Project Activities and Main Results of the Second Year

UNIVERSITÀ DI PISA

According to the project objectives during the second year have been developed the **design,** the **manufacturing** and the **testing phase of the Future-Wing Unit** (a small scale model) moreover **FSI analyses have been carried out on a Future-Wing model**, a **numerical model of the complete Future-Wing Aircraft** has been constructed and analyzed and finally the **Flight Simulator of a Future-Wing Aircraft has been completely developed and tested**.

Project Activities and Main Results of the Second Year

- **Numerical study of the Future-Wing Unit *(….)***

  Preliminary Analyses of morphing wing sections (modification of the skeleton curvature)

  Preliminary FE analyses of the Future Wing Unit

  Design of two distinct technical solutions for the Future Wing Unit

  Design of the FW-Unit-1 (technical drawings)

- **Manufacturing of the Future Wing Unit 1 *(…)***

- **Numerical analyses of morphing wing sections *(…)***

  Model and FSI analyses of a Reference Wing section (aileron-wing section)

  Model and FSI analyses of a Morphing Wing section (piezo-wing section)

  Discussion of the results

Project Activities and Main Results of the Second Year

- **3D Numerical models and FSI analyses: the Reference Wing and the Future Wing *(…)***

  Model and FSI analyses of the Reference Wing (aileron-wing)

  Model and FSI analyses of the Morphing Wing (piezo-wing)

  Comparison of the aeromechanical performances of the wings (a rolling maneuvre)

- **3D Numerical models and aeroelastic analyses of a Future-Wing aircraft *(…)***

  Model and aeroelastic analyses of the Reference Aircraft

  Model and aeroelastic analyses of the Future Wing Aircraft (with morphing wings)

  Comparison of the aeromechanical performances of the aircraft's models

- **Computer Aided Creative Design concept *(…)***

  Dynamic control of the geometry of morphing three-dimensional wings

Project Activities and Main Results of the Second Year

- **Final implementation of the flight simulator *(…)***

  The Reference aircraft (Piaggio P180 Avanti)

  The Future Wing aircraft (a thinking of the Piaggio P180 Avanti with morphing wings)

- **Set up of the electronic control system for the Future Wing Unit *(…)***

- **Test of the Future Wing Unit 1 *(…)***

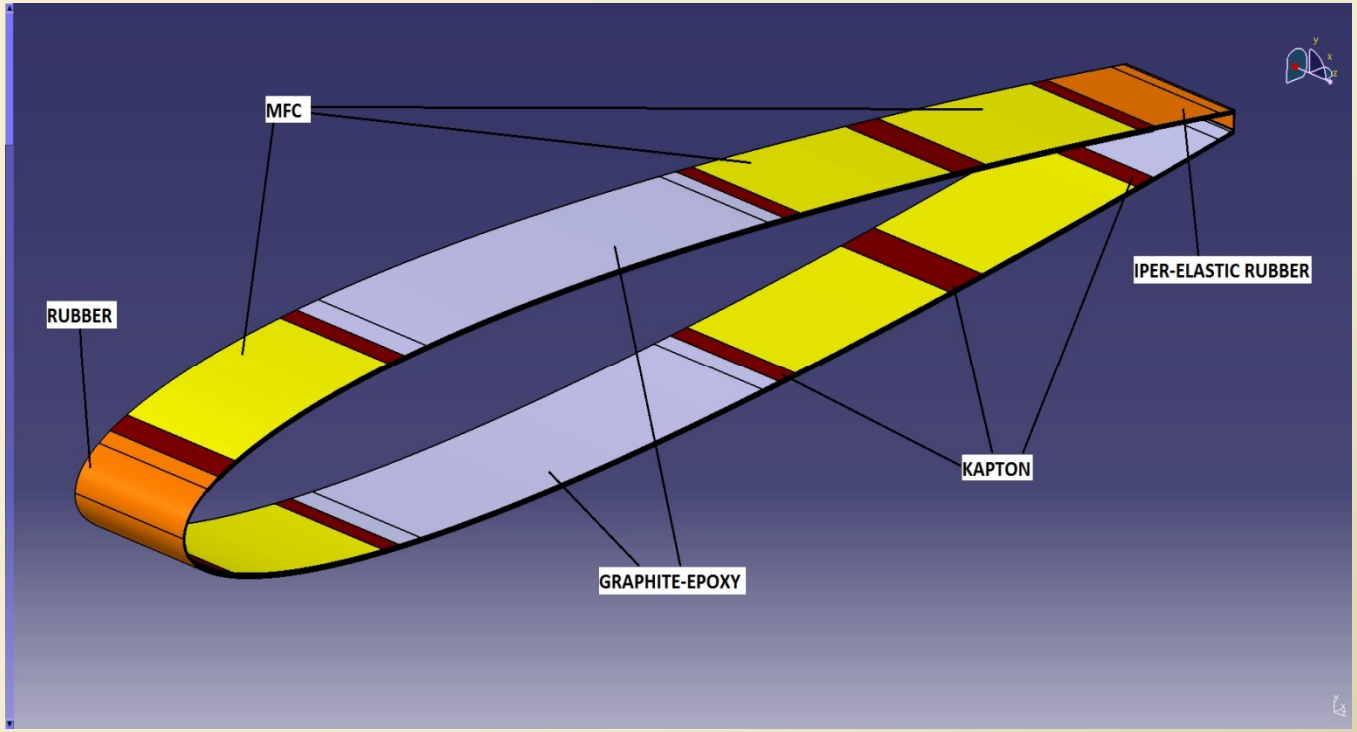
  Set up of the test apparatus

  Measurement of the displacements

  Preliminary development of a multi-channel dynamic control system

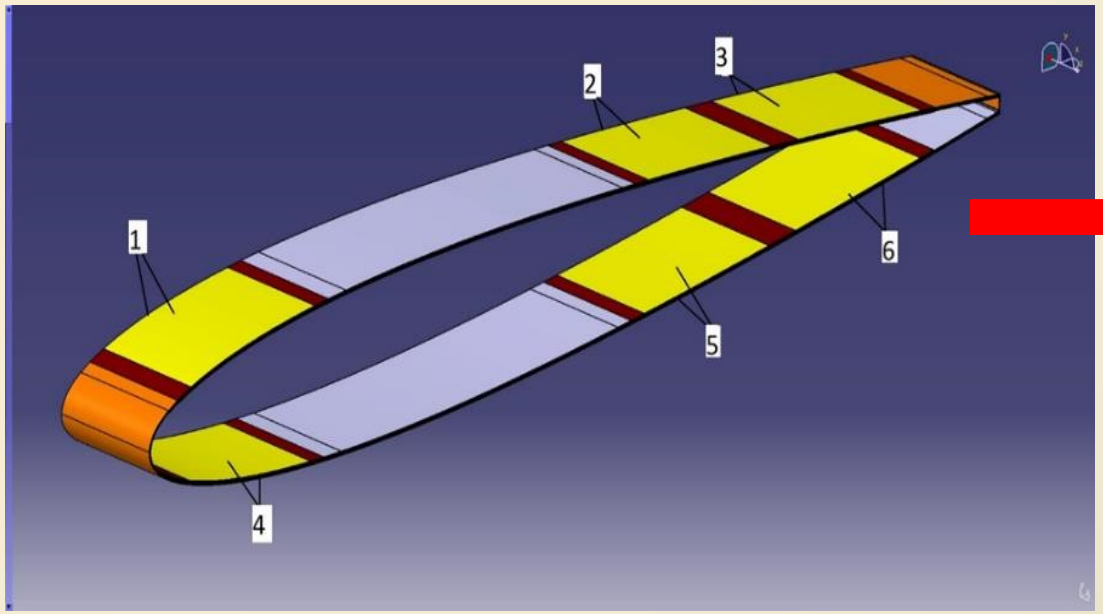
Numerical study of the Future-Wing Unit

Geometry and numerical model of a piezo-controlled NACA 0012 wing section.



Numerical study of the Future-Wing Unit

Patches nomenclature and voltage loads for the NACA 0012 wing section.

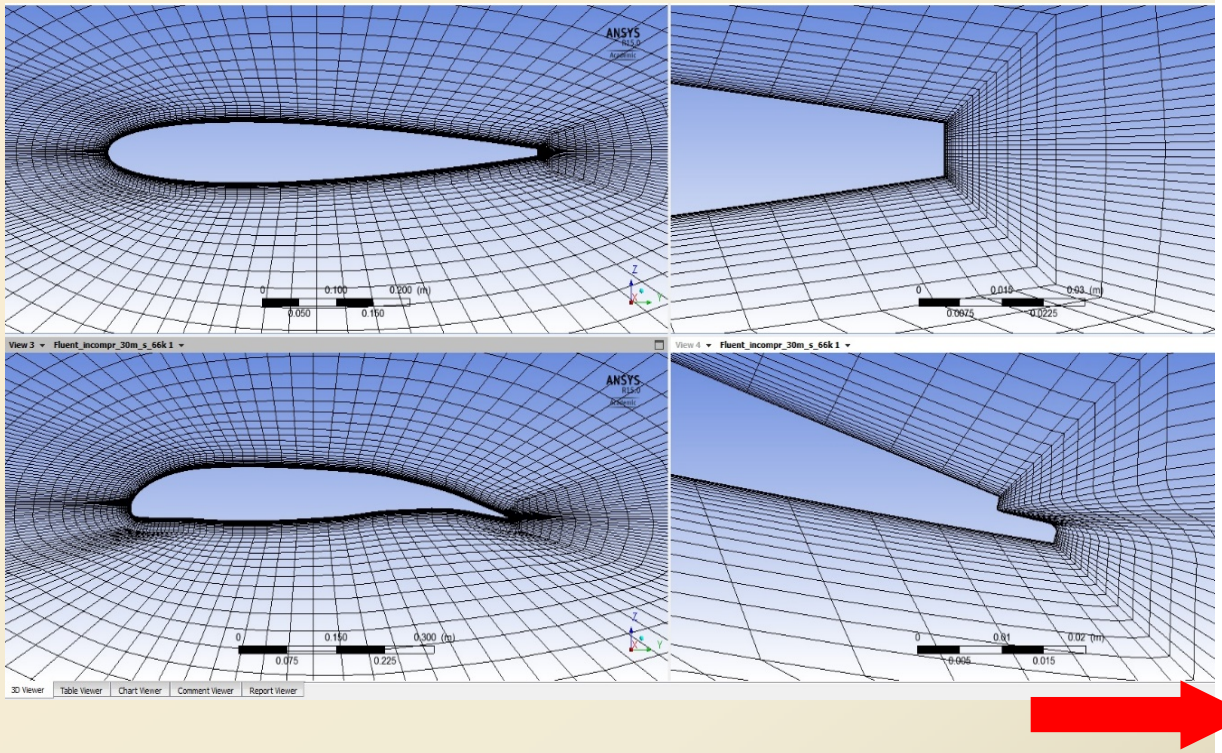


Case	Patches	Voltage [V]
0	MFC 1/2/3	0/0
	MFC 4/5/6	0/0
1	MFC 1/2/3	600/-200
	MFC 4/5/6	600/-200
2	MFC 1/2/3	900/-300
	MFC 4/5/6	900/-300
3	MFC 1/2/3	1200/-400
	MFC 4/5/6	1200/-400
4	MFC 1/2/3	1800/-600
	MFC 4/5/6	1800/-600
5	MFC 1/2/3	2400/-800
	MFC 4/5/6	2400/-800
6	MFC 1/2/3	2700/-900
	MFC 4/5/6	3300/-1100
7	MFC 1/2/3	2700/-900
	MFC 4/5/6	3900/-1300

The Case 2 corresponds to the ratio V/V* = 1 (V* = 900 V).

Numerical study of the Future-Wing Unit

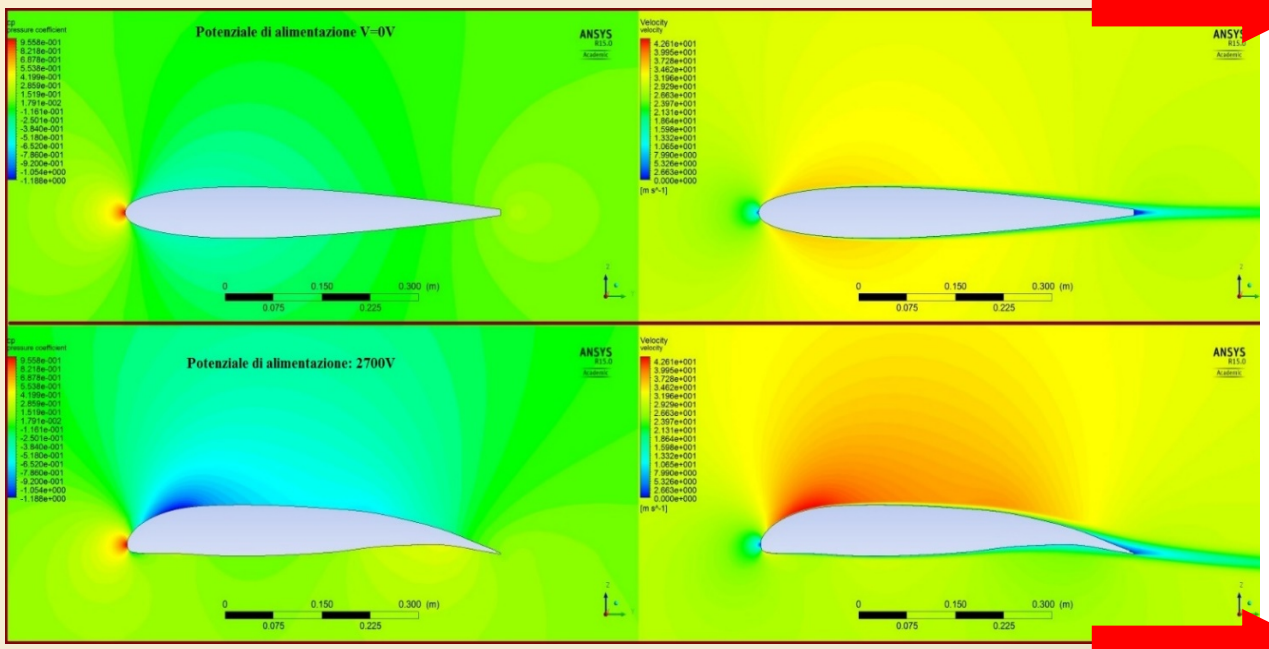
Sketch of deformed grid: Case 7 (NACA 0012 wing section)



Case	Patches	Voltage [V]
0	MFC 1/2/3	0/0
	MFC 4/5/6	0/0
1	MFC 1/2/3	600/-200
	MFC 4/5/6	600/-200
2	MFC 1/2/3	900/-300
	MFC 4/5/6	900/-300
3	MFC 1/2/3	1200/-400
	MFC 4/5/6	1200/-400
4	MFC 1/2/3	1800/-600
	MFC 4/5/6	1800/-600
5	MFC 1/2/3	2400/-800
	MFC 4/5/6	2400/-800
6	MFC 1/2/3	2700/-900
	MFC 4/5/6	3300/-1100
7	MFC 1/2/3	2700/-900
	MFC 4/5/6	3900/-1300

Numerical study of the Future-Wing Unit

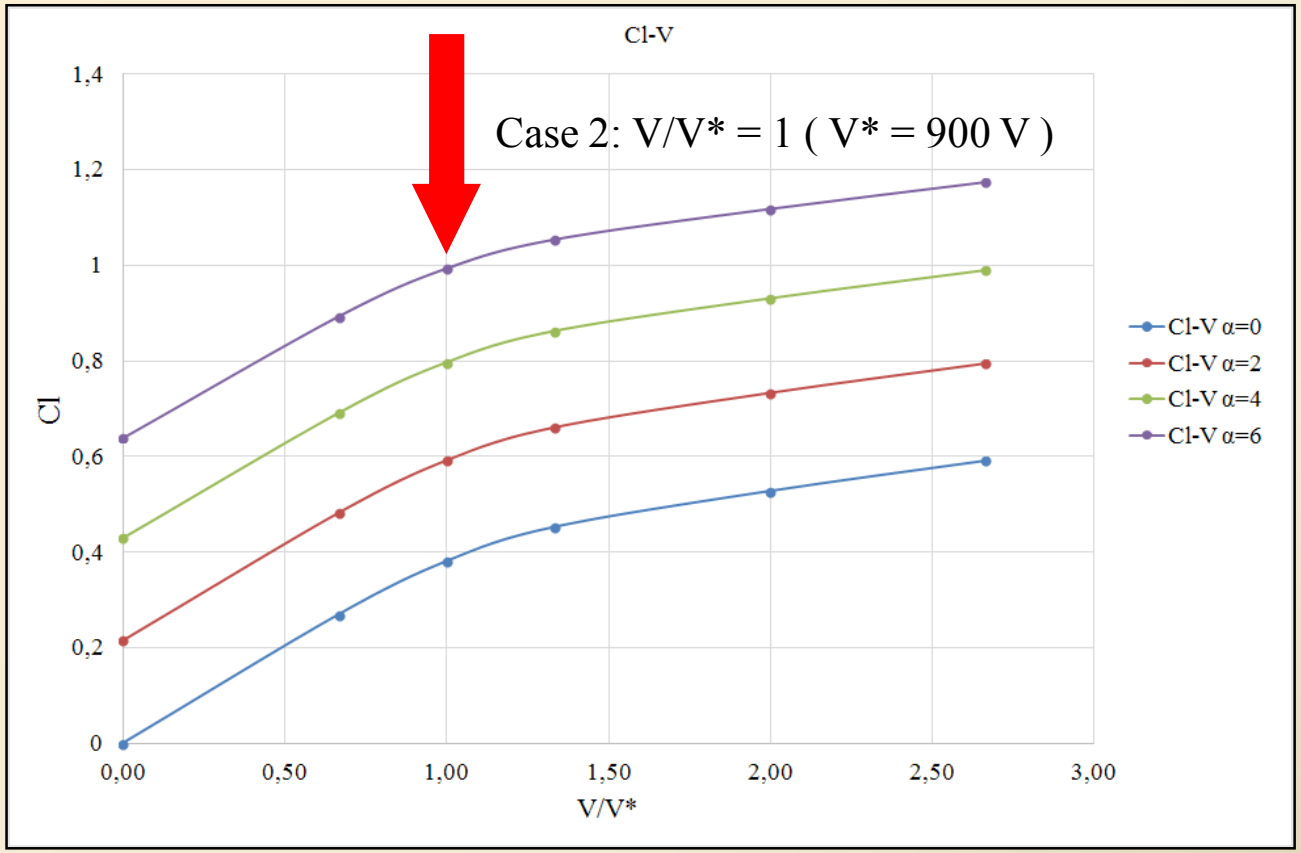
FSI results: Cp fields and velocity fields: Case 0 and Case 7 h = 0 m, α = 2 deg (NACA 0012).



Case	Patches	Voltage [V]
0	MFC 1/2/3	0/0
	MFC 4/5/6	0/0
1	MFC 1/2/3	600/-200
	MFC 4/5/6	600/-200
2	MFC 1/2/3	900/-300
	MFC 4/5/6	900/-300
3	MFC 1/2/3	1200/-400
	MFC 4/5/6	1200/-400
4	MFC 1/2/3	1800/-600
	MFC 4/5/6	1800/-600
5	MFC 1/2/3	2400/-800
	MFC 4/5/6	2400/-800
6	MFC 1/2/3	2700/-900
	MFC 4/5/6	3300/-1100
7	MFC 1/2/3	2700/-900
	MFC 4/5/6	3900/-1300

Numerical study of the Future-Wing Unit

Cl-V/V* curves (NACA 0012 wing section) – reference voltage V* = 900 V



Reference:

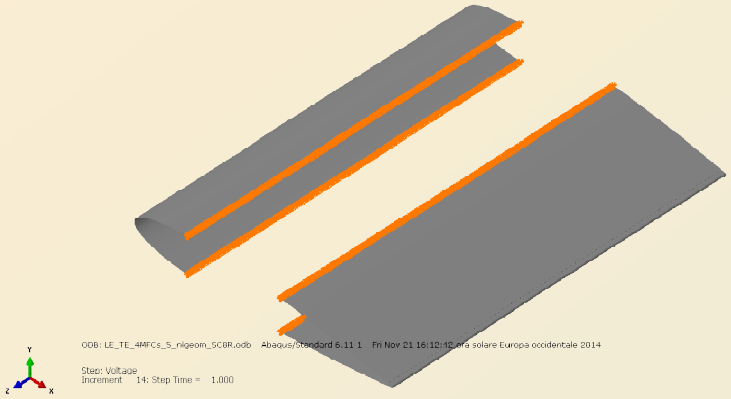
Deliverable D.8.1

In preparation

Numerical study of the Future-Wing Unit

FE analyses of the FW-UNIT-1

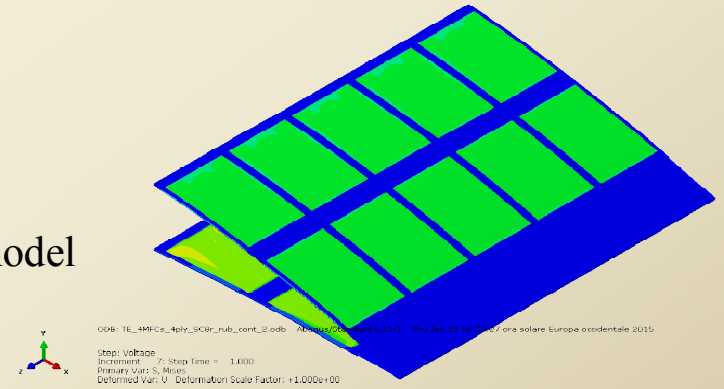
Boundary Conditions



Reference:

