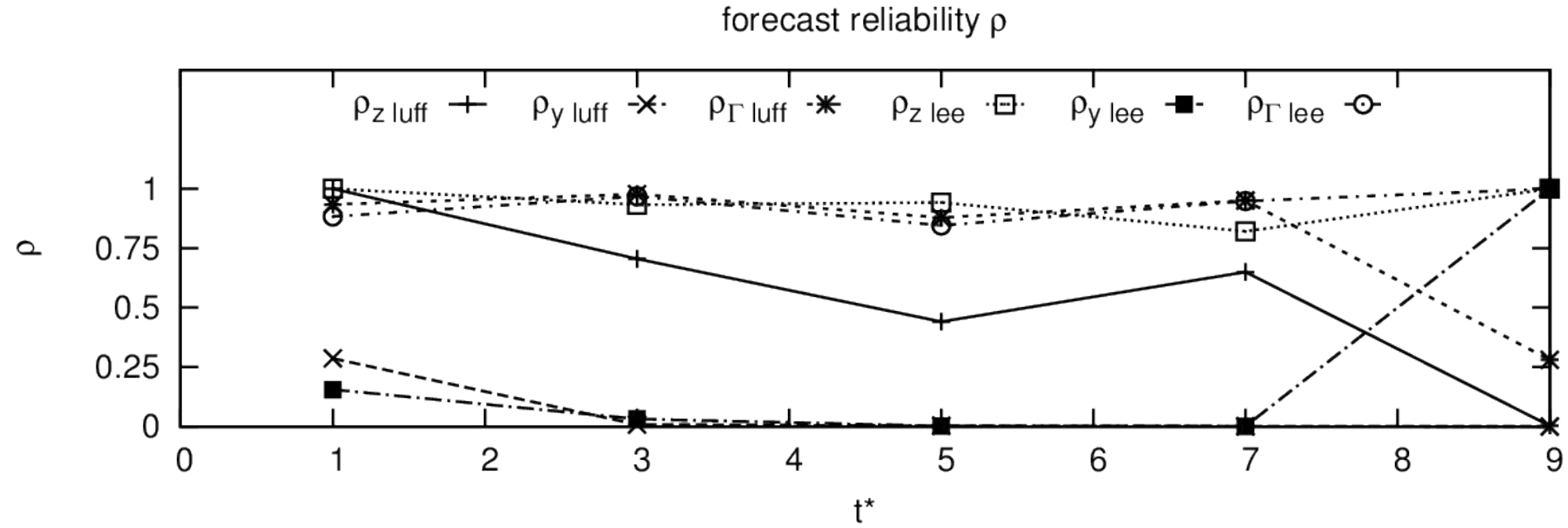
w_0= vortex descent speed

Results

REA forecast reliability (one single landing)

$$\tilde{\rho} = \frac{\sum_i R_i^2}{\sum_i R_i}$$

- Low reliability for y-forecast
- Medium reliability for z_{luff} - forecast
- High reliability for Γ and z_{lee} - forecast



Results

REA scoring

- 100 WakeMUC cases
- skill factor s:

$$s = \frac{6}{\sum rms_n / rms_{REA,n}}$$

	rms z^*_{luff}	rms y^*_{luff}	rms Γ^*_{luff}	rms z^*_{lee}	rms y^*_{lee}	rms Γ^*_{lee}	s
REA	0.177	0.775	0.116	0.211	0.601	0.101	1.000
DEA	0.178	0.769	0.171	0.206	0.598	0.123	0.901
D2P	0.185	0.720	0.128	0.241	0.576	0.117	0.993
APA 3.2	0.172	0.752	0.240	0.186	0.569	0.179	0.842
APA 3.4	0.179	0.781	0.188	0.203	0.589	0.135	0.867
TDAWP 2.1	0.202	0.746	0.128	0.225	0.605	0.105	0.949

- REA rms error always less than rms error of worst model

- ensemble outperforms individual forecasts in circulation

- skill of REA best (considering all quantities at once)

Conclusions

- ensemble partly outperforms best member in average

	rms Γ^*_{luff}	rms Γ^*_{lee}
REA	0.116	0.101
DEA	0.171	0.123
D2P	0.128	0.117
APA 3.2	0.240	0.179
APA 3.4	0.188	0.135
TDAWP 2.1	0.128	0.105

- always outperforms worst member
- skill increase however yet behind expectations

	s
REA	1.000
DEA	0.901
D2P	0.993
APA 3.2	0.842
APA 3.4	0.867
TDAWP 2.1	0.949

Further Development

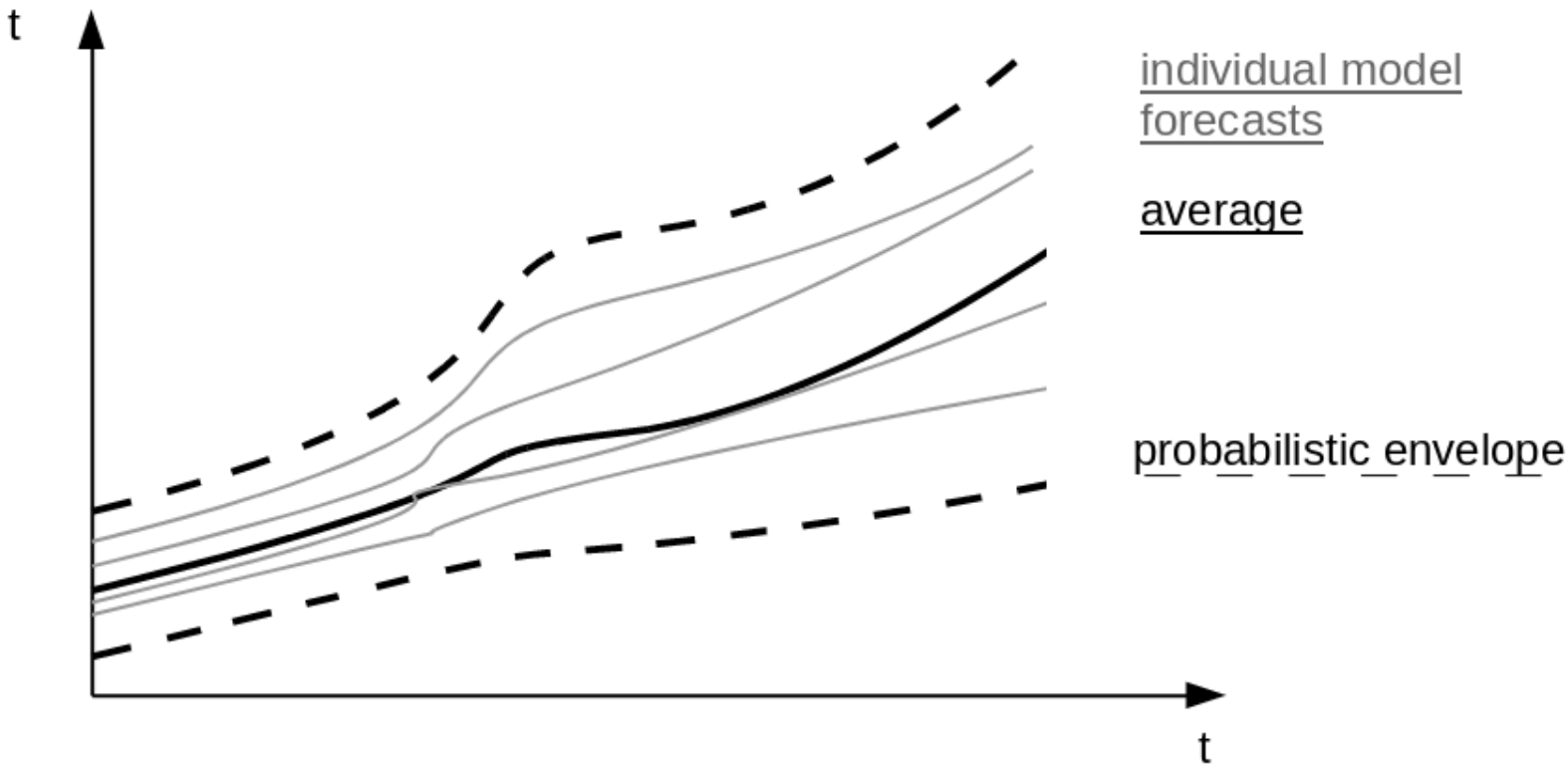
- further investigation on natural variability [e.g. nv(t)]
- increase number of landings for training and evaluation
- determine probability level of uncertainty bounds
- investigation on Bayesian Model Averaging (BMA)

Backup

Multi-Model Ensemble

benefit

- increase deterministic skill
- predict forecast skill
- provide probabilistic forecast



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Revisiting wake vortex mitigation by means of passive devices – Demonstration and validation of a novel device

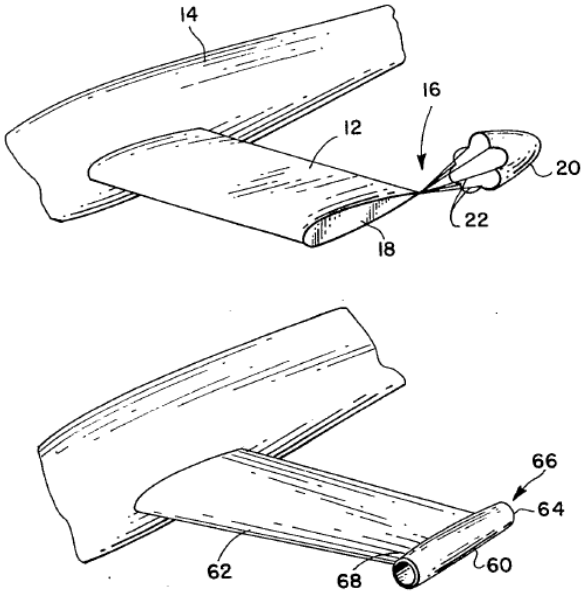
4th EASN Association International Workshop on Flight Physics and Aircraft Design
Aachen, October 28th 2014

Contents

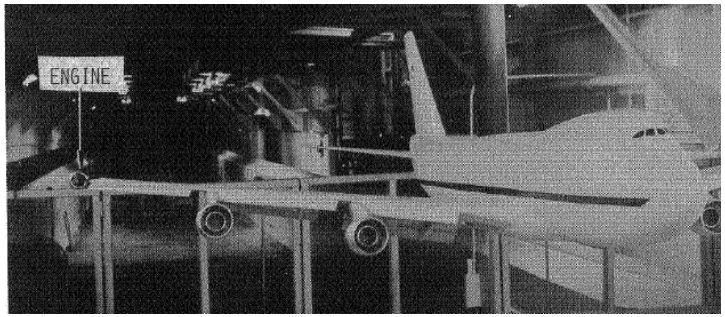
- Known on-board vortex mitigation techniques
- Concept of VACS: **V**ortex **A**lleviation **C**one **S**ystem
- Validations:
  I. In the nearfield with a generic model
  II. In the nearfield with a realistic model
  III. In the farfield with a realistic model
- Summary & Questions

Known on-board vortex mitigation techniques

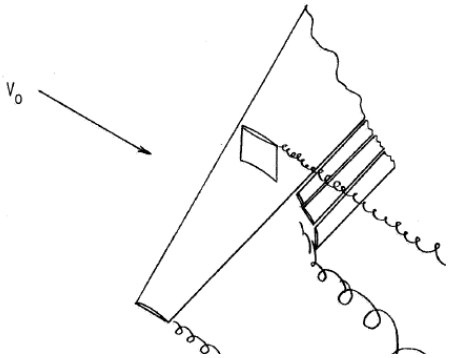
Several devices, EU-projects AWIATOR and C-Wake [1], 2006



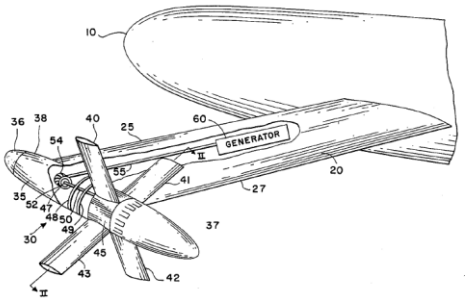
NASA [2], 1974



Blowing at the wingtip [4], 1977



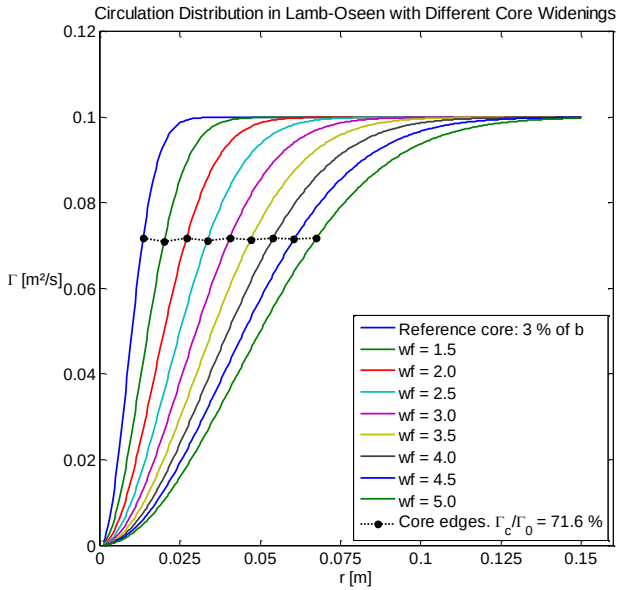
Vortex generators [4], 1977

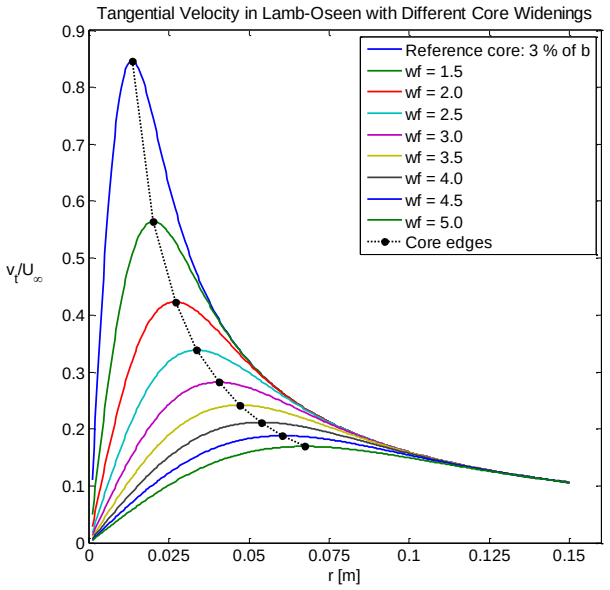


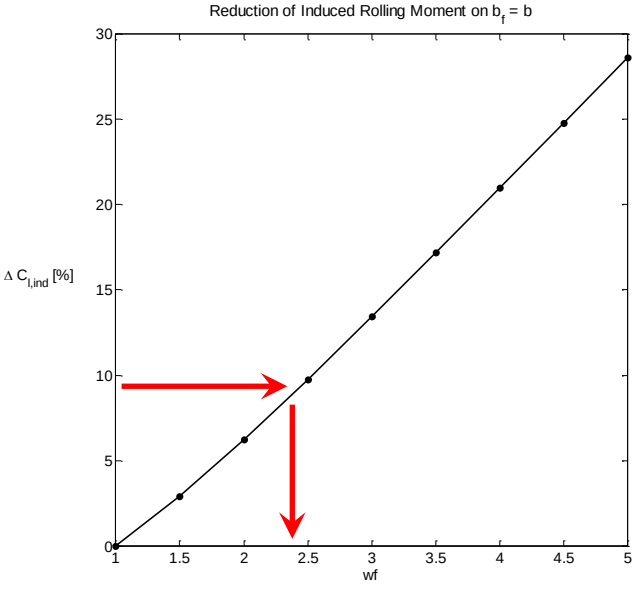
NASA [3], 1988

Concept of Vortex Alleviation Cone System

- **Conceptual approach:**
  - Highest w/v encounter during approach phase: Alleviation in this phase
    - Modest drag is acceptable
    - Device needs to be deployable, possibly retrofitted
      - Simple, light, small, passive, robust, safe, independent
- **Aerodynamic approach:**
  - Momentum conservation: vortex widening for reduced intensity

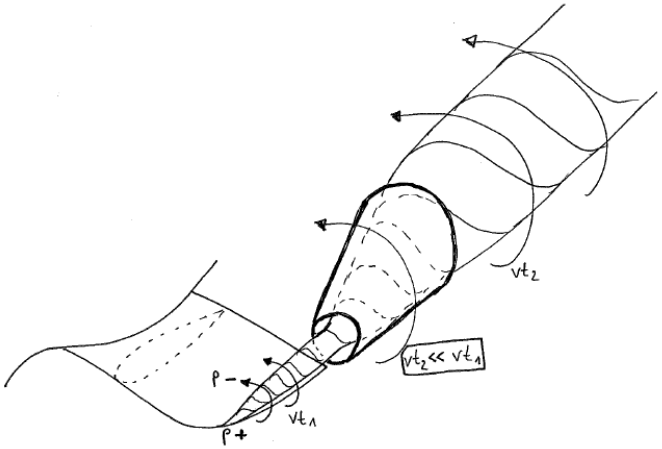




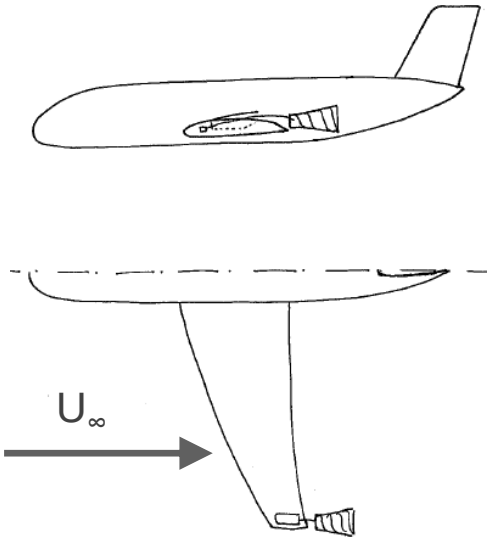


Concept of Vortex Alleviation Cone System

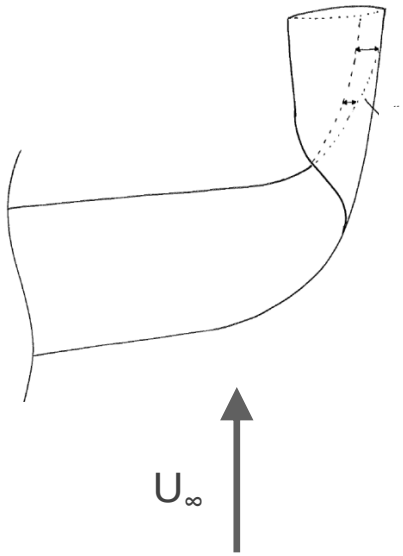
- Effective approach:
  - Widening of the established vortex core by w_f = 2-3 using a conical tube behind the wing- /flap-tip [5]
  - Textile / inflatable device or integrated surface



Working mechanism



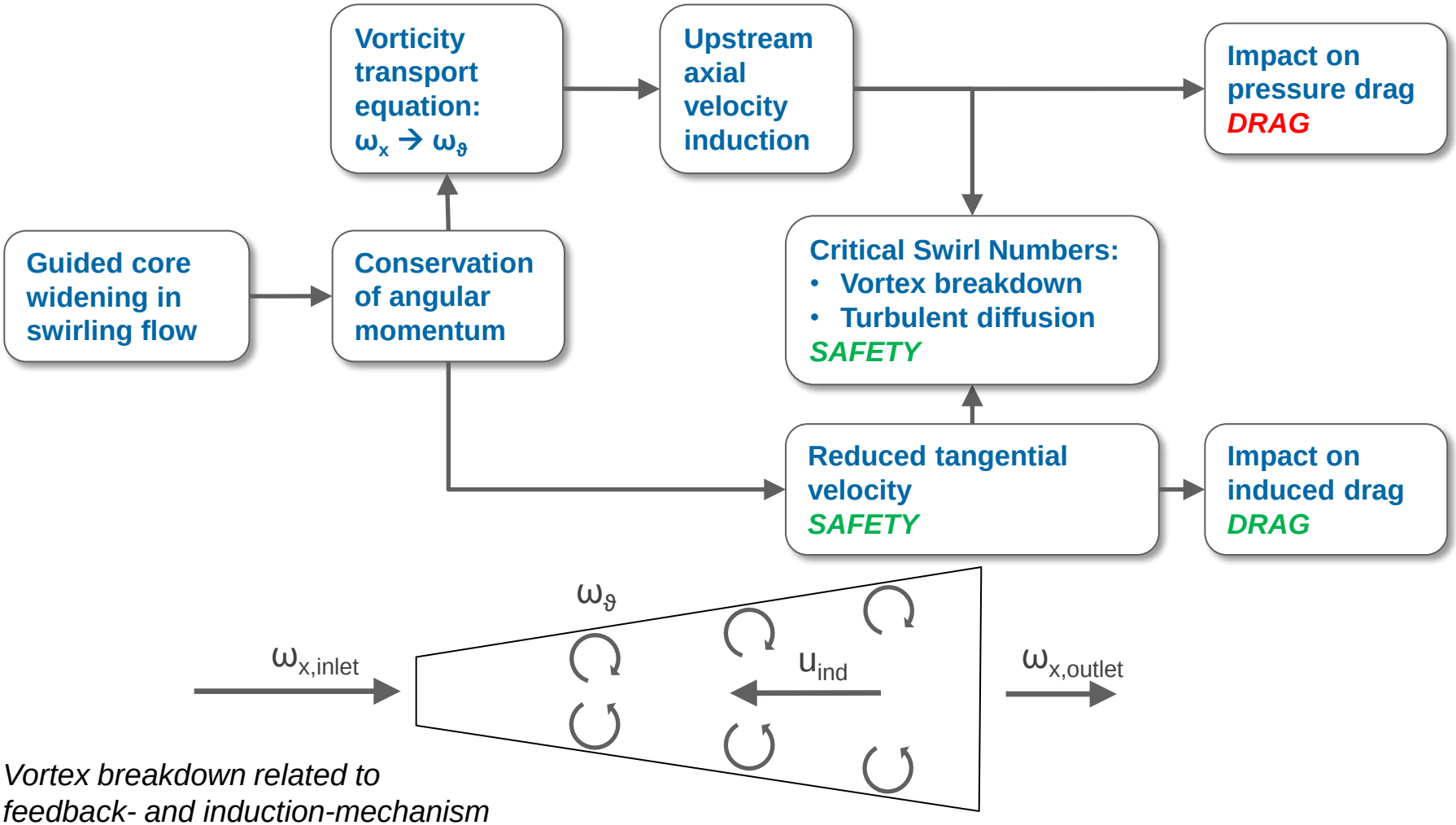
Retractable wing-/ flaptip device



Integrated and adaptable wing-/ flaptip feature

Concept of Vortex Alleviation Cone System

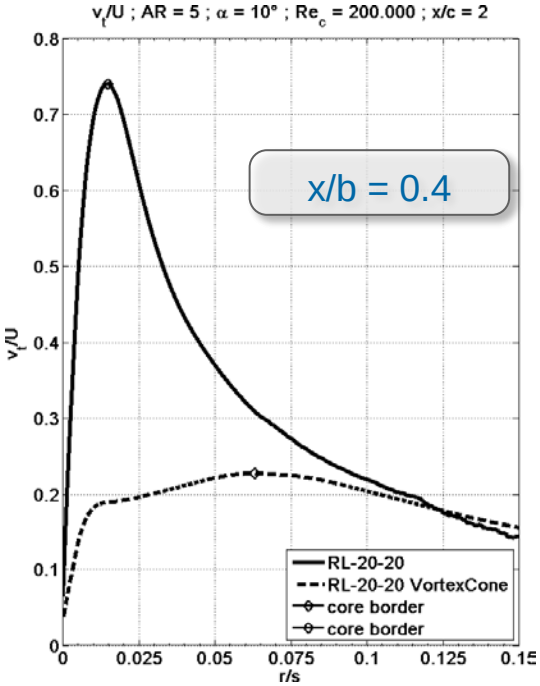
- Physical effects:

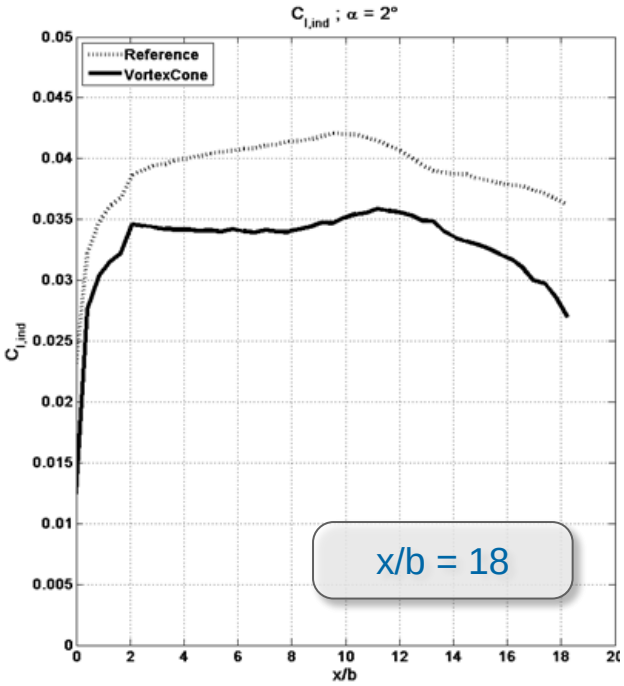


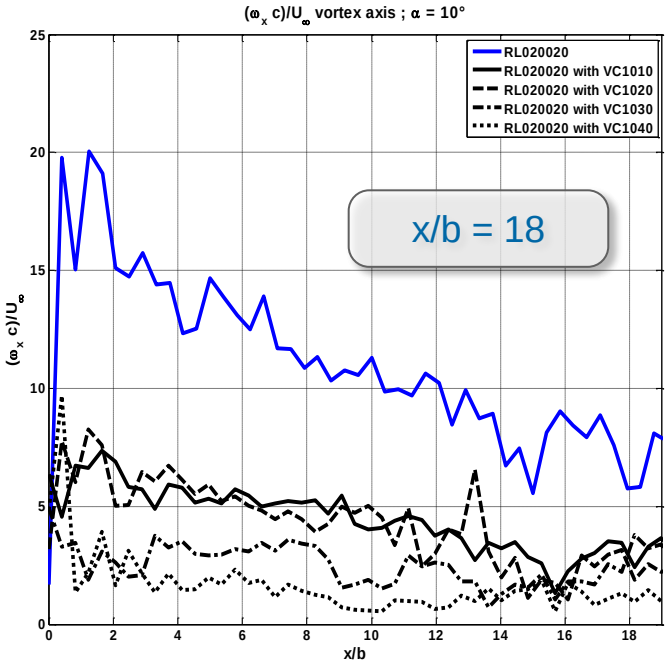
Vortex breakdown related to feedback- and induction-mechanism

I. Validation in the nearfield

- Preliminary investigations at RWTH Aachen using generic wing-model







70 % reduction of $v_{t,max}$, $w_f = 3$

15 % reduction of $c_{Roll,ind}$, $w_f = 3$

Progressive reduction of $\omega_{x,max}$ with w_f

Current project scope

- RWTH Aachen University project funded by “Innovationsfond”
  - Validation of the effectiveness and efficiency of VACS
- Project scope
  - **WP 1: Analysis of lift, drag, effectiveness, and noise (ILR)**
  - WP 2: Analysis of vortex intensity long-time development (ILR)
  - WP 3: Analysis of air traffic benefits and solution trade-off (VIA*)
  - WP 4: Joint workshop on expertise level (ILR & VIA*)

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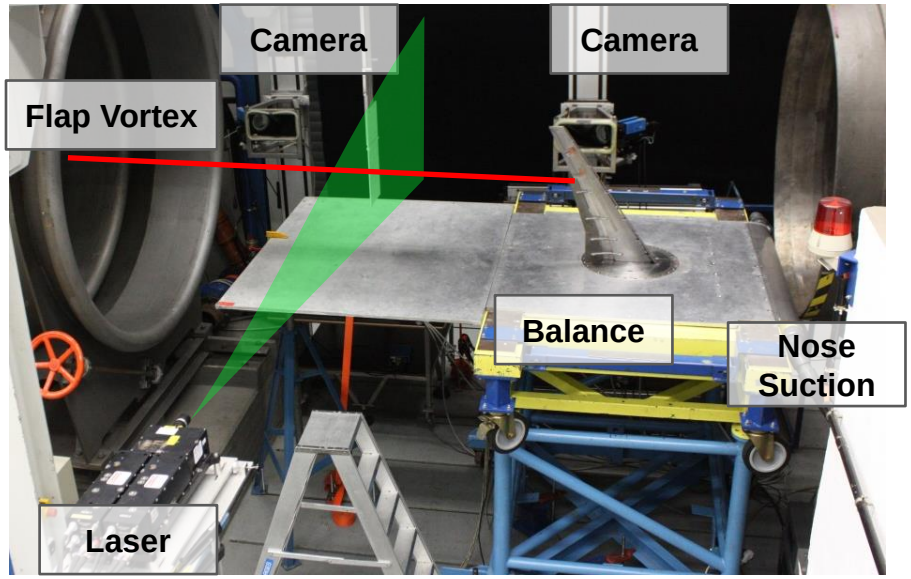
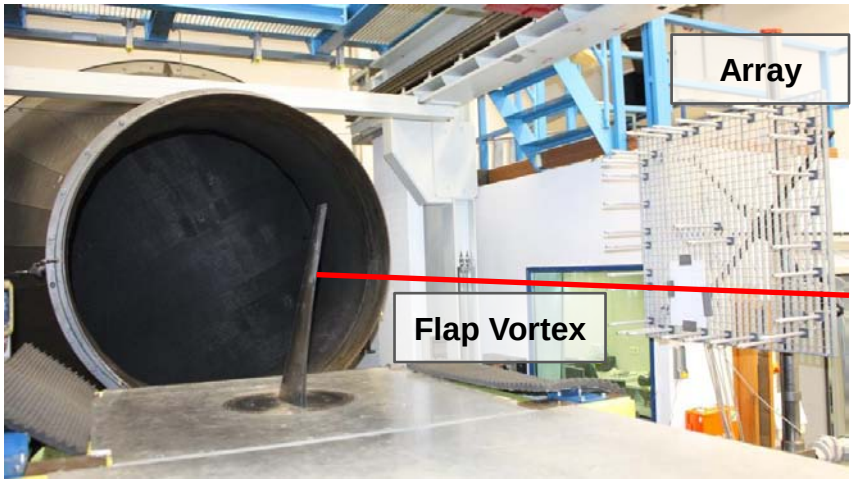
RWTH Aachen University

II. Validation in the nearfield

- Windtunnel and experimentals



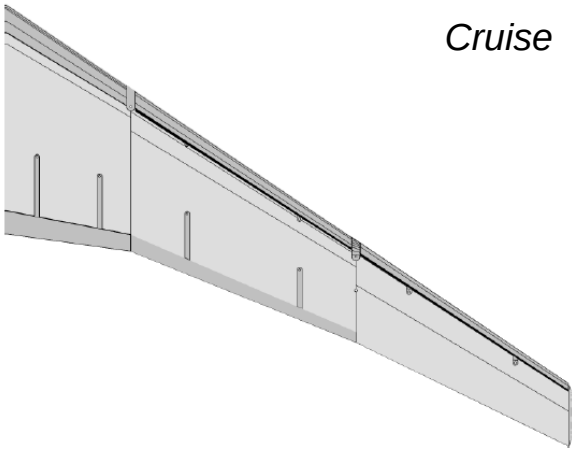


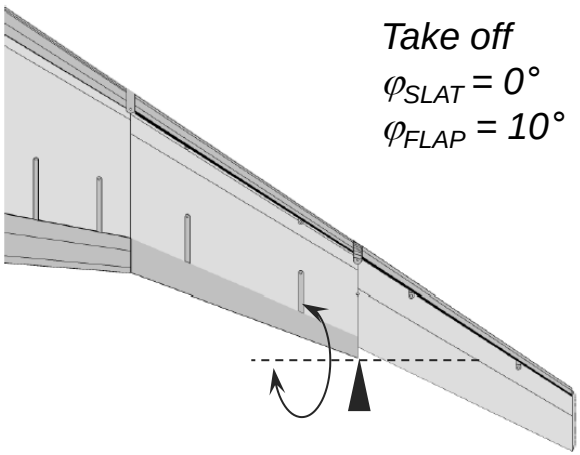
- **Low speed windtunnel**
  - Rec = 300.000 | V ~ 29 m/s
  - Nose suction
- **6C Balance**
  - DMS, temperature compensated
- **3C PIV**
  - 4 MPx Cameras
  - Davis by LaVision PIV software
  - 16x16 px² with 50 % overlap

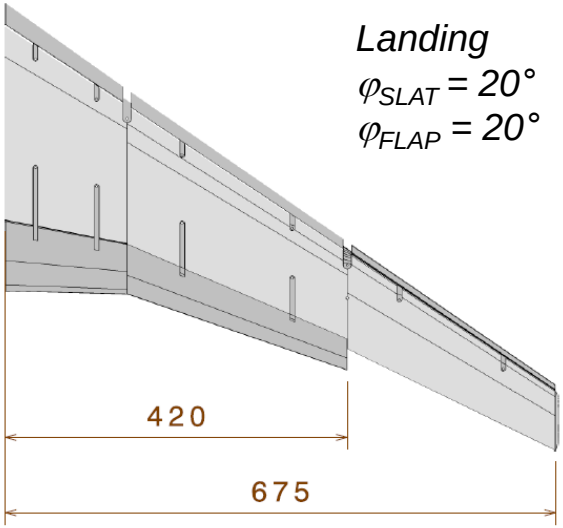
- **Acoustic Array**
  - 32 microphones
  - Still under investigation

II. Validation in the nearfield

- Wing half-model and VACS devices
  - Articulated H/L features, BAC 3-11/RES/30/21 airfoil, s = 675 mm
  - VACS devices with w_f = 1 - 5
  - d_{inlet} = 10 mm ~ d_{core}
  - l_{VACS} = 70 mm = 40 % c_{mac}
  - Attachment:
    - Capturing viscous core
    - Hinged mounting

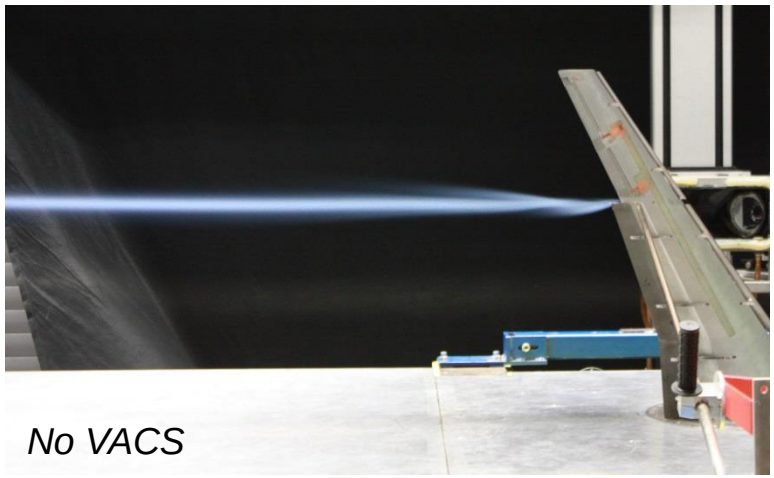




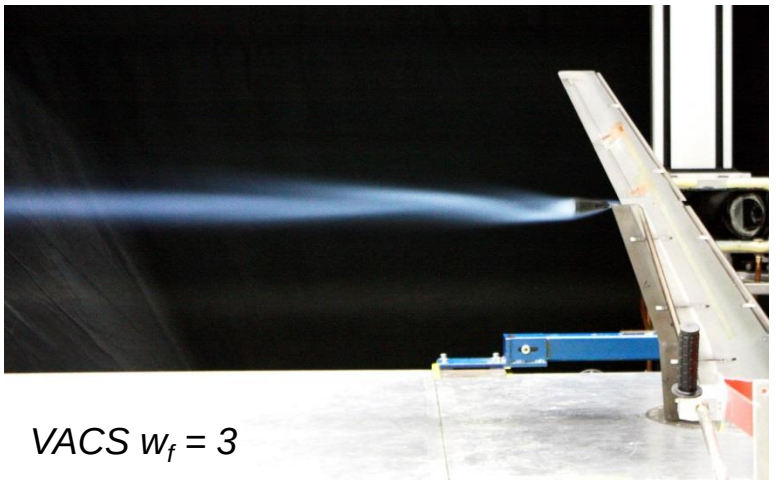


II. Validation in the nearfield

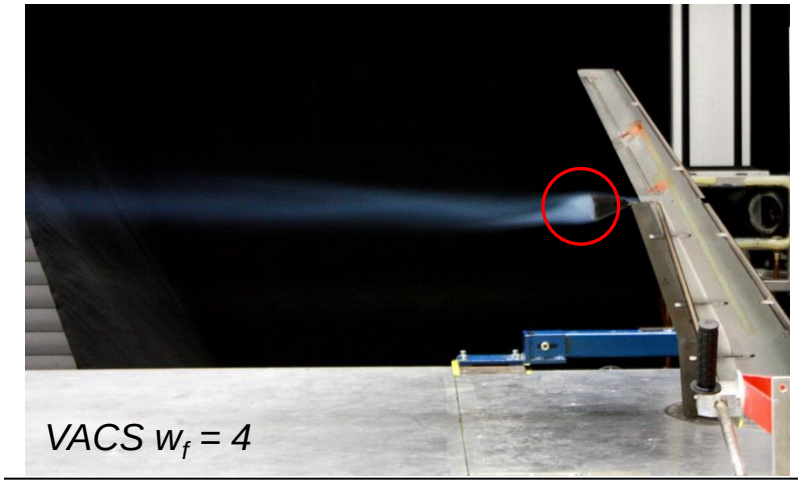
- Smoke visualization, landing configuration



No VACS



VACS $w_f = 3$



VACS $w_f = 4$

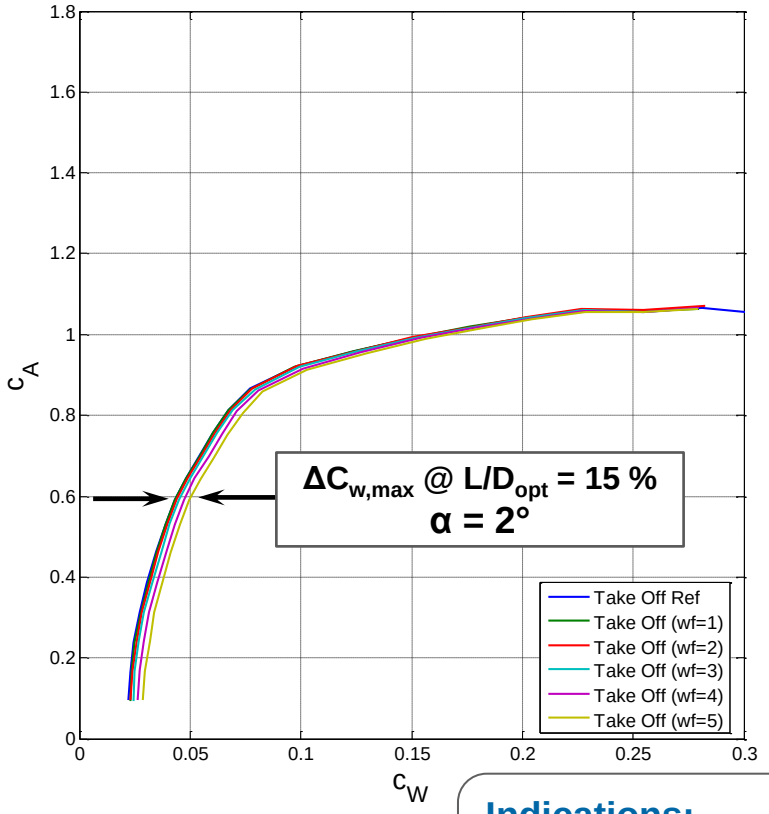
Indications:

- Increasing diffusion of vorticity with increasing w_f
- High w_f produce circulating breakdown region behind the outlet
- Drag penalty and effectiveness?

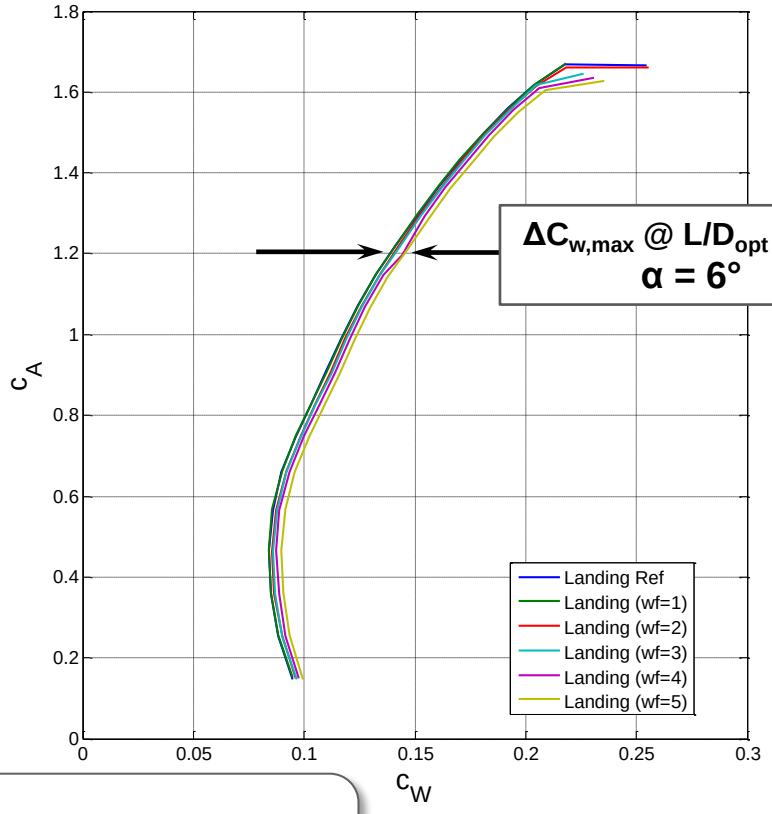
II. Validation in the nearfield

- VACS influence on lift (c_A) and drag (c_W) in best L/D points

c_A / c_W ; Take-off Configuration



c_A / c_W ; Landing Configuration



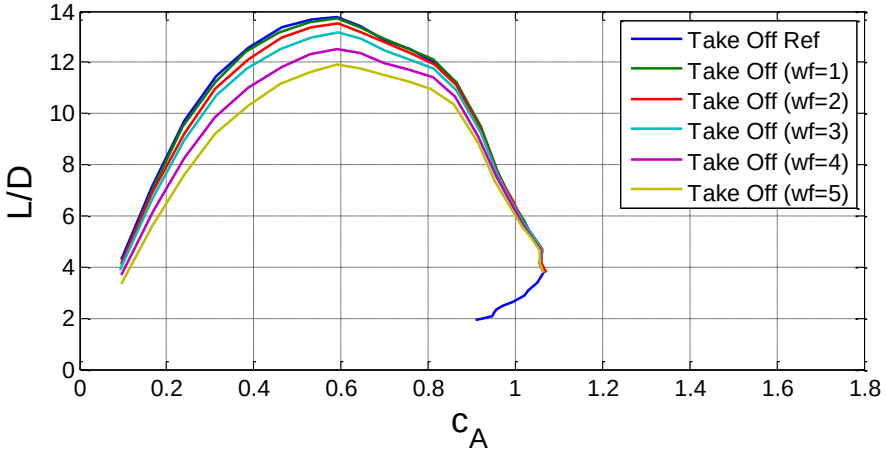
Indications:

- Drag dominated by $c_{W,0}$ with increasing w_f
- $c_{W,D}$ increase > $c_{W,IND}$ reduction

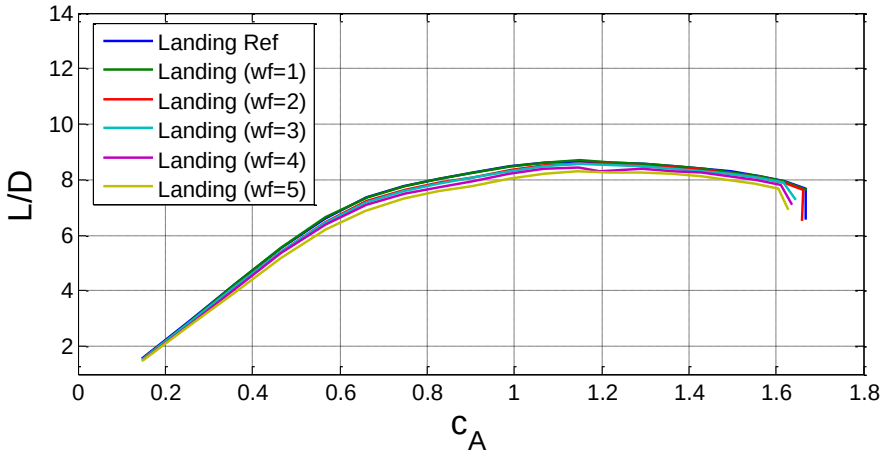
II. Validation in the nearfield

- VACS influence on L/D

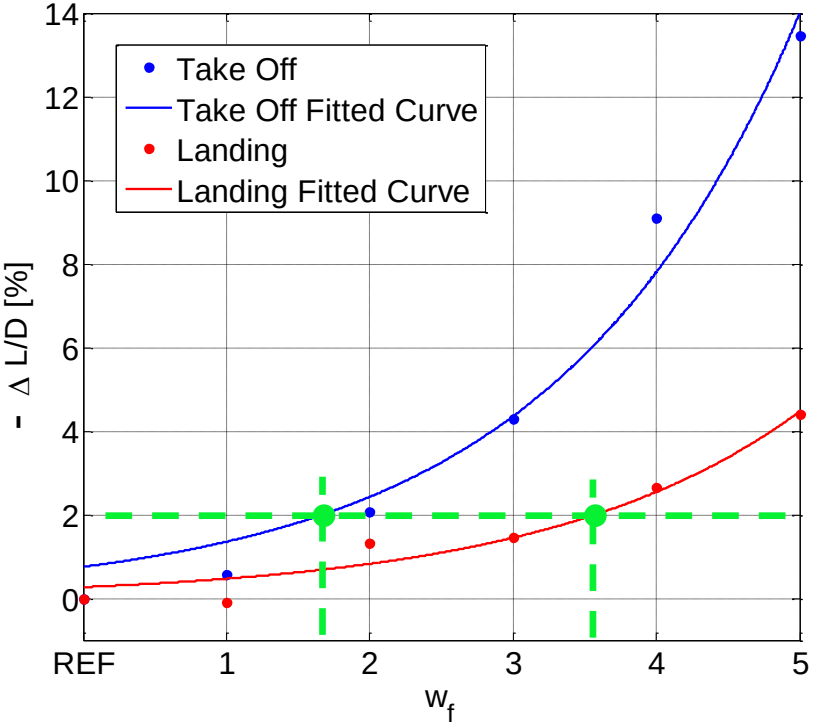
L/D over c_A ; Take-off configuration



L/D over c_A ; Landing Configuration



Δ L/D for Take-off (α = 2°) and Landing Configuration (α = 6°)

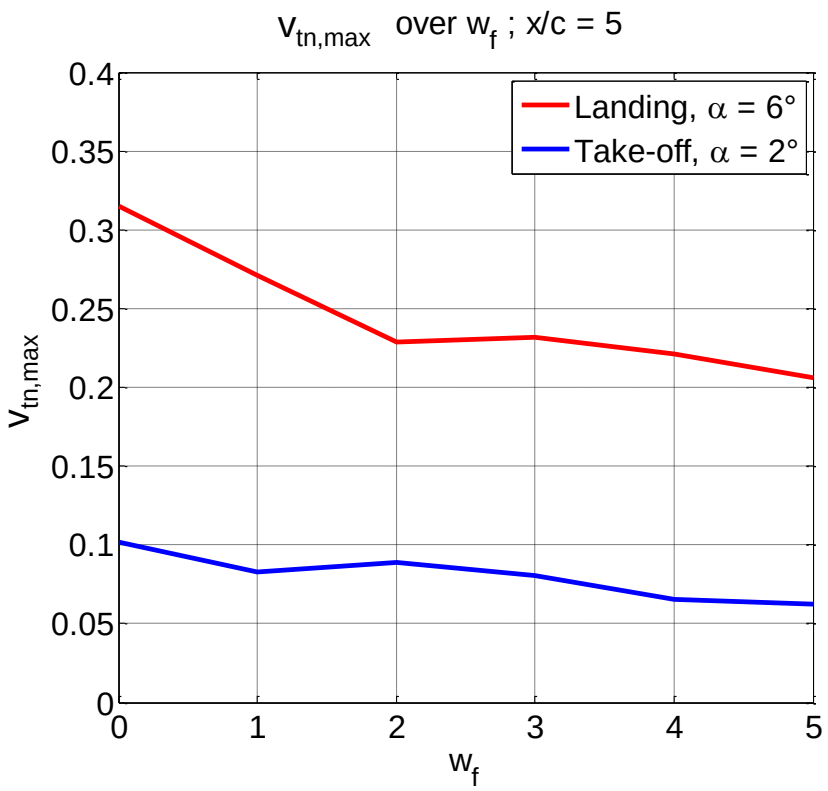


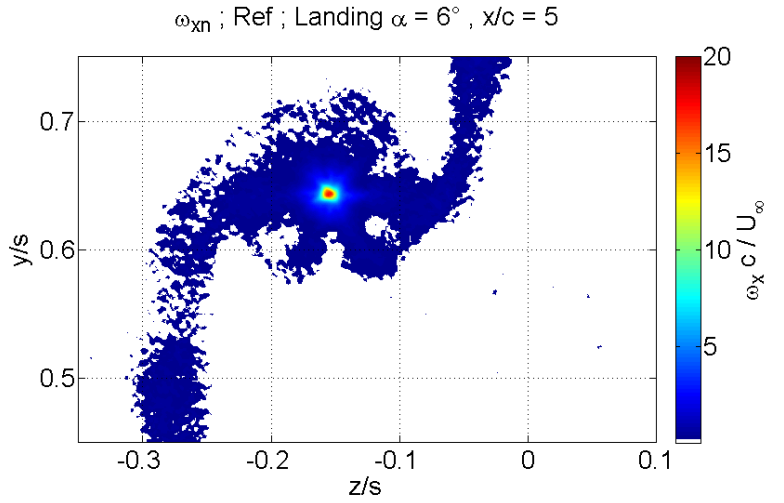
Performance degradation:

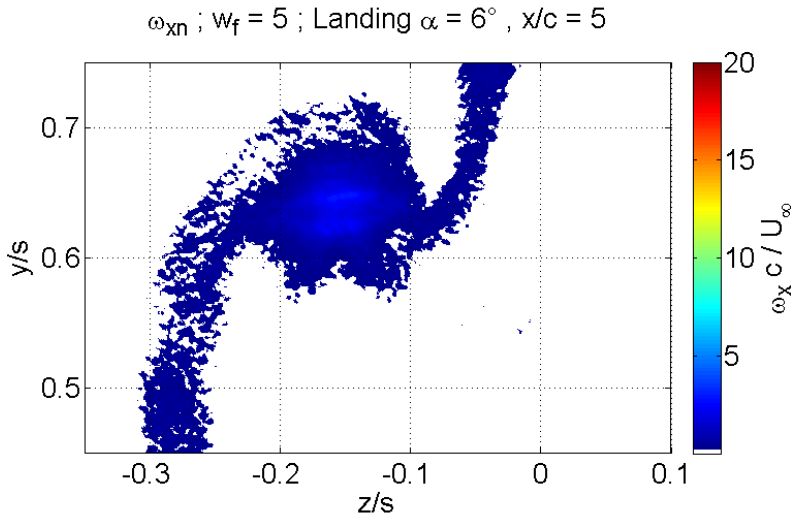
- Moderate for landing, excessive for take-off
- w_f adaption for low drag service?

II. Validation in the nearfield

- 3C-PIV: Mitigation potential





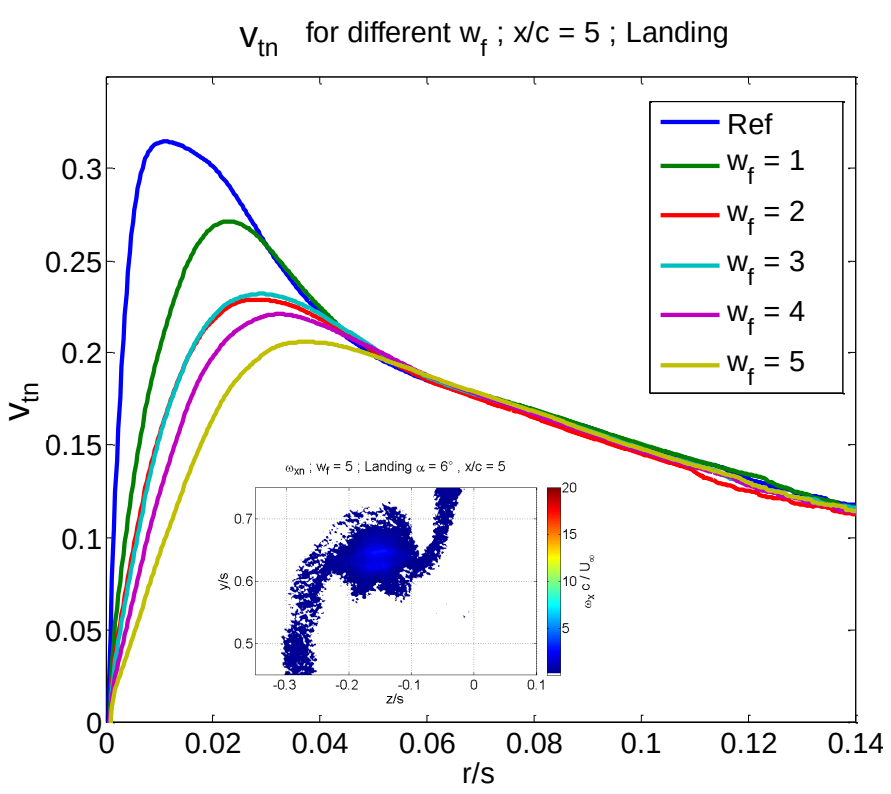


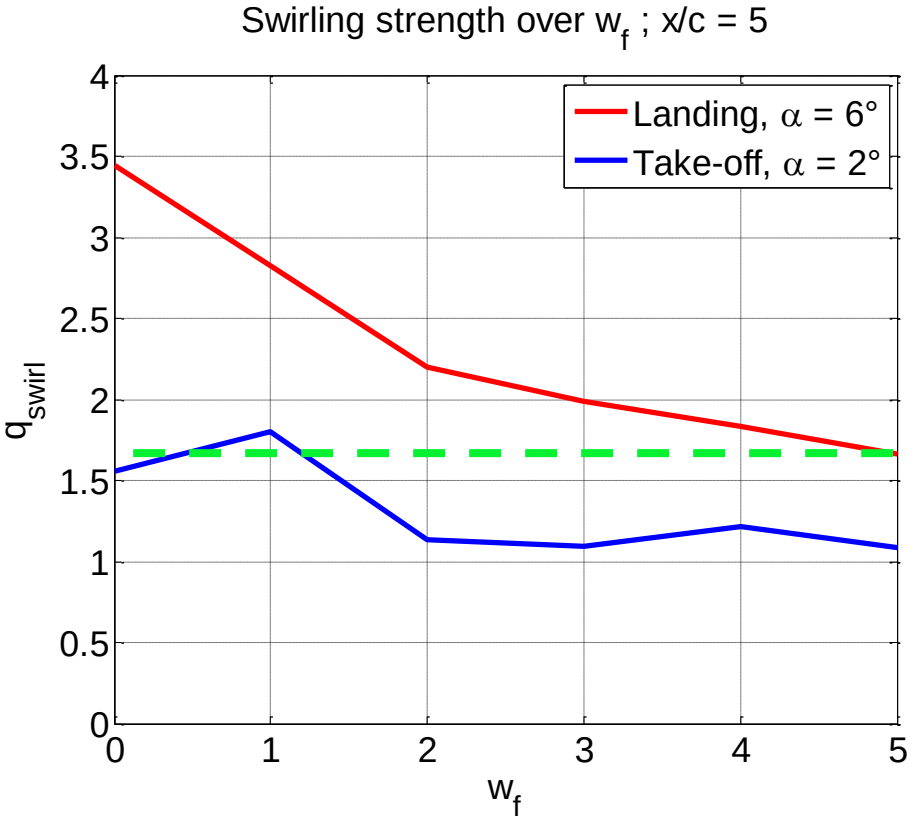
Reduction of vortical motion:

- $\omega_{x,max}$: 85 % (Landing), 75 % (Take-off)
- $v_{tn,max}$: 40 % (core growth ~ 3) (both)

II. Validation in the nearfield

- 3C-PIV: Mitigation potential



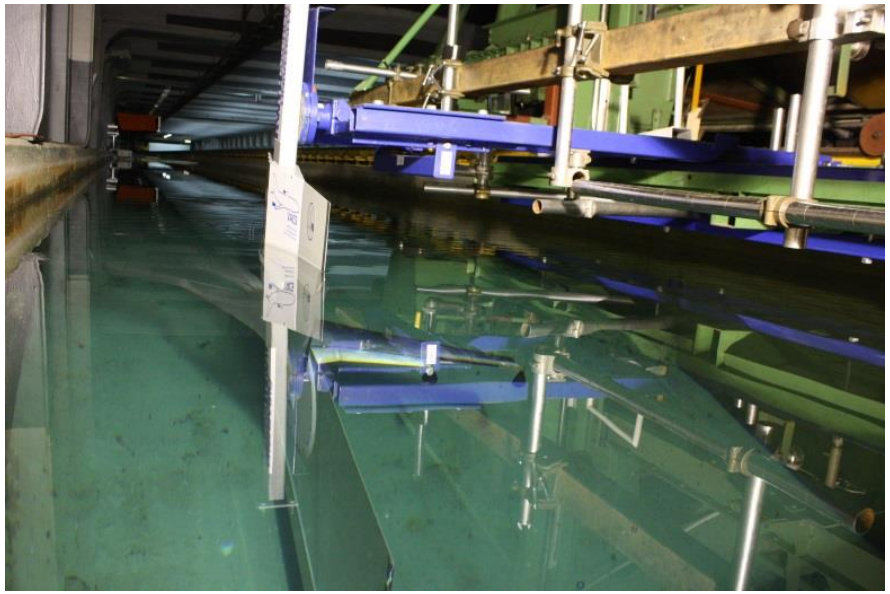


Potential for $c_{Roll,ind}$ reduction:
- Needs to be assessed for completely rolled-up vortex in the farfield

Potential for swirl instability:
- Enhancement of turbulent diffusion?

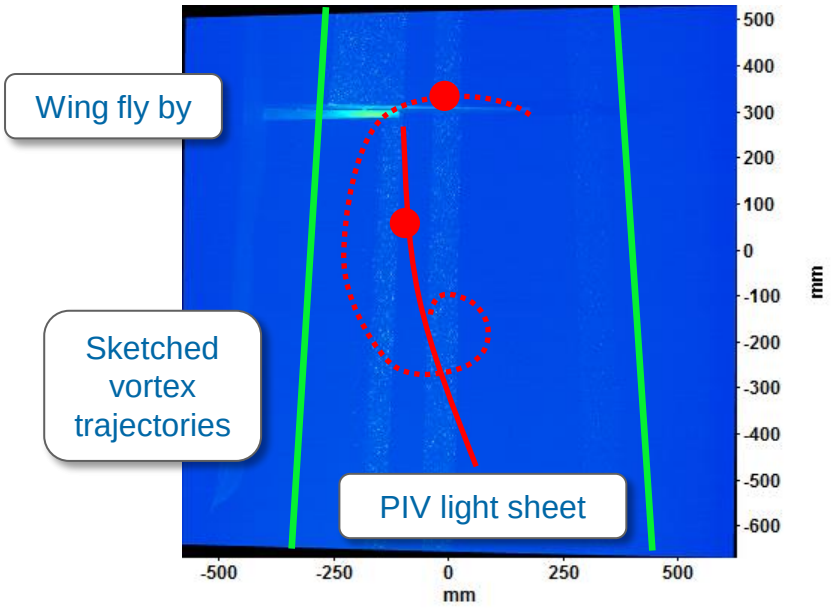
III. Current validation in the farfield

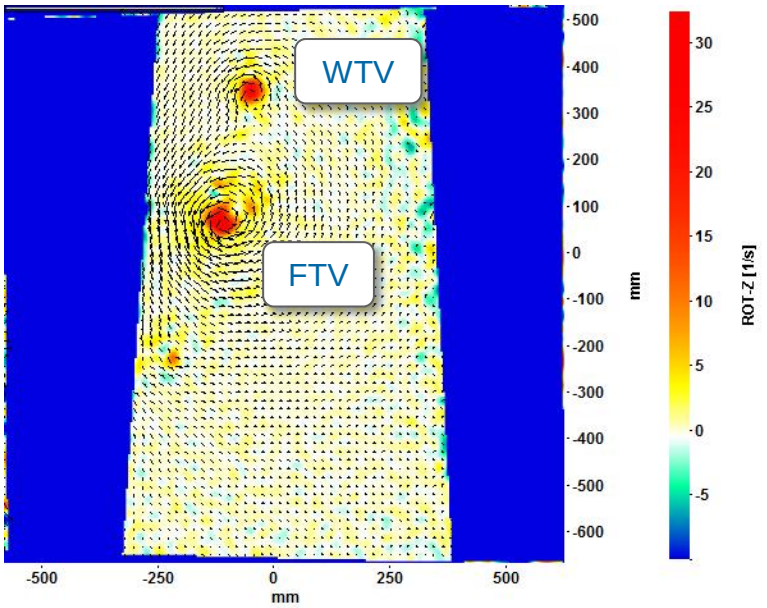
- Towing tank facility DST in Duisburg, Germany
  - Tank cross section: 3 m wide (~ 4.5 s), 2.6 m deep (~ 3.8 s)
  - Towing length: 54 m
  - Speed: 1.85 m/s – with profiled start- and stop- accelerations
- Experimentals
  - Vortex surveillance distance: 35 - 40 spans
  - Start- and stop-effects arrive noticeably later in the measuring plane



III. Current validation in the farfield

- Preliminary effects
  - H/L vortex shedding from flap and tip – with and without VACS
  - Shear layer roll-up, merging, vorticity concentration and diffusion





Lessons learned:

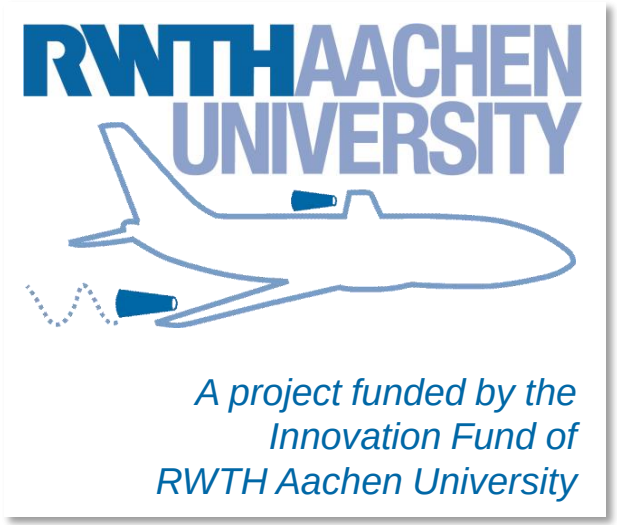
- Necessary affection of <u>both vortices</u> because of vorticity alignment of the wing-tip vortex WTV during merging with flap-tip vortex FTV
- Vorticity reduction, core growth, and $c_{Roll,ind}$ reduction to be processed

Summary

- VACS effect
  - Vortex intensity reduction by guided feed-back mechanism for efficient momentum transfer
- VACS application
  - Nearfield: e.g. possible helicopter BVI reduction
  - Farfield: Potential for w/v mitigation (still processing)
- VACS obstacles
  - L/D: decrease (drag-effect) 4 % @ $w_f = 5$ for landing configuration
  - Noise: no critical noise sources so far (further analysis)
  - Miniaturization
- VACS outlook
  - DE and PCT patent processes pending
  - Acoustic noise assessment
  - Joint expert workshop in 2015

Thank you!

Questions?



References

[1] *"Wake Vortex Research Needs for Improved Wake Vortex Separation Ruling and Reduced Wake Signatures", WakeNet2-Europe, Part II – Specialist's Reports FINAL, April 2006*

[2] *"Wingtip Vortex Dissipator for Aircraft", US 3,984,070, 1974*

[3] *"Wingtip Vortex Turbine", US 4,917,332, 1988*

[4] *Dunham, R.: "Unsuccessful Concepts for Aircraft Wake Vortex Minimization", NASA Langley Research Center, 1977*

[5] *"Tragflügel", DE Patent pending, 2013*

Outlook

- Further analysis:
  - Comparing drag components from balance and 3C-PIV
  - Assessment of swirl and turbulence
  - Acoustic noise assessment
  - Optimization / miniaturization / adaptivity / trade-offs
- Further direct project scope
  - WP1: Analysis of lift, drag, effectiveness, and noise (ILR)
  - **WP2: Analysis of vortex intensity long-time development (ILR)**
  - WP 3: Analysis of air traffic benefits and solution trade-off (VIA*)
  - WP 4: Joint workshop on expertise level (ILR & VIA*)
- Water towing tank experiments at DST** in Duisburg, Germany, Oct. 2014
  - 2C-PIV, VACS at flap-tip and possibly wing-tip
  - Start-stop investigation / mitigation
  - 120 span vortex mitigation assessment

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RWTH Aachen University

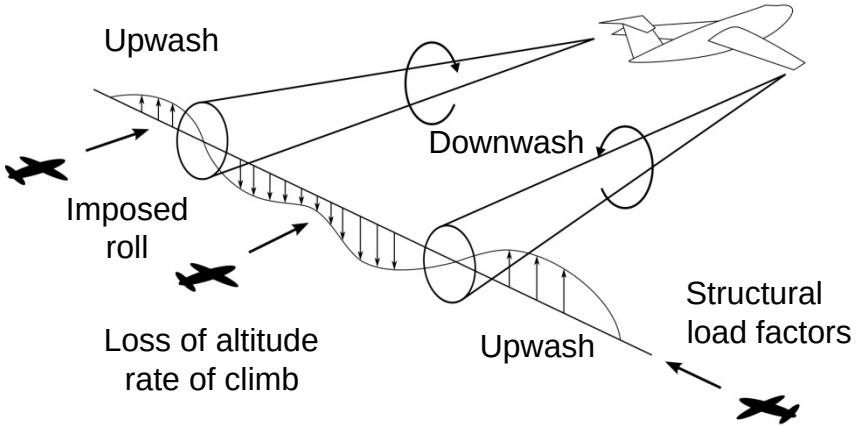
Numerical Simulation of Vortex Roll-Up Processes at Elliptical Wings Using Reynolds Stress Models

4th EASN Association International Workshop, Aachen, Germany

Introduction

- Wingtip vortices are unavoidable results of lift generating surfaces
- Potential hazard for following airplanes
- Limiting factor for the capacity of civil airports
- Physic of vortex roll-up process not fully understood
  - axial velocity in the vortex cannot be predicted by theory
  - axial velocity deviations are known for increasing vortex decay /decreasing vortex stability

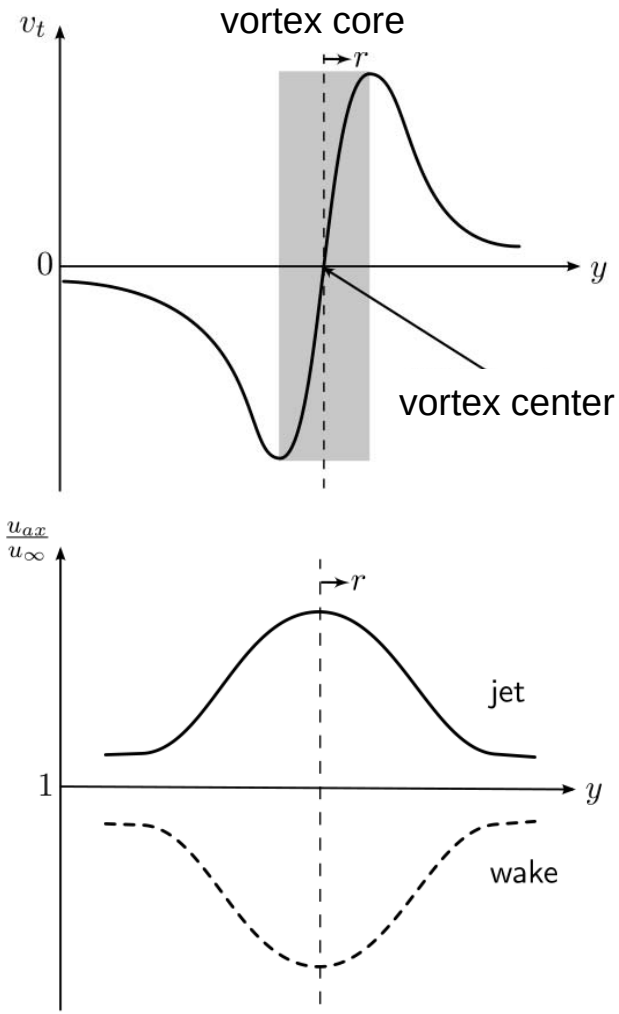
➡ need for a better understanding of the vortex roll-up process



Objectives

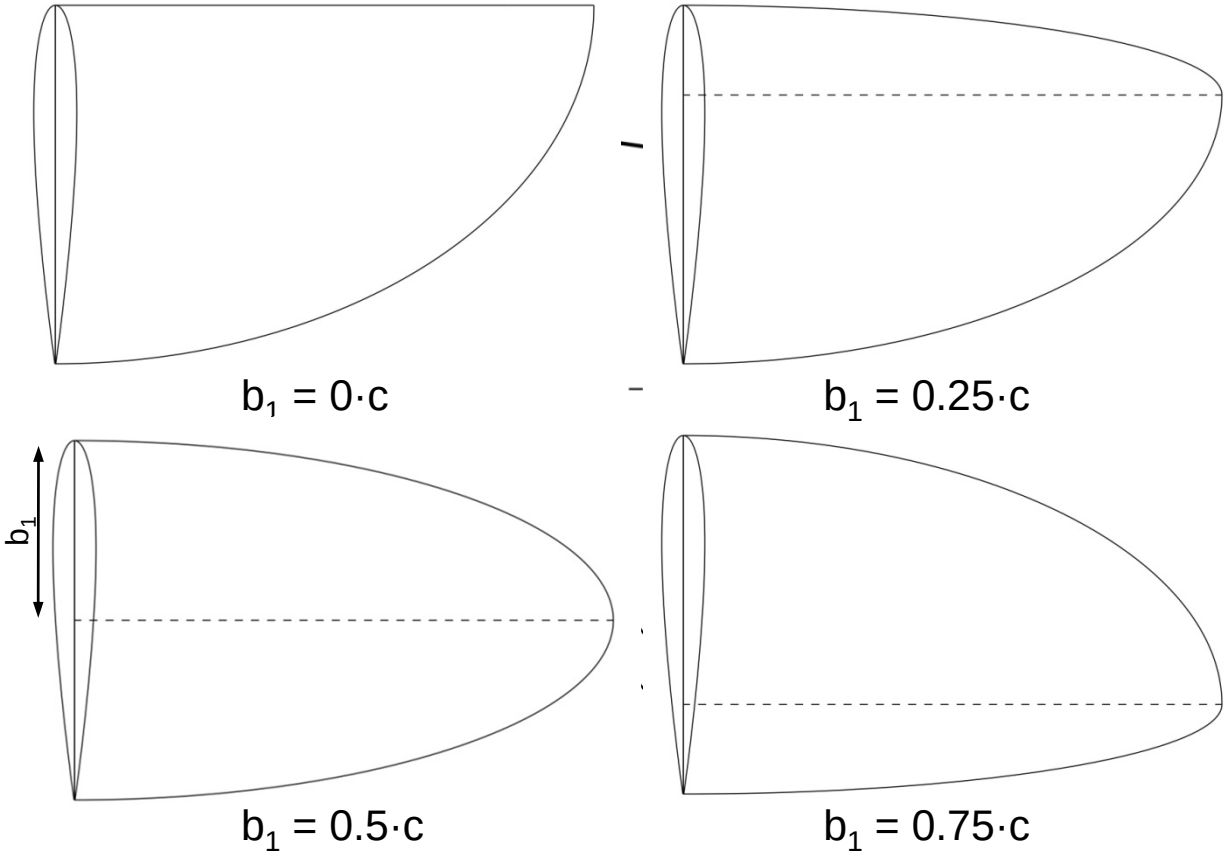
Dependence of axial velocity in the vortex core on:

- Wing geometry
  - location of maximum thickness
  - pressure distribution
- Boundary layer effects
  - Reynolds number
- Angle of attack (AoA)
  - lift of the wing
  - total circulation of the vortex



Test Cases

- Generic elliptical wing
- NACA 0012 airfoil, chord length c = 1.2m, aspect ratio Λ = 3.8
- Re = 2.8 – 4.6 · 10^6 ; AoA = 6°, 8°, 10°



Aspect ratio as well as wing area remain unchanged

Numerical Setup

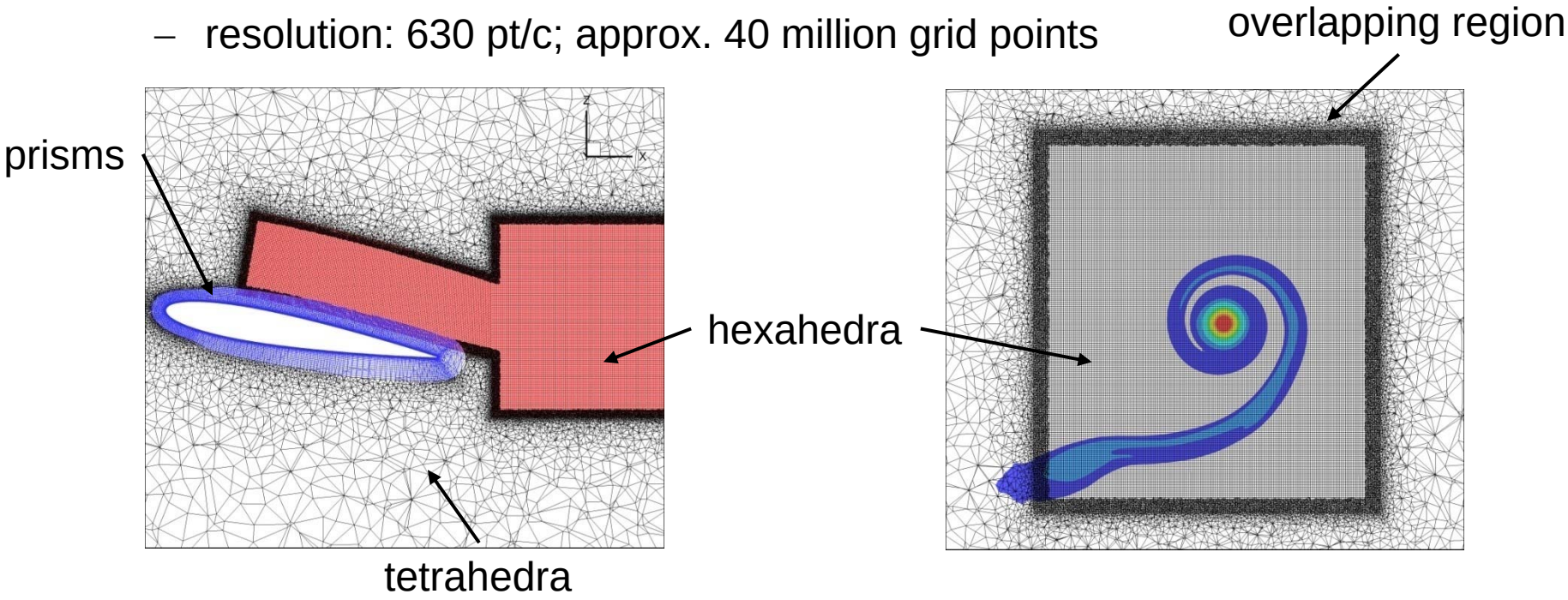
- Solver:
  - DLR TAU code
  - unstructured finite volume solver for the compressible Reynolds-averaged Navier-Stokes (RANS) equations

- Turbulence:
  - SSG/LRR-ω model
  - Reynolds Stress Models directly build on the modeled transport equations for the Reynolds stress tensor
  - production term is given exactly
  - ➡ much better prediction of vortex physics compared to eddy-viscosity models

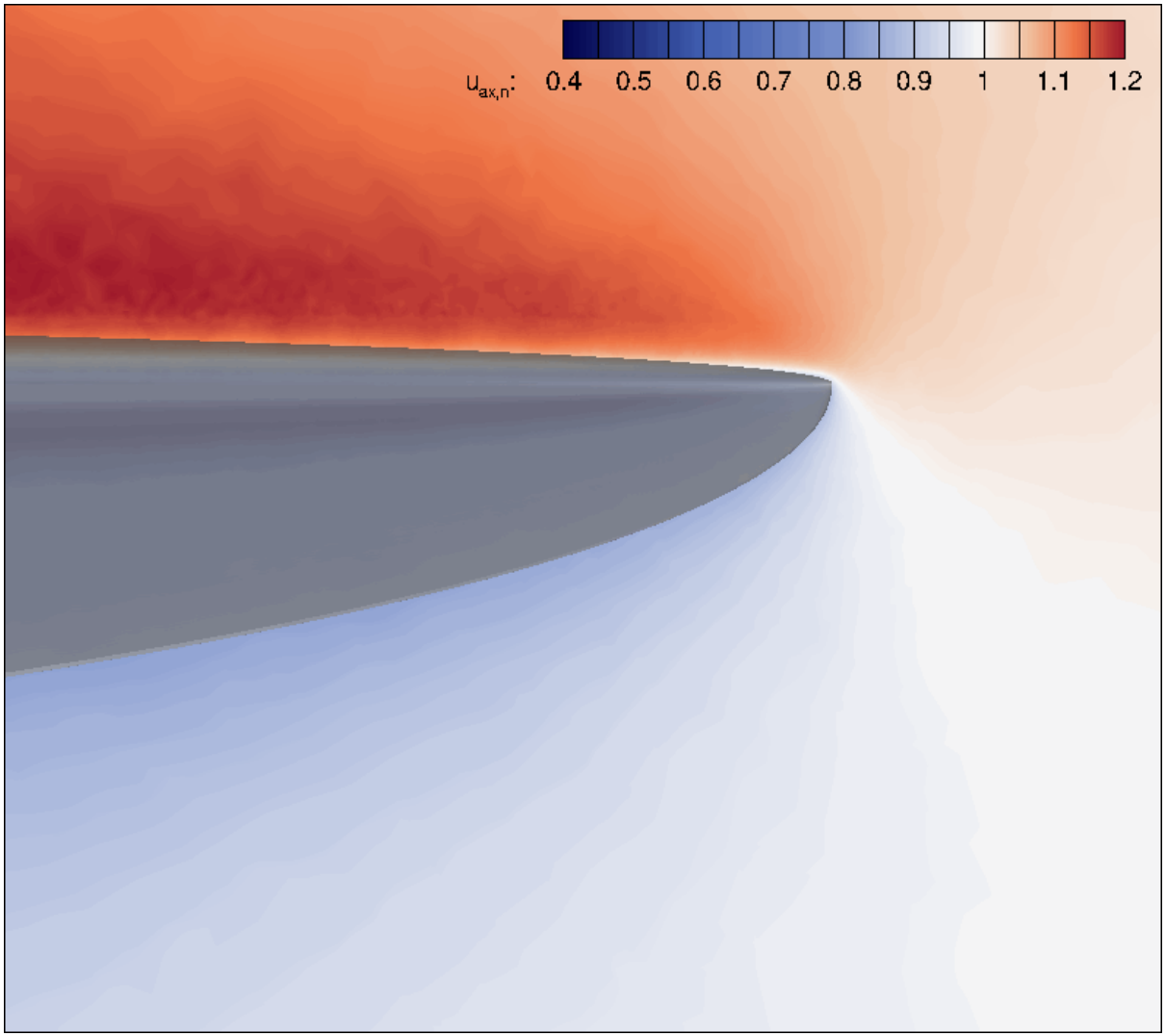
- Hardware:
  - High-Performance Computing system of RWTH Aachen University
  - overall usage: 340,000 core hours

Mesh Topology

- Grid was created using the Centaur and Pointwise mesh generator
- Overset Grids (Chimera grid technology)
  - hybrid mesh: prism layers to resolve the wing boundary layer and the initial vortex roll-up + tetrahedra
  - hexahedra block: structured mesh to resolve the rolled up vortex and to reduce numerical dissipation
  - resolution: 630 pt/c; approx. 40 million grid points

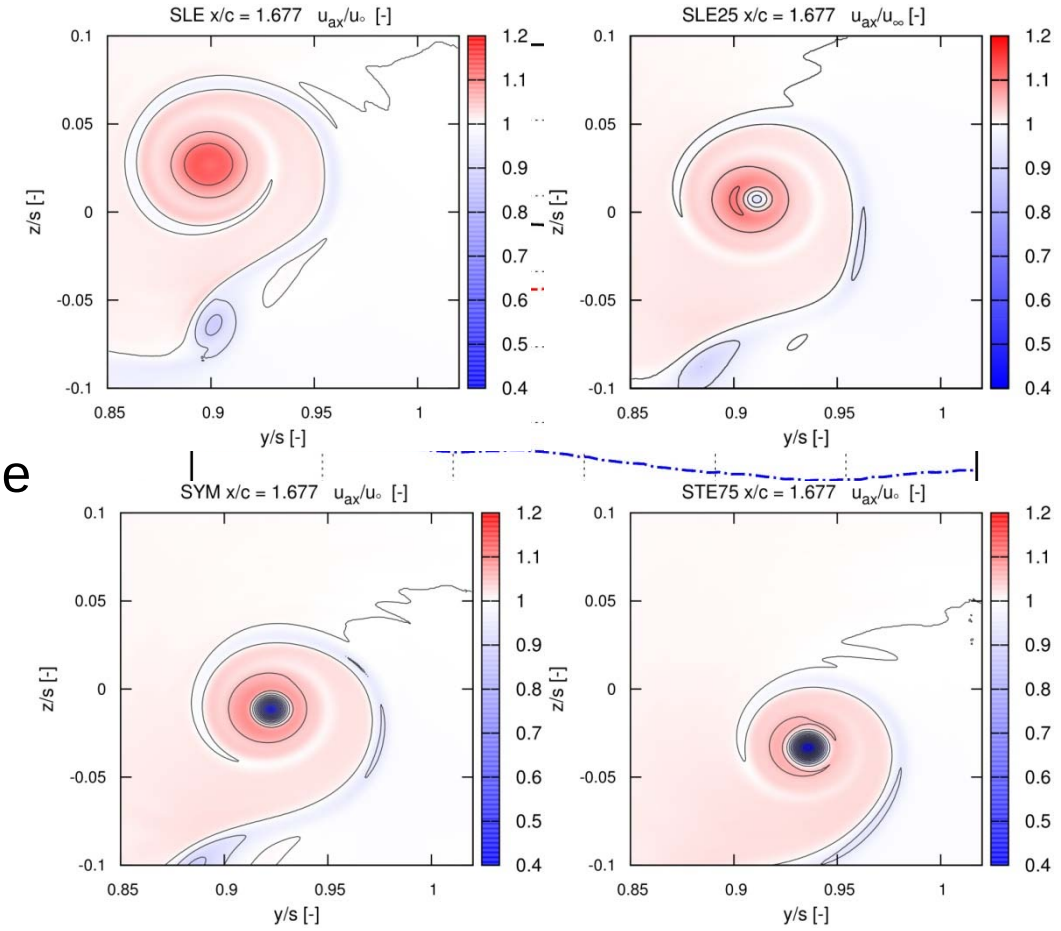


Vortex Roll-Up Process



Effects of Wing Geometry on Axial Velocity

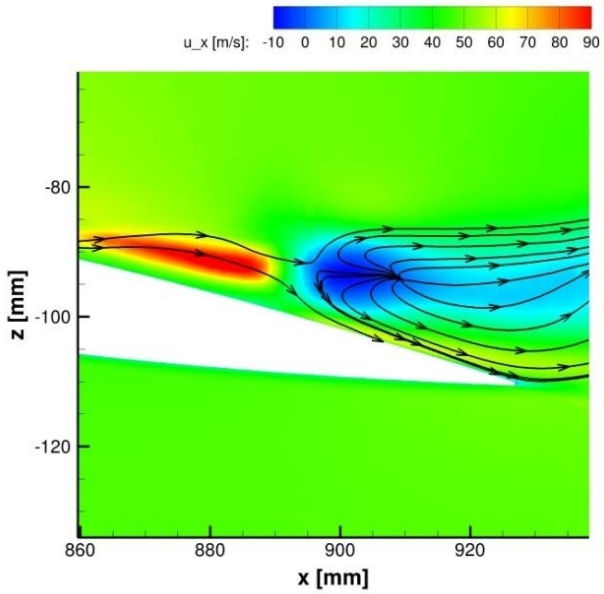
- Jet as well as wake can be observed
- Velocity excess surrounding the vortex core
- Axial velocity decreases while location of maximum thickness moves downstream

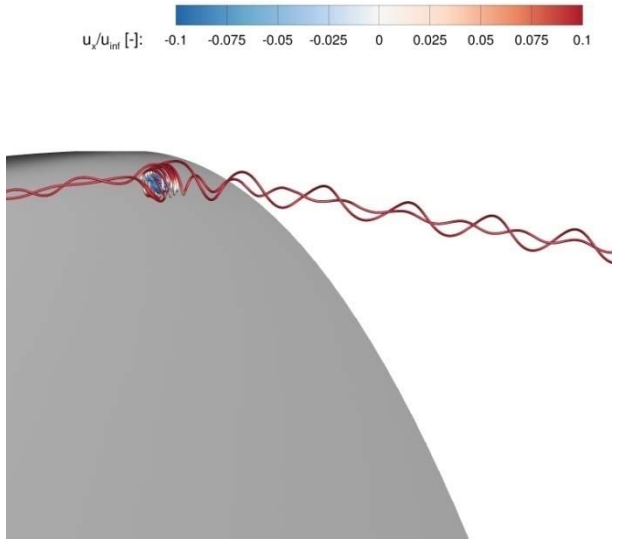


$Re = 4.6 \cdot 10^6$, AoA = 10°

Vortex Breakdown

- Extreme wake caused by vortex breakdown
- Axial pressure gradient dp/dx > 0
- Cannot be overcome by kinetic energy of fluid particles
  - ➞ stagnation and recirculation flow
  - ➞ bubble breakdown



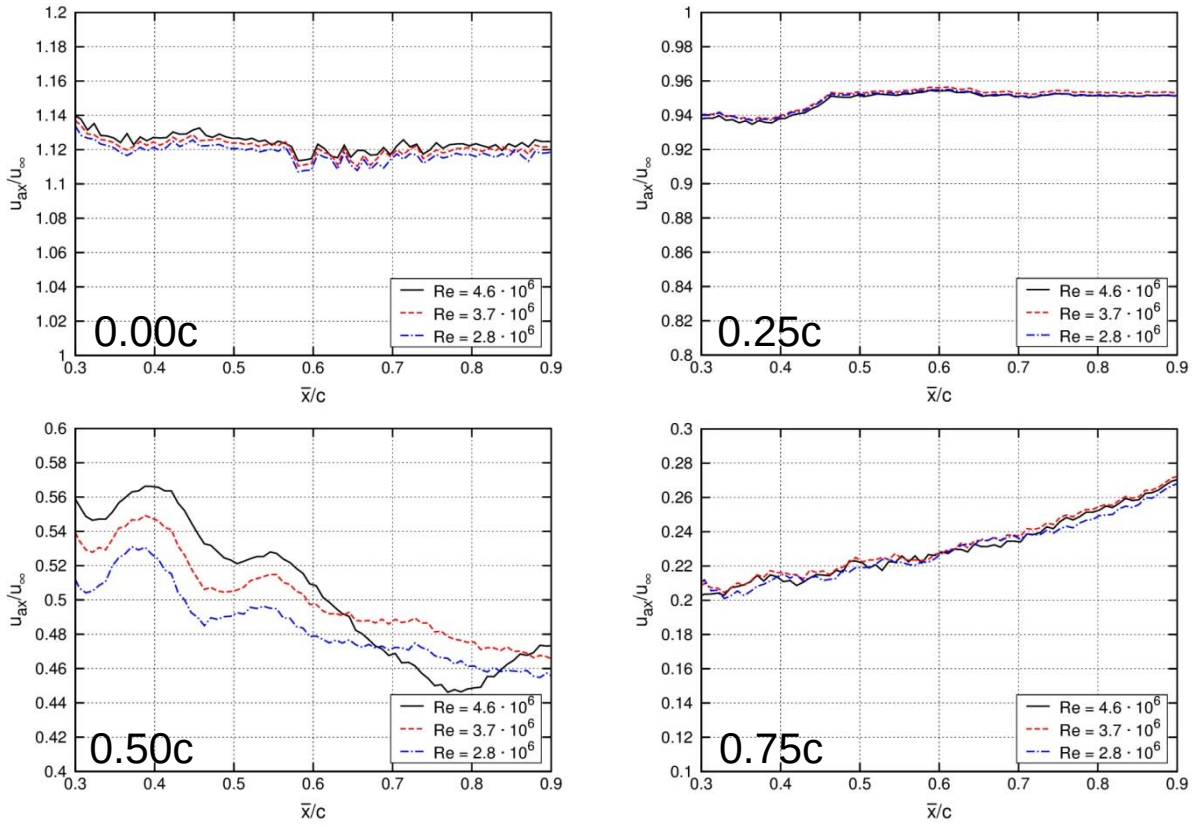


$b_1 = 0.75 \cdot c$

Reynolds Number

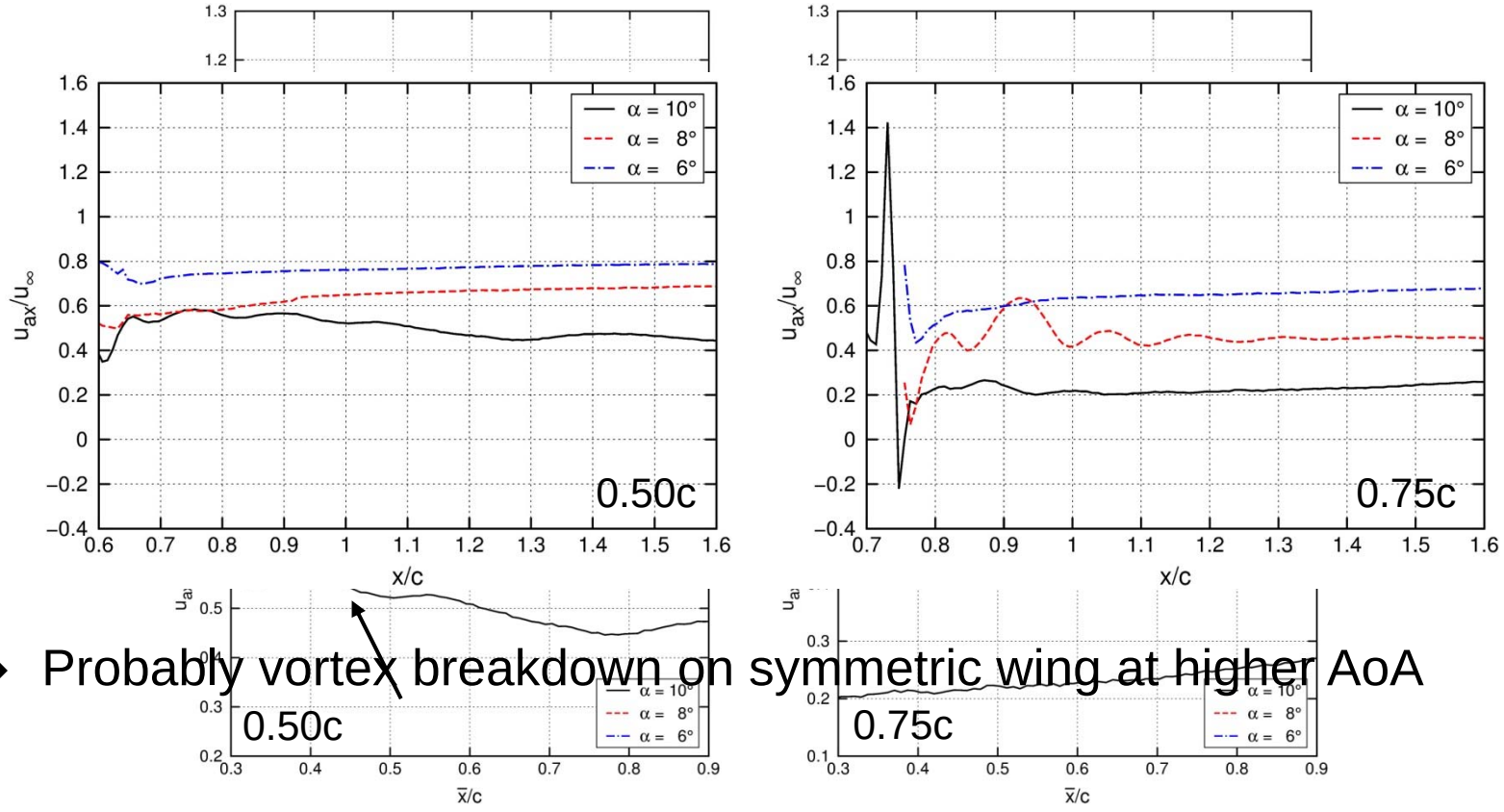
- Small impact on axial velocity in the investigated flow regime

➡ Effect of increasing Reynolds number is probably reduced at high Reynolds numbers



Angle of Attack

- Crossover point between wakelike and jetlike axial flow
- Impact depends on wing planform



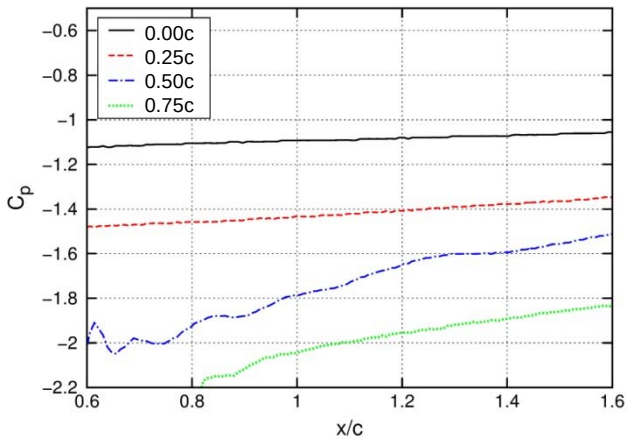
➡ Probably vortex breakdown on symmetric wing at higher AoA

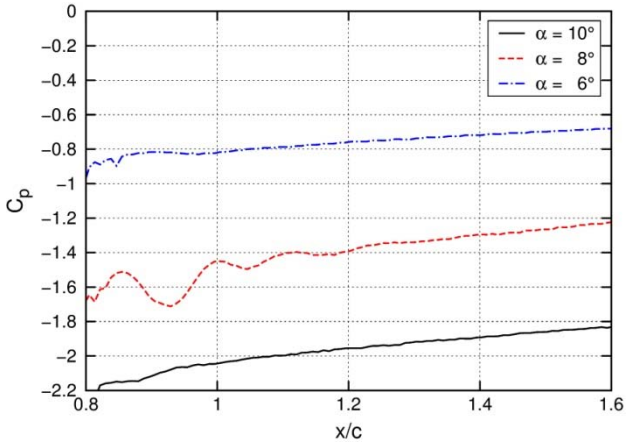
Pressure Distribution

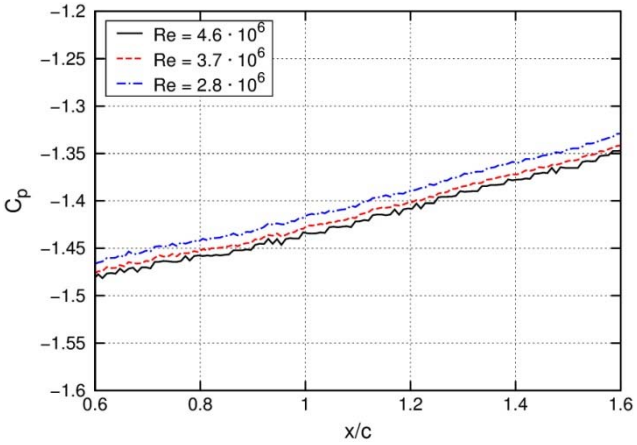
- Positive axial pressure gradient dC_p/dx at the vortex center
- Higher angle of attack
- Higher Reynolds number

} lower static pressure

- Pressure decreases while location of maximum thickness of the wing moves downstream
- Lowest pressure at lowest axial velocity







α = 10°, Re = 4.6·10^6 0.75c 0.25c

Conclusion

- Small impact of Reynolds number

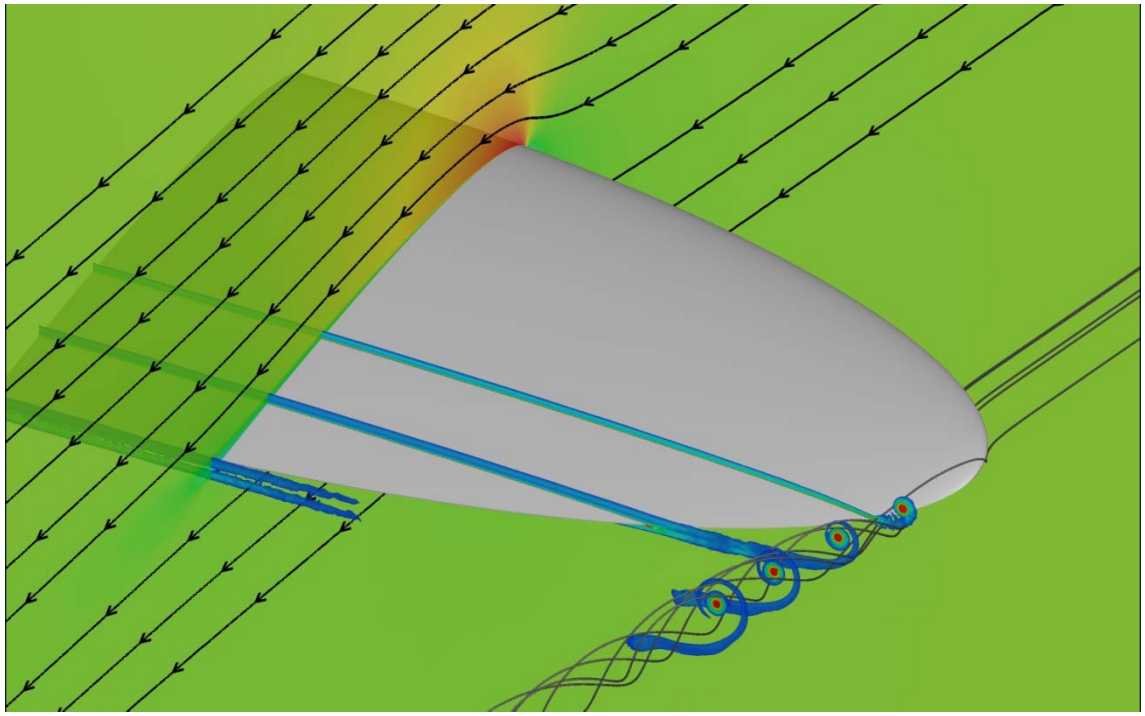
➞ Effect of increasing Reynolds number is probably reduced at high Reynolds numbers

➞ Viscous effects are not main factor of influence

- strong dependency of wing planform on axial velocity as well as on impact of AoA

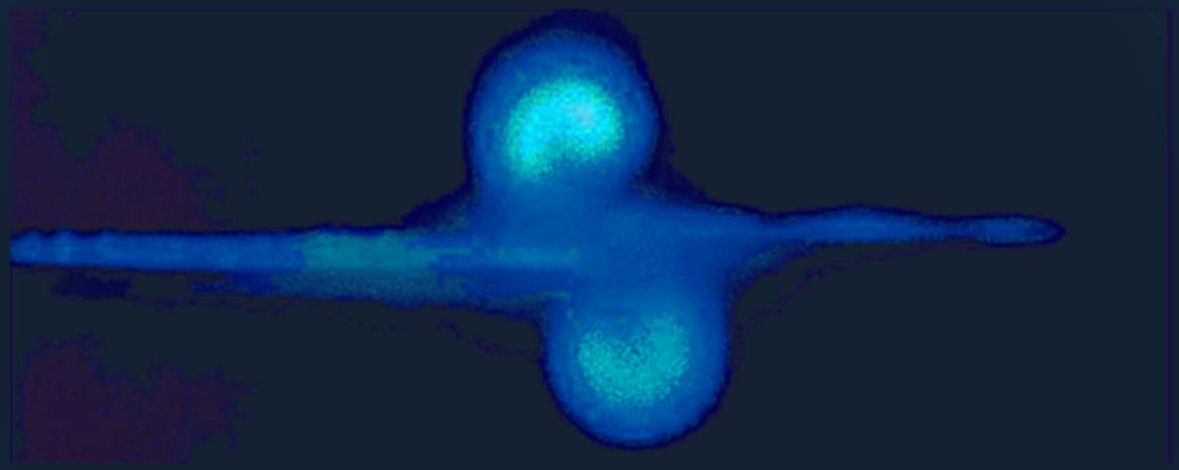
➞ High influence of the airfoil induced flow field during roll-up process

Thank you for your attention!



4th EASN Association International Workshop on Flight Physics & Aircraft Design,
27-29 October 2014, Aachen,

Co-rotating Vortex Interaction



Alexandros Romeos, Athanasios Giannadakis,
Konstantinos Perrakis, Thrassos Panidis

Laboratory of Applied Thermodynamics
Mechanical Engineering & Aeronautics Department
University of Patras

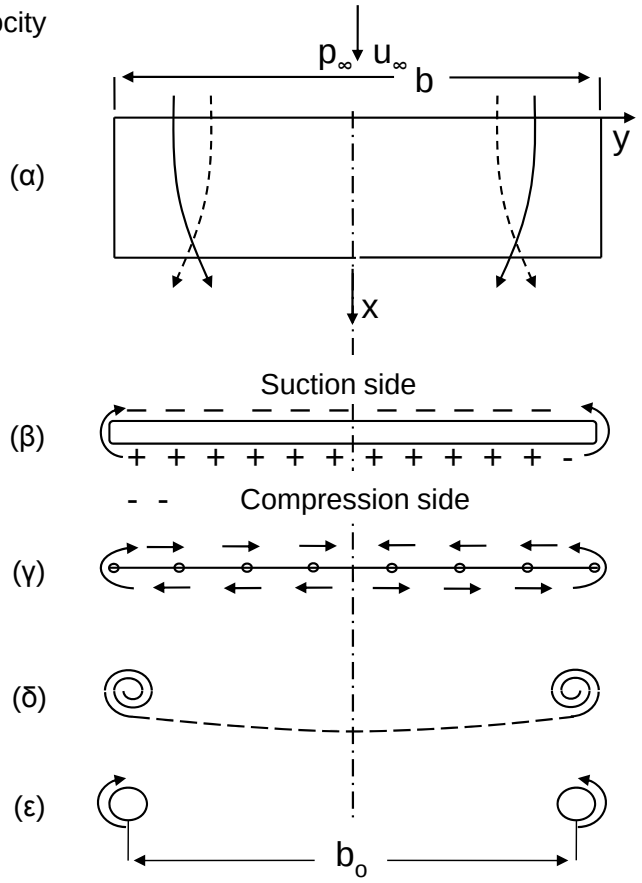
Introduction

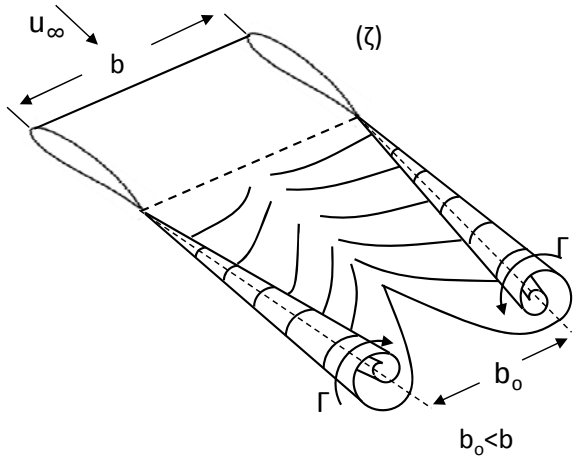
- The emergence of vortex wakes as a potential hazard and its importance is directly related to the advent of large high-speed aircraft and their increased use in the aviation
- The goal is to control and destroy trailing wake vortices behind aircraft due
  - Financial reasons
  - Reason of air transport safety
  - Jet – vortex interaction impact to the environment

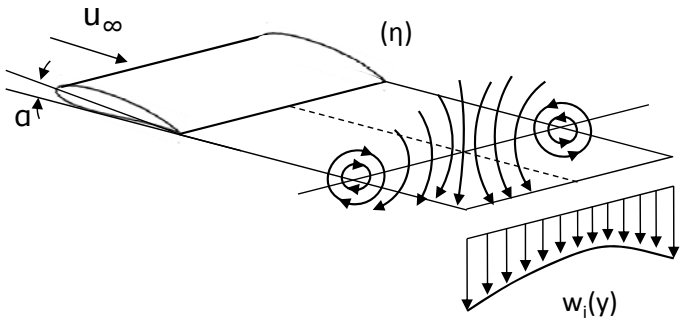
Finite span of wing & Creation of lift

$w_i(y)$: induced velocity

Γ: circulation

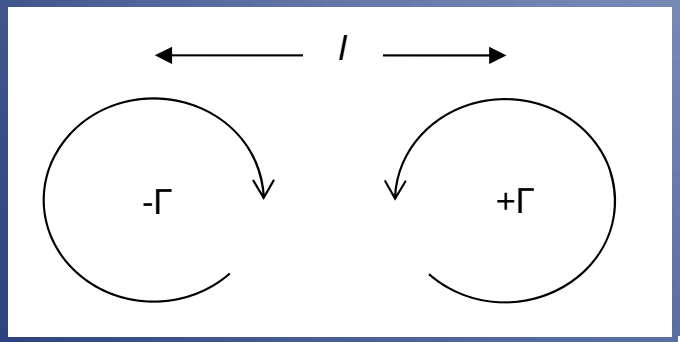




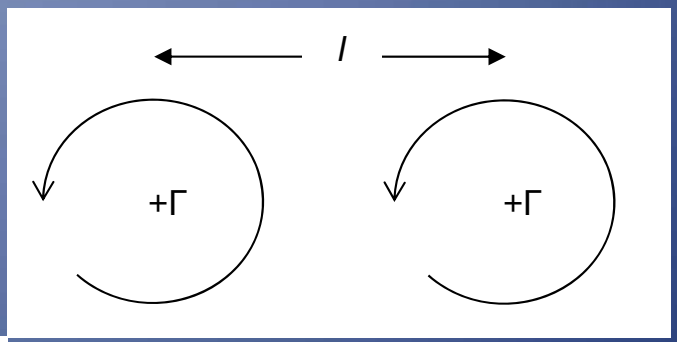


Wake vortex interaction

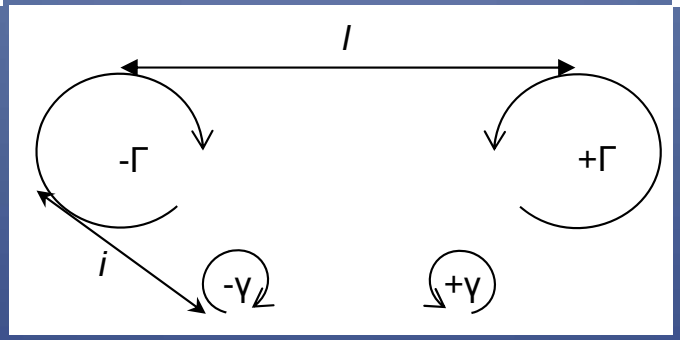
Counter rotating



Co - rotating



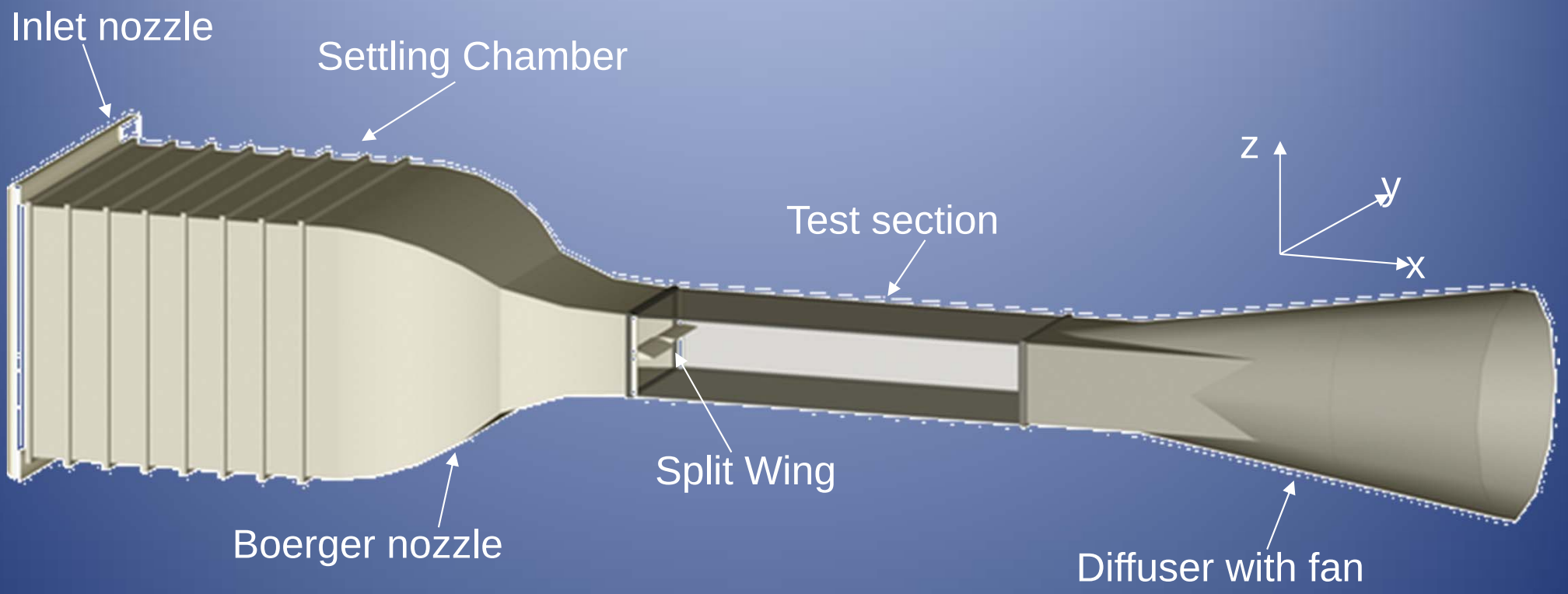
Multiple Vortex interaction



Literature review

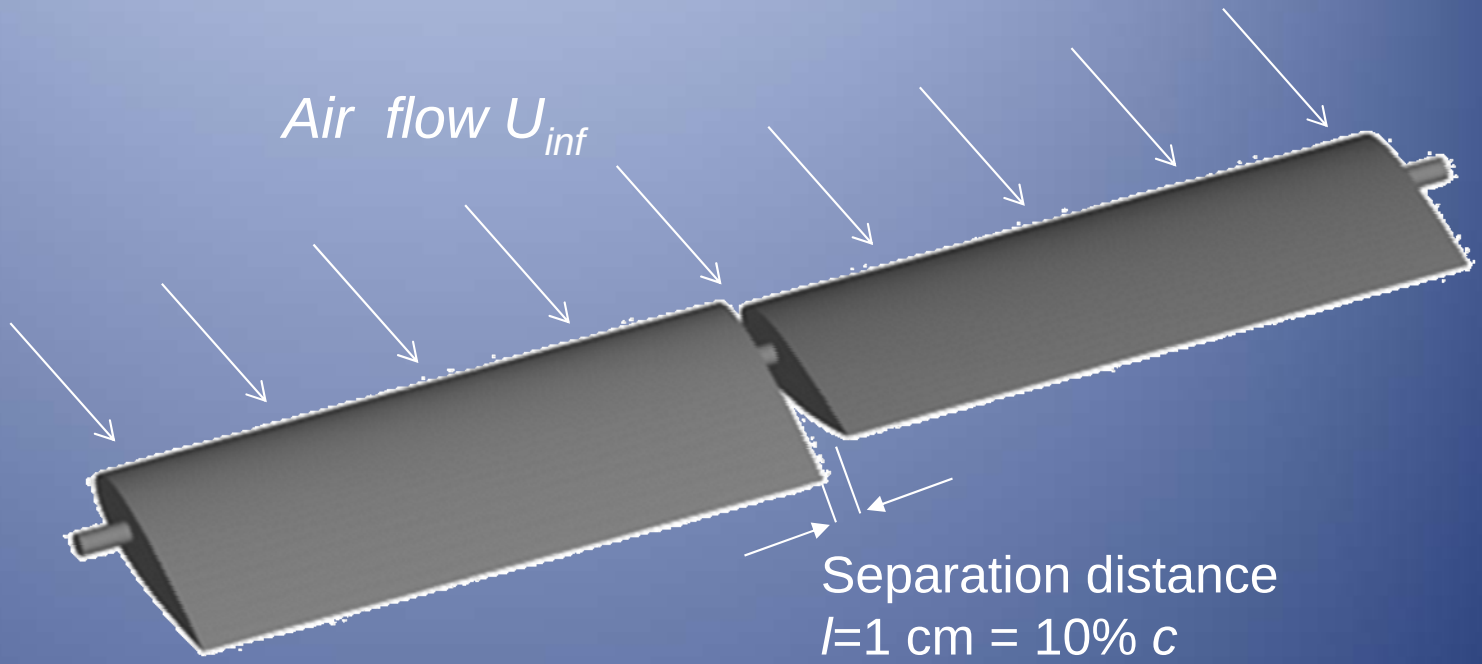
Investigators	Re_c	x/b	Instrumentation	Models	Remarks
Bandyopadhyay et al	100,000	9.2	HW	half-wings, NACA-0012	vortex structure in turbulent stream
Bertenyi & Graham	304,000	n/a	5HP	half-wings, NACA-0012	vortex merger
Bilanin et al	440,000	7.5	HW	model, NACA-0018	model verification
Cerretelli, Williamson	5,700	n/a	PIV	two thin half-wings	vortex merger
Chen et al.	82,000	52	PIV	cambered thin wing	vortex merger
Devenport et al.	530,000	7.5	HW	half-wings NACA-0012	vortex structure, merger
Jacob et al.	37,000	175	PIV	wing, NACA-0012	pulsed jets
Jacquin et al	200,000	9	HW, LDV	A300 model (1:100)	wake formation and development
Laporte, Leweke	n/a	n/a	PIV	flaps	counter-rotating pair instability
Li, Jacob	240,000	3.7	PIV	half wings, NACA-0012	vortex merger
Meunier, Leweke	n/a	n/a	PIV	two flaps	vortex merger
Romeos et al.	133,000	2.9	HW	half wings, NACA-0012	corotating pair
Rossow et al.	660,000	13.8	BALANCE	B747 model (0.03)	vertical fin on wing
Sarpkaya	n/a	n/a	PIV	wing, NACA-0012	vortex decay arguments

Wind tunnel


Inlet nozzle
Settling Chamber
Test section
z
y
x
Split Wing
Boerger nozzle
Diffuser with fan

Current approach

- Opposite angle of attack
- Close proximity of wing tips
- Center body between wings
- Relatively High Reynolds number
- 3D vortex interaction

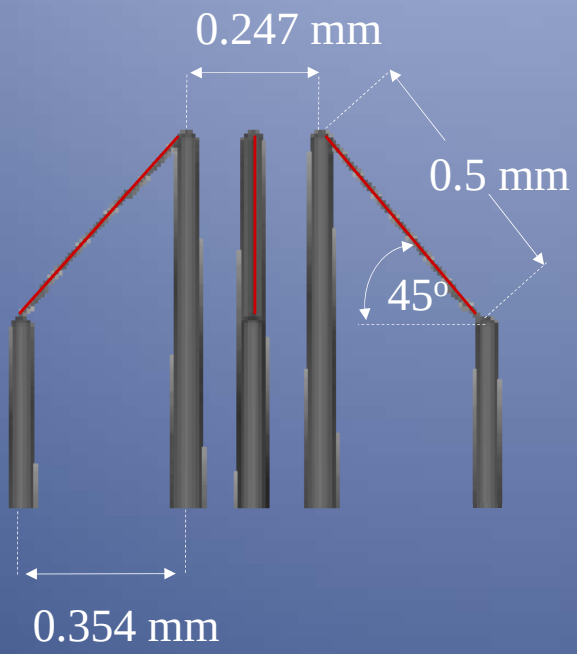


NACA 0030
cord, c=10 cm
span, b=24.5 cm

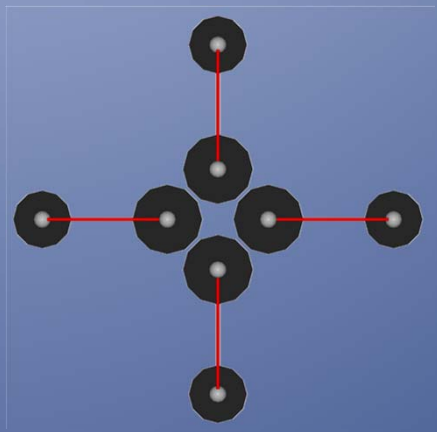
$\alpha=\pm 8^0$
U_{inf} = 20 m/s
Re_c= 133000

In-house manufactured 4-hotwire velocity probe

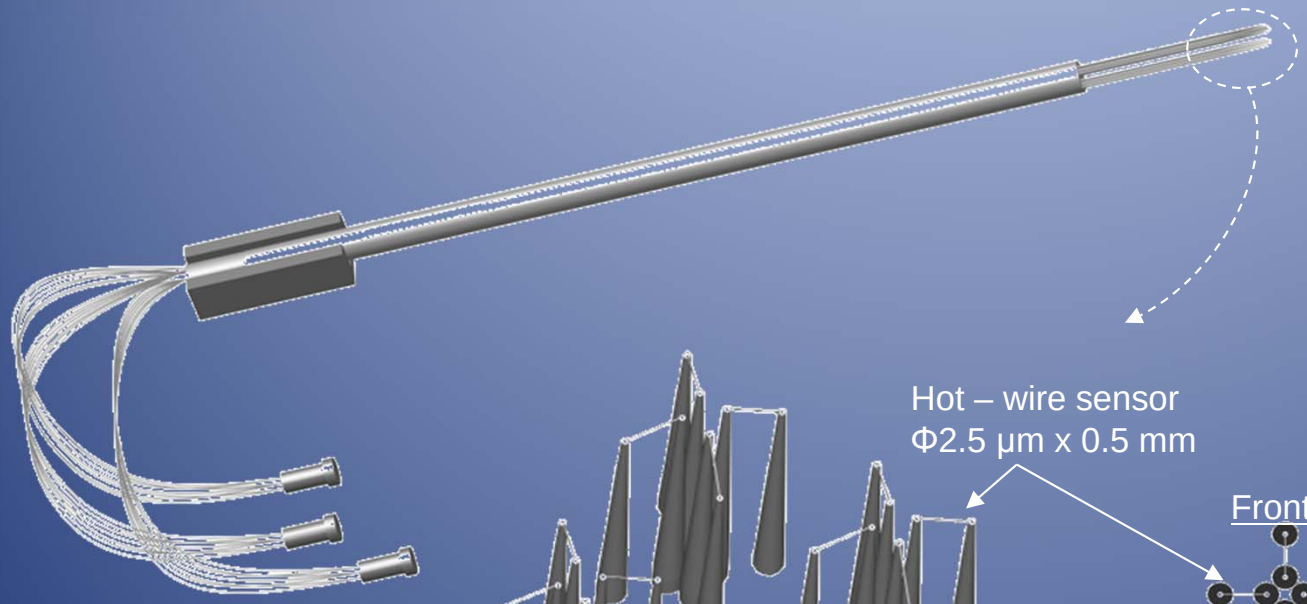
Side view



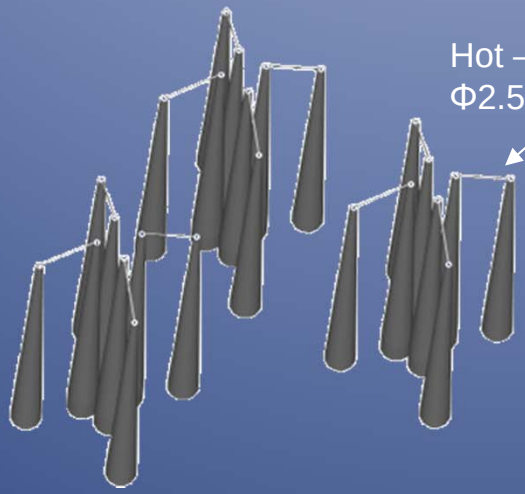
Front view



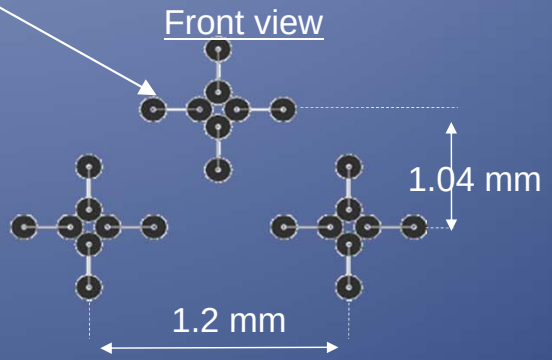
In-house manufactured 12-hotwire vorticity probe



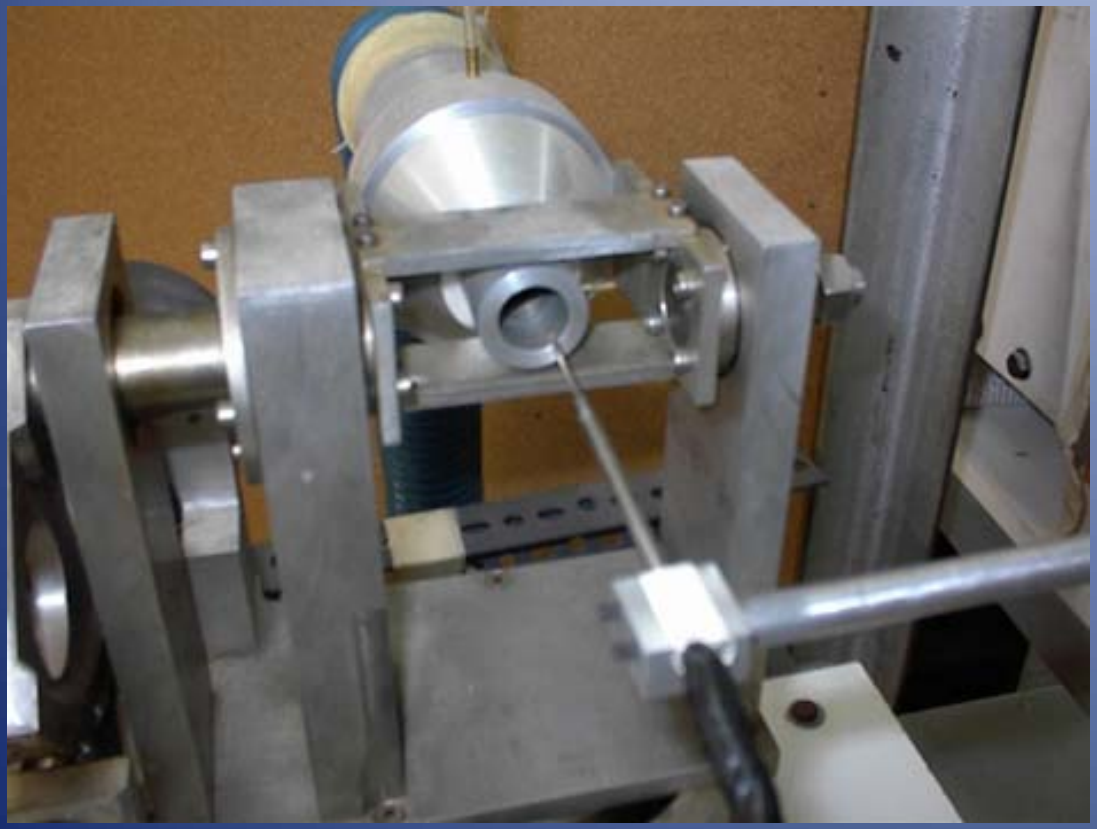
The probe consists of three closely separated orthogonal 4–wire velocity sensor arrays

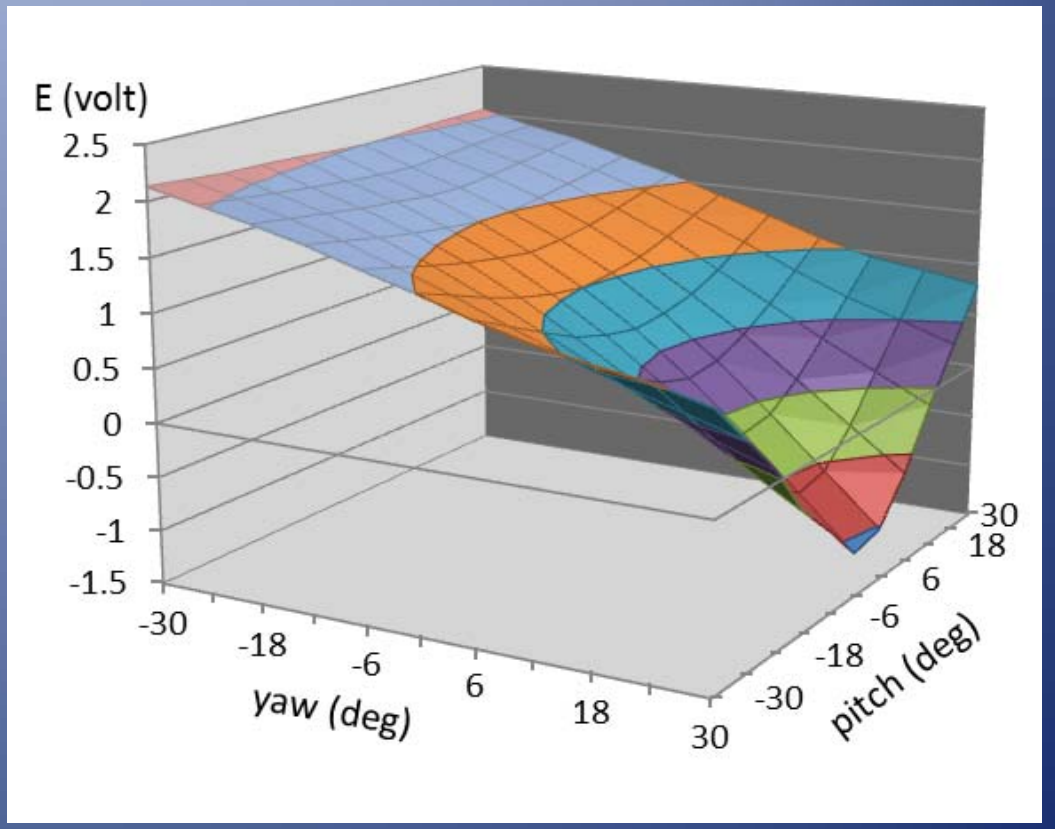


Hot – wire sensor
Φ2.5 μm x 0.5 mm

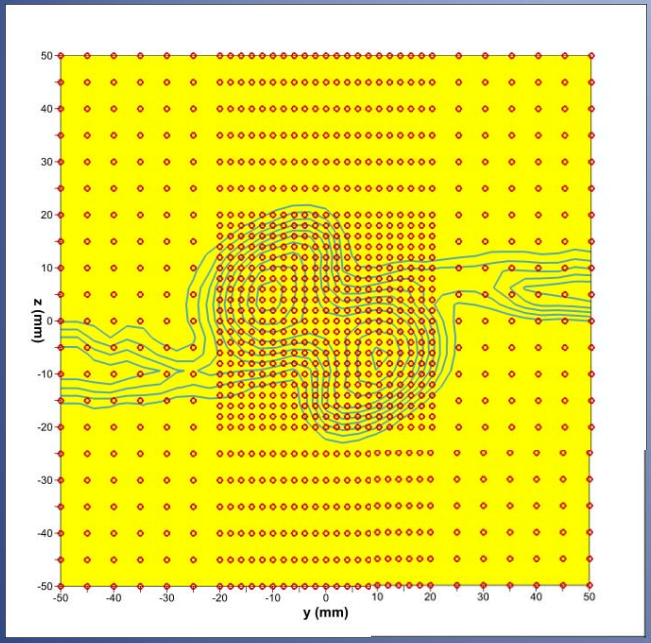


Calibration

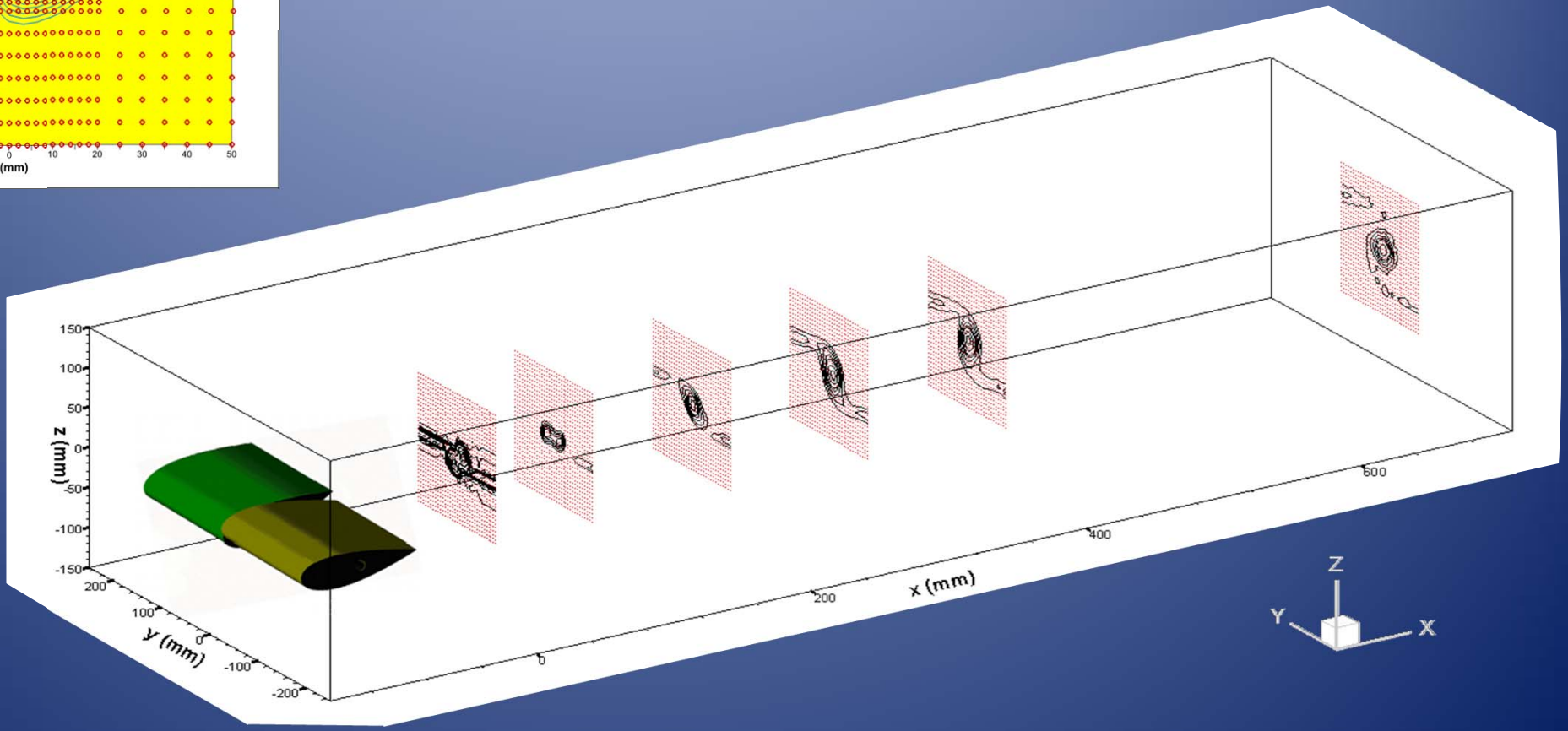




Measurement stations



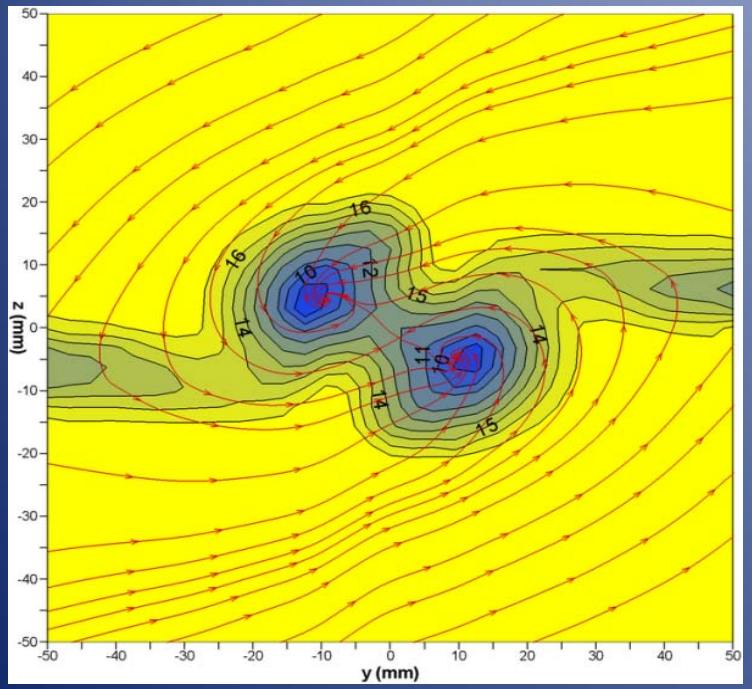
Measurement stations	1	2	3	4	5	6
x/c	0.3	1	2	3	4	7
Grid (mm)	100x100	160x160	160x160	160x160	160x160	160x160
Grid points	945	1089	1089	1089	1089	1089



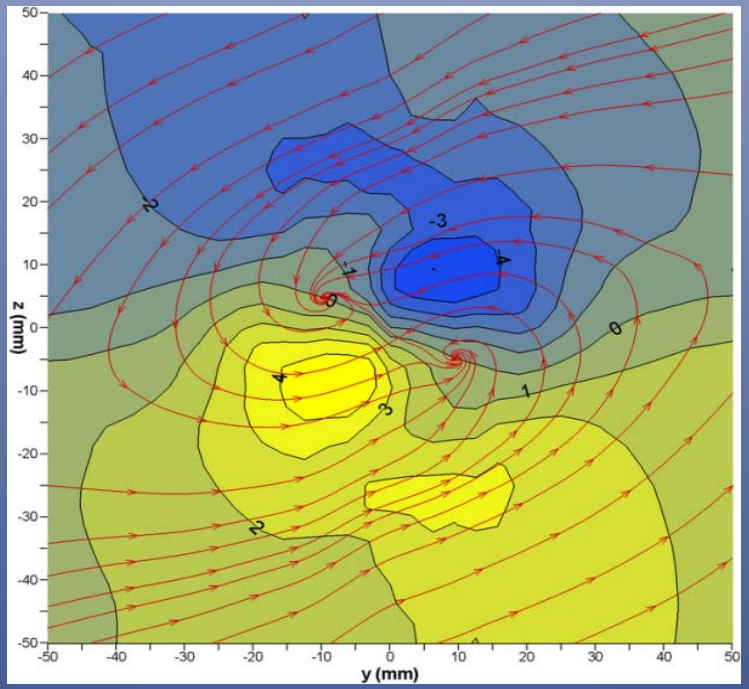
Near field interaction

Mean velocity components measured by 12-wire probe at x/c=0.3

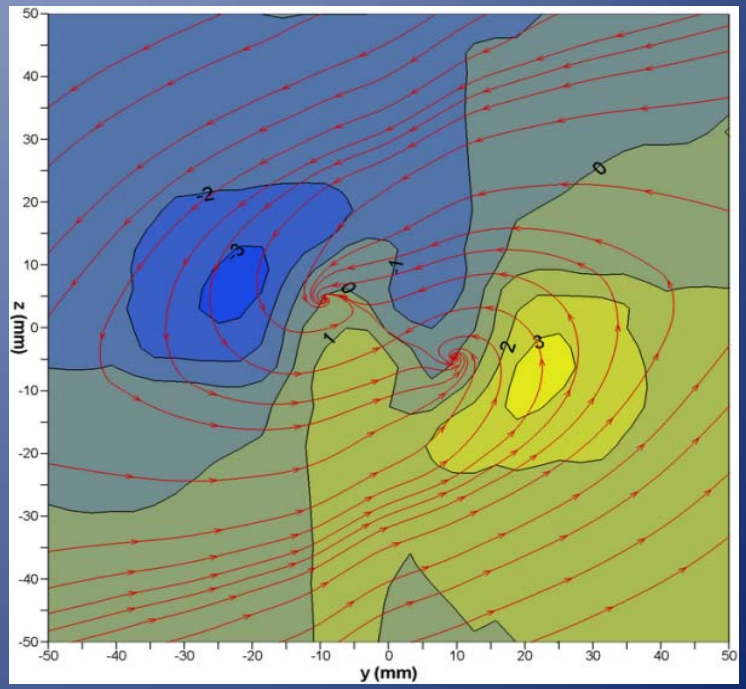
(red solid lines represent the flow streamlines)



U (m/s)

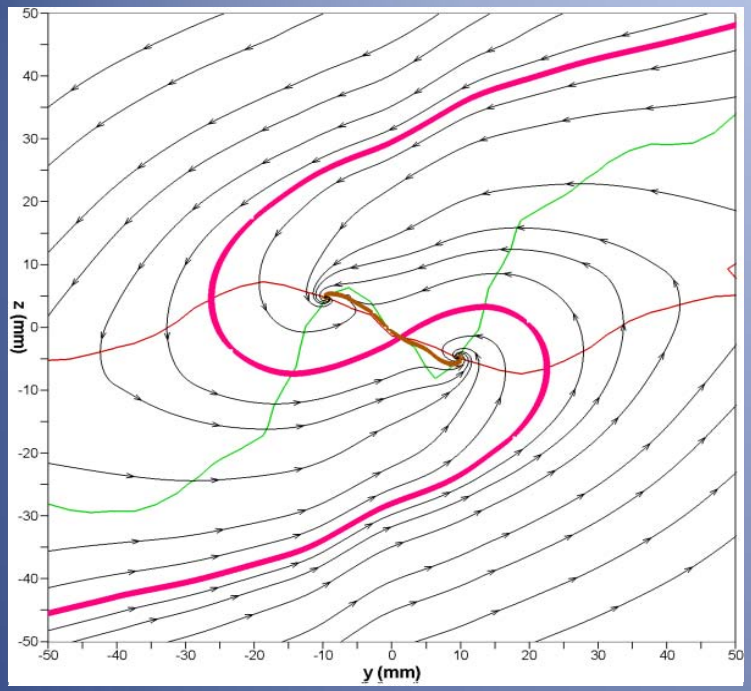


V (m/s)



W (m/s)

Interaction mechanism



Streamlines and topology characteristics lines

Close proximity of wing tips

⇩

''head on'' collision of the mobilized fluid in the region between the two vortex centres

⇩

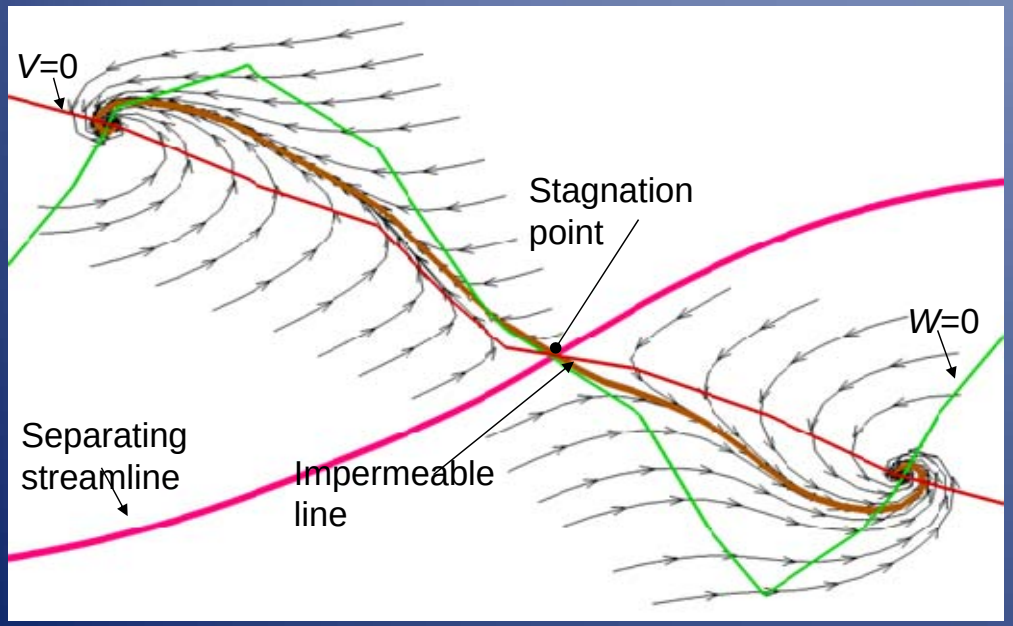
Formation of Impermeable line joining the two vortex centers

⇩

Along this line fluid is directed towards vortex centers

⇩

- Vortex cores expansion
- Separation increment



Enlargement of vortex centers area

Interaction mechanism

Close proximity of wing tips

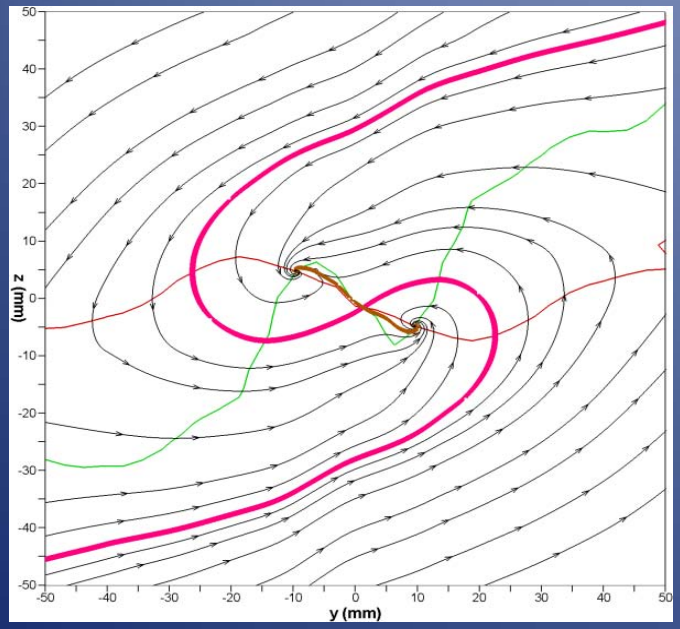
''head on'' collision of the mobilized fluid in the region between the two vortex centres

Formation of Impermeable line joining the two vortex centers

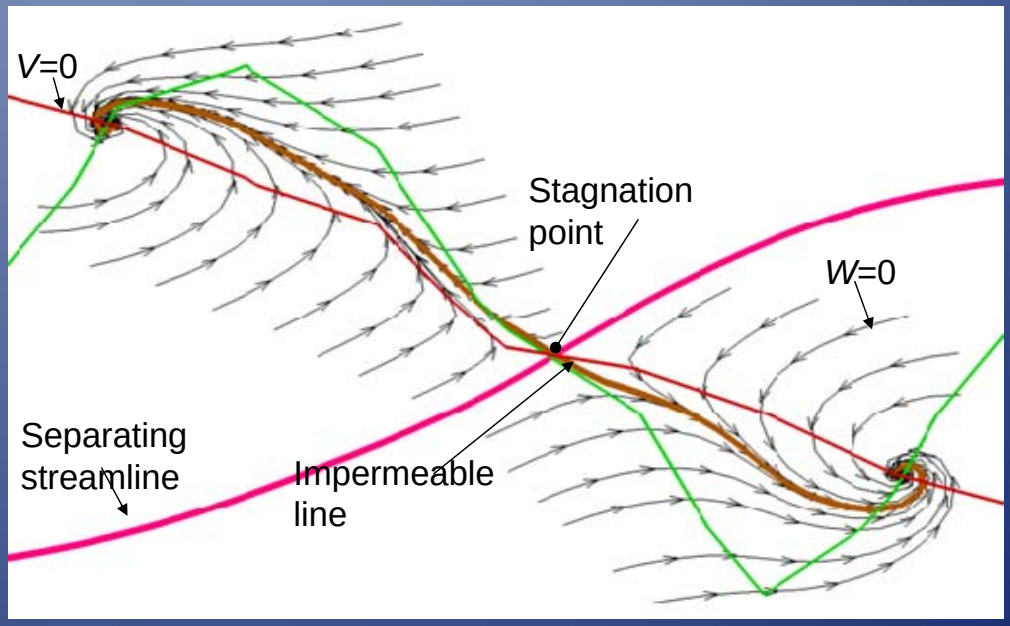
Along this line fluid is directed towards vortex centers

•Vortex cores expansion
•Separation increment

Streamlines and topology characteristics lines



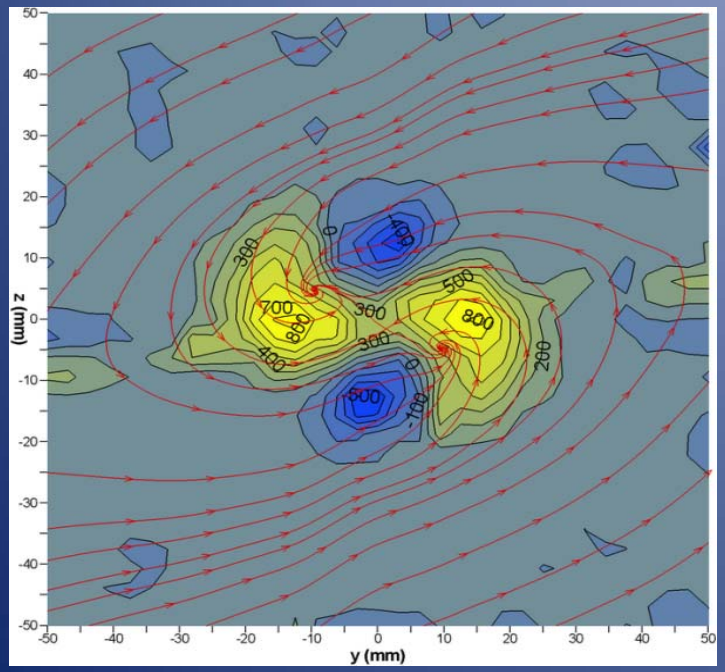
Enlargement of vortex centers area



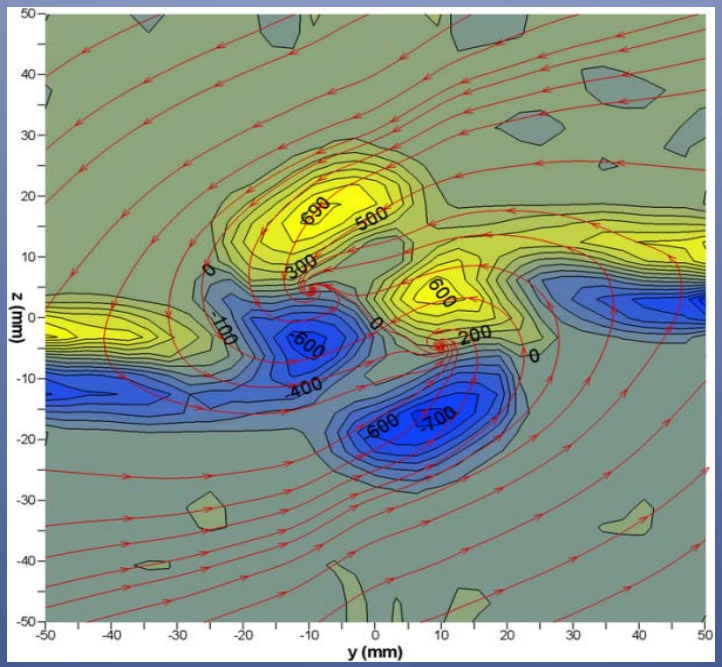
Vorticity field

Mean vorticity components measured by 12-wire probe at x/c=0.3

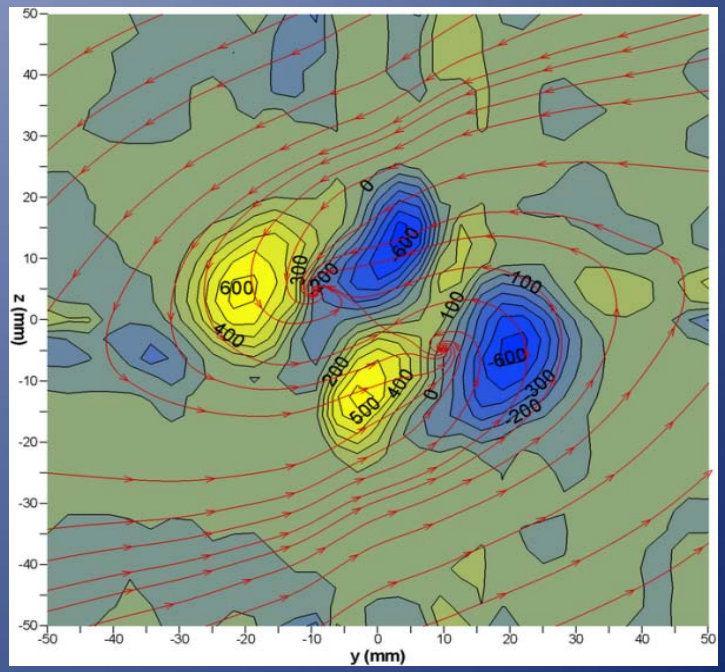
(red solid lines represent the flow streamlines)



Ω_x (1/s)



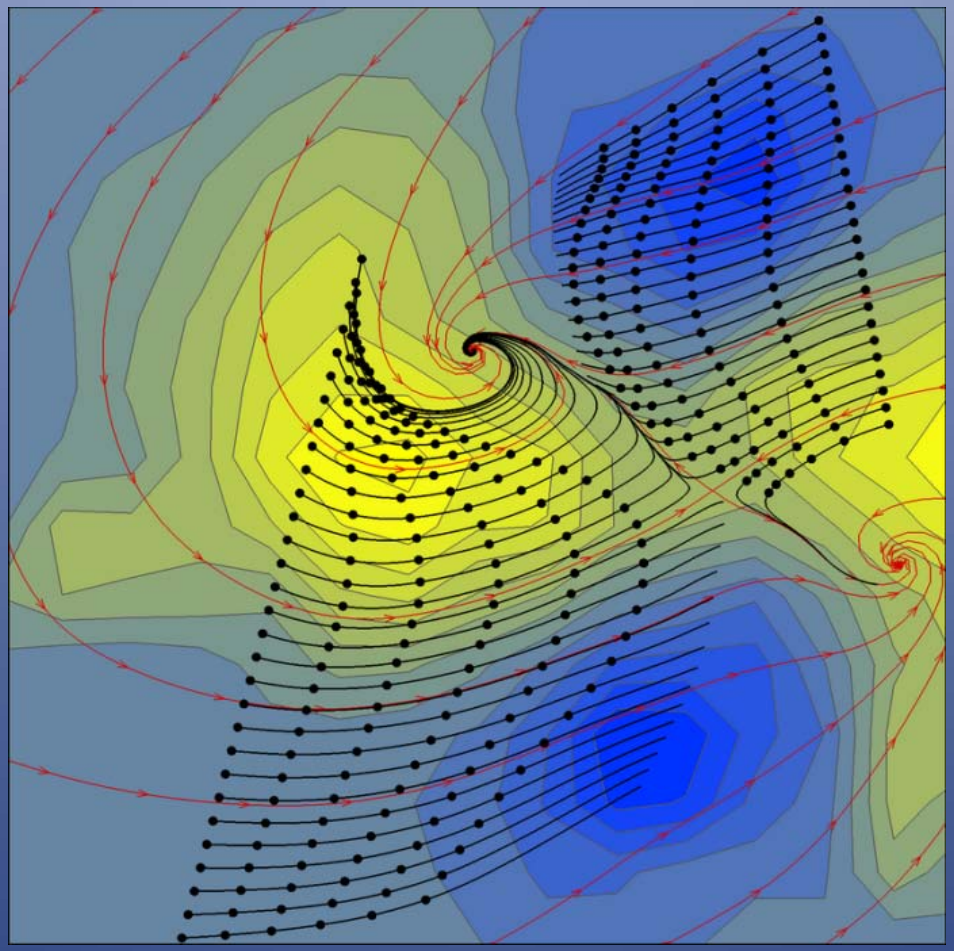
Ω_y (1/s)



Ω_z (1/s)

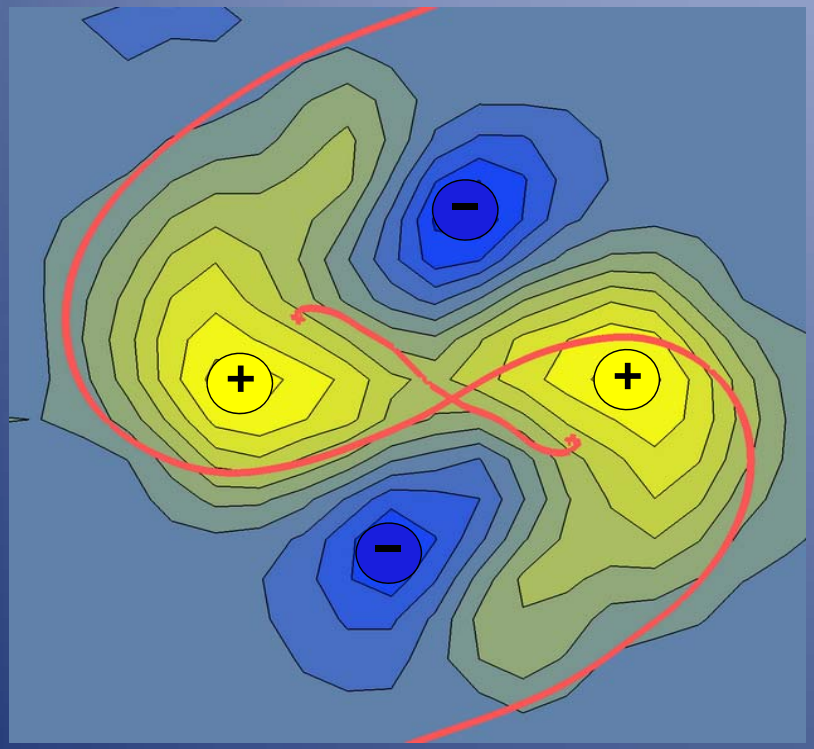
Vorticity dipole

Streamwise vorticity plot along with equi-time spaced streamlines markers

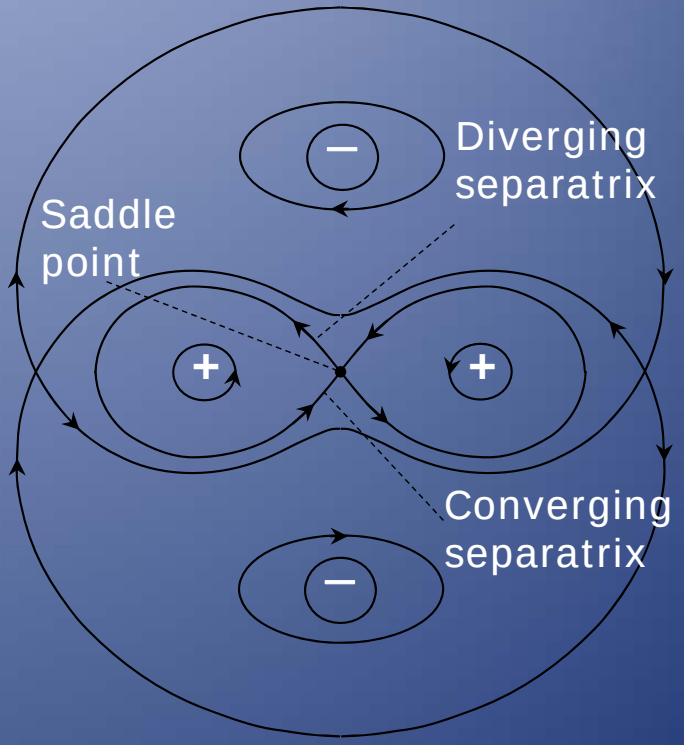


Topology comparison

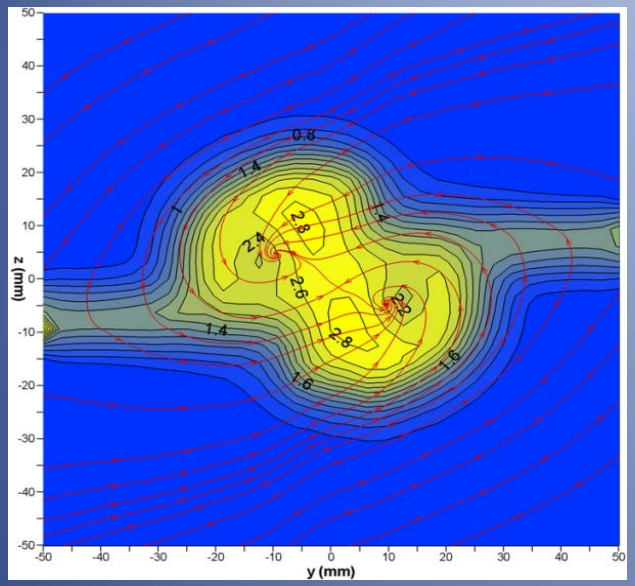
Characteristic streamlines and measured vorticity field



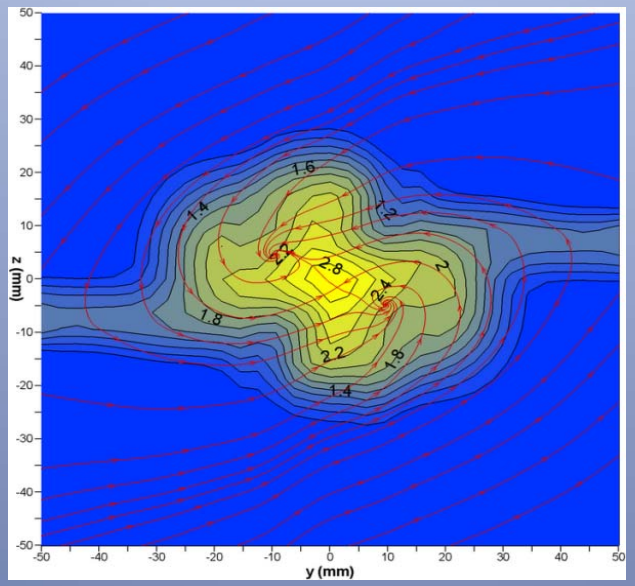
Reference co-rotating vortex pair topology



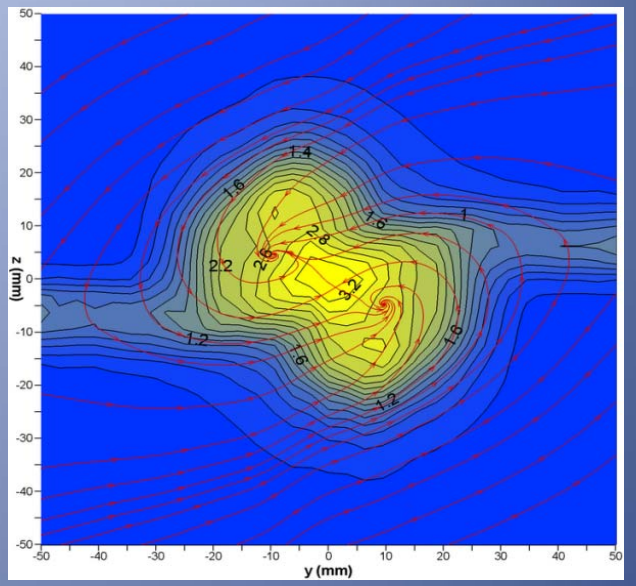
Near wake - Turbulent flow field



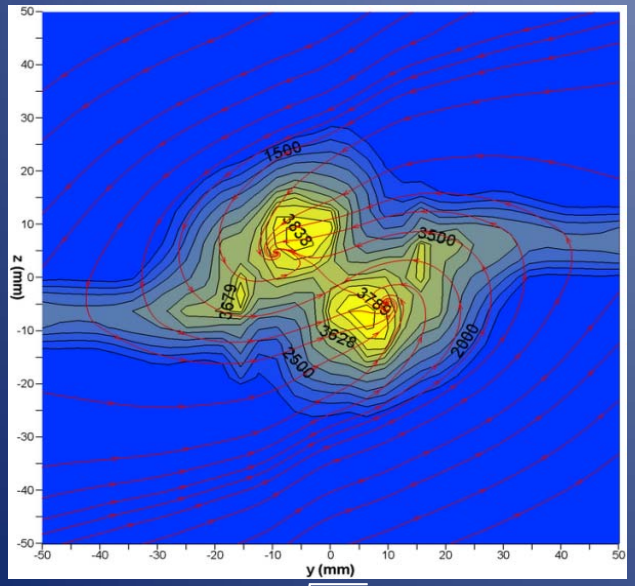
$\sqrt{u^2}$



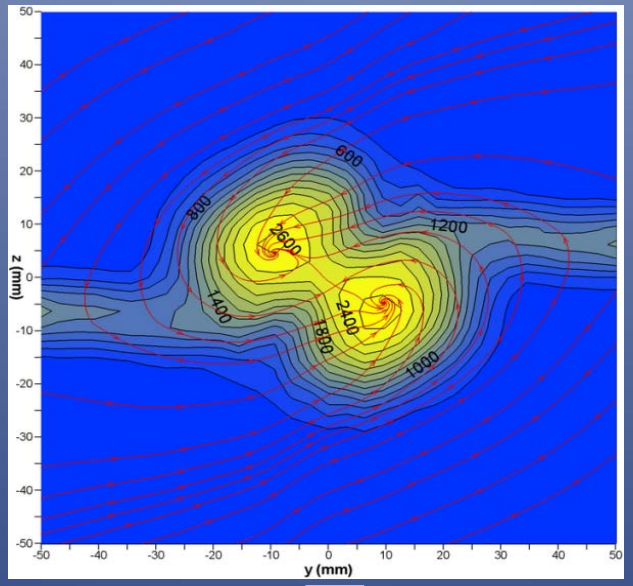
$\sqrt{v^2}$



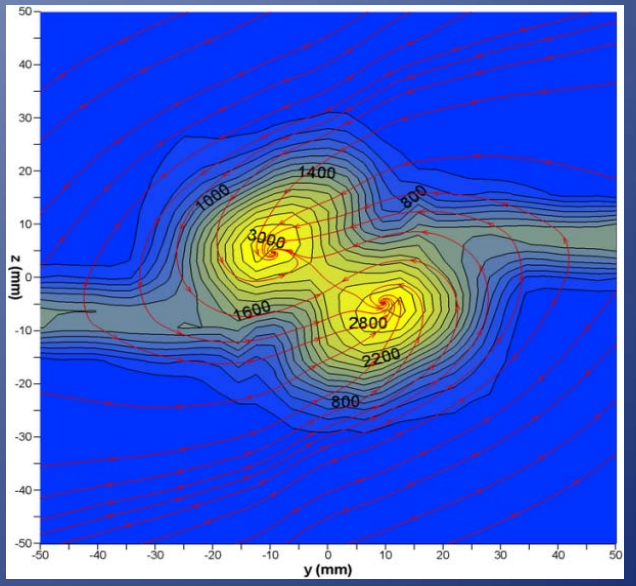
$\sqrt{w^2}$



$\sqrt{\omega_x^2}$

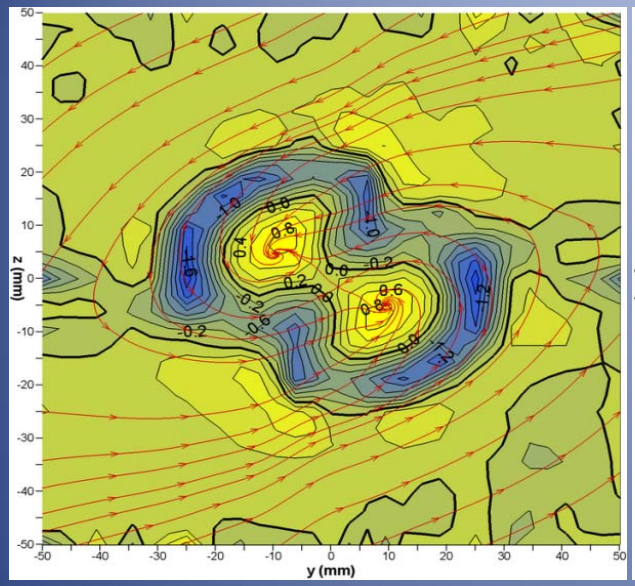


$\sqrt{\omega_y^2}$

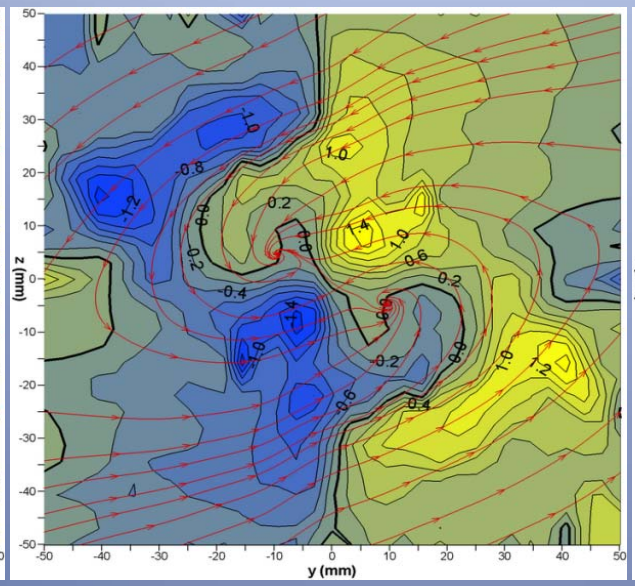


$\sqrt{\omega_z^2}$

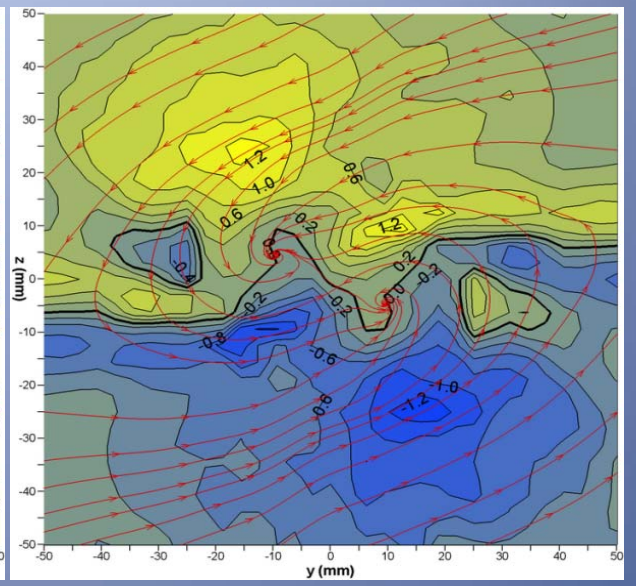
Near wake - Turbulent flow field



S_x

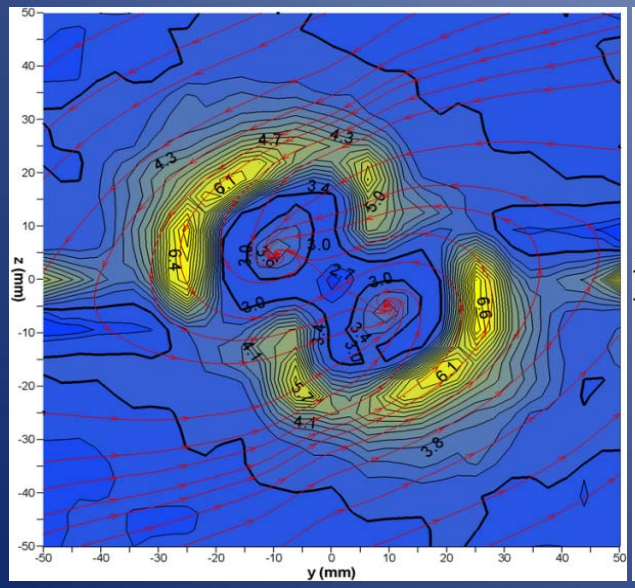


S_y

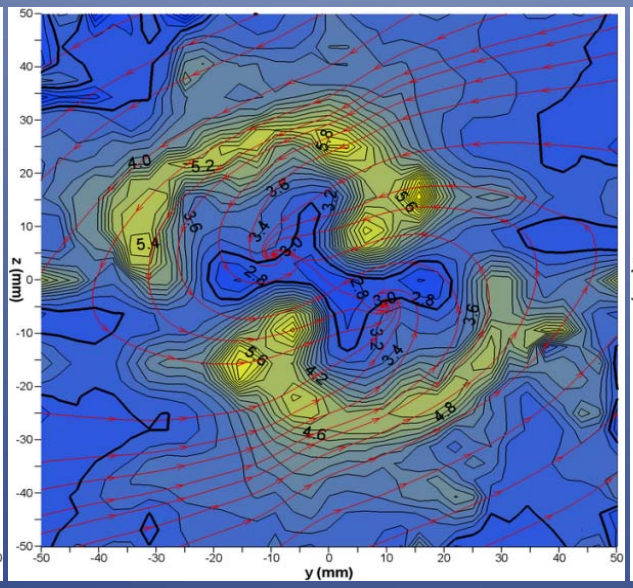


S_z

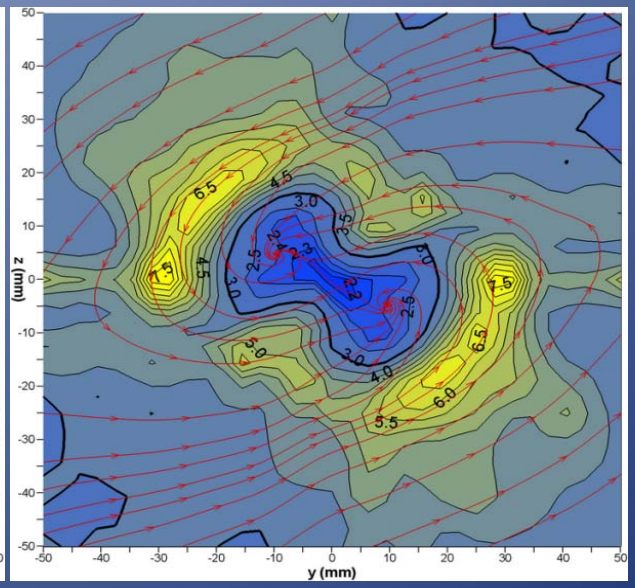
Velocity Skewness factor x/c=0.3



F_x



F_y

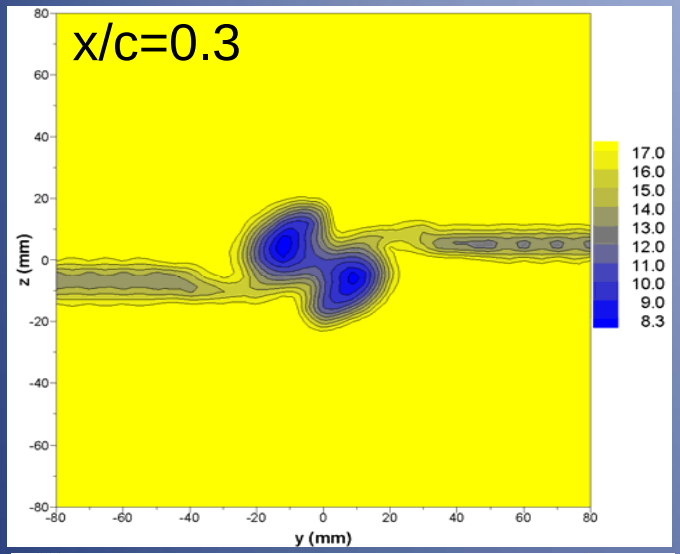


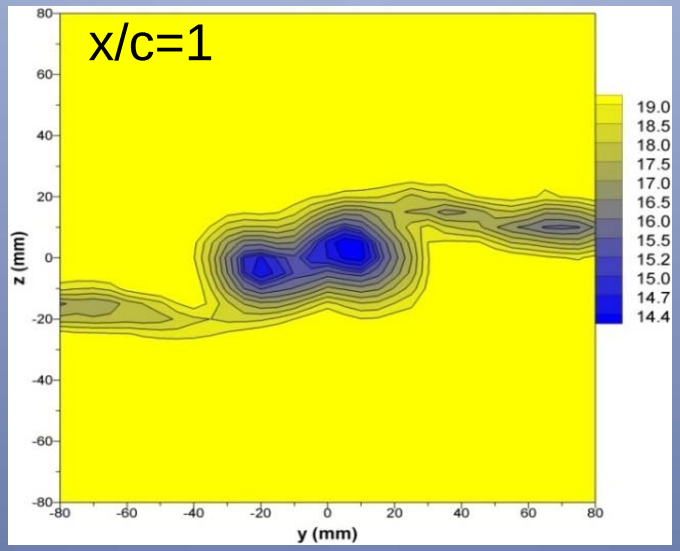
F_z

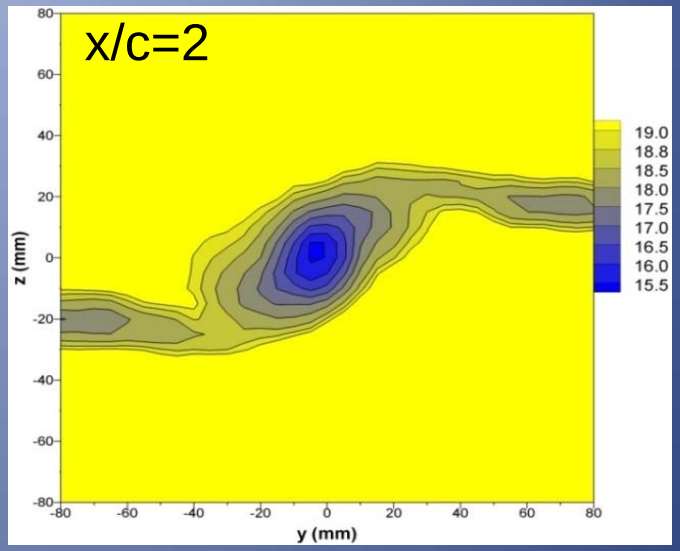
Velocity Flatness factor x/c=0.3

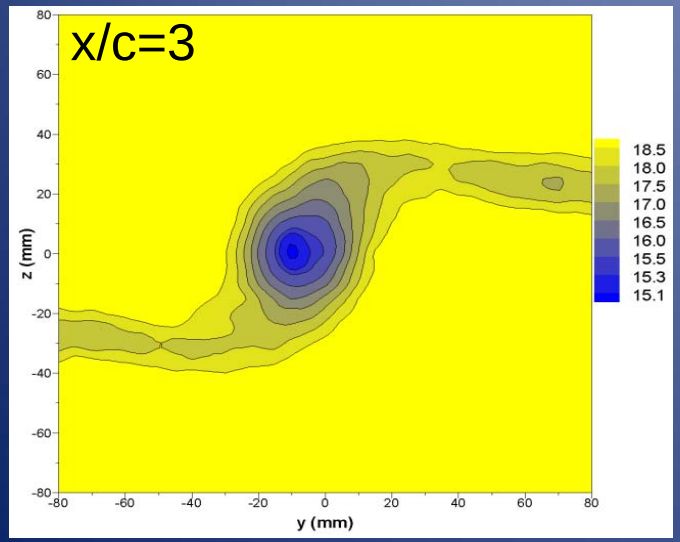
Evolution of co-rotating vortex interaction

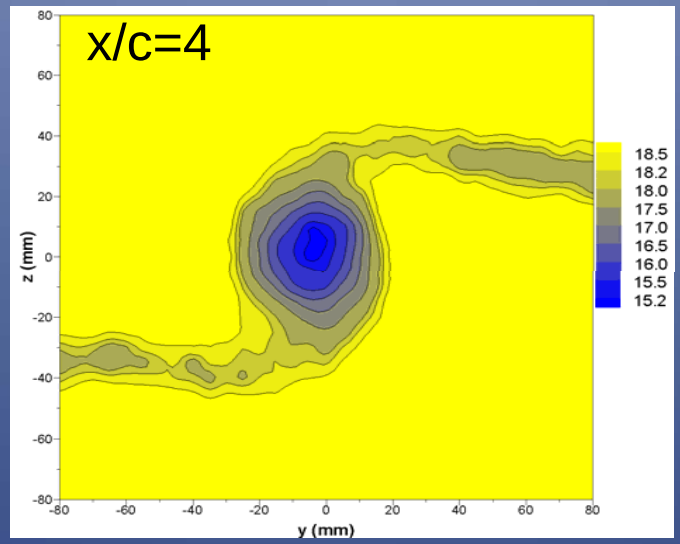
Streamwise mean velocity component, U (m/s)

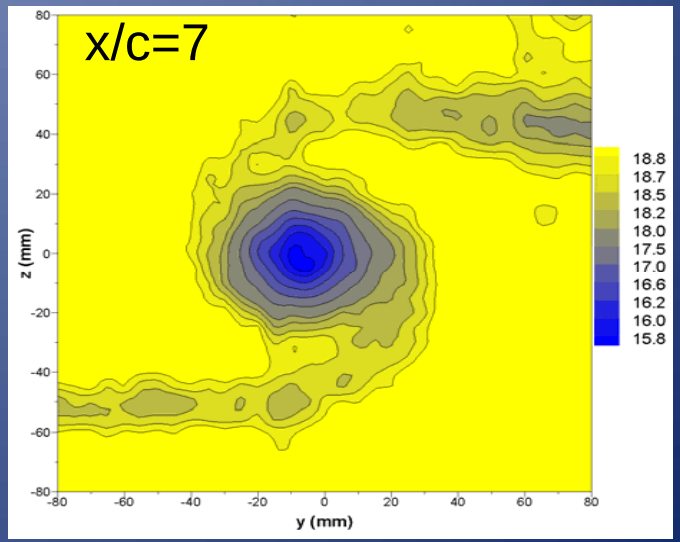






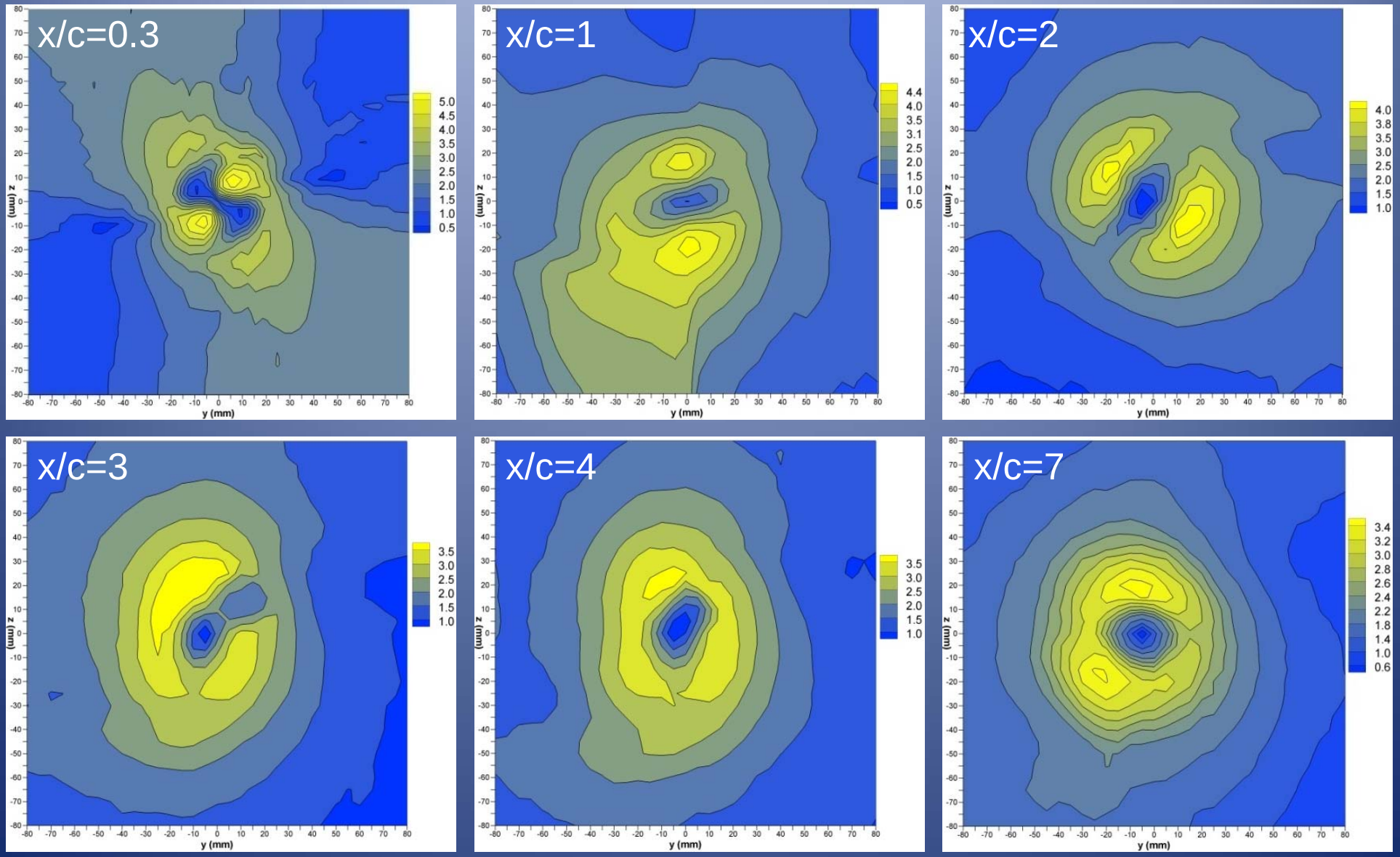




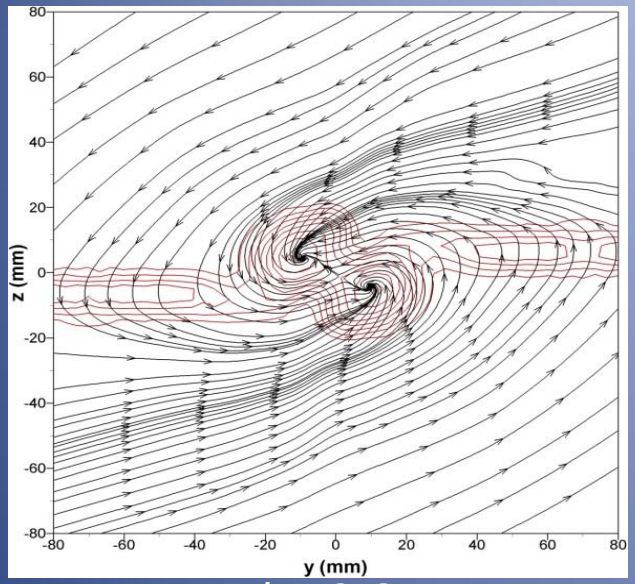


Velocity cross plane flow field

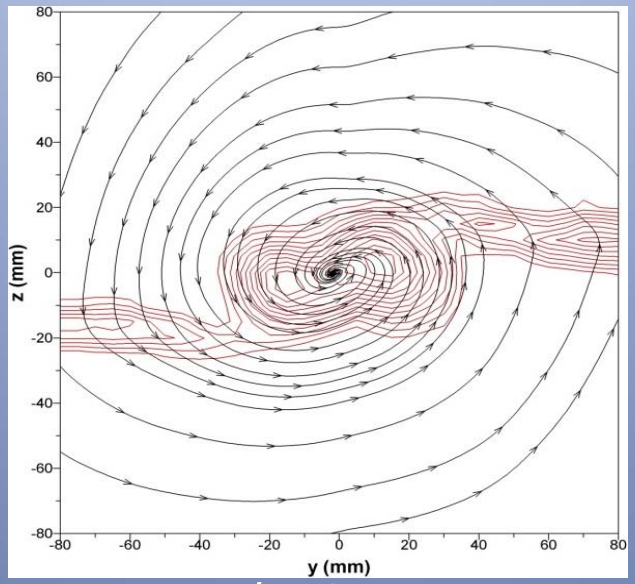
$$\sqrt{V^2 + W^2}$$



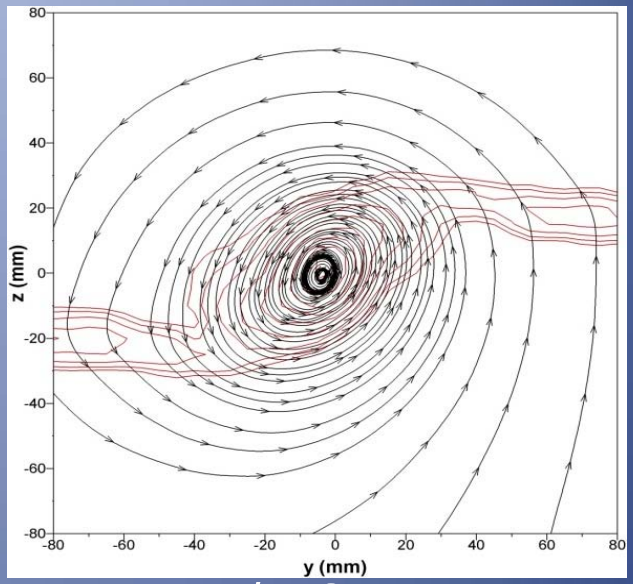
Streamlines Flow field



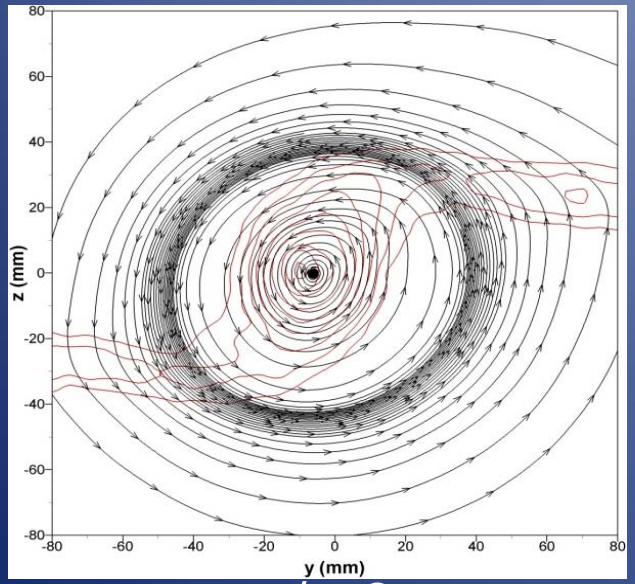
x/c=0.3



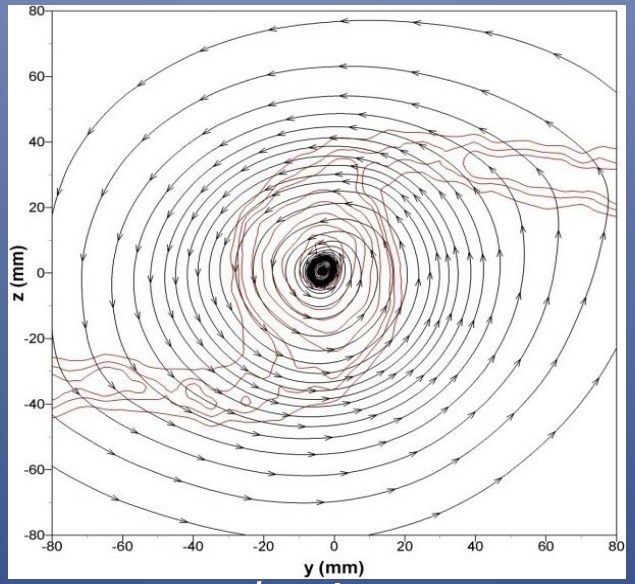
x/c=1



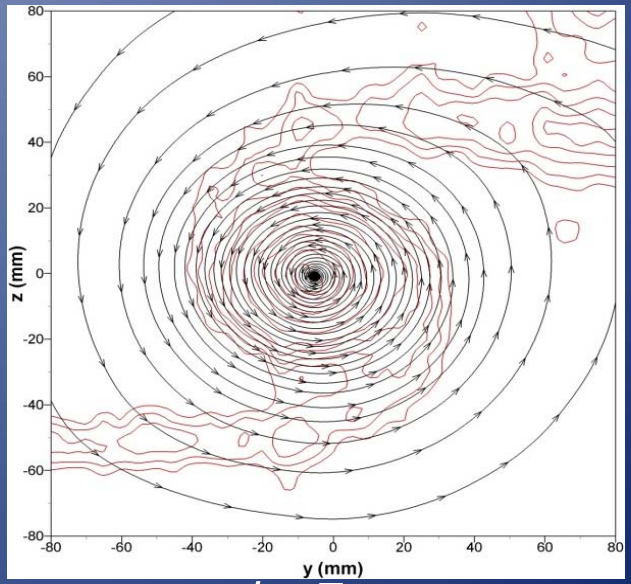
x/c=2



x/c=3



x/c=4

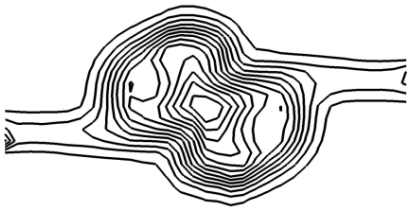


x/c=7

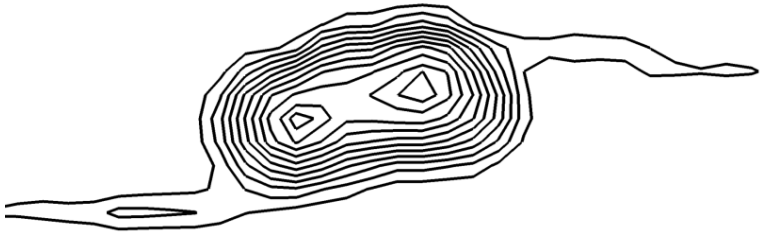
Turbulent Kinetic Energy

$$k = \frac{1}{2}(u^2 + v^2 + w^2)$$

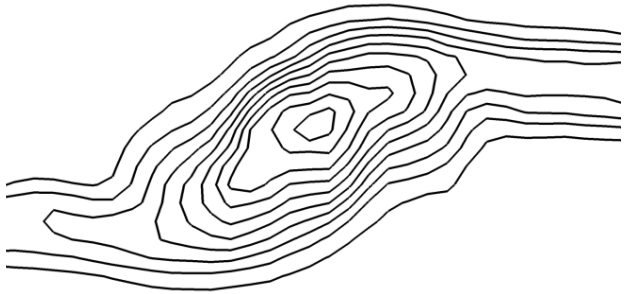
x/c=0.3



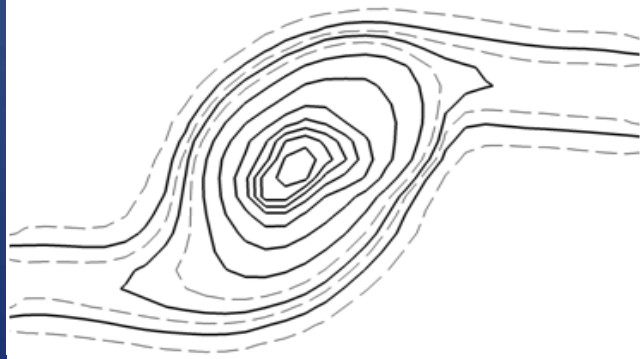
x/c=1



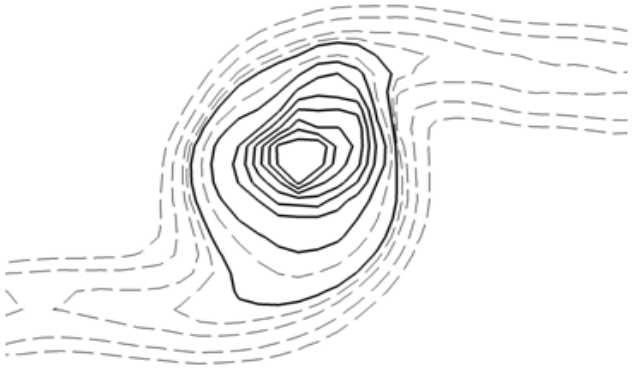
x/c=2



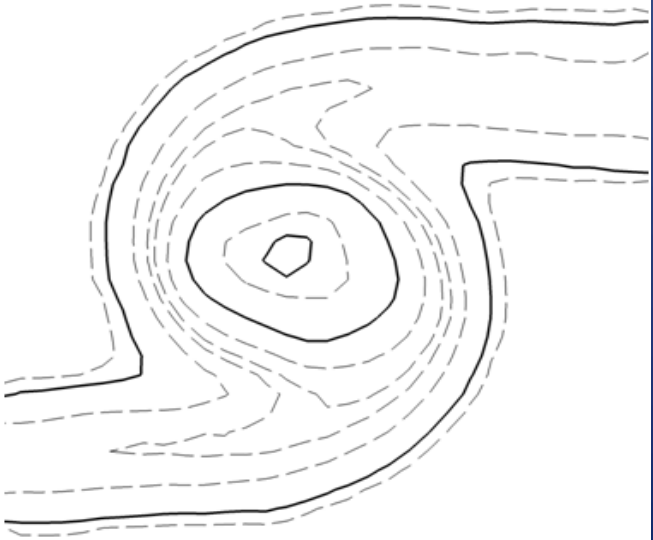
x/c=3



x/c=4

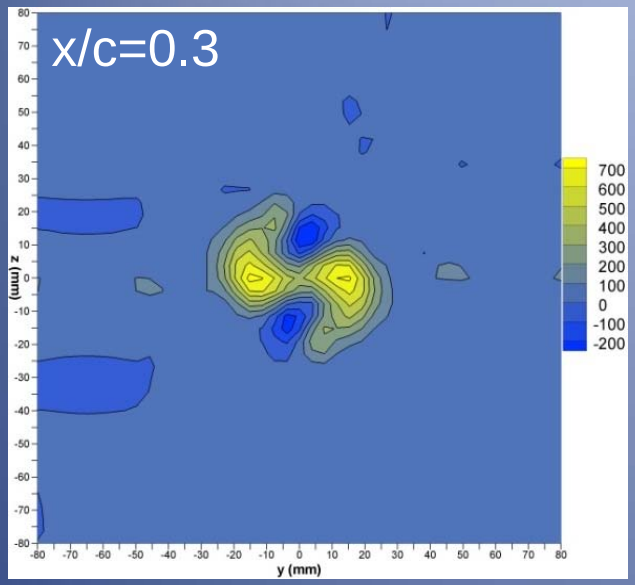


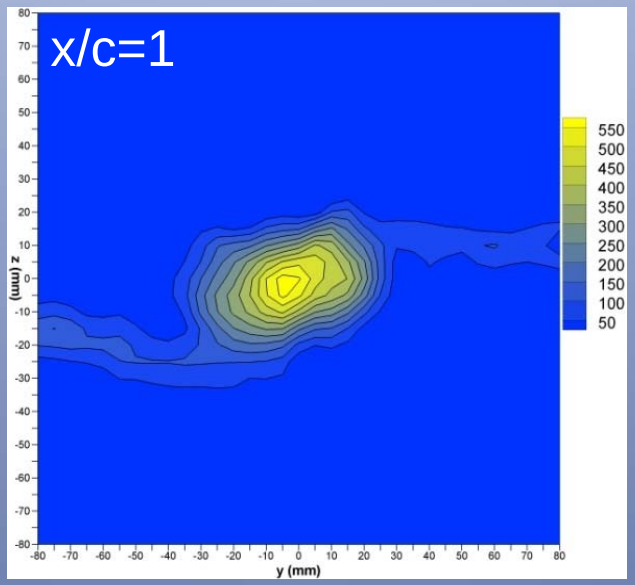
x/c=7

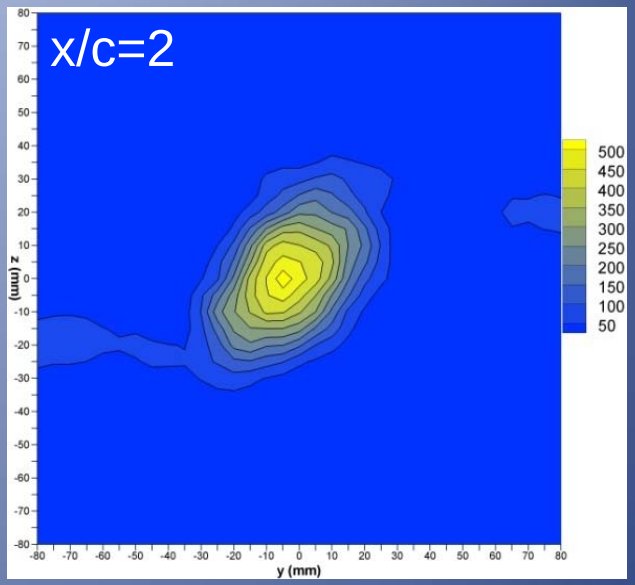


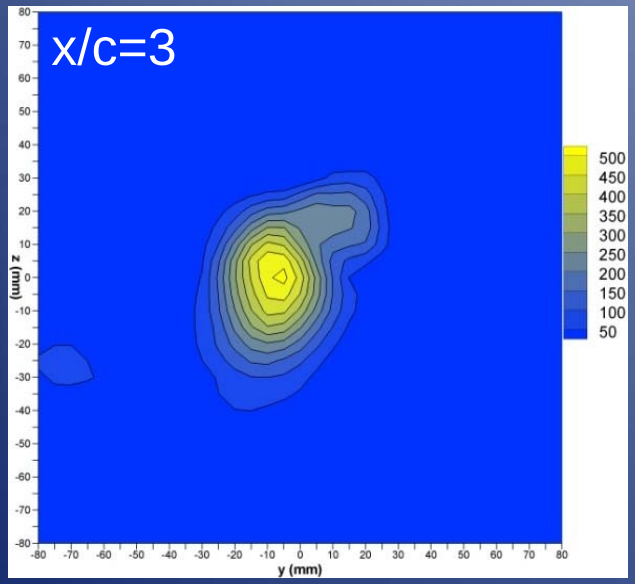
Streamwise Vorticity evolution

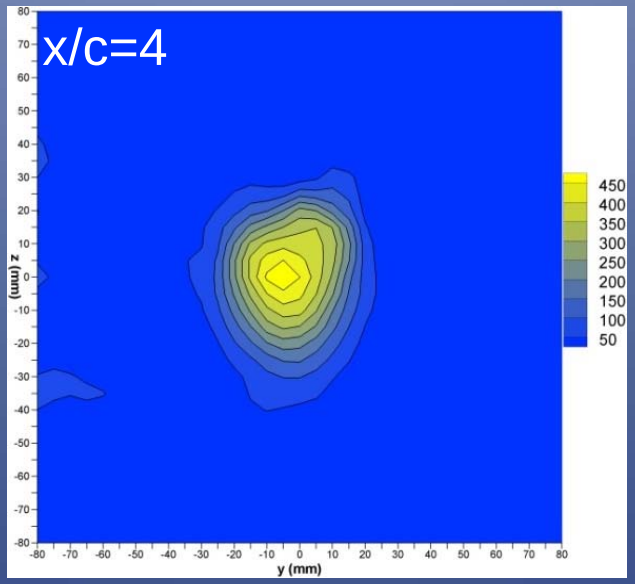
Ω_x (1/s)

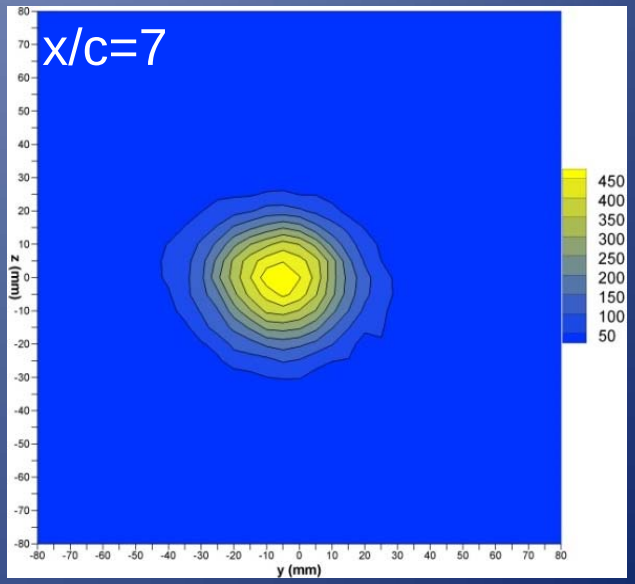






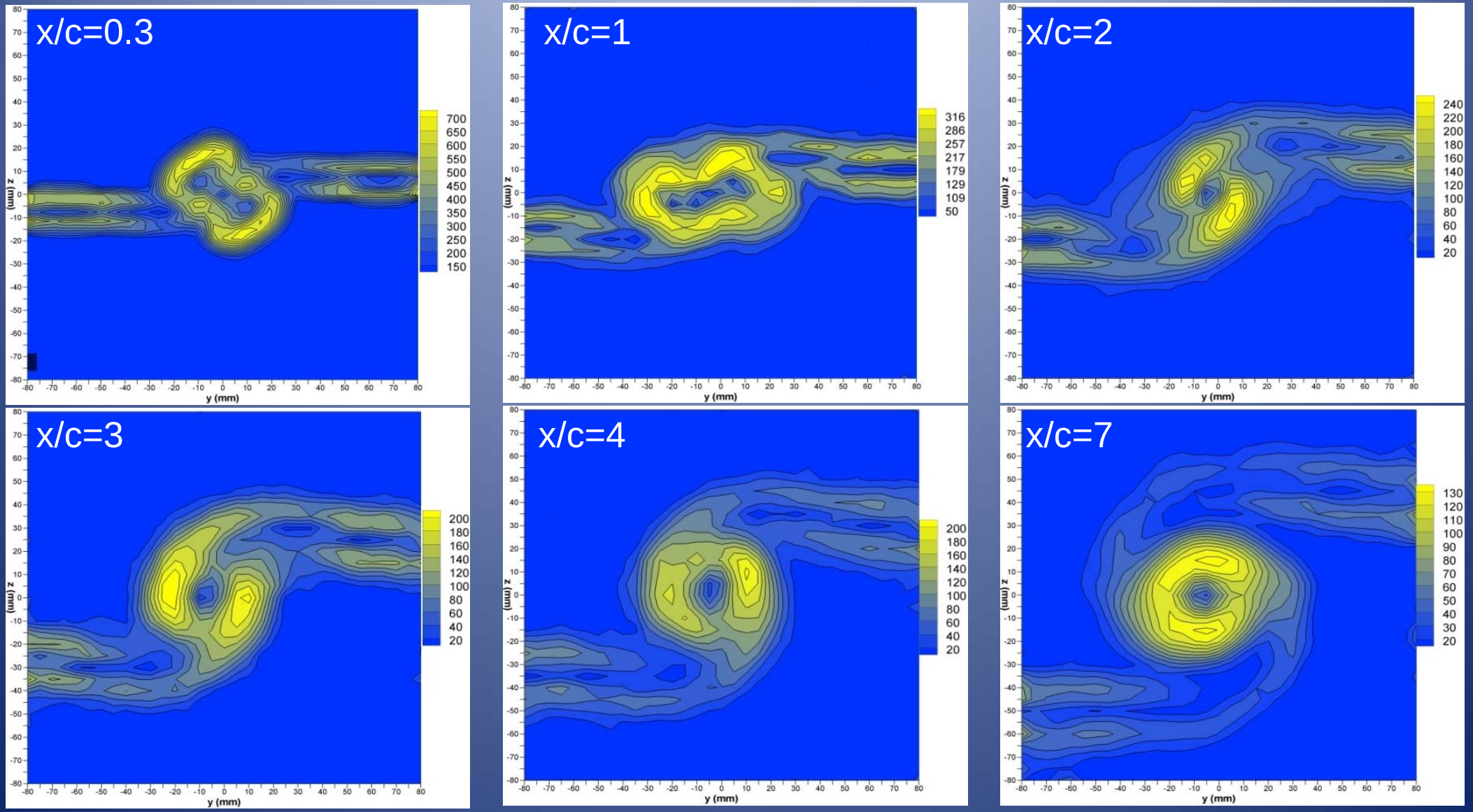




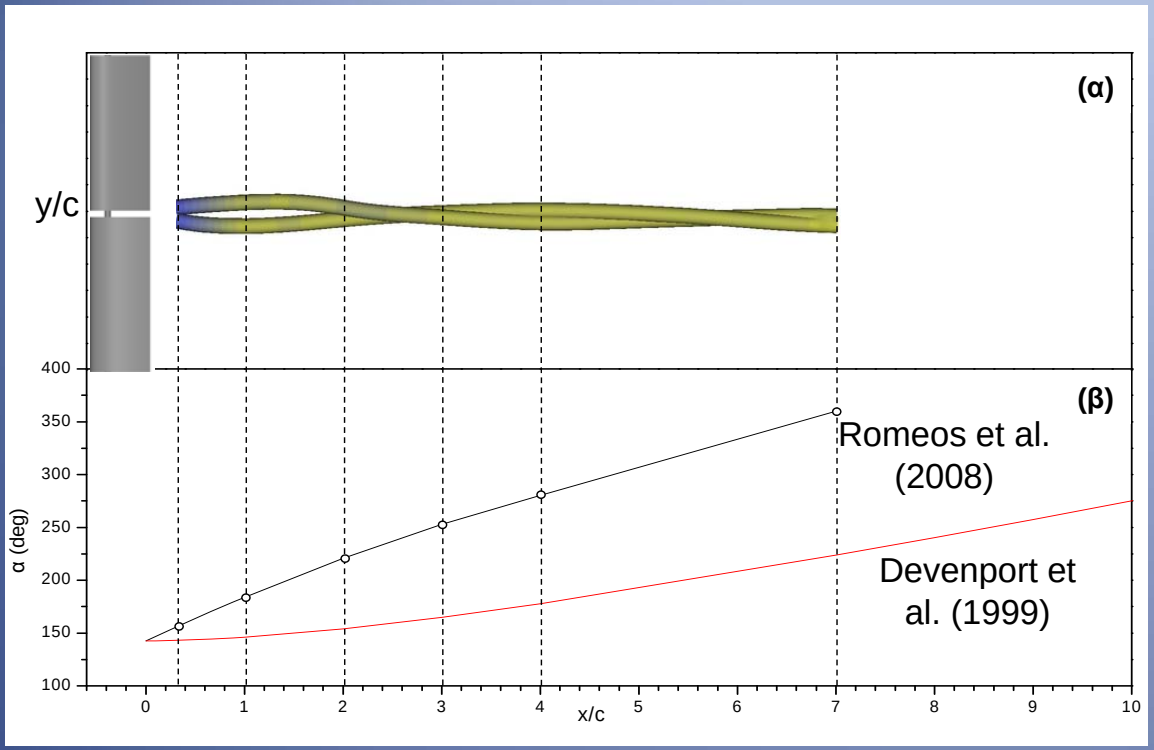


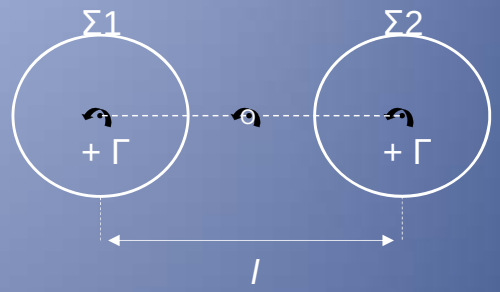
Cross plane vorticity field

$$\sqrt{\Omega_y^2 + \Omega_z^2}$$



Flow topology



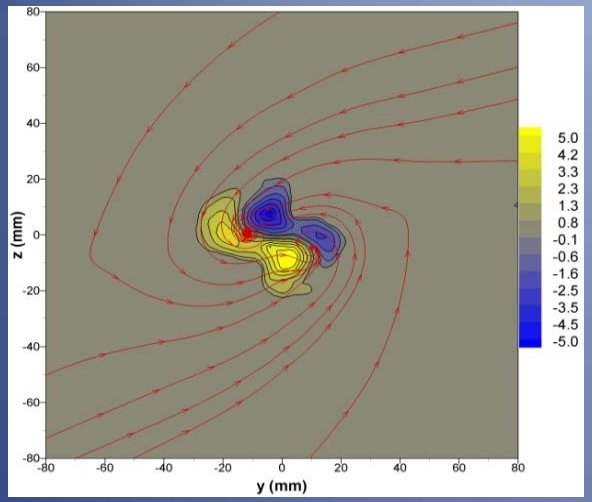


Cross plane vortex pair rotation

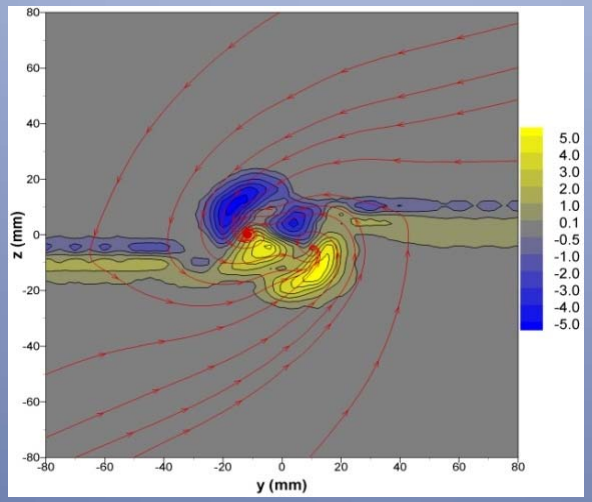
Evolution of the vortex pair rotation

Vortex pair topology characteristics during merging.					
	x/c=0.3		x/c=1		x/c=7
	Vortex A	Vortex B	Vortex A	Vortex B	Single Vortex
r_c/c	0.117	0.117	0.127	0.127	0.215
V_θ/U_{inf}	0.233	0.250	0.170	0.162	0.169
U/U_{inf}	0.390	0.400	0.785	0.781	0.790
$2\pi r_c V_\theta/U_{inf} c$	0.171	0.183	0.135	0.129	0.228
l_c/c	0.24		0.29		-

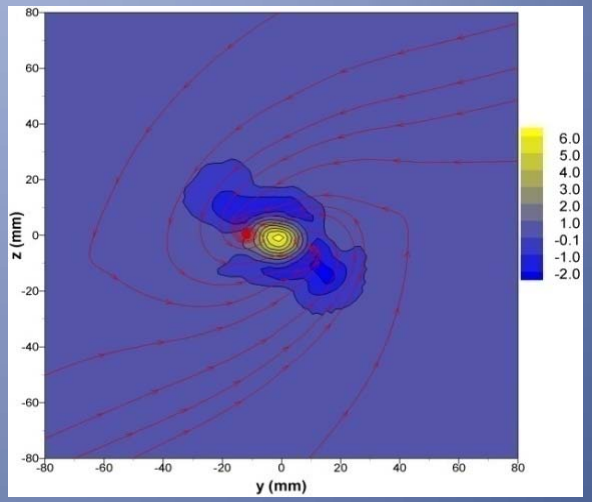
Reynolds Stresses



uv (m^2/s^2)

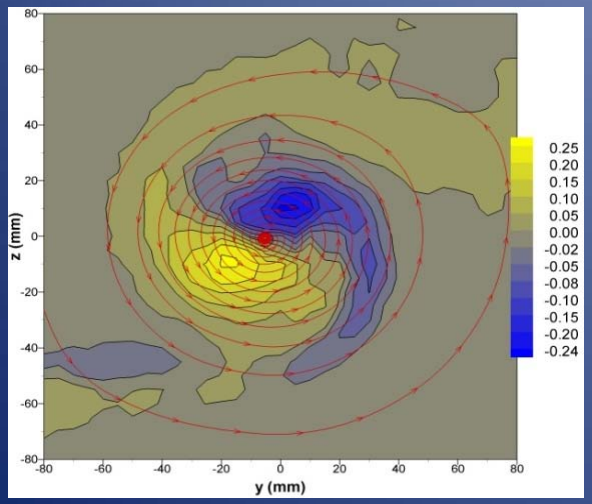


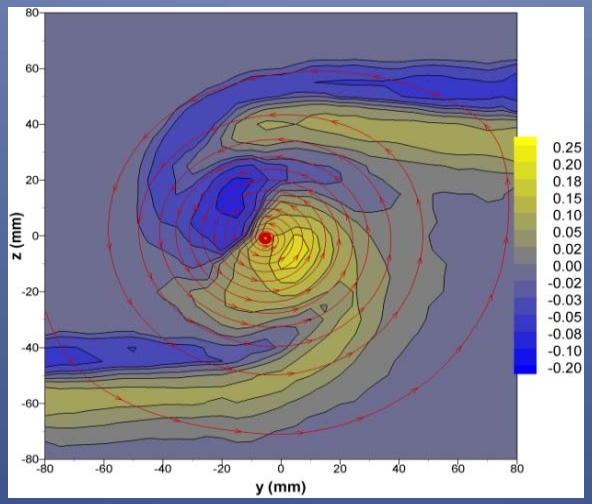
uw (m^2/s^2)

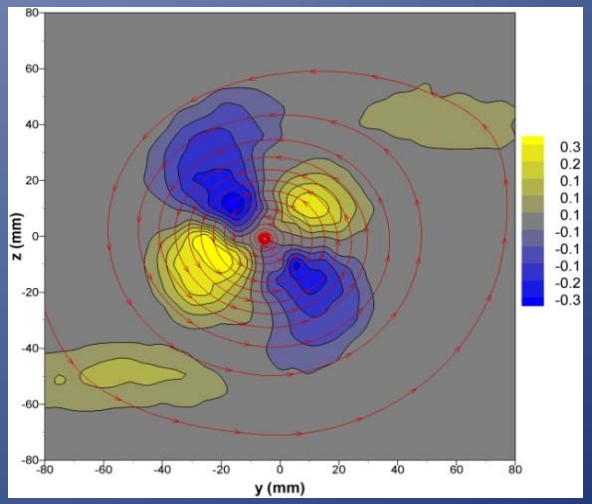


vw (m^2/s^2)

x/c=0.3





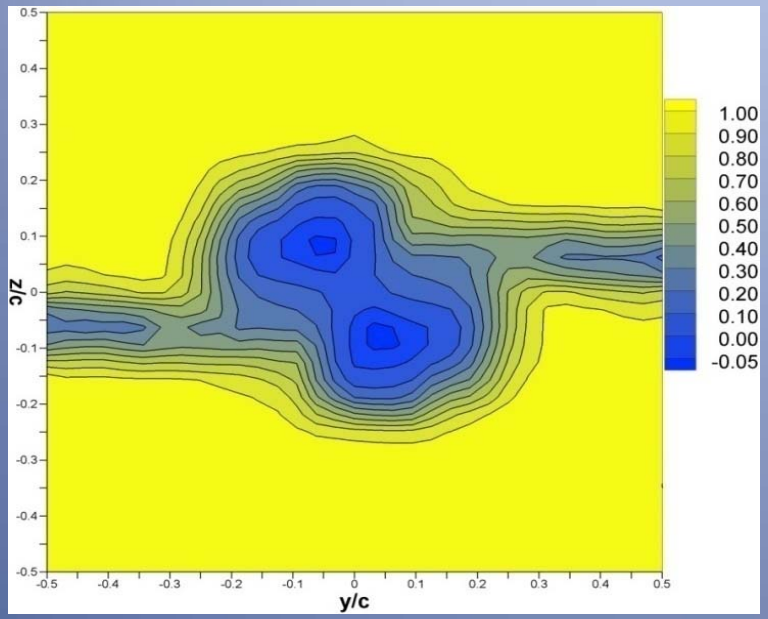


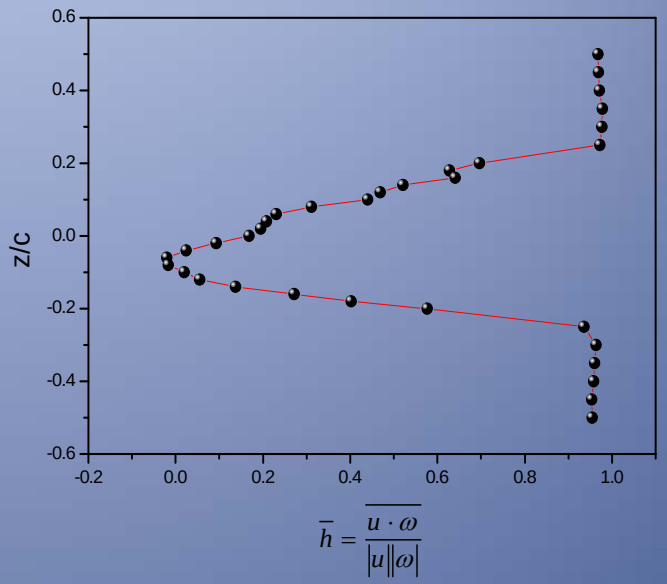
x/c=7

Helicity and Coherent structures

Relative Helicity Density

$$h = \frac{u \cdot \omega}{|u| \cdot |\omega|} = \cos\theta$$

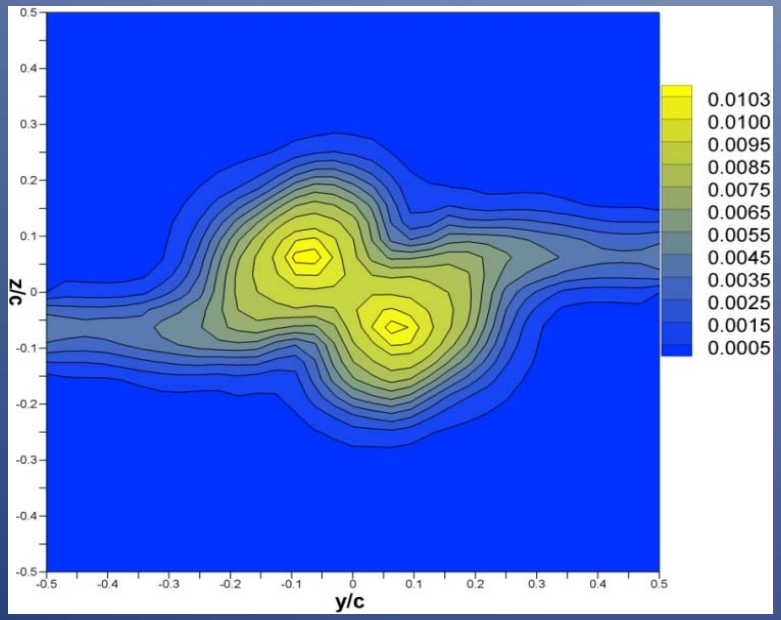


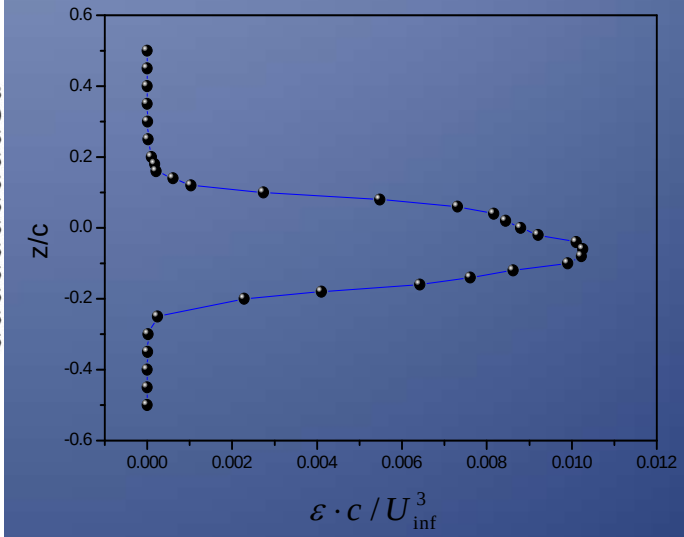


Relative Helicity Density at vortex centre x/c=0.3

Dissipation rate

$$\varepsilon \cdot c / U_{\infty}^{2}$$





Dissipation rate at vortex centre x/c=0.3

Concluding remarks

- ✓ Due to the close proximity of the wings, the flow streams rolling up around each wing tip to form the vortices collide in the area between the two wings
- ✓ Fluid streams penetrating between the wings collide, creating on the cross plane flow a stagnation point and an “impermeable” line joining the two vortex centres. Along this line fluid is directed towards the two vortices, expanding their cores and increasing their separation distance.
- ✓ The rotational flow within the vortices obligates an adverse streamwise pressure gradient leading to a significant streamwise velocity deficit characterizing the vortices
- ✓ The appearance of a dipole of negative and positive vorticity in each vortex illustrates that the vortex formation is dominated by the roll up of the fluid streams and the vortex feeding process just described, in distinction with vortex formation due to concentrated vorticity on an axis
- ✓ The turbulent flow field is the result of fluctuations of the intensity of formation and wandering effects

Concluding remarks

- ✓ Taking into account the contour plots at all stations, the measurements indicate that after shedding the two vortices are swept along the streamwise direction.
- ✓ The cores initially move away from each other and increase in dimension (from ~0.24c at x/c=0.3 to ~0.29c at x/c=1).
- ✓ The rotational velocity field around each core induces a counter clockwise rotational velocity to the other vortex and thus both vortex cores are spiralling around each other (30° from x/c=0.3 to 1)
- ✓ Braid of two vortices, deforming towards the external flow field in the downstream direction.
- ✓ Gradually the interaction flow field links both vortices together until the final merging and the formation of a new stable linear vortex (rc≈0.22c).
- ✓ The co-rotating vortex pair is observed to fully merge at about 0.6 orbit periods and at a downstream distance of 7c from wing tips.

THANK YOU

4th EASN Association International Workshop

THREE SURFACE AIRCRAFT (TSA) CONFIGURATION – PROFITS AND PROBLEMS

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Warsaw University of Technology

Tomasz Antoniewski

AT-P Aviation Sp. z o.o.

Aachen 27.10-30.10.2014

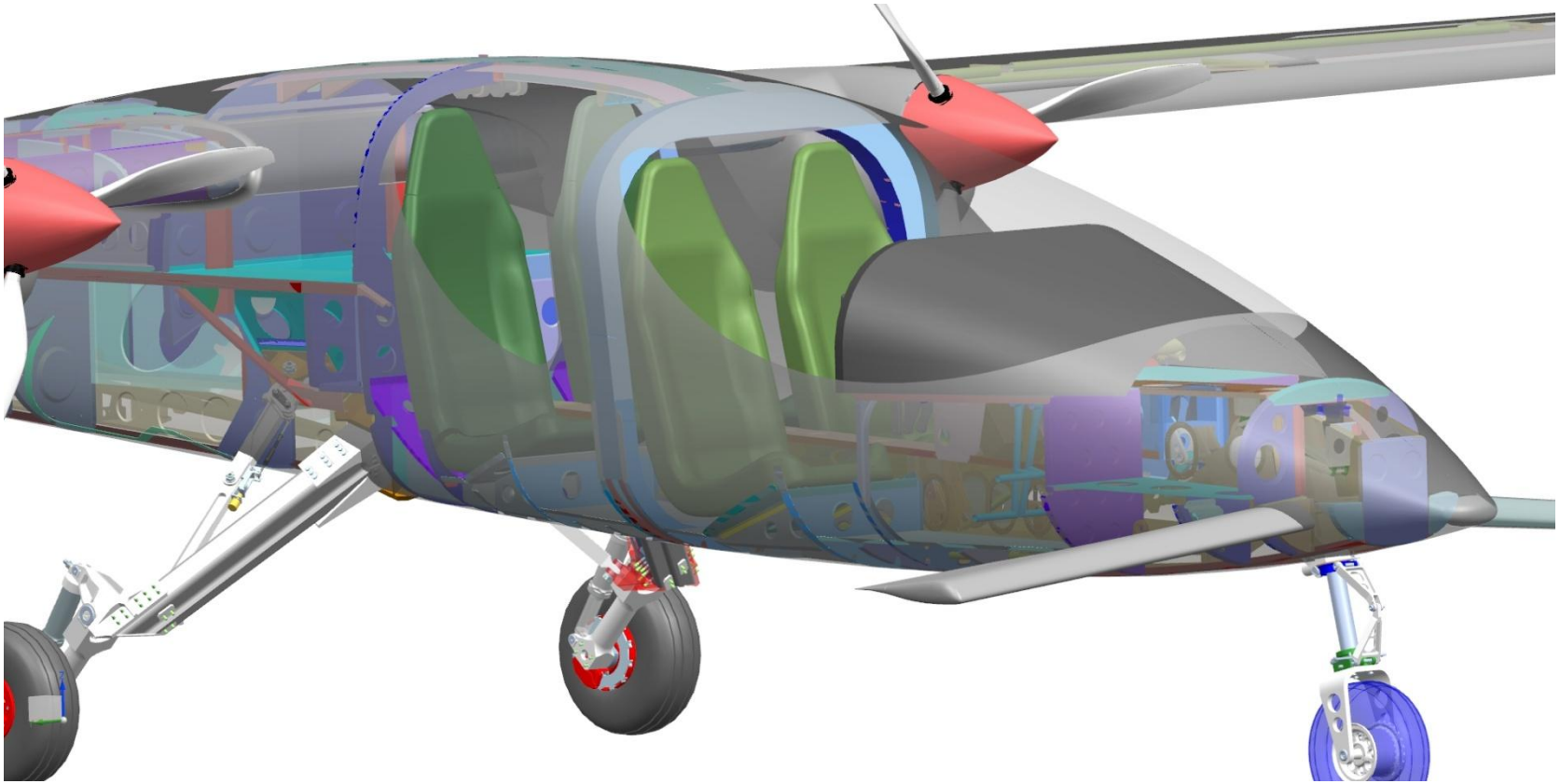
Introduction

- The fundamental feature of today aircraft has to be its ability to sell.
- Design of a new aircraft is always a challenge: how to design a new aircraft, which is better than competitive:
  - by improving the opposite features – it is difficult for classical configuration with current engines
  - PSE - Performance Safety & Economy

Introduction

- PSE - Performance Safety & Economy:
  - **Safety** was satisfied by use of two engines and parachute recovery system.
  - The **economy** was due to two Rotax engines, which are able to use the fuel used also by cars.
  - Advanced aerodynamic project had to give good characteristics to improve **economy** and **performance** as well. Additionally innovative flaps, which are deflected up in cruise condition and partially retracted to decrease wetted area, increase the aerodynamic effectiveness

Main ideas



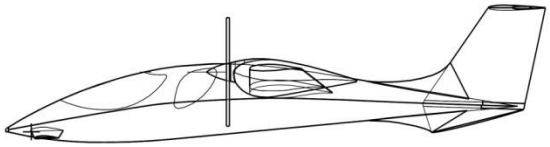
Initially the ergonomics of cabin was the starting point

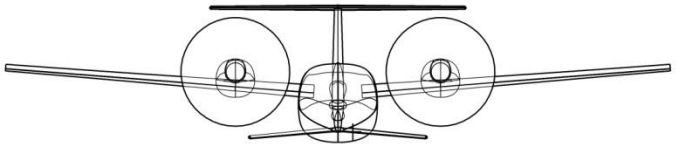
Main ideas

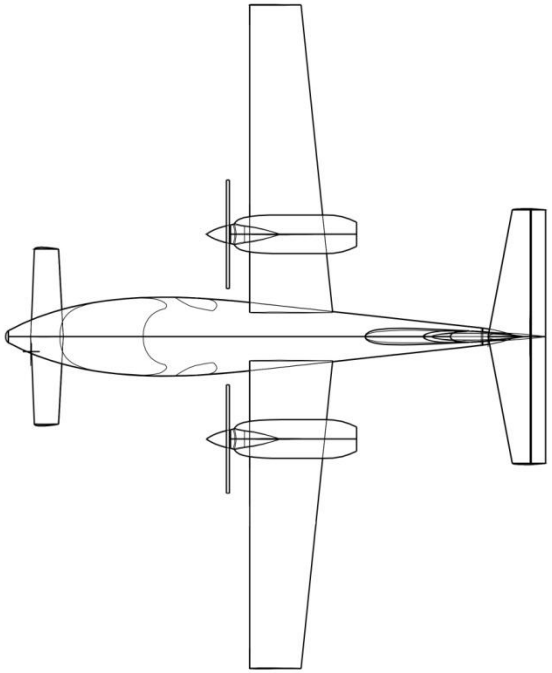
- The visibility from cabin had to be similar to visibility from helicopter cabin, not as in small Cessna case, so it should be highly glazed cabin
- Easy entering for each pilot and passenger, thus one large glazed door for pilots and two “gull wing” doors for each passenger
- It results, that wheel base of landing gear was increased and, what is most important, main wing was shifted back, which caused, that gravity center is located in front of the leading edge of main wing.
- Such extreme CG position forces the additional lifting surface on the front of fuselage (canard) to satisfy trim and to decrease very big, negative force on the horizontal tail.
- Thus the concept of three surface aircraft (TSA) was born and it was named AT-6.

Unconventional configuration requires to check flying qualities as early as possible

AT-6 - Initial version



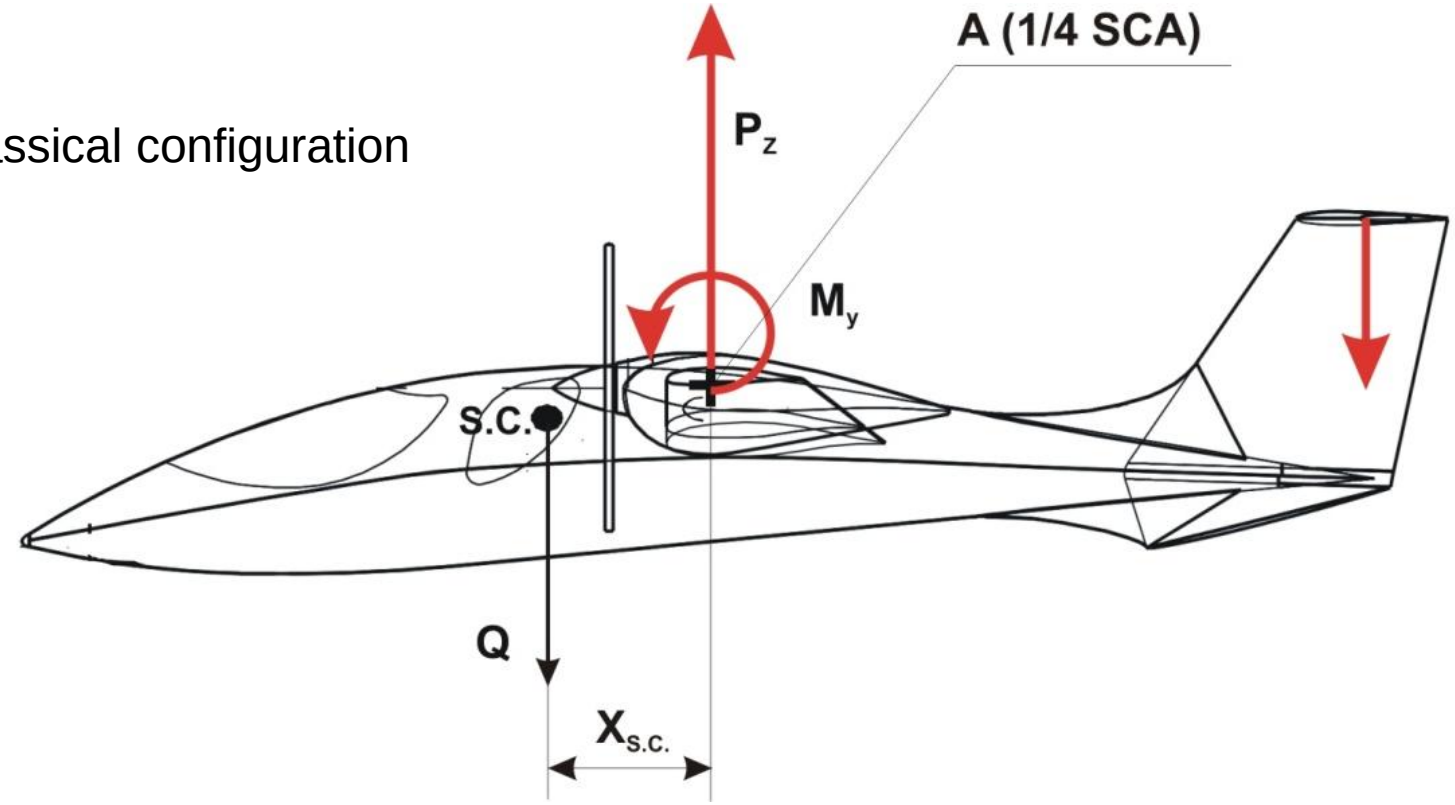




Wingspan 11.0 m
Length 9.0 m
Height 3.0 m
Wing area 12.5 m2
Max. TO weight 1280 kg
W/S 103 kg/m2
Engines power 230 HP
Minimum airspeed 90 km/h
Cruise airspeed (at sea level) 280 km/h
Cruise airspeed (at 14000ft) 320 km/h
Ceiling 18000 ft

Main advantage of TSA

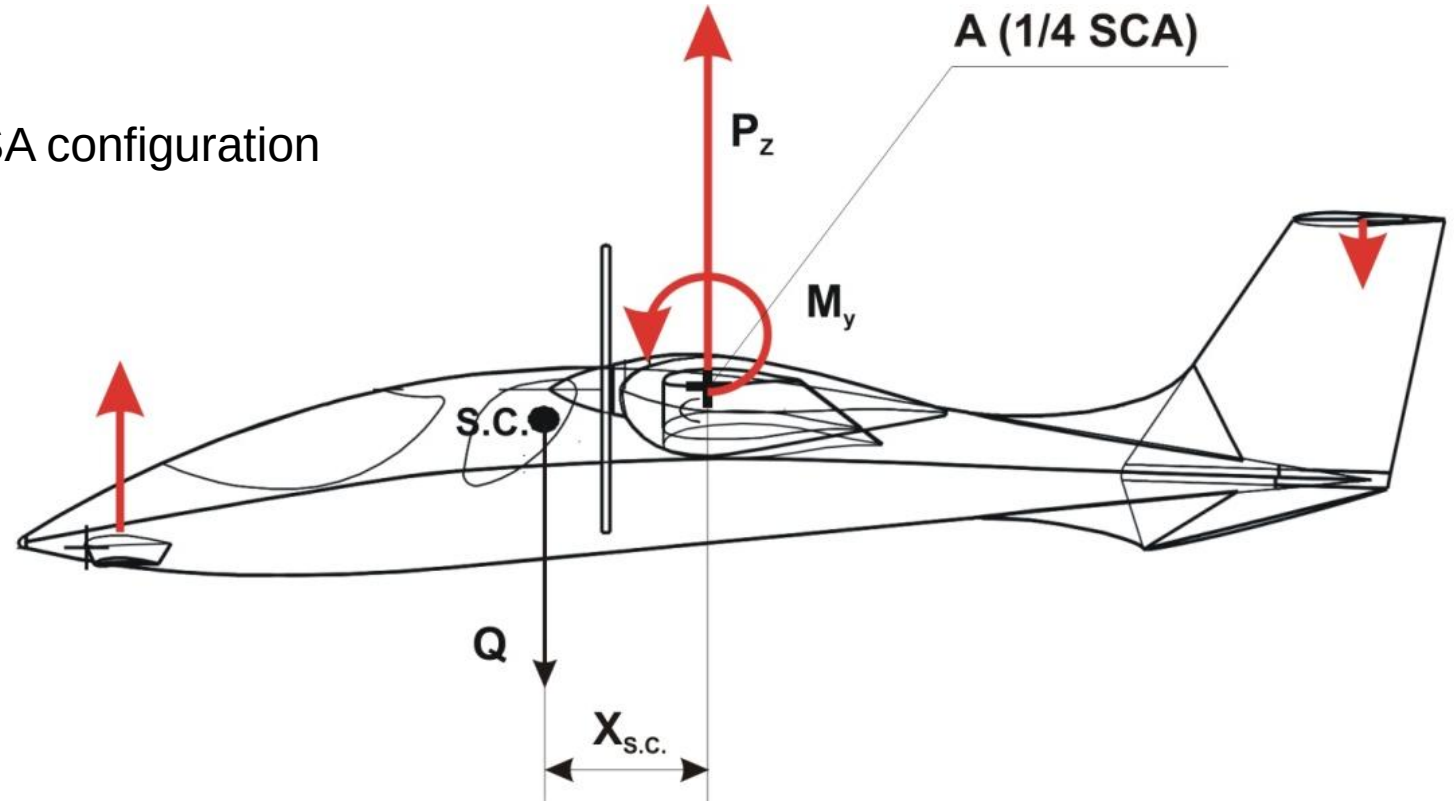
classical configuration



Extreme front CG position requires significant negative force on the horizontal tail

Main advantage of TSA

TSA configuration



Additional 3rd surface decreases negative lift on the horizontal tail and improves the lift balance and classical horizontal tail satisfies longitudinal stability

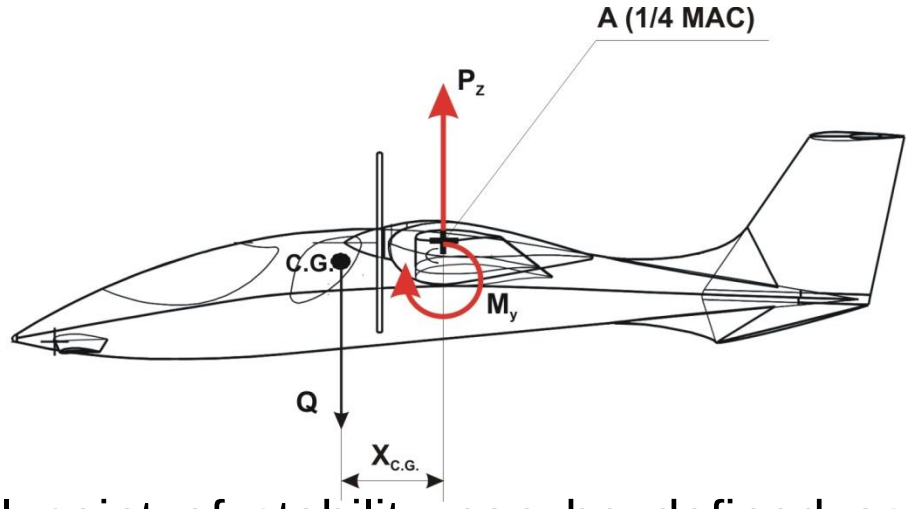
Main problems

- stability
  - longitudinal
  - lateral
- equilibrium
- forces on the tail should be decreased

Methodology of analysis

The stability and trim analysis needs aerodynamic characteristics, including the stability and control derivatives. They were computed by use of the **PANUKL** package, which is a low order potential solver. The trim and stability analysis was performed using **SDSA** (part of CEASIOM system).

Neutral point of stability



The neutral point of stability can be defined as the point which satisfies condition, that pitching moment coefficient is constant versus angle of attack or lift coefficient:

$$\frac{\partial C_{m,N}}{\partial C_Z} = 0$$

The equation of moment balance according to figure above can be written as follows:

$$\sum M_{CG} = M_Y - P_Z x_{CG}$$

Neutral point of stability

The equilibrium equation presented on the previous slide can be extended by aerodynamic forces to the following form:

$$\sum M_{CG} = \frac{1}{2}\rho S V^2 C_a C_{mCG} = \frac{1}{2}\rho S V^2 C_a \left(C_m - C_Z \frac{x_{CG}}{C_a} \right)$$

Differentiating this equation side by side and assuming that CG (center of gravity) is located in the neutral point, we obtain:

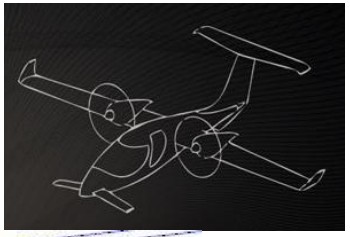
$$\frac{\partial C_{mN}}{\partial C_Z} = \frac{\partial C_m}{\partial C_Z} - \frac{x_N}{C_a} = 0 \qquad \text{thus} \qquad \bar{x}_N = \frac{\partial C_m}{\partial C_Z}$$

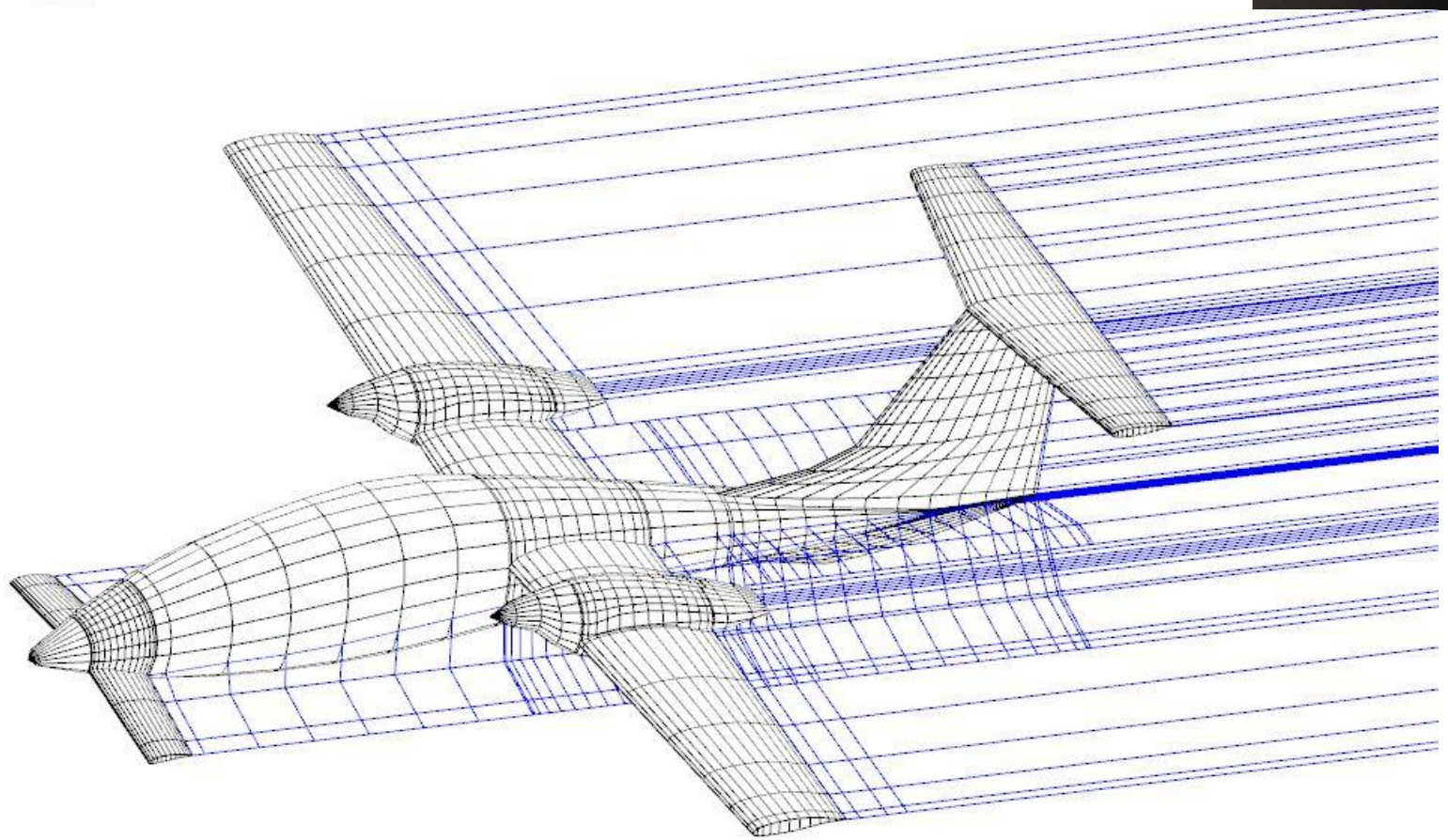
Neutral point of stability

The positive sign of X_N denotes, that neutral point is located forward with respect to point of aerodynamic forces reduction. The computation of the pitching moment coefficient versus angle of attack was done using the panel method (PANUKL).

Position of the neutral point of stability allows to compute the static margin, which is the distance from center of gravity to neutral point, measured in percentage of MAC. This value is the basis for estimating the handling qualities of an aircraft.

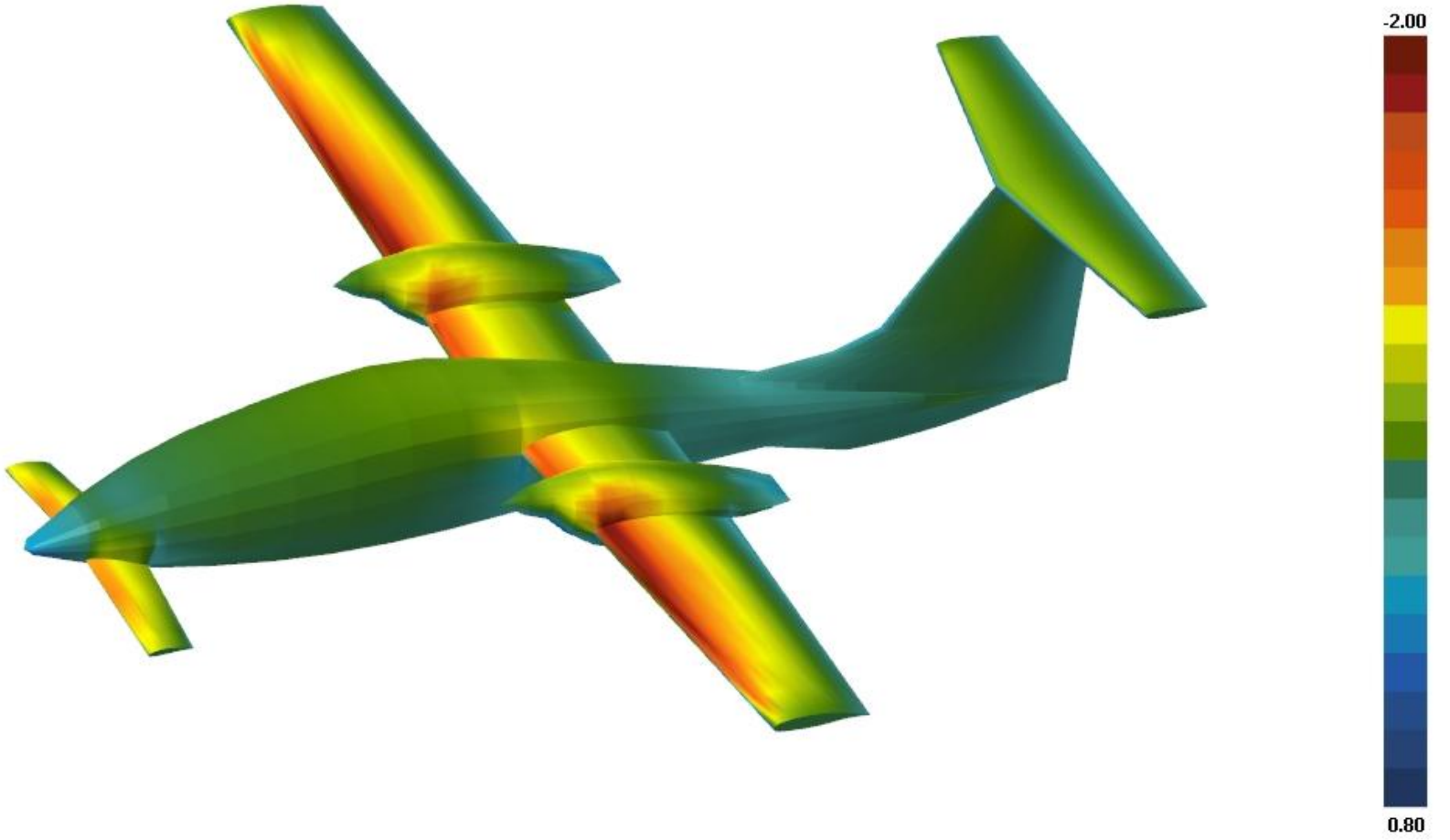
Neutral point of stability





Computational model of AT-6 (first version) - mesh of 3609 panels

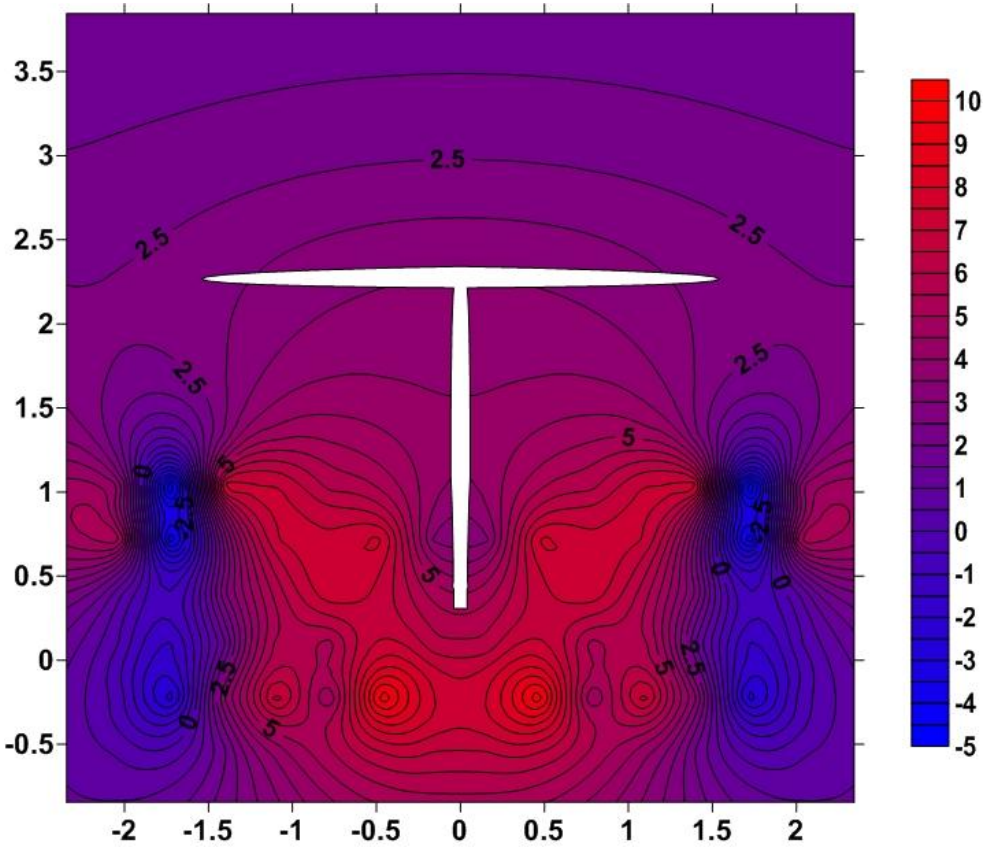
Neutral point of stability



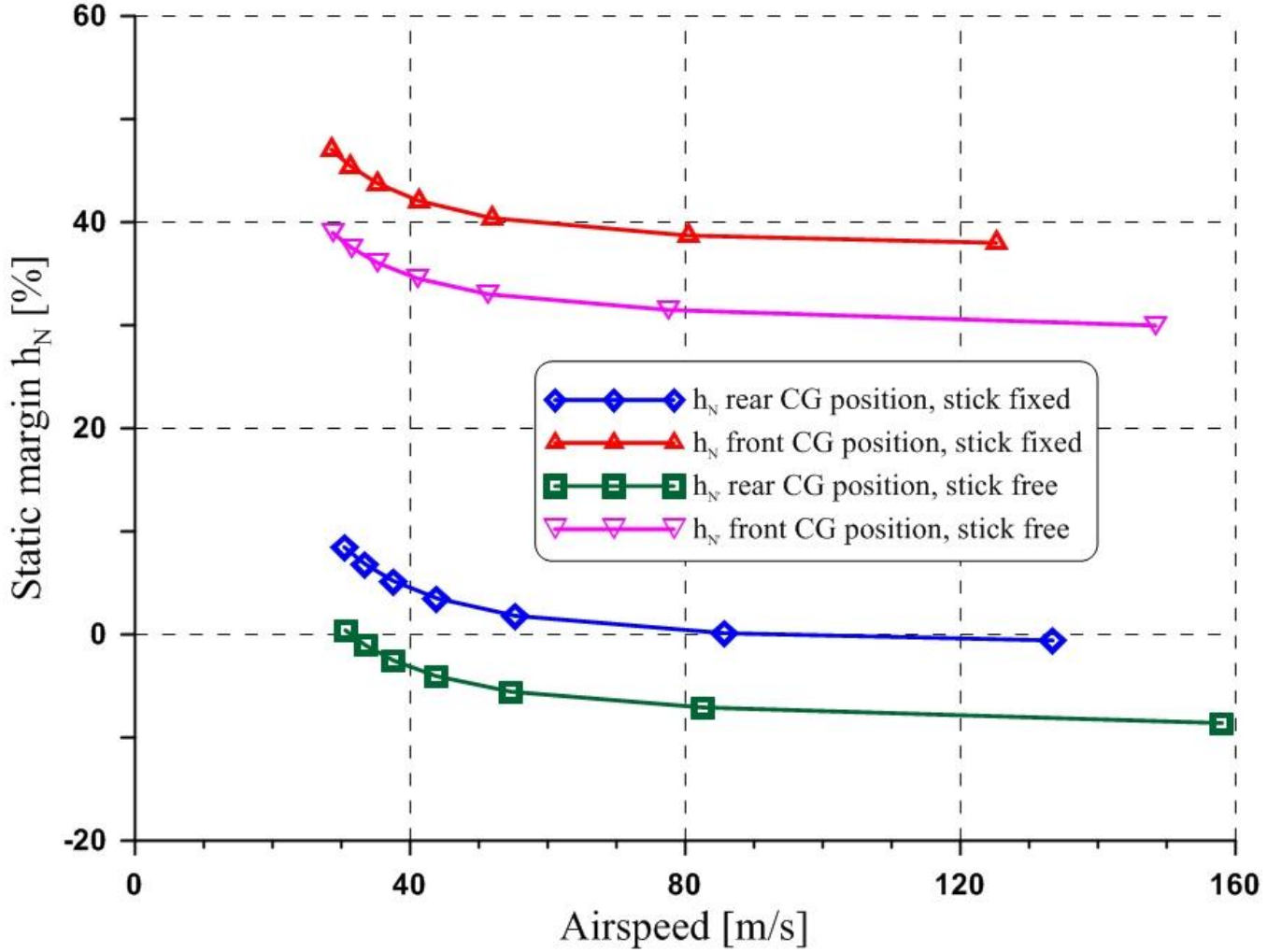
Pressure distribution, angle of attack α = 7.5°

Neutral point of stability

The static margin in case of free stick, is computed using the similar method. However it requires to compute moment coefficient in case when elevator is free. This in turn requires the calculation of free elevator deflection versus angle of attack. To compute such characteristics hinge moment coefficient of elevator is needed. It was estimated using sufficient (ESDU) reports. The necessary downwash characte-ristics were obtained from panel code (PANUKL).



Longitudinal static stability



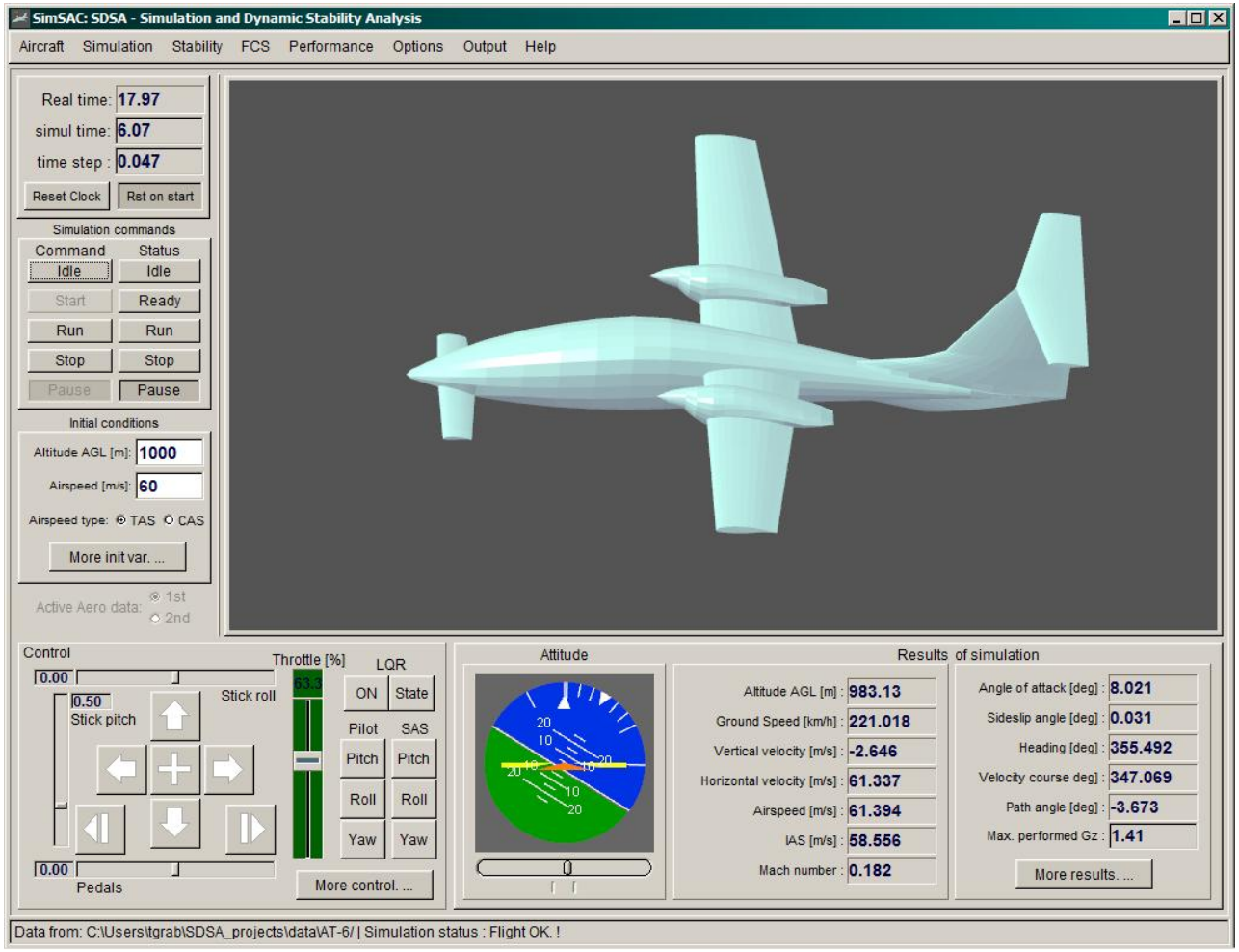
Lateral dynamic stability initial version

The aircraft configuration, especially major part of fuselage in front of main wing and big dihedral angle of main wing, is the reason why particular attention must be paid to the lateral stability.

The basic factor of directional static stability, i.e. derivative of yawing moment with respect to sideslip angle is positive, which means, that aircraft is statically stable.

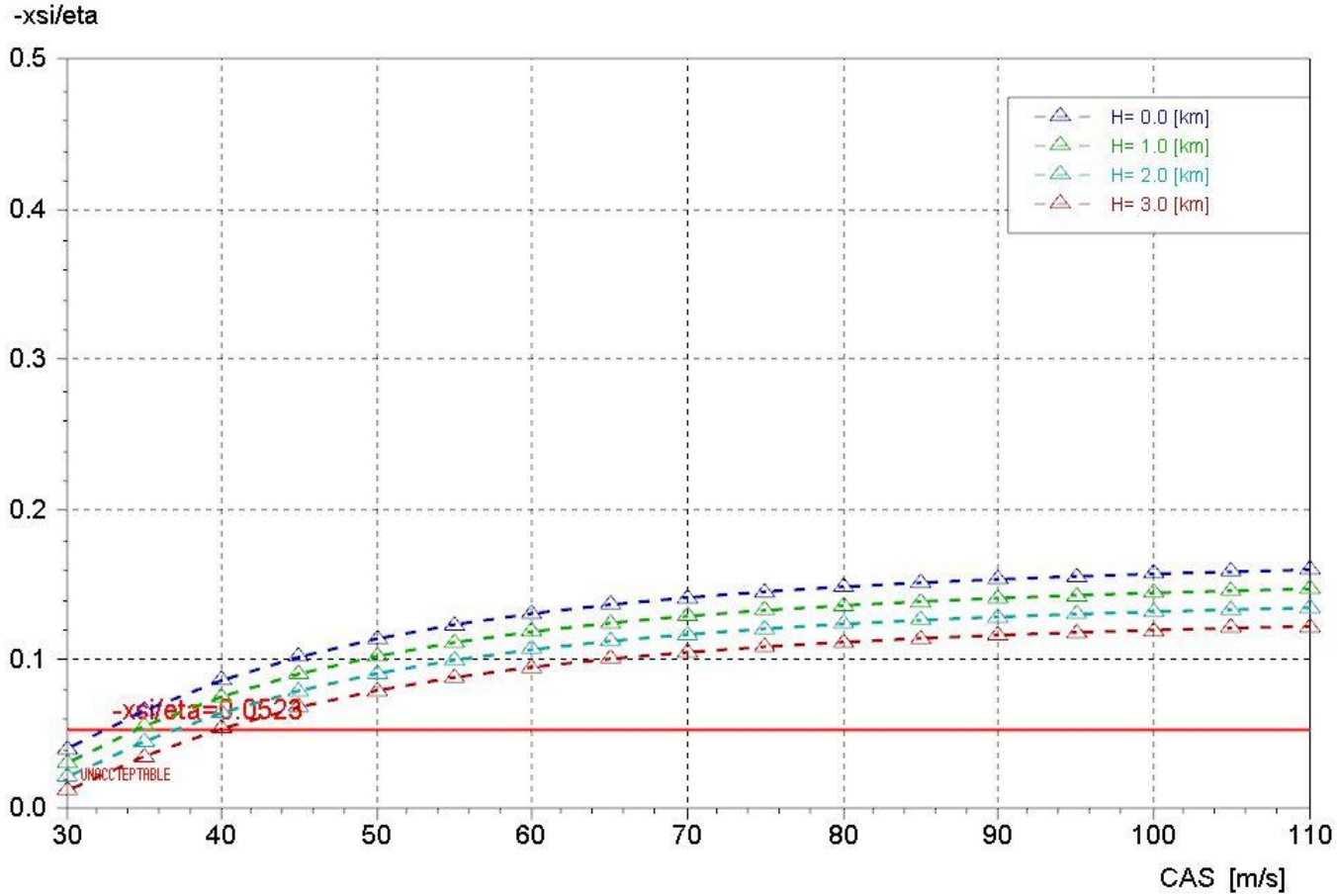
The dynamic analysis showed, that characteristics of the most important, from flying qualities point of view, lateral mode of motion, i.e. Dutch roll may not be satisfying and it can even be unstable for higher angle of attack.

Dynamic stability



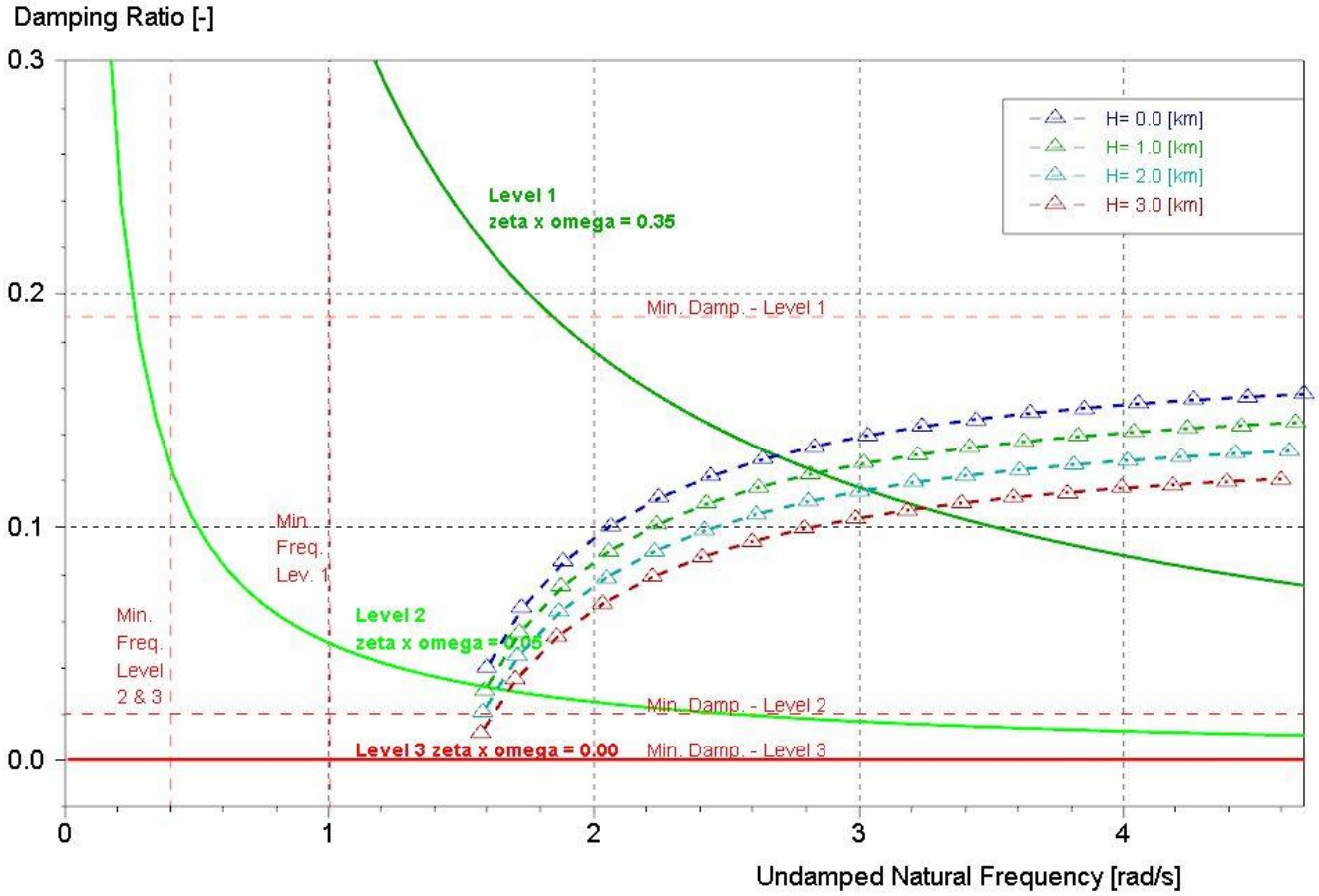
SDSA window - AT-6 flight simulation

Lateral dynamic stability initial version



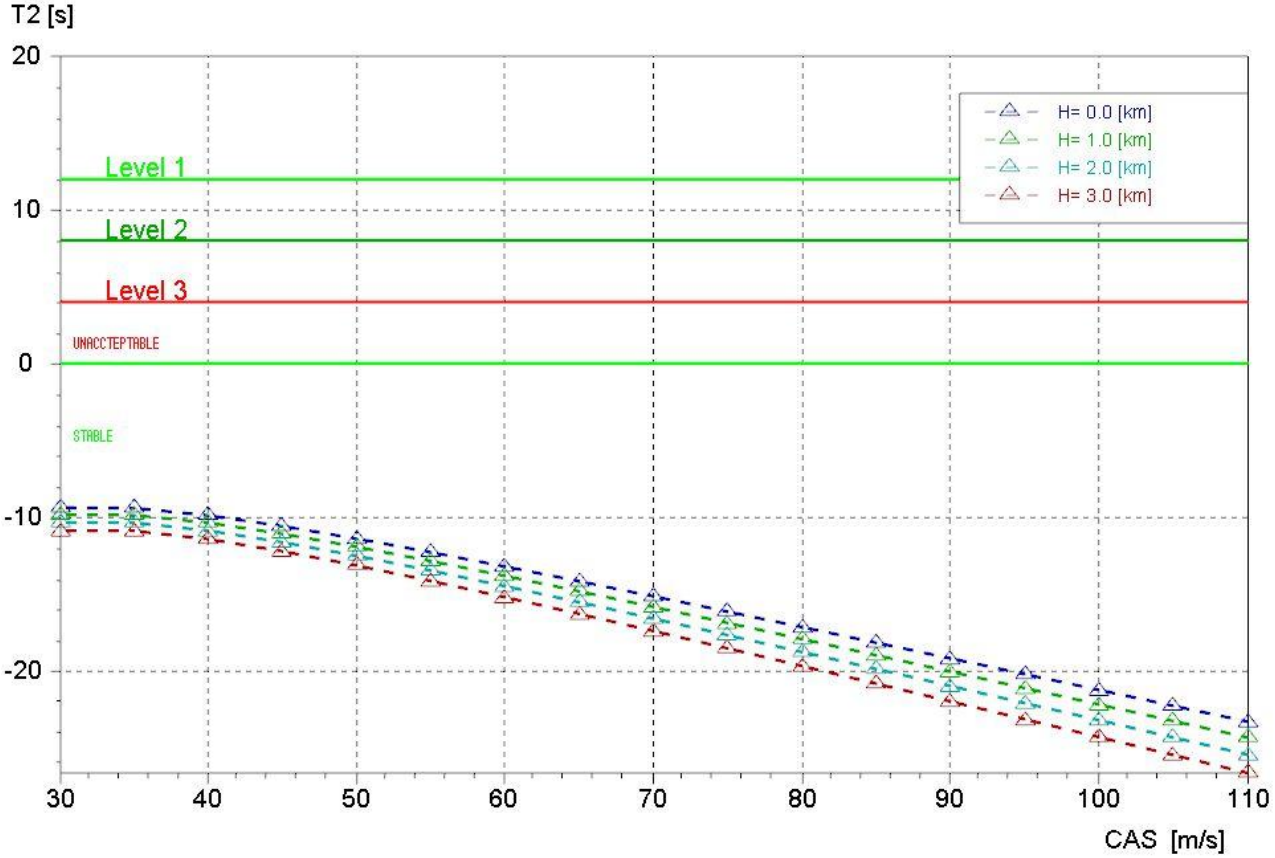
Dutch roll characteristics versus calibrated airspeed (CS-23.181 criterion)

Lateral dynamic stability initial version



Dutch roll characteristics against background of MIL-F-8785C criteria

Lateral dynamic stability initial version

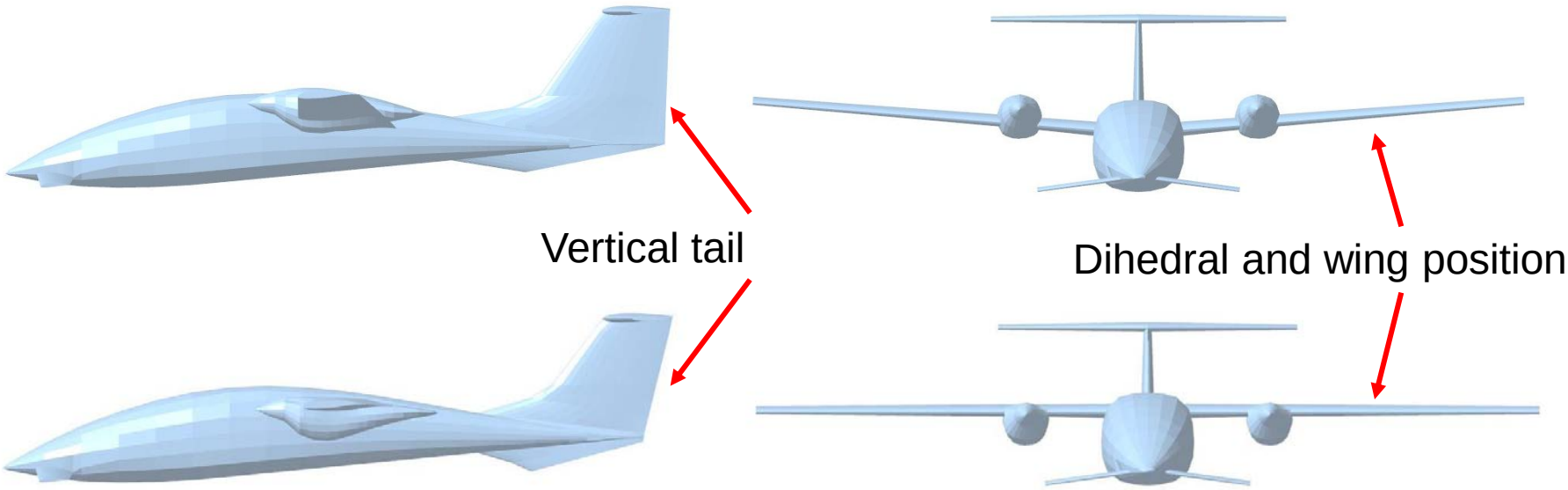


Second essential lateral mode of motion is spiral mode. This mode is stable in whole airspeed range – figure above (MIL-F-8785C criteria).

Handling qualities - results changes in configuration

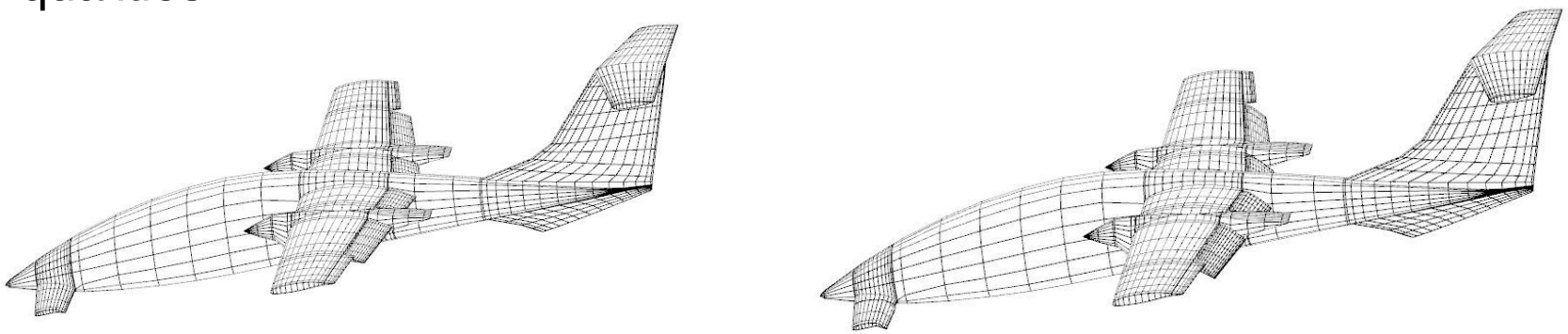
- The results of stability analysis of the first version of presented aircraft were not satisfying. Both longitudinal and lateral characteristics had to be improved.
- Longitudinal stability was improved by changing the internal layout of the aircraft and by rearranging of the weights breakdown.
- The lateral stability was improved by decreasing dihedral angle to zero and moving the main wing up, to perform the same position of engines. It improved Dutch roll and allowed to decrease the vertical tail area.

AT-6 – change of geometry



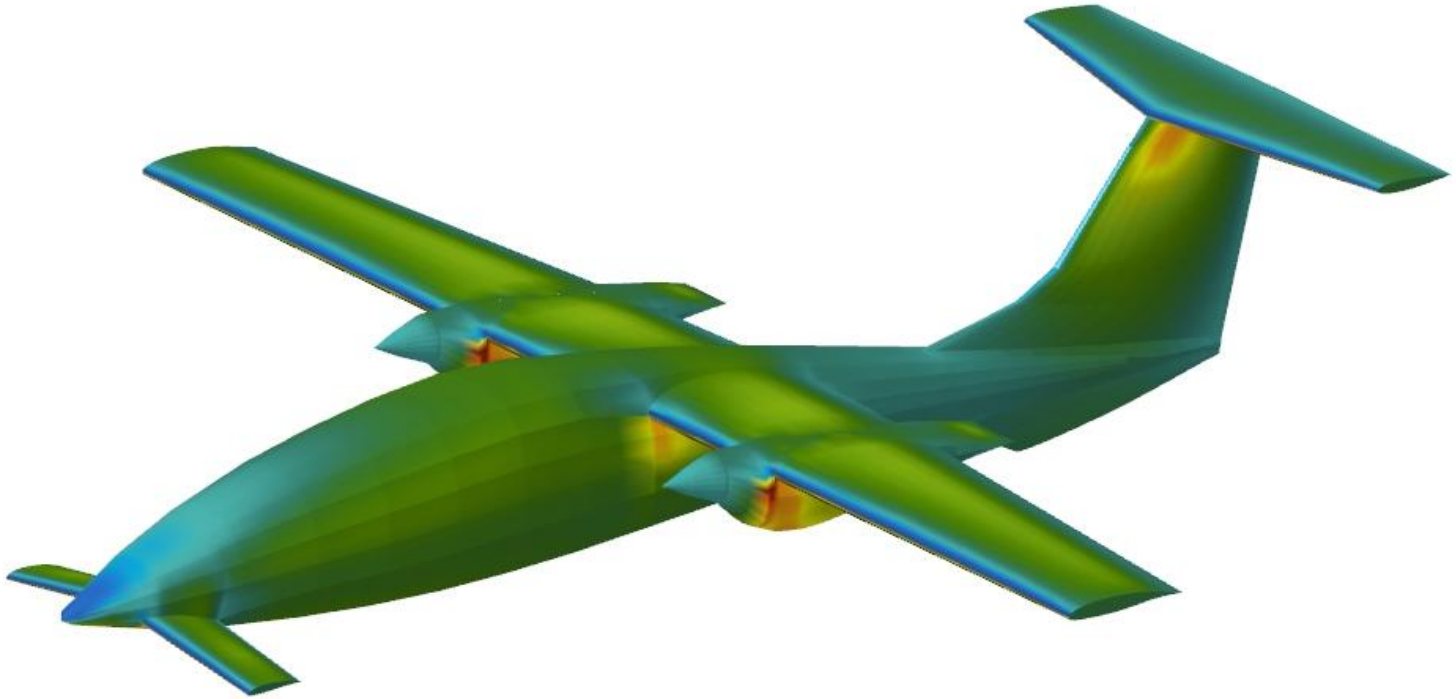
Handling qualities final version

New configuration was tested. Three aerodynamic configurations were considered: clean, take-off (flaps 15°), landing (flaps 30°) – next figures. The aerodynamic characteristics were obtained using panel methods (PANUKL). All modes of motion were checked, taking into account requirements from airworthiness regulation for handling qualities.



New configuration AT-6 meshes
main wing flaps deflected with: 15°(left), 30°(right).

Handling qualities - final version

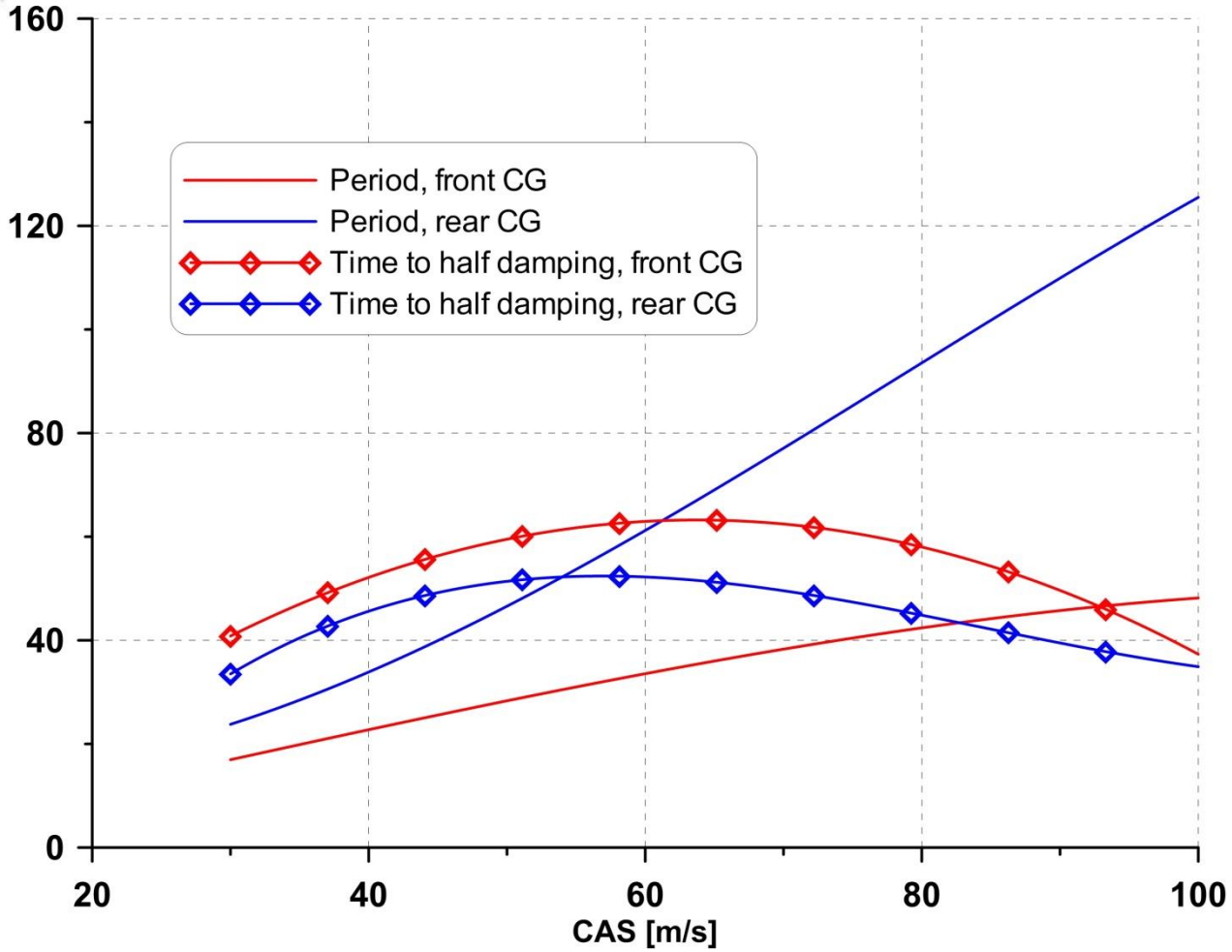


New configuration of AT-6 - example of pressure distribution (PANUKL), angle of attack α = -5°

Dynamic analysis - phugoid

The dominating state variable in phugoid mode is the airspeed, and angle of attack is almost constant. The period is usually long and oscillations are well damped. The airworthiness requirements are not strong: "**Any long-period oscillation of the flight path (phugoid) must not be so unstable as to cause an unacceptable increase in pilot workload or otherwise endanger the aeroplane**." (CS-23.181). The results obtained for AT-6 show (next slide figure), that phugoid is stable in the whole range of CG position. Time needed to damp the amplitude to half is comparable with the period and varies between 40-60 s.

Dynamic analysis - phugoid

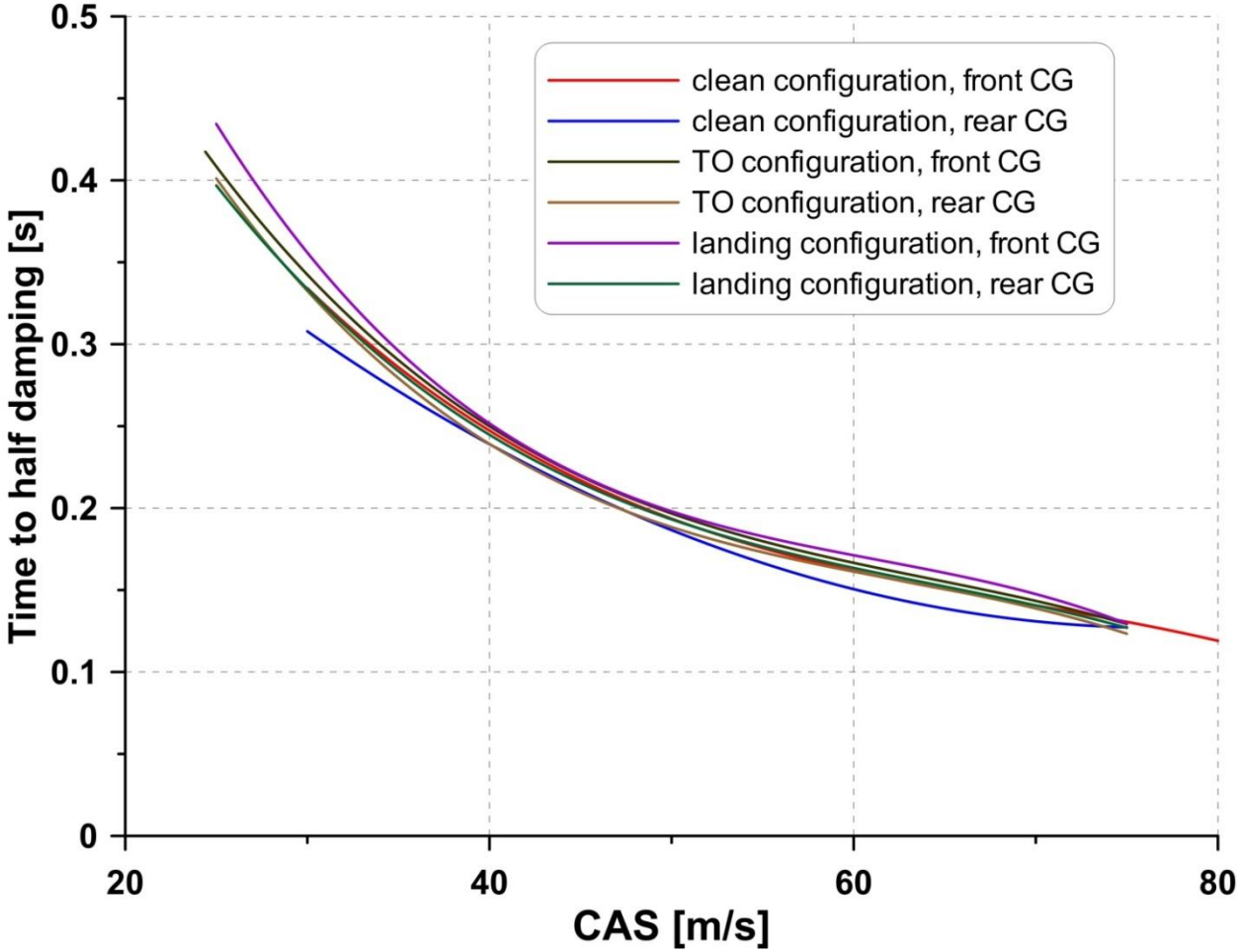


Phugoid - period and time to half damping versus calibrated airspeed

Dynamic analysis – Short Period

The short period oscillations connect rapid changes of angle of attack with pitch rate. The period is usually very short. The requirements according to CS-23.181 say: "**Any short period oscillation not including combined lateral-directional oscillations occurring between the stalling speed and the maximum allowable speed, appropriate to the configuration of the aeroplane must be heavily damped ...**". The results of computation show, that short period oscillations are well damped (next slide figure), however for clean configuration in case of rear CG position, periodical character vanishes. Two non-periodical modes are stable.

Dynamic analysis
Short Period



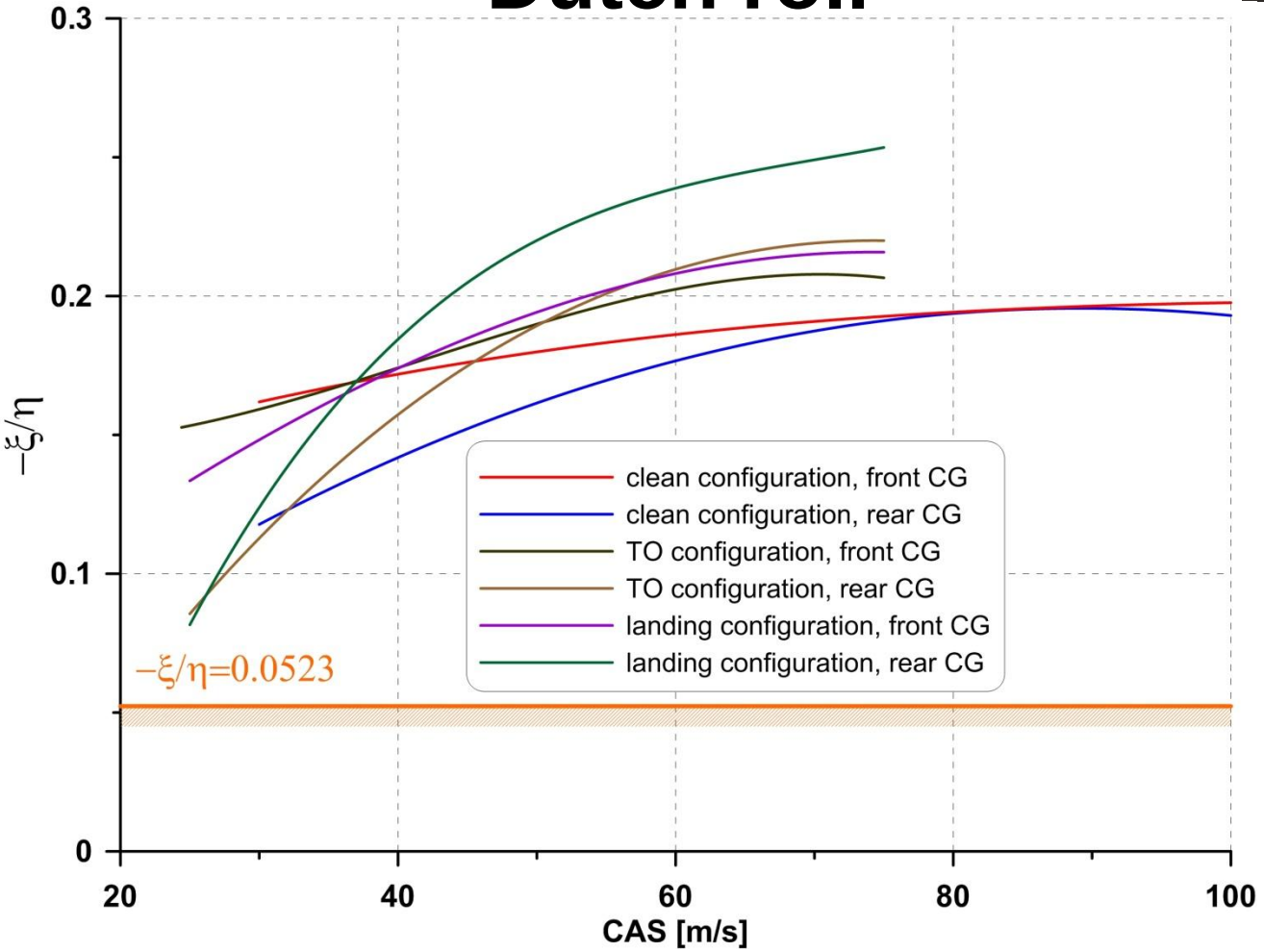
Short Period oscillation - time to half damping versus calibrated airspeed

Dynamic analysis – Dutch roll

Dutch roll requirements according to CS-23.181 are well defined: "Any combined lateral-directional oscillations ("Dutch roll") occurring between the stalling speed and the maximum allowable speed appropriate to the configuration of the aeroplane must be damped to 1/10 amplitude in 7 cycles ...".

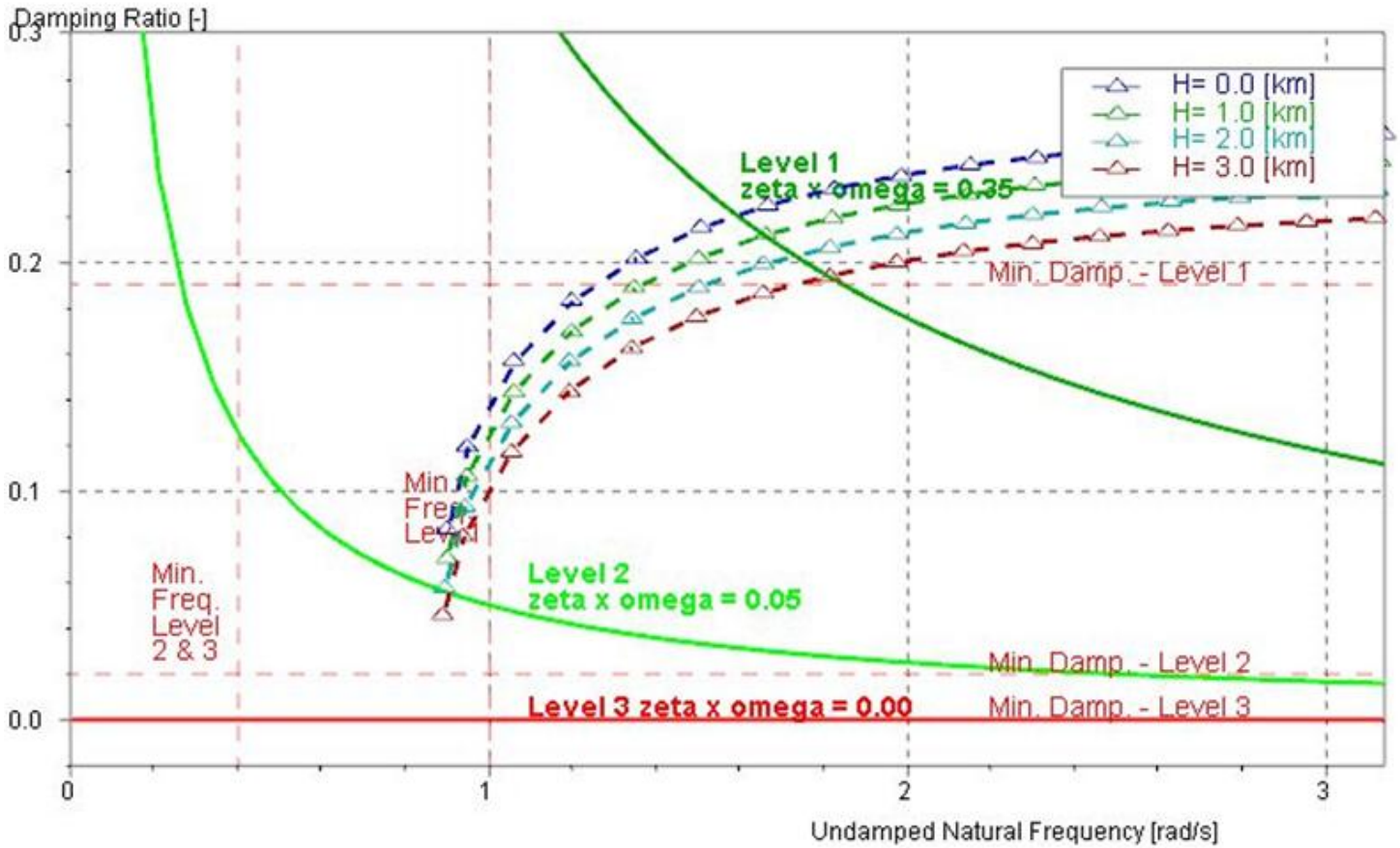
The obtained results show, that all configurations satisfy this criterion.

Dynamic analysis
Dutch roll



Dutch roll characteristics versus calibrated airspeed (CS-23.181 criterion)

Dynamic analysis
Dutch roll

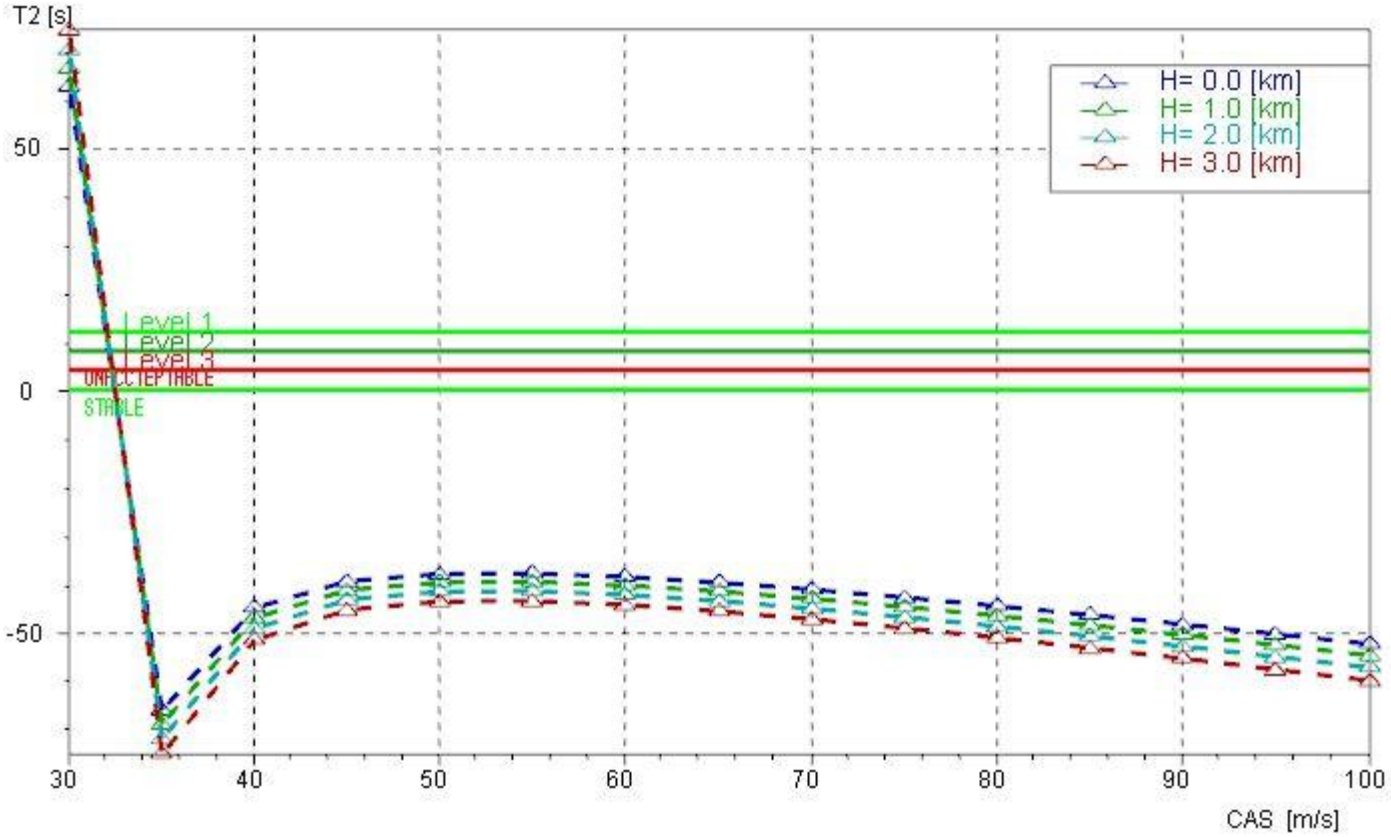


Dutch roll characteristics against background of MIL-F-8785C for landing configuration and rear CG position criteria. It also shows good Dutch roll characteristics, which are in Level 1 & 2 for whole flight envelope.

Dynamic analysis – Spiral mode

After improvement of the previous version, spiral is the only mode, that is worse. However, airworthiness requirements are not strong - CS-23-BOOK2: "... a slowacting mode called the spiral which may be stable, but is often neutrally stable or even mildly divergent in roll and yaw?". Similar requirements are in MIL-F-8785-C. Figure on the next page presents time to double of spiral mode, which shows, that spiral is unstable only for small values of airspeed and time to double is sufficiently big.

Dynamic analysis – Spiral mode



Time to double for spiral mode against background of MIL F-8785C for clean configuration, front CG position criteria

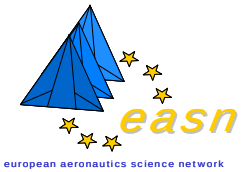
Concluding remarks

According to the results of flight tests of the scaled model, which is dynamically similar, we can be optimistic for the achievement of the objectives set for the full-size aircraft, namely:

- cruising speed should be greater, that 150 knots,
- minimum airspeed, for configuration with flaps, corresponds to aircraft with bigger area (with the same weight),
- “aerodynamic safety” is satisfied – stall, spin characteristics, static and dynamic stability
- good visibility and comfort of cab
- other performance and low operating costs resulting from the aerodynamic characteristics (L/D over 15)

The End

Thank you for attention



European Aeronautics Science Network

4th EASN Association International Workshop on
Flight Physics & Aircraft Design
27th-29th October 2014, Aachen, Germany

New Small Aircraft Concepts and Required Technologies Following FlightPath 2050 and Single European Transport Area

Krzysztof Piwek, Witold Wiśniowski

instituteofaviation
warsaw, since 1926

A comprehensive response to Vision 2020

Strategic Research Agenda

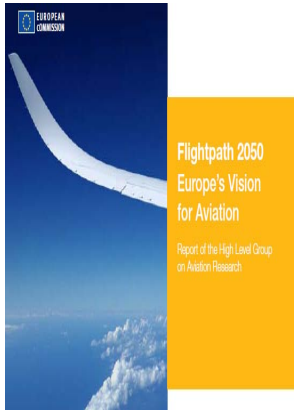
- ***Responding to society's needs***
- ***Securing global leadership for Europe***

SRA-1

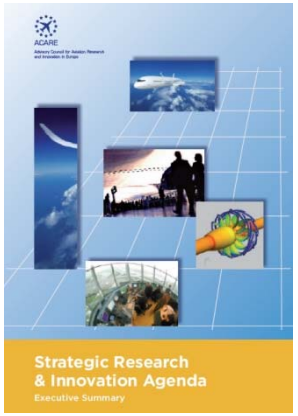
SRA-2

Addendum

A decade of Successful Innovation



Flightpath 2050



SRIA- 2012

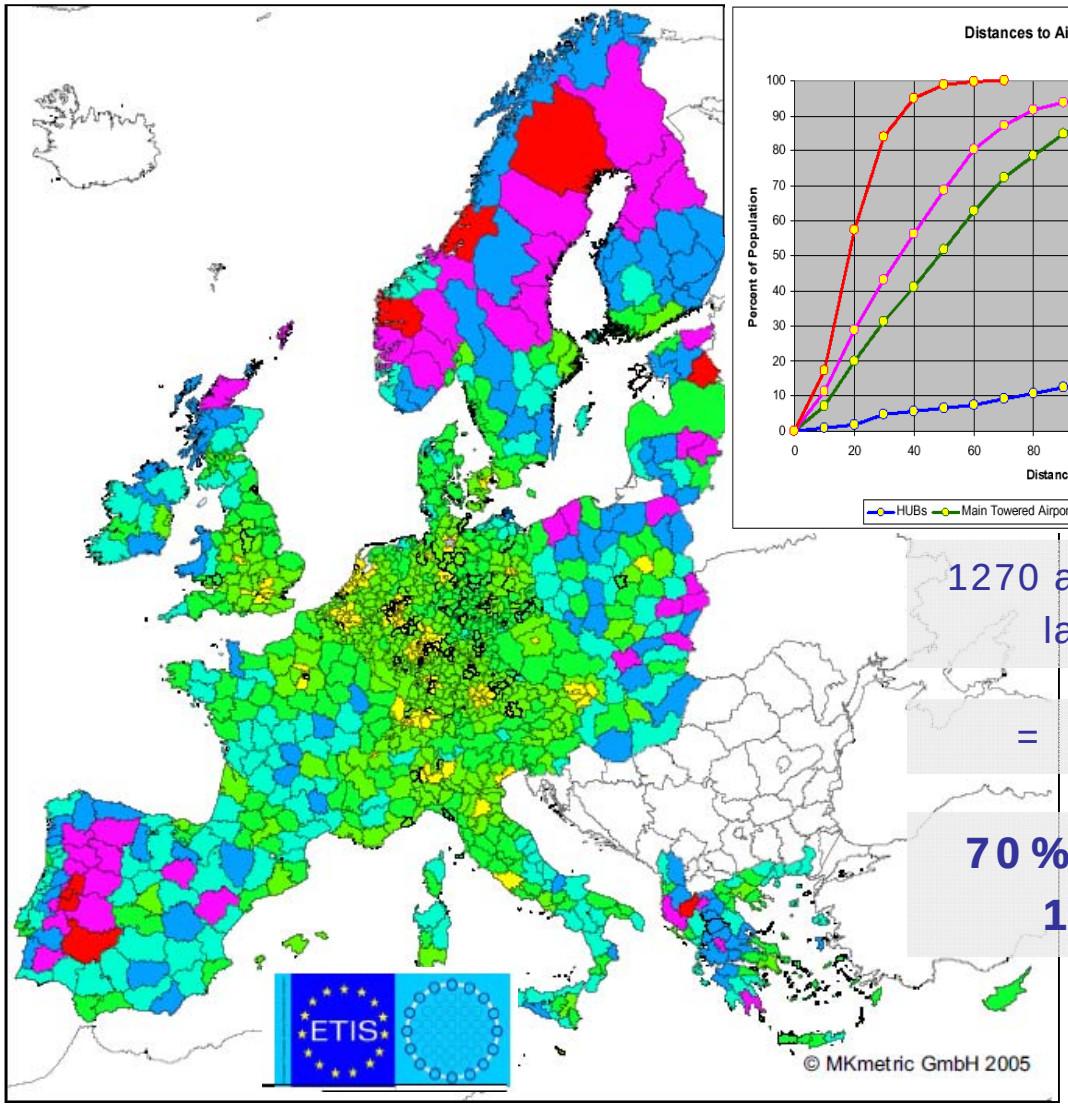
Crucial Transport Goals in FP 2050

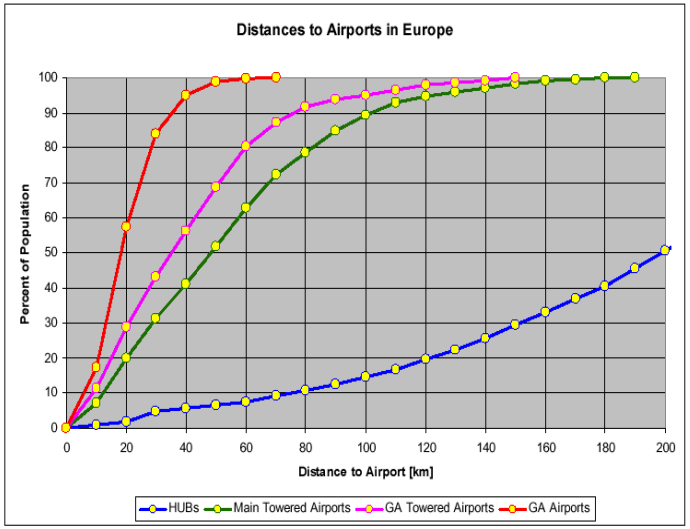
Meeting Societal and Market Needs

- European citizens are able to make informed mobility choices
- 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours.
- Flights arrive within 1 minute of the planned arrival time
- Air traffic management system is capable of handling 25 million flights a year in Europe
- A coherent ground infrastructure is developed

What is average travel time by air transport for regions?

- **10** and more hours
- **9** to **10** hours
- **8** to **9** hours
- **7** to **8** hours
- **6** to **7** hours
- **5** to **6** hours
- **4** to **5** hours





1270 airports and 1300 landing fields

= 2570 airfields

70% traffic = top 15 airports

Small Air Transport (SAT)

The SAT Mission

The mission of SAT is to provide **accessible and affordable high speed mode** of transport on European interregional network connections with **low-intensity traffic** (less than 30 thousand passengers per year)

This mode allows **origin-destination travel in time less than 4 hours** (according to Flight Path 2050 Europe's Vision "90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours")

The system provides an **equivalent level of safety** close to passenger aircraft and is clean and **environmentally more friendly than a personal car.**

The SAT Vision

The SAT is a segment of high-speed transport market, that serves local and regional low traffic connections

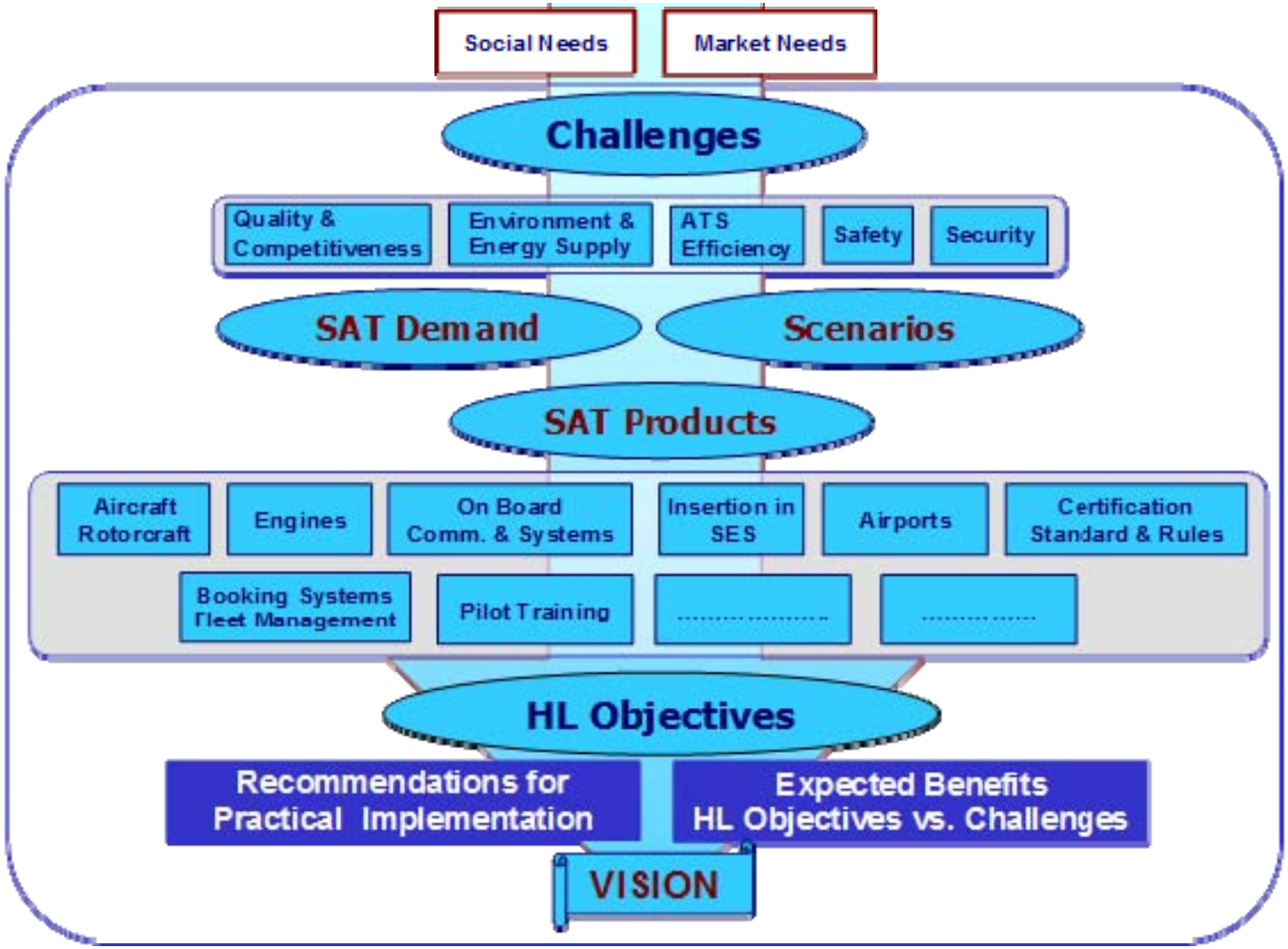
Aircraft - small 4 to 19 seats, that are low DOC, green, safe, and secure

Infrastructure on the ground and in the air - Regional Airports + ATM/ATC services integrated in SESAR

Net – Centric Management & Acquisition – ICT based logistic and management system for SATS, integrated within the SESAR's System Wide Information Management (SWIM)

http://sat-rdmp.eu **http://sat-rdmp.eu**

The SAT Common Vision



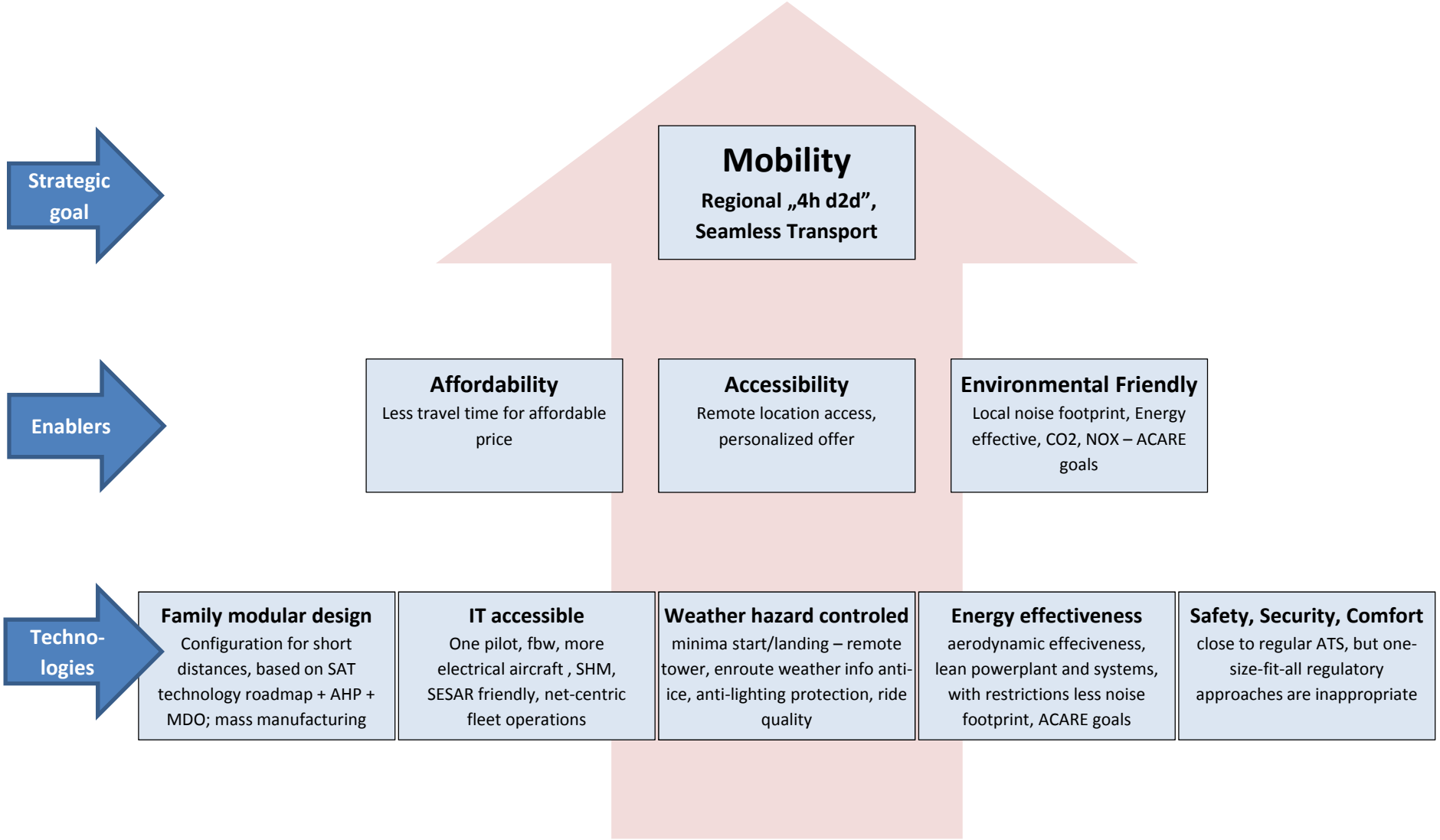
Overall approach to Vision Building Source SAT Rdmp D1.1 Common Vision

The SAT Common Vision

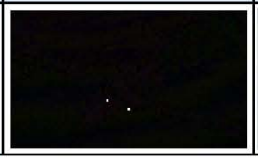
Panel (SAT Common Vision Workshop, Bruss, Sept 2011):

- The **SAT system should be part** of the European Integrated Transport System
- **SAT-Rdmp Project is compliant with Fligfhtpath 2050** challenges ” 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours”.
- **There is a social need** for mobility specifically for some regions and city-pairs
- The **business model** to be adopted **is an essential element** for the success of a SAT System. It has to be affordable and reliable.
- A **pilot phase testing** some different business models should be set up in the short term; this would allow building up a success story, to increase trust in the approach, to support public acceptance and political leverage.
- There is an agreement that **SAT System might become a small scale platform to demonstrate** the European Integrated Transport functionality.
- **Currently the enabling conditions are in a poor status**. European manufacturer are suffering from this situation.

The New Small Aircraft Concept



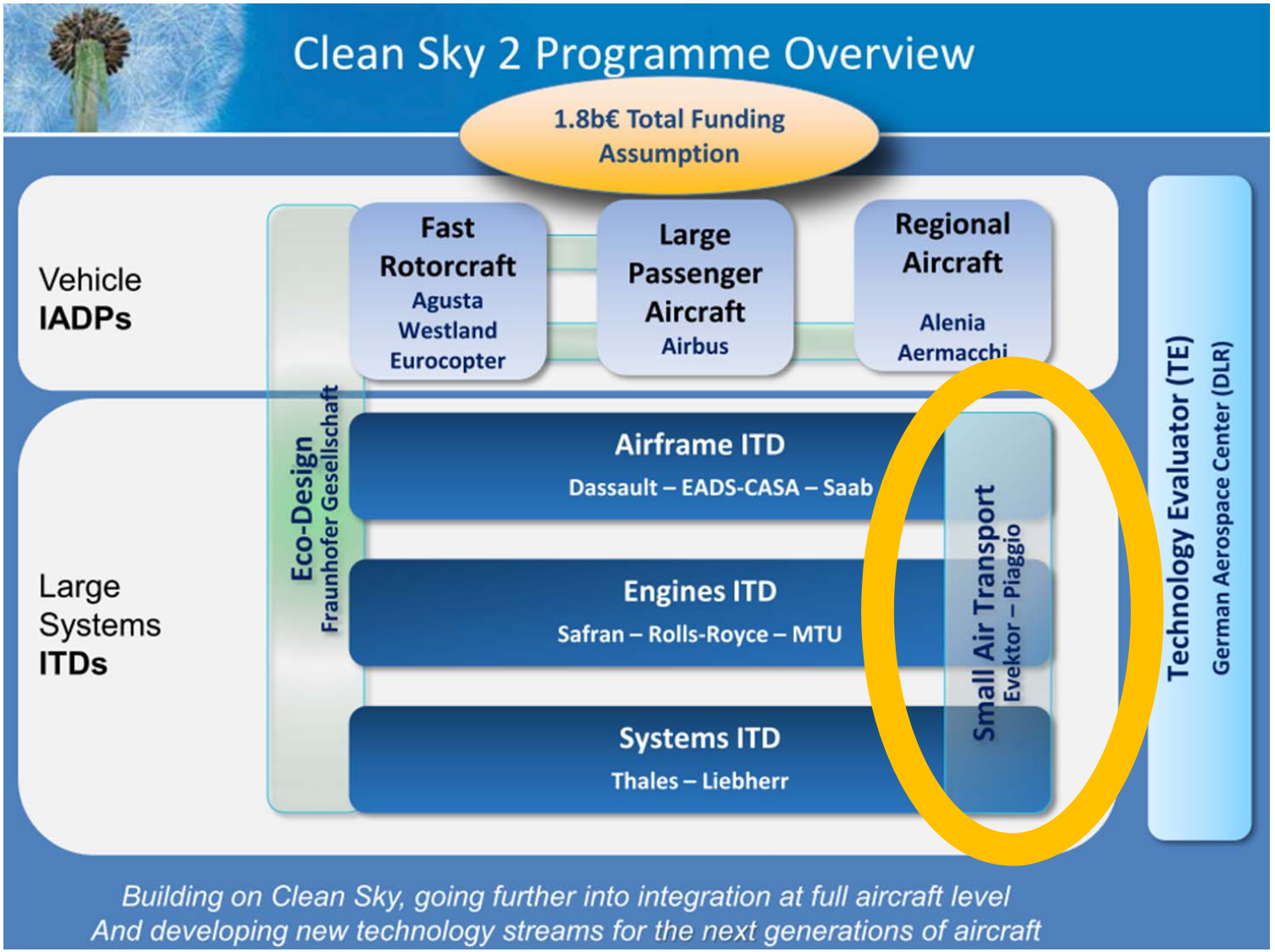
The New Small Aircraft Concept

SAT class	Pistons + hybrid		Turboprop		Fan	
Subclass	**ACP-1**	**ACP-2**	**ACT-1**	**ACT-2**	**ACJ-1**	**ACJ-2**
Main Mission	Private and business travel, air-taxi service available on request, a short distance, middle class of service,	Air-taxi on demand, a short distance, middle class of service,	Business and private travel, air-taxi service on demand; available to the majority of the population,	Commuter according to flight schedules and on demand, for small passenger flows and a variety of routes; available for most of the population,	Corporate travel, business and private travel, air-taxi service on demand; for passengers with significant time value,	Commuter on request and according to flight schedules, corporate, business and private travel, high class service for passengers with a very high value of time.
Crew+Pax	**1+3**	**1+5**	**1+9**	**2+19**	**1+5**	**1+9**
Reference aircraft						

Deploy Product Demonstrators

- **Design phase:**To define parameters of SAT aircraft via optimization process taking into account condition of commercially reasonable SAT system operation - matching to level of specific region needs (depends on prognosis of passenger flows, time value of travelers, communication networks and regional GNP)
- **Development phase:** – working out Technology Demonstrators of Clean Sky2 SAT Transverse Activity
- **Deployment phase:** – based on set of aircraft missions, and technologies reaching TRL 6 – starts to design process for program SAT Aircraft Family. Two demonstrators the types ACT-1 and ACT-2 (colored green) can be modules using the same turboprop engine (ACT-1 – one engine 9 passengers, ACT-2 – two engines, 19 passengers). Third demonstrator ACP-1 can possess commonality modules of functionality – with more challenging modern diesel-hybrid power plant.

Impact and Implementation



Conclusions – main message

- FP 2050 **“90% d2d 4h” challenge – justifies SAT** – for multiple but thin passengers flows;
- **SAT can be “smart regions” specialization** of the Single European Transport Area;
- **Demonstration of SAT aircraft technologies** find place in **CS 2 – SAT Transverse Activity;**
- New small aircraft concepts based on assumption that exists **family of aircraft**. Features of family members depends of transport system optimized for specific regions (passenger flows, passenger time value spectrum, infrastructure);
- New **small aircraft for SAT system** should fulfil requirements of:
  - Regional „4h d2d” and seamless transport,
  - Affordability, accessibility,
  - Safe and security,
  - Energy efficiency and acceptable environmental impact,
  - Key role of revitalization of European Small Aviation Industry.

Flight Path 2050 challenges

- „90% d2d 4h within Europe”

will not be obtained without implementing

Small Aircraft Transport Mode as a component of European Personalized Air Transport System!

4th EASN Association Workshop on Flight Physics and Aircraft Design, 27th -29th October, 2014, Aachen, Germany

Evaluation of Variable Camber Concept for Aircraft in Formation Flight

Institute of Aerospace Systems (ILR)

Yaolong Liu, Fabian Peter and Eike Stumpf

Content

1. Motivation

2. Review of the Previous Results on Formation Flight

3. Analysis Methods of Formation Flight with Variable Camber Concept

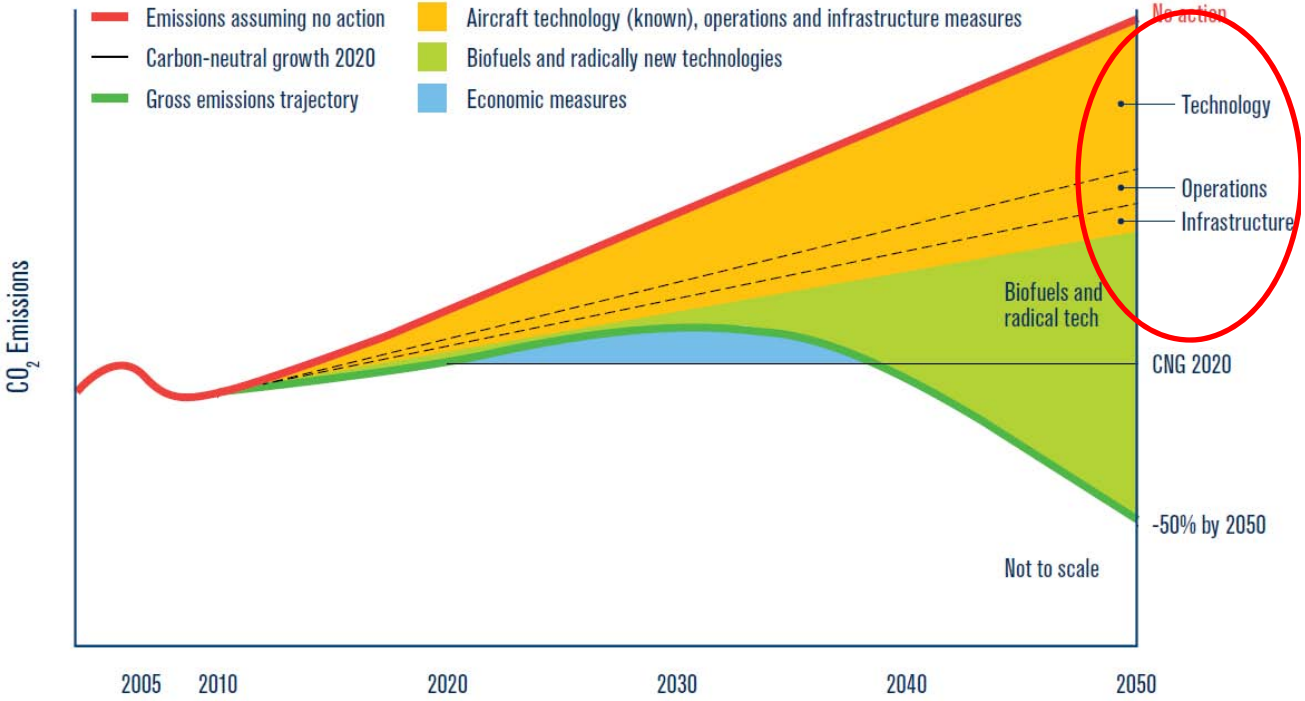
4. Case Study and Results

5. Conclusion and Outlook

Motivation - why formation flight?

- Goals on reducing fuel burn and emissions
  - *The Air Transport Action Group Goals*
    - Improving fuel efficiency by **1.5 %** per annum between now and 2020
    - stabilizing the net carbon emissions from aviation
    - reducing the aviation carbon emissions to **50 %**
  - *IATA FLIGHT PATH 2050 Goals*
    - **75 %** reduction in CO2
    - **90 %** reduction in NOx emissi
    - **65 %** reduction of noise emis

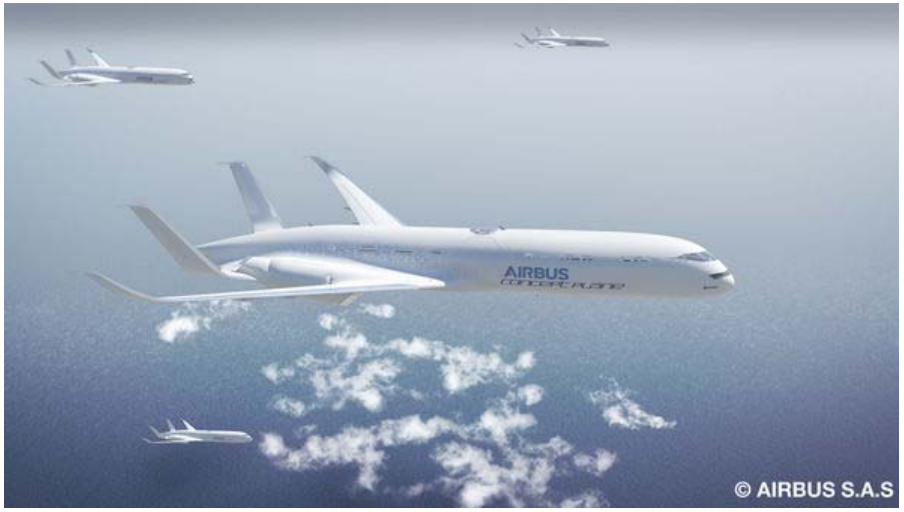
Current technologies alone are unlikely to deliver these emission and fuel burn goals, so other operational and policy measures should also be considered



Source: IATA International Air Transport AssociationTECHNOLOGY ROADMAP 2013

Motivation - why formation flight?

- Formation flight is the operational concept of reducing induced drag due to the upwash effect
  - Originally observed in nature where birds migrate large distances
  - This concept has been adopted for strategic military missions
  - Potential application: Commercial carriers and cargo carriers



Motivation - why formation flight?

- **Results from literature:**
  1. Migrating birds extend their range by up to **71 %** [1]
  2. Trailing a/c C_{Di} reduction, **≈ 60 %** HVM, VLM [2] and **≈ 54 %** CFD [3]
  3. Flight test proven total drag and fuel burn reductions for trailing a/c around **20 %** and **10 %** respectively [4]

- **Problems and challenges for flying in formation:**
  - Trimming
  - Safety
  - Comfort
  - Regulations

FEDERAL AVIATION REGULATIONS

Home > Aviation Regulations > Parts Index > Part 91 > Sec. 91.111 - Operating near other aircraft.

Sec. 91.111 — Operating near other aircraft.

(a) No person may operate an aircraft so close to another aircraft as to create a collision hazard.

(b) No person may operate an aircraft in formation flight except by arrangement with the pilot in command of each aircraft in the formation.

(c) No person may operate an aircraft, carrying passengers for hire, in formation flight.

[1] P B Lissaman and C A Shollenberger. Formation flight of birds. Science (New York, N.Y.), 168:1003–1005, 1970.

[2] William Blake and Dieter Multhopp. AIAA-98-4343: Design, Performance and Modeling Considerations for Close Formation Flight, 1998.

[3] Ning, S. A., Flanzer, T., and Kroo, I., “Aerodynamic Performance of Extended Formation Flight,” Journal of Aircraft, Vol. 48, No. 3, May 2011, pp. 855–865,

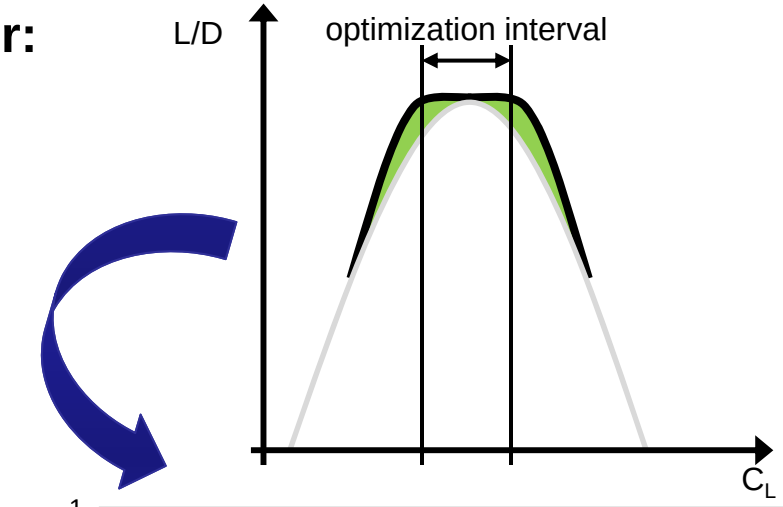
[4] R. J. Ronald, "Flight test techniques used to evaluate performance benefits during formation flight," 2002.

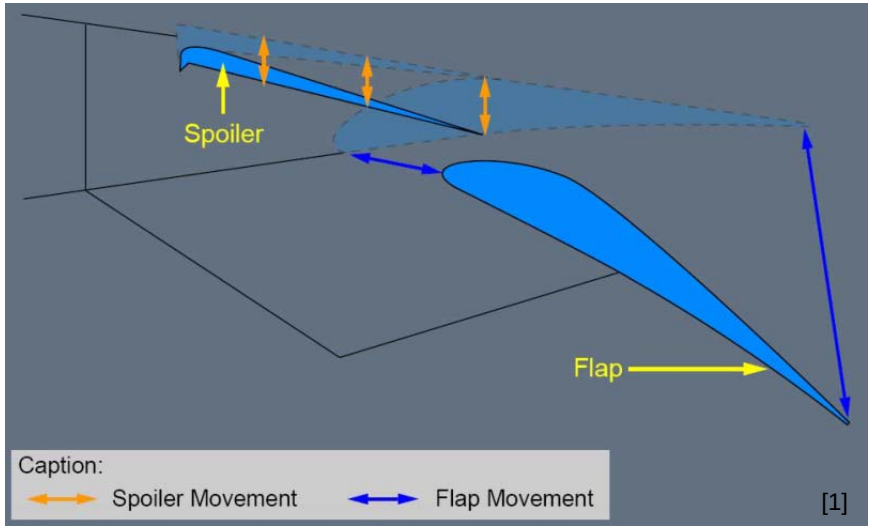
Motivation - why variable camber in formation?

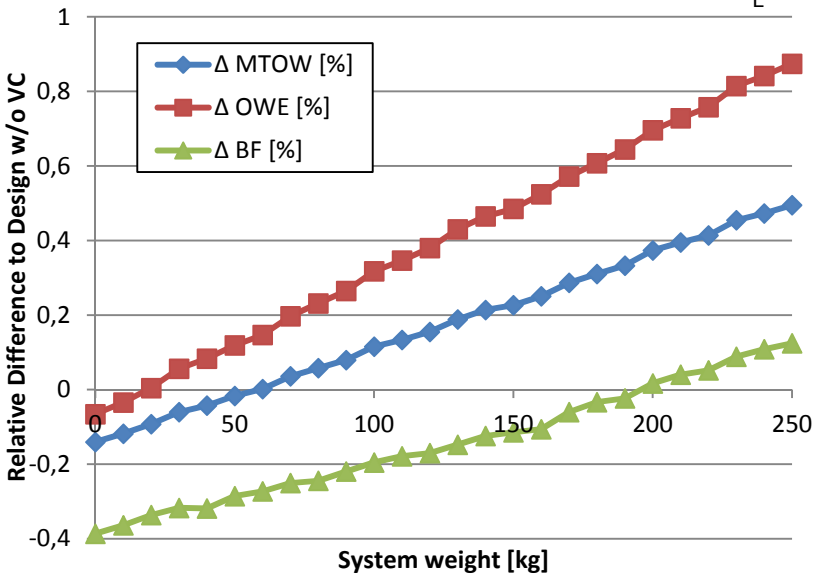
General goals of using variable camber:

The variable camber adapts slightly the flaps deflection (in or out) during the cruise

- **Minimize drag in cruise**







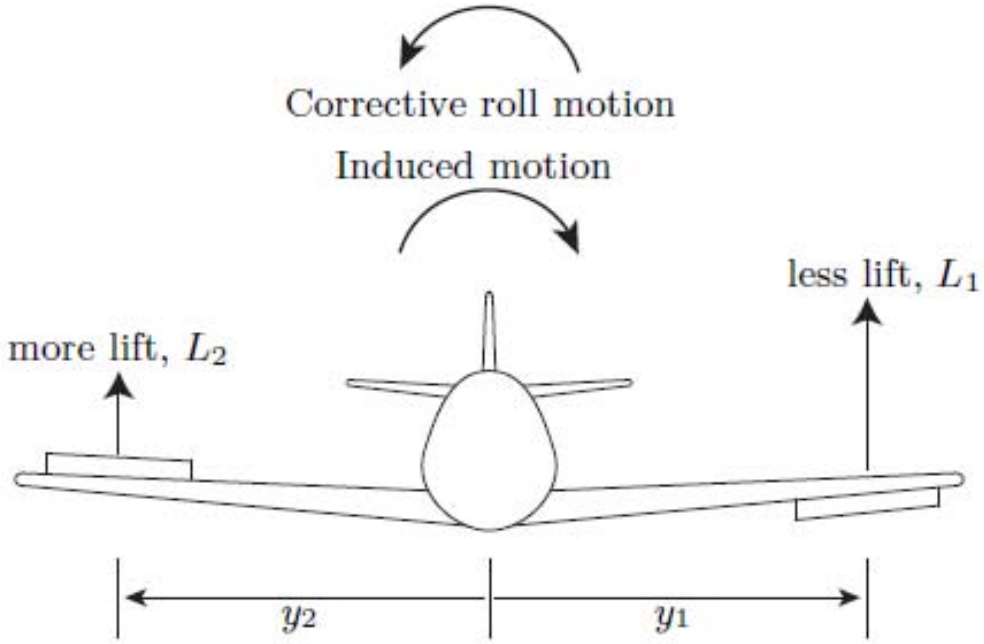
[1] A350-900 Flight Deck and Systems Briefing for Pilots, Flight Operations Support and Services Customer Services Directorate, Oct 2009

Motivation - why variable camber in formation?

General goals of using variable camber:

The variable camber adapts slightly the flaps deflection (in or out) during the cruise

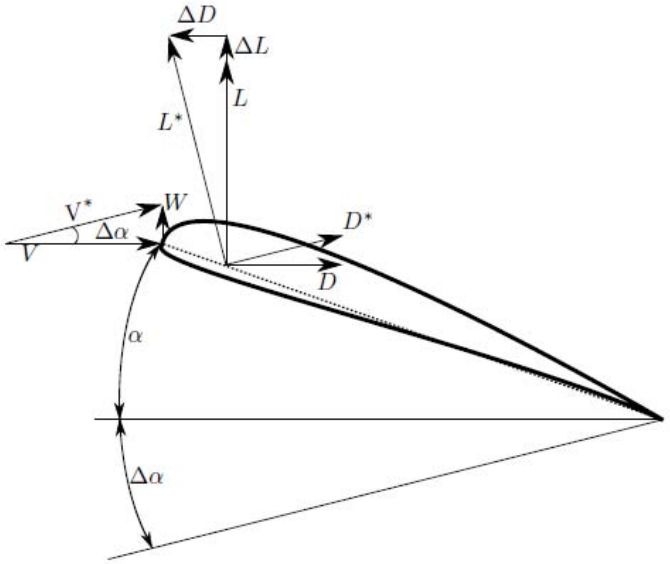
- Minimize drag in cruise
- **Perform an optimized Lateral Trim function.**



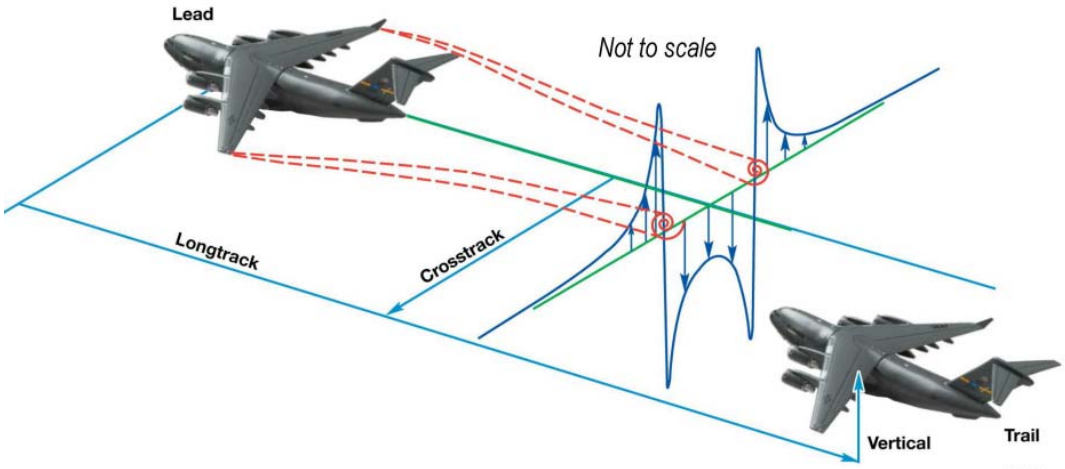
Review of Formation Flight Results at ILR

- **Theoretical Background:**

1. Trailing a/c in **upwash** field of leading a/c
2. Rotation of **lift and drag** due to upwash
3. Reduction in **vortex-induced drag** for trailing a/c
4. Total **drag & fuel burn** reduction for trailing a/c and FF system



Rotation of lift and drag due to up-wash



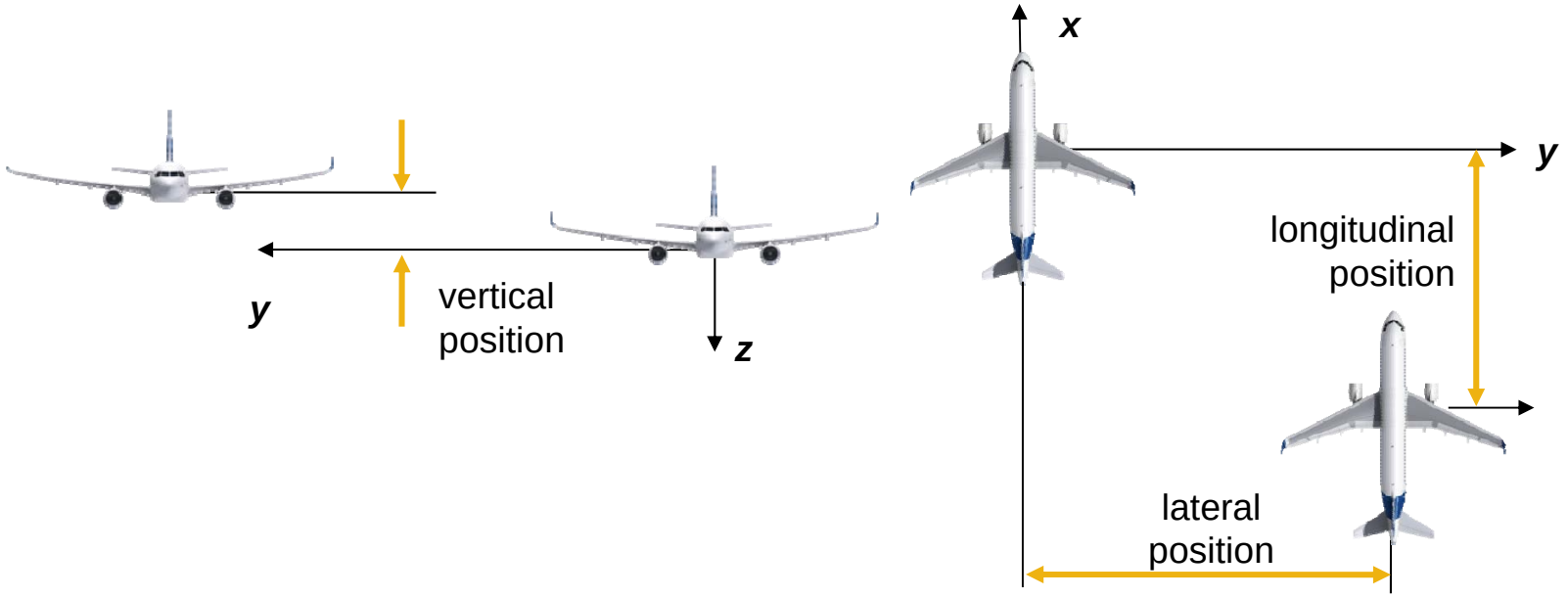
$$\Delta\alpha = \tan^{-1}\left(\frac{W}{V}\right) \approx \frac{W}{V}$$

$$\Delta D \approx \frac{L'W}{V}$$

Reduction of drag

Review of Formation Flight Results at ILR

- **Results of formation flight with two a/c**
  - Definition of relative a/c positions in formation flight (FF)
  - Induced drag reduction of trailing a/c with different relative a/c spacings
  - Comparisons of results from different approaches in literature
  - Trimming influences



Review of Formation Flight Results at ILR

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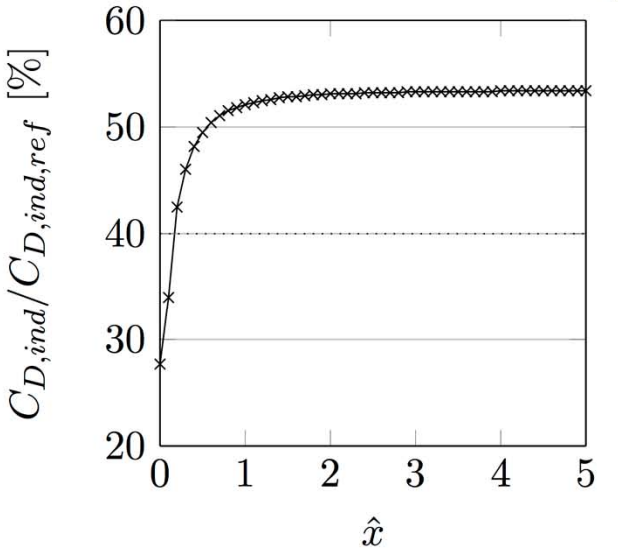
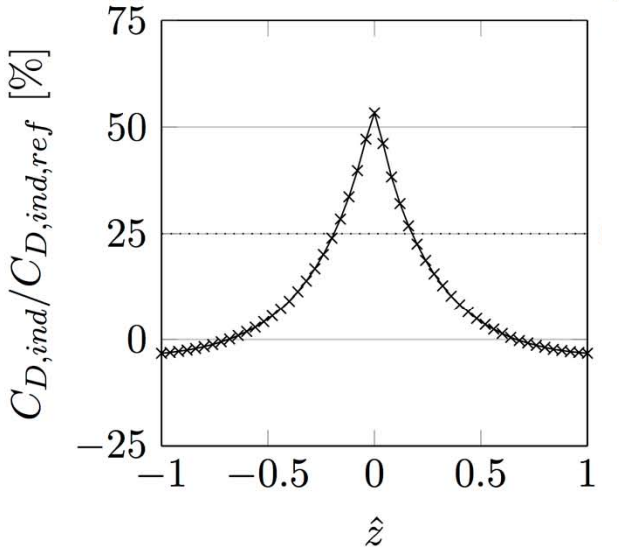


for $\hat{y} = 0.9$ and $\hat{z} = 0$



for $\hat{x} = 3$ and $\hat{y} = 0.9$

Review of Formation Flight Results at ILR

- **Results of formation flight with two a/c**
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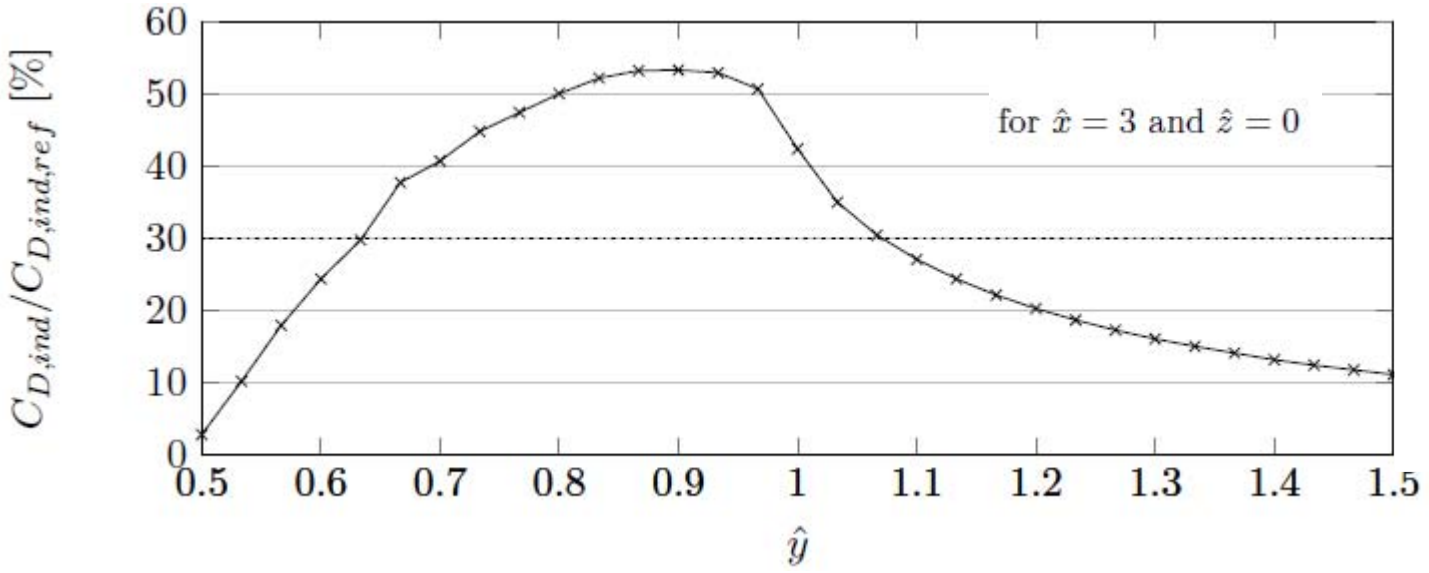

Trailing aircraft spacing parameter dependency of untrimmed two-aircraft echelon formation

Review of Formation Flight Results at ILR

- **Results of formation flight with two a/c**
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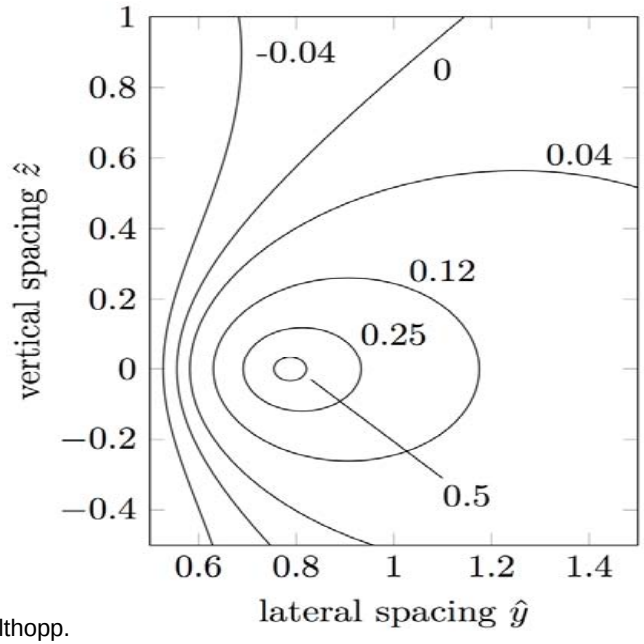
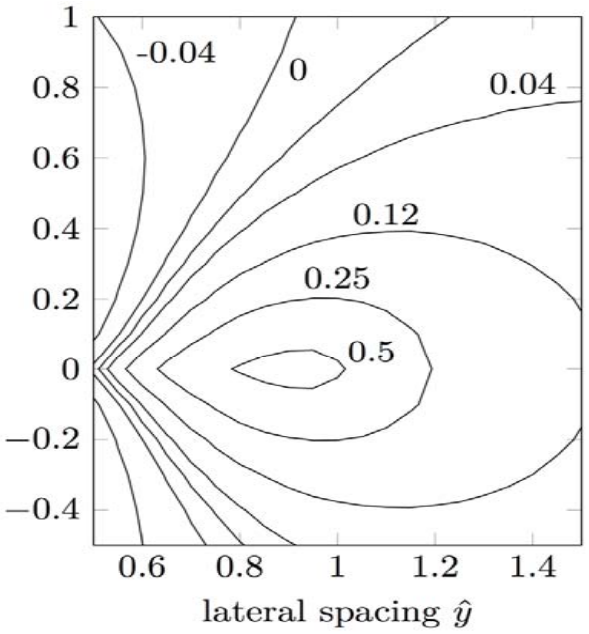


[1]Induced drag reduction calculated by HVM, Blake et al.



Induced drag reduction calculated by VLM , ILR

[1] William Blake and Dieter Multhopp. AIAA-98-4343: Design, Performance and Mod- eling Considerations for Close Formation Flight, 1998.

Review of Formation Flight Results at ILR

- **Results of formation flight with two a/c**
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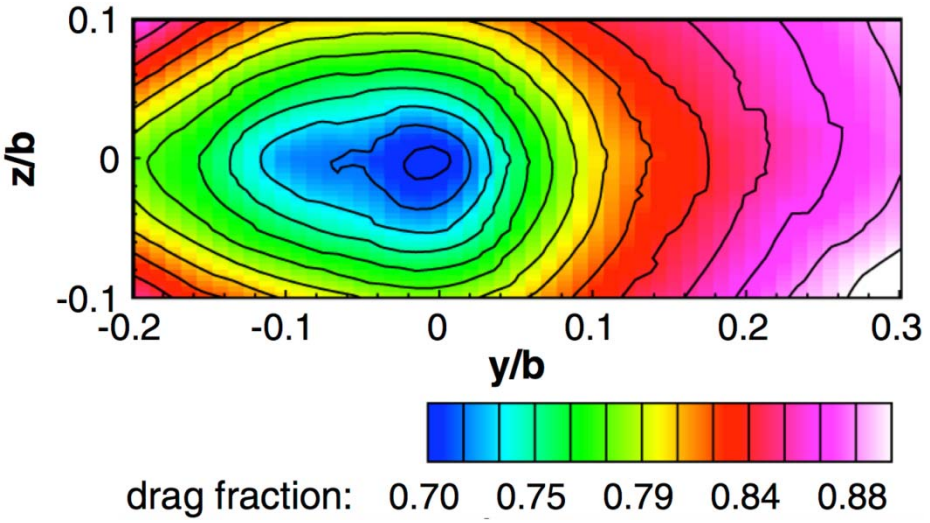
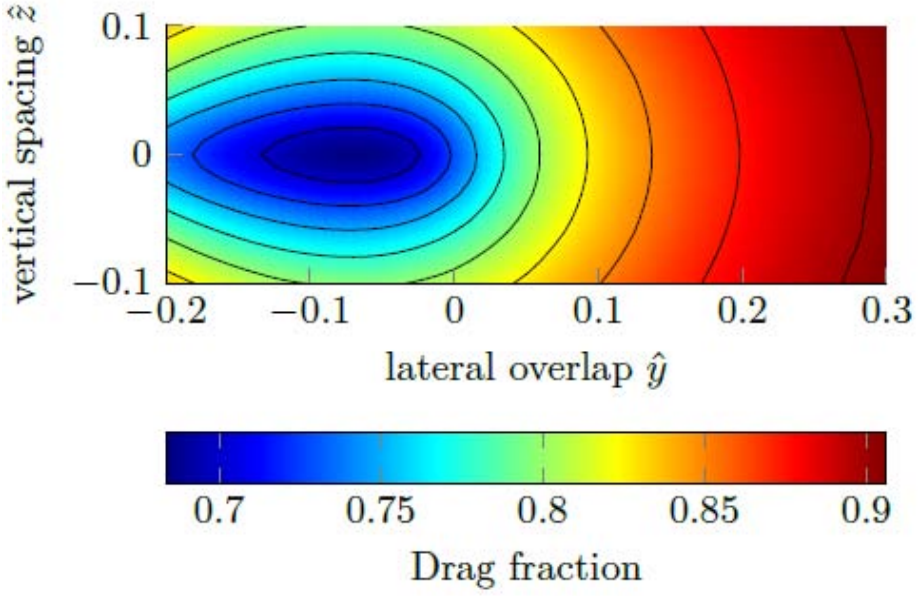


Drag fraction by Kless et al [1], CFD



Calculated drag fraction of trailing rectangle wing

[1] James E. Kless, Michael J. Aftosmis, S. Andrew Ning, and Marian Nemec. Inviscid Analysis of Extended-Formation Flight. AIAA Journal, 51(7):1703–1715, July 2013.

Review of Formation Flight Results at ILR

- **Results of formation flight with two a/c**
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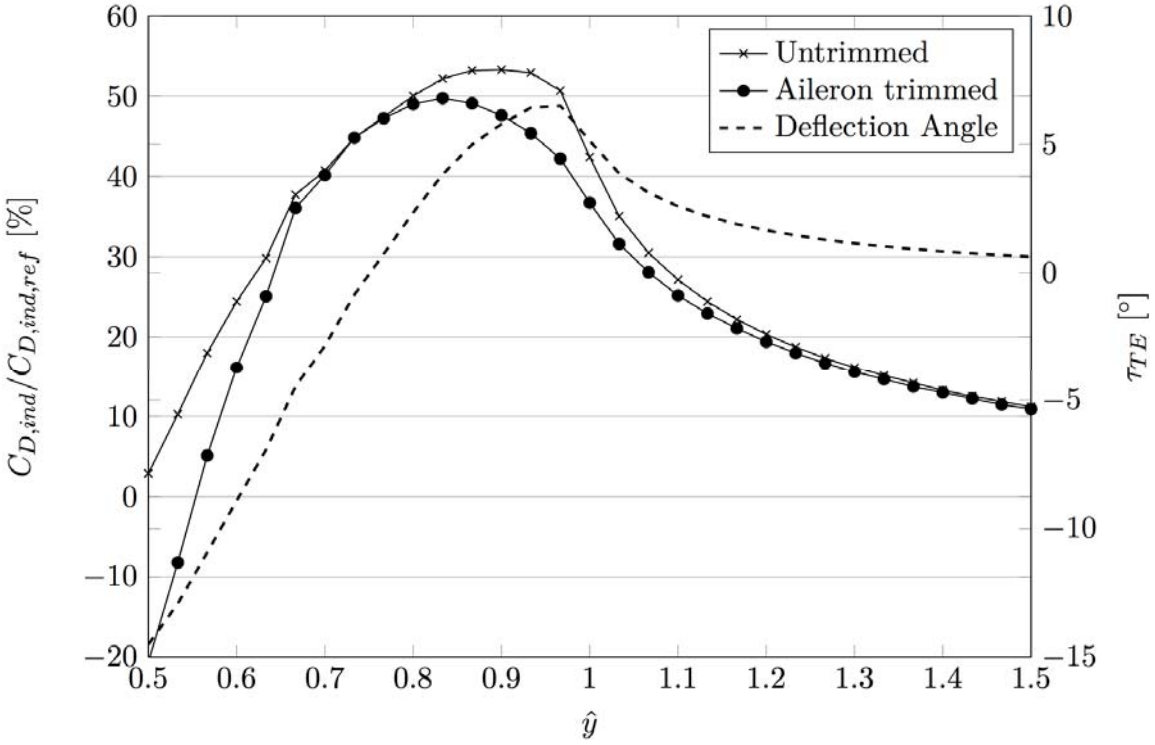
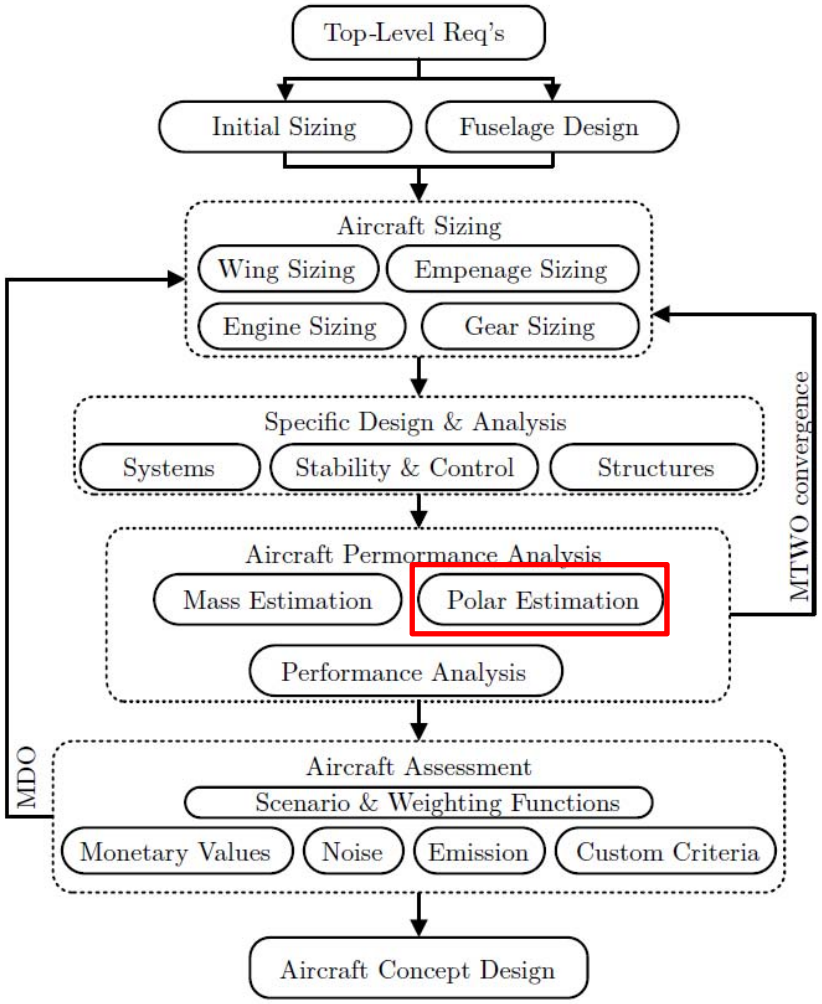


Aileron trimming influence

- Induced drag increase
- Change of the optimal relative positions

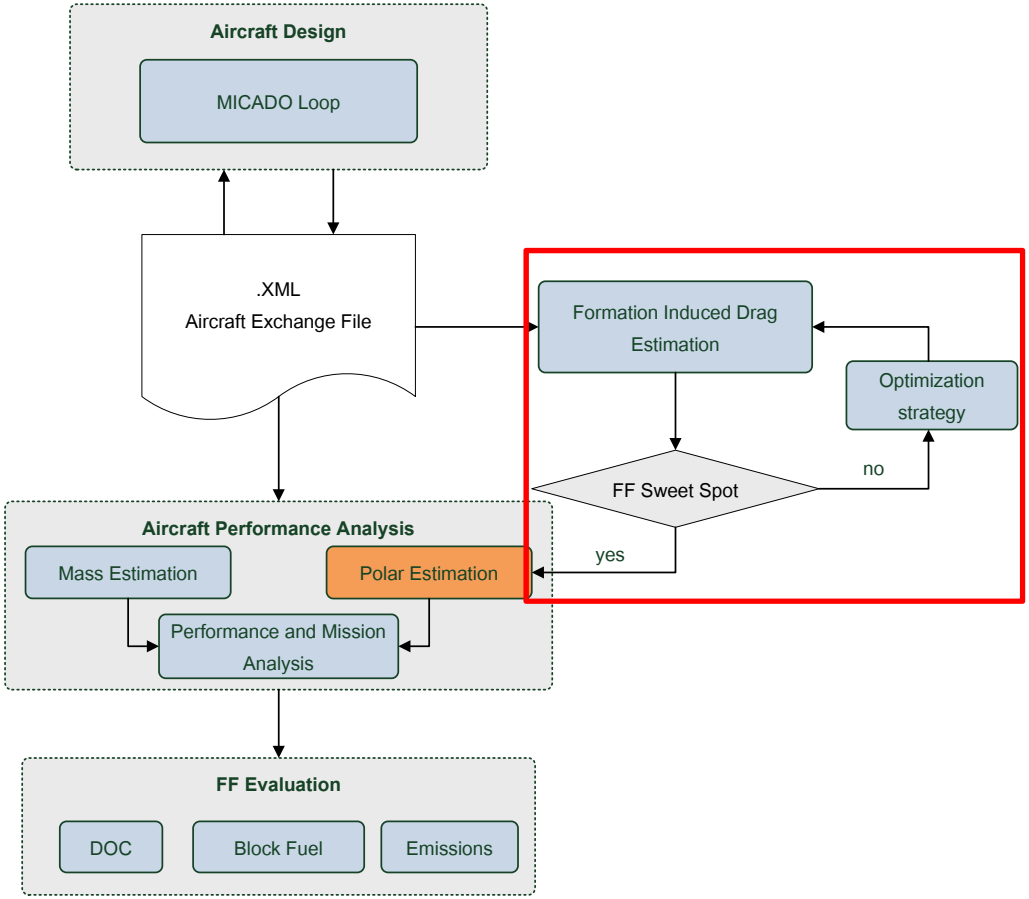
Review of Formation Flight Results at ILR

- **Methods and tools**
  - Multidisciplinary Integrated Conceptual Aircraft Design and Optimization (**MICADO**) Environment
    - ILR a/c design and optimization platform
    - Automated design synthesis with min. user input
    - Fast exploration of wide design spaces
    - Technology integration and assessment
  - Extension of MICADO Aero Module for formation flight calculation



Review of Formation Flight Results at ILR

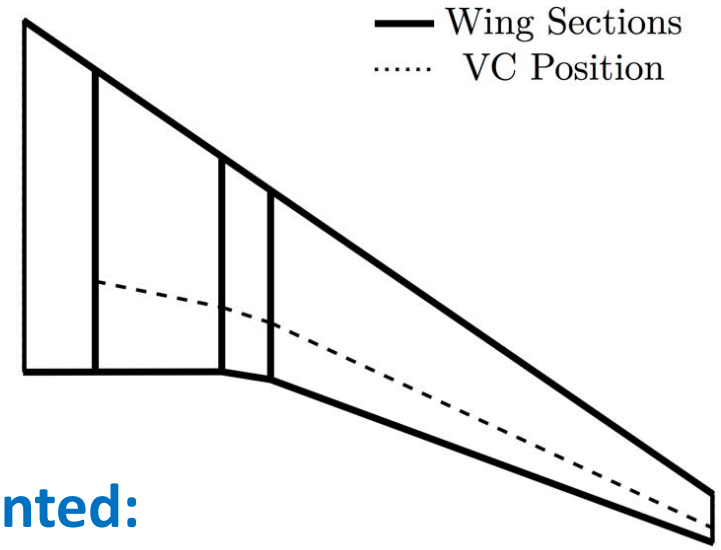
- **Implementation of the tool**
  - Overview of formation flight assessment approach



Variable Camber Concept - Approach

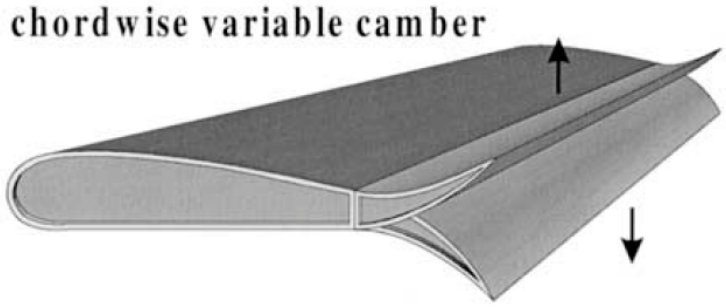
- **Assumptions:**
  - Only trailing edge variable camber considered
  - Rear spar position does not exceed 70 % chord length

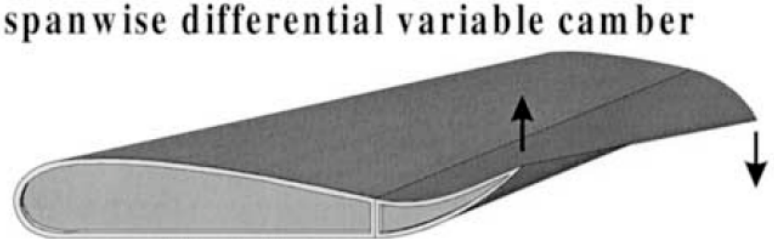
  -> Variable Camber (VC) device with a length of 30 % local chord



- **Two trimming routines were implemented:**
  - Chordwise
  - Spanwise differential

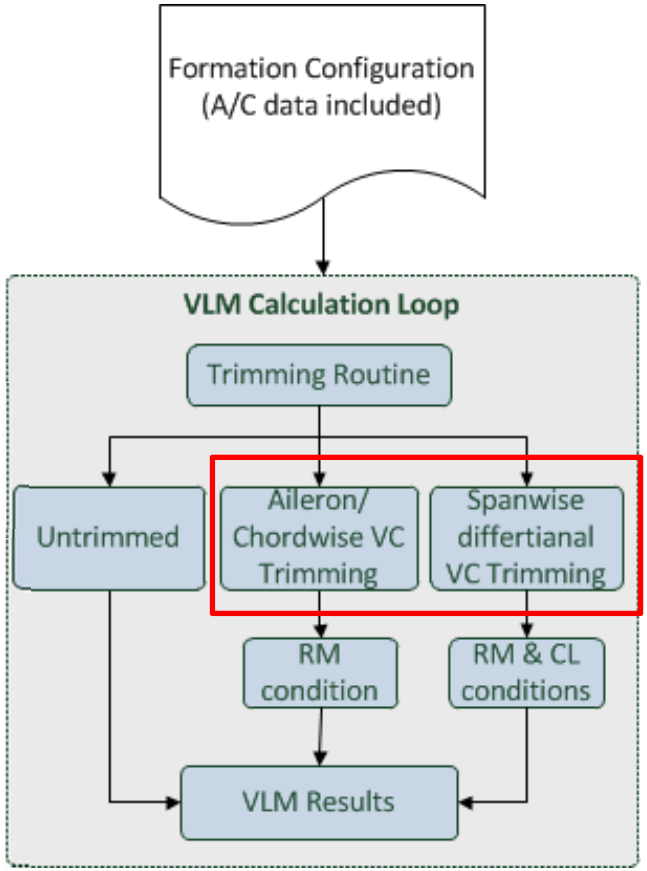
  } camber variation along the wing





Variable Camber Concept - Approach

- **Overall scheme:**
  - Camber variation
  - VLM calculation loop
  - Local C_L value and rolling moment
  - VC trimming routine



Camber variation steps

1. Approximation for camber line change

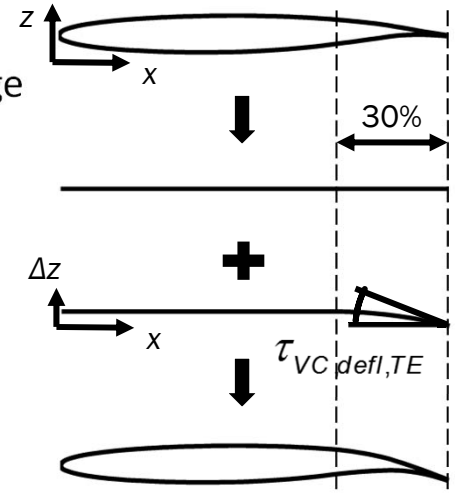
$$\Delta z_{camberline} = F \cdot x^2$$

$$z_{camberline} = z_0 + \Delta z_{camberline}$$

2. Control parameter

$$\tau_{VC,defl,TE} = \tan^{-1}\left(\left.\frac{\partial z}{\partial x}\right|_{x=1}\right)$$

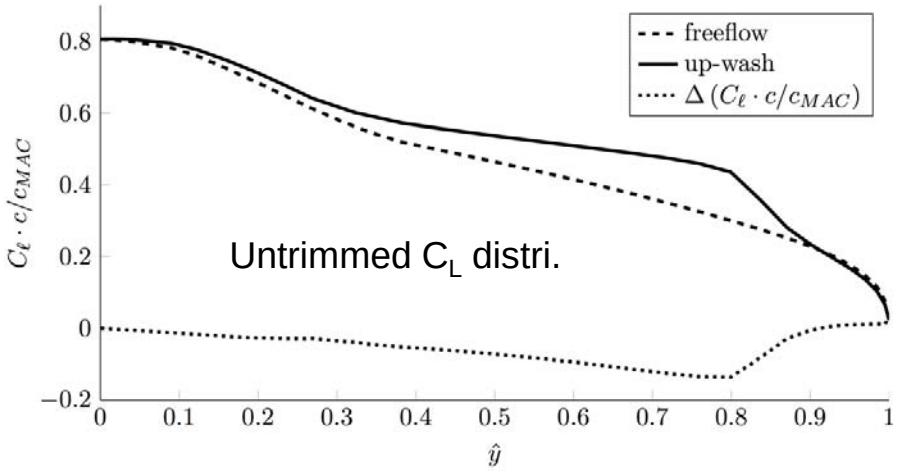
3. Generation of the new airfoil

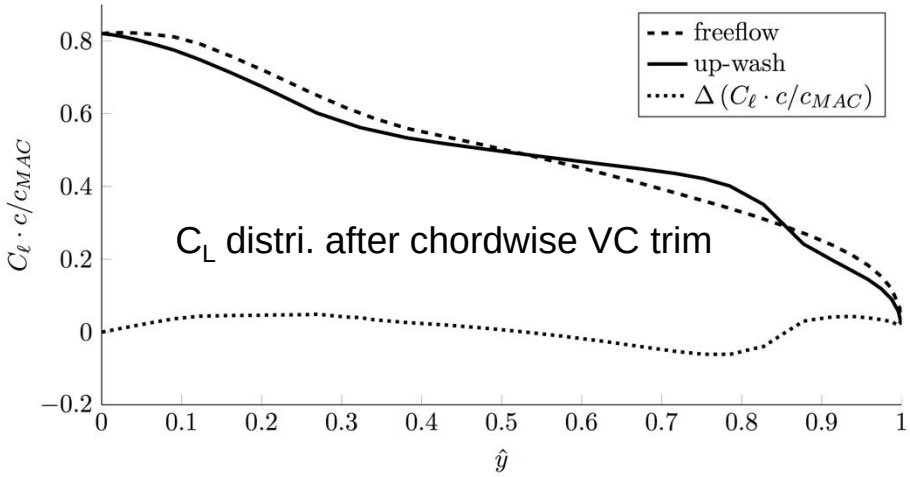


Variable Camber Concept - Realization

VC trimming routine: chordwise

- All section profiles belonging to the VC device are modified uniformly → Single VC deflection angle for all sections
- Iteration criterion is the rolling moment, RM = 0

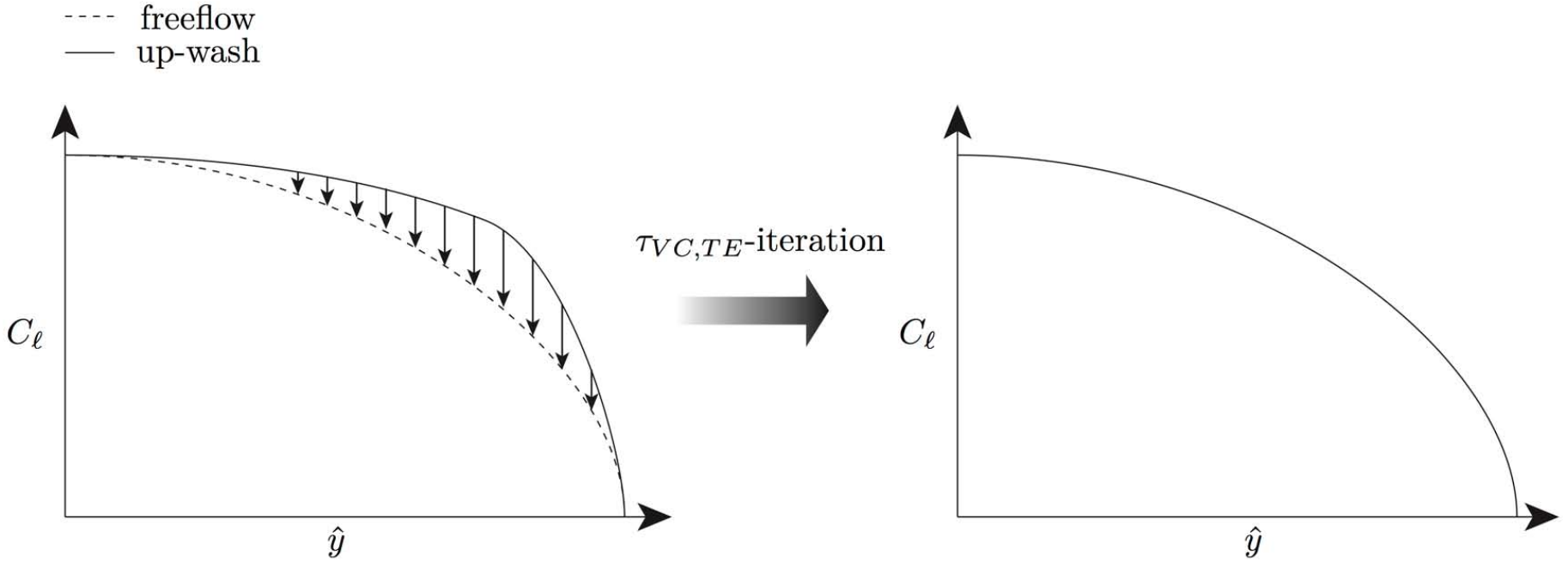




Variable Camber Concept - Realization

VC trimming routine: spanwise differential VC

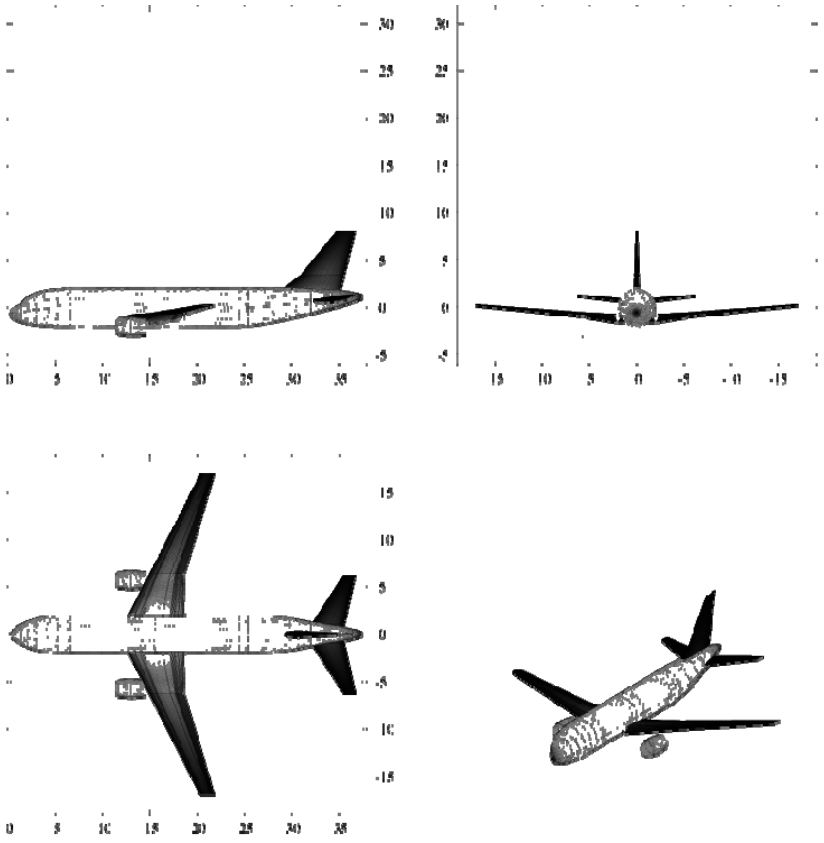
- ❑ Assumptions:
  - Minimal induced drag of aircraft under design flight conditions
  - Formation flight has no effect on the wing exposed to the free flow
- ❑ Iteration criteria are the rolling moment and local C_l, RM = 0 & $\Delta C_l = 0$



Case Study and Results

CSR-01 reference aircraft data:

- Key aircraft characteristics of reference a/c
  - *Design range: 2500 NM*
  - *Design payload: 17000 kg*
  - *Max. payload: 20000 kg*
  - *MTOW: 77000 kg*
  - *Cruise Mach number: 0.78*
  - *Initial cruise altitude: 33000 ft*
  - *Wing area: 122.4 m^2*
  - *Wing span: 34.04 m*



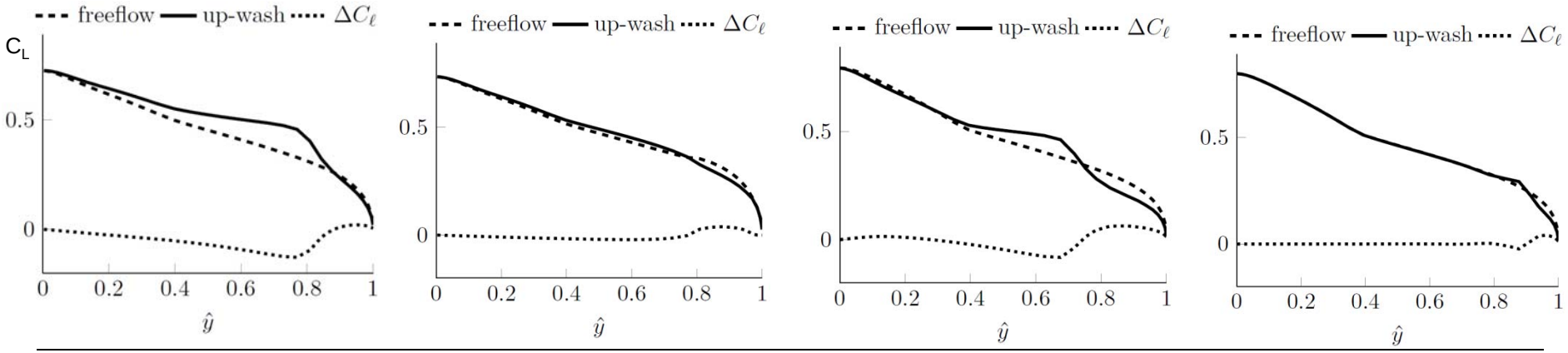
- Two CSR-01 a/c in formation
- Design parameters of the CSR-01 unchanged
- Fuel burn reductions calculated within MICADO, with a corrected drag polar for formation flight

Case Study and Results

Case study of CSR-01 in formation – Drag reductions of different trimming methods

Trimming case	Optimal lateral spacing (ref. b)	C_{Di} reduction (%)	Calculation condition
			$C_L = 0.5$ C_{Di} solo = 0.01368

Induced drag reduction of different trimming methods



Case Study and Results

Case study of CSR-01 in formation – fuel burn reductions of different trimming methods

- Resulting fuel burn reductions:

Trimming case		Block fuel (2500 NM)	Fuel burn reduction
Solo flight		14703 kg	-
Formation Flight	Untrimmed	12560 kg	14.58 %
	Aileron trim	12686 kg	13.71 %
	Chordwise VC trim	12640 kg	14.03 %
	Spanwise VC trim	12713 kg	13.53 %

- Aileron trim results do not account for parasite drag due to trim and wave drag
- These erode inviscid drag savings by 15 % under transonic flight conditions [Kless et al]
  → fuel burn reduction also eroded
- For VC trimming no additional drag is generated

Conclusion and Outlook

Summary and Conclusions:

- Preliminary investigations showed large potentials for FF
- Development of variable camber concept for formation flight
- Integration of two variable camber approaches for lateral trimming
- Evaluation of the proposed VC methods at the preliminary aircraft design level

→ **Chordwise VC can slightly enhance the trim efficiency**

→ **Spanwise differential VC showed some drawbacks in terms of drag savings**

Outlook:

- Enhancement of the mathematical model of camber variation
- Iteration at the whole aircraft design process
- High fidelity approach validation of VC trimming results

Thank you for your attention!

