FEA and CFD Mesh Morphing with Ansys RBF Morph

Wed, Feb 21, 2024 10:00 AM - 11:00 AM GMT

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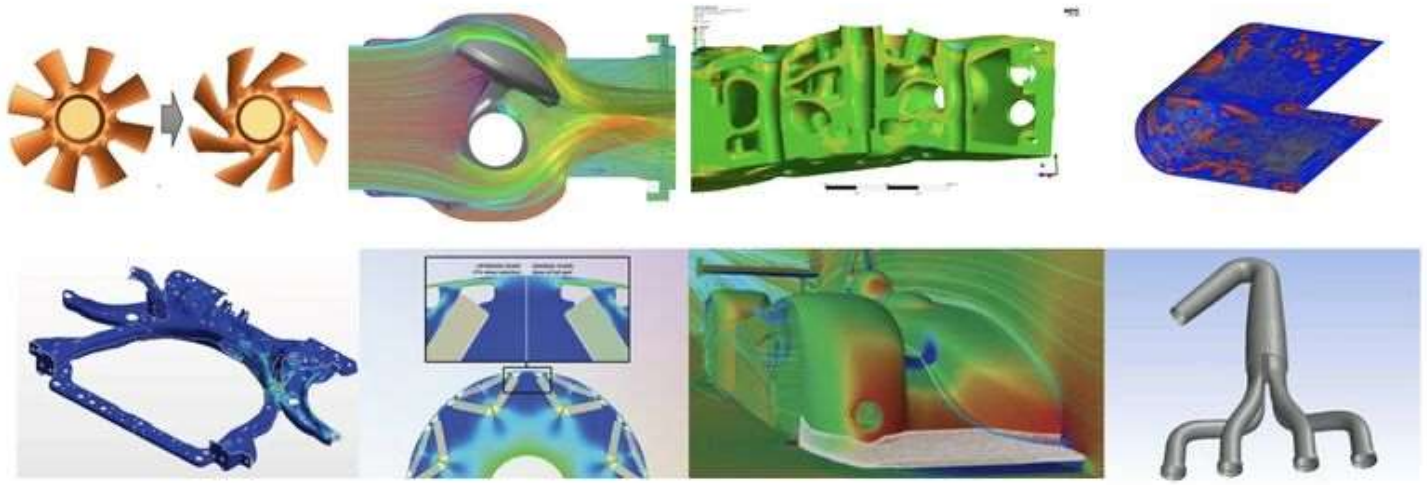
CTO and company founder

Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

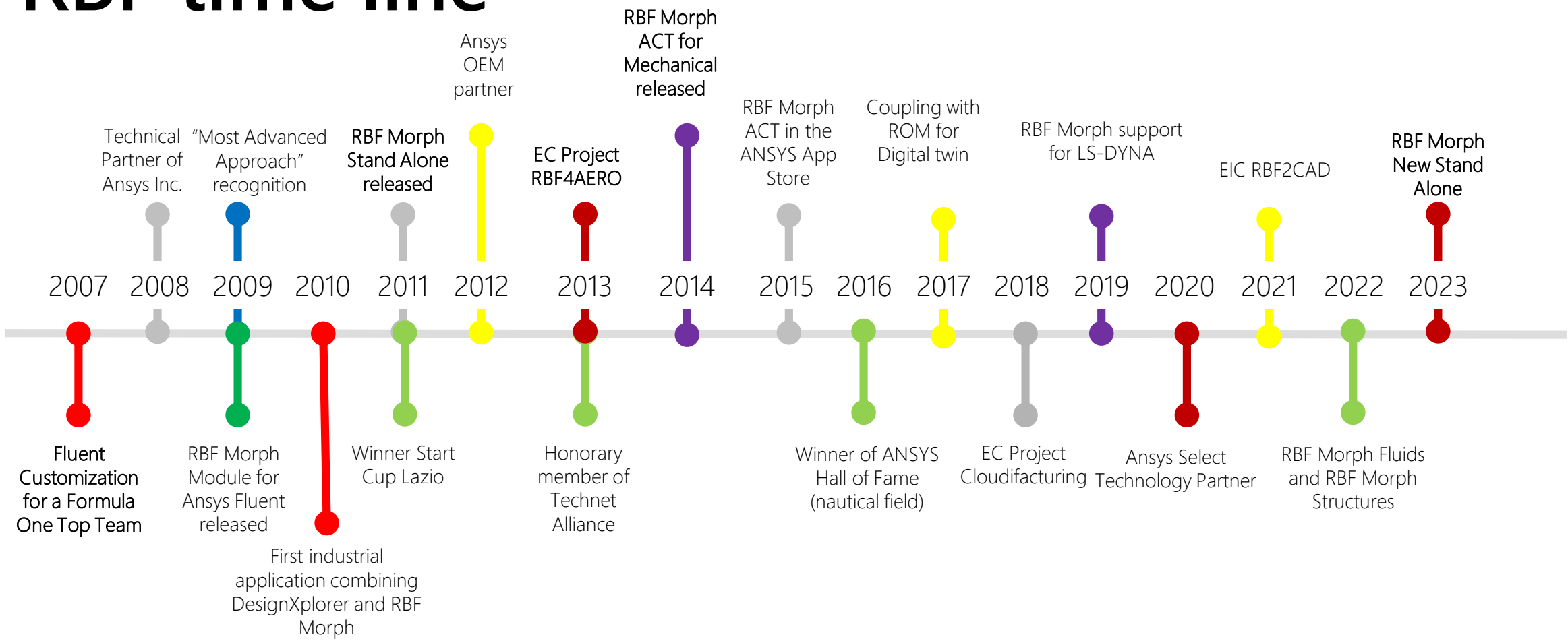
Outline

- A quick introduction of RBF Morph
- Main uses of RBF Morph
- Quick Hands-On
  - Ansys RBF Morph Structures
  - Ansys RBF Morph Fluids
- Mesh morphing examples for CFD and FEA applications
  - Aerospace
  - Healthcare
  - Automotive
  - Electronics
  - Oil&Gas
- Additional resources



