Reshaping the future of aircraft design

RBF4AERO

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Industrial Design & CAE

RINA Consulting S.p.A

December 14th 2017, Rome

FLEXIBLE ENGINEERING

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RBF4AERO Overview

rbf4aeroFSI solver: implementation and test case

Exploitation initiatives (Fortissimo 2 | Experiment n. 906)

What's next....

OUTLINE

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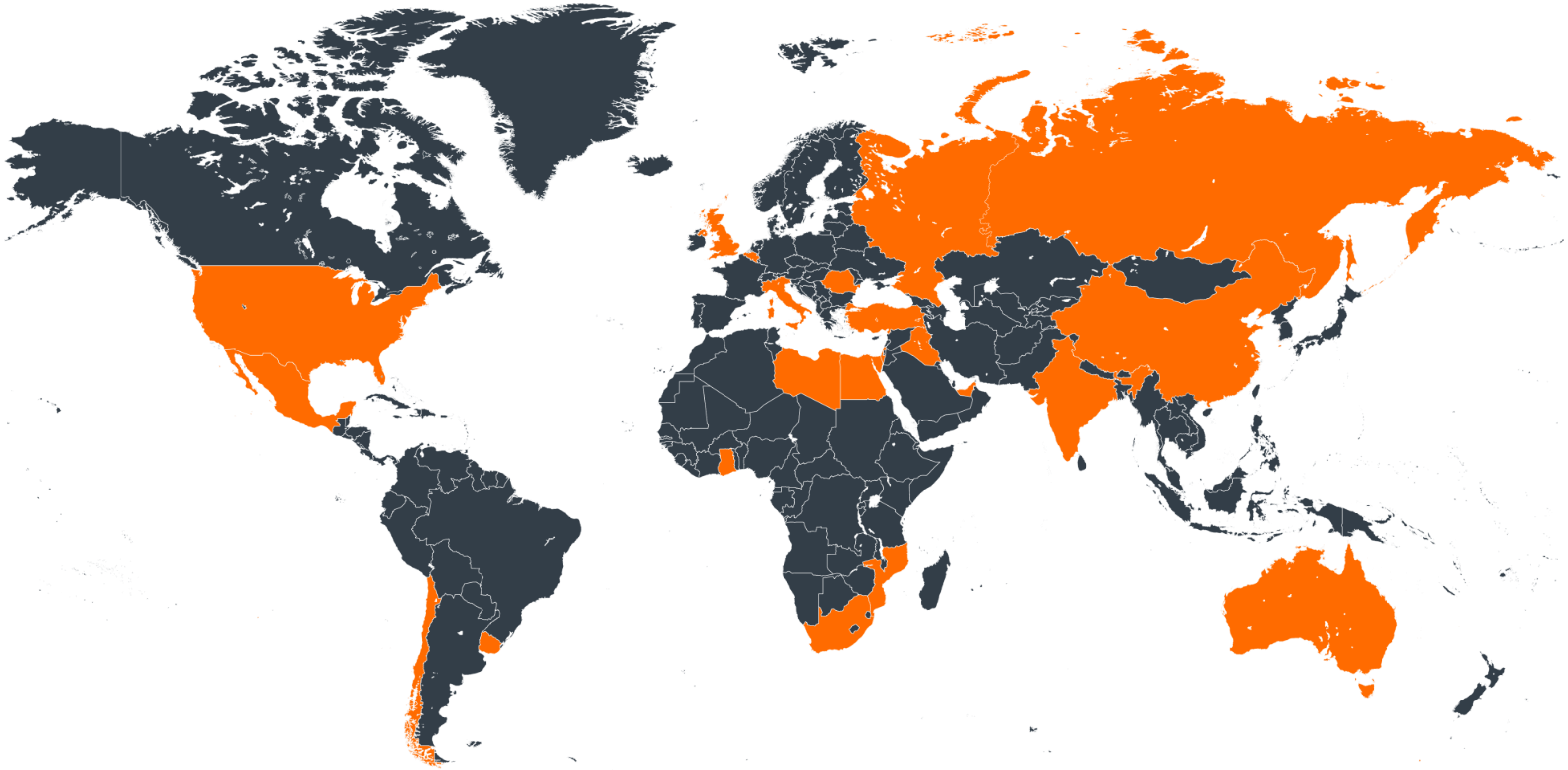

RINA Consulting is an **Italian engineering consulting company**

Offices in **21 countries**

Revenue is more than **160M Euro** (forecast 2017)

Personnel: about **1700**

Sectors: Oil & Gas, Power Generation, Transmission & Distribution, Renewables & Sustainability, **Materials, Technology & Innovation** (MTI), Space & Defense, Transport & Infrastructure

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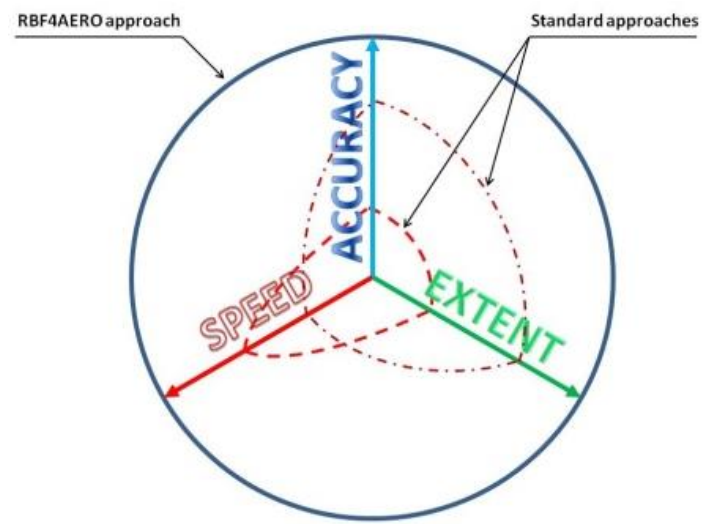
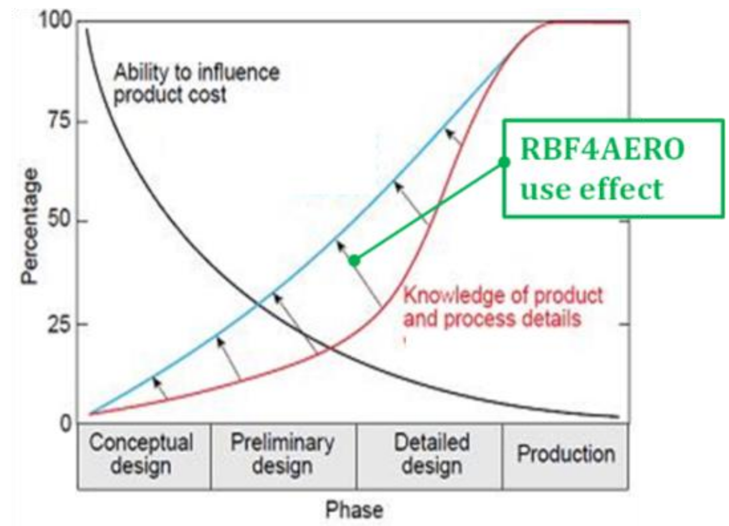
Challenge

To develop **cross-platform** and **cross-solver** tools and methodologies for **CAE-based design** in the **aviation sector**, in order to free the user from the compromise between the contrasting targets of **speed**, **accuracy** and **extent**.

