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UGM2024
Brooklands Museum
Weybridge, England
23 to 25 of October

RBF Morph

Interactive sculpting and FSI with the rbfCAE platform

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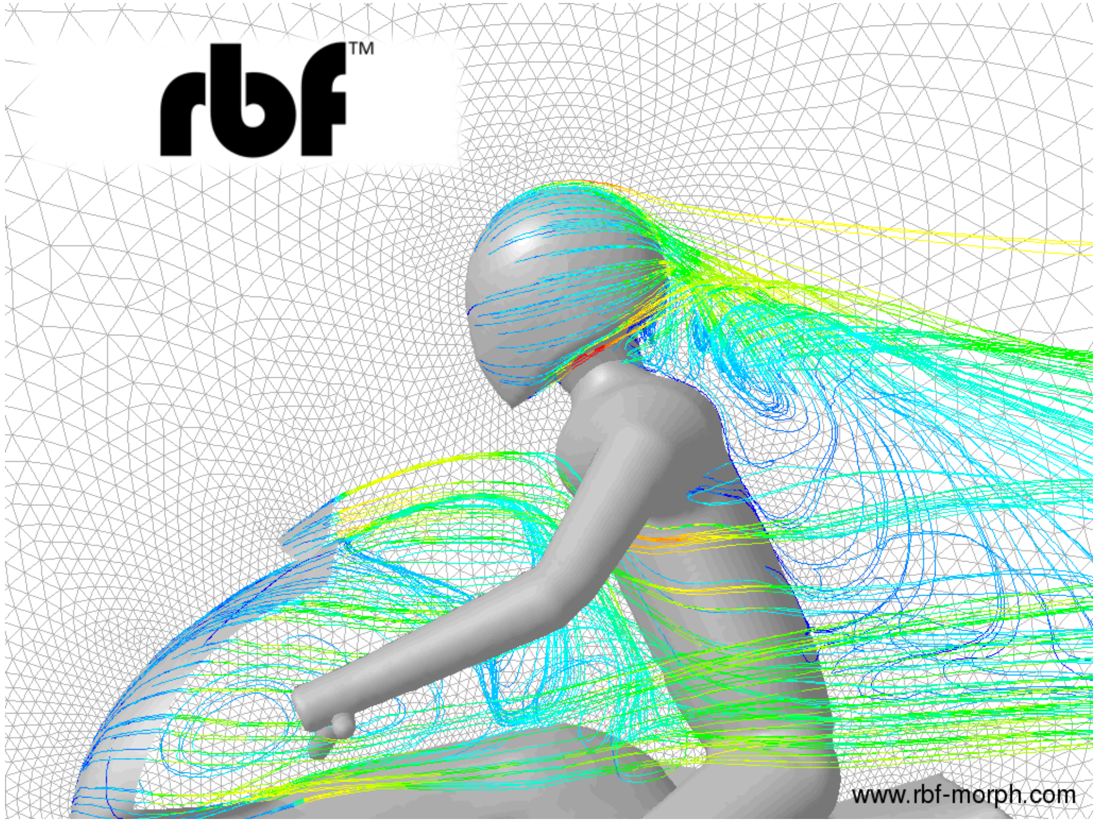
Outline

- An overview about the rbfCAE platform
- Typical usage scenarios and applications
- Fast design exploration with interactive adjoint sculpting
- Fluid-structure interaction example by modes embedding
- Next steps? Automatic CAD connection, ROM and VR
- Conclusions

rbfCAE platform overview

radial basis functions morphing of CAE models - rbfCAE

- Geometric control by **r**adial **b**asis **f**unctions **CAE** morphing
  - Surface shape changes
  - Volume mesh adaption
- A **new shape** of the CAE model **ready to run**
  - for structures in the FEA solver
  - for flows in the CFD solver



Radial Basis Functions Excellence

- We offer best in class **Radial Basis Functions** (RBF) to drive CAE morphing from a list of source points and their displacements
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing

$$\begin{cases} s_x(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^x \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ s_y(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^y \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ s_z(\boldsymbol{x}) = \sum_{i=1}^{N} \gamma_i^z \varphi(\|\boldsymbol{x} - \boldsymbol{x}_{s_i}\|) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \end{cases}$$

EU-funded research projects

RBF4AERO

FORTISSIMO

RIBES

CloudiFacturing

EUROfusion

spinner
next generation spine experts

MEDITATE

ff4EuroHPC

rbfCAE solution benefits

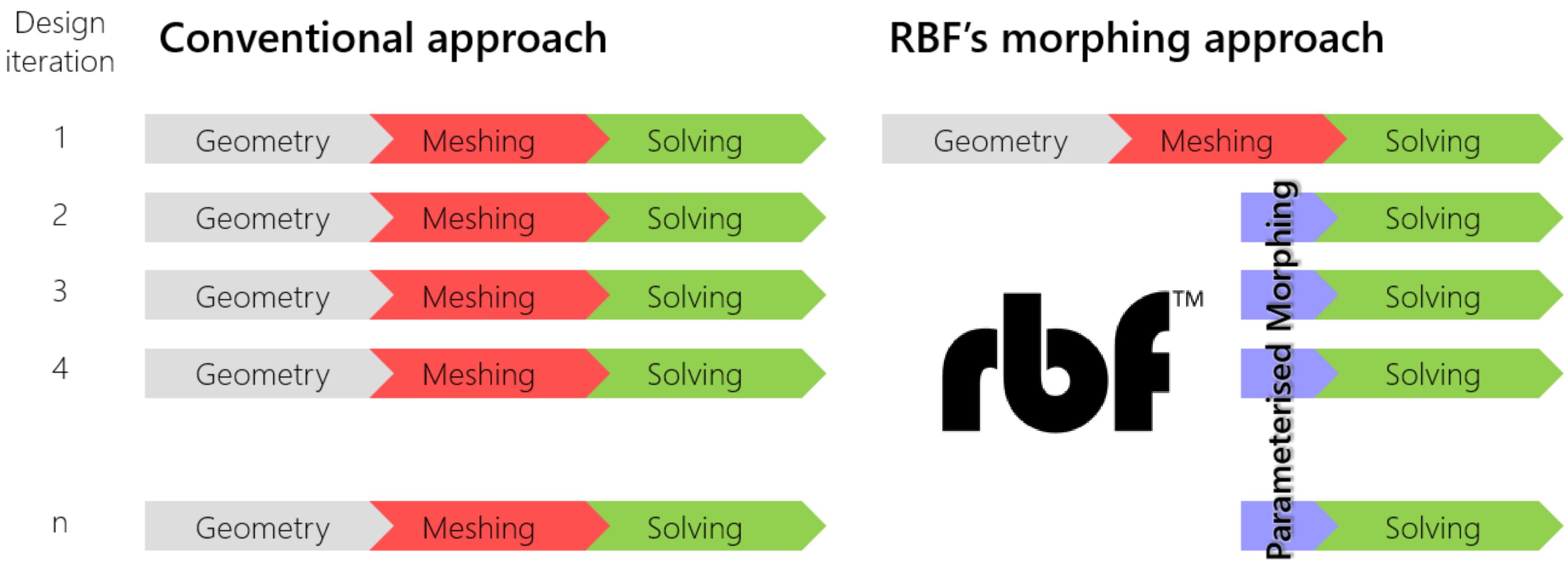
rbf™

www.rbf-morph.com

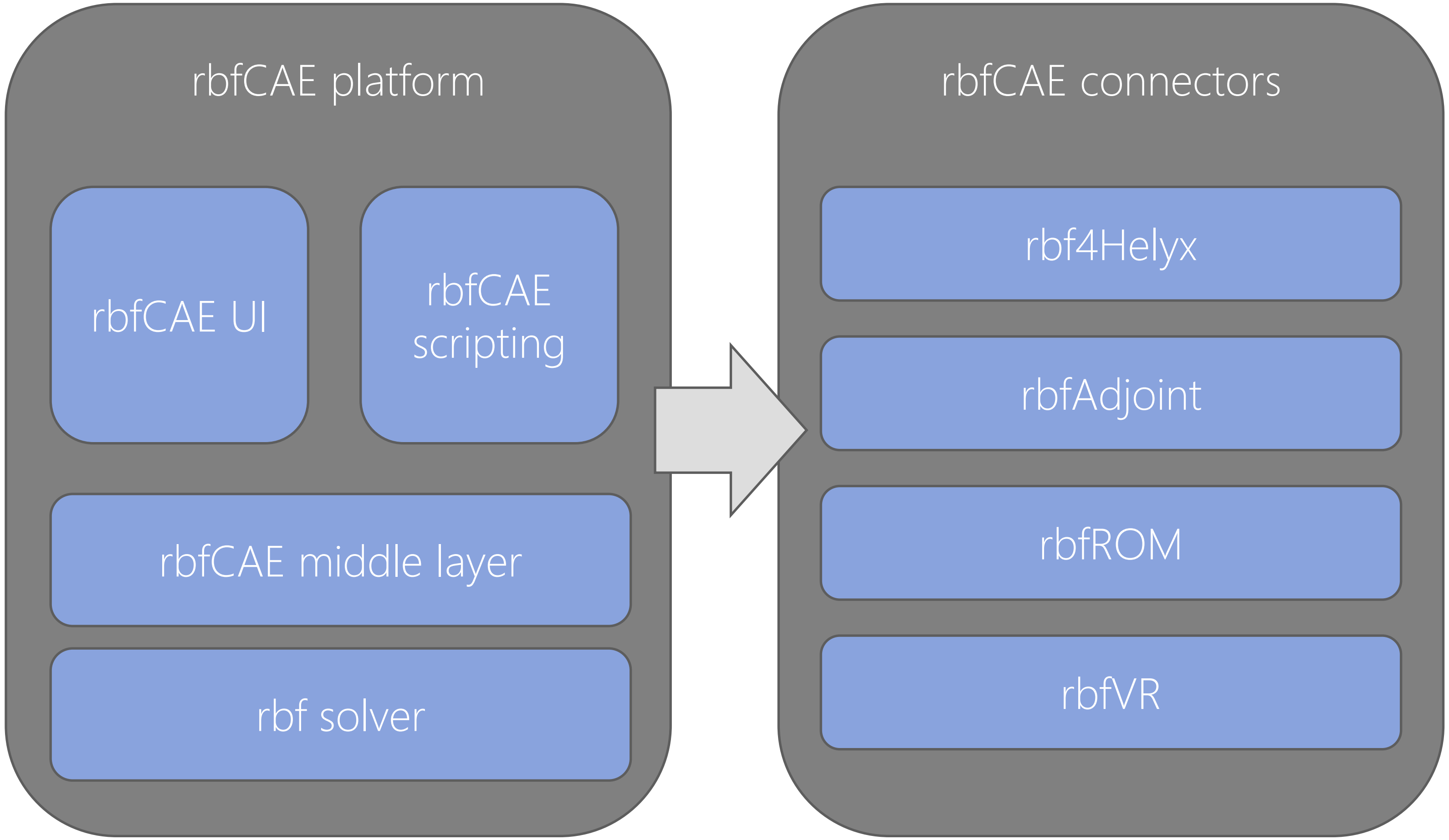
- No re-meshing
- Can handle any kind of mesh
- Can be integrated in the CAE solver (FEM/CFD/FSI)
- Highly parallelizable
- Robust process
- The same mesh topology is preserved (adjoint/ROM)
- CAD morphing (iso-brep)