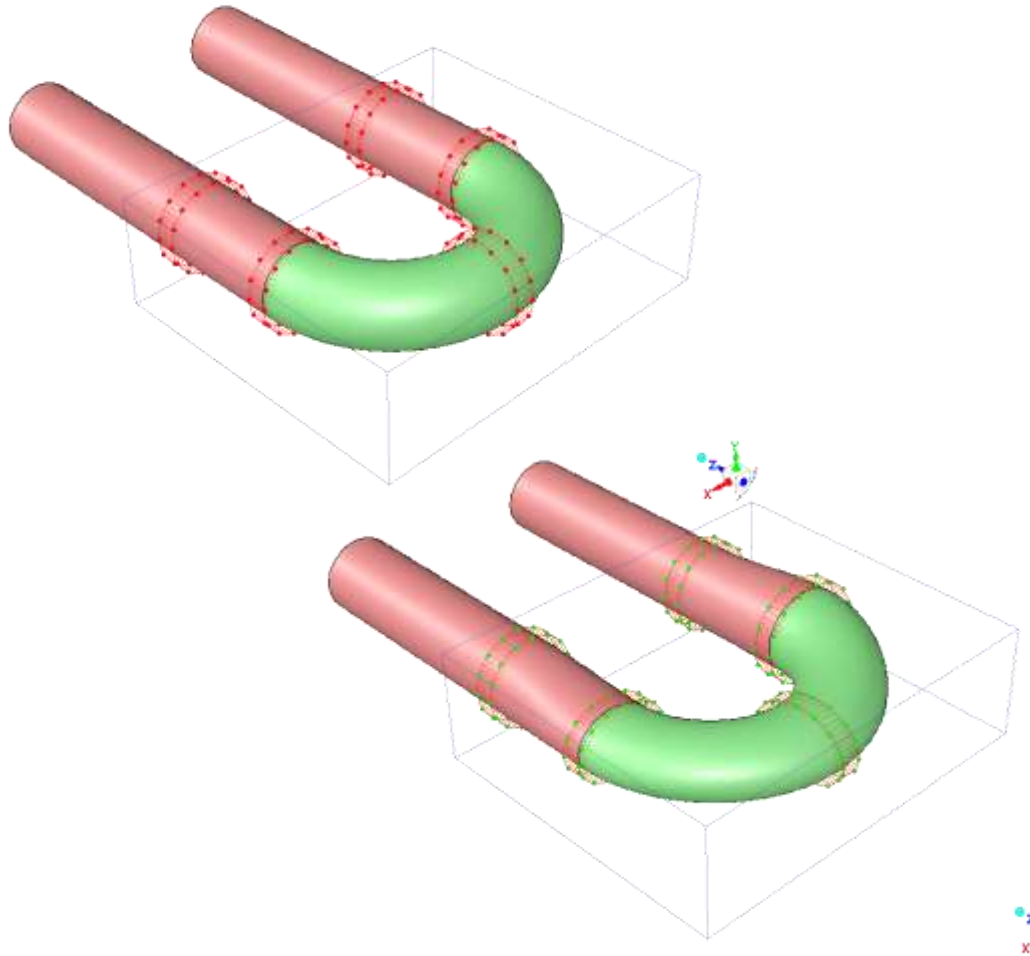
A quick introduction of RBF Morph

RBF time line



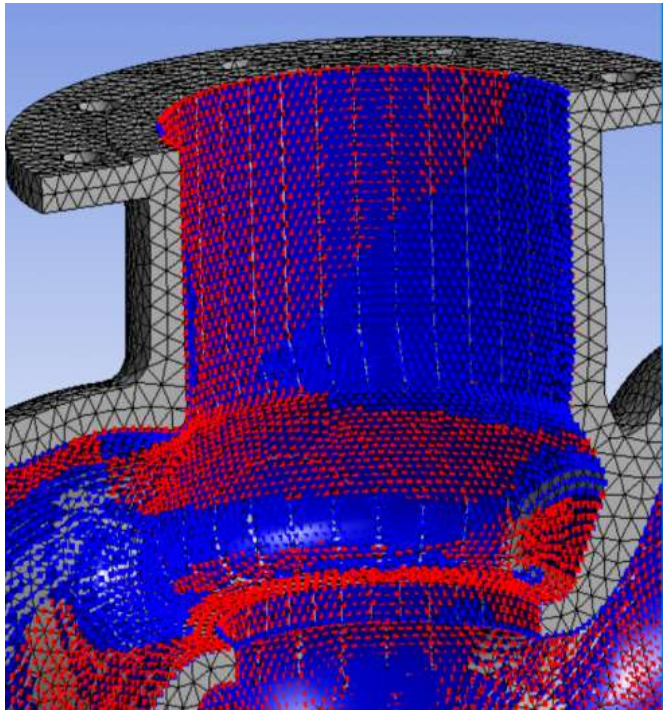
Shape parameterization strategy

- 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



Radial Basis Functions mesh Morphing

- We adopt **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements
  - Surface shape changes
  - Volume mesh smoothing
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing



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

Radial Basis Functions mesh Morphing

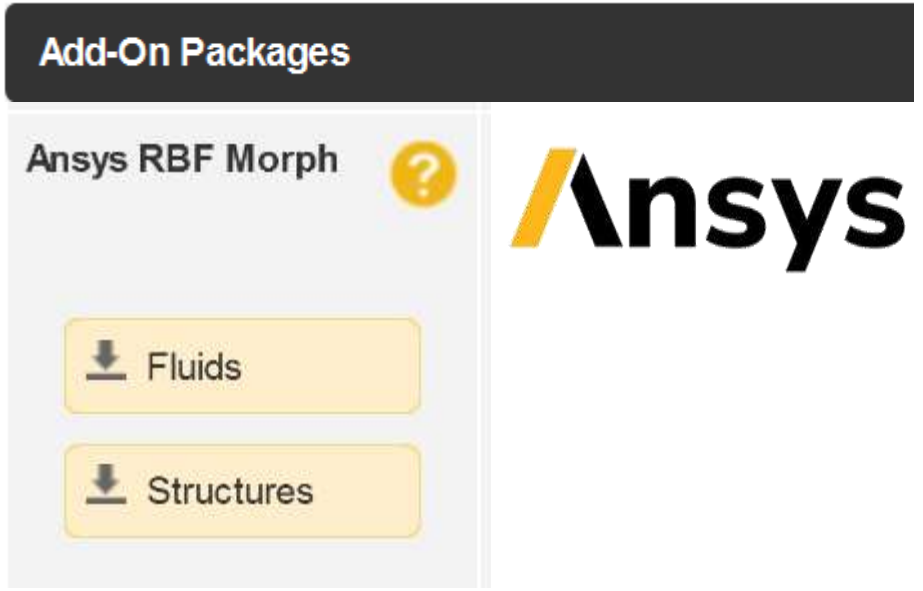
www.rbf-morph.com

- 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)

Ansys RBF Morph products

- 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**

Ansys OPTISLANG



Ansys

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

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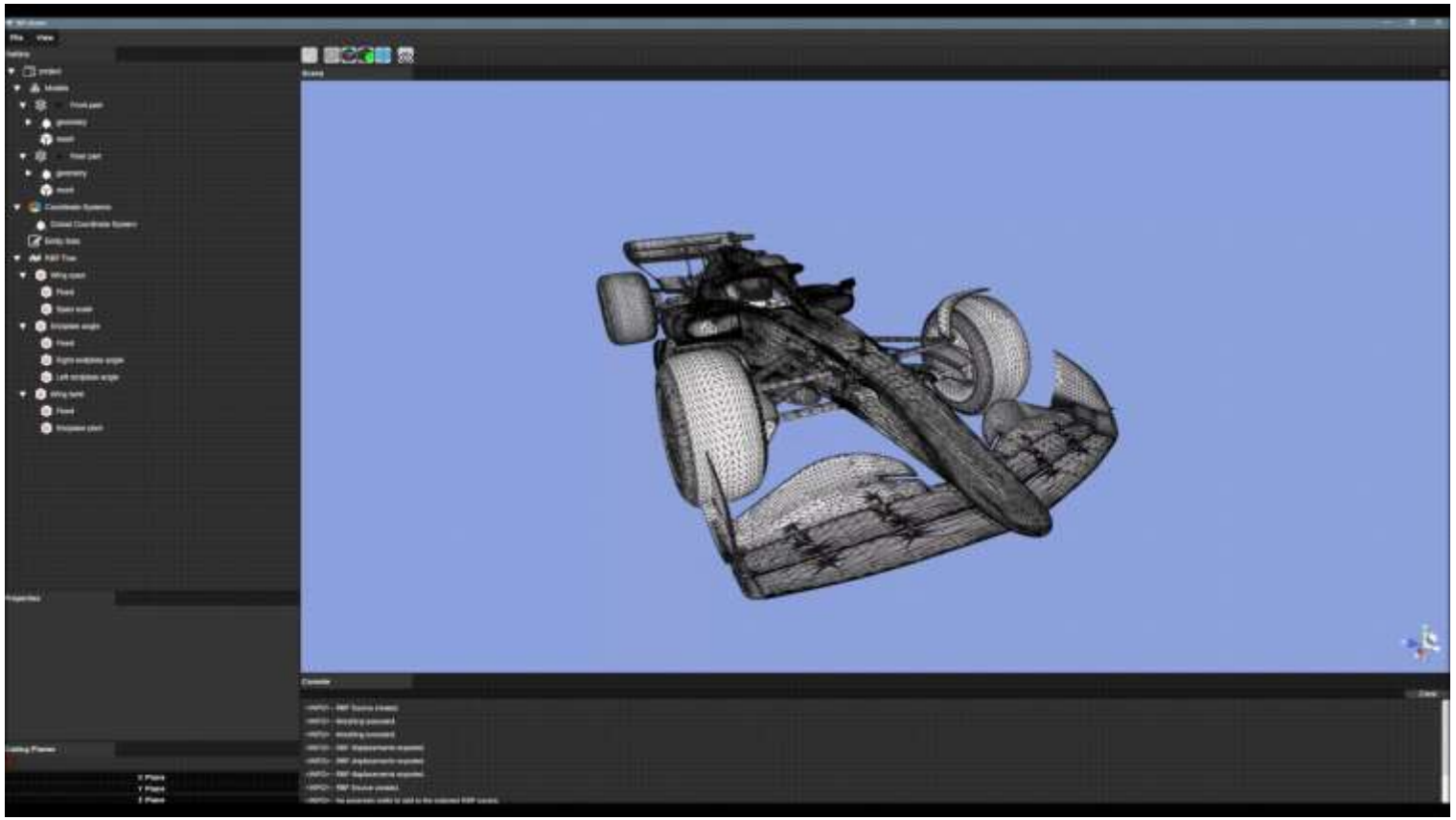
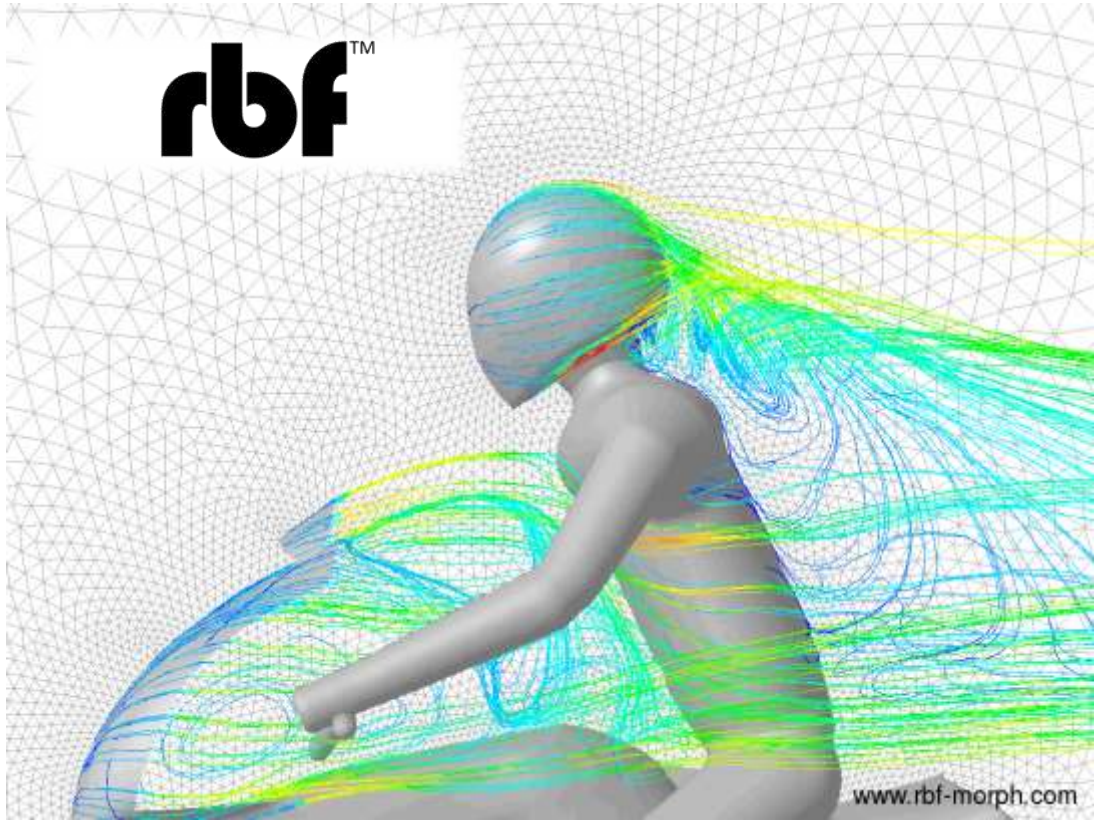
RBF Morph Stand Alone



