A SMART LEADING EDGE ARCHITECTURE AIMED AT PRESERVING LAMINAR REGIME

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- an innovative approach → the '*morphing*'
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- two working modalities: '*self adaptive*' and '*motor aided*'
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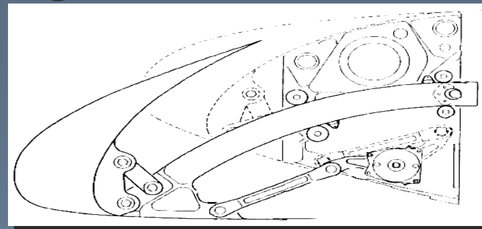
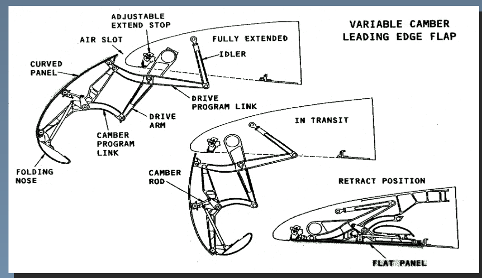
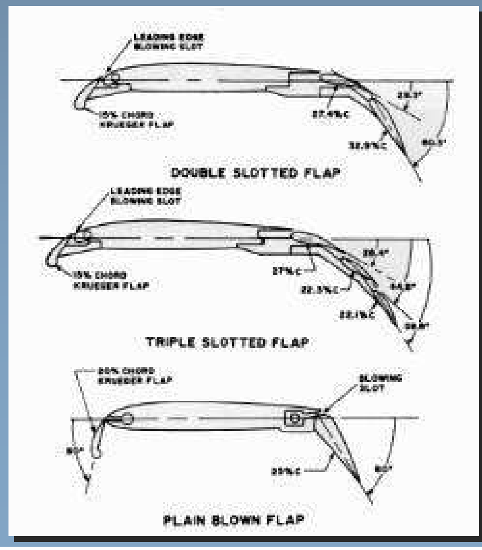
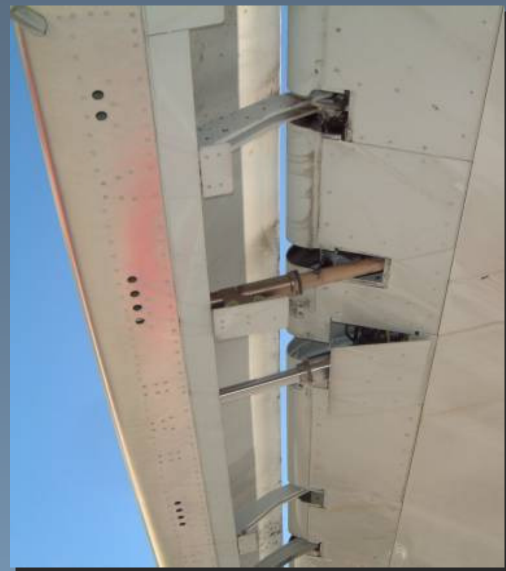
Traditional high lift devices → pros & cons









➢ Pros:

- curvature, chord increase
- flow energisation through the slots
- consequent High Lift improvement

➢ Cons:

- heavy actuation mechanisms (up to 50% of wing total weight)
- gaps induced discontinuities even in cruise condition
- Turbulence priming

Motivation of the work (2/3)

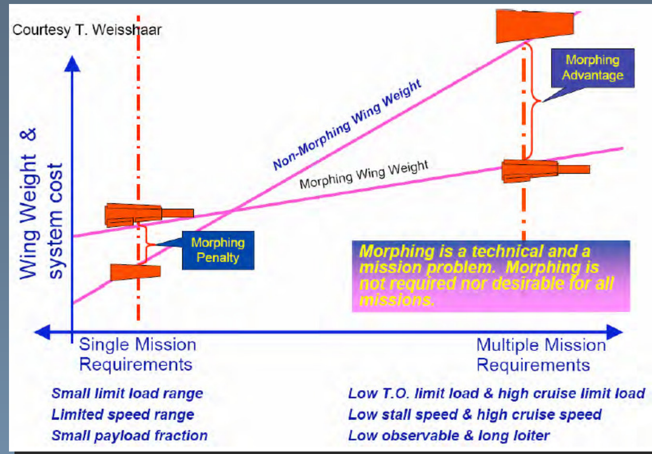
An innovative approach → the '*morphing*'

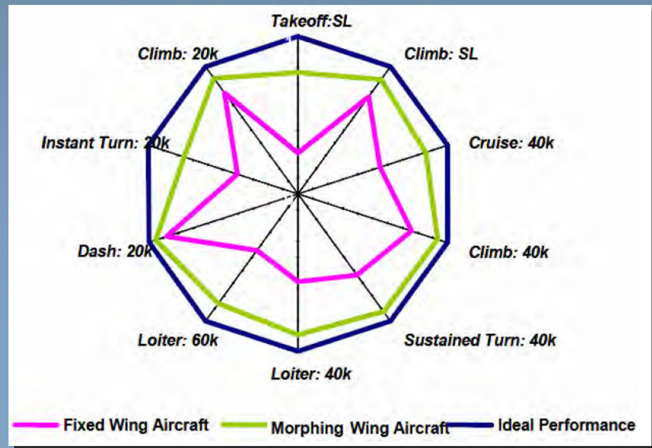
➢ Morphing:

- *μορφή, -ῆς, ἡ :* shape
- smooth and at same time large variations of geometry
- a paradox: the structure must morph (→ flexibility) and withstand aerodynamic loads (→ rigidity)
- technical solutions: '*Smart Structure and Material*' concept

➢ Advantages in aeronautics:

- adaptability → versatility to a wide variety of flight conditions
- multi-point → accommodation of even contradictory mission scenarios
- efficient → improvement of weight, volume, costs…





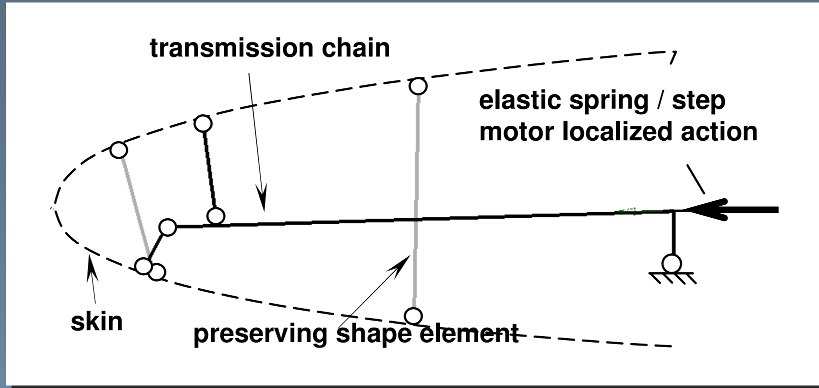
Objective of the work

- Design of a 'Smart Leading Edge' (SLE) architecture for:
  - High Lift generation
  - Laminar regime preserving for different flight conditions (cruise, take-off and landing)
- Innovation:
  - self-adaptive under external loads…