rbfCAE parametric models

- **rbfCAE** makes the CAE model **parametric**
- Shape parameters can be driven by **an orchestrator**
- Shape parameters can be used to generate snapshots for real time Digital Twins (**ROM/AI**)



rbfCAE solution



- Released in 2024
- Read in **STL, STEP**
- **Unity - OpenCascade**
- Solver independent process that supports **many mesh formats**
- **Scriptable** via python

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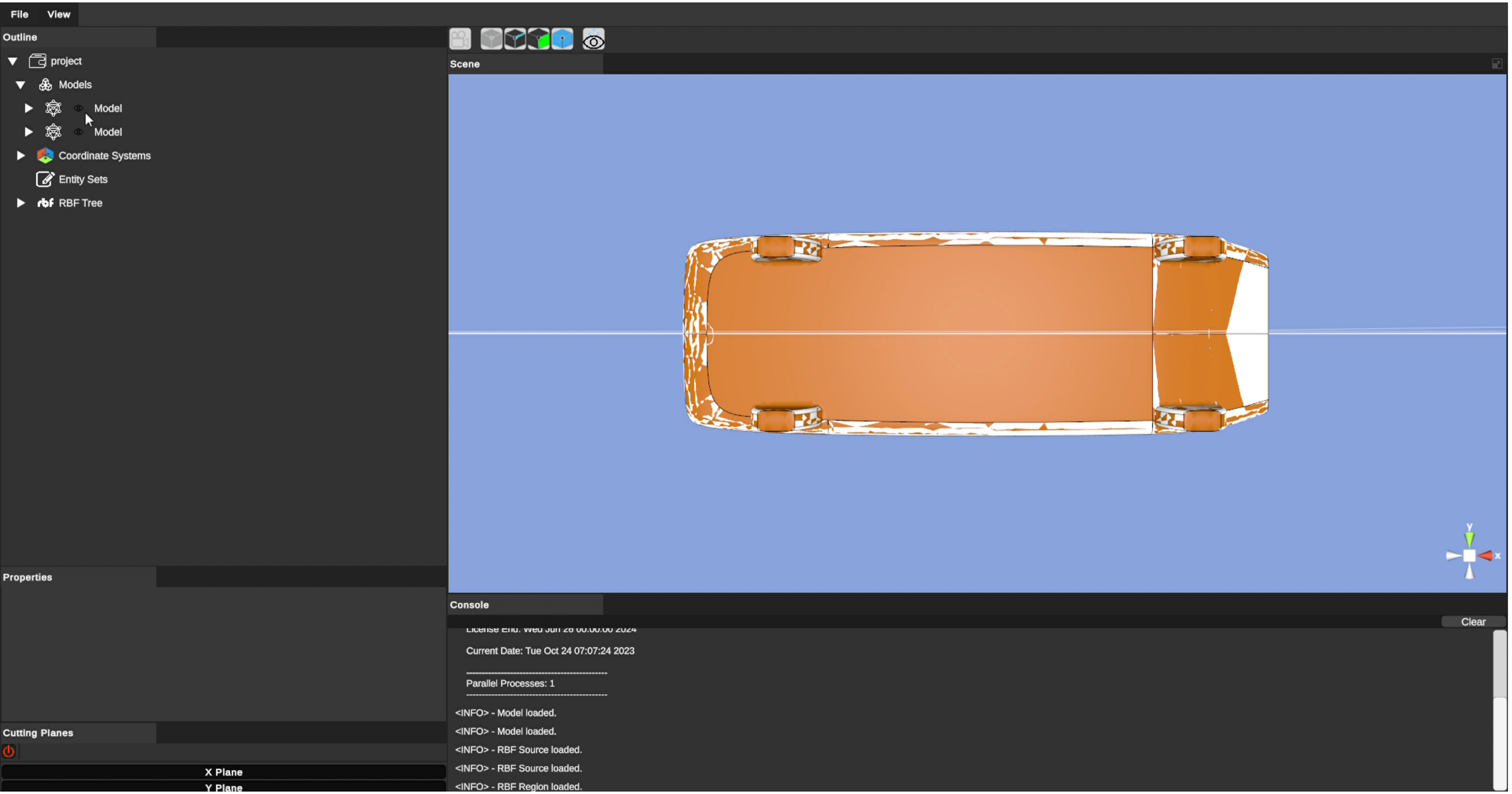
rbfCAE UI



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Typical usage scenarios and applications

Main uses of rbfCAE

Usage	FEA	CFD	Optimizer	AI
Automated and quick variable design space exploration.	✓	✓		
Optimization (Single physics or multi-physics). Shape optimization for stress reduction, mass reduction, fluid-structure interaction	✓	✓	✓	
Digital twin development (static ROMs)	✓	✓	✓	✓
Lifing applications simulate defects such as corrosion pits, spalling of material, erosion, chips, etc.	✓	✓		
Examine the effects of non-conformance and manufacturing variability	✓	✓		
Robust Design	✓	✓	✓	

Served industries

100+
Global Customers

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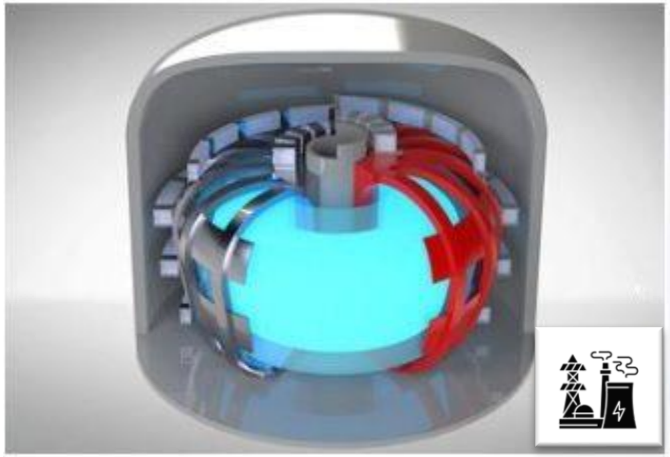