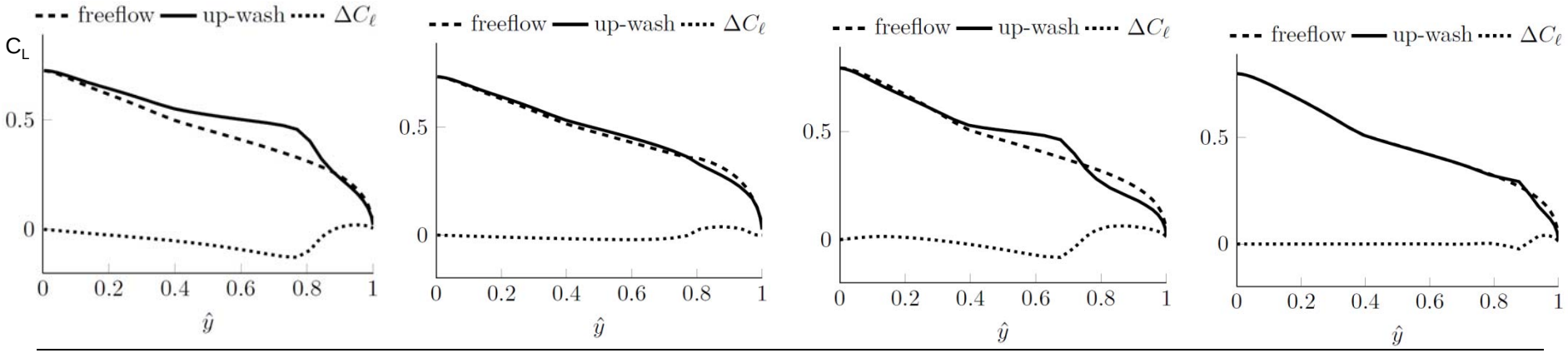
Questions?

Case Study and Results

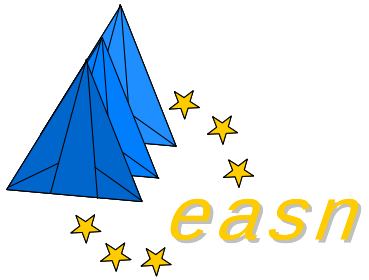
Case study of CSR-01 in formation – Drag reductions of different trimming methods

Trimming case	Optimal lateral spacing (ref. b)	C_{Di} reduction (%)	Calculation condition
Untrimmed	0.9	53.28	$C_L = 0.5$ C_{Di} solo = 0.01368
Aileron trim	0.825	49.21	
Chordwise VC trim	0.875	50.60	
Spanwise VC trim	0.95	48.32	

Induced drag reduction of different trimming methods



4th EASN Association International WORKSHOP on Flight Physics and Aircraft Design

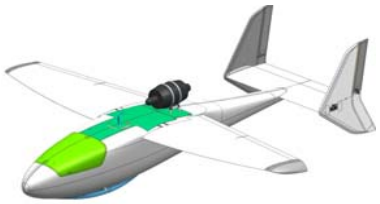


Design challenges for novel concept of highly manoeuvrable flying target

Zdobyslaw Goraj, Andrzej Frydrychewicz, Marek Malinowski

Warsaw University of Technology, Poland

Aachen, 27th - 29th October 2014



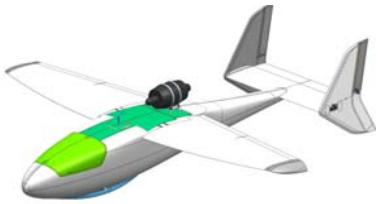
Introduction

1. **Flying targets are widely used by military forces for training in different test ranges, different countries for many years;**

2. **This paper is focused on the selected design challenges associated to optimisation of a Jet Aerial Target being tackled within a research grant (Jet Air Targets, 2012) supported by National Centre for Research and Development;**

3. **Main design goals include repeatability, longer endurance and manoeuvrability;**

Selected Flying Targets used in Poland



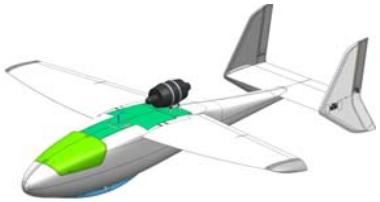
Configuration layout (1/4)

1. High wing configuration improves lateral stability and decreases the probability of wing damage at belly landing;

2. Asymmetric, relatively thin wing section (NACA 1410) decreases aerodynamic drag at flights with higher speeds;

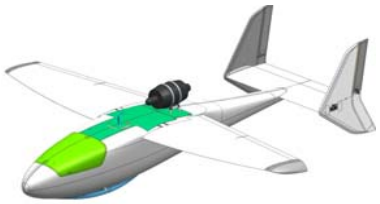
3. Application of flaps and ailerons, which can be used as flaperons, decreases the stall speed and improves the safety aspects at take-off and landing;

4. Half-elliptic wing shape and the optimised wing tips (winglets) will minimise the induced drag;



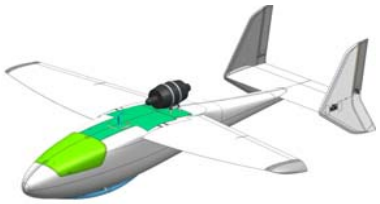
Configuration layout (2/4)

5. Placement of the control actuators (servos) on the ventral side of the wing and horizontal tailpalne decreases the aerodynamic interference between various aircraft components and improves aircraft performance;
6. Monocoque structure of the fuselage and the integral fuel tank create a compact, stiff and light design of small dimensions and relatively low wet surface what results in lower aerodynamic drag;
7. Access to the on-board equipment is easy through the holes in the fuselage, normally closed in the flight with 2 covers. These holes of small diameters have negligible influence on the state of stress and stain and from the other side make possible a very easy access to the interior of the fuselage, what can not overestimated in the field conditions during flight tests;



Configuration layout (3/4)

8. Engine externally attached to the dorsal part of fuselage makes an easy access to the engine control equipment and protects in the most of cases against damages and different contamination when landing;
9. The ventral skid plays a protecting function during landing. A streamlined shape of this skid increases the aerodynamic drag only slightly. Easy and quick replacement of this skid is possible when it is damaged in landing and makes it possible to have aircraft ready for successive flight, even if belly landing was hard;
10. H-shaped empennage protects vertical tail and rudder against exhaust gas of high temperature. Simultaneously, H-shaped empennage is enough flexible to install either one bigger engine or two smaller engines on the dorsal part of the fuselage;

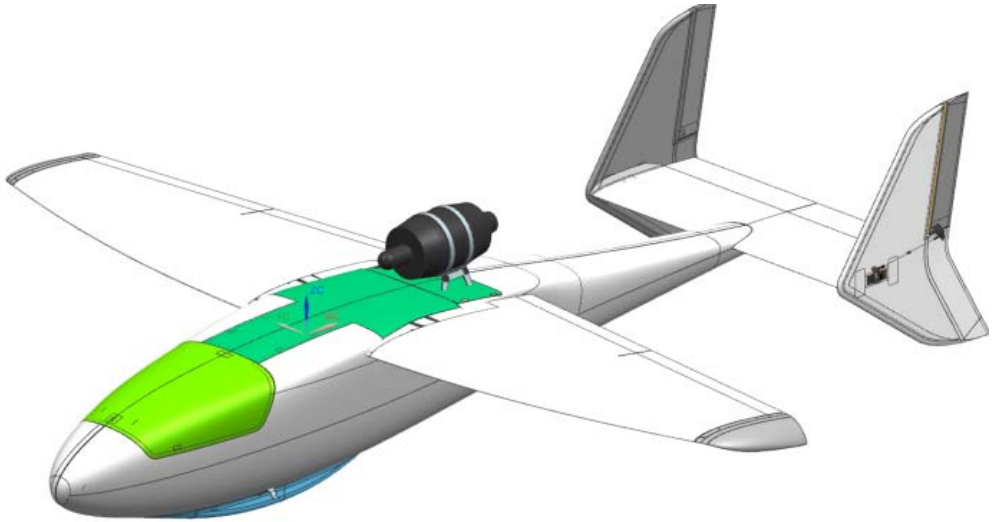


Configuration layout (4/4)

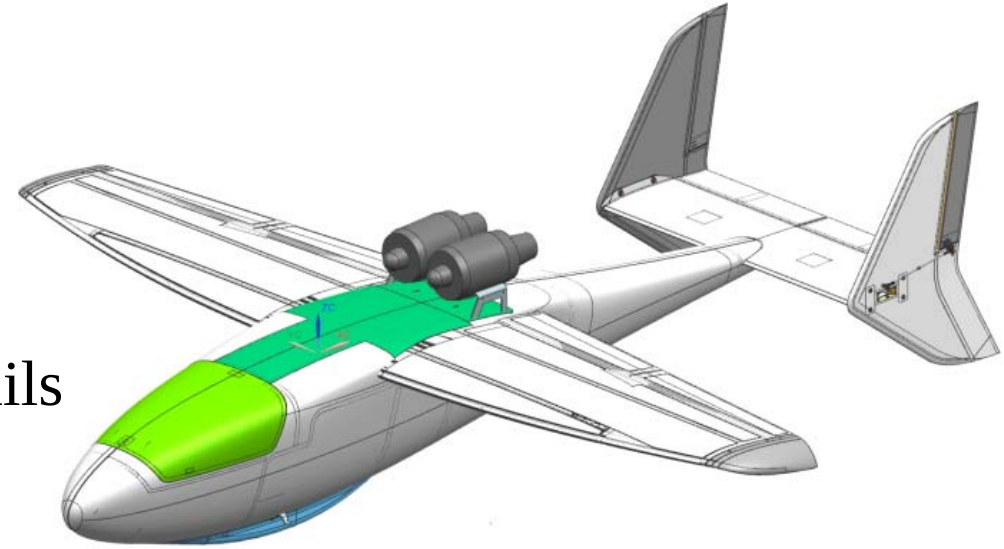
11. Vertical tailplane, especially its ventral part, can be partly or fully damaged during landing without damaging of horizontal part of empennage or fuselage. A very simple way of attachment between horizontal and vertical components of empennage makes it possible to manufacture a sufficient number of spare items at a moderate production cost and replace them at the field conditions;

12. Elevator consists of 2 independent parts what increases its reliability when it is partly blocked.

Power unit



single, more efficient but also more risky when engine fails



and double, less efficient but less risky if one of 2 engines fails

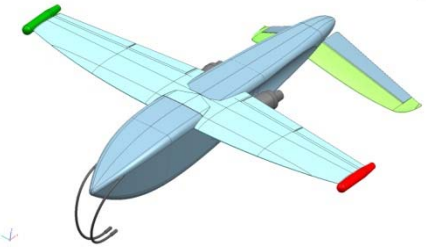
On-board equipment (case of single engine)

1. **Autopilot integrated with navigation and communication modules;**
2. **Control system together with receiver/emitter module for remote control;**
3. **Energy supply unit;**
4. **JET engine together with control module and fuel system;**
5. **Recovery system including main and auxiliary parachutes.**

Main on_board equipment

Equipment name	Weight [kg]	Number of items
On-board computer	0,7	1
Radiomodem SATEL SATELLINE 3AS	0,25	1
Anntena GPS	0,07	1
Anntena for radiomodem	0,06	1
Receiver RC including main board	0,05	1
Serwo Hitec HS-7980TH	0,08	6
Serwo Hitec HS-7955TG	0,07	2
Panel of switches	0,15	1
Cables	1,0	1
Package 7S	1,9	1
Power board	0,2	1
Pump with filter	0,25	2
Venting container BVT	0,14	1
Pump JETCAT	0,1	1
ECU	0,11	1
JETCAT P400-RX	3,65	1
Auxiliary parachute	1,6	1
Main parachute	0,3	1
All together	**10,68**	25

OCP-JET-1-2013; Weight breakdow

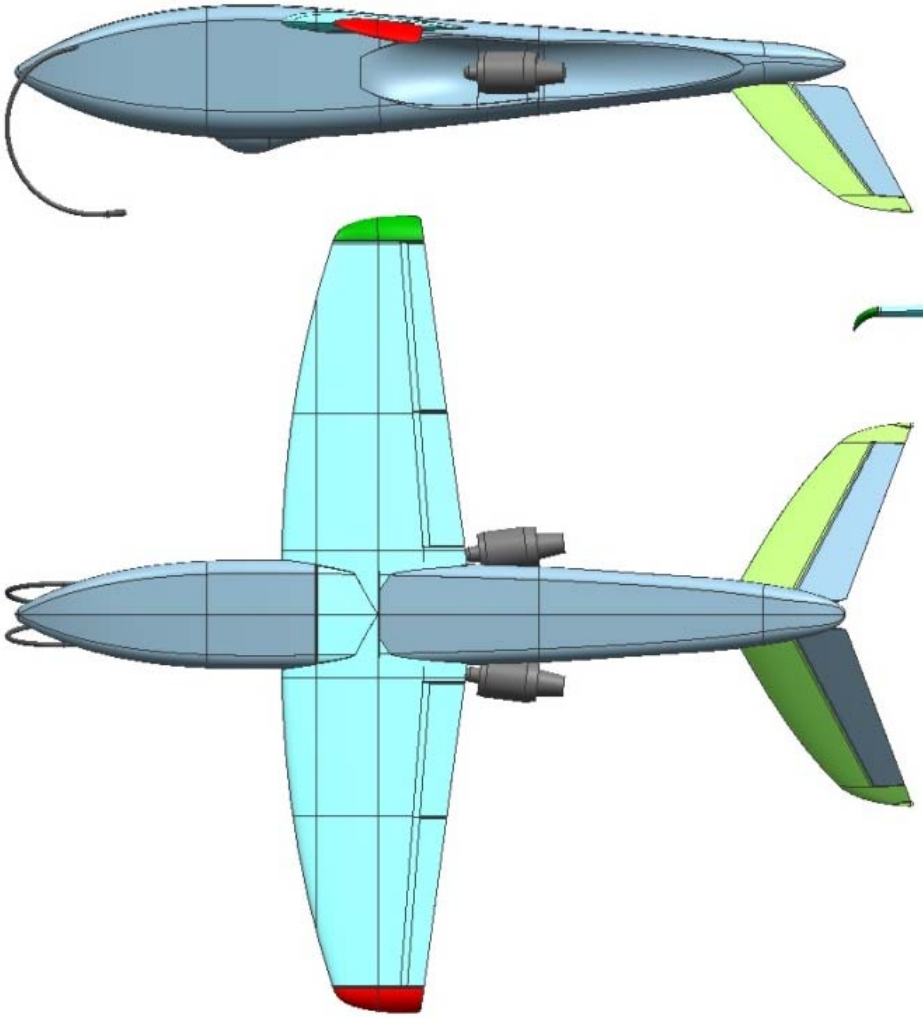


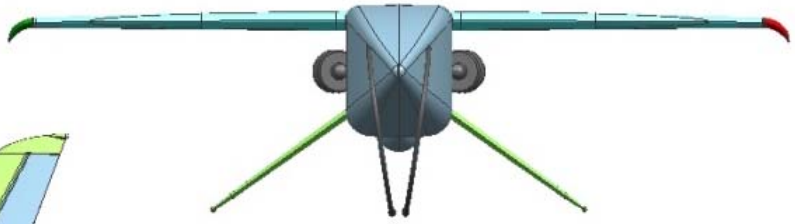
Structure	***–***	***15 kg***
Main on-board equipment	***–***	***11kg***
Structure + Main on-board equipment	***–***	***26 kg***
Mission equipment (payload)	***–***	***9 kg***
Structure + all on-board equipment	***–***	***35 kg***
Fuel per 1 flight hour	***–***	***40 kg***
MTOW	***–***	***80 kg***

Restriction:

In the initial phase of testing the fuel weigth will be limited to 25 kg and MTOW to 60 kg

Initial version of OCP-JET-2 with inverse V-tailplane

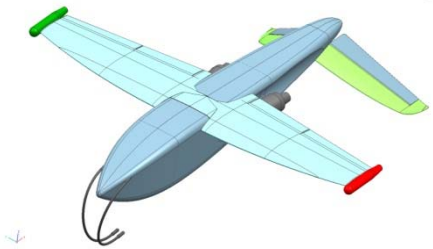




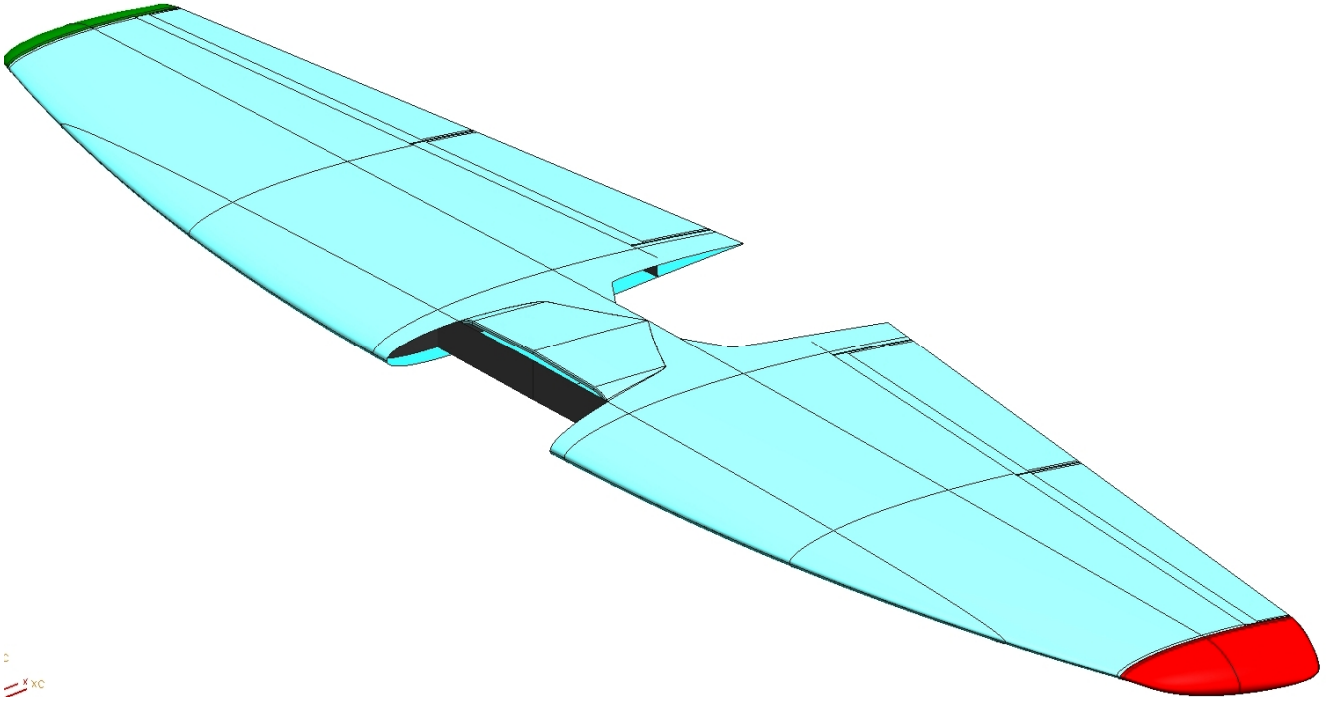
Technical Data:

Wing span	**–**	***350 mm***
Length	**–**	***2750 mm***
Wing gross Area	**–**	***1,05*** m^2
Wing aspect ratio	**–**	***5,3***
Fuel tank capacity	**–**	***90 l***

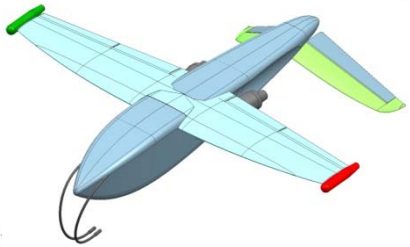
OCP-JET-1-2013



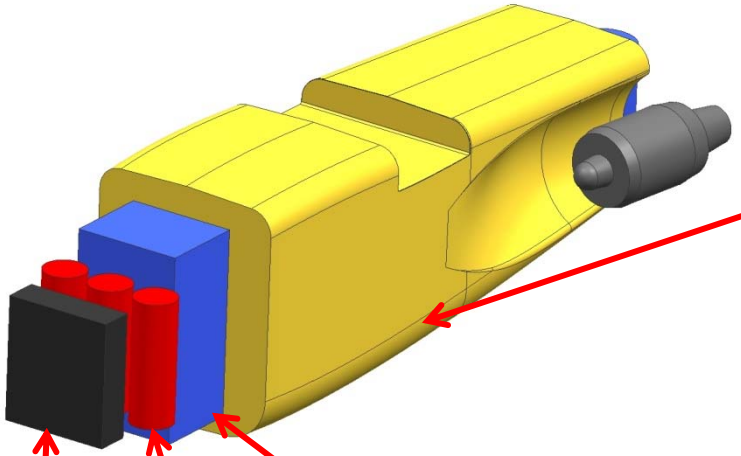
Wing section	**–**	***NACA 1410***
Wing incidence	**–**	***2^0***
Wing torsion	**–**	***$-1{,}5^0$***
Planform shape	**–**	***half-elliptic***

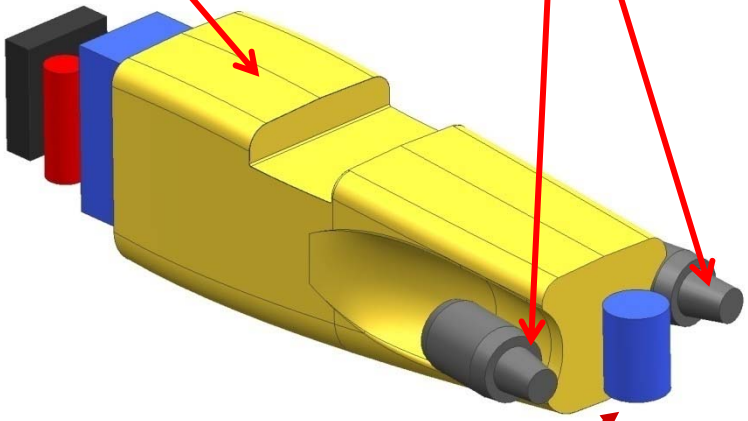


OCP-JET-1-2013



How payload is distributed in fuselage:





Fuel (90 l)

2 engines

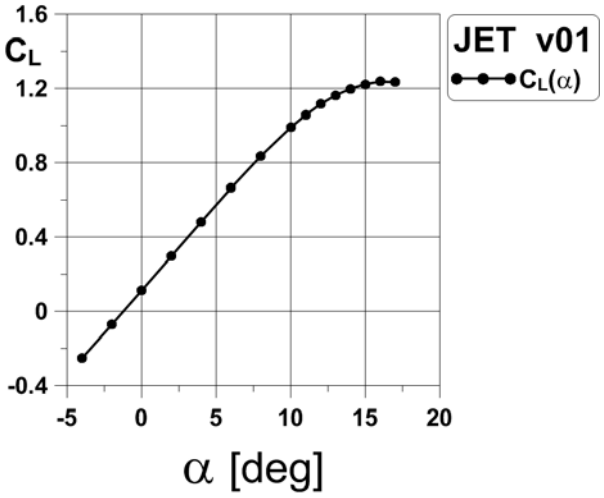
Batteries

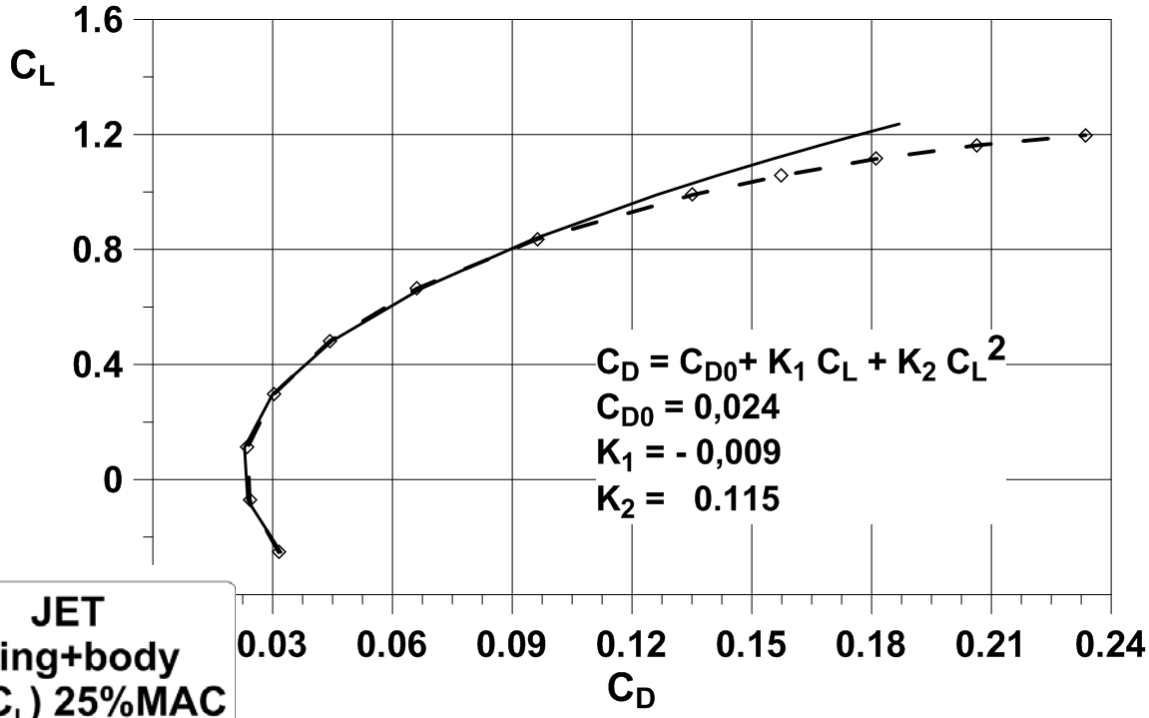
Autopilot

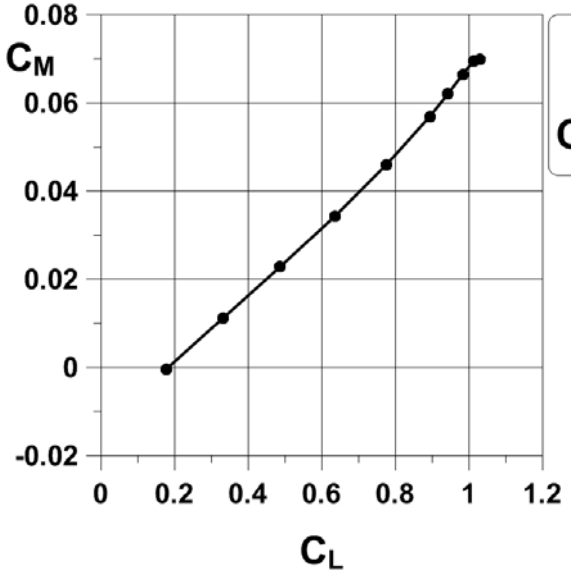
Parachute for landing in emergency

Breaking parachute

Aerodynamic characteristics - MGAERO

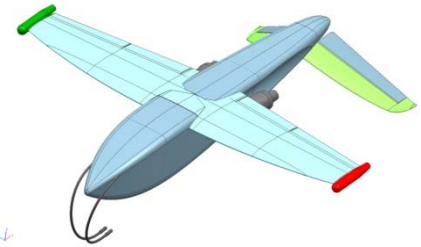


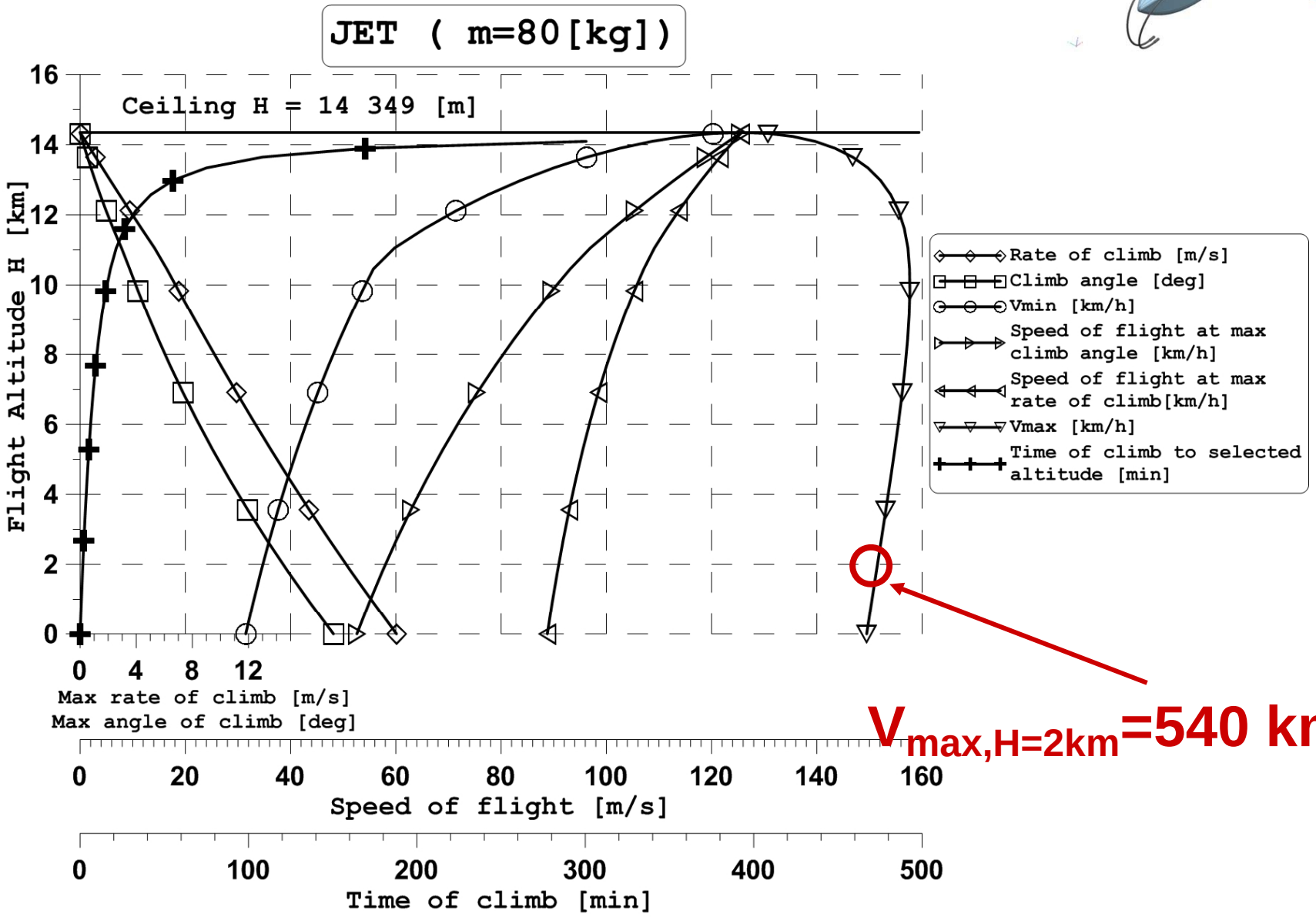




JET
wing+body
$C_M(C_L)$ 25%MAC

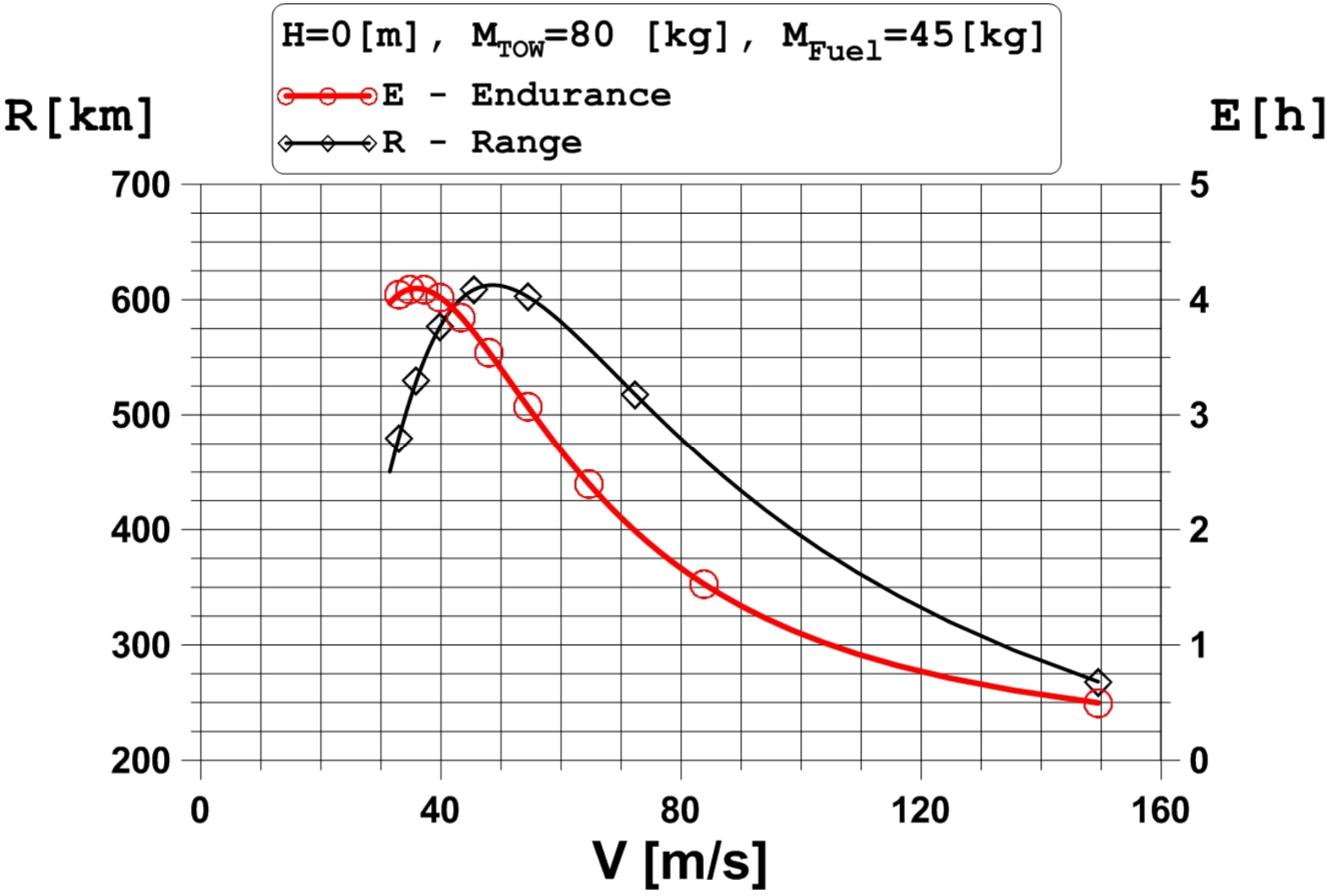
Performance (MTOW=80

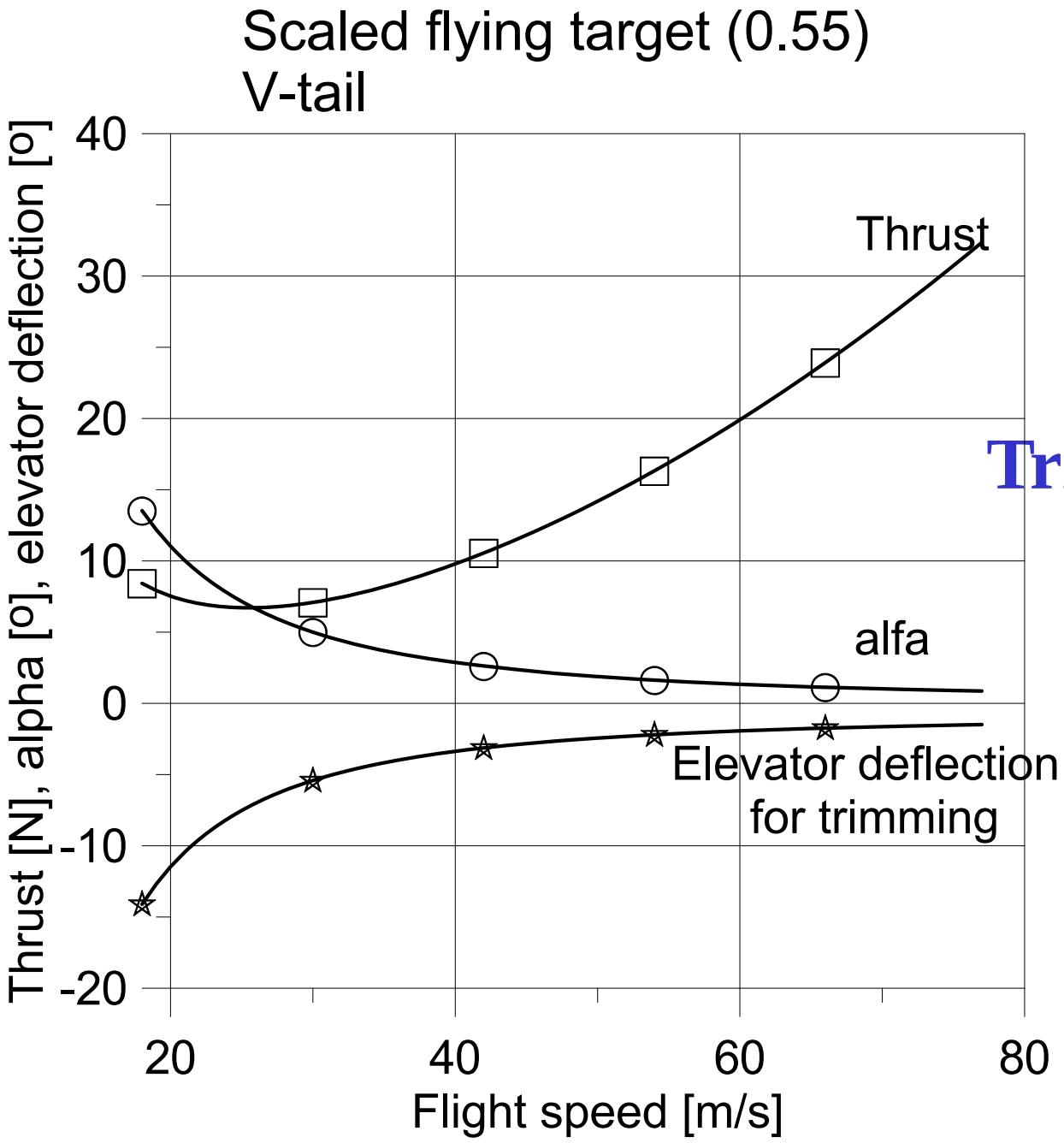




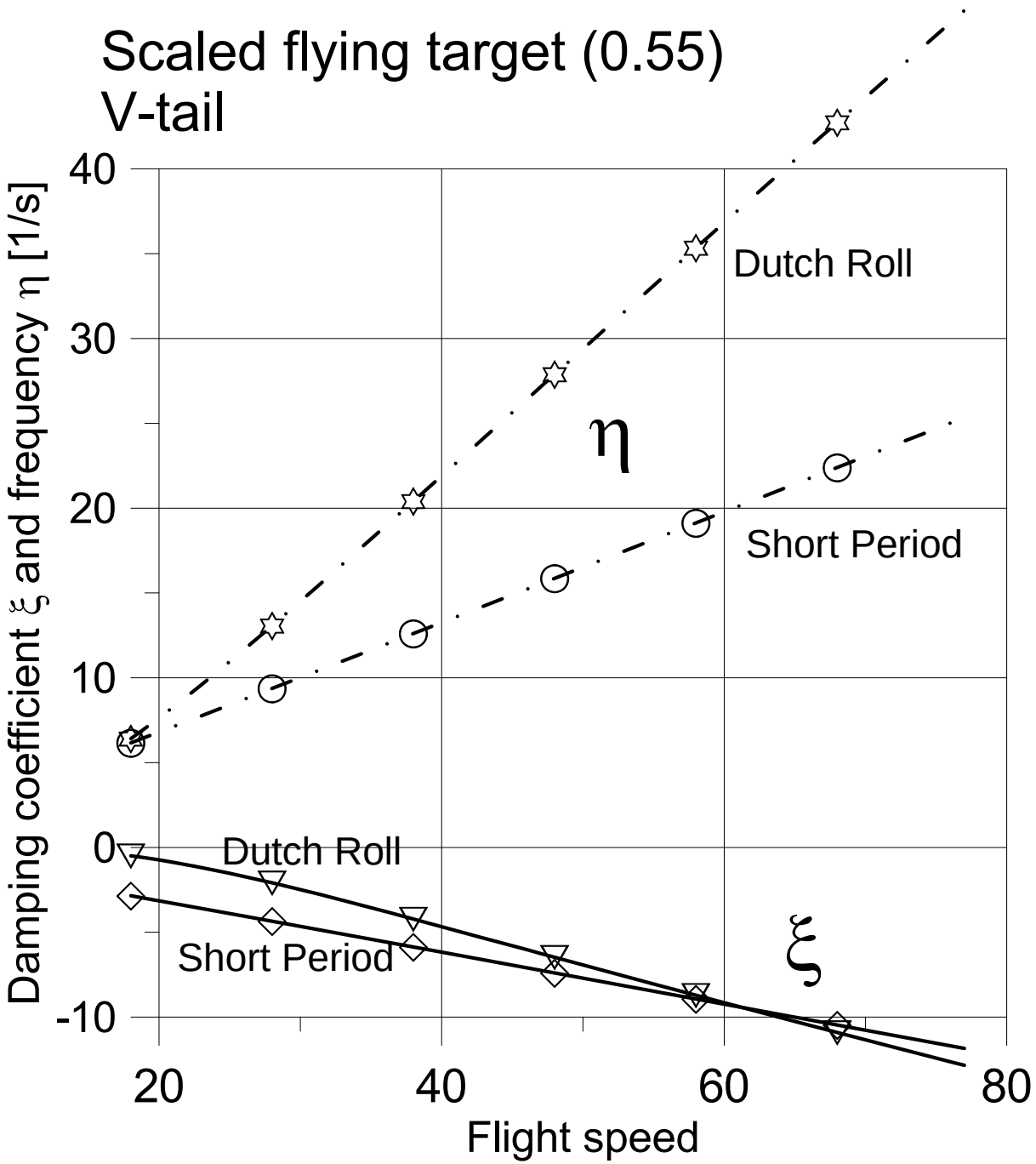
$V_{max,H=2km}$=540 km/h

Endurance and range, MTOW= 80 kg

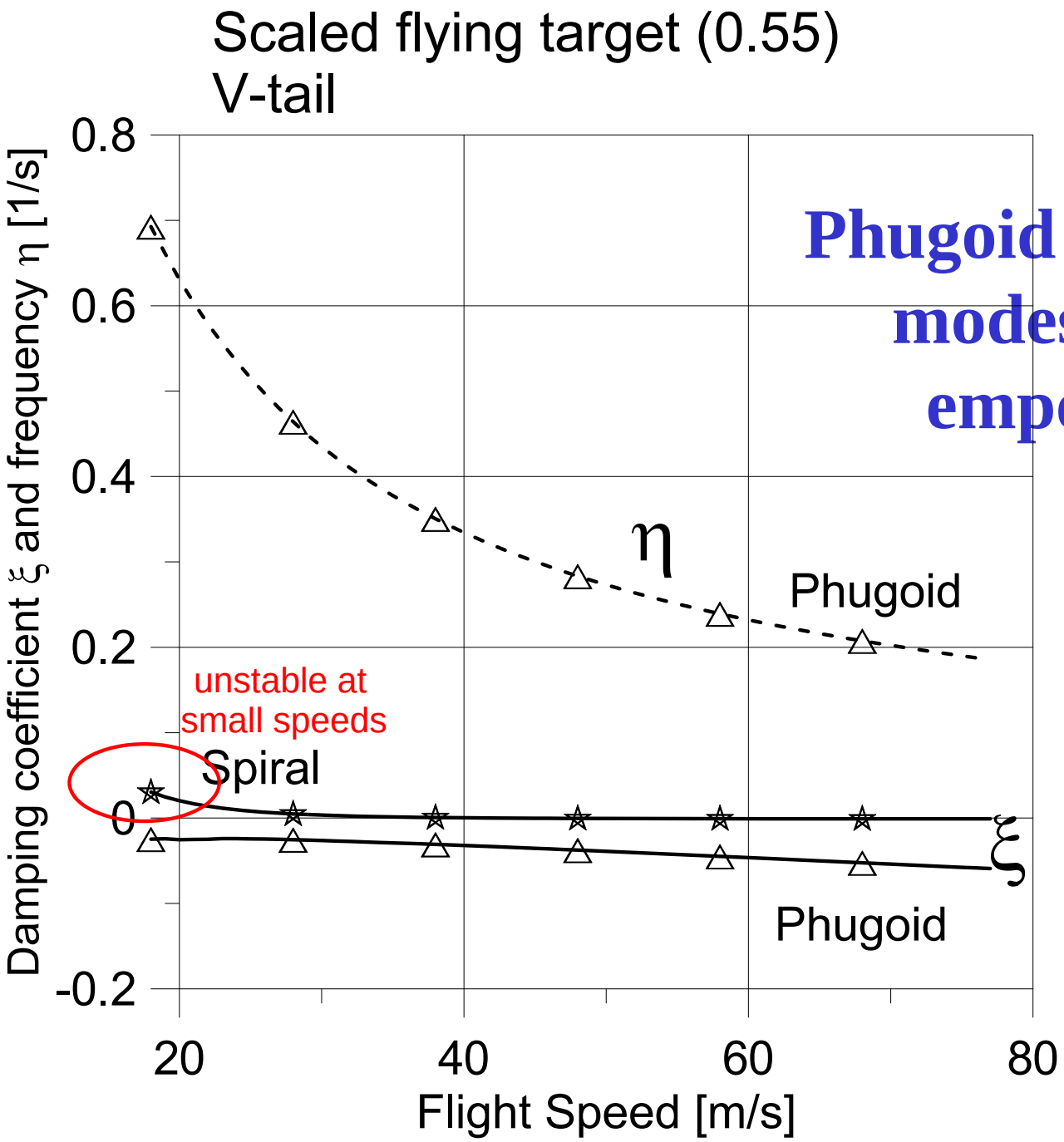




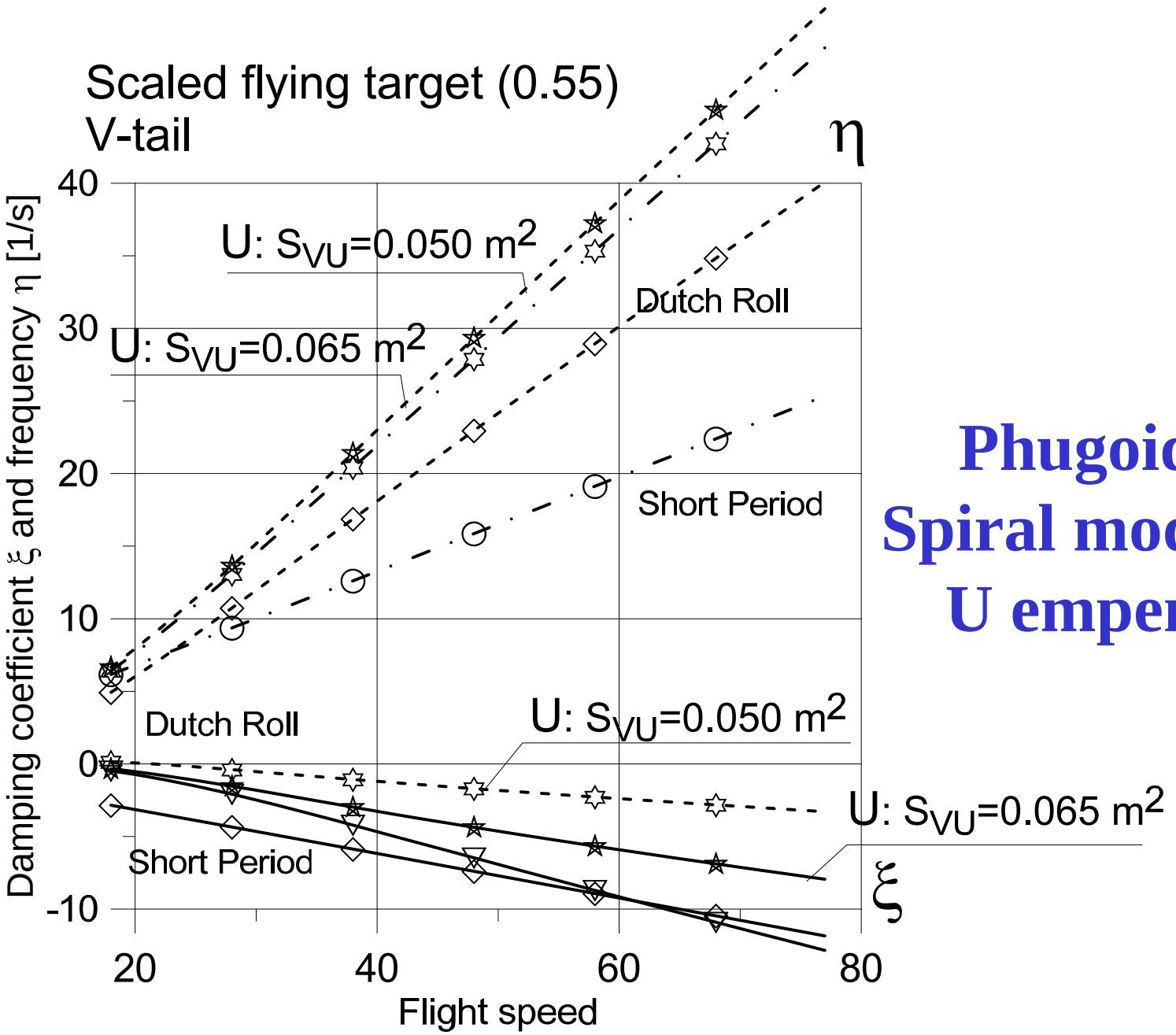
Trim conditions



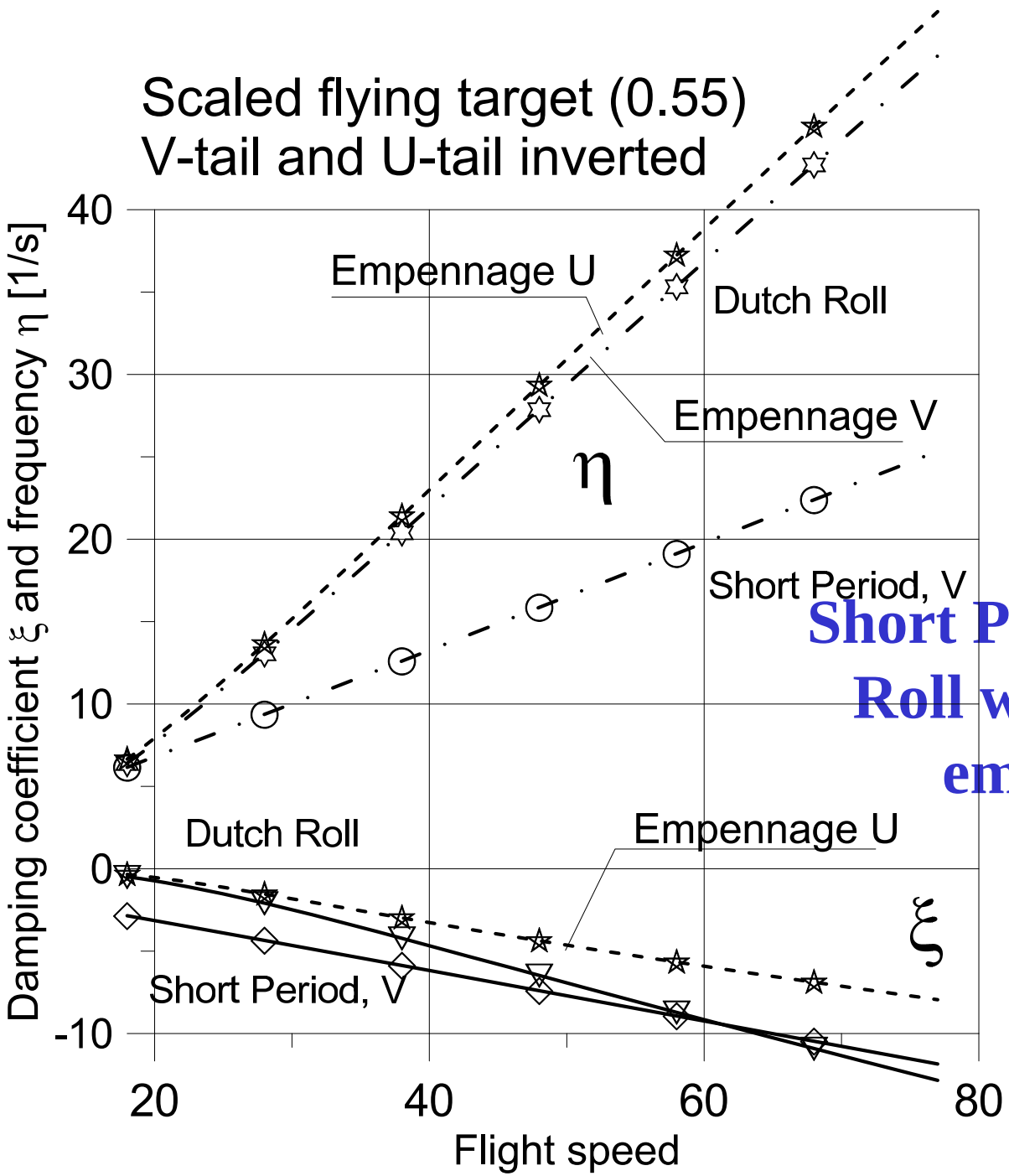
Short Period + Dutch Roll



Phugoid and Spiral modes with V empennage



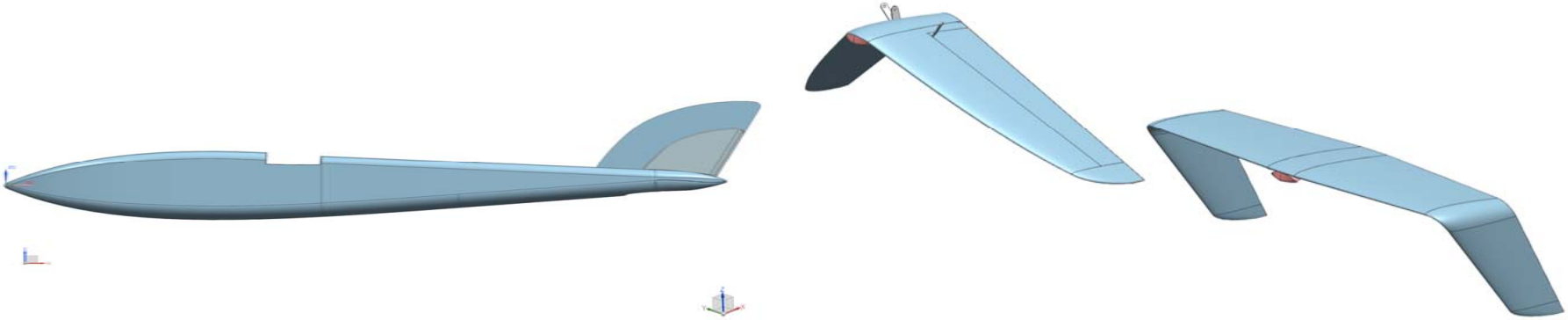
Phugoid and Spiral modes with U empennage



Short Period + Dutch Roll with U and V empennage

Scaled flying model (55 %)

Configuration	Horizontal tailplane volume	Vertical tailplane volume
V-tail	0,35	0,034
U-tail	0,93	0,044
V-tail + small fin	0,35	0,049
V-tail + enlarged fin	0,35	0,074
U-tail + small fin	0,93	0,059
U-tail + enlarged fin	0,93	0,084

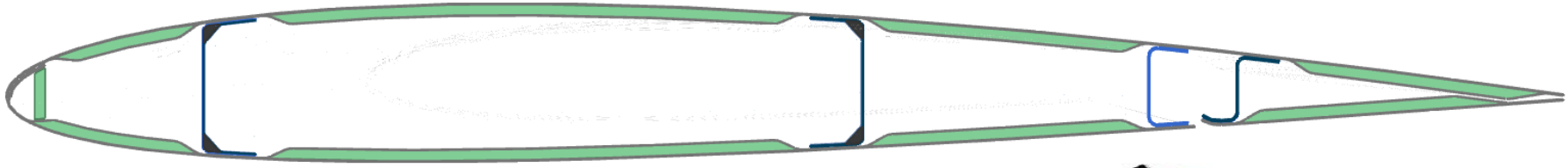


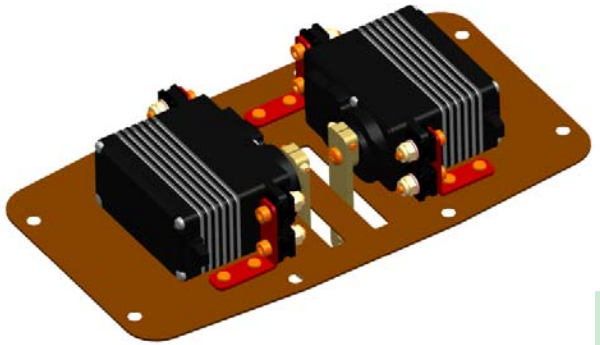
At the beginning: Take-off

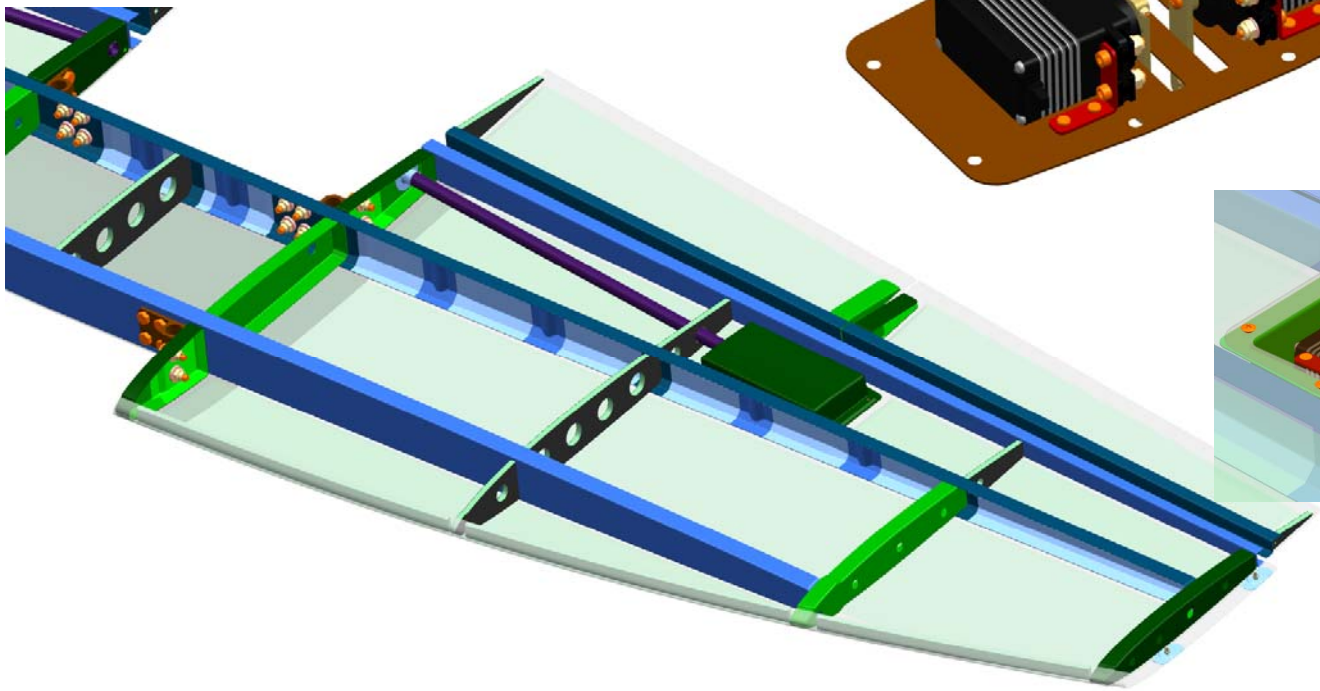
Catapult take-off, flight, net-landing, ...

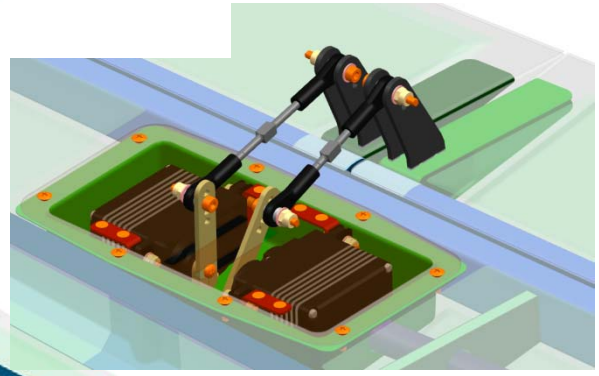
Model scaled to 55%

Sandwich and laminar ribs, a box where servoactuators are placed

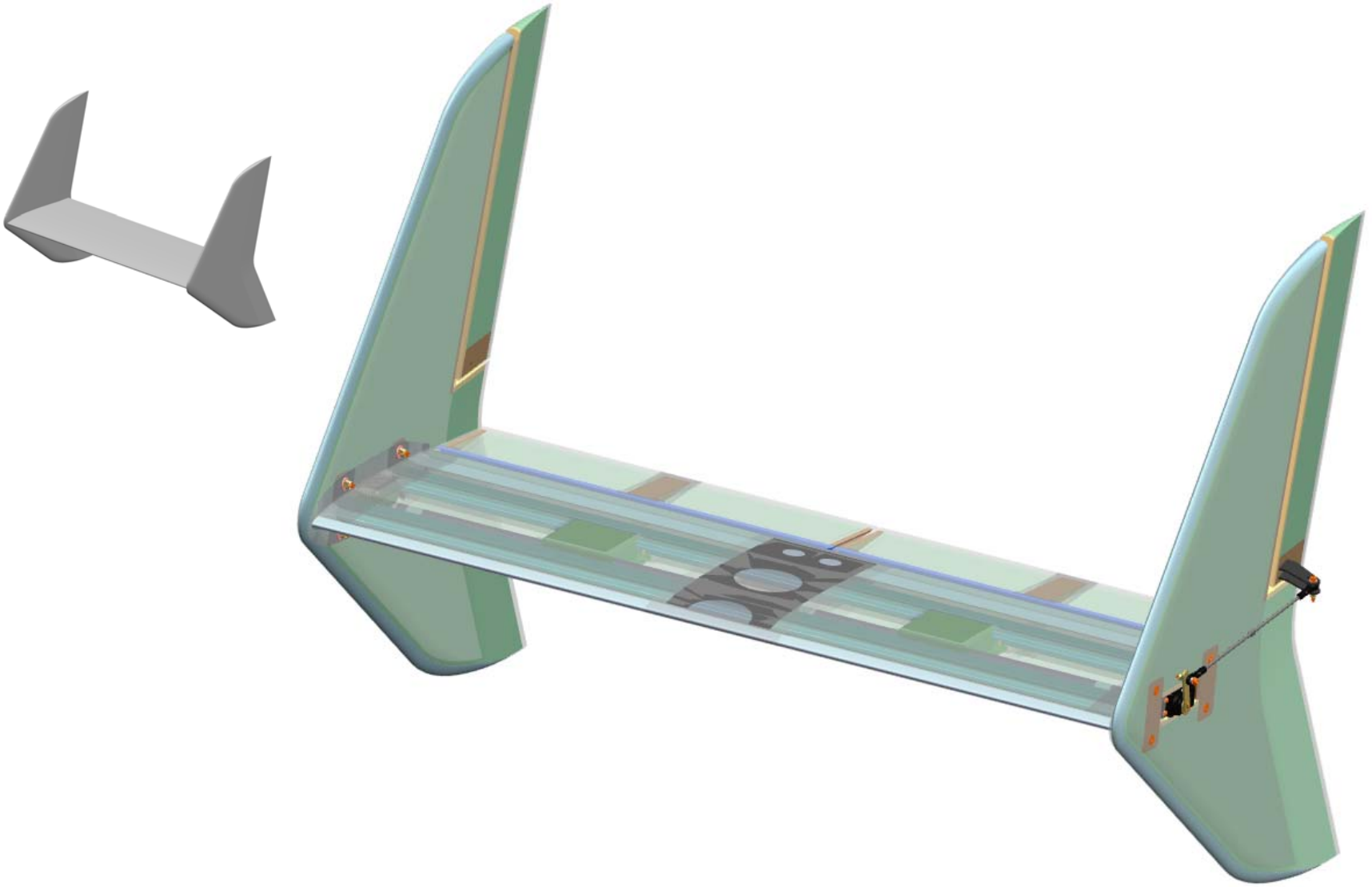




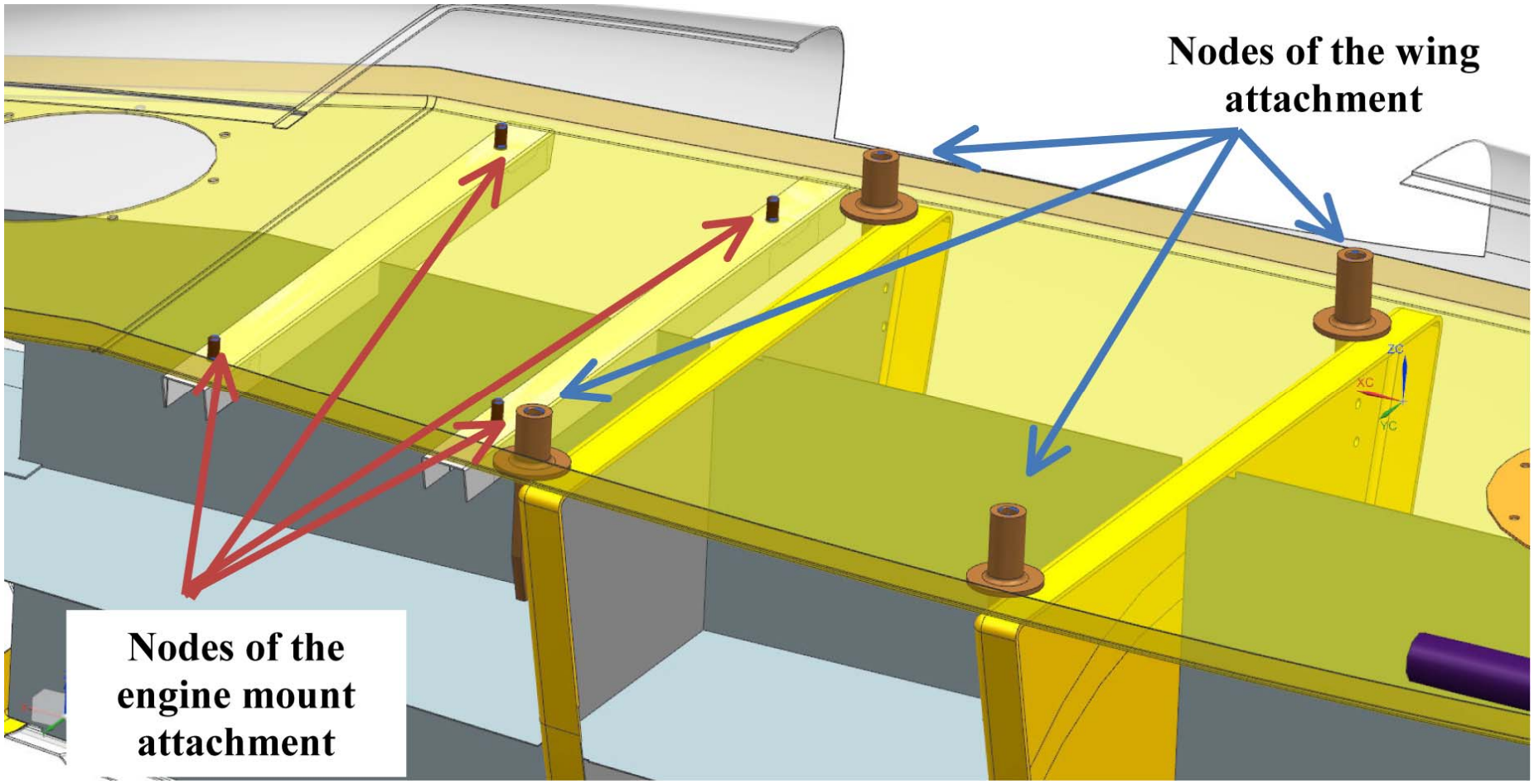




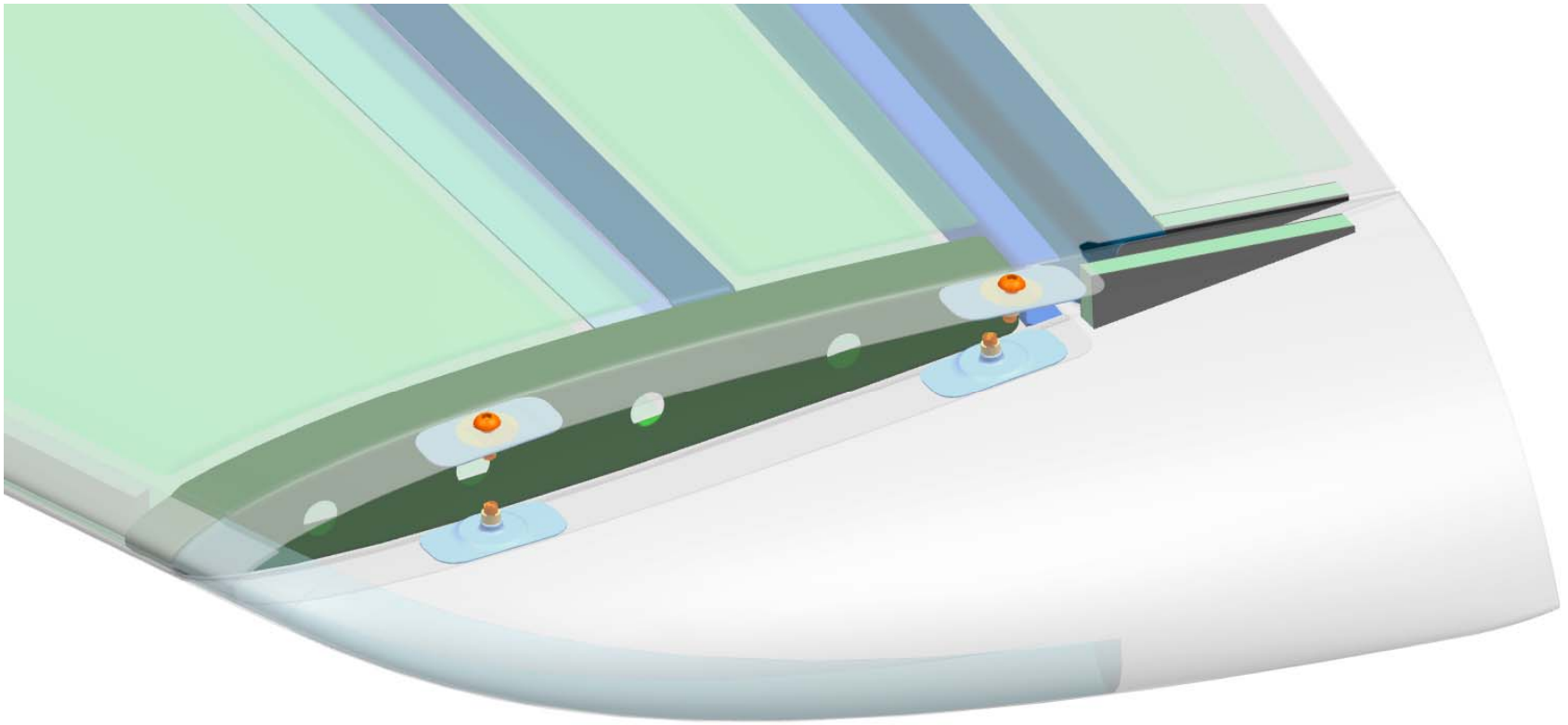
Details of internal design of empennage



Nodes of the wing and engine mount attachment



Wing tips are attached to the main wing with 4 screws enabling quick replacement



Conclusion and recommendation

- Design and multi-**optimisation process** of a highly manoeuvrable flying target is in progress;

- Basing on the experience gained during former projects, advanced computational methods and flight tests we believe we get more advanced design which can offer lighter and cheaper unmanned aircraft of longer endurance and higher speed;

- Current status of the project is very optimistic, however it must be validated finally in the flight testing before manufacturing a number of prototypes to be sent to the army.

An Analysis of FanWing Flight Physics and Potential Business Cases
October 29th, 2014, Aachen Germany

Project Participants:

FANWING

UNIVERSITÄT DES SAARLANDES

DLR

Presentation Overview

Introduction
- What is the FanWing?
- How Does the FanWing Work?
- FanWing History
- SOAR Project Year 1 Objectives

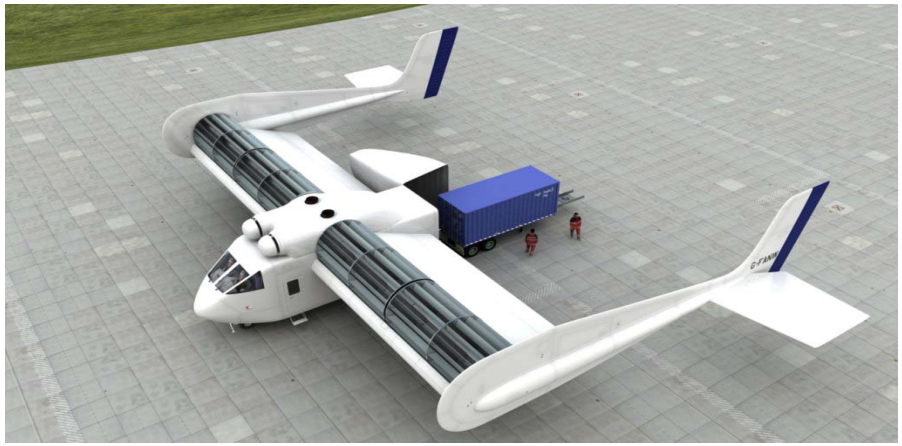
Aerodynamic Results
- Wind tunnel Test
- Wind tunnel Results
- Unsteady CFD Results

Market Selection Results
- Fixed Wing Aircraft Markets
- VTOL Markets
- Final Market/Mission Selection

Summary & Questions

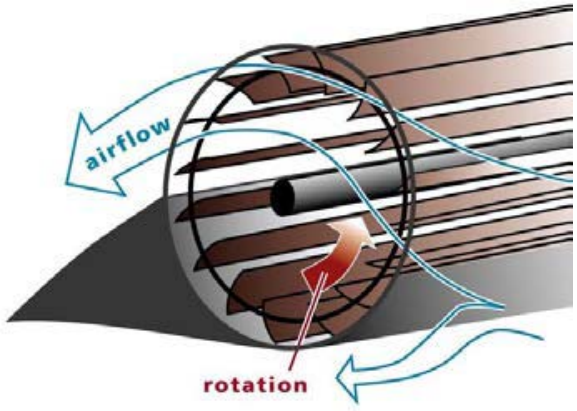
What Is the FanWing?

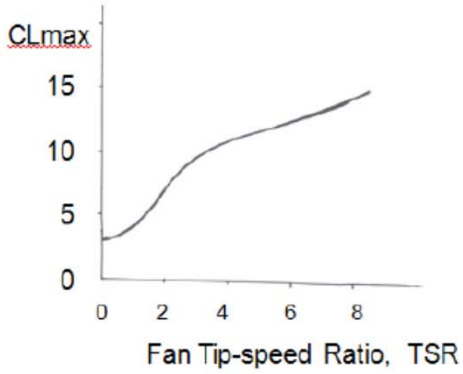
- Distributed Propulsion Ultra Short Takeoff & Landing (USTOL) Aircraft

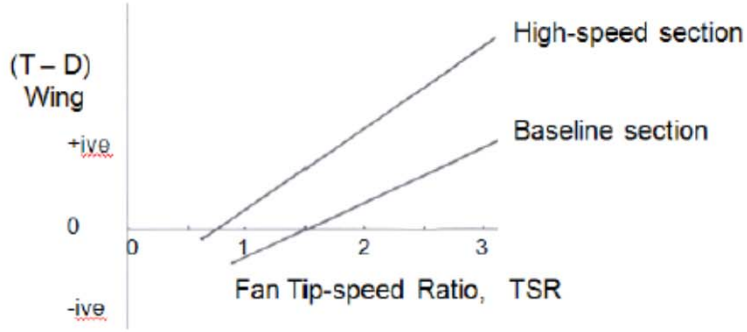


- Takeoff & Landing area: Shorter than a fixed wing aircraft, longer than a helicopter
- Cruise Efficiency: higher than a helicopter, lower than a fixed wing aircraft
- Can STOL qualities be exploited to…
  - Improve carbon footprint, operating costs, productivity in helicopter markets?
  - Reduce mission distance, economic cost of using a long fixed runway away from area of interest?
  - Create new markets for STOL aircraft?

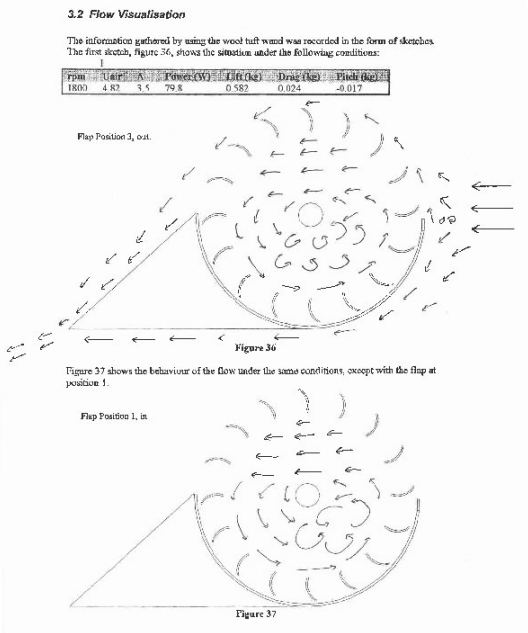
How Does the FanWing Work?







- Rotating fan forms a vortex and creates low pressure zone on top of the wing, increasing the net lifting force
- Accelerates air with large inlet area along the wing to produce thrust
- Low Pressure zone increases CLMax for improved takeoff length, “helicopter like” takeoff profile


3.2 *Flow Visualisation*

The information gathered by using the wool tuft wand was recorded in the form of sketches. The first sketch, figure 36, shows the situation under the following conditions:

rpm	Uair	A	Power(W)	Lift (kg)	Drag (kg)	Pitch (kg)
1800	4.82	5.5	79.8	0.582	0.024	-0.017

Flap Position 3, out.

Figure 36

Figure 37 shows the behaviour of the flow under the same conditions, except with the flap at position 1.

Flap Position 1, in

Figure 37

FanWing History

- 1998: First take-off/proof of concept. Initial wind-tunnel tests conducted by Pat Peebles at the University of Rome

- 1999: Vortex first measured in flying UAV, Imperial College London
- 2002: UK Government SMART Award and private investment funded wind-tunnel tests completed at Imperial College

- 2004: University of Belfast work completed on OHS tail

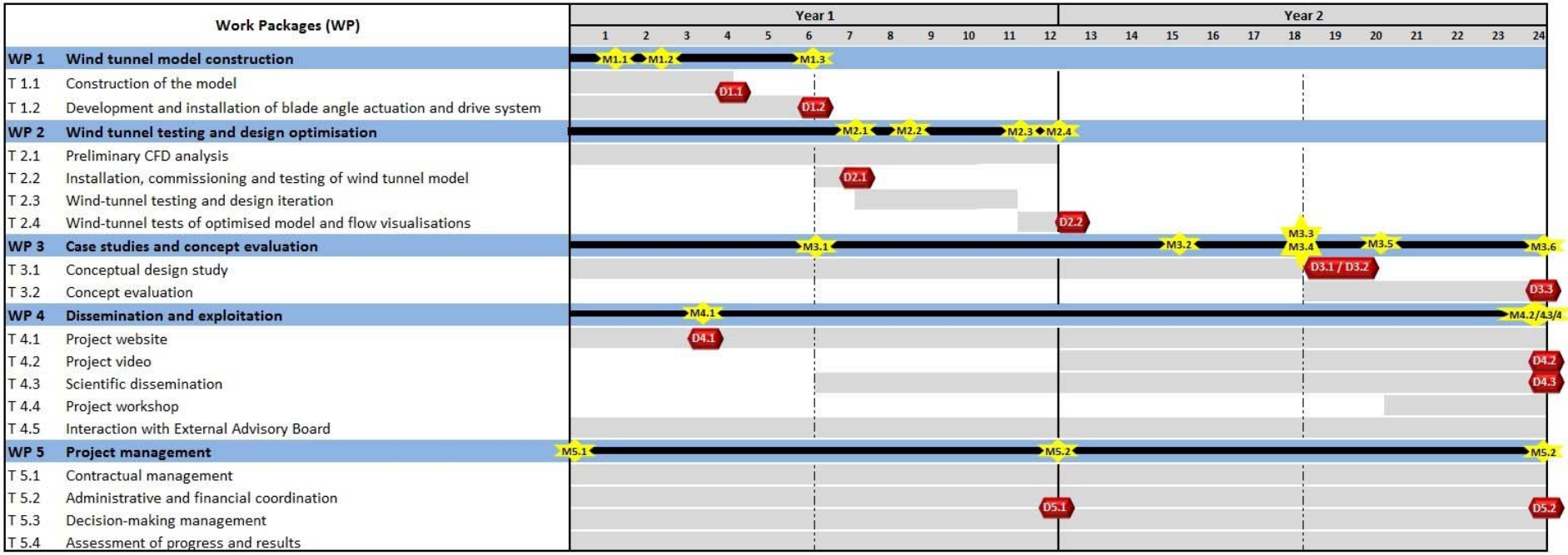
- 2007 STOL UAV urban surveillance prototype demonstrates short-take-off of a 1 m roll without payload and 3m on lower power (see video on this website and Flight Global online archives).

- 2010 FanWing prototype flies at Farnborough Airshow

- 2013-Present → SOAR EU Project

FanWing Flight Video

SOAR Project Objectives & Milestones



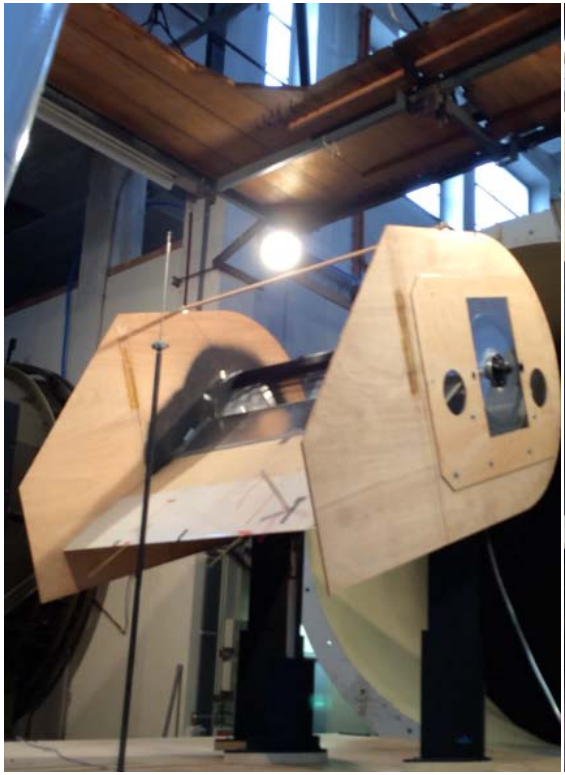
Powered Wind tunnel Test -- Von Karman Institute

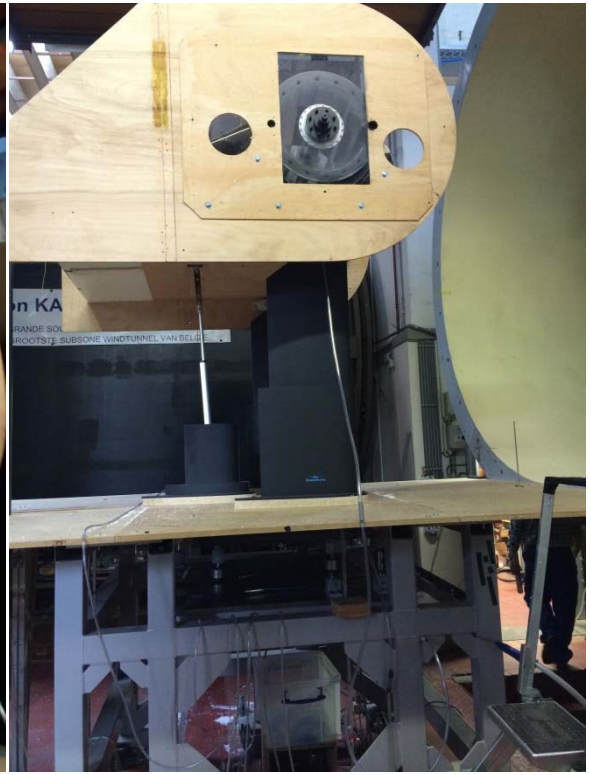
Test Parameters:

- Tunnel Speed: 0 - 20m/s
- Fan Speed: 0-1200 RPM
- Supported by unsteady CFD analysis from VKI

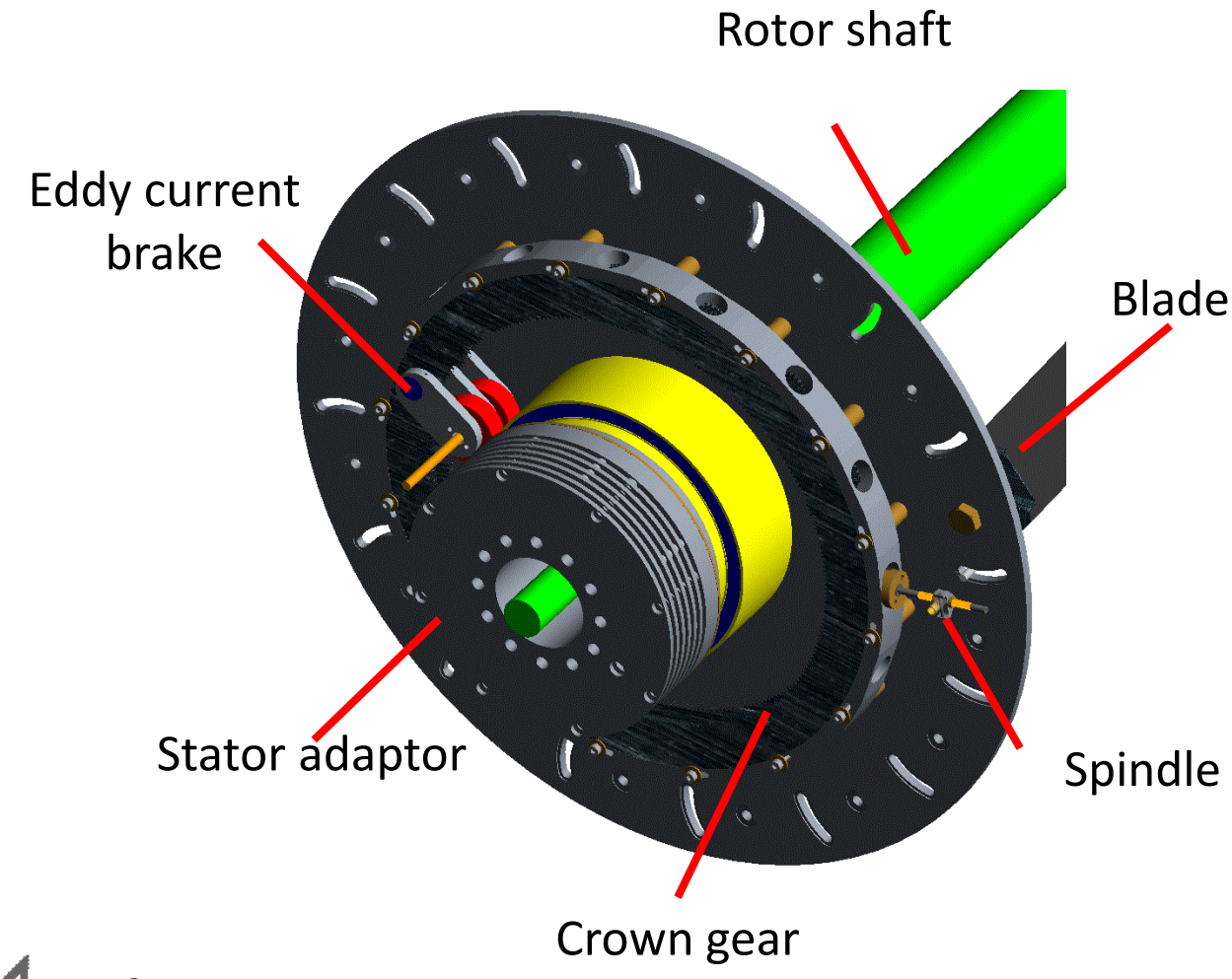
Objectives:

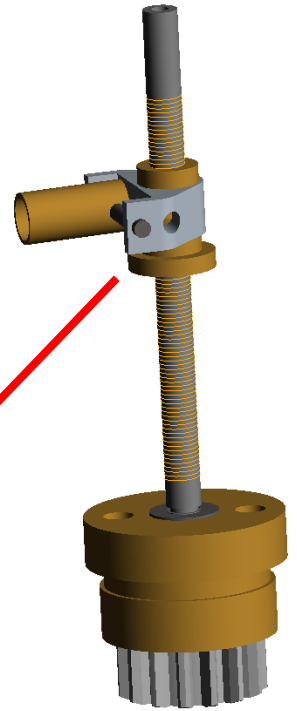
- Validate/find inconsistencies in aerodynamic performance
- Find optimized fan blades and wing geometry
- Create an aerodynamic/ power required database to support Year 2 aircraft design & economic assessment



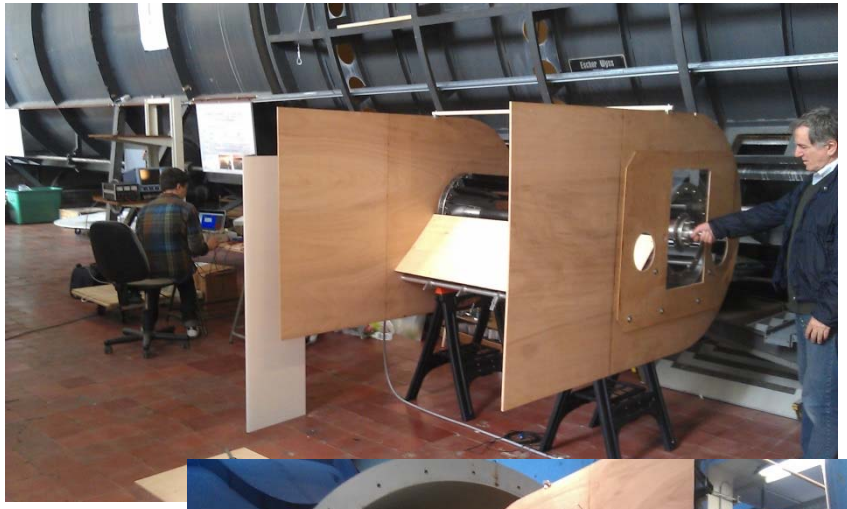


Powered FanWing Model: Electric Motor (Saarland University, Laboratory of Actuation Technology)



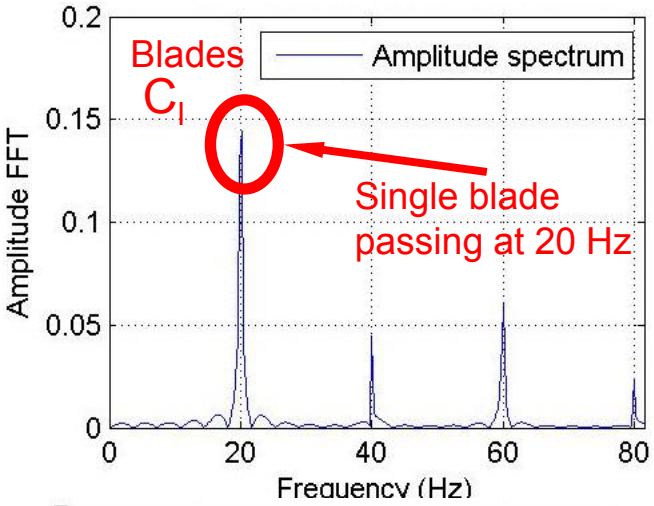


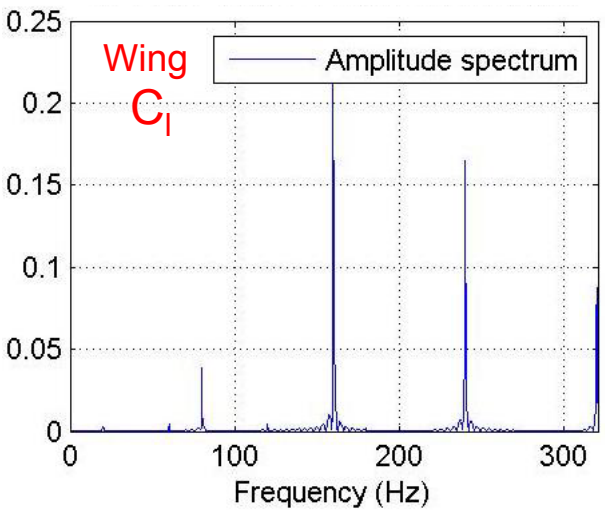
Installation in the Wind Tunnel



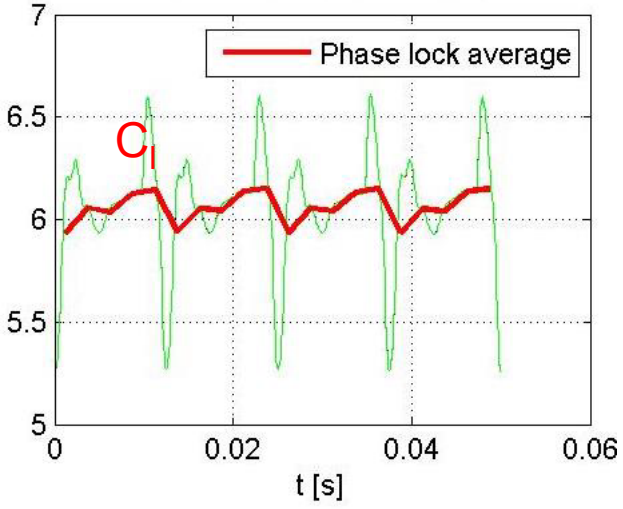
CFD RESULTS– Transient analysis and convergence

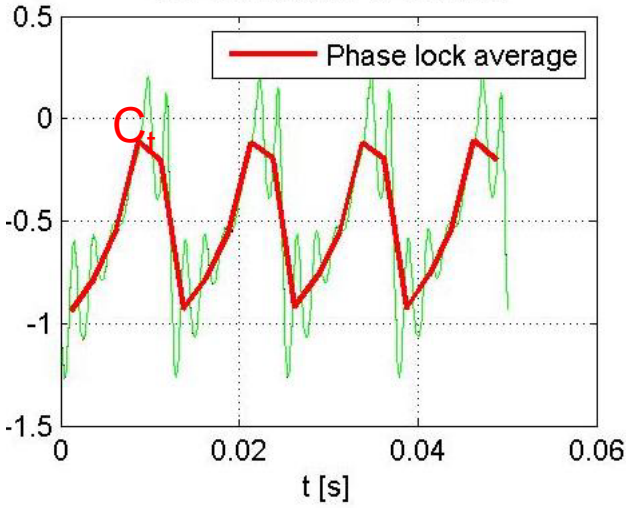
σ = 4 ω= 1200 rpm TSR = 3

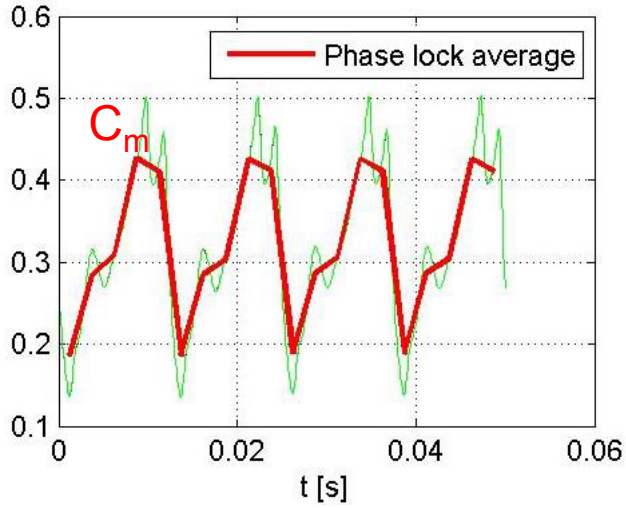




- Unsteady convergence assured by several repeated periods in the lift, thrust and moment
- The signature of blade passing on the lift coefficient spectrum

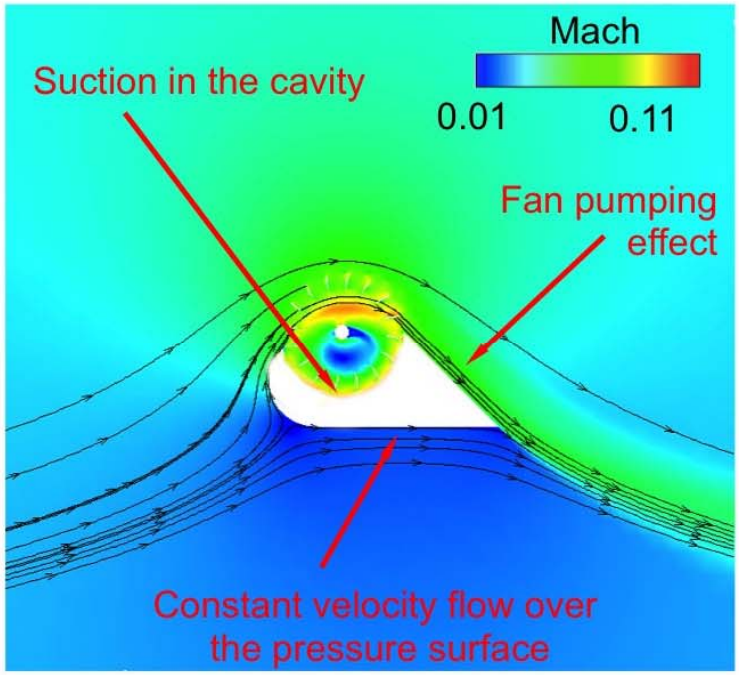


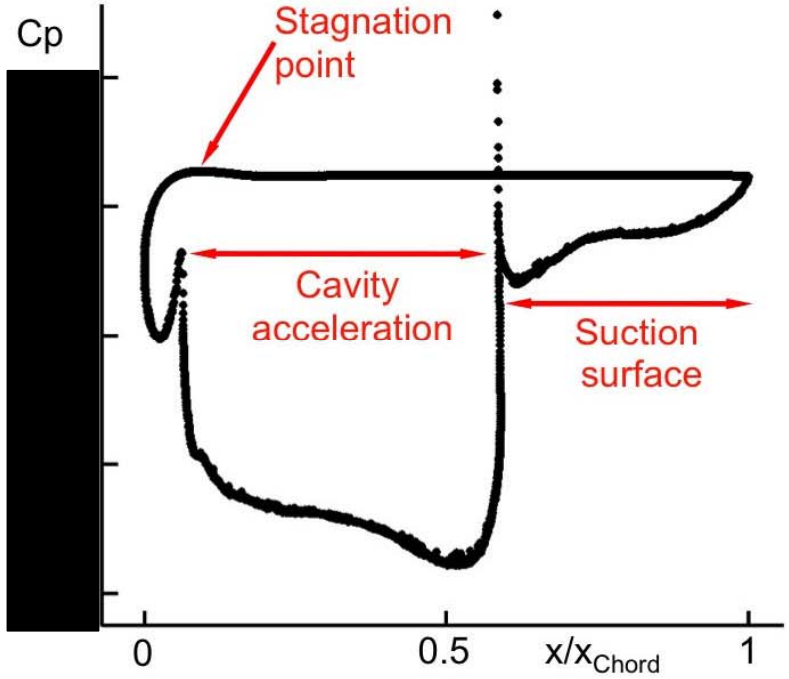




CFD RESULTS– Flow field

σ = 16 ω= 1200 rpm TSR = 3

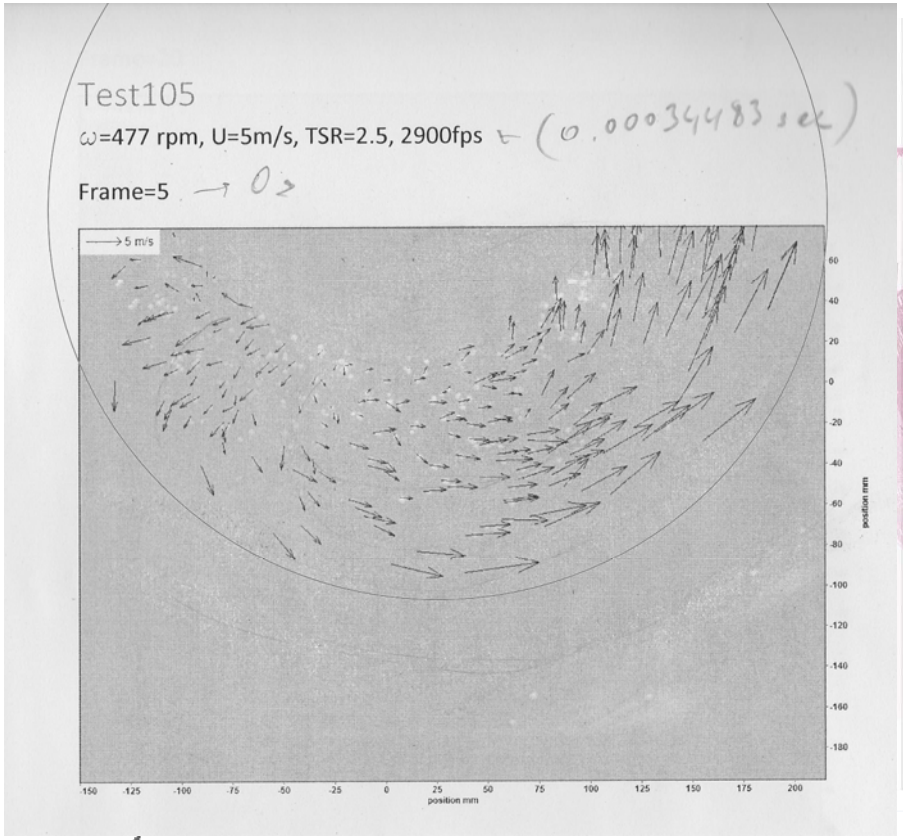


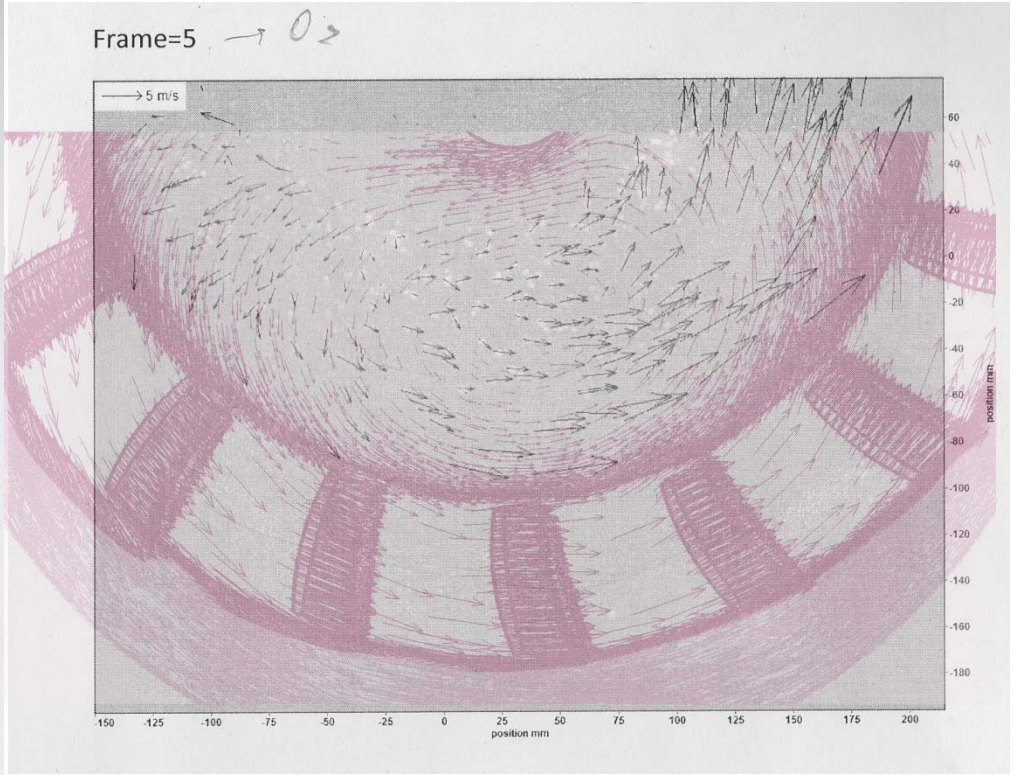


- Incoming flow sucked from the leading edge and pumped towards the trailing edge
- Creating lower pressure zones for the wing lift
- Major portion of the lift generated at the cavity below the fan cage
- Suction created by the fan proportional to the fan RPM

RESULTS: Particle Tracking Velocimetry

- Initially, the vortex was not observed in the wind tunnel model (both with wind on and no wind) → leads to lower CLMax & reduced STOL capabilities





Wind Tunnel vs. CFD Results: Powered and Unpowered

Addressing the vortex and other objectives

- Results did improve by 30% after the cavity imperfections were mitigated, but, no velocity profiles were taken with the optimal configuration

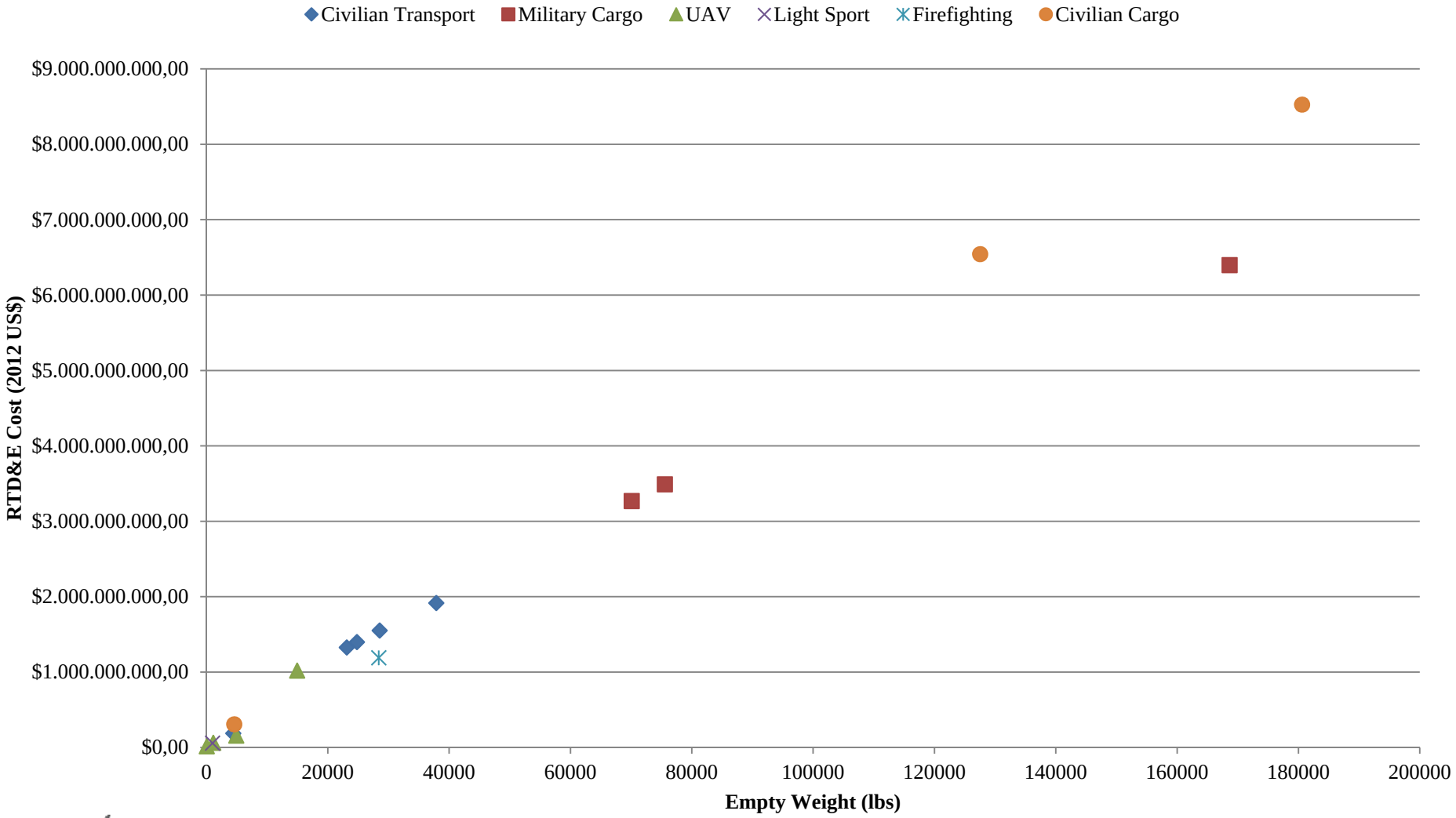
- CFD testing was conducted with 5% turbulence, wind tunnel has 1% turbulence

- Optimal blade and cavity configurations were found, databases for power required and aerodynamic performance were completed

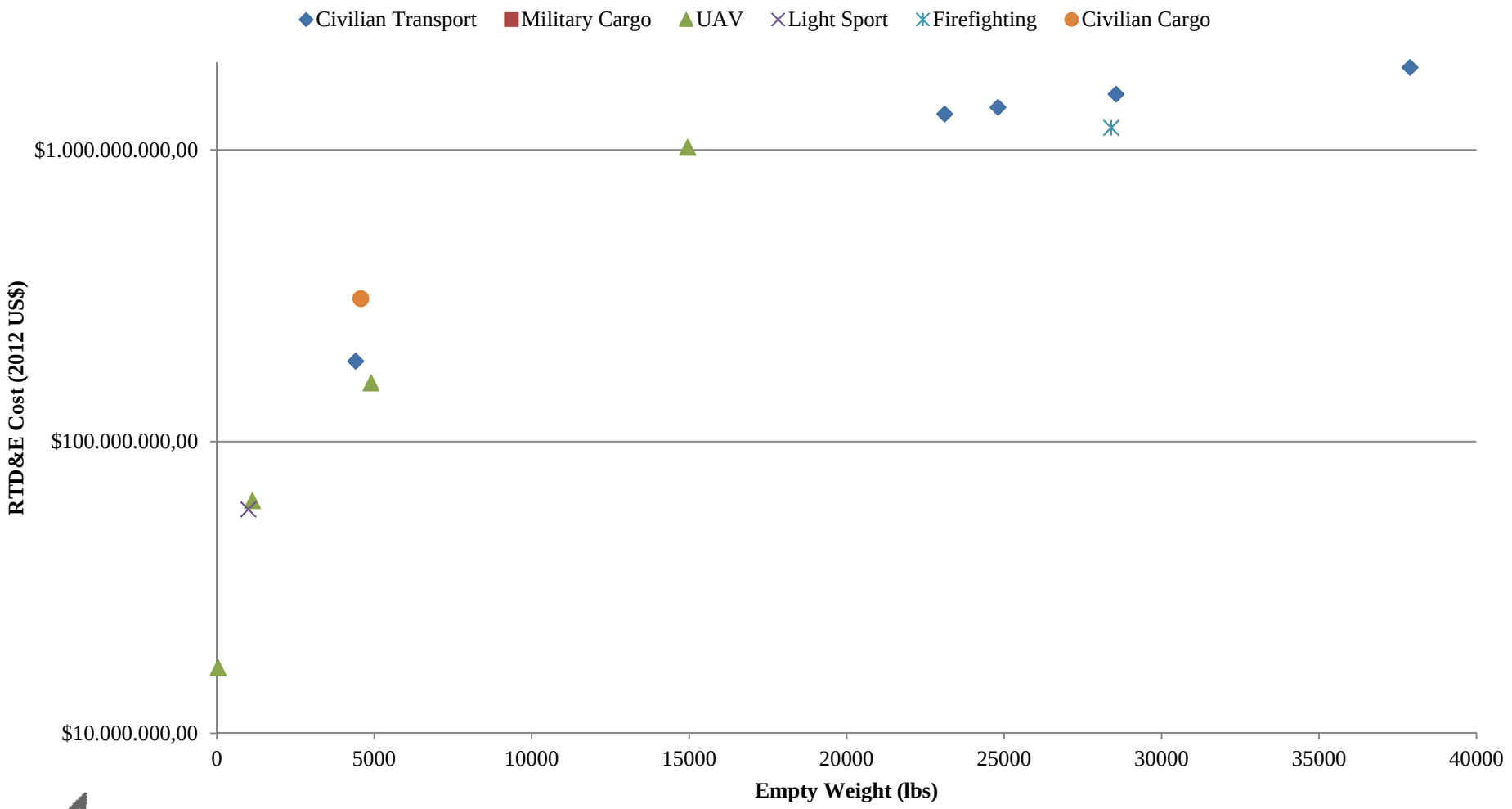
Remaining questions

- Under what conditions does the vortex scale up to larger vehicles?

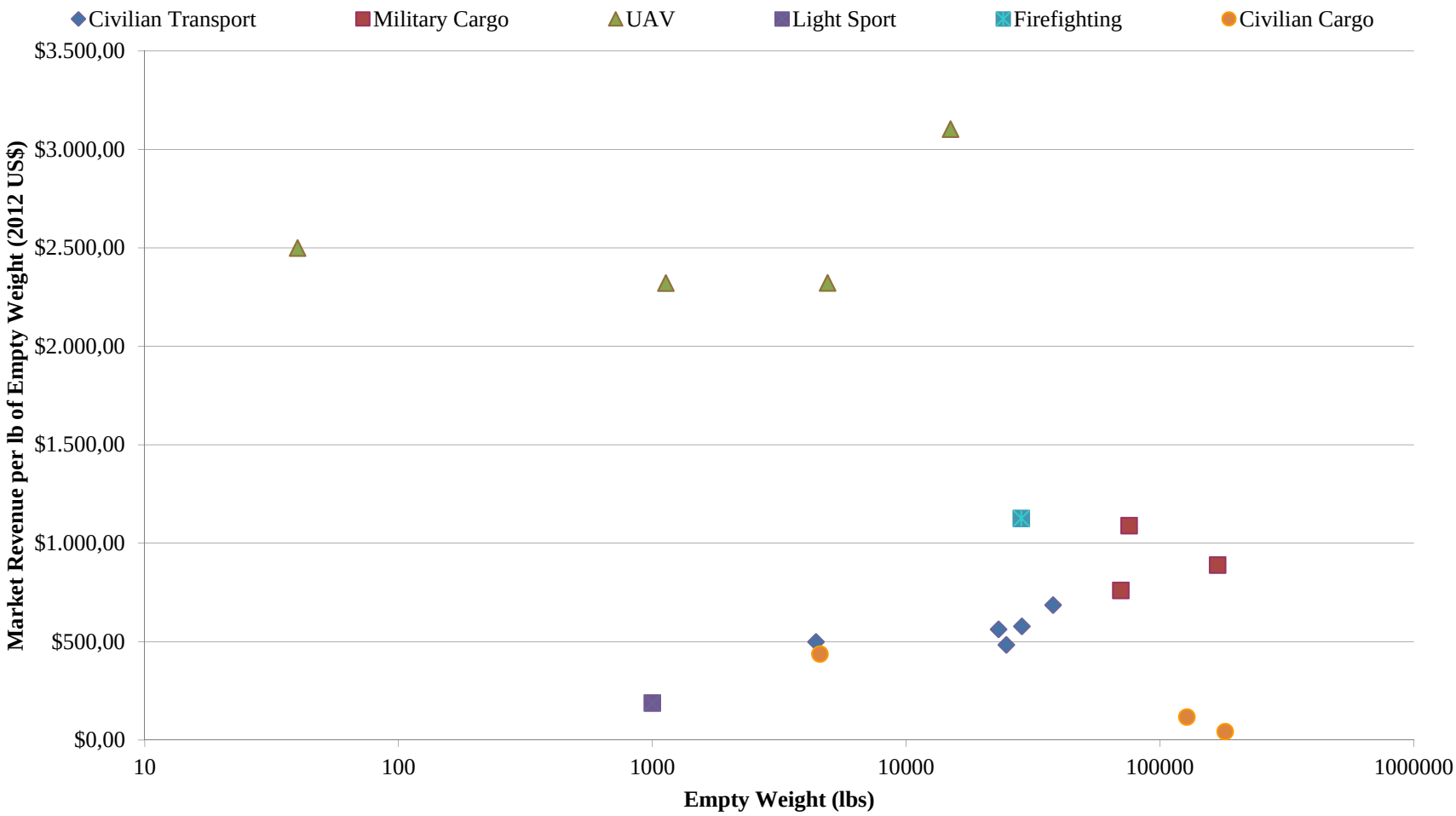
Potential Fan Wing Markets and Capital Required



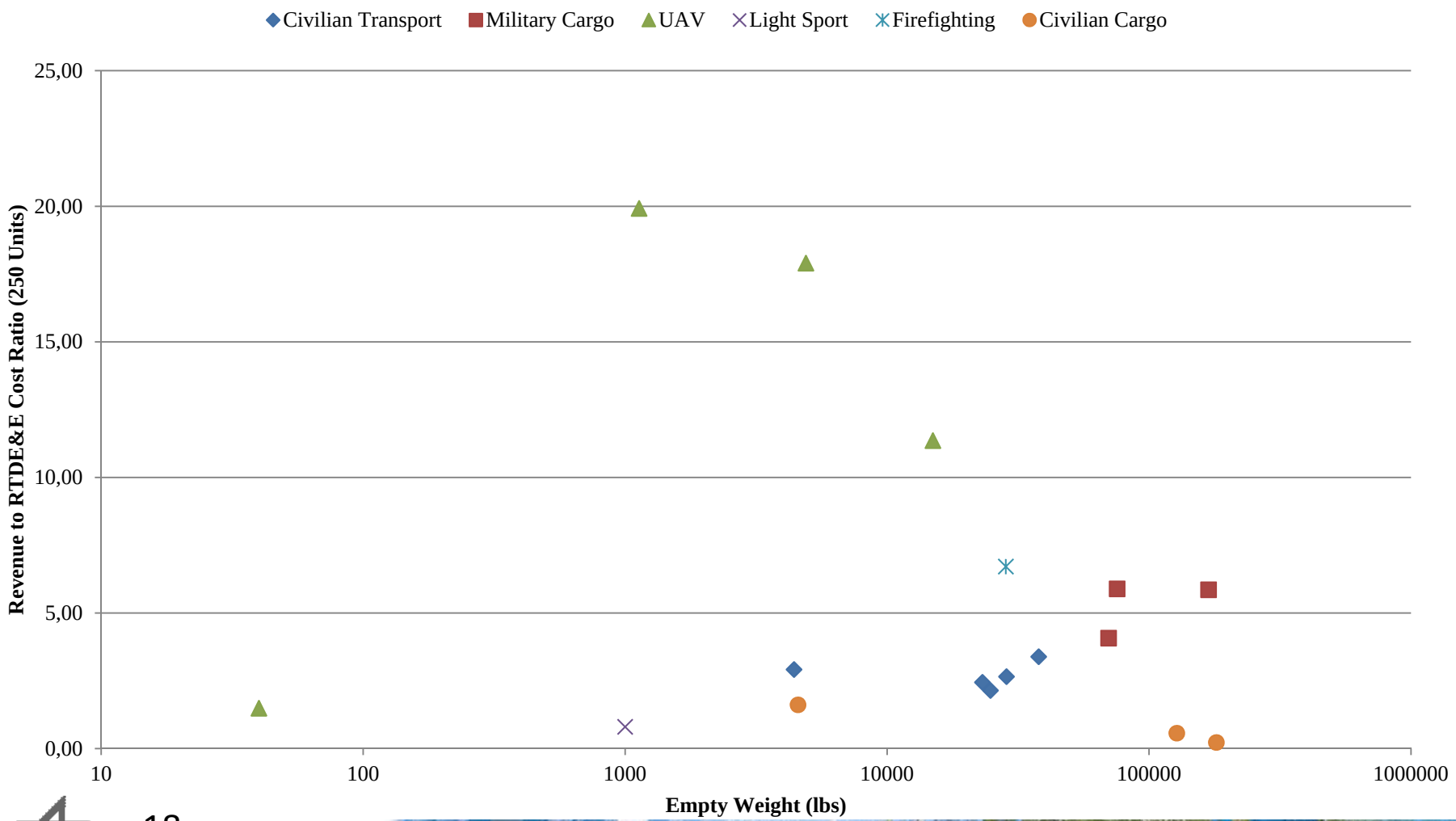
Potential Fan Wing Markets and Capital Required



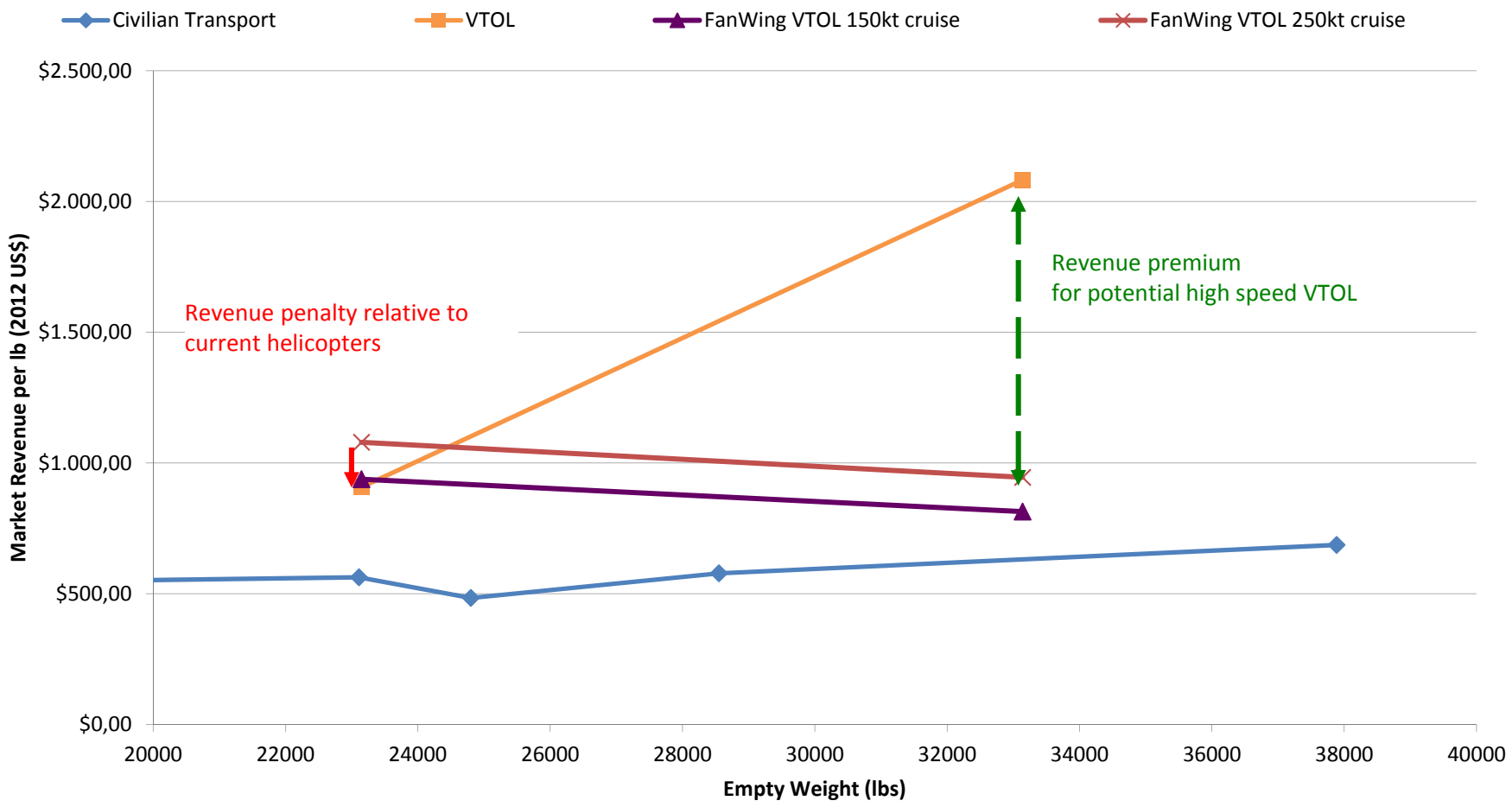
Potential Fan Wing Markets and Capital Required



Potential Fan Wing Markets and Capital Required



Potential VTOL Markets



Selected Missions

Payload	Speed	VTOL	Markets	Estimated Development & Certification Costs
1-10 (lbs)	25 kts	Yes	Door to Door Package Delivery	~$15 Million
1,000-5,000 (lbs)	150 kts	No	Civilian UAV surveillance, Crop dusting, Passenger transport, Emergency or Construction Cargo Delivery	~$60-$180 Million
10,000-20,000 (lbs)	150 kts	No	Passenger transport, Firefighting, Cargo, port operations	~$1.5 Billion-$2 Billion
20,000 (lbs)	150 kts-250 kts	Yes	Military Cargo Transport, Civilian Oil Refinery Transport	~2 Billion

Competing Aircraft

Payload	Markets	Competitor 1	Competitor 2	Competitor 3
10-50 (lbs)	Door to Door Package Delivery	Truck Delivery	Self pickup	Quad Copter
5000 (lbs)	UAV, Crop Dusting	General Atomics MQ-1 Predator	Air Tractor 502B, Thrush 510P, EMB 202 Ipanema	Tecnam P2012 Traveller
10,000-20,000 lbs	Intermodal Shipping, Firefighting, Passenger	Airship[1]	Large Truck Delivery	Helicopter Delivery
20,000 lbs	High Speed VTOL	Sikorsky S-97	V-22 Osprey Tiltrotor	Eurocopter X3

[1] Aviation Week: "UK Government Supports Airship Development"., June 26th, 2013 http://m.aviationweek.com/commercial-aviation/uk-government-supports-airship-development

Summary

- Further unsteady aerodynamics investigation needed to understand vortex conditions

- Agriculture appears to be the most promising market for STOL to add value

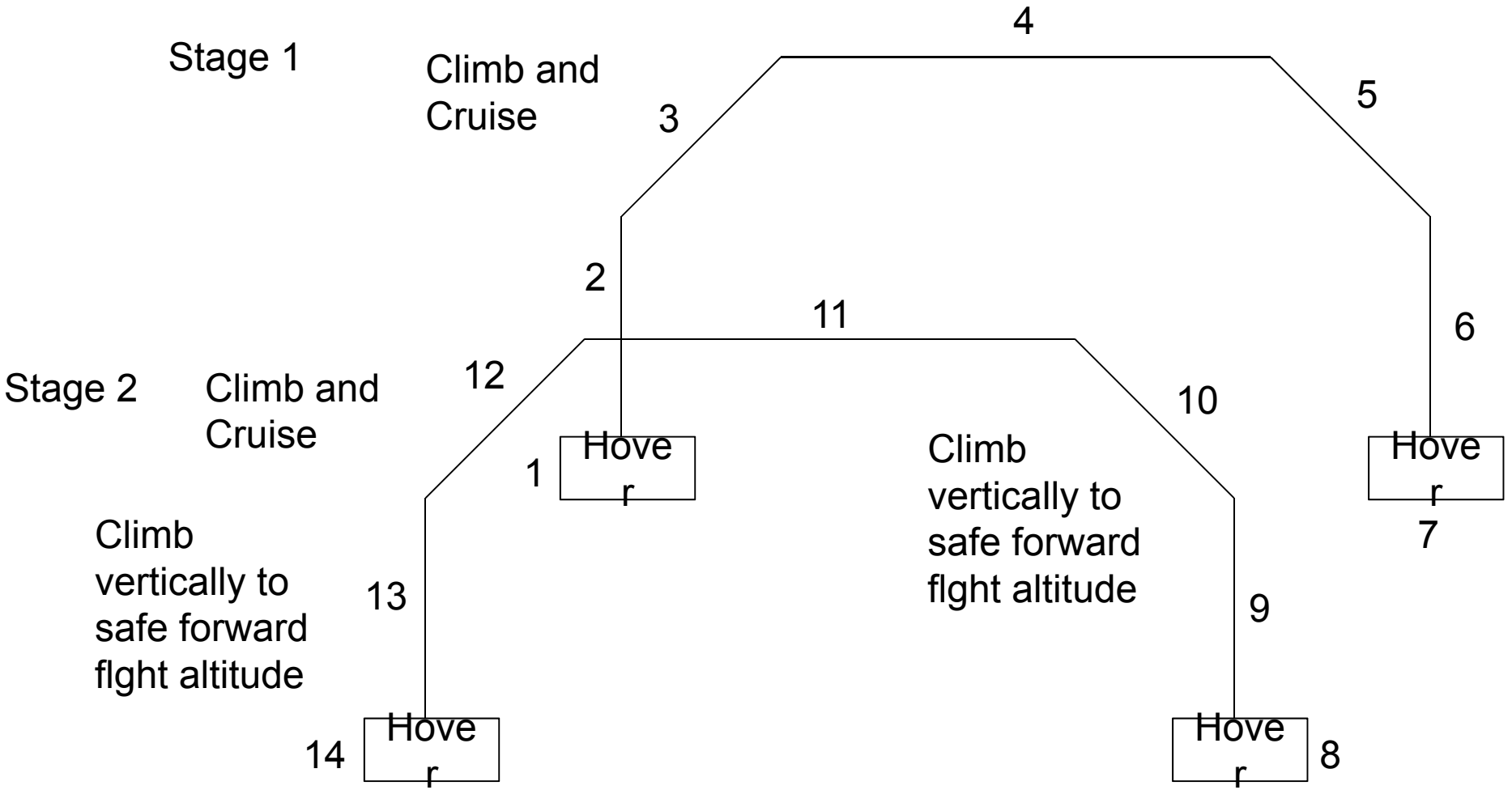
- VTOL markets exist with the large potential for premiums but STOL will not be sufficient to address this markets –> vortex will be critical to achieving competitive performance in these markets

Questions

http://www.soar-project.eu/

Backup Slides

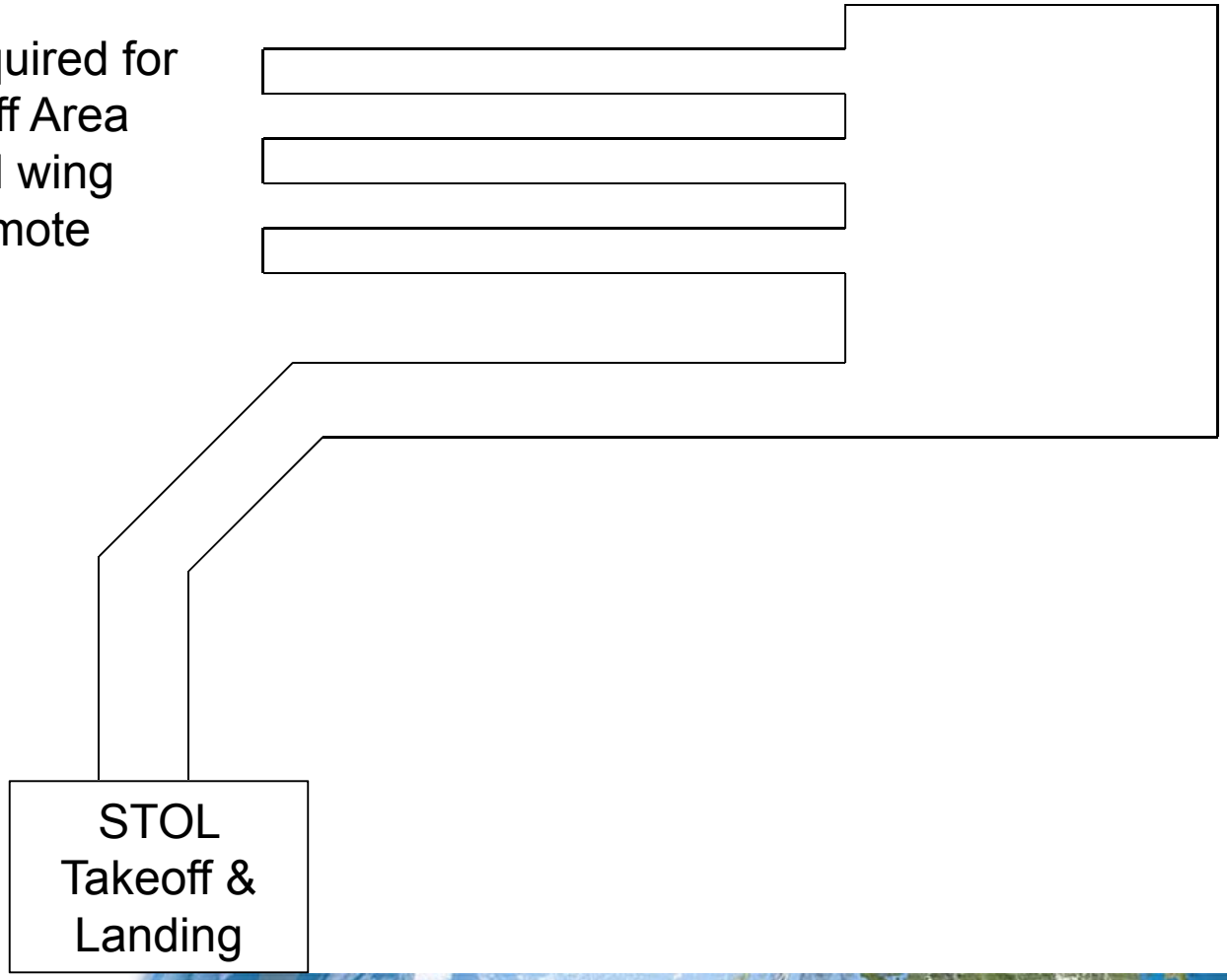
0-50 lbs, & 20,000lbs Payload (VTOL)



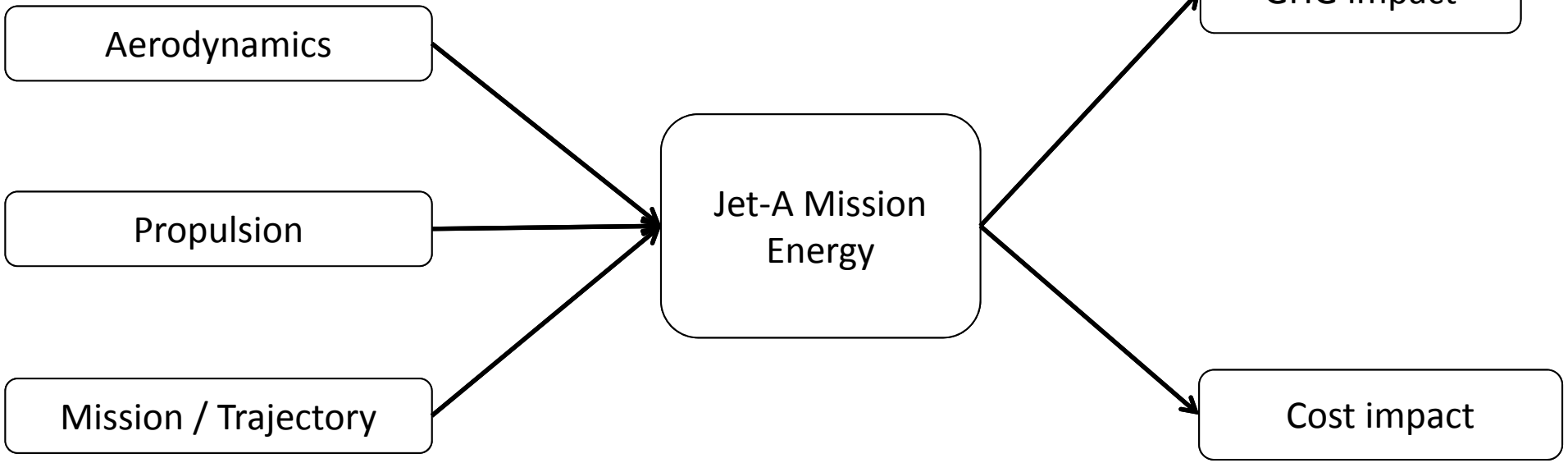
1,000-5,000 lbs payload (crop dusting)

Important Factors

- Turning radius
- Space & cost required for FATO and Takeoff Area
- Compare to fixed wing spraying from remote airport



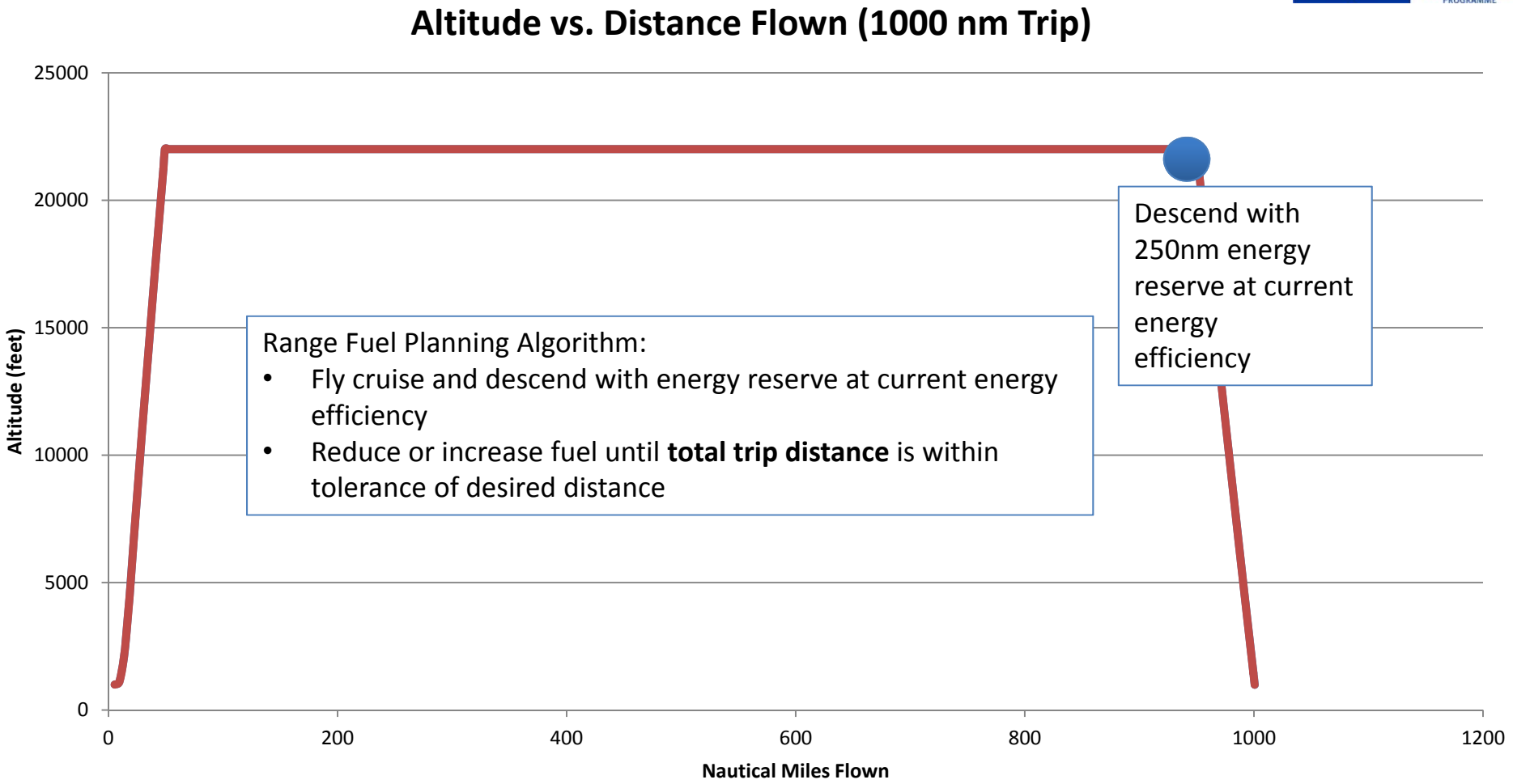
FYI Code



$$gCO_2e_{Mission} = \square \frac{JetgCO_2e}{MJ} * JetMissionEnergy$$

$$MissionCost = \square \frac{Jet\$}{MJ} * JetMissionEnergy$$

FYI Code: sample trajectory



RBF4AERO Project

Innovative benchmark technology for aircraft engineering design and efficient design phase optimization

D'Appolonia S.p.A.
Hellenic Aerospace Industry
University of Rome "Tor Vergata"
Pipistrel
National Technical University of Athens
Piaggio Aero Industries S.p.A.
Tusas Engine Industries Inc.
von Karman Institute
Istituto per le Applicazioni per il Calcolo

Summary

- RBF4AERO Project
- Partnership
- Context and Challenges
- Objectives
- Project Bases
- Project Integrated Tasks
- Benchmark Technology Featured Analyses
  - Shape Optimization
  - FSI
  - Ice Accretion
  - Adjoint-Morphing Coupling
- Contacts

RBF4AEO Project

The RBF4AERO project aims at developing the RBF4AERO Benchmark Technology (BT), **an integrated numerical platform and methodology** to efficiently face the most demanding challenges of aircrafts design and optimization.

The purpose of this technology is to **reduce the aerodynamic design** process duration and to satisfy the ever-growing demand of the aeronautic design optimisation.

For specific applications that reduction time could range **up to 80%.** Moreover, other applications (FSI, adjoint-morphing coupling) **become feasible** even with high-fidelity models.

RBF4AEO Project

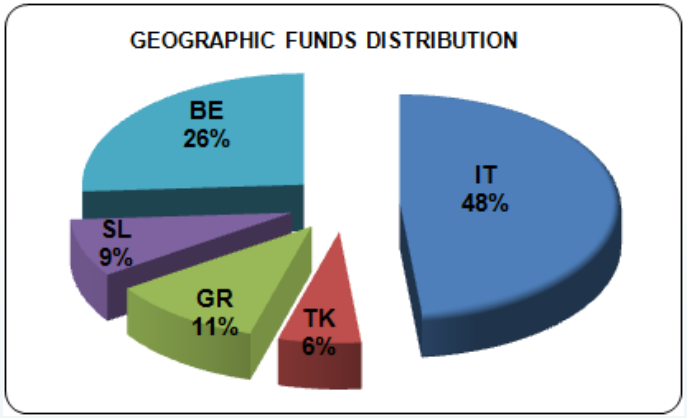
Project details:

- Programme: Small or Medium-scale focused research project
- Type of Project: FP7 Cooperation Work Programme: Aeronautics and Air Transport (Design and Tools)
- Call Identifier: FP7-AAT-2013-RTD-1
- Project Number: ACP3-GA-2013-605396
- Project M0: September 1st 2013 for a duration of 3 year
- Total EC Funding of ≈ 2. 4·10^6 € (global costs ≈ 3.5 ·10^6 €)

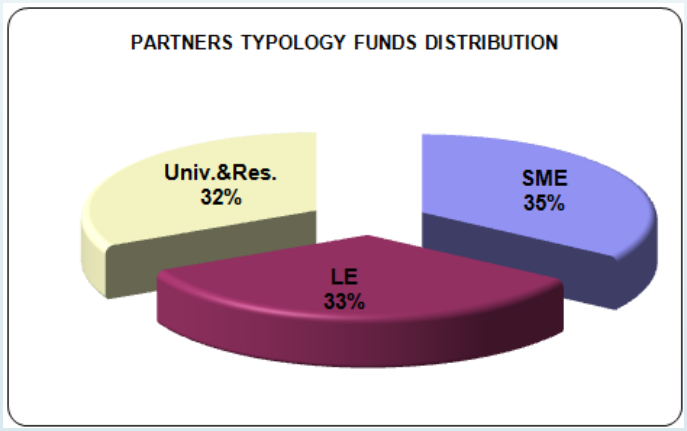
Partnership

The RBF4AERO Consortium is composed by **9 partners** from **5 countries** (Italy, Belgium, Greece, Slovenia and Turkey), of which 6 Industrial partners, 1 Research Establishment and 2 Universities.

Partners Origin



Funding per Partner Nationality

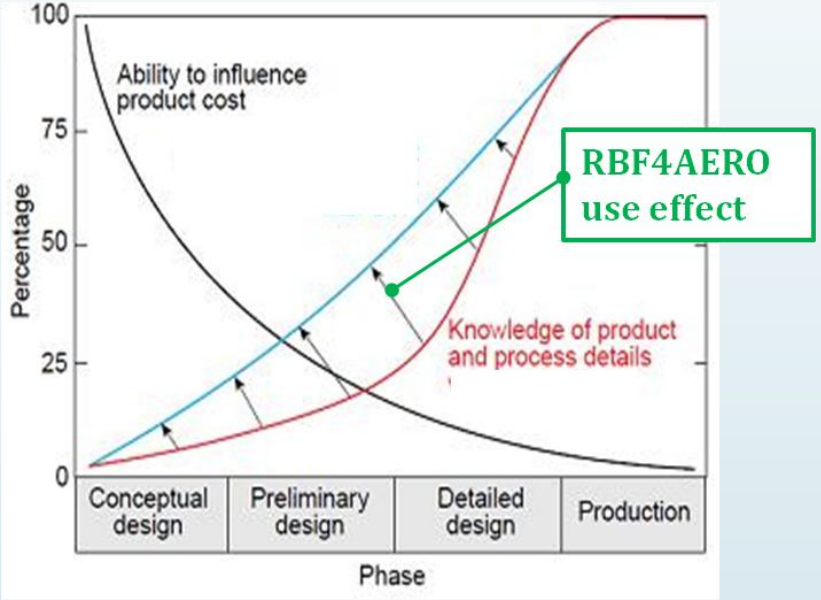


Funding per Partner Typology

Context and Challenges

To date, several years are required to aeronautical industries to develop a new product, with considerable efforts in the research and technology acquisition phases. Considering an aircraft production cycle, the ability to **reduce production costs decreases rapidly** during the first phases of the project (conceptual and preliminary design).

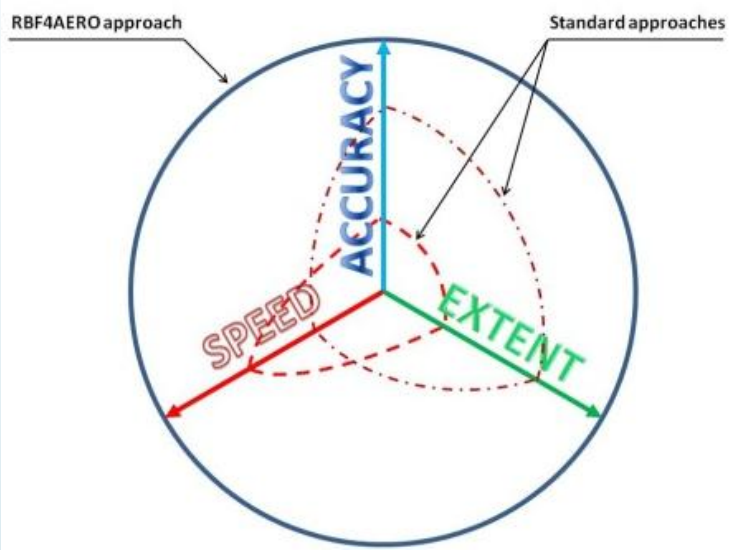
The capability to fast investigate different solutions during the early phases allows to **shorten the knowledge of physical behaviour** of the aircraft components so as to reduce production costs.



Objectives

The tools and methodologies developed and used in RBF4AERO will enable the user to perform design and optimization analyses avoiding the compromise between the contrasting targets of **speed** (time required to complete computing), **accuracy** (high-fidelity numerical models) and **extent** (different configurations tested).

The basic idea is to make the **CFD model parametric** through the use of a shape optimization environment based on a morphing technique founded on radial basis functions (**RBFs**) mathematical framework.



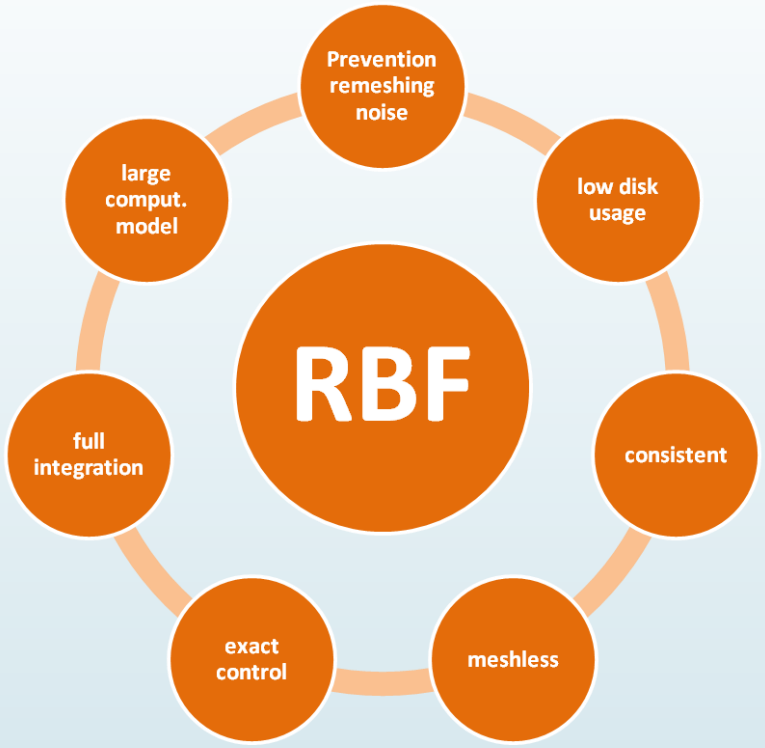
RBF4AERO approach

Objectives

RBFs are a class of mathematical **interpolation functions**. In computer-aided engineering (**CAE**) applications, such functions can be used to drive morphing (smoothing) of computational mesh nodes applying predefined displacements to **source points**.

From mathematical point of view, the RBF fit is defined once the coefficients γi and βi are determined.

$$\begin{cases} s_x(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^x \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{k_i}\|) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ s_y(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^y \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{k_i}\|) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ s_z(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^z \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{k_i}\|) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \,. \end{cases}$$



Objectives

For what stated, the RBF4AERO numerical platform will allow aeronautical designers to perform, in a **dramatically shorter time** with respect to current practices and using their own numerical models and computing platforms, the following studies concerning shapes:

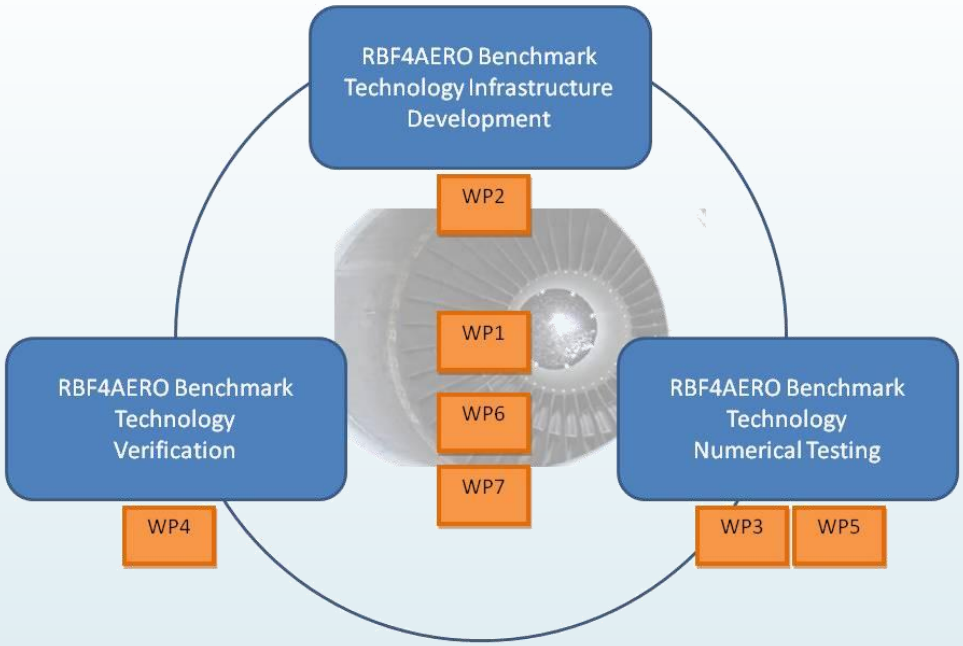
- multi-objective optimization (MOO);
- multi-disciplinary optimization (MDO);
- FSI;
- Ice growth simulation;
- CFD optimization through the adjoint-morphing coupling technique.

The whole project is based on two existing numerical tools developed by consortium partners (UTV and NTUA): **RBF Morph™**, that is the morpher tool available as ANSYS® Fluent® add-on and **stand-alone**, and **EASY** (**E**volutionary **A**lgorithms **SY**stem) which is a general purpose, high-fidelity software for the search of optimal solutions in single- or multi-objective problems.

Project Integrated Tasks (PITs)

The project work plan develops through a robust industrial-based process summarized in three integrated tasks:

1. Benchmark Technology Infrastructure Development (PIT1);
2. Benchmark Technology Verification (PIT2);
3. Benchmark Technology Numerical Testing (PIT3).

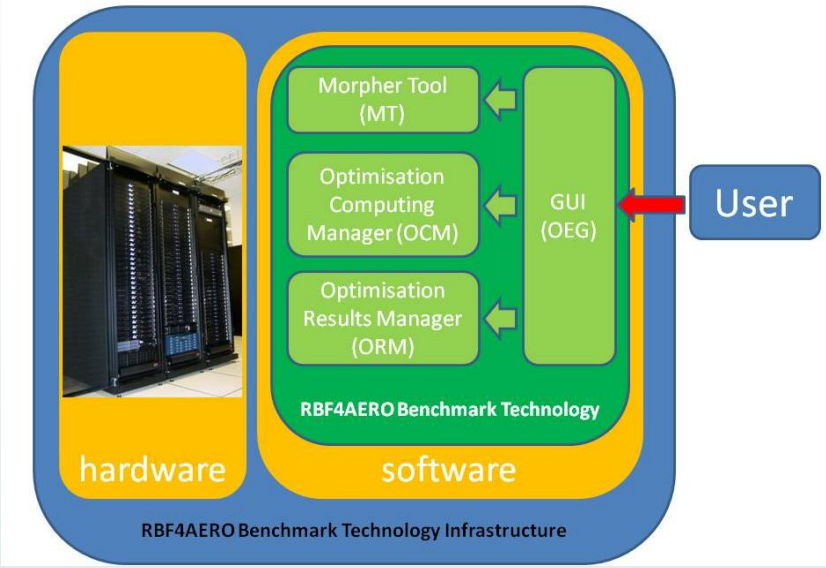


PITs of the RBF4AERO Benchmark Technology Development

BT Infrastructure Development

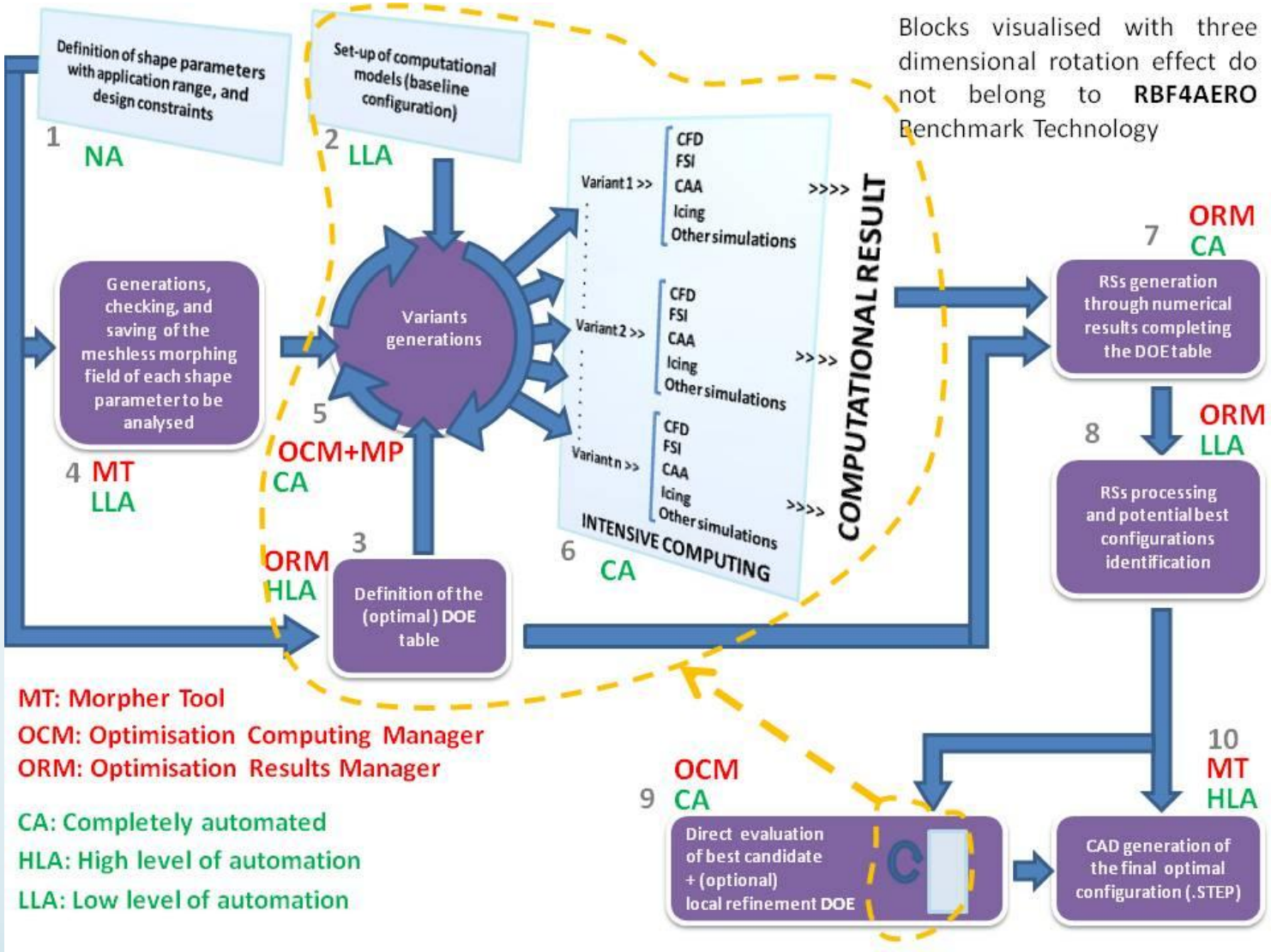
PIT1 is the integrated system designed to develop the RBF4AERO Benchmark Technology that makes the RBF4AERO process and strategies usable by the professional industrial users.
It is mainly constituted by the following software components:

1. Morphing Tool that generates numerical model variants;
2. Optimisation Computing Manager that schedules and manages simulations;
3. Optimisation Results Manager (DOE tables, metamodels, adjoint models, etc);
4. Optimisation Environment GUI that allows the user to manage the constituting components.



RBF4AERO Benchmark Technology Infrastructure Constituting Components

BT Infrastructure Development

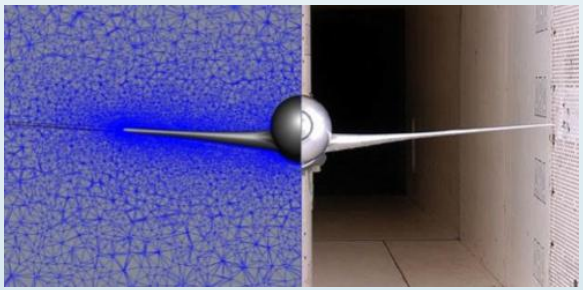


BT Verification and Testing

Since the Benchmark Technology deals with several numerical strategies and approaches with elements of innovation, it needs a rationale and accurate verification and testing process. Such a process will be achieved pursuing two different verification pilot lines:

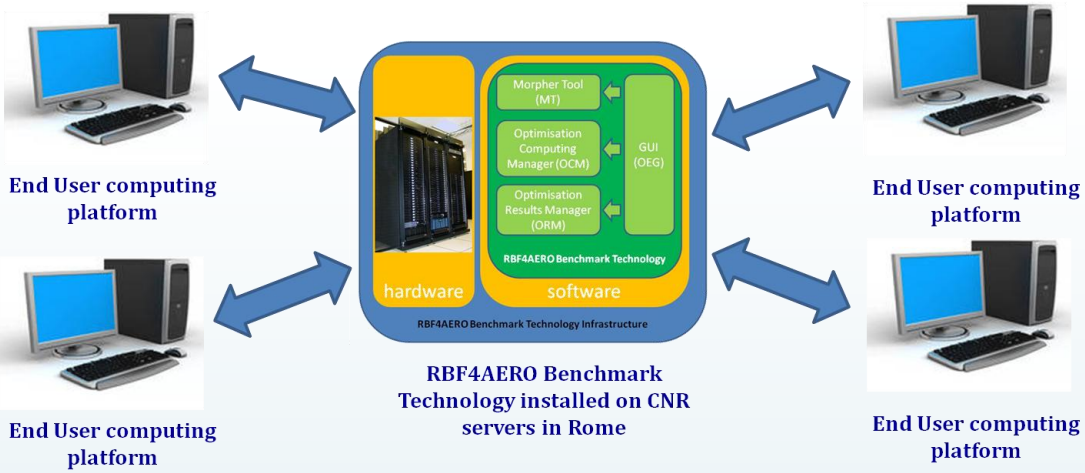
1. **verification** of RBF4AERO optimisation approach against documented **low-** and **medium-size models** (PIT2);
2. **testing** of RBF4AERO optimisation performances against **real case applications of industrial use** (PIT3).

Relating to **testing**, the background knowledge from End Users and **experimental data** available in literature and produced within the project (PIT3) will be employed as well.

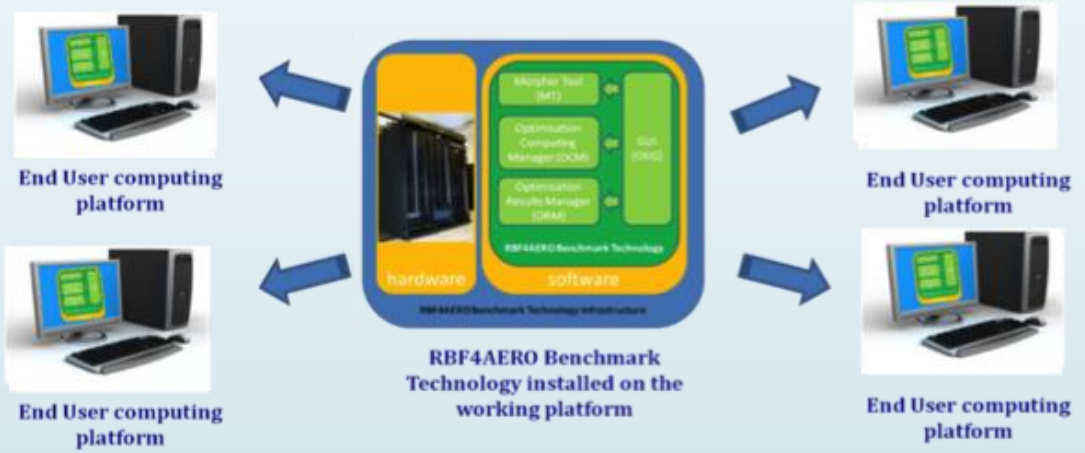


BT Verification and Testing

In the first phase of the Project (**PIT2**) the usage of the Benchmark Technology is envisaged to be performed remotely (**7 test cases**).



In the second phase of the Project (**PIT3**), the use of the Benchmark Technology is principally envisaged on End Users' own computing platforms (**9 test cases**).



BT Testing

Three test cases of industrial interest were selected to confirm the capability of the BT in obtaining the desired alteration and to quantify the accuracy of the morphing action (**PIT3**).
In particular, the aerodynamic optimisation test cases (internal and external) scheduled to verify consistency of the proposed tool will specifically concern:

1. LPT (Low-pressure Turbine) blade optimisation;
2. Turbine internal cooling (TIC);
3. CROR (Contra-Rotating Open Rotors).

Shape Optimization

Relating shape optimization approach, the **Stochastic optimization tool based on Evolutionary Algorithms** will be used:

- **DoE Table Generation module:**
  - Random sampling.
  - Full factorial design.
  - Fractional factorial design.

- **Evolution Operators module:**
  - Apply the evolution operators (parent selection, crossover, mutation) to define the new population of candidate solutions to be evaluated.

- **Response Surface Methods (RSM) module:**
  - Build RSM based on a DB of evaluated individuals.
  - Use RSM to approximate the objective function value(s) of a new generation of candidate solutions.

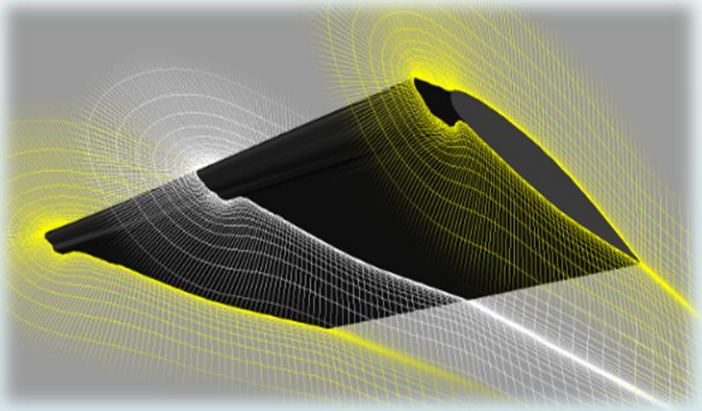
FSI

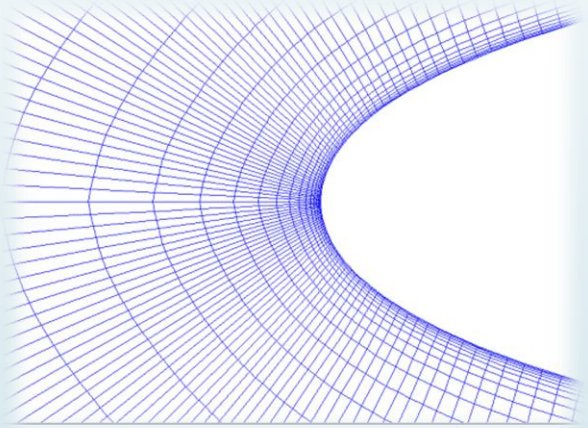
FSI problems will be managed according to three techniques:

- **Analytic method**: exploits the simplified calculation of structure modes;
- **Two-way coupling**: CFD pressures are mapped onto the FEM mesh using RBF and FEM deformations are used to update the CFD mesh using the mesh morphing tool;
- **Modal superposition**: deformed configurations, obtained by properly combining modal modes of the structures, are used to drive the mesh morphing.

Ice Accretion

The characteristic **accuracy** of the RBF mesh morphing approach allows to locally **control** the computational model nodes so as to adjust the geometry during time in function of ice profiles.
Exploiting such a capability, the ice formation on specific areas of the external surfaces of 2D and 3D models will be simulated according to a pre-defined growth (**constrained** approach) and evolution model (**"on the fly"** approach).

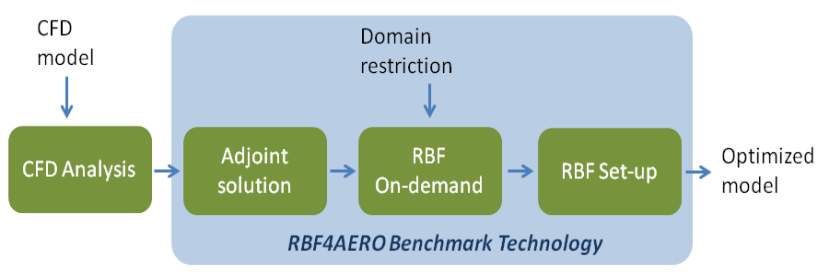




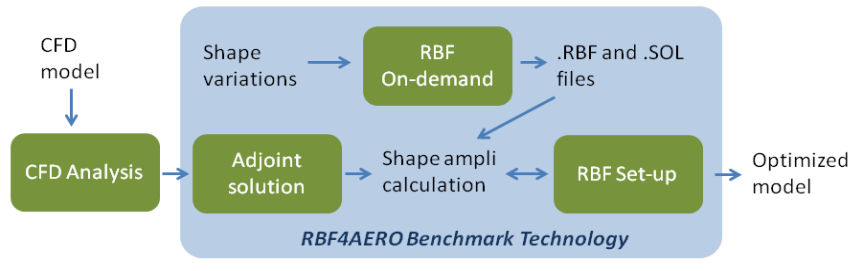
Adjoint-Morphing Coupling

In the RBF4AERO Benchmark Technology two main strategies will be available for the adjoint-morphing coupling:

- **Adjoint Sculpting**: after the CFD analysis, the adjoint solution can be used as input for the shape modifications. Several regions of the same domain can be individually controlled so that a convenient parameterization can be used to conduct the optimization.



- **Adjoint Preview**: this strategy will allows to exploit adjoint information with respect to a set of prescribed geometry changes, in order to identify the design variables with the greatest impact on the objective functions.



Contacts

Thank you for your kind attention!

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E-mail: *emiliano.costa@dappolonia.it*

Project Website: *www.rbf4aero.eu*

RBF4AERO

4th International Workshop on Flight Physics & Aircraft Design
easn
27-29 October, 2014
Aachen, Germany

Morphing Technique: Mesh quality verification

Costa, E., Travostino, G., D'Agostini, G., Biancolini, M.E., Groth, C..

SEVENTH FRAMEWORK PROGRAMME

Summary

- Introduction
- Icing through RBF mesh morphing
- Flow and icing conditions
- 2d airfoil set-up
- 2d airfoil results
- 3d airfoil set-up
- 3d airfoil results
- Concluding remarks

Introduction

In this presentation the approach adopted in the RBF4AERO project to simulate ice growth on airfoils and preliminary results obtained on 2D and 3D models are described.

The first set of simulations concerning ice accretion foresees that ice profiles / surfaces are predicted in terms of surface nodes displacements through an in-house developed tool and, then, applied to the computational model by exploiting the precise control of the morphing action on mesh nodes position.

The morpher tool (RBF Morph™) embedded in the RBF4AERO Benchmark Technology will allow to simulate ice growth through data identifying the coordinates of mesh nodes and their displacement.

Introduction

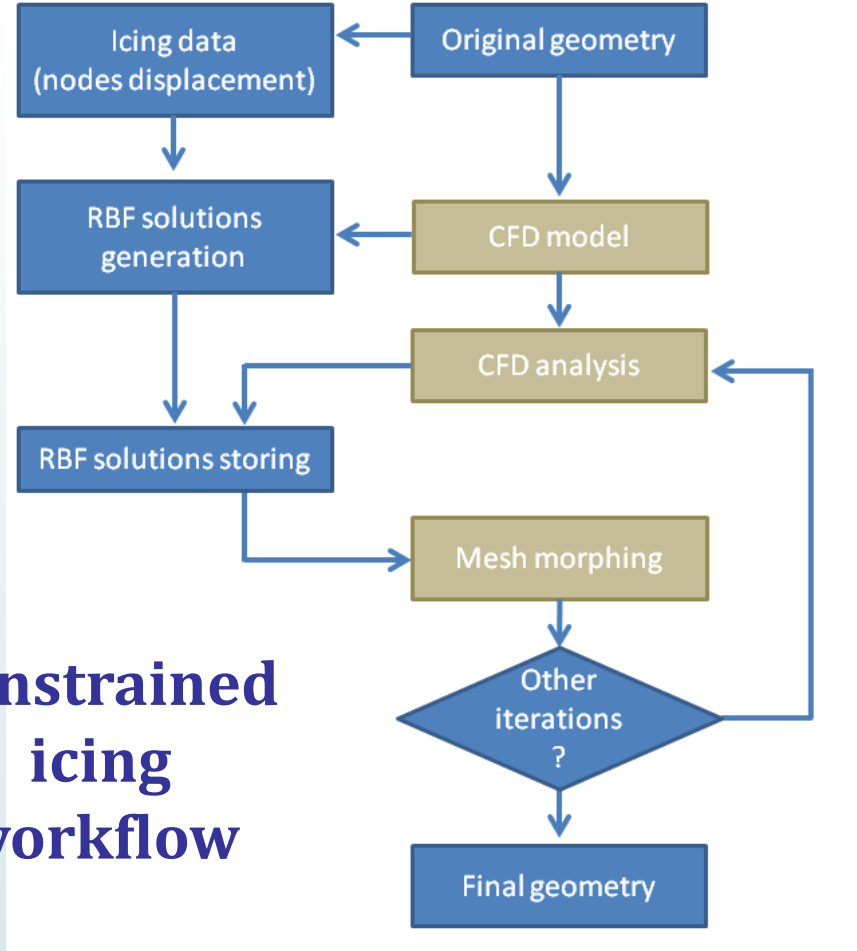
Flying in icing atmospheric conditions can be a serious safety problem because it can be such to cause a variation in the overall vehicle fluid dynamics. In fact, lifting surfaces icing causes not only stall to occur at lower AoAs, but an uneven ice distribution can diminish dangerously the vehicle manoeuvrability.

Two methodological approaches, envisaged to be put in practice in the Project, are icing simulation through the imposition of already calculated profiles (**constrained**) at specific times and "**on the fly**" directly during CFD computing.

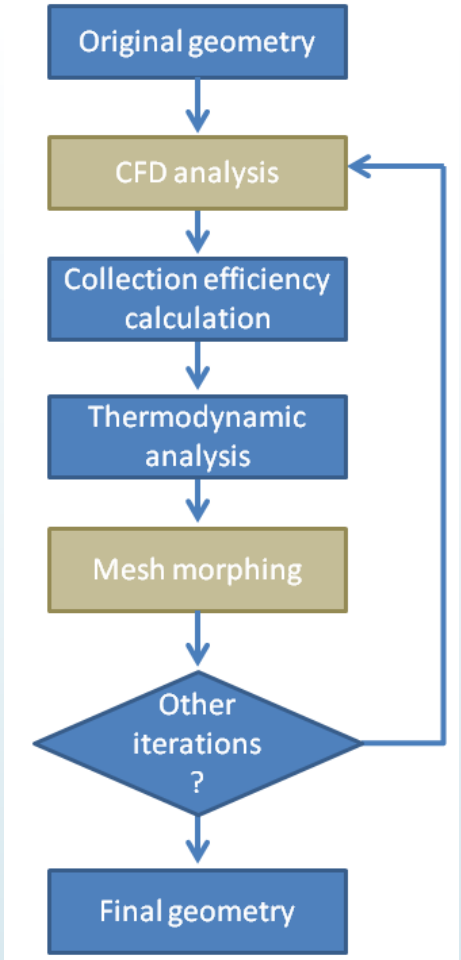
The results related to the first approach only are the aim of the presentation.

Ice formation on an aircraft's wing

Icing through mesh morphing



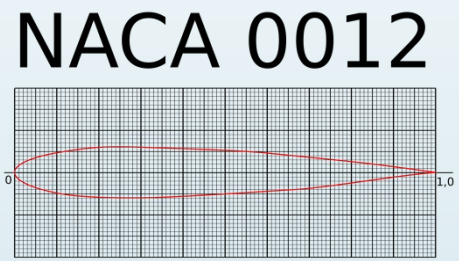
Constrained icing workflow



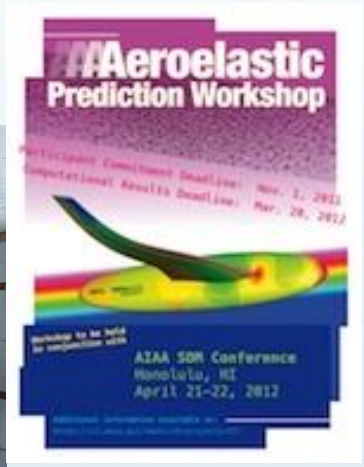
"On the fly" icing workflow

Flow and icing conditions

The geometries used are NACA0012 and HiReNASD model (AePW). The flow and icing conditions imposed for both numerical models are Mach=0.5, Re=$11.56 \cdot 10^6$, 4650 ft and Delta Isa -25°.
The AoAs considered were 0, 2 and 4 degrees, the MVD was 20 μm, whilst the ice growth was simulated till 21 minutes.



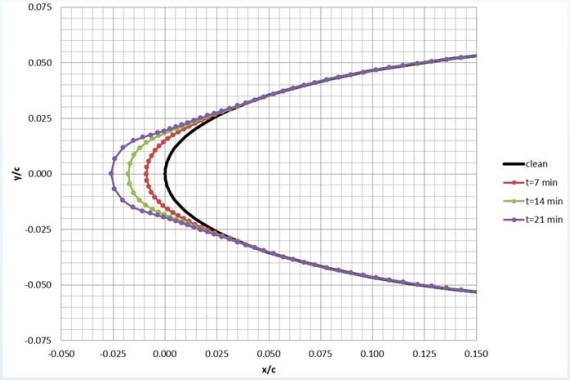
NACA0012 airfoil



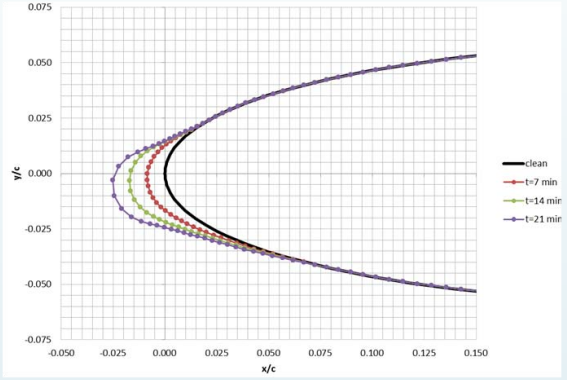
HiReNASD model

2d airfoil set-up

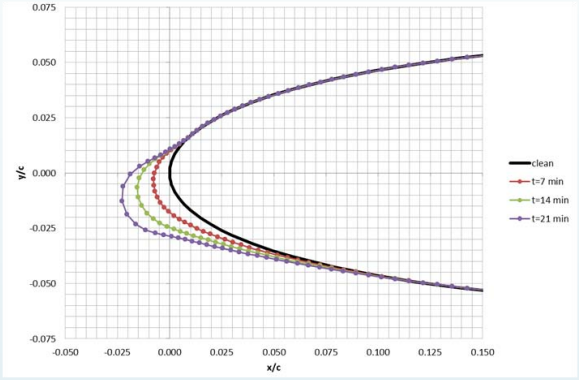
The icing profiles at 7, 14 and 21 minutes were evaluated by means of CFD++® ice accretion tool. Such profiles were utilized to define data needed by the morpher tool to apply surface mesh smoothing.



AoA=0°



AoA=2°

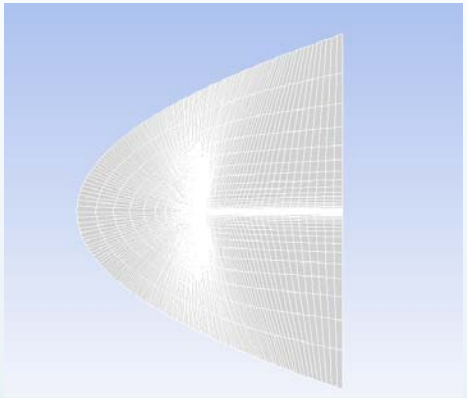


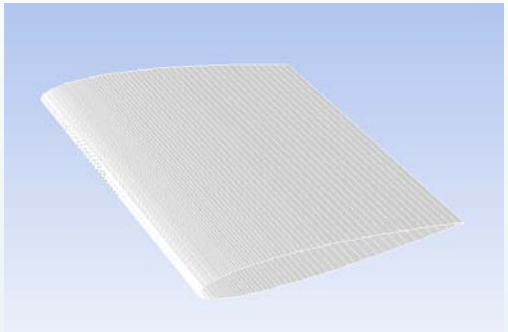
AoA=4°

2d airfoil set-up

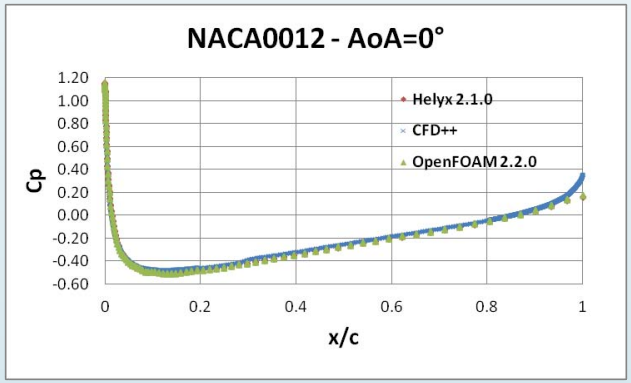
A hexahedral structured mesh composed by 9.8 ·10^3 cells was utilized to gain the steady solution for the different values of AoA. CFD simulation were run using HELYX®, OpenFOAM®, ANSYS® FLUENT® and CFD++®.

Volume mesh for 2d airfoil

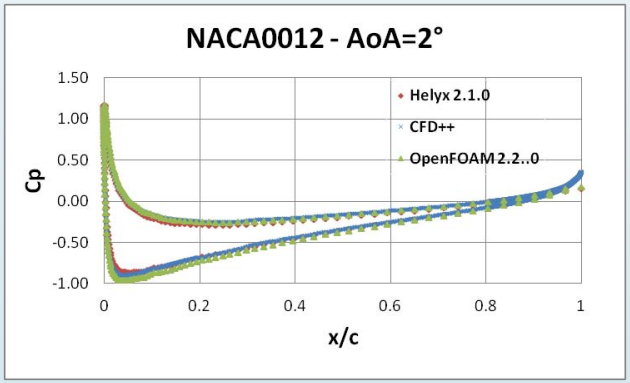




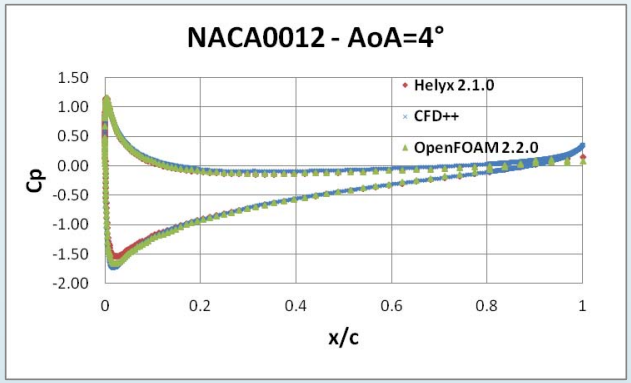
Surface mesh of 2d airfoil



AoA=0°



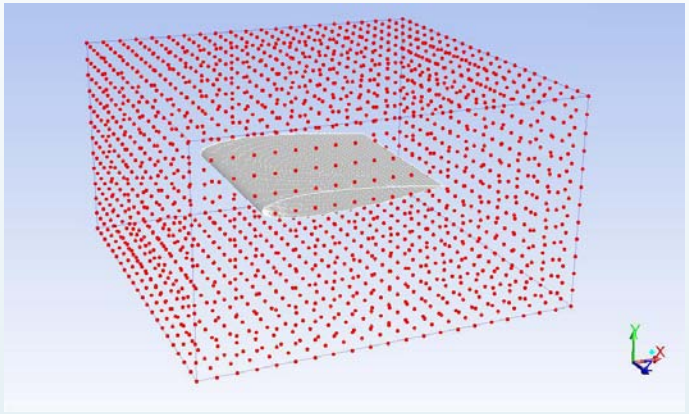
AoA=2°



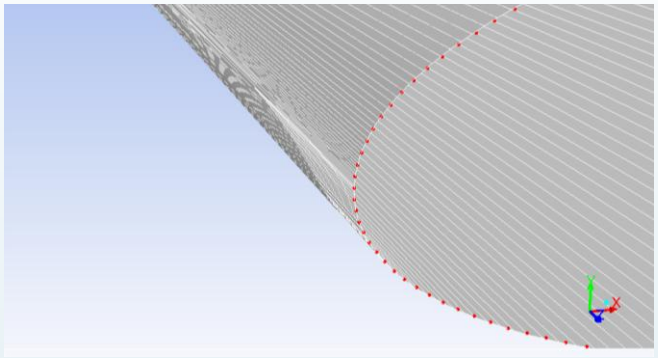
AoA=4°

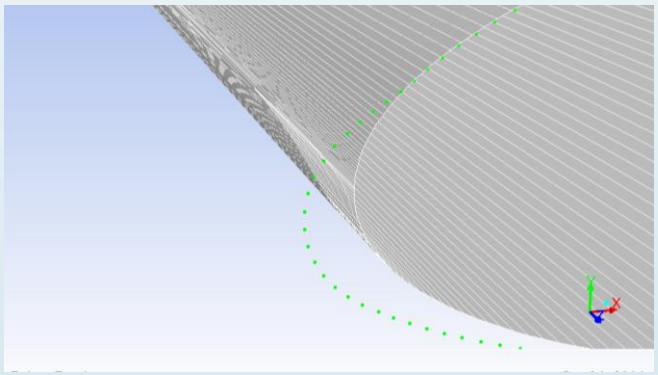
2d airfoil set-up

The RBF solutions were generated adopting the two-step procedure of the morpher. Nodes displacements were imposed to the source nodes extracted from mesh surface and a domain encap was used to delimit morphing.



Source nodes on domain encap

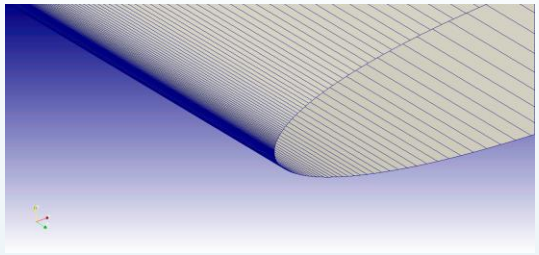
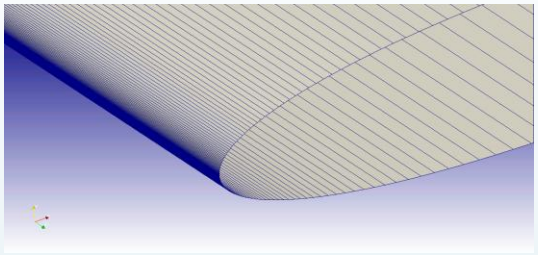
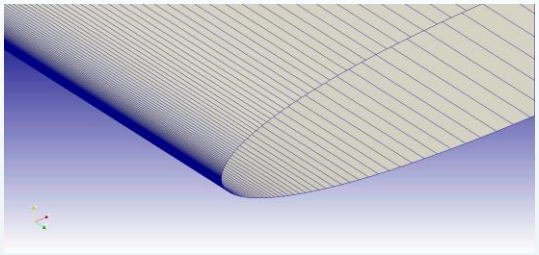
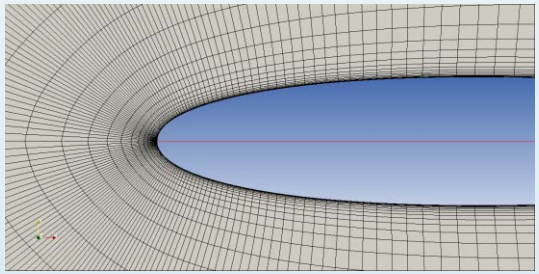
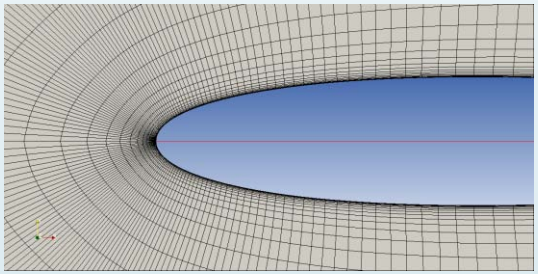
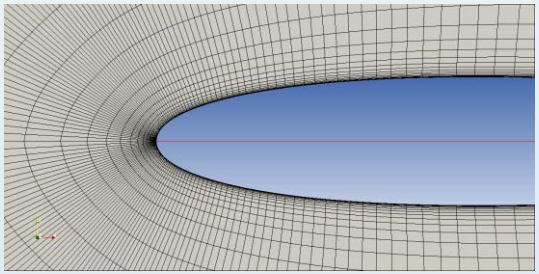




Source nodes position before and after morphing (7 min – AoA=4°)

2d airfoil set-up

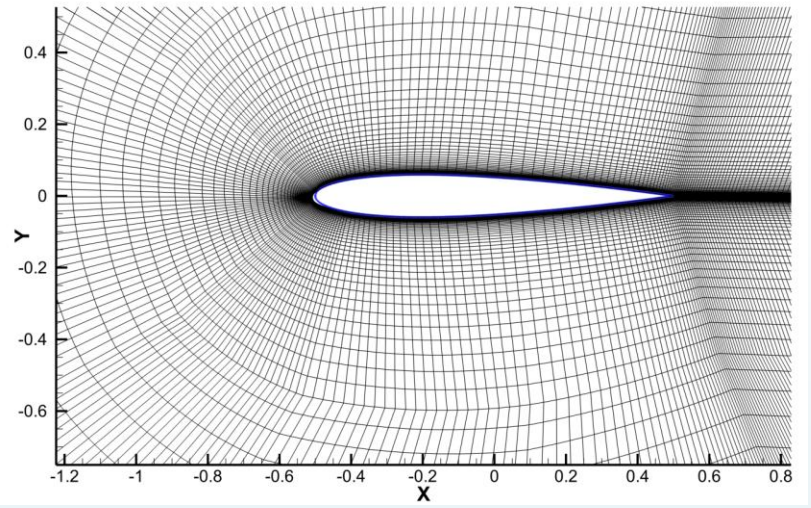
The numerical analyses concerning icing were run by means of OpenFOAM® and CFD++® using batch files.

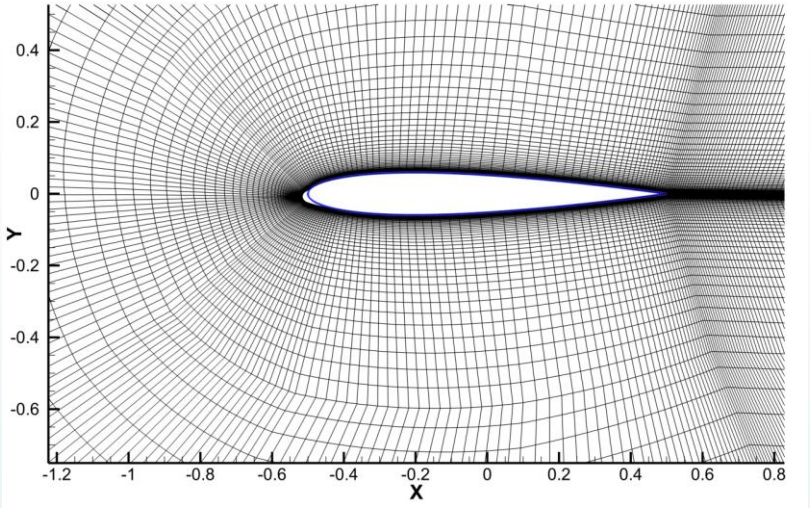







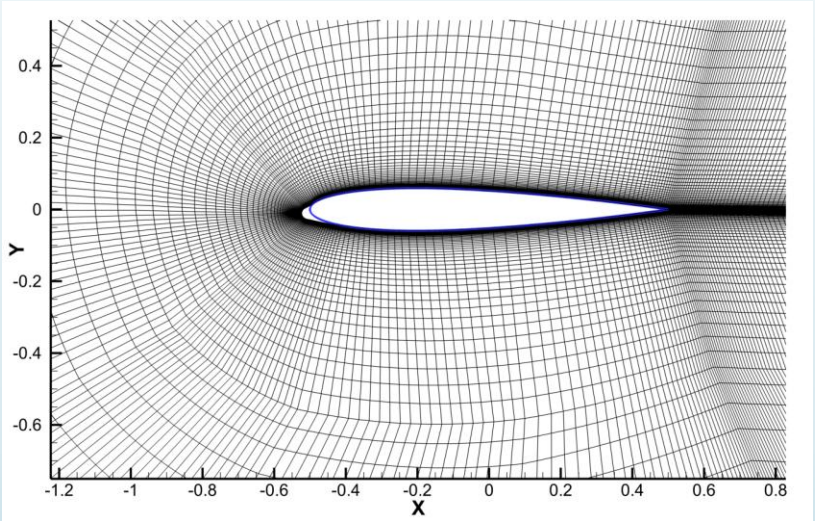
AoA=0° **AoA=2°** **AoA=4°**

2d airfoil set-up

Dedicated grids were created in order to run 2D CFD++® simulations.

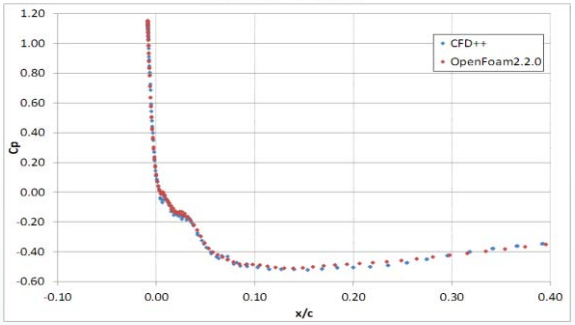




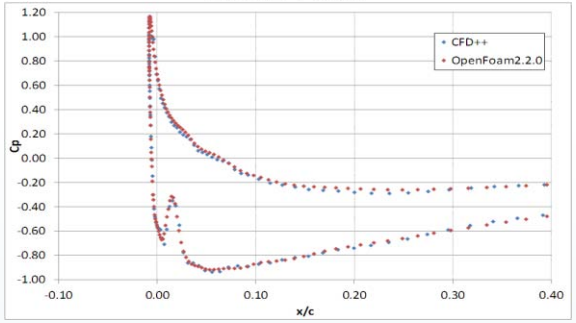


2d airfoil set-up

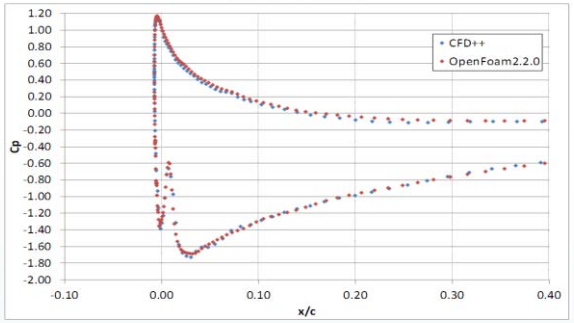
AoA0-7min



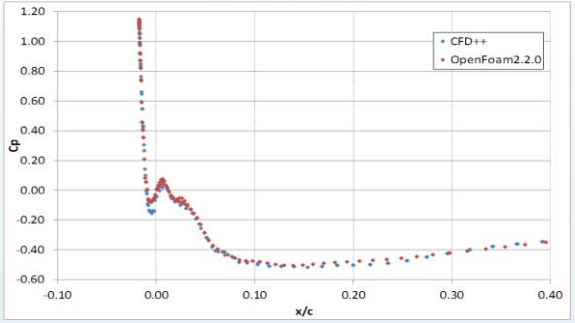
AoA2-7min



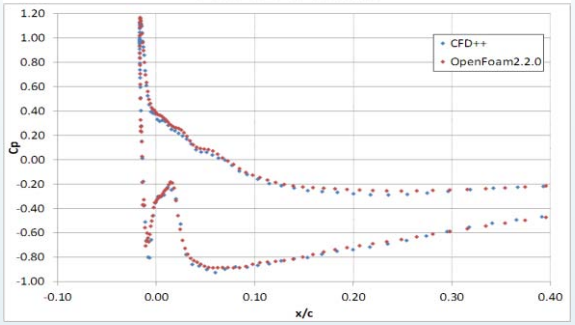
AoA4-7min



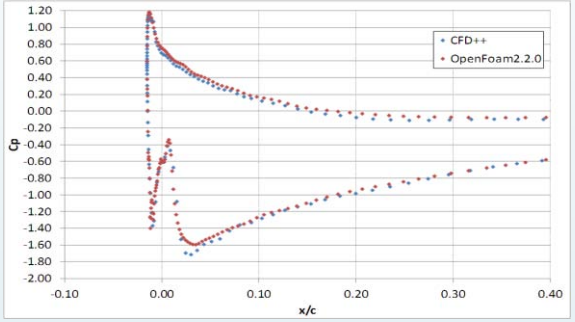
AoA0-14min



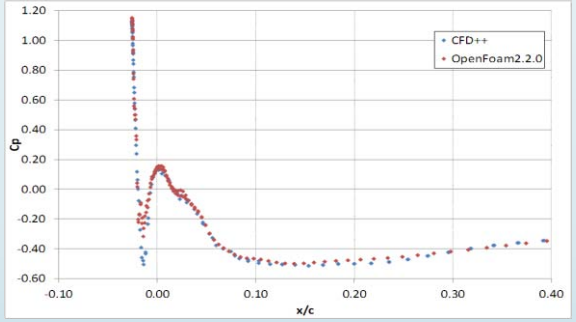
AoA2-14min



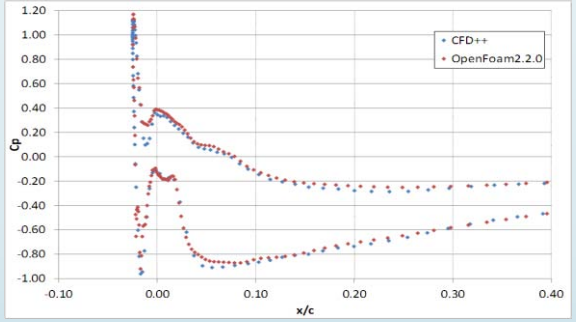
AoA4-14min



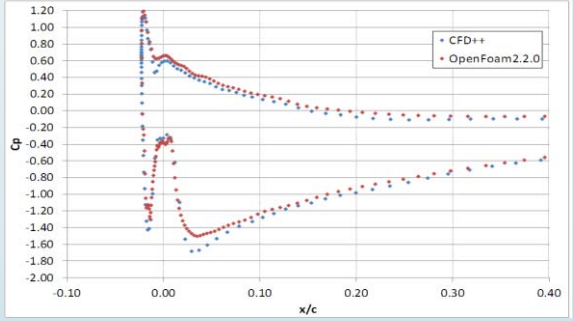
AoA0-21min



AoA2-21min

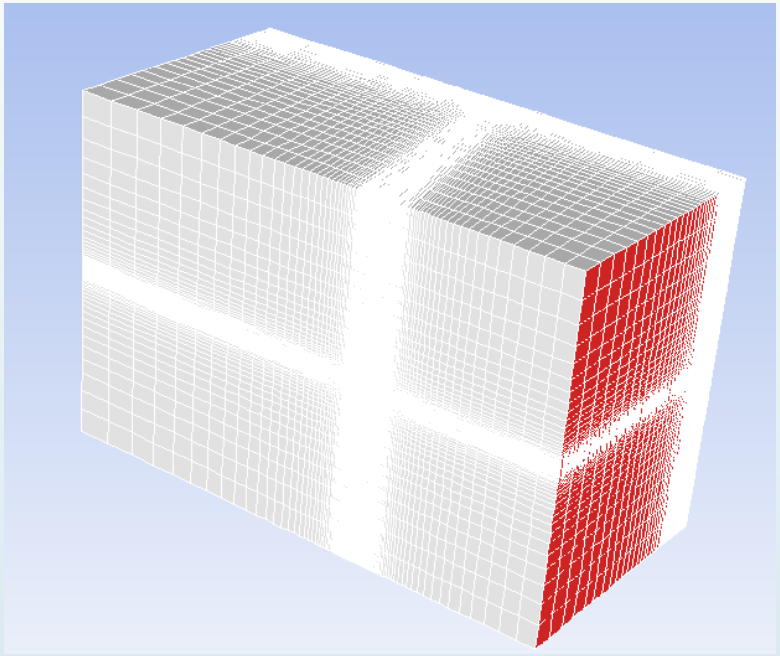


AoA4-21min

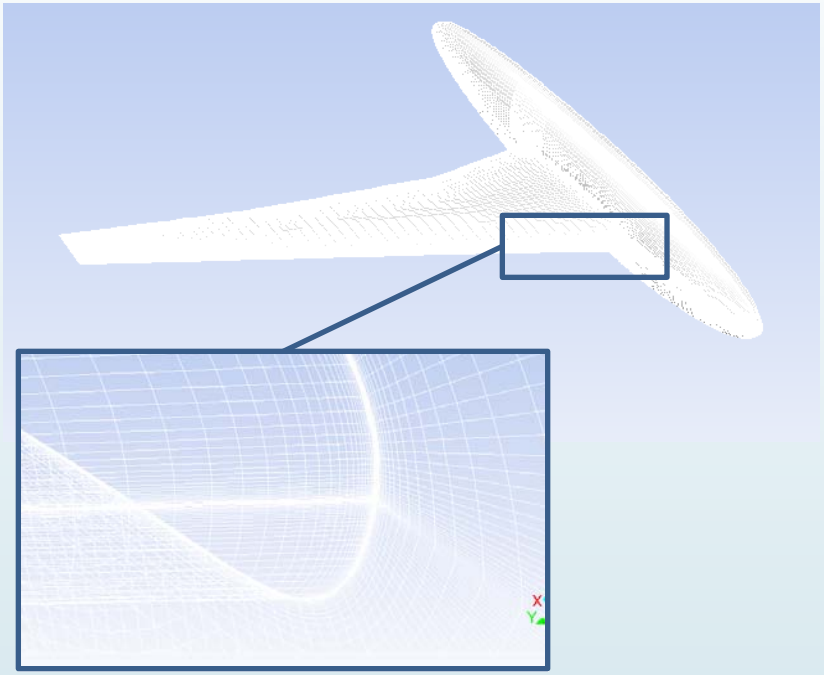


3d airfoil set-up

A hexahedral structured mesh composed by $8.9 \cdot 10^6$ cells was used to perform CFD + icing simulations.



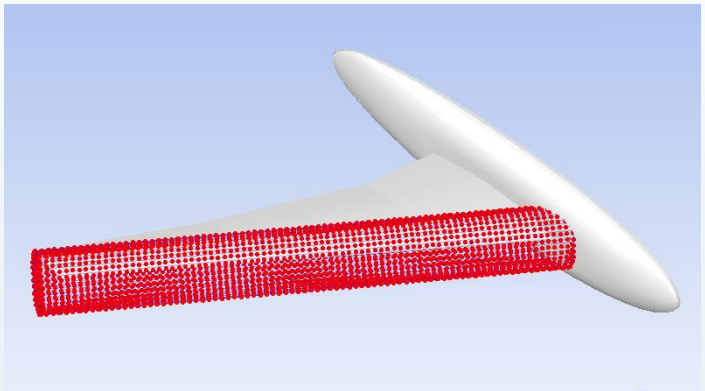
Volume mesh

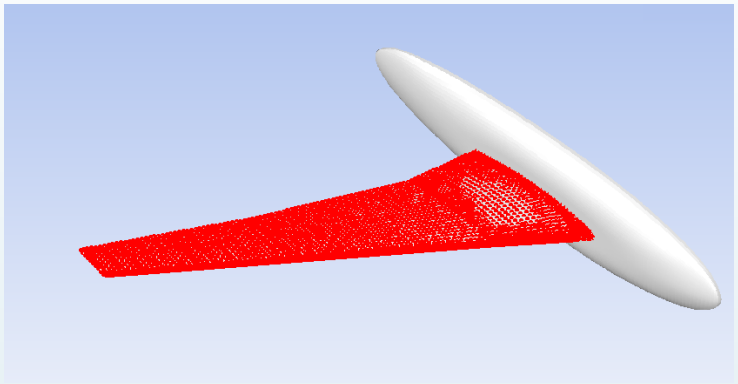


Surface mesh of HiReNASD

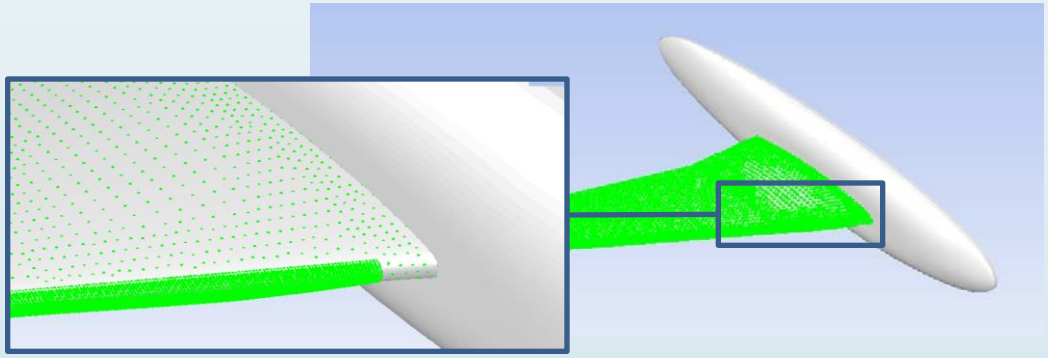
3d airfoil set-up

To generate the RBF solutions, in the case of the HiReNASD model the same strategy employed for NACA0012 was adopted.





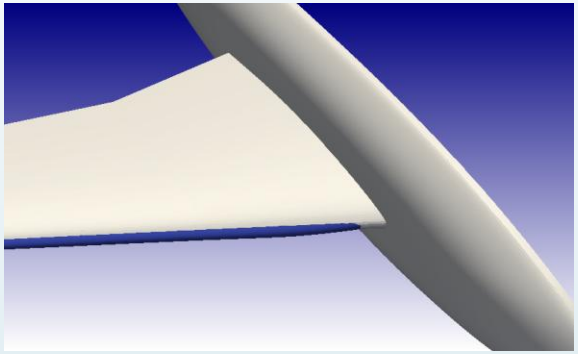
Source nodes on Domain encap



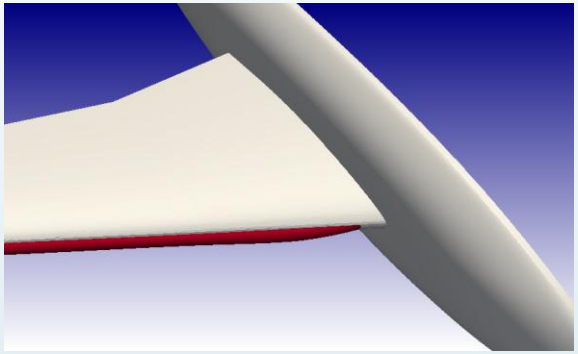
Source nodes position after morphing (7 min)

3d airfoil set-up

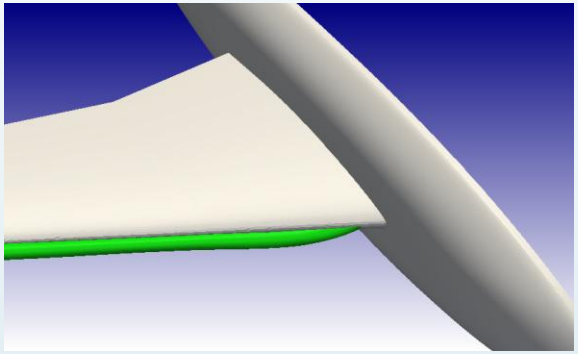
The numerical analyses concerning icing were run by means of ANSYS® FLUENT® and RBF Morph™ using a journal file.



Ice surface at 7 min



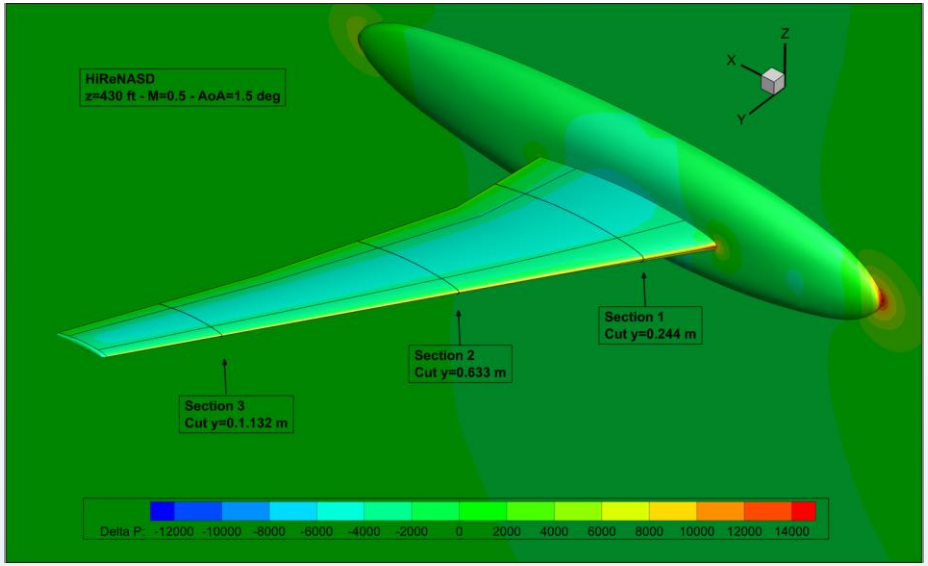
Ice surface at 14 min

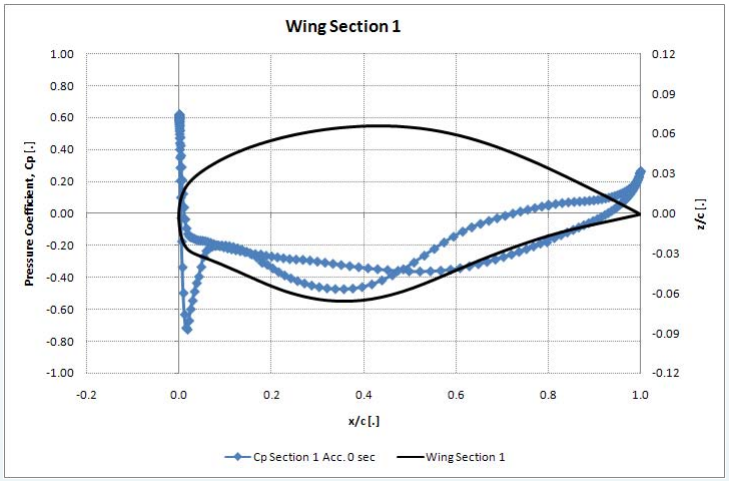


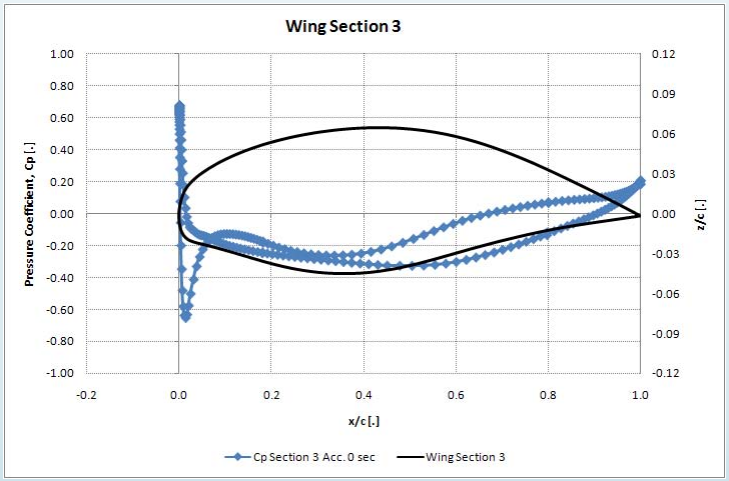
Ice surface at 21 min

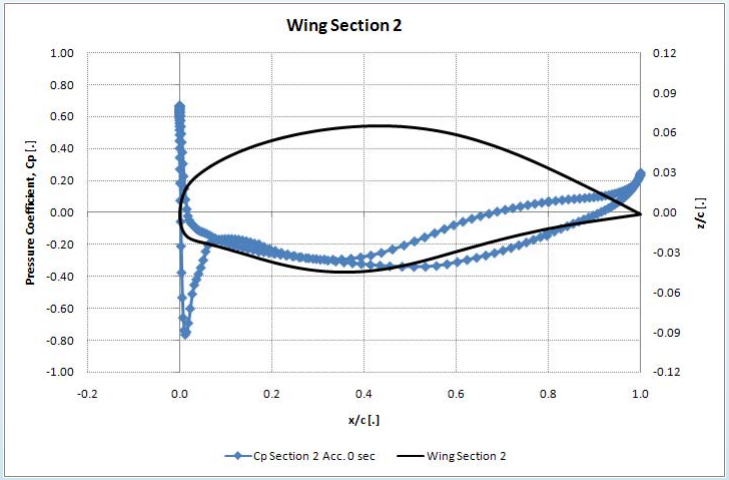
3d airfoil results

Cp profiles at different wing sections without ice accretion (baseline)



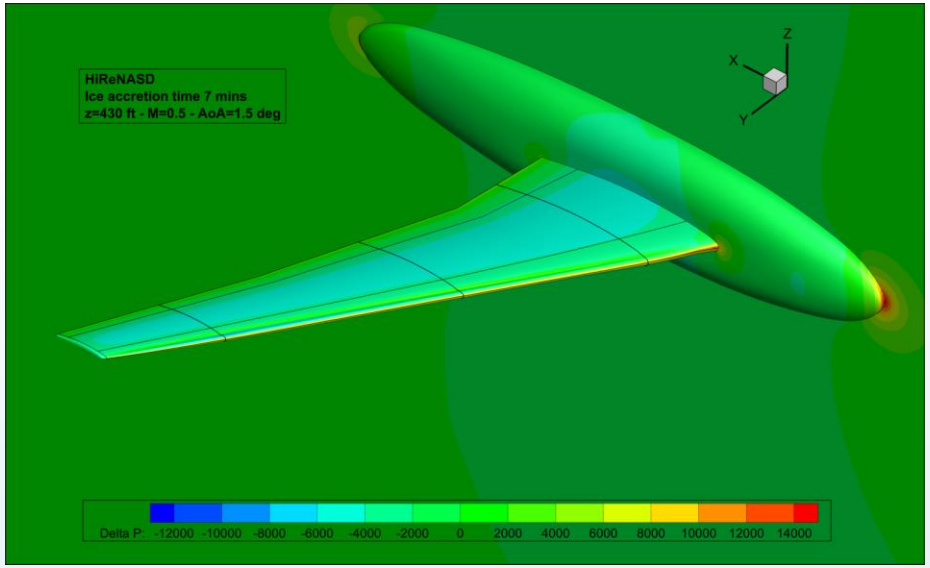


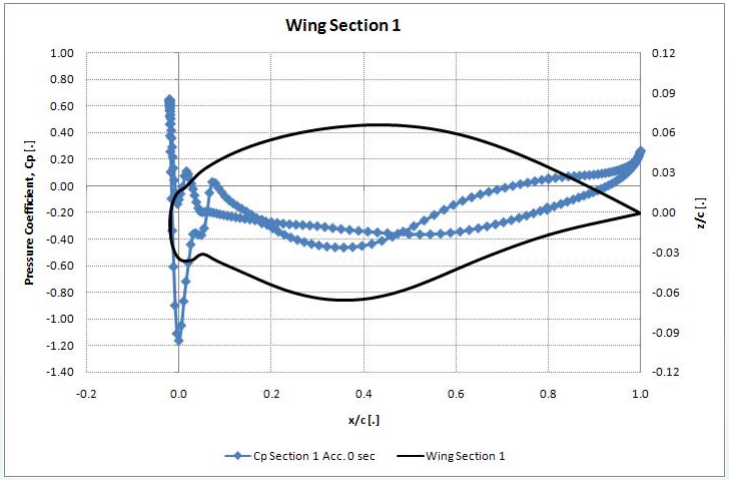


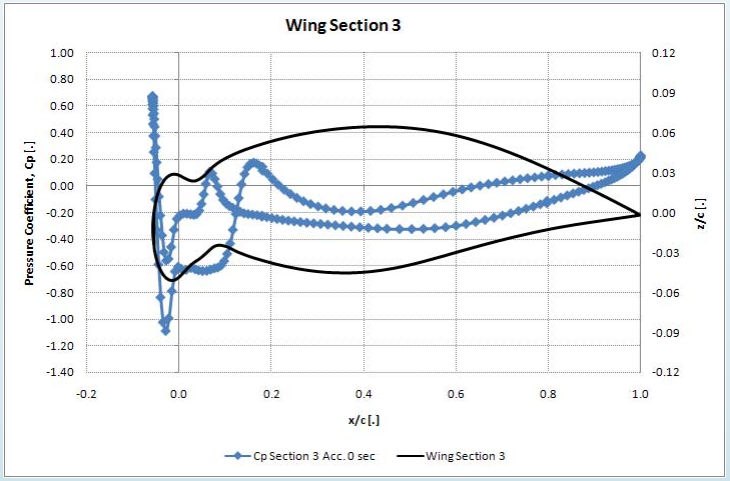


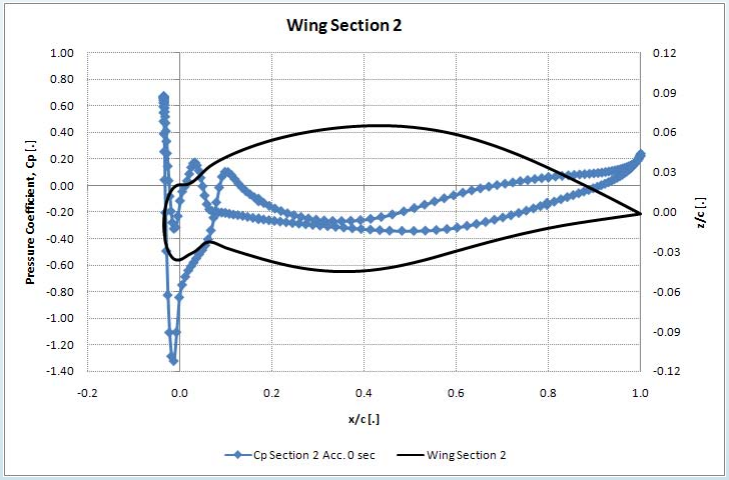
3d airfoil results

Cp profiles at different wing sections at accretion time t=7 min



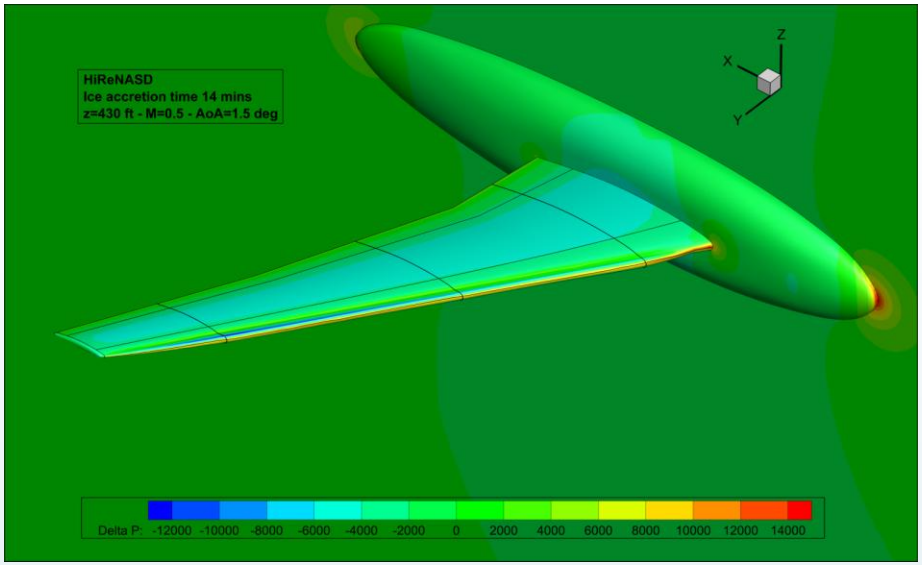


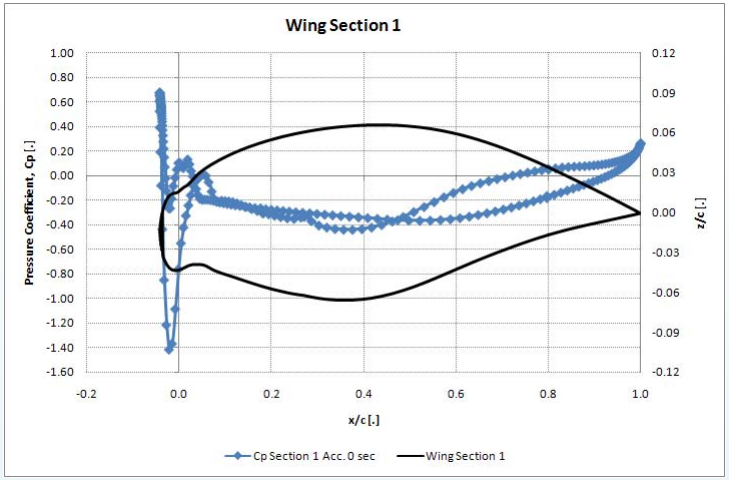


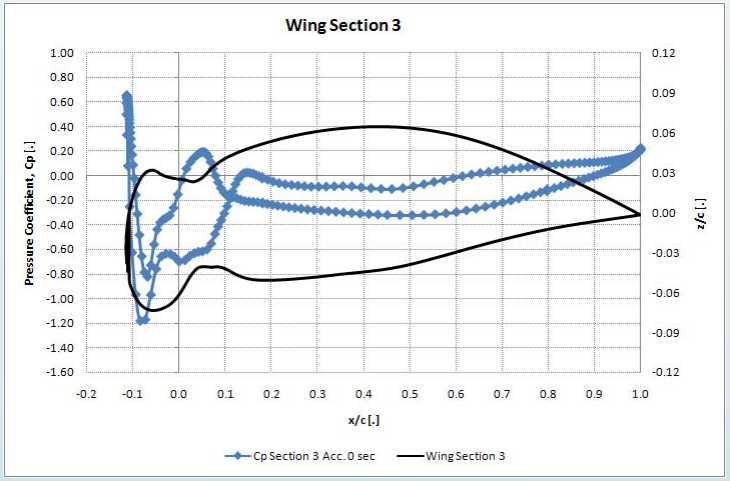


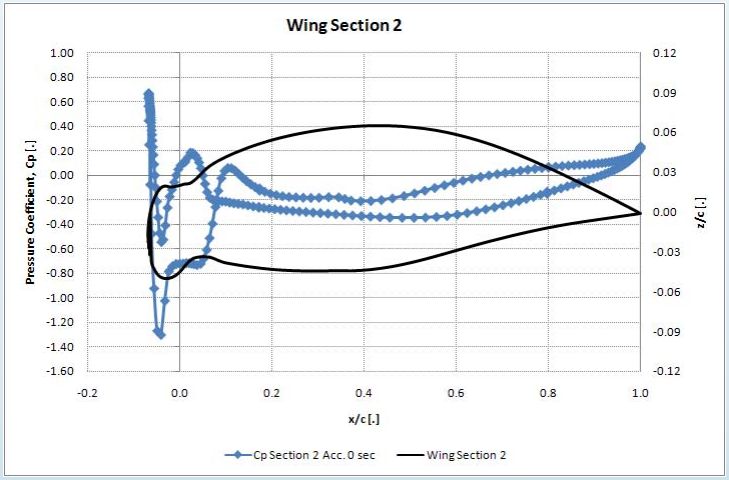
3d airfoil results

Cp profiles at different wing sections at accretion time t=14 min



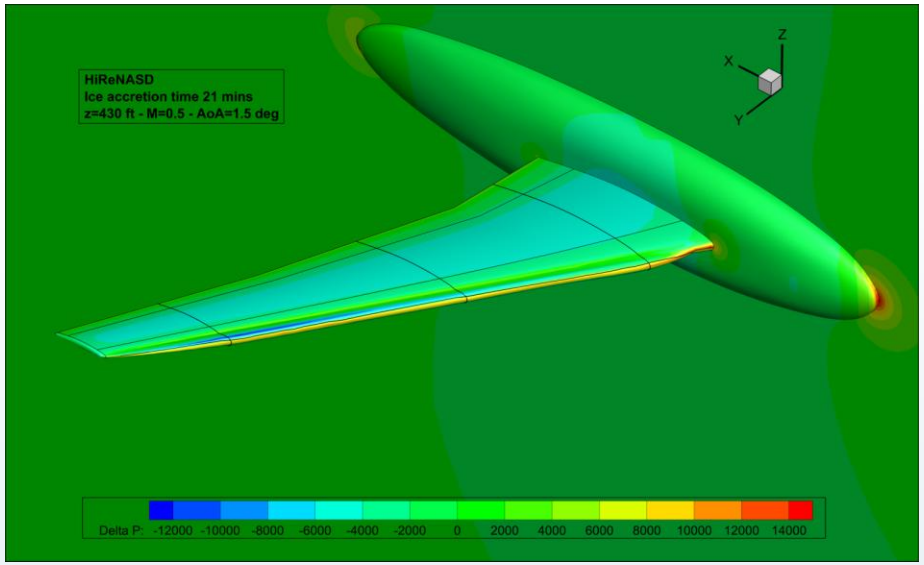


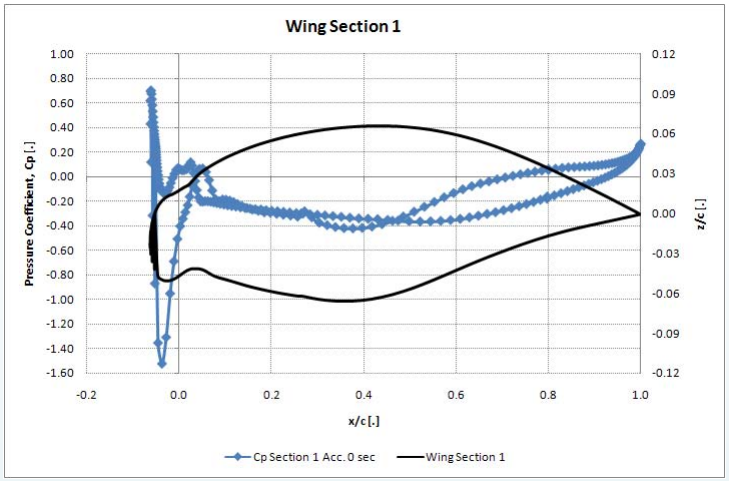


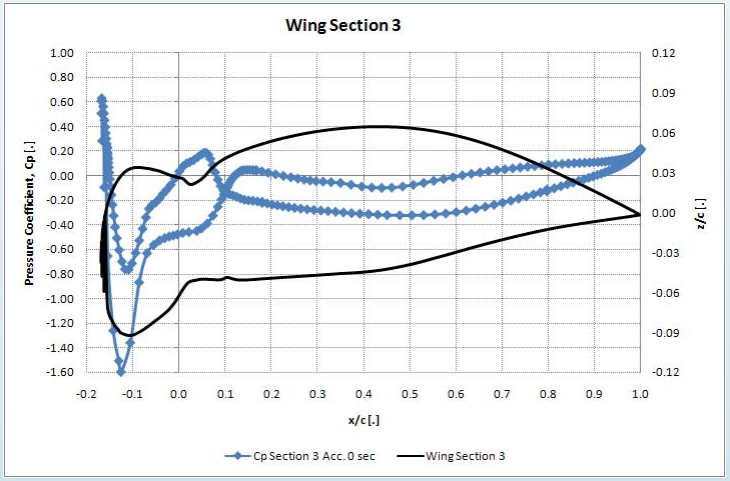


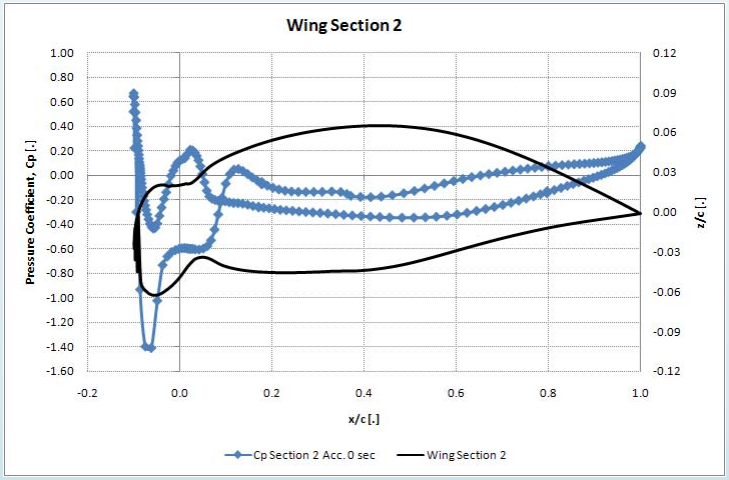
3d airfoil results

Cp profiles at different wing sections at accretion time t=21 min









Concluding remarks

- According to the **constrained** approach, the RBF mesh morphing based method and strategy, adopted to simulate icing growth on 2d and 3d models, turned out to be effective and stable.
- Precise control of surface mesh was evidenced even for a high-challenging 3d growths.
- To gain satisfactory and accurate results, the mesh of the computational model is required to be structured and of high quality.
- Considering what gained so far, the mesh morphing numerical strategy is a good candidate to handle the "**on the fly**" approach. Referring to this latter topic, some studies performed by UTV on 2d and 3d models, currently on-going, have provided promising results.

RBF4AERO

4th International Workshop on Flight Physics & Aircraft Design
easn
27-29 October, 2014
Aachen, Germany

RBF4AERO Project

Explorative Studies

Costa, E., Lagasco, F., Porziani, S., Biancolini, M.E., Groth, C., Cella, U., Gregor, V., Andrejasic, M., Giannakoglou, K., Asouti, V., Papoutsis, V..

SEVENTH FRAMEWORK PROGRAMME

Summary

- FSI Study
  - Introduction
  - Modal Superposition Set-up
  - Numerical Results
  - Concluding Remarks
- Shape Optimization Analysis
  - Introduction
  - Baseline Model and Results
  - Optimization Process
  - Optimal Shape and Results
  - Concluding Remarks
- Morphing-adjoint Coupling
  - Preliminary results

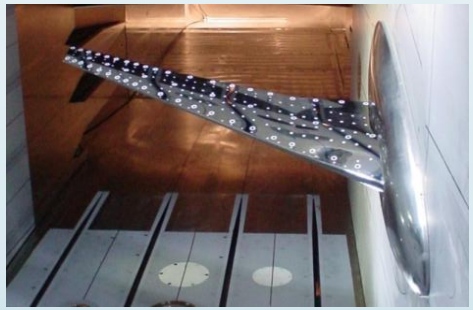
Introduction

The following FSI analysis is part of a set of preliminary studies for the RBF4AERO Benchmark Technology development, whose aim is to explore the actual capabilities of the RBF based mesh morphing technique.

The simulations were performed using RBF Morph™ (add-on version) and ANSYS® Fluent® , managed through ANSYS® Workbench™.

Two approaches for FSI, envisaged to be implemented in the Project, were tested on HIRENASD model deeply investigated in NASA AePW:

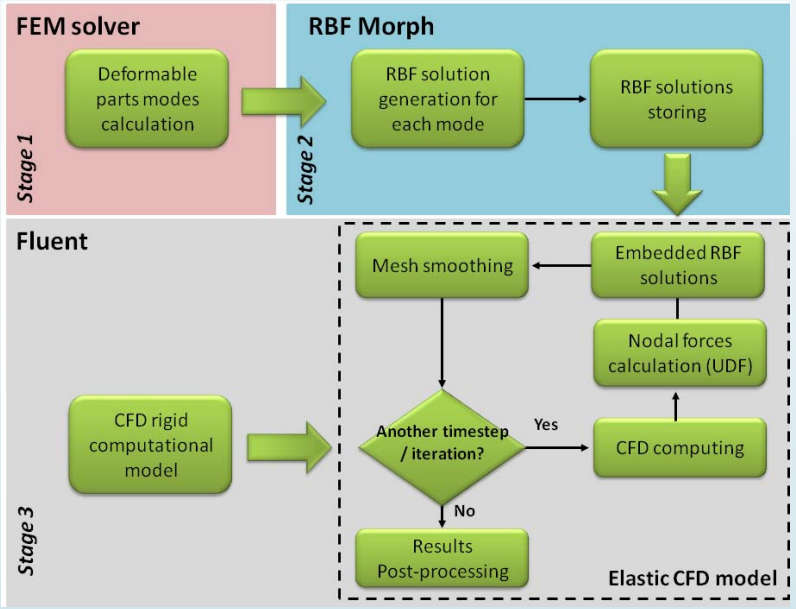
- **Two-way**: it iterates the exchanging of data between the CSM (via pressure mapping) and CFD model (via morphing) until convergence is achieved;
- **Modal superposition**: structure's modes are imported into the CFD model using RBF Morph so that it is made "elastic" (morphing).



Modal Superposition Set-up

Modal basis was validated using, as reference, FEM results with mapped CFD pressure (**two-way**). The workflow proposed to apply **model superposition** approach is composed by three sequential stages:

- **Stage 1**: modes calculation
- **Stage 2**: RBF solutions generation and storing
- **Stage 3**: FSI computing using the CFD model linked to RBF solutions



Modal Superposition Set-up

Modal basis needed for modal superposition FSI analyses was obtained by means of NX Nastran employing the tuned FEM model relating to AePW activity (357 545 nodes, 225 112 elements). The first six modes were extracted.

Mode 1 - 25.5 Hz

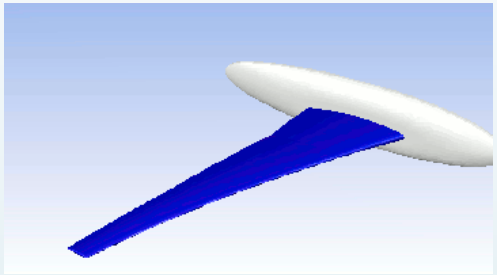
Mode 2 - 80.2 Hz

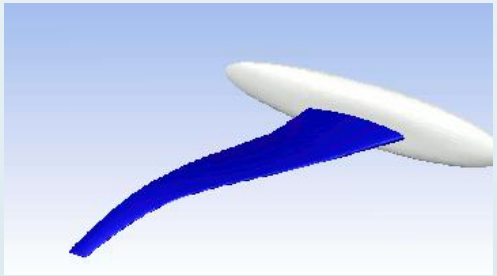
Mode 3 – 106.1Hz

Mode 4 –160.3 Hz

Mode 5 – 241.9 Hz

Mode 6 – 252.2 Hz





Morphed configuration corresponding to mode 1 and 2

Modal Superposition Set-up

A $13.2 \cdot 10^6$ cell mesh (SOLAR unstructured grid from DLR & NASA) was employed to gain the steady solution using Nitrogen as medium operating at 136180 Pa and 278.5 K (Ma=0.8 and Re=7 10^6) with AoA of 1.5 degrees. Second order schemes and SA turbulence model were also utilized.

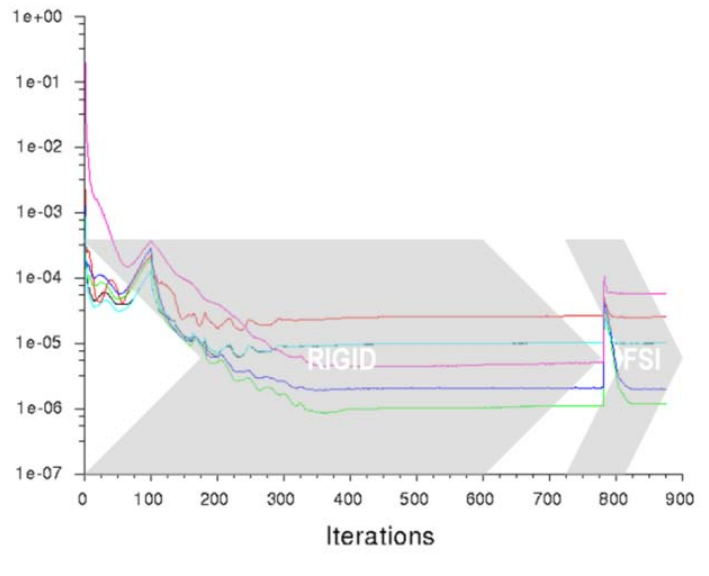
Trailing edge tip position was monitored for verification purpose.

Number of modes	Maximum wing displacement (mm)	Relative difference (%)
1	15.26	-5.64
2	14.18	1.81
3	14.18	1.80
4	14.26	1.29
5	14.26	1.29
6	14.26	1.29
Two-way (mapping)	14.44	-

Basis validation of the first six modes with respect to mapping FSI methodology

Numerical Results

The convergence of the CFD elastic model was reached after 5 mesh updating iterations using the first 6 modes (mainly to minimize the error).

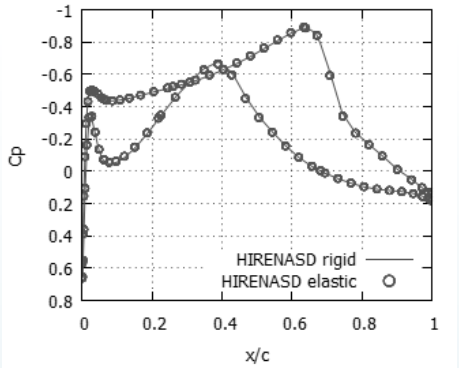


Aerodynamic coefficient	Rigid model			Elastic model			Elastic influence	
	Proposed model	NASA model	Diff. (%)	Proposed model	NASA model	Diff. (%)	Proposed model (%)	NASA model (%)
C_l	0.3567	0.3542	-0.70	0.3394	0.3373	-0.62	4.85	4.77
C_d	0.0152	0.0173	12.14	0.0144	0.0166	13.25	5.26	4.05
C_m	-0.5589	-0.5516	-1.32	-0.5291	-0.5231	-1.15	5.33	5.17

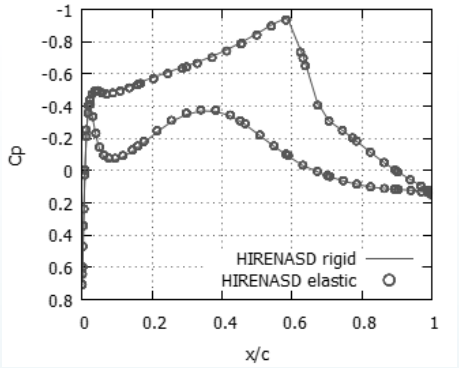
Comparison of obtained aerodynamic coefficients

Numerical Results

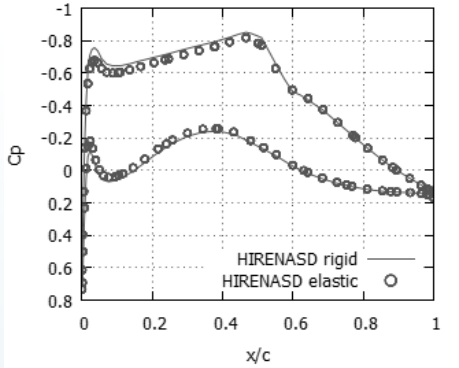
Pressure coefficient: elastic model vs rigid model



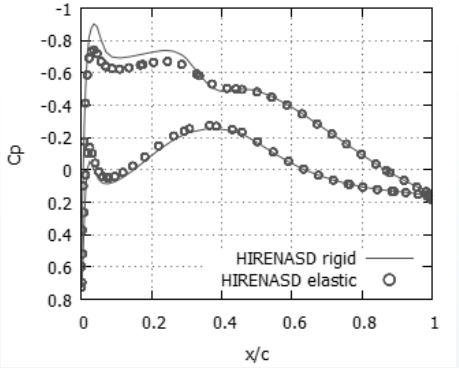
η=14.5%



η=32.3%

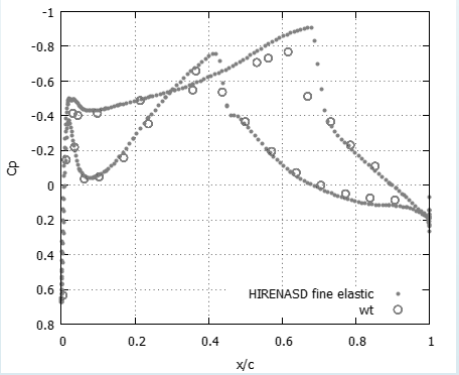


η=65.5%



η=95.3%

Pressure coefficient: elastic model vs experimental data



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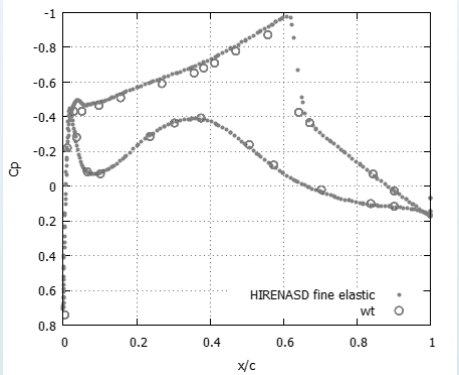

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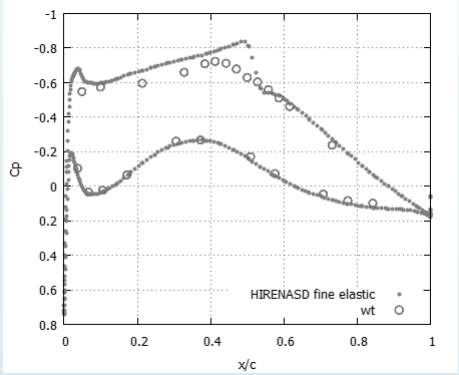

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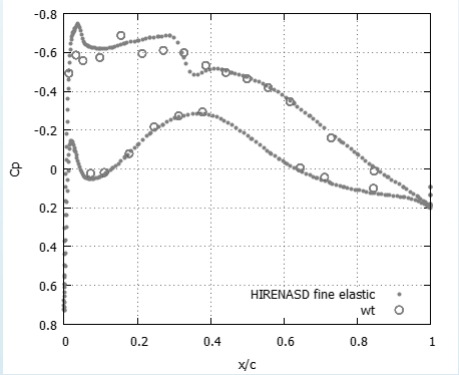

η=95.3%

Concluding Remarks

- "Flexible" CFD model can be used for both steady and transient high-fidelity FSI with a minimum overhead because overall calculation is similar to a CFD "rigid" run
- Such a methodology:
  - was and it is currently adopted to manage FSI for very large in motorsport applications (Dallara, Indy Car IR5 with $160 \cdot 10^6$ cells)
  - was adopted to perform FSI due unsteady flow due to modally-excited wing (ANSYS Inc. et al., IFASD-2013-1D paper)
  - was adopted to simulate the unsteady behaviour of a wing due to store separation taking into account for inertial effects and material damping (UNINA, UTV and ANSYS Inc., 4th Aircraft Structural Design Conference paper)
- Actual modal coordinates can be linked to FEM for stress recovery

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Introduction

- Taurus – two seat, self-launching glider
- Pipistrel d.o.o. Ajdovščina, Slovenia
- Middle wing configuration
- Performance affecting separation occurring in the wing-fuselage junction region at high angles of attack

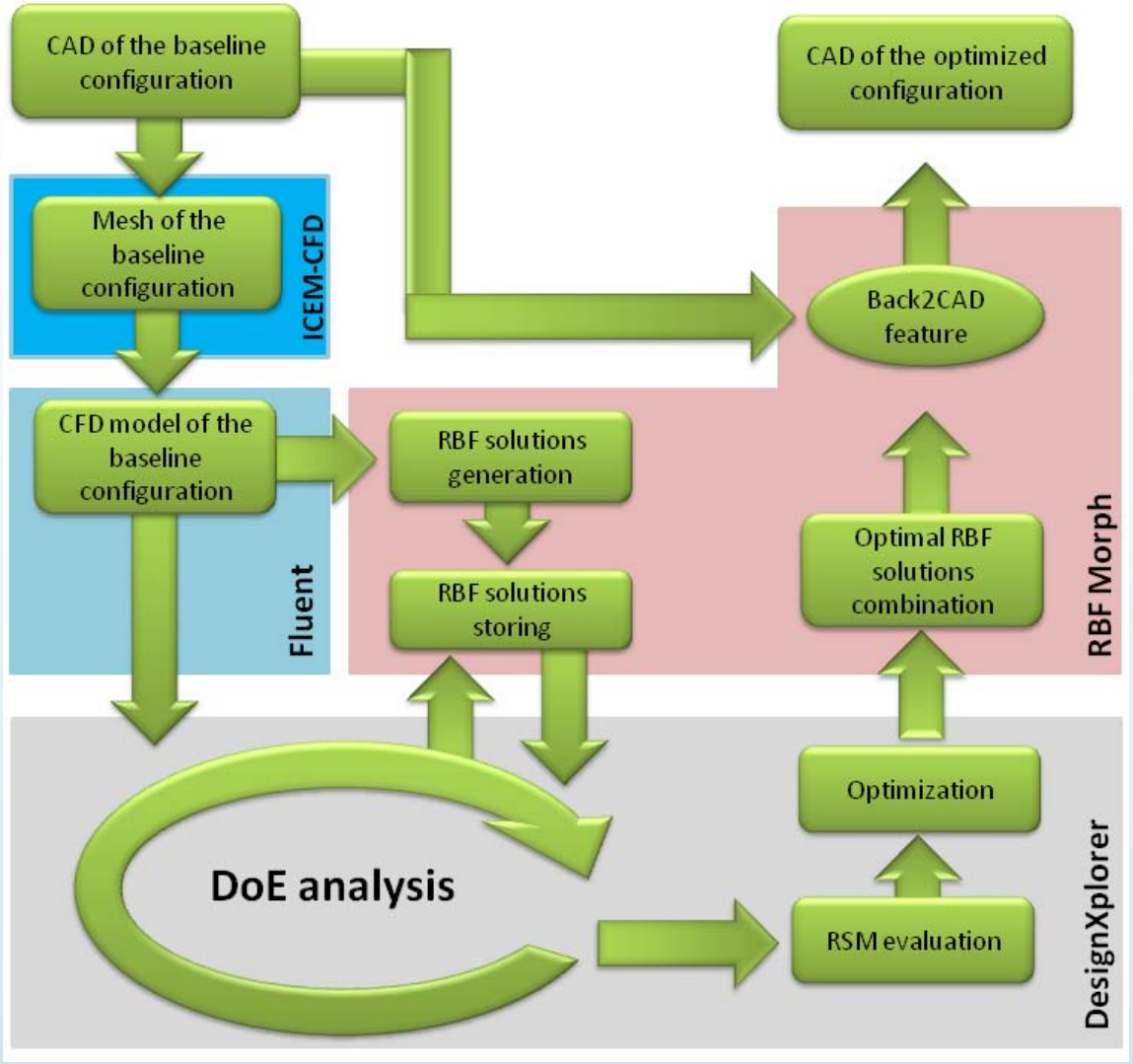
Taurus glider

- Apply a shape optimization numerical procedure based on mesh morphing to:
  - diminish the separation region
  - increase aerodynamic efficiency
- Low-demanding computational model

Flux detachment in experimental tests

Optimization Process

Optimization workflow procedure in ANSYS® Workbench™ environment



Baseline Model and Results

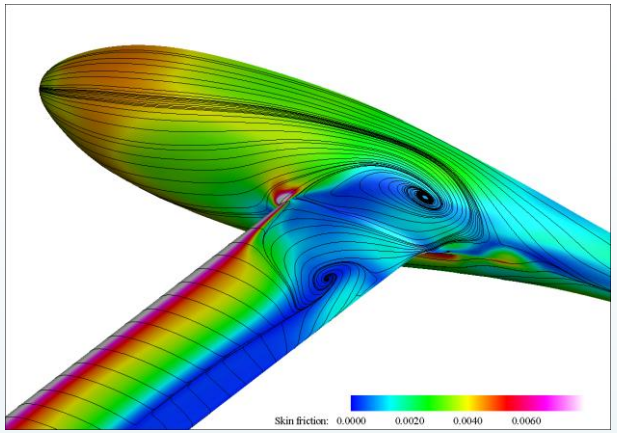
CFD analyses setup:

- Solver: ANSYS® Fluent®
- AoA = 8°
- M = 0.08 and Re = 1.24M
- Incompressible solver
- Turbulence model: k-ω SST
- Mesh:

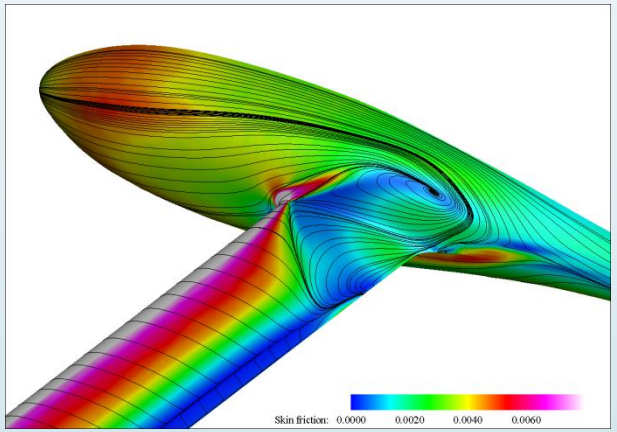
  - coarse: 1.4M cells, 15 < Y+ < 100

  - fine: 7M cells, Y+ < 1

Coarse model – streamlines and friction coefficient



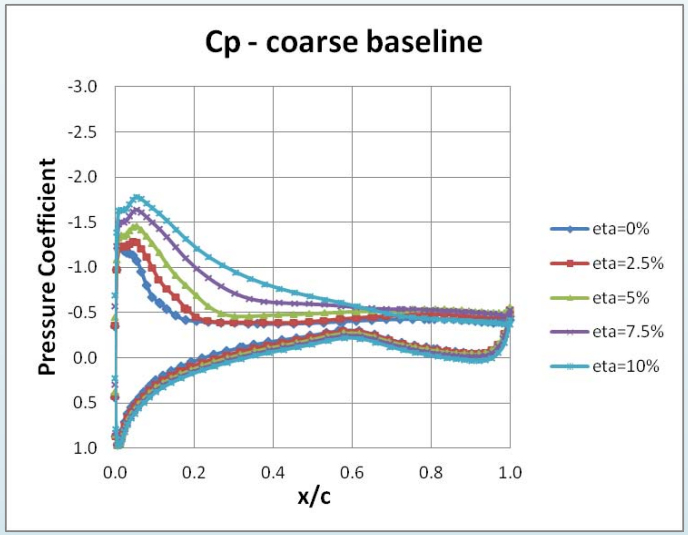
Fine model – streamlines and friction coefficient

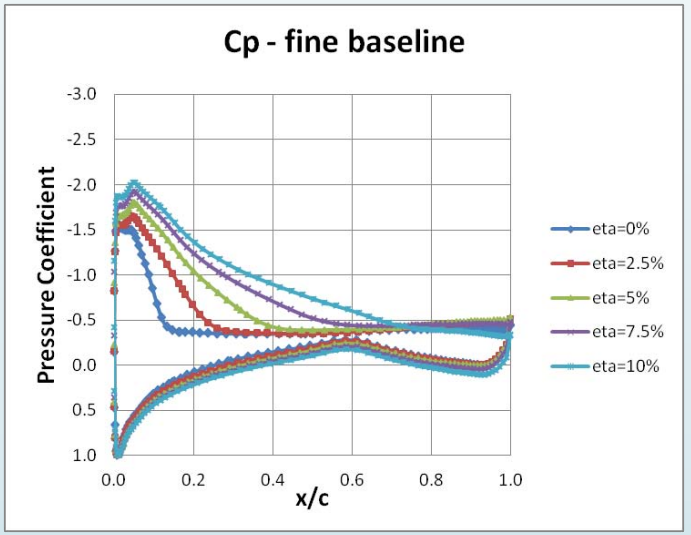


Baseline Model and Results

Parameter	Coarse	Fine
C_d	0.081	0.076
C_l	1.018	1.131
Aerodynamic efficiency	12.56	14.88

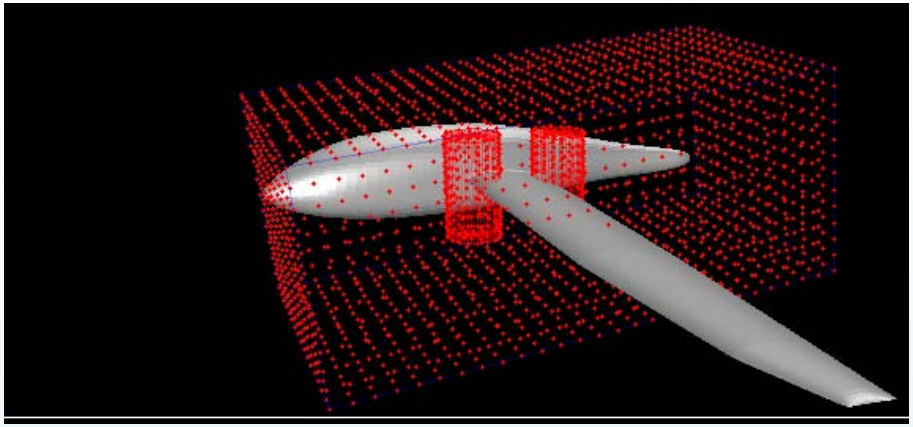
Aerodynamic coefficients for the baseline configuration



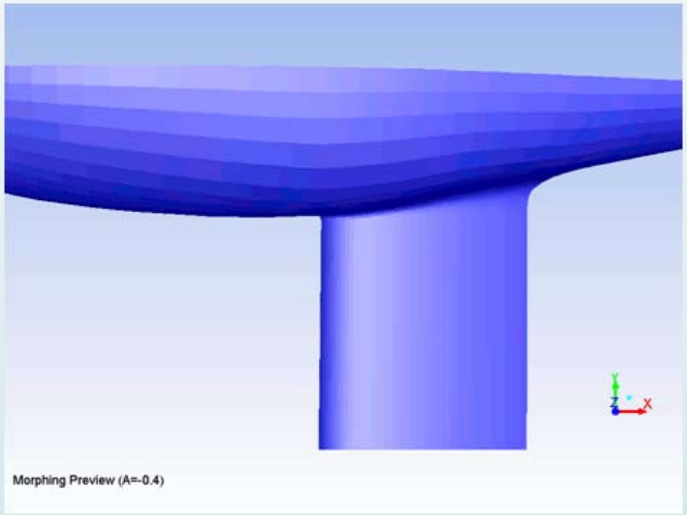


Optimization Process

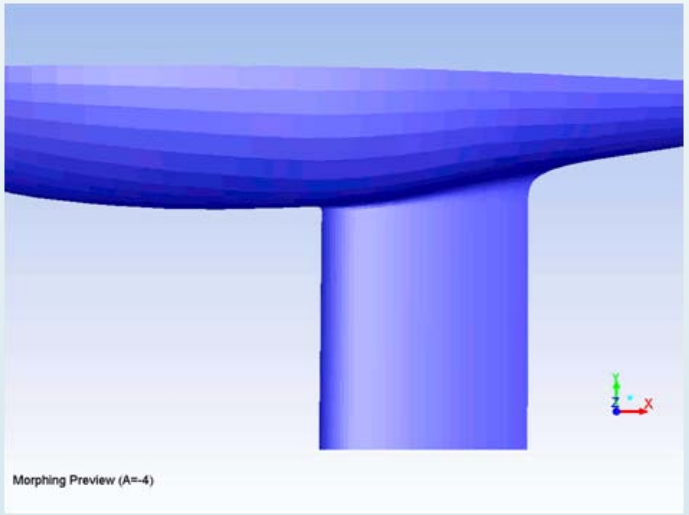
Shape modifications using RBF Morph™



Source nodes positions before applying morphing



Leading edge shape modifier (P1)

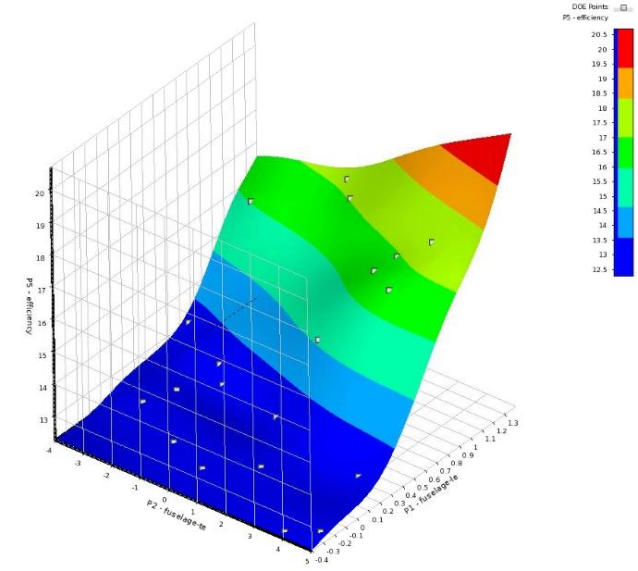


Trailing edge shape modifier (P2)

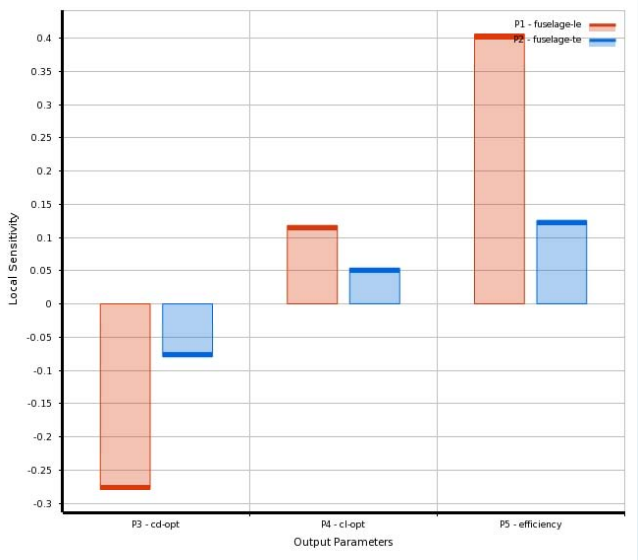
Response Surface

First set of 20 Design Points (DPs) and local sensitivity analysis:

- Input parameters: LE shape modifier (P1), TE shape modifier (P2);
- Objective Functions: Cd (P3), Cl (P4), Aerodynamic Efficiency (P5);



Response surface



Local sensitivity

- Most interesting area is the result of mathematical approximation;
- P1 has higher influence than P2 on Objective Functions.

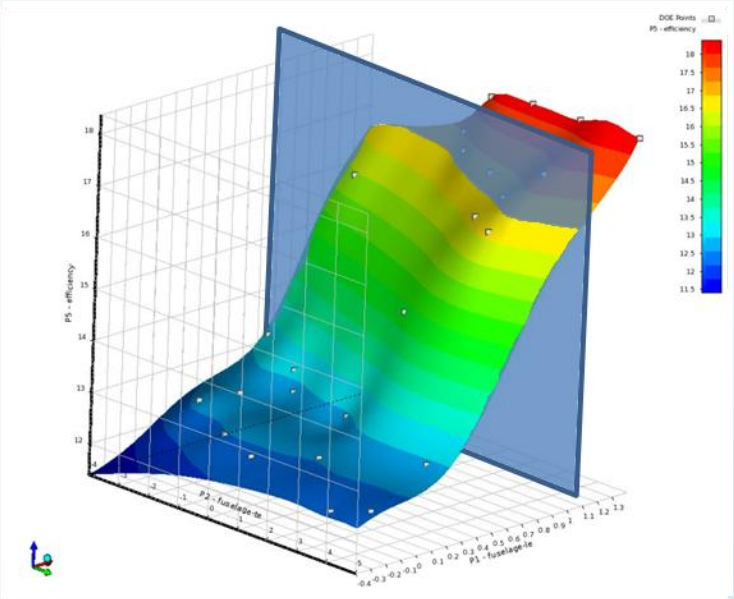
Response Surface

Response surface updated with 5 more DPs to refine it in the higher efficiency zone:

- Slight changes in the upper design space;
- Since neither absolute nor relative maximum was identified, design constraint were imposed to limit LE displacement to 10 cm;

Name	P1 - fuselage-le	P2 - fuselage-te	P3 - cd-opt	P4 - cl-opt	P5 - efficiency	
					Parameter Value	Variation from Reference
Candidate Point 1	0.99547	1.997	0.065132	1.0938	★★ 16.794	0.13 %
Candidate Point 2	0.99349	1.9489	0.06518	1.0934	★★ 16.775	0.01 %
Candidate Point 3	0.99824	1.8974	0.065184	1.0933	★★ 16.773	0.00 %

Optimal candidates

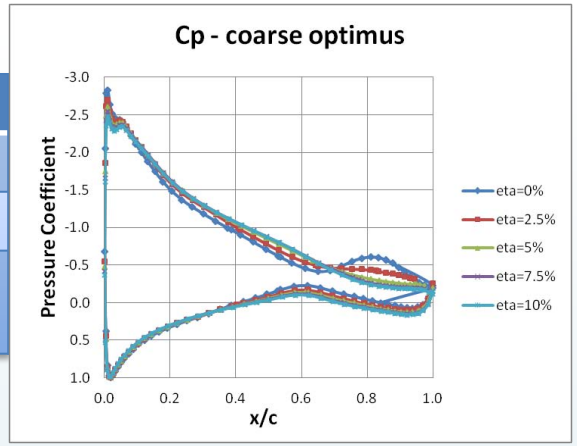


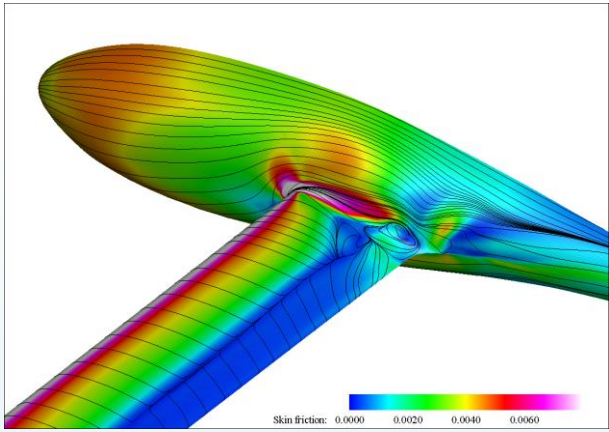
Response surface

Optimal Shape and Results

Coarse model

Parameter	base	opt	Diff.
C_d	0.081	0.065	-19.75%
C_l	1.018	1.093	7.36%
Aerodynamic efficiency	12.56	16.77	33.51%

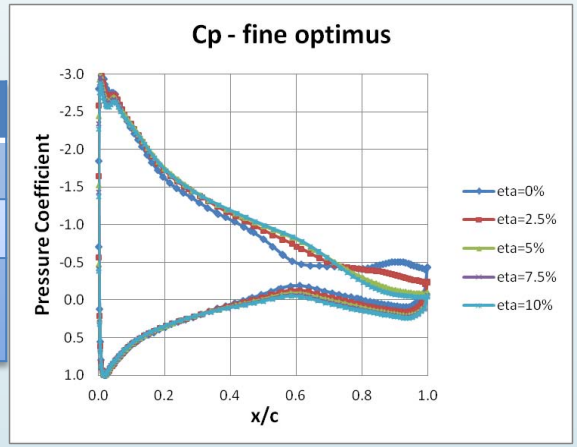


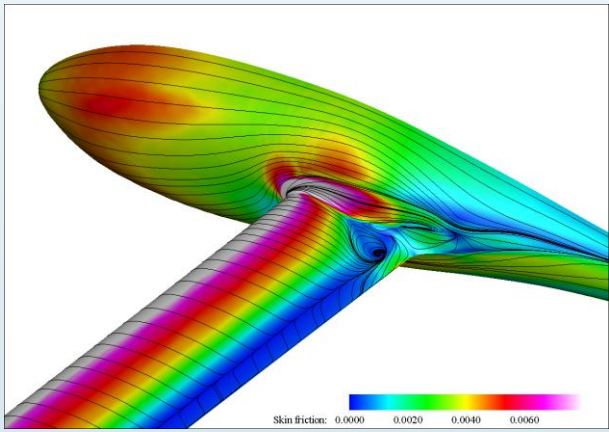


Streamlines and friction coefficient

Fine model

Parameter	base	Opt	Diff.
C_d	0.076	0.061	-19.73%
C_l	1.131	1.216	7.51%
Aerodynamic efficiency	14.88	19.93	33.93%

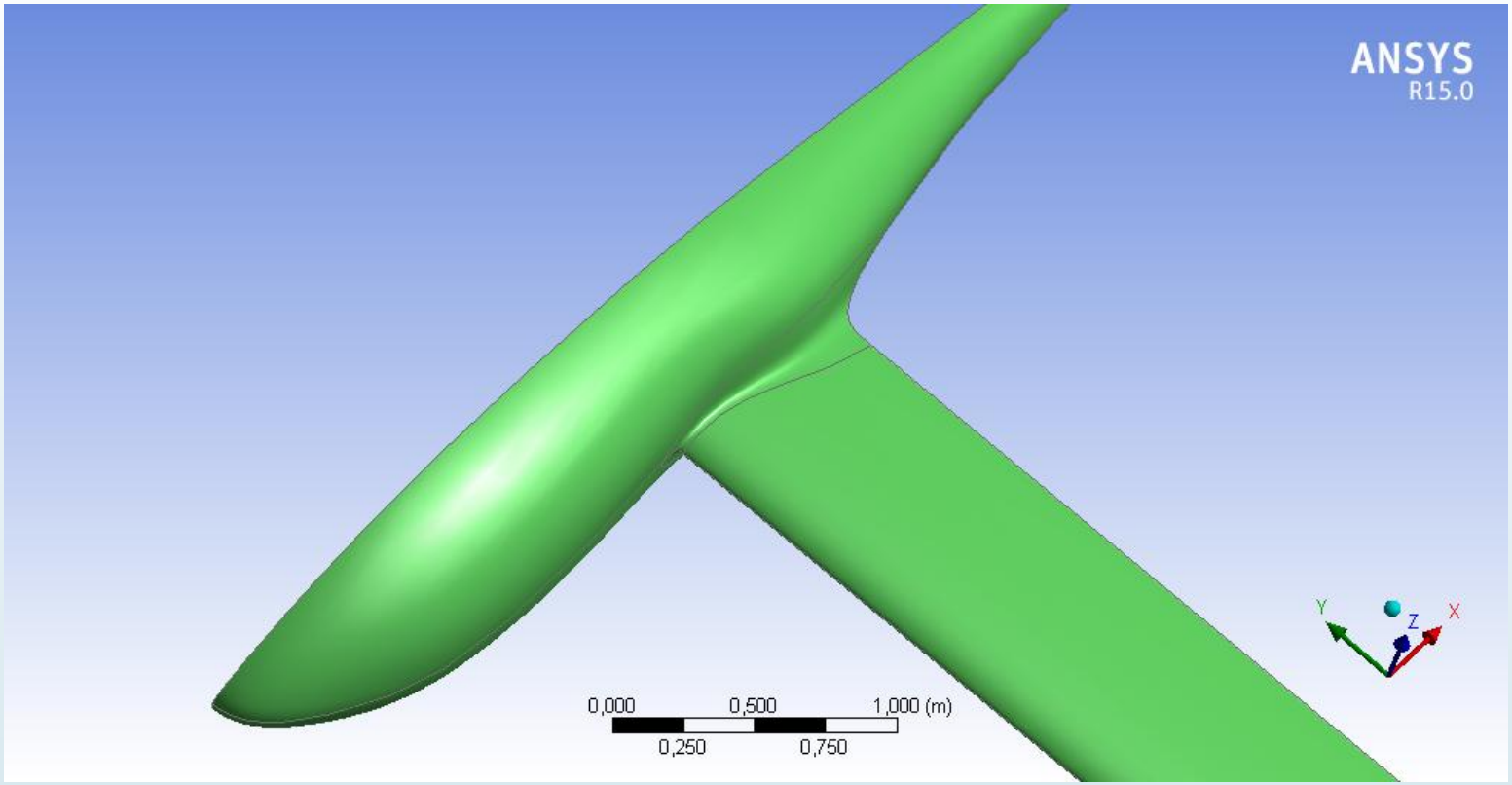




Streamlines and friction coefficient

Optimal Shape and Results

The identified optimal values for shape modifications can be applied to the baseline CAD geometry to obtain an optimized CAD representation that can be employed for manufacturing purposes.



CAD model of the optimized configuration

Concluding Remarks

- The proposed methodology for shape optimization, that combines DoE techniques with RBF-based mesh morphing, has proven to be efficient and reliable;
- The methodology was tested on an aeronautical industrial case and the investigated shape modifications turned out to be effective in reducing the flow detachment area;
- The performed explorative activities took advantage of a low-demanding computational CFD model whose results were verified by means of a more accurate numerical one;
- This optimization methodology can be suitable also for small size HPC facilities.

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Adjoint-morphing coupling

The Continuous adjoint to the incompressible Navier-Stokes equations provided by NTUA is OpenFOAM-based (v2.2), includes the Spalart-Allmaras turbulence model and considers aerodynamic objective functions (lift and drag).

CFD adjoint solution allows to estimate where and how is opportune to modify the shape of a model in order to have a positive influence on objective functions.

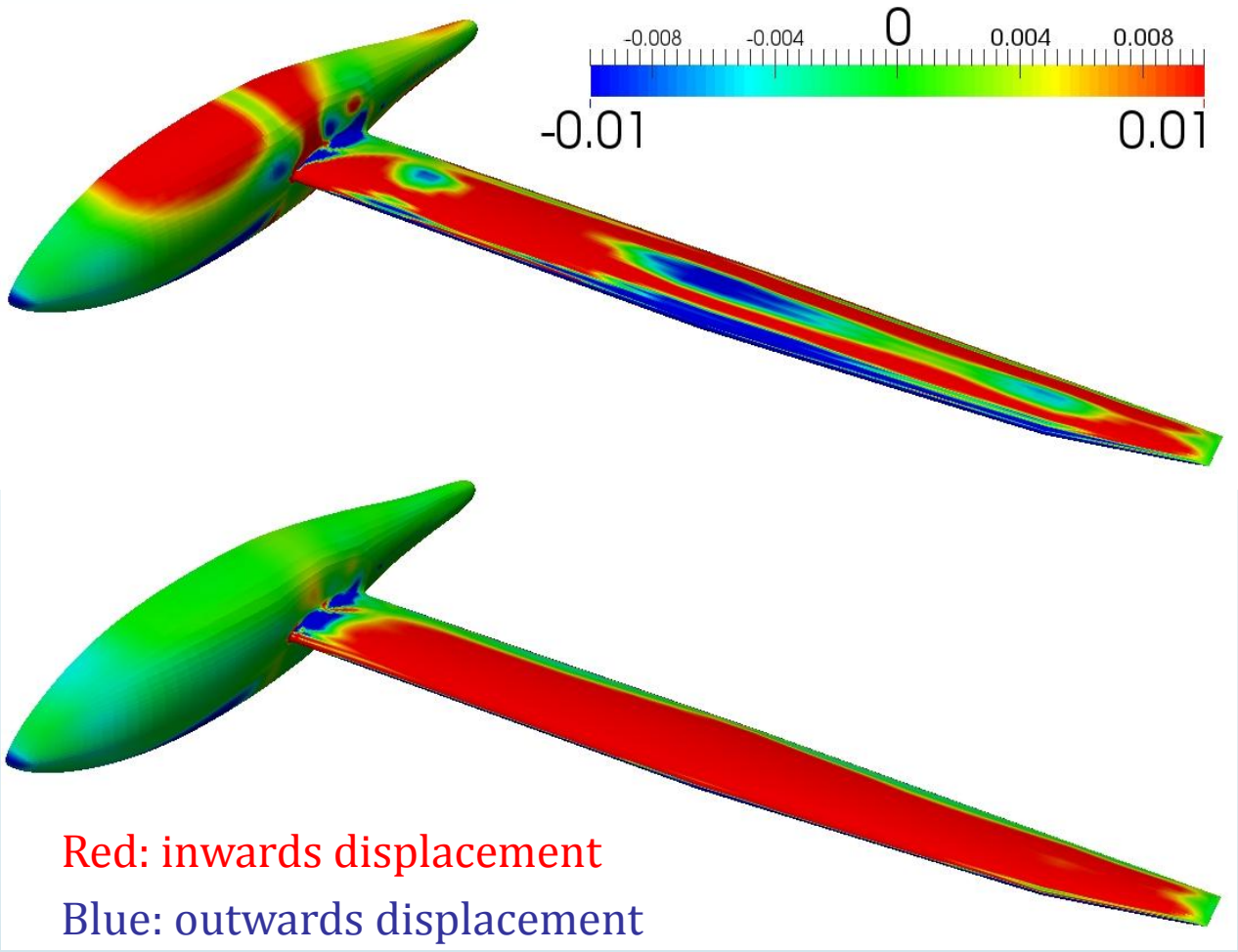
The preliminary analysis on Taurus model highlighted the importance of accounting for turbulence in adjoint computing.

Adjoint-morphing coupling

Sensitivity maps on taurus geometry

'Frozen' turbulence

Adjoint to the Spalart-Allmaras turbulence model



Red: inwards displacement

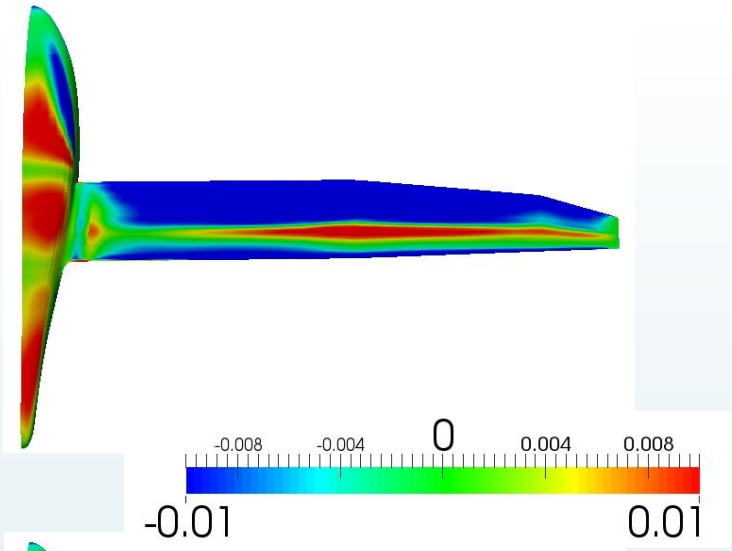
Blue: outwards displacement

Adjoint-morphing coupling

Sensitivity maps on taurus geometry

'Frozen' turbulence

Adjoint to the Spalart-Allmaras turbulence model



Bottom view

Top view

SEVENTH FRAMEWORK PROGRAMME

TOICA
Thermal Overall Integrated Concept Aircraft

EASN
27-29 October 2014, AACHEN

TOICA – Vision & Objectives (Part A)

Pierre Arbez
Airbus Operations SAS

v1

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Content

Our objectives

Impacts and benefits

How is TOICA structured ?

What to demonstrate?

INDUSTRY CHALLENGES

The **TOICA project is one milestone in a competitive race**, where the key success factor is the ability to deliver innovative, greener and more efficient aircraft to our customers in the shortest possible time.

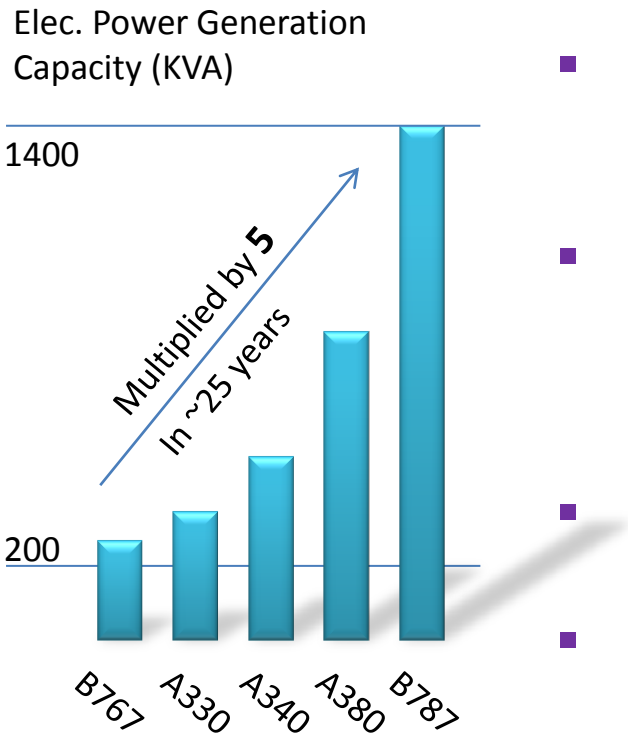
Thanks to its experienced Consortium and innovative plateau organisation, TOICA is an important enabler for H2020 objectives:

- More robust, integrated and efficient **aircraft architectures**
- **New cost and lead time reduction strategies** in the development and installation of aircraft systems
- **Closer collaborations** with the whole supply chain

AIRCRAFT ARCHITECTURE CHANGE AND OPPORTUNITIES

Thermal Overall Integrated Concept Aircraft

Thanks to its focus on trade-off mechanisms and the complex integration of more dissipative systems in the aircraft, TOICA will contribute to a significant breakthrough in the approach to systems integration by:



- Investigating **faster convergence** strategies to attain more integrated systems functions in the aircraft
- Developing capacity to perform thermal **assessments earlier to reduce risks and uncertainties** and get right first time architecture solutions
- Reducing the overall development **lead time**
- Offering new modelling and simulation capabilities to **enlarge and agilely explore** more complex design spaces

AMBITIONS DRIVING RESEARCH AND TECHNOLOGY

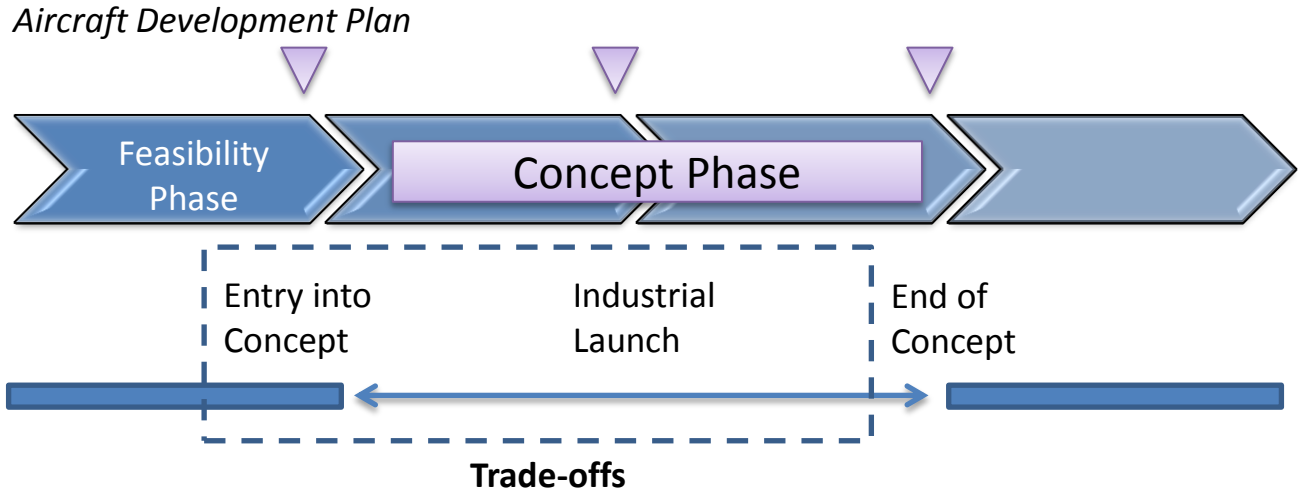
Thermal Overall Integrated Concept Aircraft

The project will drive new methods to help architects and designers to:

- Design new thermal concepts of aircraft enabling an overall **optimisation of the heat dissipation**
- Control the design envelopes of more complex systems by **strengthening** both the **specifications** and the **confidence** in physical behaviours
- Secure the selection of emerging **innovative** solutions for new **cooling strategies**
- **Reinforce** their **links with** components and systems **suppliers**

TOICA FOCUSES ON

Thermal Overall Integrated Concept Aircraft



- **Minimising integration risks** during new Technology introduction
- **Closing the gap** between the "future project" evaluations (feasibility phase) and the specific detailed simulations launched by disciplines in the concept phase
- **Enabling flexible & integrated multi-level/disciplinary** approach for concept phase architecture trade-offs

Technology solutions are selected in line with new Aircraft Programme objectives

Content

Our objectives

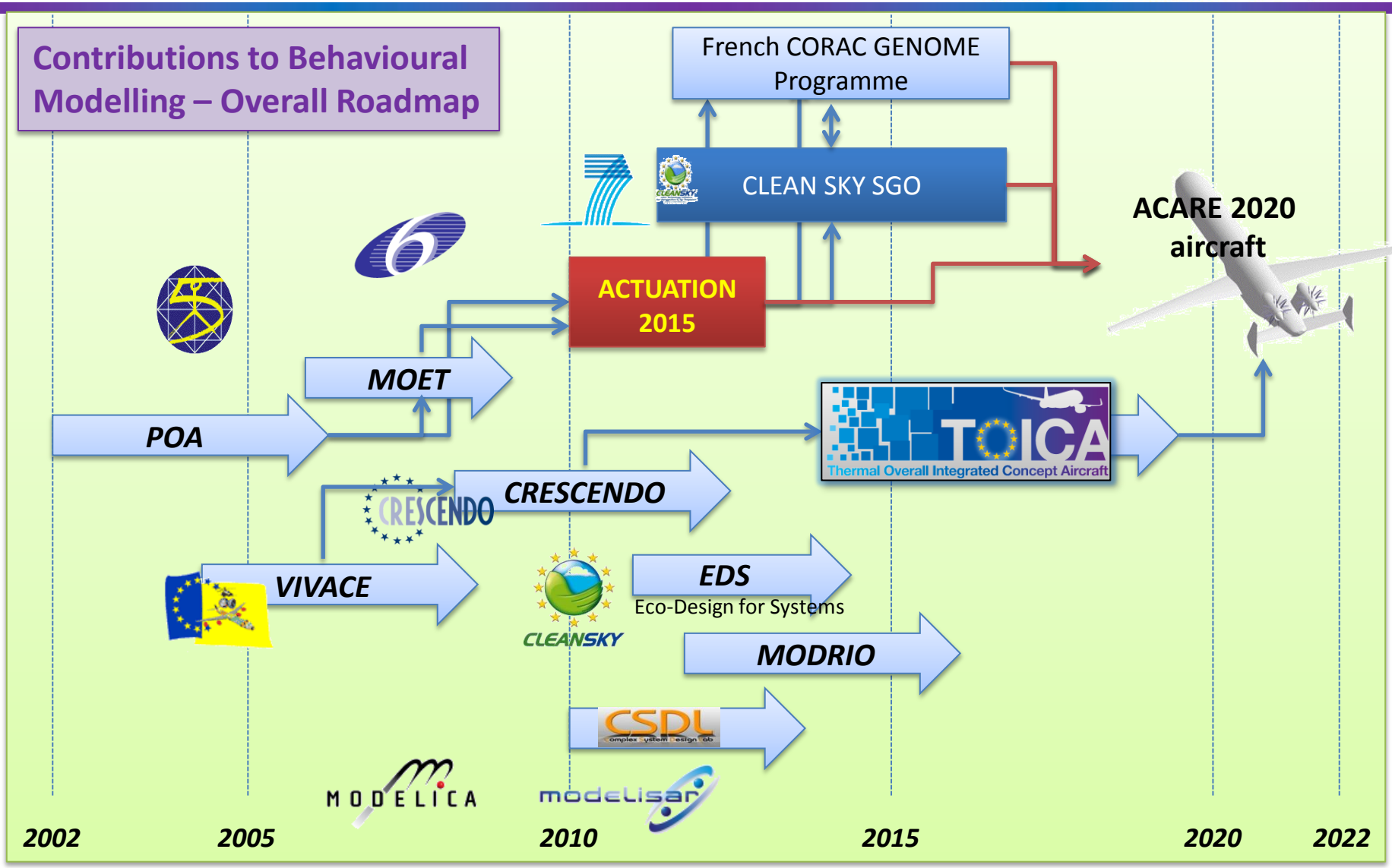
Impacts and benefits

How is TOICA structured ?

What to demonstrate?

The history of TOICA

Thermal Overall Integrated Concept Aircraft



Behavioural Digital Aircraft in the Extended Enterprise

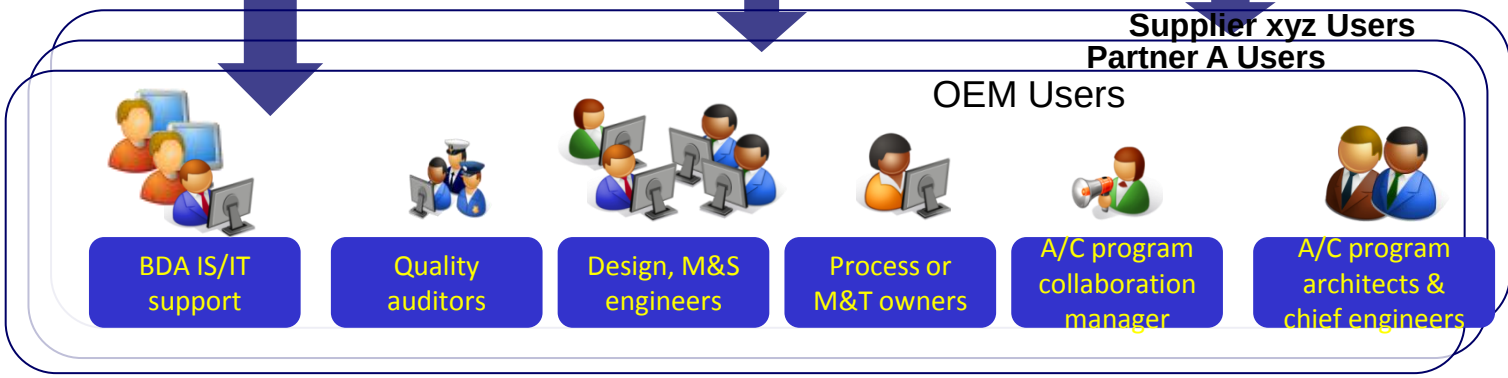
1 BDA Dataset in program context

A BDA Dataset is a multi-partner, multi-level, multi-discipline, multi-quality behavioural digital representation of the evolving Aircraft and all its constituent systems and sub-systems.

10 - 100 BDA Platforms in multiple instances

BDA Platforms implement collaborative and multi-physics capabilities to manage, manipulate, preserve, re-use and enrich all the models & simulation data needed to create, evolve & mature the BDA Dataset.

1000's BDA Users & Teams in extended enterprise



TOICA Consortium

Thermal Overall Integrated Concept Aircraft

Industry

- AIRBUS
- ALENIA
- DASSAULT AVIATION
- AIRBUS HELICOPTERS
- GKNAES
- ZODIAC
- LIEBHERR
- SNECMA
- THALES

Software Editors

- DASSAULT SYSTEMES
- EUROSTEP
- SAMTECH
- MAYA HTT
- MSC
- SIEMENS

SMEs

- ARTTIC
- ATHERM
- CENAERO
- EPSILON
- XRG

Research centres

- AIRBUS GROUP
- DLR
- NLR
- ONERA

Universities

- CAMBRIDGE
- CHALMERS
- CRANFIELD
- PADOVA
- QUB

Due to its **specific Consortium structure** and innovative plateaus organisation, TOICA will be an important enabler for **the reduction of development costs and added value for the complete supply chain.**

TOICA High Level Objectives

Thermal Overall Integrated Concept Aircraft

TOICA defined 4 high-level objectives to improve the methodologies and processes for the aircraft design.

1. **HLO1**: Develop **customised collaborative and simulation capabilities** improving the generation, the management, and the maturity of the **B**ehavioural **D**igital **A**ircraft (**BDA**) dataset

2. **HLO2**: Develop **new concepts for improved thermal load management** for aircraft components, systems or equipment, which will integrate innovative cooling technologies and products

3. **HLO3**: **Assess and validate** the developed capabilities and technology concepts **against different common reference aircraft** targeting both "EIS 2020 and EIS 2030+ Thermal Concept Aircraft"

4. **HLO4**: Optimise aircraft design by **enabling highly dynamic allocation and association between requirements, functions and product elements** (Super integration) for product innovations

TARGET AIRCRAFT CONFIGURATIONS

Thermal Overall Integrated Concept Aircraft

Two target aircraft are considered within TOICA:

1. **EIS 2020**:
   Next aircraft entering into service in 2020's, derived from existing aircraft and integrating innovative solutions for a set of components and/or systems or engine. Targeted aircraft families include **single aisle family** (Airbus), **Falcon business jet family** (Dassault Aviation) and **ATR regional aircraft family** (Alenia Aermacchi).

2. **EIS 2030+**:
   Next aircraft entering into service in 2030's, considering integration of a broader set of technologies with more radical aircraft configurations. The typical baseline is the next generation of **short range aircraft family** (A30X) from Airbus. This baseline will integrate most of the mature technical solutions investigated through the use cases in order **to reach an efficient thermal concept aircraft aligned with the 2050 vision**.

Trade-offs on the aircraft internal configurations remain the major focus of TOICA

TOP Priorities

Thermal Overall Integrated Concept Aircraft

For Trade-offs:

- **Faster decision making** in the selection of aircraft alternatives
- **Adapted accuracy of the predictions** according to aircraft milestones expectations
- Adaptative **cascades of integrated models** according to trade-offs objectives
- **Learning, Flexible and agile Engineering**

For Simulation

- **Parameterisation** of the aircraft modelling capabilities to support trade-offs
- **Coupled and multi-disciplinary** Modelling and Simulations (M&S) techniques
- **Multi-level M&S** capabilities to address multiple scales of interests during trades-offs
- **Confidence and traceability** in M&S from End to End.

- **Expected gains in the management of the key design criteria**
- **Time reduction to the most mature desired configuration**

Content

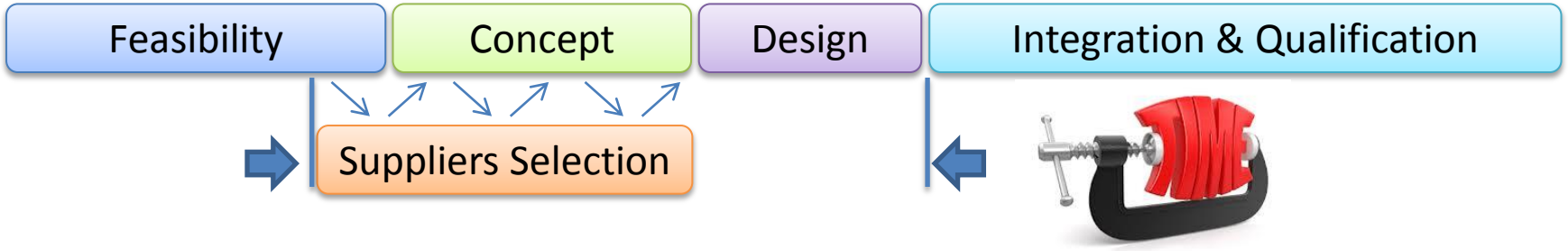
Our objectives

Impacts and benefits

How is TOICA structured ?

What to demonstrate?

Expected impacts (1/3)



Through the 6 TOICA use cases, new methods and processes will be investigated for more efficient system architectures in order to contribute to:

- Improve **the overall multidisciplinary conception** of aircraft during the architecture phases
- **Reduce thermal constraints** on systems and structure, and thermal integrated risks
- Optimise **the overall energy management** of the aircraft through a reduction of the aircraft energy consumption
- **Reduce weight and complexity** through a fully integrated structure / systems thermal design

Expected impacts (2/3)

Thermal Overall Integrated Concept Aircraft

TOICA WILL CONTRIBUTE TO REDUCE:	TARGETS	IMPACTS
▪ **Lead time** of an aircraft thermal architecture assessment	**< 3 Months**	**Development costs**
▪ Equipment development process	**- 6 Months**	
▪ Equipment development **cost** and need for late rework	**-10%**	**Supply chain efficiency**
▪ Costs & time associated to **integration and installation** of systems in aircraft		
▪ **Energy/power consumption** used for active cooling or controlling of systems	**-5%**	**Operational costs**
▪ **Mean Time Between Failure** (MTBF) as the direct impact of more adapted specifications	**+15%**	

Expected impacts (3/3)

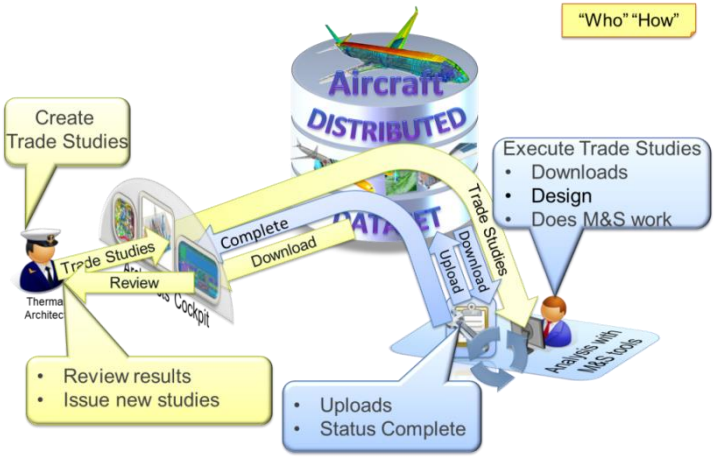
Thermal Overall Integrated Concept Aircraft

IMPACT ON AERONAUTICAL SUPPLY CHAIN

We are close to standardising the way complex datasets representing the functional and physical descriptions of products can be shared with efficiency and consistence along the life cycle.

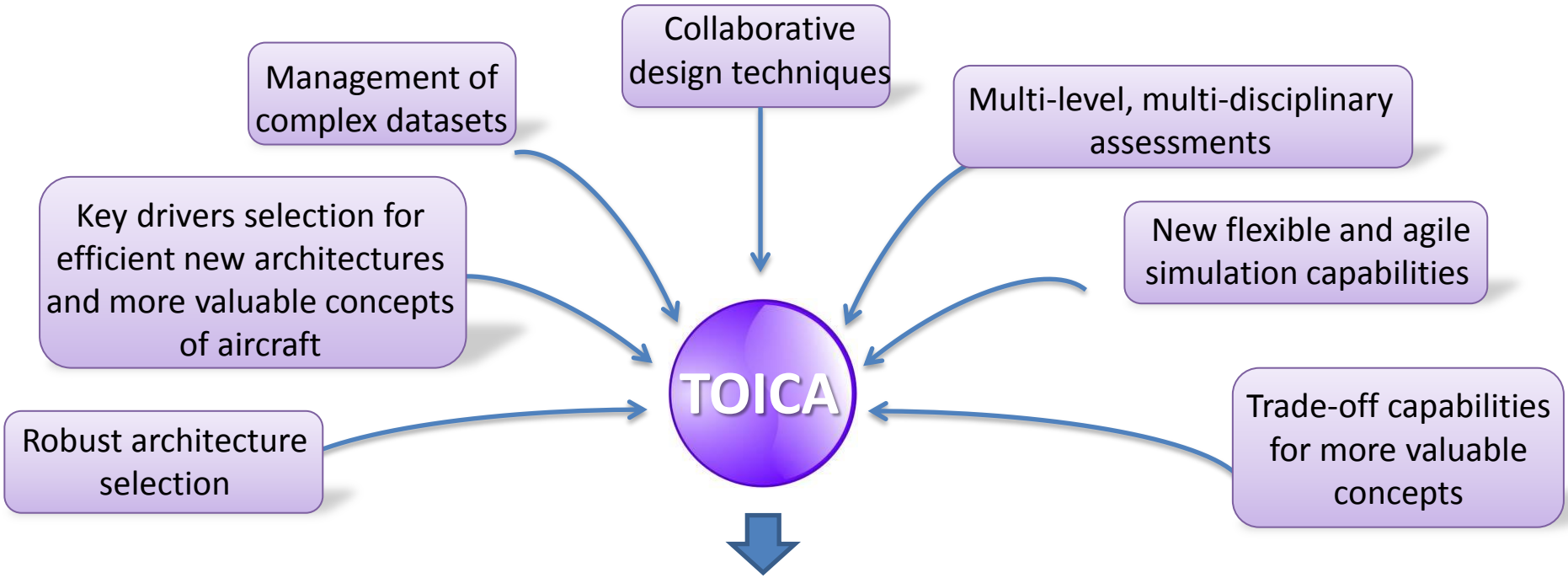
This **standardisation approach** will lead to:

- reinforcing the local research work of each partner
- maturing “BDA standards” with software editors
- enabling collaborative multi-partner plateau work
- preparing adoption/deployment for normal business
- demonstrating benefits through first exploitation



Consistent “integration” of new capabilities

Thermal Overall Integrated Concept Aircraft



Next 2020 & 2030 generation of aircraft with application of spin-off benefits to derivatives

Next generation of engineering design capabilities

SEVENTH FRAMEWORK PROGRAMME

TOICA
Thermal Overall Integrated Concept Aircraft

EASN
27-29 October 2014, AACHEN

TOICA – Methodology (Part B)

Pierre Arbez
Airbus Operations SAS

v1

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Content

Our objectives

Impacts and benefits

How is TOICA structured ?

What to demonstrate?

DIRECTIONS AND OBJECTIVES

PERIOD 3

M25→ M36

- **Validate & deliver trade-off capabilities to Architects and Experts for the definition of more integrated thermal concept of aircraft**
- Promote changes in Methods, Processes for trade-offs
- Demonstrate Benefits and Impacts on Aircraft design

DESIGN

PERIOD 2

M13→ M24

- Validate & consolidate needs
- Launch trade-offs
- Assess/improve first trade-off capabilities
- **Evaluate new design options**

EXPLOIT
ADAPT

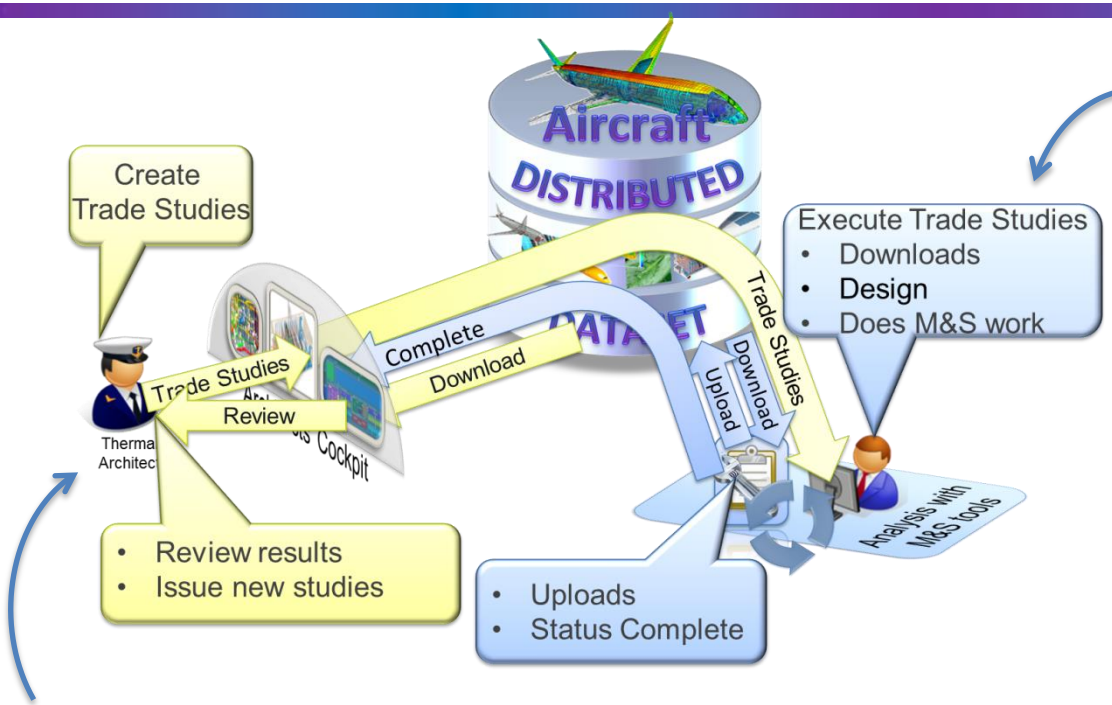
PERIOD 1

M1→ M12

- Describe needs and roadmaps
- Define Aircraft baselines and targets
- Develop the use case studies
- **Prepare the key trade-off capabilities**
- **Define and organise concept of Plateau**

PREPARE
DEFINE
SPECIFY

The overall TOICA approach

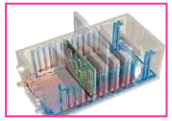


Architects supervising plateau, to :

- Define trade-off targets
- Describe scenarios & targeted confidence
- Specify key drivers and parameters
- Request functionalities supporting trade-off operations
- Drumbeat studies and decision along the configuration evolution through the alternative selections
- Ensure representativeness of the demonstrations

Use Cases steered by Disciplines

Evaluation of thermal aircraft architectures



Equipment thermal integration

Cooling technologies

Aircraft heat sinks

Thermal (energy) management for system optimisation

Powerplant integration

Application & Use Cases

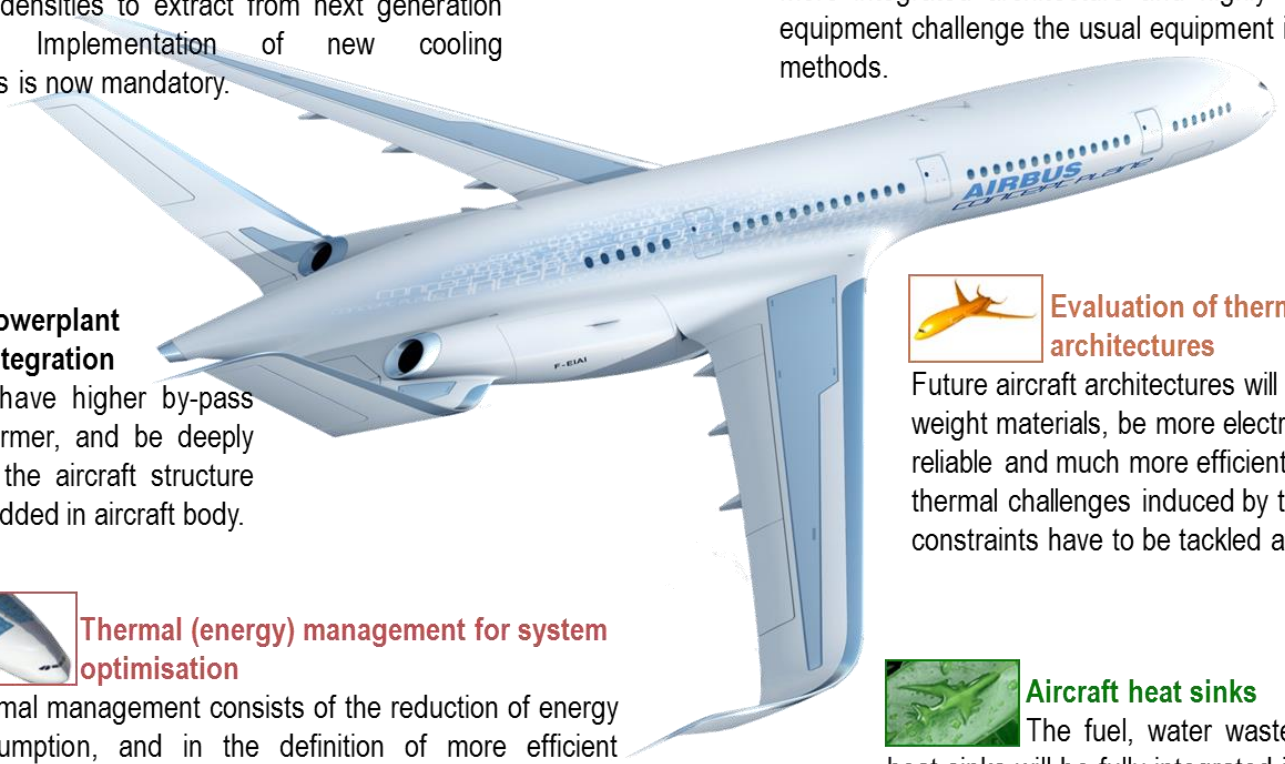
Thermal Overall Integrated Concept Aircraft

Cooling technologies

Traditional air cooling solutions reach their efficiency limits regarding the important heat dissipation densities to extract from next generation equipment. Implementation of new cooling technologies is now mandatory.

Equipment thermal integration

The thermal environment of equipment drives both equipment performance and reliability. More integrated architecture and highly dissipative equipment challenge the usual equipment integration methods.



Powerplant integration

Engines will have higher by-pass ratios, be warmer, and be deeply integrated in the aircraft structure or even embedded in aircraft body.

Evaluation of thermal aircraft architectures

Future aircraft architectures will use light-weight materials, be more electrical, more reliable and much more efficient. The thermal challenges induced by these constraints have to be tackled at all scales.

Thermal (energy) management for system optimisation

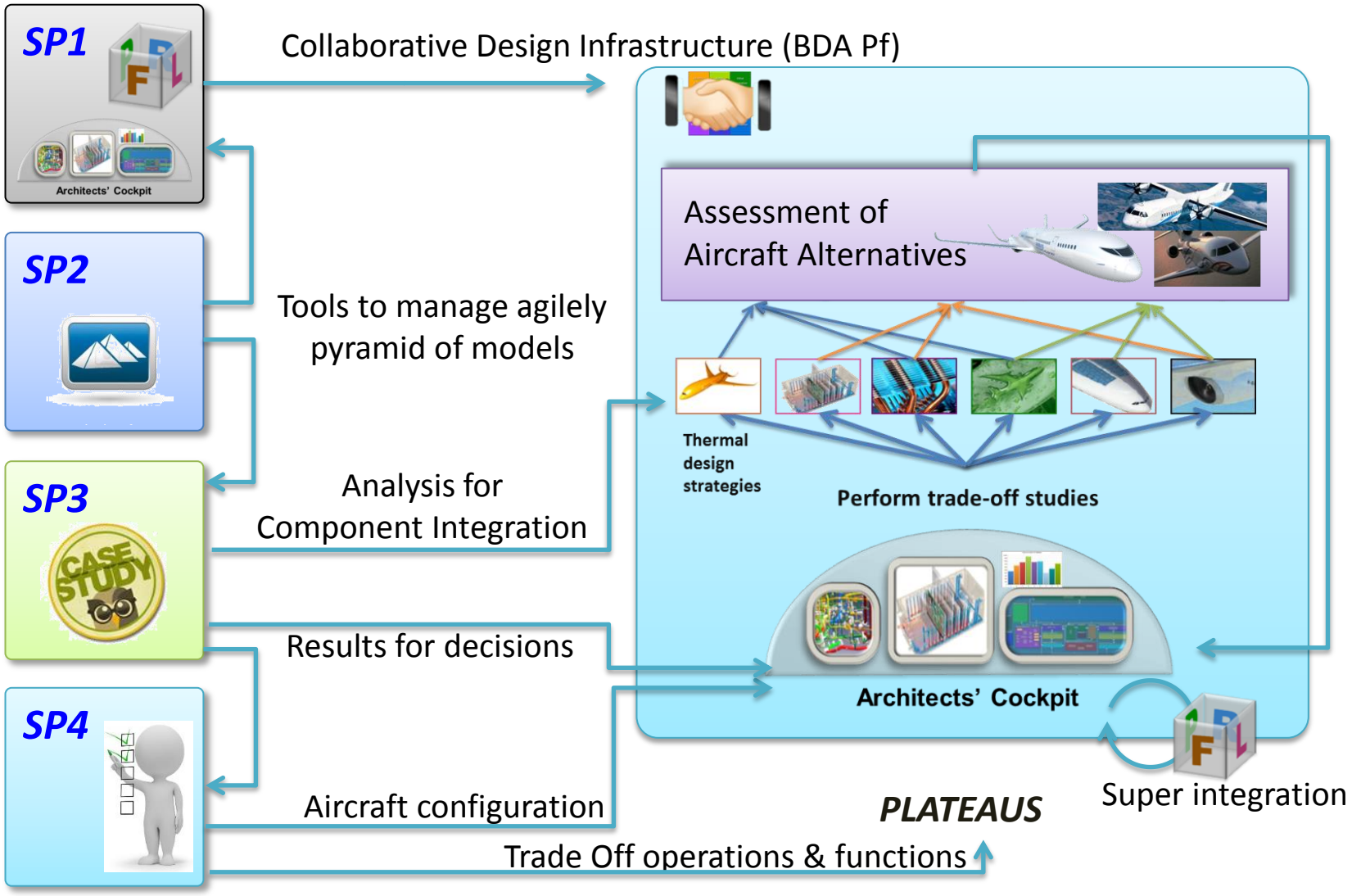
Thermal management consists of the reduction of energy consumption, and in the definition of more efficient transport of calories from sources to heat sinks. Thermal management is a promising research area for all industries in the coming years.

Aircraft heat sinks

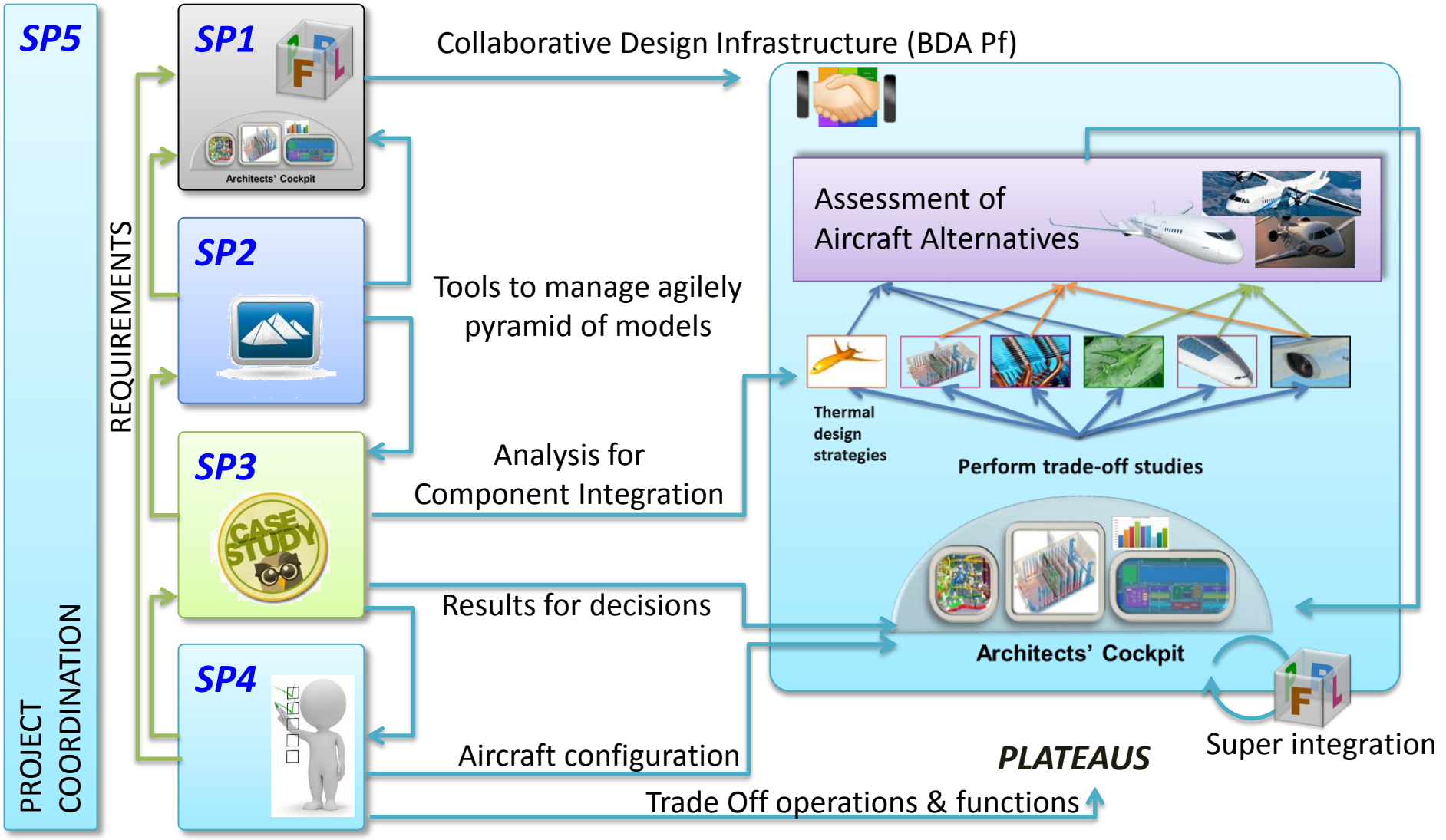
The fuel, water waste, and other heat sinks will be fully integrated in the overall thermal management strategy for greener aircraft.

1

Trade off scenarios



Trade off scenarios



WBS - SP Interactions

SP1
Collaboration Capabilities

- 1.1 Super Integration
- 1.2 Architect cockpit
- 1.3 BDA

SP2
M&S capabilities

- 2.1 Flexible models
- 2.2 Model pyramid
- 2.3 Multi-physics coupling
- 2.4 Optimisation
- 2.5 Robust analysis

SP3
Thermal studies

- 3.1 Thermal A/C
- 3.2 Equipment integration
- 3.3 Cooling technos
- 3.4 Heat sinks
- 3.5 Thermal management
- 3.6 Power Plant integration

SP4
Plateaus & trade-offs

Integrate SP capabilities and associated models to perform thermal trade-offs on collaborative plateaus and assess benefits for aircraft architecture.

Content

Our objectives

Impacts and benefits

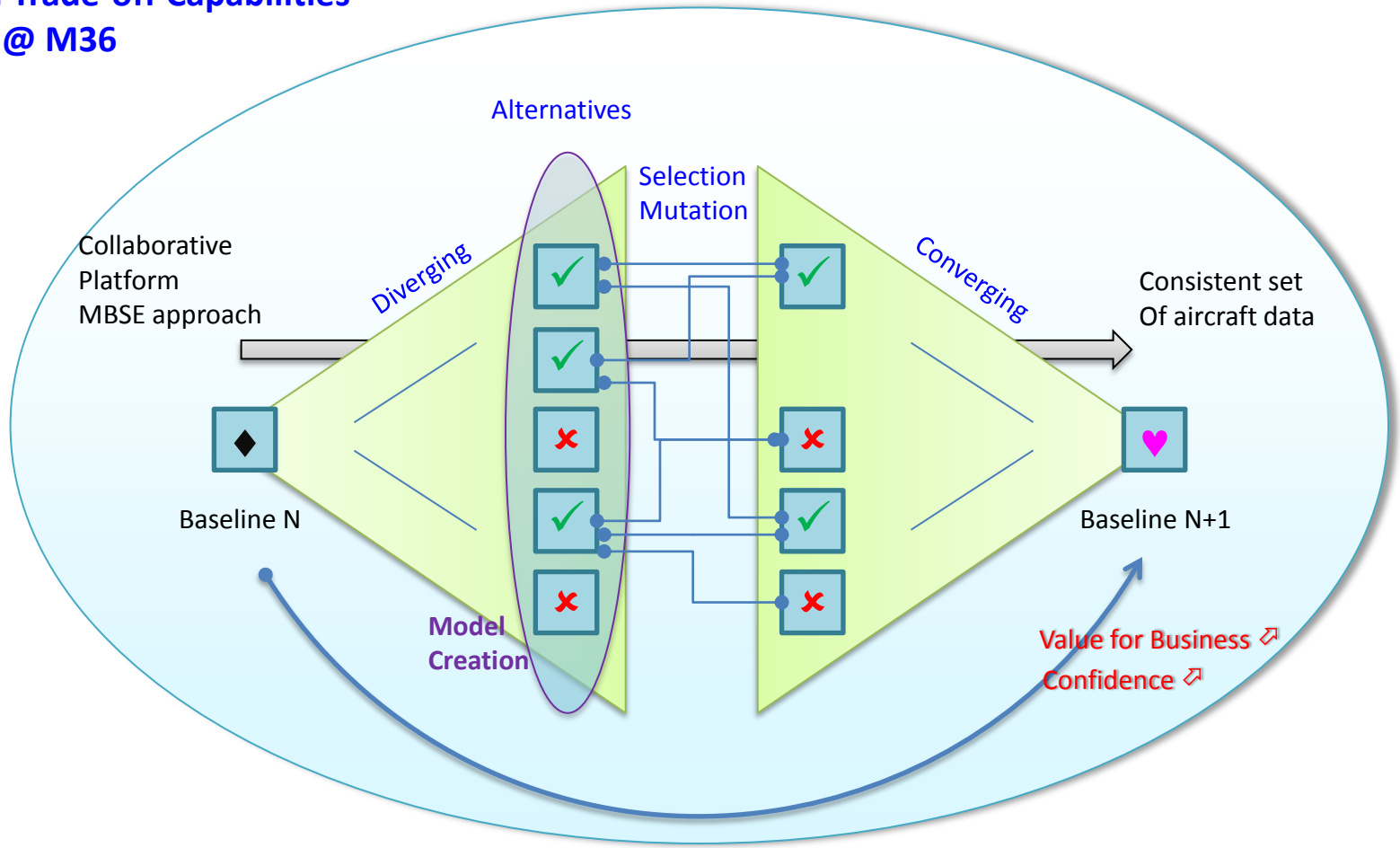
How is TOICA structured ?

What to demonstrate?

Thermal Trade Off Capabilities
To-Be envisaged by TOICA Consortium

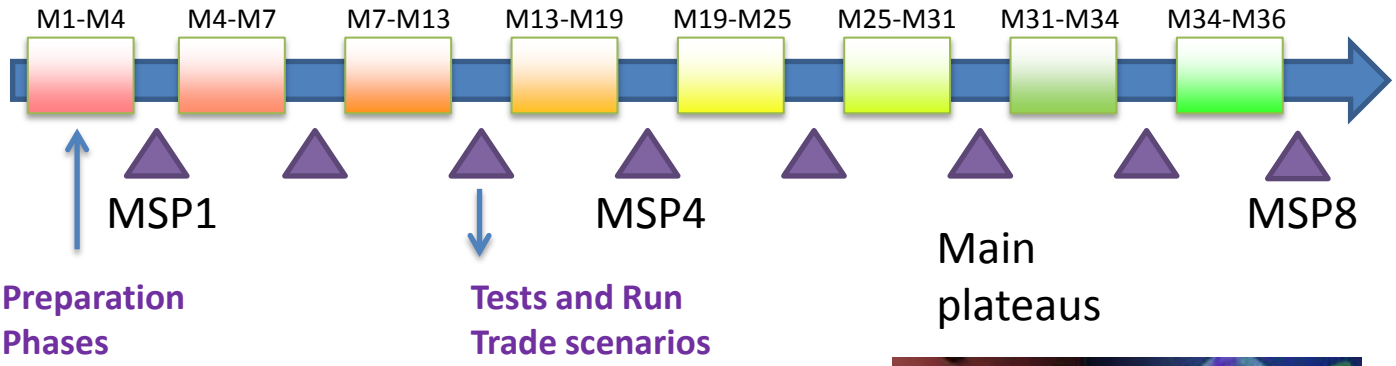
Thermal Overall Integrated Concept Aircraft

Thermal Trade-off Capabilities
→ TRL4 @ M36



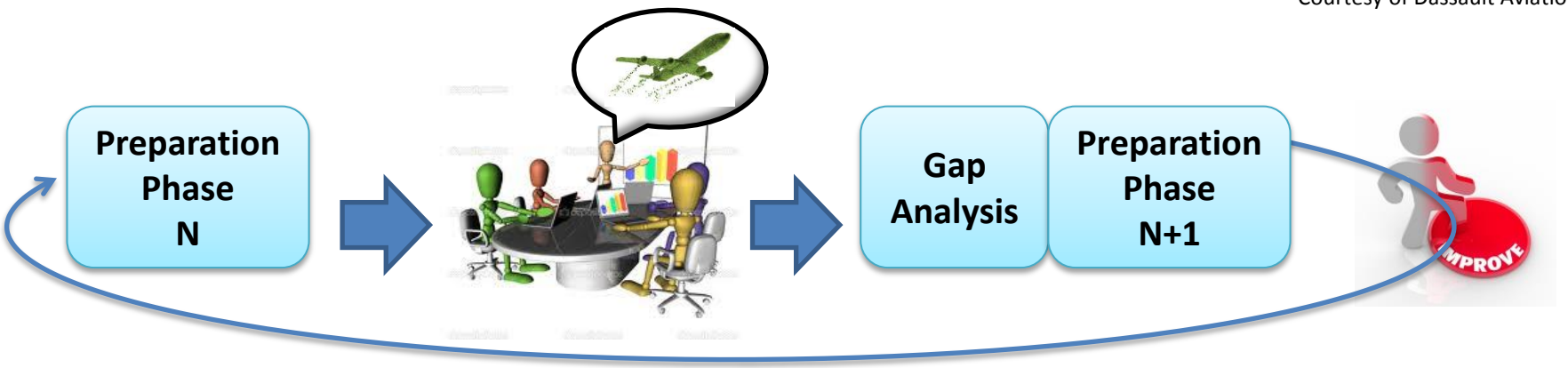
Feasibility | Concept | Design | ...

Aircraft design reviews on plateaus



Courtesy of Dassault Aviation

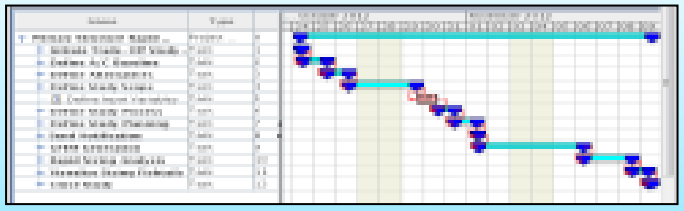
→ **The intent is to exploit the new capabilities in plateaus in order to develop, operate and improve them in 'program-like' conditions:**

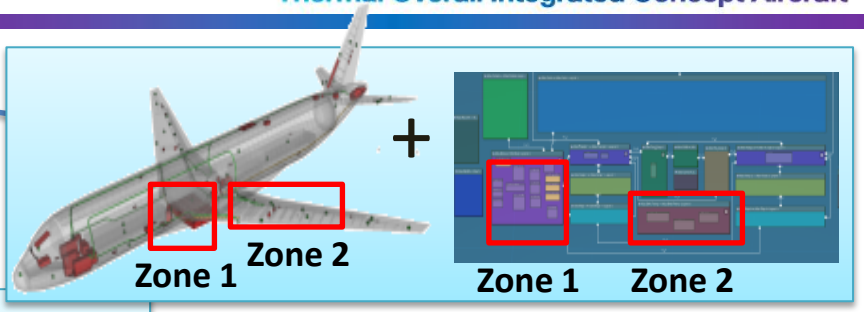


Prepare Trade-offs

Thermal Overall Integrated Concept Aircraft

Schedule



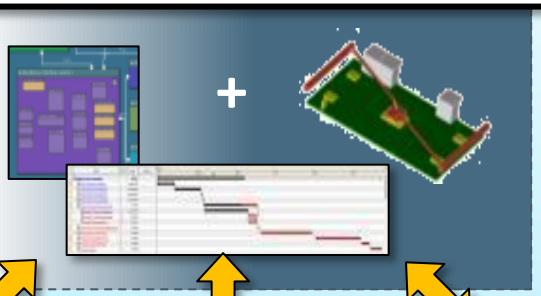


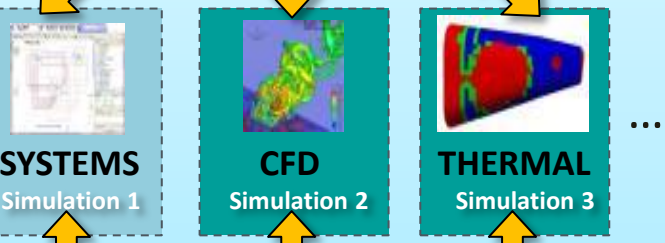
i= 1 to J

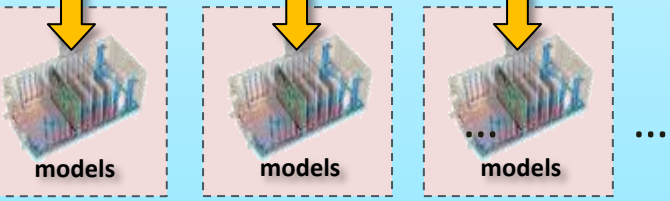
Contribution from Use Case (i)

- Set-up study
- Orchestrate simulations

Trade-off studies, by OEM/Partners

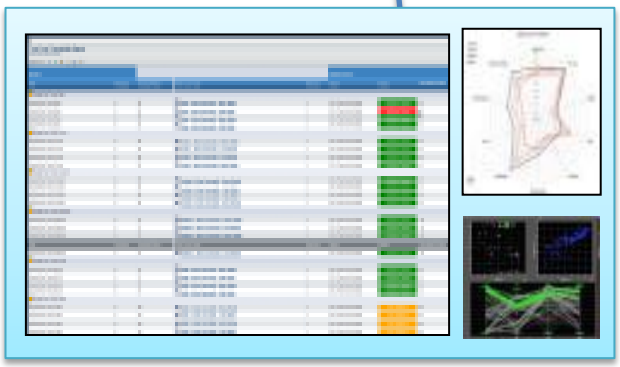






Alternatives

- Define n alternatives
- Orchestrate studies
- Select best alternative

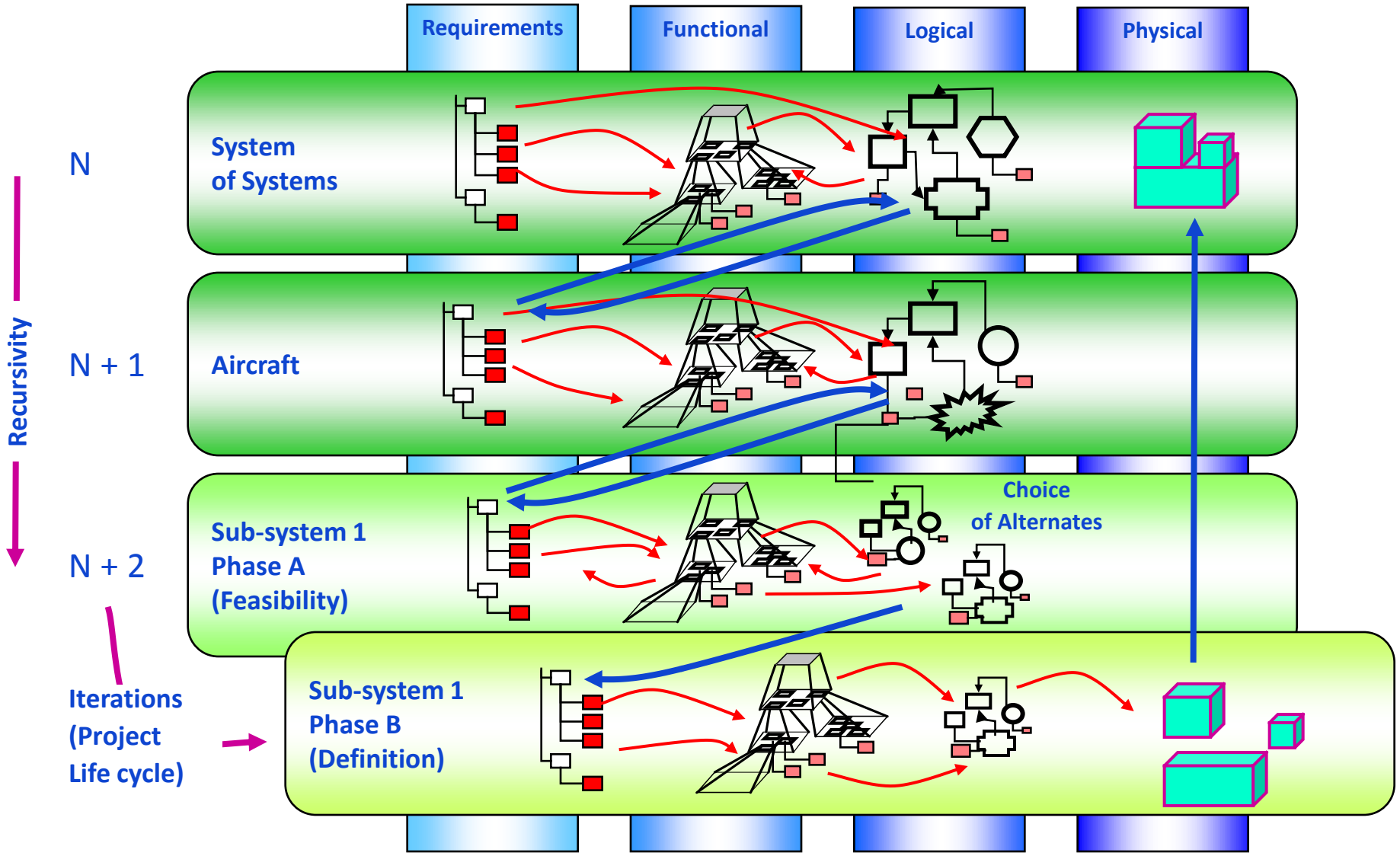


Analyse

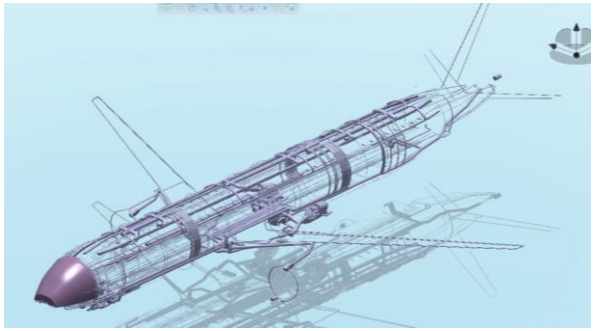
Experts: environments for simulation specialists

Suppliers: environments for equipment designers

System of Systems

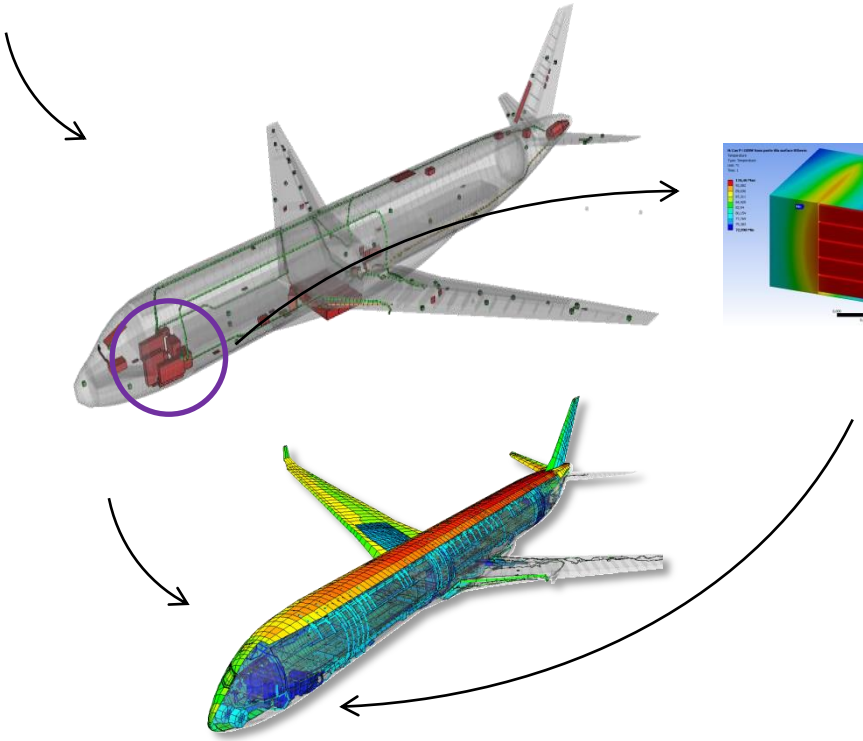


Concept of Pyramid of models

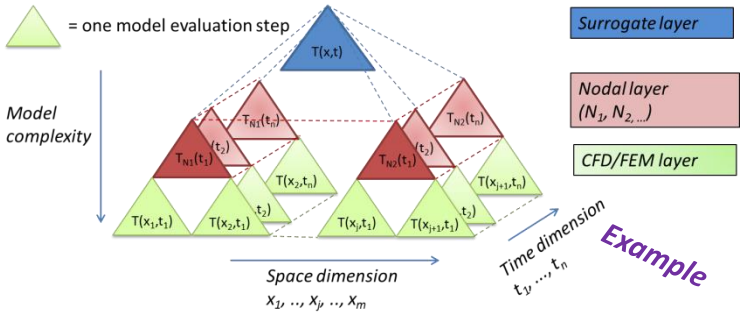


Flexible Model Generation, Parametrisation

Assembly, Flexible Model Generation



Concept of Pyramid of model enabling overall Aircraft behaviour assessment

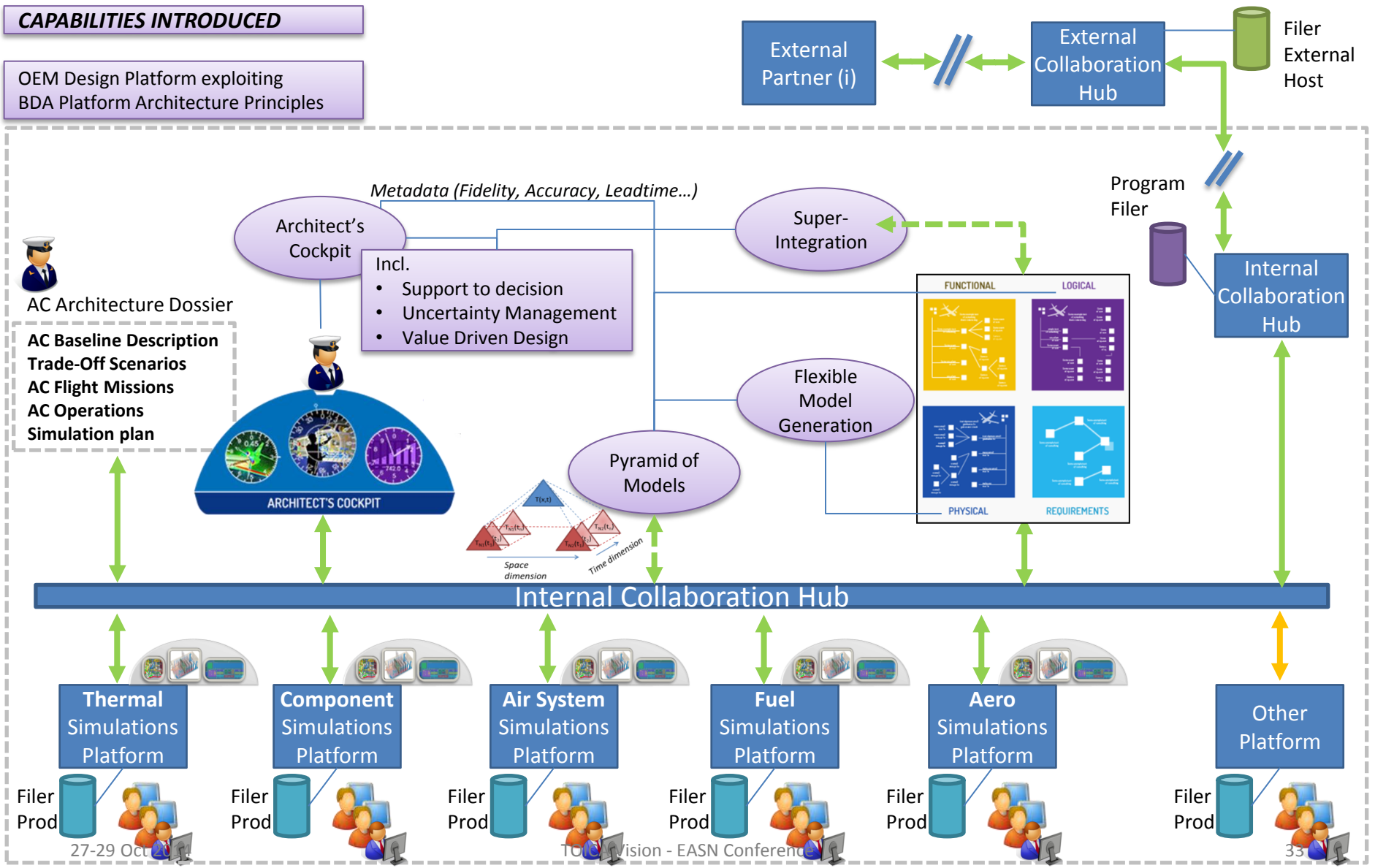


Collaborative Platforms
(Behavioural Digital Aircraft Concept – BDA -)

Thermal Overall Integrated Concept Aircraft

CAPABILITIES INTRODUCED

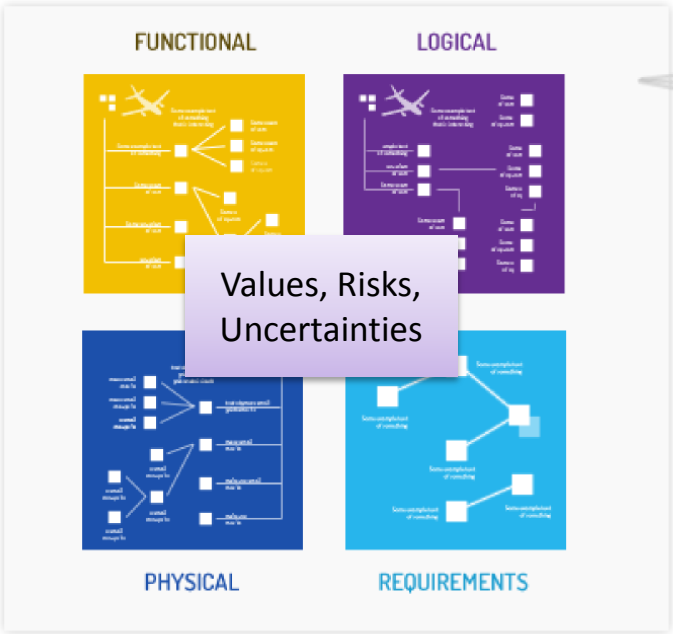
OEM Design Platform exploiting
BDA Platform Architecture Principles



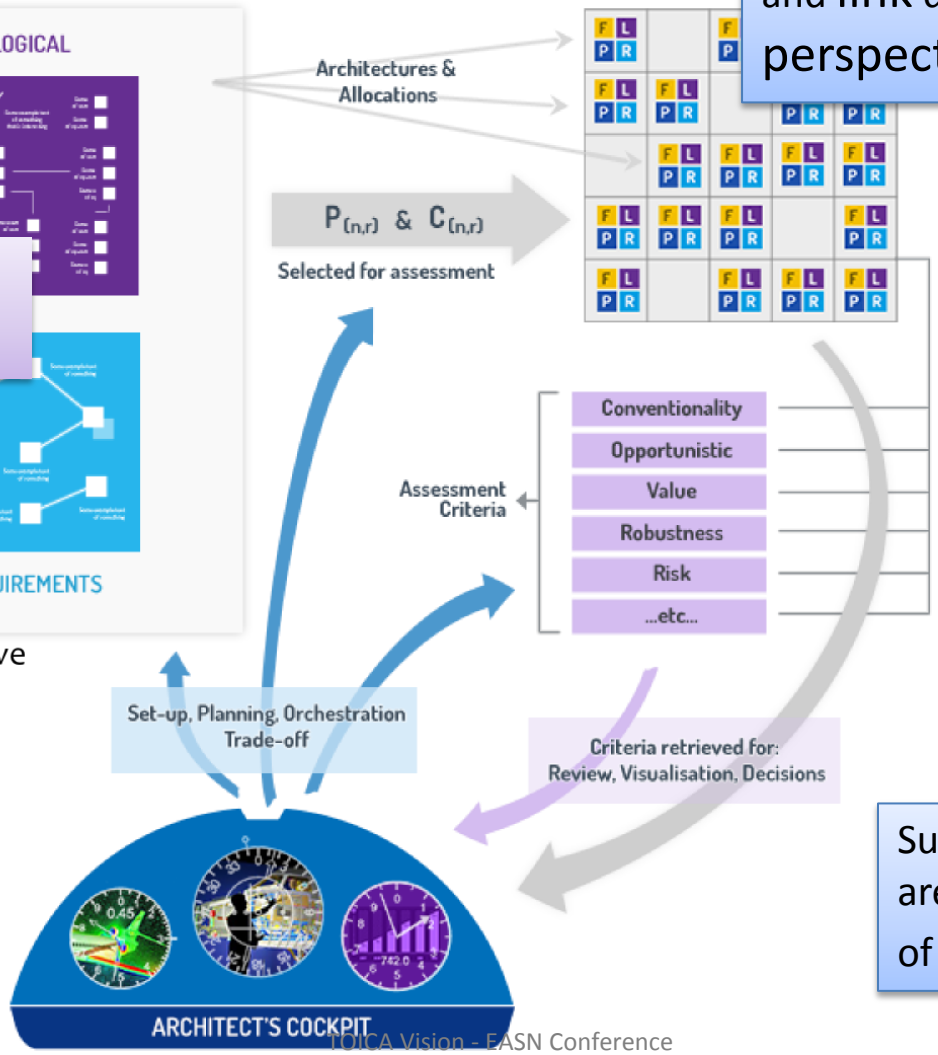
Concepts of - Super Integration - Architect Cockpit

Thermal Overall Integrated Concept Aircraft

Architects are able to manipulate and link different aspects of multi-perspective architectures



Multi-Perspective Architectures



to

Seek rapidly & pursue agilely valuable architectures at all levels of granularity

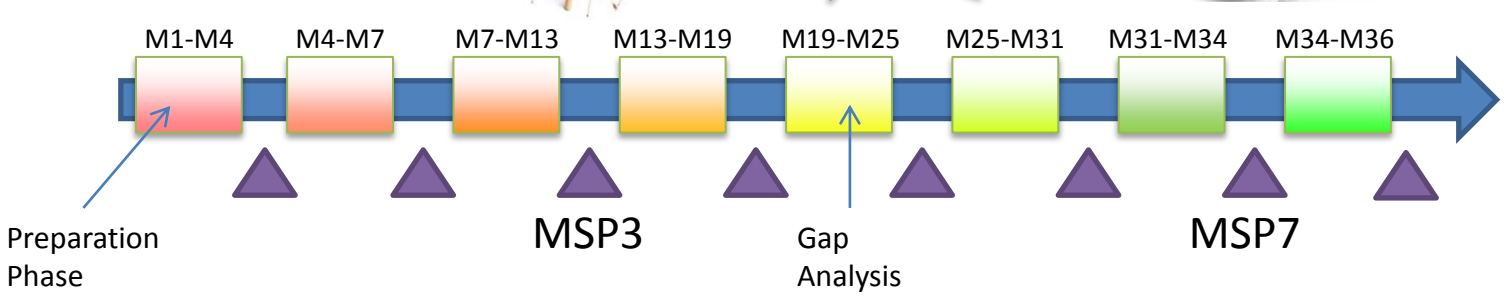
using

Super Integration Capabilities are exploited through the use of the Architects' Cockpit

Prepare Plateaus

First tests:
Everything fails !

Last plateau:
Everything has to run !!



EXPLOIT PLATEAUS

CHECK MATURITY vs ARCHITECT EXPECTATIONS

GAP ANALYSIS

TECHNOLOGY READINESS ASSESSMENT

BENEFITS

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment
- TRL 6 – technology demonstrated in relevant environment

Overall Roadmap (SP3/SP4)

TOICA
Thermal Overall Integrated Concept Aircraft

M1-M12 → M13-M24 → M25-M36

2014 2015 2016

- Assembly of the main bricks
- Main concepts validated by Architects
- Dataset available in Platforms
- BDA Partner connections started

Plateau objectives

Kick-Off

MSP1 Architect Needs

M12

WTS

TRL1

MSP2

1 ✓

Trade-off Scenarios

Data set creation

MSP3

TRL2

2

Define Trade Off Operations

Validate Trade Off Capabilities vs Operations

TRL3

3

MSP4

TRL4

MSP5

4

Define SI scenarios

Experiment Super Integration

MSP6

Closure

Validation of the TOICA HLO

MSP7

MSP8

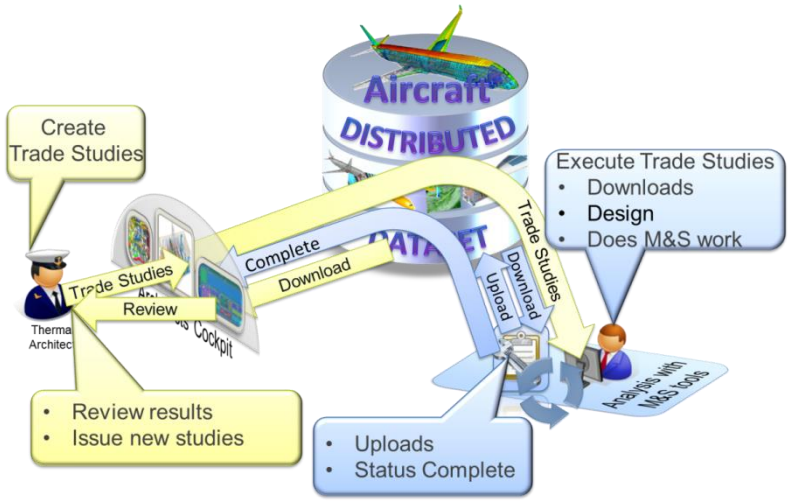
Forum

Project TRLs

Intermediate TRLs

Plateaus

Finally TOICA will produce



- A context to practise
- Representative A/C datasets within a collaborative environment,
- Explicit cascade from the architect value design drivers to the system design targets (specifications)
- New collaborative process for Thermal A/C trade offs, including new architecture decision making process

- Architect Cockpit for A/C Thermal Configuration Assessments & selection
- End-to-end Trade-off scenarios
- Capabilities enabling flexible creation of pyramid of models
- Set of new pyramids supporting Trade-off and Integration
- Demonstrations that Programs can perform Thermal Assessments at A/C level from the early concept phase.

Questions

'The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 604981.'

Thank you

TOICA
Thermal Overall Integrated Concept Aircraft

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SEVENTH FRAMEWORK PROGRAMME

TFAST

SEVENTH FRAMEWORK PROGRAMME

IMP PAN GDAŃSK

Transition Location Effect on Shock Wave Boundary Layer Interaction

TFAST presentation

4th EASN Association International Workshop on Flight Physics & Aircraft Design

Presentation outlook

- Motivation
- Main objectives
- Project structure
- Details on the research plan
- Closing remarks

Motivation

- Progres in laminar technology for wings,
  laminarity maintained up to the shock location
- Compressor fan blockage due to laminar separation (tip section)
- Highly turning turbine HP blades maintain laminar B.L. over long distances

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Background

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

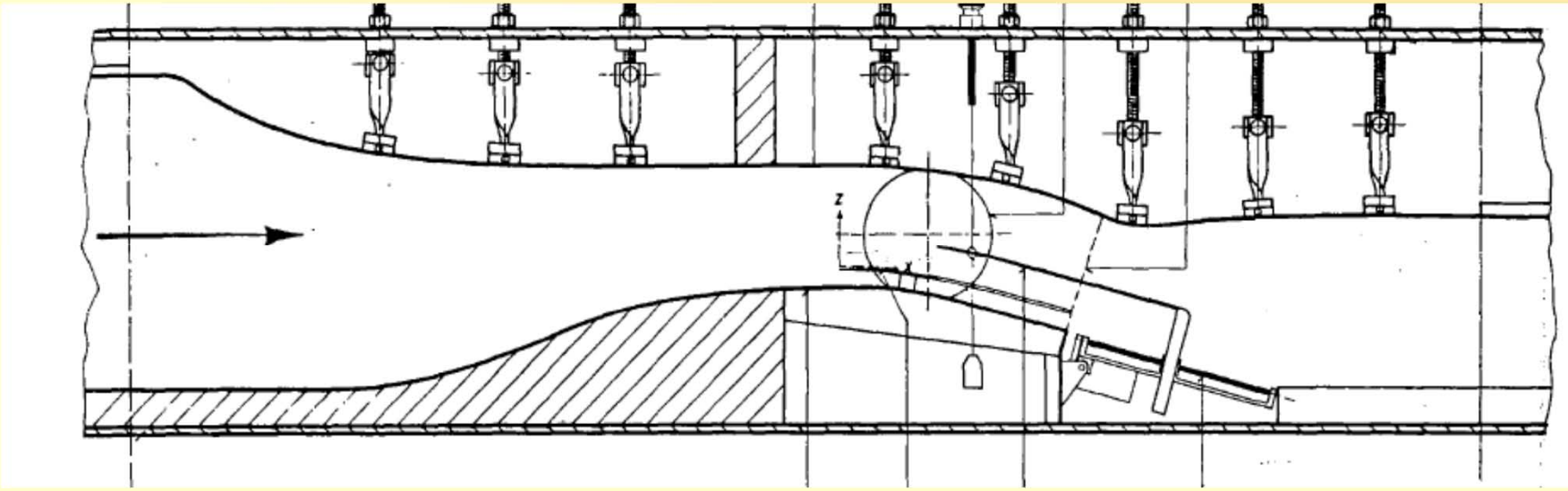
TECHNICAL MEMORANDUM

No. 1113

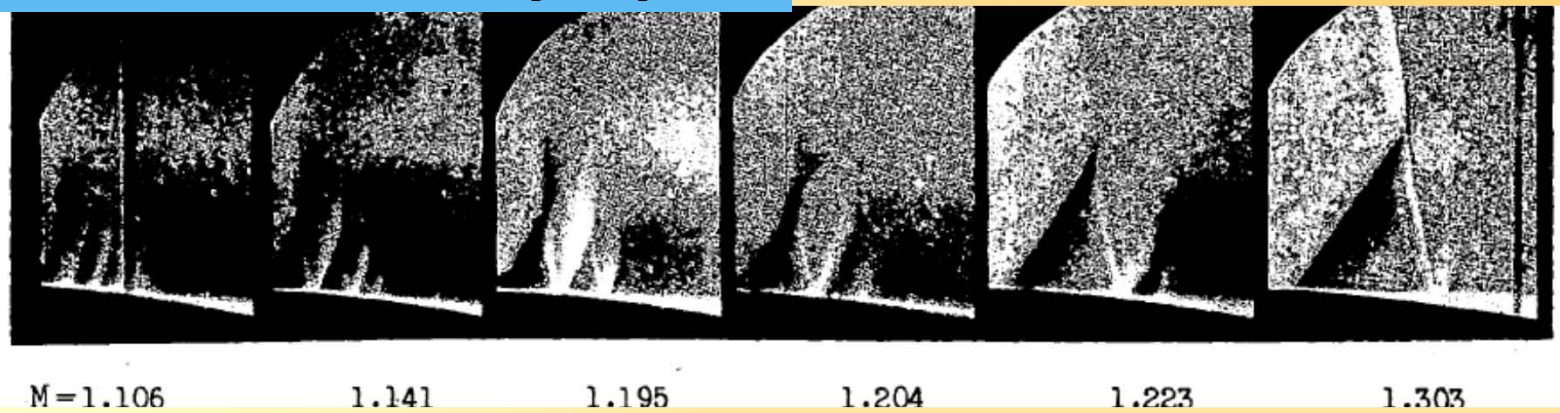
INVESTIGATIONS OF COMPRESSION SHOCKS AND BOUNDARY LAYERS IN GASES MOVING AT HIGH SPEED

By J. Ackeret, F. Feldmann, and N. Rott

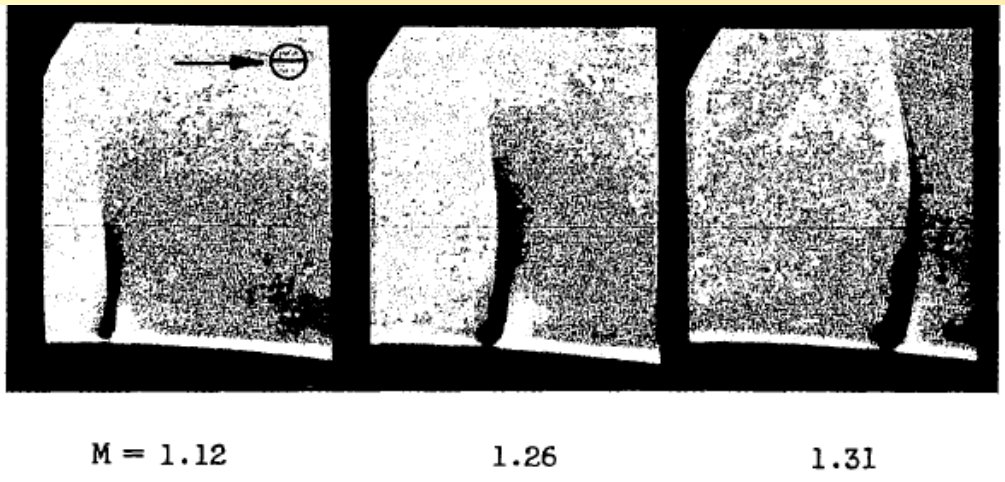
1946



Laminar boundary layer



Turbulent boundary layer



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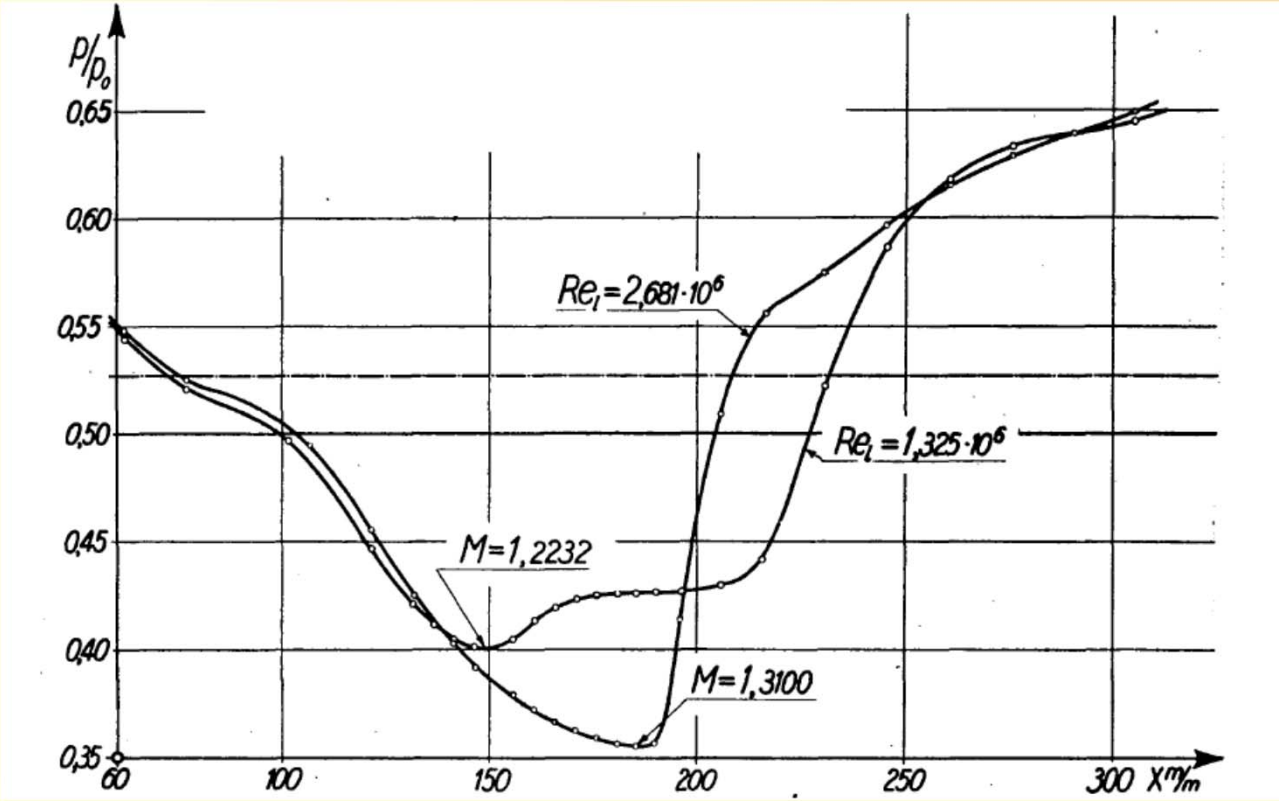
Background

TRANSITION LOCATION EFFECT ON SWBLI



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TRANSITION LOCATION EFFECT ON SWBLI

Daniel Arnal and Jean Délery **2004**

Laminar-Turbulent Transition and Shock Wave / Boundary Layer Interaction

Shock reflection

NATO RTQ-EN-AVT-116

Key application to a transonic laminar wing

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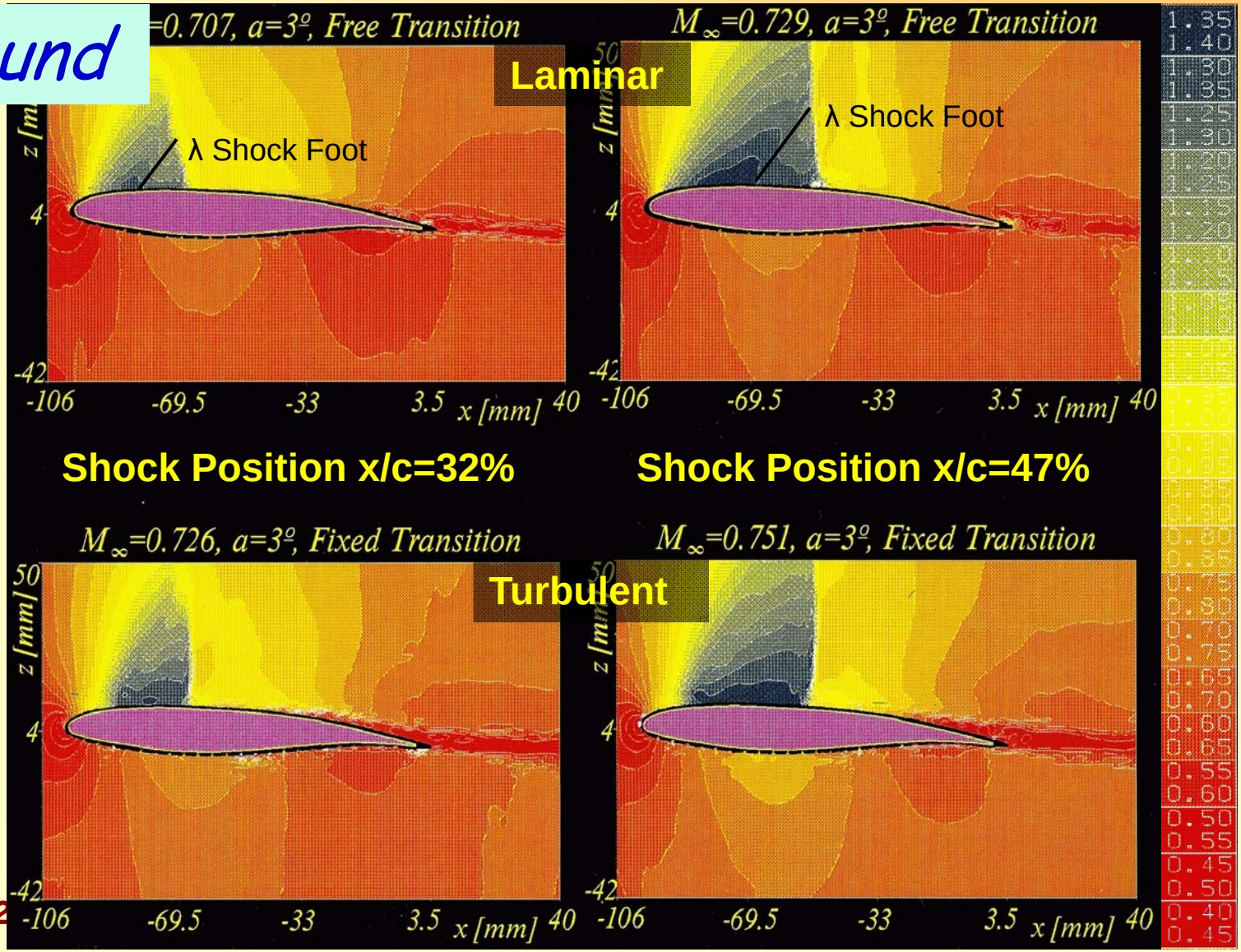
Background

TRANSITION LOCATION EFFECT ON SWBLI

Dr Marius Swoboda
RRD



Summary of the TFAST project

Objective is:

- transition location for turbulent SWBL interaction
  - internal flows
  - external flows

Research is divided to:

- basic flows with shock waves
- application flow cases (wing, compressor and turbine blades)

Crucial issue:

- implementation of the flow control devices for transition induction
- modelling of the flow control devices Task-2.3
- application of these models to 3-D simulation of a wing Task-5.3

Objectives

TFAST objective **is not to improve** knowledge of laminar boundary layers and of transition. The general aim of TFAST **is to avoid** that the laminar boundary layer is penetrated by the shock wave.

Two limiting conditions:

- flows with a laminar boundary layer or with natural transition
- fully turbulent flow - tripped close to the leading edge

To investigate the appropriate place for transition to have a turbulent character of the SWBLI.

Important topic in the TFAST project is to understand how transition can be induced by control devices, until now used only in turbulent BL.

Objectives

The knowledge on laminar or transitional interaction with a shock wave is limited, and it jeopardizes the efficient use of laminar technology.
Project objectives drive the knowledge beyond the present state of the art.

These innovative goals may be summarized as:

a. find out natural transition location in compressible flows with shock wave by means of experiment and a number of modern techniques basing on LES and DNS and compare it with the traditional transition location approaches in RANS and URANS

b. numerical simulations and experimental investigations of the unsteady interaction at different locations of the transition in relation to the shock wave.

c. investigation of the flow control methods operation in laminar boundary layer to understand the physics involved and to relate this to the induction of laminar-turbulent transition

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TRANSITION LOCATION EFFECT ON SWBLI

TFAST Partners:

16 institutions from 9 countries

CFD

EXP

No	Participant name	Short	Contry
1	IMP PAN	IMP	Poland
2	Rolls-Royce Deutschland, Berlin	RRD	Germany
3	Dassault- Aviation	DAAV	France
4	CNRS Lab. IUSTI, UMR 6595, Marseille	IUSTI	France
5	ONERA: (DAFE, DAAP)	ONERA	France
6	DLR Köln, Göttingen	DLR-K	Germany
7	NUMECA, Belgium, SME	NUMECA	Belgium
8	Institute of Aviation, Warsaw	IoA	Poland
9	RAS Siberian Branch, Novosibirsk, Inst. of Theor. App. Mech.	ITAM	Russia
10	University of Cambridge, Dept. of Engin.	UCAM	England
11	Delft Univeristy of Technology, Aero. Lab.	TUD	Holland
12	University of Southampton, (SES)	SOTON	England
13	University of Rome "La Sapienza",	URMLS	Italy
14	University of Liverpool, Dept. of Aero. Eng..	LIV	England
15	Institute Mécanique des Fluides de Toulouse - INPT	IMFT	France
16	Ukrainian Academy of Sciences	UAN	Ukraine

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TRANSITION LOCATION EFFECT ON SWBLI

WP-1 Reference cases of laminar and turbulent interactions
- Task-1.1 Test section design and construction
- Task-1.2 Fully laminar interaction
- Task-1.3 Fully turbulent interaction

WP-2 Basic investigation of transition effect
- Task-2.1 Study of operation of transition control devices
- Task-2.2 Interaction sensitivity to transition location
- Task-2.3 Physical modeling of the control devices

WP-3 Internal flows – compressors
- Task-3.1 Single passage test section
- Task-3.2 Basic compressor cascade flow
- Task-3.3 Compressor cascade flow with transition control

WP-4 Internal flows – turbine
- Task-4.1 Turbine blade suction side model
- Task-4.2 Basic turbine cascade flow
- Task-4.3 Turbine cascade flow with transition control

WP-5 External flows - wing
- Task-5.1 Transonic flow over laminar wing
- Task-5.2 Buffet limit for laminar profile
- Task-5.3 Numerical simulation of 3-D wing

basic

application

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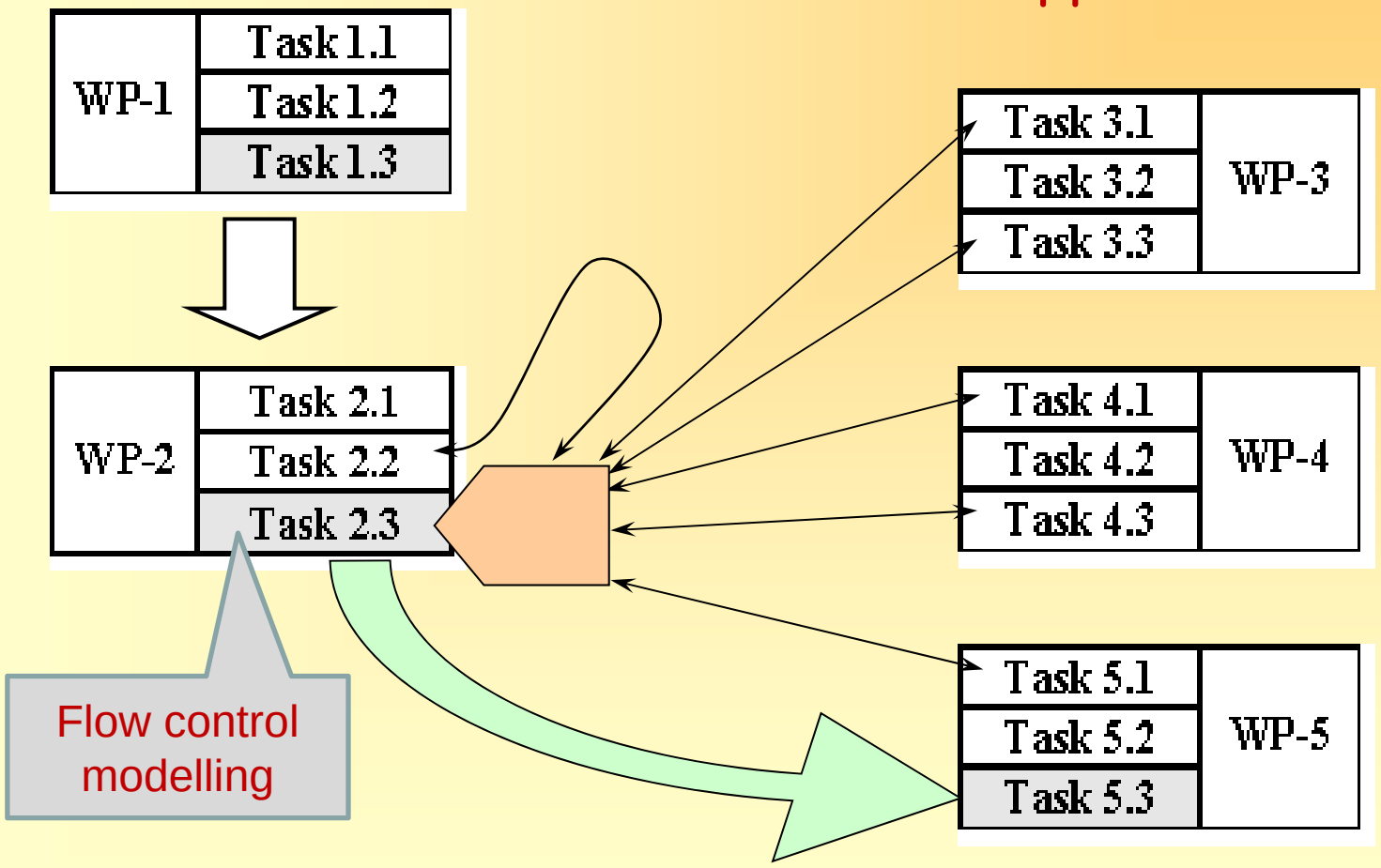
TRANSITION LOCATION EFFECT ON SWBLI

basic

application



Flow control devices:

Not included:
-Synthetic jets
-Vane type

> Tripping by wire,
> Tripping by roughness element (patches) (ONERA)

> Tripping by streamwise Vortex Generators (VG)

1) AJVG (Air Jet Vortex Generator) using main stream P0
2) AJVG using jet outlet Mach number M=2.2
3) RVG (Rod Vortex Generator) (Its height and inclination angles will be determined by IMP PAN).