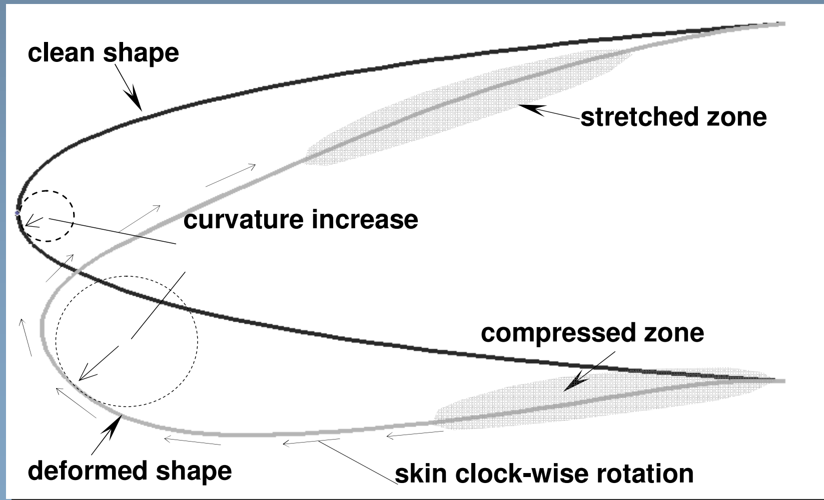
Strategy definition (1/3)

Internal compliant mechanism

- **The SLE is constituted by:**
  - a skin element → transmission of external load to the structure
  - an internal mechanism → actuation of deformation



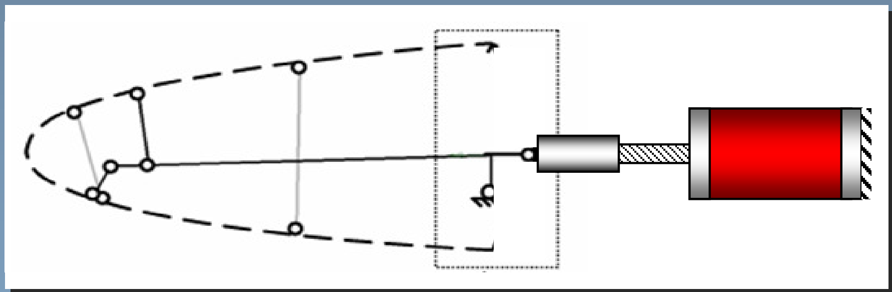
- **Internal cinematic chain design criteria:**
  - transmission of max vertical displacement
  - leading edge radius increase
  - no collapse or instability within the skin
  - aerodynamic shape maintenance



Two working modalities

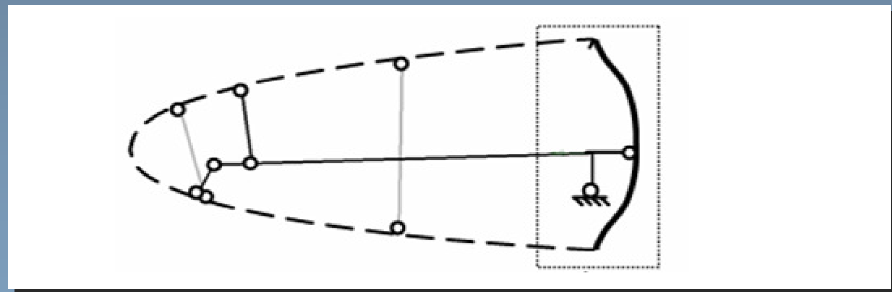
'*Motor aided*' configuration:

- the deformation is caused by an actuator (located in the wing box available space)
- actuator performance must guarantee deformed shape under external loads



'*Self-adaptive*' configuration:

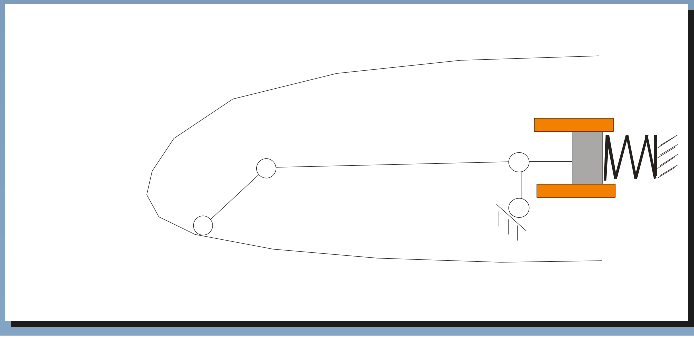
- the deformation is caused by a variable stiffness spring (locked and unlocked by a brake)
- spring rigidity is tuned on expected aerodynamic loads



'*Self adaptive*' flow chart

Strategy definition (3/3)

Action	Effect
The pilot switches on LE system	The springs, released, recover pre-deformation, moving nose down and system freezes this configuration
The aircraft accelerates on the runway and takes off	Lift increase
The aircraft reaches cruise condition: the pilot switches off the compliant systems	Nose unfrozen: initial condition recovery under the external aerodynamic loads and final freeze of the configuration



Action	Effect
The pilot acts on the elevator to increase the attitude	Lift increase
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The aircraft touches the ground and the systems unfreezes nose and flap	Under the external dynamic pressure nose and flap return to the undeformed condition
The system freezes nose and flap in the undeformed condition	The system is ready for future take off manoeuvres.

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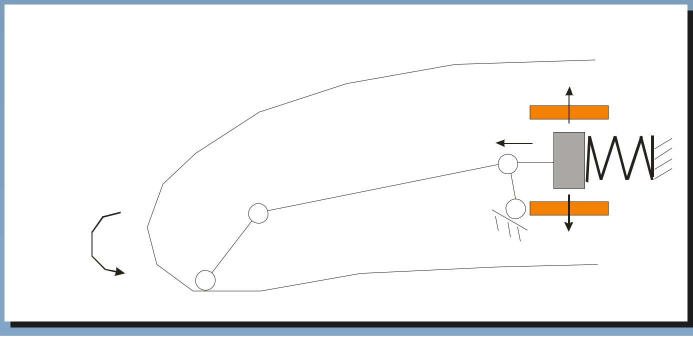

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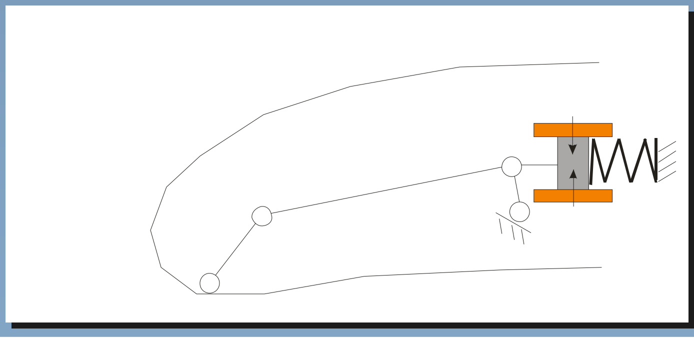