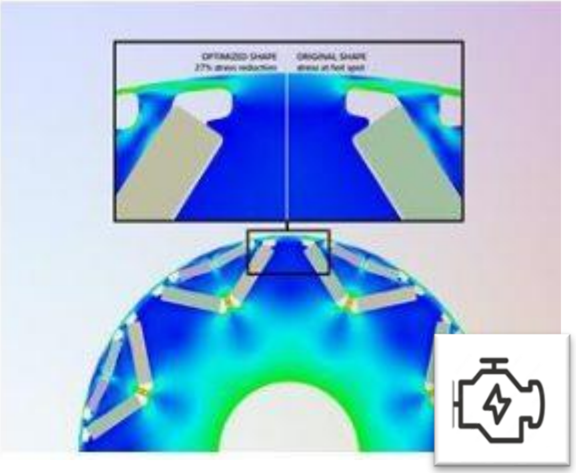

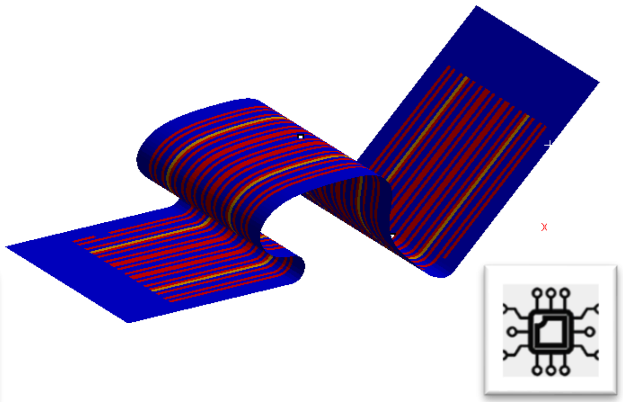

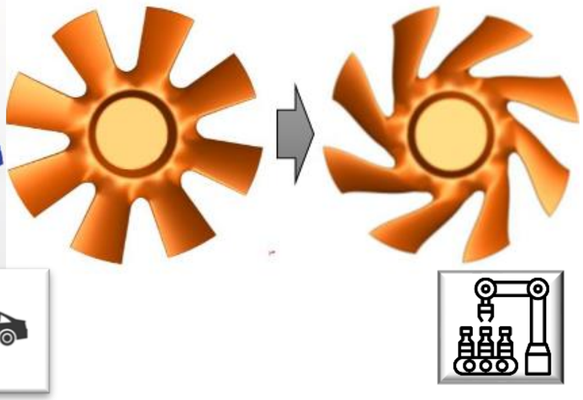
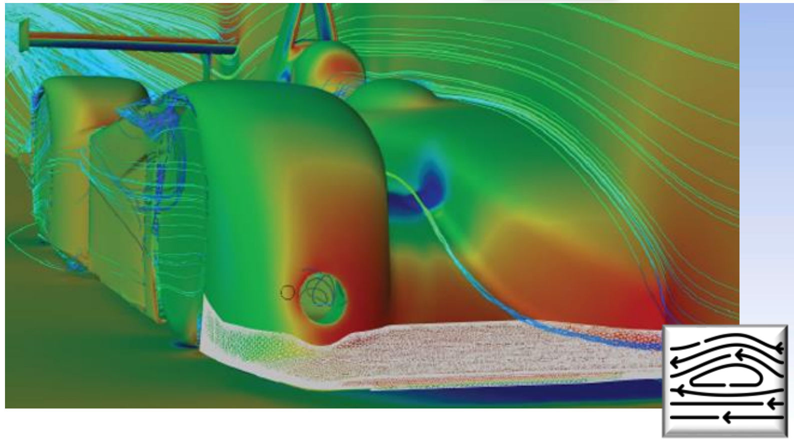
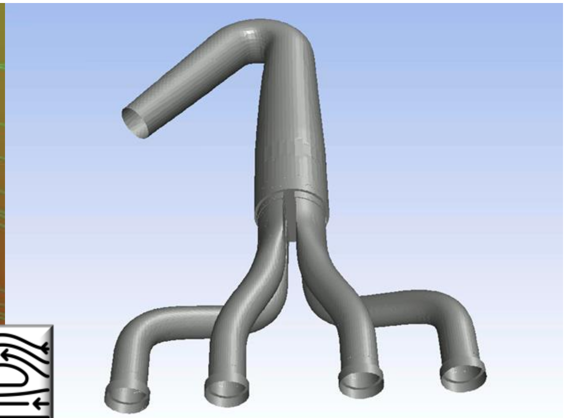

Fast design exploration with interactive adjoint sculpting

Adjoint sensitivities in combination with shape parameters

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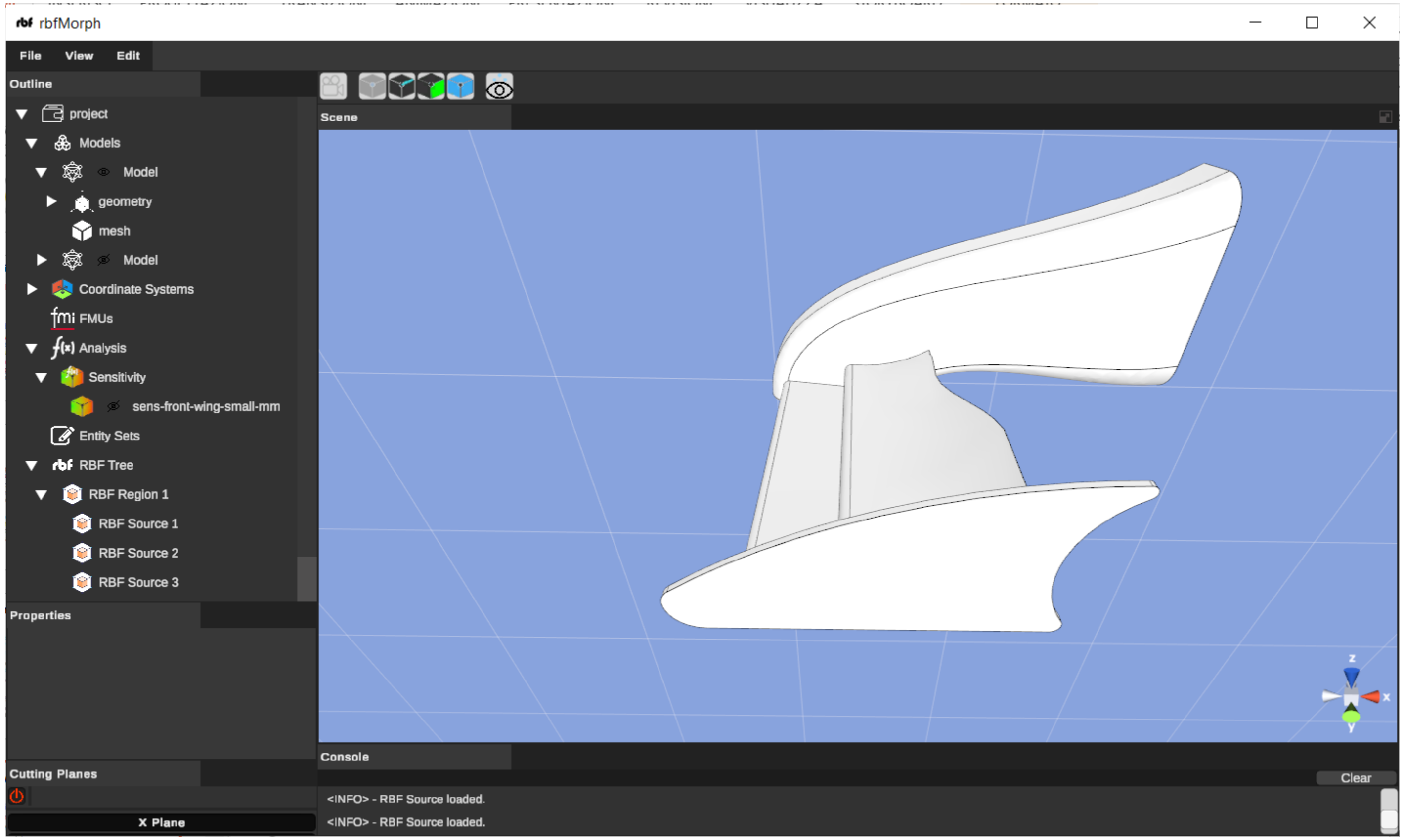
- The CFD adjoint formulation provides the **sensitivities** of an objective function **with respect to surface displacements**.

$$\frac{\delta F}{\delta \vec{b}} = \frac{\delta F}{\delta x_\kappa} \frac{\delta x_\kappa}{\delta \vec{b}}$$

- **rbfCAE** provides the **deformation velocity**.
- The deformation velocity can be mapped onto the high fidelity mesh where the sensitivities are known regardless the mesh we use to warp the surface (topology, spacing).
- The design parameter b can be mesh based (rotation, translation, scaling, offset of a node, edge, surface, …) or CAD based (tweaking of a spline, a NURBS, …)

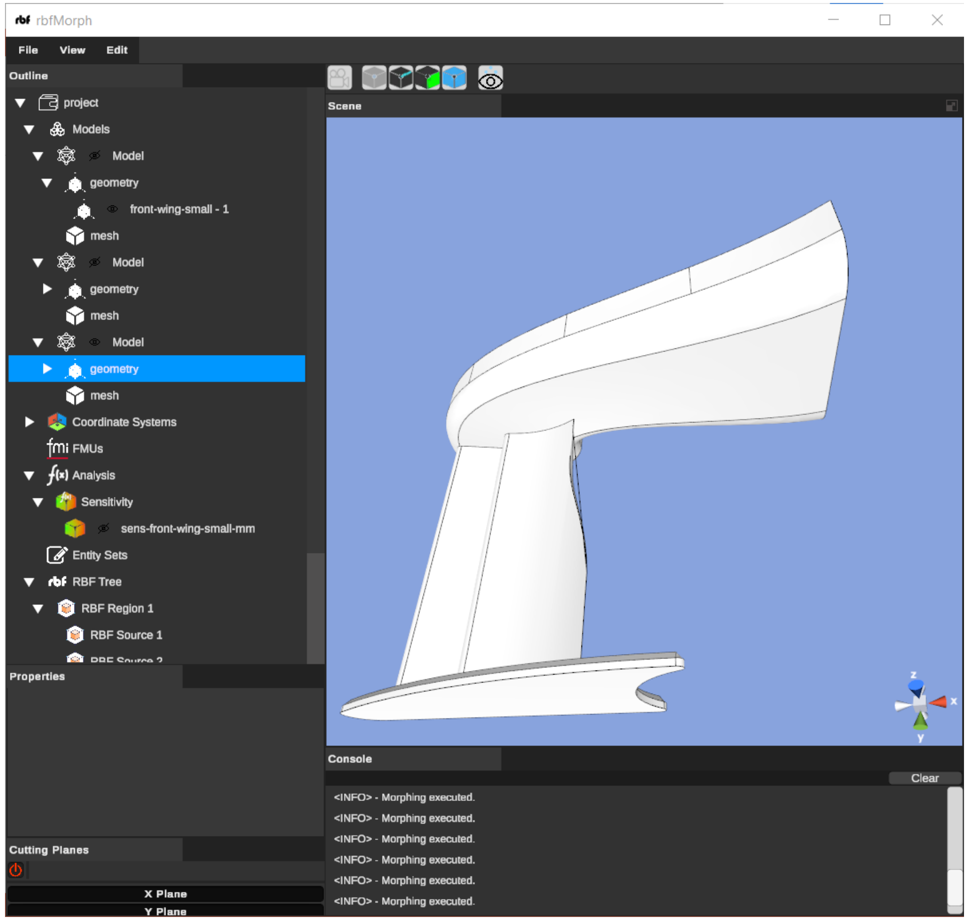
rbfAdjoint usage example

- The adjoint sensitivity on the CFD surface mesh computed by HELYX
- The **efficiency** of a simple Formula 1 front end is investigated



