RBF Morph

Empowering Automotive External Aerodynamics Using Advanced RBF Mesh Morphing Methods

Marco Evangelos Biancolini
CTO and company founder

rbf™

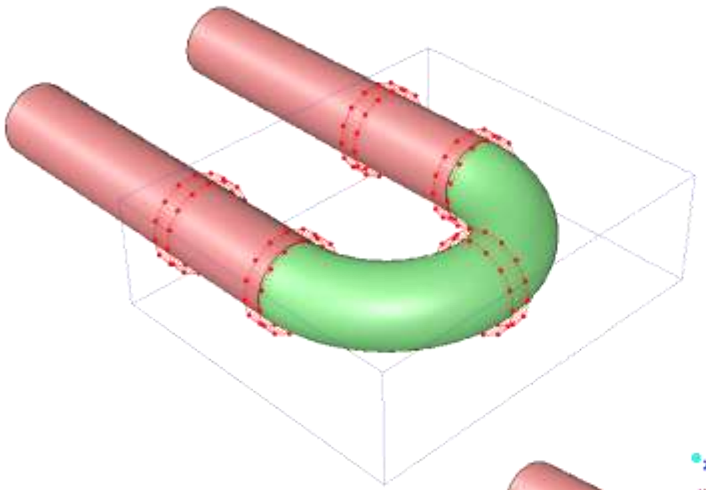
Outline

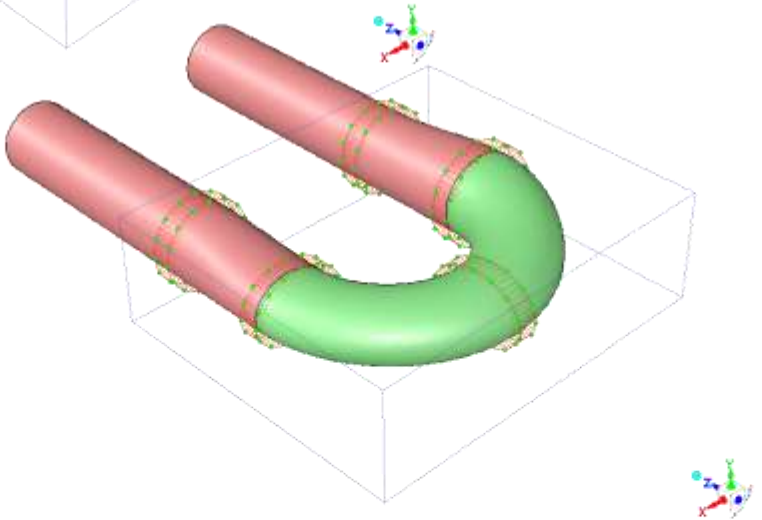
- A short introduction of RBF Morph technology and company
- Typical usage scenario and applications
- The solution offered in combination with ENGYS
- Examples
- What’s next?
- Conclusions

A quick introduction of RBF Morph

Shape parameterization strategy

- Geometric parameterization by **mesh morphing**
- The principle is to take the control on a set of point and to transfer the deformation to the whole mesh
- A **new shape** of the CAE model **ready to run**
  - for structural analysis in the FEA solver
  - for flow analysis in the CFD solver





engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

Radial Basis Functions mesh Morphing

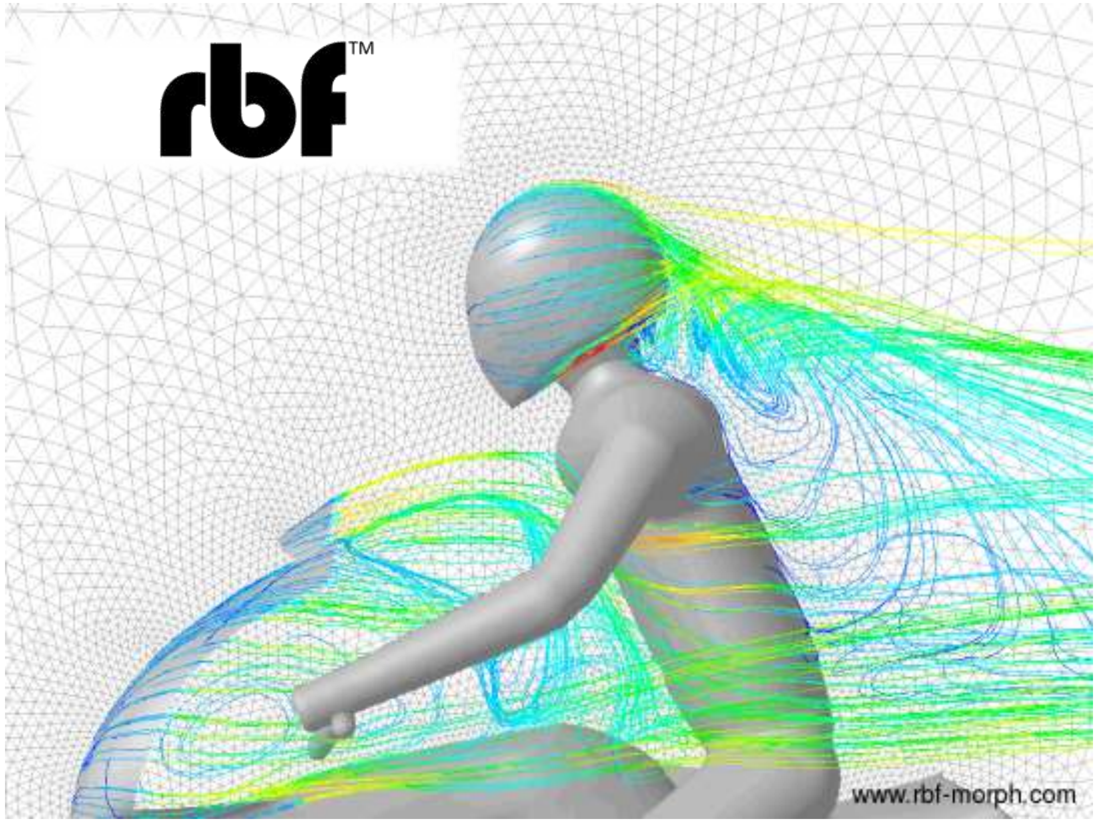
- We offer **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements

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

- RBF are recognized to be one of the **best mathematical tool** for mesh morphing

Radial Basis Functions mesh Morphing

- Geometric control by **R**adial **B**asis **F**unctions mesh **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



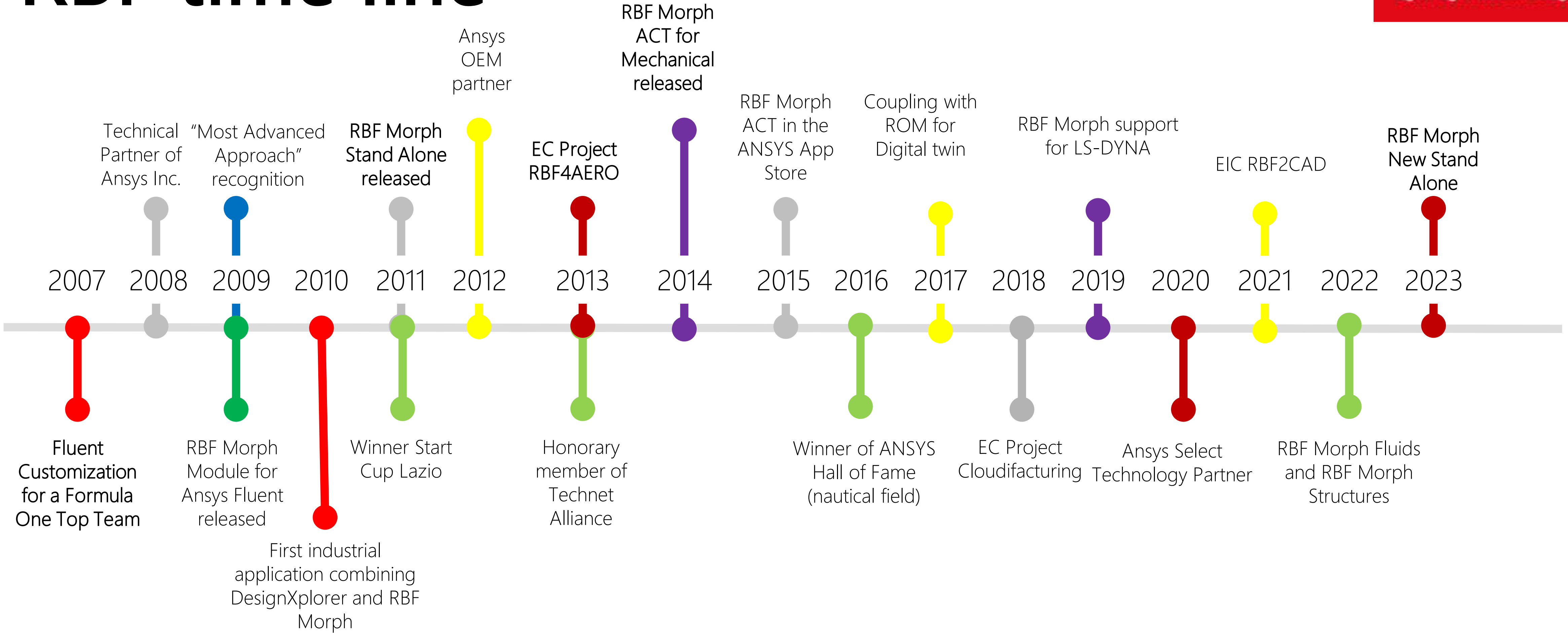
Radial Basis Functions mesh Morphing

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)

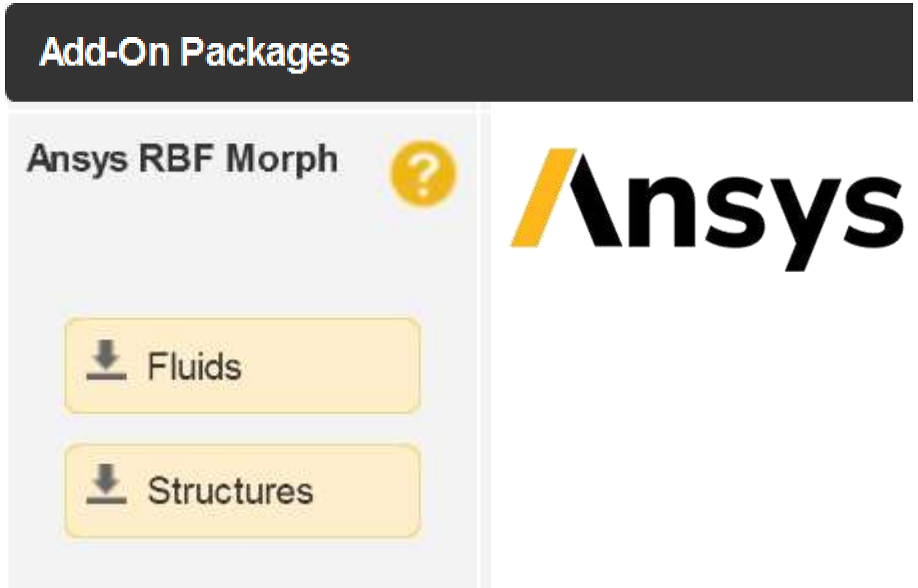
RBF time line



Ansys RBF Morph products

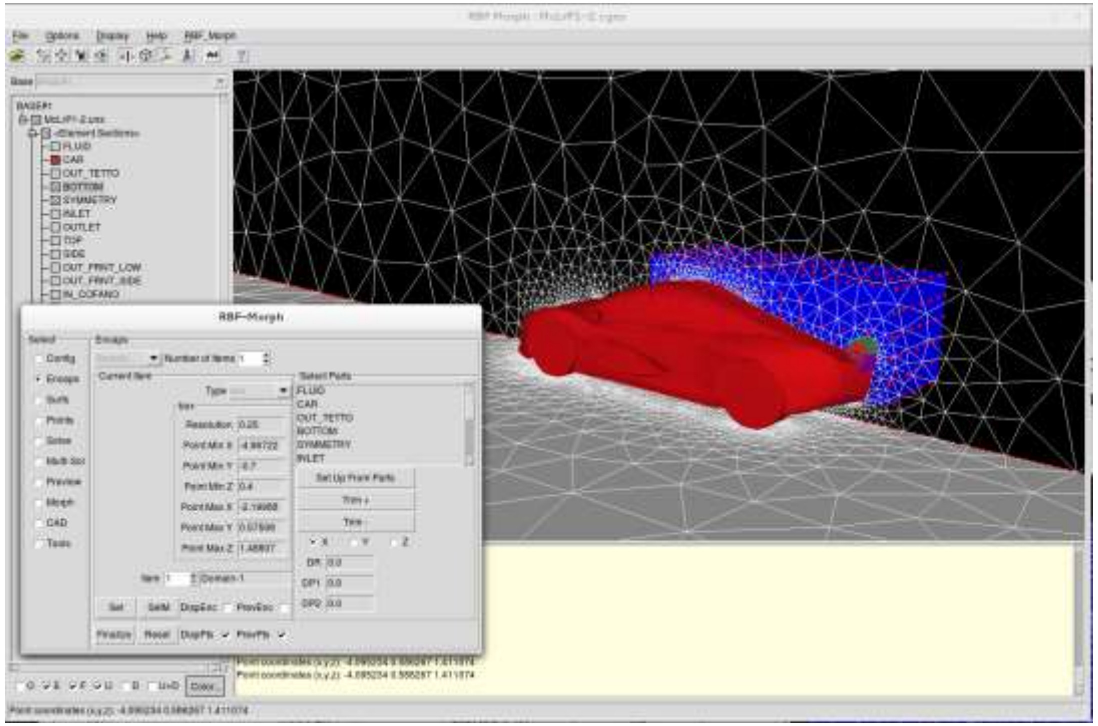
engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

- An RBF mesh morphing solution fully embedded in Ansys
  - RBF Morph Fluids – an Add On for Fluent
  - RBF Morph Structures – an ACT App for Mechanical
- Full integration with optiSLang and Twin Builder
- Support for LS-DYNA and APDL



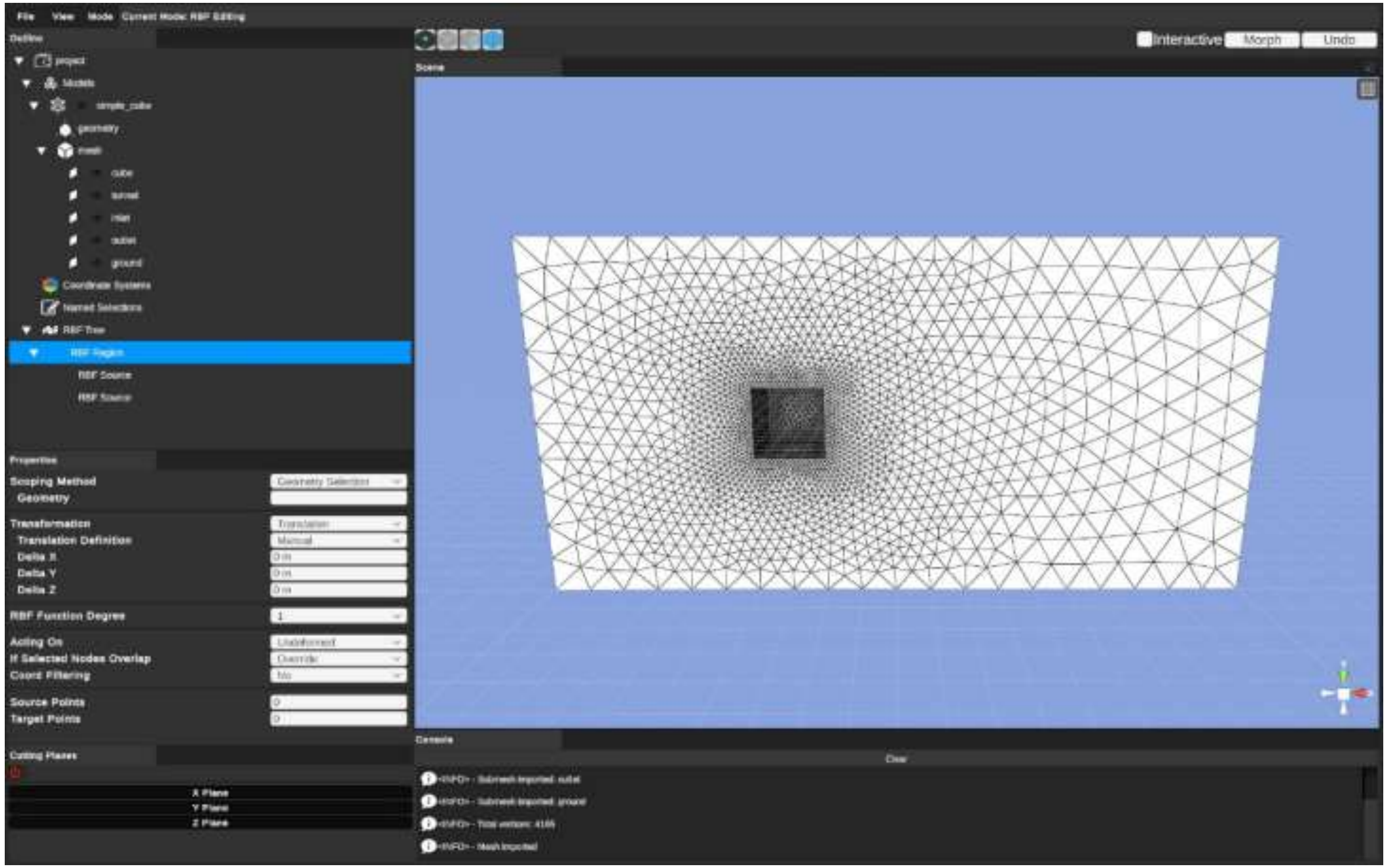
https://www.rbf-morph.com/wp-content/uploads/2023/05/RBFMorph_Brochure.pdf

RBF Morph Stand Alone



- Released in 2011
- Read in **STL and CGNS file formats**.
- Solver independent process that supports **many mesh formats**
- **Scriptable** via tcl
- Same working approach of the Fluent Add On