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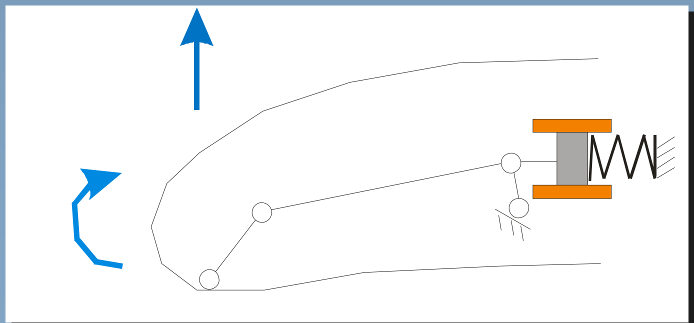

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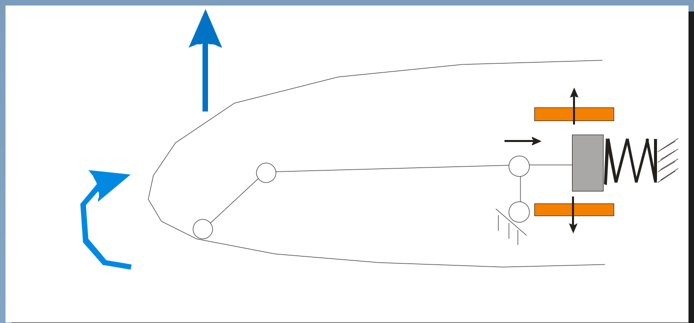

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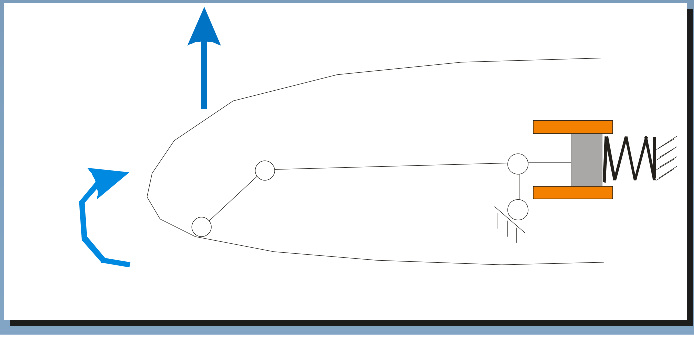

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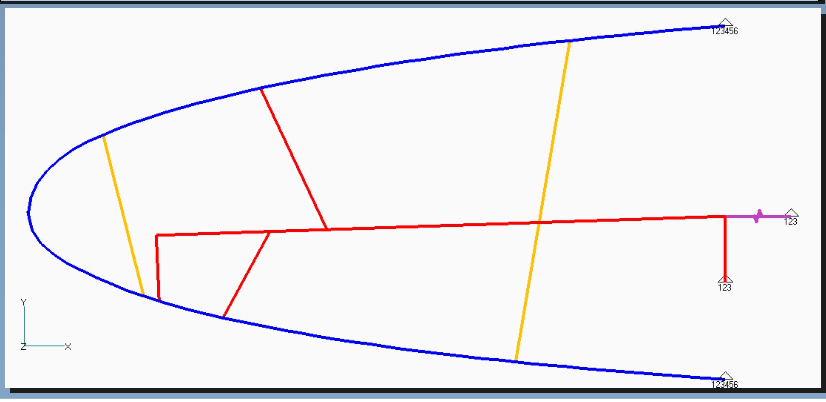
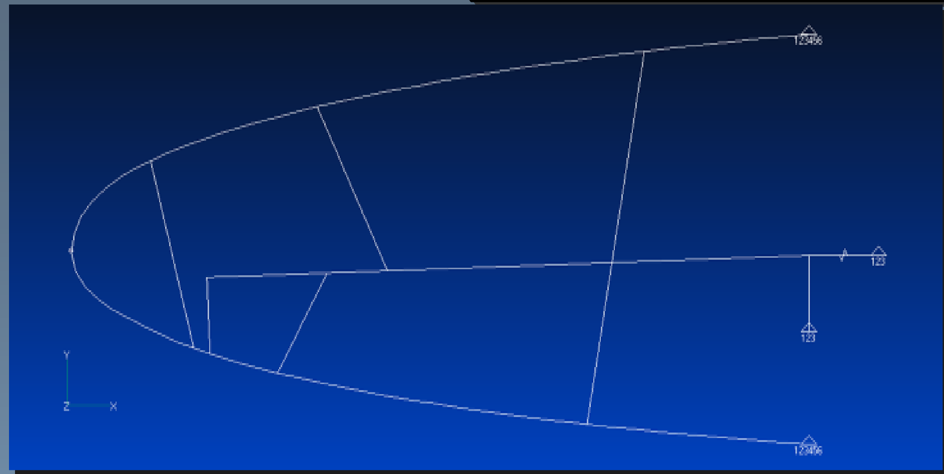
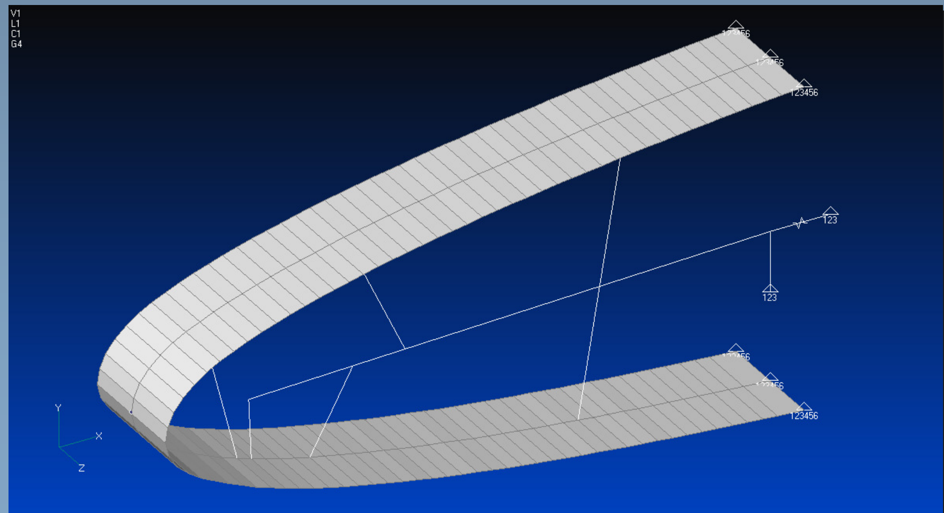
Finite Element Modeling (1:6 scaled)

Design and modeling (1/7)