Objectives

- to reduce (**up to 80%** for specific applications) the aerodynamic design process duration;
- to **make feasible** some applications (e.g. FSI) even with high-fidelity models.





PROJECT OVERVIEW

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PROJECT OVERVIEW

The **RBF4AERO** (www.rbf4aero.eu) project aimed at developing an i**ntegrated numerical platform** and **methodology** to efficiently face the most demanding challenges of **aircrafts design** and **optimization**.

The project **ended** on 31st August 2016 after **3 years** with Total EC Funding of ≈ 2.4 M€ (global costs ≈ **3.5 M€**).

The Consortium is composed by **9 partners from 5 countries** and **RINA Consulting** (formerly D'Appolonia) was the **project coordinator** and **UTV** the technical leader.

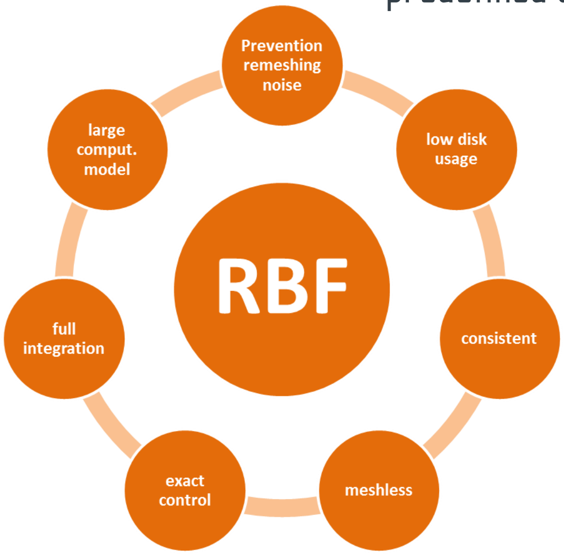
Solution

The basic idea is to make the **numerical model parametric** through the use of a mesh **morphing technique** founded on radial basis functions (**RBF**) mathematical framework.

Core technology

RBF mesh morphing is the core technology of the **RBF4AERO** platform which is based on the **integration** of pre-existing numerical tools developed by consortium partners (e.g. Morpher Tool).

RBF are a class of mathematical **interpolation functions**. In **CAE** applications, such functions can be used to drive **mesh morphing** (smoothing) of computational nodes applying predefined displacements to **source points**.



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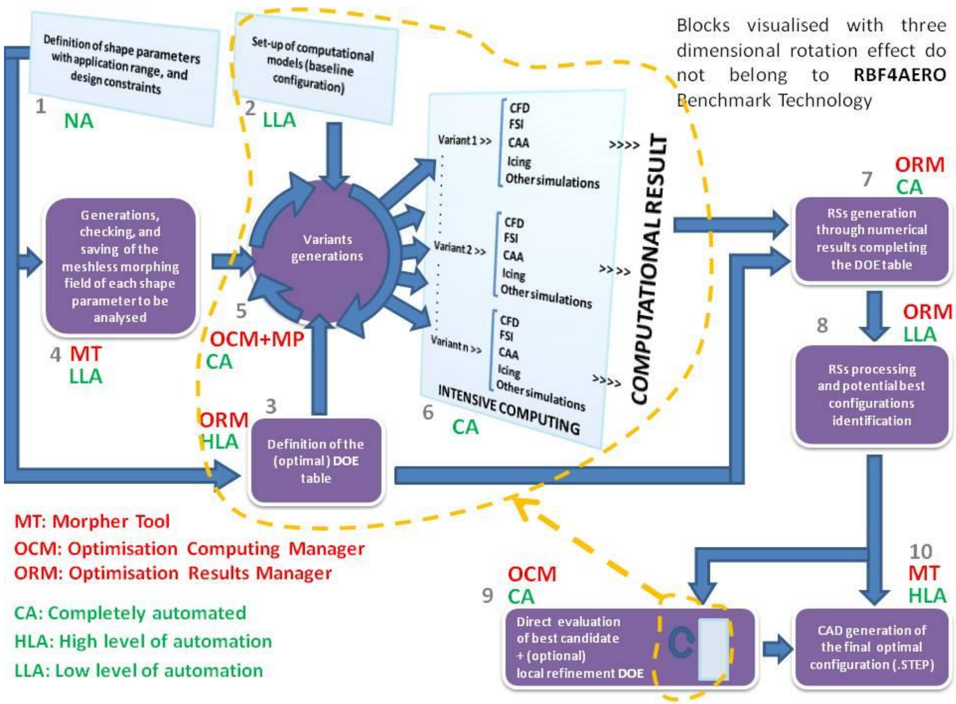
The **RBF4AERO** platform allows to carry out:

- MOO/MDO using **EA** (evolutionary algorithms) with DoE sampling + metamodel;
- CFD optimizations through **adjoint-morphing coupling** (adjoint preview and sculpting);
- **icing** simulation (constrained and on-the-fly);
- **FSI** (two-way and mode-superposition in EA-Opt).