> Tripping by a cold plasma, three methods will be applied (ITAM):

1) standard approach – plasma on the surface as in UFAST.
2) new approach – plasma induced suction/blowing
3) Spark discharge plasma excitation

Strategy of the work plan

WP-1 and WP-2 focus on basic interaction configurations for:

- normal shock wave in a range of M = 1.25 to 1.3 (incipient separation parameters)
- the oblique shock reflection for M=1.6 (as in HISAC project), including off-design Mach numbers of M = 1.5 and 1.7.

Laminar – separation
Turbulent - attached

WP-1 study of fully laminar and fully turbulent interactions will acquire new knowledge for the experimental data bank, but will test the numerical codes and will serve as a reference for further investigations of flows with natural and controlled transition.

WP-2 will focus on transitions induced by flow control methods. The experimental results will determine the numerical method. The obtained experimental and numerical results will become a basis for the formulation of physical models of flow control devices

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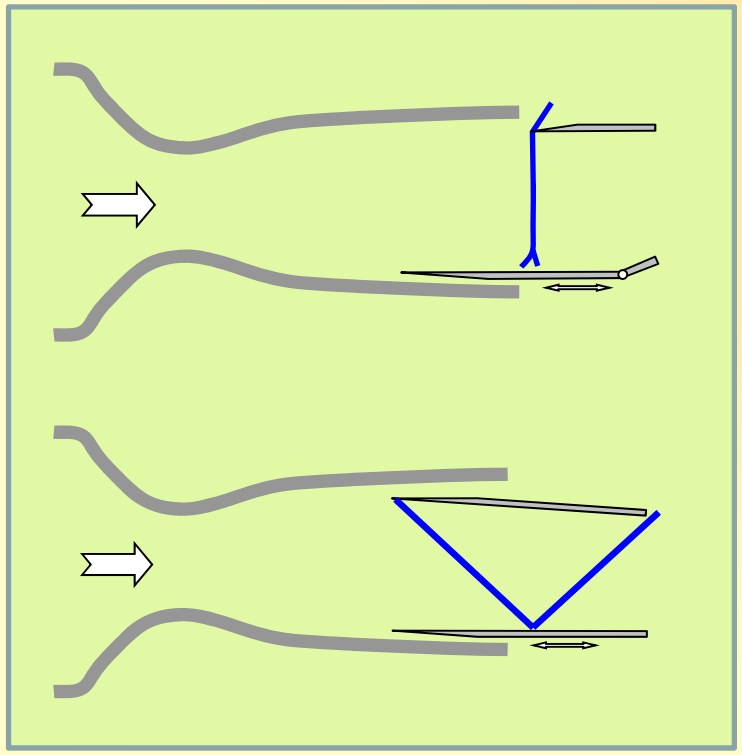
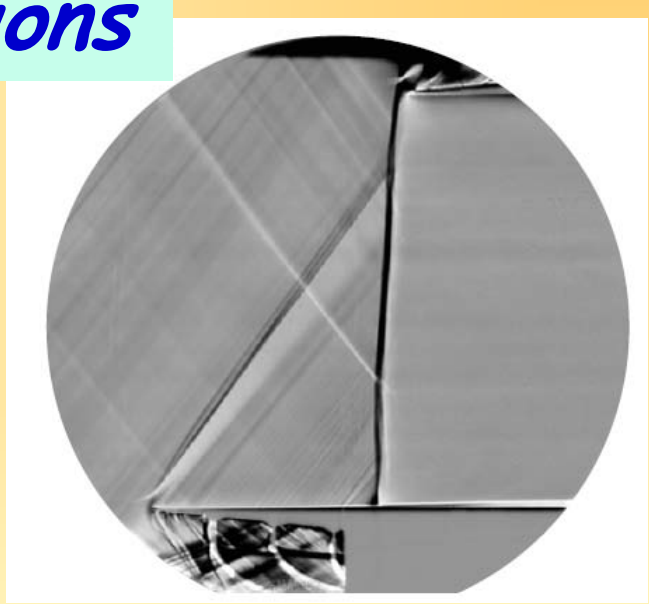
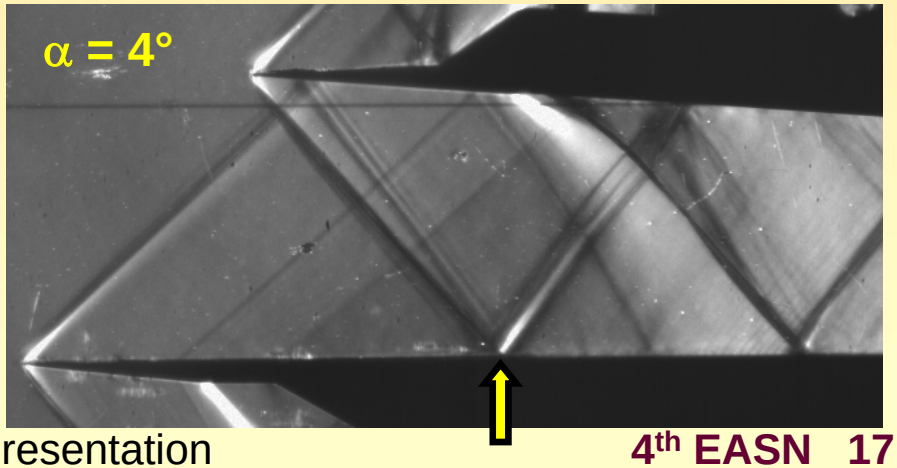
Basic investigations

TRANSITION LOCATION EFFECT ON SWBLI







Strategy of the work plan

The basic research in WP-1 and WP-2 is closely related to three Work Packages concerning technical applications where the location of transition is a dominant issue in their further improvement of performance.

These technical cases concern:

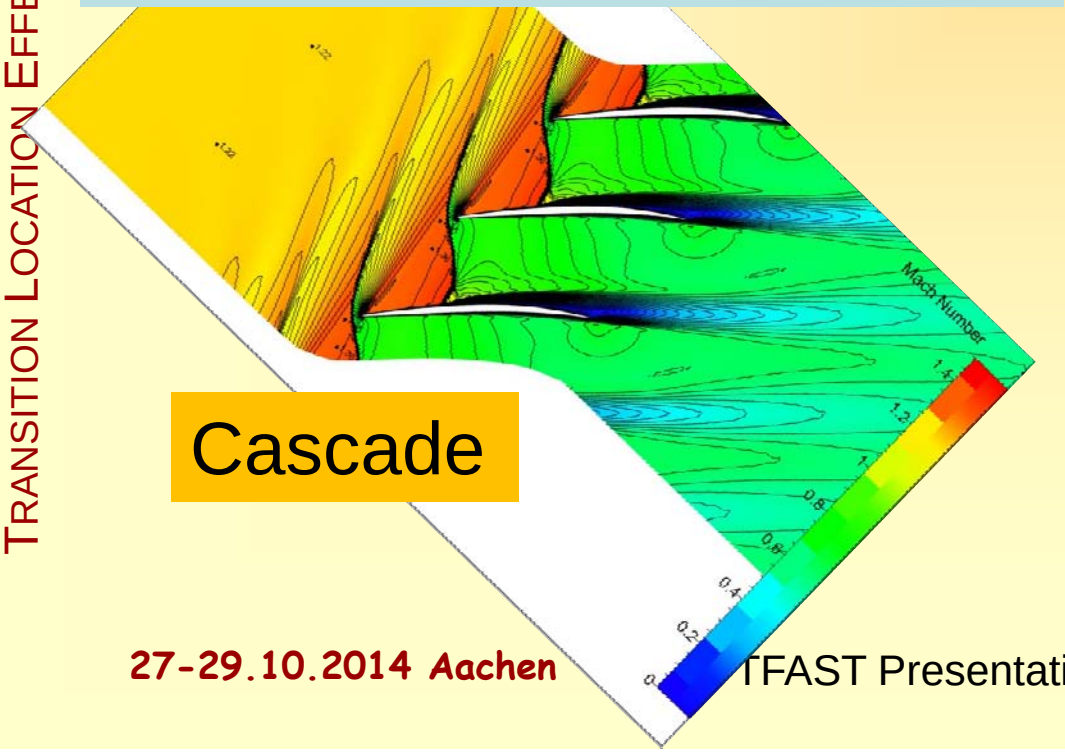
- flow in transonic compressor cascade, WP-3;
- high pressure turbine cascade with cooling system, WP-4;
- and a transonic laminar wing, WP-5.

Each of WPs include only those transition control devices which are technically realisable in their particular case.

Internal flows

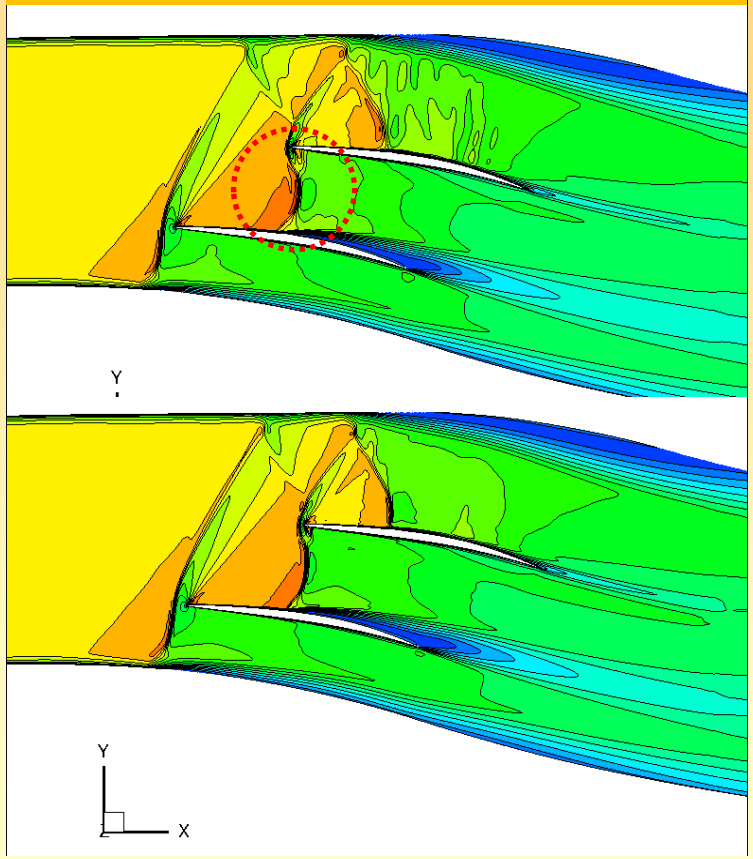
Besides basic experiments it is essential to carry out measurements in cascades.
DLR has potential and great experience in such measurements:

➔ compressor cascade in Köln



Cascade

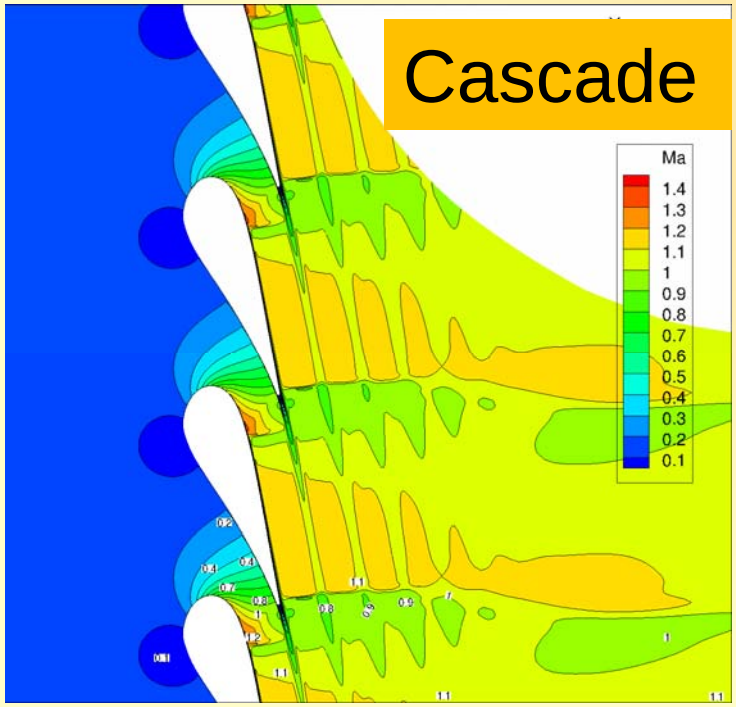
Single passage

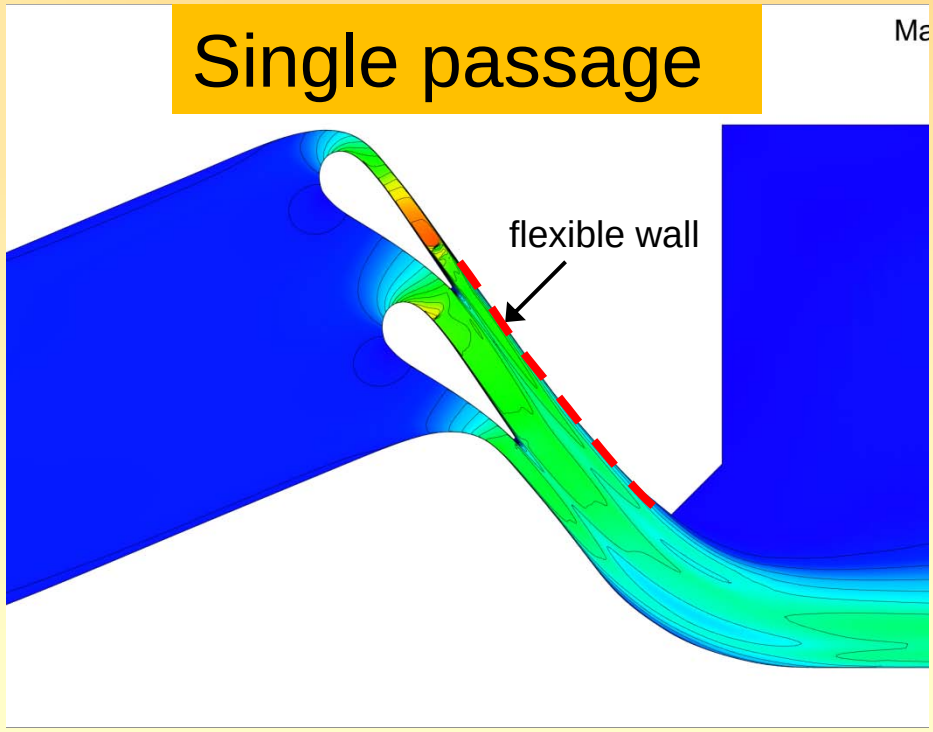


Internal flows

TRANSITION LOCATION EFFECT ON SWBLI

➔ turbine cascade in Göttingen





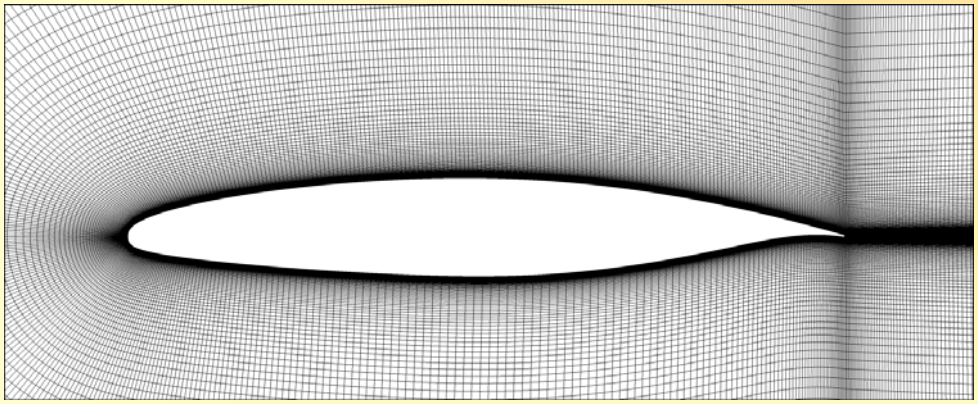
External flows

Laminar profile

Designed by Dassault

In laminar boundary layer incipient separation takes place at M≈1.2 and causes strong separation

In turbulent boundary layer incipient separation takes place at M≈1.3



In laminar boundary layer compression and separation is upstream.
Turbulization of boundary layer may influence significantly the lift and drag.

TRANSITION LOCATION EFFECT ON SWBLI

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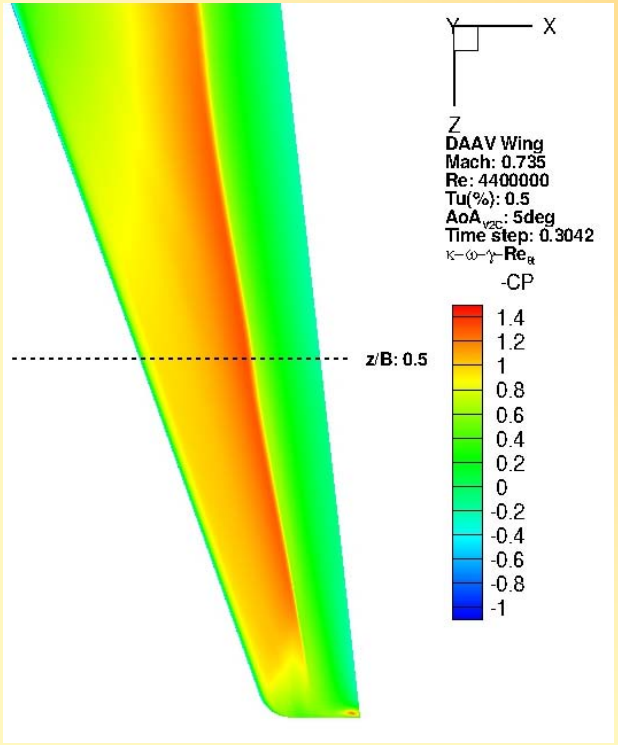
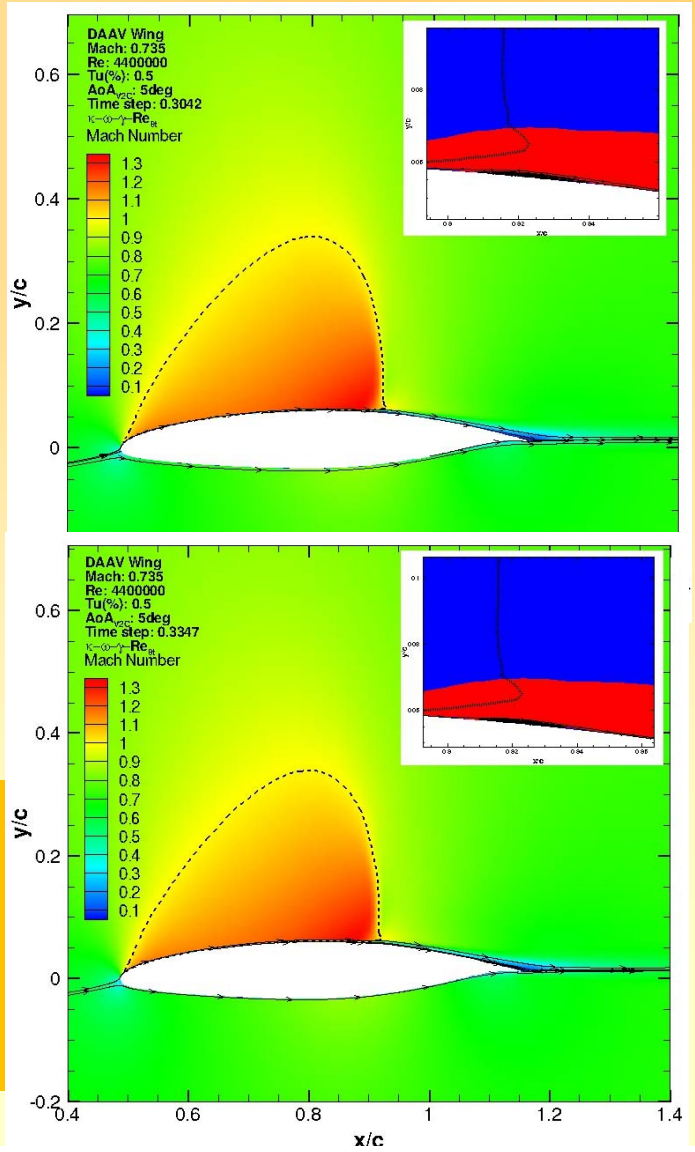
Application of flow control devices **models**





Surface pressure on the upper surface of the wing for $\kappa-\omega-\gamma-Re_{\theta t}$ conditions
M_∞ 0.735, Re_c 4.4×10^6, a=5deg
Mach number contour mid-span of the wing
t=0.3042s (upper) t=0.3347s (lower)

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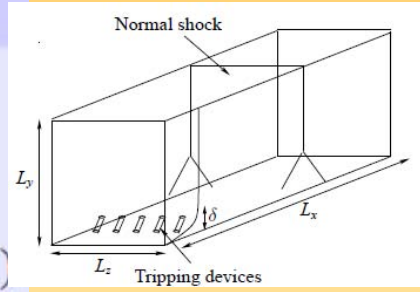
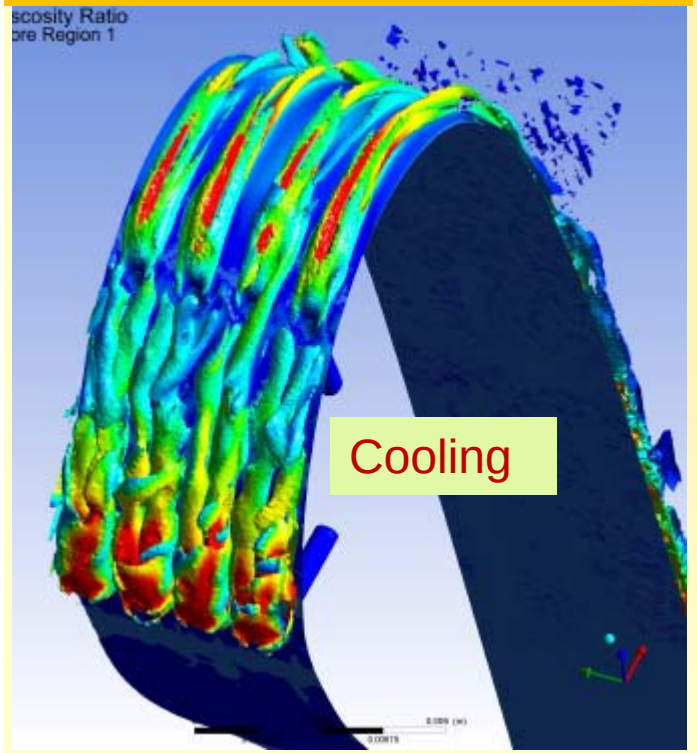
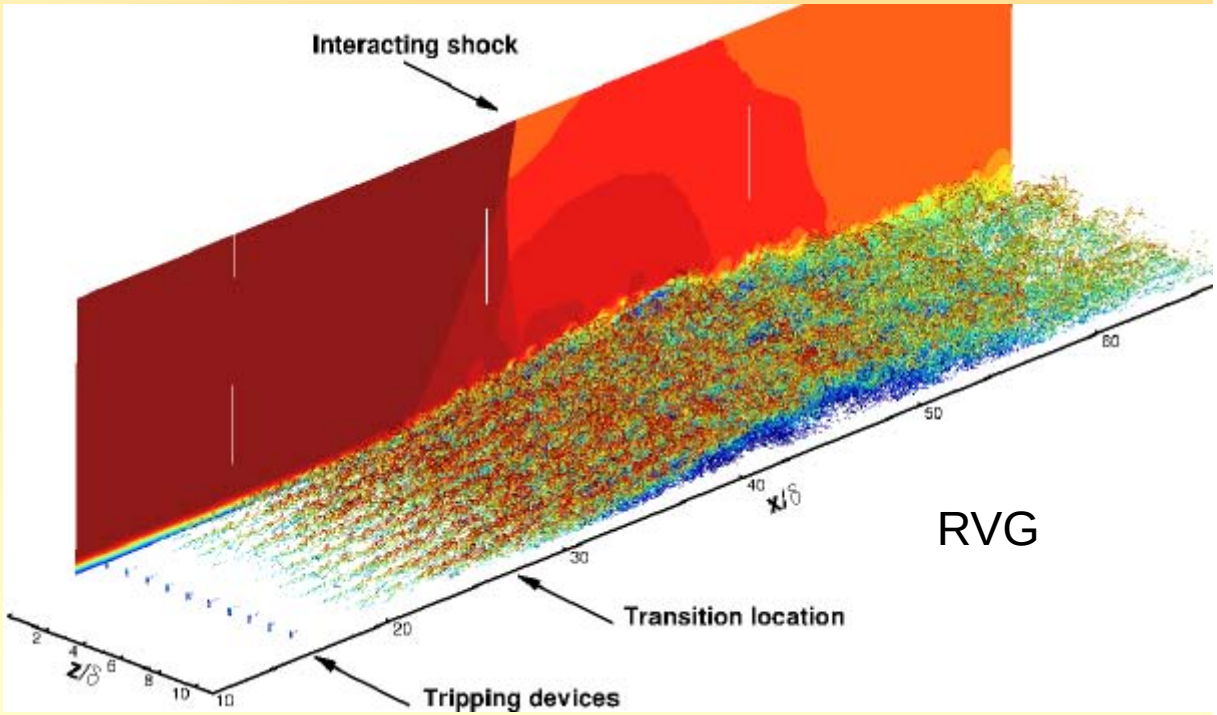
- Intermittency <0.7 close to coolant jets and t/e shock
- No indication of turbulent flow
- No significant differences between SAS and yRe_θ

Computational parameters

- Domain size $L_x \times L_y \times L_z = 150\delta \times 200\delta \times 5.5\delta$
- Grid points $N_x \times N_y \times N_z = 10240 \times 512 \times 768$ (4.0 Billion total)







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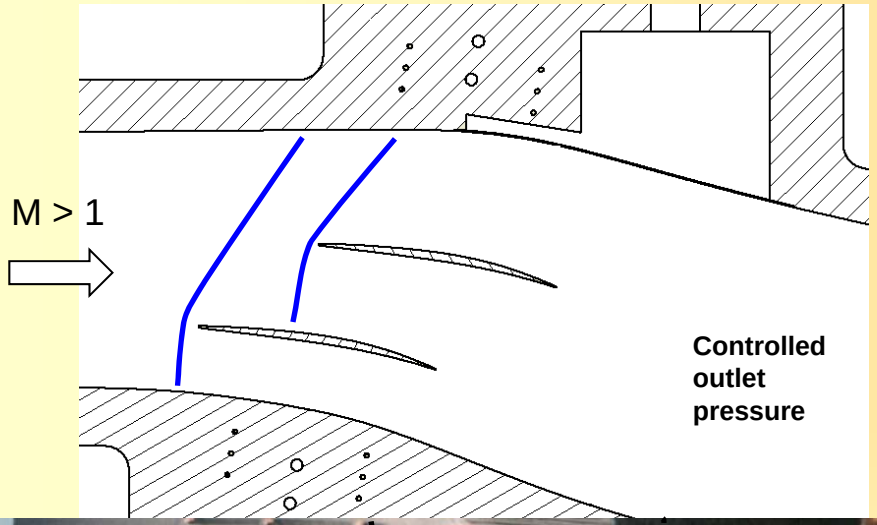
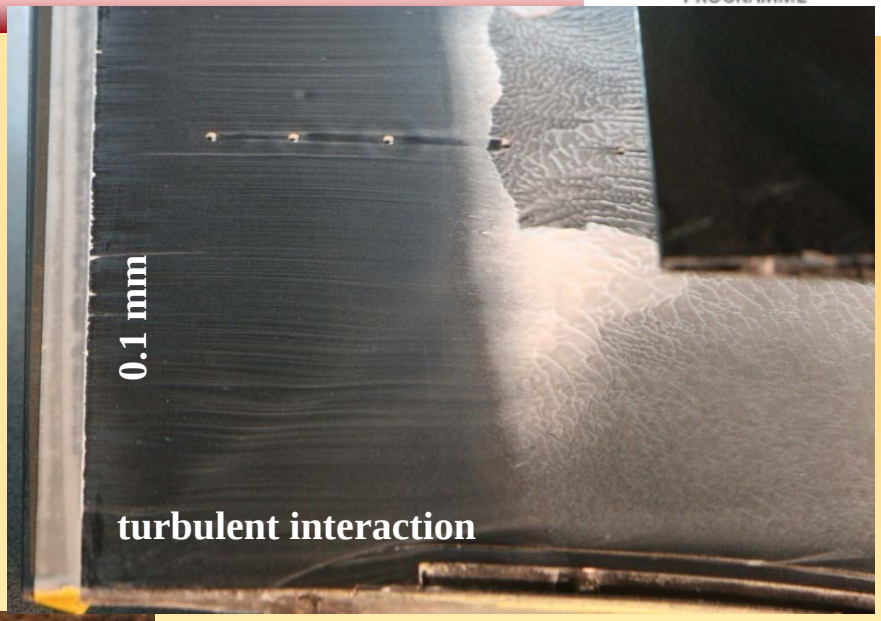
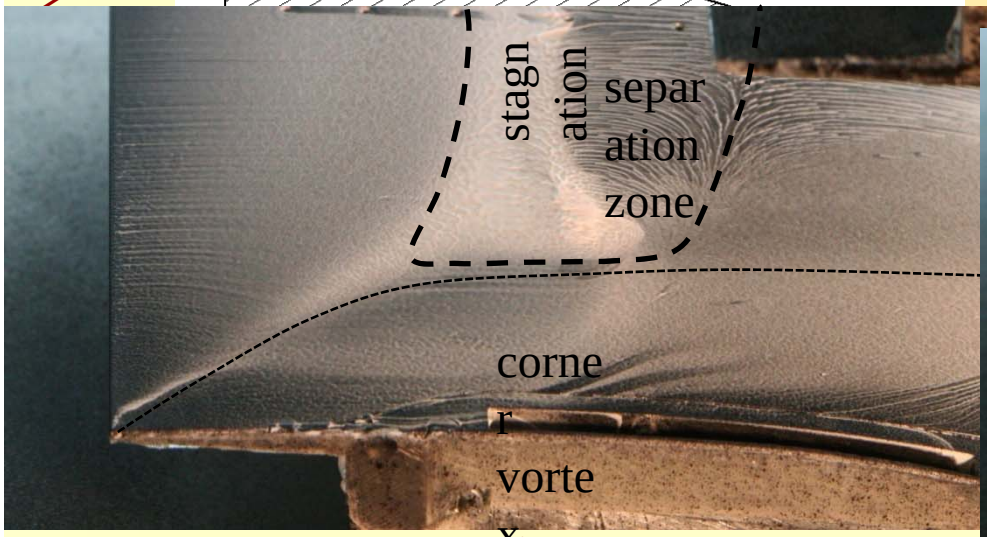
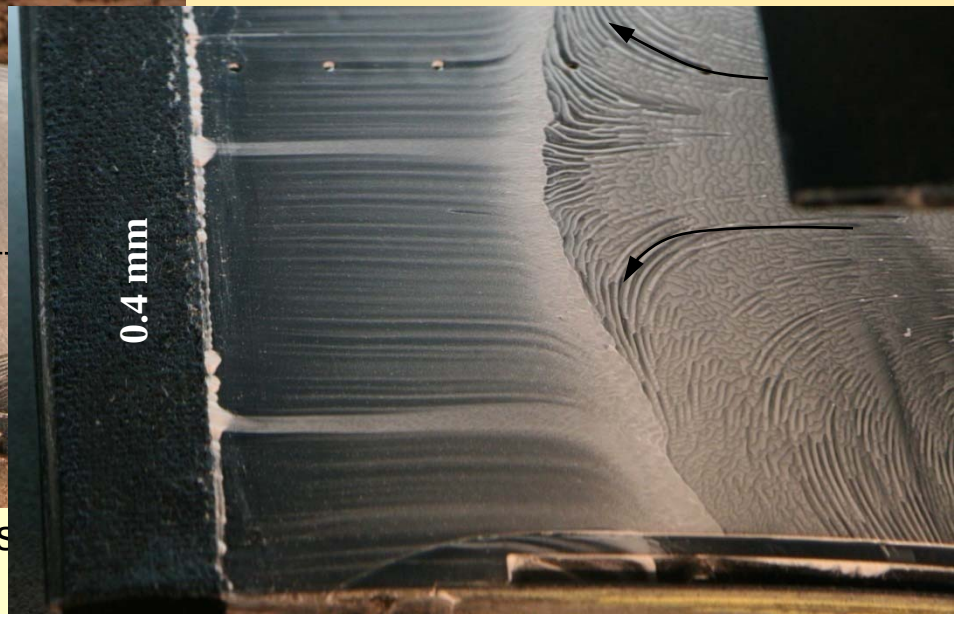
N EFFECT ON SWBLI









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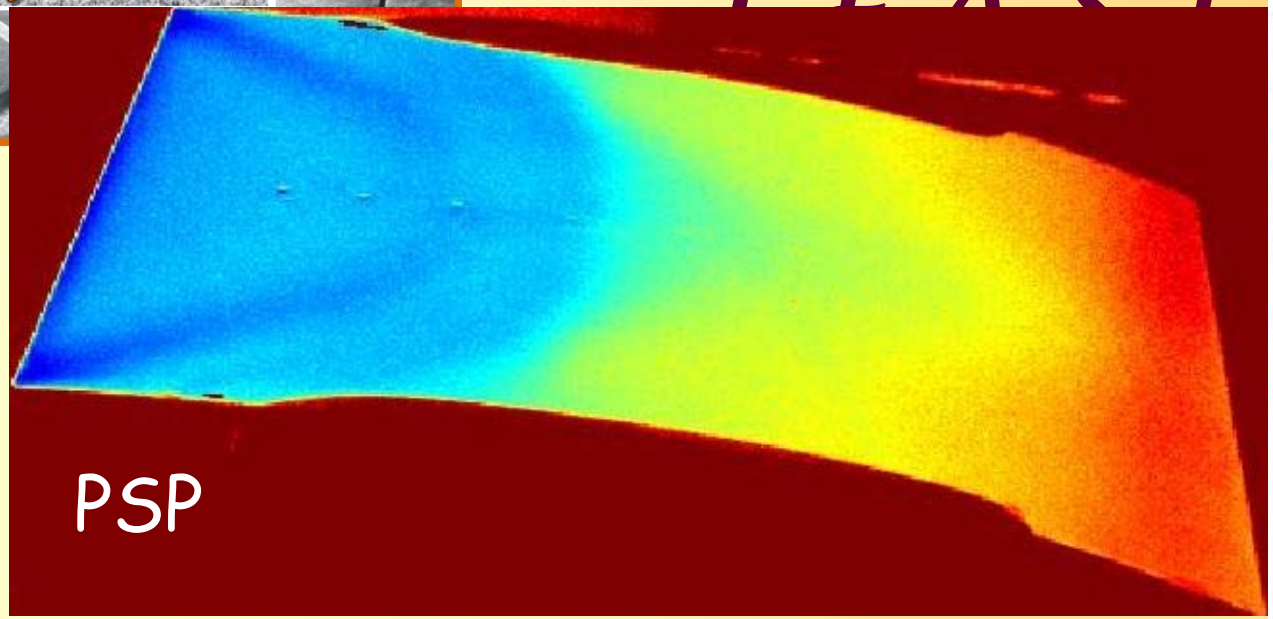
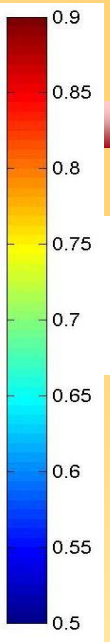
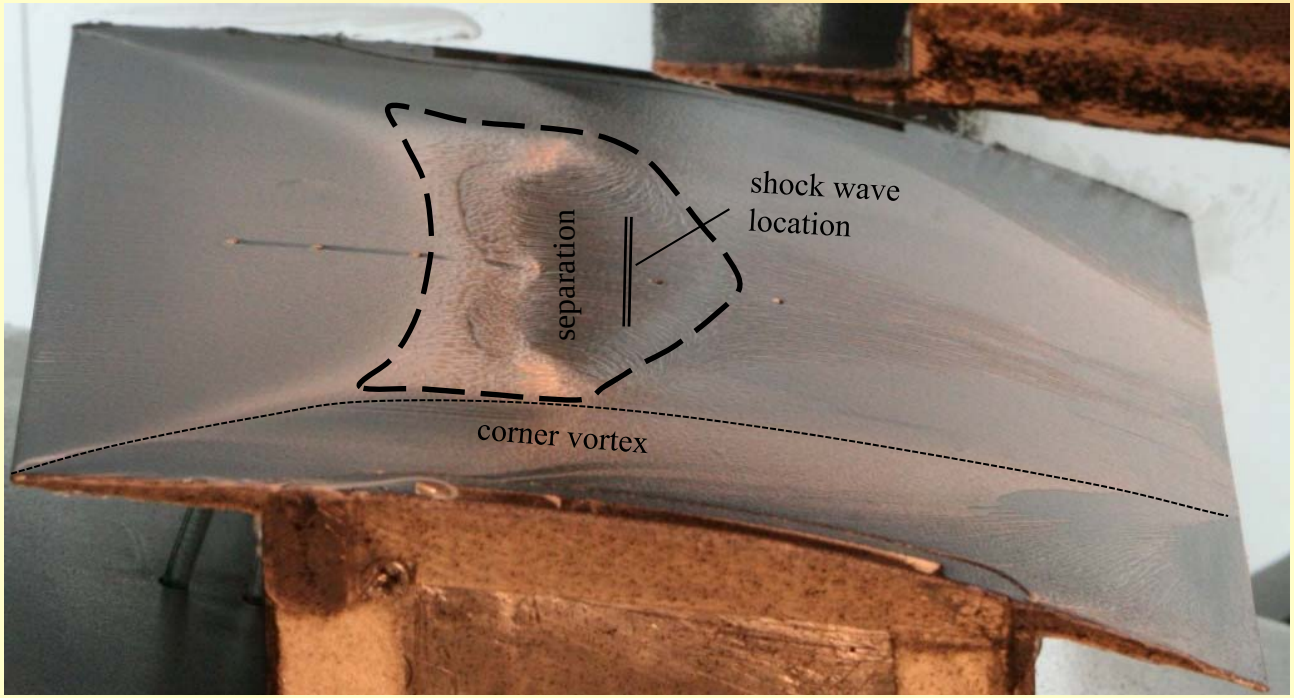
TRANSITION LOCATION EFFECT ON SWBLI







Conclusions:

Work has accelerated now because all test sections are running

CFD after the blind test phase starts having experimental material for comparison

There are two main issues:

- laminar or turbulent cases on blades and profiles have inherently connected thickness issue - weak turbulisation
- operation of flow control devices in laminar or turbulent boundary layer needs clearly defined reference

To have positive effect one does not need a fully developed turbunt B.l.

4th EASN Association International Workshop
on Flight and Aircraft Design

IMPLICIT CFD METHODS FOR TRANSITIONAL SHOCK WAVE - BOUNDARY LAYER INTERACTION

G. N. Barakos and G. Zografakis

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INSTITUT DE MECANIQUE DES FLUIDES DE TOULOUSE

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LABORATORY

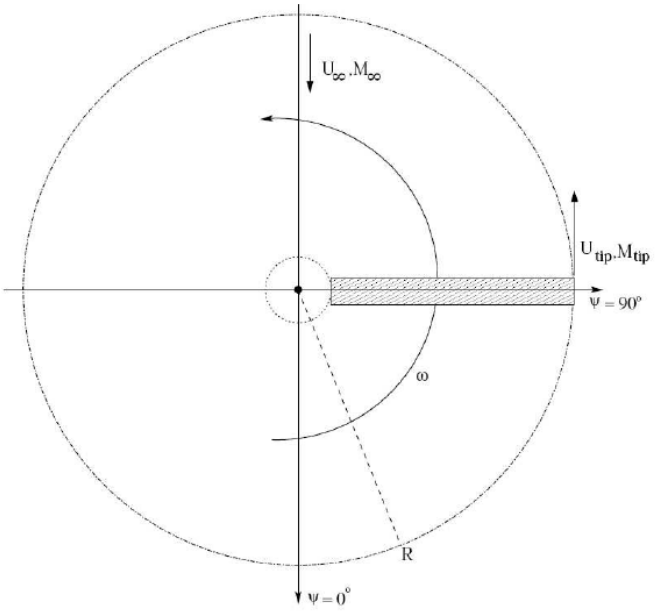
Motivation

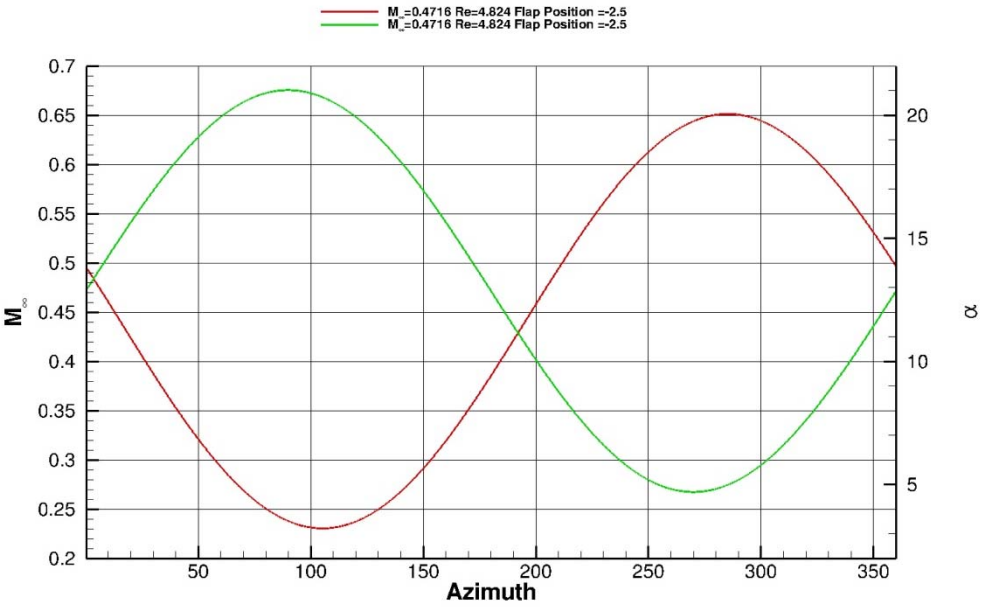
- Highly swept wings have reduced wave drag
- Highly swept wings show early transition to turbulence and so increased friction drag
  - Cross-flow instability
- Sweep angle reduces planform efficiency
- Reduced sweep leads to reduced cruise speed
  - Perhaps this is acceptable
- Reduced sweep may allow the boundary layer to stay laminar up until the shock, leading to reduced friction drag
- It may be the case that a laminar wing with lower sweep may offer a good design compromise between speed and efficiency.
- Any shock/boundary layer interaction may lead to flow separation especially if the boundary layer is laminar ahead of the shock
  - So, rapid transition to turbulence may help the boundary layer survive the shock with little separation

dMdt Computations

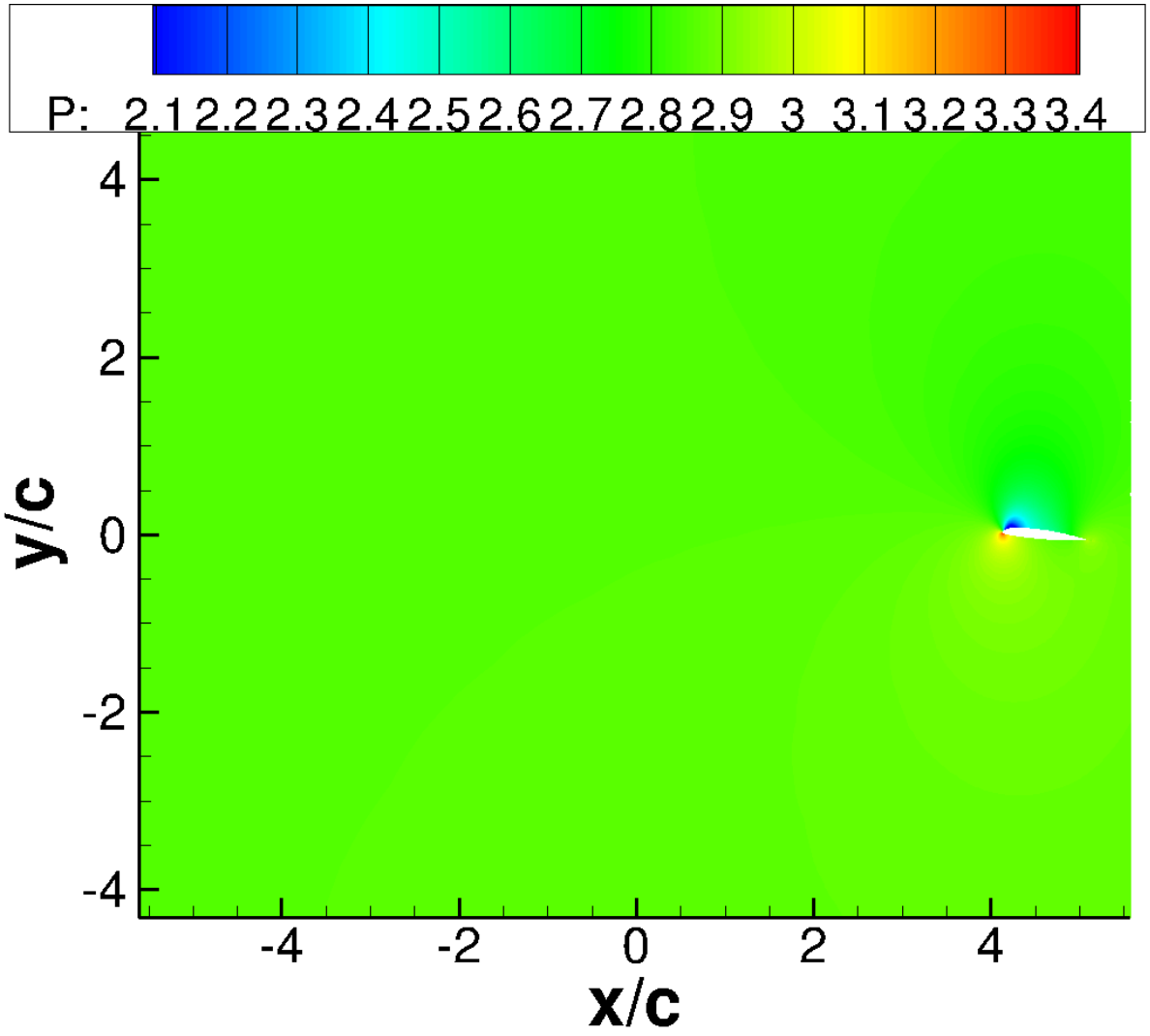
$$x = x_0 + \sum_{i=1}^{N_h} x_s \sin(2kit) + x_c \cos(2kit)$$

$$U = U_{tip}\frac{r}{R} + U_\infty \sin(\omega t)$$





- AUM 11,500 kg
- Forward Speed 135 kts
- Inboard Station
- Fundamental question on the relationship between aerodynamic coefficients and dMdt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y/c
-4
-2
0
2
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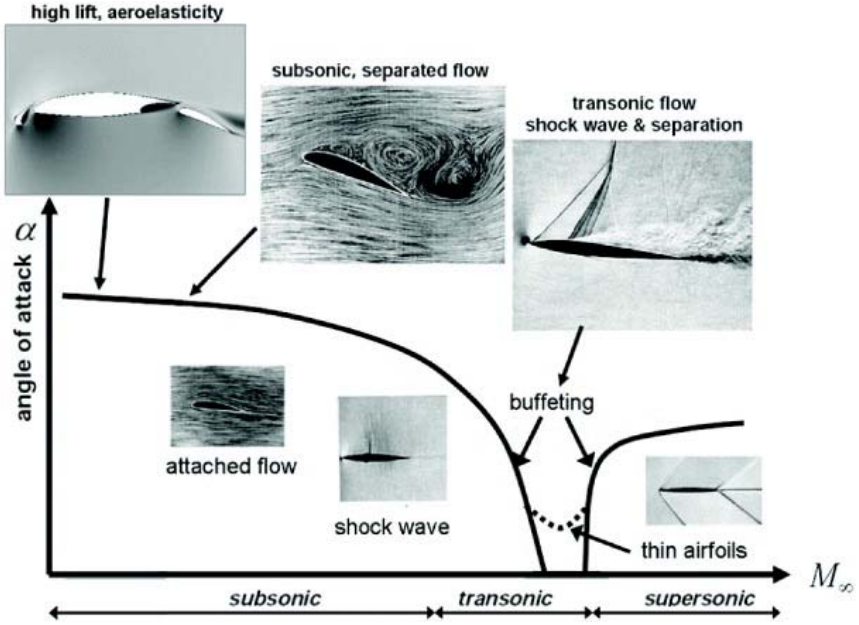
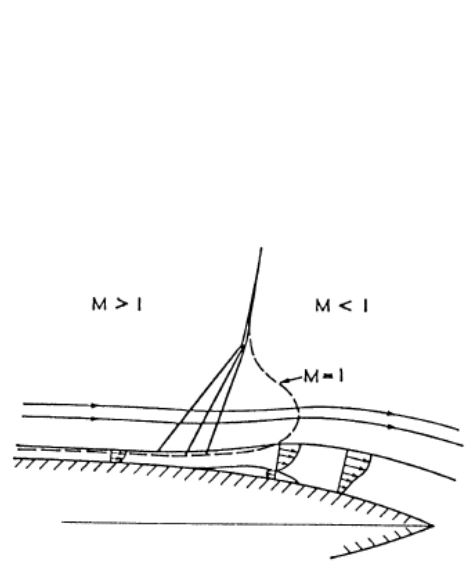
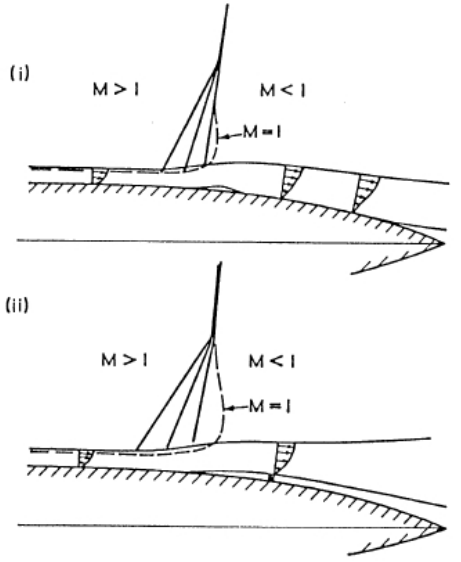
x/c

Shock Boundary Layer Interaction and Buffet

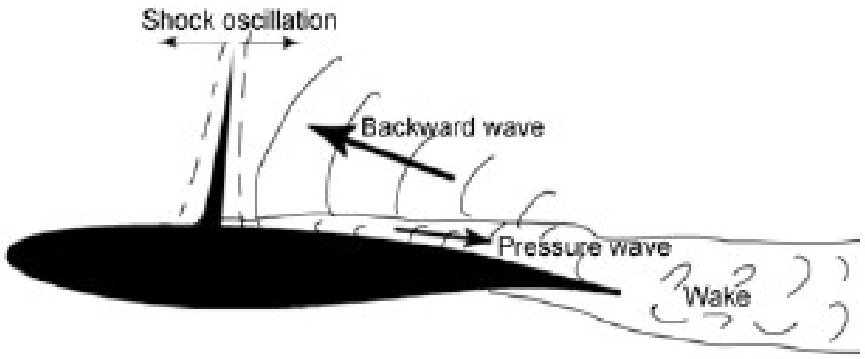




(a) Model A at expanding bubble stage



(b) Model B (i) at early stage with localised shock bubble and rear separation
(ii) at later stage with one separation extending from shock to trailing edge



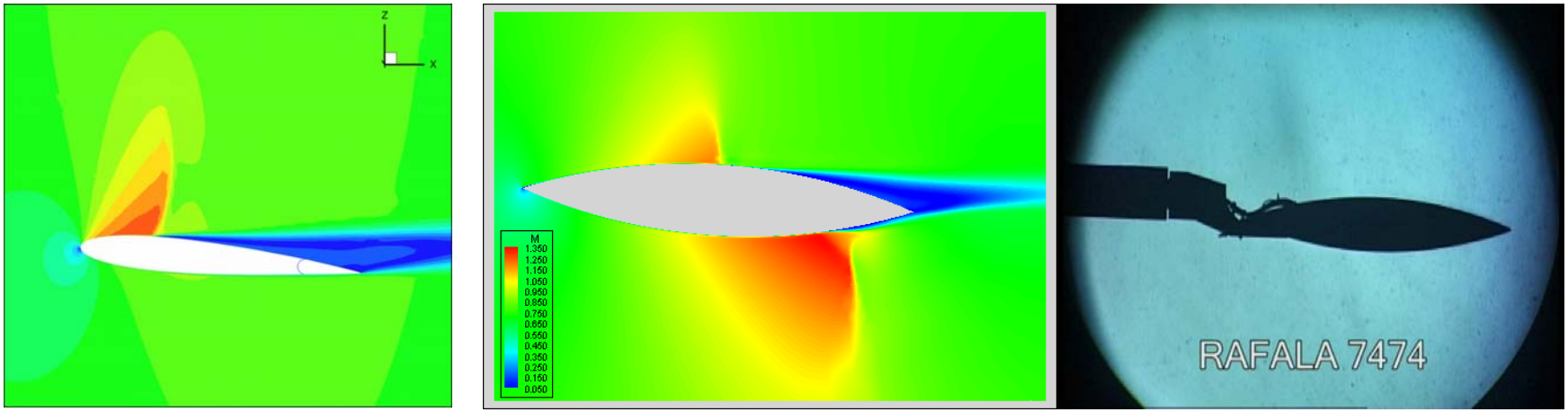
Sketch of shock boundary layer interaction with (a) bubble separation and (b) bubble and rear separation [1]

Interplay between shock wave, BL and TL pressure leads to Buffet feeding mechanism

[1] Pearcey, Osborne and Haines (1968)

UFAST – Low Frequency Shock Motion Cases

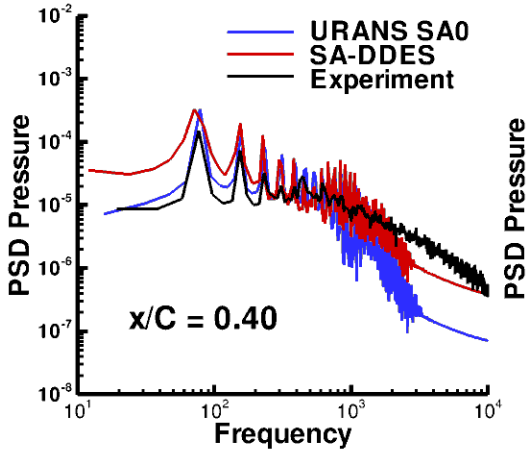
- Transonic buffet – Turbulent boundary layer
  - Circular arc sections
  - UFAST database – NACA0012 and circular arc
  - Experiments by ONERA Jacquin et al, AIAA 2005, 09

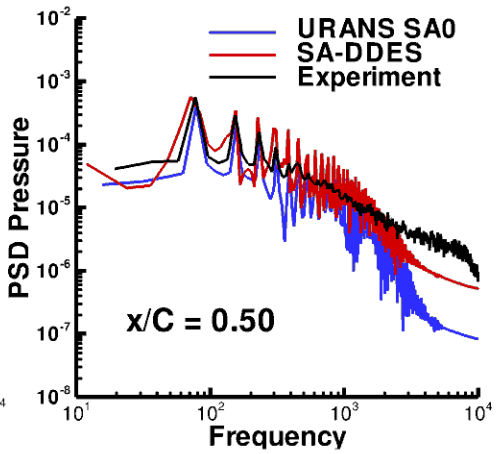


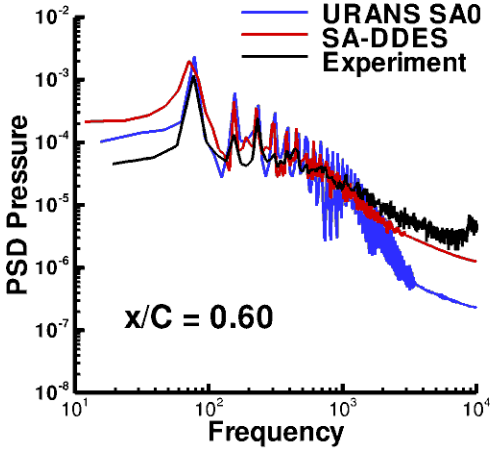
INCAS Experiments

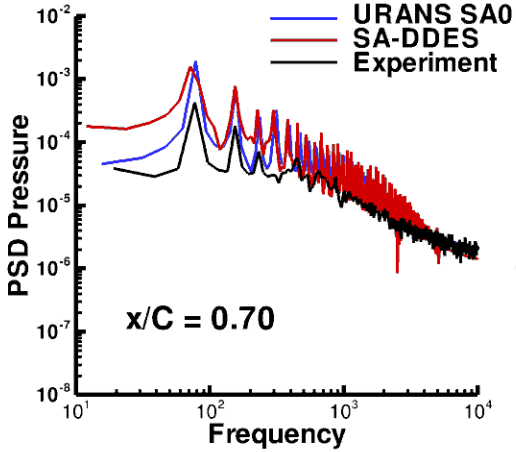
- TFAST aims to be the first project to investigate buffet with transitional boundary layers

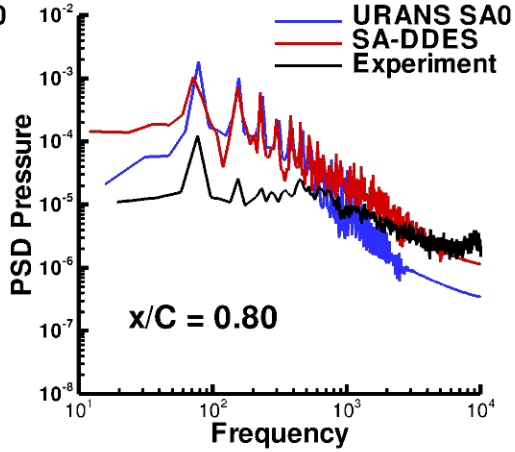
V2C - UCAM WT – INCAS Experiments (UFAST)











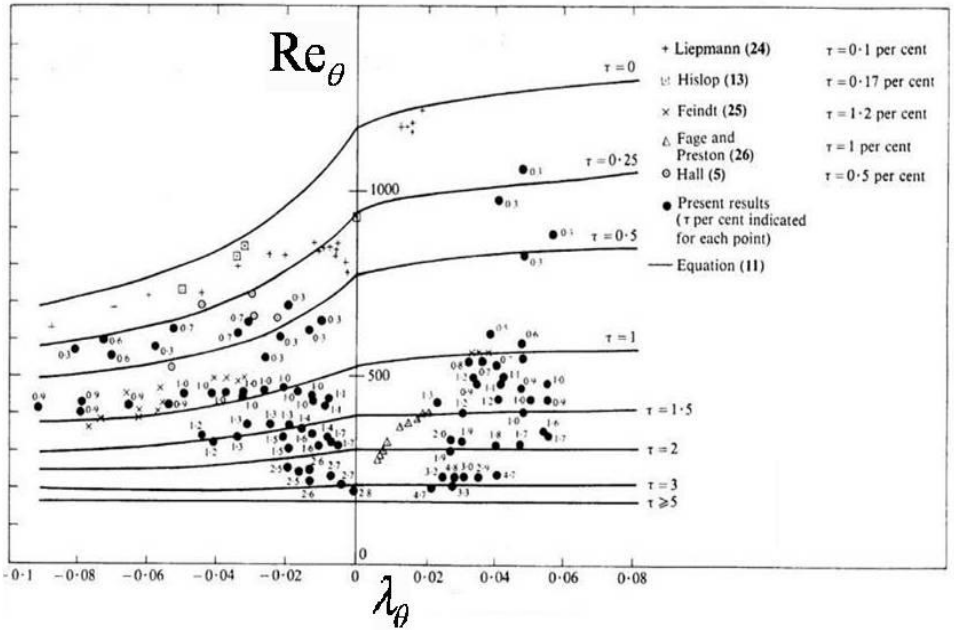
Final UFAST results

Transition Models - Classification

Several ideas have been proposed, current trend is for more complex models:

- Correlation-Based Models
  - Michel's criterion *(ONERA, Technical Report 1/1578A, 1951)*
  - Cebeci-Smith method *(Analysis of turbulent Boundary Layers, Academic Press,1974)*
  - Abu-Ghannam and Shaw method *(Journal of Mechanical Engineering Science, 22(5), 1980)*
- Linear Stability Theory based Models
  - e^N method (*Proc. 9th. Int. Cong. Appl. Mech.*, 4, 1956)
- Models based on Transport Equations
  - Cho and Chung *(Journal of Fluid Mechanics, 237, 1992)*
  - Steelant and Dick *(Int. J. Num. Meth. Fluids, 23(3),1996)*
  - Suzen and Huang *(NASA, CR-1999-209313, 1999)*
  - Menter and *et al.* *(Journal of Turbomachinery, 128(3), 2006)*
- Models based on Numerical Receptivity
  - Johnson (*Journal of Turbomachinery, 124(4), 2002*)

Correlation-based Models: Abu-Ghannam & Shaw



Based on experiments on flat plates[1]

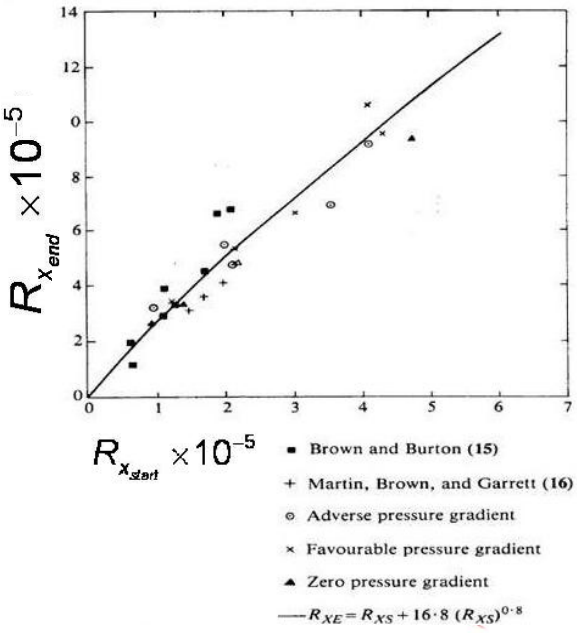
Transition onset given by:

$$\mathrm{Re}_{\theta t} = 163.0 + e^{\left(F(\lambda_\theta) - \frac{F(\lambda_\theta)}{6.98}\tau\right)}$$

End of transition predicted by:

$$\mathrm{Re}_{x,end} = \mathrm{Re}_{x,start} + 16.8\left(\mathrm{Re}_{x,start}\right)^{0.8}$$

where λ_θ is the pressure gradient parameter and Tu is the free-stream turbulence intensity.



[1] B.J. Abu-Ghannam and R. Shaw, J. of Mech. Eng. Science, 22(5):213-228, 1980

Transport Equation Models

Model	Steelant and Dick	Cho and Chung	Suzen and Huang	Menter and *et al.*
Number of equations	13	3	3	4
Pointwise	No	No	No	Yes
Empirical Correlation	No	No	Yes	Yes

- Do not require boundary layer integral quantities
- Take into account 'history effects' on transition
- Most of these models require only local variables
- Better suited for implementation in CFD codes since CFD solvers already have the framework for solving transport equations
- Overhead in terms of CPU time, memory, robustness
- Coupling with statistical turbulence models

Transport Based model: κ–ω–γ–$Re_{\theta t}$

The κ-ω-γ-Re_θ model is based on local information

Transport equation for the intermittency:

$$\frac{\partial}{\partial t}(\rho\gamma)+\underbrace{\frac{\partial}{\partial x_j}(\rho u_j\gamma)}_{\text{convection}}=\underbrace{P_{\gamma 1}-E_{\gamma 1}}_{\text{transition sources}}+\underbrace{P_{\gamma 2}-E_{\gamma 2}}_{\text{destruction/ relaminarisation sources}}+\underbrace{\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_f})\frac{\partial\gamma}{\partial x_j}]}_{\text{diffusion}}$$

Transport equation for the scalar transition momentum Reynolds number:

$$\frac{\partial}{\partial t}(\rho\,\tilde{\mathrm{R}}\mathrm{e}_{\theta t})+\underbrace{\frac{\partial}{\partial x_j}(\rho u_j\,\tilde{\mathrm{R}}\mathrm{e}_{\theta t})}_{\text{convection}}=\underbrace{P_{\theta t}}_{\text{source}}+\underbrace{\frac{\partial}{\partial x_j}[\sigma_f(\mu+\mu_t)\frac{\partial\,\tilde{\mathrm{R}}\mathrm{e}_{\theta t}}{\partial x_j}]}_{\text{diffusion}}$$

The transition model is coupled with the SST turbulent model as follows:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho u_j k)=\tilde{P}_k-\tilde{D}_k+\frac{\partial}{\partial x_j}[(\mu+\sigma_k\mu_T)\frac{\partial k}{\partial x_j}]$$

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_j}(\rho u_j\omega)=P_\omega-D_\omega+\frac{\partial}{\partial x_j}[(\mu+\sigma_\omega\mu_T)\frac{\partial\omega}{\partial x_j}]$$

$$\tilde{P}_k=\gamma_{eff}P_k \qquad \tilde{D}_k=\min\left[\max\left(\gamma_{eff},0.1\right),1.0\right]D_k \qquad \mu_T^*=\gamma\mu_T$$

Transport Based Models: k-ω-γ-Re_θ

Empirical correlation for the $Re_{\theta t}$ where transition starts to happen

$$\mathrm{Re}_{\theta t} = [110.0 + e^{(7.08 + Tu)}]F(\lambda_\theta, K)$$

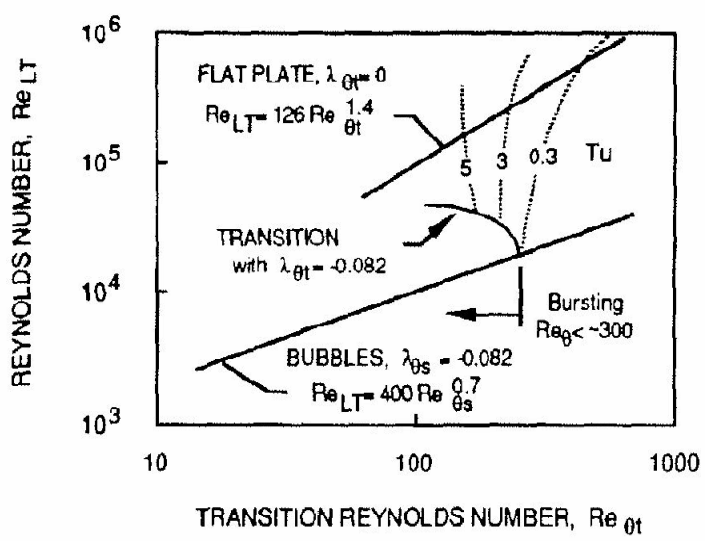
Empirical correlation for the length of the transition region

$$F_{length} = 1260\ \tilde{\mathrm{R}}\mathrm{e}_{\theta t}^{1.4}\ \frac{\mu}{\rho U}\ \frac{1}{\mathrm{Re}}$$

Empirical correlation for the $Re_{\theta c}$ where γ starts to increase in the boundary layer

$$\mathrm{Re}_{\theta c} = 0.9\ \tilde{\mathrm{R}}\mathrm{e}_{\theta t}$$

All the functions are calculated using local information



$Re_{\theta t}$ and Re_{LT} for various turbulent intensities and pressure gradient parameters, *from Mayle 1991*

λ_θ: *pressure gradient parameter*

K : *flow acceleration parameter*

Tu : Free-stream turbulence intensity

T. Misaka and S. Obayashi, In 44*th AIAA Aerospace Sciences Meeting*, AIAA 2006-918

Transport Based Models: k-ω-γ-Re_θ

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$$\mathrm{Re}_{\theta c} = 0.9\ \tilde{\mathrm{R}}\mathrm{e}_{\theta t}$$

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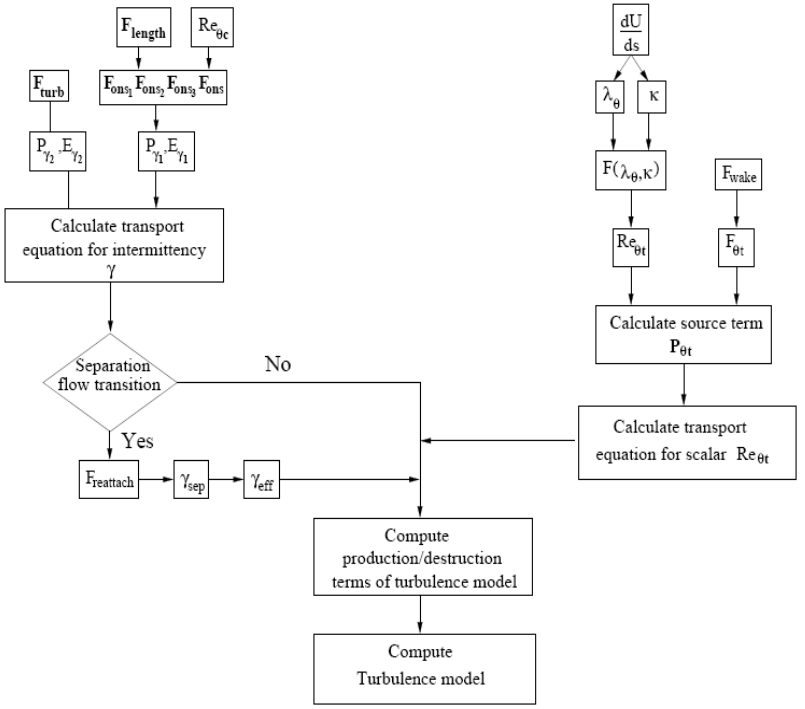


Road map for the κ-ω-γ-Re_θ model

λ_θ: pressure gradient parameter

K: flow acceleration parameter

Tu : Free-stream turbulence intensity

T. Misaka and S. Obayashi, In 44*th AIAA Aerospace Sciences Meeting*, AIAA 2006-918

Transport Based Models: k-ω-γ-Re_θ

New crossflow transition onset criterion based on streamline radius curvature (R) and local crossflow velocity (U_{CF})

$$\mathrm{Re}_{CF} = \frac{U_{CF} \cdot R}{\nu} \quad \text{where} \quad U_{CF} = |u \cdot r_1| + |v \cdot r_2| + |w \cdot r_3|$$

Crossflow transition criterion is integrated inside the F_{onset1} function:

$$F_{onset1} = \max\left(\frac{\mathrm{Re}_v}{2.193 \cdot \mathrm{Re}_{\theta c}}, \frac{F_{\theta t} \cdot \mathrm{Re}_{CF}}{2}\right)$$

Suzen, Y. B. and Huang, P. G., "An Intermittency Transport Equation for Modeling Flow Transition," AIAA 2000-0287, 2000.

Ambient Turbulence Sustaining Terms

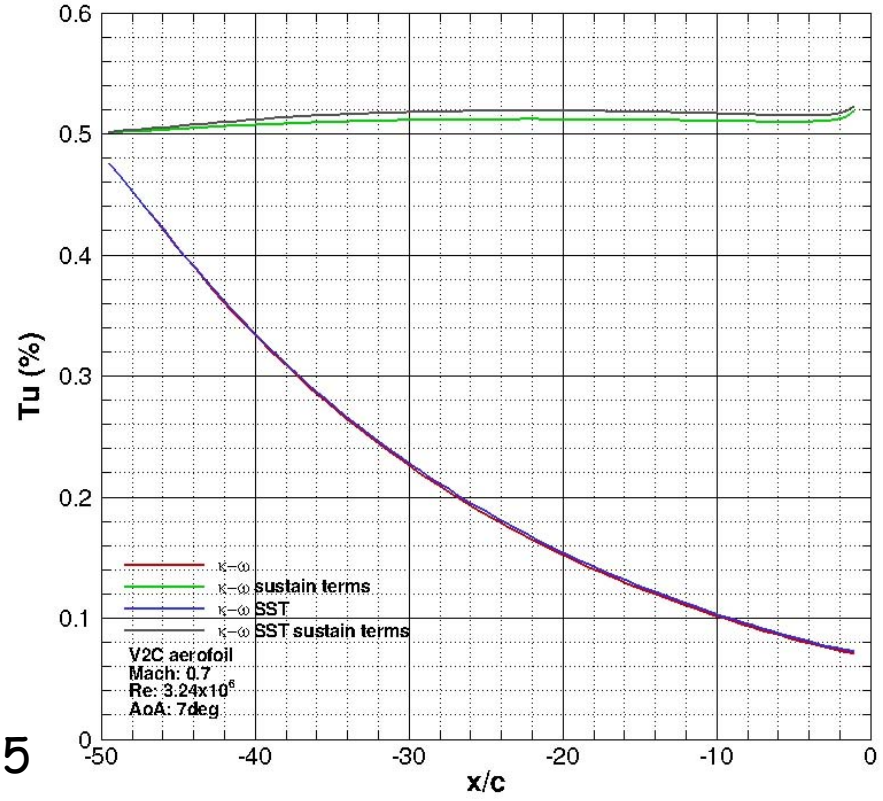
An addition on the existing k-ω turbulent model to reduce the decays throughout the computational domain.

Additional weak source terms on k and ω transport equations:

$$\beta^* \omega_{ambient} \kappa_{ambient}$$

and

$$\beta \omega^2_{ambient}$$



Turbulence intensity for V2C aerofoil
M_∞ 0.7, Re_c 3.24x10^6, a=7deg Tu(%)= 0.5

Scale-Adaptive Simulation

The SAS model is an improved URANS formulation.

Transport equations for the SST-SAS equations:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho u_j k)=P_k-D_k+\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_T}{\sigma_k})\frac{\partial k}{\partial x_j}]$$

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_j}(\rho u_j \omega)=P_\omega-D_\omega+\frac{\partial}{\partial x_j}[(\mu+\sigma_\omega\mu_T)\frac{\partial \omega}{\partial x_j}]+(1-F_1)\frac{2\rho}{\sigma_{\omega 2}}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}+Q_{SAS}$$

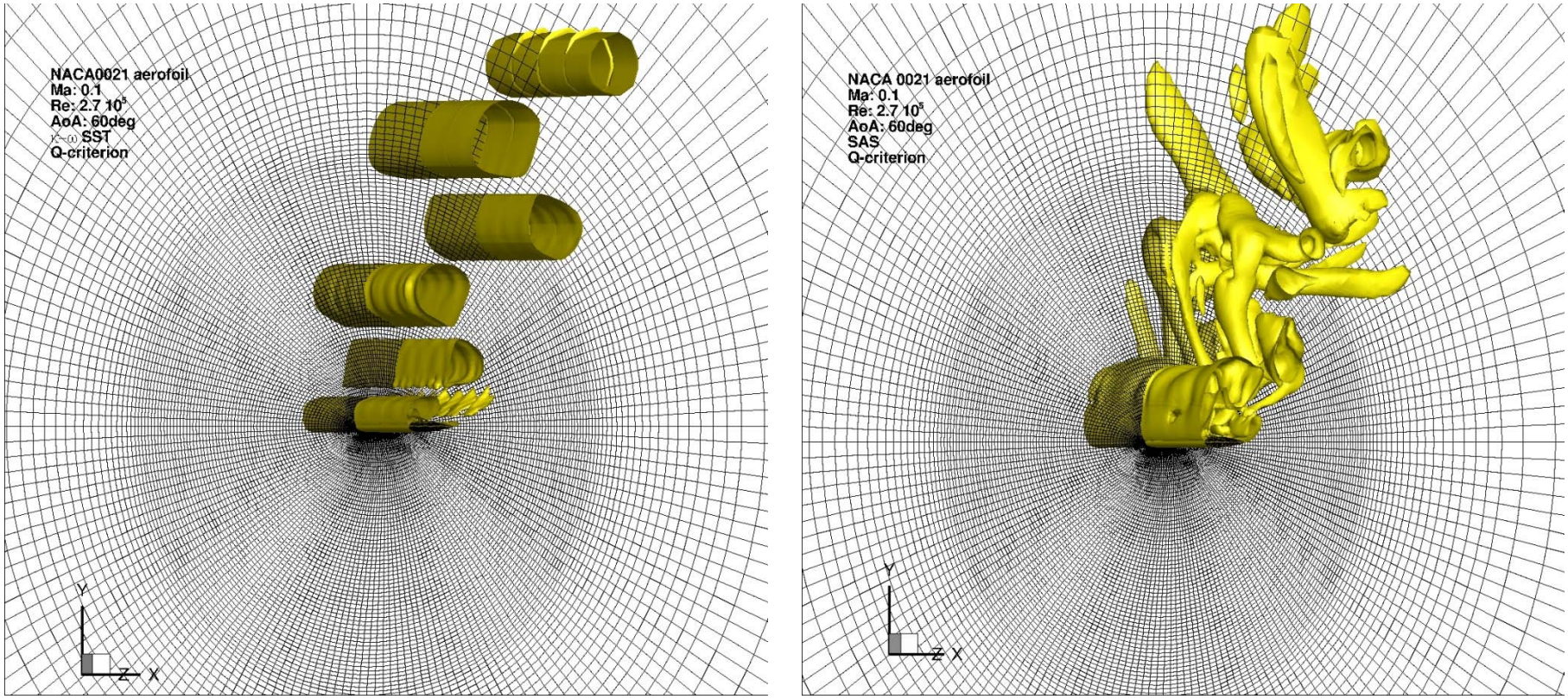
The additional source term:

$$Q_{SAS}=\max\left[\rho\zeta_2\kappa S^2(\frac{L}{L_{vK}})^2-C\frac{2\rho k}{\sigma_\phi}\max\left(\frac{1}{\omega}\frac{\partial\omega}{\partial x_j}\frac{\partial\omega}{\partial x_j},\frac{1}{k}\frac{\partial k}{\partial x_j}\frac{\partial k}{\partial x_j}\right),0\right]$$

The length scale and von Karman length scale are:

$$L=\frac{\sqrt{k}}{c_\mu^{1/4}\omega}\qquad L_{vK}=\frac{\kappa S}{|U''|}\qquad \text{where}\qquad |U''|=\sqrt{\sum_{(i)}\frac{\partial^2 x_i}{\partial x_j\partial x_j}}$$

Scale-Adaptive Simulation



Q-criterion for NACA0021 aerofoil (α=60*deg.*, M_∞ =0.1, Re_c =2.7x10^5)
Comparison between URANS (left) and SAS (right) SST turbulence models

SST - DES/DDES/IDDES

The Detached Eddy Simulation is a hybrid formulation that switches from RANS close to the walls to LES away from them.

$$\ell_{DES} = \min(\ell_{DES}, C_{DES}\Delta_{\max})$$

where the length scale for the k-ω SST model is $\ell_{SST} = \dfrac{\sqrt{k}}{\beta^{*}\omega}$

An improvement of DES model for the GIS situation led to *Delayed Detached Simulation*.

$$\ell_{DDES} = d - \max(0, \ell_{SST} - C_{DES}\Delta_{\max})$$

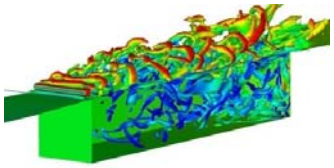
A combination of DDES with Wall-Modelled LES has driven into hybrid model of *Improved Delayed Detached Simulation*.

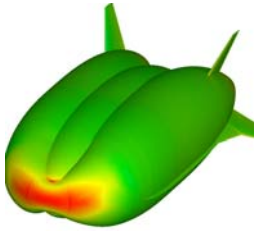
$$\ell_{IDDES} = \tilde{f}_d(1+f_e)\ell_{SST} + (1-\tilde{f}_d)\ell_{LES}$$

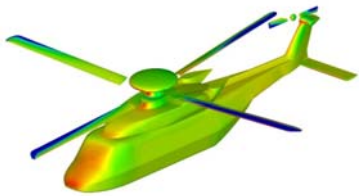
where the length scale for the WMLES is given

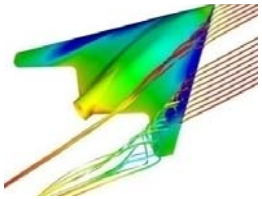
$$\ell_{LES} = C_{DES}\,\min(C_w \max(d_w, h_{\max}), h_{\max})$$

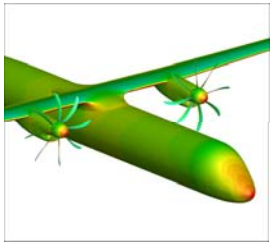
CFD Solver – Core HMB2 Features



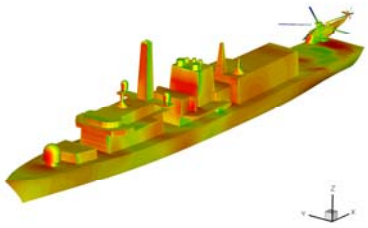








- Control volume method
- Parallel - Shared and Distributed memory
- Multi-block structured grids
- Moving grids, sliding planes, overset grids
- URANS - Variety of turbulence & transition models LES/DES/SAS
- Implicit time marching
- Time and Frequency domain solver
- Osher, All Mach Roe, AUSM for convective fluxes
- MUSCL scheme – nominal 3rd order
- Central differences for viscous fluxes
- Hover formulation, rotor trimming, blade actuation
- Flight mechanics module
- Aeroelastic method



Overview of the HMB Implicit CFD Scheme

Conservation of Mass
Newton's Second Law
Conservation of Energy
Turbulence Model
Transition Model
No Slip Wall B.C.
Far-field B.C. etc

Governing PDEs + B.C.s

Semi –Discretised

$$\frac{\mathrm{d}}{\mathrm{d}t}(W_{ijk}V_{ijk}) = -R(W_{ijk})$$

Density
Velocity (u,v,w)
Pressure
k,ω,
Passive scalars,
Transition quantities

$$\frac{W_{ijk}^{n+1} - W_{ijk}^{n}}{\Delta t} = -\frac{1}{V_{ijk}} R(W_{ijk}^{n+1})$$

Implicit

Linearize $$W_{ijk}^{n+1} = W_{ijk}^{n} - \left[\frac{V_{ijk}}{\Delta t} + \left(\frac{\partial R}{\partial W}\right)_{ijk}^{n}\right]^{-1} R(W_{ijk}^{n})$$

Jacobian Matrix

As time step gets very large, the implicit method recovers the convergence rate of Newton's method

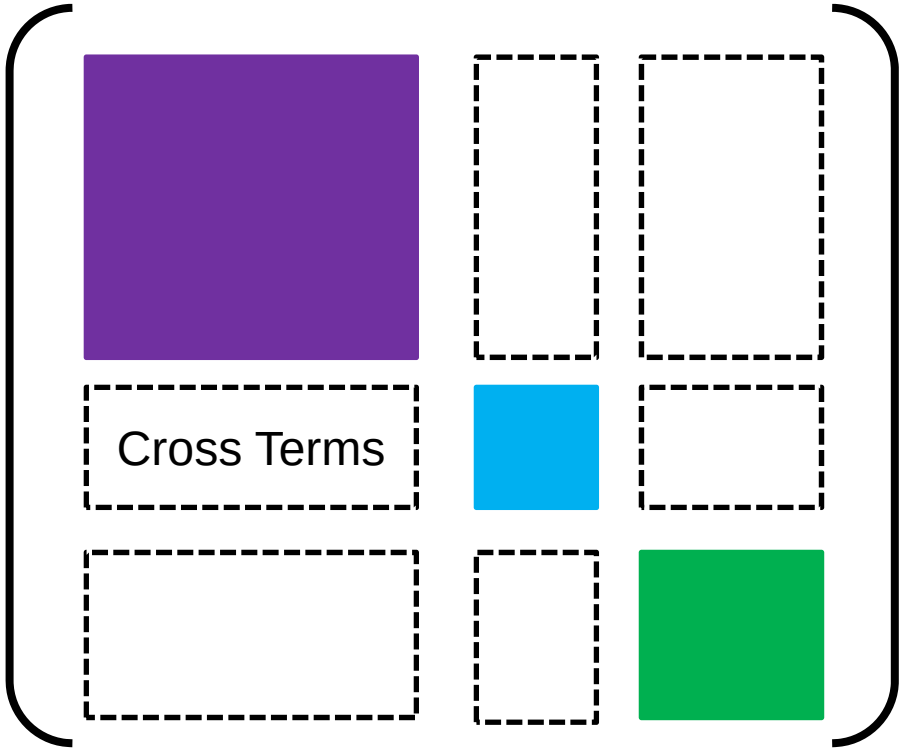
An approximate Jacobian matrix solved using iterative method

General Matrix Format (within each block)

Flow Variables

Turbulence & Transition Variables

Other Variables (brownout particles, water drops for icing, etc)



Multiple patterns for within a cell

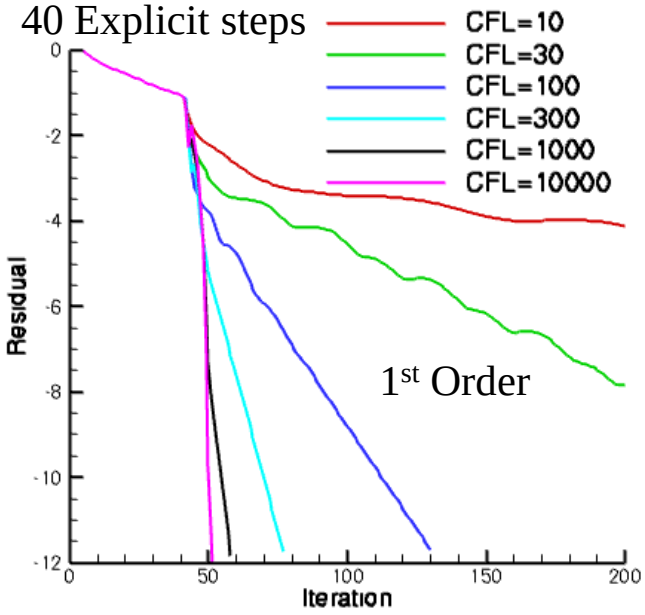
Optimized routines for common patterns
- Fluid only
- Fluid + 2 eq. Turbulence
- Others

For other transport equations, block will be diagonal

Cross terms do not have to use dense matrix storage

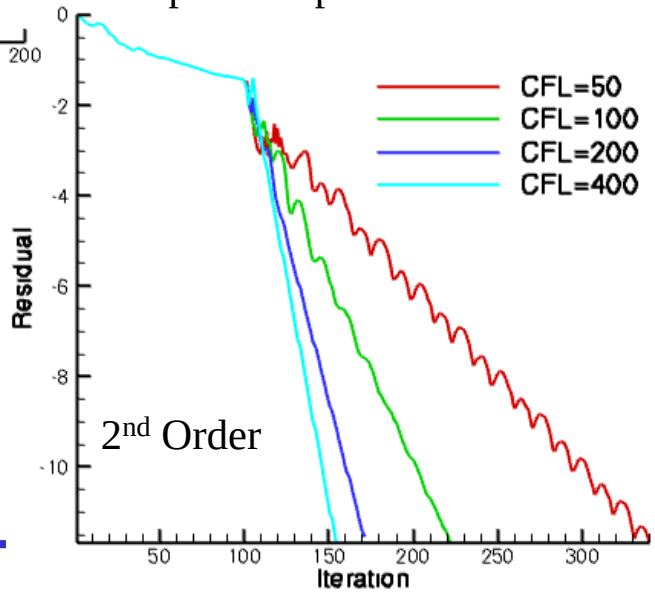
Demonstration of Approximate Jacobian

40 Explicit steps

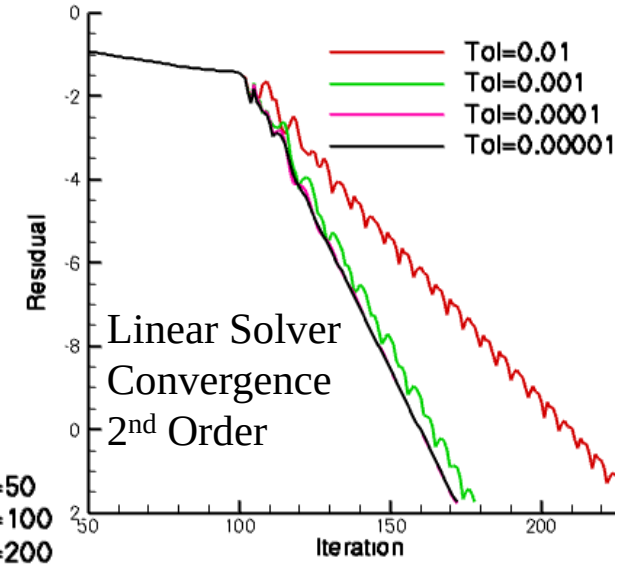


Full Newton at very high CFL numbers

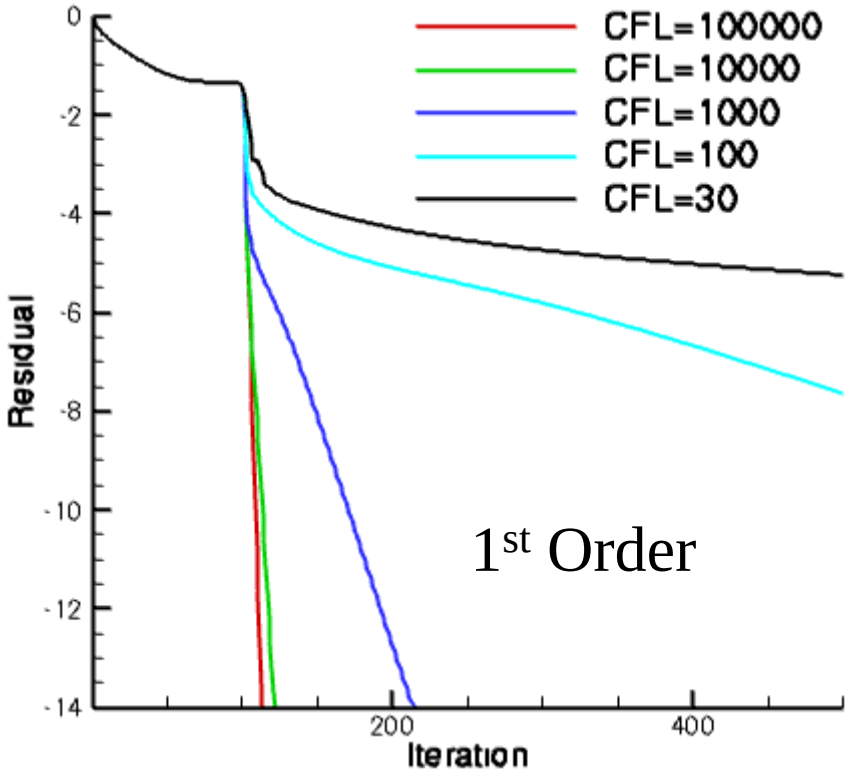
100 Explicit steps



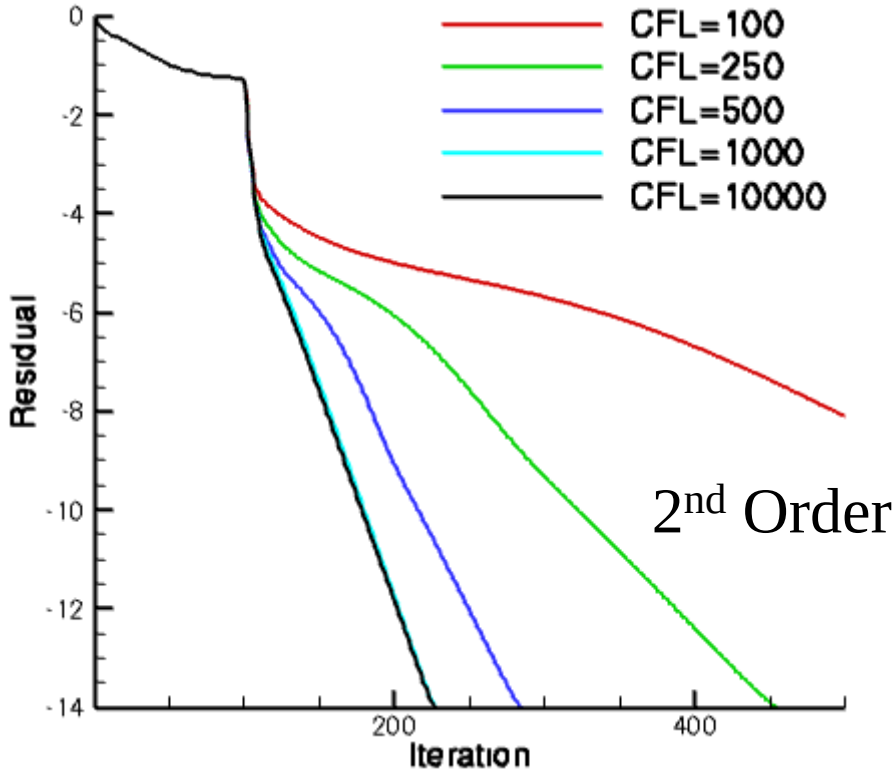
100 Explicit steps



Approximate Jacobian for NS



Converges in 14 iterations
almost quadratic convergence



Requires more iterations
CFL>1000 does not help convergence

Performance of Sparse Matrix-Vector Product

Pattern	Float/Double	Millions of Non Zero Terms per Second	
		7 Cells	13 Cells
CSR	Float	353	402
CSR	Double	254	296
VBR	Float	494	505
VBR	Double	420	428
BCSR	Float	965	972
BCSR	Double	513	520

- (B) CSR: (Block) Compressed Sparse Row
- VBR : Variable Block Row
- CSR too much indexing
- VBR uses fact that all cell blocks are the same to reduce indexing over general VBR.
- BCSR has equation depended inner loops which has big gains for floats

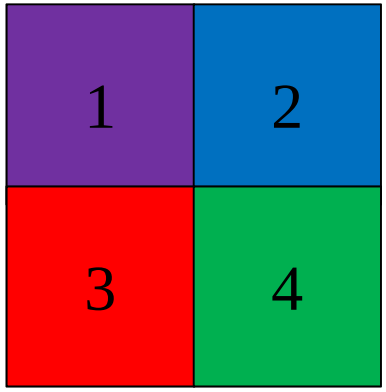
Memory Footprint per Cell

		Euler	2 Eq Turbulence Model		Transition Model	Transition + Scalar
			No Cross Terms	Cross Terms		
Block Data	Meshes	144	144	144	144	144
	Metrics	136	136	136	136	136
	Edge Data	48	48	48	48	48
	Solutions	160	224	224	288	320
Linear Solver Data	Bases etc	460	644	644	828	920
	Matrix	700	812	1372	924	952
	Precon	700	812	1372	924	952
Total		2348	2820	3940	3292	3472

The table assumes the linear solver is stored in floats

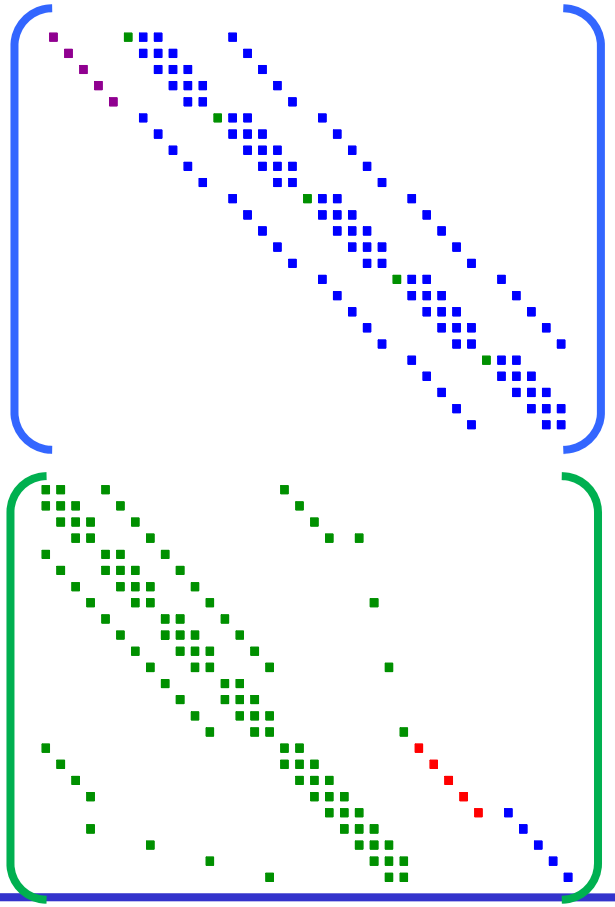
Parallel Implementation

- Full blocks partitioned amongst processors
- Preconditioner decoupled between blocks on different processors
- Local reordering between all blocks on same processor



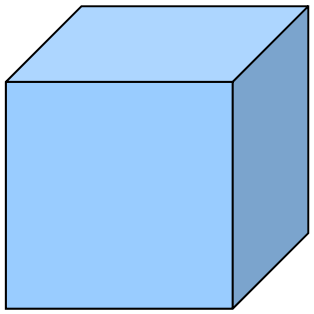
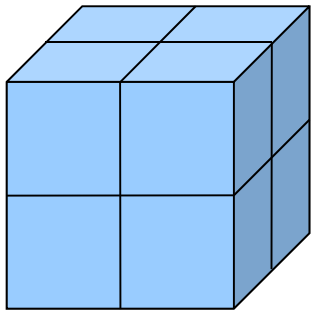
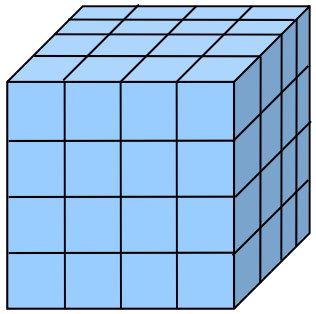
5	11	17	23	29	35
4	10	16	22	28	34
3	9	15	21	27	33
2	8	14	20	26	32
1	7	13	19	25	31
-	6	12	18	24	30

-	32	33	34	35	36
30	21	22	23	24	25
29	20	4	8	12	16
28	19	3	7	11	15
27	18	2	6	10	14
26	17	1	5	9	13



Parallel Performance Improvements (small block sizes)

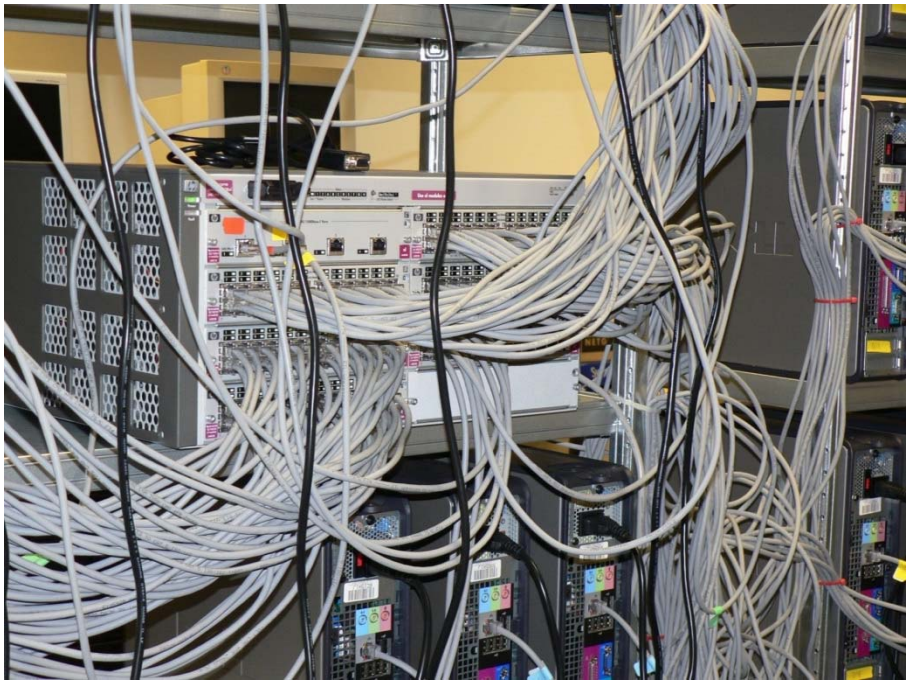
- Blocks on the same processor are concatenated together

	1 40x40x40 block		8 20x20x20 blocks		64 10x10x10 blocks	
	Old	New	Old	New	Old	New
No of Messages	6	6	24	6	84	6
Size of messages (cells)	10584	9600	11616	9600	12096	9600
Precond. terms dropped	9600	9600	19200	9600	38400	9600
Blocks in implicit solve	1	1	8	1	64	1

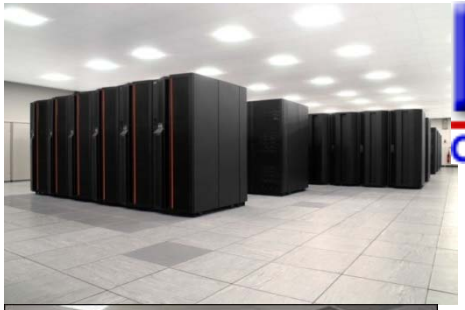
Messages in linear solver are now all MPI_FLOAT
All Messages are passed in place saving temporary storage

Parallel Computer – Low Cost Clusters



Parallel PC Cluster exclusive to CFD Lab

–1997	jupiter 1	16, 200MhZ nodes
–2000	jupiter 2	32, 700 MHz nodes
–2003	jupiter 3	130, 2.5 GHz nodes
–2006	jupiter 4	196, 3.0 GHz nodes
–2008	**jupiter 5**	**512, 3.2 GHz nodes**



HPCx
CAPABILITY COMPUTING

CSAR

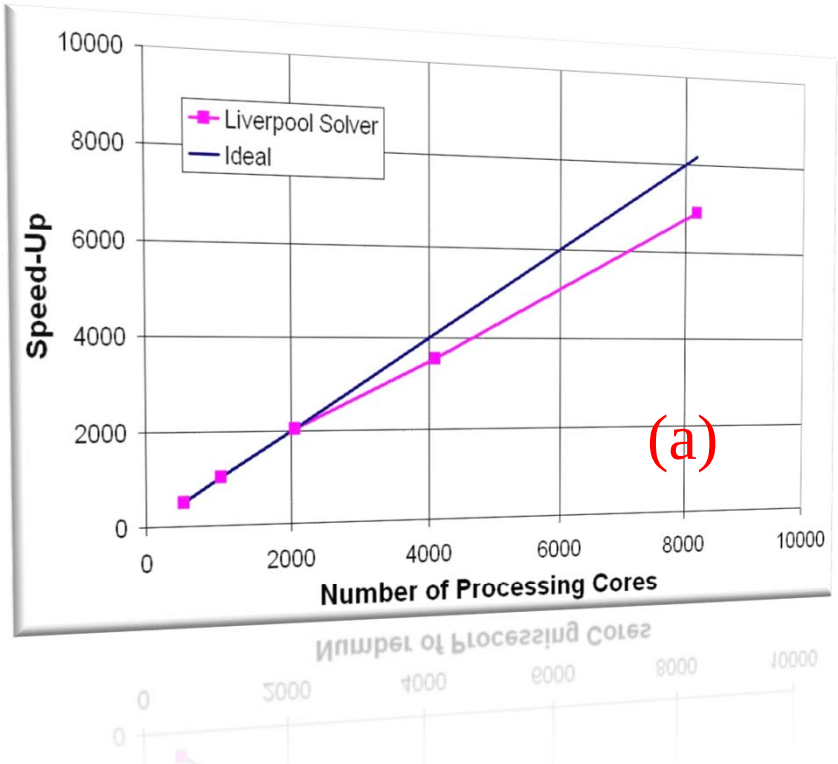
IPP rzg RECHEN-ZENTRUM GARCHING

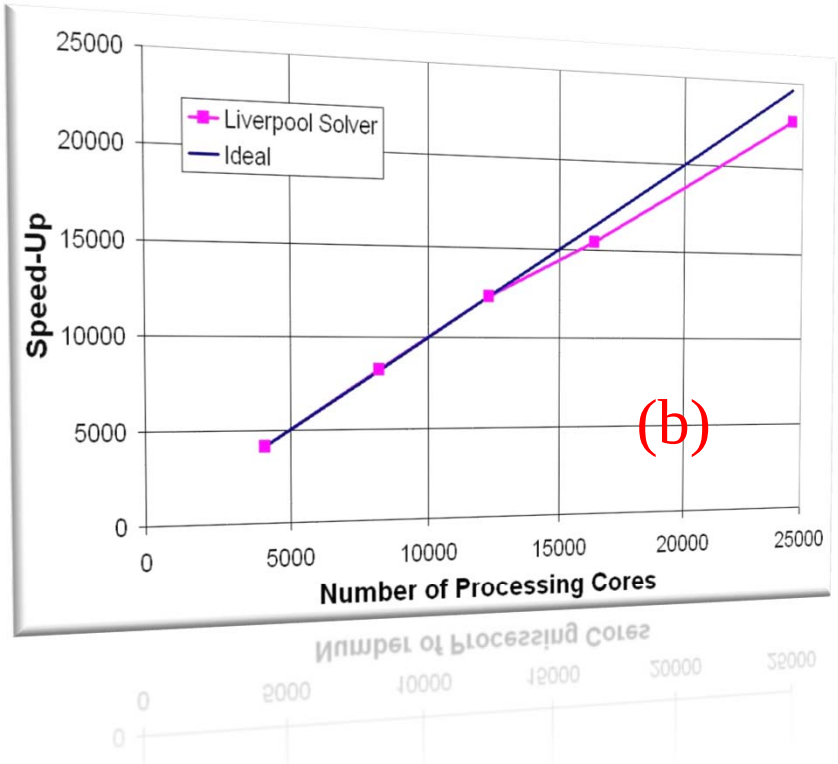
BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Quadrics

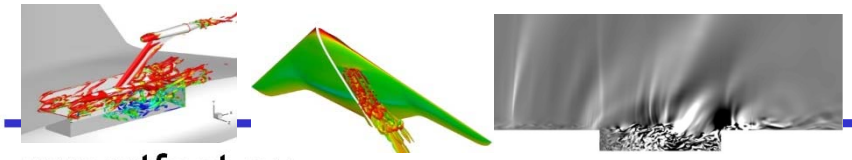
CESGA

Hector Phase 2B



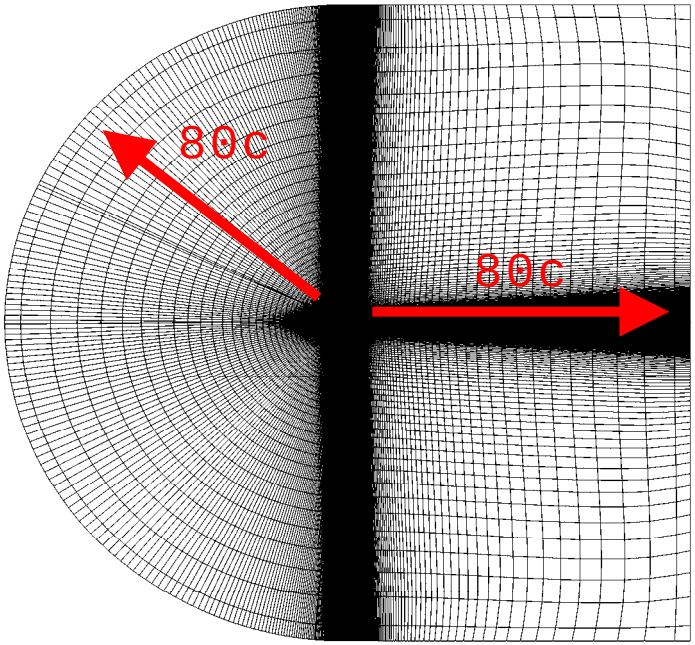


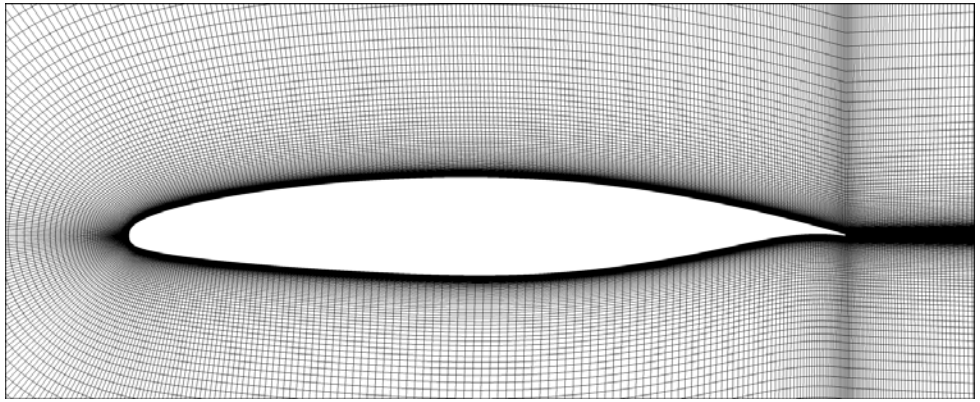
Helicopter Multi-Block solver using (a) 105 million point mesh with 24576 blocks and (b) 1100 million point mesh with 196608 blocks



www.tfast.eu

CFD Mesh

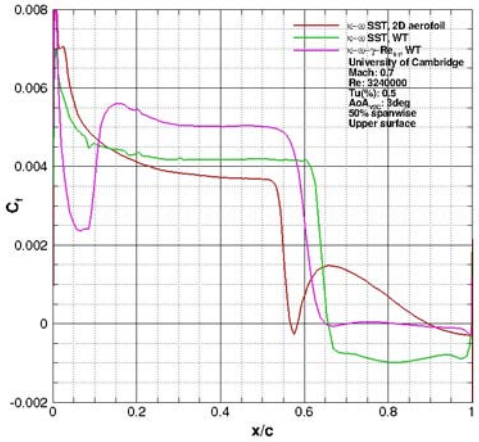


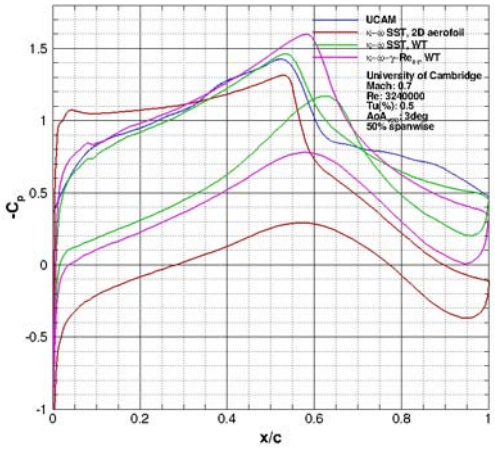


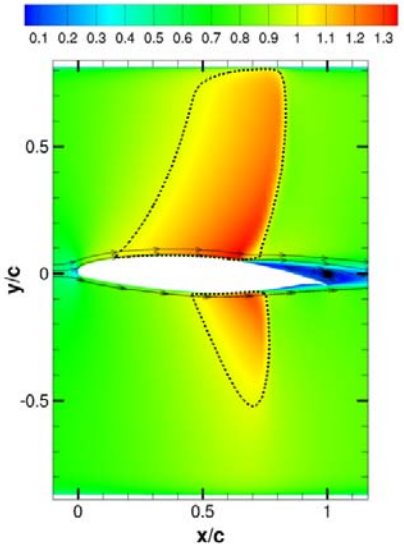
No. cells	
Upper surface	234
Lower surface	192
Trailing edge	42
Normal direction	192
Wake direction	192
Total	**163 584**

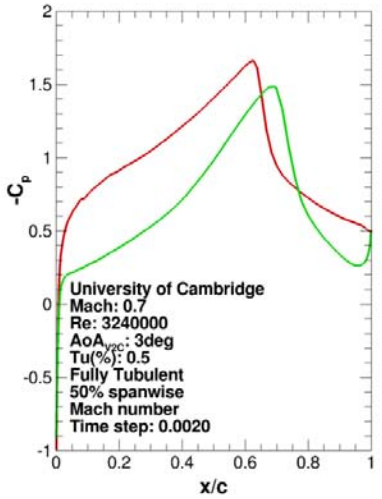
Normal distances	
1st cell height	5e-7 c
y+ average	0.259
y+ maximum	0.535

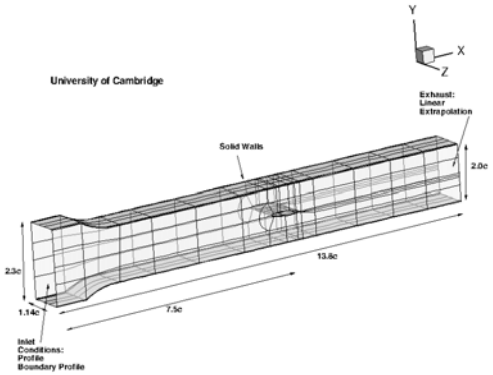
V2C aerofoil – With and without WT wall
k-w and $\kappa-\omega-\gamma-Re_{\theta t}$
M_∞ 0.7 Re_c 3.24x10^6 a:3deg



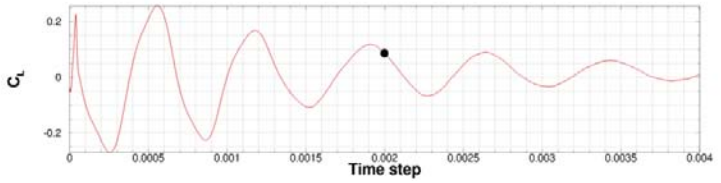






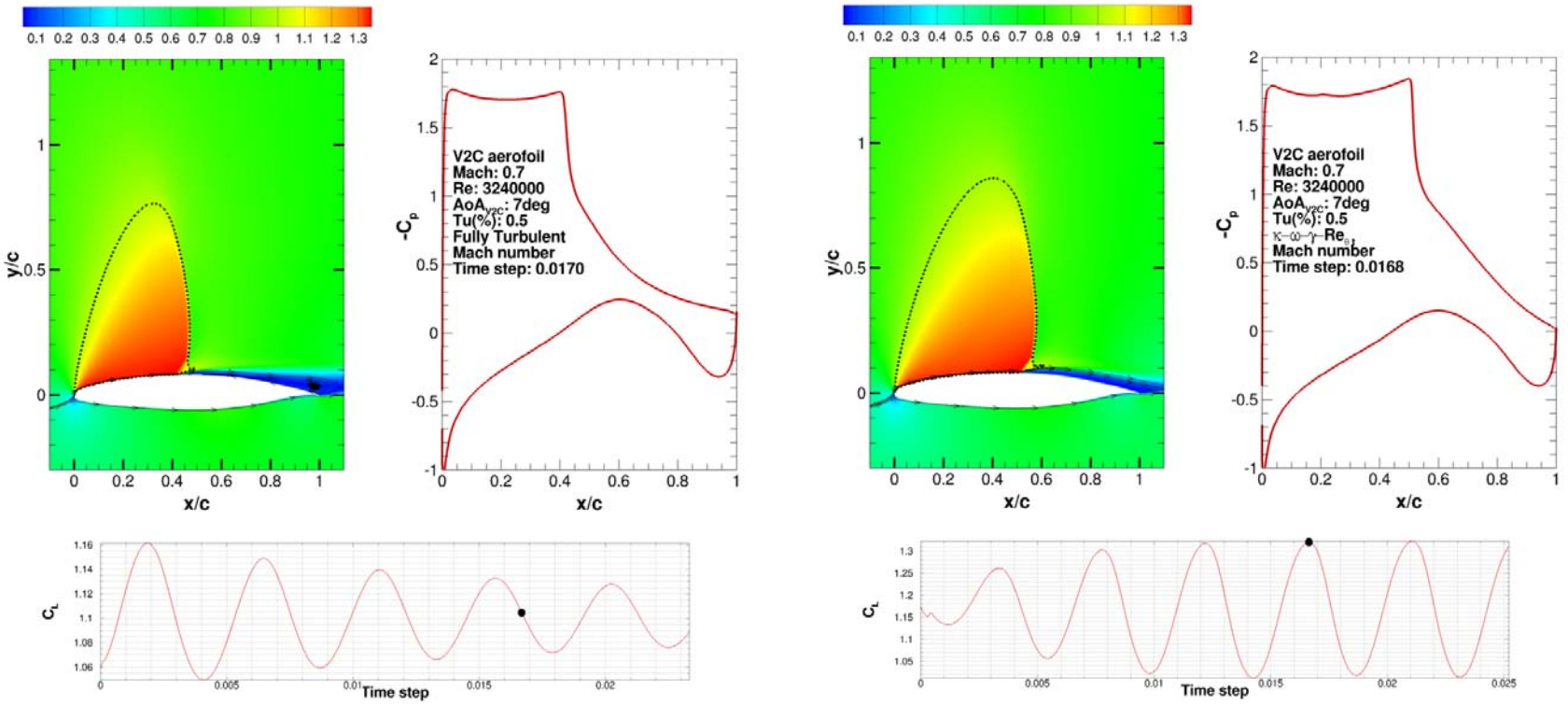


Surface skin friction(left) and pressure distribution(right) for $\kappa-\omega$ SST model and $\kappa-\omega-\gamma-Re_{\theta t}$ model. Comparison with measurements from UCAM



M_∞ 0.7, Re_c 3.24x10^6, a=3deg, Tu(%)= 0.5

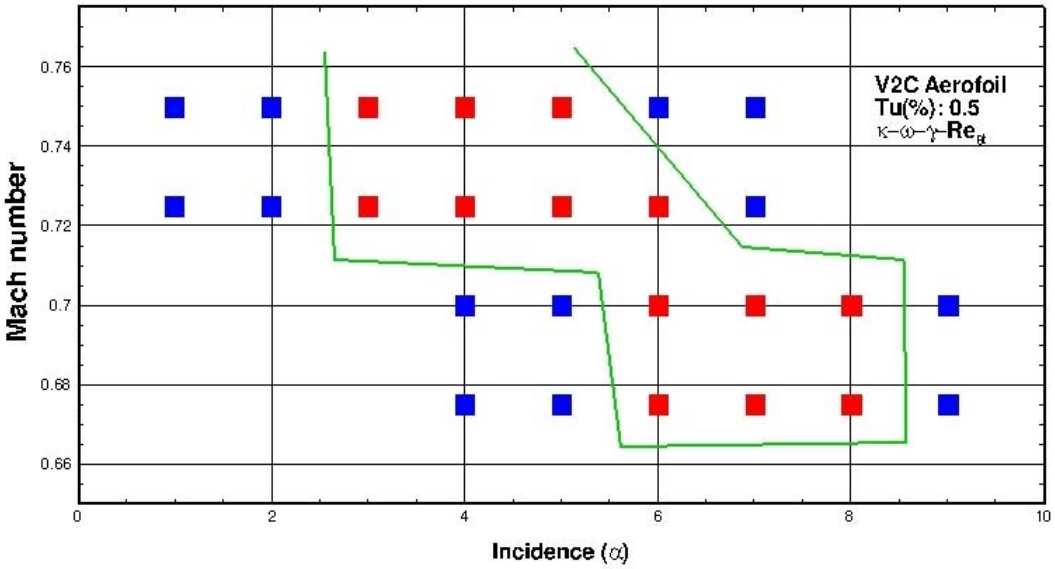
V2C aerofoil - Unsteady Calculations
$\kappa-\omega$ and $\kappa-\omega-\gamma-Re_{\theta t}$
M_∞ 0.7 Re_c 3.24×10^6 a:7deg



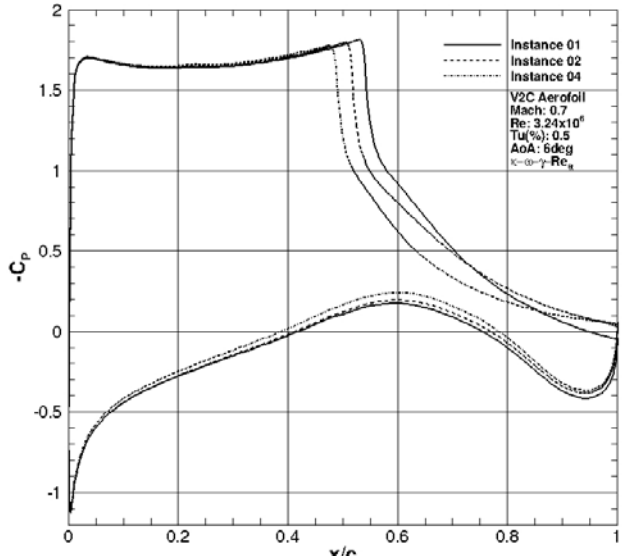
Mach number visualisation and surface pressure distribution mid-span of the section for $\kappa-\omega$ SST model and $\kappa-\omega-\gamma-Re_{\theta t}$ model

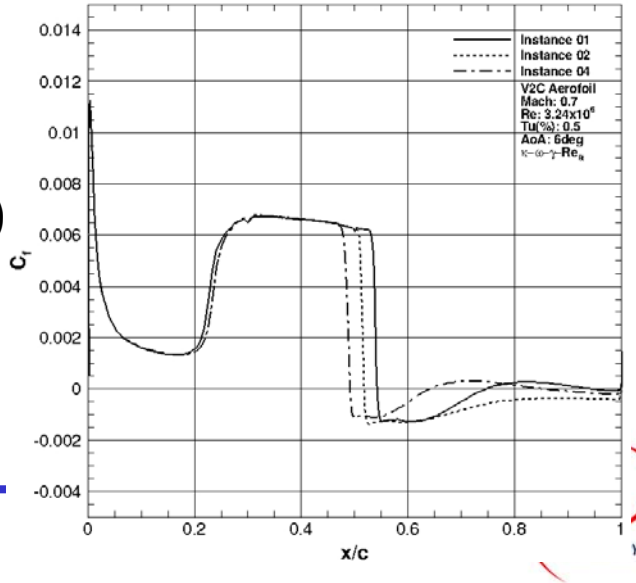
M_∞ 0.7, Re_c 3.24x10^6, a=7deg, Tu(%)= 0.5

V2C aerofoil - Unsteady Calculations $\kappa-\omega-\gamma-Re_{\theta t}$ M_∞ 0.7 Re_c 3.24×10^6



Buffet boundary for $\kappa-\omega-\gamma-Re_{\theta t}$ model

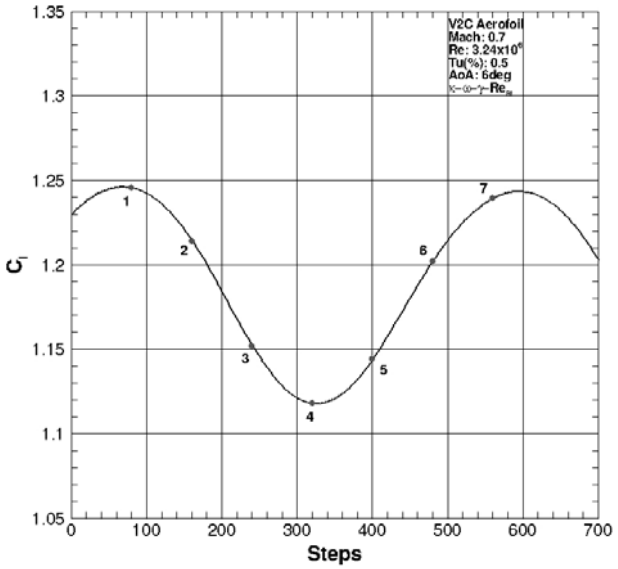




Surface pressure (upper) and skin friction (lower) coefficients mid-span of the section for $\kappa-\omega-\gamma-Re_{\theta t}$ model and at different times

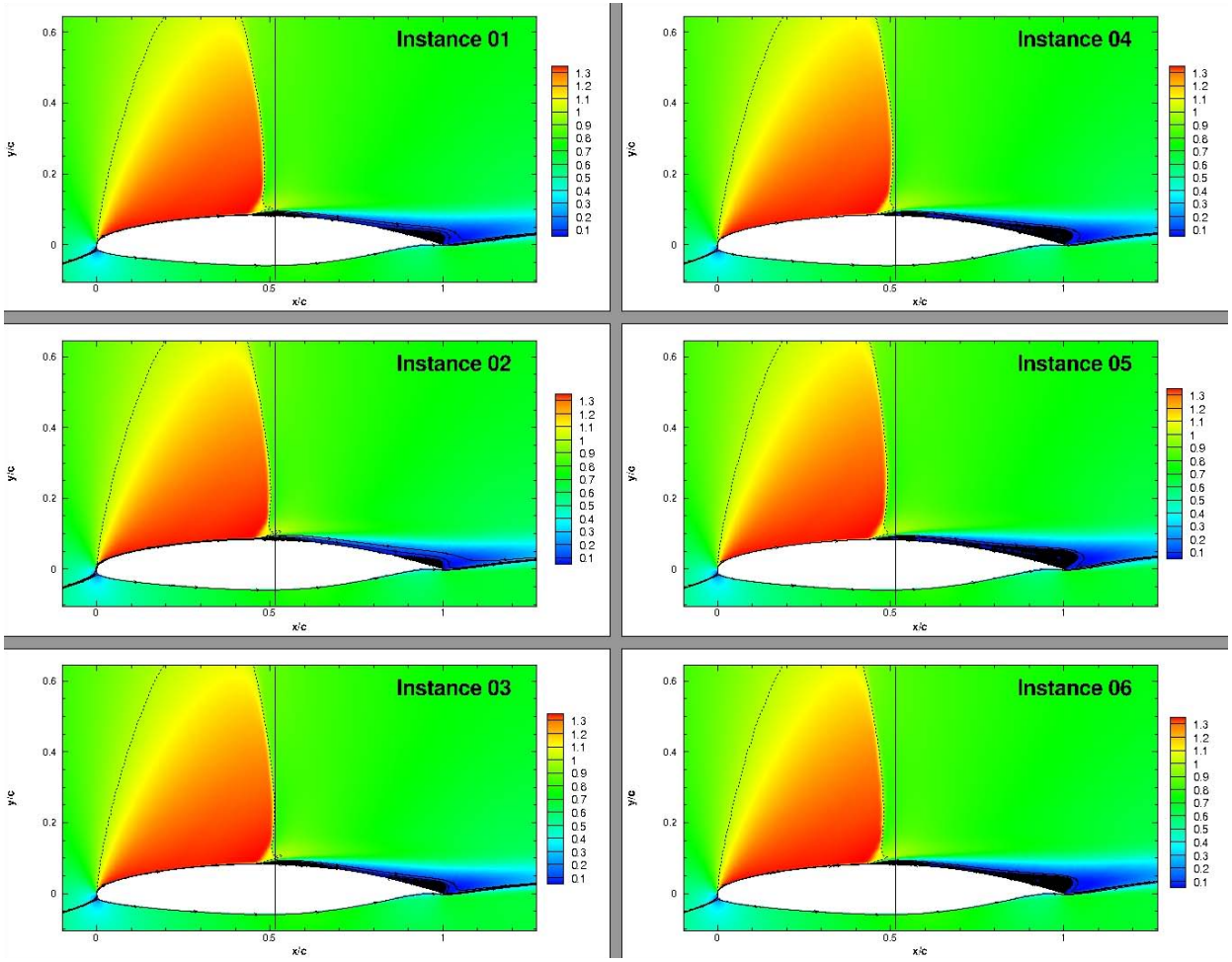
M_∞ 0.7, Re_c 3.24x10^6, Tu(%)= 0.5

V2C aerofoil - Unsteady Calculations $\kappa-\omega-\gamma-Re_{\theta t}$ M_∞ 0.7 Re_c 3.24×10^6



Mach number visualisation mid-span of the section for 6 instances of buffet cycle using $\kappa-\omega-\gamma-Re_{\theta t}$ model

M_∞ 0.7, Re_c 3.24x10^6, a=6deg, Tu(%)= 0.5

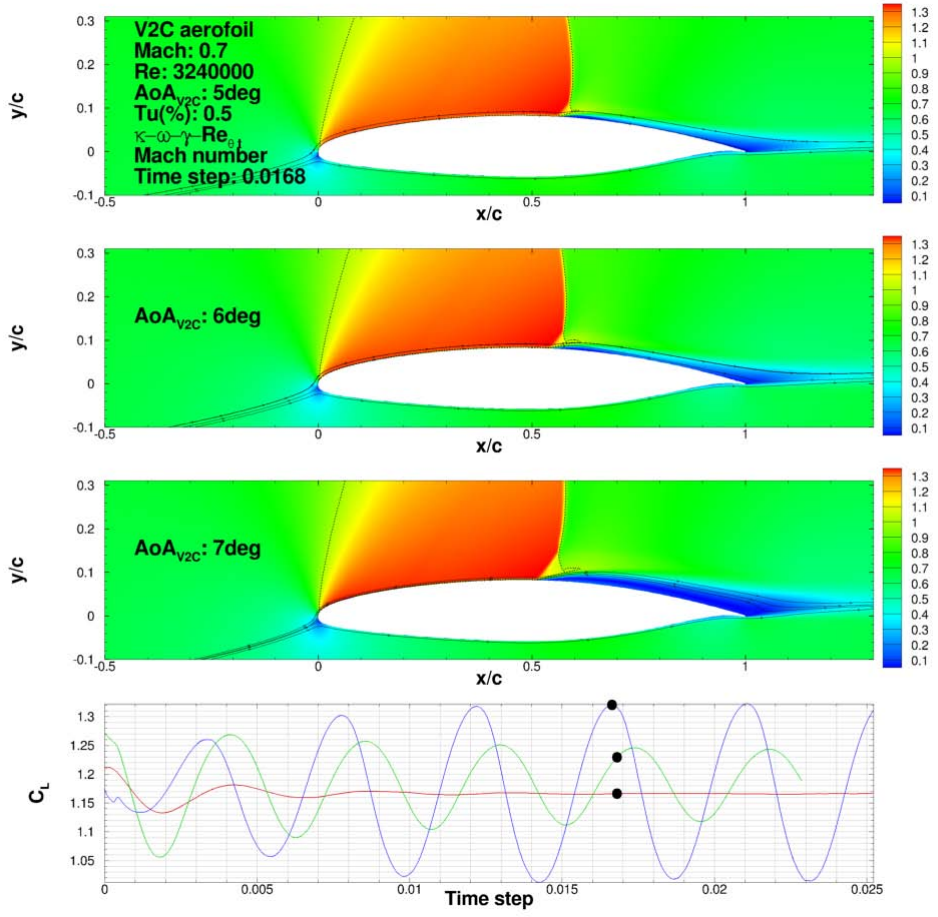


V2C aerofoil - Unsteady Calculations $\kappa-\omega-\gamma-Re_{\theta t}$ M_∞ 0.7 Re_c 3.24×10^6

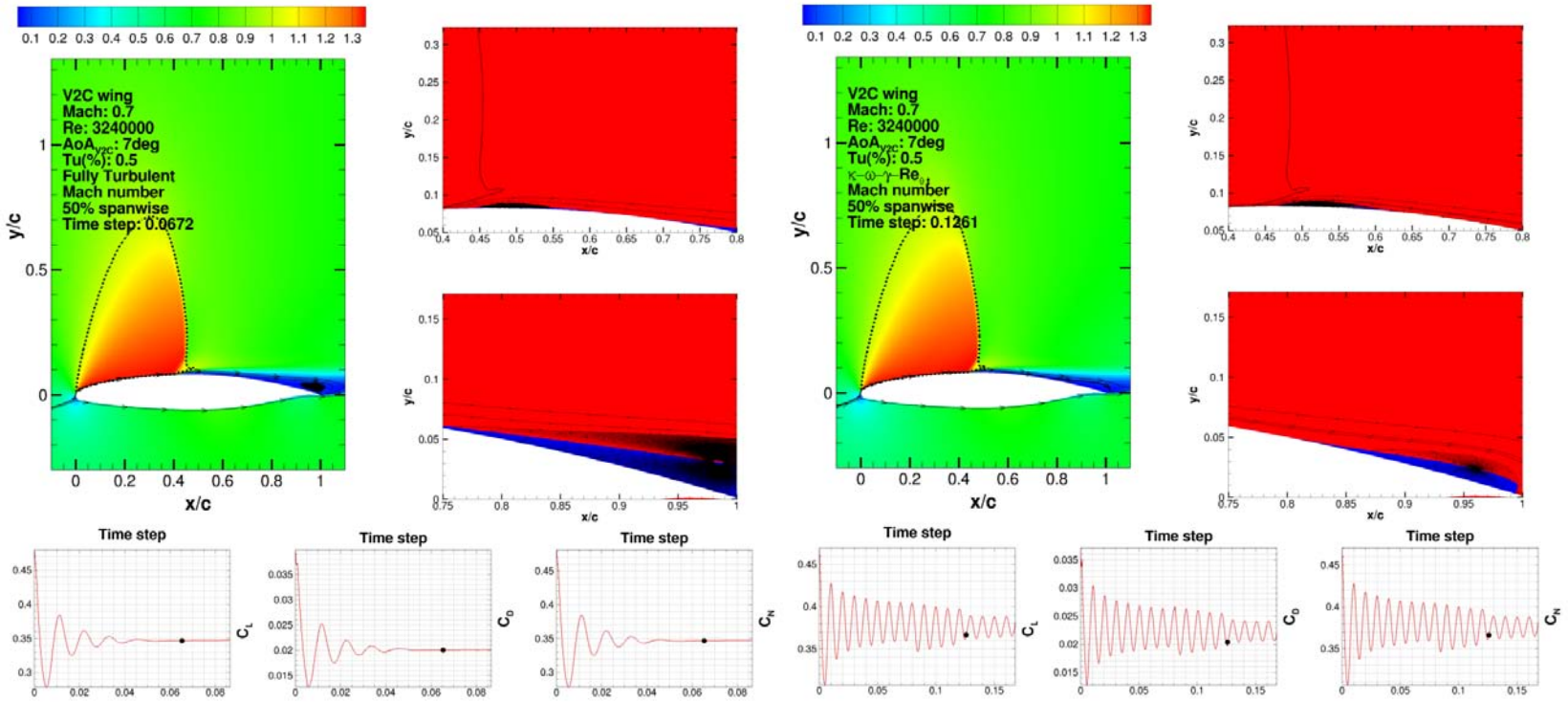
Mach number visualisation mid-span of the section for $\kappa-\omega-\gamma-Re_{\theta t}$ model and for three different incidence angles

M_∞ 0.7, Re_c 3.24x10^6, Tu(%)= 0.5

Buffet Frequency 89hz



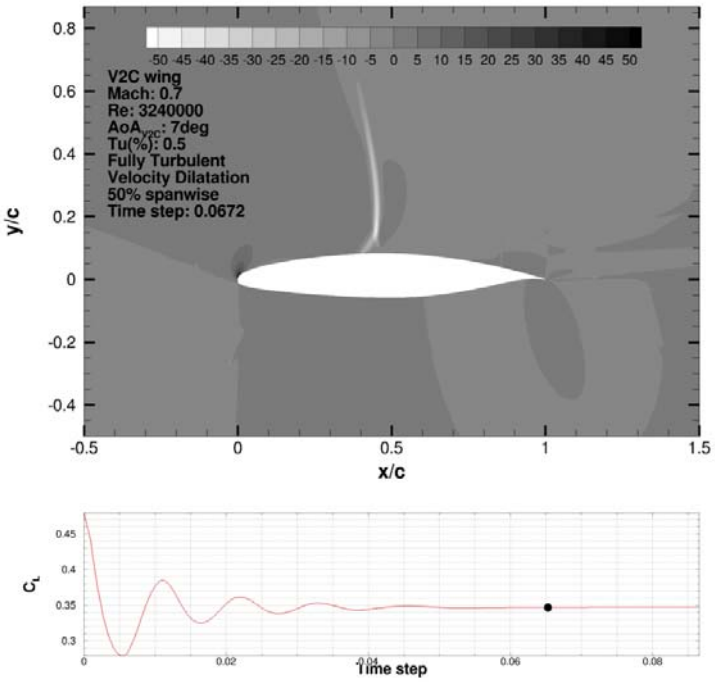
V2C 3D aerofoil - Unsteady Calculations
$\kappa-\omega$ and $\kappa-\omega-\gamma-Re_{\theta t}$
M_∞ 0.7 Re_c 3.24×10^6 a:7deg

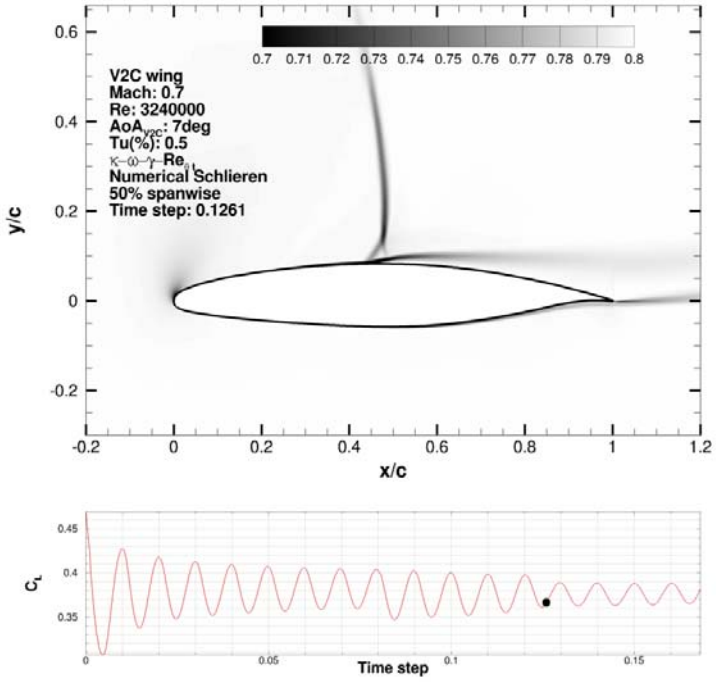


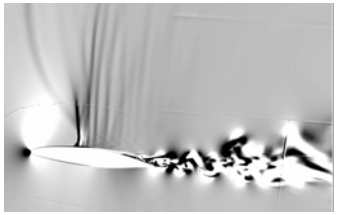
Mach number visualisation at mid-span
of the section for $\kappa-\omega$ SST and $\kappa-\omega-\gamma-Re_{\theta t}$ models

M_∞ 0.7, Re_c 3.24x10^6, a=7deg, Tu(%)= 0.5

V2C 3D aerofoil - Unsteady Calculations
$\kappa-\omega$ and $\kappa-\omega-\gamma-Re_{\theta t}$
M_∞ 0.7 Re_c 3.24×10^6 a:7deg

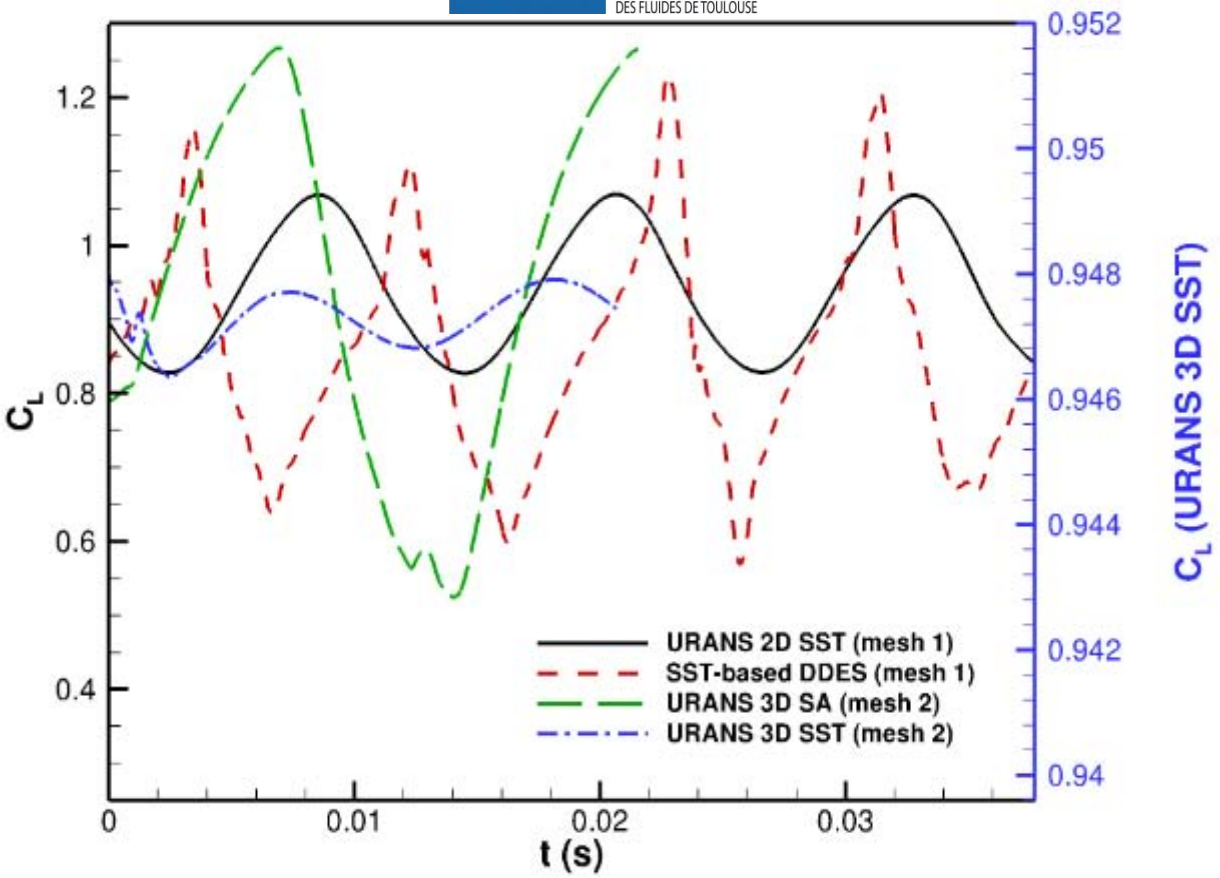




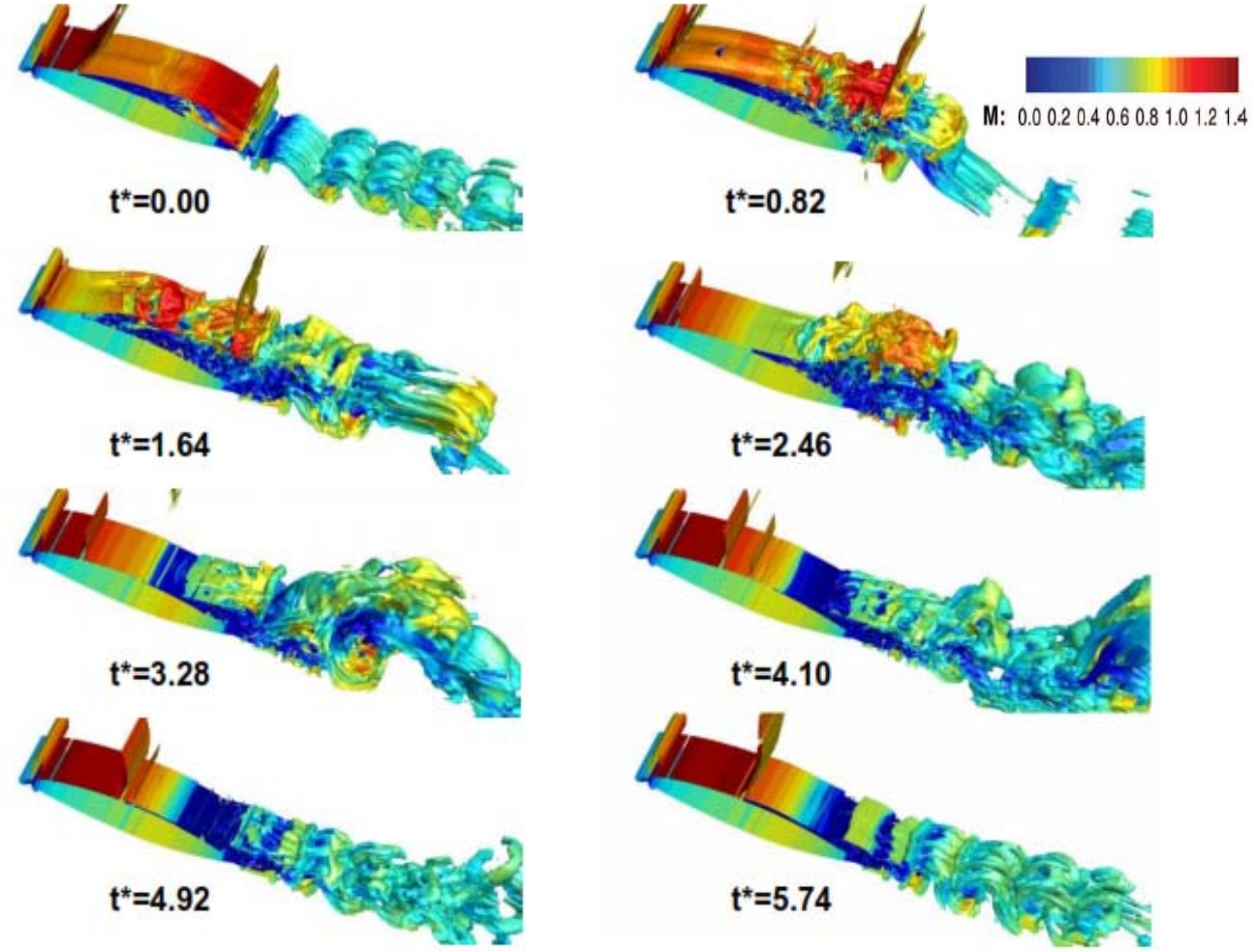


Numerical Schlieren at mid-span
of the section for $\kappa-\omega$ SST and $\kappa-\omega-\gamma-Re_{\theta t}$ models
M_∞ 0.7, Re_c 3.24×10^6, a=7deg, Tu(%)= 0.5

- Re = 3.245×10^6
- Mach = 0.70
- AoA = 7°
- $\Delta t = 5 \times 10^{-6}$s
- Spanwise: 0.33 x C (79 cells)



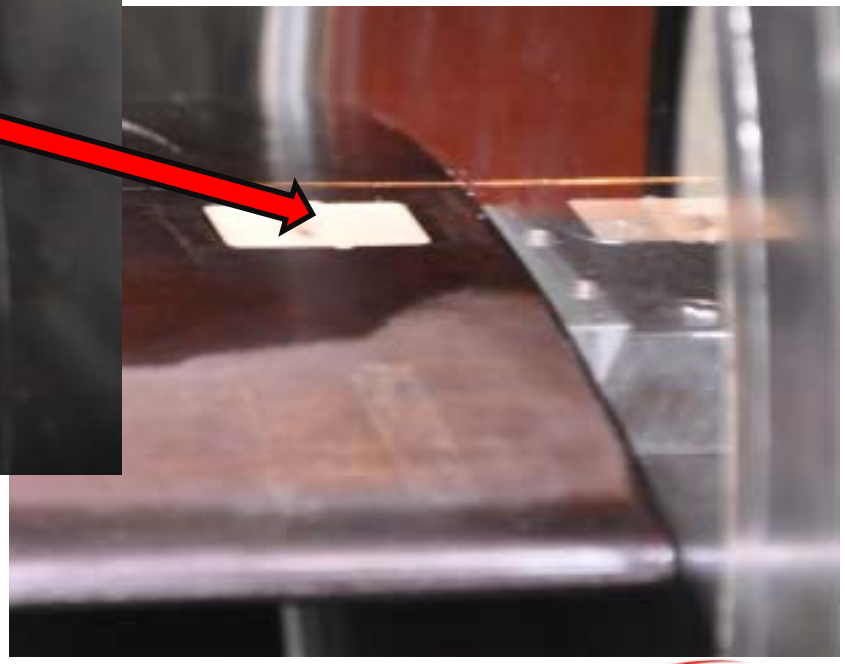
Instantaneous Q-critirion isosurfaces for $Q(c/U)^2$ =75



Buffet Frequency around 90 hz

8. RMS – test equipment

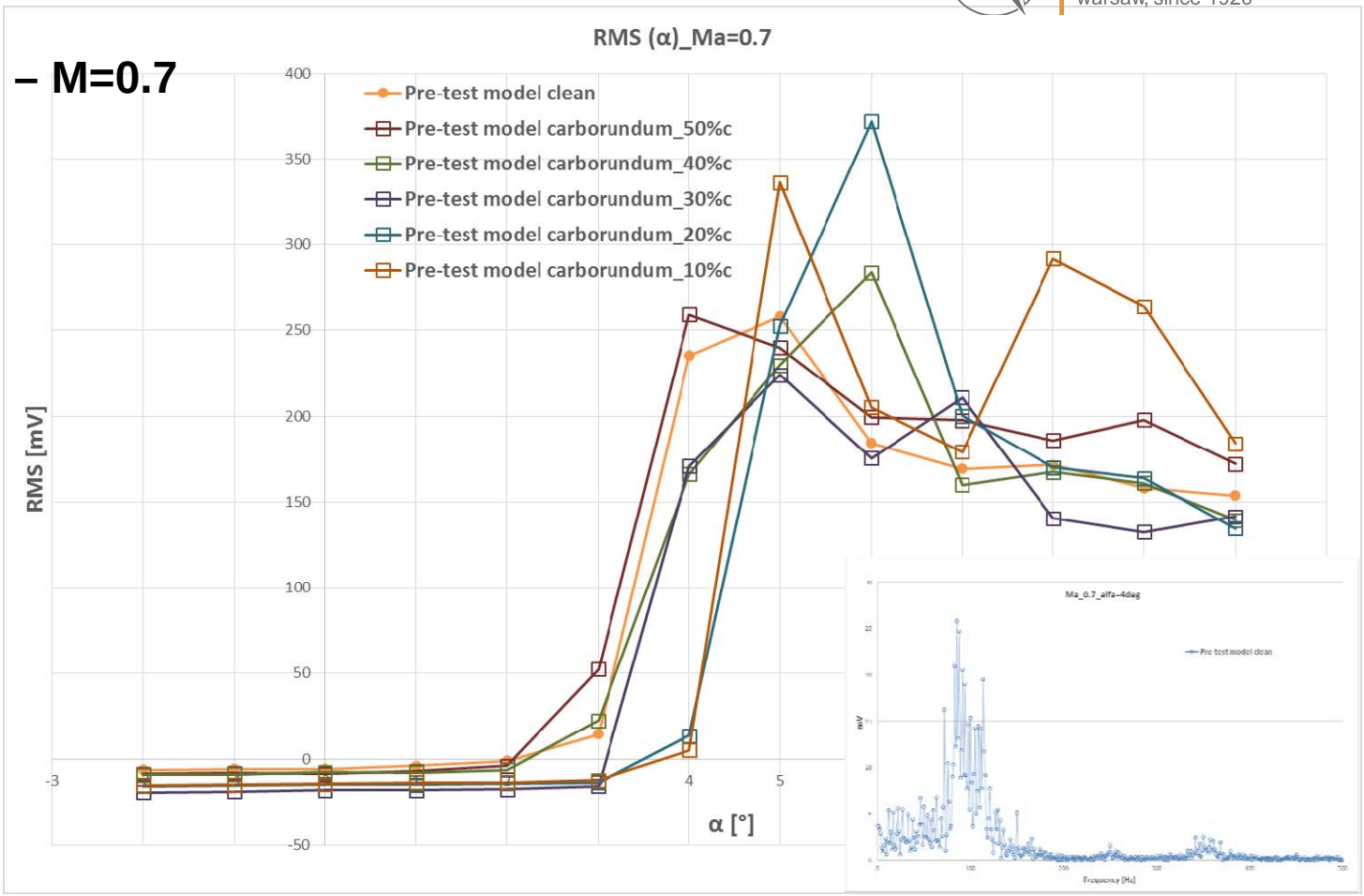
Strain gauge for buffet onset indication mounted on upper and bottom model surface at 42%c



(Straing gauge scan rate 10 kHz)

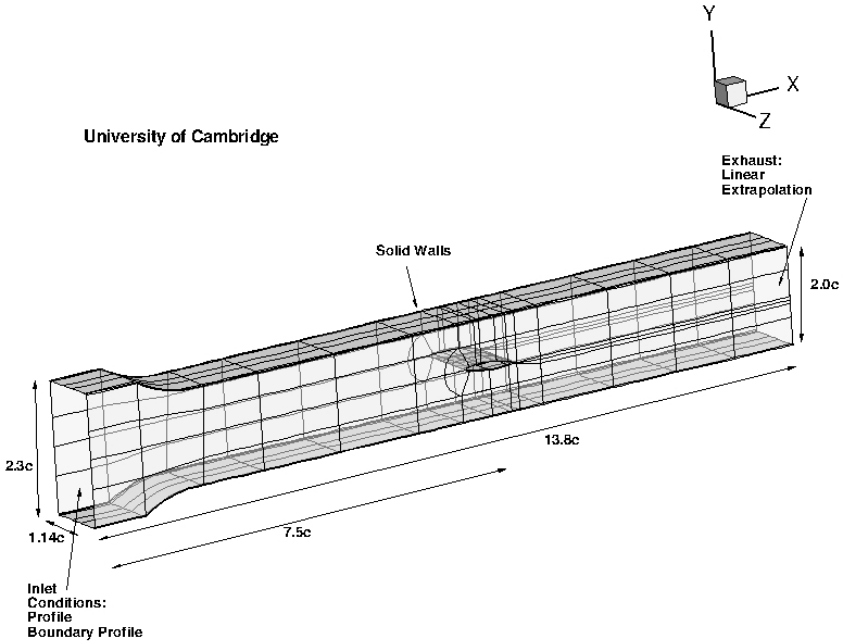
instituteofaviation
warsaw, since 1926

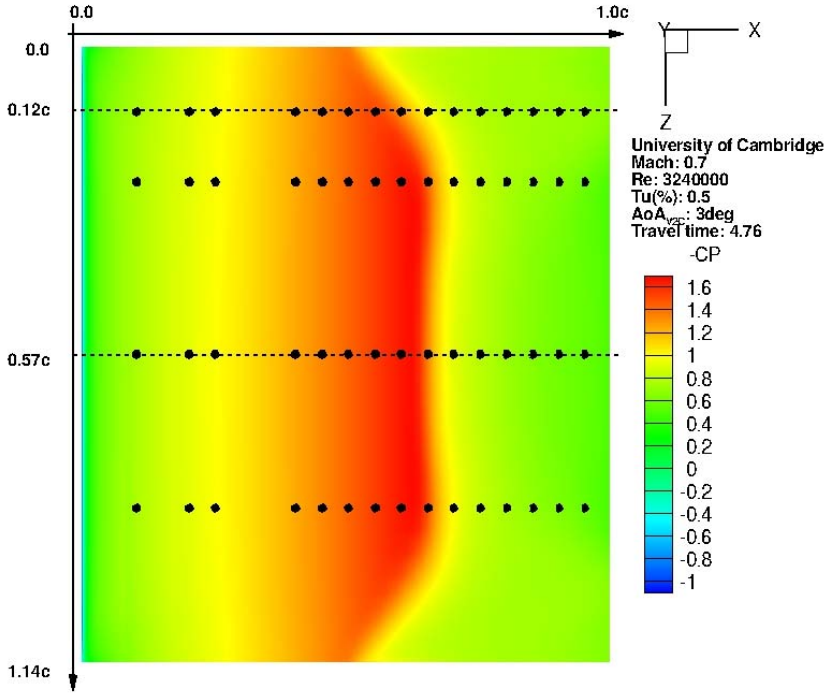
RMS – M=0.7



LABORATORY

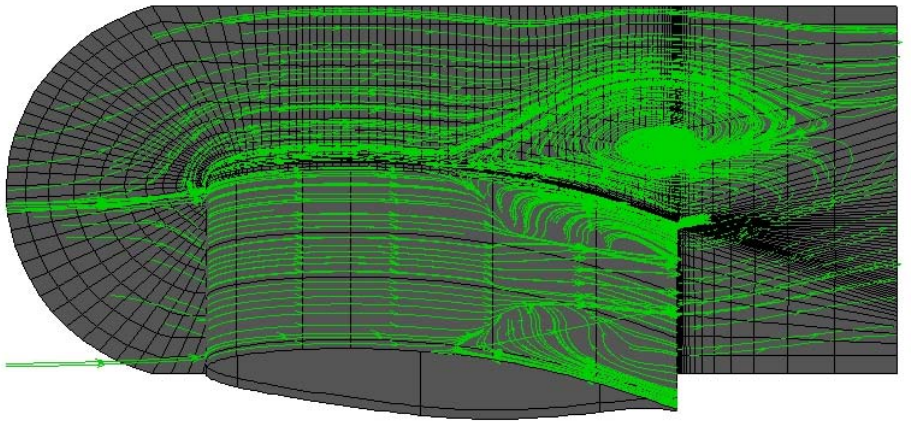
V2C - UCAM WT - κ–ω SST
M_∞ 0.7 Re_c 3.24×10⁶ a:3deg



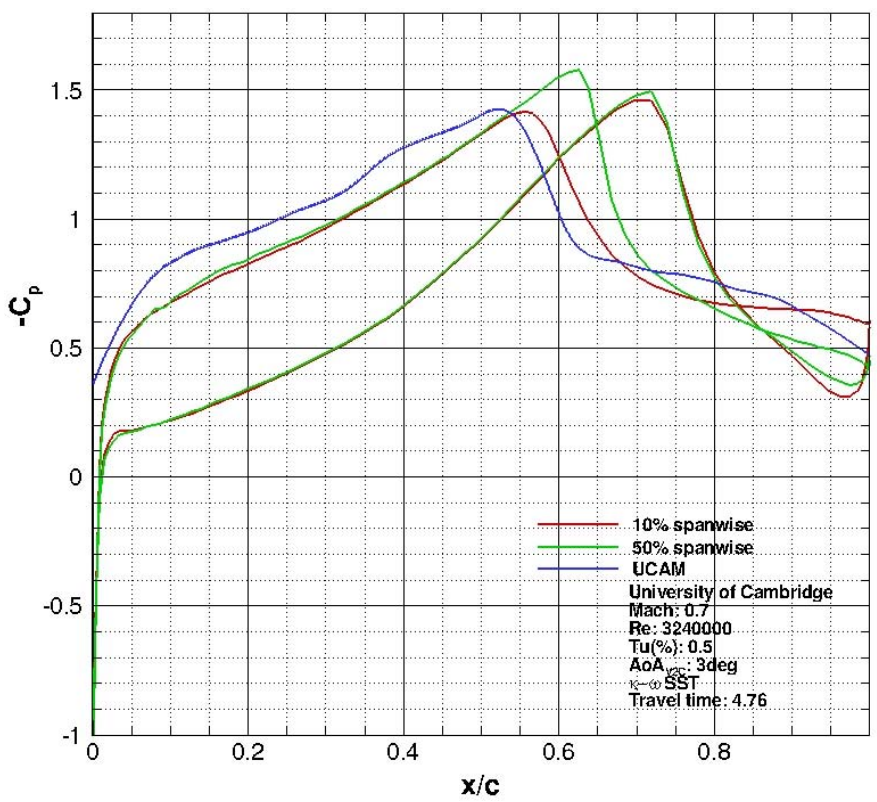


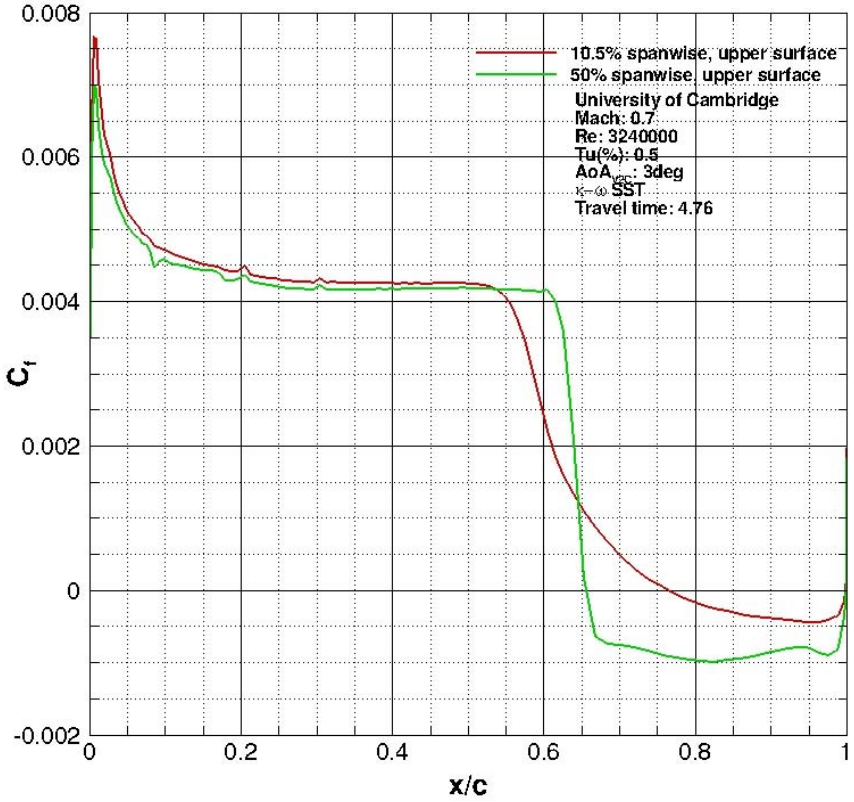
Surface flow and pressure coefficient on the V2C aerofoil

M_∞ 0.7, Re_c 3.24x10⁶, Tu 0.5% a=3deg



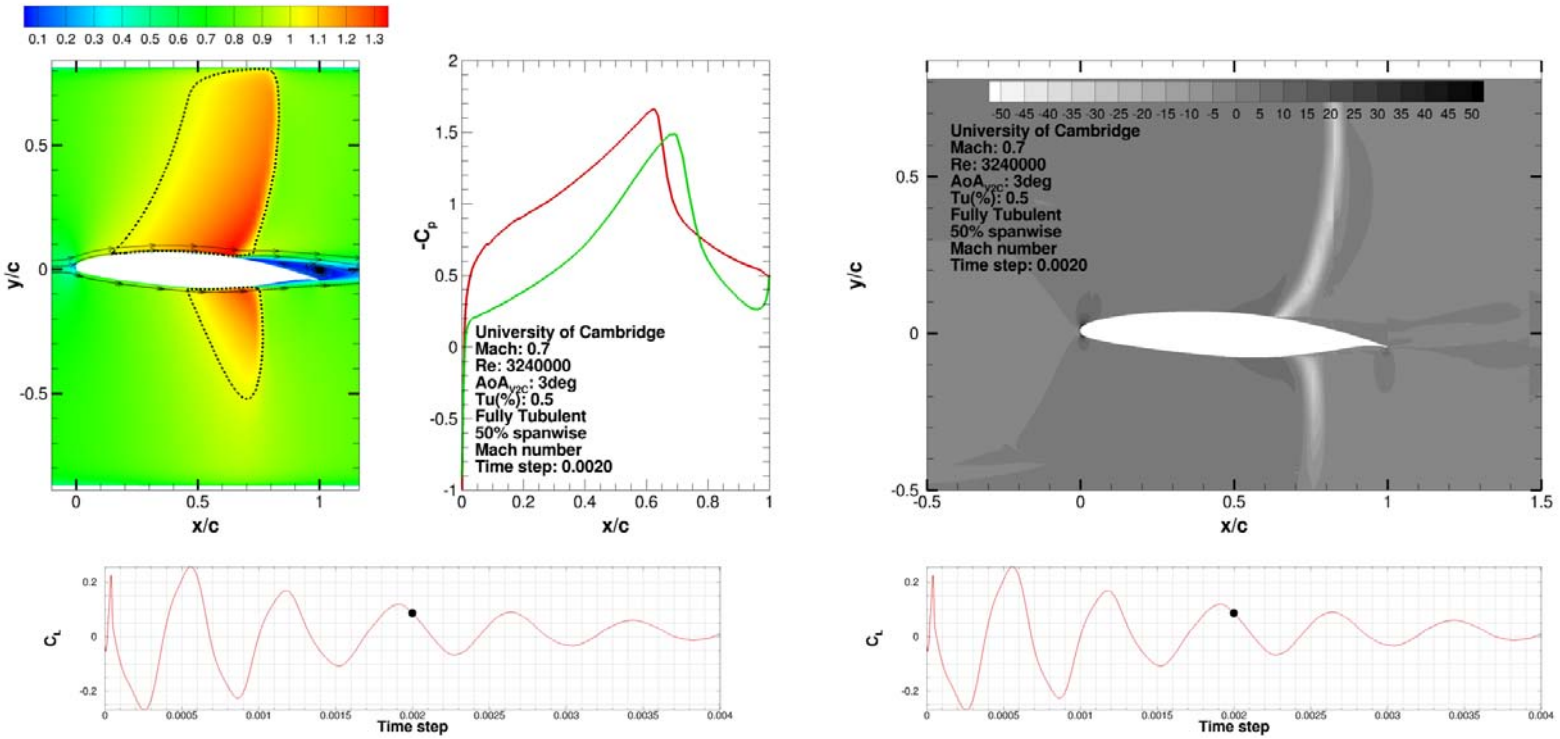
V2C - UCAM WT - κ–ω SST
M_∞ 0.7 Re_c 3.24×10⁶ a:3deg





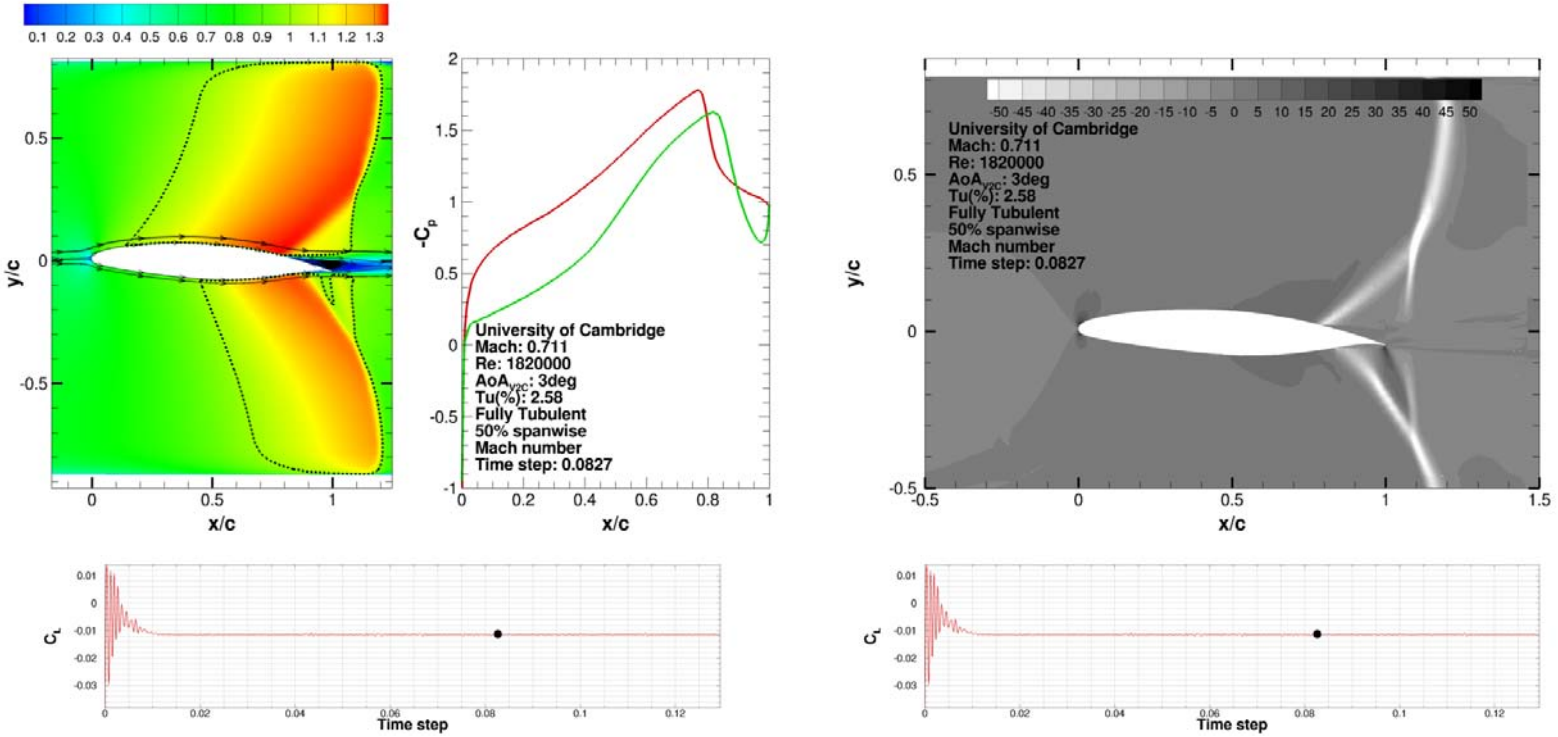
Surface pressure and skin friction (on the upper surface) on two different span locations of the section at travel time:4.76
M_∞ 0.7, Re_c 3.24x10⁶, Tu 0.5% a=3deg, 10.5% (red) – 50% (green)
Comparison with preliminary UCAM data is indicative at this stage

V2C - UCAM WT - κ–ω SST
M_∞ 0.7 Re_c 3.24×10^6 a:3deg



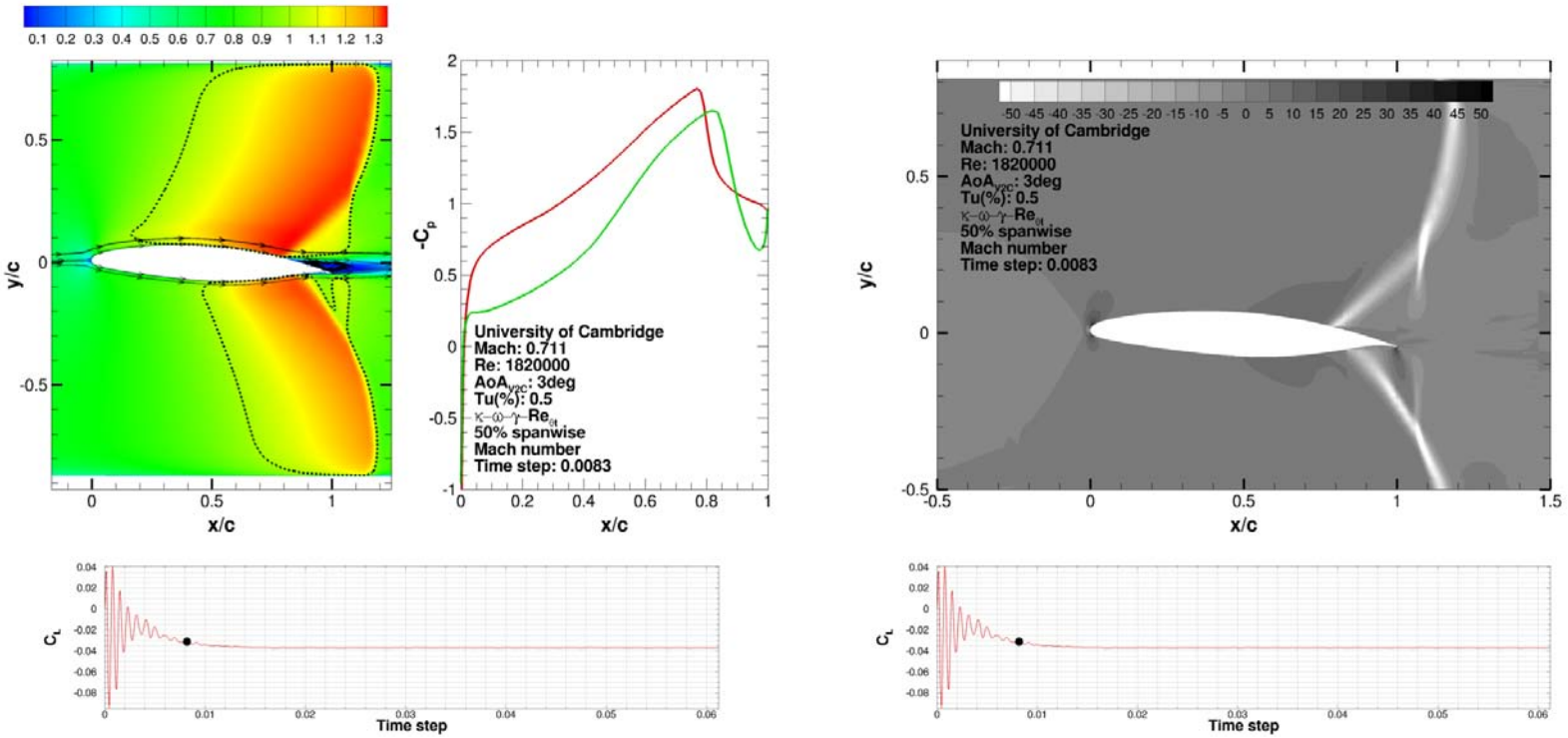
Mach number contour (left) and schlieren images (right)
on mid-span location
of the section of the UCAM wind tunnel using κ-ω SST model
M_∞ 0.7 Re_c 3.24x10^6, Tu 0.5% a=3deg

V2C - UCAM WT - κ–ω SST
M_∞ 0.711 Re_c 1.82×10⁶ a:3deg



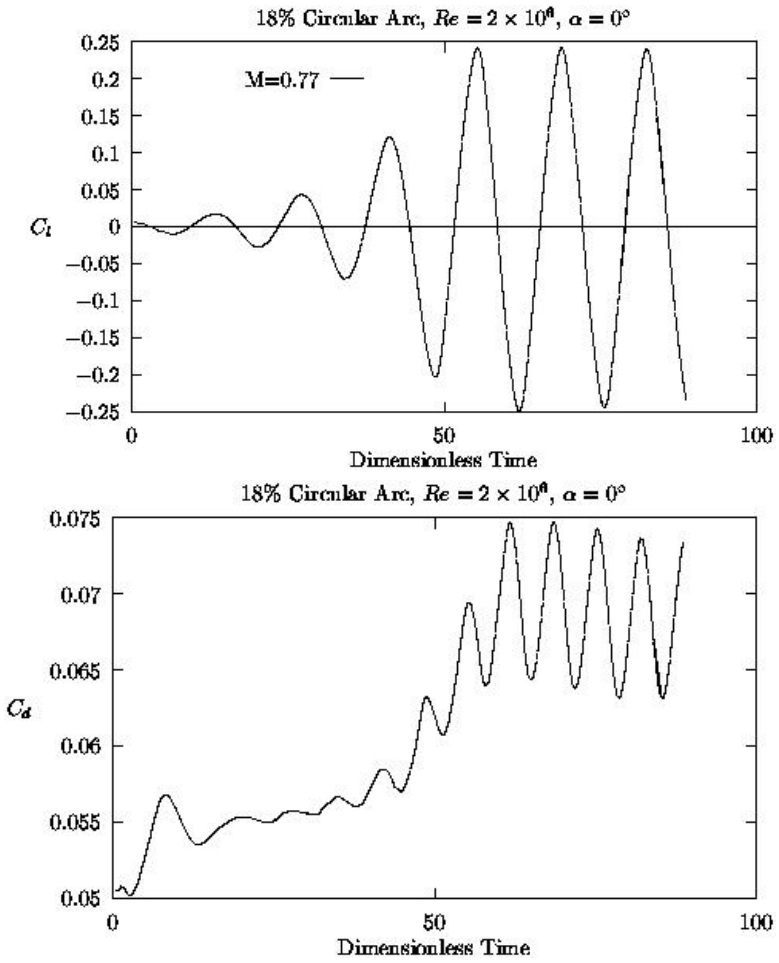
Mach number contour (left) and schlieren images (right)
on mid-span location
of the section of the UCAM wind tunnel using κ-ω SST model
M_∞ 0.711 Re_c 1.82x10⁶, Tu 0.5% a=3deg

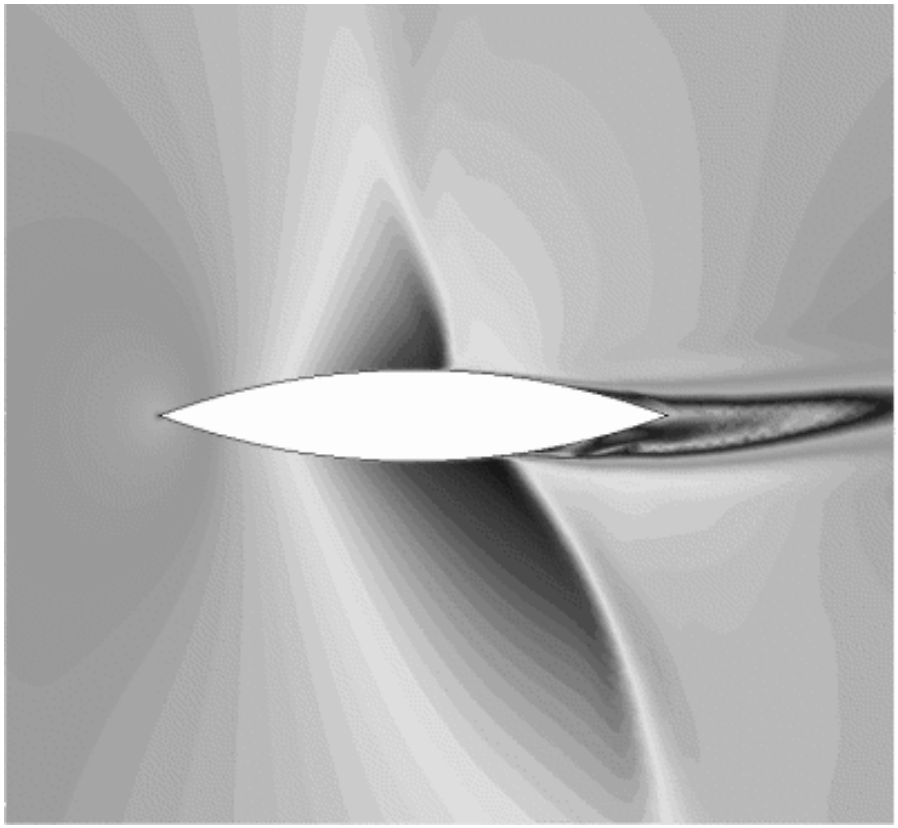
V2C - UCAM WT - $\kappa-\omega-\gamma-Re_{\theta t}$ model
M_∞ 0.711 Re_c 1.82×10^6 a:3deg



Mach number contour (left) and schlieren images (right)
on mid-span location
of the section of the UCAM wind tunnel using κ-ω-γ-$Re_{\theta t}$ model
M_∞ 0.711 Re_c 1.82x10^6, Tu 0.5% a=3deg

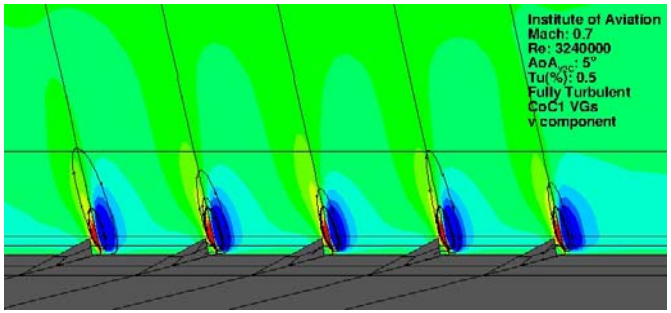
V2C - UCAM WT – Circular arc Airfoil





18% thickness, Zero degrees pitch
Mach number 0.77, Re_c 2x10^6

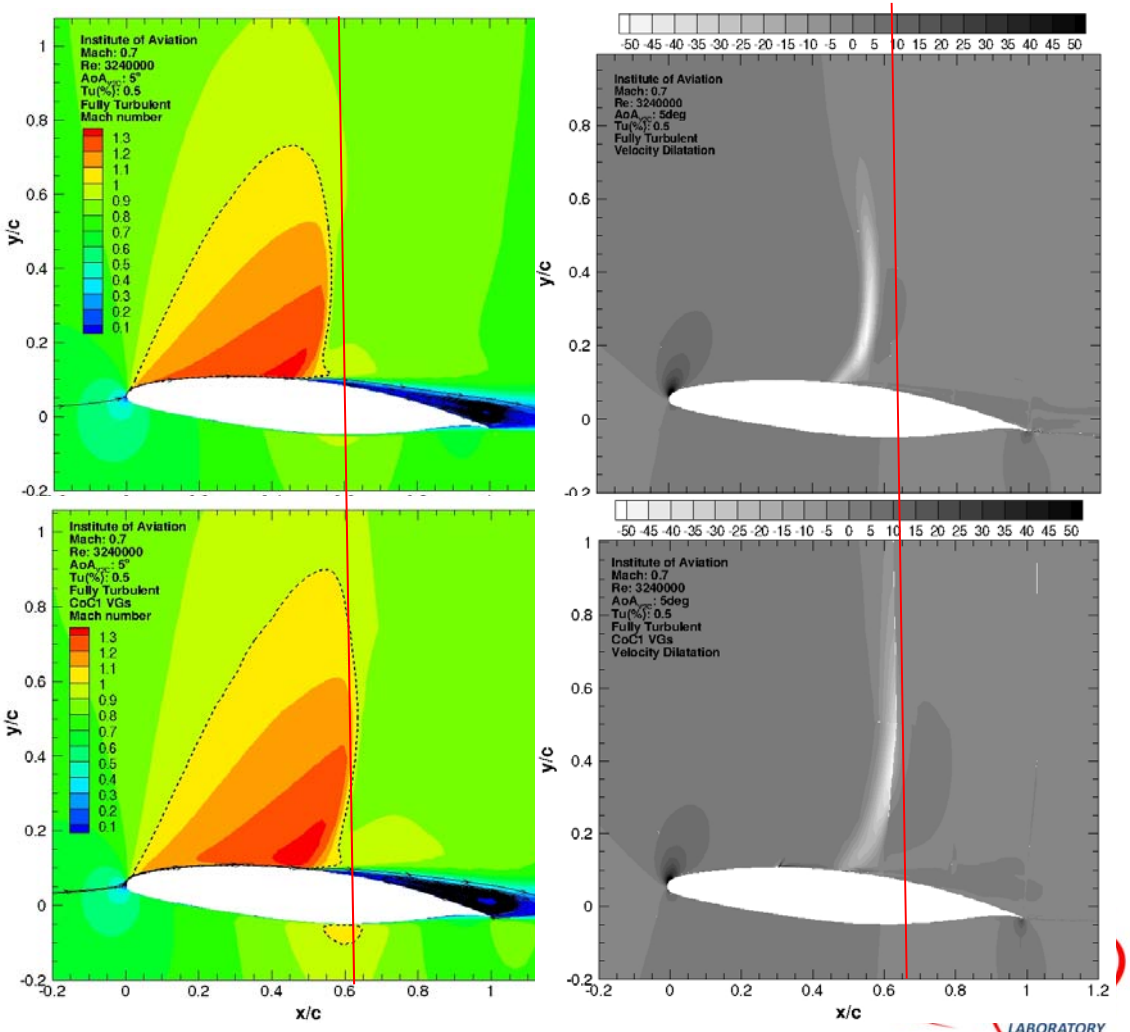
V2C – CoC1 VGs
IoA WT - κ–ω SST
M_∞ 0.7 Re_c 3.24×10^6 a:5deg



v component of velocity using 5 CoC1 VGs.

Comparison of Mach number and Velocity dilatation without (upper) and with (lower) VGs.

M_∞ 0.7, Re_c 3.24x10^6, a=5deg, Tu(%)= 0.5

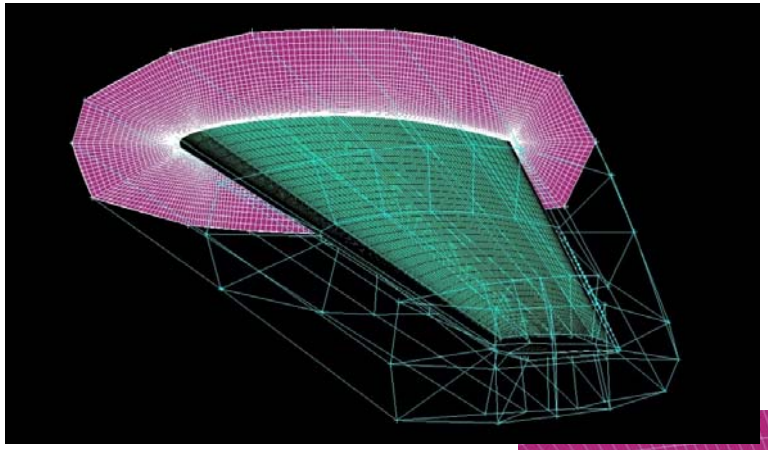


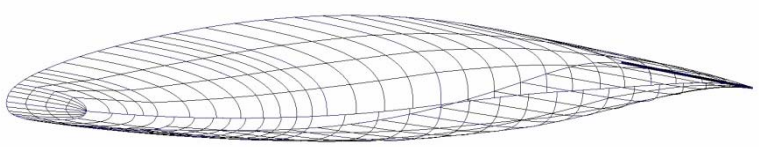
DAAV wing (TFAST)

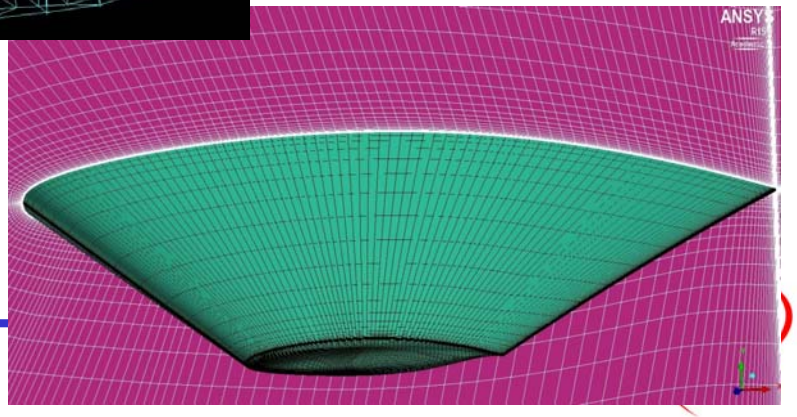
Details of the DAAV wing

Aspect ratio	8
Taper ratio	1/3
Leading edge sweep	20°
Twist angle	2° (linear)
Wing root	3.75m
Wing tip fairing	1.25m
Span	20m
S_{ref}	$50m^2$

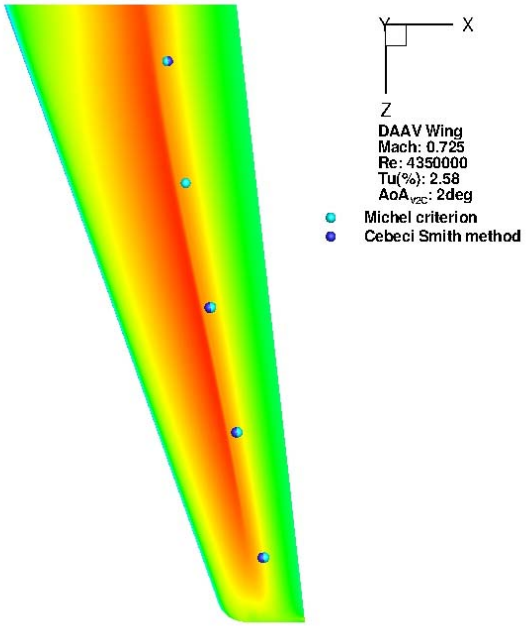
	Upper Surface	Lower Surface	Trailing edge	Spanwise
Grid points	136	122	28	71
	Wake Distance	Wake Number of points	Farfield Distance	Farfield Number of points
	10c	41	10	72







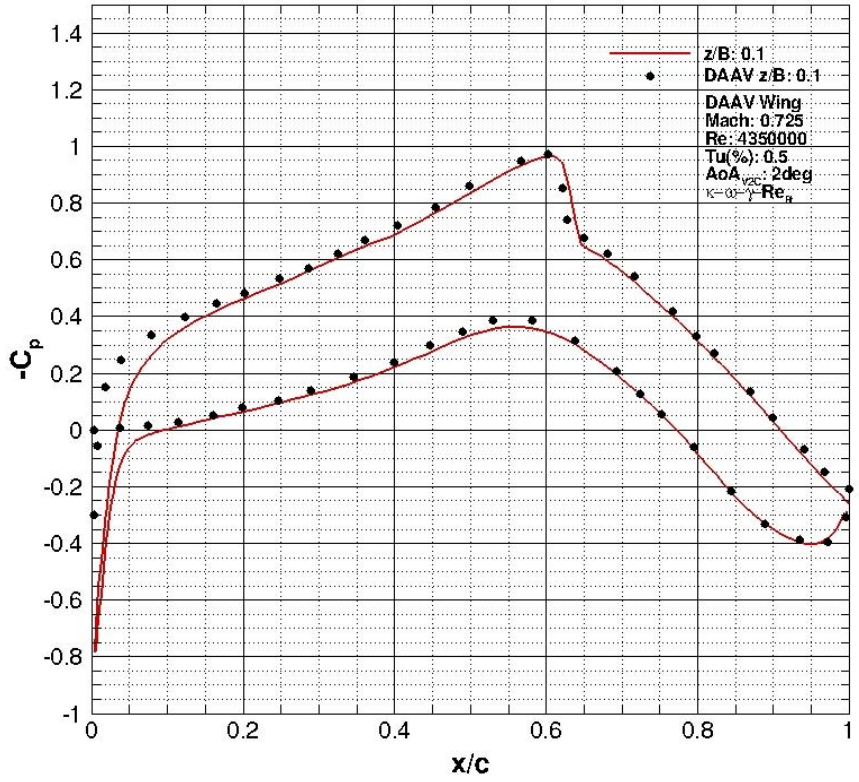
DAAV wing – Steady Calculations
M_∞ 0.725 Re_c 4.35×10^6 α: 2deg



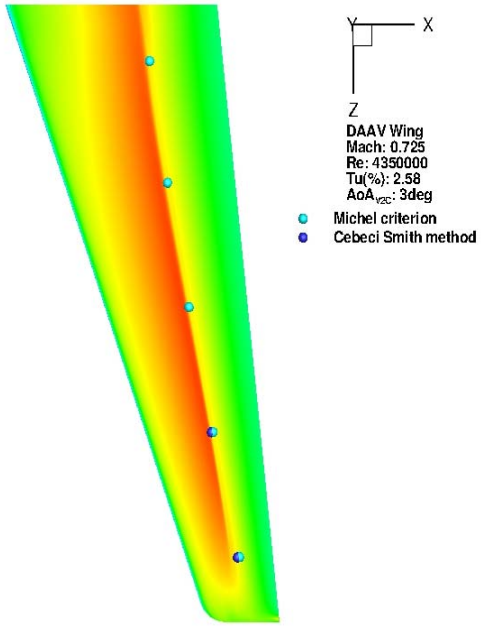
Transition location using Michel criterion and Cebeci-Smith model.

M_∞ 0.725, Re_c 4.35x10^6, α=2deg, Tu(%)= 0.5

Surface pressure distribution at α=2deg using the $\kappa-\omega-\gamma-Re_{\theta t}$ (lower)

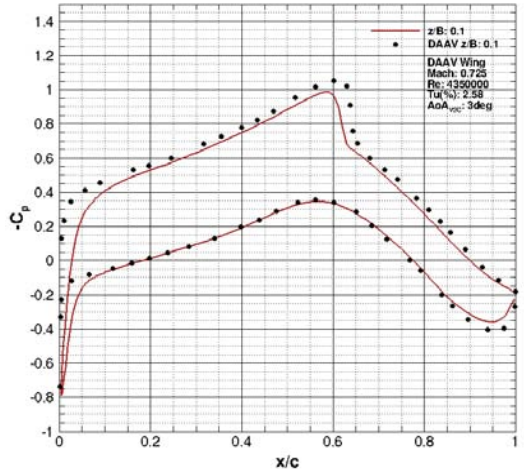


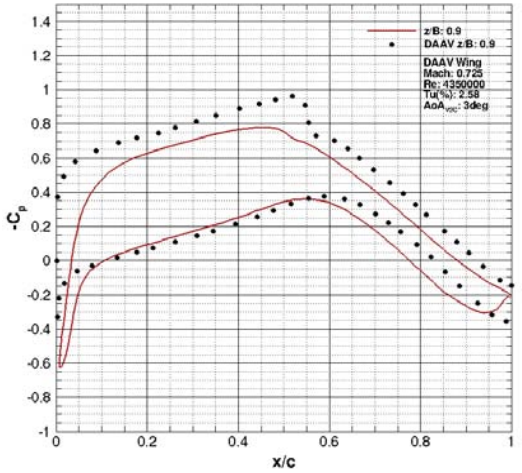
DAAV wing – Steady Calculations
M_∞ 0.725 Re_c 4.35×10^6 α: 3deg



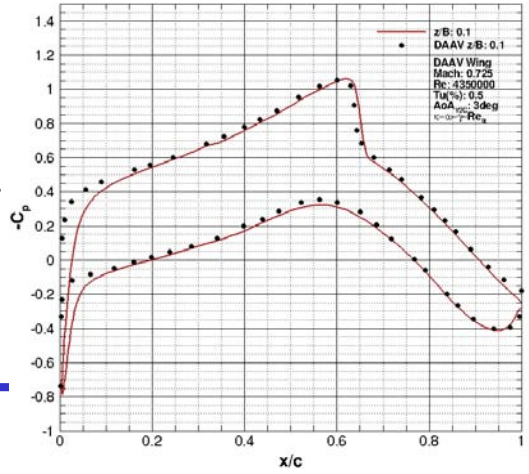
Transition location using Michel criterion and Cebeci-Smith model.

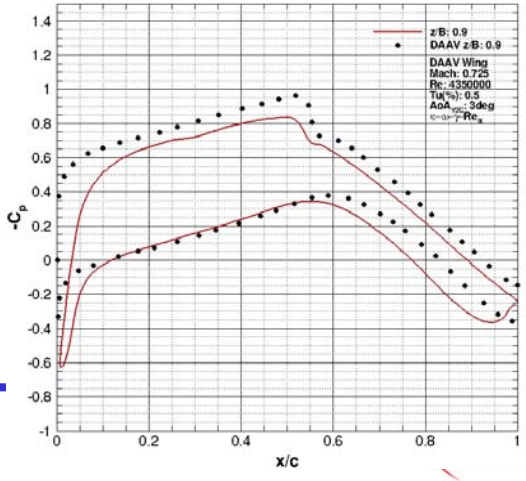
M_∞ 0.725, Re_c 4.35x10^6, α=3deg, Tu(%)= 0.5



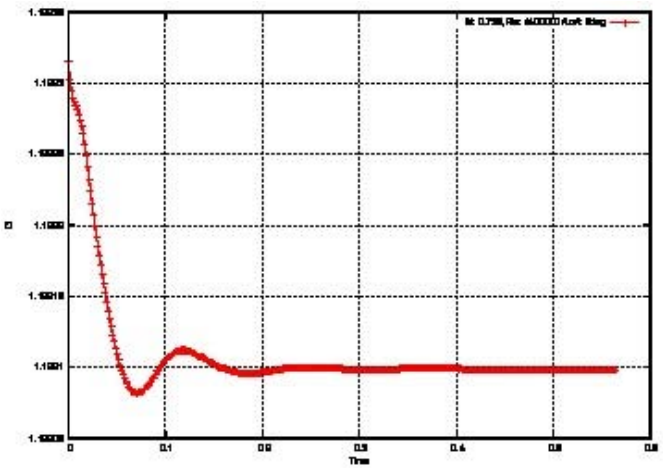


Surface pressure distribution at α=3deg using κ–ω SST model (upper) and κ–ω–γ–$Re_{\theta t}$ (lower)

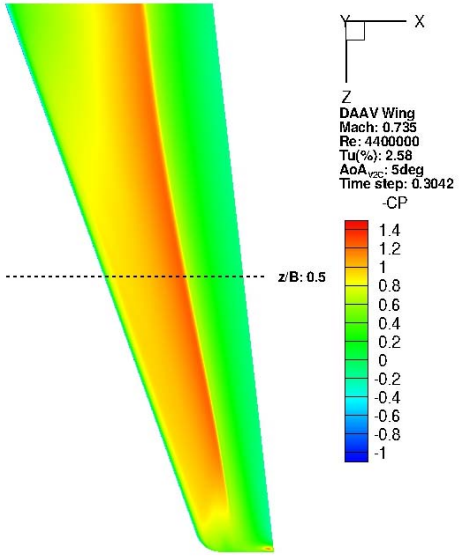


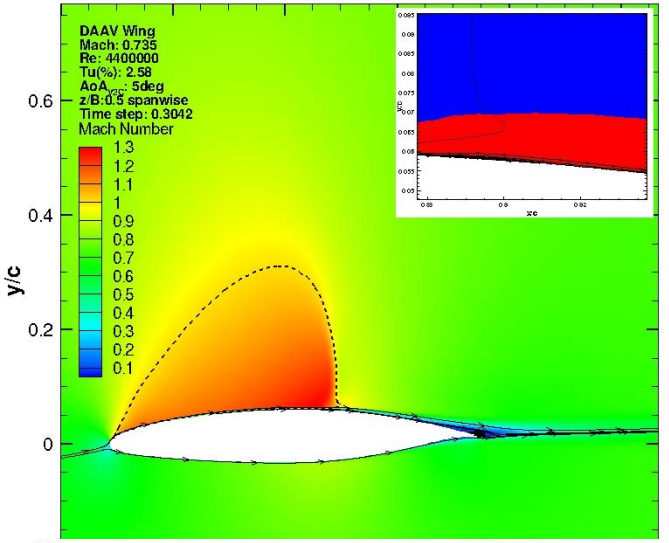


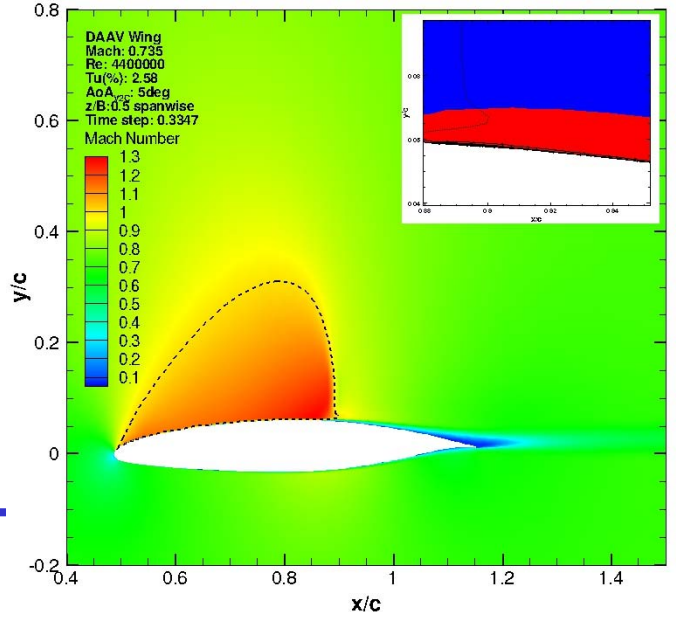
DAAV wing – κ–ω SST model - Unsteady Calculations
M_∞ 0.735 Re_c 4.4×10^6 a: 5deg



C_L of the wing



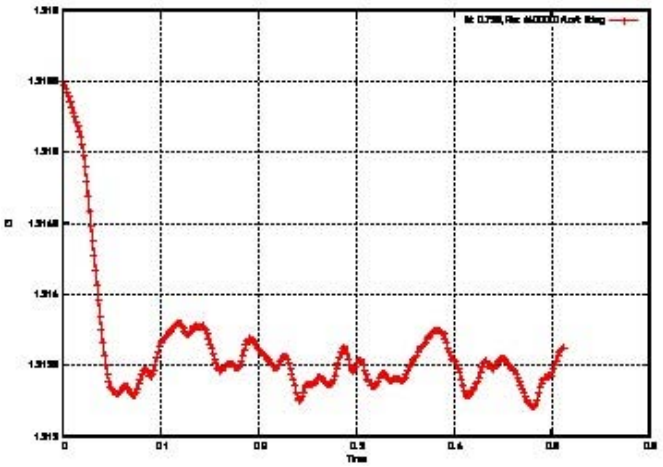




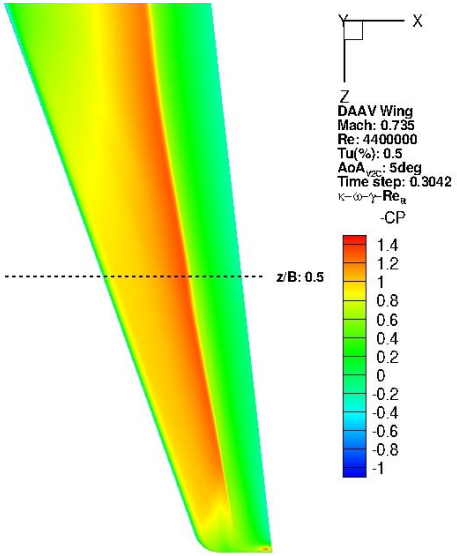
Surface pressure on the upper surface of the wing for κ–ω SST conditions
M_∞ 0.735, Re_c 4.4x10^6, a=5deg

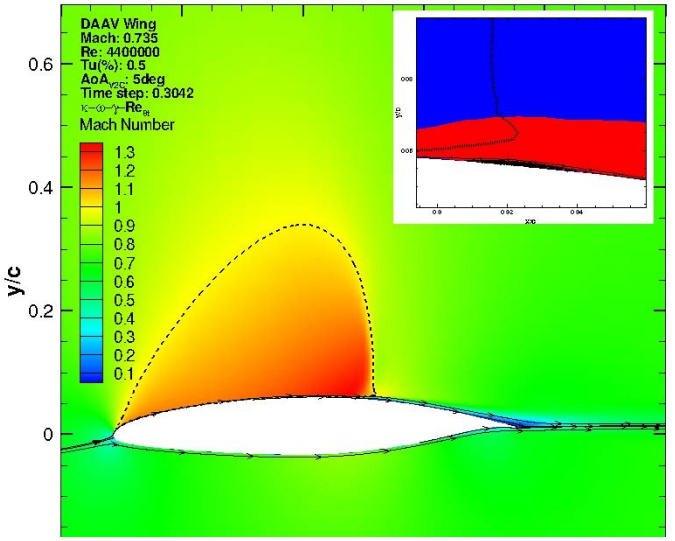
Mach number contour mid-span of the wing
t=0.3042s (upper) t=0.3347s (lower)

DAAV wing – $\kappa-\omega-\gamma-Re_{\theta t}$ model - Unsteady Calculations
M_∞ 0.735 Re_c 4.4×10^6 a: 5deg

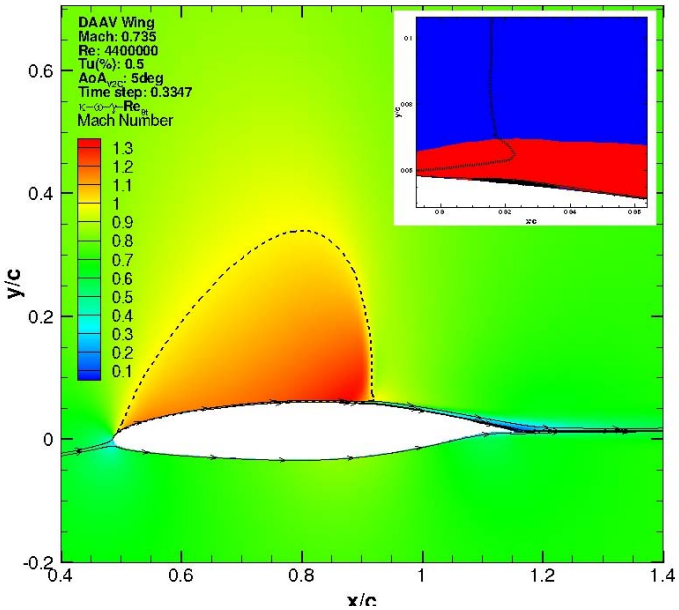


C_L of the wing





Surface pressure on the upper surface of the wing for $\kappa-\omega-\gamma$-$Re_{\theta t}$ conditions
M_∞ 0.735, Re_c 4.4×10^6, a=5deg

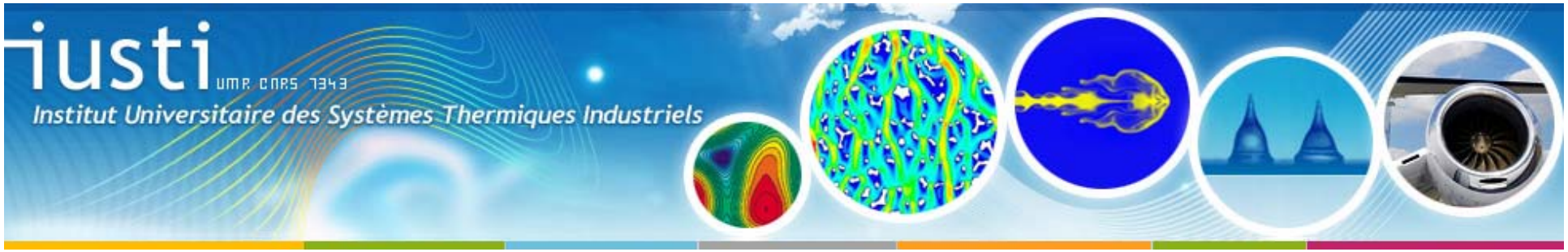


Mach number contour mid-span of the wing
t=0.3042s (upper) t=0.3347s (lower)

Summary and future work

- Implicit implementation allowed for high CFL numbers when using the transition model – especially for unsteady flow cases
- The use of SST with the LCTM appears to be a pragmatic way for unsteady computation of shock/ boundary layer interaction
  - Validation against the TFAST data pending
  - Exact buffet onset to be identified
  - Buffet frequency predicted at about 90hz
  - Wind tunnel data influenced by walls, further work underway to quantify the effect
  - Flow control also to be attempted
- First experimental data imminent
- DAAV wing computed with URANS/SST/LCTM
  - Buffet onset predicted
  - No experiments planned for this case
  - Code-to-code and model-to-model comparisons
- Planned computations include DES/SAS initially with fixed transition
- Flow control studies underway

TFAST



SEVENTH FRAMEWORK PROGRAMME

The TFAST Project:

Physical and Experimental Challenges

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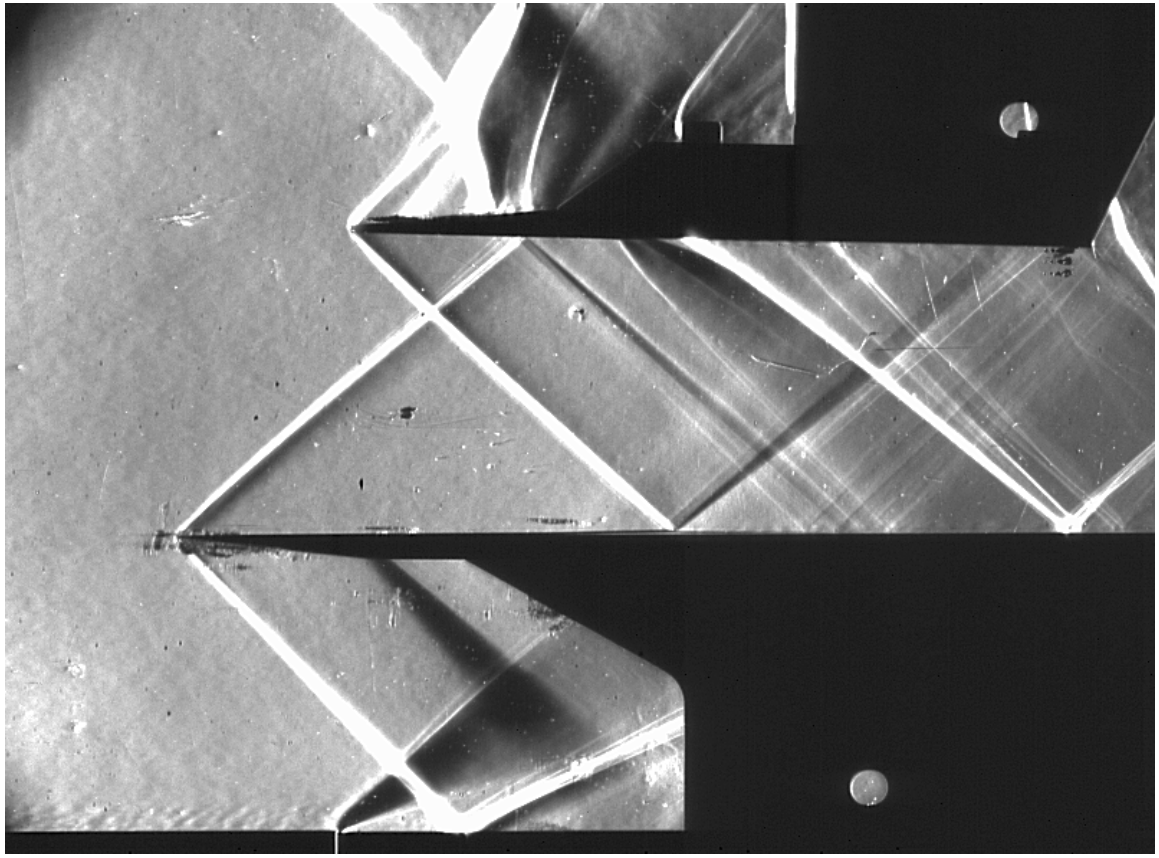
EASN Workshop, Aachen, October 27-29, 2014

Outline

- The Physical Issues
- The Experimental Challenges
- Conclusions and Perspectives

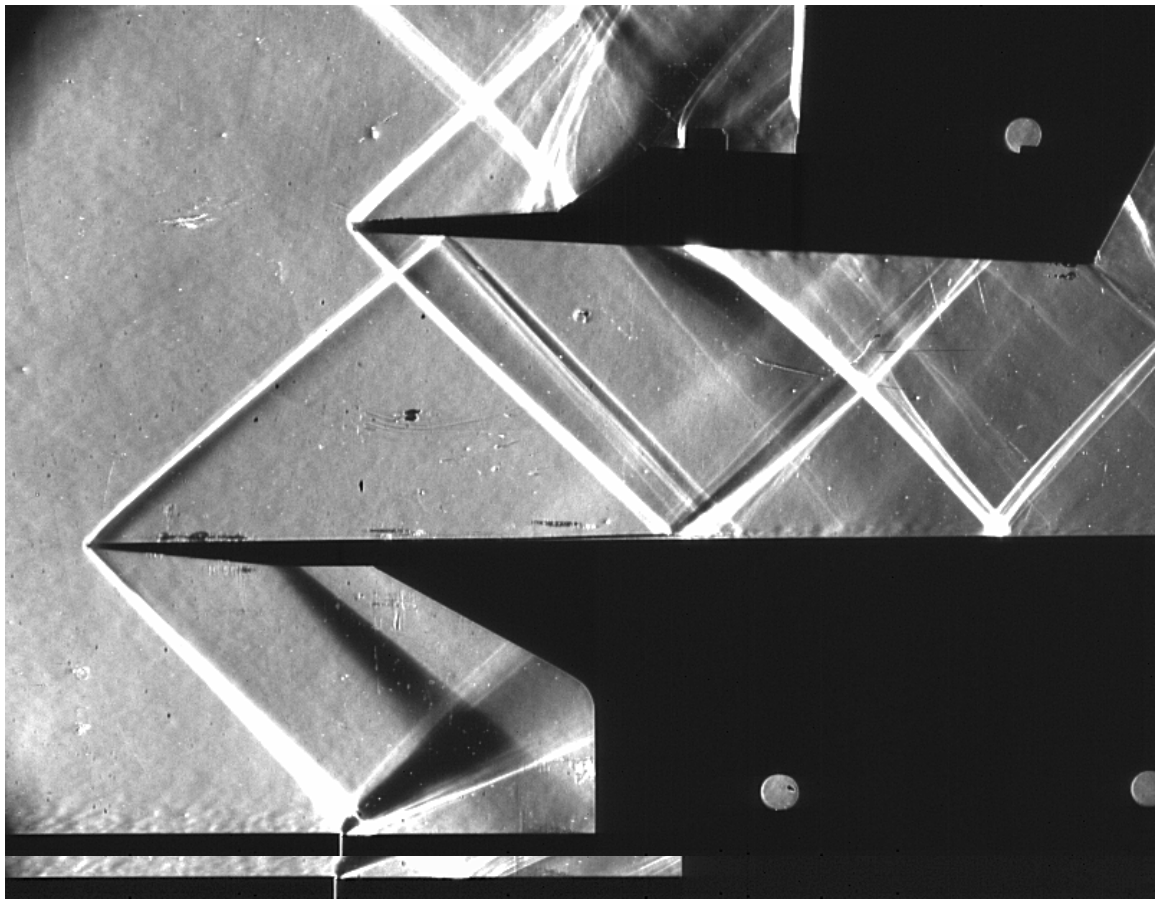
Effect of the Reynolds number at the shock impact point

$0.64 \leq Re_{Xl} (\times 10^6) \leq 0.92$ - $\alpha = 1.5^\circ$, M=1.6



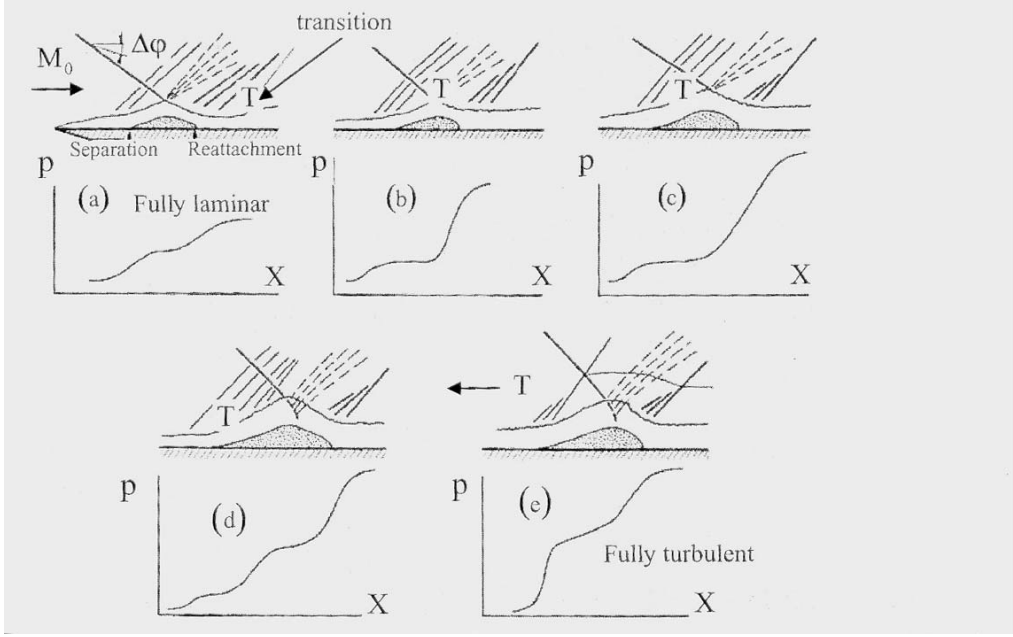
BL transition downstream of the interaction region for all Re_{Xl}. *Courtesy R. Bur, ONERA.*

Effect of the Reynolds number at the shock impact point
$0.46 \leq Re_{XI} (\times 10^6) \leq 1.09$ - $\alpha = 3^\circ$



BL transition within the interaction region for all Re_{XI} , *Courtesy R. Bur, ONERA.*

What phenomena should we simulate numerically & experimentally?



- Case a: difficult to produce it for moderate Mach numbers
- Case e: studied in UFAST

- Cases b, c, d: loss of symmetry for the shape of the separated zone. Wall pressure distributions very sensitive to the state of turbulence at the shock impingement point.

Adapted from Gadd et al. 1954, quoted in Délery 2011. *Courtesy J. Délery*

The Physical Issues 1: what should we simulate numerically & experimentally?

The point of transition depends on:

- The initial state of fluctuations
- The Reynolds number
- The Mach number

Amplification mechanisms:

- The mean shear $(\partial U/\partial y)$
- The compression $(\partial U/\partial x)$

Generation of vorticity through baroclinic mechanism

Likely situation in the mixing layer: amplification mainly by the mean shear

Possibility of generation of vorticity in some other zones

Problem of definition of incoming conditions on fluctuations.

The Physical Issues 1: what should we simulate numerically & experimentally?

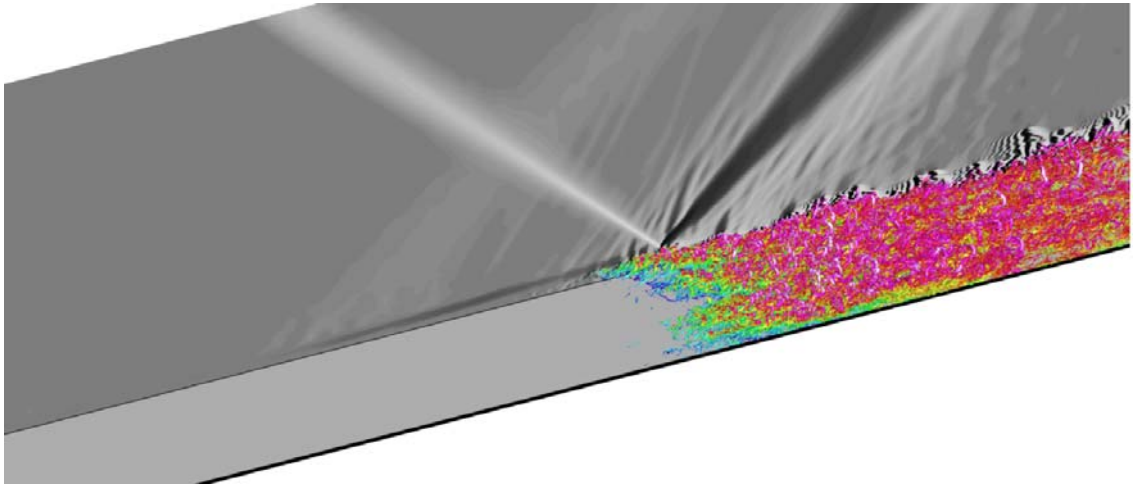
In numerical simulations, how are the initial fluctuations defined?

Two families of choices:
- Optimum modes from linear stability theory (inside/outside)
- « White » noise: SEM (bypass)

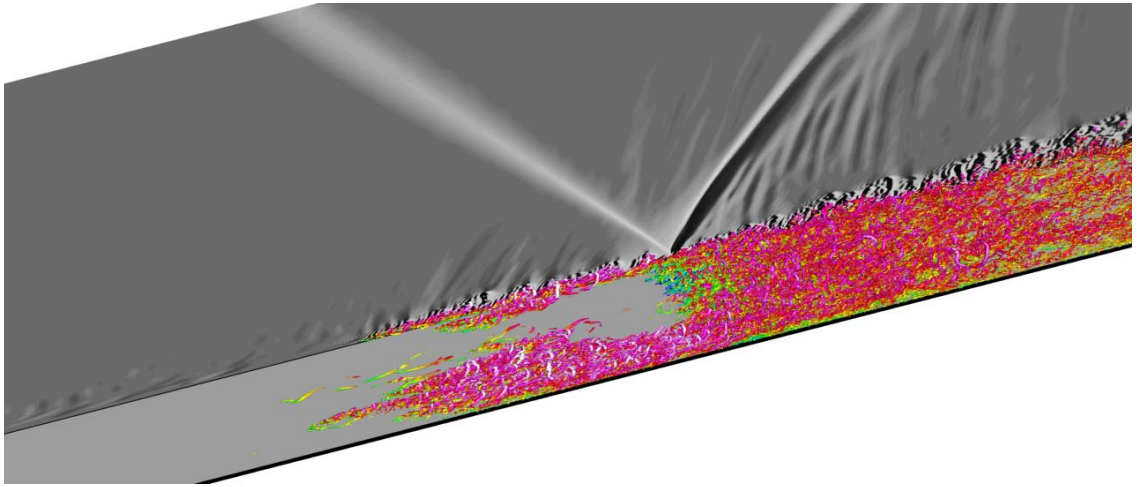
Question 1: Are the results independent of the method of generation of the incoming fluctuations?

Question 2: What are the relations with the experiments (receptivity)?

The Physical Issues 1: what should we simulate numerically & experimentally?

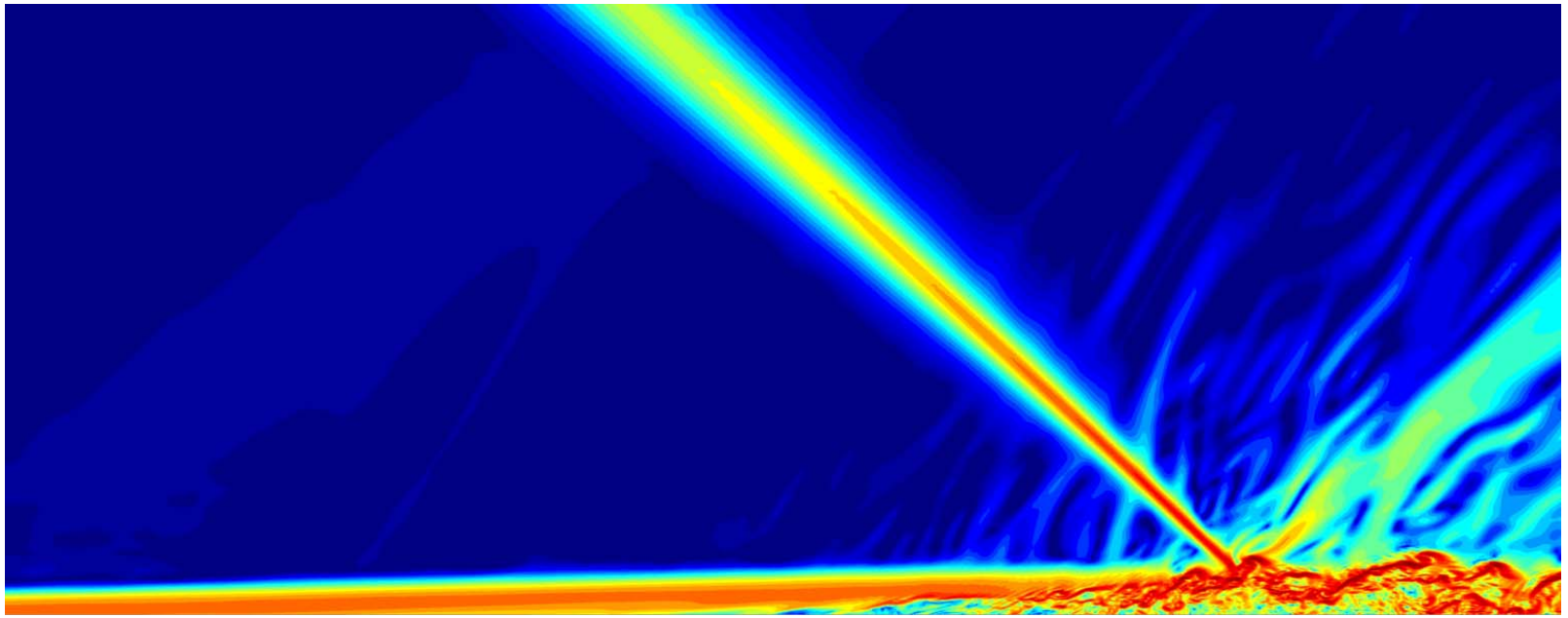


LES. M=1.6.Turbulent just upstream of shock impingement IUSTI, Marseille



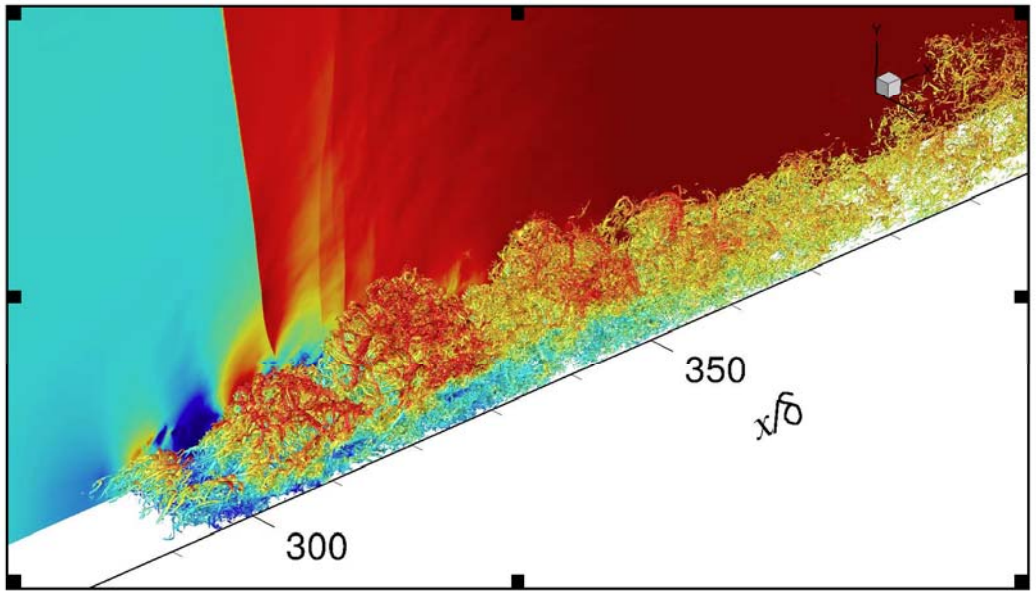
LES. M=1.6.Transitional upstream of shock impingement

The Physical Issues 1: what should we simulate numerically & experimentally?



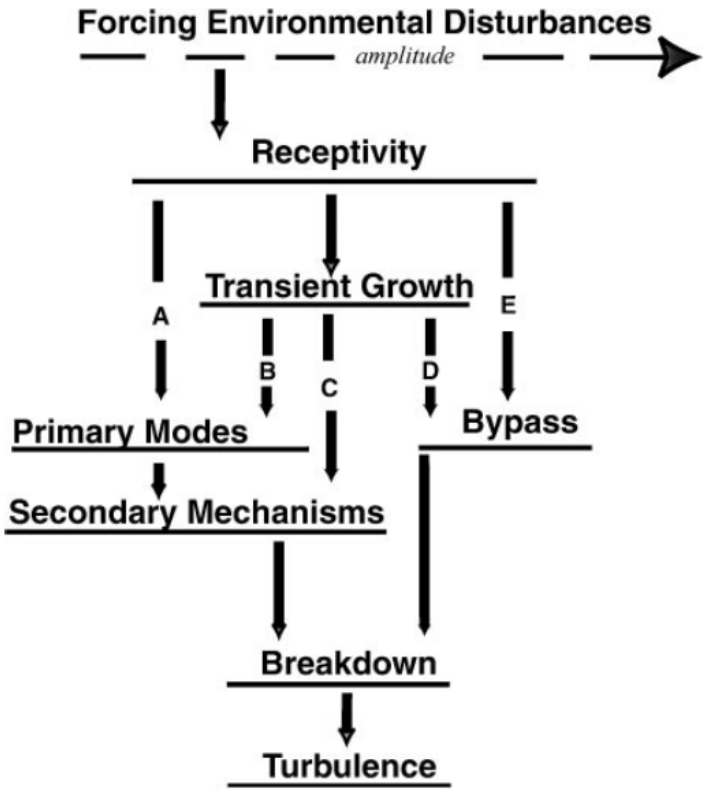
LES. M=1.6. Numerical Schlieren (IUSTI, Marseille). Turbulent mixing layer upstream of shock impingement. P_i=0.5 bar, Tu=0.06%

The Physical Issues 1: what should we simulate numerically & experimentally?



DNS (Bernardini, Pirozzoli 2013, URMLS), normal shock, M=1.2

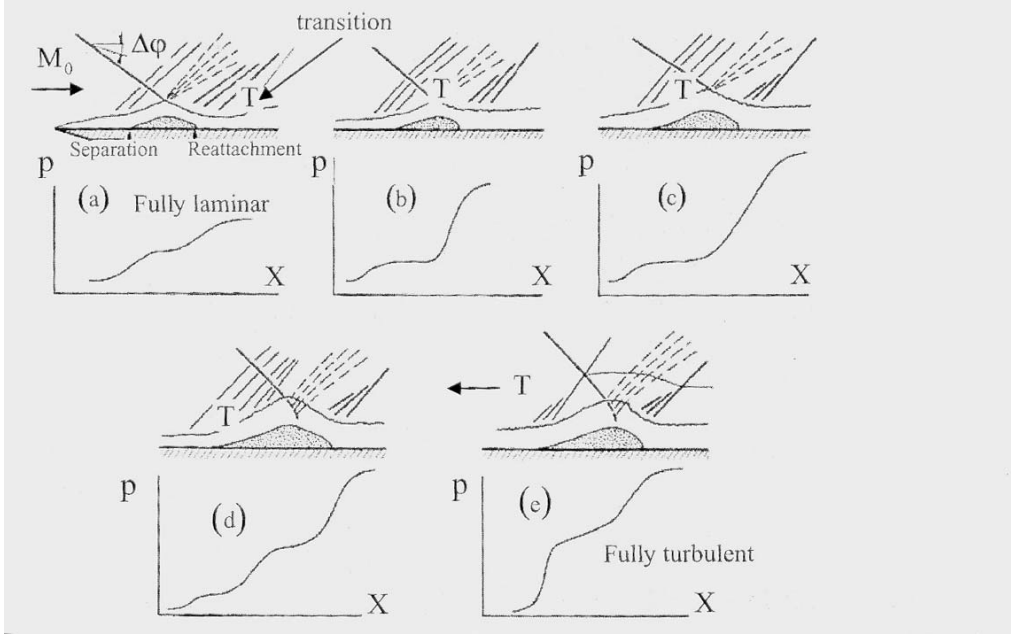
The Physical Issues 1: what should we simulate numerically & experimentally?



The hope is that the final state is the same, whatever the beginning of the story. Note that the resulting turbulence is, in our case probably not completely ordinary, not standard, not asymptotic.

From Morkovin 1994.

The Physical Issues 2: What about unsteadiness?



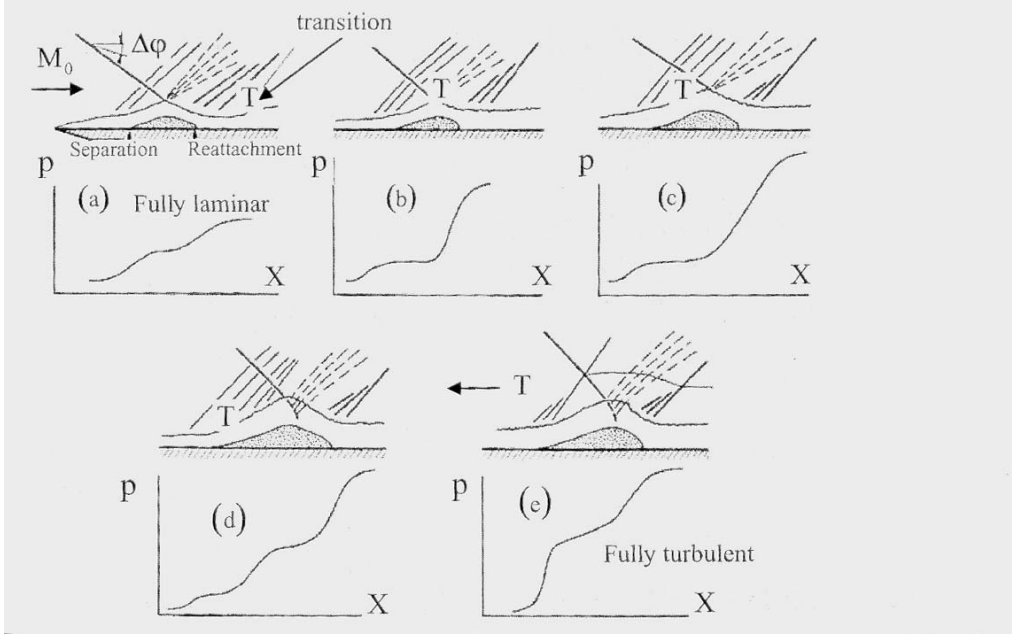
This question is not the core of TFAST: many points have to be solved before this stage. However, this is a question for which we should be prepared.

Case a: unsteadiness just due to the incoming fluctuations.

Case e: studied in UFAST.

UFAST argument: mass entrainment-discharge mechanism (Piponniau et al. 2009, Clemens & Narayanaswamy 2014) .
Frequency scales with the length of the interaction and with the spreading rate of the *turbulent* mixing layer (Mach number dependent).

The Physical Issues 2: What about unsteadiness?



How can this be applied to cases b- d?

In laminar interactions, $L/\delta \cong 50$, in the turbulent case $L/\delta \cong 5$!
It should be checked if the Strouhal number fL/U_e is still close to 0.03.
As the laminar mixing layer has a weak mass entrainment, it is possible that an equivalent length of interaction should be used, restricted to the turbulent part.

The Experimental Challenges: experimental conditions

Two types of interactions are considered:

Normal shock interactions (Mach numbers 1.2, 1.35)
Oblique shock reflection (Mach numbers 1.4, 1.6, 1.7)

Measurements in such conditions are extremely challenging
See, for example, the pioneering work of Degrez, Boccadoro, Wendt (1987)

The Experimental Challenges: experimental conditions

Oblique shock reflection

	TU-Delft	ITAM	ONERA	IUSTI
M	1.7	1.43	1.6	1.63
Pt [bar]	2.3	0.7	1	0.4
Re_u [10^6 m^{-1}]	35	10.5	14	5.27
Re TR_0	2	1?	-	>1.8
Re TR ½ (M)	2.5	1.3?	-	-
Re turb.(M)	3	3	2 triggered by comp. waves??	-
δ_0 [mm]	0.2	0.5?	-	0.92

The Experimental Challenges: experimental conditions

	TU-Delft	ITAM	ONERA	IUSTI
Re_u [10^6 m^{-1}]	35	10.5	14	5.27
$(\rho U)'$ [%]	1.3 (HW)	0.15-0.2? (HW)	-	<0.1 (HW)
	-			PSD (f≈ 3-5kHz)
U' [%]	0.5 (PIV)	-	-	<0.1(HW)
	PDF (u' and v')			PSD (f≈ 3-5kHz)

The Experimental Challenges: some issues

All experimental methods (excepted wall measurements, PSP, TSP…) are uneasy in such flows because:

The shear layers are thin (HWA, LDA, PIV)

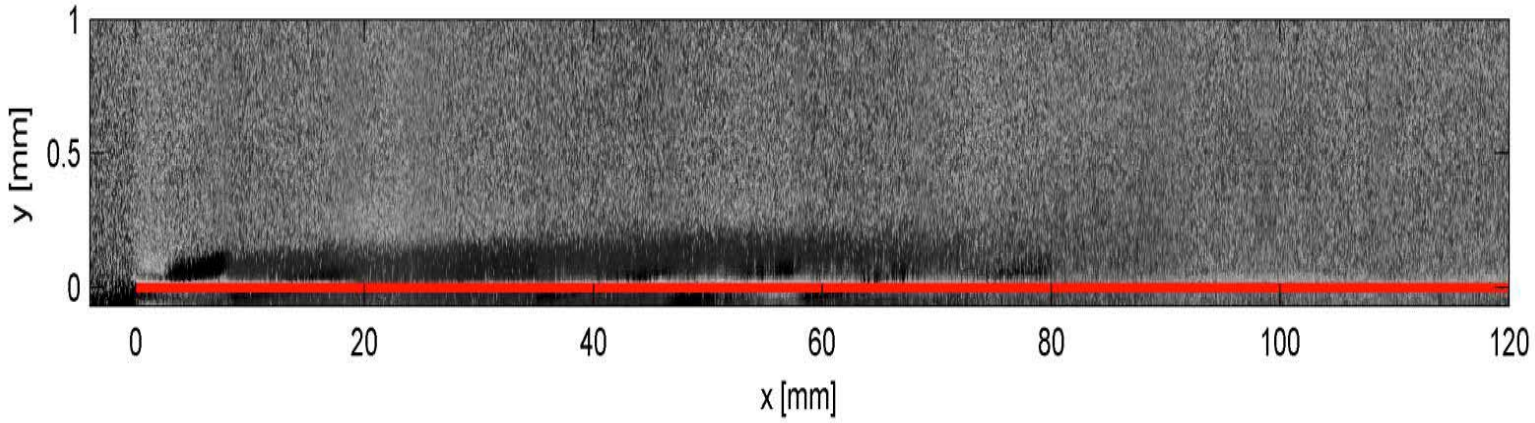
The layers are laminar (LDA, PIV)

The flows have important transonic zones (HWA)

The Experimental Challenges: some issues 1

•Seeding a laminar layer, and related consequences (TU Delft)

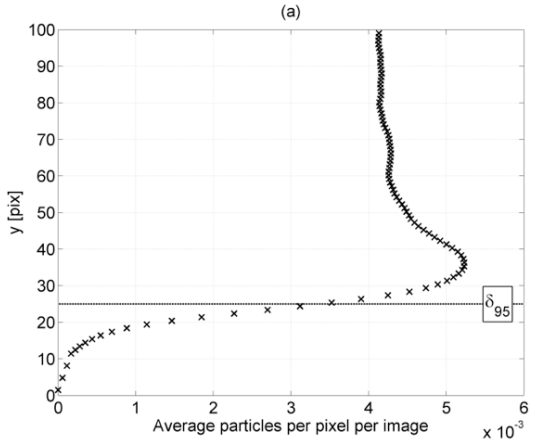
M=1.7
PIV requires a large number of particles.
The boundary layer thickness is about 0.2 mm
Just a few particles in the laminar part.

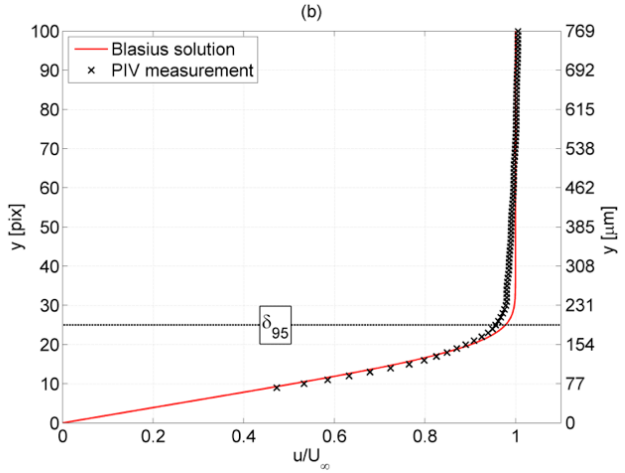


From Giepman, Schrijer, van Oudheusden 2014, TU Delft.

Probably due to a Magnus effect!

The Experimental Challenges: some issues 1





Particle density

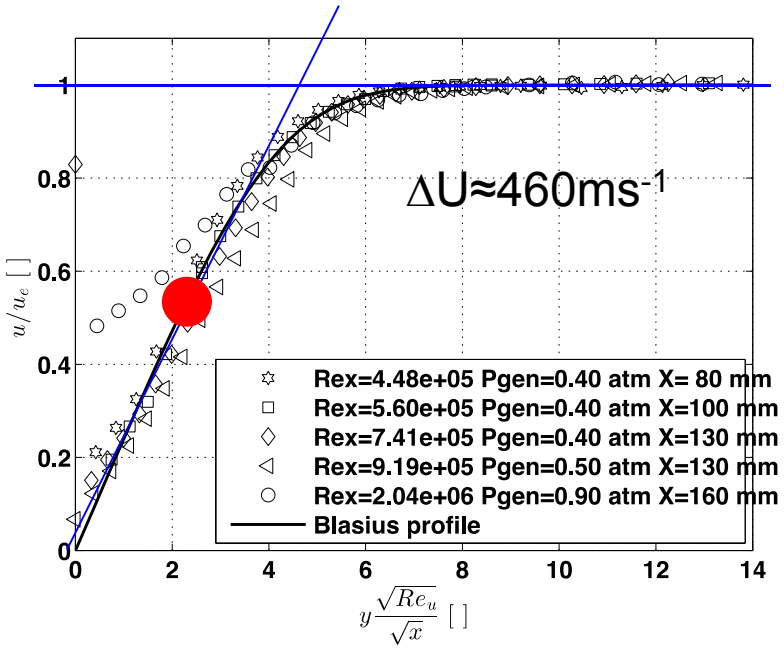
Resulting velocity profiles

From Giepman, Schrijer, van Oudheusden 2014, TU Delft.

Boundary layer thickness≅0.2 mm
Measurements corrected for plate vibrations.

The Experimental Challenges: issue 2, measurement accuracy

•Sensing thin shear layers (LDA, PIV)



TU-Delft (δ_0=0.2mm):

PIV, sensor 60μm: ΔU≈200ms-1 for U=Ue/2: ΔU/U≈50%

IUSTI (δ_0≈1mm):

LDA, same sensor size : ΔU≈40ms-1 for U=Ue/2: ΔU/U≈10%

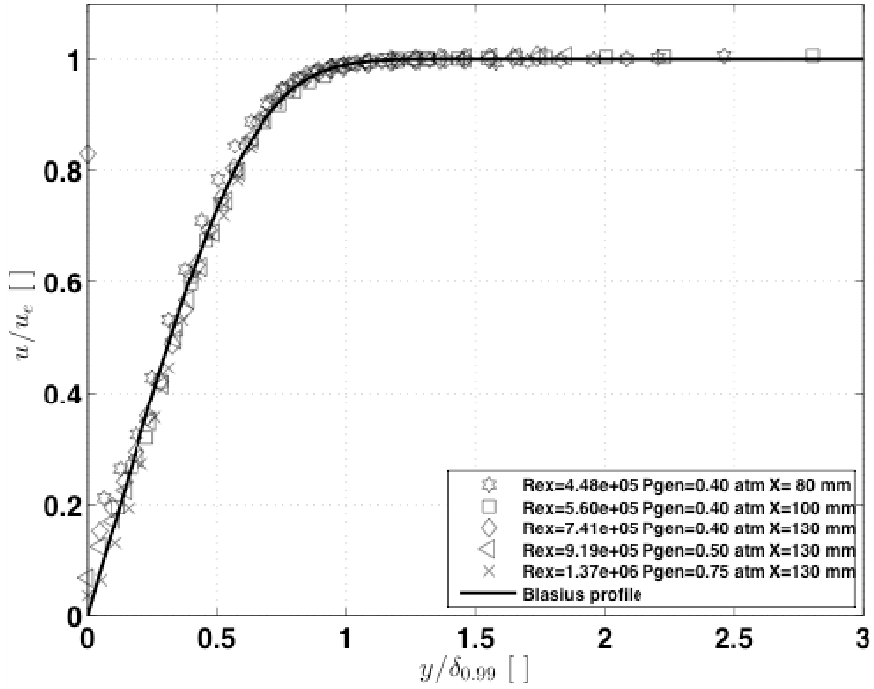
ITAM/IUSTI:

HW, sensor 5μm: OK but amplitude of the probe vibrations have to be less than 60μm

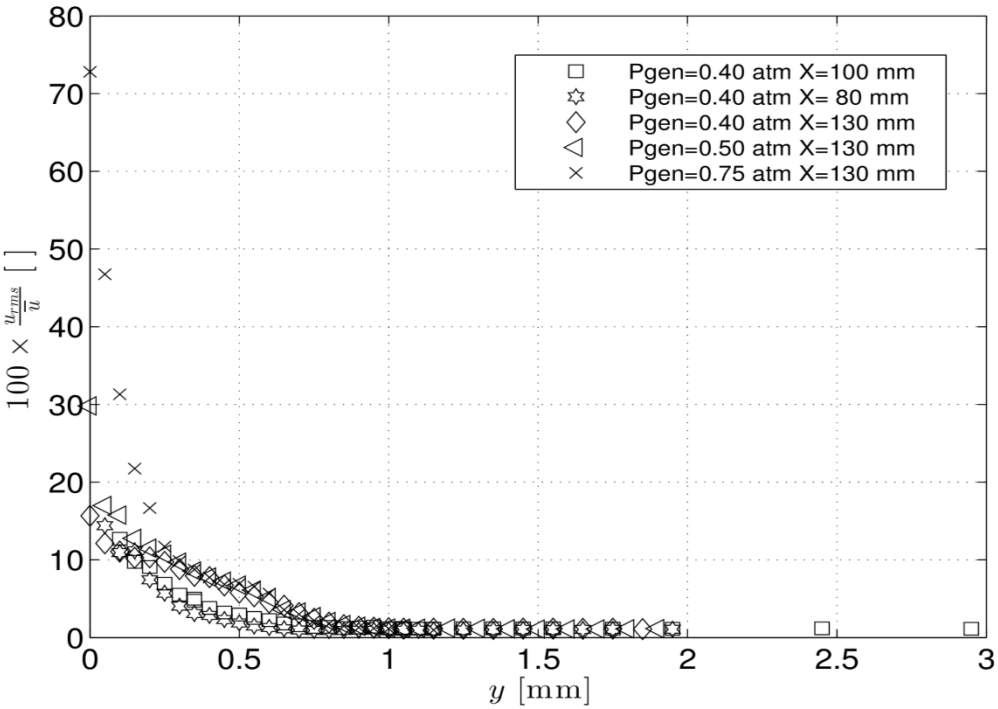
Problem for turbulence measurements (RMS, cross-correlations, PSD)
Accuracy of the measurements has to be qualified

The Experimental Challenges: issue 2, measurement accuracy

LDA measurements (IUSTI, Marseille)



Mean velocity profiles

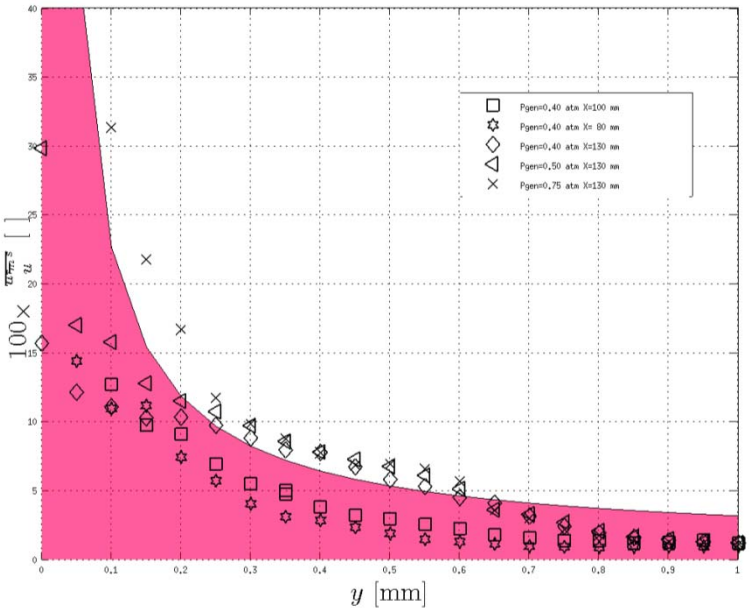


Turbulence intensity, u'/U, %

The Experimental Challenges: issue 2, measurement accuracy

LDA measurements (IUSTI, Marseille)

Statistical estimate of the space integration effect (uniform probability) over the measurement volume (of size Φ)



$$\frac{\sqrt{\overline{u'^2}}}{U} = \frac{1}{2\sqrt{3}}\frac{\Phi}{y}$$

or

$$\frac{\sqrt{\overline{u'^2}}}{u_\tau} = \frac{1}{2\sqrt{3}}\Phi^+$$

with $u_\tau = \sqrt{\tau_w/\rho_w}$ friction velocity

$$\Phi^+ = \Phi u_\tau / \nu_w$$

Conclusions, perspectives

Physical problems are interesting for both basic research and applications.

Experiments currently performed.
Ouput:
Unique data base, consistently documented with background fluctuation qualification, detailed mean field exploration, turbulence measurements when possible, and assessment of measurement accuracy.
First characterization of unsteadiness.

Advanced measurement methods (HW, LDA, PIV, PSP, TSP)
Adaptation required for difficult conditions

Basis for efficient flow control (VG's, roughness, plasma actuators)

The consortium has confirmed its expertise for performing experiments in difficult conditions (Transition+almost transsonic range+ thin flows)

Progress expected in the understanding of the physics of the flow (amplification vs. generation, interactions CFD-expts) , and on the methods of numerical prediction.

Questions

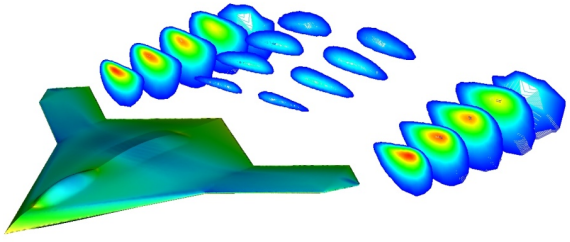
Azure: High-order CFD Software for Aerospace Applications

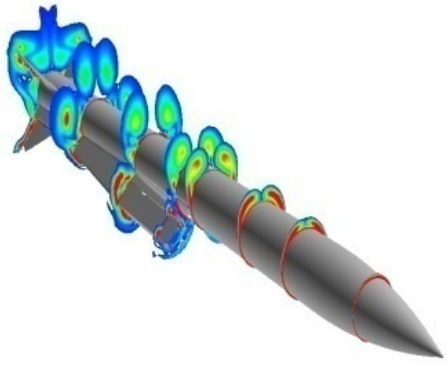
Dimitris Drikakis, A. Antoniadis, Z. Rana, P. Tsoutsanis

Fluid Mechanics and Computational Science Centre
Institute of Aerospace Sciences
Cranfield University, UK

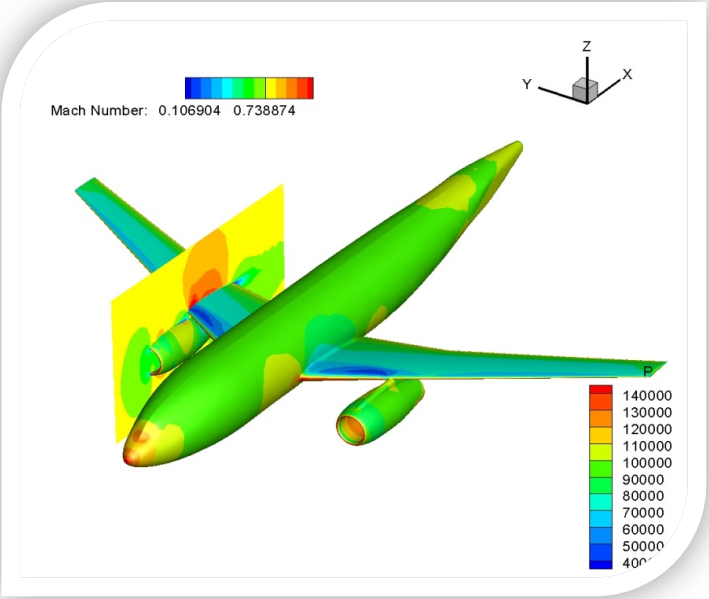
Motivation

- Advances in computational methods have increasingly enabled the simulation of complex flows, heat transfer, acoustics, and fluid-structure interaction phenomena.
- Advances in high performance computing (HPC) have allowed more complex simulations to be performed at shorter turn-around times.
- However, the design and condition monitoring of advanced aerospace systems increasingly require more detailed and accurate understanding of complex phenomena and conditions at all scales.
- Reducing the uncertainty in engineering simulations by increasing the accuracy, while making computations more efficient still remains a scientific challenge

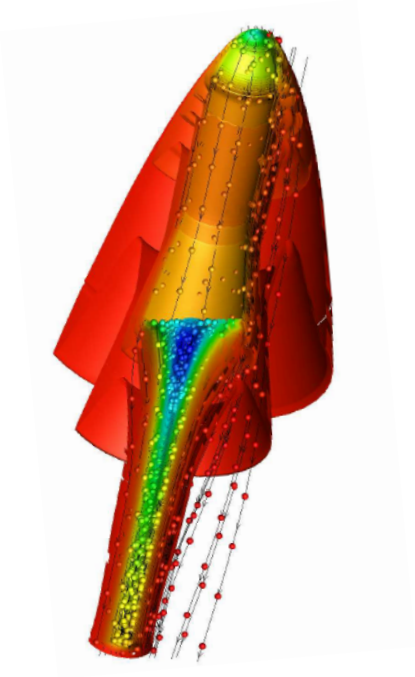




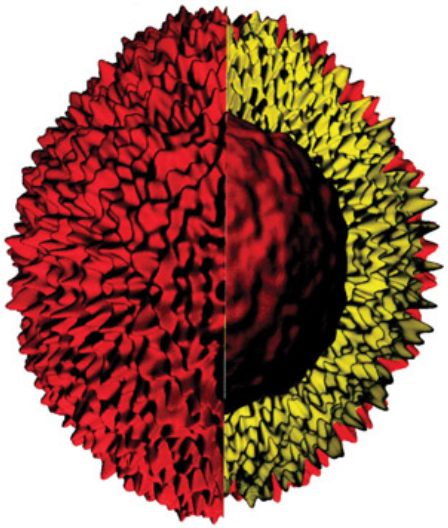
Diverse applications



Subsonic and transonic



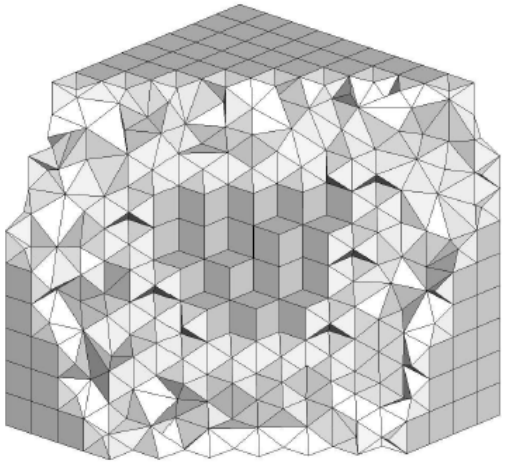
High-speed

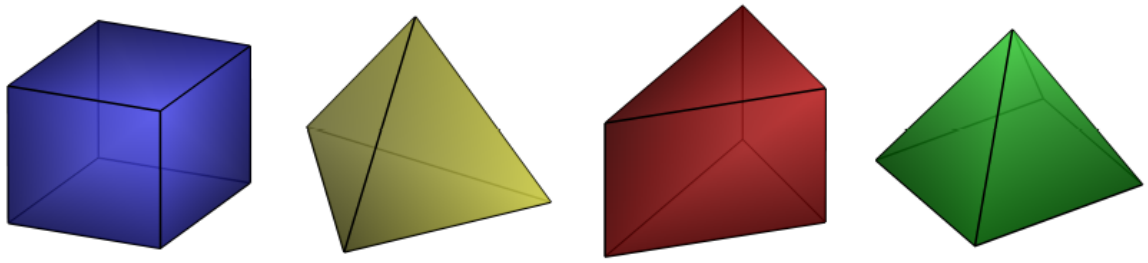


Inertial Confinement Fusion

Unstructured grids

- Consist of different types of element shapes to improve efficiency in representing complicated geometries accurately by using the minimum number of cells
- Prismatic and Hexahedral elements ideal for being used in the boundary layer region

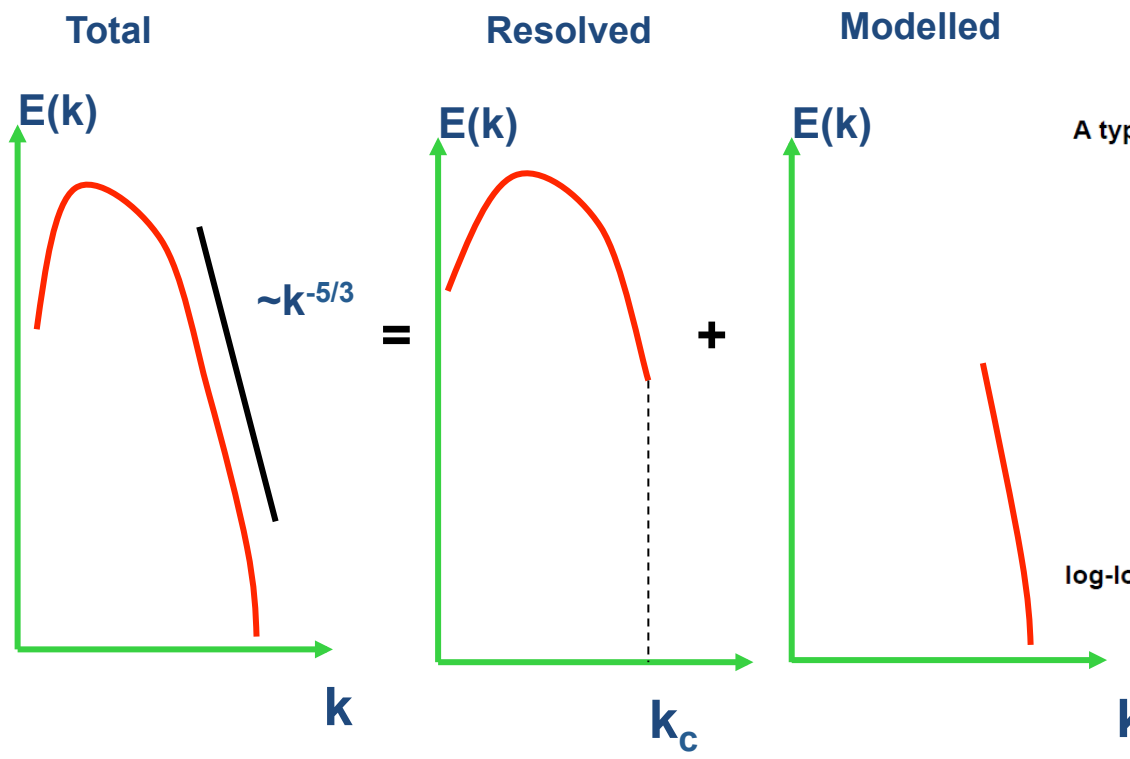




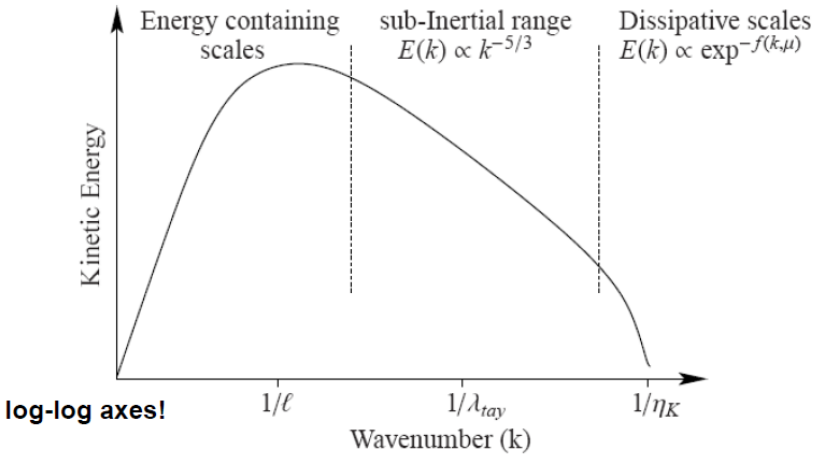
(a) Hexahedral (b) Tetrahedral (c) Prism (d) Pyramid

Figure 3.1: Convex polyhedrons

Energy cascade in Large Eddy Simulation



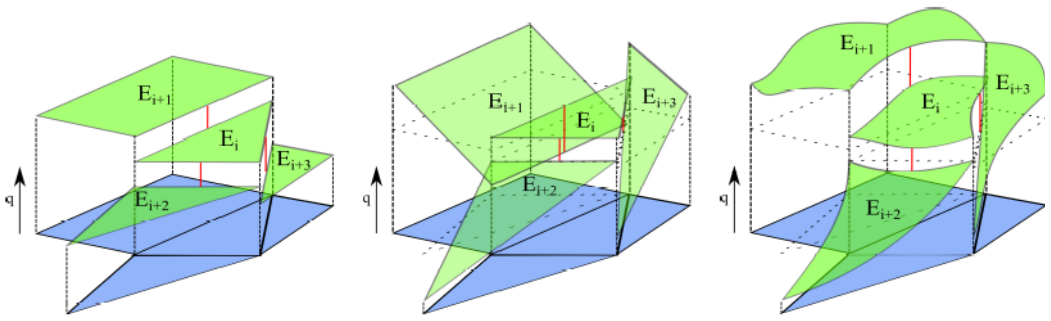
A typical turbulent kinetic energy spectrum looks like the following:



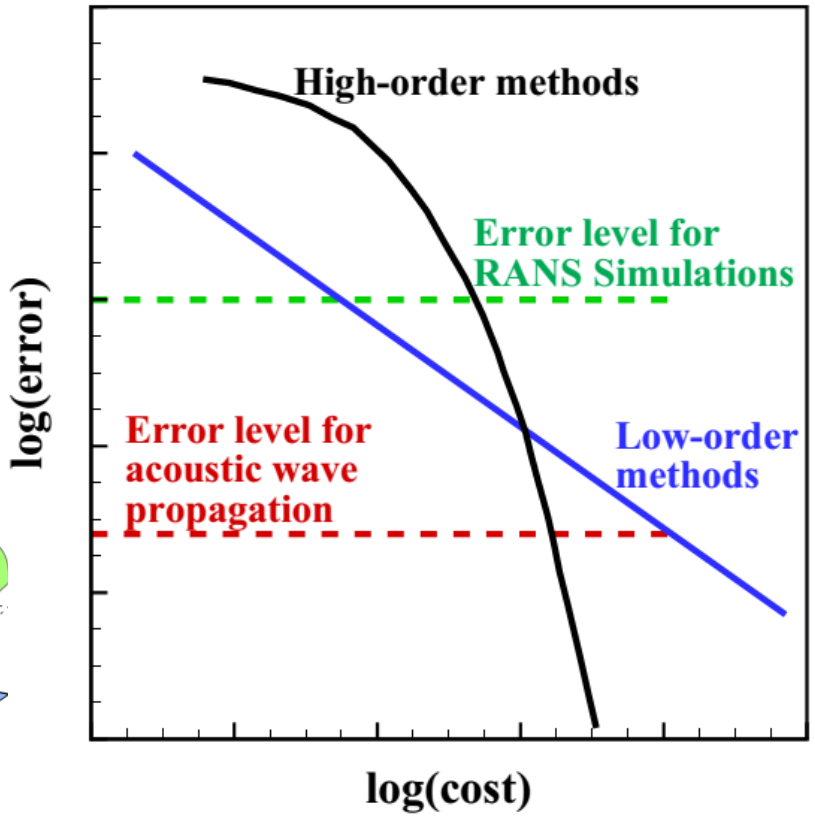
log-log axes!

Spatial discretisation

- High-order of accuracy obtained by performing an interpolation (reconstruction) using the cell averages of the neighbourhood of considered cell
- Legendre type of polynomials employed for this purpose

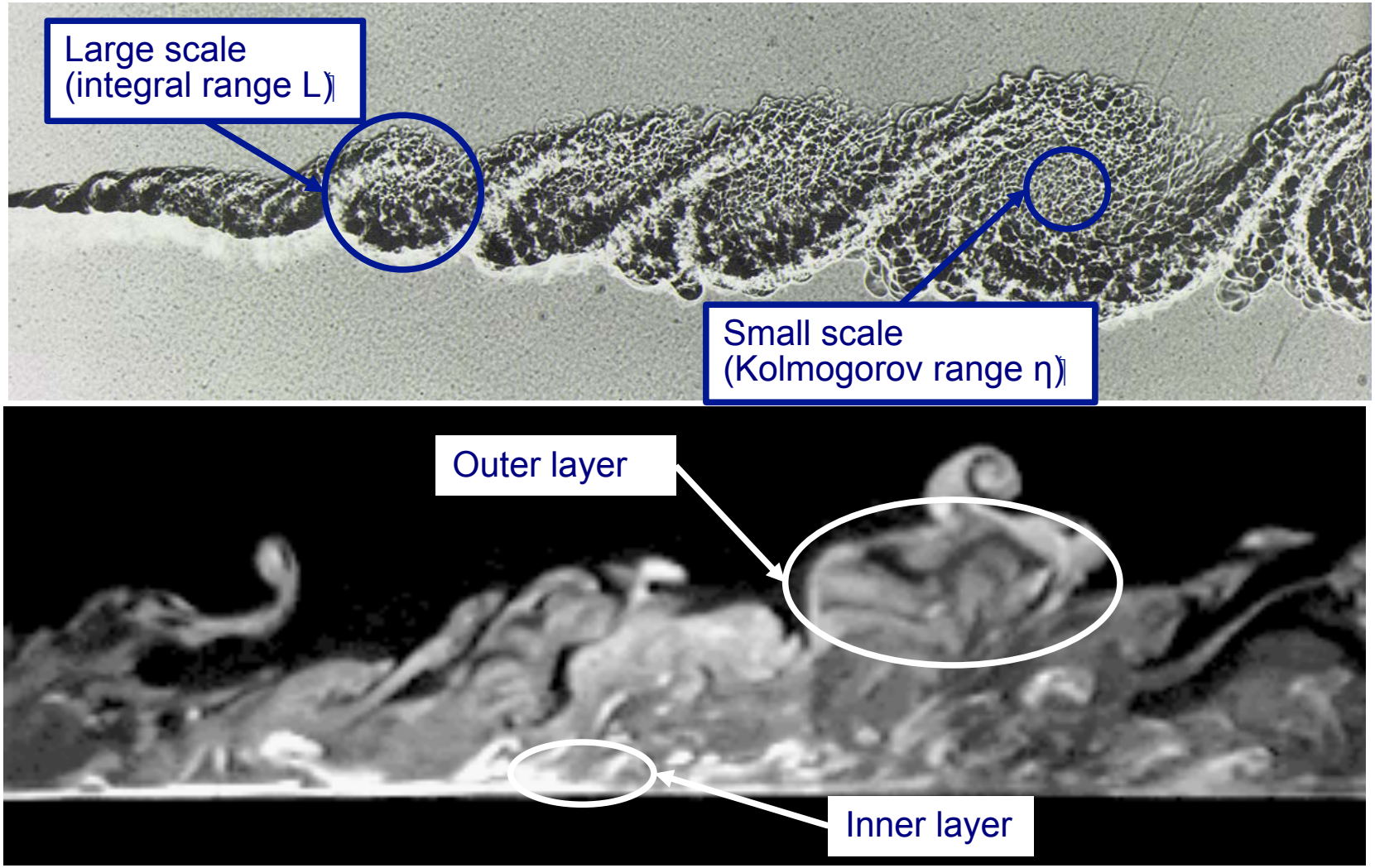


(a) Piecewise constant 1st-order (b) Piecewise linear 2nd-order (c) Piecewise non-linear higher-order



Error vs cost for high and low-order methods

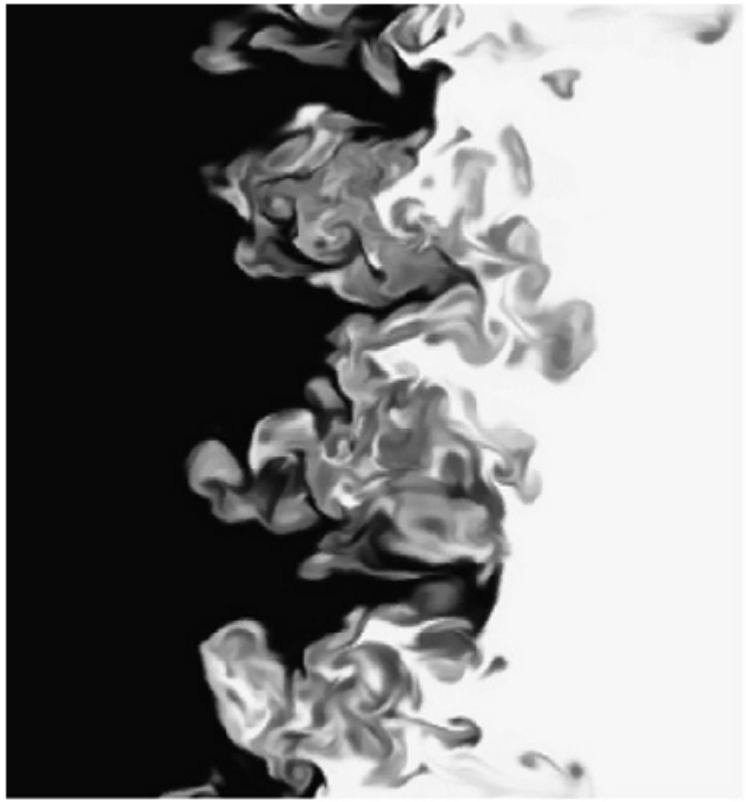
Rationale for different Turbulence Simulation Approaches



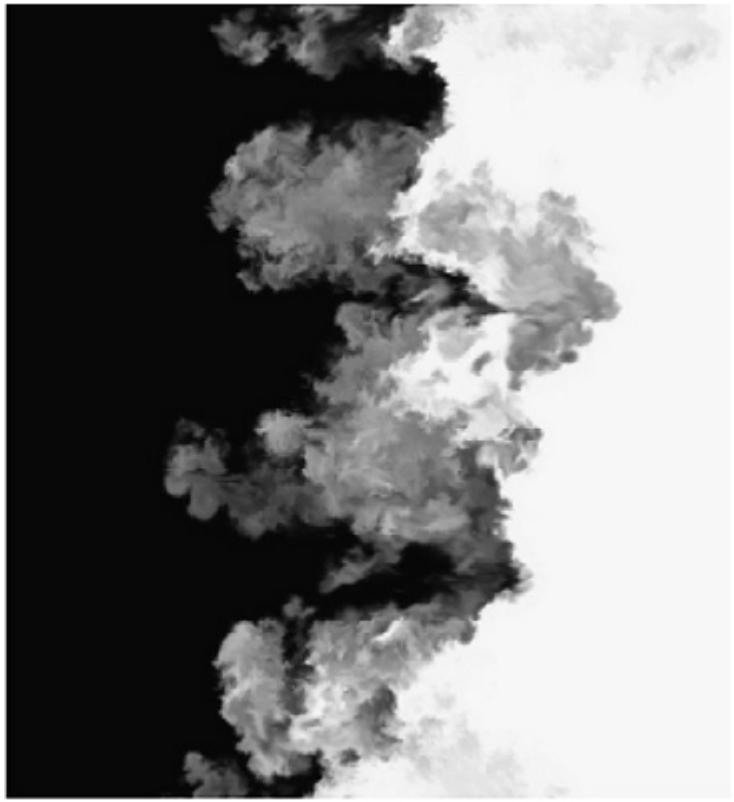
Low Mach Corrections

Example: Compressible Turbulent mixing, Richtmyer-Meshkov instability

5th-order method

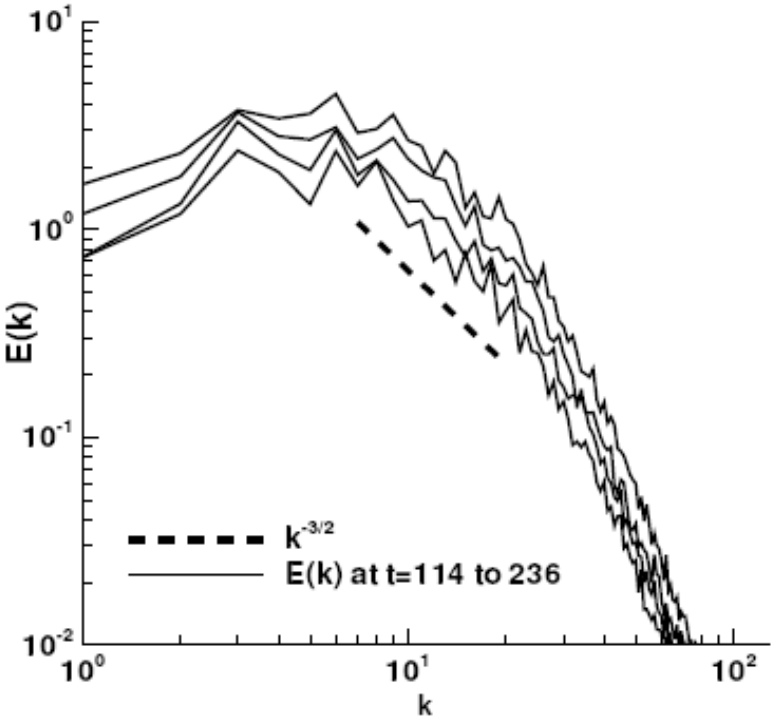


5th-order +
low Mach corrections

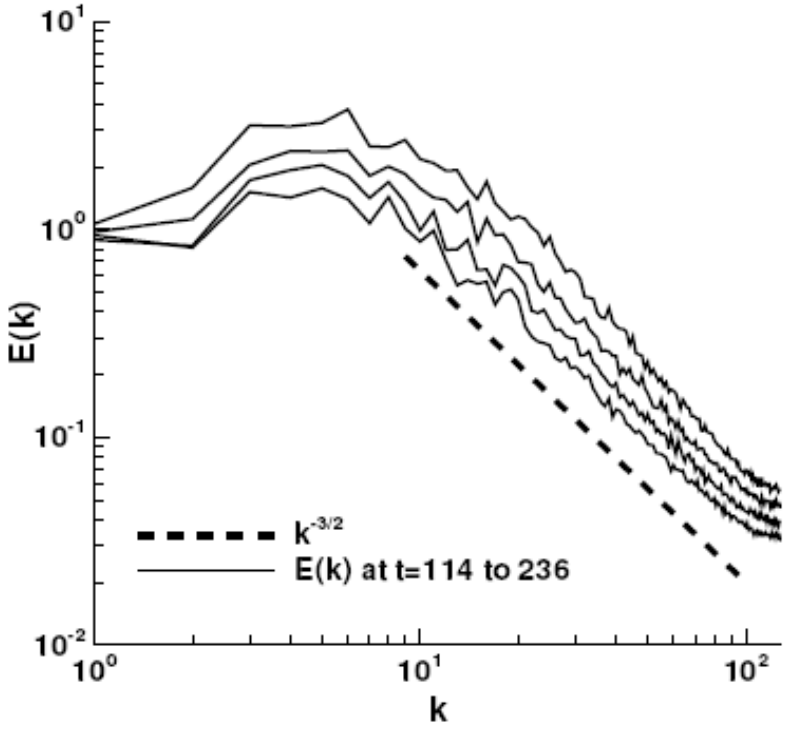


Effects on turbulence spectrum

5th-order method



5th-order +
low Mach corrections



Implicit & Classical Large Eddy Simulation (LES)

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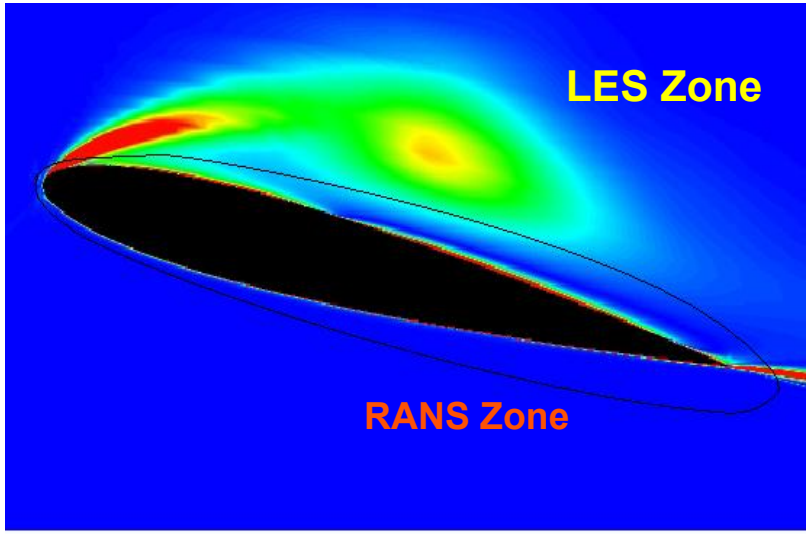
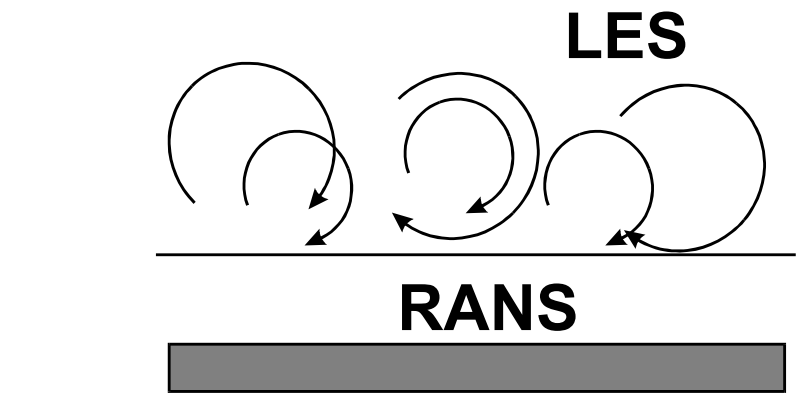
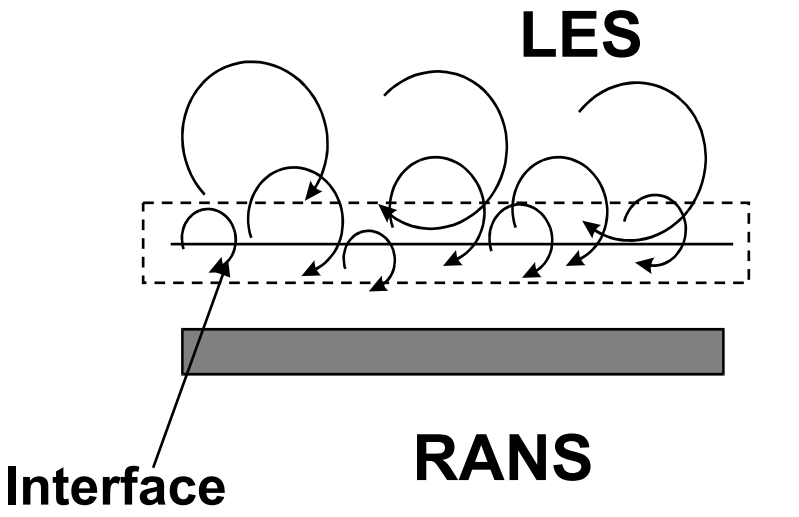
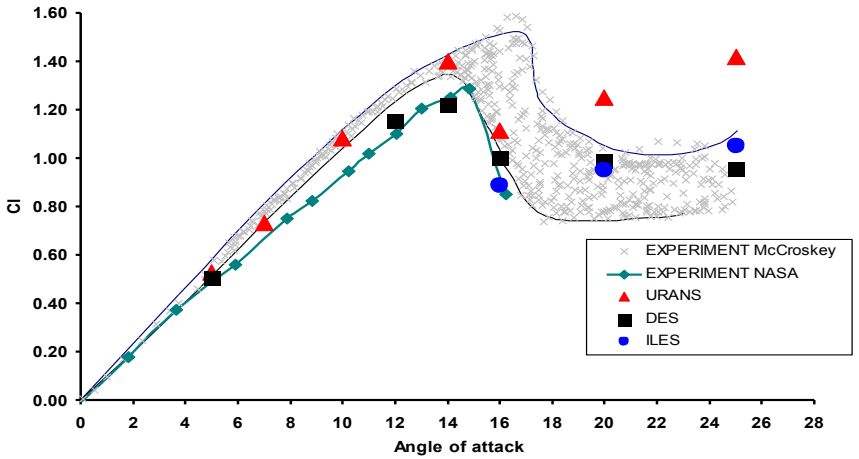
- Large Eddy Simulation
  - Implicit LES
  - Classical LES
- Detached Eddy Simulation

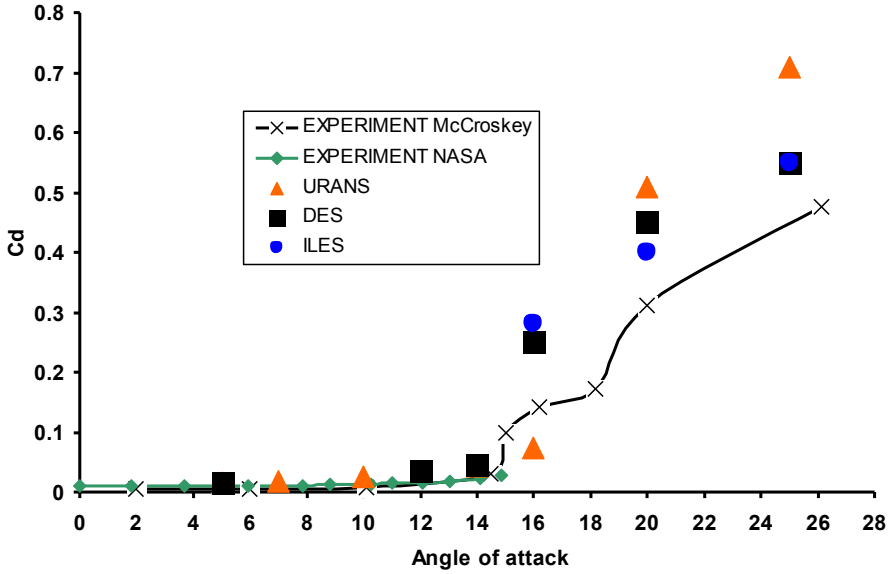




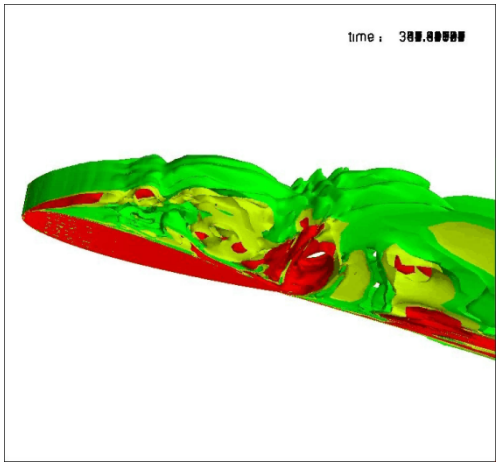


Comparison of RANS, DES & ILES

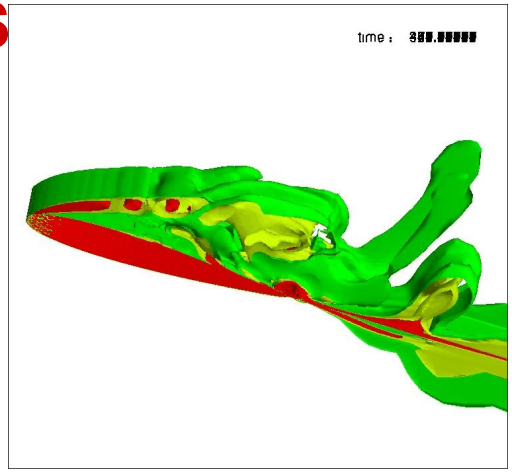




ILES

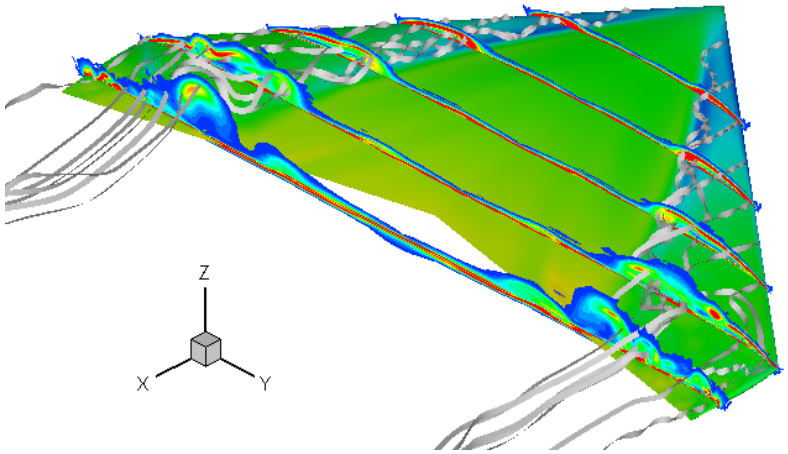


DES



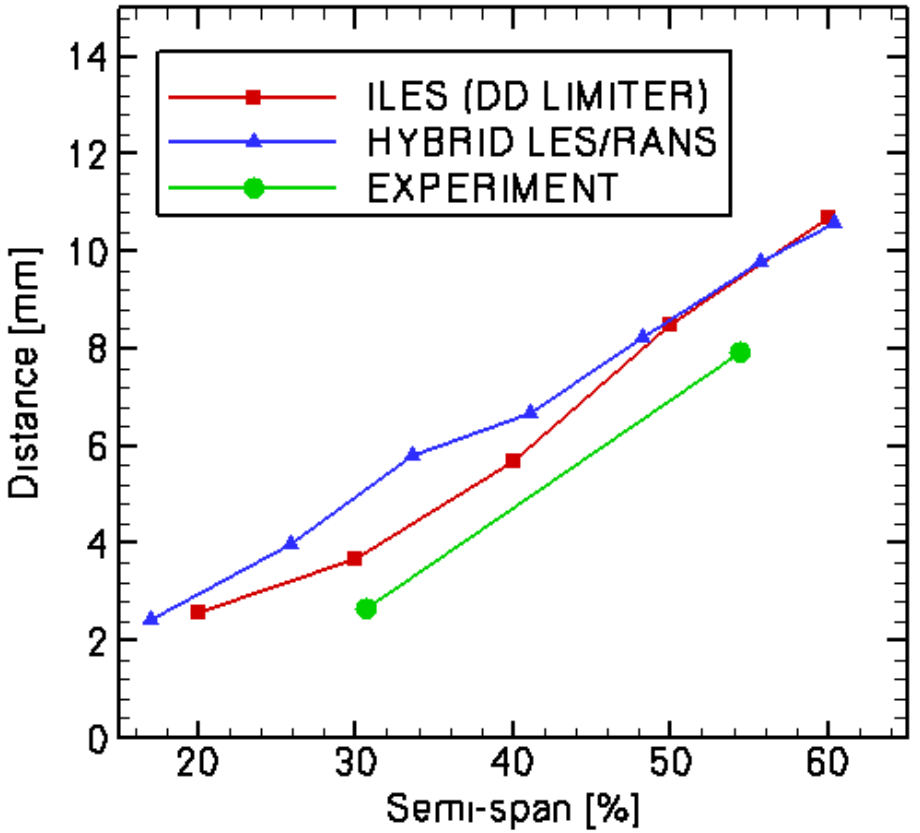
Separated flows – Swept wings

$Re=2x10^5, M=0.03$



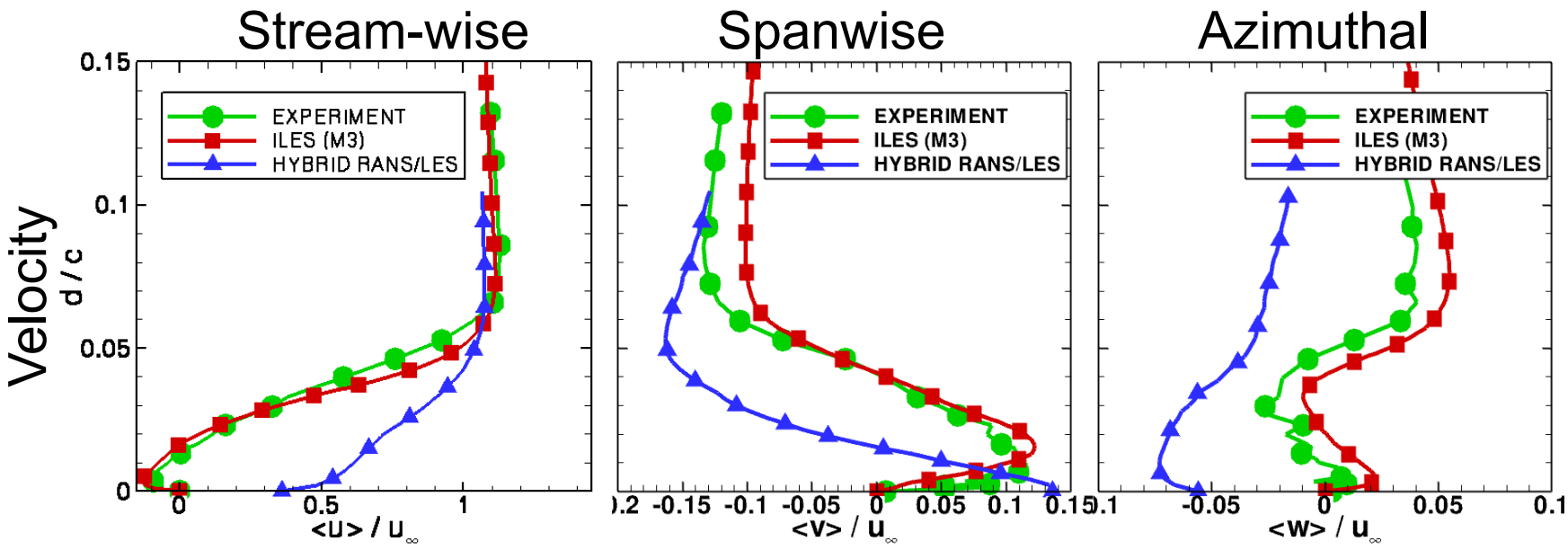
Instantaneous streamlines, vorticity and pressure

Clearance of the vortex core



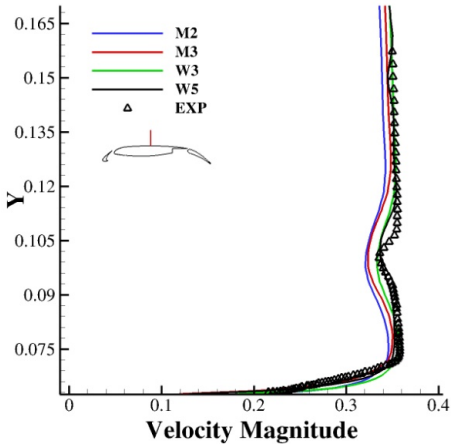
ILES vs hybrid RANS/LES

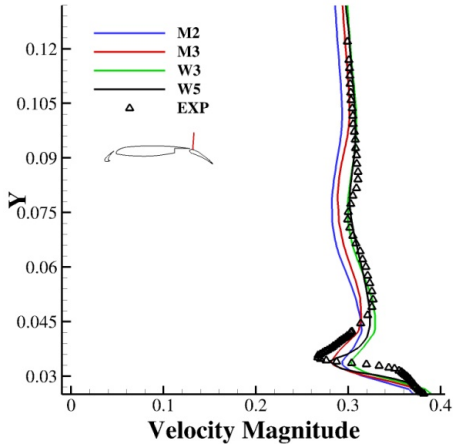
90% half-span, 50% local chord

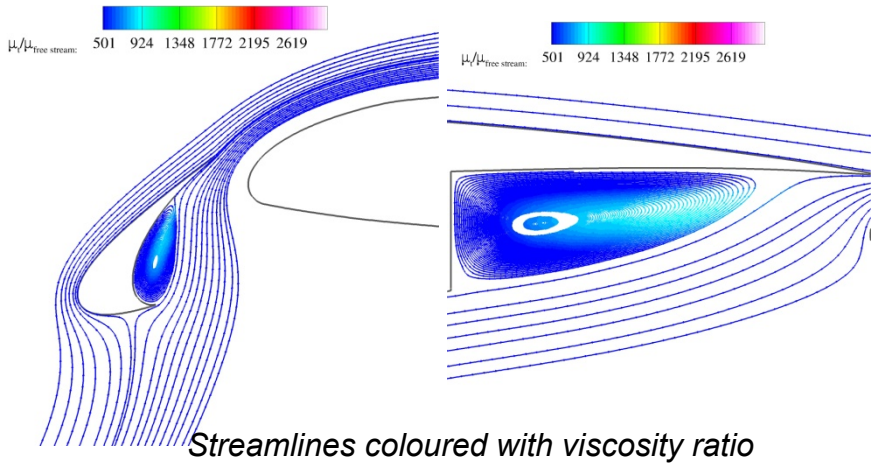


Subsonic Flows

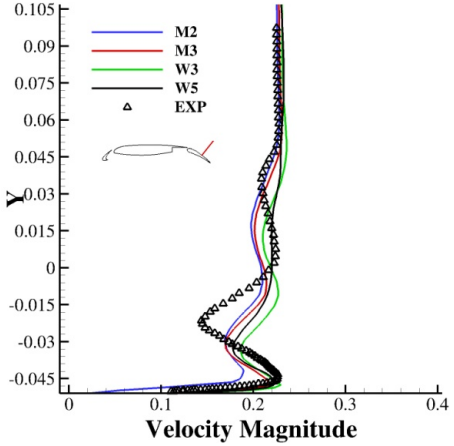
MDA 30P-30N

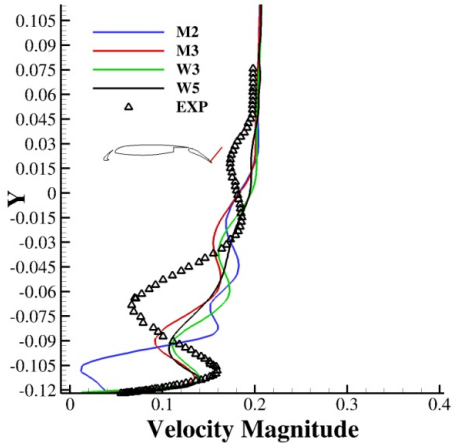


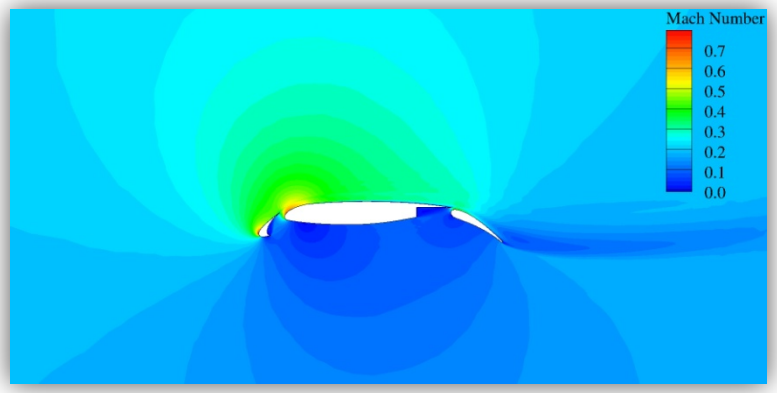




Streamlines coloured with viscosity ratio

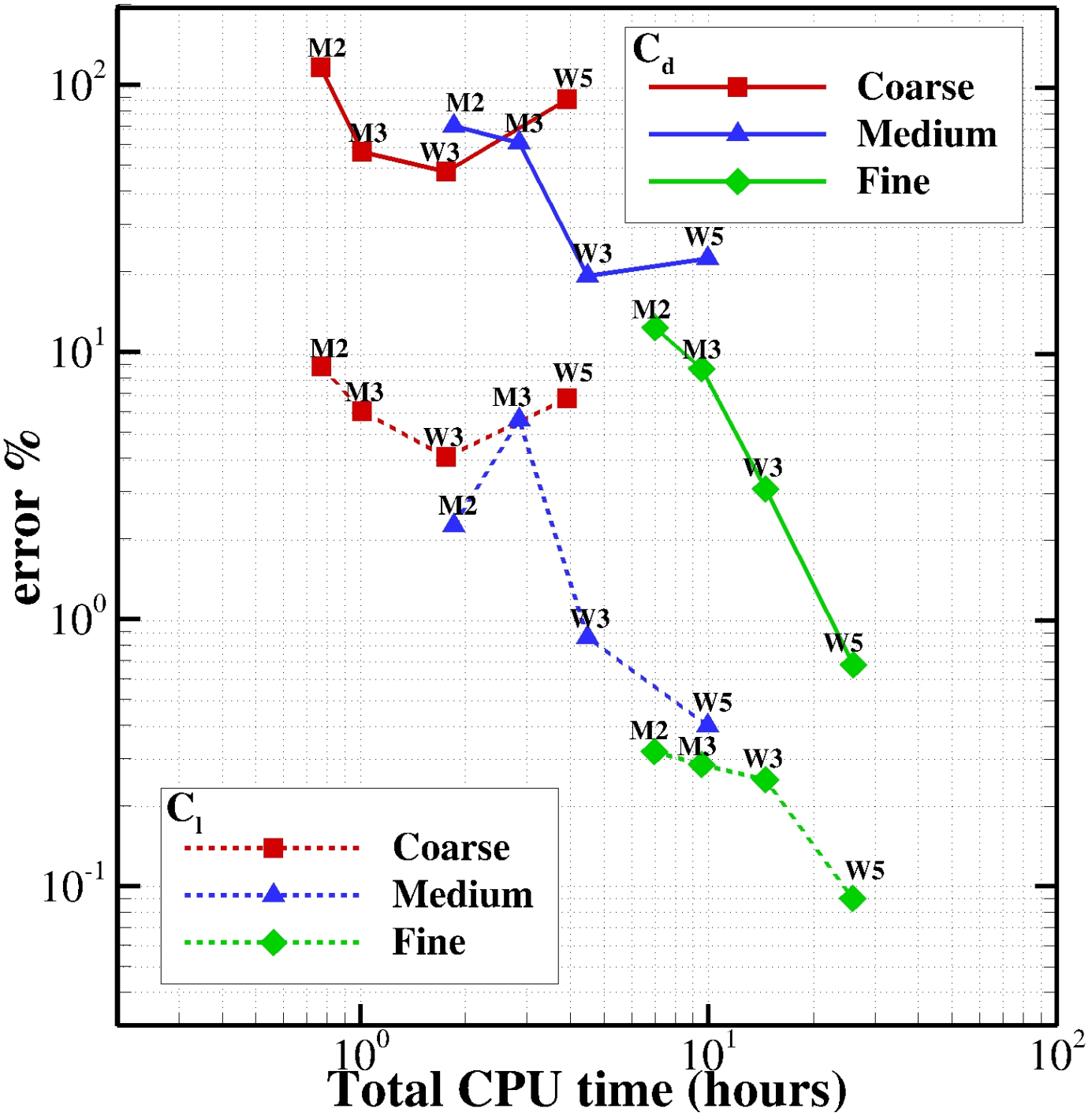






Mach number contours for the WENO 5th order

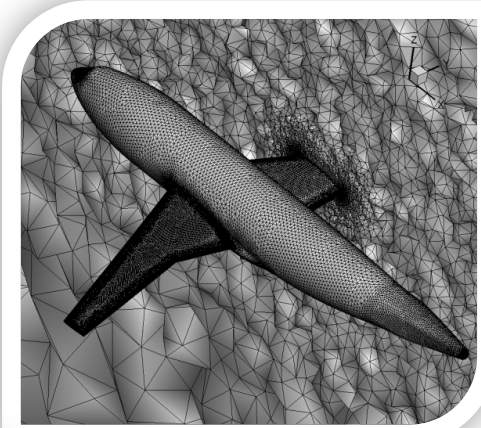
Computational efficiency vs error reduction

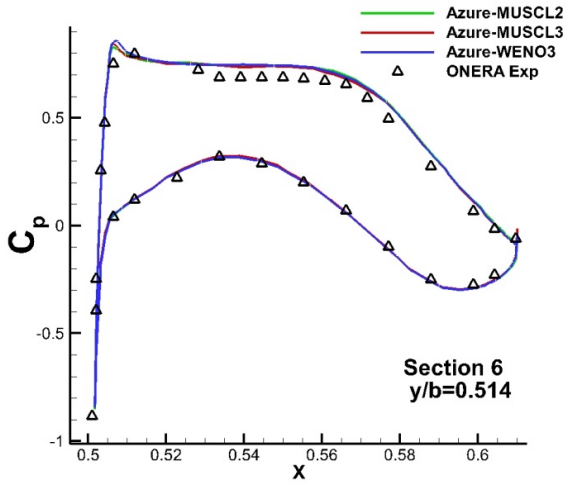


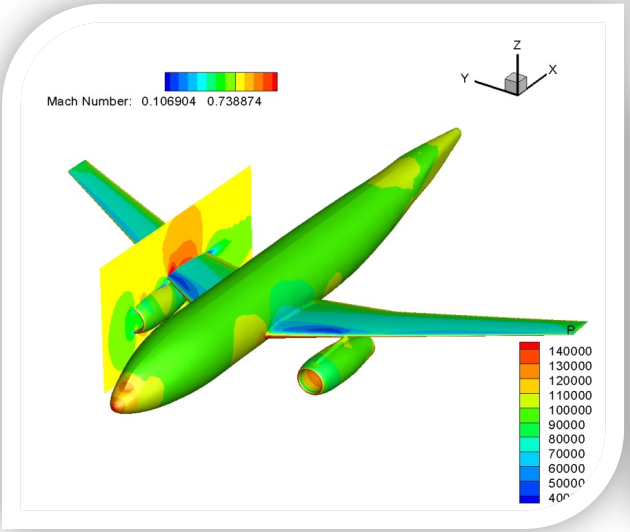
Transonic DLR F6 aircraft
Azure CFD code

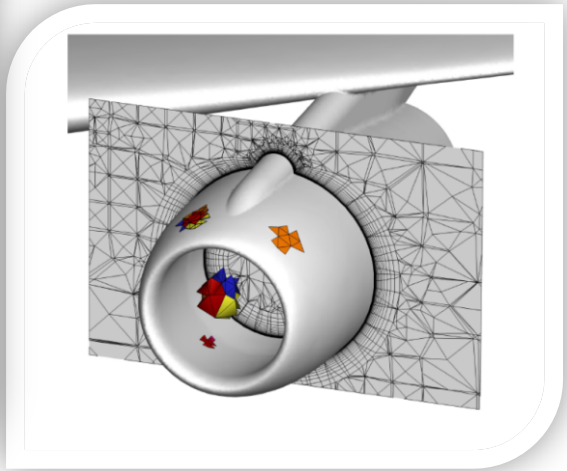
Cranfield UNIVERSITY

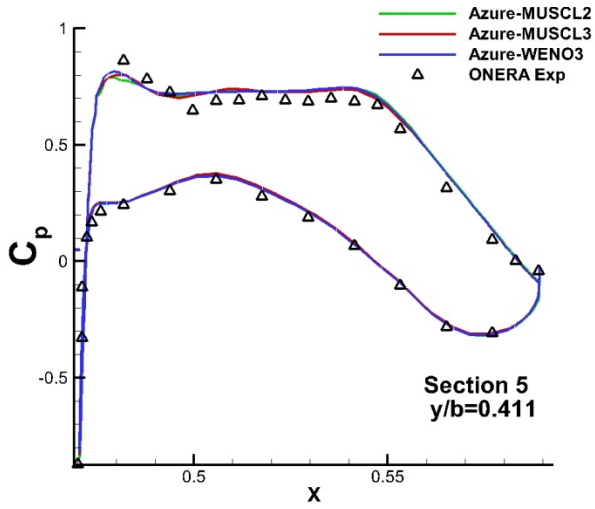
Convergence achieved in less than 17 hours for a WENO 3rd-order scheme, on one node of 16 CPUs, 5M grid points



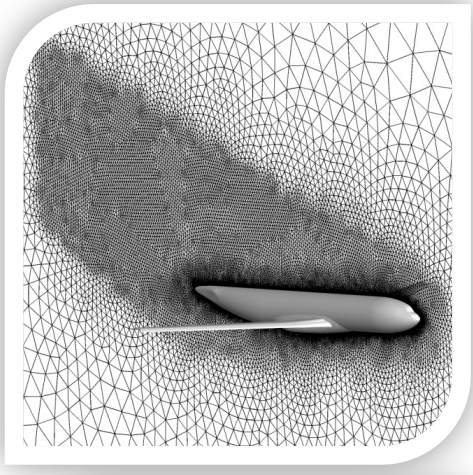


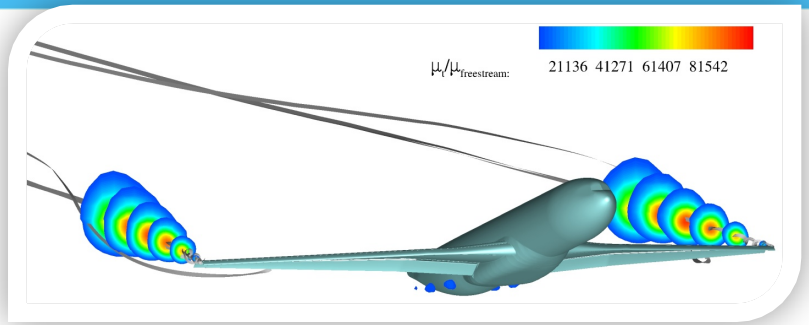


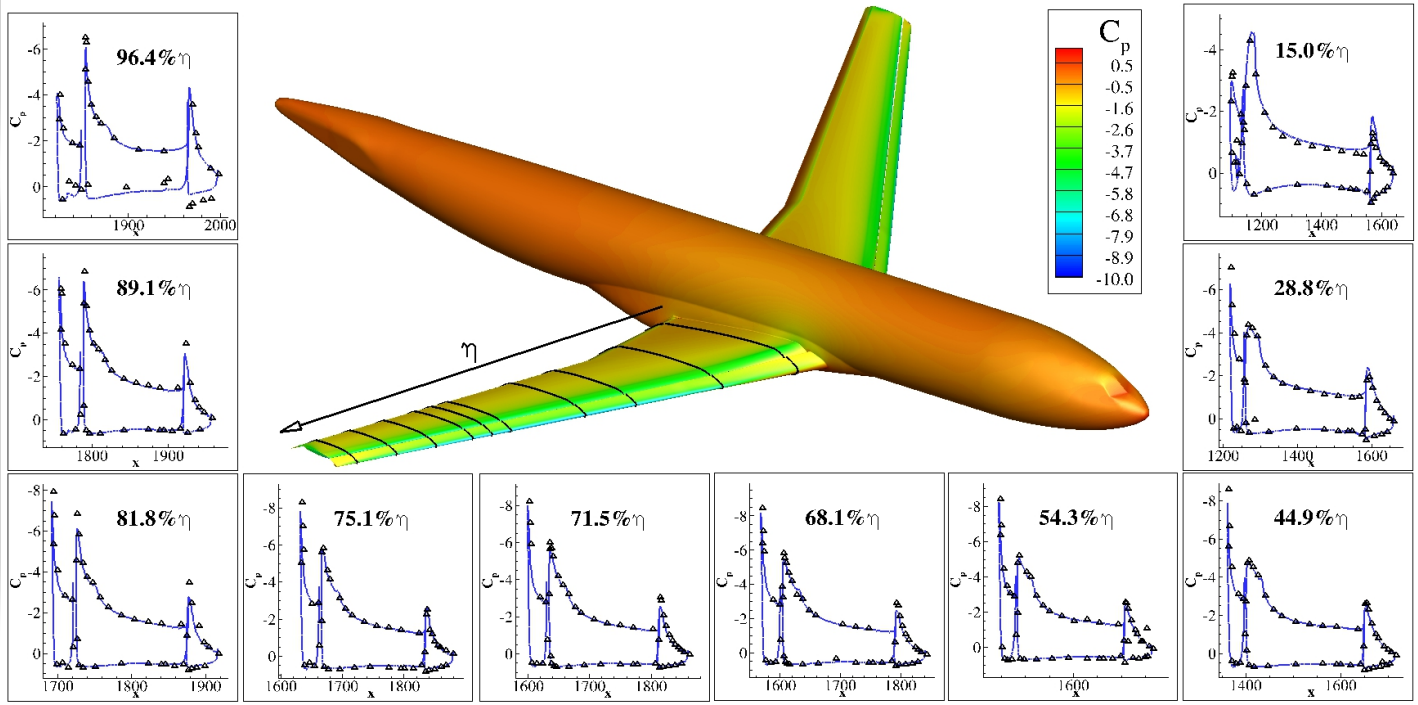




DLR F11 aircraft – *Azure* CFD code





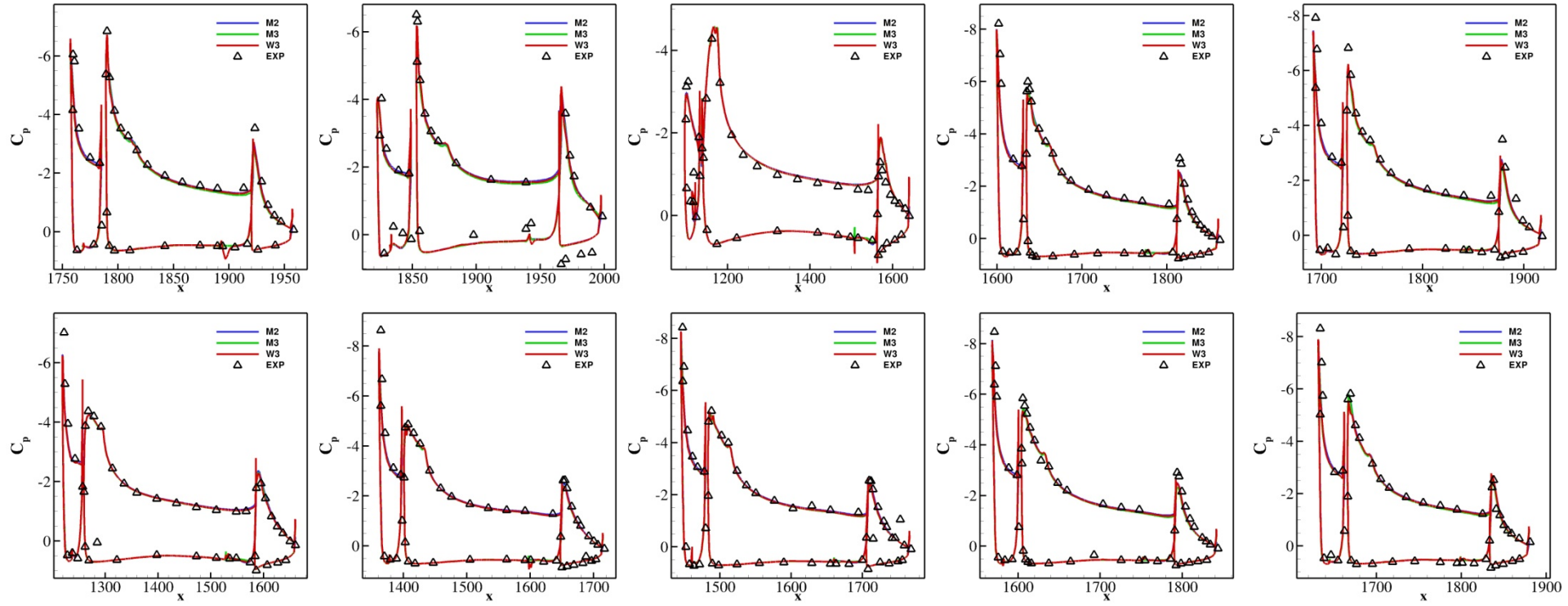


Pressure coefficient – comparison of methods

Cranfield UNIVERSITY

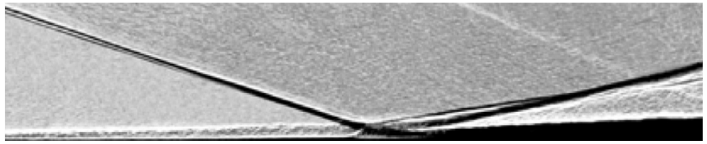
Full aircraft DLR-F11 high-lift configurations

with MUSCL 2nd, 3rd and WENO 3rd order schemes

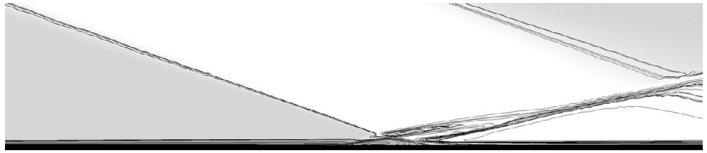


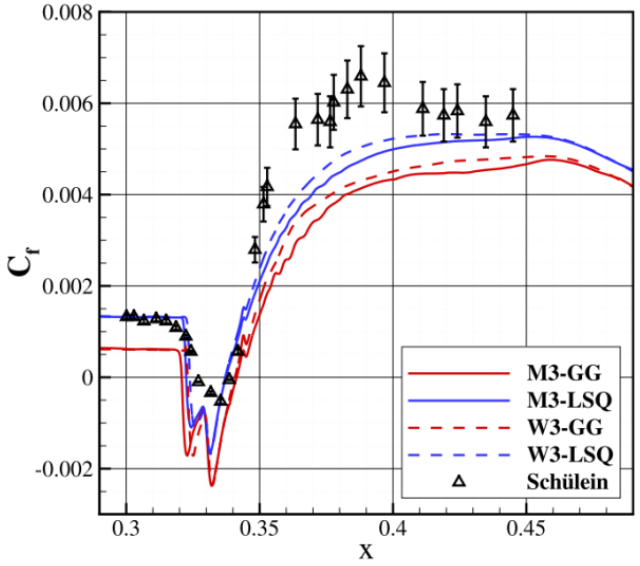
Shock wave/boundary layer interaction

- **Qualitative results showing the computed density for the WENO 3rd order scheme illustrating the shock structure compared with the shadowgraph from the experiment.**
- **Comparison of gradient reconstruction Green Gauss (GG) and least-square (LSQ) with the experimental data**

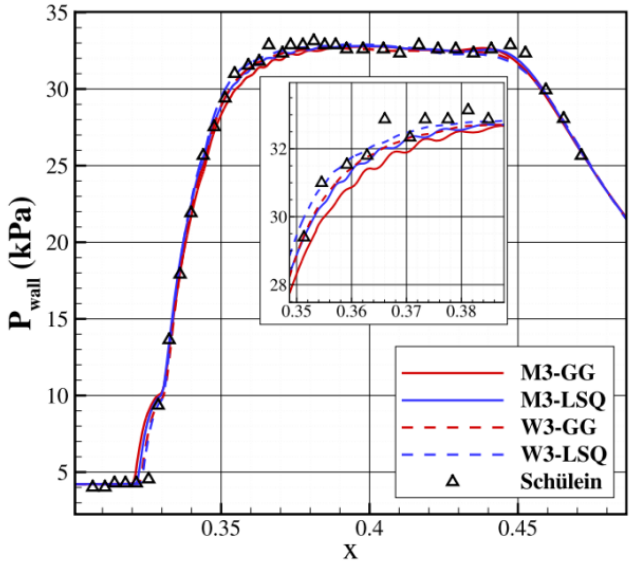


(a) Experimental shadowgraph





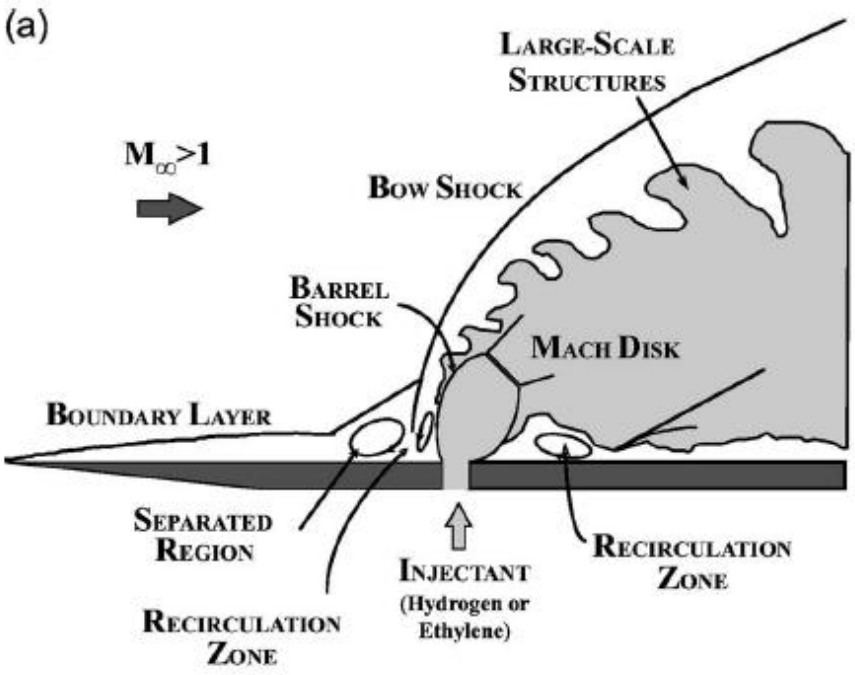
Skin friction coefficient (C_f)

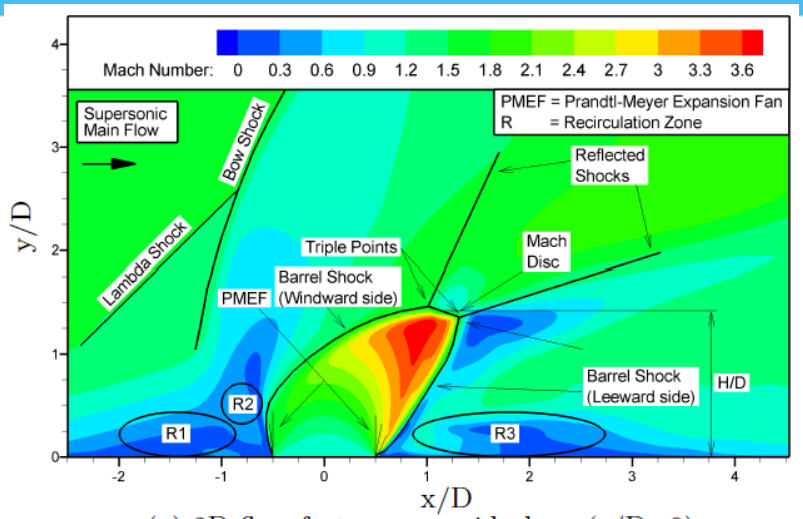


Wall pressure (P_{wall})

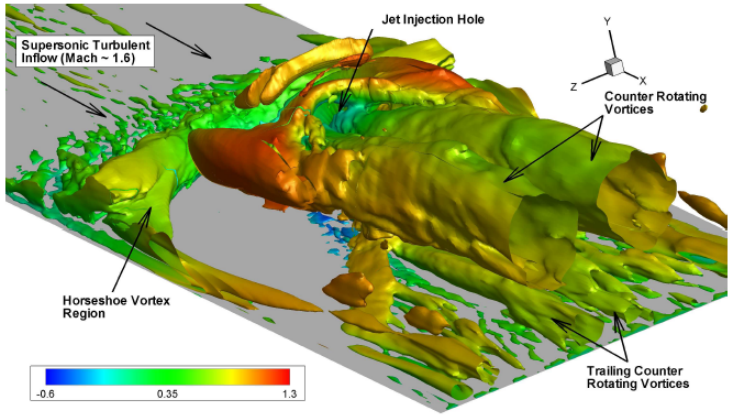
Sonic Transverse Jet in a Supersonic Cross-flow (JISC)

JISC was studied experimentally to understand the effects of the injection of a sonic circular jet on a supersonic cross-flow transversely.





(a) 2D flow features on mid plane (z/D=0)



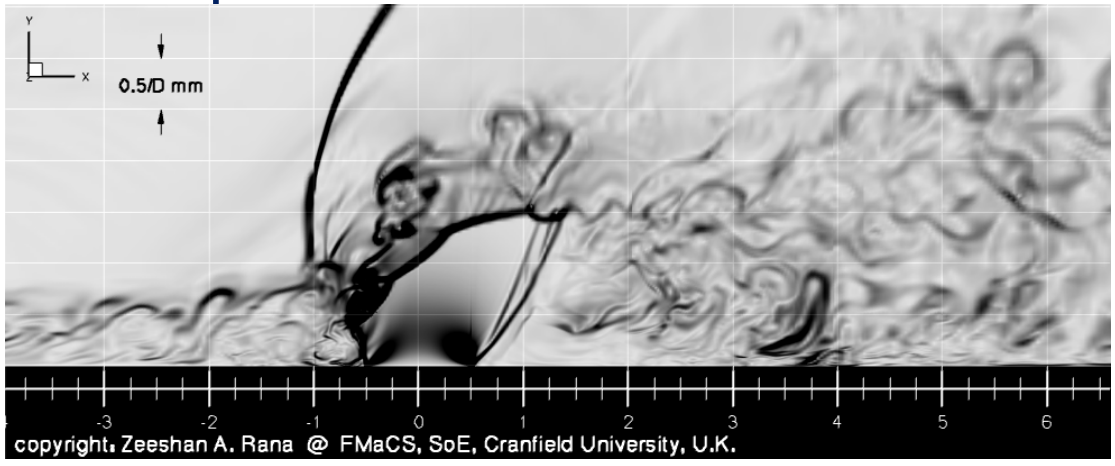
(b) 3D flow features; Q criterion Iso-Surfaces

JISC

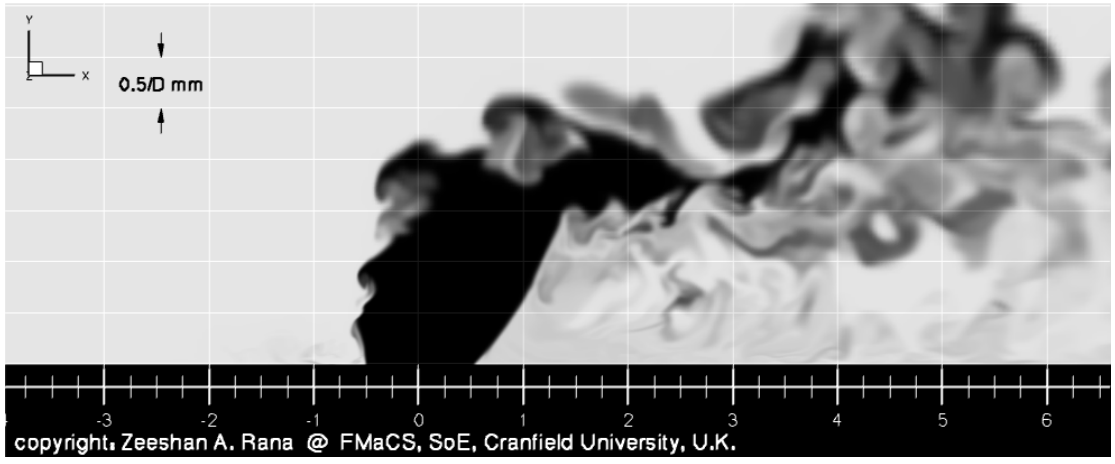
Results – Mach 1.6 JISC Experiment:

- Flow animations:

(a) Density Gradient,



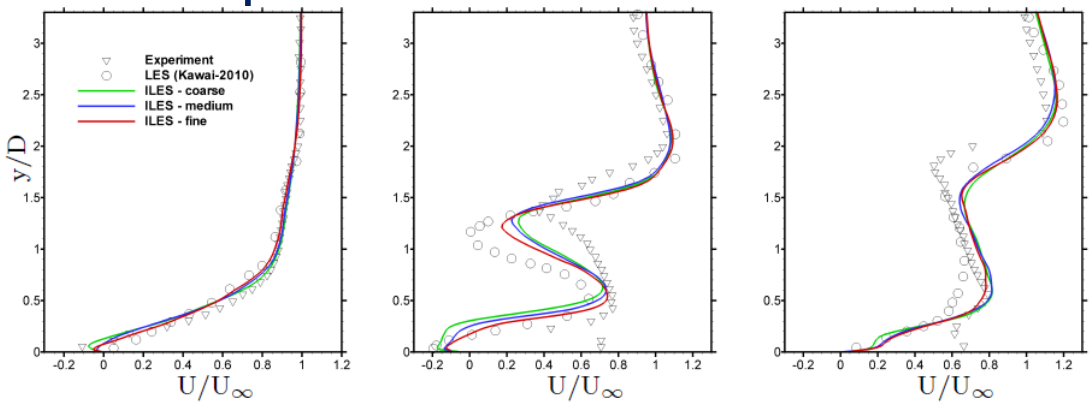
(b) Passive Scalar



JISC

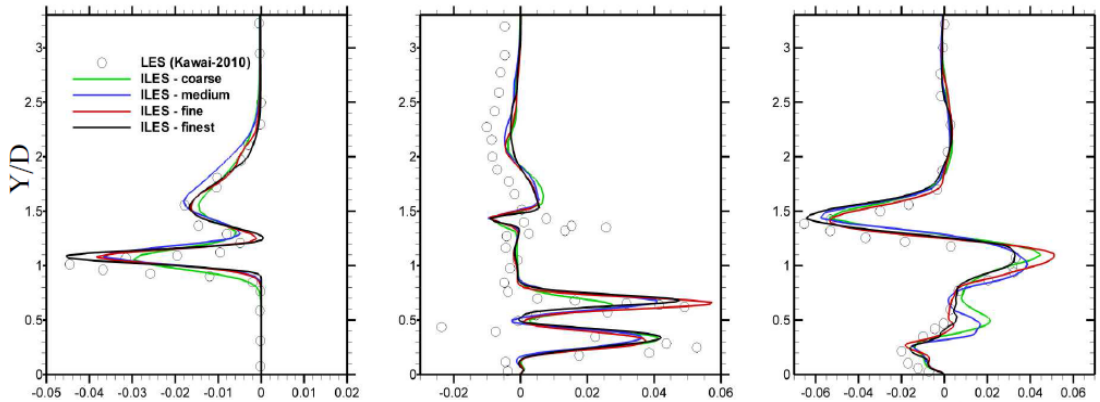
Results – Mach 1.6 JISC Experiment:

Streamwise Velocity Profile Comparison at mid-plane (z=0)



(a) x/D = -1.5 (b) x/D = 2 (c) x/D = 3

Turbulent Kinetic Energy Profile Comparison at mid-plane (z=0)

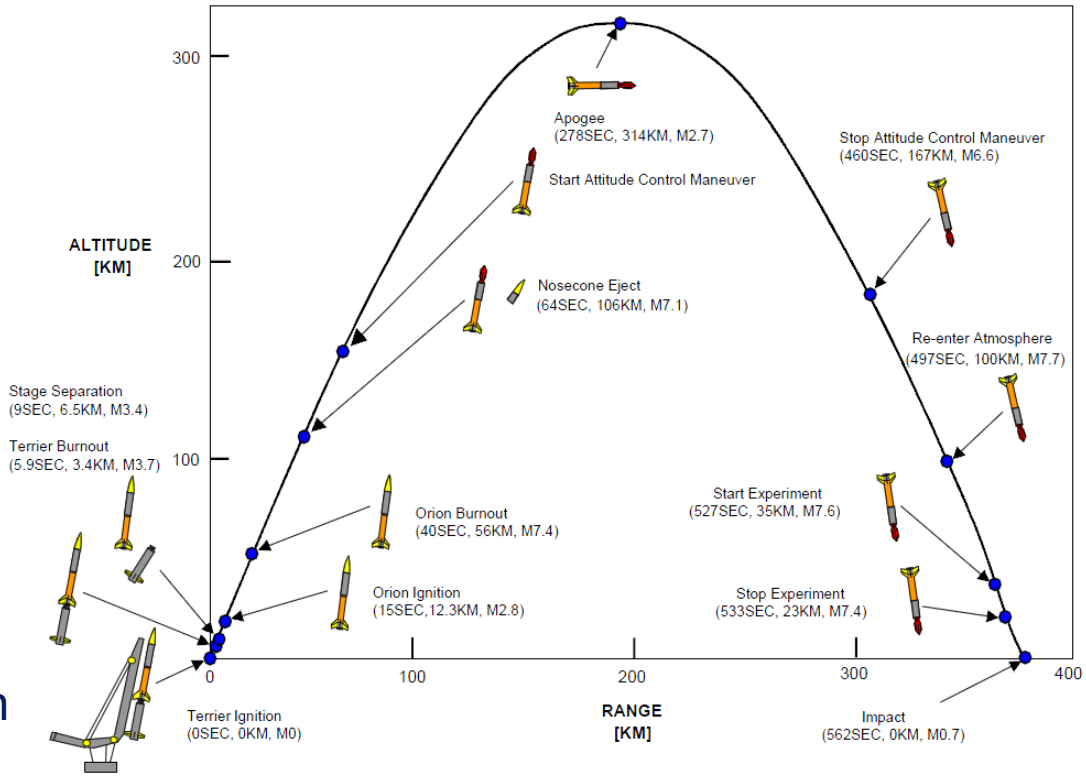


(a) *X/D = 0* (b) *X/D = 1* (c) *X/D = 2*

HyShot-II

HyShot-II Scramjet:

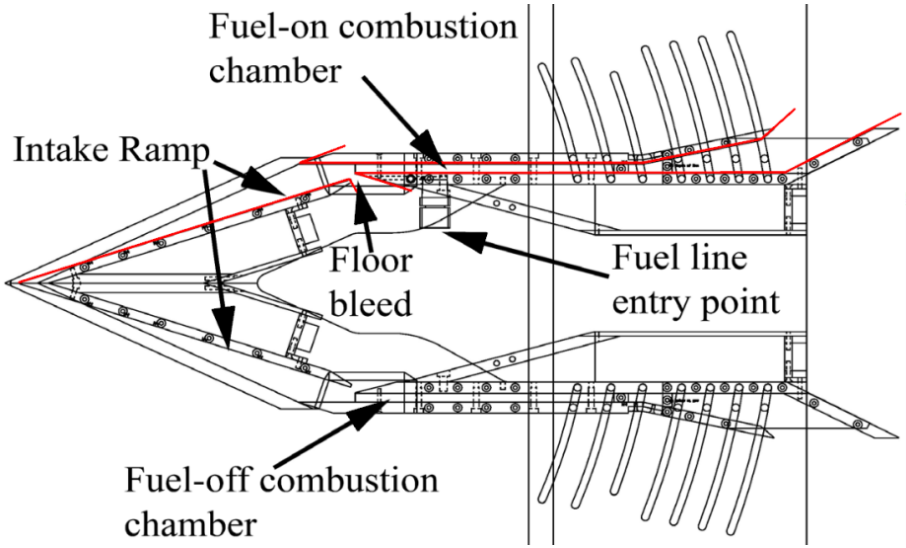
- Successful test flight – 30th July 2002
- Achieved Supersonic Combustion (SC) at Mach 7.6 at altitude of between 35 km and 23 km.
- Fuel - Gaseous Hydrogen
- Highly parabolic trajectory (near Vertical decent) to obtain correlations over a range of ambient pressures.

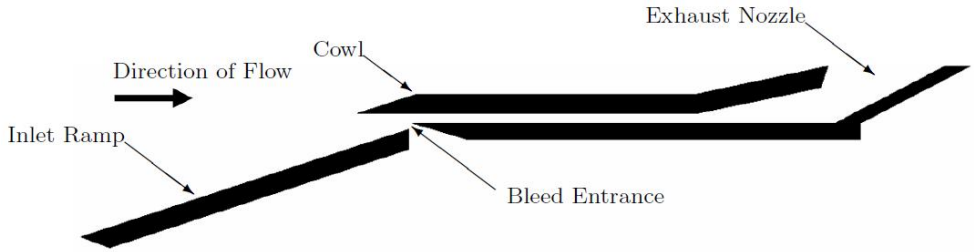


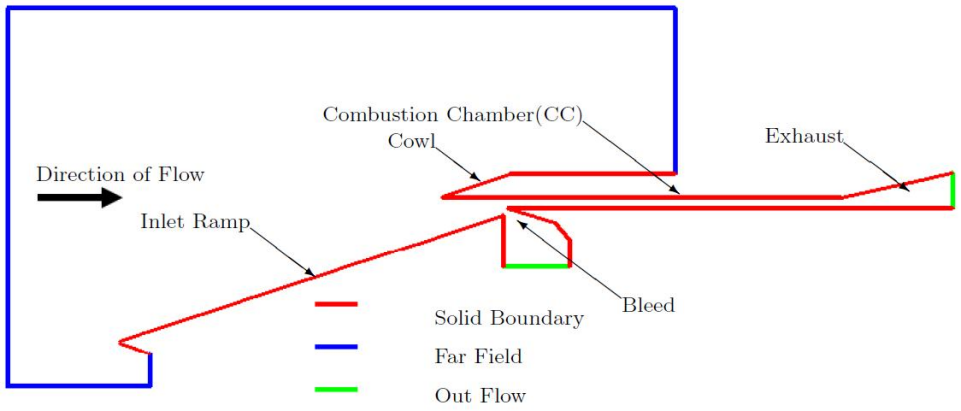
HyShot-II

Results – Analysis of the HyShot-II Scramjet:

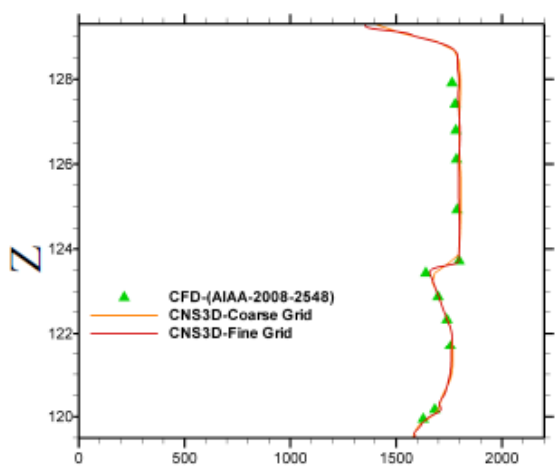
- Pressure measurements - the primary means for obtaining the correlation
- Combustion and non-combustion investigations on the geometry are carried out at DLR, Germany using HEG and CFD.

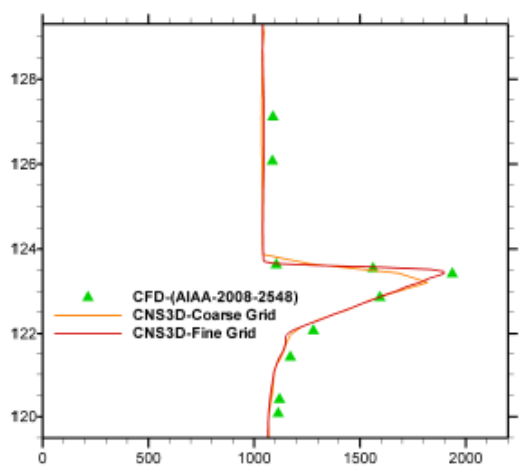


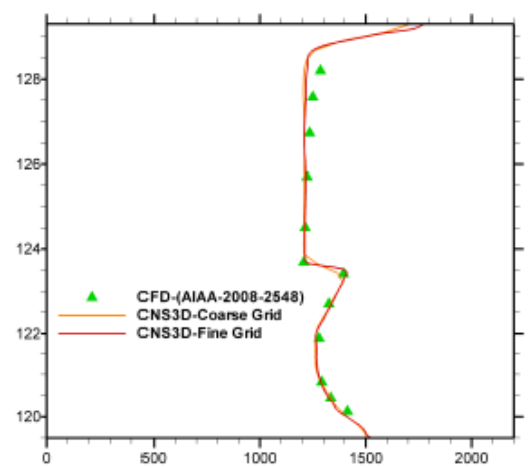


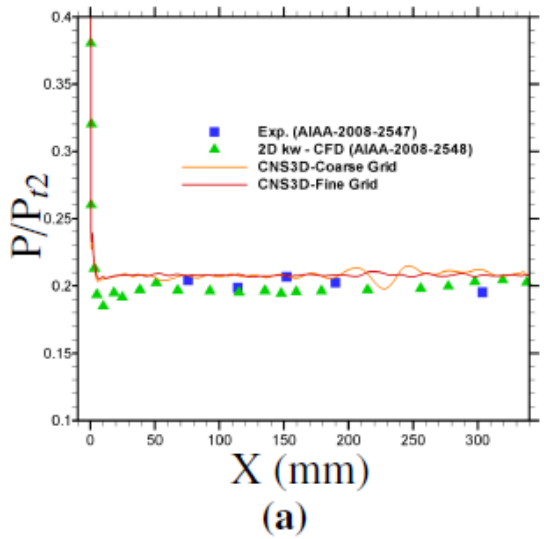


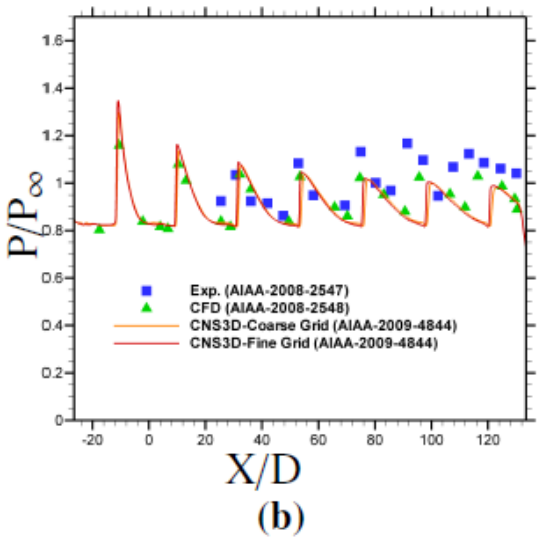
HyShot-II

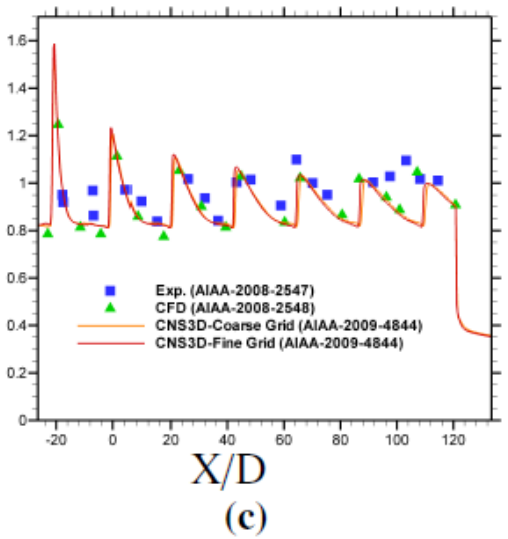

Z
CFD-(AIAA-2008-2548)
CNS3D-Coarse Grid
CNS3D-Fine Grid
Velocity (m/s)
(a)


CFD-(AIAA-2008-2548)
CNS3D-Coarse Grid
CNS3D-Fine Grid
Temperature (K)
(b)


CFD-(AIAA-2008-2548)
CNS3D-Coarse Grid
CNS3D-Fine Grid
Pressure (hPa)
(c)

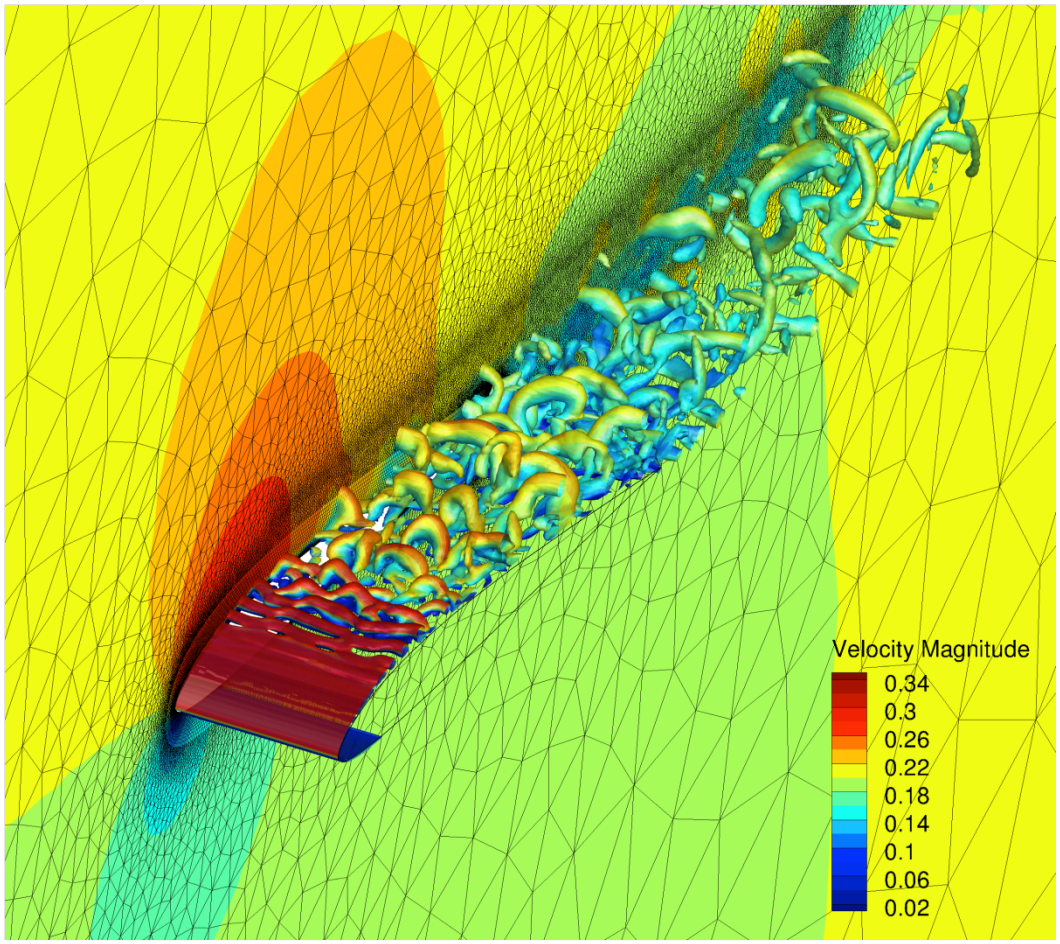

P/Pt2
Exp. (AIAA-2008-2547)
2D kw - CFD (AIAA-2008-2548)
CNS3D-Coarse Grid
CNS3D-Fine Grid
X (mm)
(a)


P/P∞
Exp. (AIAA-2008-2547)
CFD (AIAA-2008-2548)
CNS3D-Coarse Grid (AIAA-2009-4844)
CNS3D-Fine Grid (AIAA-2009-4844)
X/D
(b)


Exp. (AIAA-2008-2547)
CFD (AIAA-2008-2548)
CNS3D-Coarse Grid (AIAA-2009-4844)
CNS3D-Fine Grid (AIAA-2009-4844)
X/D
(c)

ILES – SD7003 wing

- ILES on hybrid unstructured mesh of 3 million cells
- Reynolds 60,000 (transitional regime)
- 8 degrees AoI, Mach number 0.2
- WENO 5th order FV formulation
- 4th order accurate linear scheme for viscous terms
- 750 million degrees of freedom per conserved variable
- 3rd order Runge-Kutta TVD scheme for time advancement
- 96% parallel efficiency at 19,200 Processors (195 cells per Processor) of ARCHER CRAY XC30
- 11 million iterations required for obtaining sufficient turbulent statistics



Concluding remarks

- High-resolution and High-order CFD methods encompass significant potential in addressing design challenges
- They also provide a promising approach for applying Implicit Large Eddy Simulations in complex geometries.
- Implementation and use of a range of methods within Azure CFD enables Quantification/Reduction of Uncertainty Aerospace Applications

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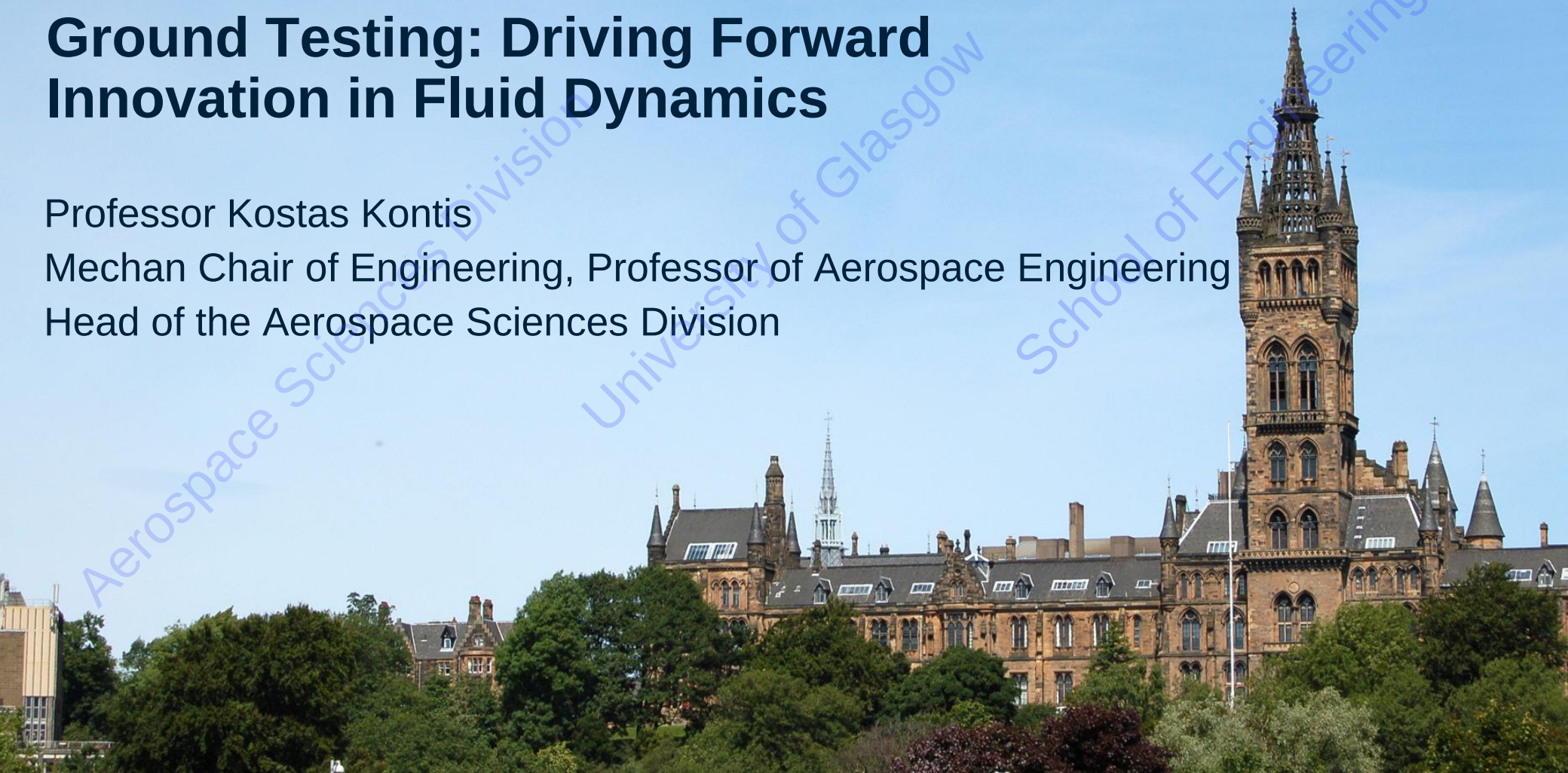
Ground Testing: Driving Forward Innovation in Fluid Dynamics

Professor Kostas Kontis
Mechan Chair of Engineering, Professor of Aerospace Engineering
Head of the Aerospace Sciences Division

Aerospace Sciences Division
University of Glasgow
School of Engineering



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Engineering at the University of Glasgow

- The University of Glasgow appointed the first Professor of Engineering in the U.K. in 1840.
- Followed in 1880 by the John Elder Chair of Naval Architecture – ship building being a major industry in Glasgow
- Percy Pilcher – first manned flight in the U.K. 1895
- Faculty of Engineering Founded in 1923

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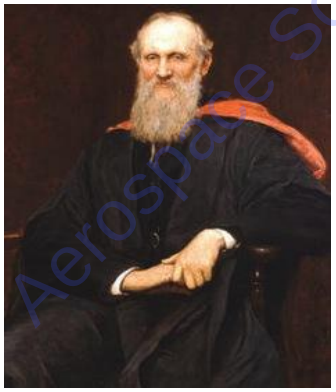
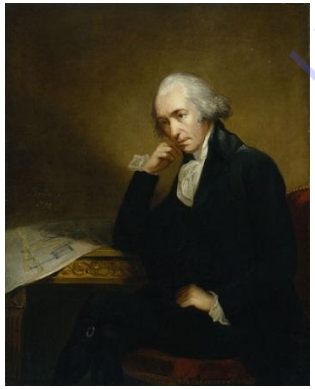
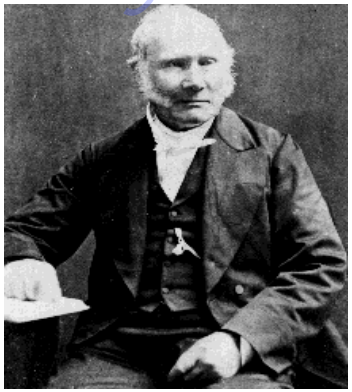


William Thomson
(Lord Kelvin)



James Watt
Engineer

William Rankine
Thermodynamicist



Rev Robert Stirling

John Logie Baird
Television

Mission:

To gain full benefit from the University's diverse research capability and to become internationally recognised as a centre of excellence in aerospace research, and innovation.

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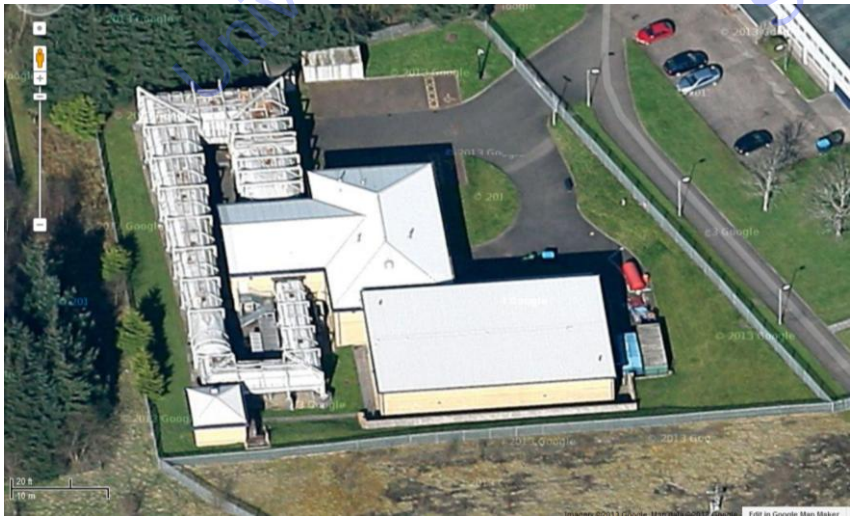

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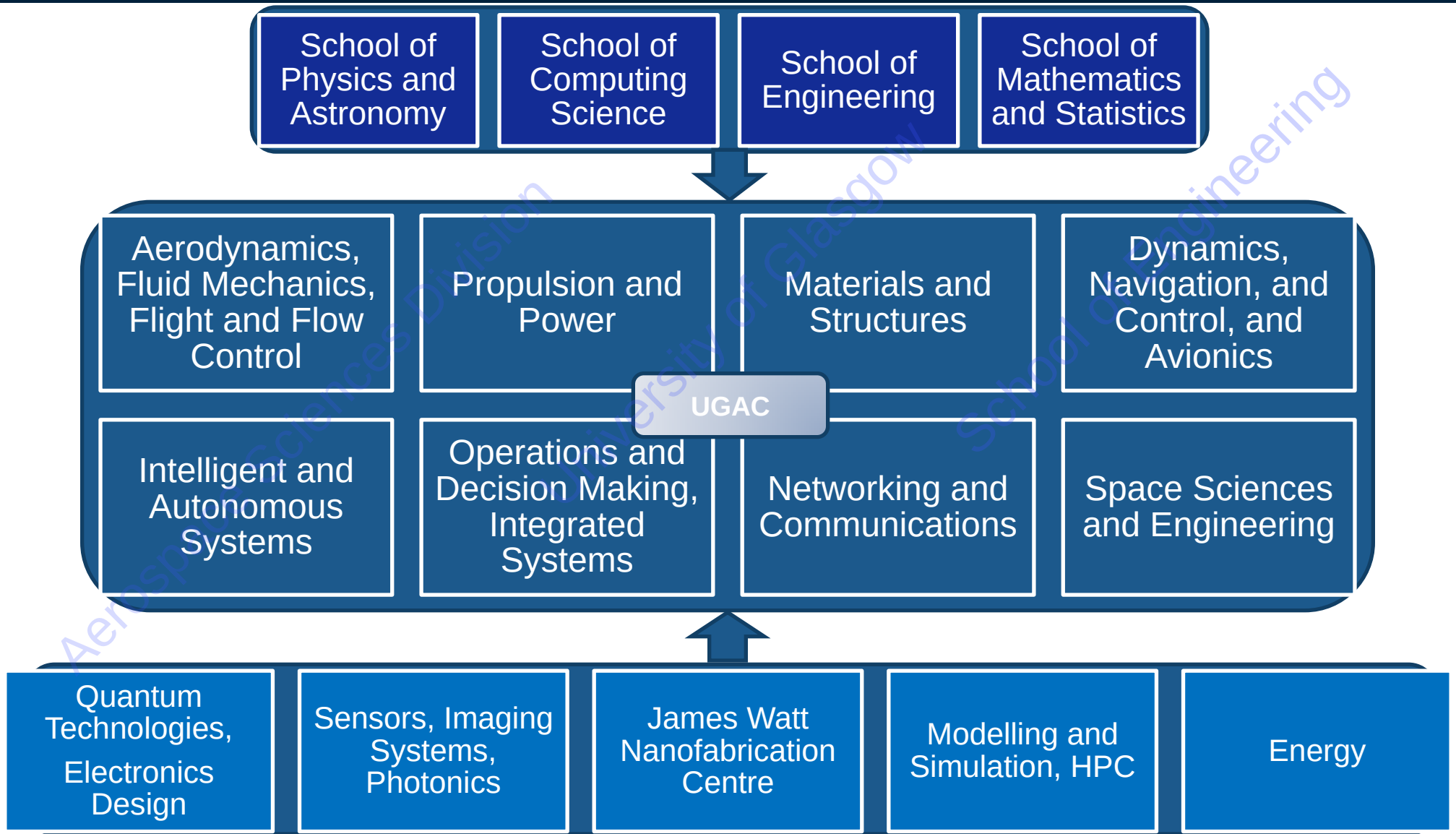
University of Glasgow Aerospace Centre - UGAC



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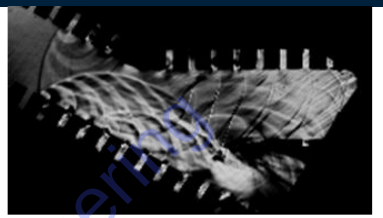
Collaborations

- **Present And Past Sponsors:**

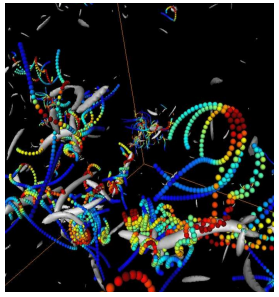
  USAF, US-NAVY, Royal Academy of Engineering, BAe Systems, Airbus, Rolls-Royce, EPSRC, DSTL/MOD, ESA/ESTEC, UK-Space Agency, Royal Society, Nuffield Foundation, MHI, IHI, EU, DIUS, ETW, FGE, SELEX, DOWTY, SMEs…

- **International collaborations:**

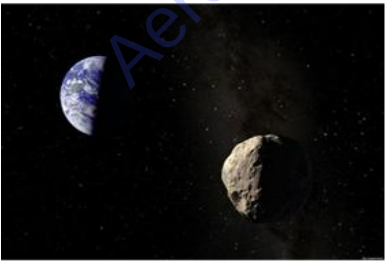
  NATO/RTA AVT, Aoyama-Gakuin University, Tohoku University, Univ. of Tokyo, IISc-Bangalore-India, Nagoya University, NASA-Langley, U. Texas at Arlington, ADD, DSTO-Australia, JAXA, BUAA, NUAA, CARDC, AVIC, Tsinghua University, DLR, KTH, Rutgers University, University of Florida…



Shock propagation over grooves

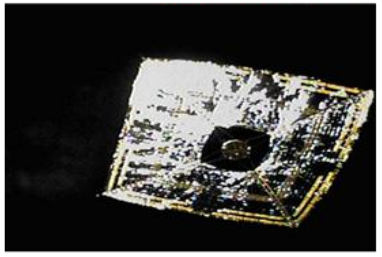


Risk



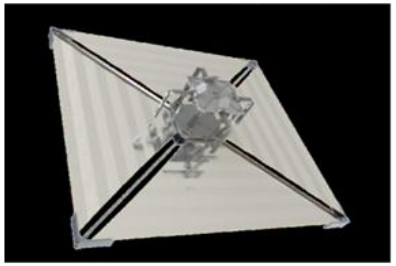
Laser asteroid deflection

Mission Analysis



Solar sailing and orbital analysis

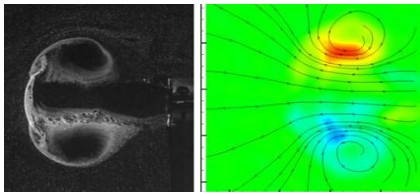
Technology



Antennae for space applications

Exploring and Understanding

Ultrasonic rock drilling & polishing



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The Need for Innovation: University of Glasgow Aerospace Centre

1. **Perform Fundamental Research:**
   Discover new technologies for future vehicle generations

2. **Demonstrate Technology:**
   Understand technologies and their product applications

3. **Validate Integrated Technologies:**
   Secure a 'Step Change' in product innovation

R&T

4. **Implement and Deploy**

5. **Exploitation**
   Provide a bridge between the pure academic research and industry
   Develop new technology that can diffuse out into the supply chain

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Research Areas

- Unsteady fluid dynamics
- Helicopter aerodynamics
- Computational Fluid Dynamics
- Wind turbine aerodynamics
- Active Flow/Load Control
- Bio-inspired flows
- Supersonic/Hypersonic flow
- Flow Diagnostics
- Fluid-structure interaction
- Aero-acoustics and Noise control
- Gust alleviation
- Multi-phase flows and heat-transfer

- Mathematical Modelling & Simulation
- Autonomous Systems
- Space Systems Engineering
- Rotorcraft Flight Dynamics
- Interdisciplinary shock wave phenomena
- Aero-thermodynamics
- Combustion
- Turbo-machinery

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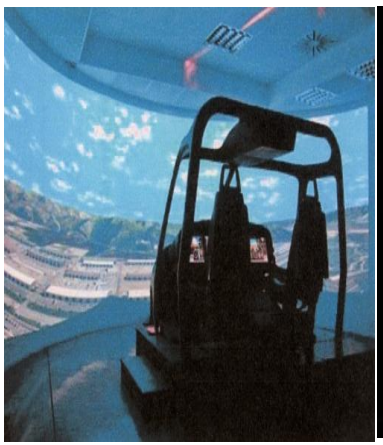

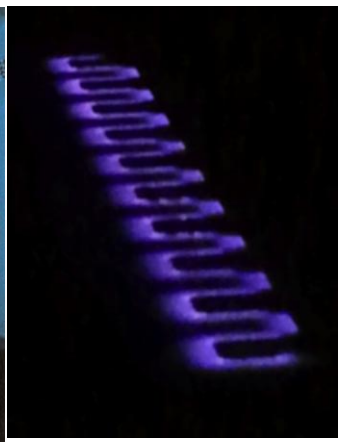

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Research Areas

- Applied aerospace systems (UAV/MAVs, etc.)
- Smart sensors and vision based navigation
- Aero-hydro-servoelasticity
- Space hazards – asteroids and debris
- Formation flying
- Solar power satellites
- Mission analysis and design

- Composite materials
- Smart materials
- Structural health monitoring
- Smart grid
- Energy harvesting
- Controller design
- Renewable energy systems
- Forecasting
- Power ultrasonics
- Non-destructive evaluation

- Biosignal and image analysis
- Brain-Computer-Interface
- Biorehabilitation
- Radar, sonar and communications,
- Beamforming, target detection, estimation and tracking
- Computer-automated design
- Multi-objective optimisation

- Security protocol , design and analysis
- Access control & policy-based management
- Key distribution & management
- Crime prevention
- Embedded systems
- Building automation and control
- "Internet-of-things"
- Network modelling and simulation (WSNs)
- Machine-to-machine communications
- Multicore and Cloud computing

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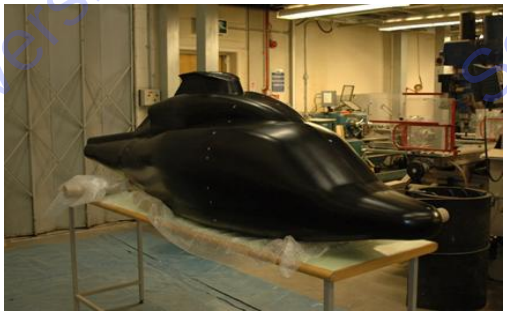
Flight Test & Simulation Facilities

- **Instrumented Autogyro Aircraft**
- G-UNIV: Modified Montgomerie-Parsons 2-seat autogyro.
- **Indoor Flight Testing of Micro UAVs**
- Establishment of lab funded by SELEX



- **Flight Simulator**
- **ART FlightLab**
- **In-house Simulation Codes**
- **Inverse Simulation**

Augusta-Westland Simulator in Verase

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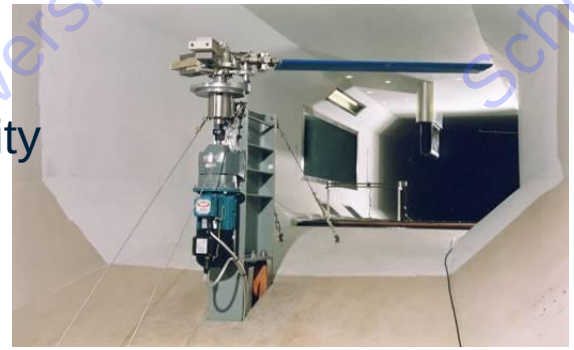
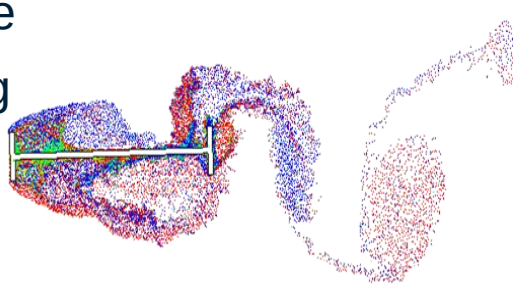
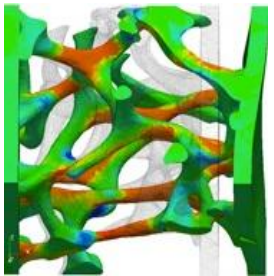
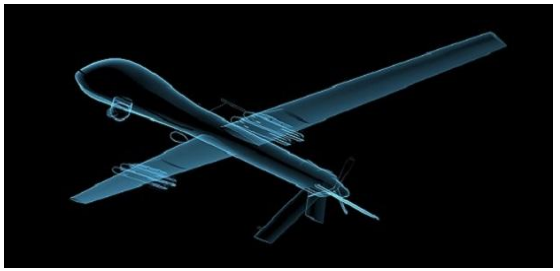
Wind Tunnel Testing Facilities

- 9ft x 7ft de Havilland Tunnel, 85m/s
- 7ft x 5ft Handley Page Tunnel, 65m/s
- 3 other smaller scale subsonic tunnels
- Supersonic/Hypersonic facilities
- Shock tubes
- National Facility
- National Rotor Rig
- Complete flow diagnostics, instrumentation, and testing capability
- Dynamic Stall Rig
- Load Cells for Force Measurement,
- Specialised Sting Balance
- High Speed Data Logging
- Model Manufacture









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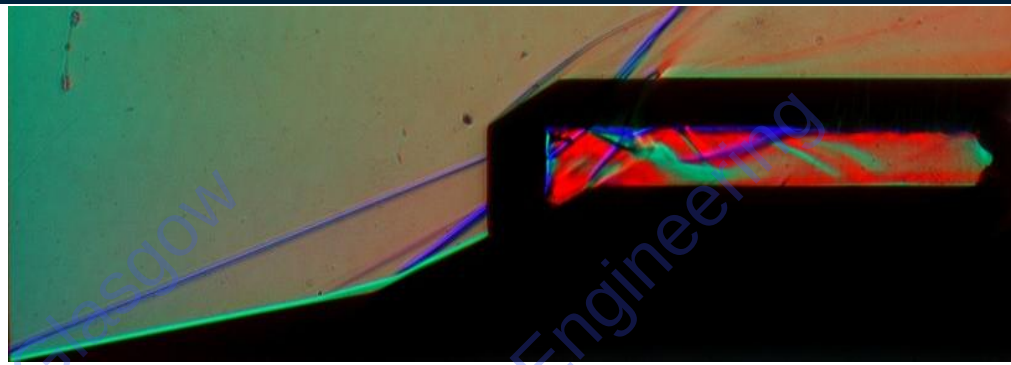
Facilities Upgrade – University Investment



Shock tunnel

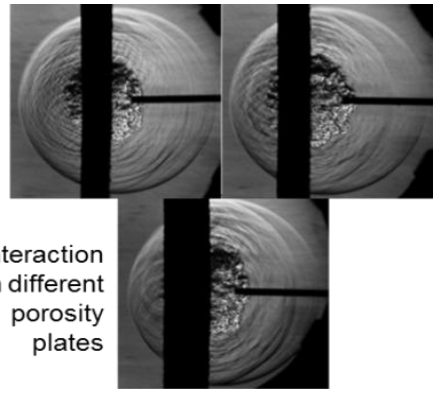
- 0.5 ×0.4 m^2
- Mach 6 to 10

Transonic/Supersonic wind tunnel

- Mach 0.5 – 3.5 (covering speeds of modern airliners and supersonic business jets)

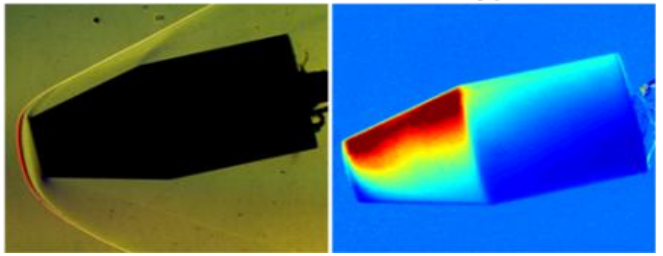
Shock tubes

- High speed flow interactions
- Fundamental flow physics



Interaction with different porosity plates

AA-PSP, Truncated cone in hypersonics



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National Wind Tunnel Facility

– UK Aerodynamics Centre coordinated response to closed call from EPSRC to create a distributed National Wind Tunnel Facility (NWTF)

- EPSRC contributed £11m to the project
- UK Aerodynamics contributed £2.3m funding
- Consortium of 7 universities
- Proposal was submitted end-Oct 2013
- Funding was announced in January 2014 by David Willets

– Glasgow focus: aerodynamics and unsteady measurements

- Glasgow received £1.7m
- De Havilland tunnel has been modified to include a gust capability

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National Rotor Rig Facility

– National rotor rig facility:

- Development a rotor rig sized for our tunnel and should also fit into a number of others around the UK
- Rotor rig will be capable of testing helicopter rotors, propellers, tilt rotor configurations and wind turbines

– UK Aerodynamics providing strong support as project of national strategic importance

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Aerodynamics and Fluid Dynamics Technologies

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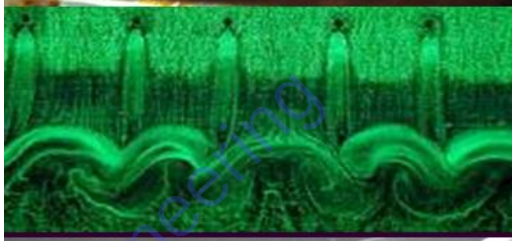
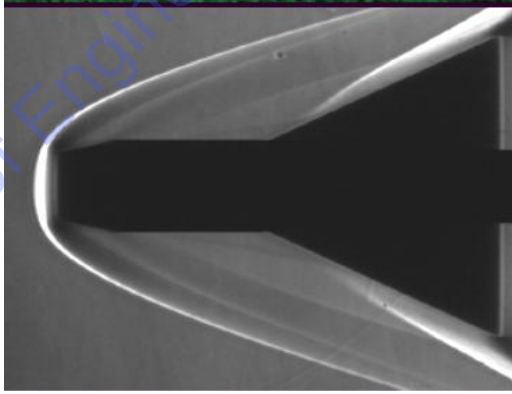
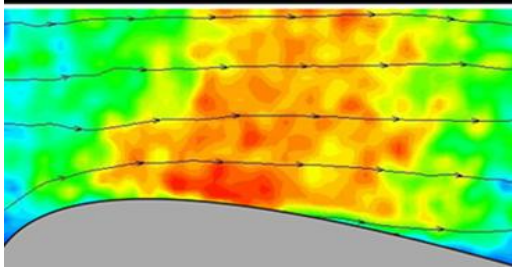
The focus is on the investigation of complicated flow problems and interactions related to **flow, flight, load control**, **unsteady aerodynamics, fluid-structure interactions, heat-transfer, interdisciplinary shock wave phenomena** and **aero/thermodynamics**, and the development and application of advanced **flow diagnostics**.







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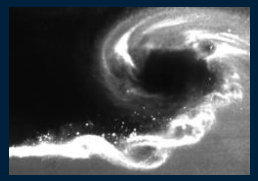

Fluid Dynamics Technologies

- **Research topics cover a broad spectrum from Low speed to High speed.**

Examples include:

– Flow control technologies for subsonic flows:

- **Piezo-electrically driven pulsating elastic surfaces** for drag reduction and separation control on aerofoil configurations;
- **Dielectric Barrier, Corona, Sliding Discharge plasma actuators** for control of boundary layers and leading-edge vortices in swept wings, drag manipulation, and separation control

– Shock-vortex, shock-boundary layer and shock-shock interactions;

– Turbulence and instabilities;

– Detonation interactions and attenuation;

– Flow control for transonic, supersonic and hypersonic flows.

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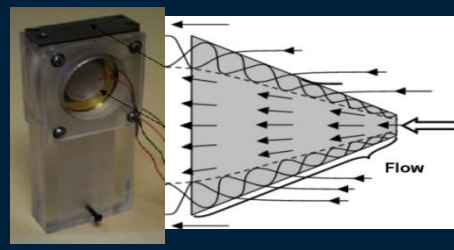

Projects related to low speed research:

- Effect of **lateral and longitudinal oscillation** in boundary layers;
- Flow control of cavities using **micro-jets**;
- Boundary layer control using **synthetic jets** and **grooves**;
- Circulation control and boundary layer control in supercritical aerofoils using **single and dual pneumatic actuation** along a Coanda trailing edge.