FE entities	
Nodes number	283
Elements total number	195
Skin elements (MSC/Nastran CQUAD4)	178
Tie rods elements (MSC/Nastran CBEAM)	16
Spring element (MSC/Nastran CEALS2)	1
SLE geometry	
SLE chord	112 mm on a total chord of 500 mm
SLE span	20 mm
Skin features	
Tickness	0,25 mm
Materials: AISI 301 Stainless Steel	E=210 GPa ν=0,32 σ_u=800MPa
Tie rods features	
Equivalent area	50,27 mm^2
Inertia moments	$I_1=I_2=201mm^4$
Material 7075 T6 Aluminium Alloy	E=70 GPa ν=0,32 σ_u=472MPa







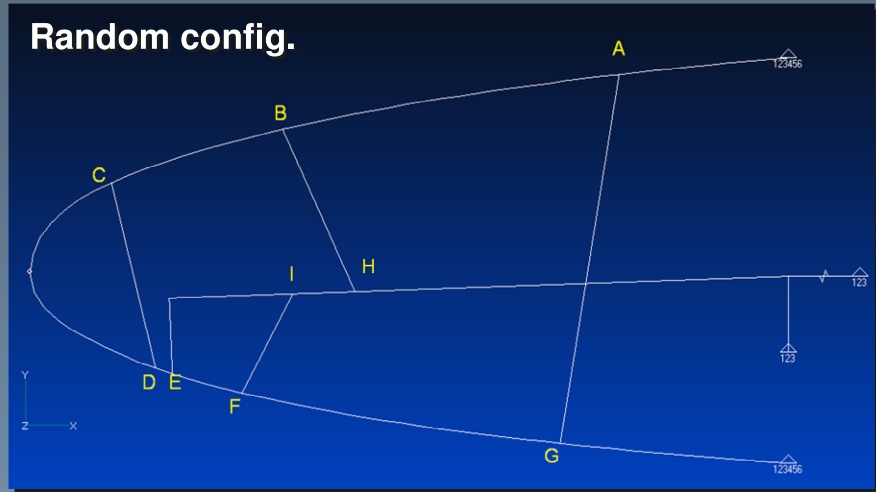
Design and modeling (2/7)

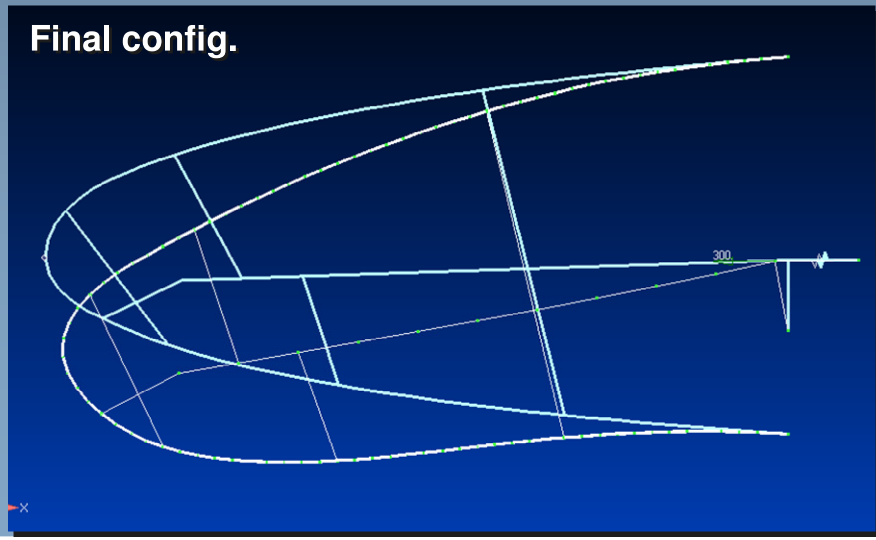
Optimization

- **Target:**
  - achieve preliminary aerodynamic requirements: vertical displacement, leading edge radius

- **Constraints:**
  - allowable stress not exceeded
  - reasonable moving limits for rods extremes

- **Design variables:**
  - actuator force: 1
  - rods extremes position (letters from "A" to "I"): 14
  - parameters total number: 15

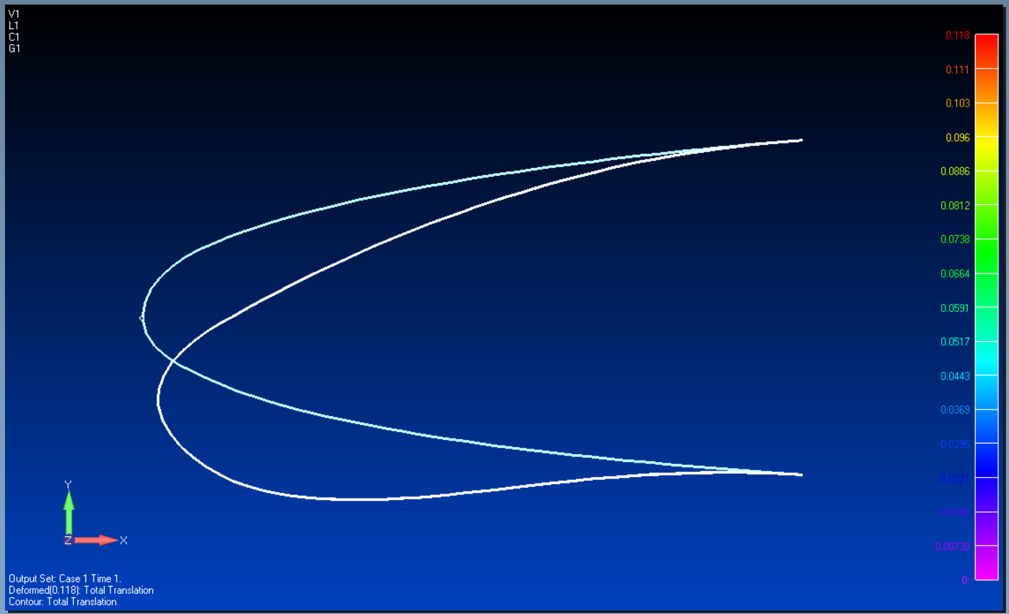


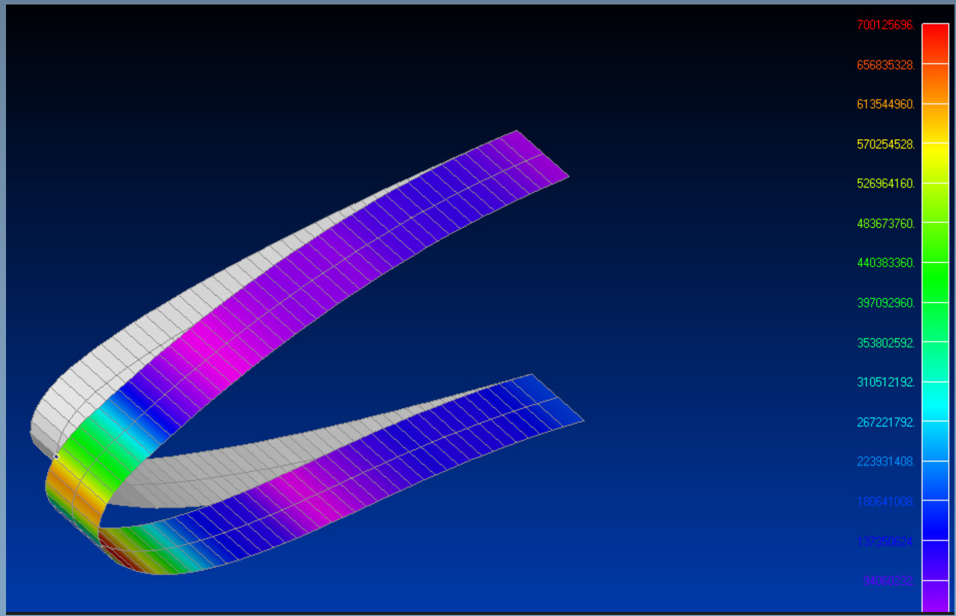


Design and modeling (3/7)