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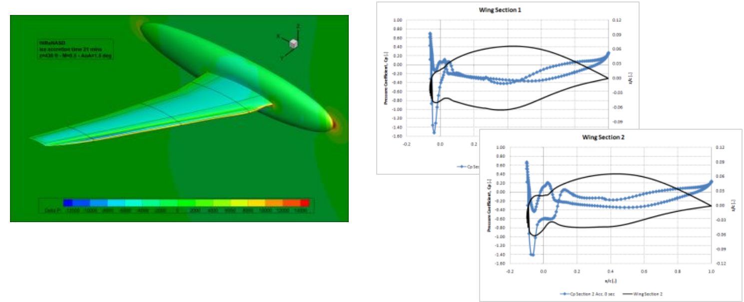
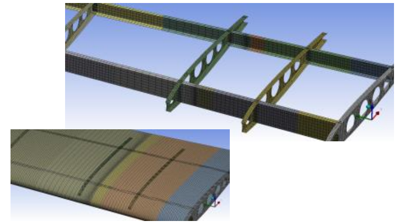
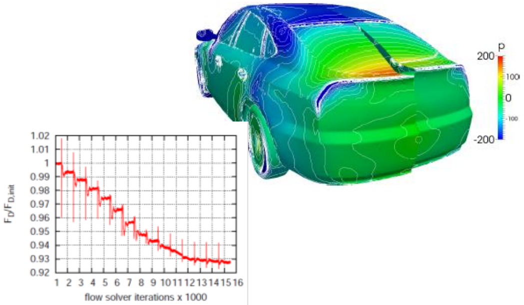
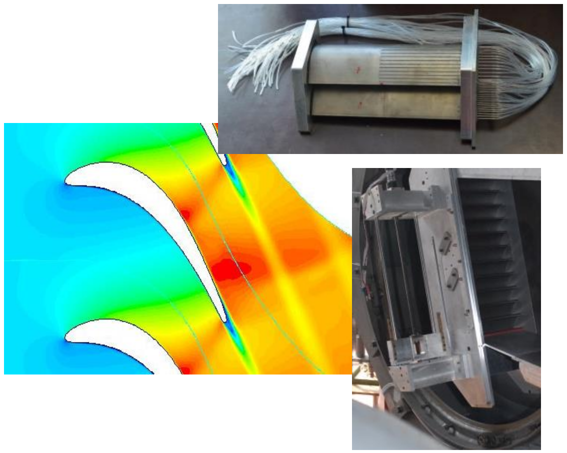
RBF4AERO platform testing / validation / verification:

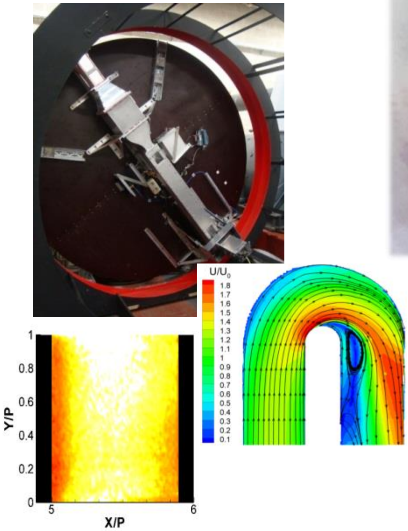
- **Numerical testing**: 18 numerical test cases ranging from NACA airfoil to real aircraft were studied and optimised
- **Numerical validation**: aero-elastic numerical procedures for static FSI were validated
- **Experimental verification**: 3 numerical test cases (low-pressure turbine, turbine internal cooling and contra-rotating ducted rotors) were also verified by experiments

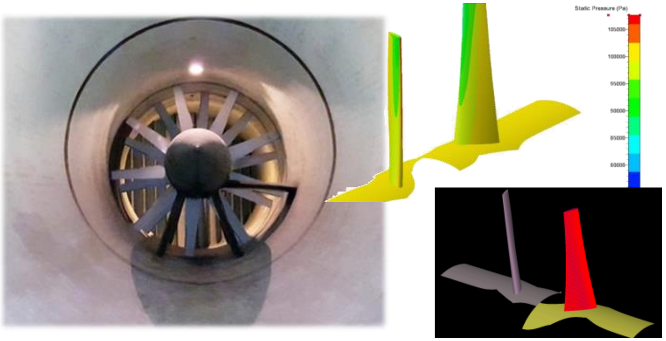












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RBF4AERO promo video

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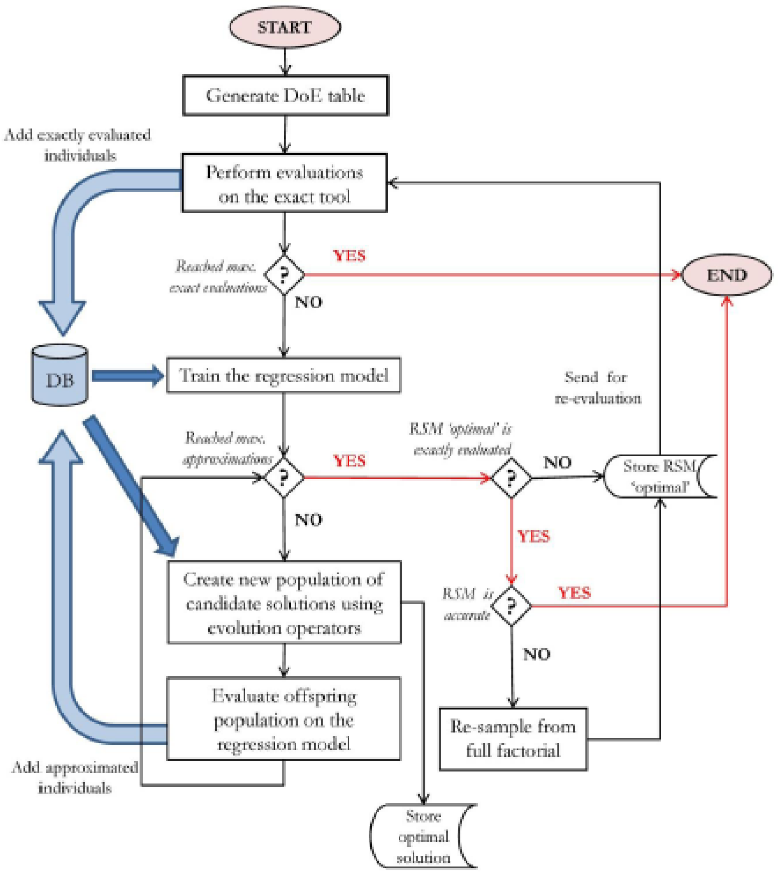
rbf4aeroFSI is one of the features implemented and managed by the RBF4AERO platform.

It consistis of an **EA-based optimization** (see figure) in which the elasticity (**FSI module**) of deformable components is accounted in each design point (DP).

The **EA-based optimization** is assisted by **metamodels** trained on data collected during the **Design-of-Experiment** (DoE) phase and supported by the **Response Surface Models** (RSM) that reduces the number of evaluation tool calls.



