SEVENTH FRAMEWORK PROGRAMME

Aerodynamic Optimization of a Two-Dimensional Two-Element High Lift Airfoil with a Smart Droop Nose Device

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Motivation

Year 2001:
European Aeronautics
A vision for 2020

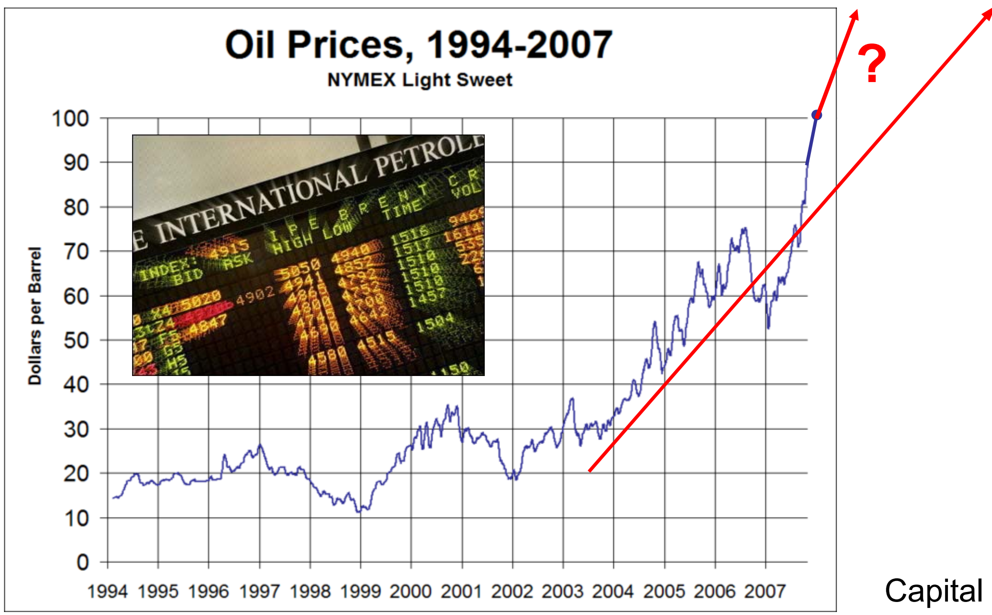
→ Advisory Council for Aeronautics Research in Europe (ACARE)

„A reduction in perceived noise to one half of average levels“

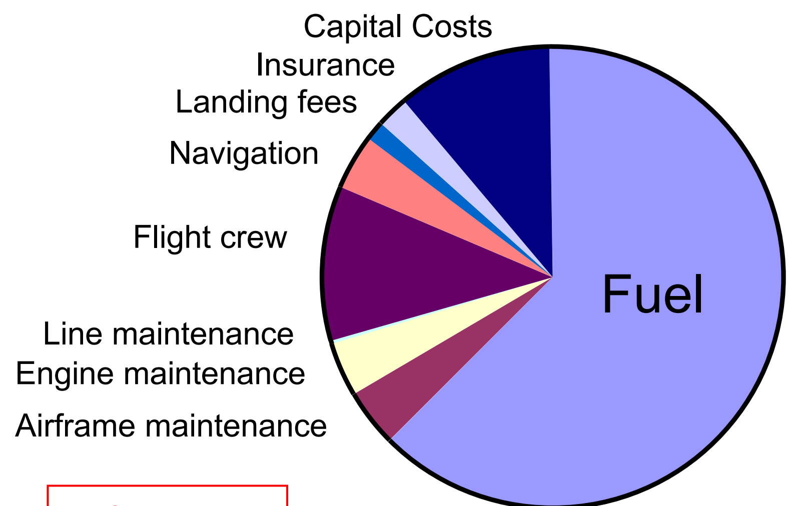
„A 50% cut in CO_2 emissions per passenger kilometre (which means a **50% cut in fuel consumption** in the new aircraft of 2020) and an 80 % cut in nitrogen oxide emissions“

L/R DOC Sensitivity for Fuel Price Development

Oil price hit 100 $/Barrel for the first time on Jan 3rd 2008 !