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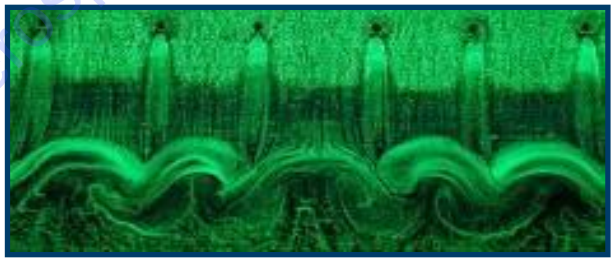

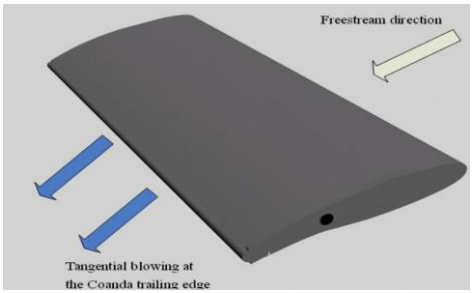

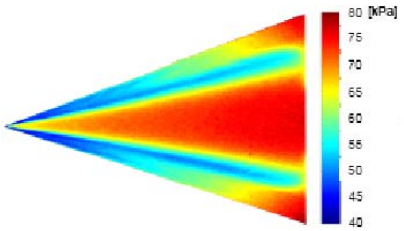

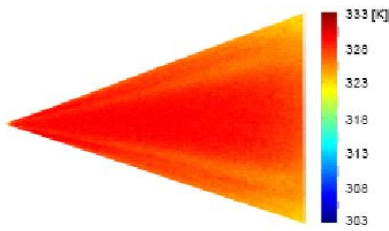

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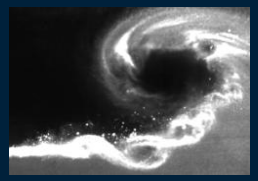

Fluid Dynamics Technologies

- **World-class experimental facilities able to simulate/create with high accuracy and repeatability various environmental conditions;**
- **In-house developed specialist diagnostic technologies applied to a variety of situations:**

– Schlieren video/photography to visualise flow phenomena

– Velocity measurements, e.g., Particle Image Velocimetry (PIV)

– Pressure Measurements, e.g., Pressure Sensitive Paints (PSP)

– Temperature Measurement Capability, e.g., Temperature Sensitive Paints (TSP) and Thermographic Phosphors

– 2D and 3D Numerical simulation capability

- **Results are also used for validation of numerical codes.**

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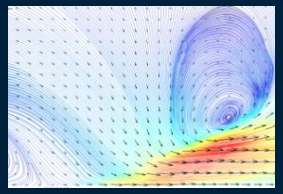


Diagnostic Methods

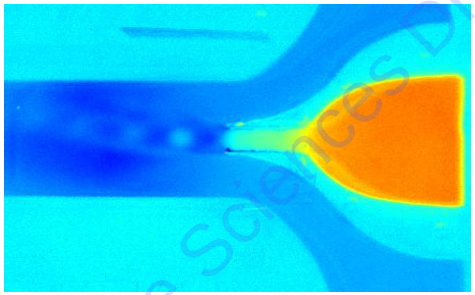
- **Pressure measurements:**

– National Instruments (NI) Data Acquisition (DAQ) systems

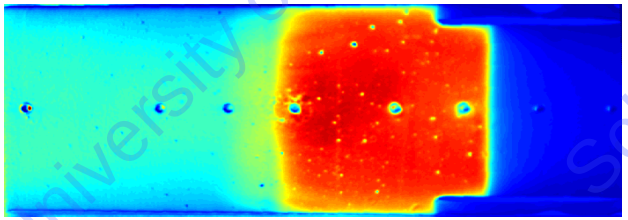
– LabVIEW software

– Static calibration rig from vacuum up to 6bar

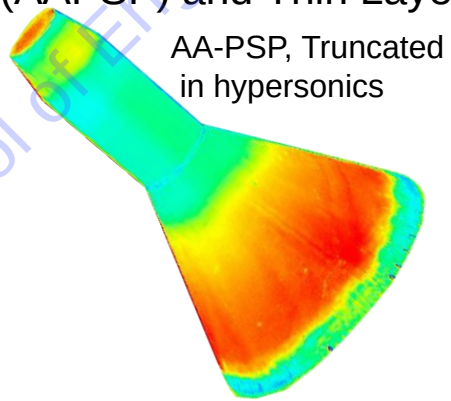
– Pressure sensitive paint (PSP) including Anodised Aluminium PSP (AAPSP) and Thin Layer Chromatography (TLC) for unsteady flows



PSP, Convergent nozzle

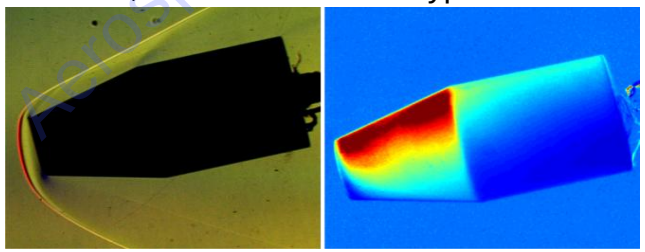


AA-PSP, Double ramp in hypersonic flow

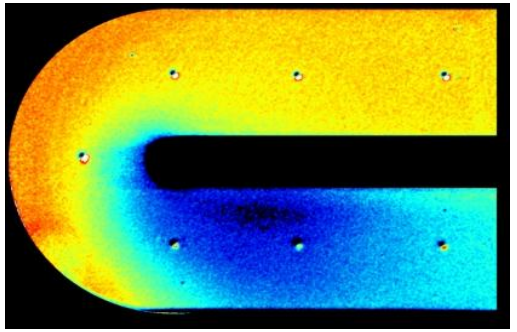


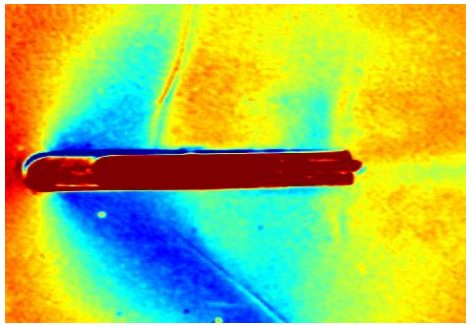
AA-PSP, Truncated flare in hypersonics

AA-PSP, Truncated cone in hypersonics



PSP, Flow round U-bend





PSP, Transonics, fin with dimples

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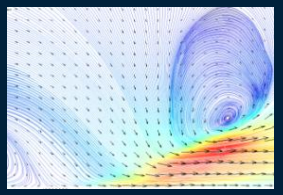
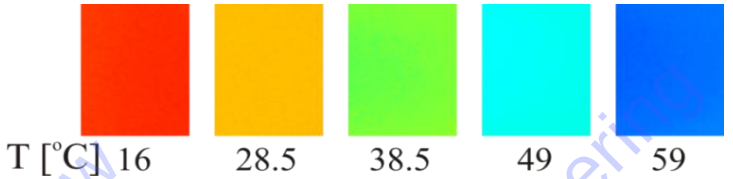
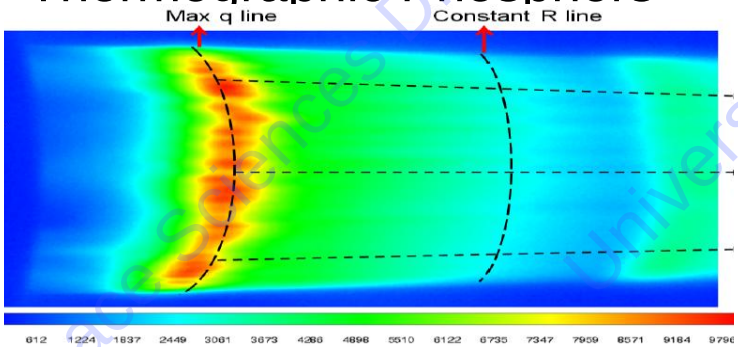


Diagnostic Methods

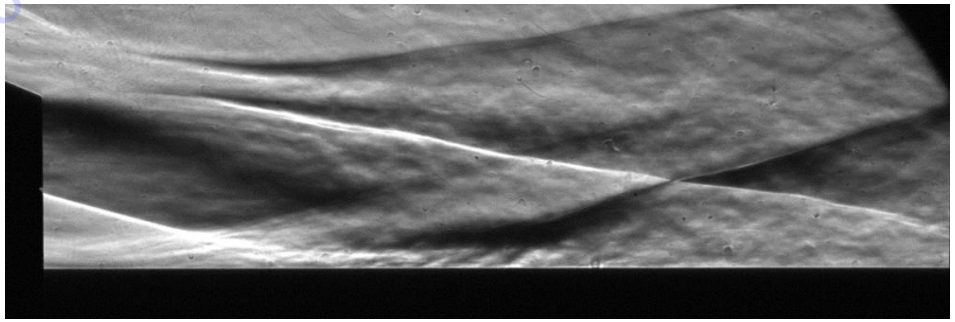
- **Temperature measurements:**
  - Temperature sensitive paint (TSP)
  - Infra-red imaging
  - Thermocouples
  - Thermographic Phosphors

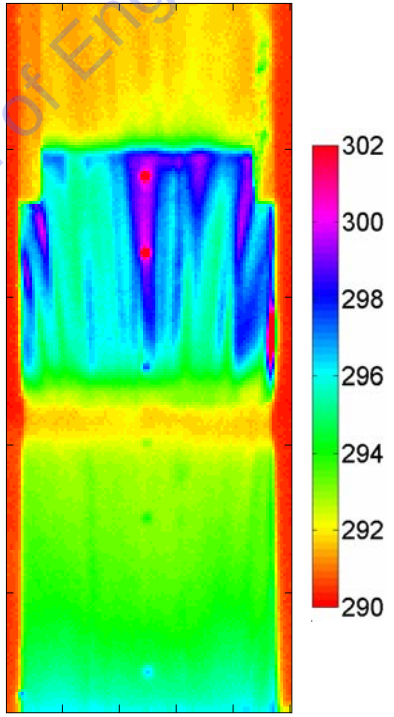


TSP, Variation of intensity with temperature



IR of Shock-boundary layer interaction





TSP image of double ramp in a high speed flow

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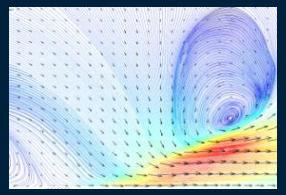
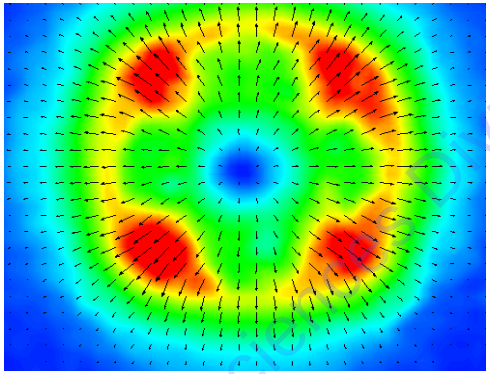
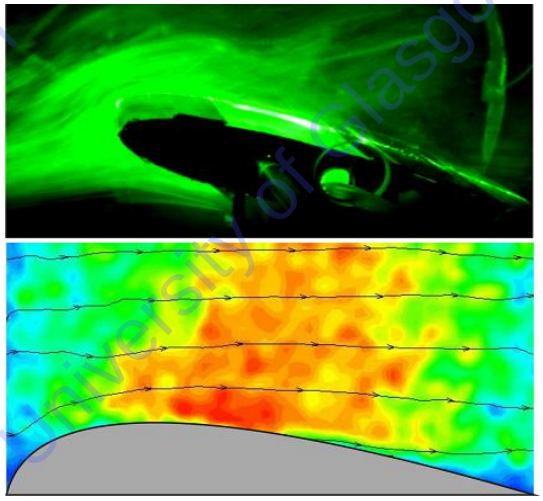


Diagnostic Methods

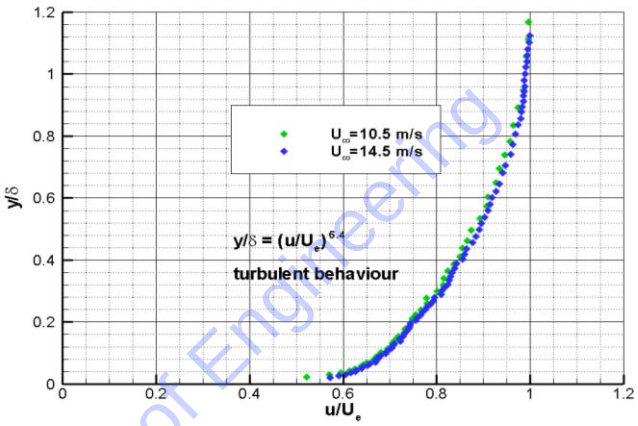
- **Velocity measurements:**
  - Hotwire – single and cross-wire
  - Particle Image Velocimetry (PIV)



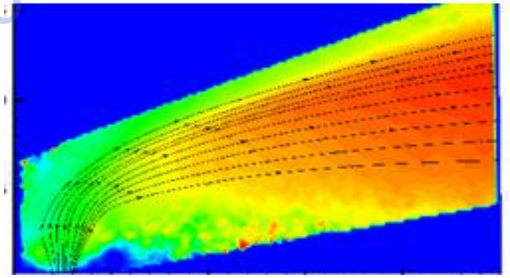
Head-on PIV in a square shock tube



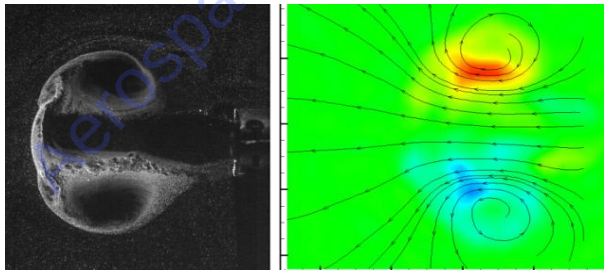
Flow over NACA0015, Re=1.5×10^5



Boundary layer profile in wind tunnel

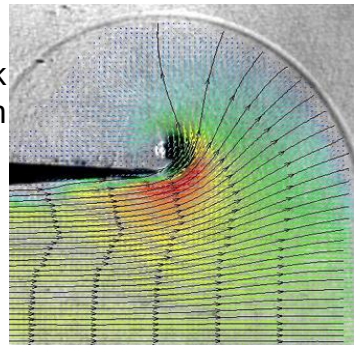


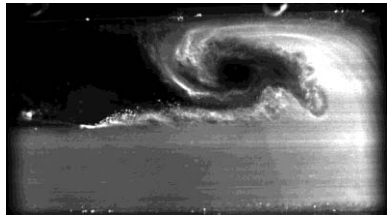
Jet in M=5 cross flow



Elliptic vortex loop from shock tube

Shock diffraction





PIV, Shock diffraction

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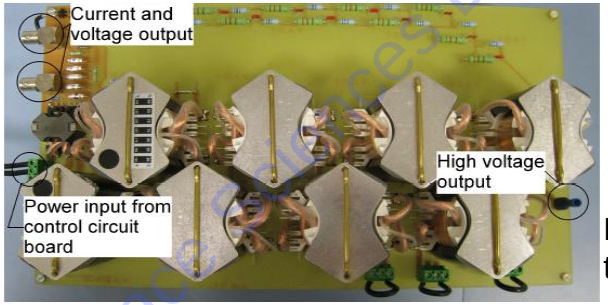
Plasma Systems

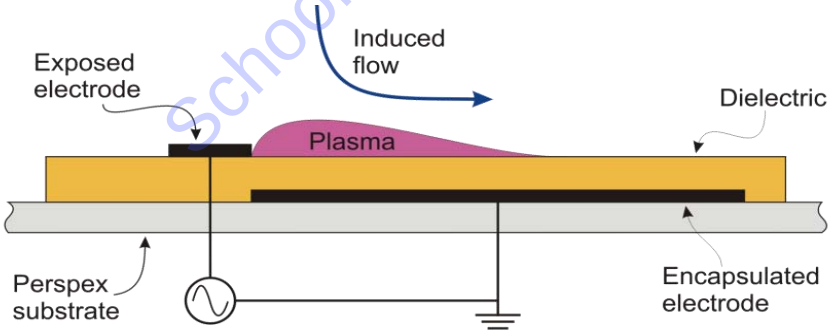
- **Plasma systems with various voltage and frequency outputs**
  - Voltages from 10kV$_{p-p}$ (peak to peak voltage) to 78kV$_{p-p}$
  - Frequencies ranging from 20kHz to 1.5MHz
- **Expertise in Single and Multiple Encapsulated Electrode (MEE) configurations**
- **DBD, Nano-pulse, Sliding discharges generators, lasers, spark-jets, microwaves**

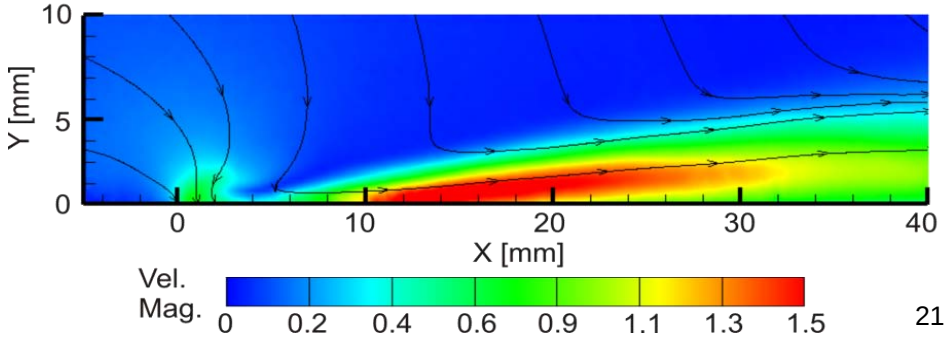
Annular plasma



High-voltage transformer cascade

Single dielectric barrier discharge plasma actuator

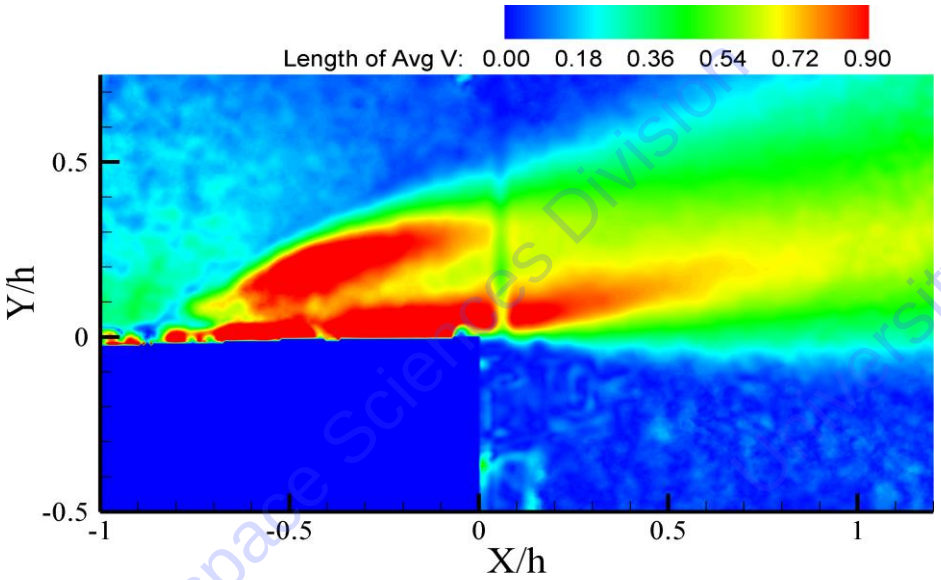




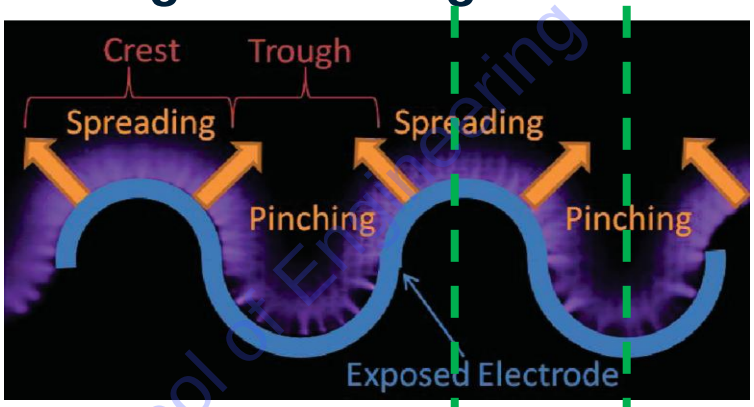
Aerospace Sciences Division, University of Glasgow, School of Engineering

Results – Quiescent Serpent

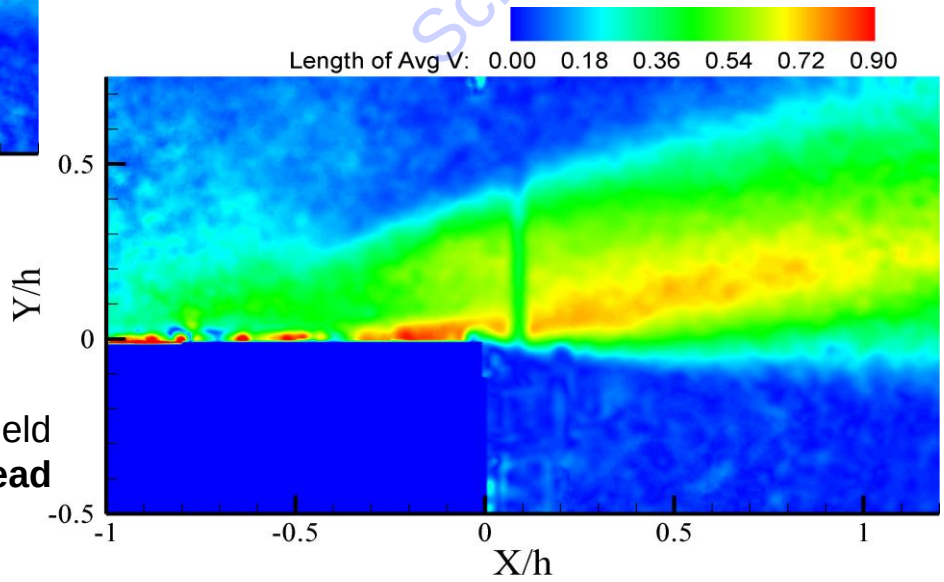
- **PIV measurements conducted with light sheet along once along the Pinch and once along the Spread**



Velocity field along **Pinch**



PIV laser light sheet locations



Velocity field along **Spread**

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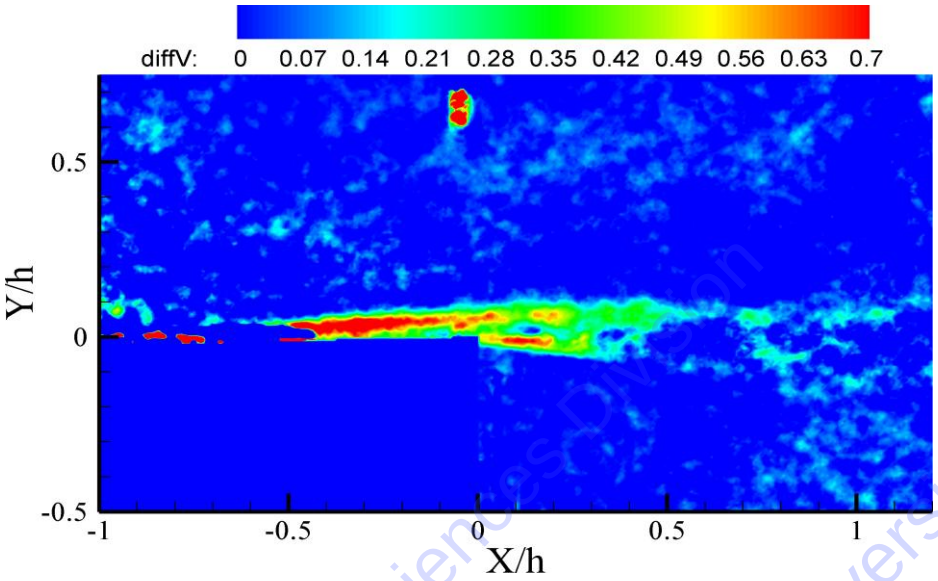
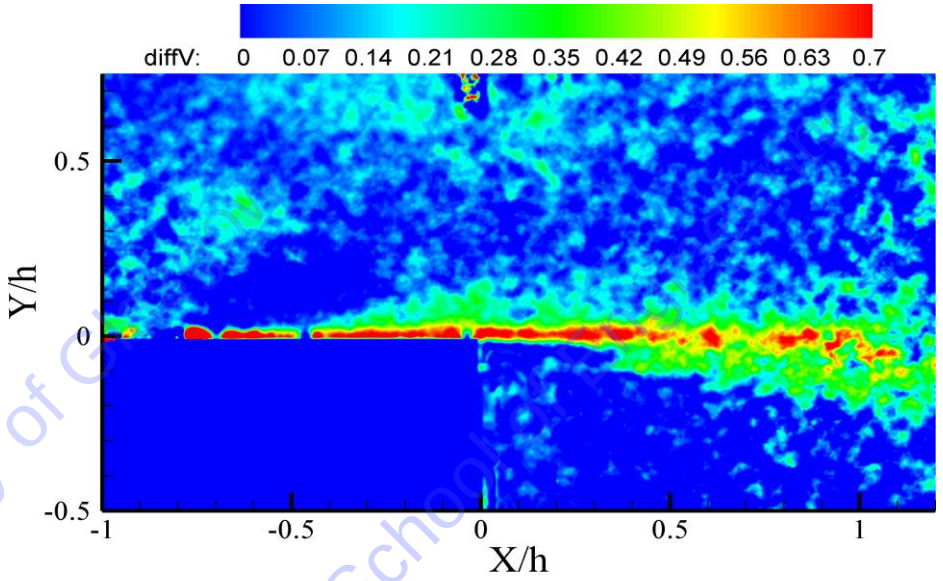
Results – Serpent with Flow



Difference in velocity magnitude along **Pinch**



Difference in velocity magnitude along **Spread**

- **Pinch portion of the actuator has a greater influence upstream of the backwards facing step, due a vectored jet forcing the flow upwards**
- **Spread portion influences more the separated shear layer downstream of the step**

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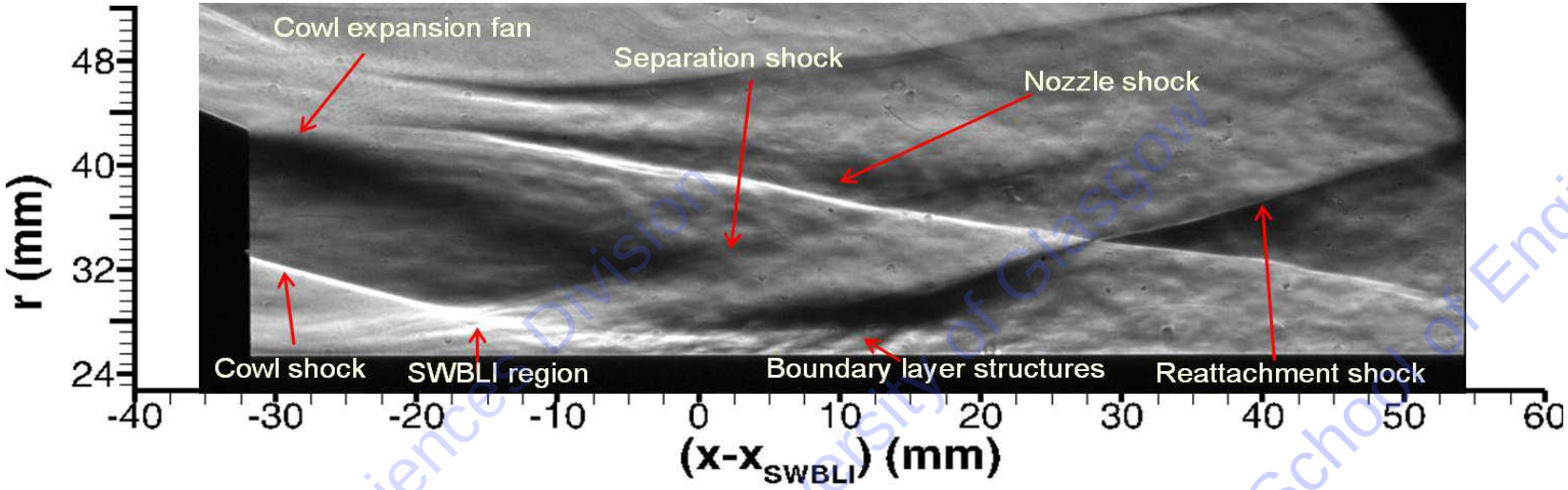
High Speed Transition

exposure 750nsec

SWBLI @255mm



SWBLI @255mm

As the intermittency is increased boundary layer becomes more turbulent and skin friction coefficient rises. Hence it becomes more resistant to adverse pressure gradient imposed by the impinging shock, which would result in a relatively smaller SWBLI region.

SWBLI regions are somewhat similar for all cases.

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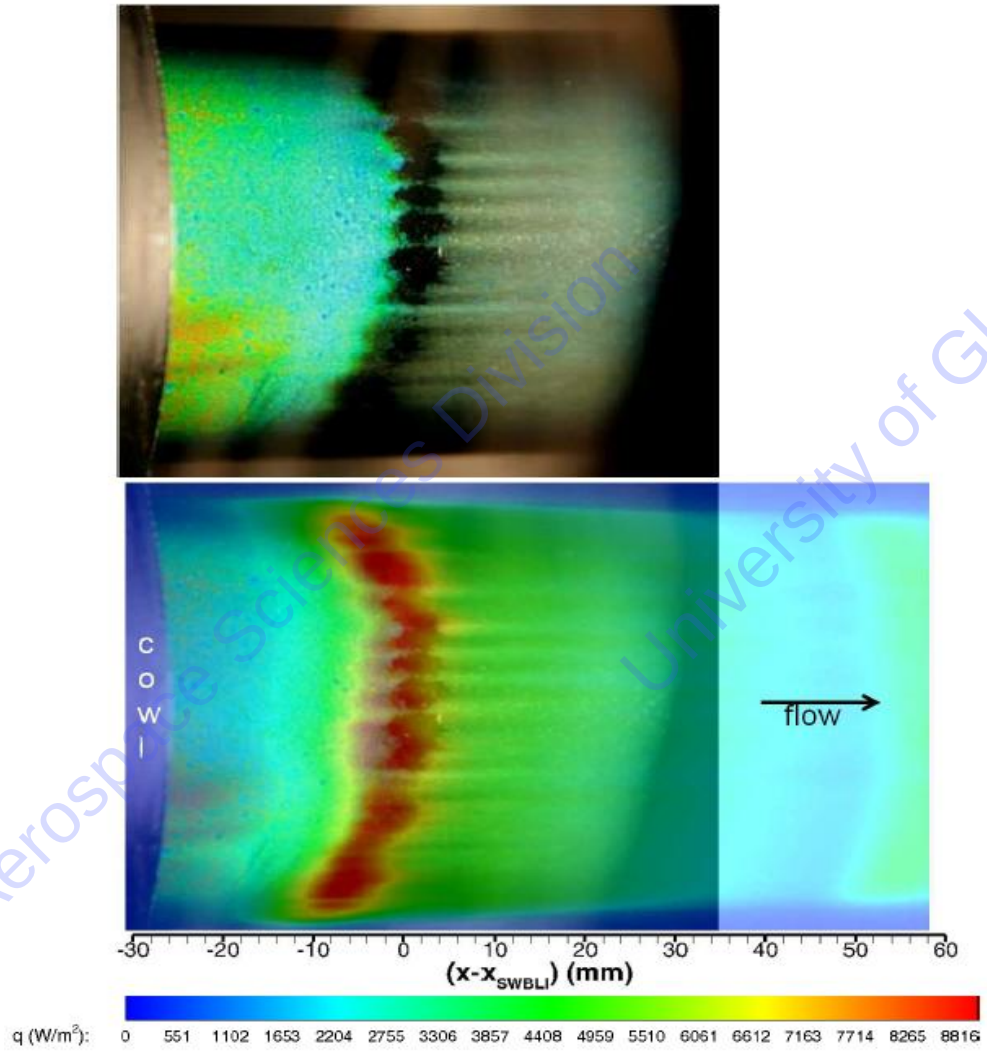
High Speed Transition



Wall shear stress overlaid on heat flux contours

Direct relation with shear stress distribution and heat flux distribution is observed for all cases.

SWBLI @190mm and 200mm cases experience minor leading edge influence.

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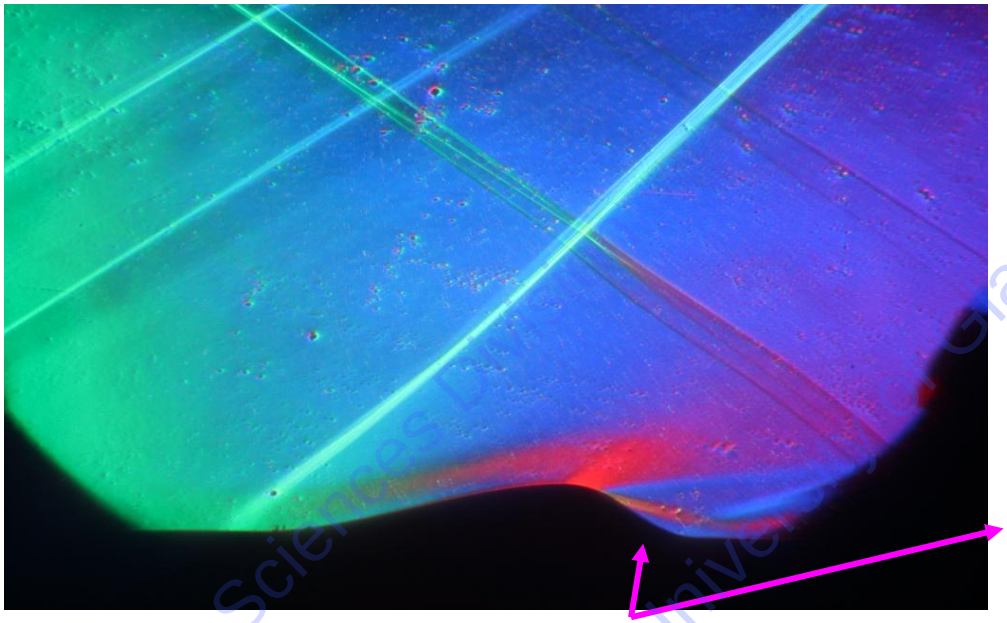
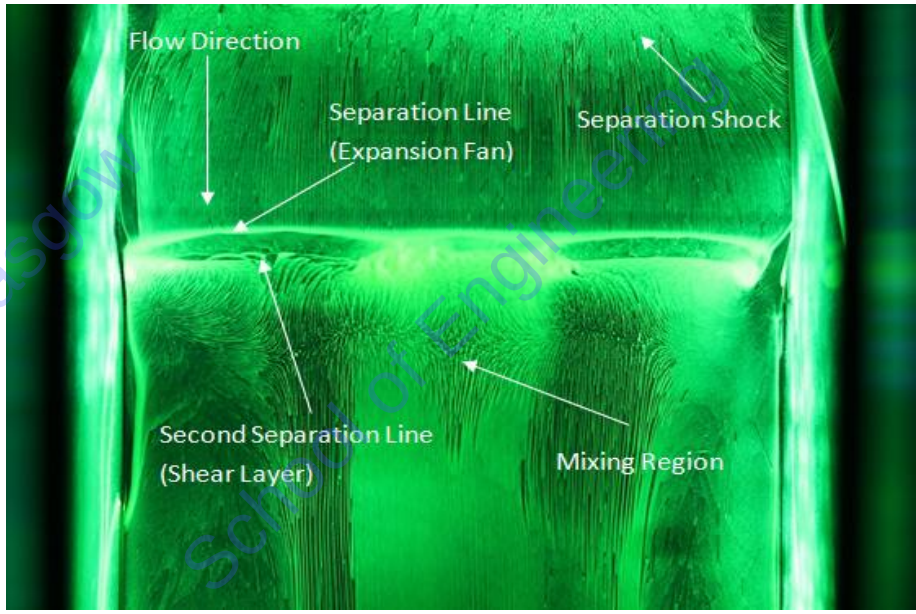
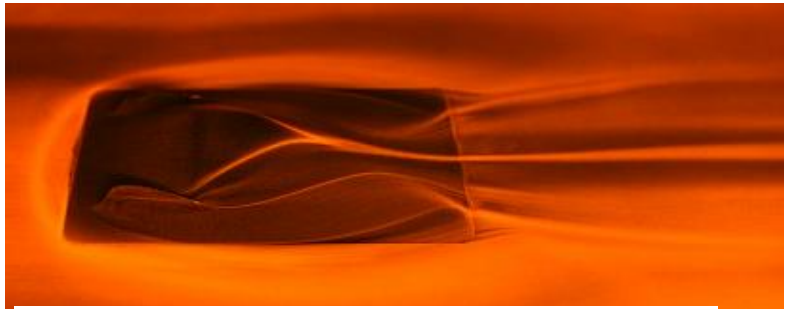




Transonic flow over 2D bumps



Transonic flow over a 3D bump with fins

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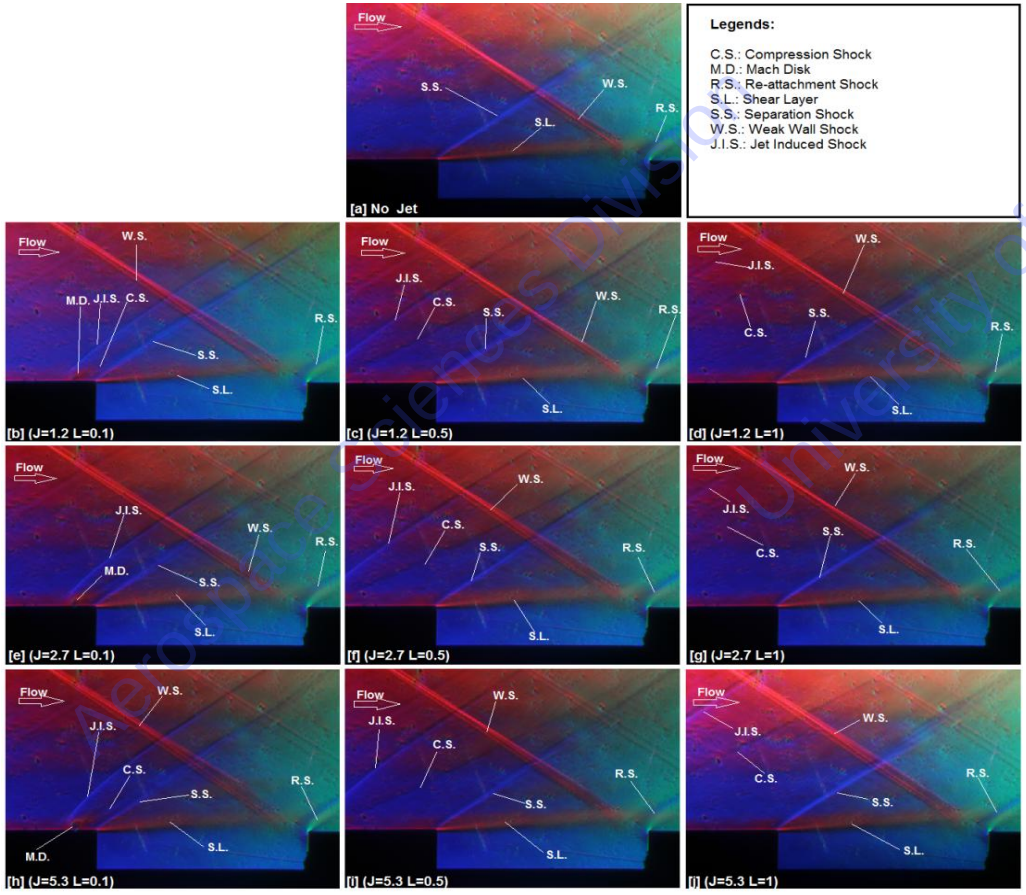
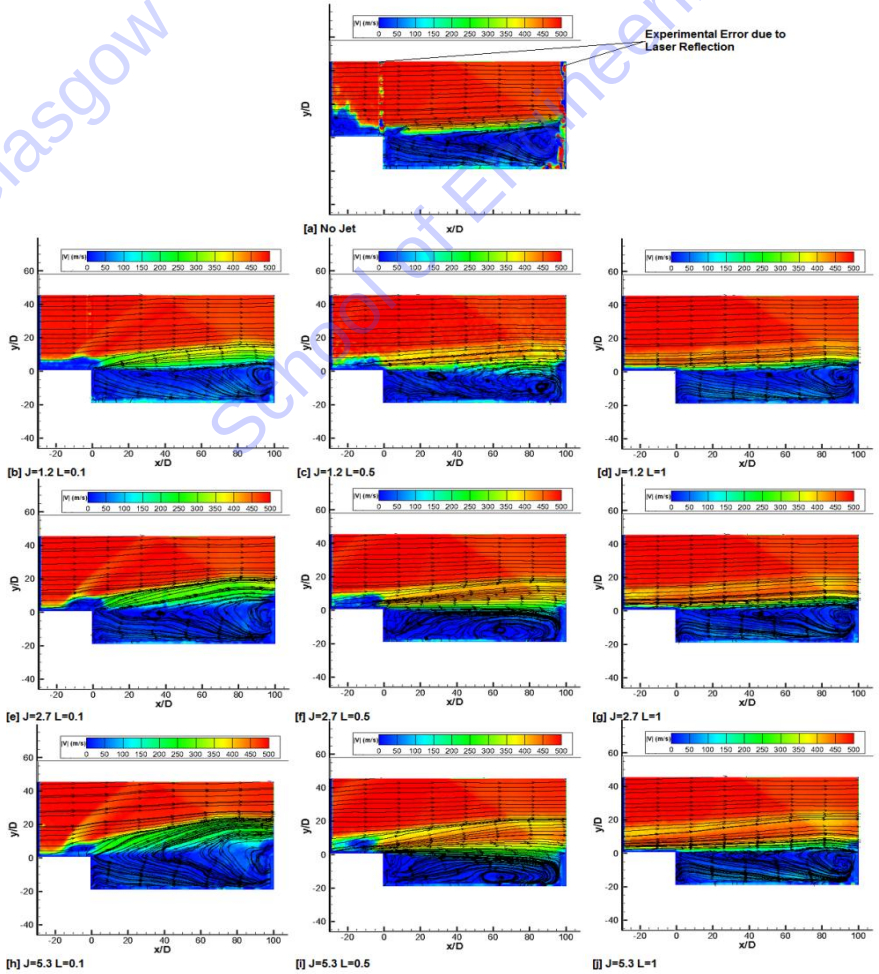
- **Supersonic flow over open cavities.**
- **Jet was injected upstream of the leading edge of the cavity to affect the flow pattern along the cavity.**





Colour Schlieren images and PIV data of flow over an open cavity at different jet injection pressures in a Mach 1.9 free-stream

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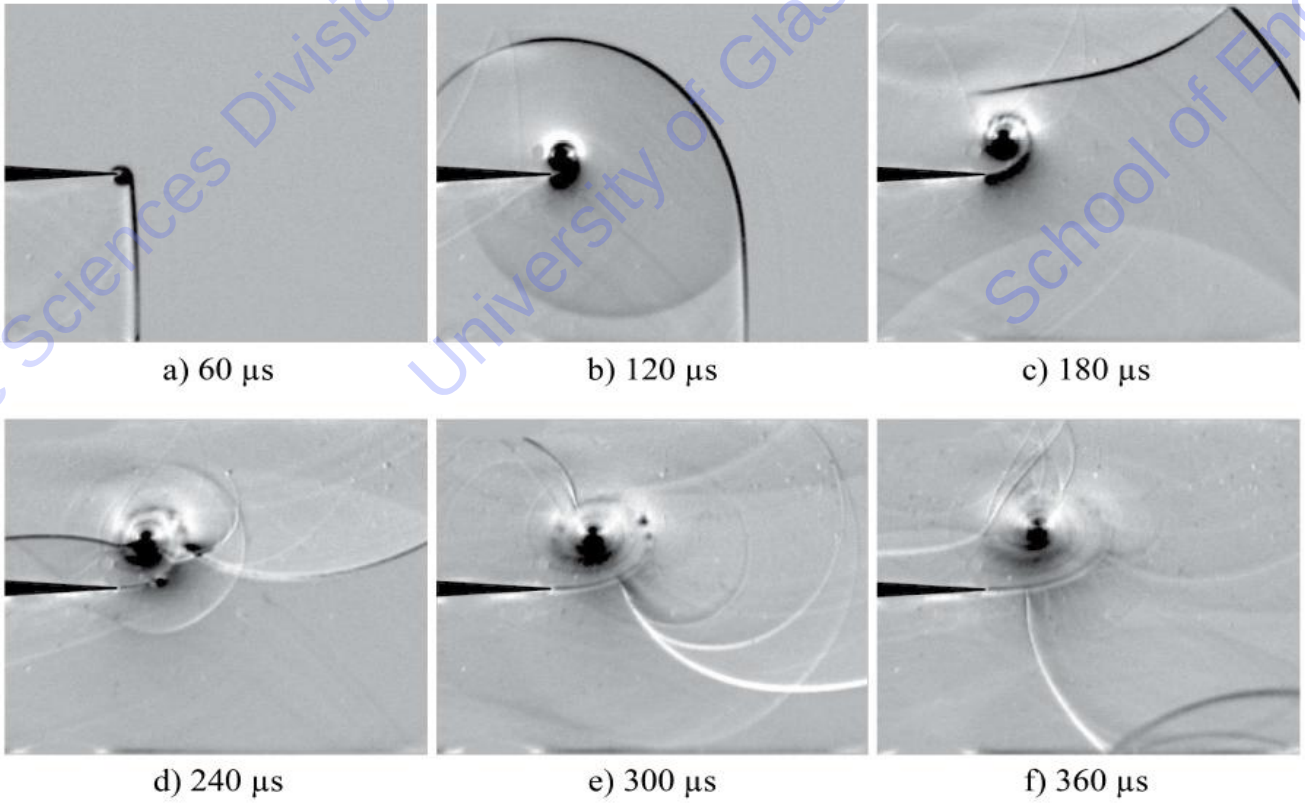
- **Unsteady shock wave phenomena.**
- **Studied by using shock tubes.**
- **Pressure ratios (P_1/P_2) employed $4<P_1/P_2<12$.**
- **Different sharped and rounded corner models were used.**



Instantaneous Schlieren images of shock diffraction over a sharp corner under a normal shock Mach number of 1.30.

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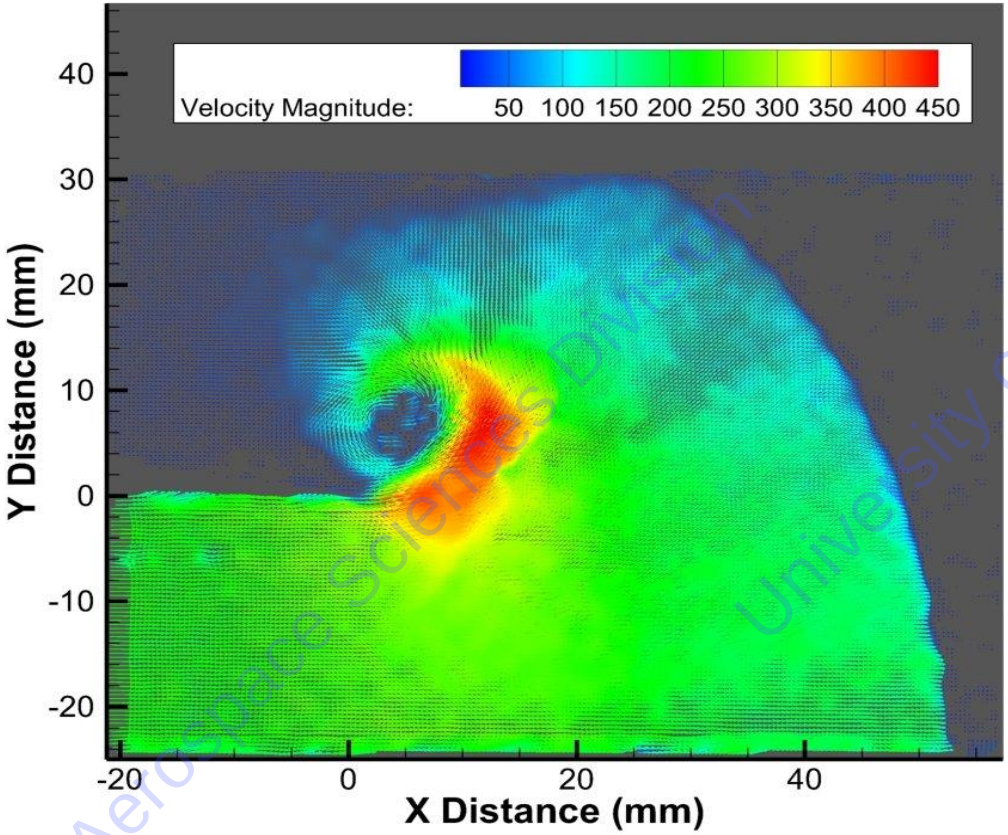
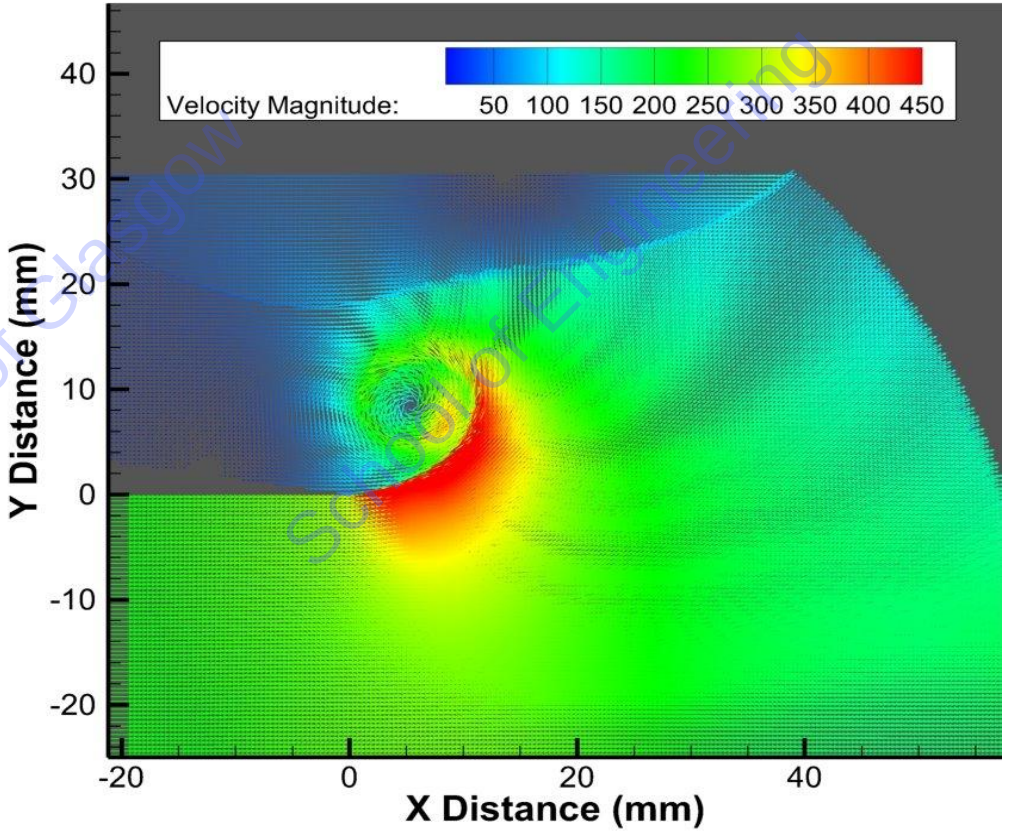


PIV Velocity Vectors



CFD Velocity Vectors

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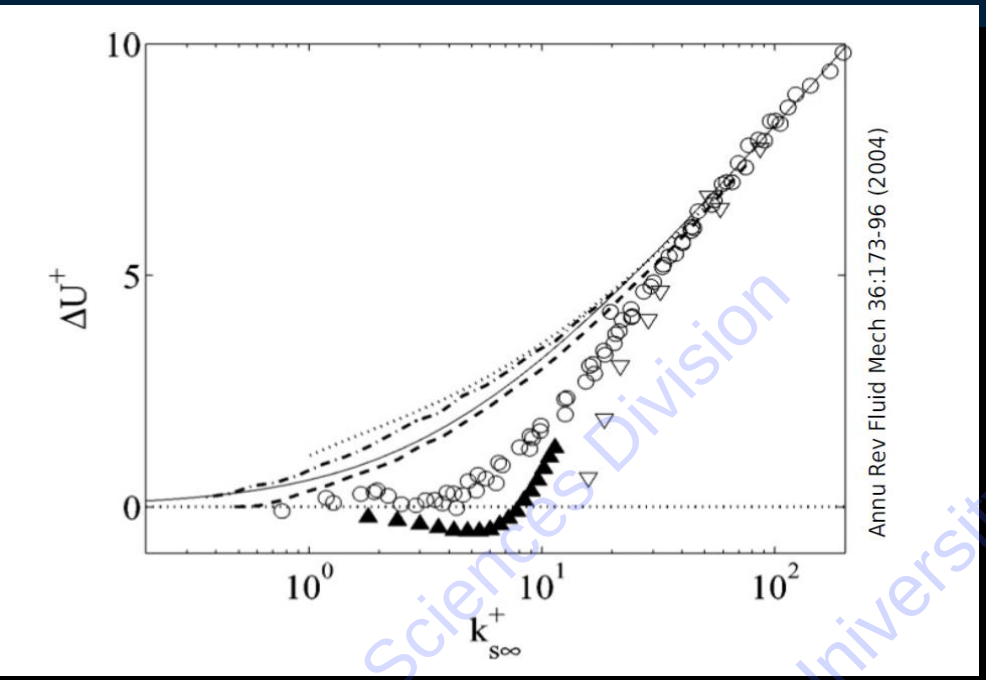

- **EXP-CFD on roughness**
- **relationship between roughness shape and fluid dynamic properties**

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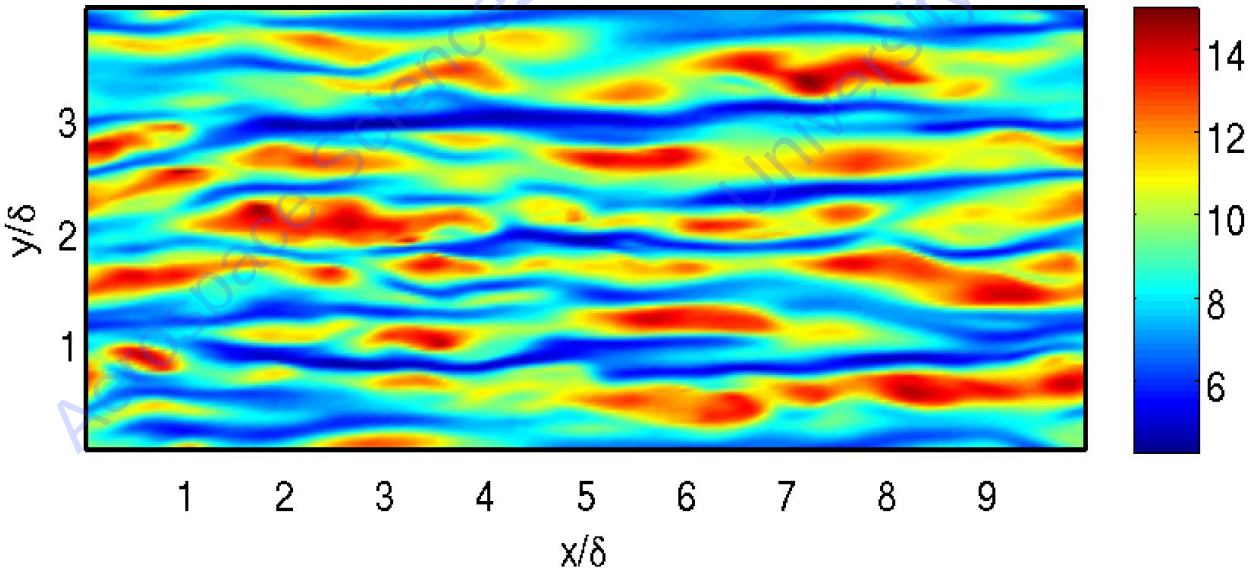
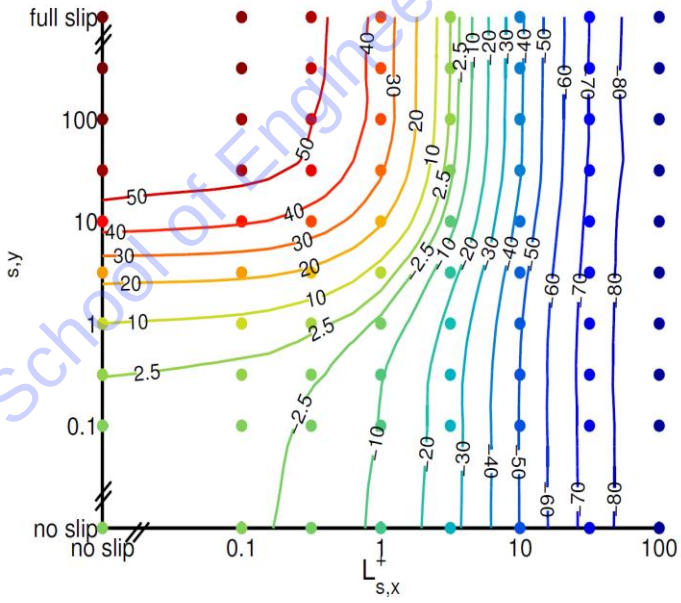
Study of flows over super-hydrophobic surfaces





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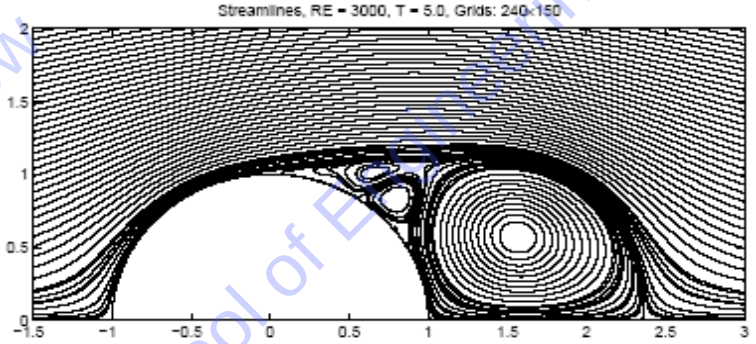
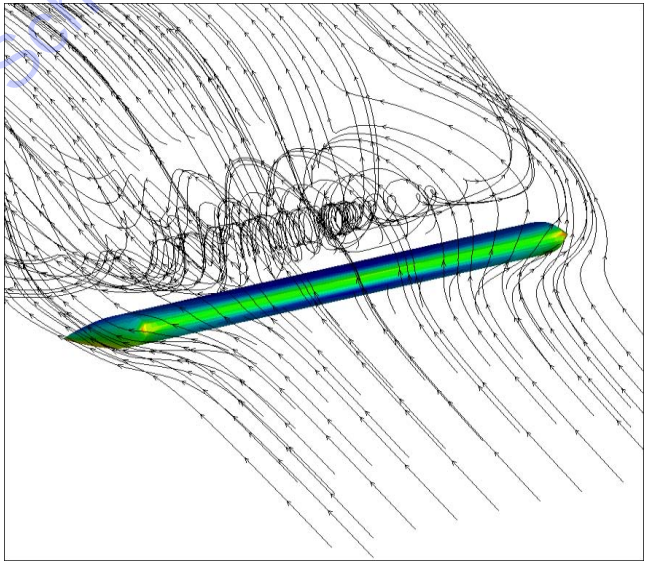
School of Engineering

- **Studies with 2-D version have demonstrated accuracy & efficiency of hybrid vortex approach**



- **3-D method was subject of recent research project at GU under DARP programme**



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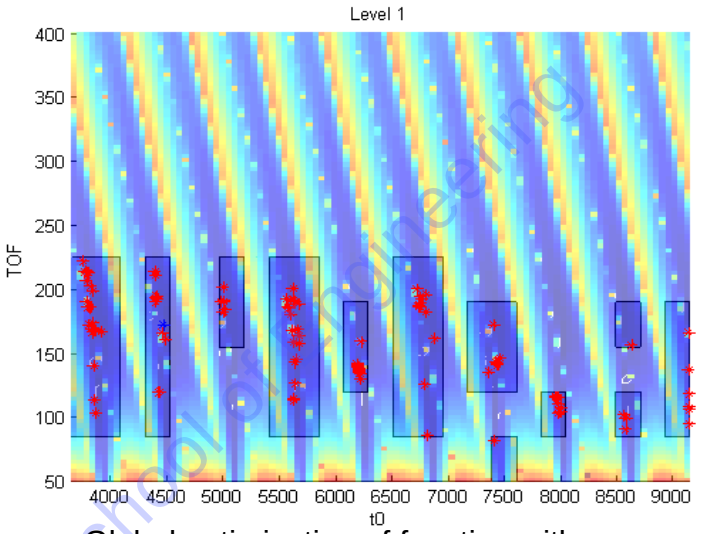
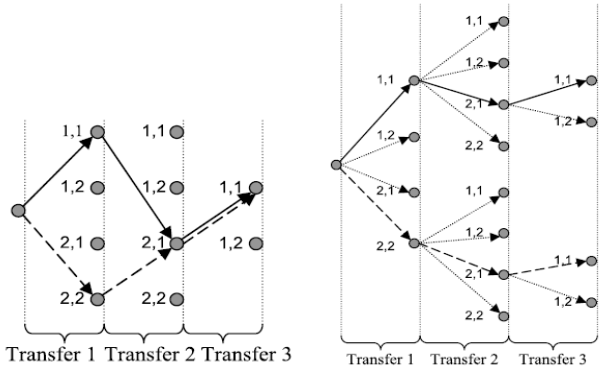
- **Global optimisation**
  - Evolutionary Algorithms (GA, NSGA-II, DE, …)
  - Single or multi-objective (multi-modal/discontinuous functions, Pareto-fronts)
- **Combinatorial optimisation, tree search**
  - Ant Colony Optimisation (ACO)
- **Mixed integer/continuous optimisation**
- **Local optimization**
  - Direct (Pseudo-spectral) and indirect (in-house) methods
- **Optimal trajectory design**
  - Continuous-thrust trajectories
  - Single or multi-objective (mass, time, …



Global optimisation of function with multiple local minima



Two types of tree search with a modified ACO algorithm

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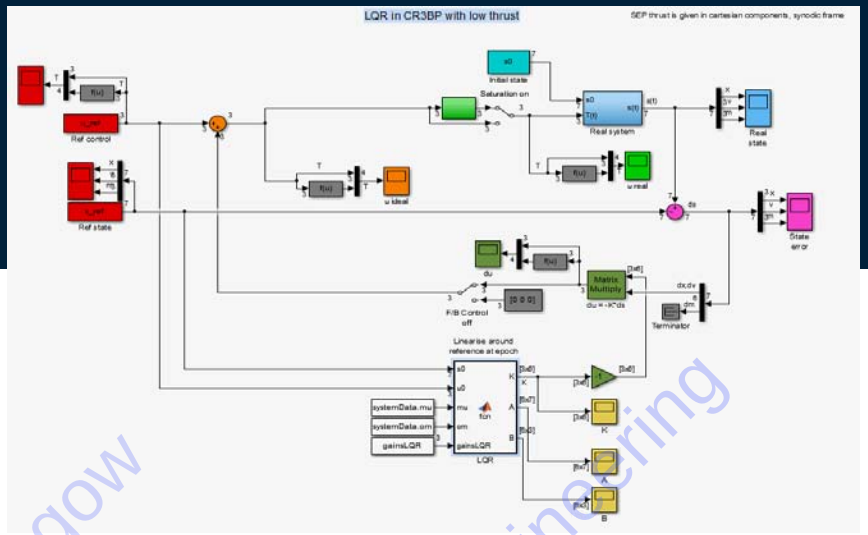
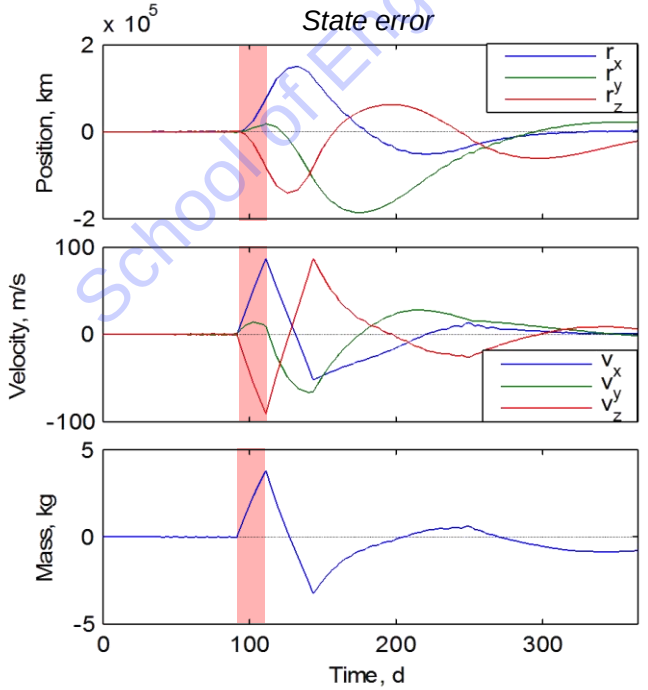


- **Optimal control of flying vehicles**
- **Linear and non-linear feedback control techniques**
- **Continuous and digital control design and tuning**
- **Modelling using MATLAB/Simulink**



Real-time spacecraft control simulating a temporary thruster failure

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Thank You

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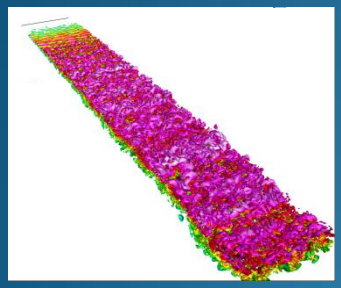
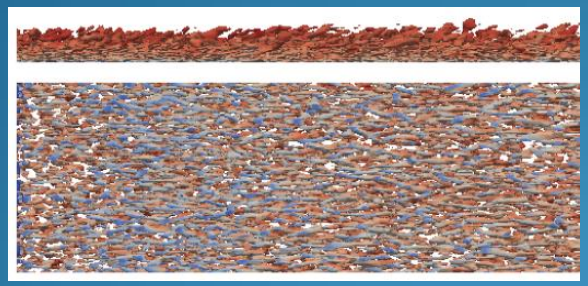
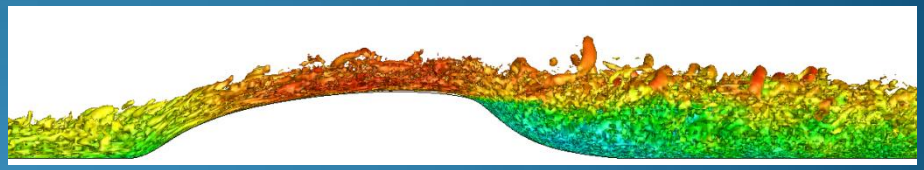
Aerospace Sciences Division University of Glasgow School of Engineering

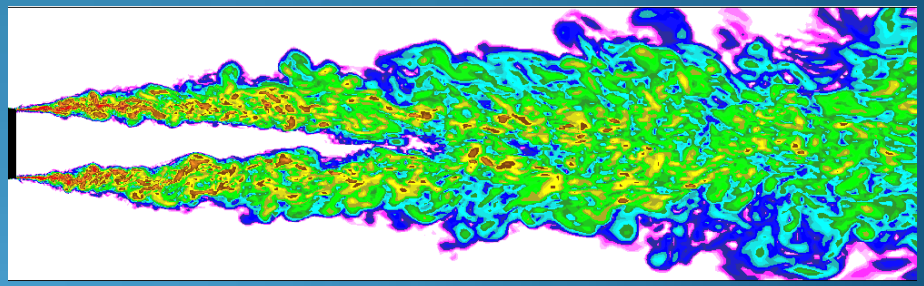
Go4Hybrid

Improved methods for turbulence-resolving CFD: The Go4Hybrid Project









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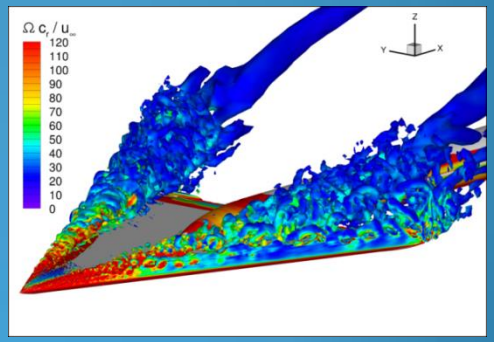
charles.mockett@cfd-berlin.com

CFD Software E+F GmbH

CFD Software Entwicklungs- und Forschungsgesellschaft mbH



Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

Example results

Non-zonal approaches

Embedded approaches

Conclusion

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The Go4Hybrid project

Work plan

Work packages

Test cases

Example results

Non-zonal approaches

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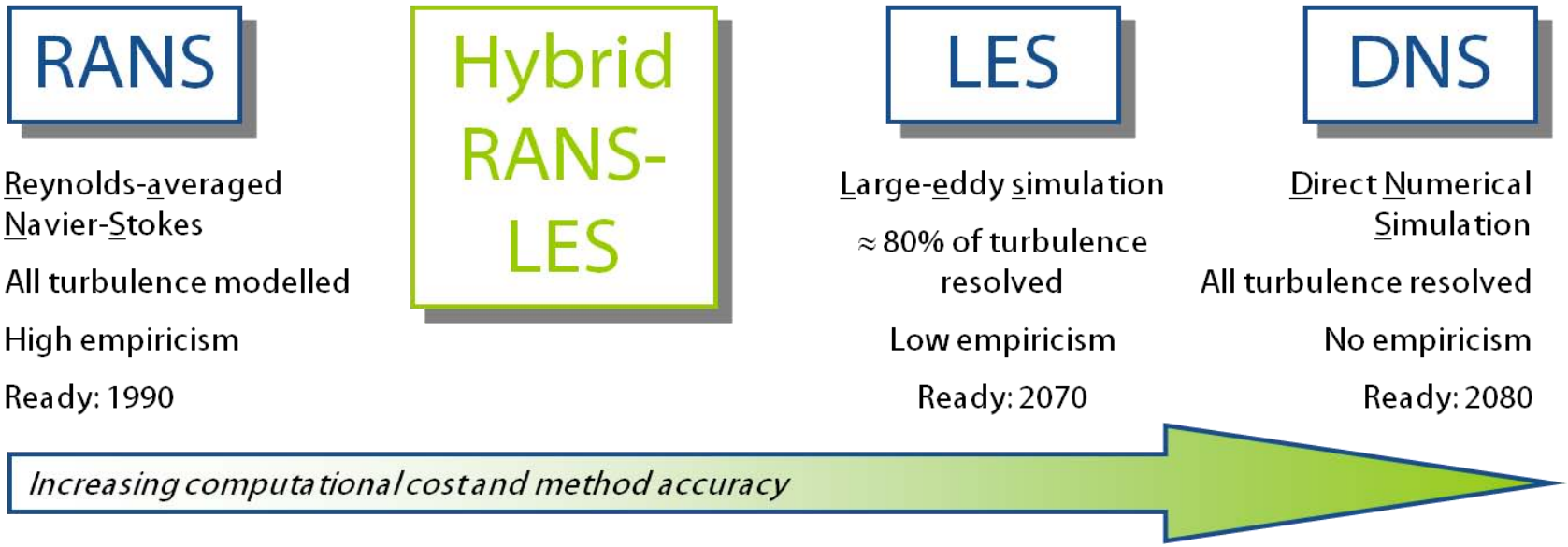
Conclusion

Motivation of hybrid RANS-LES

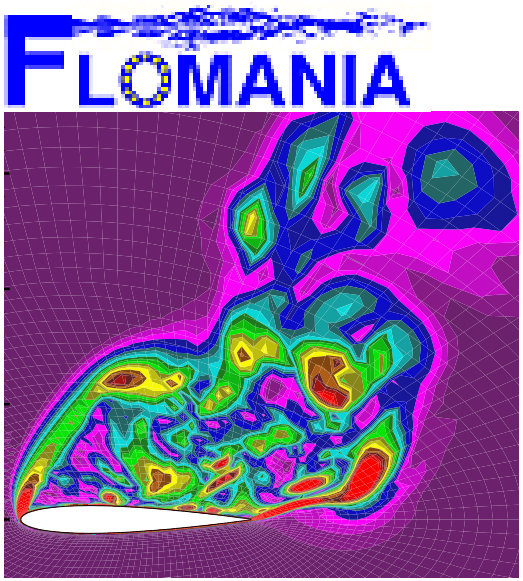
- Strategies for turbulent flows in CFD



- Hybrid RANS-LES:
  - Combine strengths of RANS and LES
  - Target current and near-future computing capacity

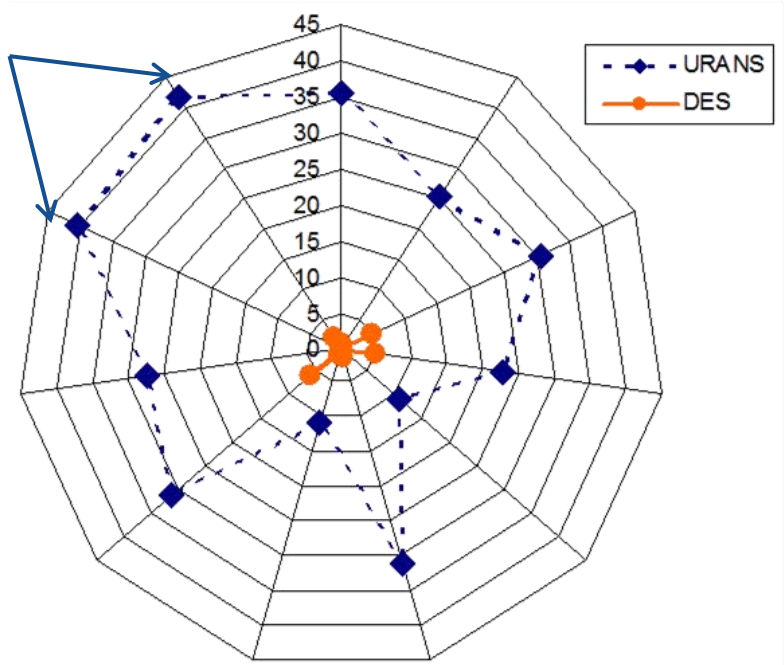
Strengths of hybrid RANS-LES

- Example of early DES study (EU FLOMANIA project)
- Dramatic increase in accuracy and reliability of DES compared to URANS for **massively-separated flow**



Mean drag coefficient:
% deviation w.r.t. experiment

Each "spoke" denotes a data set

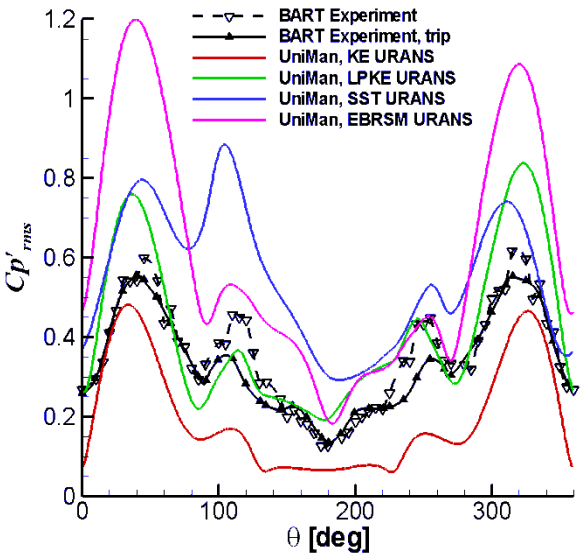


Strengths of hybrid RANS-LES

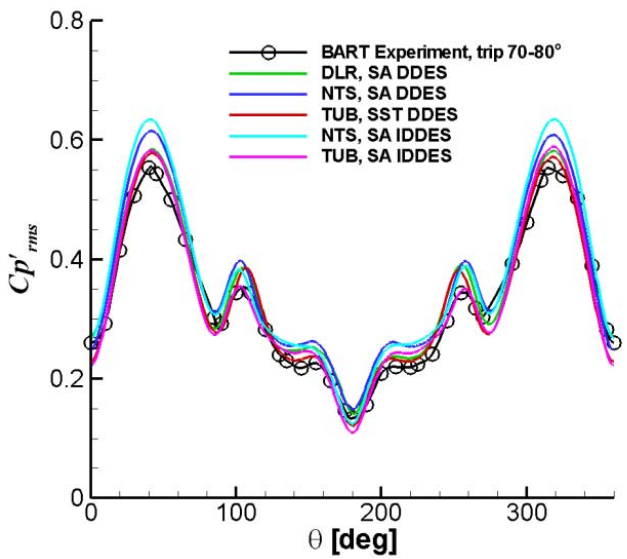
- Recent DES study (EU ATAAC project)
- Tandem cylinder configuration, different codes & models
- Similar improvement for **massively-separated flow**

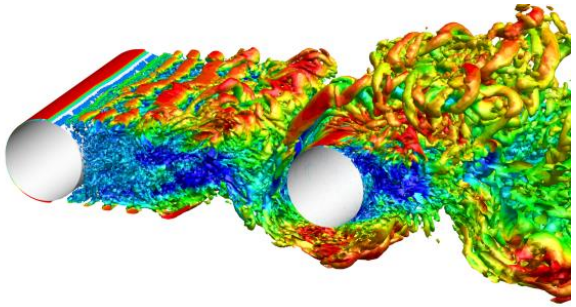
Comparison of surface pressure fluctuations on downstream cylinder

URANS



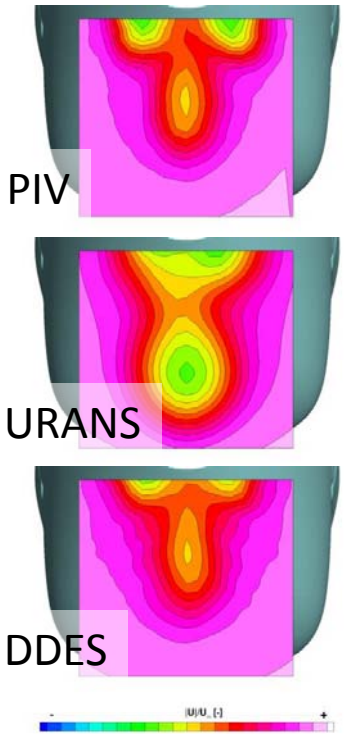
DES

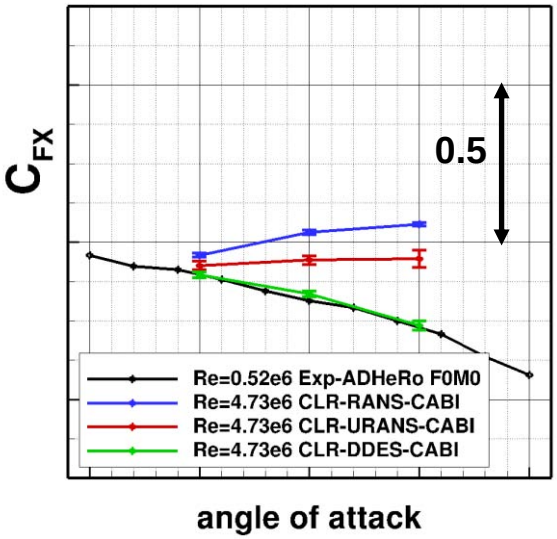




Strengths of hybrid RANS-LES

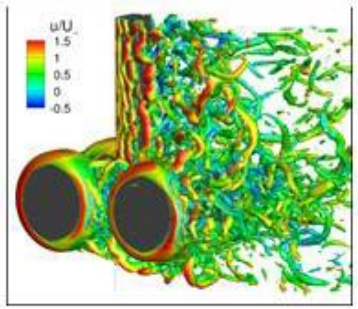
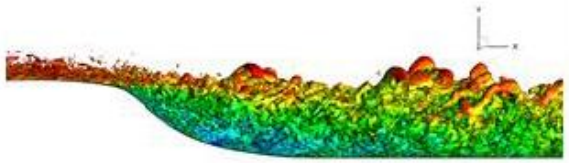
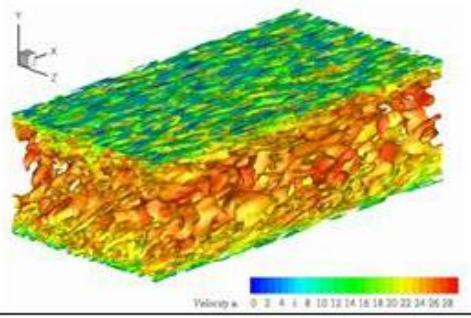
- Recent DES study (EU CleanSky project HELIDES)
- Applicability to complex industrial problems
- Again, significant improvement for **massively-separated flow**





Best-practice output from ATAAC (2012)

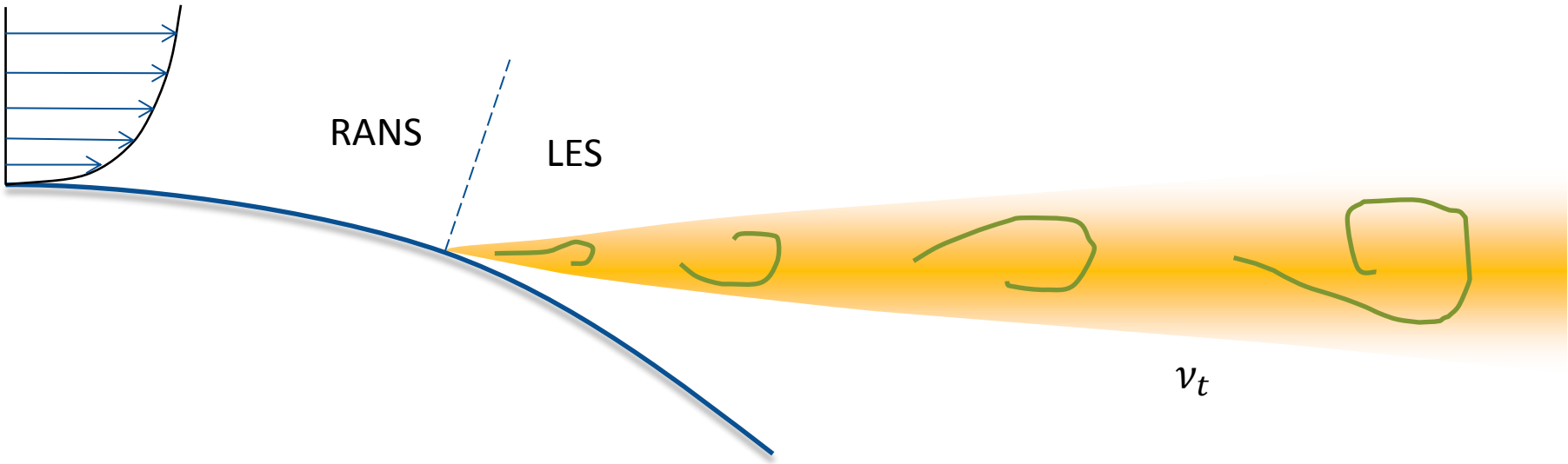
- Method suitability for different classes of flow

"Globally unstable" flows	"Locally unstable" flows	"Stable" flows
		
Applicability of DES-like methods		
Applicability of SAS	(SAS requires forcing to enter scale-resolving mode)	
		Embedded approaches necessary
		Applicability/suitability of WMLES methods
	Embedded approaches recommended if separation location can be readily defined and/or if definition of RANS/LES zones is practicable Otherwise careful use of shielded DES-like approaches (e.g. DDES) recommended.	

"Weakly separated" flows are poorly handled by hybrid RANS-LES methods:
The Grey Area problem

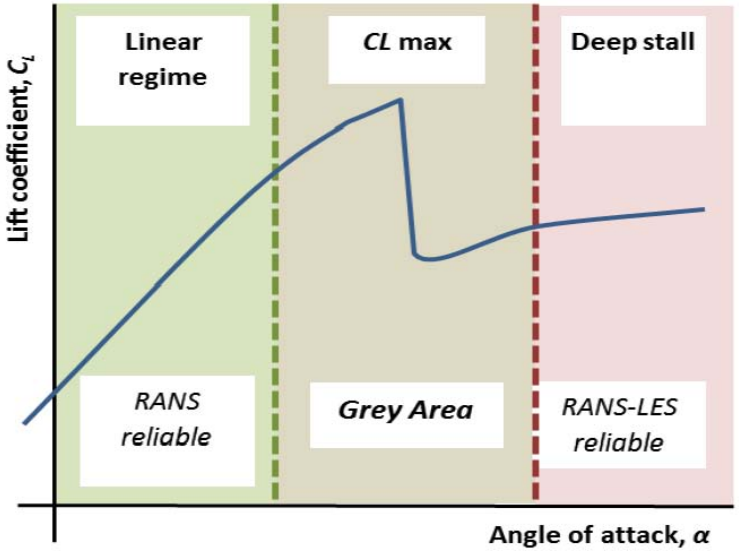
The Grey Area problem

- Essentially the detrimental influence of the “RANS to LES transition” (RLT) region in the early shear layer
- Model switches to LES mode after separation
  - No turbulent fluctuations from upstream
  - Fluctuations must be generated by natural shear layer instability

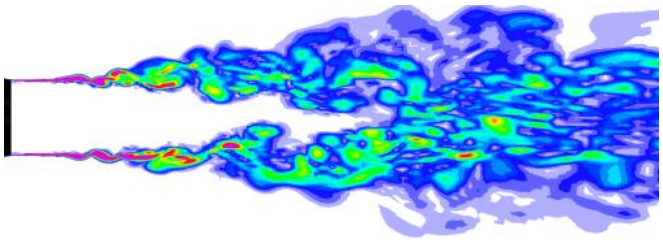


Impact of the Grey Area in practice

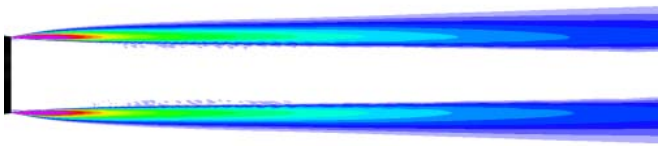
- Unfortunately, weakly-separated flows generally represent the most important cases in practice
  - Limits of performance
  - Flight envelope boundaries
  - Maximum turbine blade loading
- Both RANS and current hybrid RANS-LES methods are unreliable here
- Another prominent example of the Grey Area problem in practice:
  - Jet flows, e.g. jet noise simulations



What we want…



…what we get!



Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

Example results

Non-zonal approaches

Embedded approaches

Conclusion

The Go4Hybrid project

- "Grey Area Mitigation for Hybrid RANS-LES Methods"
  - Funded by EU in final call of FP7
  - 2 years duration (Oct 2013 – Sept 2015)
- 7 test cases from academic to complex
- Consortium:
  - 7 Partners: University, SMEs & research establishments
  - 10 Industrial Observers
    - Input to project via attendance to meetings
      - Ensure industrial relevance
      - Dissemination of project information to end users
    - No budget from project
  - 2 Associate Partners
    - Do not attend project meetings
    - Contribute specifications and data for application-oriented test cases
    - Receive reports of project results for their test cases in return

Partners

CFD Software E+F GmbH

CFD Software Entwicklungs- und Forschungsgesellschaft mbH

(Coordinator)

DLR

FOI

ONERA

THE FRENCH AEROSPACE LAB

NLR

New Technologies NTS and Services

MANCHESTER 1824

Observers

ANSYS

BOMBARDIER
the evolution of mobility

EDF

Das Auto.

Exa

PSA PEUGEOT CITROËN

SAAB TECHNOLOGIES SAAB

NUMECA INTERNATIONAL

GE Global Research

ROLLS ROYCE Rolls-Royce

Associate Partners

AIRBUS DEFENCE & SPACE

AIRBUS HELICOPTERS

Addressing the Grey Area issue

- In Go4Hybrid we pursue a dual strategy, reflecting the most promising avenues to resolving the Grey Area issue:
  - Develop techniques for Grey Area mitigation in **non-zonal methods**
  - Improve flexibility and fidelity of **embedded approaches**
- Non-zonal methods (e.g. DES)
  - The model decides where to apply RANS and LES, not the user
  - Generally more flexible and suitable for complex applications
  - Suffer from the Grey Area
- Embedded approaches
  - Explicit treatment used to translate modelled turbulence into resolved eddies at a user-defined RANS-LES interface
  - Solves the Grey Area issue
  - However less flexible, less widely-applicable to complex applications

How can this be achieved?

- Non-zonal Grey Area mitigation:
  - Reduction of eddy viscosity in early separated shear layer
  - Addition of energy / triggering of instabilities in early separated shear layer
  - Challenges: Generality, robustness
- Improved embedded approaches:
  - Improvement of synthetic turbulence generators (reduction of “recovery length”)
  - Improvement of flexibility, e.g. arbitrary interface positioning
  - Challenges: Maintaining full two-way coupling between RANS and LES regions

Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

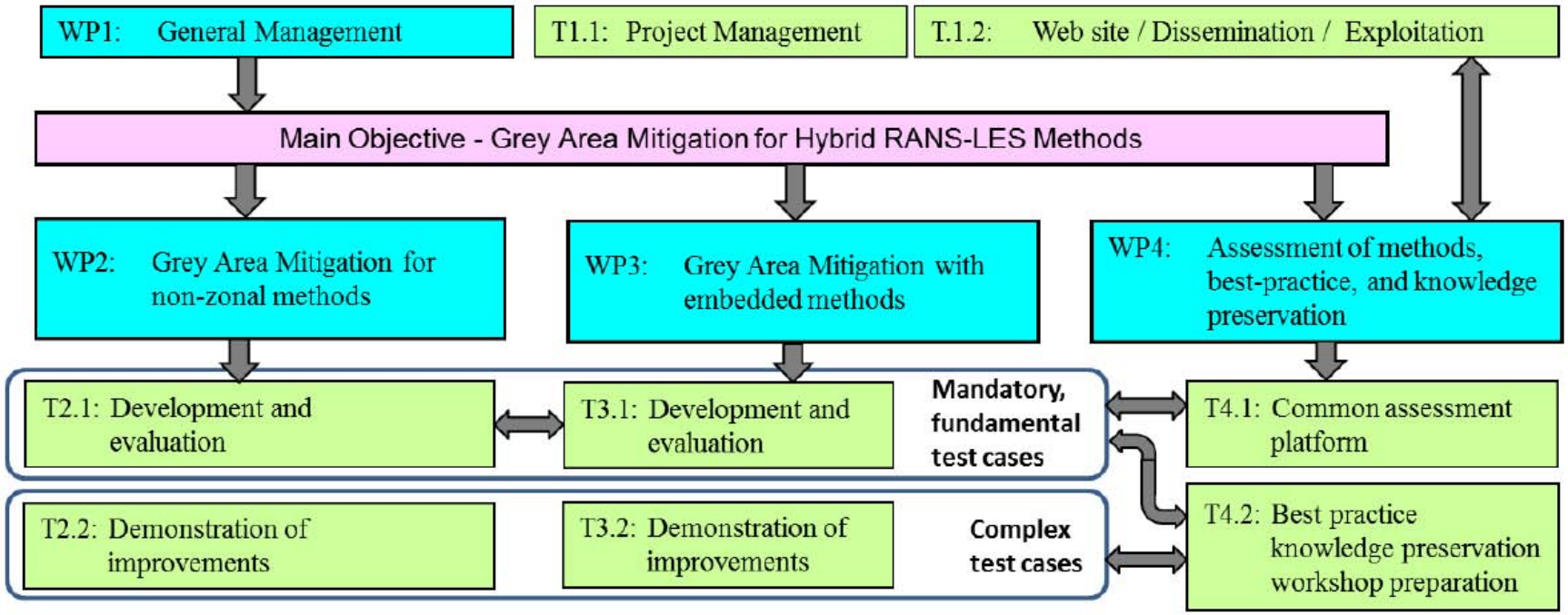
Example results

Non-zonal approaches

Embedded approaches

Conclusion

Work packages



Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

Example results

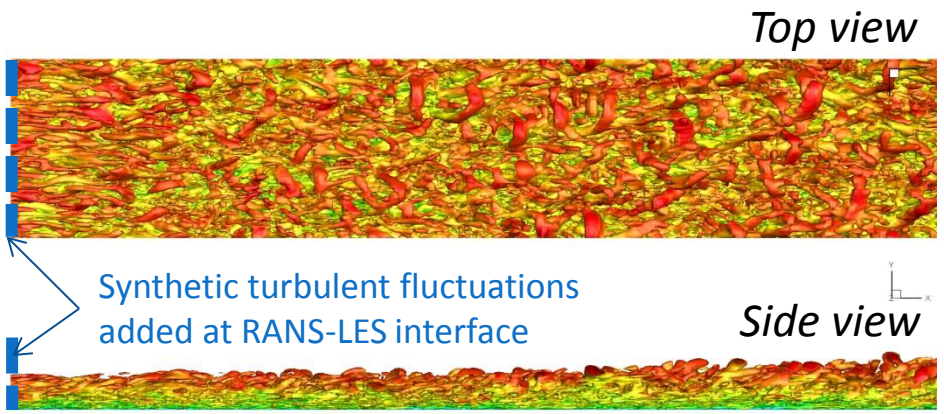
Non-zonal approaches

Embedded approaches

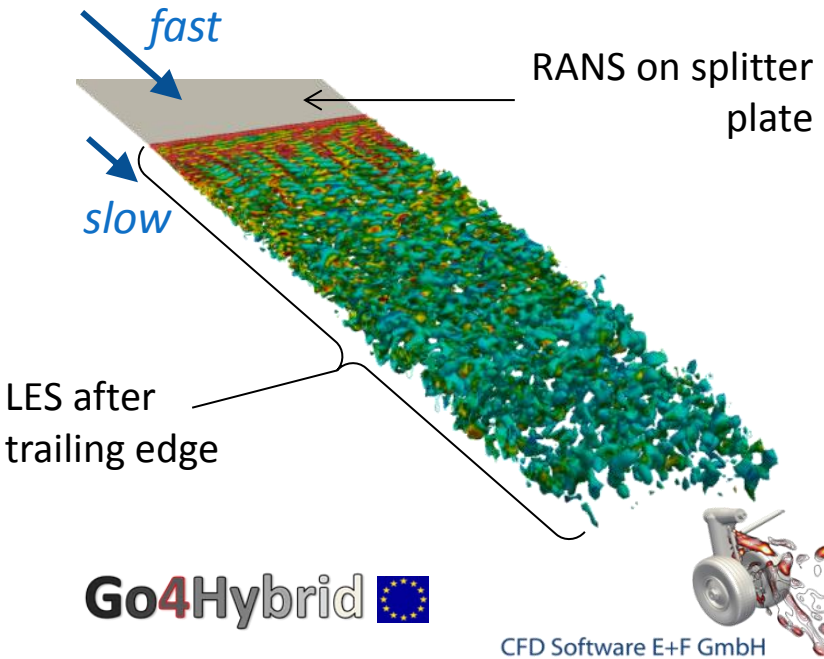
Conclusion

Fundamental test cases

- Flat plate boundary layer
  - For evaluating improved embedded approaches
  - RANS-to-LES and LES-to-RANS interfacing
  - Mandatory for all WP3.1 activities



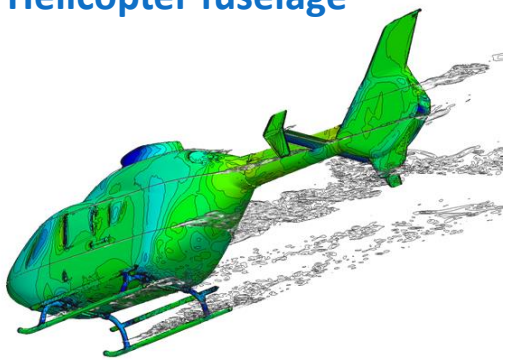
- Spatial shear layer
  - For evaluating improved non-zonal approaches
  - RANS boundary layer to LES shear layer transition
  - Mandatory for all WP2.1 activities



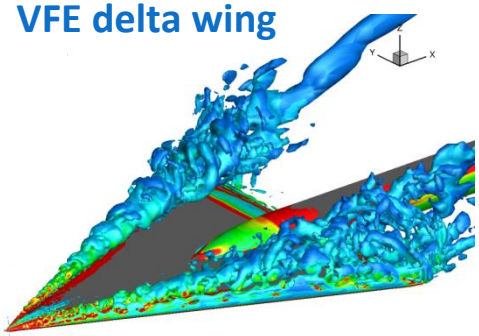
Complex demonstration cases

- To investigate more complex flow topologies
- To demonstrate improvements for real-world applications

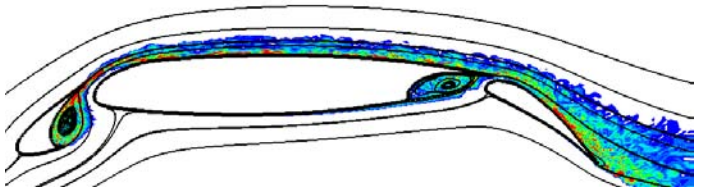
Helicopter fuselage

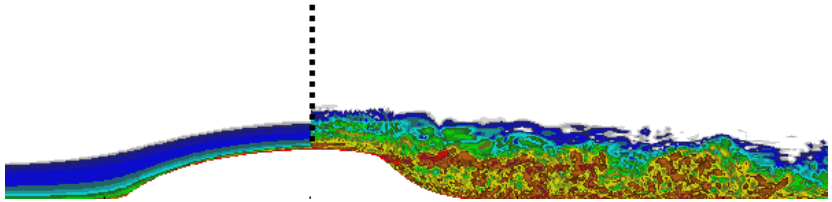


VFE delta wing

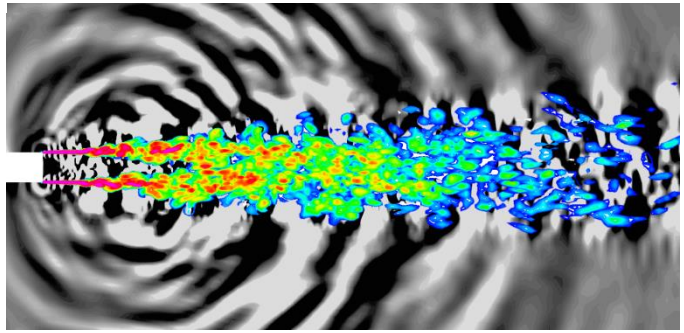


LEISA 3-element airfoil





2D hump (separating-reattaching flow)



M=0.9 round jet (aeroacoustics)

Work package 4

- “Assessment of methods, best practice and knowledge preservation”
  - WP4.1: Common assessment platform
    - Grid dependency will be eliminated by mandatory grids
    - However each partner uses a different CFD solver
    - To eliminate numerics dependency, the most promising methods from each partner will be implemented into one code and compared directly
    - Platform: OpenFOAM
      - Widely-used open-source CFD solver in industry and academia
    - CFDB to implement non-zonal methods (from WP2.1)
    - UniMAN to implement embedded approaches (from WP3.1)

Work package 4

- “Assessment of methods, best practice and knowledge preservation”
  - WP4.2: Best practice, knowledge preservation, workshop preparation
    - The findings of the project will be analysed to derive best practice guidelines
    - Contribution of descriptions and results of selected test cases to the ERCOFTAC Knowledge Base Wiki (knowledge preservation)
    - Organisation of data input from WP2 and WP3 for the two assessment workshops (M15 and M24)
    - WP4.2 is essentially the “hub” of the project and a major output of Go4Hybrid

Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

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Plane shear layer: CFDB results

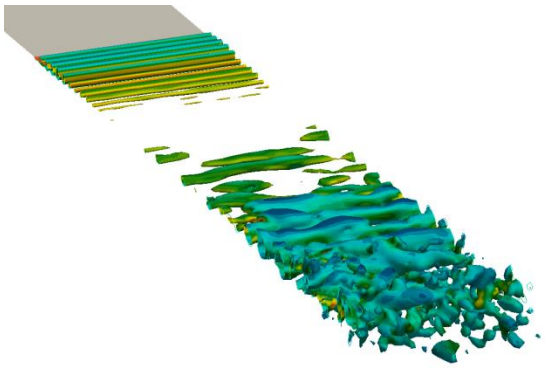
- Approaches aim to reduce eddy viscosity in early shear layer in generally-applicable manner

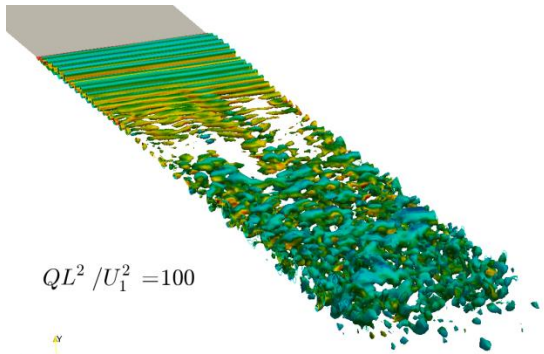
Std. DDES

Improved DDES 1

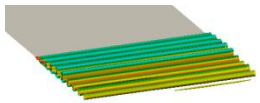
Improved DDES 2

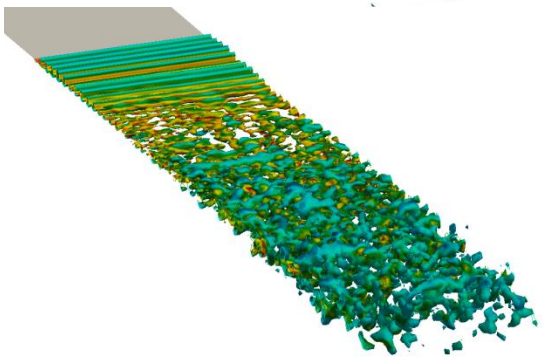
Std. Δ_{max}

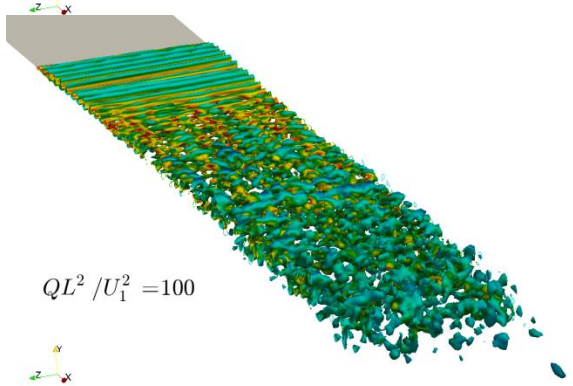




Improved $\tilde{\Delta}_{\omega}$



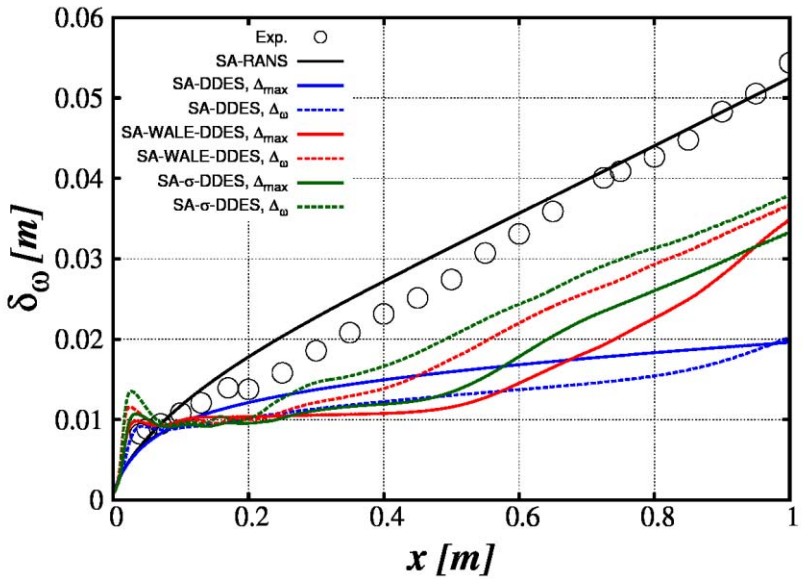




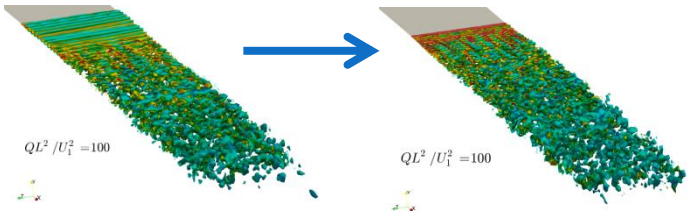
Plane shear layer: CFDB results

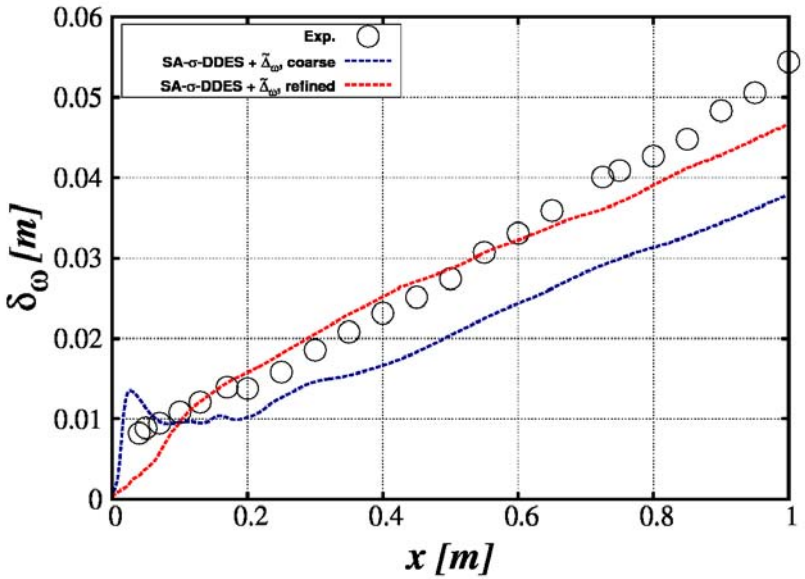
- Strong improvement in shear layer development
- Further improvement with grid refinement

Comparison of approaches on coarse grid



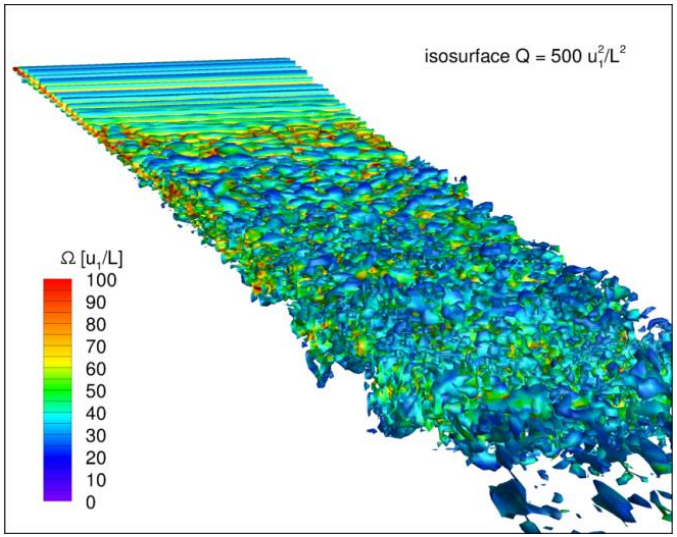
Coarse Fine



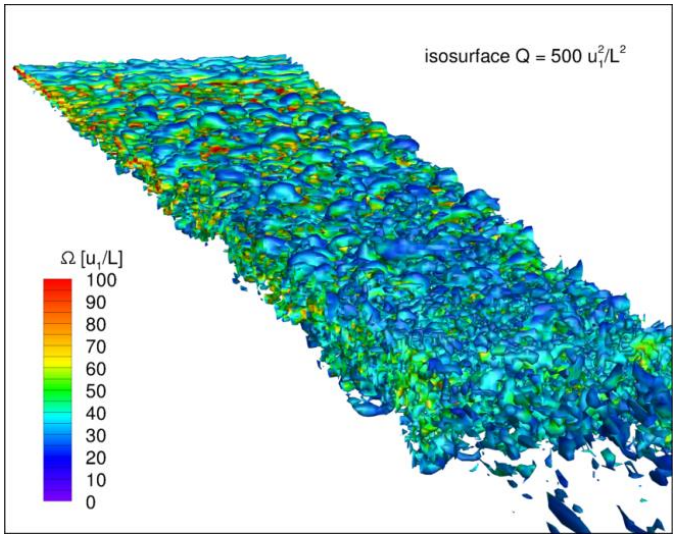


Plane shear layer: NLR results

- Variety of non-zonal approaches explored:
  - Reduction of eddy viscosity: High-pass filtering, alternative SGS models
  - “Stirring” of instabilities: Stochastic eddy viscosity & backscatter approaches



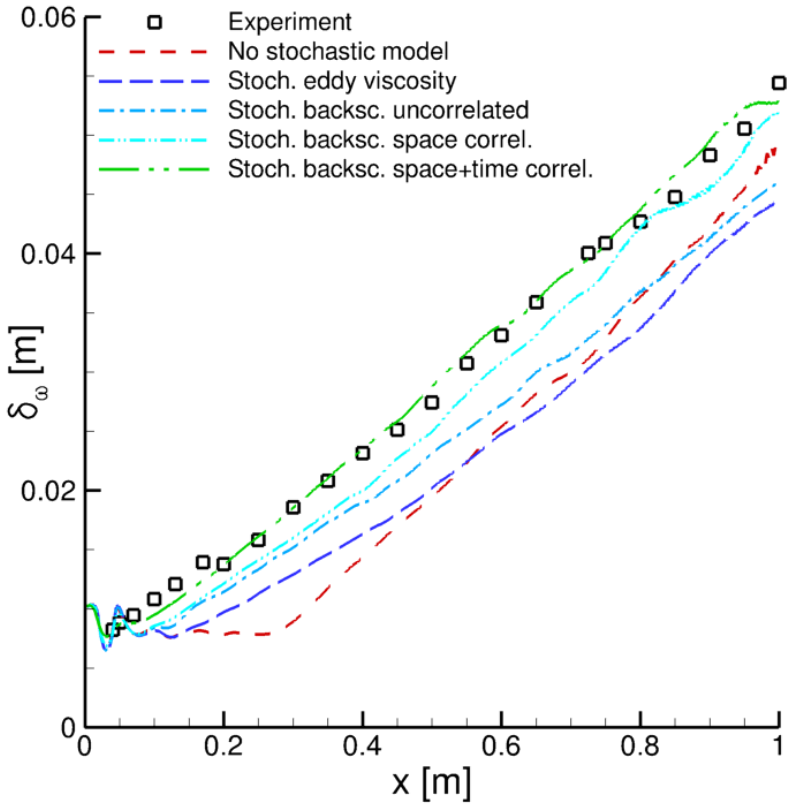
Equivalent approach to CFDB
(no backscatter)



Stochastic backscatter
(spatial & temporal correlated)

Plane shear layer: NLR results

- Addition of backscatter further improves prediction of shear layer development

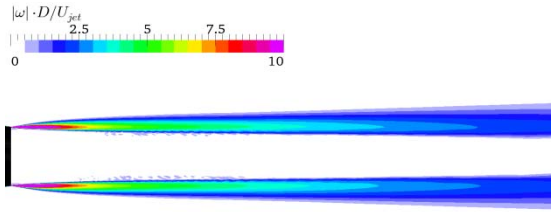


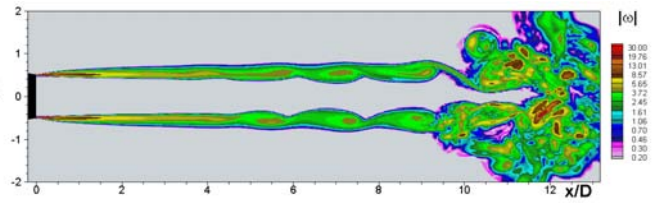
Round jet: CFDB & NTS results

CFDB (coarse grid)

NTS (fine grid)

SA-DDES

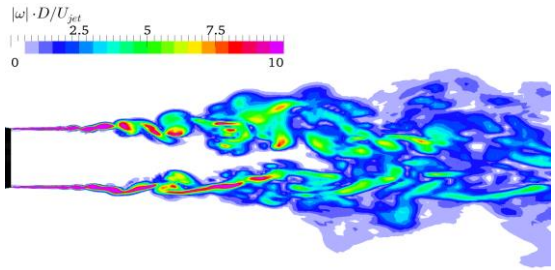


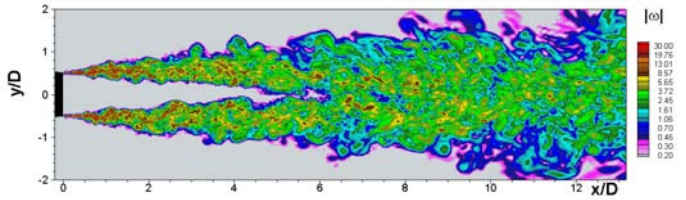


SA-DDES

SA-σ-DDES

$\Delta_{\max}$



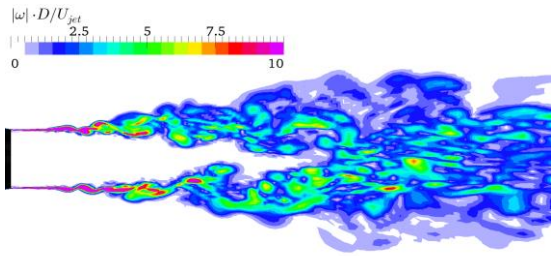


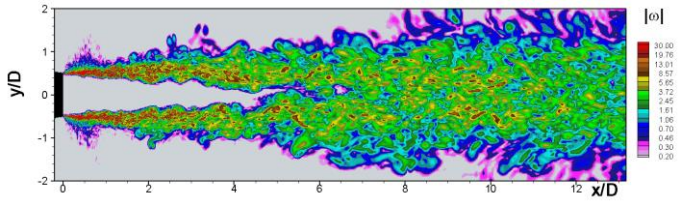
SA-DDES

Δ_{NTS}

SA-σ-DDES

$\widetilde{\Delta}_{\omega}$





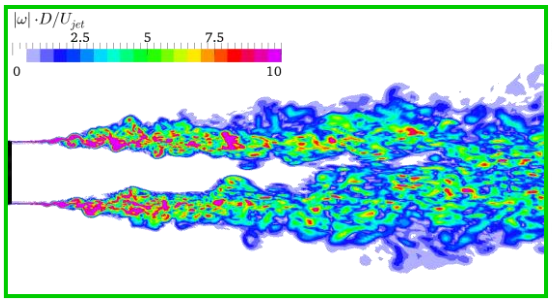
Zonal Implicit LES

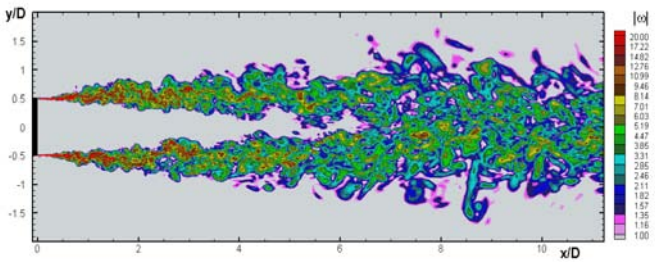
Round jet: CFDB & NTS results

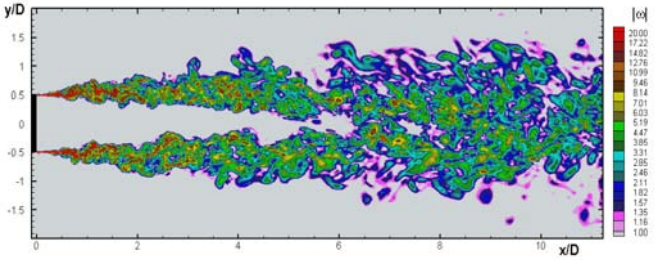
CFDB: SA-σ-DDES +

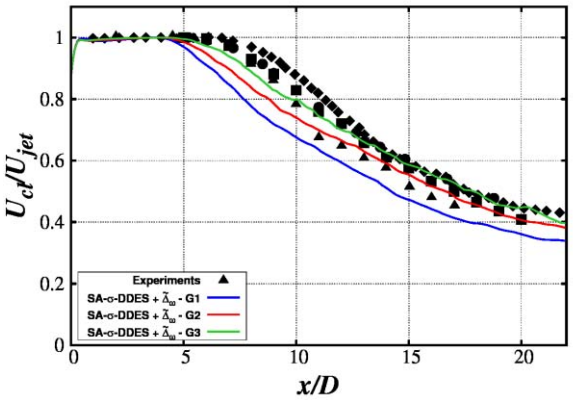
NTS: WALE DDES + $\widetilde{\Delta}_{\omega}$

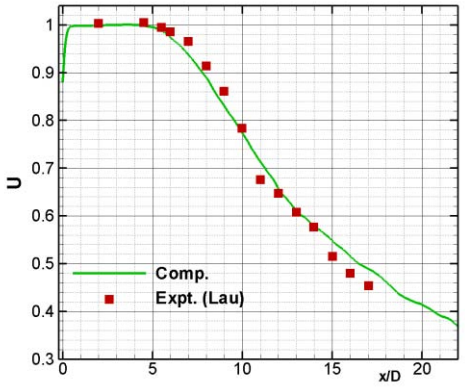
NTS: SA DDES + Δ_{NTS}

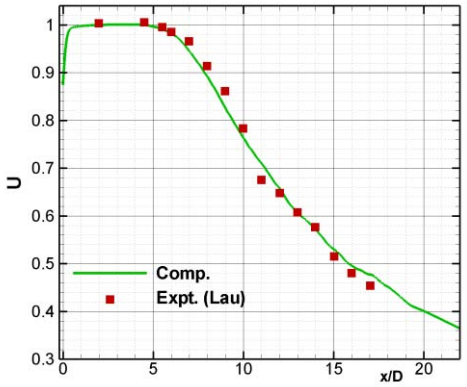








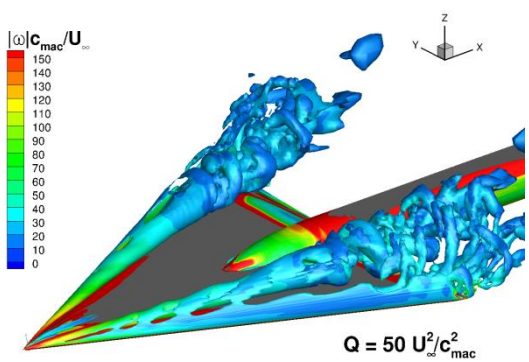




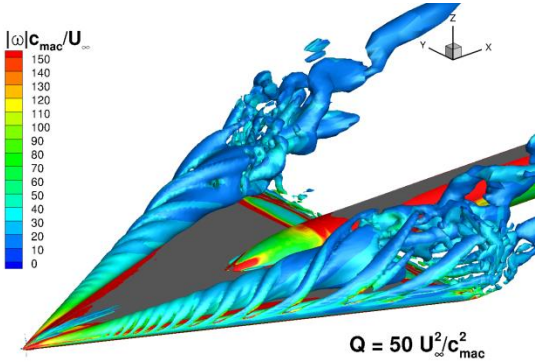
Delta wing: CFDB and NLR results

- Both partners see dramatic effect of grey area mitigation strategies

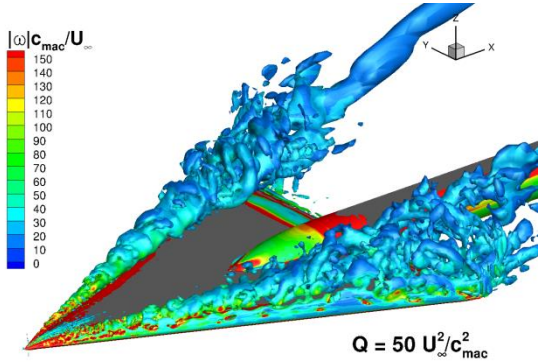
CFDB



std. SA-DDES + Δ_{max}

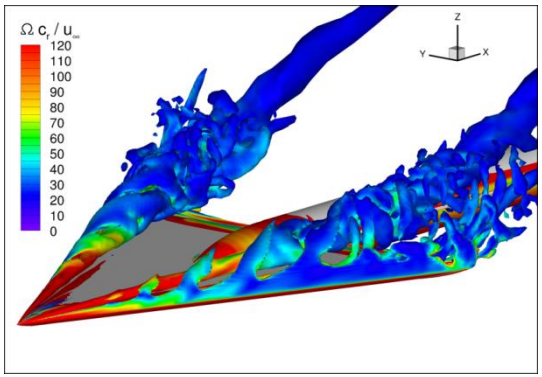


SA-WALE-DDES + $\widetilde{\Delta}_{\omega}$

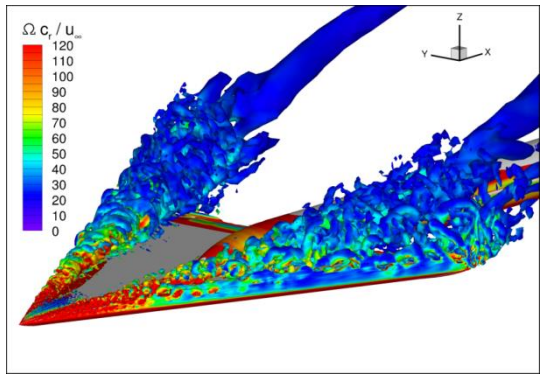


SA-σ-DDES + $\widetilde{\Delta}_{\omega}$

NLR



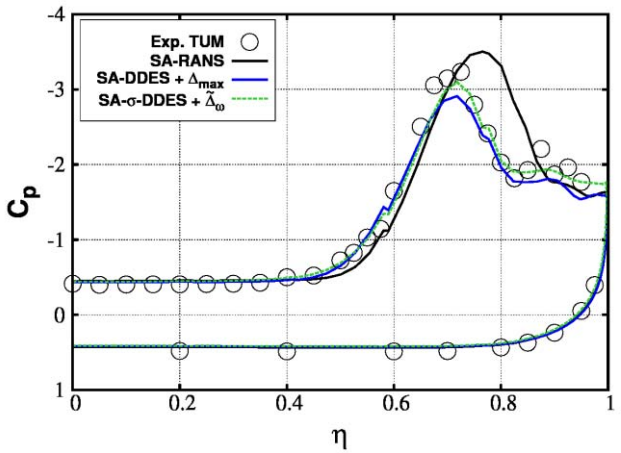
std. SST-DDES

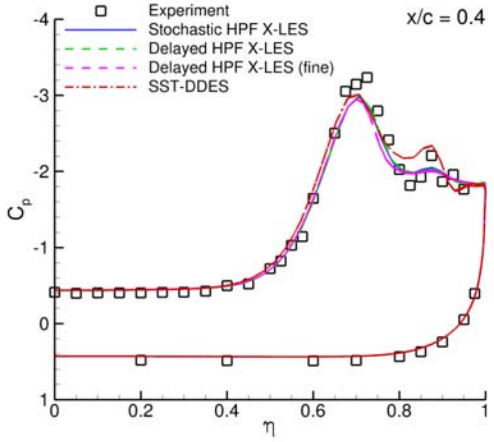


HPF X-LES

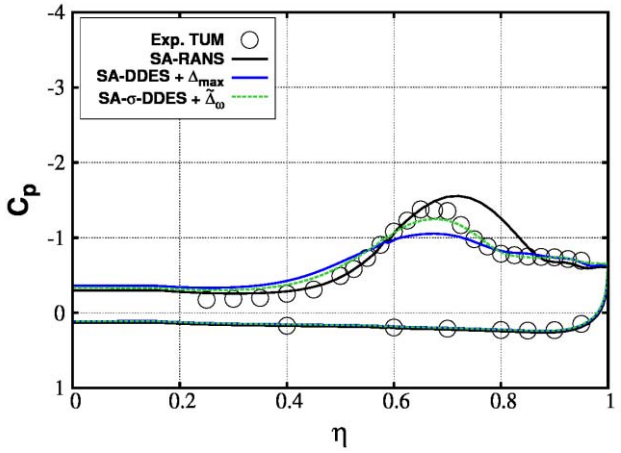
Delta wing: CFDB and NLR results

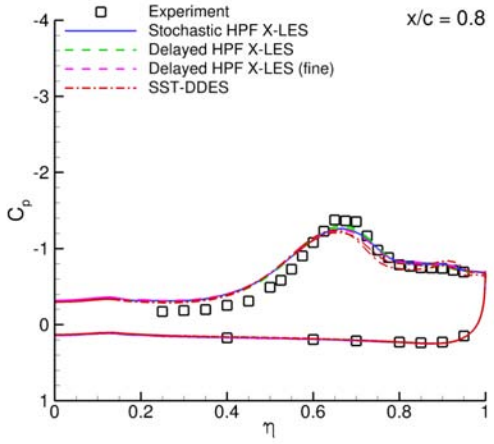
$x/c_r = 0.4$





$x/c_r = 0.8$





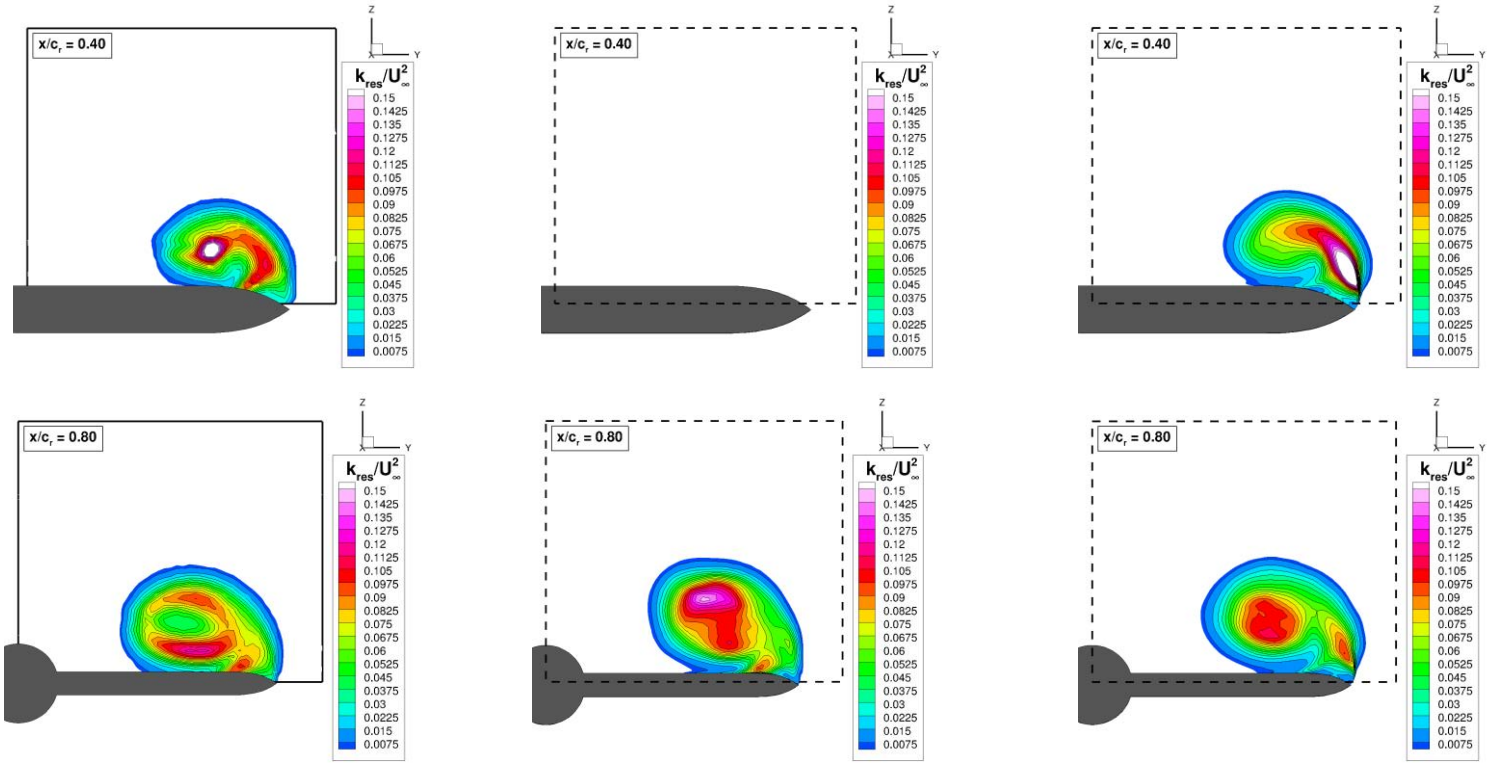
CFDB

NLR

Delta wing: CFDB results

$x/c_r = 0.4$

$x/c_r = 0.8$



Experiment | Std. DDES | Improved DDES

Introduction

Background and motivation

The Go4Hybrid project

Work plan

Work packages

Test cases

Example results

Non-zonal approaches

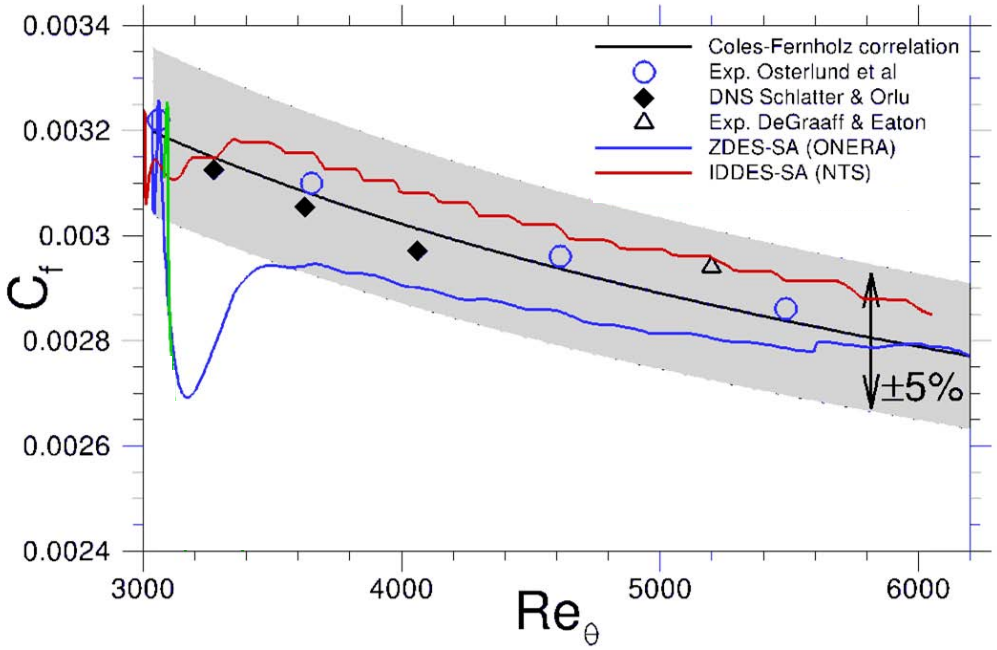
Embedded approaches

Conclusion

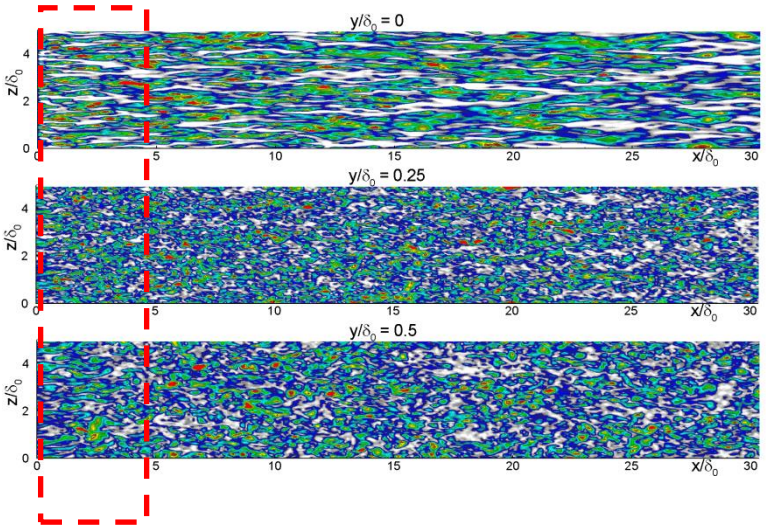
Flat plate: NTS and ONERA results

- Encouraging results: recovery of boundary layer within 10 δ
- Two different synthetic turbulence methods compared
  - Harmonic STG method (NTS)
  - Variant of Synthetic Eddy Method (ONERA)

Streamwise profile of skin friction coefficient

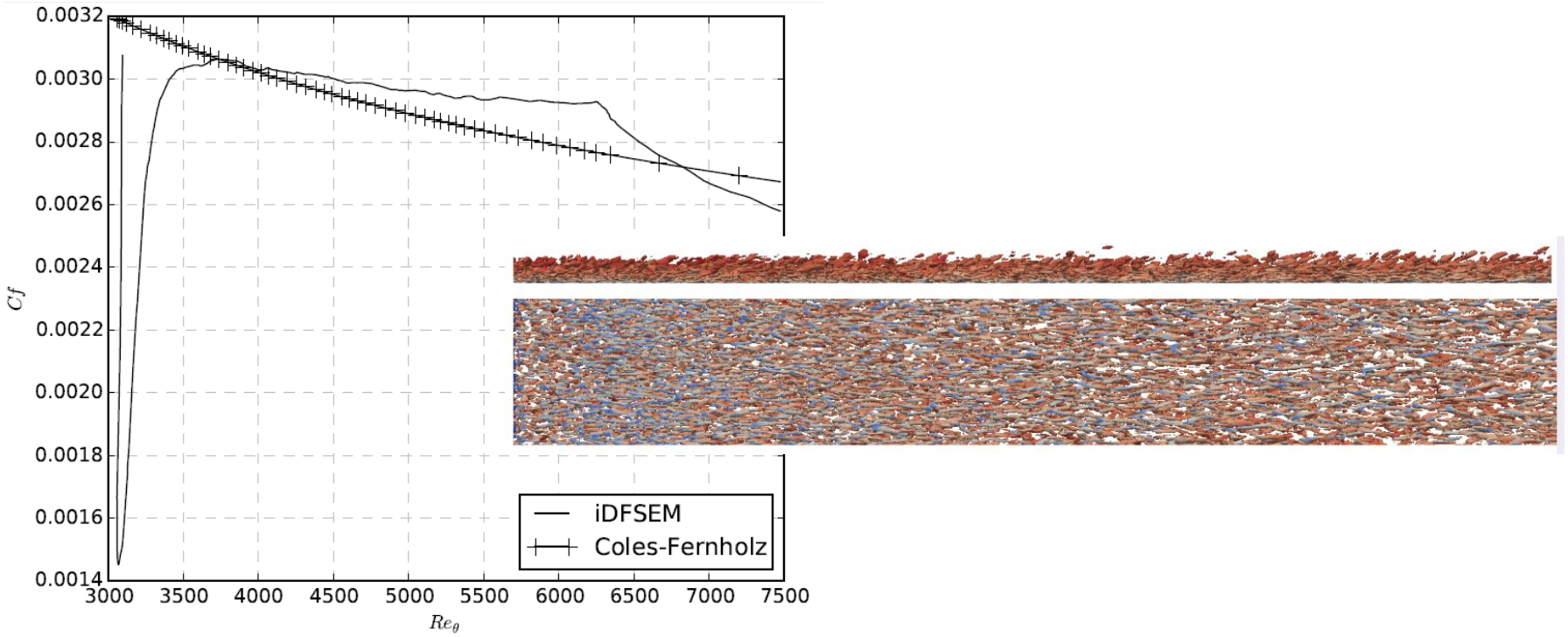


Flow visualisation (NTS)



Flat plate: UMan results

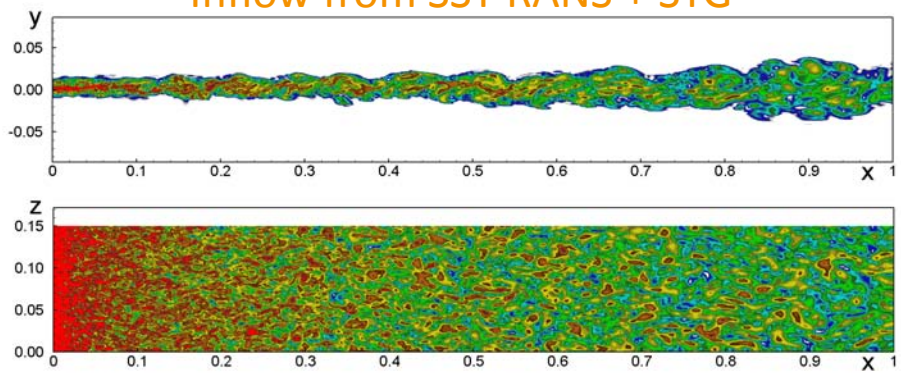
- Encouraging results: recovery of boundary layer within 10 δ
- Improved version of SEM



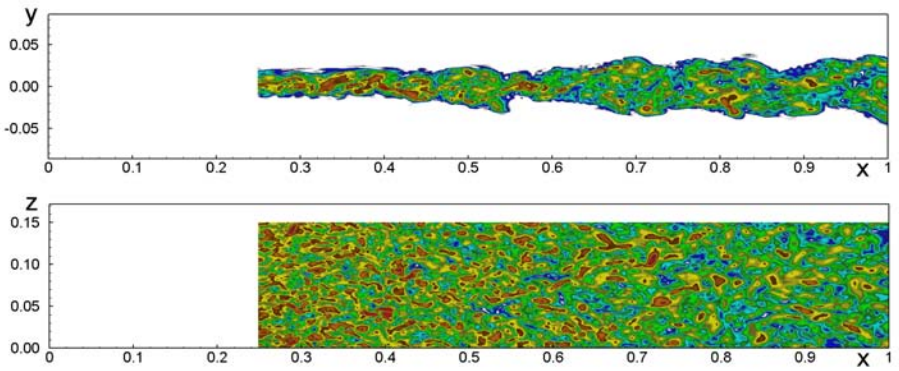
Shear layer: NTS results

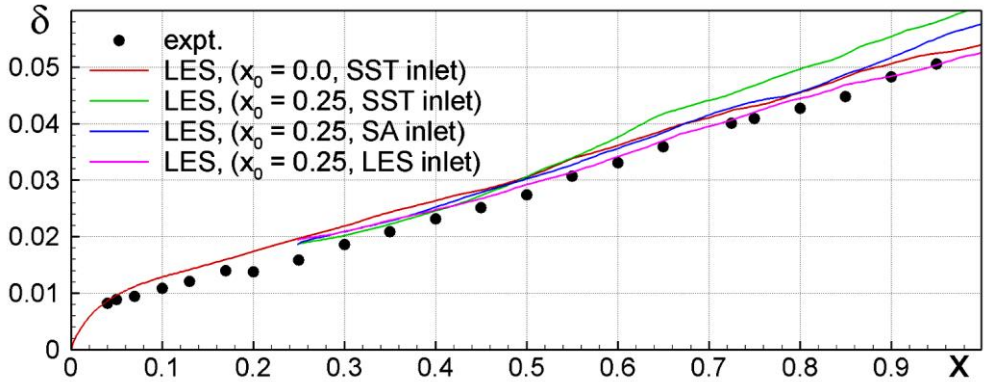
- Synthetic turbulence interface at different streamwise locations

Interface at TE (**x=0**),
Inflow from SST RANS + STG



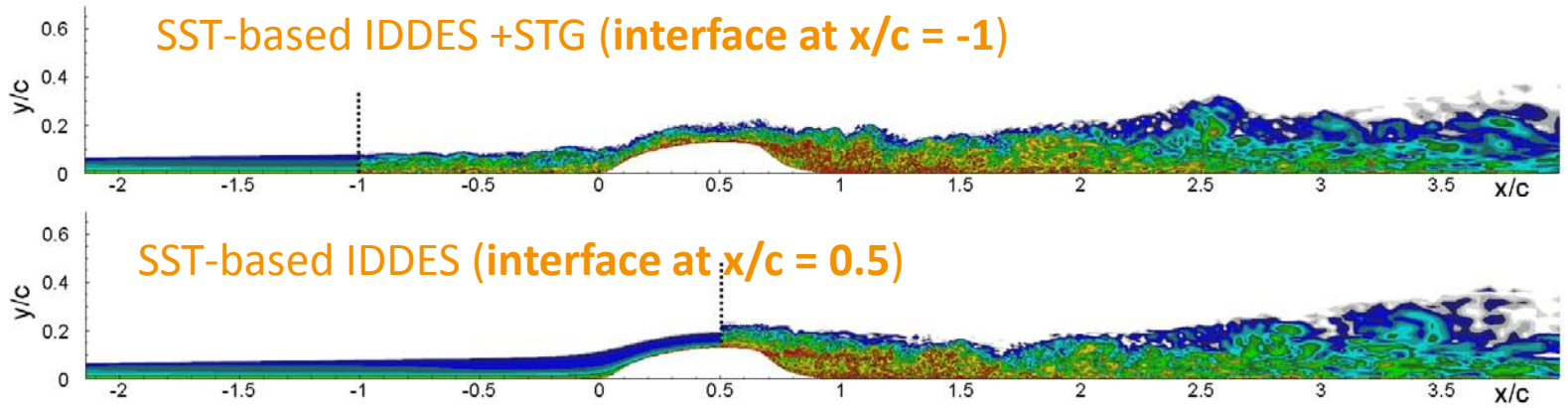
Interface at x=**0.25m**,
Inflow from SST RANS + STG

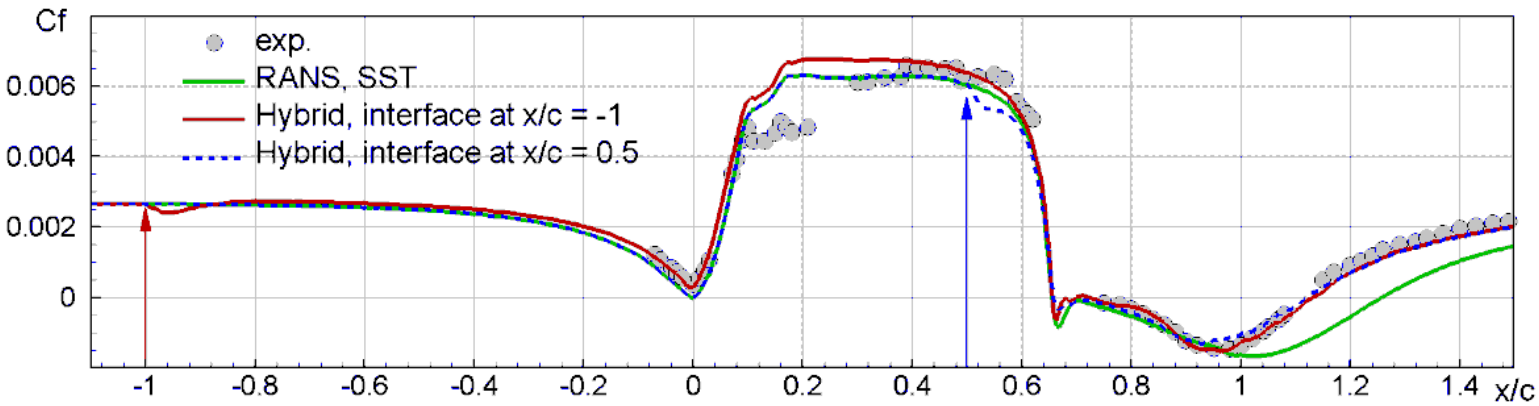




2D hump: NTS results

- Synthetic turbulence interface at different streamwise locations





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Conclusion

- Go4Hybrid is a highly-focussed R&D effort aiming at improvement for one of the major remaining issues in hybrid RANS-LES
- Progress made towards:
  - Reduced Grey Area severity for non-zonal methods
  - Improved accuracy and flexibility of embedded methods
- Industrial relevance and applicability is a high priority
  - Industrial observers and associate partners a key vehicle to assure this
- Very promising situation at mid-term:
  - Promising results for improved methods
  - Progress on track, despite ambitious time plan
- Priorities for the final year:
  - Direct comparison of methods in “Common Assessment Platform”
  - Further demonstration of fidelity & robustness for complex cases
  - Compilation of conclusions and extraction of best-practice guidelines
  - Final open workshop: To be announced soon

Thank you for your attention

Investigation on Nonlinear Transonic Aeroelasticity using a Harmonic Balance Method

4th EASN Flight Physics Workshop
Aachen, Germany

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Outline

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1 Overview

2 Motivation

3 Aeroelastic-Harmonic Balance

4 Uncertainty Quantification

5 Results

6 Conclusions & Outlook

Contents

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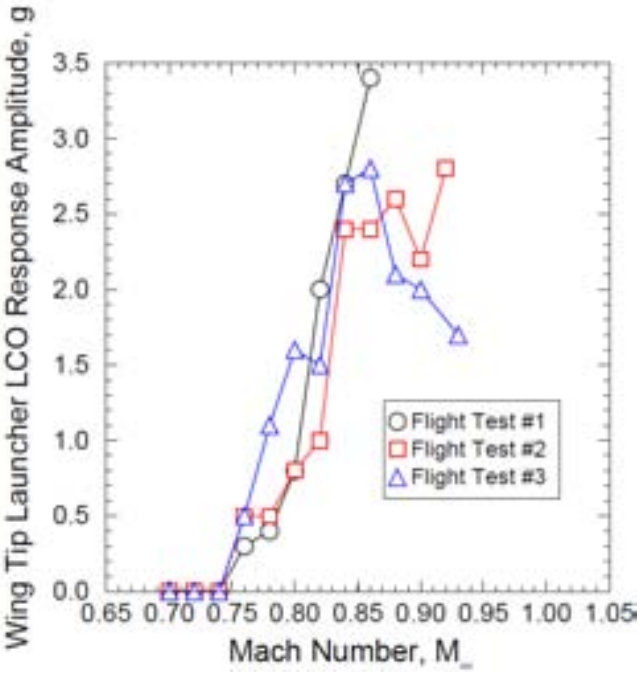
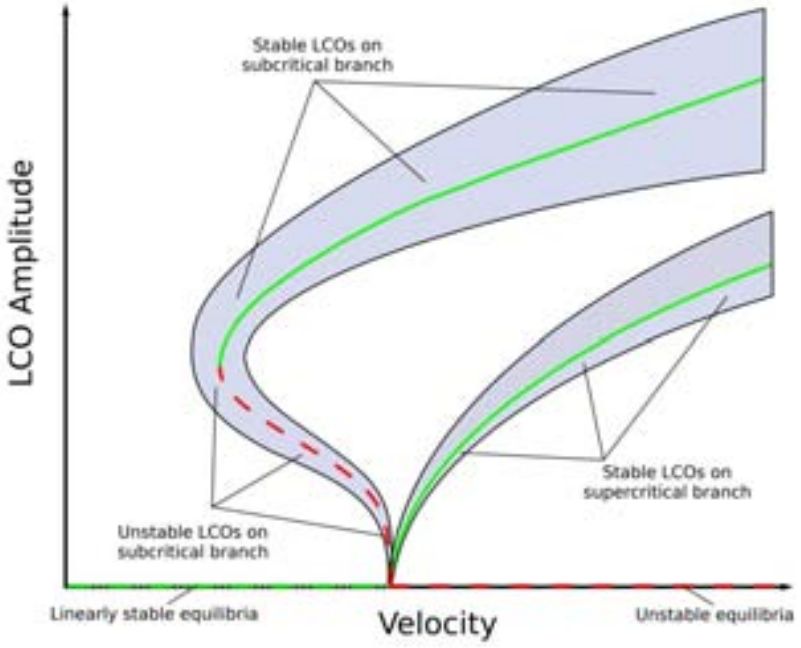
Motivation



F-16 Flight Test Variability[1]



Sub-critical and Super-critical LCO

[1] Thomas *et al.* , AIAA paper 2010-2632

Motivation
Simulation Requirements

Hence, for such problems we need:

- Physics Based (nonlinear) Simulations $\rightarrow$ High-Fidelity Analysis
- Uncertainty & Variability $\rightarrow$ Probabilistic/Possibilistic
- Large Paramenter Spaces $\rightarrow$ Efficient Methods
- Integration of Available Measurements $\rightarrow$ Model Updating and Calibration

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Harmonic Balance Methodology

- Consider a generic dynamic system described by the equations of motion:

$$\mathbf{M}\ddot{x} + \mathbf{C}\dot{x} + \mathbf{K}x = \mathbf{F}$$
$$\dot{\mathbf{W}} + \mathbf{R} = 0$$

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- Assume the solution is periodic, it is approximated by a truncated Fourier series of N_H harmonics and fundamental frequency ω

$$\begin{aligned} x(t) &\approx \hat{x}_0 + \sum_{n=1}^{N_H} (\hat{x}_{2n-1}\cos(n\omega t) + \hat{x}_{2n}\sin(n\omega t)) \\ x(t) &\approx \mathbf{G}\hat{\mathbf{x}} \\ \mathbf{G} &= [1, \cos(\omega t), \sin(\omega t), \cos(2\omega t), \sin(2\omega t), \cos(3\omega t), \sin(3\omega t), \ldots] \end{aligned}$$

HB for CFD

Consider the general form of the fluid Euler equations:

$$\frac{\partial \mathbf{W}(t)}{\partial t} + \mathbf{R}(t) = 0$$

HB for CFD

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$$\frac{\partial \mathbf{W}(t)}{\partial t} + \mathbf{R}(t) = 0$$

Apply Fourier expansion to $\mathbf{W}$ & $\mathbf{R}$ and re-write eq. in the frequency domain:

$$\omega \mathbf{A}\hat{\mathbf{W}} + \hat{\mathbf{R}} = 0$$

$$\hat{\mathbf{W}} = \mathbf{E}\mathbf{W}, \quad \mathbf{E} = \frac{2}{2N_H + 1} \begin{bmatrix} 1/2 & 1/2 & \cdots & 1/2 \\ \cos t_0 & \cos t_1 & \cdots & \cos t_{2N_H} \\ \sin t_0 & \sin t_1 & \cdots & \sin t_{2N_H} \\ \cos 2t_0 & \cos 2t_1 & \cdots & \cos 2t_{2N_H} \\ \sin 2t_0 & \sin 2t_1 & \cdots & \sin 2t_{2N_H} \\ \vdots & \vdots & \cdots & \vdots \\ \cos N_H t_0 & \cos N_H t_1 & \cdots & \cos N_H t_{2N_H} \\ \sin N_H t_0 & \sin N_H t_1 & \cdots & \sin N_H t_{2N_H} \end{bmatrix}$$

HB for CFD

Recast the Fourier coefficients in the time domain and solve:

$$\underbrace{\frac{\partial \tilde{\mathbf{W}}}{\partial \tau}}_{pseudo-time} + \underbrace{\omega \mathbf{D} \tilde{\mathbf{W}}}_{Unsteady\ \ Source} + \underbrace{\tilde{\mathbf{R}}}_{residual} = 0$$

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$$\underbrace{\frac{\partial \tilde{\mathbf{W}}}{\partial \tau}}_{pseudo-time} + \underbrace{\omega \mathbf{D}\tilde{\mathbf{W}}}_{Unsteady\ \ Source} + \underbrace{\tilde{\mathbf{R}}}_{residual} = 0$$

where:

$$\mathbf{D} = \mathbf{E}^{-1}\mathbf{A}\mathbf{E}, \quad \tilde{\mathbf{W}} = \begin{bmatrix} \mathbf{W}(t_0) \\ \mathbf{W}(t_1) \\ \vdots \\ \mathbf{W}(t_{2N_H}) \end{bmatrix}$$

$$t_i = \frac{i2\pi}{2N_H + 1}, \quad i = \{0, 1, 2, \ldots, 2N_H\}$$

Aeroelastic - Harmonic Balance (A-HB)
How to develop an aeroelastic analysis method?

Consider a generic, undamped, structural system described by the equation of motion:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{F}(\mathbf{W})$$

Aeroelastic - Harmonic Balance (A-HB)
How to develop an aeroelastic analysis method?

Consider a generic, undamped, structural system described by the equation of motion:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{F}(\mathbf{W})$$

Recast in state-space form

$$\dot{\mathbf{y}} = \mathbf{A}_s\mathbf{y} + \mathbf{B}_s\mathbf{F}$$

where:

$$\mathbf{A}_s = \begin{bmatrix} 0 & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & 0 \end{bmatrix}; \quad \mathbf{B}_s = \begin{bmatrix} 0 \\ \mathbf{M}^{-1} \end{bmatrix}; \quad \mathbf{y} = \begin{bmatrix} \mathbf{x} \\ \dot{\mathbf{x}} \end{bmatrix}$$

HB for CFD

Applying the same transformations, we obtain a coupled system in the HB format:

$$\frac{\partial \tilde{\mathbf{y}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{y}} + (\mathbf{A}_s\tilde{\mathbf{y}} + \mathbf{B}_s\mathbf{F}) = 0$$

$$\frac{\partial \tilde{\mathbf{W}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{W}} + \tilde{\mathbf{R}} = 0$$

HB for CFD

Applying the same transformations, we obtain a coupled system in the HB format:

$$\frac{\partial \tilde{\mathbf{y}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{y}} + (\mathbf{A}_s \tilde{\mathbf{y}} + \mathbf{B}_s \mathbf{F}) = 0$$

$$\frac{\partial \tilde{\mathbf{W}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{W}} + \tilde{\mathbf{R}} = 0$$

Even CFD unsteady problems can be computed efficiently, as long as N_H does not become excessive and ω is known.

LCO Prediction

- However, we don't know ω_{LCO}

LCO Prediction

- However, we don't know ω_{LCO}
- New approach based on frequency updating

LCO Prediction
HB with Frequency Updating

Define the following residual:

$$\mathbf{R}(\omega, \mathbf{y}) = \omega \mathbf{D}\mathbf{y} - (\mathbf{A}_s\mathbf{y} + \mathbf{B}_s\mathbf{f})$$

From the residual, define the following figure of merit:

$$\mathbf{L}_2 = \frac{1}{2}\mathbf{R}^T\mathbf{R} = \frac{1}{2}\left[\omega \mathbf{D}\mathbf{y} - (\mathbf{A}_s\mathbf{y} + \mathbf{B}_s\mathbf{f})\right]^T \left[\omega \mathbf{D}\mathbf{y} - (\mathbf{A}_s\mathbf{y} + \mathbf{B}_s\mathbf{f})\right]$$

LCO Prediction
HB with Frequency Updating

We then propose the following algorithm to determine LCOs:

Find $[\omega, \mathbf{F}]$ that minimizes $\mathbf{R}(\omega, \mathbf{y})$ using:

$$\frac{\partial \tilde{\mathbf{y}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{y}} + (\mathbf{A}_s \tilde{\mathbf{y}} + \mathbf{B}_s \mathbf{F}) = 0$$

$$\downarrow$$

$$\frac{\partial \tilde{\mathbf{W}}}{\partial \tau} + \omega \mathbf{D}\tilde{\mathbf{W}} + \tilde{\mathbf{R}} = 0$$

$$\downarrow$$

$$\frac{\partial \mathbf{L}_n}{\partial \omega} = \left(\mathbf{D}\mathbf{y} - \mathbf{B}_s \frac{\partial \mathbf{f}}{\partial \omega} \right)^T \left[\omega \mathbf{D}\mathbf{y} - (\mathbf{A}_s \mathbf{y} + \mathbf{B}_s \mathbf{f}) \right]$$

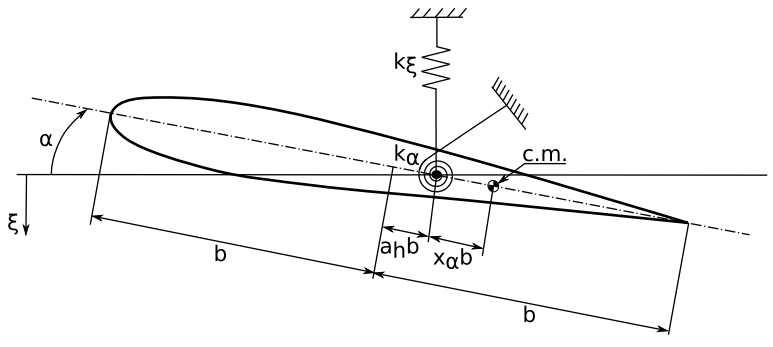
Outline

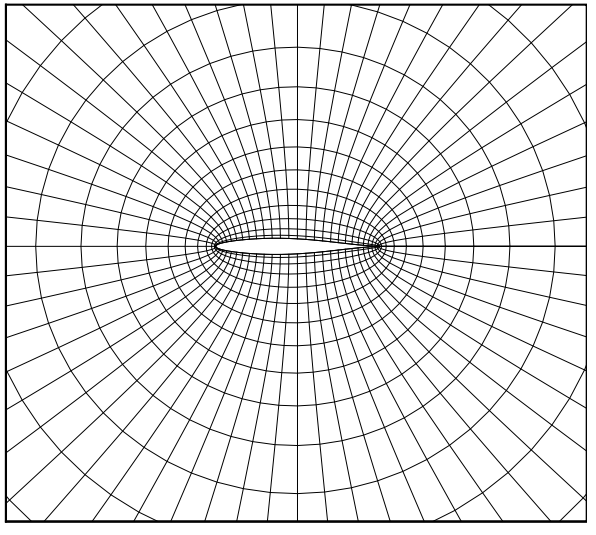
3 Aeroelastic-Harmonic Balance
- Validation

Transonic pitch/plunge Aerofoil

NACA 64_A010, Inviscid, Transonic Flow ($M_\infty = 0.8$)

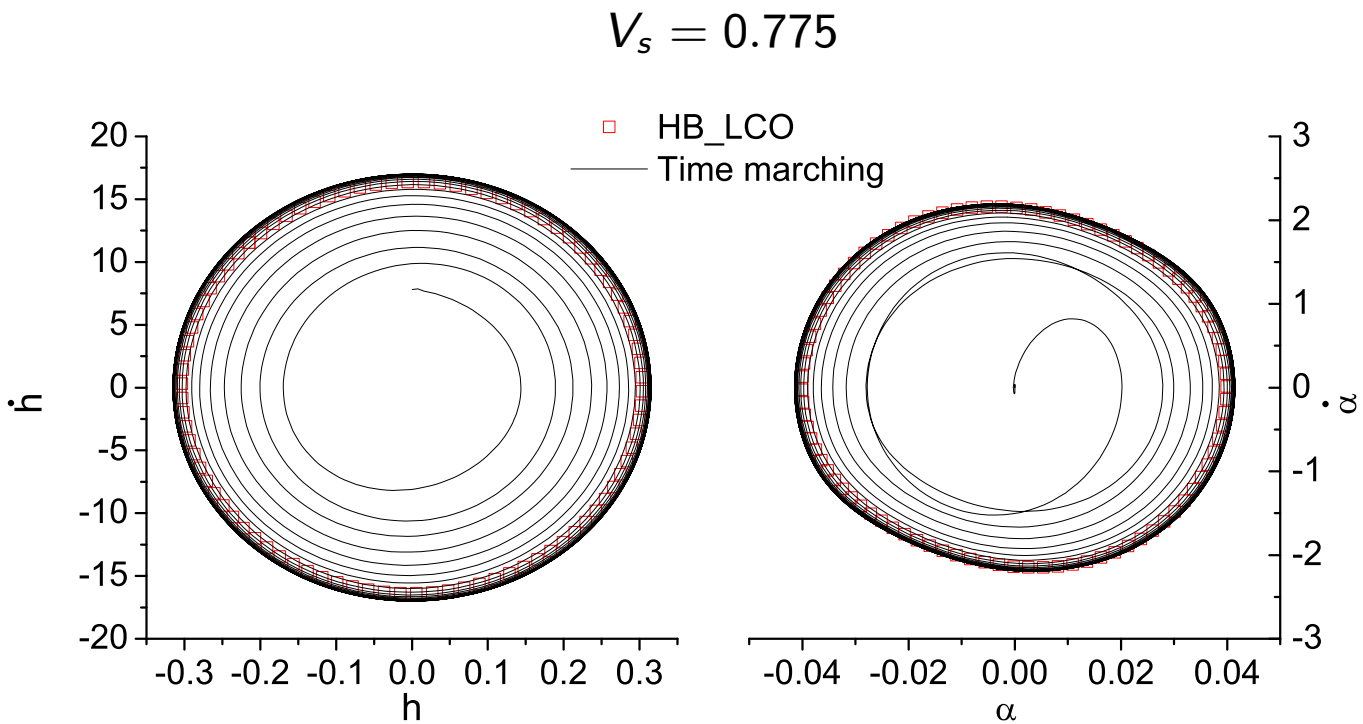
$$m\ddot{h} + S_\alpha \ddot{\alpha} + k_h h = -q_\infty c C_l$$
$$S_\alpha \ddot{h} + I_\alpha \ddot{\alpha} + k_\alpha \alpha = -q_\infty c^2 C_m$$



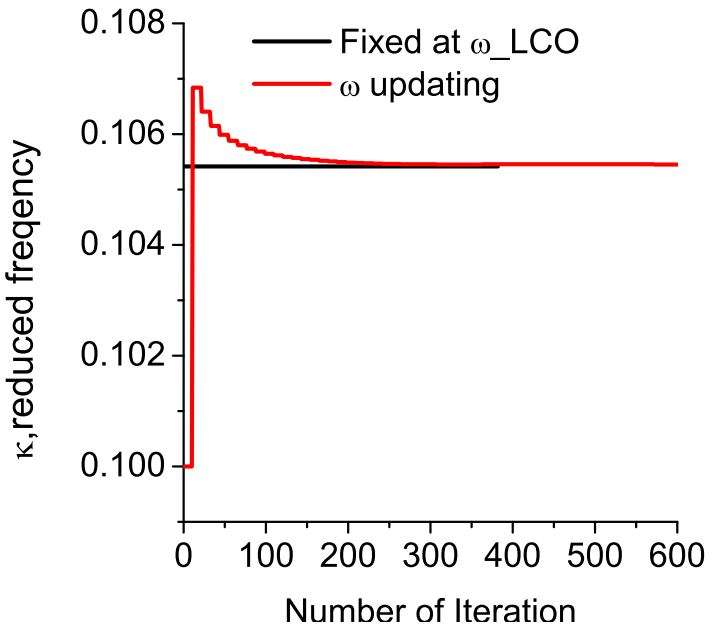


The flutter condition is $[\omega, V_s] = [0.1089, 0.693]$

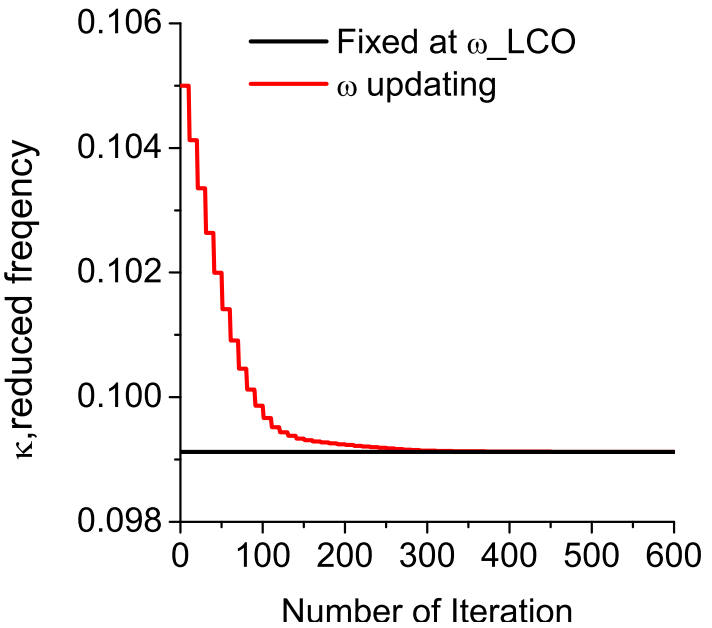
Transonic pitch/plunge Aerofoil



Transonic pitch/plunge Aerofoil

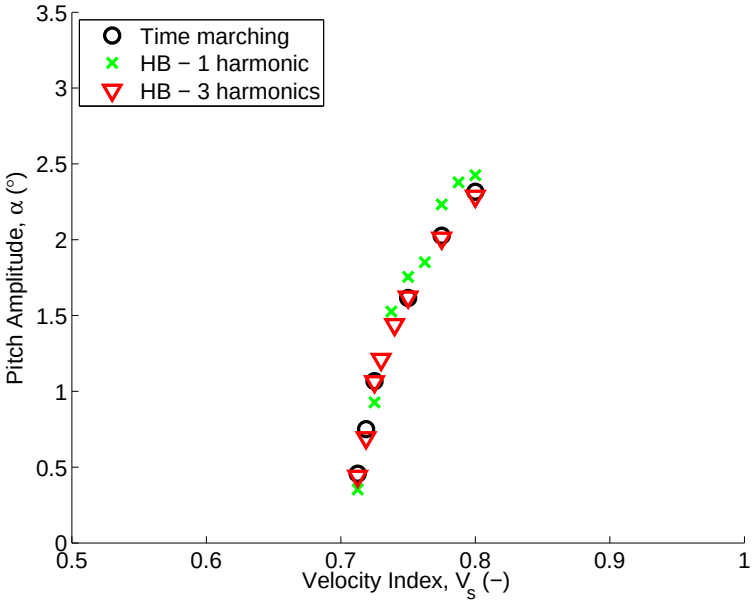


$V_s = 0.775$

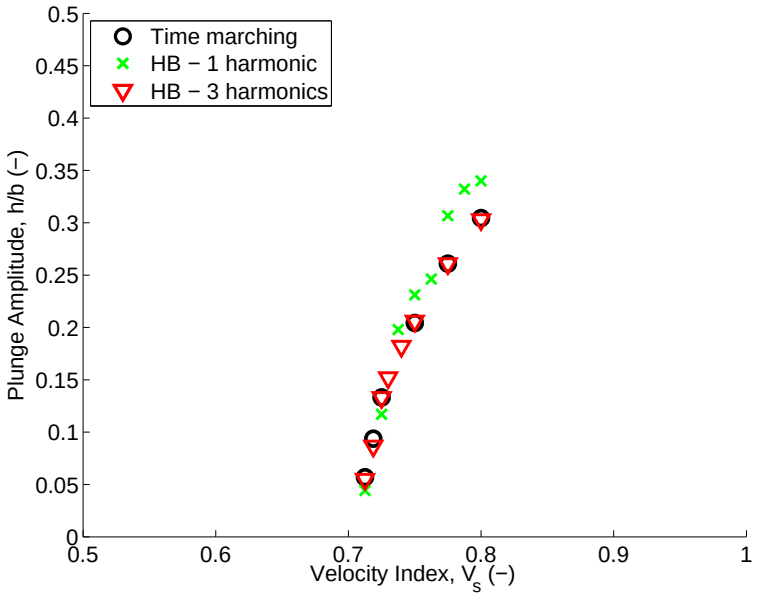


$V_s = 0.80$

Transonic pitch/plunge Aerofoil

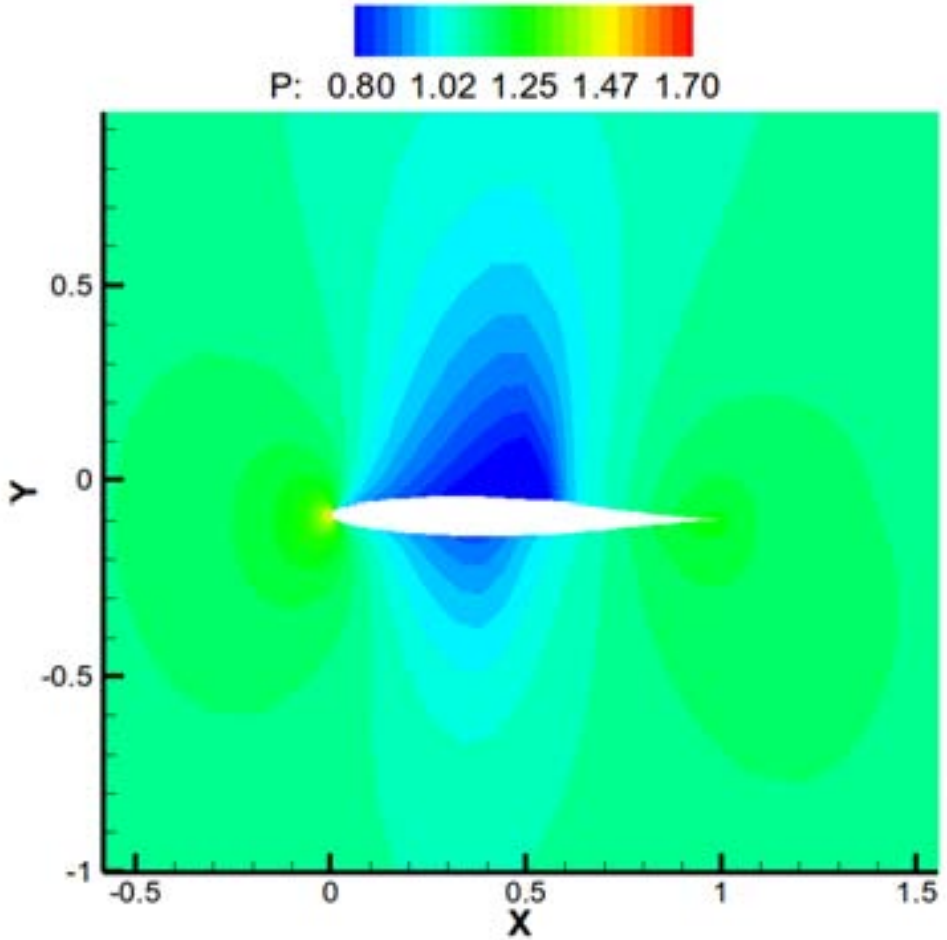


(a) LCO pitch amplitude



(b) LCO plunge amplitude

Transonic pitch/plunge Aerofoil
Impact of Mach n.



Outline

1 Overview

2 Motivation

3 Aeroelastic-Harmonic Balance

4 Uncertainty Quantification

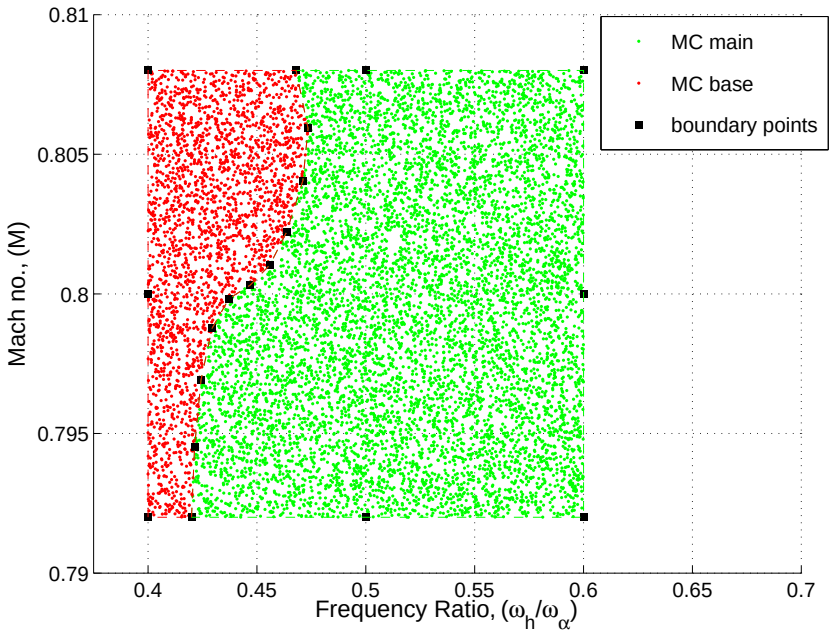
5 Results

6 Conclusions & Outlook

Non-Intrusive PCE - *Adaptive* Point Collocation

Point Collocation:

- Sample using LHS distribution of ξ^a
- Identify discontinuity and oversample
- Solves least squares data fit for all coefficients at once: $\Psi(\xi) = \alpha \mathbf{R}$
- Run MC LHS using regression model



[a] ξ represents independent identically distributed uniform random variables

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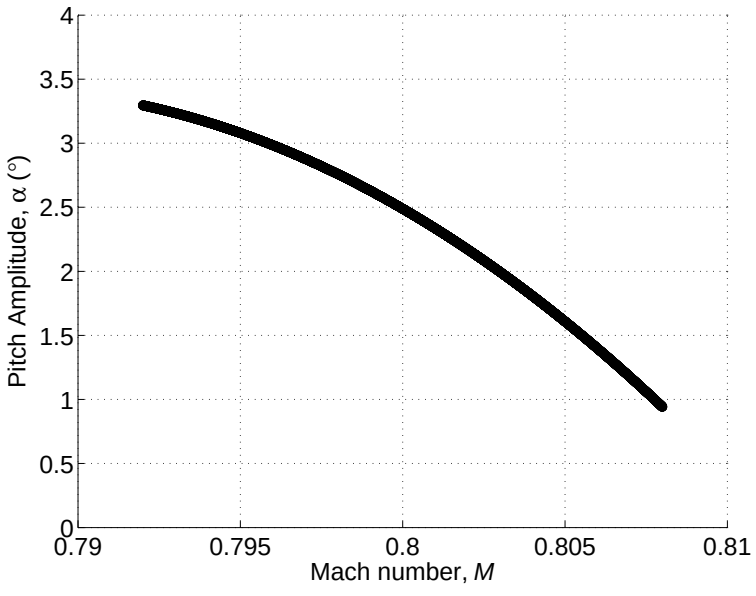
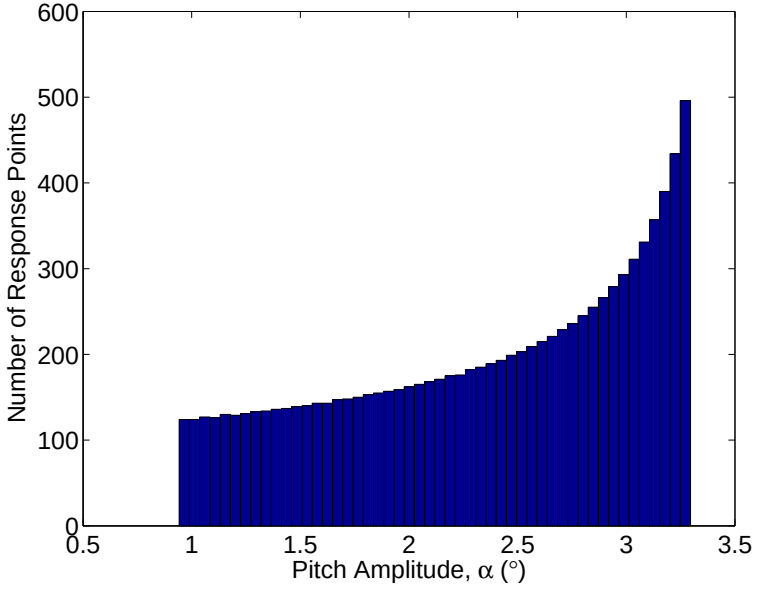
Transonic pitch/plunge Aerofoil
Mach number variability



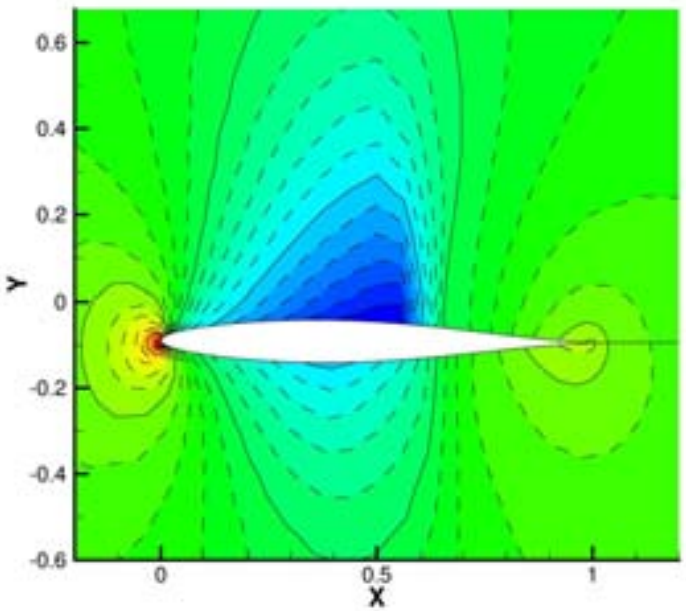
(c) $M_\infty \pm 1\%$ scatter



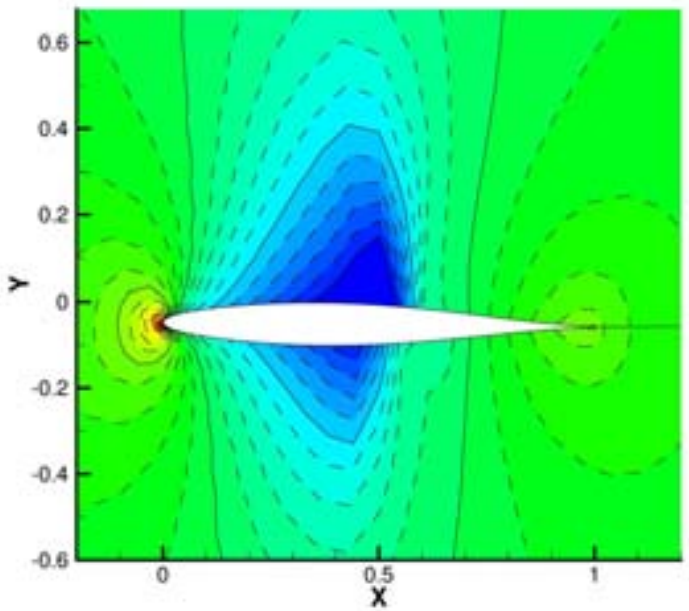
(d) $M_\infty \pm 1\%$ histogram

Transonic pitch/plunge Aerofoil Mach number variability

Flowfield solutions, $\alpha = 0.65°$, pitching upwards



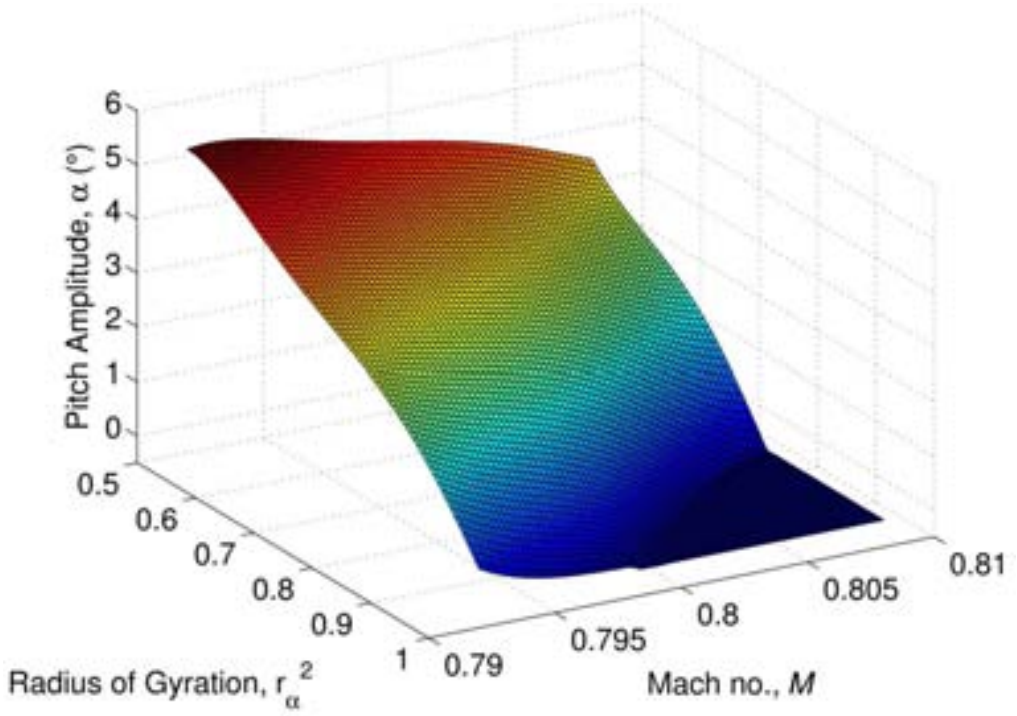
(e) $M_\infty = 0.792$



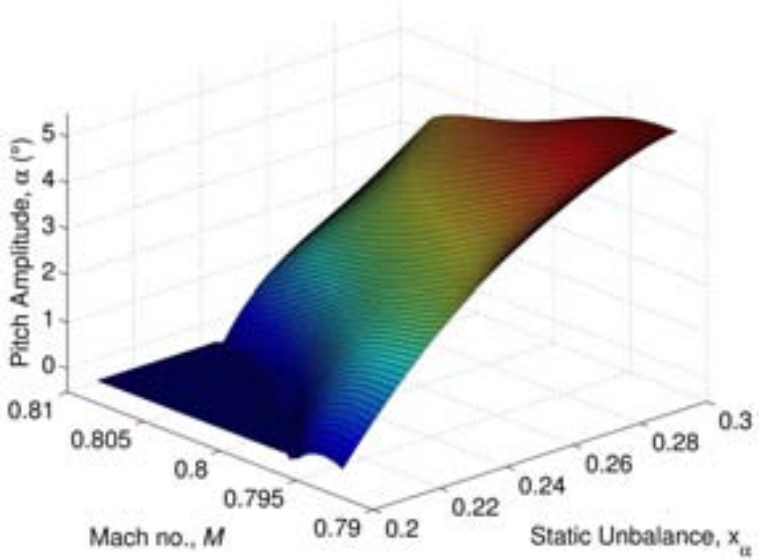
(f) $M_\infty = 0.808$

Structural Variability

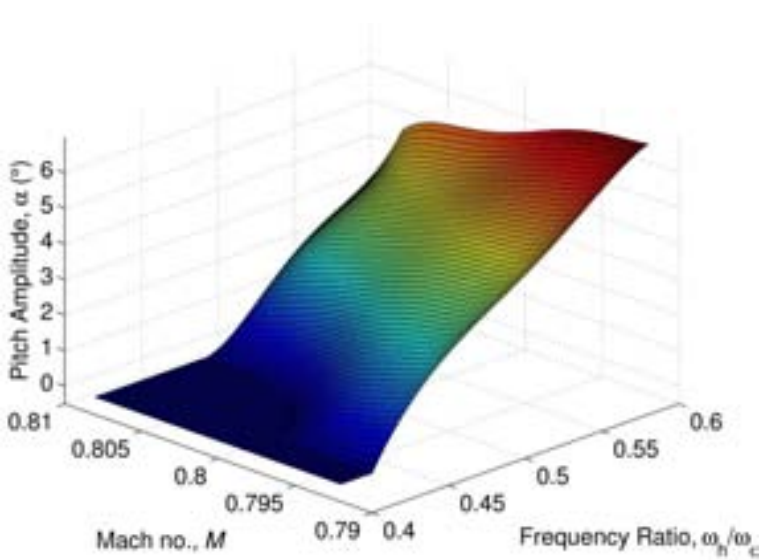
Supercritical bifurcation with varying $M_\infty \pm 1\%$ and ${r_\alpha}^2, \pm 33\%$



Transonic pitch/plunge Aerofoil Structural Variability



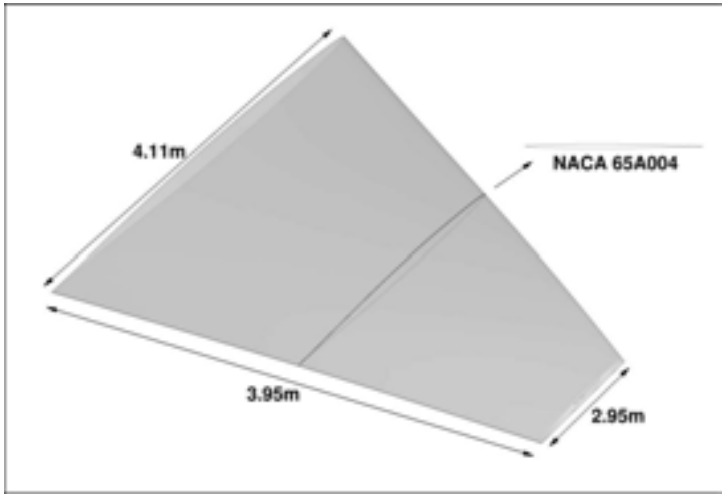
(g) $M_\infty \pm 1\%$ and $x_\alpha, \pm 20\%$

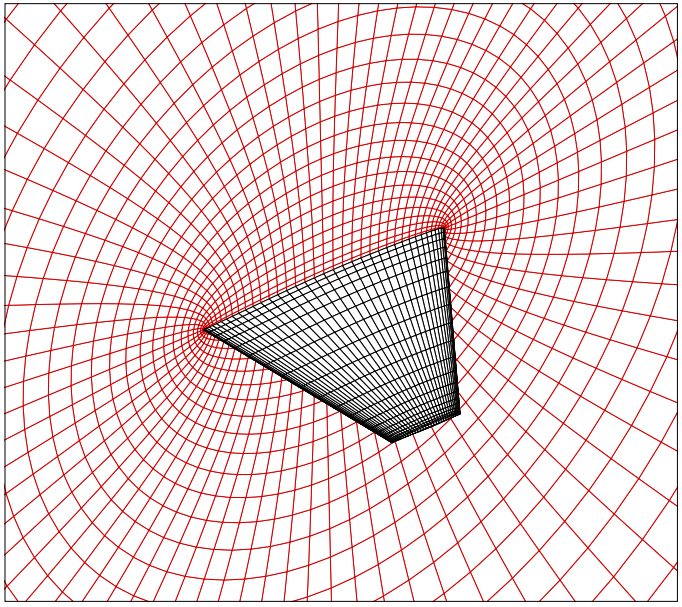


(h) $M_\infty \pm 1\%$ and $\frac{\omega_h}{\omega_\alpha} \pm 20\%$

Delta Wing

Generic Fighter Delta Wing [2]

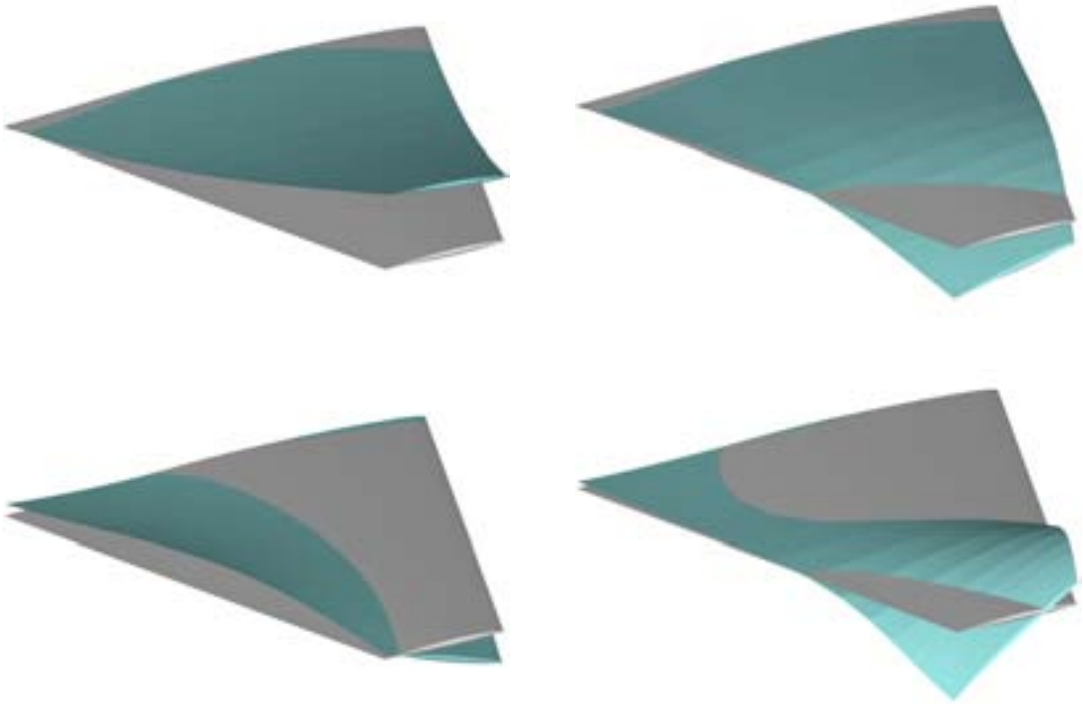




[2] W. Yao, S. Marques, Prediction of Transonic Limit Cycle Oscillations Using an Aeroelastic-Harmonic Balance Method, AIAA paper 2014-2310

Delta Wing

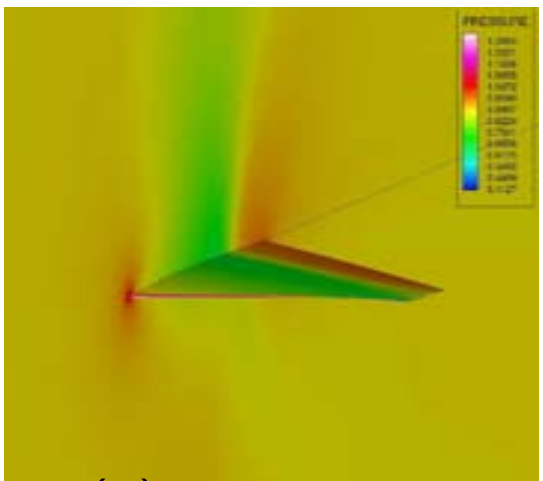
Generic Fighter Delta Wing [3] - Mode Shapes



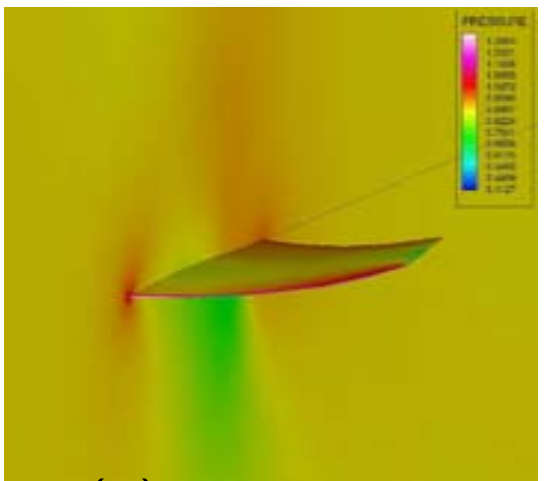
[3] W. Yao, S. Marques, Prediction of Transonic Limit Cycle Oscillations Using an Aeroelastic-Harmonic Balance Method, AIAA paper 2014-2310

Delta Wing

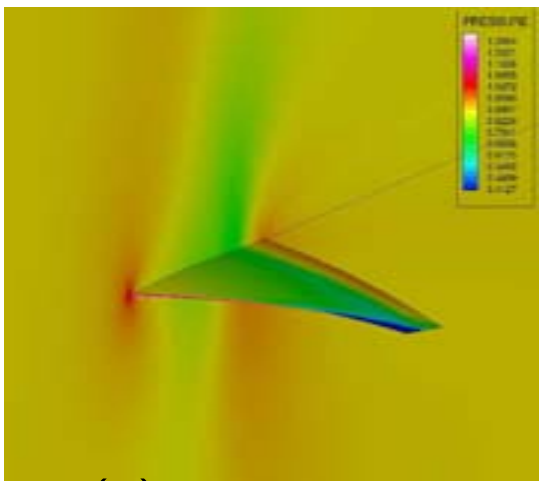
Delta Wing Pressure Contours snapshots during LCO cycle, $q = 0.850 q_{sl}$



(a) sub-level 1



(b) sub-level 2



(c) sub-level 3

Delta Wing

LCO Prediction - $M_\infty = 0.91;\ \alpha = 0°;\ q_{flutter} = 0.759 q_{sl}$

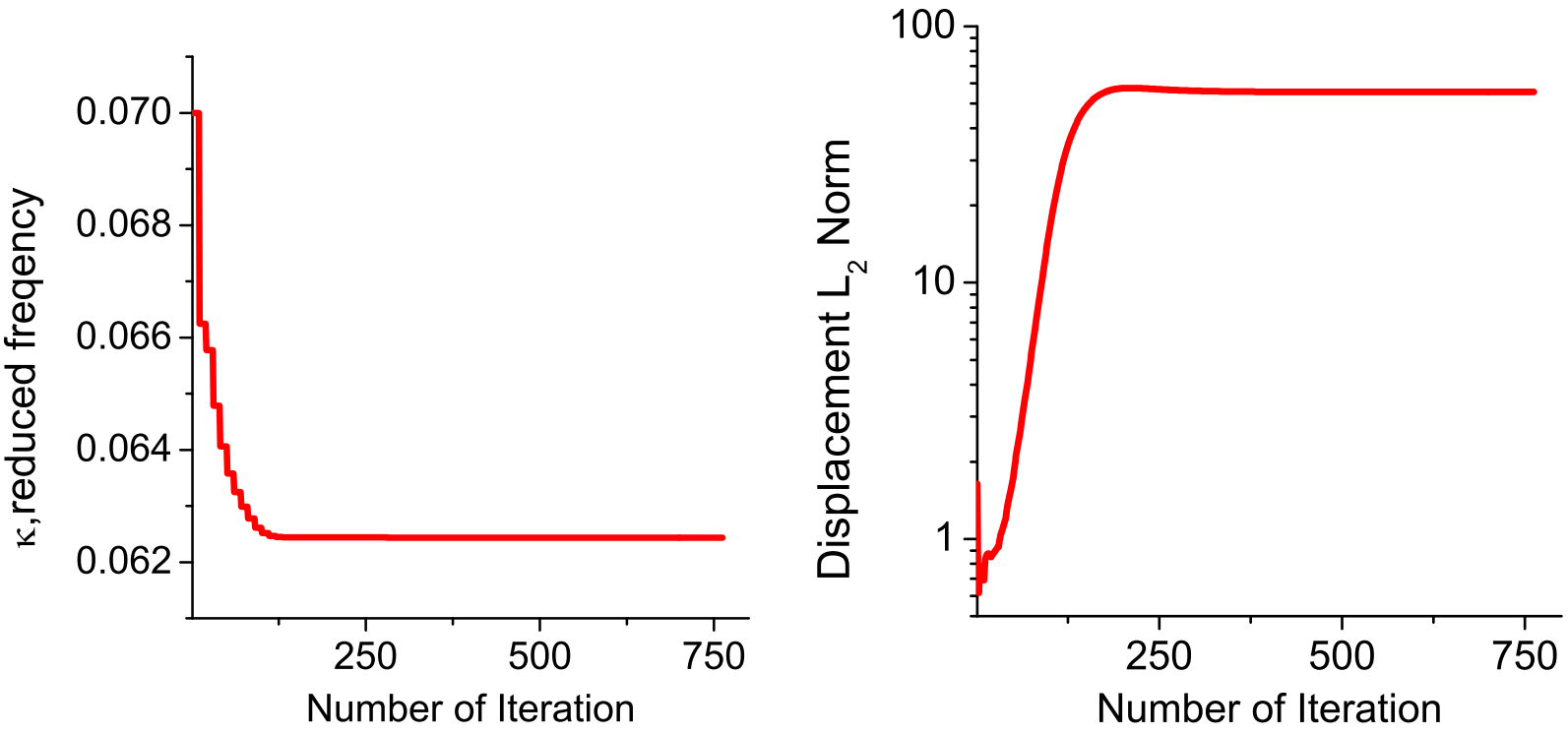
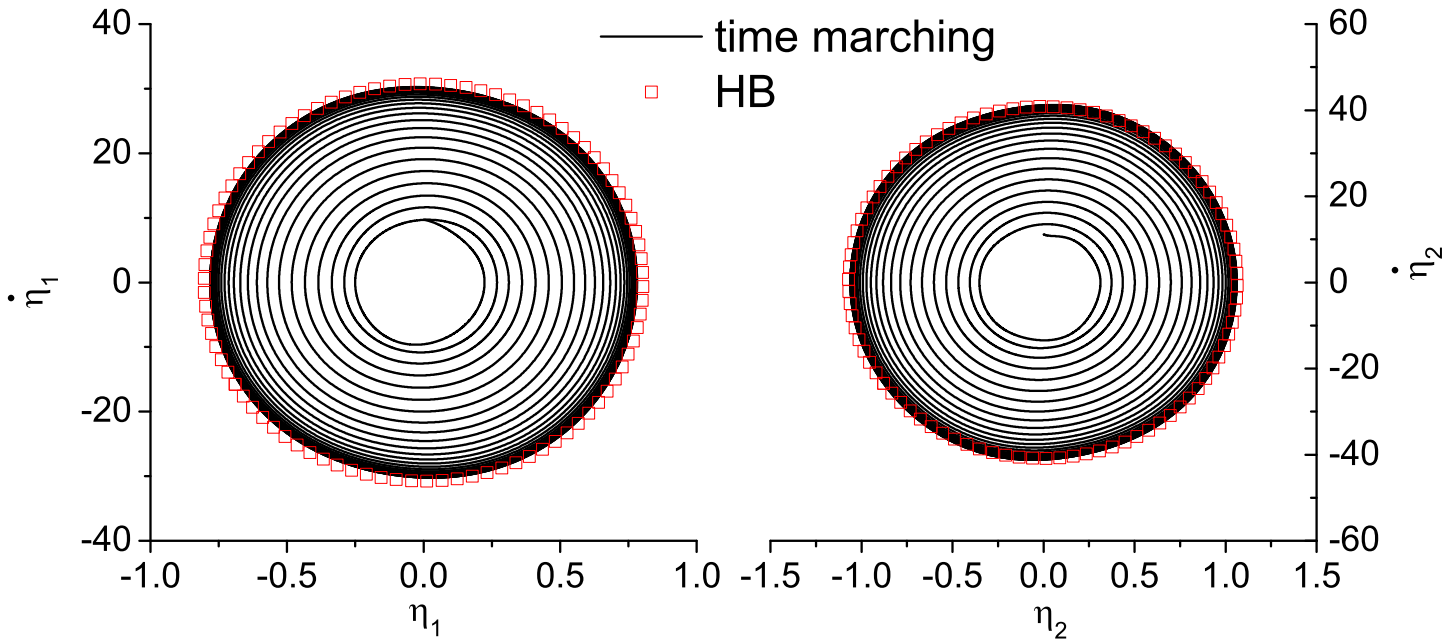


Figure : $q_{LCO} = 0.85 q_{sl}$

Delta Wing

Position-Velocity Diagram ($q_{LCO} = 0.85 q_{sl}$)



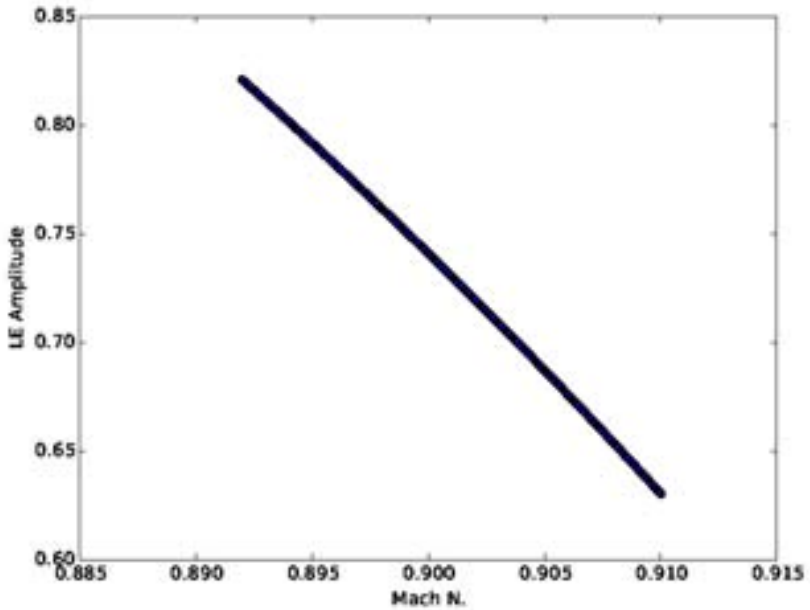
Solver Efficiency

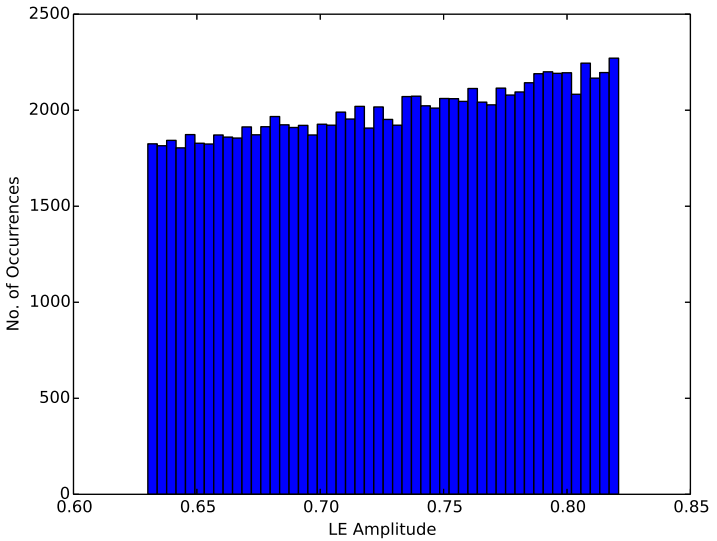
Method	Wall Clock [hours]	Speed-Up
Time Marching ($81 \times 41 \times 41$)	207	1.0
A-HB 2nd MUSCL ($81 \times 41 \times 41$)	8.4	24
A-HB 5th MP[4] ($41 \times 21 \times 21$)	3.7	56

[4]W. Yao, S. Marques, An Aeroelastic Harmonic Balance Solve Using High-Order CFD, RAeS Applied aerodynamics Conf., 2014

Delta Wing

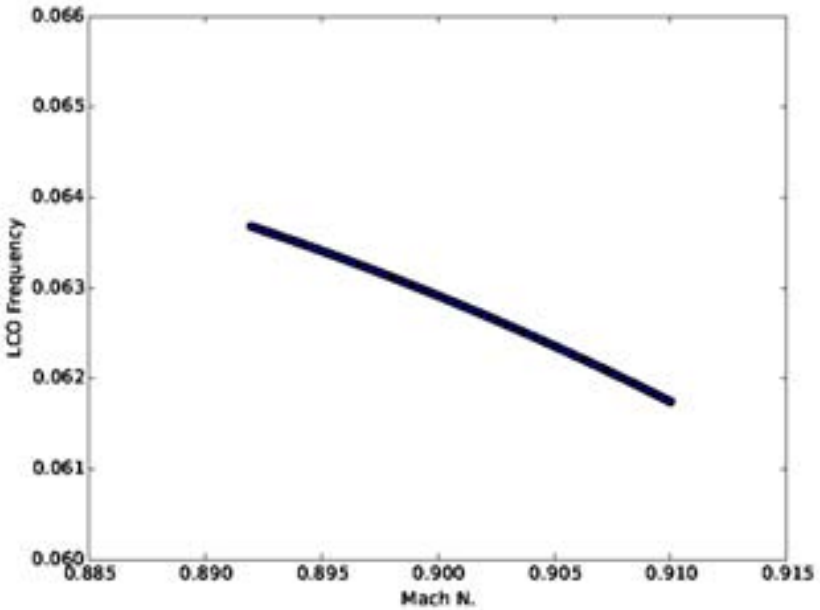
$M_\infty \pm 1\%$

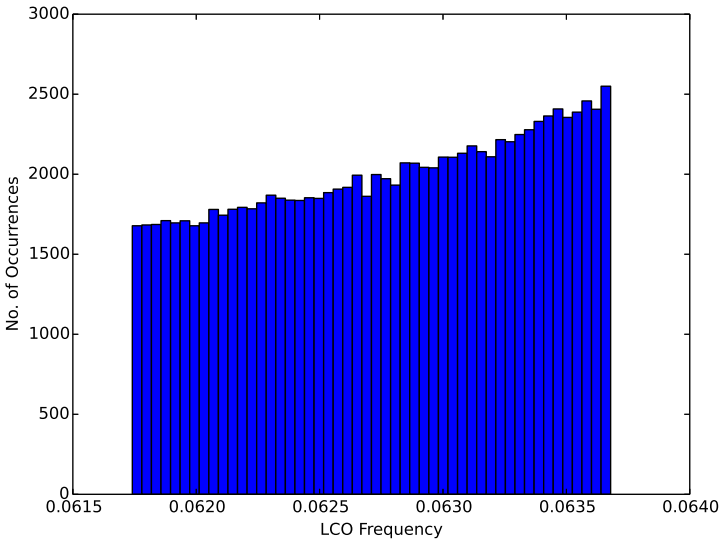




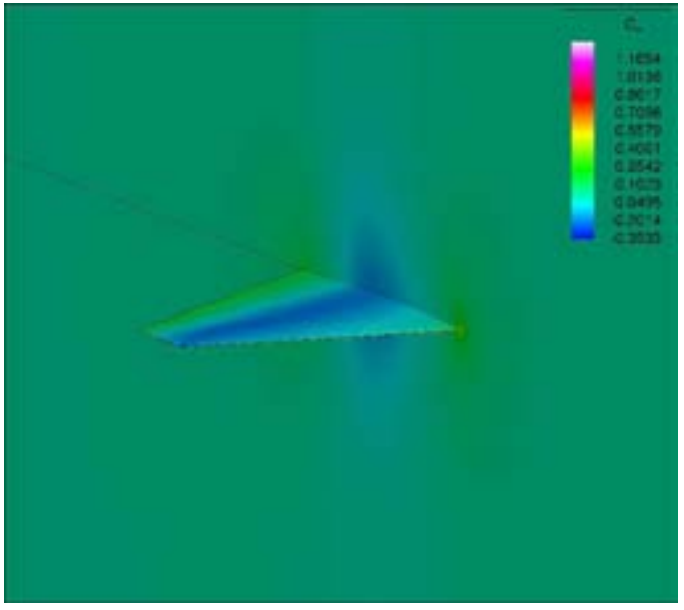
Delta Wing

$M_\infty \pm 1\%$





Delta Wing



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Conclusions

- LCO conditions are determined using a frequency updating algorithm that accounts for both aerodynamic and structural influences

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Conclusions

- LCO conditions are determined using a frequency updating algorithm that accounts for both aerodynamic and structural influences
- the new approach shows significant speed-ups w.r.t. time-domain, without compromising accuracy
- In 2D, M_∞ is a driving force of LCO behaviour.
- For the 3D case examined, M_∞ has a smaller impact.

Current & Future Work

- Extend test case database.

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- Current work is focus on introducing structural nonlinearities.

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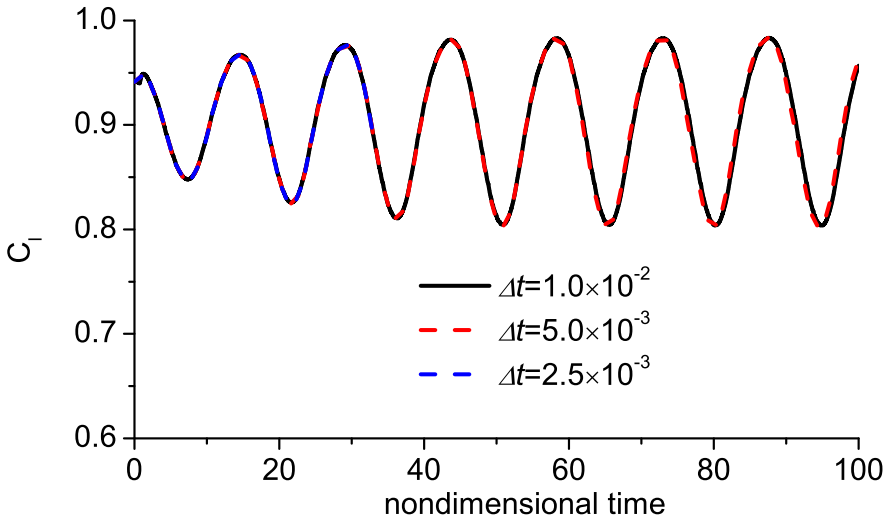
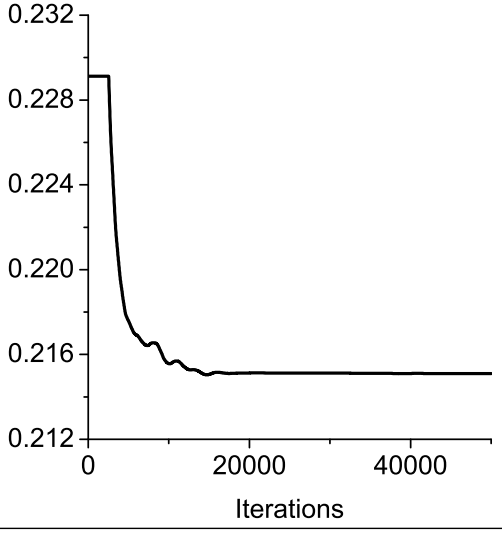
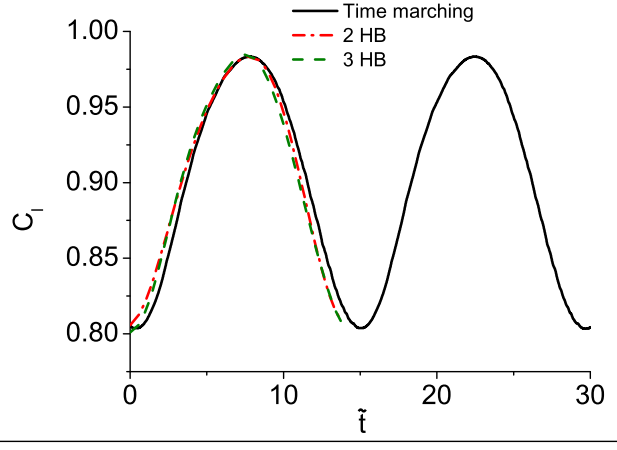
- Extend test case database.
- Current work is focus on introducing structural nonlinearities.
- Frequency updating shows potential to capture flow instabilities such as buffet

Current & Future Work
Buffet - OAT15A Aerofoil







Current & Future Work
Buffet - OAT15A Aerofoil

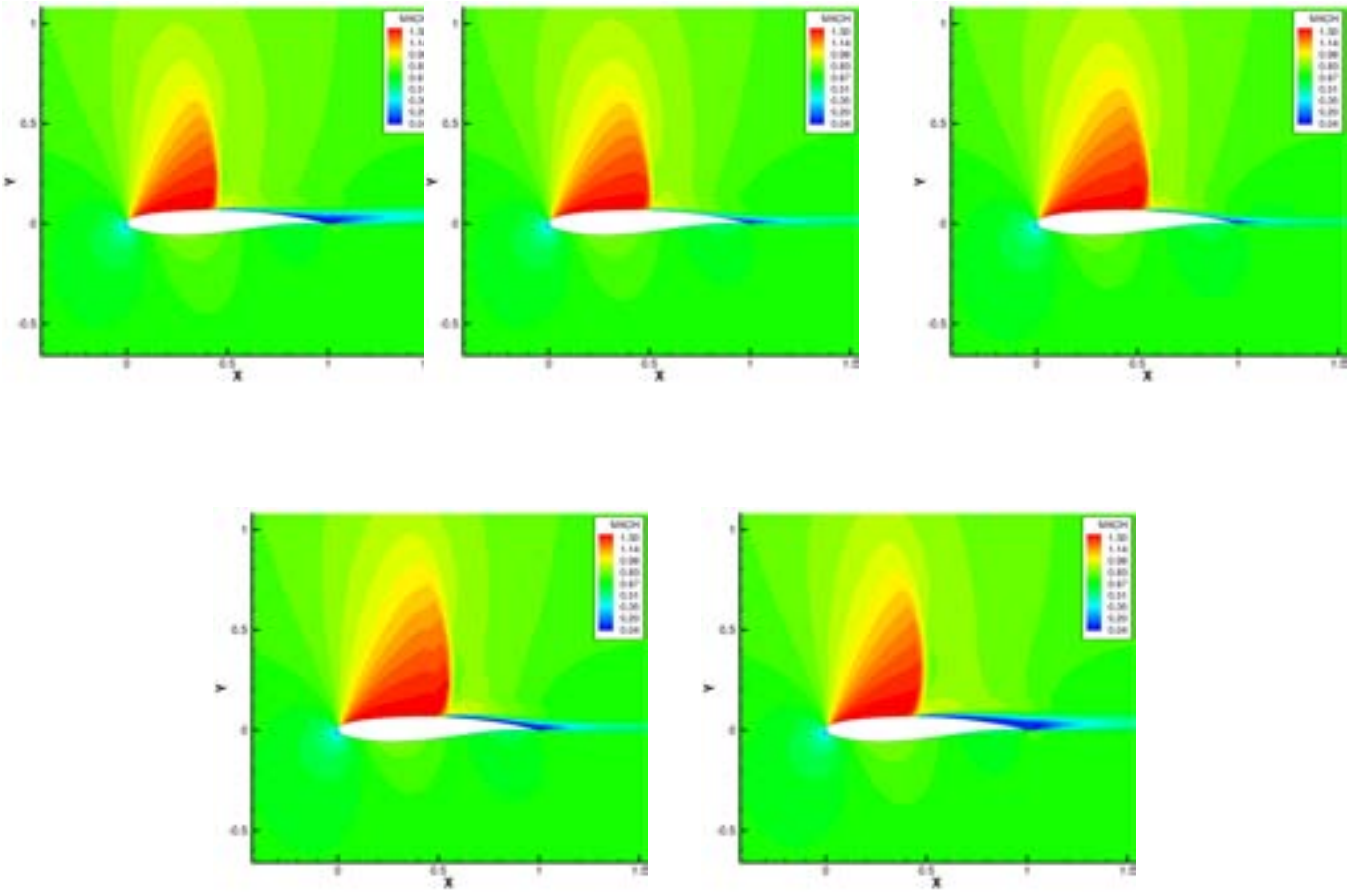


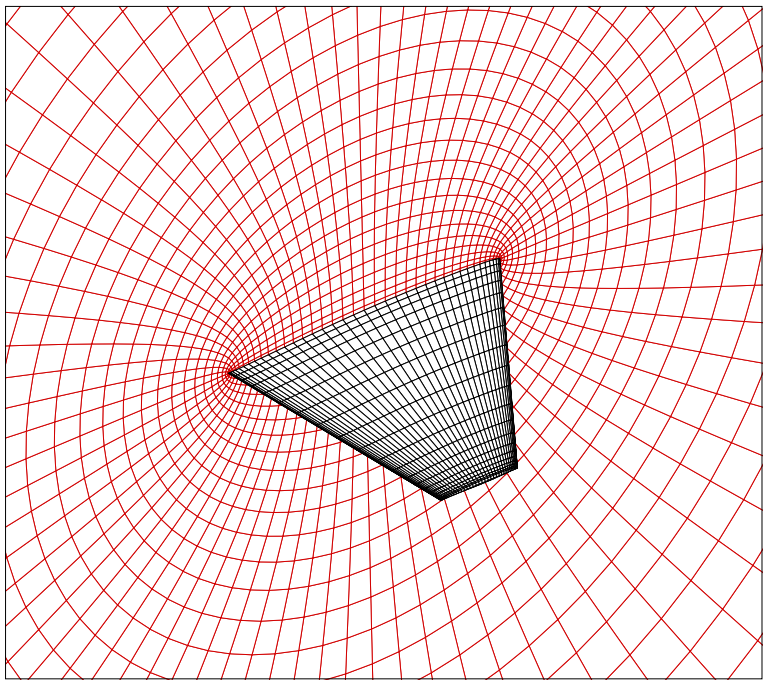
Figure : $AUSM^{+} - up$ with 2nd order MUSCL, SA-EDW+CC

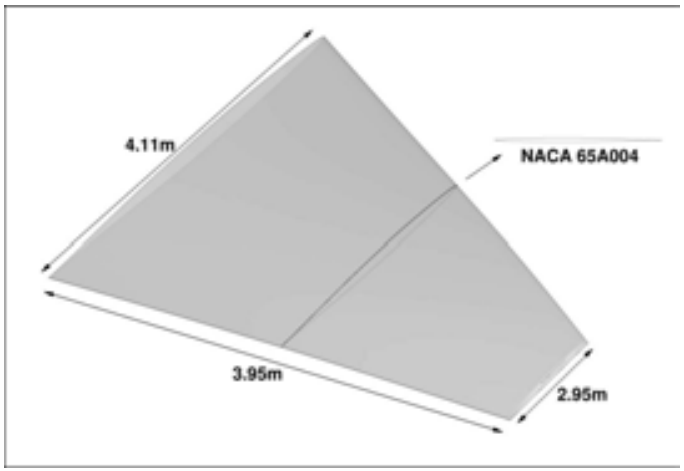
Q & A

Thank you for your attention

Questions Welcome

Q & A





- Grid size: $160k$
- NACA 65A004

Q & A

Flutter Calculations:

Eigenvalue Problem

$$\begin{bmatrix} A_{ff} & A_{fs} \\ A_{sf} & A_{ss} \end{bmatrix} \mathbf{p} = \lambda \mathbf{p}$$

this can be reduced to a small nonlinear eigenvalue problem, by applying the Schur Complement Method[5]

Schur Formulation

$$S(\lambda)\mathbf{p}_s = \lambda \mathbf{p}_s$$

where

$$S(\lambda) = (A_{ss} - \lambda I) - A_{sf}(A_{ff} - \lambda I)^{-1} A_{fs}$$

[5] Badcock, Timme, Marques, *et al.* Envelope searches and uncertainty analysis with transonic aeroelastic simulation.Progress in Aerospace Sciences, 47(5), 2011.

Q & A

Flutter Calculations:

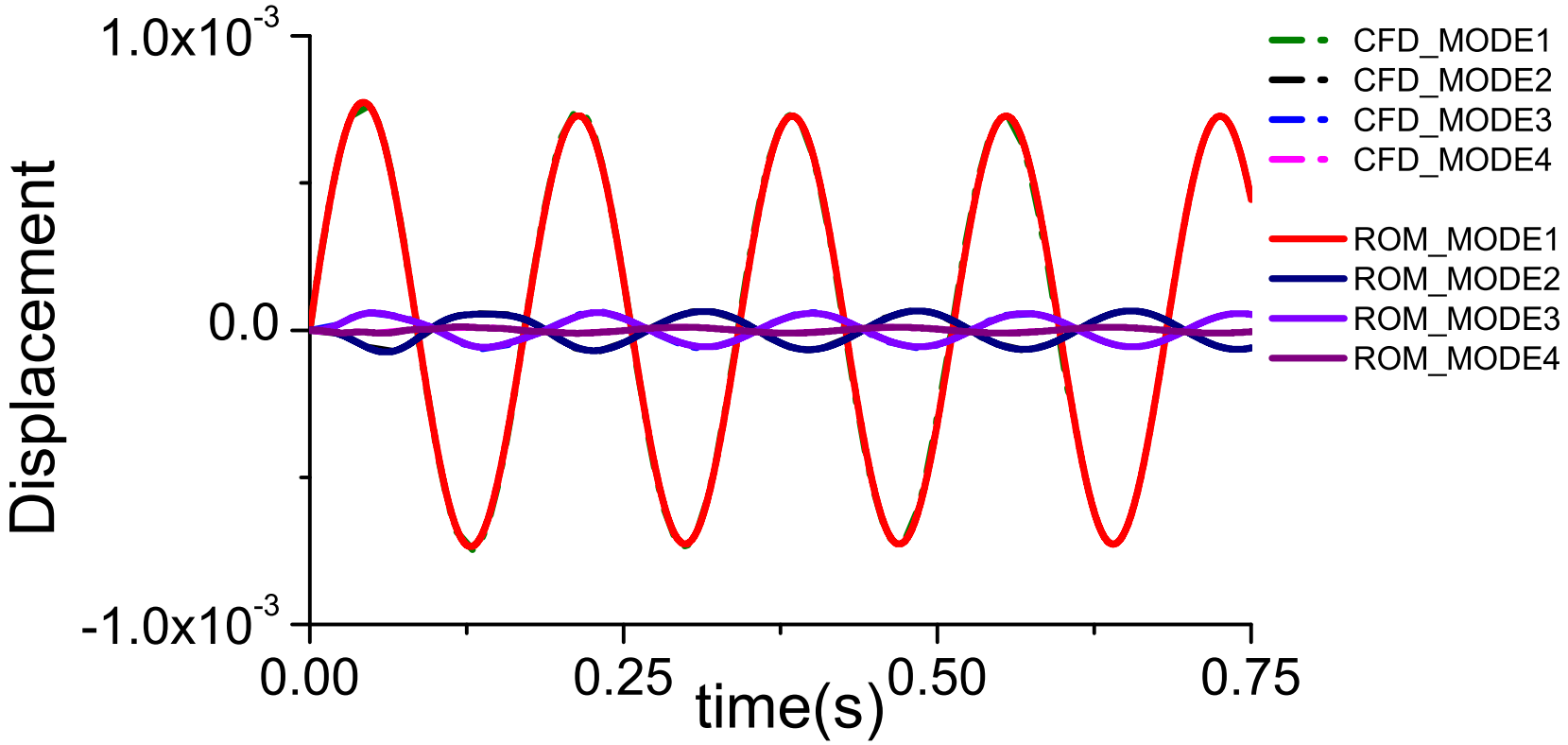
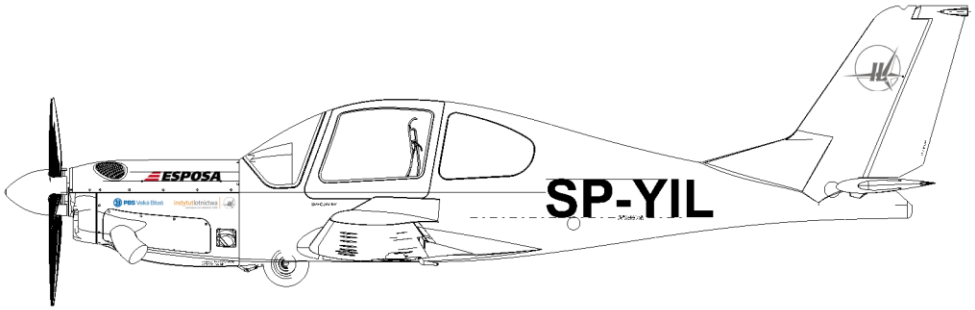


Figure : Delta Wing Flutter response with Volterra Series 808th ROM

DYNAMIC PROPERTIES OF LIGHT TURBOPROP AIRCRAFT INCLUDING WEAK AND STRONG GYROSCOPIC EFFECTS



Zdobysław Goraj

Ewa Cichocka

Aachen, 25 November 2014

REASONS FOR THE RESEARCH ON GYROSCOPIC EFFECTS

- Constantly growing number of light 2-4 passenger propeller-driven aircraft
- Development of novel highly-powered compact gas turbine engines for light aircraft
  → increasing share of turboprops on General Aviation sector
- Easy access to GA aircraft flying for common, inexperienced users
  → private flying, for recreation, in Aero Clubs / Flying Schools…
- Many accidents due to side effects of rotating propeller
- Trend to make modification in engines: upgrading the piston aircraft to turboprops or to more powerful engine aircraft
- Obligation of meeting the gyroscopic loads requirements
  → Certifications Specifications for light aircraft: FAR-23.371 / CS-23.371

Aquila A-211 piston-engine aircraft

Aquila A-211T turboprop

THE MAIN SCOPE

Assessment of influence of gyroscopic effects on dynamics of light turboprop aircraft

Gyroscopic Effects

Dynamic stability

Manoeuvre flight

Proposals of different methods to eliminate or reduce gyroscopic moments

Achieving ideal symmetrical flight after disturbance in pitch

Lack of changes in pitch after disturbances in yaw and roll

No additional pilot control actions to counteract gyroscopic precession

SEQUENCE OF CALCULATION PHASES

1) Modelling phase:

Model of light turbopropeller aircraft

for the dynamic stability & response to rapid manoeuvres analysis

→ Physical model of aircraft

→ Definition of reference frames, control and aerodynamics coefficients notation

→ Mathematical model of an aircraft for dynamic stability analysis

→ Mathematical model of an aircraft for manoeuvre flight analysis

2) Input data preparation → calculations of dimensionless aerodynamic derivatives

3) Equilibrium flight conditions calculations

4) Assessment of dynamic stability including gyroscopic effects

5) Analysis of aircraft behaviour following a sudden deflections of control surfaces or gusts

6) Results overview and conclusions

PHYSICAL MODEL OF AN AIRCRAFT

The main assumptions:

1) Aircraft – rigid body of 6 Degrees of Freedom (6DoF)
2) Aircraft mass, mass distribution and position of the Centre of Gravity - constant
3) Control surfaces – moveable, weightless, and vibrations-free
4) The mathematical model of aerodynamics is Quasi-steady
5) Oxy is an aircraft plane of symmetry of mass distribution, geometry, aerodynamics
6) Airflow over the aircraft body is:
   - subsonic: $M_a \ll M_{a_{kr}}$ → compressibility effect is neglected
   - potential, inviscid
   - may be unsymmetrical → sideslip / crosswind
6) Atmosphere – conformable with International Standard Atmosphere
7) Gyroscopic Effects of Propeller Engine are included in analysis
8) …

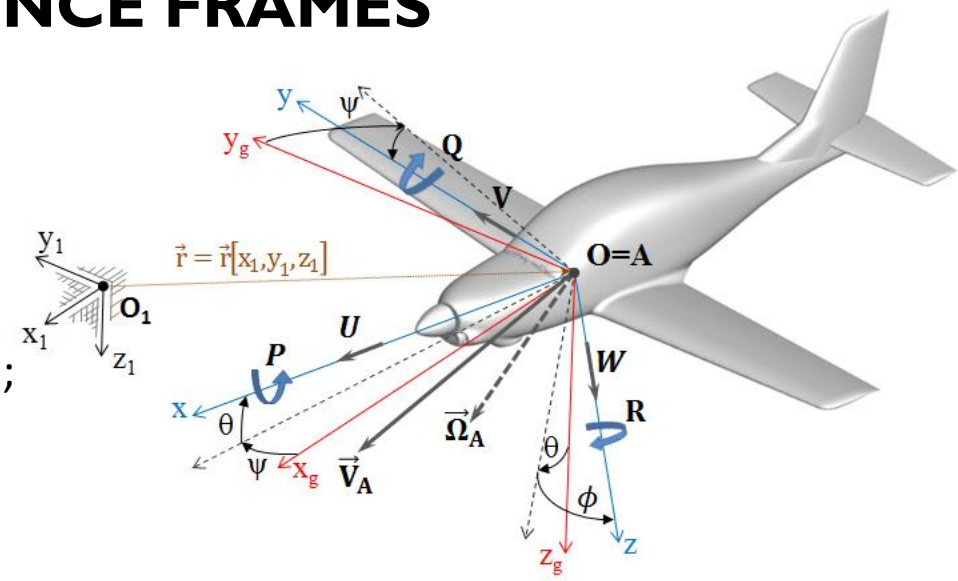
REFERENCE FRAMES

$O_1x_1y_1z_1$ - fixed gravity coordinate system

- origin on the surface of the earth;

$Ox_gy_gz_g$ - movable coordinate system

- parallel to the fixed gravity coordinate system;
- fixed in the aircraft body;
- origin at point A - coincident with the ¼ MAC;

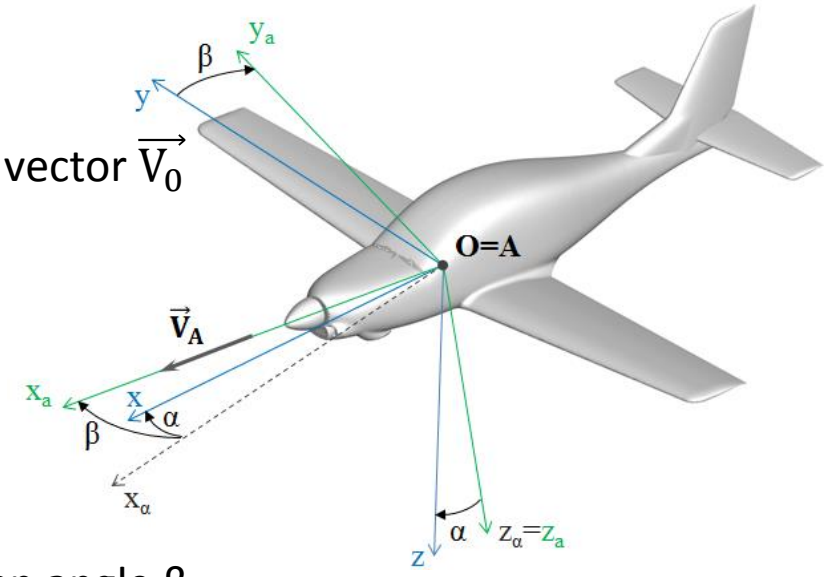


$Oxyz$ – aircraft body axes system

- axis Ox - parallel to the MAC, and pointed forward; axis Oz - pointed down; Oy - to the right wing;
- in this axes system the components of main velocity vector $\overrightarrow{V_0}$ and main angular velocity vector $\overrightarrow{\Omega}$ are defined ;

$Ox_ay_az_a$ – velocity axes system

- axis Ox - parallel to the total velocity vector $\overrightarrow{V_0}$;
- fixed in the aircraft body
- created by the rotation of axes system Oxyz around the Oy axis at an angle α, around the Oz_a at an angle β



MATHEMATICAL MODEL FOR DYNAMIC STABILITY ANALYSIS

⇒ An integral model → coupling between longitudinal and lateral-directional motions

⇒ Set of differential non-linear dynamic equations:

$$\frac{\partial \vec{\Pi}}{\partial t} + \vec{\Omega} \times \vec{\Pi} = \vec{F}$$

$$\frac{\partial \overrightarrow{K_O}}{\partial t} + \vec{\Omega} \times \overrightarrow{K_O} + \overrightarrow{V_O} \times \vec{\Pi} = \overrightarrow{M_O}$$

+ kinematical relations:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{y}_1 \\ \dot{z}_1 \end{bmatrix} = A_V \cdot \begin{bmatrix} U \\ V \\ W \end{bmatrix} + \begin{bmatrix} V_{w_x} \\ V_{w_y} \\ V_{w_z} \end{bmatrix} \qquad \begin{bmatrix} \dot{\Phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = A_\Omega \cdot \begin{bmatrix} P \\ Q \\ R \end{bmatrix}$$

⇒ The linear equations of motion:

$$\mathbf{M_8}\,\dot{\mathbf{x}}_\mathbf{8} = \mathbf{B}_8\,\mathbf{x}_8$$

Generalised inertia matrix — Generalised damping matrix — The state vector

⇒ Non-dimensional form of the eigenvalues problem of the state vector:

$$\left[\bar{\mathbf{M}}_\mathbf{8}^{-1}\bar{\boldsymbol{B}}_\mathbf{8} - \mathbf{I}\lambda\right]\bar{\mathbf{x}}_\mathbf{8} = 0$$

MATHEMATICAL MODEL
- SOLUTION OF THE EQUATIONS OF MOTION -

The Issue:

to solve the eigenvalues problem:

$$\left[\bar{\mathbf{M}}_{\mathbf{8}}{}^{-\mathbf{1}}\bar{\boldsymbol{B}}_{\mathbf{8}} - \mathbf{I}\lambda\right]\bar{\mathbf{x}}_{\mathbf{8}} = 0$$

The solution of the eigenvalue problem:

the general form:

$$\boldsymbol{\lambda_j = \xi_j + i\,\eta_j}$$

ξ_j - damping coefficient; $\left[\frac{1}{s}\right]$

η_j - frequency coefficient; $\left[\frac{1}{s}\right]$

T - period; $[s]$

$T_{½}$ - time to half (or to double – in unstable cases) amplitude; $[s]$

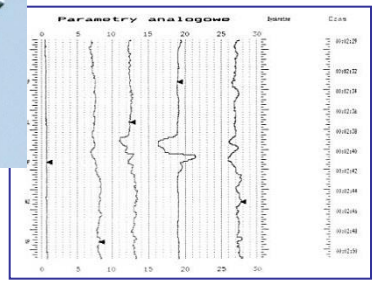
ω_n - undumped natural frequency; $\left[\frac{1}{s}\right]$

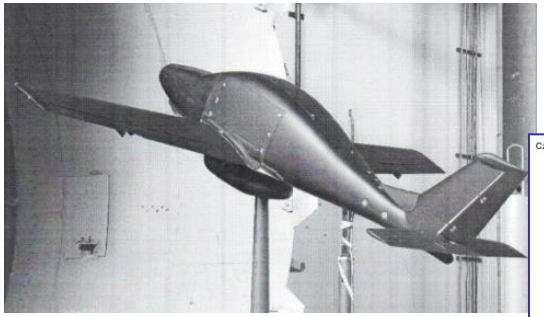
ζ - damping ratio; $[-]$

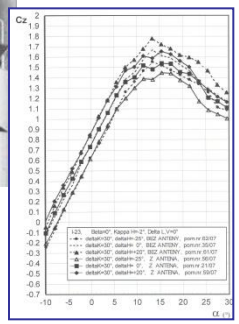
DIMENSIONLESS AERODYNAMIC DERIVATIVES

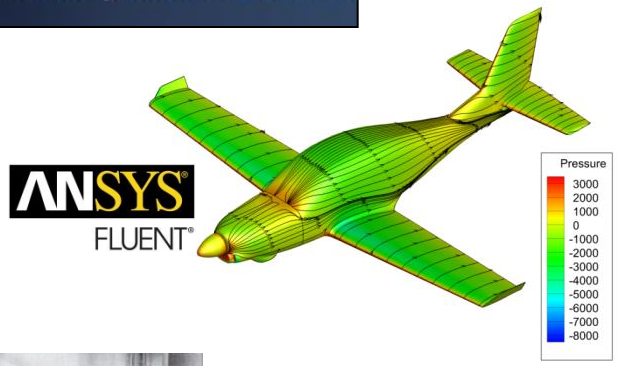
Input data sources:

- Analytical calculations based on stability reports:
  → ESDU, NASA Technical Papers, NACA Technical Reports, …
- USAF Stability & Control Digital DatCom (Matlab)
- CFD calculations (ANSYS® Fluent®)
- Tunnel tests of scale aircraft model
- Flight tests of the aircraft



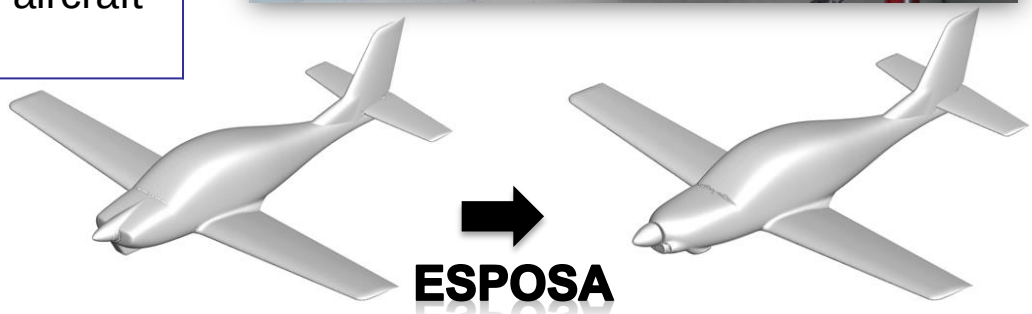






SELECTION OF GENERAL AVIATION AIRCRAFT

I-31T TURBOPROP AIRCRAFT	
Role	4-seat, composite, tractor single-engine aircraft
National origin	Poland
Status	First prototype in assembly
MTOW	1150 kg
Airframe design based on certified piston-engine **I-23 Manager** aircraft (FAR-23; Normal Category)	



	I-23 Manager	I-31T
Powerplant	1 x Lycoming O-360-A piston engine; 132kW	1 x PBS TP-100 gas turbine engine; 180kW
Propeller	2-blade / CW (right) Hartzell HC-C2YR-IBF/F7666A-4	5-blade / CCW (left) MT-Propeller MTV-25-1-D-C-F/CFL-180-05
Total Length	7.10m	7.65m

SELECTION OF GENERAL AVIATION AIRCRAFT

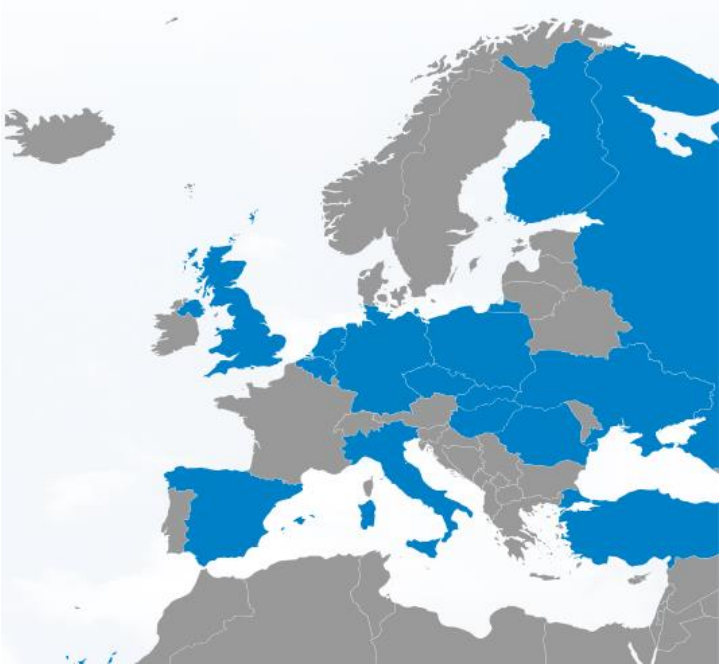
ESPOSA

Efficient Systems and Propulsion for Small Aircraft

SEVENTH FRAMEWORK PROGRAMME

www.esposa-project.eu

FUNDED BY THE EUROPEAN COMMISSION
IN THE SEVENTH FRAMEWORK PROGRAMME
GRANT AGREEMENT NO. ACP1-GA-2011-284859-ESPOSA

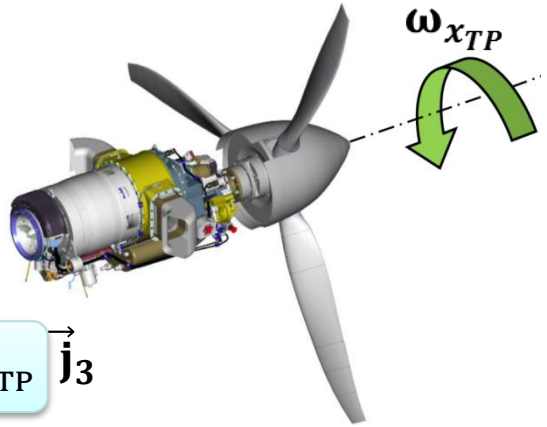


ILOT: I23 - tractor single engine a/c

M-M: Orka - pusher twin-engine a/c

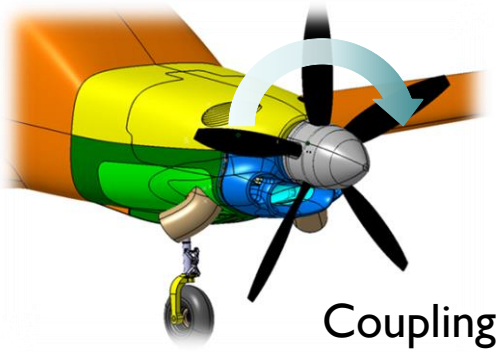
Winner Helico: single engine light helicopter

GYROSCOPIC EFFECTS DUE TO TURBOPROPELLER ENGINE



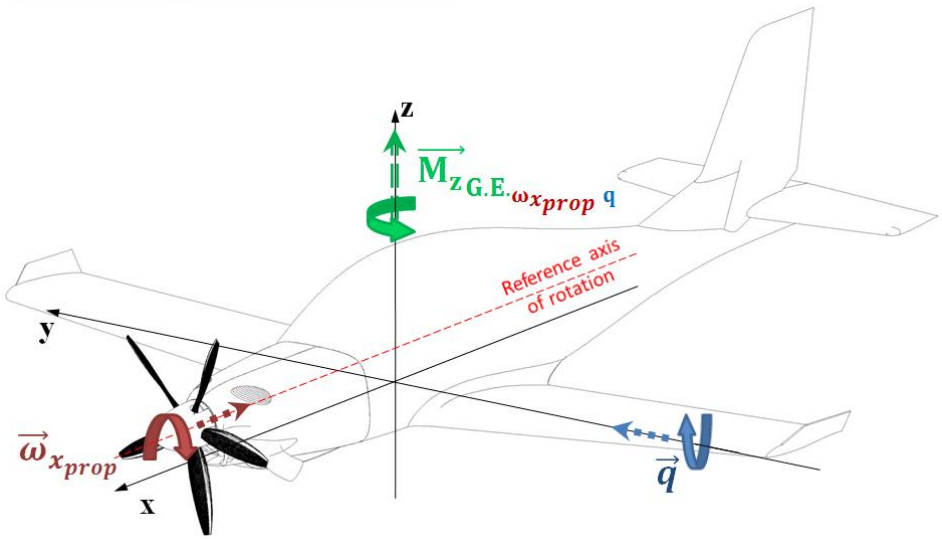
Additional terms added to equations of motion of aircraft!

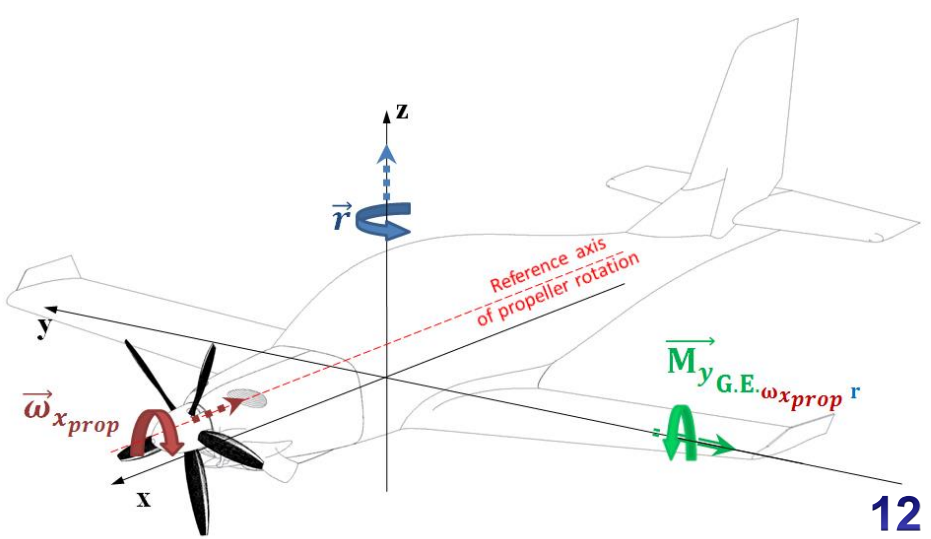
$$\frac{d}{dt}(I_{TP}\vec{\omega}_{TP})=\frac{d}{dt}\left(I_{xx_{TP}}\omega_{x_{TP}}\vec{i}_3\right)=\cdots=-q\,I_{xx_{TP}}\omega_{x_{TP}}\vec{k}_3+r\,I_{xx_{TP}}\omega_{x_{TP}}\vec{j}_3$$



$$I_{xx_{TP}}\omega_{x_{TP}}=\sum_{i=1}^{n}(I_{xx_{engine}}\omega_{x_{engine}})+I_{xx_{prop}}\omega_{x_{prop}}$$

Coupling between longitudinal and lateral-directional motions !!!





GYROSCOPIC EFFECTS REQUIREMENTS IN CERTIFICATION SPECIFICATIONS FOR LIGHT AIRCRAFT

Gyroscopic and aerodynamic loads:

FAR 23.371 & CS 23.371

Necessity of gyroscopic loads determination according to procedure:

- for 2-blades propeller:

$$M_{G.E.} = 2 \cdot I_{p\,prop} \cdot \omega_1 \cdot \omega_2$$

- for more than 2-blades propeller:

$$M_{G.E.} = I_{p\,prop} \cdot \omega_1 \cdot \omega_2$$

for all possible combinations of the following conditions:

- the maximum continuous engine and propeller rotation : $\omega_1 = \omega_{x_{prop\ MAX}}$;
- yaw velocity: $r = 2.5\ \left[\frac{rad}{s}\right]$;
- pitch velocity: $p = 1.0\ \left[\frac{rad}{s}\right]$;
- normal load factor: $n_z = 2.5\ [-]$;
- the maximum continuous thrust $T = T_{MAX}$.

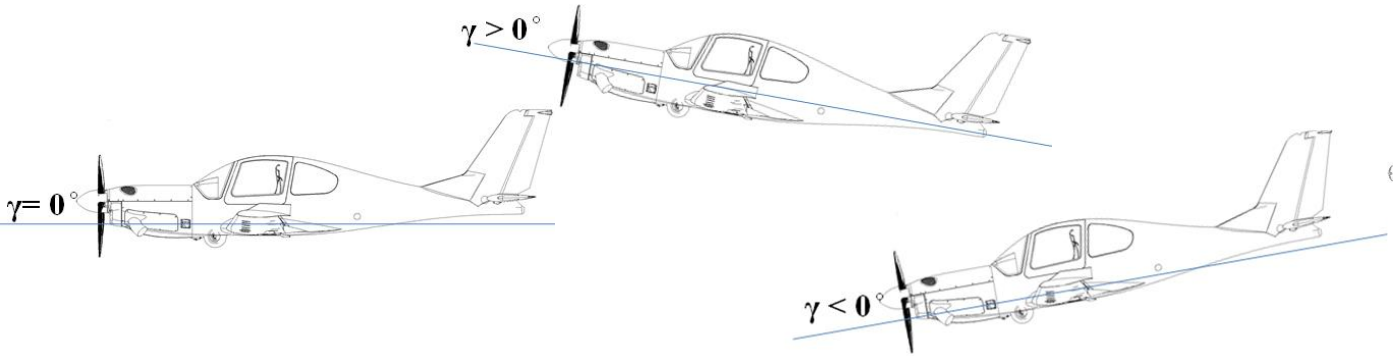
DYNAMIC STABILITY ANALYSIS OF LIGHT TURBOPROP AIRCRAFT

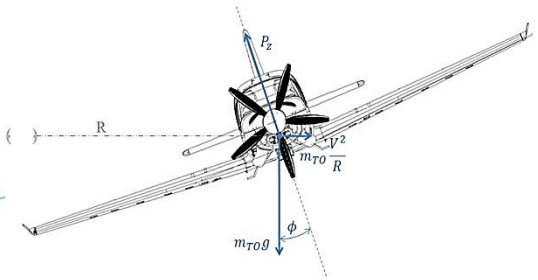
1) Assessment of the influence of gyroscopic effects on aircraft dynamic stability in various cases

- different **flight conditions** (changes of flight altitude and airspeed)
- different **airflow conditions** (symmetric, sideslip or crosswind flight)
- combination of **geometric** and **mass parameters** (within aircraft balance envelope)
- **configuration of flaps** deflection:

  clean (cruise) take-off landing clean (in steady manoeuvres)
- **steady-state flight phases**:

  level-flight climbing descending steady coordinated turn



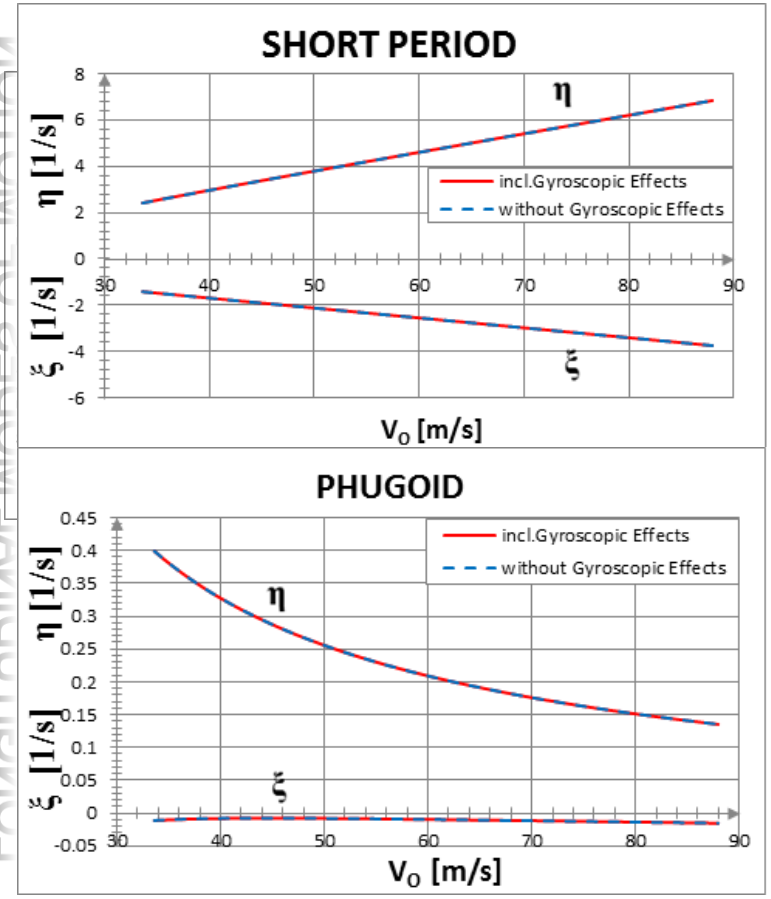


2) Evaluation of the level of changes of **dynamic stability modes of motions**

→ sensitivity analysis for the dynamic stability due to propeller parameters

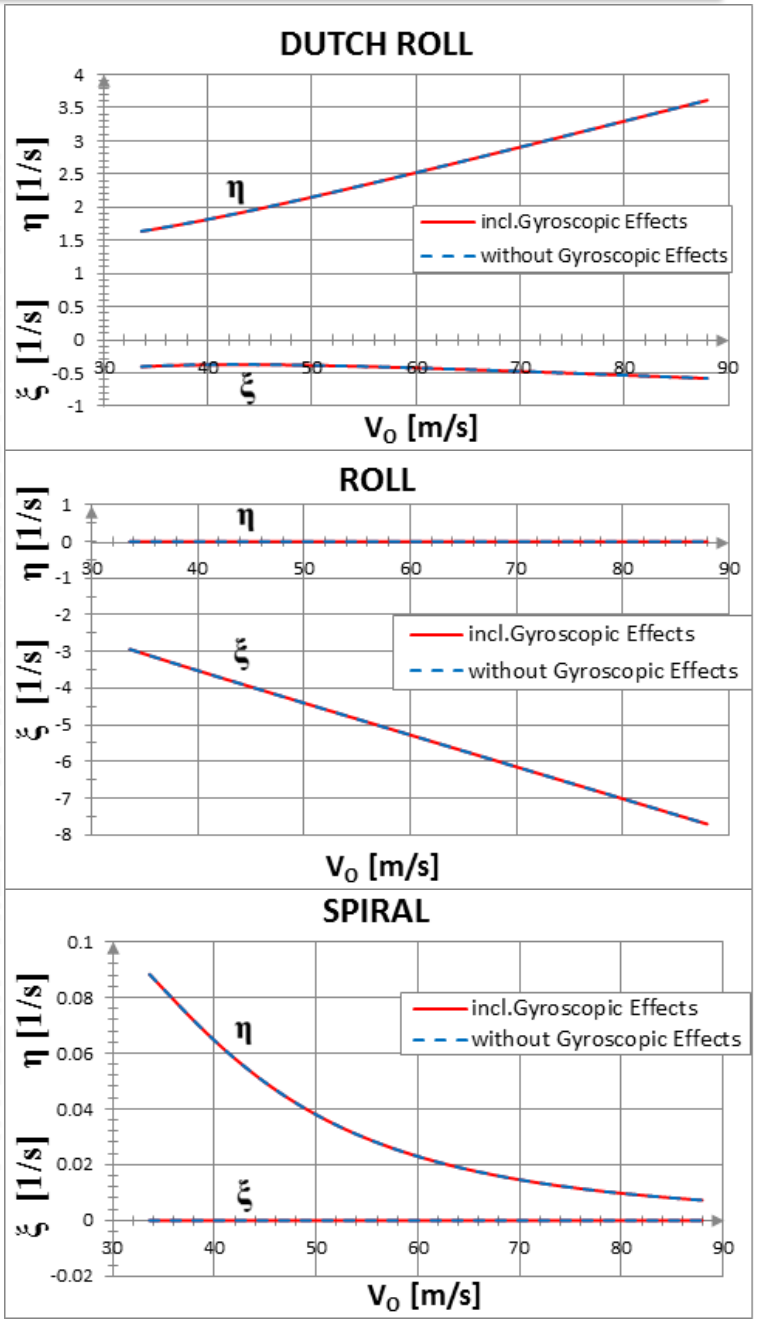
DYNAMIC STABILITY RESULTS

LONGITUDINAL MODES OF MOTION



Weak influence of **gyroscopic effects**
on dynamics stability modes of aircraft motion

LATERAL-DIRECTIONAL MODES OF MOTION



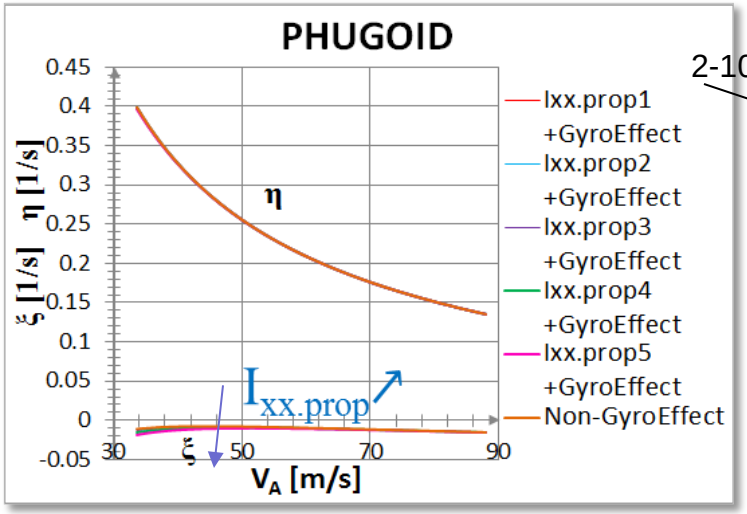
SENSITIVITY ANALYSIS FOR THE DYNAMIC STABILITY

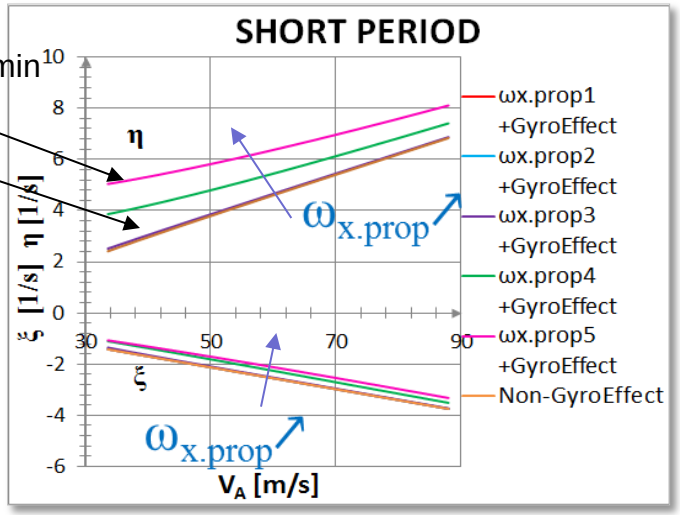
CHANGE IN

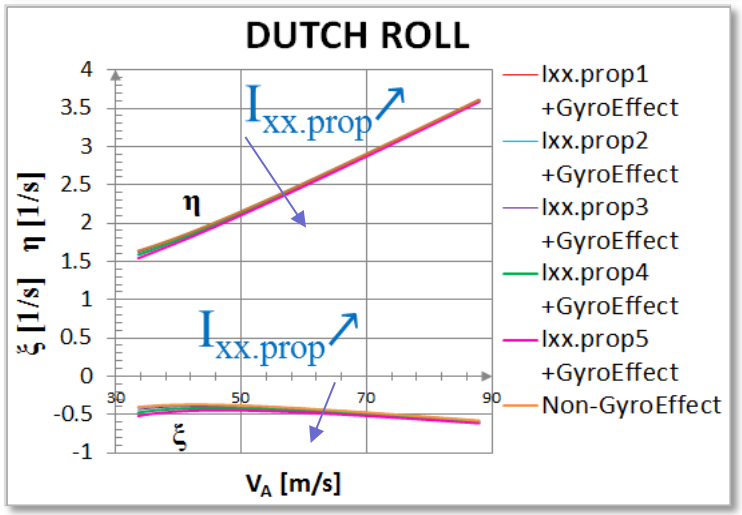
PROPELLER MOMENT OF INERTIA

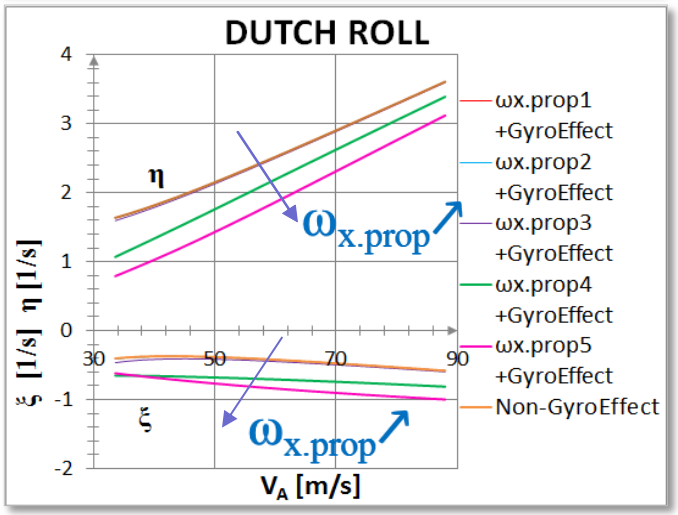
PROPELLER ROTATING SPEED

2-10; 40; 60 *10E3 r/min









INFLUENCE OF GYROSCOPIC EFFECTS ON MANOEUVRE FLIGHT

Dynamic response of an aircraft
on sudden deflection of:

- elevator
- rudder
- ailerons
- various combination of control surfaces

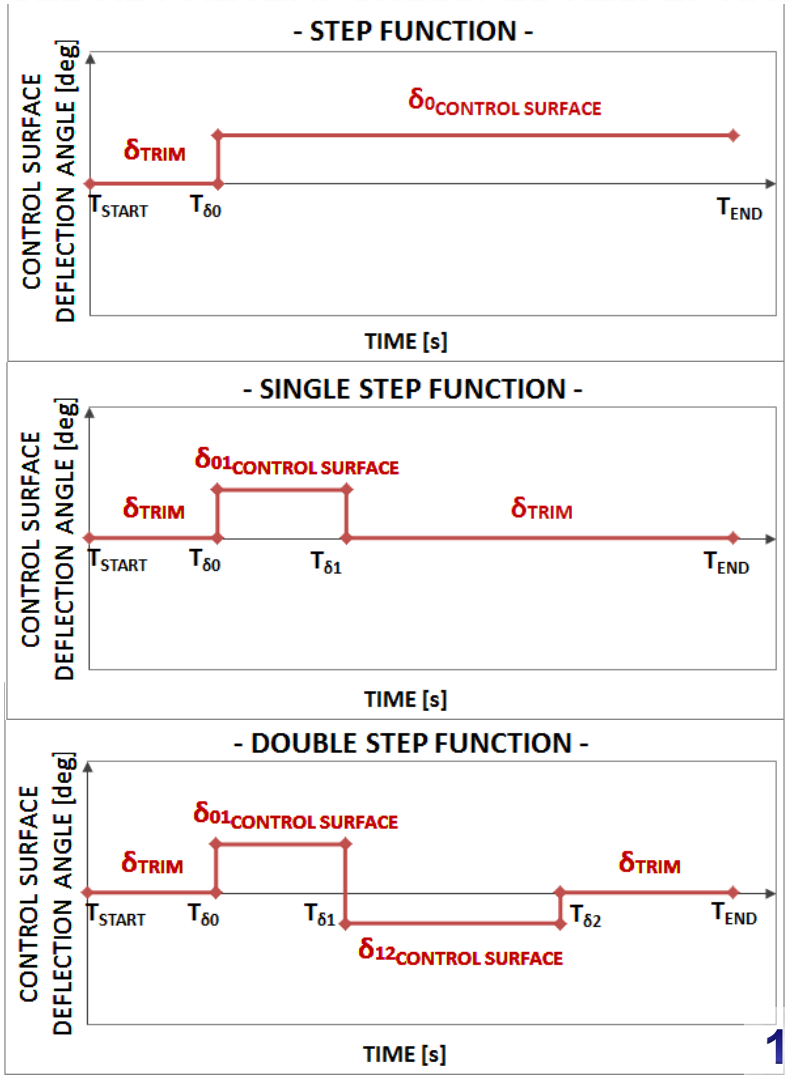
Assessment of influence of:

- inertial coupling effects
- gyroscopic effects

on aircraft behaviour during rapid manoeuvres

Different mathematical models
of aircraft dynamic motion

TYPE OF CONTROL SURFACES DEFLECTION



MATHEMATICAL MODELS FOR RAPID MANOEUVRES ANALYSIS

⇒ Set of differential non-linear dynamic equations:

$$\mathbf{M_6}\,\dot{\mathbf{x}}_6 = \mathbf{B_6}\,\mathbf{x_6} + \mathbf{C_{61}}(\mathbf{x_6}) + \mathbf{C_{62}}(\mathbf{x_6})$$

Inertia matrix

Damping matrix with gyroscopic effects terms included

Thef state vector

The vector of general forces (incl. linear aero forces)

The vector of **non-linear** aerodynamic forces

+ kinematical relations:

$\mathbf{C_6}(\boldsymbol{\mathcal{J}_6})$

transformation from aircraft-body to gravity axes system

$$\begin{bmatrix}\dot{x}_1\\ \dot{y}_1\\ \dot{z}_1\end{bmatrix} = A_V \cdot \begin{bmatrix}U\\ V\\ W\end{bmatrix} + \begin{bmatrix}V_{w_x}\\ V_{w_y}\\ V_{w_z}\end{bmatrix} \qquad \begin{bmatrix}\dot{\Phi}\\ \dot{\theta}\\ \dot{\psi}\end{bmatrix} = A_\Omega \cdot \begin{bmatrix}P\\ Q\\ R\end{bmatrix}$$

Mathematical issue:

The set of 12-equations of aircraft motion within of gyroscopic moments terms

$$\begin{bmatrix}\dot{\mathbf{x}}_6\\ \dot{\boldsymbol{\mathcal{J}}}_6\end{bmatrix} = \begin{bmatrix}\bar{\mathbf{M}}_6^{-1}\bar{\boldsymbol{B}}_6 + \bar{\mathbf{M}}_6^{-1}\{\bar{\boldsymbol{C}}_{61} - \bar{\boldsymbol{C}}_{62}\}\\ \bar{\boldsymbol{C}}_6\end{bmatrix}$$

MATHEMATICAL MODELS FOR RAPID MANOEUVRES ANALYSIS

- The vector of non-linear aerodynamic forces

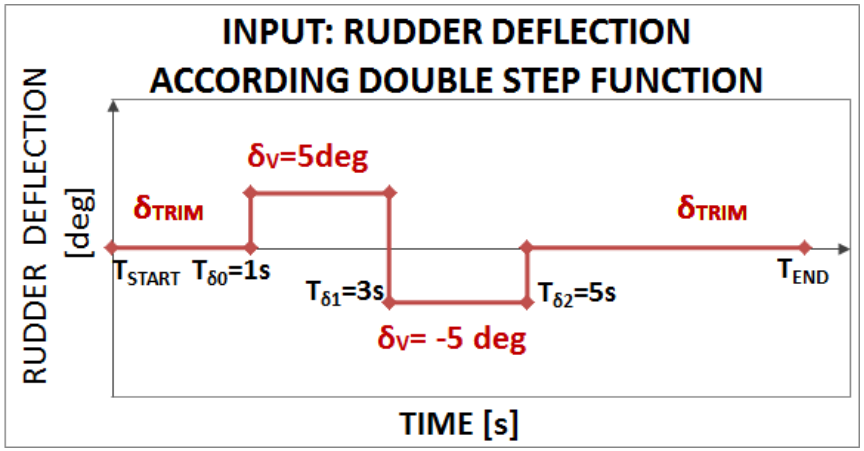
$$C_{62}(x_6) = \begin{cases} 0 & \rightarrow \text{Linear model} \\ f\left(m_{TO}, [I_{ij}], \vec{\Omega}, \overline{AC}\right. & \rightarrow \text{Non-linear model} \end{cases}$$

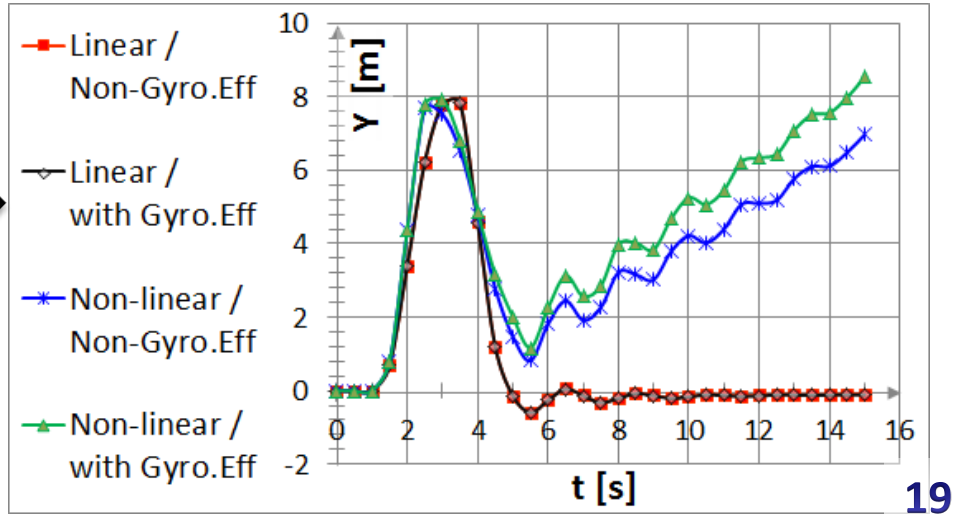
- The gyroscopic effects additional terms in damping matrix B_6

$$B_{6^*} = \begin{cases} 0 & \rightarrow \text{with Gyroscopic Effects} \\ f\left(Ix_{prop}, \vec{\Omega}_{prop}\right) & \rightarrow \text{non-Gyroscopic Effects} \end{cases}$$

Four mathematical models for rapid manoeuvres analysis

Influence of the selected mathematical models on rapid manoeuvre results



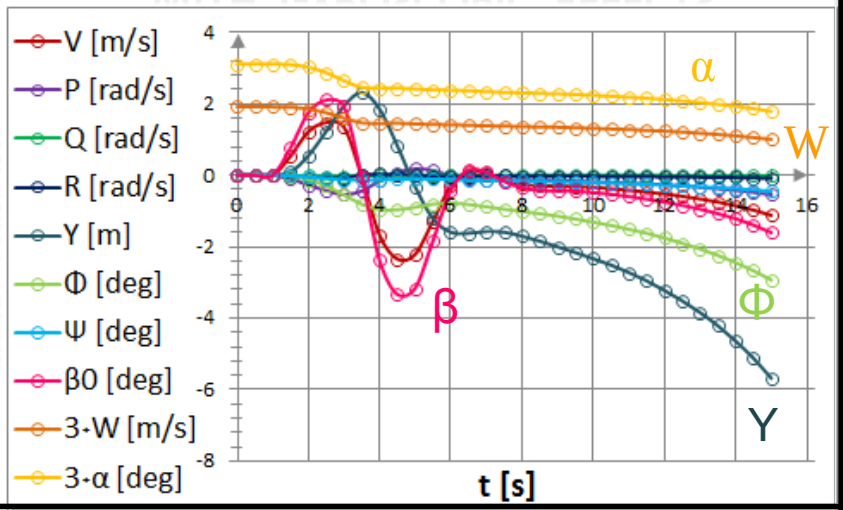
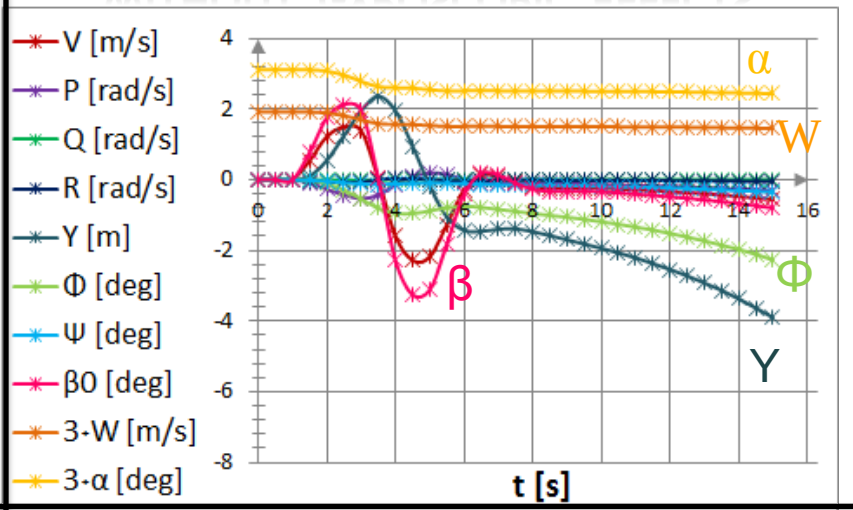
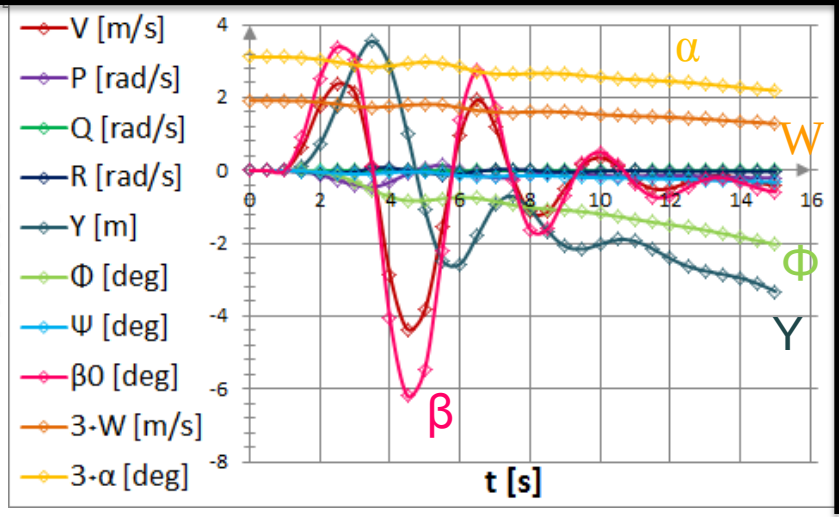
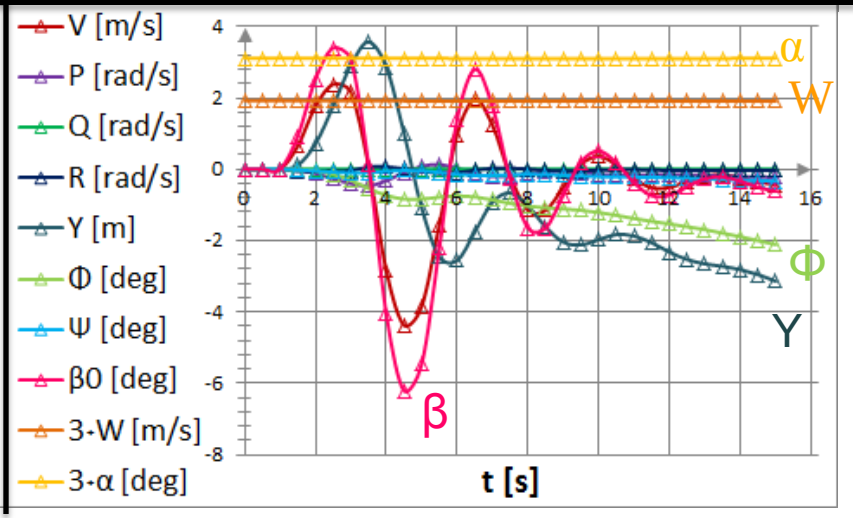


MANOEUVRE FLIGHT RESULTS

DYNAMIC REACTION OF THE AIRPLANE FOLLOWING RUDDER DEFLECTION

MATHEMATICAL MODEL OF AIRCRAFT MOTION

AERODYNAMIC TERMS

	WITH GYROSCOPIC EFFECTS	WITHOUT GYROSCOPIC EFFECTS
NON-LINEAR		
LINEAR		

➡ **Strong** influence of **gyroscopic effects** on manoeuvre flight

MANOEUVRE FLIGHT RESULTS

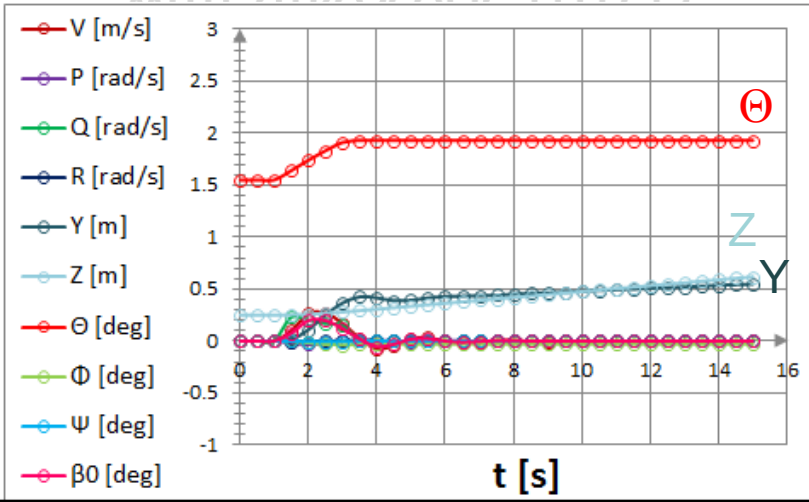
DYNAMIC REACTION OF THE AIRPLANE FOLLOWING ELEVATOR DEFLECTION

MATHEMATICAL MODEL OF AIRCRAFT MOTION

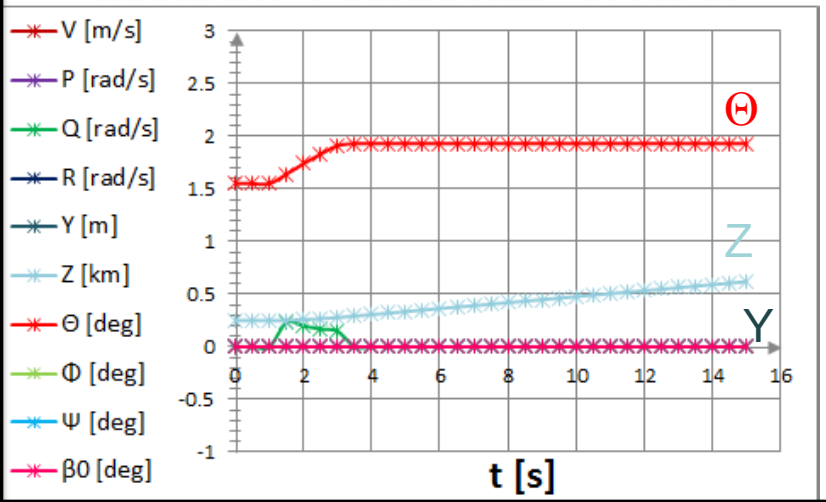
AERODYNAMIC TERMS

NON-LINEAR

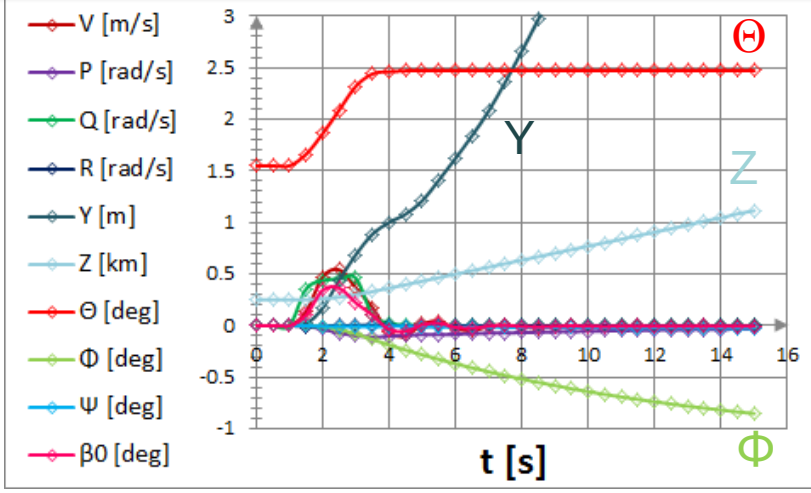
WITH GYROSCOPIC EFFECTS

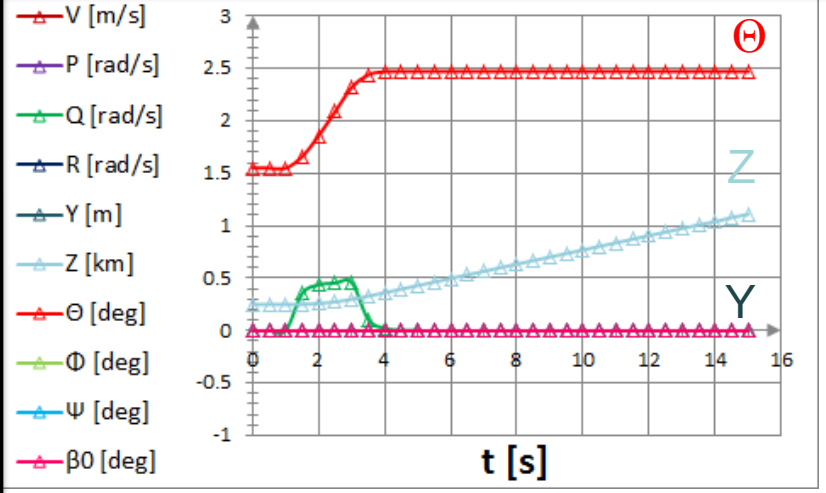


WITHOUT GYROSCOPIC EFFECTS



LINEAR





➡ **Strong** influence of **gyroscopic effects** on manoeuvre flight

HOW TO MINIMISE GYROSCOPIC EFFECTS ?

1) Appropriate selection of propeller type and operating parameters

- Decreasing propeller moment of inertia:
  - **Composite propeller** instead of propeller made of duraluminium
  - **Reduce number of propeller blades** or **propeller diameter**
- Decreasing **rotational velocity of propeller**

⬇

Degradation in engine efficiency and power to weight ratio ☹

⬇

Correct approach to design:

Matching propeller to the engine! ⇒ Aim: **the best aircraft performance!**

instead of trying to eliminate gyroscopic effects!

HOW TO MINIMISE GYROSCOPIC EFFECTS ?

2) Application of **contra-rotating propeller**

☺ Advantages:

- increasing power for a given propeller diameter
- cancelling gyroscopic precession effects
- reset the propeller torque reaction →reduction of the structural loads
- lack of swirl of the air in the slipstream → minimisation of the energy losses
  → less asymmetric flow around the aircraft → improvement of handling qualities

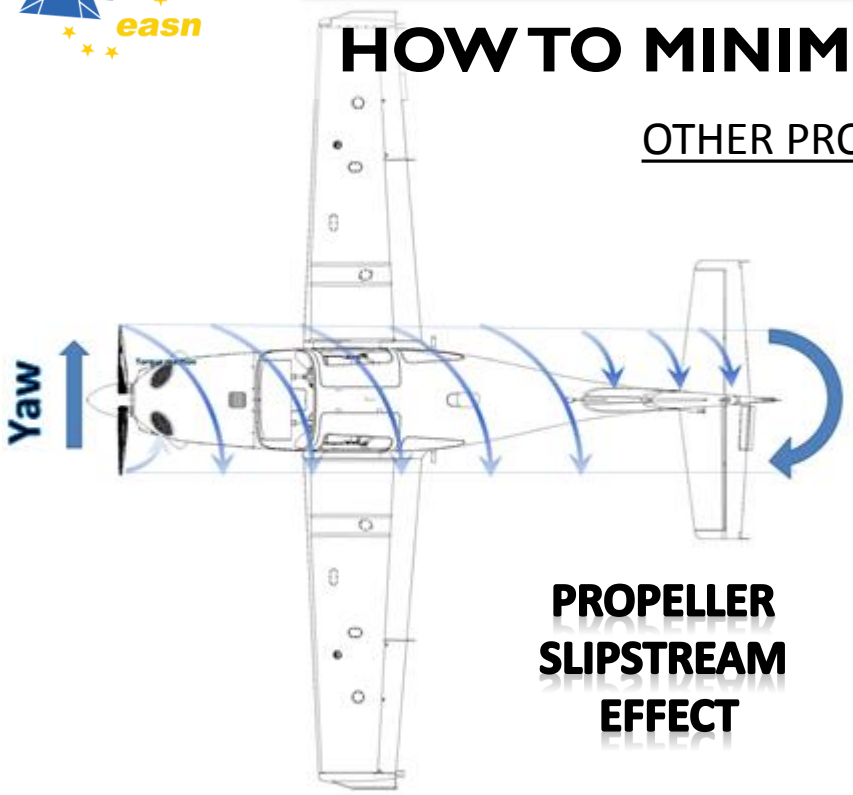
☹ Drawbacks:

- noise caused by the highly alternating flow
- added weight of the necessary, heavy gearbox (planetary or spur)
- extra strong engine mount needed → increase in aircraft total weight
- mechanical complexity – advanced construction (complicated engine installation)
- additional designing costs and expensive maintenance costs

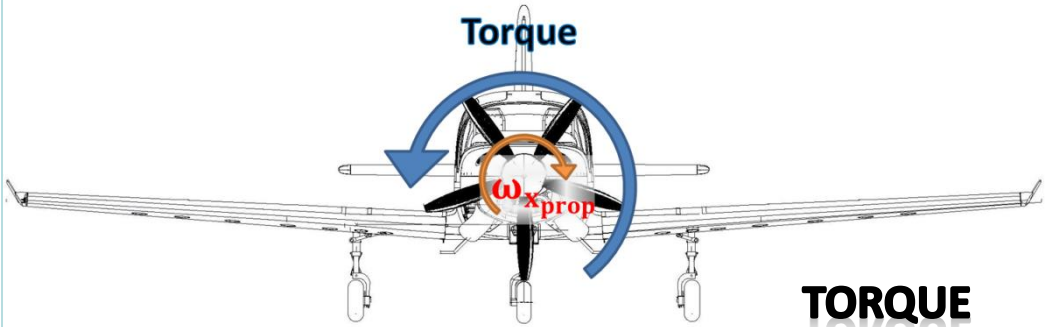
HOW TO MINIMISE GYROSCOPIC EFFECTS?

OTHER PROPELLER SIDE EFFECTS

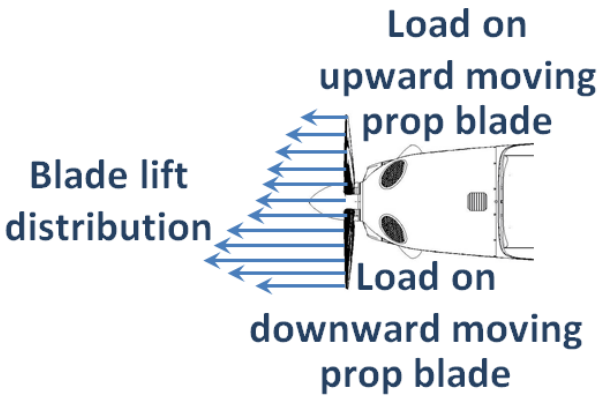
➡ How to turn weakness into strength?

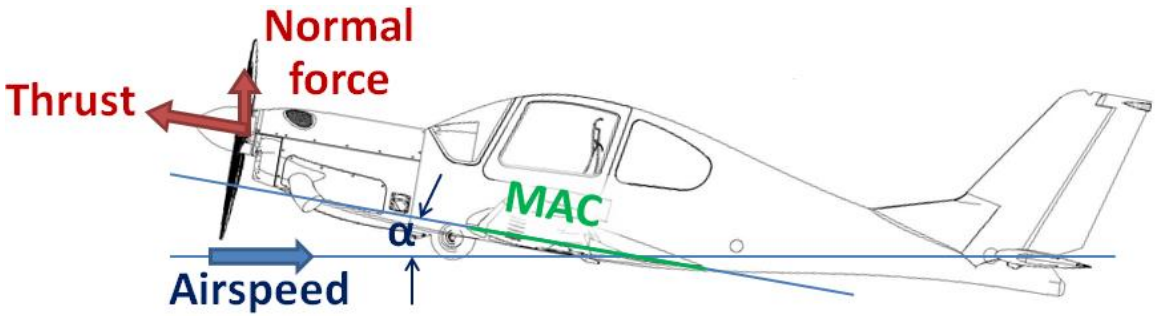


PROPELLER SLIPSTREAM EFFECT



TORQUE EFFECT





P-FACTOR

asymmetric propeller blades loading

CONCLUSION

1) Gyroscopic moments due to rotating propeller depends on type of disturbances from steady-state flight and on aircraft response to external inputs:
   - ➢ Dynamic stability ↔ small perturbation ⇒ Weak Gyroscopic Effects
   - ➢ Rapid manoeuvres ↔ type of flight disturbance ⇒ Strong Gyroscopic Effects

   ⬇

   - ▪ random inputs → gust
   - ▪ control inputs → deflection of { rudder, elevator, ailerons }

2) Gas turbine engine gyroscopic effects are significantly lower than propeller-induced gyroscopic effects

3) All obtained results are dependent on:
   - ➢ input data: external geometry, mass distribution, dimensionless aerodynamic derivatives, propeller type and operating parameters, flight conditions…
   - ➢ accuracy of mathematical model of aircraft motion

4) Influence of gyroscopic effects on light aircraft dynamic stability can be neglected

5) Results of dynamic stability analysis without consideration of inertia coupling are sufficiently accurate

CONCLUSION

Rapid manoeuvres ↔ gyroscopic effects

1) The greater disturbances from trim condition, the stronger gyroscopic effects

2) For selected steady-state flight conditions, assessment of aircraft response following rapid manoeuvre depends on:
   - deflection of control surface, duration and type of control input
   - type and parameters of atmospheric gusts

3) Choice of the mathematical model for the analysis of aircraft response following rapid manoeuvre is of crucial importance and does influence on results

4) Mathematical model of aircraft motion with nonlinear terms added to aerodynamic forces and moments results in:
   - more reliable response and solutions
     → more accurate model of motion
   - aircraft disturbed motion is better damped
     → larger value of damping ratio

CONCLUSION

Rapid manoeuvres ↔ gyroscopic effects

5) Mathematical model of aircraft motion based on linear model of aerodynamics

- If gyroscopic effects are included
  - the most significant deviation from steady-state flight as a response to rapid manoeuvres of aircraft

- If gyroscopic effects are not included:
  - lack of gyroscopic precession after disturbance from trimmed flight
    → aircraft returns to steady-state flight conditions
  - lack of coupling between longitudinal motion and lateral-directional motions

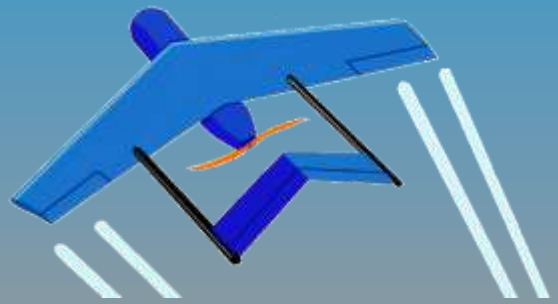
6) Gyroscopic terms in equations of aircraft motion cause:
- decrease in damping of disturbed aircraft motion
- coupling between longitudinal and lateral-directional aircraft motions

Gyroscopic effects have to be always considered in light aircraft dynamic analysis!

7) Among different methods to reduce or fully eliminate gyroscopic moments, the most desire and effective method consists in usage of the propeller side effects (P-factor, torque and slipstream effects)

Thank you for your attention !

4th EASN Association International Workshop on Flight Physics & Aircraft Design

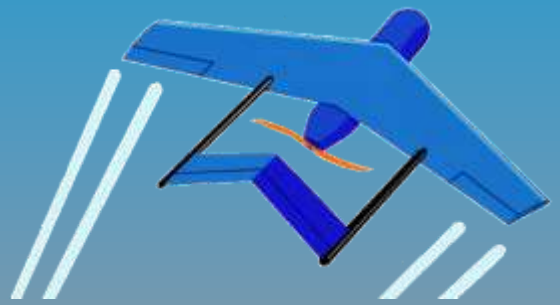


Small UAV autopilot synthesis: tests and results

by
Sergey Lyovin
&
A.V. Ledovskiy, R.M. Murzagalin, N.D. Ageev and V.D. Kobtsev

27-29 October, 2014, Aachen, Germany

Outline



- Intro
- Automatic flight control system
  - Modeling
  - Flight tests
- Conclusion

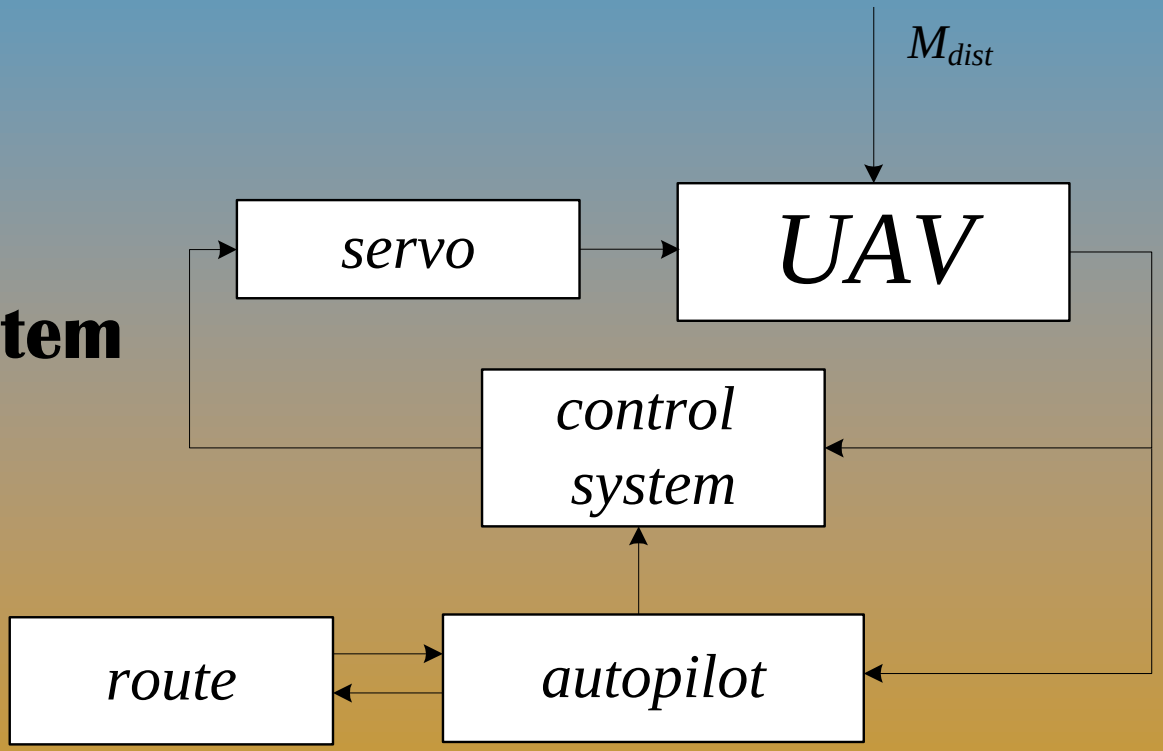
Intro

Wing span	1.2 m
Take-off weight	2.5 kg
Cruise speed	18 m/s (65 km/h)
Flight range	60-120 km
Payload	100-700 g

Automatic flight control system

Structure

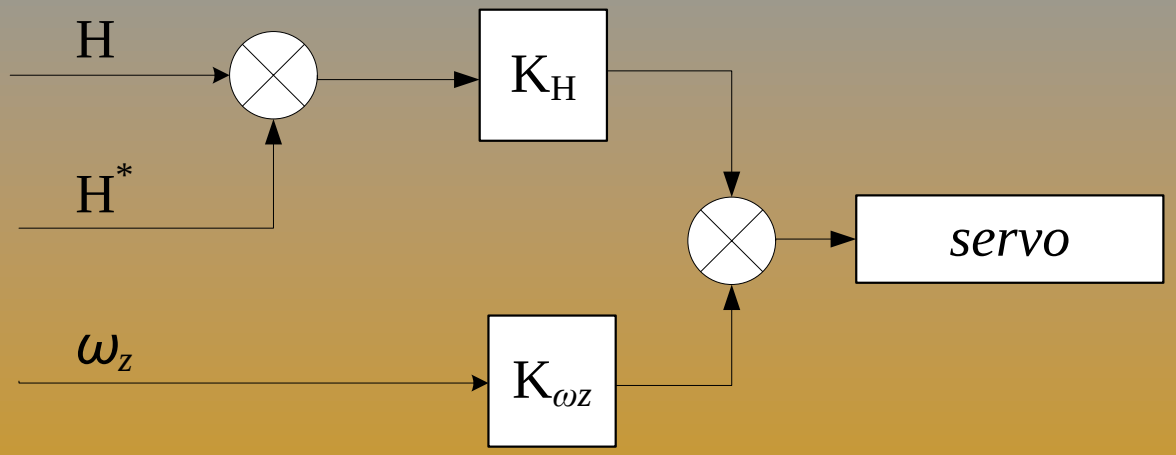
- **Stabilization system**
- **Autopilot**



Automatic flight control system

Modeling

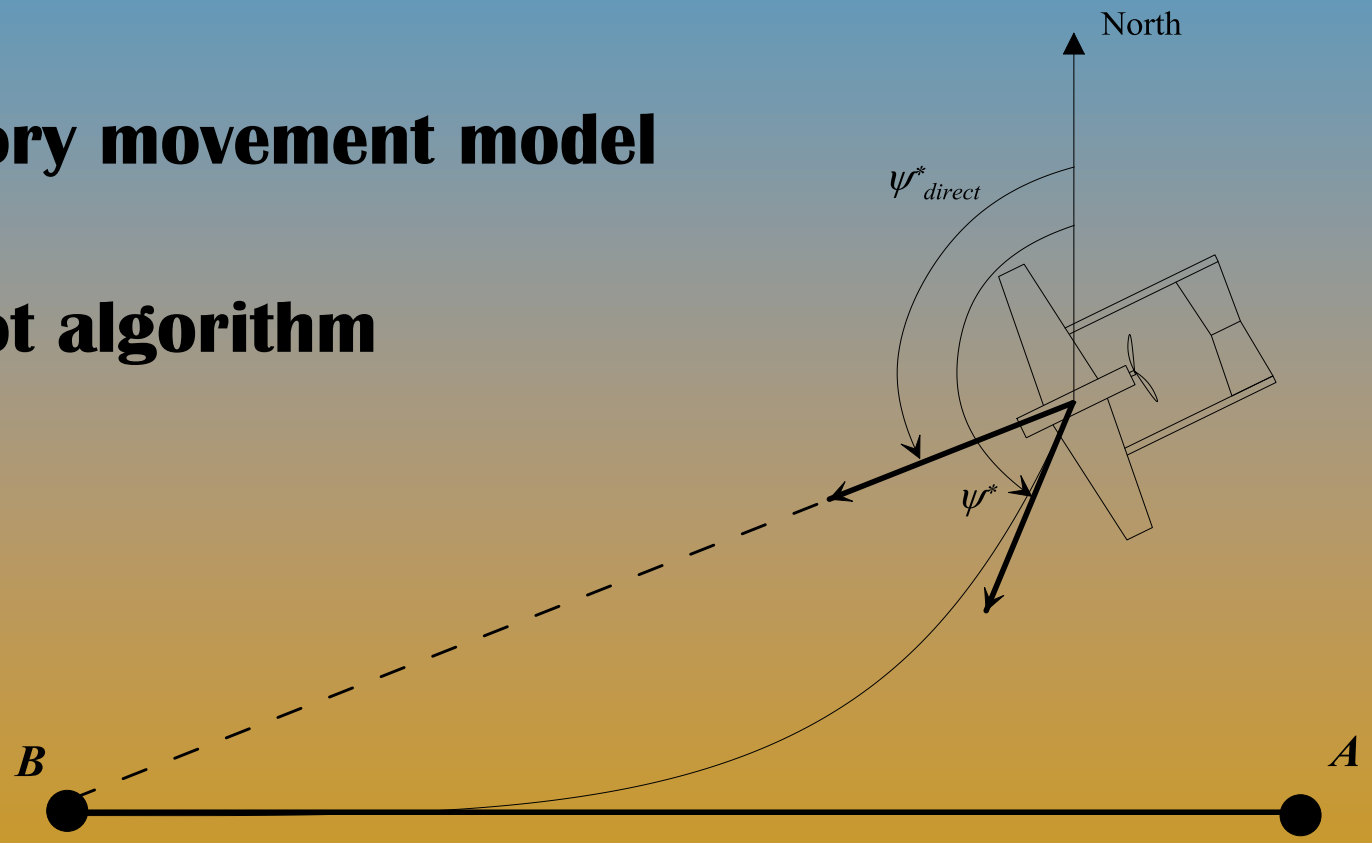
- Aerodynamic model
- Dynamic model
- Control algorithms:



Automatic flight control system

Modeling

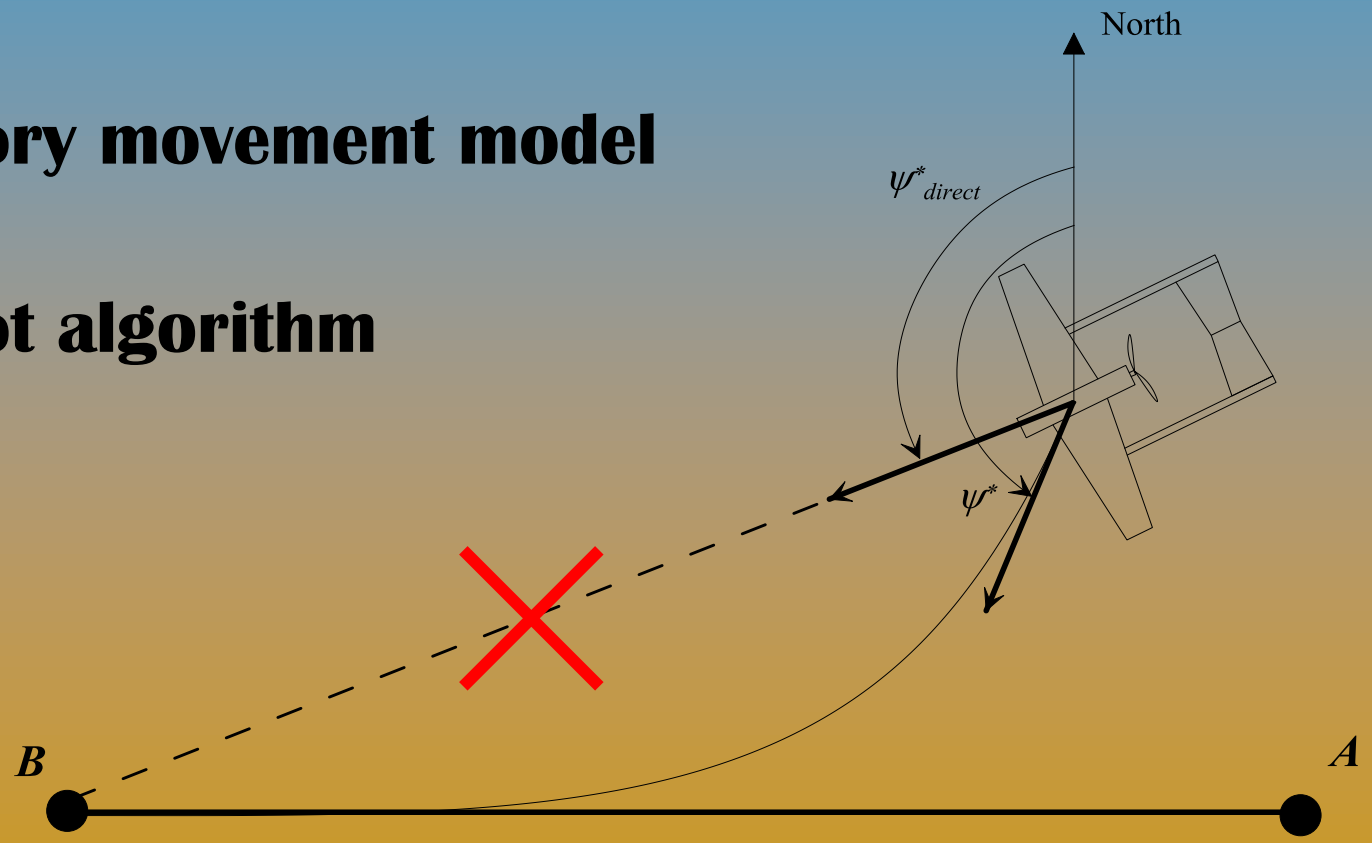
- **Trajectory movement model**
- **Autopilot algorithm**



Automatic flight control system

Modeling

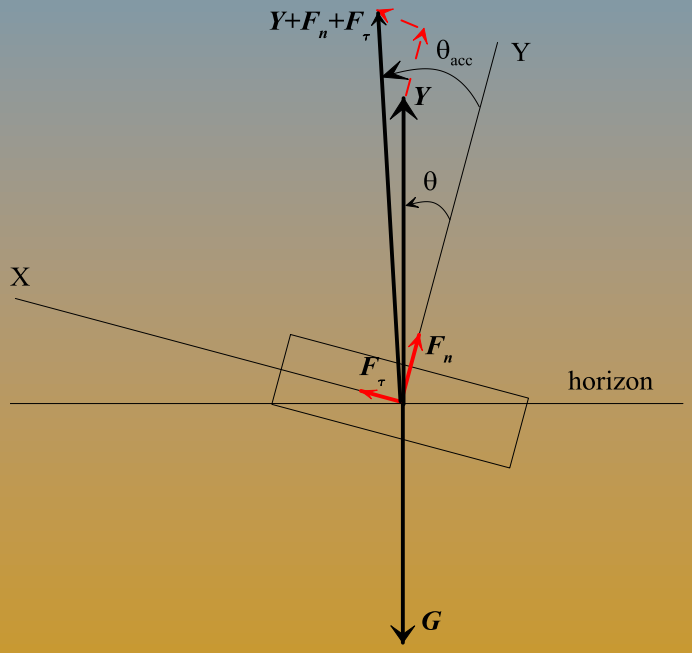
- **Trajectory movement model**
- **Autopilot algorithm**

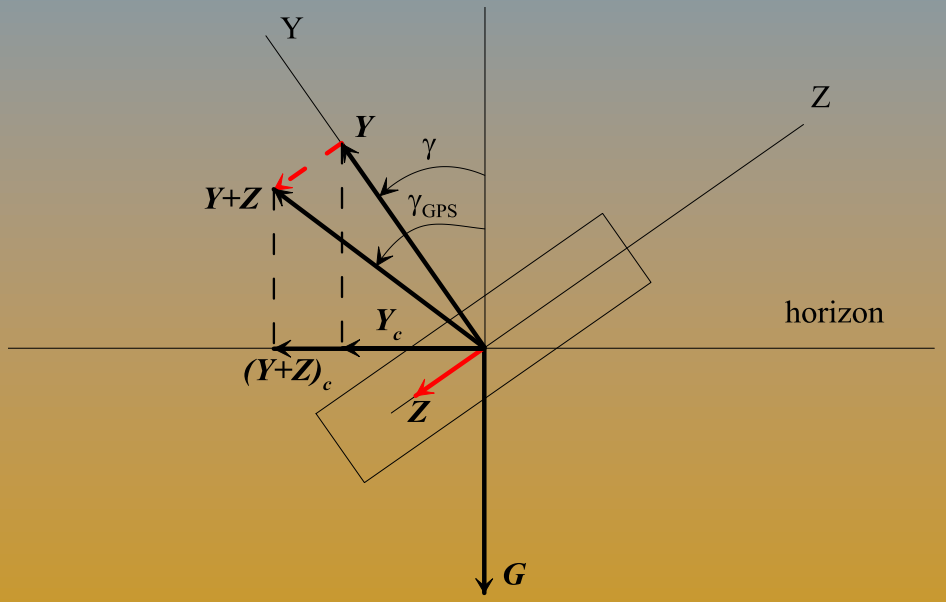


Automatic flight control system

Flight Test

- **Attitude and heading reference system test**

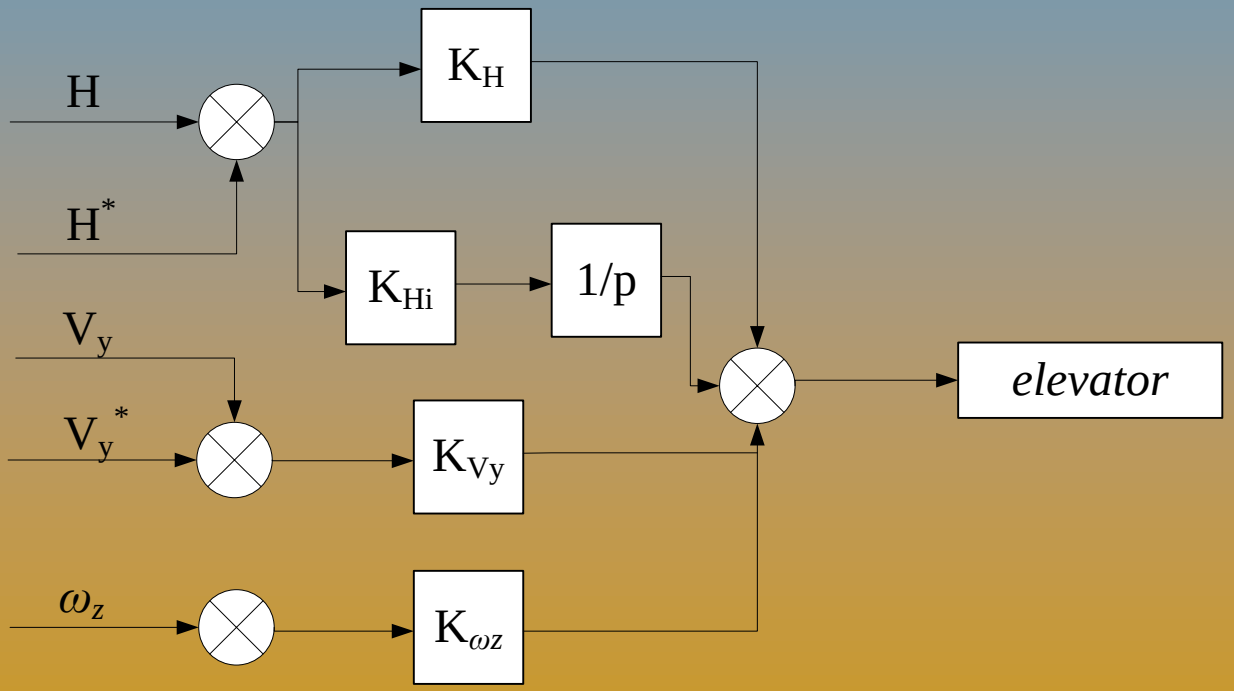




Automatic flight control system

Flight Test

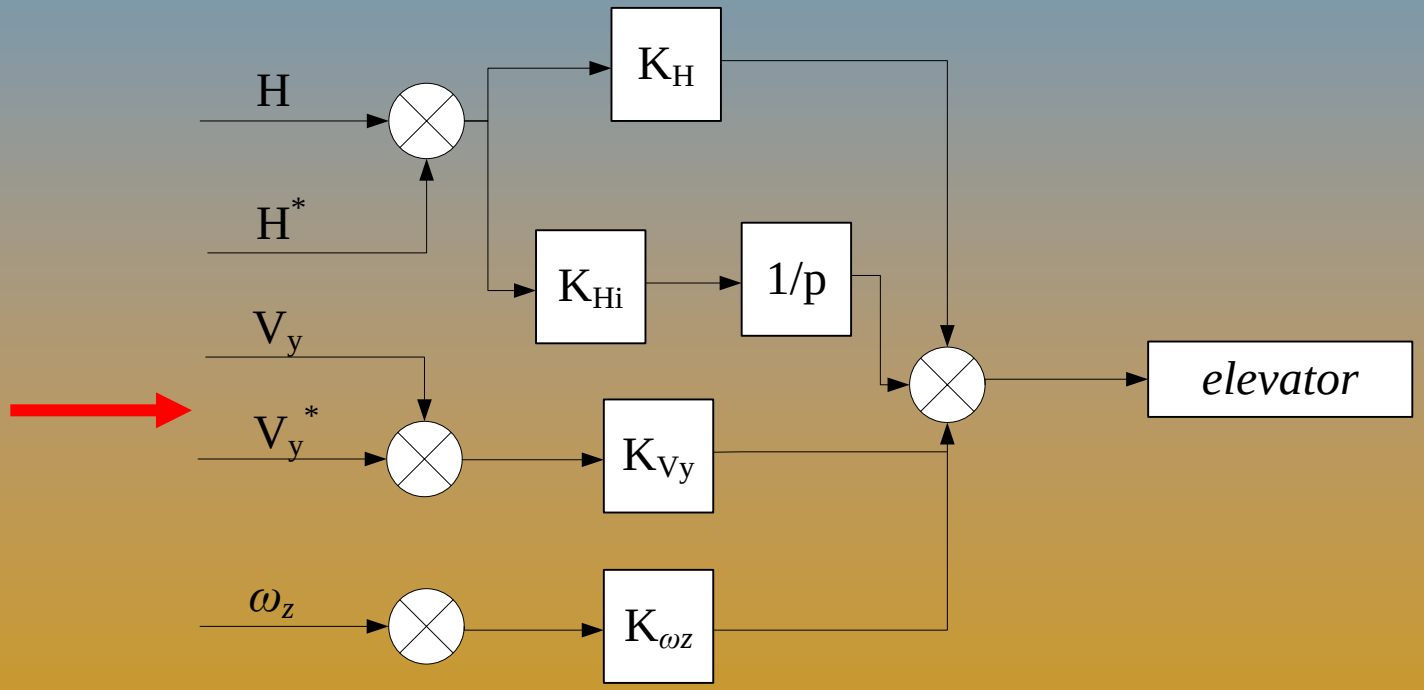
- **Stabilization system algorithms test**



Automatic flight control system

Flight Test

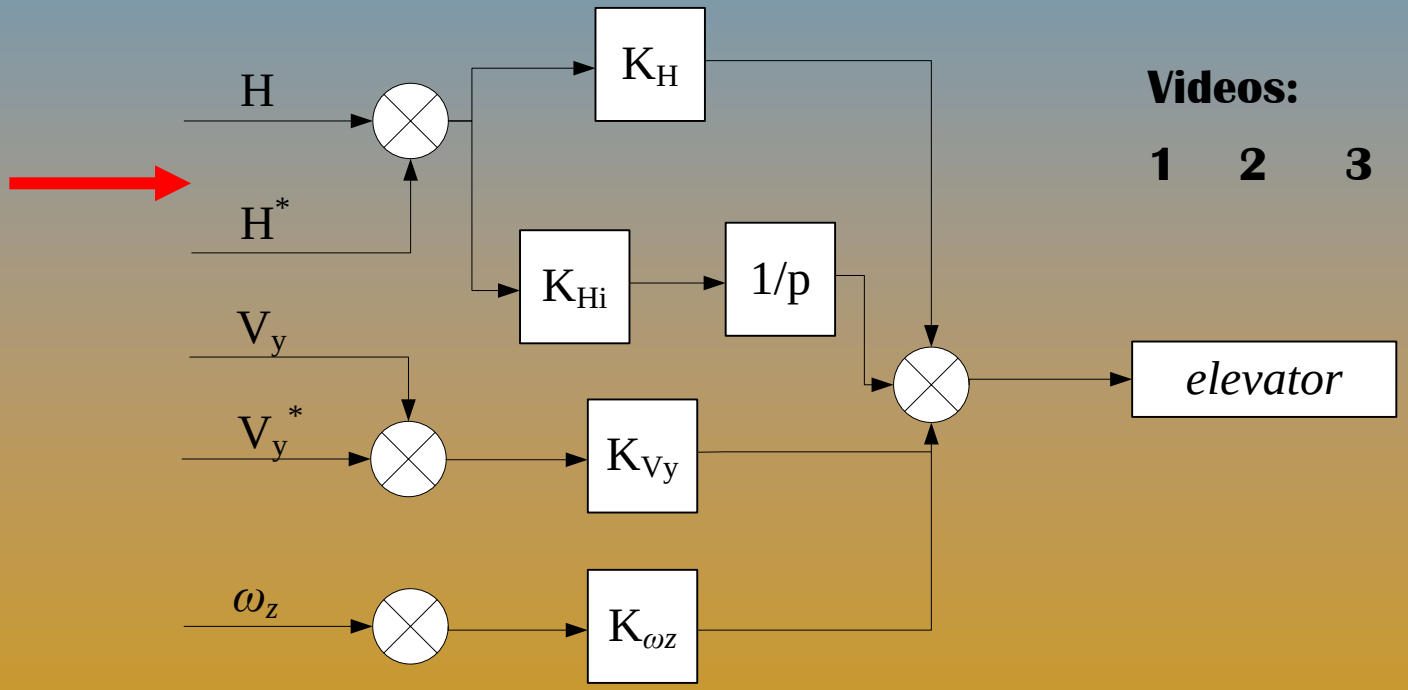
- **Stabilization system algorithms test**



Automatic flight control system

Flight Test

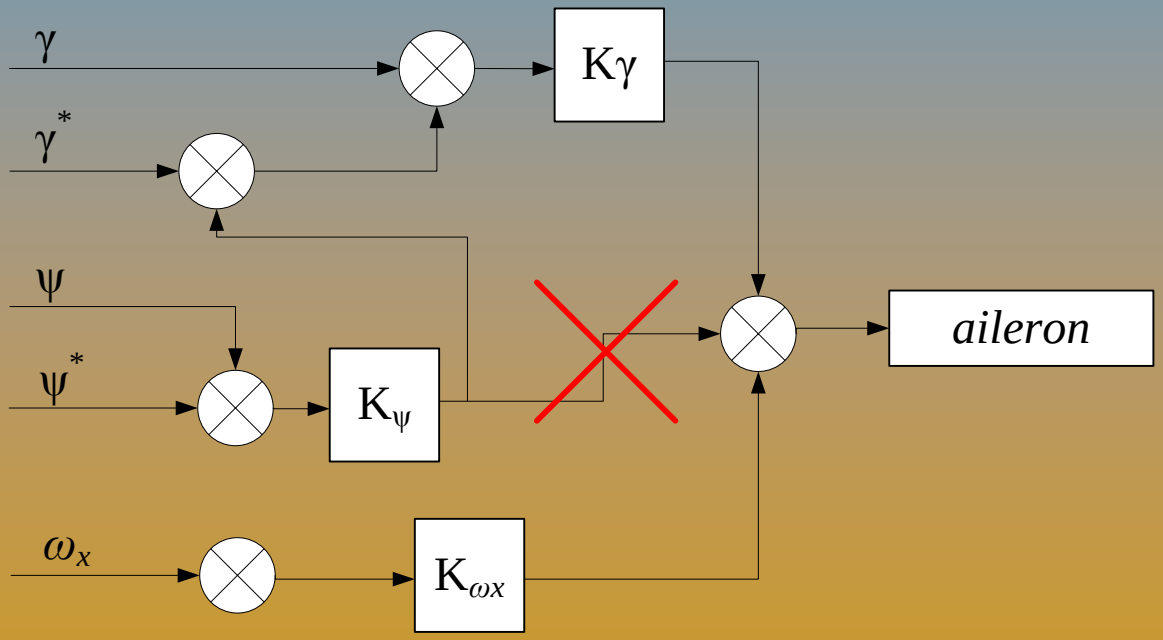
- **Stabilization system algorithms test**



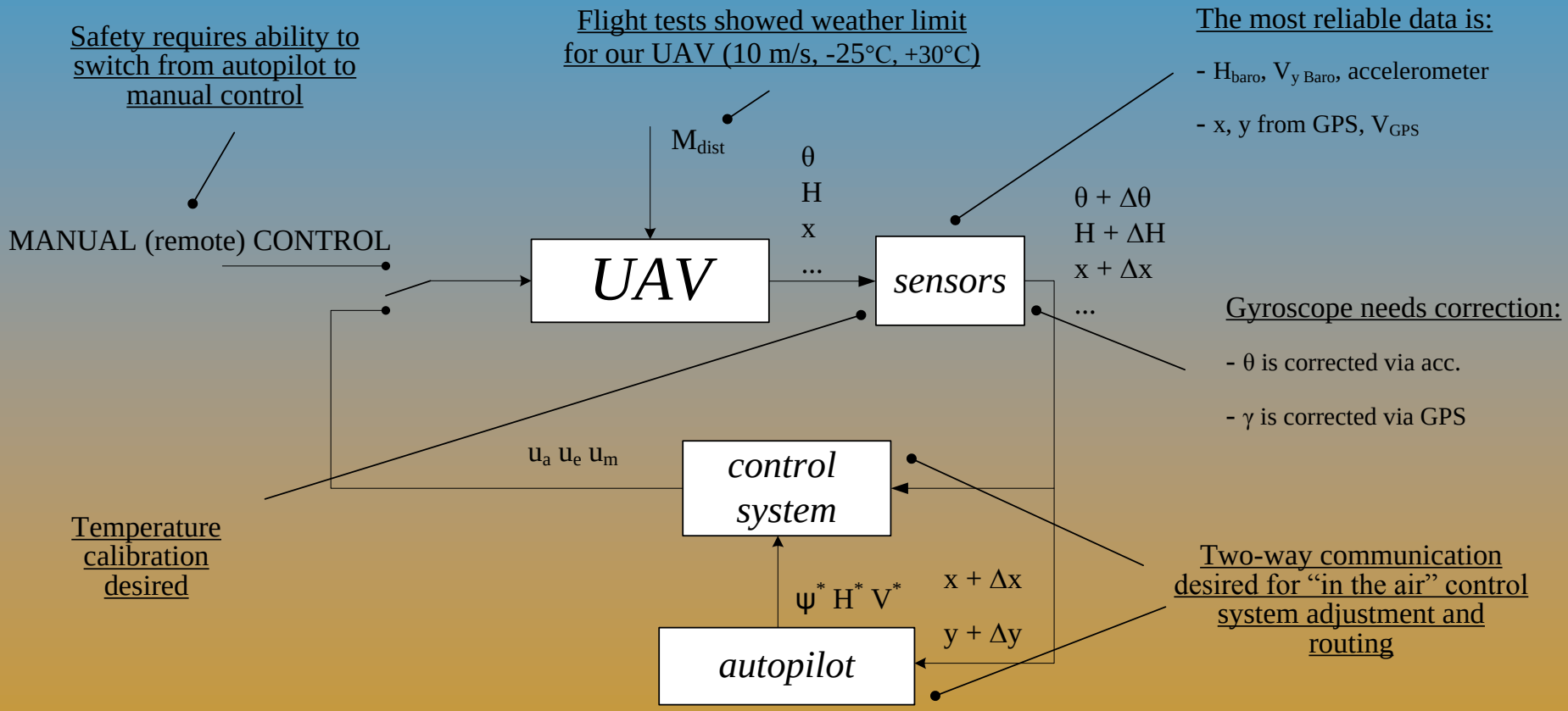
Automatic flight control system

Flight Test

- **Autopilot algorithms test**

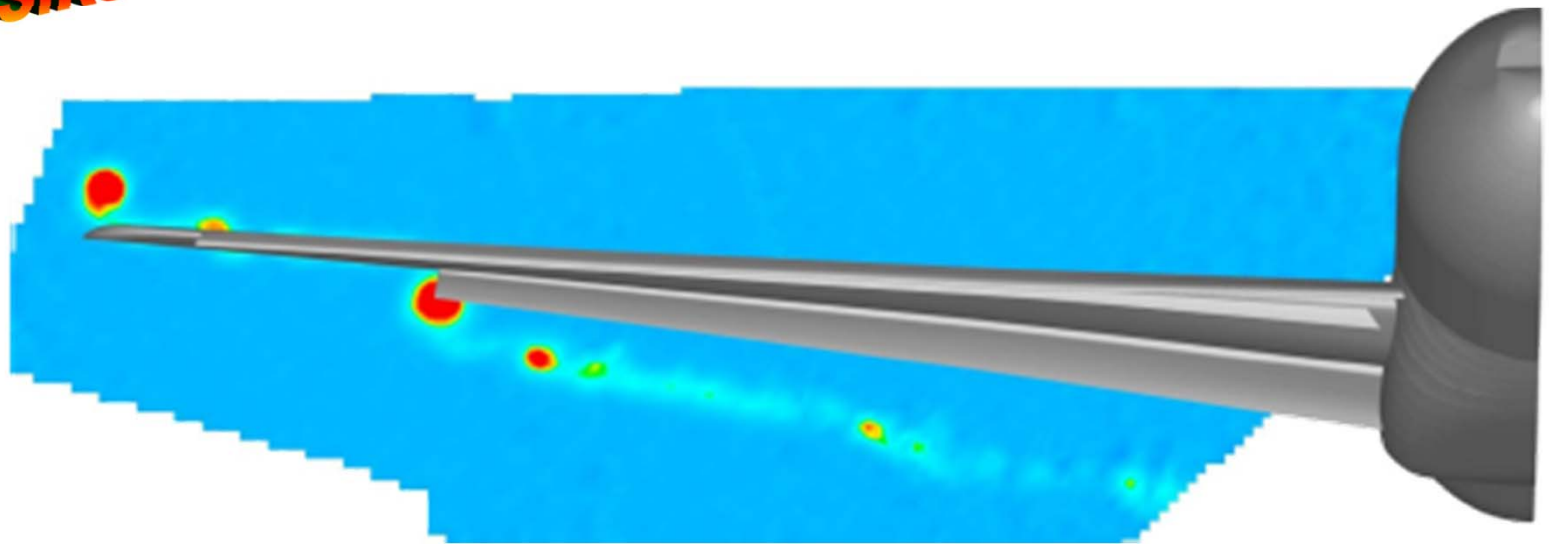


Conclusion


Safety requires ability to switch from autopilot to manual control
MANUAL (remote) CONTROL
Flight tests showed weather limit for our UAV (10 m/s, -25°C, +30°C)
M_{dist}
θ
H
x
...
UAV
sensors
θ + Δθ
H + ΔH
x + Δx
...
The most reliable data is:
- H_{baro}, $V_{y\ Baro}$, accelerometer
- x, y from GPS, V_{GPS}
Gyroscope needs correction:
- θ is corrected via acc.
- γ is corrected via GPS
u_a u_e u_m
control system
Temperature calibration desired
ψ^* H^* V^*
x + Δx
y + Δy
autopilot
Two-way communication desired for "in the air" control system adjustment and routing

The End

Questions are welcomed

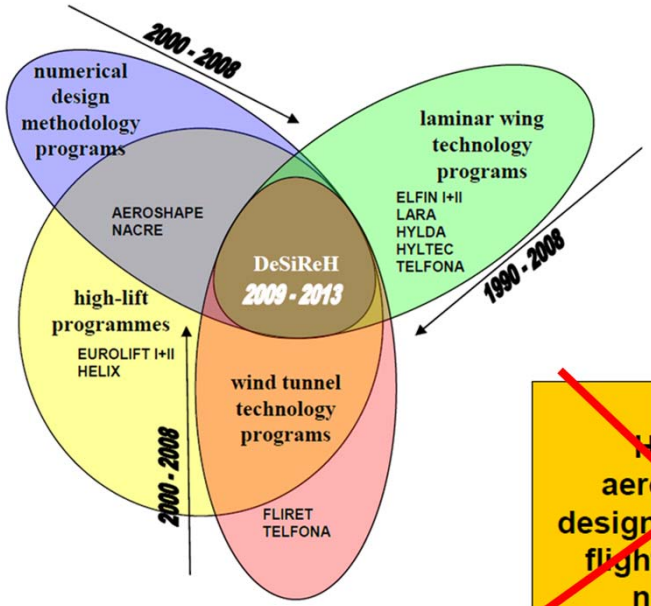


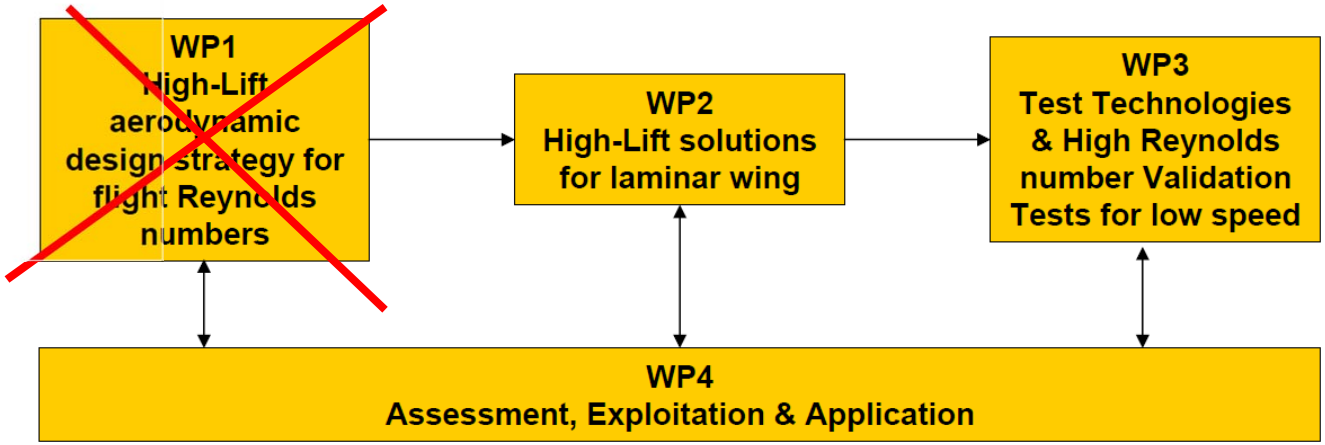
Aerodynamic Design of a High-Lift System compatible with a Natural Laminar Wing within the DeSiReH Project

Ulrich SCHOLZ, Airbus Operations GmbH
prepared by Henning STRÜBER, Airbus Operations GmbH

DeSiReH – Project

- DeSiReH = **De**sign, **Si**mulation and Flight **Re**ynolds Number testing for advanced **H**igh Lift Solutions
- Founded within 7th EU-Framework (ACP8-GA-2009-233607), 2009-2013





Involved Partners

- Industry:
- SMEs:
- Non-profit public bodies:
- Universities

DeSiReH - Goals

Design chain based on high-fidelity methods

Embed and apply high-fidelity methods and advanced optimization approaches tailored for high-lift designs.

Reduce time to market

Improved capability to provide reliable predictions at flight conditions without the need of existing experience as benchmark through industrial embedded high-fidelity methods based optimization chain.

Reduction of environmental impact

Make a significant step beyond conventional high lift systems by designing and testing high lift for future high-lift concepts (low complexity, especially focusing “enabling” solutions for laminar wings)

High-Lift Performance prediction for “sharp edge” optimized design

Provide more precise prediction of 3D complex high lift flows addressing advanced optimization approaches including fluid-structural coupling and improved physical modelling (DES, turbulence models).

DeSiReH - Objectives

- **Maximum lift improvement up to 5%**

  Advanced optimization approache in terms of multi-physics & multi-objectives suited to design advanced & more efficient 3D high-lift systems.

- **Cost reduction of up to 5%**

  Provide **best practice approach** for reliable high-lift flow simulation for complex industrial high-lift configurations for a faster aircraft design

- **Reduction of environmental impact**

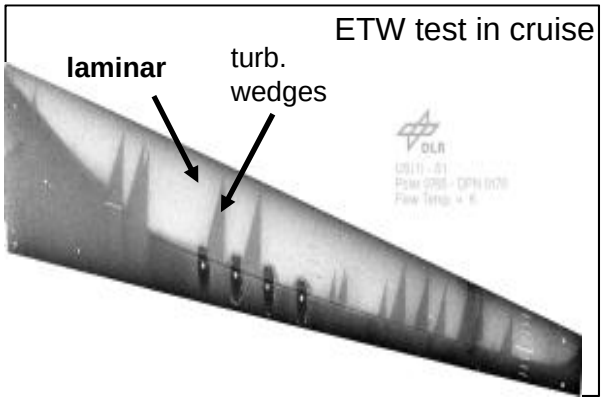
  Step beyond conventional high-lift systems by **designing and build a high-lift system for laminar wings** without degradation in high-lift performance

- **Drag reduction by 15%**

  Support a 15% drag reduction through laminar wing technology with installed high-lift system

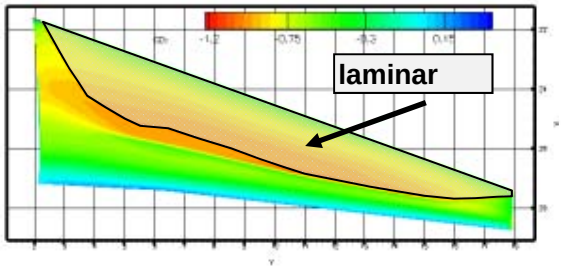
Fuel burn reduction
Contribution of aircraft components

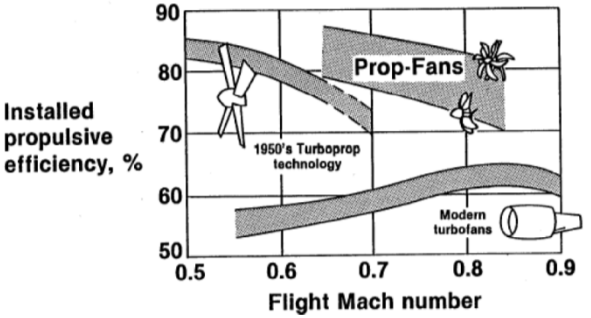
- Natural Laminar Flow (NLF) wings have a large potential to reduce AC drag in cruise
- Other components contribute like
  - Engine (fuel burn, emissions)
  - Tail, Winglets, Fairings (drag)
  - Airframe (weight)
  - …



TELFONA performance wing
at Ma=.75 Re=high CL=design

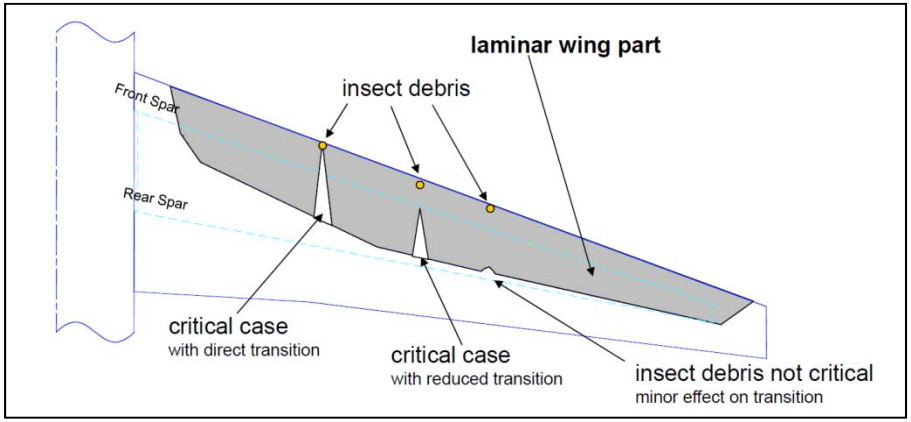
CFD prediction for
typical laminar wing design

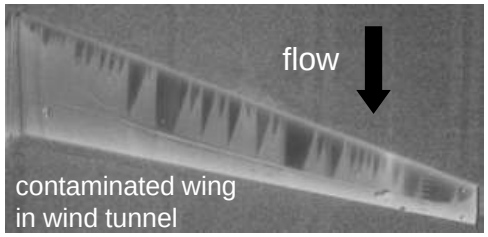


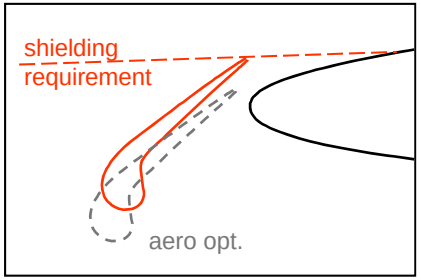


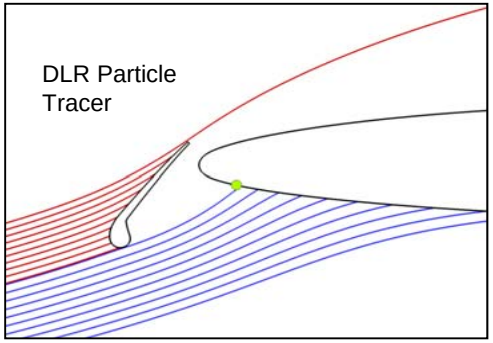
High Lift System as NLF Enabler

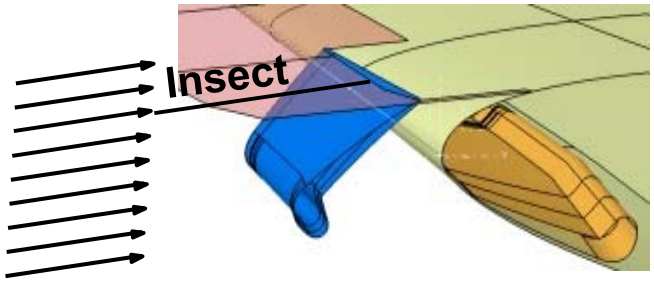
- Operational application of NLF requires effective shielding against insects/debris by Krüger device
- Shielding requirement is a key design driver for Krueger chord length and setting, with significant impact on
  - kinematics/system design and weight
  - space allocation in the wing FLE
  - high-lift aero performance









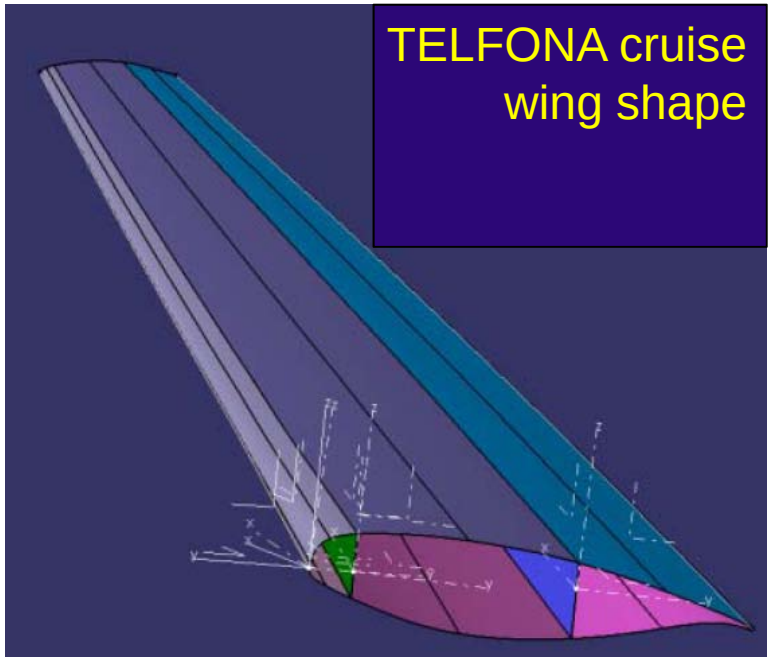


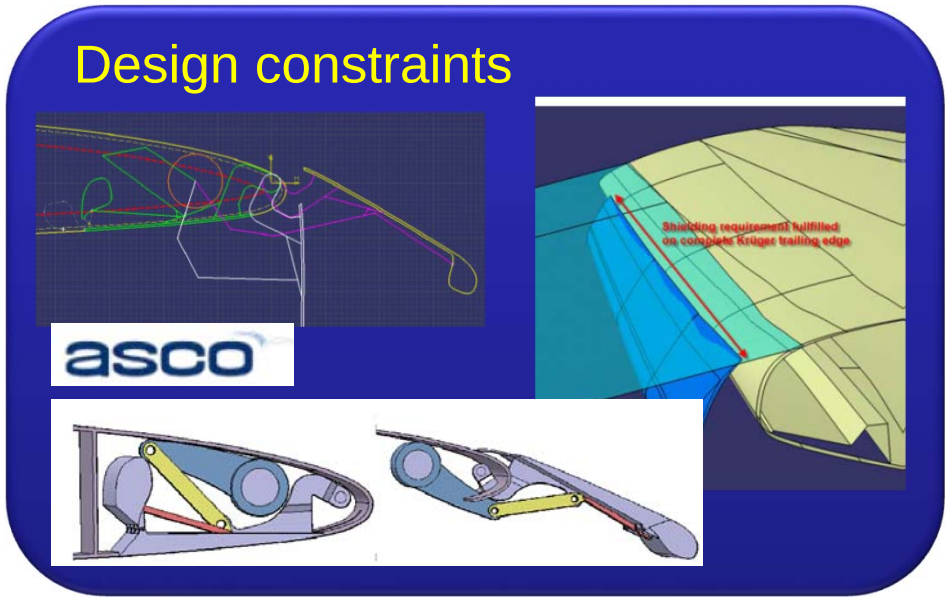
High Lift System as NLF Enabler
Desireh Design Targets

- NLF wing shape from TELFONA project
- Realistic TLAR for C_{Lmax} target
- Multidisciplinary design constraints:
  - Space allocation constraints
  - Shielding requirement

Design Target

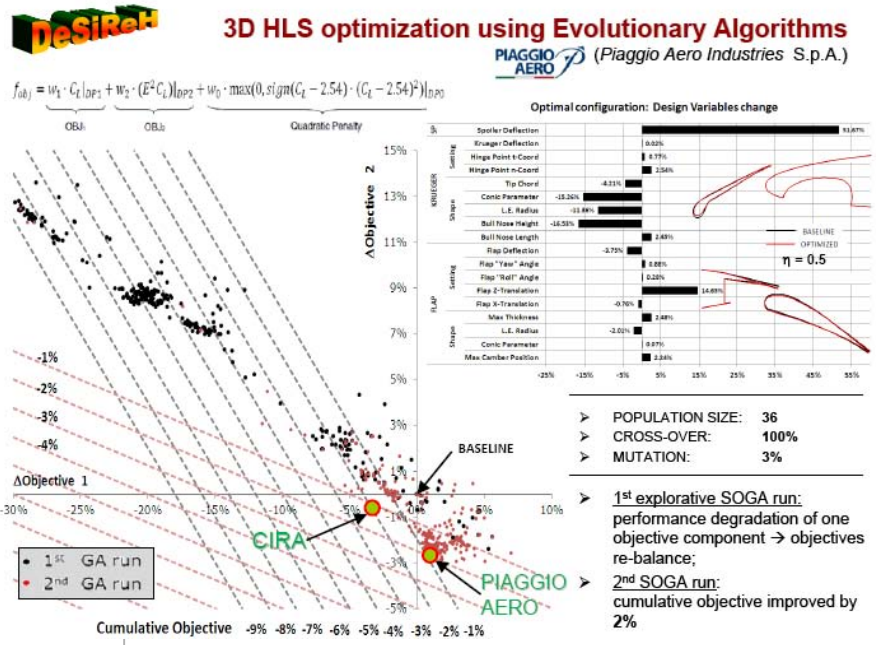
m	67 t
A_ref	118.08 m^2
V_ref (CAS)	135 kts
Ma (CAS)	0.20
Alt above MSL	0 ft
Temp_ISA+t	288.15 K
Pressure_ISA+t	101325 Pa
CL_ref	1.88
V_stall (TAS)	109.76 kts
CL_max	2.885



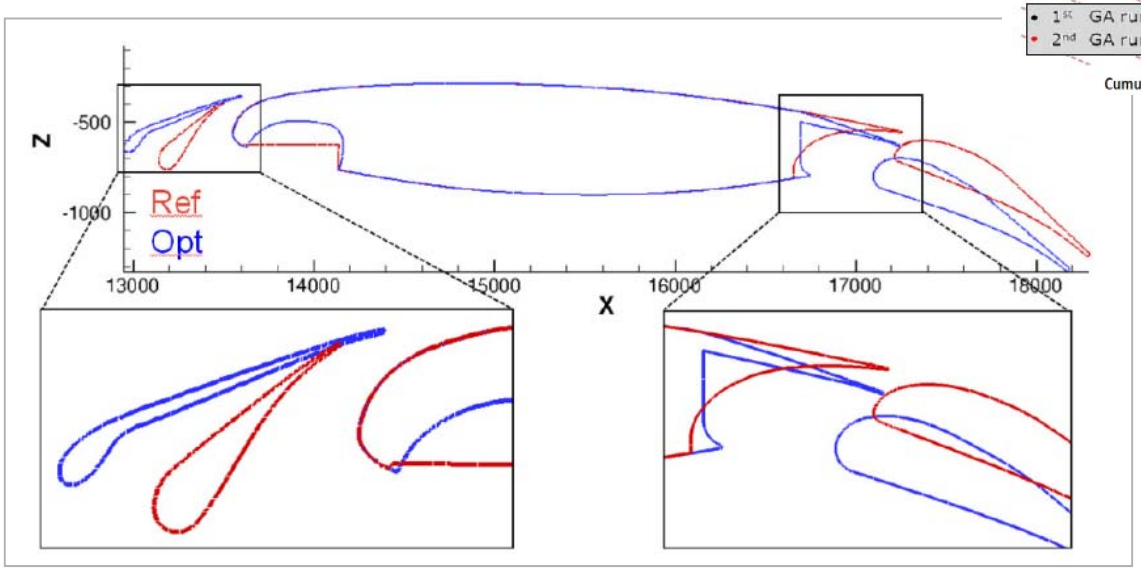


High Lift System as NLF Enabler
Desireh Design Solutions

- Independent design of two high-lift systems:
  - ***Reference*** design with industrial design process by AID
  - ***Optimised*** design applying evolutionary algorithms on 3D wing by PIA



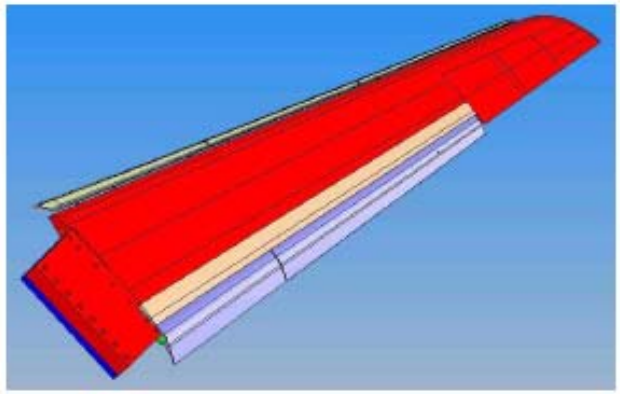
Designed HL Systems



- ***Reference***
  - ***1-piece droplet Krüger (low defl.)***
  - ***Single Slotted Flap***
- ***Optimised***
  - ***Folding bullnose Krüger (high defl)***
  - ***Single Slotted Flap with Spoiler droop***

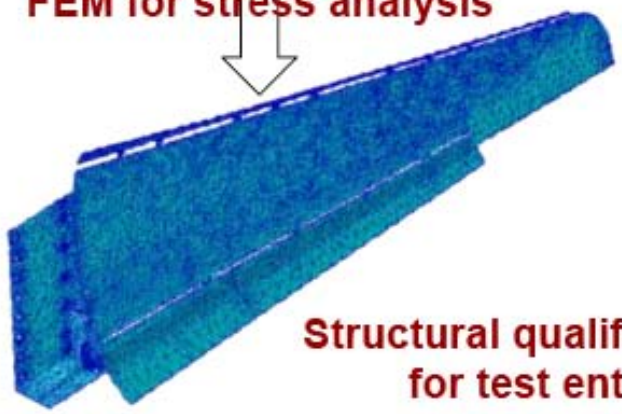
Development of structural models for the high high-lift wing design

Wind tunnel model design

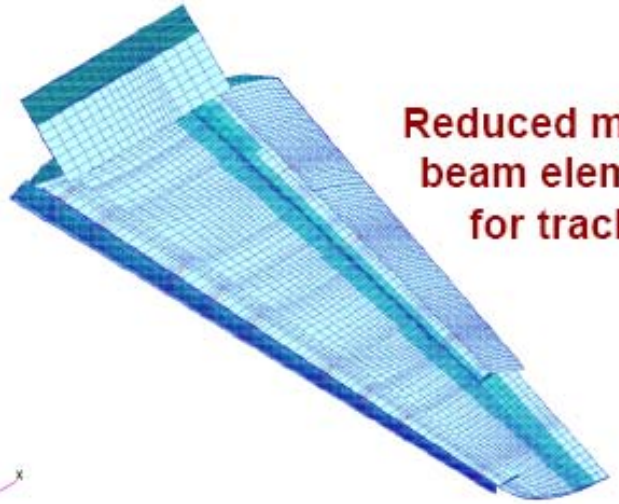


FEM for fluid-structure interaction analysis

FEM for stress analysis

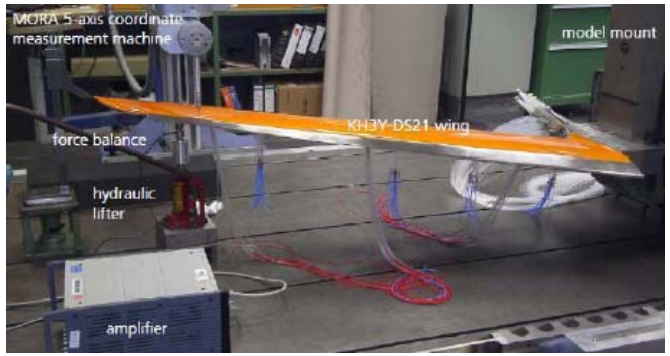


Structural qualification for test entry

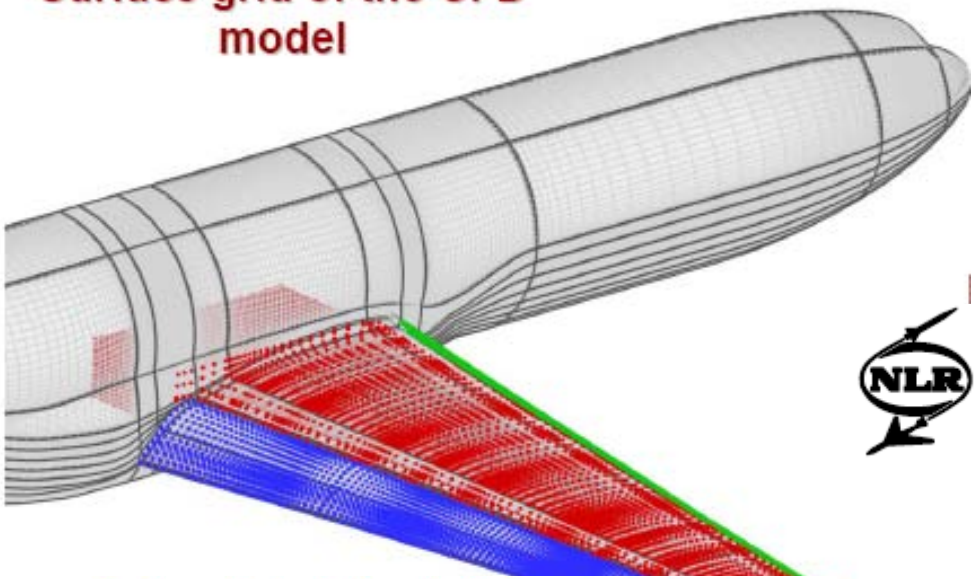


Reduced model: beam elements for tracks

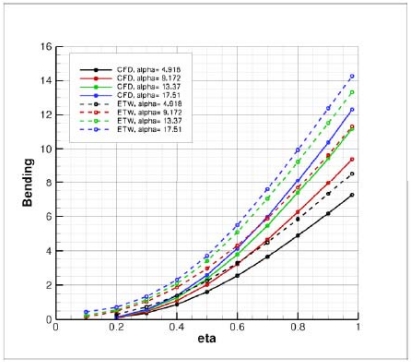
Coupling of models for static aero static aero-elastic simulations

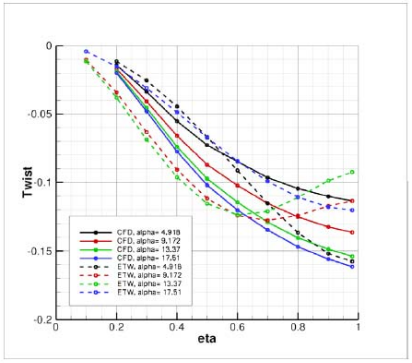


Surface grid of the CFD model



Bending and torsional deformation for the main-wing element

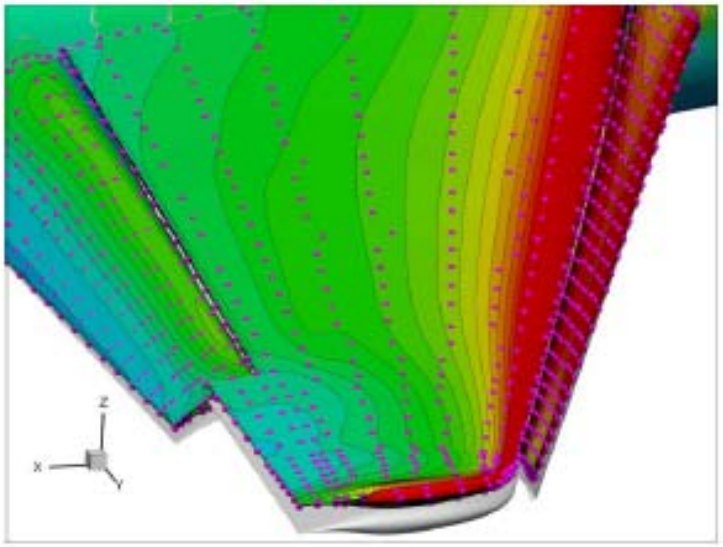




- Excellent comparison of wing deformations along the span
- Discrepancy of 1-2 mm for a wing span of b/2= 1504.3 (mm)

- Good comparison of twist range
- Twist deformations hampered by SPT measurement accuracy of θ= +/- 0.1 (degree)

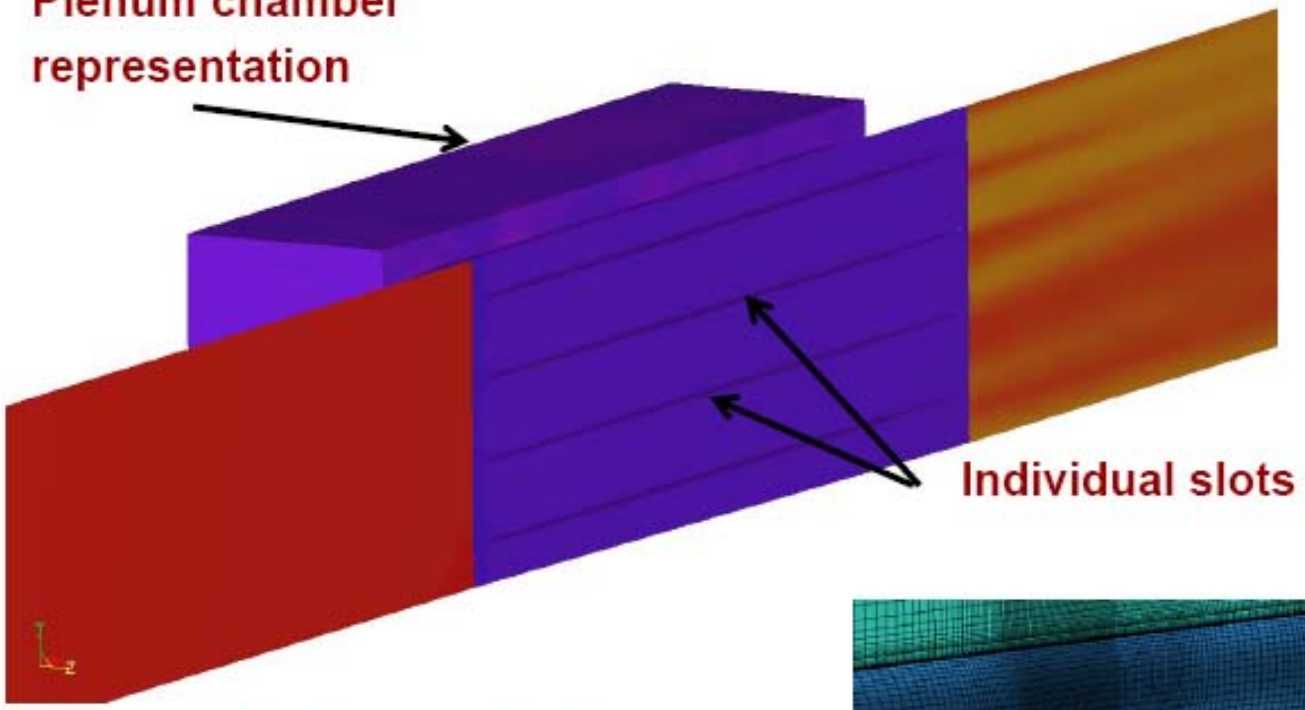
Rigid and deformed wing shapes



M_∞=0.20, Re_∞=16.7 million,
alpha=18, Q_∞=11400 Pa

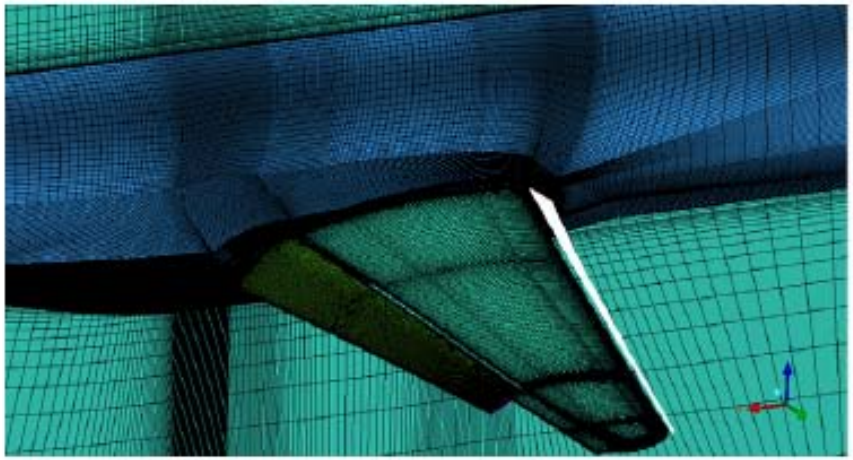
Closed wall and slotted wall interference effects to the high-lift characteristics of the reference design

Plenum chamber representation

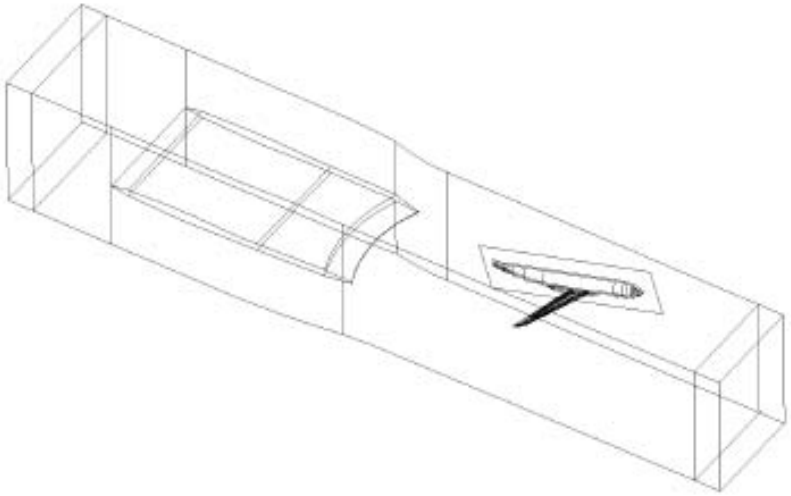


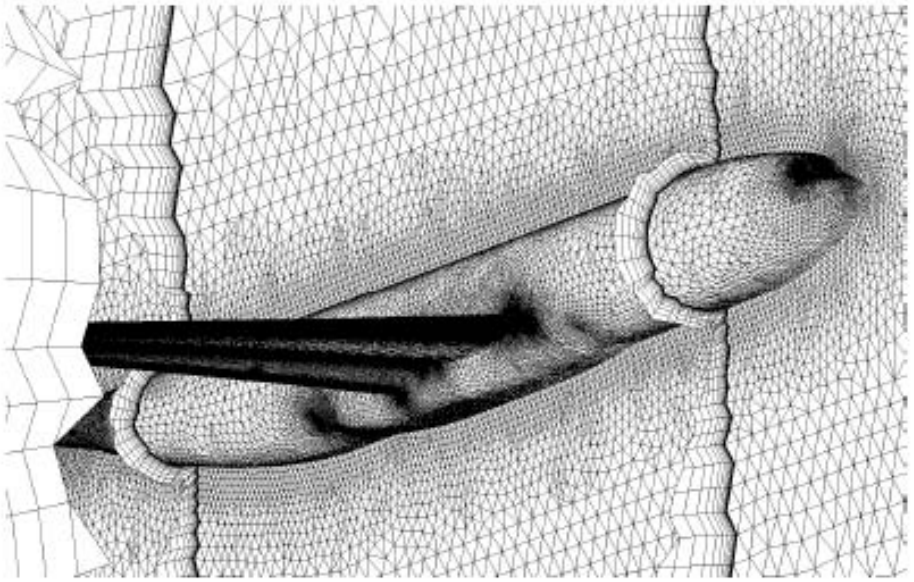
Mesh characteristics:

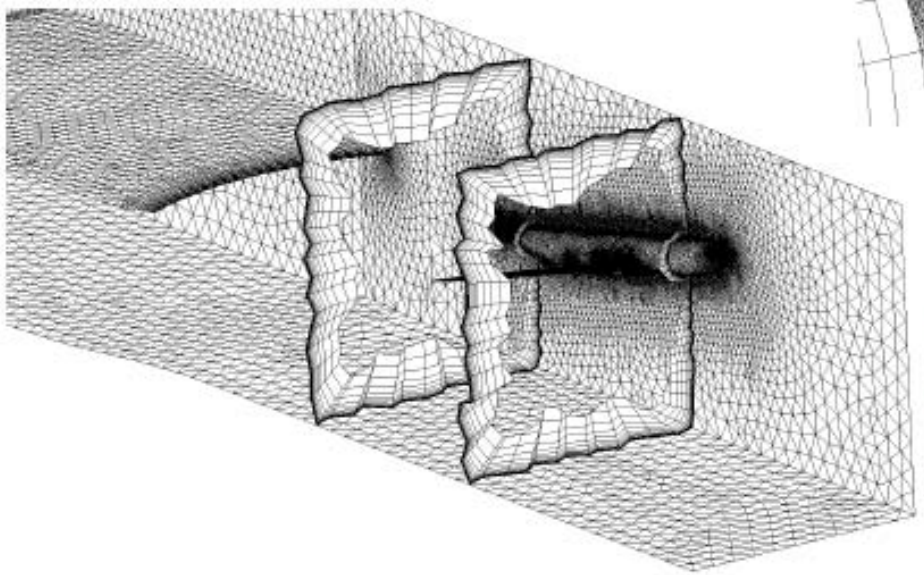
- 14.3 M points model in air
- 19.8 M points model in WT with slots



Assessment of tunnel interference effects due to closed test section walls of ETW



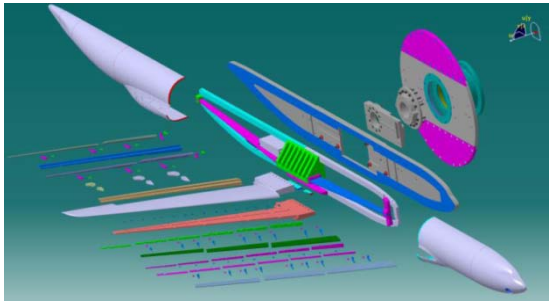


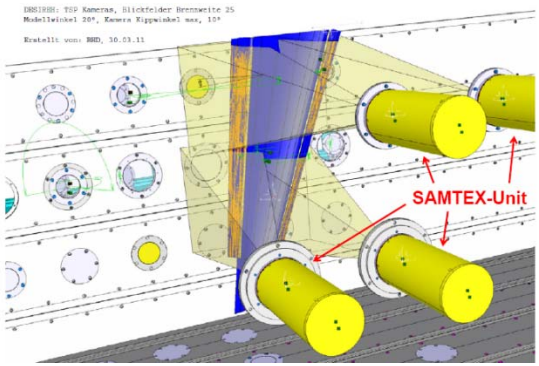


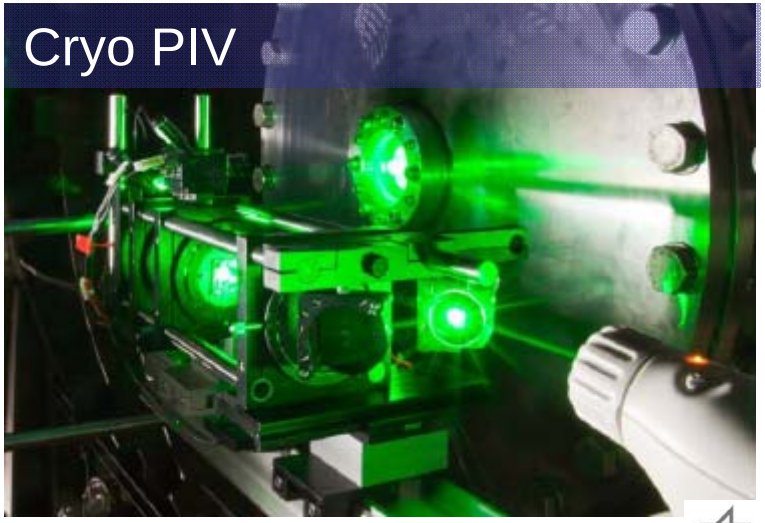
- Unstructured grid approach.
- Hybrid grid with 19 million points and 50 prismatic layers.
- RANS computations with Spalart-Allmaras turbulence model.

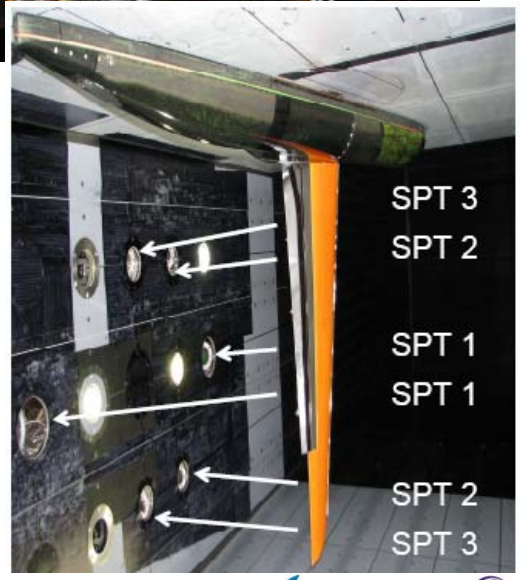
Wind Tunnel Model Design and Advanced Measurement Techniques

- Simultanious application of advanced measurement techniques
  - Cryo Particle Image Velocimetry (PIV)
    → Wake measeurements
  - Stereo Pattern Tracking (SPT)
    → Model deformation (wing box & high Lift devices)
  - Temperature Sensitive Paint (TSP)
    → BL transition detection

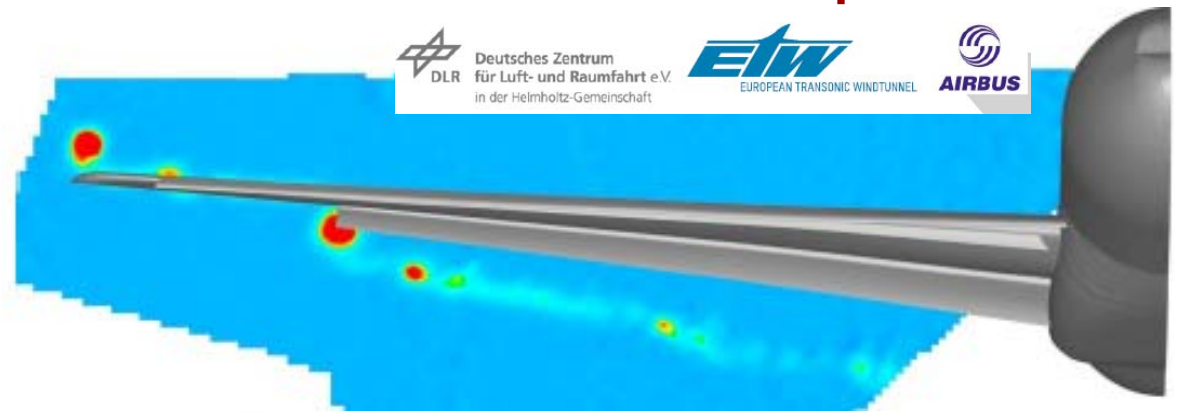


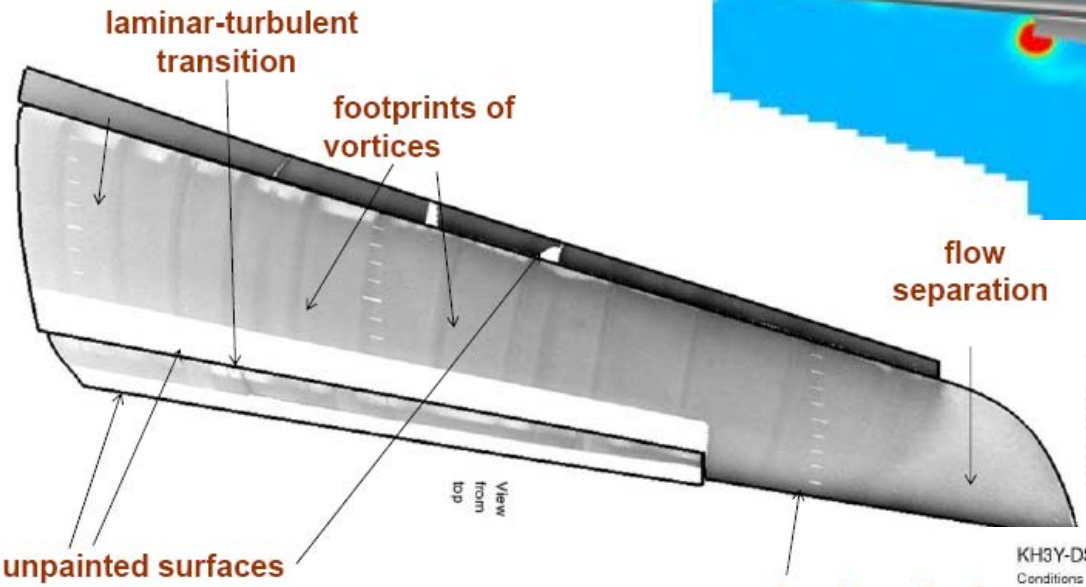


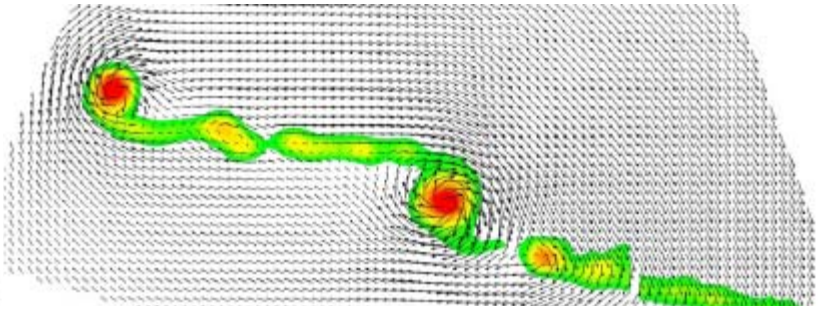


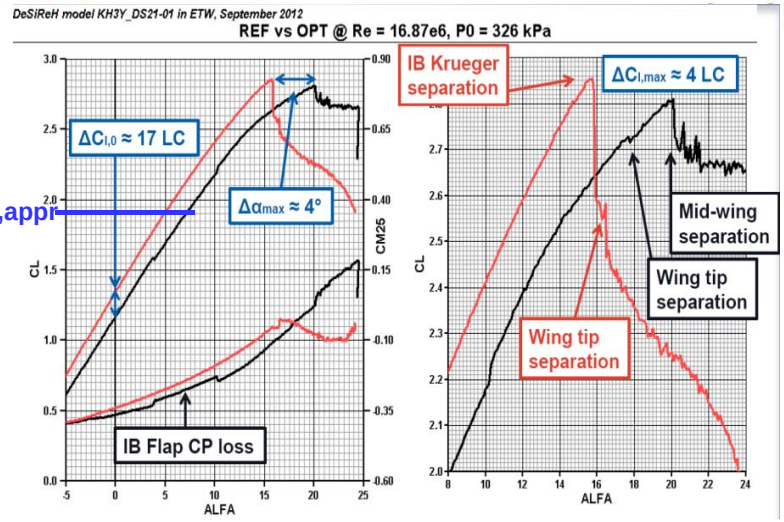


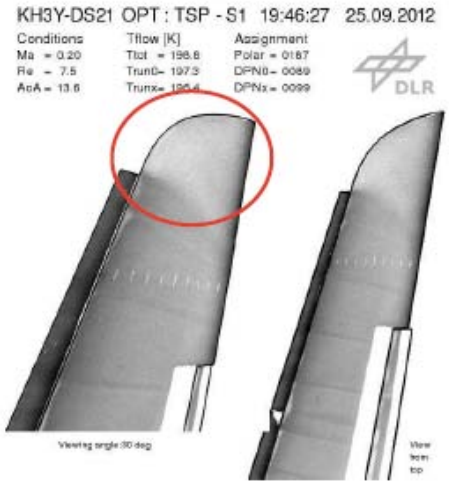
Results of advanced measurement techniques

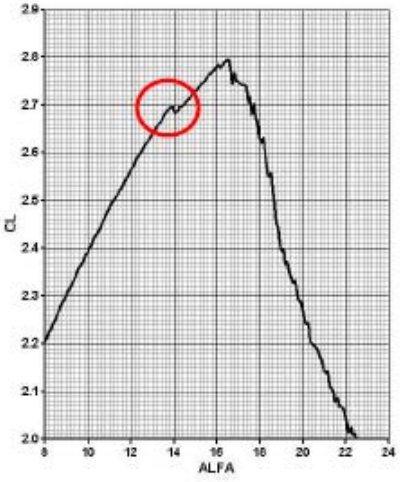








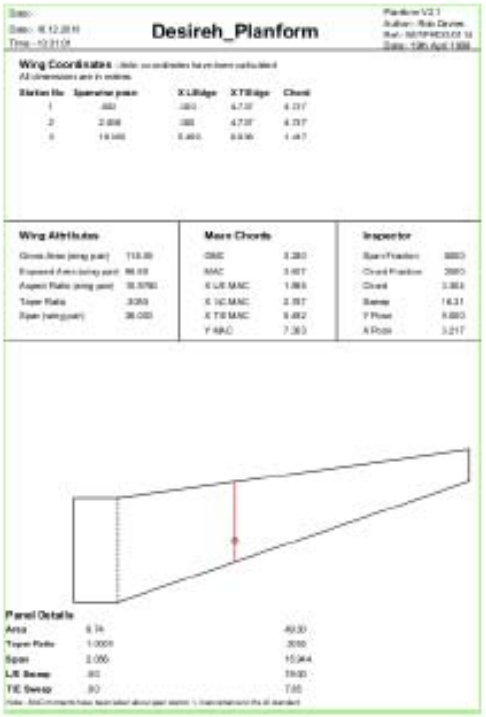


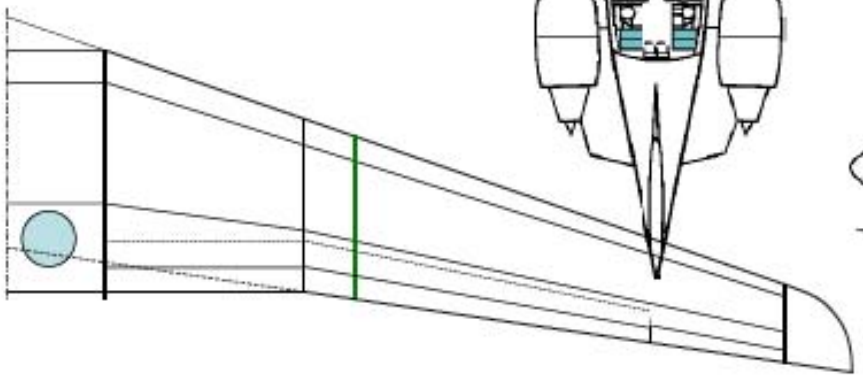


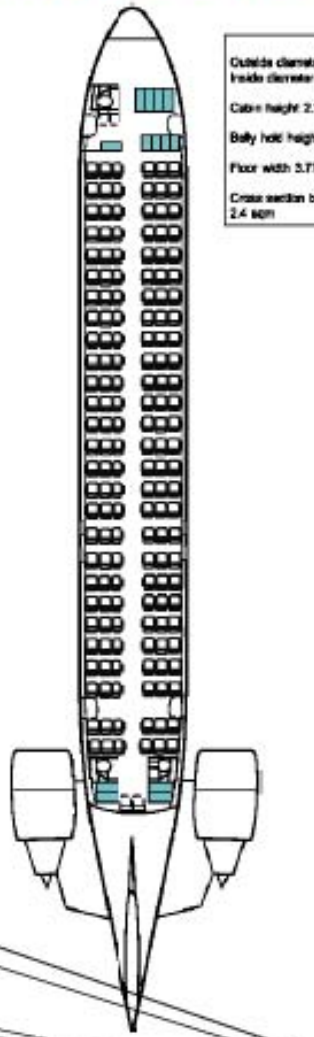
TSP-Image

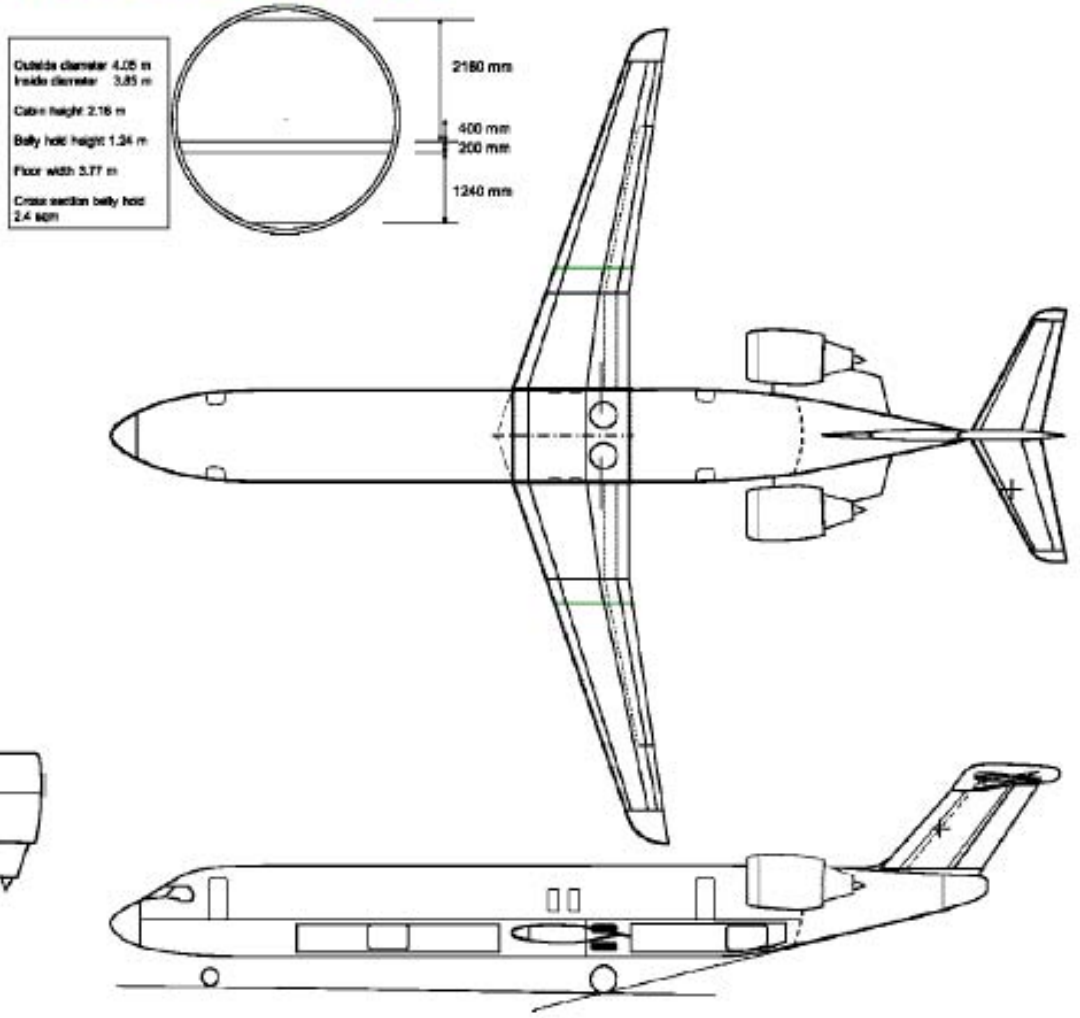
Balance data

Assessement on AC level
Geometry AD1401 and AD1602









Assessement on AC level
AC data - AD1401 and AD1602

Laminar flow design

AD1401 Main Data	
wing span (m)	36.0 m
wing area (sqm)	118.9 sqm
fuselage outside diameter (m)	4.05 m
Fuselage length (m)	39.0 m
length overall (m)	42.5 m
Tailplane span (m)	11.3 m
tailplane area (sqm)	25.0 sqm
Fin area (sqm)	17.2 sqm
Engine fan diameter (")	72"
Engine thrust (Static, max T.O., SL/ISA)	21400 lbs
	95.4 kN
With APR	23800 lbs
	105.9 kN

Design Mass (kg)	
MTOW	70000
MLW	64000
MZFW	59000
OEW	38000

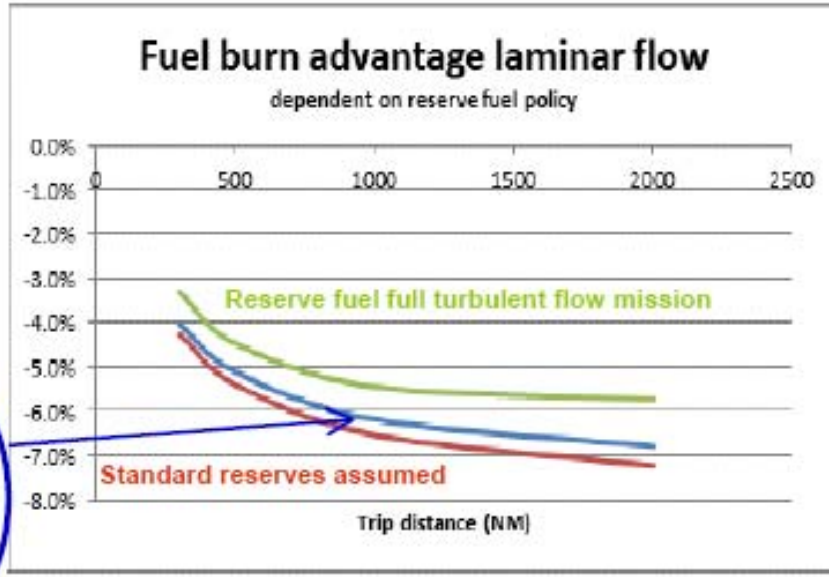
Turbulent flow design

AD1602 Main Data	
wing span (m)	36.0 m
wing area (sqm)	118.9 sqm
fuselage outside diameter (m)	4.05 m
Fuselage length (m)	39.0 m
length overall (m)	42.5 m
Tailplane span (m)	11.3 m
tailplane area (sqm)	25.0 sqm
Fin area (sqm)	17.2 sqm
Engine fan diameter (")	74
Engine thrust (lb Static, max T.O., SL/ISA)	22500
	100 kN
With APR	24900
	111 kN

Design Mass (kg)	
MTOW	71200
MLW	64300
MZFW	59400
OEW	38400

Assessement on AC level
Results: Fuel burn

Performance comparison	AD1401 Laminar Flow	AD1602 Turbulent flow	
Takeoff field length (m)			
SL, ISA+10C, TOW 2500 nm	1912	1822	
SL, ISA+10, 500 nm trip	1402	1334	
2000 ft, ISA+20, MTOW	2429	2157	
Landing distance dry RWY	1489	1497	
Approach speed at MLW (kts, SL/ISA)	133.5	133.9	
Initial Cruise Altitude (ft)	36500	36100	
After takeoff with MTOW, Mach 0.75			
Specific Range NM/kg fuel			
Top of Climb 1000 nm trip, FL390, M 0.75	0.2323	0.2149	8.1%
Range (max pax payload, nm)	2595	2574	
Block fuel with max pax payload (kg)			
300 nm	2140	2230	**-4.0%**
500 nm	2973	3133	**-5.1%**
1000 nm	5155	5495	**-6.2%**
2000 nm	9804	10518	**-6.8%**

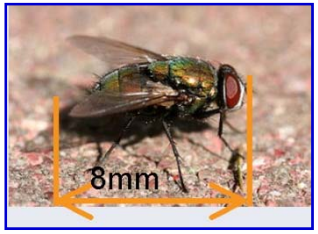


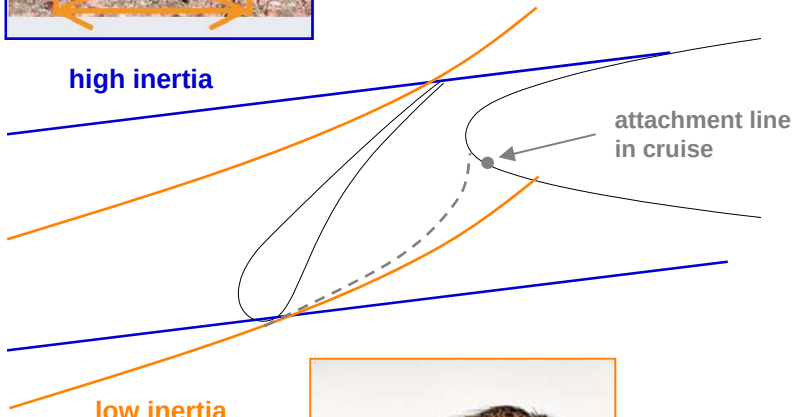
Laminar flow technology saves 5 to 7% fuel burn on trips between 500 nm and 2000 nm
Benefit is significantly less with conservative assumptions for reserve fuel
Match between field performance and cruise is not the same: both AD1401 and AD1602 could be optimised

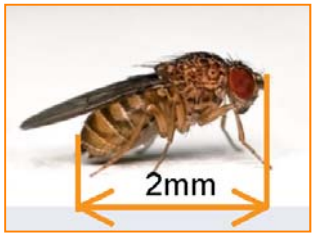
Thank you for your attention!