RBF4AEROFSI IMPLEMENTATION

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Two approaches for **FSI**, envisaged to be implemented in the Project, were validated on the **HIRENASD** model deeply investigated in **NASA** aero-elastic prediction workshop (**AePW**):

- **Two-way**: the exchange of data between the CSM (via pressure mapping) and CFD model (via morphing) is iterated until convergence is achieved;
- **Modal superposition**: structure modes are imported into the CFD model using the morpher tool so that it is made "elastic" (morphing). FSI cycles run until convergence is achieved.

Main features / characteristics:

- Cross-solver
- Highly automated numerical processes
- Parallel computing
- RBF are used for mapping CFD loads (two-way) and to morph the CFD model.

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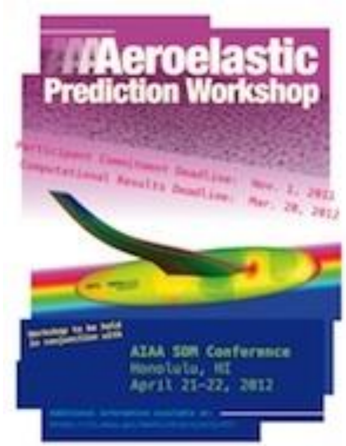
The HIRENASD model of the aero-elastic prediction workshop (**AePW**) was selected to accomplish the validation of **both FSI approaches**.

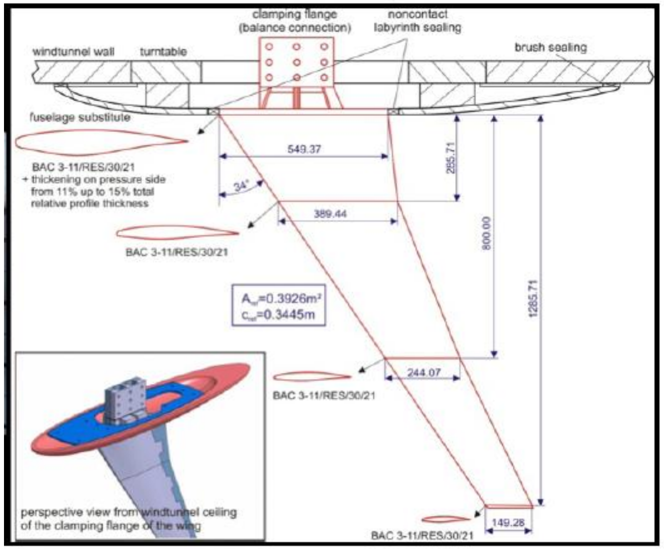
High-fidelity (extensively tested) models made available by the AePW committee were used.

Wind tunnel model



Test n. 132

Parameter	Value	Units
Mach	0.8005	-
Reynolds	6.999999	-
Velocity	256.5	m s^{-1}
Density	1.22	kg m^{-3}
Static pressure	89289	Pa
Static temperature	246.9	K
AoA	1.5	-



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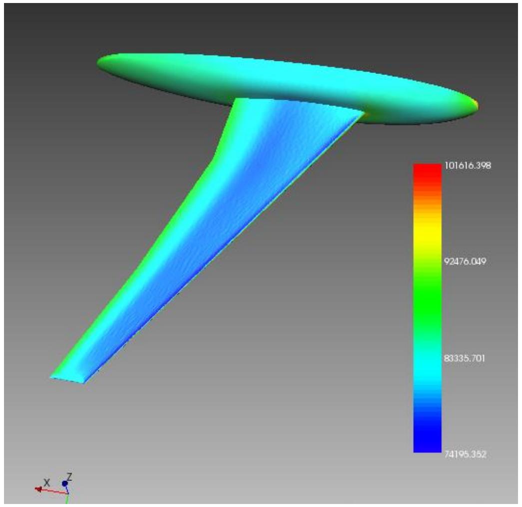
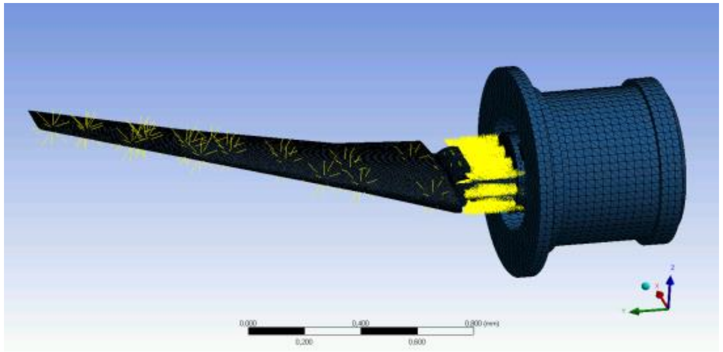
<u>CFD model</u>: **SU2** and **ANSYS Fluent** were used and an hybrid mesh with about 1.5 million of mixed cells was employed.

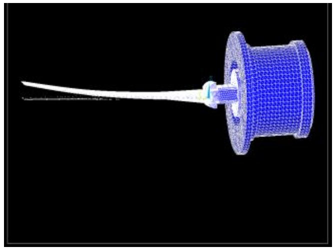
<u>FEM model</u>: **ANSYS APDL** solver was used to calculate deformations (2W) and natural frequencies and modes (MS) starting from the import of the FEM model in NASTRAN format.

CFD and CSM models

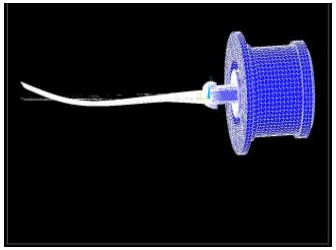




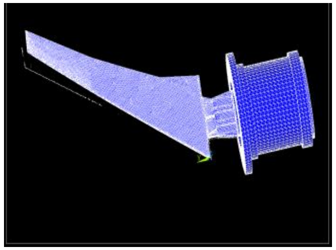
Mode-superposition (MS): wing modes were extracted with the CSM model and used to prepare RBF shape modifications.