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

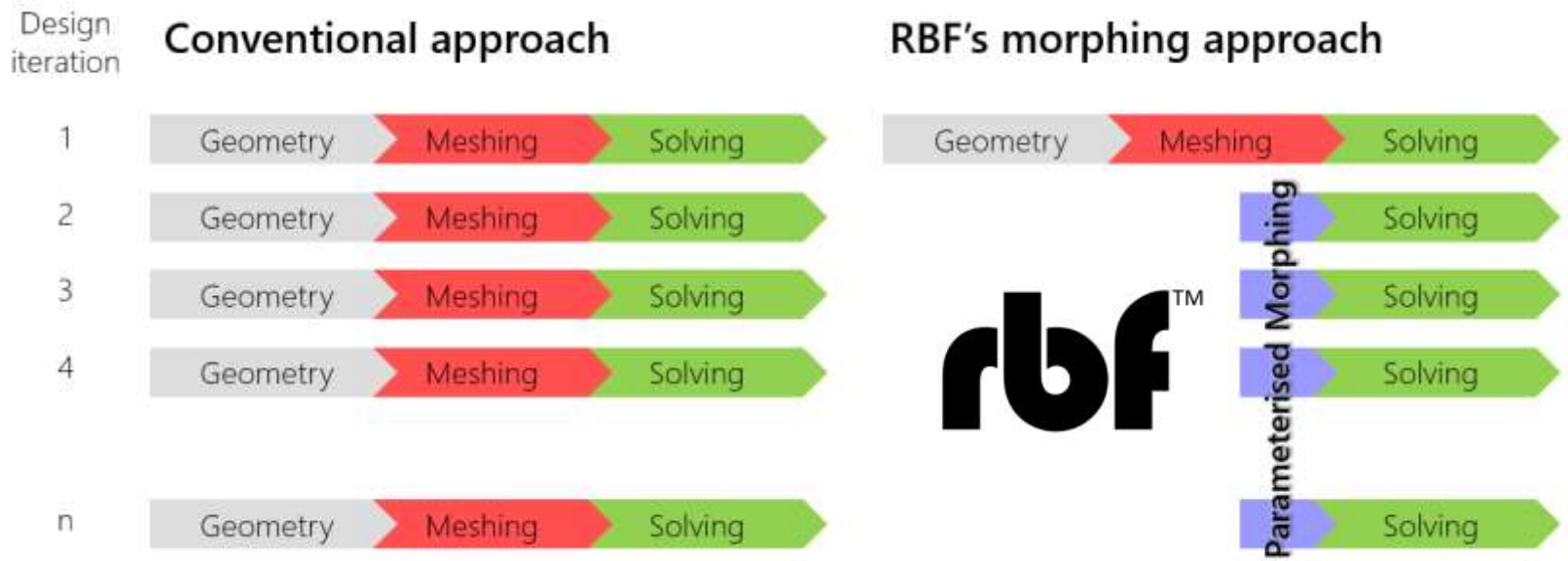
We make CAE models parametric

- 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**)

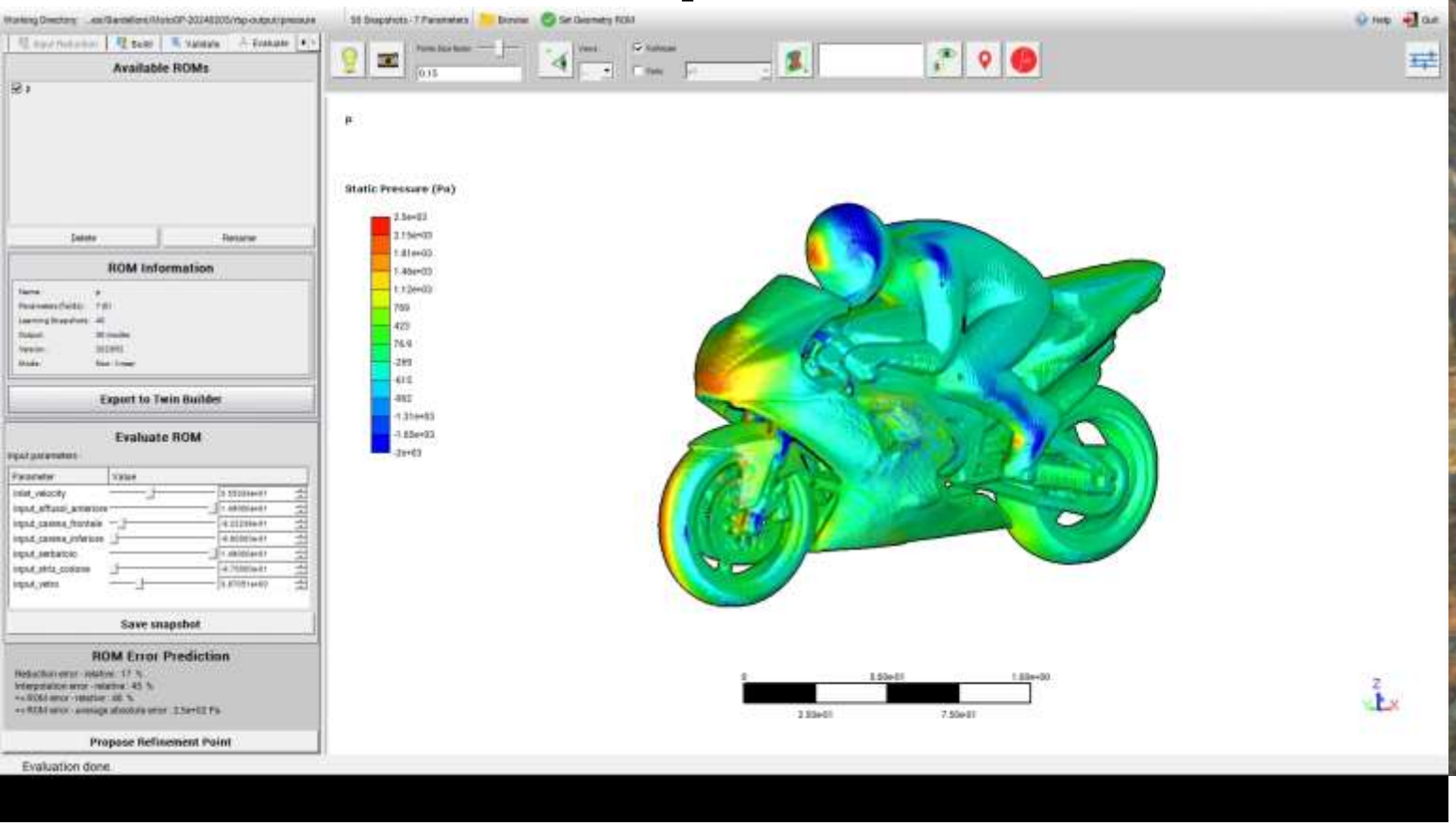


We make CAE models parametric

- Morphing is a **key enabler** for optimization and Digital Twins
- The turnaround time of the optimization is usually **reduced by a factor five** (weeks becomes days)