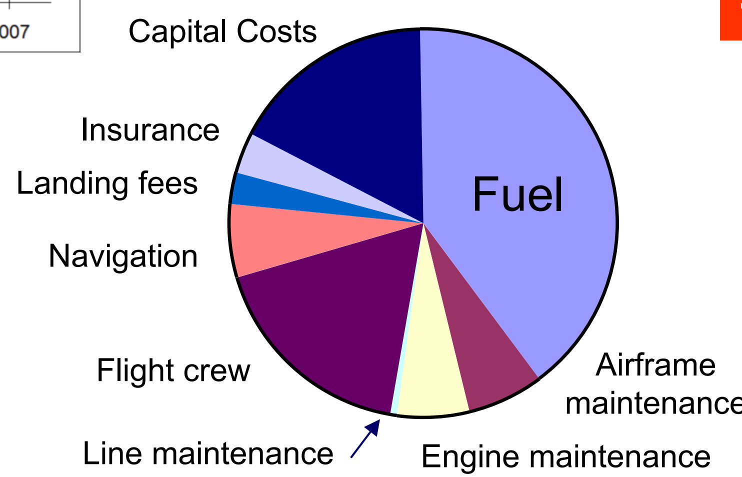


5 $/USgal



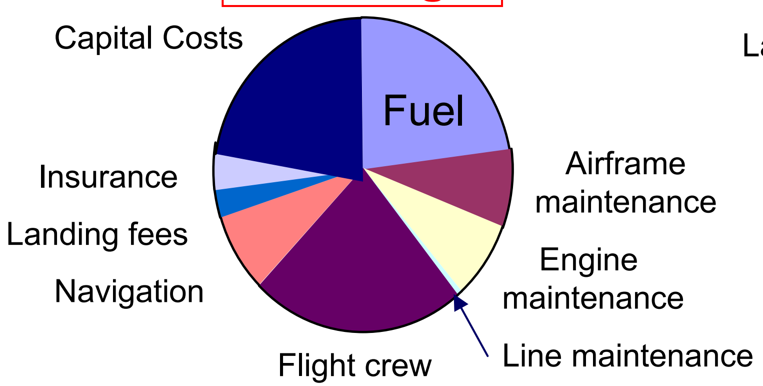
+104 %

2 $/Usgal



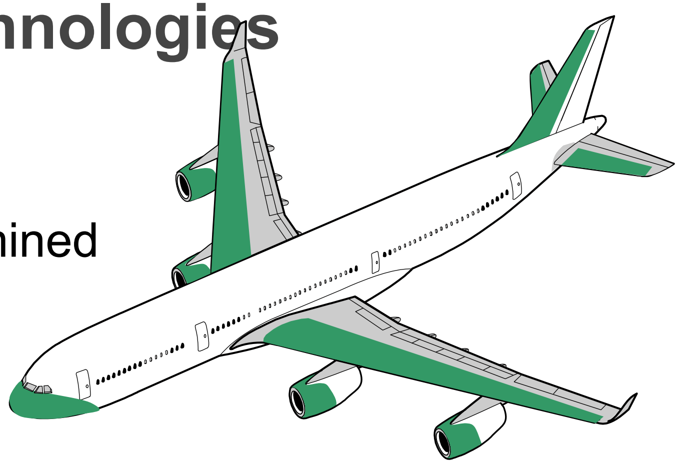
+28 %

0.9 $/Usgal



based on A330-200 type a/c with *1990* technology

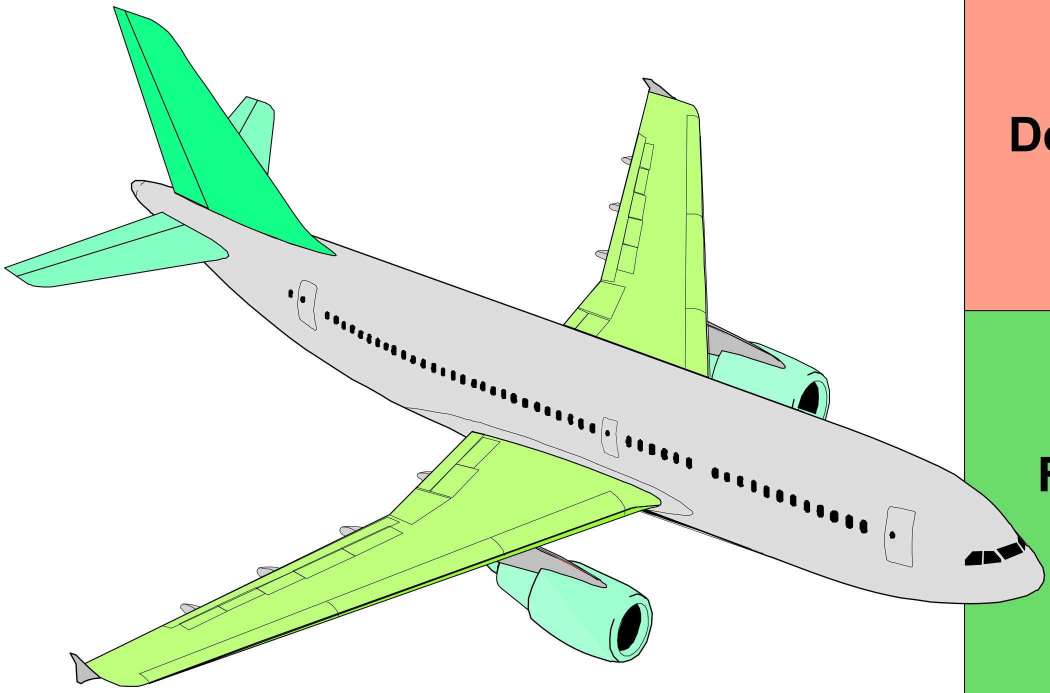
Motivation – Drag Reduction Technologies