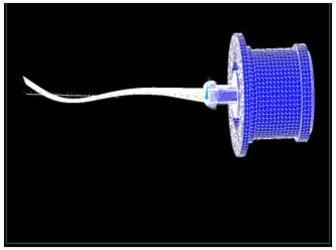
Mode 1 - 25.5 Hz



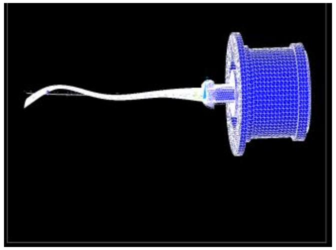
Mode 2 - 80.2 Hz



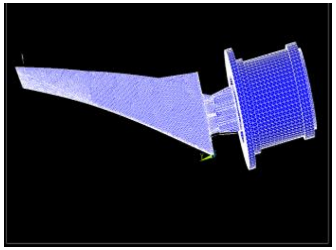
Mode 3 – 106.1 Hz



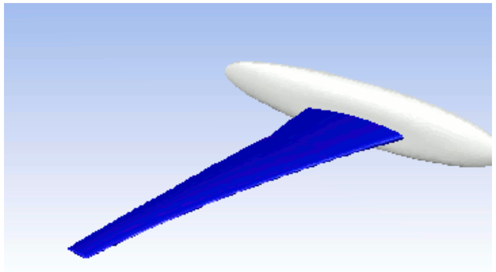
Mode 4 –160.3 Hz

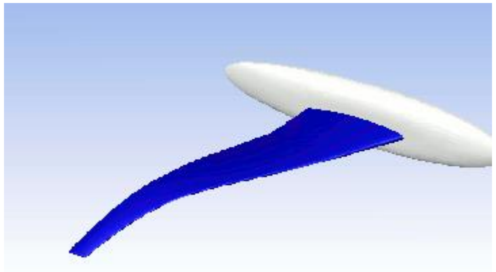


Mode 5 – 241.9 Hz



Mode 6 – 252.2 Hz





Morphed configuration corresponding to mode 1 and 2

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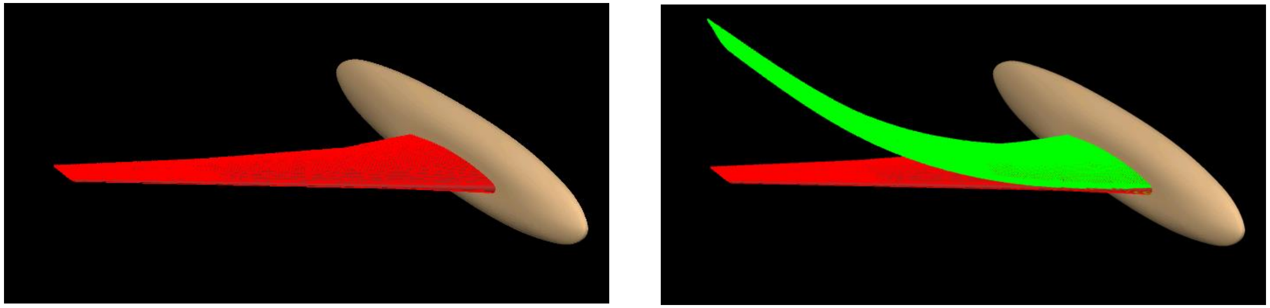
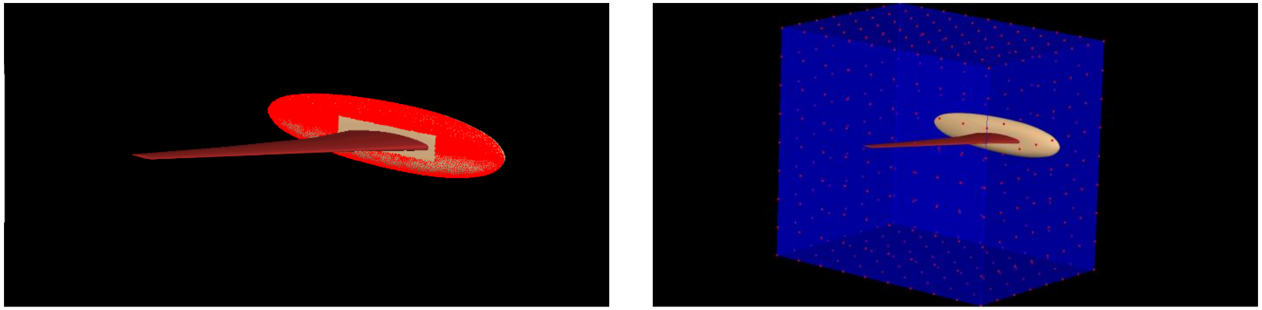
Mode-superposition



Preview of the source points before and after morphing (Mode 1)



Fixed source points and delimiting domain source points

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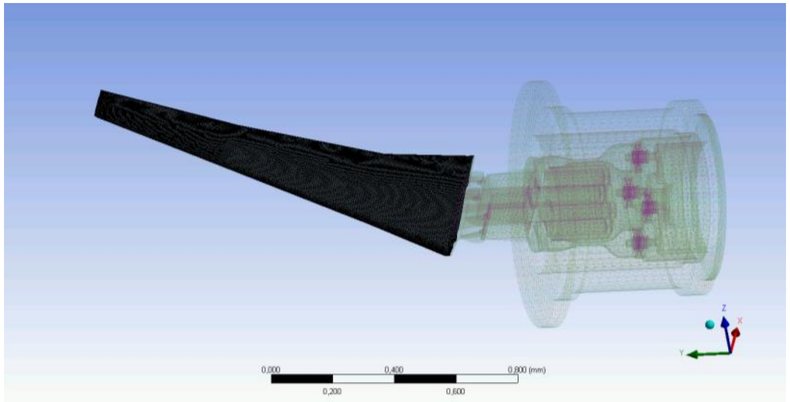
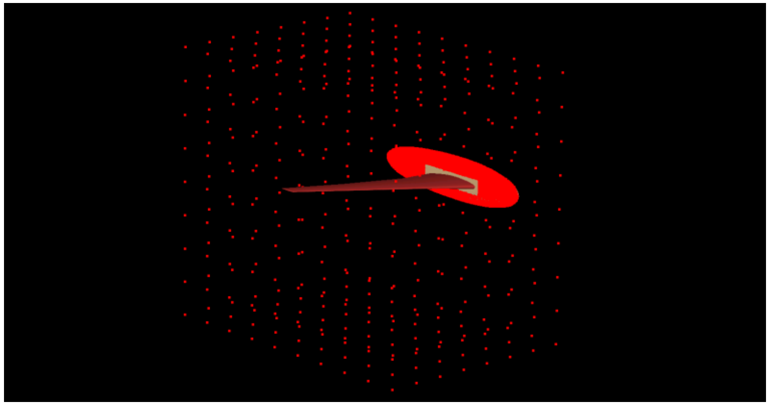
Two-way (2W): RBF shape modification to morph the CFD mesh is set up by defining a 'fixed' RBF solution that has to be updated with displacement obtained with the FEM analysis at each FSI cycle.