Finite Element Modeling (1:6 scaled, skin thickness: 0.25mm)

- max displacement, droop nose: 16 mm (14.3 % of the SLE chord, 3.2% of the total chord);
- max stress (within the skin): 700 MPa



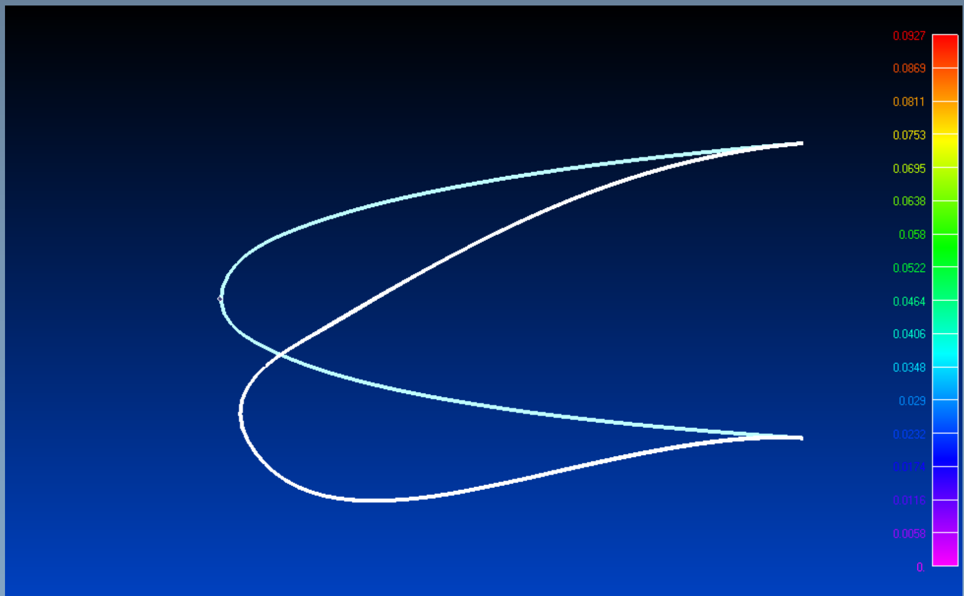


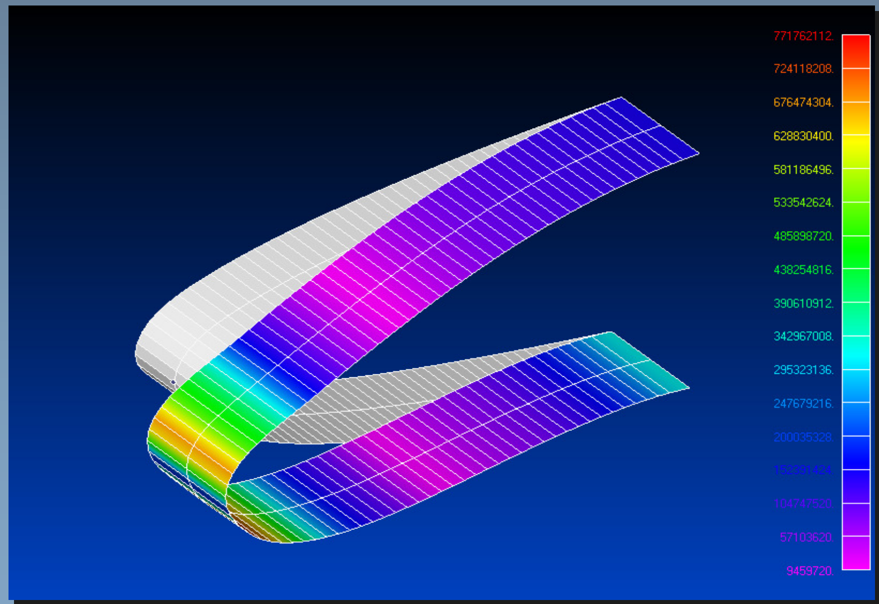
Design and modeling (4/7)

Finite Element Modeling (real size, skin thickness: 2.0 mm)

- max displacement, droop nose: 118 mm (13.2 % of the SLE chord, 3.1% of the total chord);

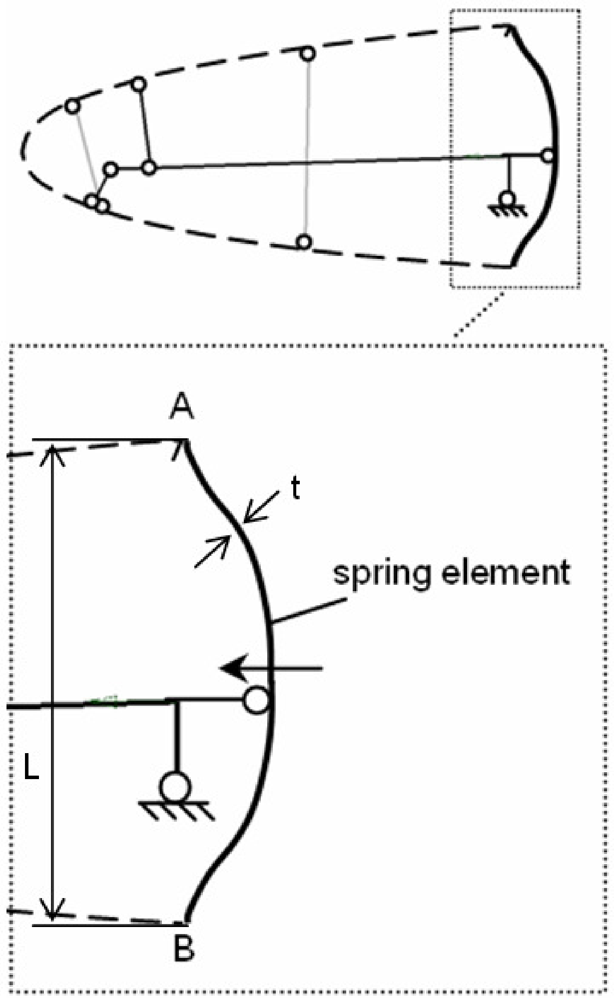
- max stress (within the skin): 700 MPa





Design and modeling (5/7)