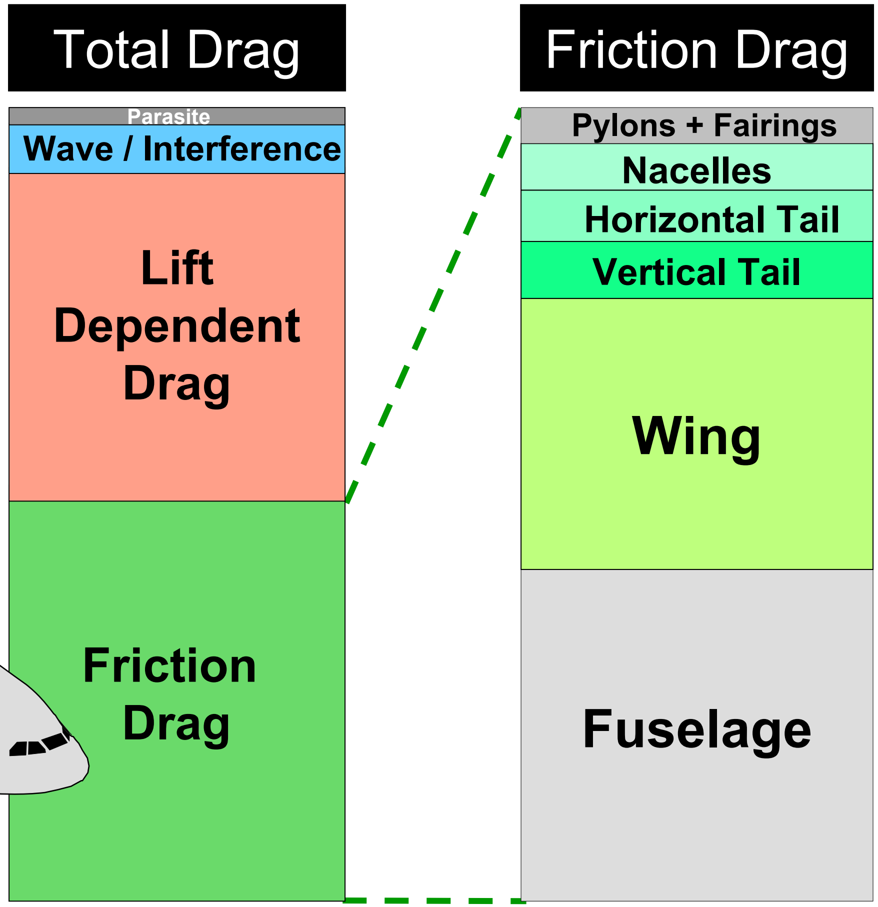


- Many technologies have been and are examined
  - Laminar flow,
    distributed roughness, bumps,
    dimples, plasma, synthetic jets, ...
- Laminar flow technology is the only single technology with the potential to reduce drag and hence fuel consumption considerably.
- Snowballing effects add to the effect of pure drag reduction and pay off in lower mass.
- NLF or HLF with simplified suction systems are feasible.
- Operational aspects (loss of laminarity) can be handled similar to ETOPS.
- The potential of laminar flow technology is big:
  – 15 - 20% overall aircraft drag reduction feasible

Drag Reduction – Where ?