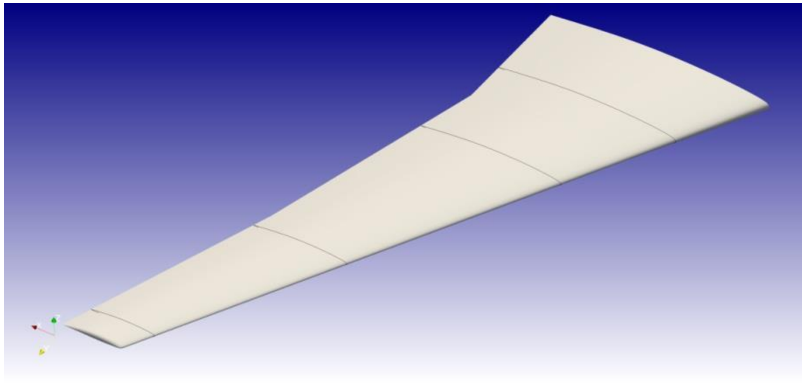
Surface element of the FEM model that host the CFD loads



Source points of the constrained solution

The validation has been performed taking into account the **data available** in scientific literature that are:

- **pressure coefficient distribution** at four **monitoring stations** located at 14.5% (Section 1), 32.3% (Section 2), 65.5% (Section 6) and 95.3% (Section 7) of the total wing span;
- **maximum displacement of the trailing edge** in proximity of the wing tip.



Monitoring stations chosen to carry out the FSI validation

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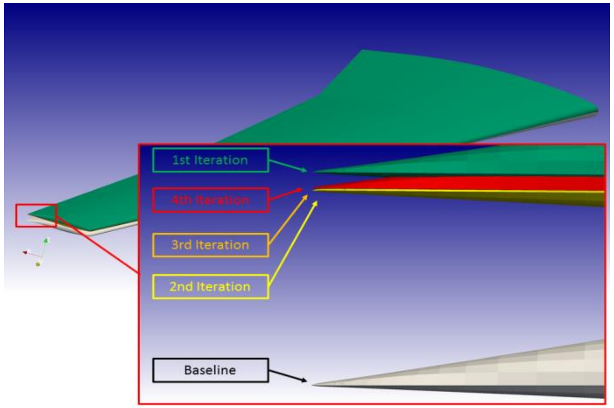
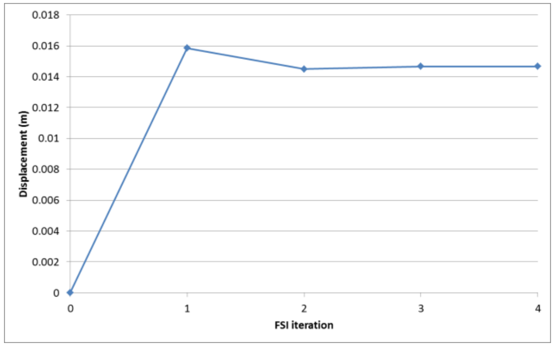
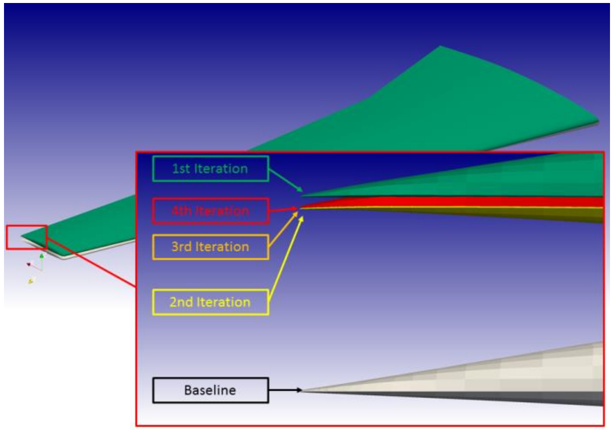
Aeroelastic convergence

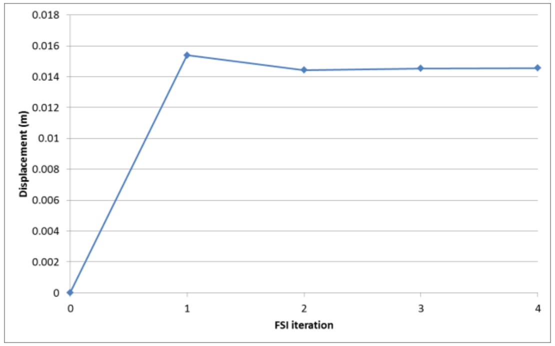
Mode-superposition





Two-way





Wing displacement

Profile of the vertical displacement of the monitoring point

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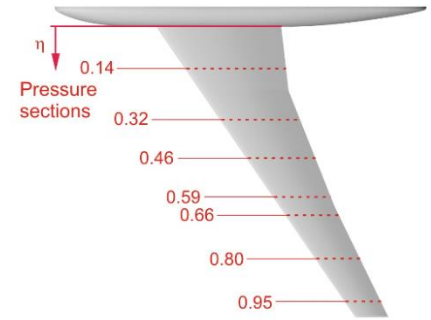
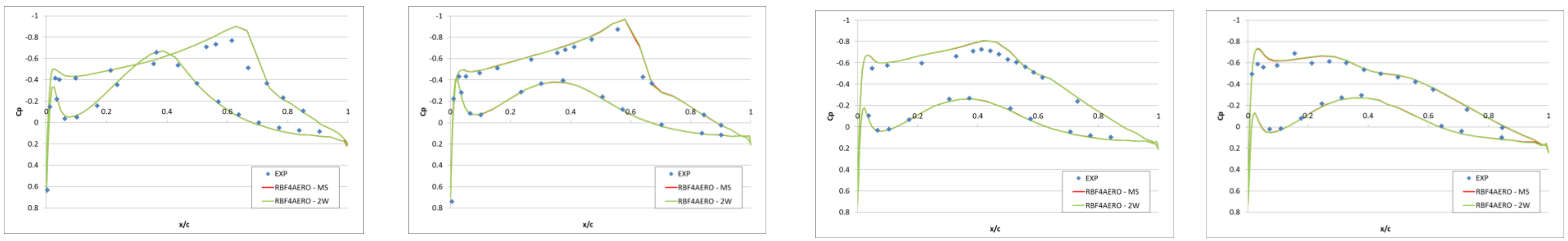
TEST CASES RESULTS | FSI VALIDATION

90% time saved in the pre-processing phase wrt a parametric hexa-block approach.