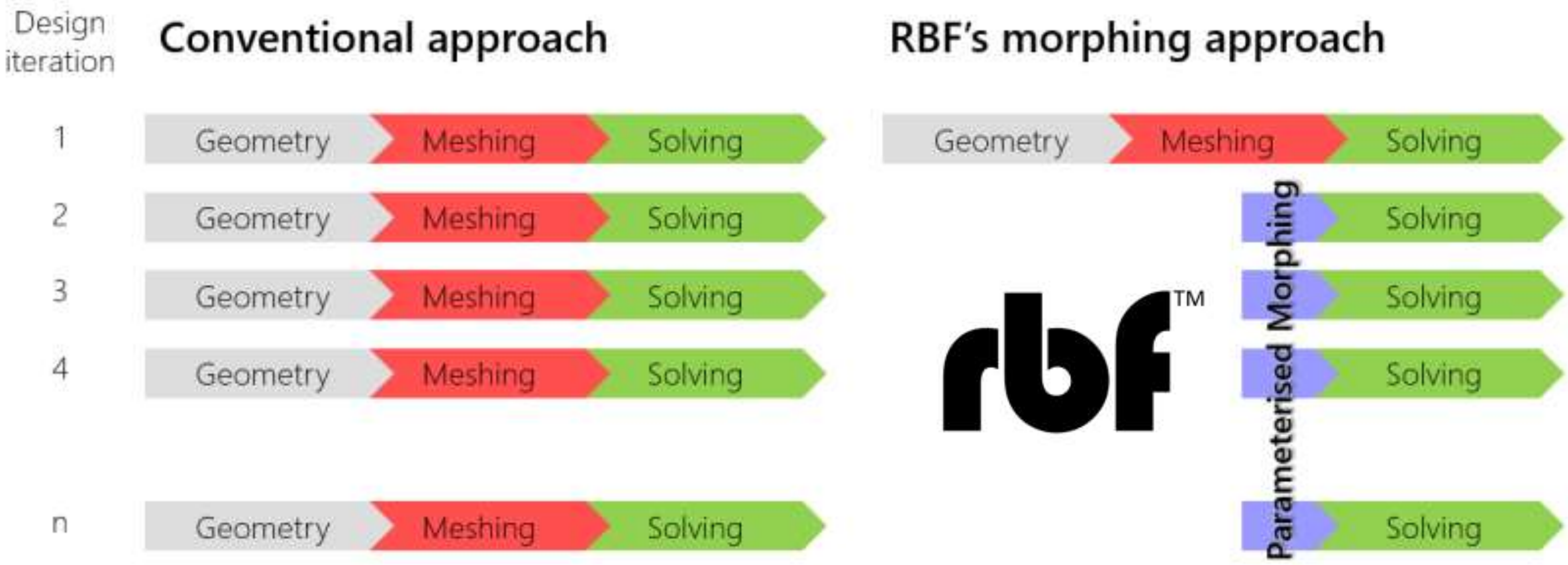
New RBF Morph Stand Alone



- To be (hopefully!) released in 2024
- Read in **STL, STEP**
- **Unity - OpenCascade**
- Solver independent process that supports **many mesh formats**
- **Scriptable** via python
- Same working approach of ACT for Workbench

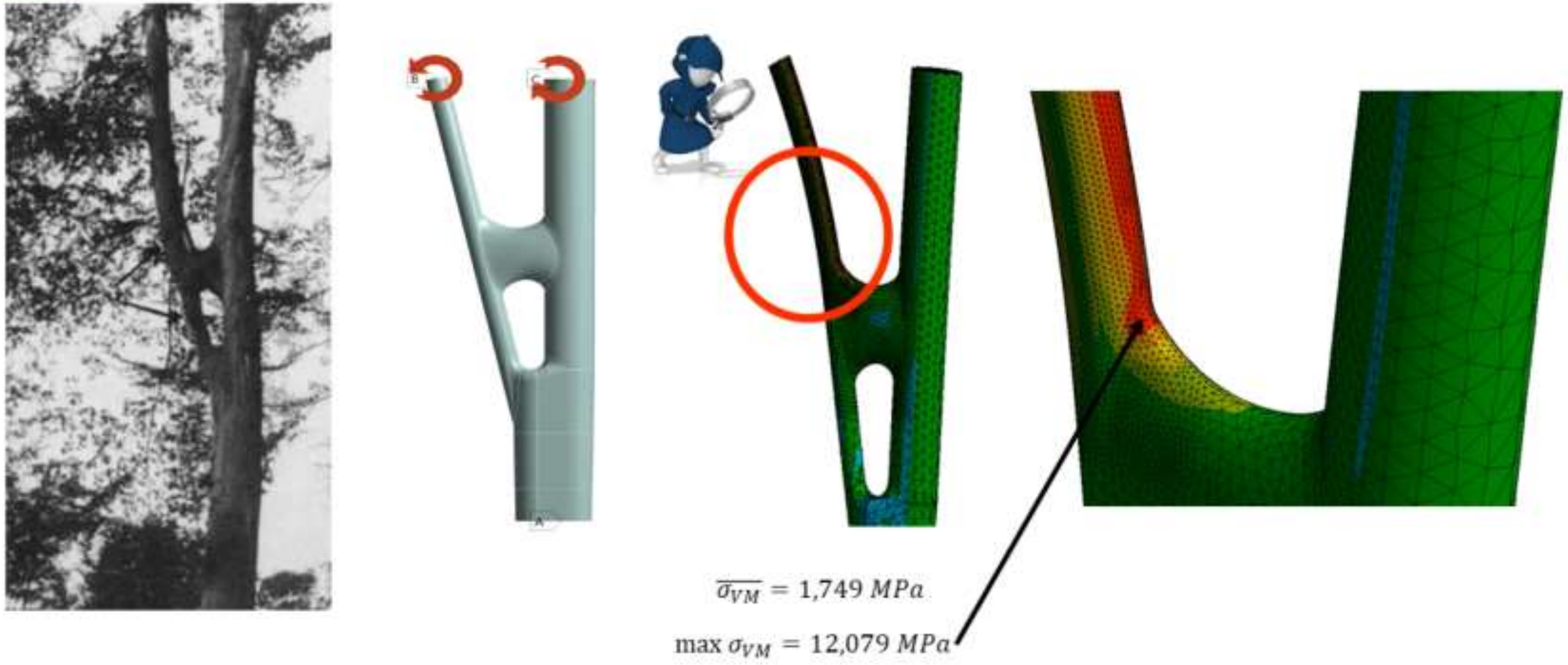
We make CAE models parametric

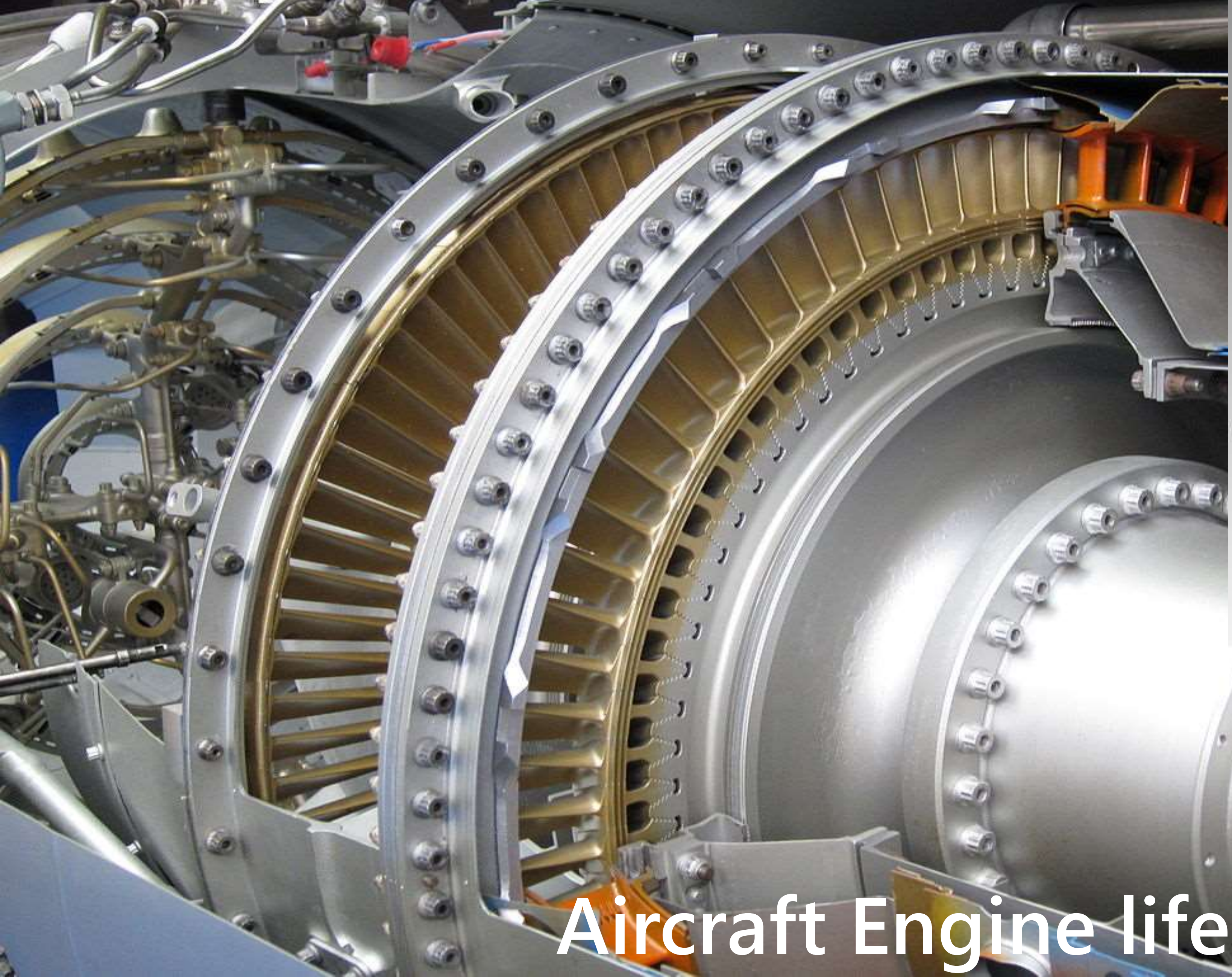
- RBF Morph makes the CAE model **parametric**
- Shape parameters are driven by **an orchestrator**
- Shape parameters can be used to generate snapshots for real time Digital Twins (**ROM/AI**)

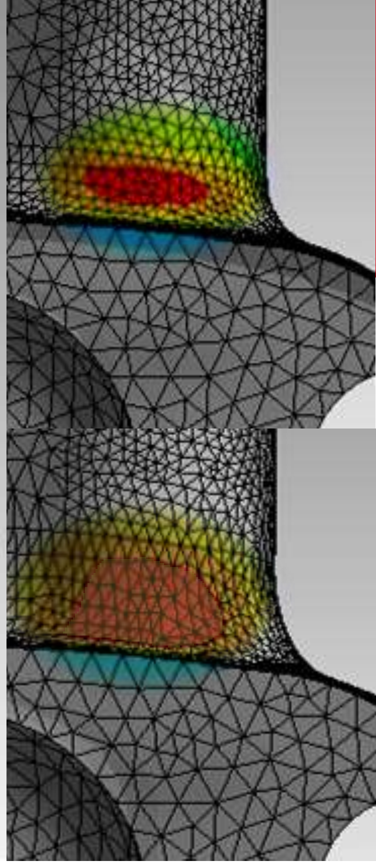


Parameter-free shape optimization

- The new shape can be guided by the CAE solution itself (organic shapes)
  - Coupled with the **CFD adjoint solver**
  - BGM (Biological Growth Method) optimizer in **FEA solver**







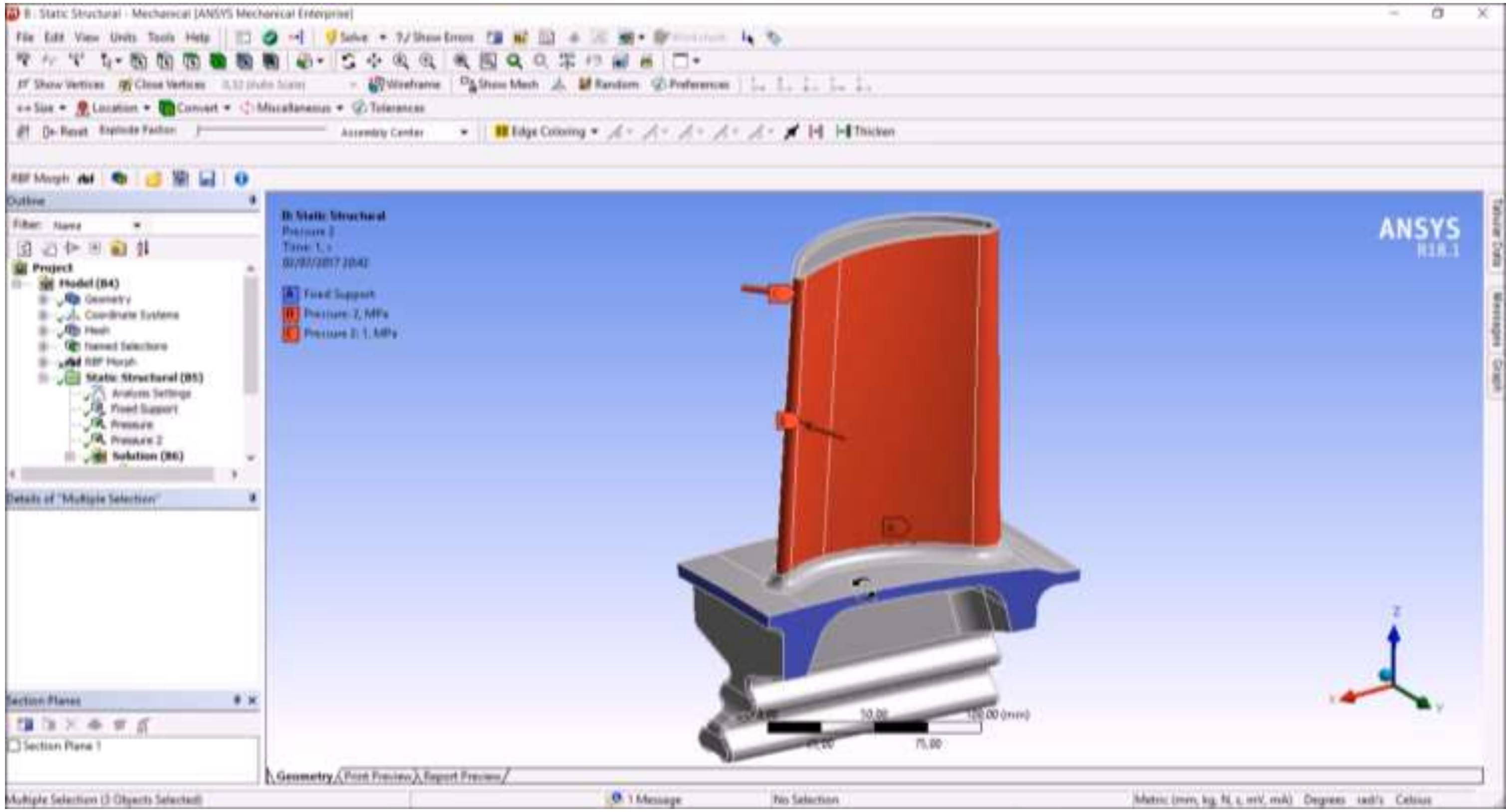
Aircraft Engine life extended!

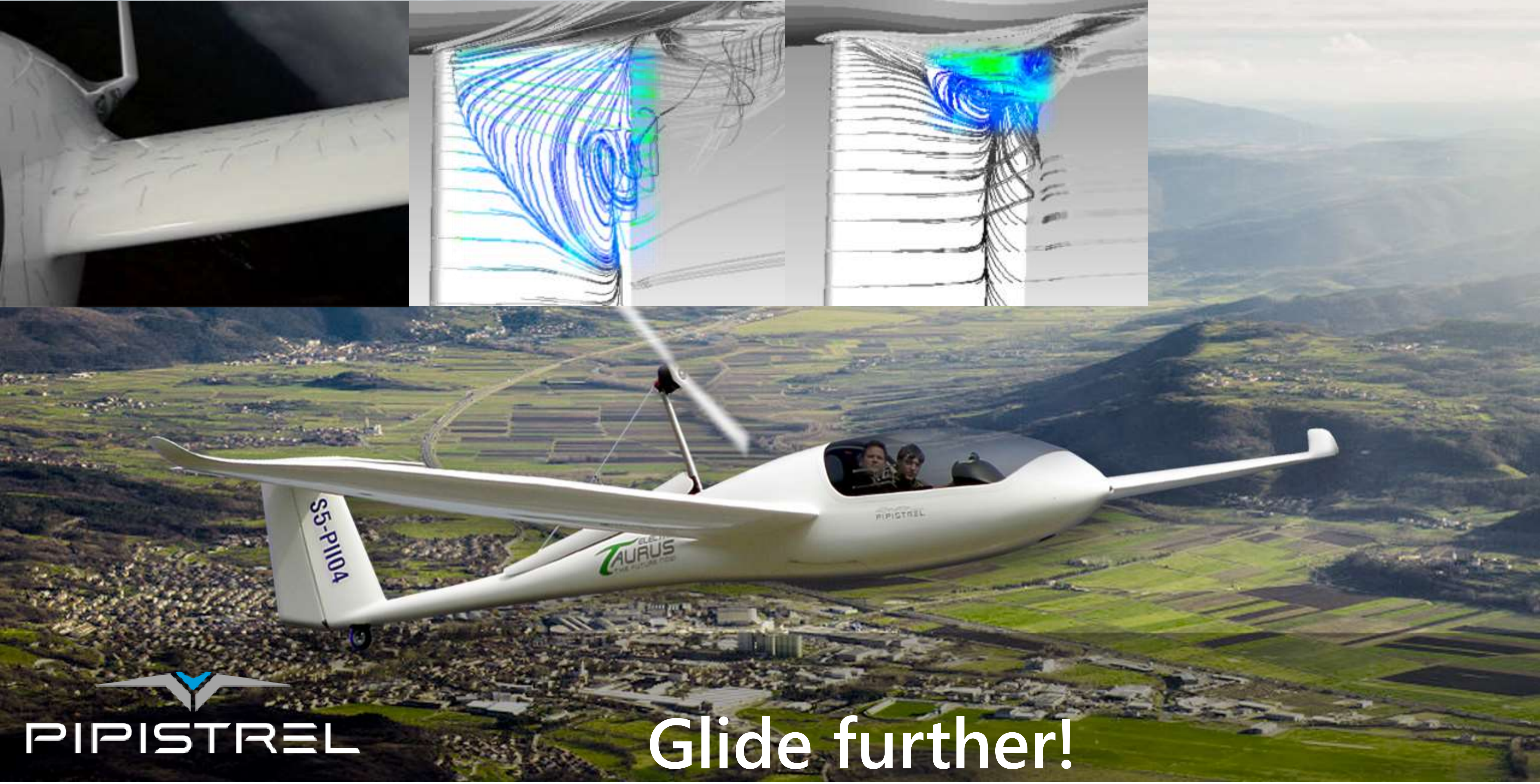
25% stress reduction

Parameter based mesh morphing (design points/snapshots)

engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

- **Morphing regions** are identified and added to the tree (volume mesh)
- Surface are controlled by modifying two closed **curves**
- Design points are computed by changing the **two parameters** to achieve the optimal design