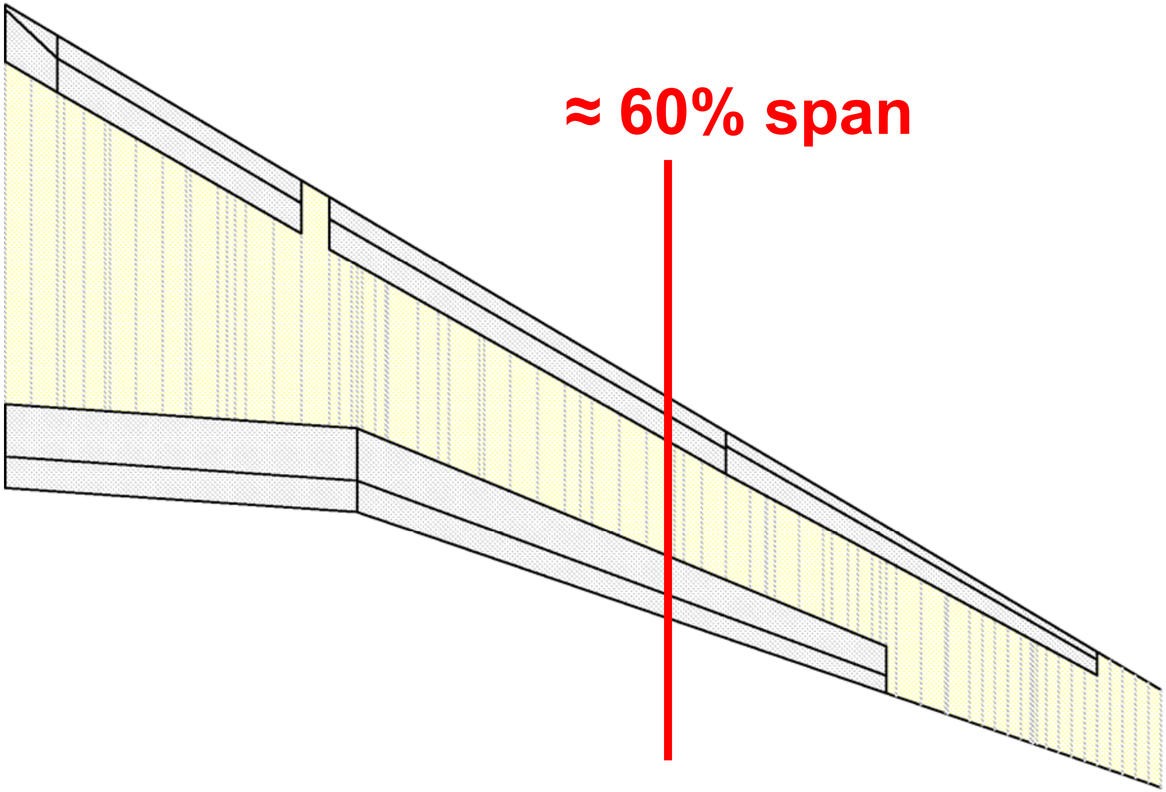
Drag distribution on aircraft level





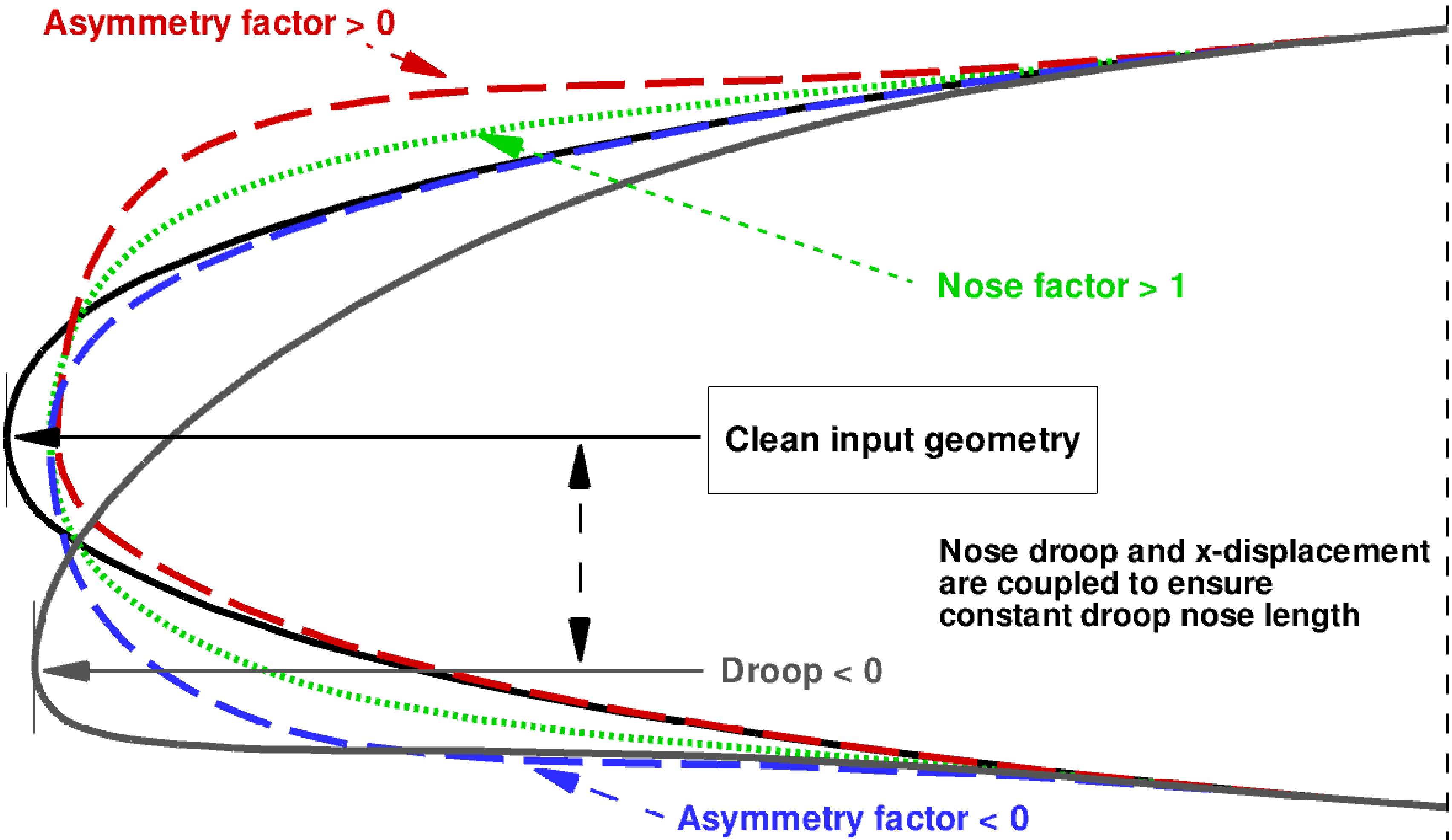
> **Wing offers** (besides fuselage) **highest potential for friction drag reduction**

Model



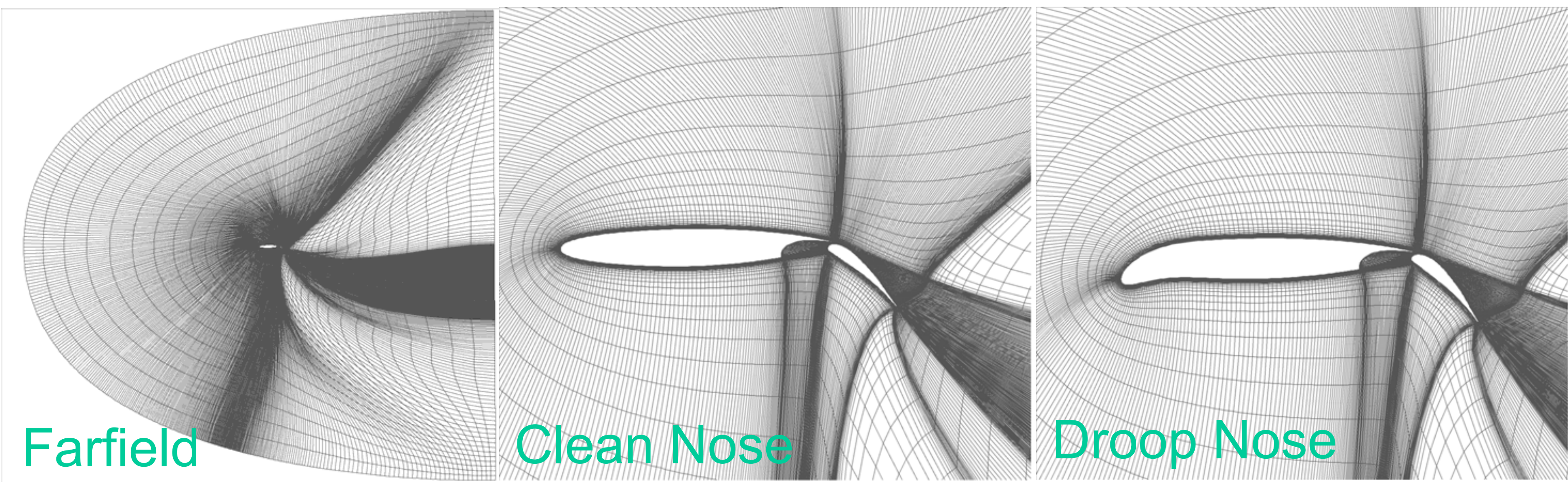
Flügel Neuer Generation = New Generation Wing