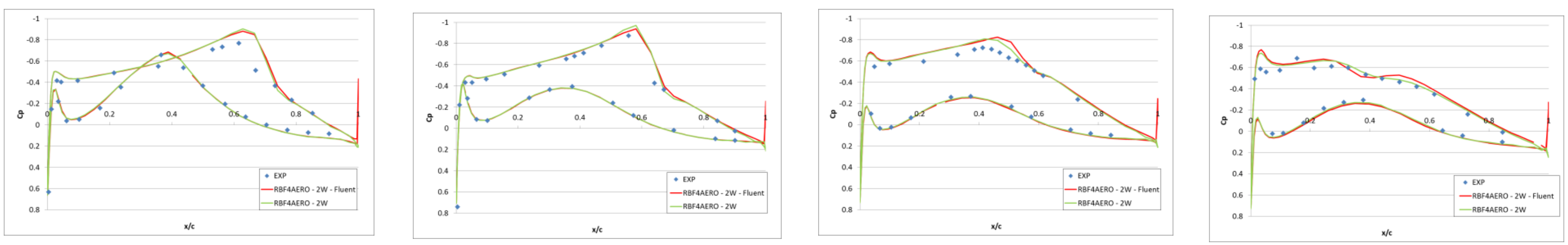
66% time saved for each FSI cycle wrt a hybrid mesh approach.



Numerical-experimental comparison: SU2 solver (2W+MS)



Numerical-experimental comparison: SU2 + ANSY Fluent solver (2W)



Section 1 Section 2 Section 6 Section 7

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Solver: EA-based + FSI (rbf4aeroFSI)

FSI approach: mode-superposition

FEM: Abaqus FEA (5 modes)

CFD: OpenFOAM

Boundaries: incompressible, SA turbulence, 2300 and 2550 RPM (MRF)

Modifications: pitch and twist of the blade

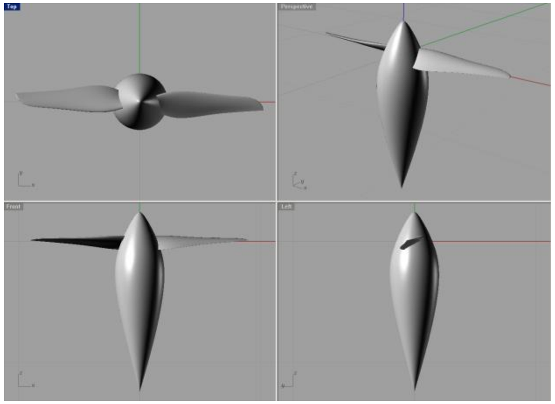
Target: Propeller efficiency ν (thrust, velocity and power) maximization in **cruise** and **take-off** conditions (MOO)

$$F(t,p) = \frac{1}{2}\nu_{CRUISE} + \frac{1}{2}\nu_{TAKE-OFF}$$

where $$\nu = \frac{TV}{P}$$

Constraints: Surface deformations limited to a determined area.

WATTsUP propeller



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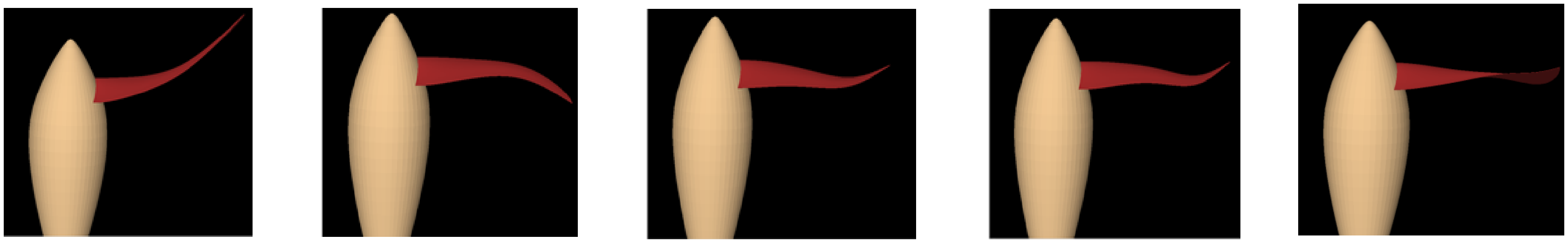
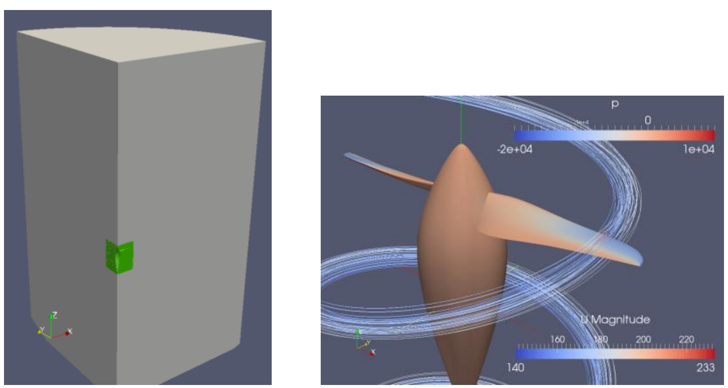
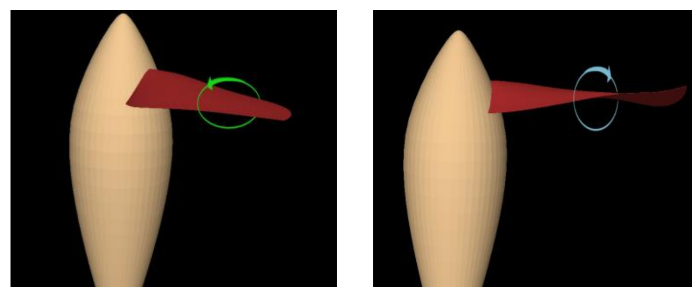


Propeller modes

Simulation volume and CFD results (baseline)