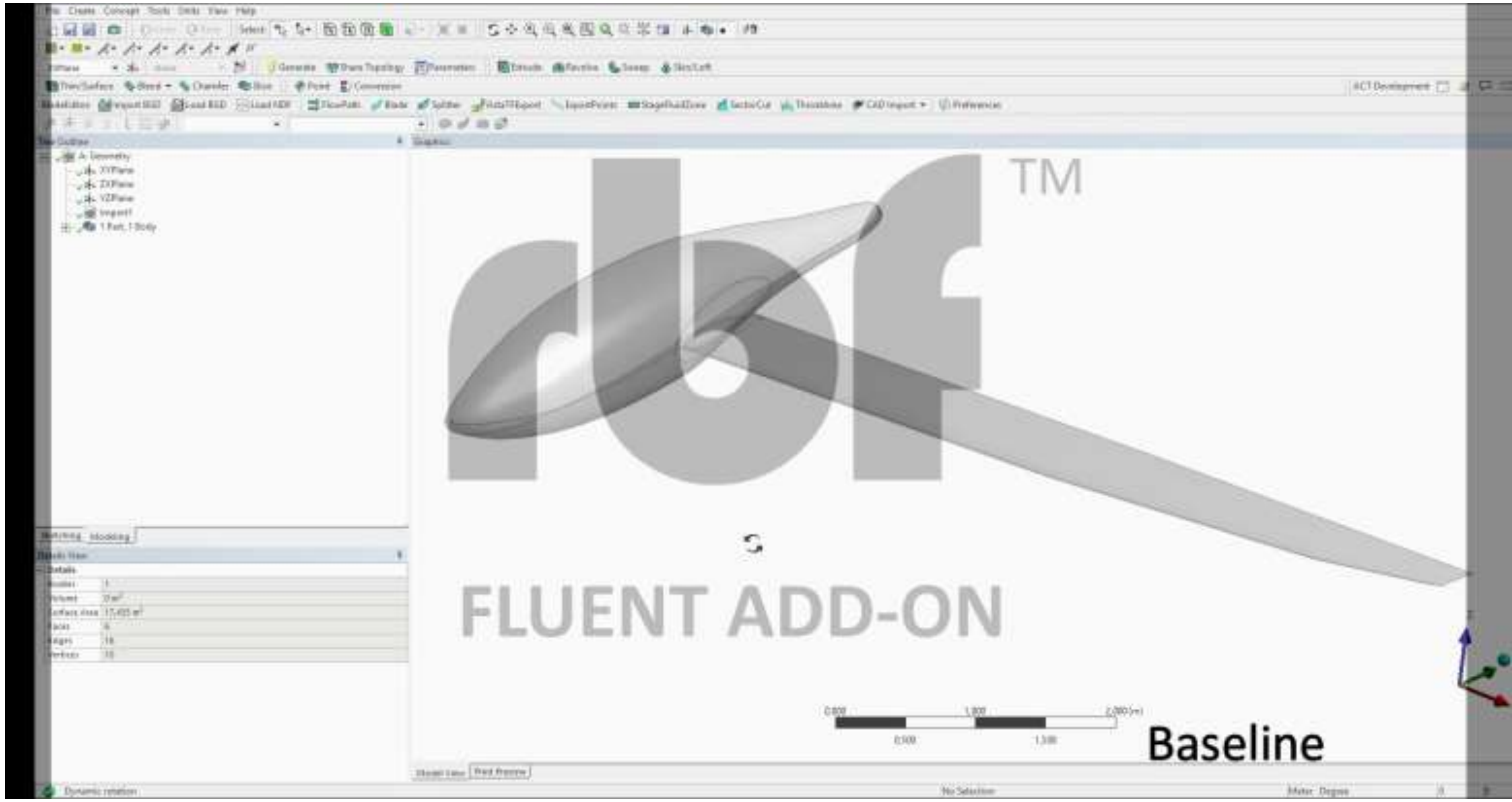


Glide further!

35% more wing efficiency

Parameter based mesh morphing (design points/snapshots)

- **Morphing regions** are identified by fluid zones or by user defined domains
- Surfaces are controlled by two sculpting tools (cylinders)
- Design points are computed by changing the **two parameters** to achieve the optimal design

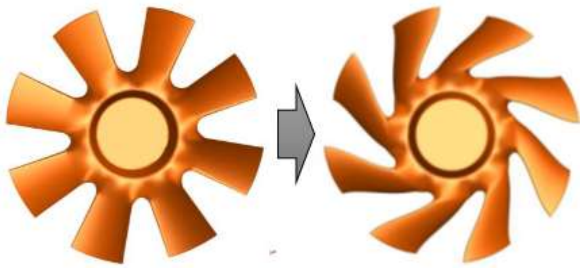


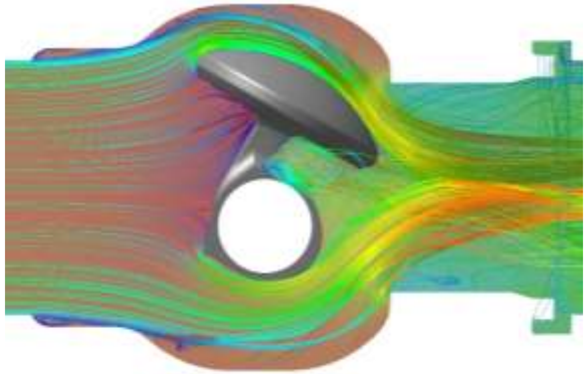
Typical usage scenario and applications

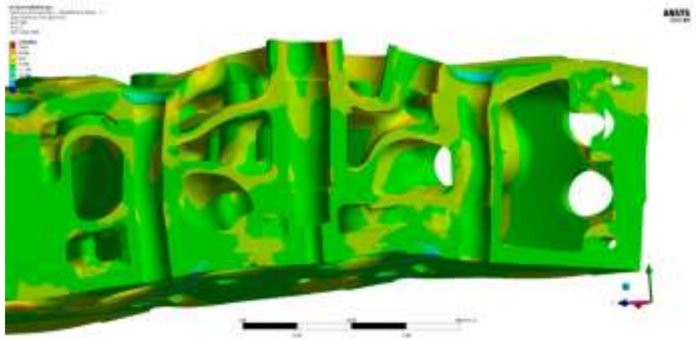
Main uses of RBF Morph

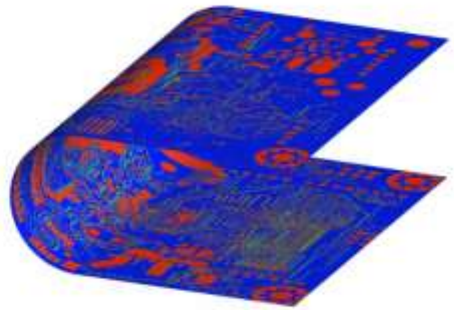
Usage	FEA	CFD	Optimizer	AI
Automated and quick variable design space exploration.	✓	✓		
Optimization (Single physics or multi-physics). Shape optimization for stress reduction, mass reduction, fluid-structure interaction	✓	✓	✓	
Digital twin development (static ROMs)	✓	✓	✓	✓
Lifing applications Simulate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

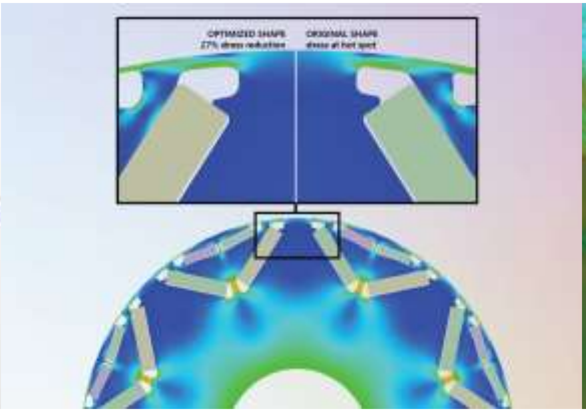
Applications

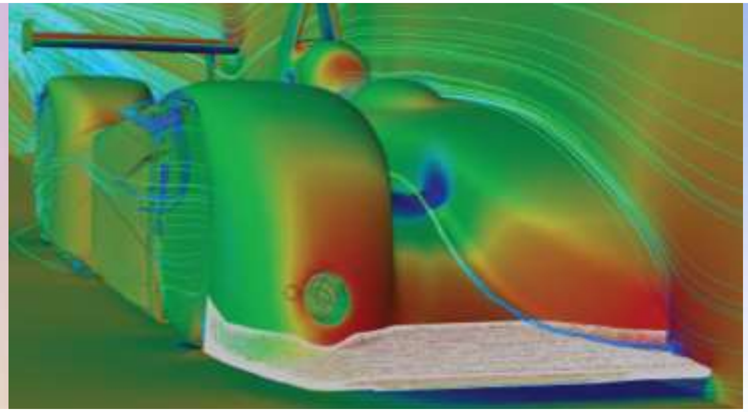












engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

EU-funded research projects

RBF4AERO

FORTISSIMO

RIBES

CloudiFacturing

EUROfusion

spinner
next generation spine experts

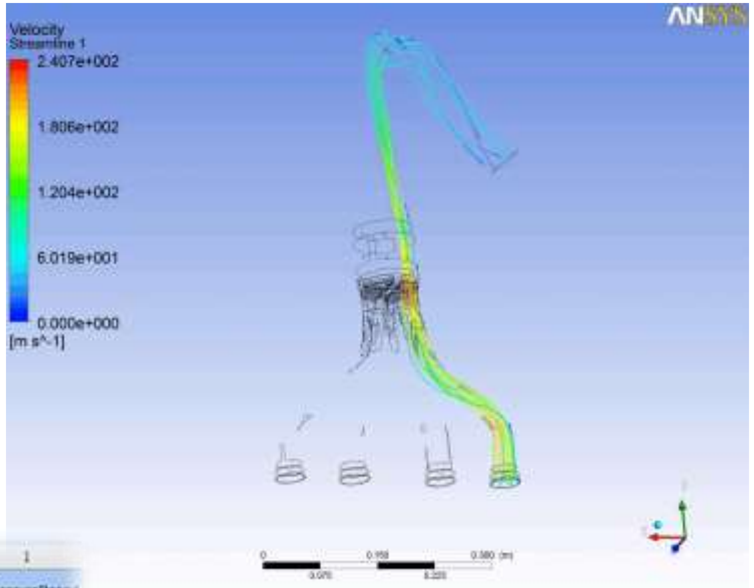
MEDITATE

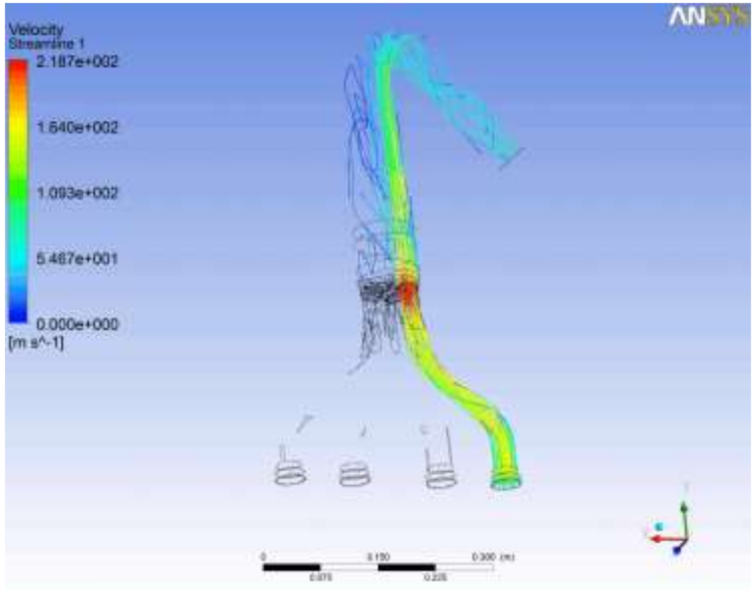
ff4EuroHPC

engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

Exhaust manifold

MIRA





A	B	C	D	E	F	G	H	I
Name	P5 - Pipe1Curve1	P6 - Pipe2	P7 - Pipe4Curve1	P8 - Pipe3	P1 - PressureDrop1	P2 - PressureDrop2	P3 - PressureDrop3	P4 - PressureDrop4
					Pa	Pa	Pa	Pa
Current	4	4	4	4	12892	11366	13028	16619
DP 1	3	3	3	3	12882	11247	13487	16731
DP 2	2	2	2	2	12897	11546	13554	16911
DP 3	1	1	1	1	13403	11477	13920	17666
DP 4	0	0	0	0	13555	11750	13967	17718