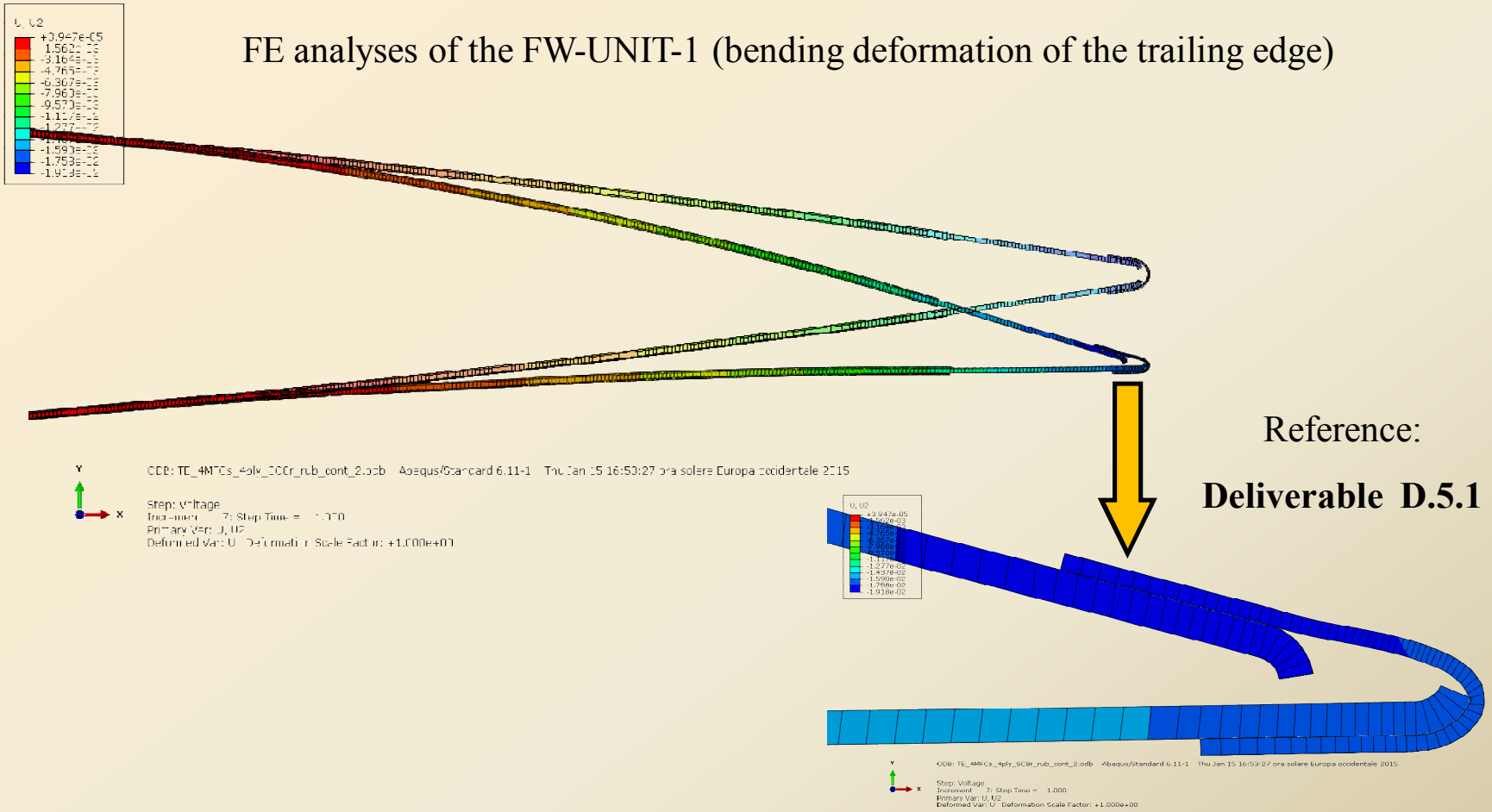
Deliverable D.5.1

Trailing Edge: MFC Patches model



Numerical study of the Future-Wing Unit

FE analyses of the FW-UNIT-1 (bending deformation of the trailing edge)

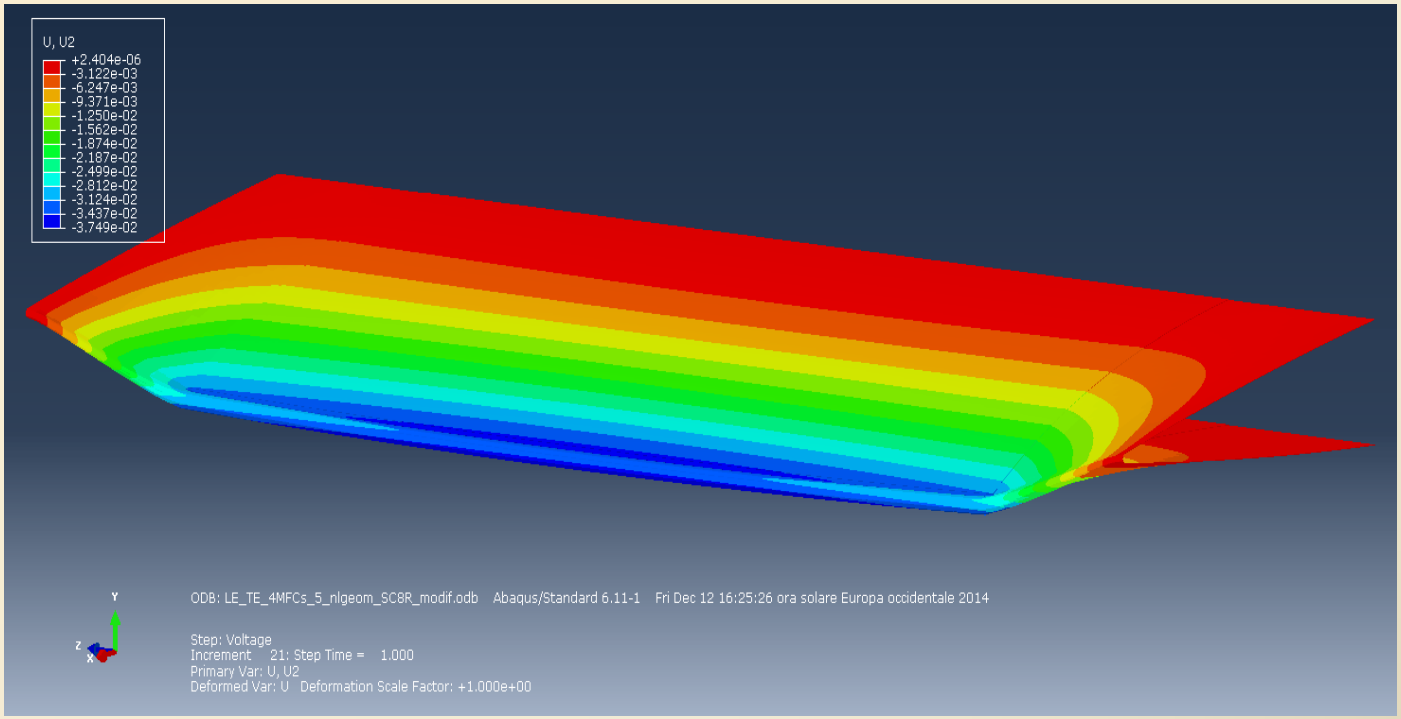


Reference:

Deliverable D.5.1

Numerical study of the Future-Wing Unit

FE analyses of the FW-UNIT-1 (bending deformation of the trailing edge)

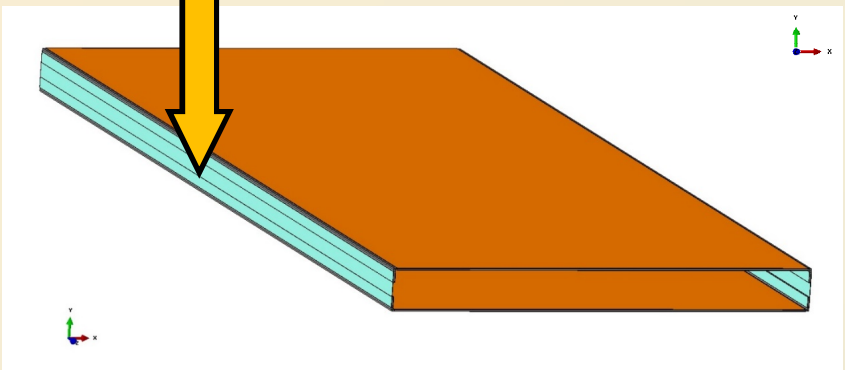


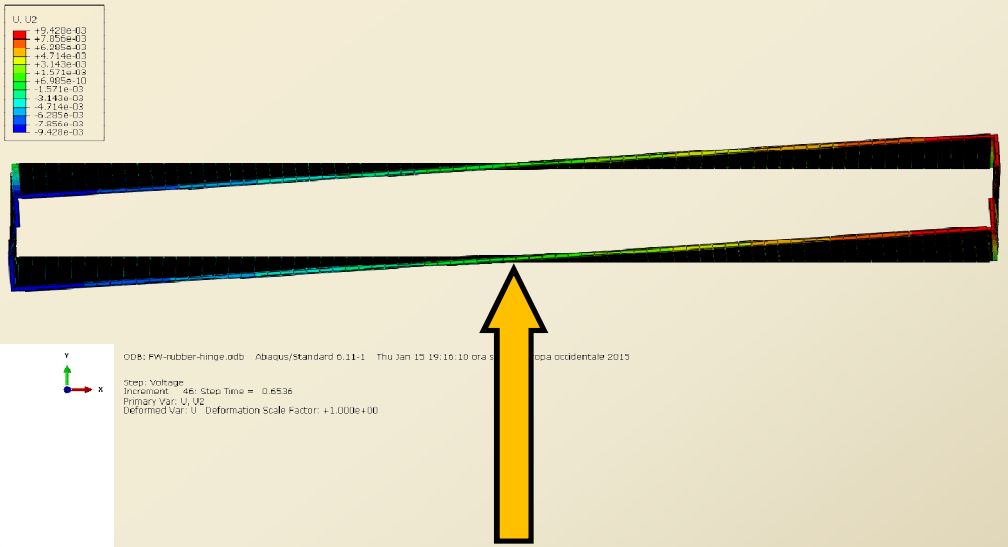
Reference: **Deliverable D.5.1**

Numerical study of the Future-Wing Unit

FE analyses of the FW-UNIT-2 (torsion deformation of the Unit)

Elastomeric material



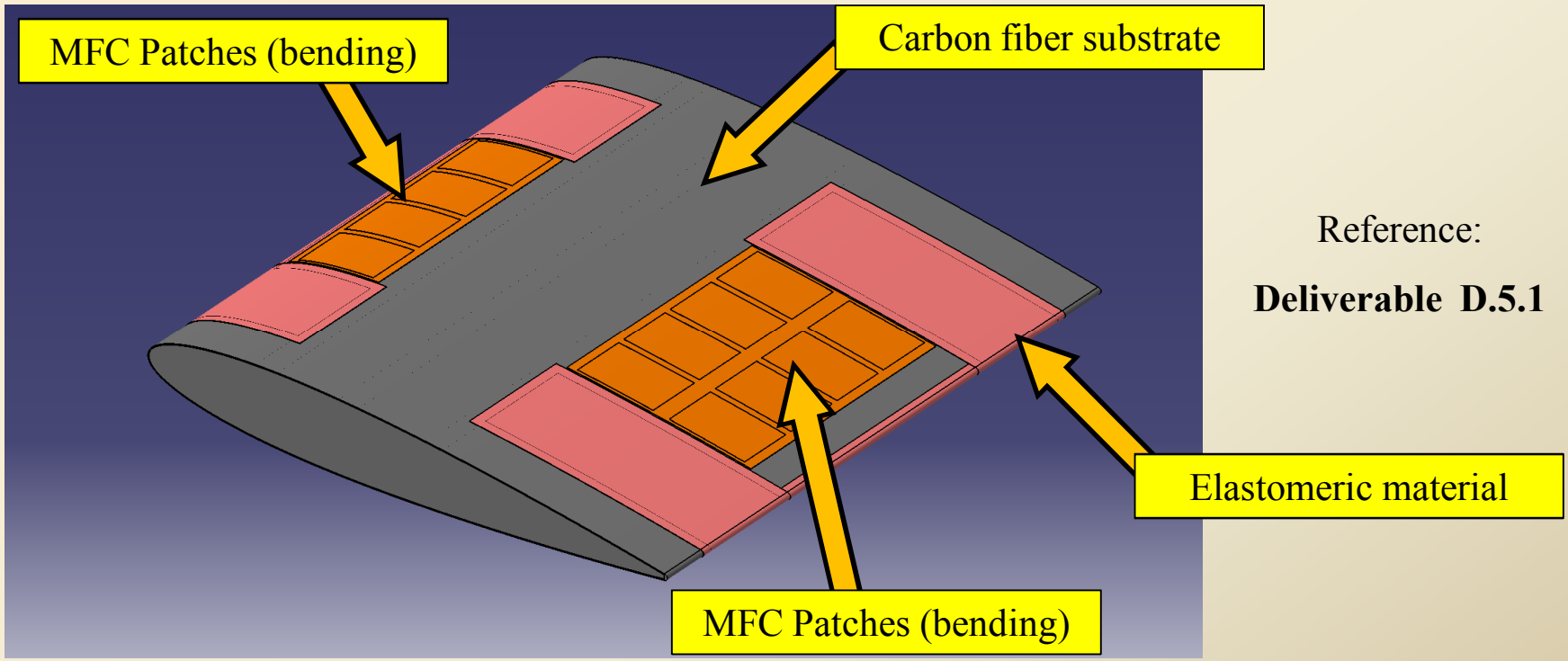


The Centre of Rotation remains unchanged

Reference: **Deliverable D.5.1**

Numerical study of the Future-Wing Unit

Design of the Future Wing Unit 1 (skeleton curvature's change)

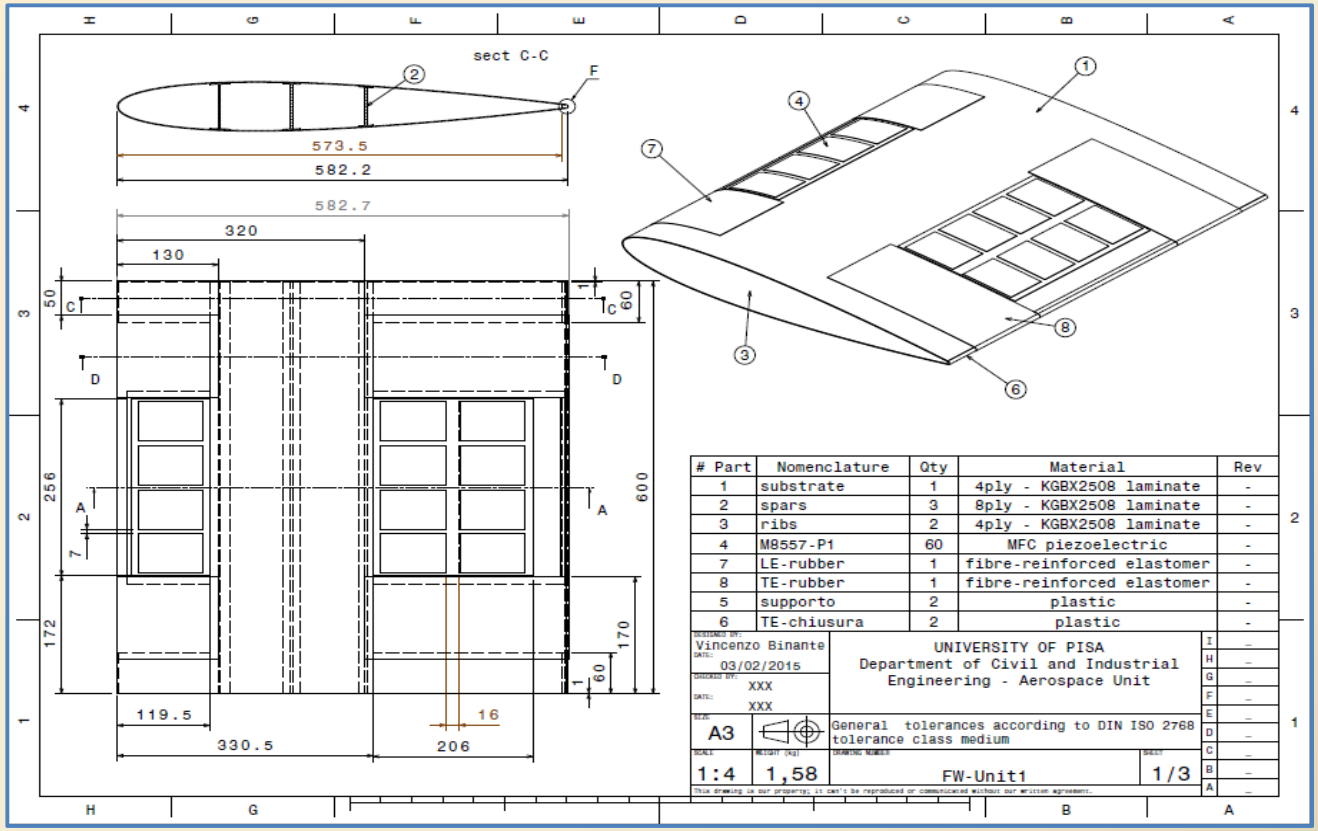


Reference:

Deliverable D.5.1

Numerical study of the Future-Wing Unit

Design of the Future Wing Unit 1 (technical drawings)

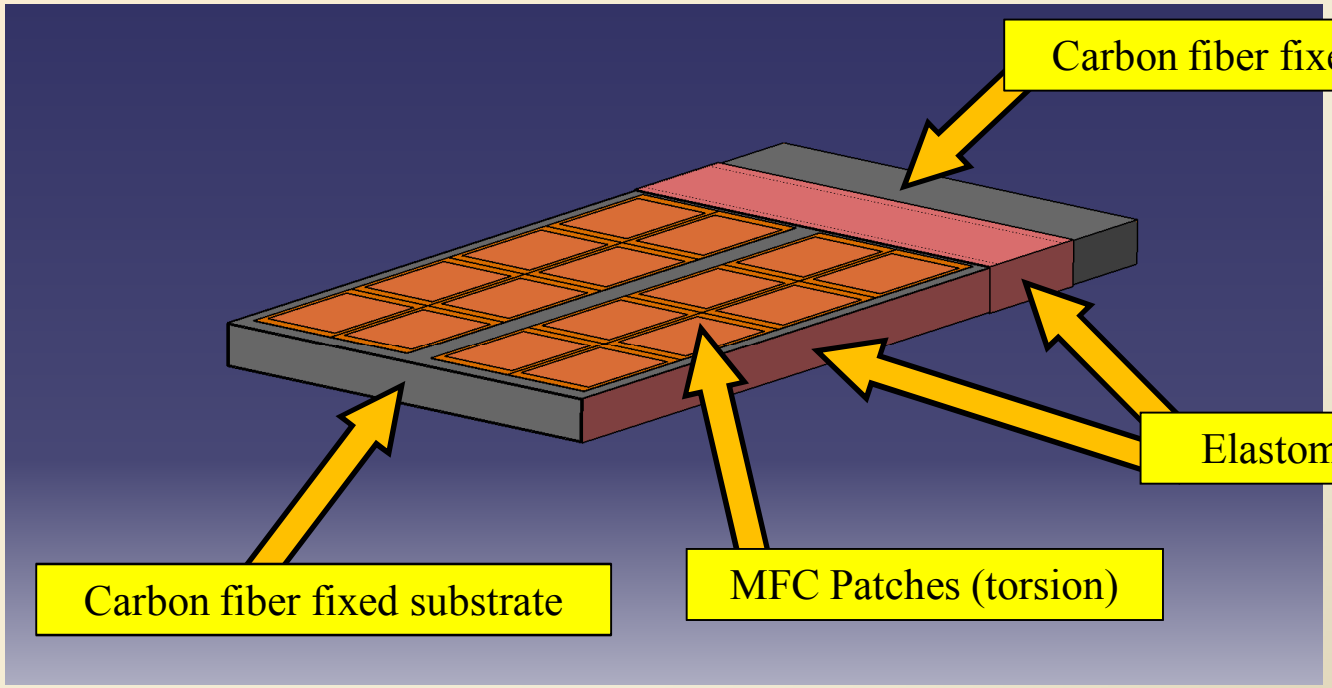


Reference:

Deliverable D.5.1

Numerical study of the Future-Wing Unit

Conceptual design of the Future Wing Unit 2 (torsion control)
(grey=structure – orange=active patches – pink=elastomer)

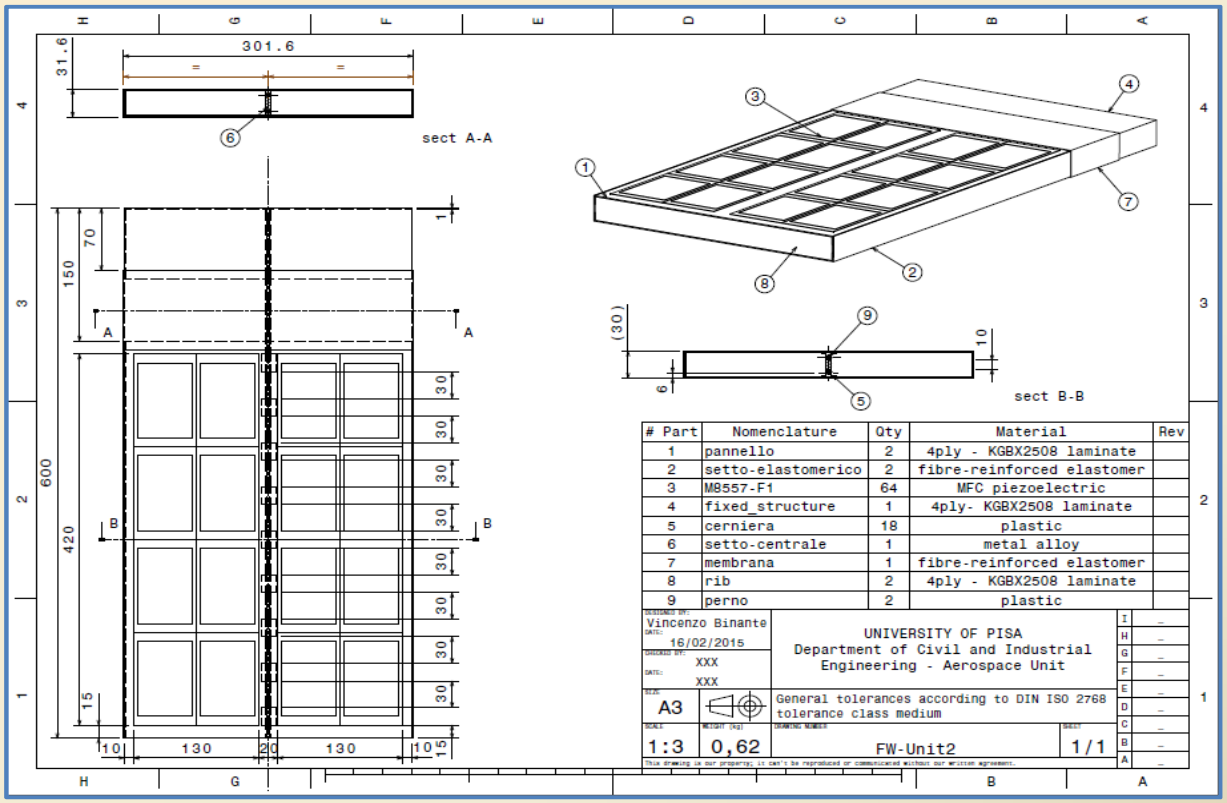


Reference:

Deliverable D.5.1

Numerical study of the Future-Wing Unit

Conceptual design of the Future Wing Unit 2 (torsion control)
(technical drawings)



# Part	Nomenclature	Qty	Material	Rev
1	pannello	2	4ply - KGBX2508 laminate	
2	setto-elastomerico	2	fibre-reinforced elastomer	
3	M8557-F1	64	MFC piezoelectric	
4	fixed_structure	1	4ply- KGBX2508 laminate	
5	cerniera	18	plastic	
6	setto-centrale	1	metal alloy	
7	membrana	1	fibre-reinforced elastomer	
8	rib	2	4ply - KGBX2508 laminate	
9	perno	2	plastic	