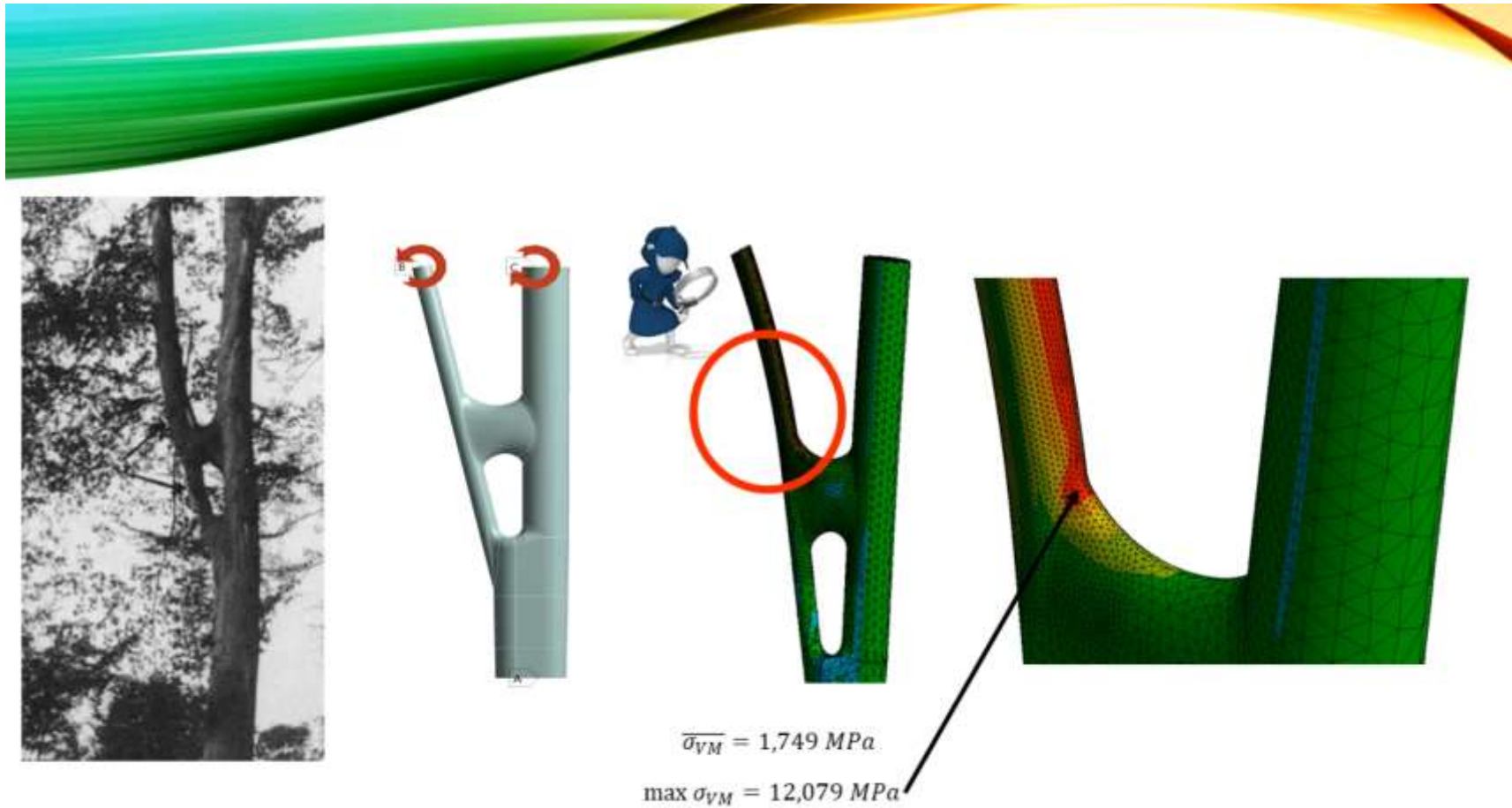
Coming soon - Interactive aero development in VR



- RBF Morph Fluids + Twin Builder + Fluent = FMU VR ready

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**



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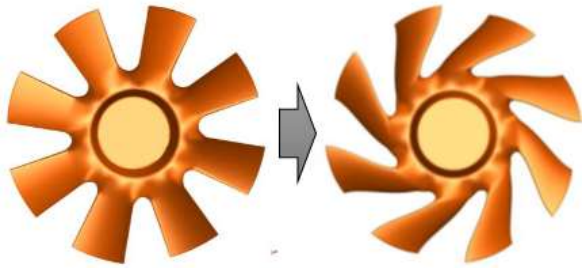
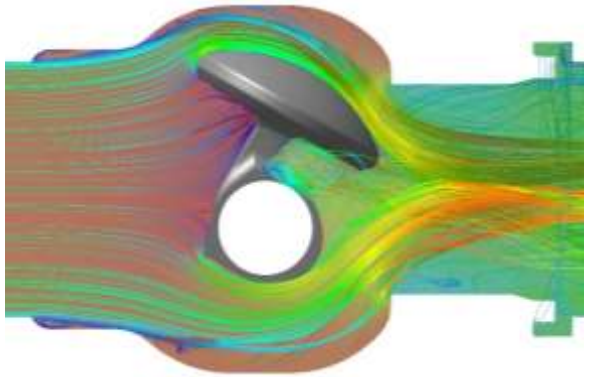
Main uses of RBF Morph

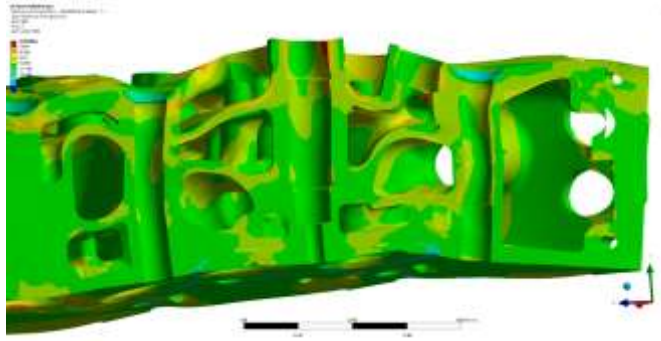
Main uses of RBF Morph

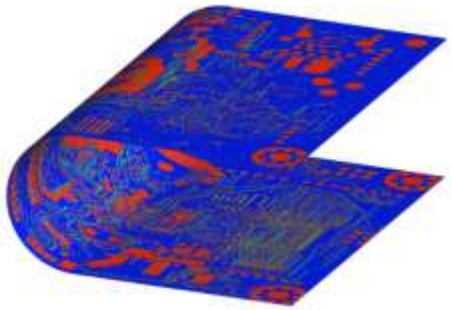
Usage	FEM	CFD	Orchestrator	AI
Automated and quick variable design space exploration.	✓	✓		
Optimization (Single physics or multi-physics). Shape optimization for stress reduction, mass reduction, fluid-structure interaction	✓	✓	✓	
Digital twin development (static ROMs)	✓	✓	✓	✓
Lifing applications Simulate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