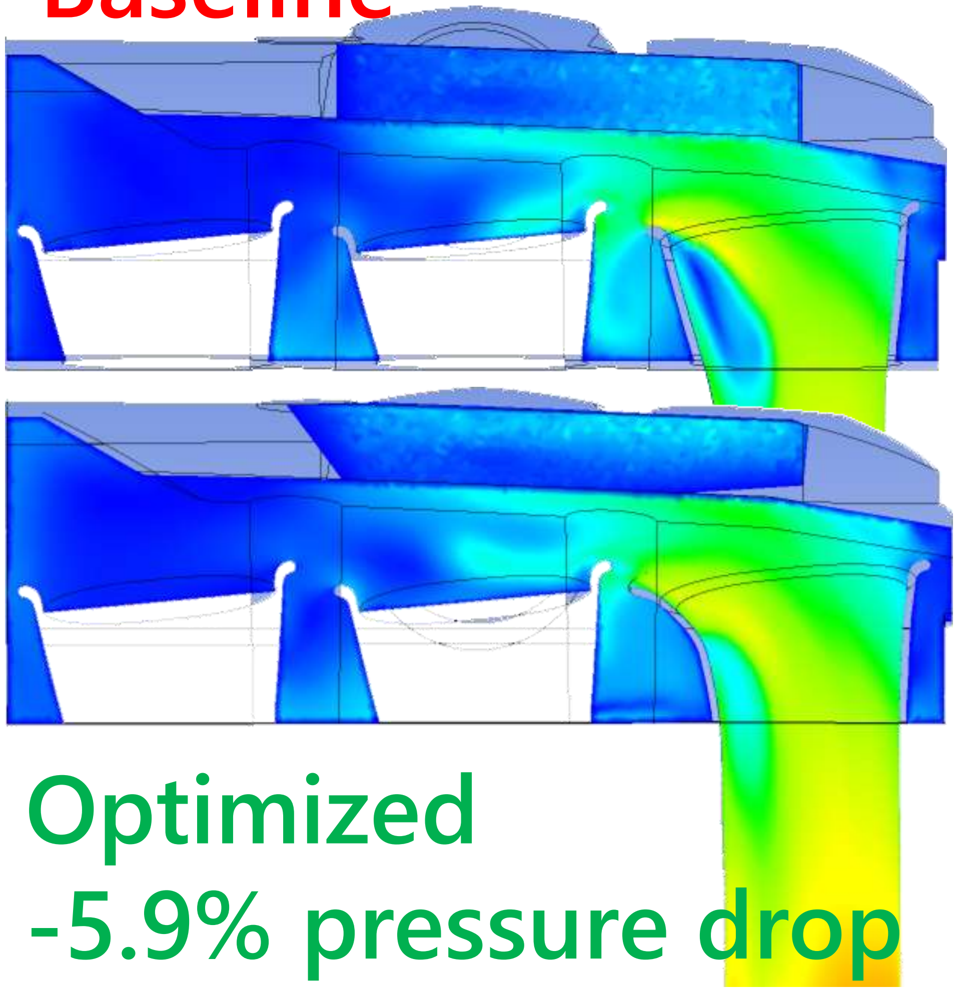
Balanced flow and 8% less pressure drop

FORTISSIMO

engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

Lamborghini Aventador engine air box

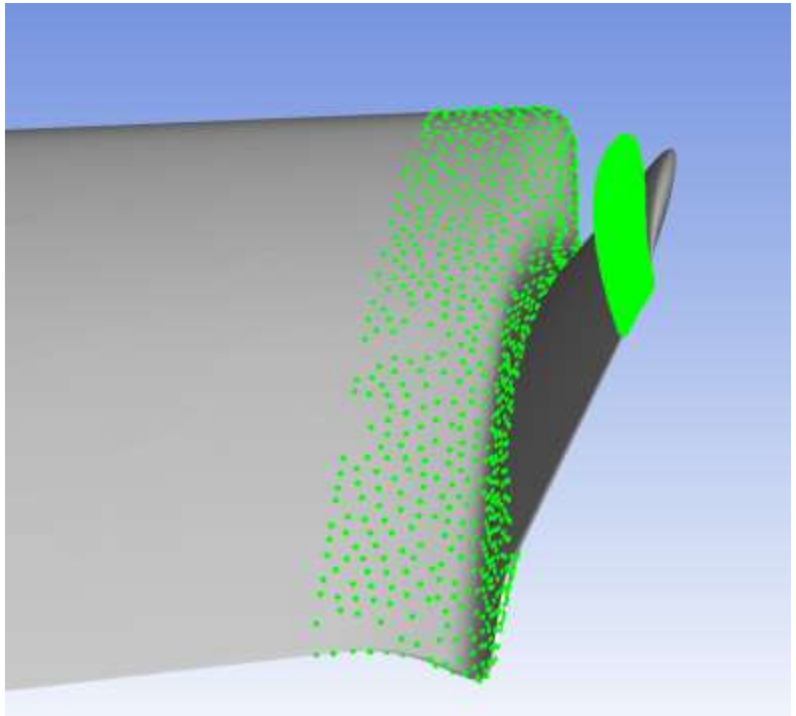
Baseline

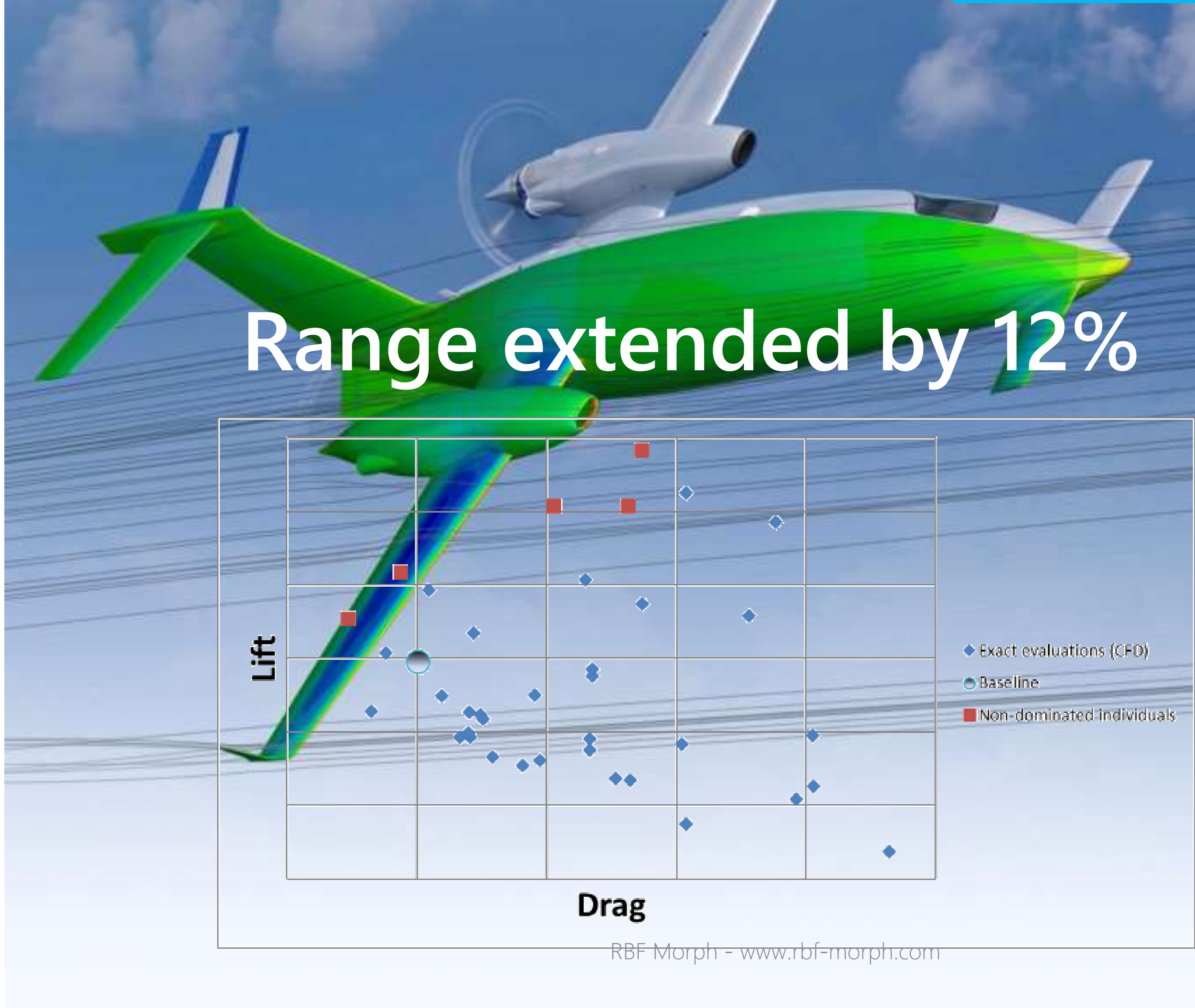


Optimized
-5.9% pressure drop

https://www.rbf-morph.com/wp-content/uploads/2015/12/HSLCAE-CONFJO-07NOV.pdf

FSI winglet optimization

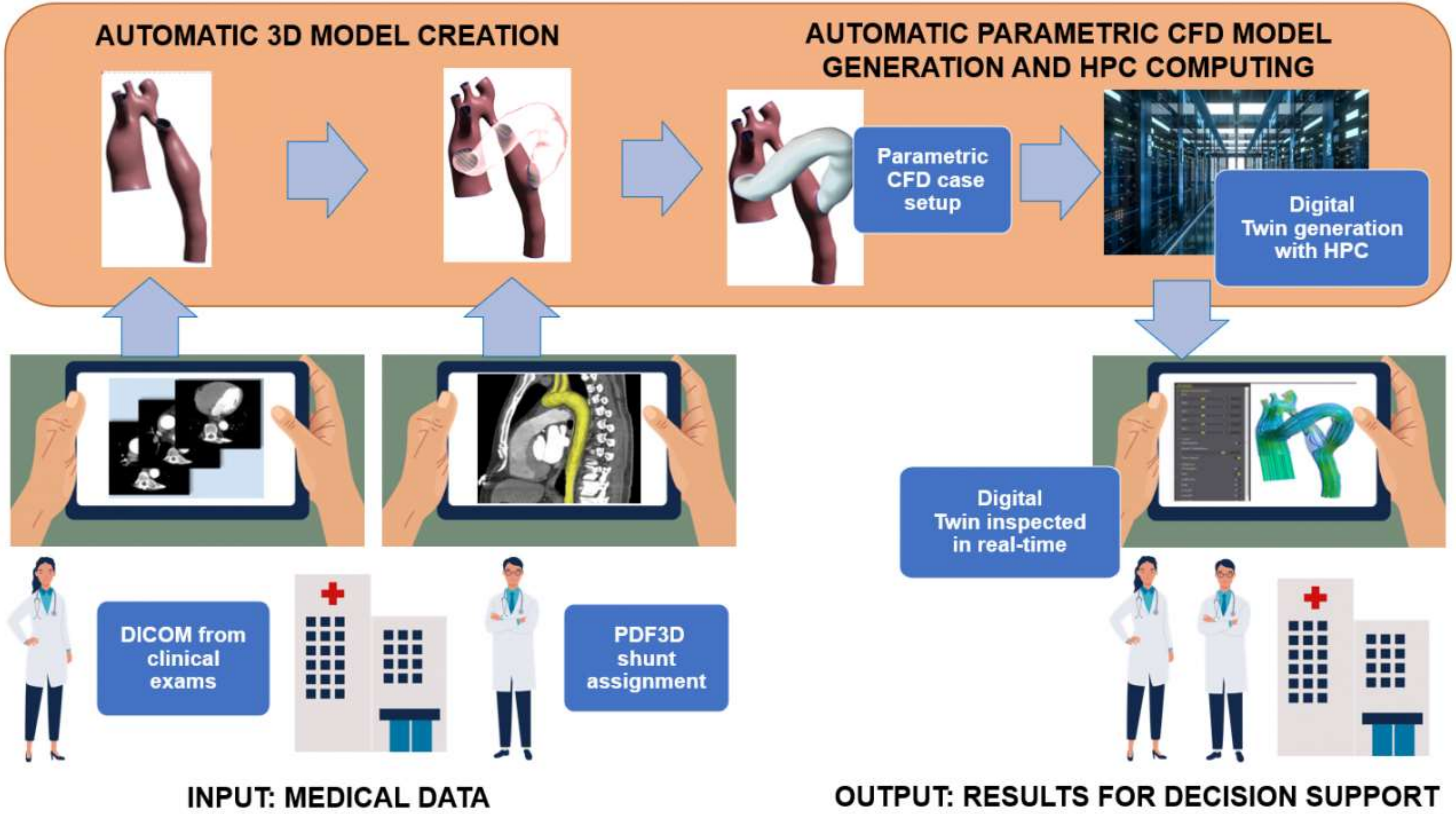




Alpha Electro Propeller

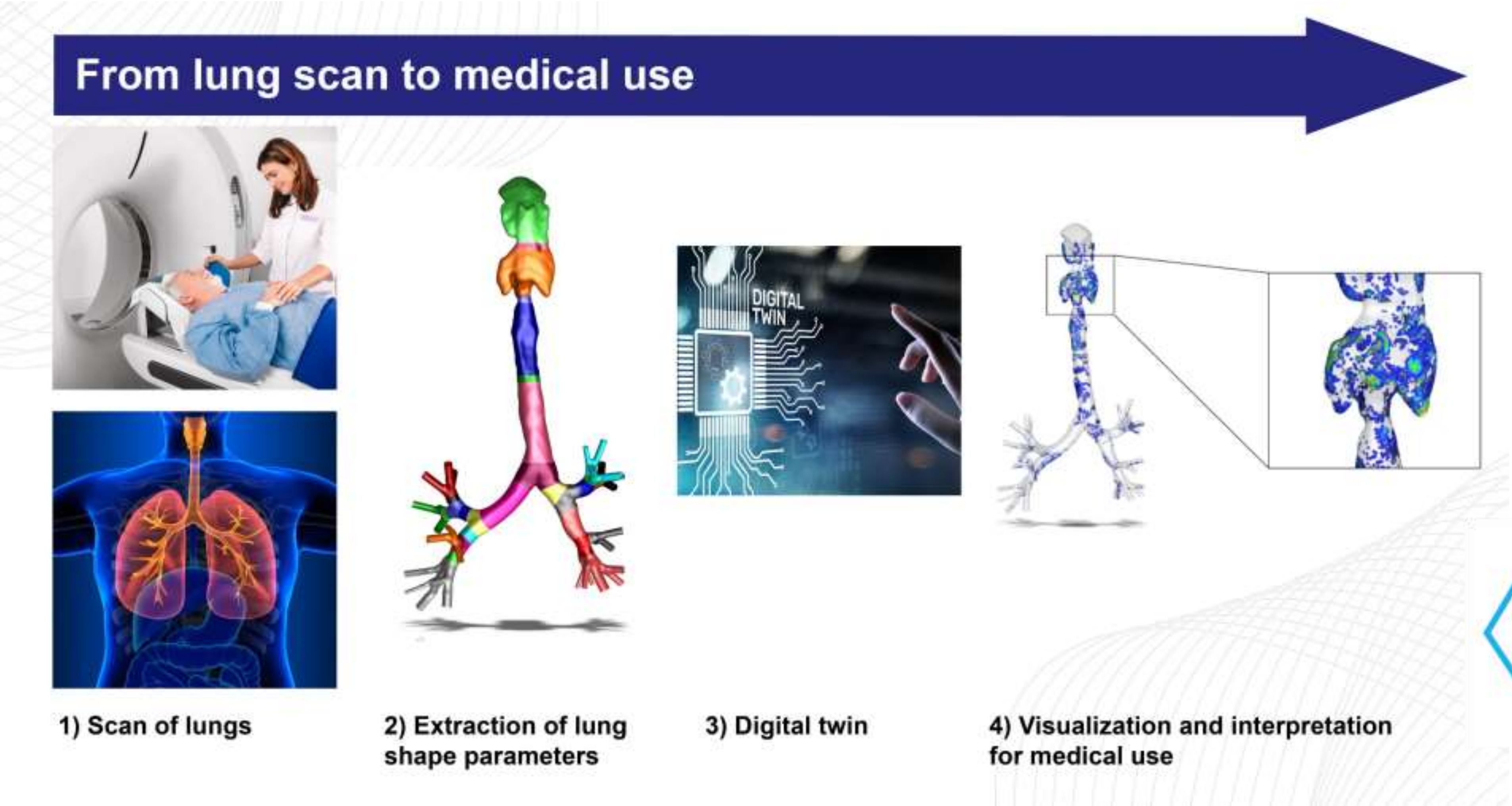
- Mesh morphing for shape **parametrization** of numerical grids (CFD/FEM)
- FSI based on mapping and modal superposition
- Performance of the **propeller** are optimised for the specific needs of **electric propulsion (+4% efficiency)**

Medical Digital Twin Copernicus



https://www.ff4eurohpc.eu/en/experiments/2021070910512579/cloudbased_hpc_platform_to_support_systemicpulmonary_shunting_procedures

Medical Digital Twin DiTAiD



https://www.ff4eurohpc.eu/en/experiments/2022031514424665/digitaltwin_for_airflow_and_drug_delivery_in_human_airways

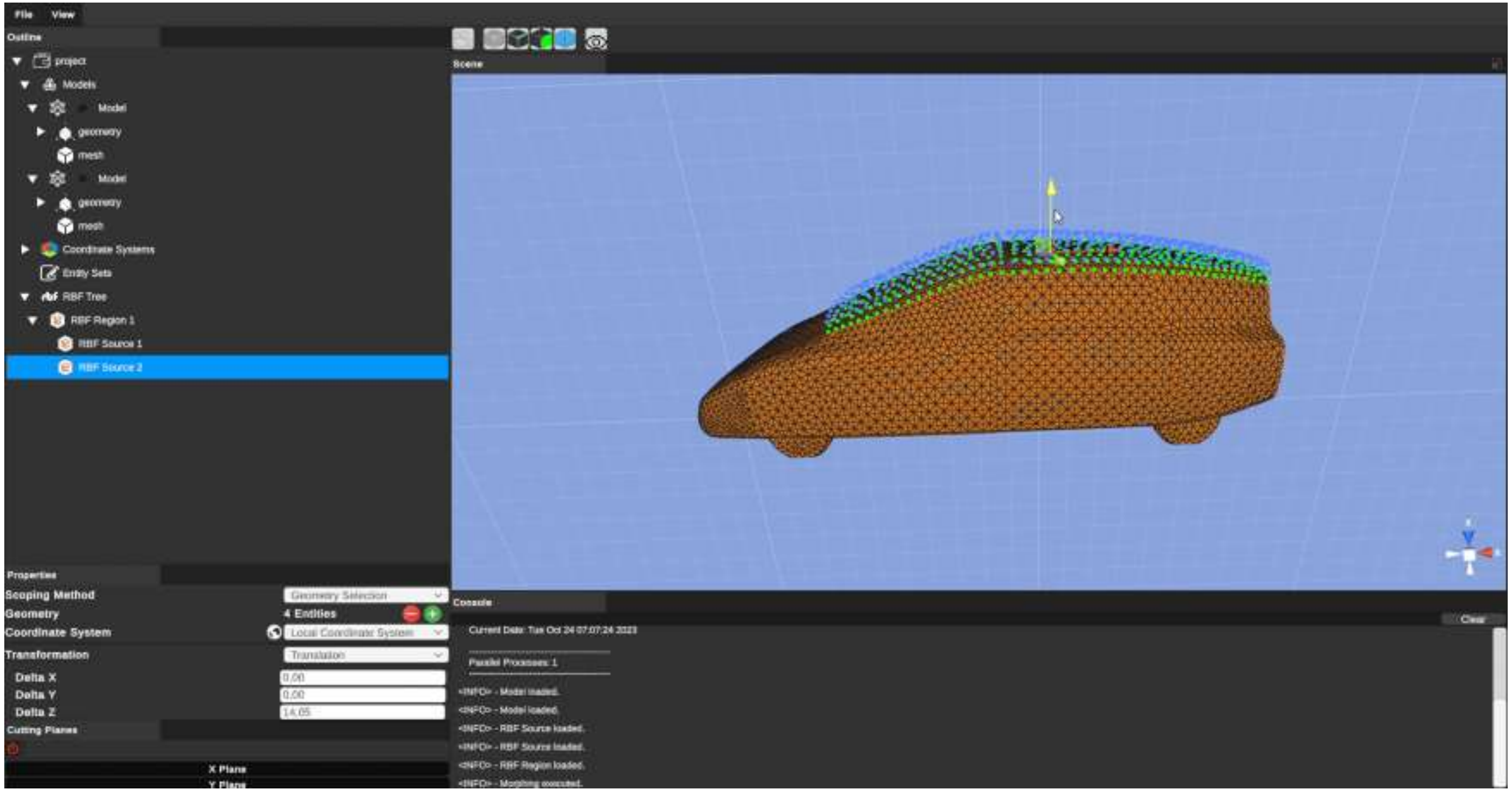
The solution offered in combination with ENGYS technology

HELYX Mesh Morphing

- RBF Morph Stand Alone allows to apply defined shape modifications to HELYX meshes according to two different approaches:
  - **Surface mesh morphing**: mesh morphing is applied to STL files on which HELYX builds the volume mesh
  - **Volume mesh morphing**: the baseline volume mesh is morphed and no mesh built action is required

engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

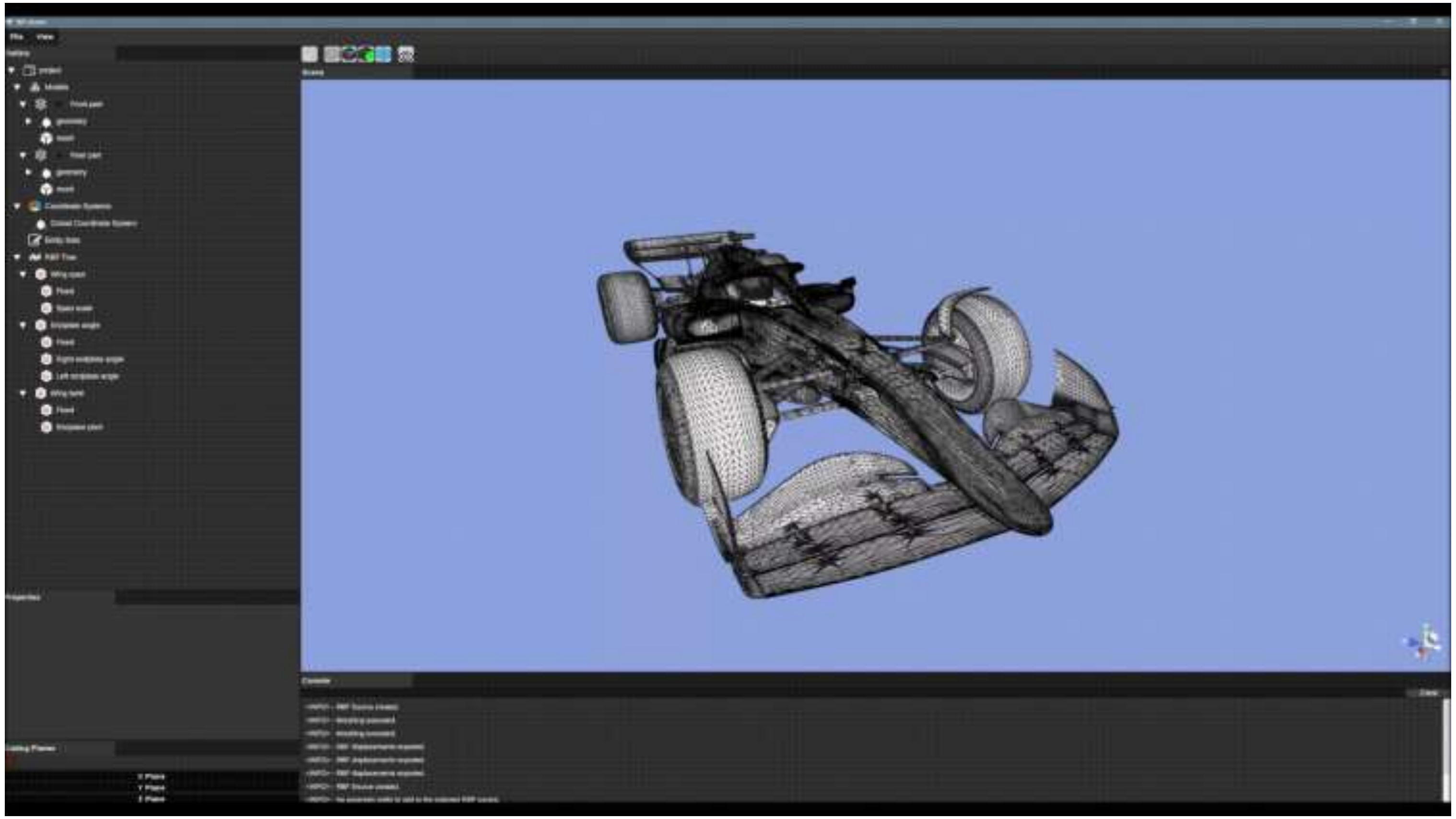
HELYX Mesh Morphing



Workflow details

- The current workflow is not automated yet. For each shape modification the surfaces are controlled in the UI and cloud of points are exported to file
- A python script reads in the cloud of points and combine them with encapsulation boxes (at the moment hard-coded in the script)
- The script walks across the partitioned file system and updates the nodes of the volume mesh