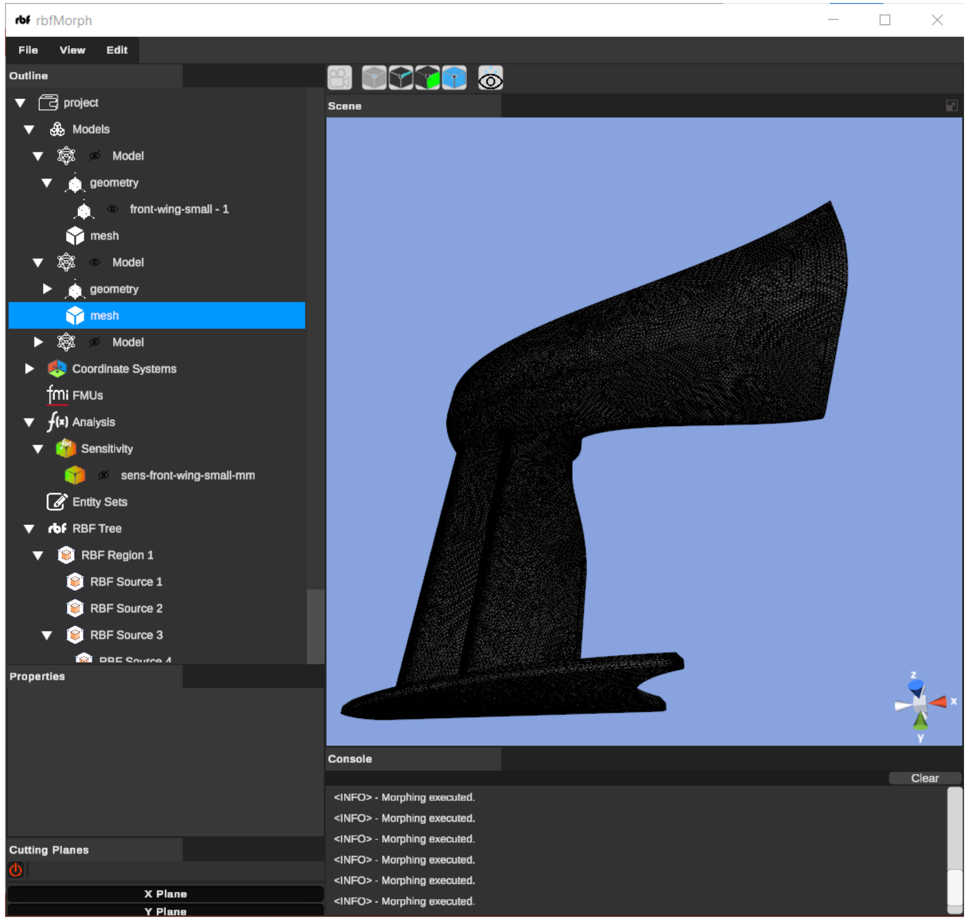
Step 1 – read in the CAD model

- Baseline CAD is imported as a step file
- The entities on the CAD (edges, surfaces) are controlled
- Simple operations are possible (scaling, rotation, translation)
- Combined operations are possible (nesting operations on different entities)



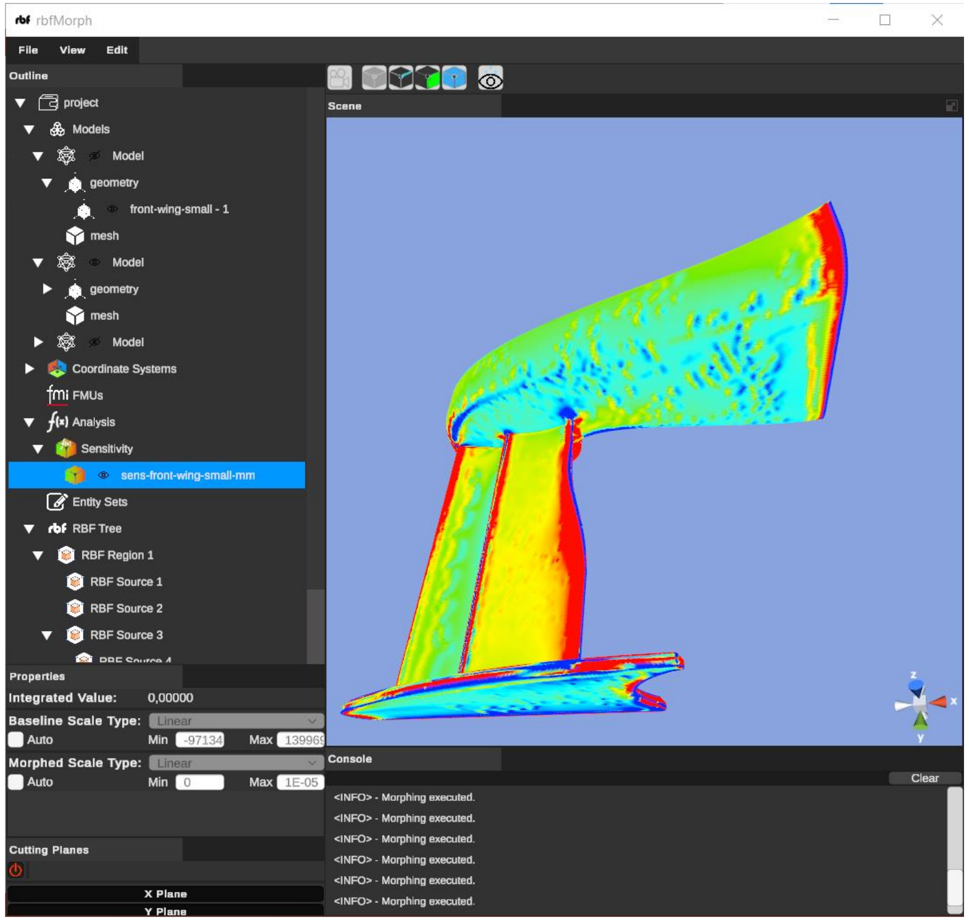
Step 2 – read in the CFD mesh

- The surface mesh of the CFD model is imported as an STL file
- The mesh matches the underlying CAD in space
- The topology is not related to the CAD (dead mesh)
- The resolution is very fine making the mesh capable to represent new geometries



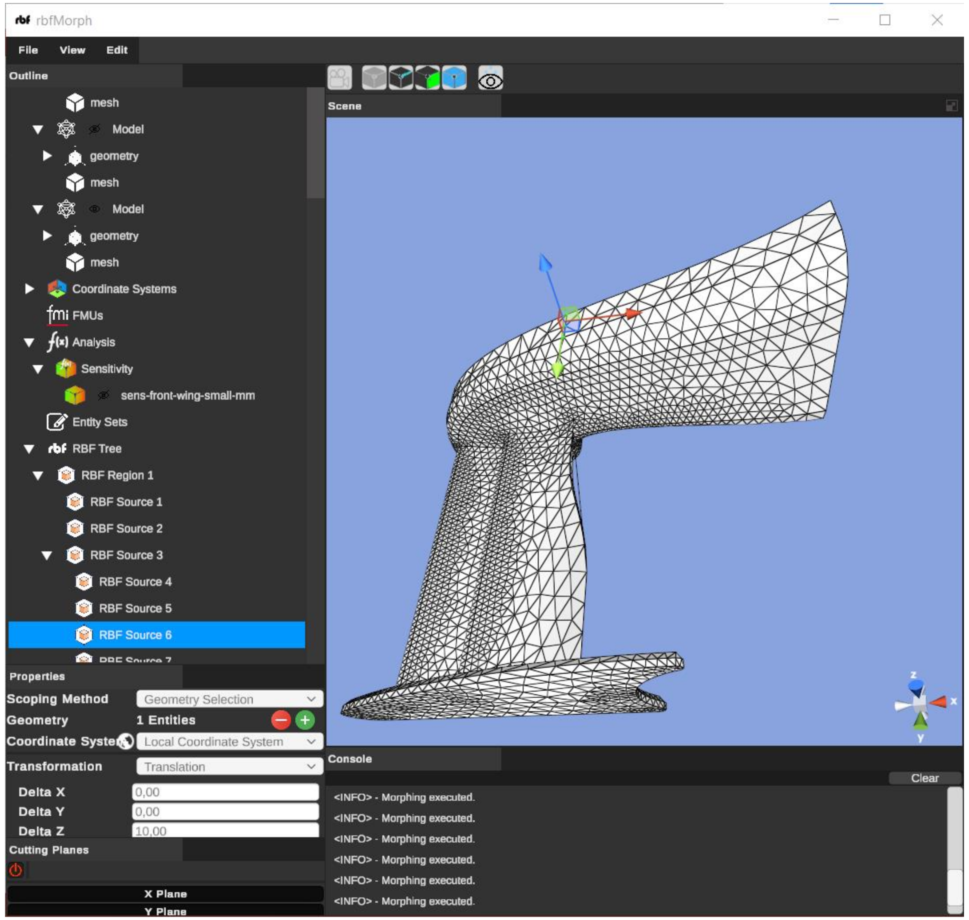
Step 3 – read in the adjoint sensitivities