Parameterization



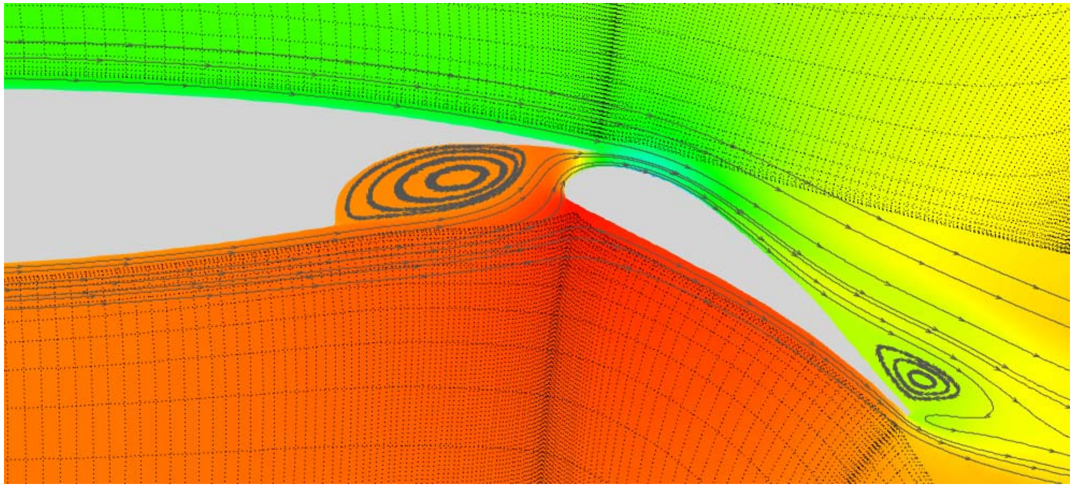
Numerical Setup - Mesh

- Structured grid generator MegaCads
- Parametric grid setup allows deformation of mesh during optimization (clean nose -> droop nose)
- 65,200 nodes in 16 blocks



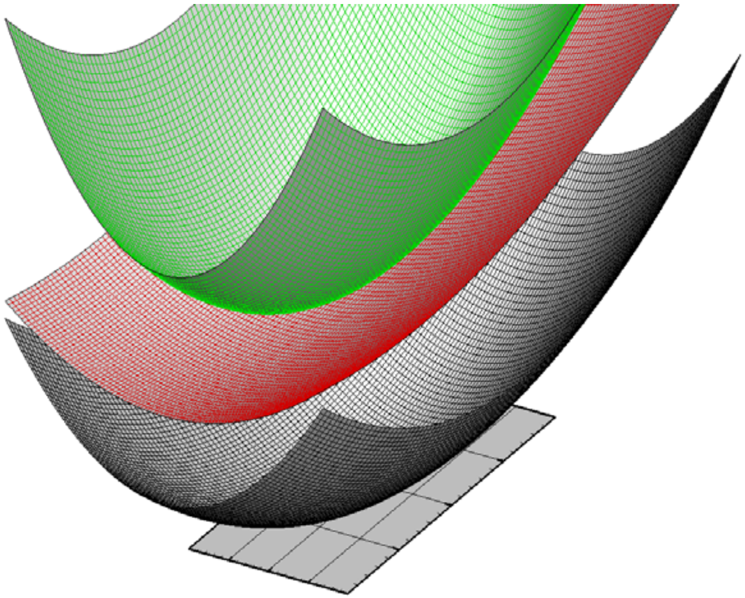
Numerical Setup – Flow Solver

- Block Structured Flow Solver DLR FLOWer
- SAE – Spalart Allmaras Turbulence model with Edwards Modification
- Convergence Acceleration (3w Multigrid Cycle, implicit residual smoothing)
- CFL number 9.5
- Automatic $C_{L,Max}$ routine for maximum lift calculations



Numerical Setup – Optimization Framework

- CHAeOPS is a DLR in-house optimization package
- Includes several optimization strategies (deterministic methods, gradient-based methods, stochastic models)
- Here: SUBPLEX (Rowan 1990)