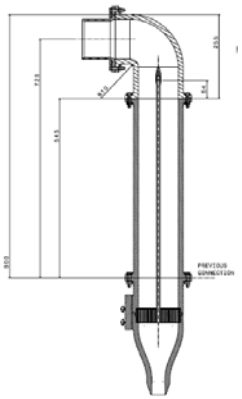
High Lift System as NLF Enabler 2

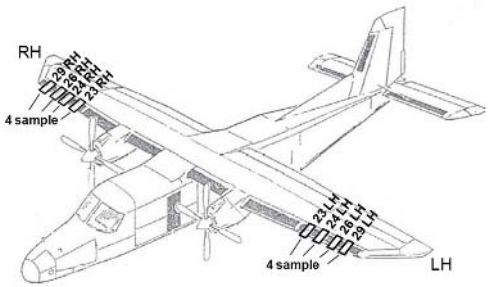
- Numerical prediction capability for insect impacts and validated criteria for contamination (e.g. impact angle & impulse) are required
- → dedicated experiments and flight testing conducted and planned

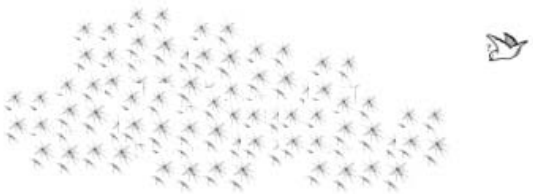












Kristof Risse

Florian Schültke, Eike Stumpf

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Preliminary Design of Hybrid Laminar Flow Wings for Optimum Cruise Conditions

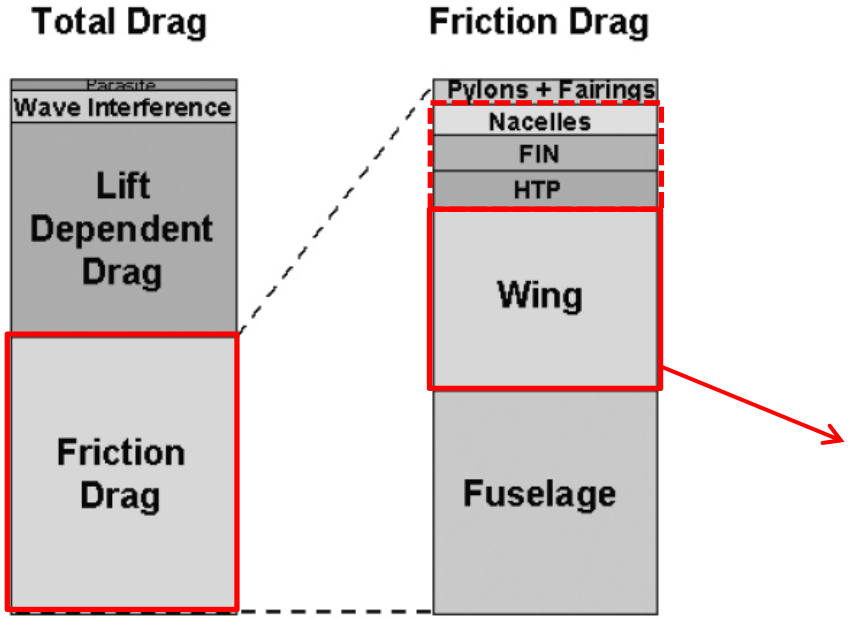
4th EASN Workshop on Flight Physics & Aircraft Design
28th October 2014, Aachen

Overview

1. Motivation and Problem Statement
2. HLFC Aircraft Design Approach
3. HLFC Systems Sizing
4. HLFC Airfoil Design and Database
5. HLFC Aircraft Design Studies
6. Conclusions and Outlook

Motivation: Application of HLFC Technology

- High fuel saving potential of Hybrid Laminar Flow Control (HLFC)
- Technology demonstrated on A320 and Boeing 787 fins (see photos)
- Can HLFC be applied to wings of future long range aircraft?



[Status and perspectives of laminar flow, G. Schrauf, The Aeronautical Journal, 2005]

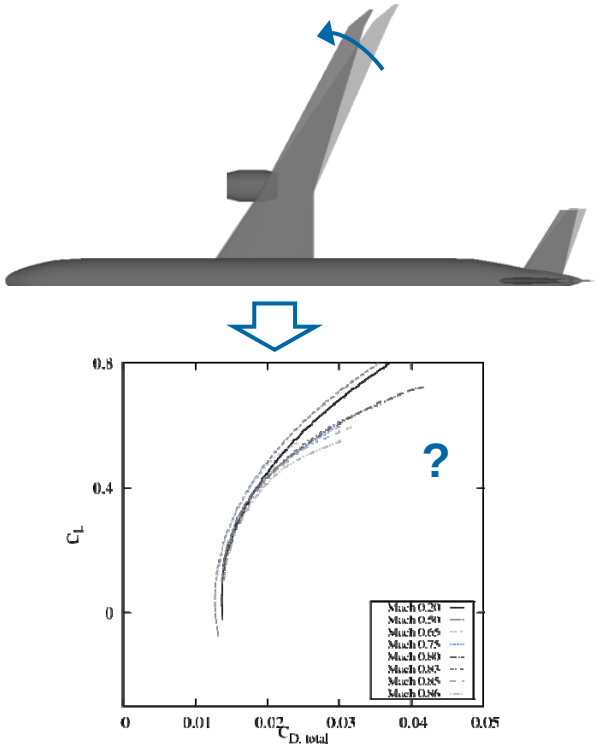
Motivation: Overall Aircraft Design with HLFC

1. Trade-offs for HLFC assessment on aircraft level:
   - Laminar drag reduction
   - Wing mass changes
   - HLFC systems mass
   - HLFC systems power off-takes → SFC

Aircraft net benefit?
(block fuel, COC, …)

2. Challenges in HLFC aircraft design:
   - Variation of a/c design parameters
     → unknown transition and drag behavior
     → unknown HLFC systems layout
   - Exploitation of resizing potential and design interactions requires integrated approach

→ **Aircraft design environment required with integrated HLFC sizing methods**



MICADO: OAD Platform & Integration of HLFC Methods

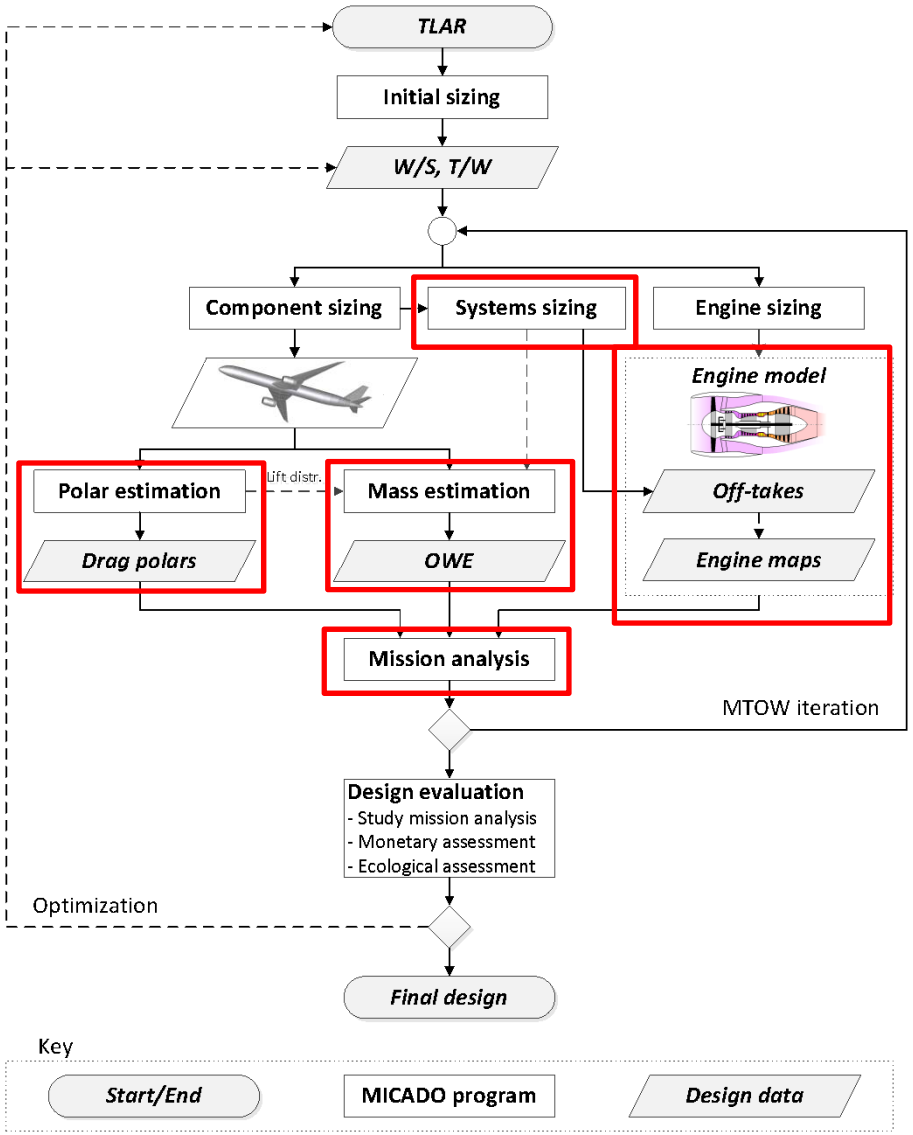
MICADO:

(**M**ultidisciplinary **I**ntegrated **C**onceptual **A**ircraft **D**esign and **O**ptimization)

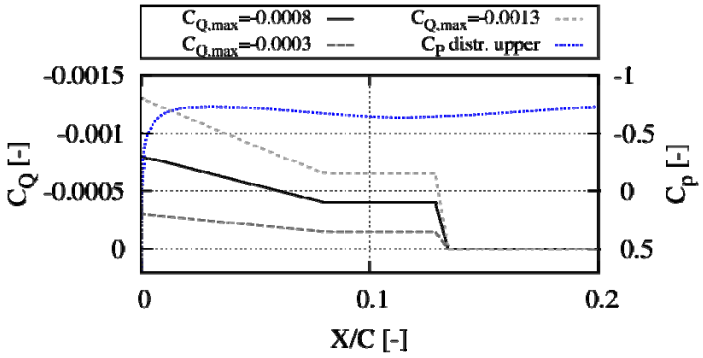
- ILR a/c design & optimization platform
- Automated design synthesis
- Fast exploration of design spaces

Assessment of HLFC technology:

- MICADO aerodynamics module enhanced by HLFC airfoil database
- HLFC systems design methodology integrated into systems module
- Relevant effects are captured by:
  - Mass estimation program
  - Thermodynamic engine model
  - Detailed mission simulation module



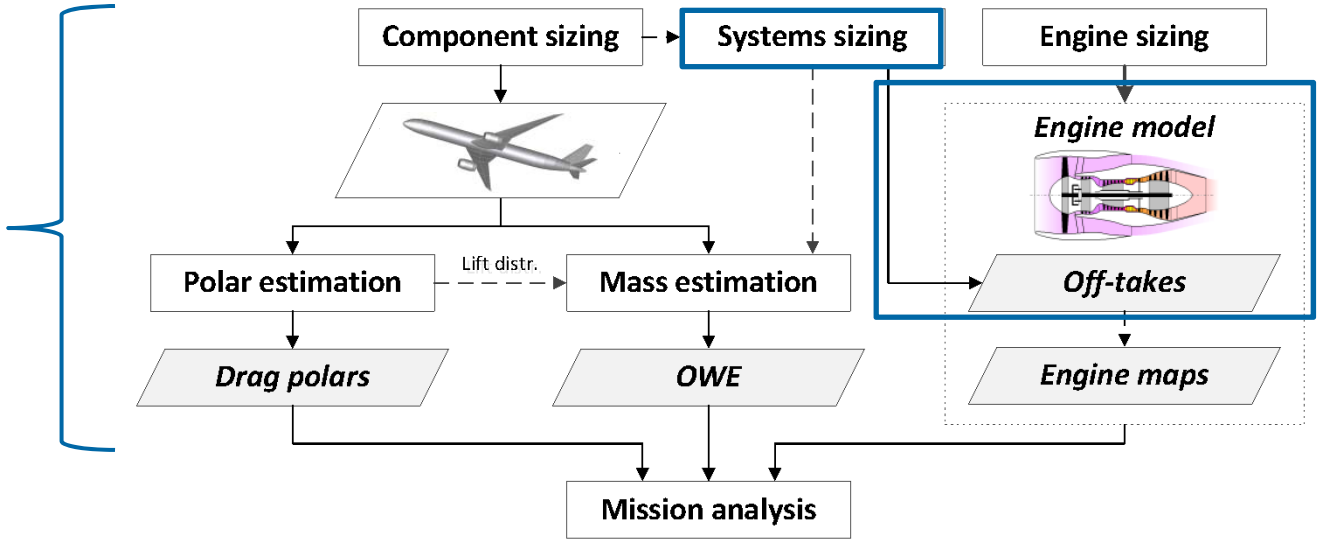
HLFC Systems Component Sizing



HLFC Systems Sizing Module

- HLFC systems component masses
- HLFC systems power req's → shaft power off-takes

- Wing geometry
- Airfoil geometry
- Cp distributions
- Cq distributions

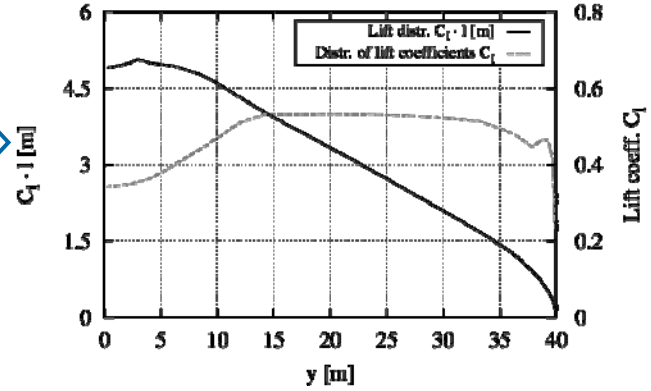


Full Aircraft Configuration Aerodynamics

Ma

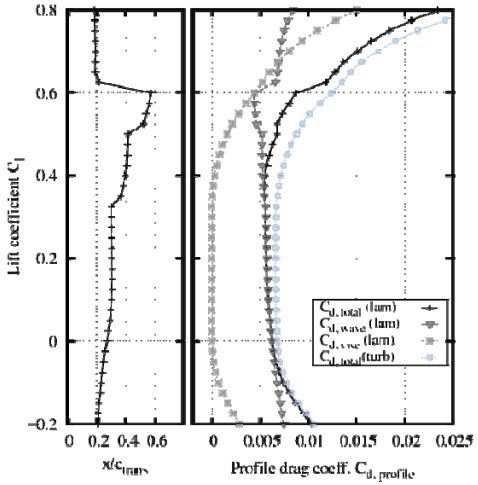
C_L

Lift and CL distribution

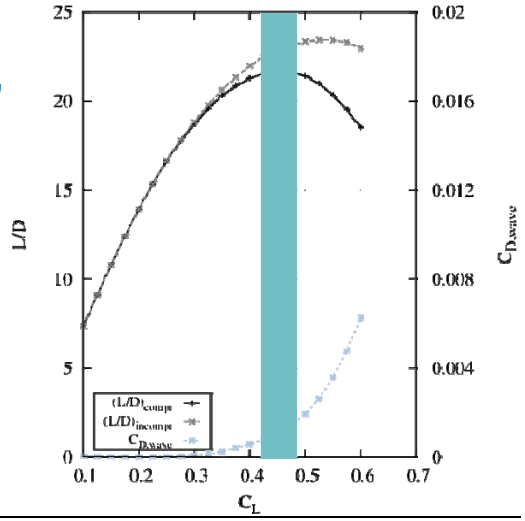


HLFC airfoil database

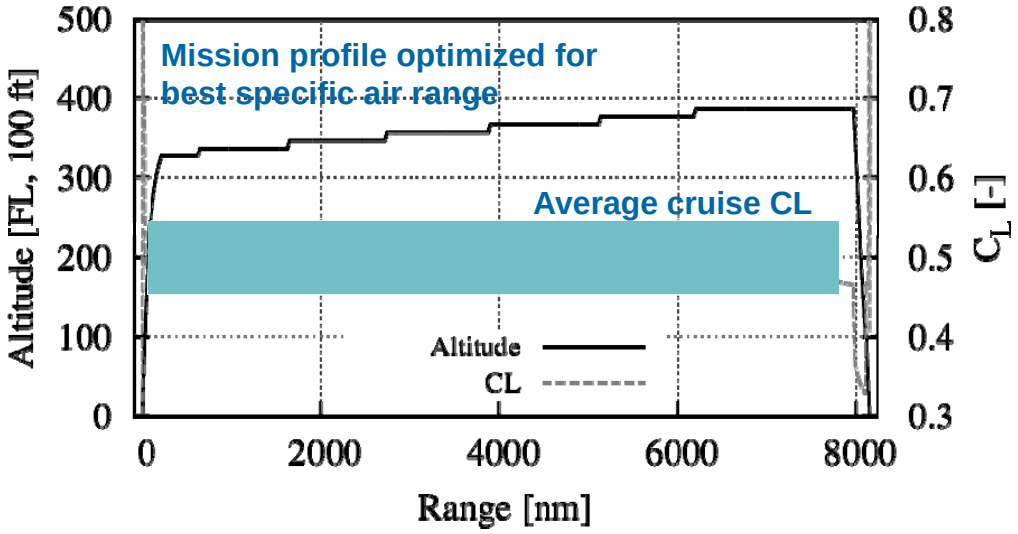
Airfoil and wing polars (incl viscous & wave drag)



Full a/c config. polars (incl. induced drag & drag of other components)



(incl. engine maps, offtakes, a/c mass)



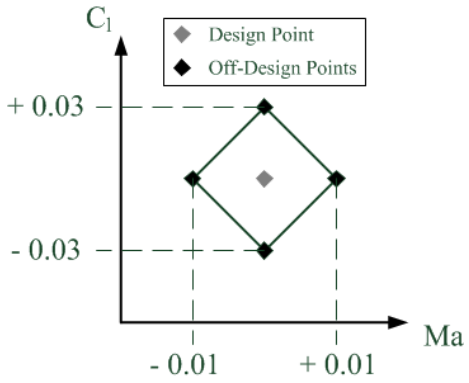
HLFC Airfoil Analysis Process

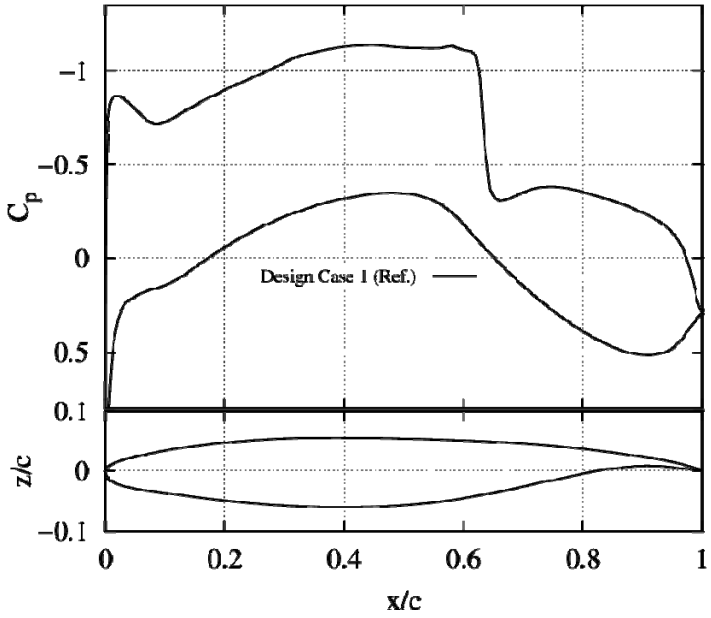
$$Ma' = Ma\cos\varphi_{ref}$$

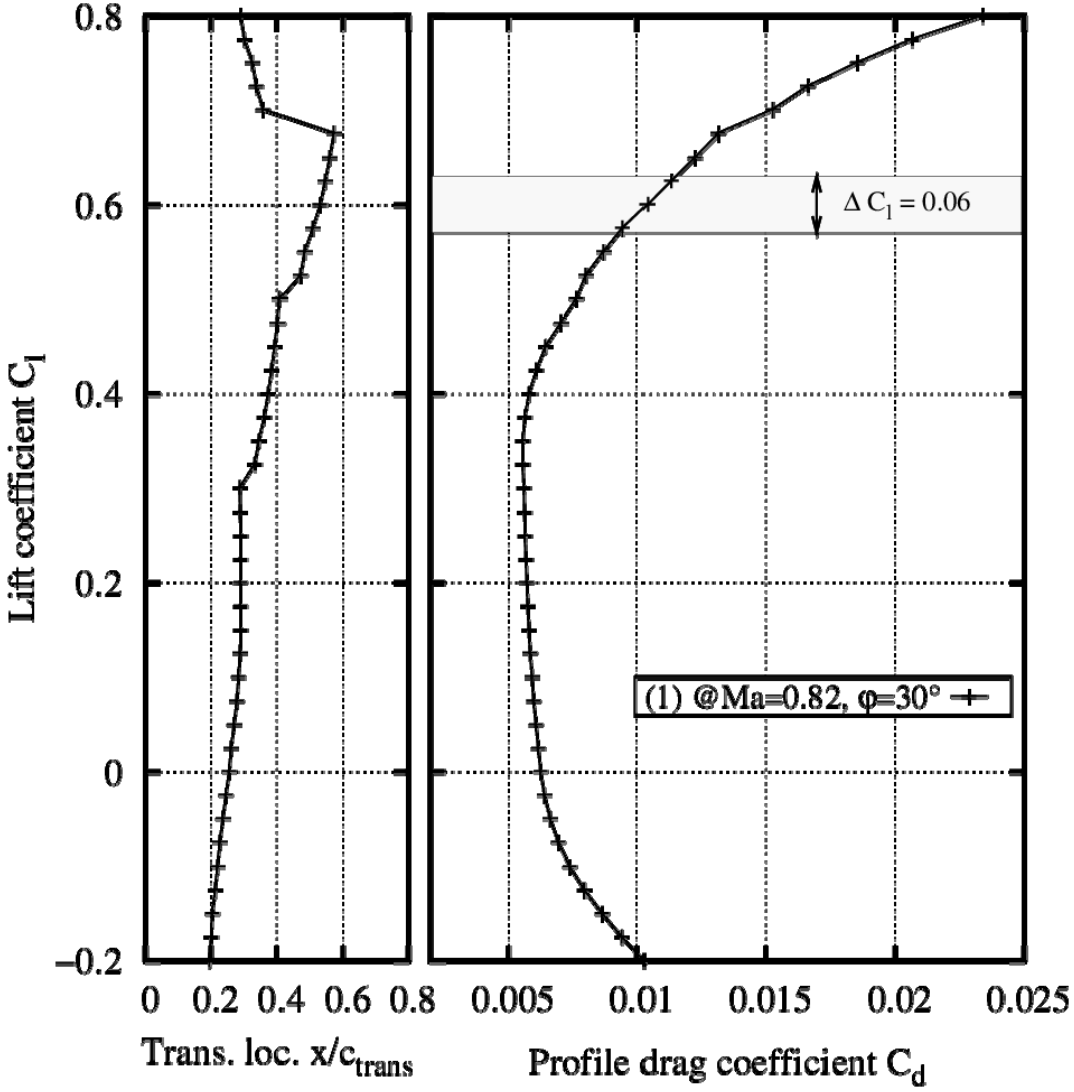
$$C_l' = \frac{C_l}{\cos^2\varphi_{ref}}$$

[Schrauf, G.: COCO: A program to compute velocity and temperature profiles for local and conical stability analysis of compressible, conical boundary layers with suction, ZARM Technik Report, Airbus, Bremen, 1998]

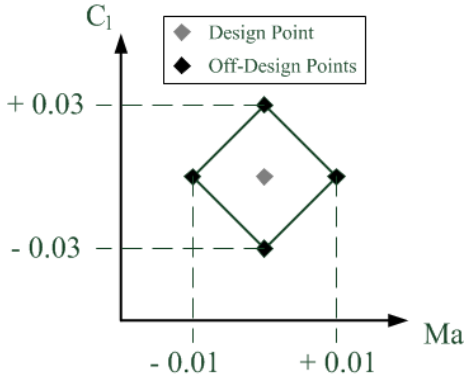
HLFC Airfoil Design and Analysis

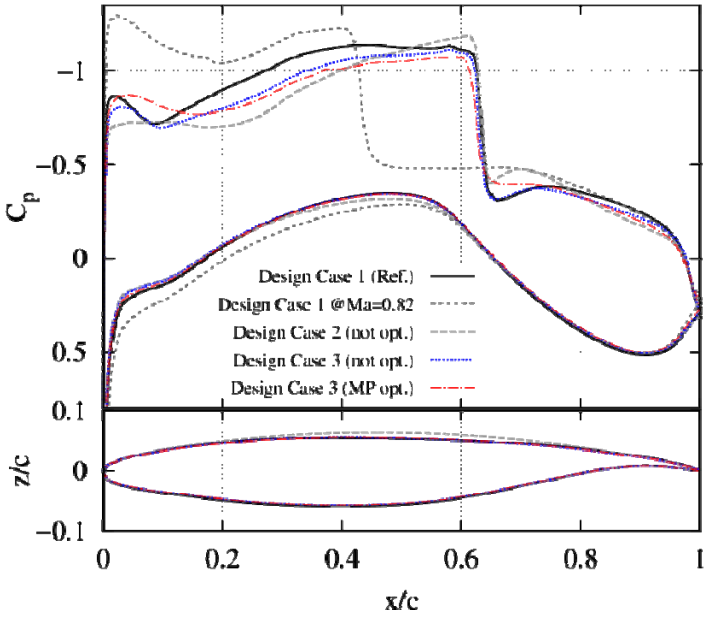


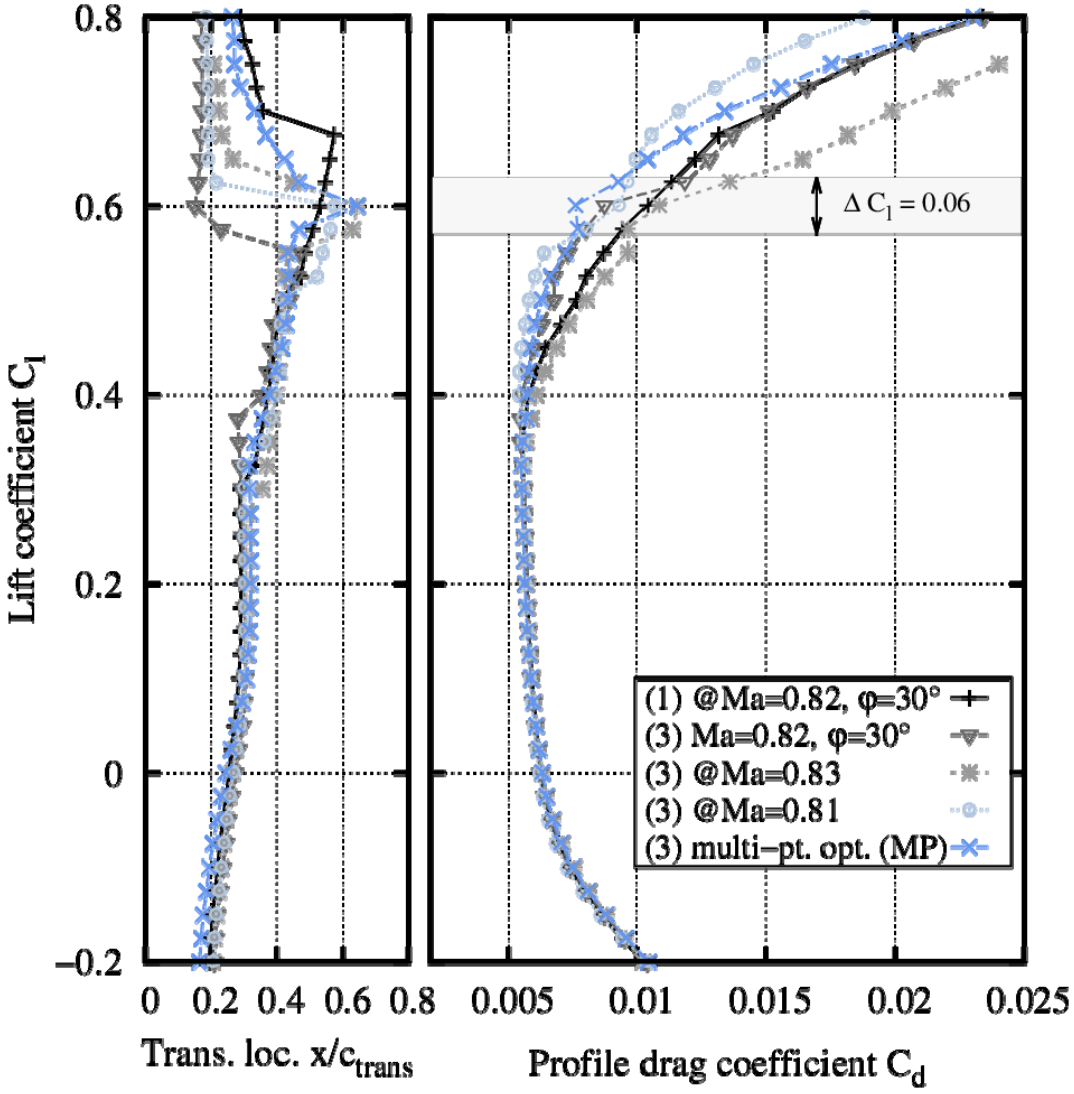




HLFC Airfoil Design and Analysis







HLFC Airfoil Database

- **Airfoil Design + Multi-Point Opt. for selected conditions:**
  - Mach number
  - Design lift coefficient
  - Wing section sweep angles

- **Automated off-design calculation** (implemented into robust C++ module) → drag polars

- **Cubic Splining**

- **Import to SQLite database** ⟶

- **Access by MICADO Aero Module**

profil_id	name	Ma3D	Cl3D	Ma2D	Cl2D	Re	phi_LE	phi_TE
1	hlfc_3-1_phi30	0.7813	0.4954	0.71	0.6	49006300	30	18.6418
2	hlfc_3-1_phi40	0.8755	0.395	0.71	0.6	55004500	40	30.9258
3	hlfc_3-3_phi30	0.701	0.6611	0.71	0.8	49067400	30	18.6418
4	hlfc_3-3_phi40	0.8745	0.5273	0.71	0.8	54941700	40	30.9258
5	hlfc_4-2_phi30	0.7967	0.5875	0.73	0.7	50053000	30	18.6418
6	hlfc_4-2_phi40	0.891	0.4698	0.73	0.7	55978300	40	30.9258
7	hlfc_4-3_phi30	0.7945	0.6753	0.73	0.8	49915600	30	18.6418
8	hlfc_4-3_phi40	0.888	0.5406	0.73	0.8	55789900	40	30.9258
9	hlfc_5-1_phi30	0.8254	0.4954	0.75	0.6	51856900	30	18.6418
10	hlfc_5-1_phi40	0.9238	0.3955	0.75	0.6	58039100	40	30.9258
11	hlfc_5-2_phi30	0.8168	0.5901	0.75	0.7	51316600	30	18.6418
12	hlfc_5-2_phi40	0.9124	0.473	0.75	0.7	57322000	40	30.9259
13	hlfc_5-3_phi30	0.8125	0.6816	0.75	0.8	51046500	30	18.6418
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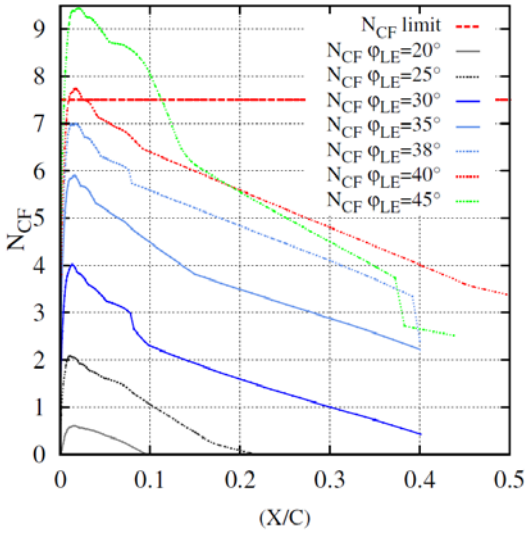
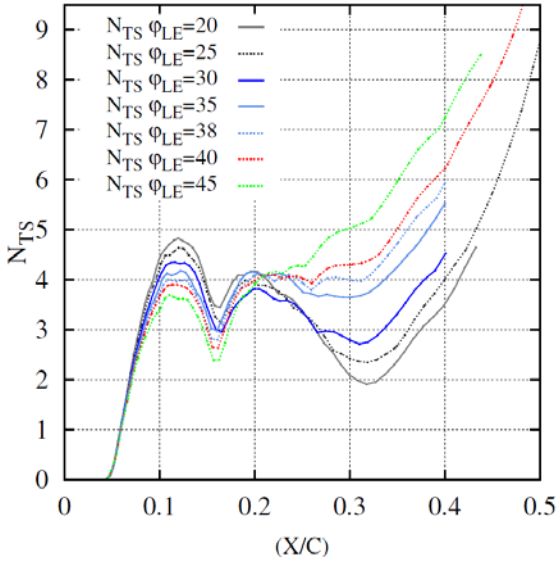
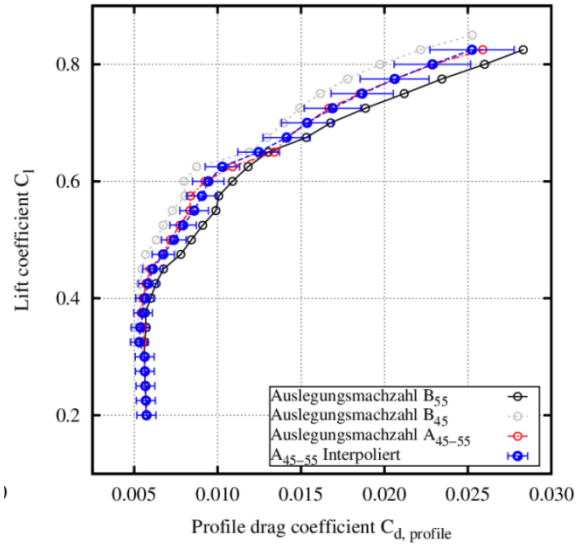
17	hlfc_1-1_phi30	0.7366	0.4965	0.67	0.6	46277900	30	18.6418
18	hlfc_1-1_phi40	0.8262	0.3946	0.67	0.6	51907200	40	30.9258

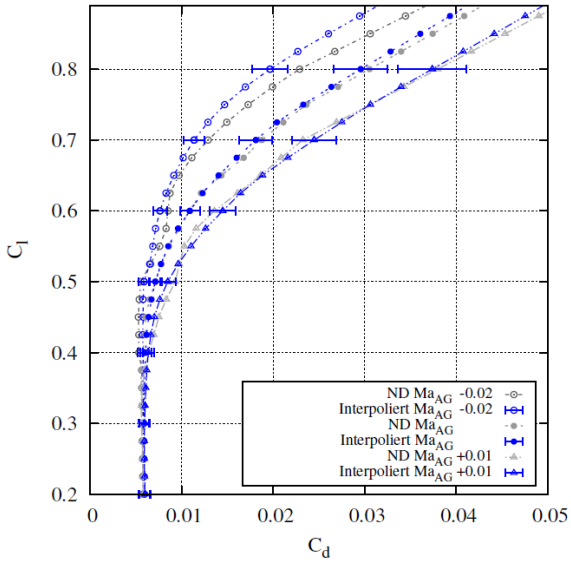
AOA_lam	Cd_total_lam	Cd_visc_lam	Cd_wave_lam	shock_u_loc_t...	shock_u_loc_l...	trans_upper	p
2.55056	0.022277	0.008683	0.013594	0.59872	0.63001	0.219	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
NAN	NAN	NAN	NAN	NAN	NAN	NAN	5
-0.839328	0.005801	0.005801	0	0.25	0.25	0.286	5
-0.692335	0.00577	0.00577	0	0.25	0.25	0.285	5
-0.541433	0.005739	0.005739	0	0.25	0.25	0.285	5
-0.390798	0.005711	0.005711	0	0.25	0.25	0.285	5
-0.244515	0.00569	0.00569	0	0.25	0.25	0.285	5
-0.0947686	0.005668	0.005668	0	0.25	0.25	0.285	5
0.0531131	0.00564	0.00564	0	0.25	0.25	0.287	5
0.193179	0.005601	0.005601	0	0.25	0.25	0.296	5
0.328271	0.00551	0.005509	0.000001	0.25	0.25	0.313	5
0.233568	0.005544	0.005503	0.000041	0.50748	0.52312	0.342	5
0.348414	0.005681	0.005517	0.000164	0.52275	0.53842	0.346	5
0.443142	0.005978	0.0055	0.000478	0.54599	0.56161	0.352	5
0.54338	0.006398	0.005511	0.000887	0.565285	0.58478	0.357	5
0.650465	0.007032	0.00555	0.001482	0.58459	0.60024	0.361	5
0.738814	0.007748	0.005534	0.002214	0.59227	0.61571	0.369	5
0.83871	0.008728	0.005595	0.003133	0.60774	0.63116	0.377	5
0.950298	0.009973	0.005706	0.004267	0.61542	0.63885	0.374	5
0.807972	0.010059	0.003941	0.006118	0.6231	0.67762	0.659	5
0.898968	0.0116087	0.004061	0.00754767	0.630705	0.687863	0.668667	5

HLFC Database: Sensitivities and Interpolation Validation





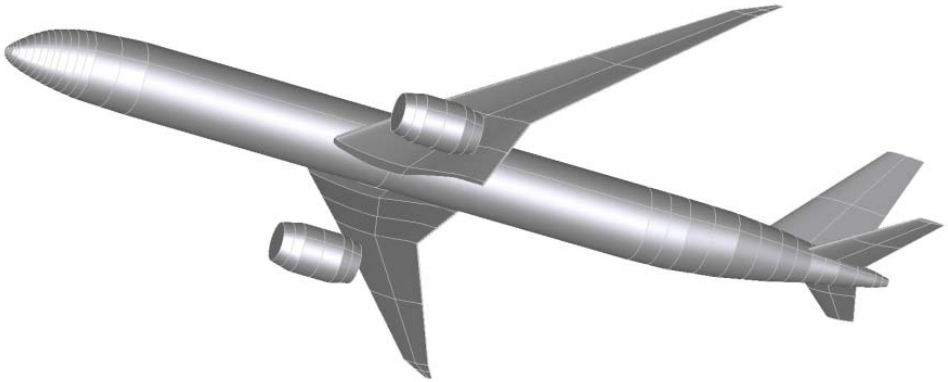


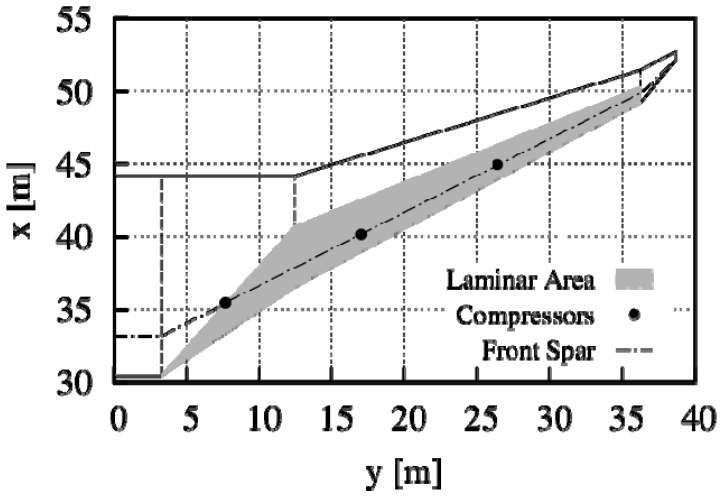


HLFC Long Range Case Study: Turbulent Baseline Design

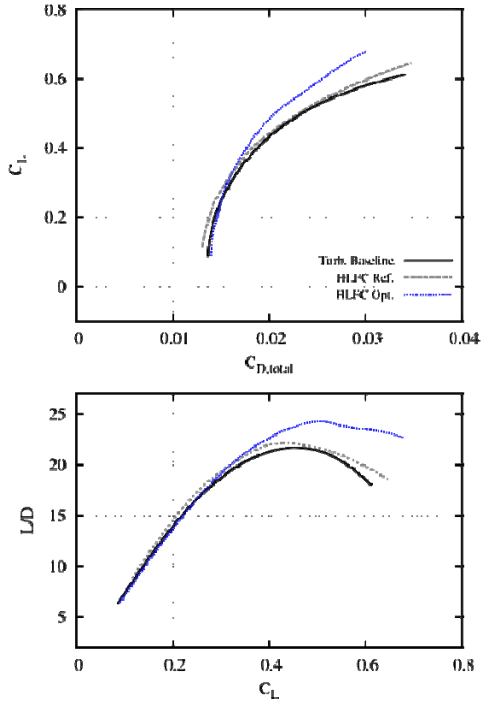
- Turbulent baseline aircraft design with MICADO according to TLARs in table (specified by Airbus in line with LuFo project HIGHER-LE)
- Parameter variation of HLFC main drivers Mach number and wing sweep angle
- Application of HLFC sizing methods
- Full resizing with MICADO and assessment on 4000NM study mission

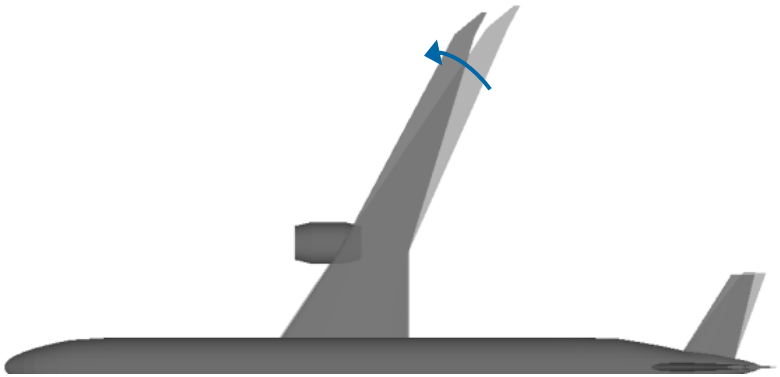
Top-level requirements		
Design range	8150	NM
Std. passenger number	470	–
Design payload	44650	kg
Cruise Mach number	0.85	–
Initial cruise altitude	33000	ft
Take-off field length	3261	m
Landing field length	2073	m
Key aircraft characteristics		
Maximum take-off weight	405.0	t
Operating weight empty	212.2	t
Wing area	565	m^2
Wing span	80	m
Sea-level static thrust	511	kN
Block fuel (design mission)	134.3	t
Block fuel (4000 NM mission)	63.5	t

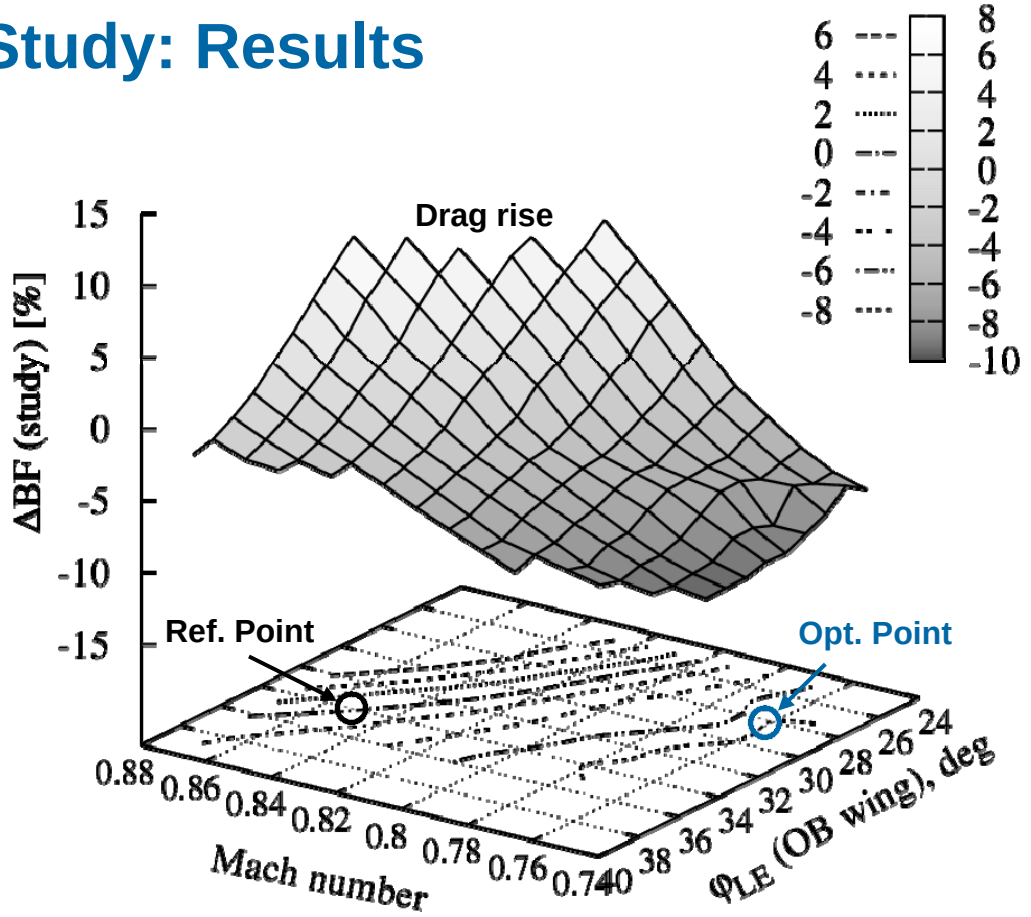


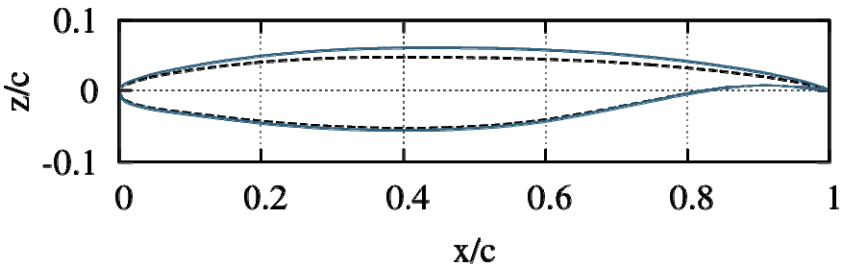


HLFC Long Range Case Study: Results

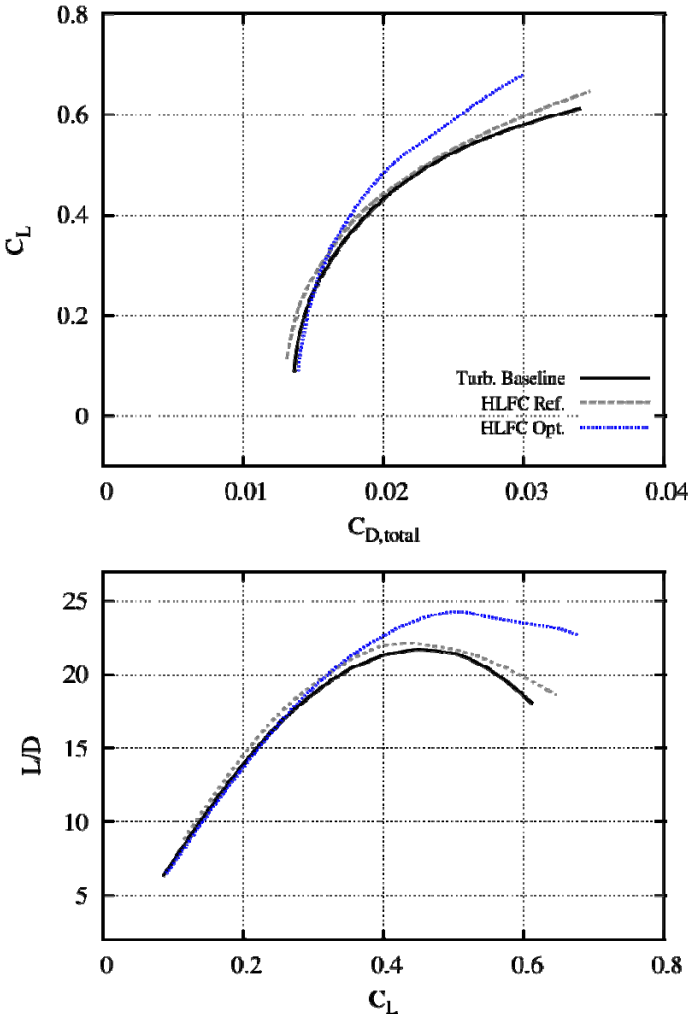




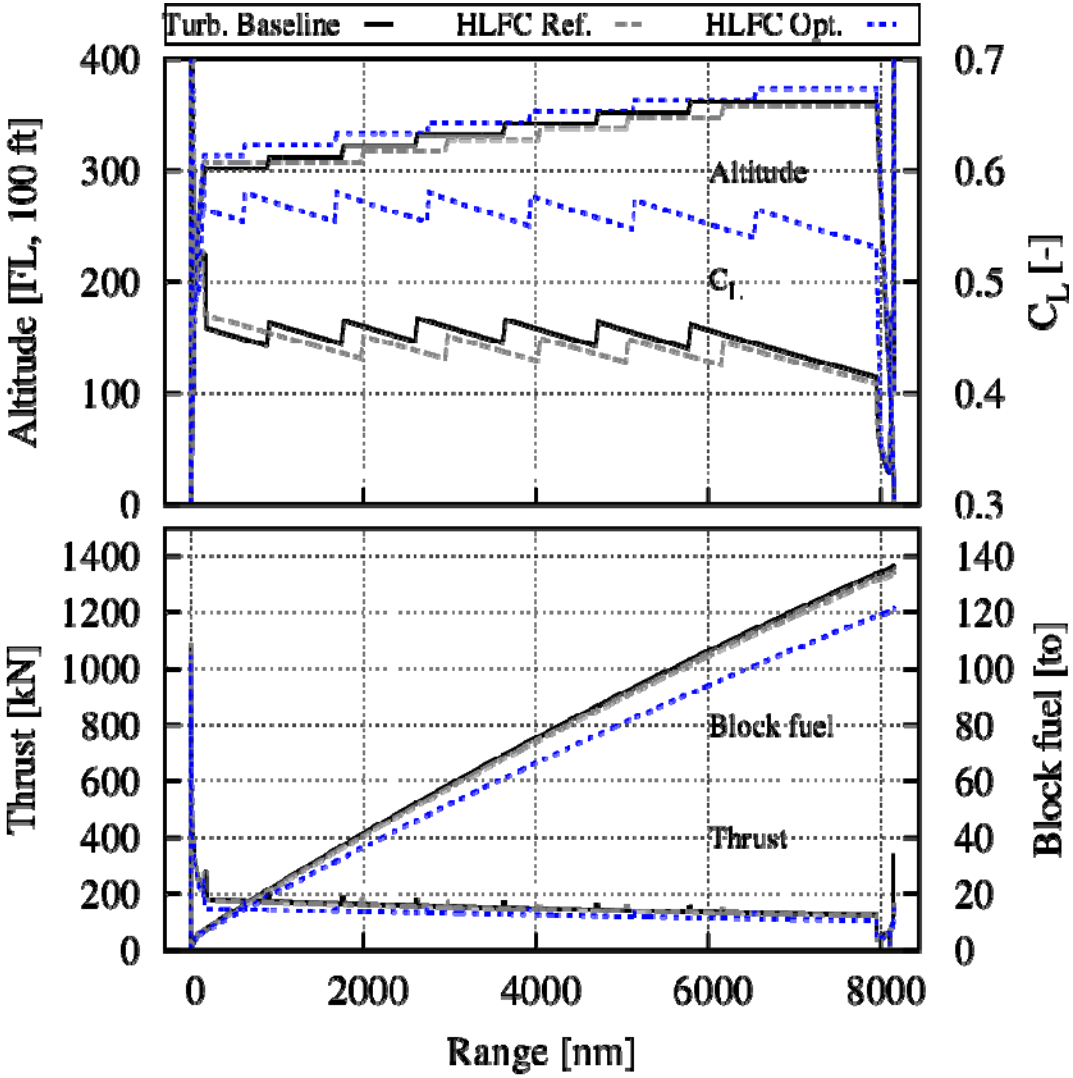




HLFC Long Range Case Study: Results



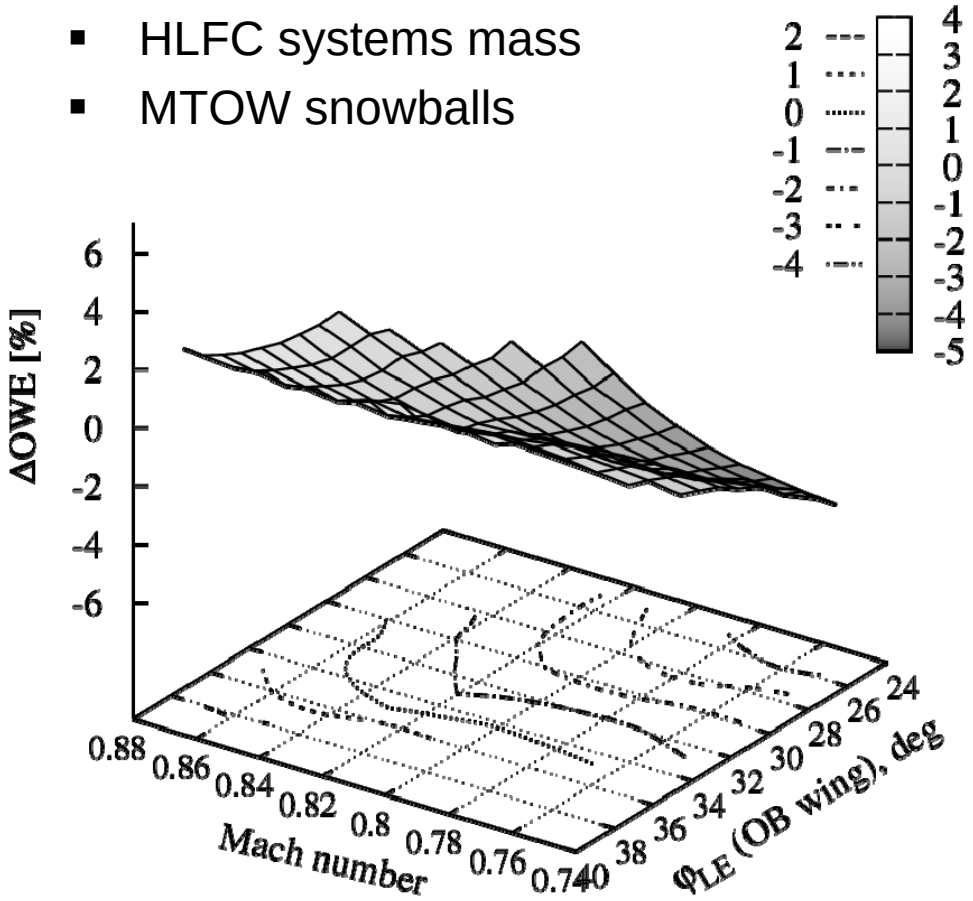
Full a/c configuration trimmed cruise polars



HLFC Long Range Case Study: Results

OWE driven by:

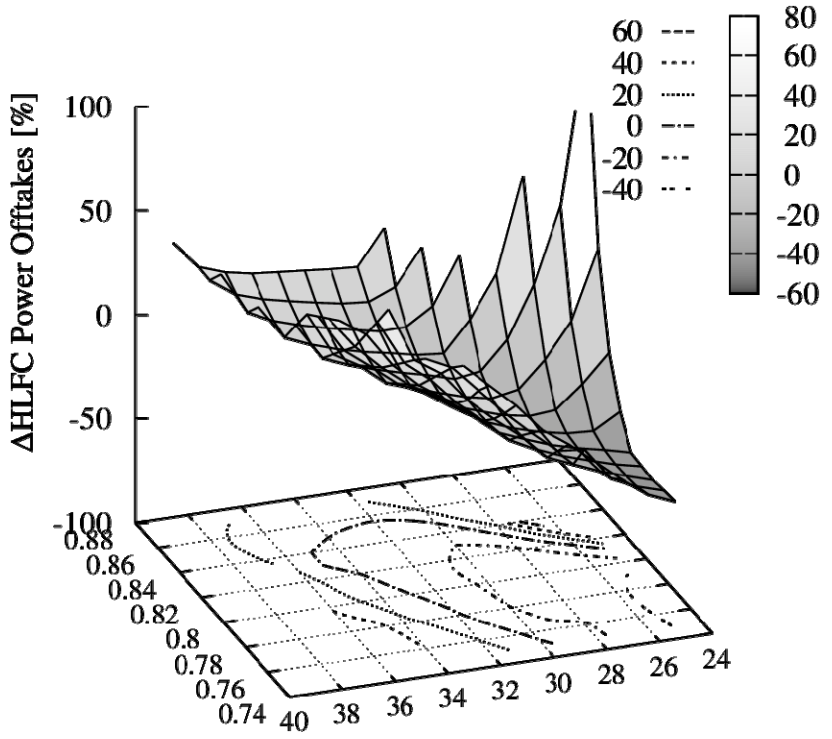
- Wing mass (sweep and t/c)
- HLFC systems mass
- MTOW snowballs



HLFC Systems Power:

Low @

- Low Ma (mass flow)
- Low sweep angles (low Cq)



Conclusions and Outlook

Summary and Conclusions:

- Overall aircraft design platform MICADO developed
- Enhancement of MICADO by
  - HLFC airfoil process chain and database
  - Methods for sizing of HLFC system components
- Integrated methodology allows to capture single effects (aerodynamics, masses, power off-takes) into key evaluation parameters (e.g. block fuel, COC)

→ Integrates transition prediction methods into conceptual design studies

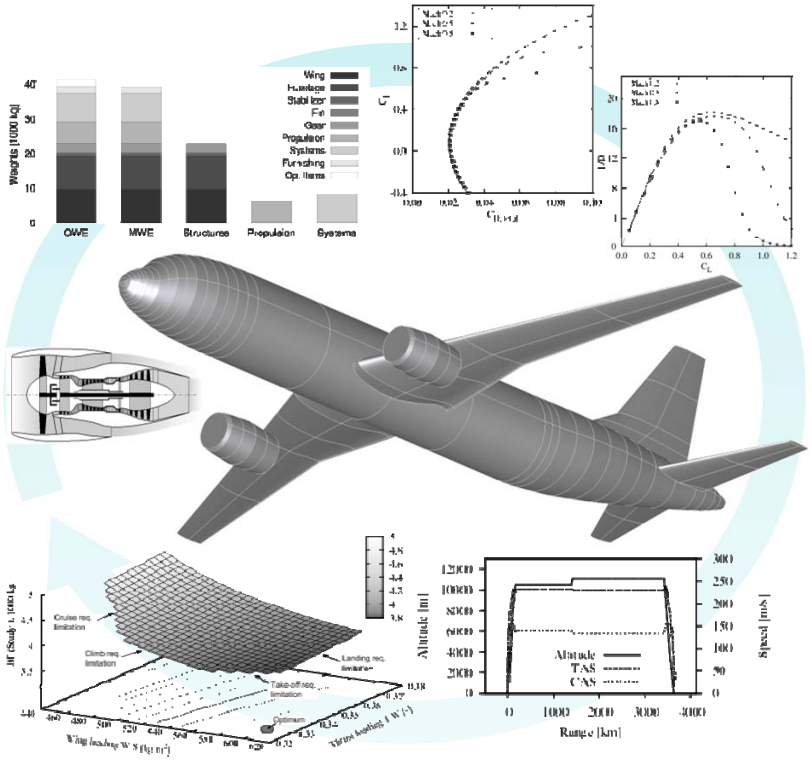
→ Missing link for reliable assessment of HLFC technology on aircraft level

→ Applicability to industrial long range baseline aircraft shown

Outlook:

- Final design studies to exploit full HLFC potential on aircraft level
- Description and analysis of final design studies in PhD thesis

Thank you for your attention!



Questions?

INSTITUT FÜR
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INSTITUTE OF
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ACTIVE FLOW- LOADS & NOISE CONTROL ON NEXT GENERATION WING

OVERVIEW AND RESULTS (after 1st project year)

EASN 2014
Aachen, Germany
28 October 2014
Avraham (“Avi”) Seifert
Tel Aviv University
Originator: Dr. M. Fischer, Airbus-D

AFLoNext
2ND GENERATION ACTIVE WING

AFLoNext

OVERVIEW

Introduction

Design requirements for large civil aircraft

The large integrated research project AFLoNext

Status after 1st project year

Conclusion

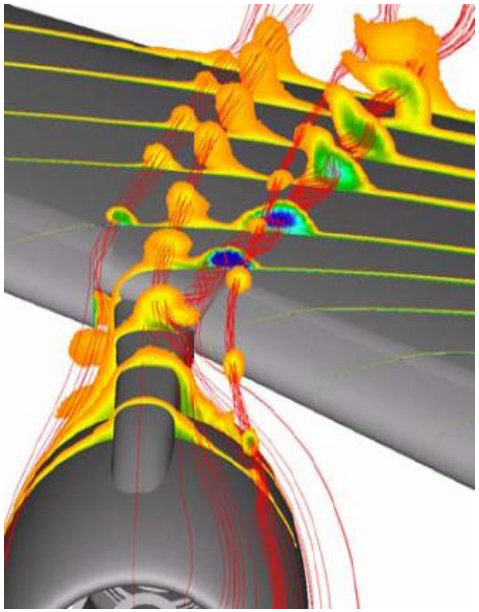
- Introduction –

World Air trafic volume expected To grow x2 over 15 years

During the past 40 years:
-20dB noise
-70% fuel burn and emmissions

World traffic growth

Efficiency depends on:
Light weight structures
Efficient powerplant
Efffcient aerodynamics: High lift, High L/D, low airframe noise, Well integrated powerplant and airframe, FLOW CONTROL



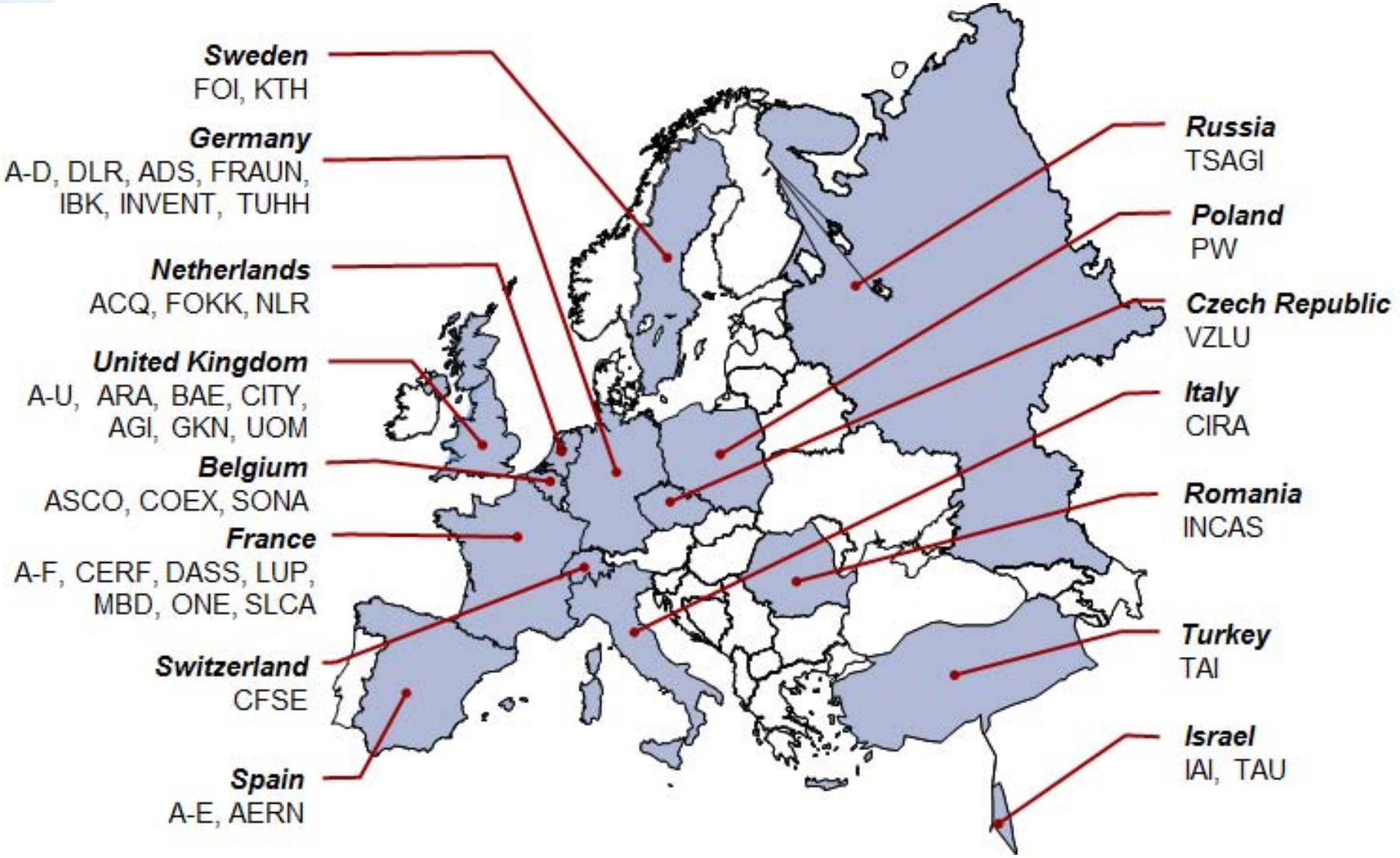
- AFLoNext - Consortium and Statistics -

EU L2 Project with ~ ***37 M€*** *total cost (**23.6 M€** effective funding)*

*Project duration: **4 years** (2013-2017), start: **1st of June 2013***

Project top level ranked and evaluated as "excellent"

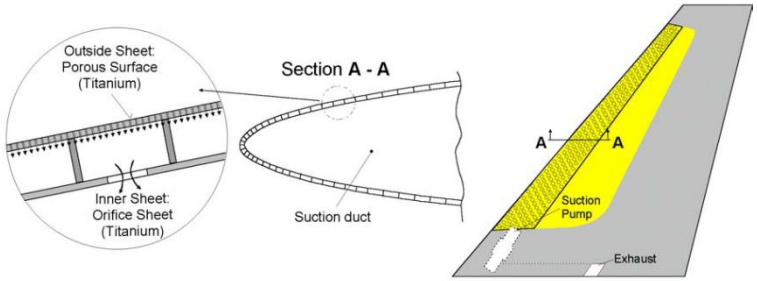
-The European Footprint of the Consortium-



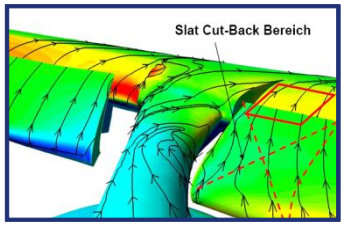
- Major Objectives -

To mature and demonstrate promising flow control technologies up to high maturity levels (TRL 4-5) to validate them later in a fully integrated large scale demonstrator (Clean Sky 2) up to TRL 6.

Hybrid laminar flow technology (HLFC) for aircraft drag reduction.



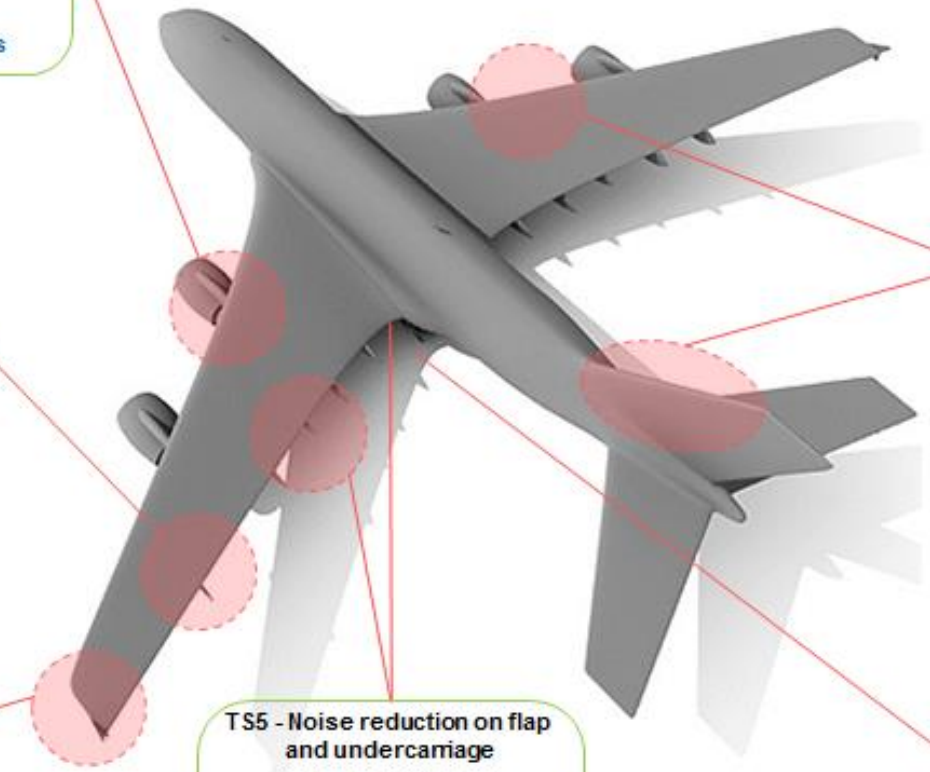
Active/passive flow-, load- and noise-control technologies for local applications for performance increase and improved environmental compatibility.



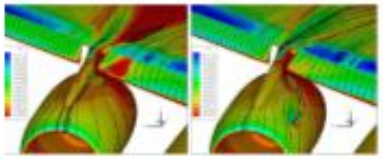
Development and assessment of AFloNext topics as part of an ***integrated future wing/airframe design***.

- Detailed Objectives -

Technologies are clustered into "Technology Streams" (TS)

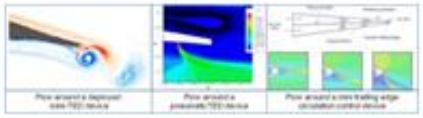


TS3 - Active Flow Control on wing / pylon



-> enables integration of UHBR engines

TS4 - Active Flow Control on wing trailing edges



-> up to 1-2% fuel saving

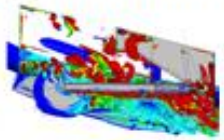
TS2 - Active Flow Control on outer wing

-> up to 2% fuel saving

TS1 - Hybrid Laminar Flow Control on wing and fin

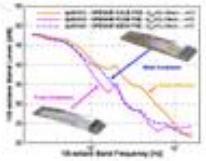
-> up to 9% fuel saving

TS6 - Vibrations mitigation/ control in undercarriage area



> weight reduction of 100-200 kg on landing gear doors

TS5 - Noise reduction on flap and undercarriage



-> reduction of 2-3 EPNdB in approach

TS1 - Hybrid Laminar Flow Control on Fin -
- Major Deliverables -

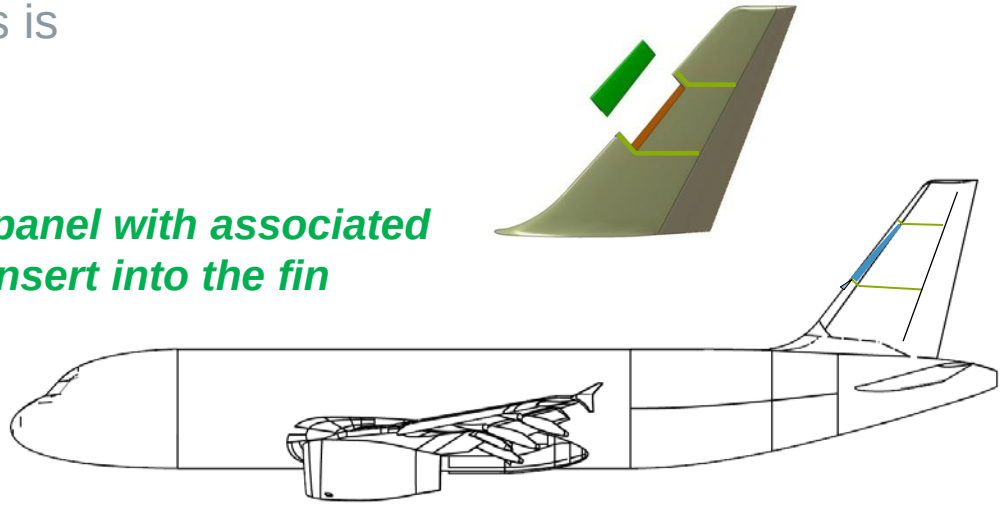
\ Engineering feasibility of advanced HLFC technology proven by means of prototype demonstration in operational environment (flight test demonstration).

\ Gain first operational experience with advanced HLFC technology.

\ Systems architecture and design has fully operational status, interfaces and interactions with the surrounding structure (loads, deformations) are known and determined.

\ Manufacturing process and tooling for the HLFC suction chamber and systems is demonstrated and qualified.

Perforated suction panel with associated suction system as insert into the fin



TS1 - Hybrid Laminar Flow Control on Fin -

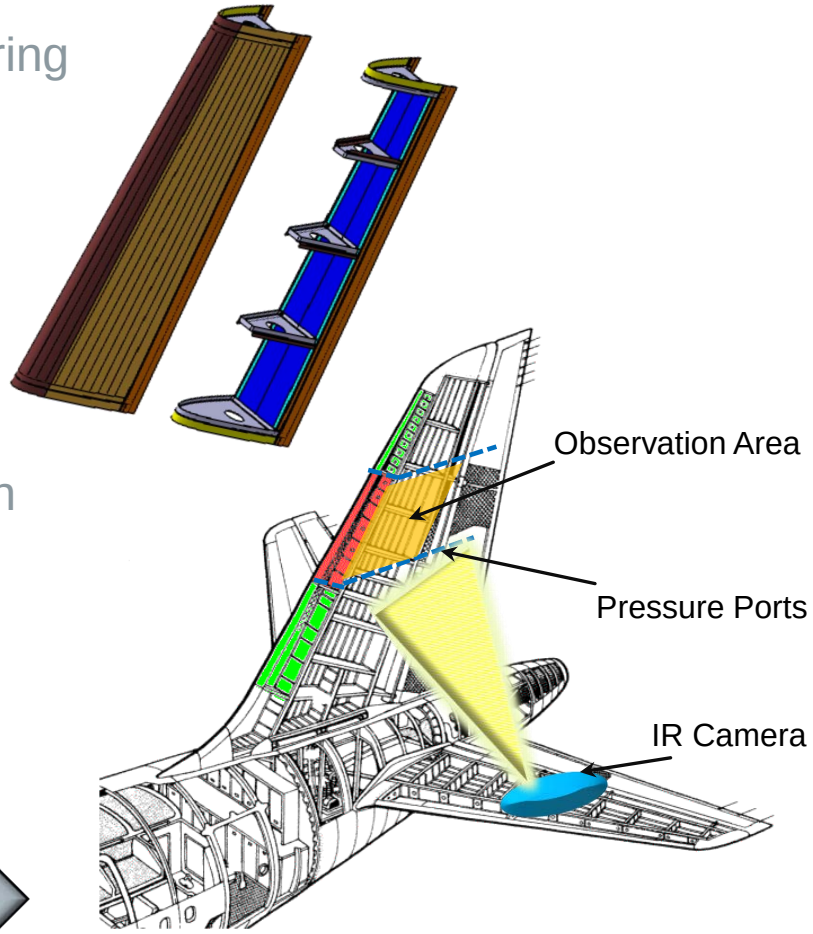
- Achievements after 1st Project Year -

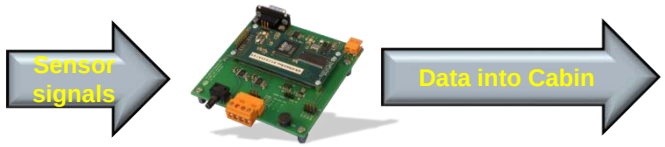
\ PDR imminent for the structural and manufacturing concept of a simplified HLFC fin leading edge.

\ FT preparation in full progress aligning at the same time the test targets of TS1, 5, 6.

\ Pre-order process running to purchase a new fin which will be modified for the test purposes.

\ The preliminary design of the monitoring and measuring system has been completed.





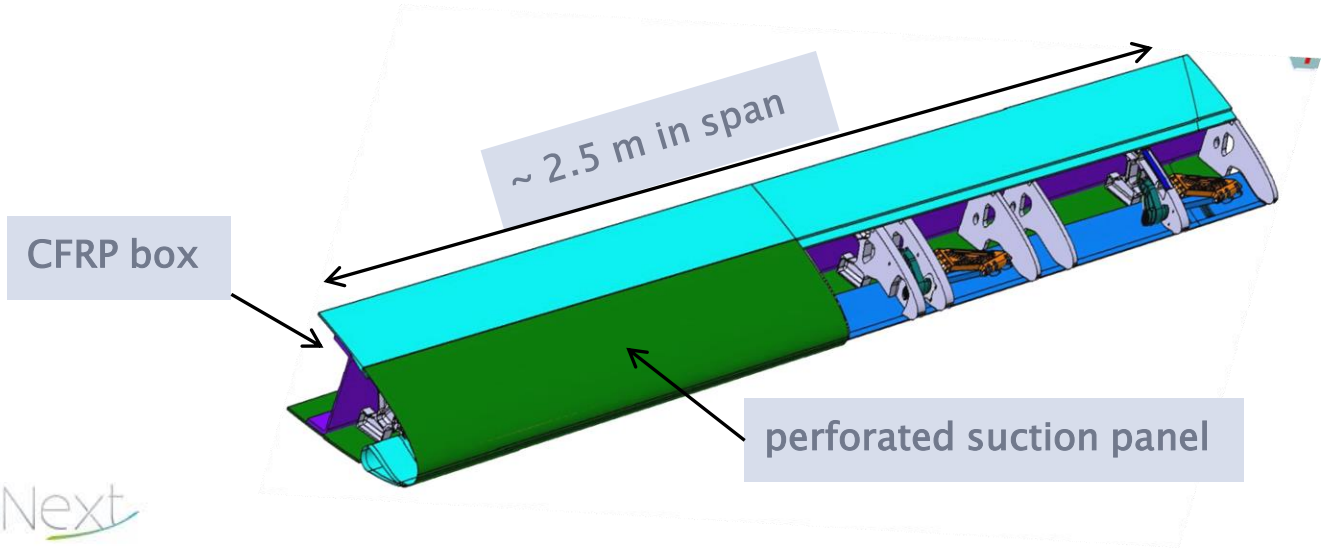
Sensor interface card

TS1 - Hybrid Laminar Flow Control on Wing -
- Major Deliverables -

\ Design and testing of a fully integrated wing leading edge section featuring advanced HLFC technology. The design represents all critical structural parts and systems including box joint, joint filler solutions, Krueger shielding mock-up, further sub systems for positioning and anti-ice. Essential sub structures and sub systems will be tested and validated under realistic test conditions.

\ First level integration of advanced HLFC technology in a large scale wing leading edge section based on optimised aero-loads-structures CFRP design.

\ Manufacturing process and materials for the leading edge are identified.



TS1 - Hybrid Laminar Flow Control on Wing -

- Achievements after 1st Project Year -

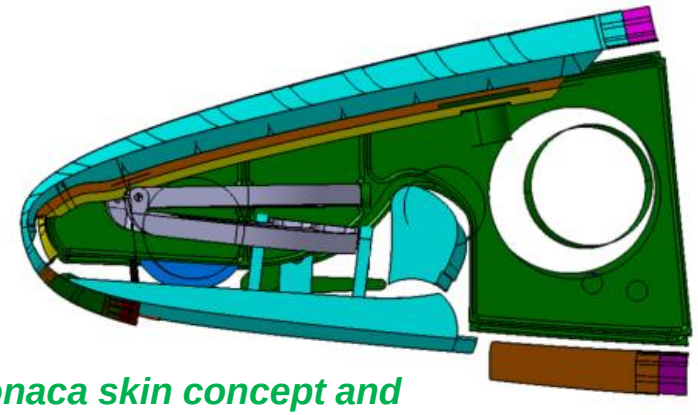
\ Aero shape of the HLFC wing leading edge designed respecting 3D curvature constraints. Based on the given aero shape system design is progressing well for:

\ Leading edge high-lift system (2 Krueger solutions are under development). Candidate selection at upcoming PDR.

\ Suction skin (3 structural design principles are under development), “superplastic forming”, “composite with metallic erosion shield”, “metallic foam”. Upcoming coupon tests for all 3 design principles.

\ Wing ice protection system (2 solutions are under development, “pneumatic”, “electric”. Final selection depending on preferred suction skin type. Preparation of WT icing test ongoing (test matrix compiled).

\ Digital Mock-Up (DMU) developed for the complete HLFC wing leading edge, which will be the origin for the ground-based demonstrator to validate the integration concept.



DMU with Sonaca skin concept and Krueger design by INCAS

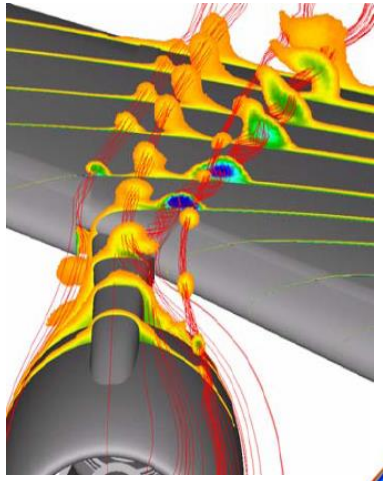
TS2/3/4 - Local application of “active” flow control (AFC) technologies on airframe -

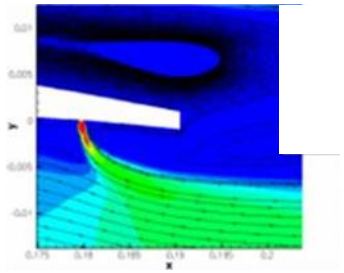
- Major Deliverables -

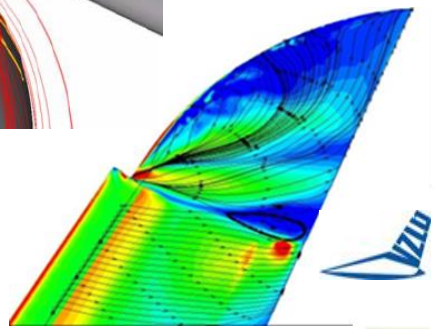
\ Experimental demonstration (mid- to large scale wind tunnel models) of locally applied active flow control technologies for performance increase and/or loads control.

\ Integration readiness considers a realistic systems architecture and systems integrated in large-scale wind tunnel models.

- AFC on outer wing (TS2)
- AFC on wing / pylon (TS3)
- AFC on wing trailing edges (TS4)





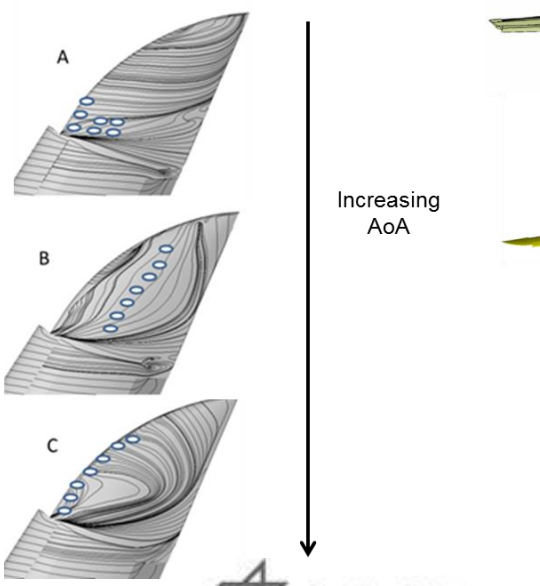


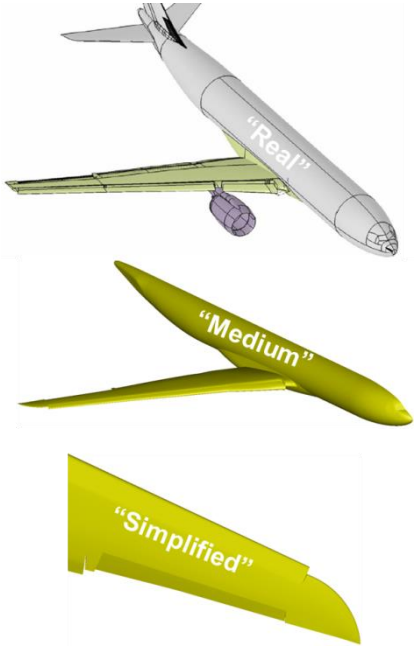
TS2 - Local application of AFC on Outer Wing -
- Achievements after 1st Project Year -

\ Numerical investigations performed by many partners on configurations of different complexity to investigate progressively the

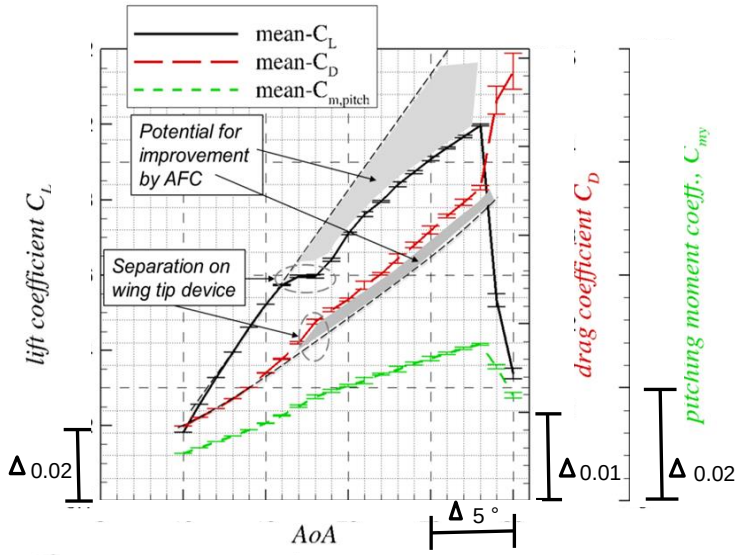
… flow physics at the outer wing (2 types of wing tips)

… potential locations for AFC





… AFC as enabler for improved performance



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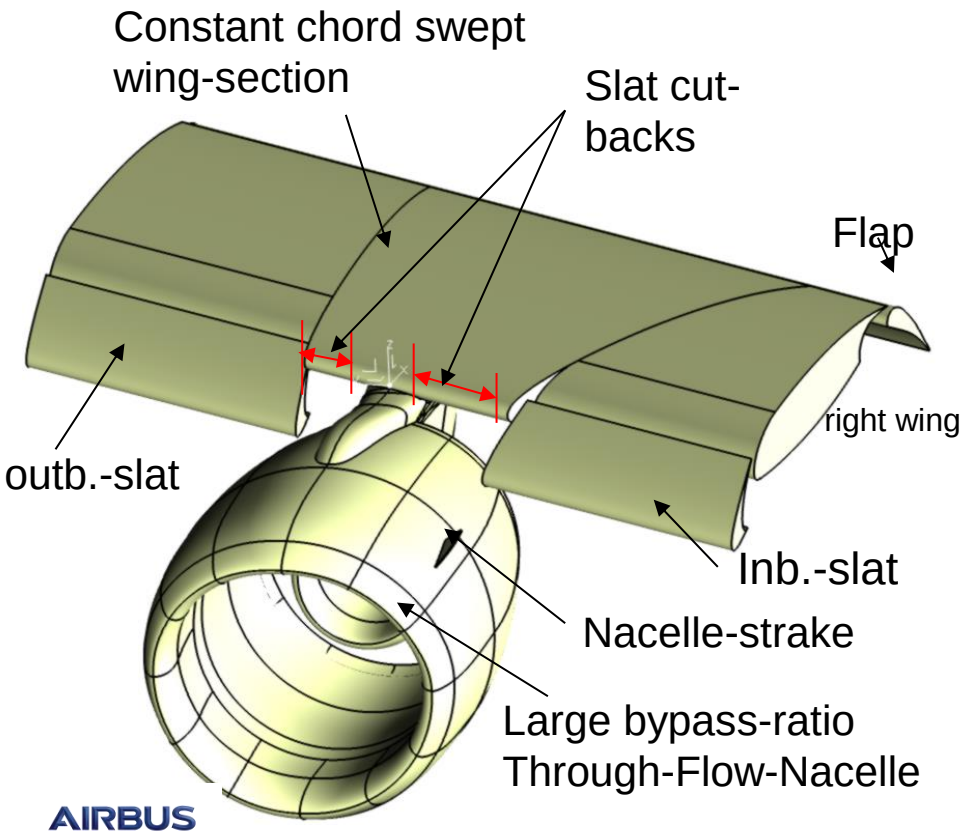
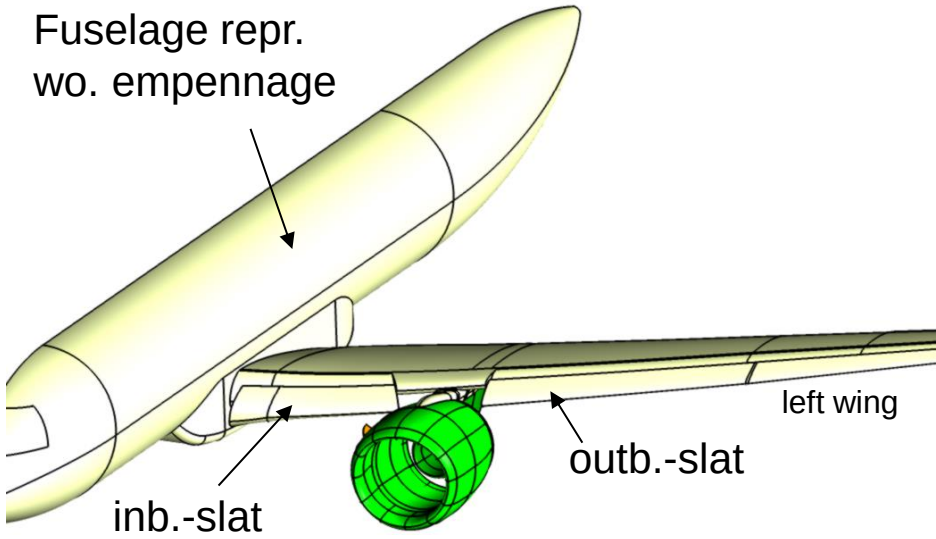
TS3 - Local application of AFC on Wing/Pylon (1/3) -
- Achievements after 1st Project Year -

Baseline (modified 2.5 D SADE WT model)



Realistic Configuration (FNG)

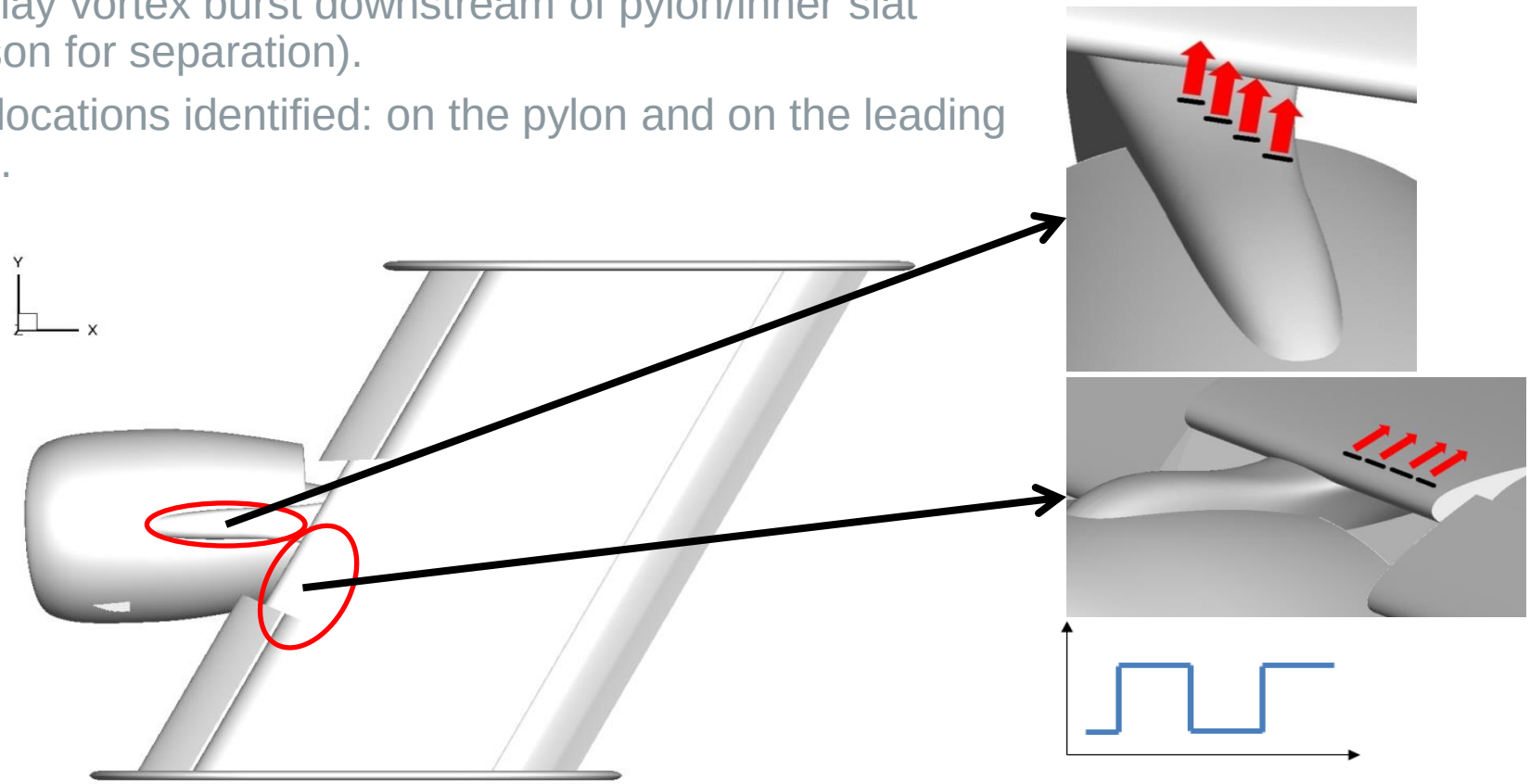


\ Design of WT model („Baseline“) and validation of the flow topology against „Realistic Config.“ (2.5 D -3D)

TS3 - Local application of AFC on Wing/Pylon (2/3) -

- Achievements after 1st Project Year -

- Pulsed or synthetic blowing identified as suitable means to delay vortex burst downstream of pylon/inner slat (reason for separation).
- Two locations identified: on the pylon and on the leading edge.



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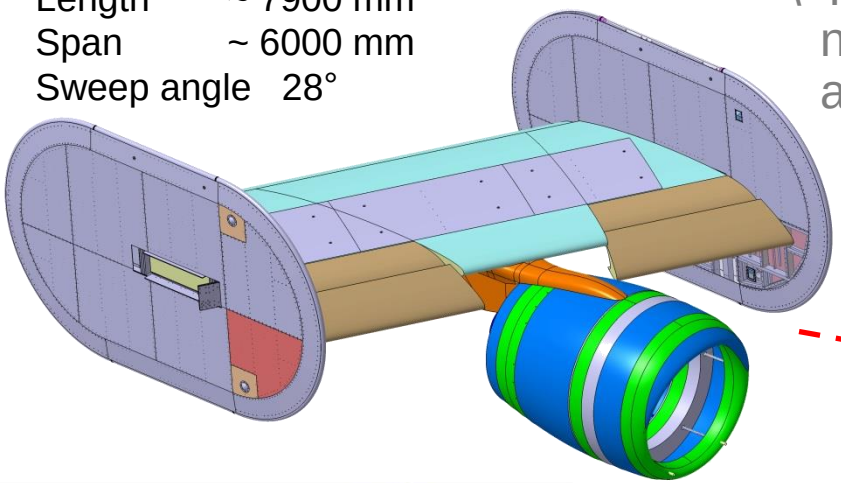
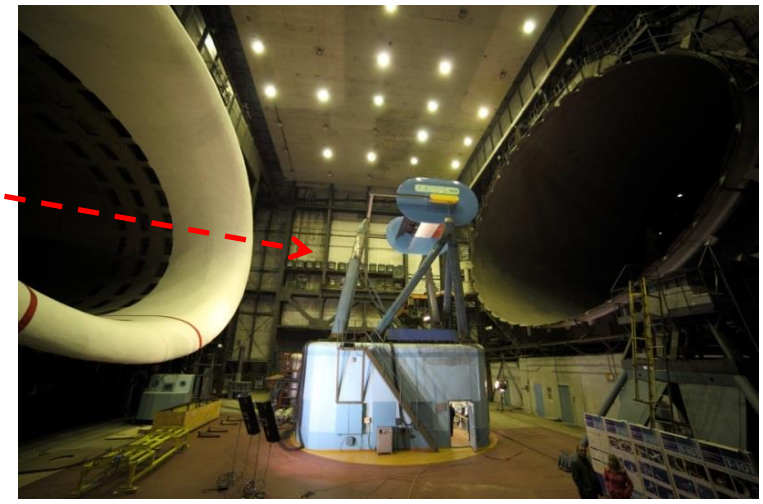
TS3 - Local application of AFC on Wing/Pylon (3/3) -
- Achievements after 1st Project Year -

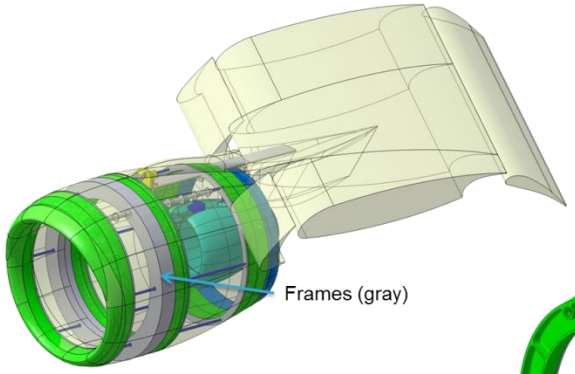
Length ~ 7900 mm
Span ~ 6000 mm
Sweep angle 28°

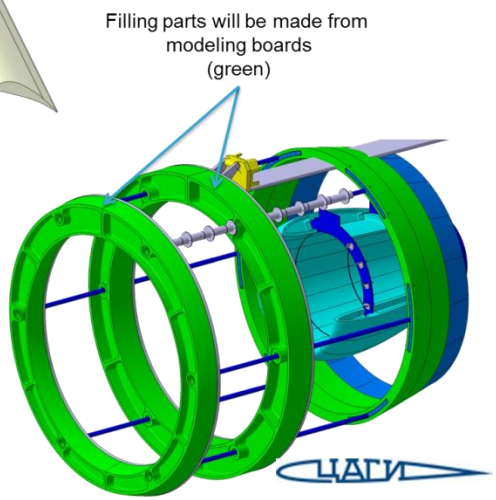


\ TsAGI has started design work of the necessary modifications of the “SADE” model and preparation of a DMU.



Modified 2.5 D SADE WT model)
will be tested in TsAGI WT T-101, autumn 2016





Preliminary design of nacelle

TS2/3/4 - Actuator Development for AFC -

- Achievements after 1st Project Year -

\ Technology definition, testing and integration strategy of actuator concepts for different applications on airframe.

- ***Pulsed Jet Actuators (BAE)***

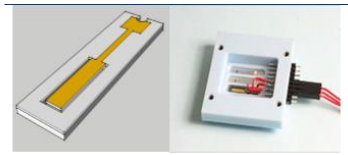


Fig. 1. Actuator concept and prototype housing (from previous projects)

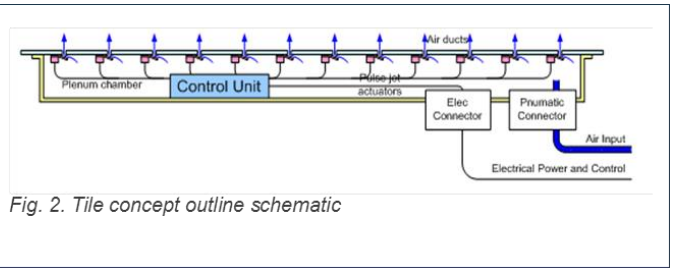
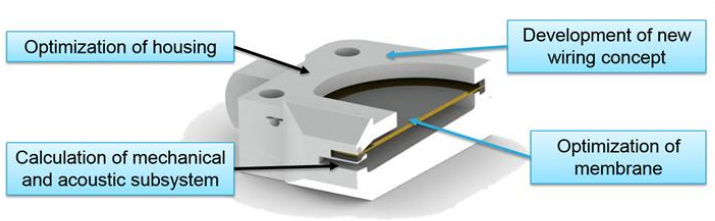


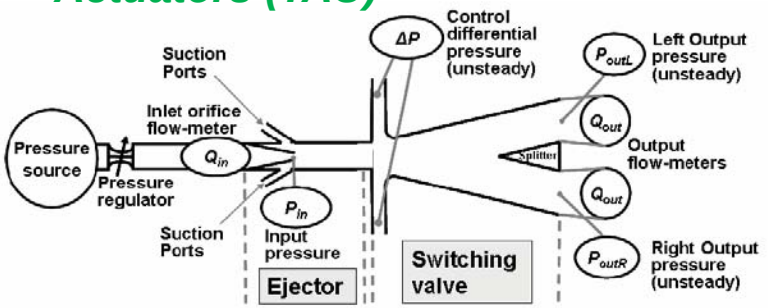
Fig. 2. Tile concept outline schematic

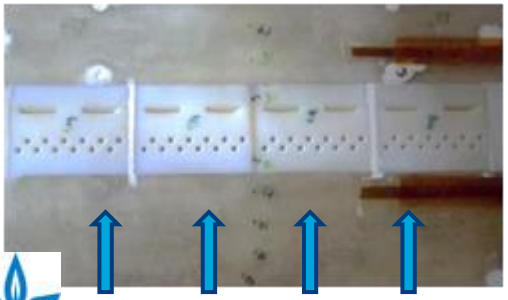
- ***Synthetic Jet Actuators (FRAUN + EADS)***

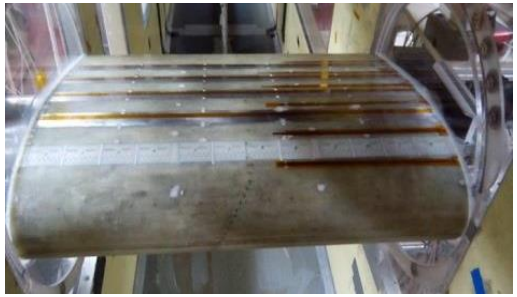


BAE SYSTEMS Fraunhofer AIRBUS DEFENCE & SPACE

- ***Suction and Oscillatory Blowing Actuators (TAU)***







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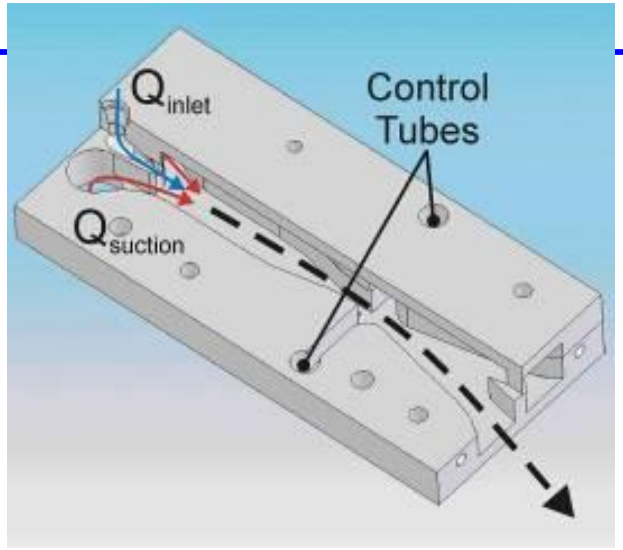
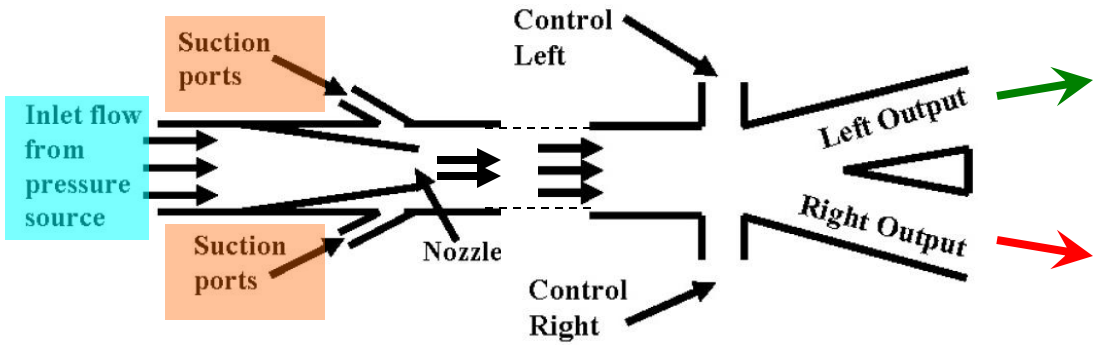
SaOB (Suction & Oscillatory Blowing) Actuator

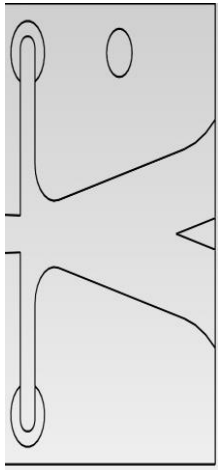


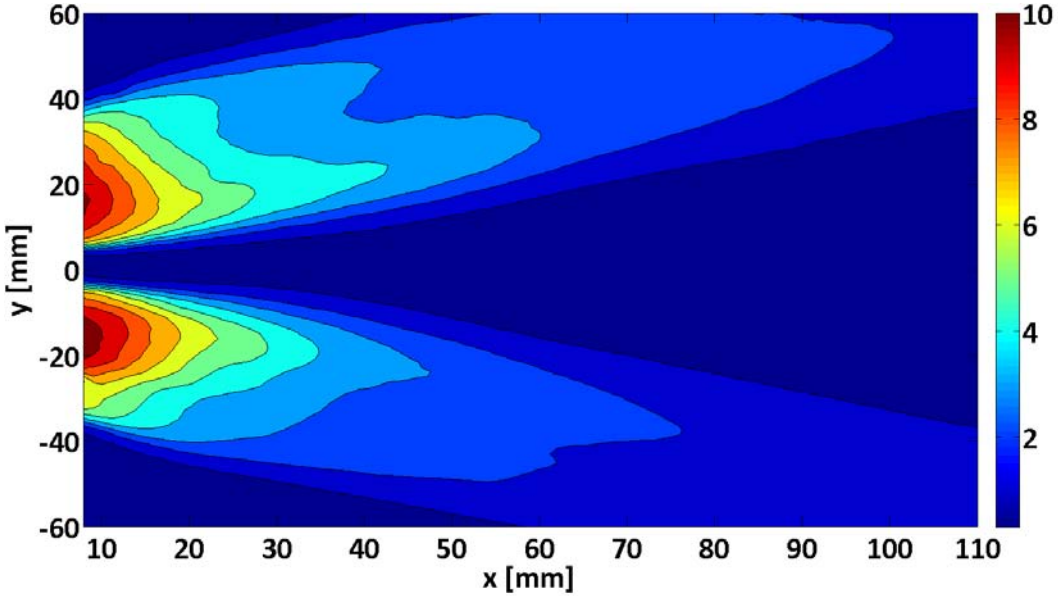


(Arwatz et al, 2006, AIAA Journal, Dayan MSc, Thesis)

NOTE: Frequency and Amplitudes are coupled

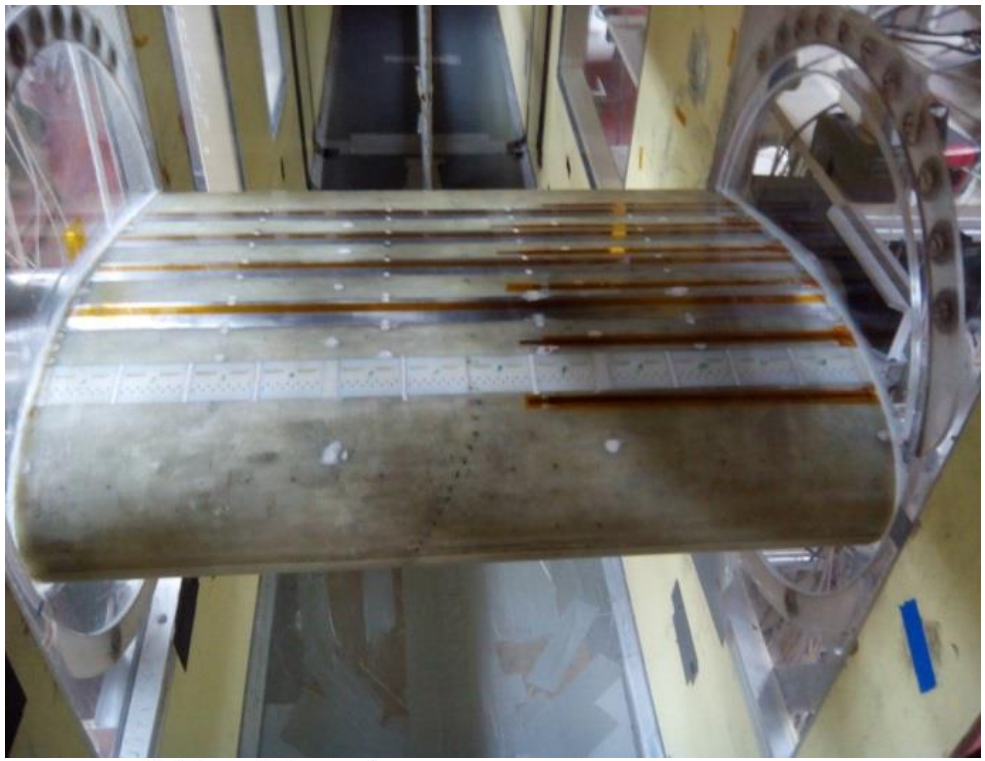
- **PIV data**
- **Average velocity**
- **Two oscillatory Sideways jets**
- **Up to Sonic**
- **Steady suction**
- **Up to 50m/s**

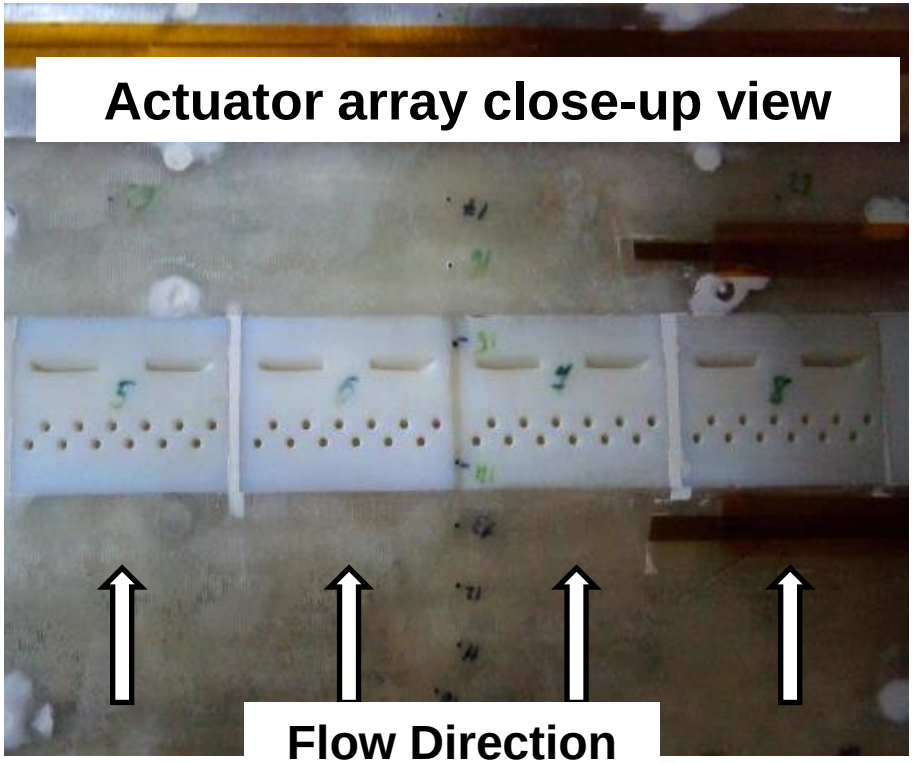




TAU WP 2.2.4: Part Span Slat / AFC

- **PI: A. Seifert, MSc Student: D. Sarkorov, IAI: Detinis, Bauminger**
- **Clean AH93-300 airfoil installed in TAU Knapp-Meadow Wind Tunnel**
- **t/c=0.31, 12 SaOb actuators at x/c~0.2, 96 press taps, wake rake**
- **Reynolds numbers 0.3-1.5x10^6**





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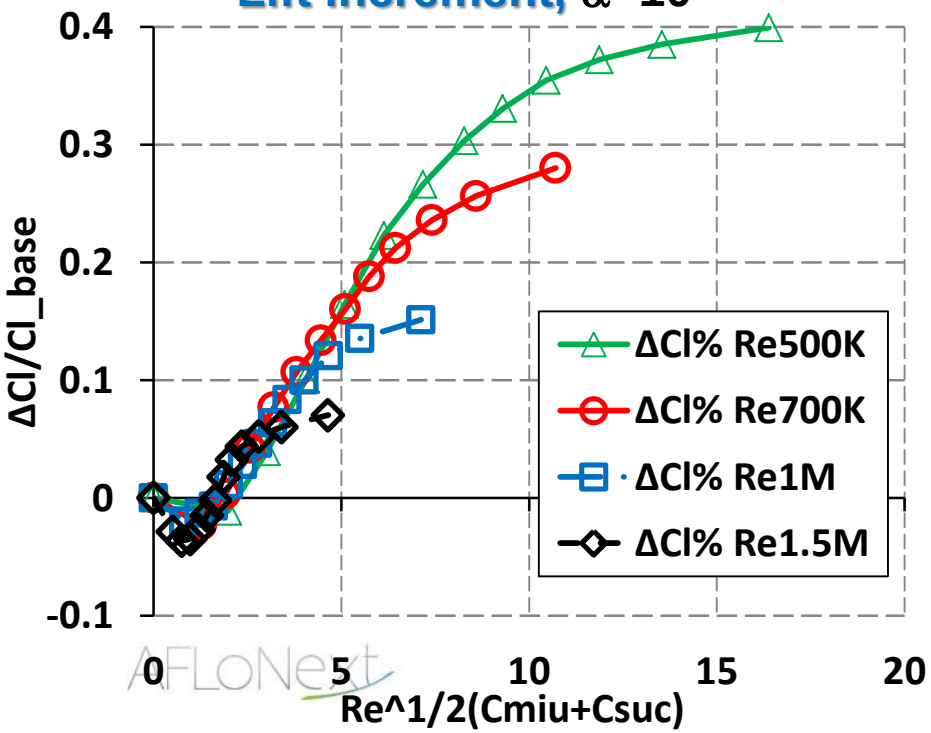
Effect of AFC on Performance and Efficiency

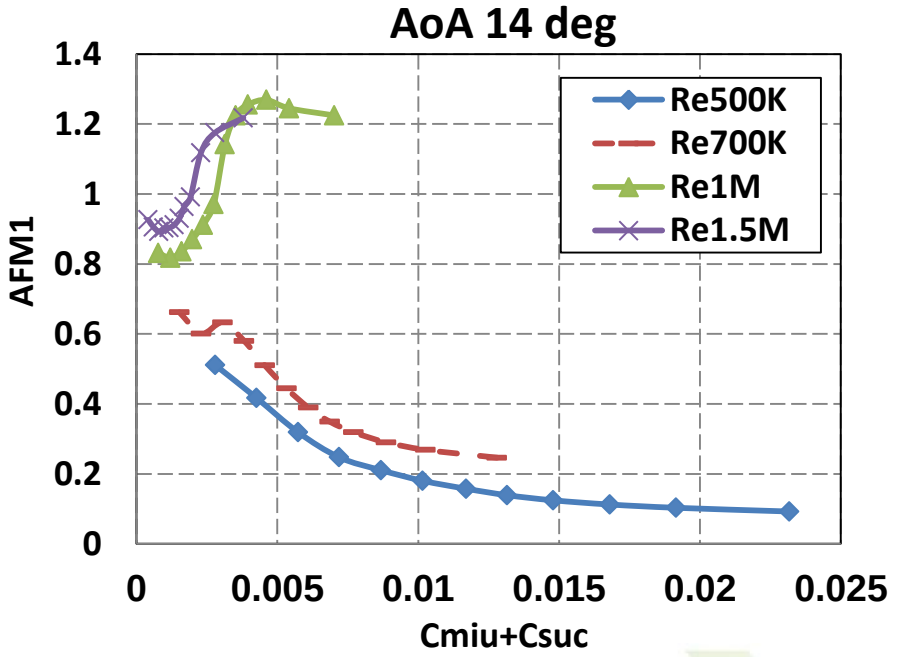
- Relative change in Lift (left side) and Drag (not shown) at α=10°
- Reynolds number indicated in legend
- Combined pulsed blowing and suction momentum coefficients

$$Csuc = \sum_j \frac{A_{suc}\overline{U_{suc\_j}}^2}{c \cdot b \cdot U_\infty^2} \qquad C\mu = \sum_i \frac{A_i\overline{U_{b\_i}}^2}{c \cdot b \cdot U_\infty^2}$$

$$AFM1 = \left(\frac{L_c \cdot U_\infty}{D_c \cdot U_\infty + P_{afc}} \right) \Big/ \frac{L_b}{D_b}$$

Lift increment, α=10°





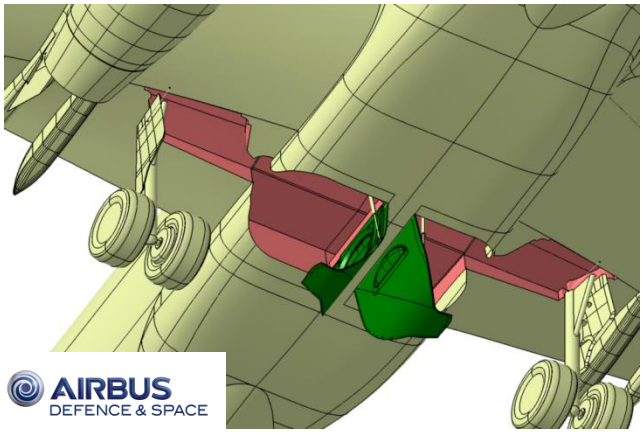
TS5/6 - Local Application of “Passive” Control Technologies on Airframe -

- Major Deliverables -

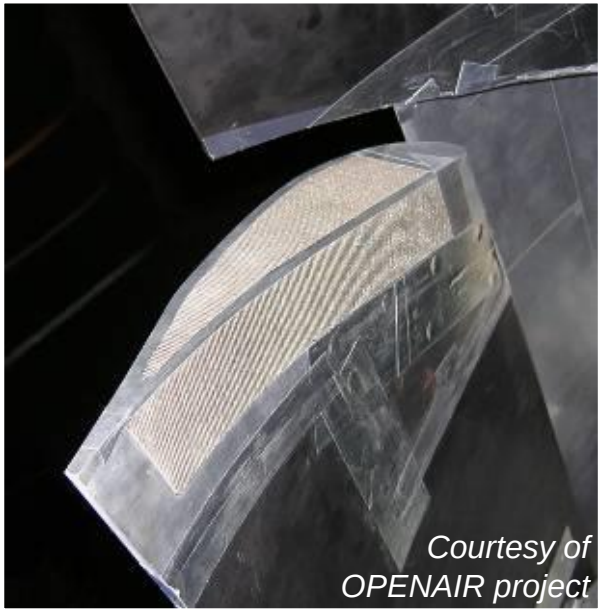
\ Flight test demonstration of locally applied passive control technologies for noise and vibrations mitigation on the airframe.

\ Engineering feasibility of noise and vibrations technologies proven by means of prototype demonstration in operational environment.

\ Manufacturing readiness demonstrated for passive solutions through material specifications and identification of according manufacturing processes.



\ Noise reduction on flap and undercarriage (TS5)



\ Vibrations mitigation / control in undercarriage area (TS6)

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TS5 – Noise Reduction on Flap and Undercarriage (1/3)-

- Achievements after 1st Project Year -

\ Complex flow field around undercarriage during approach numerically investigated.

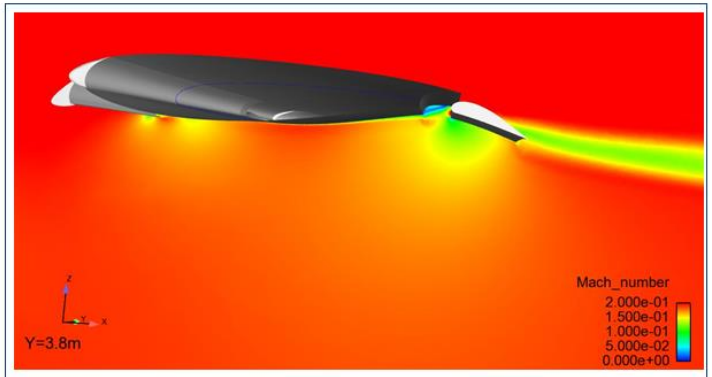


Figure 29: Mach number pattern of field data at spanwise position y=3.80m, CONF 3 (22/20), LG up, AoA=6°, M=0.20, Re=19.3Mio

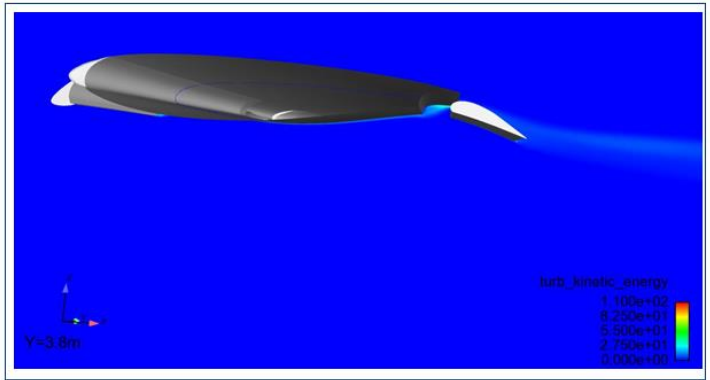


Figure 47: Turbulent kinetic energy pattern of field data at spanwise position y=3.80m, CONF 3 (22/20), LG up, AoA=6°, M=0.20, Re=19.3Mio

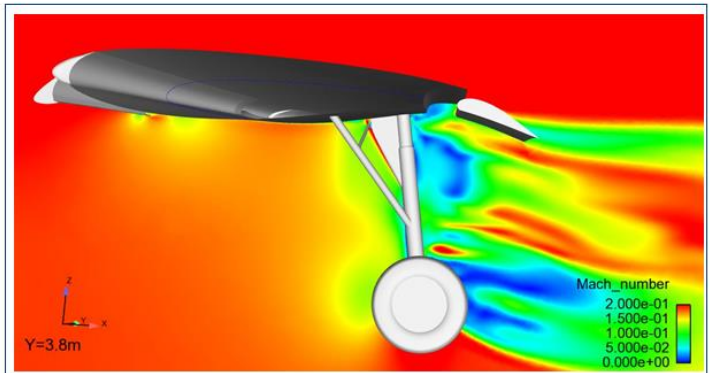


Figure 30: Mach number pattern of field data at spanwise position y=3.80m, CONF 3 (22/20), LG down, AoA=6°, M=0.20, Re=19.3Mio

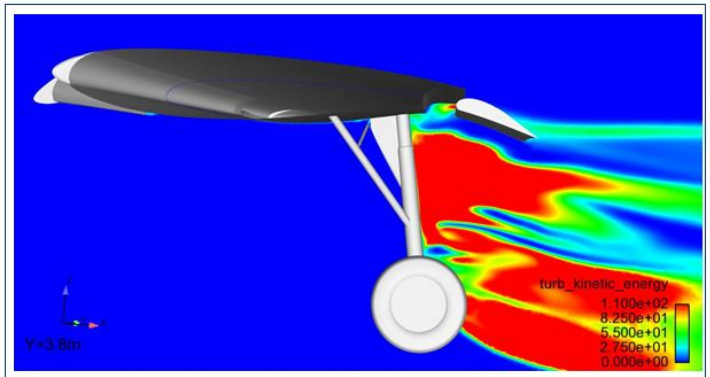


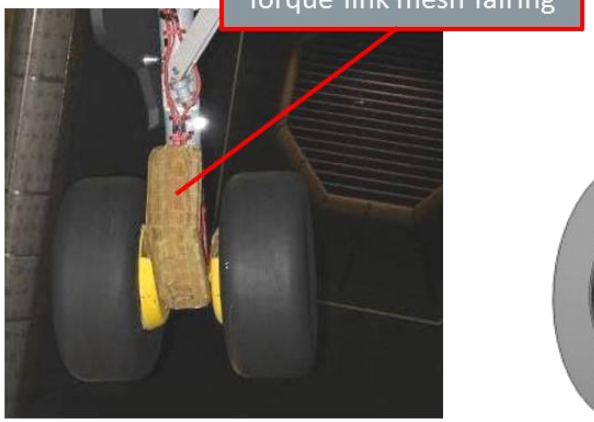
Figure 48: Turbulent kinetic energy pattern of field data at spanwise position y=3.80m, CONF 3 (22/20), LG down, AoA=6°, M=0.20, Re=19.3Mio

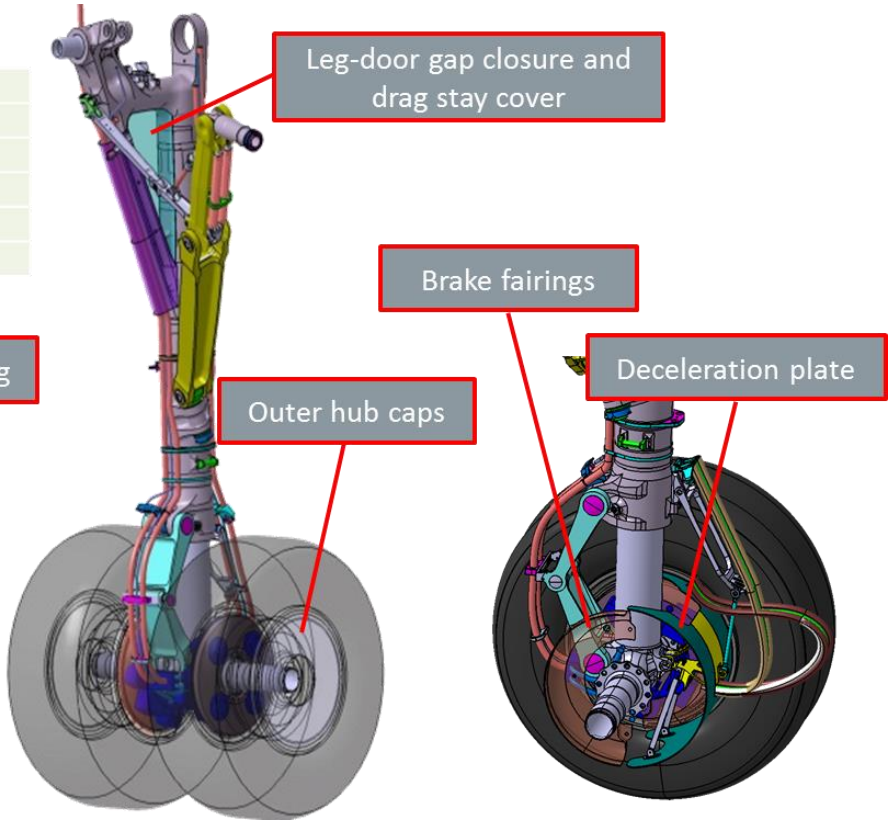
TS5 – Noise Reduction on Flap and Undercarriage (2/3)-

- Achievements after 1st Project Year -

\ Definition of suitable technologies to reduce LG noise and LG-flap interaction has been performed. The design activities has started and preparation of large-scale WT test (LG model) is in progress.

Low Noise Devices
MLG - Torque link mesh fairing
MLG - Brake fairings
MLG - Outer hub caps
MLG - Leg-door gap closure and drag stay cover
MLG - Deceleration plate (from OPENAIR)

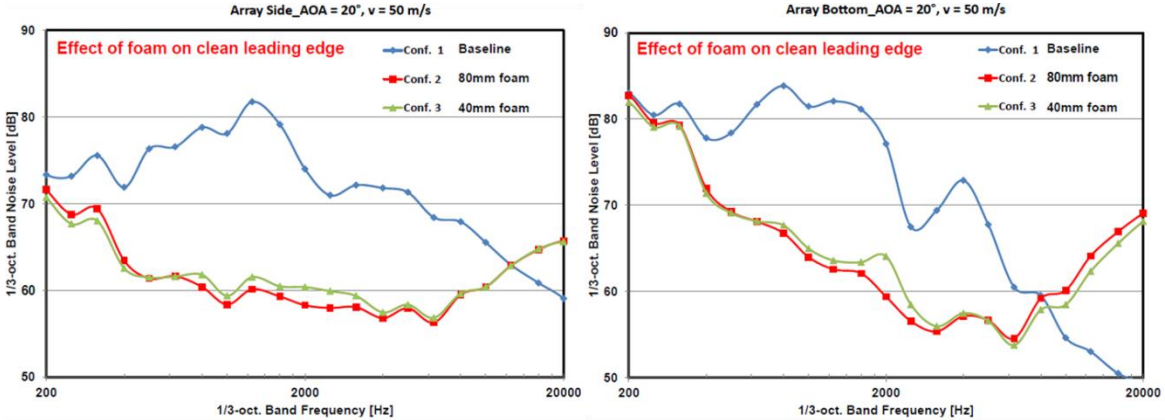


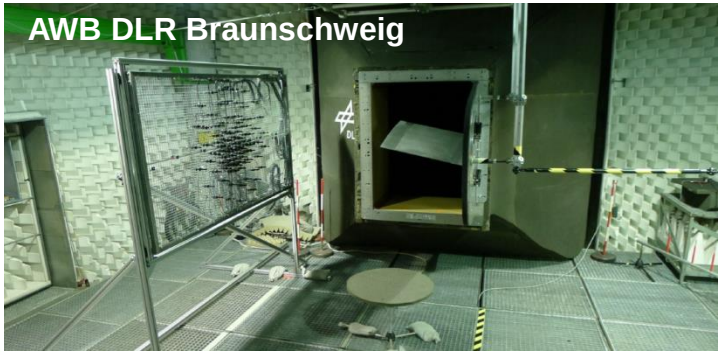


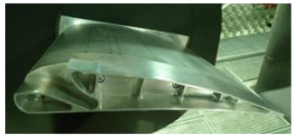
TS5 – Noise Reduction on Flap and Undercarriage (3/3)-

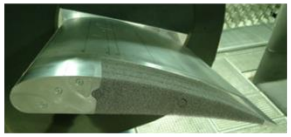
- Achievements after 1st Project Year -

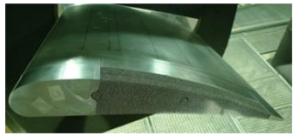
\ Definition and design for Porous Flap Side Edge (PFSE) using A320 geometry has been performed and already successfully tested in WT.

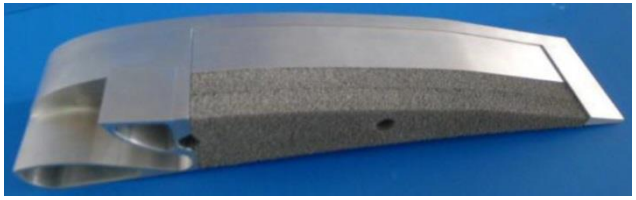


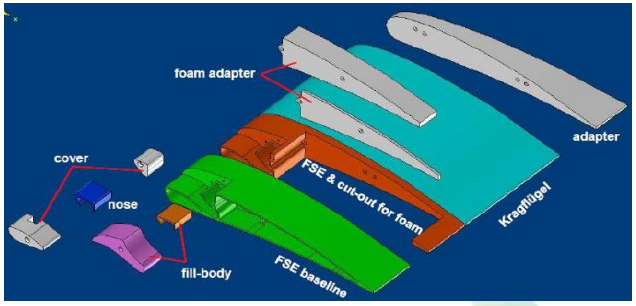



Conf. 1 Baseline


Conf. 2 80mm foam


Conf. 3 40mm foam



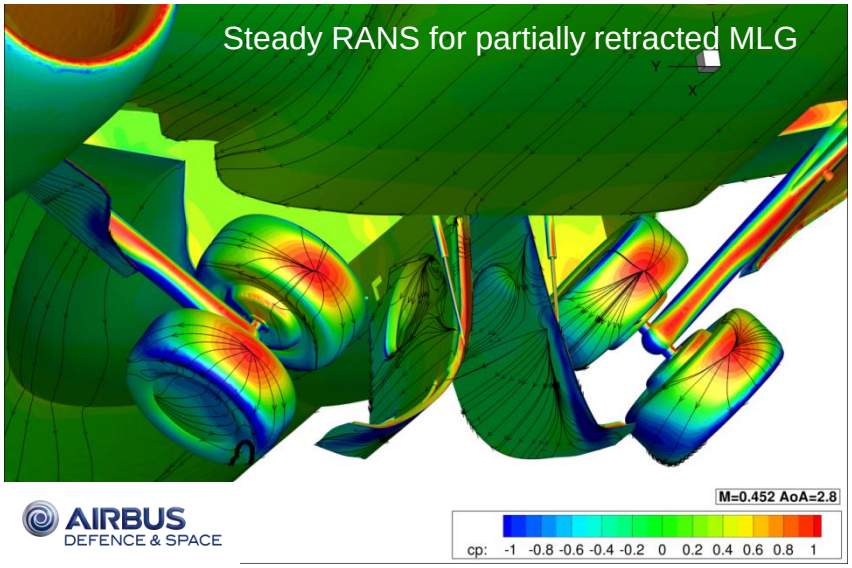


\ FT preparation in progress and pre-order of flaps started.

TS6 –Vibrations Mitigation/Control in Undercarriage Area -

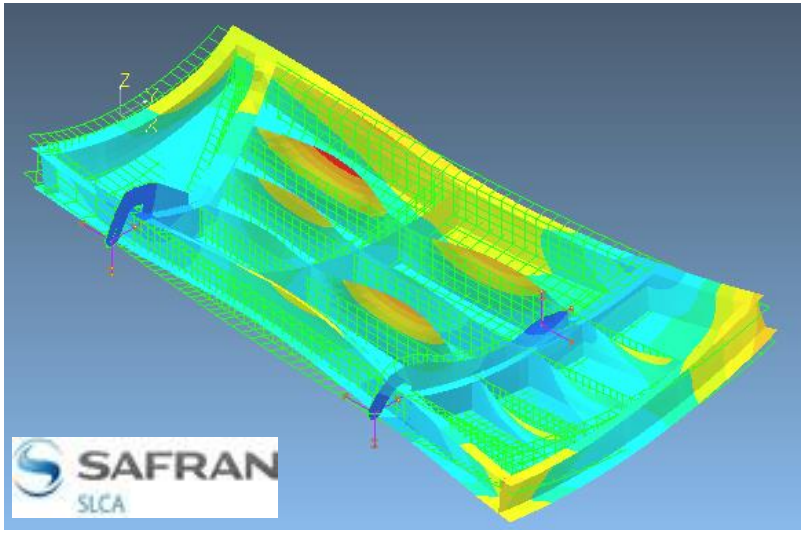
- Achievements after 1st Project Year -

\ CAD geometry and FE model of undercarriage situation developed. Numerical investigations (RANS/URANS) running to explore the flow physical situation and the structural dynamics. Basis for definition of the most suitable devices to reduce vibrations.



\ FT and GVT preparation in progress

Theoretical model validated by „ping test“, here shown 2nd global mode



\ Design, structural characterisation and manufacturing principle for monolithic NLG door developed.

- Flight Test Strategy -

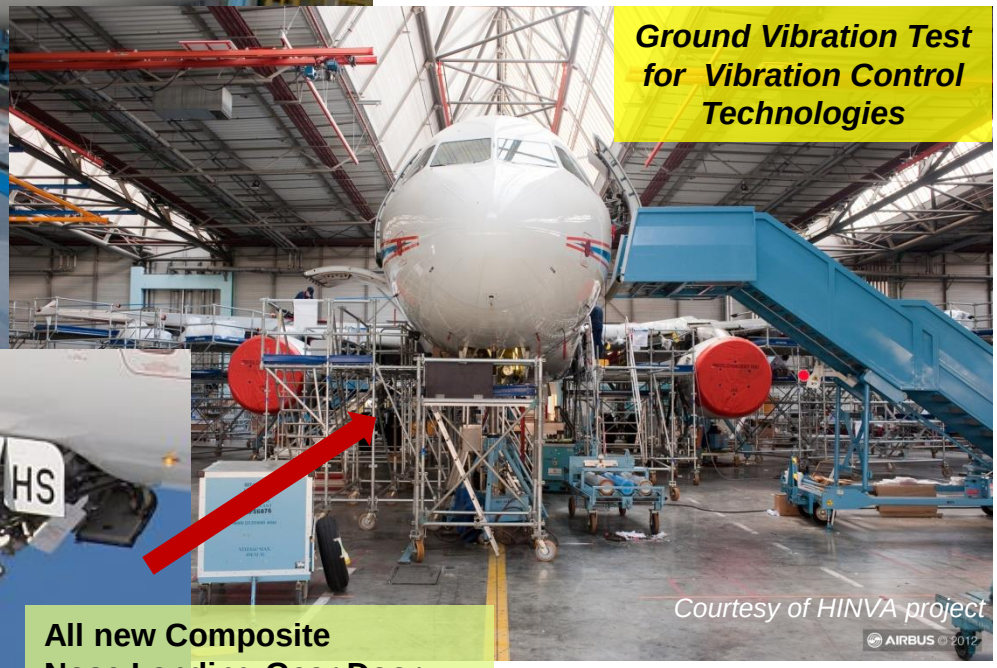
All new VTP with integrated HLFC nose

Flight Test with HLFC Technology

Flight Test with Noise and Vibrations Control Technologies

Courtesy of HINVA project

Ground Vibration Test for Vibration Control Technologies



DLR's 'ATRA' as common testing platform for TS1, TS5, TS6

All new Composite Nose Landing Gear Door

- Conclusion - Outlook

- The project is well on track after 1st year of operation.
- The consortium is the strongest asset of the project, providing world-class capabilities. A very good team spirit is present despite the difficulty to lead and bring together such a widespread team from across Europe.
- The 2nd year will face the project with strong challenges such as:
  - The further development and provision of large hardware (fin, flaps, doors, etc.)
  - Preparation of large WT campaigns and ground-based demonstrations
- In summary, the technologies which are being developed in AFLoNext are today more than ever required by customer needs. Forward looking, Clean Sky 2 is the next logical step to mature some of the most promising flow control technologies up to pre-serial level, making these technologies available to aircaft industry at the beginning of the next decade.

Interested in AFLoNext? See www.aflonext.eu

Acknowledgement by the EU: "This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under Grant Agreement No 604013, AFLONEXT project".

NUMECA INTERNATIONAL

A new wave in fluid dynamics

Uncertainty Management for Robust Industrial Design in Aeronautics – UMRIDA a project overiew

www.umrida.eu

Dirk Wunsch, Charles Hirsch

Aachen, 28.10.2014

The role of uncertainties in Virtual Prototyping

Paradigm shift in Virtual Prototyping (VP) methodology

- Virtual Prototyping (VP) has become the key technology for industry
  - Reduce product development cycle costs
  - Respond to the challenges of designing sustainable products and responding to the environmental challenges
- These objectives require a highly integrated computer-based design system,
  - Relying on advanced massively parallel hardware, making the virtual product development and qualification process more realizable
- Limitation in extensive application of analytical tools at the basis of VP
  - Is connected to the level of uncertainty introduced in the analysis and design process
- **Example**: 3-D viscous flow analysis of engine components uncertainties:
  - In the boundary conditions representing the operational environment;
  - On the geometry resulting from manufacturing tolerances and assembly process.
  - In modeling uncertainties and numerical errors (such as grid dependences)

The role of uncertainties in Virtual Prototyping

Paradigm shift in Virtual Prototyping (VP) methodology

- These uncertainties lead to a global uncertainty on the results of the analysis
  - Which is used as the basis for design decisions!
- Reliable Risk Management requires
  - Ability to quantify the impact of these uncertainties on the predicted behavior of industrial components
  - To be able to account for these uncertainties in the design process
  - Managing the design process in light of these uncertainties is therefore the key to robust design
- Introducing the probabilistic nature of the uncertainties in the simulation software systems is a highly challenging undertaking
  - Whole process transforms the resolution of deterministic physical conservation laws, to non-deterministic methods, governed by stochastic partial differential equations (SPDE)

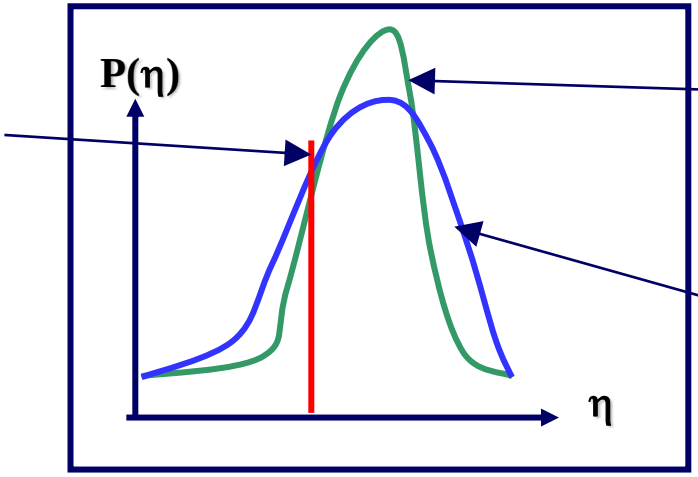
The role of uncertainties in Virtual Prototyping

Paradigm shift in Virtual Prototyping (VP) methodology

- Predicted quantities, such as loads, lift, drag, efficiencies, temperatures, ….
  - Now represented by a Probability Density Function (PDF)
  - This PDF provides a domain of confidence associated to the considered uncertainties

- This corresponds to a fundamental shift in paradigm for the whole of the VP methodology

Result of deterministic CFD simulations for mean value of measured uncertainty parameter as input



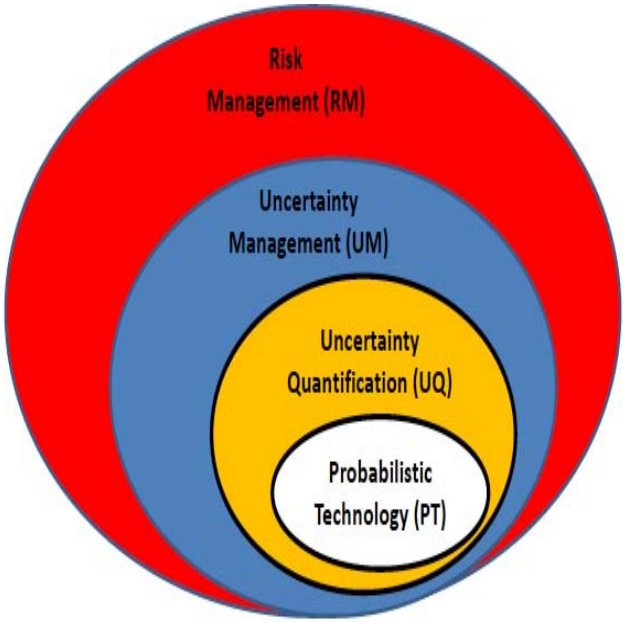
PDF of non-deterministic CFD simulations for given PDF of uncertainty parameter as input

PDF of deterministic CFD simulations for randomly sampled uncertainty parameter as input

Uncertainty Quantification

The area of Uncertainty Quantification covers the following activities

- **Uncertainty Identification**
  - Data: operational uncertainties or geometrical variability
  - Model: physical model, gird dependence, convergence
- **Uncertainty Categorization**
  - Reducible: epistemic (due to lack of knowledge)
  - Irreducible: aleatory (inherent randomness)
  - *Epistemic* uncertainty is a property of the modeler/observer, *aleatory* uncertainty is a property of the system being modeled
- **Uncertainty Quantification (input uncertainties)**
  - Statistical description of input uncertainties, PDF type
- **Uncertainty Propagation**
  - Probabilistic definition of the output quantities
  - Monte-Carlo, Method of Moments, Polynomial Chaos
- **Uncertainty Analysis**

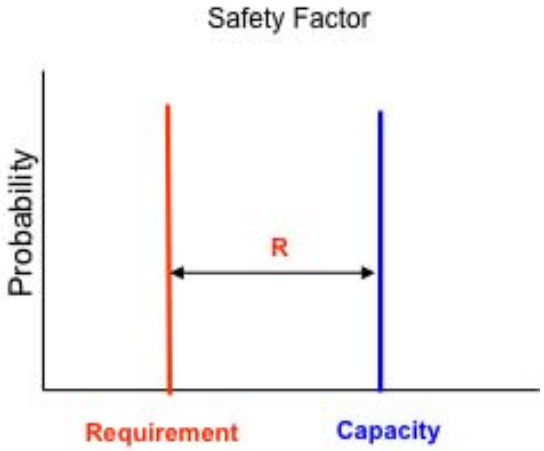


From: Green *et al.* (2008)

Uncertainty Quantification and Safety Factors

Traditional approach to risk management: safety factors

- Deterministic value is estimated for the load xR (*requirement*) and a value is provided, as best as possible, for the maximum *capacity* xC
  - On basis of which a safety factor k=xC/xR is imposed on the system



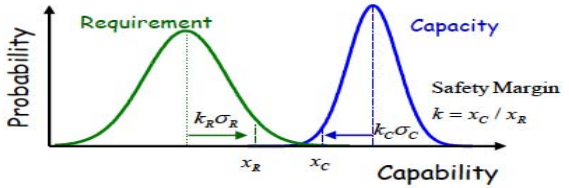
- Taking the safety factor at a sufficiently high value minimizes risk
  - This will generally have detrimental consequences on cost and performance

Uncertainty Quantification and Safety Factors

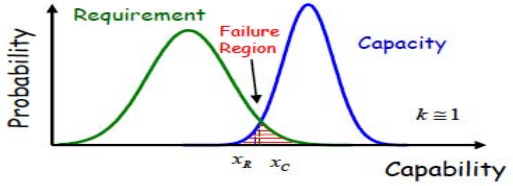
Traditional approach to risk management: safety factors

- Considering uncertainties and their PDF's
  - Allows ranges (under the form of PDF's) for requirements (loads) and capacity (resistance) to be evaluated in a rational way
  - Allows to define a failure region where the two PDF's overlap. Full safety, taking into account the known uncertainties, is obtained for k>1

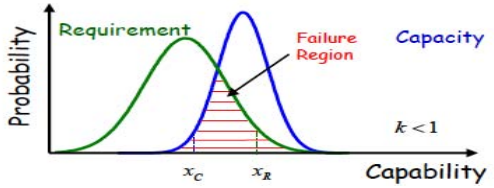
k>1, the design is perfectly safe (top)



k≅1, a certain risk factor will exist (middle)



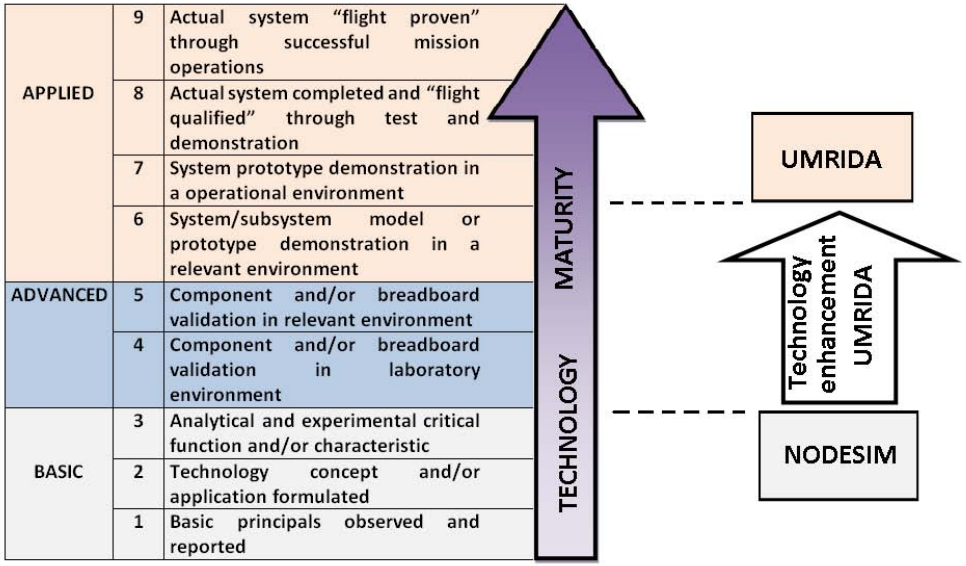
k<1, a large failure region exists, which would lead to a catastrophic design, of course to be rejected (bottom)



From: Green (2011)

UMRIDA - Uncertainty Management for Robust Industrial Design in Aeronautics

- FP7 Level 1 project with a consortium of 21 partners
  - Comprising of universities, research institutes, industrial partners and SME's
- Project website: www.umrida.eu
- Aiming at a **paradigm shift in virtual prototyping** away from deterministic design and towards design under uncertainties
- Bridging the gap from basic research to industrial applications where large numbers of simultaneous uncertainties are accounted for



UMRIDA project

Consortium

General objectives of UMRIDA

Scientific and technical objectives

- Development of innovative methods to address before mentioned challenges
- Development of new methods for large-scale introduction of UQ in RDM
  - Produce designs incorporating the major uncertainties
- Apply UQ and RDM to predefined industrial challenges with prescribed uncertainties
  - Creation of new generation of database, including controlled uncertainties from experiments
  - **Validate** developed methods on this database
- Advance Technology Readiness Level (TRL) from currently 2-3 to 5-6
  - Quantifiable objective: **At least 10 simultaneous uncertainties, in a turn-over time of less than 10 hours on a 100 core parallel computer**
- Facilitate co-operation and dissemination of UQ and RDM awareness towards European industries, research establishments and universities

Technical objectives of UMRIDA

Progress beyond the state of the art

- Advances in methods for uncertainty quantification and propagation
  - Method of moments, perturbation and adjoint based methods
  - Monte-Carlo Methods
  - Polynomial Chaos and collocation methods (intrusive and non-intrusive)
- Identification of most important uncertainties, quantifying input uncertainties
- Advances in robust design and optimization methodologies
- Co-operation and dissemination
  - Workshops allowing quantitative comparison between UQ and RDM
  - Preparation of Best Practice Guide of UQ and RDM, exploitation and communication of results

Technical objectives of UMRIDA

Advances in methods for uncertainty quantification and propagation

Method of moments (perturbation method) and adjoint based methods

- ❑ Principle: Use a Taylor Series to expand output quantity around its mean
- ❑ Key element is the evaluation of first and second order sensitivity derivatives

UMRIDA objectives

- ❑ Explore possibility to use 2nd order sensitivities in analysis of general geometric uncertainties
- ❑ Advantages: Weak increase in cost with number of simultaneous uncertainties (no more than linearly)
- ❑ Challenges: Intense intrusive, strongly dependent on details of analysis code

Technical objectives of UMRIDA

Advances in methods for uncertainty quantification and propagation

Monte-Carlo Methods

- Principle: Perform high number of deterministic simulations with sampled parameters and evaluate output quantities

UMRIDA objectives

- Development of surrogate models and response surfaces to reduce cost of methods
- Evaluate most promising approaches, such as multilevel methods

- Advantages: Non-intrusive, directly applicable to any code

- Challenges:
  - Very large numbers of samples even for single uncertainty
  - Cost increases significantly with increasing number of uncertainties

Technical objectives of UMRIDA

Advances in methods for uncertainty quantification and propagation

Polynomial chaos or collocation methods (Intrusive and non-intrusive)

- Intrusive formulation
  - Set of conservation laws for each of the coefficients of the PC expansion
- Non-intrusive formulation
  - No modification of code, such as Monte-Carlo methods
  - Curse of dimensionality, cost increases exponentially with number of uncertainties

UMRIDA objectives:

- Reduce costs by reducing number of simultaneous uncertainties using
  - (Adaptive) sparse collocation techniques
  - Surrogate models
  - Coupling with adjoint techniques to reduce number of simultaneous uncertainties

Technical objectives of UMRIDA

Reduction of number of uncertainties, Quantify input uncertainties

- Identify most important uncertainties
  - Use approaches like SS-ANOVA, Morris Method, PCA, Sobol indices, Karhunen-Loeve expansion
  - Use adjoint technique to reduce number of uncertainties and then run PCM or MC
- Surrogate models or Reduced order models
  - Reduce cost of UQ and RD methods
- Quantify input uncertainties
  - Mean and standard deviation of output PDF can be highly dependent on shape of input PDF
  - Need for a method to derive correct information on input PDF from generally scarce experimental data

Technical objectives of UMRIDA

Advances in robust design and optimization methodologies

Robust design and optimization

- Objectives are designs less sensitive to uncertainties conditioning their operation
  - Robust design problems: design insensitive to small changes
  - Reliability-based design problems: design with probability of failure less than an acceptable value
- Design under uncertainties is a new field of research
  - Unclear so far how to enforce robustness, robust objective/constraint formulations and dependence on used optimizers
- Inverse multi-objective robust design
  - Optimize mean output performance
  - Maximize standard deviation or tolerance on input variables
  - While keeping the required constraints satisfied

Validation database with prescribed uncertainties

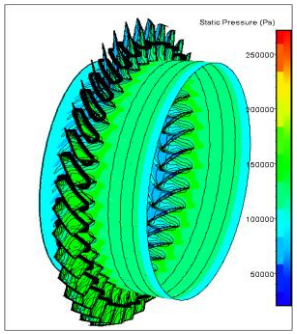
Construction of unique validation database with prescribed uncertainties

- The FP7 UMRIDA project (www.umrida.eu) on *Uncertainty Management for Robust Industrial Design in Aeronautics* includes the creation of a validation database with prescribed uncertainties
  - Industrial multiphysics challenges defined by industrial project partners
  - Advance Technology Readiness Level to "Advanced/Applied"
  - Quantifiable objective: *At least 10 simultaneous uncertainties, in a turn-over time of less than 10 hours on a 100 core parallel computer*
- Specific focus on multidisciplinary applications such as
  - FSI, CHT, combustion, aero-acoustics
- Uncertainties provided by industry experts
  - Contains also one experimental set-up with controlled uncertainties during measurement campaign

Validation database with prescribed uncertainties

UMRIDA validation database: Basic Challenges (1/3)

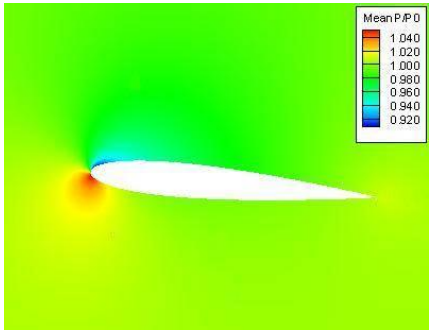
BC-01:
NUMECA



Description:
- NODESIM-CFD test case
- NASA Rotor 37

Uncertainties:
- Inlet Pt, outlet pressure
- Geometrical: tip clearances
- Symmetric beta-pdf
- Blade thickness, blade angle, ... in 10 sections
- LE angle, twist distribution, non-uniformity of blade spacing

BC-02:
NUMECA



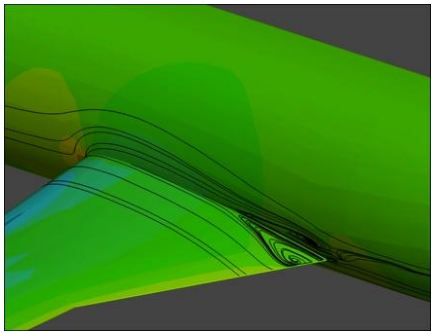
Description:
- NODESIM-CFD test case
- RAE 2822 airfoil
- Mach = 0.734
- Angle of incidence 2.79°
- Reynolds = 6.5 e6

Uncertainties:
- Angle of incidence: std 0.1°
- Thickness-to-chord ratio: std 0.005
- Mach number: std 0.005
- Uncertainties with either a uniform or normal distributed PDF

Validation database with prescribed uncertainties

UMRIDA validation database: Basic Challenges (2/3)

BC-03:
DLR



Description:
- DLR-F6 wing/body
- From Drag prediction workshop (DPW III) with/without fairing
- ATAAC test case
- M = 0.75
- Re = 5e6
- CL = 0.5

Uncertainties:
- Mach number
- Angle of attack
- Reynolds number
- Wing thickness
- LE shape

BC-04:
EADS

Description:
- F11 (KH3Y) TO2 Configuration
- Flap setting on a three-element high-lift airfoil
- M = 0.1715, Re = 11e5
- AoA = 9.6°
- Slat deflection = 20°
- Flap deflection = 22°

Uncertainties:
- Uncertainties: flap deflection

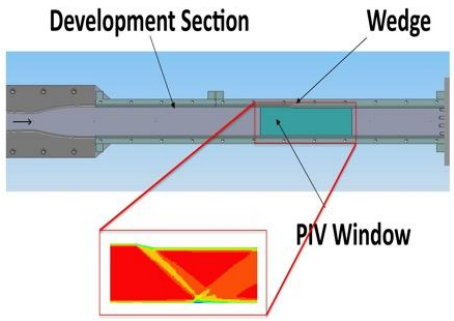
i) Gaussian distribution with mean notional setting and s=2% of flap chord

ii) Beta PDF with mean equal to notional setting and +-2% of flap chord

Validation database with prescribed uncertainties

UMRIDA validation database: Basic Challenges (3/3)

BC-05:
STANFORD
CIRA



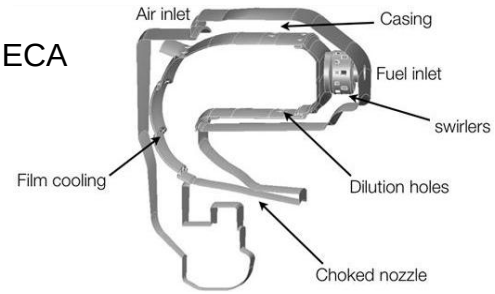
Description:
- New experimental data on shock boundary layer interaction with uncertainties
- Test configuration is a 24° compression wedge in a Mach 2 flow

Uncertainties:
- Distributed geometrical uncertainty of the upstream wall
- Controlled geometrical modifications to introduce flow perturbations
- Validation of UQ simulation for shock location by MC with hundreds of sampled configurations

Validation database with prescribed uncertainties

UMRIDA validation database: Industrial Challenges (1/5)

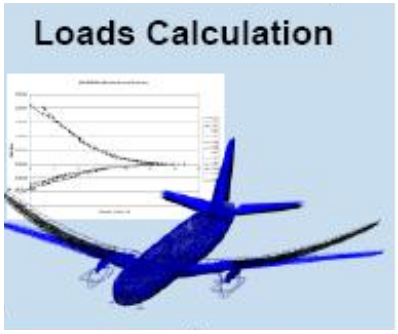
IC-01:
TURBOMECA



Description:
- Database of pressure signal recods taken in the combustor
- Existence of thermo-acoustic instabilities by high amplitude of pressure measurements

Uncertainties:
- Varying operating conditions and geometrical definitions of the combustion chamber
- Uncertainties in the acoustic boundary conditions for the Helmholtz solver

IC-02:
EADS-IW



Description:
- Undertainty in the determination of design loads
- Aerodynamic force distribution across the full flight envelope
- Landing gear data for loads
- Stiffness distribution
- Mass distribution

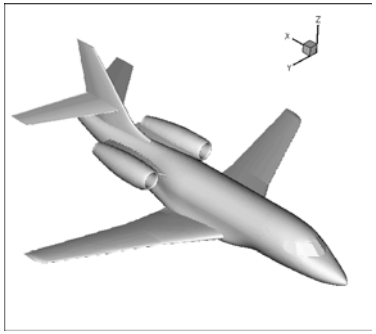
Uncertainties:
- Quantify uncertainties in all process inputs
- Propagate these through loads calculations and evaluate variance of design loads estimations
- Within practicle time-scales on ~100 processor cluster

Validation database with prescribed uncertainties

UMRIDA validation database: Industrial Challenges (2/5)

- **Industrial challenges**

IC-03:
DASSAULT



Description:
- Falcon jet configuration
- Fuselage, wing, nacelle, tail, ...

Uncertainties:
- Robustness/operational uncertainties (free stream Mach, AoA, Reynolds number)
- Geometrical uncertainties (wing spanwise twist distribution)

IC-04:
SATURN

Description:
- Fan stage for FSI optimization

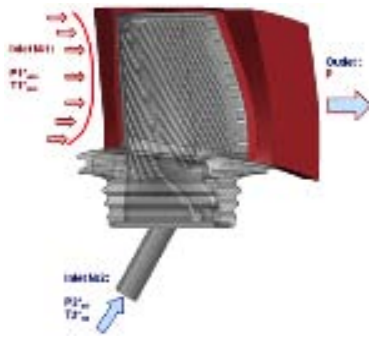
Uncertainties:
- Leading/Trailing edge radius
- Inlet angle, output edge middle line angle
- Blade thickness/angle
- Section deflection in several sections

Validation database with prescribed uncertainties

UMRIDA validation database: Industrial Challenges (3/5)

- **Industrial challenges**

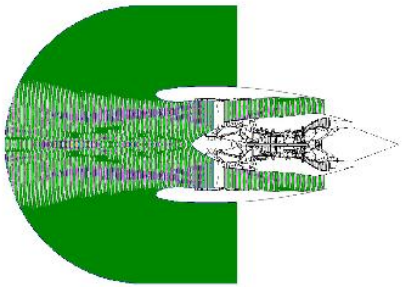
IC-05:
SATURN



Description:
- Cooled turbine blade

Uncertainties:
- Operational uncertainties
- P1*abs, T1*abs
- P2*rel, T2*rel
- Turbulence parameters

IC-06:
AAEM



Description:
- RD procedure for optimal design of acoustic panels installed in typical business-jet aero-engine intakes

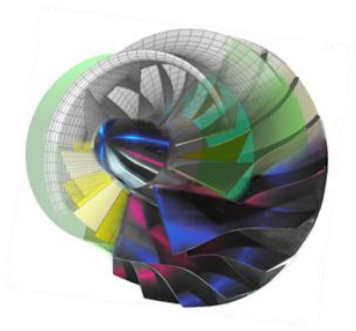
Uncertainties:
- Manufacturing tolerances (facing-sheet effective open area, hole diameters and shape)
- Uncertainties on acoustic parameters identifying the operative environment

Validation database with prescribed uncertainties

UMRIDA validation database: Industrial Challenges (4/5)

- **Industrial challenges**

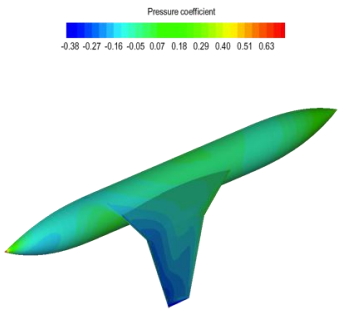
IC-07:
MAN



Description:
- Industrial compressor stage

Uncertainties:
- Operational uncertainties (gas properties, pressure, temperatures)
- Manufacturing (surface roughness, deformation due to heat treatment)
- Lifetime (erosion, fouling)

IC-08:
CIRA/
DASSAULT



Description:
- Supersonic/Transonic laminar flow design of business jet aircraft
- Design of swept wing and airframe with a large extension of laminar flow in their working conditions

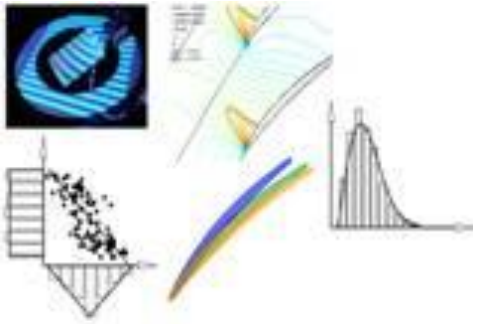
Uncertainties:
- Uncertainties in modelling the laminar/turbulent transition process combined with geometrical uncertainties

Validation database with prescribed uncertainties

UMRIDA validation database: Industrial Challenges (5/5)

- **Industrial challenges**

IC-09: RRD



Description:
• High Pressure Compressor blade design

Uncertainties:
• Uncertainties in boundary conditions and geometrical shape

Other objectives of UMRIDA

Co-operation and dissemination

- Increase awareness, understanding in EU industry and academia
- Two workshops planned
  - Allowing quantitative comparison between UQ and RDM approaches on industrial challenges
- Best Practice Guides (BPG) for industrial aeronautical users
  - Based on gained experience and workshop outcomes
- Broad exploitation and communication towards industry, academia and public
  - Book containing most significant advances within UMRIDA will be published at end of project

UMRIDA workshops

UNCERTAINTY MANAGEMENT FOR ROBUST INDUSTRIAL DESIGN IN AERONAUTICS
UMRIDA

UMRIDA Workshop on Uncertainty Quantification -

Application of UQ methods accounting for a large number of simultaneous uncertainties

15th to 16th April 2015

TU Delft

The Netherlands

www.umrida.eu

The focus of the UMRIDA workshop on Uncertainty Quantification (UQ) lies on the application of UQ)techniques to test cases with a ***large number of uncertainties***. The overall objective is the assessment and application of UQ methods capable of fulfilling the following quantitative objective, which can also be regarded as a challenge to all workshop participants:

"*Development and application of UQ methods for a **large number of uncertainties (~10)** within an acceptable **CPU return time of 10 hours** on no more than **100 cores parallel processors**."*

These test cases are part of a ***unique validation database with prescribed uncertainties***, built within the UMRIDA consortium. A series of test cases such as rotors, wing-bodies, high-lift systems and airfoils are **open to participants from outside the consortium**.

Participants from academia and industry are welcome to participate in the quantitative challenge on one or several of the proposed test cases!

Besides the participation to the open test cases, participants can contribute with presentations on:

- Application of UQ to industrial relevant configuration
- New developments in the field UQ

The program will be completed by applications of UQ methods to multidisciplinary industrial test cases including aero-acoustics, fluid-structure interaction, turbine cooling or combustion from professionals from inside the consortium and by **invited speakers** who are addressing state-of-the art research in the field of uncertainty quantification.

UMRIDA workshops

UNCERTAINTY MANAGEMENT FOR ROBUST INDUSTRIAL DESIGN IN AERONAUTICS
UMRIDA

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Test cases open to workshop participants

The following test cases are open to participation. Please click on the test case for full description with prescribed uncertainties or visit the URL indicated.

BC-01: NASA rotor 37
BC-02: RAE 2822 airfoil
BC-03: DLR F6 wing-body
BC-04: F11 (KH3Y) TO2 configuration
IC-08: Supersonic/Transonic flow design of business aircraft

Workshop deadlines

Intention to participate on UMRIDA test cases:	**30 November 2014**
Submission of abstract:	**15 December 2014**
Abstract acceptance (latest):	**9th January 2015**
Registration to workshop (150 €)	**7th April 2015**

Submission of presentations on test case results: **7th April 2015**

Partners progress: Building the database

- Industrial partners provide complex test case based on industrial experience
  - NPO-Saturn
    - FSI on fan blade treating geometrical uncertainties obtained from measurement of more than 1000 blades
    - High pressure turbine blade with cooling channels: operational uncertainties from more than 90 gas turbines
  - Alenia Aermacchi
    - Building experimental facility and measurements of performance characteristics of acoustic liners in dependence of manufacturing tolerances
  - MAN
    - Uncertainties for radial compressors over product life cycle (geometrical uncertainties)
  - Dassault Aviation
    - Test case on Falcon Jet

Partners progress: UQ methods

- Efforts to identify most influential uncertainties
  - VUB
    - Non-intrusive reduced basis approach using regression based PC
    - Number of nodes corresponds to the nodes from POD
  - ESTECO
    - Three tools to identify most important uncertainties if a large number of uncertainties is present
  - ONERA
    - Kriging based surrogate model for BC-02 test case

Partners progress: UQ tools

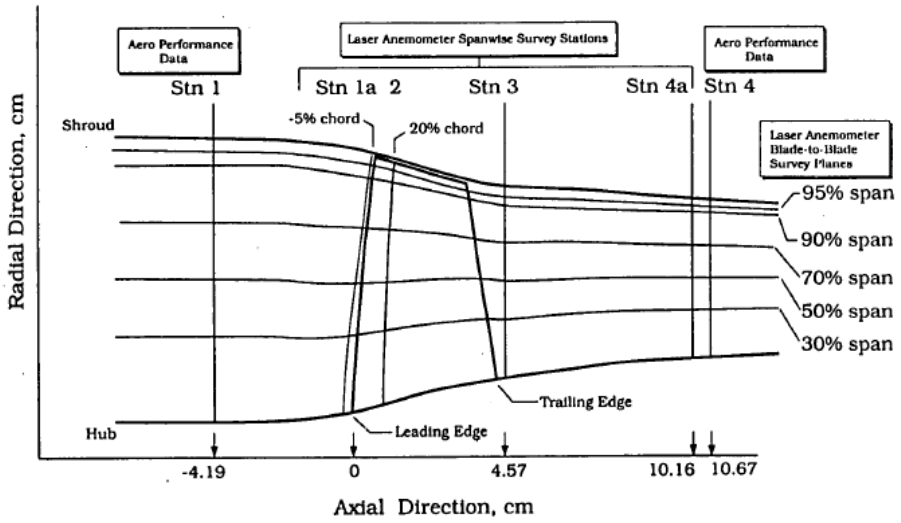
- Some partners develop tools to ease the use of UQ in daily engineering practice
  - Airbus
    - OpenTURNS platform: Define and sample random geometries and build highly accurate meta-models in an efficient way
  - ESTECO
    - Three tools to identify most important uncertainties, if a large number of uncertainties is present
    - Introduction of these methods into modeFRONTIER in view of robust design
  - Numeca
    - FINE™: Automatic tool for handling of simultaneous operational and geometrical uncertainties based on sparse collocation methods

First results from UMRIDA

Test case description: Rotor 37

- Detailed description of geometry, exp. set-up and a series of simulations cross-plotting the predictions can be found in [Dunham (1998)]

- Test case and UQ model
  - Mesh size: 2 639 973 and 4 702 629 cells
  - RANS + Spalart-Allmaras
  - Rotating Hub: 17188 rpm
  - Use of CPU-Booster in FINE™/Turbo



- Uncertainties: all PDFs are Gaussian
  - i. 5 uncertainties: total inlet pressure, static outlet pressure, tip gap, LE angle, TE angle
  - ii. 9 uncertainties: total inlet pressure, static outlet pressure, tip gap, LE angle (3 sections), TE angle (3 sections)

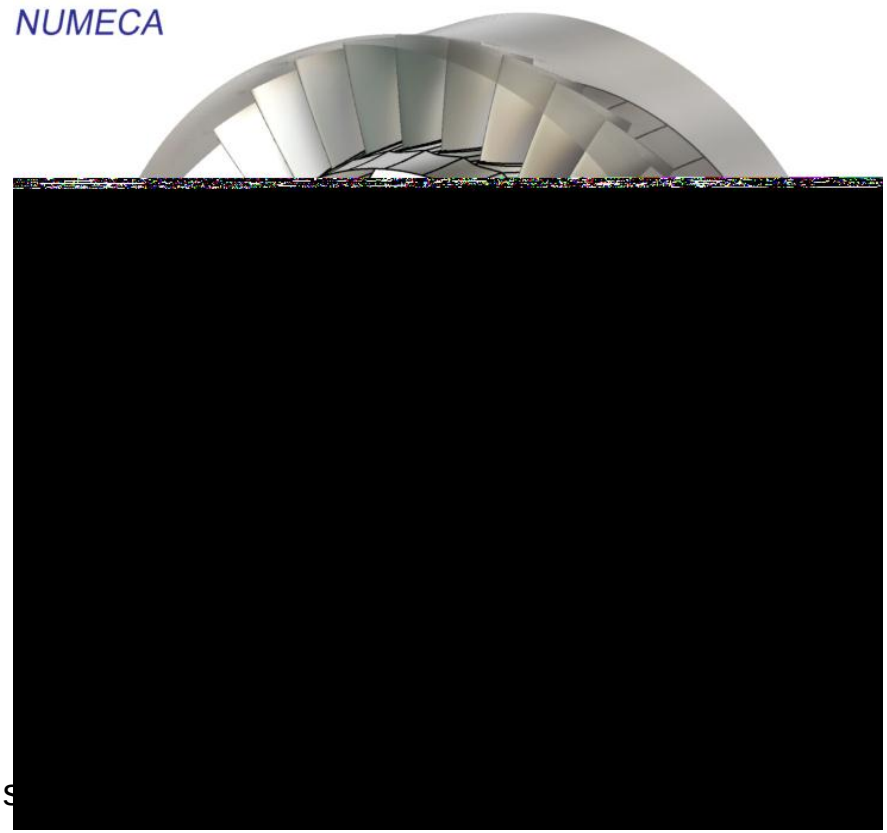
First results from UMRIDA

Overview of imposed uncertainties

- Operational and Geometrical uncertainties

Uncertainty	Most likely value (m)	Minimum value (a)	Maximum value (b)	PDF-type
Inlet total pressure	Table at station 1 in [Dunham (1998)]	95% m	105% m	Symmetric beta-PDF
Static outlet pressure	Table 1 below	98% m	102% m	Symmetric beta-PDF

Uncertainty	Most likely value (m)	Minimum value (a)	Maximum value (b)	PDF-type
Tip clearance	M_{tip}=0.356mm	50% M_{tip}	150% M_{tip}	Symmetric beta-PDF
Leading edge angle	LE_{angle}=5	95% LE_{angle}	105% LE_{angle}	Symmetric beta-PDF
Trailing edge angle	TE_{angle}=-70	95% TE_{angle}	105% TE_{angle}	Symmetric beta-PDF

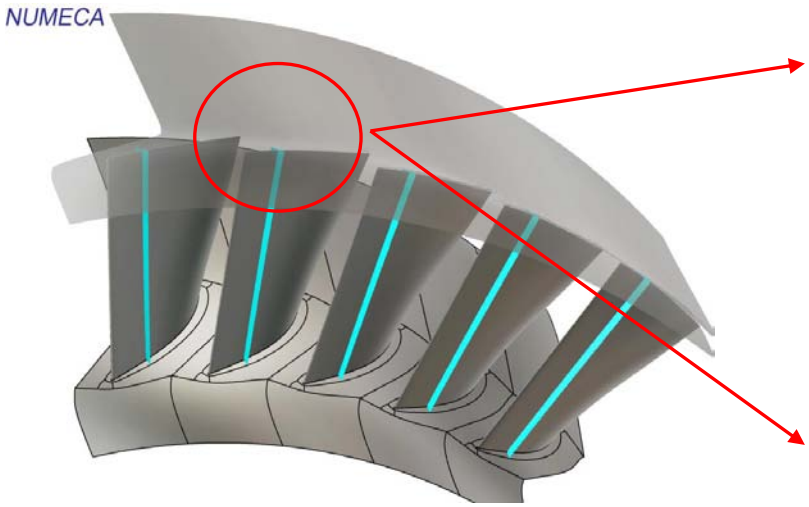


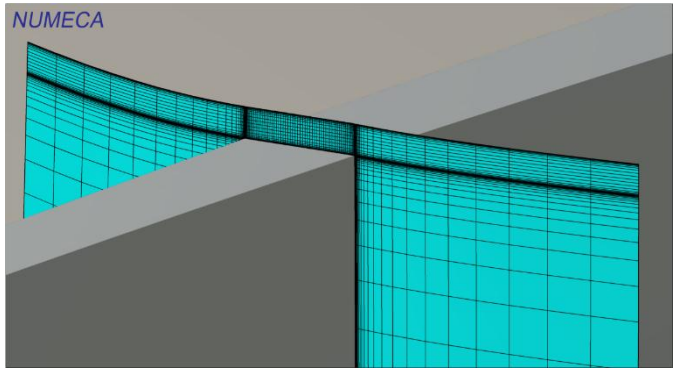
- 5 uncertainties: LE and TE variation identical for each s
- 9 uncertainties: LE an TE variation is different for 3 sections

First results from UMRIDA

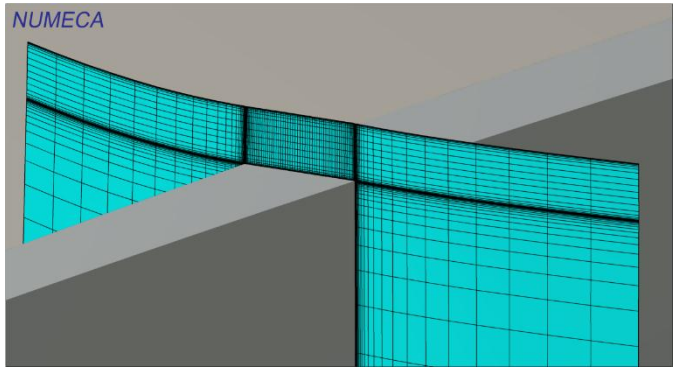
Automatic generation of meshes with varying tip gap

- Same mesh size for <u>automatically</u> generated geometries with **varying tip gap**





Smallest tip gap



Largest tip gap

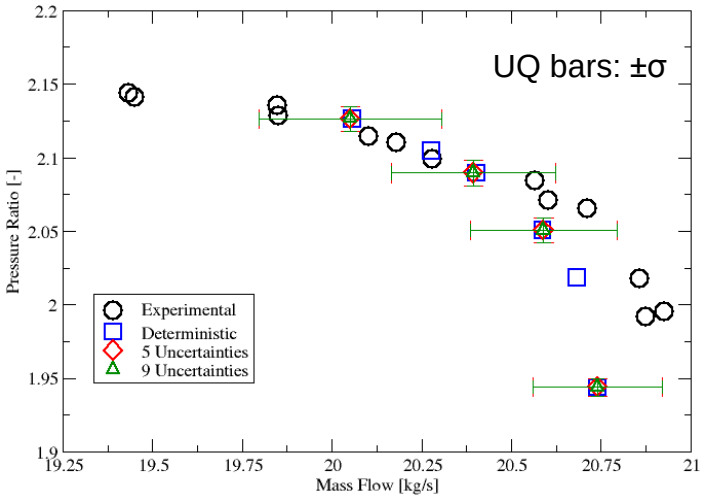
First results from UMRIDA

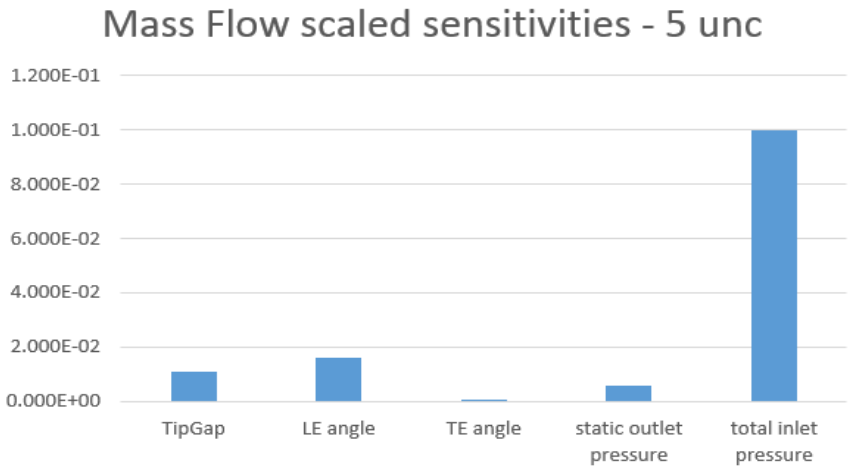
Scaled sensitivity derivatives

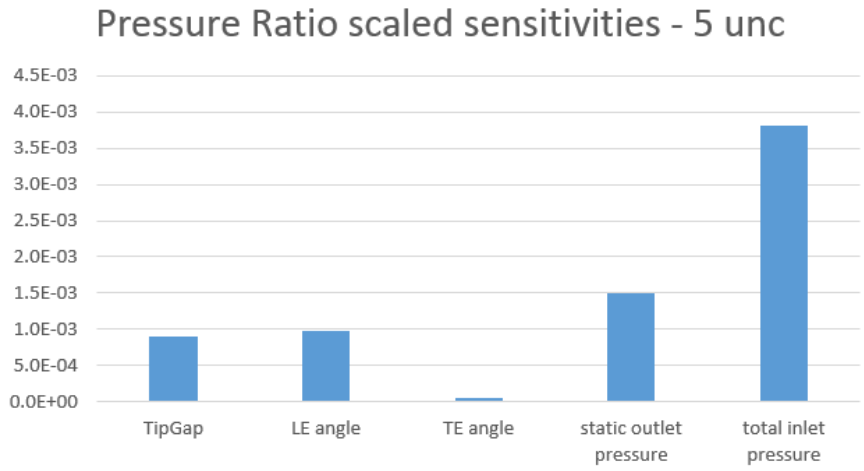
- Sensitivity derivatives allow to assess influence of a given uncertainty on the non-deterministic output systematically

$$S = \sigma_i \frac{\partial u}{\partial a_i}$$

- Total inlet pressure most dominant for pressure ratio and mass flow rate



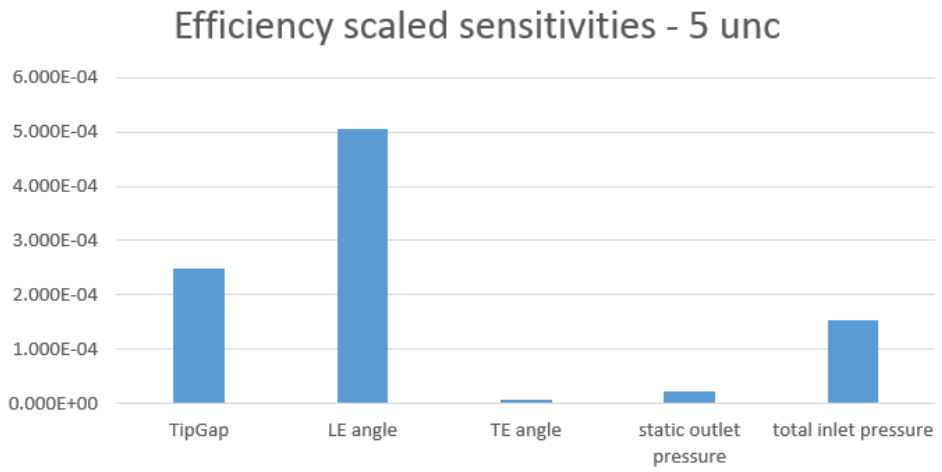


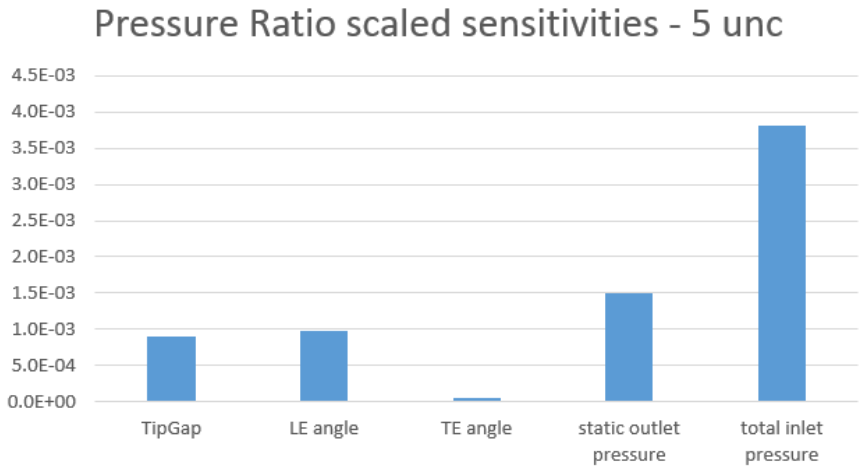


First results from UMRIDA

Scaled sensitivity derivatives

- Sensitivity derivatives allow to assess influence of a given uncertainty on the non-deterministic output systematically
- Most influential parameter for efficiency is the LE angle
- Dimension of scaled sensitivities is the as the quantity for which it is built





Acknowledgement

“The research leading to these results has gratefully received funding from the European Union’s Seventh Framework Programme (2007-2013) under grant agreement number 605036, UMRIDA project.”

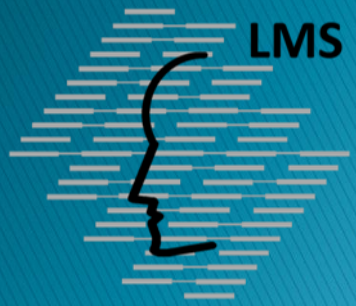
Immersive Semantics-based Virtual Environments for the Design and Validation of Human-centred Aircraft Cockpits

i-VISION Project

4th EASN Association International Workshop on Flight Physics & Aircraft Design

October 28th 2014 – Aachen, Germany

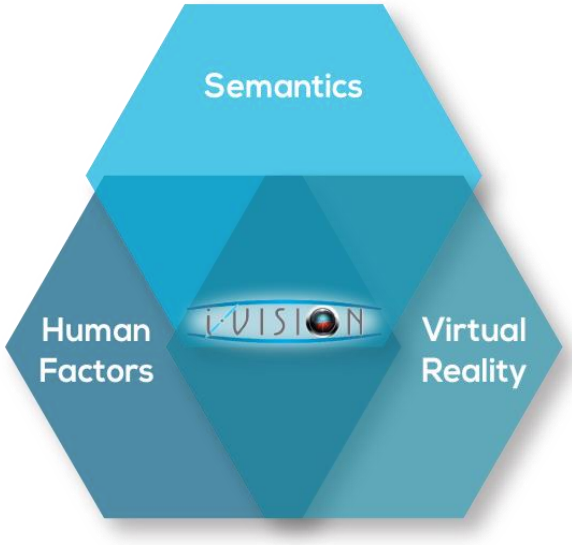
Dr. Loukas Rentzos, Dr. Dimitris Mavrikios, Prof. George Chryssolouris



Laboratory for Manufacturing Systems and Automation
Director: Prof. G. Chryssolouris
Department of Mechanical Engineering & Aeronautics
University of Patras, Greece
www.lms.mech.upatras.gr

Project

- **i-VISION** aims at supporting human factors design and validation activities in aircraft cockpits during the early phases of the product life-cycle through knowledge-based immersive virtual reality technologies.
- The objective is to increase the flexibility and reduce the cost of aircraft cockpit design and evaluation.
- It combines 3 distinct areas of research into a single advanced design and validation tool.



- Started: September 2013 - Ends: August 2016
- Budget: approx. 3 M Euros

Consortium

Project Co-ordinator:
Laboratory for Manufacturing Systems & Automation
University of Patras, Greece

Airbus Group Innovations, Germany

Airbus Group Innovations, France

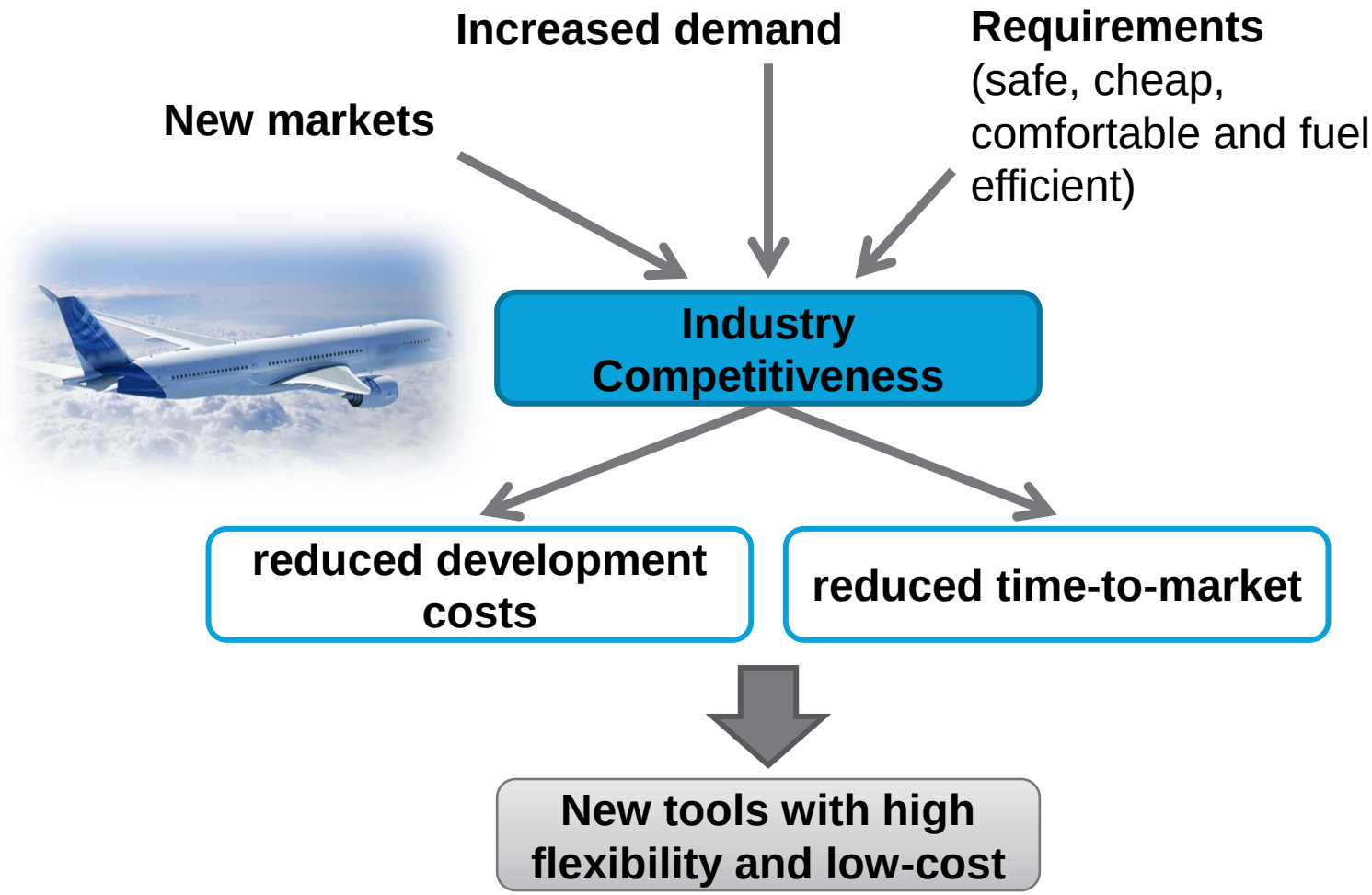
OPTIS S.A., France

Karlsruhe Institute of Technology, Germany

University of Southampton, UK

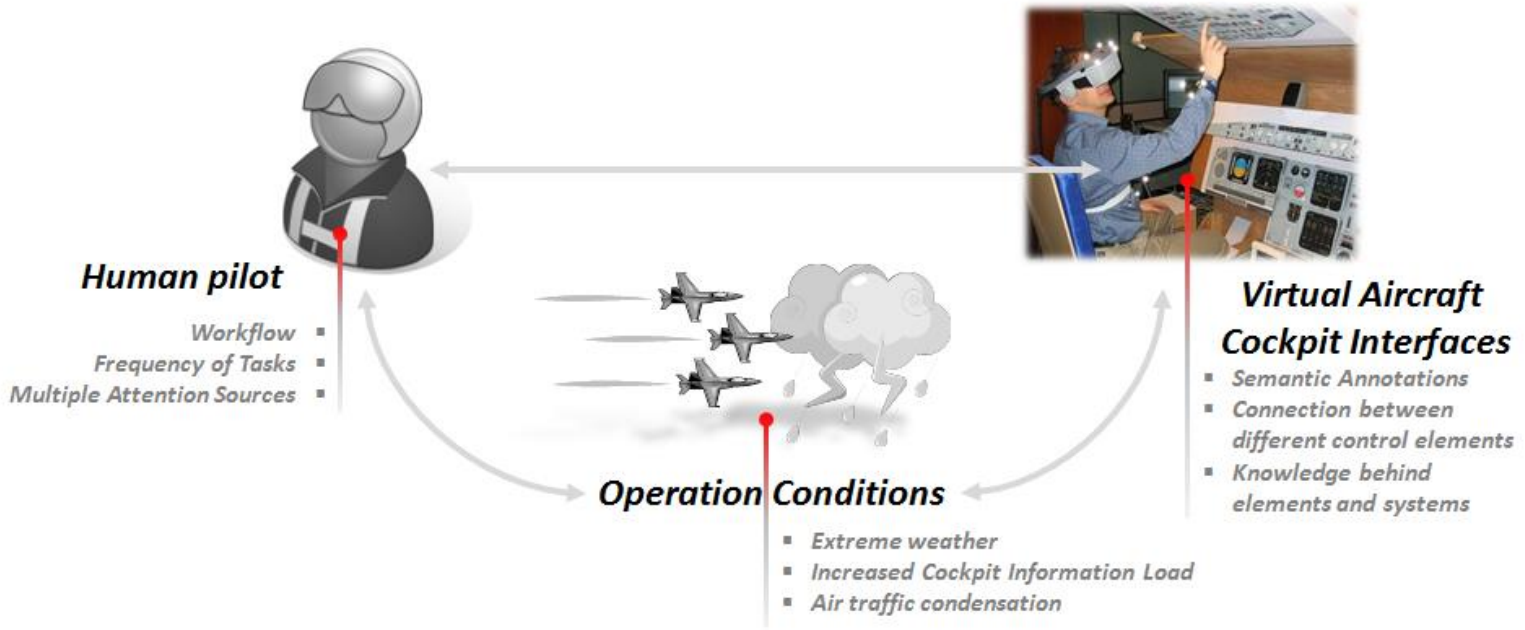
European Aeronautics Science Network, Belgium

Motivation


Increased demand
New markets
Requirements
(safe, cheap, comfortable and fuel efficient)
Industry Competitiveness
reduced development costs
reduced time-to-market
New tools with high flexibility and low-cost

Motivation

- Future operating conditions (weather, traffic, etc.) will be characterized by a significant increase of human operator workloads inside the cockpit.
- Need to seamlessly integrate a large number of low-level 3D geometries with domain-specific knowledge and tools so that human factors experts can effectively query, interpret, evaluate and manipulate the virtual cockpit in an immersive and interactive environment.



Objectives

- **Human-Cockpit Operations Analysis**

  Human factor methods for analysing human procedures

- **Semantic Virtual Cockpit**

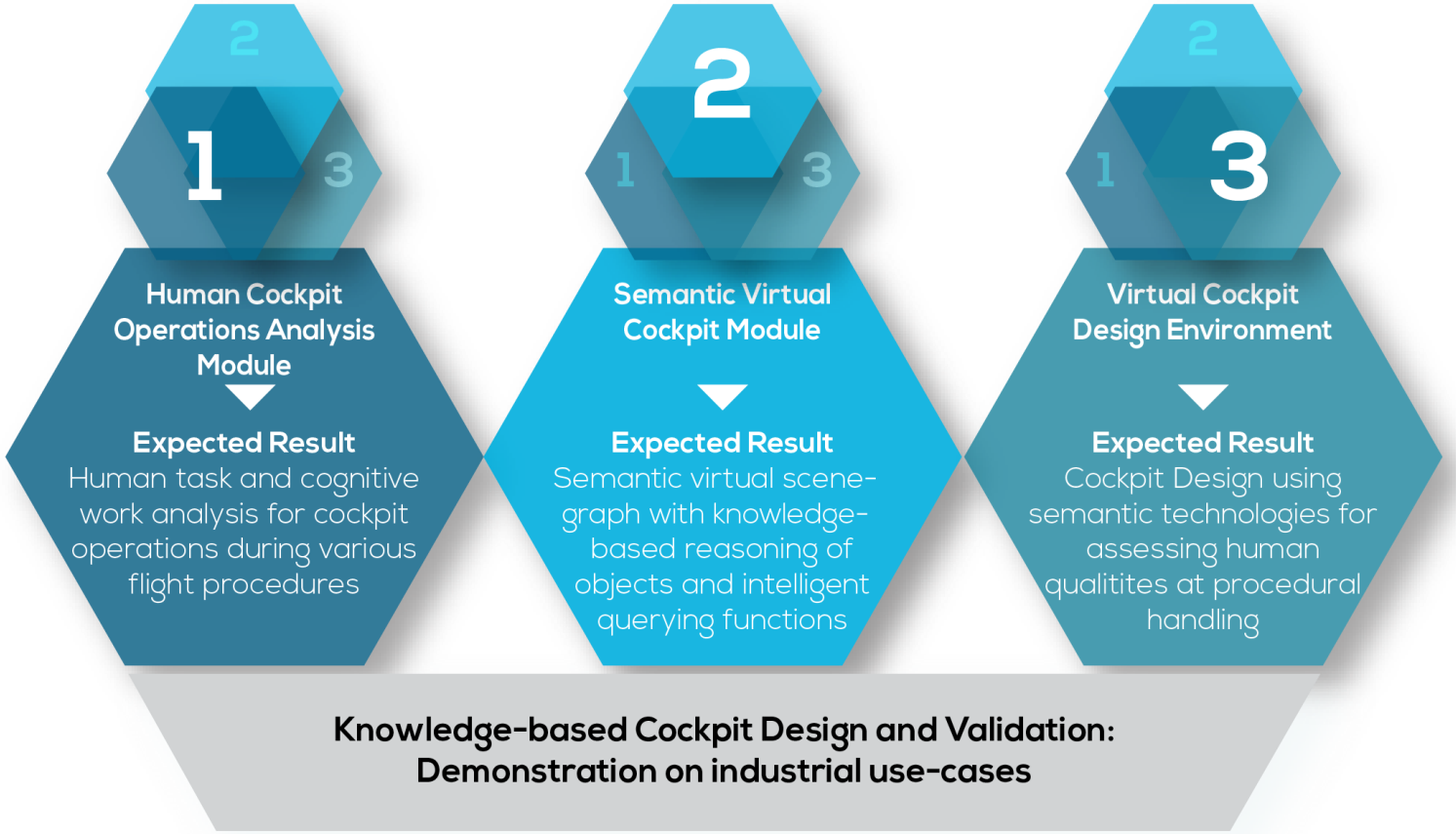
  Semantic technologies enrich geometric datasets with semantic annotations

- **Virtual Cockpit Design Environment**

  VR environment as reusable and low-cost simulation test-bed for experimenting configurations of virtual cockpits.

Technological Components

i-VISION will deliver three distinct technological components:



Technological Components

i-VISION will deliver three distinct technological components:

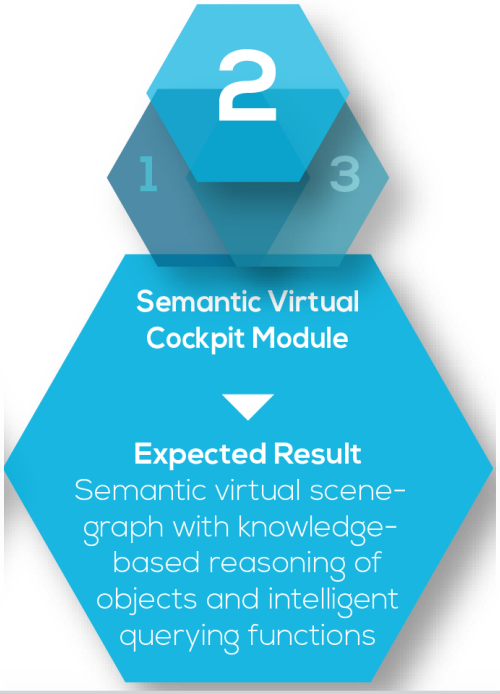
- **Advanced human factors methods**
- **Record and analyze**
- **Human procedures and tasks during various phases and operating conditions**

Knowledge-based Cockpit Design and Validation: Demonstration on industrial use-cases

Technological Components

i-VISION will deliver three distinct technological components:

- **Semantic Web technologies**
- **Enrich pure geometric datasets with semantic annotations.**
- **Knowledge about procedures and cockpit concepts**



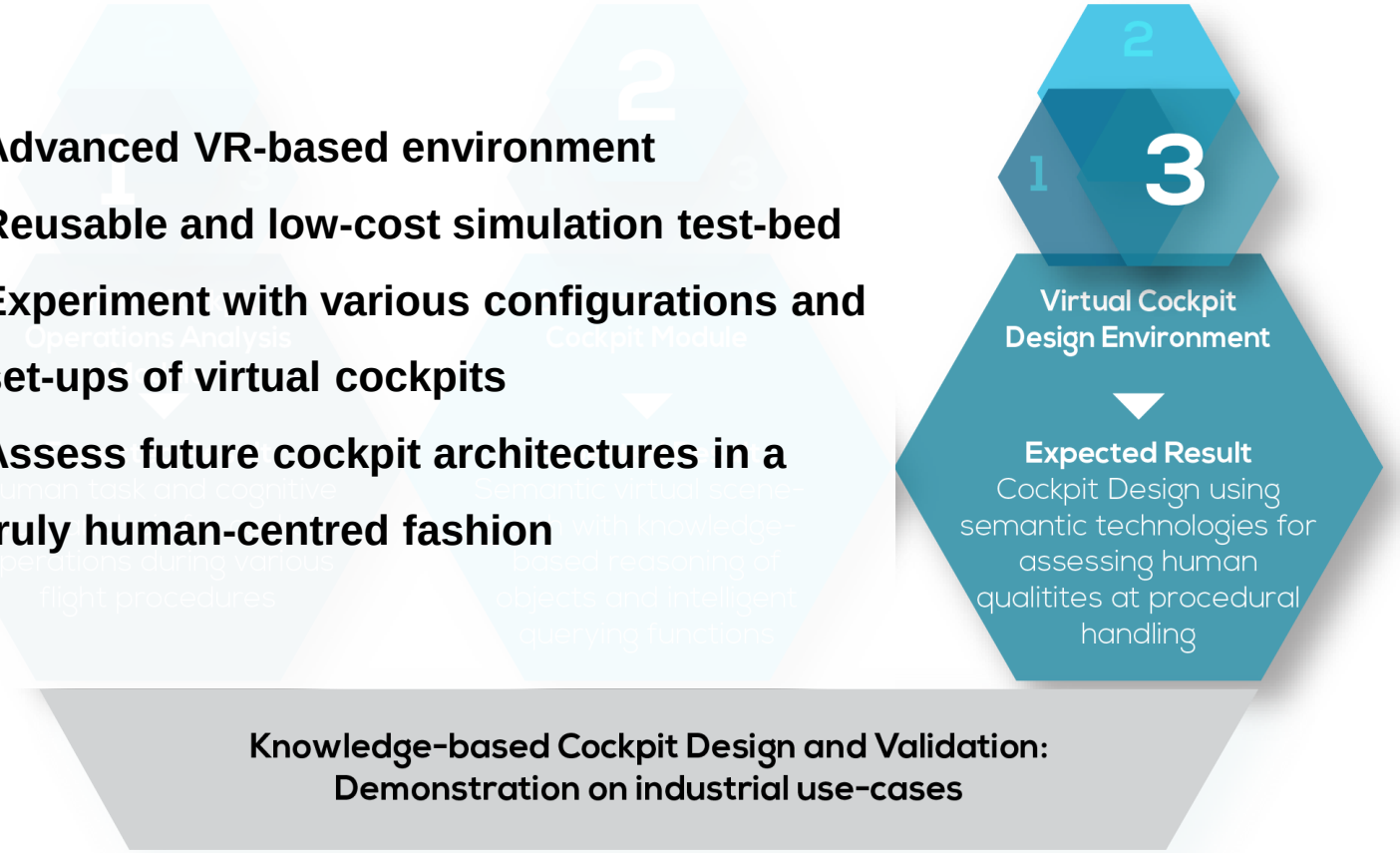
- **Engineers and human factors experts can assess, query, interpret and manipulate human task results**

Knowledge-based Cockpit Design and Validation: Demonstration on industrial use-cases

Technological Components

i-VISION will deliver three distinct technological components:

- **Advanced VR-based environment**
- **Reusable and low-cost simulation test-bed**
- **Experiment with various configurations and set-ups of virtual cockpits**
- **Assess future cockpit architectures in a truly human-centred fashion**



Workplan

September 2013 — August 2016

Requirements / Specifications

- Product and Human Factors requirements
- Early models and use-cases

Technology Development

- Human-Cockpit Operations Analysis Module
- Semantic Virtual Cockpit Module
- Virtual Cockpit Design Module

Integration / Validation

- Industrial Pilot Cases
- Validation

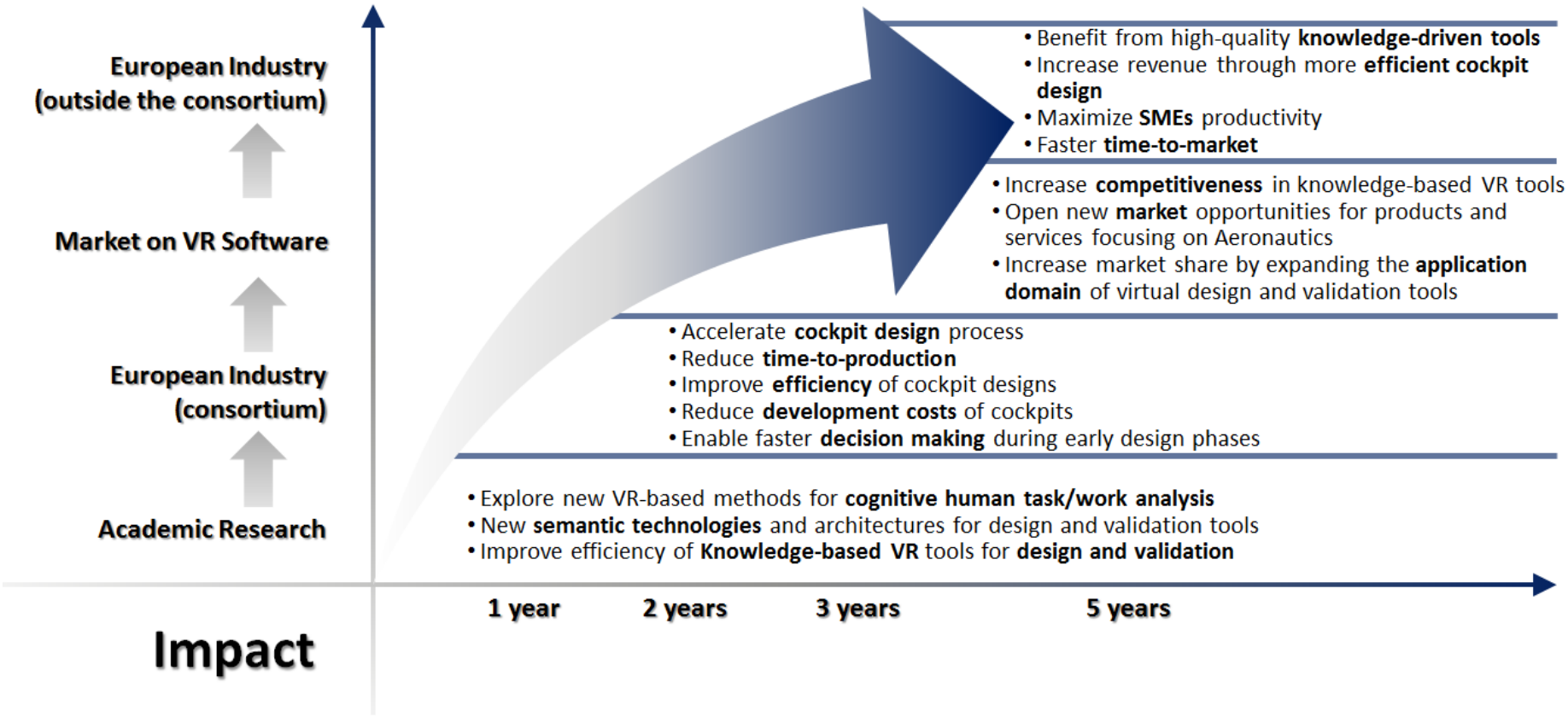
Exploitation & Dissemination

Management

Impact

- **The knowledge-based technologies:**
  - Accelerate the design process through the systematic reuse of knowledge
  - Allow for faster and more flexible prototyping of aircraft cockpits.
- **The analysis of human operations:**
  - Result in highly competitive cockpits from the end-user's perspective and
  - Increase the utilization of future aircrafts by allowing human pilots to operate in extreme weather and traffic conditions.

Impact


European Industry (outside the consortium)
Market on VR Software
European Industry (consortium)
Academic Research
Impact
• Benefit from high-quality knowledge-driven tools
• Increase revenue through more efficient cockpit design
• Maximize SMEs productivity
• Faster time-to-market
• Increase competitiveness in knowledge-based VR tools
• Open new market opportunities for products and services focusing on Aeronautics
• Increase market share by expanding the application domain of virtual design and validation tools
• Accelerate cockpit design process
• Reduce time-to-production
• Improve efficiency of cockpit designs
• Reduce development costs of cockpits
• Enable faster decision making during early design phases
• Explore new VR-based methods for cognitive human task/work analysis
• New semantic technologies and architectures for design and validation tools
• Improve efficiency of Knowledge-based VR tools for design and validation
1 year
2 years
3 years
5 years

Thank you for you attention!

Laboratory for Manufacturing Systems and Automation
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http://www.lms.mech.upatras.gr/

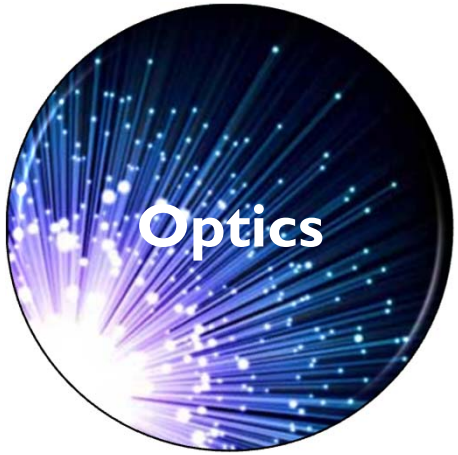
For more information:
http://www.ivision-project.eu/

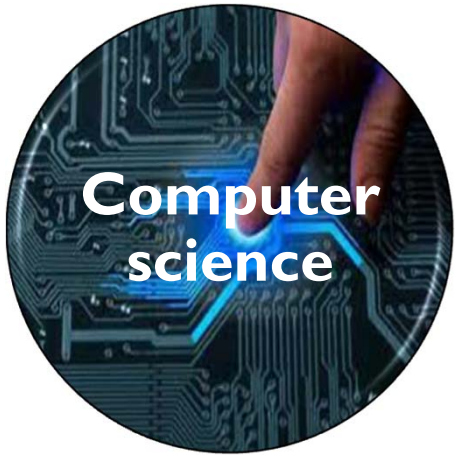
OPTIS HIM on i-Vision

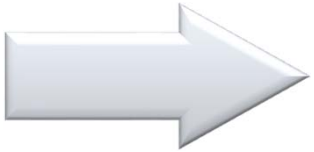
28.10.2014

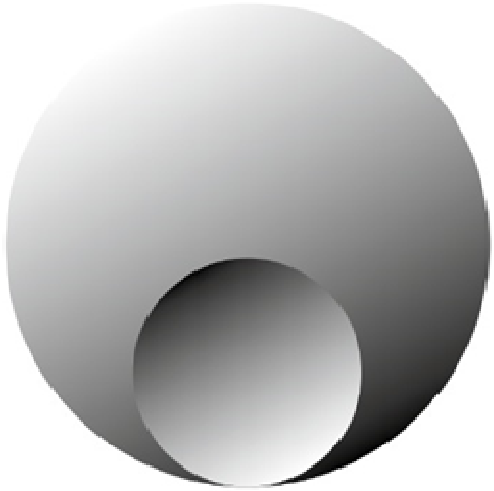
Ralph Habig – Business Development Manager OPTIS GmbH

The OPTIS experience









OPTIS

Simulation and visualization software vendor

Worldwide leader

Custom services

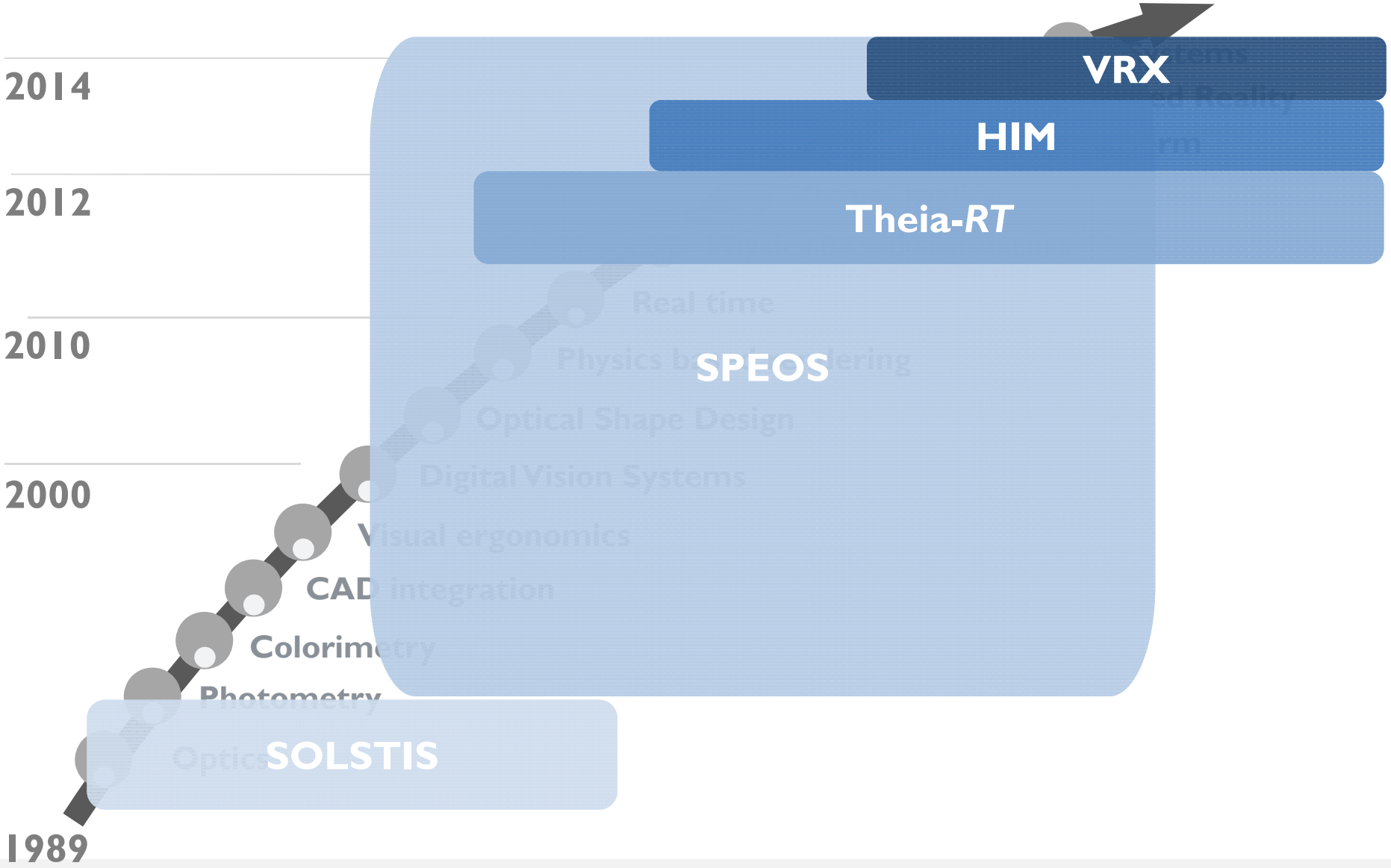
Prestigious partners

Worldwide direct presence

Continuous growth

Highly skilled collaborators

25 years of innovation



25 years of growth and expansion

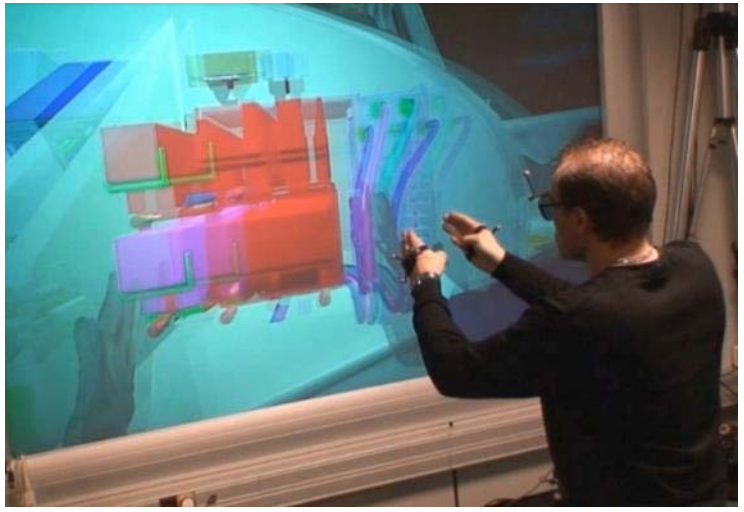
HIM
HUMAN CENTRIC DESIGN

OPTIS

Virtual Reality platform allowing everyone (Engineer, Technician, Commercial…) to be easily immerse in digital products in order to interact with them

- Stereoscopic vision (3D visualization)
- Scale 1:1
- Motion capture

Perform human experimentation on virtual products

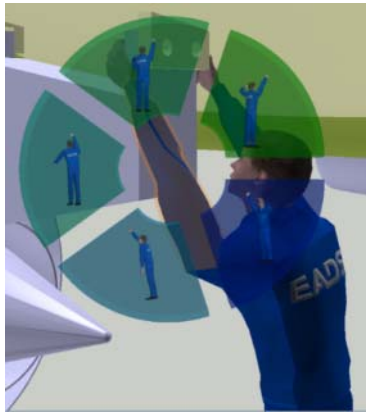


HIM
HUMAN CENTRIC DESIGN

OPTIS

Some features

- Create full body manikin in HIM or import them from CATIA
- Define different postures for a manikin
- HIM manikins are 95 percentile
- Constrain several body parts for handling
- Full motion capture to control a manikin
- Record play manikin animations

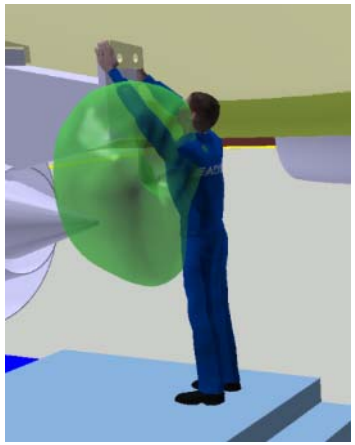
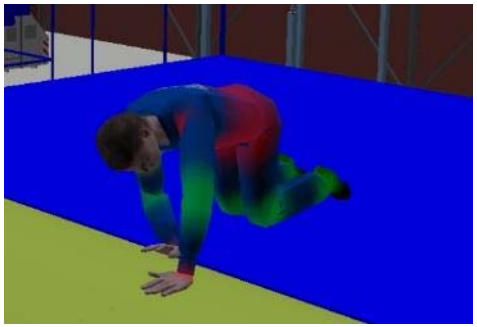
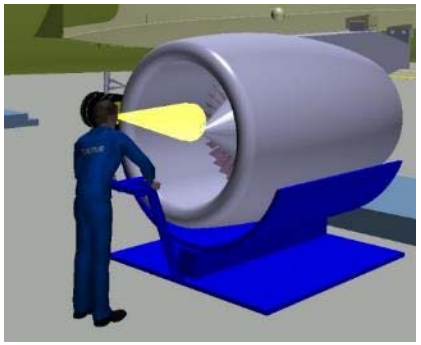


HIM
HUMAN CENTRIC DESIGN

OPTIS

Some features

- Reachability / Comfort envelopes
  (based on NFEN-1005-4 and NFEN-1005-5 and ISO11226:2000)
- Effort indicators (based on OWAS standards)
- Field of view analysis (scientific study)
- Equilibrium measurement (mechanical analysis)
- Back Indicator

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Use Case Assembly / Disassembly Radar

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HUMAN CENTRIC DESIGN

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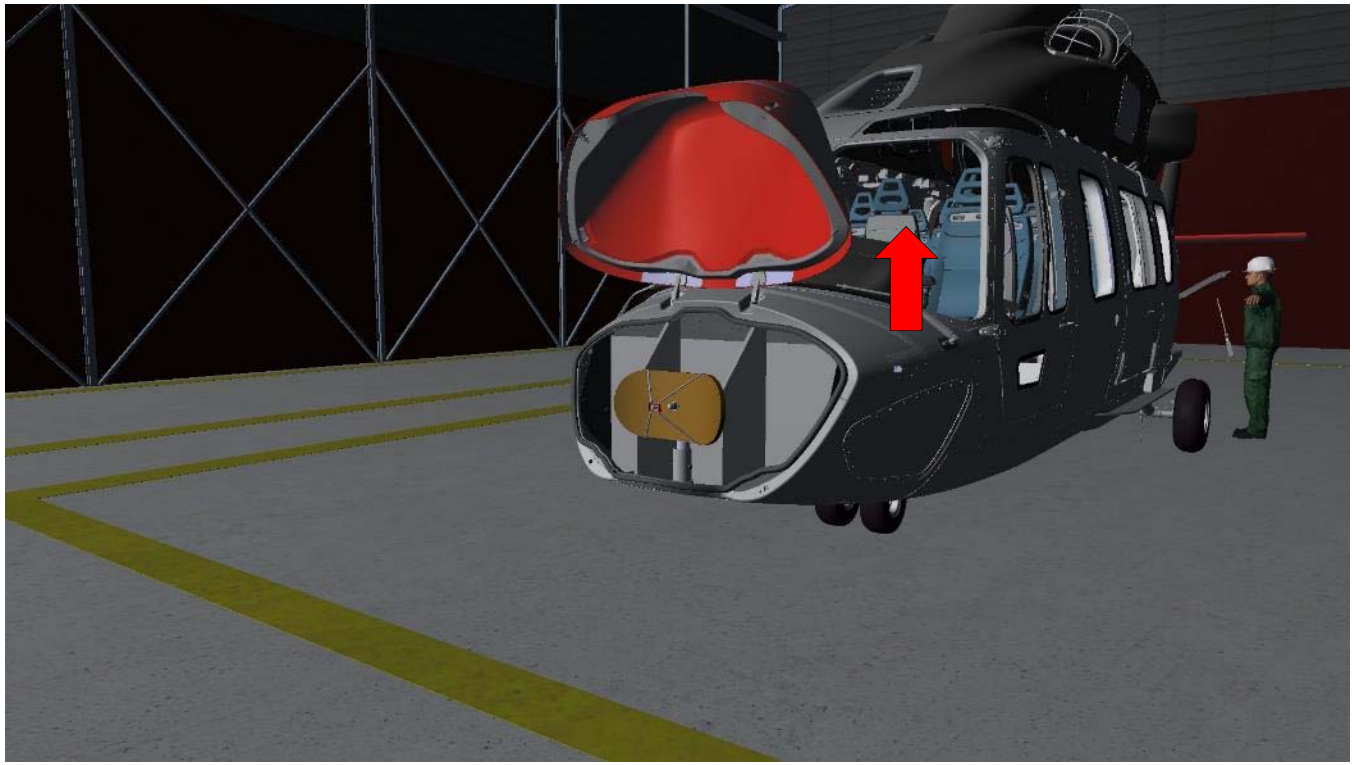
Use Case Assembly / Disassembly Radar

- Lift up (there is a kinematics) or hide the nose in order to access the radar



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Use Case Assembly / Disassembly Radar

- Take the old radar

HIM
HUMAN CENTRIC DESIGN

OPTIS

Use Case Assembly / Disassembly Radar

- And remove it

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HUMAN CENTRIC DESIGN

OPTIS

Use Case Assembly / Disassembly Radar

- Put it on the trolley and grab new assembly

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HUMAN CENTRIC DESIGN

OPTIS

Use Case Assembly / Disassembly Radar

- Install new radar assembly

HIM
HUMAN CENTRIC DESIGN

OPTIS

Use Case Assembly / Disassembly Radar

- Close Helicopter nose

HIM
HUMAN CENTRIC DESIGN

OPTIS

Use Case Special Operations

HIM
HUMAN CENTRIC DESIGN

OPTIS

Use Case Field-of-View Analysis Cockpit

The

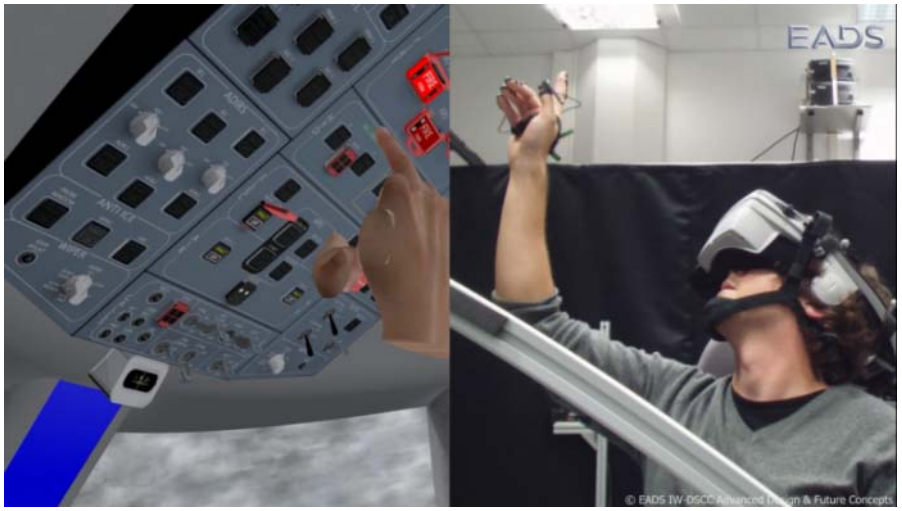
Project

The Future of Human-centric Cockpit Design

- Funded by the EU under the FP7
- Human-Cockpit Operations Analysis
- methods for analyzing procedures in a VR-based aircraft cockpit
- Pilot's workflow analysis
- Define Semantic Virtual Cockpit
- Virtual Cockpit Design Environment
- Accelerate the design process
- reusable and low-cost simulation test-bed for experimenting virtual cockpits
- Platform for partners collaborative work
- Assess a virtual aircraft cockpit in time and cost-effective way

Interacting with the virtual cockpit mockup

- Various interaction devices
  - Finger-tracking (ART, CyberGloves, …)
  - Wireless controllers (FlyStick, Wiimote, …)
  - Ergoneers eye-tracking
- Physics engine
  - Collisions between objects
  - Realistic behaviour
- Animate cockpit elements
  - Kinematics
  - Key frames mechanism
  - SDK for external control
  - Scripting



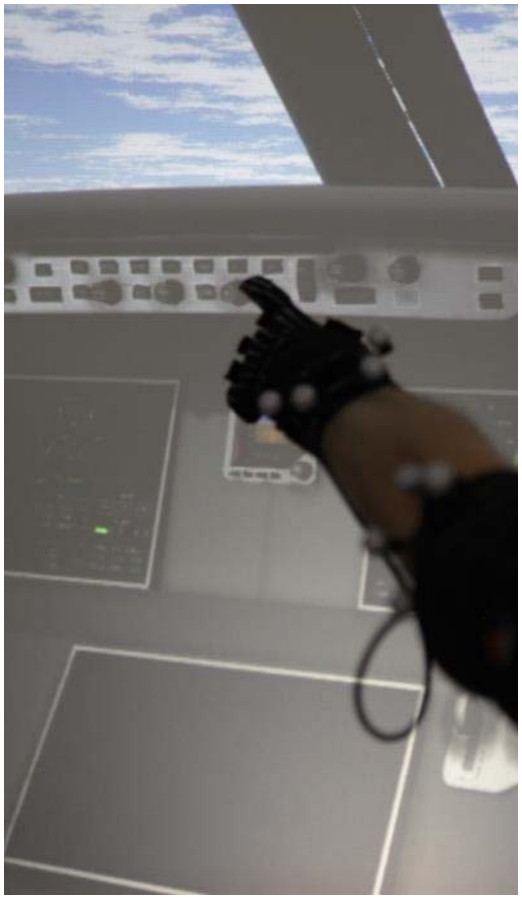
Flight deck experiments with HIM

- Fully tracked pilot and co-pilot (collaborative simulation)
- Network interaction with the i-VISION flight simulator
  - Virtual touch screens as main instrumentation panel
  - Head-Up Displays
  - Cockpit elements' state
  - Aircraft attitude
  - External environment (scenery and weather)

- 3D sound system for more realistic system responses and flight deck workflows

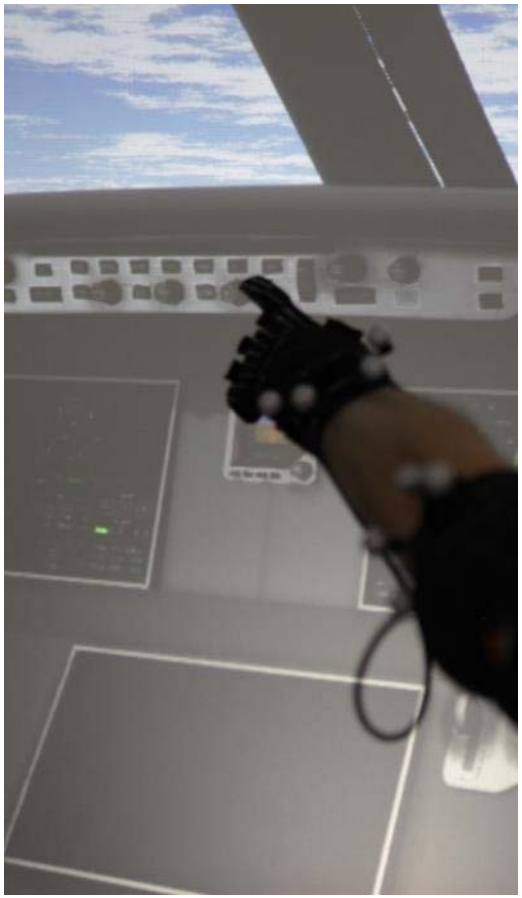
Cockpit validation contribution of HIM

- Highlighting the direct **field-of-views** of the cockpit crew or manikin
- Highlighting the cockpit items in easy/medium/no **reach** for each manikin
- Providing a **semantic-based** visualization of cockpit elements and flight procedures workflow
- Using computer-animated manikins for cockpit crew training



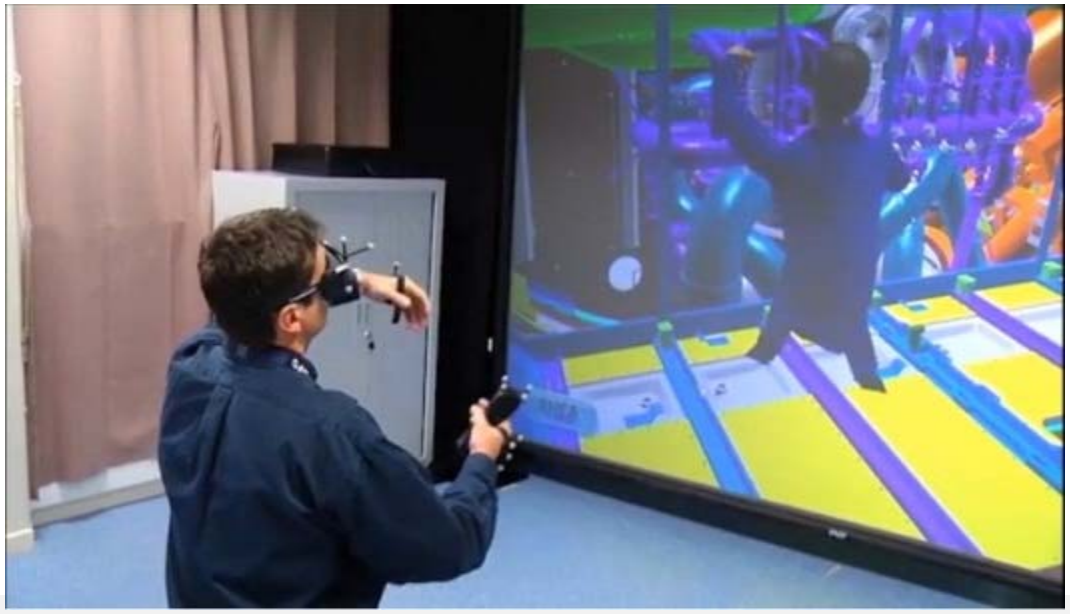
Next steps

- Integrate **eye-tracking and finger-tracking** enabling pilot action detection
- Plan scenarios for i.e. starting and/or emergency procedures
- Integrate Haption haptic devices (object's position detection by user manipulation)



Virtual Training Environment for MRO (VTE4MRO)

- Kick-Off October 2nd , 2014
- To be funded by EU funding
- AR – VR Integration for AMC
- analyzing human procedures / tasks in a VR-based aircraft environment
- Interactive manual workflow analysis
- Accelerate design process
- Get certified by EASA Part-66 & Part-147
- To be used for future education of techicans, engineers, maintenance worker



Thanks for your attention

Questions ?
Comments ?
Remarks ?
Suggestions ?

Max-Planck-Institut
für biologische Kybernetik

myCopter – Enabling Technologies for Personal Aerial Transportation Systems

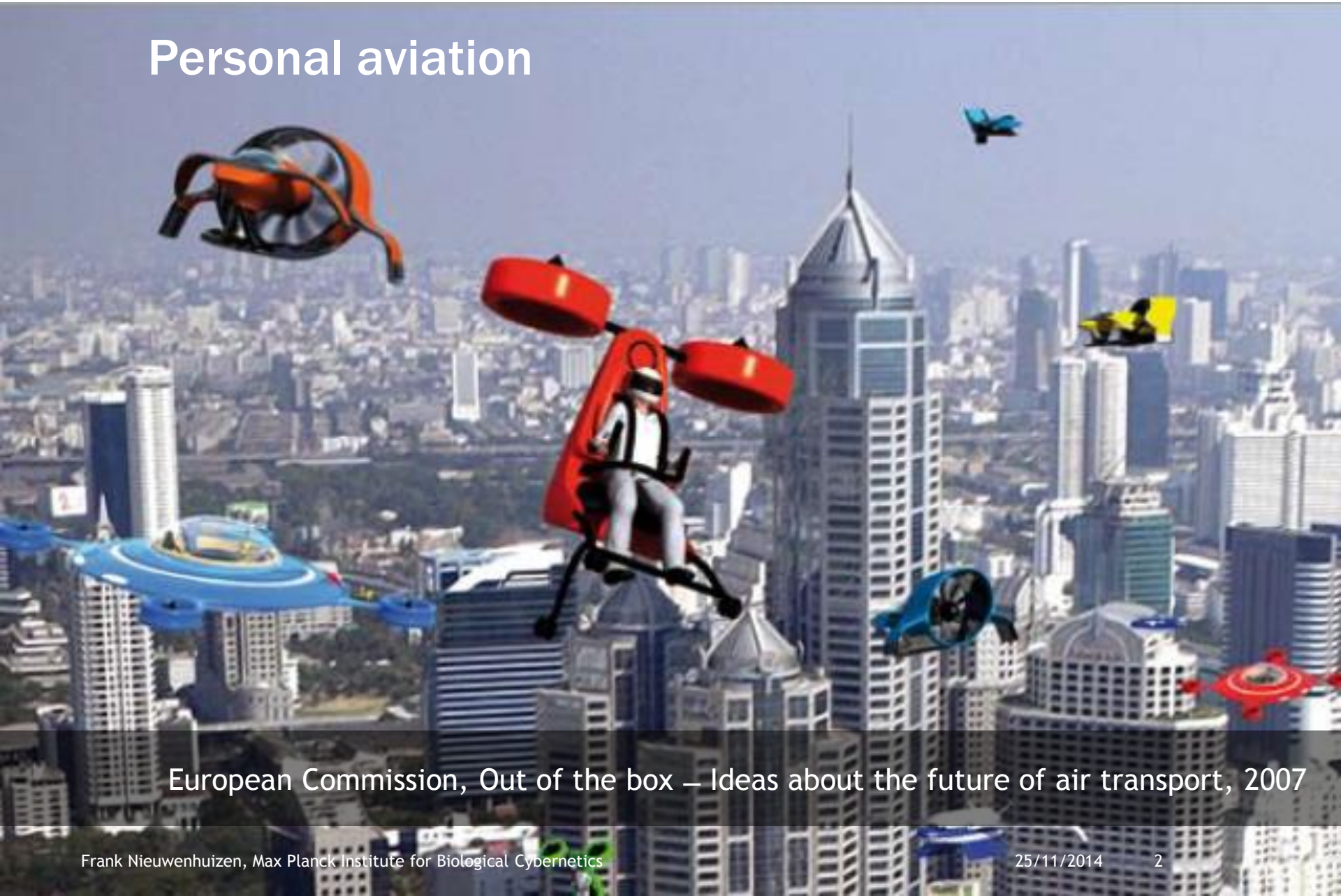
Frank Nieuwenhuizen & Heinrich Bülthoff

mycopter

http://www.mycopter.eu

This project has received funding from the
European Union's Seventh Framework Programme
for research, technological development and demonstration
under grant agreement no 266470

Personal aviation



European Commission, Out of the box – Ideas about the future of air transport, 2007

Motivation for personal aviation

100 Billion Euro is lost yearly in the EU due to congestion

"Green Paper – Towards a new culture of urban mobility," Sept. 2007, Commission of the European Countries, Brussels.

Motivation for personal aviation

20x more fuel is wasted in the USA in traffic jams than is used by the entire General Aviation fleet

"2009 Urban Mobility Report," The Texas A&M University System, 2009

Motivation for personal aviation

In large European cities, car drivers spend **more than 50 hours per year** in traffic jams

"Roadmap to a Single European Transport Area," 2011

Pioneering the air transport of the future

"Designing the air vehicle is only a relative small part of overcoming the challenges… The other challenges remain…" [EC, 2007]

It is necessary to explore

- "innovative technologies that might facilitate the step change required for air transport" [FP7]
- "technologies … which will enable future individual air transportation" [FP7]

"Personal air transport … has been regarded as a possible solution to the ever increasing congestion in road traffic, providing at the same time greater speed and flexibility" [FP7]

European Commission, Out of the box – Ideas about the future of air transport, 2007
FP7 Transport call for research, November 2007

EU-project **myCopter**

- Duration: Jan 2011 – Dec 2014
- Project cost: €4,287,529
- Project funding: € 3,424,534

Max-Planck-Institut
für biologische Kybernetik

UNIVERSITY OF LIVERPOOL

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

KIT Karlsruhe Institute of Technology

DLR

Personal Aerial Vehicles

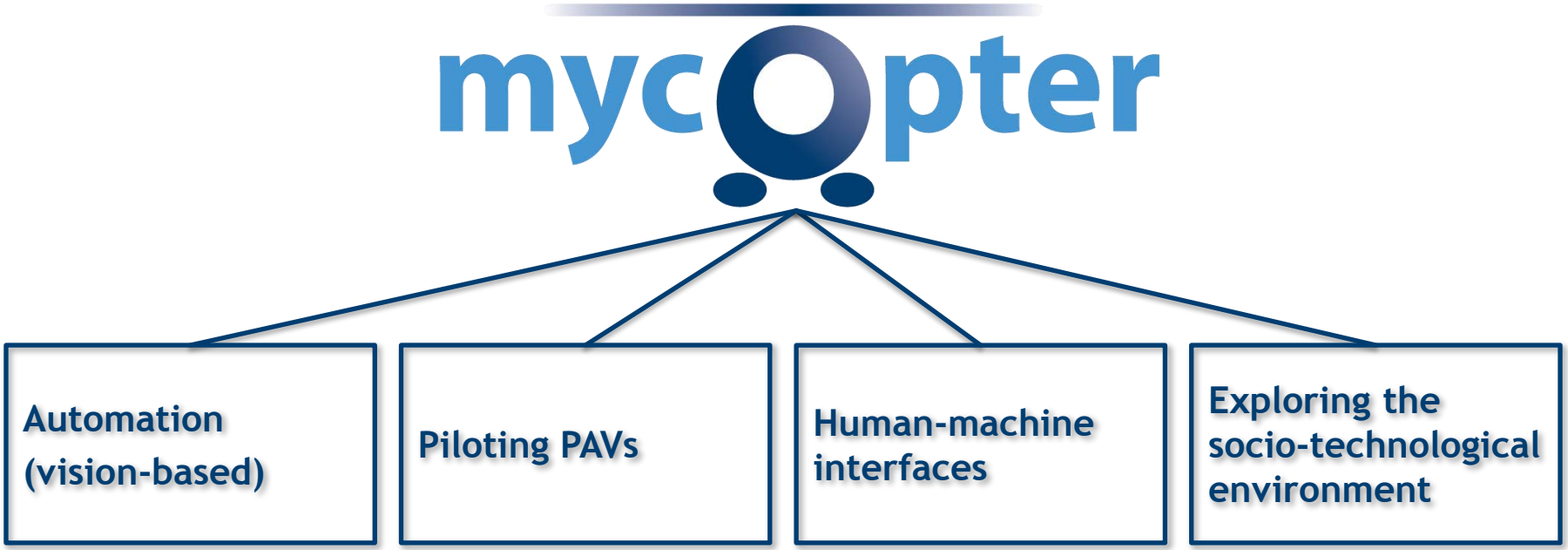
Technology exists to build aircraft for individual transport

- many concepts have already been developed

Drawbacks of current designs

- needs a pilot license
- needs infrastructure (landing strip)
- focus on vehicle design instead of transport system

Enabling technologies for personal aviation



- Navigation
- Landing place assessment
- Collision avoidance

- Handling Qualities for PAVs
- Training requirements

- Control interfaces and displays
- Multi-sensory feedback

- Acceptance: safety, noise, fuel, cars overhead
- Integration into current transport systems

Novel approaches to automation

Develop robust novel algorithms for vision-based control and navigation

Challenges

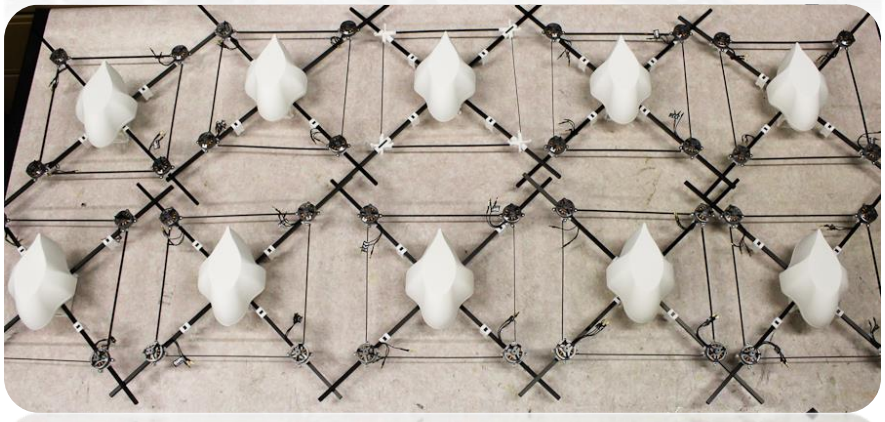
- Current techniques are limited and unreliable
- Real-time performance
- Emulate VFR pilots
  - Obstacles / other traffic
  - Surfaces to land on
  - Season and weather conditions

Collision avoidance strategies

Take inspiration from crowd behaviour

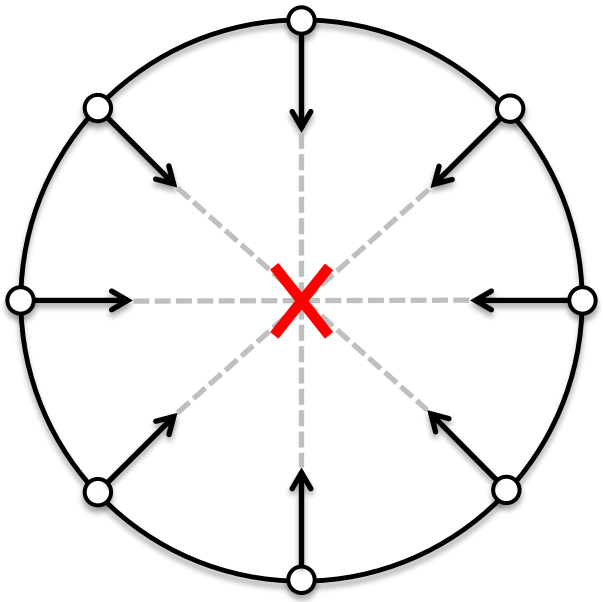
- Distributed, collaborative, reactive, individual goals
- Testing with swarm of UAVs

Guy et al., Eurographics Symposium on Computer animation, 2010



Collision avoidance strategies

50 vehicles at the same altitude fly from a point on a circle to a point on the opposite side



Human-machine interfaces

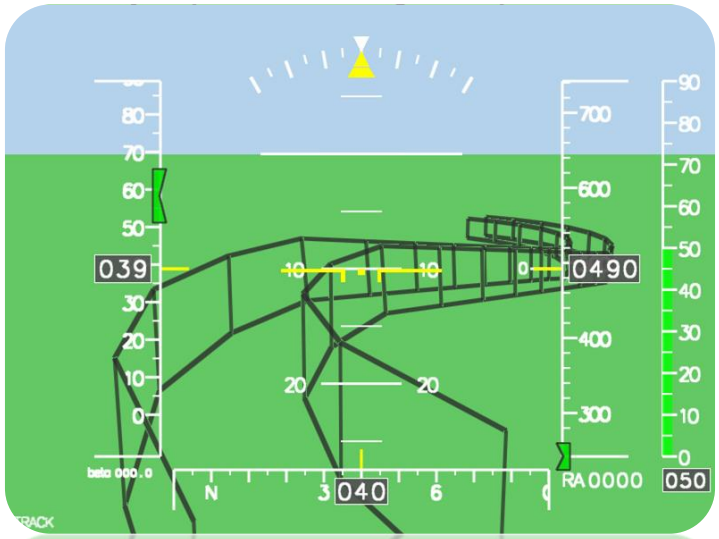
Develop human-machine interfaces that make flying as easy as driving a car

Challenges

- Current flight controls and displays are not intuitive
- Multisensory perception is not taken into account
- No reliable objective measurements of pilot workload

Intuitive displays and controls

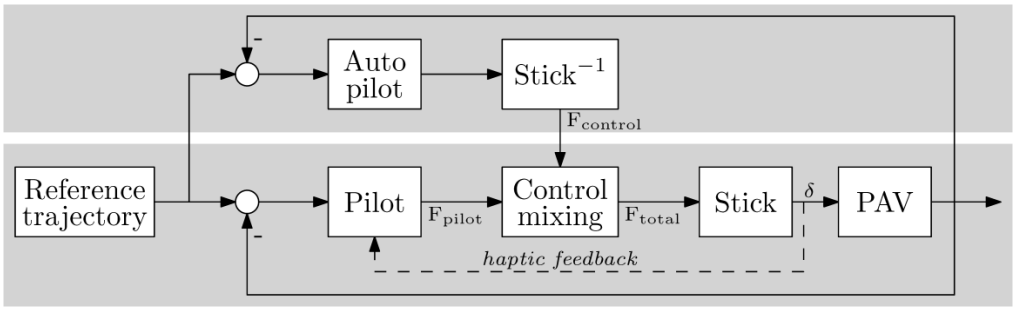
- Highway-in-the-Sky display
- Active sidestick to feel the highway (guidance forces)

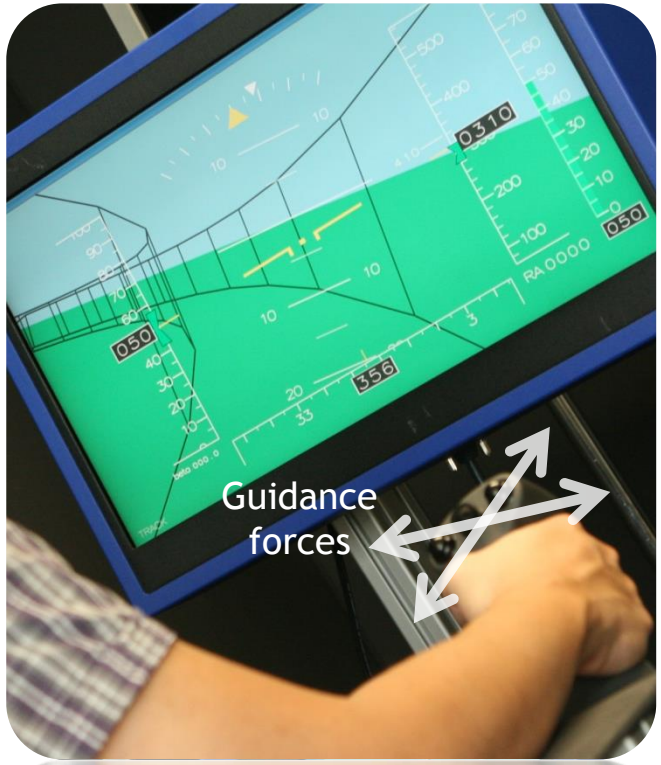


Multi-sensory human-machine interfaces

Novel HMI: haptic shared control

- Combining the advantages of manual and automatic control
- The pilot remains in control and can overrule the automatic control system

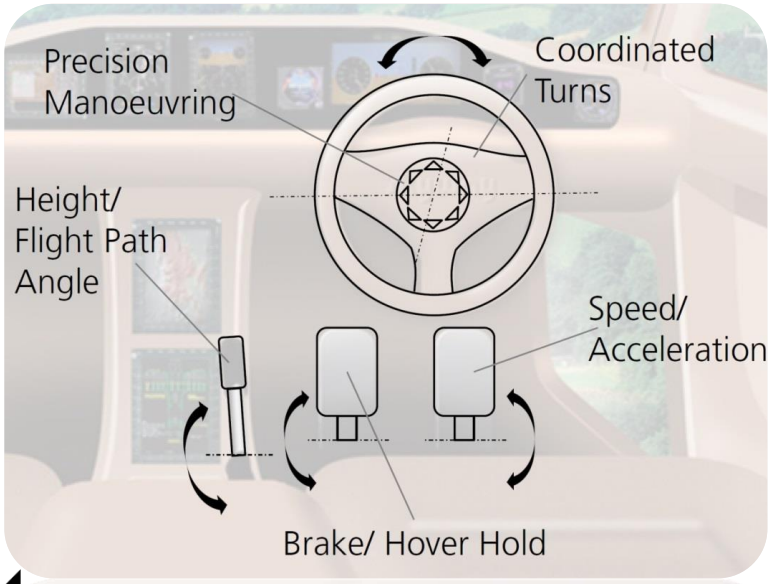




Make flying as easy as driving

Novel inceptors for safe and efficient operation of PAVs

- Exchange helicopter flight controls with a steering wheel and pedals



Exploring the socio-technological environment

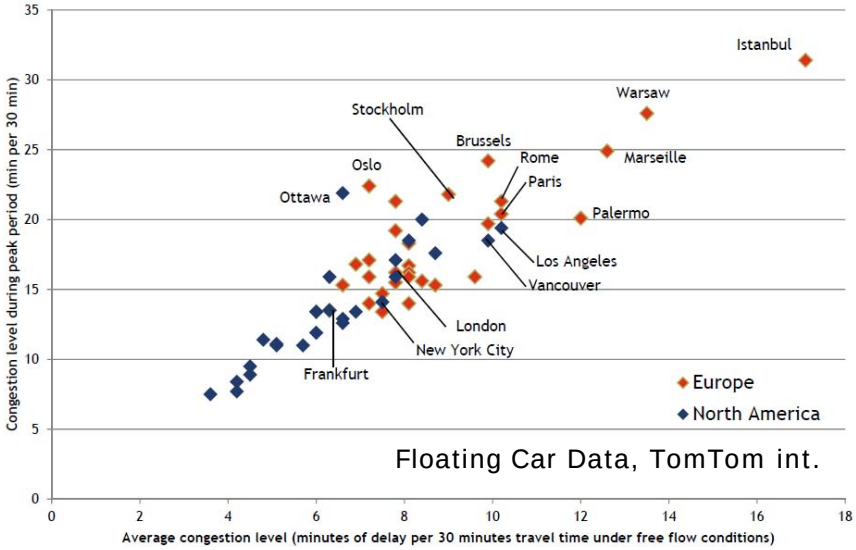
Generate knowledge on the demands and preferences of society towards PAVs

Challenges

- Identifying hurdles for introducing PAVs
- User expectations and objections
- Investigating where PAVs could have an impact

Which challenges are we addressing?

- 90% of commuting trips to work is shorter than 25 km and do not take longer than 30 minutes
- Peak hour delays in most European cities are generally about 15 to 20 minutes
- Weather may limit availability and reliability
- Key factors for transportation choice are availability, cost, reliability and door-to-door travel times



How do people see personal air transport?

Focus group interviews in 3 European countries to determine user perceptions and expectations

1. Discussion on mobility patterns and behaviour as well as perceived promises and actual expectations on PAV / PATS
2. Demonstration of a PAV ride in a simulator
3. Discussion on PAV-specific aspects such as design, operational environment, autonomy, usability, etc.

User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
- Leisure use
- Emergency situations

Other
- Use for tourism
- Forest monitoring
- Medical evacuation

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User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…thousands of these buzzing around and have their emissions, are noisy, produce shade…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
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User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…only on certain routes, so on highways or above railway lines…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
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- Privacy

Level of autonomy
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User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…you'd have to start building cities thinking about this…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
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- Emergency situations

Other
- Use for tourism
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- Medical evacuation

User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…I'd prefer fully automatic… because I wouldn't trust anyone else…I trust the technology…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
- Leisure use
- Emergency situations

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- Use for tourism
- Forest monitoring
- Medical evacuation

User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…if it's all automatic
and…
an accidents happens…,
whose fault is it…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
- Leisure use
- Emergency situations

Other
- Use for tourism
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- Medical evacuation

User Perceptions and Expectations

Safety
- On board
- On the ground

Environmental issues
- Noise
- Visual pollution

Ownership
- Own vs. share

"…a shared one is going to have less cost than having your own…"

Infrastructure
- Landing
- Maintenance

Legal issues
- Accidents
- Communication
- Privacy

Level of autonomy
- Fully autonomous vs. manual operation
- Leisure use
- Emergency situations

Other
- Use for tourism
- Forest monitoring
- Medical evacuation

Demonstrating enabling technologies for personal aviation

myCopter Project Day
20 November 2014, Braunschweig

Demonstrating enabling technologies

- New concepts for control of PAVs
- Novel human-machine interfaces
- Camera-based PAV automation and landing place assessment
- Collision avoidance strategies
- Uses and risks of PAVs on society

myCopter Project Day

WHEN: 20 November 2014

WHERE: German Aerospace Center (DLR)
Braunschweig, Germany

mycopter

Register on www.mycopter.eu

Max-Planck-Institut für biologische Kybernetik
UNIVERSITY OF LIVERPOOL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
KIT Karlsruhe Institute of Technology
DLR

ETH zürich

Vision Based Control And Navigation For Personal Aerial Vehicles (in GPS restricted Environments)

Markus Achtelik, Simon Lynen, Stephan Weiss, Margarita Chli, Roland Siegwart

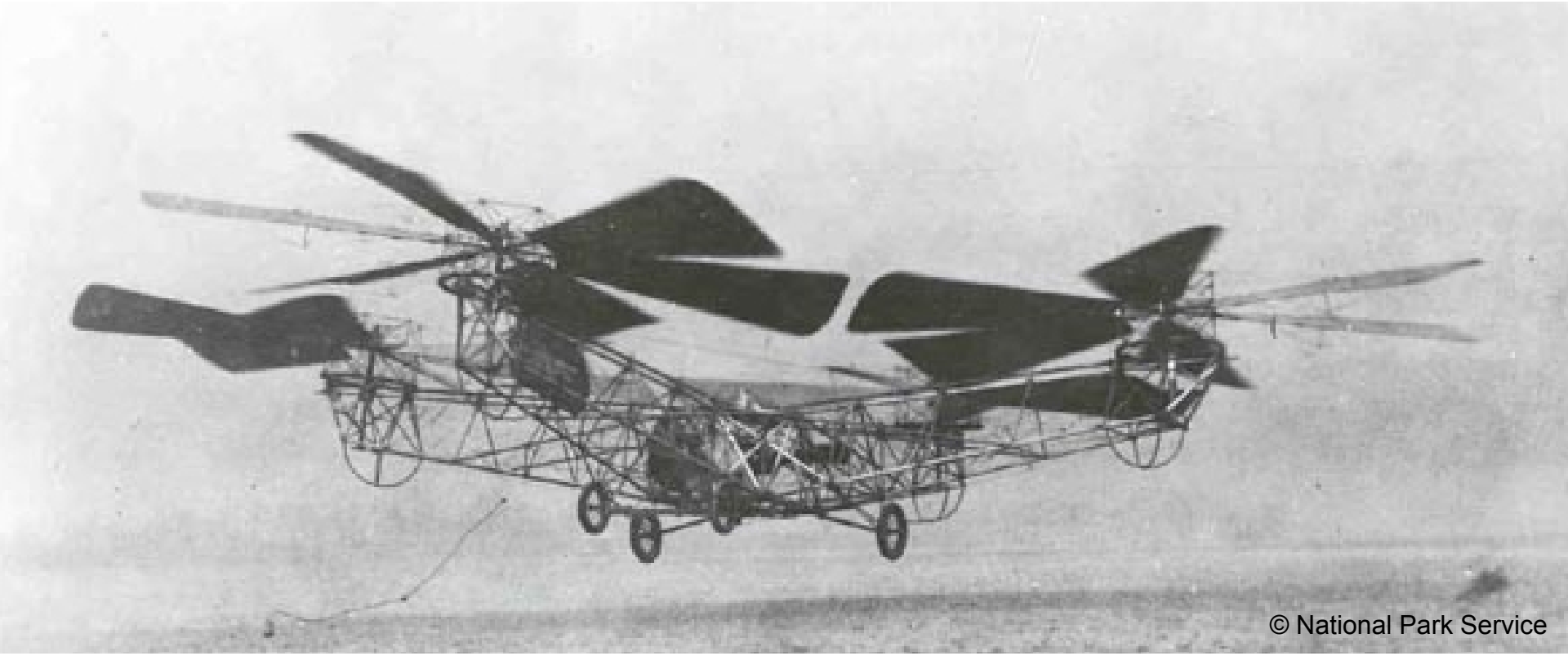
Micro Aerial Vehicles (MAVs) and PAVs

- Multi-rotor helicopters
- All rotors aligned in a plane
- Rotor axes perpendicular to that plane
- Take off weight ≈ 1.5 kg

Illustration: Gareth Padfield

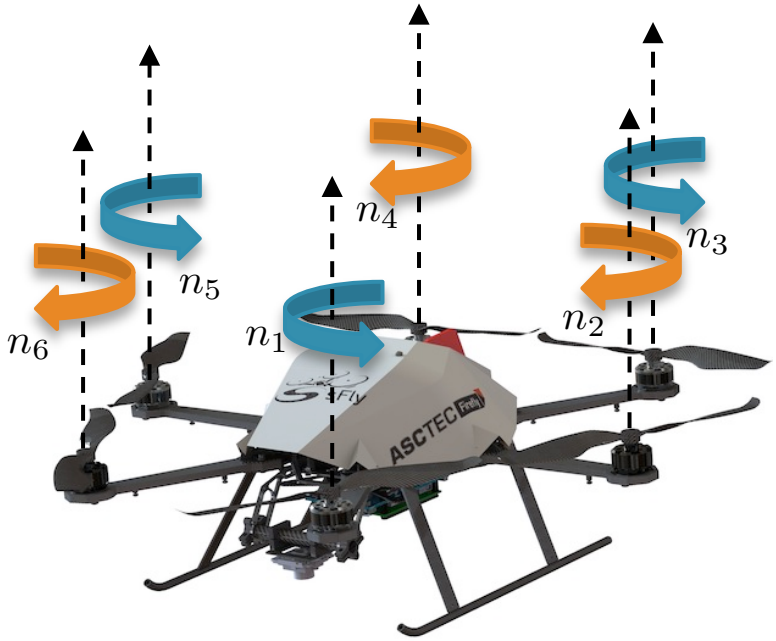
Image: e-volo GmbH

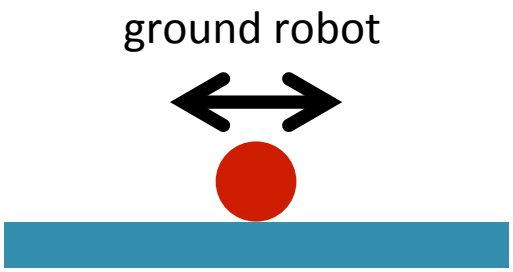
Jerome-de Bothezat Quadrotor 'Flying Octopus' in 1922

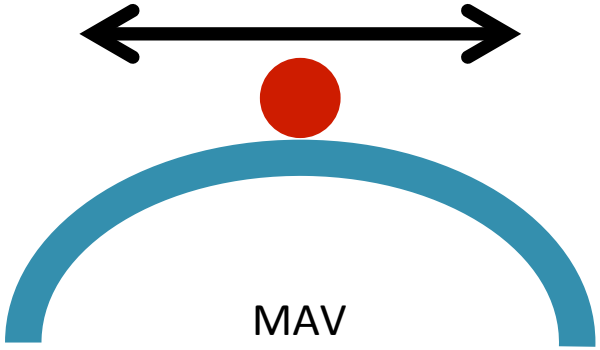


Challenges for MAVs

- Degrees of freedom
- Coupled dynamics
- Fast dynamics
- Constant motion and inherent instability





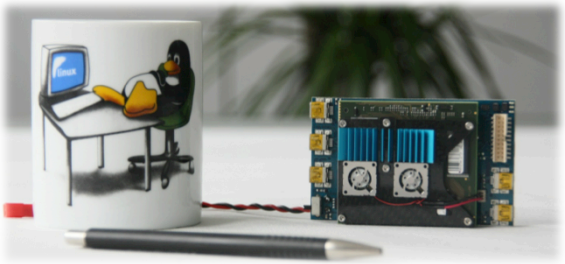


Challenges for MAVs

- Sensing payload (1g payload → ≈100 mW hovering power)

- Onboard processing power

NASA Ames Research Center/Tom Trower

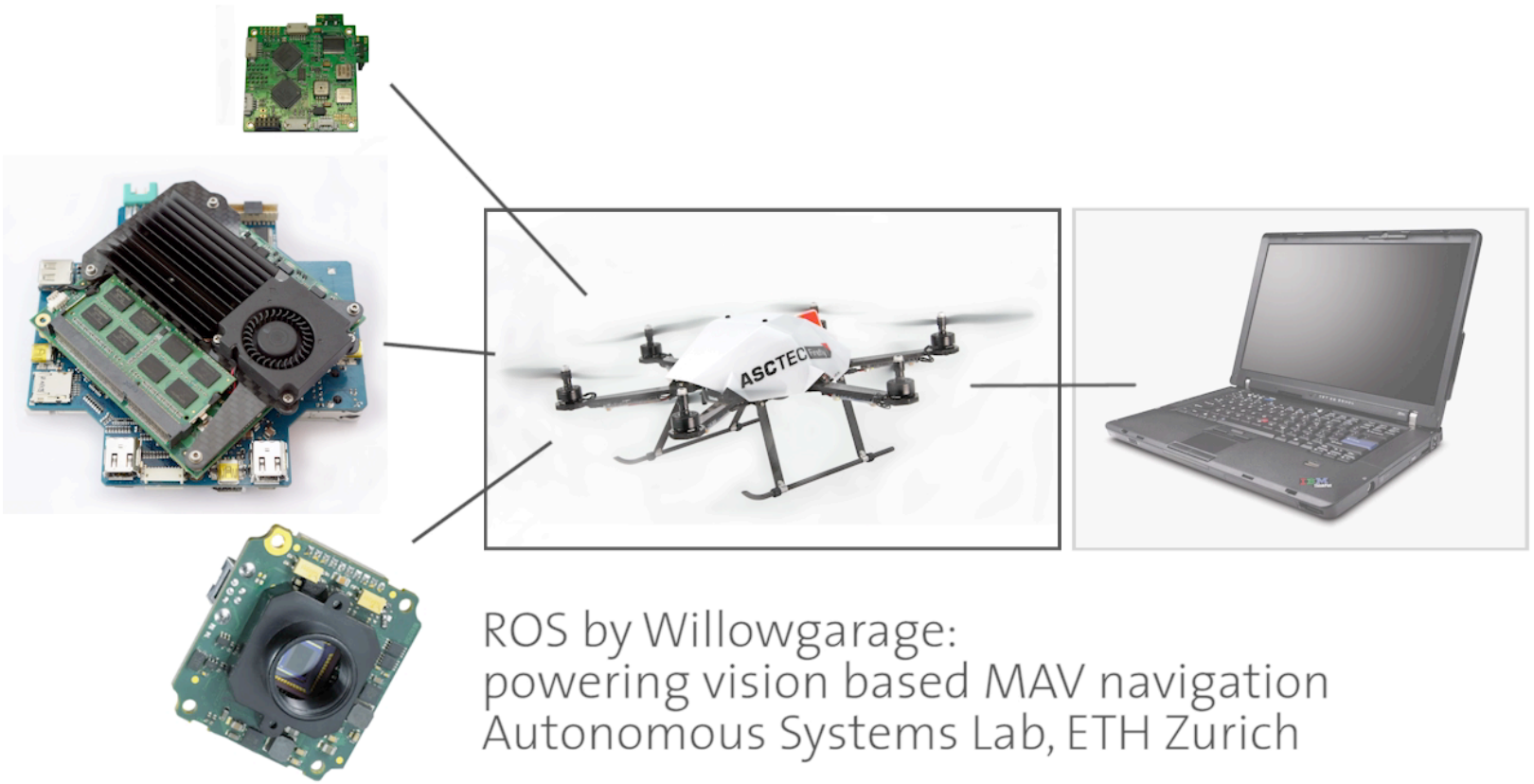

Ascending Technologies

- Wireless data-links: bandwidth, delay, QoS …

Challenges Visualized

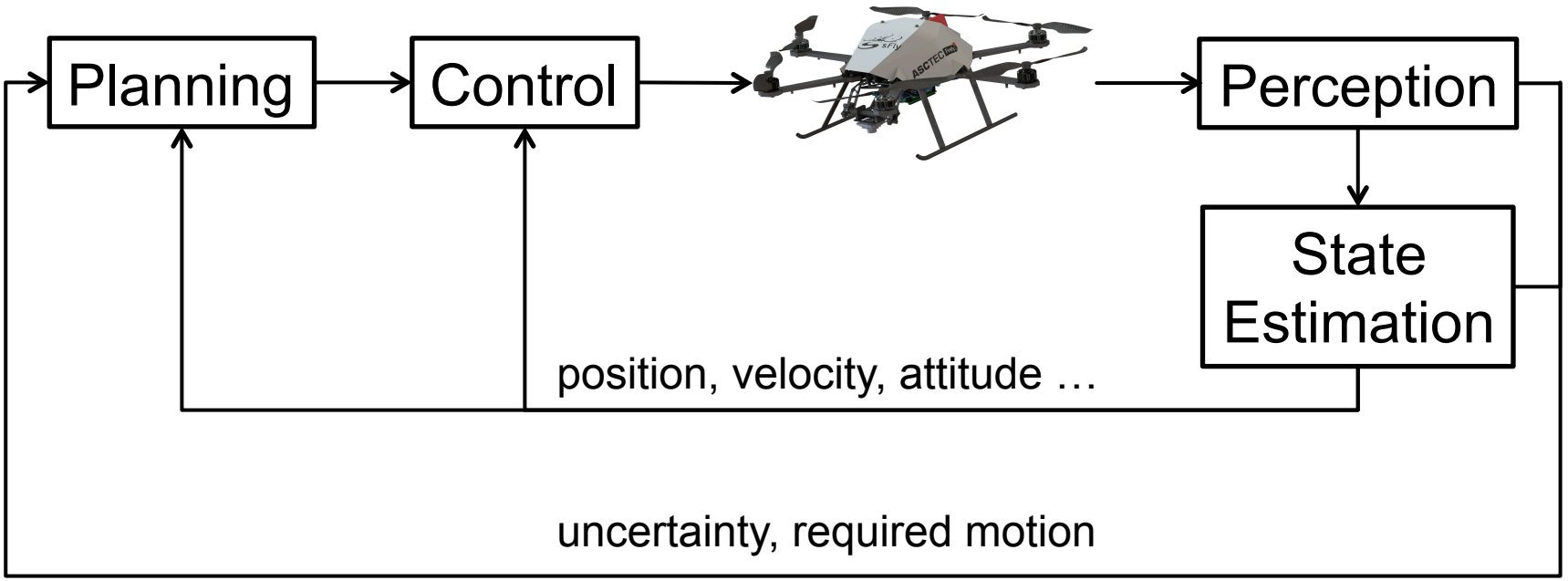
Challenges Visualized

Closed Loop Visual Navigation for MAVs

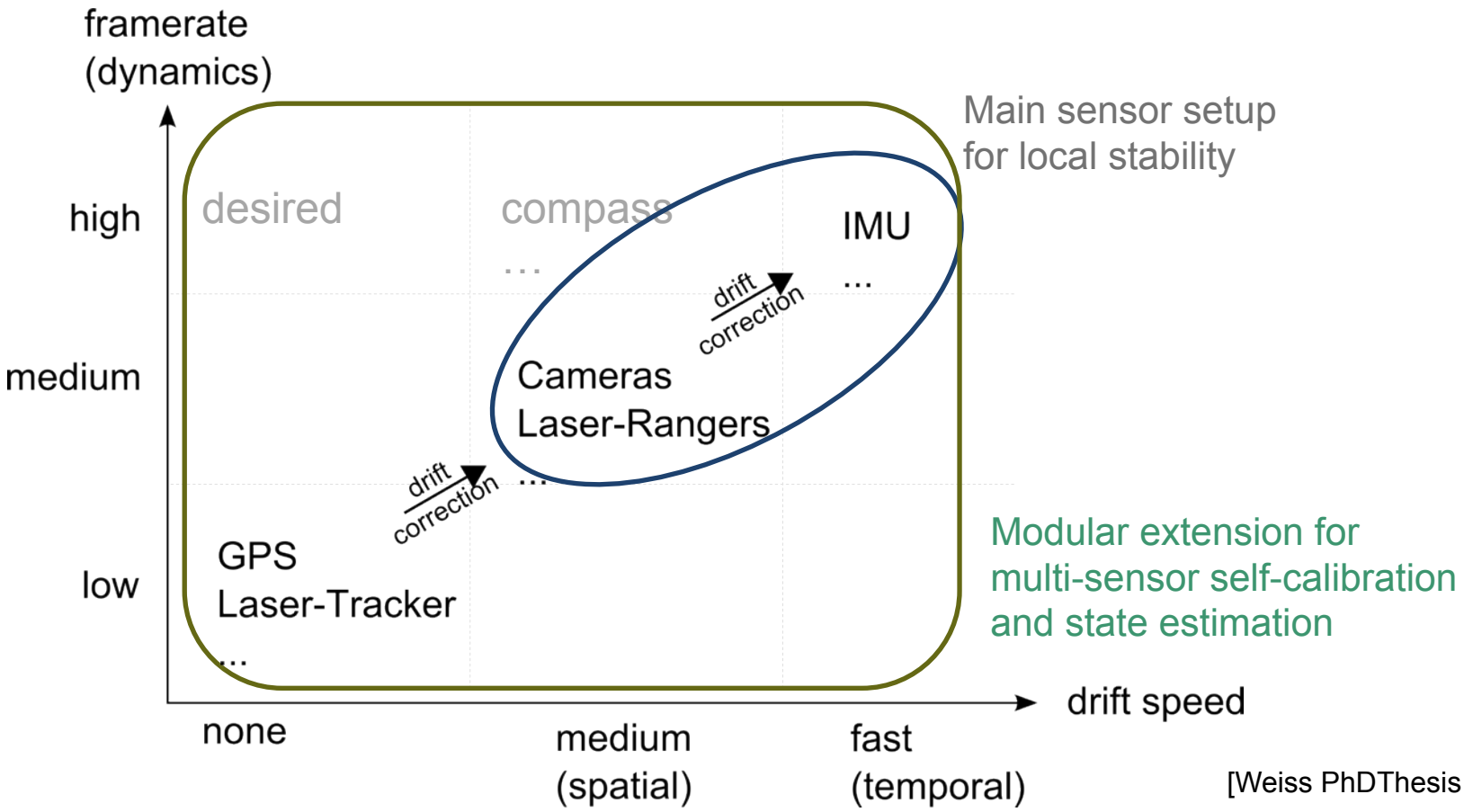


ROS by Willowgarage:
powering vision based MAV navigation
Autonomous Systems Lab, ETH Zurich

Components of an Autonomous MAV



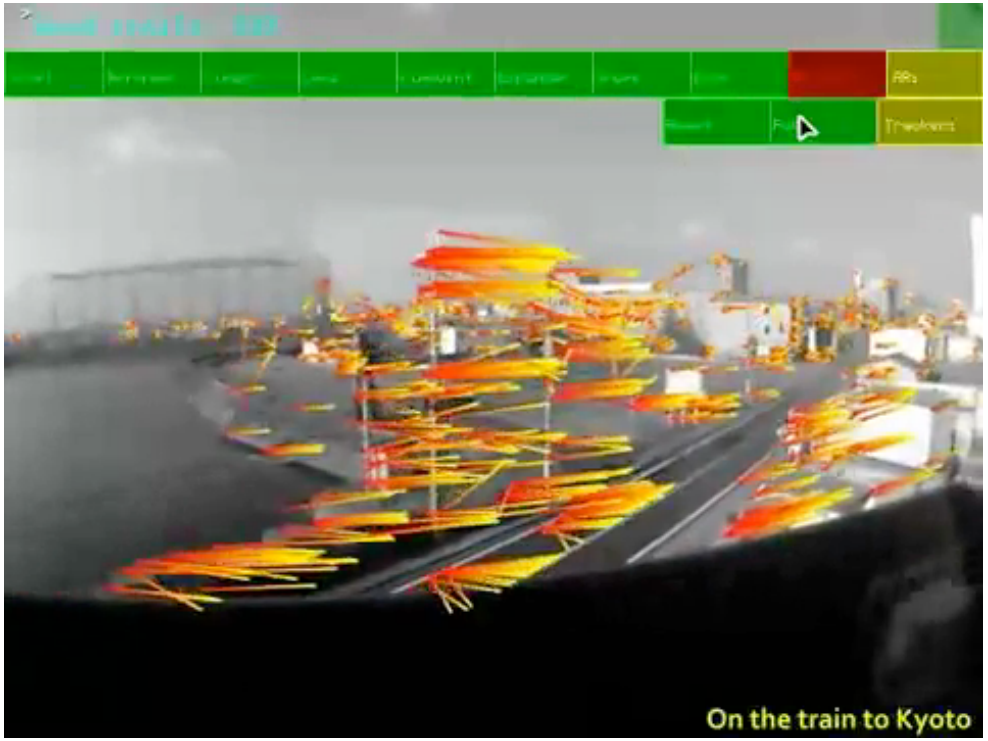
A sensor classification attempt, considering framerate and drift



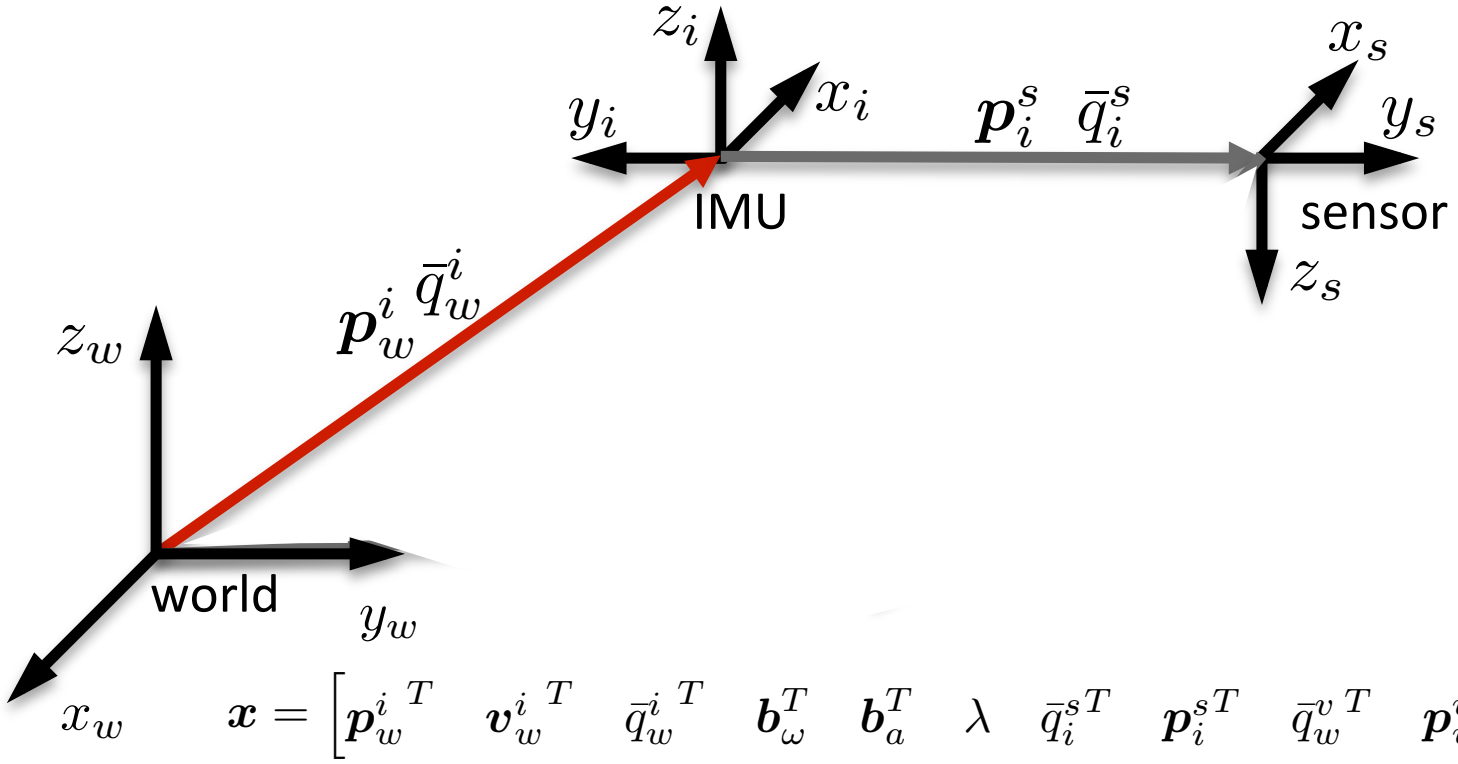
[Weiss PhDThesis 2012]

Localization: Keyframe Based Visual SLAM

- Parallel Localization And Mapping (PTAM) [Klein & Murray ISMAR07] [JFR 2011, ICRA 2012, JFR 2013]
  - Tracking and mapping in separate threads
  - Originally designed for small workspaces
  - Monocular vision approach
    → unknown, arbitrary translational scale
  - Here: used as “black box” providing a “5D” pose



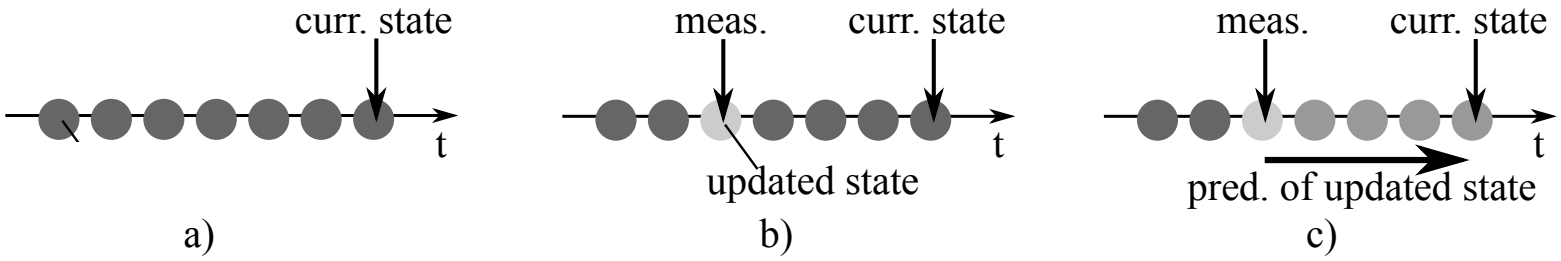
State Estimation: Sensor Setup



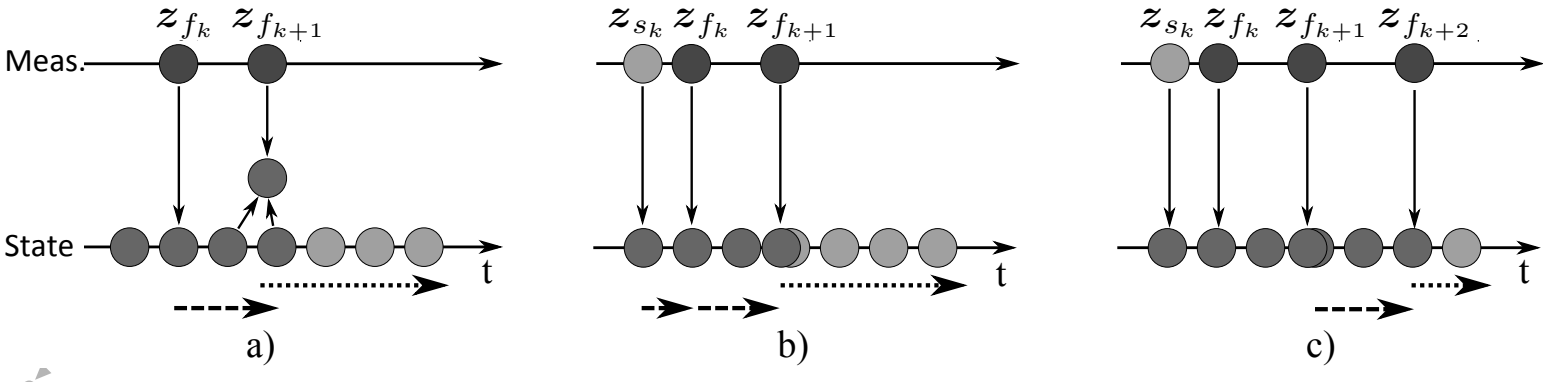
- IMU-sensor calibration and measurement scale are observable, given sufficient motion [Mirzaei, Kelly, Martinelli, Weiss]

Measurement Delay Compensation

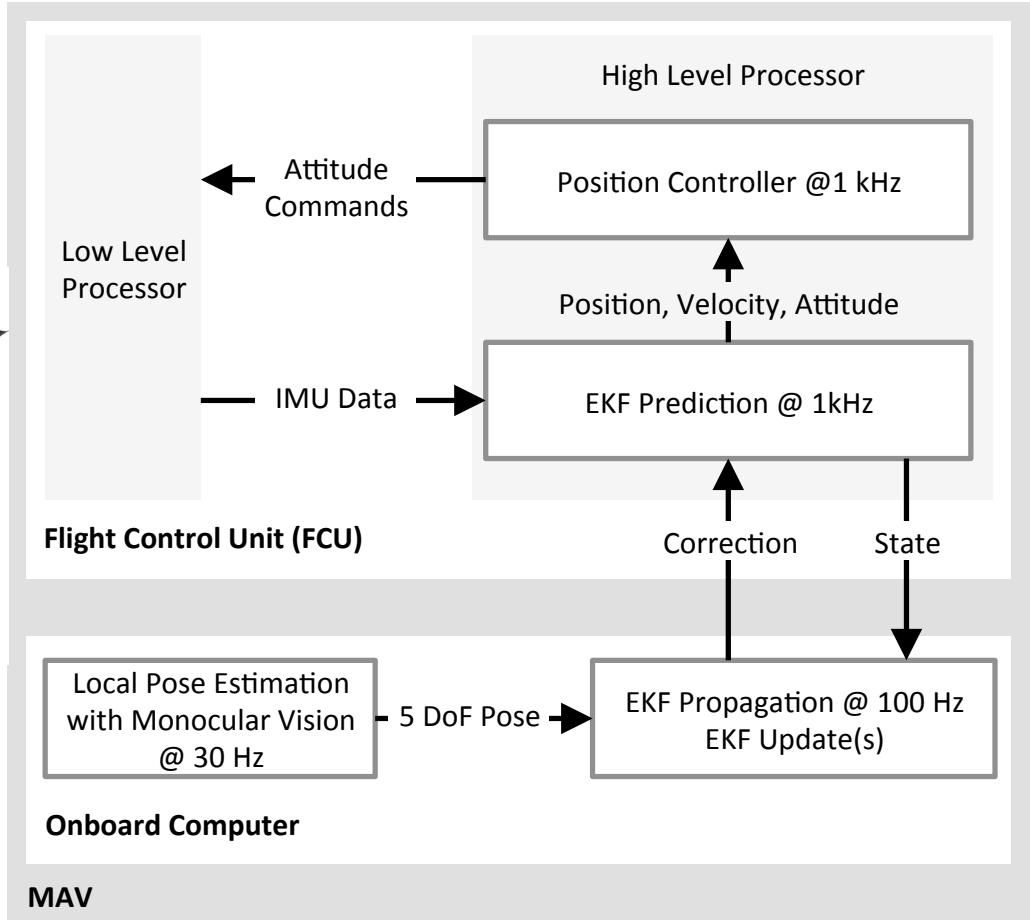
- Single sensor:



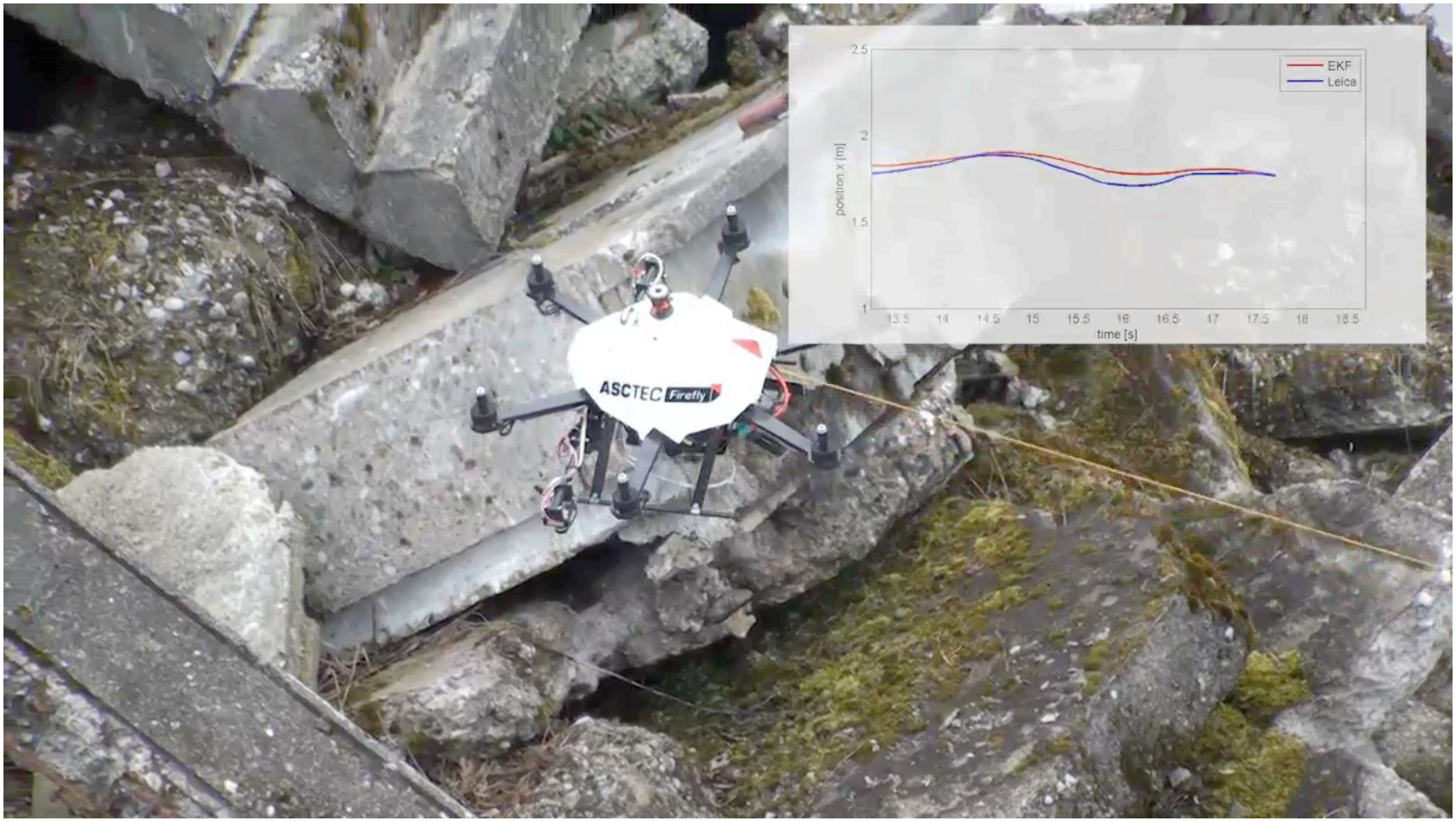
- Multiple sensors:



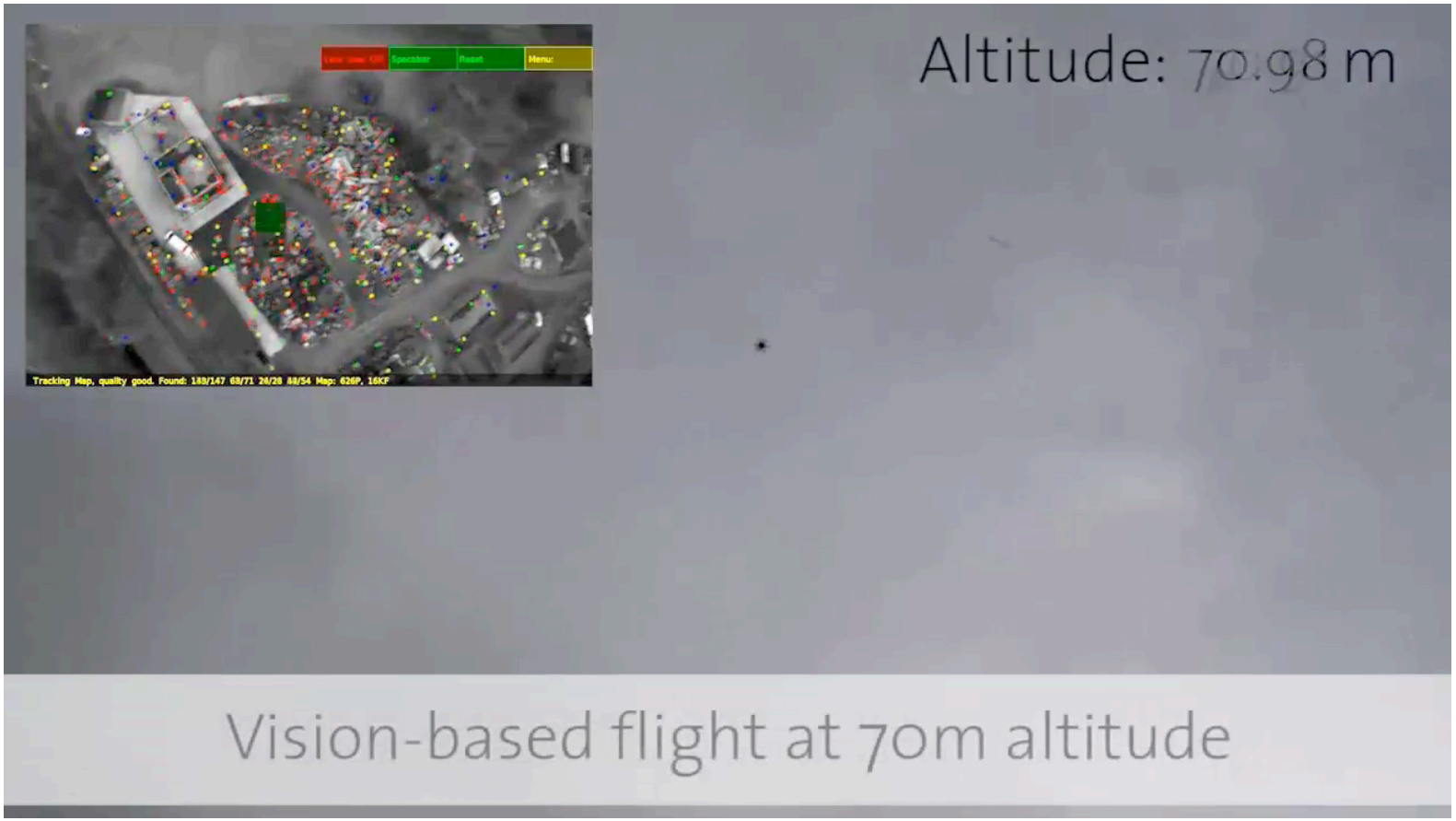
Sensor Fusion Integration



Results: Robustness to Disturbances



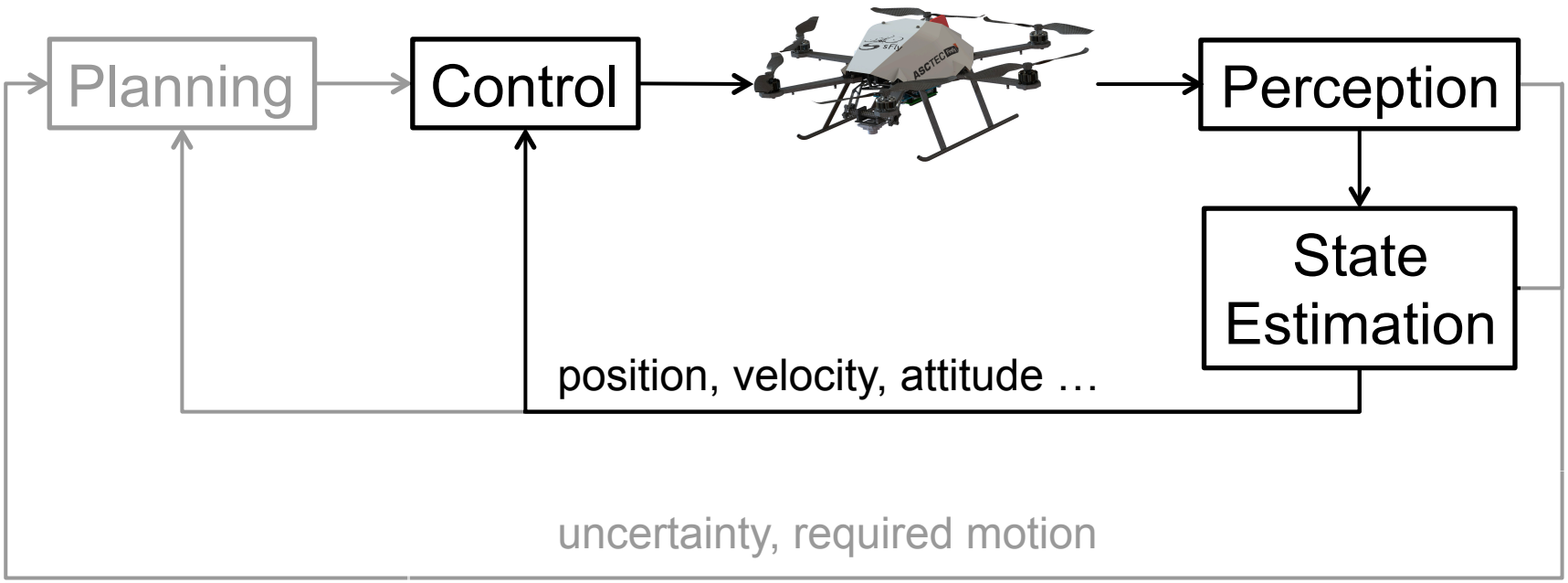
Results: Altitude Changes

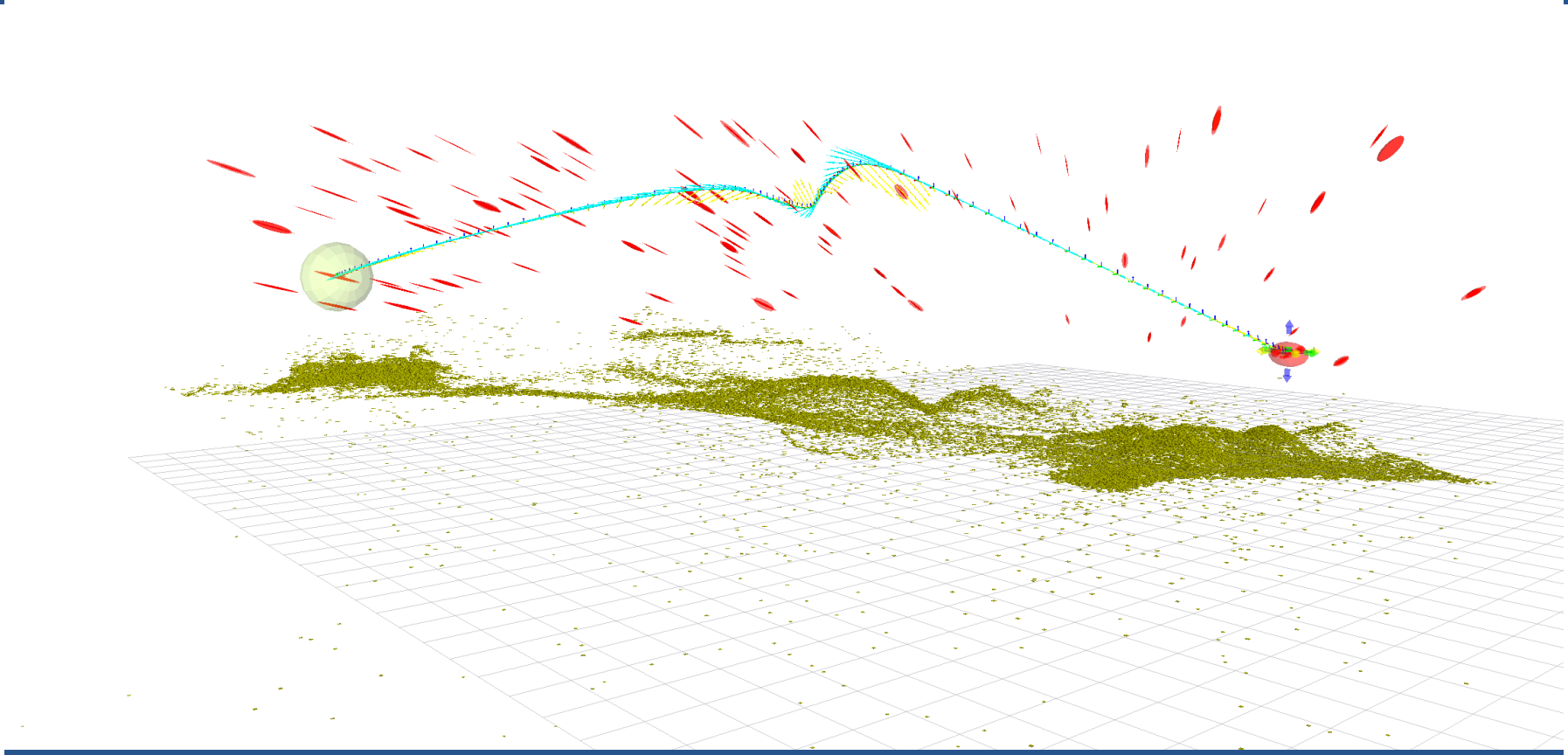


Results: PTAM / VSLAM -- up to 4 m/s

[Achtelik et al. IROS 2013]

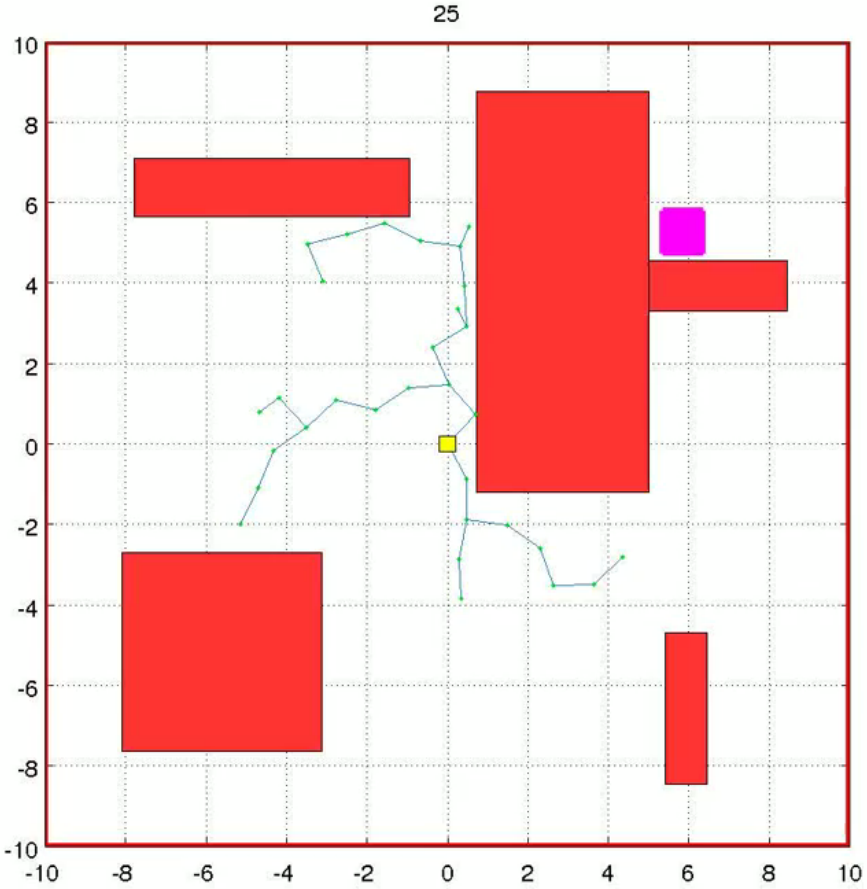
Outline


Planning
Control
Perception
State Estimation
position, velocity, attitude …
uncertainty, required motion



Motion and Uncertainty Aware Path Planning

Random Sampling Based Planning Methods

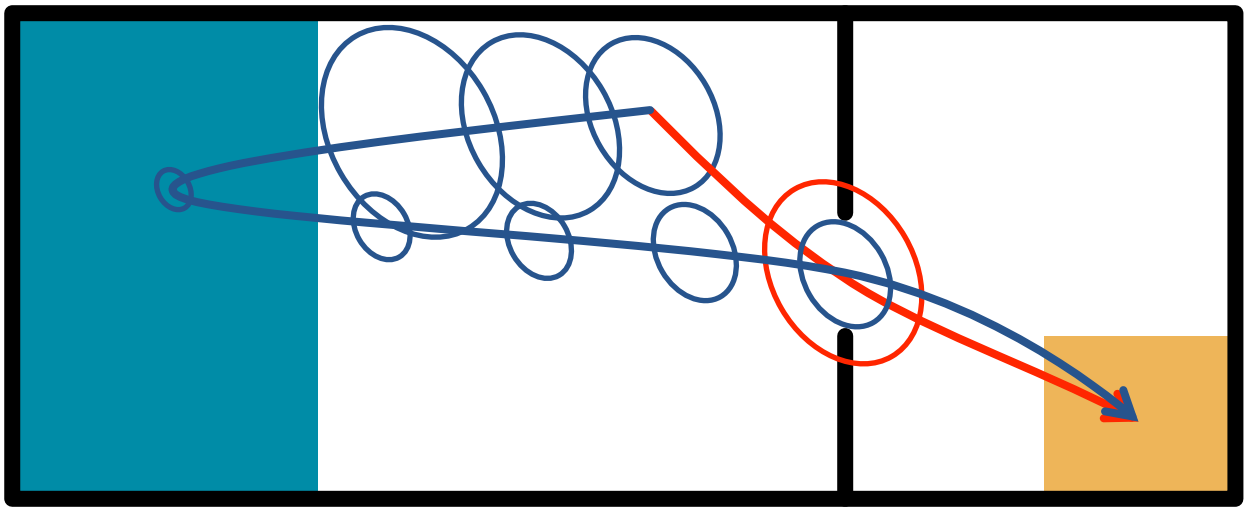


Video: S. Karaman

Rapidly-exploring Random Belief Trees (RRBT)

[Bry and Roy, ICRA 2011]

- Extends sample-based algorithms to handle measurement uncertainty
- Searches over candidate paths as an extension of the RRT* framework

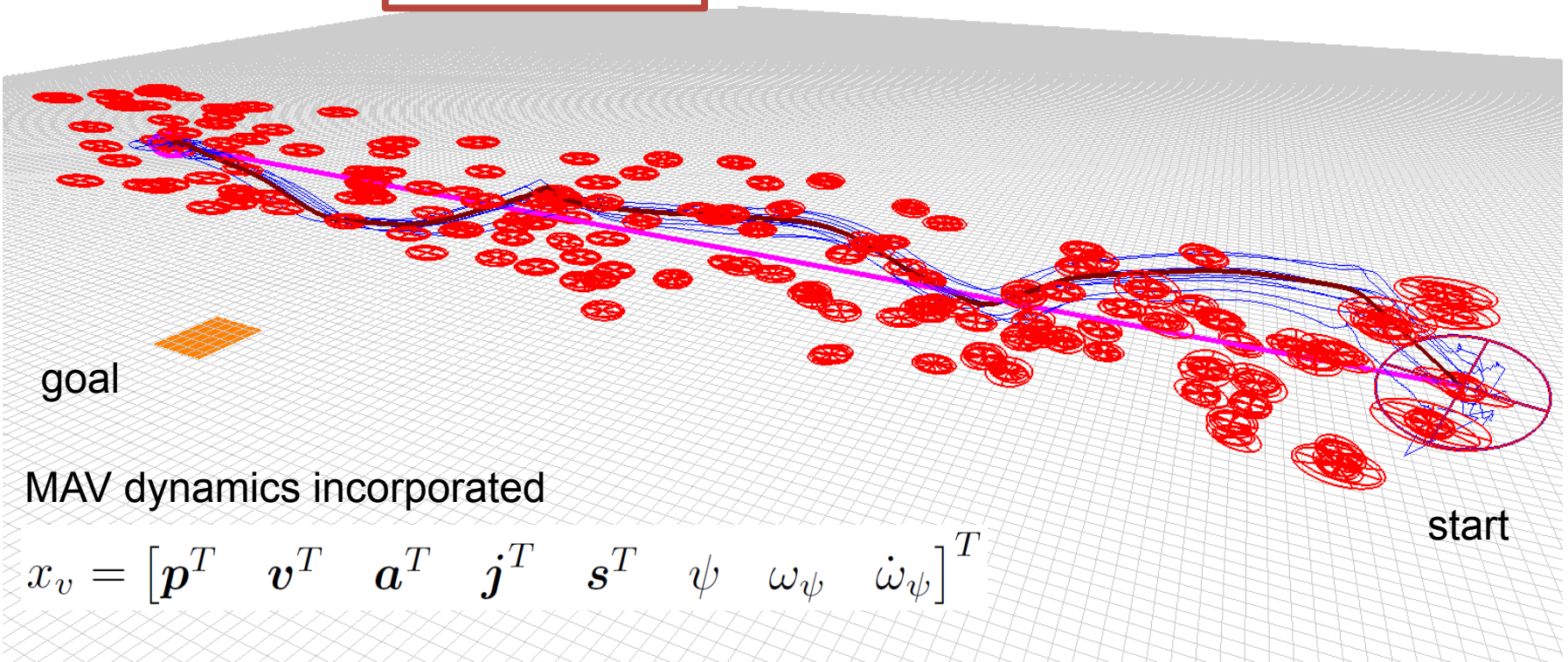


Motion Aware Path Planning

EKF state

$$x_f = \begin{bmatrix} \boldsymbol{p}_w^{i^T} & \boldsymbol{v}_w^{i^T} & q_w^{i^T} & \boldsymbol{b}_\omega^T & \boldsymbol{b}_a^T & \lambda & \boldsymbol{p}_i^s & q_i^s \end{bmatrix}^T$$

need excitation !

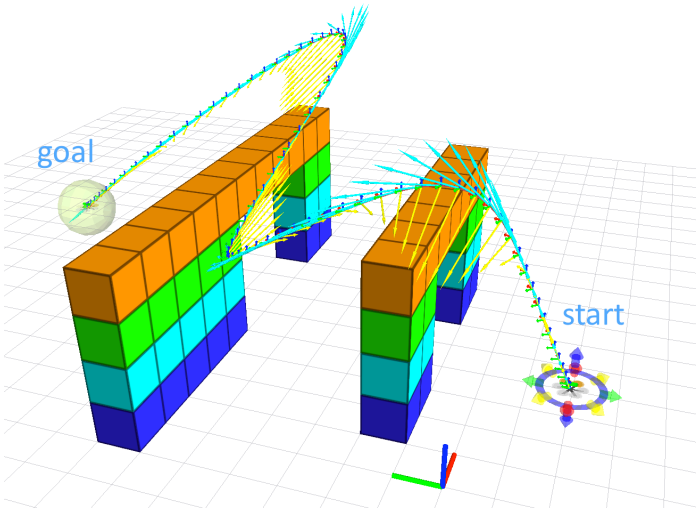


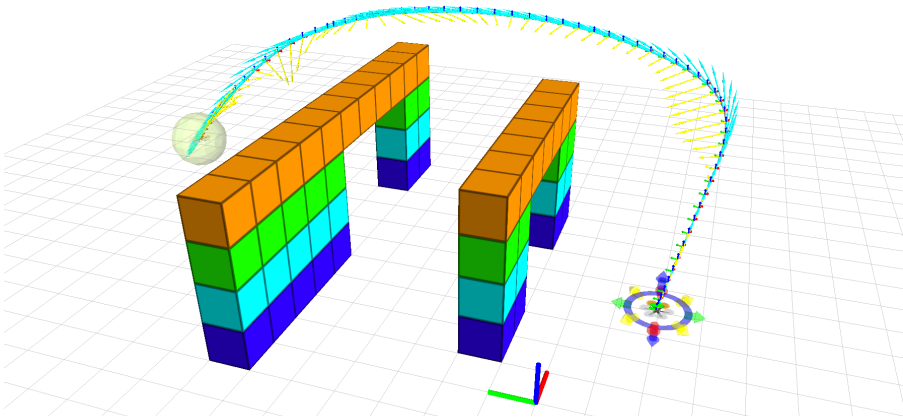
MAV dynamics incorporated

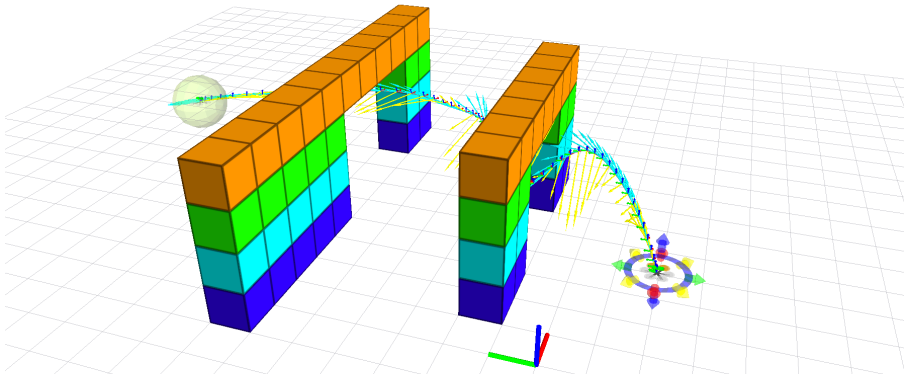
$$x_v = \begin{bmatrix} \boldsymbol{p}^T & \boldsymbol{v}^T & \boldsymbol{a}^T & \boldsymbol{j}^T & \boldsymbol{s}^T & \psi & \omega_\psi & \dot{\omega}_\psi \end{bmatrix}^T$$

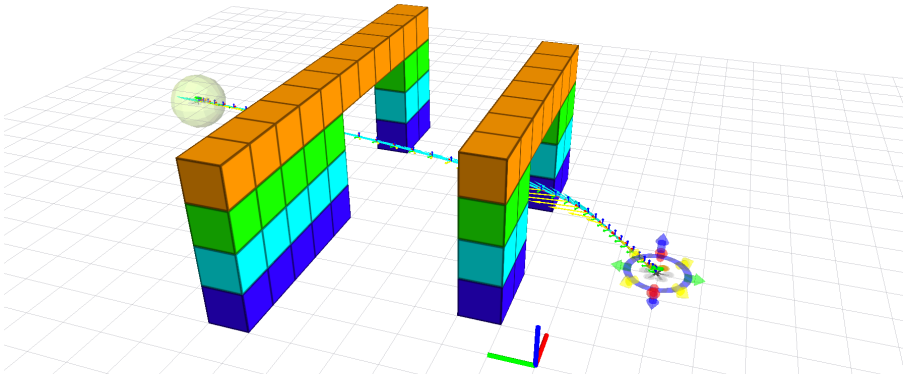
[Achtelik et al., ICRA 2013]

Obstacle Avoidance



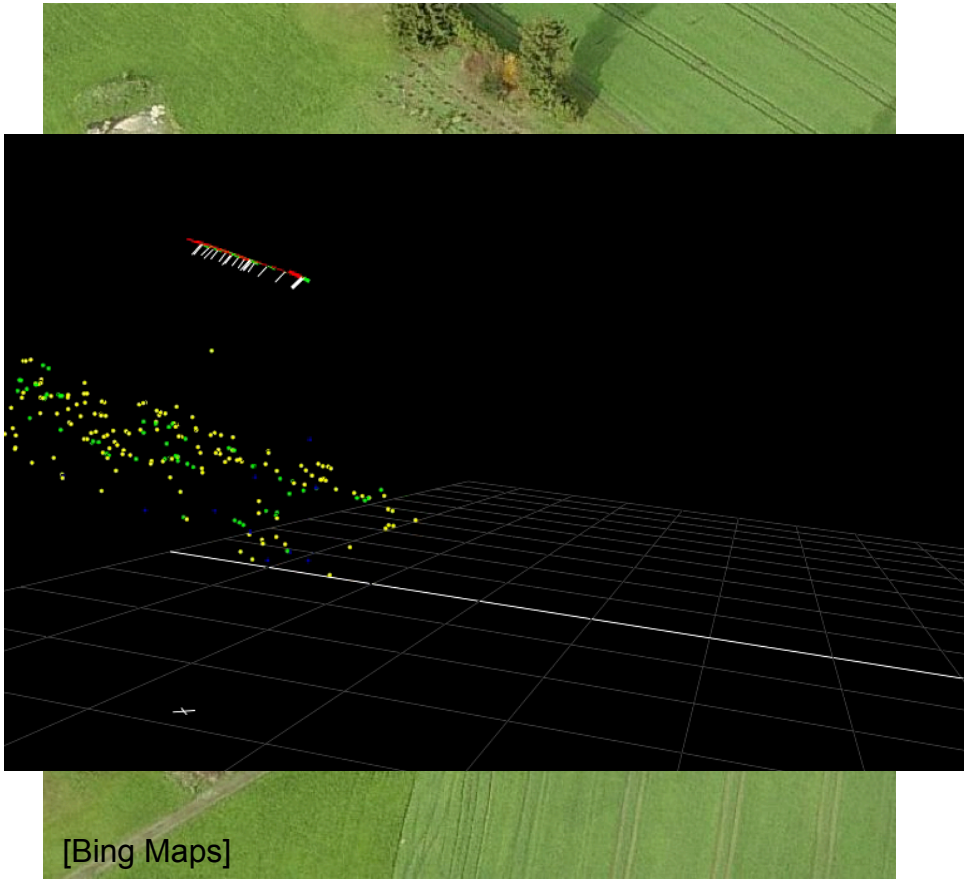




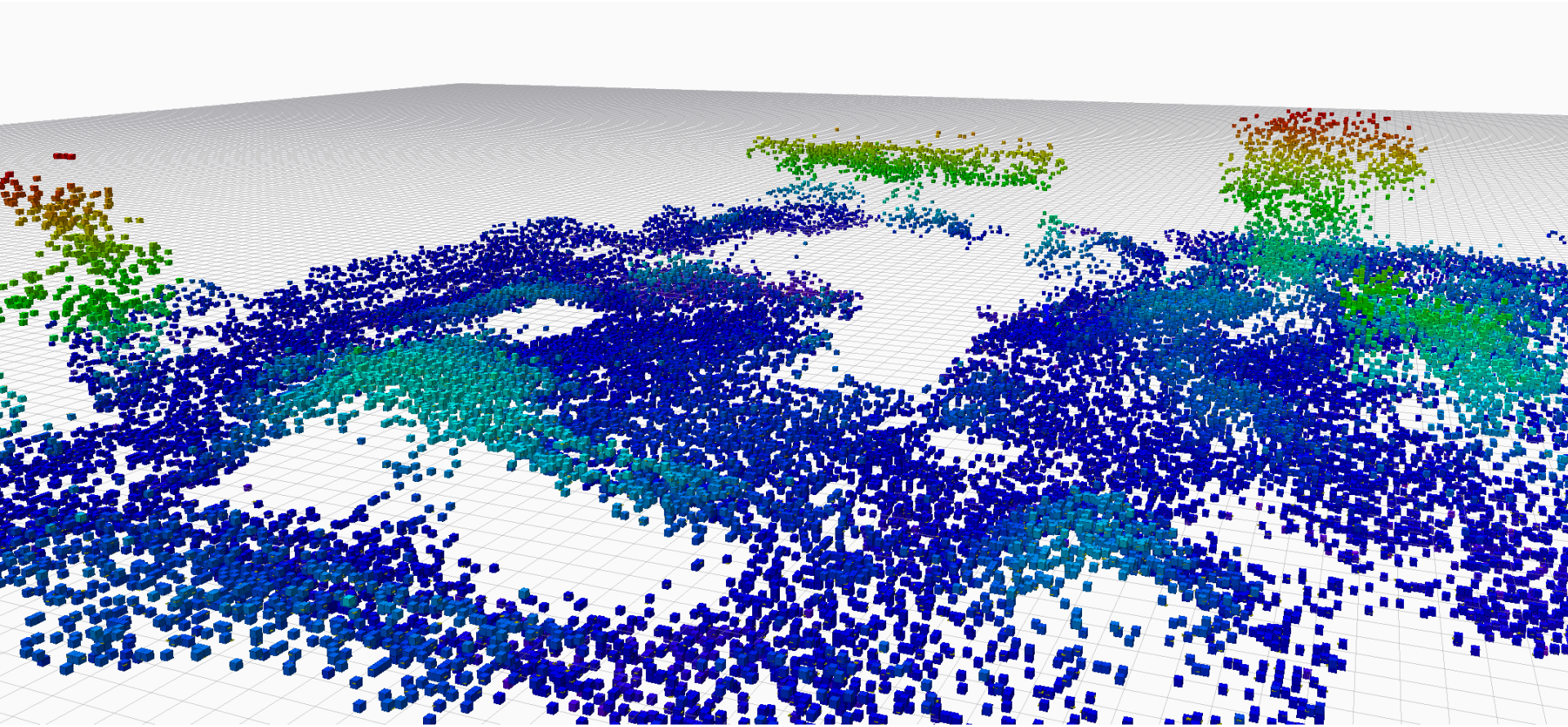


Field Tests

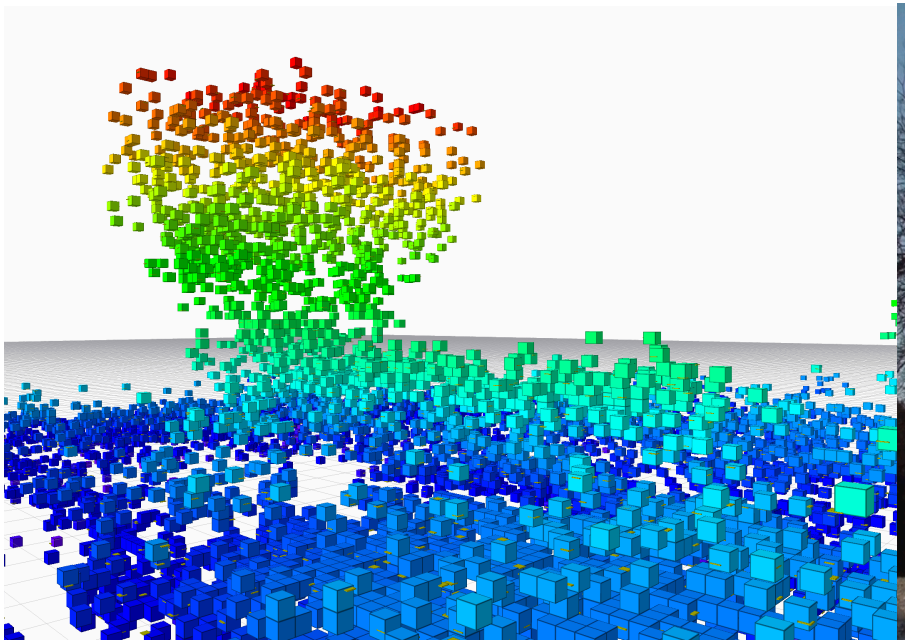
- Map construction from fly-over in safe altitude “approach and land”
- Point clouds from VSLAM
- Inserted as “laser-scans” into occupancy grid
- → Obstacle-lookups and covariance computation during RRBT steer- and propagation phase



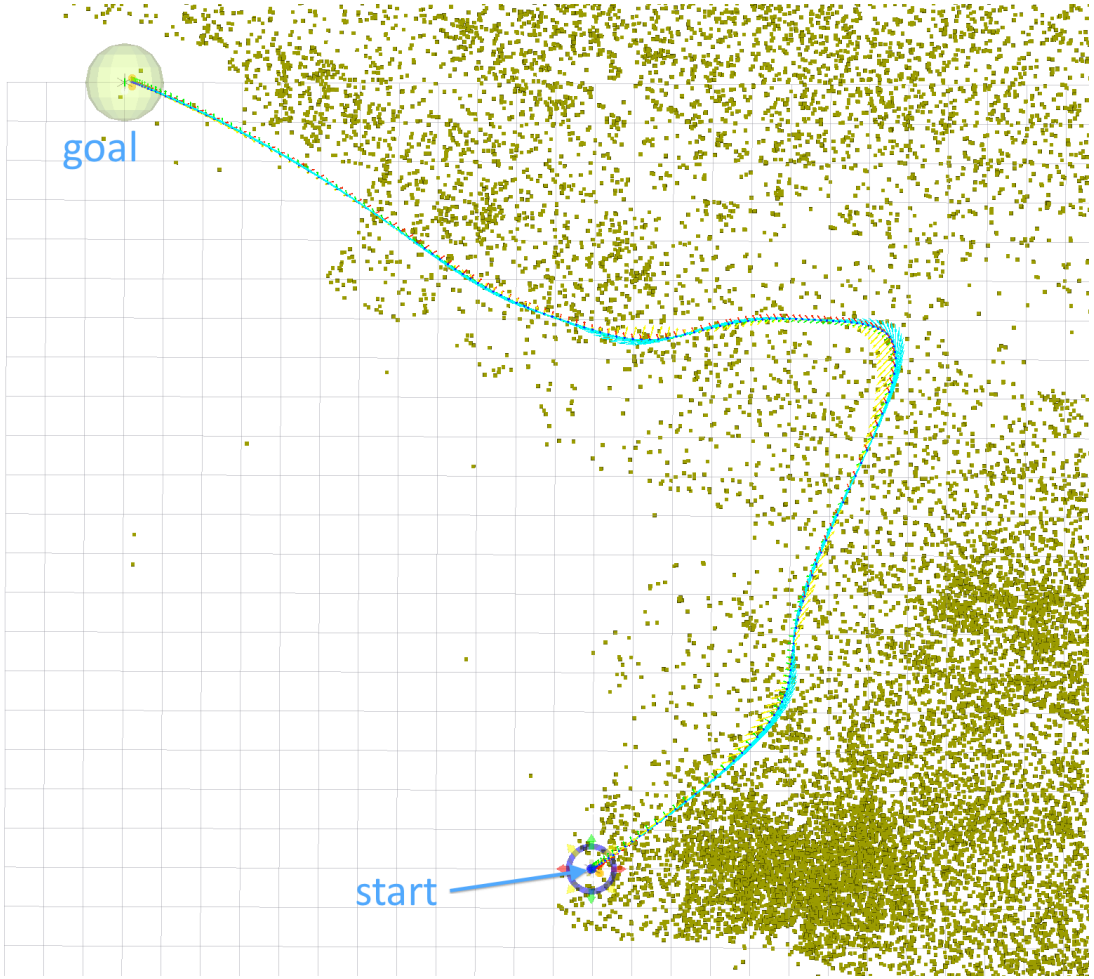
Field Tests – Map Generation



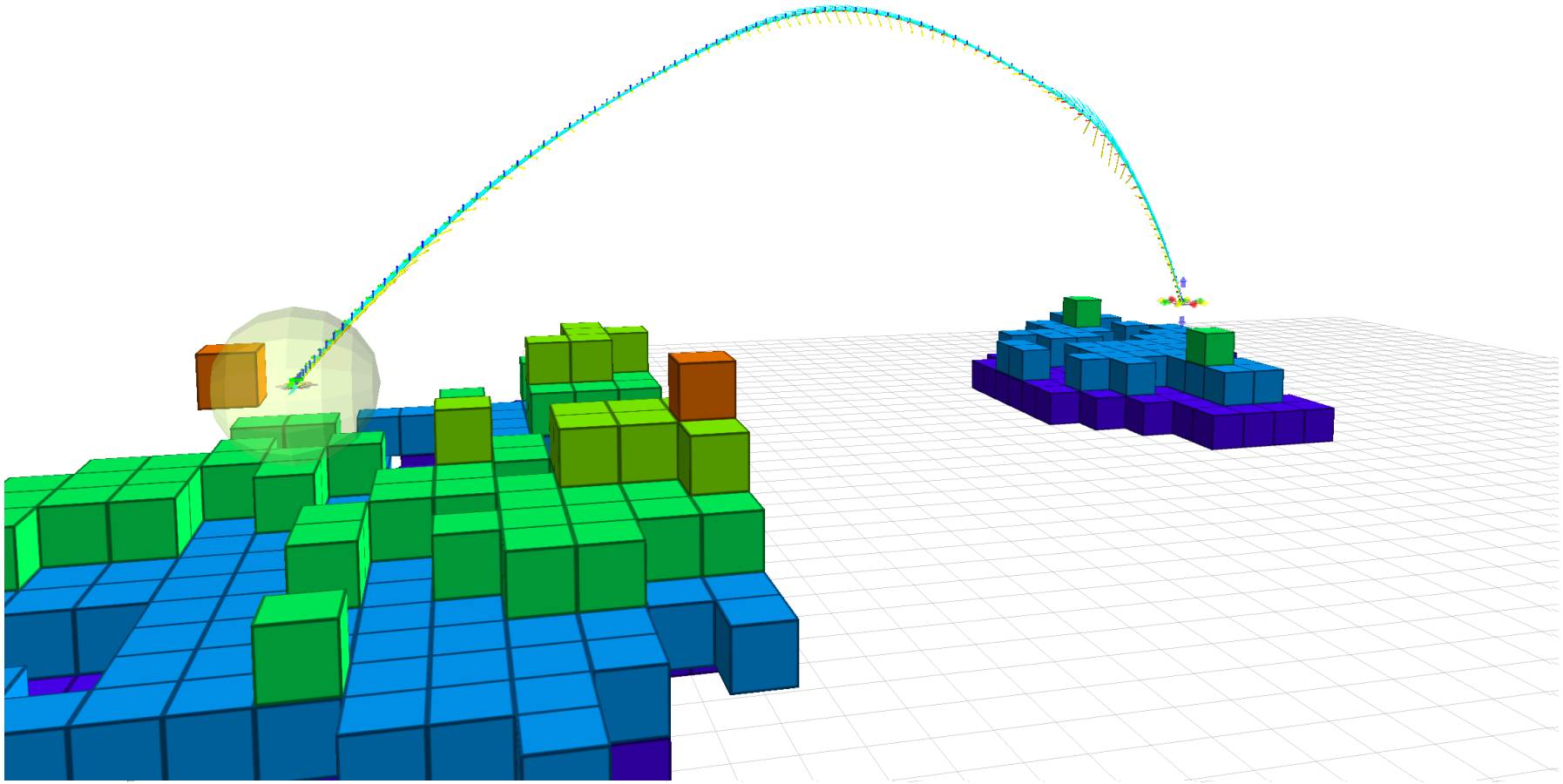
Field Tests – Map Generation



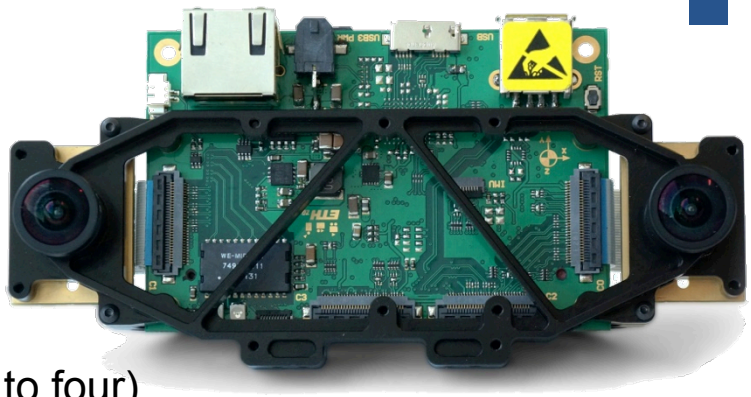
Tests with featureless areas



Tests with featureless areas



Outlook: Visual-Inertial Sensor



- Vision: Global Shutter Aptina MT9V034 (up to four)
  Thermal Camera: FLIR Tau 640, 14 bit HDR
- IMU: Analog Devices ADIS 16488/16448
- Calibration: Camera-IMU fully calibrated & time-synchronized [1]
- FPGA: XILINX Zynq 7020
  SoC Dual-Core ARM Cortex A9

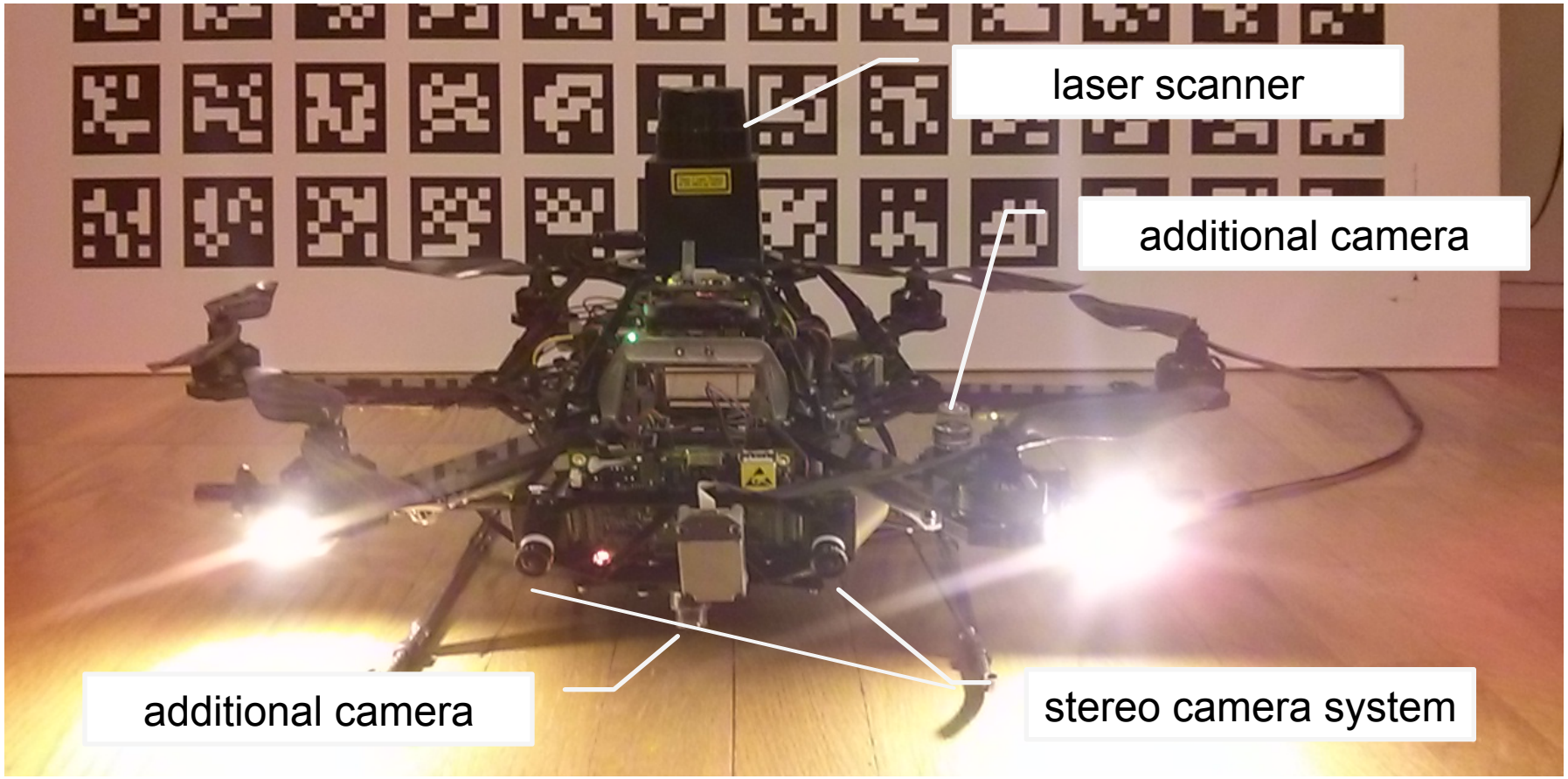
- Lighting: LED flasher
- Interface: GPS & Laser scanners

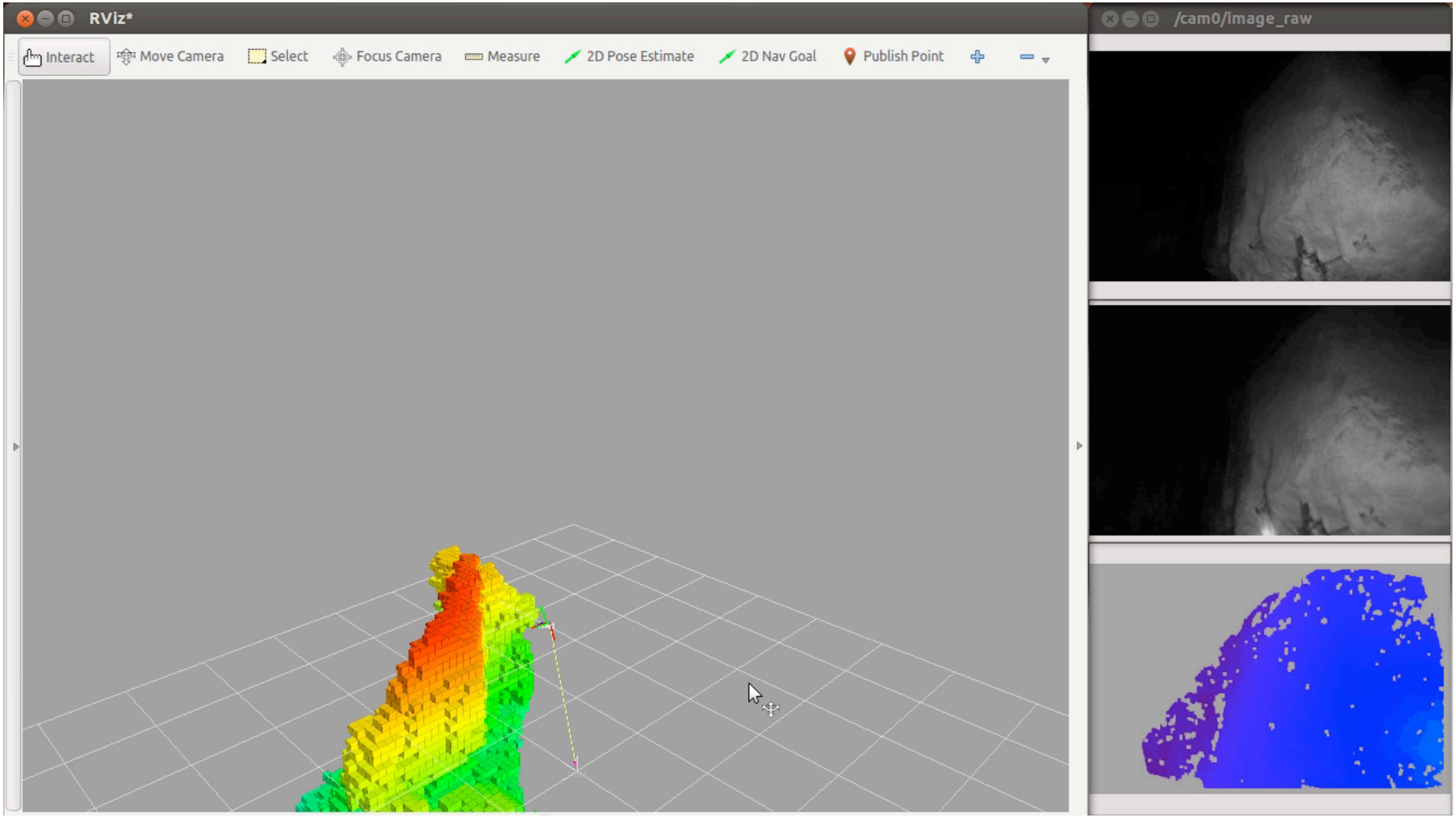
- I/O: GigE, USB-powered (<10W)
- Weight: 130 g (incl. 2 cams + sensor mount)

[1] P. Furgale et.al, “Unified Temporal and Spatial Calibration for Multi-Sensor Systems”, IROS 2013

Outlook – Inspection Tasks in Industry

Sensors and Illumination Integrated on Hex-Rotor



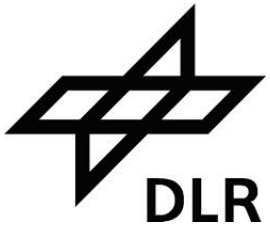

RViz*
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Nav Goal
Publish Point
/cam0/image_raw

Conclusions

- Efficient position / trajectory controller.
- Modular multi-sensor fusion framework and robust localization.
- Path planning framework, planning safe paths that provide sufficient motion.

Conclusions

- Frameworks developed and published are used by



Thank you for your attention!

An envisioned Personal Aerial Vehicle, Gareth Padfield, Flight Stability and Control

UNIVERSITY OF LIVERPOOL

Handling Qualities and Training Requirements for Personal Aerial Vehicles

Dr. M. Jump
Dr. P. Perfect
Dr. M.D. White
Dr. L. Lu

mycopter

Project funded by the European Union under the 7th Framework Programme

http://www.mycopter.eu

Outline

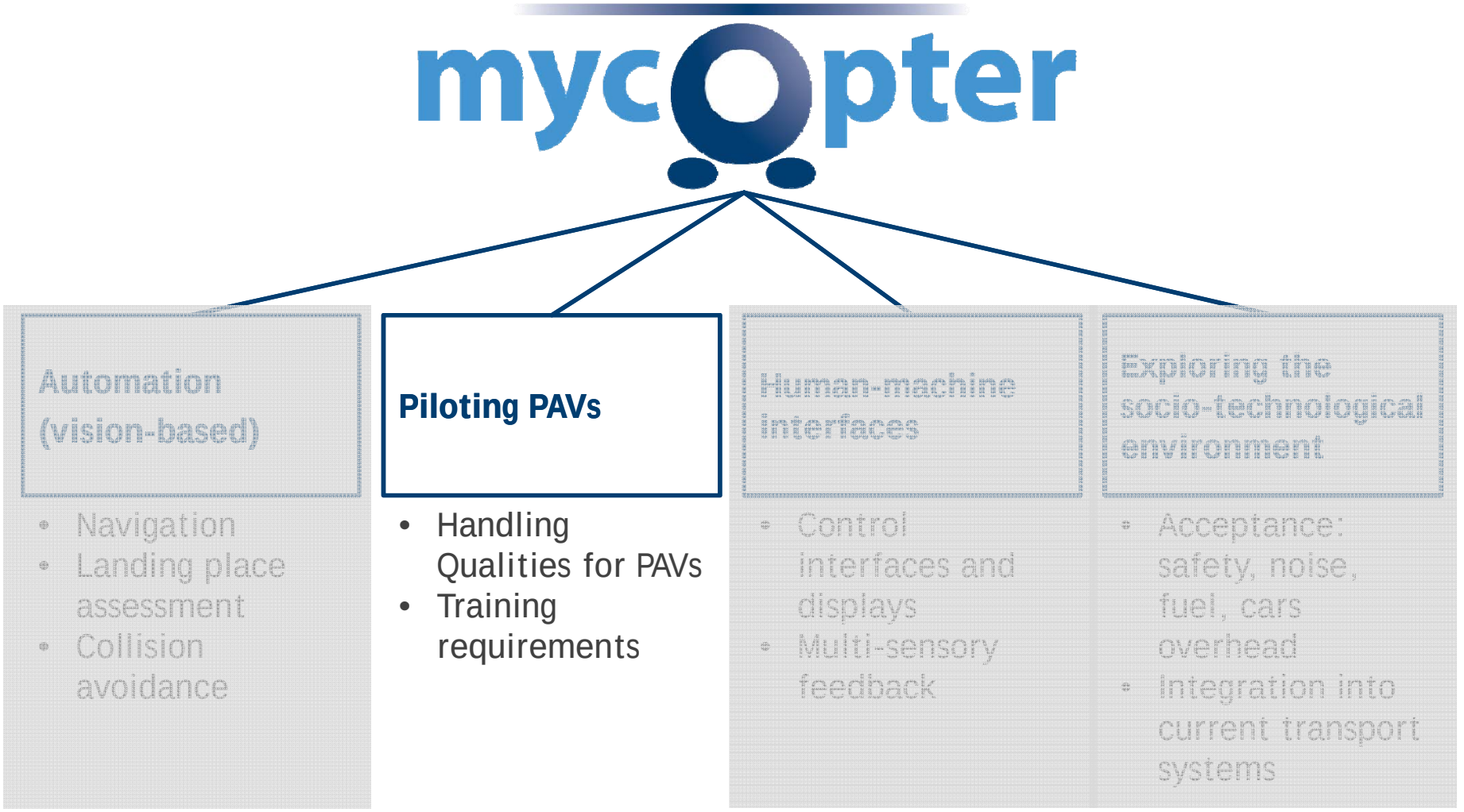
- The *myCopter* Project
- Preparatory Activities
- Favoured Response Type
- Training Programme Definition
- Concluding Remarks

Background to the *myCopter* project

- Vision for a Personal Aerial Transportation System (PATS) to relieve congestion on roads in and around cities

- Project envisages a small VTOL Personal Aerial Vehicle (PAV)
  - 1-2 occupants
  - 80-120kts cruise speed
  - 50-60 mile range

[1]Jump, M. *et al*, "myCopter: Enabling Technologies for Personal Air Transport Systems", RAeS Conference "The Future Rotorcraft", London, June 2011


mycopter
Automation (vision-based)
Navigation
Landing place assessment
Collision avoidance
Piloting PAVs
Handling Qualities for PAVs
Training requirements
Human-machine interfaces
Control interfaces and displays
Multi-sensory feedback
Exploring the socio-technological environment
Acceptance: safety, noise, fuel, cars overhead
Integration into current transport systems

Adopted a Rotary Wing Handling Qualities Approach

- Handling Qualities – "*those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role*"
- Approach from: ADS33E-PRF, Aeronautical Design Standard Performance Specification Handling Qualities Requirements for Military Rotorcraft
- ADS33 intent is to ensure that no limitations on flight safety or on the capability to perform intended missions will result from vehicle deficiencies
- Goal is to achieve Level 1 Handling Qualities
- Rotary Wing → PAV needs to be VTOL capable

Why are “new” PAV handling qualities requirements needed?

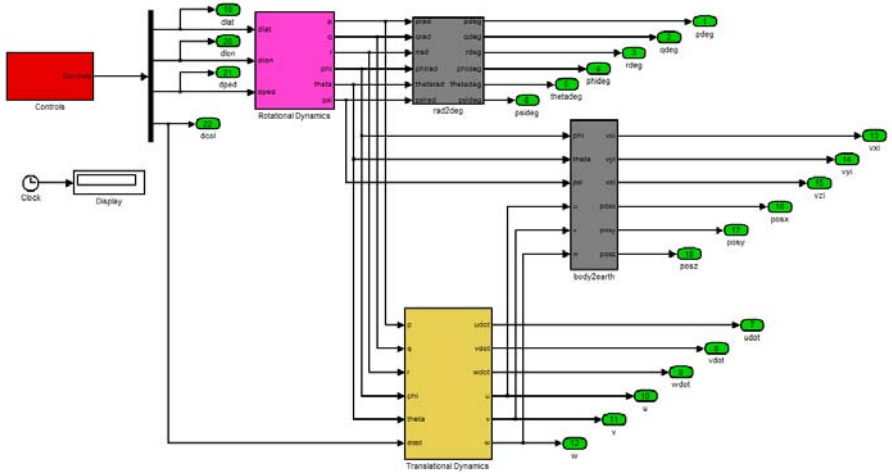
- Desirable for the PAV to be suitable for mass-market adoption
  - Necessary to significantly reduce costs compared to existing GA flight
  - Required degree of ‘skill’ should be lower for a PAV than that for typical light helicopter, ADS33 starts at Rate Command for Level 1 HQ
  - Current HQ methods may not read across to flight-naïve pilots

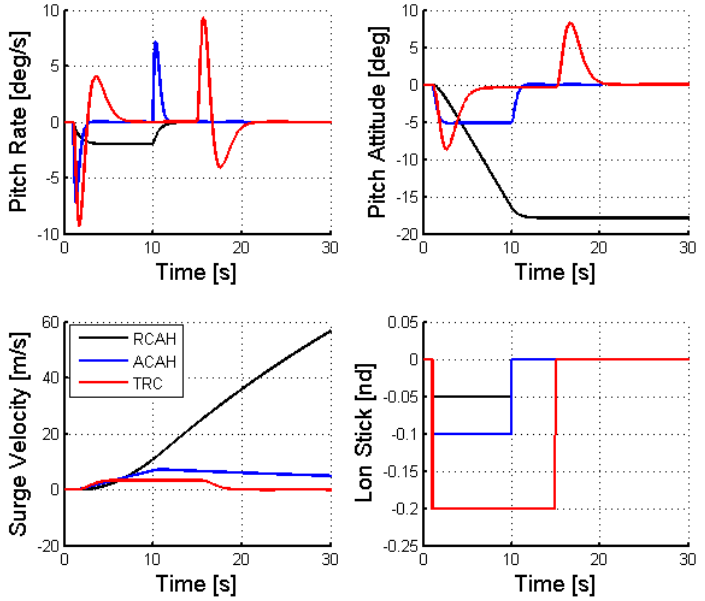
- Possible to introduce autonomy to the PAV but…

- For manual flight, the operation of the aircraft is more straightforward than a current GA helicopter
  - Handling Qualities should be significantly better, but by how much?
  - What is the level of skill required for different handling configurations?
  - What are the training requirements for the selected configuration?

Preparatory Activities

- Flight dynamics model created with RC, ACAH and 'Hybrid' response types[1]
- Model developed such that HQ Levels could be directly conferred

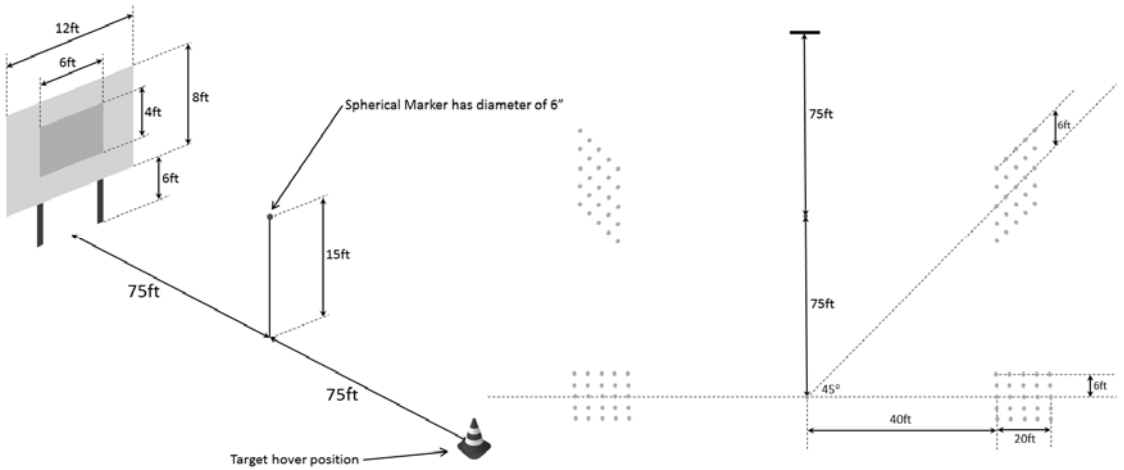


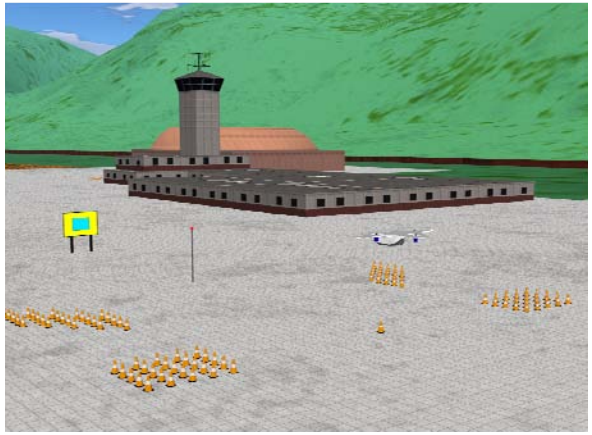


[1]Perfect, P. *et al*, "Development of Handling Qualities Requirements for a Personal Aerial Vehicles", 38th European Rotorcraft Forum, Amsterdam, The Netherlands, September 2012

Preparatory Activities

- MTEs relevant to a commuter journey developed[1]
- 5 low speed and hover MTEs the main focus

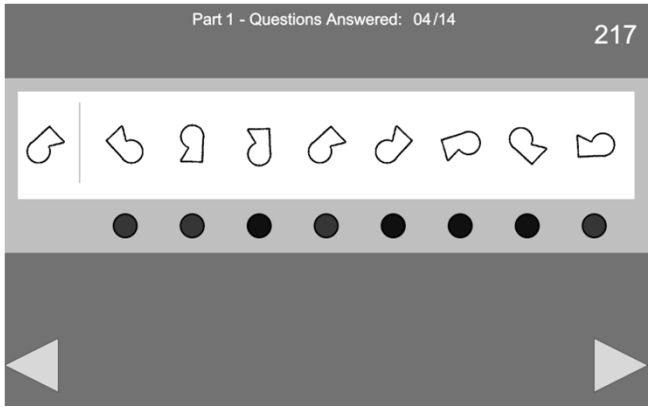


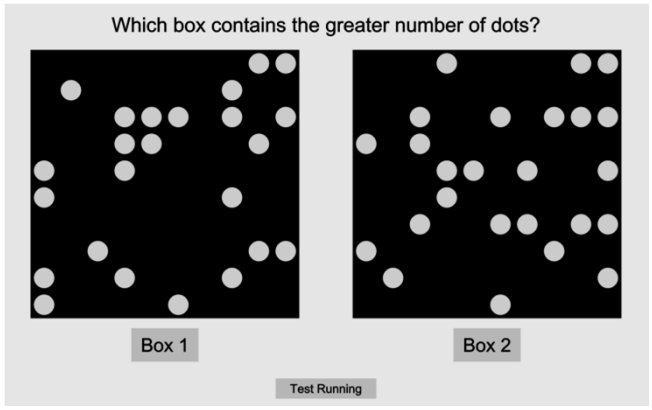


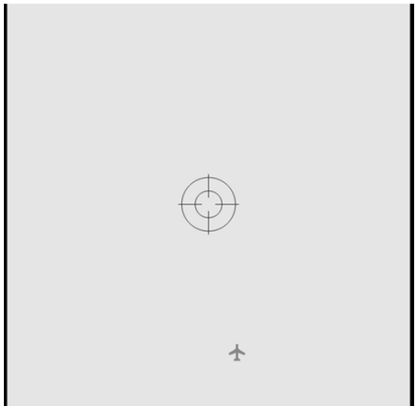
[1]Perfect, P. *et al*, "Development of Handling Qualities Requirements for a Personal Aerial Vehicles", 38th European Rotorcraft Forum, Amsterdam, The Netherlands, September 2012

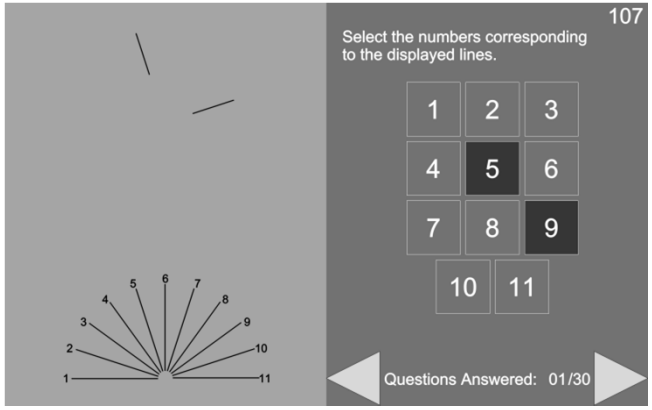
Preparatory Activities

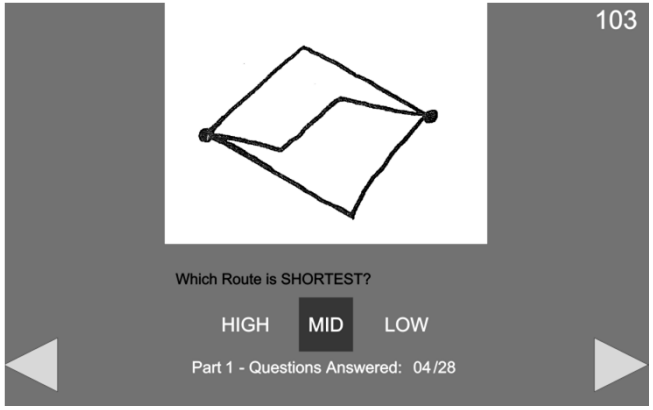
- Aptitude tests developed to ‘categorise’ test subjects

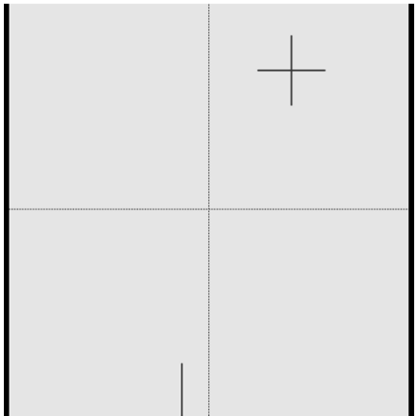






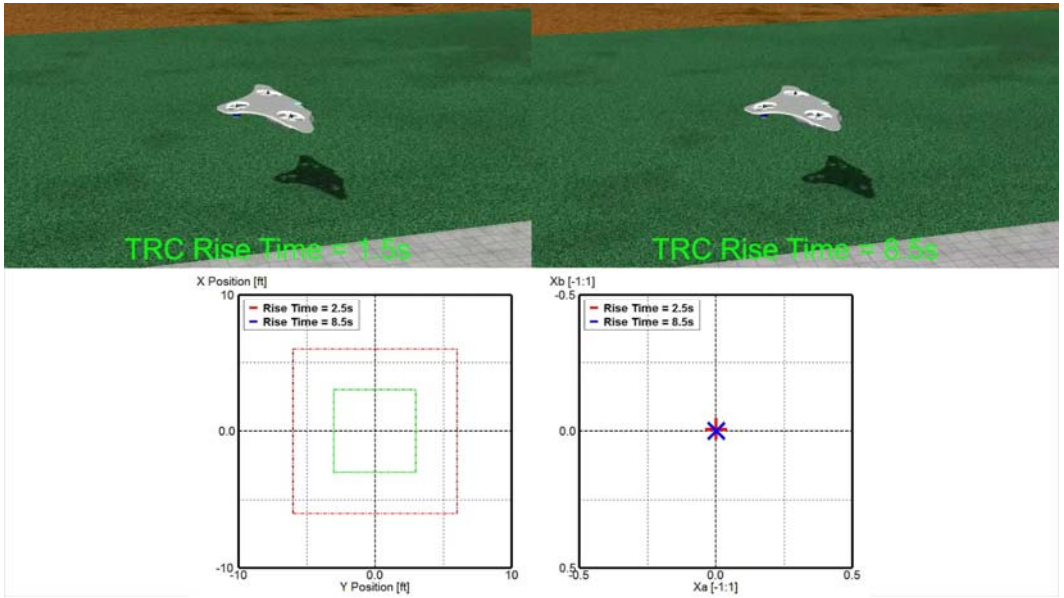






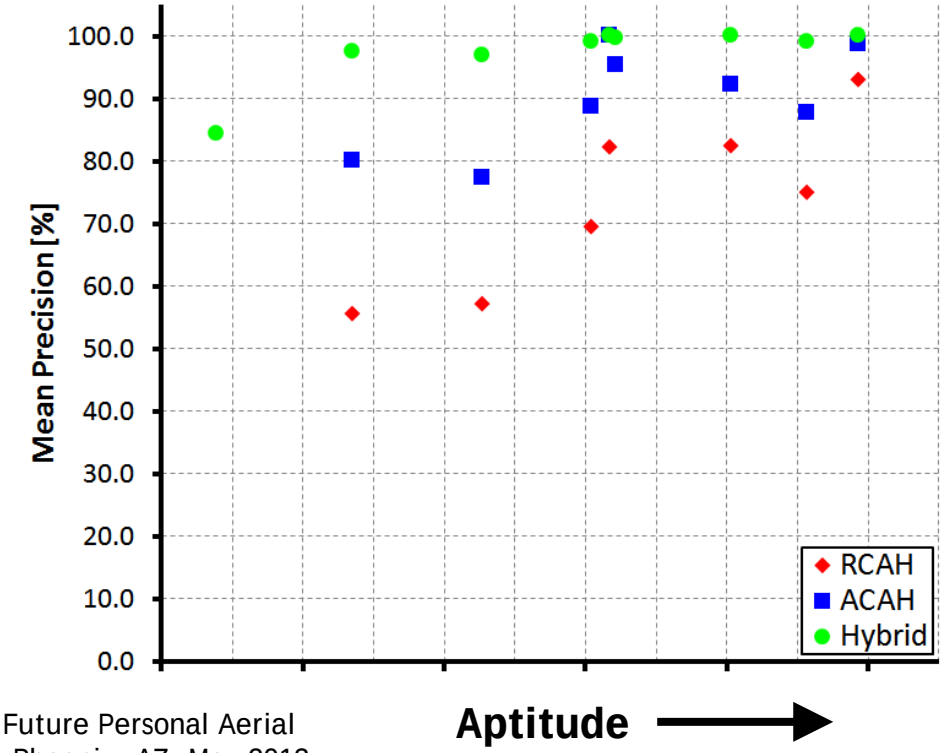
Study: Response Type & Response Type Characteristics

- Tested different response types and response type characteristics to find a combination that worked for a wide range of flight-naïve pilot aptitudes



Study: Response Type & Response Type Characteristics

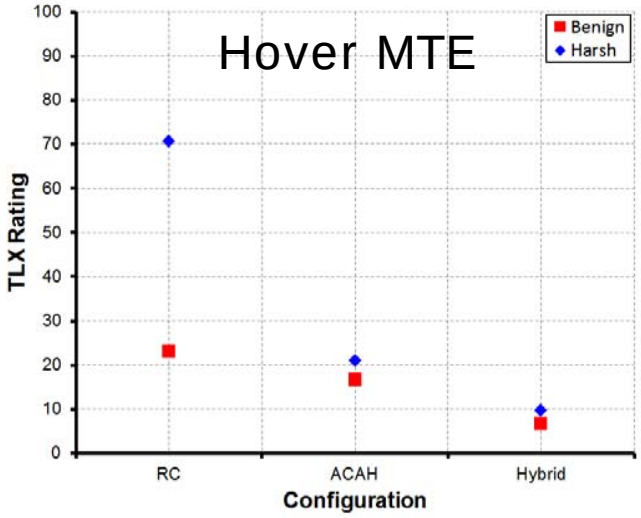
- The research showed that the Translational Rate Command (TRC) response type of a 'Hybrid' system was most suitable for use on a future PAV for hover and low speed flight[2]
  - Broad spectrum of aptitude levels able to achieve excellent precision
  - Lowest subjectively reported and objectively measured workload of the systems assessed

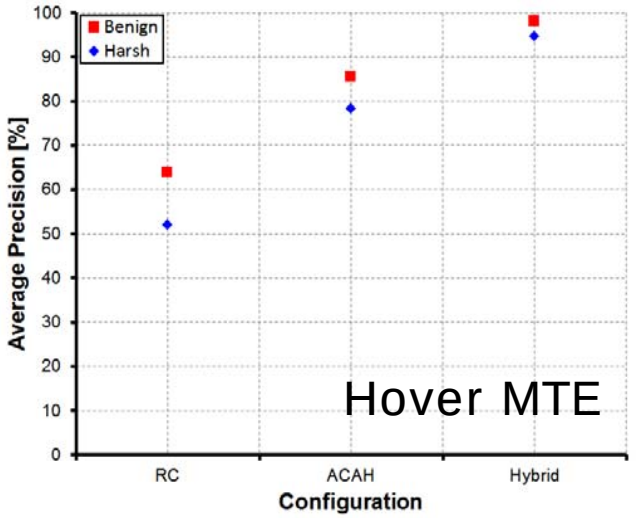


[2]Perfect, P. *et al*, "Towards Handling Qualities Requirements for Future Personal Aerial Vehicles", 69th Annual Forum of the American Helicopter Society, Phoenix, AZ, May 2013

Study: Harsh Environmental Conditions

- It has also been shown that TRC response type was suitable for hover and low speed flight in a 'harsh' environment[3]
- Interesting as ADS33 shows increased augmentation required for Level 1 HQs as UCE degrades





UCE = 2

[3]IPerfect et al., Investigation of Personal Aerial Vehicle Handling Qualities Requirements for Harsh Environmental Conditions, 70th Annual Forum of the American Helicopter Society International, Montreal, Canada, May 2014

Study: Test Syllabus Development[4]

- Hybrid configuration selected to train flight-naïve pilots on

Speed Range	Pitch	Roll	Yaw	Heave
<15kts	TRC	TRC	RC	VRC
blend	Instantaneous at 15kts (accel) and 0kts (decel); internal logic to eliminate transients	Smoothed transition between 15-25kts	Smoothed transition between 15-25kts	Smoothed transition between 15-25kts
>25kts	ACSH	ACAH	$\beta C + TC$	γC

[4]IPerfect et al., Development of Pilot Training Requirements for Personal Aerial Vehicles, 40th European Rotorcraft Forum, Southampton, September 2014

Study: Test Syllabus Development

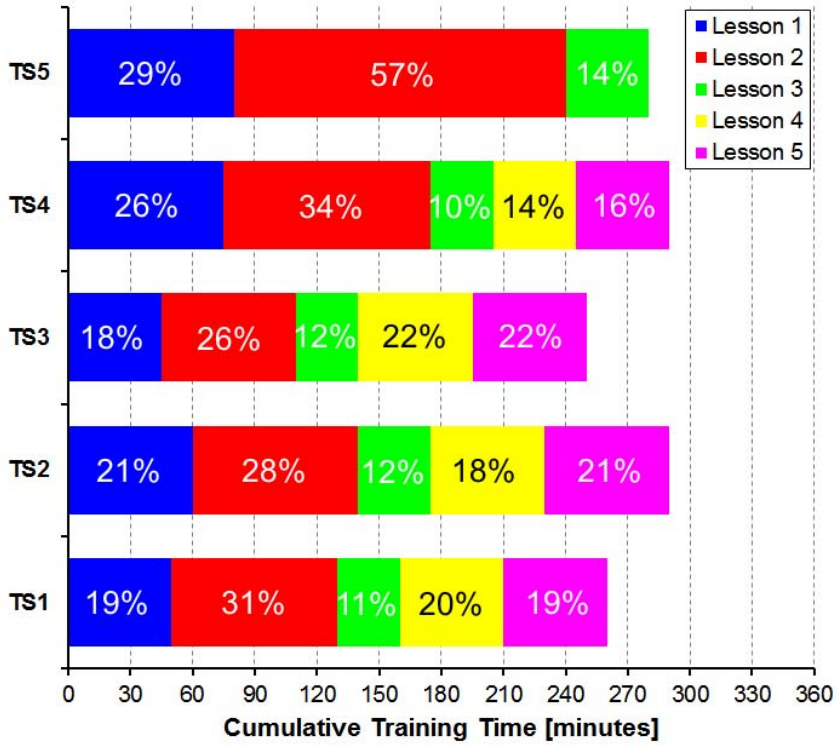
- Existing relevant (UK) syllabi and philosophies for driver and private pilot training were reviewed
  - Interview with Driving Instructor instructors
  - Interview with Private Pilot instructor
- Training programme developed based upon this review
- Kirkpatrick's Four Level Model used to assess the training programme's effectiveness
  - Level 1 – trainees engagement and satisfaction – questionnaire
  - Level 2 – immediate demonstration of learning – skills test
  - Level 3 – longer term application of the learning – commute scenario
  - (Level 4 – long term benefit – not used for this study)

Study: Training Programme Development

- 24 skills identified
  - Using longitudinal inputs in hover to control forward speed (TRC)
  - Using lateral inputs in hover to control lateral speed (TRC)
  - …
- Exercises designed to introduce each skill
- 5 Lessons created from these exercises
  - Hover and Low Speed Flight
  - Cruising Flight
  - Transition
  - Advanced Functions
  - Typical PAV-specific Manoeuvres e.g. vertical landing, descending approach to hover
- Brief, demonstrate, do, practice

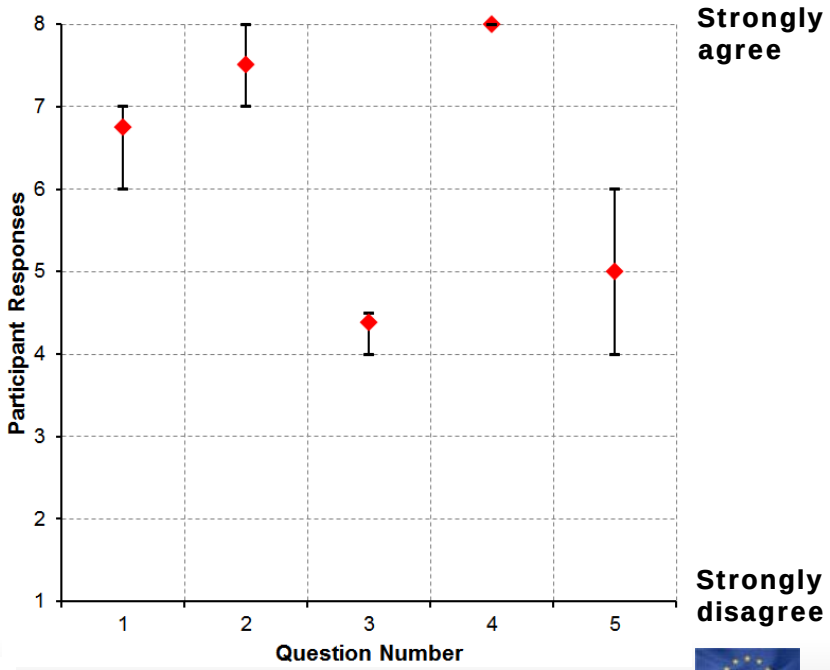
Study: Training Programme Development

- 5 test subjects (TS). 4 male, 1 female. Age 22 – 45. 5 – 25 years driving experience. No flying experience.
- 4 of 5 TS completed the syllabus < 5 hours
- 1 did not complete in 5 hours (aptitude testing indicated this might be the case)
- Consistent distribution of lesson time required although amount of time differs
- Lesson 2 was more demanding – simultaneous multiple coordinated control inputs required



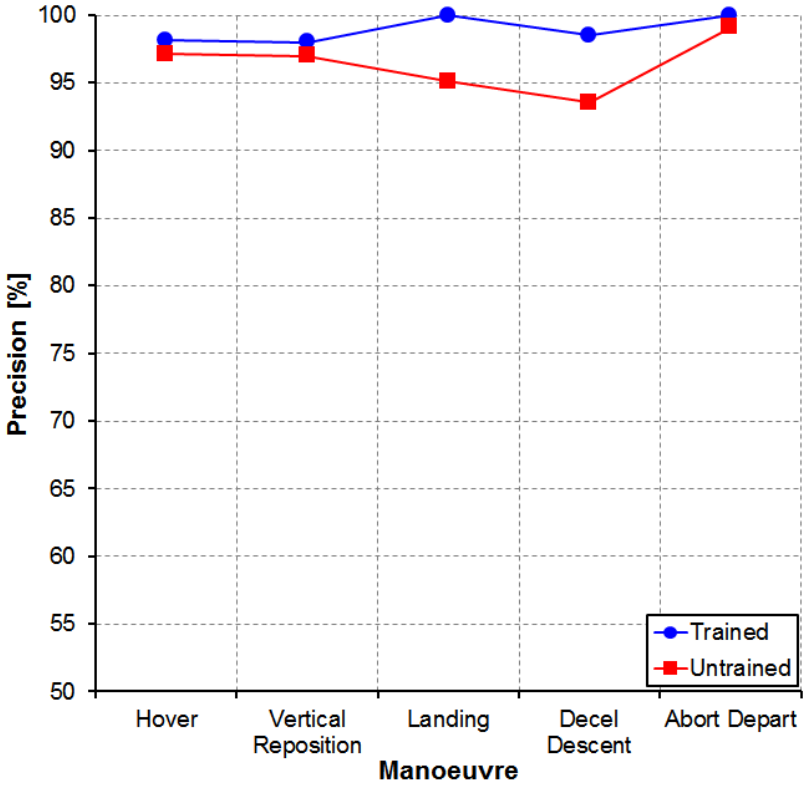
Level 1 Evaluation – Participant Satisfaction

- 5 specific questions with quantitative answers plus a number of open questions to explore their responses
  1. To what extent do you feel that you have learned the skills necessary to fly a PAV from the programme?
  2. Was the programme stimulating?
  3. Was the pace of the programme appropriate for you?
  4. Was the programme sufficiently flexible to meet your needs?
  5. Was the programme challenging?
- Rated as being effective
- Neither too slow not too fast
- Sufficient challenge to engage



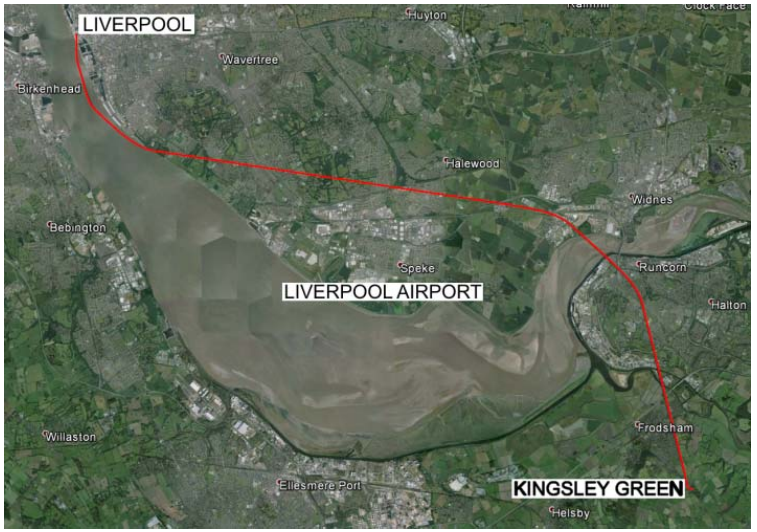
Level 2 Evaluation – Skills Test

- Skills test consisted of 5 MTEs defined earlier in the project
- 'Desired' performance boundaries set
- 'Precision' – a measure of time spent within desired boundaries
- Some improvement, but TRC has already been shown to be 'intuitive'



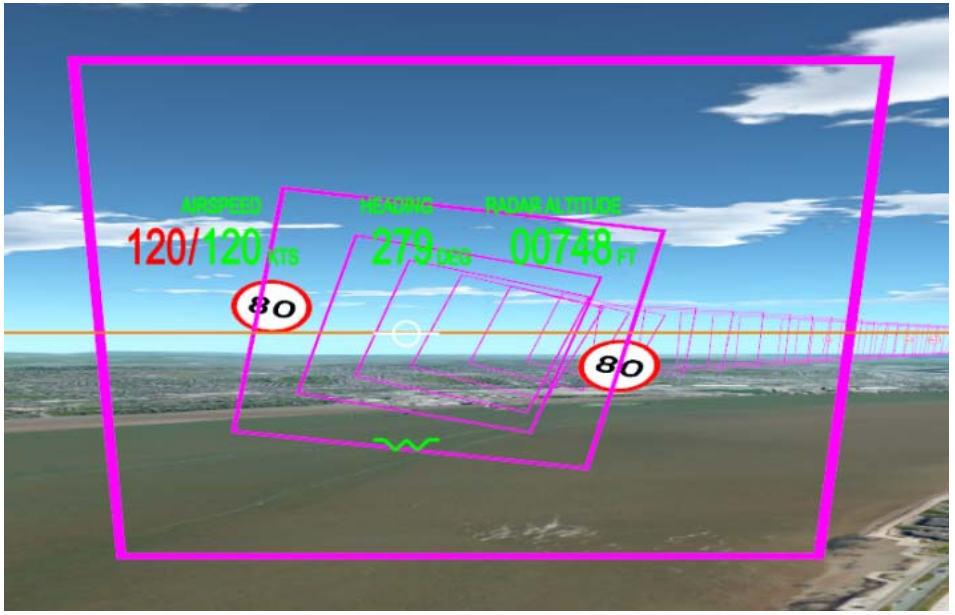
Level 3 Evaluation – Real World Commute

- Psuedo-equivalent to ‘driving test’ or ‘qualifying cross country’
- Check to see if skills developed allowed the TS to fly a ‘real-world’ task
- Commute from Kingsley Green to Liverpool waterfront



Level 3 Evaluation – Real World Commute

- Considerably higher traffic densities and management are assumed to exist as part of the scenario
- Highway-in-the-Sky developed to aid navigation (not part of syllabus)
- Separate part of project assessing 'optimum'



Level 3 Evaluation – Real World Commute

- 4 TS's that completed their training also completed this test without incident
- TLX average of 24, maximum 30 (c.f. 55 – 60 for simulated urban environment)

Concluding Remarks

- 'Hybrid' configuration shown to be the one most suited for the widest range of aptitude pilots from those tested
- 'Hybrid' configuration suitable for both benign and harsh environmental conditions – no requirement to increase augmentation beyond this as per ADS33
- Training programme developed – preliminary results indicate that it is possible to train flight-naïve pilots to have the necessary handling skills within a reasonable time frame
- These result now provide early design requirements for PAV manufacturers

The work reported in this presentation was funded by the EC FP7 research funding mechanism under grant agreement no. 266470

Thank you for your attention

QUESTIONS?