Spring identification for ‘*self adaptive*’ modality



1:6 scaled	
Re	7,00E+06
M	0,6
V inf (m/s)	210
Applied force (N)	1700
Applied force per 1 mm span (N/mm)	85
Point displacement (m)	0,0020617
Elastic constant (N/m per mm span)	41228

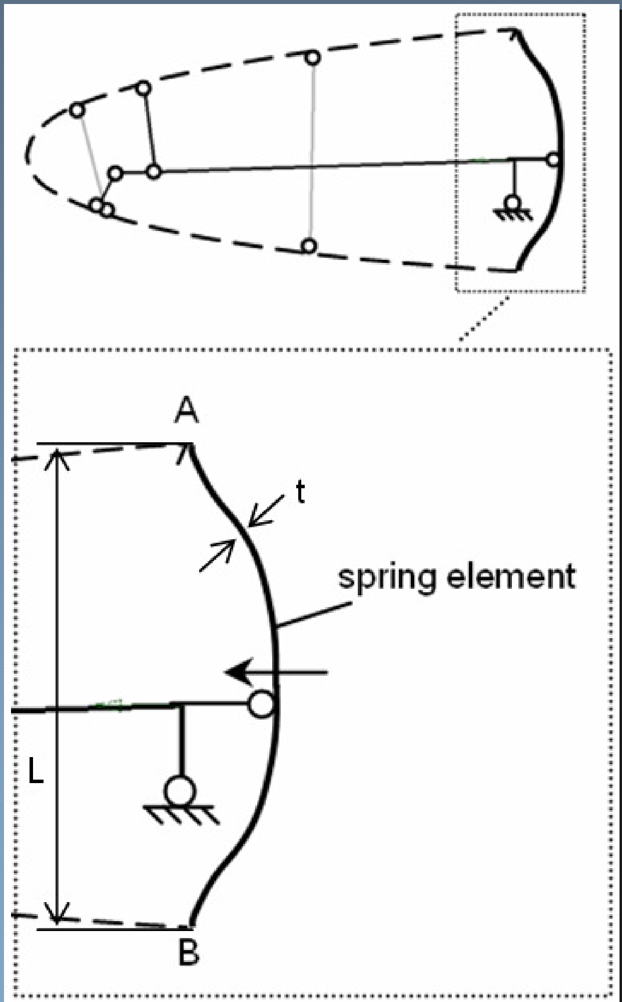
Spring features	
Shape	Thin long plate
Material	Alluminum alloy
Constraint condition	Clamped-clamped
Length (mm)	0,055
Thickness (mm)	1,8
Depth (mm)	1,0

1:6 scaled	
Re	1,00E+06
M	0,08
V inf (m/s)	29,2
Applied force (N)	110
Applied force per 1 mm span (N/mm)	5,5
Point displacement (m)	0,001905
Elastic constant (N/m per mm span)	2887

Spring features	
Shape	Thin long plate
Material	Alluminum alloy
Constraint condition	Clamped-clamped
Length (mm)	0,055
Thickness (mm)	0,8
Depth (mm)	1,0

Design and modeling (6/7)

Spring identification for '*self adaptive*' modality



Real sized	
Re	7,00E+06
M	0,075
V inf (m/s)	25,5
Applied force (N)	5000
Applied force per 1 mm span (N/mm)	31,25
Point displacement (m)	0,021547
Elastic constant (N/m per mm span)	**1450**

Spring features	
Shape	Thin long plate
Material	Alluminum alloy
Constraint condition	Clamped-clamped
Length (mm)	0,44
Thickness (mm)	4,8
Depth (mm)	1,0

Real sized	
Re	1,37E+06
M	0,14
V inf (m/s)	50
Applied force (N)	10000
Applied force per 1 mm span (N/mm)	62,5
Point displacement (m)	0,020355
Elastic constant (N/m per mm span)	**3070**

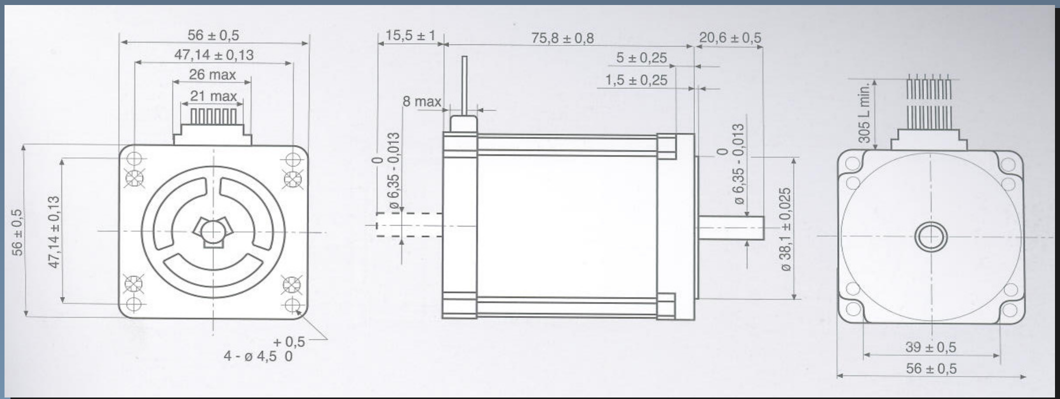
Spring features	
Shape	Thin long plate
Material	Alluminum alloy
Constraint condition	Clamped-clamped
Length (mm)	0,44
Thickness (mm)	6,2
Depth (mm)	1,0

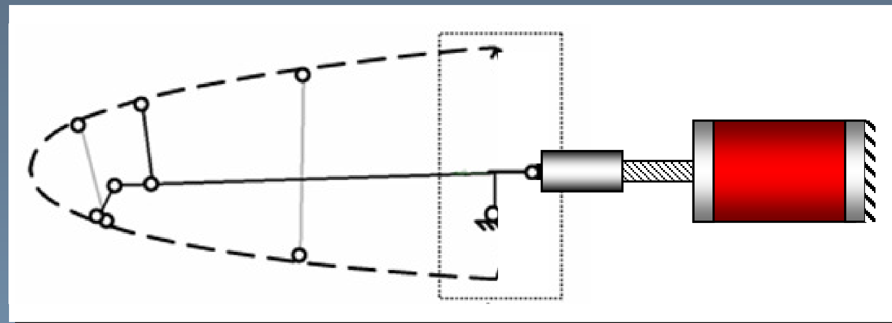
Real sized	
Re	2,19E+06
M	0,23
V inf (m/s)	80
Applied force (N)	20000
Applied force per 1 mm span (N/mm)	125
Point displacement (m)	0,017566
Elastic constant (N/m per mm span)	**7116**

Spring features	
Shape	Thin long plate
Material	Alluminum alloy
Constraint condition	Clamped-clamped
Length (mm)	0,44
Thickness (mm)	8,1
Depth (mm)	1,0

Design and modeling (7/7)