Objective Function

Landing

$$f_{obj,L} = -C_{L,Max} - C_{L,\alpha=0}$$

Maximum Lift Performance

Lift Performance at lower AoA

Take Off

$$f_{obj,TO} = C_D\Big|_{1.13V_S} + C_D\Big|_{1.5V_S}$$

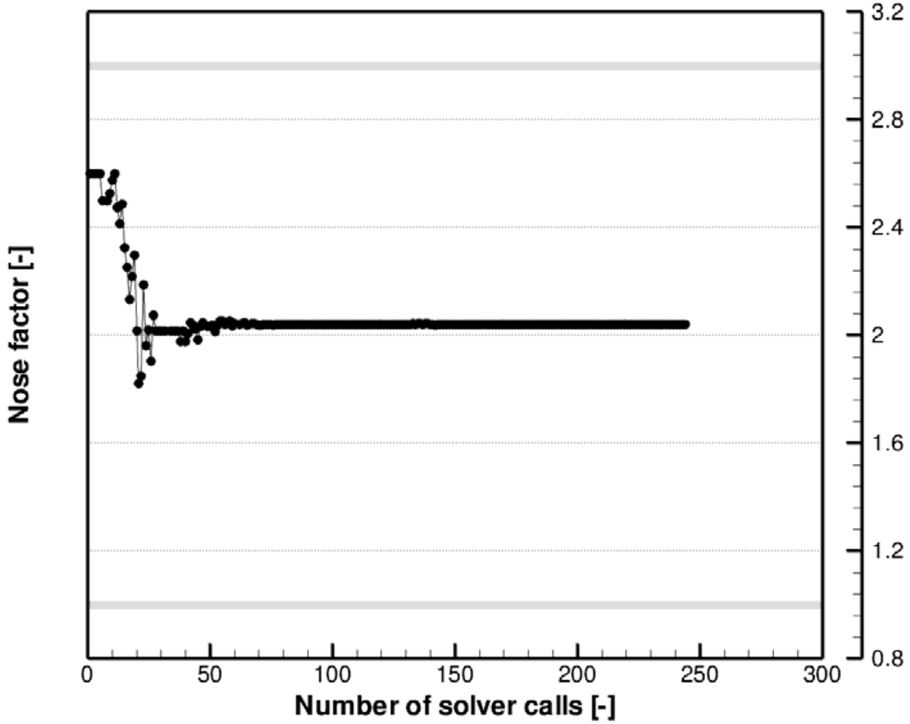
Design Point 1

Design Point 2

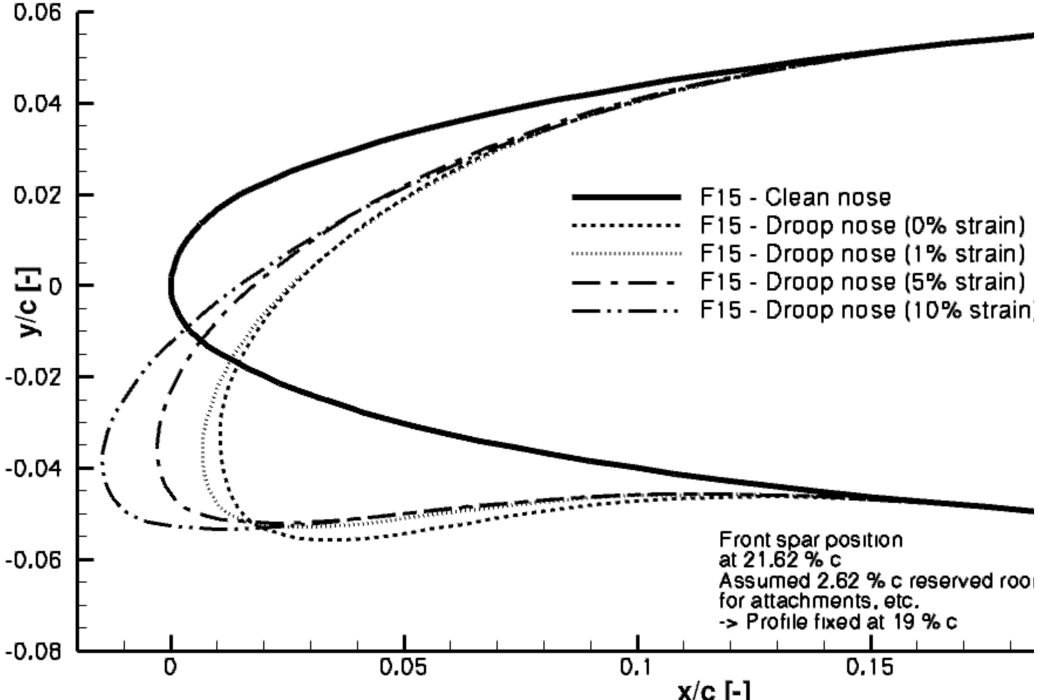
Minimum Drag at 2 Design Points during Take Off (Maximization of lift to drag ratio)

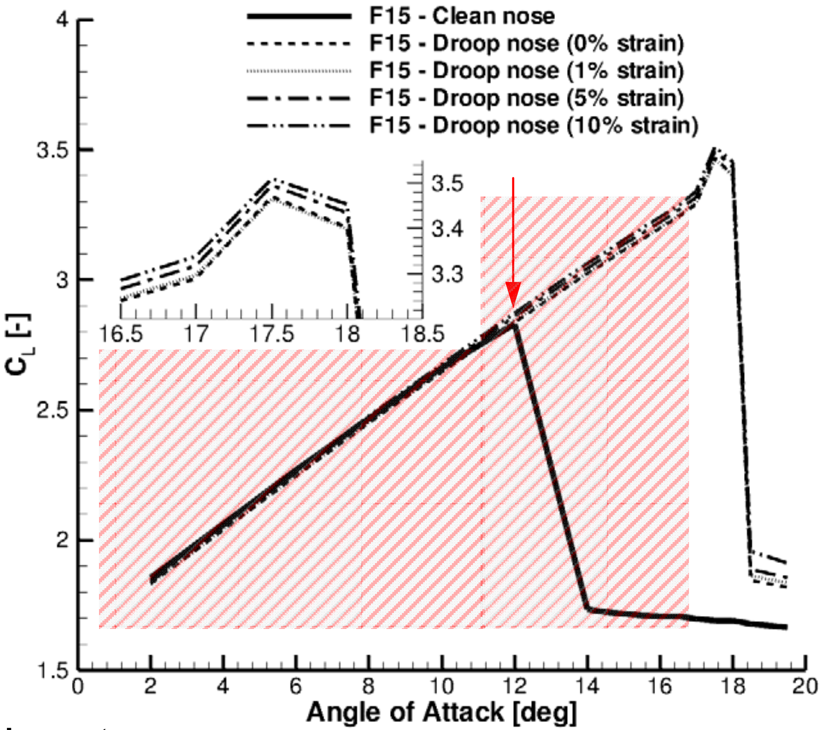
Results – Convergence Behaviour

- Convergence between 90 and 250 Iterations for the Optimizer
- Convergence is reached for a minimum difference of $1 \cdot 10^{-4}$ of the objective function within the last 10 Iterations