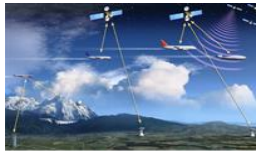
Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

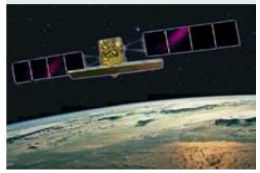
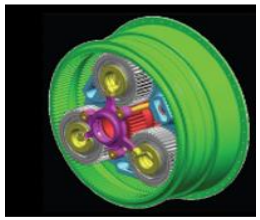
The Stratosphere Challenges to Aeronautics & Space R&T

4th EASN Association International Workshop, 29th October 2014
Aachen, Germany

Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

The Challenges



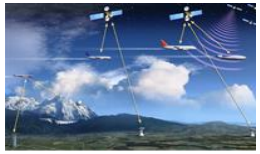



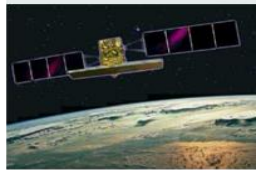
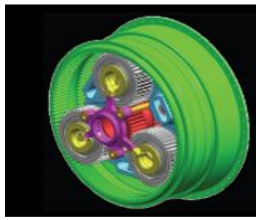
- The hypersonic flight is a technological challenge:
  - The past experience in the context of supersonic flight, hypersonic and space
  - The various key technologies that may be enabling to integrate a system that can achieve high flight Mach and to shorten the time of travel.
- The hypersonic flight is also a political challenge:
  - Why shorten the time?
  - Who will benefit and with that kind of perspective?

TWO VISIONS

Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

Two Visions

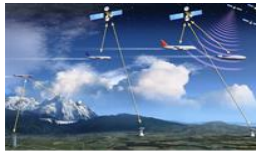


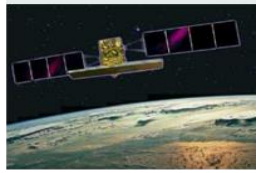
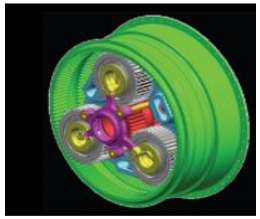



- Two types of vision: civil and military
  - The civil view – mainly EU vision - in which the technology allows intercontinental travel in less time with a level of comfort comparable to that in the Concorde, opening a new chapter of human transport if mature technological conditions but also economic, a business model based on the application of hypersonic flight at a competitive price.
  - On the military side – mainly the US vision – based on the ability to transport payloads to hypersonic speed that could lead to a new paradigm of air power, with the anti missile defence or anti aircraft rendered obsolete by the speed of penetration.

Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

Recent International Symposium



- A stock-taking of the latest developments in the field of hypersonic flight and an open discussion among all concerned stakeholders leading to the identification of possible synergies and innovative forms of national, European as well as international cooperation.
- Progress on practical application of enabling technologies both in favour of current activities in space as well as of the orderly and shared utilization of that sector of the sub-orbital space.

- Among the speakers:
  - Pasquale Preziosa, Chief of Staff of the Italian Air Force;
  - Roberto Battiston, President, Agenzia Spaziale Italiana;
  - Jean-Pierre Darnis, D. Director, Security & Defence Sector, Istituto Affari Internazionali, Roma;
  - Richard Morgan, Director, Centre for Hypersonic, The University of Queensland;
  - Roberto Vittori, Astronaut, Space Attaché, Italian Embassy, Washington, DC

Hypersonic

from 100.000 to 400.000 ft

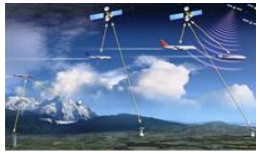
First Symposium on Hypersonic Flight

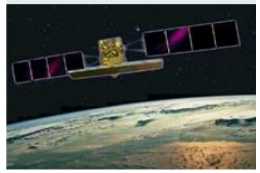
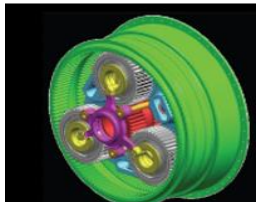
ROME
JUNE 30th
JULY 1st
2014

ASSOCIAZIONE ARMA AERONAUTICA
CESMA
Centro Studi Militari Aeronautici Giulio Douhet

CTNA
Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

Activities on Hypersonic Flights



USA Space-planes

(with huge investments)

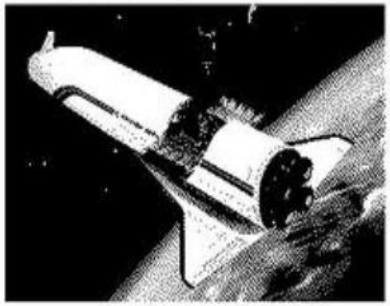
- X-vehicles high speed
- NASP / Rockwell/X-30
- DC-X (BMDO)
- SSTO X-33/Venture Star
- ASTP
- Scramjet experiments

ESA Launch Systems

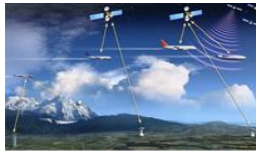
- A5 + Hermes
- Hotol
- Saenger II
- FESTIP
- FLTP
- FLPP

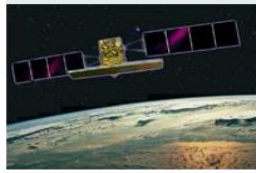
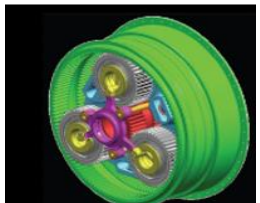
PROPOSED

Horizontal Take Off and Landing Spacecraft (HOTOL)



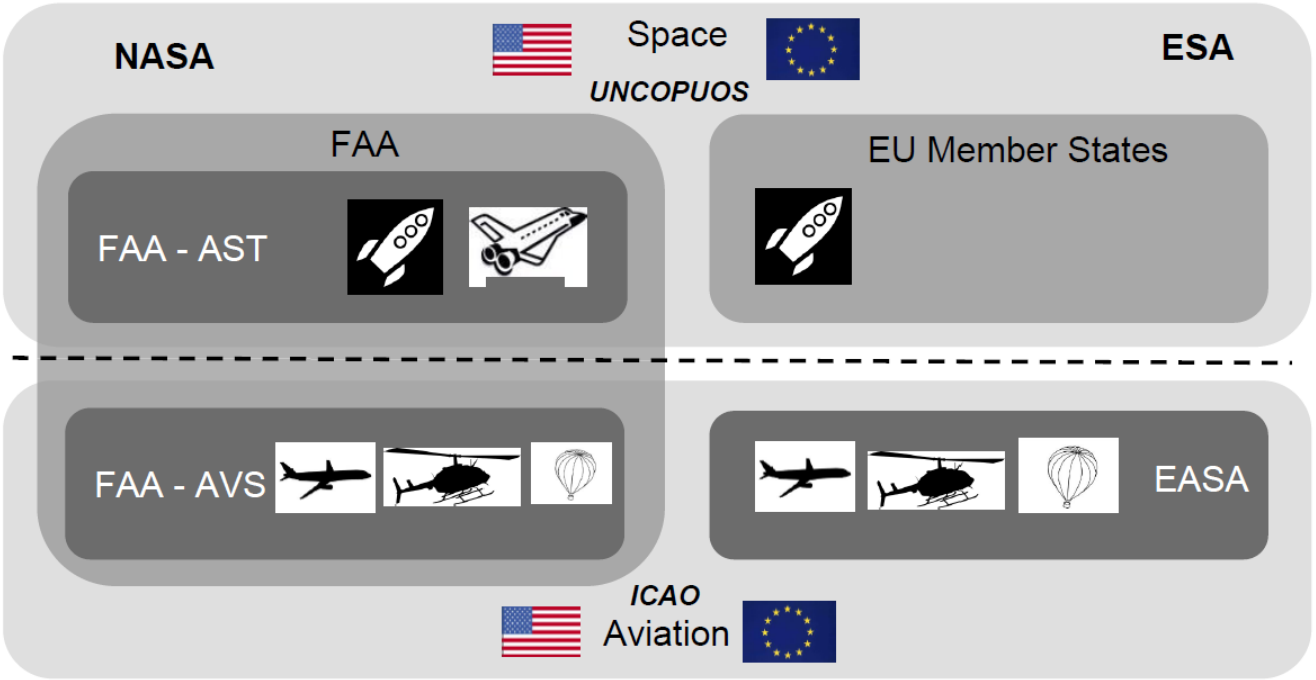
Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology



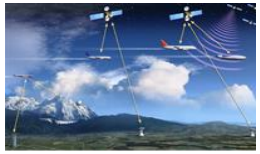



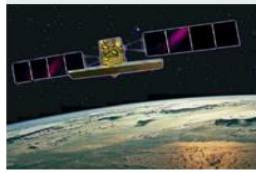
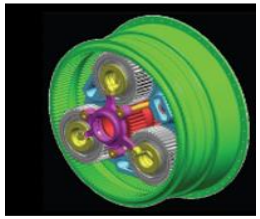
EU-US differences

EU has not decided on jurisdiction for commercial hypersonic and on regulatory framework



Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

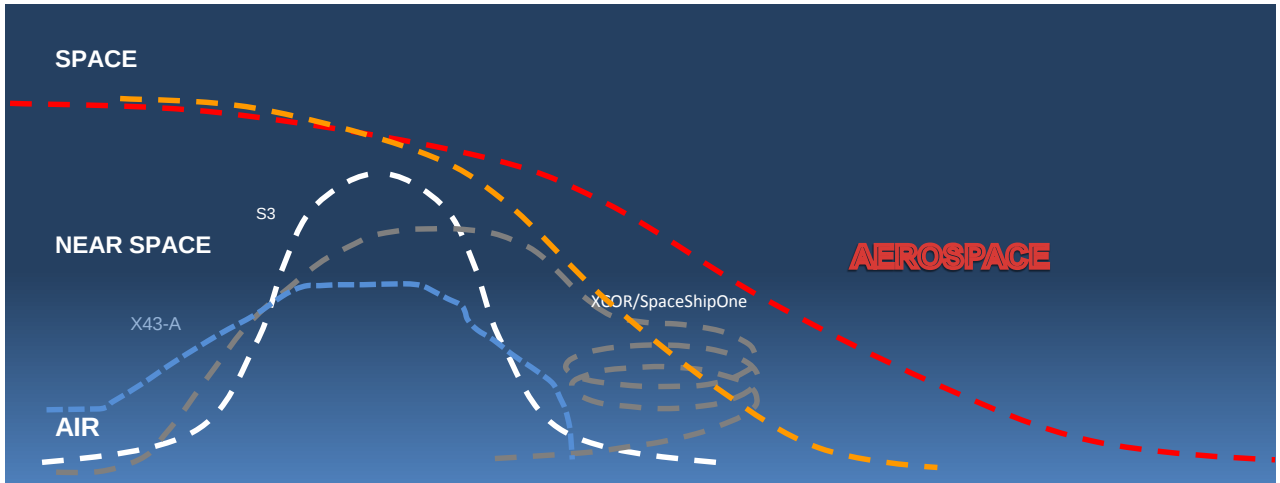


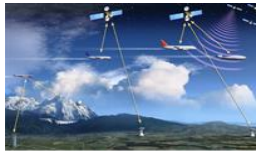
Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

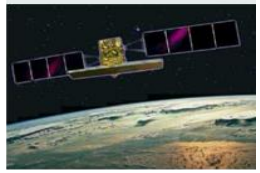
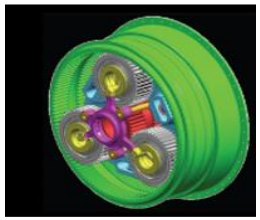
EU Regulatory effort

- Scattered regulatory effort on going in EU
  - Netherlands: regulation is to be launched in Curacao for Space Expedition Corporation operations
  - Sweden: works towards a national regulation to allow to fly from Spaceport Sweden
  - UK: the UK Space Agency and Airworthiness Authority have instituted a working group from 2011 to address regulatory matters for commercial space flights
  - Italy: ENAC-FAA Memorandum of Cooperation signed on may 2014 for the introduction of sub-orbital flights in the national airspace



EU Position

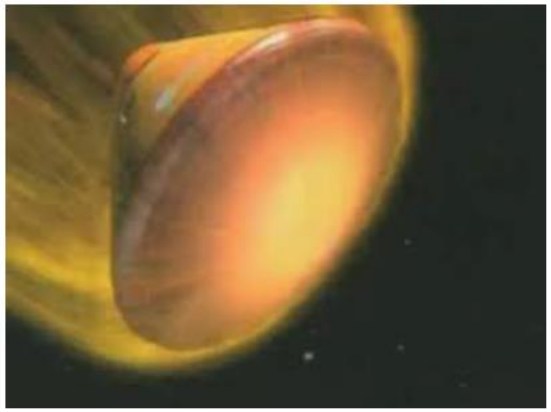


- Europe must be present on parts of the fundamental technology, but also as a potential partner of the USA in the generation of future systems, even to meet the needs huge capital to invest.

- Most parts of Europe will develop key technology, the greater will be its voice in chapter within the Atlantic Alliance, not only with regard to the production but also for the use of technology (ITAR Regulation)

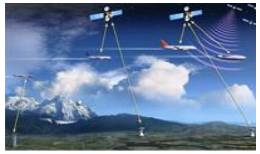
ARD Athmospheric Reentry Demostrator

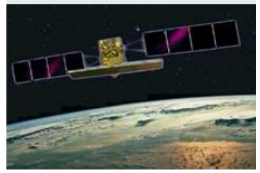
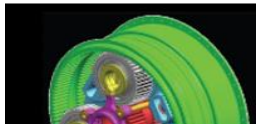


IXV - Intermediate Experimental Vehicle

Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

Italian situation



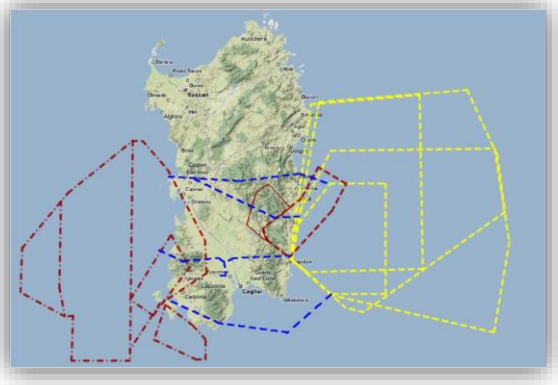
Italy has become a major player in Europe on hypersonic re-entry systems & technologies, leading the major projects currently running

Existing Facilities

- Centre for Italian Aerospace Research (CIRA) for engineering support
- Existing airports easily tailored to sub-orbital requirements and presented in the fashion of Spaceports
- Test Ranges and Flight Test Centre to manage experimental aerospace campaigns
- Ground Systems for surveillance and tracking of airspace and near-space systems used during sub-orbital flights

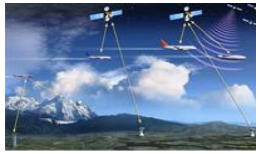
Personnel & Expertise

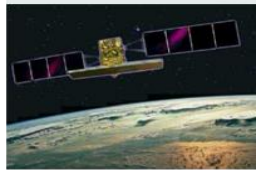
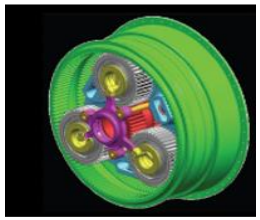
- ITAF knowledge to manage flight tests/trials with a focus on launch and re-entry:
- Astronauts from Italian Air Force
- Experimental Test Pilots & Engineers
- Flight surgeons
- ENAC Professionals for certification, licensing and oversight



CTNA
Cluster Tecnologico Nazionale Aerospazio
Italian Cluster for Aerospace Technology

EU way ahead



- Europe must step up its efforts in this area, leaving space for the development of dual use technologies that can then be the fundamental "tiles“ for future systems in the field of new materials, engine, systems ...
- Europe has always had a special relationship with science and technology, as proven by history that the ESA from the framework Programmes for Research and Innovation of the European Commission. The hypersonic represents a further opportunity to make progress, and to contribute to the development of technological and industrial capabilities of the European sector.
- It could be an opportunity to push the European Commission, at the time of the further definition and specification of the Horizon 2020 Work Programmes following the 2016 Programme to focus on research projects enabling technologies related to hypersonic flight, for example in the field of materials and avionics.

Main activities in Flight Physics & Aircraft Design in Clean Sky

Giuseppe Pagnano

Clean Sky *- Coordinating Project Officer*

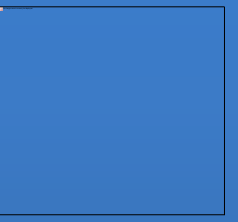
4th EASN Association International Workshop on Flight Physics and Aircraft Design
University of Aachen – 27-29 October 2014

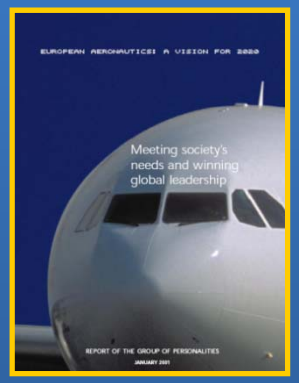
www.cleansky.eu

Summary

1. Background
2. Clean Sky current activities in ITDs and demonstrators. Flying Test Beds
3. H2020 / Clean Sky 2
4. Concluding remarks

Background: The ACARE SRA Goals for 2020





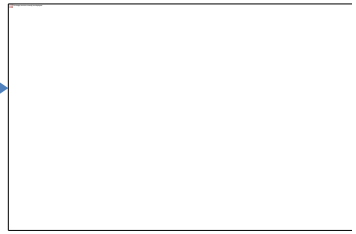
June 2000: Vision 2020

October 2002 SRA-1

October 2004 SRA-2

February 2008
Take-Off

2007 - 2013



CO_2 emissions reduced by 50%

NO_X emissions reduced by 80%

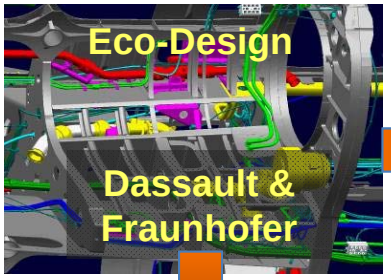
Noise reduced by 50%

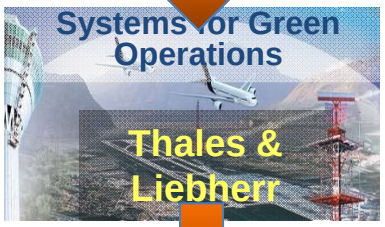
Clean Sky
JOINT UNDERTAKING

Integrated Program Structure

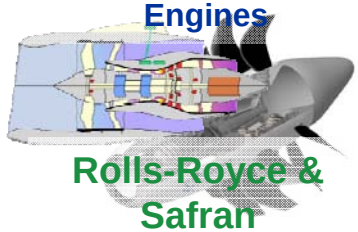
Clean Sky Technology Evaluator
DLR & Thales

Concept Aircraft





Sustainable and Green Engines



TECHNOLOGIES & DEMONSTRATORS

Clean Sky
JOINT UNDERTAKING

University participation in Clean Sky

106
Calls-1-16

Clean Sky 2

Flight Physics & Aircraft Design activities

Clean Sky 2

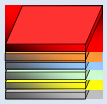
Green Regional Aircraft ITD

5 Technological Domains

Innovative structures (Low Weight Configuration)

- ✓ Lower weight
- ✓ Lower maintenance costs **through**

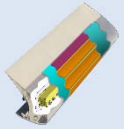
multifunctional composites, advanced metallic materials, structure health monitoring



Innovative systems (All Electrical Aircraft)

- ✓ Lower fuel consumption **through**

Bleed less architectures, Limited hydraulics, Energy management



Advanced aerodynamics (Low Noise Configuration)

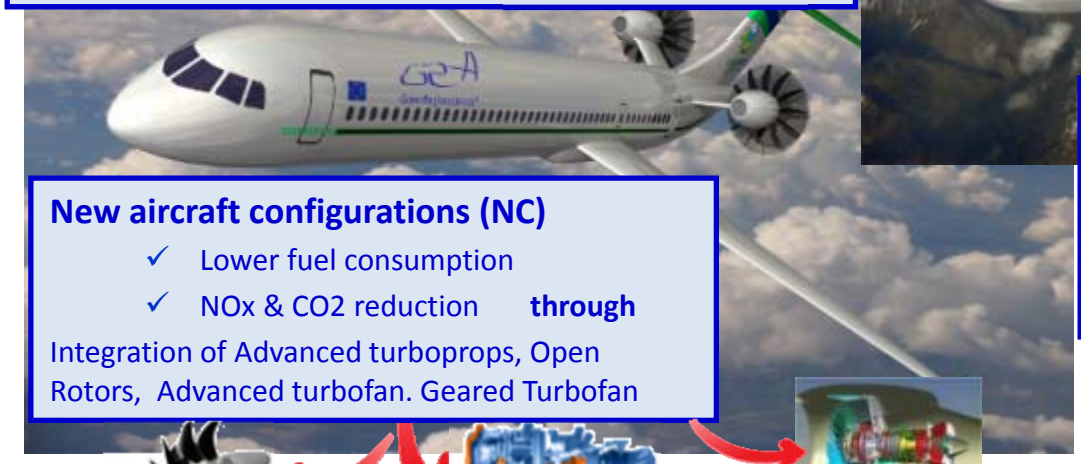
- ✓ Improved aerodynamic efficiency
- ✓ Drag reduction
- ✓ Lower Airframe external noise **through**

innovative solutions for wing and high lift devices and **landing gears**

New aircraft configurations (NC)

- ✓ Lower fuel consumption
- ✓ NOx & CO2 reduction **through**

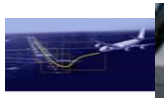
Integration of Advanced turboprops, Open Rotors, Advanced turbofan. Geared Turbofan



Evaluation of new avionics architecture in MTM domain for

- ✓ Fuel & noise reduction
- ✓ Lower Maintenance costs **through**

Upgraded capabilities for MTM



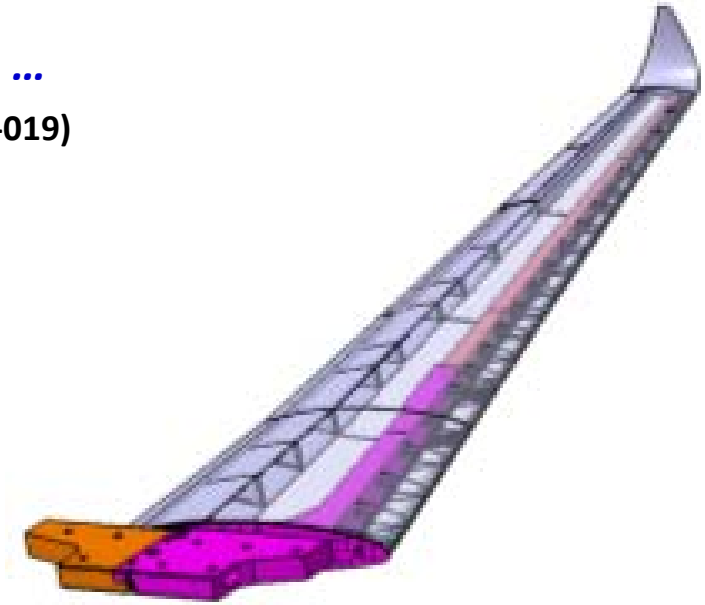
Clean Sky
JOINT UNDERTAKING

Green Regional Aircraft - Low Noise Configurations

Toward Technologies Demonstrations …

Project ETRIOLLA (CfP JTI-CS-2012-01-GRA-02-019)

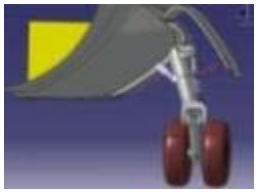
- **WT Model mechanical design**
- **WT Model manufacturing**

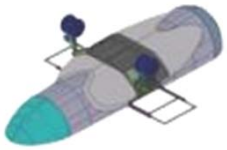


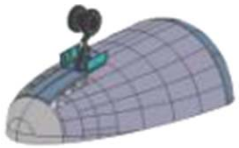
NLF WING
1:3 (≈ 5.3m span)
WT FLEXIBLE MODEL
MECHANICAL DESIGN

Green Regional Aircraft - Low Noise Configurations

Project ALLEGRA







MLG installed configuration (gear, bay, doors, belly fairing, portion of fuselage) **1:2 WT Model**

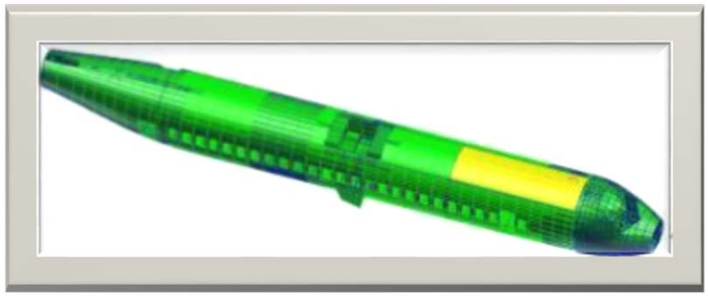
NLG installed configuration (gear, bay, doors, portion of Fuselage) **1:1 WT Model**

- ❑ **WT Models mechanical design**
- ❑ **NLG WT Model manufacturing**
- ❑ **MLG WT Model manufacturing**
- ❑ ***NLG WT Tests:*** Oct. 2014 - Pininfarina, Turin, Italy
- ❑ ***MLG WT Tests:*** Dec. 2014 - Pininfarina, Turin, Italy

NLG 1:1 WT Model

Clean Sky
JOINT UNDERTAKING

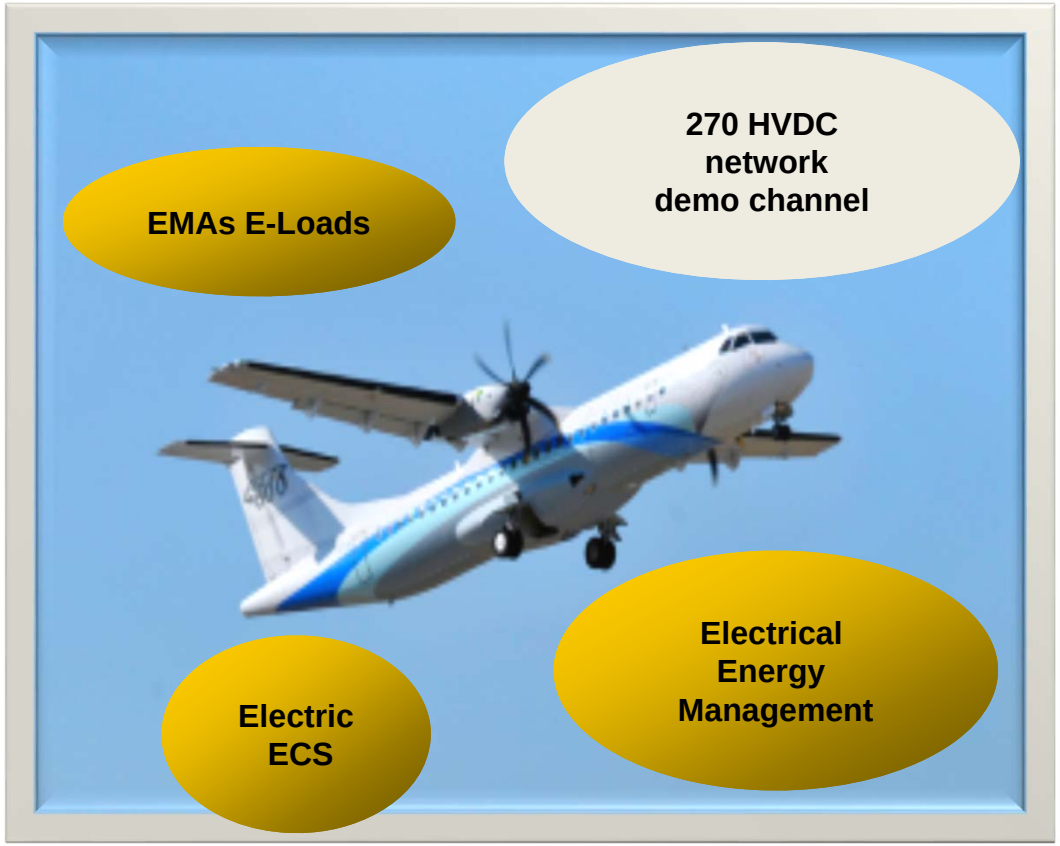
ATR 72 Flight Test Demonstrator:
Applied Modification



Low Weight Configuration

Current planning:

- **Characterization tests in Dec 14**
- **Install of fuselage panel and instrumentation**
- **Structure Tests in March 15**
- **After restoring the structure, electrical mods and tests (June 15)**



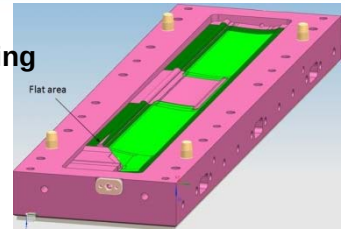
All Electrical Aircraft

Clean Sky
JOINT UNDERTAKING

Green RotorCraft

GRC1 - Rotor blades

Section of Model rotor blade tooling



- **Active Gurney Flap**
- Model blade; 2D Static test; 2D dynamic tests.
- AGF Main Blade design

- **Active Twist rotor blade**

- **Optimized Passive blade**.

Mould for Active Twist blade specimen

GRC2 - Drag Reduction

- EC135 demonstrator

ERICA optimised geometry in RUAG wind tunnel (DREAM-Tilt)

- Wind tunnel tests of **ERICA tilt-rotor** optimized geometry in RUAG

Common H/C platform in PoliMi wind tunnel (ROD)

- Wind tunnel tests of the optimised geometry of the **common helicopter platform**

.

- EC155 model featuring optimised hub fairings

Green RotorCraft Technical Progress

GRC4- High Compression Engine

(Diesel burning kerosene)

Engine bench tests on bench (Partners project **HIPE AE-440**):

- Core engine endurance finished in Sept 2014
- Powerpack endurance (needed for Permit to Fly)

Flight Demonstrator Helicopter (Airbus-Helicopters):

- Iron Bird test exploitation confirms addressed risks successfully removed
- Flight Demonstrator assembly finished
- **Ground tests scheduled Nov 2014**

Extra activities agreed, to be implemented in GAM Amendment:

- **Flight demonstration** campaign (TRL6 gate): **mid-Dec 2014 to end March 2015**

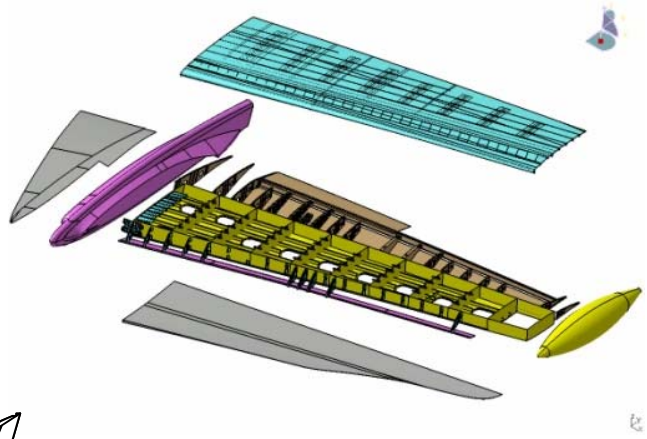
Smart Fixed Wing Aircraft

A340 FTB – Breakthrough Laminar A/C demonstrator

Smart Fixed Wing Aircraft

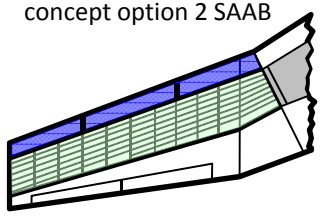
Smart Passive Laminar Flow Wing

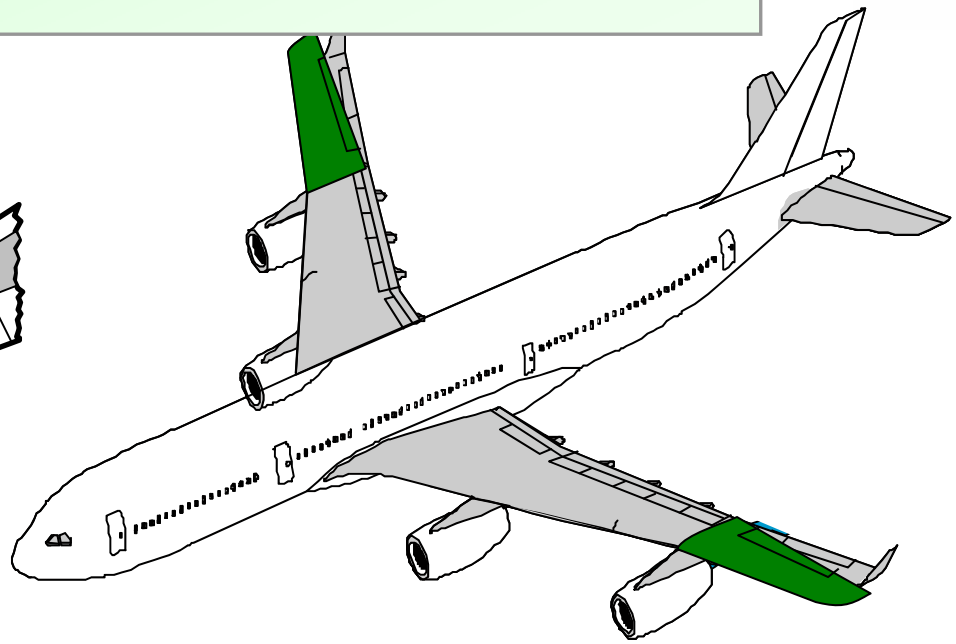
- Design of an all new natural laminar wing
- Proof of natural laminar wing concept in wind tunnel tests
- Use of novel materials and structural concepts
- Exploitation of structural and system integration together with tight tolerance / high quality manufacturing methods in a large scale ground test demonstrator
- Large scale flight test demonstration of the laminar wing in operational conditions



Port wing

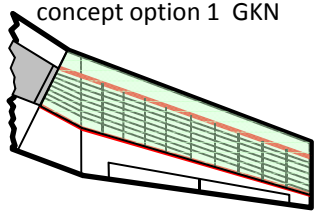
Laminar wing structure concept option 2 SAAB





Starboard wing

Laminar wing structure concept option 1 GKN



Clean Sky
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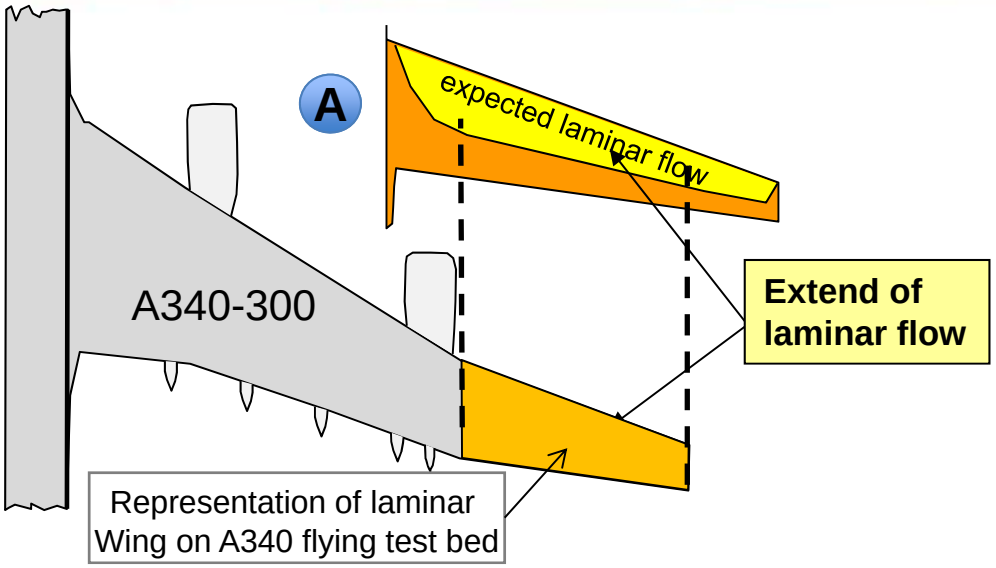
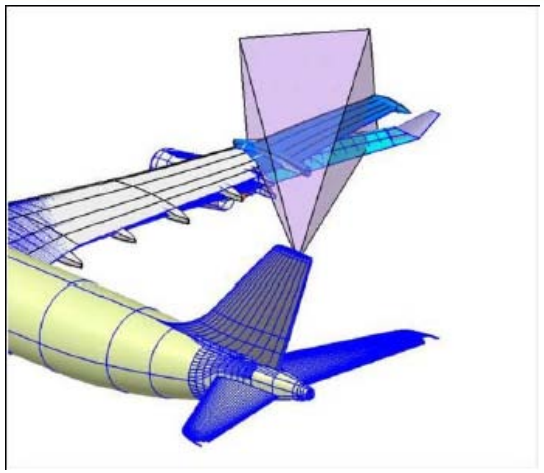
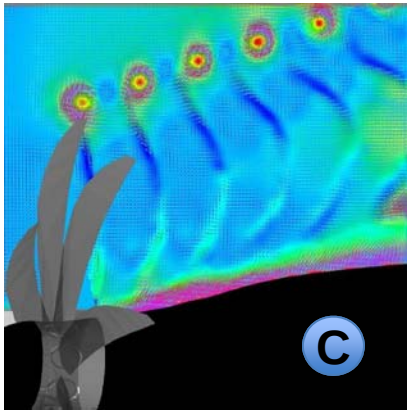
Smart Fixed Wing Aircraft

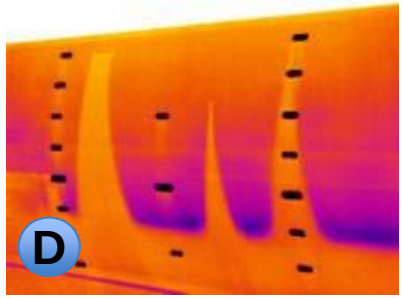




Smart Wing observation camera view angle from new observer pod position on top of fin(Airbus) B



Phase locked PIV for quantitive wake-flow diagnostics of CROR-blades in flight (Illustration: DLR, 2009)



Infrared Image of laminar – turbulent flow transition on wing surface (ONERA)

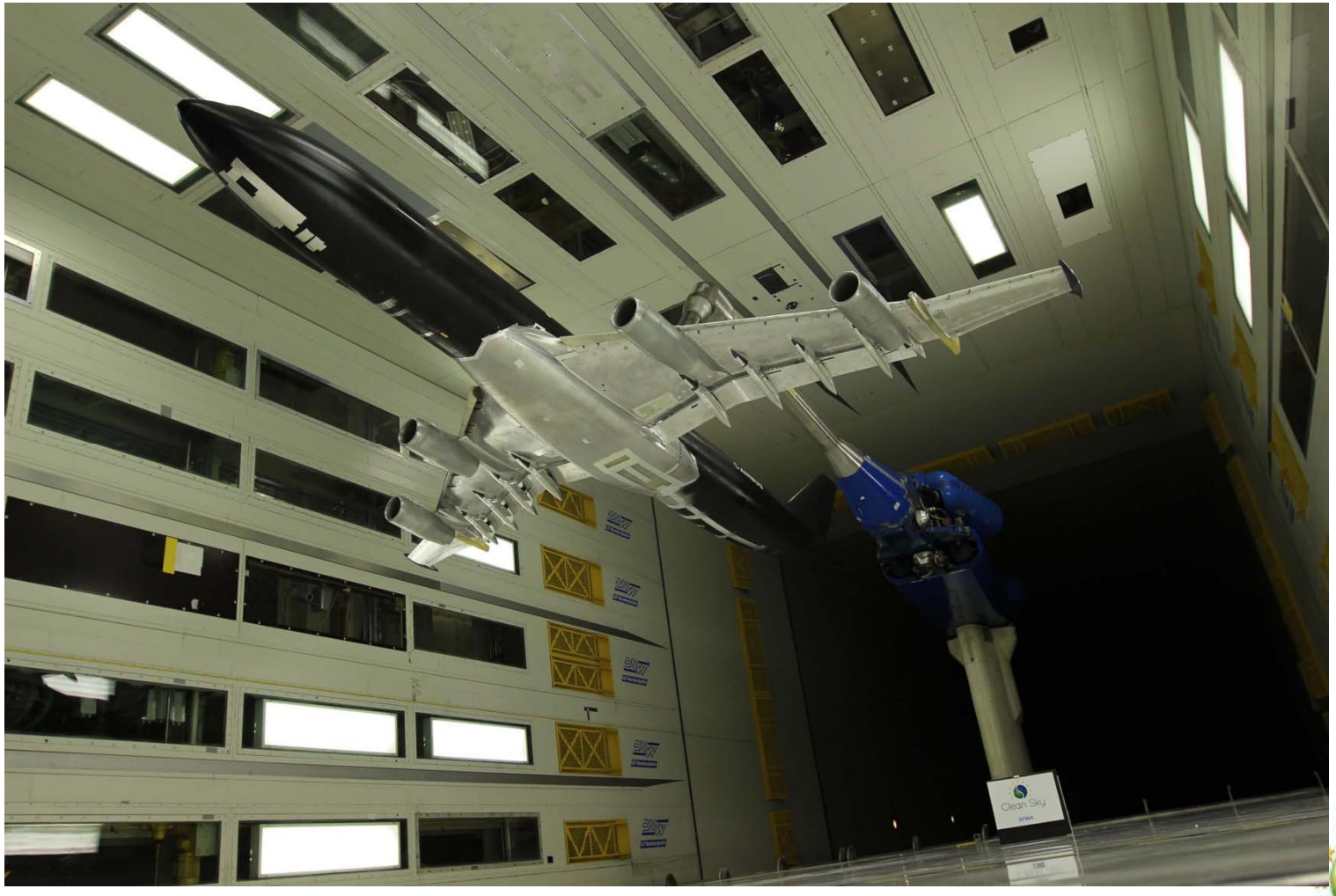
Flush mount hot film sensor for the detection of flow separation (ONERA)

In-Flight Monitoring of Wing Surface with Quasi tangential Reflectometry and Shadow Casting "WING REFLECTOMETRY" (FTI)

CleanSky Confidential

Smart Fixed Wing Aircraft

A340 FTB – Breakthrough Laminar A/C demonstrator

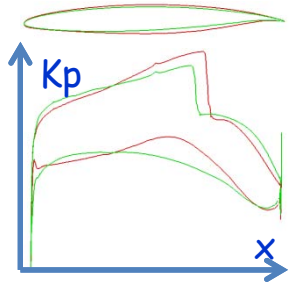


SFWA-ITD Progress

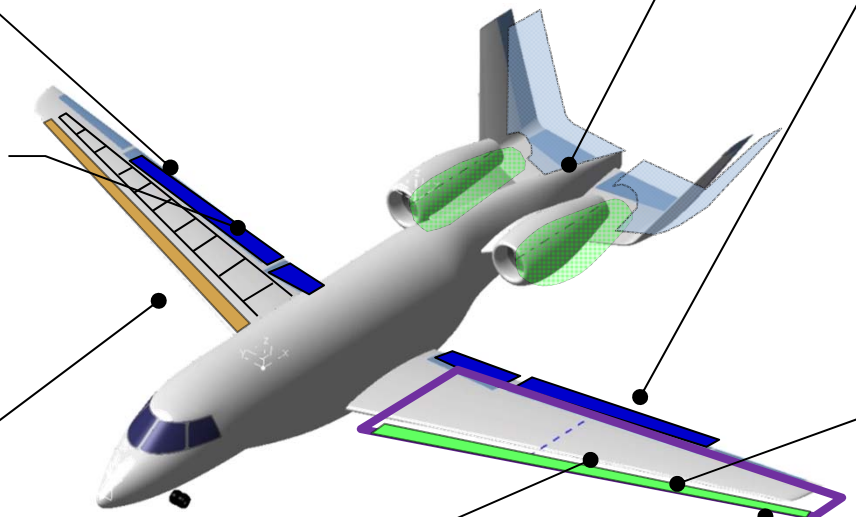
Smart Flaps

Innovative Rear Empennage

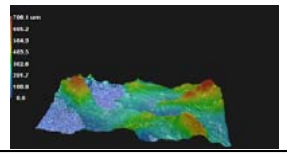
Natural Laminar Flow Wing



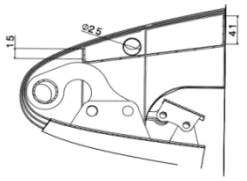
Structures and systems integration for innovative Wing



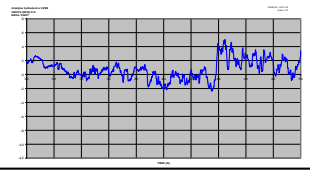
Leading Edge Coating



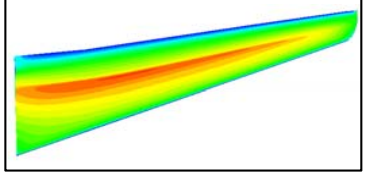
Krueger Flaps for laminar wing



Load and vibration alleviation



High Aspect Ratio

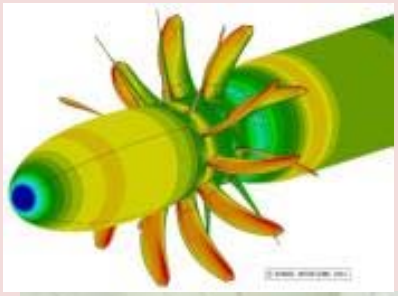


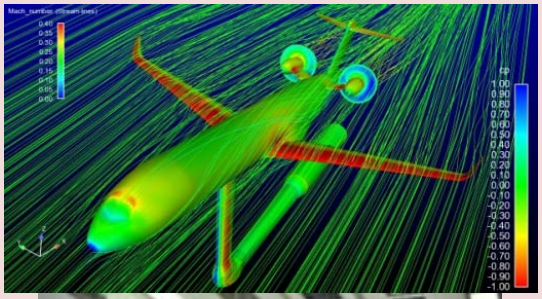
CROR aerodynamics and acoustics progress

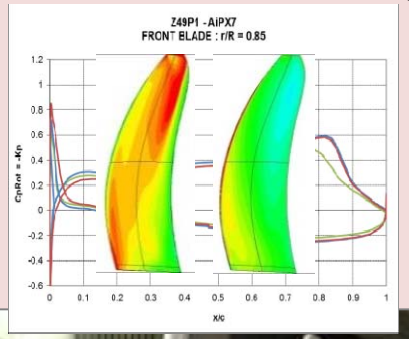
Progress in numerical simulations

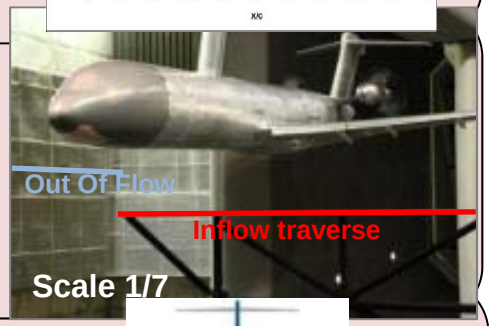
High Fidelity Wind Tunnel Testing

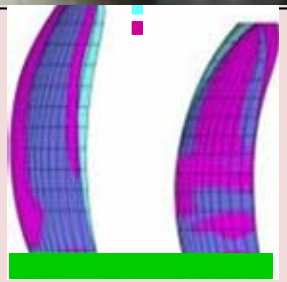
Analysis and design

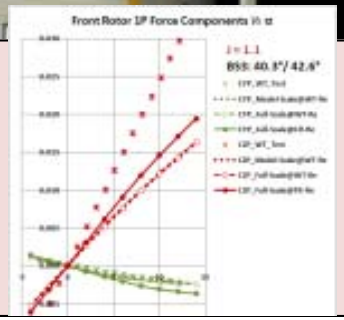


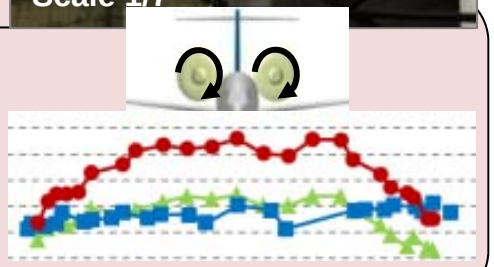




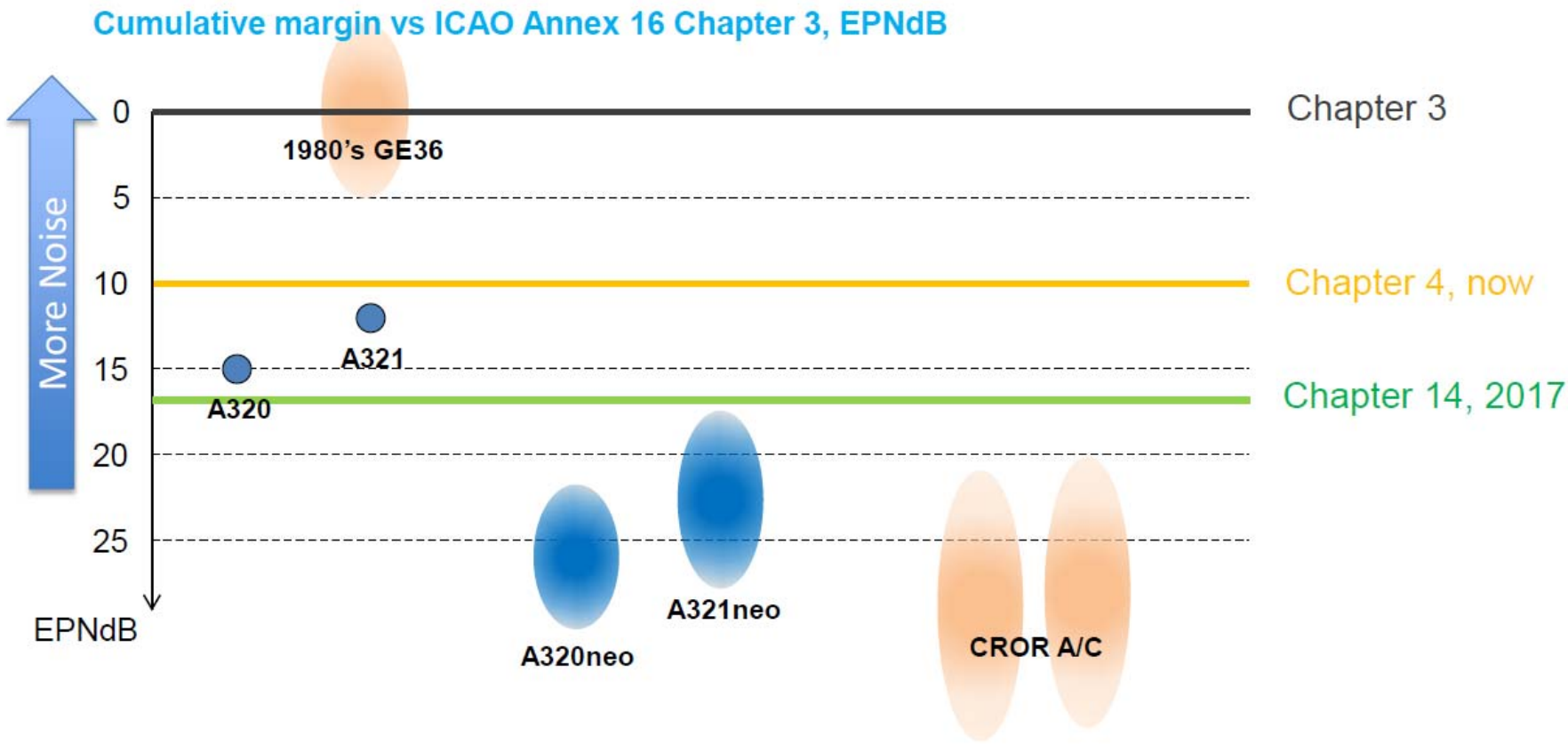








CROR aerodynamics and acoustics progress



CROR Aircraft community Noise Levels are expected to be compliant with future regulations

Clean Sky

SAGE 3 Progress

Advanced Low Pressure System (ALPS)

Composite Fan test

- Engine installed on RR test stand at Stennis, USA.
- Outdoor crosswind and tailwind testing completed, key tests for flight clearance.
- Currently waiting test bed re-configuration to continue with noise and outdoor flutter testing.

Flying test bed

- **First flight on 15 October**

Clean Sky
JOINT UNDERTAKING

H2020 / Clean Sky 2

Clean Sky 2

General Overview of *Clean Sky 2*

Innovation Takes Off

www.cleansky.eu

Clean Sky 2

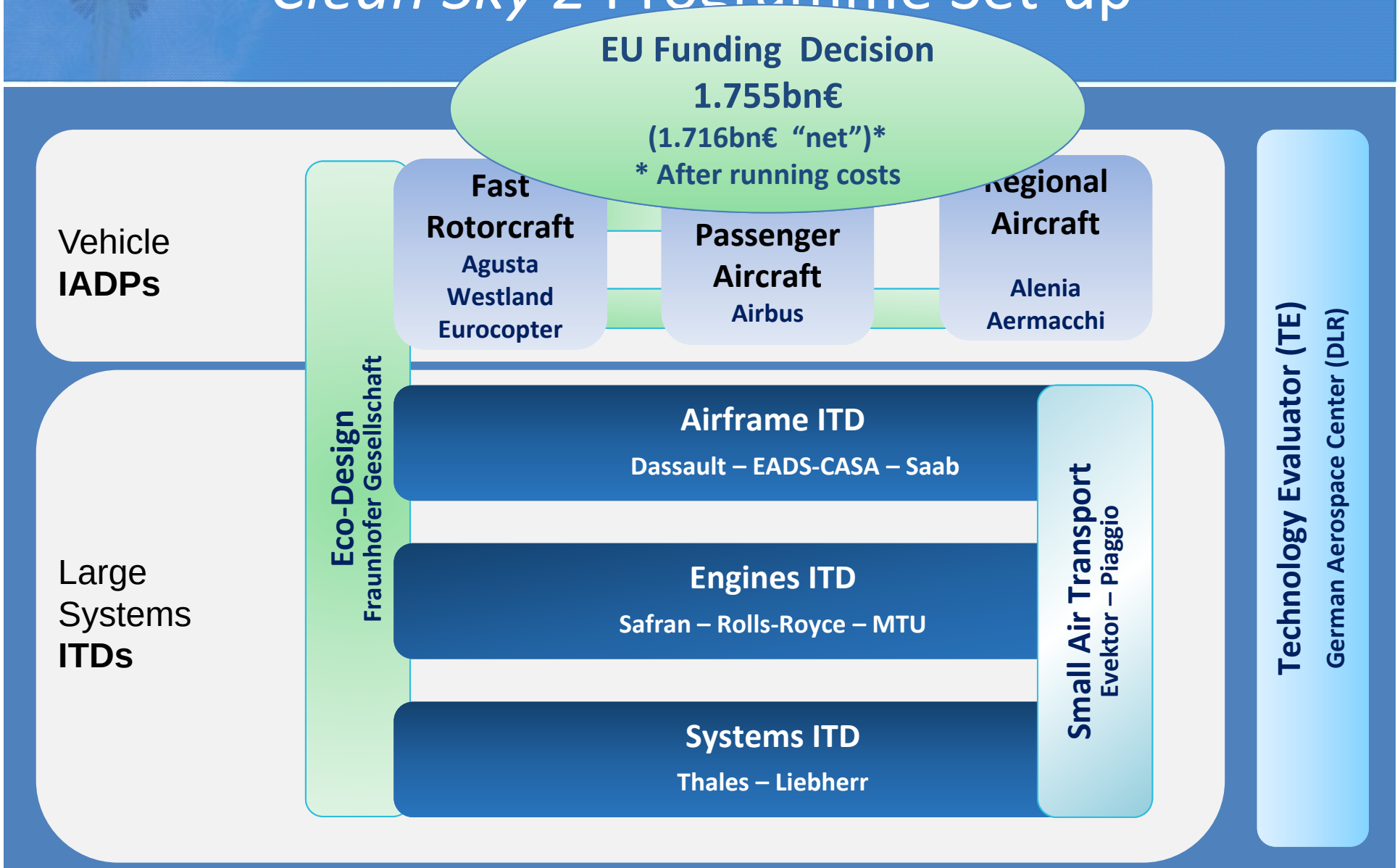
Addressing the Horizon 2020 Challenges

- **"Smart Green and Integrated Transport"**
  - **Resource efficient transport that respects the environment**
  - **Ensuring safe and seamless mobility**
  - **Building industrial leadership in Europe**

Enhancing and leveraging innovation capability across Europe, with a strong emphasis on SME participation

Clean Sky
JOINT UNDERTAKING

Clean Sky 2 Programme Set-up



Building on Clean Sky, going further into integration at full aircraft level
And developing new technology streams for the next generations of aircraft

Not legally binding

Example of CS2 program content

Large Passenger Aircraft (LPA)

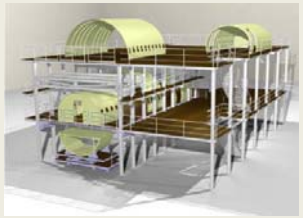
TRL 4-6
Aircraft Level

„Platform 1 - OAD“	„Platform 2 - OPD“	„Platform 3 - OSD“
Advanced Engine and Aircraft Configurations	Innovative Physical Integration Cabin-System-Structure	Next Gen. Electrical A/C Systems, Cockpit Systems & Avionics

Next Generation Propulsion system & integration

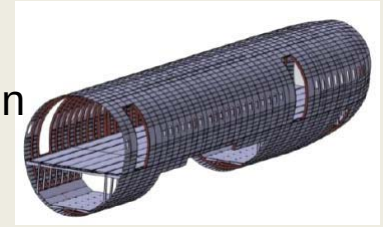
New aircraft configuration

Next Generation Cabin-Cargo

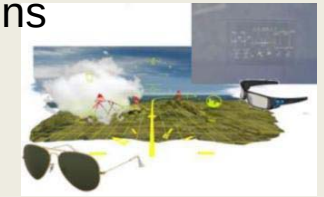


Next Generation Lower Fuselage

Integrated Structure, Cabin and Systems fuselage



Enhanced flight operations and functions



Next generation cockpit

Concluding Remarks

- Cost and complexity of demonstration in flight keep increasing
- Clean Sky has a fundamental role in demonstration funding for next years
- H2020 / Clean Sky 2 must adapt to the requirements from both industry and research
- Innovative configurations vs. Incremental development are conditioned by the EIS of new aircraft

CAPPADOCIA – Coordination Action Pro « Production, Avionics, Design » On Cost-efficiency in Aeronautics

CSA – FP7/2012/AAT

N°605414

Coordinated by: Efficient Innovation

Coordinator: Mr. Fabien Marty

CAPPADOCIA consortium

Legal Entity	Country	Membership	Contact person
Efficient Innovation	France	Aerospace Valley	Fabien Marty
ECD	Germany	Euromart IMG	Sepp Huber
AIRBUS	France	Euromart IMG	Jean-Claude Dunyach
EASN	Greece	EASN	Irene Pantelaki
CIRA	Italy	EREA	Marcello Amato
AERNNOVA	Spain	Euromart IMG	Miguel Angel Castillo
Aerospace Valley	France	EACP	Aude Nzeh Ndong
TAI – Tusas Turkish Aerospace Industries	Turkey	Euromart IMG	Erhan Solakoglu
NLR	Netherland	EREA	Johan Kos
INCAS	Romania	EREA	Claudia Dobre

CAPPADOCIA main objectives

- CAPPADOCIA will focus on research activities that address solely or mainly the SRA goal of **cost efficiency in Aeronautics and Air Transport** and in particular the following three technical domains:
  - **Design systems and tools**
  - **Production and maintenance**
  - **Avionics**
  - **Other relevant domains dealing with cost efficiency such as propulsion…**

- **Within** those major areas of the cost efficiency research landscape, CAPPADOCIA will:
  - **Analyse state-of-the-art**
  - **Identify scientific and technological gaps as well as bottlenecks to innovation and more**
  - **Formulate strategic recommendations** with the ambition to support the European Commission for orientation of future Work Programmes i.e. Horizon 2020

- CAPPADOCIA will **perform experts interviews and impact assessment campaign on EU-funded projects' achievements towards related cost efficiency ACARE goals.**

CAPPADOCIA expected main achievements

- CAPPADOCIA will enable to answer the **following main questions**:
  - Which are the main **gap and bottlenecks** (innovation, regulation, financing, etc) to the implementation of solutions with a significant impact on the achievements of cost efficiency objectives set by research policy makers?
  - Which are the most commonly encountered **cost reduction practices** in aviation for Design System and Tools, Production, Avionics?
  - Which actions should be launched or strengthened to **support the competitiveness** of the air transport sector ?

- CAPPADOCIA will contribute to a better coordination of research and innovation in the field of Aeronautics and Air Transport through:
  - A **yearly strategic recommendations report** to address the cost efficiency targeted research domains in term of state of the art and impact assessment towards ACARE goals and solutions achievements

- CAPPADOCIA will be committed to ensure:
  - A successful **dissemination of its results towards the targeted policy maker** audience through ACARE and the organised stakeholders (ASD, EREA, IMG4)
  - The **sustainability of the CAPPADOCIA achievements** after its contractual duration

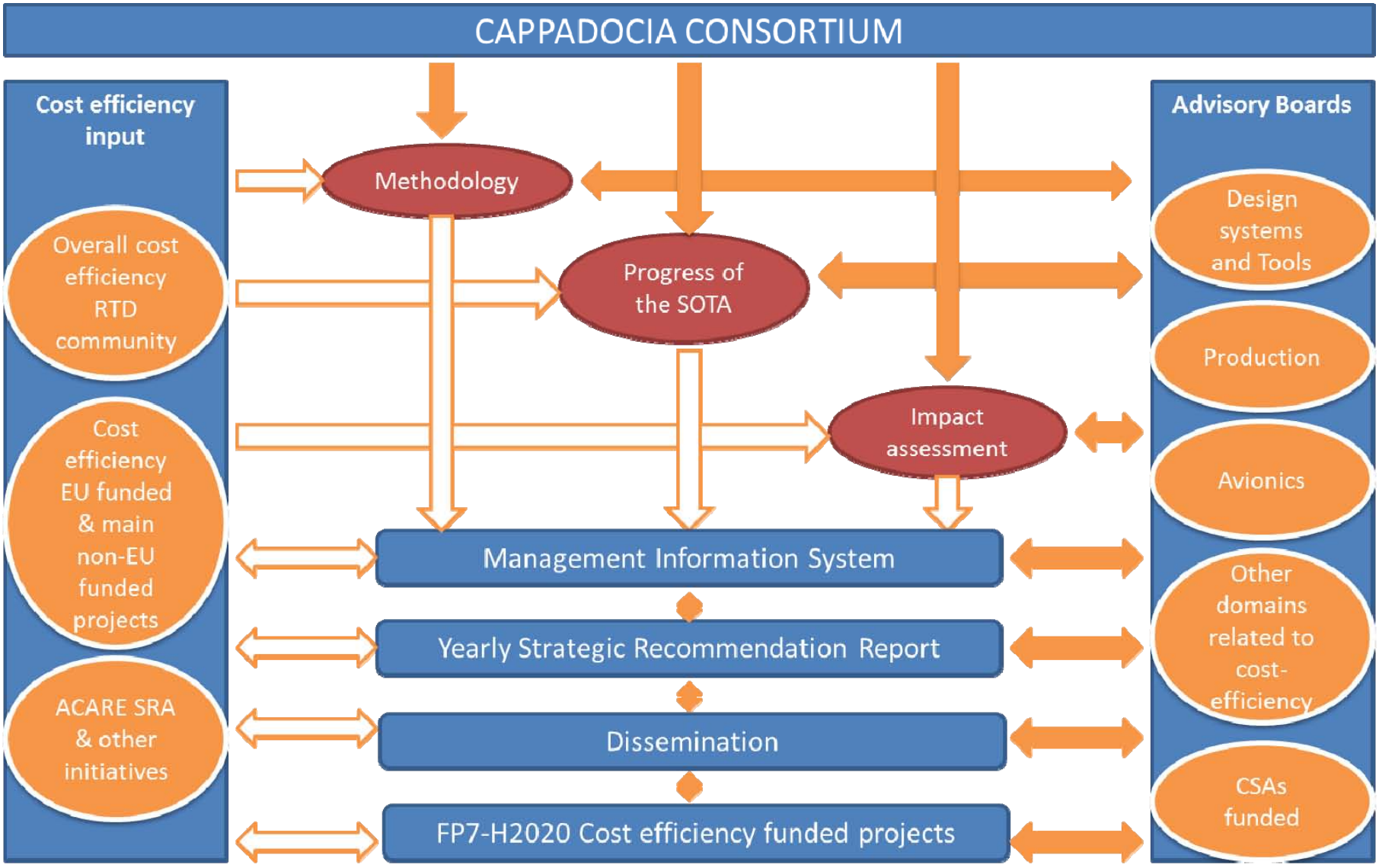
CAPPADOCIA collaboration with other CSAs

- The CAPPADOCIA project will encourage and set-up, when appropriate, a close coordination of all its activities carried out with other similar initiatives running and especially with the **other three CSAs-funded within the same call: CATER, FORUM-AE, OPTICS**

- The objective of such inter-coordination is to:
  - **Benefit from synergies between and among CSAs born from the AAT.2013.7-1 call**
  - **Save funds and avoid duplication of means**, in particular on dissemination and burden in the activities carried out and towards the entities investigated

- Such collaboration will enable to enhance CAPPADOCIA whole achievements coherence towards **other complementary strategic research policy making recommendations, impact assessment and dissemination activities in the field of Aeronautics and Air Transport (AAT).**

CAPPADOCIA work flow



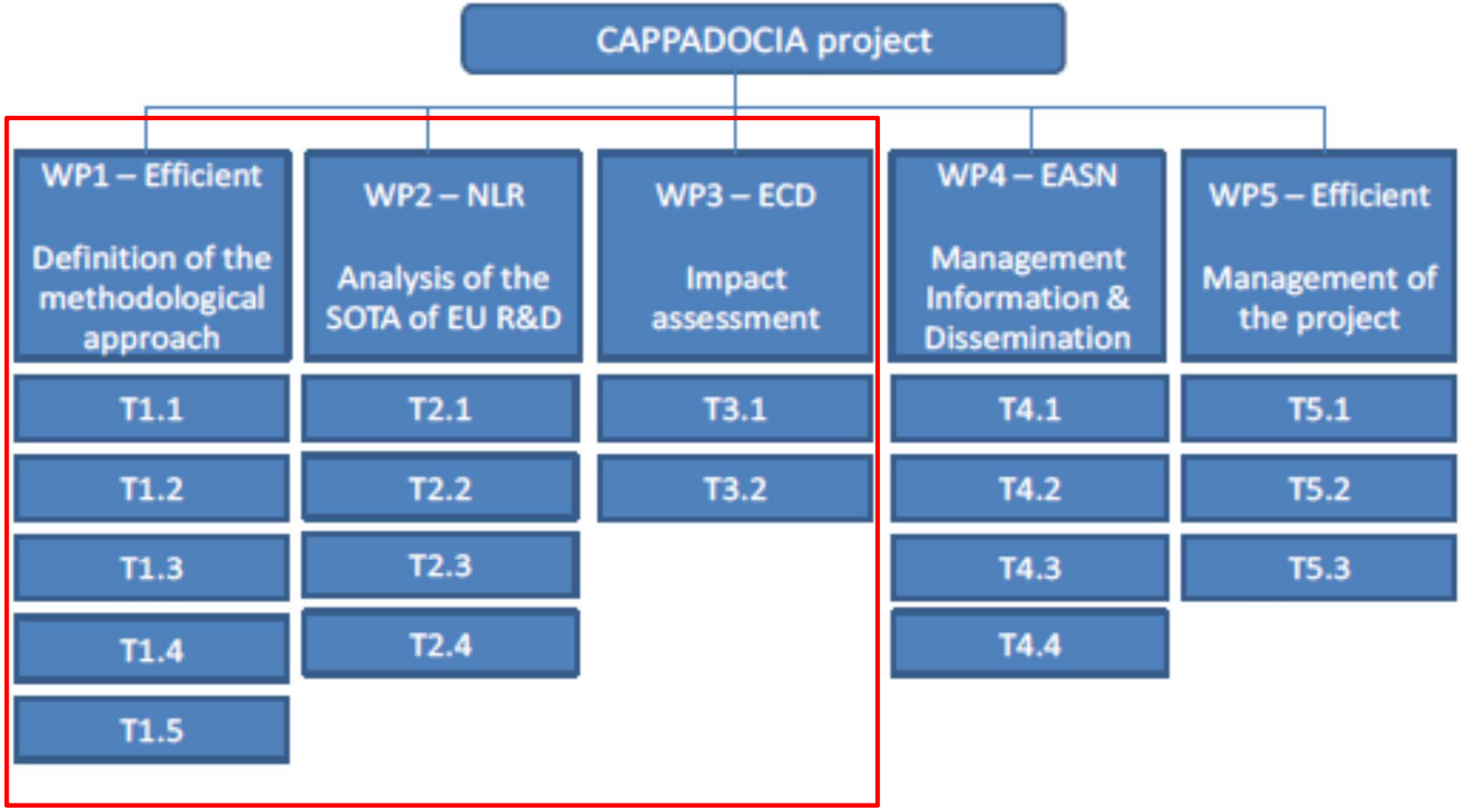
CAPPADOCIA Advisory Board committees

- Four advisory board committees will be present all along the project corresponding to:
  - **Steering committee (ACARE Working Group 2)**
  - **Cost efficiency assessment experts**
  - **Leaders of each value chain link**
  - **ACARE Working Group Integration**

- Selected accordingly to their expertise, the role of the Advisory Board Members will be mostly to contribute towards the :
  - **Overall methodological approach**
  - **Interview process of experts**
  - **Recommandations and white paper compilation in their respective research area**

Name	Organisation	Country
Helge Pfeiffer	Katholieke Universiteit Leuven	Belgium
Joseph Huysseune	Thales	France
Olivier Hiernaux	Thales Avionics	France
Dr Peter Kortbeek	Fokker Aerostructures	Netherlands
Xavier Baricha	Rockwell Collins	France
A. Napolitano	SESM	Italy
Prof. Dr. Volker Krajenski	DLR	Germany
Francesco Salvato	Alenia	Italy
Christiane Michaut	Onera	France
Martin Wiedemann	DLR	Germany
Chris Ovenden	General Electric Aviation	United Kingdom
Pedro Filipe	Inteli	Portugal
Bernard Boime	EADS	France
Prof. Dr. Ünver KAYNAK	TOBB University of Economics and Technology, Department of Mechanical Engineering, Chairman	Turkey
Ruben Alblas	KLM	Netherlands
Patrice QUENDERFF	AIRBUS (Value Engineering & Design to Cost Aircraft Architecture and Integration / Technical Management – EIVT)	France

CAPPADOCIA work plan structure



WP1 – Multidimensional methodological approach & strategic recommendations reporting

- Lead: Efficient Innovation

- Objectives :
  - Define the overall multidimensional methodological approach of the CAPPADOCIA project
  - Define the operational character of the set up Advisory Board

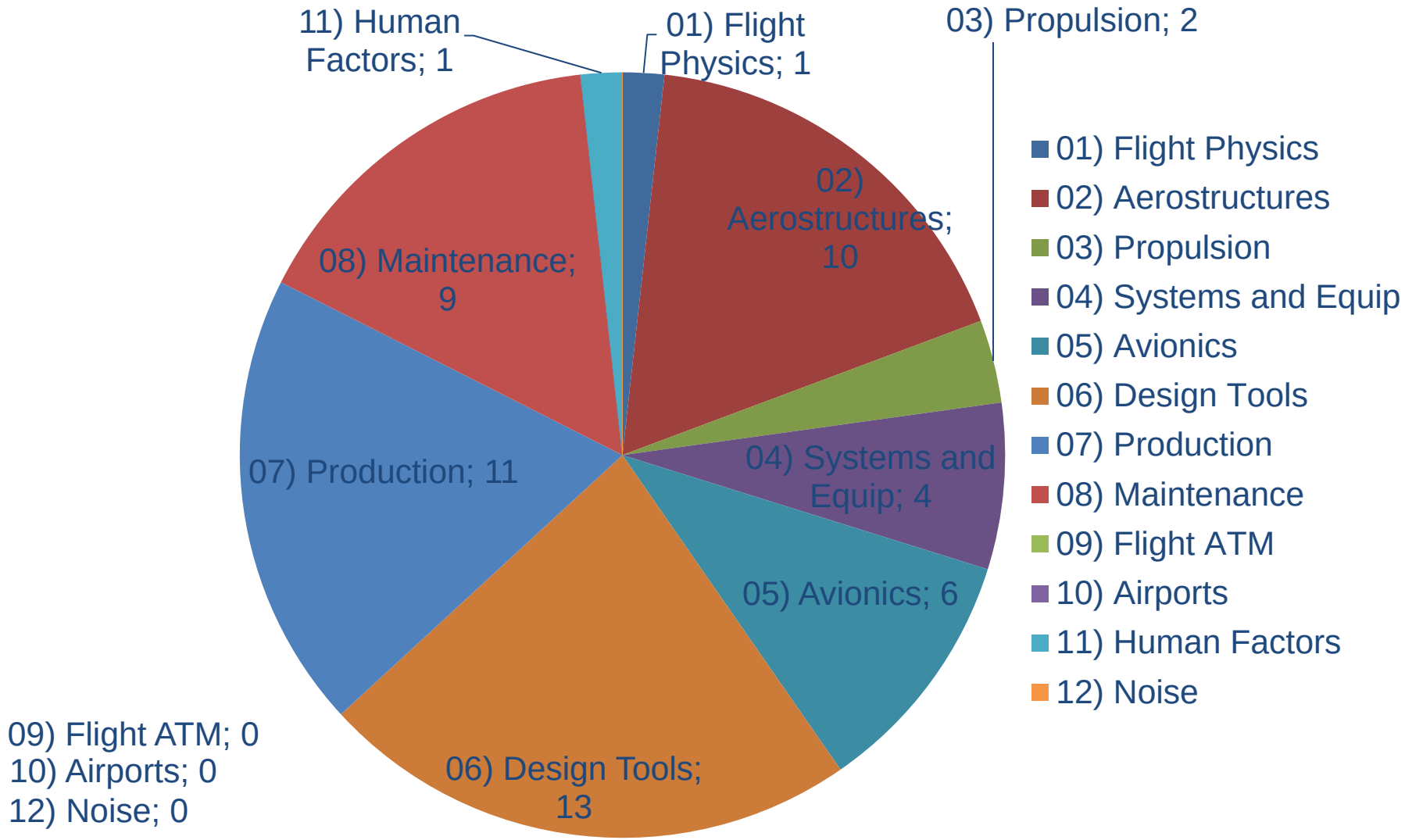
- Task 1.1: Identification, selection, integration and distribution of ABM
- Task 1.2: Identification and mapping of EC-funded projects and other relevant main projects
- Task 1.3: Review and identification of ACARE and other relevant initiatives objectives and solutions taking into accoung external influencing factors
- Task 1.4: Overall multidimensional state-of-the-art and impact assessment methodological grid definition
- Task 1.5: Compilation of strategic recommendations and edition of a common strategic report

- Deliverables : (see next slide)

WP1 – Deliverables

Deliverables
CAPPADOCIA Advisory Boards composition
CAPPADOCIA list of relevant EC-funded projects to be considered per targeted research topics & updated
CAPPADOCIA list of ACARE and other relevant initiatives objectives and solutions to be considered as reference per targeted research topics & updated
CAPPADOCIA multidimensional methodological grid definition & updated
CAPPADOCIA yearly strategic report

57 Projects related to Cost Efficiency (1st year)



Relevant projets selection to be assesed (1st year)

- **First year : 10 EC-funded projects**
  - L2 representative projects distributed over the main technical fields (Call 1 & 2)
  - L1 most representative projects on cost efficiency
- **Following years : 47 EC-funded projects (+ others) identified as « Cost Efficiency » relevant**
  - Involvement of Cappadocia partners
  - Large structuring projects (L2)
  - Projects (Mostly small projects) with major contribution on cost efficiency (>50% costs of the project dedicated to cost efficiency)
  - Linked to SRIA « technical fields »

1st year EC-funded Projects assessed (1st year)

		01) Flight Physics	02) Aerostructures	03) Propulsion	04) Systems and Equip	05) Avionics	06) Design Tools	07) Production	08) Maintenance	09) Flight ATM	10) Airports	11) Human Factors	12) Noise	CSA-Other	Pioneering-others
FP7-AAT-2011-RTD-1	ACTUATION2015				■										
FP7-AAT-2012-RTD-1	ALAMSA								■						
FP7-AAT-2008-RTD-1	CRESCENDO						■								
FP7-AAT-2011-RTD-1	ESPOSA			■											
FP7-AAT-2008-RTD-1	IAPETUS								■						
FP7-AAT-2007-RTD-1	MAAXIMUS		■												
FP7-AAT-2007-RTD-1	MISSA						■								
FP7-AAT-2010-RTD-1	PRIMAE					■									
FP7-AAT-2008-RTD-1	SANDRA					■									
FP7-AAT-2011-RTD-1	SARISTU		■												

Analysis of Strategic Research and Innovation Agenda (SRIA) Vol. 2 (1st year)

- Extensive table of research and innovation objectives described along the axis (columns):
  - Cluster of enablers
  - Enabler
  - Capability
  - Sub-capability
  - R&I needs
  - Domain [categories: Knowledge, Technology, Concepts, Policy]
  - Achievements for 2020, 2035 and 2050
  - Key Performance Indicator
- Clusters of enablers: for CAPPADOCIA the relevant one is: “Competitiveness”.

CAPPADOCIA SRIA Mapping (1st year)

Objectives/Challenges

1. The whole European Aviation industry is strongly competitive
2. Europe maintains leading edge design, manufacturing and system integration capabilities and jobs
3. Streamlined systems engineering, design, manufacturing, certification and upgrade processes have addressed complexity and decreased development costs.

Enablers

1. Development of technology, its demonstration and flight test
2. Efficient development and manufacturing process
3. Continuous and focused investment
4. Definition of regulations and standards to create a global level playing field

Capabilities and sub capabilities have also been selected according to their topic (only technology enablers have been taken into account).

WP2 – Analysis of the state of the art of research and innovation for CAPPADOCIA targeted research area

- Lead : NLR
- Objectives :
  - Review of the state of the art of research and innovation (capacity, main performers)
  - Identification of gaps in the research landscape
  - Identification of bottlenecks to innovation (regulation, financing)
  - Strategic recommendations to address the gaps and bottlenecks to innovation related to Cost Efficiency

- Task 2.1: EU-funded Cost Efficiency projects and relevant practices analysis
- Task 2.2: Identification of gaps in the Cost Efficiency research landscape
- Task 2.3: Identification of bottlenecks to innovation in the Cost Efficiency research landscape
- Task 2.4: Formulation of strategic recommendations towards Cost Efficiency state of the art

- Deliverables :

Deliverables
Identification of gaps in the Cost Efficiency research landscape
Identification of bottlenecks to innovation in the Cost Efficiency research landscape
EU-funded Cost Efficiency projects and relevant practices analysis

CAPPADOCIA SRIA Analysis Questionnaire (WP2 - 1st year)

Thinking about the RTD topics identified for your business in the last 3 years and looking at SRIA Vol. 2 Cluster of enablers "Competitiveness" (focusing on the part relevant for your business):

- Are there any enablers/capabilities/sub-capabilities missing in the SRIA Vol. 2 Cluster of enablers "Competitiveness" (see the enclosed file SRIA Vol2 Competitiveness_v4.xlsx, tab Q9...)?
- Are achievements in the SRIA Vol. 2 Cluster of enablers "Competitiveness" missing (see the enclosed file SRIA Vol2 Competitiveness_v4.xlsx, tab Q10...? Which achievements are missing?
- Are achievements in the SRIA Vol. 2 Cluster of enablers "Competitiveness" still valid? Are the achievements in the SRIA Vol. 2 Cluster of enablers "Competitiveness" sufficiently detailed or too much detailed (contents; steps in the roadmap 2020-2035-2050)?
- Is the timing (2020, 2035, 2050) of the achievements in the SRIA Vol. 2 Cluster of enablers "Competitiveness" still valid?
- Do the KPIs in the SRIA Vol. 2 Cluster of enablers "Competitiveness" related to the specific achievements need to be updated?
- Who are the main parties to reach these achievements? [academia, research institutes, industry, policy makers, other[specify]]

WP3 – Impact assessment of relevant past and ongoing EC-funded projects

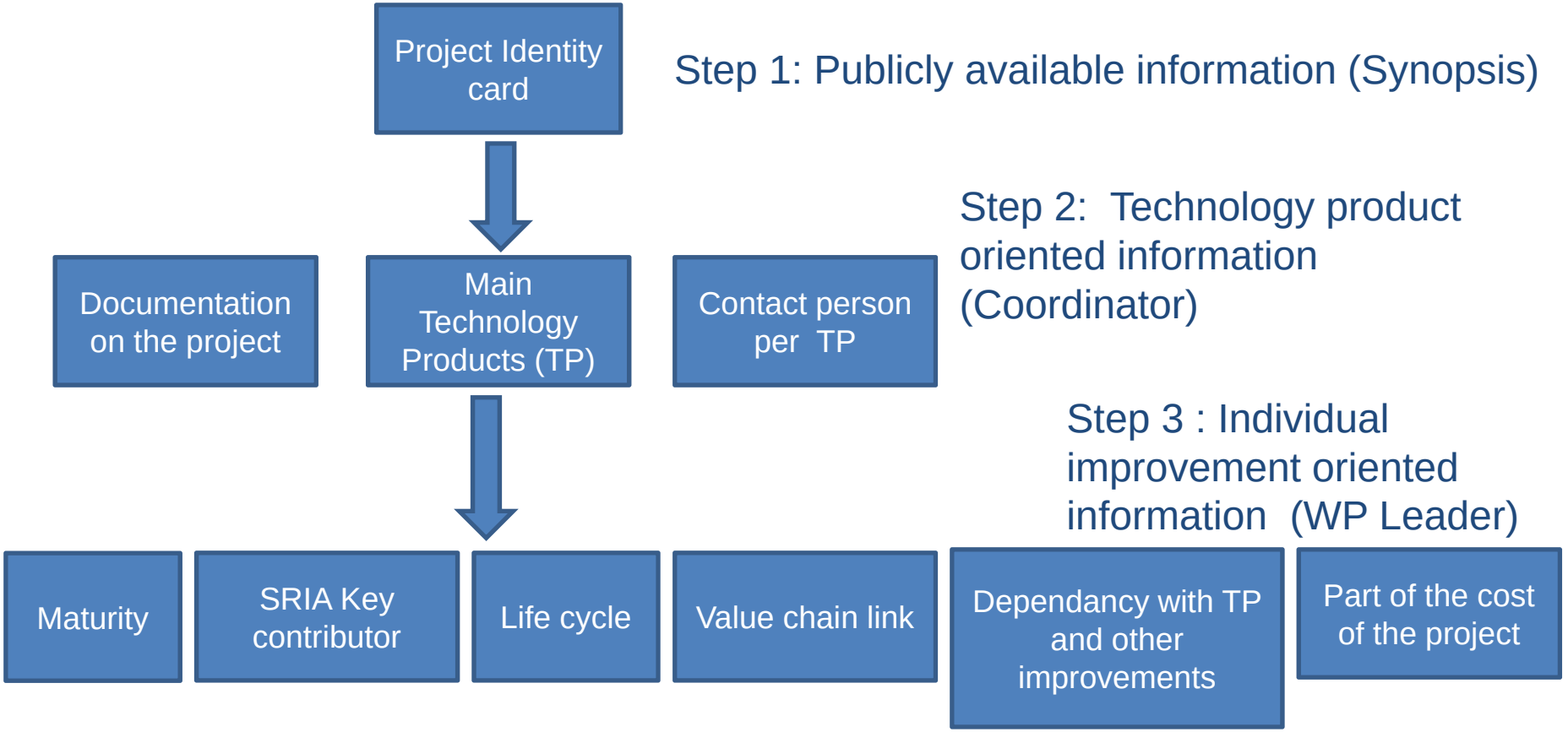
- Lead : ECD
- Objectives :
  - Impact assessment of EC-funded projects towards ACARE goals and solutions achievements
  - Analysis of impact assessment data collected
  - Strategic recommendations to progress towards ACARE goals and solutions

- Task 3.1: Impact assessment with respect to ACARE goals and solutions as well as other relevant initiatives
- Task 3.2: Formulation of strategic recommendations to progress towards ACARE goals and solutions achievements

- Deliverables :

Deliverables
Impact assessment of EC-funded projects, including data analysis

Project assessment proposed approach (WP3 - 1st year)



Simplified impact scale implemented (1/2)

IMPACTS ON THE PRODUCT LIFECYCLE

Simplified impact scale implemented (2/2)

CAPPADOCIA 1st Year Overall Achievements

- **CAPPADOCIA approach:**
  - Methodological approach devoted to the SRIA vol.2 analysis: SoA, S&T Gap and Bottlenecks
  - Methodological approach devoted to Cost efficiency related EC funded projects (FP7)

- **CAPPADOCIA expressed views and assessment:**
  - 15 individual Experts interviewed and CAPPADOCIA consortium partners
  - 7 EC funded projects interviewed and fully assessed

- **CAPPADOCIA analysis and recommendations:**
  - Identification of most frequently shared Gap and Bottlenecks as well as associated recommendations
  - Prospective improvements of the initial methodological approach

CAPPADOCIA bottlenecks identifications

(in progress - extract)

- **SRIA for "Competitiveness" bottlenecks:**
  - Fragmented and not steering the initiation of RTD
  - Missing KPIs and overall not measurable expected achievements
  - Lacking priorities to proposed research including for collaborative research in air transport through H2020
  - Lacking support of certification authorities
  - Lacking contribution of SMEs innovative capabilities to increase air transport competitiveness
  - Lacking opportunity of integration of technology developments in other sectors for air transport competitiveness (RTD synergies with other sectors)
  - Lack of opportunity of incorporation of technology developments in other sectors for air transport competitiveness
  - Long term vision strategy to be implemented

CAPPADOCIA prospective recommendations
(in progress - extract)

- **SRIA for "Competitiveness" recommendations:**
  - Promote a vision on global leadership in SRIA, common industry/government, Europe supplying globally. Demonstrator programs could be helpful to reach common goals
  - Identify ways forward (procedures and methodologies) with respect to certification of new technologies
  - Propose selected list of topics (based on SRIA) for prospective aeronautics calls on the appropriate level for Horizon2020, for further priority ranking by ACARE WG2 and EUROMART
  - Promote air transport research priorities within EU funding scheme (NMP, FoF, ICT, Energy, Security, SME, JTIs, PPPs, etc.)
  - Increase RTD cross-sectors cooperation with air transport
  - Define priorities for increased future competitiveness (megatrend beyond 2020 to set up large research program in FP9)

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http://cappadocia-fp7.eu/

CATER Coordinating Air transport Time Efficiency research

EASN workshop – CATER activity

Brussels 21.10.2014

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

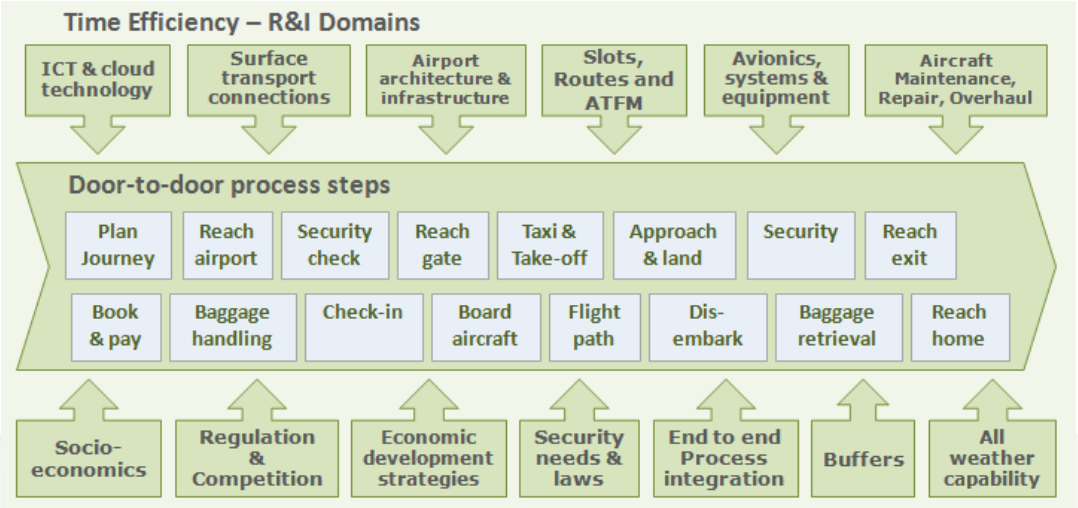
Contents

- CATER topic
- CATER partners
- CATER objectives
- R&I Framework
- Research Projects Assessment
- CATER website

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

CATER Topic

- CATER topic stands for the research coordination on time efficiency of the **air transport system:**
  - **Mobility**
  - **interoperability with the others transport systems (i.e. inter-modality) and technological areas (e.g. ICT & cloud)**
- CATER door-to-door framework will be followed to make effective the project activities.



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CATER partners

Partner	Competency for CATER
SESM A Finmeccanica Company	Research, innovation and development in air traffic management and logistics
ALTRAN	Consulting leader in 20 countries with 3000 professionals in aeronautics
ICTS	Security services to airports and airlines
Targu Mures Airport	Airport operations
ISDEFE	ATM and airport systems design and integration
ONERA	Aeronautics application-oriented research
CTECH	Technology innovation and transfer SME present in 12 countries. Expert provider of project networking and dissemination platforms.
EASN	Association for the advancement of the aeronautics sciences and technologies

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

CATER Objectives

- CATER will focus on four main assets:
  - Assessment: past EU research and innovation, national, regional research and innovation program.
  - Gap analysis/recommendation:
    - **R&I versus the SRIA Needs**
    - Addressing recommendations on future **SRIA Needs** to reach the **Vison 2020 and Flightplan 2050 goals** related to **Meeting societal & market needs**
  - Monitoring:
    - on the achievement of **SRIA Nee**ds
    - coherence between EU, national and regional program
  - Communication
    - making accessible and readable in easy way the project results
    - doing the SRIA readable and interconnected with the project results

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

R&I Framework

- In the WP2 a huge work has been done to build up a proper R&I framework :

✓useful to accomplish in a systematic way the projects assessment

✓a subset of metrics have been agreed among the CSA's

✓a tool, excel based has been developed to make easy its use

- The Framework has been used as an input for the WP3, which has performed the projects assessment stage
- R&I framework is an ever ongoing activity, to be updated every time a new need is identified:

✓Integration of the section related to "Gap and opportunities"

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

- **R&I methodology is tailored within the project**
  - **Methodology:**
    - **R&I Framework:**
      - Consolidated considering WP2/3 requirements
      - Addresses D2D process model (4 Transport Modes + Multi-Modality)
      - CATER Taxonomy based upon ACARE Taxonomy, consists of R&I domains relevant to time efficiency throughout the D2D process
    - **R&I Needs/Opportunities:**
      - **Project assessment**: project by project; coordinated within WP2 and with WP3 to classify and assess relevant projects. (CATER cross WP Methodology)
      - **Strategic assessment**: focusing on the D2D process model and SRA's including Multi-Modal, to identify strategic needs and opportunities

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- **R&I frame addresses all modes of transport**
  - Documents analysed:
    - Aviation:
      - Flightpath 2050
      - ACARE (Agenda, Taxonomy)
      - ARDEP (Analysis of Research and Development in European Programmes)
    - Railway: ERRAC (Agenda, Roadmap)
    - Road: ERTRAC (Agenda, Roadmap)
    - Maritime and inland waterways: WATERBORNE (Agenda, Roadmap)
    - Multi-modal: ERTRAC-ERRAC-Waterborne-ACARE-ECTP Task Force (roadmap for cross-modal transport infrastructure innovation)

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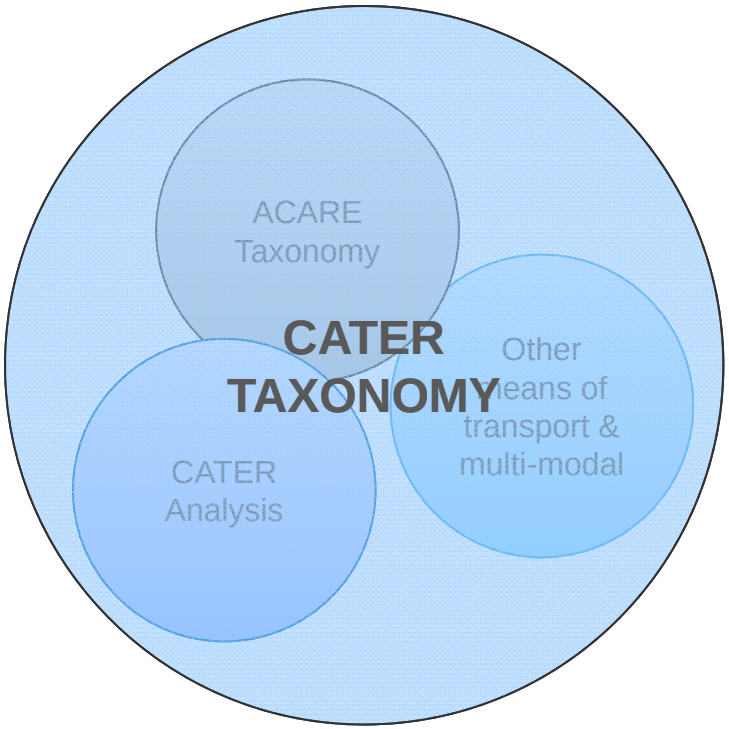
- **CATER Taxonomy includes R&I domains for the full D2D process**



EXAMPLE	ACARE Taxonomy	CATER Taxonomy
Area	8. Airports	8. Transport Nodes
Number of domains	4	9
Number of Sub-Domain	18	--
Domains	8.1. Security equipment 8.2. Crisis management 8.3. Airport external safety 8.4. Airport security	8.1. Security equipment 8.2. Crisis management 8.3. Transport node external safety 8.4. Transport node security 8.5. Total Airport Management 8.6. MM transport nodes & corridors: optimal location, operation and accessibility to and within terminals, hubs and gateways 8.7. MM transport nodes & corridors: seamless interchange of freight and passengers 8.8. MM transport nodes & corridors: synchro-modality over key transport corridors 8.9. User information management: coordinated travel process management

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R&I needs & ACARE SRIA targets

› Methodology for the identification of **R&I Needs**, based primarily on the contribution to the target:

90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours

1) *Preliminary identification of Enabler / Capability / Need against potential impact on TE*

- Identification of R&I Needs, evaluating Enabler/Capability/Need information from the ACARE SRA

2) *Analysis of R&I Needs identified, understanding the concepts behind*

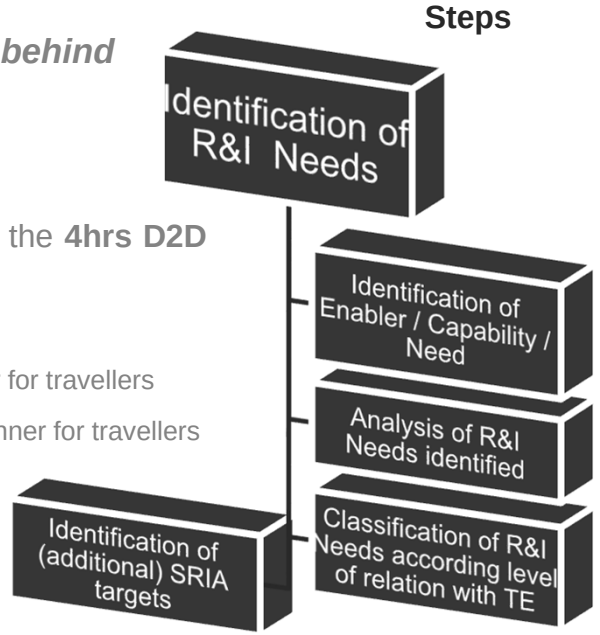
- Refinement by assessing pre-selected R&I Needs one-by-one

3) *Classification of R&I Needs according to relation with TE*

- Classification of Needs in three types, according to their contribution to the **4hrs D2D target**:
  - **Type 1**: directly linked to the 4hrs door-to-door target
  - **Type 2**: relevant on improving Time Efficiency in a directly perceptible manner for travellers
  - **Type 3**: relevant on improving Time Efficiency in a non-directly perceptible manner for travellers

4) Identification of (additional) SRIA targets

- In addition to the '*4 hrs door-to-door target*', other targets from Flightpath 2050 may have close relation with TE, and significant relation with specific R&I Needs



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- **Flightpath 2050 targets related to TE**

90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours
Flights arrive within 1 minute of the planned arrival time regardless of weather conditions
European citizens are able to make informed mobility choices and have affordable access to one another, taking into account: economy, speed, and tailored level of service
An air traffic management system is in place that provides a range of services to handle at least 25 million flights a year of all types of vehicles, (fixed-wing, rotorcraft) and systems (manned, unmanned, autonomous) that are integrated into and interoperable with the overall air transport system with 24-hour efficient operation of airports
A coherent ground infrastructure is developed including: airports, vertiports and heliports with the relevant servicing and connecting facilities, also to other modes
Weather and other hazards from the environment are precisely evaluated and risks are properly mitigated
Efficient boarding and security checks allow seamless security for global travel, with minimum passenger and cargo impact

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R&I tool functionalities

- **New Project:** This option provides a friendly way to introduce projects in the database
- **Edit Project:** the selected project´s information is available to be modified
- **Search Project:** the selected project´s information is available as well as a spider graph that draws some of the project assessment information
- **Dashboard:** A global view of the R&I Framework key indicators is available

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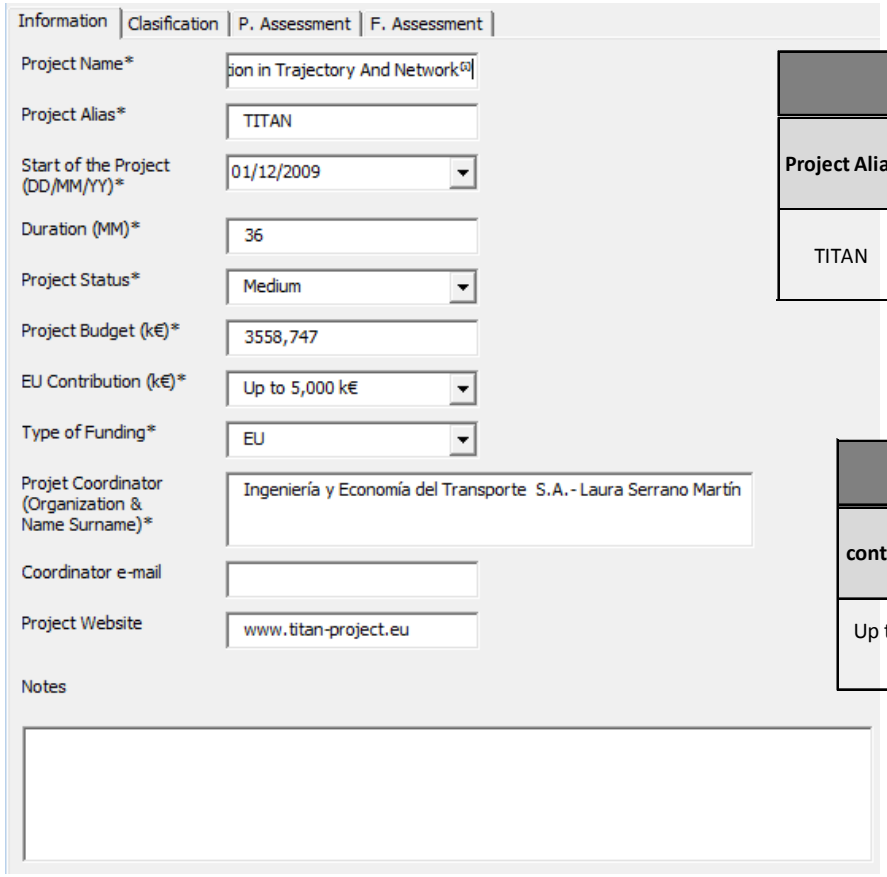
- **R&I Database**



Project Info					
Project Alias	**Project Name**	**Start of the project (DD/MM/YY)**	**Duration (MM)**	**Project Status**	**Project budget (k€)**
TITAN	Turnaround Integration in Trajectory And Network(i)	01/12/2009	36	Closed	3558,747

Project Info				
EU contribution (k€)	**Type of funding**	**Project coordinator (Organization - Name Surname)**	**Coordinator e-mail**	**Website link**
Up to 5,000 k€	EU	Ingeniería y Economía del Transporte S.A.- Laura Serrano Martín		www.titan-project.eu

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

*R&I Project overview (1/2)

Project Info	
Project Name	Turnaround Integration in Trajectory And Network[(i)]
Project alias	TITAN
Start of the project	01/12/2009
Duration	36 months
Project Status	Medium
Project budget (k€)	3558,747 k€
EU contribution (k€)	Up to 5,000 k€
Type of funding	EU
Project coordinator (Org. - Name Surname)	Ingeniería y Economía del Transporte S.A.- Laura Serrano Martín
Coordinator e-mail	
Website link	www.titan-project.eu

Project Classification	
D2D model General	Flight
D2D model Specific	Standing
Type of activity	Infrastructure
Project Area 1	6. Integrated Design & Validation (methods & tools)
Project Domain 1	6.25. Transport Node Operations Performance Assessment
Mode of Transport	Air
SRIA Capability 1	From Airports to Air Transport Interface Nodes - Design of more efficient and effective air transport interface nodes, including their systems and processes
SRIA Enabler 1	Optimised Process for passenger, baggage, freight (time, seamlessness, convenience, predictability, etc)
SRIA Need 1	Identification of areas to be improved for passengers / baggage / freight (customer needs and experience, also building upon enabler C-1 'Customer expectation and role in transport and mobility' capability 2) especially with regards to process flexibility, increased predictability and reduced processing time s for essential functions, infrastructural requirement, improved guidance and information

Project Preliminary Assessment	
Flightpath 2050 Goal 1	Efficient boarding and security checks allow seamless security for global travel, with minimum passenger and cargo impact
Implementation (R&I)	Commercial implementation, ongoing use
Industrial involvement	Major Aerospace company (in top 20-PWC)
End Users Involved	Yes
Potential Impact DURATION	Yes
Potential Impact PUNCTUALITY	Yes
Potential Impact PREDICTABILITY	Yes
Potential Impact SPEED	Yes
Potential Impact FREQUENCY	
Potential Impact CONNECTIVITY	No
Potential Impact RELIABILITY	Yes

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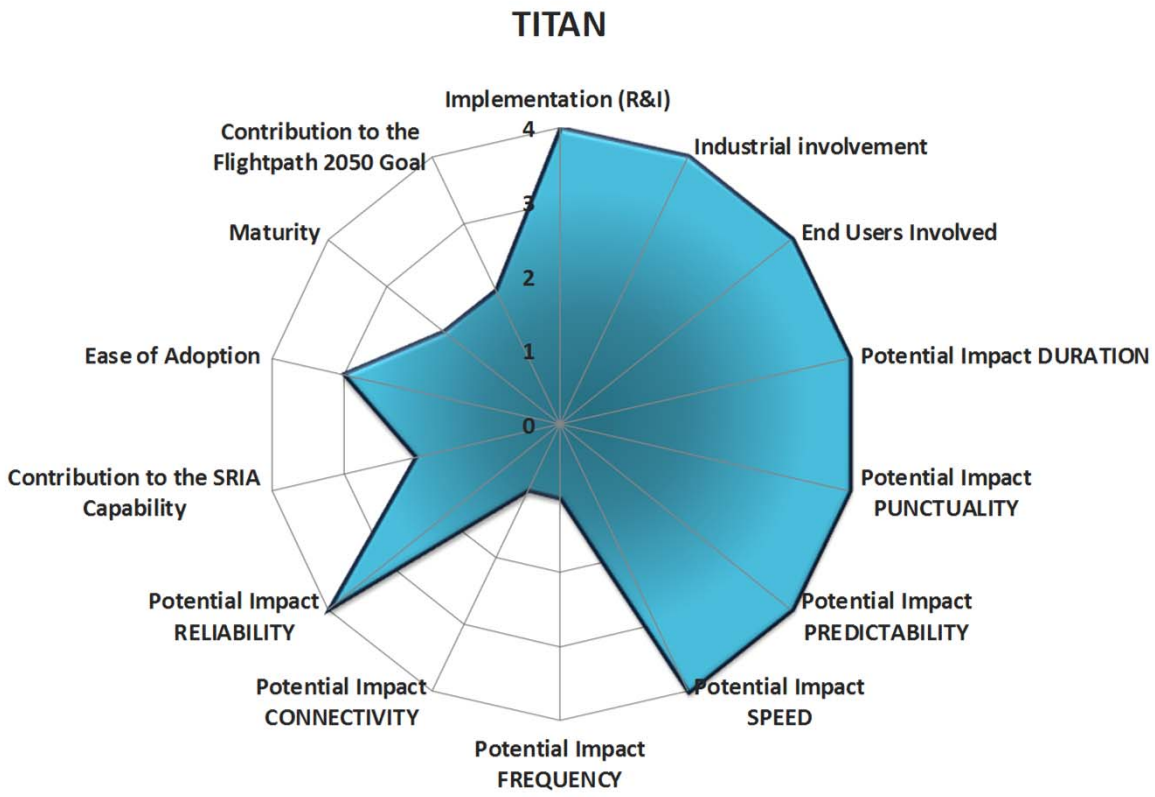
* Project overview (2/2)

Project Full Assessment	
Contribution to the SRIA Capability	Medium
Ease of Adoption	High
Maturity	Medium
Evidence Provided	Public deliverable "Analyse of the current situation" available on its website
Contribution to the Flightpath 2050 Goal	Medium

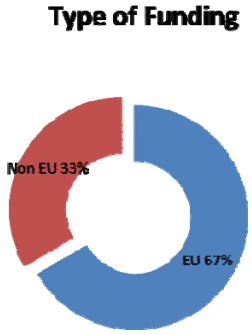


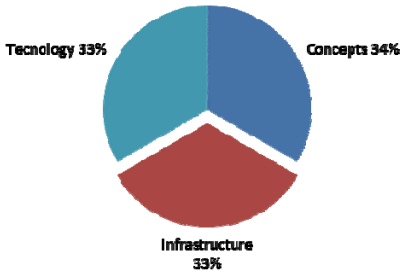
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

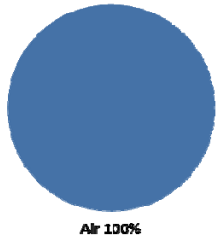
*Dashboard for each project (1/4)

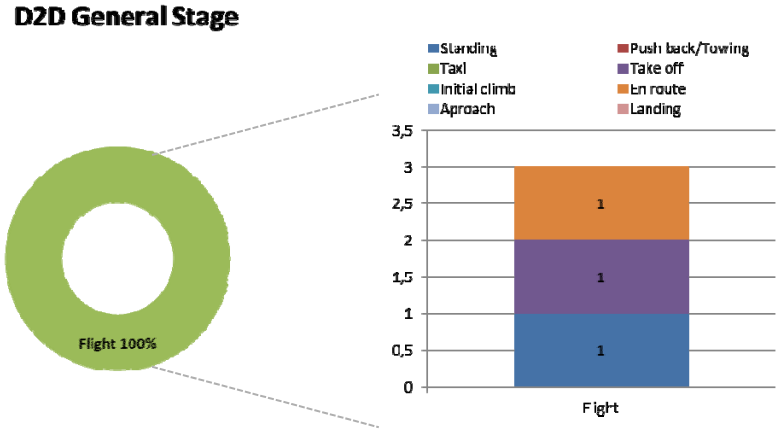
Number of projects: 3
Active: 0
Closed: 3

Average duration: 27 months









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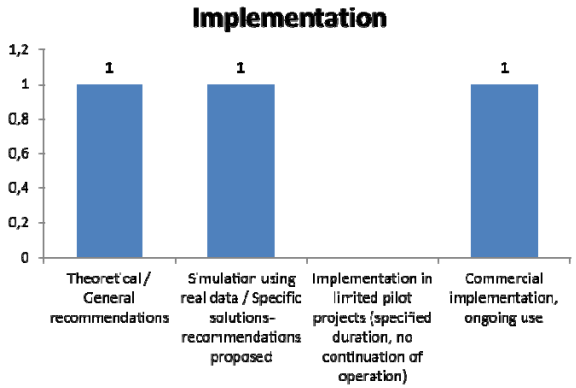
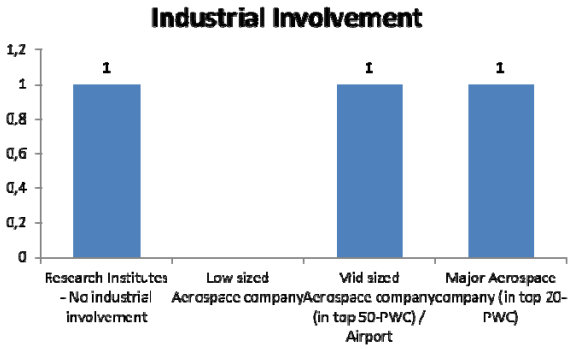
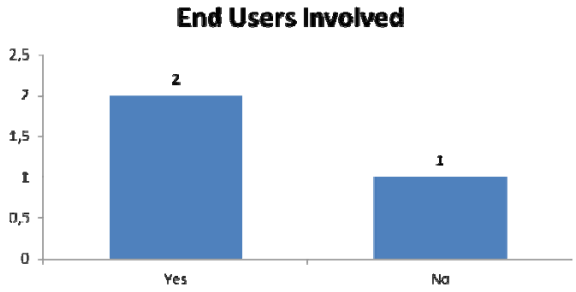
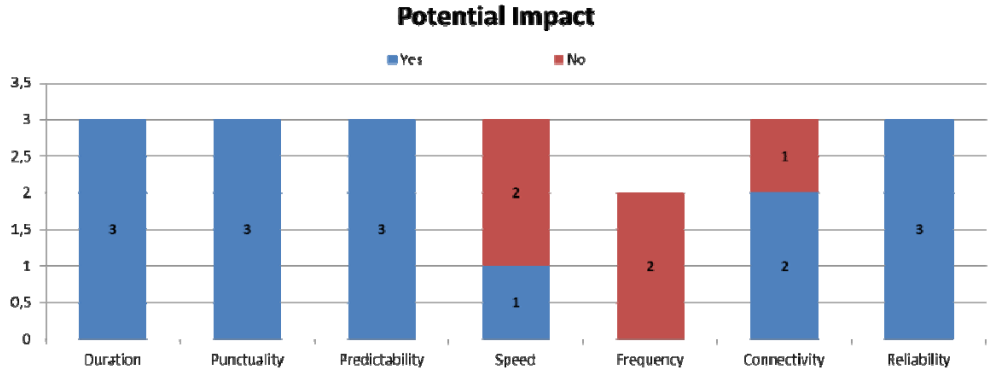
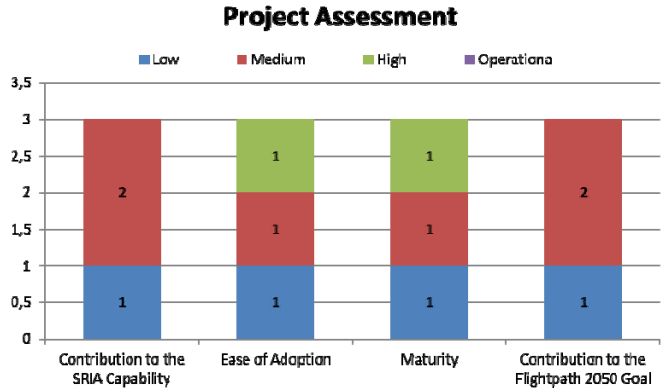
* Dashboard on overall projects (2/4)











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* Dashboard on overall projects (3/4)

Project Area	Projects
1. Physics	0
2. Structures	0
3. Propulsion	0
4. Vehicle Systems and Equipment	0
5. Mechanics	0
6. Integrated Design & Validation (methods & tools)	2
7. Traffic Management	2
8. Transport Nodes	0
9. Human Factors	0
10. Innovative Concepts & Scenarios	0

R&I Domain detail: 7. Traffic Management

Area	7. Traffic Management
Etiquetas de fila	Suma de Total
7.1. Overall Traffic Management	1
7.10. User Operations	1
7.11. Meteorological	0
7.12. R&D Management and Co-ordination	0
7.2. Airspace Management	0
7.3. Flow and Capacity Management	0
7.4. Communications and Systems Technology	0
7.5. Navigation Systems	0
7.6. Surveillance Sensor Systems	0
7.7. Traffic Management Automated Support	0
7.8. Intelligent Traffic Management	0
7.9. Transport Node Operations	0
Total general	2

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* Dashboard on overall projects (4/4)

SRIA Enabler detail Management of Air Traffic – Services to Airspace Users

Capability	Management of Air Traffic – Services to Airspace Users - Optimized management of Air Traffic (including non transport diverse air vehicle operations) in normal and exceptional operational scenarios
Etiquetas de fila	Suma de Total
New concepts and legislative measures to facilitate the provision of innovative and competitive services to airspace users. Institutional and Economic framework for these services	
Identify areas where ATM and aeronautical developments need to be coordinated	0
New operational concept and new aviation services to enable a high performance agile and resilient system, able to manage 25 million commercial flights a year safely arriving within one minute of the planned arrival time, while accommodating other vehicle missions and aerial applications	
Assess potential and implementation issues of new services to airspace users	0
Assess potential and integration issues of all (innovative) types of air vehicles	0
Develop new breaking technology for a true ATM	0
Develop technologies for integration of all air vehicles, the introduction of new services to airspace users and increased airspace capacity	0
Develop technologies to support e.g. increased operator productivity through more automation and/or sector less air traffic management	0
Infrastructure supporting performance needs	0
Operational concept describing the provision of new services	1
Support introduction of new services to airspace users and the integration of all air vehicles with adequate rulemaking and funding	0
Technologies supporting new services and vehicles	0
Update operational concept with regards to new (e.g. more collaborative) services to airspace users and integrating all types of air vehicles	1
Total general	2

Project SRIA Capability	Projects
Assessment of mobility choices - Methodologies for unbiased assessment of the different modes of transport, enabling customers to make informed travel decisions	0
Assessment of Mobility System Concepts - Understanding and Identification of potential benefits of new Mobility System concepts	0
Aviation Ground Infrastructure Environment - Ensuring that design of multilateral measures (airport operations, air vehicle operations and technology, etc.) to lower the environmental impact of aviation ground infrastructure to its neighbouring residents is effective	0
Continuous and focussed investment	0
ards, certification rules, facilitating Innovation	0
ment - Customer-oriented journey disruption management and recovery mechanisms	0
evelopment & Manufacturing Processes	0
From Airports to Air Transport Interface Nodes - Design of more efficient and effective air ce nodes, including their systems and processes	1
ions - Information, Communication, Navigation & Surveillance ructure in support of new operations	0
thods, processes and services which ensure the pro-active of current and future security threats to the total air transport system	0
s - Exploitation of information system application development d in-journey decision-making across all modes of transport	0
vices to Airspace Users - Optimized management of Air Traffic air vehicle operations) in normal and exceptional operational scenarios	2

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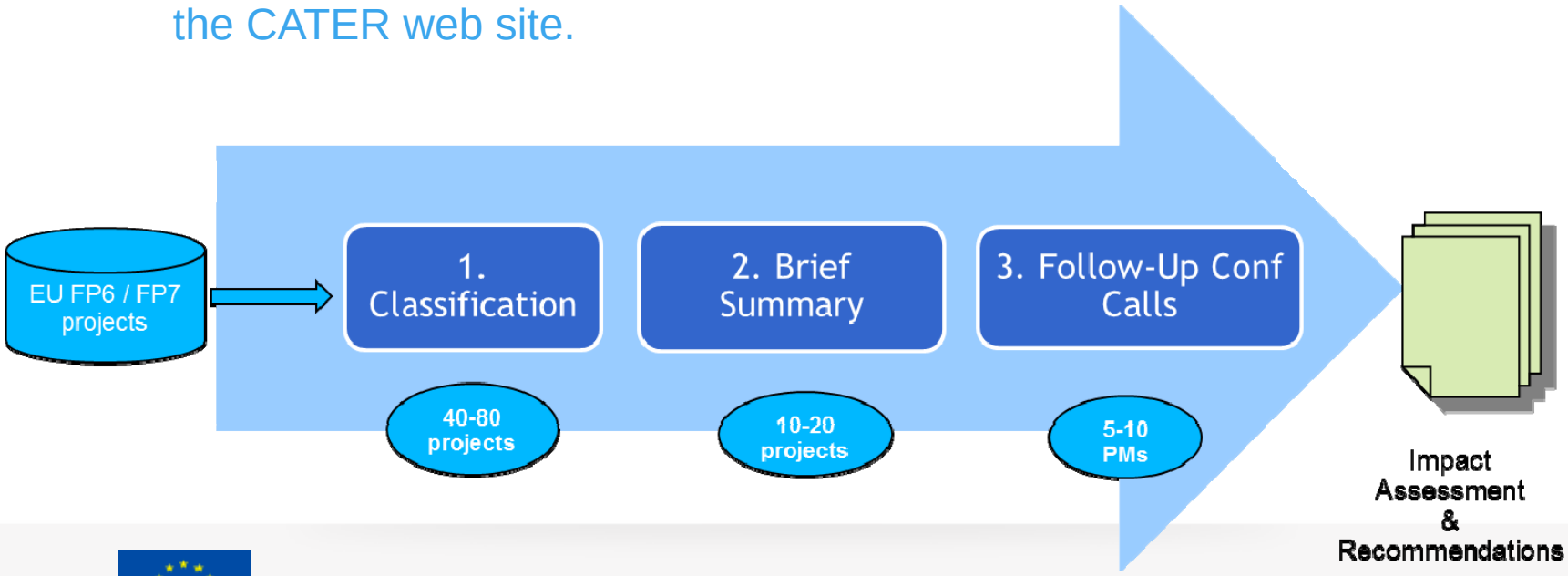
FP6 and FP7 assessment stage

- The assessment in the first year is has been dedicated to FP6 and FP7 projects, as well as other project addressing the concepts of multimode and intermodal transport
- R&I framework has been utilized to accomplish it
- Assessment outcomes is going to be delivered in the next month into the CATER web site.



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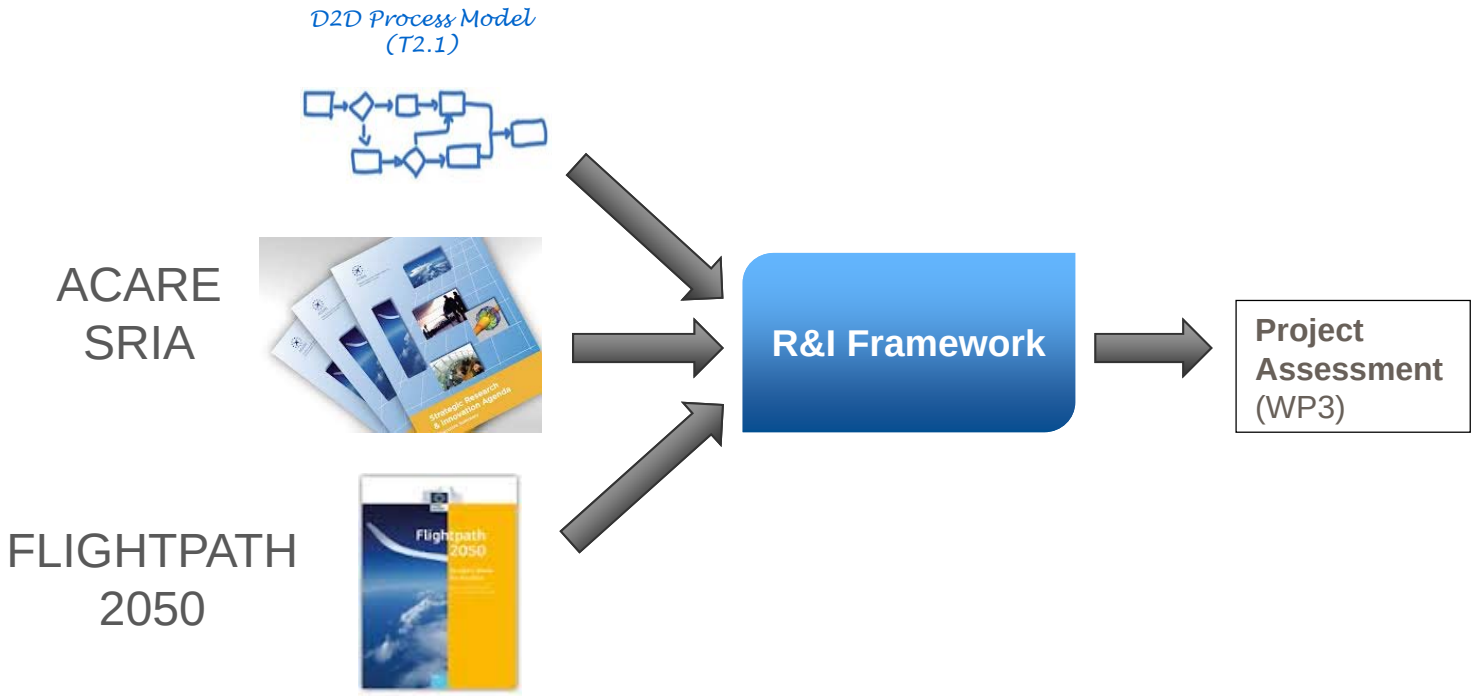
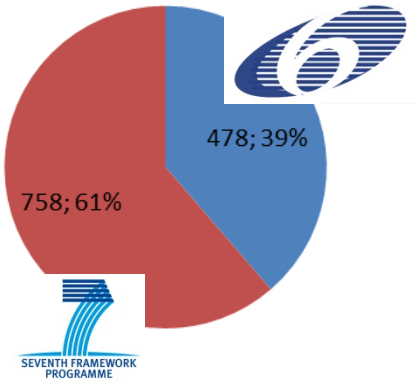
CATER assessment approach



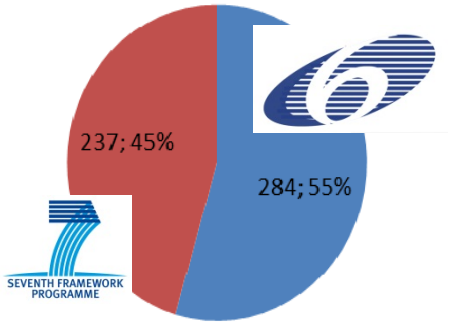
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

FP6 / FP7 Project Review & Selection

1.236 FP6 & FP7
Transport related projects



521 FP6 & FP7
Door to door related projects



- Original search was focused on FP6-Aerospace & FP7 Transport
- Original focus was on Air-Transport mode of travel
- Few Multimode projects were among the list of results.
  - But..
- We need to cover Door-to-Door which includes other modes of transport.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

FP6 / FP7 Project Review & Selection

- The search was expanded to include multimode / intermodal content in Cordis.
- A long list of 637 projects was reviewed
- Additional projects were selected for preliminary analysis.

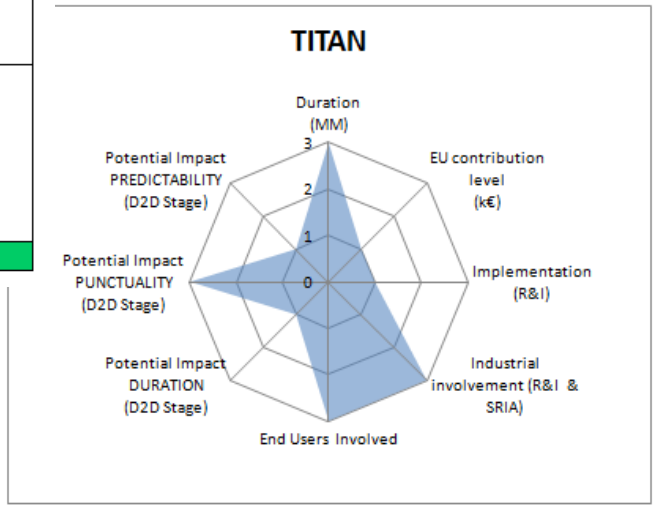
The following additional Multimode projects were added to the list:

FP6-NMP	2
FP6-SUSTDEV	8
FP7-ICT	2
FP7-SECURITY	7
FP7-SME	1
FP7-TRANSPORT	17
Total	37

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

Assessment Example

TITAN	Turnaround Integration in Trajectory And Network[i]					
Duration:	50 Months			STATUS:	CLOSED	
Project Budget :	€ 3'600'000	EU contribution	€ 2'600'000	Contribution Level :	Till 5 M€	
Coordinator:	Laura SERRANO MARTIN (Ms.) INGENIERIA Y ECONOMIA DEL TRANSPORTE S.A. Paseo de la Habana, MADRID, ESPAÑA MADRID Spain		Web	http://www.titan-project.eu/		
			Cordis	http://cordis.europa.eu/projects/233690		
			Trip	http://www.transport-research.info/web/projects/project_details.cfm?id=41675		
D2D Stages:	1 2 3 4 5 6	Mode Of Transport		MM	End-Users Involved	YES
Project Domain	7.9. Transport Node Operations 7.1. Overall Traffic Management			Implementation (R&I)	Simulation using real data / Specific solutions-recommendations proposed	
SRIA Capability	-Optimised Process for passenger, baggage, freight (time, seamlessness, convenience, predictability, etc) -Aircraft, airport and ground handling technologies are integrated to support people in the turnaround process andlinks to other transport modes			SRIA enabler	From Airports to Air Transport Interface Nodes - Design of more efficient and effective air transport interface nodes, including their systems and processes - Human-centred automation	
Flightpath 2050 Goal	- 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours. -Flights arrive within 1 minute of the planned arrival time regardless of weather conditions. -European citizens are able to make informed mobility choices and have affordable access to one another, taking into account: economy, speed, and tailored level of service - A coherent ground infrastructure is developed including: airports, vertiports and heliports with the relevant servicing and connecting facilities, also to other modes.					
IMPACT:	DURATION	YES	PUNTUALITY	YES	PREDICATBILITY	YES



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

CATER Website

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

CATER Coordinating Air transport Time Efficiency research

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605497.

optics

Observation Platform for Technical and Institutional Consolidation of Safety research

OPTICS – Are we doing the right safety research?

Barry Kirwan, EUROCONTROL

EASN Presentation, Aachen, 29th October 2014

OPTICS is a Coordinated Action funded by the European Commission under the
Seventh Framework Programme (FP7-AAT-2013_RTD-1). Grant Agreement n° ACS3-GA-2013-605426

OPTICS Consortium

EUROCONTROL

EASA
European Aviation Safety Agency

NLR

DLR

Bauhaus Luftfahrt
Neue Wege.

CIRA
Centro Italiano Ricerche Aerospaziali

Rolls-Royce

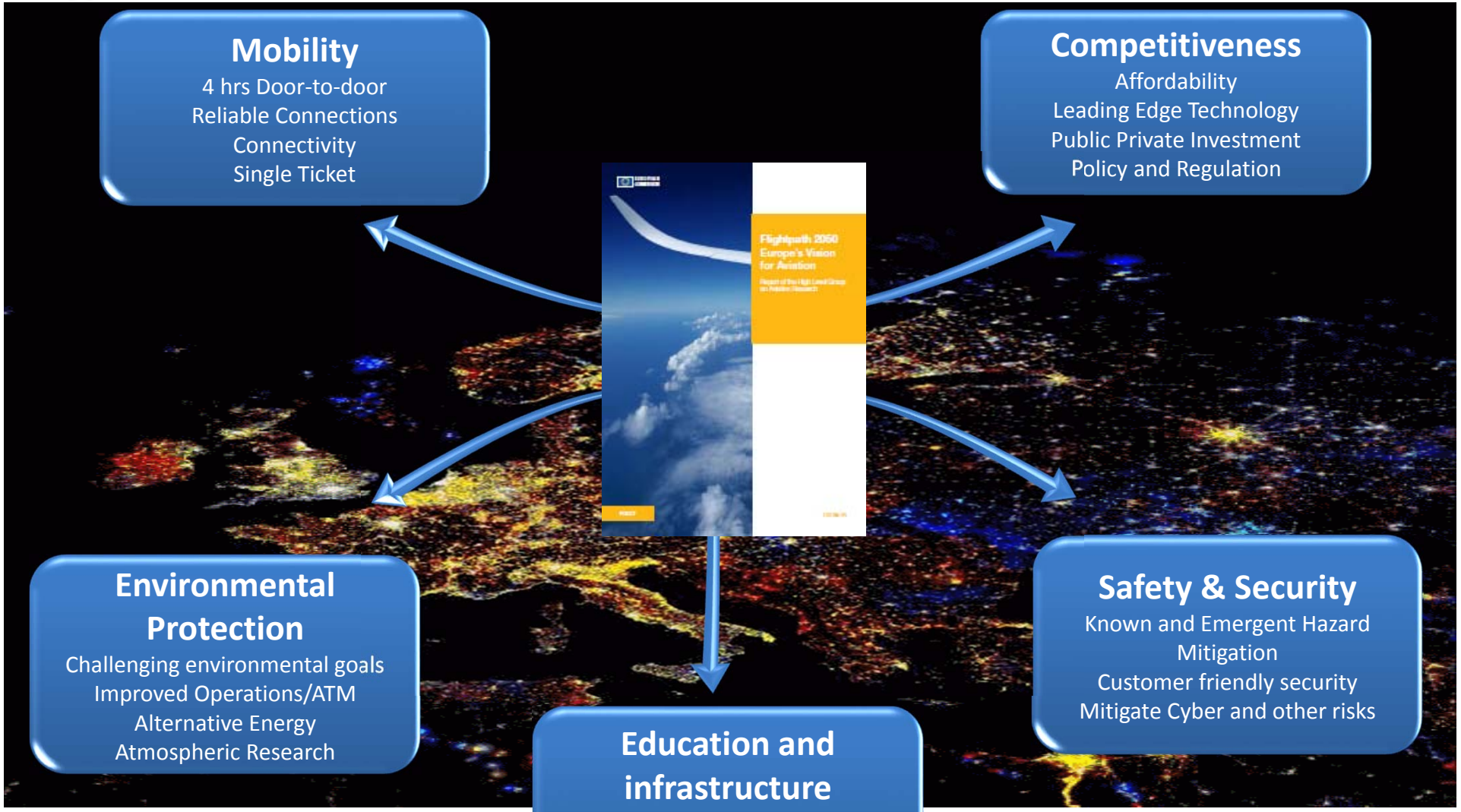
DEEPBLUE
consulting&research

CDTI Centro para el Desarrollo Tecnológico Industrial

ONERA
THE FRENCH AEROSPACE LAB

European Research & Innovation

Europe's Vision for mid-century



Europe's Vision for mid-century

Safety & Security

Known and Emergent Hazard Mitigation

Customer friendly security

Mitigate Cyber and other risks

The European air transport system has less than one accident per ten million commercial aircraft flights.

Weather and other hazards are precisely evaluated and mitigated.

Seamless operations through fully interoperable and networked systems (including manned and unmanned vehicles)

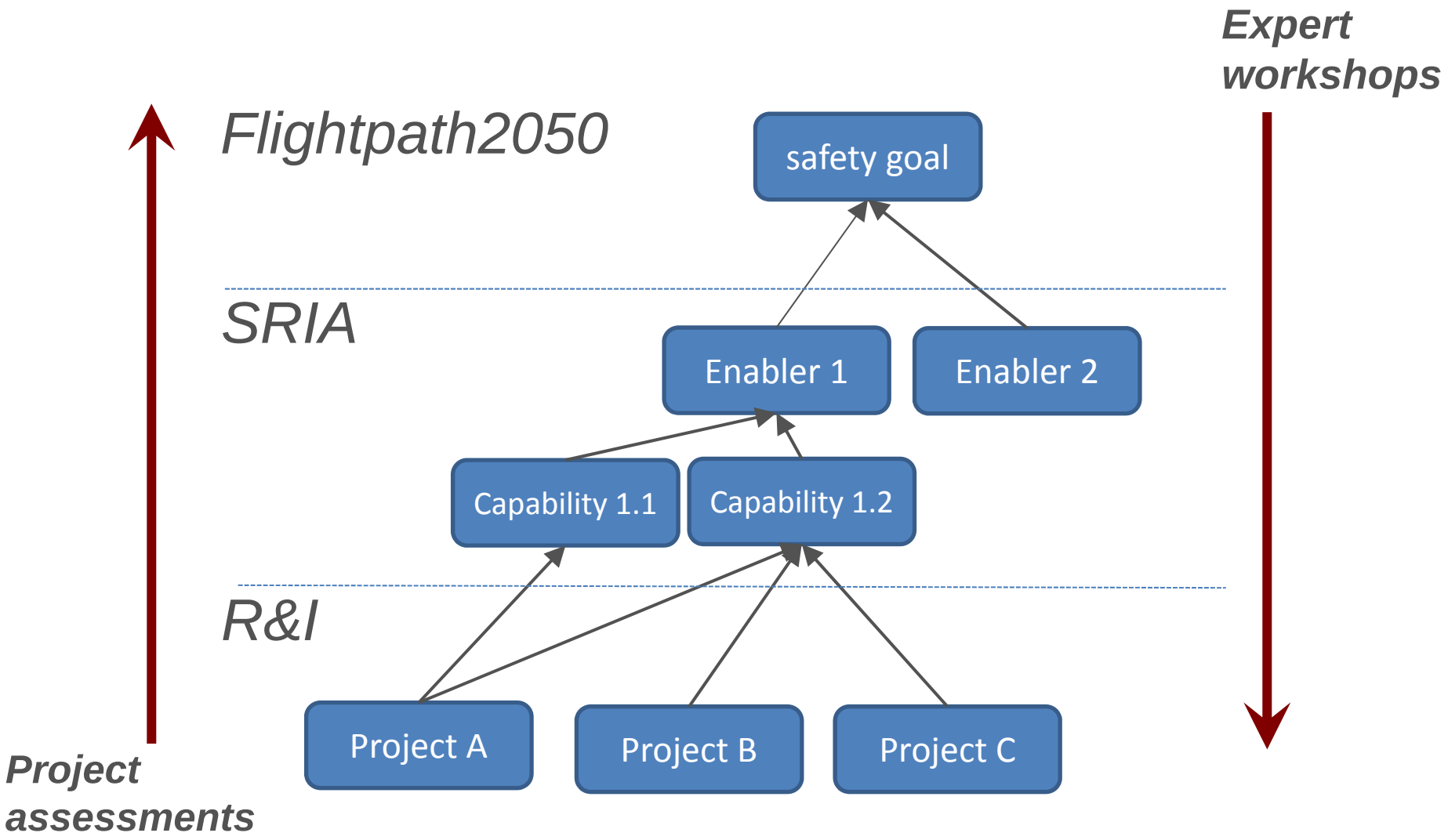
Efficient boarding and security checks allow seamless security

Air vehicles are resilient by design to security threats

The air transport system has a fully secured global high bandwidth data network.

Roadmap to 2050

Overall methodology



Four Year Strategy

Are we doing the right research?

Year 1: **FP7** Projects with explicit safety focus

Year 2: **FP7** Projects with implicit safety focus + **SESAR**

Year 3: **National** Projects with safety focus

Year 4: **International** (global) Projects with safety focus

Cumulative picture

How OPTICS works: Year 1

1 – Selecting projects

1st Year Plan Completed

2 – Assessing projects

1st Year Plan Completed

3 – Synthesizing assessment results

Completed

4 – Identifying issues

1st Release Dec 2014

Selecting projects

Reviewed 37 FP7 projects in detail

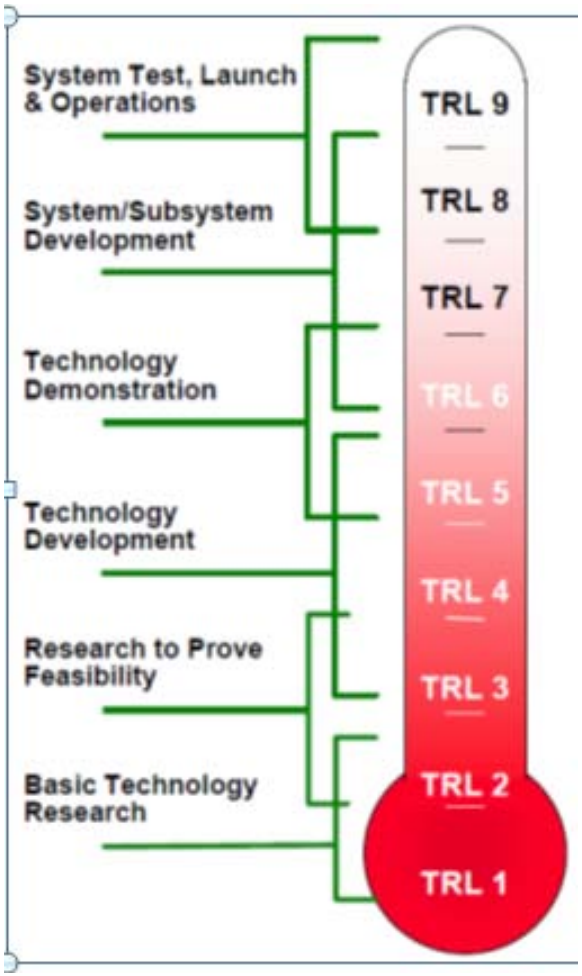
ACCENT EXTICE GREEN-WAKE HIRF-SE HISVESTA HUMAN LAYSA MISSA TRIADE AAS ADDSAFE BEMOSA DELICAT ON-WINGS PICASSO SUPRA AEROMUCO AIM² AIRCRAFTFIRE ARISTOTEL DOTNAC SMAES SVETLANA WEZARD ACROSS ALAMSA ASCOS HAIC MAN4GEN PROSPERO RECONFIGURE RESILIENCE2050 SAFUEL UFO JEDI-ACE HYPMOCES A-PIMOD

Assessing contribution

Does the subject of the project cover a small or a big part of the scope of the capability?

Project capabil.	A	B	C	D	E	F	G	H	n
1	med	high							
2			high	low	high		low		
3	low					low			
4				low			med		high
5									
6							low		
10					low			low	

Assessing Maturity



Jelmer Scholte, NLR

Maturity: Generalised scales, based on

- NASA's Technological Readiness Levels
- OPTI approach for Institutional Readiness Levels

TRL 7,8,9: out of scope of OPTICS

TRL 5,6: High maturity

TRL 3,4: Medium maturity

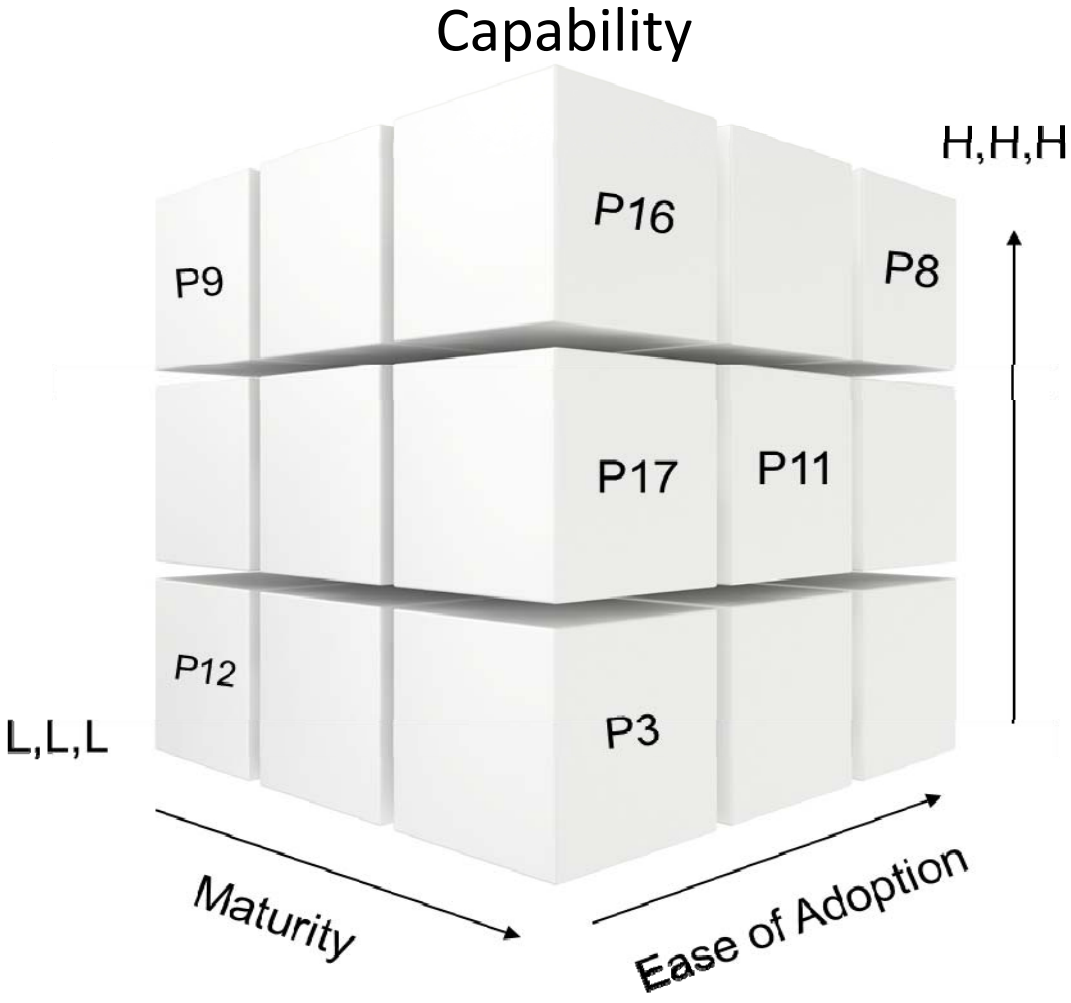
TRL 1,2: Low maturity

Assessing Ease of Adoption

Ease of Adoption:

Score	Economic	Legal	Organizational
Low	Very large costs. (e.g., high technical complexity).	Major legal constraints. Resolving requires significant effort.	Major organizational, institutional or political constraints. Resolving would take significant effort.
Medium	Required investments not significantly high. (relative to considered benefits)	Minor legal constraints.	Organizational, institutional or political constraints. Resolving will take time but is rather straightforward.
High	Low costs. (relative to considered benefits).	Fits in current legal framework.	Stakeholders keen to adopt because of perceived benefits.

Visualizing the Results



We send back our Assessments to the Project Coordinators for verification

Synthesising assessment results

Example preliminary result: Enabler 8 (Human-centred automation)

Capabilities	Projects	Coverage of capab.	Matu-rity	Ease of adoption
1. Automation supports human in both normal and degraded operations; allocation of functions between human and machine is optimized in order to maximise situation awareness, support decision making, and enhance performance execution	PLANE, ATICIA, ACROSS, ODICIS, MAN4GEN, A-PIMOD, ARISTOTEL, BRAINFLIGHT	Medium	High	M-M-M
2. Information systems support human collaboration across seamless operational concepts throughout the ATS (air & ground)	Not addressed by research yet assessed by OPTICS			
3. Preventive Maintenance and system upgrades of automated systems and information management systems are facilitated through automated processes and adapted human support systems	Not addressed by research yet assessed by OPTICS			
4. Aircraft, airport and ground handling technologies are integrated to support people in the turnaround process and links to other transport modes	AAS	Low	High	M-H-M

DRAFT

Identifying issues, gaps & bottlenecks

- promising and/or high value avenues
- gaps in research being performed (w.r.t. SRIA)
- overlaps among research projects
- gaps in the SRIA (w.r.t. real needs to achieve safety goals)
- bottlenecks to perform the needed research
- bottlenecks in the uptake and transformation of research results into products and services
- perceived delay in the realisation of the SRIA.

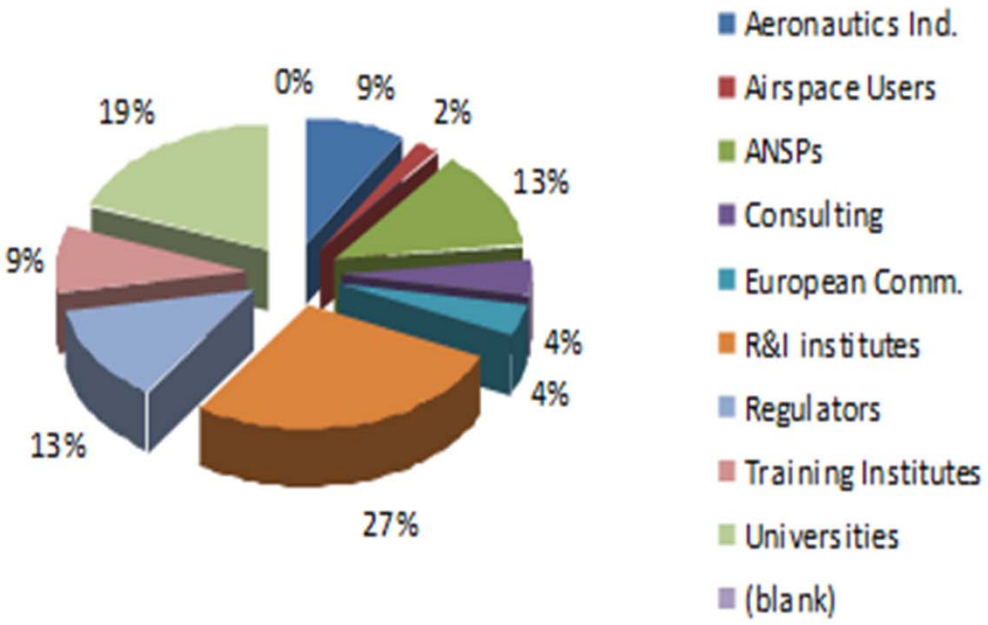
OPTICS Annual Workshops

1st Expert Workshop, 3rd July, Brussels

Human Factors – what are the safety R&I priorities?

70 HF Experts, 17 countries

Experts at 1st OPTICS Workshop



Safety Capabilities - Human Factors

	INDIVIDUAL	TEAM	ORGANIZATIONAL
TECHNOLOGIES	ADAPTIVE AUTOMATION AUTOMATION SUPPORT HF IN DESIGN AND MANUFACTURING	CREW MANAGEMENT SYSTEMS MONITORING OF CREW/TEAM CAPACITY SYSTEMS FOR HAZARD AVOIDANCE INTEGRATED TECHNOLOGIES FOR TURNAROUND INFORMATION SYSTEMS SUPPORT FOR HUMAN COLLABORATION	TOOLS AND METHODS FOR EMERGENT RISKS INTEGRATED SEARCH AND RESCUE CAPABILITIES PREVENTIVE MAINTENANCE AND SYSTEM UPGRADES COMMON FRAMEWORK FOR CERTIFICATION
METHODS	HP ENVELOPE	CISM FOR TEAMS AND ORGANISATIONS NEW TEAM CONCEPTS UNDERSTANDING MULTICULTURAL INTERACTION BTWN CREW AND PASSENGERS UNDERSTANDING CULTURAL ASPECTS OF PASSENGERS	MANAGING HUMAN BEHAVIOUR IN EMERGENCIES BEHAVIOURAL ANALYSIS TO IDENTIFY HAZARDS SAFETY PERFORMANCE INDICATORS OPERATIONAL RISK MONITORING SAFETY DATA SYSTEMATIC ANALYSIS SAFETY CULTURE SAFETY INFLUENCES

Current focus mainly on pilot side?

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Observation Platform for Technical and Institutional Consolidation of Safety research

So, what have we found?

Are we doing the right safety research?

1st OPTICS Conference 17-18th Dec, EC, Brussels

Aviation Safety R&I – Time to Take-off!

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OPTICS

Aviation Safety Research and Innovation: Time to Take-Off!

17-18 December, Brussels

Covent Garden Building, Place Rogier 16

Day 1: Are we doing the right safety research?	
08:30	Welcome and Registration
09:00	Welcome - European Commission (DG Move or DG Res)
09:15	Horizon 2020 - A safer vision of 2020 (EC, *tbd*)
09:45	How safe do we want to be by 2050? The ACARE Vision
10:15	*Coffee*
10:30	EASA's vision of safety R&I priorities
11:00	EREA's FutureSky Vision
11:30	SESAR's Vision for 2020 Safety
12:00	Panel Discussion (EASA, EC, SJU, EREA, ACARE)
12:30	*Lunch*
13:30	Views from the cockpit - Lufthansa
14:00	Views from the airframe manufacturer - Airbus
14:30	The FAA Vision of Future Safety
15:00	*Coffee*
15:20	The OPTICS Assessment of FP7 Safety R&I Projects - are we doing the right research?
16:00	Panel Discussion (Lufthansa, Airbus, FAA, OPTICS)
16:30	Wrap-up & Close of Day 1

Day 2: How will current research projects improve aviation safety?	
09:00	Introduction - Towards an Aviation Safety R&I Forum
09:15	ASCOS
09:45	PROSPERO
10:15	MAN4GEN
10:45	Discussion
11:00	*Coffee*
11:15	A-PIMOD
11:45	HAIC
12:15	AIRCRAFTFIRE
12:45	Discussion
13:15	*Lunch*
14:15	The Role of the CSA in R&I - *Stanley Tang, EC*
14:30	CAPPADOCIA - *Fabien Marty*
15:00	CATER - *Aniello Napolitano*
15:30	Discussion
15:45	Wrap-up
16:00	Close of Workshop

Questions?

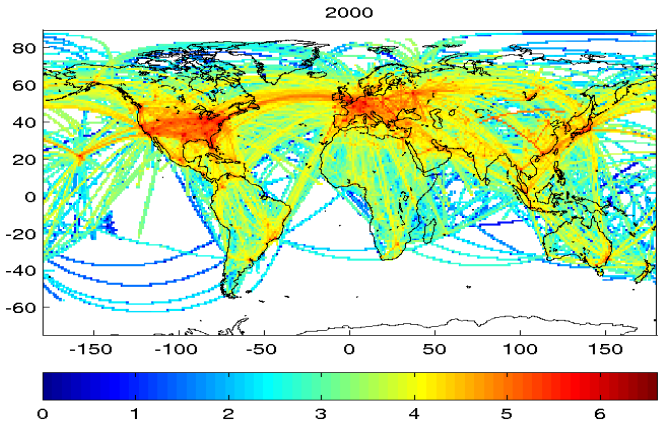
2nd OPTICS Workshop:
Air Vehicle Operations & ATM
Toulouse, end April 2015

http://www.optics-project.eu/

barry.kirwan@eurocontrol.int

FORUM on Aviation and Emissions

EASN 4th International Workshop
Aachen – 29th October 2014



FP7 European coordination action
GA 605506 ; 2013-2017
www.forum-ae.eu

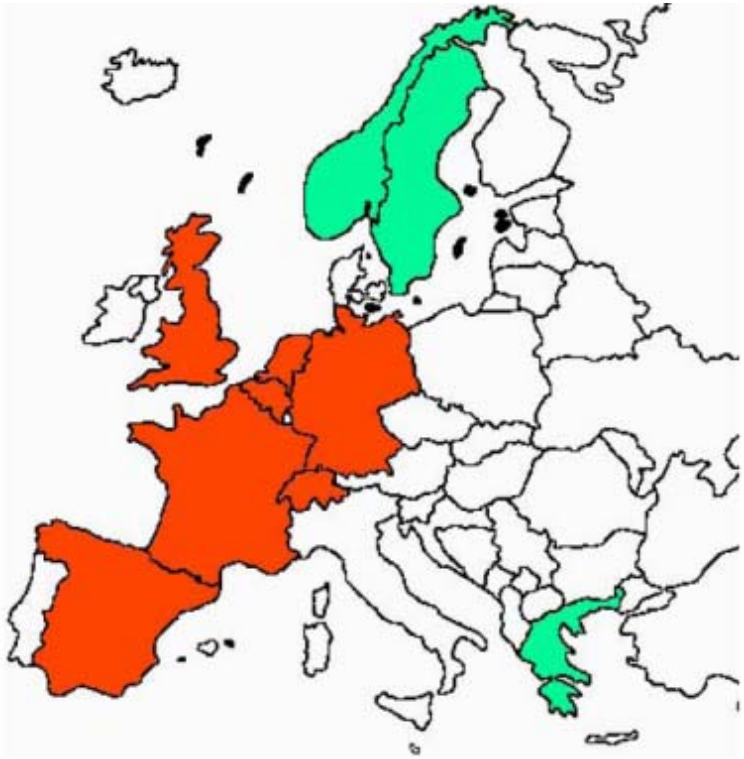
FORUM-AE MAIN OBJECTIVES

FORUM on Aviation and Emissions (& Environment)

- **Offers a European technical forum between main air transport actors**
- **Achieve a deeper understanding and larger visibility concerning:**
  - emissions environmental impacts
  - most-promising mitigation solutions
  - technical recommendations on regulation issues
- **Assess major European RTD programs progress against ACARE environmental goals**
- **Compile recommendations in terms of future RTD priorities**

FORUM-AE CONSORTIUM

Participant N°	Participant Organisation Name	Short name	Country
1 (CO)	Snecma	SN	FR
2	Airbus SAS	AI	FR
3	Deutsches Zentrum für Luft und Raumfahrt e.V.	DLR	DE
4	Deutsche Lufthansa AG	DLH	DE
5	ECATS	ECATS	BE
6	Flughafen Zurich AG	FZAG	CH
7	IFP Energies nouvelles	IFPEN	FR
8	Manchester Metropolitan University	MMU	UK
9	Stichting Nationaal Lucht - En Ruimtevaart laboratorium	NLR	NL
10	Office National d'Etudes et de Recherches Aerospatiales	ON	FR
11	Rolls Royce Group plc	RR	UK
12	Rolls Royce Deutschland Ltd & Co KG	RRD	DE
13	SENASA	SENASA	ES
14*	Eurocontrol	ECTL	FR
15*	Joint Research Center	JRC	BE
16*	Turbomeca	TM	FR

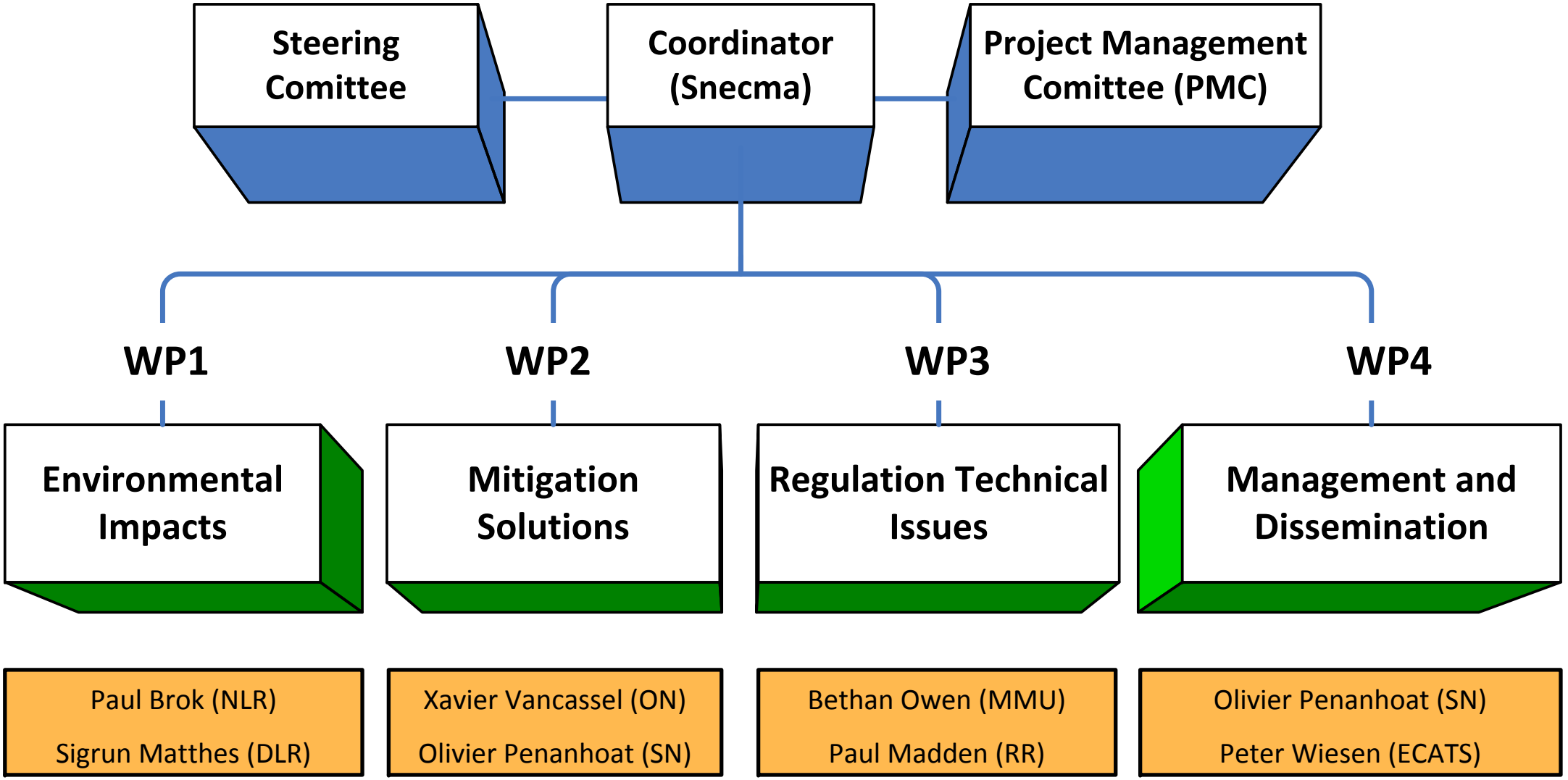


* Third parties

FORUM-AE TECHNICAL SCOPE

	Thematic Aeras	Includes	CO2	NOx (local)	NOx (global)	particules (local)	particules (global)	Link with existing networks
ENVIRONMENTAL IMPACTS	Air Quality (AQ)	*AQ impact assessment & measurements needs*		X	X	X	X	
	Climate Change (CC)	*CC impact assessement & measurements needs*	X		X		X	ECATS
	Inventories (INV)	*Inventories & long term projections*	X	X	X	X	X	
MITIGATION SOLUTIONS	Fuel Burn Technology (FB Tech)	*Aircraft new technology & architectures, Engine new technology & architectures, Electrical aircraft & APU & fuel cells, long term goals*	X					CLEAN-SKY
	Combustor Technology (Comb. Tech)	*Combustor & injection systems technology, new concepts, long term goals (ACARE)*		X	X	X	X	LECT cluster
	Operational procedures (ATM)	*Flight optimisation, SESAR benefits…*	X	X	X	X	X	SESAR / ECATS / AIRE
	Alternative Fuels (Alt. Fuels)	*Drop-in fuels benefits, long term fuel evolution*	X			X	X	CORE-JetFuel
REGULATION ISSUES	CO2 Standard (CO2 Std)	*All open technical issues*	X					Euro CO2 group
	Particles Standard (PM Std)	*All open technical issues including measurements*				X	X	Euro PM group
	NOx regulation (NOx)	*standard application to new architectures, airports regulations*		X	X			
	MBM technical issues (MBM)	*All open technical issues*	X					

PROJECT ORGANISATION



ACARE FLIGHTPATH 2050 ENVIRONMENTAL GOALS

Goals

1. In 2050 technologies and procedures available allow a 75% reduction in CO2 emissions per passenger kilometre to support the ATAG target[10] and a 90% reduction in NOx emissions. The perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000.
2. Aircraft movements are emission-free when taxiing.
3. Air vehicles are designed and manufactured to be recyclable.
4. Europe is established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy.
5. Europe is at the forefront of atmospheric research and takes the lead in the formulation of a prioritised environmental action plan and establishment of global environmental standards.

- CO_2 - 75% per pkm
- NO_X - 90% per pkm
- Reference 2000

SUPPORTED ACTIVITY AND EXPECTED OUTPUT

RTD monitoring : Relevant European RTD projects will be monitored

WP1 - **Impacts**	Scientific status, level of scientific understanding (LOSU) achieved, quantification of the impacts addressed in the projects
WP2 - **Mitigation solution**	Technological status, assessment of the maturity (TRL) and the performance (reduction achieved) for the various RTD projects
WP3 - **Regulation issues**	Technical status in the few RTD projects

Workshops

- Technical & scientific workshops in the scope of the project.
- Better understanding of the environmental priorities (WP1), of the innovative & promising mitigation solutions (WP2), of the regulation technical issues (WP3)
- Consensus views on priorities and gaps to be addressed in future RTD projects

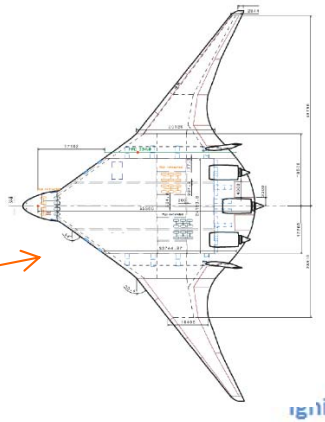
In synergy

Both approaches are run in parallel and in synergy ; jointly, they contribute to the assessment of the progress towards ACARE goals, and will contribute to SRIA (WG3) update as well as provide recommandations in H2020

RTD MONITORING

PROJECT	T0	STATUS	Coordinator	TITLE	TYPE
REACT4C	2010	On-going	DLR*	Reducing Emissions from Aviation by Changing Trajectories for the Benefit of Climate	Impacts
ECATS	2005	Foundation	ECATS*	Environmental Compatible Air Transport System => Foundation	Impacts
MOZAIC	1994	On-going	RC Jülich	Measurement of Ozone, Water Vapor, Carbon Monoxide, Nitrogen Oxide by Airbus In-Service Aircraft	Impacts
IAGOS	2008	On-going	RC Jülich	In service Aircraft for a Global Observing System	Impacts
IAGOS ERI	2009	On-going	RC Jülich	In service Aircraft for a Global Observing System / European Research Infrastructure	Impacts
CARIBIC	2004	On-going	MPI Chemie, Mainz	Civil aircraft for the regular investigation of the atmosphere based on an instrument container	Impacts
QUANTIFY	2005	Completed	DLR*	Quantifying the Climate Impact of Global and European Transport Systems	Impacts
CleanSky - SFWA	2008	On-going	AI*	SMART Fixed Wing Aircraft	Aircraft
CleanSky - GRA	2008	On-going	Alenia	The Green Regional Aircraft	Aircraft
CleanSky - GRC	2008	On-going	Eurocopter	Green Rotorcraft	Aircraft
NACRE	2005	Completed	AI*	New Aircraft Concepts Research	Aircraft
AHEAD	2011	On-going	TU Delft	Advanced Hybrid Engines for Aircraft Development	Aircraft
DISPURSAL	2013	On-going	Bauhaus	Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level	Aircraft
CleanSky - SAGE	2008	On-going	RR*&SN*	Sustainable And Green Engine	Engine
DREAM	2008	Completed	RR*	valiDation of Radical Engine Architecture systeMs	Engine
NEWAC	2006	Completed	MTU	NEW Aero engine Core concepts	Engine HP
VITAL	2005	Completed	SN*	Environmentally Friendly Aero-Engine	Engine BP
LEMCOTEC	2011	On-going	RRD*	Low Emissions Core-Engine Technologies	Engine HP
ENOVAL	2013	On-going	MTU	The Engine mOdule Validators	Engine BP
KIAI	2009	On-going	SN*	Knowledge for Ignition, Acoustics and Instabilities	Combustor
FIRST	2010	On-going	RR*	Fuel injection research	Combustor
FACTOR	2010	On-going	SN*	Turbine combustor interaction	Combustor
IMPACT-AE	2011	On-going	RRD*	Design methodologies	Combustor
TECC-AE	2008	On-going	SN*	Technology Enhancements for Clean Combustion	Combustor
INTELLECT D.M.	2003	Completed	RRD*	Integrated Lean Low-Emission Combustor Design Methodology	Combustor
TIMECOP-AE	2006	Completed	TM*	Toward Innovative Methods for Combustion Prediction in Aero-engines	Combustor
TLC	2005	Completed	SN*	Towards Lean Combustion	Combustor
LOPOCOTEP	2000	Completed	SN*	LOw POllutant COmbustor TEchnology Project	Combustor
ALFA-BIRD	2008	Completed	Eu-Vri	Alternative Fuels and Biofuels for Aircraft Development	Fuel
SWAFEA	2009	Completed	Onera	Sustainable Way for Alternative Fuels and Energy in Aviation	Fuel
burnFAIR	2010	On-going	LH*	Searching for a viable kerosene replacement	Fuel
ITAKA	2012	On-going	SEN*	Initiative Towars sustAinable Kerosene for Aviation	Fuel
SESAR	2007	On-going	JU	Single European Sky ATM Research	Operations
CleanSky - SGO	2008	On-going	Thales	System for Green Operation	Operations
AIRE	2009	On-going	SJU-FAA	Atlantic Interoperability Initiative to Reduce Emissions	Operations
ERAT	2007	Completed	To70	Environmental Responsible Air Transport	Operations
CleanSky EcoDesign	2008	On-going	DA&FHF	Eco-Design (co-leaded by Dassault & Fraunhofer)	Recyclability
CleanSky - TE	2008	On-going	Thales	Technology Evaluator	Assessment
AERONET III	2003	Completed	DLR*	Aircraft Emissions and Reduction Technologies	Network & monitoring
ELECT-AE	2005	Completed	RRD*	European Low Emission Combustion Technology in Aero Engines	Network & monitoring
OPTI	2010	Completed	ASD	Observation Platform Technological and Institutional	monitoring
X-NOISE EV	2010	On-going	SN*	Aviation Noise Research Network and Coordination	Network & monitoring for NOISE
OPTICS	2013	On-going	Eurocontrol	Observation Platform for Technical and Institutional consolidation of Safety research	Network for Safety
CATER	2013	On-going	SESM	Coordinating Air transport Time Efficiency Research	Network time efficiency
COREJet-fuel	2013	On-going	FNR	Coordinating research and innovation of jet and other sustainable aviation fuel	Network & monitoring for Fuel
Team-Play	2010	Completed	DLR*	Tool Suite for Environmental and Economic Aviation Modelling for Policy Analysis	Regulation
NEPAIR	2003	Completed	Qinetiq	Development of the technical basis for a New Emissions Parameter covering the whole AIRcraft operation	Regulation
GreenAir	2009	On-going	EADS	Generation of Hydrogen by Kerosene Reforming via Efficient and Low-Emission New Alternative, Innovative, Refined Technologies for Aircraft Application	Other

* projects whose coordinators are partners of FORUM-AE



« Aircrafts RTD programs »

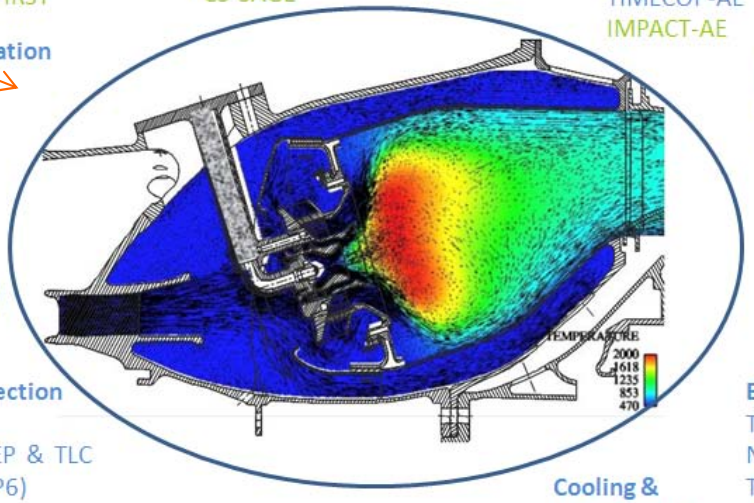
Alternative fuels
DREAM
FIRST

Ignition
INTELLECT DM
TECC-AE
KIAI
CS-SAGE

Combustion Instabilities
ICLEAC
MUSCLES
TECC-AE
KIAI

CFD Modelling
CFD4C
MOLECULES
TIMECOP-AE
IMPACT-AE

Fuel Atomisation and Spray
KIAI
FIRST



Combustor/Turbine Interaction
FACTOR
LEMCOTEC (SP3)

Diffuser Aerodynamics
INTELLECT DM
LEMCOTEC (SP3)

Advanced Combustor design
IMPACT-AE
CS-SAGE
LEMCOTEC (SP3)

Staged injection Systems
LOPOCOTEP & TLC
NEWAC (SP6)
TECC-AE
IMPACT-AE
LEMCOTEC (SP3)

Fuel Coking
TECC-AE

Soot Modelling
SIA TEAM
FIRST

Cooling & Heat Transfer
LOPOCOTEP
TECC-AE
IMPACT-AE

Extinction
TLC
NEWAC (SP6)
TECC-AE
KIAI
LEMCOTEC (SP3)

« Combustor Technology RTD pgms »

FORUM-AE

SEVENTH FRAMEWORK PROGRAMME

WORKSHOPS

➔ Well focused on key topics in the project technical scope

- Content of each workshop will be consolidated if needed in the course of the project with PMC validation
- Topics are balanced in time and in technical field
- Standardised review process for any workshop outline, agenda, and proceedings

Time	WP0 (managt & dissemination)	WP1 (Envir. Impact)	WP2 (mitigation solutions)	WP3 (regul. Tech. issues)
T0	WS(kick-off)	X	X	X
Year 1		WS(CC) WS(AQ)	WS(Comb. Tech) WS(FB Techno)	WS(particles)
Year 2		WS(Inv.)	WS(Coord. Alt Fuel)	WS(CO2)
T0+24	WS(Mid-term)	X	X	X
Year 3		WS(CC)	WS(ATM) WS(FB Techno)	WS(MBM)
Year 4		WS(AQ)	WS(Comb. Tech)	WS(NOx)
T0+48	WS(final)	X	X	X
Total	3	5	6	4

FORUM-AE WORKSHOPS IN 2014

Kick-off Meeting: general workshop

- 19th & 20th September 2013; DG RTD in Brussels

1st meeting: Air Quality + Particles

- WP1 & WP3 — MMU
- 9th & 10th Jan. 2014 — Manchester

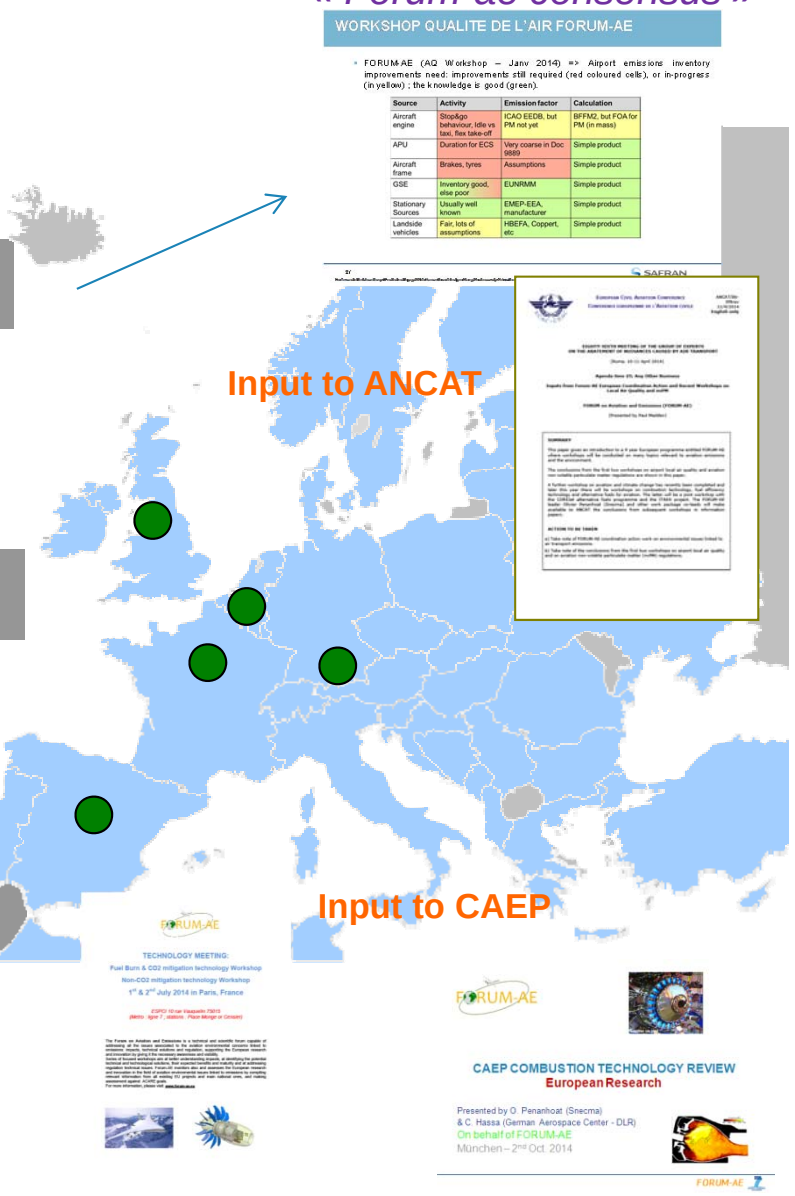
2nd meeting: Climate Change

- WP1 — DLR
- 2nd & 3rd April 2014 — Munich

3rd meeting: Combustion Technology + Fuel Burn

- WP2 — SN
- 1st & 2nd July 2014 — Paris

« Forum-ae consensus »



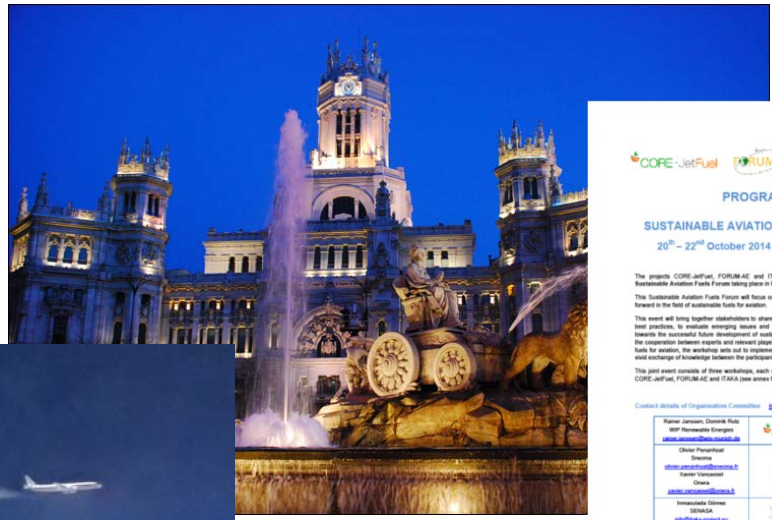
FORUM-AE

SEVENTH FRAMEWORK PROGRAMME

FORUM-AE WORKSHOPS IN 2014 AND NEXT

→ 4th meeting: Alternative Fuels (jointly with CORE-JetFuel and ITAKA)

- **WP2** **Senasa**
- **21th Oct. 2014** **Madrid**



→ 5th meeting: Basket of measures to reduce CO_2

- WP2-WP3 Possibly hosted by Airbus (TBC)
- Beginning 2015 Toulouse

FORUM-AE

SEVENTH FRAMEWORK PROGRAMME

RESULTS & CONTRIBUTIONS (AFTER ONE YEAR)

- **Synoptic table**

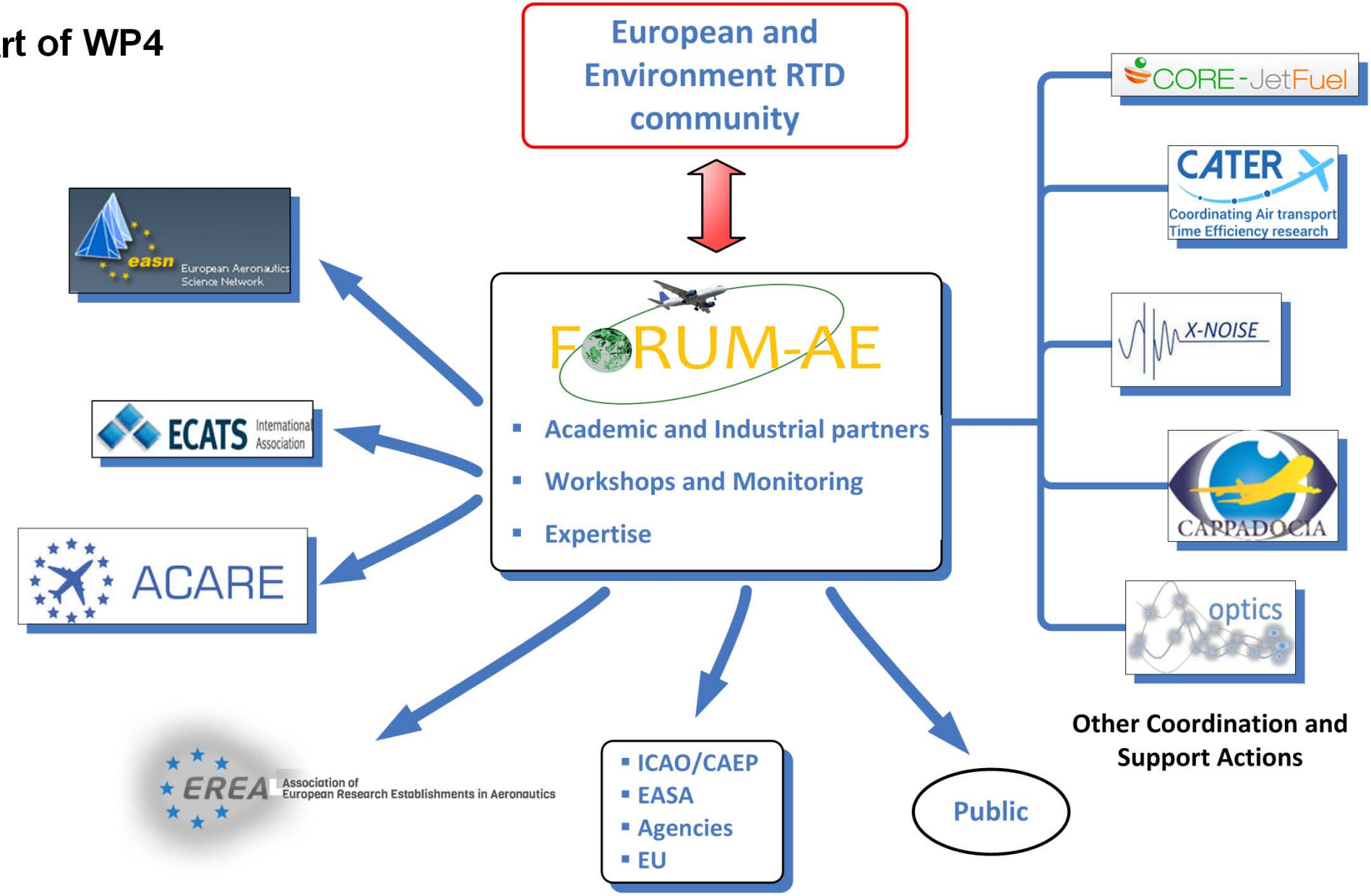
Goals	Inputs from workshops	Inputs from RTD monitoring
75% CO2 reduction	see WS n°4 (1st July 2014)	expected
90% NOx reduction	see WS n°5 (2nd July 2014)	expected
Emissions free taxiing	Year 2	
Green manufacturing	see WS n°4 & 5	expected
Sustainable alternative fuels	see WS n°6 (Oct 2014)	limited
Atmospheric research	WS n°1 (AQ) & WS n°3 (CC)	limited
Regulation expertise	WS n°2 (nvPM)	ϕ

- **Progress towards ACARE goals will be assessed quantitatively for G1, G2 and qualitatively for G3 to G7**

- **Contribution & dissemination to ANCAT, CAEP**

DISSEMINATION OBJECTIVE

Part of WP4



Thank you for your attention

BACK-UP: CONSENSUS ACHIEVED AT AQ WS

- FORUM-AE (AQ Workshop – Janv 2014) => Airport emissions inventory improvements need: improvements still required (red coloured cells), or in-progress (in yellow) ; the knowledge is good (green).

Source	Activity	Emission factor	Calculation
Aircraft engine	Stop&go behaviour, Idle vs taxi, flex take-off	ICAO EEDB, but PM not yet	BFFM2, but FOA for PM (in mass)
APU	Duration for ECS	Very coarse in Doc 9889	Simple product
Aircraft frame	Brakes, tyres	Assumptions	Simple product
GSE	Inventory good, else poor	EUNRMM	Simple product
Stationary Sources	Usually well known	EMEP-EEA, manufacturer	Simple product
Landside vehicles	Fair, lots of assumptions	HBEFA, Coppert, etc	Simple product

SEVENTH FRAMEWORK PROGRAMME

European Commission

CROP

CYCLOIDAL ROTOR OPTIMIZED FOR PROPULSION

4th EASN Workshop on Flight Physics and Aircraft Design

29th of October, 2014

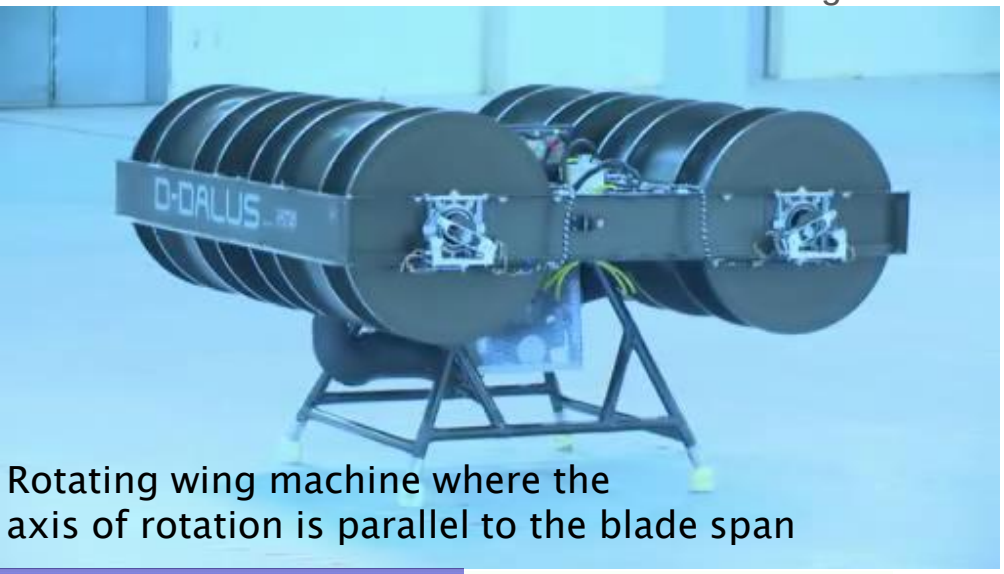
Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

C. M. Xisto*, J. C. Páscoa*, J. A. Leger*, A. Gerlach†

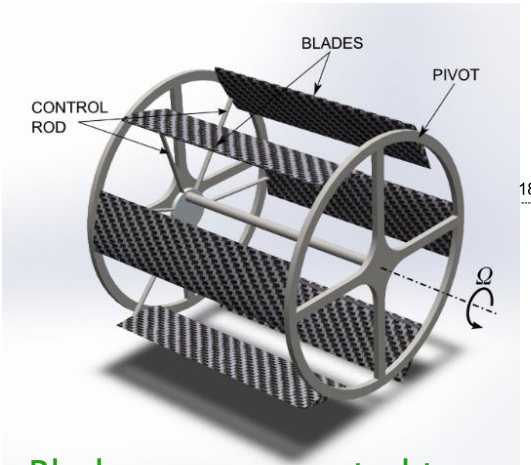
* C-MAST, Universidade da Beira Interior, Portugal
† Grob Aircraft AG, Germany

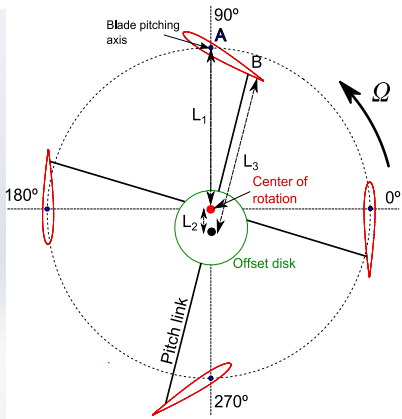
CROP || FP7-AAT-2012-RTD-L0 || GA no: 323047

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

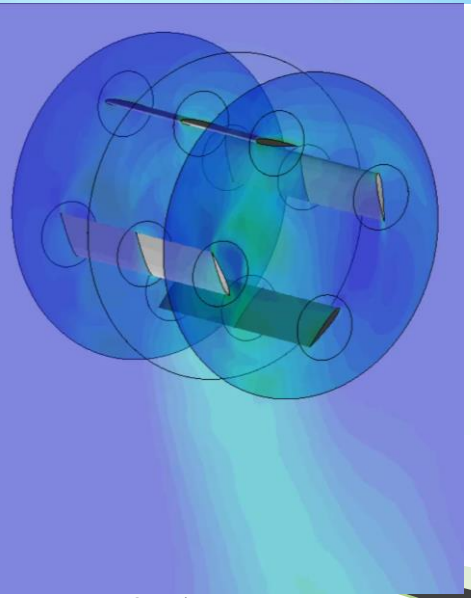


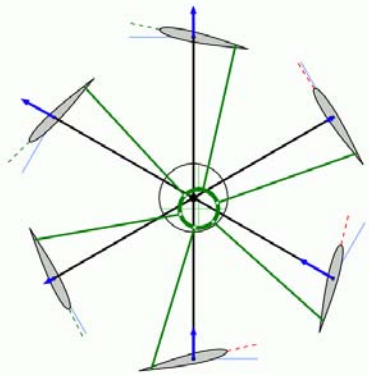
Rotating wing machine where the axis of rotation is parallel to the blade span





Blades are connected to a mechanism, preforming a predefined periodic pitching



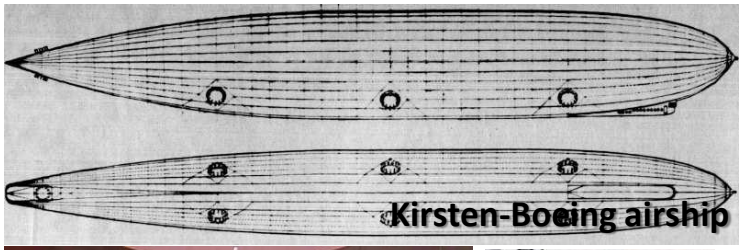


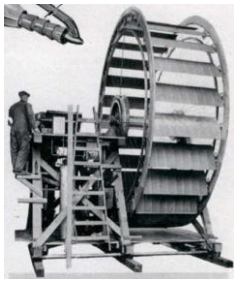
The periodic pitching creates a net aerodynamic force that could be easily controlled

Allows for a substantial increase in flight control

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

A renewed concept from the 20's – 30's

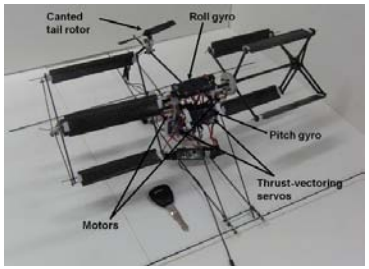




Technological limitations!

Professor Kirsten, University of Washington was a pioneer in the research of cycloidal rotors 1920-1930.

Tests were conducted in collaboration with Boeing to build a "cycloplane" and a 3D vector thrust control for an airship.



Alfred Gessow Rotorcraft Center. Department of Aerospace Engineering. University of Maryland, USA.

MAV-Scale

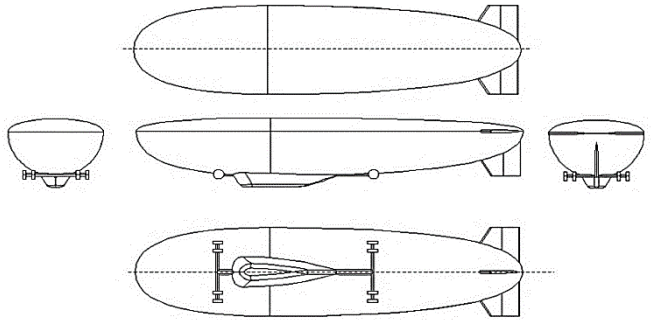
School of Mechanical and Aerospace Engineering. Seoul National University, Korea.

Small-Scale

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

Optimized wings for forward flight, thrust vectoring, STOL.

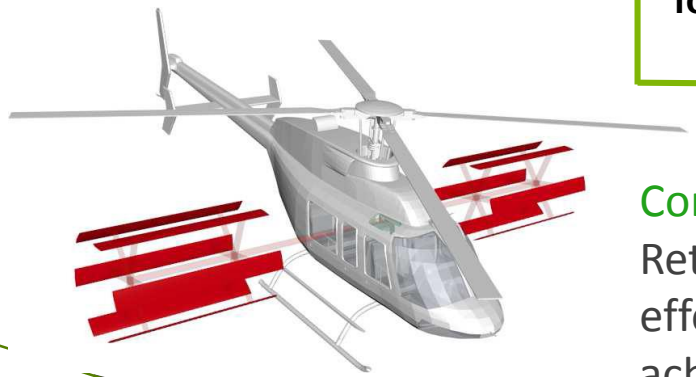
UNIMORE Concept: Airship



EU Challenge

Radical new concepts for air transport

POLIMI Concept



Compound Helicopter

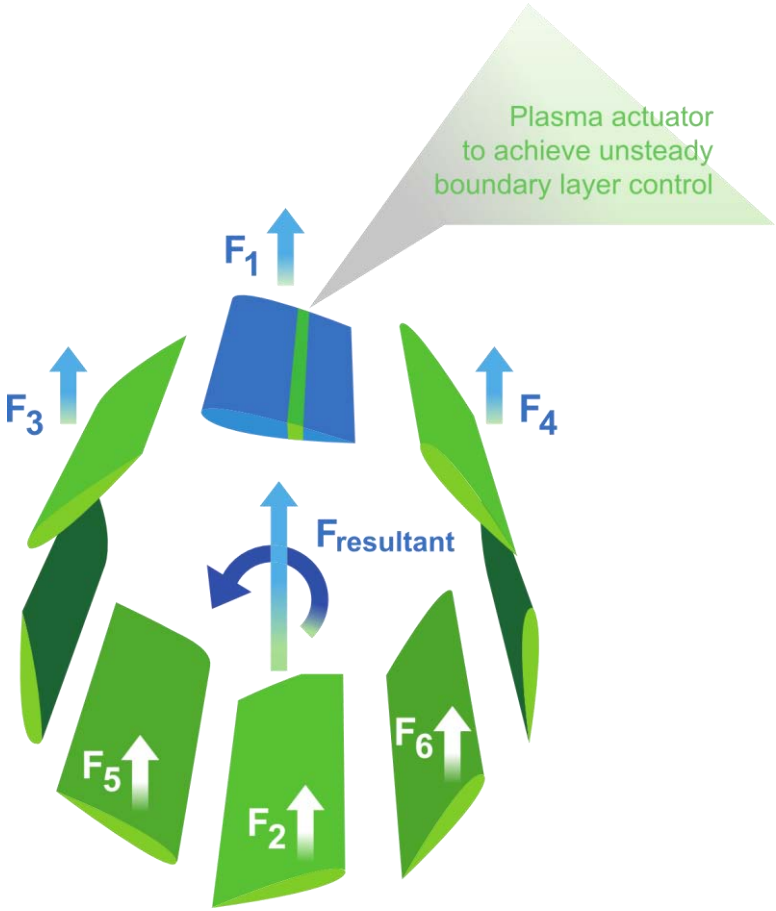
Retreating blade stall effect is reduced. It can achieve higher subsonic speeds

Cyclogiros for lift and thrust

IAT21 Concept

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

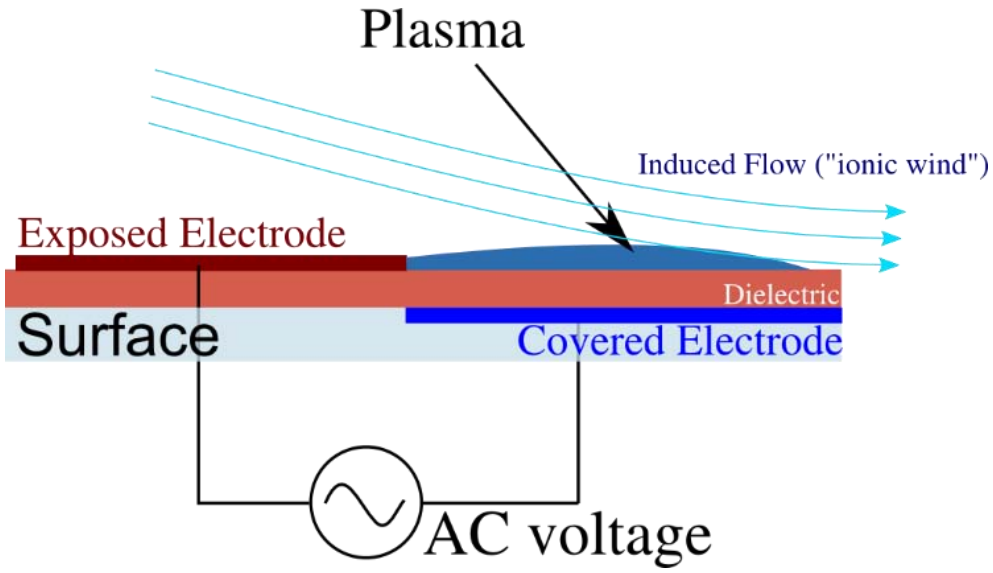
Improve the aerodynamic efficiency of the cycloidal rotor?



- The generated net force increases with the square of rotation speed.
- Increasing the number of blades could be beneficial (there is a limit).
- Increasing the blade span (rule: span=diameter).
- Selecting a more efficient airfoil (increase thickness).
- Changing the position of the pitching axis (optimal position between 25-35% of chord length).
- Increasing the pitching amplitude

  There is a limit!

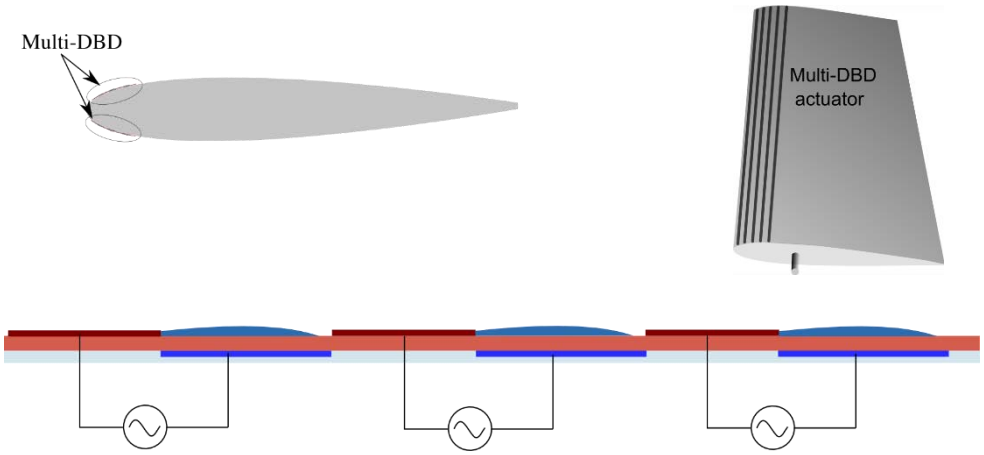
Dielectric Barrier Discharge (DBD) Plasma actuators



- Low power consumption;
- No mechanical parts;
- Easy integration;
- Very fast frequency response.
  - Real time control

- The electric field partially ionizes the air.
- The ionized air (plasma) produces a repulsion/attraction force on the charged particles.
- The charged particles (ions) collide with the neutral particles generating an induced flow.

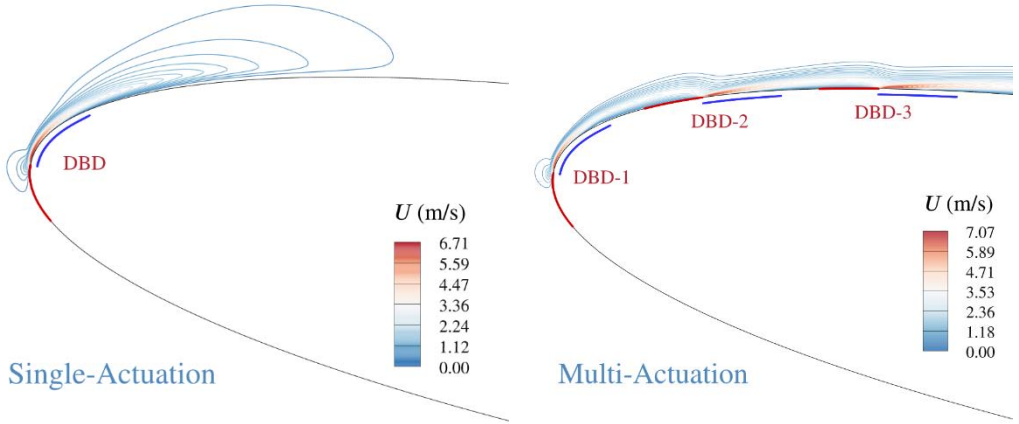
Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control



Challenges

- The DBD must be located near the flow separation point (upstream).
- Several non-constant parameters affect the flow separation point.
  - Rotation speed.
  - Pitch angle
- The usage of a single DBD is not enough.

- The multi-DBD can be adjusted by a control loop in order to activate one or a combination of DBDs.
- Multiplication factor, only works in a steady-mode of operation, where a quasi steady induced flow is achievable.
- Larger portion of the airfoil is covered.



Baseline test case

Experimental results of Lee and Gerontakos (2004)

Deep-stall

$\mathrm{Re_c} = 1.35 \times 10^5$

$U_\infty = 14$ m/s

$c = 0.150$ m

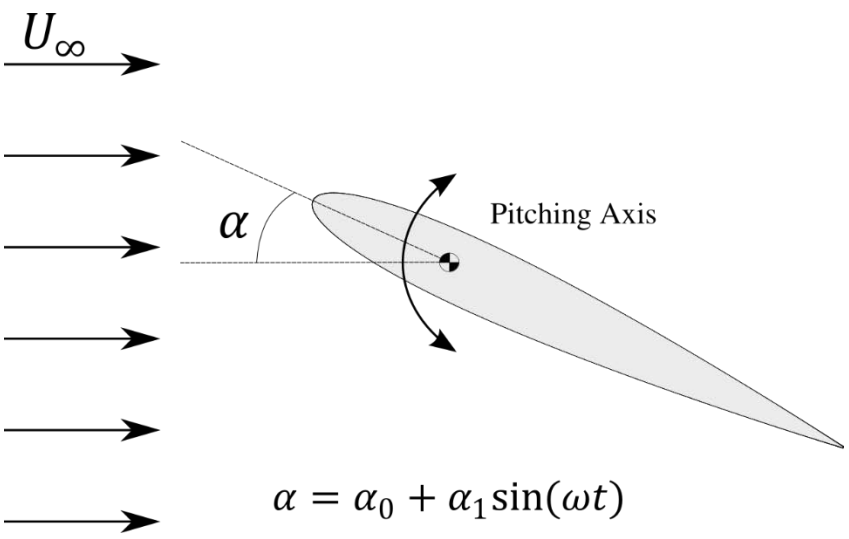
$S = 0.375$ m

$\mathrm{PA} = 0.25 \times c$

$\alpha_0 = 10\ ^\circ$

$\alpha_1 = 15\ ^\circ$

$\omega = 18.67$ rad/s

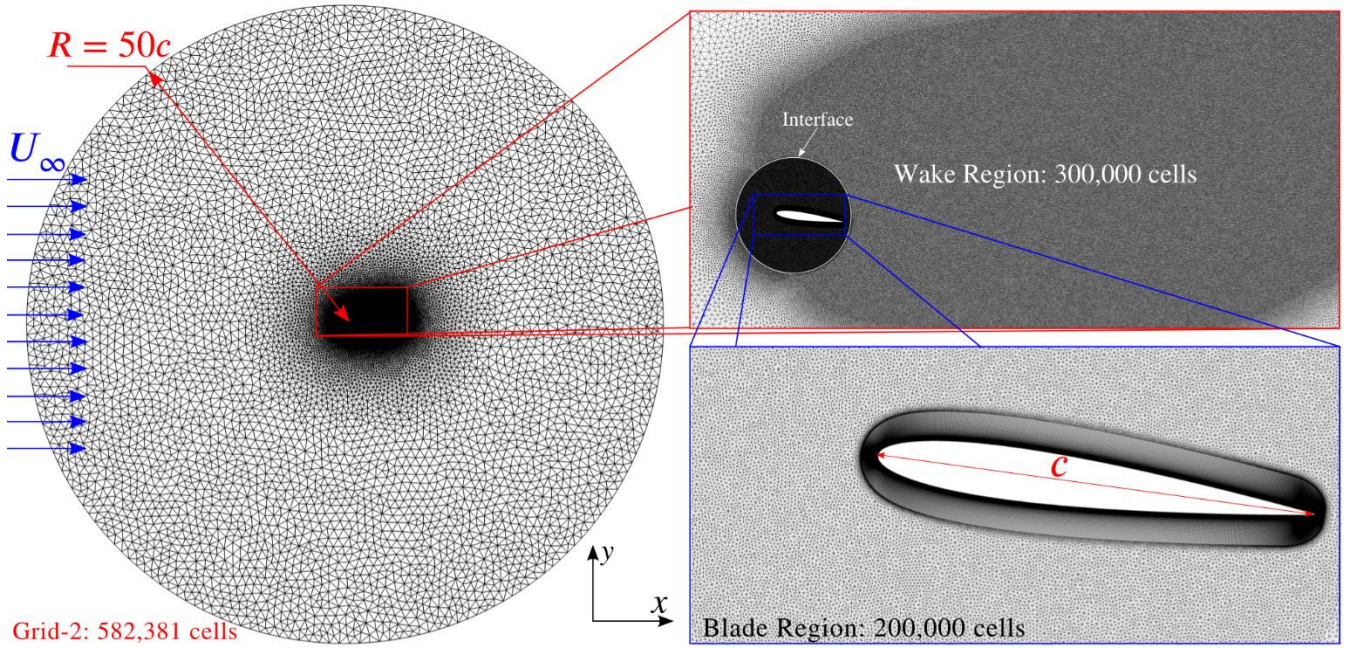


- The flow is quasi bi-dimensional at midspan (2D non-uniformity of 4%)
- Results obtained in a low-speed wind tunnel with a maximum blockage of 5%.
- Turbulent intensity of 0,08 % at 35 m/s.

The most simple equivalent system is a pitching airfoil!

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

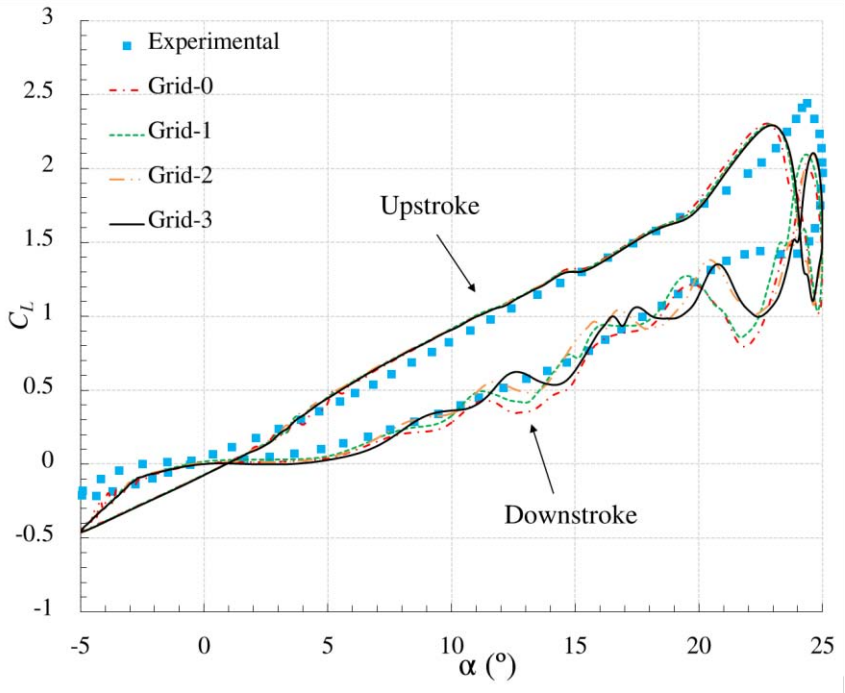
Numerical Setup

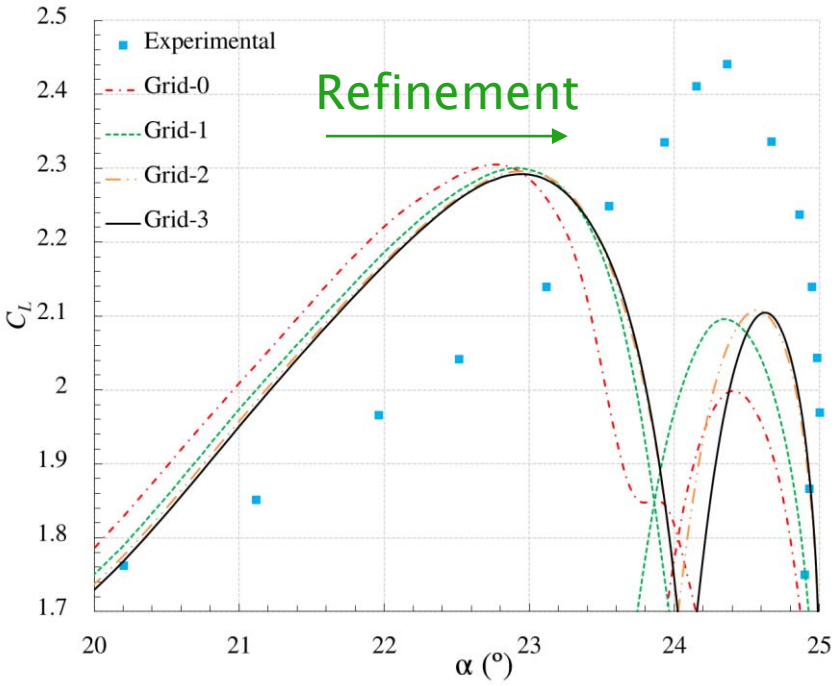


- Incompressible Navier-Stokes Equations (low free-stream velocity)
- Pressure-Based Coupled algorithm (CFL = 100 within each time-step).
- 2nd order space and time discretization.
- $k-\omega$ SST transition turbulence model (Experiments were showing clear signs of transition).

- Grid-0: 89,000 cells; Grid-1: 180,000 cells; Grid-2: 582,000 cells; Grid-3: 873,000 cells (Grid idependence study).
- 8 complete cycles were computed, time-converged (periodic) solution obtained after 4 cycles.
- dt1: T/500; dt2: T/1000; dt3: T/2000 (Time-step idependence study). .

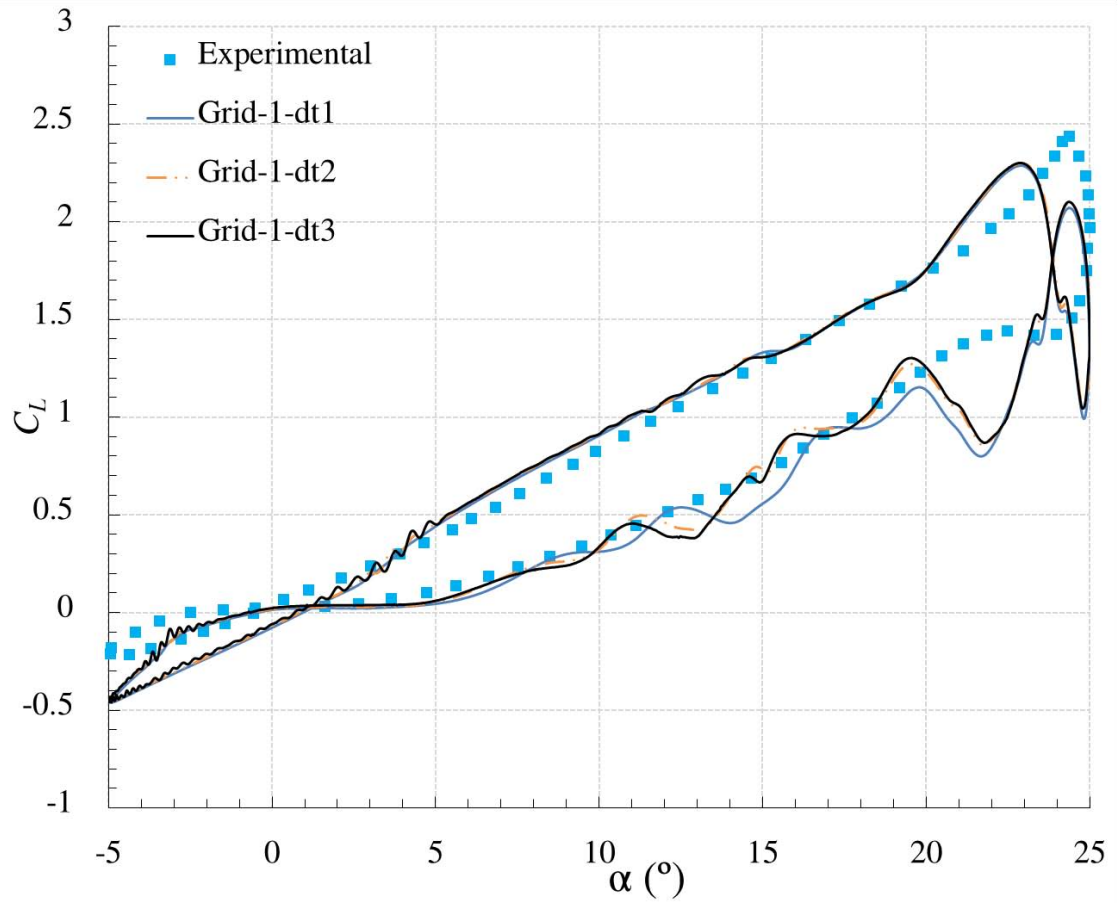
Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control





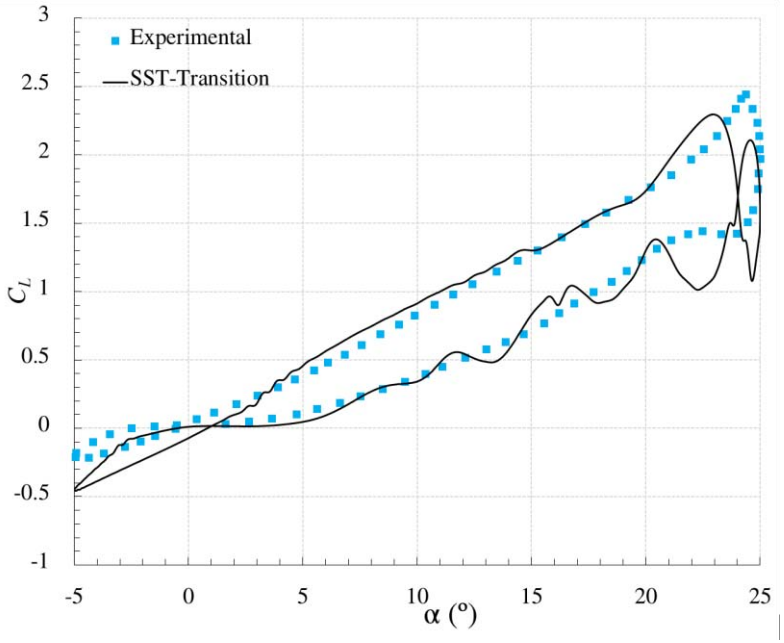
- The computed C_L almost overlap with each other on the upper cycle.
- The biggest discrepancy is located in the peak region, where the results of Grid-2 and 3 show a good agreement.
- In the downstroke phase the unsteadiness of the flow gives us a bigger discrepancy, nevertheless the results of grid-2 and 3 are similar in terms of average values.

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

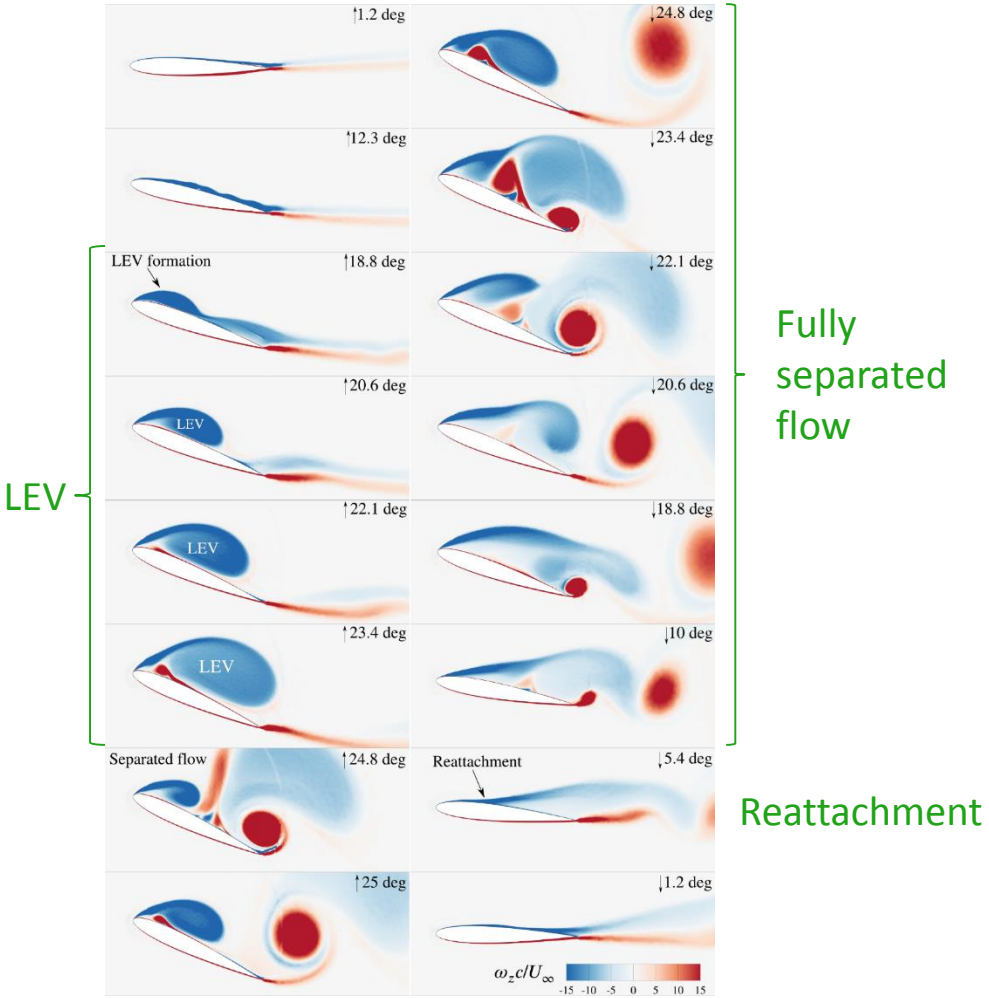


- There isn't a significant difference between dt2 and dt3.
- We can conclude that the results obtained with grid-2 and dt2 are satisfactory in terms of mesh and time-step sensitivity

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control



- The numerical model is able to predict with some accuracy the time-dependent value of C_L.
- The biggest discrepancy is located in the peak region (non-well resolved leading edge vortex).
- The LEV formation and convection over the suction surface of the airfoil delays stall.



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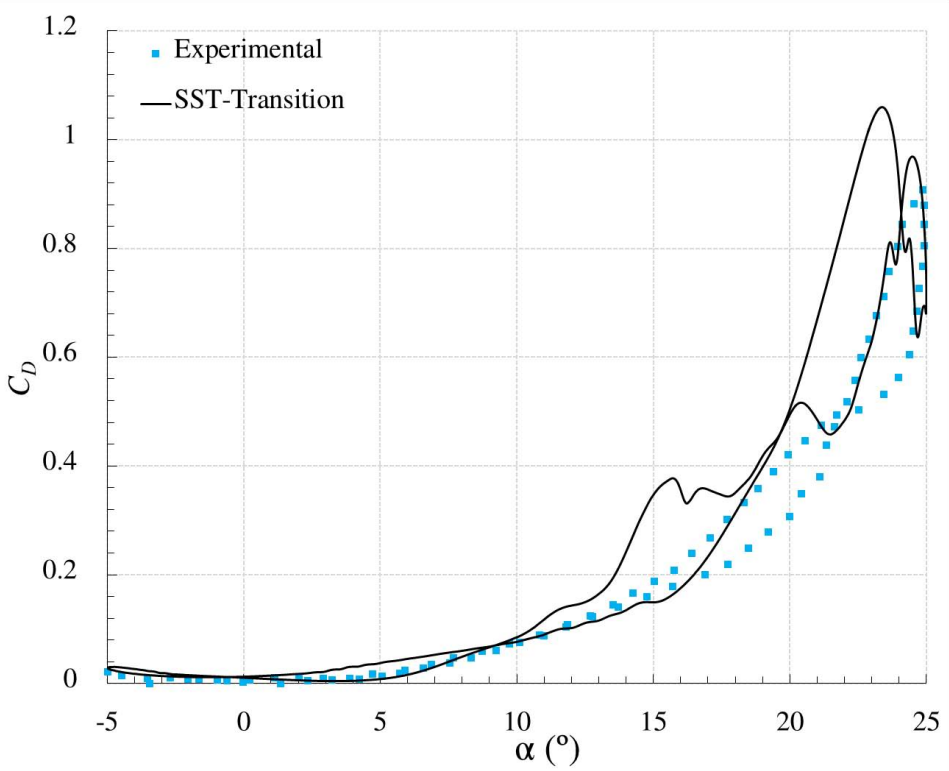
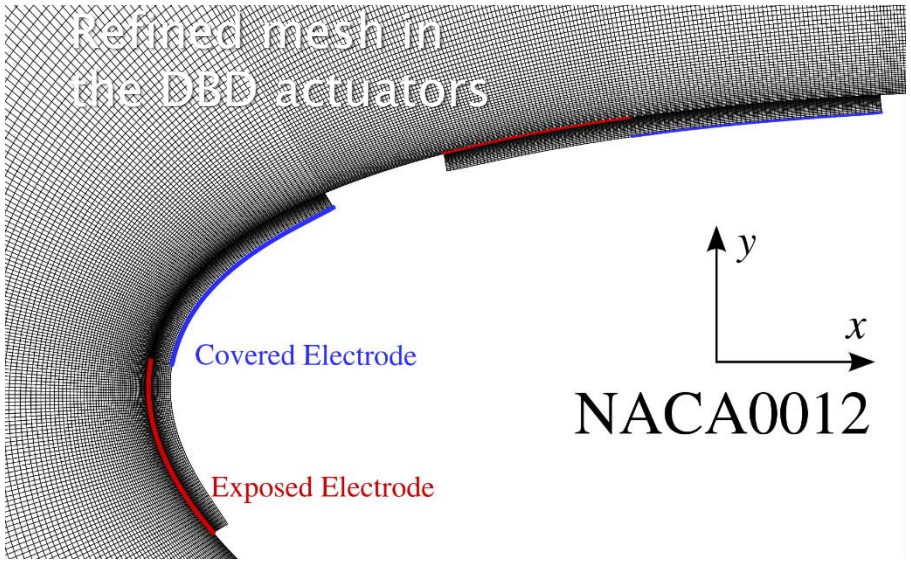
Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control



- Drag is being over-predicted at several positions, however the results could be considered satisfactory in terms of averaged values.

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control



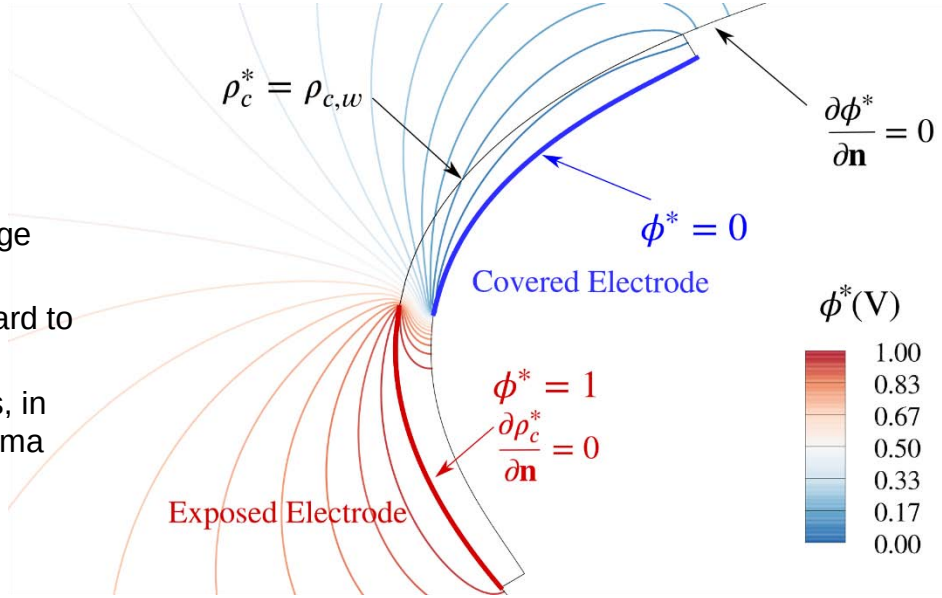
Gas dynamic Model (same as before)

- Incompressible Navier-Stokes Equations
- Pressure-Based Coupled algorithm (CFL = 100 within each time-step).
- 2nd order space and time discretization.
- $k-\omega$ SST transition turbulence model.

DBD-Model

- Phenomenological approximation.
- Consider the effect of the actuator as a body force.
- The body force is computed as a function of discharge voltage and charge density.
- Charge density is a very important parameter and hard to obtained.
- Similar grid but further refined in the actuation zones, in order to properly computed the thickness of the plasma region.

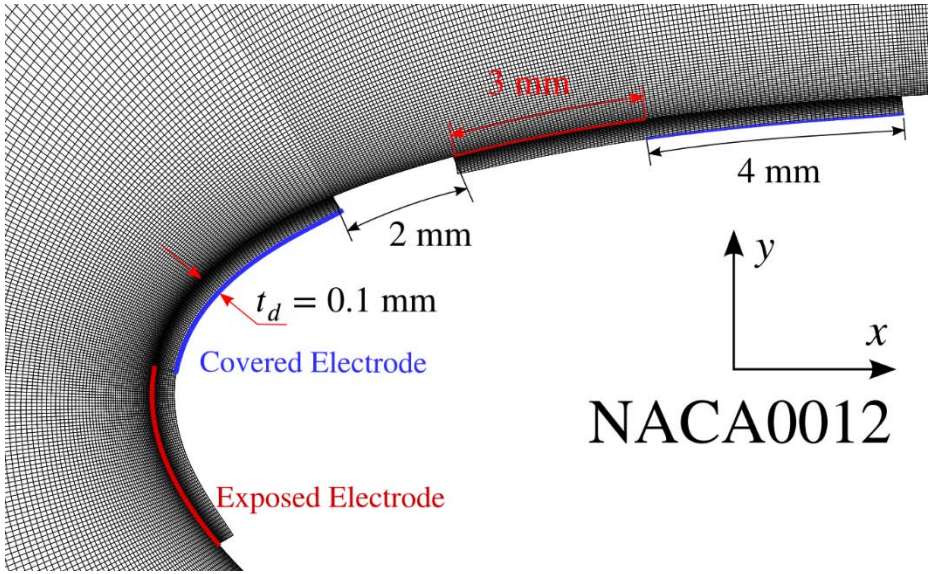
Boundary conditions



Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

Steady actuation

- The DBD is always on.
- AC frequency much higher than fluid response frequency.
- The flow will sense a constant body force.



Tested Configurations

- Single-DBD with one DBD active at the leading edge ($x/c = 0$).
- Multi-DBD with three active DBD, placed 2 mm apart.
- Length of the exposed electrode: 3 mm.
- Length of the covered electrode: 4 mm.
- Thickness of the Dielectric 100 μm (two layers of Kapton).

Supplied signal

- 7 kHz sinusoidal wave with $V_{pp} = 8$ kV

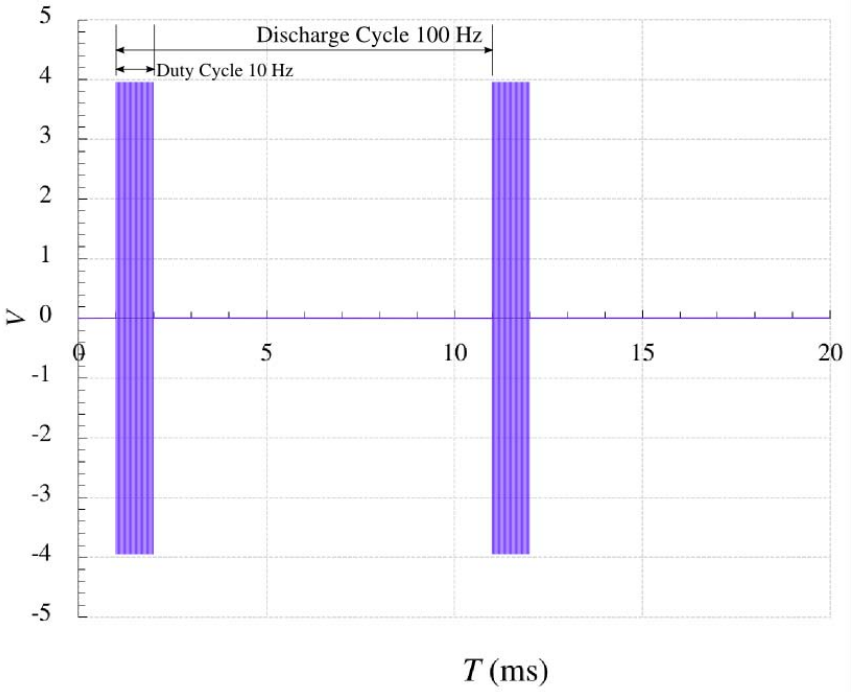
Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

Unsteady actuation

- The AC signal is cycled off and on with an unsteady period.
- The time when the AC voltage is on within that period is called duty cycle (10%).
- Promotes the creation of non-stationary disturbances that lead to vortices increasing the momentum on the suction surface.
- Allow the flow to withstand the adverse pressure gradients.

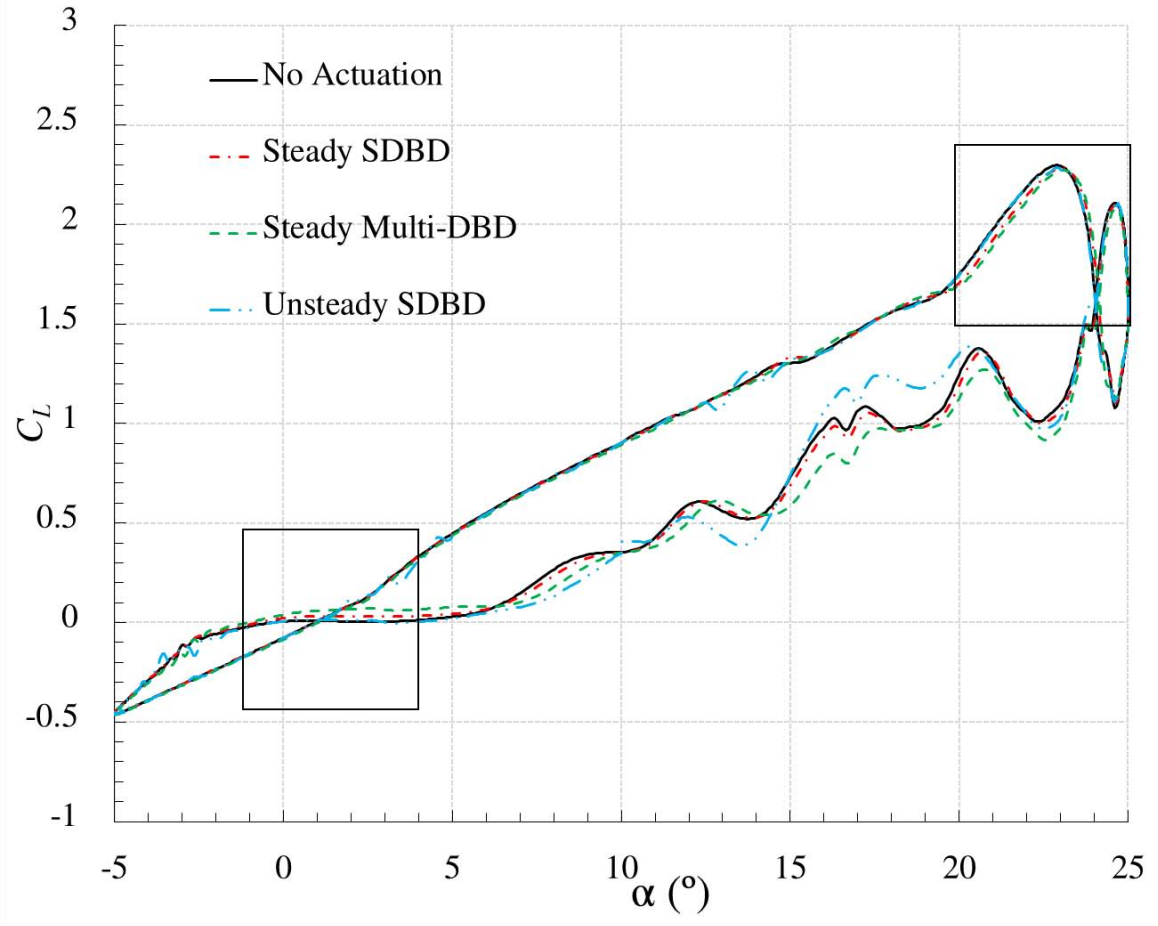
- Optimal discharge cycle is selected in a way that the DBD could generate and convect 2-3 vortices, this could attained if:

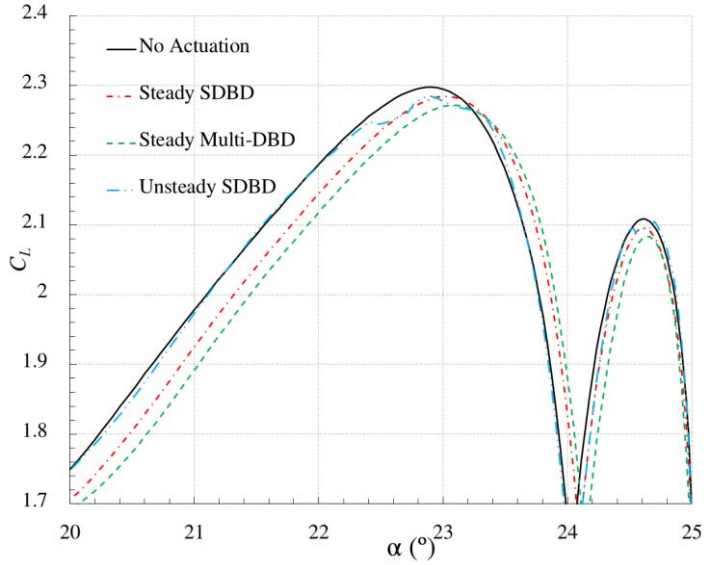
$$S_t = \frac{fc}{U_\infty} = 1 \text{ (Valid for static airfoils)}$$

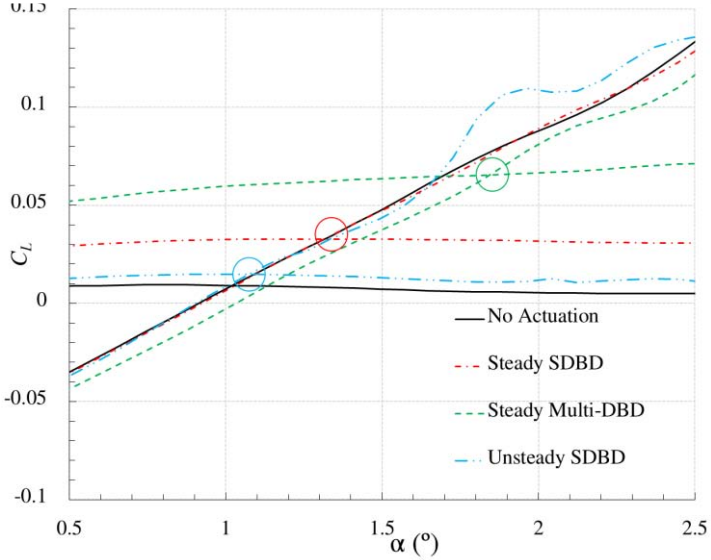


- Several researchers found out that for pitching airfoils a lower forcing frequency is more beneficial $S_t = 0.5, f = 50$ Hz.

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

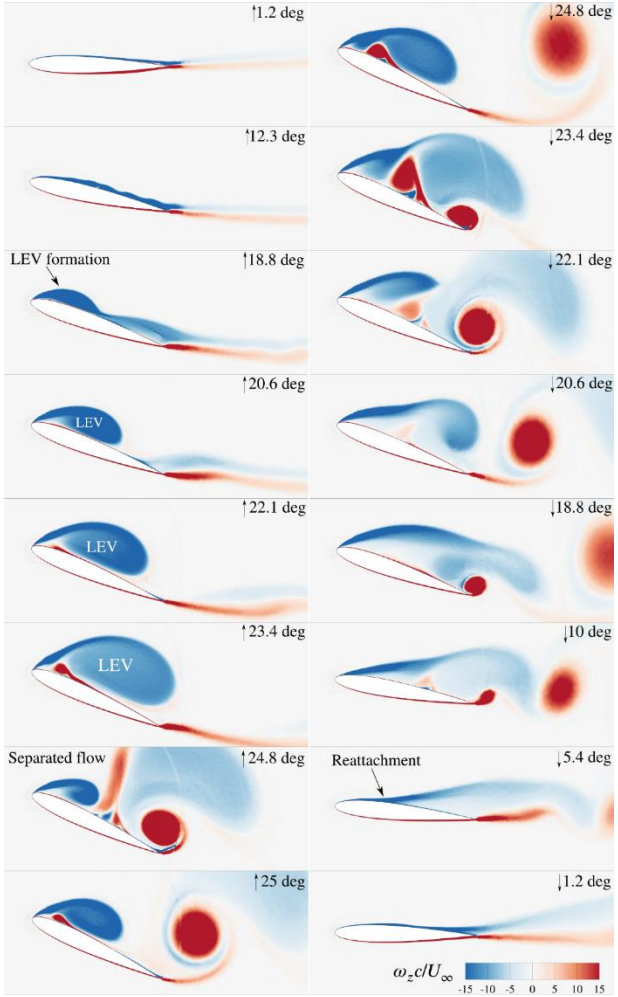


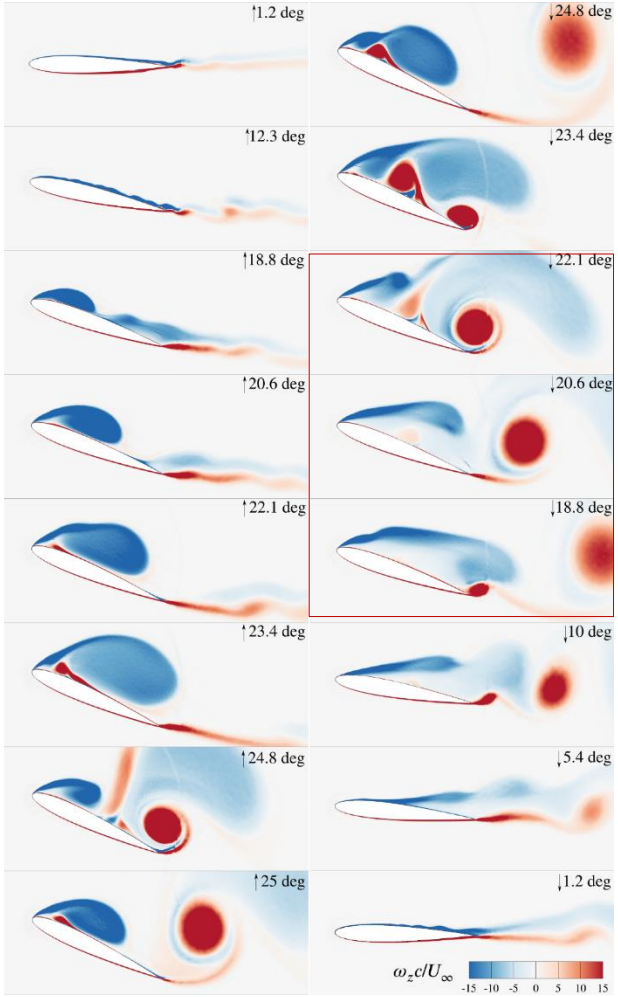




Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

No Actuation





With Unsteady Actuation

Conclusions

- The inclusion of a Multi-DBD configuration is more beneficial than using a single DBD, since it delays stall and permits a faster reattachment of the flow.
- An optimal arrangement of actuators needs to be selected in order to achieve the desirable multiplication factor.
- A control algorithm is also required, particularly in the steady-operation mode, in order to shutdown the actuation in most of the downstroke phase, where the DBDs were reducing the lift coefficient of the airfoil.
- The unsteady actuation shown a superior performance on the downstroke phase of the cycle.

Multi-Dielectric Barrier Discharge Plasma Actuator For Cycloidal Rotor Active Flow Control

CYCLOIDAL ROTOR OPTIMIZED FOR PROPULSION

Project consortium:

UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

GROB AIRCRAFT

UNIVERSIDADE DA BEIRA INTERIOR

The University Of Sheffield.

IAT21 Innovative Aerodynamic Technologies

POLITECNICO DI MILANO

The research leading to presented results has received funding from the European Union Seventh Framework Program [FP7/2007-2013] under grant agreement no. [323047].

SEVENTH FRAMEWORK PROGRAMME

European Commission

SEVENTH FRAMEWORK PROGRAMME

CROP

European Commission

CYCLOIDAL ROTOR OPTIMIZED FOR PROPULSION

CYCLOIDAL ROTOR AERODYNAMIC AND AEROELASTIC ANALYSIS

L. Gagnon, M. Morandini, G. Quaranta, P. Masarati,
Politecnico di Milano, Italy

4th EASN Workshop on Flight Physics and Aircraft Design
October 2014 in Aachen, Germany

CROP || FP7-AAT-2012-RTD-L0 || GA no: 323047

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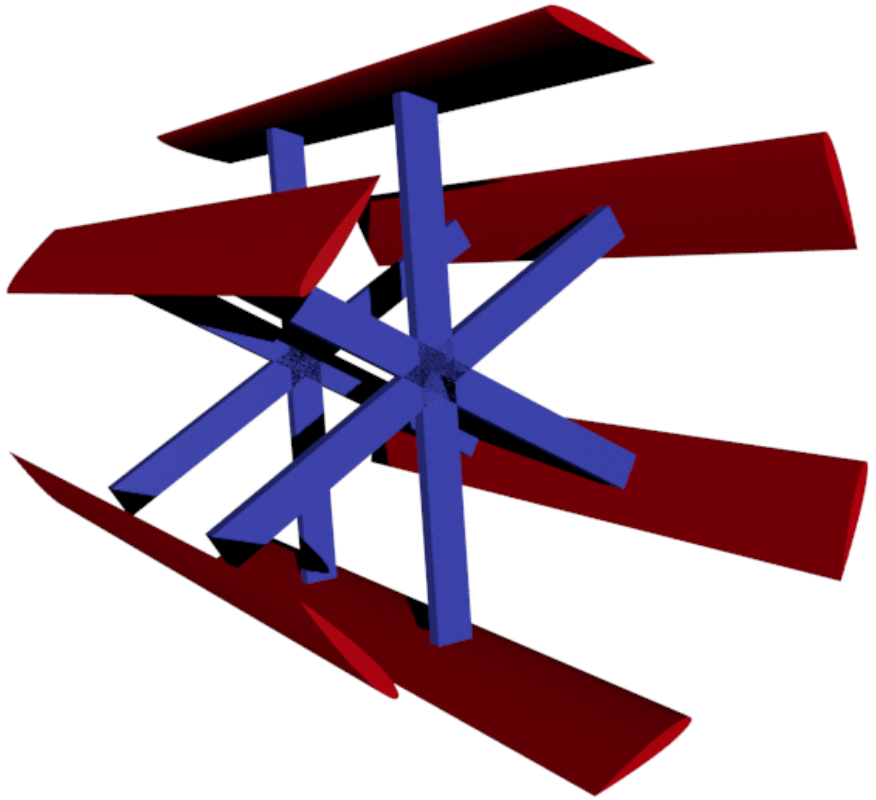
SEVENTH FRAMEWORK PROGRAMME

European Commission

The Cycloidal Rotor

A 360° Propeller

- Term coined in 1927
- Marine and air propulsion
- Micro aerial vehicles

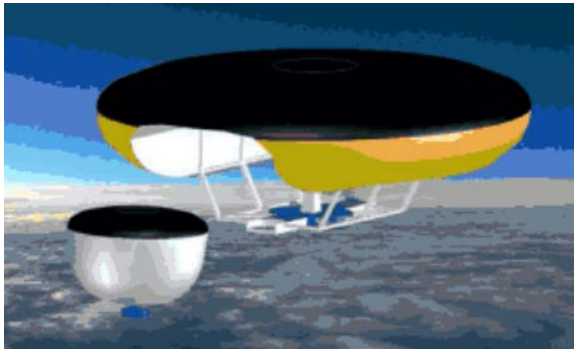


Contemporary Research

D-DALUS

- Two-seater aircraft
- CROP consortium

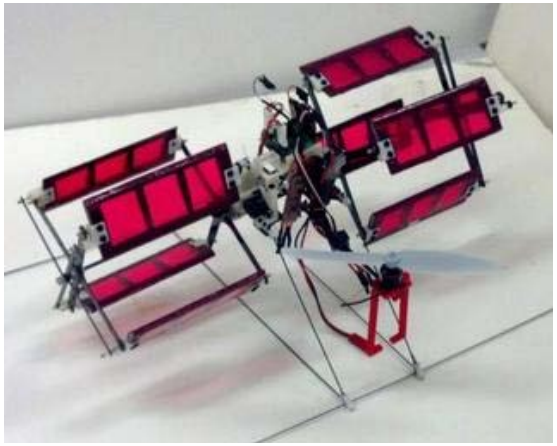
MAAT



- Advanced airship
- CROP consortium

University of Maryland

- MAV cyclocopter
- Stable flight

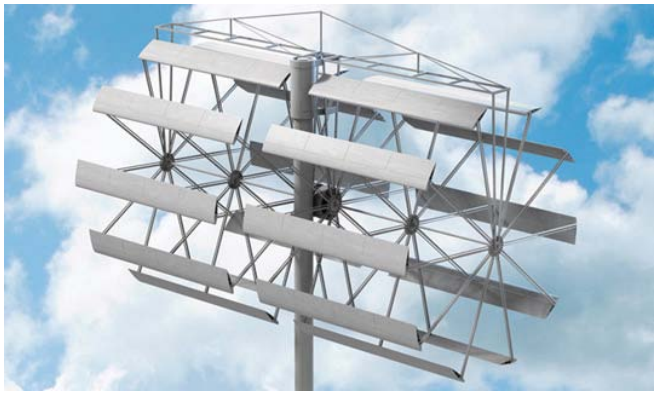


Contemporary Industry

Voith Schneider propeller

- Ship propulsion
- Highly maneuverable

Aerocam



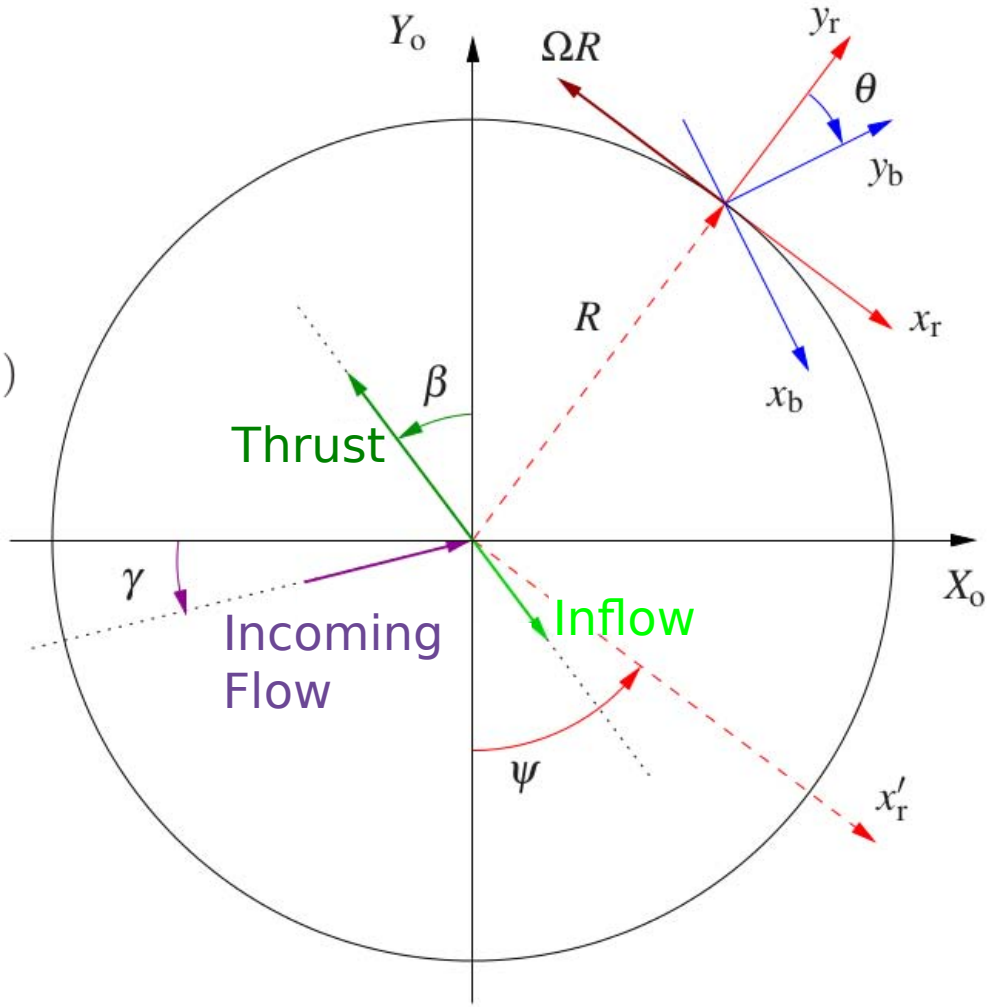
- Low cost wind energy

Mathematical Model

Analytical model

- Aerodynamic
- Uniform inflow
- Imposed pitch function

$$\theta = \theta_0 + \sum_{n=1}^{2} (\theta_{cn} \cos(n\psi) + \theta_{sn} \sin(n\psi))$$



L. Gagnon, Politecnico di Milano
Proprietary Information

Analytical Model

Yields thrust equations

- Function of
  - pitch function
  - incoming flow
  - advance ratio
  - blade properties
  - solidity
  - inflow

$$\frac{C_{T_{\|}}}{\sigma} = \frac{C_{L/\alpha}}{8}\Bigg(2\theta_{c1}\cos\gamma + 2\theta_{s1}\sin\gamma + \mu\Big(2 + \sin(2\gamma)\theta_{c2} - \cos(2\gamma)\theta_{s2}\Big) + \lambda\Big(2\sin(\beta-\gamma) + 2\cos(\beta-\gamma)\theta_0 - \cos(\beta+\gamma)\theta_{c2} - \sin(\beta+\gamma)\theta_{s2}\Big)\Bigg) + \frac{C_{D_0}}{4}\left(\lambda\sin(\beta-\gamma)+\mu\right)$$

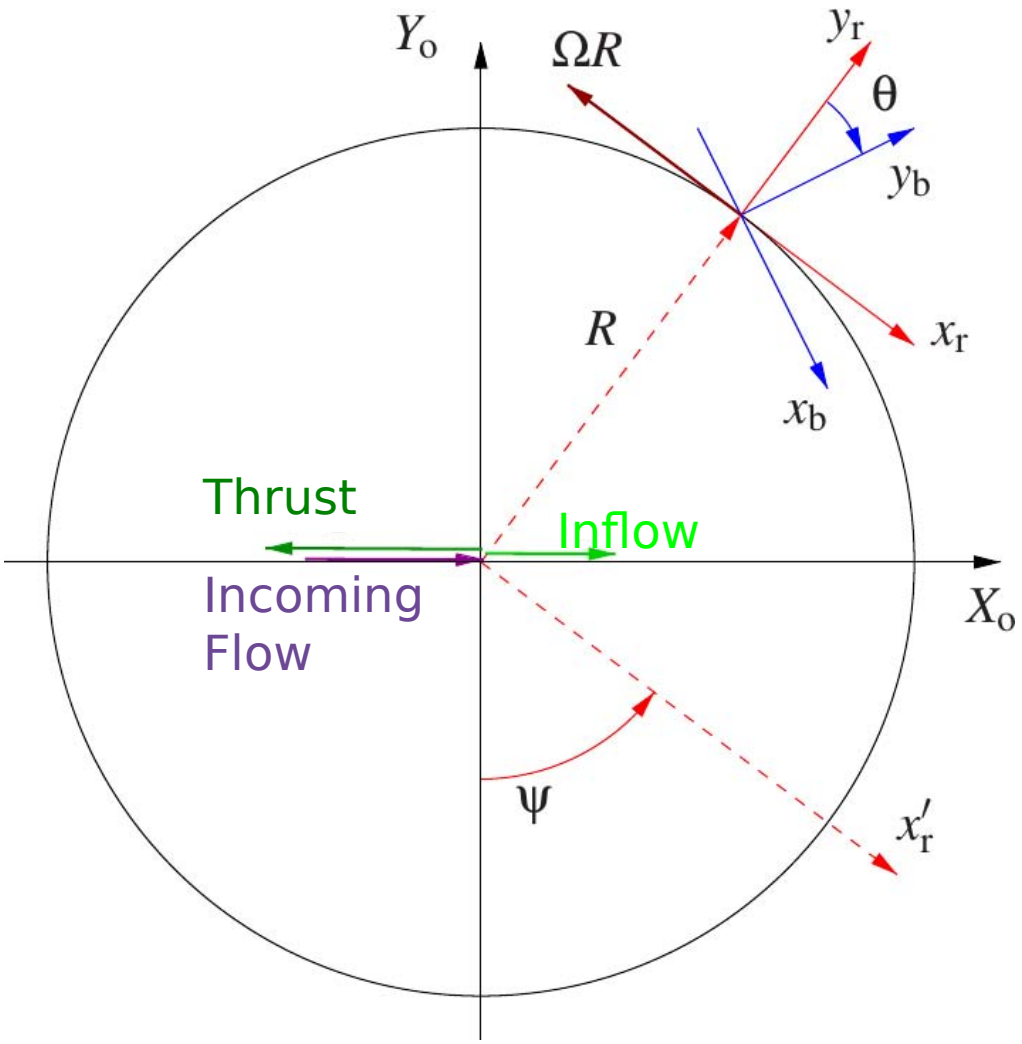
$$\frac{C_{T_{\perp}}}{\sigma} = \frac{C_{L/\alpha}}{8}\Bigg(-2\theta_{c1}\sin\gamma + 2\theta_{s1}\cos\gamma + \mu\Big(2\theta_0 + \cos(2\gamma)\theta_{c2} + \sin(2\gamma)\theta_{s2}\Big) + \lambda\Big(-2\cos(\beta-\gamma) + 2\sin(\beta-\gamma)\theta_0 + \sin(\beta+\gamma)\theta_{c2} - \cos(\beta+\gamma)\theta_{s2}\Big)\Bigg) - \frac{C_{D_0}}{4}\lambda\cos(\beta-\gamma)$$

Solving the Analytical Model

Regimes solved algebraically

- Propulsion →
  - U > 0
  - γ ≈ 0
  - T > 0
  - v_i > 0
  - β ≈ π/2

- Reverse propulsion
  - U > 0
  - γ ≈ 0
  - T > 0
  - v_i > 0
  - β ≈ -π/2



Model Peculiarities

- Solved by applying an empirical corrector to inflow parameter λ

$$\lambda_P = -\frac{\mu}{2} + \sqrt{\left(\frac{\mu}{2}\right)^2 + \frac{\pi C_{T_P}}{2}}$$

$$\lambda = \kappa\sqrt{C_T/2}$$

Johnson

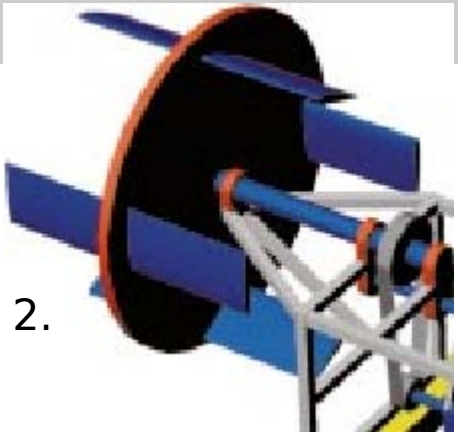
$$4\kappa_{emp}\lambda^2 = \sigma a(1+\lambda^2)\left\{(\theta-\phi)\cos\phi - \frac{C_d}{a}\sin\phi\right\}\sin^2\Psi$$

Yun et al.

Experimental Data

Author	Radius (m)	Span (m)	Chord (m)	N. Blades	3D Control
1. IAT21	0.6	1.0	0.3	6	At edges
2. Bosch	0.6	1.2	0.3	6	At midpoint
3.	0.4		0.15	6	None

1.

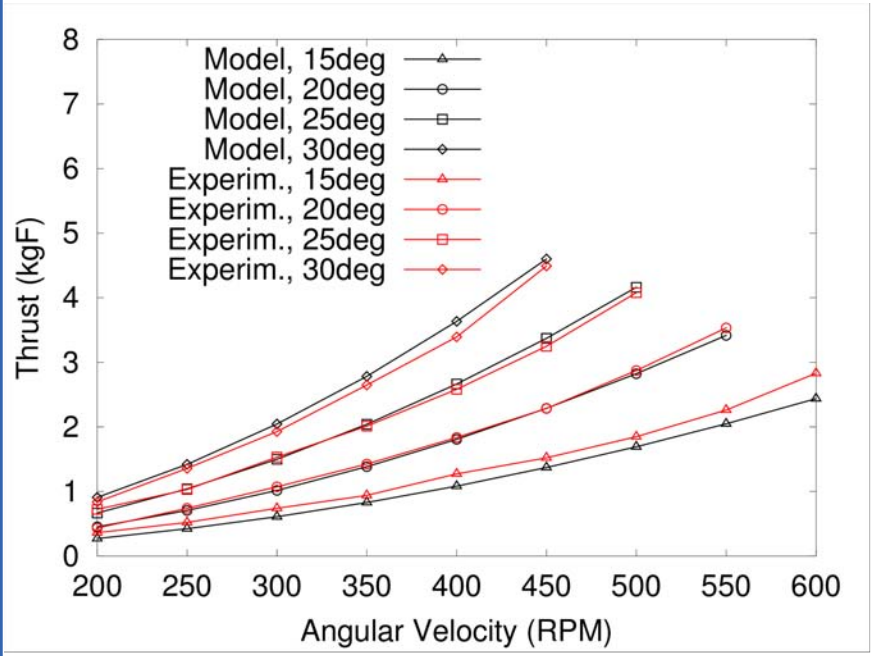
2. 

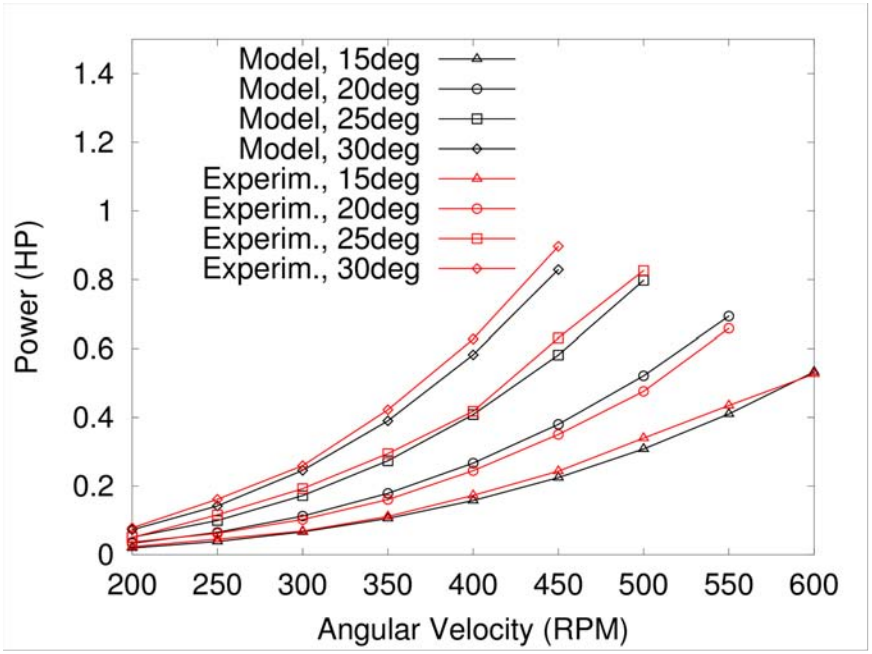
3.

Model Validation

Yun et al.

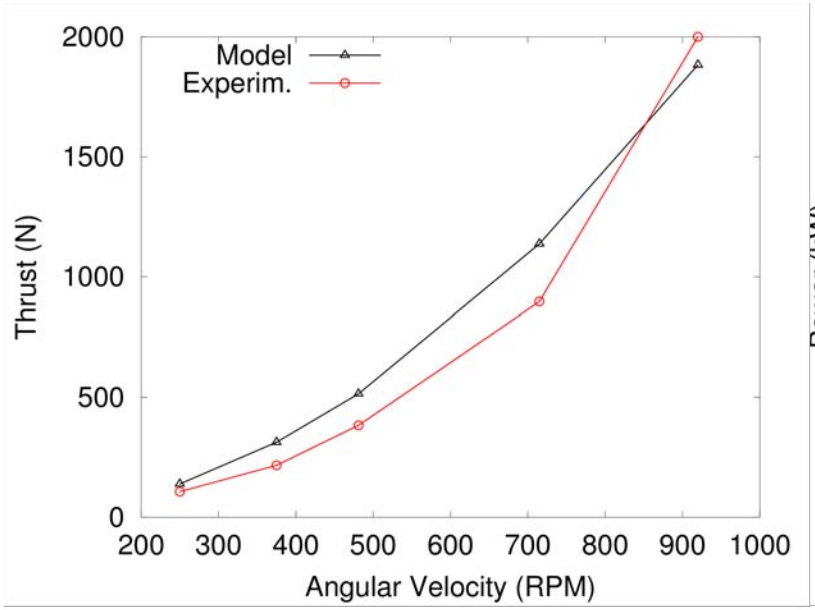
- K = 1.48

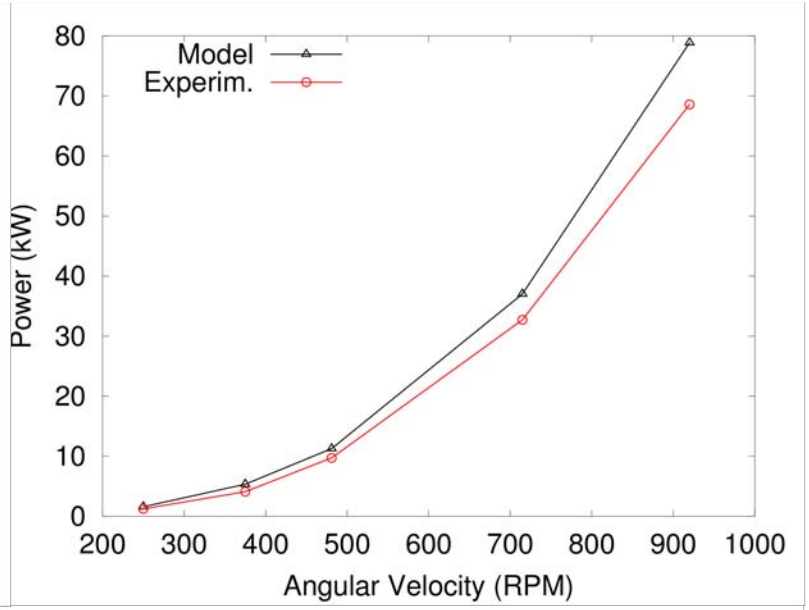




IAT21

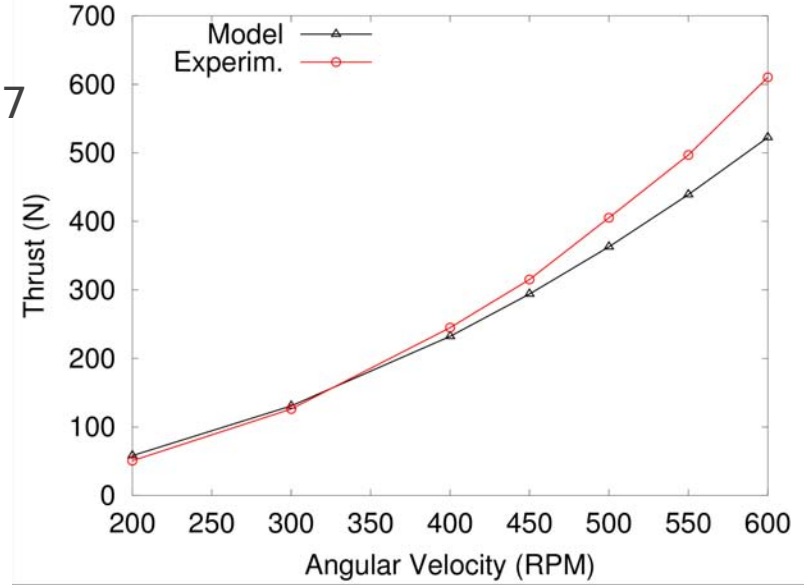
- K = 1.26

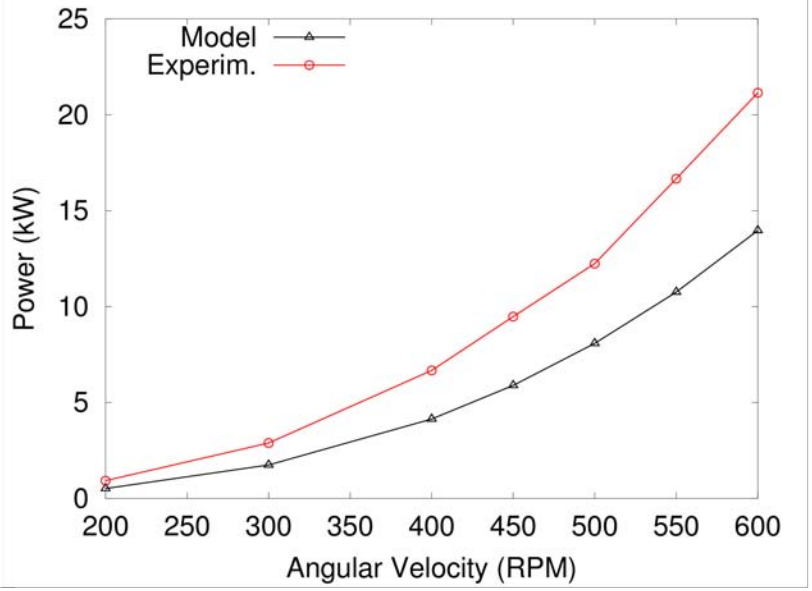




Bosch

- K = 1.08
- Cd = 0.07





Tail Vertical Arrangement

Tail Longitudinal Arrangement

Patents held by Eurocopter and IAT21

Lateral Arrangement

Analogous to Eurocopter X^3 and some compounds such as Sikorsky S-72

Original Tail Rotor: BO105 Like

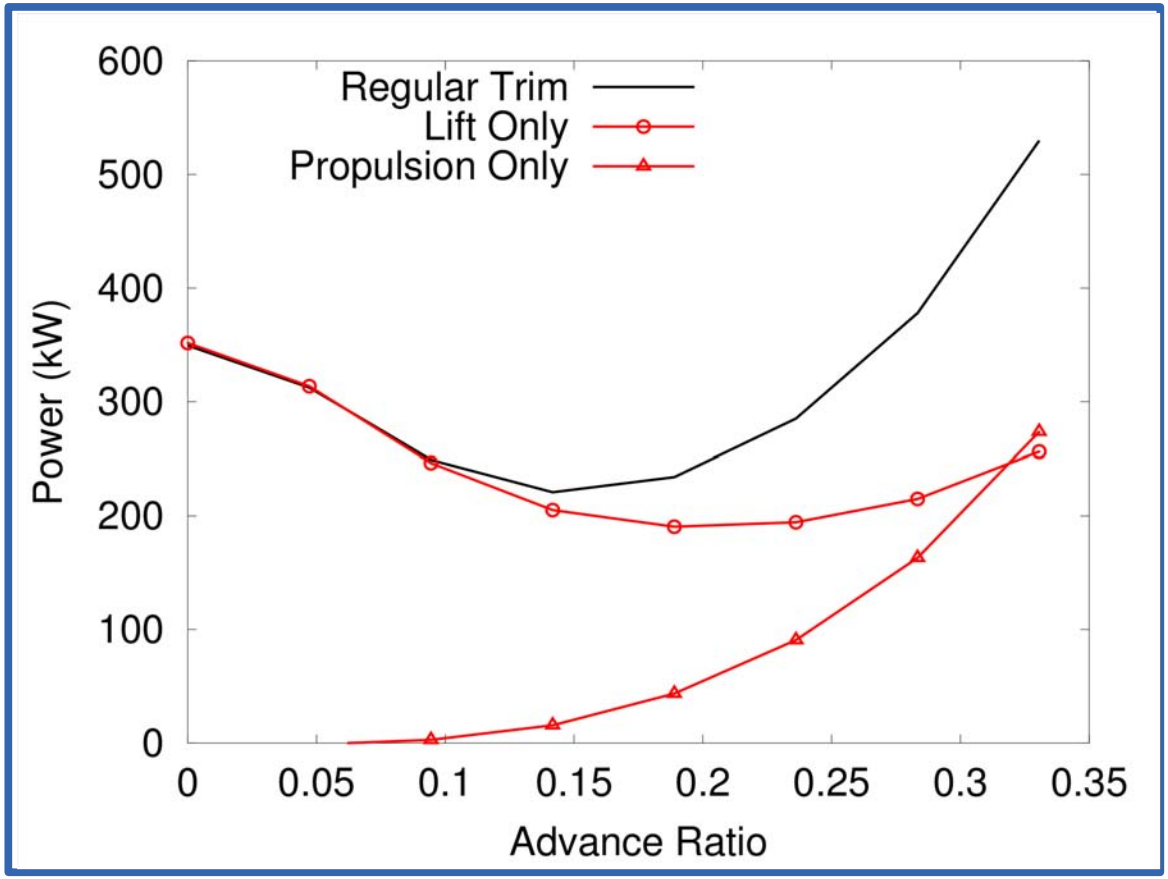
Data taken for comparison

- Fully aeroelastic model
- Main rotor power and torque
- Tail rotor power and torque
- Tail rotor thrust
  - magnitude
  - direction

Performances of the BO105

Separation of powers

- Lift
- Propulsion

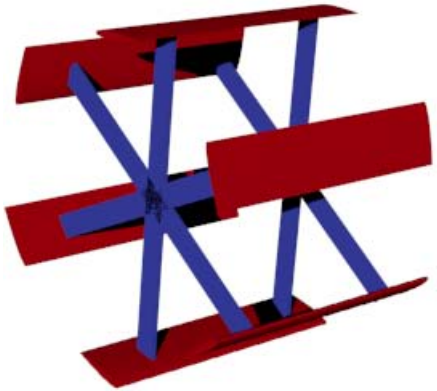


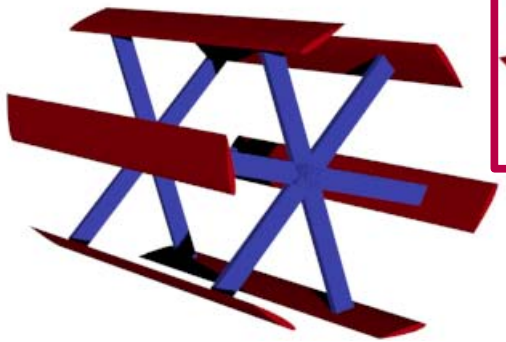
Optimization Process

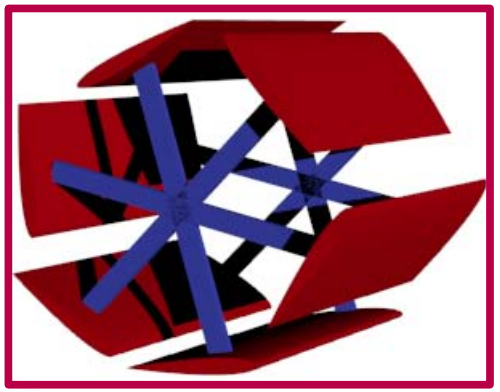
	R (m)	d_L (m)	σ	N	Mach
Low	0.10	0.01	0.001	3	0
Up	1.25	2	2	12	0.85

Coefficient of determination

- Minimal power
- Reproduce required thrust and moment







L. Gagnon, Politecnico di Milano
Proprietary Information

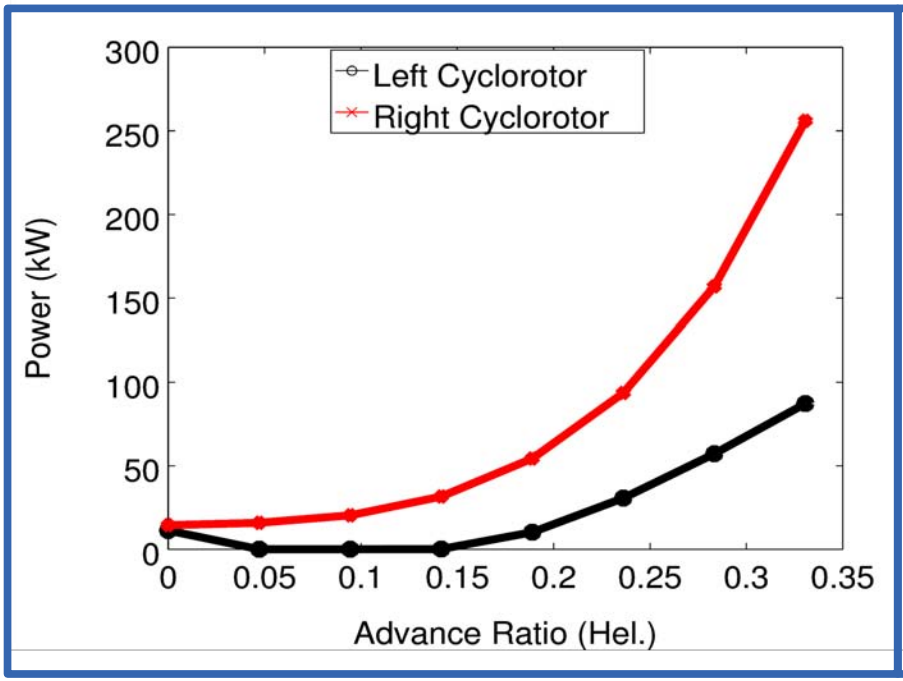
Optimized Configurations

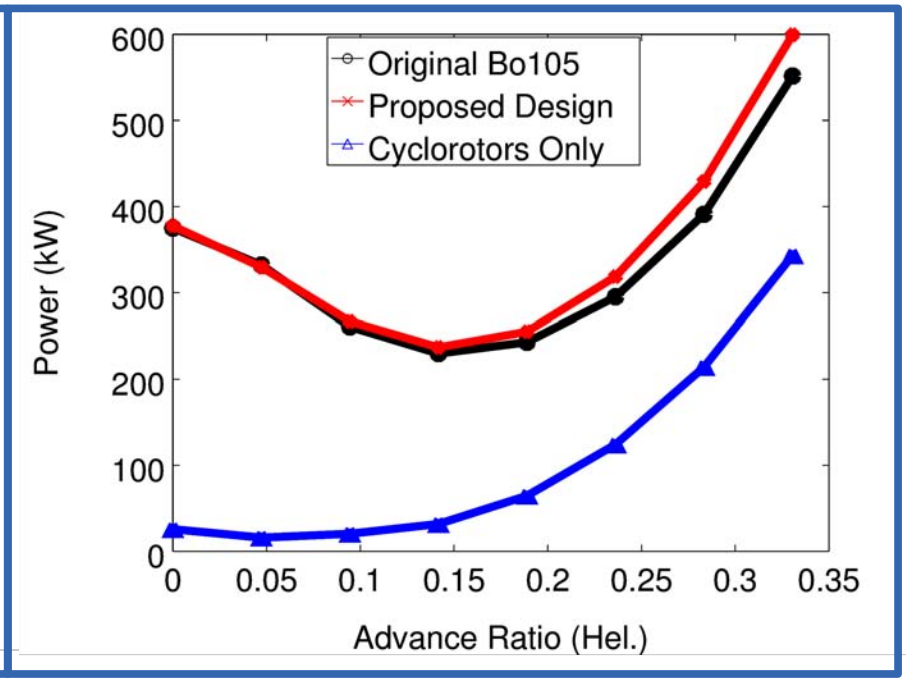
	Asymmetric		Symmetric
	Left	**Right**	**Both**
Span (m)	1.46	1.64	2.12
Lateral offset (m)	1.24	1.81	1.82
Radius (cm)	62.4	112	73.6
Angular velocity (10^3 RPM)	1.55-3.47	0.771-1.32	0.637-2.46
Solidity	0.0279	0.0368	0.0281
Tip Mach	0.42-0.73	0.33-0.67	0.27-0.77
Max angle of attack (°)	13.06	13.06	13.06
Max cycloidal rotor advance ratio	0.49	0.46	0.84

Asymmetric Advantage

Minimal power savings

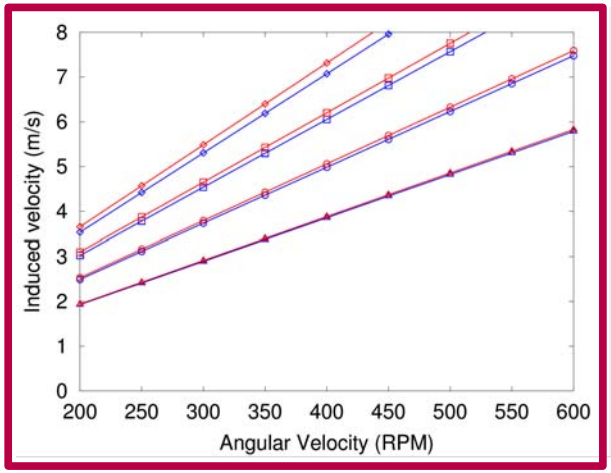
Symmetric configuration performances

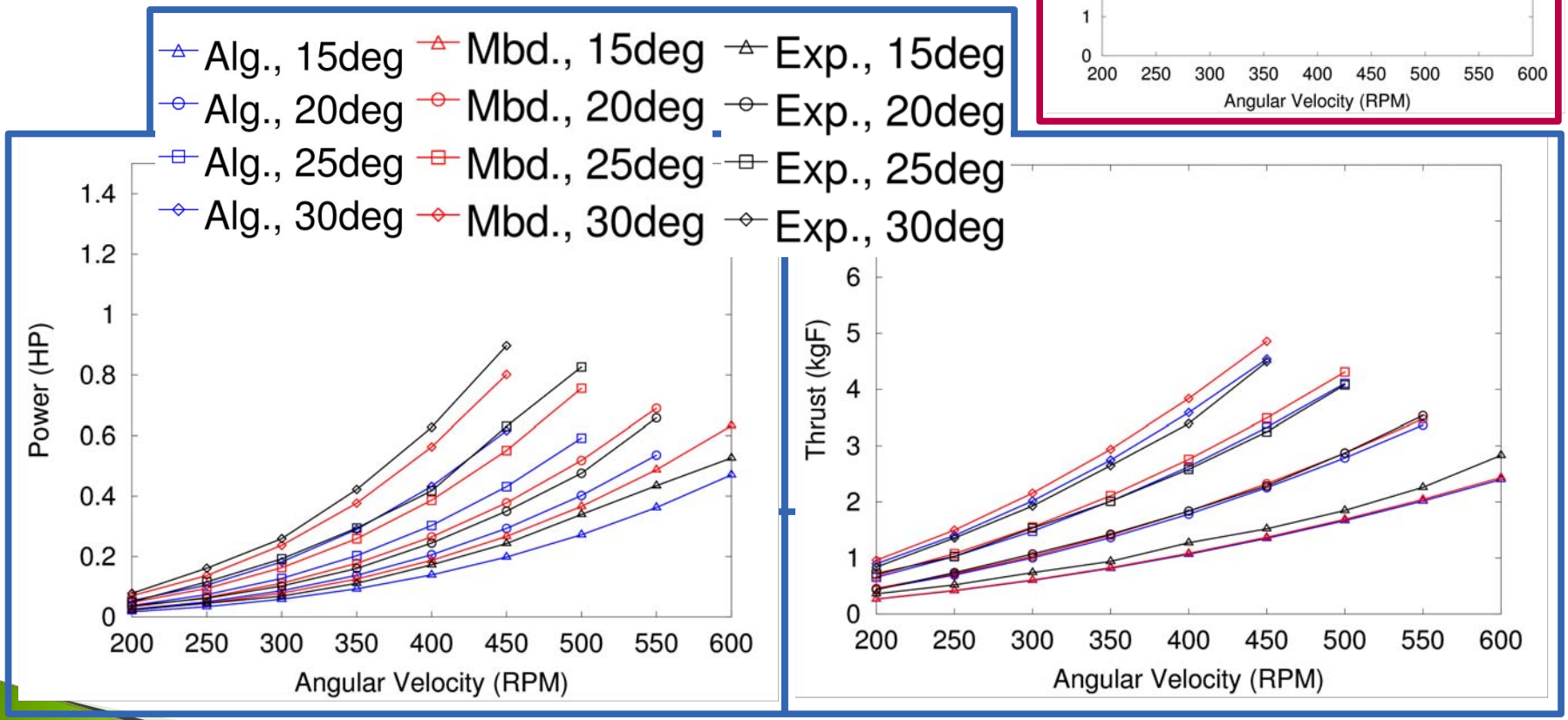




Multibody Model

Modified C_D

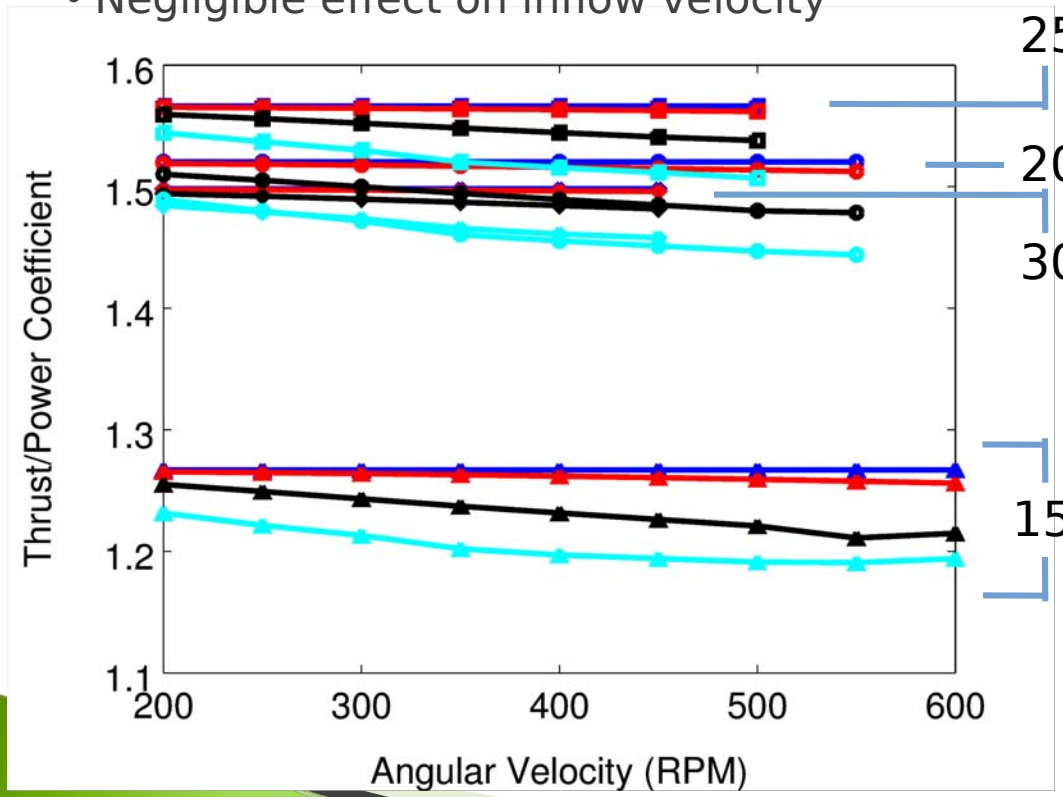




Effect of Flexibility

Multibody simulations: clamped airfoils

- Reduces efficiency
- Room for improvement
- Negligible effect on inflow velocity



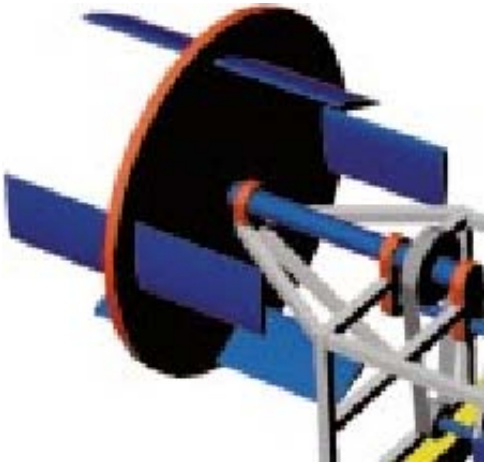
Three Dimensional Effects

Three different experimental approaches

- Yield various empirical correctors

- IAT21: endplates
- κ = 1.26

- Bosch: midplate
- κ = 1.08

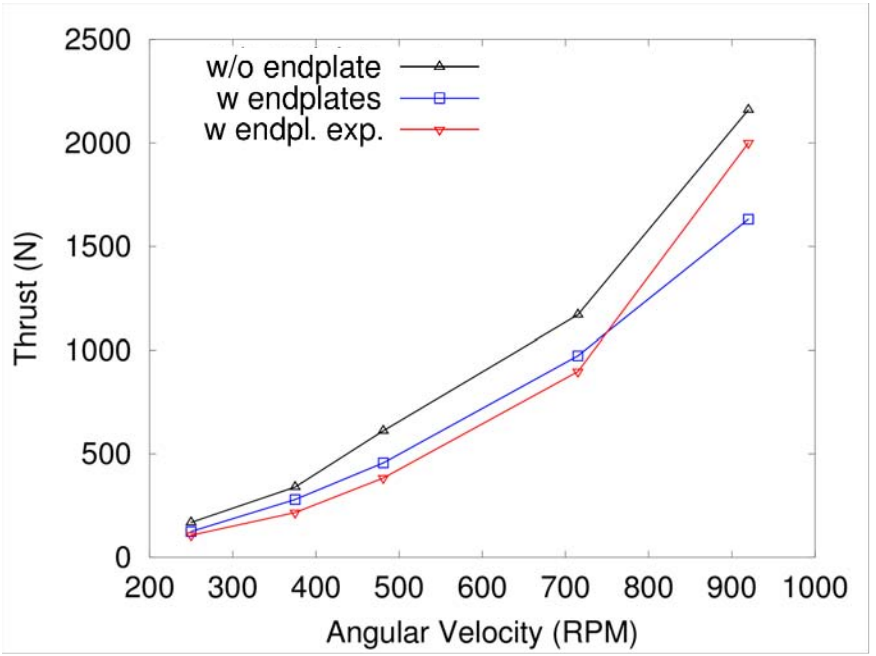


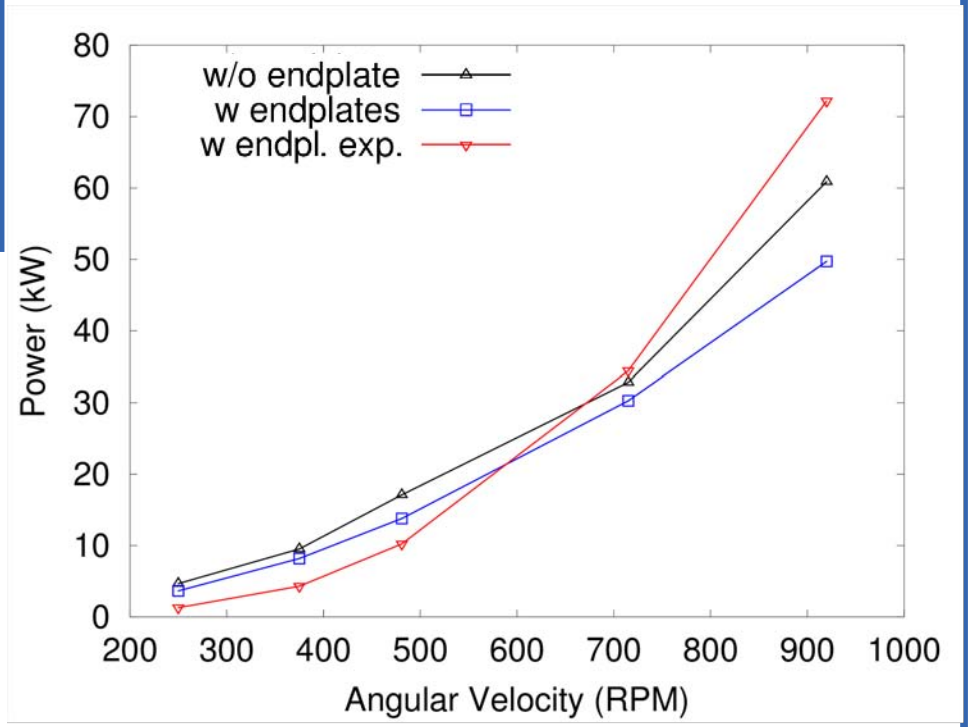
- Yun et al.: none, κ = 1.48

Three Dimensional Effects

Effect of mid- and end-plates (CFD)

- Variable empirical correctors
- Variable performance

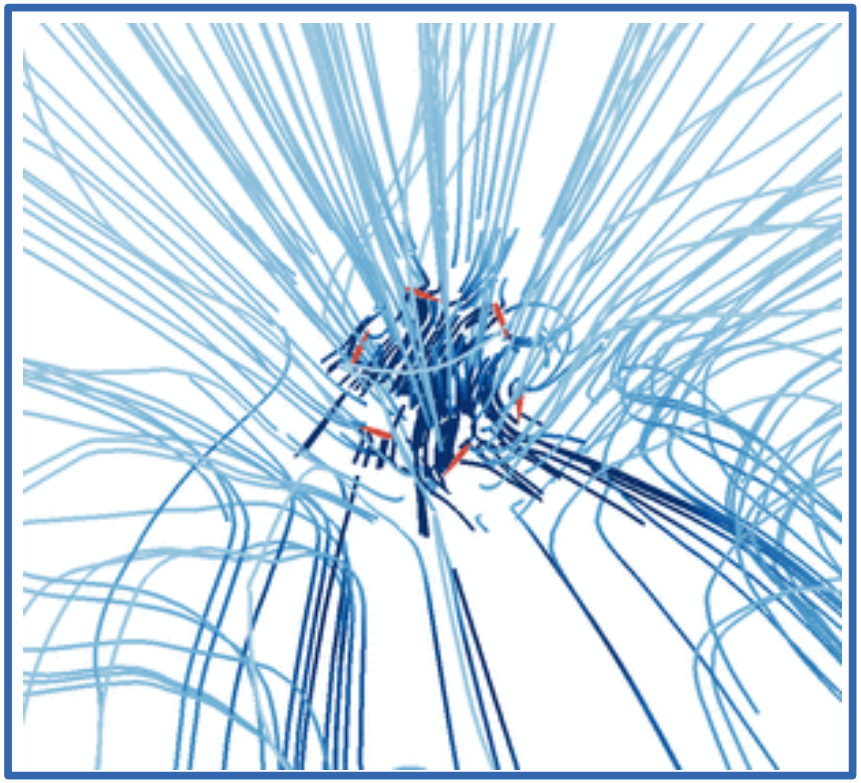


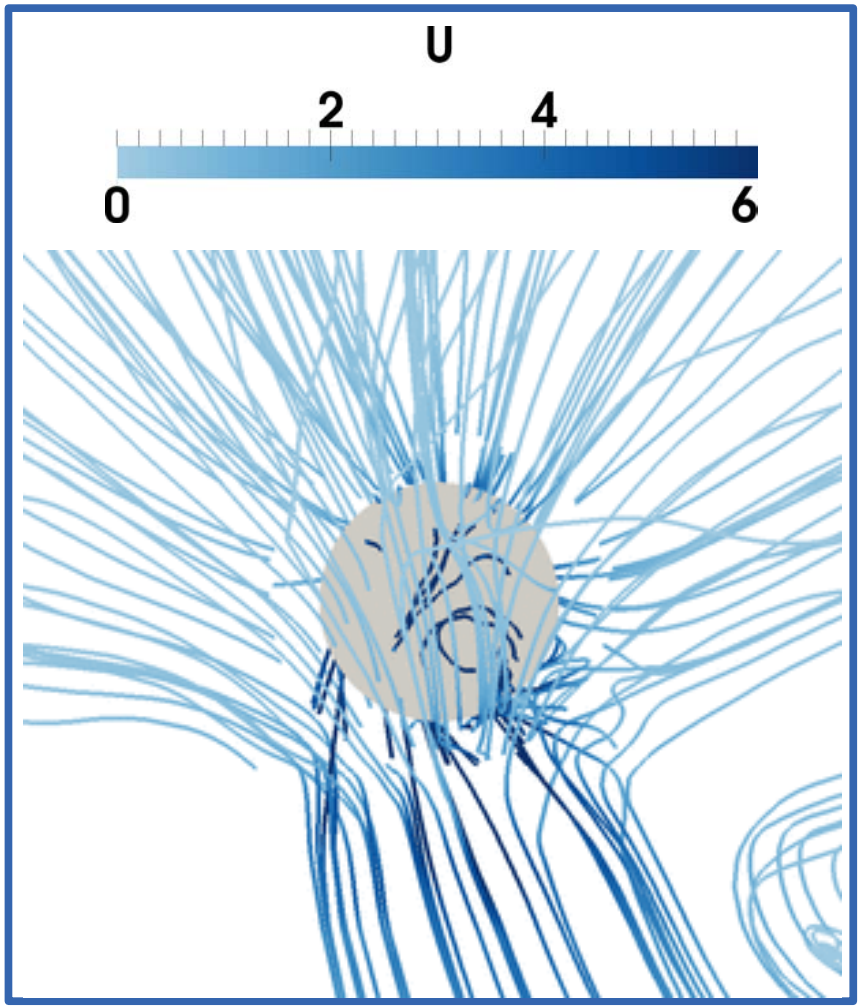


Three Dimensional Effects

Sideview of rotors (CFD)

- Restricted flow span angles

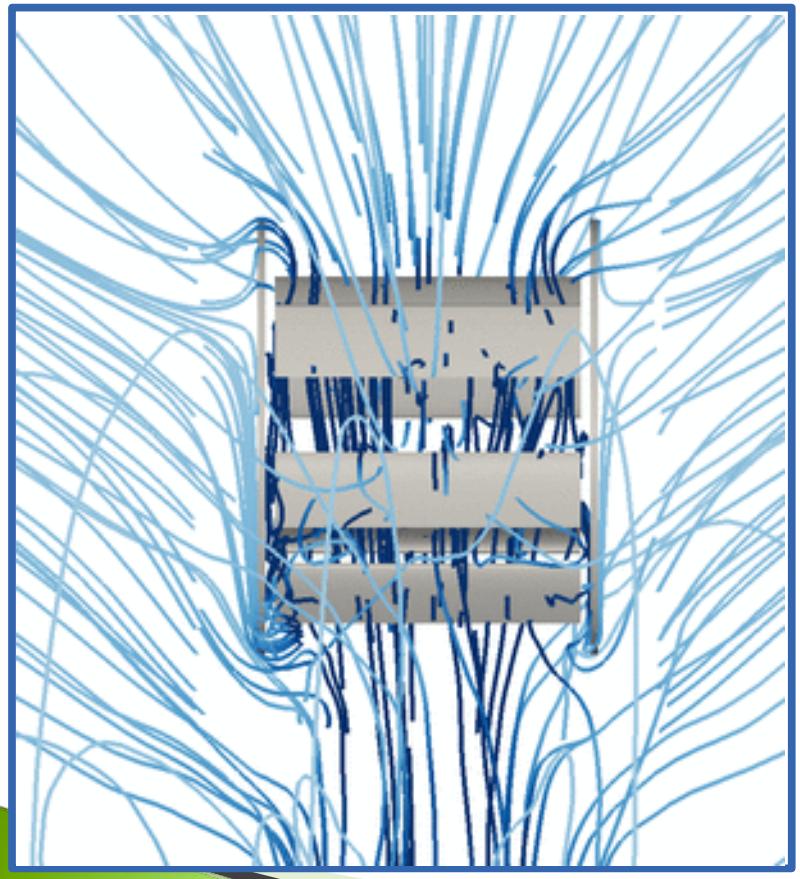


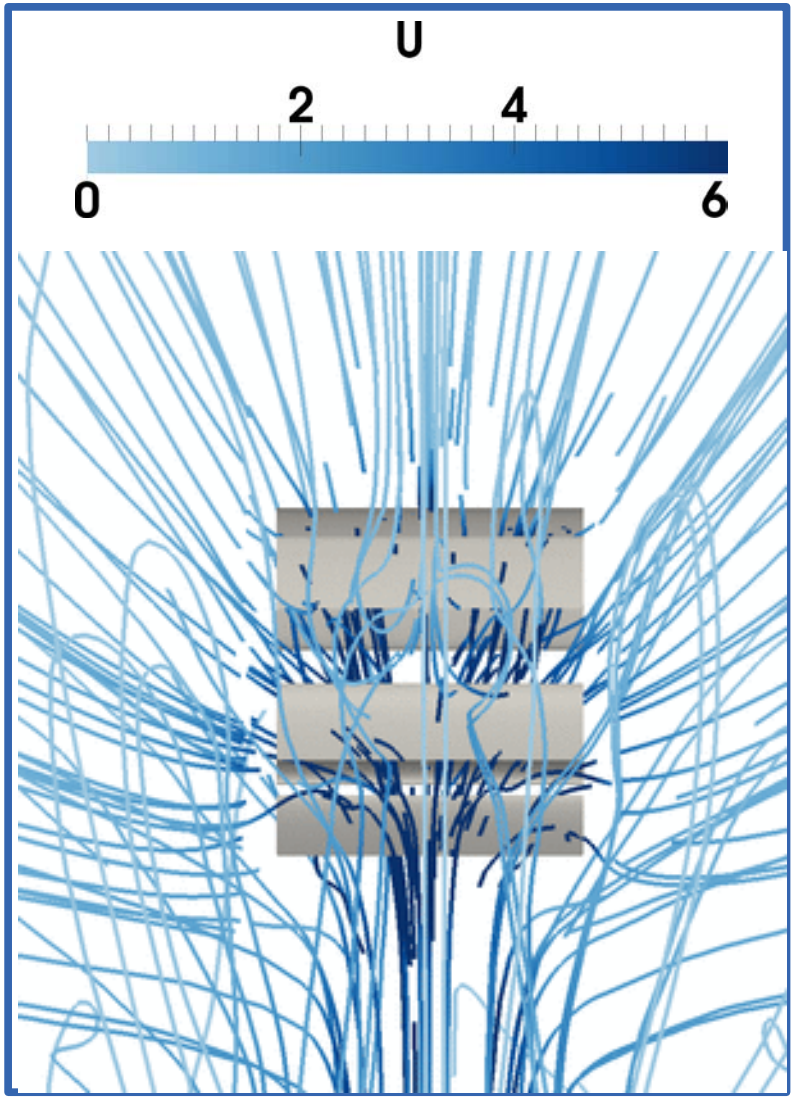


Three Dimensional Effects

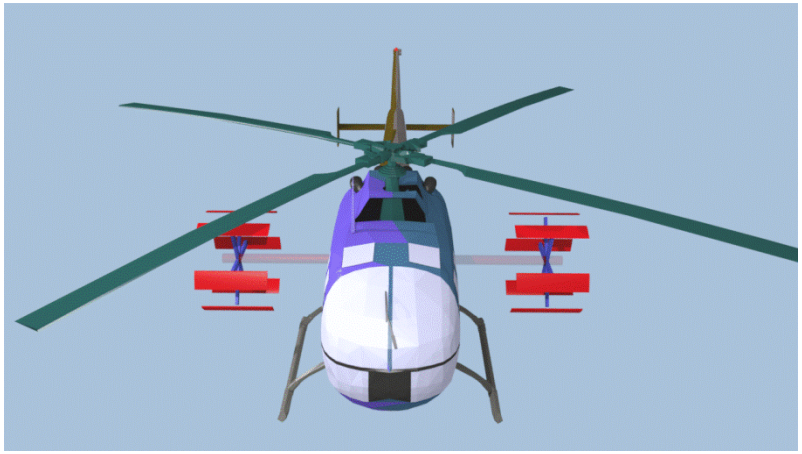
Frontview of rotors (CFD)

- Reduced three dimensionality





Conclusions



- The developed models
  - agree with experiments
  - can be solved quickly
- The studied configuration
  - gives a reasonable efficiency
    - due to the modified main rotor trim
  - should not suffer from main rotor presence
  - can fly in regimes not possible for traditional helicopters
    - possible handling advantages
  - have multiple possible configurations
- Flexibility reduces efficiency
- 3D effects are important

Future Work

Aeroelastic models

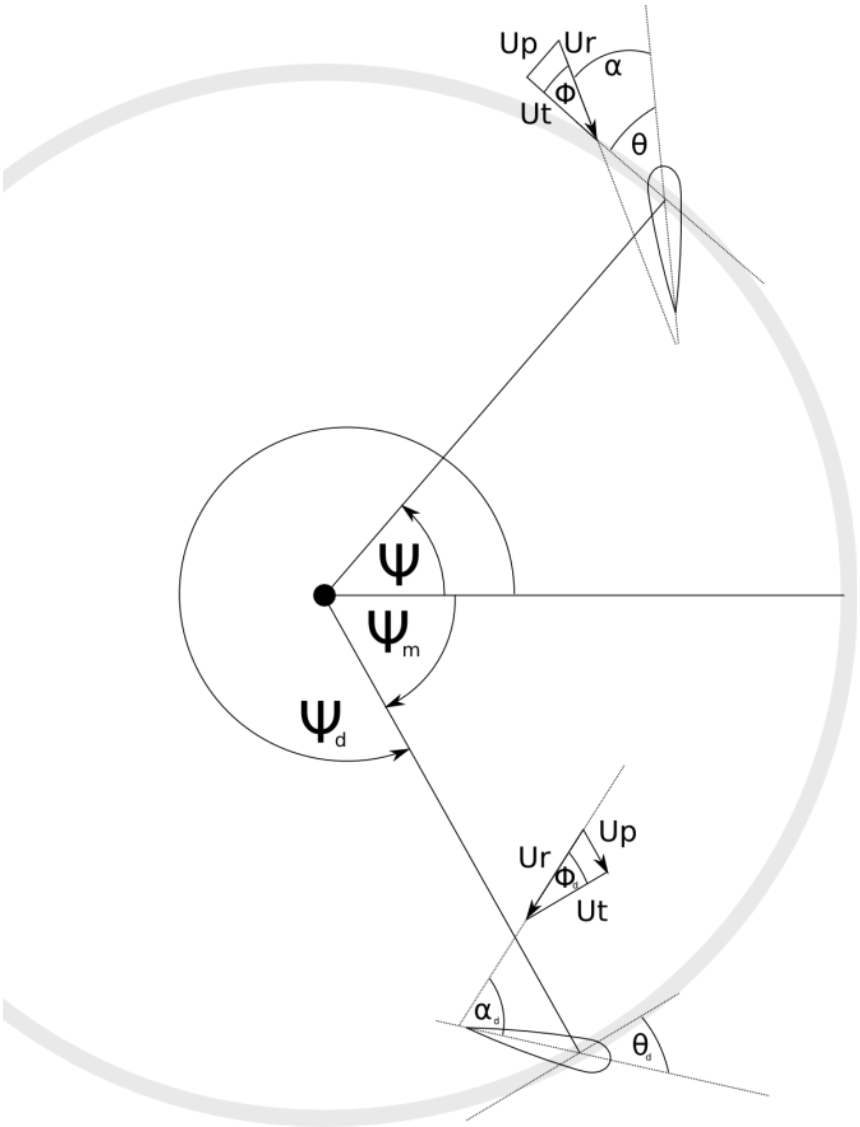
- Analytical
  - uniform inflow

Inflow model

- Use a double-multiple streamtube

Validation with 3D CFD

- Various flight regimes
- Actuator disk for main rotor



Thank you for your attention

Time for questions

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement N. 323047.

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Overview

- The Company IAT21
- European Union's Flight path 2050
- The Challenge for Air Transport
- D-Dalus concept and Cyclogyro ➔ Novel technology
- D-Dalus Milestones
- Where is D-Dalus positioned?
- Cyclogyro in comparison to Fixed Wing aircraft and Rotorcraft
- Performance and efficiency … wind tunnel test TUM
- Impressions of a manned aircraft
- IAT21 Cooperation Partners

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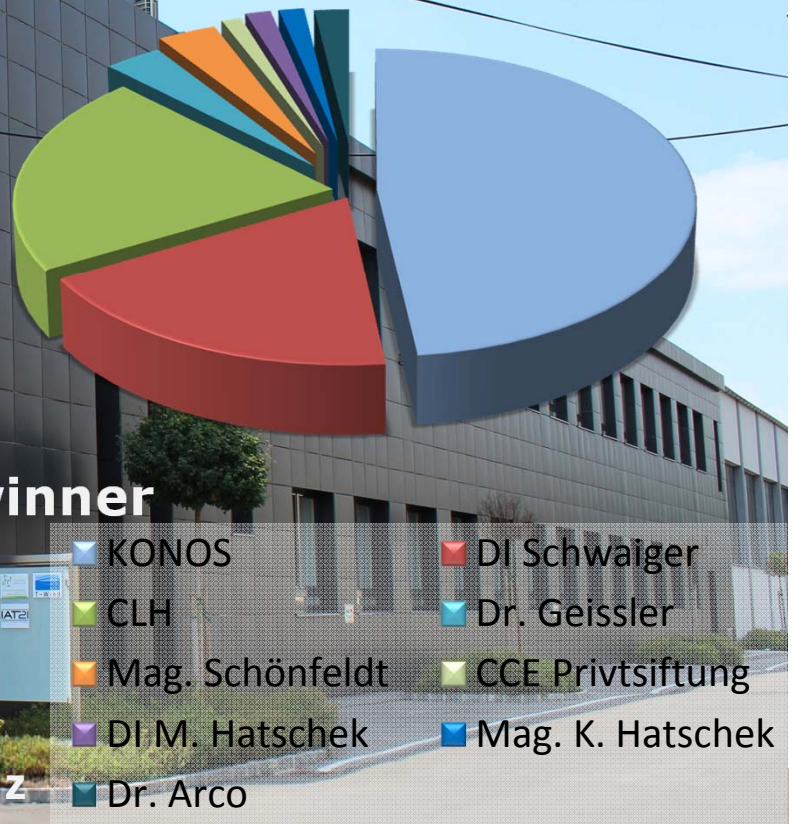
The Company IAT21

- **Private Austrian Research Company**
- **Legal form Gesellschaft m. b. H.**
- **Founded 2004**
- **Shareholder**
  - KONOS Mittelstandsfinanzierungs AG
  - Dipl.-Ing. Meinhard Schwaiger
  - CLH
  - Dr. Hermann Geissler
  - Mag. Carl Ludwig Schönfeldt
  - CCE Privatstiftung
  - Dipl.-Ing. Mathias Hatschek
  - Mag. Klemens Hatschek
  - Dr. Karl Arco
- **International & national award winner**
  - **Green Dot Awards**
  - **Austrian State Price**
  - **INVENTUM**
  - **Upper Austrian Innovation Award**
  - **The most innovative company in Linz**

Shareholder structure



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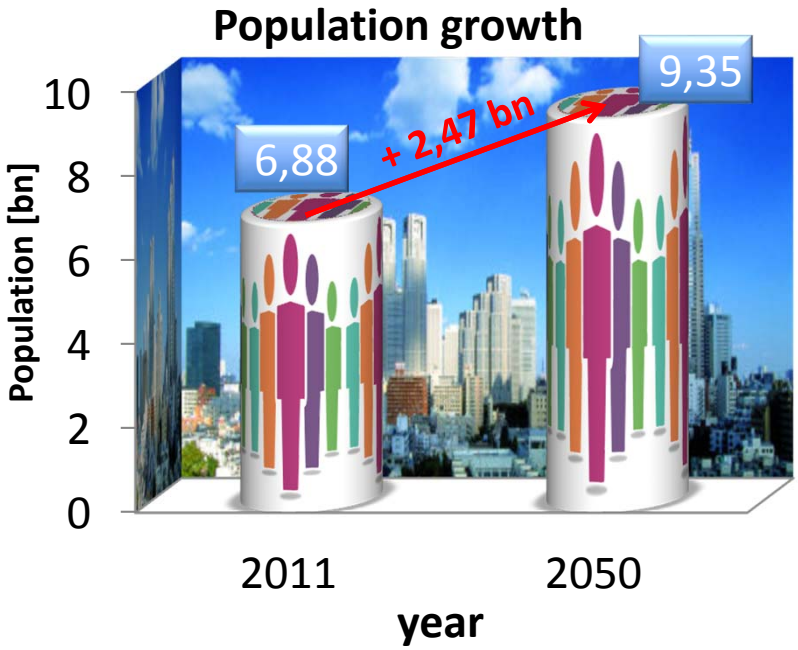
Flightpath 2050

➔Europe‘s Vision for Aviation



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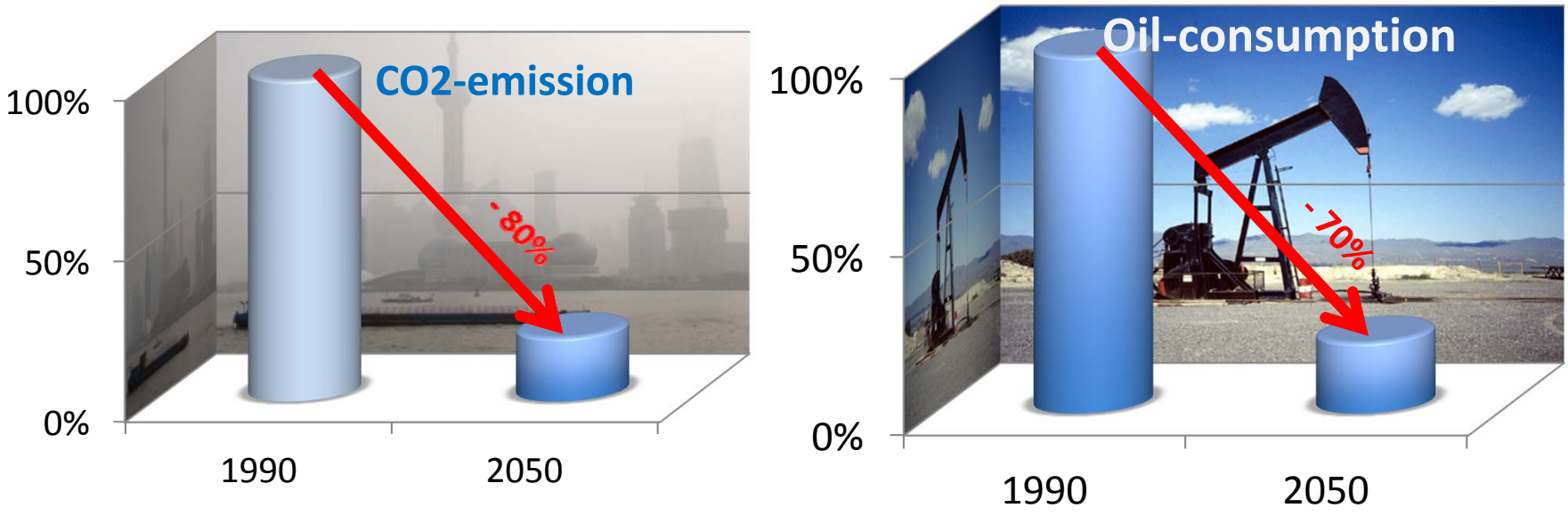
The Challenge for Air Transport

"To achieve Europe's targeted 80 % CO_2 reduction by 2050 compared to 1990, oil consumption in the transport sector must drop by around 70% from today, implying a revolution in transport fuels and the way we travel."

European Commission – Transport White Paper 2011 and Impact Assessment



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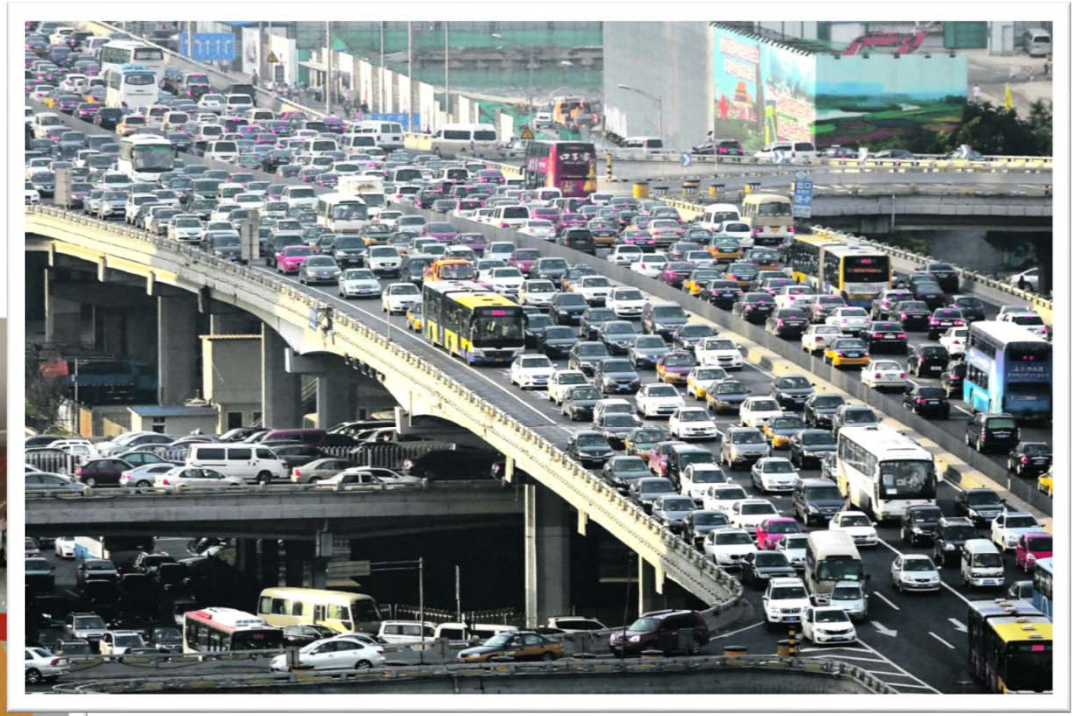
The Challenge for Air Transport

- The traffic problems in the mega-cities can not be solved by additional and faster vehicles
- No western community is able to invest in new infrastructure like highways, railroads, airports, … as it would be needed



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The Challenge for Air Transport

- The traffic problems in the mega-cities can not be solved by additional and faster vehicles
- No western community is able to invest in new infrastructure like highways, railroads, airports, … as it would be needed

This opens a window for **new air transport concepts**

- ✓ **Greener Aircraft** (*fuel consumtion, noise, …*)
- ✓ **less infrastructure** *airport,runway, launch systems*
  - ✓ **Gate to Gate**
  - ✓ **Factory to Factory**
  - ✓ **A to B**

… without the need of
additional travel and infrastructure

requires

… VTOL / VSTOL

but more efficient in forward flight like previous ones

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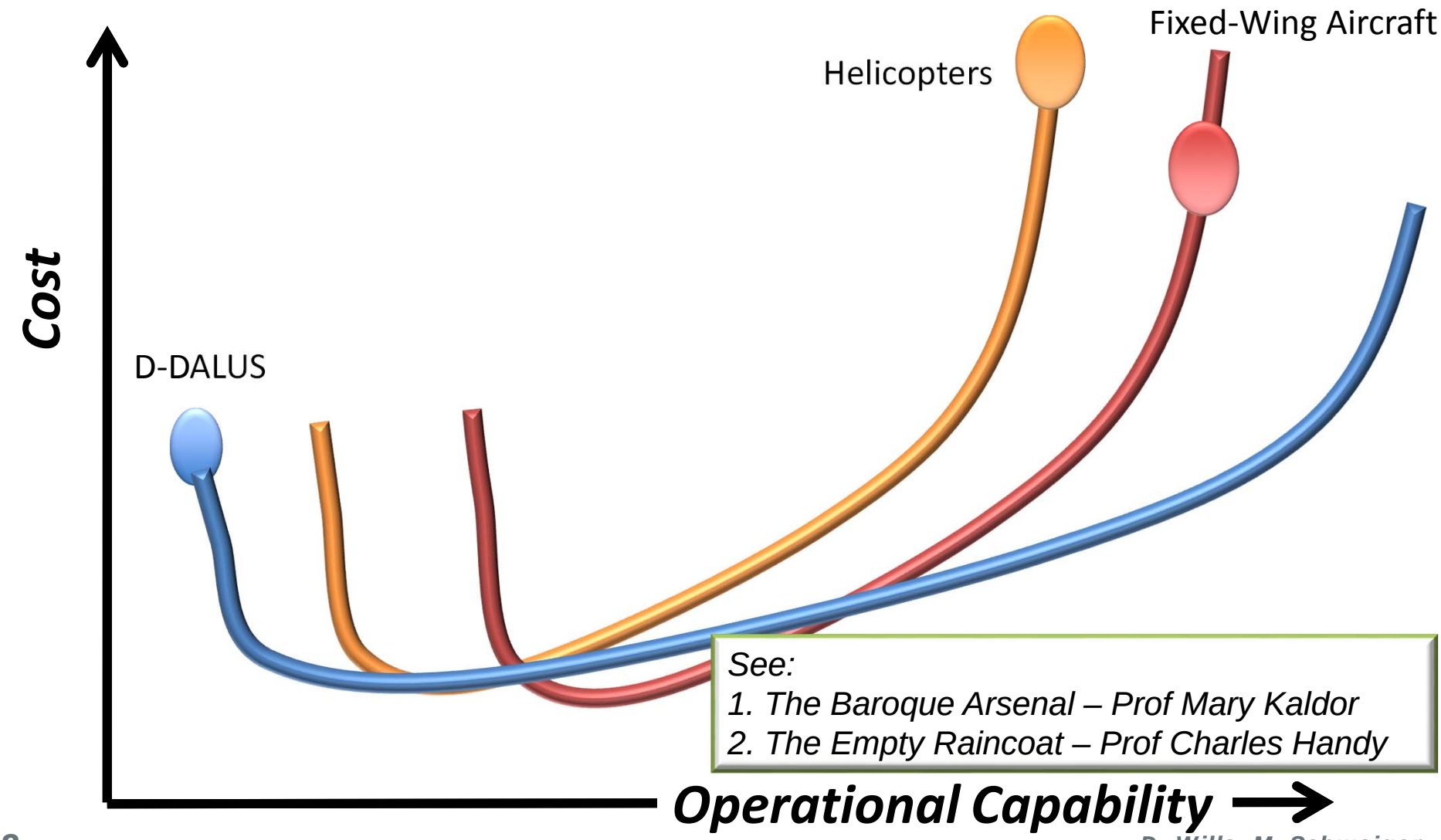
The Change Curves



See:
1. The Baroque Arsenal – Prof Mary Kaldor
2. The Empty Raincoat – Prof Charles Handy

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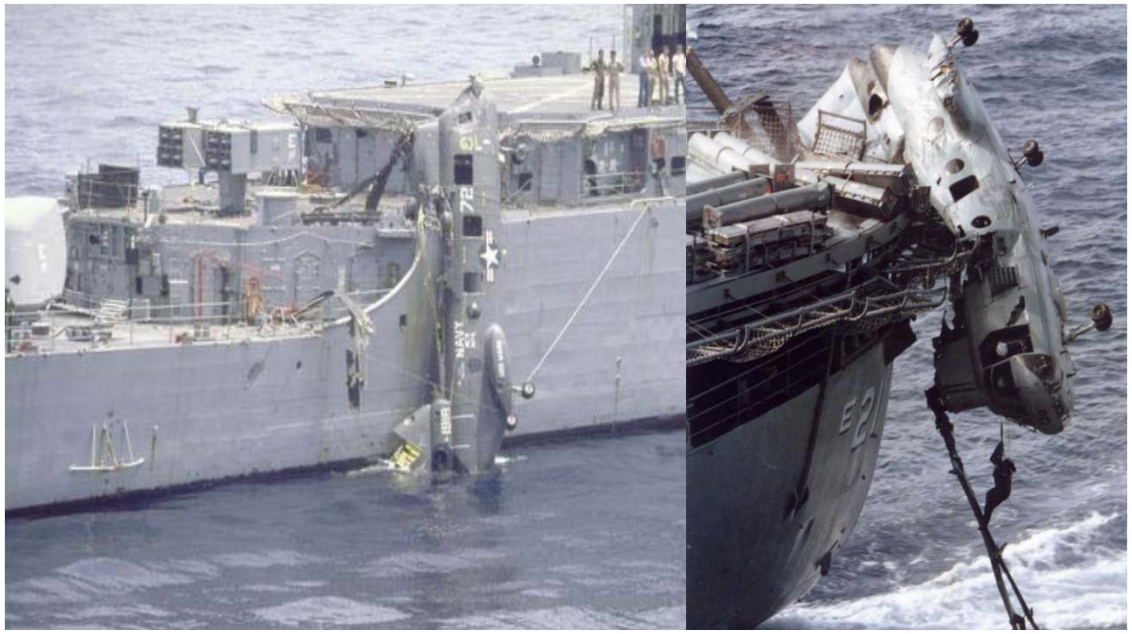
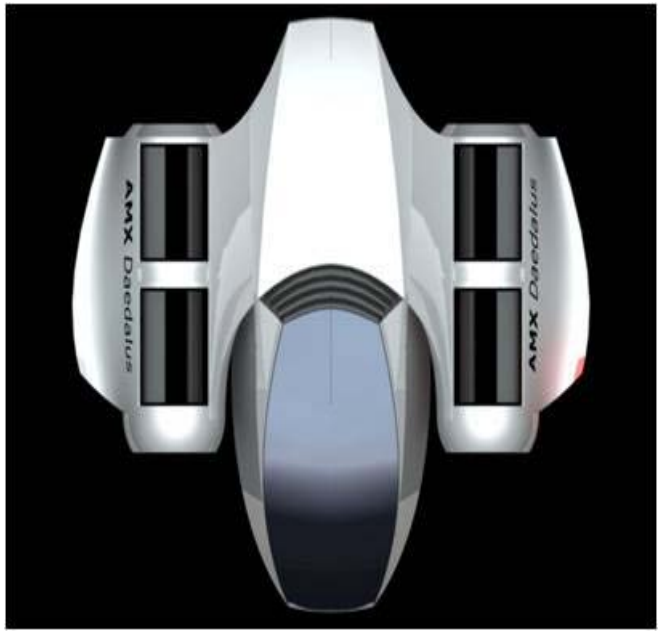
Why a new idea was born





The birth of a new idea ➔D-Dalus

The reason why … when manoeuvre chances helicopter are dynamically unbalanced and the new idea …

- Keep an air vehicle dynamically balanced by means of counter rotating rotors
- make Voith/Schneider flyable
- and patent the *perhaps* stupid idea

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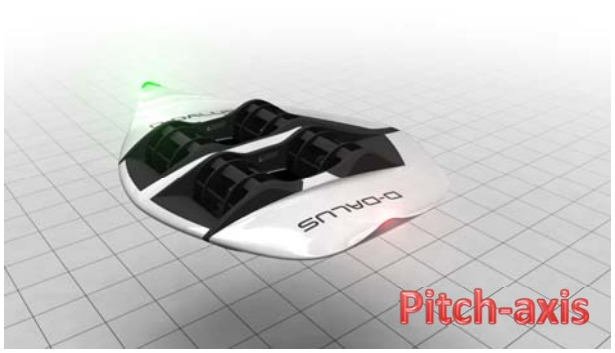
D-Dalus Concept and Cyclogyro

- **A novel technology**
- **A revolutionary *flying machine:***
  - ✓ A new form of propulsion
  - ✓ Unique Worldwide Combined Capability
    - VTOL **&** high forward speed
    - Ability to rotate in any direction about all 3 axes
    - Naturally stable
    - Ability to land on a moving platform & ‘glue down’
    - High fuel economy



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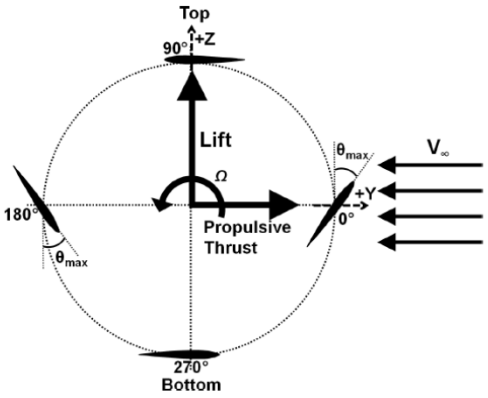
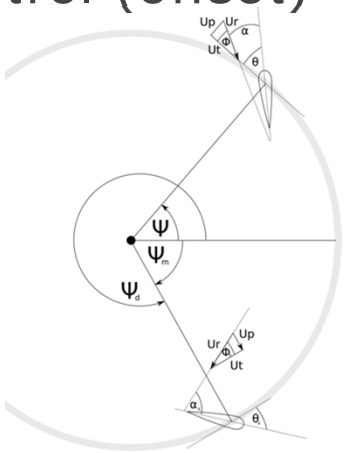
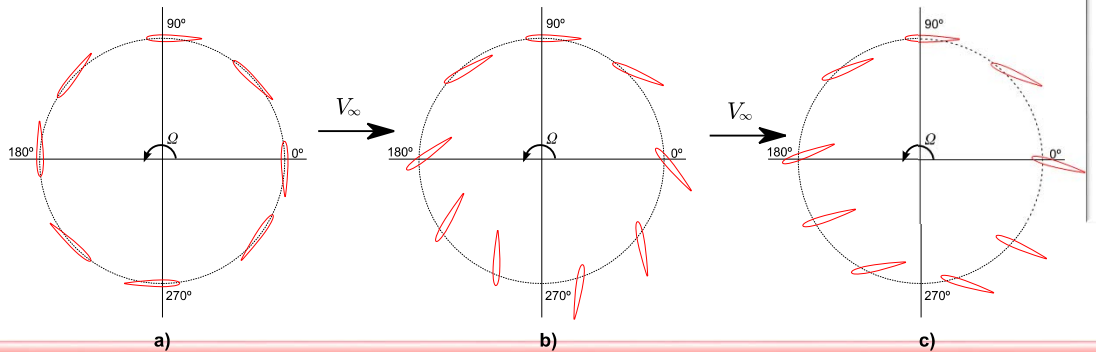
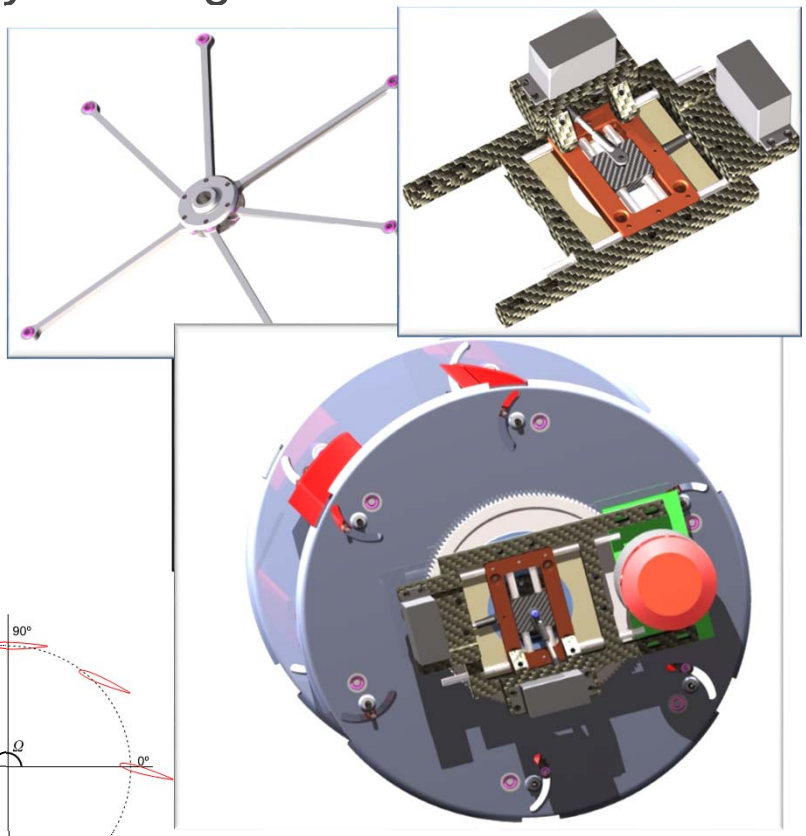
- **Cyclogyro Propulsion**
- **Cyclogyro Rotor**
  - ✓ 6 swivelling rotor blades ➔ cyclic angle of attack A0A
  - ✓ mechanically linked
  - ✓ Blade pitch control (offset)









Rotor system IAT21

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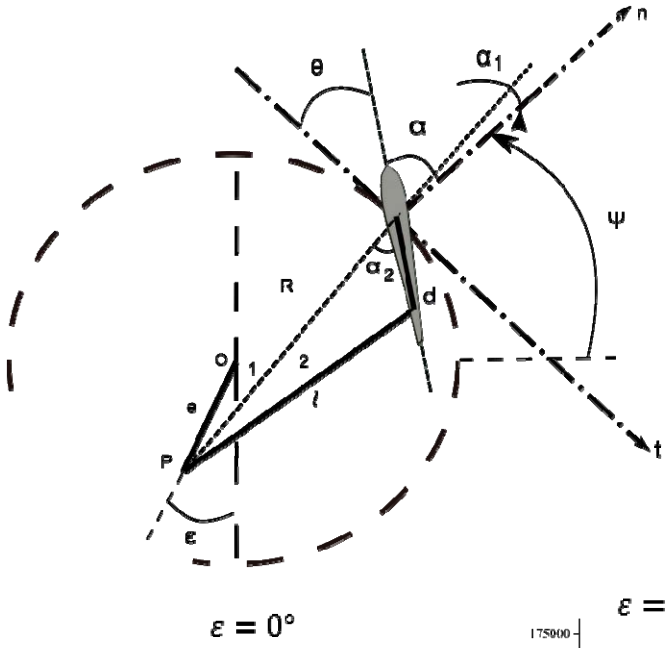
D-Dalus Concept and Cyclogyro

Four Bar Linkage Mechanism and Blades Position

$$\theta = \frac{\pi}{2} - \arcsin\left[\frac{e}{a}\cos(\Psi+\varepsilon)\right] - \arccos\left(\frac{a^2+d^2-L^2}{2ad}\right); \qquad a = \sqrt{e^2+R^2+2eR\sin(\Psi+\varepsilon)}$$

$$\theta = f[\Psi(t)], \qquad \Psi_i(0) = \Psi_1(0) + (i-1)\frac{2\pi}{N}$$

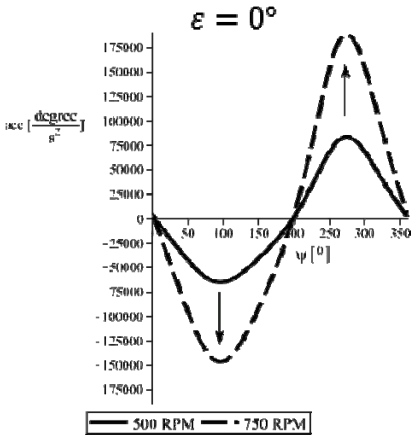
Angular velocity ω and angular aceleration acc around the pivot point ← Chain rule application

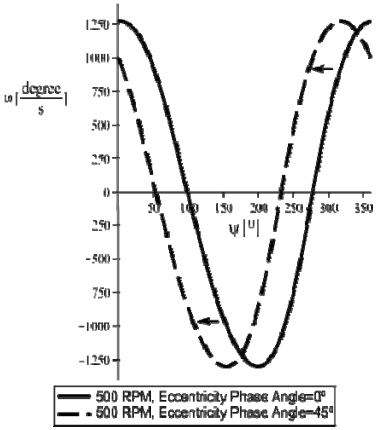


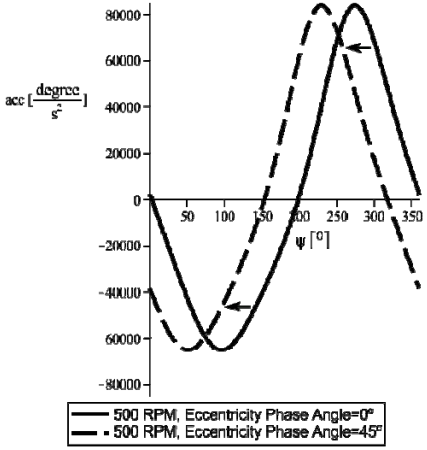
$\varepsilon = 0°$

L=0.6055 m
Magnitude of Eccentricity=0.038
d=0.09 m

Diameter=1,2 m
Span=1.2 m
Chord=0.4 m
N=6







Cyclogyro Rotor ➔ Theoretical background

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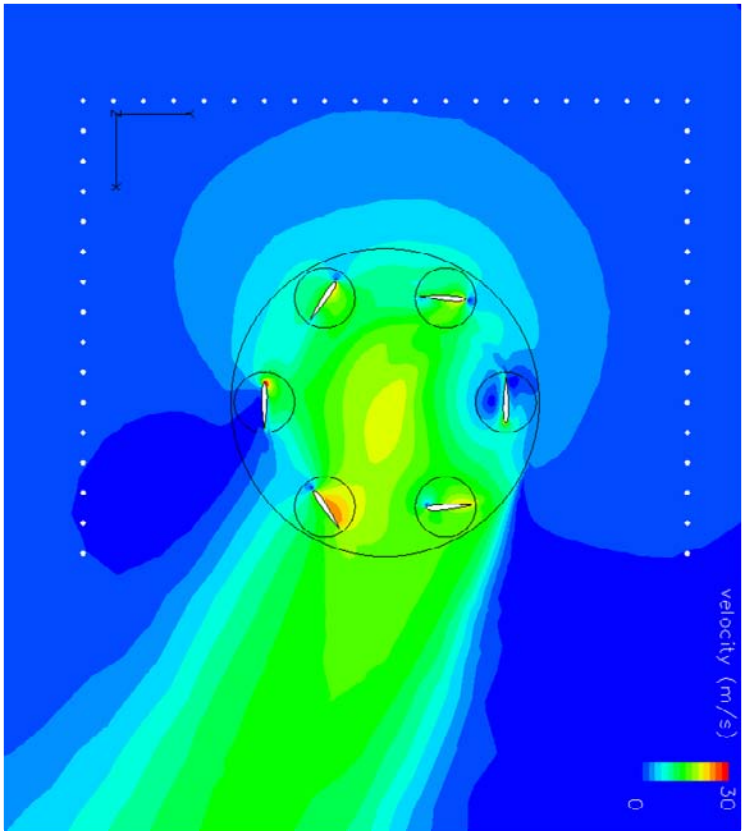
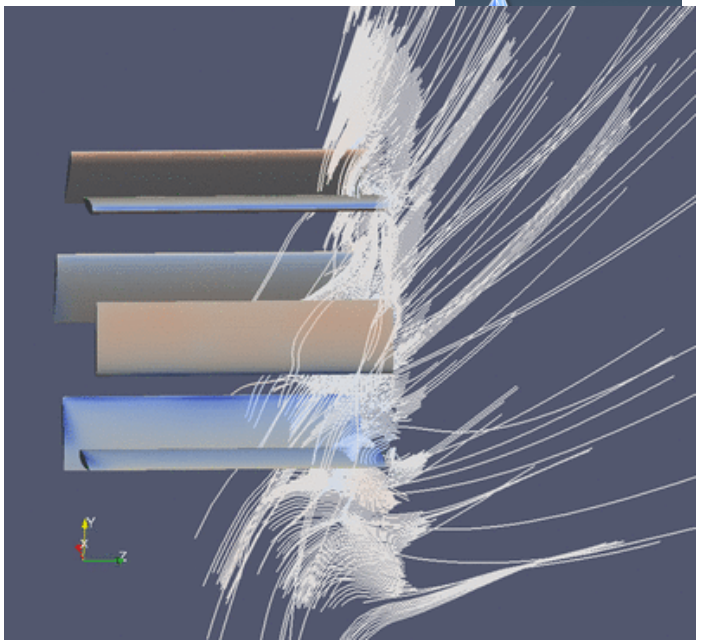
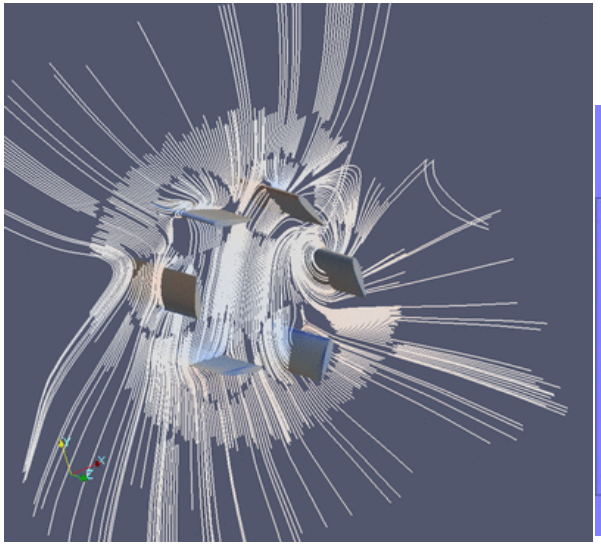
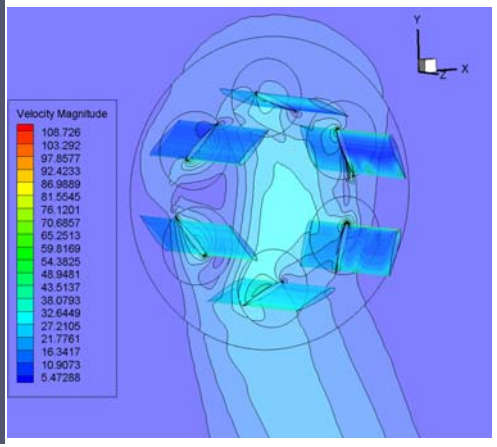
D-Dalus Concept and Cyclogyro

- **Aerodynamic**
- **CFD-Symulation**









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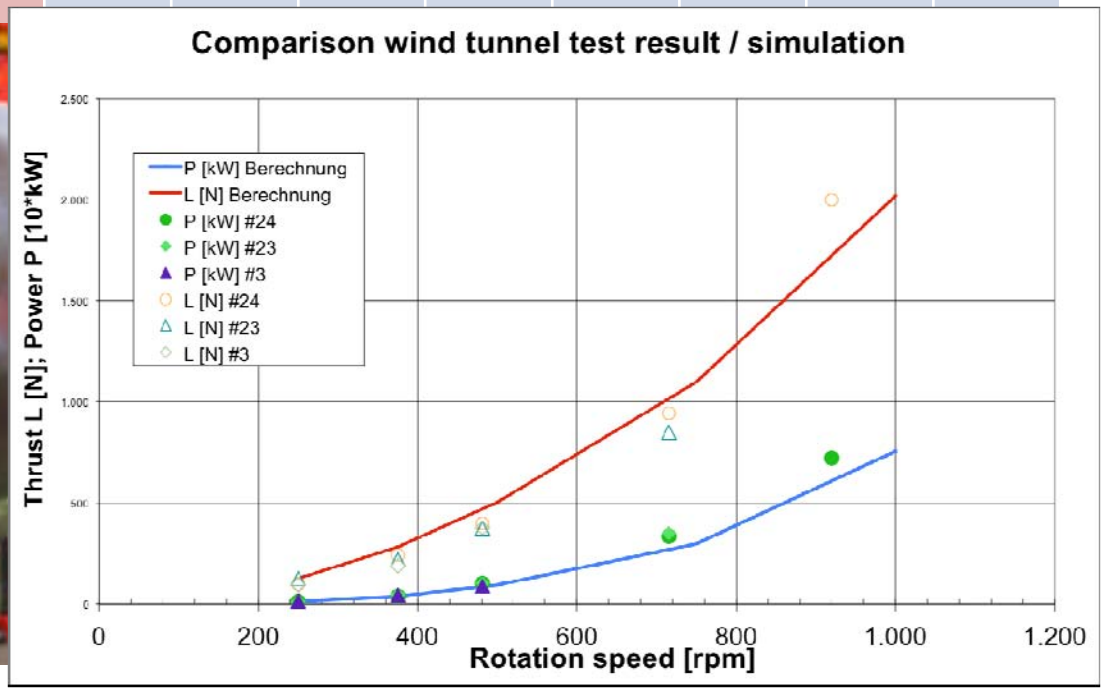
D-Dalus milestones

- **Milestones**

Wind tunnel test TU-Munich

	2004	2005	2006	2007	2014
L3		Wind-tunnel			



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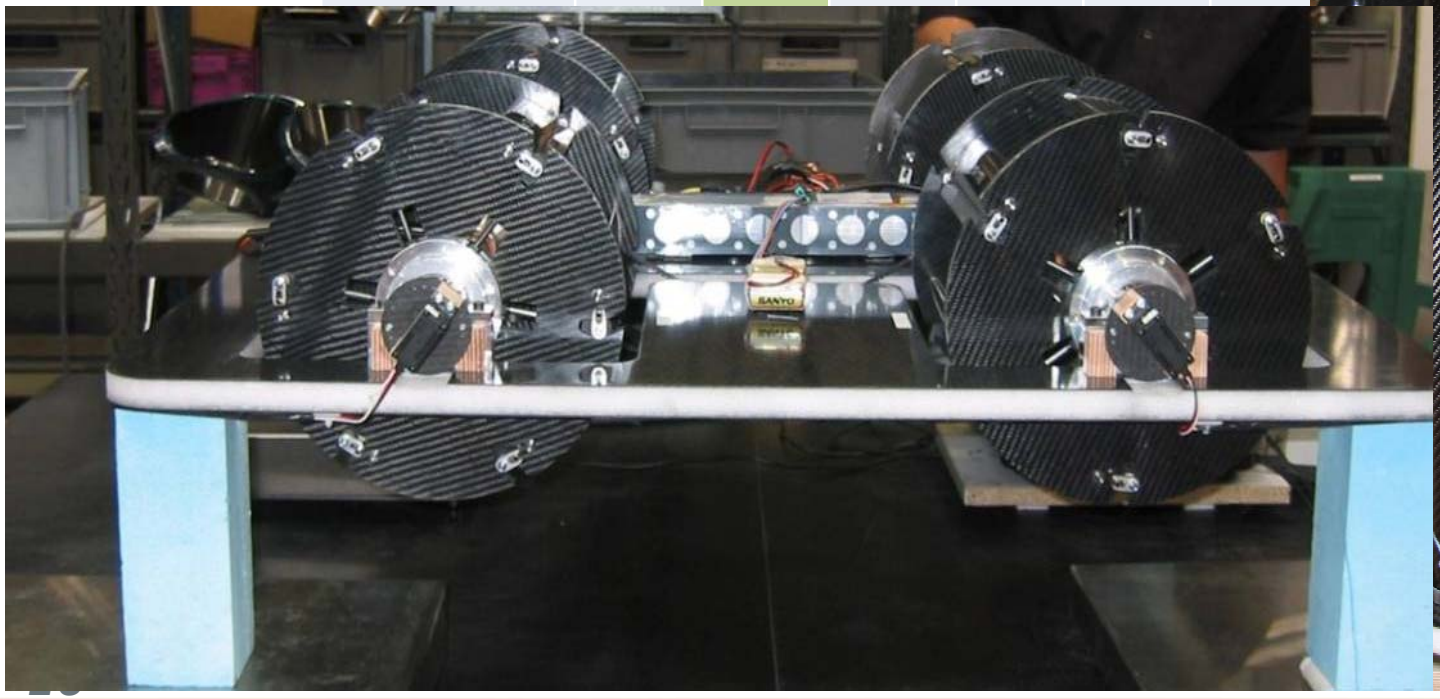
D-Dalus milestones

IAT21 Innovative Aeronautics Technologies
European Aeronautics Science Network

Milestones

L1 13th June 2006 worldwide the first successful maiden flight?

	2004	2005	2006	2014
L3		Wind tunnel		
L1 2006			Maiden flight 06/2006	



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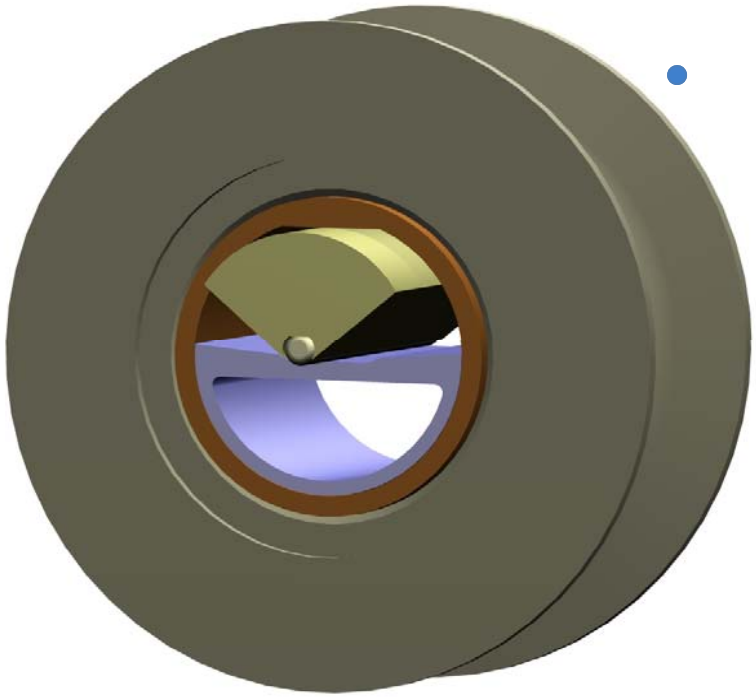
D-Dalus milestones

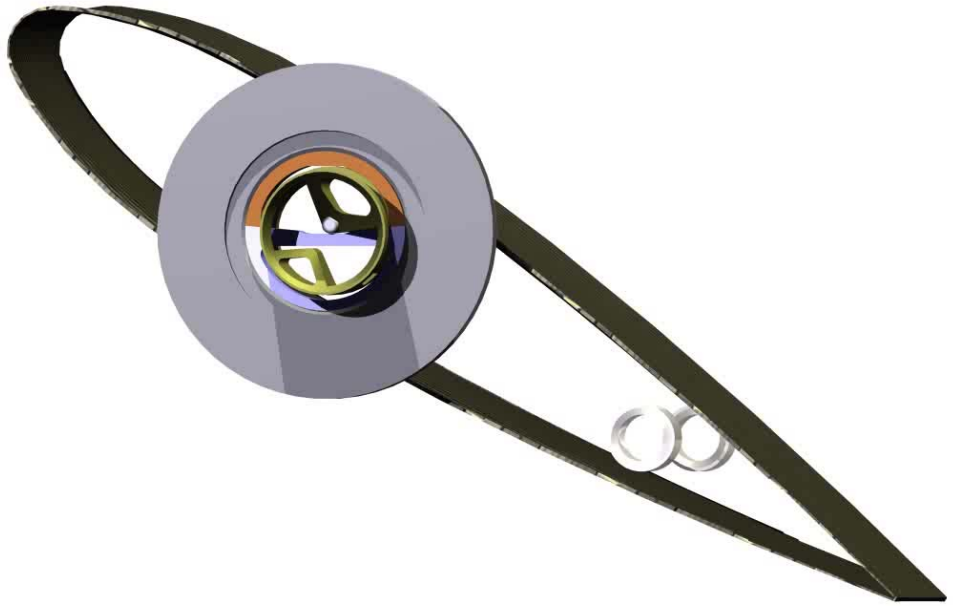
IAT21 Innovative Aeronautics Technologies

- **Milestones**

18 month → friction free swivel bearing L2-2012

	2004	2005	2006							2014
L3		Wind tunnel								
L1 2006			Maiden flight 06/2006							





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D-Dalus milestones

- Miles

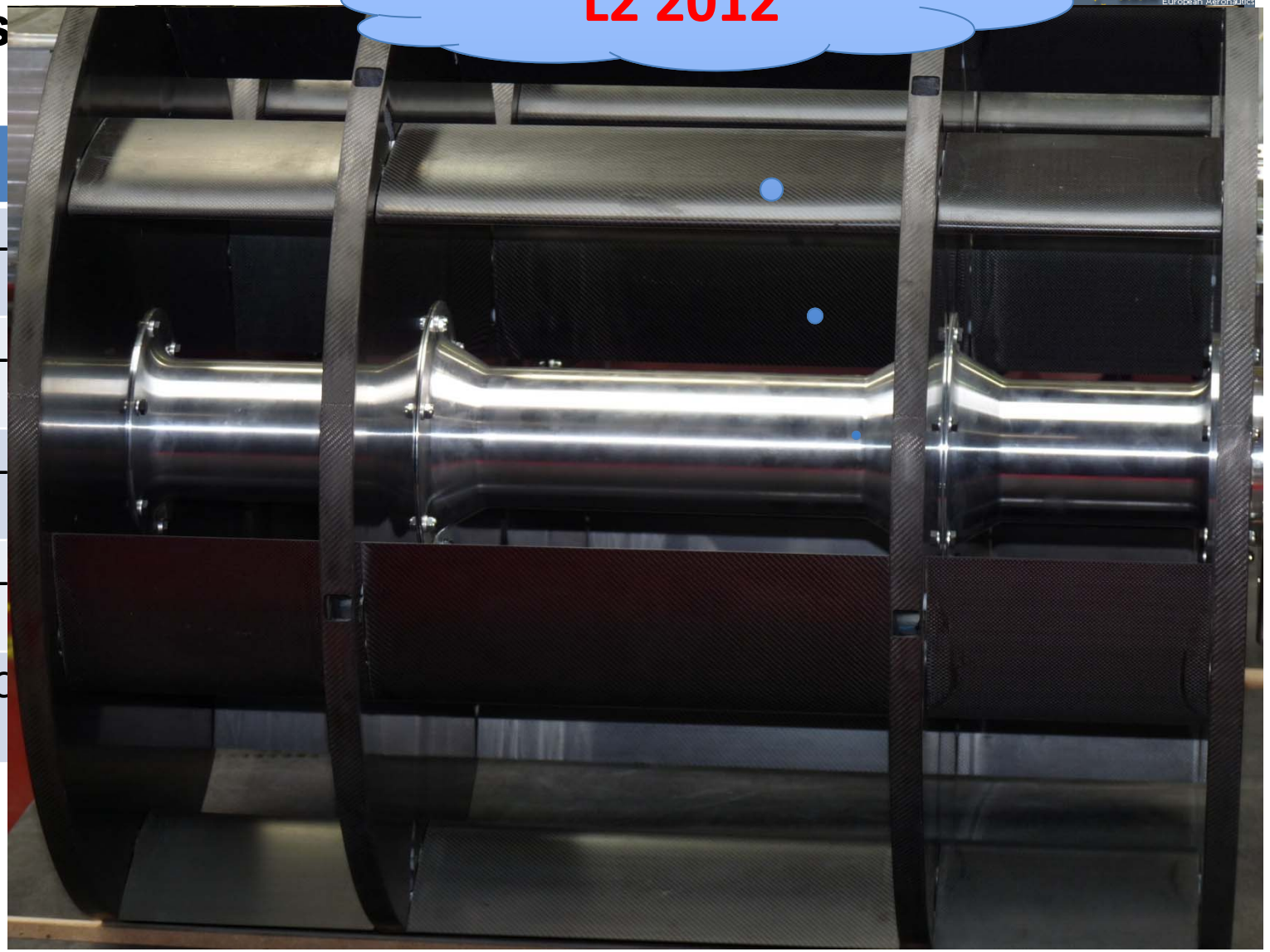
L

L

L

L

C



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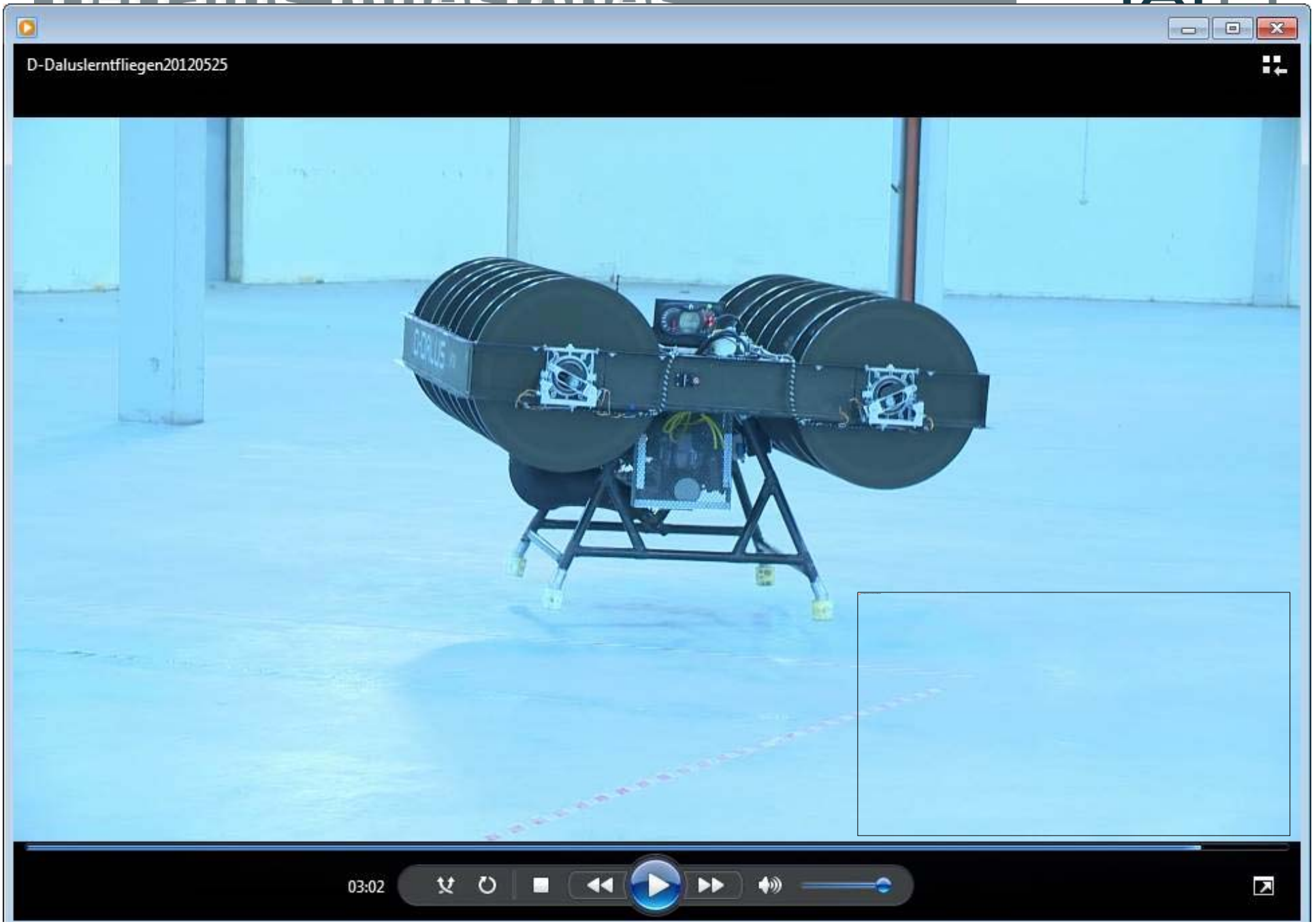
D-Dalus milestones



D-Dalus milestones

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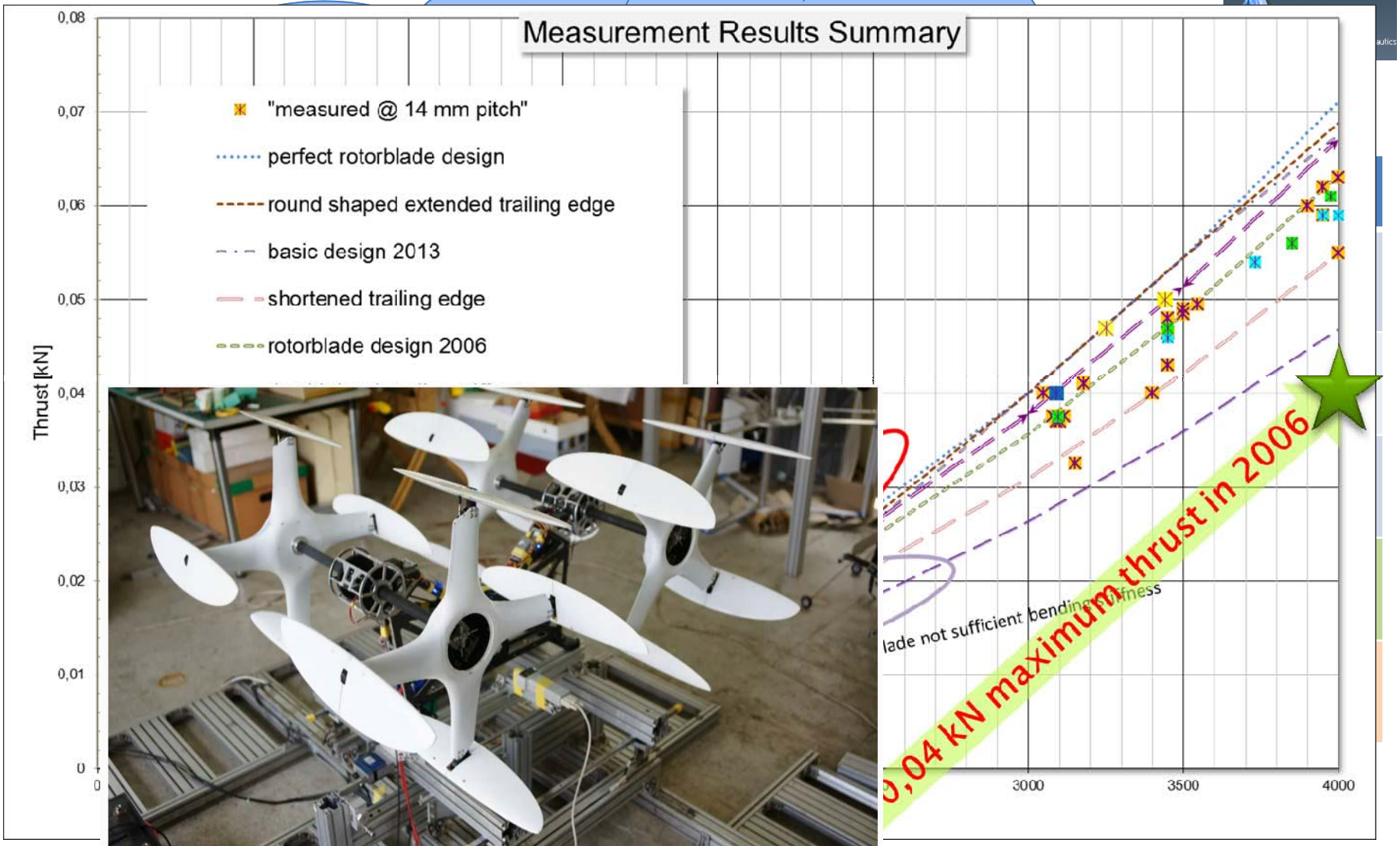
D-Dalus milestones



40 N @ $Ø_{Rotor}$500 mm, b_{length}500 mm, 1000 rpm

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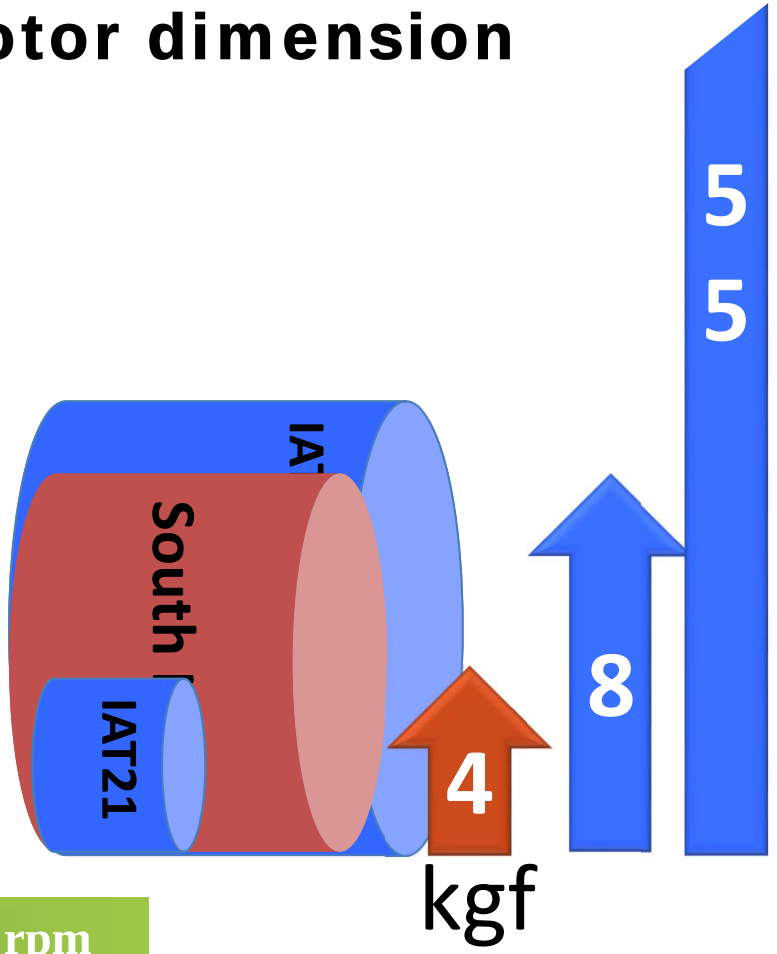
D-Dalus milestones

- Comparison

IAT21 ➔ South Koreans

- ✓ double thrust at halve rotor dimension

40 N @ $Ø_{Rotor}$500 mm, b_{length}500 mm, 1000 rpm



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Where is D-Dalus positioned?

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Where is D-Dalus positioned?