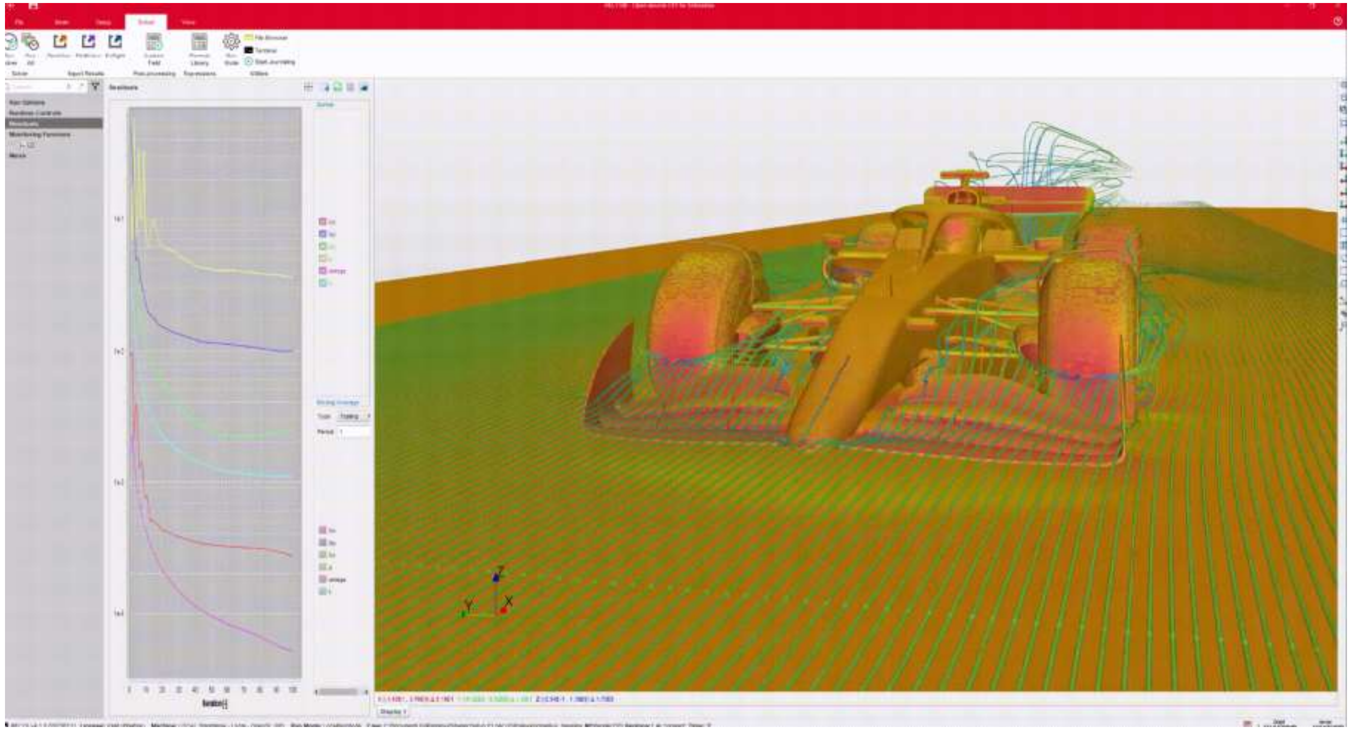
F1 Aerodynamics Challenge



- First simple mockup we used as a morphing playground
- Small mesh (12 millions)
- 3 morphing actions on the front wing
  - Wing span
  - Twist of end plates
  - Incidence of end plates

https://airshaper.com/f1-aerodynamics-challenge

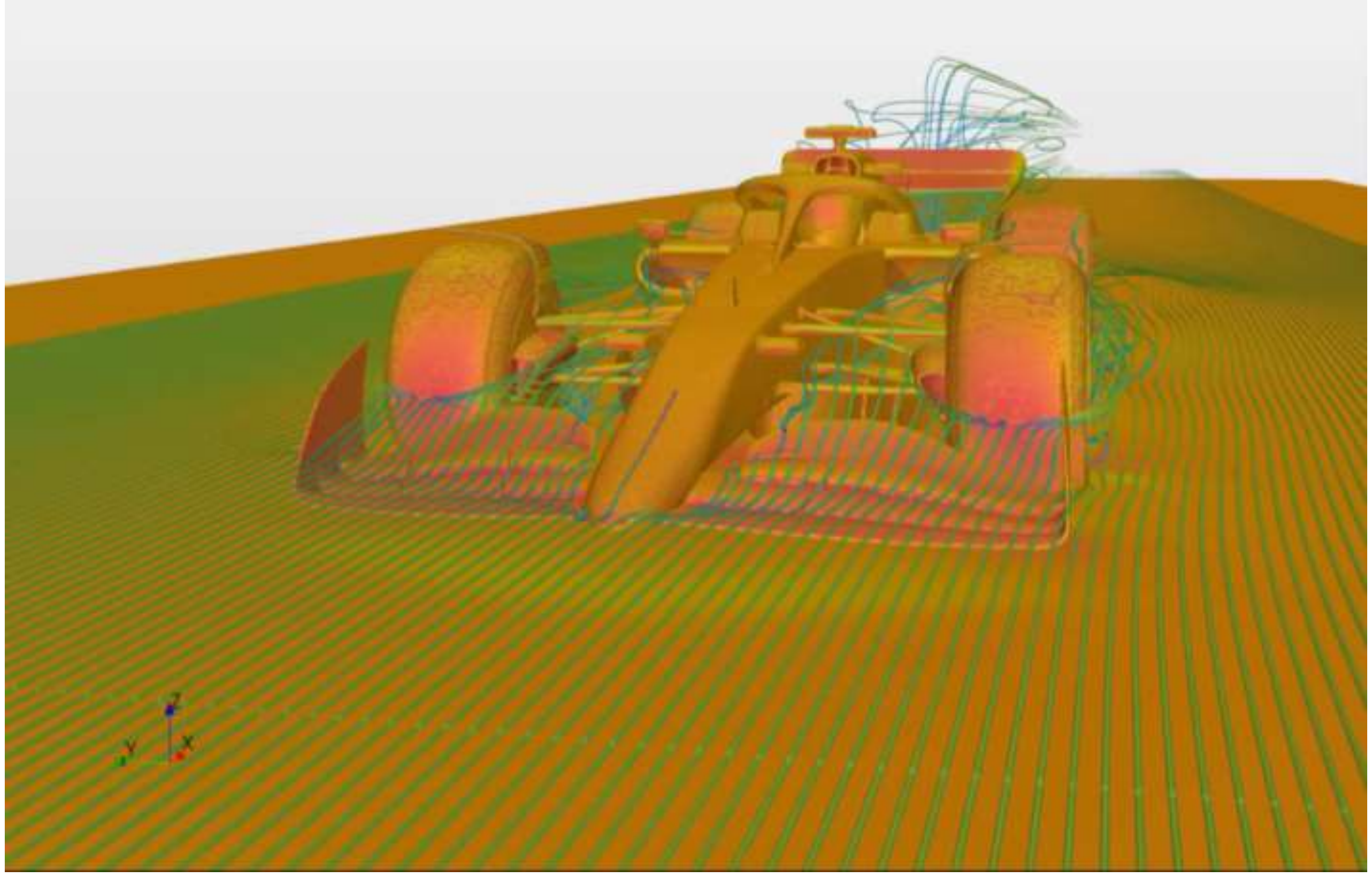
F1 Aerodynamics Challenge



- First simple mockup we used as a morphing playground
- Small mesh (12 millions)
- 3 morphing actions on the front wing
  - Wing span
  - Twist of end plates
  - Incidence of end plates

https://airshaper.com/f1-aerodynamics-challenge

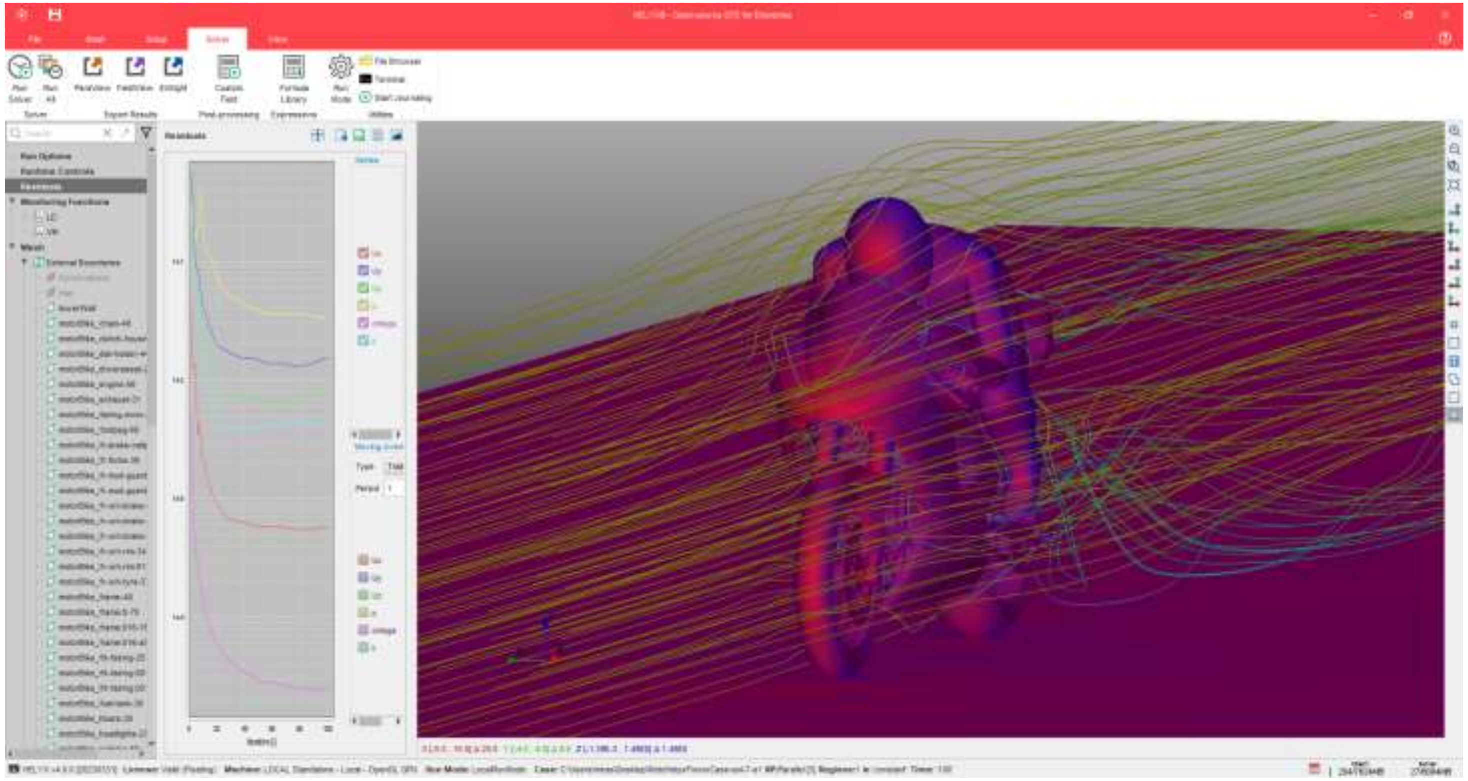
F1 Aerodynamics Challenge



- First simple mockup we used as a morphing playground
- Small mesh (12 millions)
- 3 morphing actions on the front wing
  - Wing span
  - Twist of end plates
  - Incidence of end plates

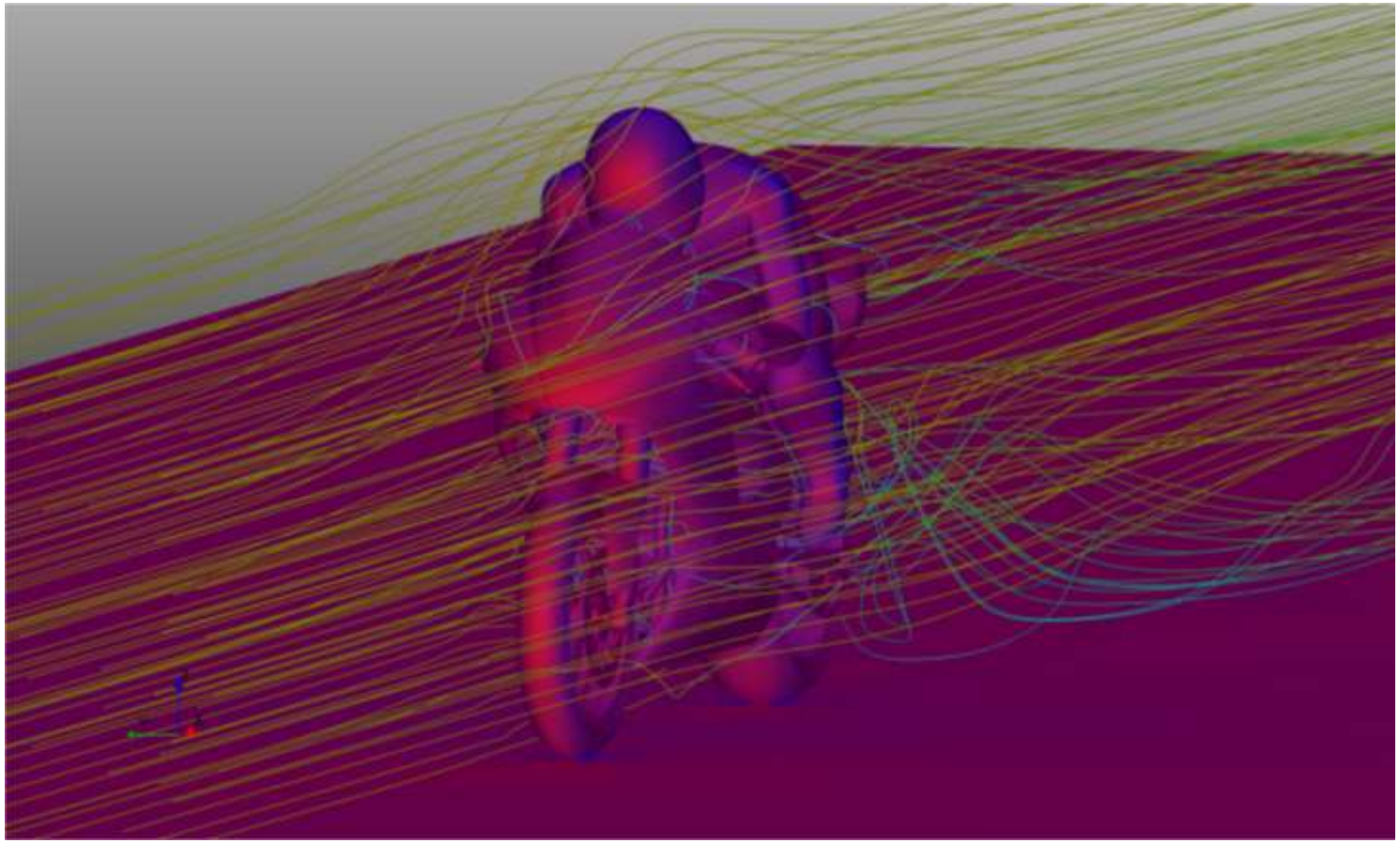
https://airshaper.com/f1-aerodynamics-challenge

motorBike Foam Tutorial



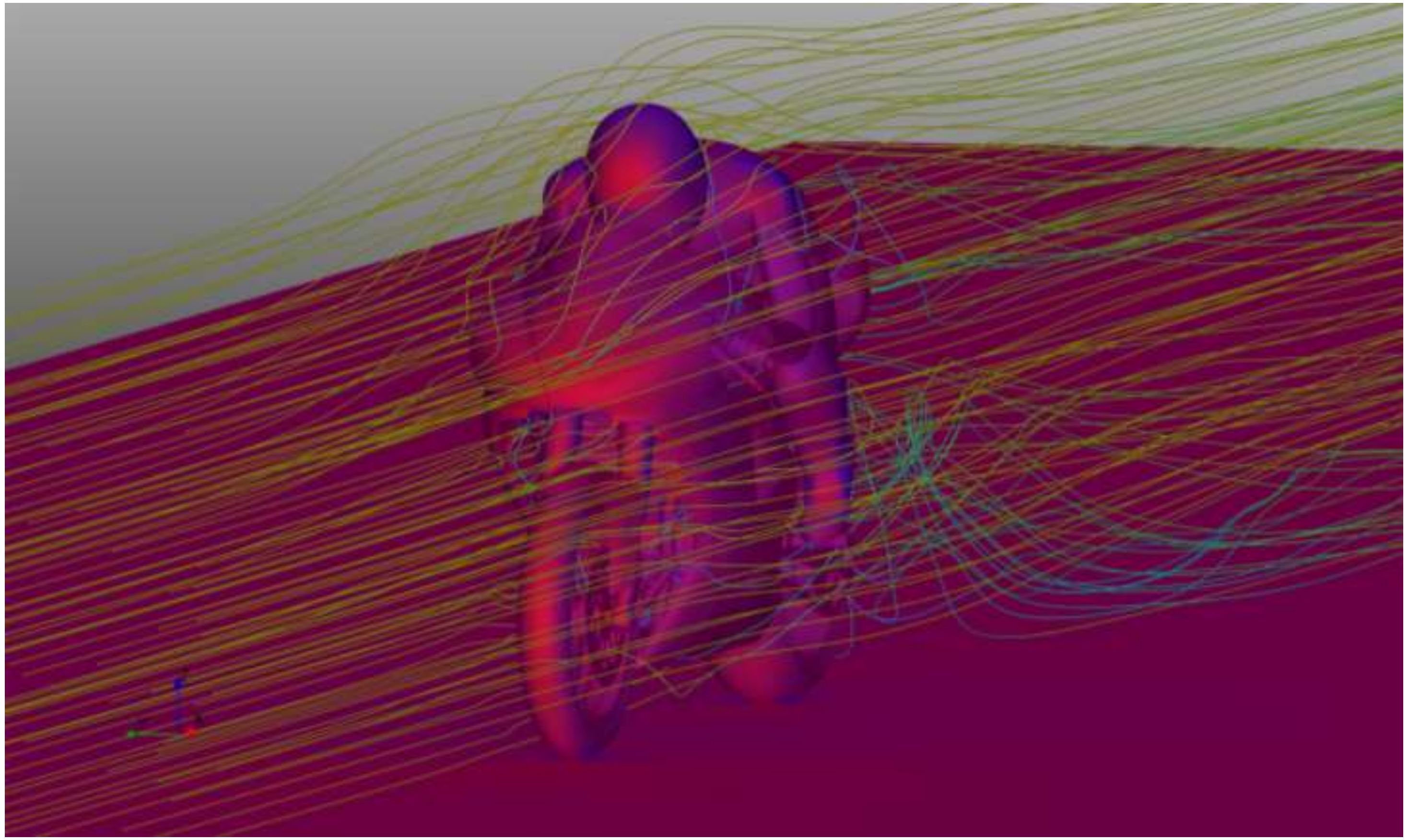
- Second simple mockup we used as a morphing playground
- Small mesh (5 millions)
- Front width