Reference:

Deliverable D.5.1

Manufacturing of the Future Wing Unit 1

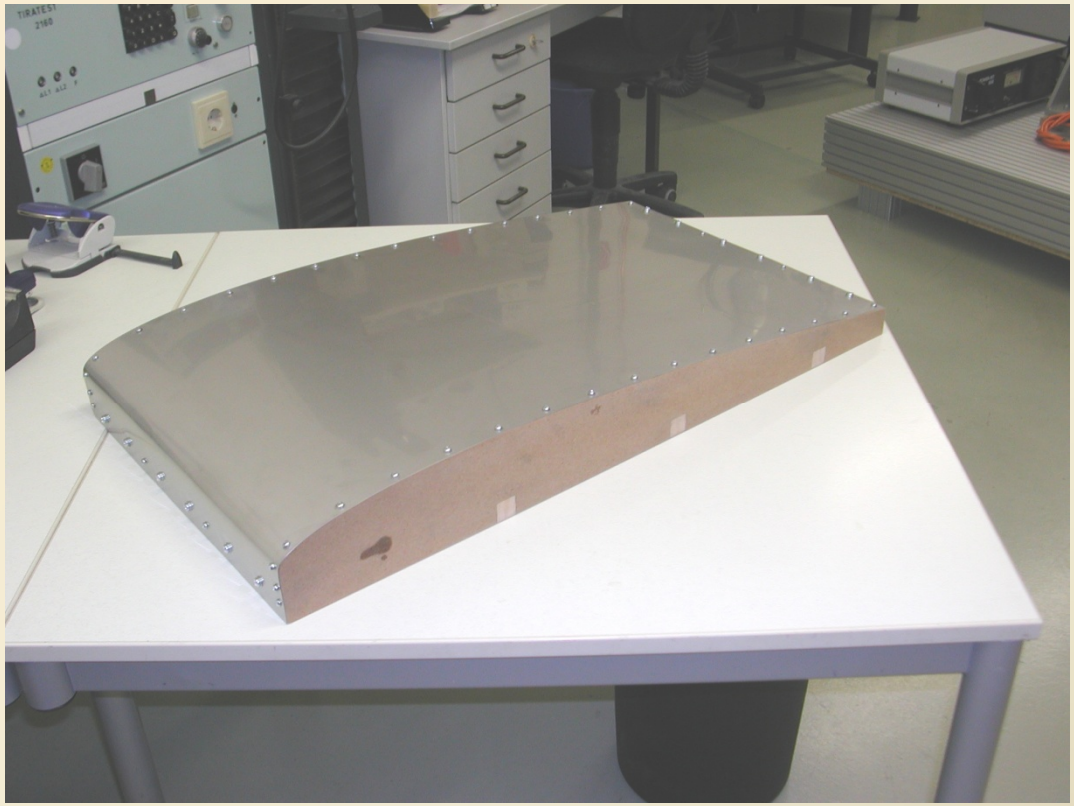
Manufacturing of the skin mold

Reference:

Deliverable D.5.2

Manufacturing of the Future Wing Unit 1

Manufacturing of the skin mold

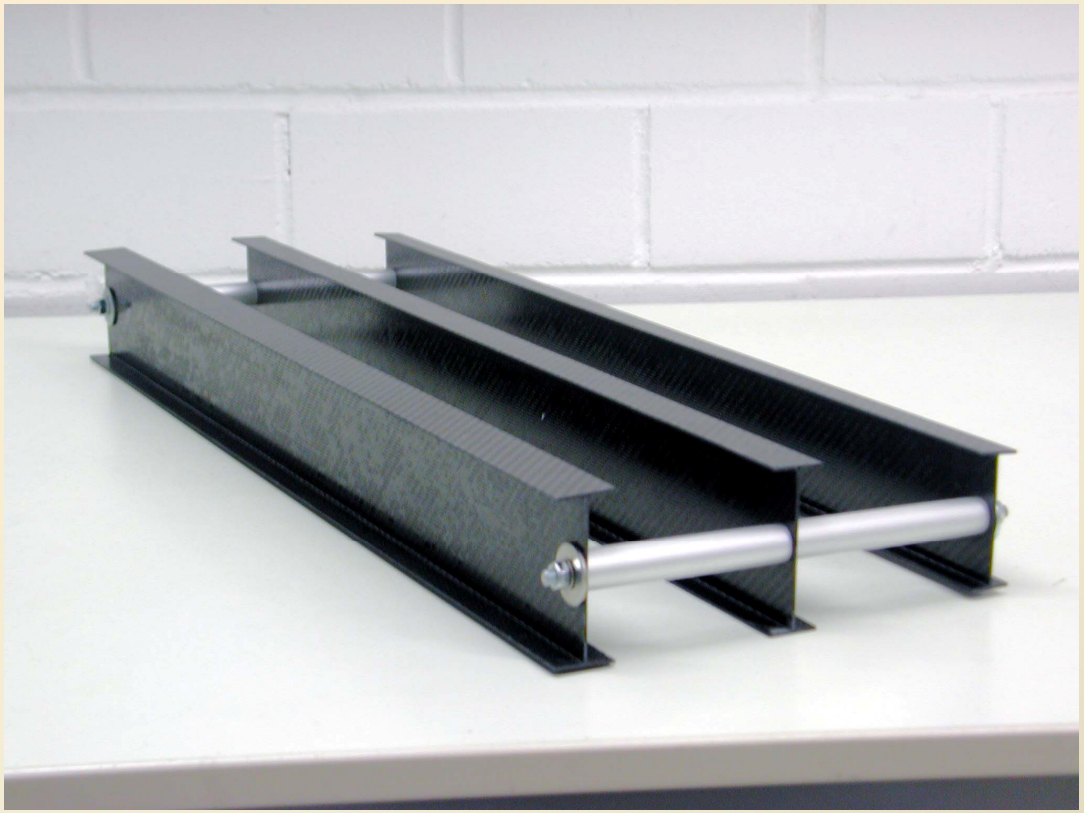


Reference:

Deliverable D.5.2

Manufacturing of the Future Wing Unit 1

The stiffeners of the Unit

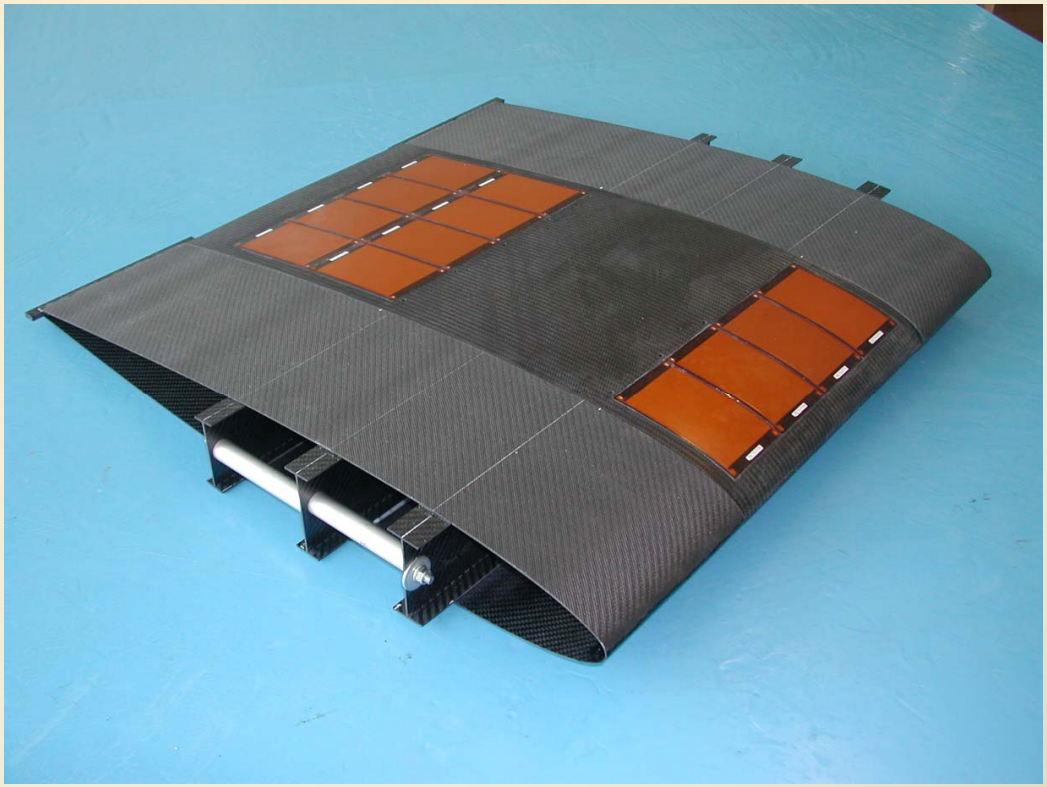


Reference:

Deliverable D.5.2

Manufacturing of the Future Wing Unit 1

The assembled Unit

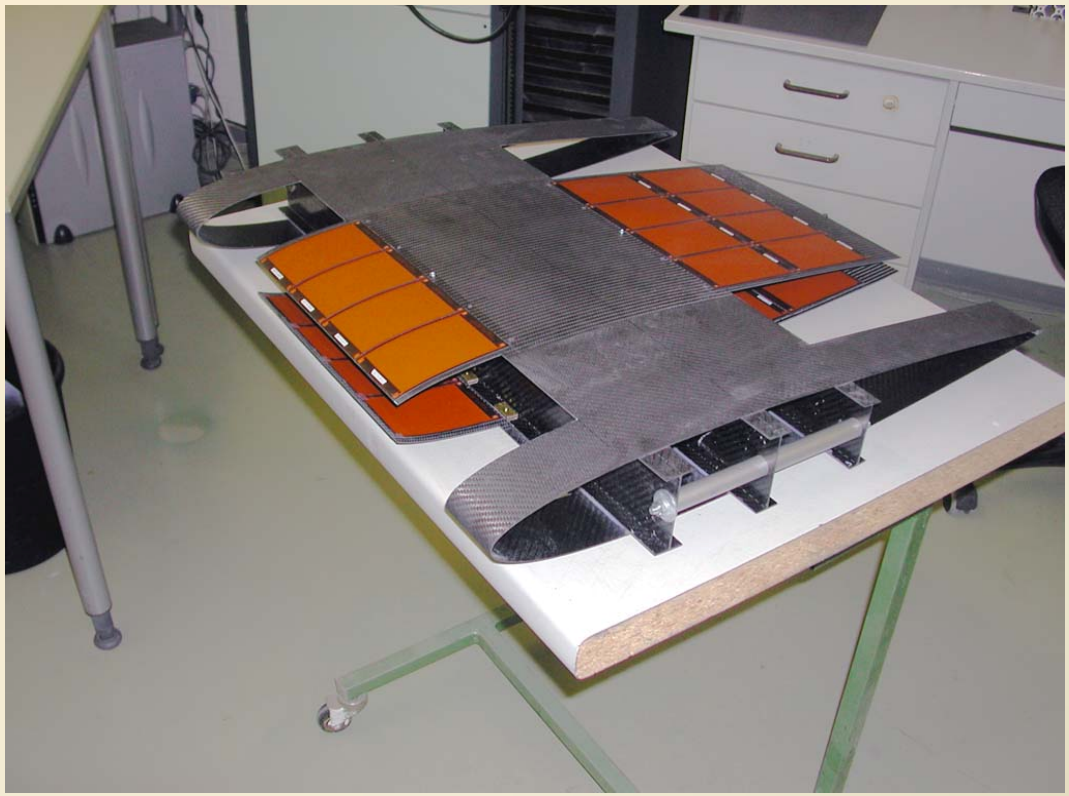


Reference:

Deliverable D.5.2

Manufacturing of the Future Wing Unit 1

The assembled Unit with cuts for the allocation of rubber sheets

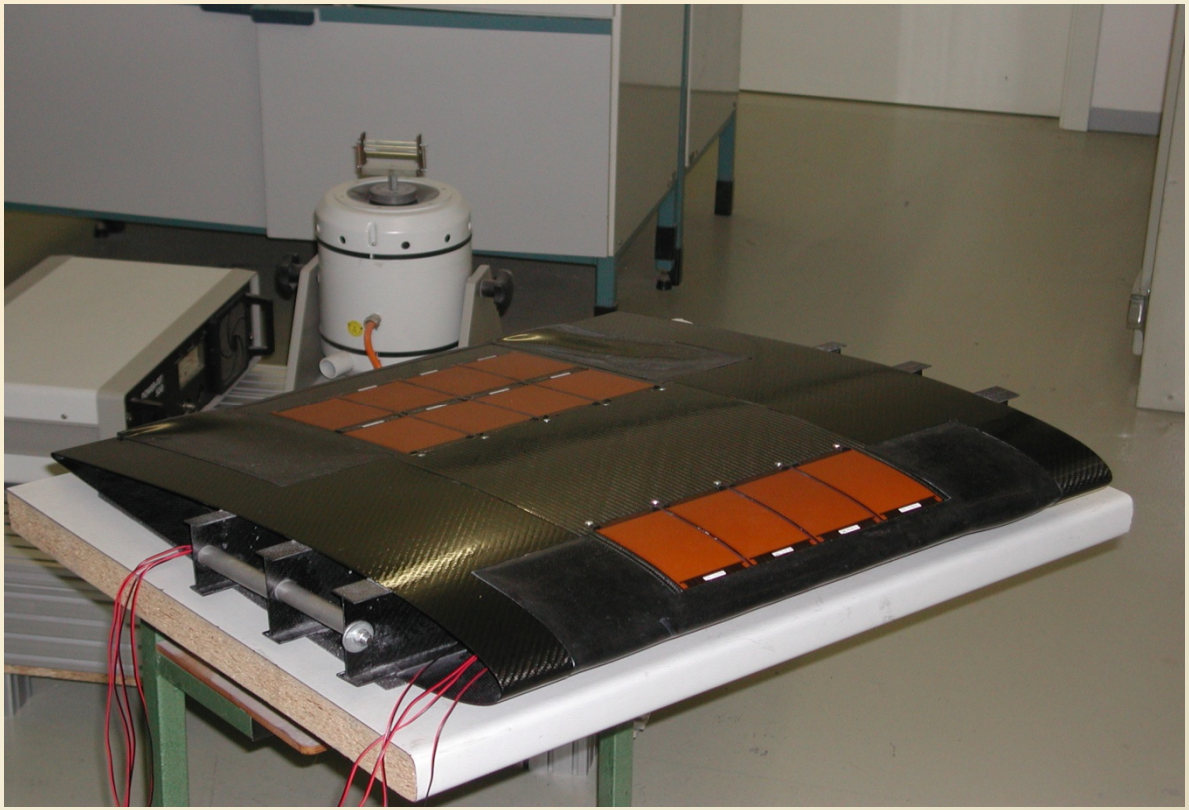


Reference:

Deliverable D.5.2

Manufacturing of the Future Wing Unit 1

The final assembly with the wiring connections for the MFC patches

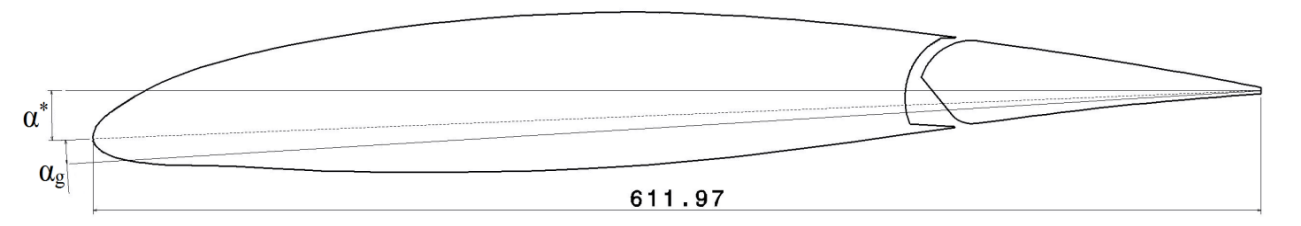


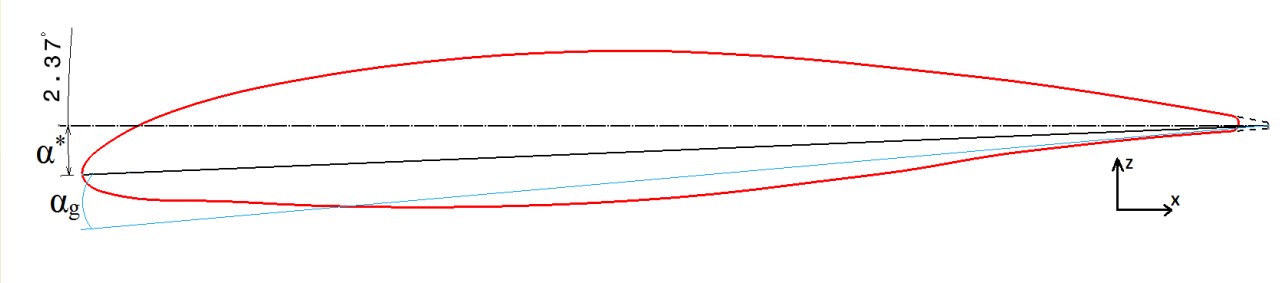
Reference:

Deliverable D.5.2

Numerical analyses of morphing wing sections

The reference aileron-section (from the P180 geometry source file) and the piezo-section





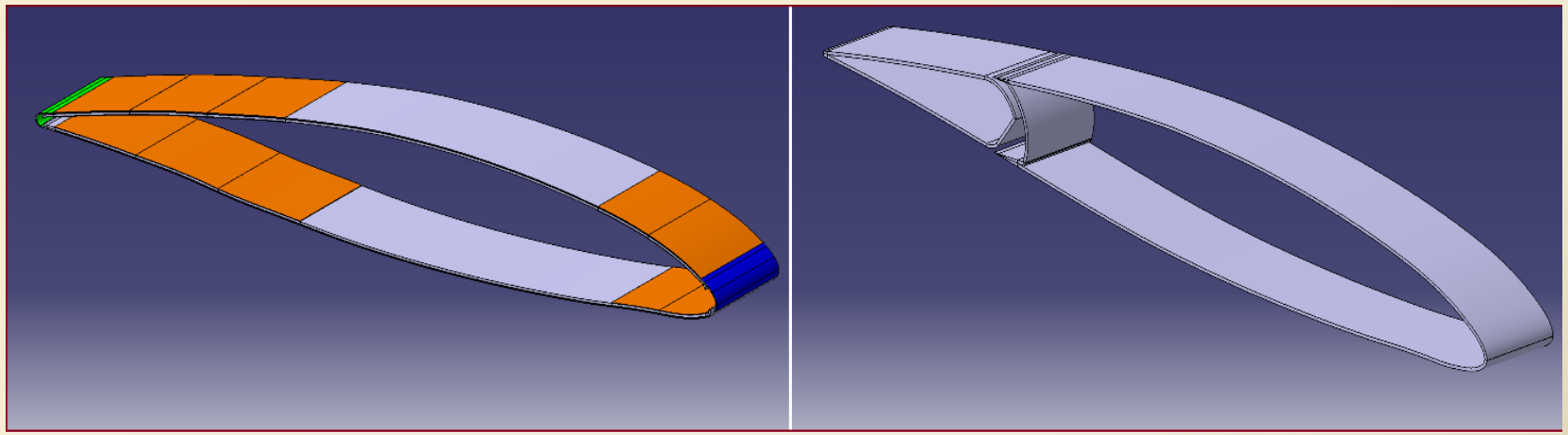
Reference:

Deliverable D.8.1

In preparation

Numerical analyses of morphing wing sections

The reference aileron-section and the piezo-section



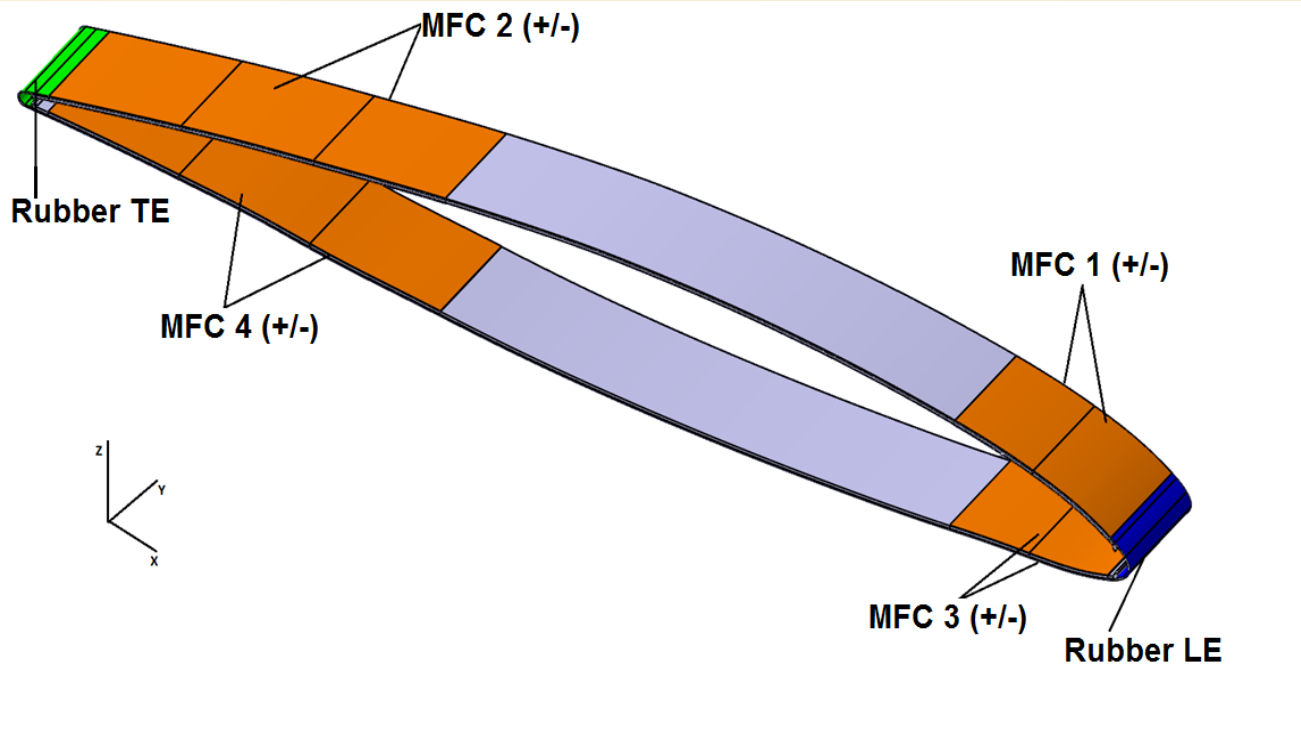
Reference:

Deliverable D.8.1

In preparation

Numerical analyses of morphing wing sections

The MFC nomenclature



Reference:

Deliverable D.8.1

In preparation

Numerical analyses of morphing wing sections

The voltage loading cases

Realistic Case

V/V*	Case	Patchs	Voltage [V]
-5	-5	MFC 1/2	-7500/15000
		MFC 3/4	-3750/7500
-2	-3	MFC 1/2	-3000/6000
		MFC 3/4	-1500/3000
0	0	MFC 1/2	0/0
		MFC 3/4	0/0
0.5	1	MFC 1/2	750/-375
		MFC 3/4	1500/-750
1	2	MFC 1/2	1500/-750
		MFC 3/4	3000/-1500
2	3	MFC 1/2	3000/-1500
		MFC 3/4	6000/-3000
4	4	MFC 1/2	6000/-3000
		MFC 3/4	12000/-6000
5	5	MFC 1/2	7500/-3750
		MFC 3/4	15000/-7500

Reference:

Deliverable D.8.1

In preparation

Numerical analyses of morphing wing sections

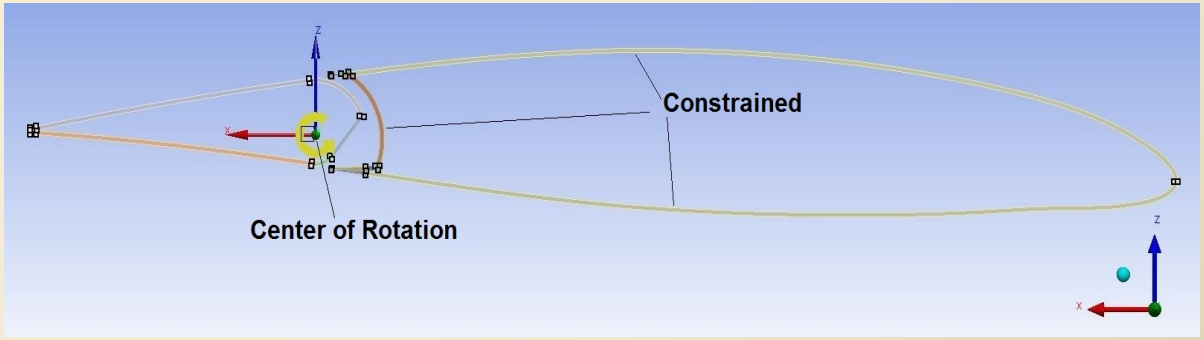
The aileron positions analyzed

Reference:

Deliverable D.8.1

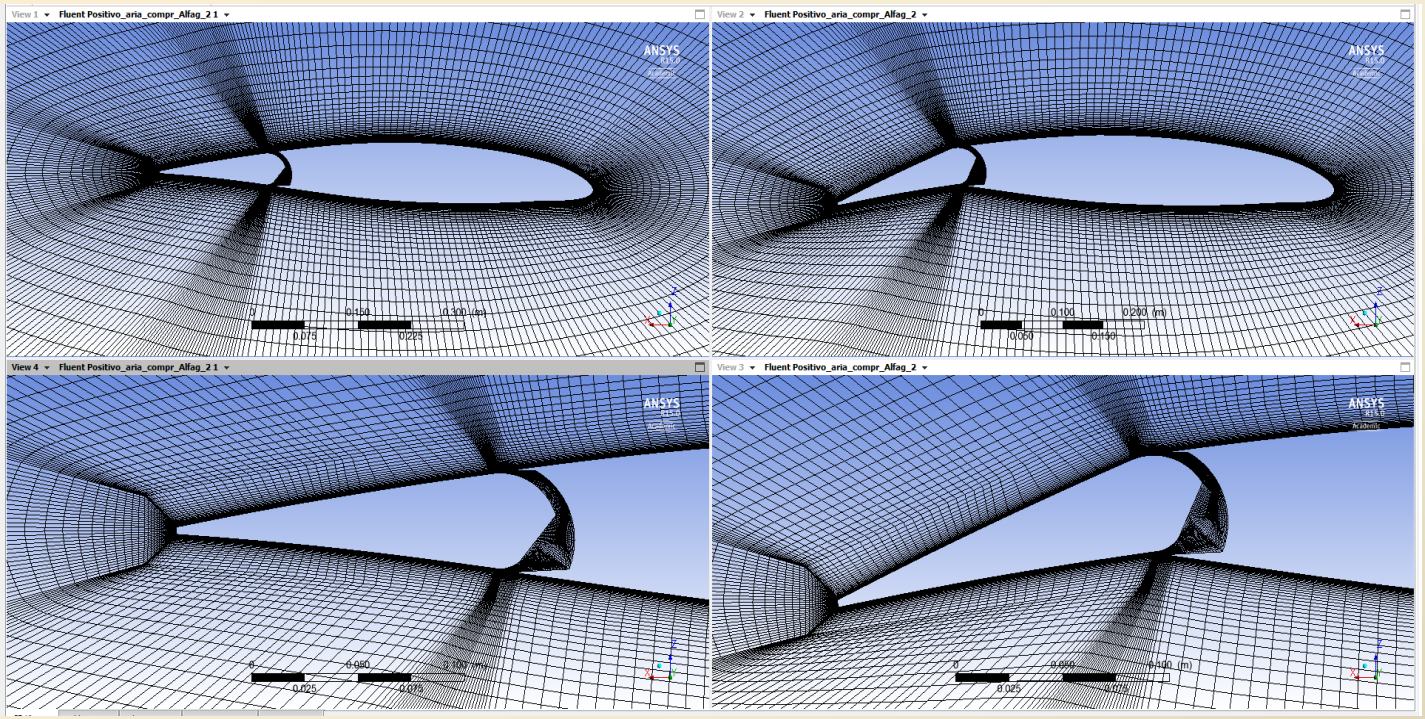
In preparation

Case Number	Aileron Deflection [deg]
0	-15°
1	-10°
2	-5°
3	0°
4	5°
5	10°
6	15°
7	18°



Numerical analyses of morphing wing sections

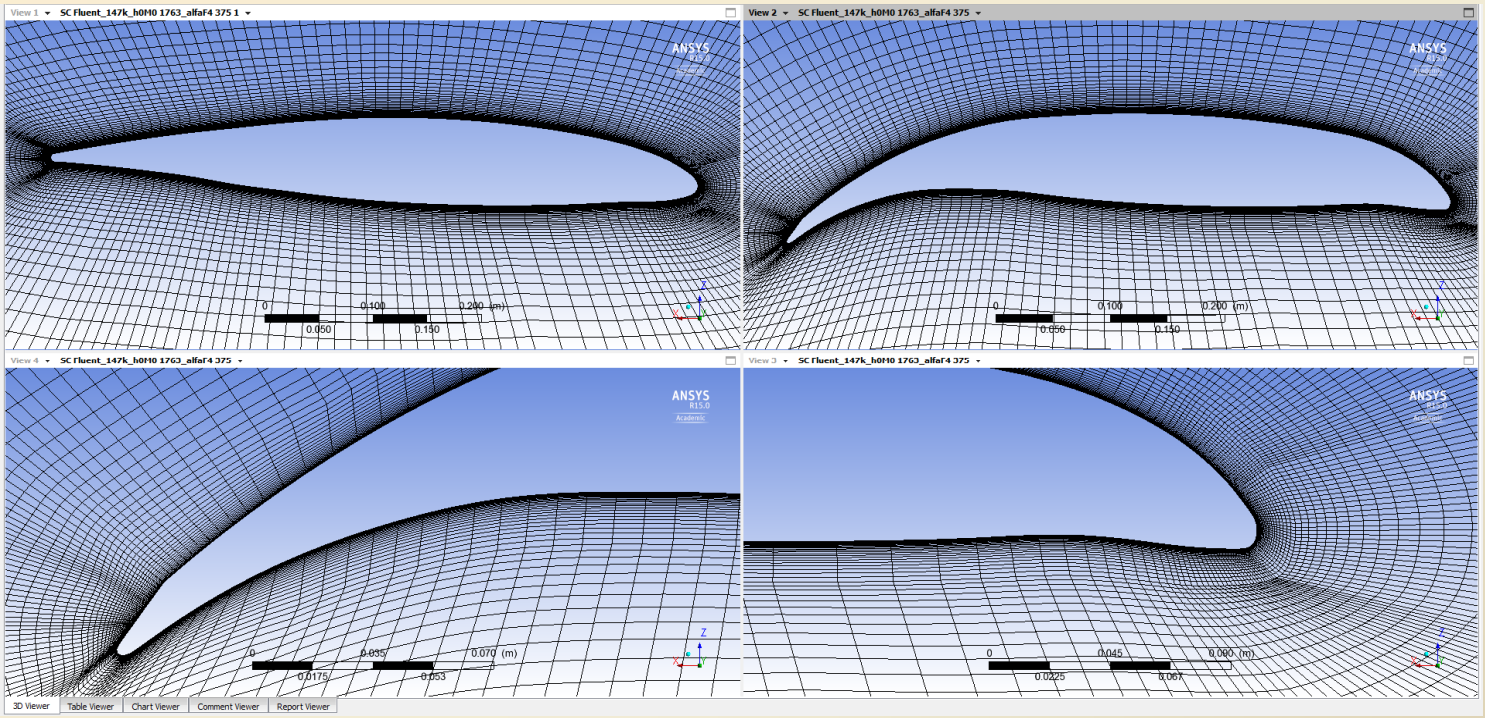
The aileron-wing section: sketch of deformed aero-grid



Reference: **Deliverable D.8.1** *(In preparation)* (δa=15°, h=0 m, αg = 2 deg, M=0.17)

Numerical analyses of morphing wing sections

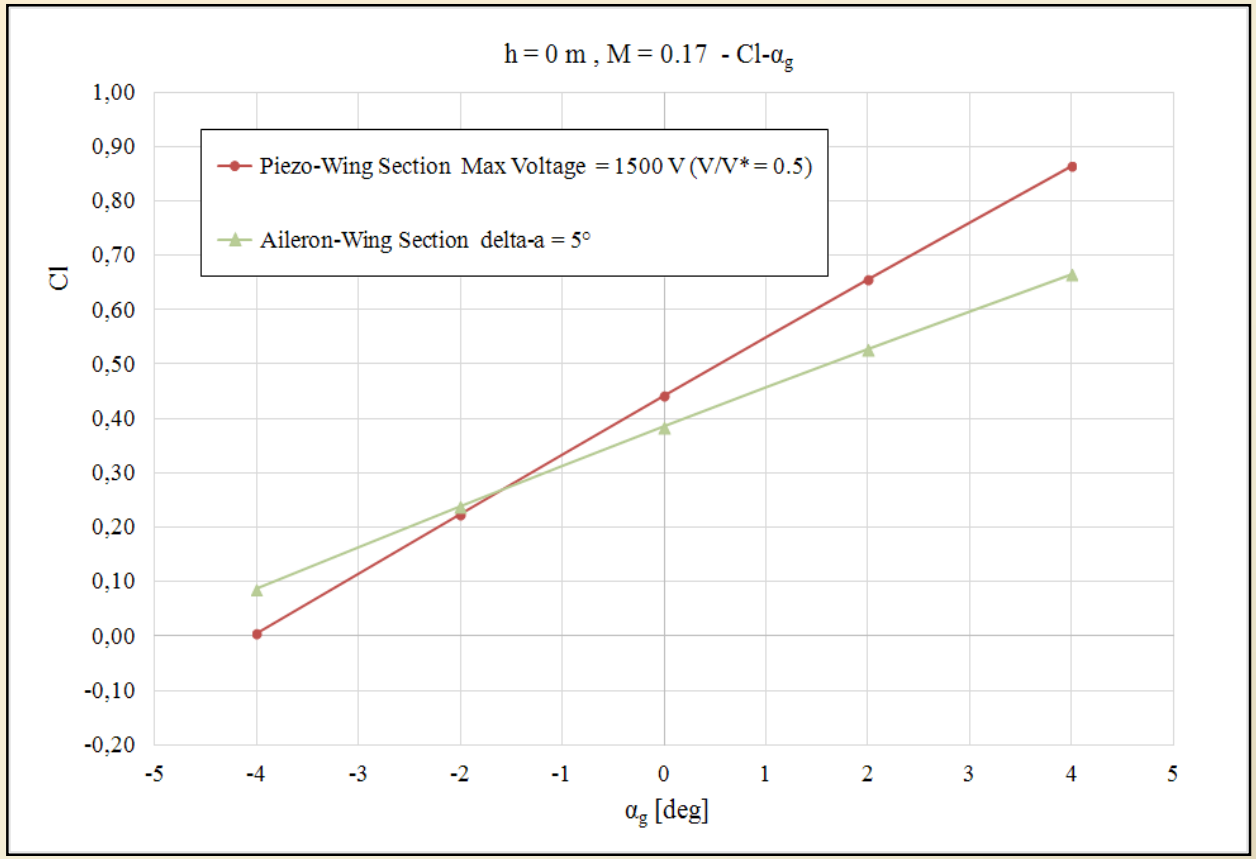
The piezo-wing section: sketch of deformed aero-grid (V* = 1500 V)



Reference: **Deliverable D.8.1** *(In preparation)* (V/V*=5, h=0 m, αg = 2 deg, M=0.17)

Numerical analyses of morphing wing sections

Comparison of the aerodynamic performances of the wing sections



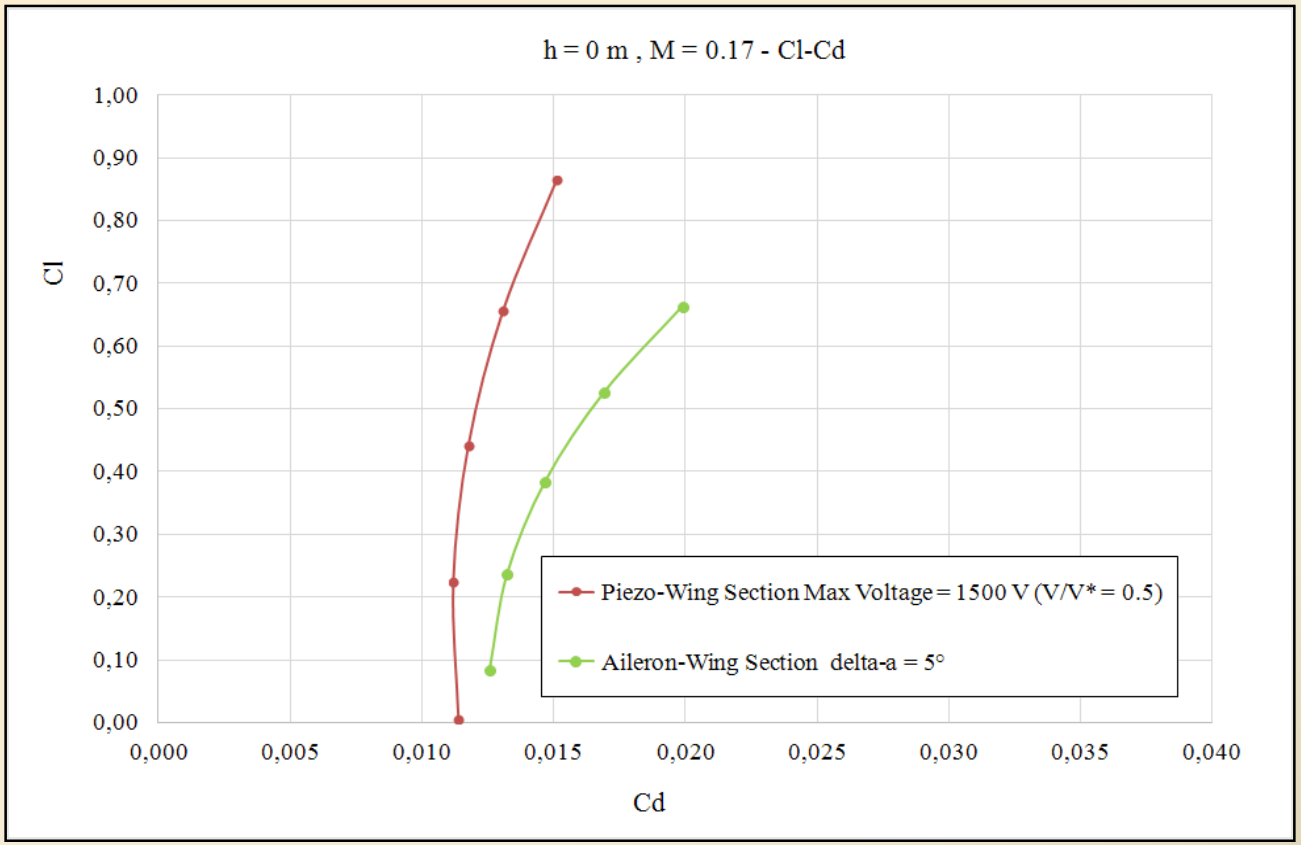
Reference:

Deliverable D.8.1

In preparation

Numerical analyses of morphing wing sections

Comparison of the aerodynamic performances of the wing sections



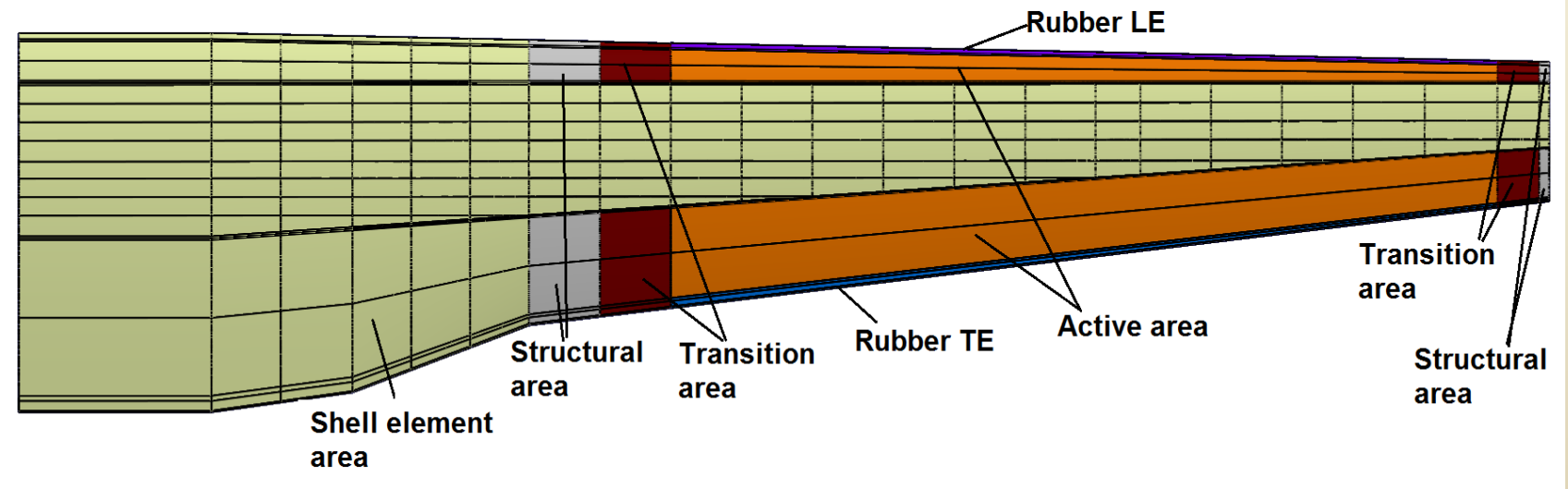
Reference:

Deliverable D.8.1

In preparation

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

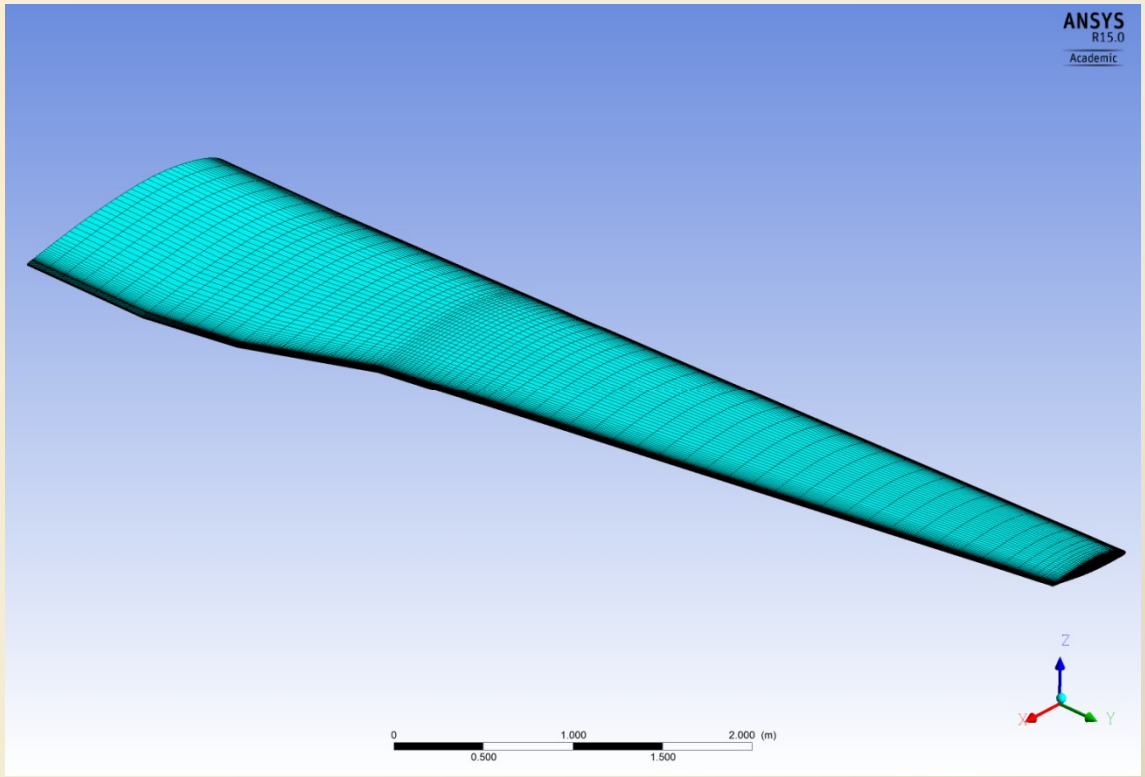
The finite element model of the Piezo-Wing