- Adjoint sensitivities on the CFD surface are exported from the CFD solver and available on surface mesh vertexes
- The information is attached to the CFD mesh imported in Step 2
- Multiple maps can be imported (Drag, Lift, …)
- The imported map of this example is the wing efficiency



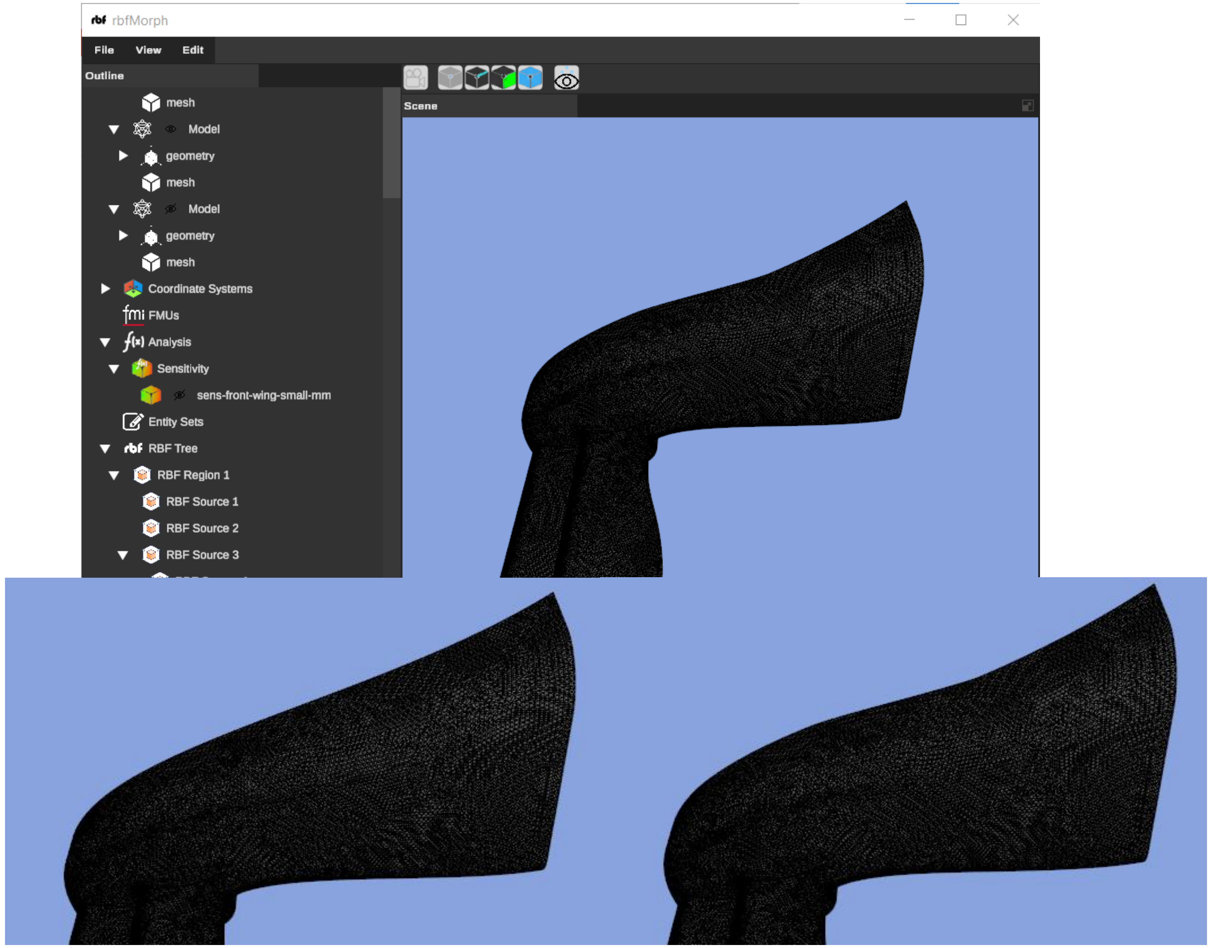
Step 4 – interactive shape control

- We use RBF editing to warp the CFD mesh
- The CFD mesh is added to the RBF Region 1 and will receive the morphing
- An auxiliary mesh is generated on the CAD to enable RBF
- The nose surface is controlled imposing the movements of the edges



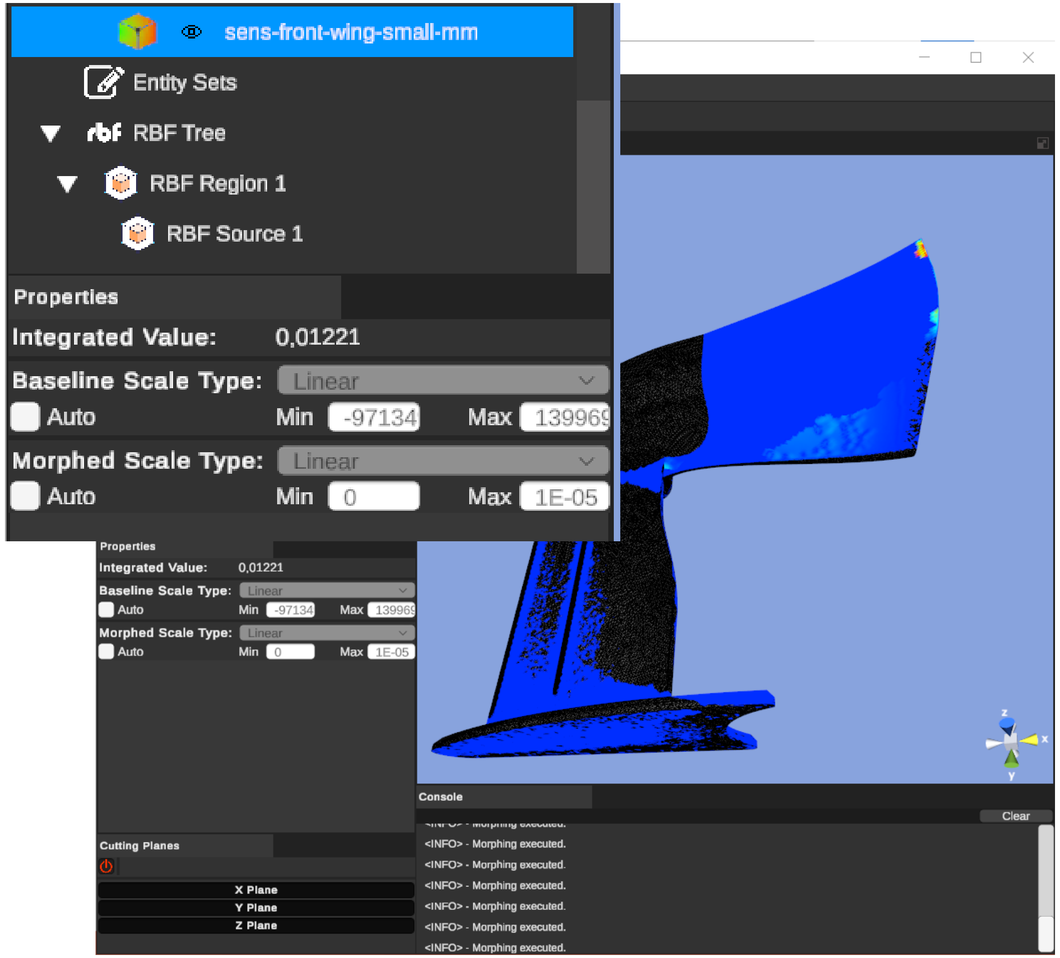
Step 5 – the CFD mesh is morphed

- The CFD mesh receives the intended morphing action
- The morphing action is controlled by the trimmed CAD model
- The morphing can be reverted and repeated while tweaking the profile of the nose



Step 6 – interactive performance evaluation

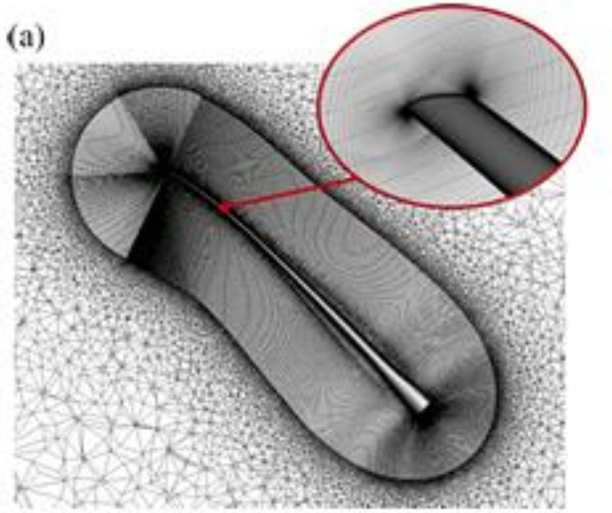
- At each morphing the sensitivities are integrated over the morphing field
- The change of the observable (the efficiency in this case) is reported in the dashboard
- The CFD mesh is now colored with the local effect (i.e. the product of the sensitivity and the displacement field)