motorBike Foam Tutorial



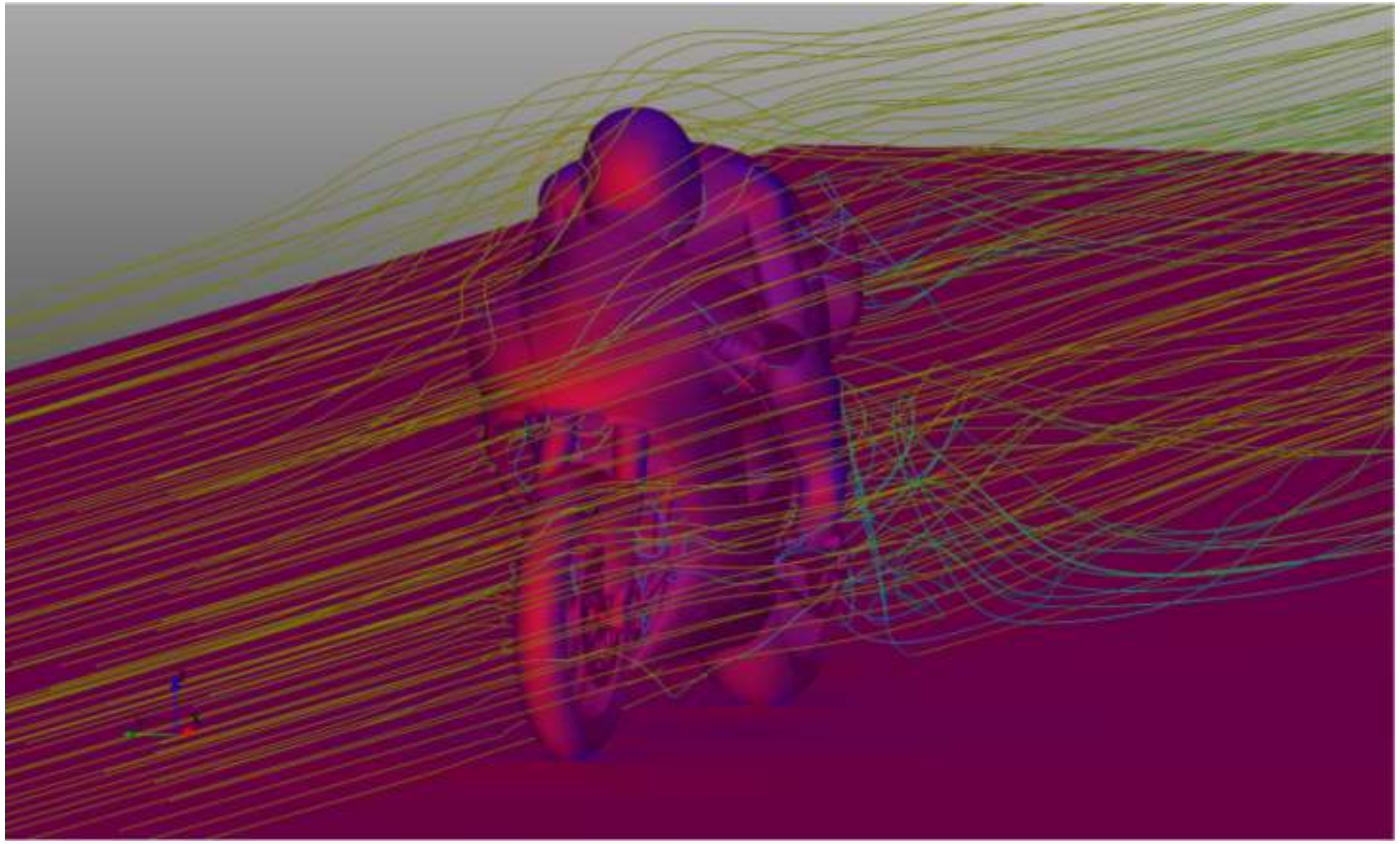
- Second simple mockup we used as a morphing playground
- Small mesh (5 millions)
- Front width

motorBike Foam Tutorial



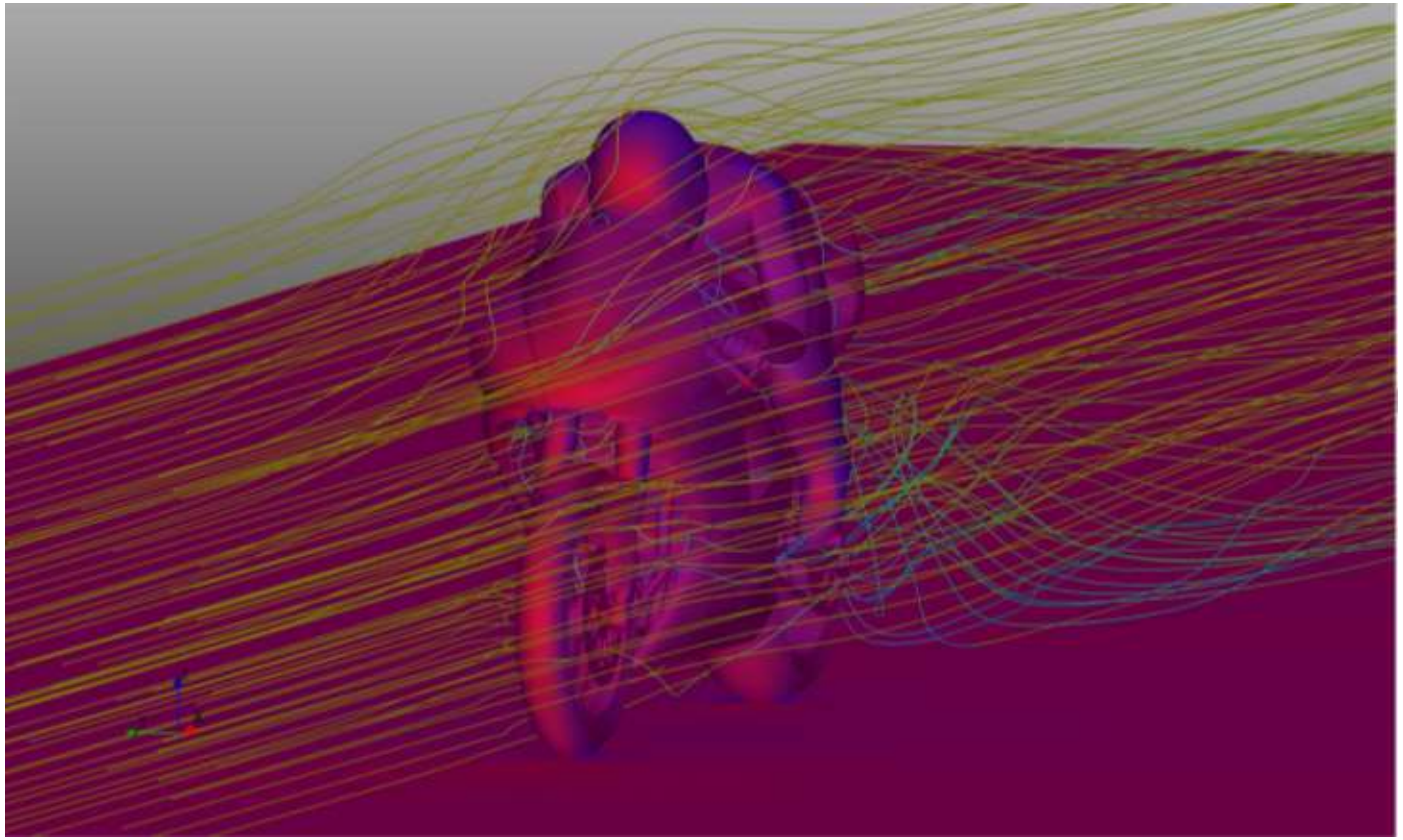
- Second simple mockup we used as a morphing playground
- Small mesh (5 millions)
- Front width

motorBike Foam Tutorial



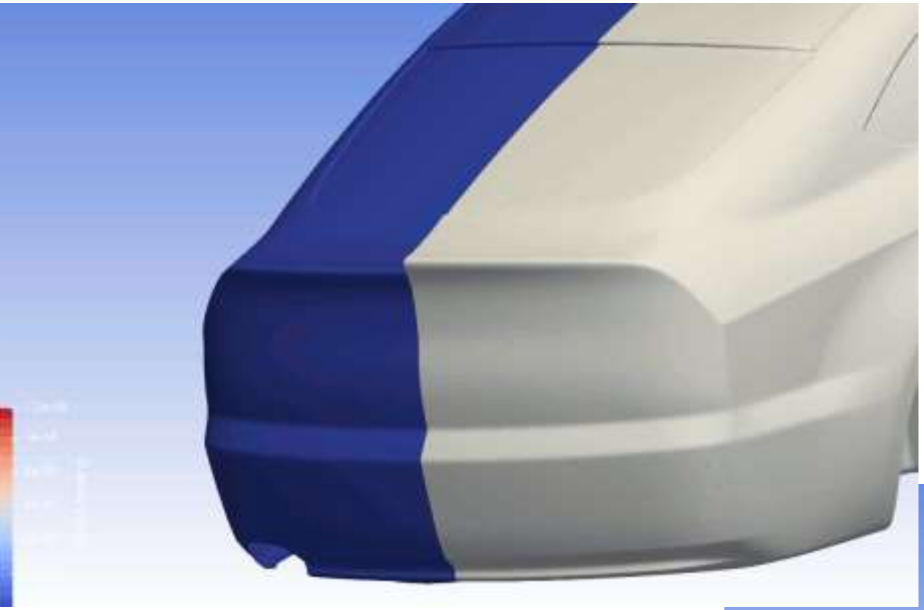
- Second simple mockup we used as a morphing playground
- Small mesh (5 millions)
- Front width

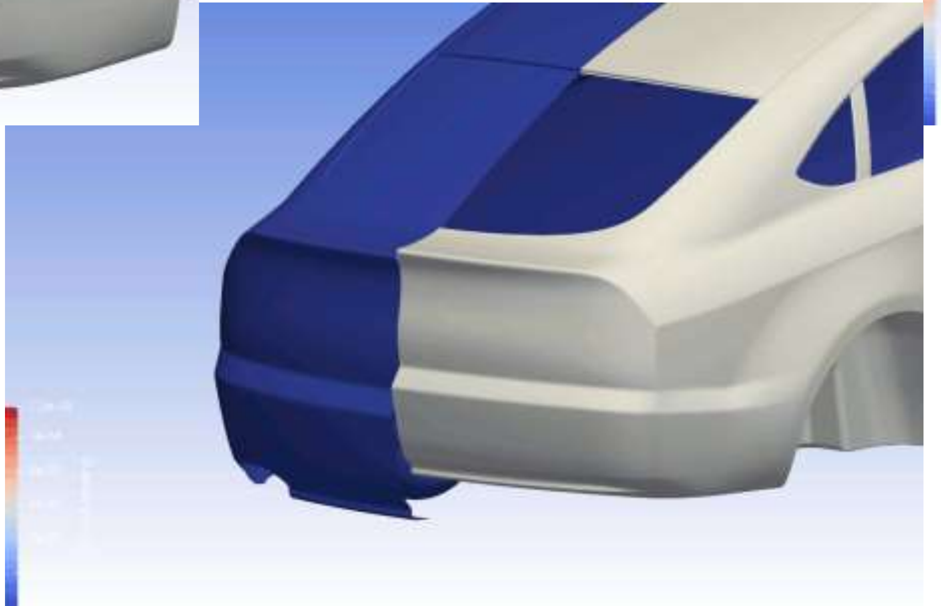
motorBike Foam Tutorial

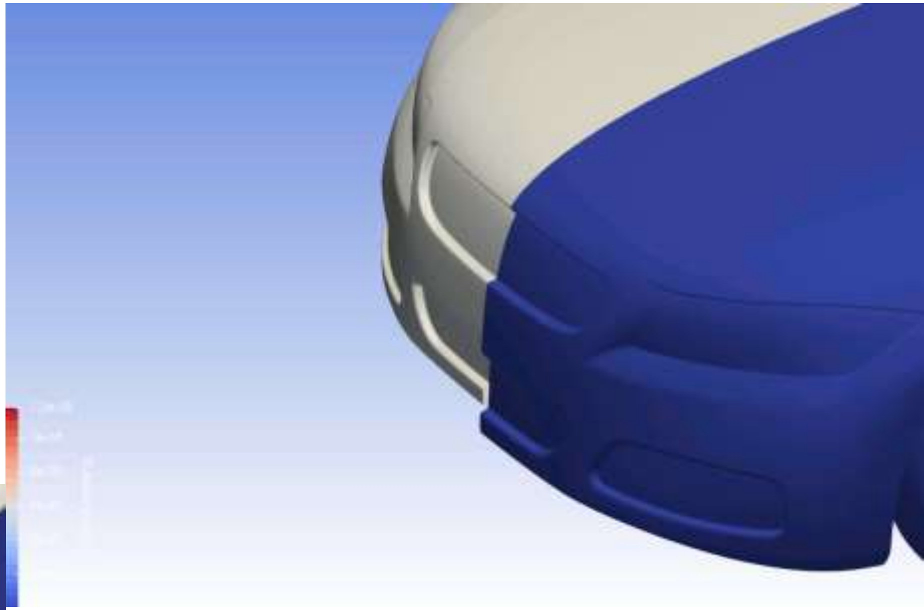


- Second simple mockup we used as a morphing playground
- Small mesh (5 millions)
- Driver position