Reference: **Deliverable D.8.1** *(In preparation)*

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

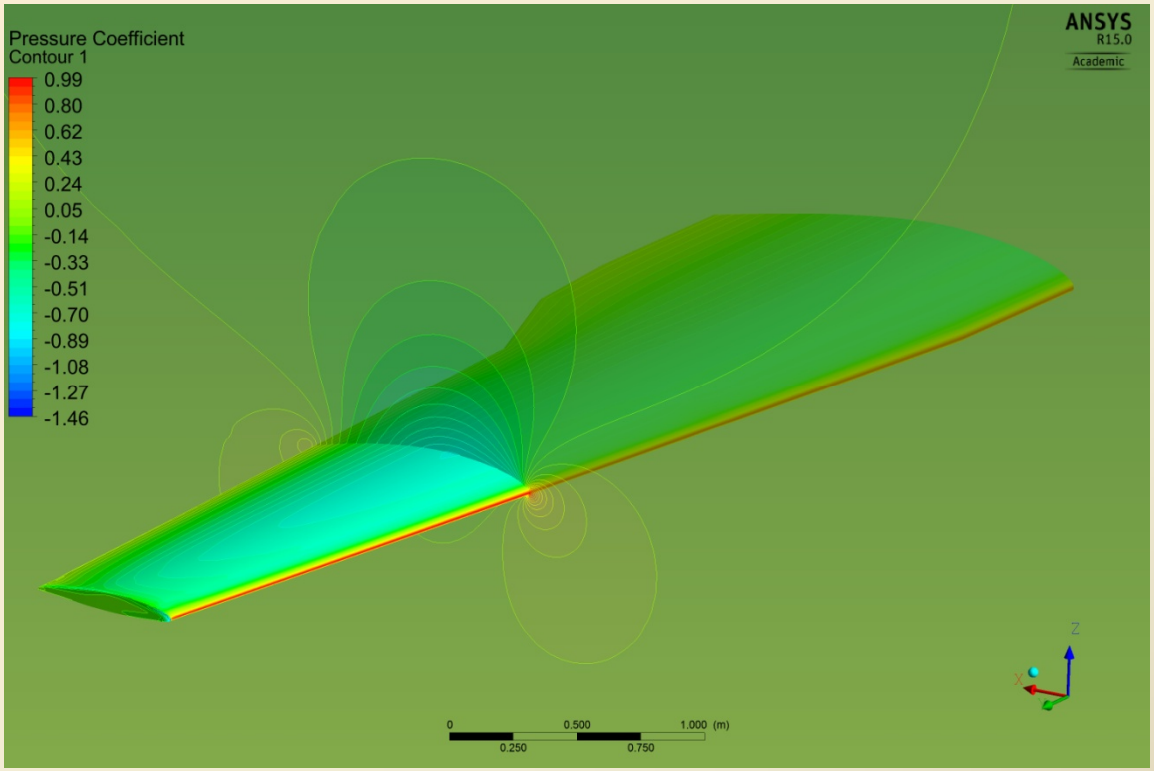
The aerodynamic model of the Piezo-Wing (the surface grid)



Reference: **Deliverable D.8.1** *(In preparation)*

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

Example of results of the FSI analyses of the Piezo-Wing (Cp distribution)



Reference:

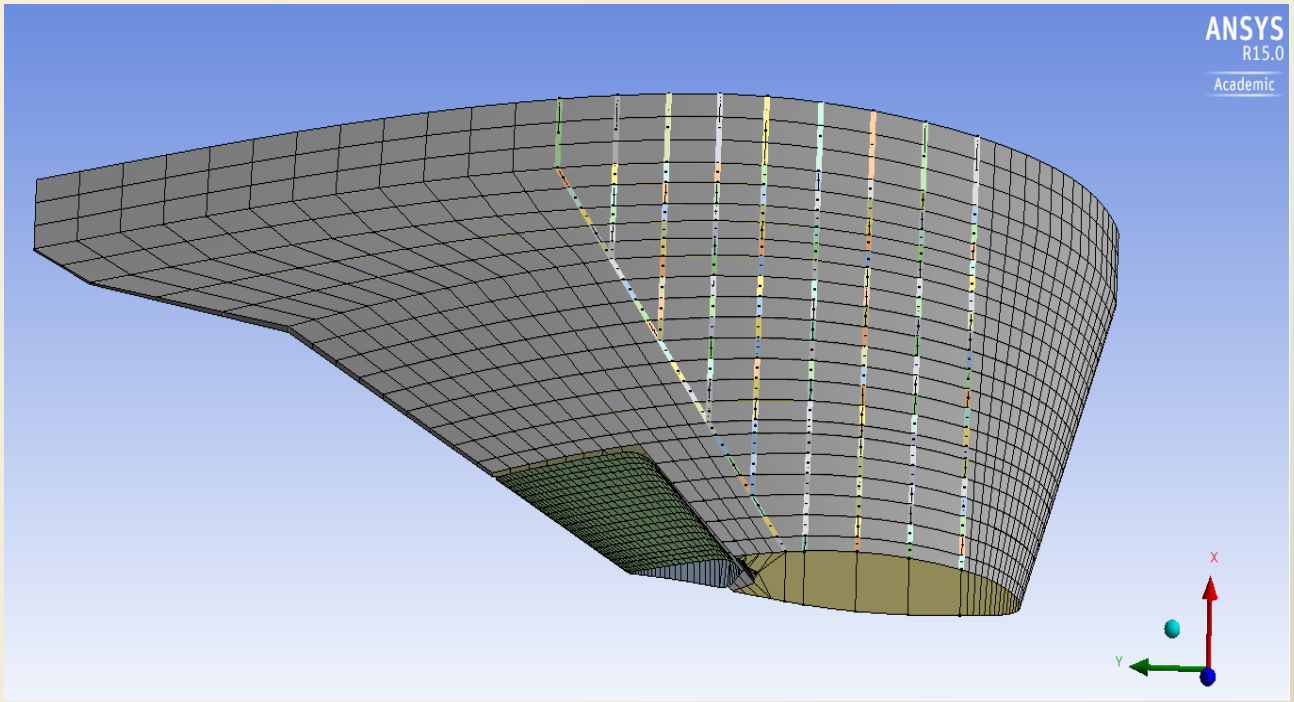
Deliverable D.8.1

In preparation

Loading case: $V/V^* = 0.225$, $\alpha_g = 0°$, h=0, M=0.1763

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

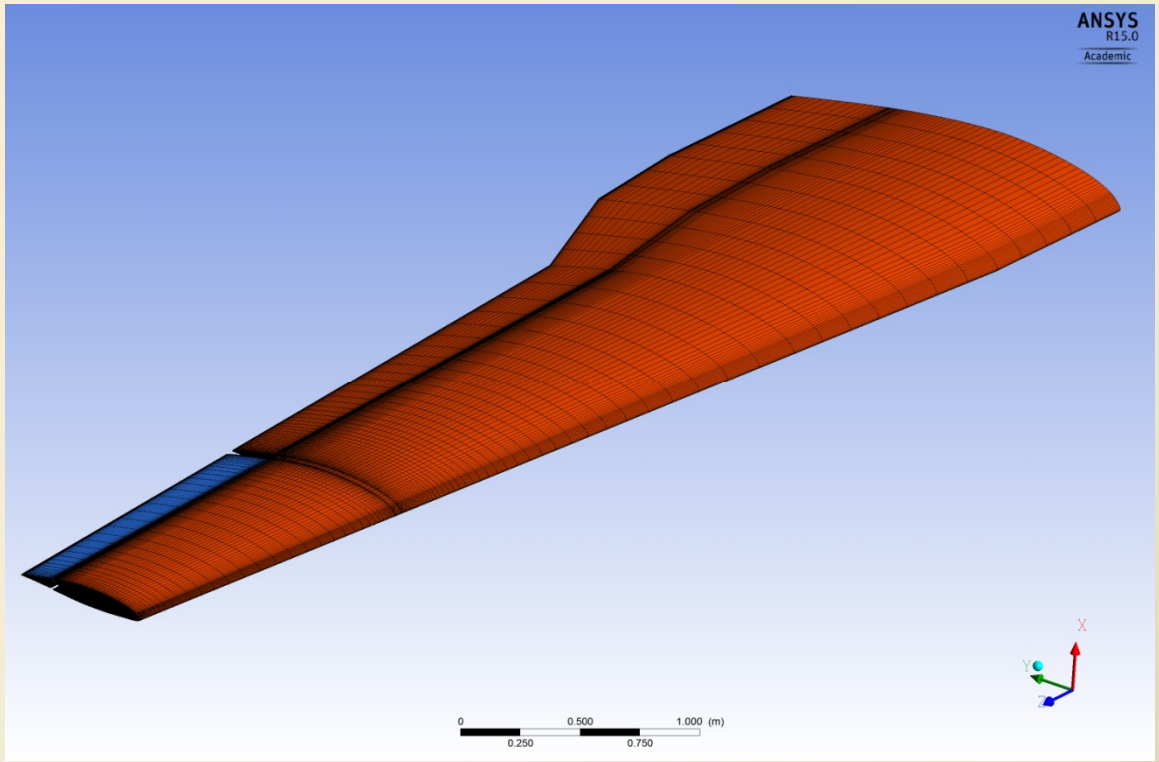
The finite element model of the Aileron-Wing



Reference: **Deliverable D.8.1** *(In preparation)*

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

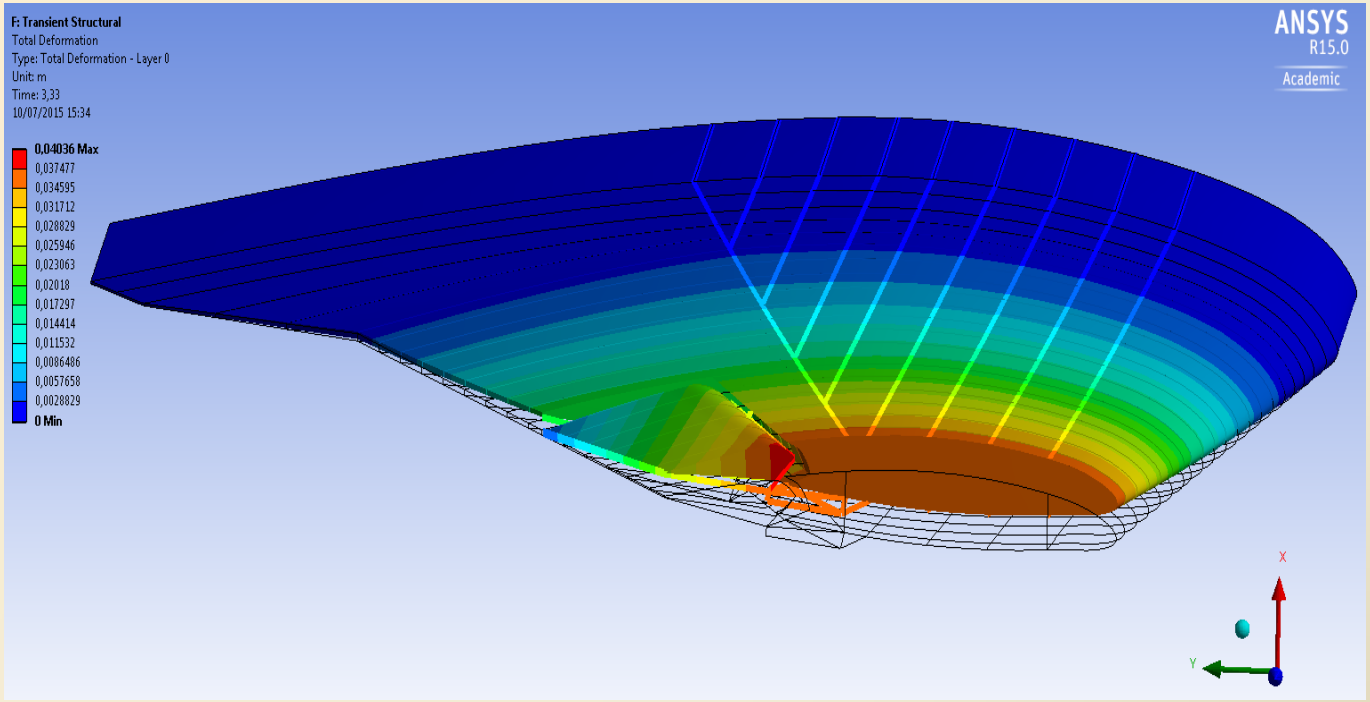
The aerodynamic model of the Aileron-Wing (the surface grid)



Reference: **Deliverable D.8.1** *(In preparation)*

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

Example of results of the FSI analyses of the Aileron-Wing (vertical displcements)



Reference:

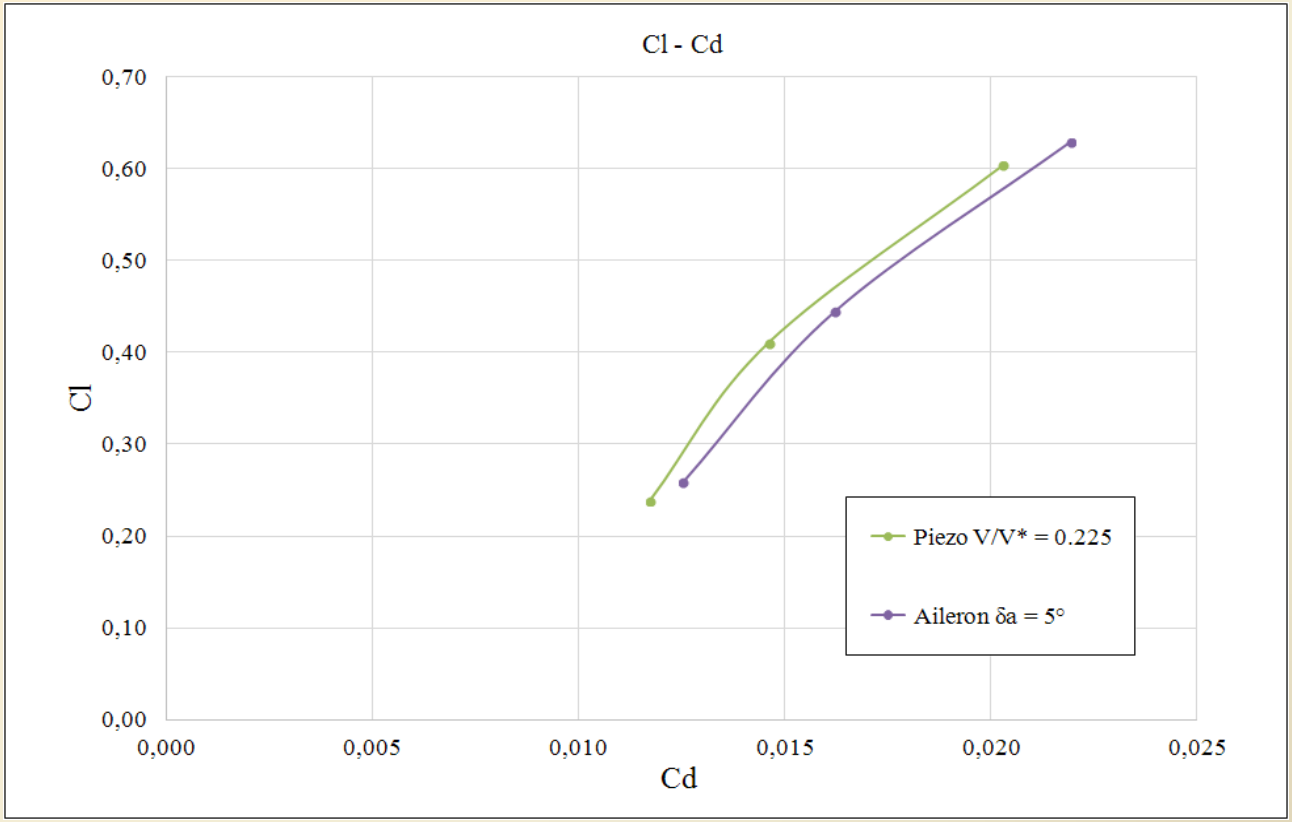
Deliverable D.8.1

In preparation

(h = 0 m, M = 0.17, δ_a=5°, α_g = 0°)

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

Comparison of results of the FSI analyses of the two wings (drag polar curves)



Reference:

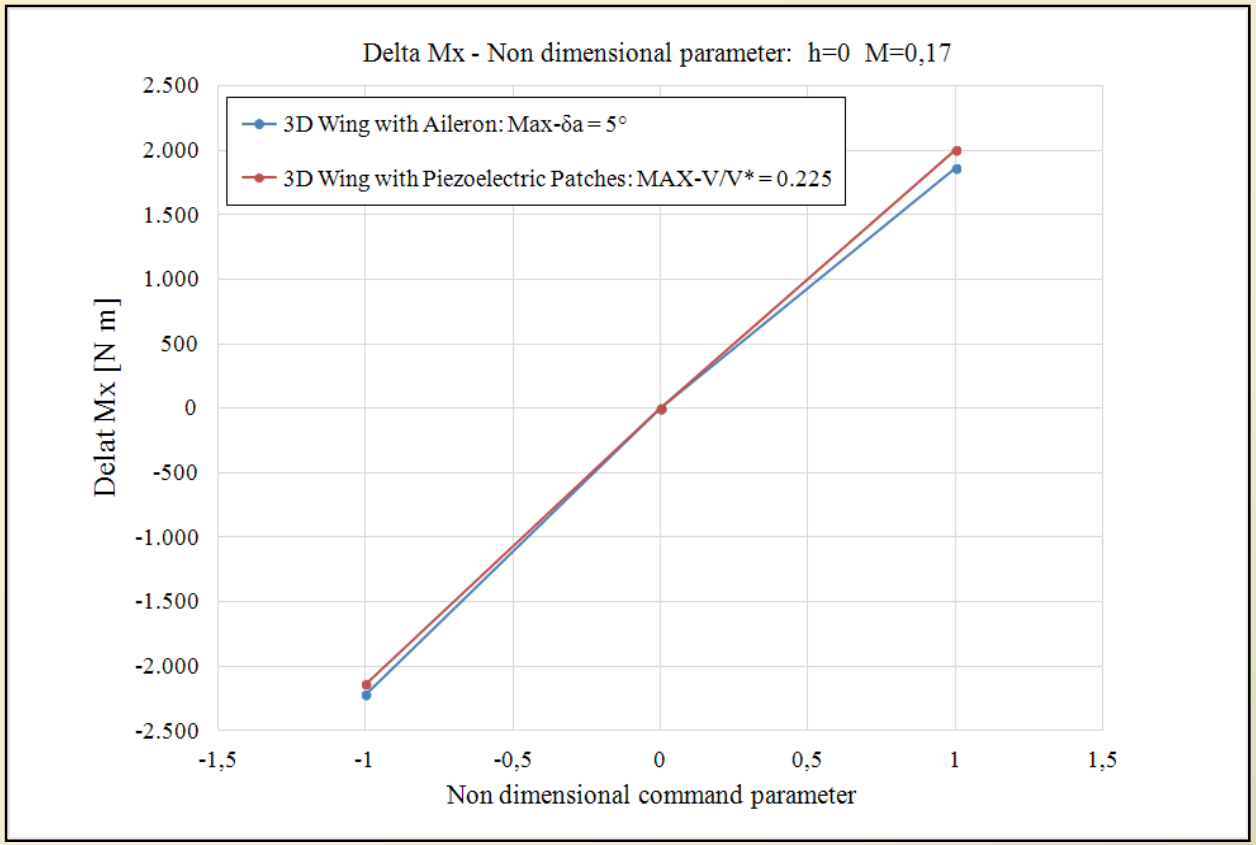
Deliverable D.8.1

In preparation

(h = 0 m, M = 0.17)

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

Comparison of results of the FSI analyses of the two wings (the rolling moment contributions)



Reference:

Deliverable D.8.1

In preparation

(h = 0 m, M = 0.17)

3D Numerical models and FSI analyses: the Reference Wing and the Future Wing

Comparison of results of the FSI analyses of the two wings (the rolling moment contributions)

Piezo-Wing h=0 M=0.17 αg=0°				
V/V* (see slide 27)	**Non dimensional parameter**	**Mx [Nm]**	**Delta-Mx [Nm]**	**Delta-Mx Tot [Nm]**
-0.225	-1	16.077	-2.138	**4,135**
0	0	18.214	0	
0.225	1	20.212	1.998	

Aileron-Wing h=0 M=0.17 αg=0°				
δa (aileron angle)	**Non dimensional parameter**	**Mx [Nm]**	**Delta-Mx [Nm]**	**Delta-Mx Tot [Nm]**
-4°	-1	17.690	-2.218	**4,078**
0°	0	19.908	0	
5°	1	21.768	1.860	

Reference:

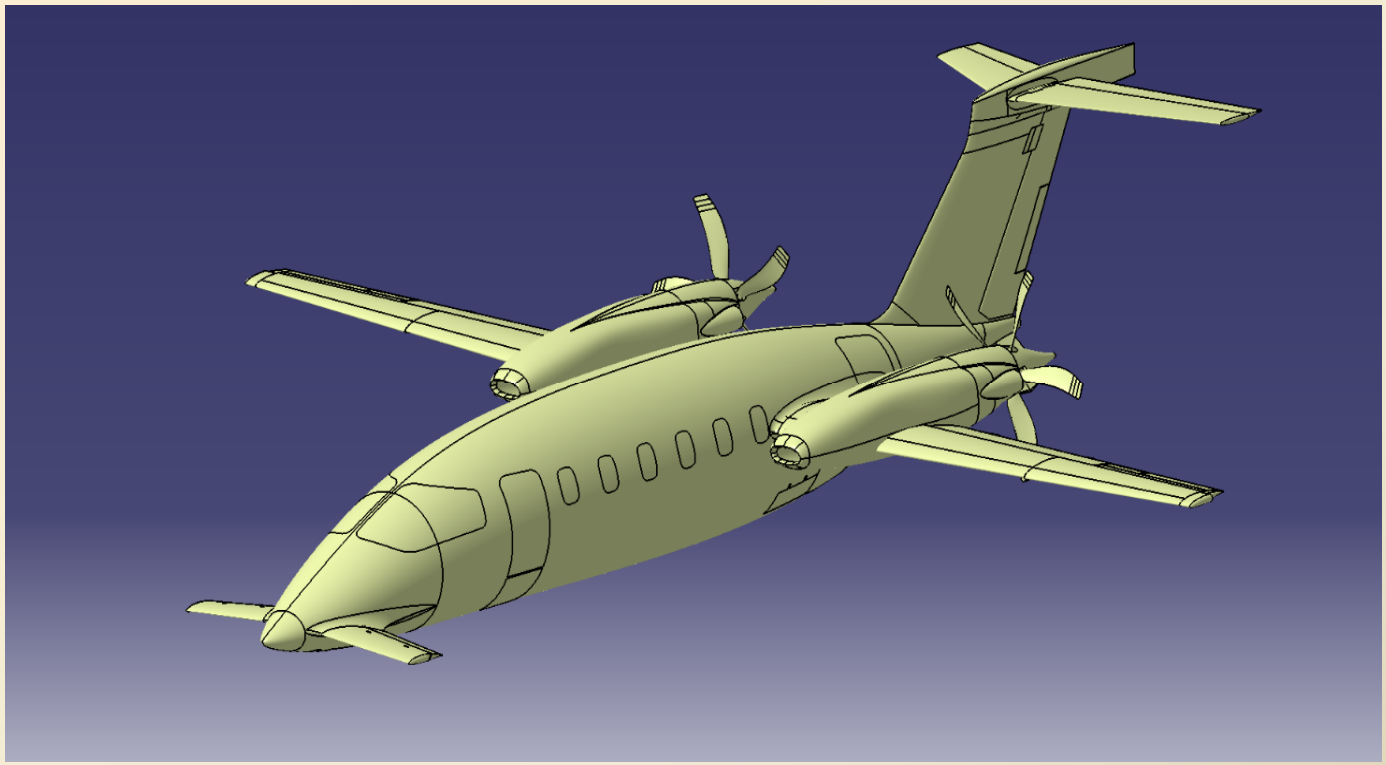
Deliverable D.8.1

In preparation

(h = 0 m, M = 0.17)