CROP example helicopter
Original Tail Rotor: BO105 Like

Data taken for comparison

- Fully aeroelastic model
- Main rotor power and torque
- Tail rotor power and torque
- Tail rotor thrust
  - Magnitude
  - Direction

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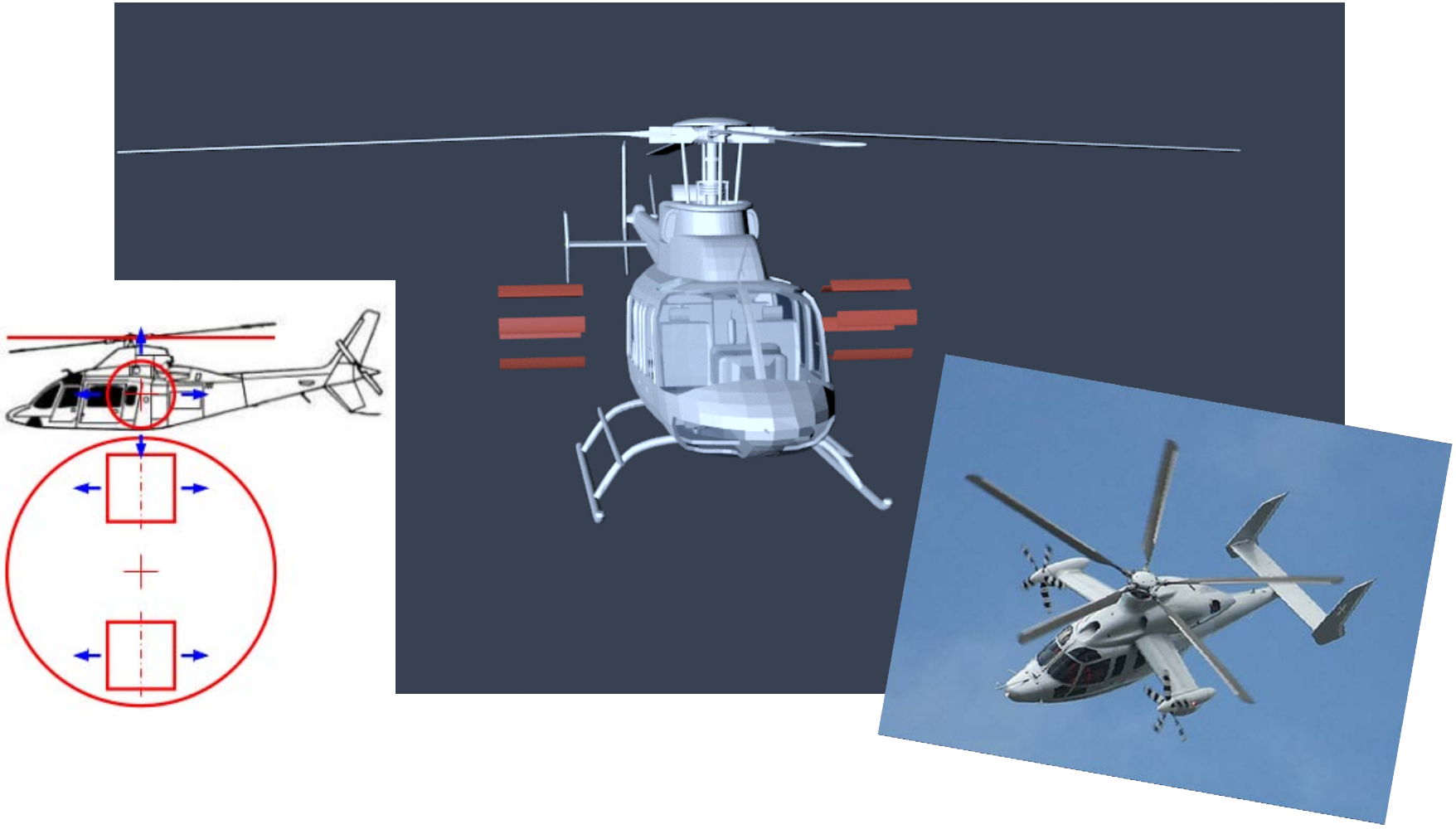
Cyclogyro Compound Helicopter

Lateral Arrangement: Similar to Eurocopter X3



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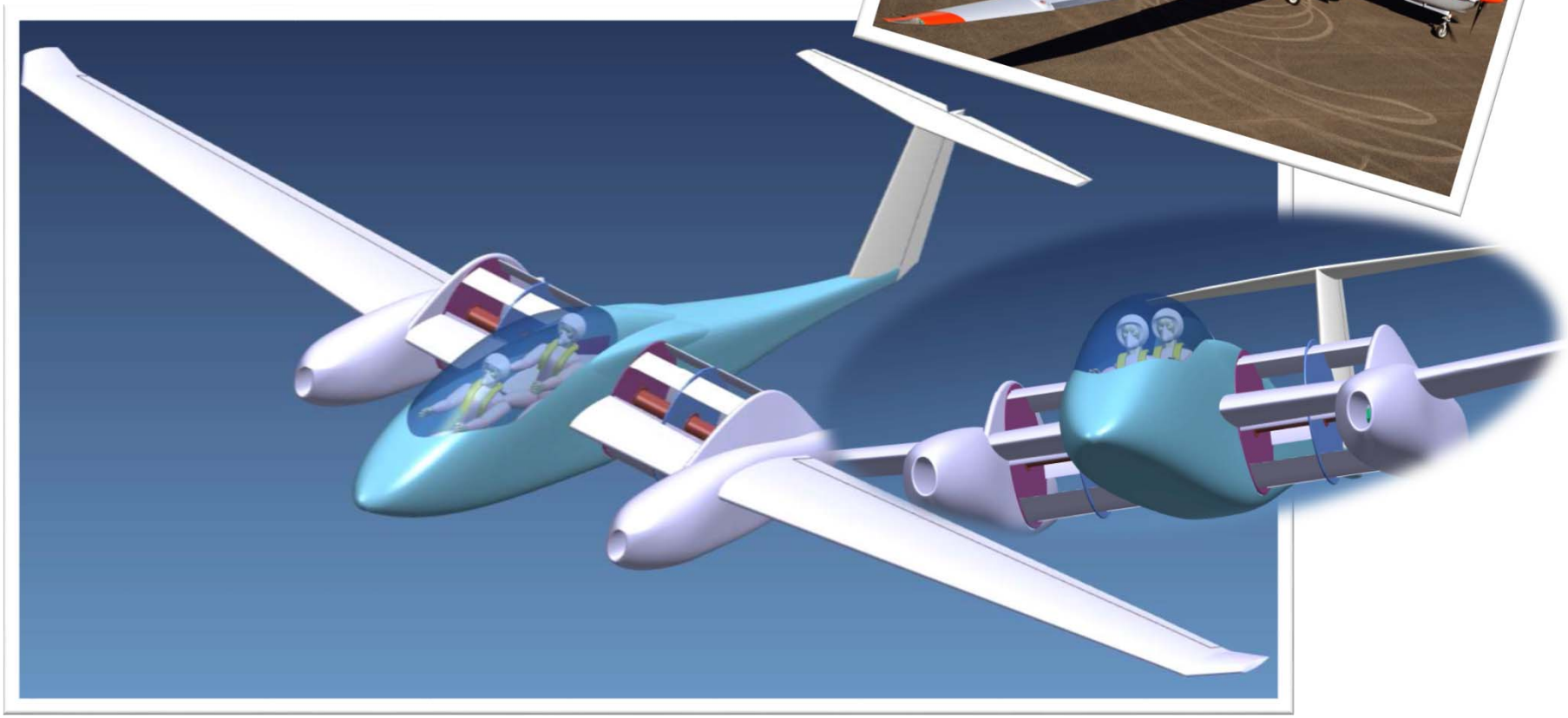
Cyclogyro Fixed Wing Aircraft

Proposed by Grob Aircraft
Replace EGRETT's propeller



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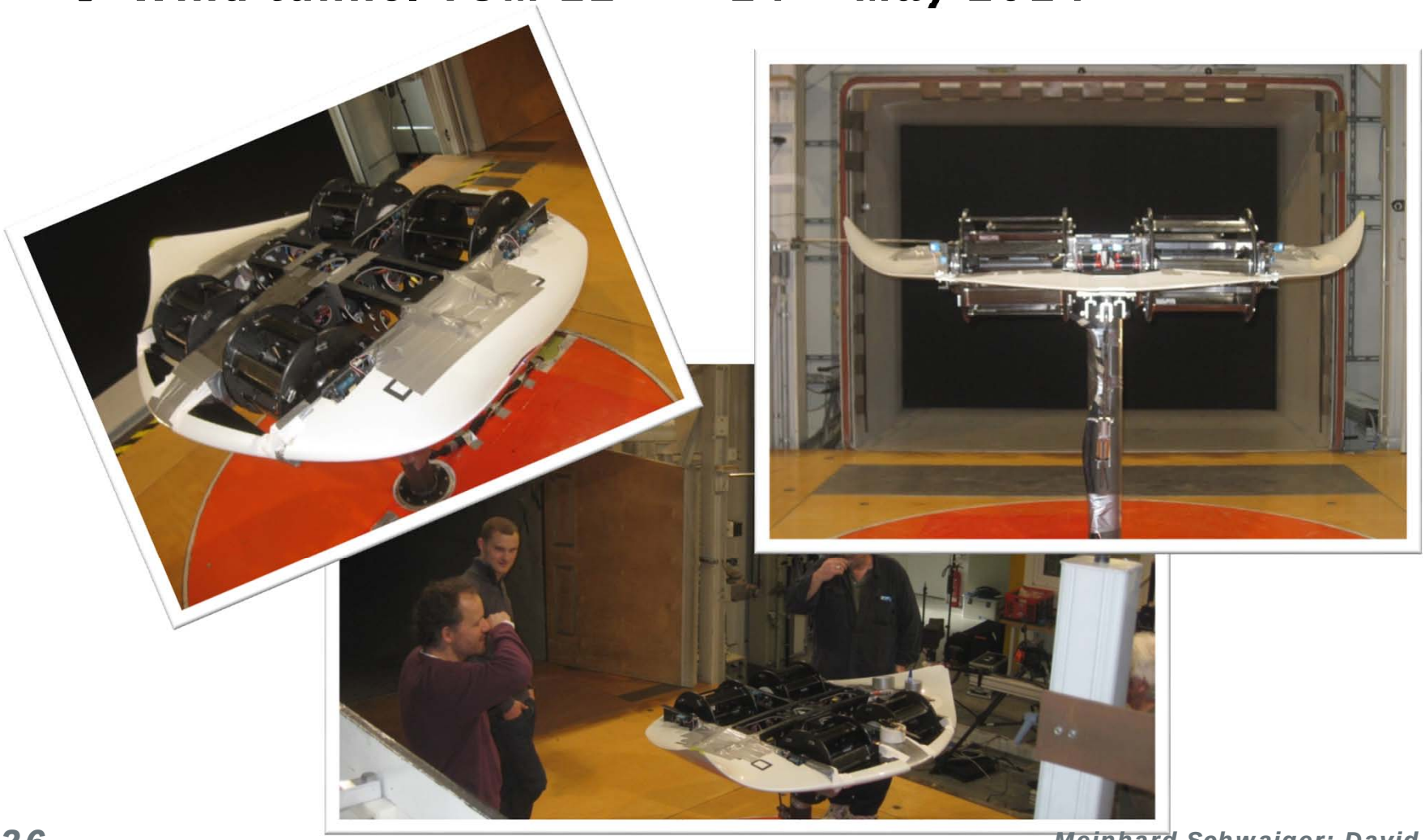
Performance and Efficiency

- **Aerodynamic and Rotor-performance**
- **➔ Wind tunnel TUM 12th – 14th May 2014**



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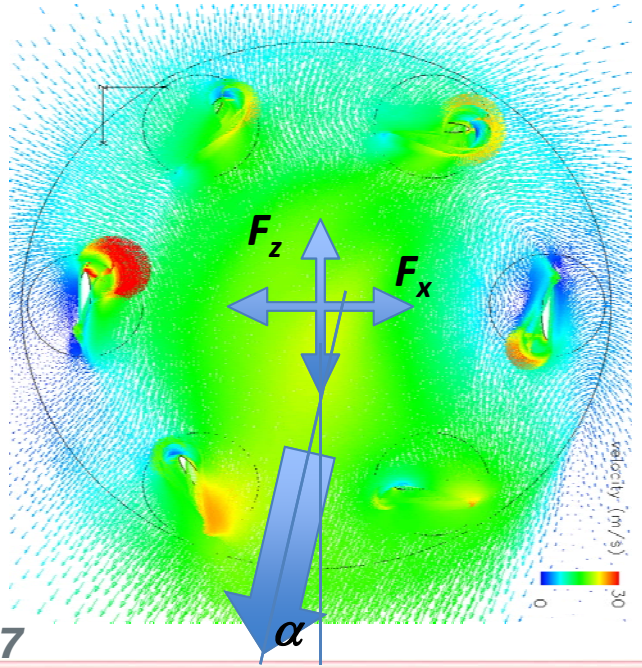
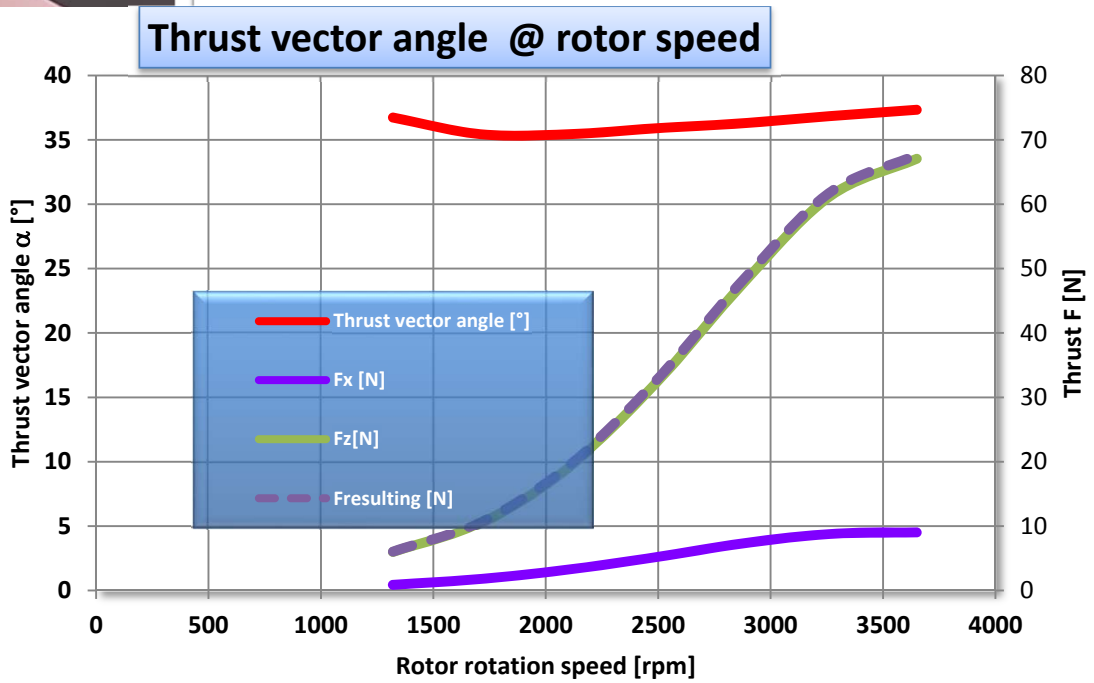
Performance and Efficiency → Thrust angle





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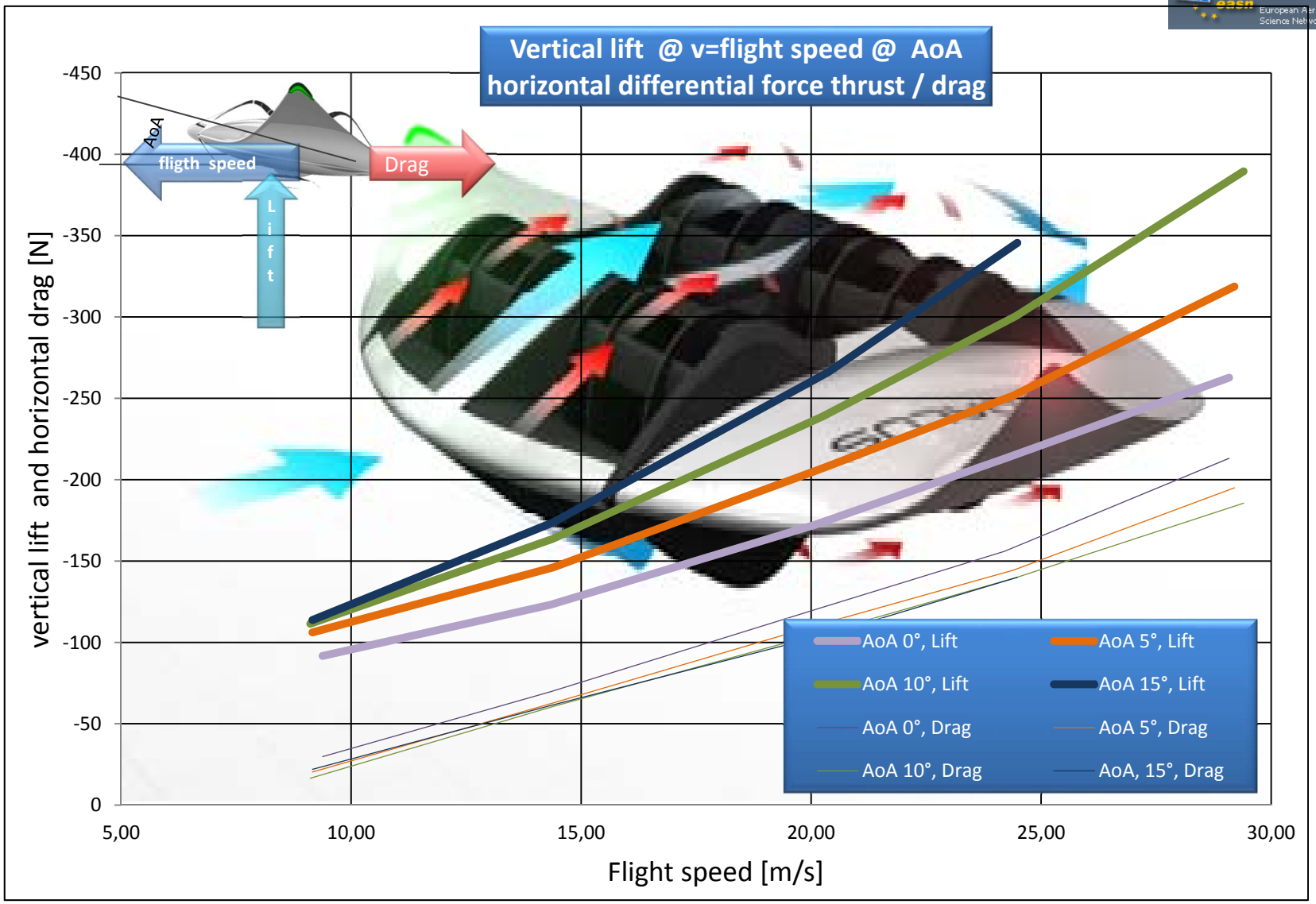
Performance and Efficiency ➔ Lift / Drag @ forward fligth



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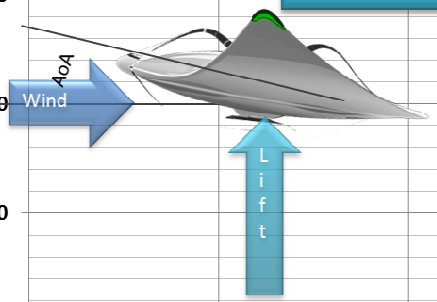
Performance and Efficiency → Rotor thrust @ forward speed

Rotor thrust influenced by forward flight speed



rotor thrust efficiency increased in forward flight speed @ AoA 0°

AoA 0° uplift, rotorspeed – 3650 rpm

AoA 0° without rotor speed

Efficiency increase

Upliftg [N]

-400
-350
-300
-250
-200
-150
-100
-50
0

300%
250%
200%
150%
100%
50%
0%

Increased thrust (==> efficiency increase) @ forward s

0
5
10
15
20
25
30
35

Forward flight speed [m/s]

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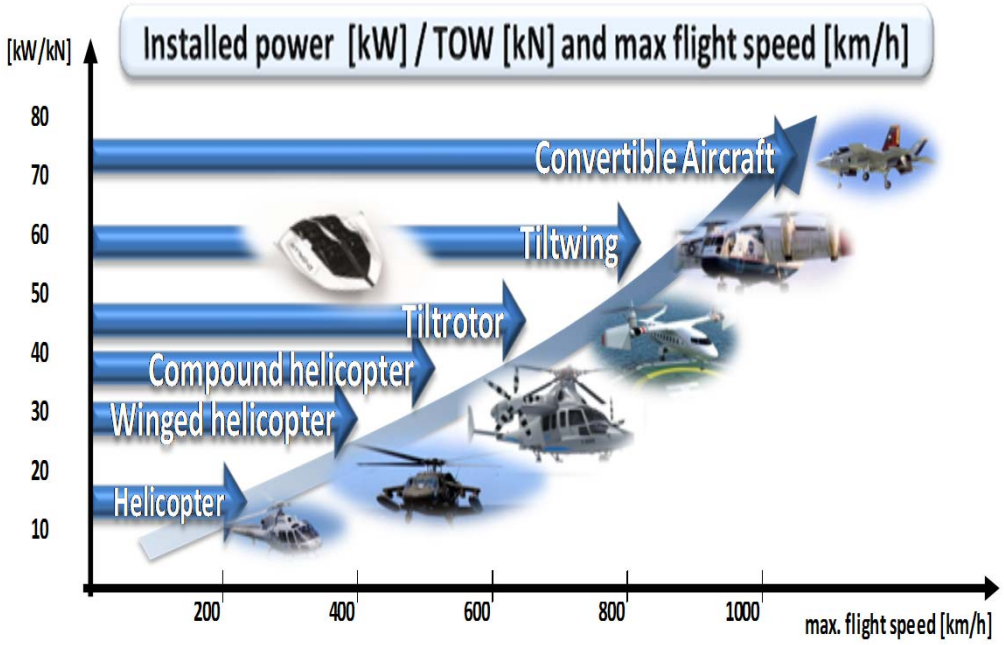
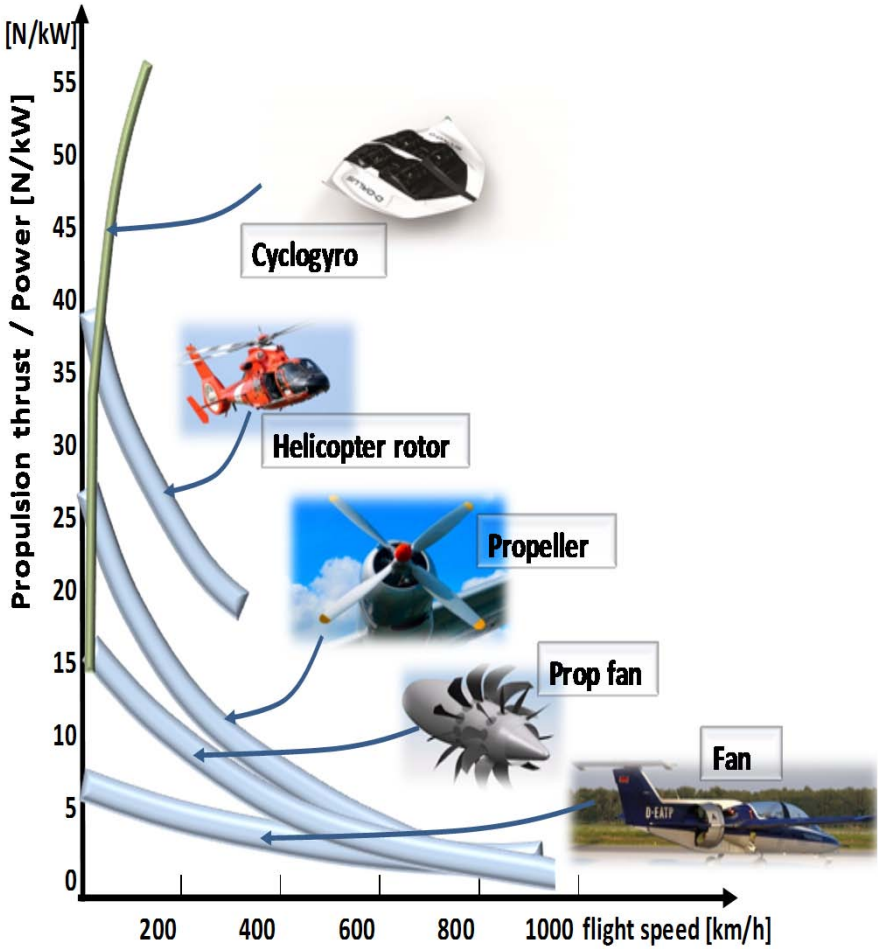
Performance and Efficiency @ forward fligth





Similar to Dr. Kessler / IAG-University Stuttgart, 2013

Meinhard Schwaiger; David Wills

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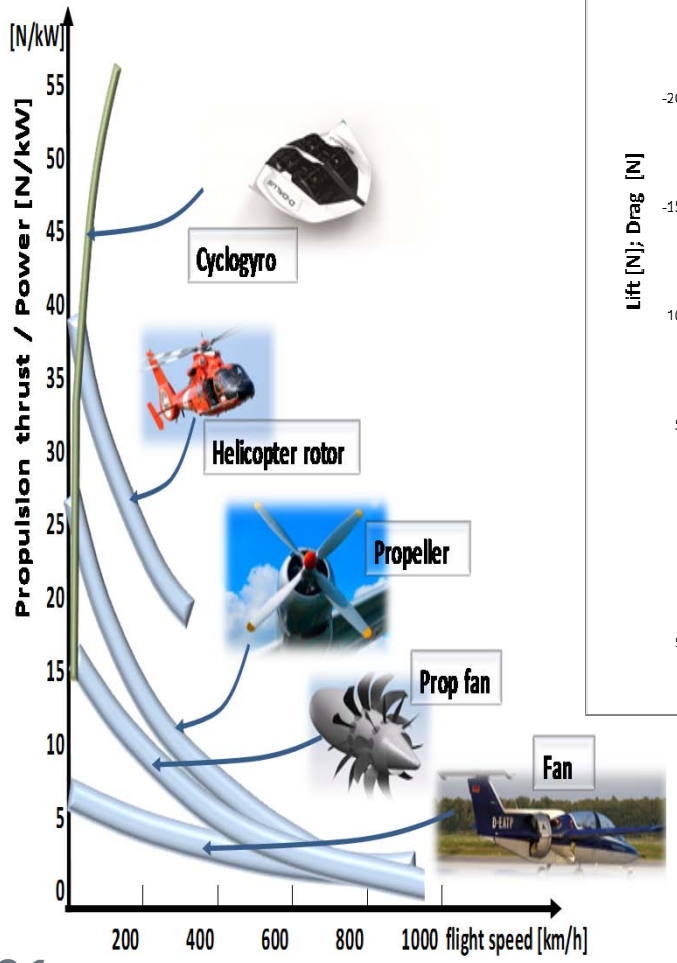
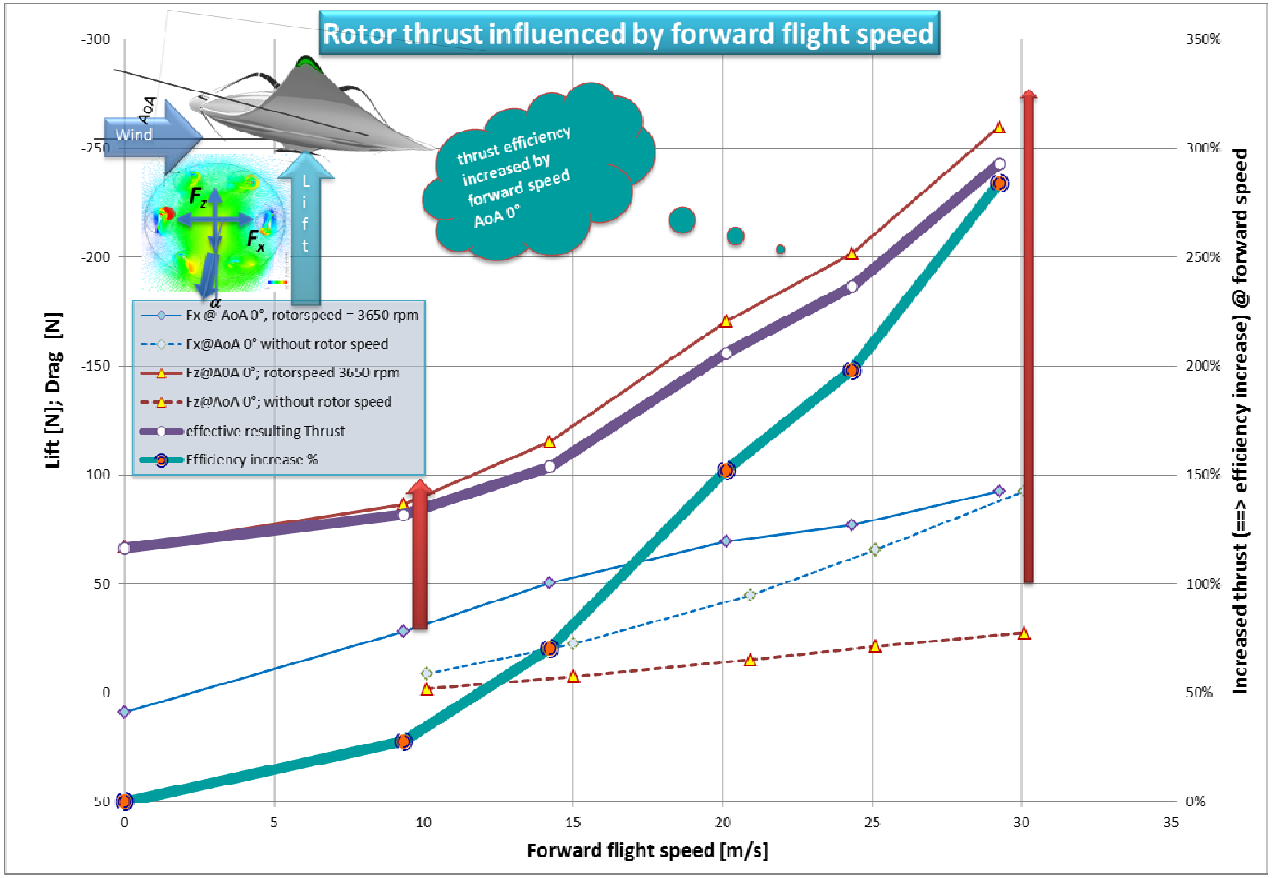
Wind tunnel test TUM → Efficiency @ forward fligth

Theoretical background – virtual chamber effect





IAT21's different effect is may be caused by elimination of the virtual chamber effect Thanks a specialized special rotor blade design

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Flight Trials

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Impression of D-Dalus manned aircraft

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Impression of D-Dalus manned aircraft

IAT21
Innovative Aeronautics Technologies

- **Proposal for a manned D-Dalus aircraft**

Meinhard Schwaiger; David Wills

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IAT21 Cooperation Partners

- Universidade da Beira Interior(PT)
  - Partner EU-funding
- Politecnico di Milano (IT)
  - CFD-Simulation
- UNIMORE (IT)
  - CFD-Simulation
- The University of Sheffield

- University of Cranfield (GB)
  - Propulsion
- University of Embry Riddle
  - Engine selection
  - Market entrance USA
- Technical University Munich
  - Aerodynamic / Wind tunnel test
  - Flight dynamik, general advise
  - Engine department / general advise

CROP || FP7-AAT-2012-RTD-L0 || GA no: 323047

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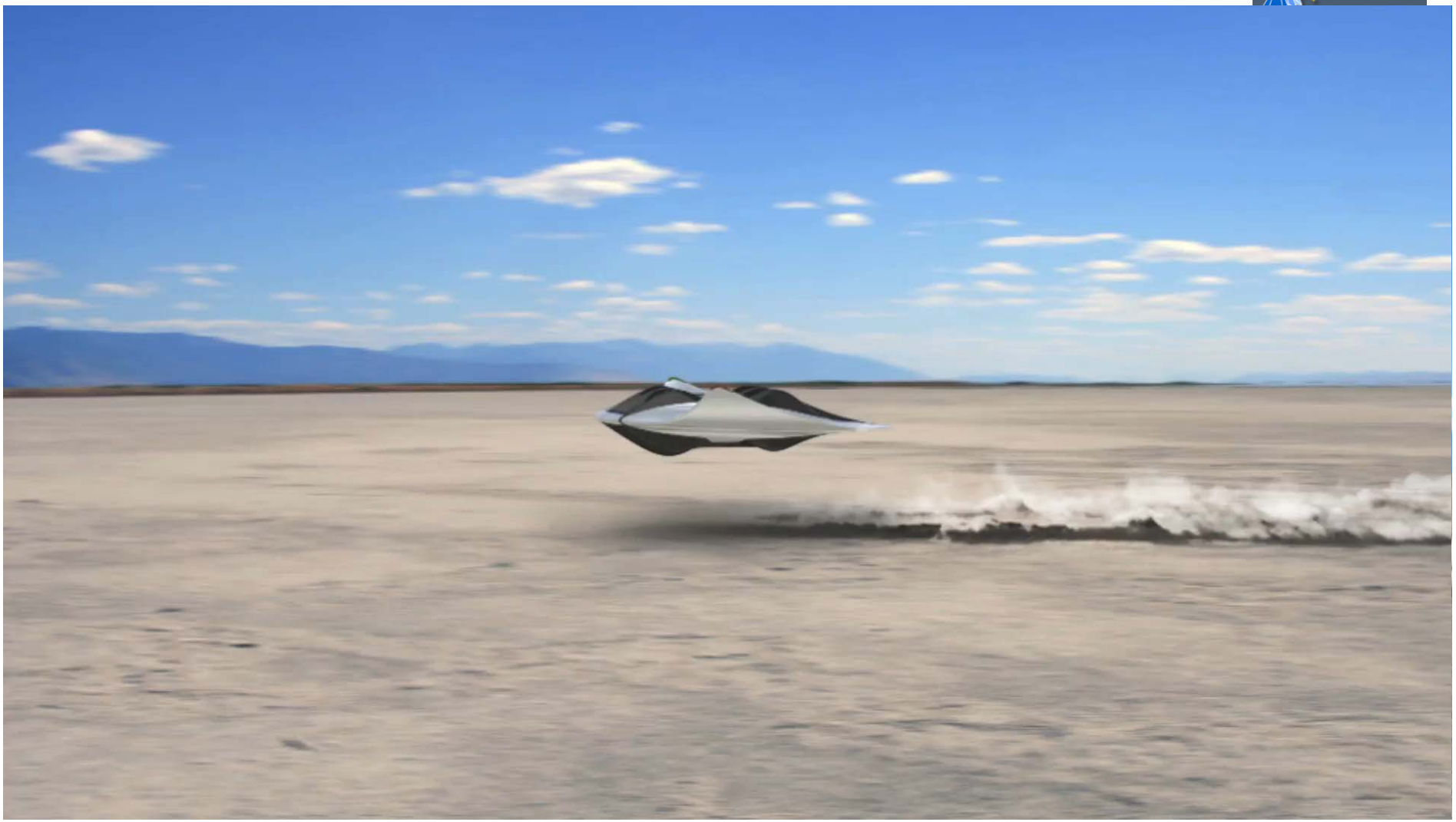

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Optimal pitching schedules for a cycloidal rotor in hovering

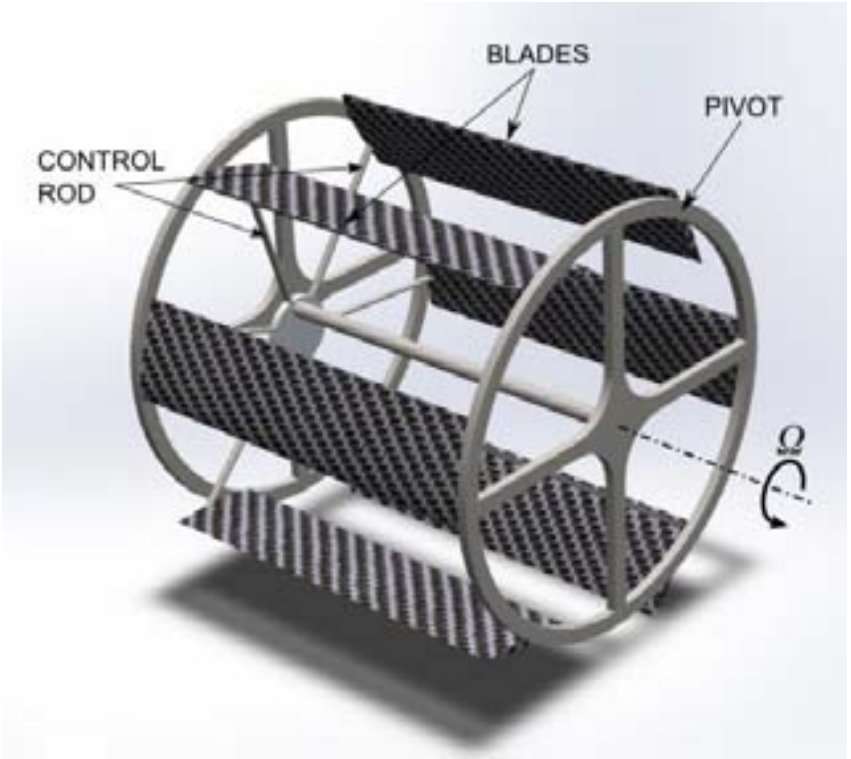
Andrea Andrisani, Diego Angeli, Antonio Dumas

DISMI - Department of Sciences and Methods for Engineering
University of Modena and Reggio Emilia, Italy

4th EASN Association International Workshop
on Flight Physics and Aircraft Design
Aachen, October 27-29, 2014

Introduction

- CROP (Cycloidal Rotor Optimized for Propulsion) is a propulsion system concept for MAV and UAV
- It is based on a rotating wing system, where the axis of rotation is parallel to the blade span
- The pitching schedule of the blades is controlled by a passive or active mechanical system that should be able to change the direction and magnitude of the resulting thrust vector, thus allowing for a substantial increase on the aircraft control
- **Aim of this work**: find a pitching schedule that minimizes power consumption for a given thrust.



Physical description

Instantaneous thrust and power
for a single blade:

$$T_x = T_x\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right)$$

$$T_y = T_y\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right)$$

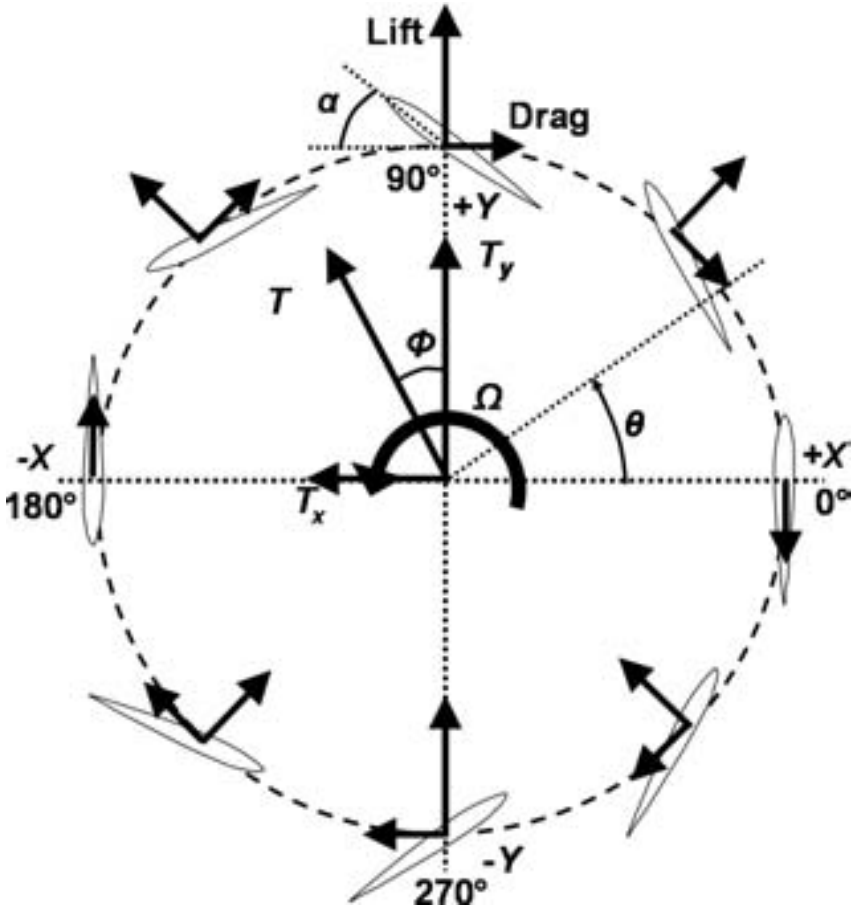
$$P = P\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right)$$

Total thrust and power over a period
(with n dynamically independent blades):

$$\bar{T}_x = \frac{n}{2\pi}\int_0^{2\pi} T_x\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right) d\theta$$

$$\bar{T}_y = \frac{n}{2\pi}\int_0^{2\pi} T_y\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right) d\theta$$

$$\bar{P} = \frac{n}{2\pi}\int_0^{2\pi} P\left(\alpha, \frac{d\alpha}{d\theta}, \frac{d^2\alpha}{d\theta^2}, \theta, \Omega\right) d\theta$$



Mathematical formulation I

The kinematics of a blade is fully described by:

- the angular velocity of the rotor Ω
- the pitching schedule $\alpha : \theta \in [0, 2\pi] \rightarrow \alpha(\theta) \in \mathbf{R}$, with $\alpha(0) = \alpha(2\pi)$

Hence, $\bar{T}_x$, $\bar{T}_y$ and $\bar{P}$ are functionals on the Banach space $\mathscr{B} = \mathscr{C}_{2\pi} \otimes \mathbf{R}$.

Objective: fixed two thrust values τ_x and τ_y, find the critical element $(\alpha, \Omega) \in \mathscr{B}$ minimizing $\bar{P}$ in the domain $\left\{(\alpha, \Omega) : \bar{T}_x(\alpha, \Omega) = \tau_x, \bar{T}_y(\alpha, \Omega) = \tau_y\right\}$:

$$\begin{cases} \left[\dfrac{\partial}{\partial \alpha} - \dfrac{d}{d\theta}\left(\dfrac{\partial}{\partial (d\alpha/d\theta)}\right) + \dfrac{d^2}{d\theta^2}\left(\dfrac{\partial}{\partial \left(d^2\alpha/d\theta^2\right)}\right)\right]\left(P + \lambda_x T_x + \lambda_y T_y\right) = 0 \\ \dfrac{\partial \bar{P}}{\partial \Omega} + \lambda_x \dfrac{\partial \bar{T}_x}{\partial \Omega} + \lambda_y \dfrac{\partial \bar{T}_y}{\partial \Omega} = 0 \\ \bar{T}_x = \tau_x \\ \bar{T}_y = \tau_y \end{cases}$$

where $\lambda \equiv (\lambda_x, \lambda_y) \in \mathbf{R}^2$ are the Lagrange multipliers of the optimization problem.

Mathematical formulation II

If $\alpha(\theta)$ is a parametric function of the type $\alpha(\theta) = f(\theta, g_1, g_2, \ldots g_i)$, the first equation becomes:

$$\frac{\partial \bar{P}}{\partial g_i} + \lambda_x \frac{\partial \bar{T}_x}{\partial g_i} + \lambda_y \frac{\partial \bar{T}_y}{\partial g_i} = 0$$

A standard choice for f is:

$$f(\alpha_0, \varepsilon) = \alpha_0 \sin(\theta + \varepsilon)$$

A more realistic parametrized profile is given by the **4-bar linkage** profile:

$$f(e, \varepsilon) = \arccos\left(\frac{e\cos(\theta+\varepsilon)}{\sqrt{e^2+R^2+2eR\sin(\theta+\varepsilon)}}\right) - \arccos\left(\frac{e^2+R^2+2eR\sin(\theta+\varepsilon)+d^2-L^2}{2d\sqrt{e^2+R^2+2eR\sin(\theta+\varepsilon)}}\right)$$

Another pitching profile was considered in some studies, connected to the possible adoption of a **3D cam** driving the pitching motion:

$$f(\alpha_0, \varepsilon) = \arctan\left(\frac{V_\infty \cos(\theta - \theta_\infty)}{\Omega R - V_\infty \sin(\theta - \theta_\infty)}\right) + \alpha_0 \sin(\theta + \varepsilon)$$

Cyclorotor model I

Main assumptions:

- steady approximation $\Rightarrow$ lift L and drag D depend on the instantaneous angle of attack only. This occurs when
$$\frac{c}{2}\left|\frac{d\alpha}{dt}\right| \ll \Omega R$$
where c is the chord of the blade and R the rotor radius
- rectilinear flow (if $c/R \ll 1$) $\Rightarrow$ the virtual camber effect is neglected
- low values of angle of attack $\bar{\alpha} \Rightarrow L = L(\bar{\alpha})$ and $D = D(\bar{\alpha})$ only
$$L = \frac{C_l}{2}\rho U^2 S\bar{\alpha}$$
$$D = \frac{1}{2}\rho U^2 S\left(C_{d_0} + C_{d_2}\bar{\alpha}^2\right) \quad \text{where} \quad C_{d_2} = \frac{C_l^2}{\pi e_0 AR}$$
The lift and zero drag coefficients, C_l and C_{d_0} can be retrieved from the literature. The Oswald efficiency number e_0 can be found by fitting of experimental data.
- uniform induced velocity: from the actuator disk theory
$$\mathbf{v_i} = \frac{\bar{\mathbf{T}}}{2\rho V S_{ad} C}$$
where $\bar{\mathbf{T}}$ is the vector of mean forces of the fluid acting on the cyclo-rotor, S_{ad} the *actuator disk surface* of the cyclo-rotor, C a correction factor and $\mathbf{V} = \mathbf{V}_\infty + \mathbf{v_i}$ with $\mathbf{V}_\infty$ the cyclo-rotor translation velocity.

Cyclorotor model II

The velocity U is defined by:

$$U_t = \Omega R - V_x \sin\theta + V_y \cos\theta = \Omega R - V \sin(\theta - \theta_0)$$
$$U_r = V_x \cos\theta + V_y \sin\theta = V \cos(\theta - \theta_0)$$
$$U = \sqrt{U_t^2 + U_r^2} = \sqrt{\Omega^2 R^2 + V^2 - 2\Omega R V \sin(\theta - \theta_0)}$$

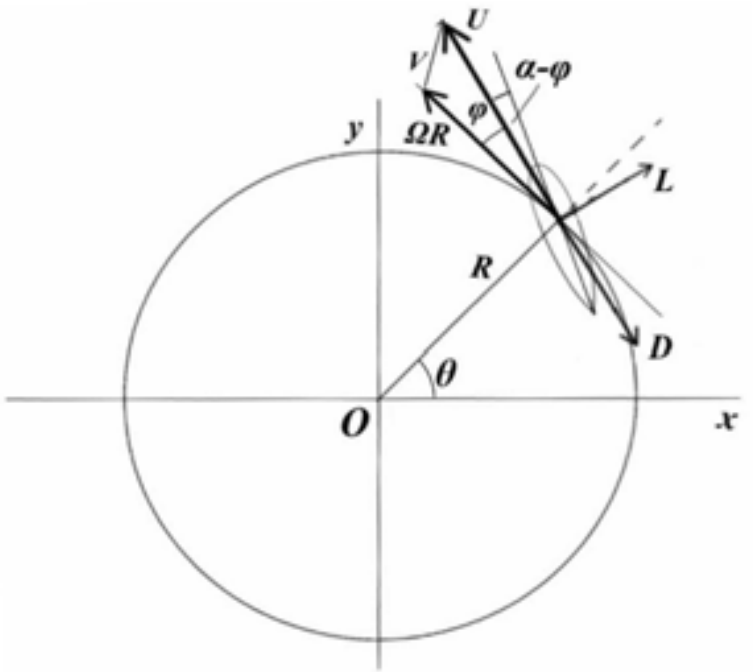
The angle of attack $\bar{\alpha}$ is given by:

$$\bar{\alpha} = \alpha - \phi$$

where the phase ϕ of the vector U, defined as

$$\phi = \arctan \frac{U_r}{U_t} = \arctan \frac{V \cos(\theta - \theta_0)}{\Omega R - V \sin(\theta - \theta_0)}$$

is the *zero-angle of attack profile*.



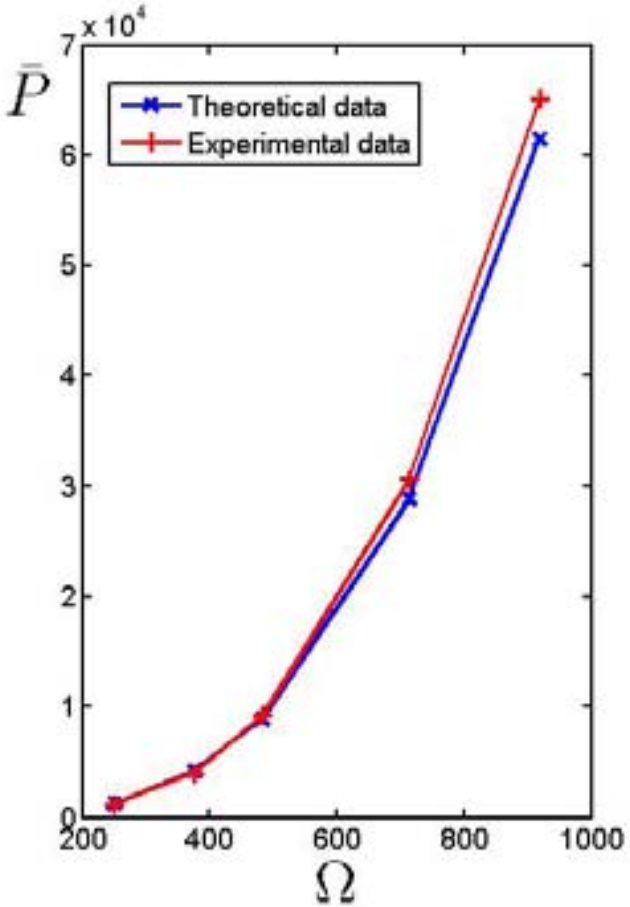
Cyclorotor model III

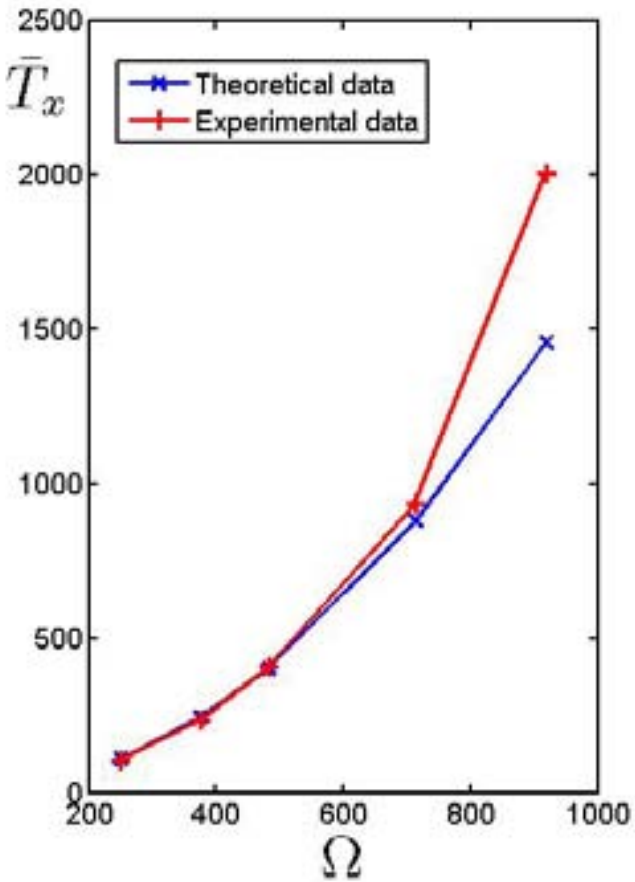
Final model equations:

$$T_x = L\cos(\theta-\phi) + D\sin(\theta-\phi) =$$
$$\frac{\rho S U^2}{2}\left\{C_l(\alpha-\phi)\cos(\theta-\phi) + \left[C_{d_0} + C_{d_2}(\alpha-\phi)^2\right]\sin(\theta-\phi)\right\} \quad (1)$$
$$T_y = L\sin(\theta-\phi) - D\cos(\theta-\phi) =$$
$$\frac{\rho S U^2}{2}\left\{C_l(\alpha-\phi)\sin(\theta-\phi) - \left[C_{d_0} + C_{d_2}(\alpha-\phi)^2\right]\cos(\theta-\phi)\right\} \quad (2)$$
$$P = \Omega R(L\sin\phi + D\cos\phi) =$$
$$\frac{\rho S U^2 \Omega R}{2}\left\{C_l(\alpha-\phi)\sin\phi + \left[C_{d_0} + C_{d_2}(\alpha-\phi)^2\right]\cos\phi\right\} \quad (3)$$

Model fine-tuning

- experimental data: **IAT21 D-Dalus L3** rotor (NACA0016, $n = 6$, $c = 0.3$ m, $R = 0.6$ m)
- estimates of $e_0 \simeq 0.83$, $C \simeq 0.3$
- relative deviations $\delta_r \bar{P} \simeq 4.7\%$ and $\delta_r \bar{T}_x \simeq 3.8\%$ (save last T_x datum)





Optimal pitching profile

By enforcing the model equations we obtain:

$$P + \lambda_x T_x + \lambda_y T_y = \frac{\rho S U^2}{2} \{ C_l (\alpha - \phi) [\Omega R \sin\phi + \lambda \cos(\theta - \phi - \phi_0)] + \left[C_{d_0} + C_{d_2} (\alpha - \phi)^2 \right] [\Omega R \cos\phi + \lambda \sin(\theta - \phi - \phi_0)] \}$$

where

$$\lambda = \sqrt{\lambda_x^2 + \lambda_y^2}, \qquad \phi_0 = \arctan \frac{\lambda_y}{\lambda_x}$$

The first equation of the optimization problem becomes:

$$\frac{\partial}{\partial \alpha} \left(P + \lambda_x T_x + \lambda_y T_y \right) = 0$$

By combining the above, we get the **optimal pitching profile**

$$\alpha \equiv \alpha(\theta; \Omega, \lambda) = \phi - \frac{C_l}{2 C_{d_2}} \frac{\Omega R \sin\phi + \lambda \cos(\theta - \phi - \phi_0)}{\Omega R \cos\phi + \lambda \sin(\theta - \phi - \phi_0)}$$

Some observations

- By inserting the optimal pitching profile in the model equations, the terms $\bar{T}_x$, $\bar{T}_y$ and $\bar{P}$ appearing in the last three equations of the optimization problem are obtained
- These cannot be solved analytically, with the exception of the case $\mathbf{V} = 0$
- when $\mathbf{V}_\infty = 0$, if we put:

$$\Omega \to \Omega' = \frac{\Omega}{\sqrt{\tau}} \quad \lambda \to \lambda' = \frac{\lambda}{\sqrt{\tau}} \quad V \to V' = \frac{V}{\sqrt{\tau}} = \frac{1}{\sqrt{2\rho S_{ad} C}}$$

we have

$$\bar{T}_x\left(\Omega', \lambda'; V'\right) = \frac{1}{\sqrt{\tau}} \bar{T}_x\left(\Omega, \lambda; V\right)$$
$$\bar{T}_y\left(\Omega', \lambda'; V'\right) = \frac{1}{\sqrt{\tau}} \bar{T}_y\left(\Omega, \lambda; V\right)$$
$$\bar{P}\left(\Omega', \lambda'; V'\right) = \frac{1}{\tau} \bar{P}\left(\Omega, \lambda; V\right)$$

$$\begin{cases} \dfrac{\partial \bar{P}}{\partial \Omega'}\left(\Omega', \lambda'; V'\right) + \lambda'_x \dfrac{\partial \bar{T}_x}{\partial \Omega'}\left(\Omega', \lambda'; V'\right) + \lambda'_y \dfrac{\partial \bar{T}_y}{\partial \Omega'}\left(\Omega', \lambda'; V'\right) = 0 \\ \bar{T}_x\left(\Omega', \lambda'; V'\right) = \cos\theta_0 \\ \bar{T}_y\left(\Omega', \lambda'; V'\right) = \sin\theta_0 \end{cases}$$

This shows that the optimal pitching profile α^* is independent of the thrust τ

- The vectors λ and τ are anti-parallel.

$V = 0$ case I

- For $V = 0$ the optimization problem is analytically solvable
- Its solutions are good starting points to numerically solve the general case $V \neq 0$
- If $V = 0$, $\phi = 0$ and the pitching profile coincides with the angle of attack
- The solution of the optimization problem (details in the paper) provides:

$$\alpha = \frac{C_l}{2C_{d_2}} \frac{\cos\left(\theta - \arctan\frac{\tau_y}{\tau_x}\right)}{\sqrt{\Lambda^2\Omega^4R^4/\tau^2 + 1} - \sin\left(\theta - \arctan\frac{\tau_y}{\tau_x}\right)}$$

and the expression of power becomes:

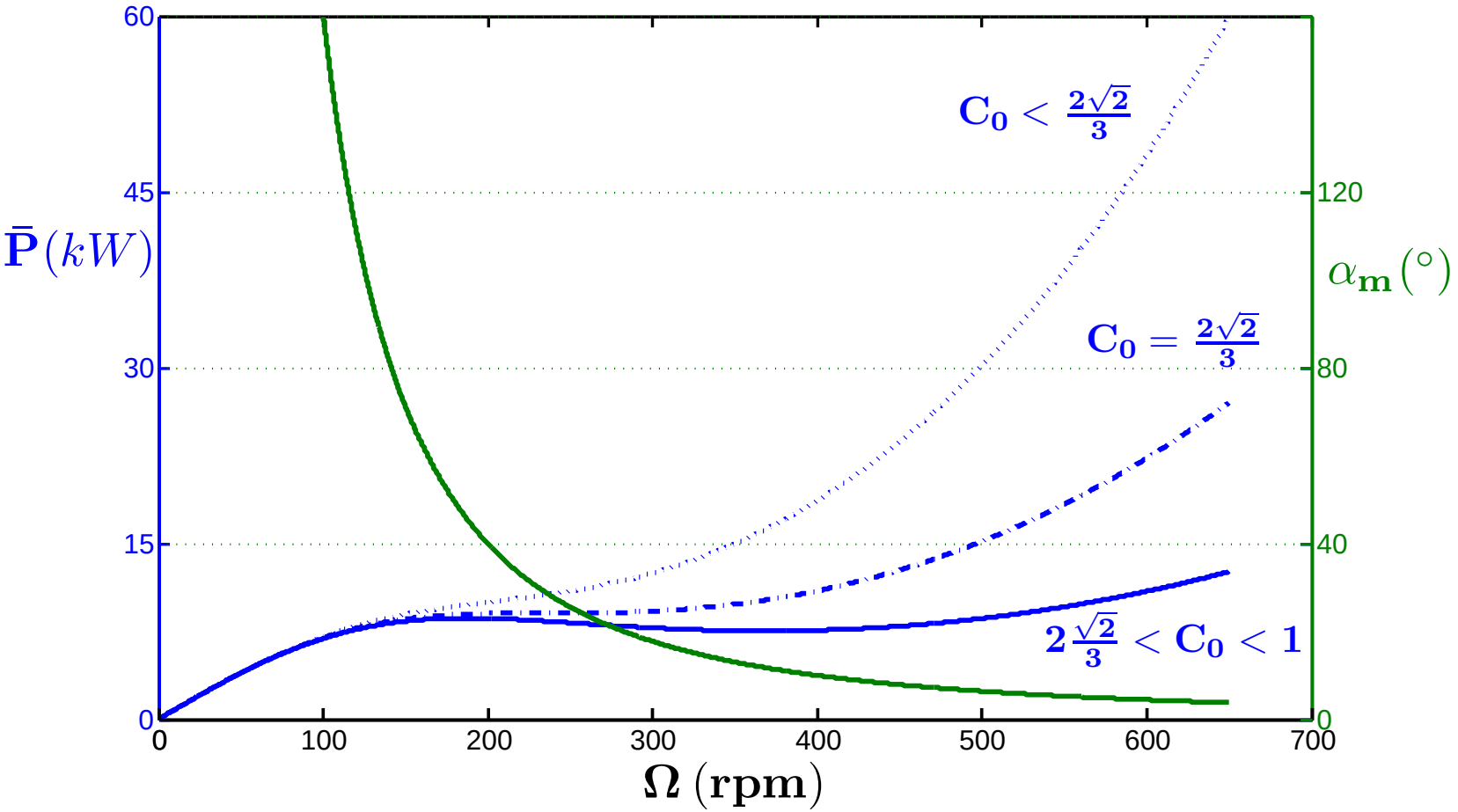
$$\bar{P} = \Lambda\Omega^3R^3\left(\sqrt{1 + \frac{\tau^2}{\Lambda^2\Omega^4R^4}} - C_0\right)$$

where

$$\Lambda = \frac{n\rho SC_l^2}{8C_{d_2}} \qquad C_0 = 1 - \frac{4C_{d_0}C_{d_2}}{C_l^2}$$

- The above equations give all the pitching profiles that, with varying Ω, generate the same thrust τ, and the corresponding power.
- The minima of $\bar{P}$ coincide with the optimal angular velocities

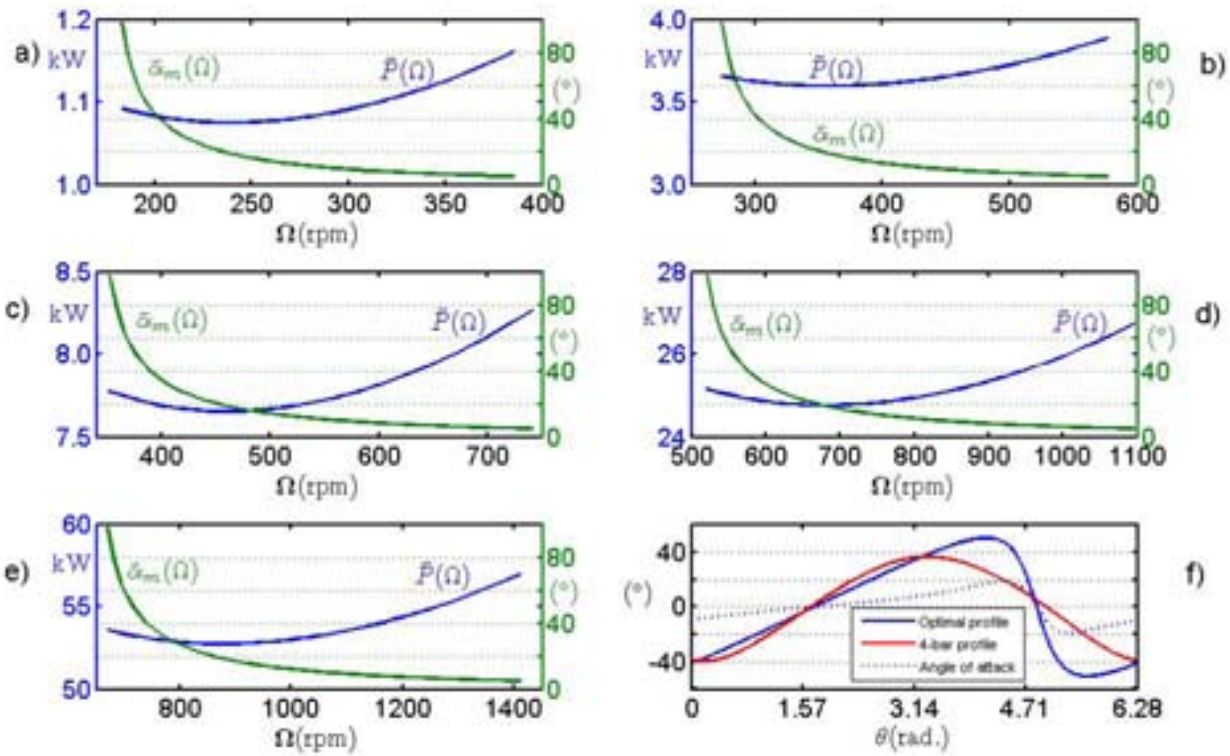
$V = 0$ case II



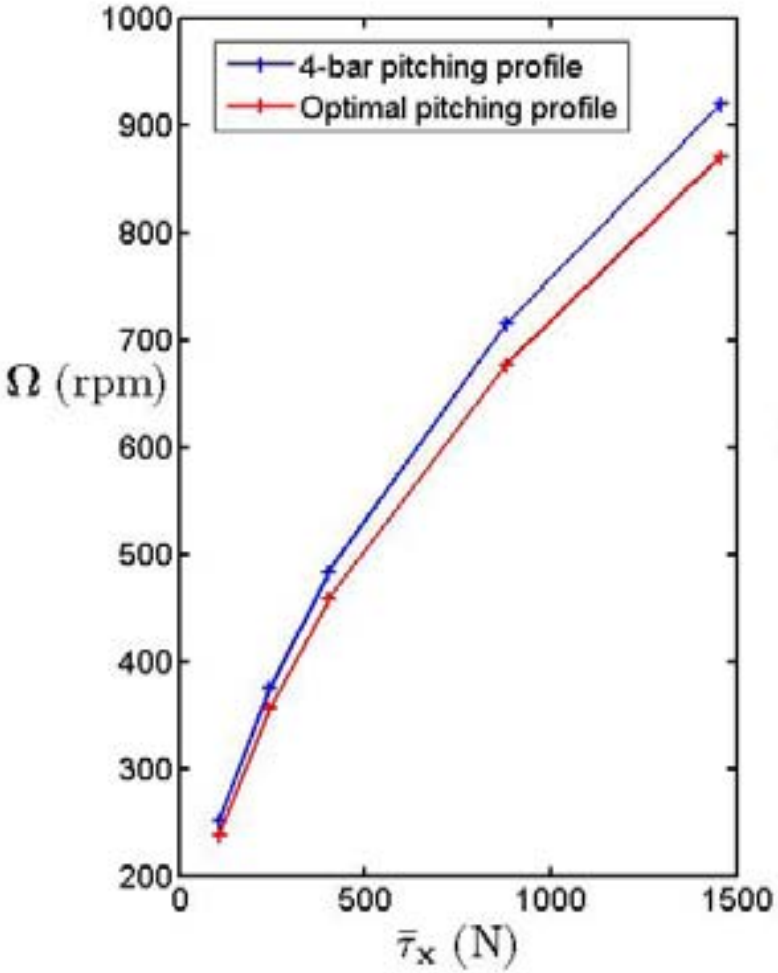
Trends of $\bar{P}$ for three values of C_0, and maximum angle of attack α_m vs Ω.
For angular velocities at which $\alpha_m > 40^\circ$ these trends have no physical meaning.

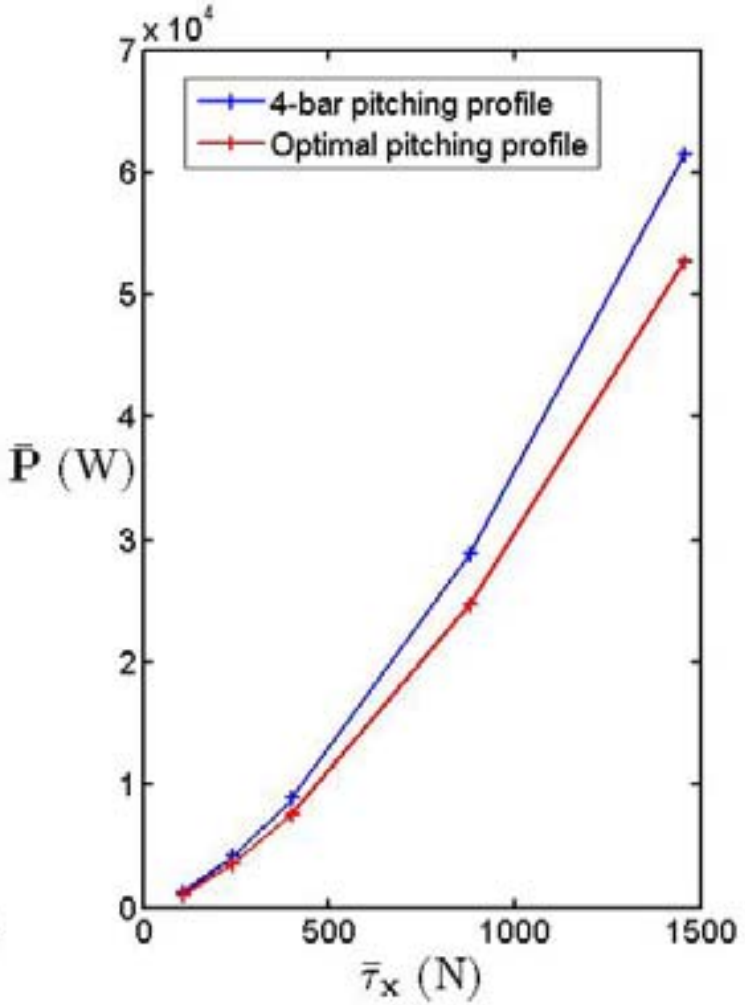
$V \neq 0$ case I

- The optimization problem is no more solvable analytically
- The IAT21 L3 Rotor was again taken as reference
- The optimal values of Ω were determined for five values of thrust, ranging from ≈ 125 N to ≈ 1500 N, and directed along the negative x-direction.
- In all cases, $V_\infty = 0$ (generalization to $V_\infty \neq 0$ is effortless)



$V \neq 0$ case II

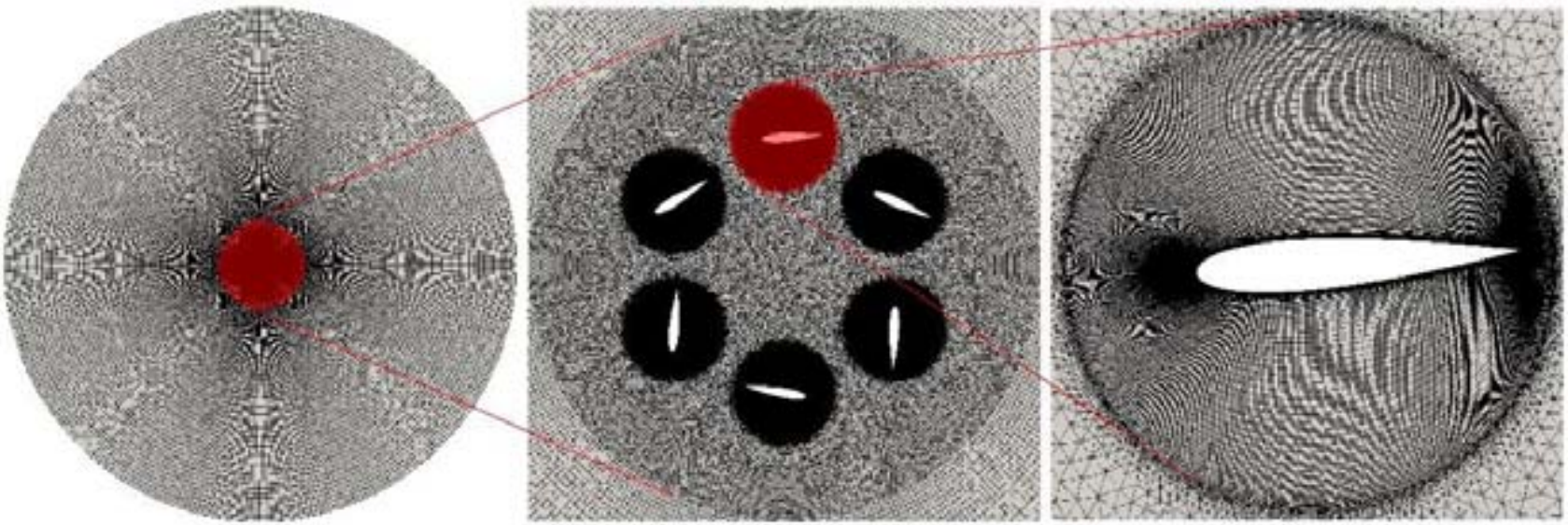




Same thrust with a reduction in Ω of $\approx 6\%$

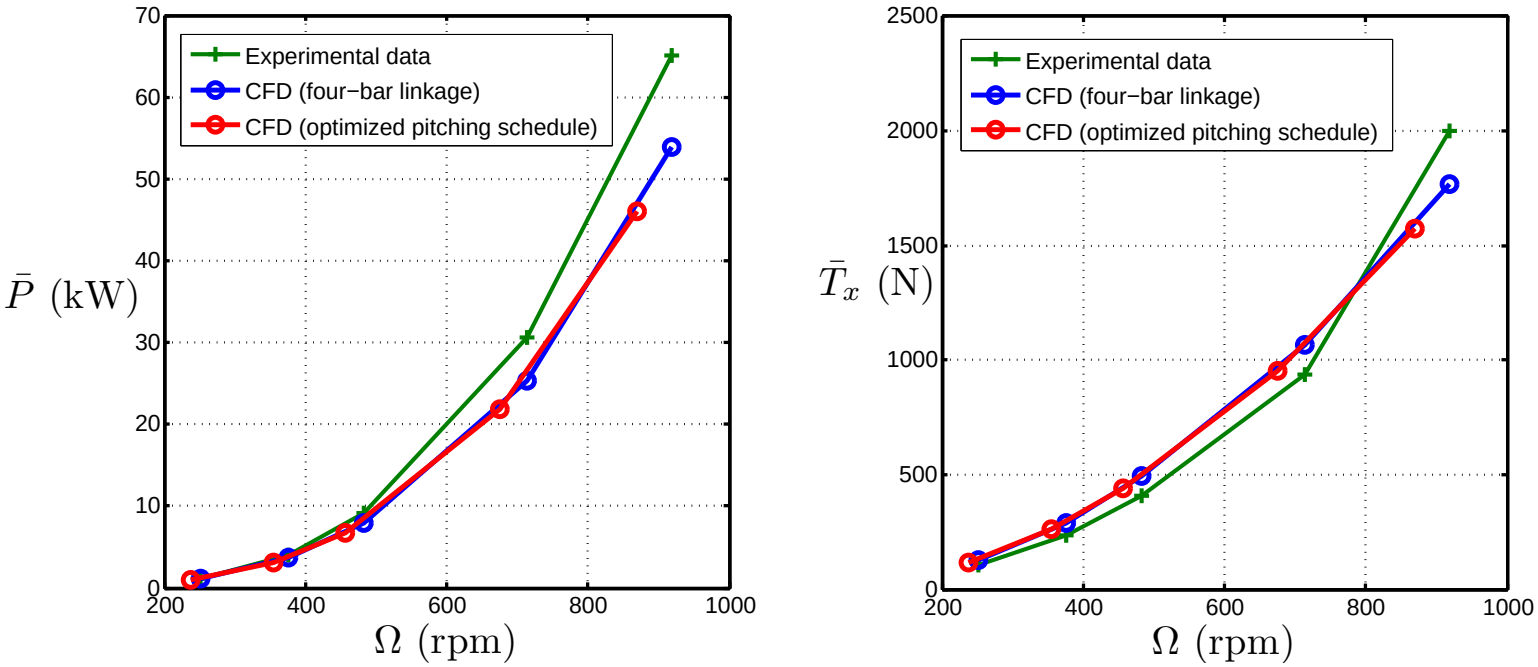
Reduction in power $\approx 14\%$

CFD: mesh and settings



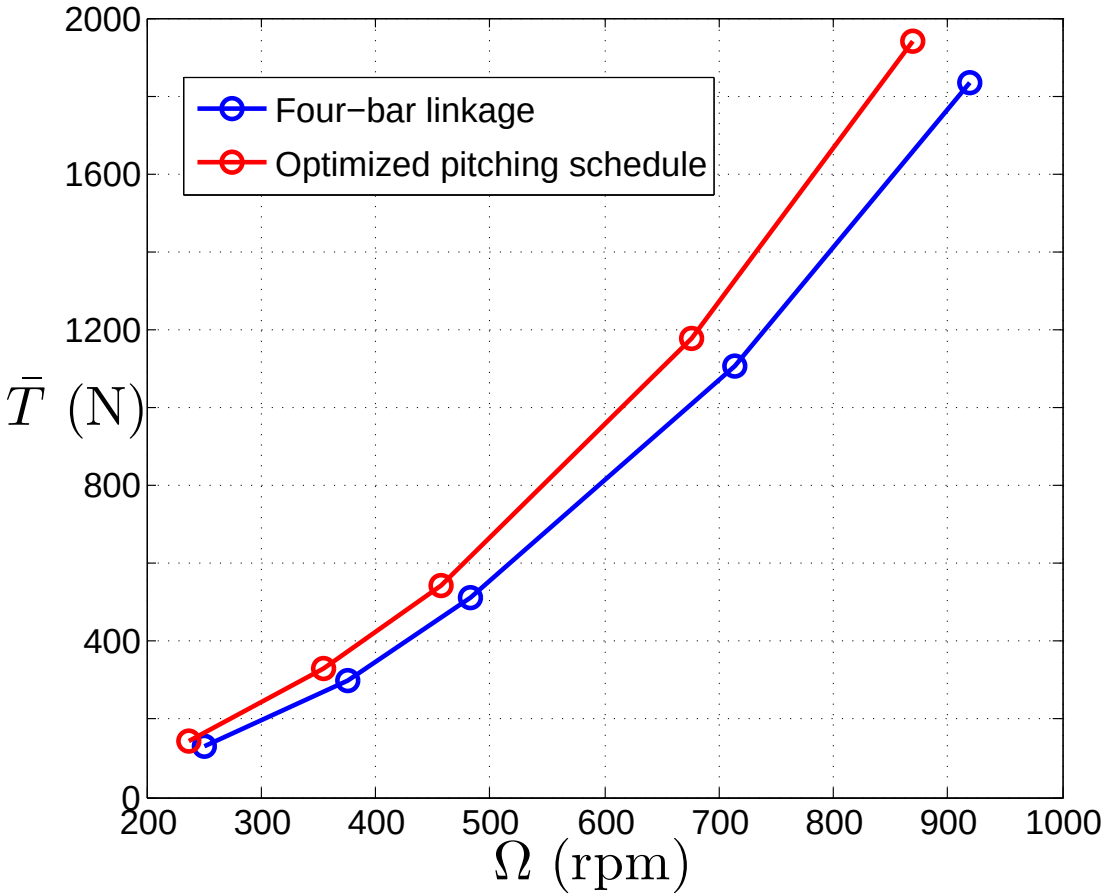
- 2D transient, incompressible RANS (Reynolds-Averaged Navier-Stokes) solver
- Second-order space and time discretisation schemes
- Hybrid PISO-SIMPLE algorithm for the decoupling of pressure and velocity
- Spalart-Allmaras turbulence model without wall functions
- Hybrid triangular and quadrilateral numerical grid
- Interpolation between fixed and moving mesh by Arbitrary Mesh Interface (AMI)

CFD: results I



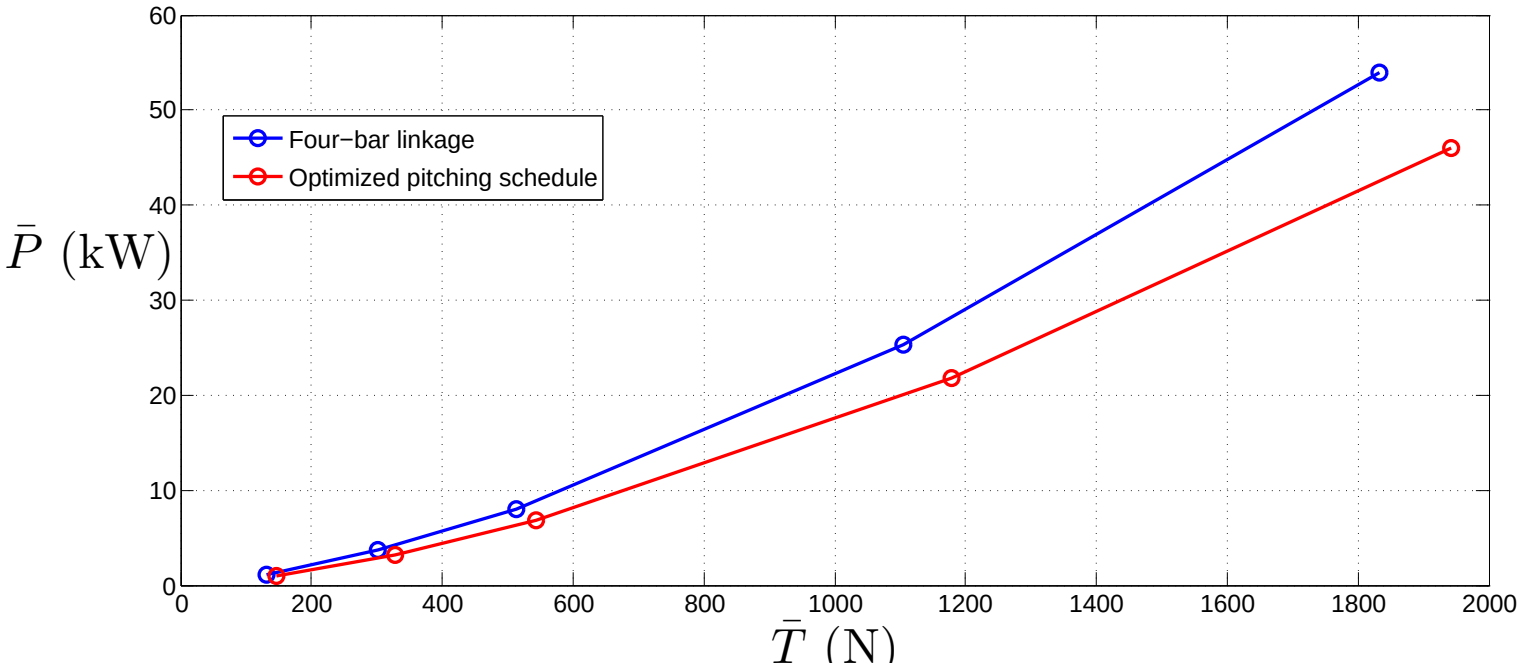
Comparison between experimental data and CFD in terms of $\bar{P}$ and $\bar{T}_x$

CFD: results II



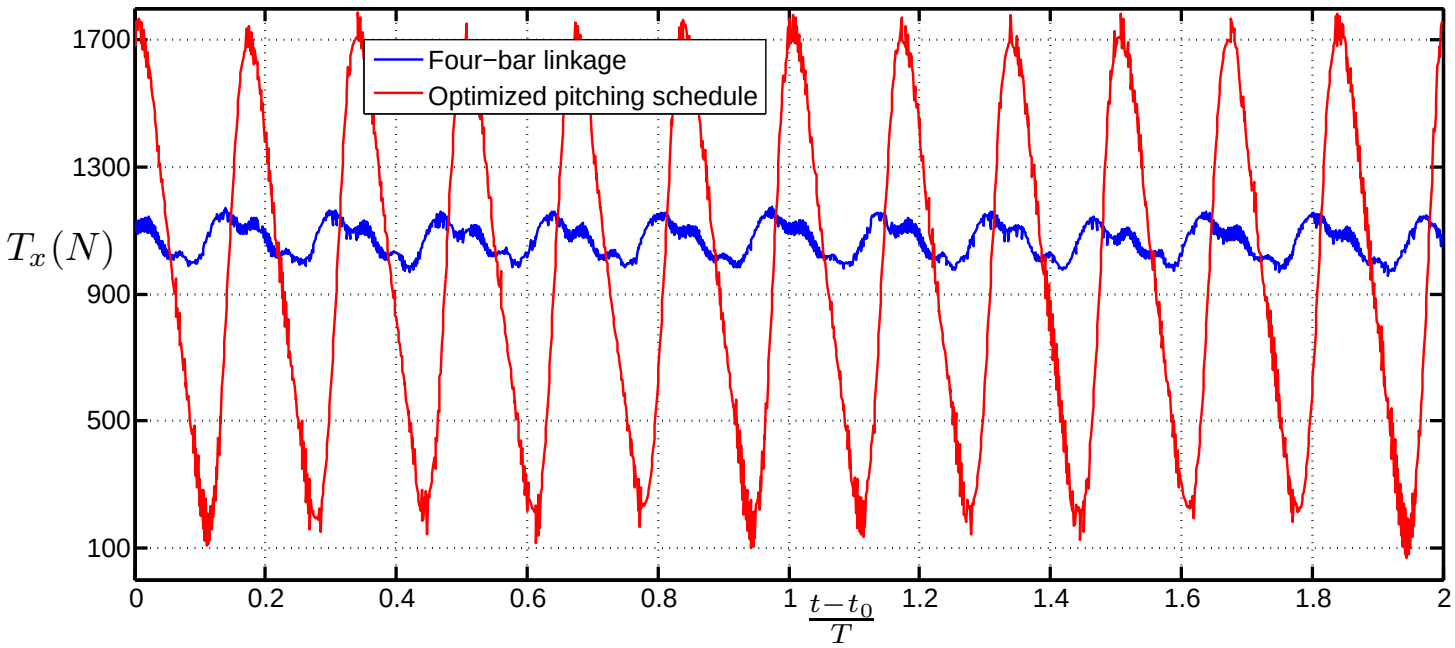
Comparison between pitching schedules in terms of $\bar{T}$ vs. Ω

CFD: results III



Comparison between pitching schedules in terms of $\bar{P}$ vs. $\bar{T}$

CFD: results IV



Time series of T_x for the case $\Omega \approx 715$ rpm

Concluding remarks

- We defined the analytical problem of the optimization of the pitching profile for a blade in a cyclorotor
- We developed and employed a simplified kinematic and dynamic model of the cyclorotor
- We derived an expression for the optimal pitching profile and found the related optimal rotational speeds for a real-world case
- By means of CFD we investigated the behaviour of the optimal pitching schedule vs. the standard four-bar linkage
- Results confirm an increase in efficiency, but suggest that the (actually sinusoidal) optimal schedule implies greater oscillations in thrust delivery, hence a greater risk of structural instability

SEVENTH FRAMEWORK PROGRAMME

European Commission

CROP

CYCLOIDAL ROTOR OPTIMIZED FOR PROPULSION

4th EASN Association International Workshop on Flight Physics and Aircraft Design

29th of October, 2014

Aerodynamic optimization of cyclorotor

A. Gerlach, Grob Aircraft AG
Proprietary Information
CROP || FP7-AAT-2012-RTD-L0 || GA no: 323047

CYCLOIDAL ROTOR OPTIMIZED FOR PROPULSION

Project consortium:

UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

GROB AIRCRAFT

UNIVERSIDADE DA BEIRA INTERIOR

The University Of Sheffield.

IAT 21 Innovative Aerodynamic Technologies

POLITECNICO DI MILANO

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SEVENTH FRAMEWORK PROGRAMME

European Commission

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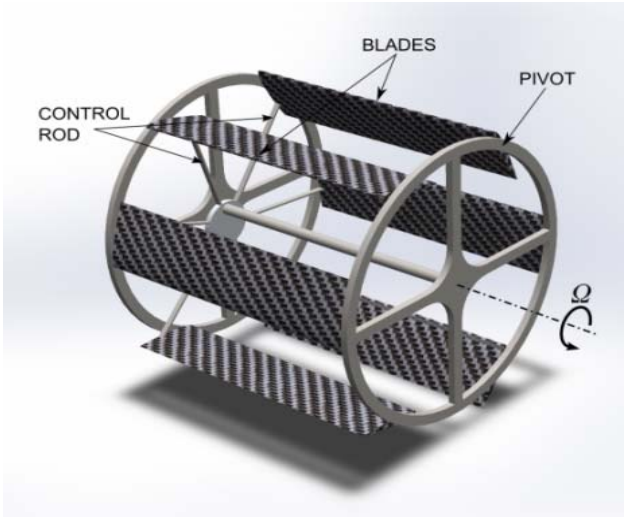
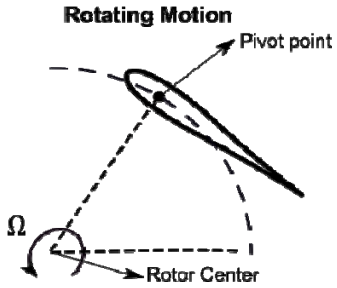
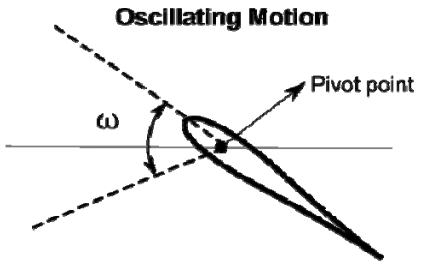
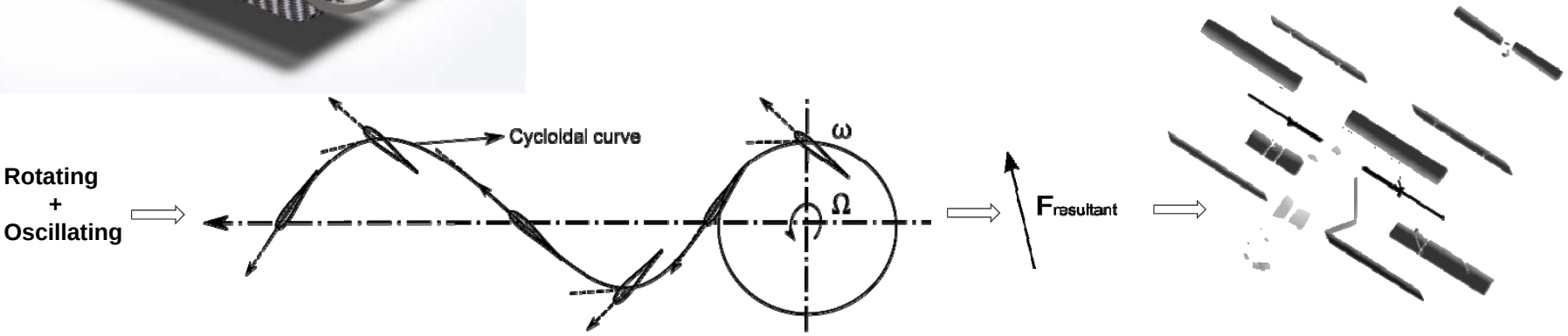
Concept



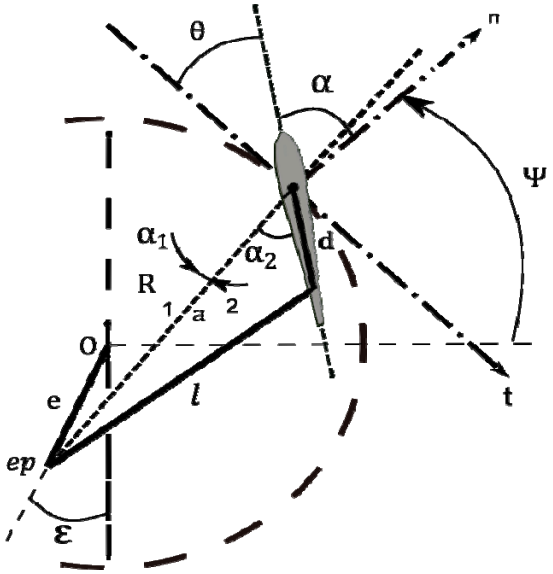






- VTOL, Forward and Backward motions, Hover: UAV, Airships, Aircrafts, etc

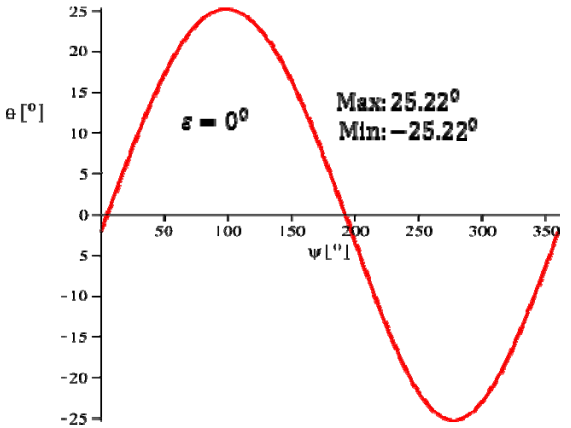
Motion: Blade pitch angle



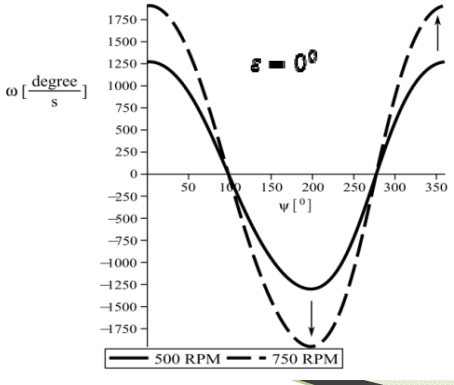
$$\theta = \frac{\pi}{2} - \sin^{-1}\left[\frac{e}{a}\cos(\Psi+\varepsilon)\right] - \cos^{-1}\left[\frac{(a^2+d^2-l^2)}{2ad}\right], \quad a^2 = e^2 + R^2 - 2eR\cos\left(\Psi+\varepsilon+\frac{\pi}{2}\right)$$

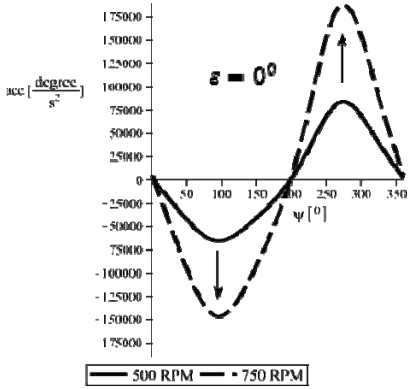
$$\Psi_i(0) = \Psi_1(0) + \frac{(i-1)2\pi}{N}$$

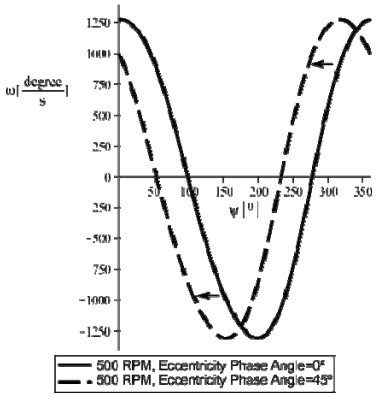
Variable	Value
Rotor Diameter (m)	1.2
Chord (m)	0.4
Length of Control Rod (m)	0.6055
Magnitude of Eccentricity (m)	0.038
d (m)	0.09

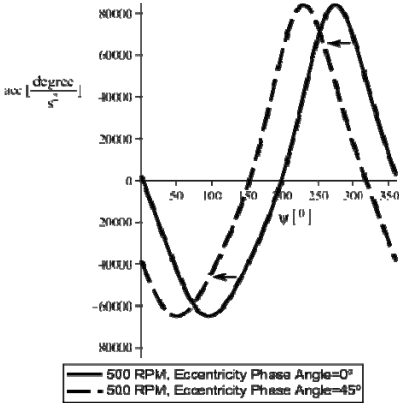


Angular velocity and angular acceleration: $\omega = \frac{d\theta}{dt} = \frac{d\theta}{d\Psi} \cdot \Omega, \quad acc = \Omega^2 \cdot \frac{d^2\theta}{d\Psi^2}$



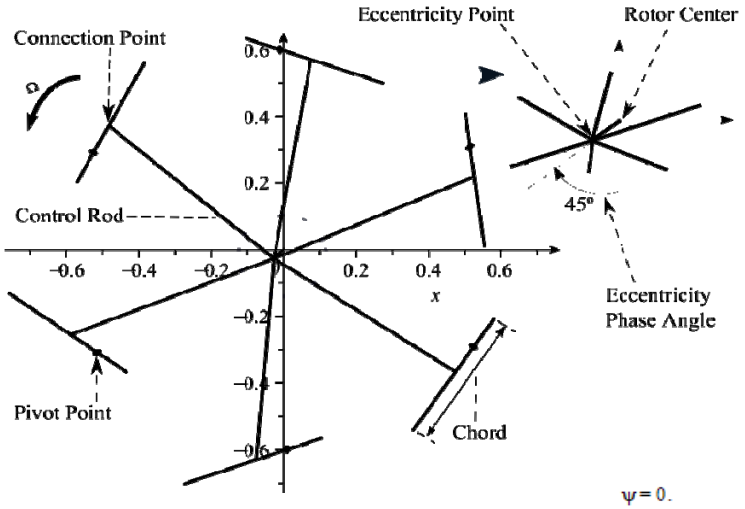






Optimization: Considerations

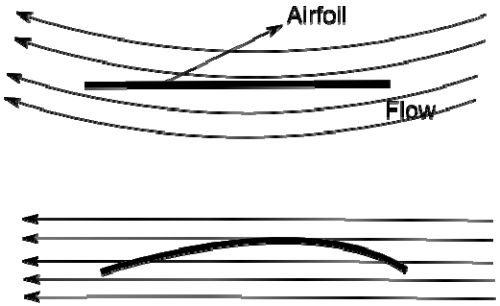
Variable	Value
Airfoil	NACA 0012
Rotor Diameter (m)	1.2
Span (m)	1.2
Chord (m)	0.4
Number of Blade	6
Length of Control Rod (m)	0.6055
Magnitude of Eccentricity (m)	0.038
d (m)	0.09
Maximum and Minimum Pitch Angle (degree)	25.2; -25.2

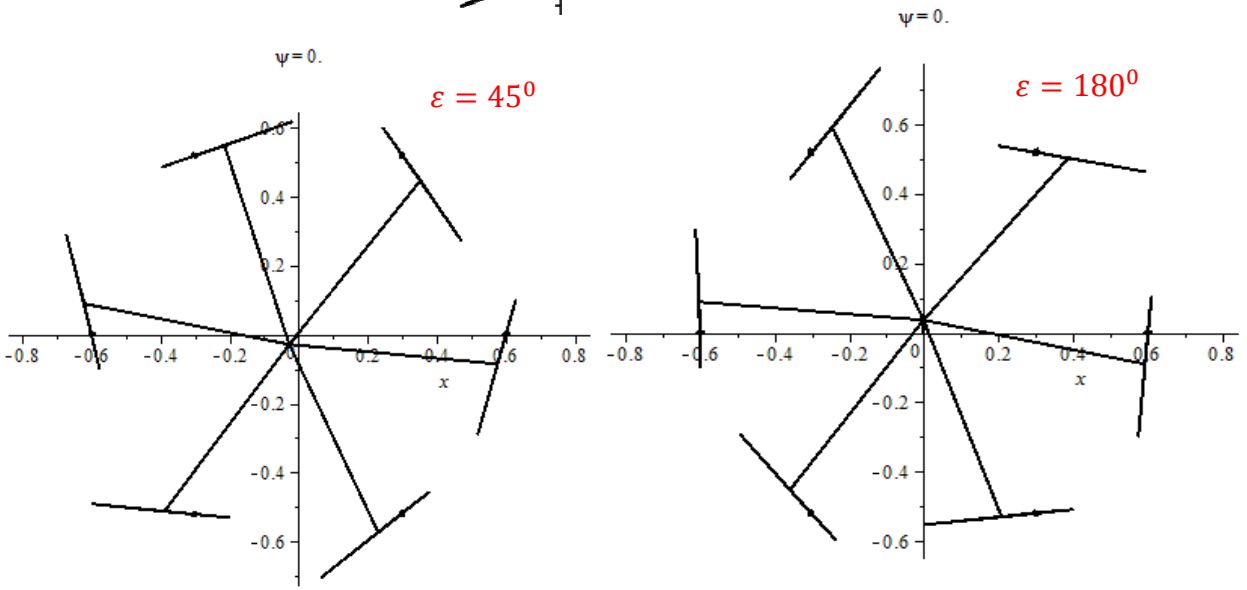


$^{c}/_{R}, \theta, R, c, \Omega, \mathrm{N}, C_{L\alpha 3D}$

- Interference effects

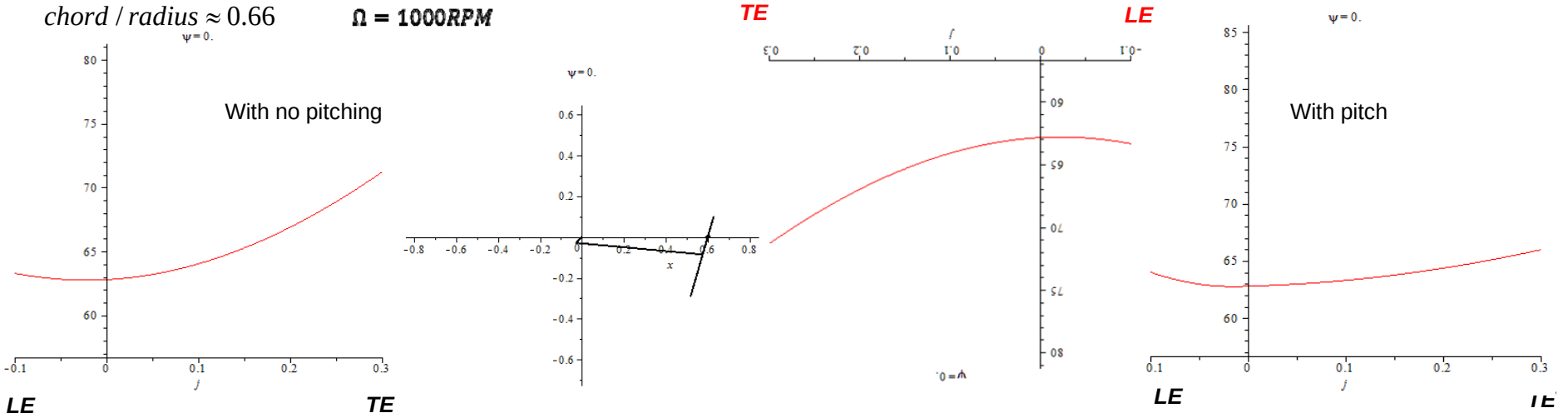
- Virtual camber in a curvilinear flow



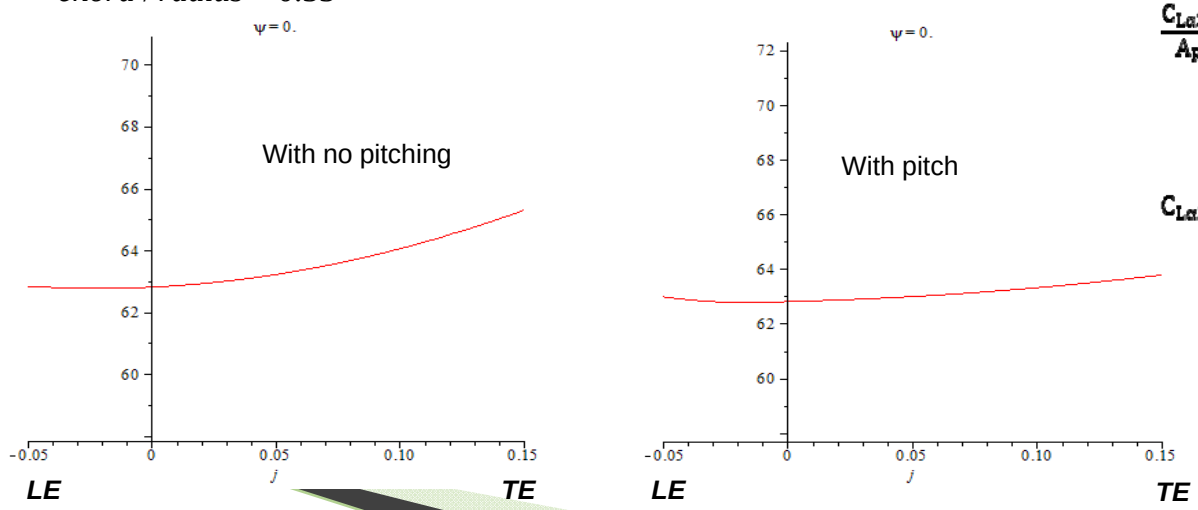


3-D Lift curve slope considerations: Velocity profile [m/s].

chord / radius ≈ 0.66 **Ω = 1000RPM**

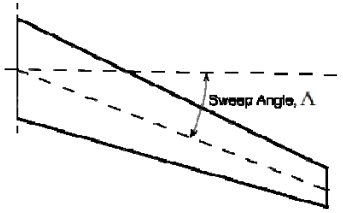


chord / radius ≈ 0.33

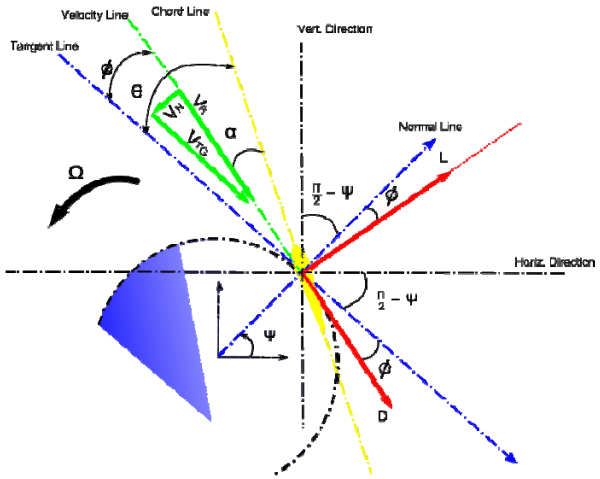


$$\frac{C_{L\alpha 3D}}{A_R} = \frac{2\pi}{2 + \sqrt{\frac{4\pi^2 A_R^2}{C_{l\alpha}^2}\left(1 + \frac{\tan^2(\Lambda)}{\beta^2}\right) + 4}}, \qquad \beta = \sqrt{1 - Mach}$$

$$C_{L\alpha 3D} = \frac{2\pi A_R}{2 + \sqrt{\frac{A_R^2 4\pi^2}{C_{l\alpha}^2} + 4}}$$



The Equivalent Rotor Model for Parametric Design of Cycloidal Rotors



$$F_Z = L\sin(\Psi - \phi) - D\cos(\psi - \phi)$$
$$F_X = L\cos(\Psi - \phi) + D\sin(\psi - \phi)$$

Unsteady aerodynamics ➔ Garrick model to take into account the effect of the blade oscillation:

$$\frac{L}{S} = \rho b^2 (V_R \pi\omega - \pi b \text{acc}) + C_{La3D}\rho V_R bF\left[V_R(\theta+\phi) + b\left(\frac{1}{2} - I\right)\omega\right] + \frac{C_{La3D}\rho V_R bG}{\Omega}\left[V_R\omega + b\left(\frac{1}{2} - I\right)\text{acc}\right]$$

Equivalent Rotor: rotor in Steday condition without induced downwash angle:

Unsteady with induced downwash angle ➔ **Equivalent Rotor: Steady with no induced downwash angle**

➔ Assumption:

The fluid is deflected vertically downward at a velocity lower than ΩR

$$\phi = \Psi, \qquad V_R = \frac{\Omega R}{E}, E > 1$$

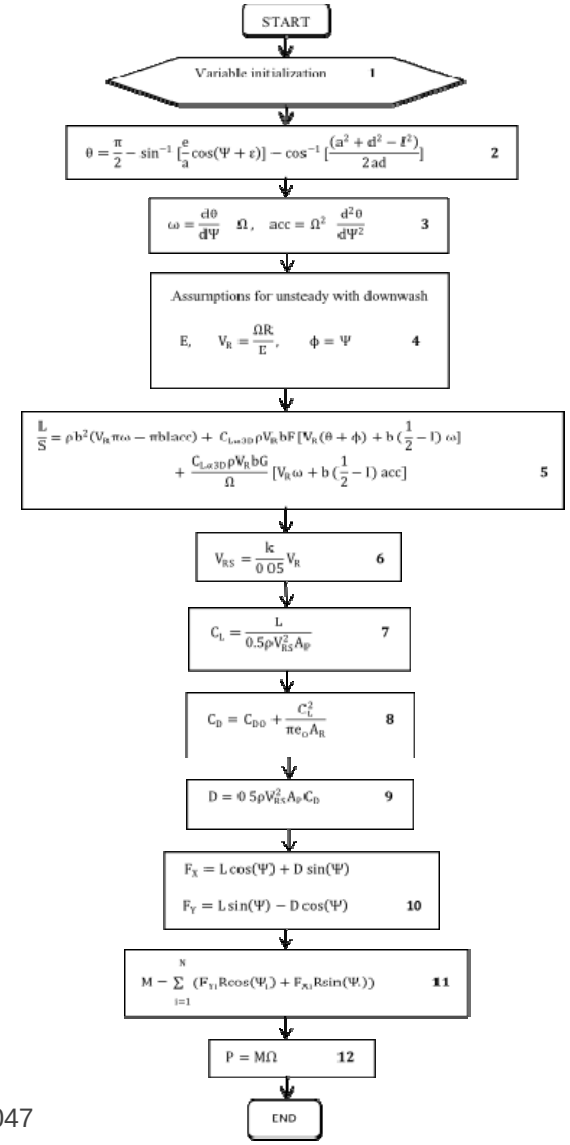
First attempt for E through experimental datas from Bosch, $E = 1.864\left[\frac{34}{\text{NCRS}\theta_{75}}\right]^{-0.187}$

$$k = \frac{c}{2R} <= 0.05$$ (the unsteady effects may be neglected)

$$V_{RS} = \frac{k}{0.05}V_R \quad ,\phi = 0$$

$$F_X = L\cos(\Psi) + D\sin(\Psi),$$
$$F_Y = L\sin(\Psi) - D\cos(\Psi)$$
$$M = \sum_{i=1}^{N}\left(F_{Yi}R\cos(\Psi_i) + F_{Xi}R\sin(\Psi_i)\right),$$
$$P = M\Omega.$$

Flowchart


START
Variable initialization 1
$\theta = \frac{\pi}{2} - \sin^{-1}\left[\frac{e}{a}\cos(\Psi + \varepsilon)\right] - \cos^{-1}\left[\frac{(a^2 + d^2 - l^2)}{2ad}\right]$ 2
$\omega = \frac{d\theta}{d\Psi}\ \Omega, \quad acc = \Omega^2\ \frac{d^2\theta}{d\Psi^2}$ 3
Assumptions for unsteady with downwash
E, $V_R = \frac{\Omega R}{E}, \quad \phi = \Psi$ 4
$\frac{L}{S} = \rho b^2 (V_R \pi\omega - \pi b acc) + C_{L\alpha 3D}\rho V_R bF\left[V_R(\theta + \phi) + b\left(\frac{1}{2} - l\right)\omega\right] + \frac{C_{L\alpha 3D}\rho V_R bG}{\Omega}\left[V_R\omega + b\left(\frac{1}{2} - l\right)acc\right]$ 5
$V_{RS} = \frac{k}{0.05} V_R$ 6
$C_L = \frac{L}{0.5\rho V_{RS}^2 A_p}$ 7
$C_D = C_{D0} + \frac{C_L^2}{\pi e_0 A_R}$ 8
$D = 0.5\rho V_{RS}^2 A_p C_D$ 9
$F_X = L\cos(\Psi) + D\sin(\Psi)$
$F_Y = L\sin(\Psi) - D\cos(\Psi)$ 10
$M - \sum_{i=1}^{N}(F_{Yi}R\cos(\Psi_i) + F_{Xi}R\sin(\Psi_i))$ 11
$P = M\Omega$ 12
END

Rotor Parameters

a) Bosch rotor

Variable	Value
Airfoil	NACA 0012
Rotor Diameter (m)	1.2192
Span (m)	1.2192
Chord (m)	0.3048
Pitching Axis Location (m)	37.5% of chord
Number of Blade	6
Length of Control Rod (m)	0.6134
Magnitude of Eccentricity (m)	0.0315
Phase Angle of Eccentricity (degree)	0
d (m)	0.075
Maximum and Minimum Pitch Angle (degree)	25; -25

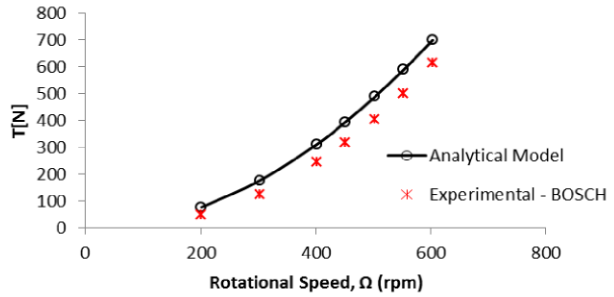
b) Seoul National University rotor

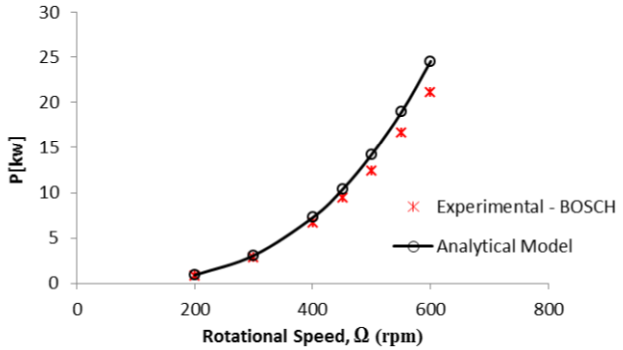
Variable	Value
Airfoil	NACA 0012
Rotor Diameter (m)	0.8
Span (m)	0.8
Chord (m)	0.15
Pitching Axis Location (m)	25% of chord
Number of Blade	2
Length of Control Rod (m)	0.4023
Magnitude of Eccentricity (m)	0.05R
Phase Angle of Eccentricity (degree)	10
d (m)	0.0475
Maximum and Minimum Pitch Angle (degree)	25; -25

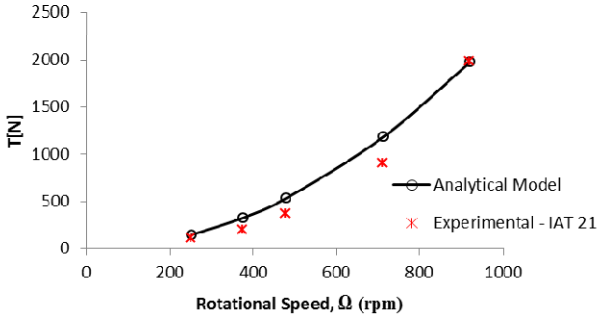
c) IAT21 rotor

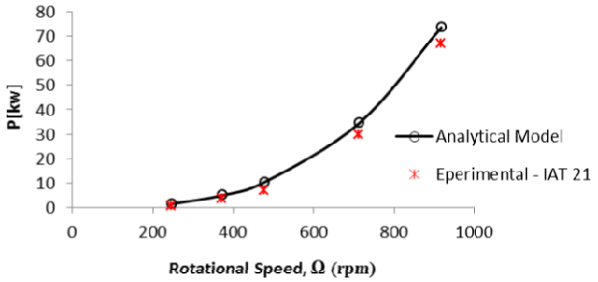
Variable	Value
Airfoil	NACA 0016
Rotor Diameter (m)	1.2
Span (m)	1.2
Chord (m)	0.3
Pitching Axis Location (m)	35% of chord
Number of Blade	6
Length of Control Rod (m)	0.61
Magnitude of Eccentricity (m)	0.072
Phase Angle of Eccentricity (degree)	0
d (m)	0.12
Maximum and Minimum Pitch Angle (degree)	36.1; -39.1

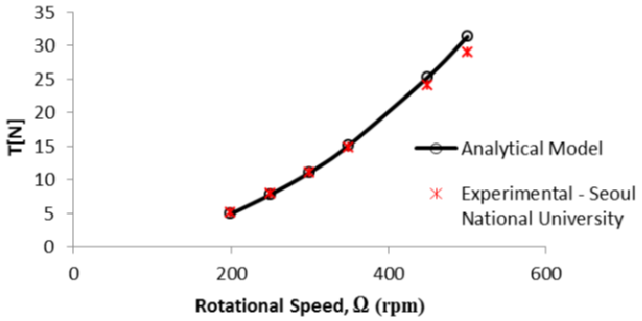
Results

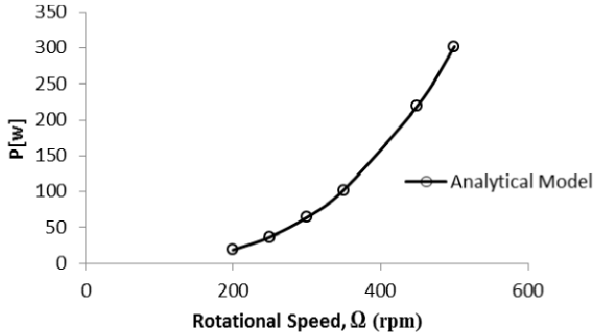

T[N]
Analytical Model
Experimental - BOSCH
Rotational Speed, Ω (rpm)


P[kw]
Experimental - BOSCH
Analytical Model
Rotational Speed, Ω (rpm)

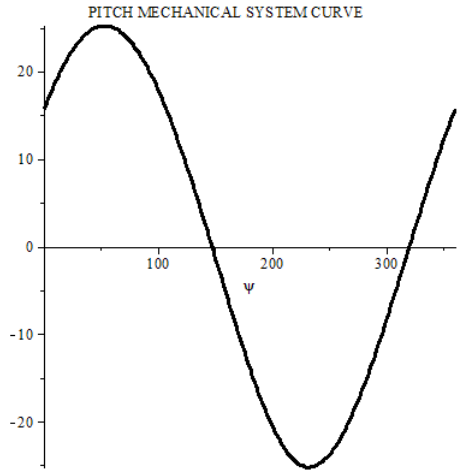

T[N]
Analytical Model
Experimental - IAT 21
Rotational Speed, Ω (rpm)

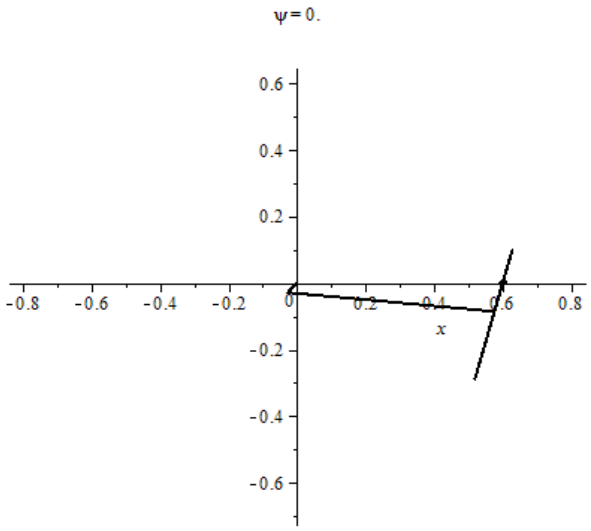

P[kw]
Analytical Model
Eperimental - IAT 21
Rotational Speed, Ω (rpm)

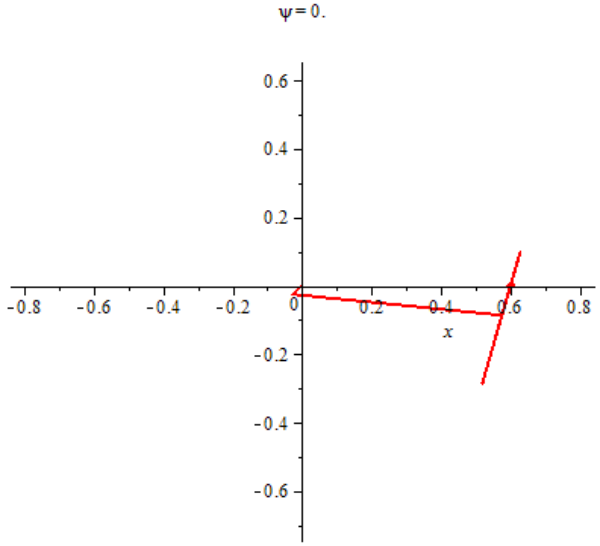

T[N]
Analytical Model
Experimental - Seoul National University
Rotational Speed, Ω (rpm)


P[w]
Analytical Model
Rotational Speed, Ω (rpm)

Optimization: Considerations







ACKNOWLEDGEMENT
The present work was supported by European Project CROP (Cycloidal Rotor Optimized for Propulsion), Grant No. 323047**.**

Thank you for your attention

光
HIKARI

High Speed Key Technologies for future Air Transport
Research and Innovation Cooperation Scheme

HIKARI:
Joining Efforts to Pave the Way towards High Speed Transport

Emmanuel Blanvillain, Airbus Group Innovations

EASN Workshop on Flight Physics and Aircraft Design - 29.10.2014
Aachen, Germany

AIRBUS
GROUP

Agenda:

- Background and Objectives
- Project Organization and Timeline
- Project Progress
  - Market Analysis
  - Vehicle Panorama, Design Guidelines and Roadmaps

BACKGROUND AND OBJECTIVES

History and Background

HIKARI

- Short history of hypersonics and cooperation with Japan
  - French-Japan Frame agreement on Cooperation on Supersonic Technologies SST - GIFAS / METI
  - DGAC Contract - ZEHST
  - FP6, FP7 projects ATLLAS, LAPCAT, FAST20XX
  - Aircraft design studies by JADC
  - JAXA programs - HYTEX, DSEND

Logical next step: **Broader cooperation**

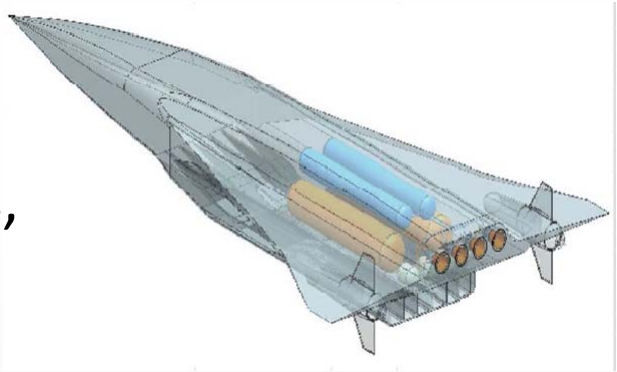
- Context: Europe-Japan cooperation on aeronautics in the frame of FP7 Call 5
  - Topic AAT.2012.6.1-5.
    Enhancing cooperation with Japan
    in the field of high speed aircraft
  - Collaborative project

SEVENTH FRAMEWORK PROGRAMME

METI

Project Objective

- Build on momentum and dynamics from projects dedicated to high transport in Europe and Japan



- Bring together the previous concepts, exchange, benchmark and understand
- Make visions converge
- Build joint design guidelines and roadmaps for technology and demonstrators

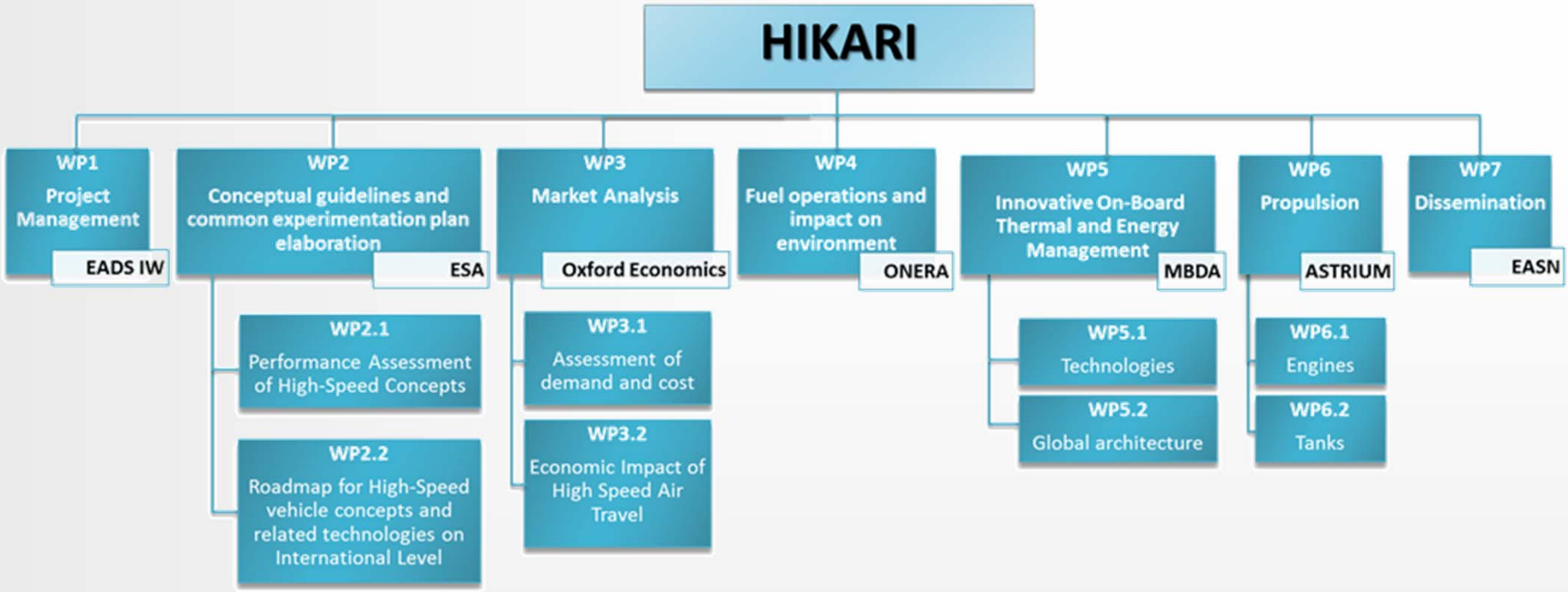
- Perform technology studies in key areas

PROJECT ORGANIZATION

Partners

Coordinator

Work Breakdown Structure



Timeline

- Duration : 2 years
  - Start: February 1st, 2013
  - End: January 31st, 2015

- Key Milestones

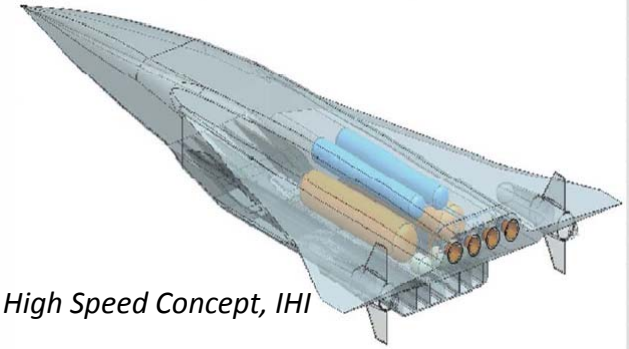
– Workshop 1 :	Leiden, NL	Sept 2013	Design Methods
– Workshop 2 :	Tokyo, JP	March 2014	Technologies
– Workshop 3:	Brussels, BE	Sept 2014	Roadmaps

PROJECT PROGRESS

Vehicle Panorama

MR2, LAPCAT, ESA

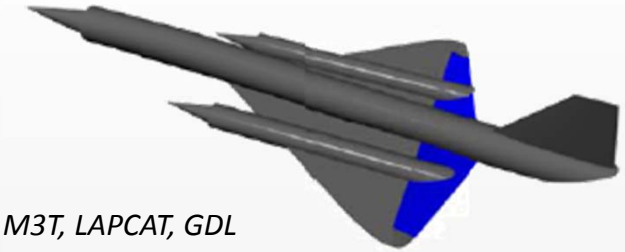
ZEHST, Airbus Group



High Speed Concept, IHI

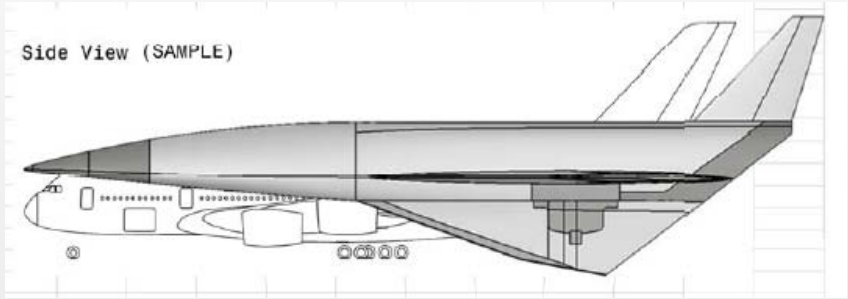
A2, LAPCAT, REL

Spaceliner, DLR



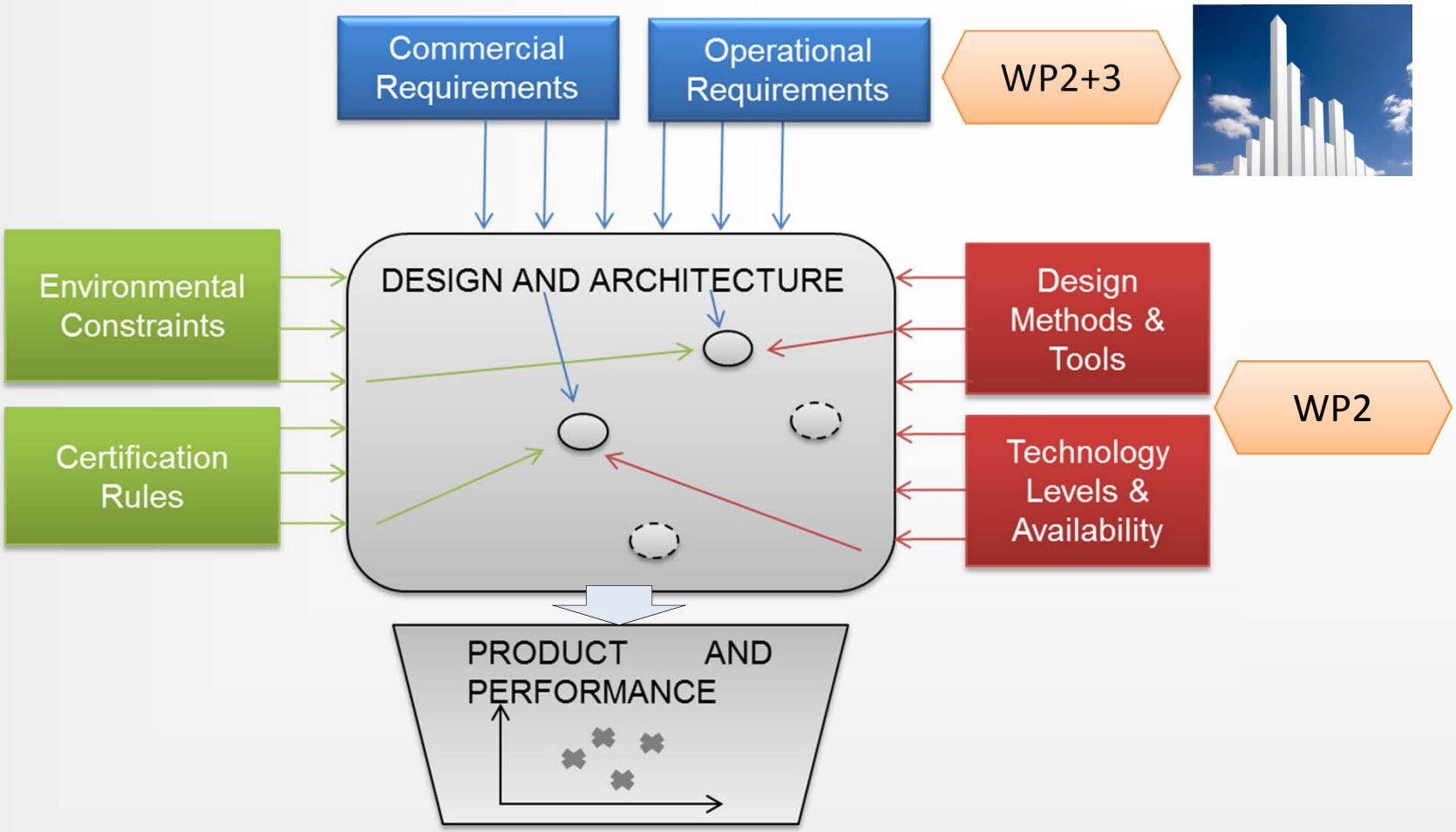
M3T, LAPCAT, GDL

JAXA HST, JAXA



M8, LAPCAT, ONERA

Progress


Commercial Requirements
Operational Requirements
WP2+3
Environmental Constraints
Certification Rules
DESIGN AND ARCHITECTURE
Design Methods & Tools
Technology Levels & Availability
WP2
PRODUCT AND PERFORMANCE

Market Analysis : Routes and Traffic

by JADC & Airbus

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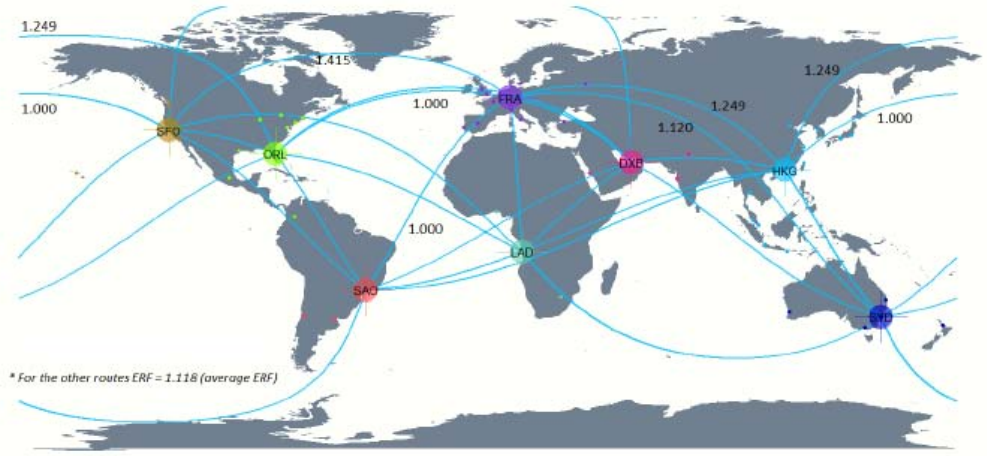
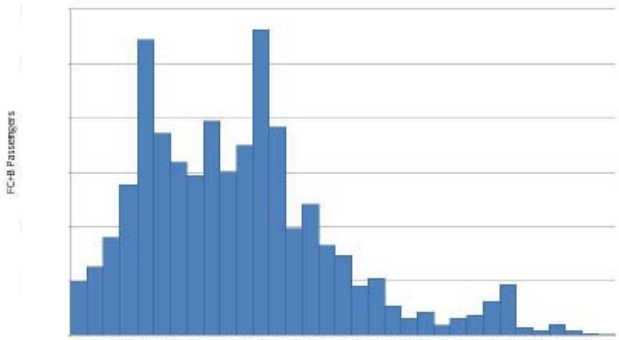
Commercial Requirements
(Market and Operations)

Figure 19 : Traffic flows, city centres in each traffic region and ERFs



Source: Airbus.

Figure 9 : FC+B passenger distribution by distance (in km), 2032



Source: Airbus GMF 2013.

Market Analysis: Demand and Offer : Fleet size

by JADC & Airbus

HIKARI

Commercial Requirements
(Market and Operations)

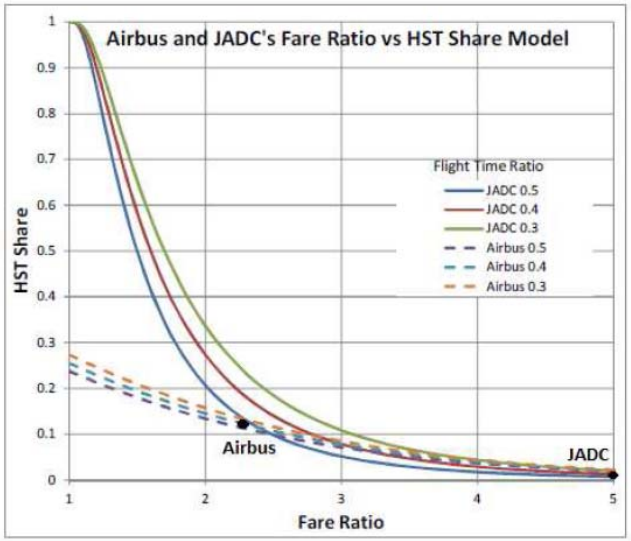
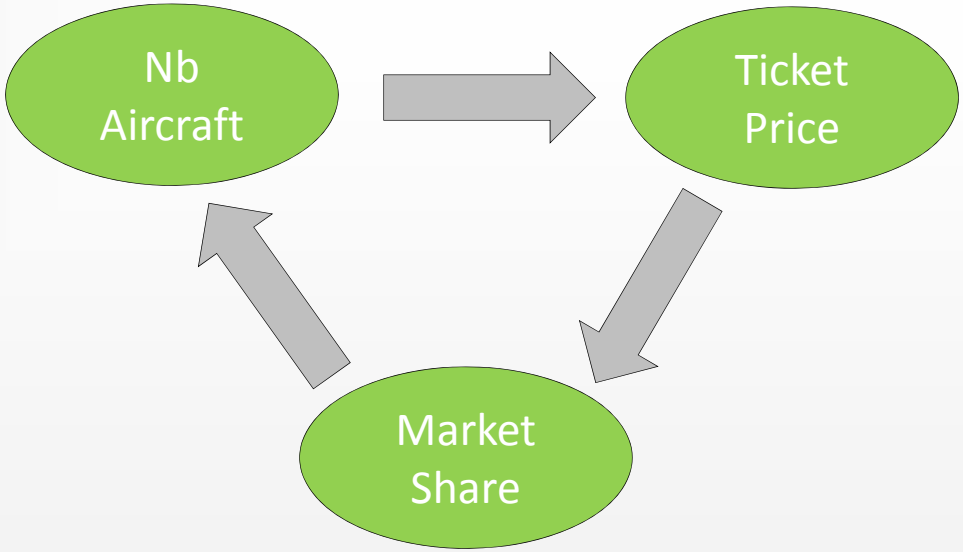


Figure WP3.38: Preliminary outcome for HS market share from JADC and Airbus modelling



Design Methodology & Concept Maturity

by ESA-ESTEC

HIKARI

Design Methods and Assumptions

- *WP2 analysed the various disciplines involved in High-speed Vehicle design, and their level of maturity on the ongoing concepts*
- *Specifically, WP2 studied the assumptions and methods used for trajectory computations and mass estimations. (WS1-ESA-DLR)*

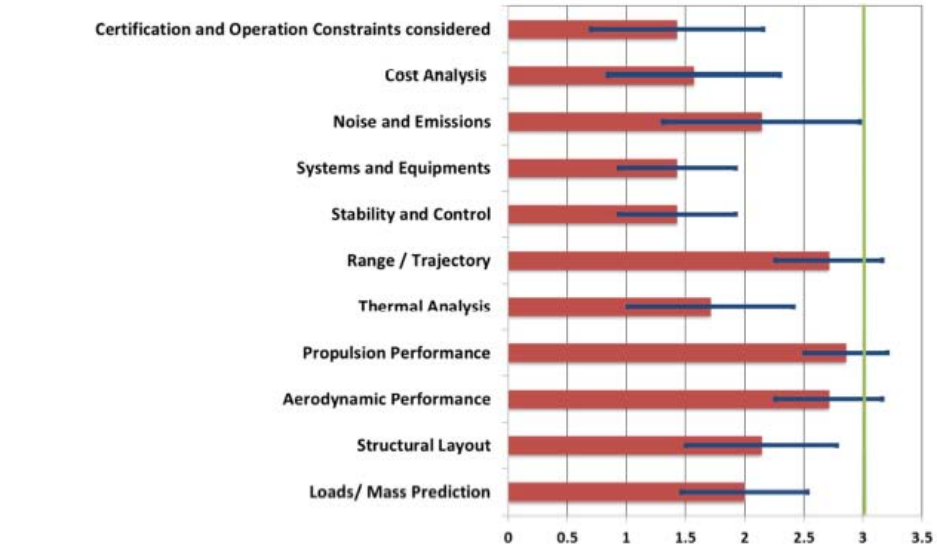
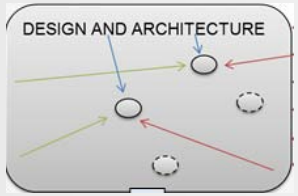
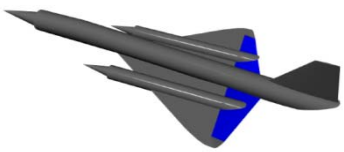
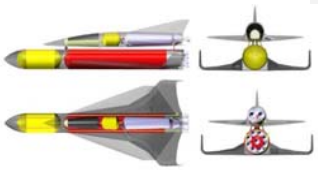


Figure WP2.20: Assessment of the design maturity of the concepts studied

Vehicle Panorama Analysis

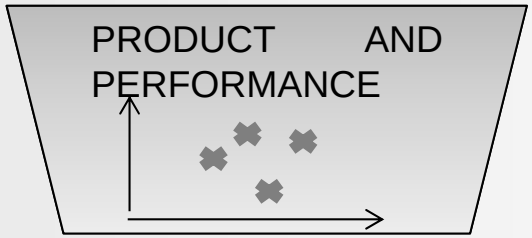


Technical Clusters

Mach	3 – 4/5	4/5 – 8	10 -25
Fuel	Storable / Kerosene	Cryogenic / LH2 (or LCH4)	LH2 + LOx
Trajectory	H-TO / Cruiser	H-TO / Cruiser	V-TO Sub-orbital
Propulsion	Air-breathing: Turbo - Ramjet	Air-breathing: Turbo-(Sc)ramjet	O.B. oxidizer: Rocket Engine
Clusters			

Vehicle Panorama Analysis

by ESA-ESTEC



- *WP2 analyzed the key design variables of each vehicles to compare them and understand the rationale behind each design decisions and their impact on performance and maturity.*

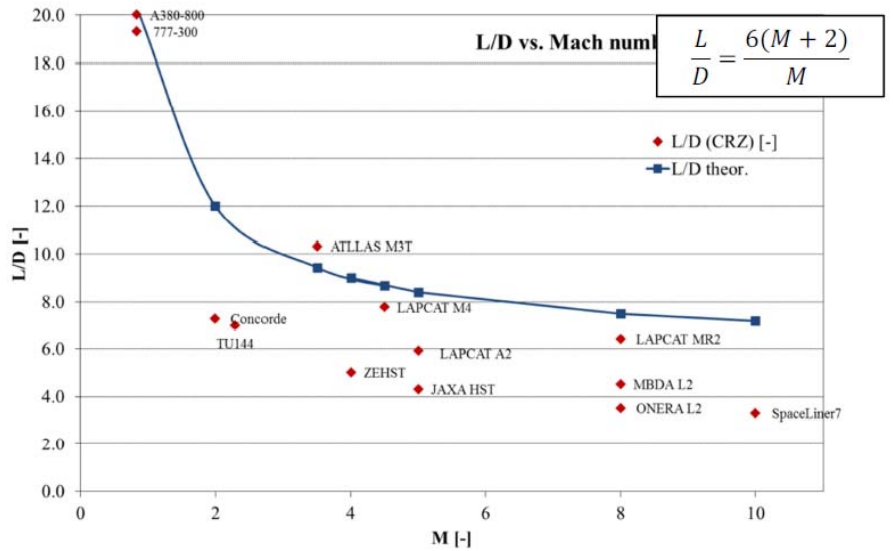


Figure WP2.22: Aerodynamic efficiency vs. the flight Mach number

Design Guidelines and Roadmaps

Fully understand

- *Key design levers and sensitivities*

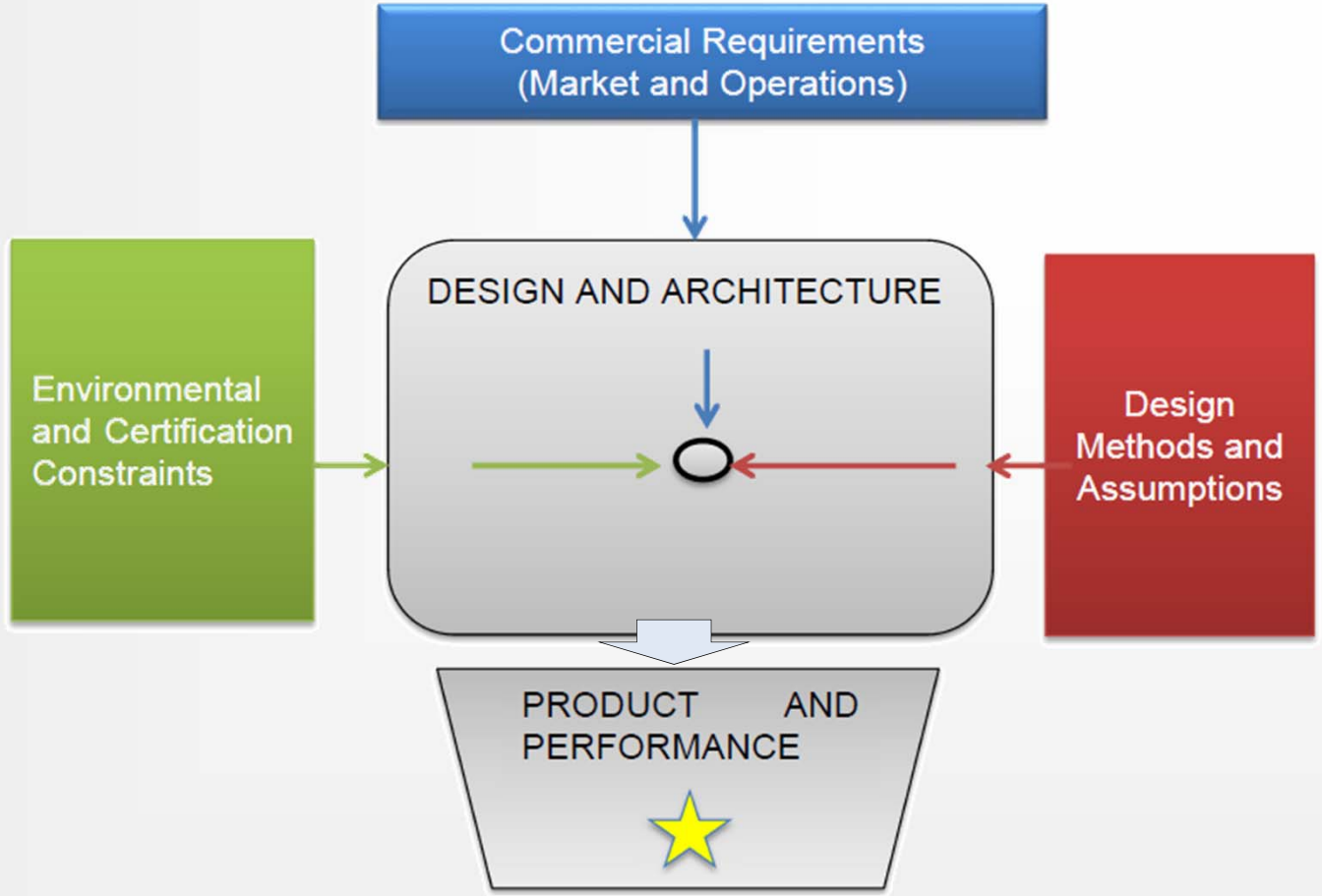
Progress towards

- *Converged market requirements*
- *Converged environment and certification constraints*
- *Shared and agreed design methodologies*

Make Joint Recommendations on:

- *Key design decisions and methods towards the **best realistic vehicle lay out***
- *Joint roadmaps for technology and ultimately vehicle demonstrations*

Towards a converged view: Guidelines and Roadmaps



Commercial Requirements - RANGE

Example

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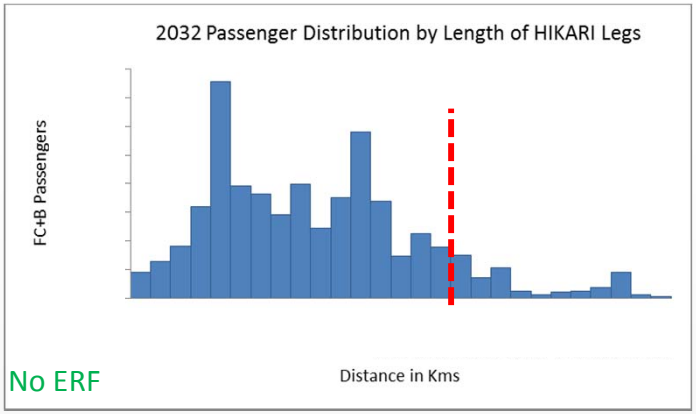
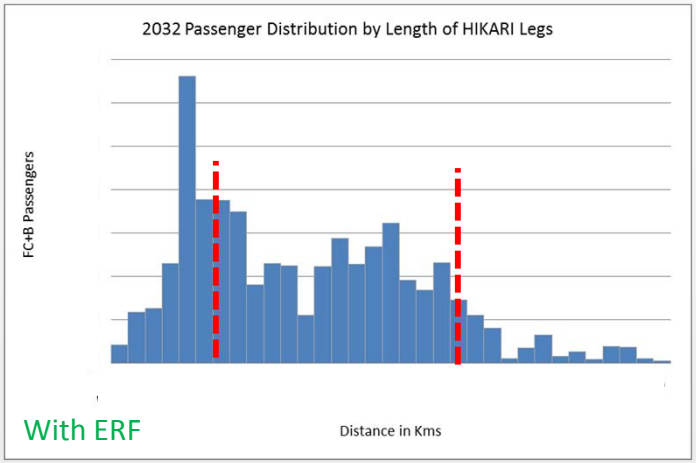
- High is Good for: Market Capture
- Low is Good for: Performance
  (Breguet equation → exponential growth of the weight with Range)
- Objective: minimize down to an acceptable market capture (90% for instance)
- Recommended Value:

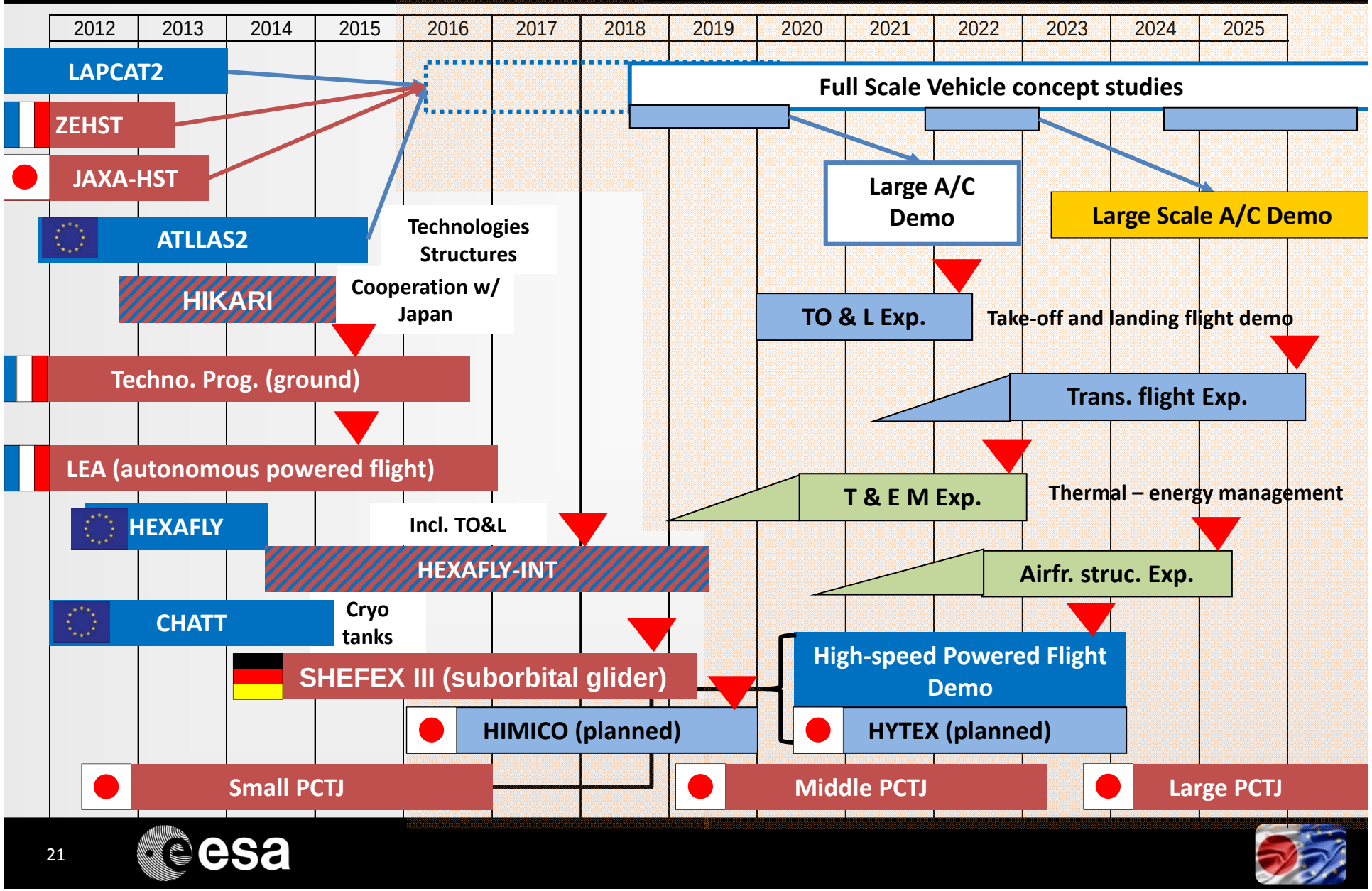
WORK IN PROGRESS
Values not finalized

- Justification :
  Capture 90% of 2032 passengers
- Source:
  Airbus WP3





EU and Japanese high-level Roadmap



Recommendations on the Way Forward

- Agree on **unified design tool** to perform quantified **trade off studies** (speed, acceleration, altitude etc …)
- Progress towards **a joint design** following the **HIKARI Guidelines**, with collaborative design team
- Develop **critical technologies** identified in the **HIKARI roadmap** (Thermal management, tanks, noise and sonic boom…)
- Progress on **regulation aspects** (certification incl. environmental aspects)
- Proceed with **Joint demonstrators** following the **HIKARI roadmap**

More about HIKARI in the Project Final Report : early 2015

Thank You !

Any question

http://www.hikari-project.eu

Thank you!

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Energy management activities and overall technical excellence in the frame of HIKARI

4th EASN Workshop on Flight Physics and Aircraft Design

S. Balland (MBDA)

Aachen – 29/10/2014

MBDA MISSILE SYSTEMS

Technology Bricks

WP4
Fuel Operations and Impact on Environment

WP5.1
Innovative On-Board Thermal and Energy Management
Technologies

WP5.2
Innovative On-Board Thermal and Energy Management
Global Architecture

WP6.1
Propulsion
Engines

WP6.2
Propulsion
Tanks

Technology Bricks

WP4
Fuel Operations and Impact on Environment

Lead: ONERA

Involved partners: Airbus Group Innovations, DLR, CNRS, JAXA, UTokyo

WP5.1
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Tanks

WP4 – Fuel Operations and Impact on Environment

Environment impact of fuel on ground process

- Identify the fuels: LH2, LCH4, liquid biofuel

- Analyze the global cycle (products & energy):
  - Production
  - Distribution
  - Storage

⇒ AIM: assessing a global environmental impact of the different fuels
(*data collected from European, national and Japanese projects)*

Impact of emission of hypersonic aircraft on atmosphere and climate

- Identify mission scenarios

- Evaluate the impact of aircraft emissions on climate and atmosphere

- Evaluate consequence on water vapor emissions and elimination process

- Estimate the conventional air traffic which would have the same long-term impact

-Establish a chemical analysis model for exhaust gas of H_2 jet engines
=> subscale experiment + CFD

Technology Bricks

WP4
Fuel Operations and Impact on Environment

WP5.1
Innovative On-Board Thermal and Energy Management
Technologies

WP5.2
Innovative On-Board Thermal and Energy Management
Global Architecture

Lead: MBDA
Involved partners: ESA-ESTEC

WP6.1
Propulsion
Engines

WP6.2
Propulsion
Tanks

WP5 – Energy management: OBJECTIVES

- To deal with high heat fluxes:
  - Over the fuselage
  - Inside the propulsion system

- To provide the right environment for the cabin

- To cool-down the on-board equipment

- To supply power for all energy consumers on board

  ⇒ DMR cannot provide mechanical or electrical power

  ⇒ Needed electrical power: ~1MW. It can only absorb a part of the heat.

WP5 – Energy management: ORGANIZATION

- WP5.1 – TECHNOLOGIES

  - Task 5.1.1 – Thermal to electrical energy converters
  - Task 5.1.2 – Use of the fuel to cool the airframe and cabin

Which technologies? Fuel cells, innovative materials, etc.

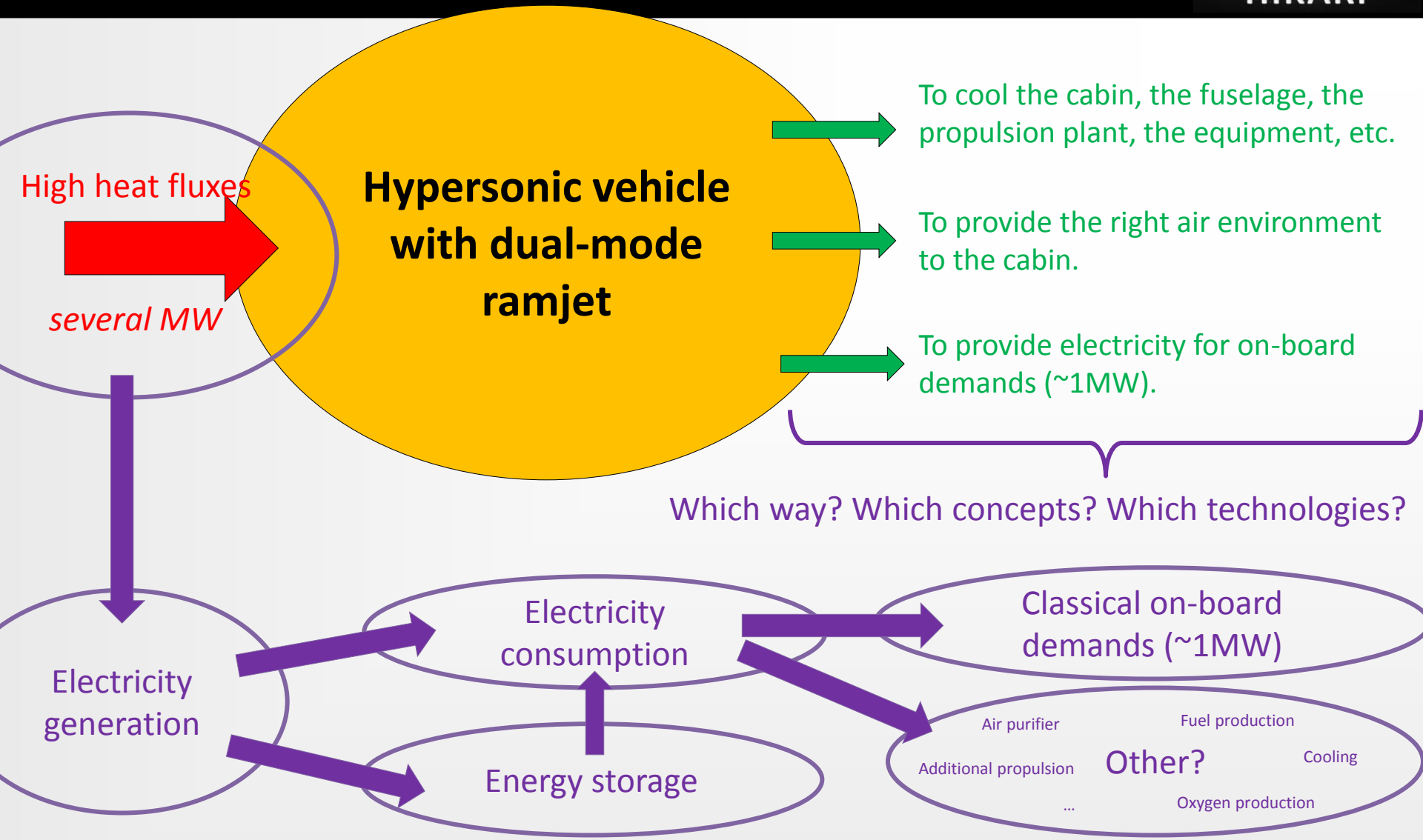
Which cycles? Which coolant medium, open or close loop, etc.?

- WP5.2 – GLOBAL ARCHITECTURE

How to simulate and optimize the system?

Which models for each components?

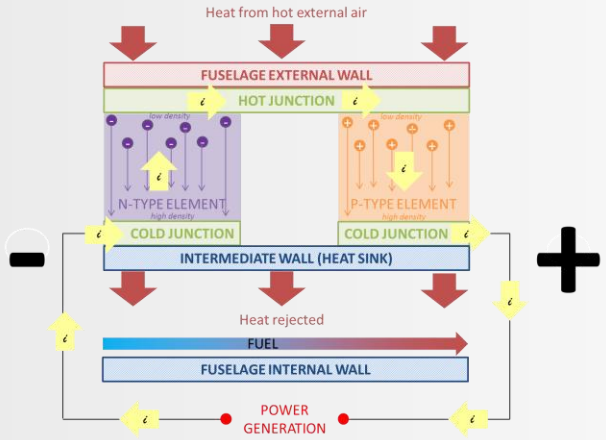
WP5 – Energy management: TECHNOLOGIES



WP5 – Energy management: TECHNOLOGIES

	ELECTRICITY			PROPULSION		COOLING	
	Production	Storage	Consumption	Additional propulsion	Fuel production	Cooling walls	Oxygen production
Thermo-electricity generator (Seebeck)	X						
Thermoelectricity cooling system (Peltier)			X			X	
Water electrolysis			X		X		X
Water electrolysis propulsion			X	X			
Water thermal decomposition					X		X
Fuel Cell		X					
Battery		X					
Unitized Regenerative Fuel Cell	X	X	X				
Electrical discharge for BL transition control			X				
Electrical discharge for additional propulsion			X	X			
Electrical discharge for air inlet flow control			X				
Boil-off compression			X		X		
Purifier for the air inside the cabin			X				(X)
Flywheel energy storage		X					

WP5 – Thermo-electricity generator



To use the difference of temperature between hot external walls and fuel cooled walls to generate electricity by thermoelectric effect.

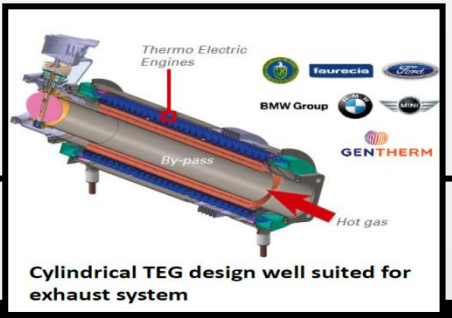
Efficiency depends on materials:
- high electric conductivity
- low thermal conductivity

Current efficiency = 5%-8% ---- Expected efficiency = 15%

PROS	CONS
reliability	efficiency
light weight	cost
small size	
no moving part	

Example of use today:
- Radioisotope thermoelectric generator for space probe, satellites etc.
- To charge cell phone during power failure

Current studies for automotive:
- 500W – 750W
- hafnium + zirconium
- Also SiGe alloys



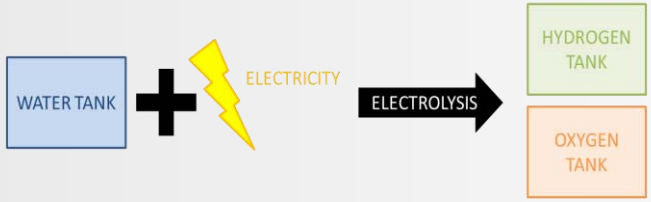
Cylindrical TEG design well suited for exhaust system

Several studies in USA.
In Europe:
- Sweden with Valeo, Siemens
- France with Valeo, Renault, Nexter

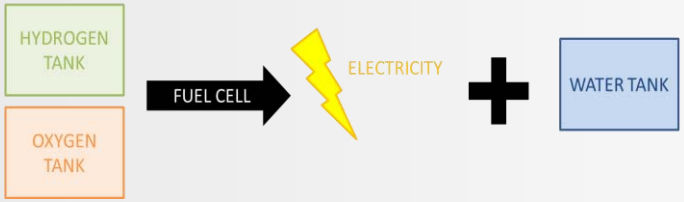
Japan: automotive project with Kelk

WP5 – Unitized Regenerative Fuel Cell

When the quantity of electricity produced is larger than needs



When the quantity of electricity produced is not enough to supply needs



When the electricity produced is larger than needs: the electricity not needed can be used to transform water into hydrogen/oxygen by electrolysis. Later, when electricity produced is not enough to supply demands, a fuel cell can use the hydrogen/oxygen previously created to produce water and electricity. The water is then stored to be later used for the electrolysis

PROS	CONS
Lighter than separated electrolyser and FC	Extrapolation feasible at large scale ?
Highest energy density compared to chemical batteries, flywheel or supercapacitors	
Long life	
No maintenance	
Good performance	

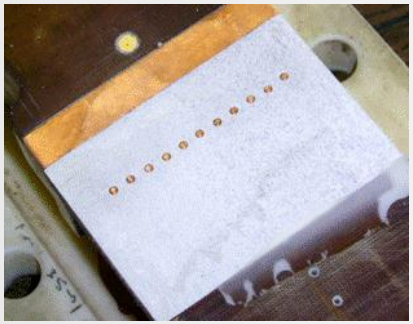
<u>Example of use today:</u>

NASA inside HELIOS (solar panel, FC and batteries)
- in 2003
- in 18,5 kW

Seems to be only at research state.

Difficulties to find current development on this topic

WP5 – Electrical discharges for flow control



To use electricity to generate electrical discharges to do aerodynamic flow control. Inside supersonic flow, electrical discharge modifies the structure of the flow by a significant supply of heat.

Example of use :

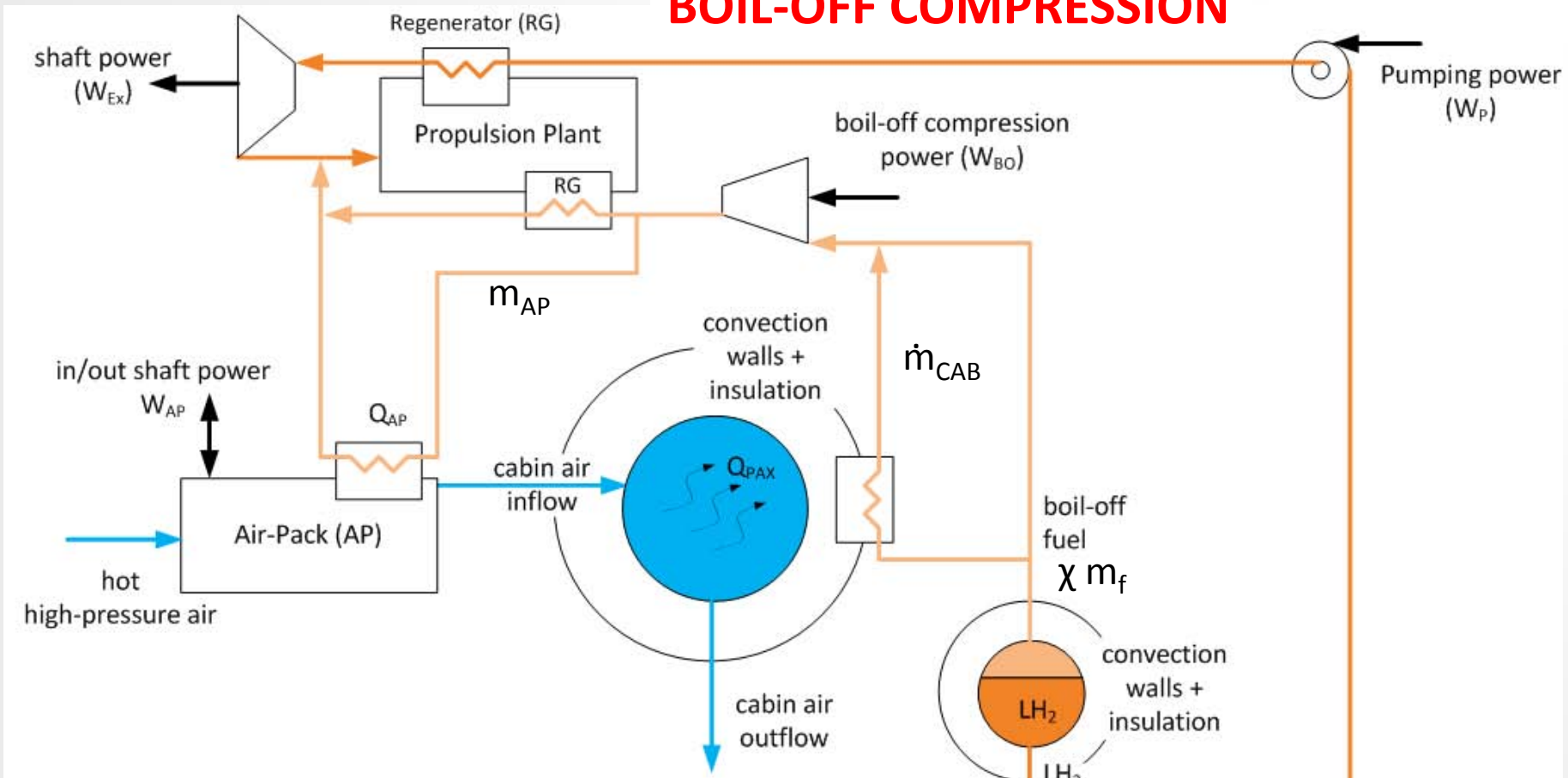
- for boundary layer transition control
- for air inlet flow control
- for additional propulsion

Eg.: some tests have been done in Russia, in France

PROS	CONS
Efficient way to modifie the flow	Electricity distribution
No mechanical element	
No moving part	

WP5 – Energy management: CYCLE ANALYSIS

BOIL-OFF COMPRESSION



The boil-off absorbs the thermal load throughout the airframe and dumps it to the propulsion plant

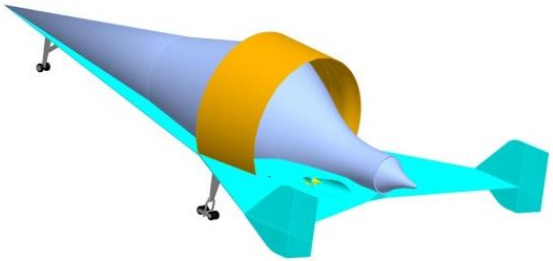
$\chi\ \dot{m}_f$ is not lost

WP5 – Energy management: FINAL AIM

Defining the best combination of such technologies to provide an efficient thermal and energy management ensuring suitable environment for passengers and on-board subsystems all along the trajectory.

To test this model on different hypersonic vehicle such as:

LAPCAT MR2 vehicle
Mach 8



LAPCAT MBDA vehicle
Mach 8

ZEHST vehicle
Mach 5

Technology Bricks

HIKARI

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WP6.1
Propulsion
Engines

WP6.2
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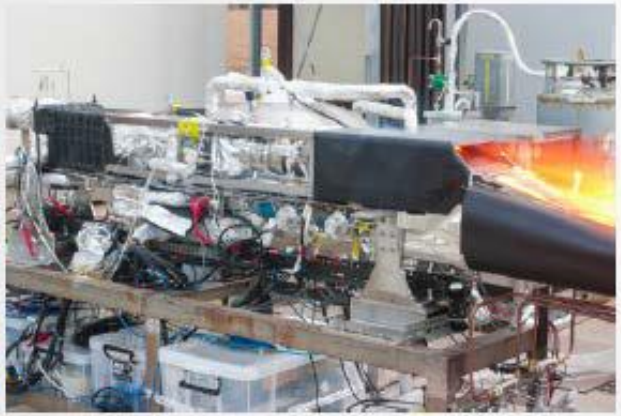
Tanks

Lead: AIRBUS Defense & Space
Involved partners: ESA-ESTEC, NLR, JAXA

AIRBUS DEFENCE & SPACE
JAXA
esa
NLR

Engines

- Single engine class
  - Turbojet running form M0 to supersonic speed / H_2 fuel
  - propulsive performance
  - overall mass



Mach 4 Direct Connect Test

- Noise of single engine class at take-off

- Multi engines class
  - Turbofan + Rocket + Dual Mode Ramjet
  - focused on rocket engine technologies
  - LOX/LH2 and LOX/LCH4 design

Tanks

- LOX/LH2 tank design
  - review of past studies on metallic tanks for reusable launchers
  - identification of the main topics from a functional point of view:
    - safety
    - evaporation
    - heat fluxes
    - feeding systems etc.

- Passive and active pressurization control of cryogenic reservoirs
  - design of the insulation system
  - parametric study for design

=> AIM: estimate the extent to which active control is needed to maintain the correct pressurization level

Thank you for your attention

Any question?

光
HIKARI

***HI**gh speed **K**ey technologies*
*for future **A**ir transport **R**esearch & **I**nnovation*
cooperation scheme

Thank you!

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IATA‘s Technology Roadmap and its connection to current aviation research and innovation

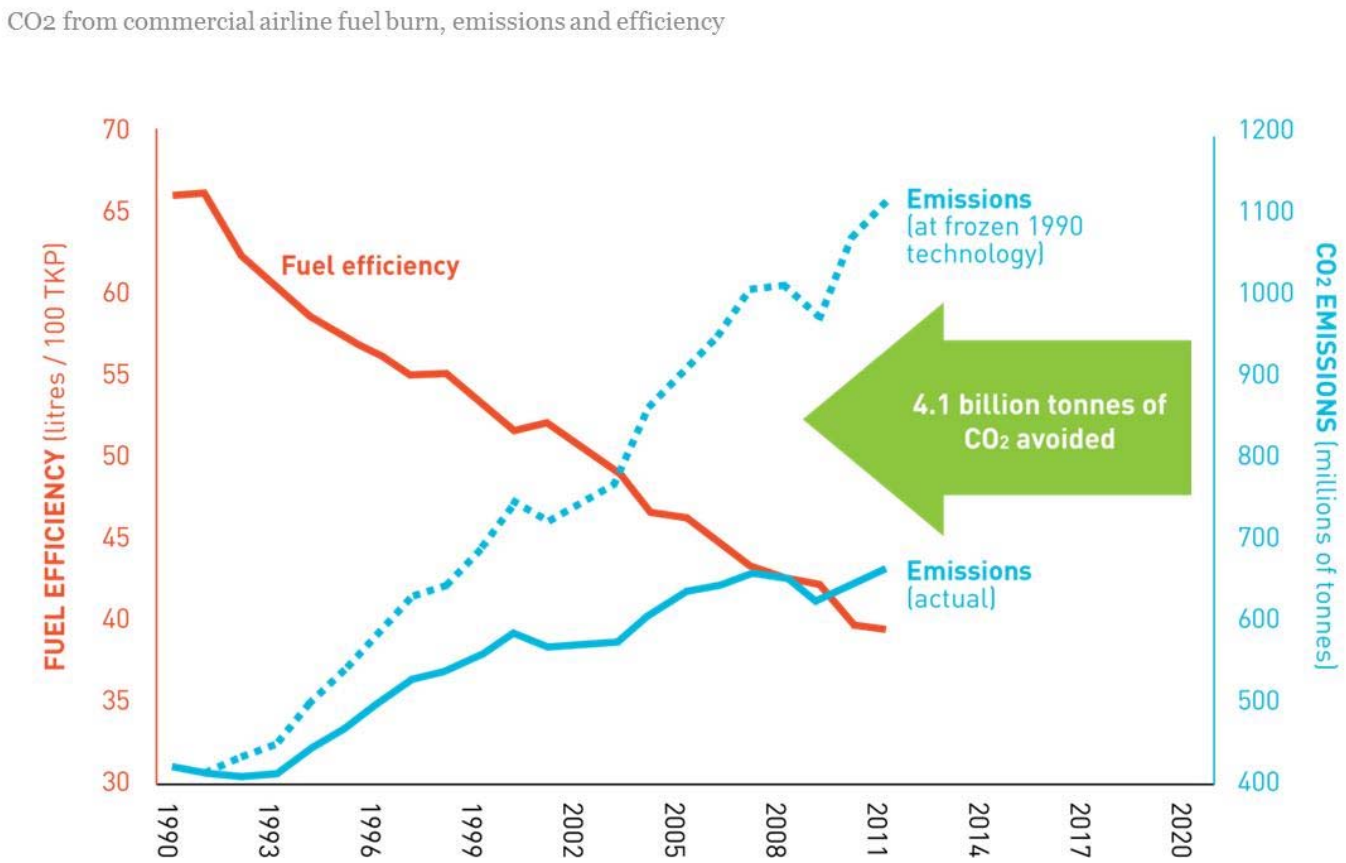
Peter Nolte, (DLR)
Thomas Rötger, (IATA)

4th EASN Workshop on Flight Physics and Aircraft Design,
Aachen, Germany, 27. – 29.10.2014

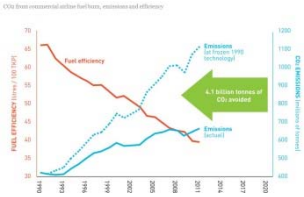
Outline

1. Introduction
2. Strategic Aviation Technology Goals
3. The TERESA Project
4. Technology Efficiency
5. Comparison with other assessments
6. World fleet modeling
7. IATA Aviation Technology Database
8. Conclusions and Outlook

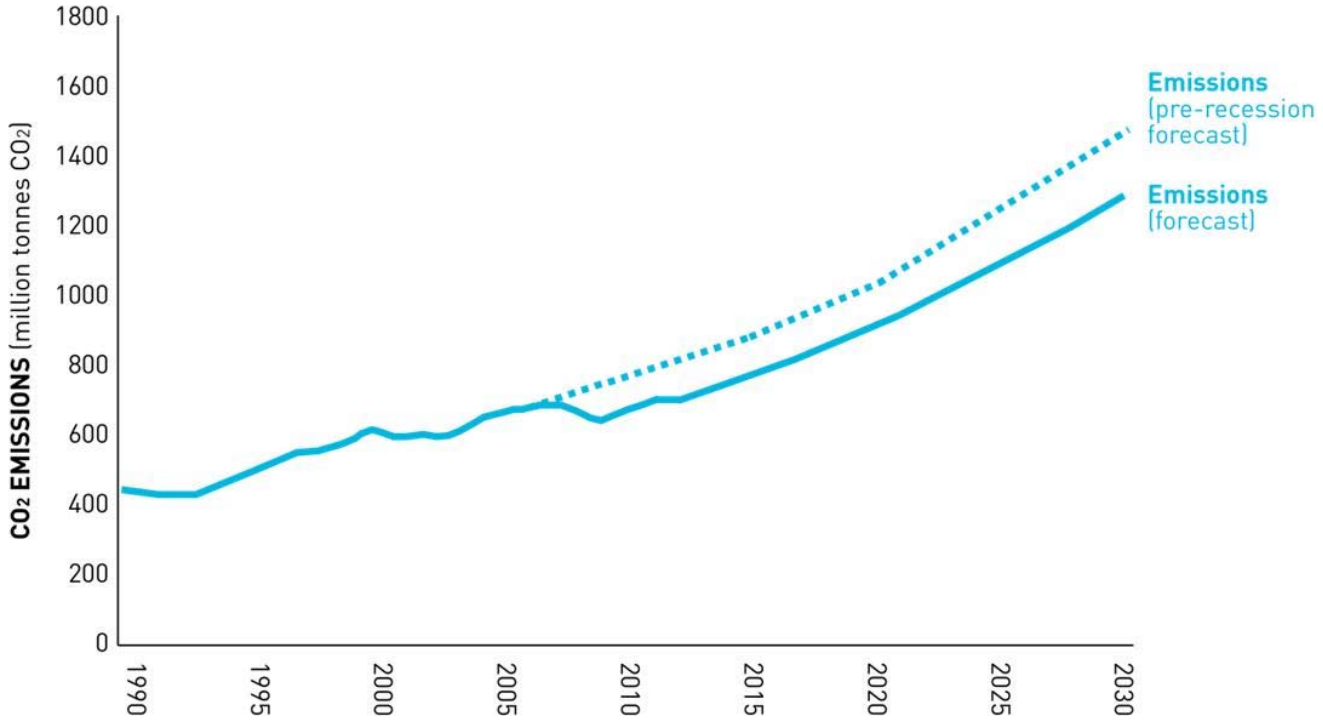
1. Introduction



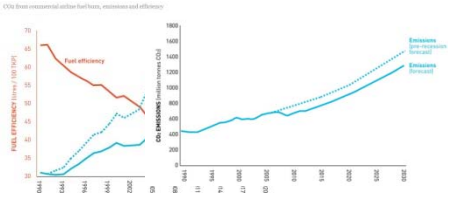
1. Introduction



Emissions from aviation, and forecast

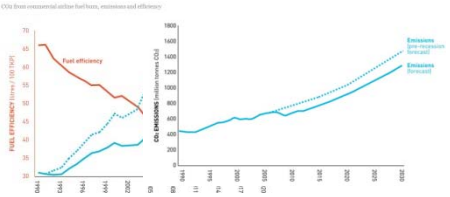


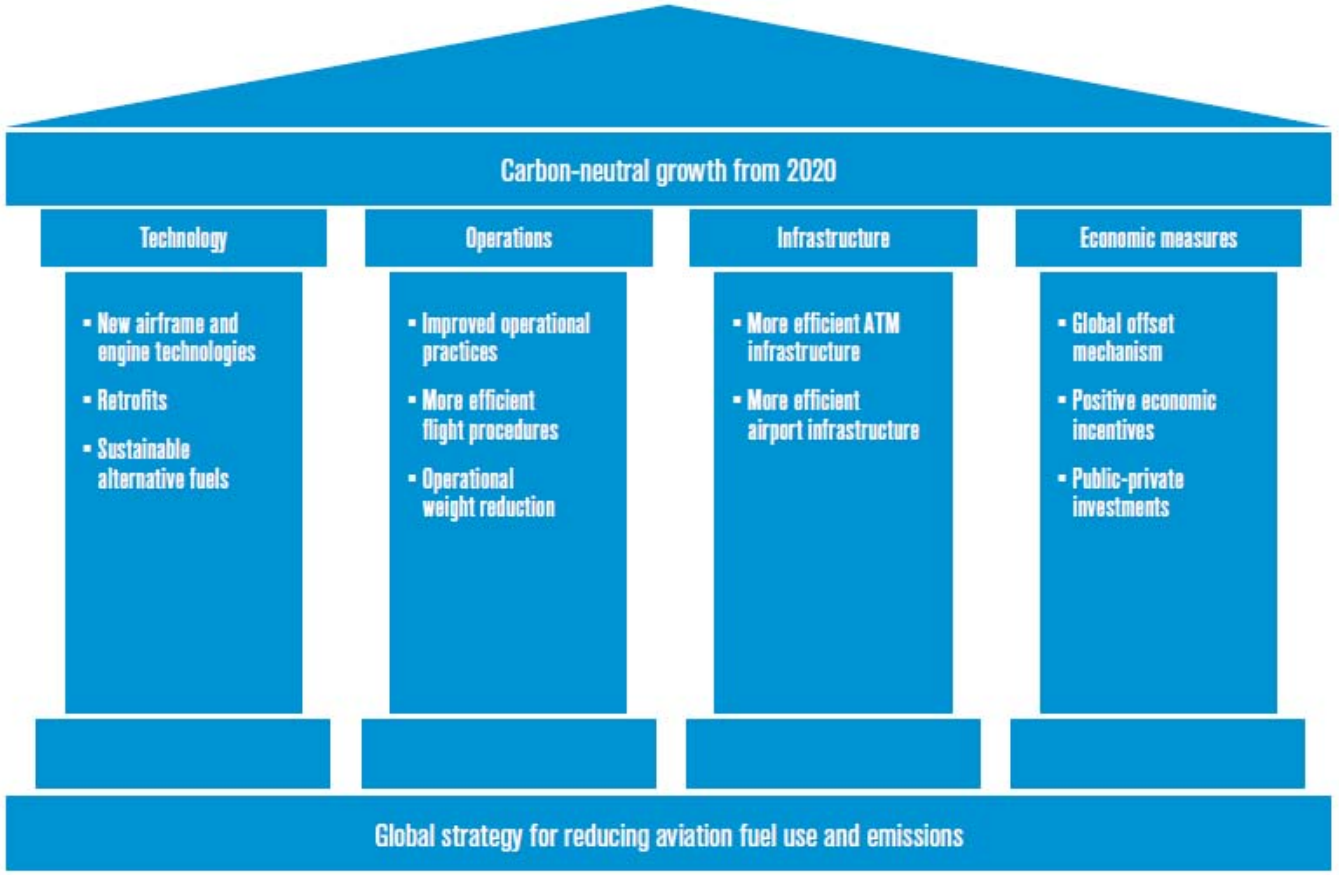
1.Introduction



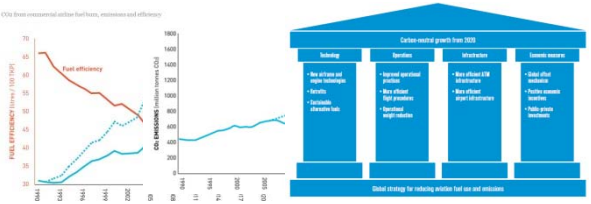
- An average improvement in fuel efficiency of 1,5% per year from 2009 to 2020
- A cap on net aviation CO_2 emissions from 2020 onwards (carbon-neutral growth)
- A reduction in net CO_2 emissions of 50% by 2050 relative to 2005 levels

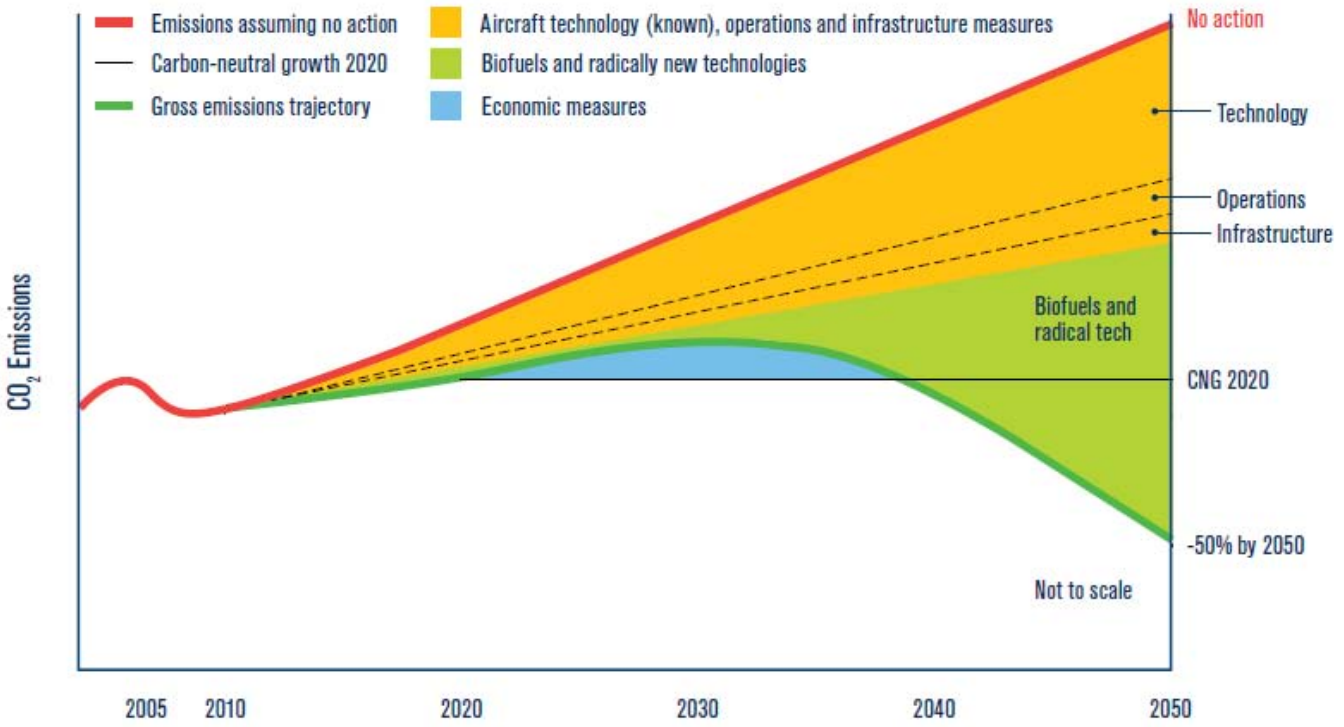
1.Introduction



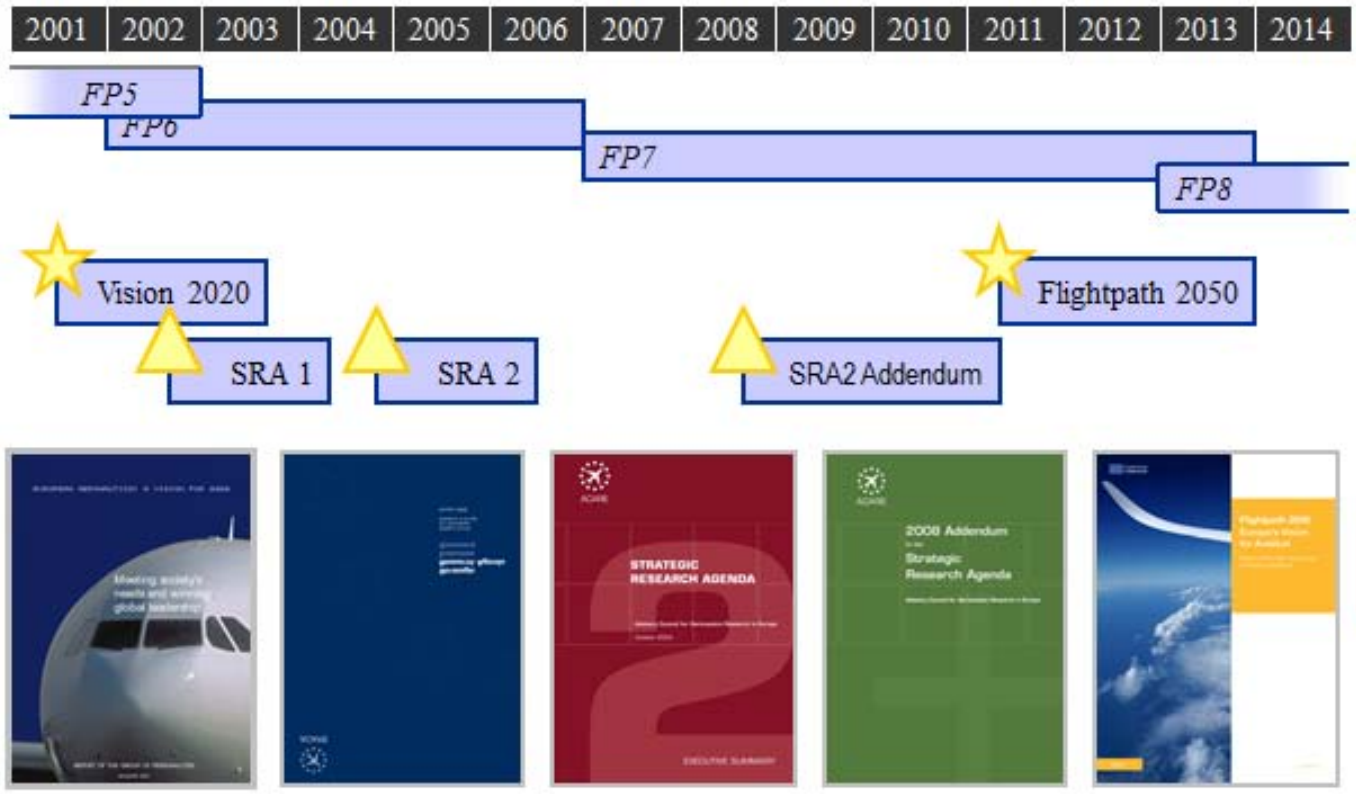


1.Introduction





2. Strategic Aviation Technology Goals



2. Strategic Aviation Technology Goals

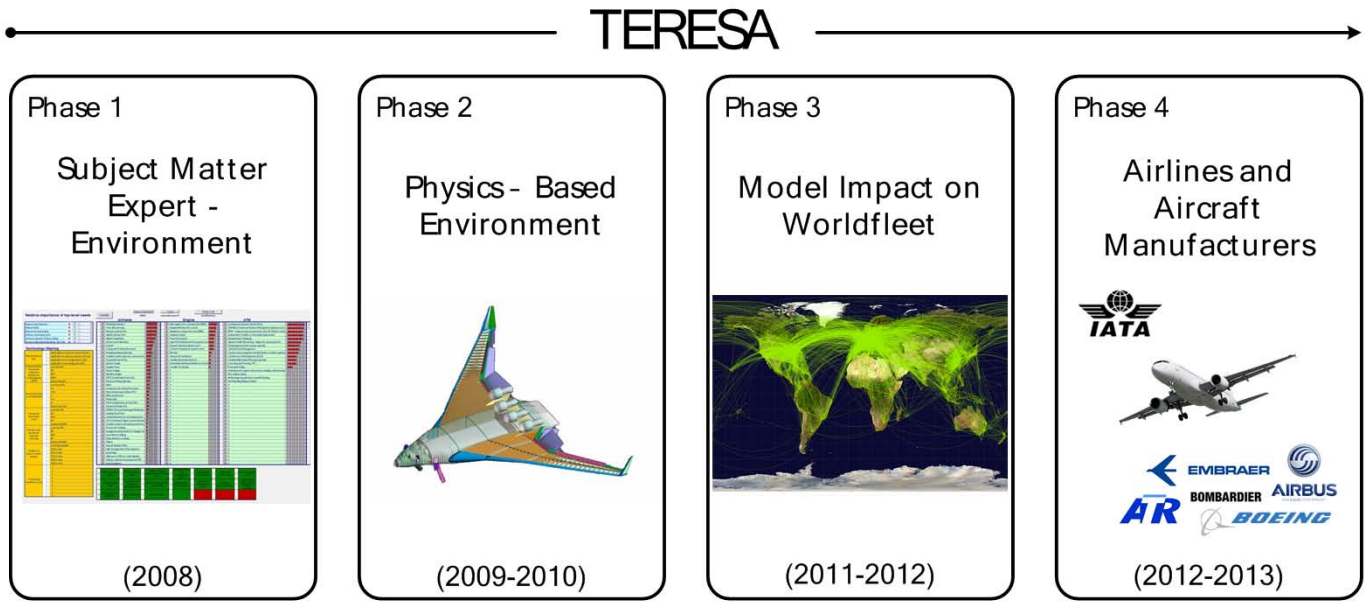
Europe

Goals	Technology benefits (year 2000 reference)	
	Vision 2020	Flightpath 2050
CO_2 reduction per passenger km	-50%	-75%
NO_x reduction	-80%	-90%
Noise reduction	-50%	-65%
Taxiing		emission-free
Manufacturing and design		all aircraft recyclable
Sustainable alternative fuels		Europe established as centre of excellence
Atmospheric research		Europe at the forefront

USA

Goals	N+1 = 2015 Single Aisle	N+2 = 2020 Large Twin Aisle	N+3 = 2025
Noise (cumulative below stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NOx Emissions (below CAEP 6)	- 60 %	- 75 %	better than -75 %
Performance: Aircraft Fuel Burn	- 33 %	- 50 %	better than -70 %
Performance: Field Length	- 33 %	- 50 %	exploit metroplex concepts

3. The TERESA Project
(TEchnology Roadmap for Environmentally Sustainable Aviation)



4. Technology Efficiency (Technology baskets)

Retrofit

- Variable Camber
- Riblets
- Winglet
- Lightweight Cabin Interiors
- Structural Health Monitoring
- Laminar Flow Drag Coatings
- Al-Li Alloys

Production upgrade

- Active load alleviation
- Advanced materials

	Central	Composite	Advanced Al	AL-Li Alloys
Wing	▪	▪	▪	
Fuselage		▪	▪	▪
Empenage		▪	▪	▪

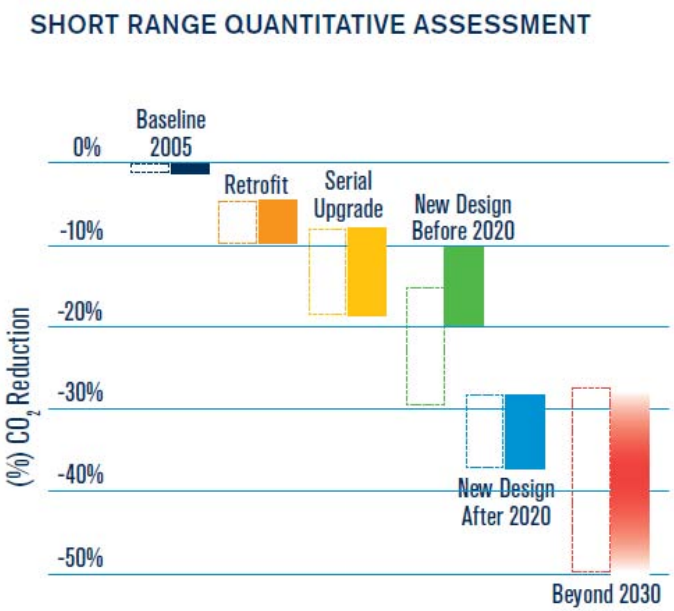
New design before 2020

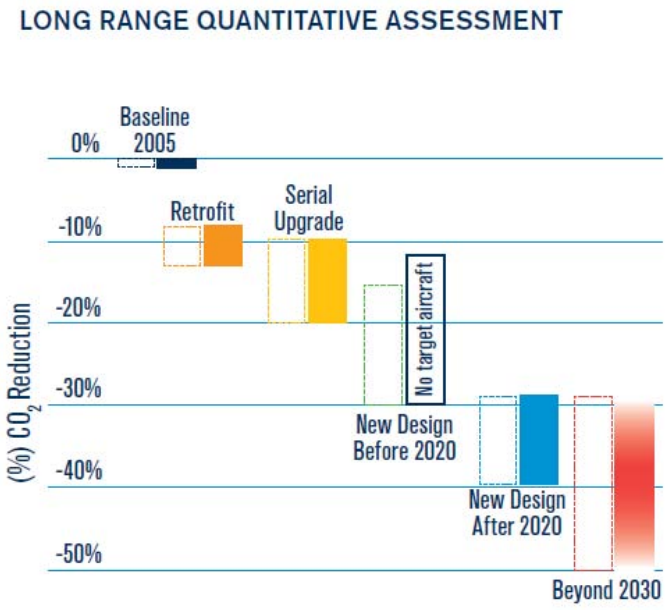
- Geared turbofan
- Advanced turbofan

New design after 2020

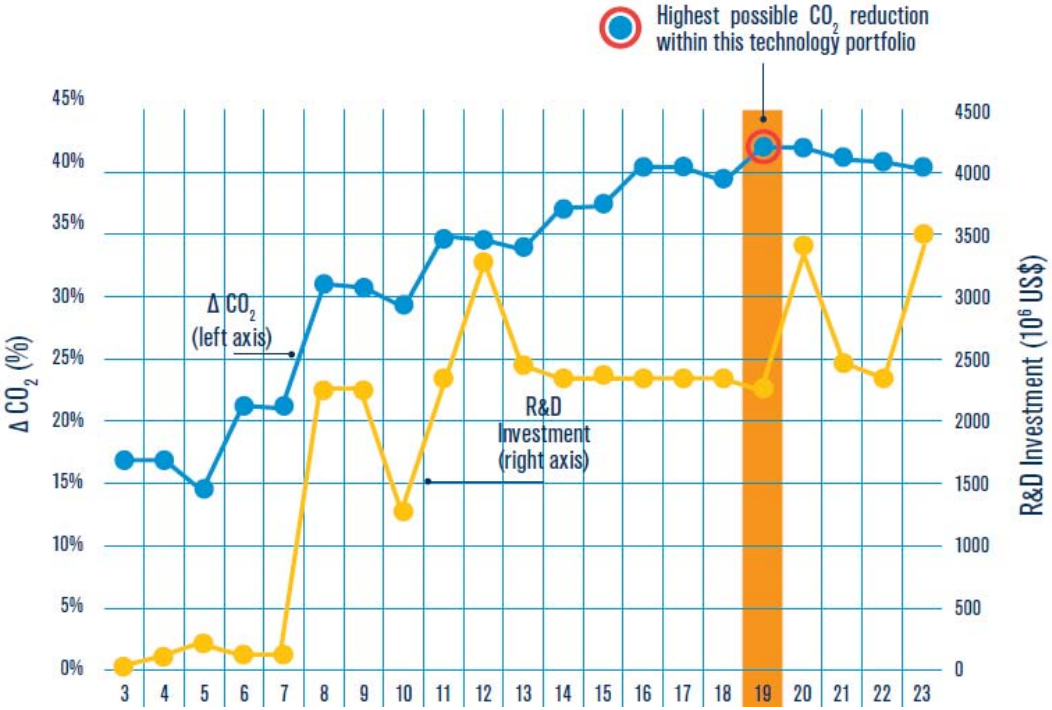
- Natural laminar flow control
- Hybrid laminar flow control
- Fuel cell for secondary power

4. Technology Efficiency (Comparison of qualitative and quantitative results)





4. Technology Efficiency
TRL – Risk – R&D Investment



		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Aerodynamics	T1 Natural Laminar Flow Control								▪	▪		▪	▪	▪	▪	▪	▪	▪		▪	▪	
	T2 Hybrid Laminar Flow Control						▪	▪			▪								▪			▪
	T3 Active Load Alleviation	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
	T4 Variable Chamber				▪	▪							▪	▪				▪	▪	▪	▪	▪
	T5 Fuel Cells									▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
	T6 Lightweight Cabin Interiors	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
	T7 Riblets				▪	▪							▪	▪				▪	▪	▪	▪	▪
	T8 Laminar Flow Drag Coatings						▪	▪	▪	▪	▪	▪			▪	▪	▪					
Wing	T9 CentrAL								▪									▪			▪	▪
	T10 Composite Primary	▪	▪	▪	▪	▪	▪	▪		▪	▪	▪	▪	▪	▪	▪		▪	▪	▪		
	T11 Advanced Aluminum																					
	T12 Al-Li Alloys																					
	T13 CentrAL																					
Fuselage	T14 Composite Primary	▪	▪		▪	▪	▪	▪	▪	▪	▪		▪	▪	▪	▪	▪	▪	▪		▪	
	T15 Advanced Aluminum			▪								▪								▪		▪
	T16 Al-Li Alloys																					
	T17 CentrAL																					
Empennage	T18 Composite Primary	▪																▪				
	T19 Advanced Aluminum		▪	▪		▪		▪			▪	▪		▪		▪			▪	▪	▪	▪
	T20 Al-Li Alloys				▪		▪		▪	▪			▪		▪		▪					
Engine	T21 Advanced Turbofan														▪	▪	▪	▪	▪	▪	▪	▪
	T22 Geared Turbofan						▪	▪	▪	▪	▪	▪	▪	▪								
	T23 Winglet	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
	T24 Structural Health Monitoring	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪	▪
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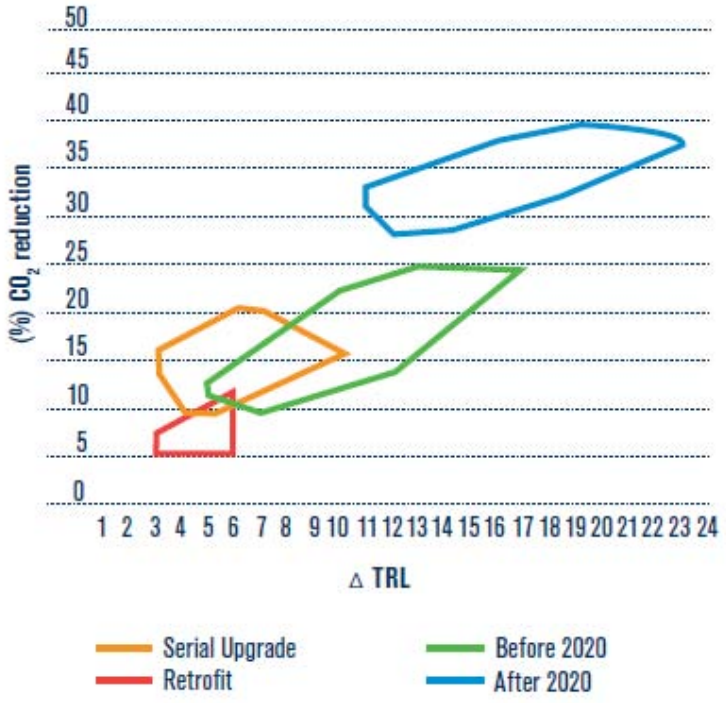
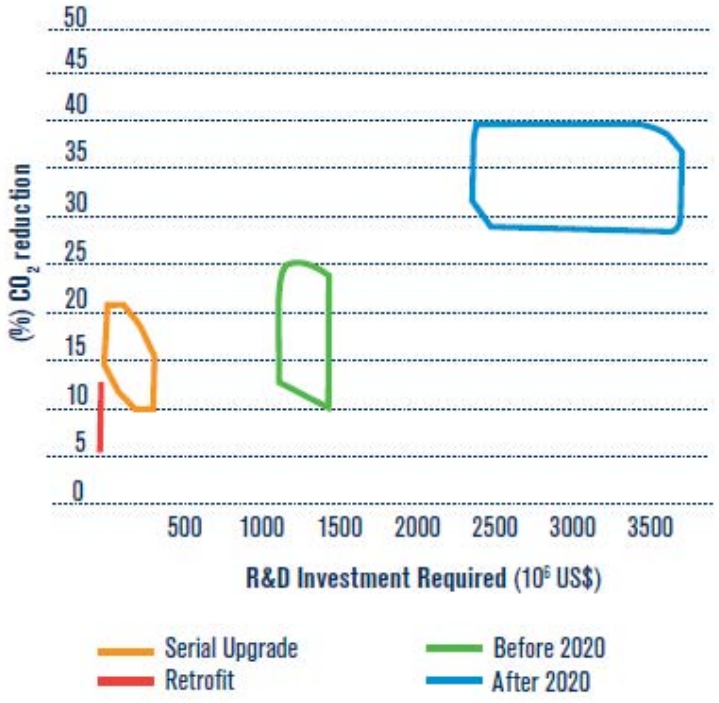
4. Technology Efficiency
TRL – Risk – R&D Investment





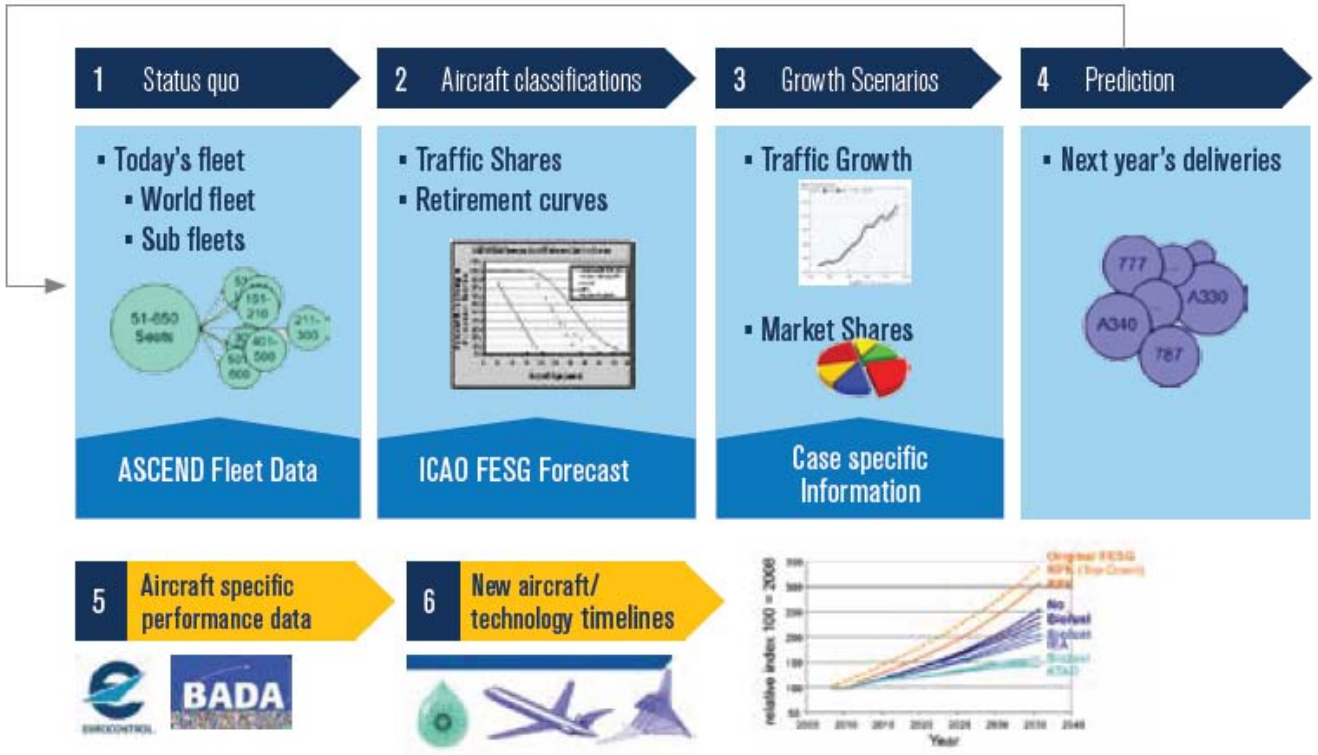
5. Comparison with other Assessments

	Before 2020				After 2020			
	Short Range		Long Range		Short Range		Long Range	
	Min	Max	Min	Max	Min	Max	Min	Max
TERESA (2009 forecast)[1]	-23%	-29%	-24%	-29%	-27%	-38%	-29%	-40%
TERESA (2013 forecast)[2]	-10%	-21%	-	-	-27%	-38%	-29%	-40%
AGAPE (Baseline 2000)[3]	-17,5%		-24%		-	-	-	-
CCC[4]	-	-	-	-	-40%		-40%	
CAEP/IEs[5]	-23%	-29%	-19%	-25%	-29%	-41%	-26%	-41%

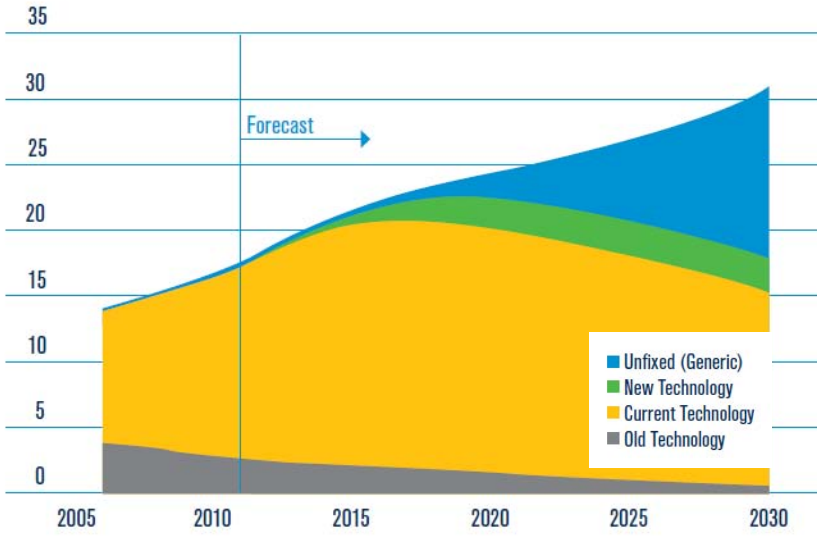
1. IATA (2009) Technology Roadmap Report , Geneva, June 2009. http://www.iata.org/publications/Pages/technology-roadmap.aspx
2. IATA (2013) Technolog Roadmap Report, Geneva, August 2013. http://www.iata.org/publications/Pages/technology-roadmap.aspx
3. AGAPE Project Final Report, June 2010. *http://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/agape_final_report_summary.pdf*
4. CCC: House of Commons: The future of aviation, first report of session 2009-10, 2nd December 2009. *http://www.publications.parliament.uk/pa/cm200910/cmselect/cmtran/125/125i.pdf*
5. *CAEP: Report of the Independent Experts on the Medium and Long term Goals for Aviation Fuel Burn Reduction from Technology, ICAO Doc 9963, 2010, ISBN 978-92-9231-765-2.*

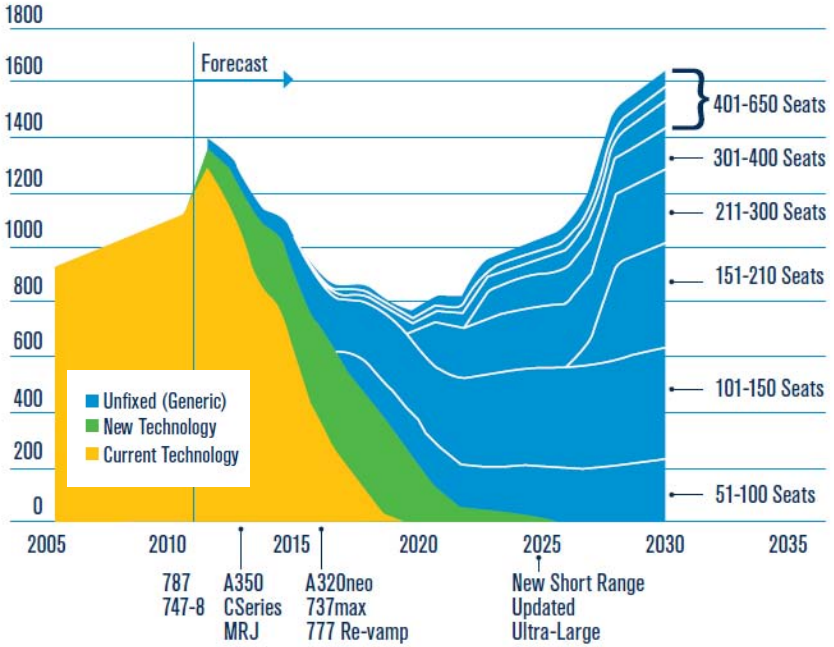
6. World Fleet Modeling

General CO_2 Forecast Schematic: Bottom-up Forecast based on Year-to-Year Dynamics



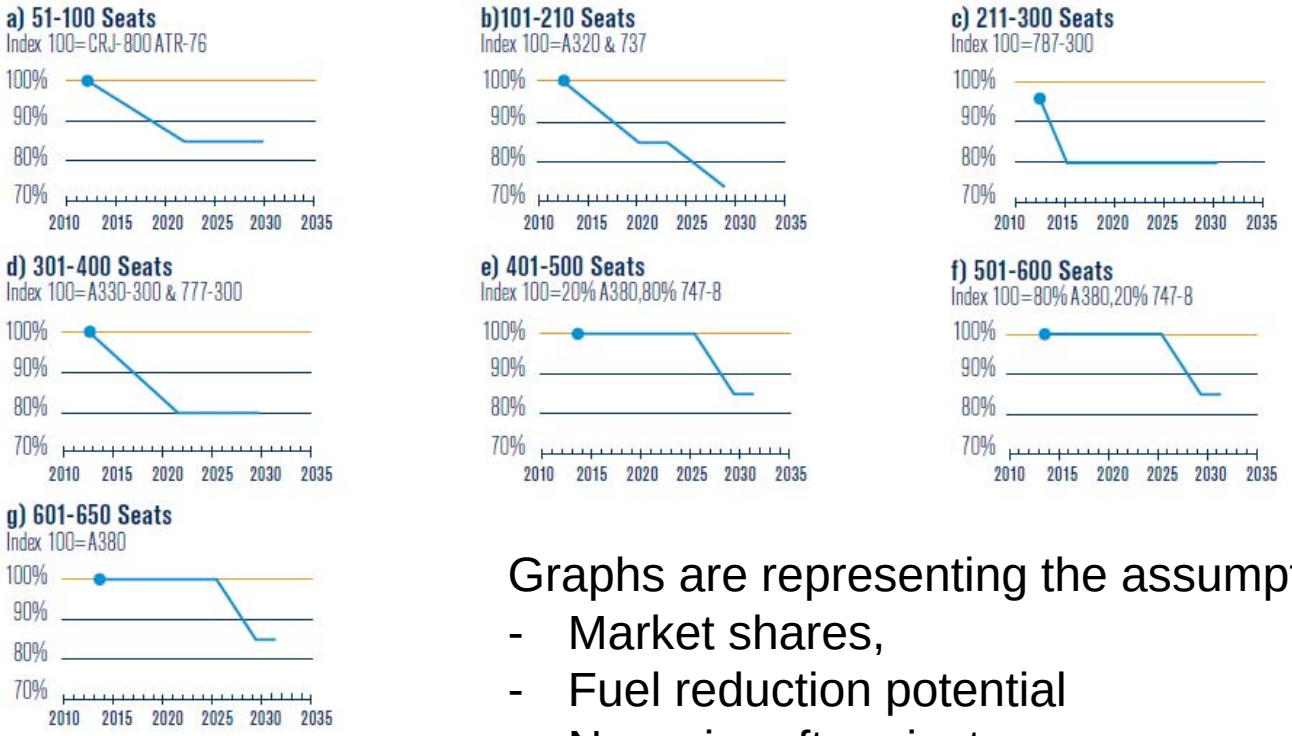
6. World Fleet Modeling





6. World Fleet Modeling

Technology Scenarios: Assumptions on Fuel Consumption of Generic World Fleet Aircraft per Seat Category



Graphs are representing the assumptions on

- Market shares,
- Fuel reduction potential
- New aircraft projects
- Ramp up times

6. World Fleet Modeling
Average Yearly Fuel Efficiency of the Entire World Fleet

7. IATA Aviation Technology Database (current work)

Category: Airframe
Group: Aerodynamics
Concept: Advanced Wingtip Devices
Technology: Blended Winglet / Sharklets

Description:
Reducing induced drag of wings with minimum interference drag and without much increase in wing span by sophisticated blending of wing and vertical winglet. Aviation Partners indicates that the blended wingelt available for the Boeing 737-800 provides a 3.0% to 3.5% fuel burn improvement on a typical 980nm mission. One potential downturn ist that a retrofitted wing may require additional stiffening, which would add extra weight.

www.boeing.com (image link)

retrofitable on current AC	applicable on regional AC	applicable on short range AC	applicable on long range AC
☑	☑	☑	☑

Technology available for commercial aviation	Aircraft program available to install technology	Research & Development investment
currently available	2010+	10 M - 100 M $

On-AC investment costs	AC retrofit costs	Annual operating costs
		lower

current TRL	Duration until TRL 9	Year of introduction
9	0	-

Technology impact on target goals

Emissions	Noise	Security	Safety	efficient operation	climate change
+	+	o	o	-	+

++ high improvement
+ improvement
o neutral or unknown
- decline
-- high decline

Benefits SR quantitative	Benefits LR quantitative
L/D + 3-5%, fuel - 3-5%	L/D + 3-5%, fuel - 3-5%
Benefits SR qualitative	**Benefits LR qualitative**
fuel savings	fuel savings
Source 1	**Source 2**
Airbus http://www.airbus.com/innovation/proven-concepts/in-design/winglets/ - c16760	
History SR	**History LR**

Related technology:
Showstopper: wing stiffening may be required
researched by: Company: Aviation Partners, Boeing, Airbus; Institution: NASA, DLR; Program: ;Person: ;
Notes:

- IDEA of a technology wiki
- Database contains 111 airframe and engine technologies (atm and alternative fuels are optional)
- Currently access based → transformation to sharepoint ongoing
- Preparation of web accessability through IATA website

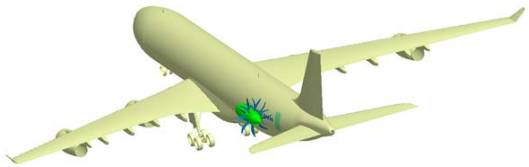
8. Conclusions and Outlook

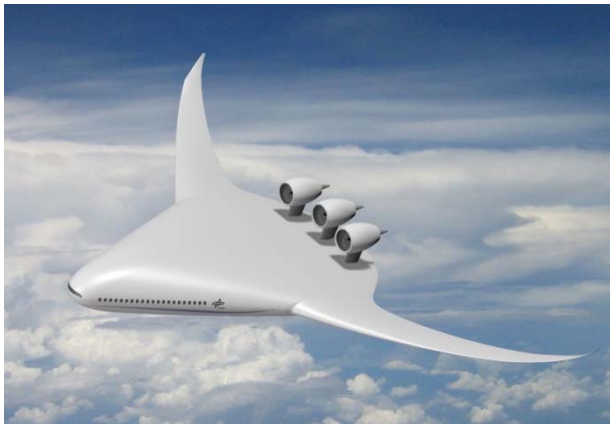
Conclusion

- Improving fuel efficiency is a strong driver for technological development
- A broad scope of technologies from aerodynamics, engine, materials and equipment is available for implementation
- A significant potential for fuel burn reduction can be expected (dependend on the time horizon)
- Technology combinations that achieve up to 30% or more of fuel burn reduction require development costs in the order of billions
- The annual fleet efficiency improvements per seat category of roughly 1-2% found in the present calculations look promising to meet the high level industry goals

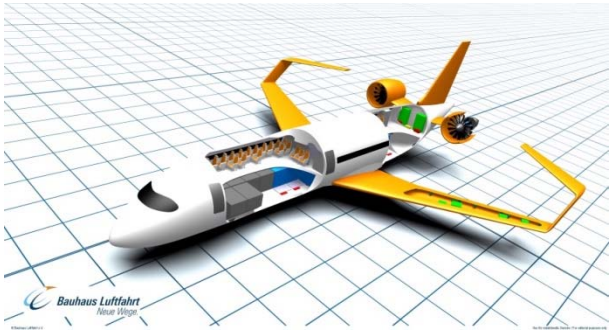
Outlook

- It is important not to under-estimate the gap between the pure technology development and implementation into an aircraft
- Airline customers and the public in general play an important role in this whole process by showing their interest and support for new technologies
- Only with the application of unconventional ideas will the remaining gap towards a radical reduction in aviations carbon footprint be closed





Let‘s get started



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Aircraft design for future operations

4th EASN Association International Workshop on Flight Physics and Aircraft Design, Aachen October 27th – 29th, 2014

Prof. Dr.-Ing. Volker Gollnick

Overview

1. Aircraft Design – How we do it today
2. Market Developments
3. Aircraft characteristics trends
3. Where do we make money of?
4. Cabin, systems, avionics
5. Design to changing operations
6. Conclusions

Aircraft Design – How we do it today

Dreaming of „Gamechanger“, „Breakthroughs“, „Exiting Shapes“, „Wild Things“

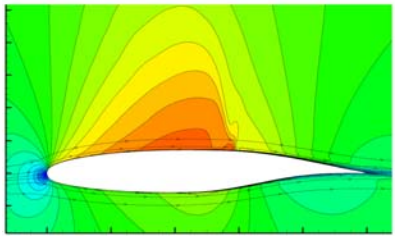
Expectations

Mobility

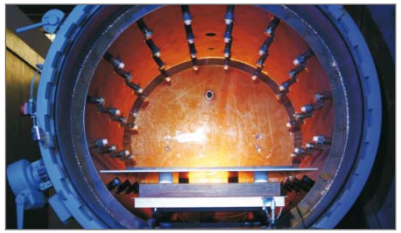
Environment

Economy

Engine



Aerodynamics

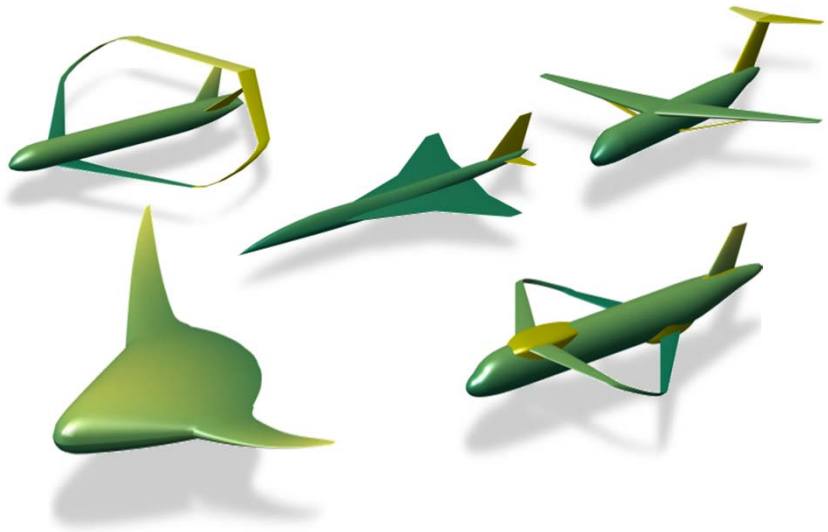


Leight weigt & Production

TECHNOLOGIES

Aircraft Design – How we do it today

Dreaming of „Gamechanger“, „Breakthroughs“, „Exiting Shapes“, „Wild things“



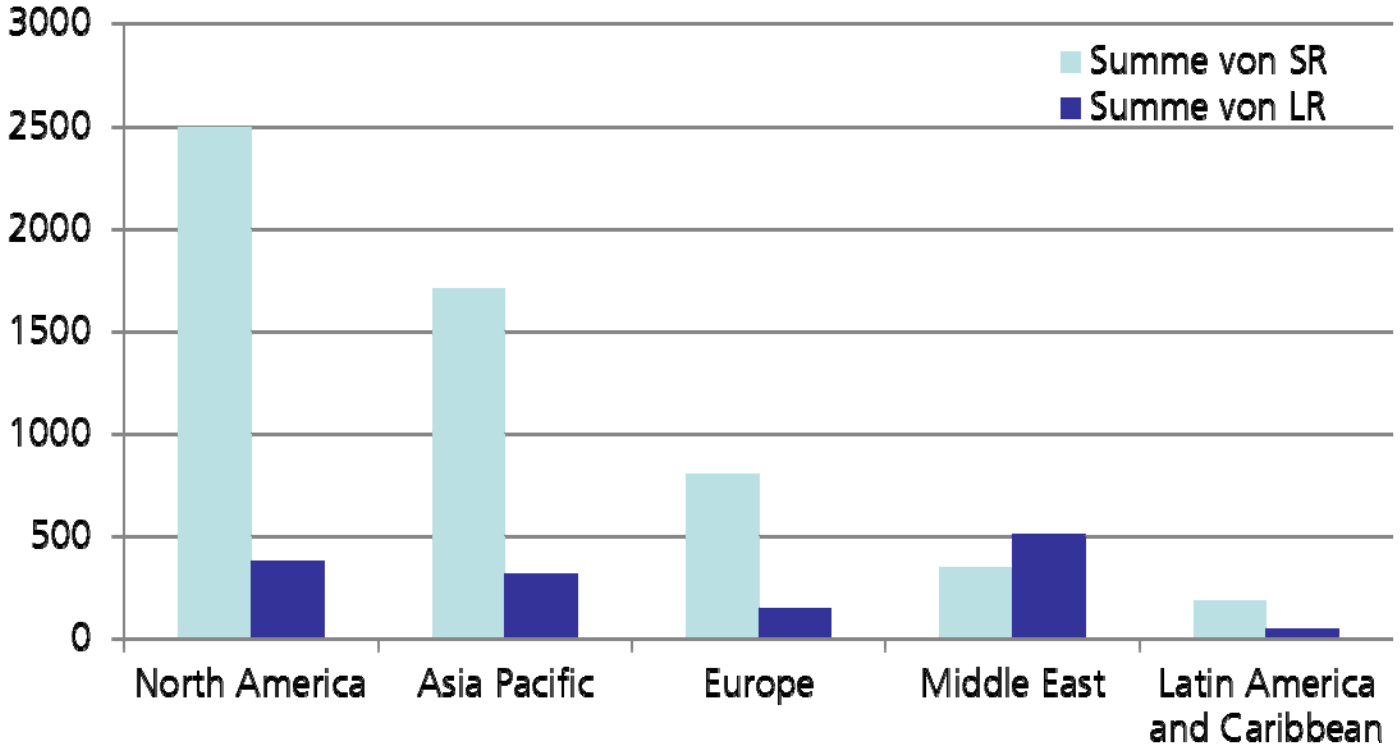
Top Level Aircraft **Requirements**:

- Δ DOC ≈ Δ SFC improvement must be at least 15%!
- Max. Payload
- Cruise Mach number
- Range
- Take Of Field Length

What we **„design“**:

- Fuselage diameter
- Fuselage Length
- L/D
- Wing span
- Wing sweep
- Aerodynamic and flight physical performance

Market Developments

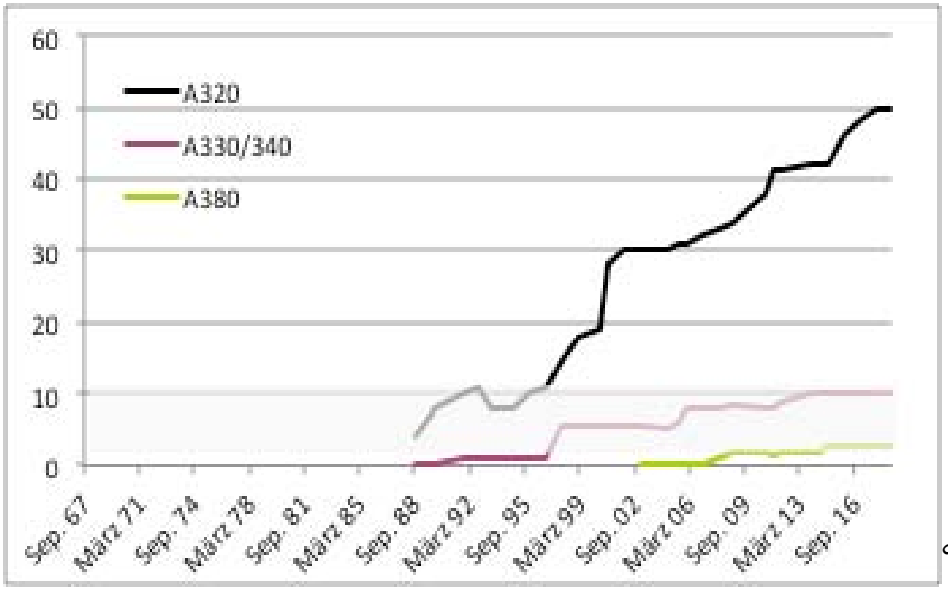


➔ Short range aircraft dominate the orderbooks

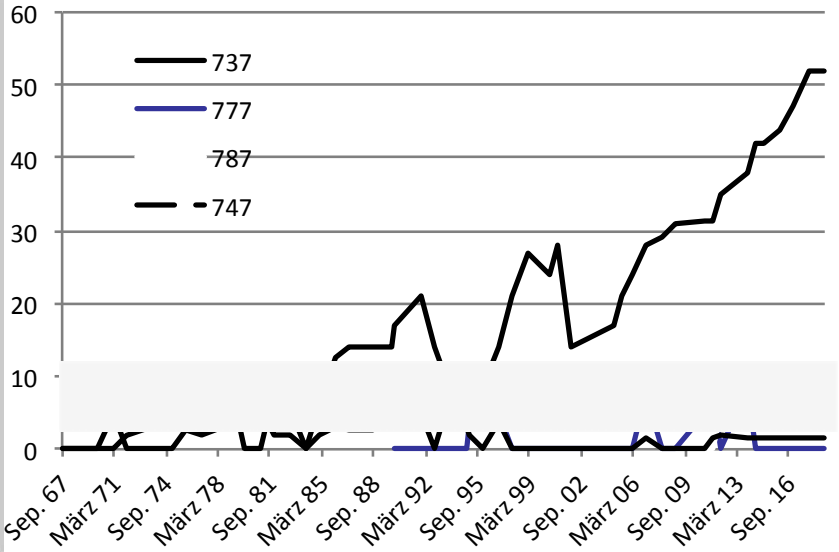
Status: July 2014

Market Developments

Airbus



Boeing



➔ Similar production rates at Airbus and Boeing:

- Production rate Big jets: ca. 3
- Production rate Long Range Aircraft: ca. 10
- Production rate Short Range Aircraft: ca. 20 – 50

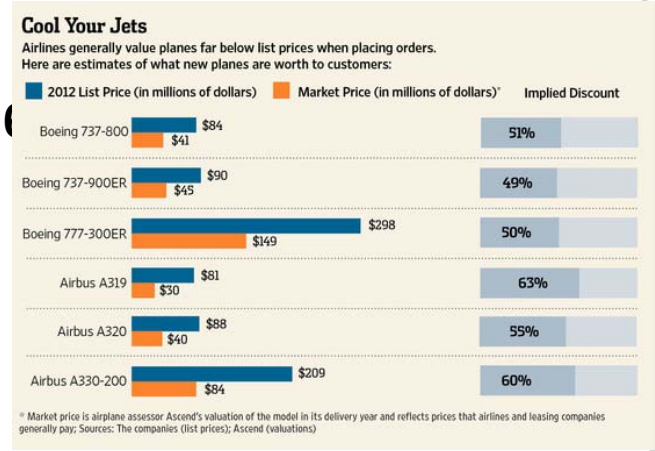
Market Developments

Relevance of short and long range aircraft

A little example:

600 SR a`80M$ and 47% discount result: **22.6 Billion $ (48 Billion $)**

100 LR a´250M$ and 47% discount result: **11.75 Billion $ (25 Billion $)**



http://online.wsj.com/news/articles/SB10001424052702303649504577494862829051078; 21.07.2014

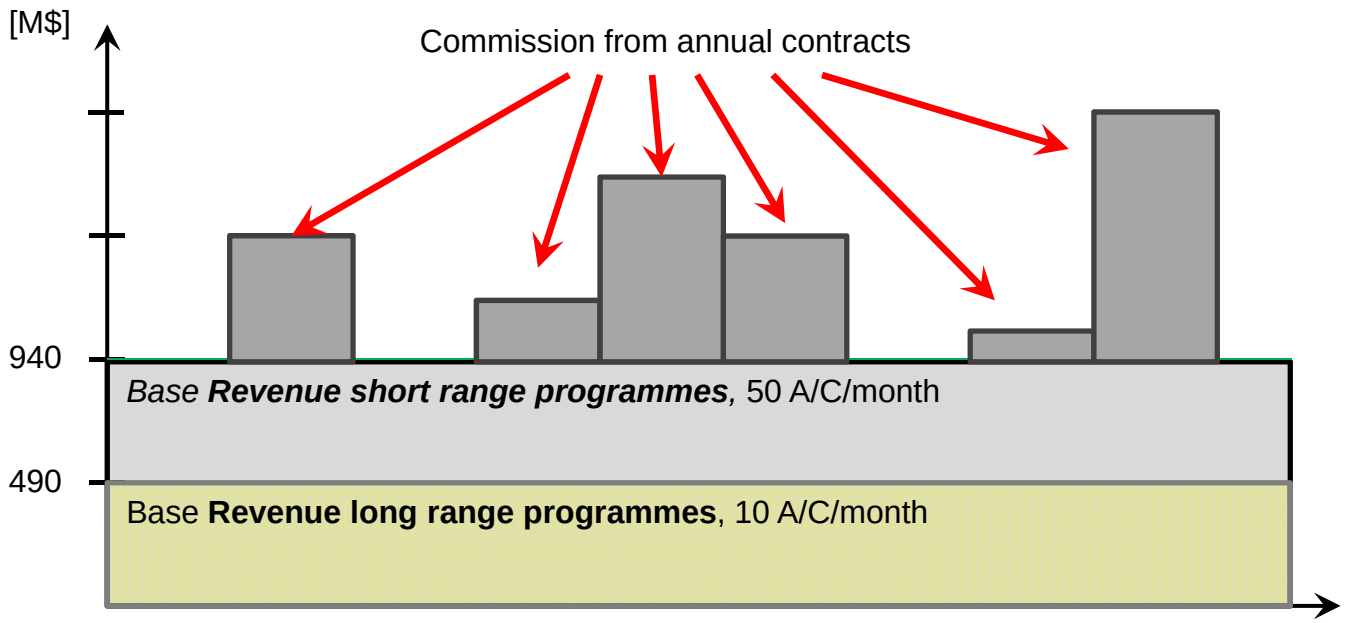
List price SR: ca. 80M$;
List price LR: ca. 250M$
Average discount, acc. Flight International 02/2014: 47%

Market share 30/30/30 means**:**
400 SR a`80M$ at 47% result: **17 Billion $!!**
(reduction of 5.6 Billion)

➔ **Short Range aircraft dominate revenue** and can be efficiently produced
➔ Increasing production counts are **vital!**

Market Developments

Principle manufacturer revenue analysis



➔ Short range A/C guarantee continous and 2/3 of annual revenue

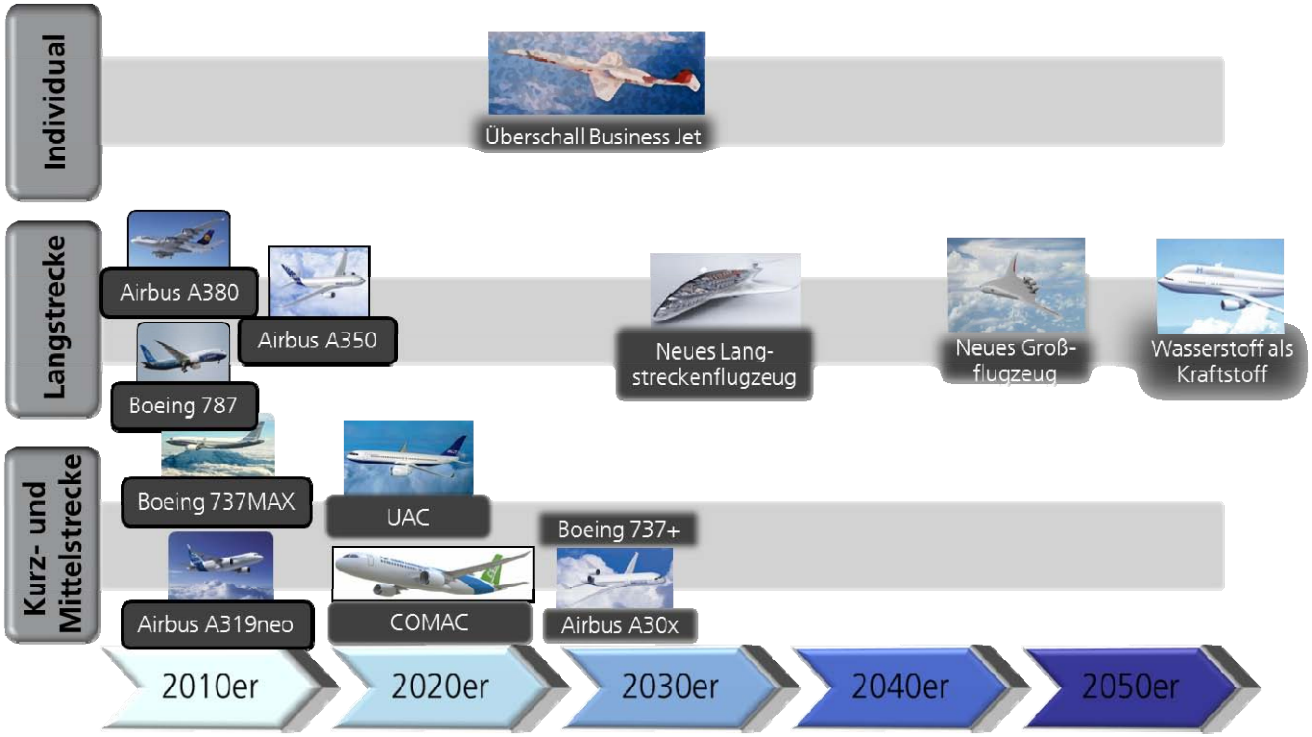
Market Developments

Impact factors for new aircraft programmes

- **Continous revenue** not to be disturbed!
- **Low investments**!
- New **technologies** only at low **risk** ➔ CFRP-structures (B787, A350?), system complexity (A380), system contributions by supplier rather than airframer (NEOs TW, Kabine)
- Min. **15% DOC reduction**
- **Production related** innovations
- **Short innovation cycles** and simple **integration** ➔ electronics, cabin, Cockpit, systems
- **After Sales** perspectives of an innovation

➔ New **Overall designs** are **risk** for cashflow!!

Market Developments



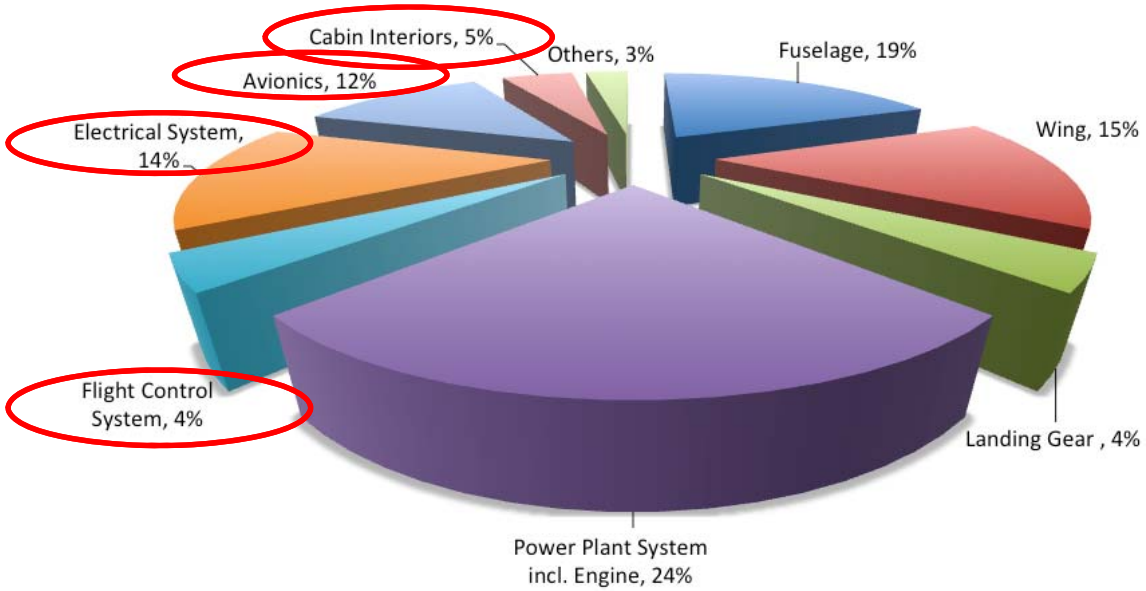
➔ **No complete new programmes** at least until 2040

➔ „New“-developments are **adaptions/upgrades** at low budget and risk

➔ Only **minor R&D-investments** required

Aircraft characteristics trends

Increasing share of systems and electronics



Electronics, systems: 35%

Wing, Fuselage: 34%

Power Plant, Engine: 24%

Electronics = Functions

How can we consider **Functions** as aircraft value at early **conceptual and pre-design phases**?

Frost & Sullivan, 2010

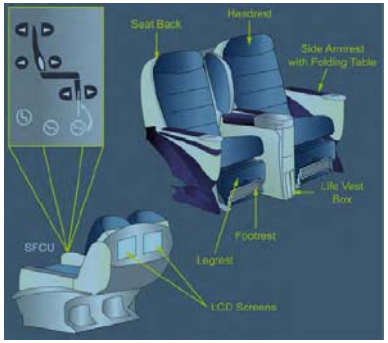
Aircraft characteristics trends

General Trends in **Aviation**

- More passenger orientation
- More process orientation
- More service orientation

General Trends in **Technologies**

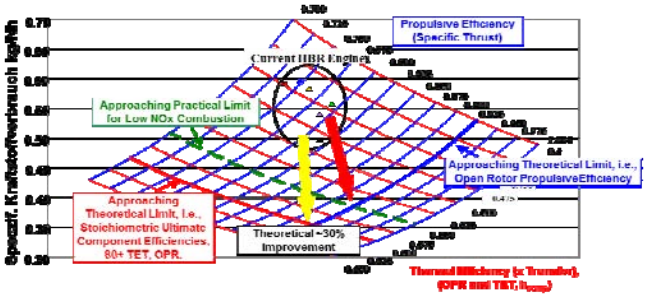
- Nano Technologies
- Micro Electronics
- Communication & Information



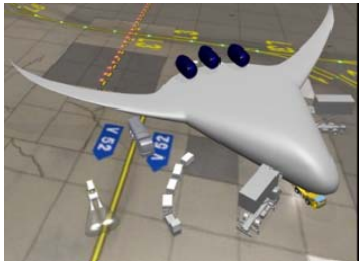
Aircraft characteristics trends

Trends in **Aviation Technologies**

- **Engine** efficiency increase by high load core and high by pass
- **Laminar features** application to tailplane
- **Cabin** technologies
- **Maintenance** functions for higher availability
- Green and efficient ground handling



No new wing, no new fuselage!



Where do we make money of?

Value creation by **short life cycle items**

- Cockpit
- Cabin components and systems
- Aircraft systems
- Engine (compared to fuselage and wing)

Value creation by **services**

- Passenger travel services ➔ consumables
- Maintenance and modifications

➔ Aircraft is an investment product, cabin is a consumable!!

Design to changing operations

The value aircraft functions is permanently increasing

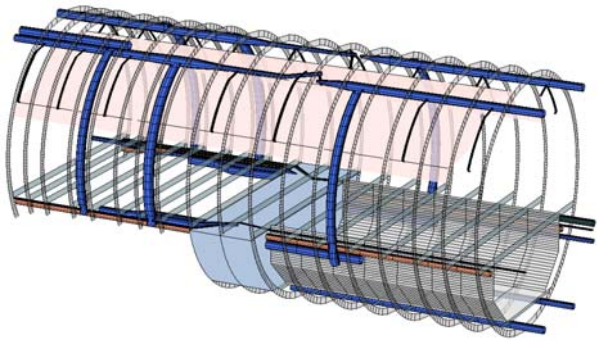
➔ How can we consider such functions in conceptual and preliminary aircraft design?

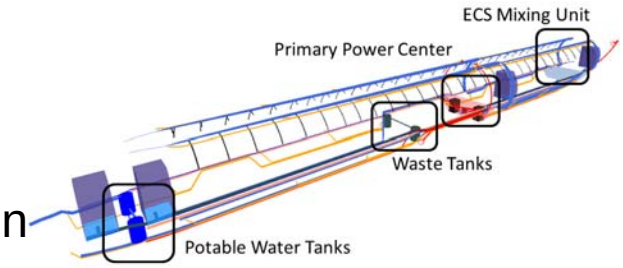
Some ideas:

➔ Adding a main **functional description** to a new concept (e.g. lines of code)

➔ Consider **weight, size, energy, routing, positioning** (miniaturization)

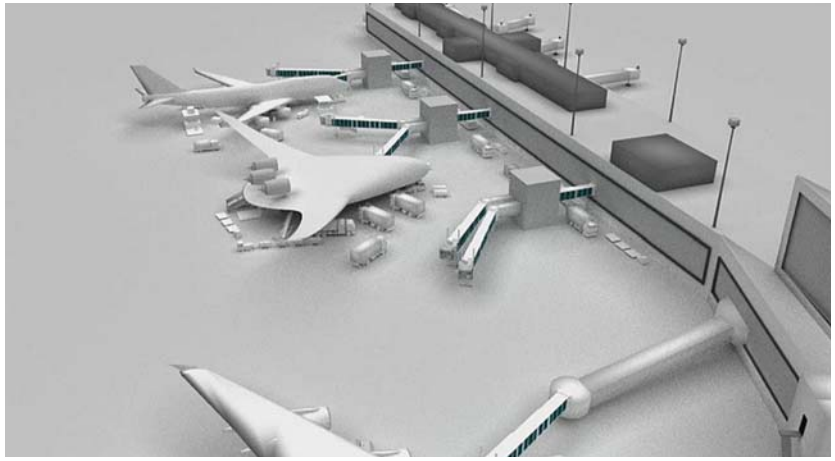
➔ Focus at **cabin and systems architectures and integration** also in conceptual and preliminary aircraft design

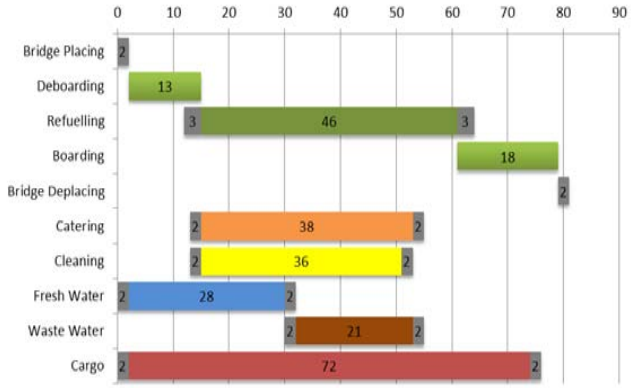




Design to changing operations

Turnaround oriented aircraft design





➔ Geometry, positioning of service points and accessability affect efficient turnaround

➔ Precision navigation allows for smaller A/C boxes and more airport capacity

Turnaround BWB 500 PAX = **82 min**

A380 555 PAX = **90 min**

3% of overall operations cost are dedicated to turnaround processes

Design to changing operations

Investigating impact of redesigned existing aircraft, e.g. A330

Evolutionary redesign provides significant potential!

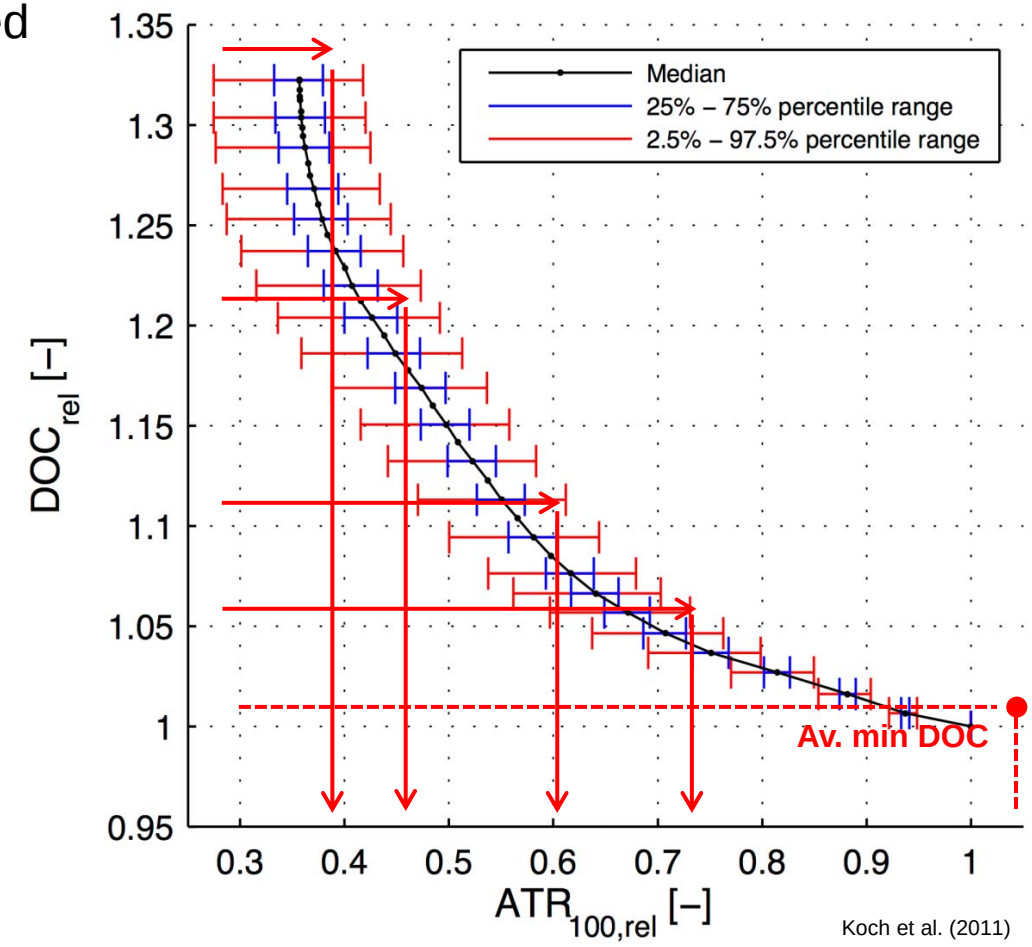
66 %

For **cost penalty** of

33 % (Rel. to min. DOC)

Mitigation effectiveness

2



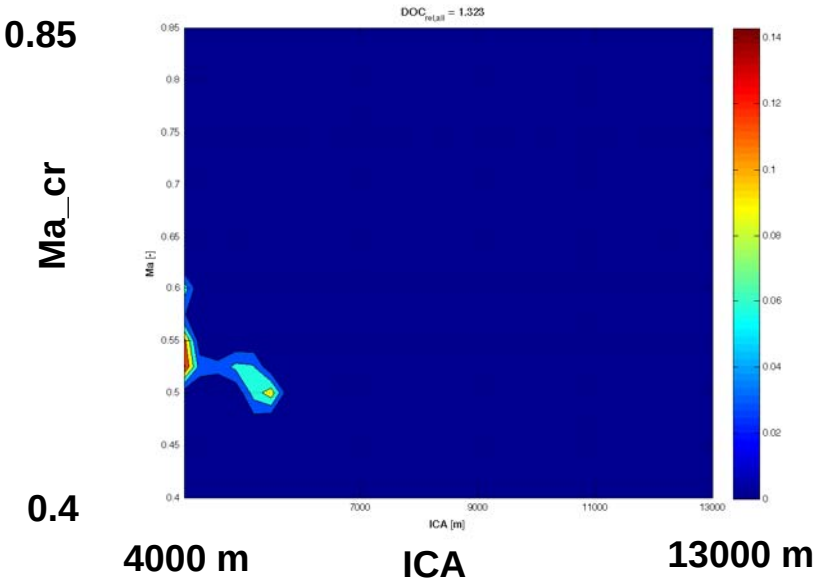
Koch et al. (2011)

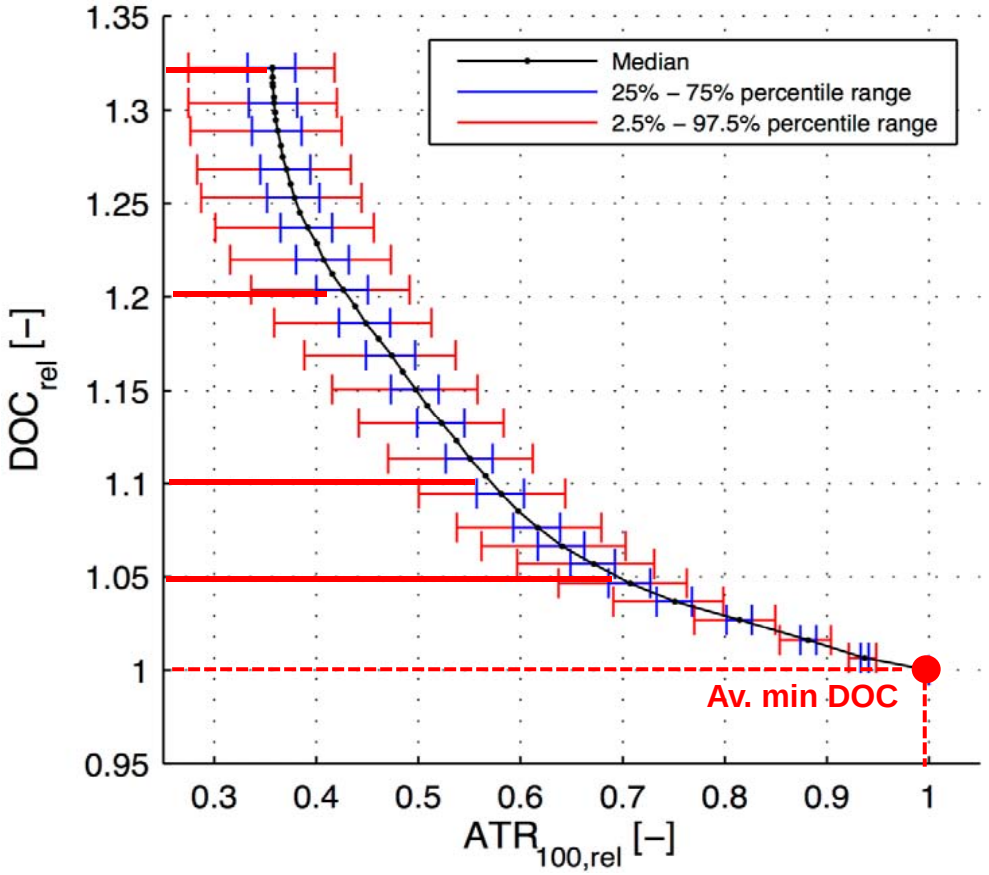
Design to changing operations

Distribution of operating points for n routes and given DOC penalty

$\Phi = Nr\ (ICA,Ma)@\ DOC(x)/Nr\ Routes$

Delivers new design point





Koch et al. (2011)

Resumeé

- No real need for a complete new configuration on short and long range for the next decades
- Reorientation in aircraft design towards passenger needs and value of functions
- Non aviation technologies drive the future aircraft design
- Cabin, systems and electronics will drive future aircraft design
- Classical conceptual aircraft design should change towards functional aircraft

Think different about aircraft design!

It´s time for discussion!

Location

Harburg Harbour

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Institut für Lufttransportsysteme der TUHH
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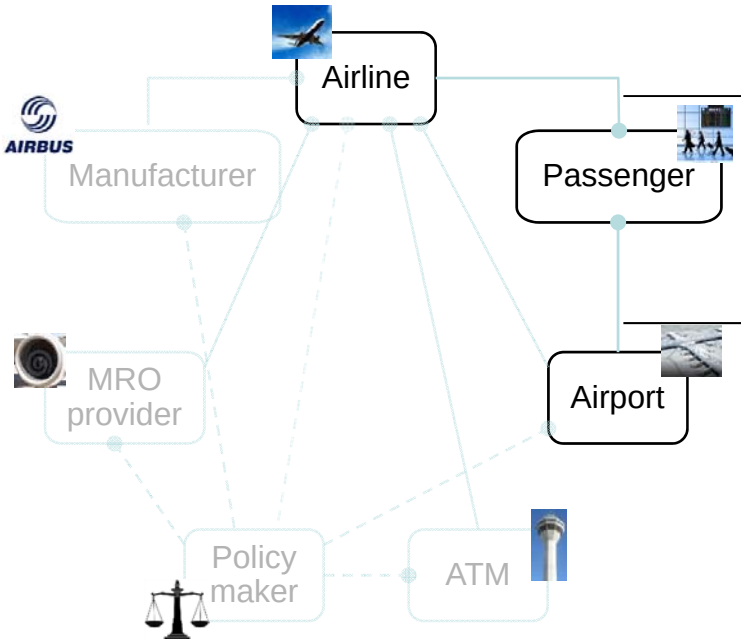
TUHH Technische Universität Hamburg-Harburg
DLR Hamburg

A customer perspective… the passenger

A ——— B A is customer of B



Overall travel Expectation :
- Connectivity
- Travel times
- Comfort
- Predictability
- Fluency

Pre-booking:
- Connectivity
- Travel times
- Predictability

In-flight:
- **Comfort**
- **Catering**
- **IFE**

Pre-flight
- Transport
- Parking
- Check-in
- Security
- Shopping
- Lounges
- Boarding

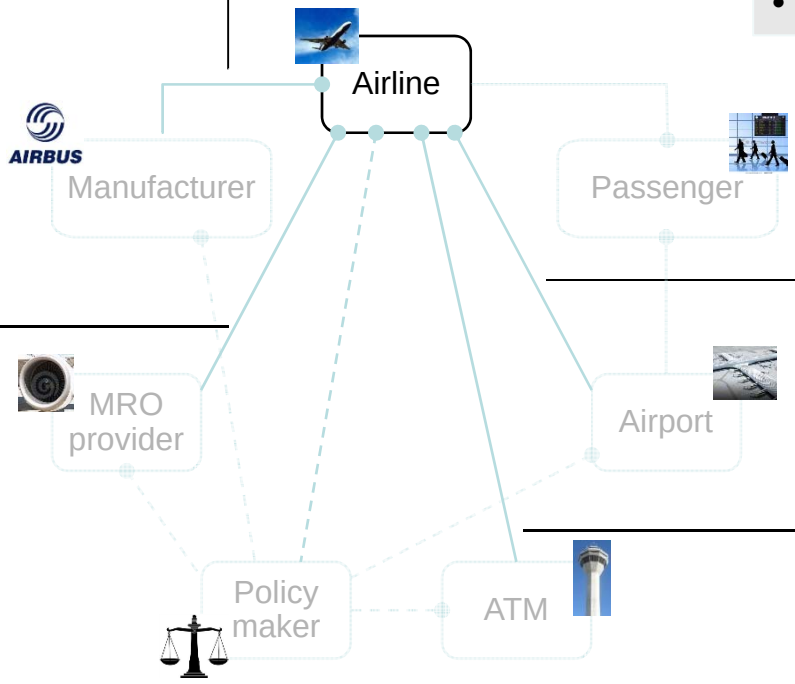
Post-flight
- De-boarding
- Baggage
- Transfer flights
- Transport

A customer perspective… the airline

A ——— B A is customer of B

Overall travel Expectation :
- Connectivity
- Travel times
- Comfort
- Predictability
- Fluency

- **Efficient aircraft (low SFC, low emissions, low MRO)**
- **Low acquisition costs**
- **Available as required**



- Sufficient capacity (slots, gates)
- Low fees
- Low **turnaround-times**
- Low transfer times

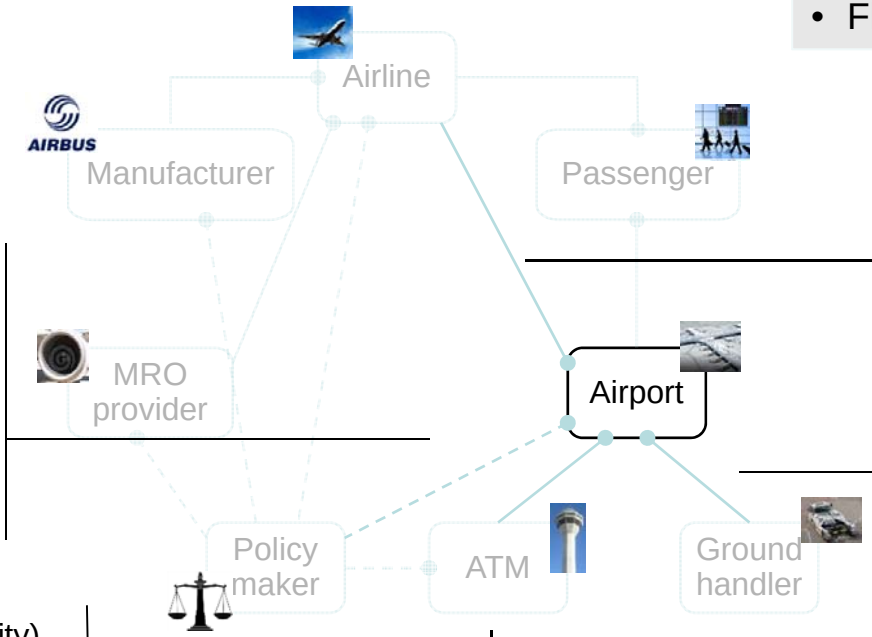
- **Low costs**
- High reliability
- High utilization)
- High availability

- Sufficient capacity
- No detours
- Low fees

A customer perspective… the airport

A ● B A is customer of B

Overall travel Expectation :
- Connectivity
- Travel times
- Comfort
- Predictability
- Fluency



- Adequate legal restrictions (noise, CO_2)
- Support for adequate airport devolopment
- Efficient landside connection

- Slot/gate compliance and information about delays
- Preparing PAX with basic informations by airlines

- Efficient work flows
- Quality (safety, reliability)

- Quality (safety, reliability)
- Short ROT/ taxi time

Responsiveness of European Airline Business Stakeholders Regarding the Inclusion of Aviation in the ETS

Presentation at the 4th EASN Association International Workshop on Flight Physics and Aircraft Design

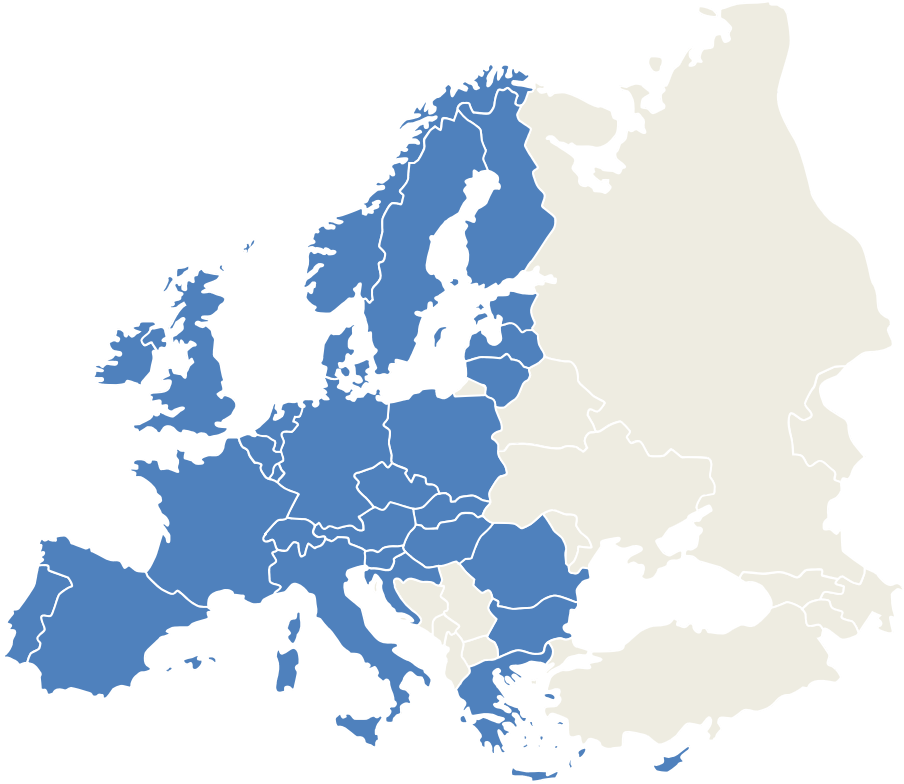
M. Naumow / P. Nolte

Agenda

Title
Introduction & Motivation
Status quo of ETS-relevant air traffic
Model Structure
Model Envelope
Results
Summary

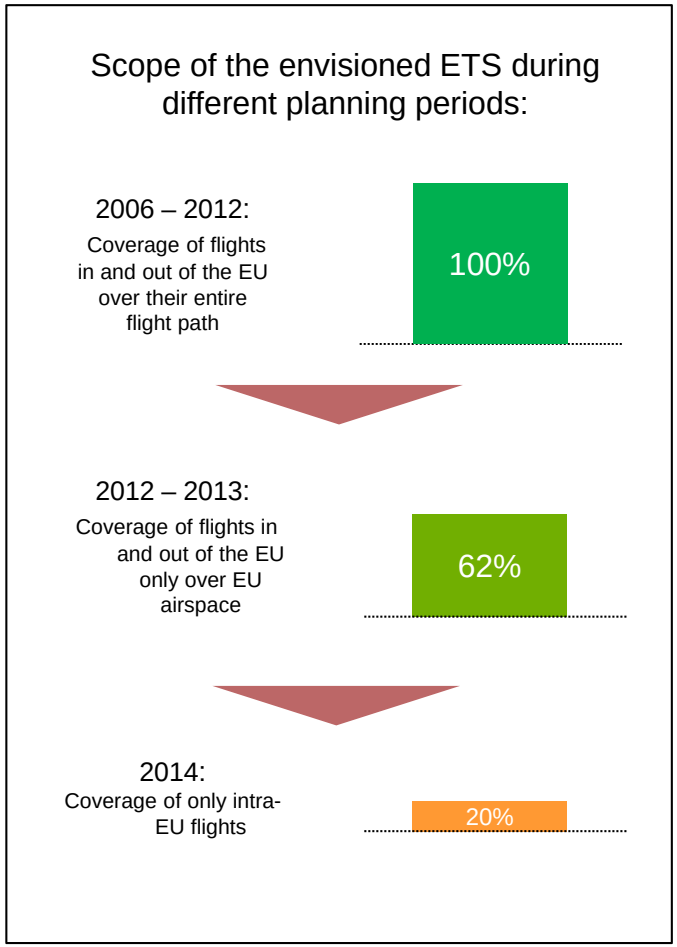
Introduction
(1/2)

- The European Emissions Trading System (ETS) is a market-based measure (MBM)
- Turning carbon emissions into a tradable commodity with a finite total amount
- In effect for static industrial facilities since 2005
- Aviation will be covered beginning 2014
- Until a decision on a global MBM is reached by the ICAO in 2016, only intra-European flights are subject to the ETS



Motivation

- The financial impact of the ETS on airlines is likely to increase in the coming years
- Different types of airlines (e.g. Low-cost or mainline carriers) are affected differently
- Previous studies have focused on rather simple case studies for specific airlines and routes/aircraft types
- Recent modifications of the ETS framework have rendered certain older studies obsolete
- Ultimate objective was the creation of an easy-to-use calculation tool for the impact of various factors



Agenda

Title
Introduction & Motivation
Status quo of ETS-relevant air traffic
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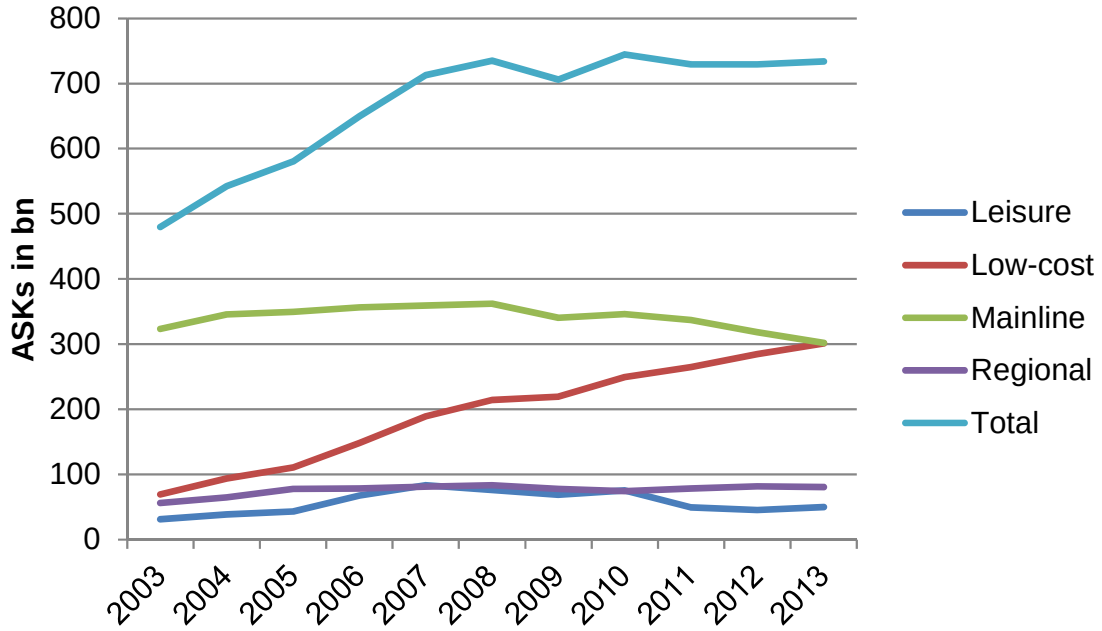
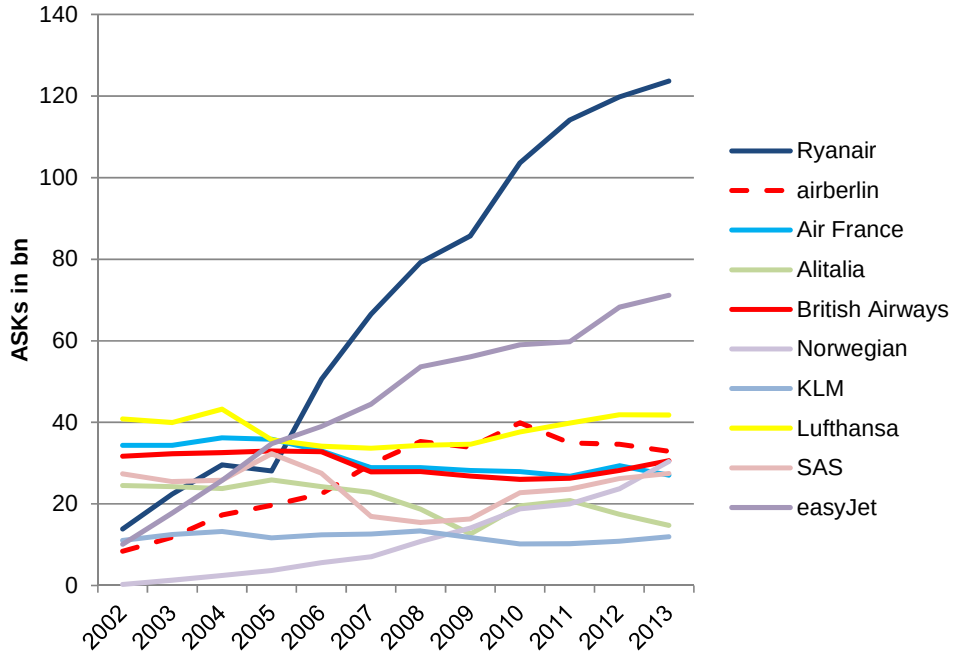
Status quo of ETS-relevant air traffic (1/2)

- Total ASKs stable since 2008
- Low-cost and mainline carriers have equalized in terms of ASKs in 2013
- Significant growth was exclusive to low-cost carriers during last decade



Status quo of ETS-relevant air traffic
(2/2)

- The ten largest carriers account for more than 50 % of the ASKs within the ETS area
- Sustained growth only by LCCs:
  - Ryanair
  - easyJet
  - Norwegian



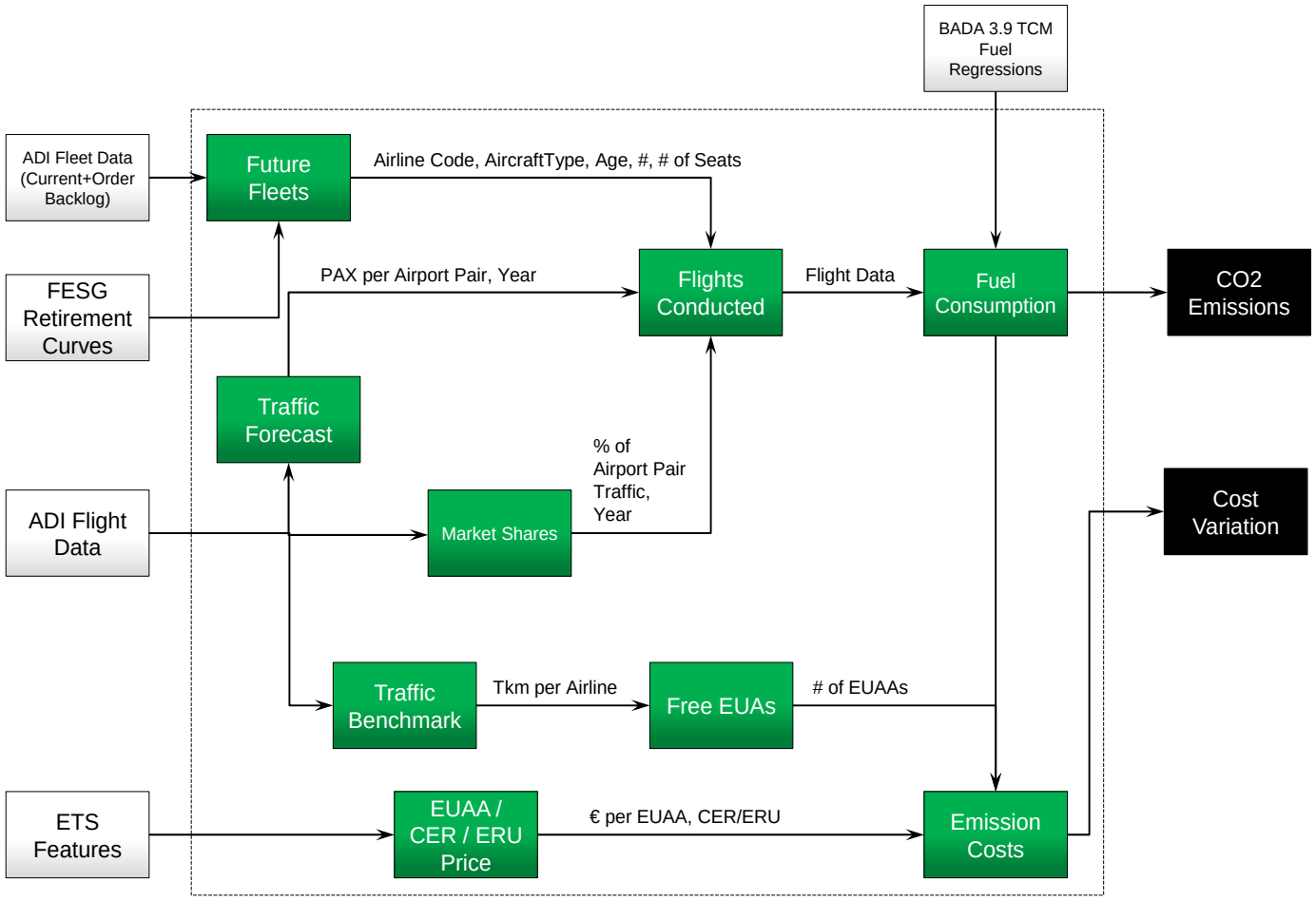
Agenda

Title
Introduction & Motivation
Status quo of ETS-relevant air traffic
Model Structure
Model Envelope
Results
Summary

Model Structure
(1/2)

- Excel/VBA-based
- Input Data:
  - Traffic: Sabre ADI Segment Data
  - Fleets: FlightGlobal Ascend
- Aircraft retirement through modified ICAO FESG modified survivor curves
- Future traffic estimates through a logarithmic regression of traffic between airport pairs and the market share development between airlines on specific routes
- Fuel burn estimation through an aircraft-type specific regression based on a BADA 3.9 trajectory calculation model

Model Structure
(2/2)



Agenda

Title
Introduction & Motivation
Status quo of ETS-relevant air traffic
Model Structure
Model Envelope
Results
Summary

Model Envelope
Coverage

- Airline types covered (>96 % of aircraft seats offered within ETS area):
    - Mainline (also known as legacy, flag or network carriers)
    - Low-cost
    - Regional
    - Leisure (scheduled)
- Not included:
    - Leisure (unscheduled)
    - Cargo
    - Business Aviation
    - General Aviation
    - Small-emitters exempted by the ETS:
        - Flights conducted by aircraft of MTOW < 7.600 kg
        - Flights operated by carriers falling under the “de minimis”-clause

Model Envelope
Assumptions

- Amount of PAX travelling between airport pairs is exogenous
- Demand sensitivity of the customer towards the flight price is zero
- Aircraft fleets of operators are utilized uniformly
- No belly freight
- Lump sum fuel burn for taxi operations and APU usage is 200 kg per flight
- Flown distances are calculated as great-circle distance +95 km to account for ATC inefficiency and holding patterns
- Average PAX weight including baggage 100 kg

Model Envelope
Limitations

- No dynamic price model for EUAAs
- New market entries or new routes cannot be estimated
    - Special market reserve of the ETS is therefore not part of the model

Agenda

Title
Introduction & Motivation
Status quo of ETS-relevant air traffic
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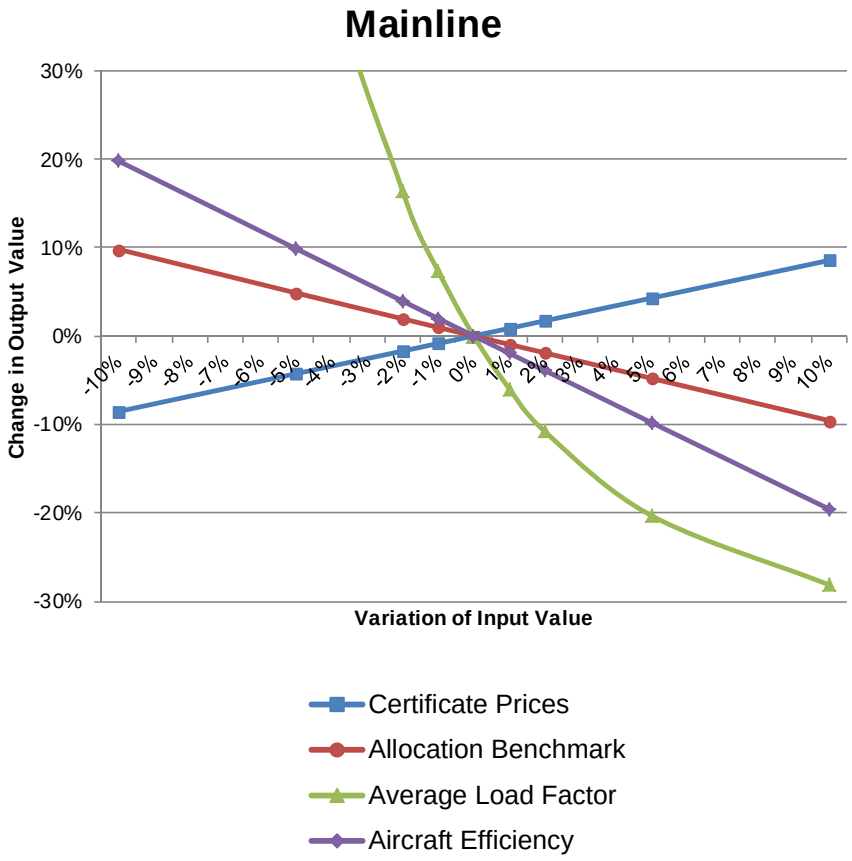
Summary

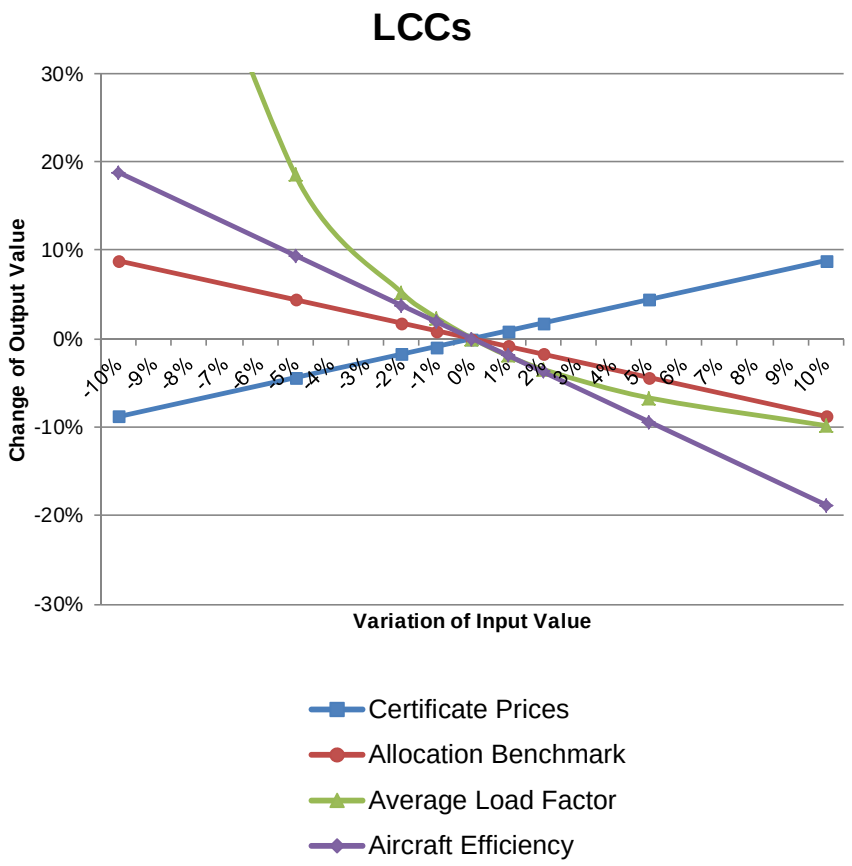
Results
Sensitivity Analysis

- Linear relationship between emission costs and:
  - EUAA prices
  - Allocation benchmark for free EUAAs
  - Aircraft efficiency
- Degressive relationship for the average load factor
- Mainline carriers have significant potential of offsetting emission costs trough LF improvement



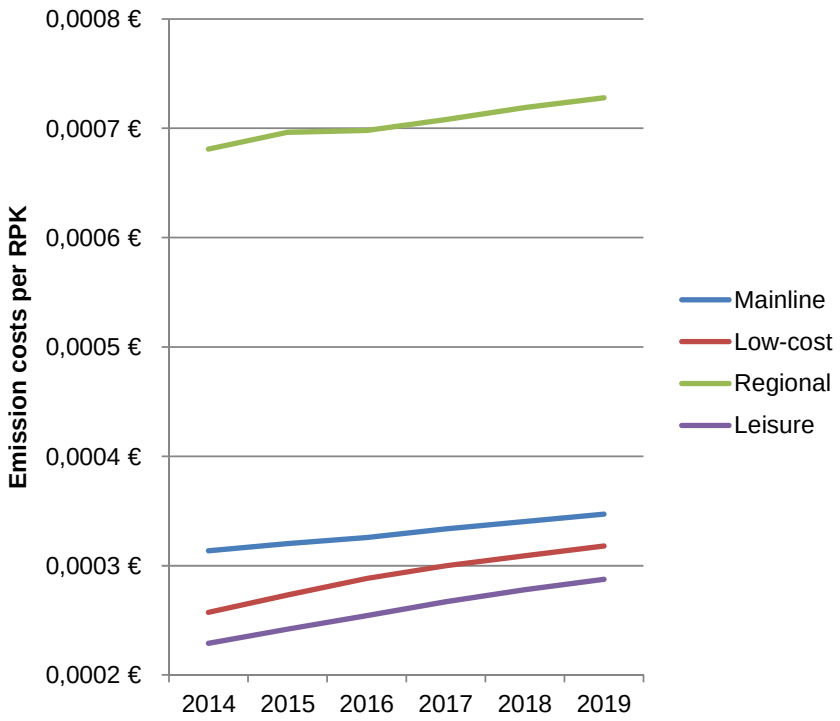
Results
Sensitivity Analysis

- Relationships between variables analogous to mainline carriers
- LCCs lack LF optimization potential
- Aircraft efficiency slightly higher than mainliners as well



Results
Conclusions

- At current EUAA prices, emissions costs from the ETS amount to about 1 % of the fuel costs on average
- Emission costs are relatively low, fleet modifications or renewals would only be induced by multitudes of current EUAA prices
- Significant increase in EUAA prices are likely to occur
- Regional carriers will experience the highest relative emission costs per RPK
- LCCs will ultimately be strained most due to lack of opportunities to offset or cross-subsidize routes



Agenda

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Introduction & Motivation
Status quo of ETS-relevant air traffic
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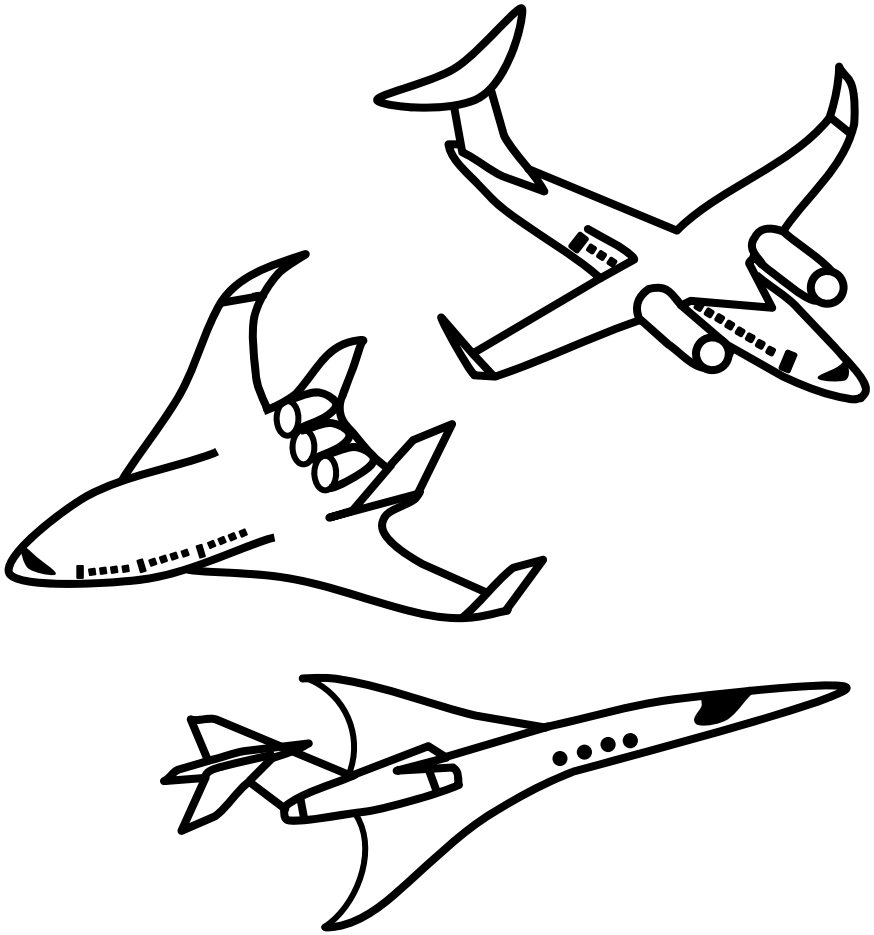
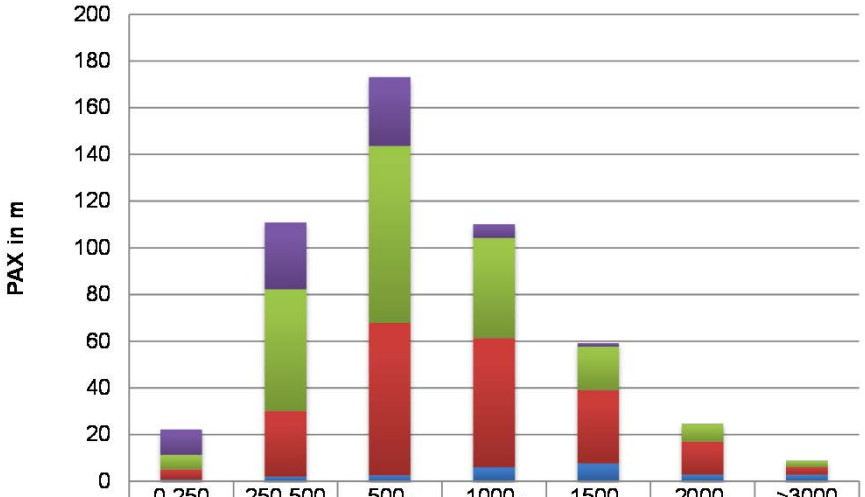
Summary

- ETS-relevant traffic until 2019 has been estimated and studied
- A system model estimating fuel consumption has been assembled
- Emission costs are very low initially but have the potential to increase significantly in coming periods
- LCCs have highest relative cost increases with the least offset opportunities

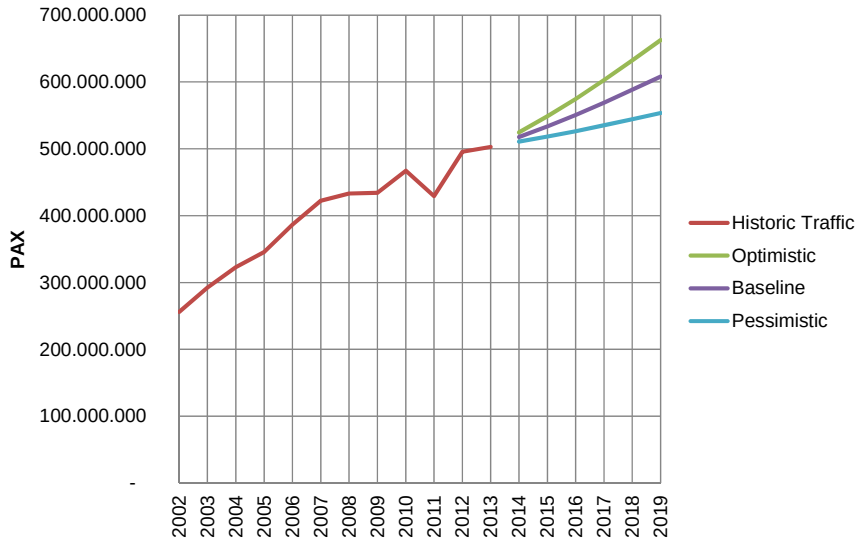


Backup

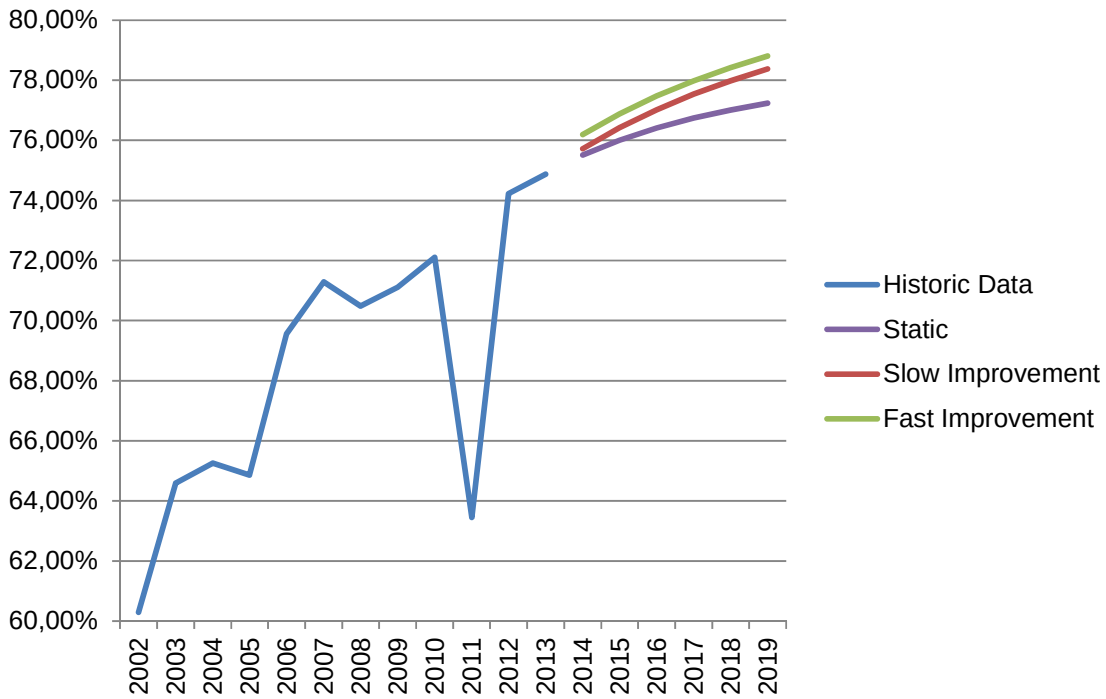


	0-250 km	250-500 km	500-1000 km	1000-1500 km	1500-2000 km	2000-3000 km	>3000 km
Regional	10,83264	28,64593	29,4361	5,813662	1,490336	0,139229	0,015989
Mainline	6,179397	52,05043	75,87758	42,90279	18,6207	7,576084	2,678003
Low-cost	4,48903	28,23438	65,23207	55,2878	31,47285	14,20561	3,242312
Leisure	0,707076	1,991843	2,518772	6,078151	7,660199	2,841849	2,91491

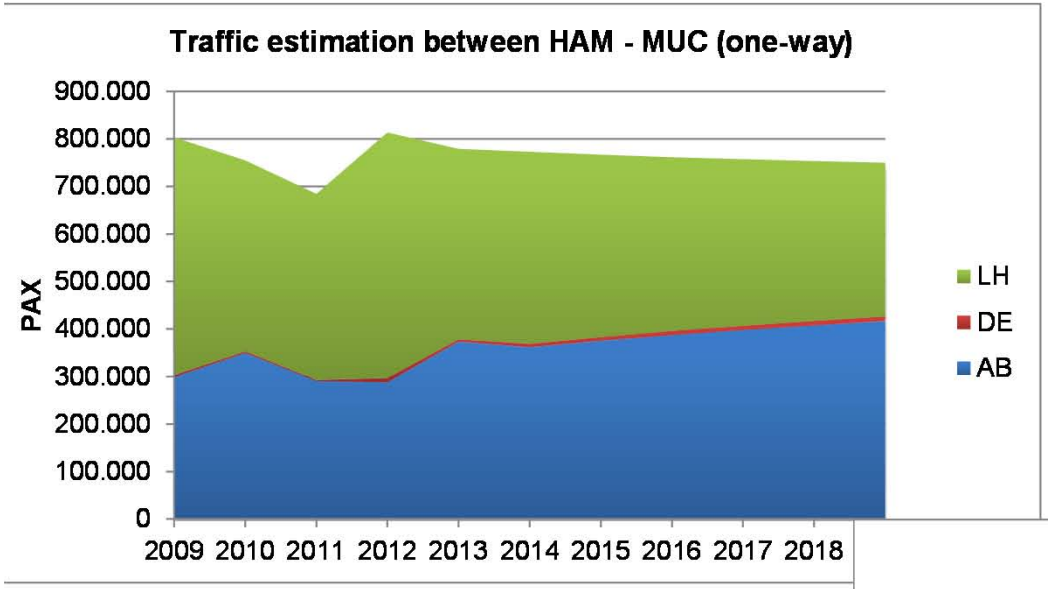
Backup

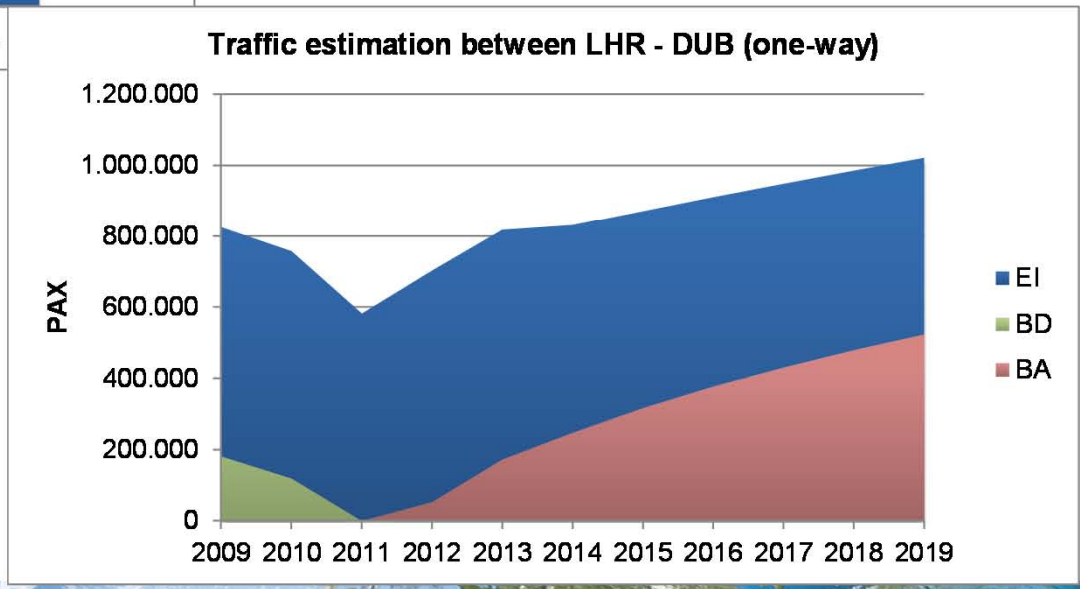

700.000.000
600.000.000
500.000.000
400.000.000
300.000.000
200.000.000
100.000.000
-
PAX
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Historic Traffic
Optimistic
Baseline
Pessimistic

Backup

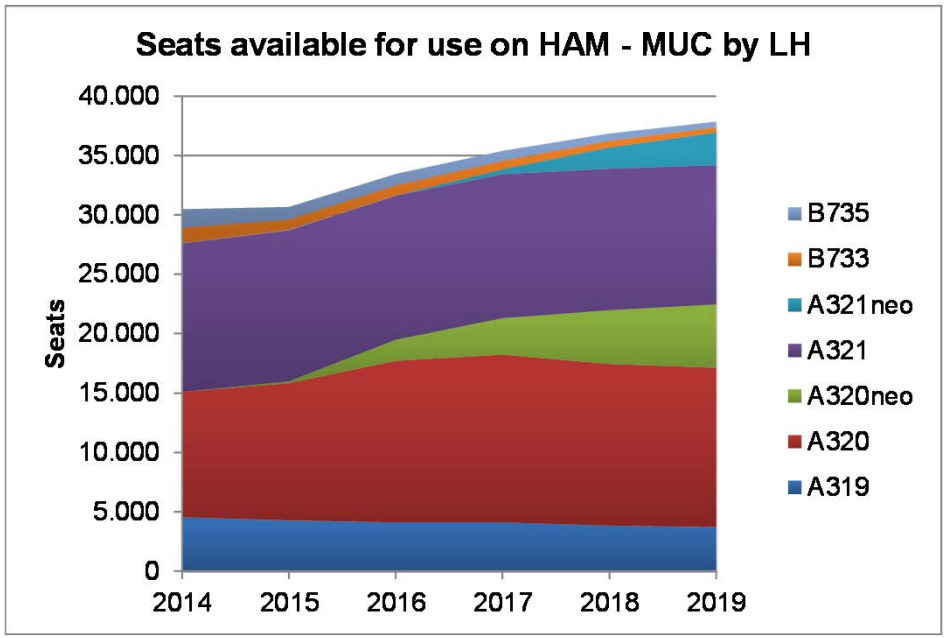

80,00%
78,00%
76,00%
74,00%
72,00%
70,00%
68,00%
66,00%
64,00%
62,00%
60,00%
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Historic Data
Static
Slow Improvement
Fast Improvement

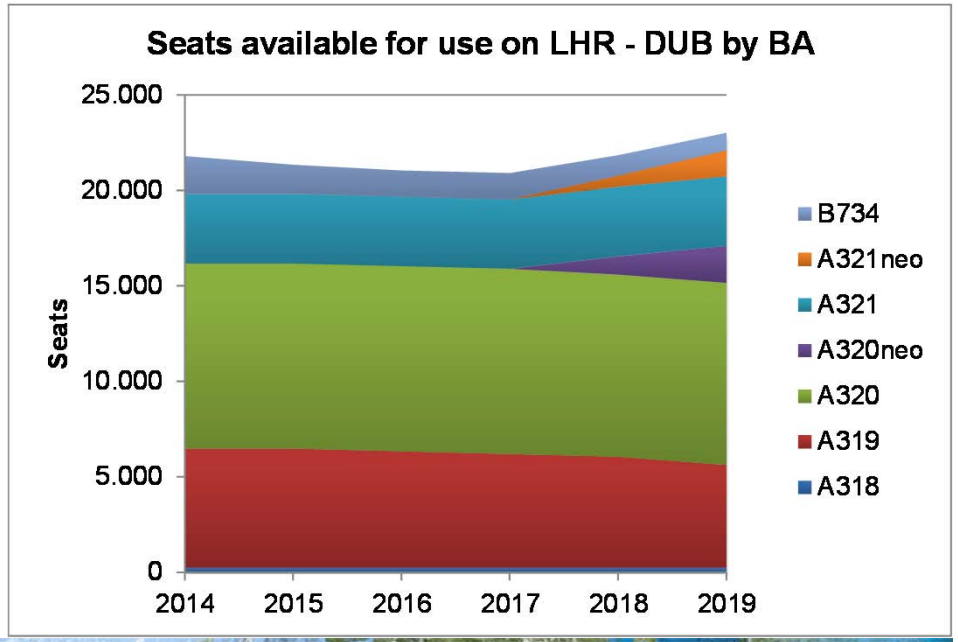
Backup


Traffic estimation between HAM - MUC (one-way)
900.000
800.000
700.000
600.000
500.000
400.000
300.000
200.000
100.000
0
PAX
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
LH
DE
AB

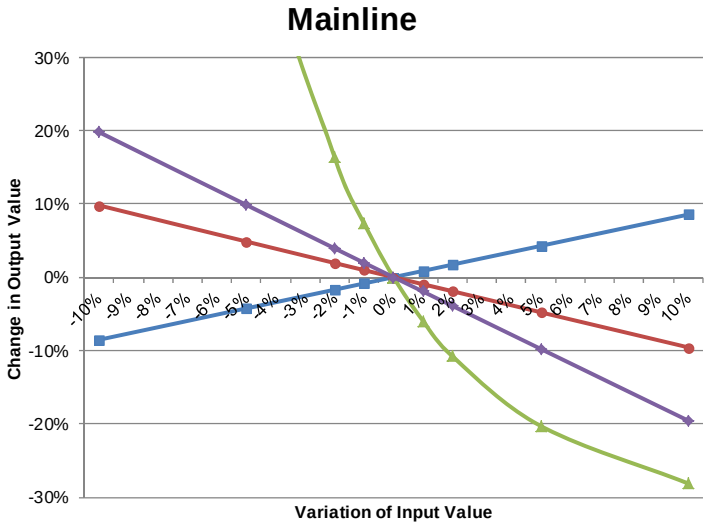

Traffic estimation between LHR - DUB (one-way)
1.200.000
1.000.000
800.000
600.000
400.000
200.000
0
PAX
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
EI
BD
BA

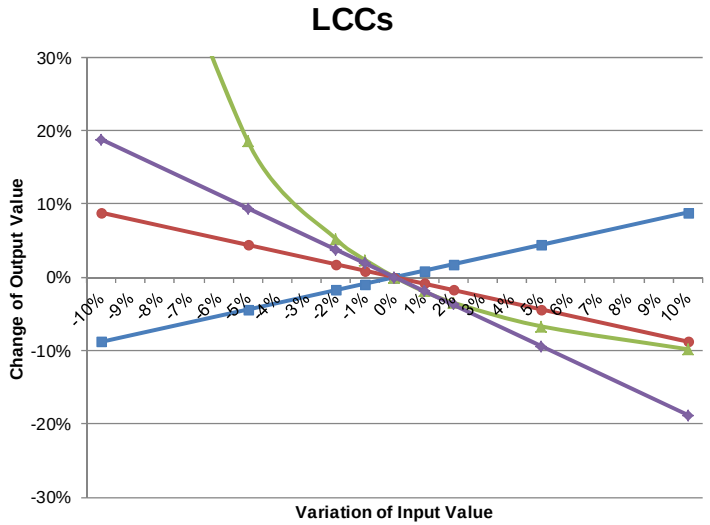
Backup

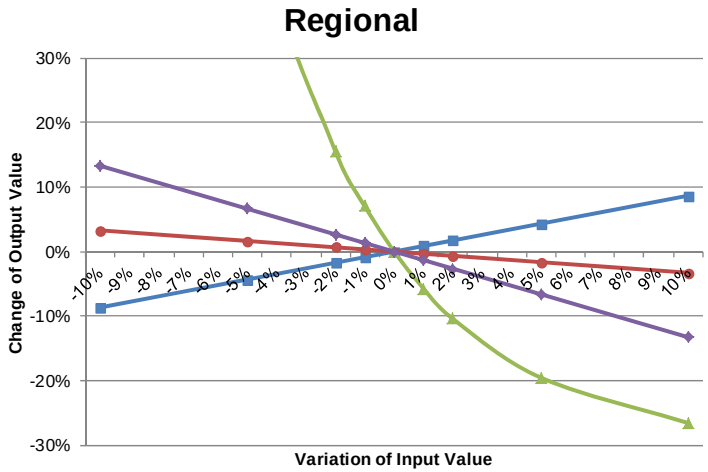

Seats available for use on HAM - MUC by LH
Seats
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0
2014
2015
2016
2017
2018
2019
B735
B733
A321neo
A321
A320neo
A320
A319

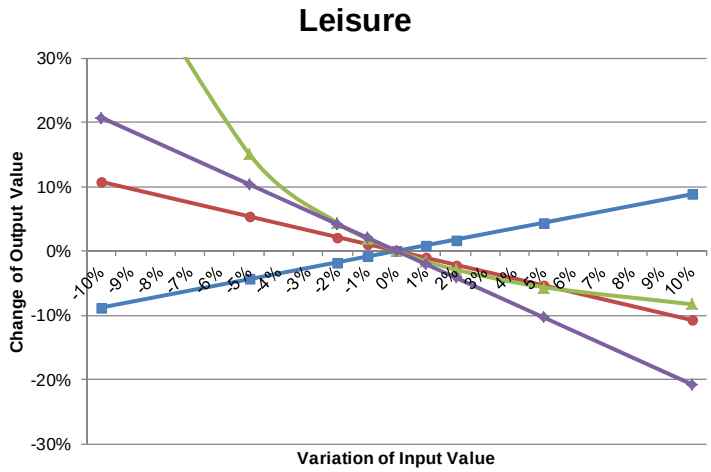

Seats available for use on LHR - DUB by BA
Seats
25.000
20.000
15.000
10.000
5.000
0
2014
2015
2016
2017
2018
2019
B734
A321neo
A321
A320neo
A320
A319
A318

Backup

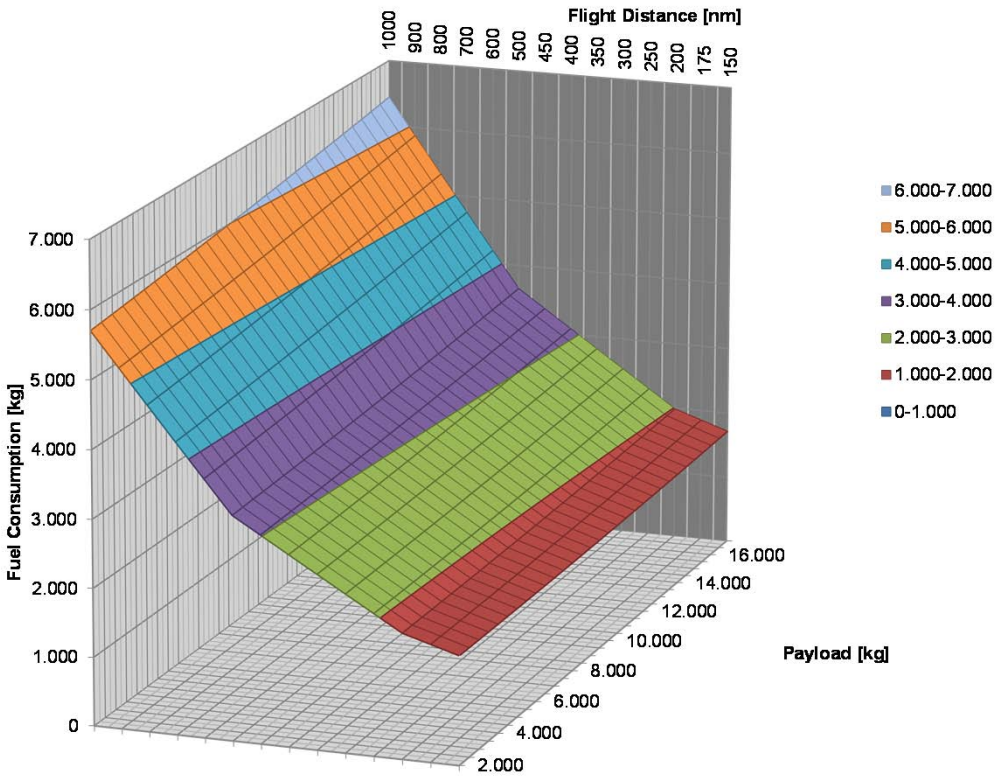

Mainline
Change in Output Value
Variation of Input Value
30%
20%
10%
0%
-10%
-20%
-30%


LCCs
Change of Output Value
Variation of Input Value
30%
20%
10%
0%
-10%
-20%
-30%

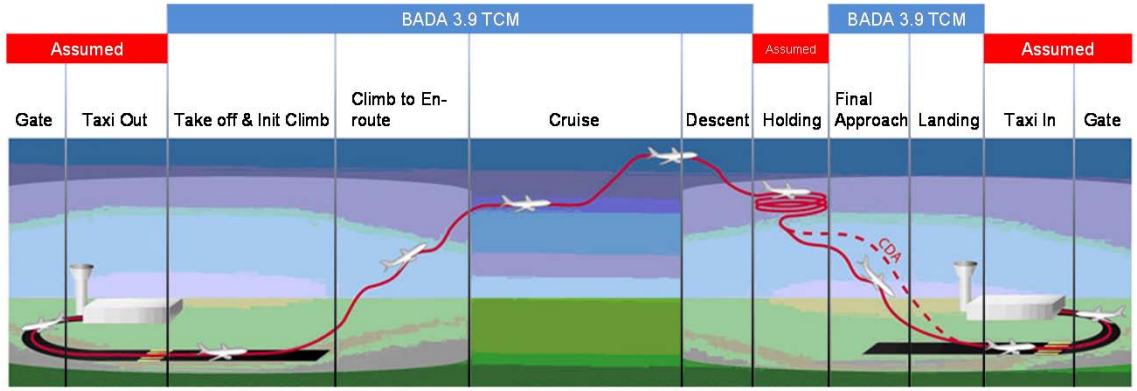

Regional
Change of Output Value
Variation of Input Value
30%
20%
10%
0%
-10%
-20%
-30%


Leisure
Change of Output Value
Variation of Input Value
30%
20%
10%
0%
-10%
-20%
-30%

Backup


Flight Distance [nm]
1000
900
800
700
600
500
450
400
350
300
250
200
175
150
Fuel Consumption [kg]
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0
Payload [kg]
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
6.000-7.000
5.000-6.000
4.000-5.000
3.000-4.000
2.000-3.000
1.000-2.000
0-1.000

Backup


BADA 3.9 TCM
BADA 3.9 TCM
Assumed
Assumed
Assumed
Gate
Taxi Out
Take off & Init Climb
Climb to En-route
Cruise
Descent
Holding
Final Approach
Landing
Taxi In
Gate
CDA

Backup

0,0600
0,0550
0,0500
0,0450
0,0400
HHI
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Year
Historic Data
Pessimist
Baseline
Optimist

Knowledge for Tomorrow

Promo Air
Your future takes off here!

Promoting Aeronautics Innovation & Research

PROMO-AIR Project:

Promoting Aeronautics Innovation & Research

Apostolos Chamos, LTSM, University of Patras

4th EASN Workshop

October 29th, 2014, Aachen, Germany

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

The project

- **Promo-Air** is a FP7 EC funded project in response to the call:

AAT.2013.7-3

"Communication of EU funded RTD project results to targeted audience"

CSA-SA-Call: FP7-AAT-2013-RTD-1

Starting date: 01/05/2013

Expected ending date: 30/04/2015

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Why Promo-Air?

State – of – the – Art

- ✓ Aeronautics related studies **face a growing competition** with other fields such as medicine, law etc.
- ✓ Number and quality of engineering students is decreasing with time
  - ➢ European Aeronautics Industry has a **shortage of engineers???**
- ✓ More fascinating **potential aeronautics related career** for secondary and technical school students.
- ✓ **Motivating the next generation** to get interested in the field of Aeronautics
  - ➢ **Key – Factor:** "Exploration" of the "World of Aeronautics"

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

High level project objective

The Concept

- ✓ to **raise the interest of young Europeans**
- ✓ to **promote scientific and technical studies and careers in aeronautics and air transport** research and industry

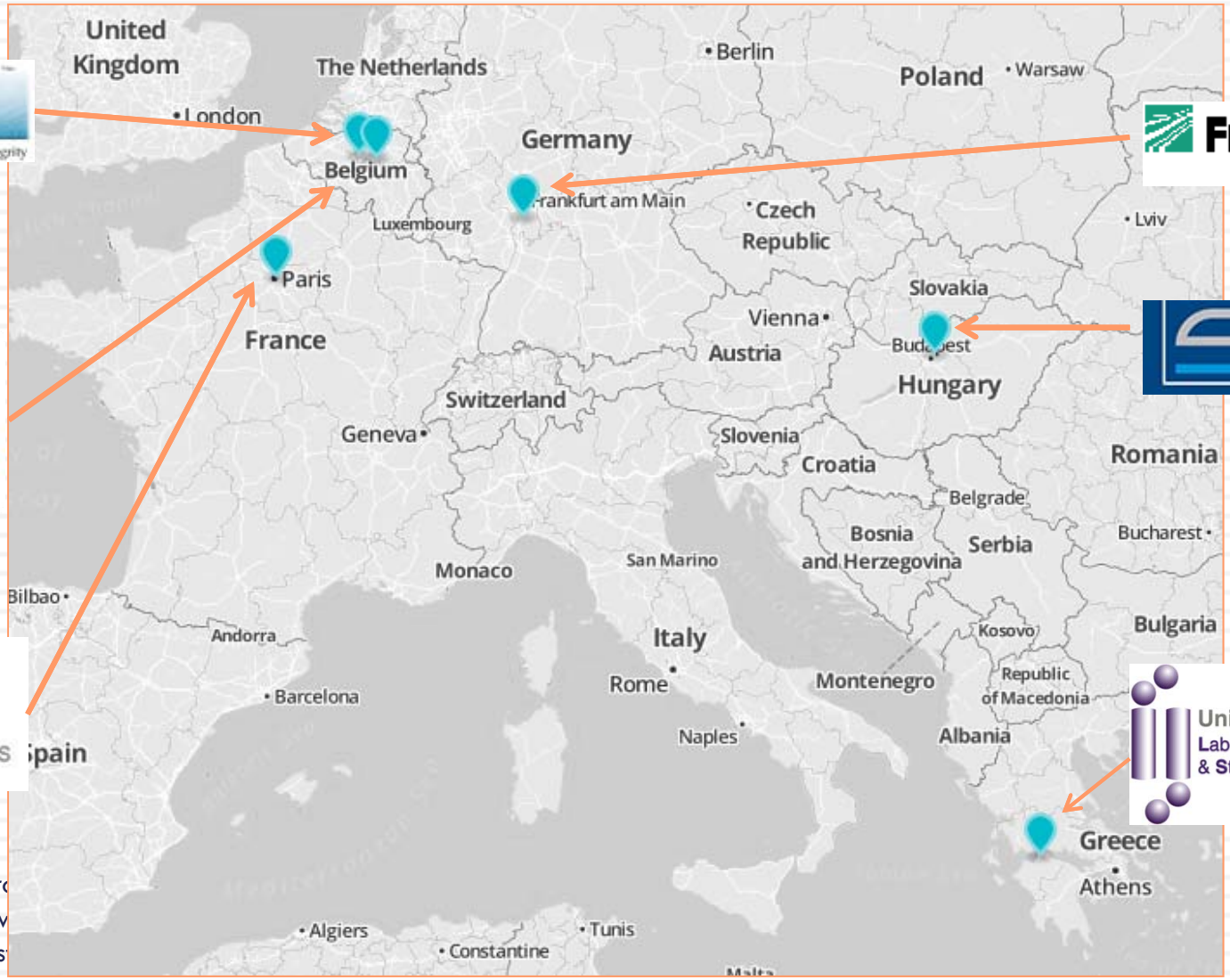
The tools

- ✓ Through the production of **attractive educational material** by incorporating state-of the-art research results of recent and current Aeronautics and Air Transport projects.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Promo Air
Your future takes off here!

The Consortium



BluSky Services - quality, reliability, integrity

Fraunhofer IED

Consulting IOT

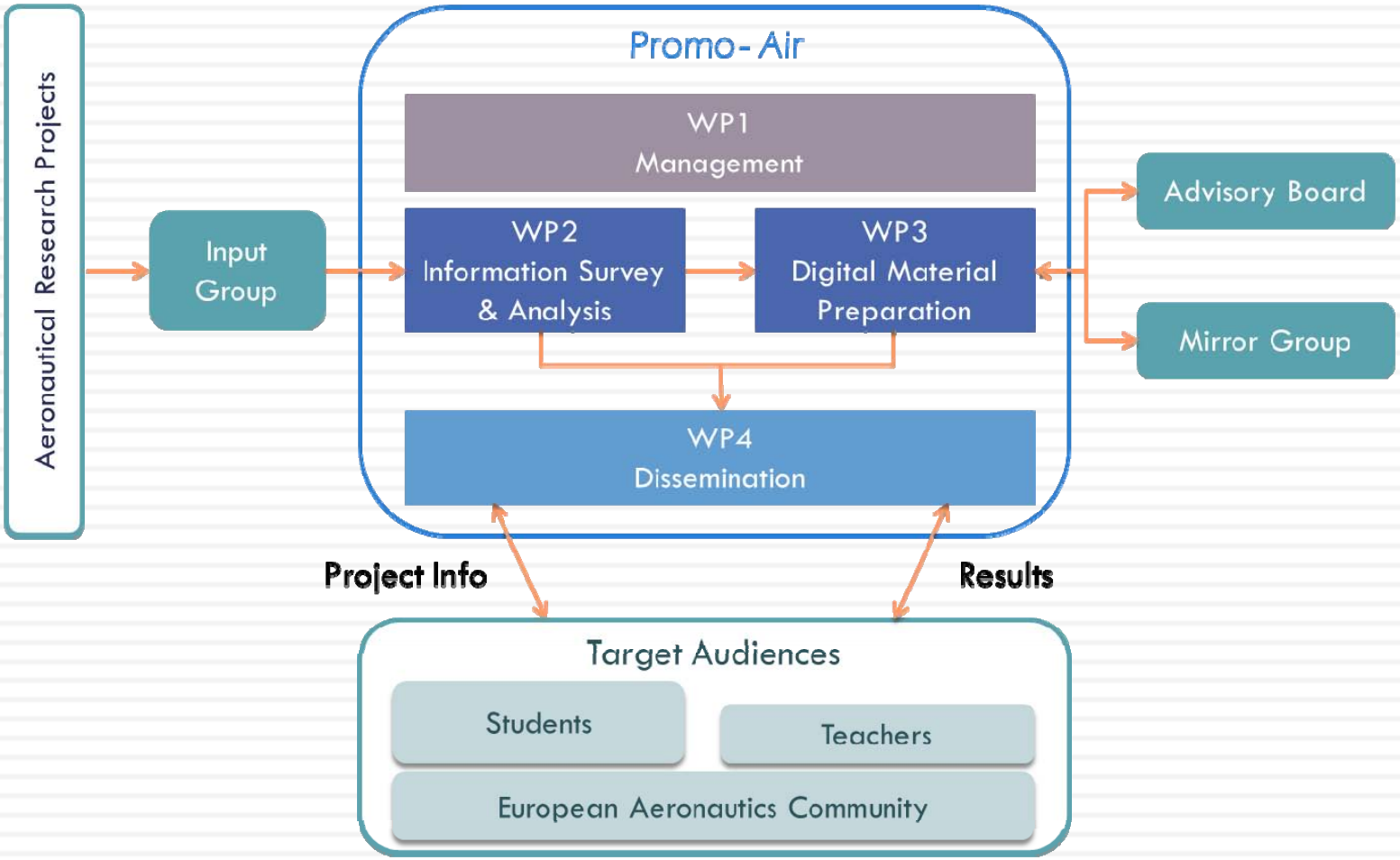
easn

PARTNERS

University of Patras
Laboratory of Technology & Strength of Materials

This pr
Framew
demons

Project Structure



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

How we selected the projects?

1. Well Represented all Activity Domains

Activity Domains

- The Greening of Air Transport
- Increasing Time Efficiency
- Ensuring Customer Satisfaction & Safety
- Improving Cost Efficiency
- Protection of Aircraft and Passengers
- Pioneering the Air Transport of the Future
- Cross Cutting Activities

2. Well Represented all Technical Fields

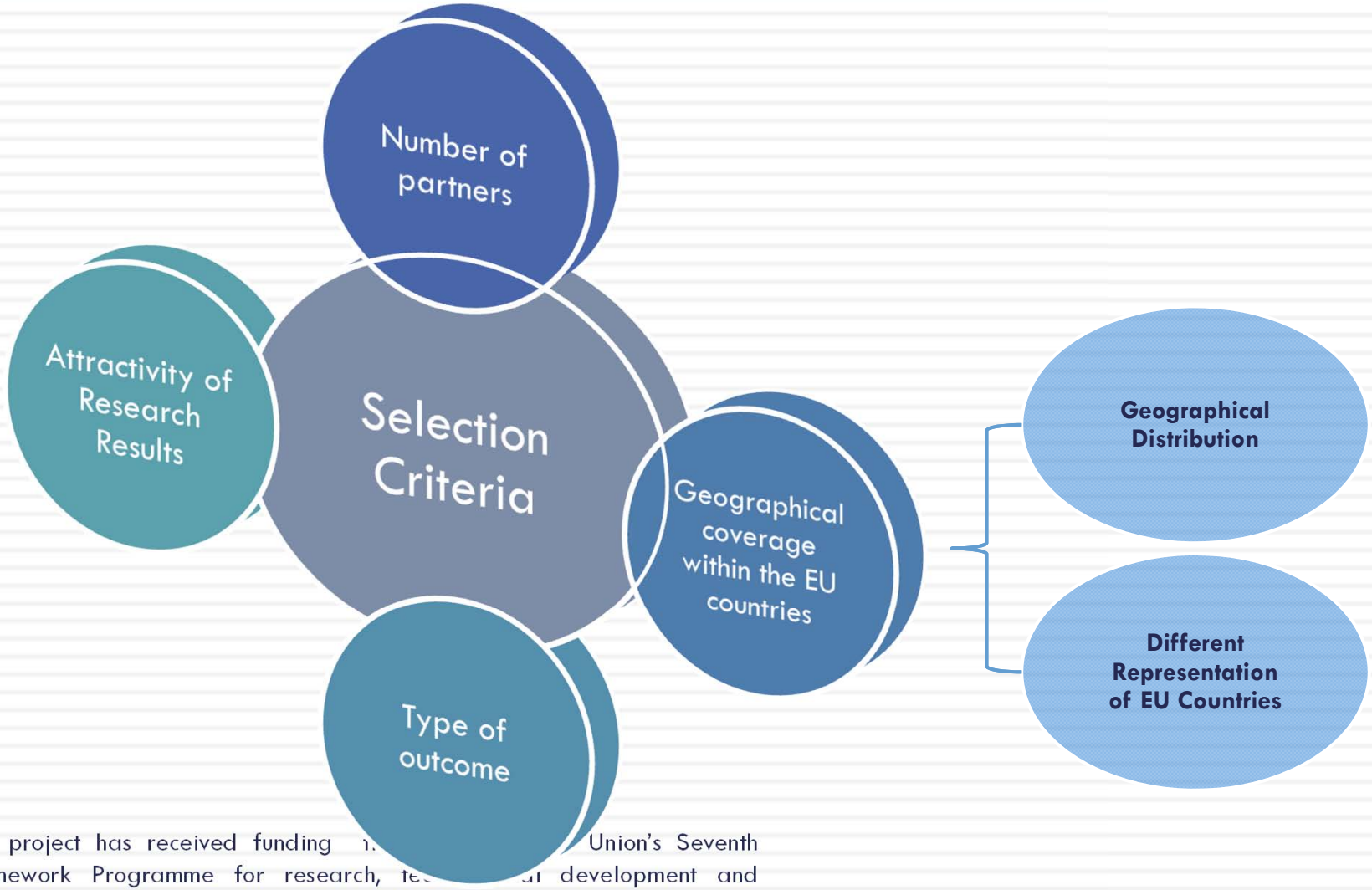
Technical Fields

- Flight Physics
- Aerostructures and Materials
- Systems and Equipment
- Avionics, Human Factors and Airports
- Propulsion
- Noise and Vibration
- Design Tools and Production
- Maintenance and Disposal
- Breakthough and Novel Concepts

Within calls 1-5 of FP7, **187 AAT projects** have been subjected to this analysis

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

How we selected the projects?



This project has received funding [illegible] Union's Seventh Framework Programme for research, [illegible] development and demonstration under grant agreement n° 605007.

Promo Air
Your future takes off here!

Our Input Group (projects selected)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

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Your future takes off here!

Visual Educational material

✓ **Videos**

i. General aeronautics sequences

ii. Project specific sequences

✓ **E-brochures**

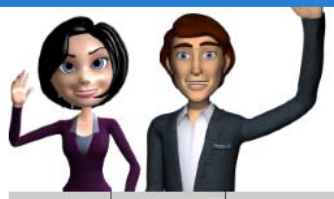
✓ **Quiz / Contest**

✓ **Animations**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Steps for a student to win!

Step 1:The visitor enters the Promo-Air website



Locate the hot areas on the interactive window above and click them to follow the selected topic...

Step 2: Discovers a 3D aircraft

The user is able to rotate the airport and to spot on different parts of them, namely hot areas (e.g. body, engine, fuel, trees etc.)

Each hot area is described by the respective educational material produced.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Promo Air
Your future takes off here!

Steps for a student to win!

Step 3: Selects a hot-area & learn about the relevant projects through the following:

E-Brochures

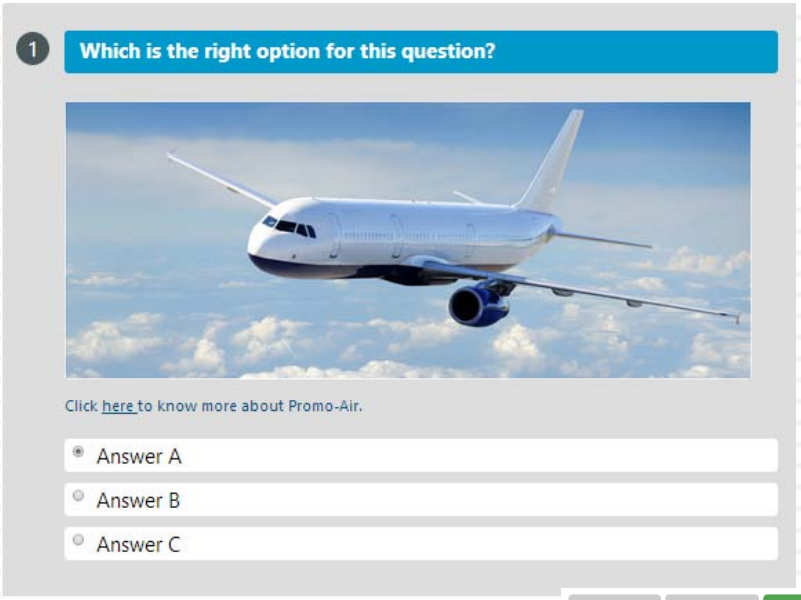
Videos

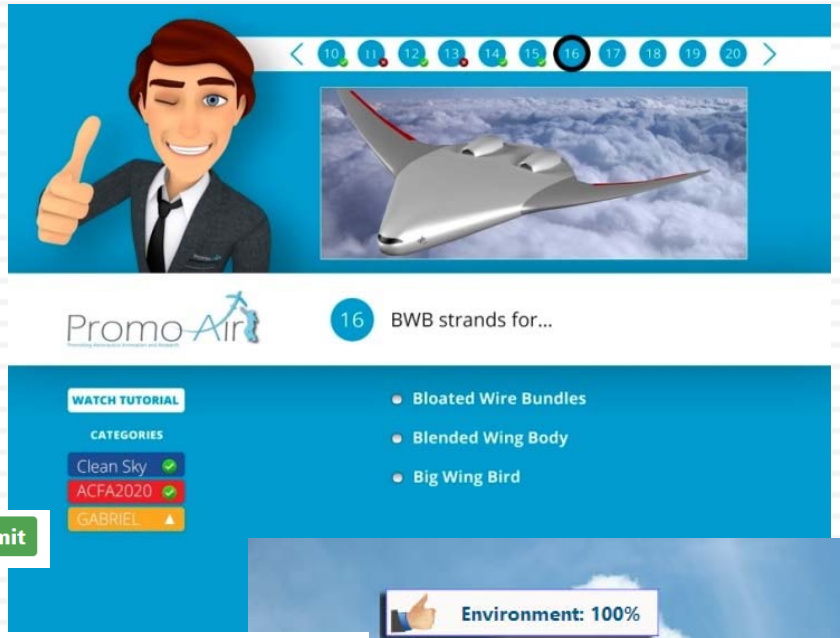
Projects' websites

This project has received funding from the European
Framework Programme for research, technological develop
demonstration under grant agreement n° 605007.

Steps for a student to win!

Step 4: Takes part through a quiz to a challenging pan-European game competition





The answer is correct

This project has received funding from the European Union's Seve
Framework Programme for research, technological development
demonstration under grant agreement n° 605007.

Promo Air
Your future takes off here!

Steps for a student to win!

Step 5: Winner's award: an all-paid tour to Airbus Assembly Line, in Toulouse, France

Sponsorship

AIRBUS GROUP

offers the visit and the tour in the AIRBUS premises in Toulouse, France as the 1st award.

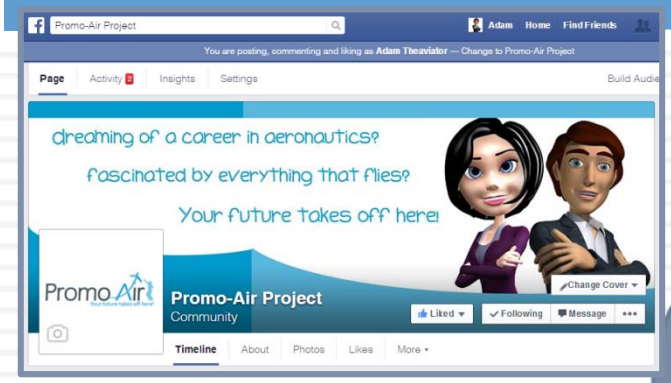
Sponsorship

easn

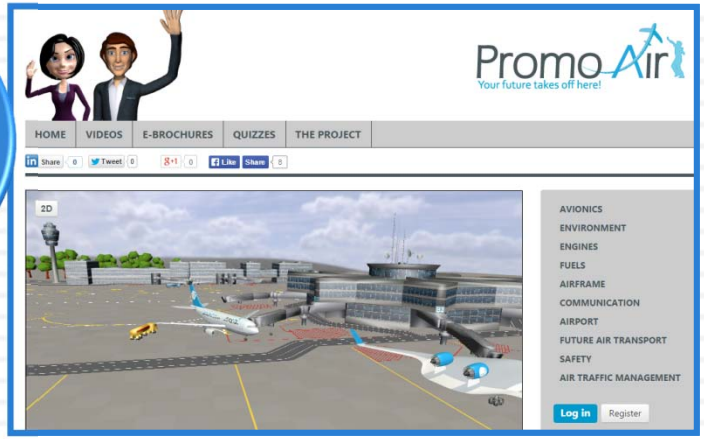
covers the travel costs and accommodation for the winner and his legal guardian.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Communication Strategy



Website



Social Media Profiles

Workshops

European Aviation Week

...he European Union's Seventh ...nological development and demonstration under grant agreement n° 605007.

Communication Strategy

The website

www.promo-air.eu

Administrators

Adam the Aviator!
Claire the Air Traffic Manager!

Hey guys!!!
Are you dreaming of a career in aeronautics?

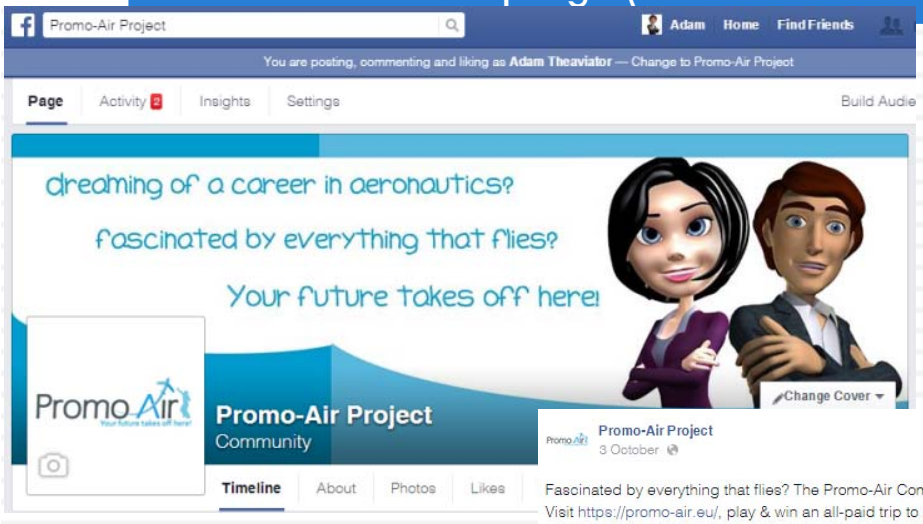
Enter **www.promo-air.eu,** learn, play and win a trip to Airbus in Toulouse

Fasten your seat-belts!!!
We will be your guides!

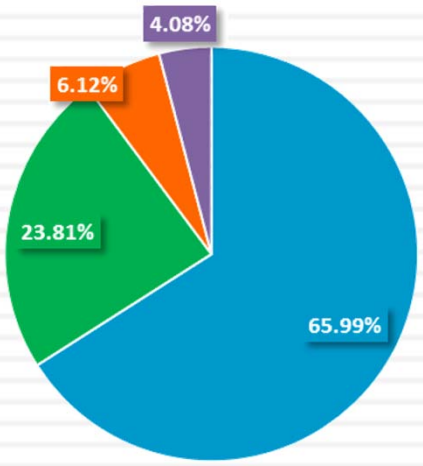
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Communication Strategy

Social Media Campaign (started a month ago and it is up and running)



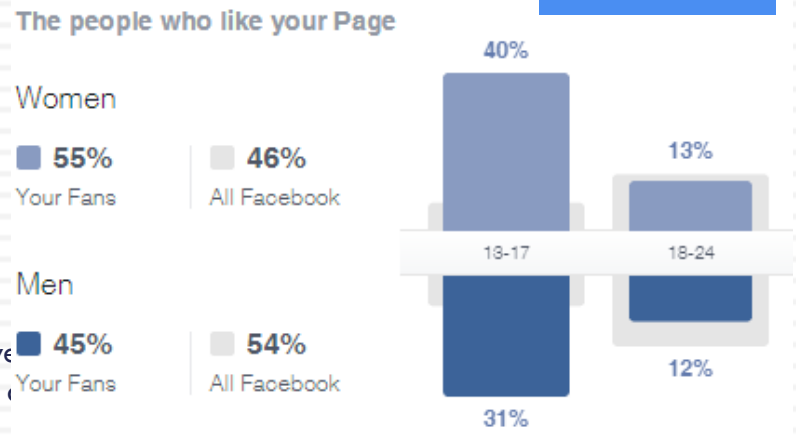
Total Likes >1.500



Website Visits

- Social
- Direct
- Referral
- Organic Search

Audience



This project has receive
Framework Programme
demonstration under gran
eve

Communication tools

The European Aeronautics Science Week

When

A week by the end of the project (**March 2015, 2nd half**)

Where

In the 28 EU countries/members in parallel

How

During this week, the invited students from local high schools will:

- **Visit a local university or an industry laboratory dealing with aeronautical research**
- **Watch the educational material prepared by Promo-Air project**

Opportunity

For students

motivate and raise the interest of young Europeans in studies and careers related to aeronautics

For Universities

To open their doors to high school students so as to show them what it's like to study aeronautics in the respective university

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Support for the Open Event

UK: 3 Cities

- ✓ Cambridge
- ✓ Manchester
- ✓ Glasgow

Ireland: 1 City

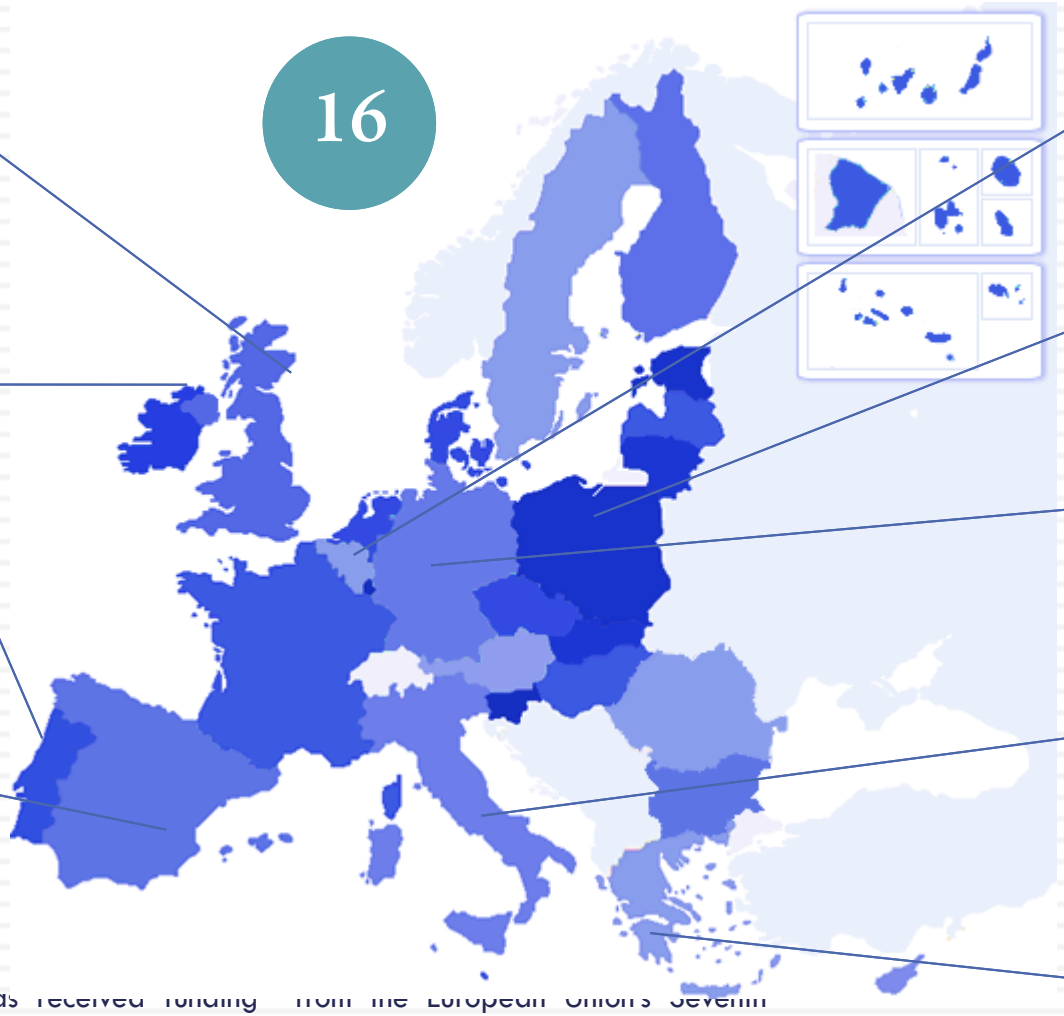
- ✓ Limerick

Portugal: 1 City

- ✓ Porto

Spain: 2 cities

- ✓ Madrid,
- ✓ Las Palmas



Belgium: 2 Cities

- ✓ Liege
- ✓ Leuven

Poland: 1 City

- ✓ Warsaw

Germany: 2 Cities

- ✓ Hamburg
- ✓ Cologne

Italy: 2 Cities

- ✓ Milan,
- ✓ Florence

Greece: 2 Cities

- ✓ Patras
- ✓ Volos

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

We need your support!

- EASN member university join and promote the European Aeronautics Science Week
- **Many positive answers so far, still we need more!**
- Encourage secondary school students of your local societies to follow Promo-Air (website & social media) and participate to the competition
- **"Promote us" through your institute and project websites**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 605007.

Promo Air
Your future takes off here!

Thank you for your attention!

Join us so as to raise the interest of young people in Aeronautics!!!

For more info:

Visit us: www.promo-air.eu

Contact us: hamosa@mech.upatras.gr
pantelak@mech.upatras.gr

...nding from the European Union's Seventh ...mme for research, technological development and ...r grant agreement n° 605007.

GRAIN2 PROJECT: GREENER AERONAUTICS INTERNATIONAL NETWORKING-2

EU-China Networking and Research Projects

Gabriel Bugeda, Jacques Périaux, and Jordi Pons-Prats

Consortium:

Generalitat de Catalunya

UNIVERSITAT POLITÈCNICA DE CATALUNYA

In colaboration with: UNESCO

OVERVIEW

- **Introduction:**
- **EU-CHINA networks and research projects**
  - **AeroChina:** Objectives and Conclusions
  - **AeroChina 2:** Objectives and Conclusions
  - **GRAIN:** Objectives and Conclusions
  - **GRAIN 2:** Objectives
  - **MARS:** Objectives and Conclusions
  - **COLTS:** Objectives
- **Lessons Learnt**
- **Pros and Cons**
- **Opportunities and Challenges**

EU-CHINA NETWORKS AND RESEARCH PROJECTS

- **NETWORKS:**
  - **Aero China**; *Promoting Scientific Cooperation Between Europe And China In The Field Of Multi physics Modeling, Simulation, Experimentation Validation And Design Methods In Aeronautics* **(2005, FP6)**
  - **Aero China2**; *Prospecting And Promoting Scientific Cooperation Between Europe And China In The Field Of Multi-physics Modeling, Simulation, Experimentation And Design Methods In Aeronautics* **(2007, FP7)**
  - **GRAIN**; *Greener Aeronautics International Network* **(2010, FP7)**
  - **GRAIN2**; *Greener Aeronautics International Network 2* **(2013, FP7)**

- **RESEARCH PROJECTS:**
  - **MARS**; *Manipulation of Reynolds Stress for Separation Control and Drag Reduction* **(2010, FP7)**
  - **COLTS**; *Casting of Large Titanium Structures* **(2010, FP7)**

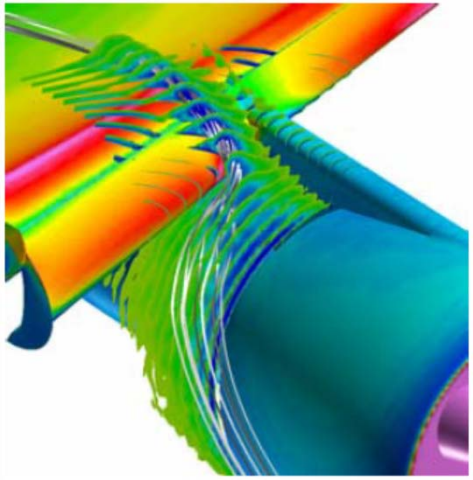
EU-CHINA PROJECTS COORDINATORS

- **COORDINATORS :**
  - Aerochina: G.Bugeda/J.Périaux (CIMNE) and BAI Wen (ACTRI/AVIC)
  - Aerochina2: G. Bugeda/J.Périaux (CIMNE) and SUN Xiasheng/SUN Jian (ASRI/AVIC)
  - GRAIN: G. Bugeda/J.Périaux/J.Pons-Prats (CIMNE) and HUA Jun (CAE)
  - GRAIN2: G. Bugeda/J.Périaux/J.Pons-Prats (CIMNE) and SUN Jian (CAE)
  - MARS : G. Bugeda/J.Périaux/J.Pons-Prats (CIMNE); NING Qin (Univ. Sheffield) and Ms SUN Jian (CAE) ; DONG Jun (ARI)
  - COLTS: Tsingua WU (Univ. Birmingham) and SUN Jian (CAE)
- **PROJECT OFFICERS :**
  - EU:
    - D. Knoerzer (Aerochina, Aerochina2, GRAIN, GRAIN2 and MARS)
    - E. Lecomte (COLTS)
  - CHINA:
    - Ms SHI Jinmin

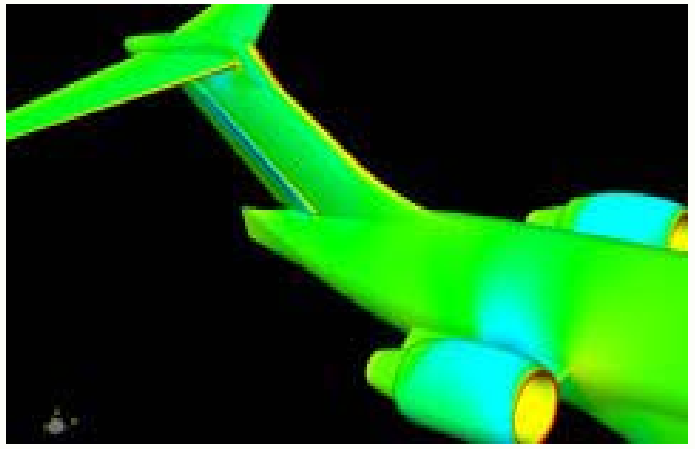
EVOLUTION OF THE NETWORK OBJECTIVES

Aero China

- Consortium:
  - **EU(12): CIMNE**, DASSAULT, EADS CRC, EADS-M/DE, AIRBUS, IUSTI-UNIV. PROV., INRIA, DLR, ERCOFTAC, UNIV. BIRMINGHAM, IFTR, INGENIA
  - **CH: (12): ACTRI**, CADI, NPU, CARIA, SARI, FAI, BUAA, TSINGHUA UNIV., NUAA, ZHEJIANG UNIV., PEKING UNIV, CAAA
- Objectives:
  - identify and implement future cooperation collaboration for the solution of multidisciplinary design problems in aeronautics, identify RTD areas of mutual interest in the field
  - collect and disseminate the existing knowledge in the field of multiphysics modelling, simulation, experimentation and design in aeronautics
- Keywords:
  - Cooperation, research, multiphysics, modelling, simulation, experimentation, design



Courtesy of DLR; Engine Interferences; C.-C. Rossow, N. Kroll, D. Schwamborn



Courtesy of FAI; CFD Methods and Tools; DANG Tiehong

CONCLUSIONS FROM AEROCHINA

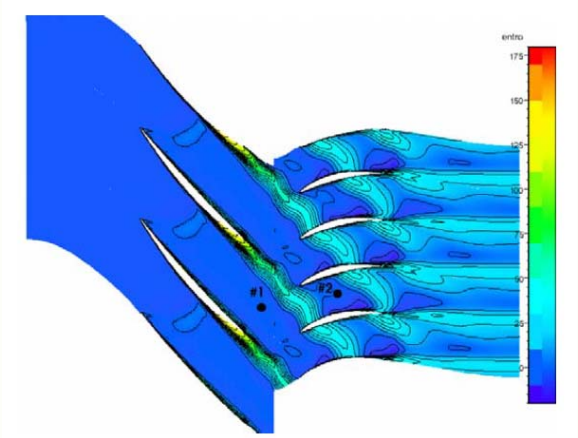
- Successful organization of an Open Short Course (Xian) and an Open Workshop (Barcelona).
- Important findings about **how to work together** in a technical and managerial point of view.
- Increase quality of dialogue despite difficulties of common English language (very much improved in later projects).
- identified joint skills, experiences and capabilities of the Chinese partners in tandem with European partners in the relevant. technological areas of Single and Multi physics problems in aeronautics through **Working Groups.**
- Developed concepts of collaboration in several areas between Chinese and the European partners which will ensure win-win situations.
- Generation of important understandings and links between European and Chinese cultural issues.
- Paved the way to management efficiency for Aerochina 2.

CIMNE

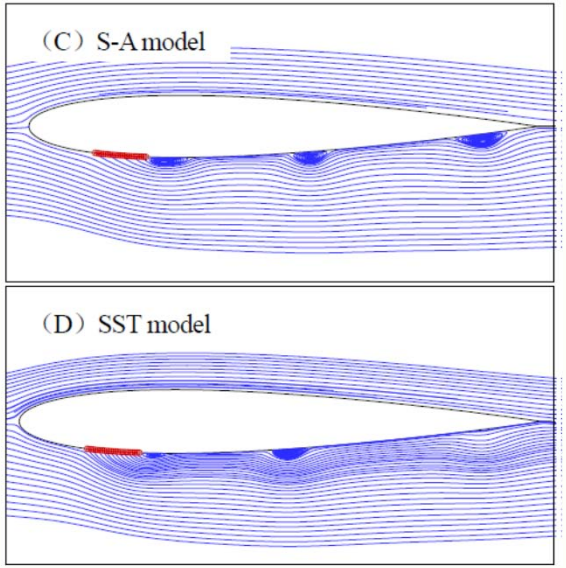
EVOLUTION OF THE NETWORK OBJECTIVES

AeroChina2

- Consortium:
  - **EU(13)**: **CIMNE**, FOI, EADS IW France, NUMECA, AIRBUS, UNIV. BIRMINGHAM, ALENIA, UNIV. SHEFFIELD, IUSTI UNIV. PROV., IFTR, INRIA, INGENIA, DLR
  - **CH(18)** : **CAE**, ACTRI, ZHEJIANG UNIV., CADI, PEKING UNIV., NPU, CAAA, CARIA, ASRI, SADRI, BIAM, FAI, GTE, BUAA, BAMTRI, TSINGHUA UNIV., IMCAS, NUAA
- Objectives:
  - identify and implement future win-win collaboration between Europe and China for the solution of multidisciplinary design problems in aeronautics
  - collect and disseminate the existing knowledge in the field of multiphysics modelling, simulation, experimentation and design in aeronautics
- Keywords:
  - Cooperation, research, multi physics, modeling, simulation, experimentation, design



Courtesy of NUMECA; Instantaneuos Entropy Field; Ch. Hirsch et al.



Courtesy of ARI; Turbulence models Comparison for Synthetic Jets Devices; DONG Jun et al.

CONCLUSIONS FROM AEROCHINA2

- Successful organization of an **Open Short Course** (Marseille) and **three Open Workshops** (Nanjing, Harbin and Brussels).
- Trustful relations between European and Chinese colleagues developed since 2005 through AEROCHINA and AEROCHINA2 networks.
- Consolidation of the different **Working Groups** started in previous AEROCHINA network.
- AEROCHINA2 contributed substantially to the scientific definition and the **launch of the first joint EU-China call for proposals**.
- Generation of a **database** with European and Chinese contributions for the identification of common interest and win-win RTD topics.
- Interest on both sides to continue with EU-China networks.

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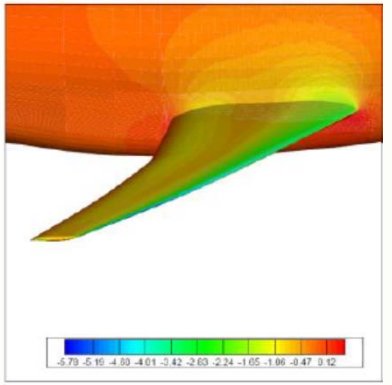
EVOLUTION OF THE NETWORK OBJECTIVES

GRAIN

- Consortium:
  - **EU (17) : CIMNE**, INRIA, AIRBUS, ALENIA, EADS-IW, INGENIA, NUMECA, SHEFFIELD Univ., BIRMINGHAM univ., CIRA, VKI, AIRBORNE, LEITAT, CERFACS, CRANFIELD univ., DLR, MANCHESTER univ.
  - **CH (14) : CAE**, GTE, ARI, FAI, ASRI, SAERI, BIAM, ACTRI, BUAA, NPU, PKU, NUAA, ZJU, THU
- Objectives:
  - identify and assess the future development for greener technologies reaching the Vision 2020 environmental goals, prepare the R&T development and exploitation
- Keywords:
  - Cooperation, research, development, green technologies, Vision2020
- Key Green Technologies (KGT):
  - KGT1: Green NOx reduced global warming Design with conceptual and detailed design tools (contrails)
  - KGT2: Green CO2 reduced drag Design with conceptual and detailed design tools
  - KGT3: Green Noise Design with conceptual and detailed design tools
  - KGT4: Green Materials
  - KGT5: Large scale High Performance Methodologies with Advanced IT tools



Courtesy of CIRA; Aeroelastic Optimization solutions; D. Quagliarella et al.

Courtesy of GTE; Low-emission DIPME combustor

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CONCLUSIONS FROM GRAIN

- KGTs (Key Green Technologies chairmen) wrote their **technology reports to identify research priorities**.

- A candidate table with clearly described **topics** achieved **as proposal of the GRAIN KGTs for future H2020 joint EU-China RTD projects**

- A Summary Report integrating the KGT achievements available for the **use by external experts** (**industry and research community**).

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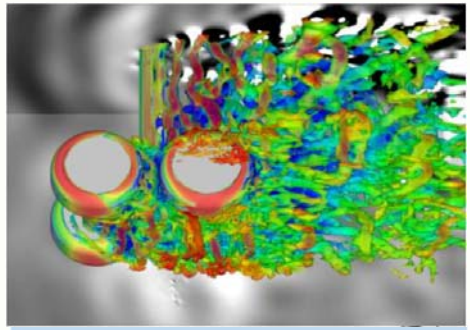
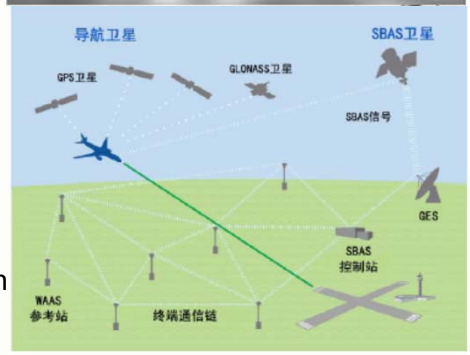
EVOLUTION OF THE NETWORK OBJECTIVES

GRAIN2

- Consortium:
  - **EU (21) :** CIMNE, AIRBUS, EUROCONTROL, HONEYWELL, EADS-IW, NUMECA, DLR, NLR, INRIA, CERFACS, CIRA, VKI, FOI, LEITAT, AIRBORNE, USFD, UNIMAN, CRANFIELD, UPC, UPM, RWTH
  - **CH (19) :** CAE, FAI, ACAE, ASRI, ACTRI, ARI, BIAM, GTE, COMAC, BUAA, NUAA, NPU, ZJU, XJTU, HUST, CQU, IACAS, NIMTE, DICP
- Objectives:
  - focus to greening activities following the Flight Path 2050
  - identify innovative R&D methods, tools and HPC environments
- Keywords:
  - Cooperation, research, development, green technologies, flightpath 2050
- Key Green Technologies (KGT):
  - KGT1: Propulsion related green technologies (including NOx and CO2reduction, contrails, mission modeling, alternative fuels, …)
  - KGT2: Airframe Flight Physics (including Drag reduction, noise reduction, HPC innovative architecture, numerical simulation, …)
  - KGT3: Environmental friendly materials and structures (including Smart structures and materials, bio-sourced materials, composite technologies, metal alloys, surface coatings, structural health monitoring, …)
  - KGT4: CNS (Communications Navigation and Surveillance)/ATM for greener air transport



Courtesy of CFD-Berlin;
Noise prediction;
F. Thiele & Ch. Mockett



Courtesy of AVIC;
Augmentation System
for GPS and GALILEO

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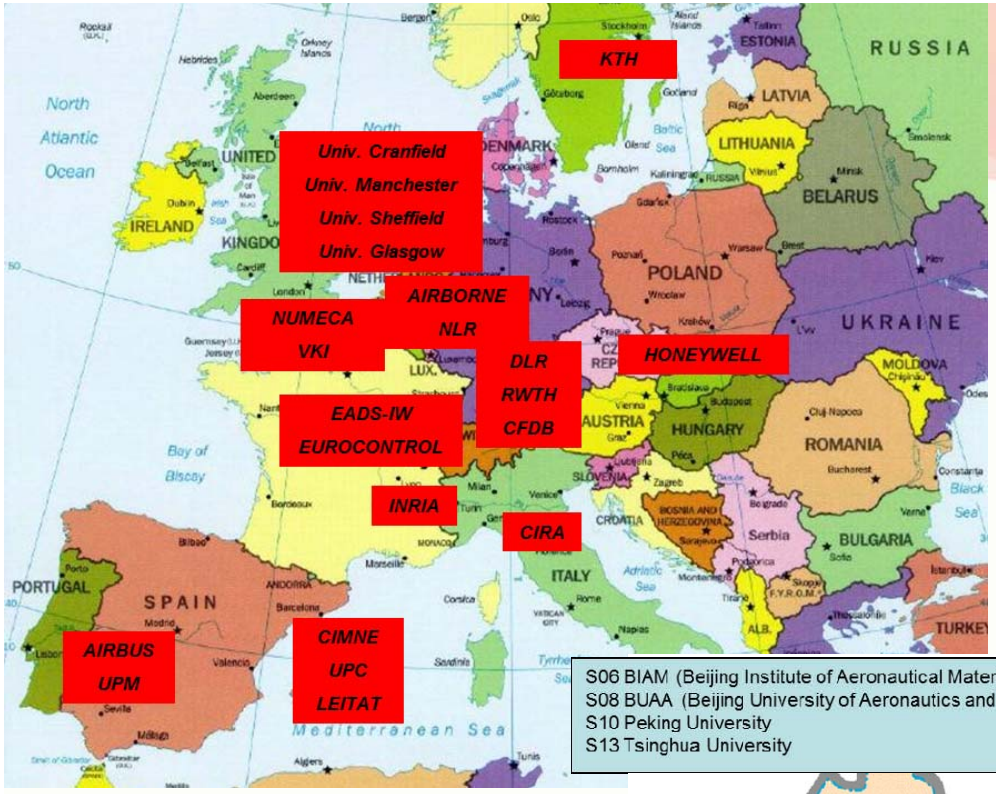
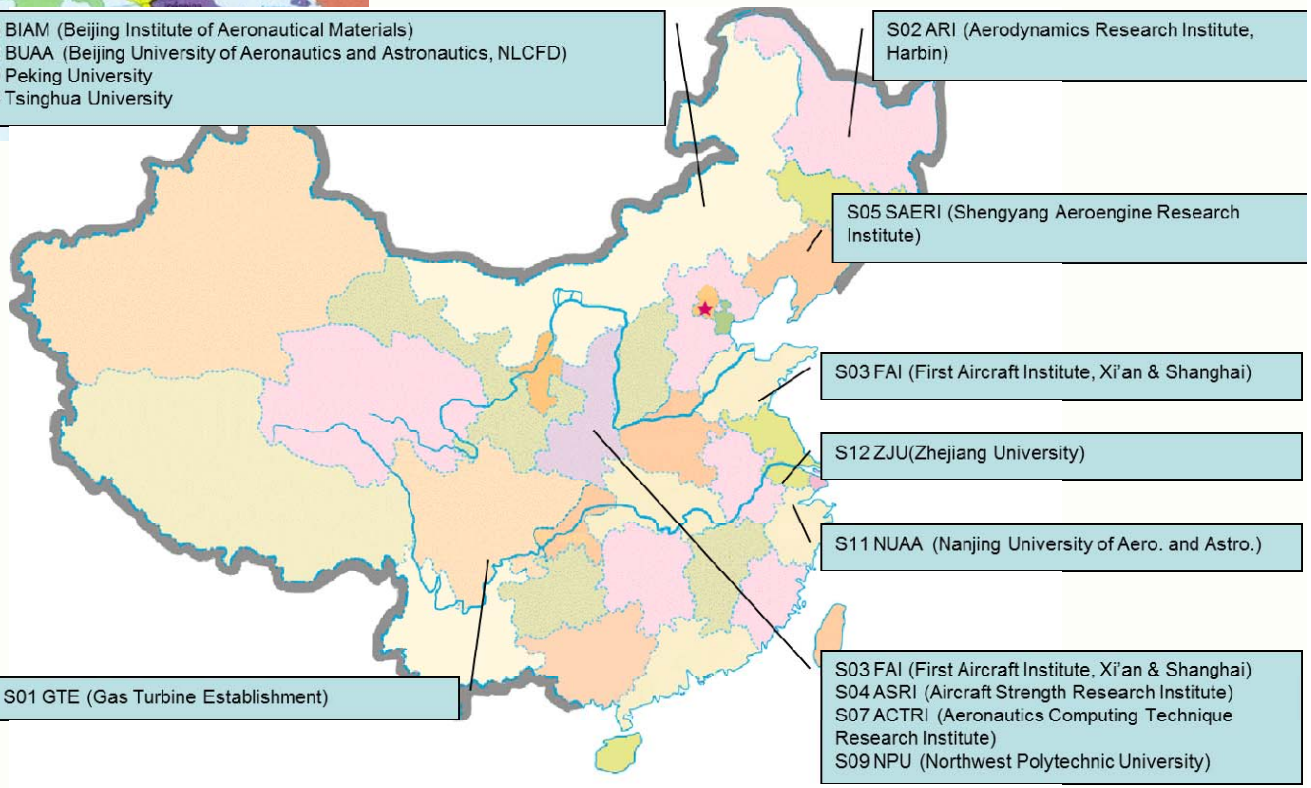
EU-CHINA NETWORKS GEOGRAPHICAL DISTRIBUTION





S06 BIAM (Beijing Institute of Aeronautical Materials)
S08 BUAA (Beijing University of Aeronautics and Astronautics, NLCFD)
S10 Peking University
S13 Tsinghua University

S02 ARI (Aerodynamics Research Institute, Harbin)

S05 SAERI (Shengyang Aeroengine Research Institute)

S03 FAI (First Aircraft Institute, Xi'an & Shanghai)

S12 ZJU(Zhejiang University)

S11 NUAA (Nanjing University of Aero. and Astro.)

S03 FAI (First Aircraft Institute, Xi'an & Shanghai)
S04 ASRI (Aircraft Strength Research Institute)
S07 ACTRI (Aeronautics Computing Technique Research Institute)
S09 NPU (Northwest Polytechnic University)

S01 GTE (Gas Turbine Establishment)

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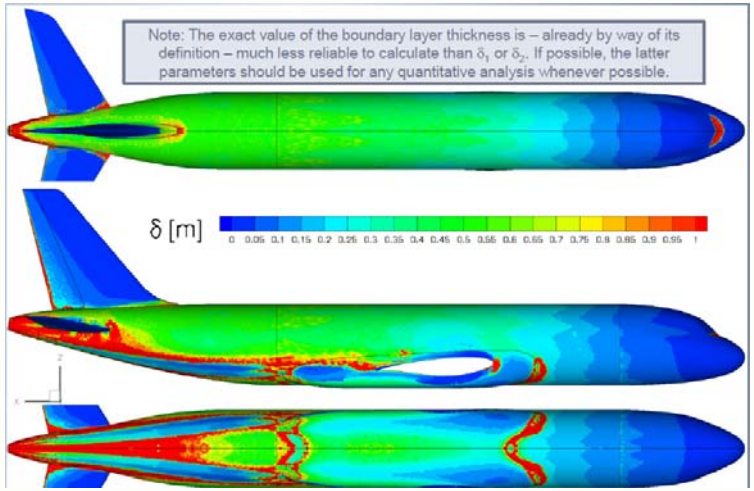
EU-CHINA Research Project

MARS

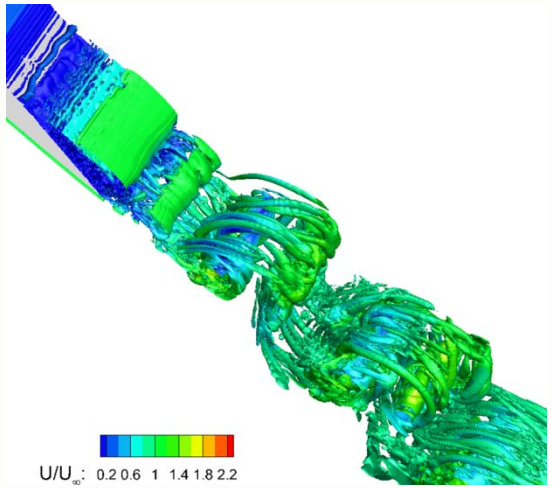
- **Consortium:**
  - **EU (12) : CIMNE**, USFD, AIRBUS, FOI, ALENIA, DLR, CNRS, DAV, NUMECA, UNIMAN, INRIA, EADS-IW
  - **CH (10) : CAE**, ARI-AVIC , NUAA, THU, FAI- AVIC, ACTRI-AVIC, NPU, PKU, BUAA, ZJU

- **Objectives**: Measure, simulate, understand the impact of active devices upon discrete turbulent structures

- **Keywords:**
  - Flow control, Reynolds stress, drag reduction, turbulence, skin friction, flow separation , BFS, NACA015 , Vortex G, Plasma actuation , Simulation tools, Experimental tools , Database of results,



Courtesy of AIRBUS; Boundary layer thickness; N. Wood et al.



Courtesy of THU; DDES turbulent formation; SONG Fu et al.

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CONCLUSIONS FROM MARS

Achieved :

- Selected upstream research **topic of interest to Industry**; still an important not mature yet active flow control devices technology, (MARS2 ??)
- **Competences built**, tools developed by **strong teams**
- A **first template** to implement joint management and technical coordination for the next China-EU Research Call (H2020)

But:

- MARS : a **slow start** but manage with a 6 months extension despite an **Excellent scientific work** (experimental and numerical) done by both sides
- **Co-operation and technical coordination may be better**
- The **involvement of industry late and too little**

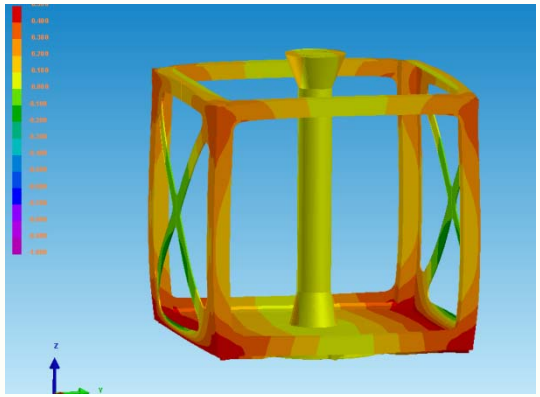
- **Finally** : a first positive experience in EU-China joint research for all involved partners of MARS (and COLTS)

CIMNE

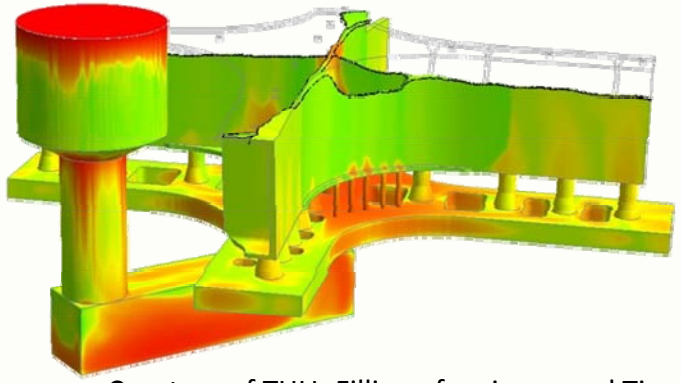
EU-CHINA RESEARCH PROJECTS

COLTS

- **Consortium:**
  - **EU (8): Birmingham Univ.**, IRC, Airbus, RR, ESA, Calcom ESI, Ingenia/CIMNE, EADS F IW
  - **CH (6) : CAE**, BIAM, BAMTRI, HUST, IMR, Tsinghua Univ.
- **Objectives:**
  - develop centrifugal and gravity casting of Ti alloys so that high integrity components can be routinely manufactured.
  - develop a strong wax and a robust casting process to achieve dimensional control for casting of large components
  - produce two selected demonstrator components
  - build up and apply modelling capabilities to accurately predict and control the essential aspects of the technical process steps
  - develop a welding process backed up by modelling for joining large Ti air frame components
- **Keywords:**
  - Ti casting, welding, manufacturing, centrifugal casting,



Courtesy of CALCOM-ESI; Filling of a Ti mould; O. Koeser



Courtesy of THU; Filling of an improved Ti mould; Qingyan Xu

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LESSONS LEARNT from the COOPERATION

- Open Networking Project events: workshops have to be more attractive and open to outside experts
- Cultural differences:
  - European learnt how to deal with Chinese top-down hierarchy regarding decision-taking procedures.
  - Chinese learnt how to comply with EC requirements in EU-China projects
- Industrial Interest : slowed down due to Industrial competition
- Priority cooperative ground: Industry in Europe looking for topics ensuring win-win situations
- Communication between European and Chinese partners could be further enhanced

CONS AND PROS from the COOPERATION

CONS

- Announcements too late on the EU-Chia projects web-sites
- After kick-offs several activities had a slow and late start
- Involvement of Chinese industry not sufficient.
- Control of Chinese authorities over the project high, avoiding a fluid communication among technical and managerial partners
- Lack of transparency in the Chinese decisions, a constraint for technical management
- Visa issues uncertain when organizing events and meetings

PROS

- International cooperation fruitful for Academia
- Trustful relations between European and Chinese colleagues developed since 2005
- Research and Academia in China showing a high technical level
- Intensive exchange of information on scientific activities of European and Chinese partners through numerous workshops
- Quality of the technical papers increased during cooperation
- Availability , tests costs and other facilities beneficial for the project development

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OPPORTUNITIES AND CHALLENGES

Opportunities

- Research capabilities in China of high quality.
- Availability of large infrastructures for industry and research in China (manufacturing facilities, test facilities)
- Ensure win-win situations in projects for industrial relationship
- "Fair" scientific and technology transfer ?
- Increase "mobility of young researchers between China and Europe (like Marie Curie) in Aeronautics

Challenges

- EU-China projects well in the line of H2020 Green Technologies since 2005
- Growing air traffic in China; ATM and communications challenges. Integration of this traffic at an international level (GRAIN2 prospect and beyond...).
- Business jet Aviation development in China (Falcon family ???)
- UAV integration in Chinese airspace for urban mobile services (surveillance, security, products delivery ,...)
- Extend Green Aeronautical technologies to Green Transport (Automotive ,Marine, Maritime,...) in China.

CIMNE

Candidate Topic List for the Joint EU-China Call 2015 of the Transport Challenge of Horizon 2020 (deadline April 2015)

1. Innovative methods and numerical technologies for airframe and engine noise reduction
2. Development of bio-sourced composite materials and environment-friendly multifunctional composites and structures for aeronautics applications.
3. Flow control and advanced numerical tools for physical modelling of unsteady flows of aircraft and its components.
4. Enhanced additive manufacturing of metal components and resources efficient manufacturing processes for aerospace applications

Thanks for your attention !

4th EASN International Workshop on Flight Physics and Aircraft Design, 27-29th Oct. 2014, Aachen, Germany

Assessment of Aircraft Noise Annoyance during Conceptual Aircraft Design

Institute of Aerospace Systems (ILR)

Abhishek Sahai and Eike Stumpf

Need for a different approach to noise assessment

- Noise reduction has so far focused on noise level reduction - expressed in dBA for noise abatement procedures and in EPNdB for aircraft design changes

- dBA does not account for the differences in aircraft noise characteristics – different engines can be louder, more tonal, sharper or rougher

- EPNdB metric will give no information if tones lie below the broadband noise and it will always follow same trends as PNL

- New unconventional engines such as Counter Rotating Open Rotor (CROR) engines may require new unconventional metrics – much stronger tonal content

A320 with V2500

B777 with GE 90

MD-80 with CROR

Need for a different approach to noise assessment

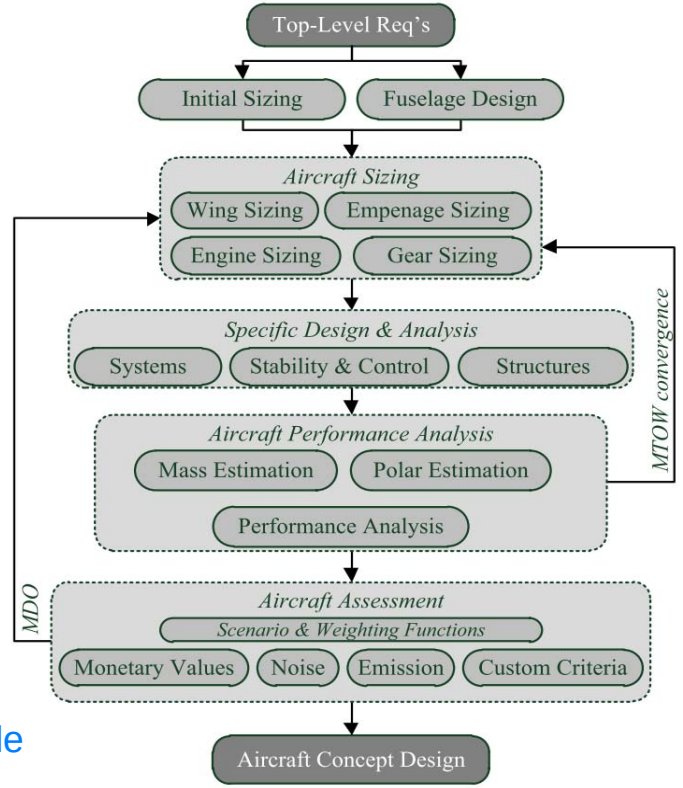
- How can engineers capture the annoyance due to aircraft noise of current and future aircraft in a better or more complete way?