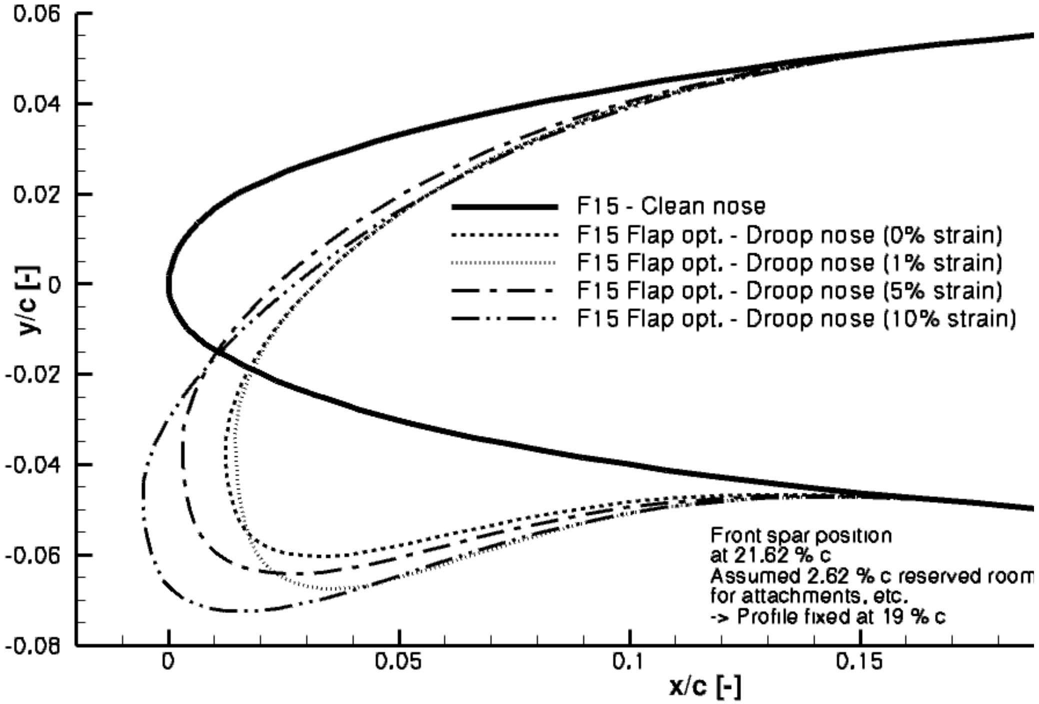
Results – Landing / Without Flap Setting

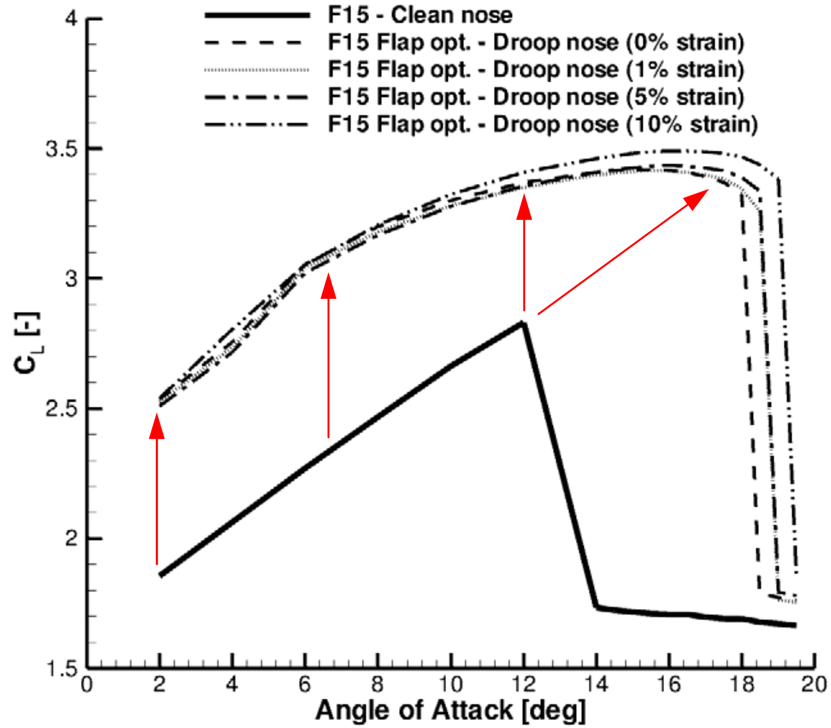




- Smooth bending of the droop nose for all strain rates
- Getting thinner for increasing strain rates (suction peak)
- Droop nose enhances α_{Max} and creates an abrupt wing stall (ill-posed initial flap setting)
- No lift gain for 1% strain; ΔC_L=0.02 for 5% strain; ΔC_L=0.04 for 10% strain