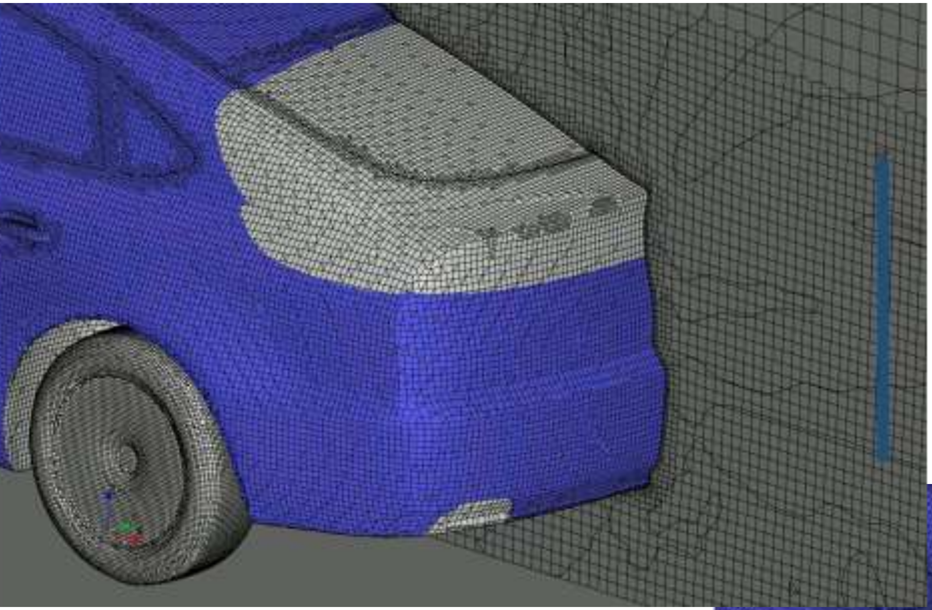
DrivAer Surface Mesh Morphing

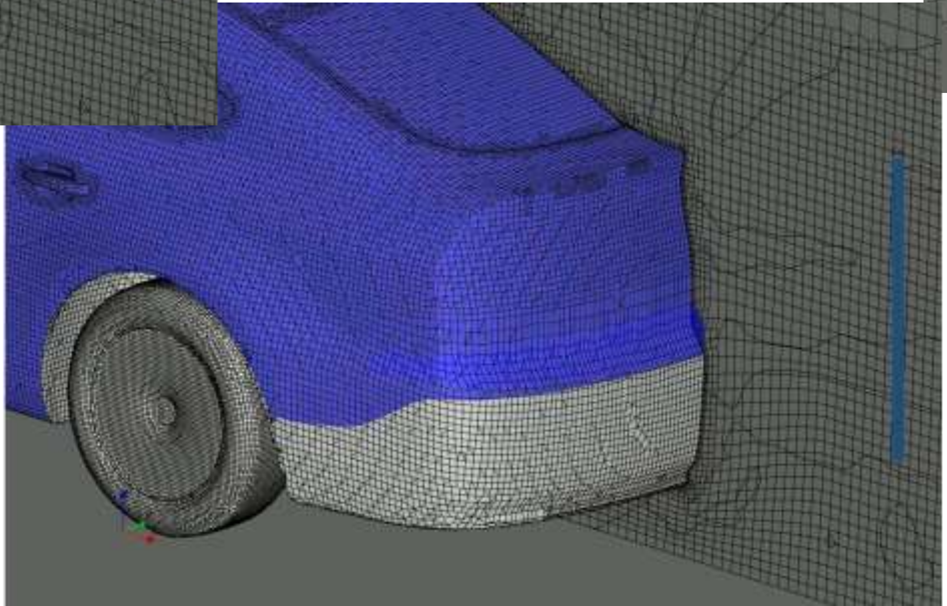


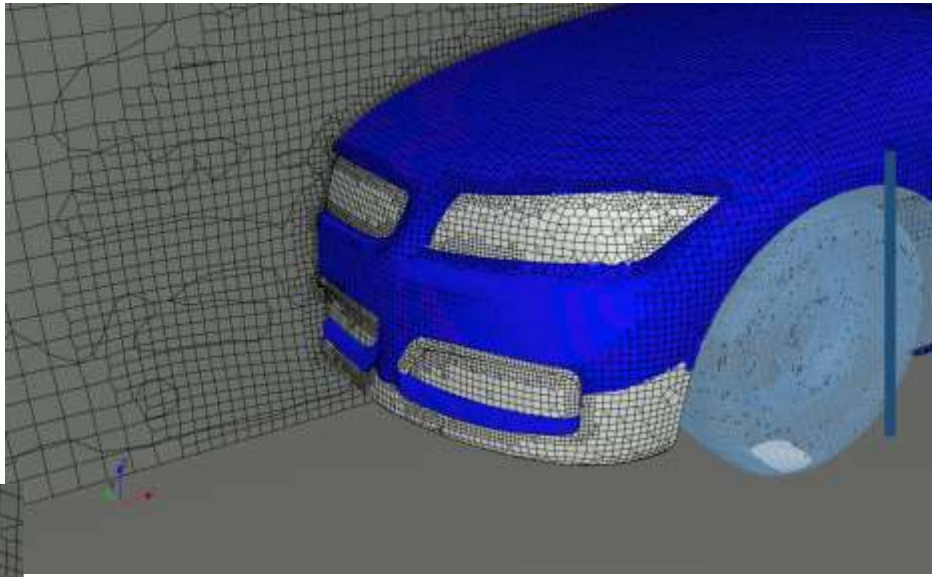




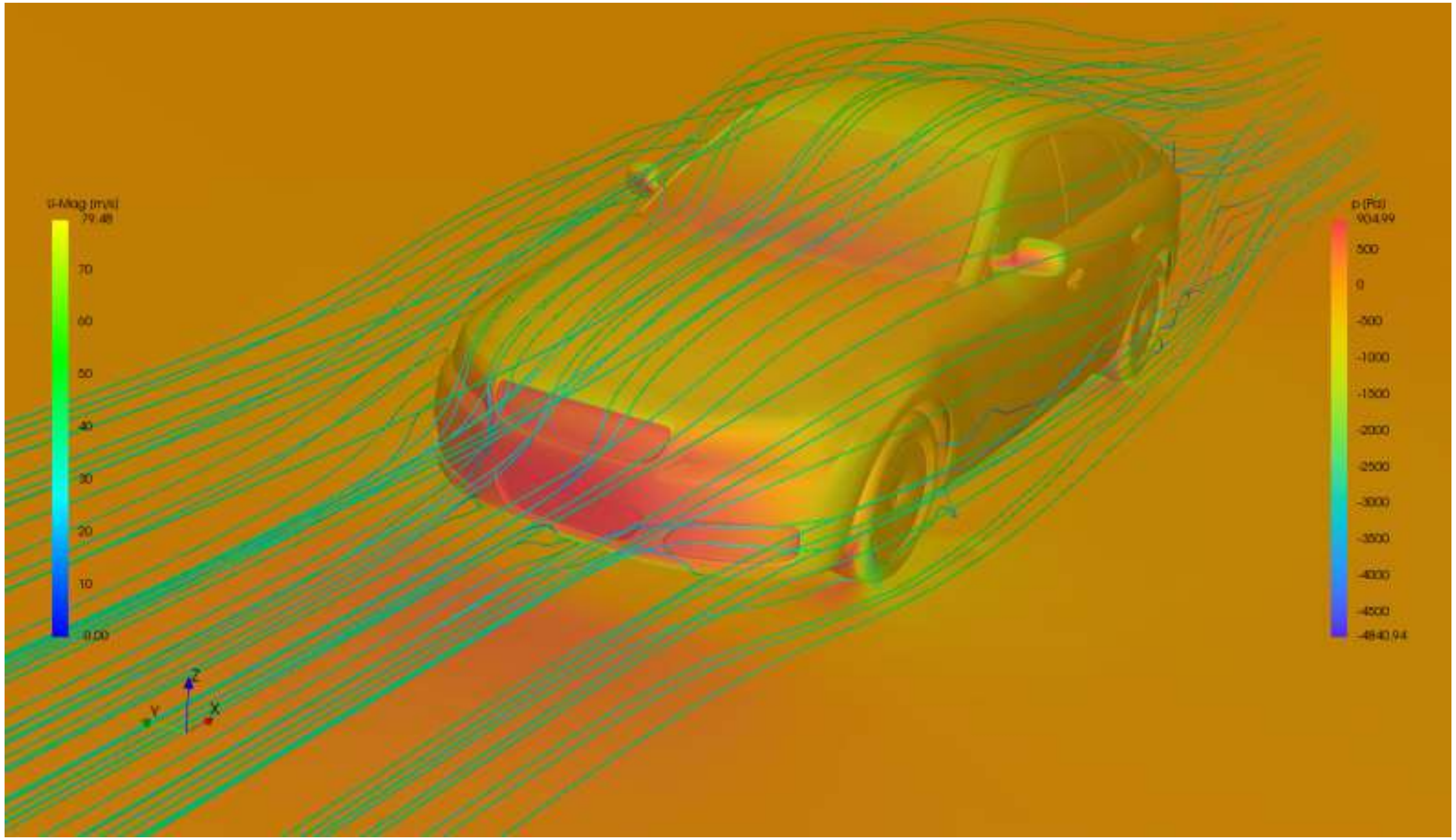
DrivAer Volume Mesh Morphing



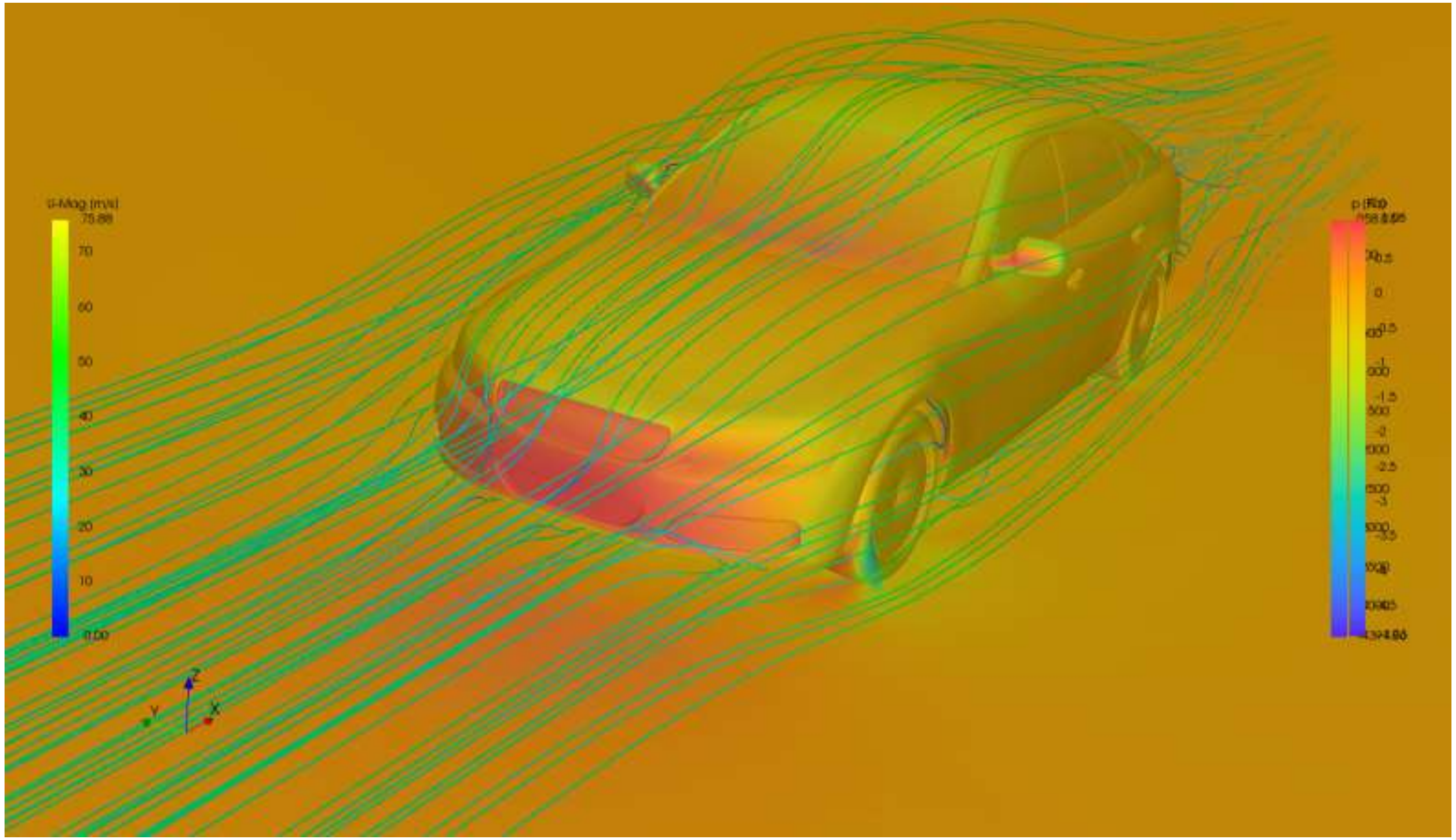




Baseline shape Cd = 0.2375

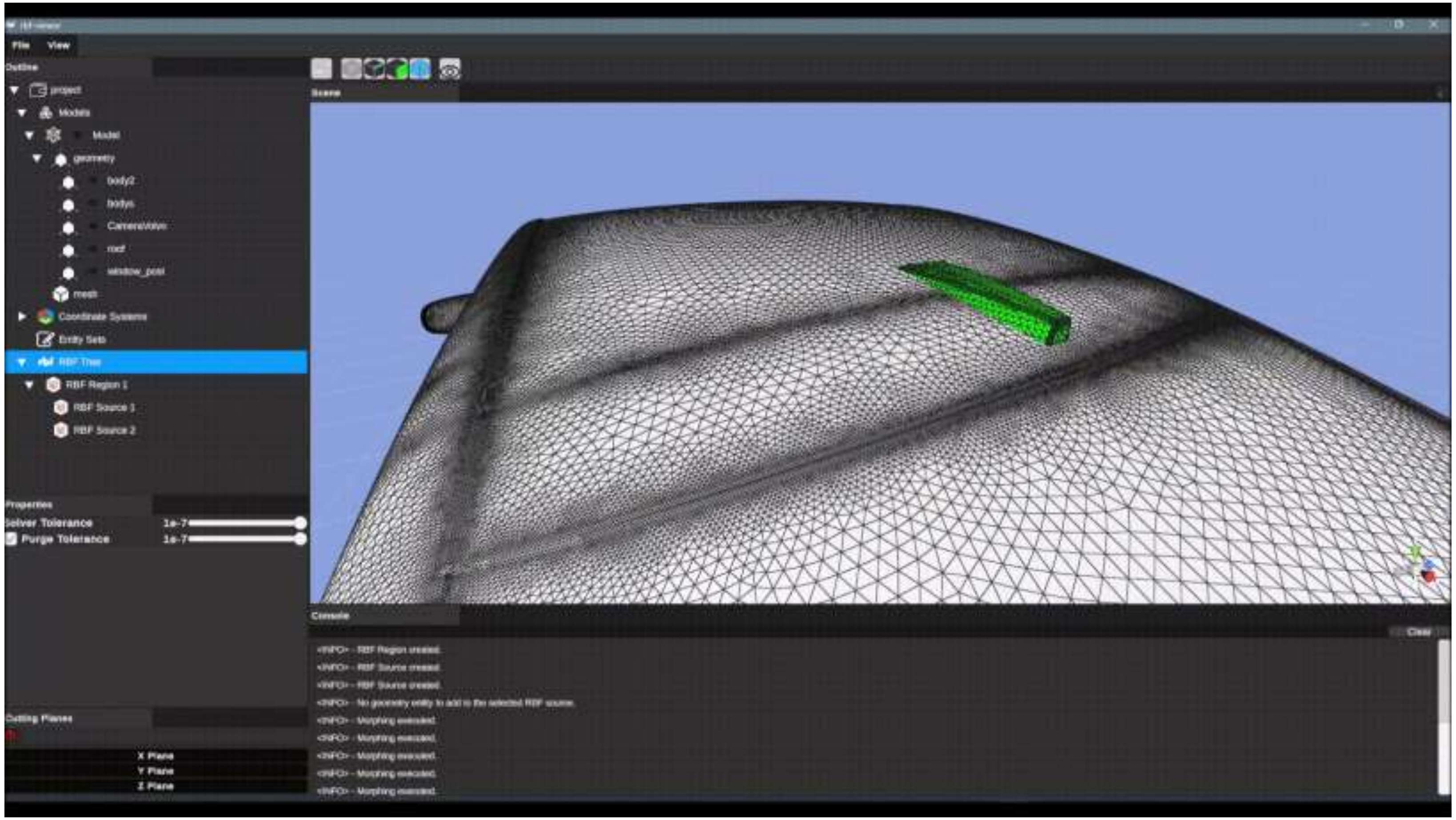


Optimized shape Cd = 0.2297



UGM2023
Frankfurt, Germany
23 to 25 October 2023

Adding a camera and match aero



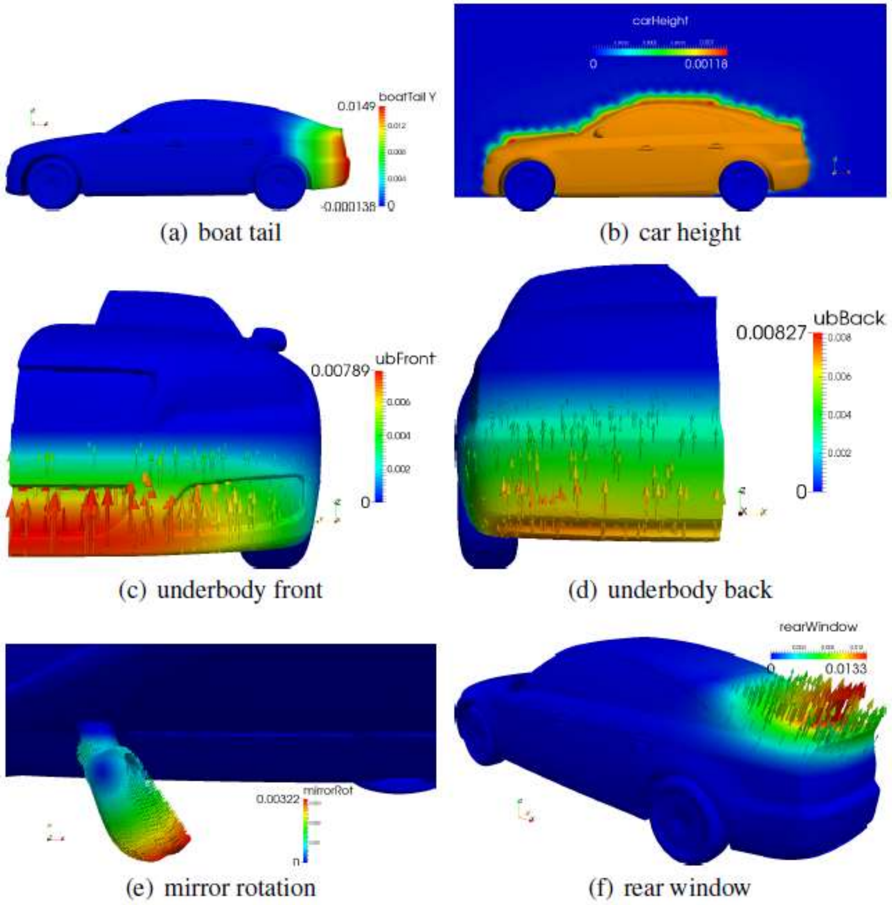
Next Steps?

Adjoint-based shape optimization

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

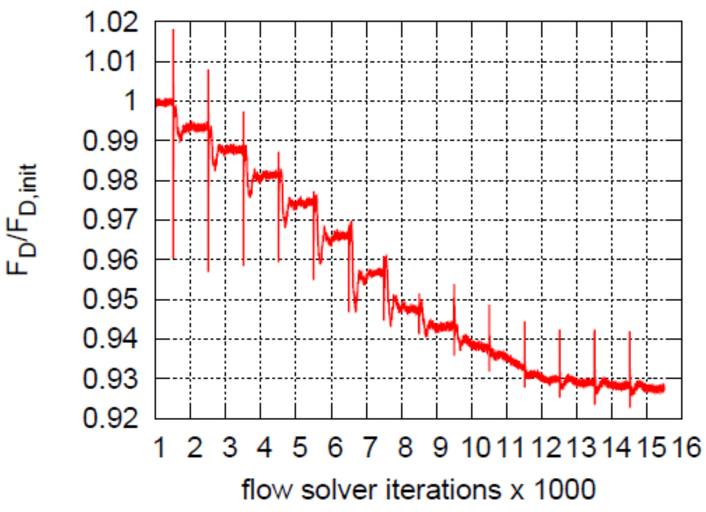
$$\frac{\delta F}{\delta \vec{b}} = \frac{\delta F}{\delta x_{\kappa}} \frac{\delta x_{\kappa}}{\delta \vec{b}}$$

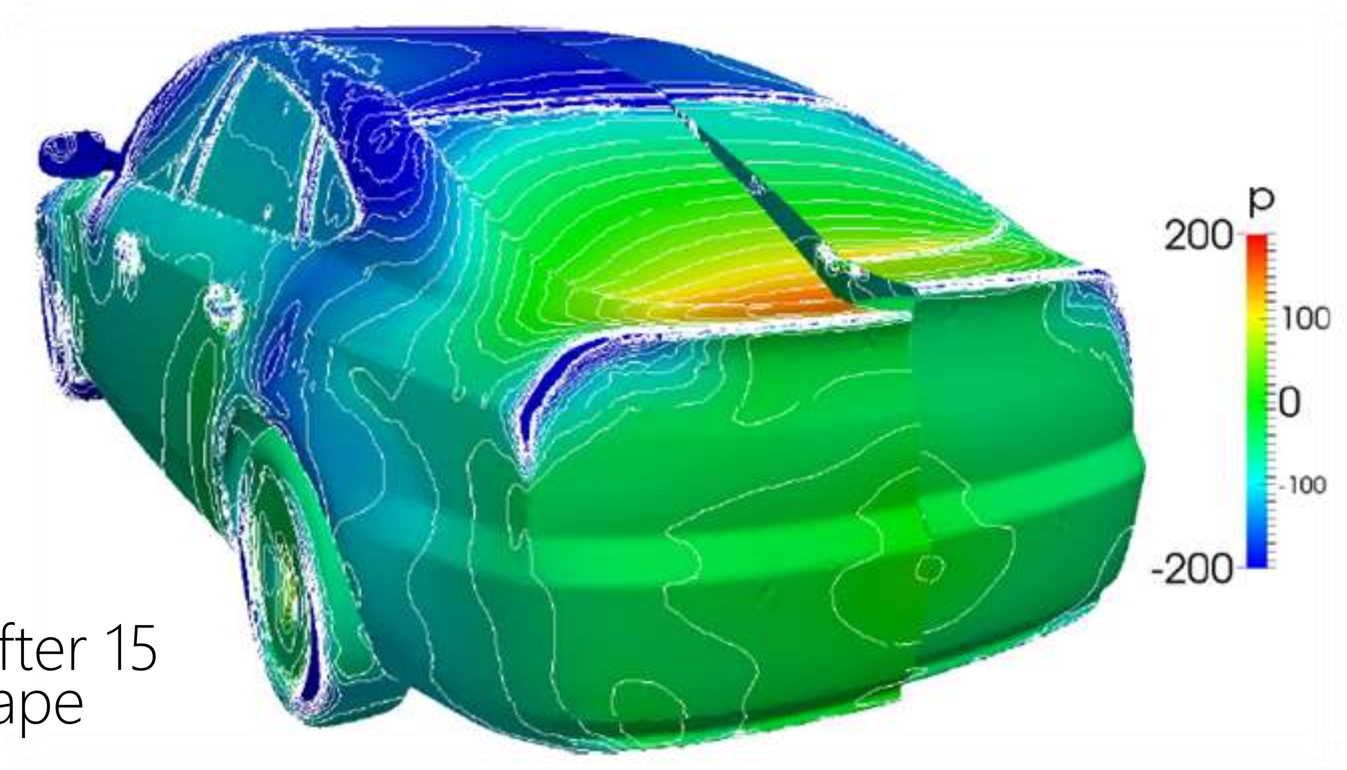
- RBF Morph provides the deformation velocity (adjoint preview).



Papoutsis-Kiachagias, E. M., Giannakoglou, K. C., Porziani, S., Groth, C., Biancolini, M. E., Costa, E., & Andrejašič, M. (2019). Combining an OpenFOAM®-Based Adjoint Solver with RBF Morphing for Shape Optimization Problems on the RBF4AERO Platform. In *OpenFOAM®* (pp. 65-75). Springer, Cham.