- *"…engineers in future are likely to focus on sound quality instead of just noise reduction. "This is what the automotive industry went through about 20 years ago – it began to look at not only the noise level but also the noise spectrum. So I think we will see jets that 'sound' better in the future that may not necessarily be quieter."*" – BBC Article "How to cut noise in a plane cabin" cited 26th Feb. 2014

- Work in current presentation attempts to look at the aircraft and engine parameters causing the noise at the source, and how they affect the sound quality at an early design stage

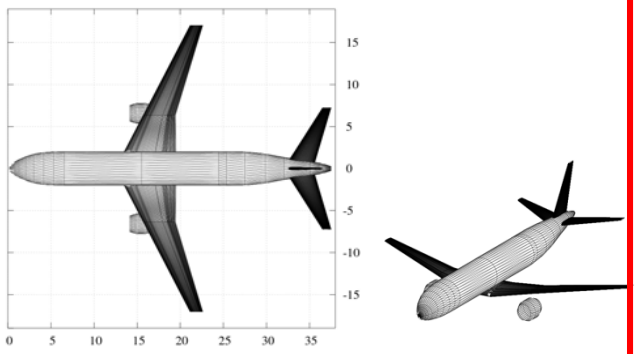
Analysis approach – Aircraft design

- Two conventional aircraft designed using ILR‘s MICADO software for the sound quality and standard metric analysis:
  - A320-200 comparable aircraft (ILR-Short Range(-SR)) powered with a V2527-A5 comparable engine model
  - 777-300 comparable aircraft (ILR-Long Range(-LR)) powered with a GE90-85B comparable engine model

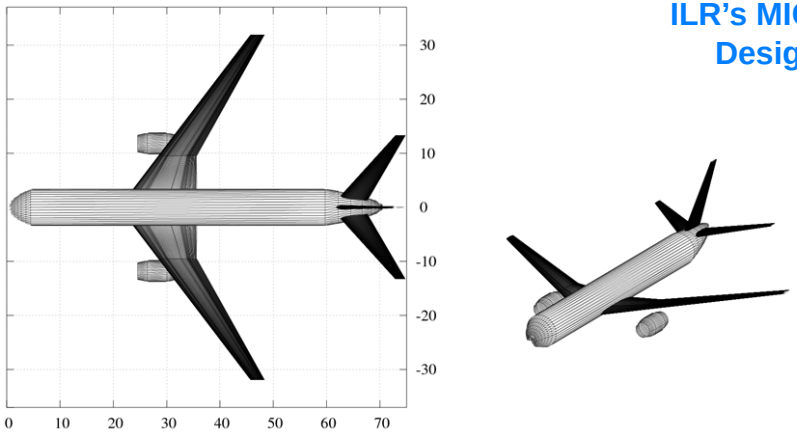


ILR's MICADO Aircraft Design software

A320-200/V2527-A5 comparable
ILR-SR



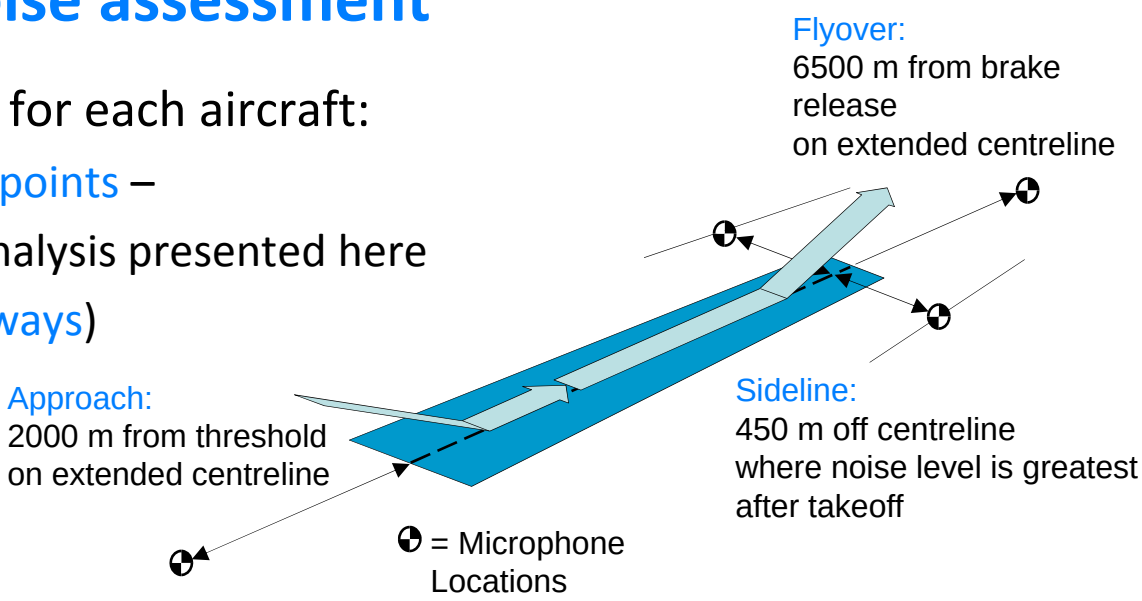
777-300/GE90-85B comparable
ILR-LR



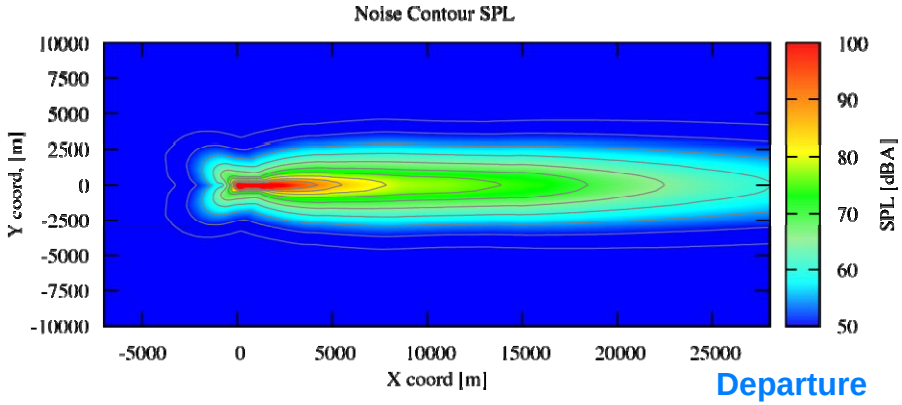
Analysis approach – Noise assessment

Analysis divided into two parts for each aircraft:

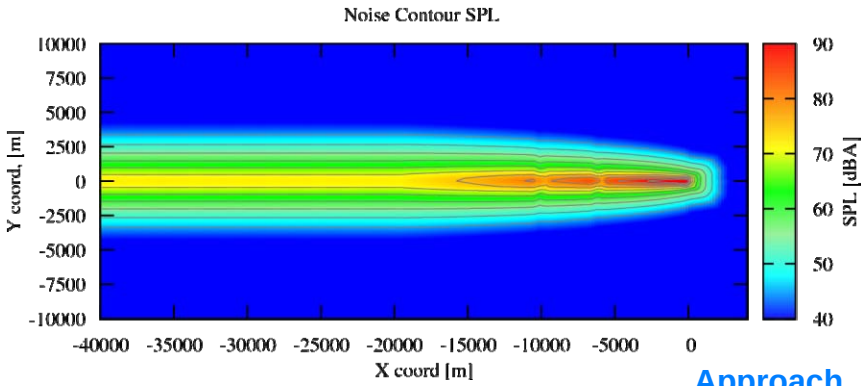
- At ICAO specified certification points –
  Flyover and approach points analysis presented here
  (Noise impact close to the runways)



- Community noise impact via area impacted in km² for each metric (Noise impact at larger distances from the runways)

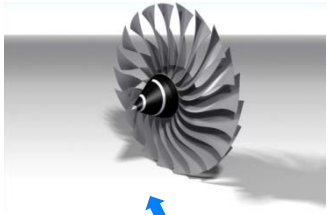


Departure



Approach

Analysis approach – Parametric variations

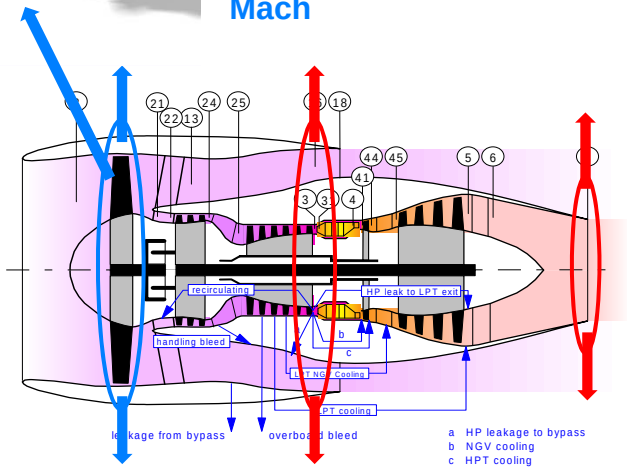


Increase and decrease **no. of fan blades, vanes, rotor-stator spacing, tip design Mach**

Uncoupled Parametric Variations

All engine geometry parameters used for the fan and jet noise calculation are varied around their modeled reference values

- The aircraft and flight path are otherwise kept constant



Vary fan and jet areas

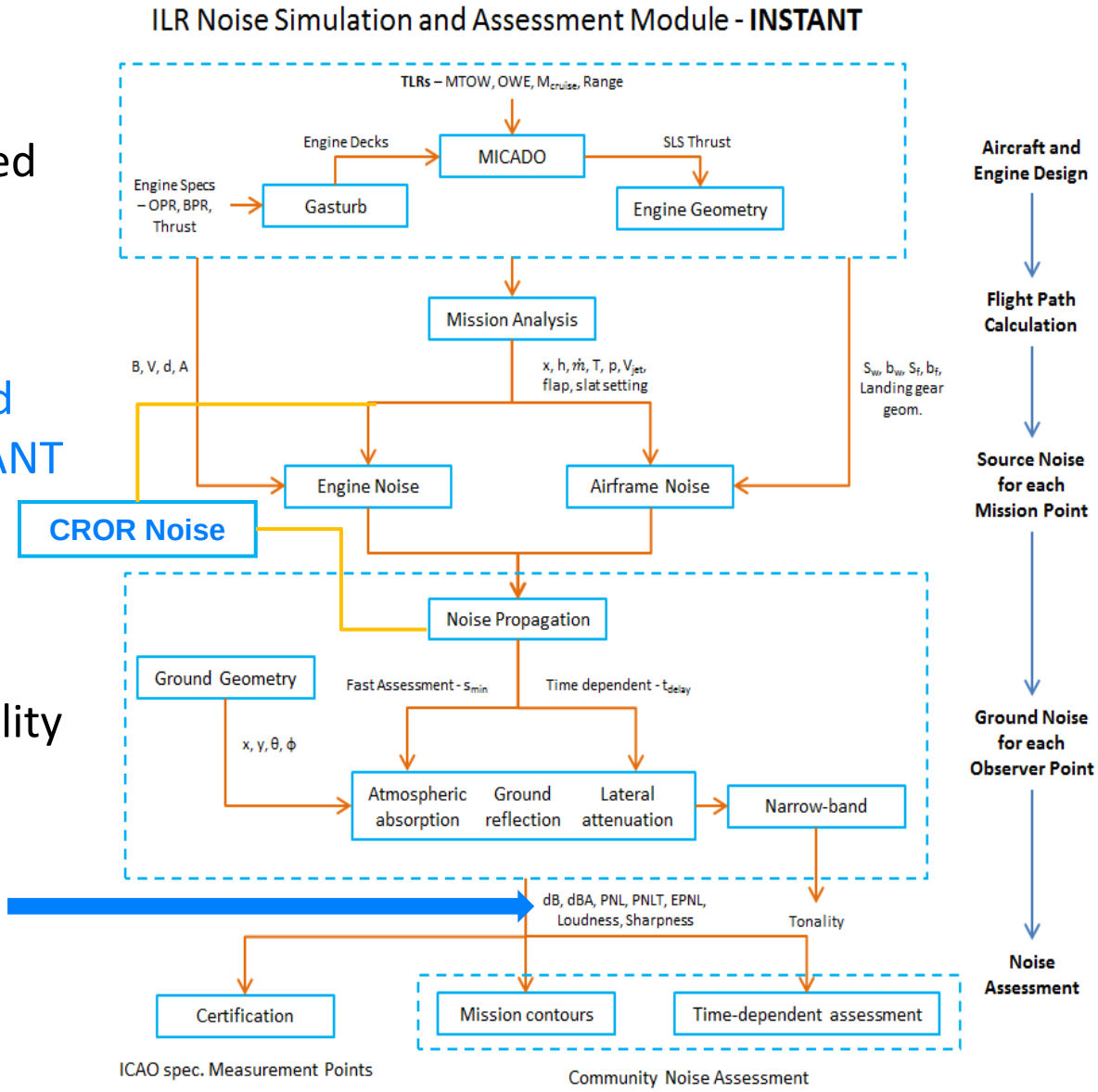
Coupled Parametric Variations

- Engine geometry parameters are kept constant and the aircraft wing geomtery is varied via the wing-loading (W/S)
  - Change in wing area and span varies the airframe noise and also changes the flight path of the aircraft
- Aircraft geometry is kept constant and engine thermodynamics as well as engine geometry are scaled via the thrust to weight ratio (T/W)

Noise modeling at the ILR – Overall structure

- A paramteric aircraft noise simulation module developed in recent years at the ILR is used for aircraft noise calculation and assessment: the ILR Noise Simulation and Assessment module – INSTANT

- INSTANT assessment capability extended to assessment in Sound Quality metrics of loudness, tonality and sharpness



Step towards new approach to noise assessment at ILR

- The annoyance aspect of aircraft noise pursued further using the help of sound quality (psychoacoustic) metrics

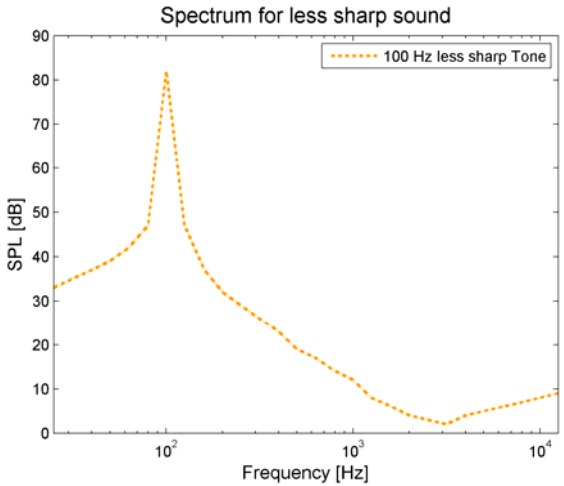
- Loudness - subjective perception of the magnitude of a sound – ISO532B, Zwicker's method
- Tonality - tonal content metric taking account of tonal prominence, frequency, bandwidth and tonal loudness relative to overall loudness - Aures' method
- Sharpness - fraction of high frequency content to low frequency content - von Bismarck's method

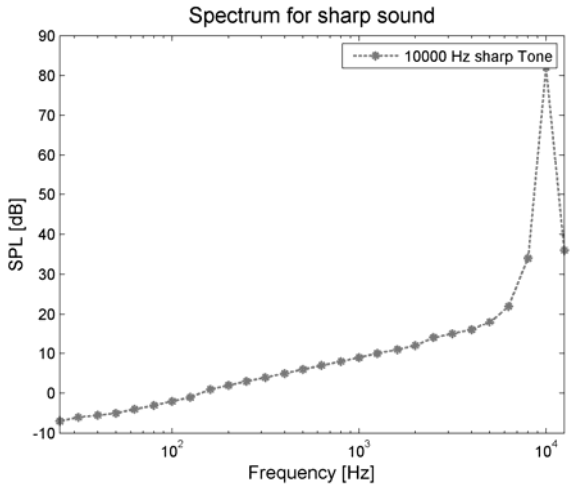
- Roughness - metric accounting for fast loudness fluctuations (50 - 90 per second) in sound; currently excluded as time-dependent variations shorter than 0.1 seconds must be synthetically introduced to the semi-empirical source noise models used

- Loudness and tonality primary contributors to annoyance, followed by roughness and sharpness (Boeing, Purdue)

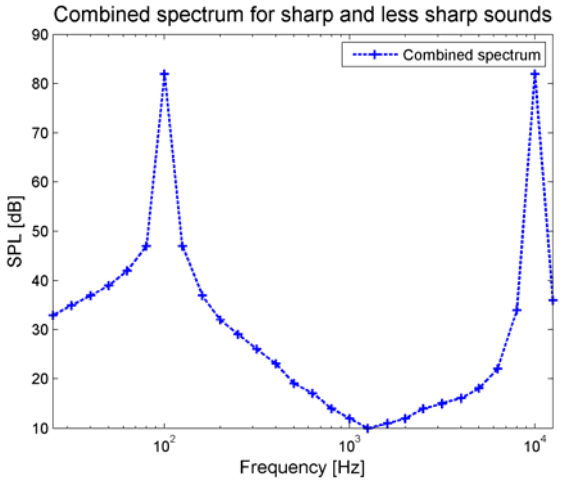
Step towards new approach to noise assessment at ILR

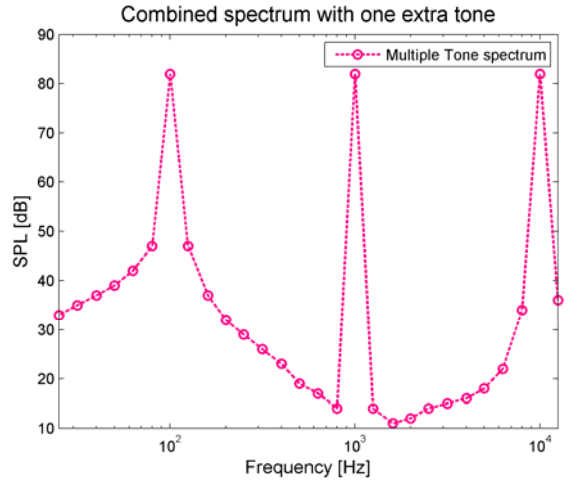
- Influence of level, frequency and tonal content on the sound quality metrics:





	100 Hz Tone Spectrum	10000 Hz Tone Spectrum
OASPL [dB]	82.0	82.0
Loudness [Sone]	11.05	7.89
Sharpness [acum]	0.31	7.49
Tonality [tu]	0.276	0.032

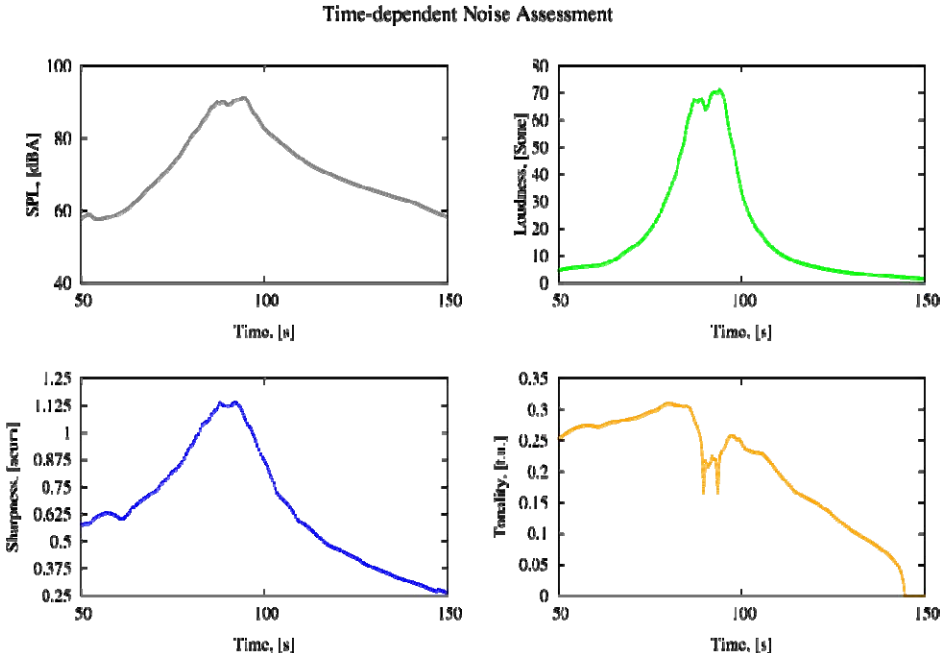




	Combined Spectrum	Multiple Tone Spectrum
OASPL [dB]	85.0	86.8
Loudness [Sone]	23.13	38.89
Sharpness [acum]	3.68	2.63
Tonality [tu]	0.280	0.297

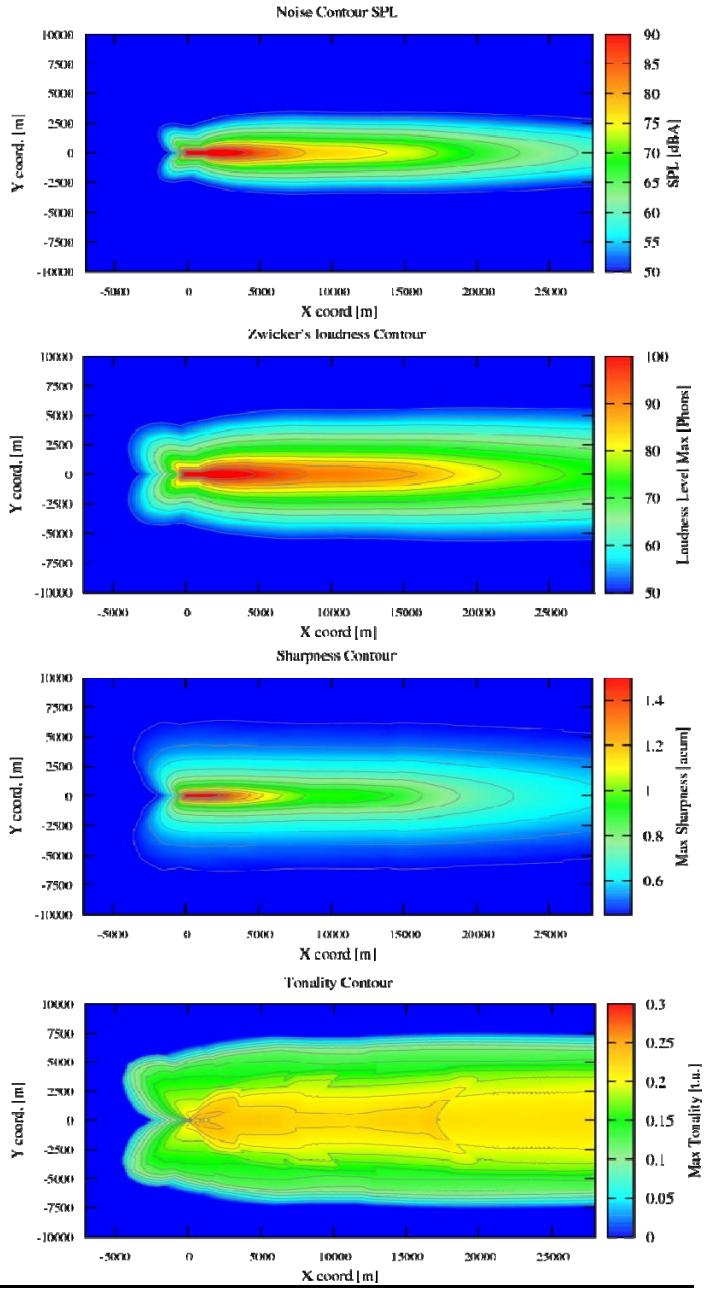
Step towards new approach to noise assessment at ILR

- SQ Assessment using INSTANT:



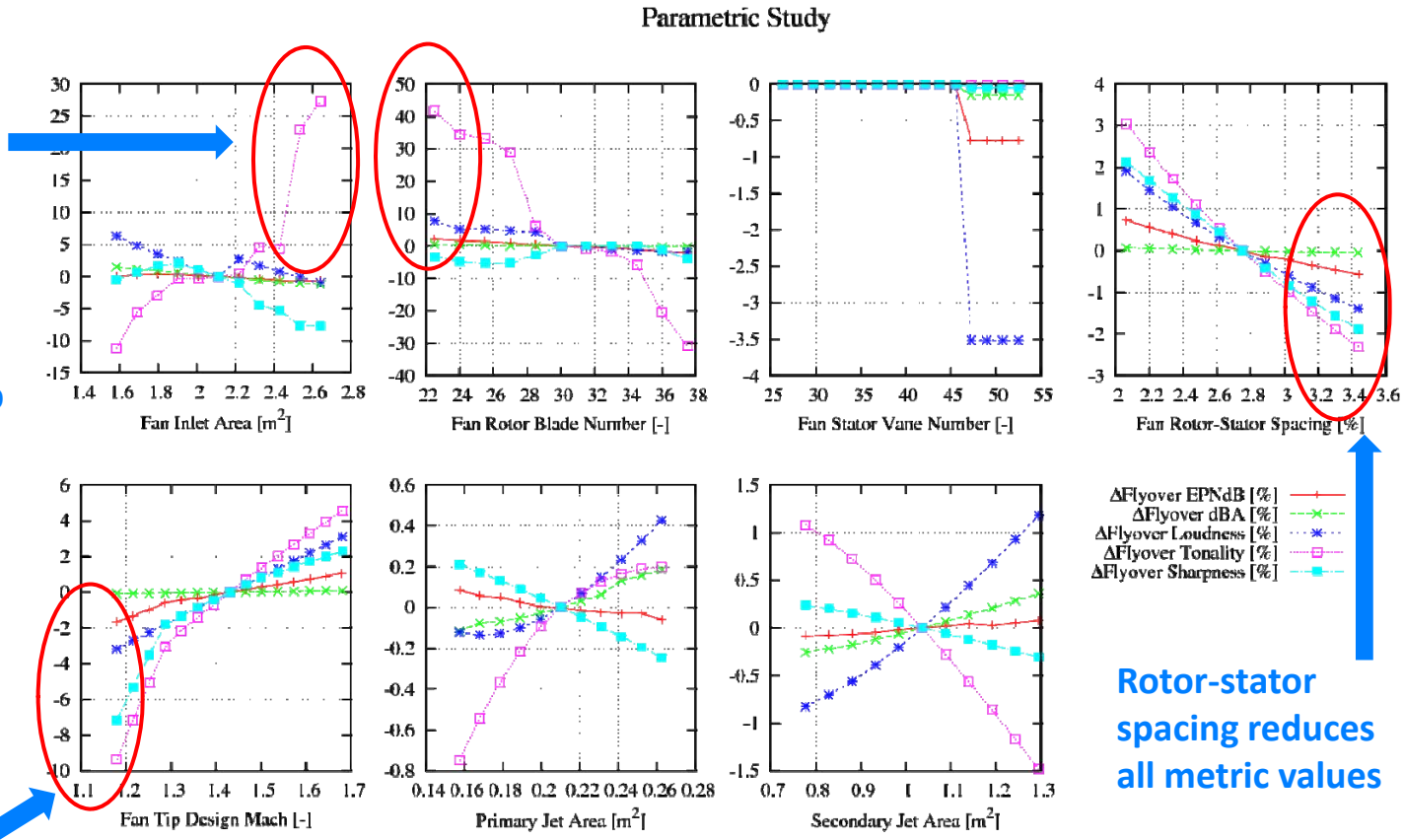
Time-dependent assessment at (x=5km,y=0km) for departure ILR-LR (777-300 comparable) aircraft

Mission assessment for departure ILR-LR (777-300 comparable) aircraft



Engine geometry parametric variation results

- ILR-SR (A320-200/V2527-A5 comparable) assessment at certification points - Flyover:



Large variations in tonality for fan inlet area and blade no.

- Flyover Ref. ILR-SR tonality quite low at 0.06 t.u., hence large changes up to 40% of ref. value (e.g. 0.06 becomes 0.036 t.u.)

- Reducing fan inlet area increases loudness and decreases tonality

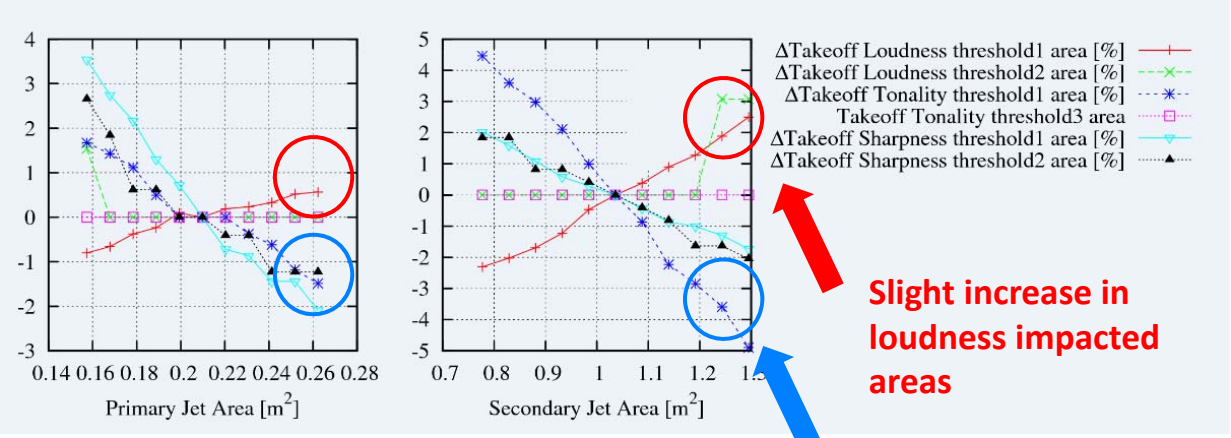
Rotor-stator spacing reduces all metric values

Tip design Mach no. also reduces all metric values

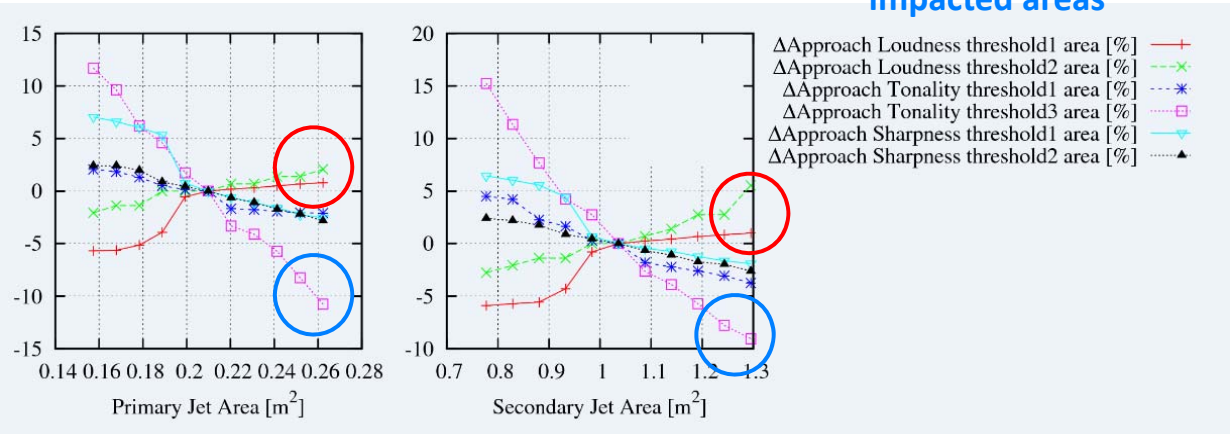
Increasing jet areas in general can increase loudness but reduce tonality – seen better for community noise impact.

Engine geometry parametric variation results

- Jet areas variation for community noise:



ILR-SR Departure



ILR-SR Approach

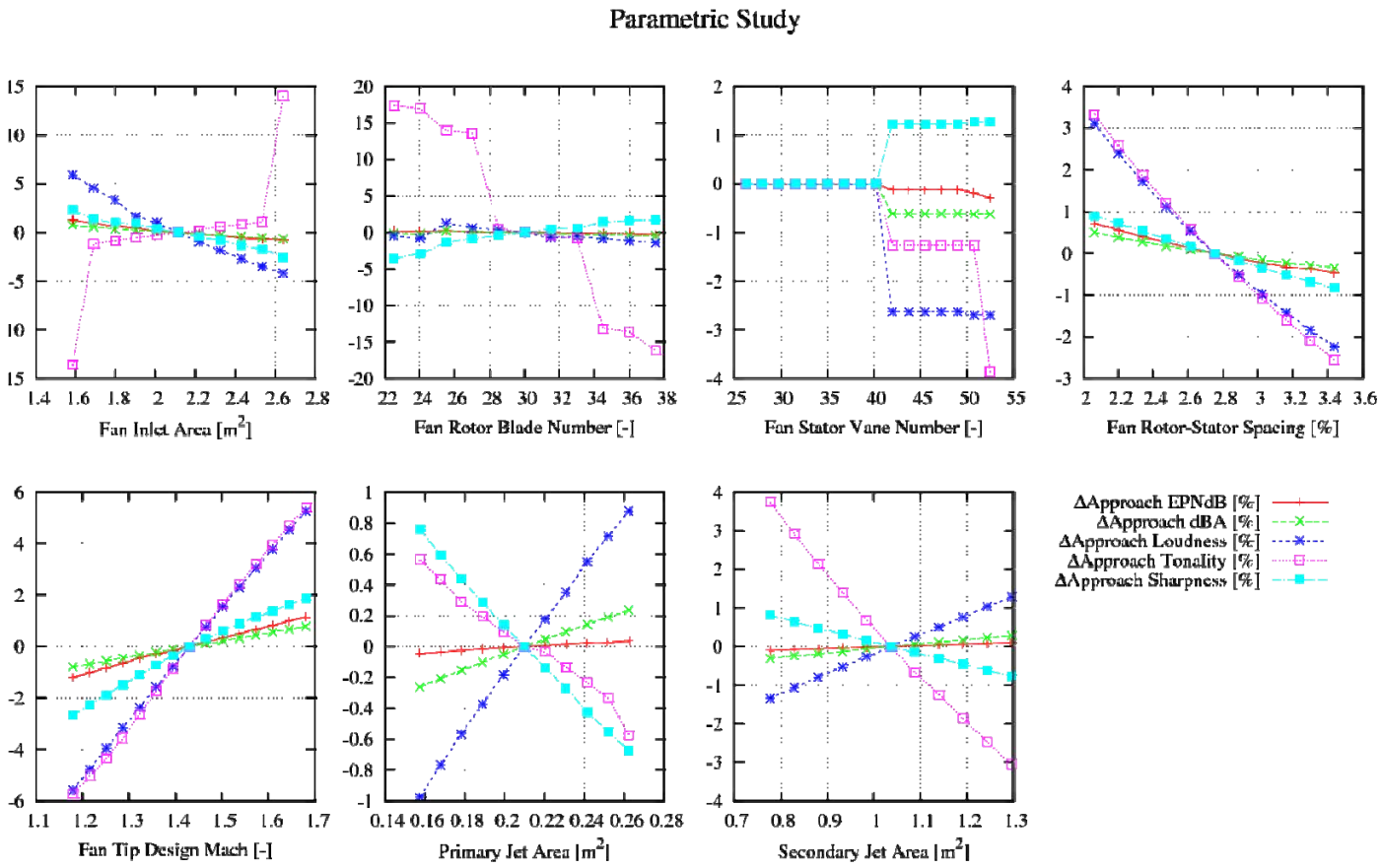
- Effect of primary jet area variation seen more clearly by looking at community noise impact

Engine geometry parametric variation results

- ILR-SR (A320-200/V2527-A5 comparable) assessment certification points - Approach:

- Similar trends at approach as at flyover certification point

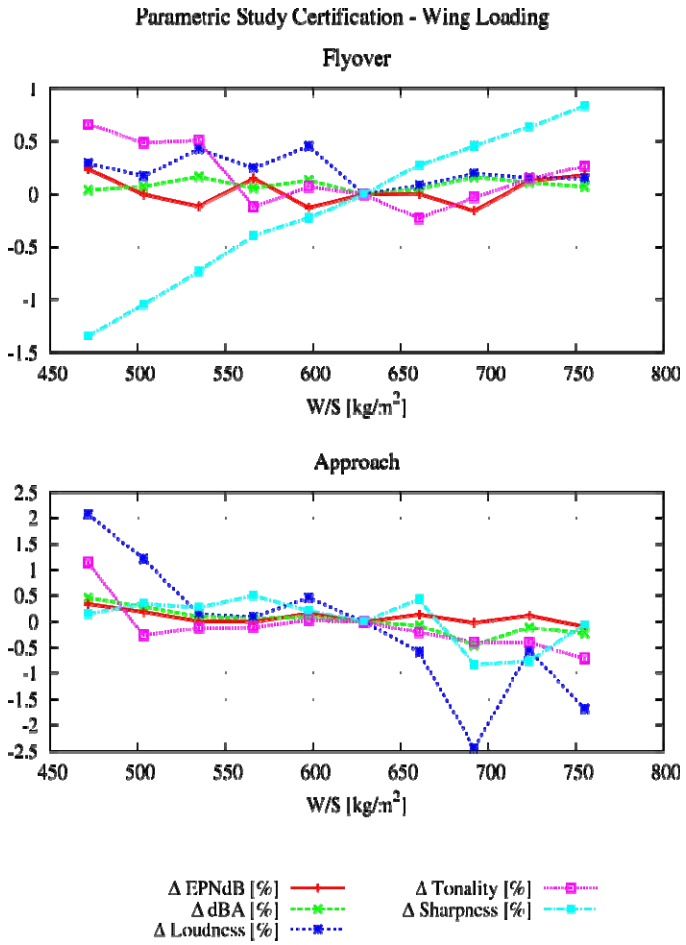
- Variations in tonality lower for approach due to higher ref. tonality of 0.192 t.u.



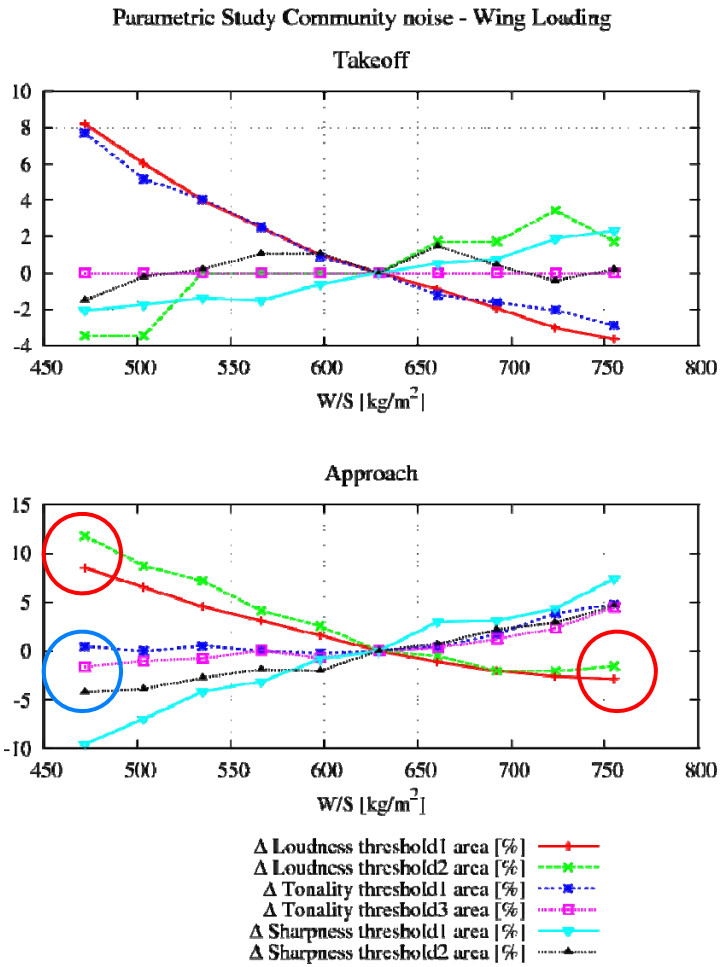
Note: All variation results seen to be enhanced for community noise impact

Coupled wing-loading parametric variation results

- Certification and community noise assessment:



ILR-SR Certification Assessment (A320-200 comparable)



ILR-SR Community Noise Assessment (A320-200 comparable)

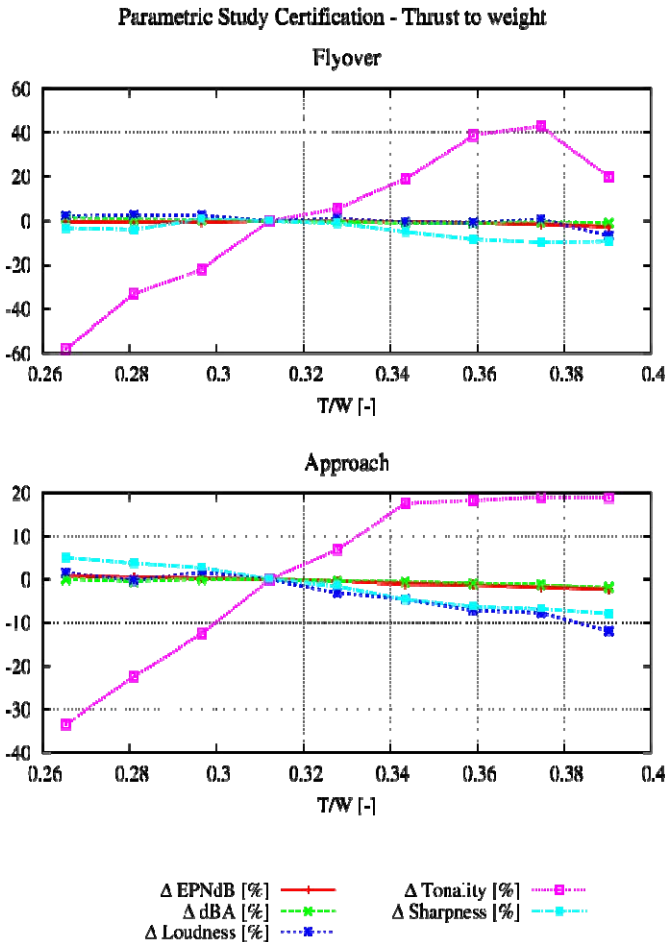
- Primary effect - change in loudness

- Loudness increase due to larger wing more pronounced than decrease due to smaller wing

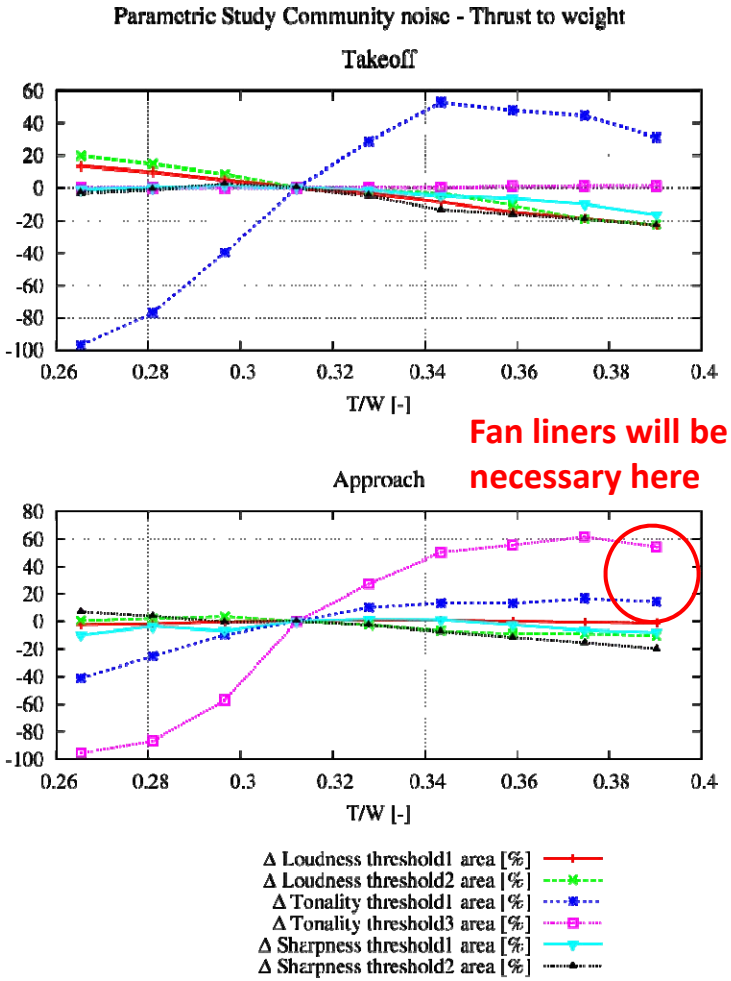
- Approach tonality here flattens out for larger wings, but can be reduced by a larger wing via masking of fan tones by the broadband airframe noise

Coupled thrust-to-weight ratio parametric variation results

- Certification and community noise assessment:



ILR-SR Certification Assessment (A320-200 comparable)



Fan liners will be necessary here

ILR-SR Community Noise Assessment (A320-200 comparable)

- Coupled thermodynamic and geometry variation of engine
- Smaller engine relatively louder but less tonal, larger engine more tonal but quieter
- Previous individual sensitivities contribute to understanding of overall engine scaling effects

Optimized aircraft for community noise impact

- NOMAD* optimized results:

	ILR-SR Ref.	ILR-SR Min. EPNL
Fan inlet area, A_{fan} [m^2]	2.058	2.585
Fan rotor blades, B [-]	31	29
Fan stator vanes, V [-]	36	59
Fan tip des. Mach, $M_{t,d}$ [-]	1.43	1.46
Primary jet area, $A_{jet,1}$ [m^2]	0.201	0.285
Secondary jet area, $A_{jet,2}$ [m^2]	1.01	1.26
Wing-loading, W/S [kg/m^2]	629	689
Wing area, S [m^2]	117.68	112.37
Thrust-to-Weight ratio, T/W [-]	0.312	0.400
SLST [kN]	113.34	151.87
MTOW [kg]	74014	**77428**
OWE [kg]	40166	**42047**
Block fuel [kg]	13910	**15235**
Cumulative 85 EPNdB area [m^2]	13.04	**7.12**
Cumulative 85 Phon area [m^2]	12.44	**9.64**
Cumulative 0.1 t.u. area [m^2]	127.84	**111.84**

* Nonsmooth Optimization by Mesh Adaptive Direct Search open-source software

Optimized aircraft for community noise impact

- NOMAD optimized results:

	ILR-SR Ref.	ILR-SR Min. EPNL	**ILR-SR Min. Loudness**
Fan inlet area, A_{fan} [m^2]	2.058	2.585	2.580
Fan rotor blades, B [-]	31	29	29
Fan stator vanes, V [-]	36	59	59
Fan tip des. Mach, $M_{t,d}$ [-]	1.43	1.46	1.46
Primary jet area, $A_{jet,1}$ [m^2]	0.201	0.285	0.285
Secondary jet area, $A_{jet,2}$ [m^2]	1.01	1.26	1.26
Wing-loading, W/S [kg/m^2]	629	689	659
Wing area, S [m^2]	117.68	112.37	117.17
Thrust-to-Weight ratio, T/W [-]	0.312	0.400	0.400
SLST [kN]	113.34	151.87	151.46
MTOW [kg]	74014	77428	**77221**
OWE [kg]	40166	42047	**42132**
Block fuel [kg]	13910	15235	**15017**
Cumulative 85 EPNdB area [m^2]	13.04	7.12	**7.24**
Cumulative 85 Phon area [m^2]	12.44	9.64	**9.56**
Cumulative 0.1 t.u. area [m^2]	127.84	111.84	**112.72**

Optimized aircraft for community noise impact

- NOMAD optimized results:

	ILR-SR Ref.	ILR-SR Min. EPNL	ILR-SR Min. Loudness	**ILR-SR Min. Tonality**
Fan inlet area, A_{fan} [m^2]	2.058	2.585	2.580	1.895
Fan rotor blades, B [-]	31	29	29	43
Fan stator vanes, V [-]	36	59	59	48
Fan tip des. Mach, $M_{t,d}$ [-]	1.43	1.46	1.46	1.41
Primary jet area, $A_{jet,1}$ [m^2]	0.201	0.285	0.285	0.172
Secondary jet area, $A_{jet,2}$ [m^2]	1.01	1.26	1.26	0.92
Wing-loading, W/S [kg/m^2]	629	689	659	556
Wing area, S [m^2]	117.68	112.37	117.17	131.35
Thrust-to-Weight ratio, T/W [-]	0.312	0.400	0.400	0.275
SLST [kN]	113.34	151.87	151.46	98.36
MTOW [kg]	74014	77428	77221	**73046**
OWE [kg]	40166	42047	42132	**39731**
Block fuel [kg]	13910	15235	15017	**13548**
Cumulative 85 EPNdB area [m^2]	13.04	7.12	7.24	**13.08**
Cumulative 85 Phon area [m^2]	12.44	9.64	9.56	**13.64**
Cumulative 0.1 t.u. area [m^2]	127.84	111.84	112.72	**12.44**

Optimized aircraft for community noise impact

- ILR-SR Ref. and ILR-SR-Min-Tonality variant assessment:

Certification	Flyover Ref.	Flyover Opt.	Approach Ref.	Approach Opt.
SPL [dBA]	73.66	74.31	90.59	90.69
EPNL [EPNdB]	84.39	84.11	99.63	100.56
Loudness [Sone]	22.98	23.69	88.20	88.98
Tonality [t.u.]	0.06	0.037	0.104	0.069
Sharpness [acum]	1.18	1.16	1.78	1.87

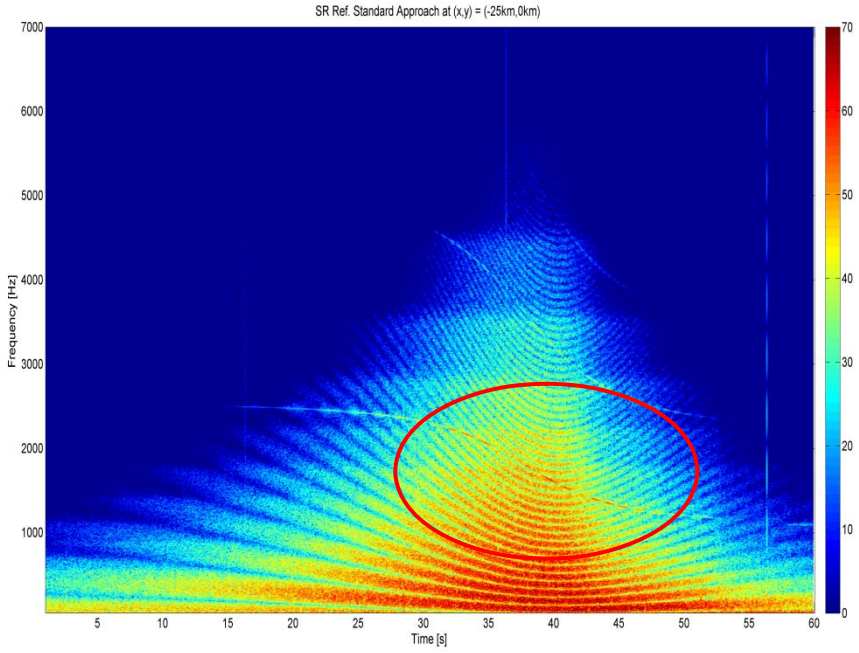
Only tonal content significantly reduced, small changes in other metrics

Community Noise	Departure Ref. [km^2]	Departure Opt. [km^2]	Approach Ref. [km^2]	Approach Opt. [km^2]
dBA threshold 1 *55 dBA* area	50.4	60.84	67.2	65.6
dBA threshold 2 *75 dBA* area	2.28	2.28	2.76	2.6
EPNL threshold 1 *65 EPNdB* area	79.56	75.2	93.2	88.0
EPNL threshold 2 *85 EPNdB* area	6.48	5.76	6.56	7.32
Loudness threshold 1 *65 Phons* area	84.92	97	102.24	103.32
Loudness threshold 2 *85 Phons* area	4.64	5.4	7.8	8.24
Tonality threshold 1 *0.05 t.u.* area	1.84	0	172.24	68.24
Tonality threshold 3 *0.10 t.u.* area	0	0	127.84	12.44
Sharpness threshold 1 *0.75 acum* area	51.12	50.88	94.84	90.4
Sharpness threshold 2 *1.0 acum* area	17.28	19.4	27.28	28.8

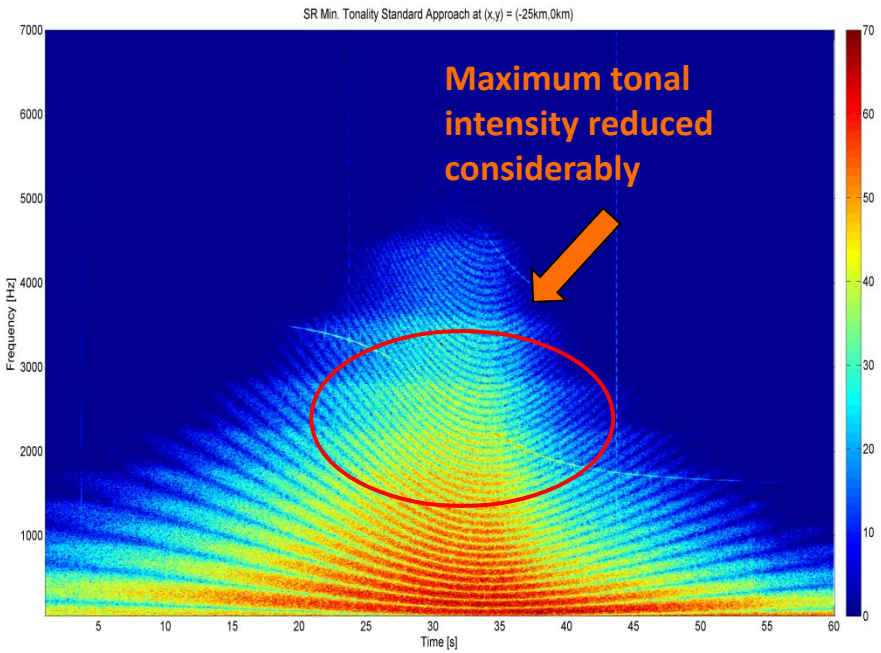
Up to 90% reduction in max. tonality impacted area, slight loudness increase

Sounds comparison

- ILR-SR – Approach at 25km from touch down directly below flight path (x= -25km,y= 0km):



ILR-SR reference approach spectrogram



ILR-SR-Min-Tonality approach spectrogram

Optimized aircraft for community noise impact

- ILR-SR Ref. and ILR-SR-Min-Loudness variant assessment:

Certification	Flyover Ref.	Flyover Opt.	Approach Ref.	Approach Opt.
SPL [dBA]	73.66	72.27	90.59	88.27
EPNL [EPNdB]	84.39	80.7	99.63	97.25
Loudness [Sone]	22.98	20.20	88.20	74.60
Tonality [t.u.]	0.06	0.073	0.104	0.123
Sharpness [acum]	1.18	1.07	1.78	1.69

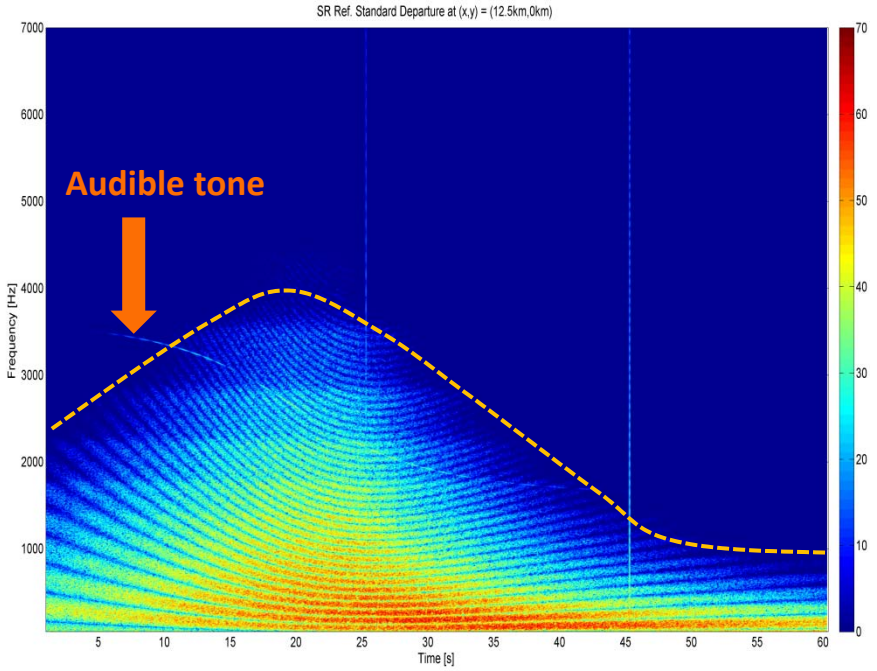
Cumulative -5.5 EPNdB, large loudness reduction, slight tonality increase

Community Noise	Departure Ref. [km^2]	Departure Opt. [km^2]	Approach Ref. [km^2]	Approach Opt. [km^2]
dBA threshold 1 *55 dBA* area	50.4	35.28	67.2	61.16
dBA threshold 2 *75 dBA* area	2.28	2.04	2.76	1.84
EPNL threshold 1 *65 EPNdB* area	79.56	41.04	93.2	62.96
EPNL threshold 2 *85 EPNdB* area	6.48	4.28	6.56	2.96
Loudness threshold 1 *65 Phons* area	84.92	58.84	102.24	94.68
Loudness threshold 2 *85 Phons* area	4.64	3.36	7.8	6.2
Tonality threshold 1 *0.075 t.u.* area	1.84	12.56	172.24	142.4
Tonality threshold 3 *0.15 t.u.* area	0	0.52	127.84	112.2
Sharpness threshold 1 *0.75 acum* area	51.12	38.24	94.84	83.2
Sharpness threshold 2 *1.0 acum* area	17.28	14.2	27.28	21.32

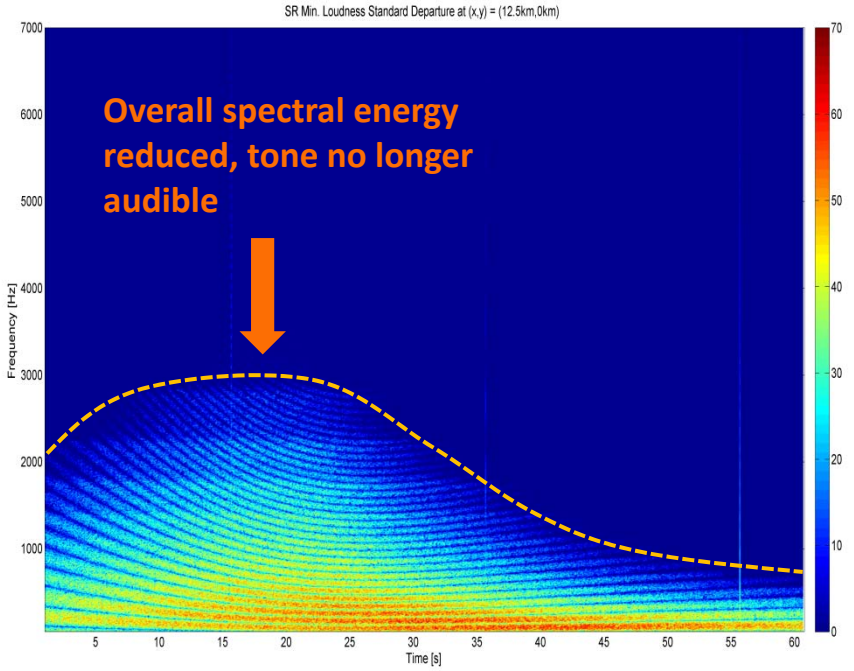
Large cumulative reduction in loudness impacted areas, particularly during departure

Sounds comparison

- ILR-SR – Departure at 12.5 km from brake release directly below flight path (x= 12.5km,y= 0km):



ILR-SR reference departure spectrogram



ILR-SR-Min-Loudness departure spectrogram

Conclusions and Outlook

- Possibility to optimize current aircraft and engine designs for sound quality exists – tune the sound of commercial aircraft and reduce their annoyance at an early aircraft design phase in a focused way

- Capability presented with which adverse sound effects due to aircraft or engine design change can be predicted at an early design stage, parallel to weight and fuel change considerations

- No radically new noise reduction technology applied, only an interplay between broadband and tonal contents considered for improvement in sound quality

- Extension of analysis to future engine concepts such as CROR engines planned - expected to be perceived as considerably more annoying than current aircraft

- Based on this approach, a promising method of reorienting noise benefits to residents could be obtained, by focusing on what actually contributes to their annoyance

Thank you for your attention!

Questions?

European Aeronautics Science Network

4th EASN Association International Workshop on
Flight Physics & Aircraft Design
27th-29th October 2014, Aachen, Germany

MDO Approach for a Light Turboprop Aircraft - Engine Integration and Improvement

Andrzej Iwaniuk, Witold Wiśniowski

instituteofaviation
warsaw, since 1926

Outline

1. Introduction
2. Design Objectives and Limitations
3. Design Decomposition
4. Optimization Process
5. Optimization Assessment
6. Conclusions

Introduction

Turboprop Engine TP 100

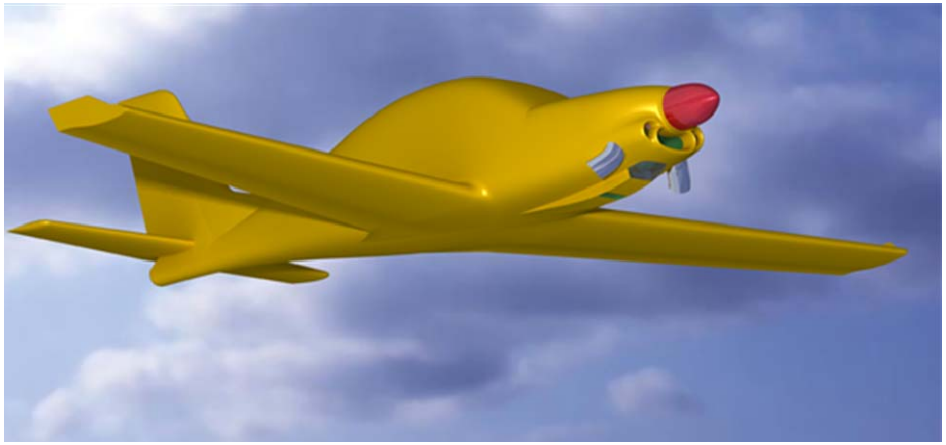
ESPOSA

Efficient Systems and Propulsion for Small Aircraft

Flying demonstrator

I-23 „Manager”

TYPE-CERTIFICATE EASA.A.200 - 2006



I-31T airplane

Special (experimental) Category CS-23

Design Objectives and Limitations

Two categories of limitations :

1. To fulfil the **requirements of engine integration** defined by the engine manufacturer (fuel-pressure and total pressure, temperature and cleanness, air-mass flow, distortion, pressure loses. acceptable level of pollution solid particulates and liquids)
2. To fulfil the **requirements for safety and airworthiness** contained in **CS-23 and environment protection** (strength of the aircraft, performance, stability, operation and maintenance, reduction of the environment burden).

Design Objectives and Limitations

Limitation of costs of next stages of the aircraft developed: - laboratory tests, ground tests and flight tests.

Additional limitations:

1. The **total weight and the total centre of gravity** for I-31T must be within the envelope for I-23.
2. **Limitations** concerning **aircraft operation** should be selected in a way that the loads and strength analyses can show that there is no need to demonstrate the strength of the aircraft except the engine compartment.

Design Objectives and Limitations

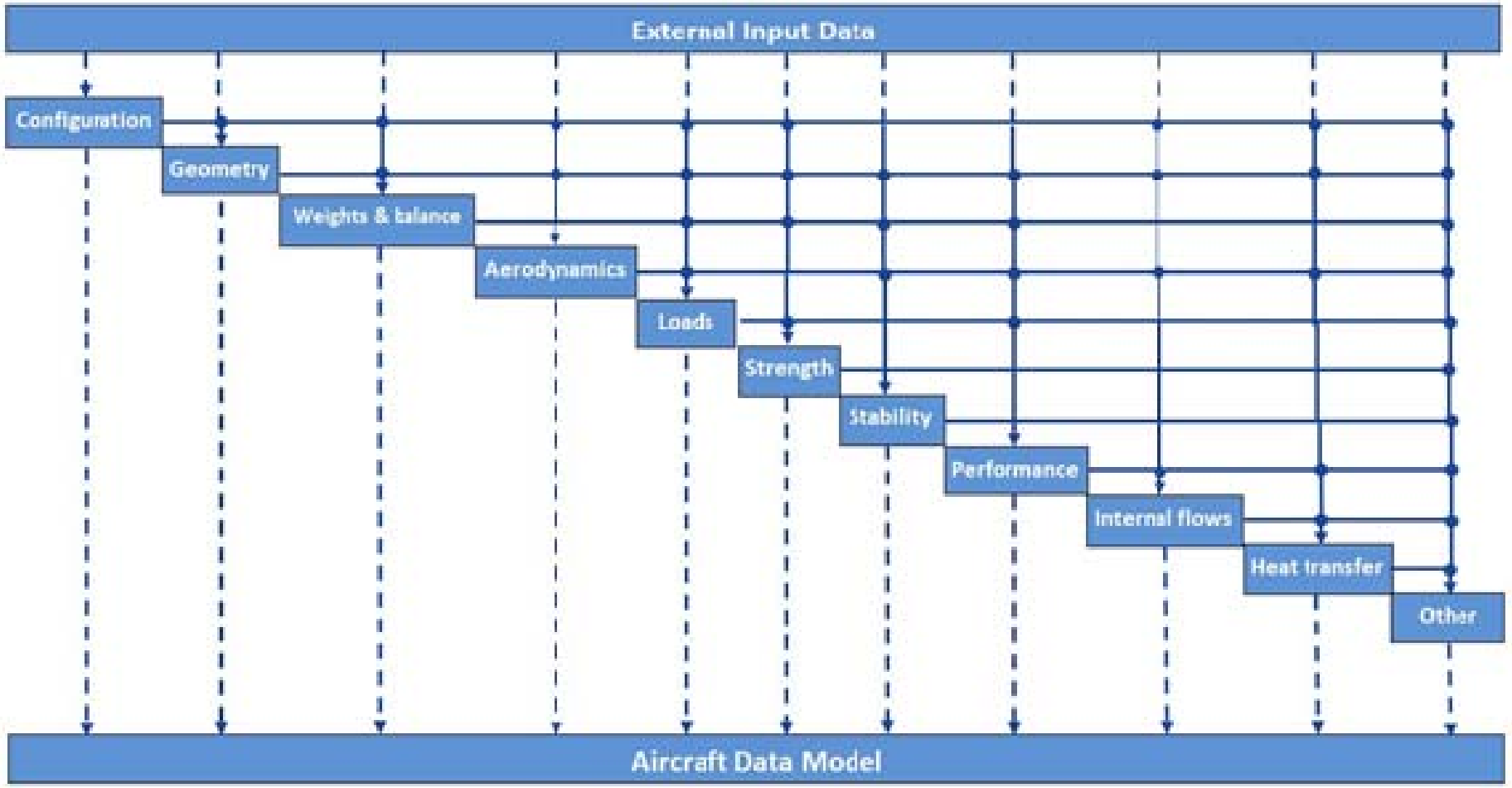
Design Objectives:

1. To fulfil the above mentioned requirements with **minimum modification the structure and the systems** of the aircraft.
2. **To minimalize of costs for the whole process of engine replacement** (design, laboratory, ground and flight tests, certification).

Design Decomposition

Range of changes	Subassemblies
New subassemblies	Engine
	Propeller
	Engine air intake
	Engine mount
	Exhaust system
	Engine control
	Engine cooling and ventilation
	Fire protection installation
	Engine cowling
	Heating and ventilation installation
	Oil installation
The modified subassemblies	Fuel system
	Electrical system
	Instrument panel

Design Decomposition



Internal information flow scheme visualized in N^2-matrix view

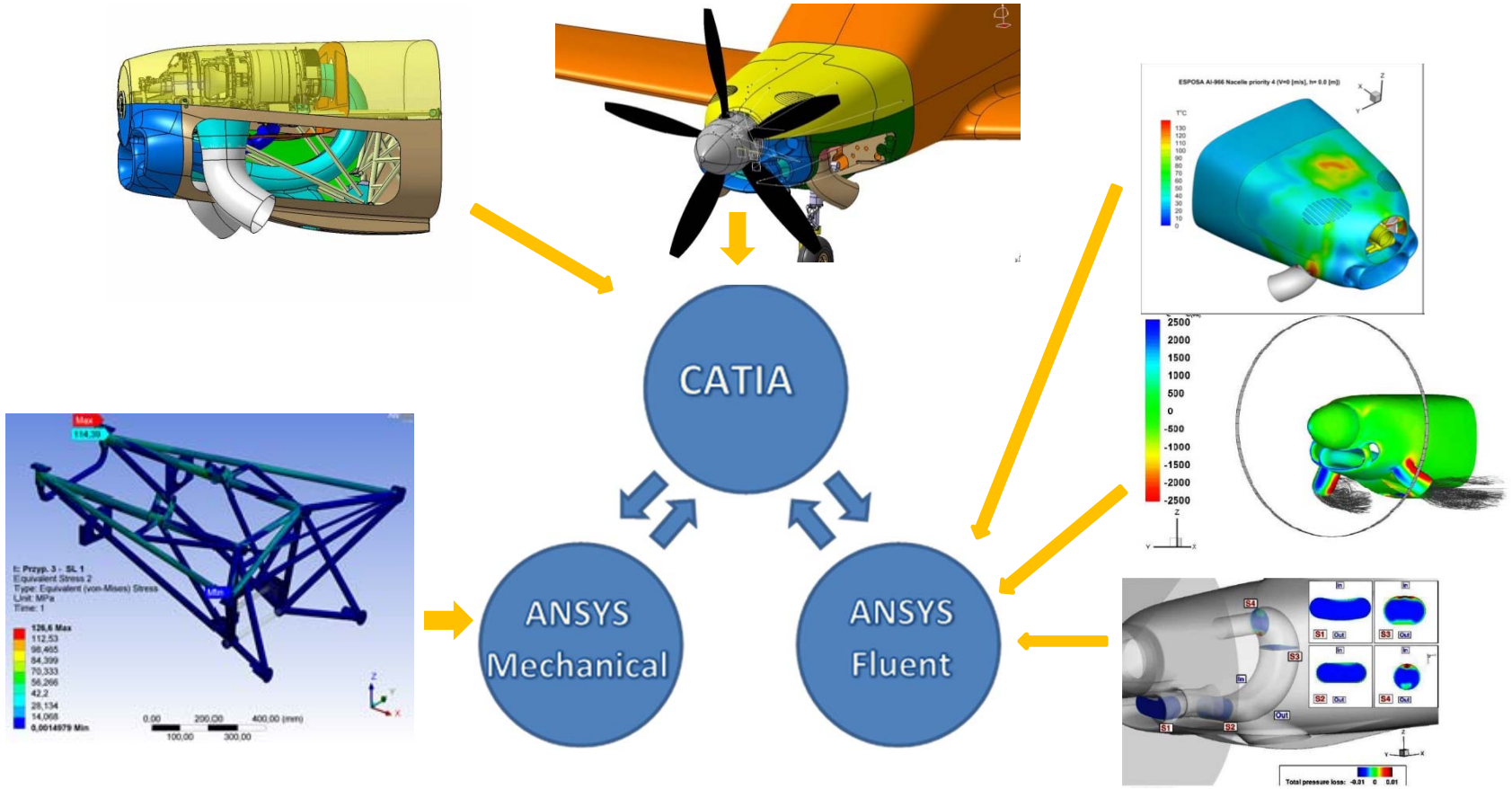
Design Decomposition

Discipline	Description of the issue related
Configuration	Configuration management - the changes and the current versions of solutions.
Geometry	Arrangement of components in three dimensional space - the changes and the current geometry.
Weights and balance	Weight and centre of gravity, the weight and balance limits , mass models
Aerodynamics	Updating data on aircraft aerodynamics - the new powerplant (turboprop engine, propeller) and the change of the aircraft geometry (new nacelles).
Loads	Updating loads for aircraft - the new powerplant and new parts (engine mount, fittings).
Strength	Calculations, analyses and tests in order to prove a sufficient strength of new components and the whole aircraft.

Design Decomposition

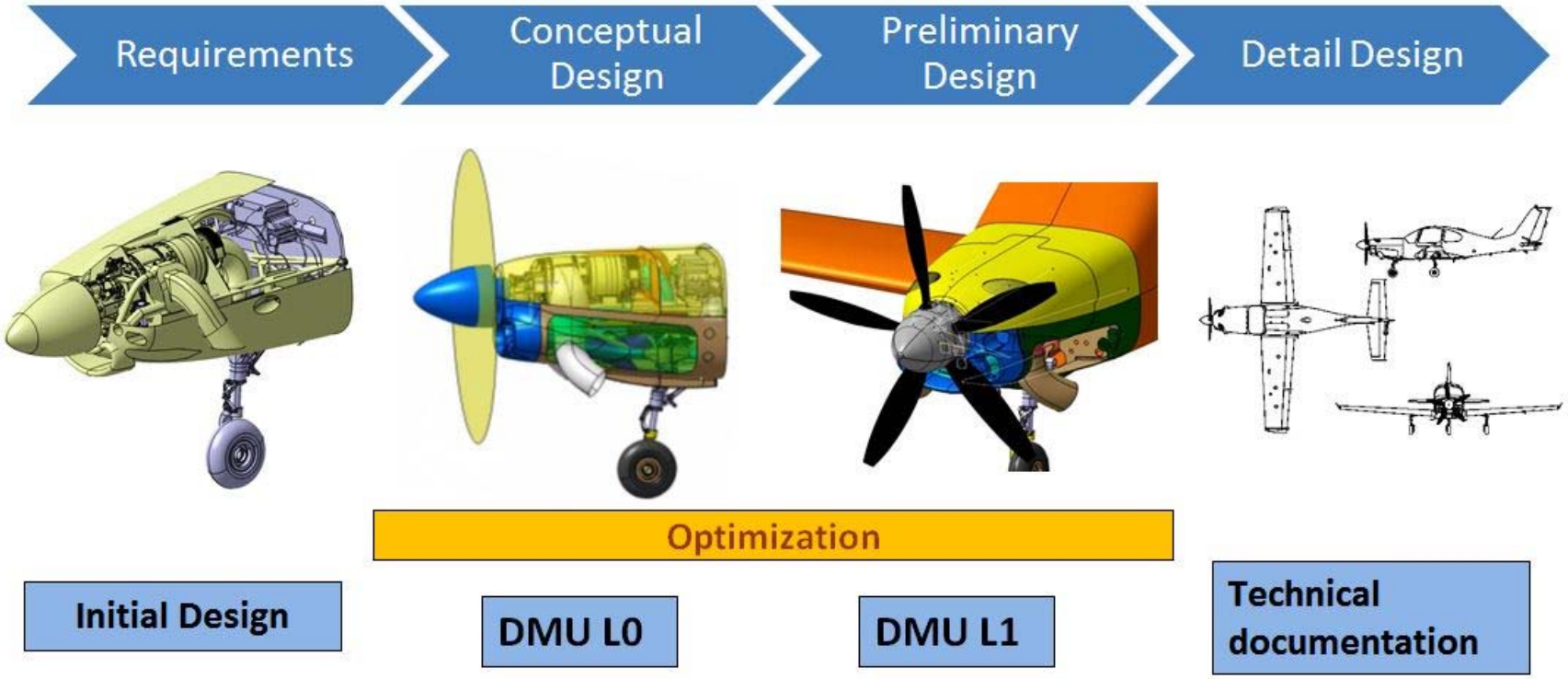
Discipline	Description of the issue related
Stability	Calculation of longitudinal, directional and lateral stability for both static and dynamic.
Performance	Calculation of the aircraft performance (stalling speed, climb speed, take-off distance, landing distance).
Internal flows	Calculation of the internal flows: the air inlet and the air supply system to the engine with the particle separator.
Heat transfer	Calculation of the internal flows (the exhaust system, the air supply system for oil cooler, the engine cooling and ventilation system, the heating and ventilation installation (cabin), the air supply system for electrical equipment).
Other	Other issues - the selection of materials and technology, costs, maintenance, environmental protection, fire protection, etc..

Design Decomposition



Scheme of information flow in the field of strength, fluid mechanics and heat transfer

Optimization Process



Scheme of design process

Optimization Process

Multidisciplinary Design Optimisation (MDO) algorithms:

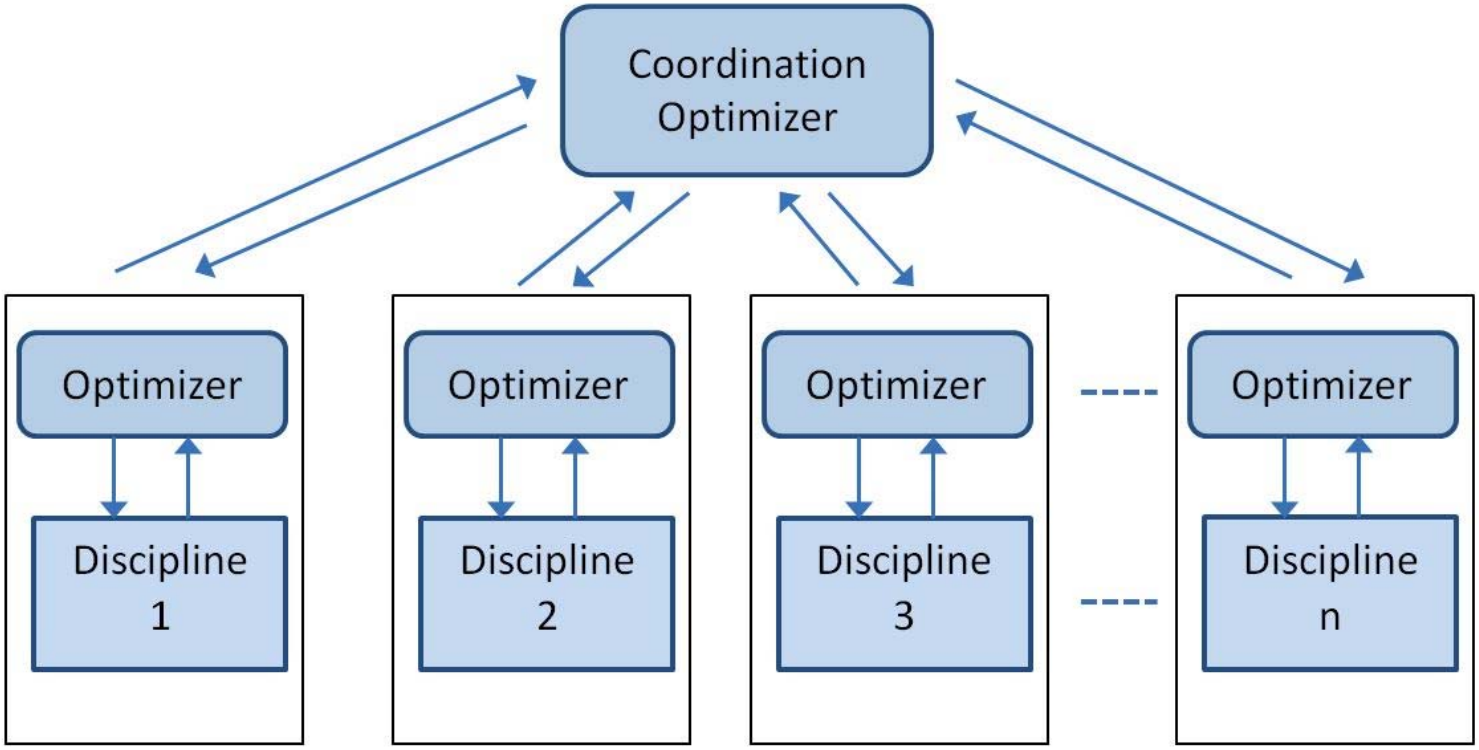
- Multi-Disciplinary Feasible Design (MDF)
- Individual Discipline Feasible (IDF)
- Collaborative Optimization (CO)
- Concurrent Subspace Optimization (CSSO)
- Bi-Level Integrated System Synthesis (BLISS)

One optimization level

Multiple optimization levels

Perez R.E., Liu H.H. T. and Behdinan K. (2004). Evaluation of Multidisciplinary Optimization Approaches for Aircraft Conceptual Design. 10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Albany, New York, AIAA 2004-4537.

Optimization Process



The Collaborative Optimization (CO) algorithm block diagram
(bi-level optimization architecture that preserves the autonomy of individual disciplines)

Optimization Assessment

Two ways of cost assessment of the optimization process

Assessment of the workload and cost of the optimization process.

The effort and the cost were slightly higher than similar projects - more computations.

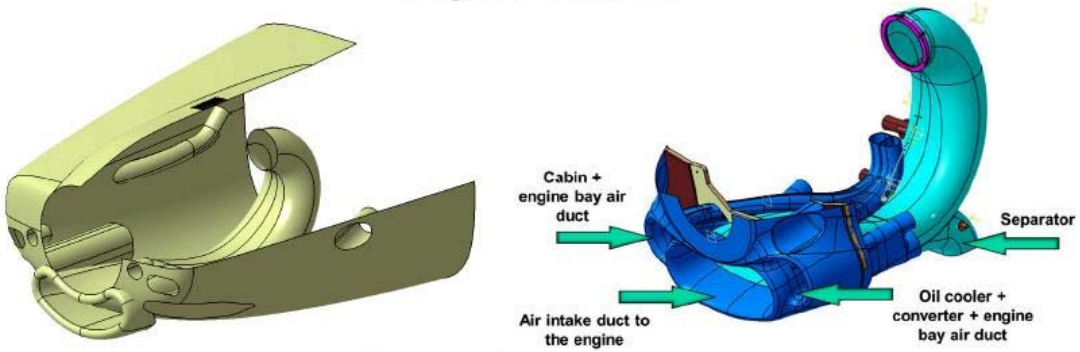
Look at the optimization process from the perspective of the whole product development process.

- Reduction of changes in the product in the next stages – reduction of cost of the whole process of the product development.
- Reduction of future product life cycle costs.

Optimization Assessment

Assessment of the optimization process - size of changes

Engine mount



Air intakes system

Comparison of the engine mount and the air intake system before and after the optimization process

Conclusions

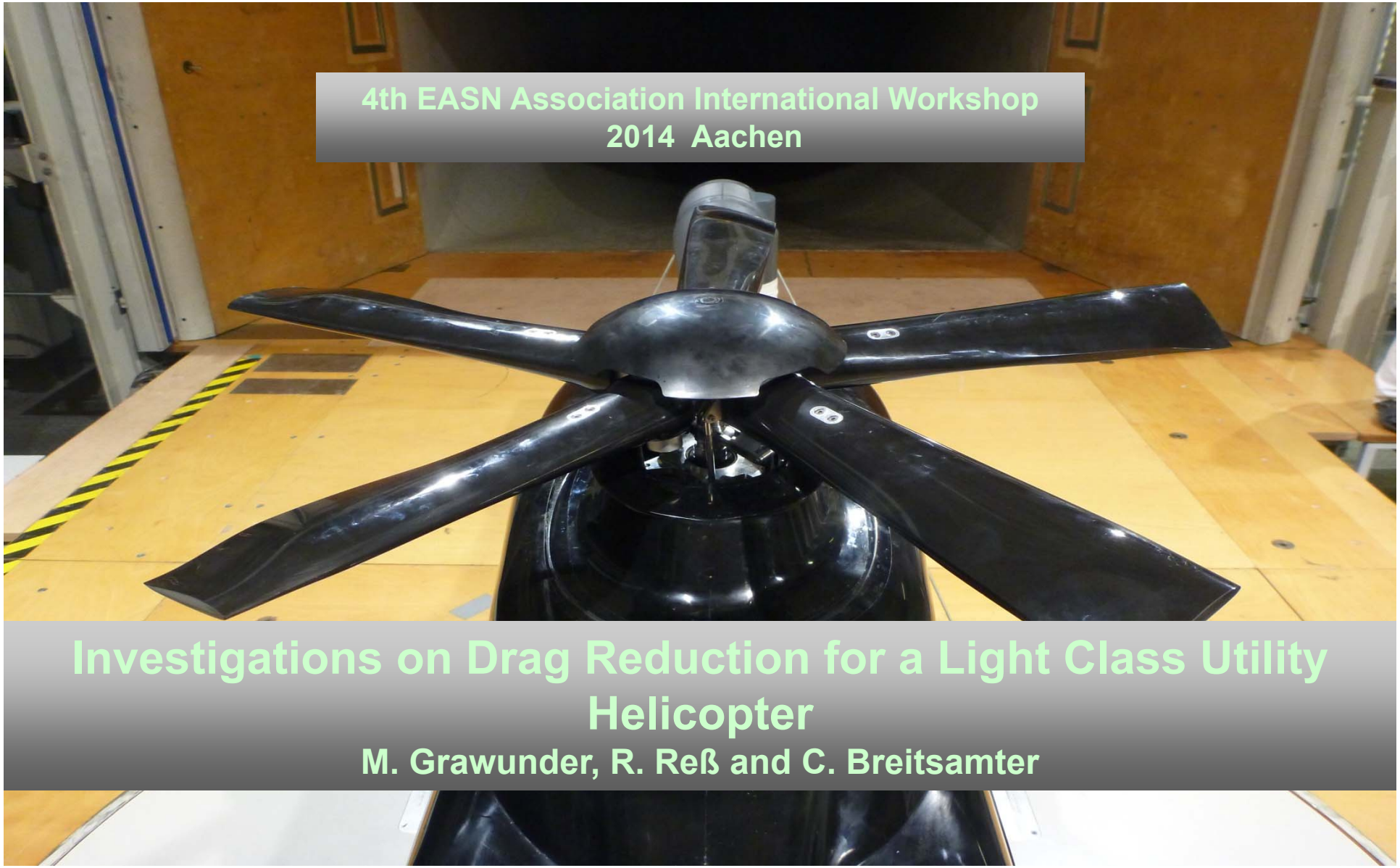
1. The **decomposition of design problem** is an important step of the whole design process and significantly affects the quality of result and efficiency of design process.
2. The design work was carried out by several teams from different organizations. The selected optimization algorithm named **Collaborative Optimization (CO)** was efficient.
3. The effectiveness of multidisciplinary optimization depends as much on **organizational parameters** as it does on **technical and technology parameters.**

To become truly effective, multidisciplinary optimization needs to be an integral part of analysis and design process.

Acknowledgements

The research was supported by the FP7-AAT-2011-RTD-1 Collaborative Project ESPOSA (Efficient Systems and Propulsion for Small Aircraft), Contract No.: 284859

Thank you for your attention



4th EASN Association International Workshop
2014 Aachen

Investigations on Drag Reduction for a Light Class Utility Helicopter

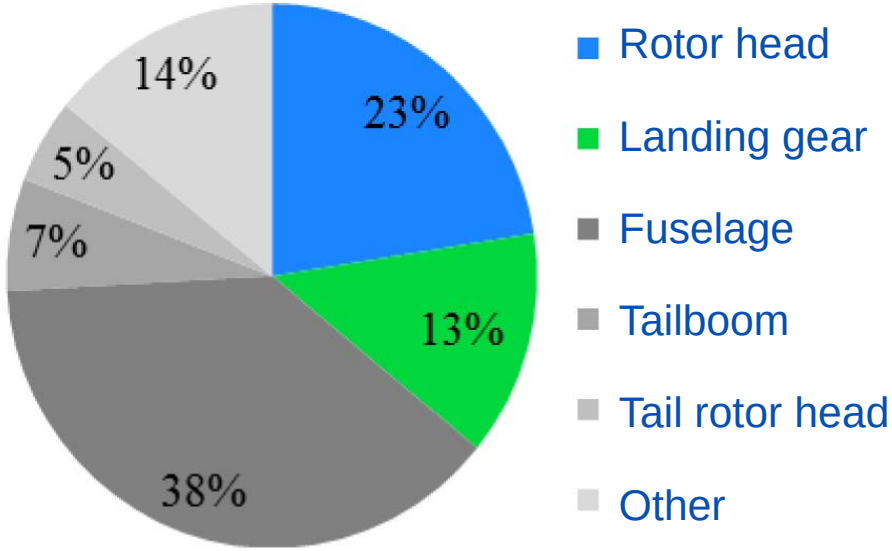
M. Grawunder, R. Reß and C. Breitsamter

Overview

- Drag reduction
- Scope
- Wind tunnel model
- Wind tunnel A
- Test equipment
- Numerical simulation
- Landing gear modification
- Strakes and vortex generators
- Mast fairing modification
- Drag reduction
- Conclusions

Drag reduction

About 75% of the parasite drag of a light class configuration originates from fuselage, rotor head, and landing gear (MBB Bo 105)



Wagner, S.N., AGARD Conf. Proc. 124, April 1973

Scope

Shape optimization of light class configuration through

- Wind tunnel tests
- Complementary numerical studies

Focus on

- Landing gear
- Flow control at the fuselage aft body
- Rotor head and mast fairing

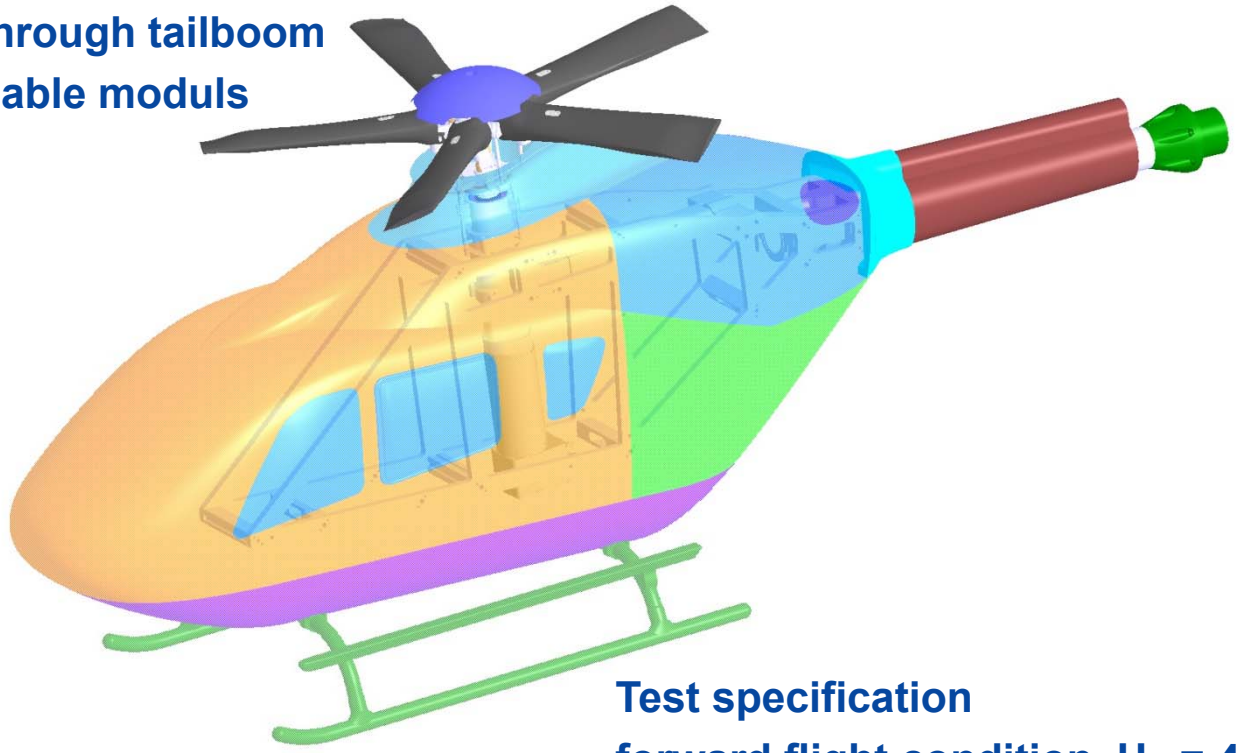
Wind tunnel model

1:5 scale with rotating rotor head

Cyclic and collective pitch adjustment

Support through tailboom

Exchangeable moduls

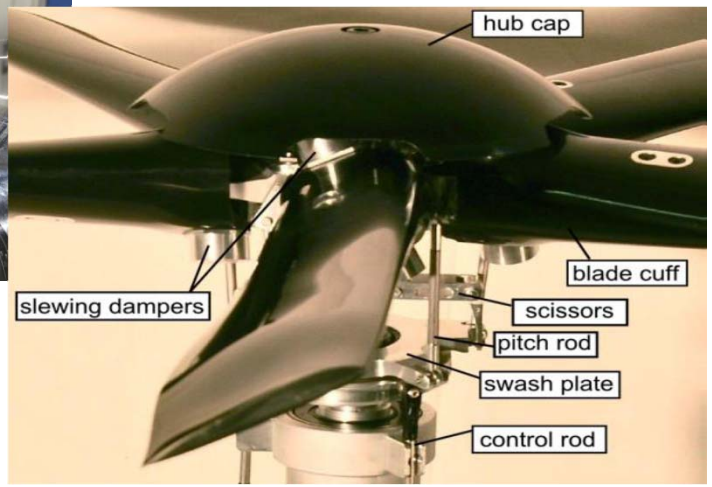


Test specification

forward flight condition, U_∞ = 40 m/s
Reynolds number = 1 x 10^6

Polars ranging from -10° to +10° AOA and AOS

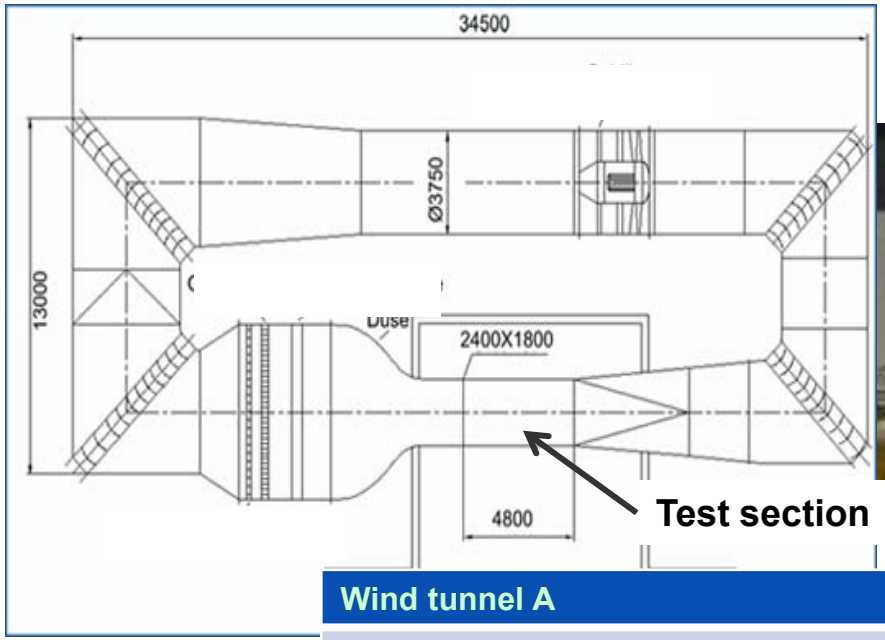
Wind tunnel model



Detailed model geometry

Functioning rotor head

Wind tunnel A



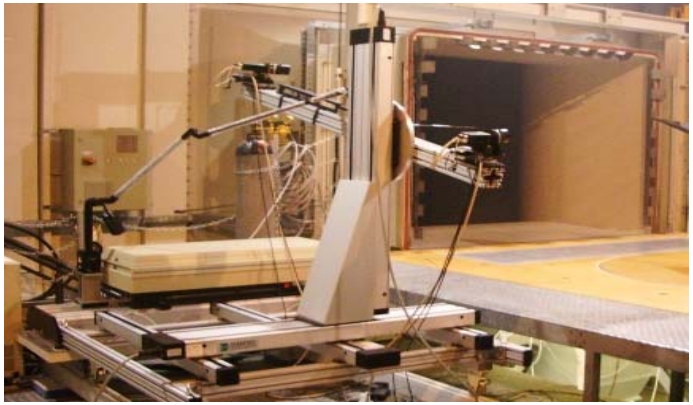
Wind tunnel A	
Cross section of test section	1.80 m · 2.40 m· 4.80m
Nozzle contraction ratio	7 : 1
Length of test section	4.8 m
Maximum power	420 kW
Maximum velocity	65 m/s (open) / 75 m/s (closed)
Turbulence intensity	$Tu_x = Tu_y = Tu_z$ < 0.4 % / < 0.2 %

Test equipment

Forces and moments

6-component- balances

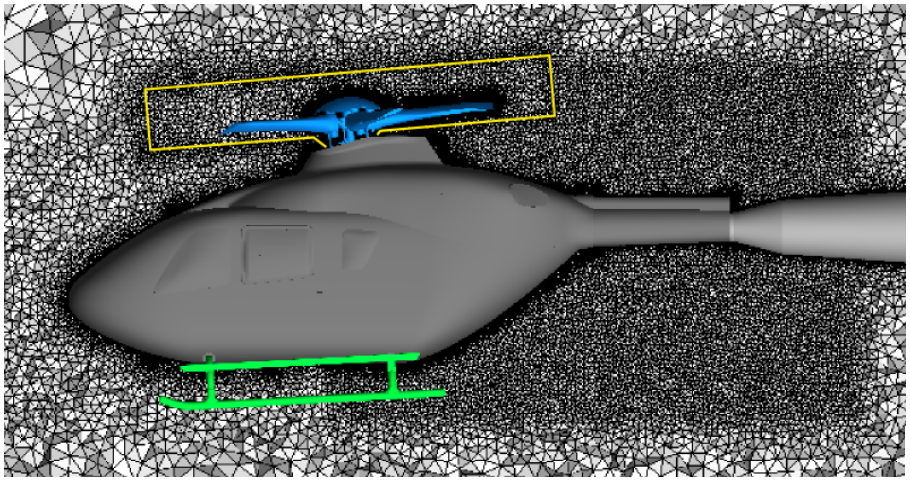
Pressure



Flowfield

Stereo-PIV

Numerical simulation



Numerical Setup

Incompressible Navier-Stokes-Equations (U)RANS - Model

Solver ANSYS CFX

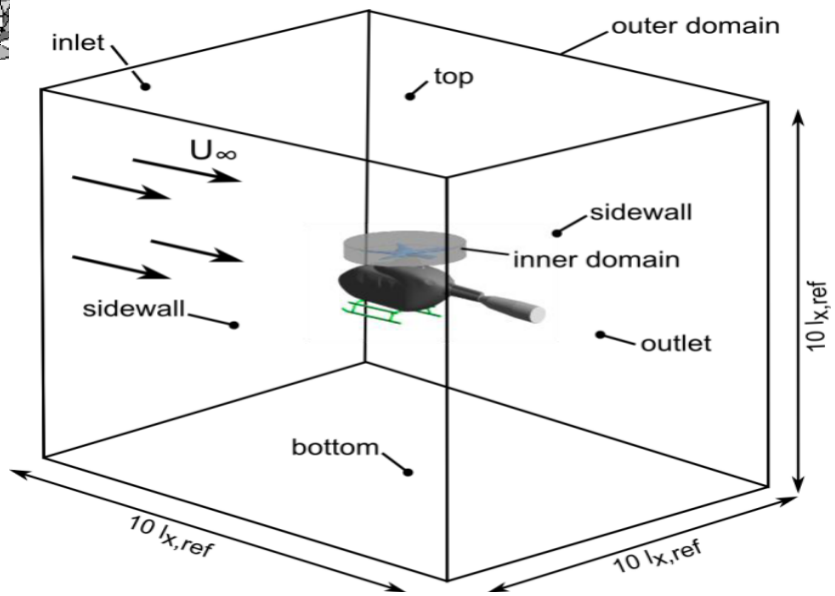
SST-Turbulence Model

Spatial discretization:

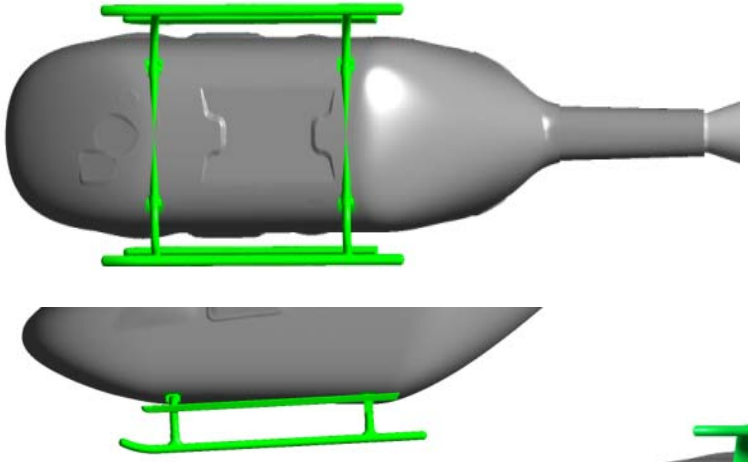
High–Resolution-Scheme

Temporal discretization:

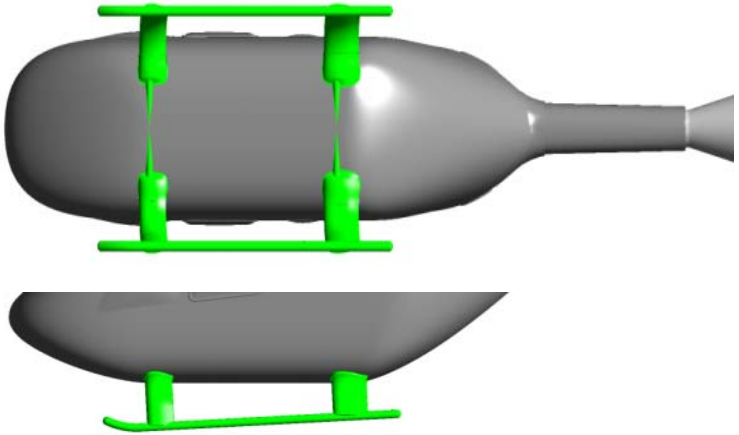
Implicit Backward – Euler – Method



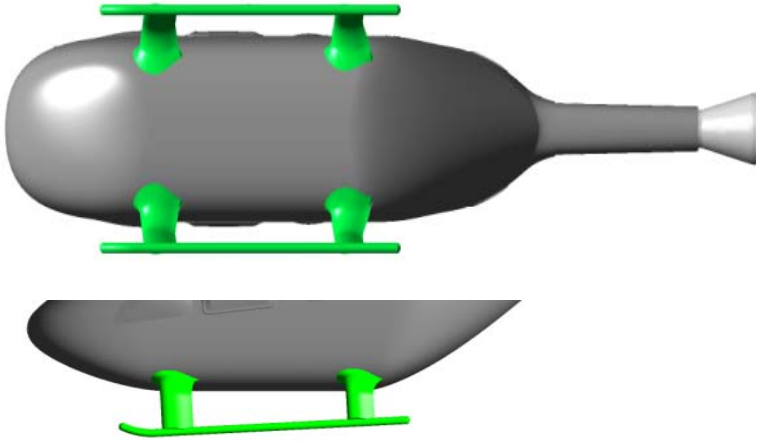
Landing gear modification



Baseline



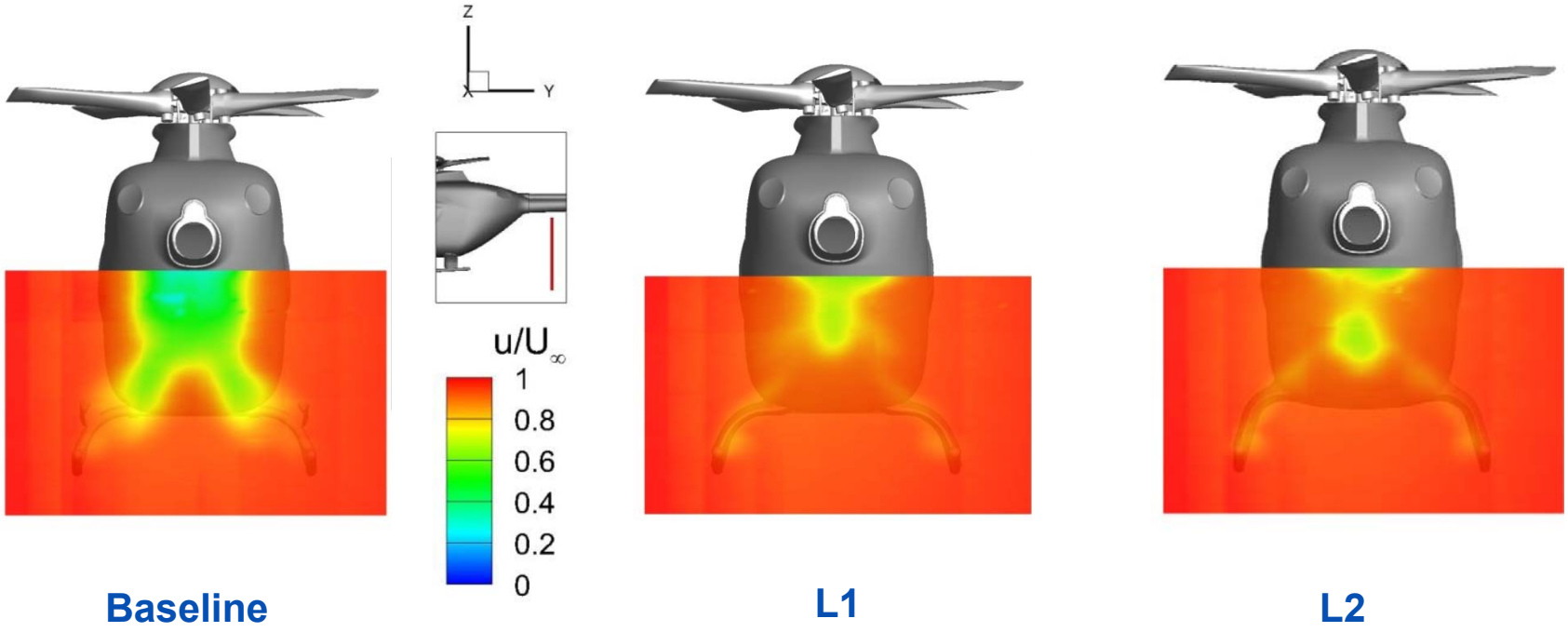
Skid landing gear L1



Skid landing gear L2

Landing gear modification

Results

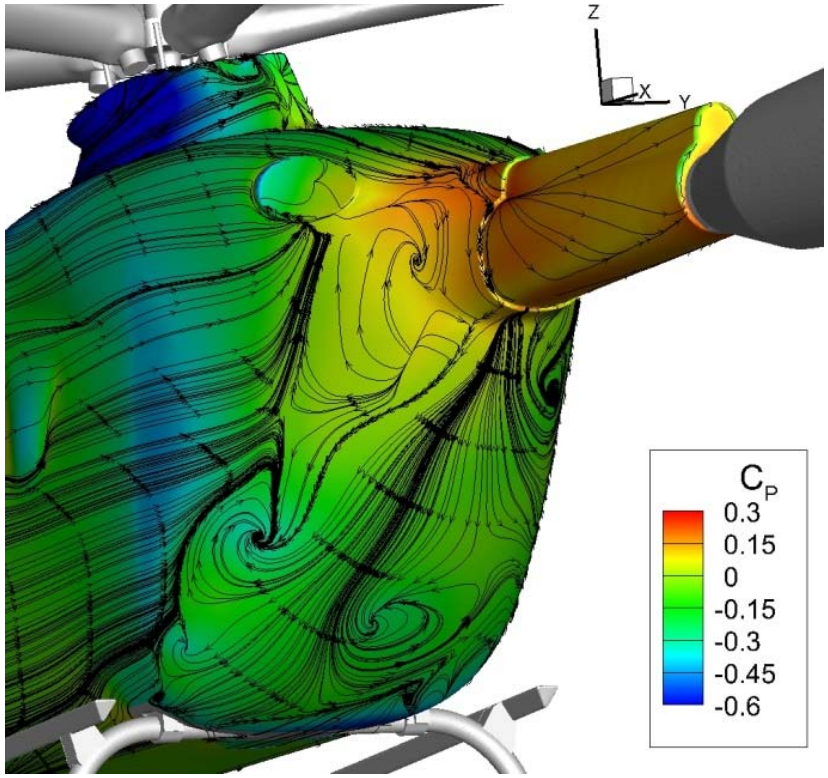


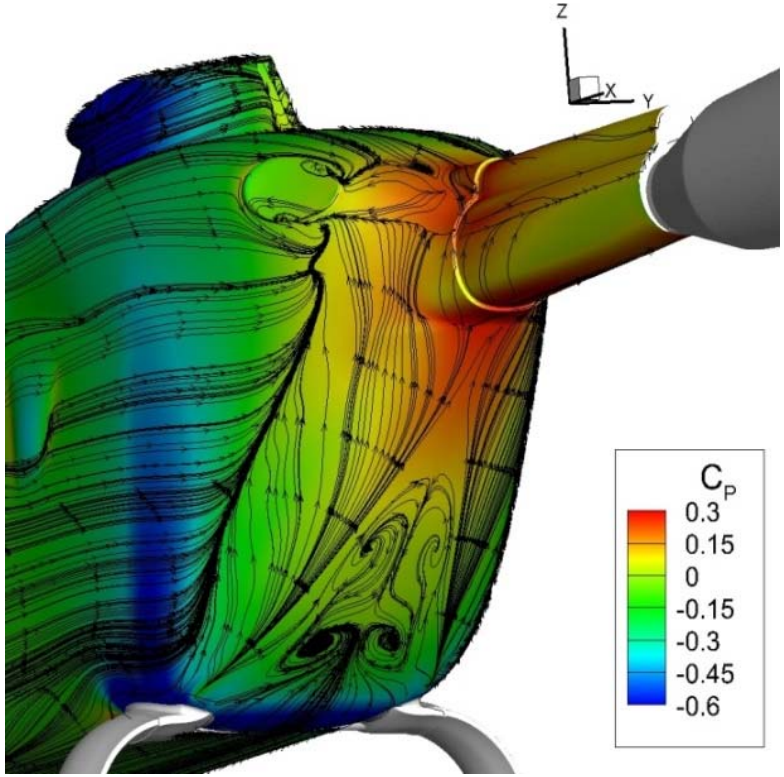
Baseline **L1** **L2**

Mean axial velocity distribution: u/U_∞ $\alpha, \beta = 0°$, $Re = 1x10^6$, experimental data (PIV)

Landing gear modification

Results

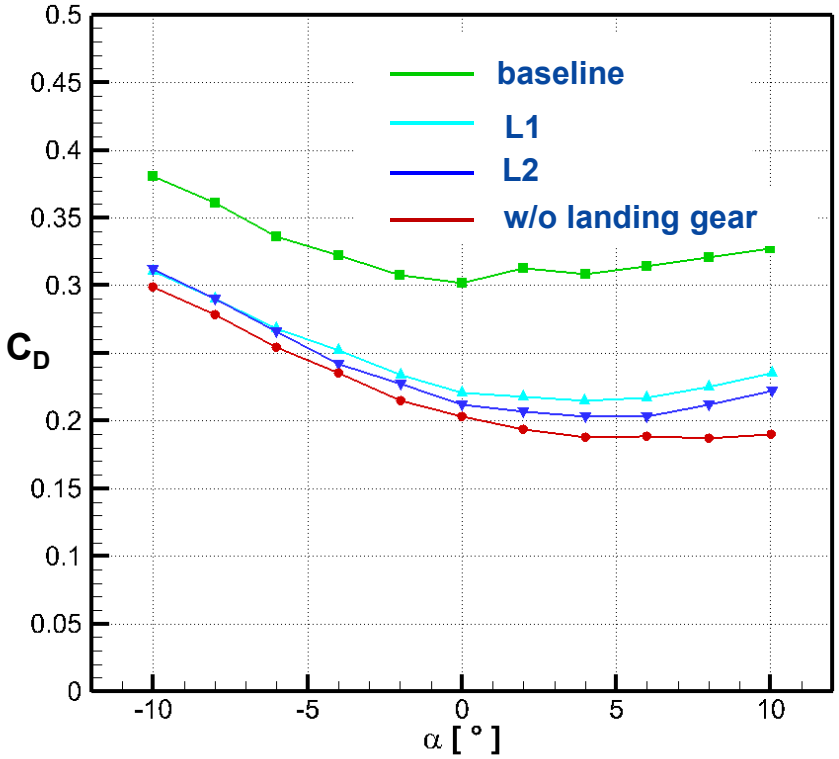


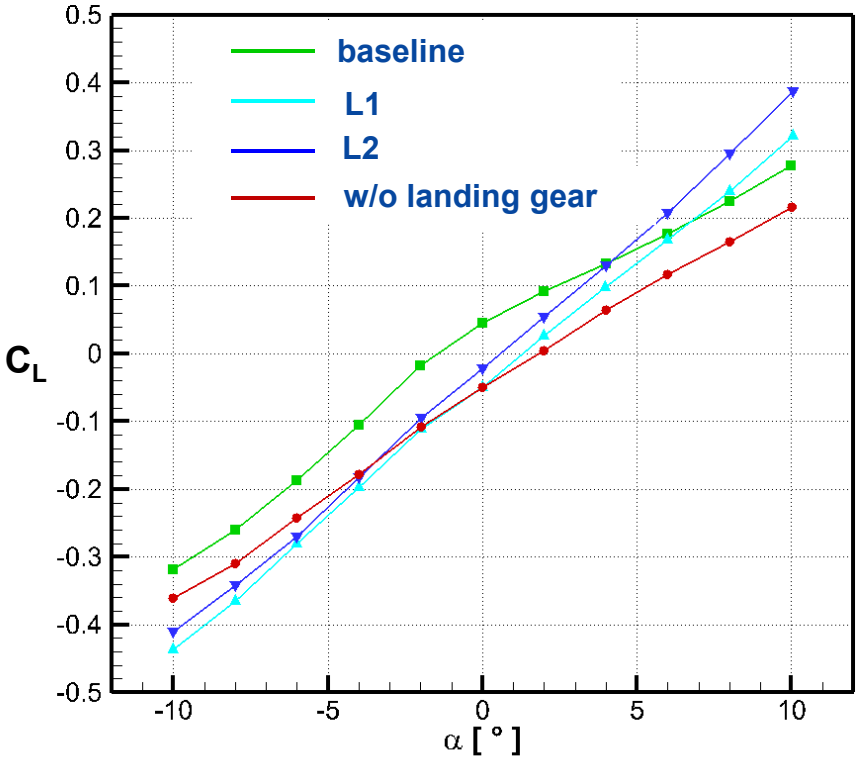


Pressure coefficient distribution and surface streamlines based on URANS-SST
Re = 1 x 10^6 , α, β = 0° , baseline(left), L1 (right)

Landing gear modification

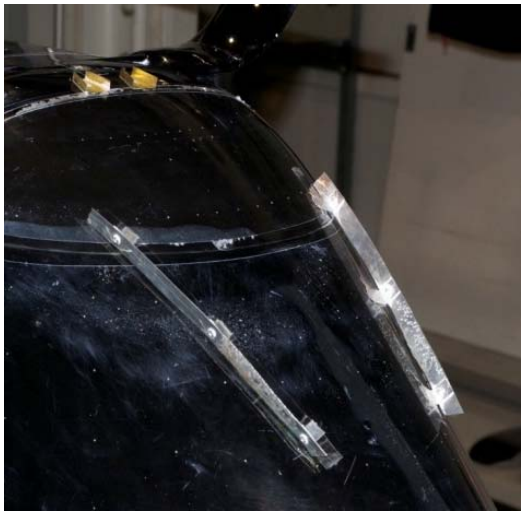
Results



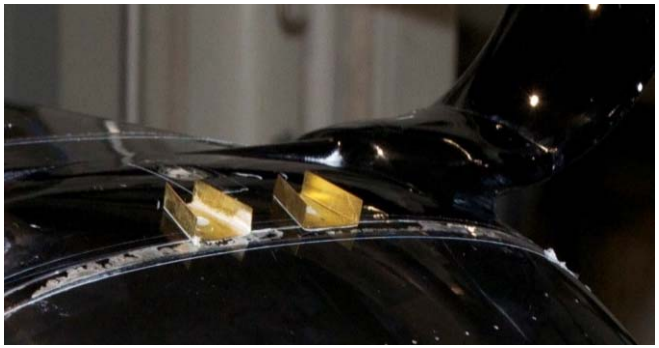


Drag- (left) and Lift- (right) coefficient vs. α, β = 0° , Re = 1x10⁶, experimental data

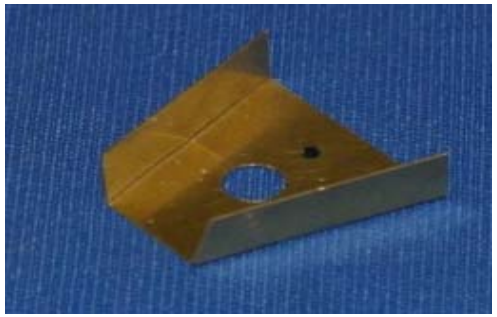
Strakes and vortex generators



Strakes S1



Vortex generators

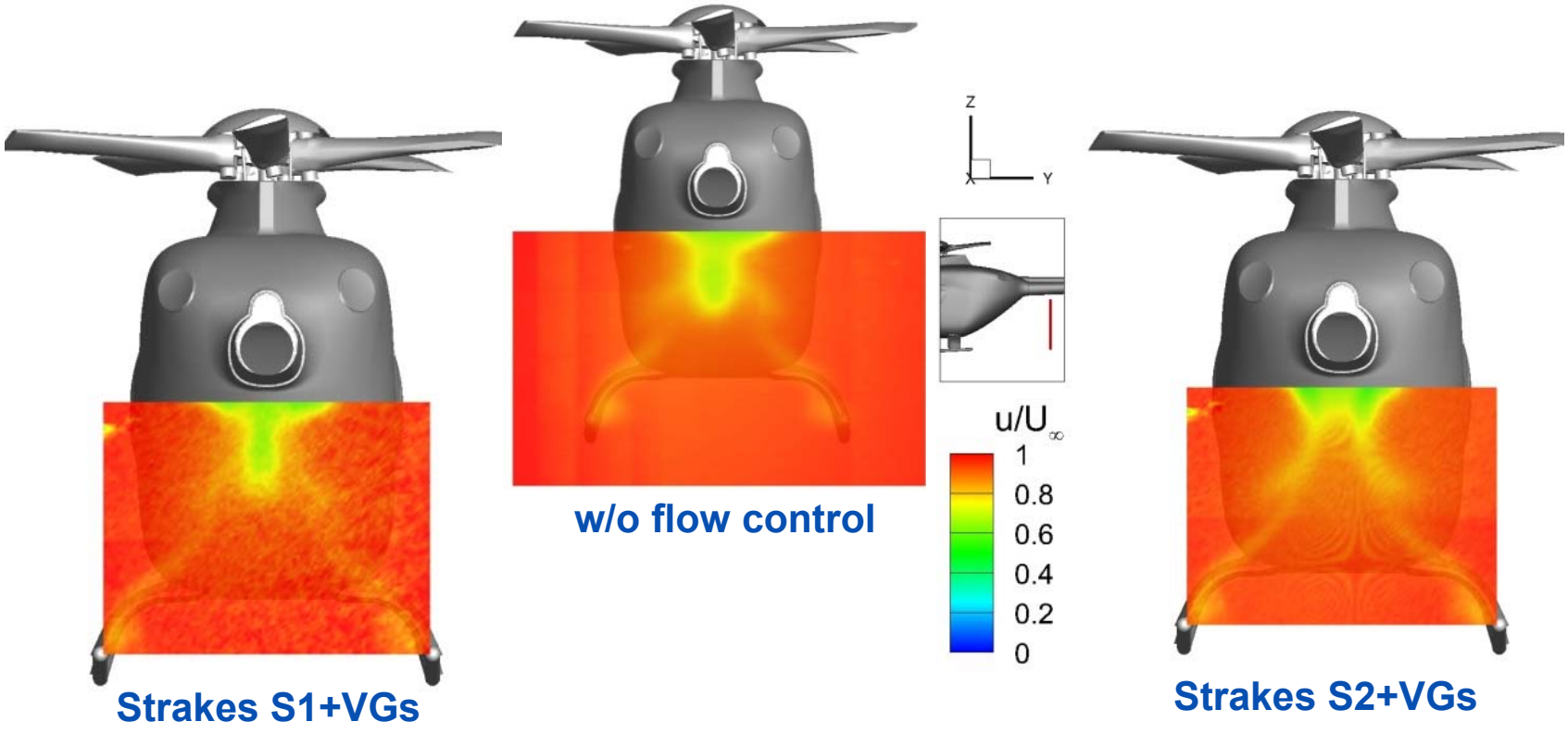


angle of inclination 15°
height δ, length 3.5 x δ

Strakes S2

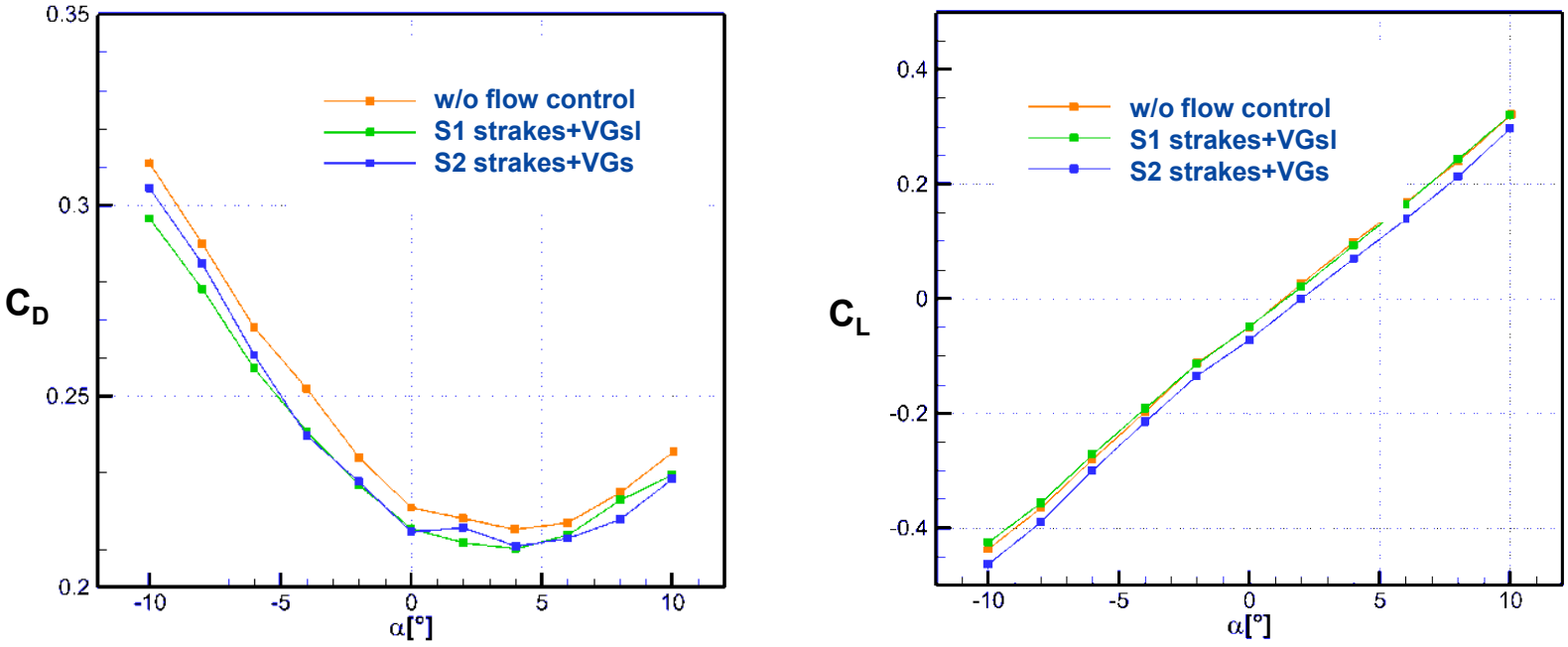
Strakes and Vortex Generators

Results



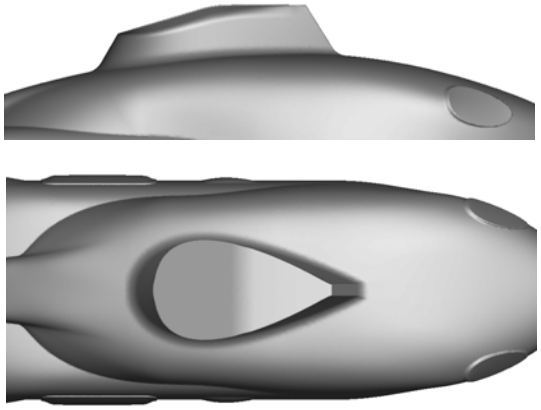
Mean axial velocity distribution: u/U_∞ $\alpha, \beta = 0°$,Re = $1x10^6$, experimental data (PIV)

Strakes and Vortex Generators Results

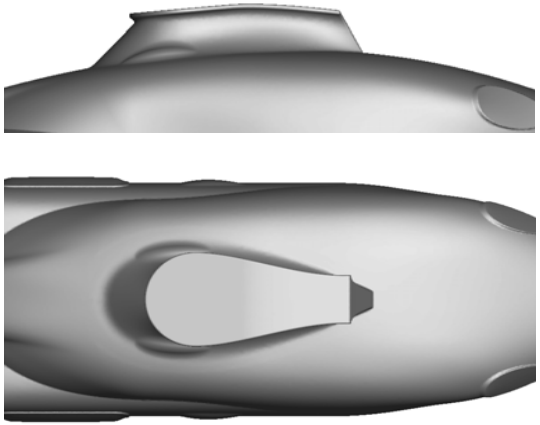


Drag- (left) and Lift- (right) coefficient vs. α, $\beta = 0°$, Re = 1x10^6, experimental data

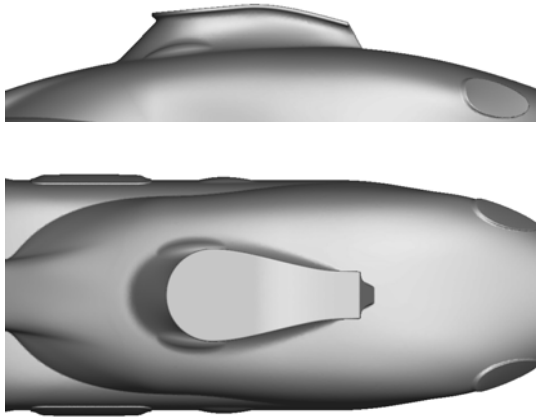
Mast fairing modification



Baseline



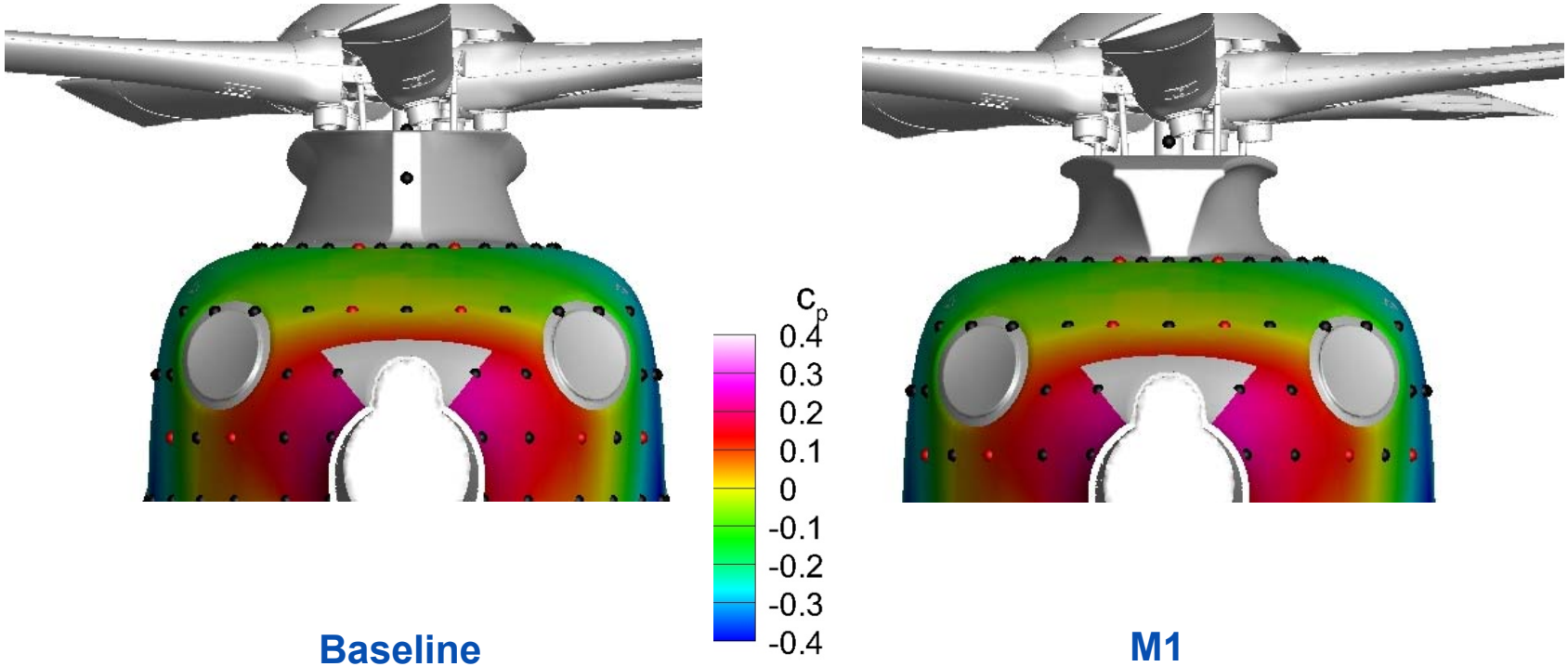
M1



M2

Mast fairing modification

Results

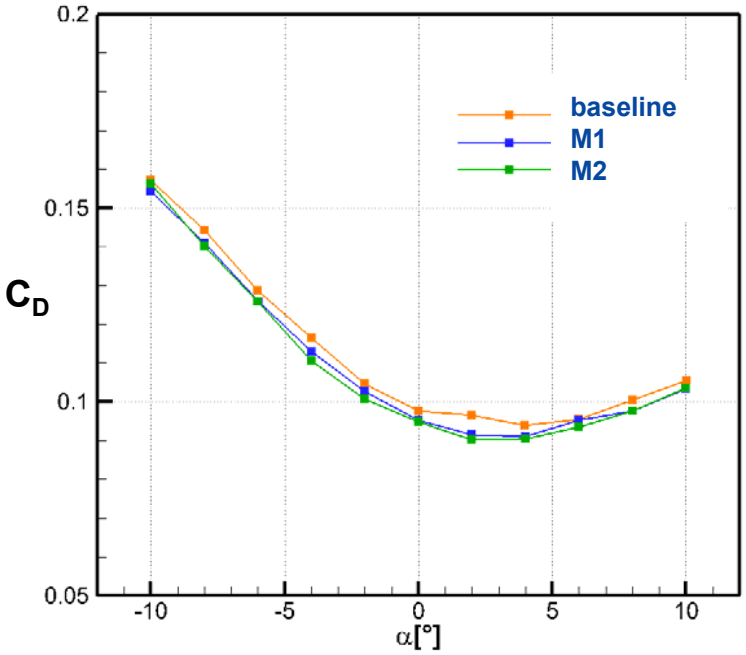


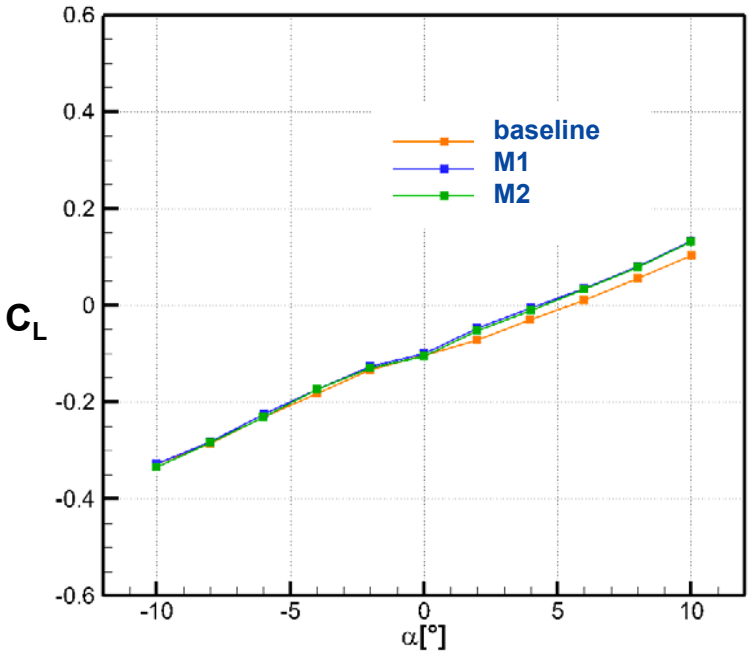
Baseline **M1**

Surface pressure distribution (C_p), Re = 1x10^6, experimental data

Mast fairing modification

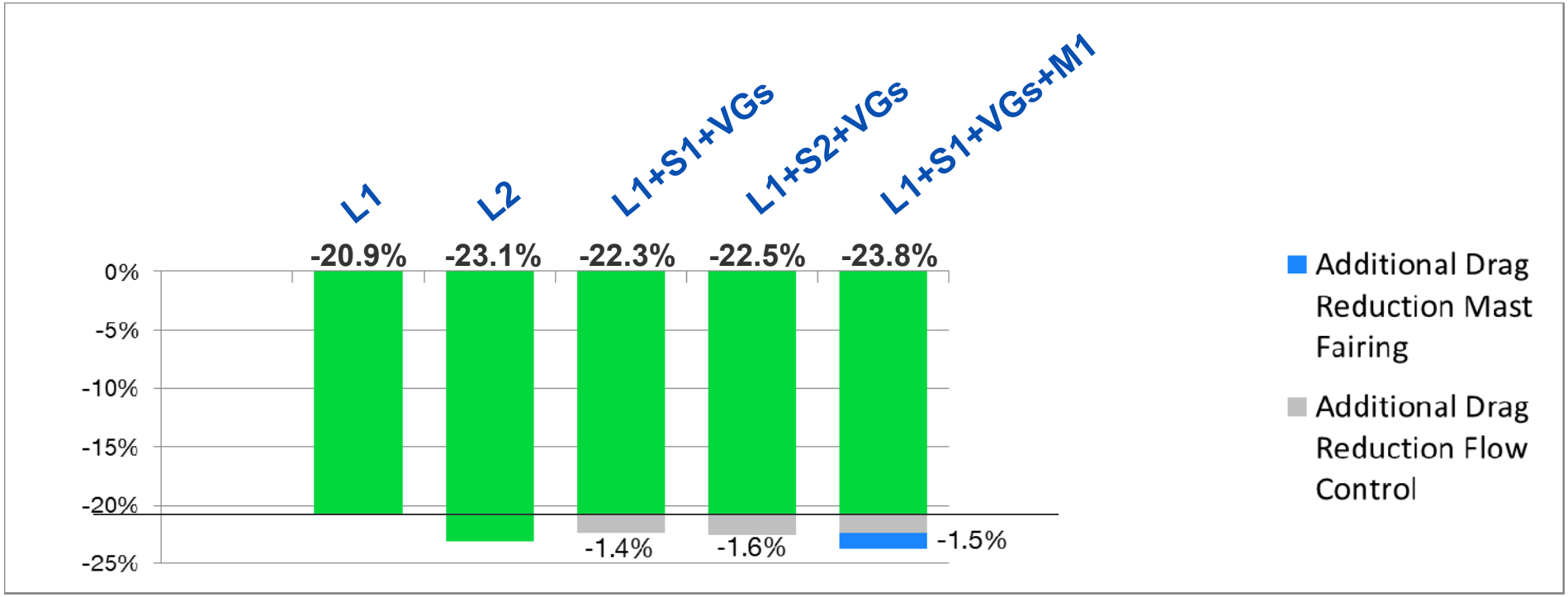
Results





Drag- (left) and Lift- (right) coefficient vs. α, β = 0° , Re = 1x10⁶ , experimental data

Drag reduction



Achieved drag savings, scaled up to an actual TEL-class helicopter α, β = 0°

Conclusions

Wind tunnel tests and numerical studies

- **Baseline**
- **Landing gear modification** — **20.9% (L1) drag saving**
- **Flow control at the aft body** — **additional 1.4% (S1)**
- **Mast fairing (and rotor hub) modification** — **additional 1.6% (M1)**

Drag saving for an actual light-class helicopter

up to 23% with retrofittable modifications

ADHeRo contributed to lifting the dicussed technologies to TRL4.

Thank you for your attention!

Aerodynamic Optimisation Using CAD Parameterisations in SU^2

4th EASN Flight Physics Workshop
Aachen, Germany

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Outline

Outline

1 Overview

2 Motivation

3 Gradient Calculation

4 Test Cases

5 Conclusions

Contents

- Overview
- Motivation
- SU^2
- CST Transformation
- Results
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Outline

1 Overview

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4 Test Cases

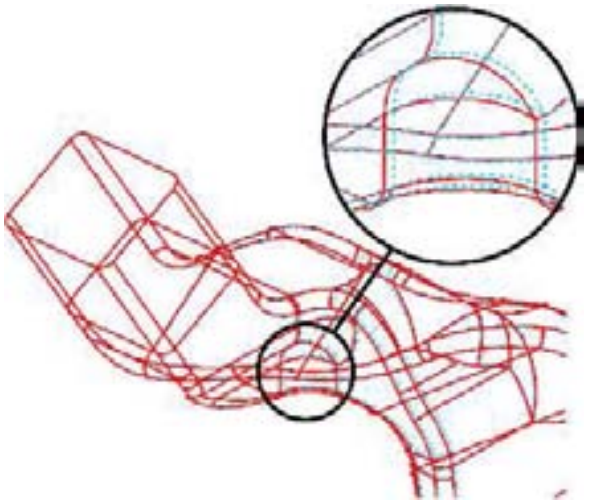
5 Conclusions

Motivation

- Increase flexibility of Adjoint Based Optimisation

Motivation

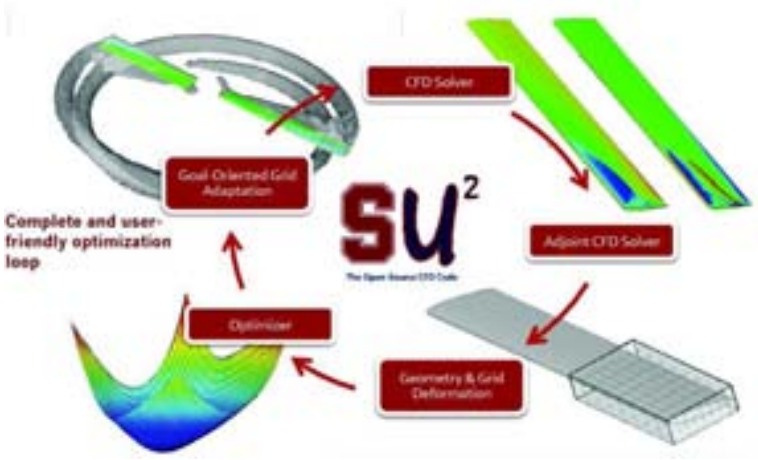
- Increase flexibility of Adjoint Based Optimisation
- Efficient calculation of any parametric sensitivity



SU^2

SU^2 is an open-source CFD/Adjoint optimisation framework[1]

- Developed at Stanford University



SU2
The Open-Source CFD Code

[1] images taken from *http://su2.stanford.edu/*

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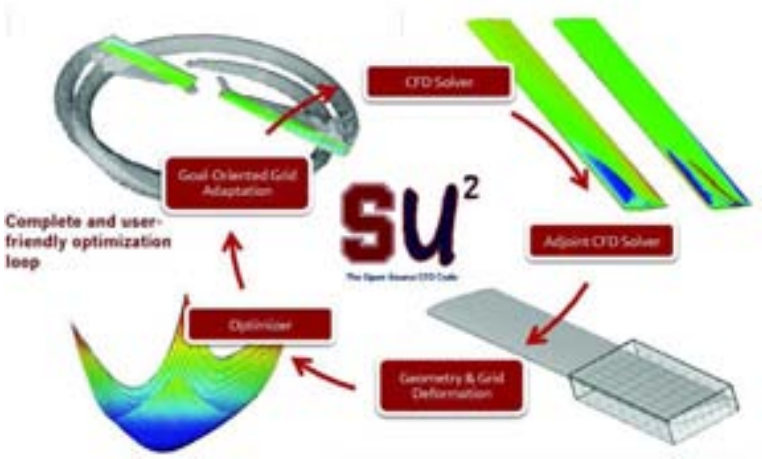

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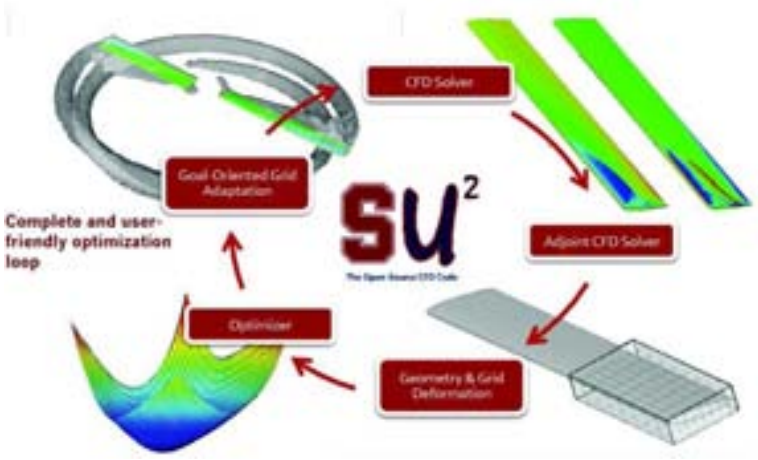

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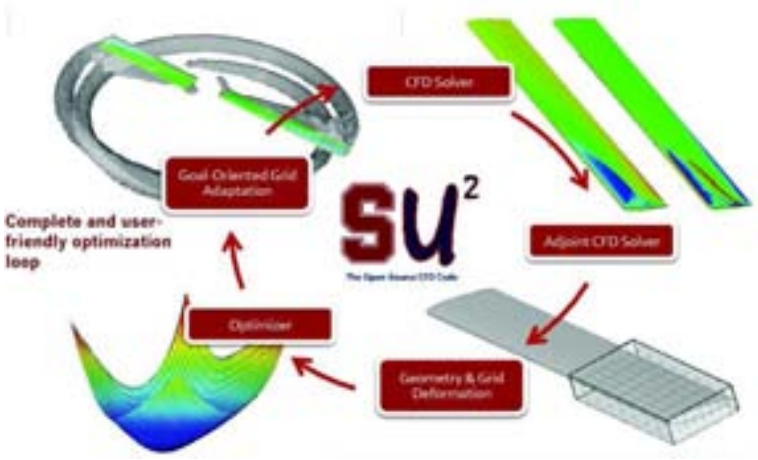
- Mesh deformation/adaptation



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- Developed at Stanford University
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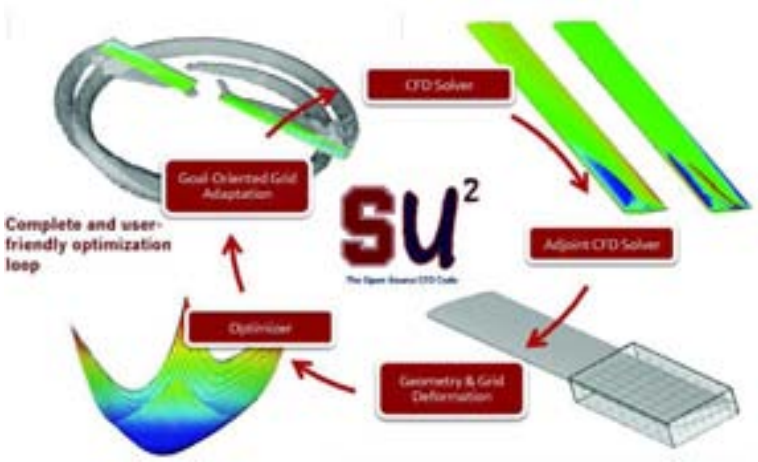
- Range of numerical schemes available (JST, ROE, MG, Euler-Implicit,...)
- Mesh deformation/adaptation
- Continuous Adjoint Solver

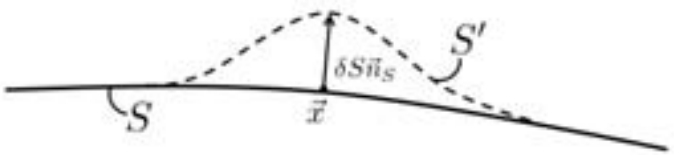


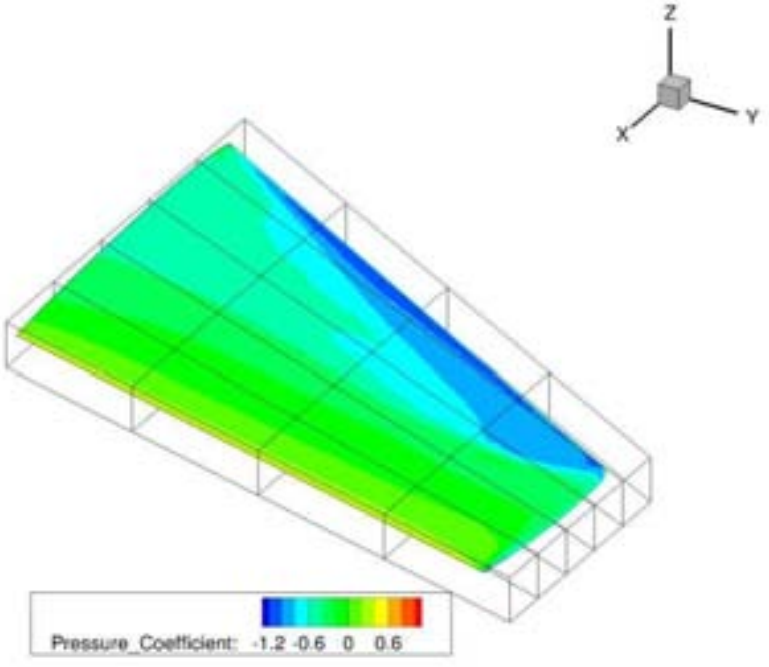
SU2
The Open-Source CFD Code

[1] images taken from *http://su2.stanford.edu/*

SU^2

Native parameterisations in SU^2 [2]

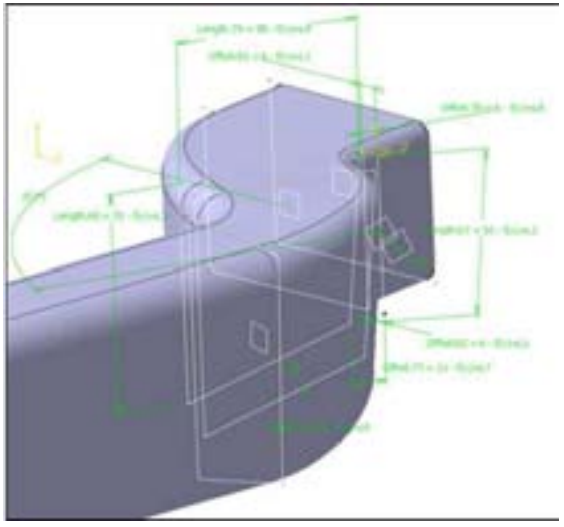




[2] images taken from *http://su2.stanford.edu/*

SU^2

How to link any parameterisation to SU^2 ?



Outline

1 Overview

2 Motivation

3 Gradient Calculation

4 Test Cases

5 Conclusions

SU^2

Adjoint Based Optimisation

- Gradients required for optimisation
- Finite differences not feasible for complex shapes with multiple parameters
- Adjoint method provides an efficient alternative

SU^2

Gradient Calculation

$$\underbrace{\begin{bmatrix} \frac{\partial f}{\partial A_1} \\ \frac{\partial f}{\partial A_2} \\ \vdots \\ \frac{\partial f}{\partial A_n} \end{bmatrix}}_{Gradients} = \underbrace{\begin{bmatrix} \frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_m} \end{bmatrix}}_{Geometric\ Sensitivities} \underbrace{\begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_m} \end{bmatrix}}_{Surface\ Sensitivities}$$

- $\frac{\partial f}{\partial A_i}$ - Gradient
- $\frac{\partial x_j}{\partial A_i}$ - Geometric Sensitivities
- $\frac{\partial f}{\partial x_j}$ - Surface Sensitivities

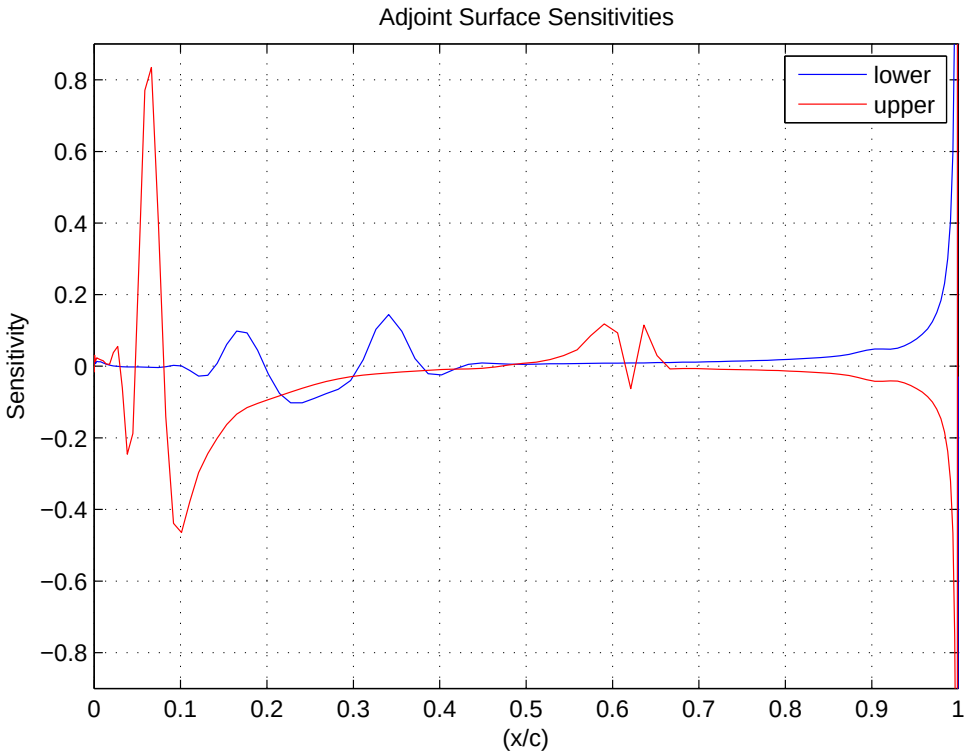
SU^2

Gradient Calculation

$$\underbrace{\begin{bmatrix} \frac{\partial f}{\partial A_1} \\ \frac{\partial f}{\partial A_2} \\ \vdots \\ \frac{\partial f}{\partial A_n} \end{bmatrix}}_{\text{Gradients}} = \underbrace{\begin{bmatrix} \frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_m} \end{bmatrix}}_{\text{Geometric Sensitivities}} \underbrace{\begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_m} \end{bmatrix}}_{\text{Surface Sensitivities}}$$

- $\frac{\partial f}{\partial A_i}$ - Gradient
- $\frac{\partial x_j}{\partial A_i}$ - Geometric Sensitivities
- $\frac{\partial f}{\partial x_j}$ - Surface Sensitivities

SU^2



Computed by SU^2

SU^2

Gradient Calculation

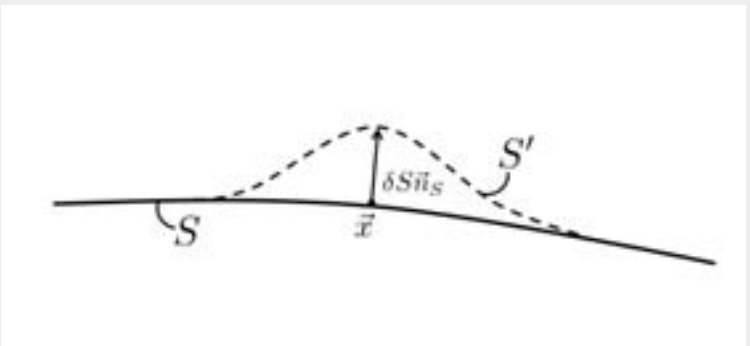
$$\underbrace{\begin{bmatrix} \frac{\partial f}{\partial A_1} \\ \frac{\partial f}{\partial A_2} \\ \vdots \\ \frac{\partial f}{\partial A_n} \end{bmatrix}}_{\text{Gradients}} = \underbrace{\begin{bmatrix} \frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_m} \end{bmatrix}}_{\text{Geometric Sensitivities}} \underbrace{\begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_m} \end{bmatrix}}_{\text{Surface Sensitivities}}$$

- $\frac{\partial f}{\partial A_i}$ - Gradient
- $\frac{\partial x_j}{\partial A_i}$ - Geometric Sensitivities
- $\frac{\partial f}{\partial x_j}$ - Surface Sensitivities

SU^2

Gradient Calculation

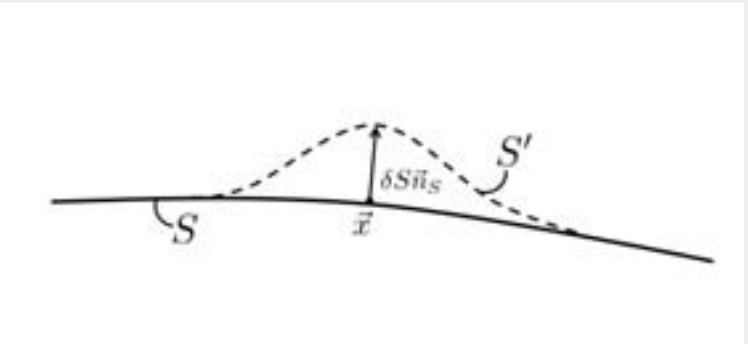
Use SU^2 native parameterisations



SU^2

Gradient Calculation

Use SU^2 native parameterisations



Gradient Calculation

Or add you own parametric sensitivities:

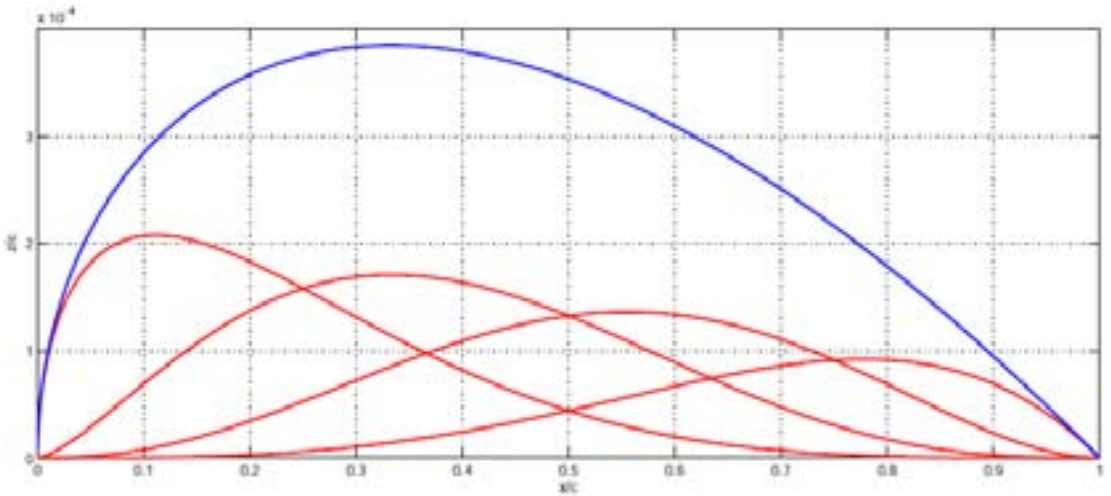
$$\Delta J = \int \phi V_n dS$$

CST Parameterisation

$$\zeta(\phi) = C_{N2}^{N1}(\phi)S(\phi) + \phi\Delta\zeta_{TE}$$

$$C_{N2}^{N1}(\phi) = \phi^{N1}(1-\phi)^{N2} \qquad \text{Class Function}$$

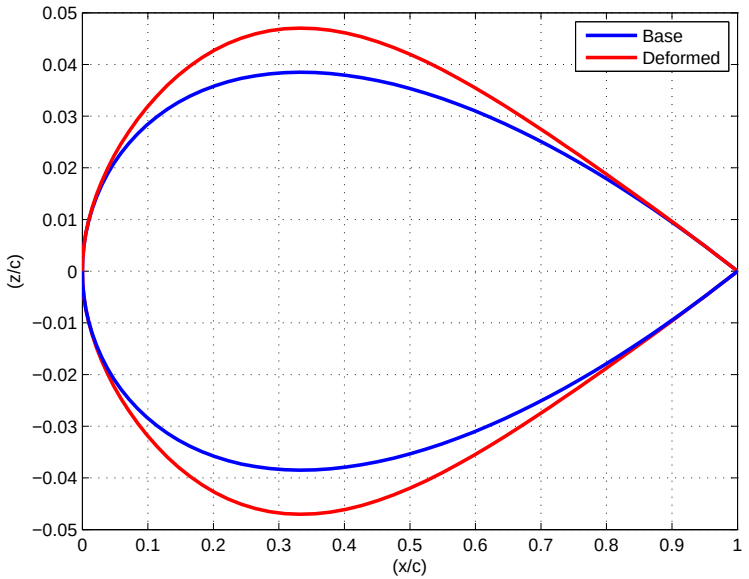
$$S(\phi) = \sum_{i=0}^{n} A_i S_i \qquad \text{Shape Function}$$



CST Parameterisation

The surface is manipulated through the choice of function weights A_i:

$$S(\phi) = \sum_{i=0}^{n} A_i S_i$$

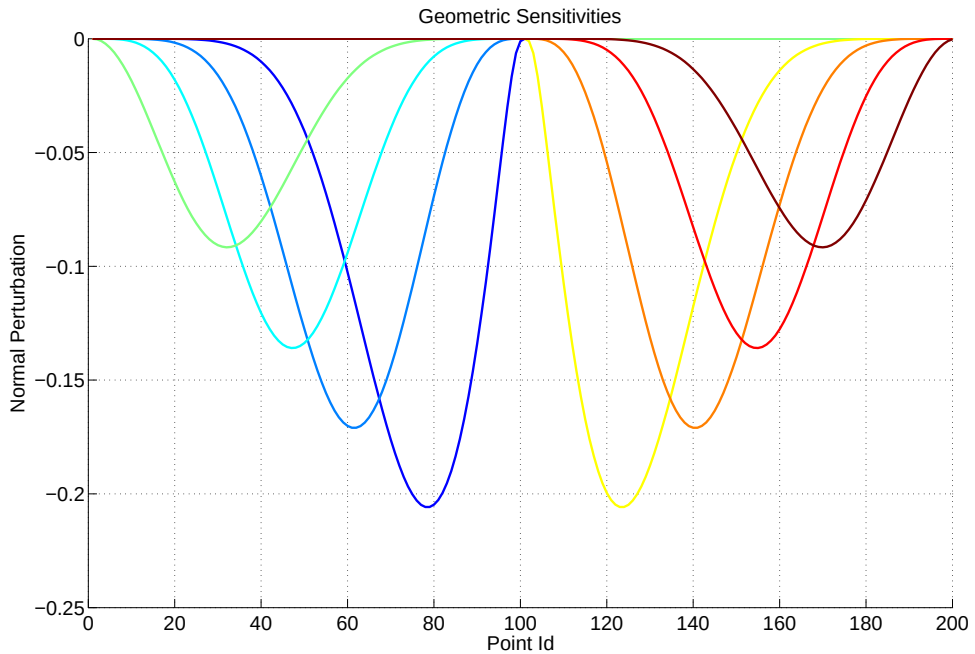


CST Parameterisation

Geometric Sensitivities ($\equiv V_n$)

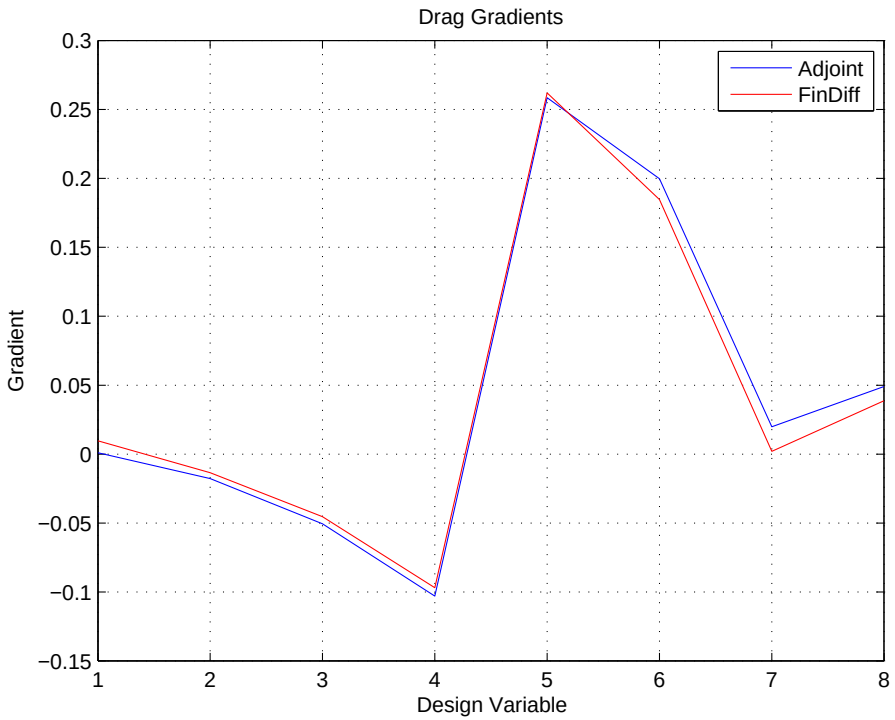
$$\frac{\partial \mathbf{x}_j}{\partial A_i} - \text{Geometric Sensitivities}$$

$$\frac{\partial \mathbf{x}_j}{\partial A_i} = \left(\frac{\partial x_j}{\partial A_i} n_x + \frac{\partial y_j}{\partial A_i} n_y + \frac{\partial z_j}{\partial A_i} n_z \right)$$

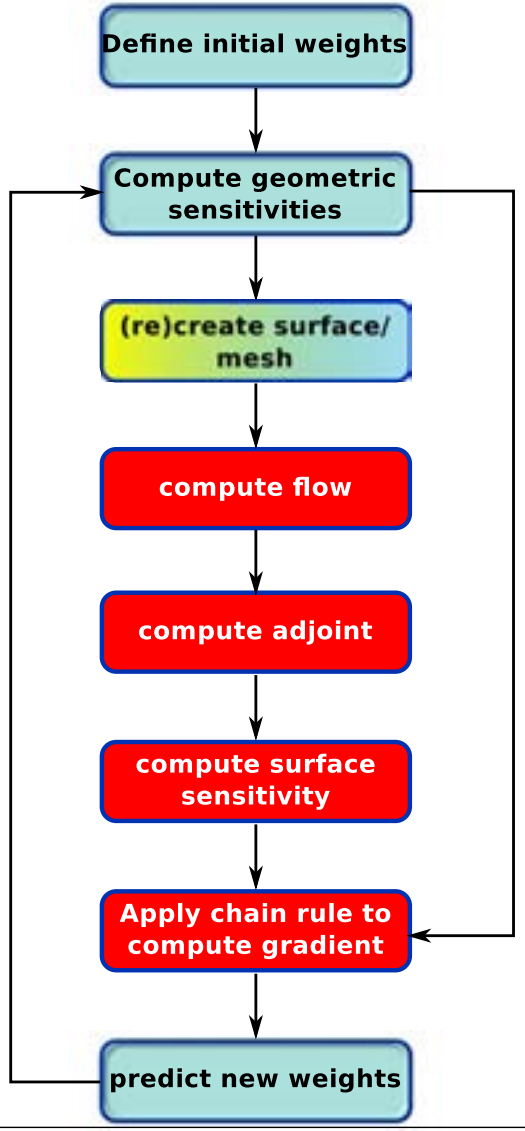


Validation - CST parameterisation

$\frac{\partial f}{\partial A_i}$ - Gradient



SU^2 Optimisation Process



Outline

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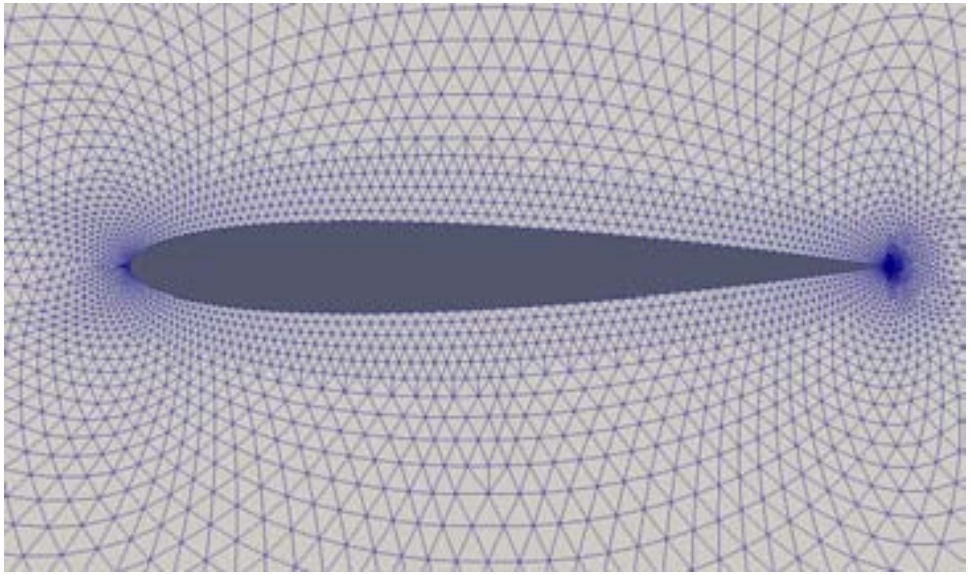
NACA0012 Drag minimization

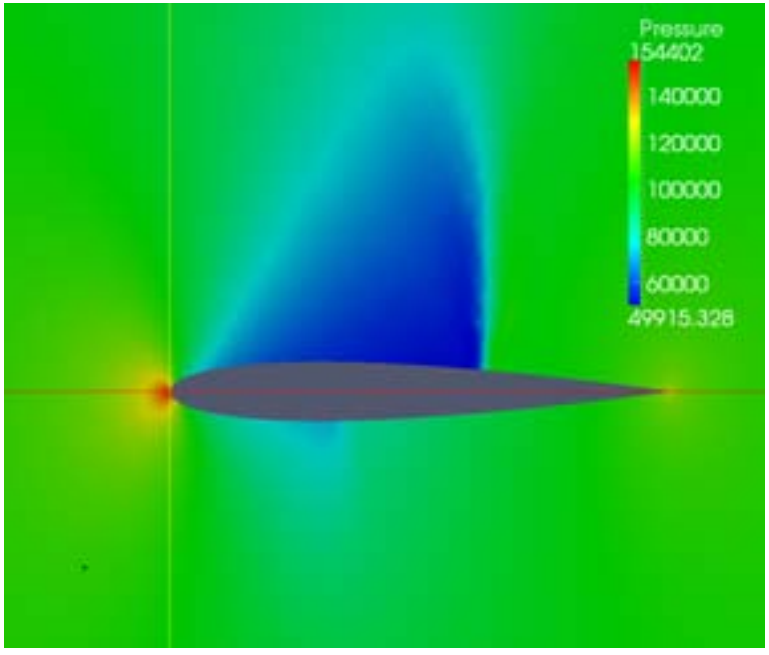
Inviscid test case: NACA0012 starting aerofoil.

- $M_\infty = 0.8$
- $\alpha = 1.25°$
- $f = min(C_d)$
- $C_l \geq 0.33$
- $C_m > 0.034$
- nDV $= 8$



NACA0012 Drag minimization

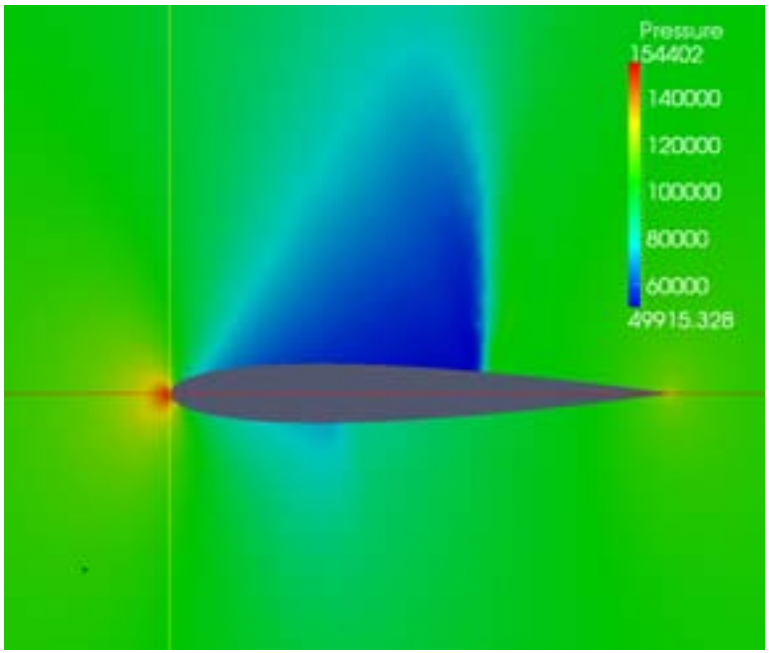
Inviscid test case: NACA0012 starting aerofoil.



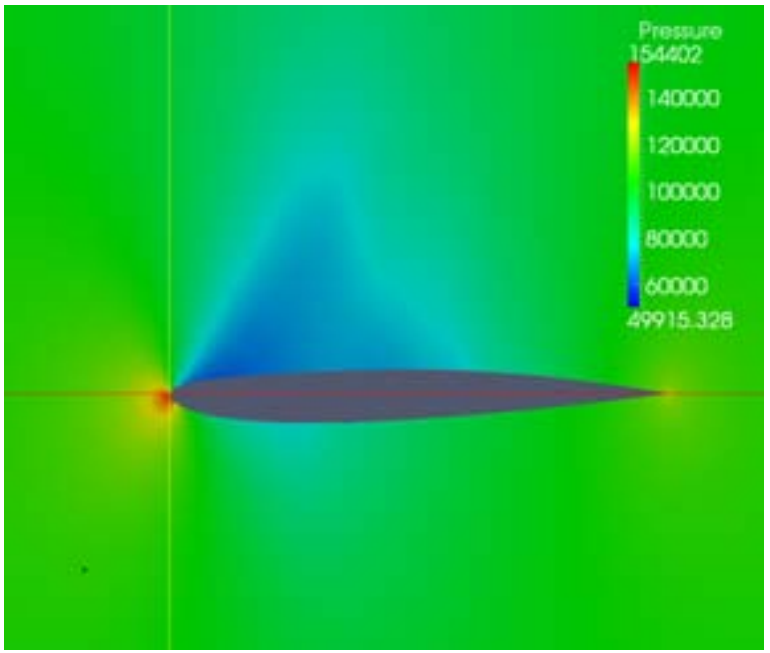
initial aerofoil

NACA0012 Drag minimization

Inviscid test case: NACA0012 starting aerofoil.



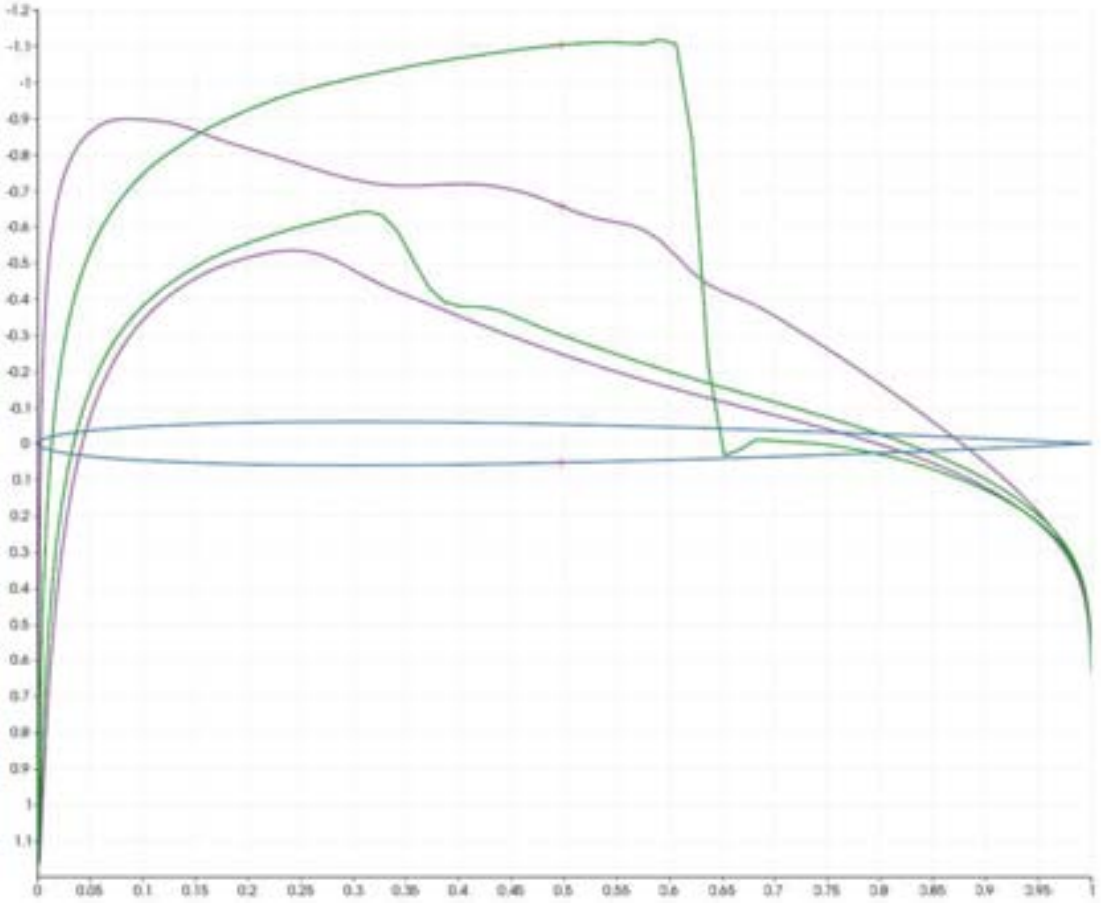
initial aerofoil



final aerofoil

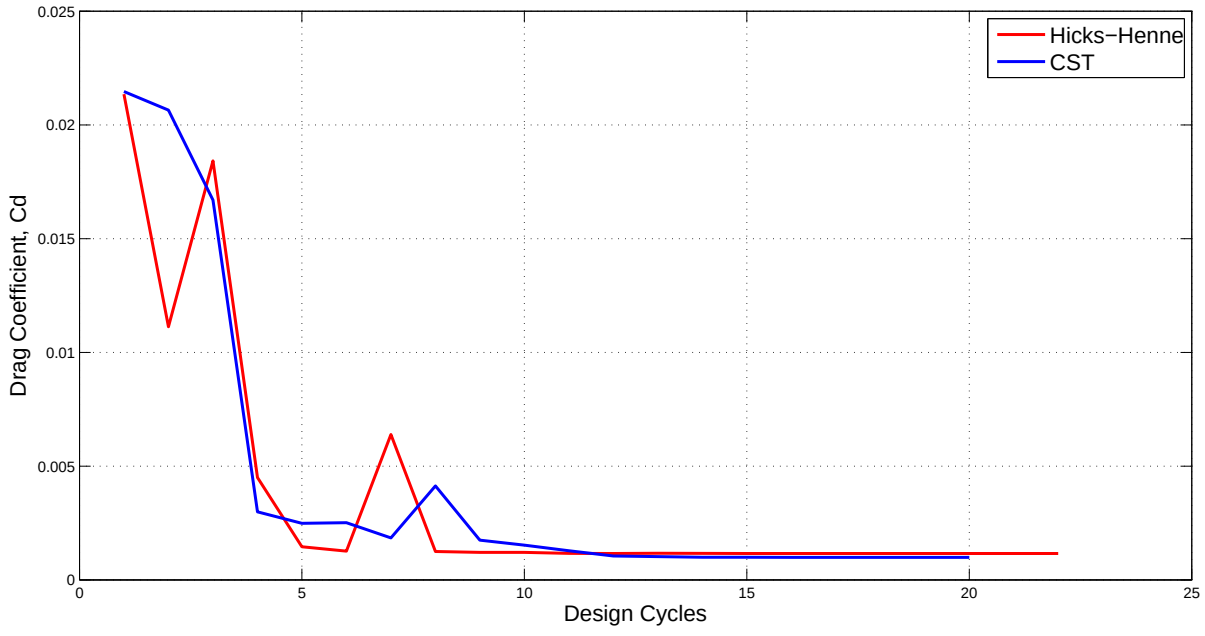
NACA0012 Drag minimization

Inviscid test case: NACA0012 starting aerofoil.



NACA0012 Drag minimization

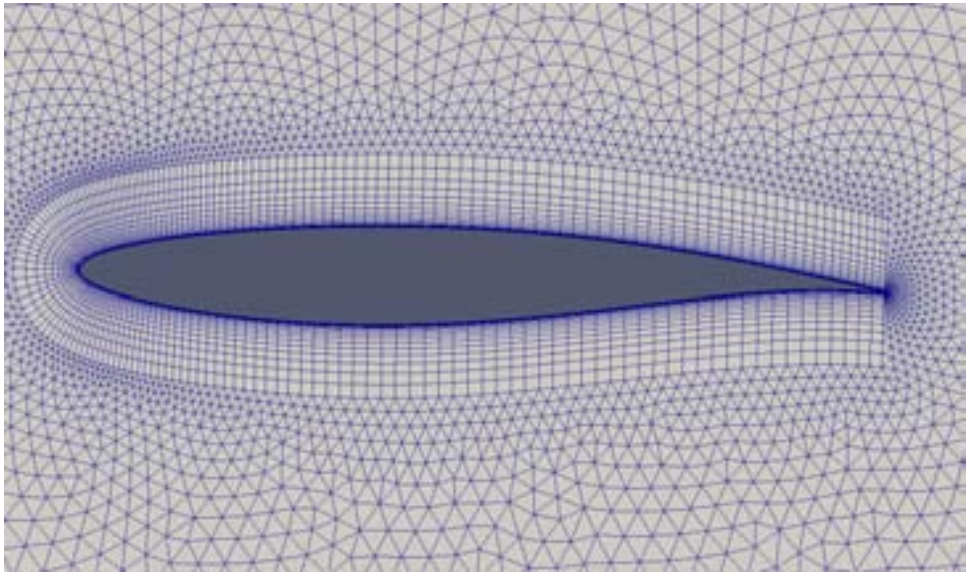
Inviscid test case: NACA0012 starting aerofoil.



RAE2822 Drag minimization

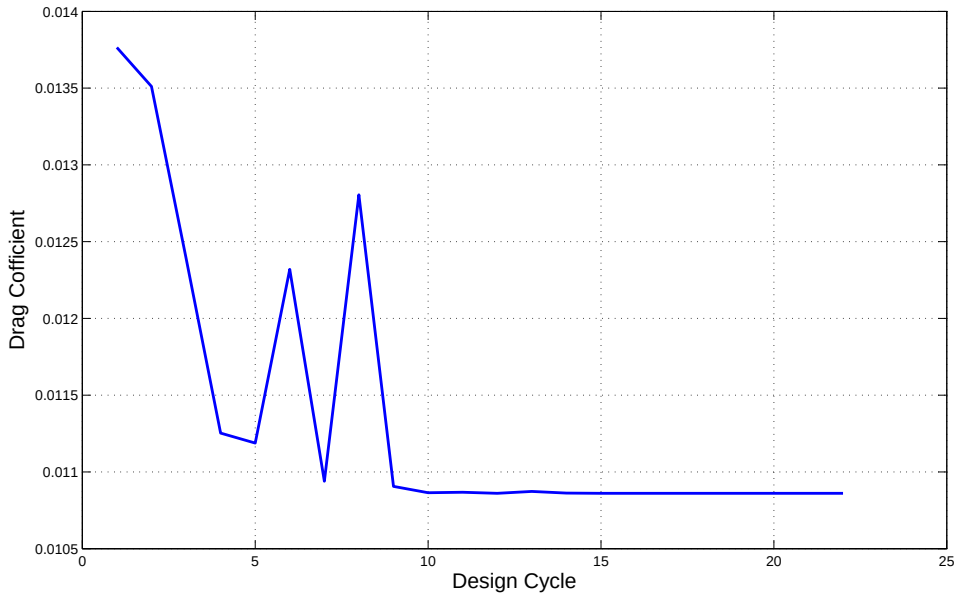
Viscous test case: RAE2822 starting aerofoil.

- $M_\infty = 0.729$
- $\alpha = 2.31°$
- $f = min(C_d)$
- nDV $= 8$
- SA turbulence model
- $y^+ \leq 5$



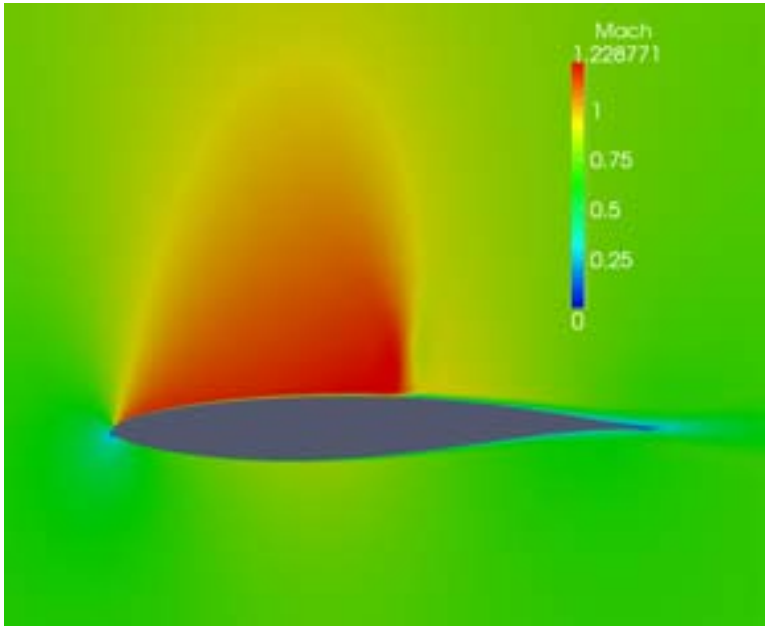
RAE2822 Drag minimization

Viscous test case: RAE2822 starting aerofoil.



RAE2822 Drag minimization

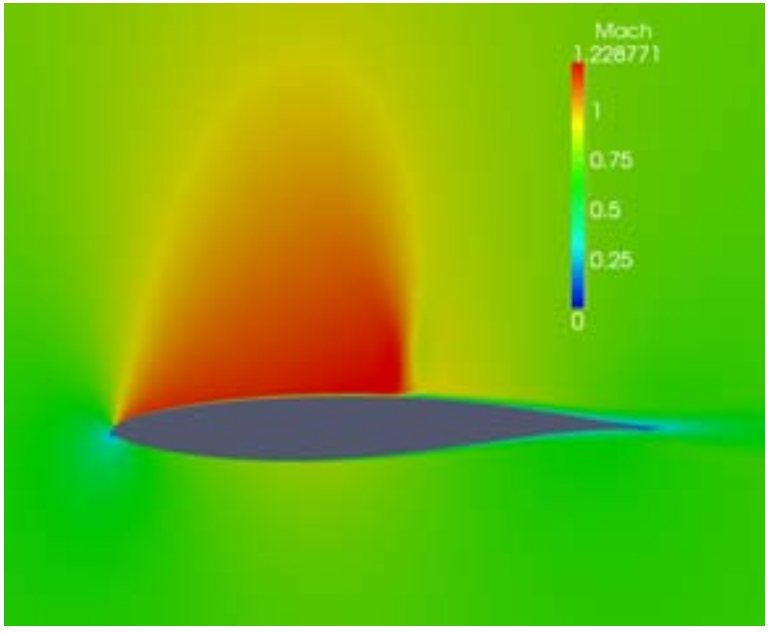
Viscous test case: RAE2822 starting aerofoil.



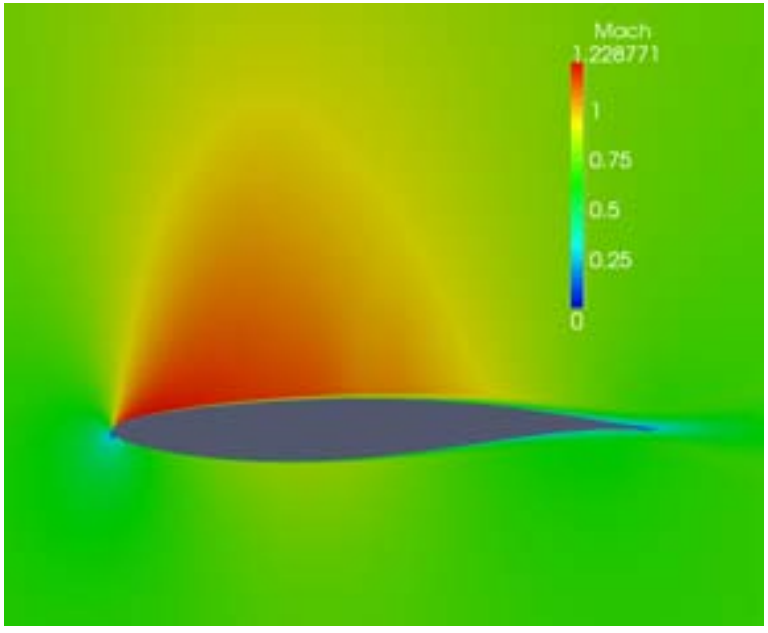
initial aerofoil

RAE2822 Drag minimization

Viscous test case: RAE2822 starting aerofoil.



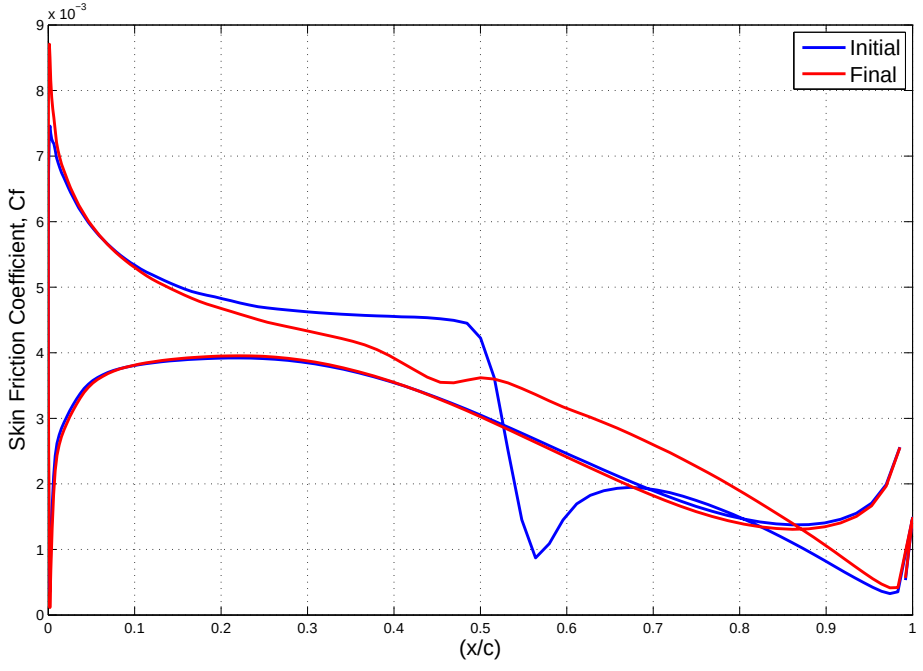
initial aerofoil



final aerofoil

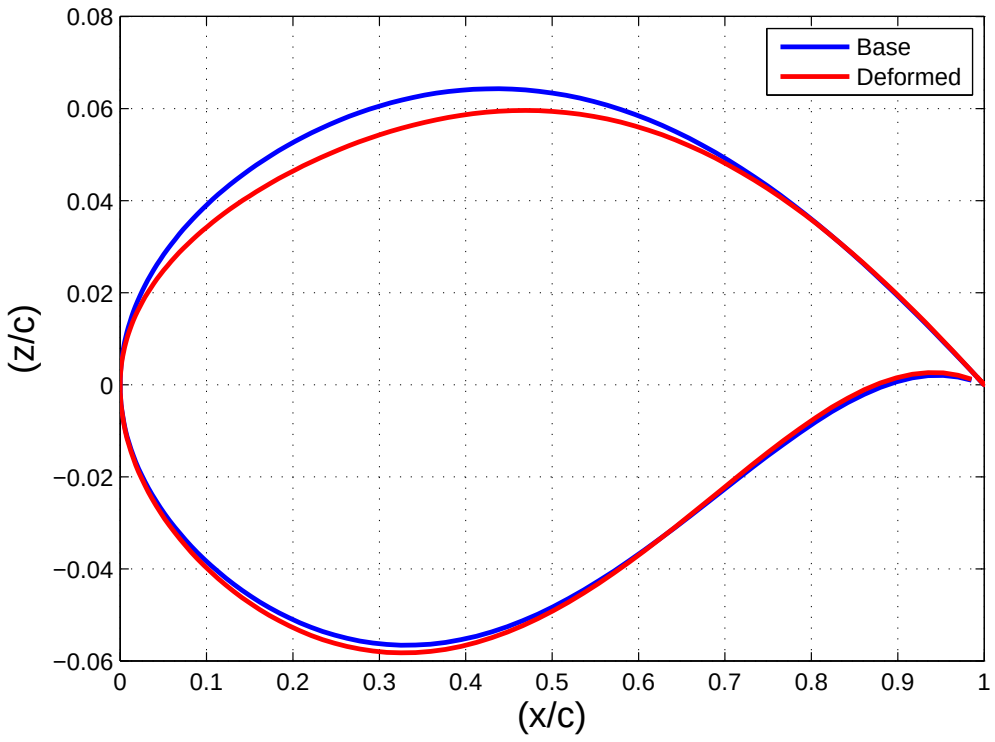
RAE2822 Drag minimization

Viscous test case: RAE2822 starting aerofoil.



RAE2822 Drag minimization

Viscous test case: RAE2822 starting aerofoil.



Outline

1 Overview

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RAE2822 Drag minimization

- An alternative parameterisation was introduced into the SU^2 suite
- Model deformation can be performed outside SU^2
- alternative approach does not compromise optimisation efficiency with respect to native parameterisations

Q & A

Thank you for your attention

Questions Welcome

CST Parameterisation

$$
\begin{aligned}
\zeta(\phi) &= C_{N2}^{N1}(\phi)S(\phi) + \phi\Delta\zeta_{TE} \\
C_{N2}^{N1}(\phi) &= \phi^{N1}(1-\phi)^{N2} \\
S(\phi) &= \sum_{i=0}^{n} A_i S_i \\
S_i &= K_{i,n}\phi^i(1-\phi)^i \\
K_{i,n} &= \binom{n}{i} = \frac{n!}{i!(n-i)!}
\end{aligned}
$$

CENTRAL AEROHYDRODYNAMIC INSTITUTE NAMED AFTER PROFESSOR N.E. ZHUKOVSKY

MINIMIZATION OF BODY OF REVOLUTION AERODYNAMIC DRAG AT SUPERSONIC SPEEDS IN THE FRAMEWORK OF RANS

Nikita Ageev

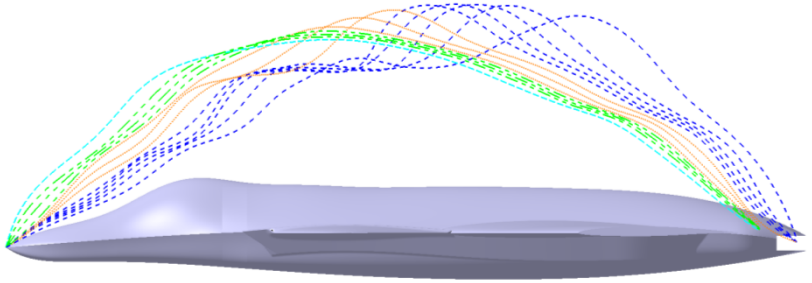
Alexander Pavlenko

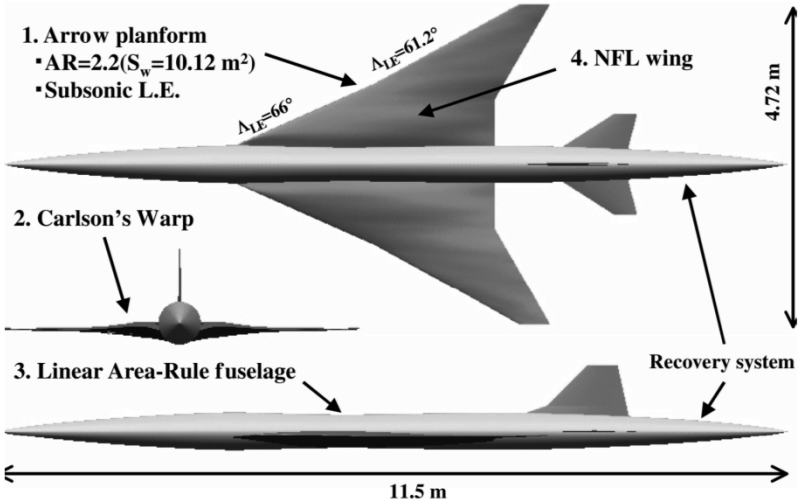
Overview

- Background
- Calculation technique
  - Mesh and method description
  - Verification
- Optimization procedure
  - Geometry construction and variation
  - Mesh for optimization features
  - Optimization technique
- Results
  - Optimal bodies
  - Causes of drag reduction
- Conclusions

Background

- Supersonic area rule (Lomax and Heaslet, 1956)
- Practical supersonic area rule use
  - Whitcomb, 1956
  - Mizobata, 2014
  - Munjulury et al., 2014
  - And others





Motivation

- Supersonic area rule has some inaccuracies:
  - Supersonic area rule is based on linearized slender body theory
  - Problems of taking into account the effect of disturbances reflection from wing, especially in case of “integrated” aerodynamic layout
  - Lift is not considered
  - Longitudinal aerodynamic torque balance is not considered
  - Viscous effects are neglected
  - Optimal equivalent body of revolution is usually based on linearized slender body theory
- Rapid development of the modern numerical methods of RANS equations solving makes optimization if the framework of RANS realizable.

General problem formulation

- Body of revolution with length L and volume V

$$L = L_0 = 15m$$

$$V \geq V_0 = 33.75m^3$$

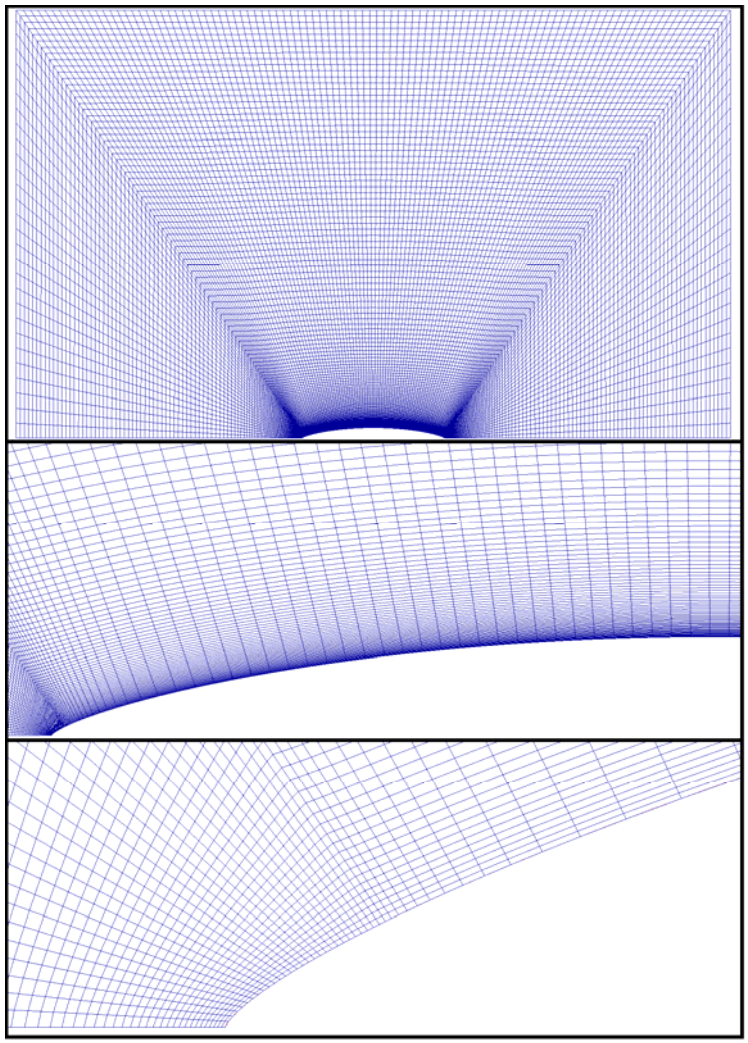
- Flow of a compressible viscous heat-conducting gas
  - International Standard Atmosphere at altitude of 11 km
- Zero Angle of Attack
- Mach number M=1.8
- Variable radius as function of body length
- Minimum drag configuration search

Initial geometry and mesh

- Geometry
  - Spline through 10k points generatrix for verification (47 points for optimization)
  - For verification along the X axis points were uniformly distributed. Ordinates of these points were calculated from the Sears-Haack body equation:

$$y_i = \sqrt{\frac{4V}{\pi^2 L}\left(\sin\left(\operatorname{acos}\left(2\frac{x_i}{L}-1\right)\right)-\frac{1}{3}\sin\left(3\operatorname{acos}\left(2\frac{x_i}{L}-1\right)\right)\right)}$$

- Mesh
  - 2D rectangular (axisymmetric) domain
    - Length of 75 m (5L)
    - Radius of 45 m (3L)
  - O-topology
  - 23700 nodes
  - Euler equations for verification

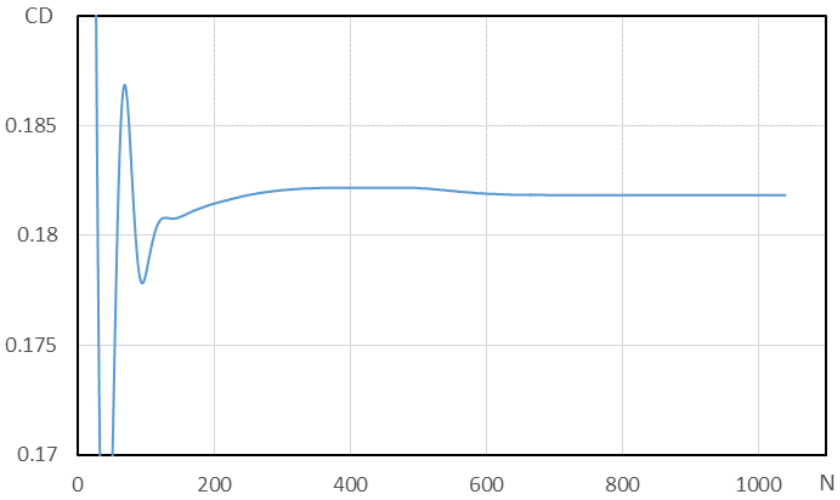


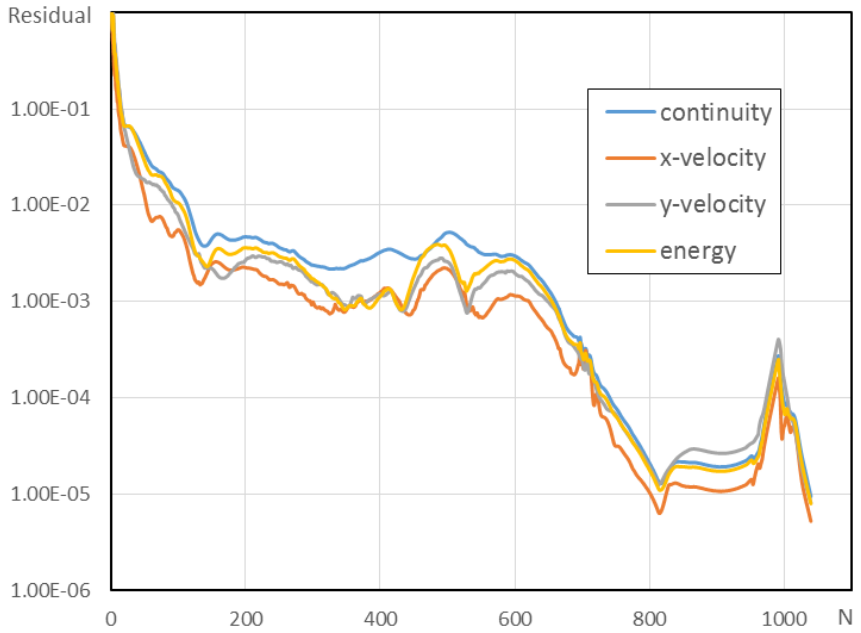
Boundary conditions and solver

- Boundary conditions
  - Front and top boundaries – pressure far field
    - Static pressure of 22700 Pa
    - Static temperature of 216.8 K
    - Mach number 1.8
  - Back – pressure outlet
    - Average static pressure of 22700 Pa
  - Lower - axis
- Solver
  - Density-based
  - Implicit
  - Second-order upwind
  - Courant number 5

Solution convergence

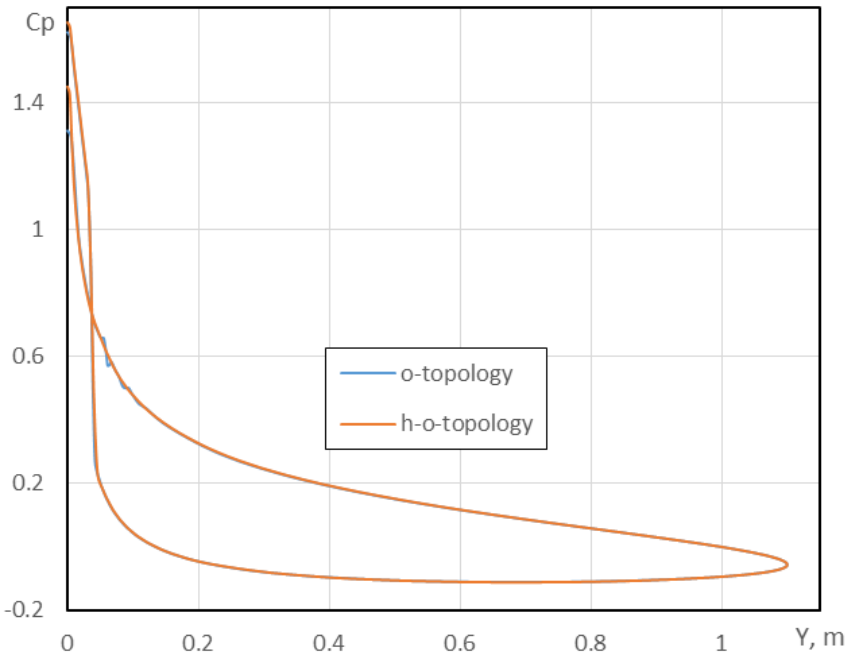
- Near 1k iterations for convergence (initial mesh)
- Convergence to CD=0.18182
- RMS residuals are about 10^{-5} after 1000 iterations; 10^{-7} after 2500 iterations

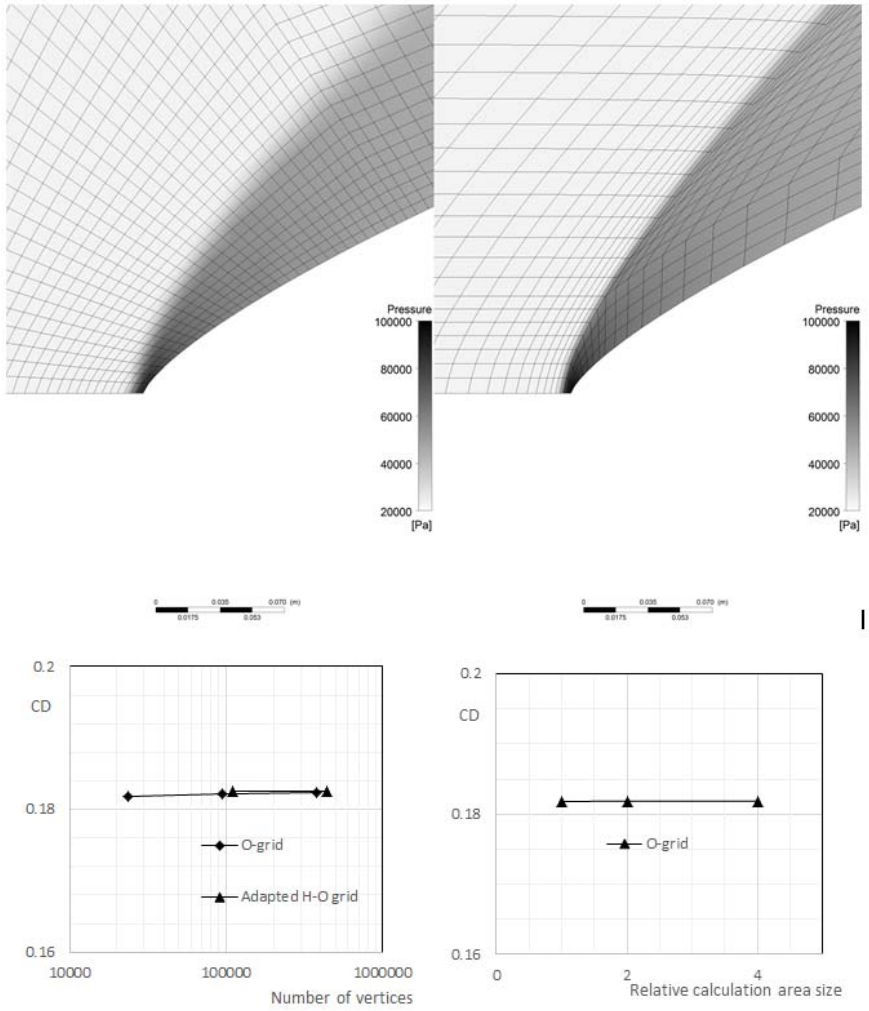




Verification results

- Topology, number of nodes and domain size were varied
- Good accordance for different meshes (about **0.4%** of CD total difference)





Geometry variation

- Body generatrix:
  - Front segment
  - Spline
    - 47 basic points
  - Rear segment
- Geometry variation:
  - Variation of 47 basic points coordinates as spline (that added to Sears-Haack ordinates):

$$\Delta y_i = a_j + b_j(x_i - x_j) + \frac{c_j}{2}(x_i - x_j)^2 + \frac{d_j}{6}(x_i - x_j)^3$$

  - Variation spline is based on 5 control points:

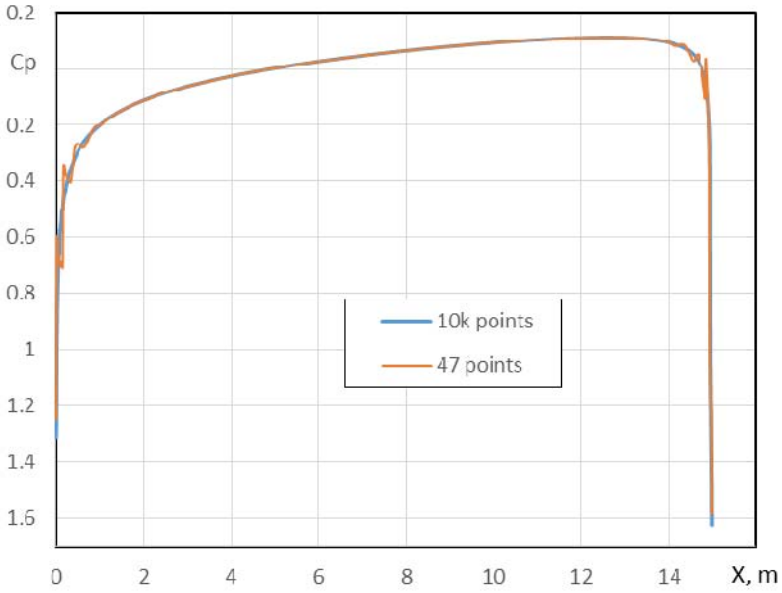
$$x_j = 0m, 3.75m, 7.5m, 11.25m, 15m$$

  - Coefficients are

$$c_1 = 0 \qquad c_5 = 0$$

$$c_2 = \frac{3}{2h^2}\left(\frac{15}{14}a_1 - \frac{17}{7}a_2 + \frac{12}{7}a_3 - \frac{3}{7}a_4 + \frac{1}{14}a_5\right)$$

$$c_3 = \frac{6}{7h^2}\left(-\frac{1}{2}a_1 + 3a_2 - 5a_3 + 3a_4 - \frac{1}{2}a_5\right)$$



Drag coefficient of Sears-Haack body based on 10k points differs from one based on 47 points by 0.5%

$$c_4 = \frac{3}{2h^2}\left(\frac{1}{14}a_1 - \frac{3}{7}a_2 + \frac{12}{7}a_3 - \frac{17}{7}a_4 + \frac{15}{14}a_5\right)$$

$$b_j = \frac{a_j - a_{j-1}}{h} + \frac{h_j(2c_j + c_{j-1})}{6}$$

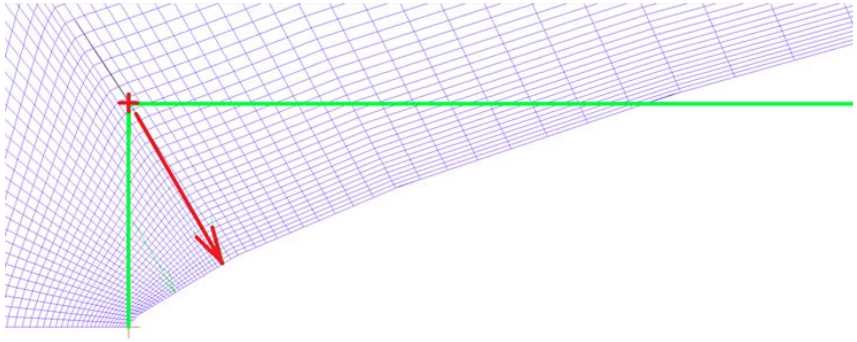
$$d_j = \frac{c_j - c_{j-1}}{h_j}$$

Volume estimation & mesh for optimization procedure

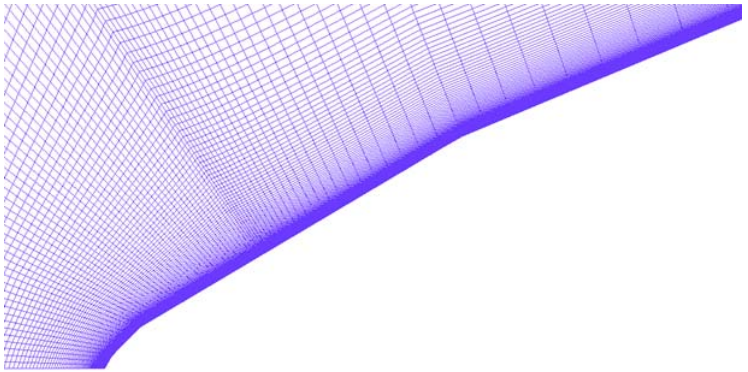
- Volume was estimated by trapezium method:

$$V = \sum_{i=1}^{46} \pi \frac{y_{i+1}^2 + y_i^2}{2} (x_{i+1} - x_i)$$

- Euler optimization mesh (additional nodes for possible butt-ends, 31200 nodes):



- RANS (with SST) optimization mesh (64480 nodes, Yplus~0.85). Pressure-based coupled solver was used.



Optimization problem formulation

- Objective function
  - Drag coefficient CD (Euler and RANS with SST calculations) - minimize

$$C_D = \frac{2F_x}{\rho V^2 S}$$

    - The same characteristic area S for different bodies for comparison

- Variable parameters:

$$a_1 = \Delta y(x = 0m) = 0...0.15m$$

$$a_2 = \Delta y(x = 3.75m) = -0.15...0.05m$$

$$a_3 = \Delta y(x = 7.5m) = -0.1...0.1m$$

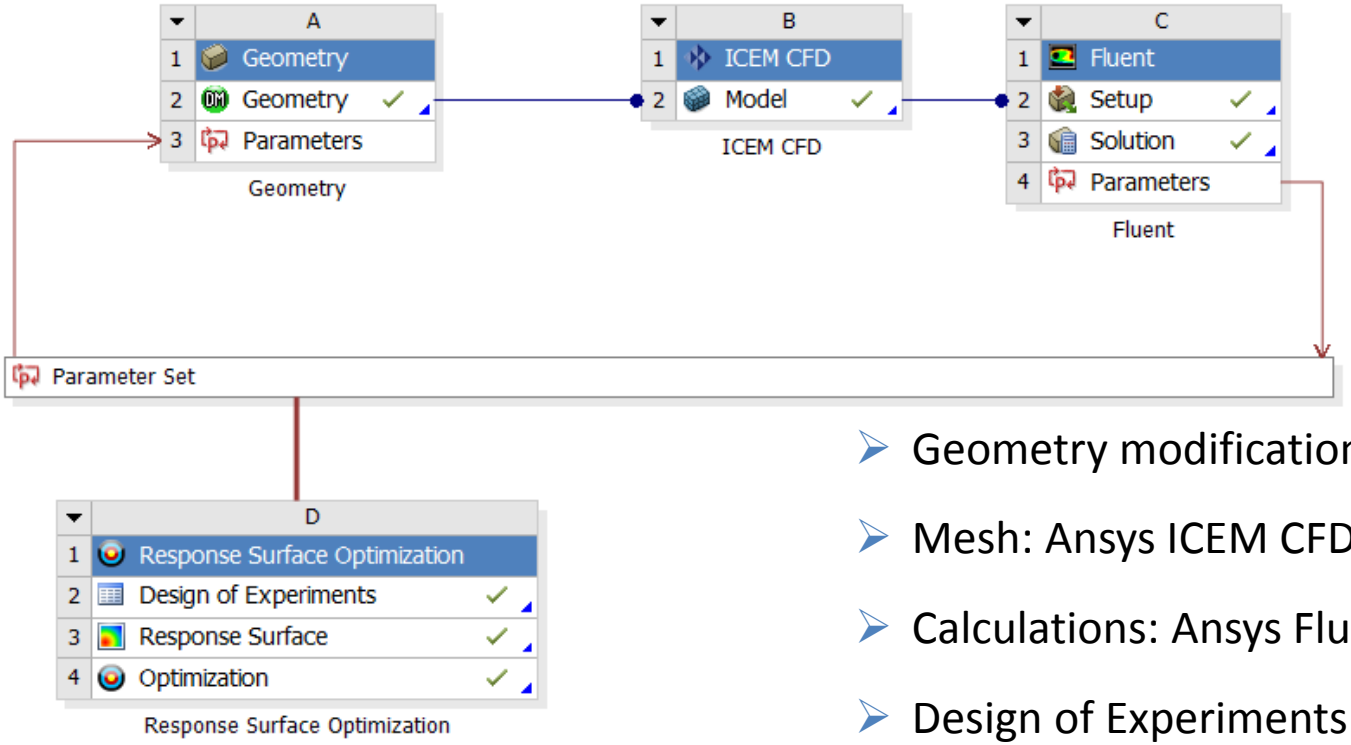
$$a_4 = \Delta y(x = 11.25m) = -0.05...0.15m$$

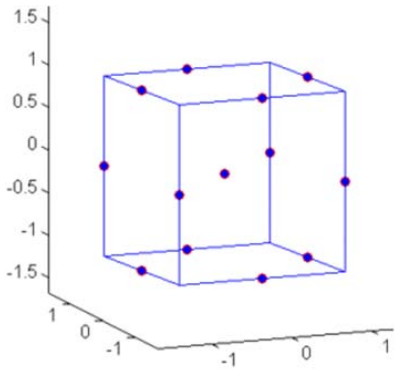
$$a_5 = \Delta y(x = 15m) = 0...0.5m$$

- Constraints:

$$V \geq V_0 = 33.75m^3$$

Optimization with Ansys DesignXplorer

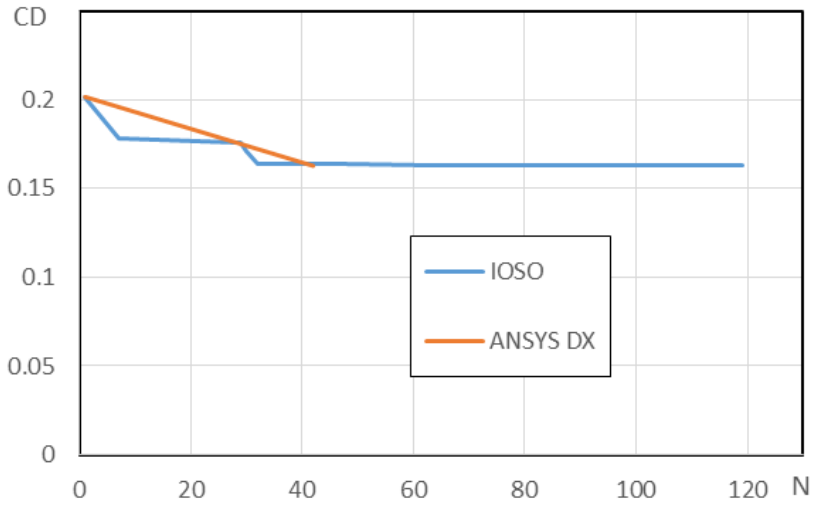




- Geometry modification: Ansys DM
- Mesh: Ansys ICEM CFD
- Calculations: Ansys Fluent
- Design of Experiments: Box-Behnken Design
- Response Surface: 2nd order polynomials
- Optimization: Mixed-Integer Sequential Quadratic Programming

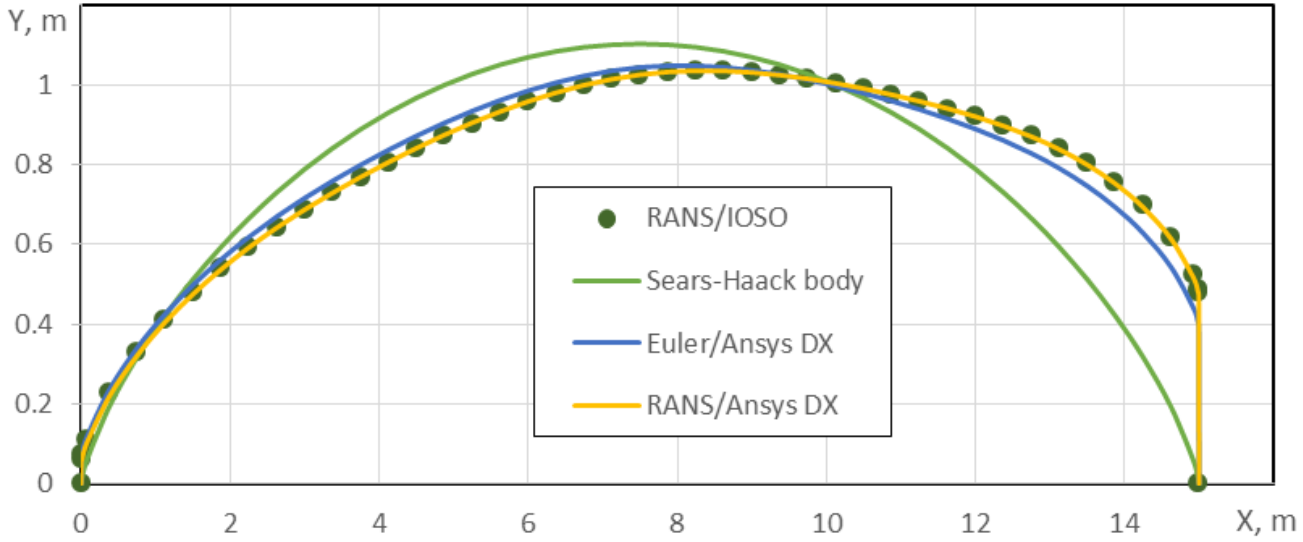
Optimization with IOSO

- Geometry modification, mesh and calculation coincide with DesignXplorer
- Optimization components(Design of Experiments, Response Surface, Optization) - IOSO algorithm (Egorov, 1998)
- Comparison with DesignXplorer (DX):



Optimization results

- Optimal bodies generatrices:



Drag reduce by approximately **20%** in comparison with Sears-Haack body.

Volume of the optimal body is equal to **minimum one** (Sears-Haack body volume)

- Parameters:

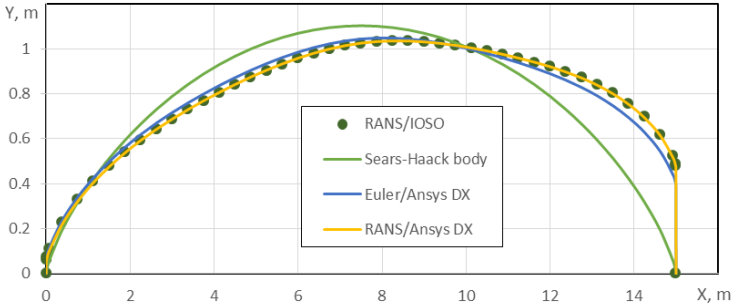
Equations type/optimization method	a1, m	a2, m	a3, m	a4, m	a5, m	CD (RANS)	V, m^3	CD improvement, %
Sears-Haack body	0.000	0.000	0.000	0.000	0.000	0.202	33.749	0
Euler/Ansys DX	0.062	-0.089	-0.059	0.050	0.391	0.164	33.749	18.4
RANS/Ansys DX	0.048	-0.120	-0.077	0.070	0.467	0.163	33.749	19.3
RANS/IOSO	0.058	-0.121	-0.078	0.069	0.474	0.163	33.749	19.3

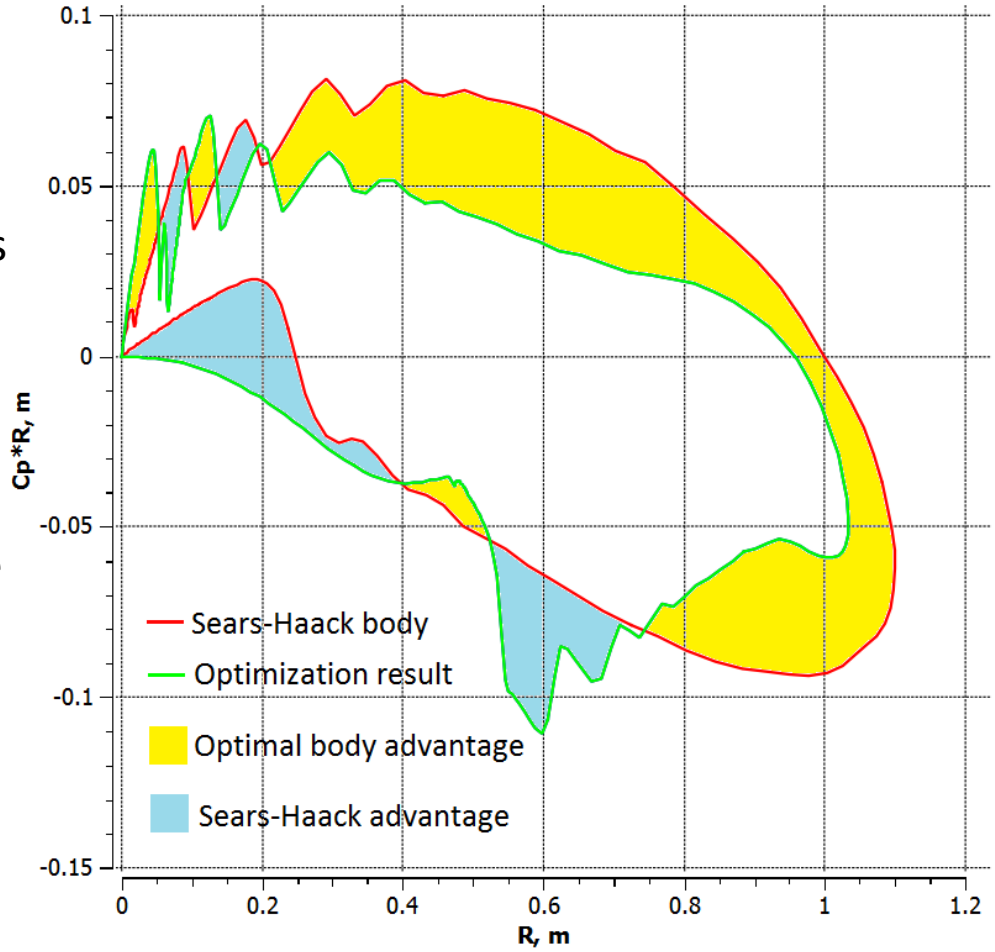
Drag reduction sources

- Drag due to pressure forces is proportional to

$$F_x \propto \int C_p R dR$$

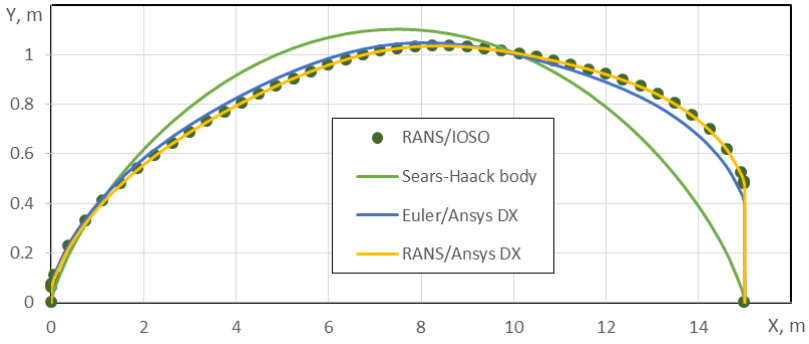
- Area under CpR as function of R chart is proportional to Drag due to pressure forces
- Linearized slender body theory underestimates influence of the front part and overestimates influence of the rear part

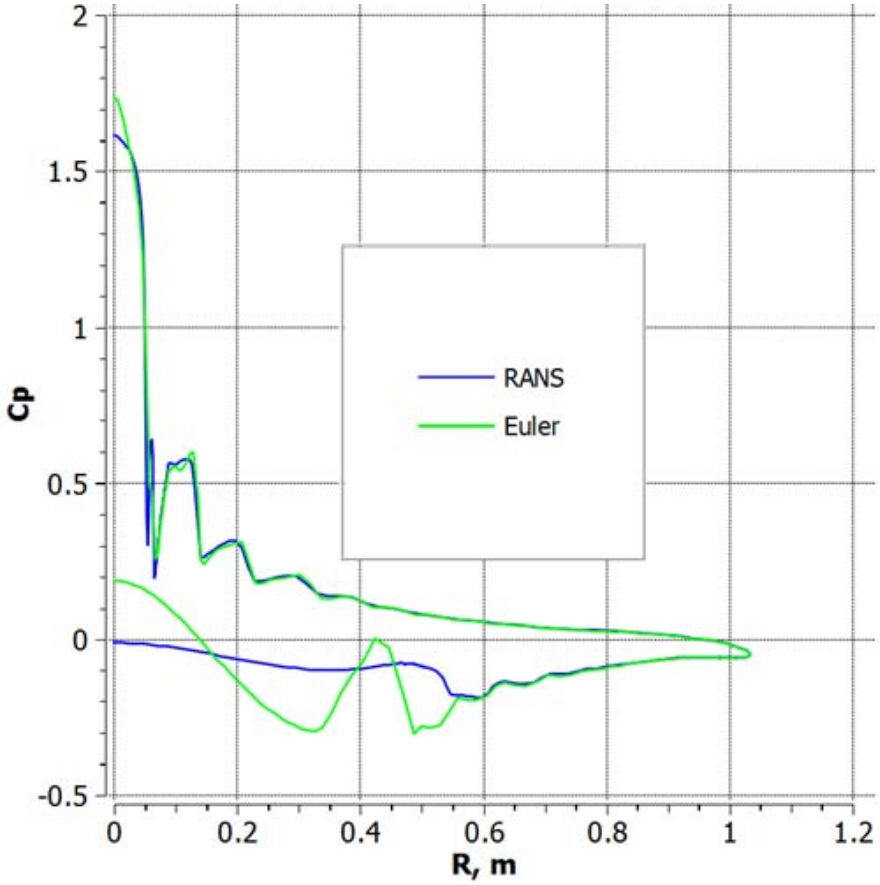




Cause of difference between Euler and RANS optimal body

- Euler equations don't simulate separation zone (it is shown at the chart)
- So in case of RANS additional volume can be placed in the rear part of the body without significant drag increase





Conclusions

- Search procedures of the body of revolution shape variation that reduced aerodynamic drag in the frameworks of RANS and Euler equations were developed.
- For the typical for supersonic aircraft aspect ratio shape variation that reduced drag by **19.3 percent** in the framework of RANS equations in comparison with Sears-Haack body was found. Shape variation, providing **18.4 percent** (according to RANS equations solution) less drag than the Sears-Haack body of the same size was found in the course of the optimization in the framework of the Euler equations.
- It has been found that drag decreasing shape variations of the body transfer part of the volume from front part of the body to the rear one with slight front and significant rear butt-end formation

Thank you for your attention!

- You can ask your questions or send them to **n.d.ageev@gmail.com**

Innovative bifunctional aircraft window for lighting control to enhance passenger comfort

4th EASN Association International Workshop

On Flight Physics & Aircraft Design

Aachen, Germany

27th – 29th October, 2014

G. Cabañero, A. Viñuales

IN-LIGHT Confidential

Project overview

INNOVATIVE BIFUNCTIONAL AIRCRAFT WINDOW FOR LIGHTING CONTROL TO ENHANCE PASSENGER COMFORT

Grant Agreement no. 314233

THEME 7: TRANSPORT (INCLUDING AERONAUTICS)

7.1. AERONAUTICS AND AIR TRANSPORT (AAT)

- **ACTIVITY 7.1.3. ENSURING CUSTOMER SATISFACTION AND SAFETY**

Area 7.1.3.1. Passenger friendly cabin

Call identifier: FP7-AAT-2012-RTD-1

Topic: AAT.2012.3.1-3. Systems and equipment

Total budget: 4.205.707 €

EC contribution: 2.980.805 €

Starting date: 1 November 2012

Duration: 3 years

OBJECTIVE

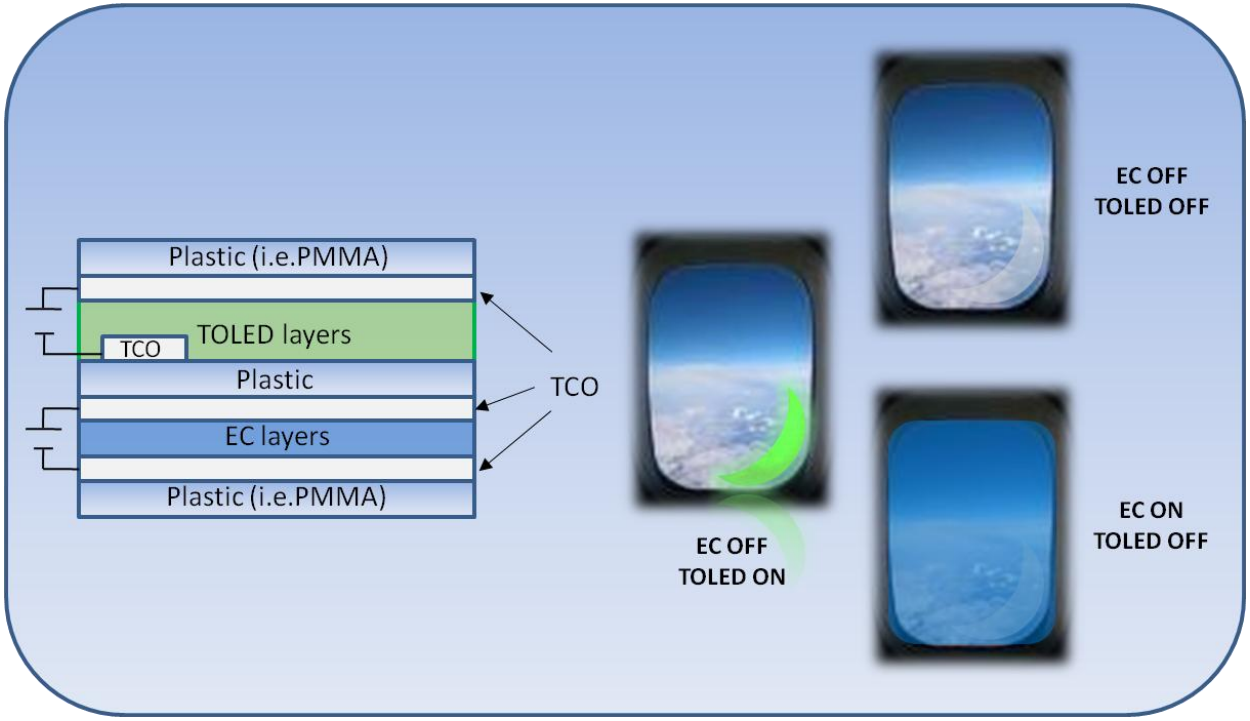
The overall objective of the IN-LIGHT project is to develop a **new concept of bifunctional smart aircraft window** combining two technologies: Electrochromism and TOLED lighting.

❖ **Electrochromic technology** will allow the passenger to control at will the amount of sun-light coming through the window, switching from a colourless transparent state to a deeply coloured transparent state.

❖ A **TOLED lighting system,** also controllable by the passenger, will be integrated in the window in the shape of small designs (i.e. the logotype of the aircraft company).

The new smart aircraft window to be developed within the IN-LIGHT project will add significant value to conventional windows and **will contribute to the passenger comfort enabling a tailored cabin environment** regarding heat and light transmittance as well as ambient lighting according to passenger preferences.

IN-LIGHT aims to develop a **high-performance plastic** electrochromic aircraft window by **low temperature processes** (< 120ºC) and focusing in the use of technologies that will lead to **all-solid state devices**, avoiding the use of liquid components in order to eliminate any risk of leakage and simplify the manufacturing process.

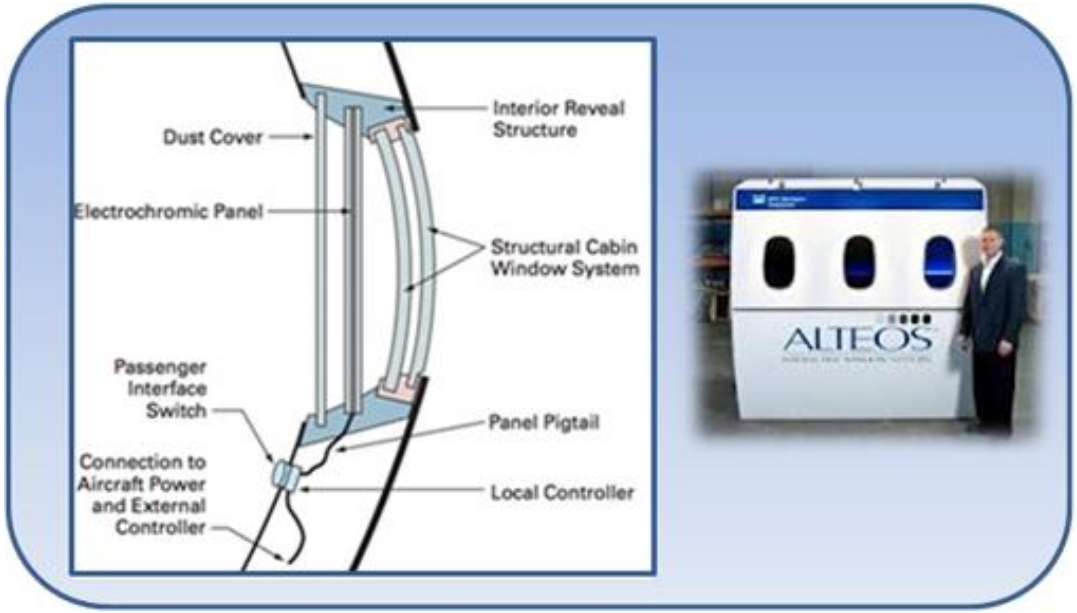


TOLED systems will be integrated in the window, being invisible in the off state and providing a **very innovative type of lighting** for the interior of the cabin.

RELATED PRODUCTS IN THE MARKET

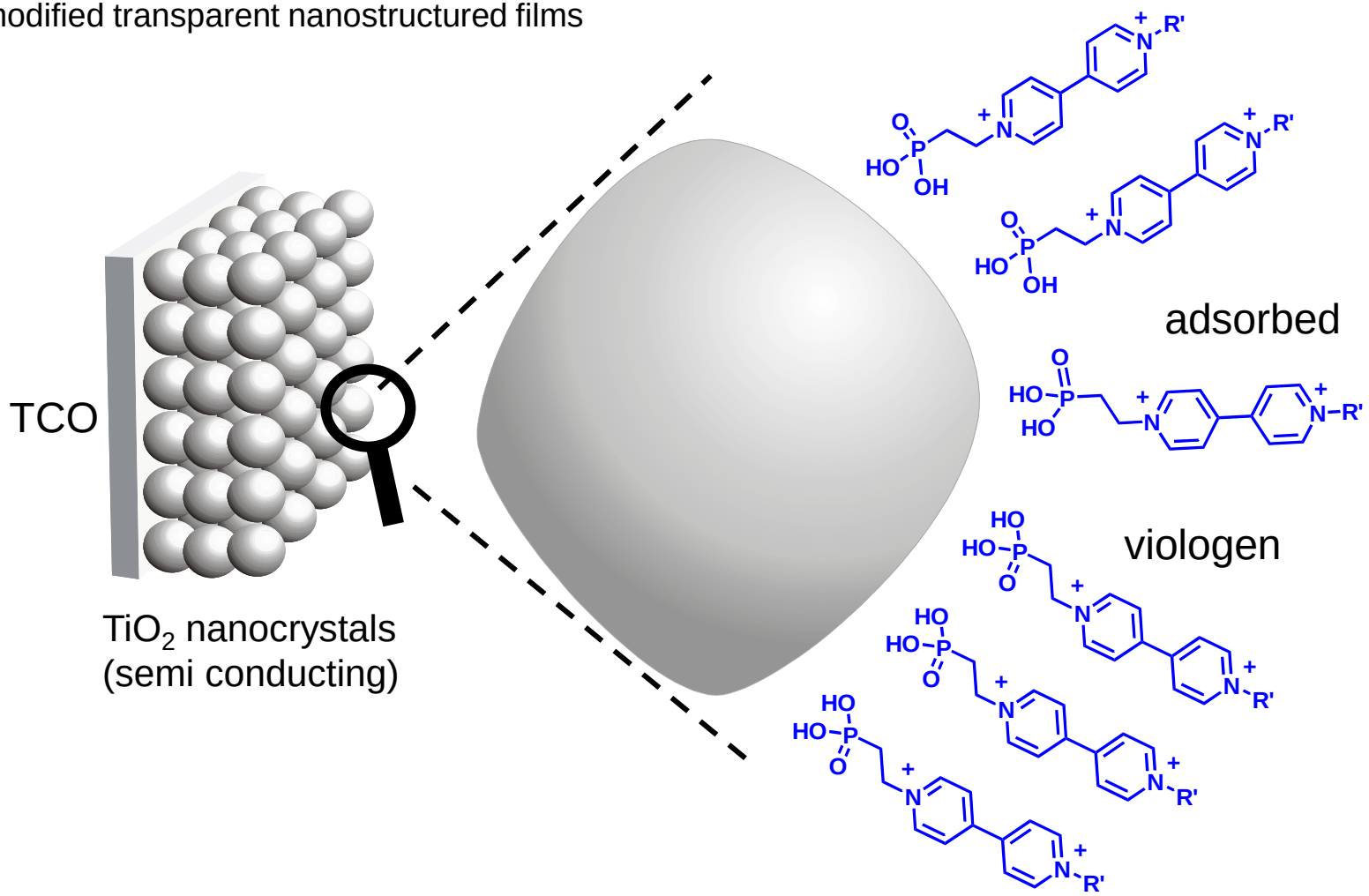
ALTEOS® Interactive Window Systems (PPG Aerospace) :
GENTEX Corp. electrochromic technology

- Premiered in commercial aircraft on the new Boeing 787 Dreamliner and in business aircraft on the new Hawker Beechcraft King Air 350i
- Electronic gel medium:
  - ❑**Risk of leakage**
  - ❑**Slow response**



PROPOSED ELECTROCHROMIC TECHNOLOGY

Viologen modified transparent nanostructured films



SoA: Previous developments based on nanostructured TiO_2 with attached viologen chromophores

High temperature-processed (>450ºC) **glass EC small windows** (up to 10x10cm^2) *[NTERA Ltd.- University College Dublin]* and **displays** *[NTERA Ltd.- Royal Institute of Technology (Sweden); NTERA Ltd.- University of Osnabrück (Germany)]*

Nanochromics™

- High temperature processing (glass)
- Transparent

Low temperature-processed (< 200ºC), **reflective** or non-transparent **plastic** displays *[NTERA Ltd.]*

- Low temperature processing (plastic)
- Non-transparent

Nanochromics™

*NTERA Limited IP currently transferred to CROSS ATLANTIC CAPITAL PARTNERS (USA)

TECHNICAL CHALLENGES OF IN-LIGHT

Development of highly **transparent** nanostructured semiconducting layers for the subsequent attachment of electrochromic molecules.

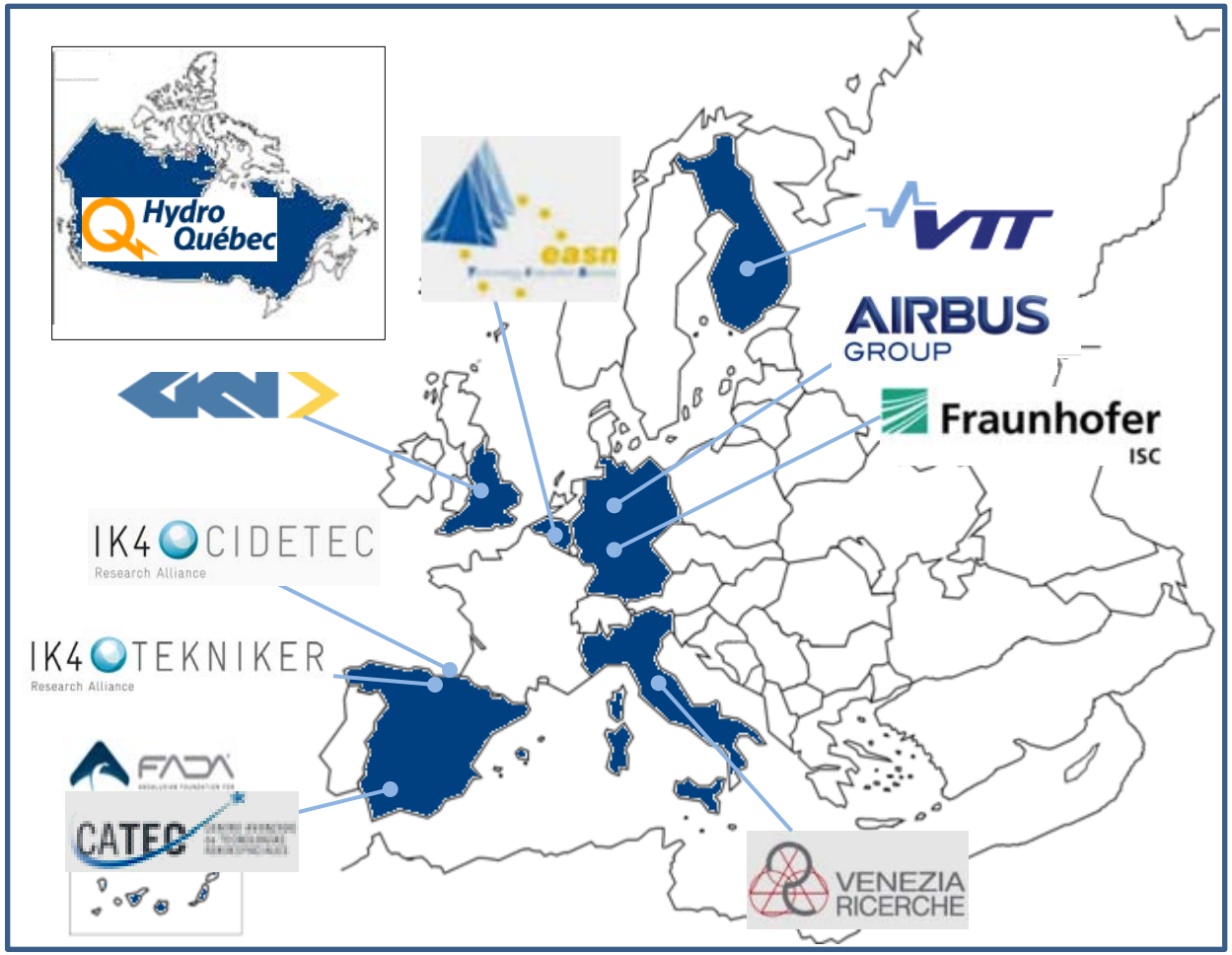
- Conventional methods for the preparation of semiconducting TiO_2 nanostructured films involve high temperature treatments (> 400ºC), which are not compatible with the use of plastic substrates.
- The critical point is to achieve layers with **adequate conductivity** and **high active surface area** suitable for the anchoring of electrochromic molecules, **avoiding high temperature** processes.

OTHER TECHNICAL CHALLENGES OF IN-LIGHT

- Creation of high performance **TCO sheets** with **low resistivity onto plastic substrates** to ensure fast and homogeneous coloration/bleaching, mainly in large-area devices.
- Development of **suitable high transparent solid electrolytes** with high ionic conductivity and optimal adhesion.
- Selection of a **UV stabilizer** concept tailored to the needs in terms of electrochromic molecules stability and aircraft cabin window components.
- Preparation of **TOLED stack** with altogether five functional layers (ANODE-HIL-ELM-ETL-CATHODE) manufactured with high-throughput wet and/or vacuum deposition technologies and reaching an overall transparency > 65%.
- The fabrication of **tandem EC-TOLED** devices
- The **scaling-up** of materials and processes to achieve a targeted size of 30x40 cm^2

IN-LIGHT CONSORTIUM

10 partners from 6 member states + 1 Third Country (Canada)



- 2 Industries
- 1 SME
- 7 Research Institutes

IN-LIGHT PARTNERSHIP AND ROLES

AIRBUS GROUP

Customer requirements specifications.

Application testing& validation

easn

Dissemination & exploitation

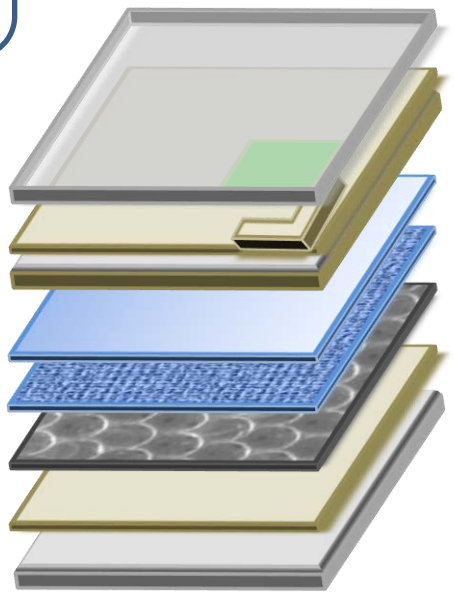
Transparent solid electrolyte

Hydro Québec

Transparent nanostructured coating

Fraunhofer ISC

Plastic substrate (PC or acrylic)



TOLED

VTT

TCO patterning (VTT)

Modification with electrochromic molecules

IK4 CIDETEC Research Alliance

TCO coating

IK4 TEKNIKER Research Alliance

Up-scaling

FADA CATEC

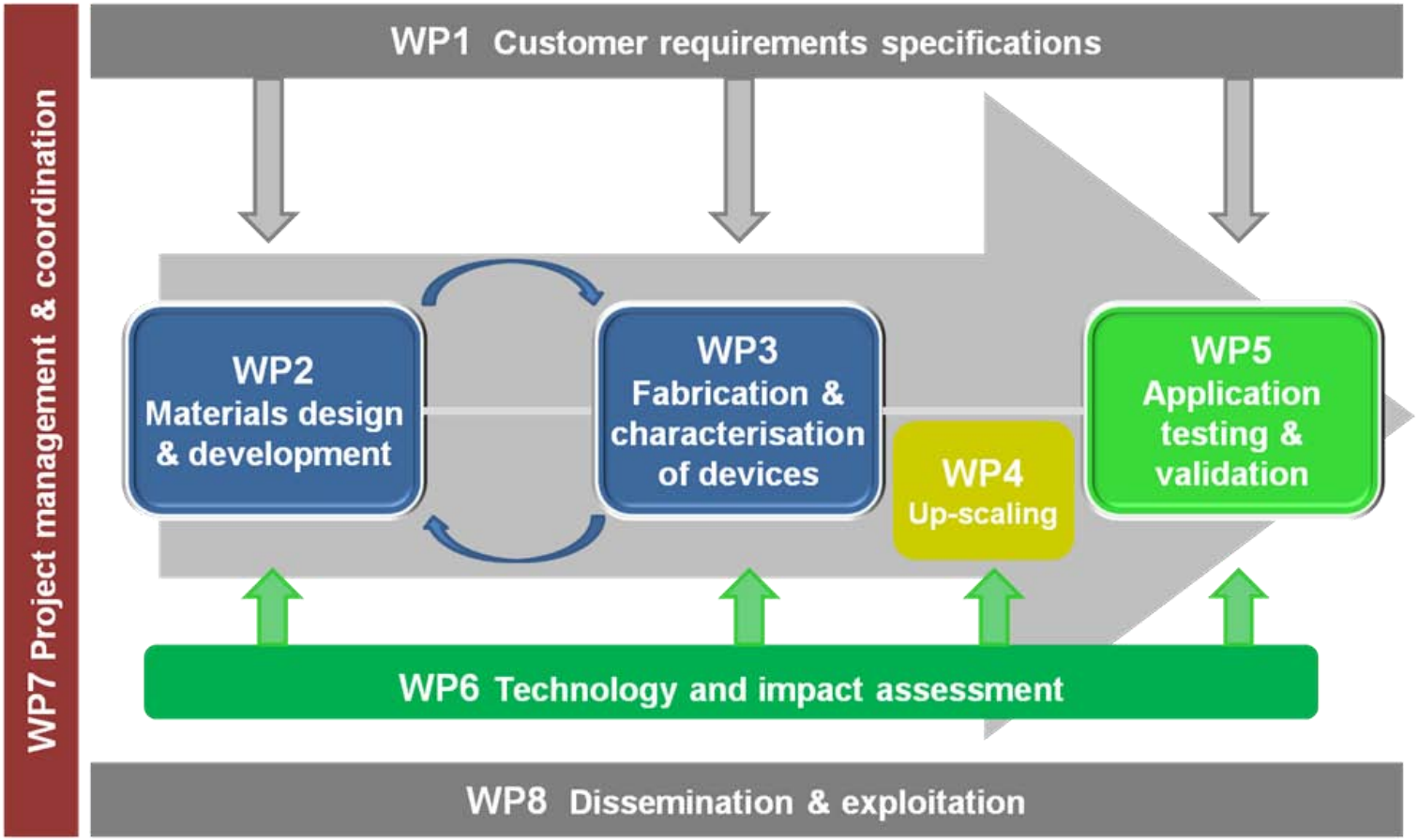
Application testing & validation.

VENEZIA RICERCHE

Life Cycle Assesment

Cost analysis

WORK PACKAGE STRUCTURE

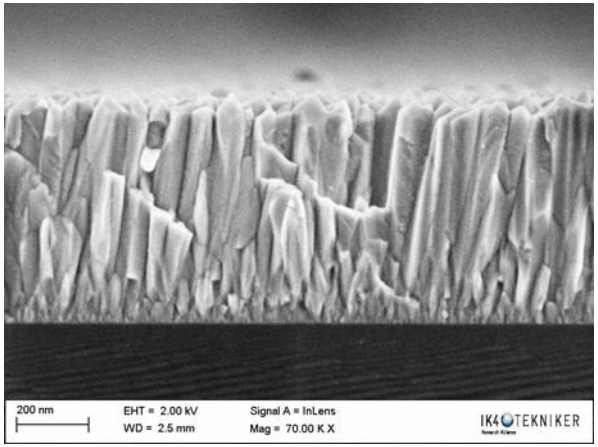


Main achievements

MAIN ACHIEVEMENTS

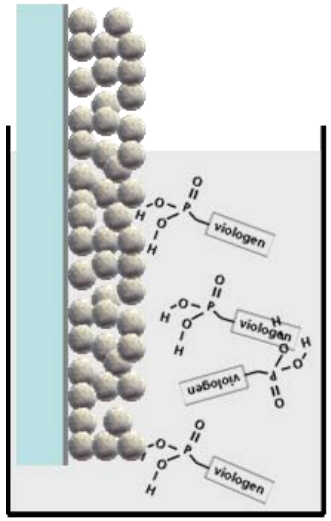
Highly transparent (83% of transmittance in the visible range) aluminium-doped zinc oxide (**AZO**) layers with **very low resistivity** (31 ohm/sq) have been developed on flexible plastic substrates.

These results are highly promising since they are beyond currently commercially available transparent conductors on plastic substrates.

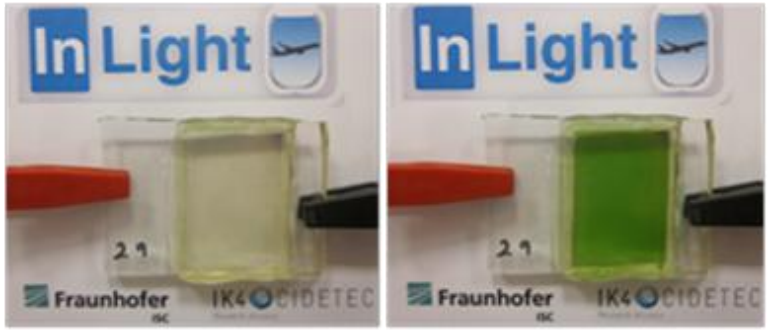


MAIN ACHIEVEMENTS

Proprietary sol-gel and hydrothermal processes have been utilized within the project to prepare well dispersed nanocrystalline TiO_2 particles with sizes well below the scattering limit (< 15 nm) to ensure transparency. From these dispersions, nanostructured films have been successfully prepared on TCO substrates (e.g. ITO/PET, FTO/glass), accomplishing the required characteristics for the fabrication of EC devices in terms of **transparency**, **conductivity** and **surface area** after a thermal treatment **at only 120ºC**.



Sample **CM1409_18**
drawing rate **20 cm/min**, dried at **120°C**.

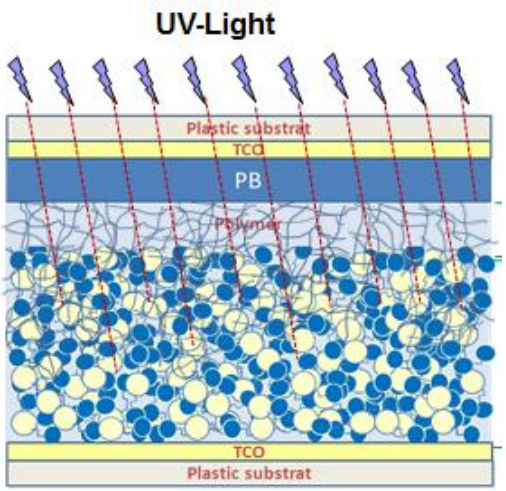


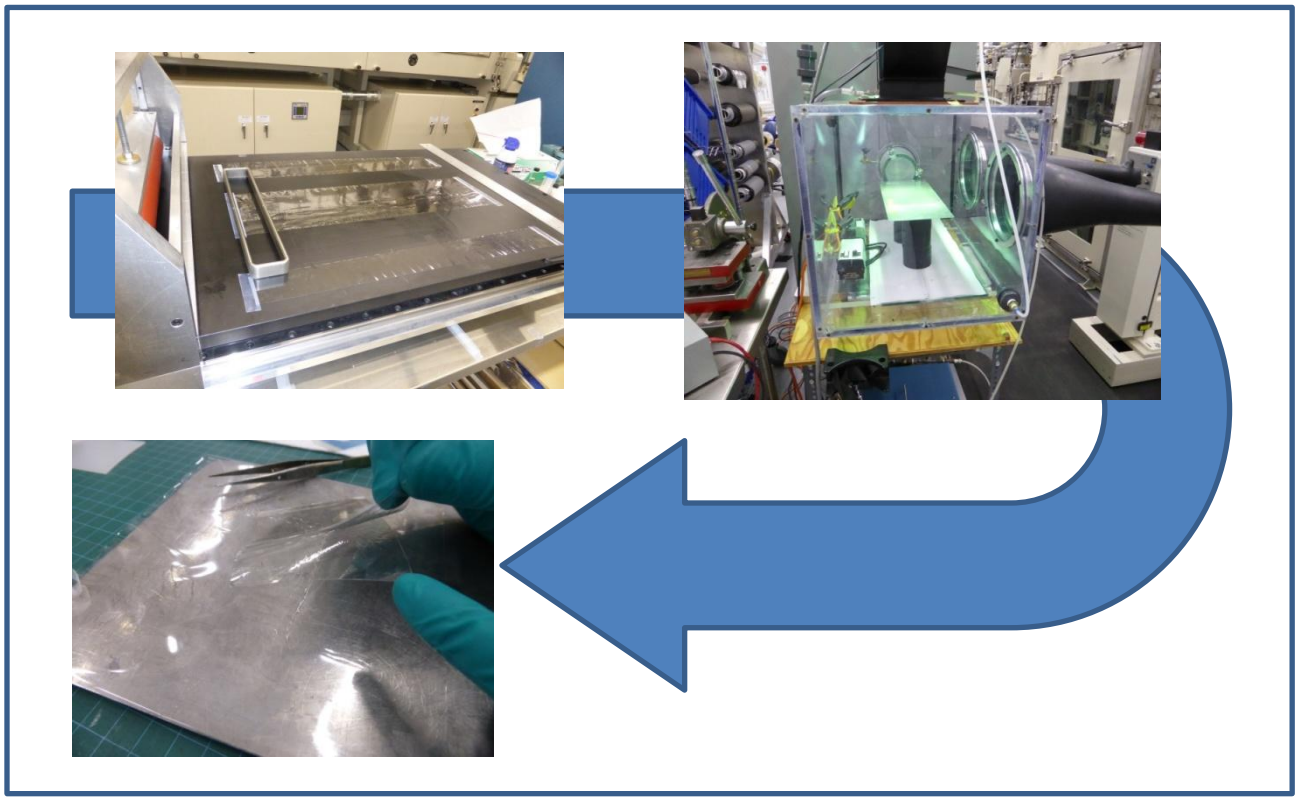
CM1409_29
drawing rate **20 cm/min**, dried at **500°C**.

Deep coloration. Fast response

MAIN ACHIEVEMENTS

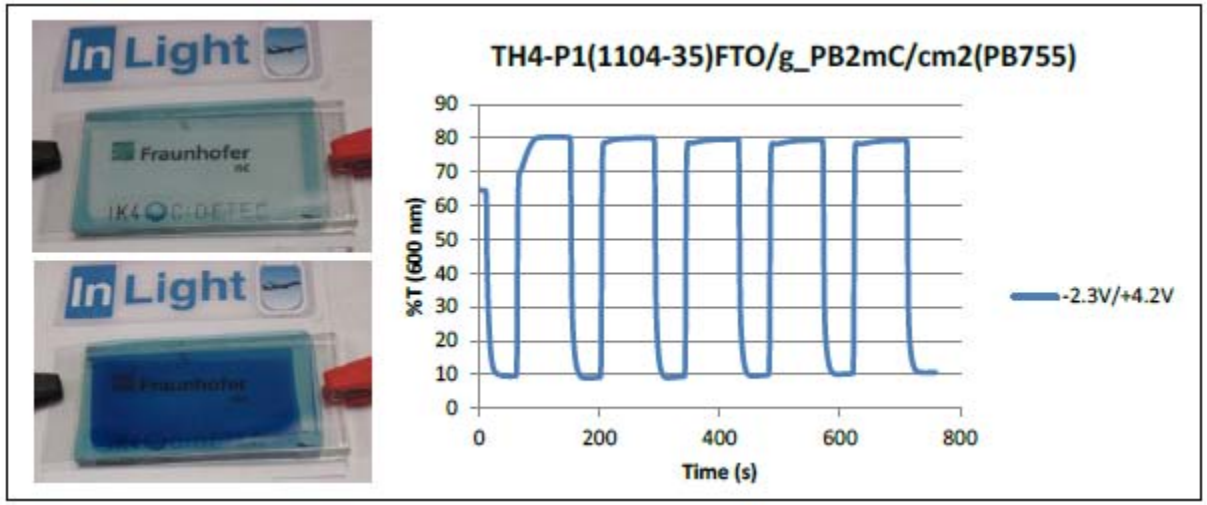
Thermal and UV-curable highly **transparent solid electrolytes** with suitable ionic conductivity have been developed.





MAIN ACHIEVEMENTS

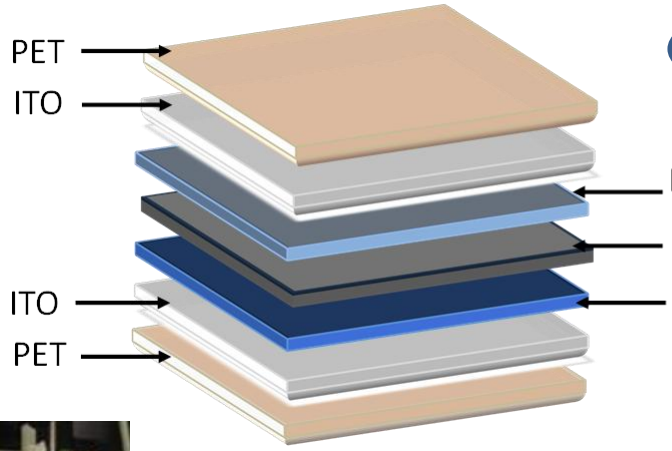
The effect of the TiO_2 layer **thickness and pore characteristics** on the optical contrast and response time was investigated on FTO/glass. The optical contrast was found to be highly dependent on the TiO_2 film thickness, while the porosity effect is almost negligible.



The developed EC technology reaches the following requirements in **FTO/glass** based devices with **liquid electrolytes**:

- Light transmittance in the bleached state => *required:* > 65-70%; *achieved:* 80%
- Optical contrast => *required:* > 63-68%; *achieved:* 71%
- Colour of shading => *required:* neutral (grey) or dark blue; *achieved:* dark blue
- Switching time => *required:* < 10 s from transparent to coloured; *achieved:* 7 s

MAIN ACHIEVEMENTS

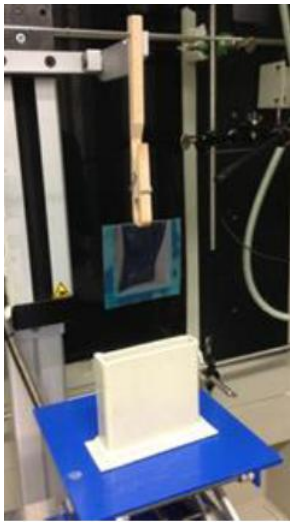


All-solid flexible plastic EC devices

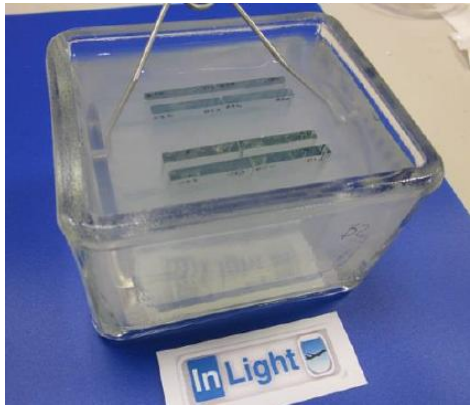
Prussian blue (2 mC/cm^2)

Solid electrolyte*

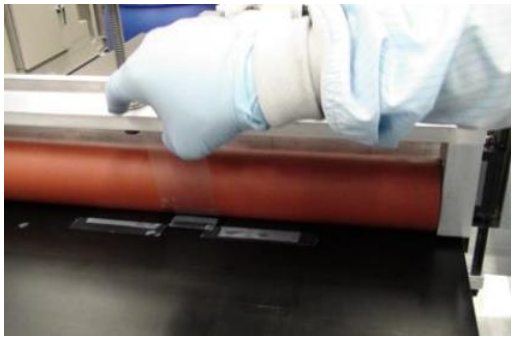
Viologen-modified TiO_2 nanostructured film
(TH2 (1300 nm); IL-B-2, 4h)



Coating of the TiO_2 layer

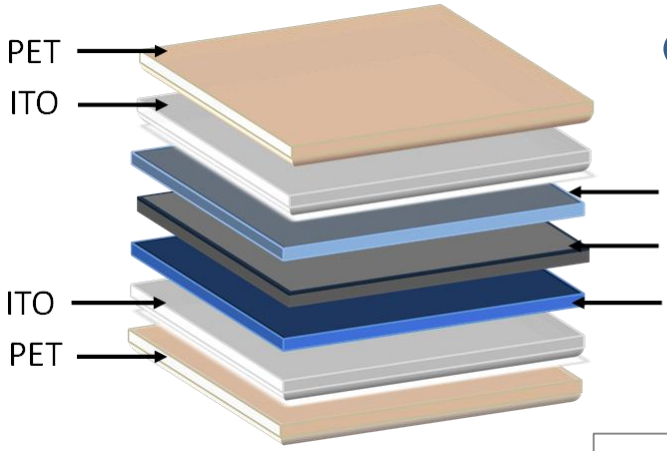


Modification of the TiO_2 layer with viologen



Lamination with the solid electrolyte

MAIN ACHIEVEMENTS



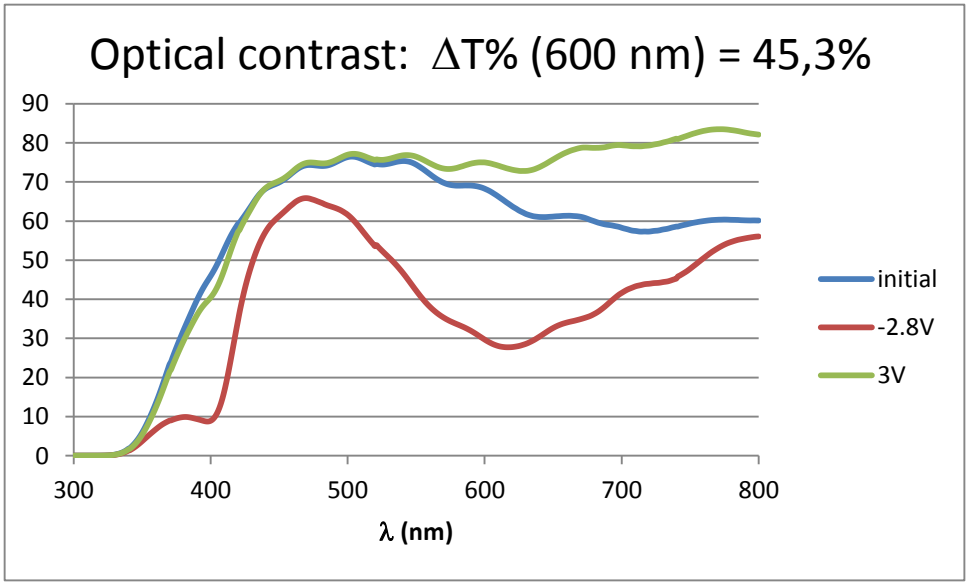
All-solid flexible plastic EC devices

Prussian blue (2 mC/cm^2)

Solid electrolyte*

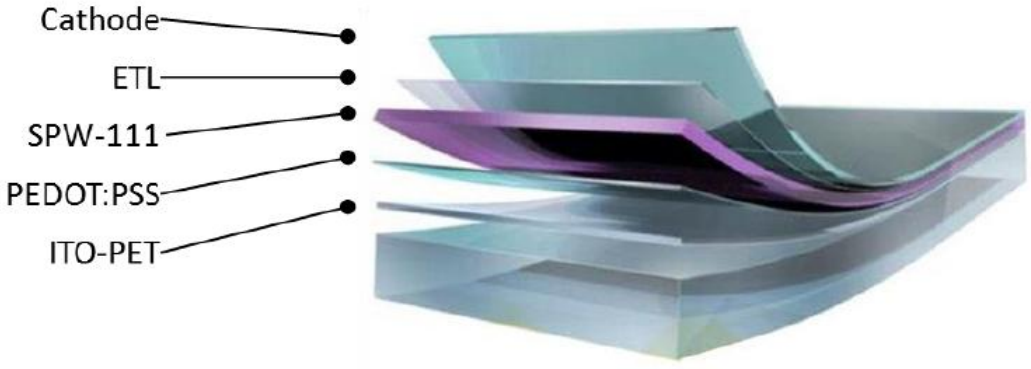
Viologen-modified TiO_2 nanostructured film
(TH2 (1300 nm); IL-B-2, 4h)

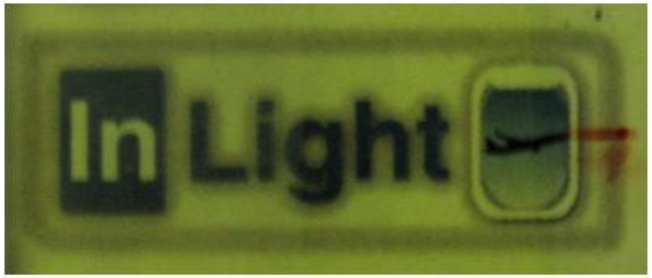
Active area: 5X5 cm^2



MAIN ACHIEVEMENTS

Production of a TOLED stack by printing methods with very high transmittance (75% at 550 nm).



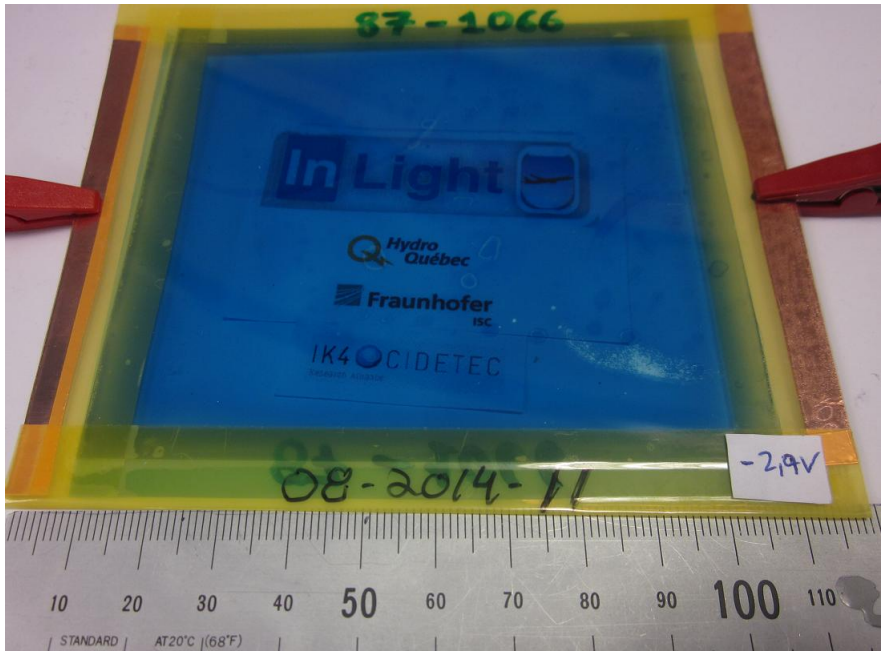


OFF -state

ON -state at 16V / 3mA

Scaling-up

EC devices: 10 X 10 cm²



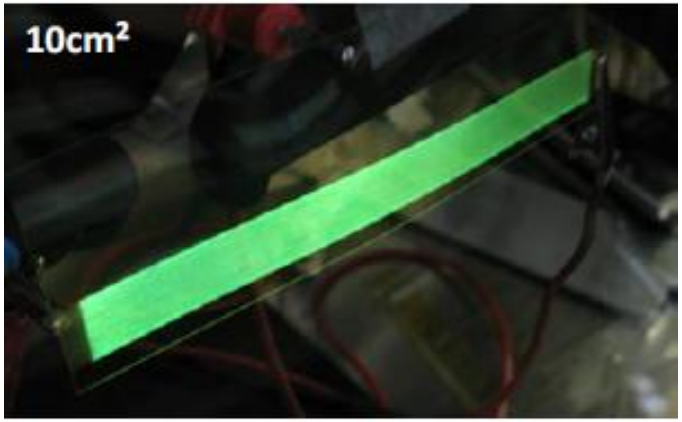
Preparation of **15x20 cm²** devices in progress.

Development of large-area electrochromic films by roll-to-roll and roller coating

Scaling-up

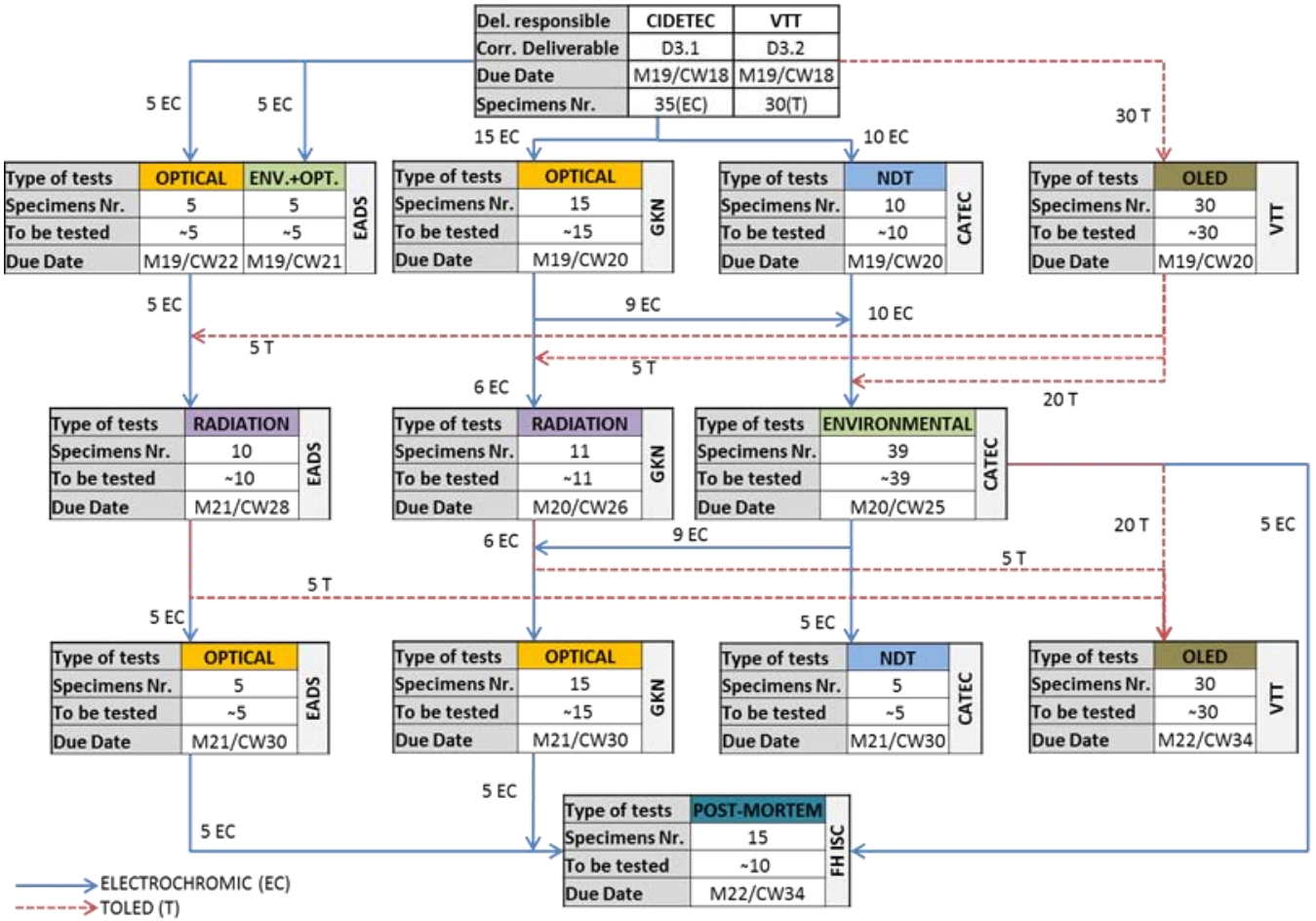
TOLED devices: 1 X 10 cm²

ROKO pilot printing line at VTT facilities



MAIN ACHIEVEMENTS

Large series of prototypes are being fully-characterized within 3 annual testing campaigns



Thank you very much for your attention

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n° 314233.

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CENTRAL AEROHYDRODYNAMIC INSTITUTE NAMED AFTER PROFESSOR N.E. ZHUKOVSKY

One Method of
Spatial Flight Path Optimization
for non-Stationary Aircraft Flight Regimes

Lyovin Sergey

Russia

Outline

intro Problem definition: maneuverable aircraft flight path optimization

1st part Direct solution – polynomial approach

2nd part Direct method investigation

end Conclusion

intro

Maneuverable aircraft flight path optimization problem

Flight path optimization – optimal control problem

- Dynamic system: $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{u}, t)$
- Boundary conditions: $\begin{cases} \boldsymbol{\psi}(\mathbf{x}, t_0) = \boldsymbol{\psi}_0 \\ \boldsymbol{\psi}(\mathbf{x}, t_T) = \boldsymbol{\psi}_T \end{cases}$
- Constraints: $\boldsymbol{\varphi}(\mathbf{x}, \mathbf{u}, t) \le 0$
- Criterion: $\int_{t_0}^{t_T} f_0(\mathbf{x}, \mathbf{u}, t)dt \to \max_{\mathbf{u} \in G_u}$

Flight path optimization – optimal control problem

Approaches:

- **Indirect methods**
  - Based on Maximum Principle
    - Lead to two-point boundary problem
- **Direct methods**
  - Reduce optimal control to NLP problem
    - Robust

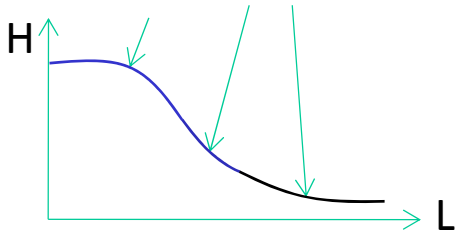
1st part

Direct solution – polynomial approach

Polynomial approach

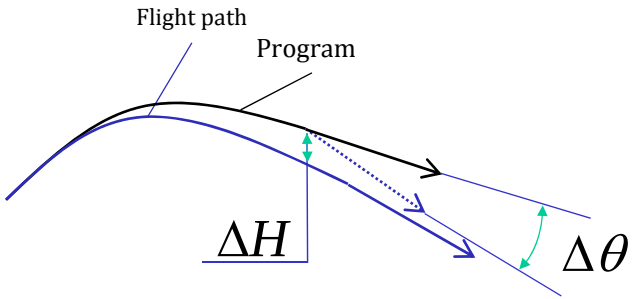
- Flight path parameterization by the sequence of 5th degree polynomial

$$H(L) = c_0 + c_1 L + c_2 L^2 + c_3 L^3 + c_4 L^4 + c_5 L^5$$



- Operation algorithm

$$\mathbf{u} = \mathbf{u}(\Delta H, \Delta\theta, H, \ldots)$$



- Physical model

$$m\ddot{\mathbf{x}} = \mathbf{F}(\mathbf{x}, \mathbf{u}, t)$$

mass point movement

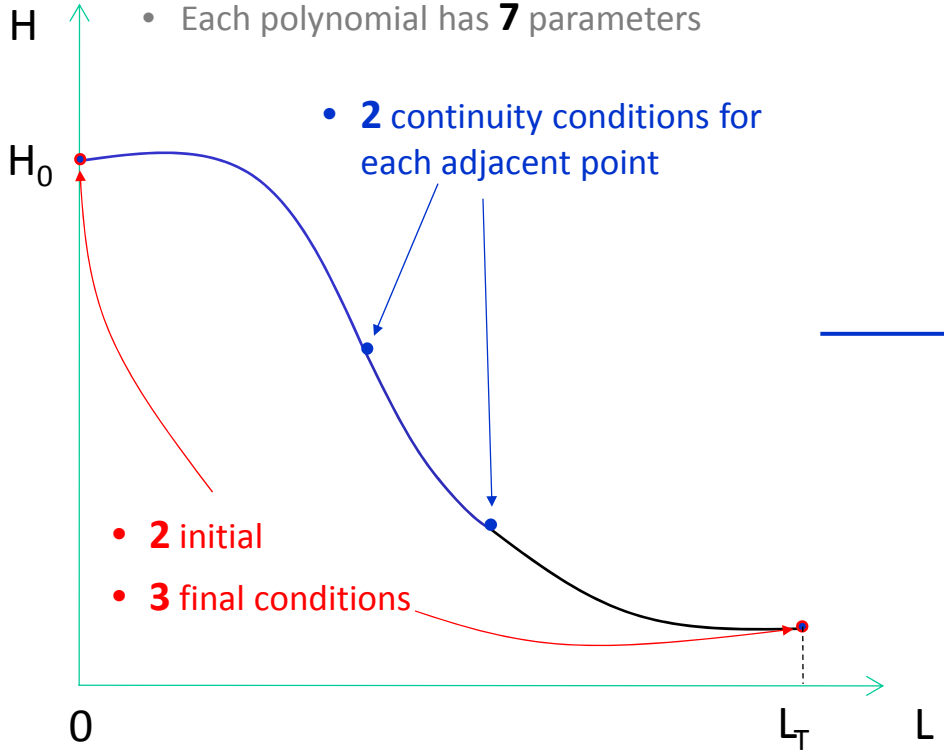
- Criterion

$$t_T \rightarrow \min_{\mathbf{u} \in G_u}$$

minimum flight time

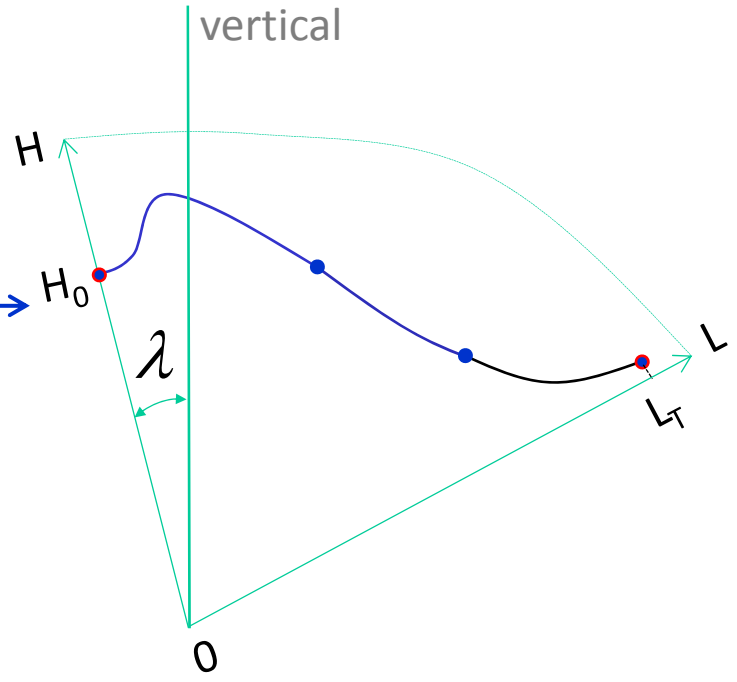
Polynomial approach

$$H(\Delta L) = c_0 + c_1\Delta L + c_2\Delta L^2 + c_3\Delta L^3 + c_4\Delta L^4 + c_5\Delta L^5,$$
$$\Delta L = (L - L_0)$$



- Each polynomial has **7** parameters
- **2** continuity conditions for each adjacent point
- **2** initial
- **3** final conditions
- **12** free parameters for 3 polynomial

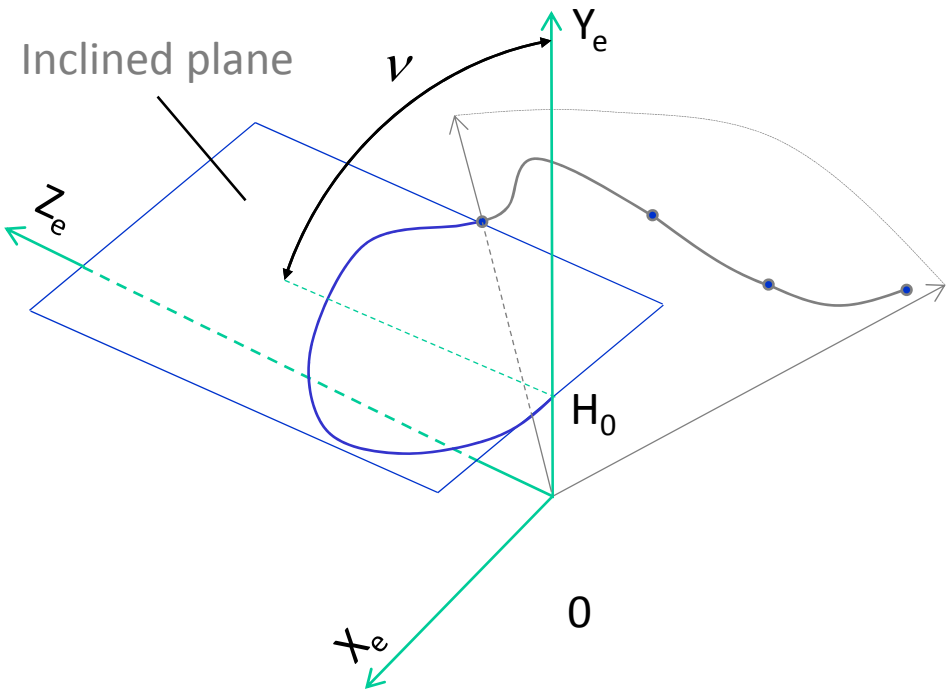
Polynomial in inclined plane



- **13** free parameters for 3 polynomial in inclined plane

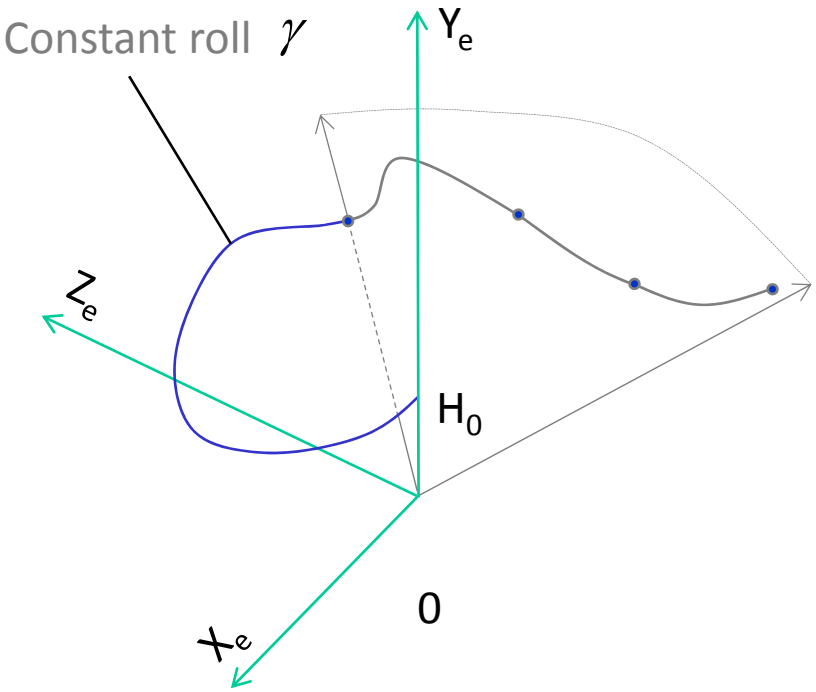
3-D maneuvers

Turn in inclined plane



- **2** free parameters for turn in inclined plane

Turn with constant roll



- **2** free parameters for turn with constant roll

Polynomial approach

Optimal control problem is reduced to the non-linear programming (NLP) problem

$$J = \int_{t_0}^{t_T} f_0(\mathbf{x}, \mathbf{u}, t)dt \to \min_{\mathbf{u} \in G_u} \longrightarrow F(c_1, c_2, ..., c_n) \to \min_{c \in G_c}$$

... ...

NLP method – Genetic Algorithm

because of:

- **No need to calculate derivatives**
- **Function could be discontinuous**
- **Easy to include limitations**

2st part

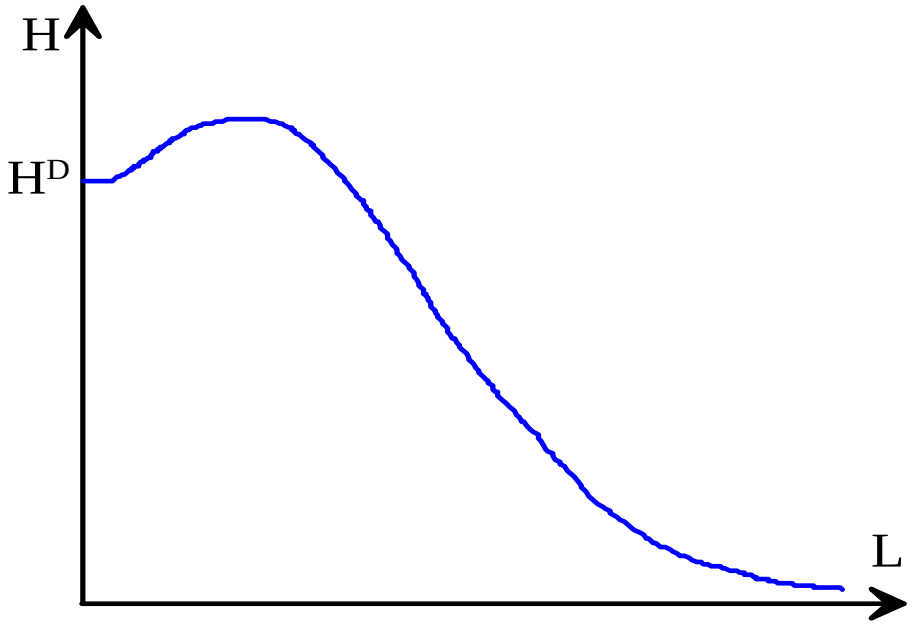
Direct method investigation

Directions of investigation

- Polynomial number influence
- Turn method influence
- Maximum flight range searching

Polynomial number influence

Calculation case - descent



Trajectory approximation:

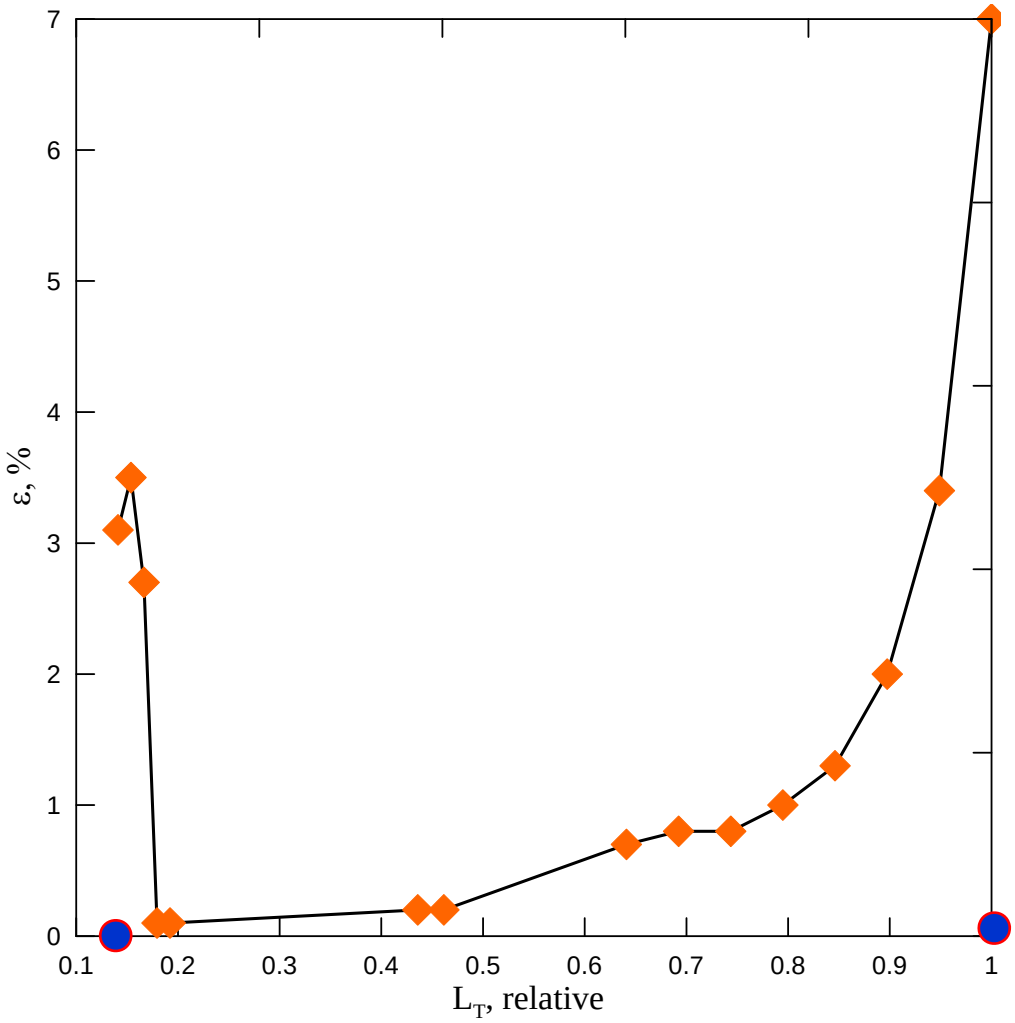
- 1
- 2
- 3

polynomial

Range:

- min
- max

Polynomial number influence

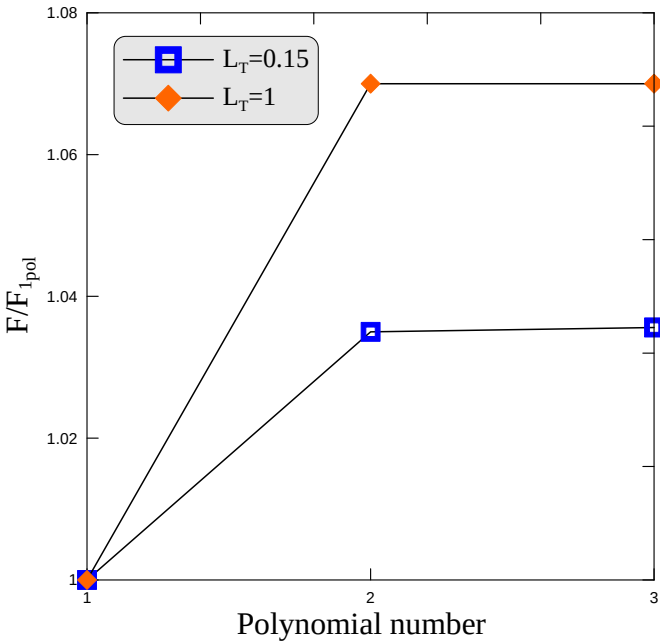


Relative criteria improvement

$$\varepsilon = \frac{F_{1pol} - F_{2pol}}{F_{1pol}} * 100\%$$

F_{1pol} - flight time with 1 polynomial

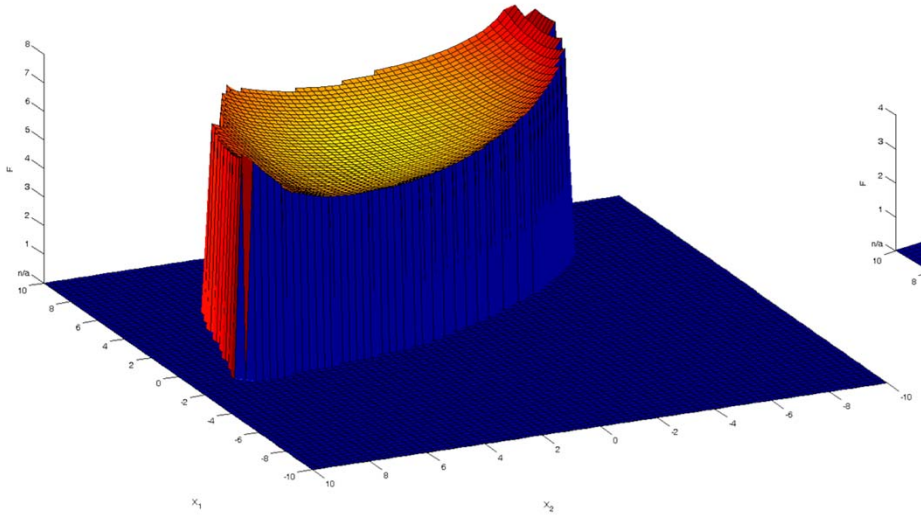
F_{2pol} - flight time with 2 polynomial



Polynomial number influence

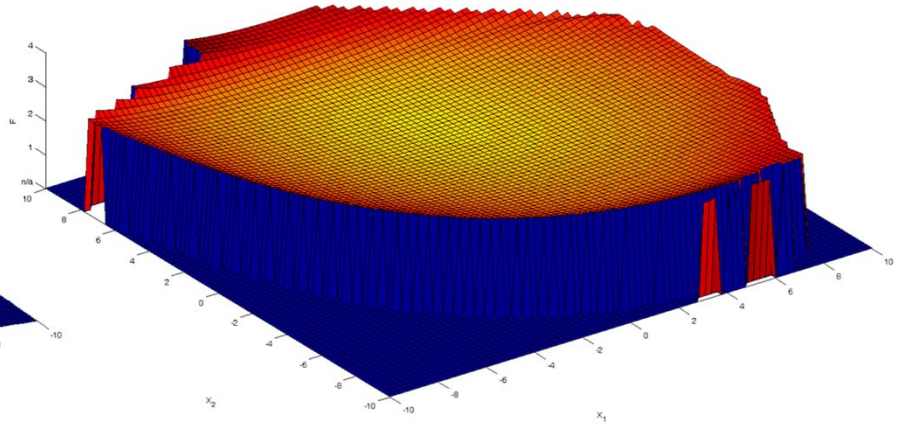
One polynomial

2 of 2 parameters variation



Two polynomial

2 of 7 parameters variation

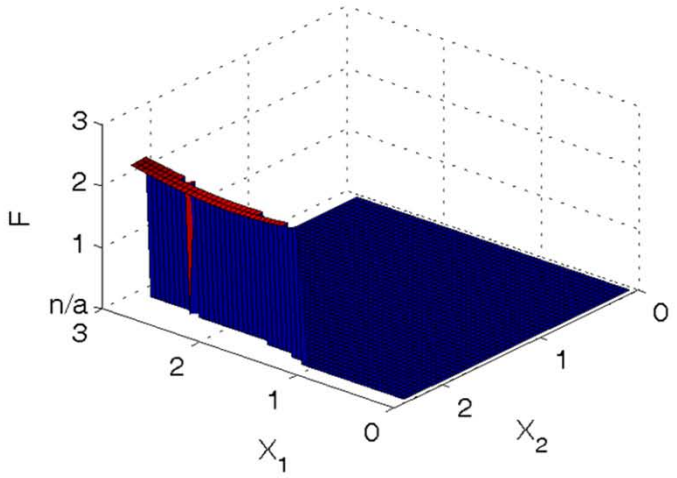


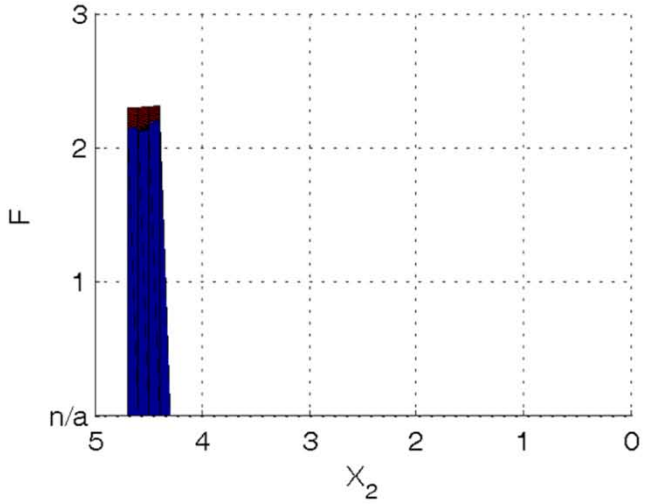
Target function becomes more flat
with polynomial number increase

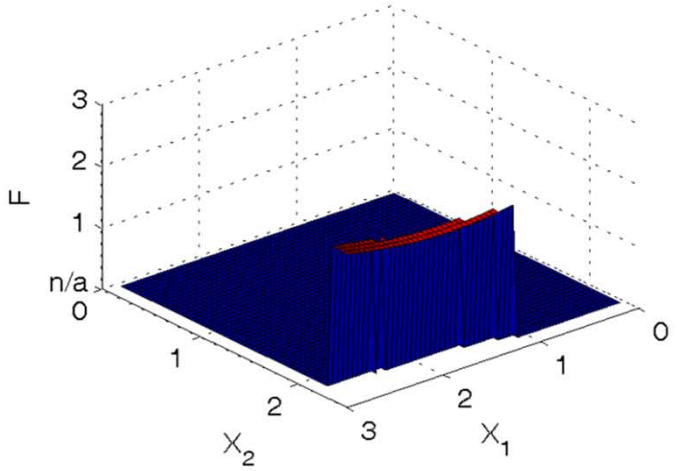
Two polynomial

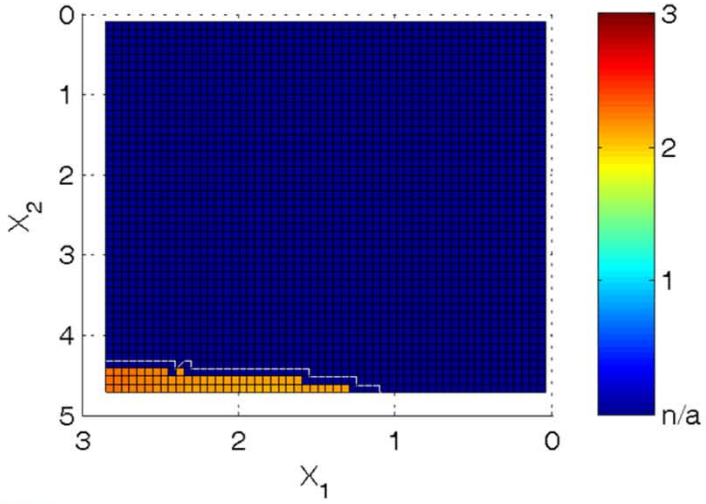
3 of 7 parameters variation

Polynomial number influence



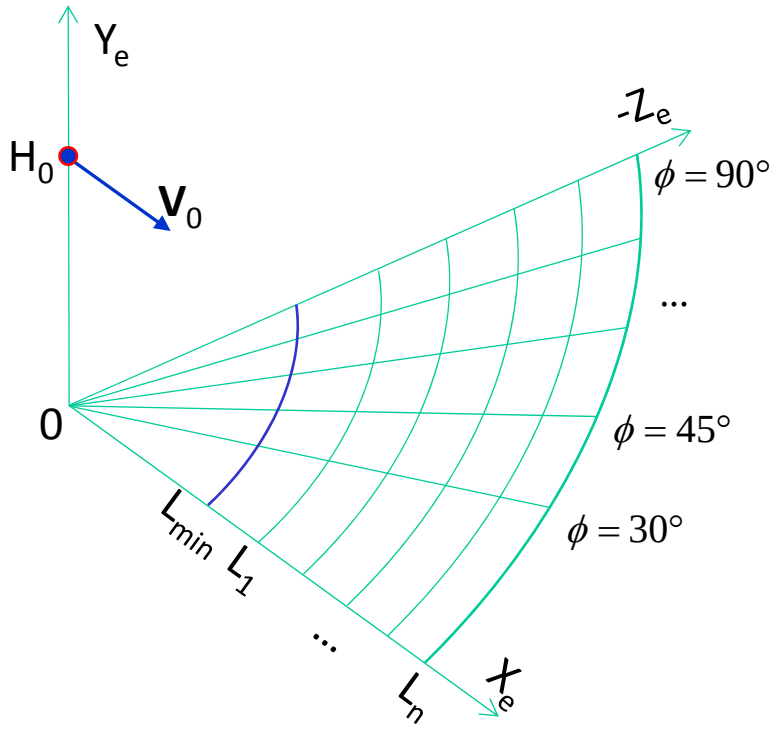






Turn method influence

Calculation case – turn and descent



Turn method

- Plane turn
- Constant roll

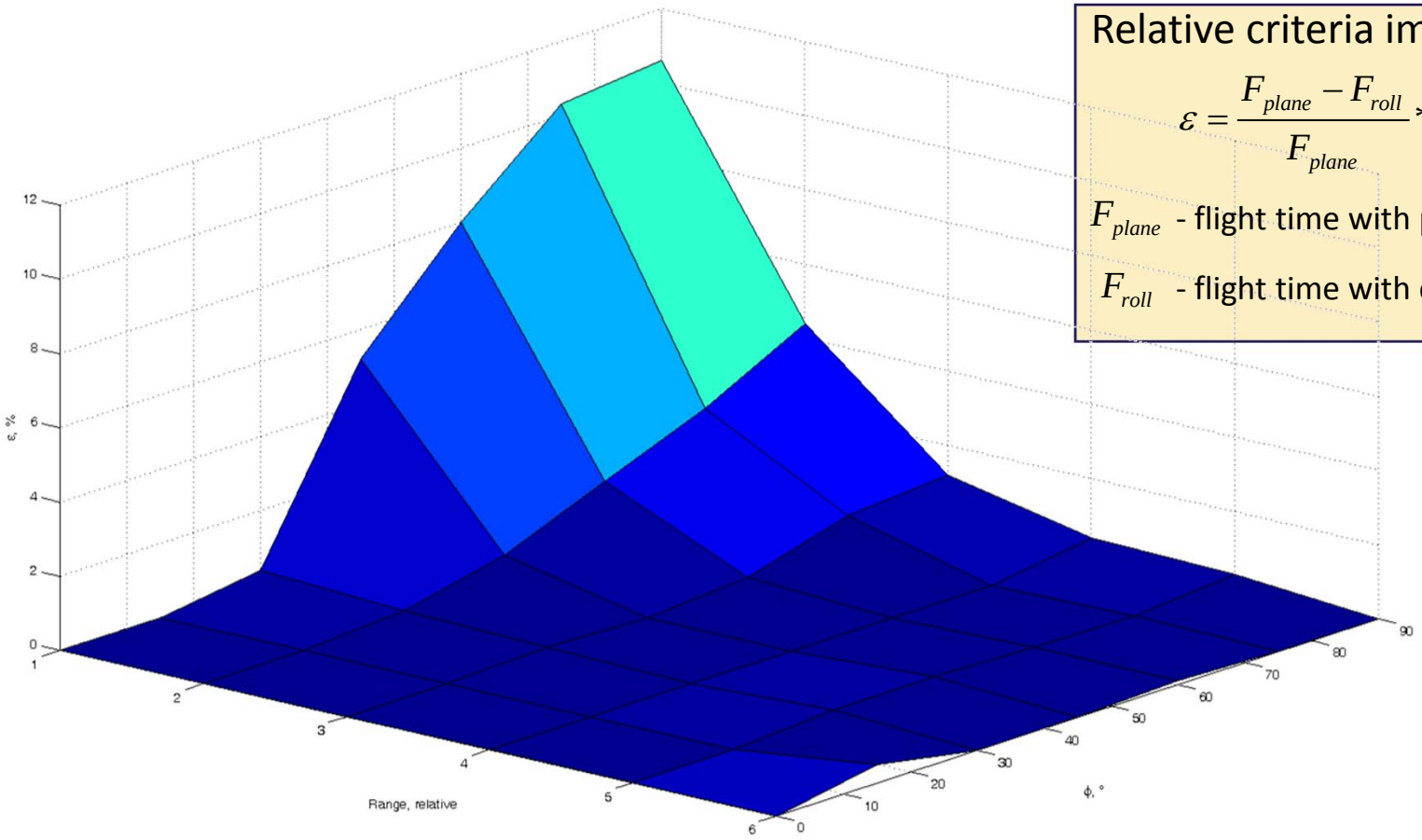
Trajectory approximation:

- 1 polynomial

Range:

- min
- medium

Turn method influence



Relative criteria improvement

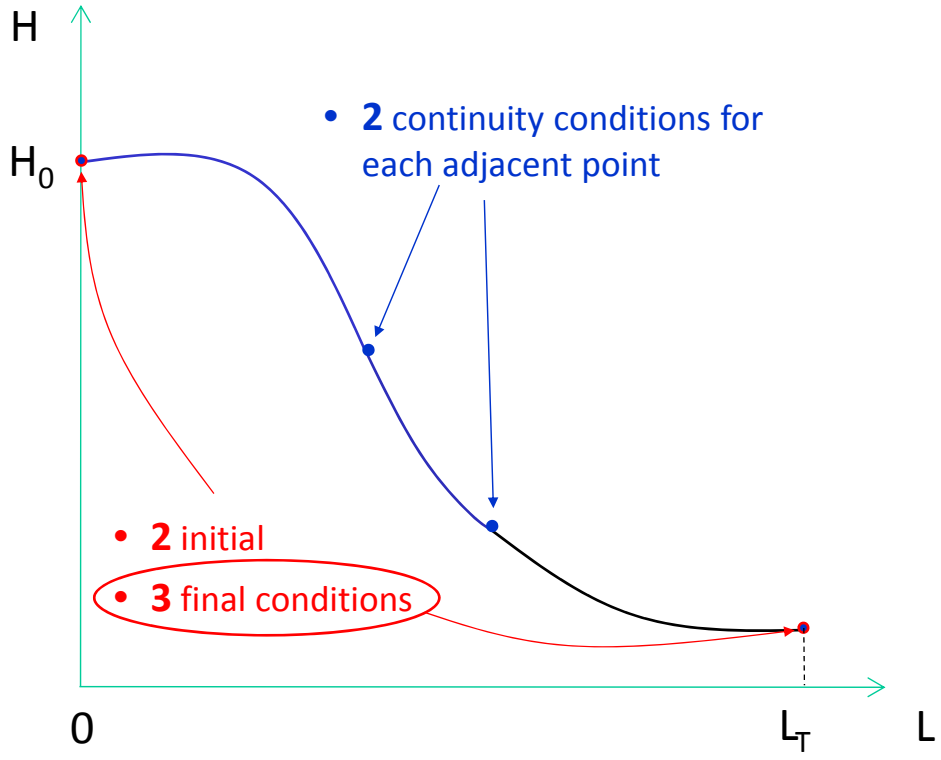
$$\varepsilon = \frac{F_{plane} - F_{roll}}{F_{plane}} * 100\%$$

F_{plane} - flight time with plane turn

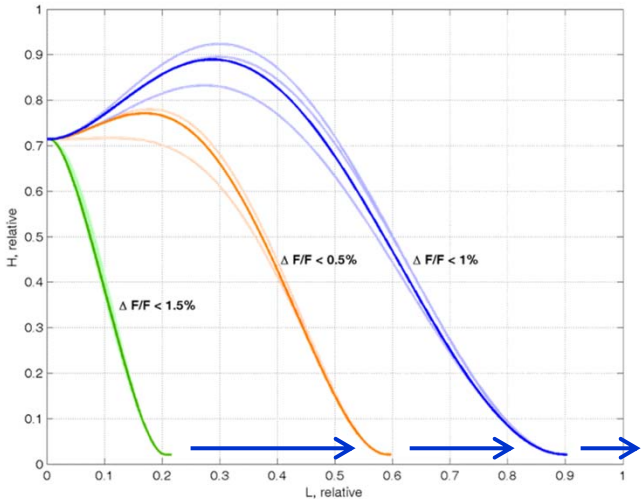
F_{roll} - flight time with constant roll turn

Maximum flight range searching

- Final trajectory point is fixed



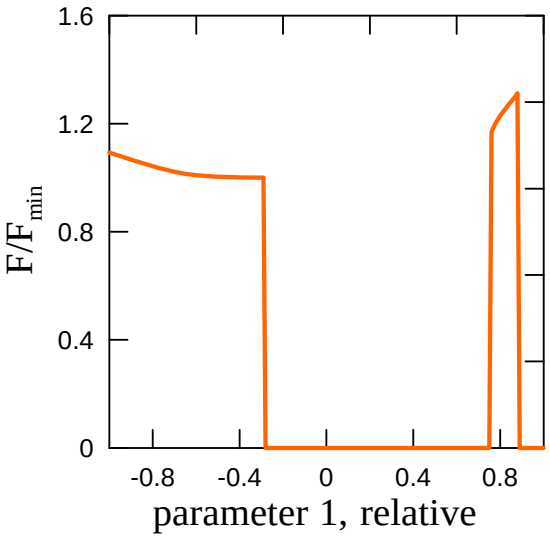
- Maximum range is searched step-by-step

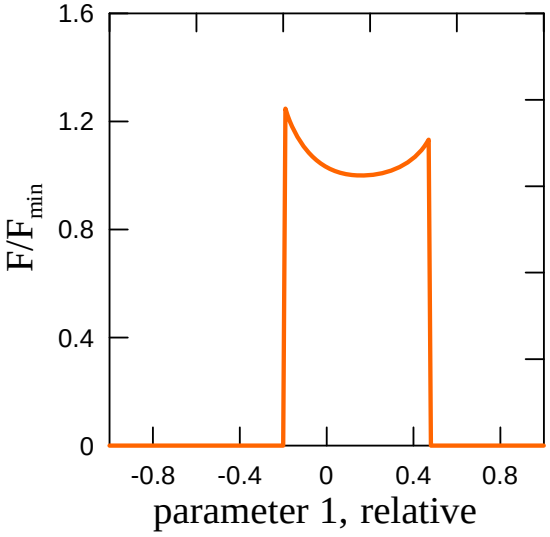


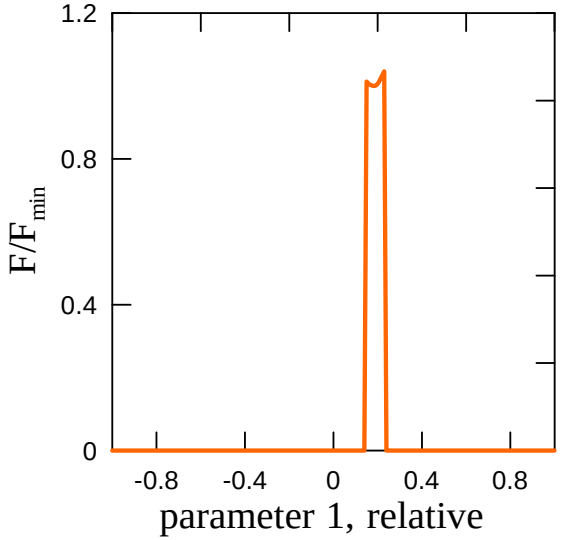
Step 1 … Step n …

Maximum flight range searching

1 polynomial





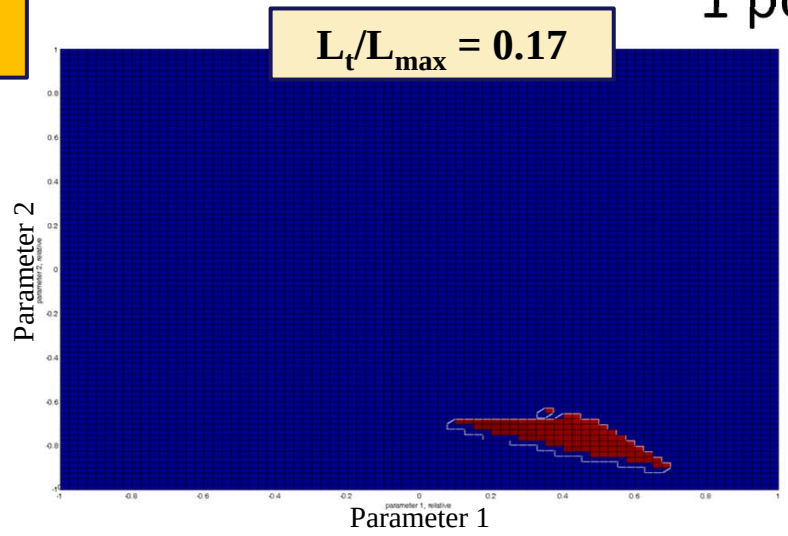


L_T/L_{max}=0.2 → L_T/L_{max}=0.6 → L_T/L_{max}=0.9

Maximum flight range searching

1 polynomial

1



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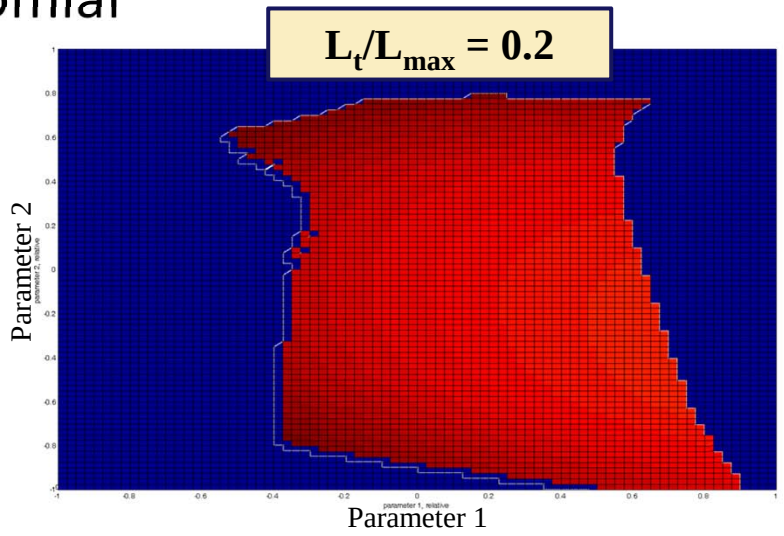

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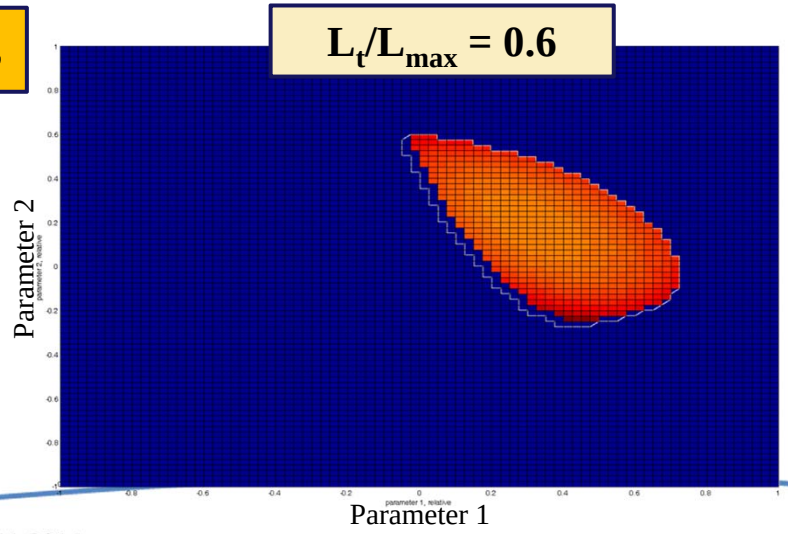
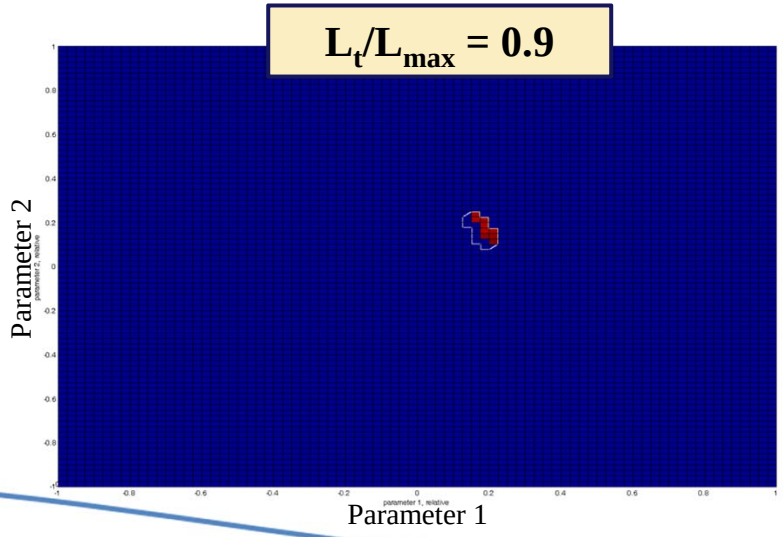
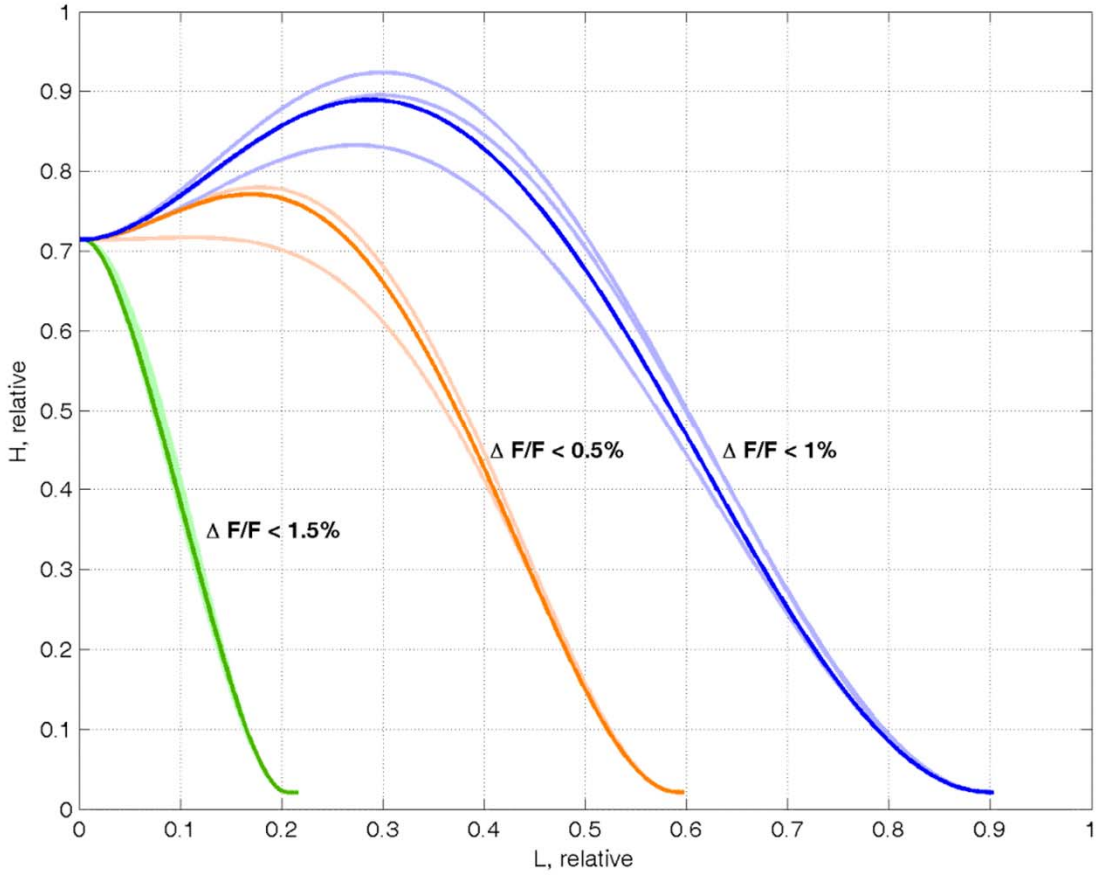


4



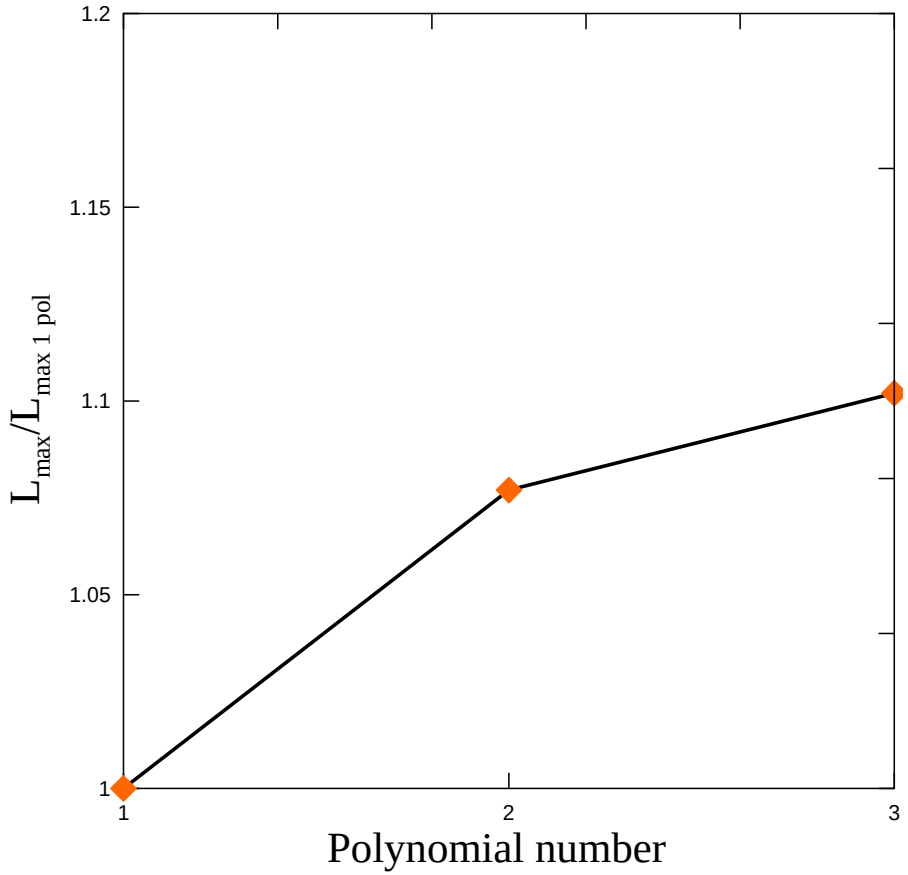
Maximum flight range searching

1 polynomial



Maximum flight range searching

3 polynomial appeared to be enough for trajectory approximation



end

Conclusion

Conclusion

- Polynomial method
- 3-D maneuvers
- Genetic algorithm

Aircraft **flight path optimization** method with **wide range** of available problem definitions (**boundary conditions**, **constraints**, **criteria**, …), **robust and flexible**.

Thank you for your attention

?

Questions are welcomed

Future RepAIR and Maintenance for Aerospace industry

Dr.-Ing. Jens Pottebaum

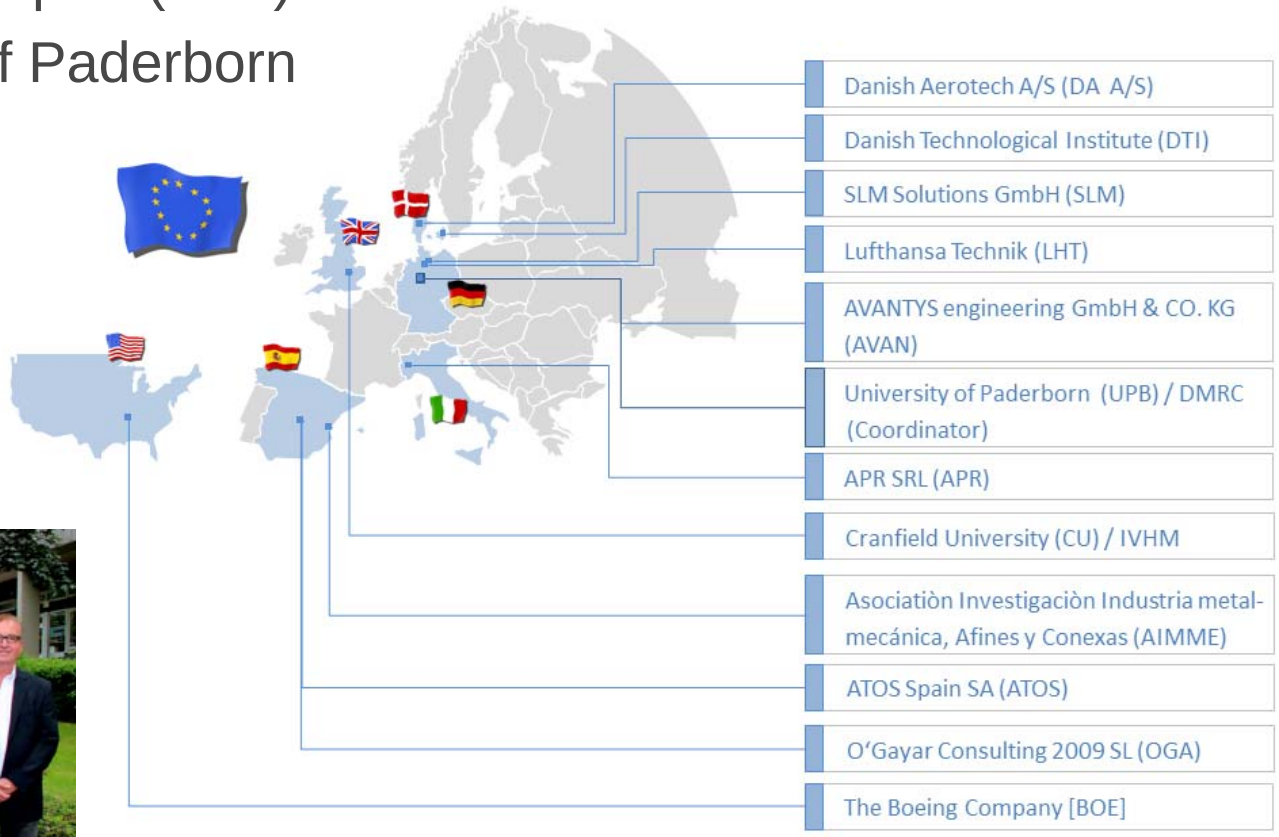
4th EASN Workshop,
29th of October, Aachen (Germany)

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605779.

www.Rep-AIR.eu

RepAIR - Overview

- Origin of funding: EU – FP7 Transport (AAT)
- Project Coordinator: University of Paderborn
- Total budget: 5.951.426 €
- Funding of EU: 4.276.352 €
- 12 partners
- Project duration: 36 Month
- Start date: 01.06.2013



Website: www.rep-air.eu

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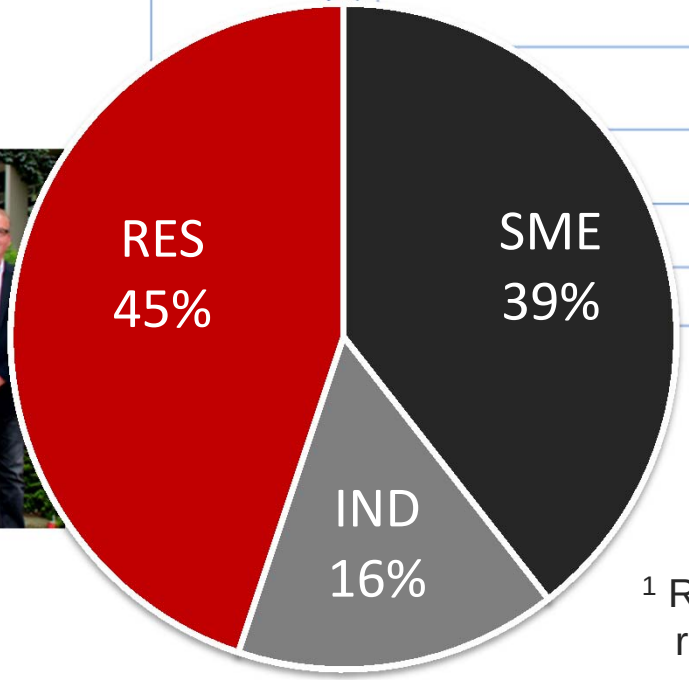
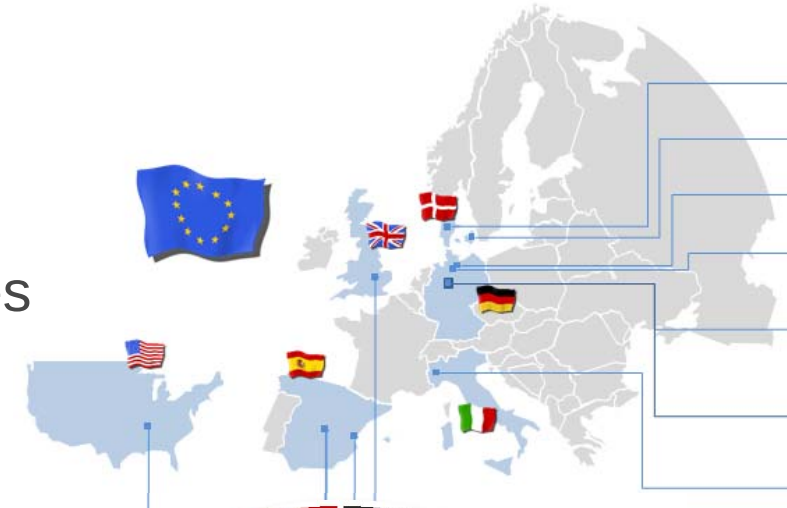
Stakeholders represented in the project

- Main ‘end users’[1]
  - Lufthansa Technik
  - The Boeing Company
- AM technology
- Integration of AM into processes
  - Pre-/post-processing technology
  - Certification and costing
  - Integrated Vehicle Health Mgmt.
  - Software integration





- Danish Aerotech A/S (DA A/S)
- Danish Technological Institute (DTI)
- SLM Solutions GmbH (SLM)
- Lufthansa Technik (LHT)
- AVANTYS engineering GmbH & CO. KG (AVAN)
- University of Paderborn (UPB) / DMRC (Coordinator)
- APR SRL (APR)
- Cranfield University (CU) / IVHM
- Asociatiòn Investigaciòn Industria metal-mecánica, Afines y Conexas (AIMME)
- ATOS Spain SA (ATOS)
- O‘Gayar Consulting 2009 SL (OGA)
- The Boeing Company [BOE]

[1] RepAIR main ‘end users‘ do not receive any funding by the EC

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Motivation

RepAIR – Future RepAIR and Maintenance for Aerospace Industry and Aeronautics & Air Transport

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Motivation – Maintenance, Repair and Overhaul Market

- Strong need to reduce costs in international markets
- Extensive MRO actions already in Asia
- European service providers have approximately 30% of higher salary costs compared to Asia and Middle East
- Maintenance of complex components is responsible for more than 43% of MRO costs
- These MRO activities are nearly all carried out in Europe

Source: mapsofworld.com

So why Additive in MRO?

- The Boeing 747 has six million parts
- 75.000 drawings were used to produce the first 747
- The 747 wing is 30 times of the weight of the first Boeing airplane (1926 B&W)
- The 747 consists of Aluminum 66.150 kg high strength aluminum
- Only one airplane out of the Boeing family
- Some Boeing, some Airbus,…….
  How many parts in total?

Source: Boeing.com

Source: Slimlivery.com

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Around the Clock and around the world

- An aircraft needs to stay in the air
- Airbus stocks 3.6 million parts
- 120.000 tools on stock
- Providing spare parts for 60 years
- Global stores in Hamburg (66.000 sqm), Washington, Beijing, Dubai, Frankfurt Singapore and Shanghai
- Parts need to be at the gate ASAP

Source: Lufthansa-Technik.com

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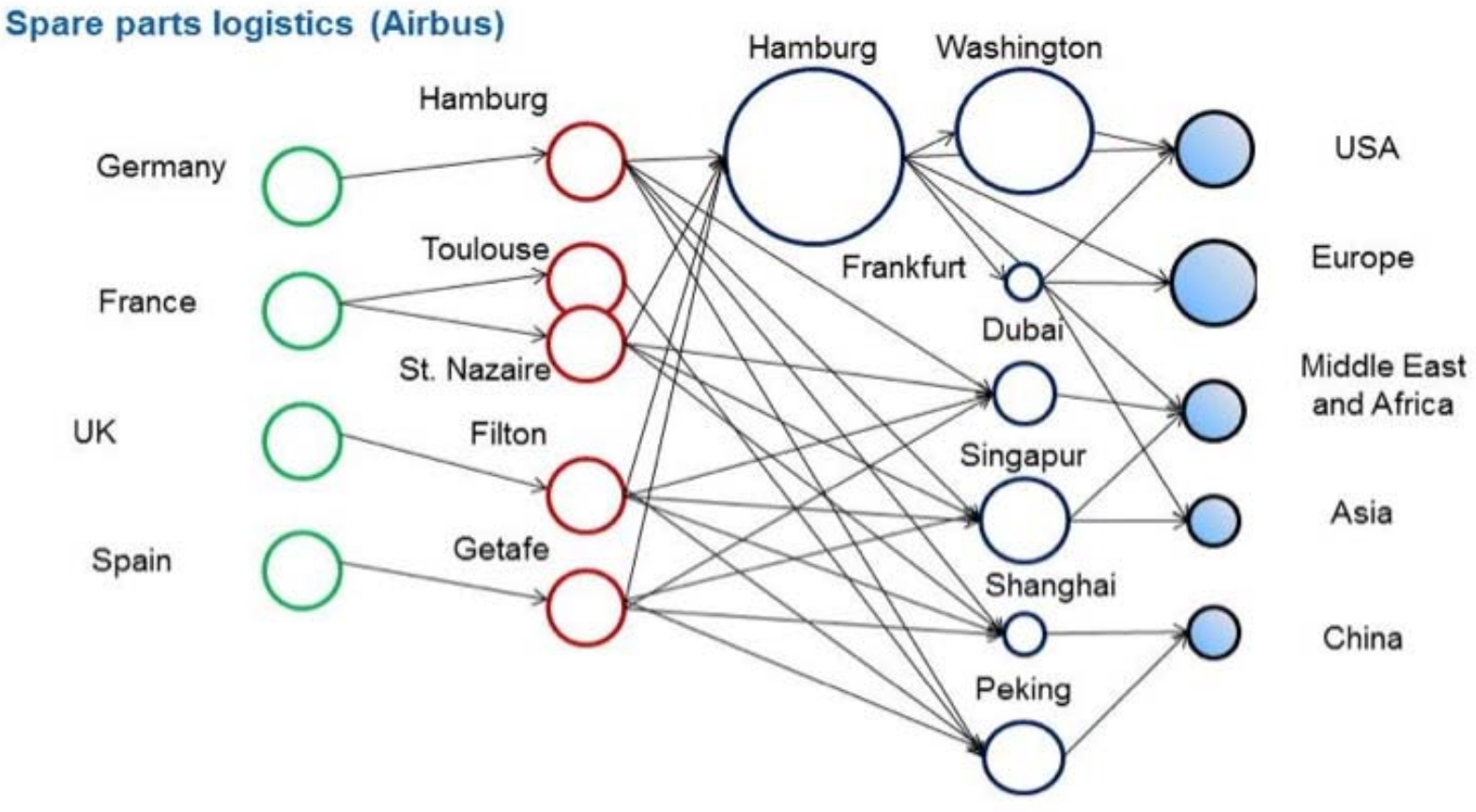

		Stations	ABV	ALA	AMS	AUH	BAH	BCN	BKK	BOS	BRE
Airbus											
A318		CFM56			●			●			●
A319 A320 A321		CFM56			●			●			●
		V2500			●			●			●
A330	-200 -300	PW4000		●			●	●	●	●	
		Trent 700	●	●		●	●	●	●	●	
		CF6-80				●	●	●	●	●	
A340	-200 -300	CFM56	●	●		●	●	●	●	●	
	-500 -600	Trent 500	●	●		●	●	●	●	●	
A380		Trent 900									
		GP7200									
Boeing											
B737	-300 -400 -500	CFM56			●			●			●
	-600 -700 -800	CFM56						●			●
B747	-400	CF6-80			●				●	●	
		PW4000			●					●	
		RB 211									
B747	-8	GE GEnx									
B757	-200	PW2000									●
	-300	RB 211									●
B767	-300	CF6-80									
		PW4000									
B777	-200 -300	PW4000									
		Trent 800		●	●	●	●	●			
		GE 90		●	●	●	●	●			
	-ERF	GE 90		●	●	●	●	●			
B787-8		GE GEnx									

Can’t the world be easier than that?

Source: Lufthansa Technik

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Vision and approach

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Our Vision for MRO Process Chain 2020

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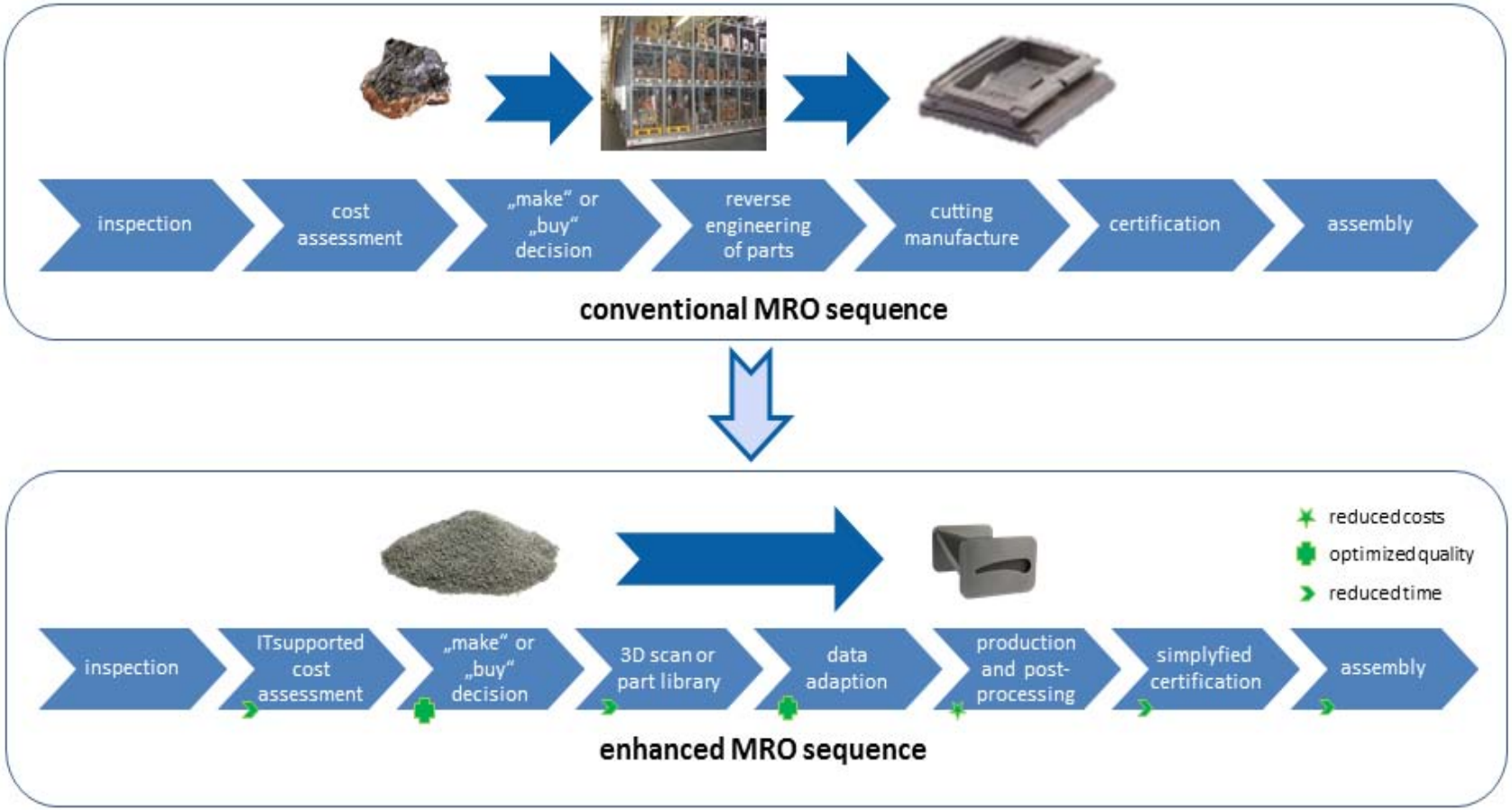
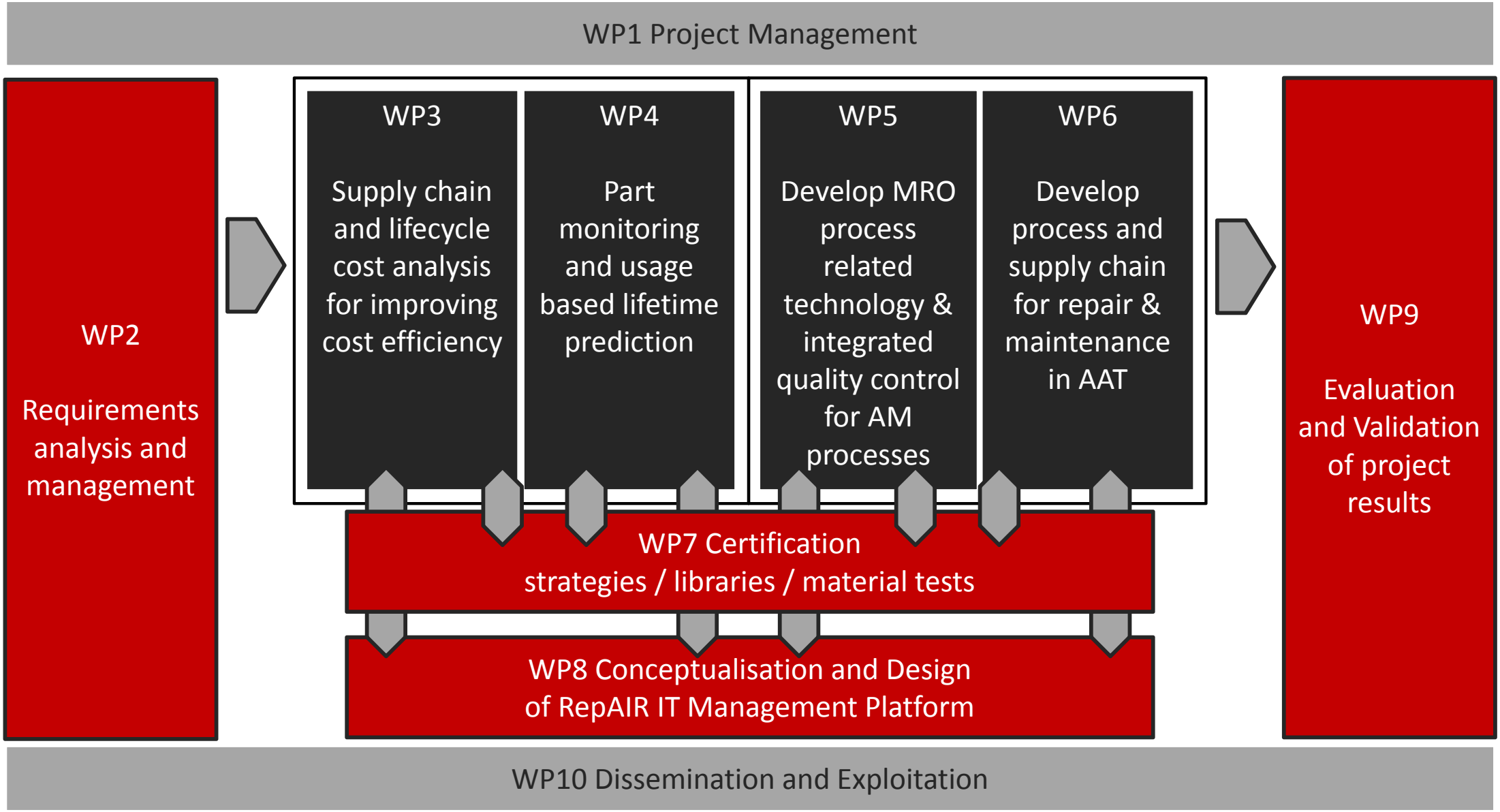
- MRO costs reduction by automation level increase and reduction of the spare parts production stages (by a complete production and supply chain integration)



Project structure



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Work Packages (1/3)

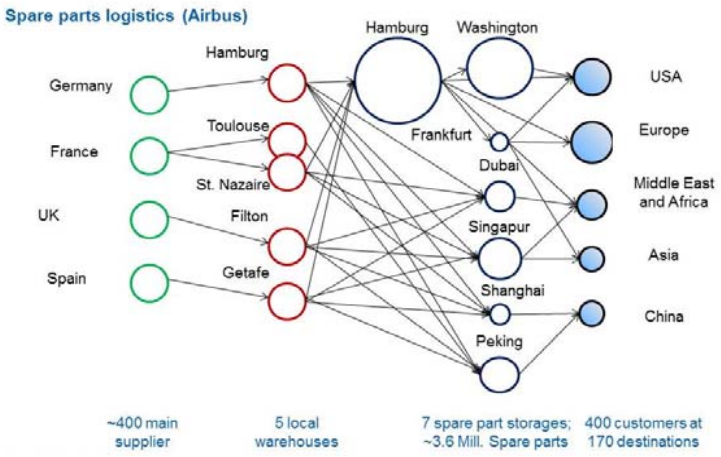
WP1 Project Management

WP2

Requirements analysis and management

- WP1: Administrative project management
- WP10: Contributions to the research community and demonstrations in the market, recommendations for viable commercial exploits

- WP2: Enable other WPs regarding “end user” needs by requirements analysis/management, sample part selection and scenario definition
- WP9: Validation of the components and the integrated system and formative/summative evaluation (incl. field trials)



WP9

Evaluation and Validation of project results

WP10 Dissemination and Exploitation

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Work Packages (2/3)

- WP7: New certification frameworks, specific procedures for the different operations in the RepAIR process, the elaboration of a structure for a library of spare parts and build conditions compliant with the certification requirements, the integration of these procedures, workflows, registers and designs in the IT platform (quality layer), and the pilot certification of a process (technology / material / conditions)
- WP8: Design and implement all functions for a lean management for MRO processes as an integrative IT management platform (Supply Chain and logistics)

WP7 Certification
strategies / libraries / material tests

WP8 Conceptualisation and Design
of RepAIR IT Management Platform

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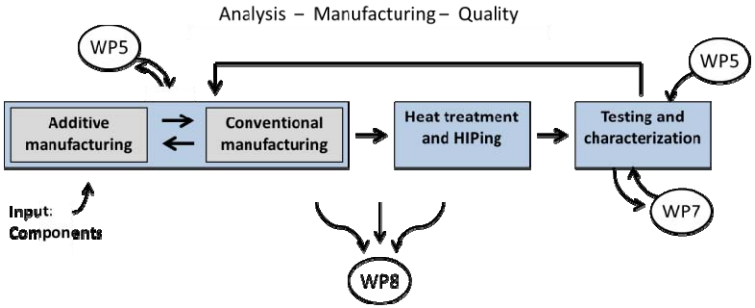
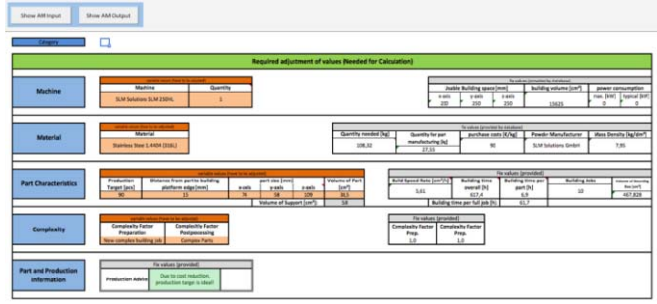
Work Packages (3/3)

WP3	WP4	WP5	WP6
Supply chain and lifecycle cost analysis for improving cost efficiency	Part monitoring and usage based lifetime prediction	Develop MRO process related technology & integrated quality control for AM processes	Develop process and supply chain for repair & maintenance in AAT





- WP3: Decision methodology and tools, analysis of cost efficiency, balance with environmental friendliness of manufacturing processes, prediction of costs and future possibilities of AM technologies for MRO
- WP4: Test rig for condition monitoring of parts, develop a hybrid part life estimation approach and integrate condition monitoring and maintenance/spares' delivery schedule optimisation in the RepAIR framework
- WP5: Develop repair process related technology and integrated quality control for AM processes – Selective Laser Melting and laser cladding
- WP6: Define and validate a hybrid manufacturing/repair chain combining additive and conventional (subtractive) manufacturing techniques for production and repair and of components

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Fields of activity

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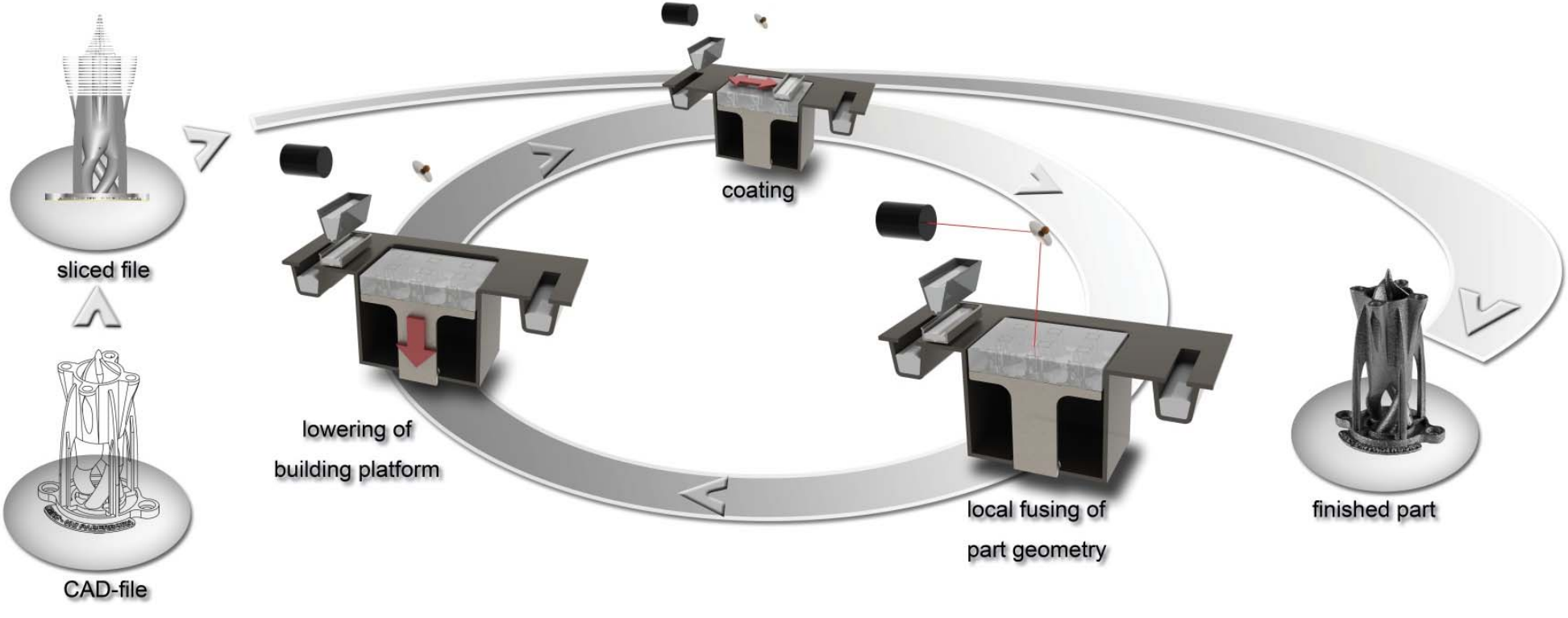
- Onsite maintenance and repair of aircraft by integrated Additive Manufacturing technology (direct digital manufacturing)



Principle of Additive Manufacturing for metals (Selective Laser Melting process), Source: DMRC

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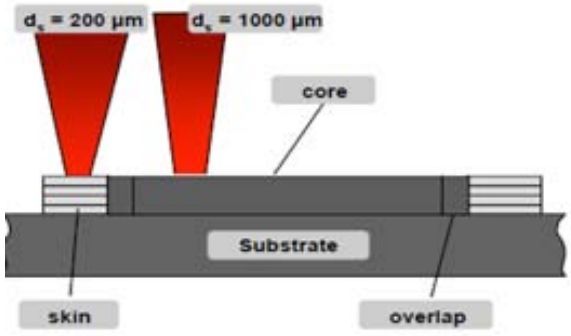
Areas of Work – Necessary for our AM Vision in MRO

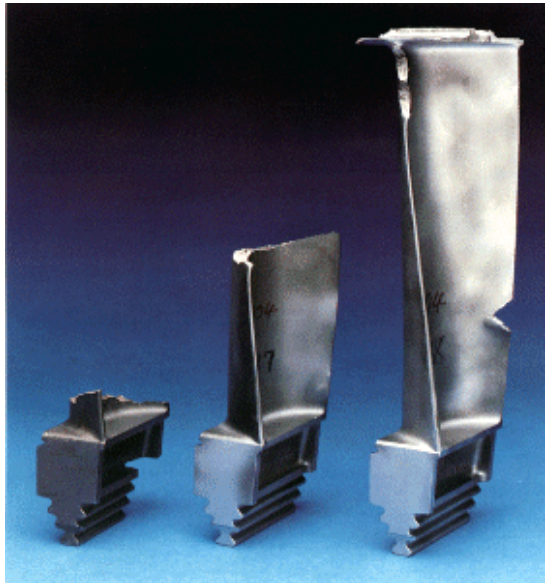
- Manufacturing speed
  - Increase of manufacturing speed
  - Tailoring a machine for the needs of MRO's
  - Further development of 2 laser concepts (SLM / DMD)

- Repair capabilities
  - Development of repair systems based on AM
  - Positioning and clamping modules development

- Integrated Repair Chain
  - Optimizing the combination of additive and traditional processes
  - Investigating more automated options



Source: Fraunhofer ILT Aachen



Source: http://www.swri.org

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Areas of Work – Necessary for our AM Vision in MRO

- Software Systems
  - Integrating Additive Manufacturing solutions in existing software solutions
  - Supply chain / production chain
  - Developing agile systems

- Certification
  - Form, Fit, Function, Fatigue
  - Research on certification aspects for AM
  - Part library

- New Business Models
  - What kinds of business models are feasible for MRO's, OEM's and Plane Manufacturers
  - Saving time – no reverse engineering

Source: FAA

Source: Itunes Store

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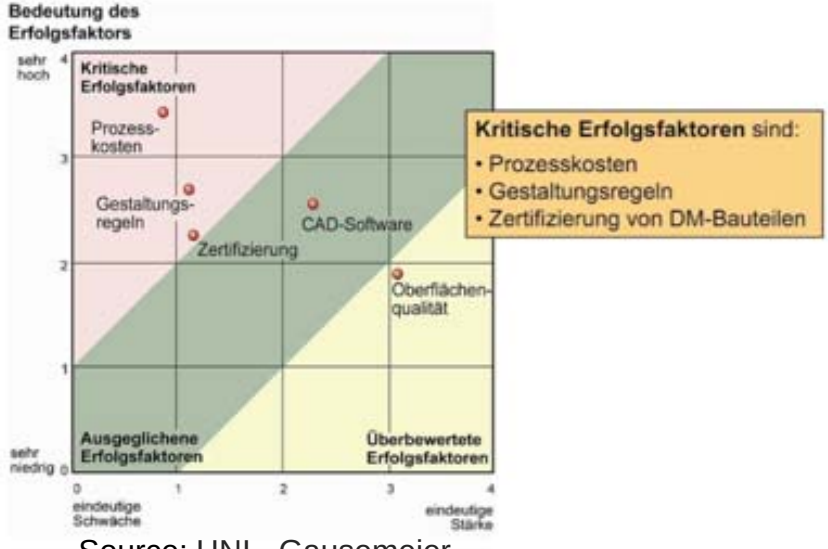
Areas of Work – Necessary for our AM Vision in MRO

- Manufacturing costs
  - Easy to use cost assessment and comparison
  - Justification for new business models
  - Justification of supply chain models

- Usage based prediction of lifetime
  - “Integrated Vehicle Health Management”
  - Enhancement of sensor monitoring possibilities
  - Research on fatigue and usage influences of AM in MRO



Source: HNI - Gausemeier

Source: http://www.cvel.clemson.edu/

Objectives and outlook

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RepAIR - Objectives

1. Reduce repair and overhaul costs of complex spare parts and the turnaround
2. Increase the automation level for spare parts production processes
3. Reduce scrap and toxic chemicals in the repair process and part weight by the use AM
4. Increase the technology readiness level (TRL) for ATT to level 4 focusing on the AM technology
5. Develop processes to decrease certification effort for additive manufactured AAT spare
6. Reduction of inspection time by integrating continuous health management
7. Strengthen the business model of European MRO service provider in the world by integrating a complete production and supply chain for complex spare parts
8. Prediction of costs and future possibilities of AM technologies for MRO in 2020

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Cost efficiency, greening and safety related aspects for 2020

- On time maintenance through sensor monitored parts
- Self inspection of aircraft enables on condition maintenance
- Repair center enables cost efficient repair:
  - shorter lead time
  - optimized fabrication in terms of material costs and
  - lower overall part cost
  - optimized supply chain
- Lightweight design of AM parts reduces part and Lifecycle costs of Airplanes

- Continious monitoring of part / just in time production
- Less Corrosion through AM optimized parts
- More safety through AM optimized parts
- Intelligent Quality Database for part optimization
- Part optimization over lifetime

- Fabrication optimized in terms of resources
- Buy to fly
- Lattice structures
- Reduction of production waste
- Reduction of carbon usage along the whole process chain

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Some results…

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Different types of Organizations in MRO as a starting point

The most important authorities: European Aviation Safety Agency (EASA)
Federal Aviation Administration (FAA)

Europe:

- Organization that deals with development of parts or repair processes

- Organizations which produce aircrafts, engines, or assembly groups

- Organizations which overhaul, exchange, repair, inspect or do modifications on parts of an aircraft.
- Only possible on provided and approved documentary reports.

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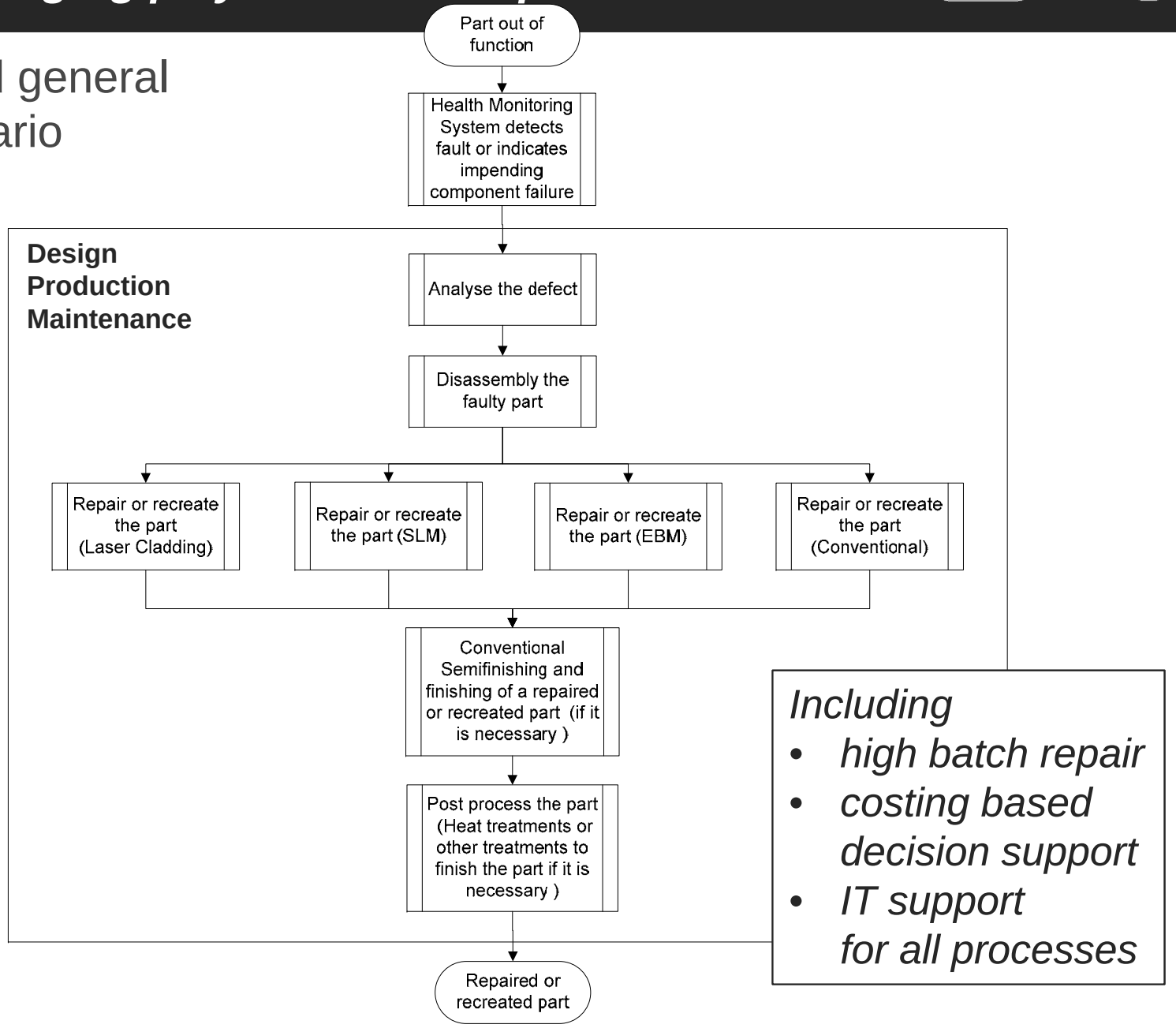
Scenario definition for RepAIR as a tool for bridging players and disciplines

- Simplified and general RepAIR scenario



Source: Portolés Griñán, L.; Jordá Ferrando, L.; Jordá Ferrando, O.: „Deliverable D2.3: Draft Requirements specification of certification processes", Paderborn, 2014.

Source: Deppe, G.; Lindemann, C.; Plaß, M.: „Deliverable D2.9 Draft specification of RepAIR scenarios", Paderborn, 2014.

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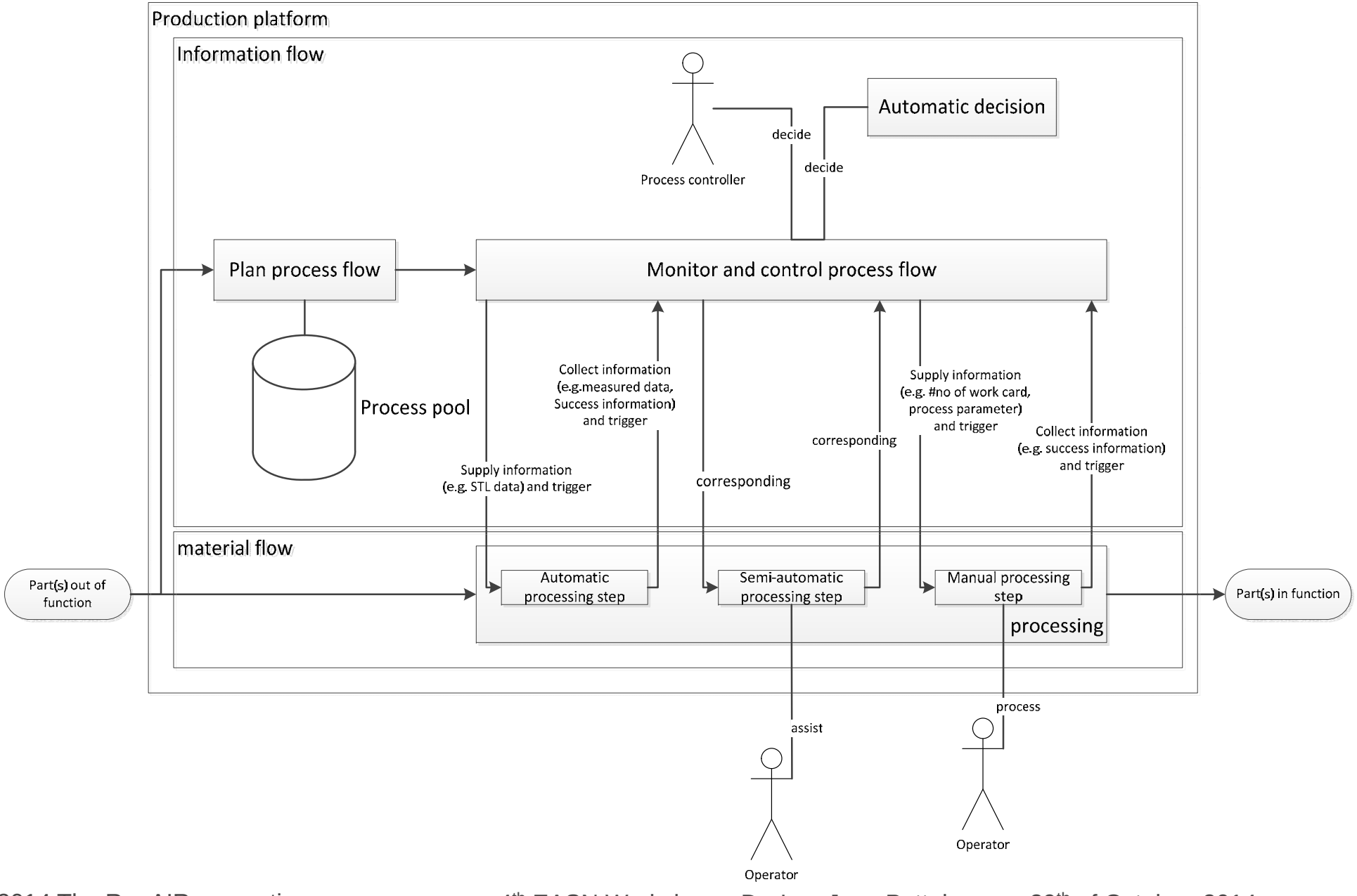
Process models as a basis for requirements specification



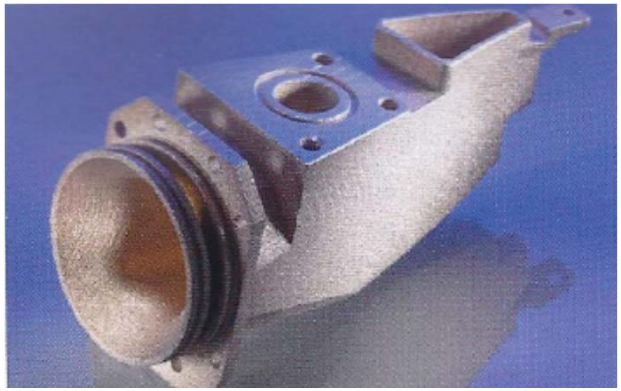
Sources:Plaß, M.; Wübbeke, B.: „Deliverable D2.5 Draft of production, supply chain and workflow requirements specifications and process control system", Paderborn, 2013.

Sample Parts from Aerospace as a core element for case studies

Combustion Chamber for Gas Turbine

Fuel Injector & Swirler

Engine Components



Air Duct

Hinge for Jet Engine

Sources: [Eose12], [Nath11], [Gebh12, p.77], [Zeli12], [www1], [Conc12]

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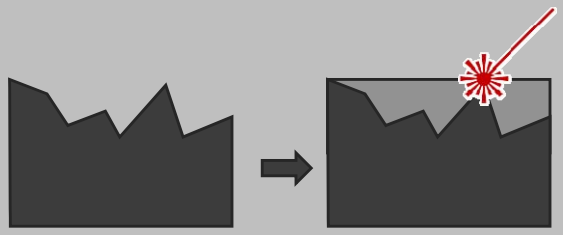
Future applications of AM in MRO as a visionary approach

1 Additional repair process

- Establish original geometry
- AM can create even complex geometries → less finishing
- Current: Geometry has to have a ground zero
- Scenario: AM can build on existing geometry
- Platform and fixture necessary



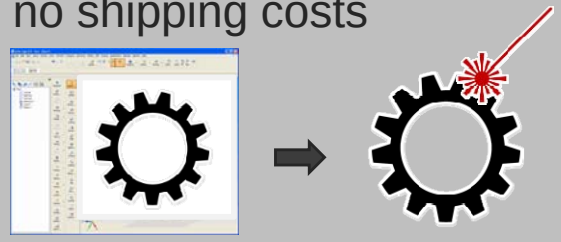
2 Spare part production

Scenario 1:

- MRO provider orders part
- OEM manufactures part
- Sends part to MRO provider

Scenario 2:

- MRO provider buys manufacturing data from the OEM (cp. iTunes)
- MRO manufactures part
- Shorter supply chain no shipping costs



3 Basic technology for aircraft design

- Lightweight and stress optimized parts
- Integrate several functions into one product
- Lower complexity and logistics
- More fuel efficient aircrafts → less carbon emissions
- Strengthens market position
- Lean & efficient supply chain
- Higher flexibility for volatile purchase order quantity

Source:Deppe, G.; Lindemann, C.: „Deliverable D3.2 Defined scenarios that will be considered in the following project steps", Paderborn, 2013.

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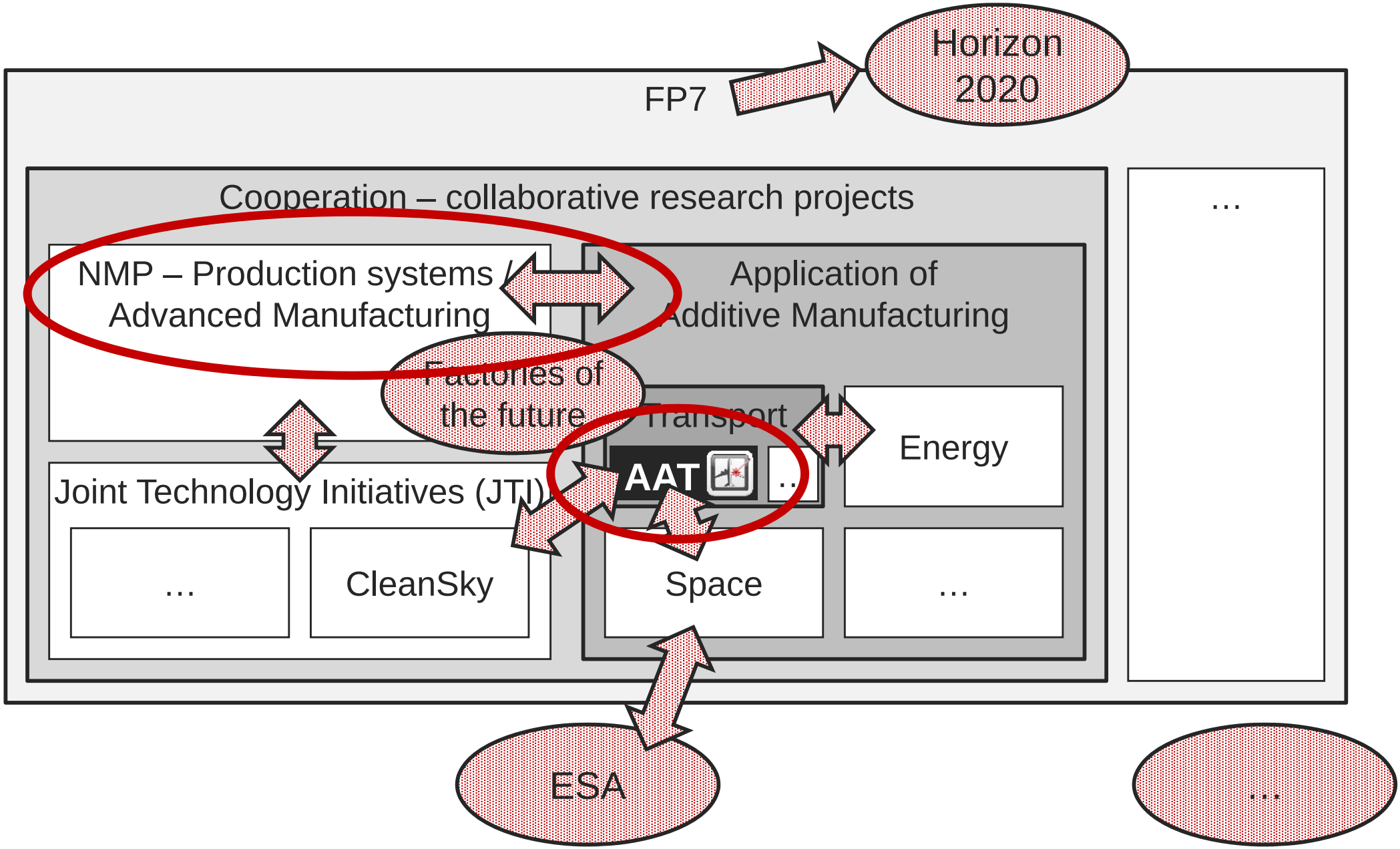
Research on related projects as a basis for strategic decisions



Many initiatives have been started…

- Keyword based EU database research – we found
  → 90 projects in total
    → 80 from FP7 Transport (including keywords like ‘additive manufacturing’)
    → 10 from FP7 NMP (including keywords like ‘aeronautics’ or ‘air transport’)

- Most relevant ones are:
  - COMPAIR (Continuous health monitoring and non-destructive assessment of composites and composite repairs on surface transport applications)
  - VIBRATION (Global in flight health monitoring platform for composite aerostructures based on advanced VIBRATION based methods)
  - MODE (Maintenance on demand)
  - AMAZE (Additive Manufacturing Aiming Towards Zero Waste & Efficient Production of High-Tech Metal Products)
  - MERLIN (Development of Aero Engine Component Manufacture using Laser Additive Manufacturing)
  - SARISTU (Smart Intelligent Aircraft Structures)

Source: Rodríguez, M.G.: „Deliverable D10.2 Dissemination Plan”, Madrid, 2014.

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Summary and outlook

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RepAIR: AM as an enabler for multidisciplinary innovation

Supply chain

AM (SLM)

Production

AM (EBM)

- **Multidisciplinary team** and knowledge
- **Collaborative approach** for designing and manufacturing aircraft parts
- Additive Manufacturing (AM) as a **key enabling technology** for Maintenance, Repair & Overhaul (MRO) of aircrafts
- Information Technology (IT) as a **supporting technology** for process oriented and innovation driven integration
- Demonstrations (parts/case studies) to bridge **research and innovation** in Aeronautics and Air Transport (AAT)

Design

AM (LC)

Costing

AAT

Certification

MRO

IT

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Summary and outlook

- Research and innovation needs to target both
  - the technology (in terms of advanced manufacturing and new production systems) and
  - the application domain (here in terms of transport/aviation)

- Process models, requirements specifications and scenarios are enablers to utilize the potential of AM for aircraft MRO
- Fulfilling certification requirements seems to be the key factor for the future
- Cost and build rates need to be improved to reach a level of competitiveness in comparison with conventional manufacturing/supply chains

- The team will demonstrate results at Euromold
- Strong interest in liaison with EU projects

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Thank you very much!

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RepAIR

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This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605779.

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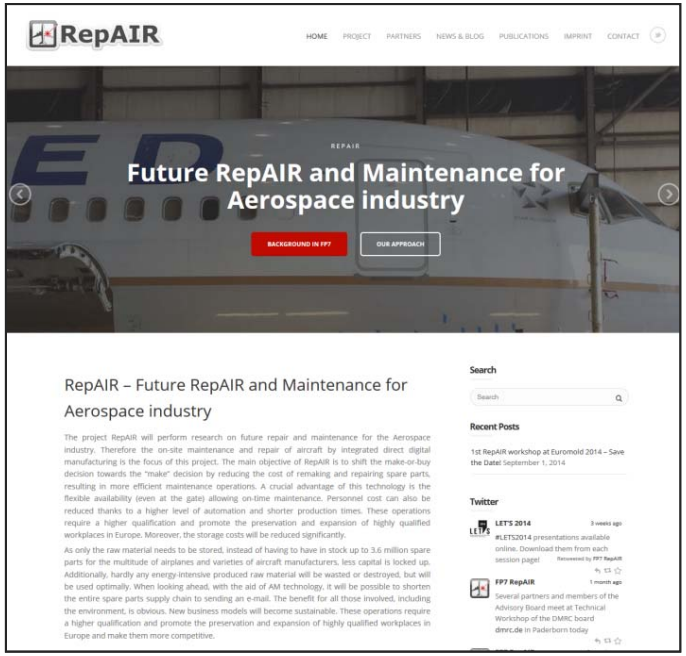
Get in touch with RepAIR



- RepAIR Website @ **www.rep-air.eu**
  - Overall Objectives
  - Role of the Partners
  - Where to meet RepAIR
  - Publications
  - Contact

- RepAIR @ linkedin.com and twitter
  - Discussion about content
  - Project news
  - Announcement of where to find RepAIR
  - Announcement of publications

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