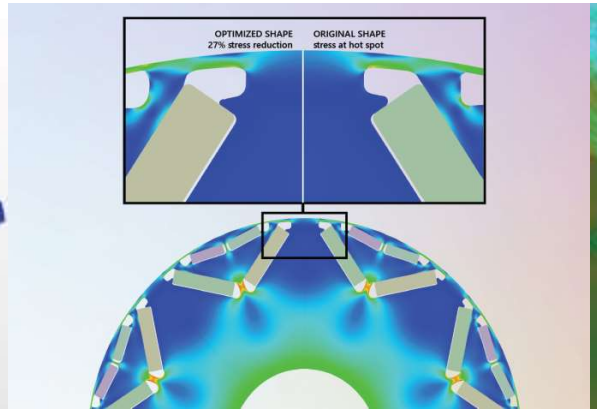
Applications

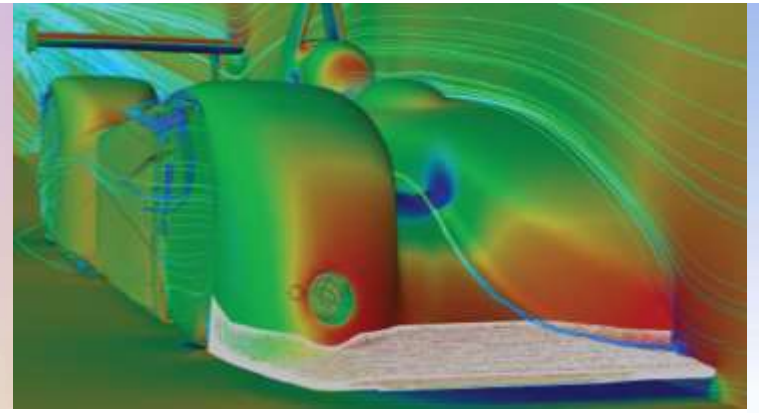












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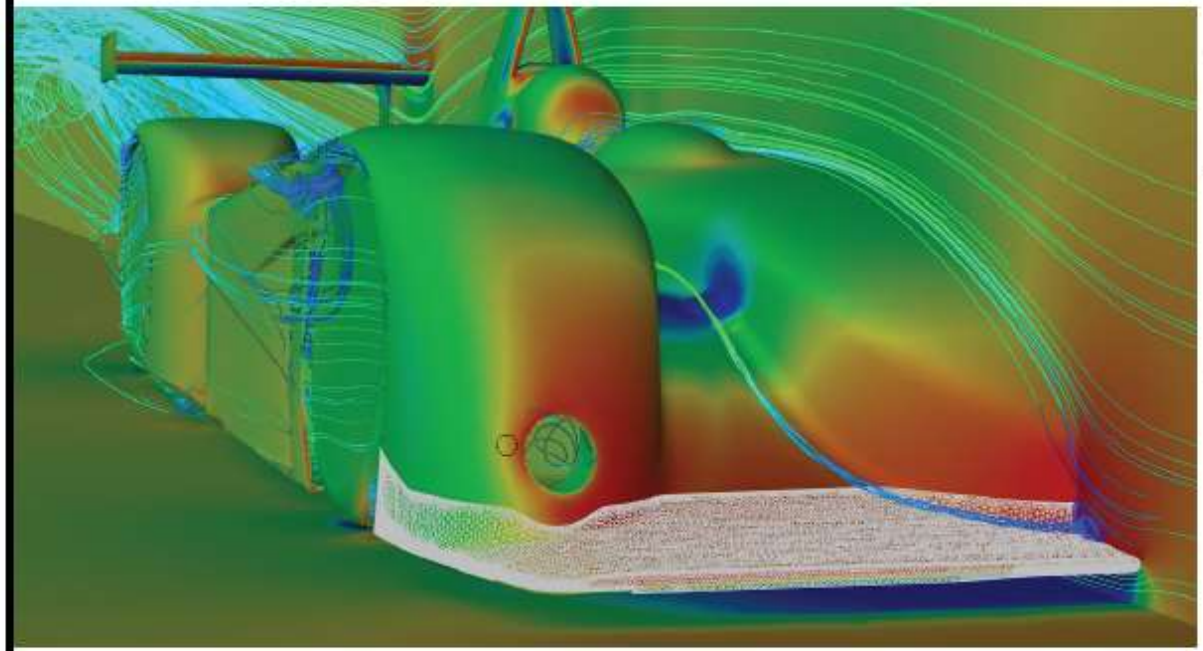
RBF Morph usage at Nissan

"We worked with RBF Morph to perform the structural optimization of the front chassis and suspension lower arms of a Nissan Micra. Our objective was an increase of driving comfort, achieved by controlling the lateral stiffness while acting on thickness and shape variation of subframe elements. RBF mesh morphing tools were essential to conduct different structural tests and finally achieve optimization".

CLAUDIO PONZO
Chassis Manager
Nissan Motor Corporation

https://www.rbf-morph.com/wp-content/uploads/2022/12/FEA-Shape-Optimization-of-a-Nissan-Micra-Front-Subframe.pdf

RBF Morph usage at Dallara



"FSI and multiphysics are key enablers for modern racing car development, where geometries are very complex and high accurate solutions are required. RBF Morph proved to be the driving tool for the FSI two-way coupled approach. It successfully faced our Morotsport challenge, matching the FEM model displacement with the aero loads mapping in a simplified model of a Dallara Le Mans prototype car".

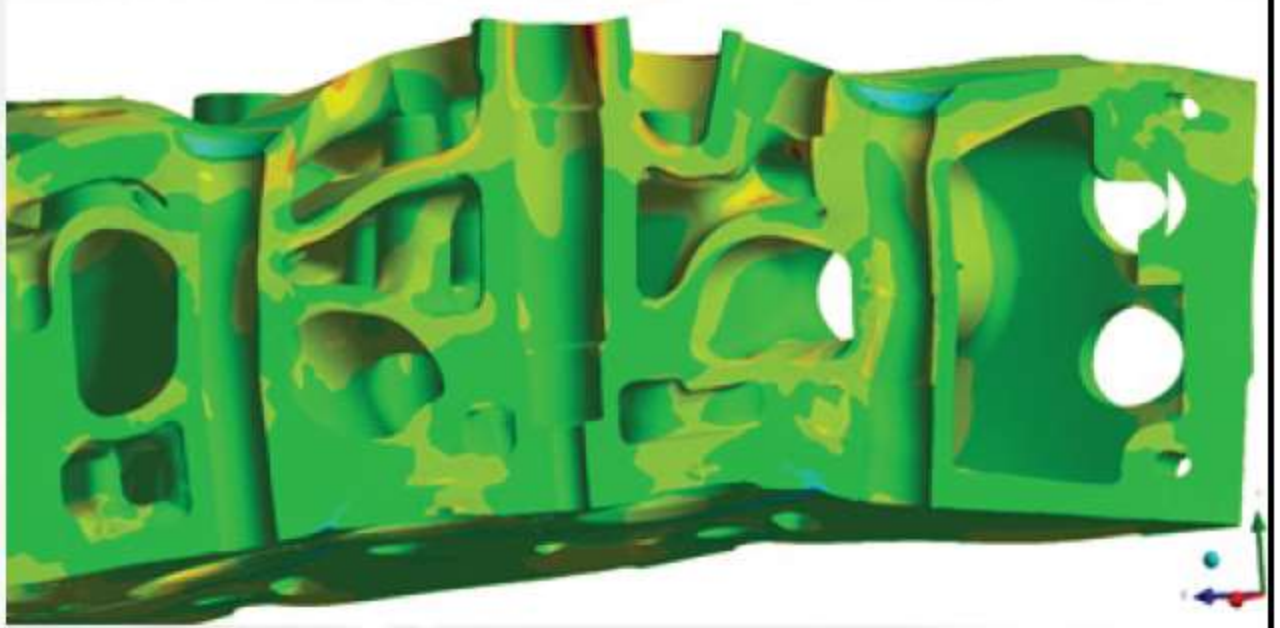
ELISA SERIOLI
Head of CFD Methodology
Dallara

https://www.rbf-morph.com/wp-content/uploads/2022/12/Two-Way-Coupled-Aeroelastic-Analysis-of-Dallara.pdf

RBF Morph usage at Cummins

"Static structural FEA and fatigue analysis was carried on a combustion engine cylinder head assembly model. Design and analysis iterations, which are typically carried out manually since the complex casting topology makes geometry parameterisation nearly impossible, were simulated with the RBF Morph Biological Growth Method which allows for effective parameterisation of complex geometry at the mesh level. The outcome was excellent".

MARCEL SCHUBERT
Applied Mechanics Analytical, Technical Advisor
Cummins, Inc.

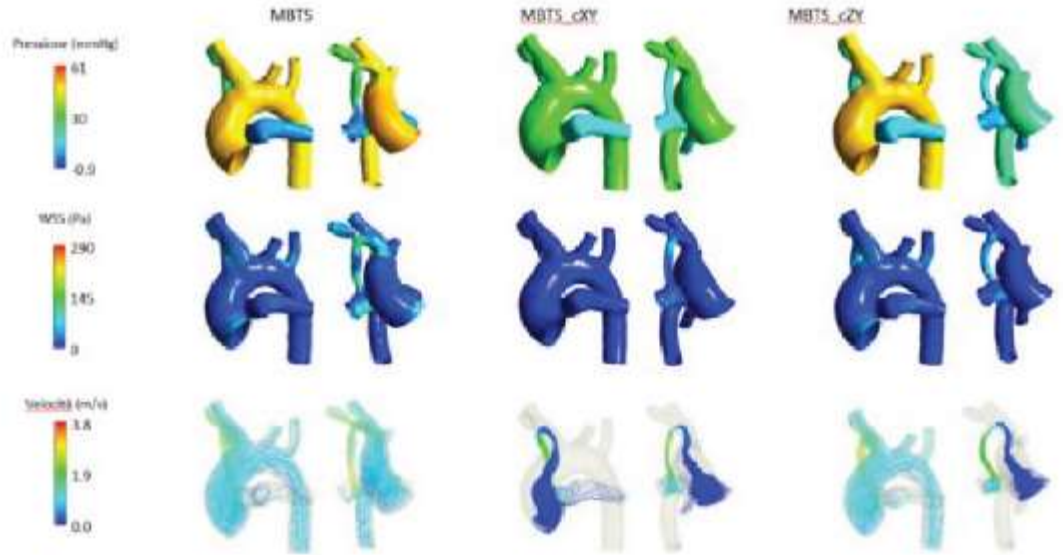


https://www.rbf-morph.com/wp-content/uploads/2022/12/Cylinder-Head-FEA-Shape-Optimisation.pdf

RBF Morph usage at RINA

"We worked with RBF Morph and other partners on the Copernicus project, whose aim was to provide a medical digital twin of the patient to support the surgery planning of Modified Blalock Taussing Shunt under critical conditions. RBF Morph Fluids was key to complete the Copernicus workflow, and it helped increase the know-how on the application of radial basis function mesh morphing in the medical sector."