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

The reference aircraft (from Piaggio P180 geometry source file)



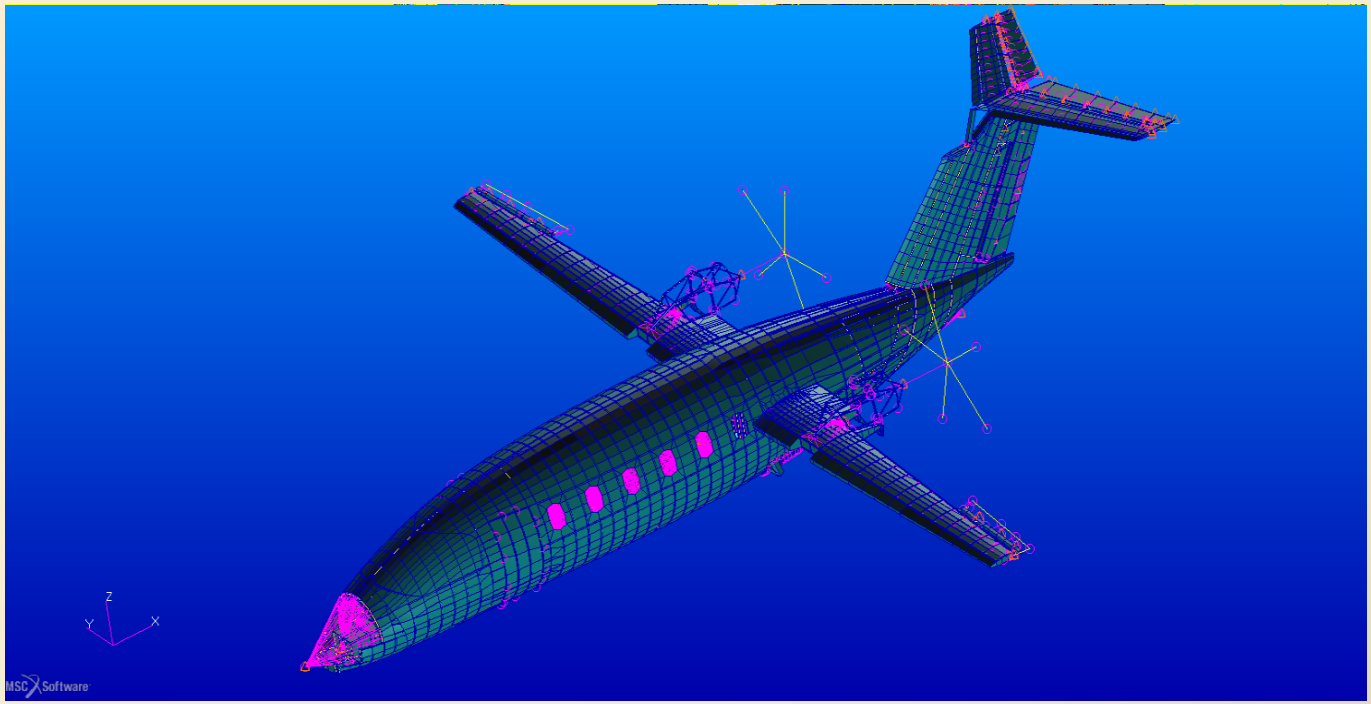
Reference:

Deliverable D.8.1

In preparation

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

The structural model of the reference aircraft (from Piaggio numerical data archive)



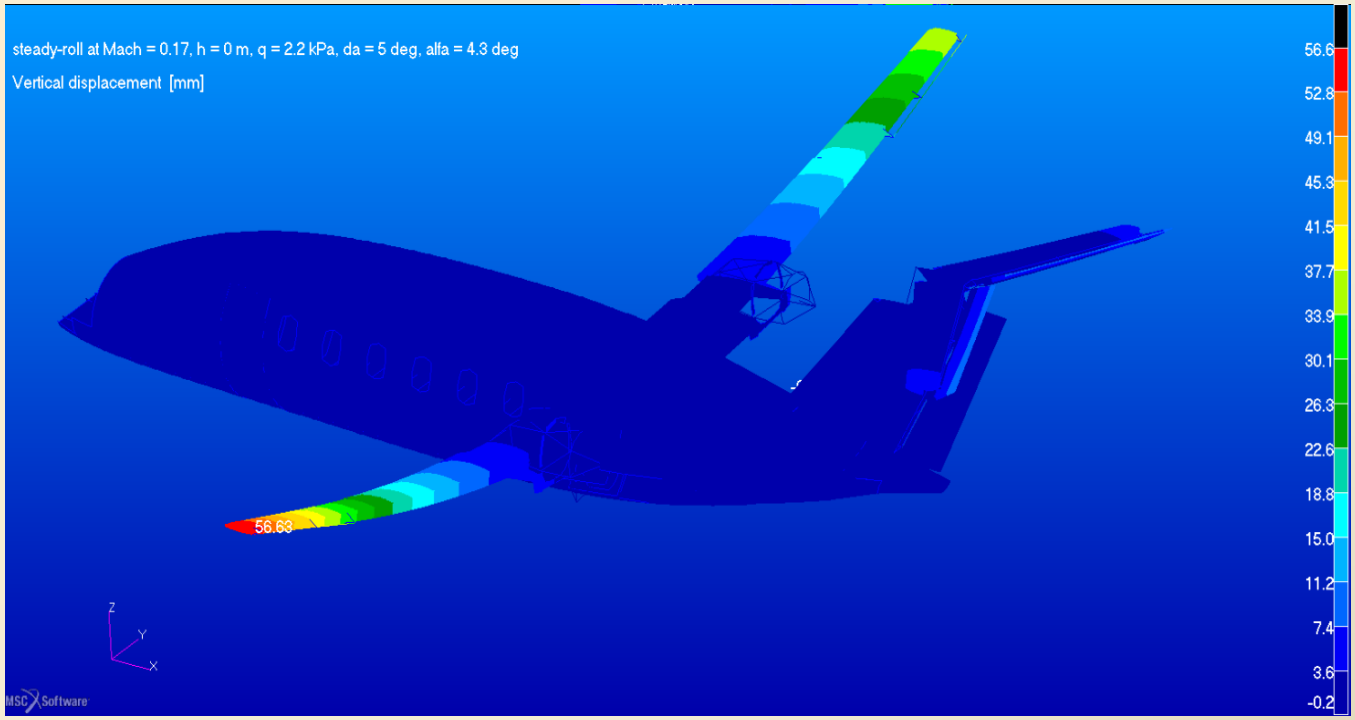
Reference:

Deliverable D.8.1

In preparation

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

Aeroelastic deformation of the reference aircraft for a steady roll maneuver



Reference:

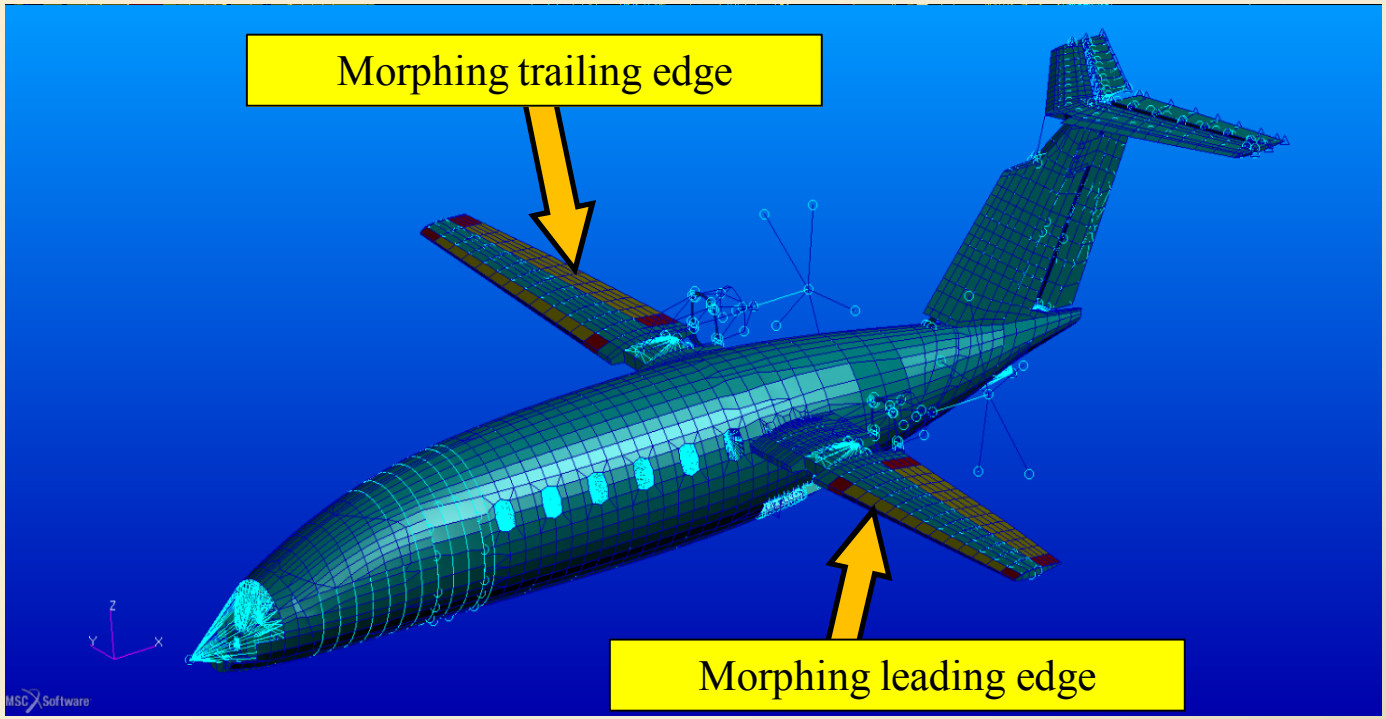
Deliverable D.8.1

In preparation

(M = 0.17, h = 0 m, δa = 5°, αnum = 4.3°)

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

The structural model of the Future Wing aircraft



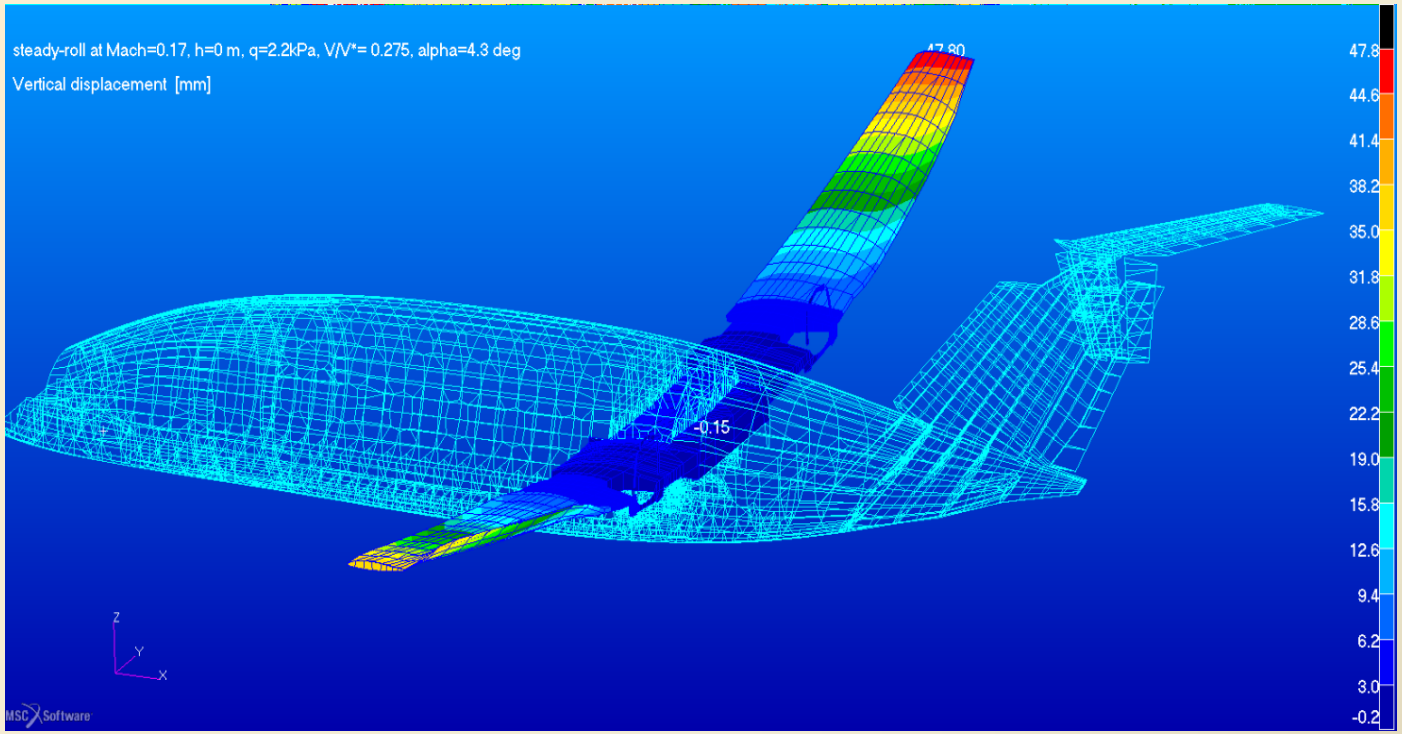
Reference:

Deliverable D.8.1

In preparation

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

Aeroelastic deformation of the Future Wing Aircraft for a steady roll maneuver



Reference:

Deliverable D.8.1

In preparation

(M = 0.17, h = 0 m, q = 2.2 kPa, V/V* = 0.275, AoA = 4.3°)

3D Numerical models and aeroelastic analyses of a Future-Wing aircraft

Example of comparison of the aeromechanical performances (rolling moment coefficient)

Reference	Steady roll at M = 0.17, h = 0 m, q = 2.2 kPa, δa = 5°, α_{TRIM} = 3° (numerical angle of attack equal to 4.3°)		
Trimmed variable	Numerical value		Piaggio flight data
	rigid	Elastic	
$C_{L\alpha}$ [rad^{-1}]	7.1	6.8	7.7
$C_{l\delta a}$ [rad^{-1}]	0.198	0.125	N/A
Cl	---	**0.01091**	0.01

Morphing	Steady roll at M = 0.17, h = 0 m, q = 2.2 kPa, V/V* = 0.275, α_{TRIM} = 3° (numerical angle of attack equal to 4.3°)		
Trimmed variable	Numerical value		Piaggio flight data
	rigid	Elastic	
$C_{L\alpha}$ [rad^{-1}]	7.1	6.8	7.7
CL	0.51		N/A
Cl	**0.0086**		N/A

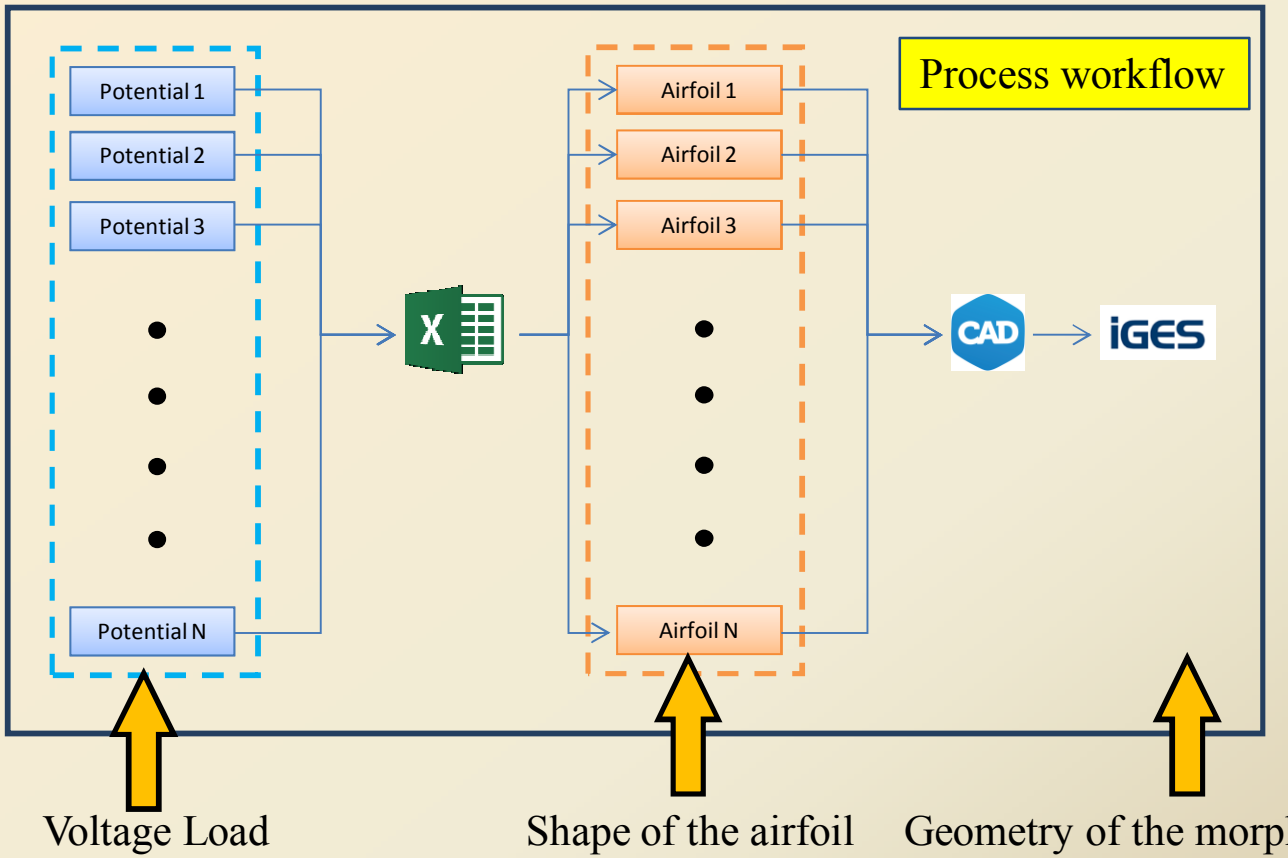
Reference:

Deliverable D.8.1

In preparation

Computer Aided Creative Design concept

Dynamic control of the geometry of morphing three-dimensional wings



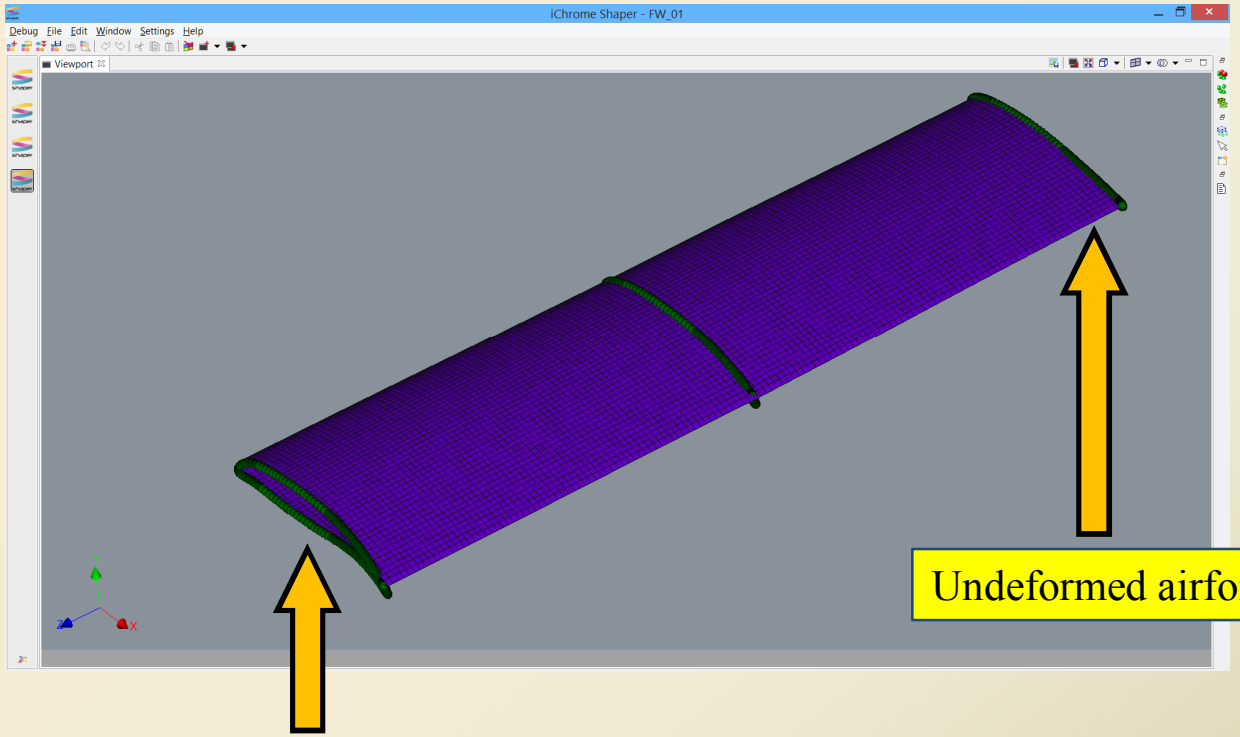
Reference:

Deliverable D.8.1

In preparation

Computer Aided Creative Design concept

Dynamic control of the geometry of morphing three-dimensional wings (example)