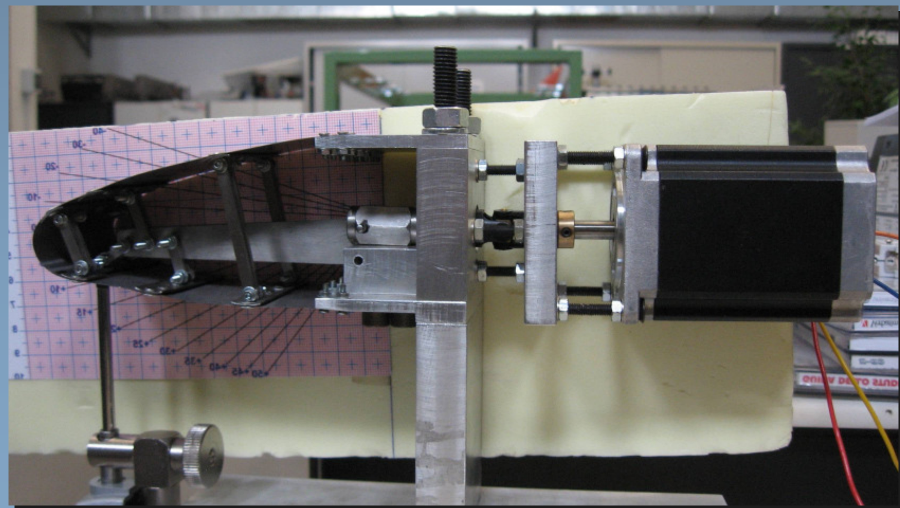
Actuator identification for ‘*aided motor*’ modality





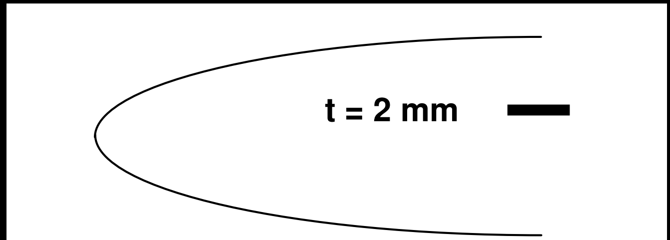
CARATTERISTICHE

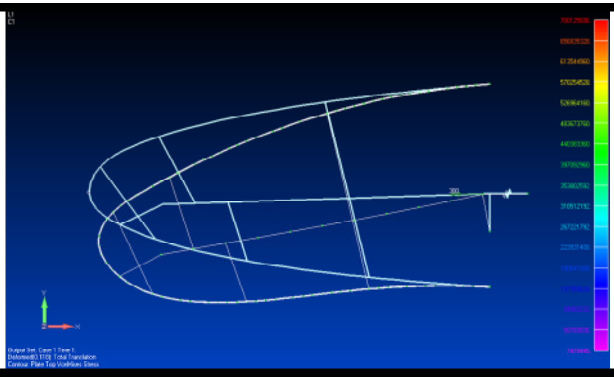
MODELLO		103 - H7126 - 0140	103 - H7126 - 0740 (103 - H7126 - 0710)	103 - H7126 - 1740 (103 - H7126 - 1712)
ANGOLO DI PASSO - TOLLERANZA		1,8° ± 0,09°	1,8° ± 0,09°	1,8° ± 0,09°
CORRENTE NOMINALE BIPOLARE	(Amp)	0,75 (*)	2,2 (*)	4
CORRENTE NOMINALE UNIPOLARE	(Amp)	1	3	
RESISTENZA DI FASE A 25°	(Ohm)	8,6	0,9	0,48
INDUTTANZA DI FASE	(mH)	19	2,2	2,2
COPPIA DI TENUTA BIPOLARE	(Ncm)	165	165	165
COPPIA DI TENUTA UNIPOLARE	(Ncm)	130	130	
MOMENTO D'INERZIA ROTORE	(Kgm ^{2} x 10 $^{-7}$)	360	360	360
ACCELERAZIONE TEORICA	(rad x sec.$^{-2}$)	45800	45800	45800
FORZA CONTRO ELETTRO MOTRICE	(V/Krpm)	92	31	31
PESO	(Kg)	1	1	1



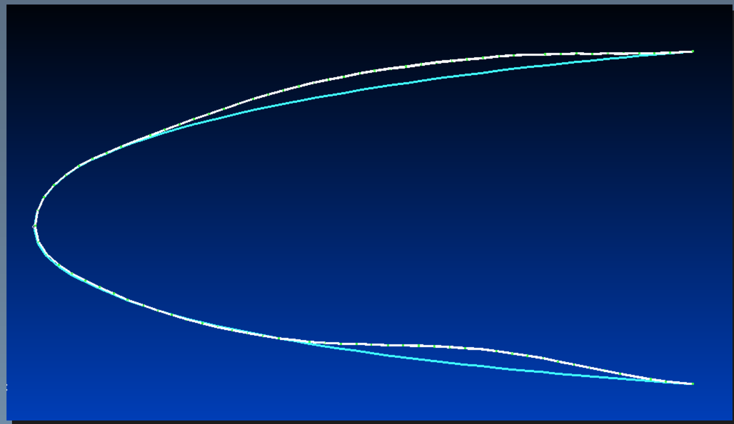
Morphing performance

Isotropic constant thickness skin





- Max vertical displacement: 3.1%
- Stress limit: 700 MPa
- Shape preserving under aerodyn. loads: 0.056% of the chord



Shape deviation (amplified)

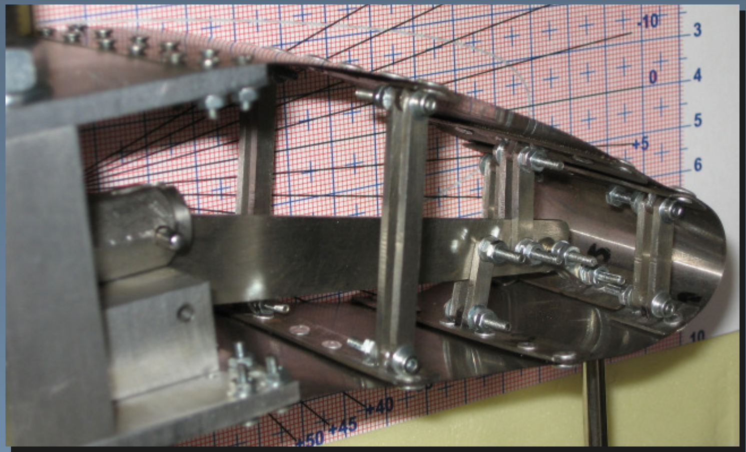
	1:6 scaled model	Real sized model
Max displacement	16 mm (14.3% of LE zone, 3.2% of total chord)	118 mm (13.2 % of LE zone, 3.1% of total chord)
Max stress (within the skin)	700 MPa	700 MPa
LE radius increase	≈70%	≈70%