ALESSANDRO BOZZOLO
Industrial Design & CAE Manager
RINA



https://www.rbf-morph.com/wp-content/uploads/2022/12/The-digital-twin-and-the-future-of-pediatric-surgery.pdf

EU-funded research projects

RBF4AERO

FORTISSIMO

RIBES

Cloudi Facturing

EUROfusion

spinner
next generation spine experts

MEDITATE

f4 EuroHPC

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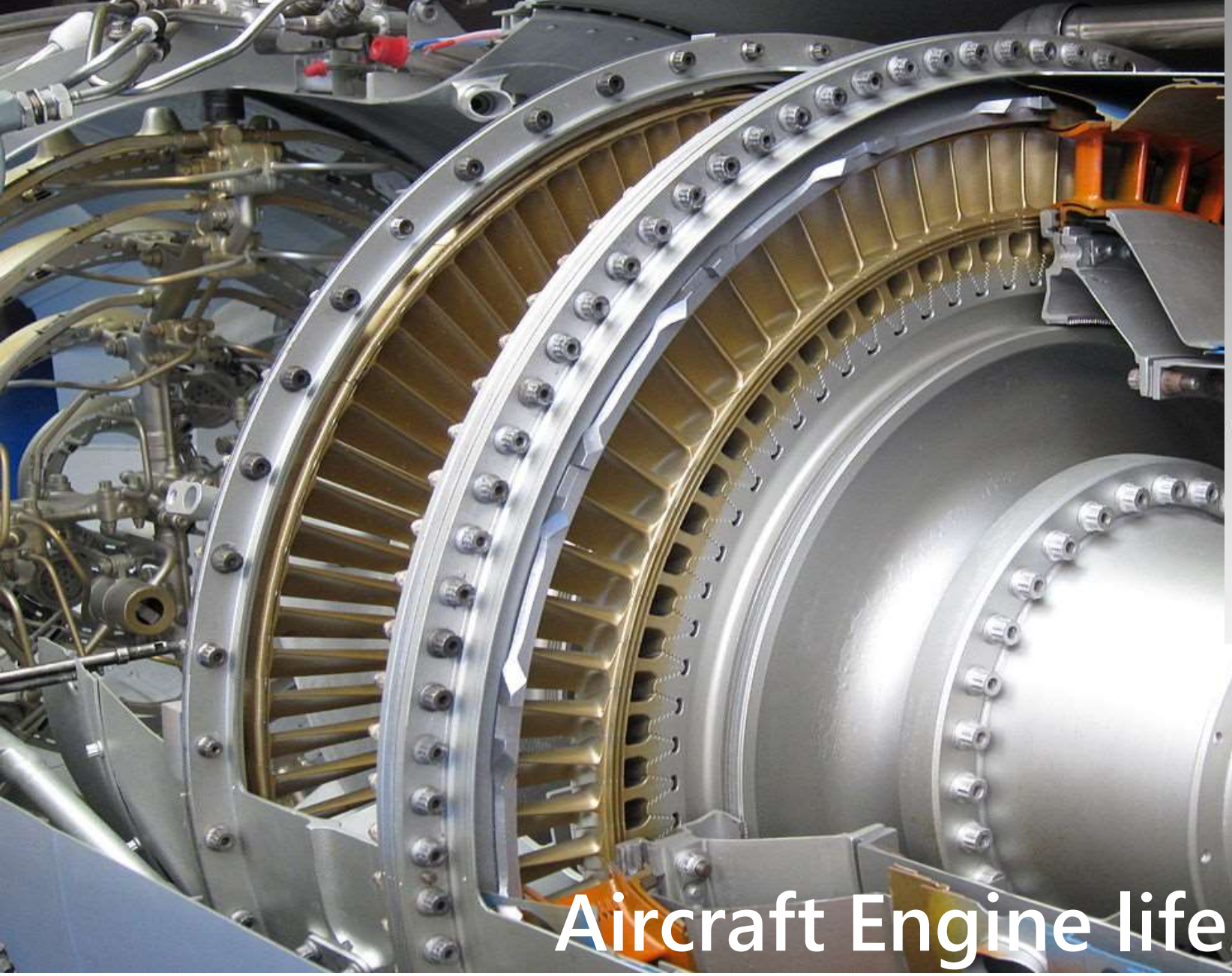
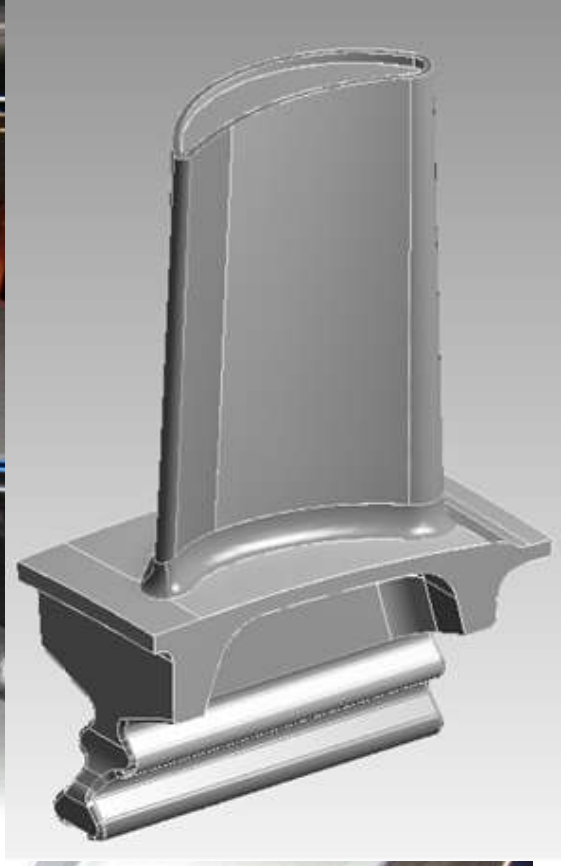
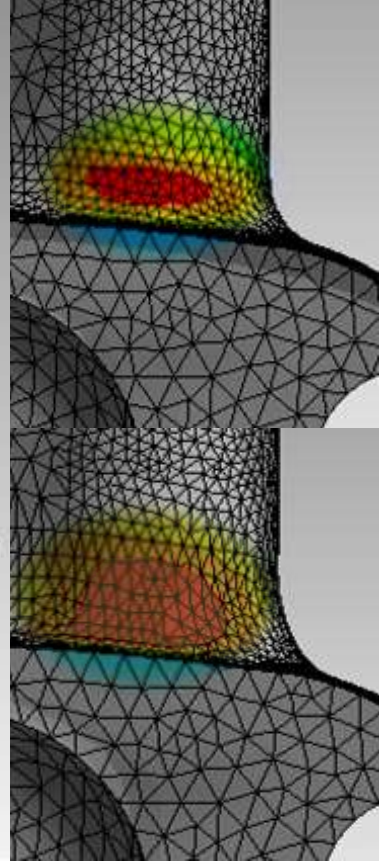
Quick Hands-On