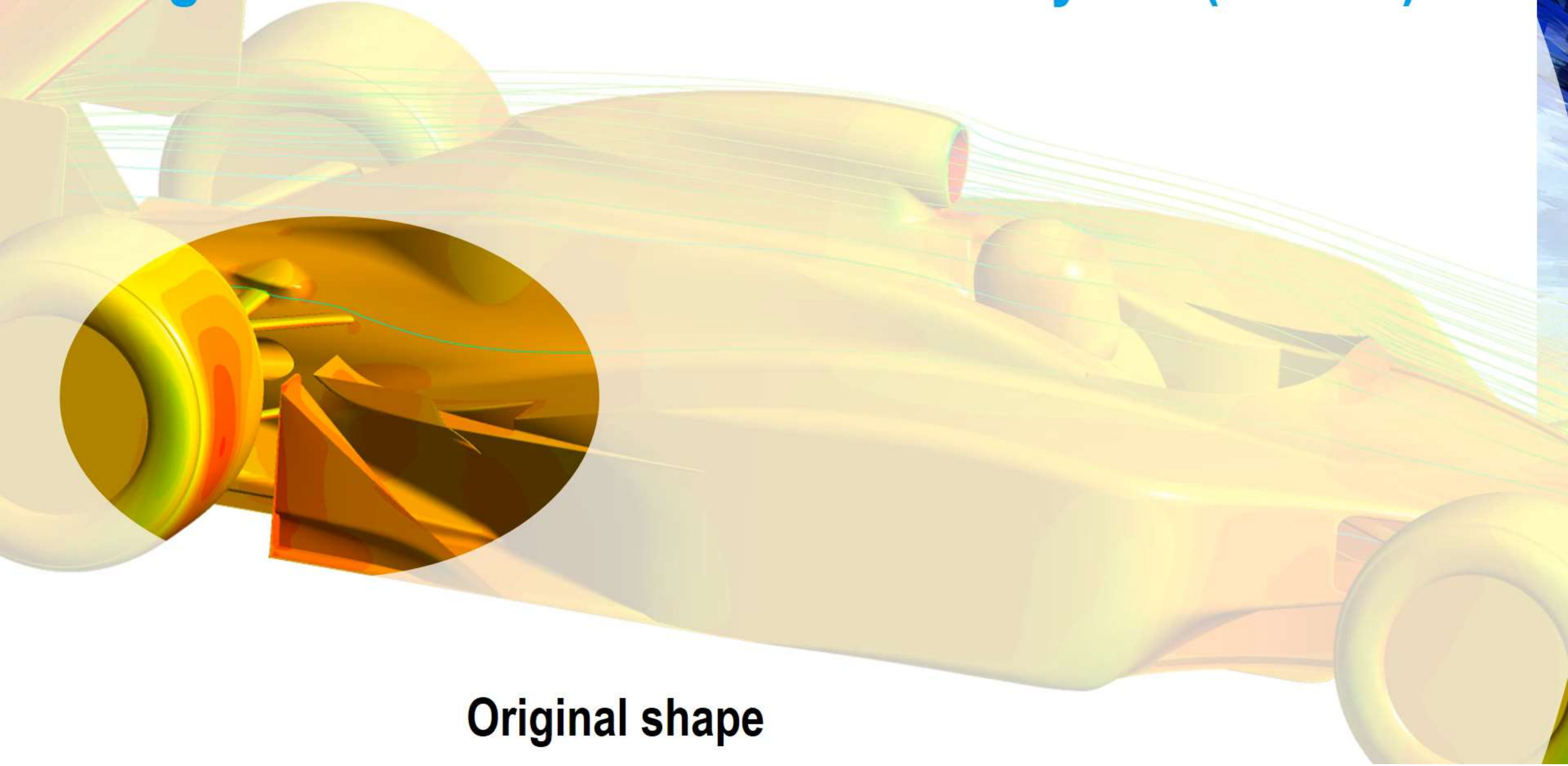
Adjoint-based shape optimization





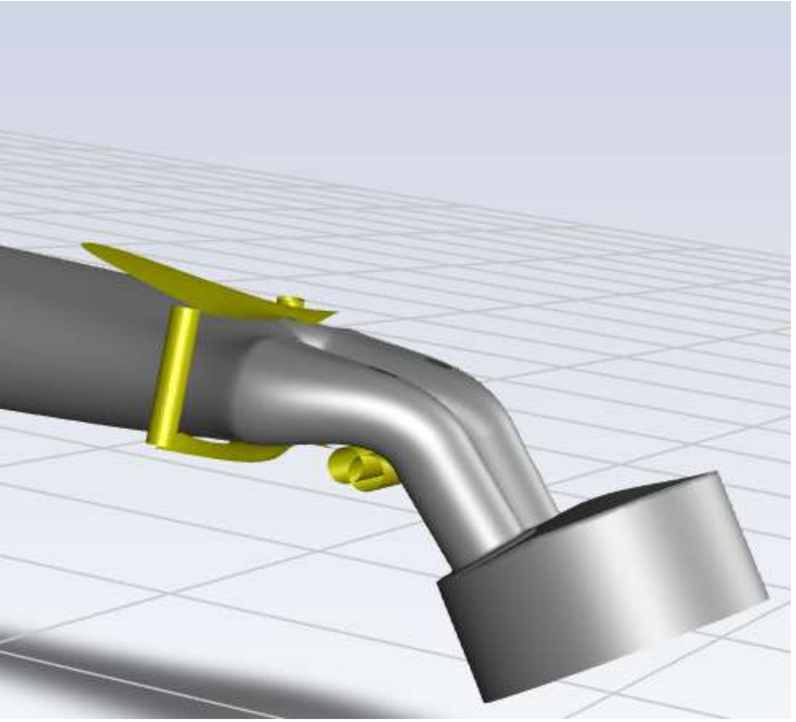
- A 7% drag reduction is observed after 15 cycles. Optimal (left) vs. original shape (right).

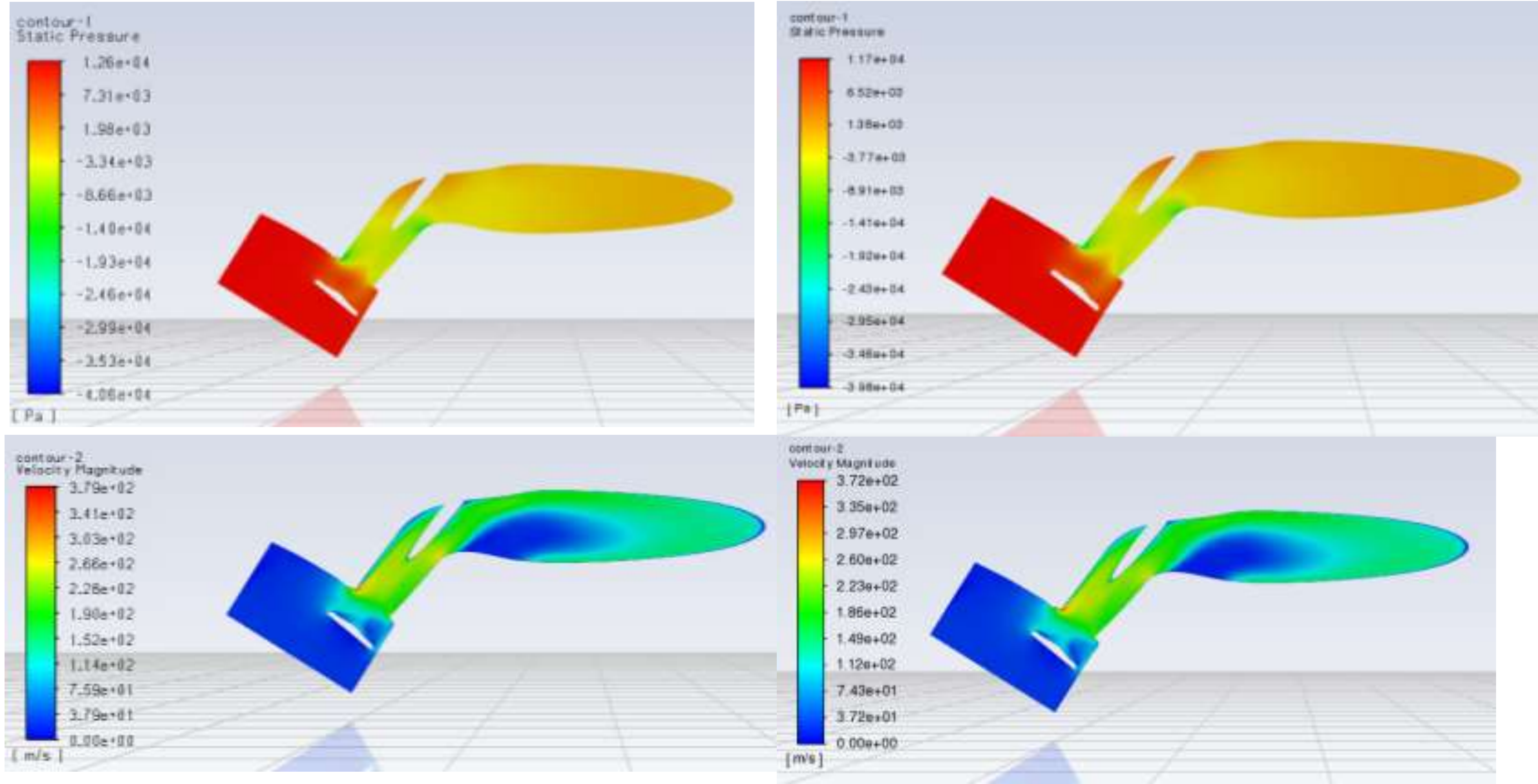
Drag reduction of a dallara Indy car (-0.98%)



Original shape

Pressure drop at exhaust port

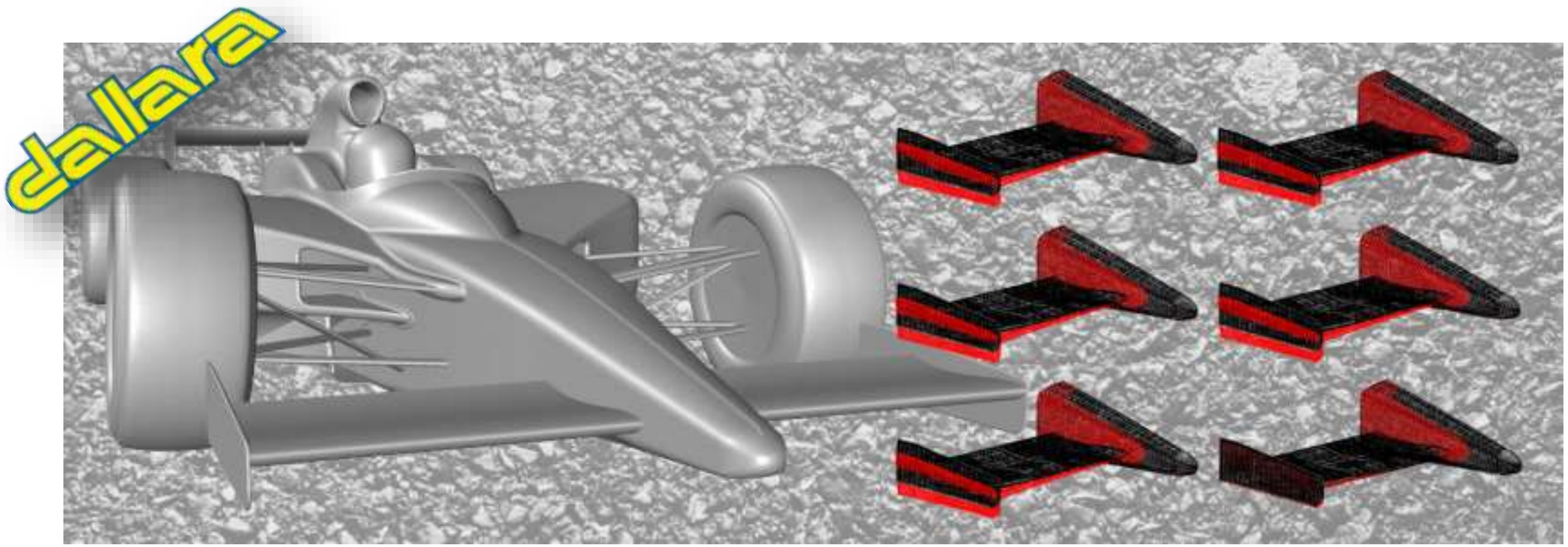


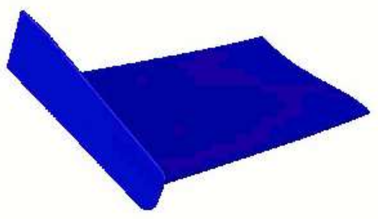


Baseline | Adjoint Optimized (-7.5%)

Transient pitching simulation – porpoising

FSI Example: Indy Race Car



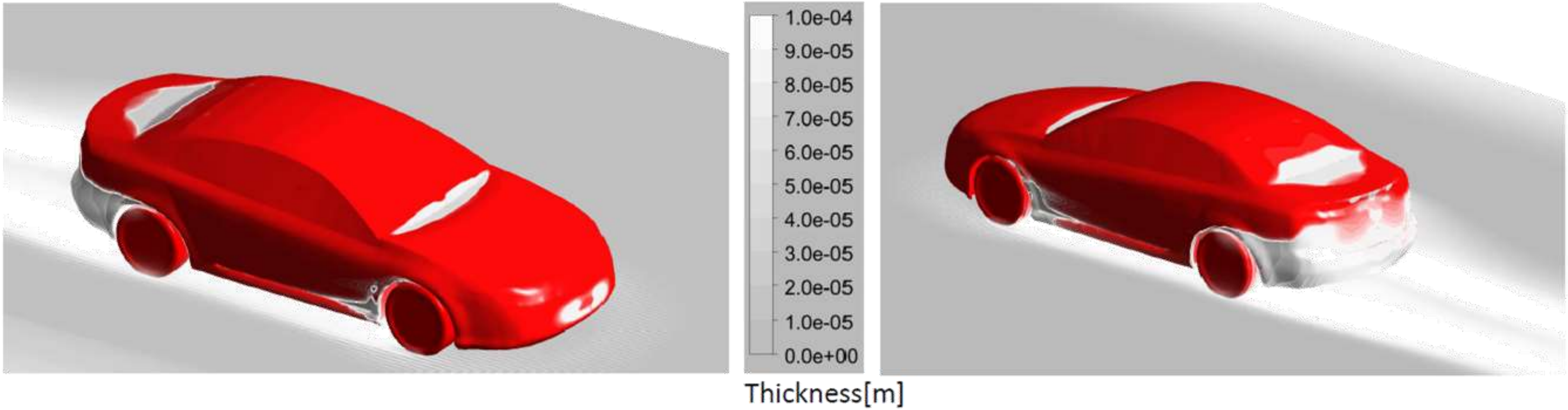


Modes used	Maximum displacement (mm)	Maximum error (%)
1	5.941	8.3
2	5.898	6.5
3	5.584	2.7
4	5.56	1.4
5	5.555	0

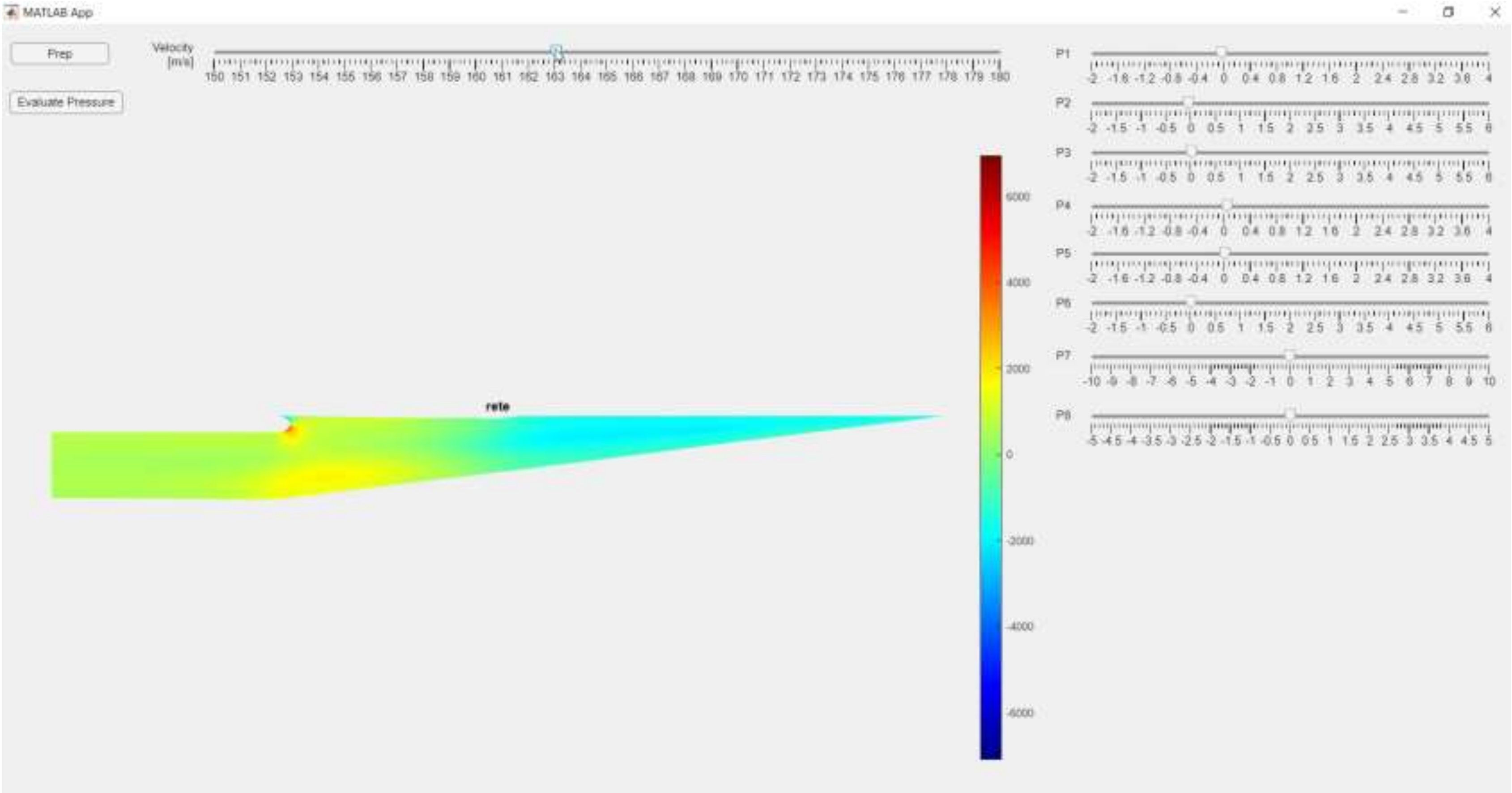
Snow accretion blowing

Snow contamination pattern on the rear of a Volvo S90 driven a distance of 100 km

- Snow contamination pattern after 15-minute solo driving



Next step: ROM and DT development



- Snapshots collection (80 DPs)
- Static ROM details:
  - Decomposition algorithms (POD) are used to reduce the number of variables
  - Machine learning allows to correlate each set of input parameters to the output quantities
  - It allows to evaluate in real time both field quantities and scalar outputs

Conclusions

- RBF Morph offers a well proven mesh morphing technology
- The new Stand Alone version is already coupled with ENGYS software
- We have a long experience (15+ years) gained in EC Projects and with industrial applications (120+)
- At the moment we can support parametric analysis in HELYX
- We will soon support
  - Fluid structure interaction
  - Adjoint
  - AI based solutions

Thank you!

engys UGM2023
Frankfurt, Germany
23 to 25 October 2023

marco.biancolini@rbf-morph.com

in linkedin.com/company/rbf-morph

YouTube youtube.com/user/RbfMorph

rbf rbf-morph.com

rbf™