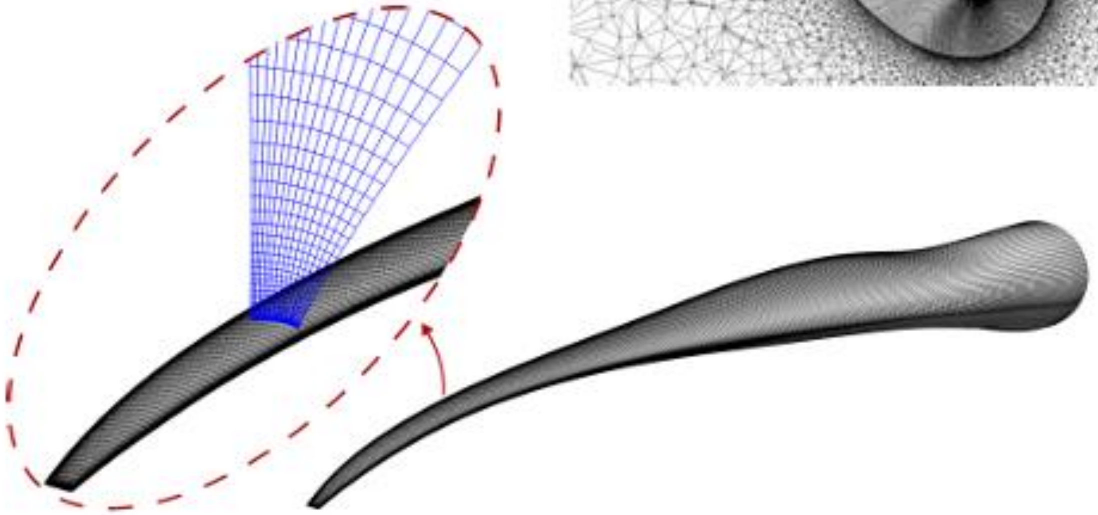


Fluid-Structure Interaction example by modes embedding

Introduction to FSI application
Mesh

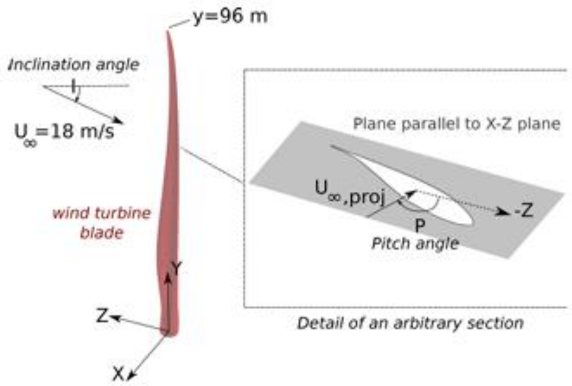
- Mesh file provided.
- Wind turbine blade immersed in a box-shaped simulation volume.
- Hybrid structured + unstructured mesh with 14,7 million cells.
- Mesh regions and blade areas were merged.

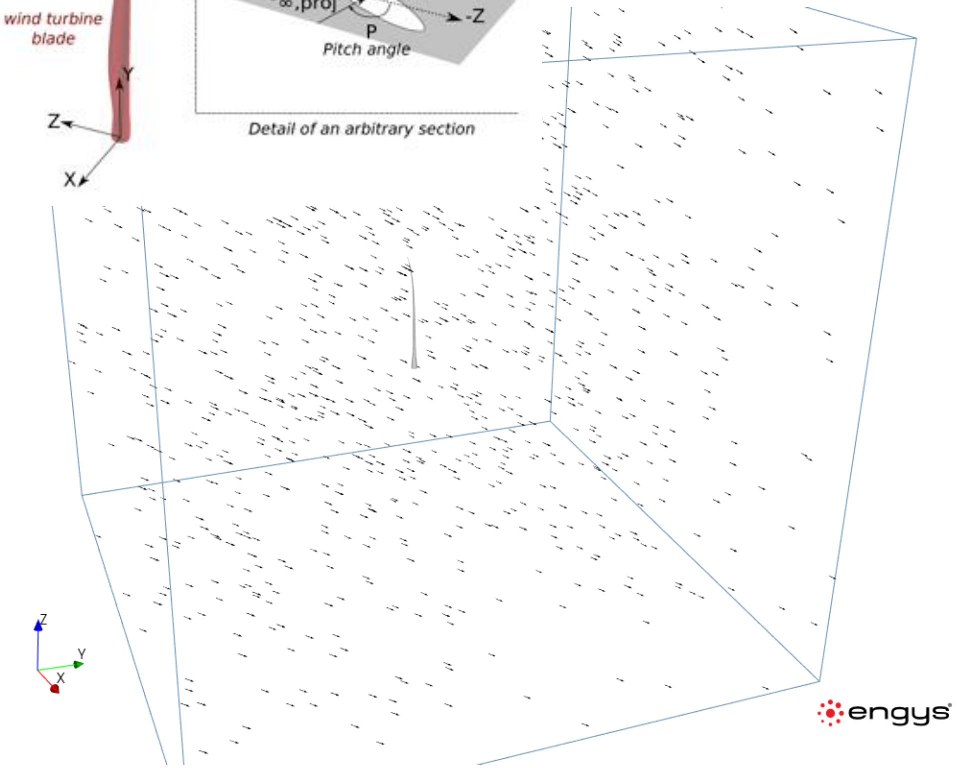




Introduction to FSI application CFD Setup

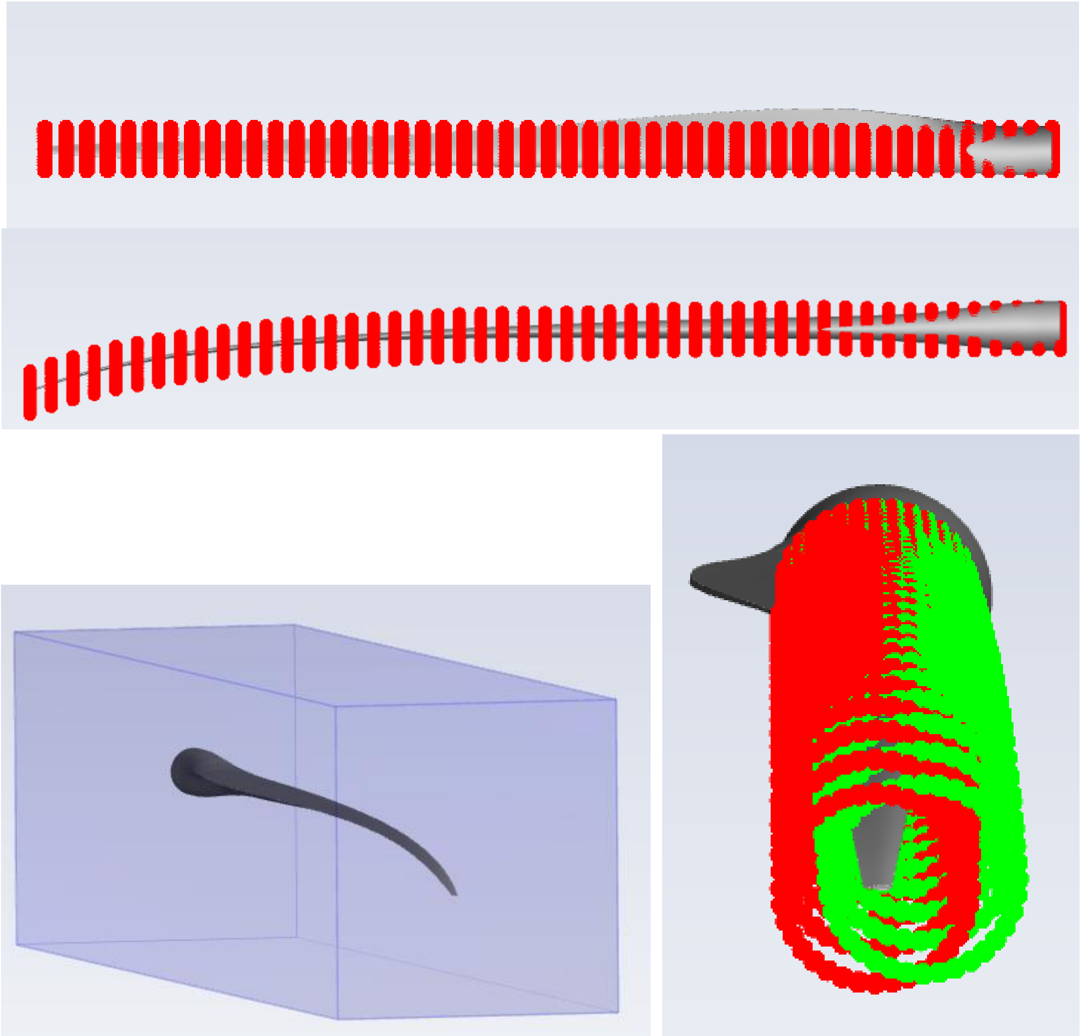
- URANS
- K-ω SST turbulence model
- HELYX-Coupled solver
- “Opening” boundary condition for simulation volume surfaces and standard “Wall” for blade
- 1 configuration analysed:
  - P100I30: Pitch 100° and Inclination 30°
  - Absolute velocity of wind 18 m/s