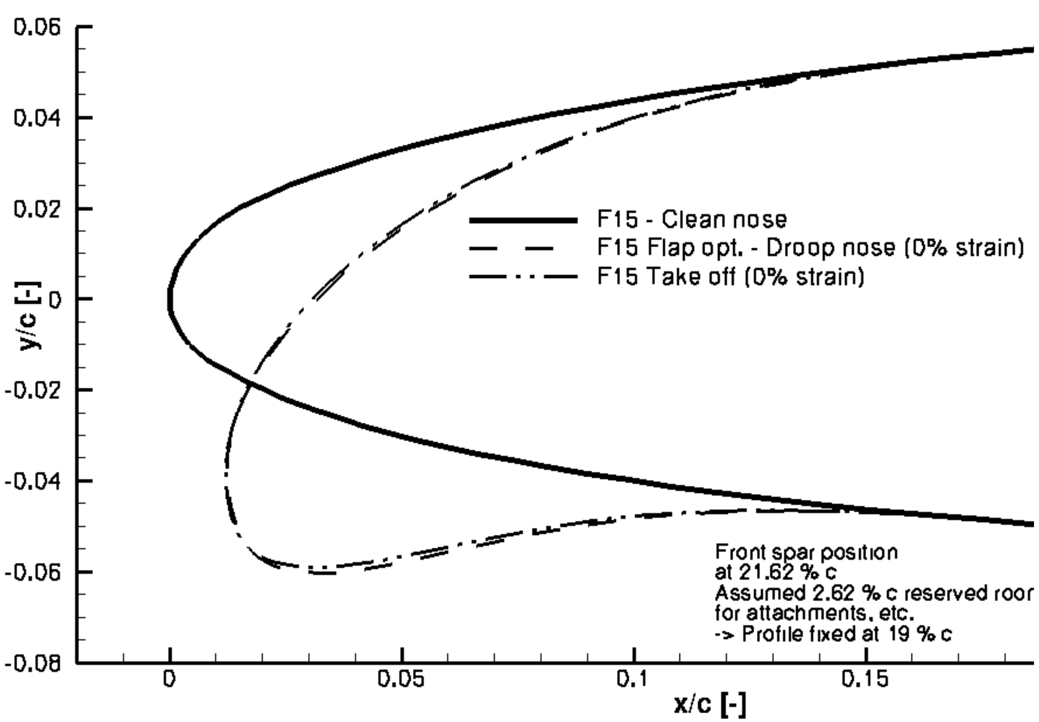
Results – Landing / With Flap Setting

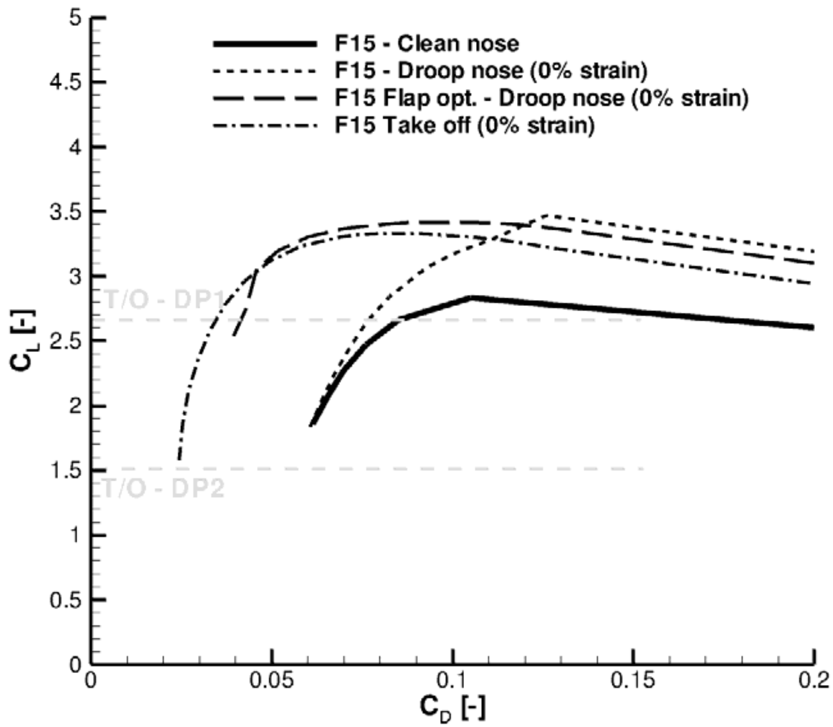




- Smaller gap (almost constant with diff. strain rates), larger overlap
- Larger droop of the leading edge compared to the one without flap setting opt.
- Noticeable improvement for lower Angles of Attack (as required in the objective)
- Improvement of $C_{L,Max}$ and α_{Max} for prolongation of the droop nose

Results – TakeOff / With Flap Setting





- Minimization of drag entails a reduction of the flap deployment angle
- Incidentally a similar droop nose shape for the take off setting
- Good high lift performance for all angles of attack, especially lower incidences
- Drag reduction at both design points

Conclusion

- Landing and Take Off settings were numerically optimized for a new smart droop nose high lift device using DLR Megacads, FLOWer and CHAeOPS
- The influence of material strain were investigated via four different strain rates (0, 1, 5, 10% prolongation)
- The Landing optimization is driven by lift optimization
- Keeping the initial flap setting constant leads to an unsatisfying final shape with large areas of separation on the flap independent of the angle of attack
- An inclusion of the flap setting parameters leads to an improved behaviour and a well adapted leading edge droop
- The take off setting is derived in a similar manner reducing drag at two design points
- The leading edge for take off is incidentally congruent to the landing equivalent

Outlook (from an Aerodynamic Point of View)

- Transfer Smart Structures to Laminar Wing Components (also addressed in SADE – HARLS wing)
- Still Room for Improvements for the Methods and Tools - Optimization Algorithms, Higher Order CFD Methods, Formulation of Target Function (addressed in EU project DeSiReH)
- Push Towards Forward Swept Wing Design

- Surface quality for CFRP materials
- Laminarity preservation for surface contamination (insect impact)
- Component integration (engines)
- …

Thank you for your attention …