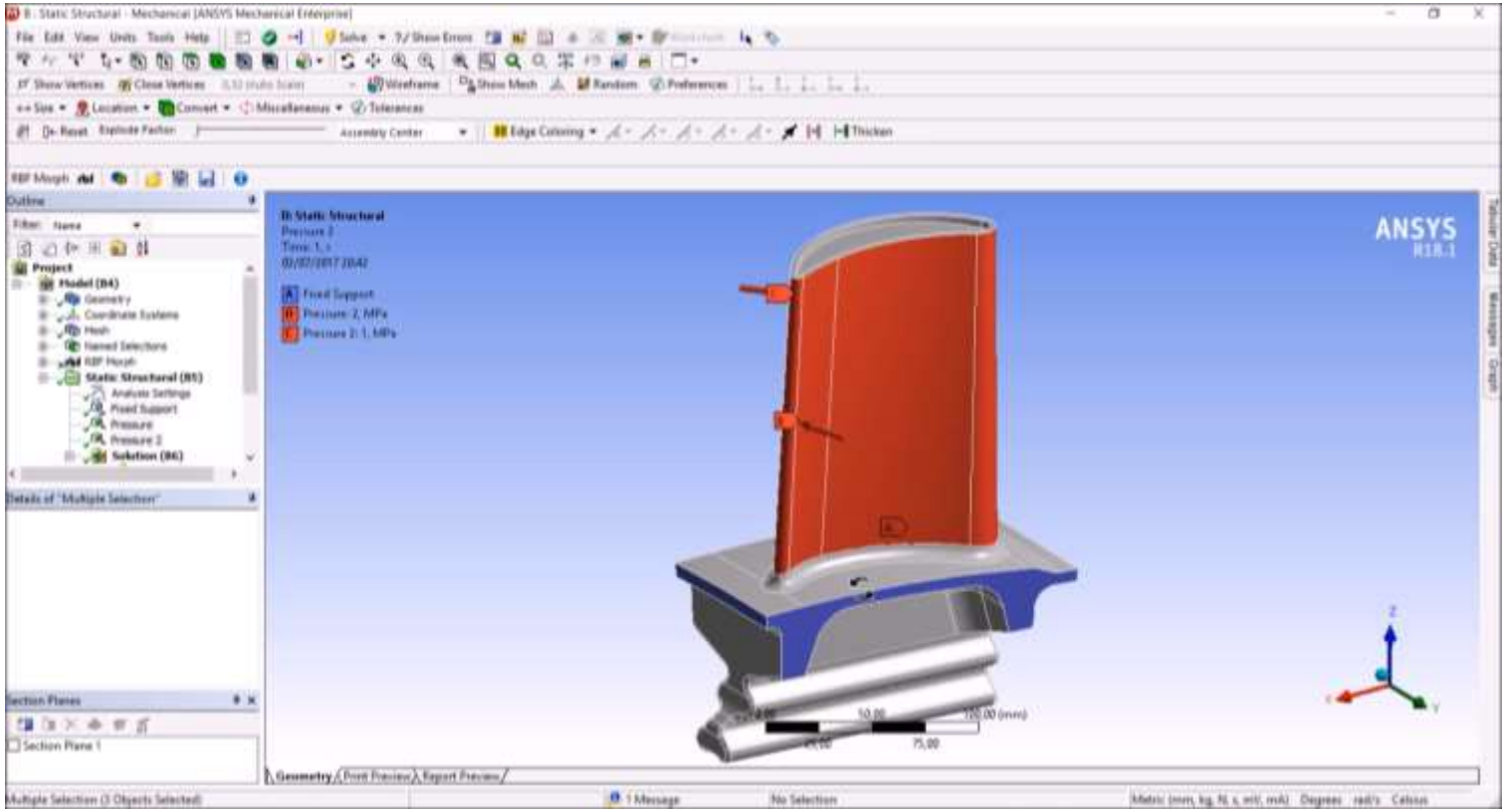
Aircraft Engine life extended!

25% stress reduction

RBF Morph - www.rbf-morph.com

Parameter based mesh morphing (design points/snapshots)

- **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



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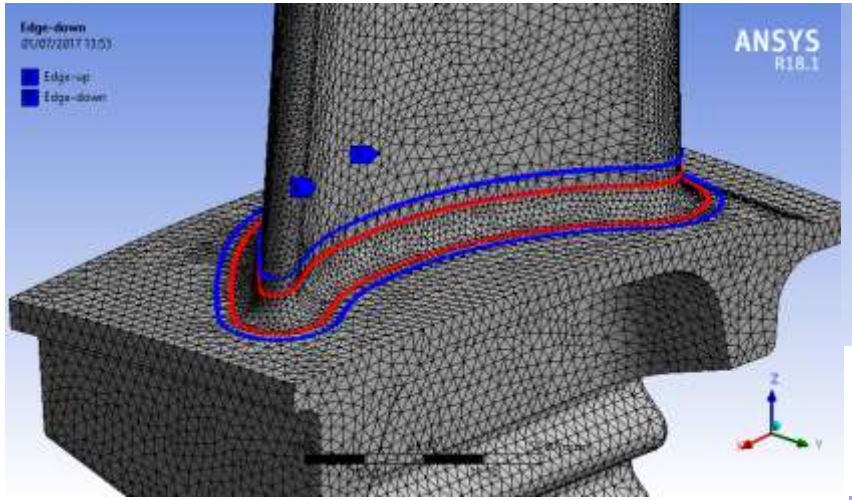
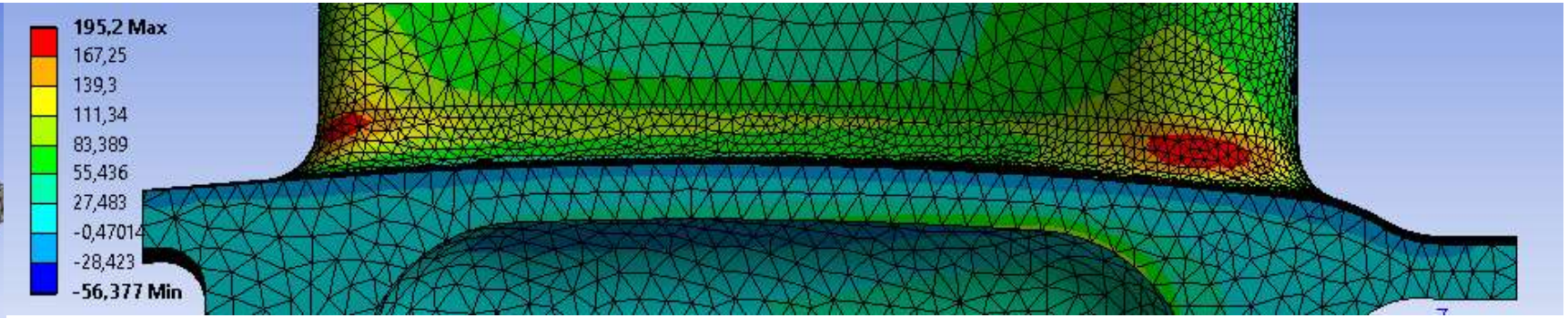
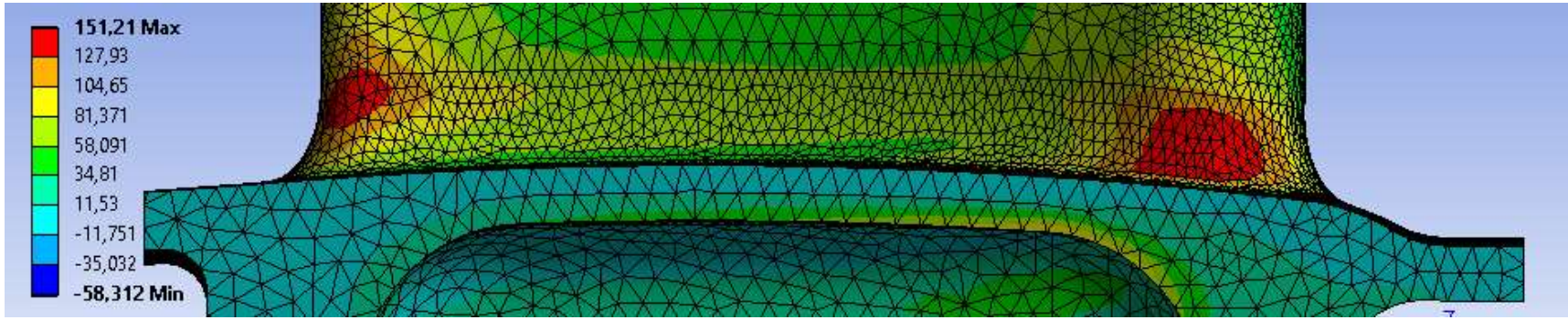
Blade fillet stress reduction

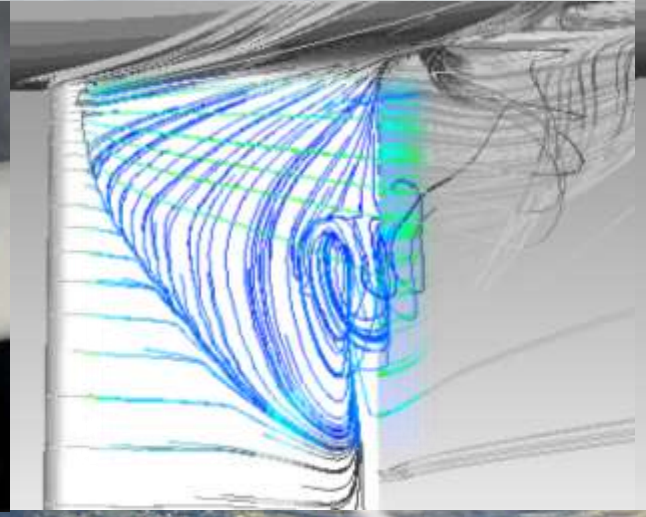


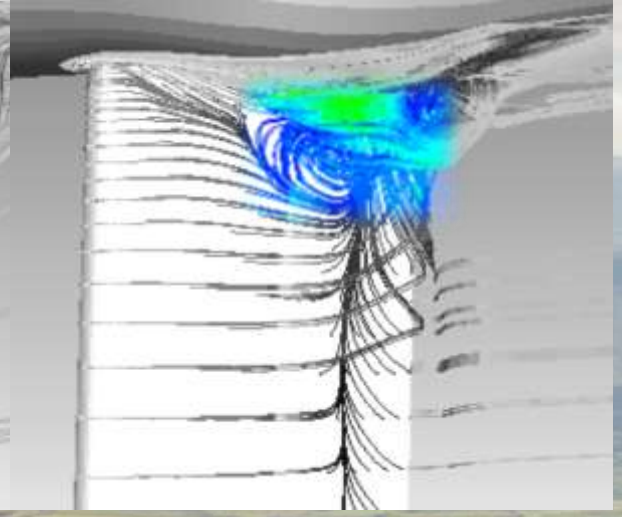




Two parameters allowed a stress **reduction** of 25%

Up to **45%** in a recent turbomachinery benchmark





PIPISTREL

Glide further!