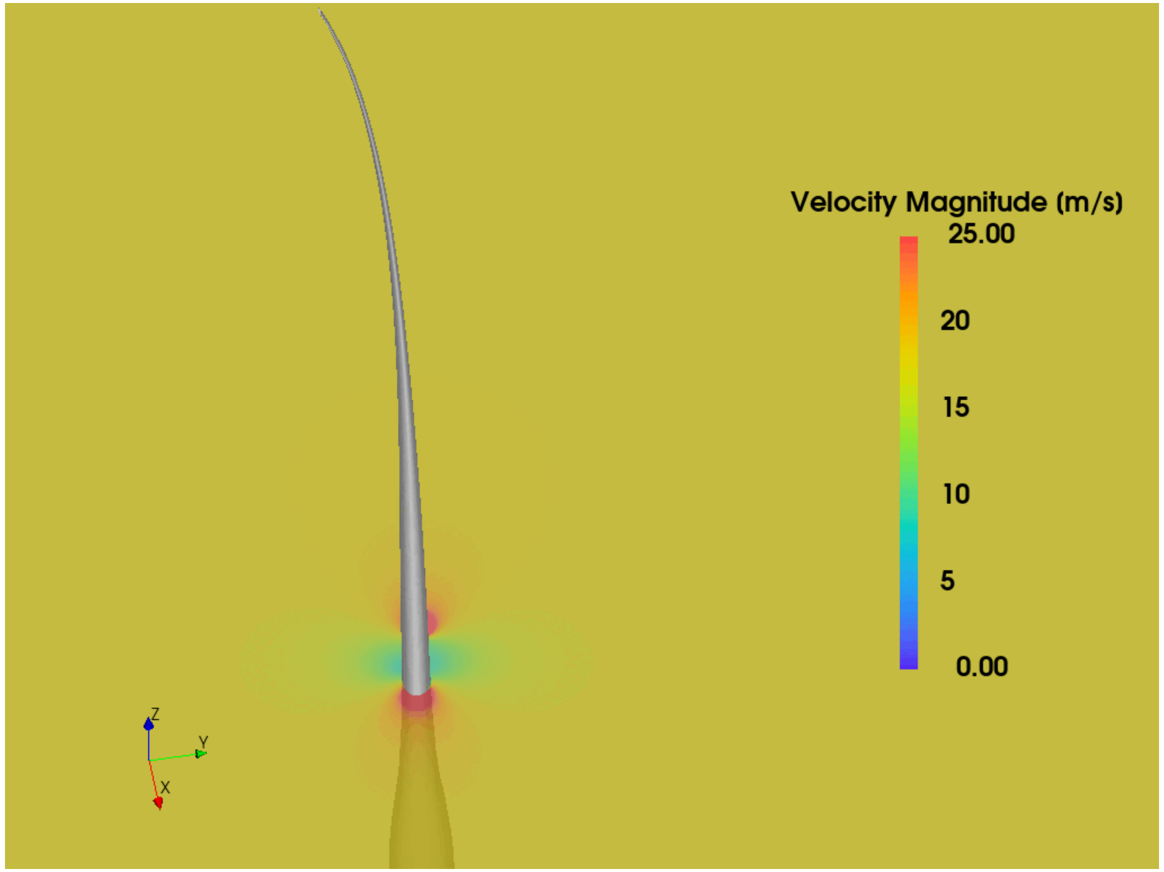
Mesh deformation

- A set of nodes were sampled along the wing's longitudinal centreline. For each sampled node set of RBF source points are generated on a circle controlled by the local cross section movements (displacement and rotations).
- A box-shaped domain was set to delimit the volume in which morphing is applied.
- The RBF solution setup was amplified according to a sinusoidal law of unit amplitude and frequency of 0.67 Hz.
- Bi-harmonic kernel phi(r)=r was adopted in the volume.
- The morphing library was used to generate the data to apply morphing during HELYX's computing.

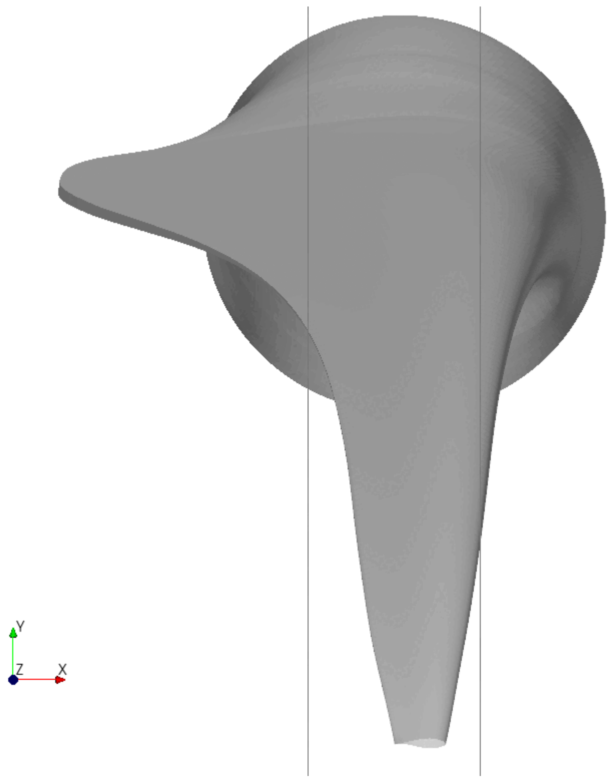


Results – General information

- The HELYX's case ran with 64 processors equipped with EPYC 7351 (2.4 GHz).
- The full run simulated 10.45 seconds of motion and took almost exactly 13 hours adopting a timestep size of t = 0.006 s.
- Main numerical results of interest in Ensight format were provided.



Results – Animations



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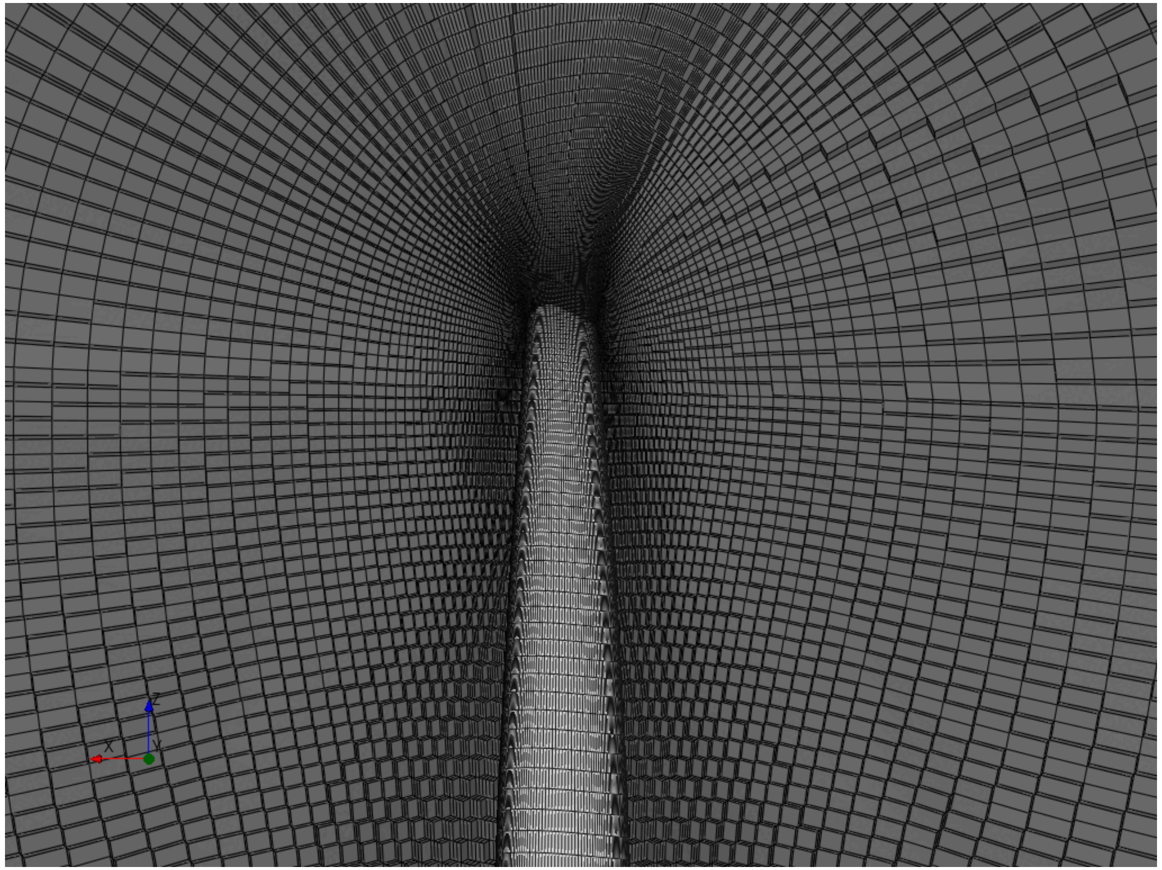
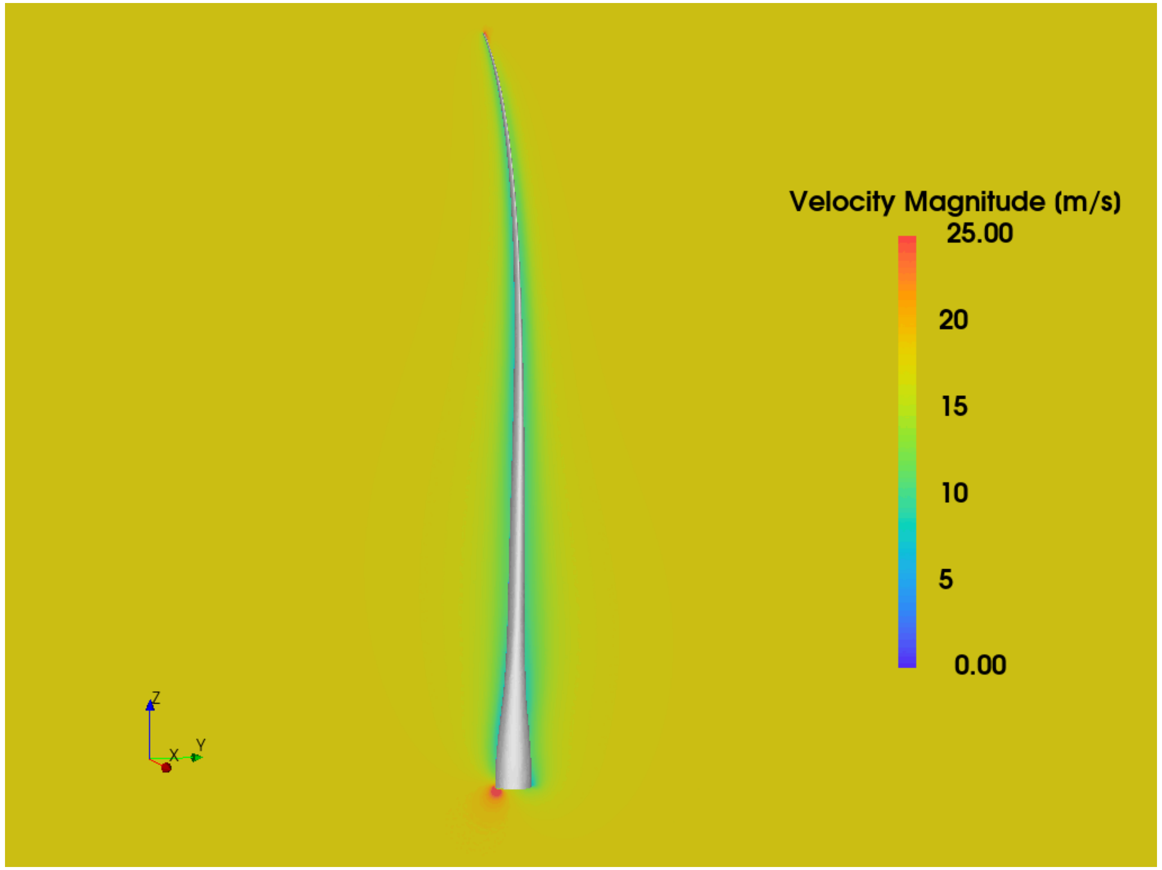