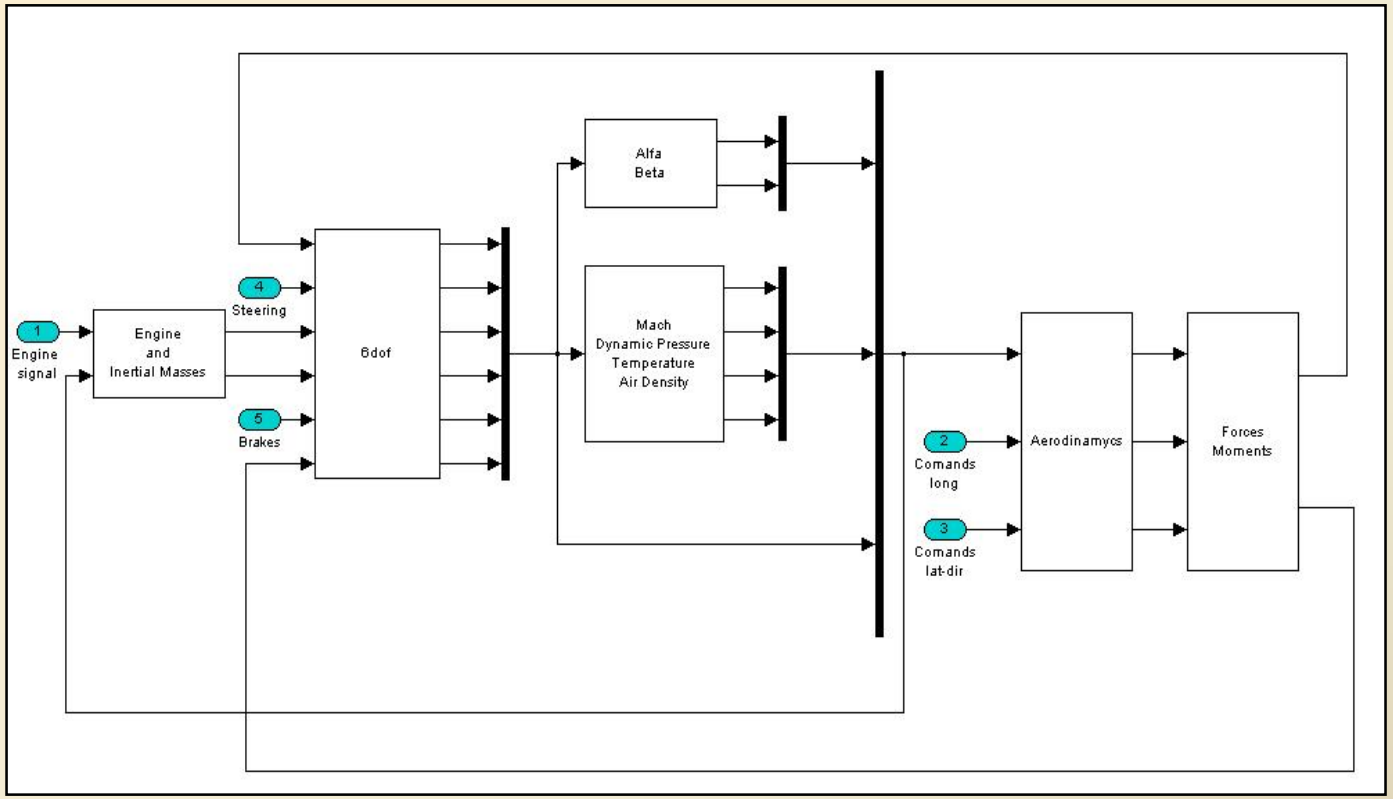
Reference:

Deliverable D.8.1

In preparation

Final implementation of the flight simulator

The flight simulator mathematical model



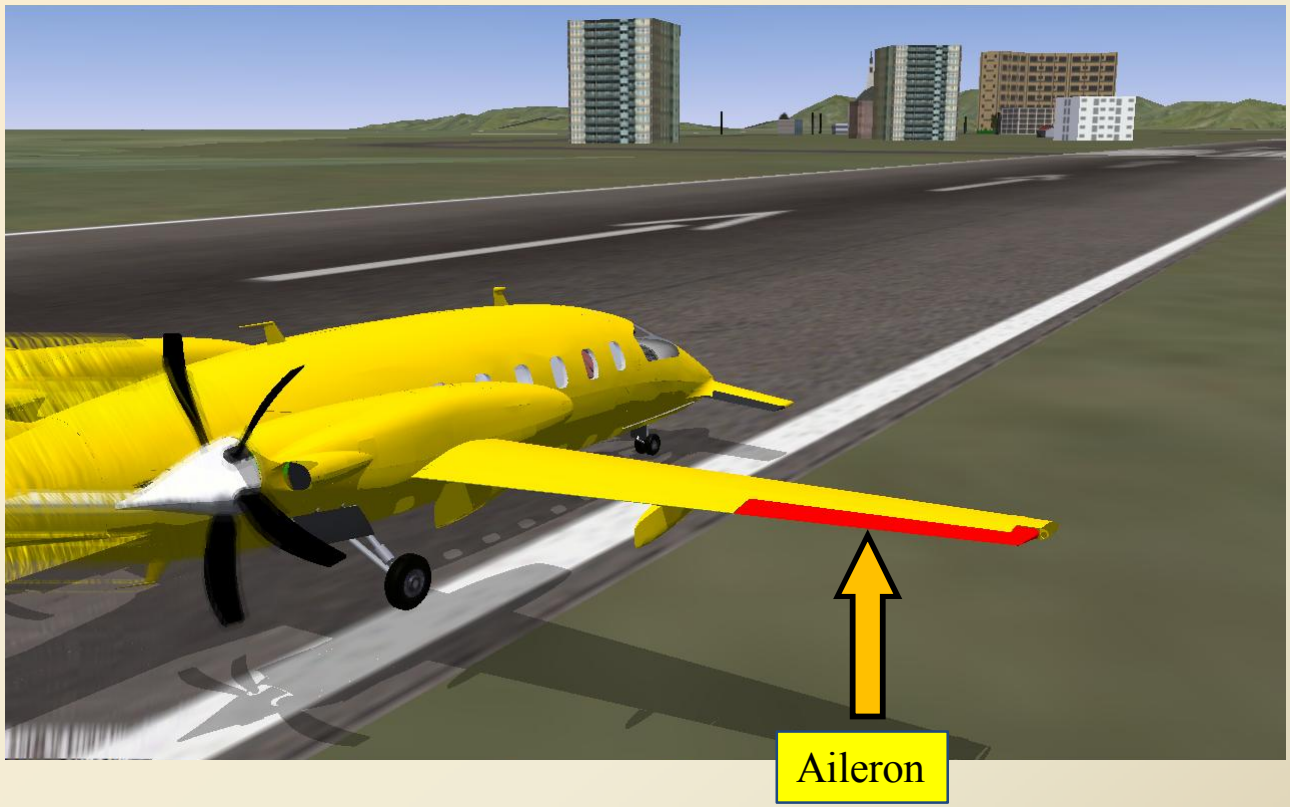
Reference:

Deliverable D.8.1

In preparation

Final implementation of the flight simulator

The reference aircraft (Piaggio P180 Avanti)



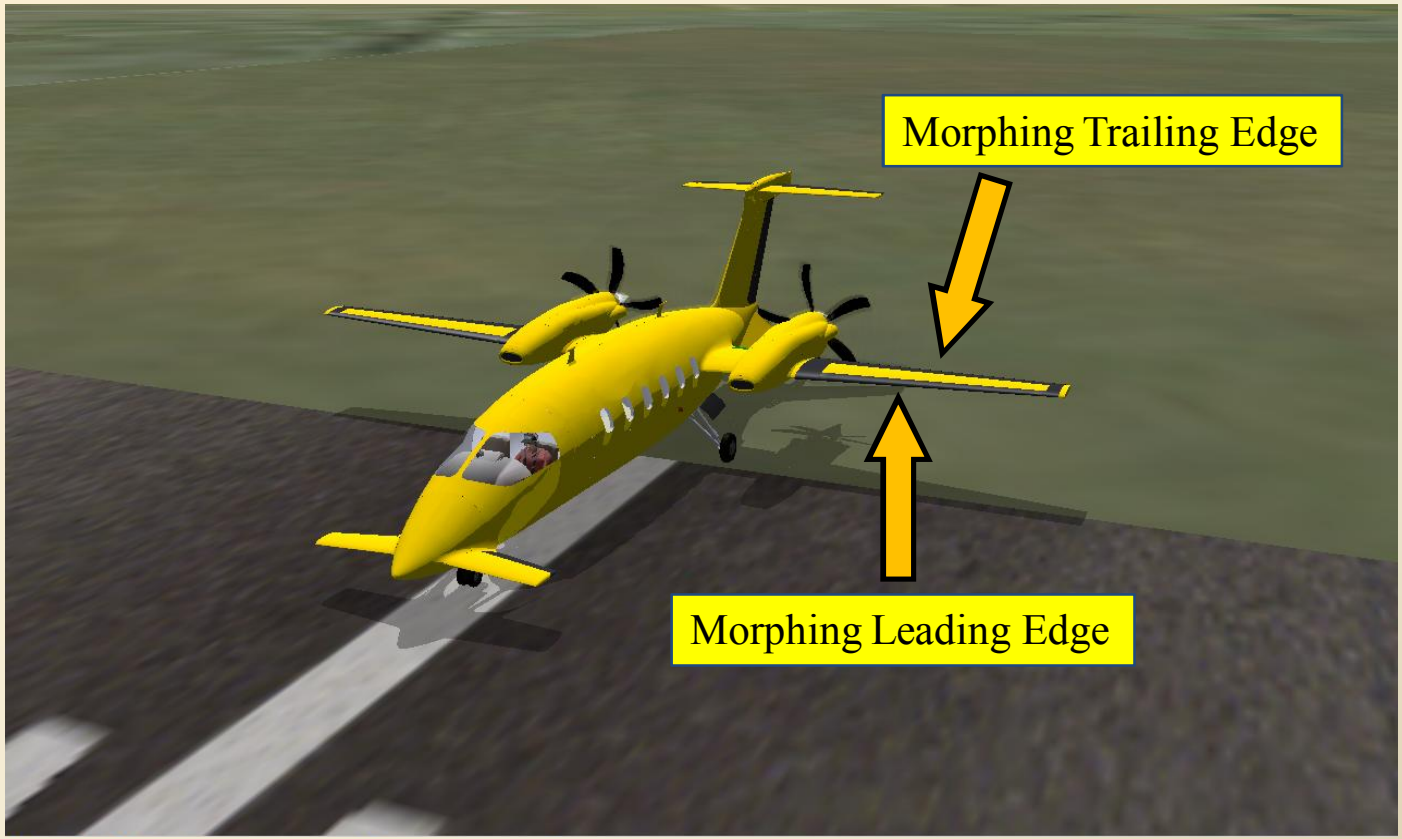
Reference:

Deliverable D.8.1

In preparation

Final implementation of the flight simulator

The implemented Future Wing Aircraft



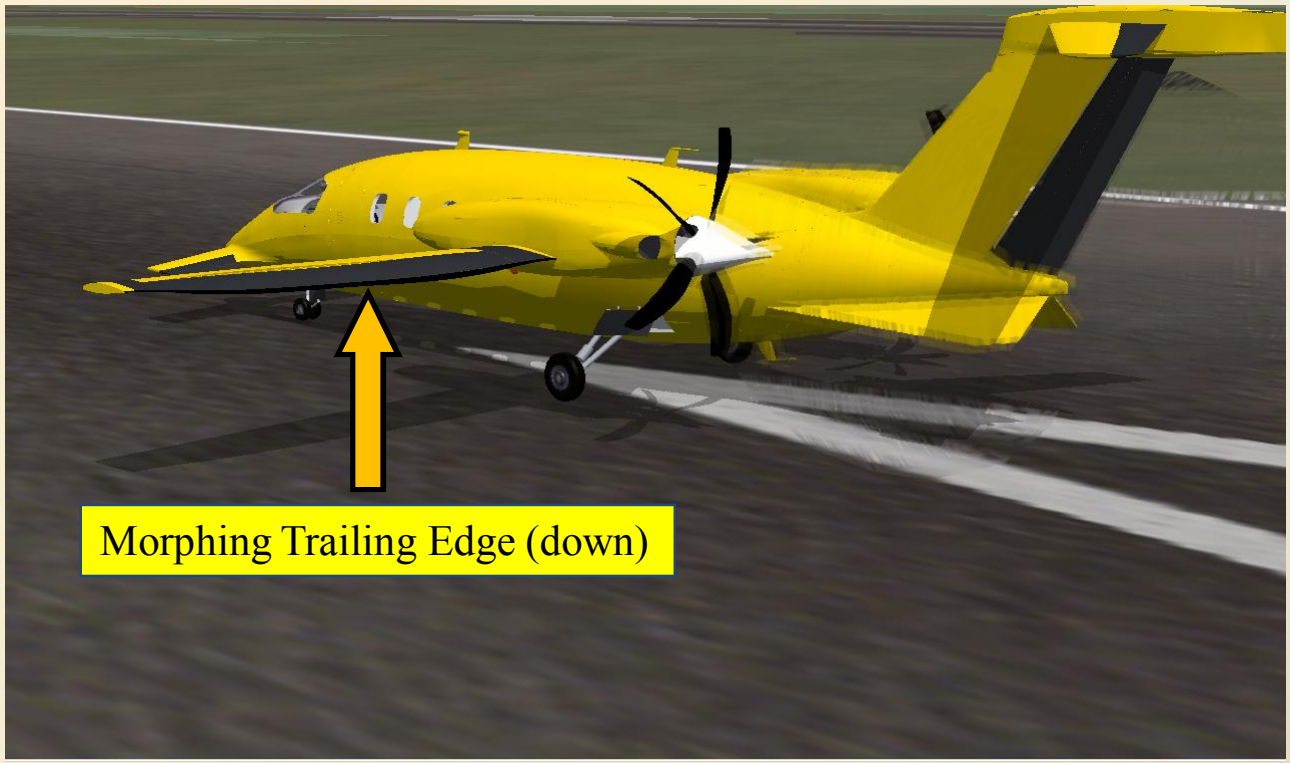
Reference:

Deliverable D.8.1

In preparation

Final implementation of the flight simulator

The implemented Future Wing Aircraft

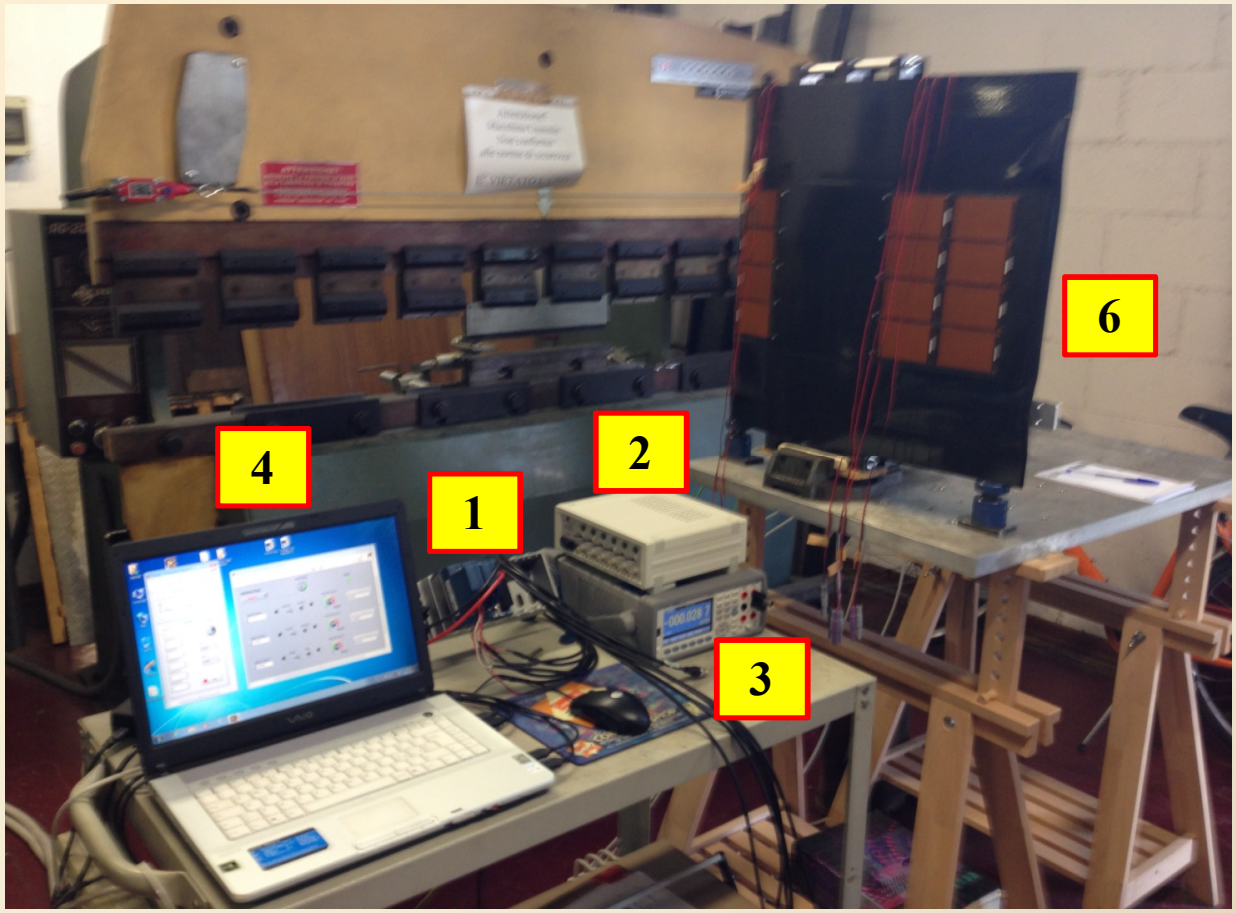


Reference:

Deliverable D.8.1

In preparation

Set up of the electronic control system for the Future Wing Unit



Reference:

Deliverable D.7.1

(1) the Digital Control Interface

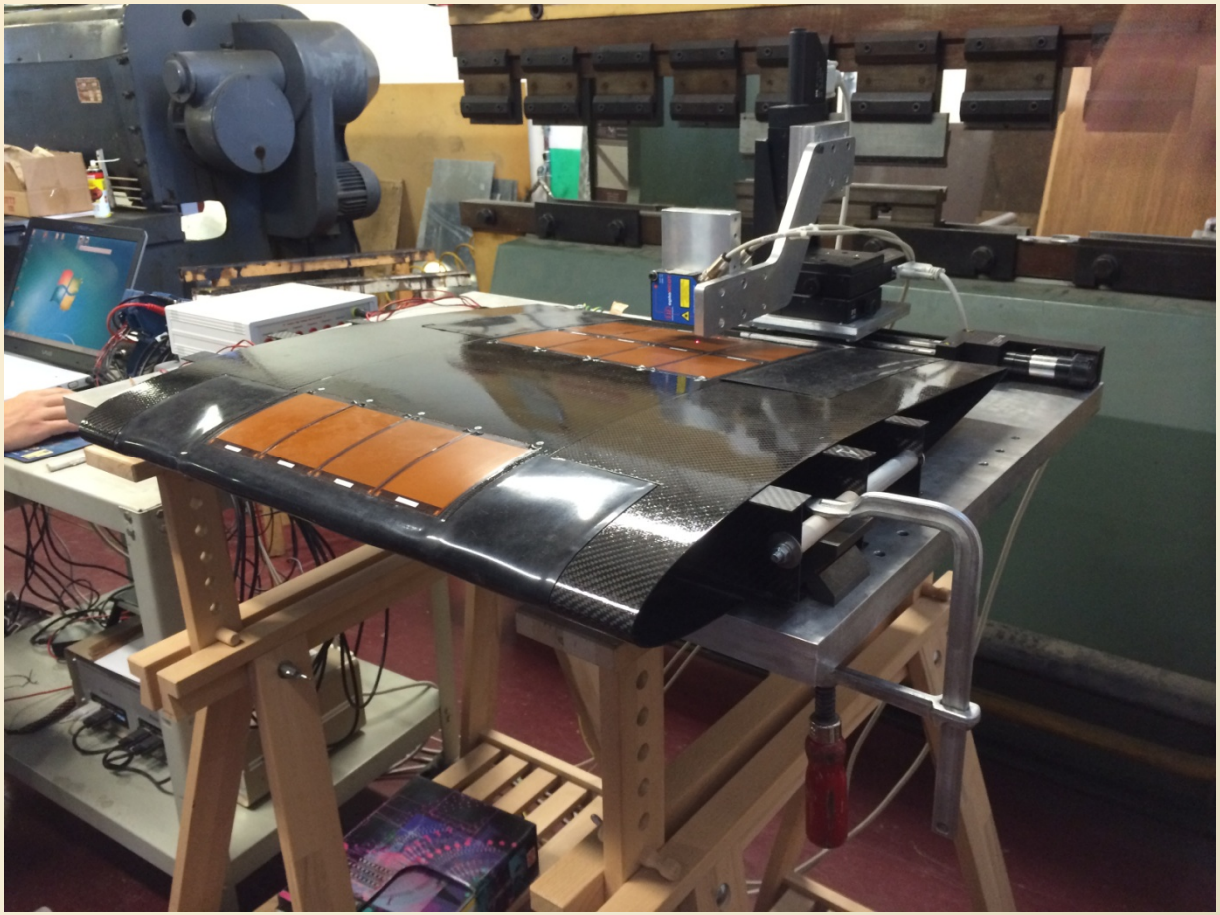
(2) the HV Amplifier

(3) the Digital Tester

(4) the Personal Computer with a dedicated multi-channels control software

(5) the FW-UNIT-1

Test of the Future Wing Unit 1



Reference:

Deliverable D.7.1

Test of the Future Wing Unit 1

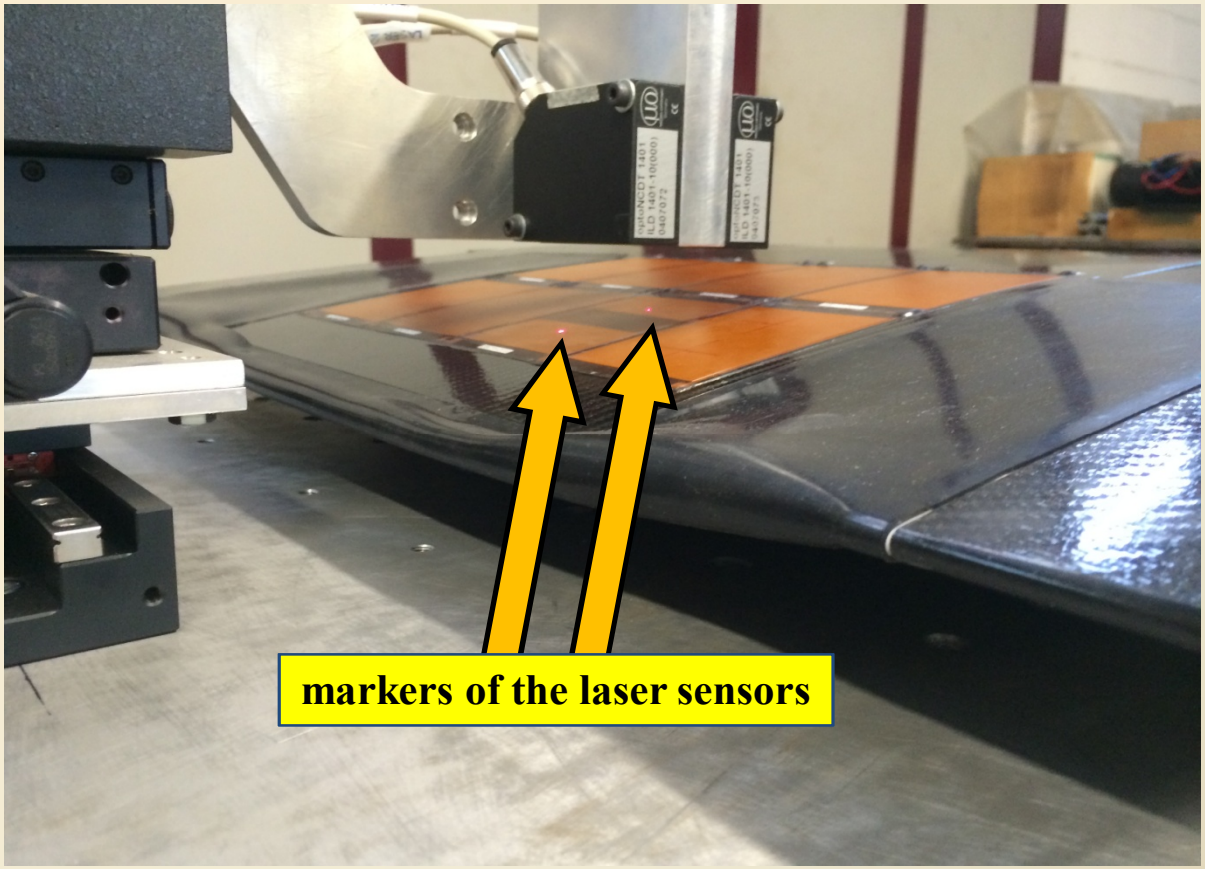
TEST N. 1 (Trailing Edge of the SKIN 1)