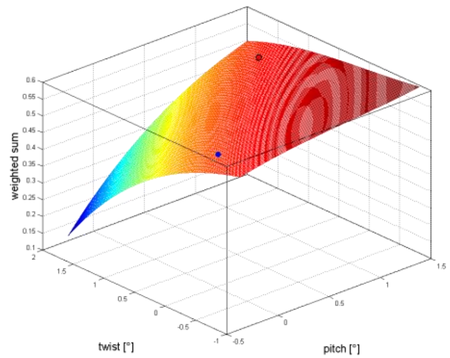
Blade pitch and twist angles



TEST CASES RESULTS | FSI OPTIMIZATION

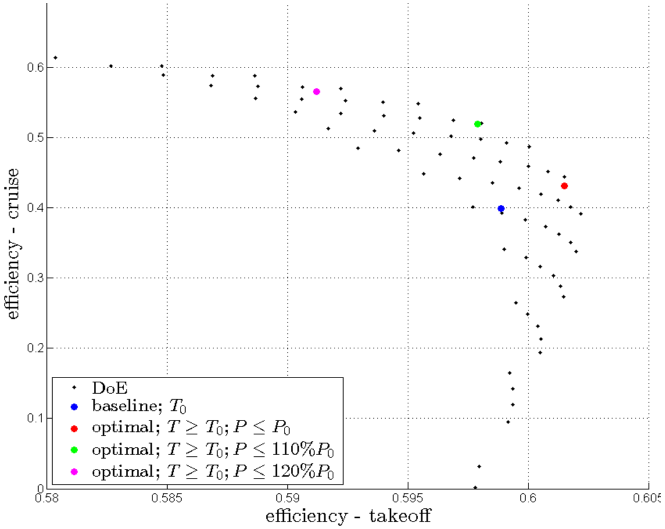
+3.5% increase of the objective function.

The RBF4AERO platform required more time during the pre-processing phase (33% more) but allowed a substantial reduction of time needed to complete the solution phase (**85% less per DP**).

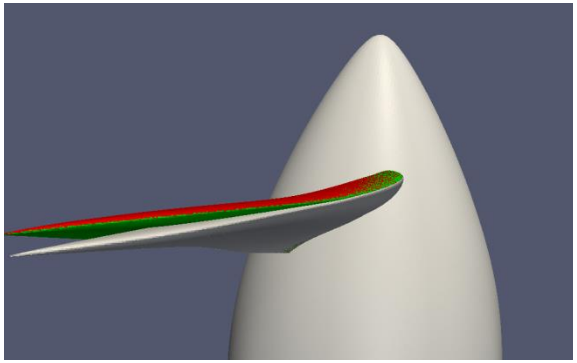


F(t,p)

Design space



Baseline vs optimal shape



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EXPLOITATION INITIATIVES | FORTISSIMO 2

The most important exploitation initiative is the **Experiment 906** of the **FORTISSIMO 2** project termed "**Cross-Solver Cloud-based Tool for Aeronautical FSI Applications**".

Challenge: to showcase the feasibility to carry out an FSI optimization of the winglet of the **Piaggio P180 Avanti EVO** through the RBF4AERO platform on an HPC system.

Objective: we intend to offer one-stop, pay-per-use, on-demand **CAE services** through **Fortissimo Marketplace** with the **RBF4AERO** platform.

https://www.fortissimo-project.eu/it/experiments/906

FORTISSIMO

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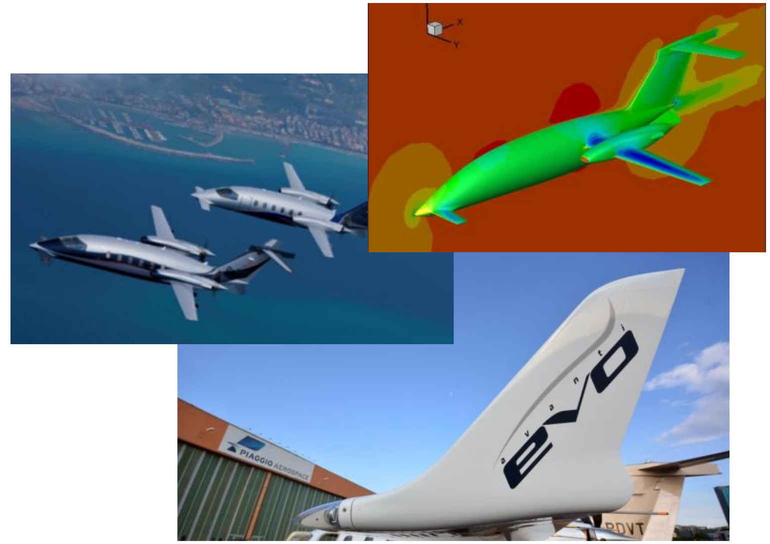

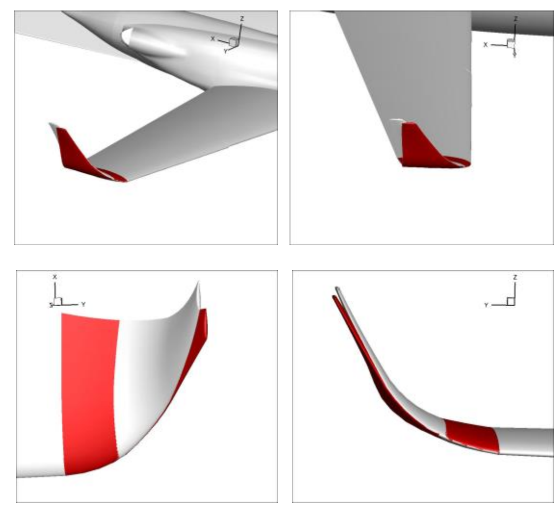

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We are working to **consolidate** the RBF4AERO platform and establish a **cloud-based solution** to offer CAE services.

We are establishing a **business agreement** to rule the pave the way to business and technological development.

We are open to undertake other initiatives such as **industrial consulting activities** and **research collaborations**.

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WHAT'S NEXT?

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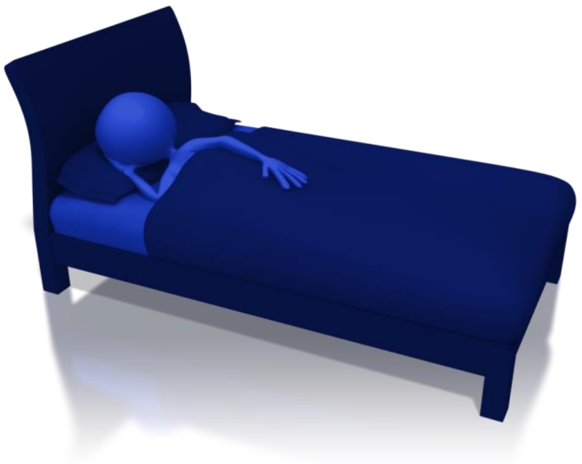

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