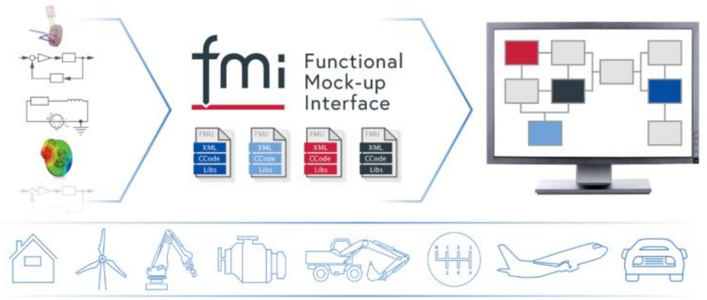
Next steps? Automatic CAD connection, ROM and VR

ROM and VR

rbfROM
- Design space sampling
- Snapshots fully computed
- POD of the mesh
- POD of the results

→

rbfVR
- ROM of the mesh (FMU)
- ROM of the solution (FMU)
- Controllers (json)
- Scene

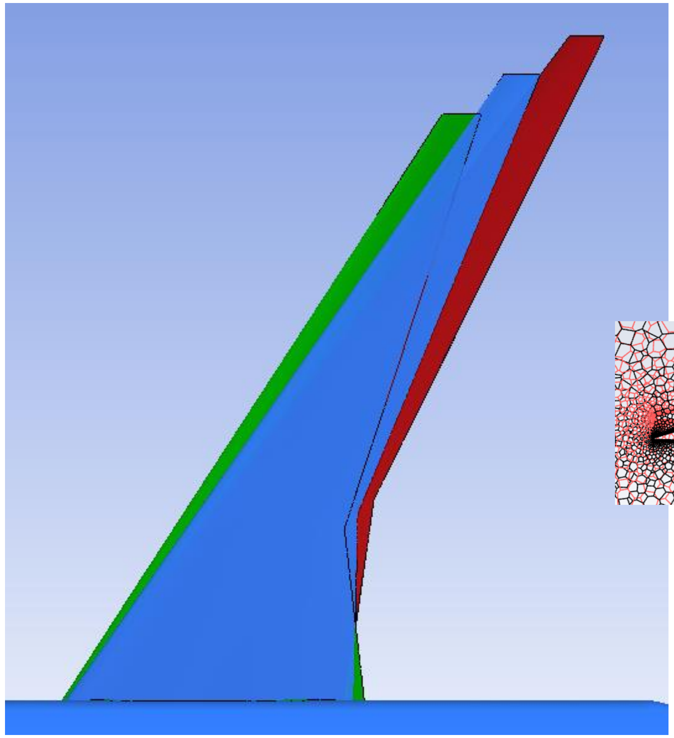


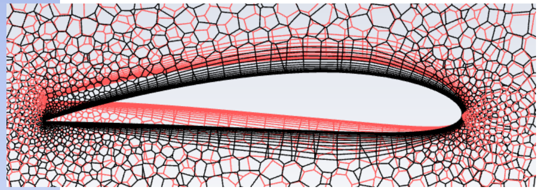
Sedan Car Aero optimization

- Two shape parameters are defined.
- Design variations explored in real-time.

Open Parametric Aircraft Model (OPAM) testcase

- Parametric CAD model of the OPAM, an aircraft model inspired by the Boeing 787-800 Dreamliner
- 6 shape parameters are considered and 66 snapshots generated
- **ROC tool** prototype in action!





	Aspect r	Sweep	Alpha b	Camber b	Alpha t	Camber t
Range	8 ÷ 10	33 ÷ 37	-5 ÷ -1	0.02 ÷ 0.06	-10 ÷ -6	0.02 ÷ 0.06
Baseline	9	35	-3	0.04	-8	0.04

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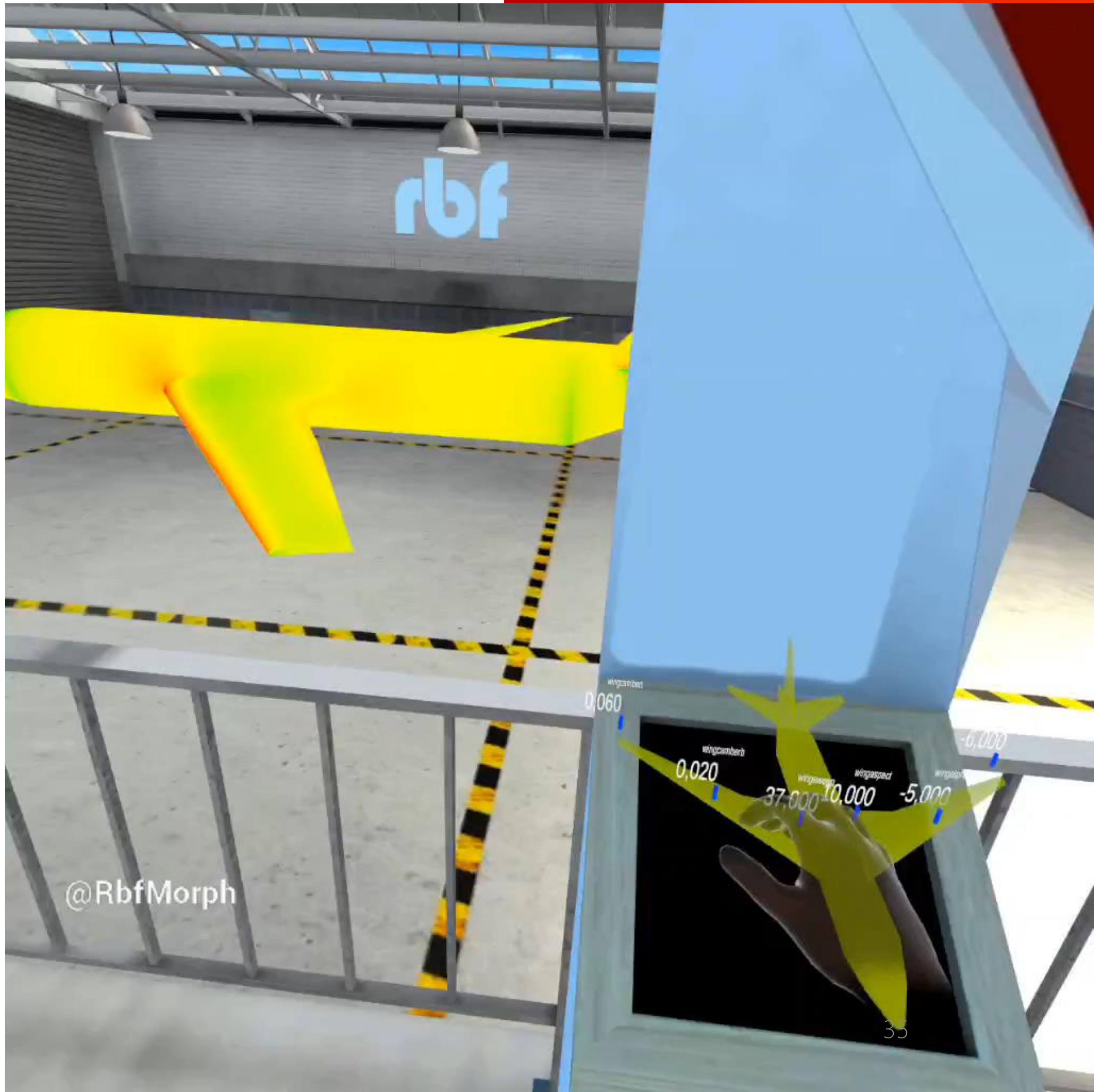

Conclusions

- The new rbfCAE platform has been introduced
- rbfCAE is coupled with ENGYS's software (rbf4Helyx connector) providing a joint solution for:
  - Automatic design exploration
  - Interactive sculpting leveraged by adjoint
  - One-way fluid-structure interaction
- We will soon support:
  - Two-way fluid-structure interaction
  - AI based solutions and ROM
  - VR interactions

Thank you!

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