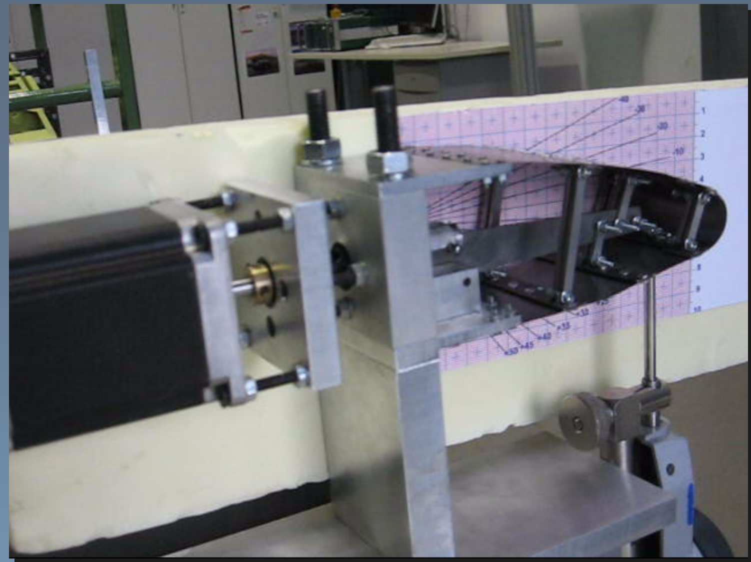
Conclusions

- **A short account on traditional high lift devices, pros and cons**
- **The morphing approach, possible applications and expected advantages**
- **Motivation of the work : design of a morphing device for a smooth (laminar preserving) droop nose effect**
- **Description of selected architecture and definition of two working principles: ‘*self adaptive*’ and ‘*motor aided*’**
- **Design and modeling → FE non linear approach:**
  - **spring identification for ‘*self adaptive*’ modality**
  - **actuator identification for ‘*aided motor*’ modality**
- **Discussion on device performance: vertical displacement, LE radius increase, shape keeping**

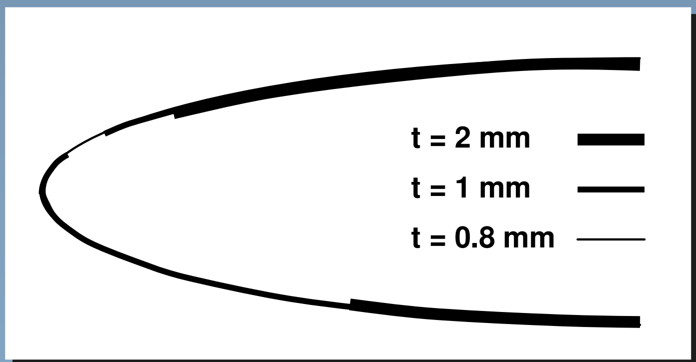
Related act. and next steps (1/2)

➢ 1:6 demonstrator realization and testing

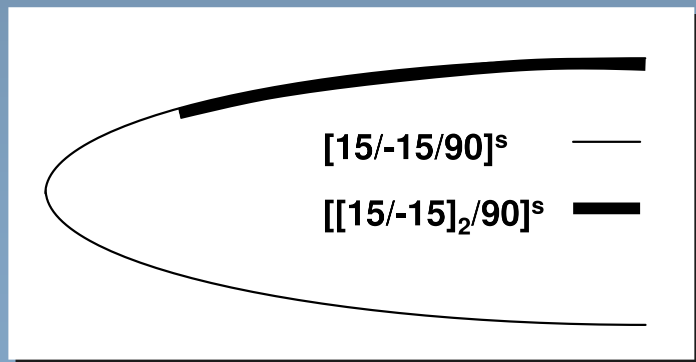




➢ Investigation on different skin typologies:



variable isotropic skin

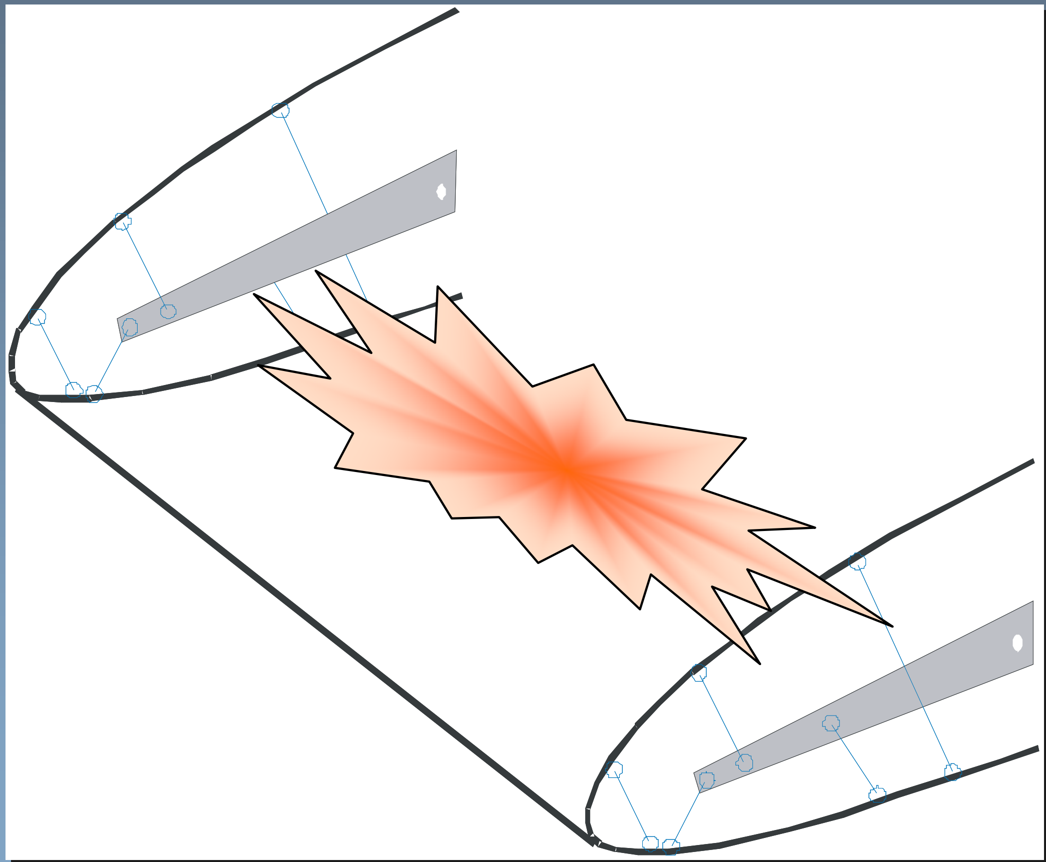


Fiber-glass laminate with variable stack sequence

Related act. and next steps (2/2)

➢ Real scale optimized demonstrator: design, realization and testing

- high actuation forces required towards chord-wise direction;
- better skin thickness distribution for stress alleviation and higher morphing performance
- a novel architecture modified to reduce actuation forces has been conceived and is under manufacturing;
- a dedicated skin solution has been taken into account



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