HV Output Channel	N. of MFC Patches connected	Position
Channel 1	8	Outer Surface of SKIN 1
Channel 2	8	Inner Surface of SKIN 1
Channel 3	8	Inner Surface of SKIN 2
Channel 4	8	Outer Surface of SKIN 2

Loading Condition	Channel 1 [V]	Channel 2 [V]	Channel 3 [V]	Channel 4 [V]
[1]	0	0	0	0
[2]	300	-100	300	-100
[3]	600	-200	600	-200
[4]	900	-300	900	-300

Reference: **Deliverable D.7.1**

Test of the Future Wing Unit 1

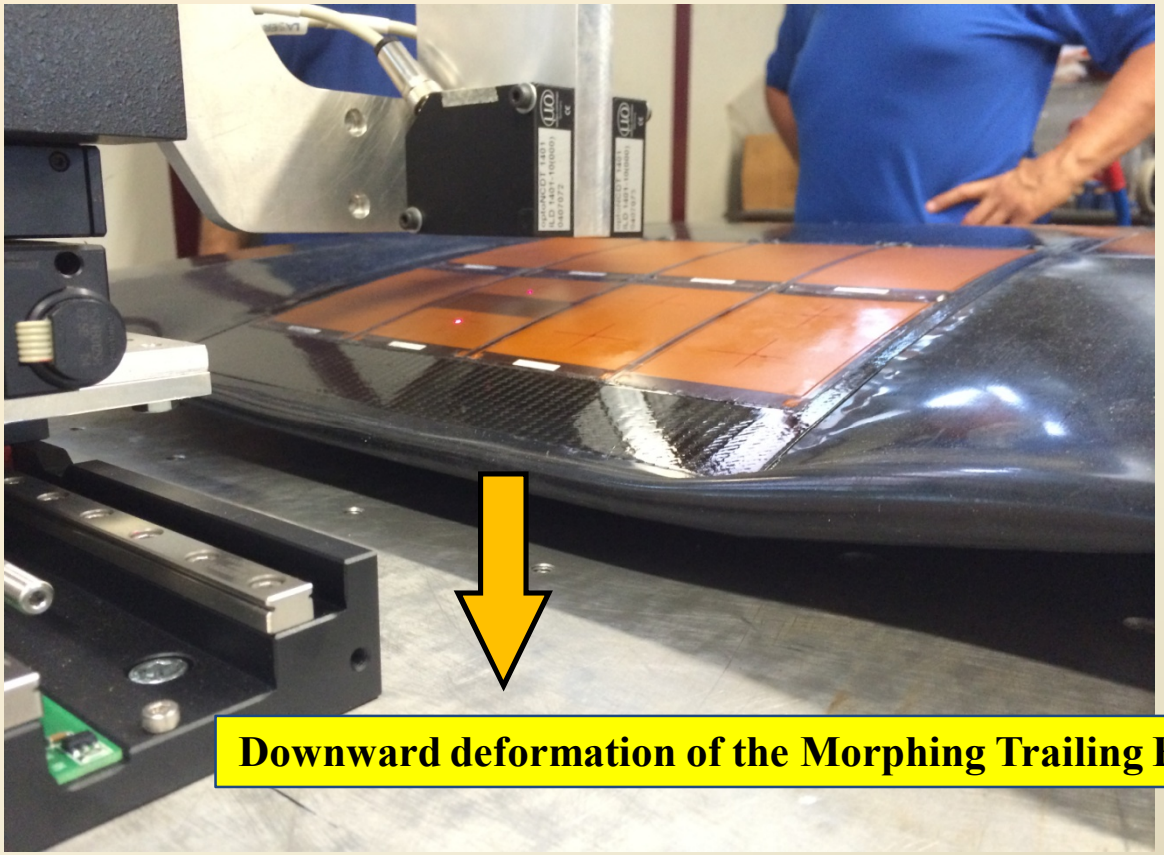


TEST N. 1

Reference:

Deliverable D.7.1

Test of the Future Wing Unit 1



TEST N. 1

Reference:

Deliverable D.7.1

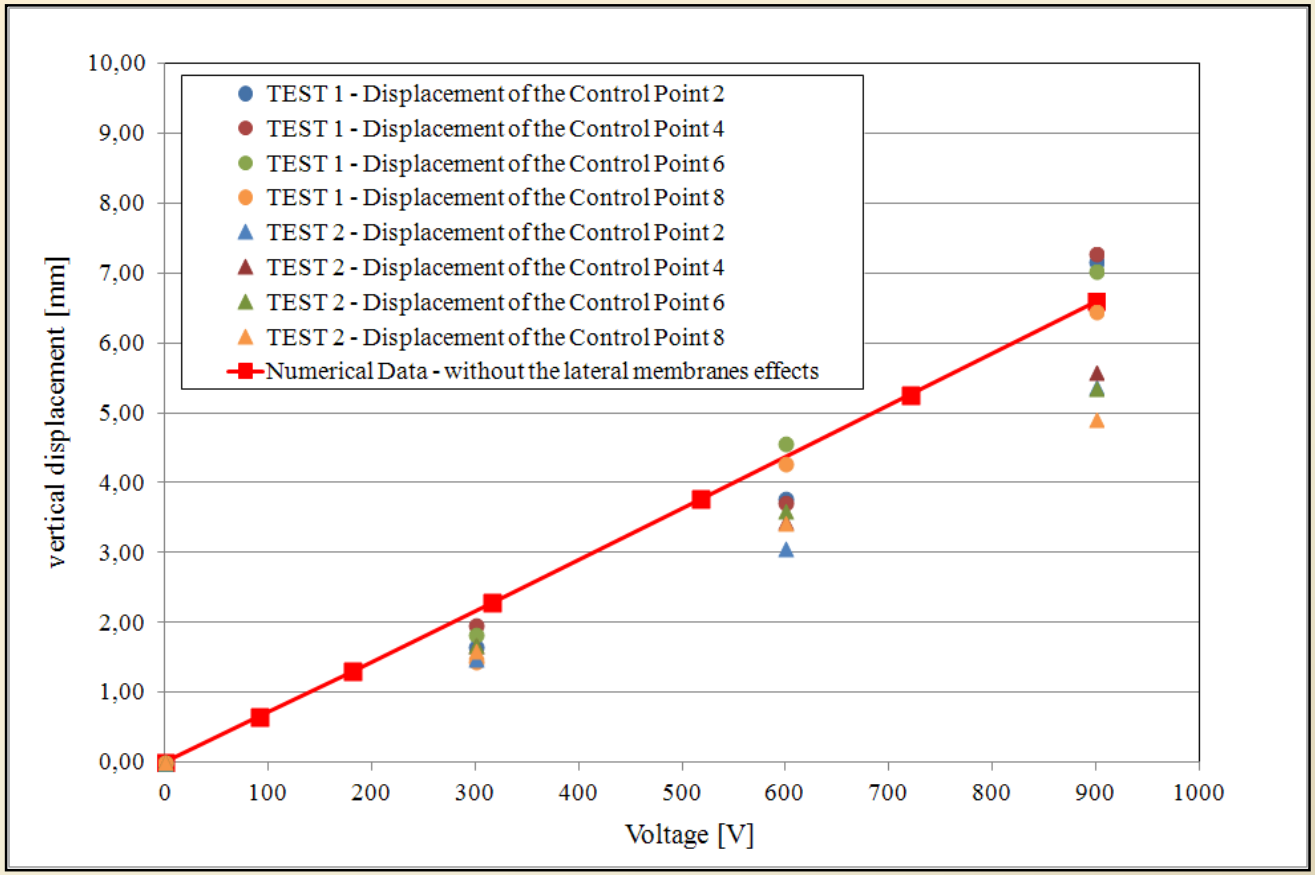
Test of the Future Wing Unit 1

TEST N. 1

Loading Condition	Control Point 1 [mm]	Control Point 2 [mm]	Control Point 3 [mm]	Control Point 4 [mm]	Control Point 5 [mm]	Control Point 6 [mm]	Control Point 7 [mm]	Control Point 8 [mm]
[1]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
[2]	0.98	1.65	1.18	1.98	1.10	1.83	0.85	1.45
[3]	2.08	3.78	2.58	3.73	2.60	4.58	2.40	4.28
[4]	4.00	7.15	4.23	7.28	4.08	7.03	3.63	6.45

Reference: **Deliverable D.7.1**

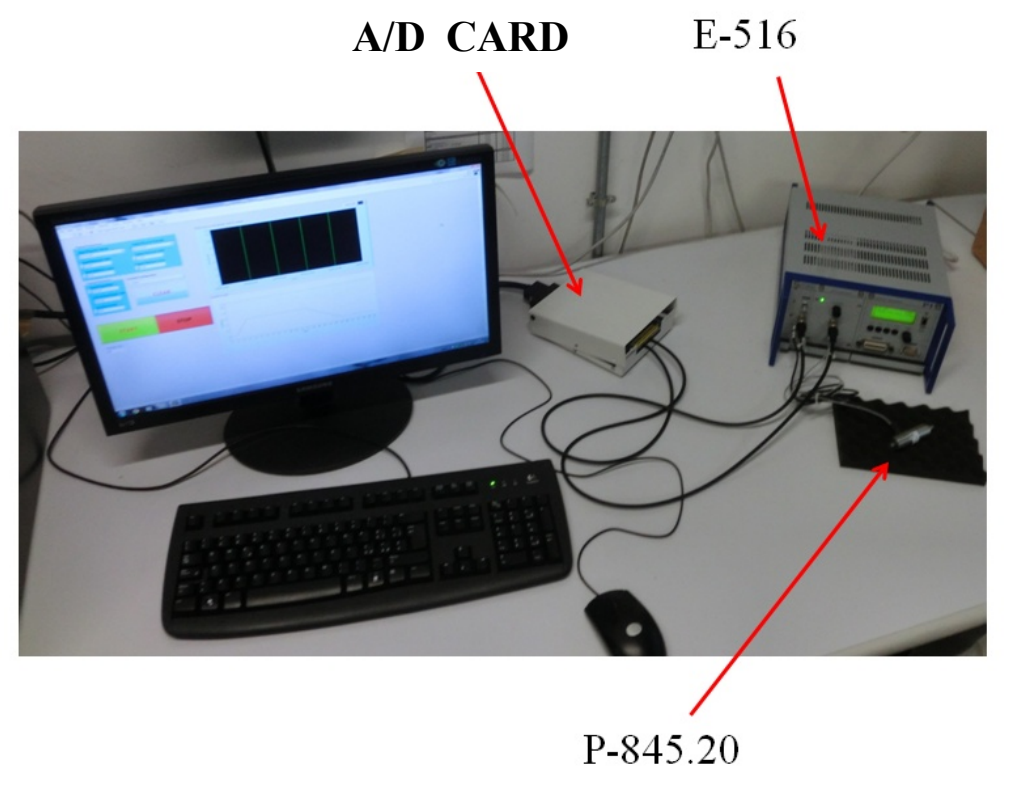
Test of the Future Wing Unit 1



Comparison of numerical and experimental results - Reference: **Deliverable D.7.1**

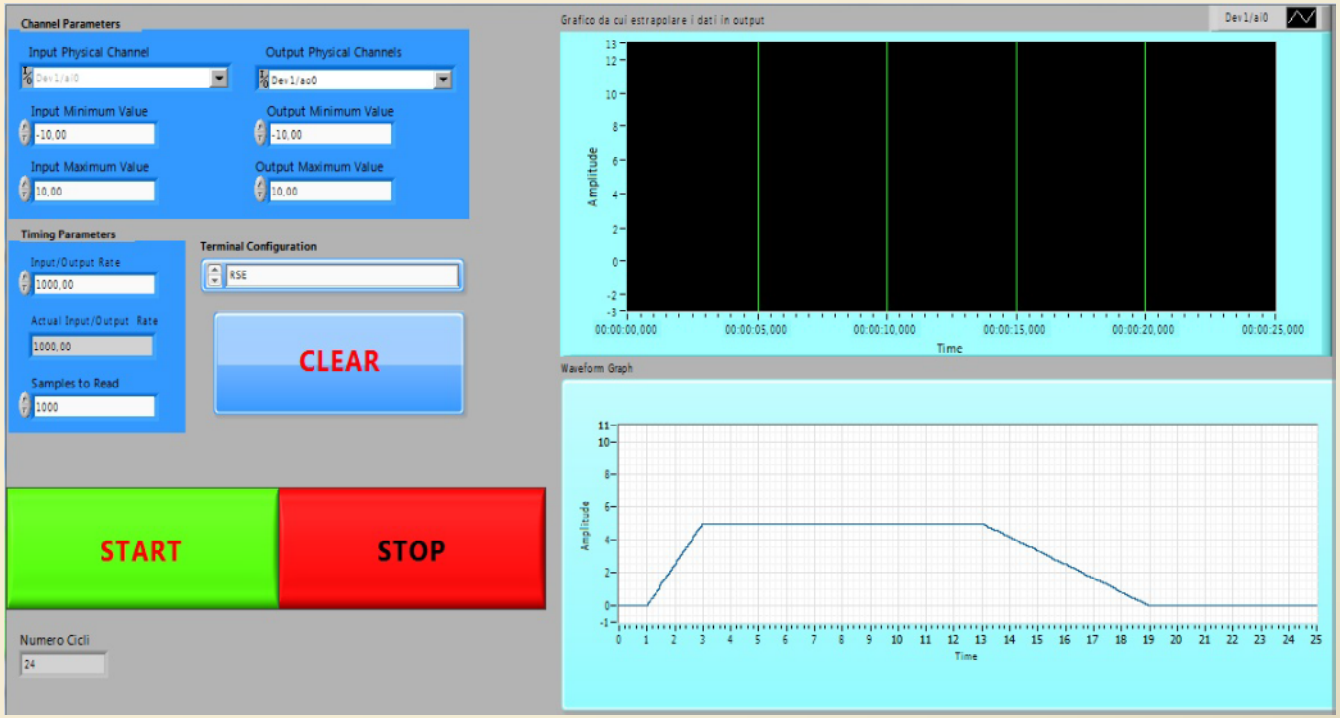
Test of the Future Wing Unit 1

Preliminary development of a multi-channel dynamic control system



Test of the Future Wing Unit 1

Preliminary development of a multi-channel dynamic control system

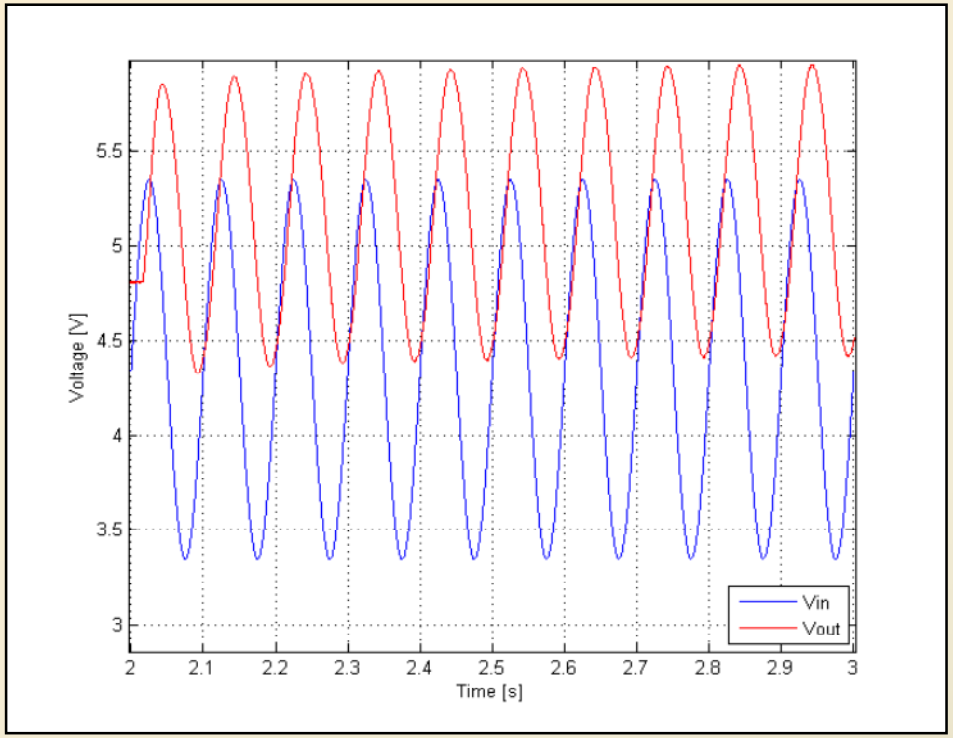


The control panel (LabVIEW environment)

Reference: **Deliverable D.7.1**

Test of the Future Wing Unit 1

Preliminary development of a multi-channel dynamic control system

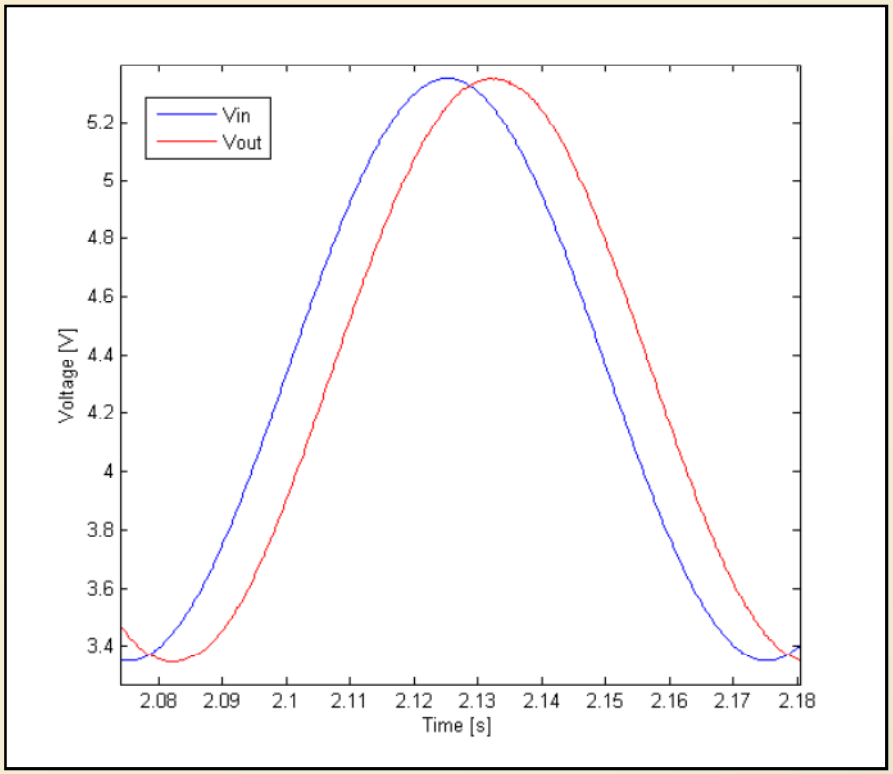


Test with a SINE WAVE INPUT at low frequency (10 Hz)
(**open loop**)

Reference: **Deliverable D.7.1**

Test of the Future Wing Unit 1

Preliminary development of a multi-channel dynamic control system



Test with a SINE WAVE INPUT at low frequency (10 Hz)
(**closed loop**)

Reference: **Deliverable D.7.1**

Second Year Technical Results (1 of 2)

- **Preliminary models for fluid structure interaction analyses of morphing wing sections**
- **Reliable numerical procedures for analyzing a Future Wing Unit**
- **Design of two distinct Future Wing units**
- **Detailed design and drawings of the Future Wing Unit 1 (curvature's change)**
- **Manufacturing of the Futre Wing Unit 1**
- **Reliable procedures for analyzing a reference wing section and a morphing one**
- **Preliminary results on the aerodynamic perfomances of a morphing wing section**
- **3D models for FSI analyses of a reference wing (with aileron)**
- **3D models for FSI analyses of a morphing wing (with piezo-patches)**

Second Year Technical Results (2 of 2)

- **Aeromechanical perfomances of the morphing wing *vs* the reference wing**
- **Aeroelastic model of a complete Future Wing Aircraft**
- **Aeromechanical perfomances of the FW Aircraft *vs* the reference Aircraft**
- **Basic procedures for a real time control of the geometry of a morphing wing**
- **Flight mechanics model of the FW Aircraft (Implementation of a Flight Simulator)**
- **Set up of the multi-channel electronic control system (High Voltage capabilities)**
- **Deformation tests of the Future Wing Unit 1**
- **Final validation of design and manufacturing technologies of a piezo-wing section**

Deliverables of the Second Year

- **D.5.1 - Detailed design of the Future-Wing model**
- **D.5.2 - Future-Wing small scale model**
- **D.6.1 - Design, implementation and testing of the Future-Wing model control system**
- **D.7.1 - Static and dynamic tests on the Future-Wing model**

  in preparation

- **D.8.1 - Flight mechanics theoretical model of a Future-Wing Concept Aircraft**
- **D.10.2 - Project Intermediate Report**

Meetings of the partnership

- **Kick-Off Meeting: Pisa 13th of June 2013**
- **Second Meeeting: Rome 10th of January 2014**
- **Third Meetimg: Dresden 20th of January 2015**
- ***The planned intermediate meeting in Bristol did not take place***
- **Final Meeting: : Pisa 27th - 28th of July 2015**

Dissemination activities

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

- **EASN - 5th International Workshop on Aerostructures**
  September 2-4, 2015 - Manchester, UK

- **Aerodays2015 - The 7th European Aeronautics Days**
  20 – 23 October 2015, London

- **Dissemination seminar for engineering students *(planned for September 2015)***