35% more wing efficiency

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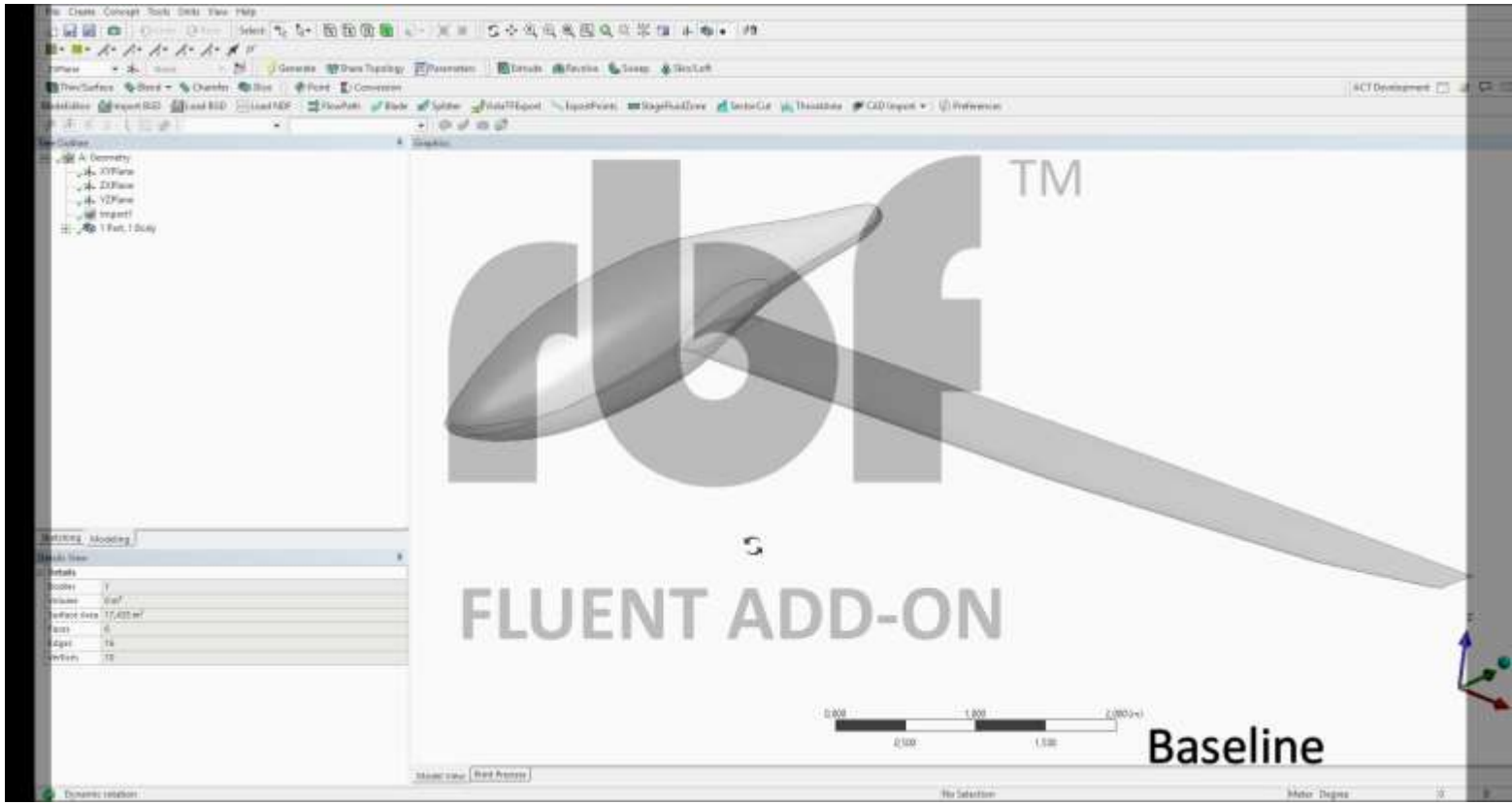
Parameter based mesh morphing (design points/snapshots)

- 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



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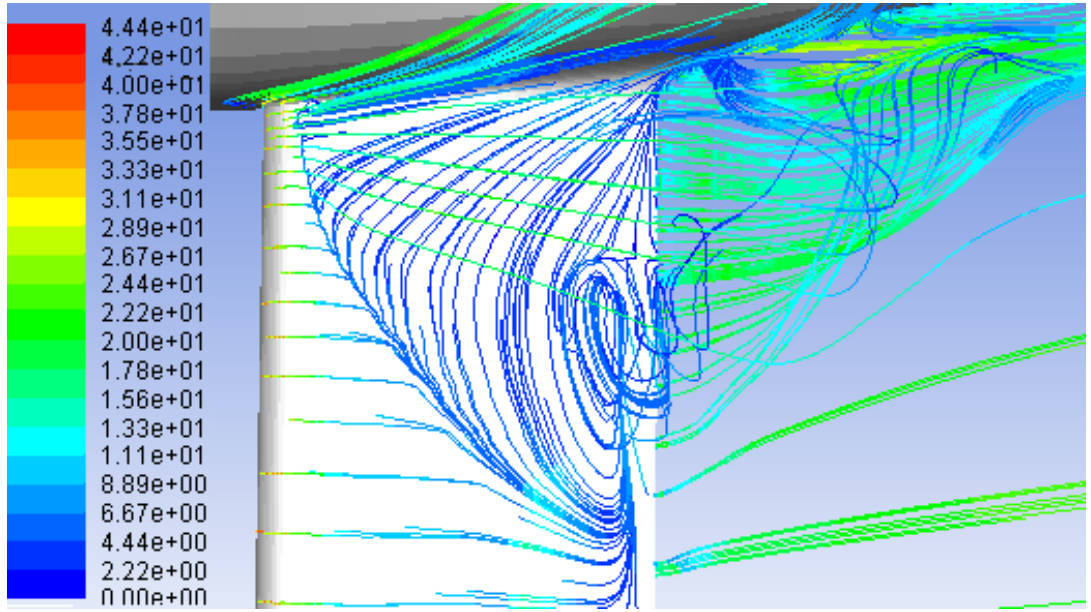
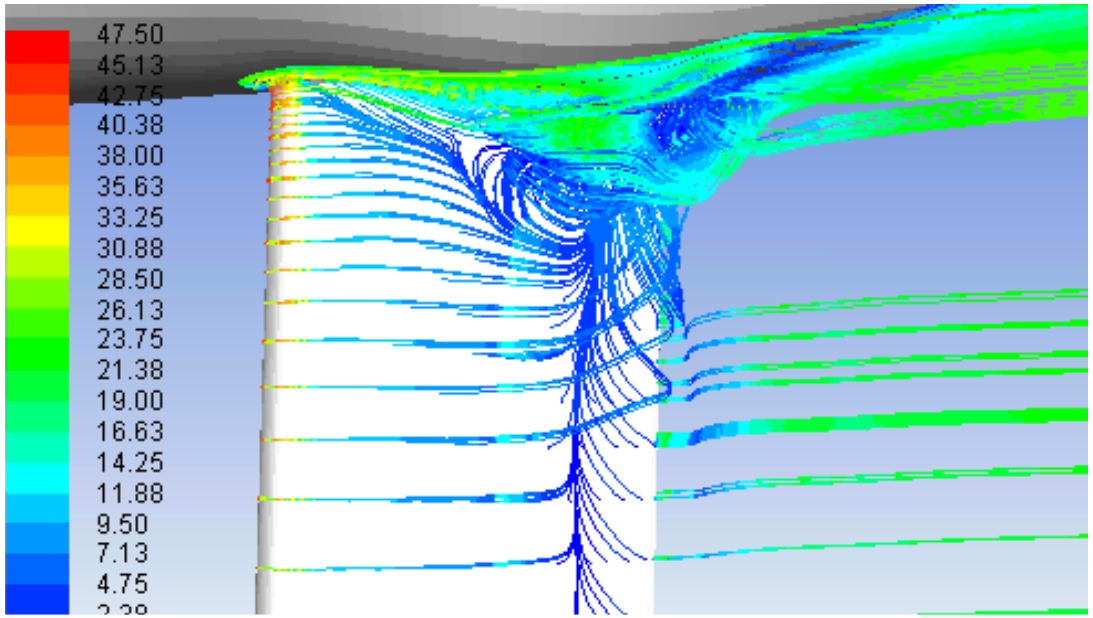
Glider optimization

Original design E=14.9



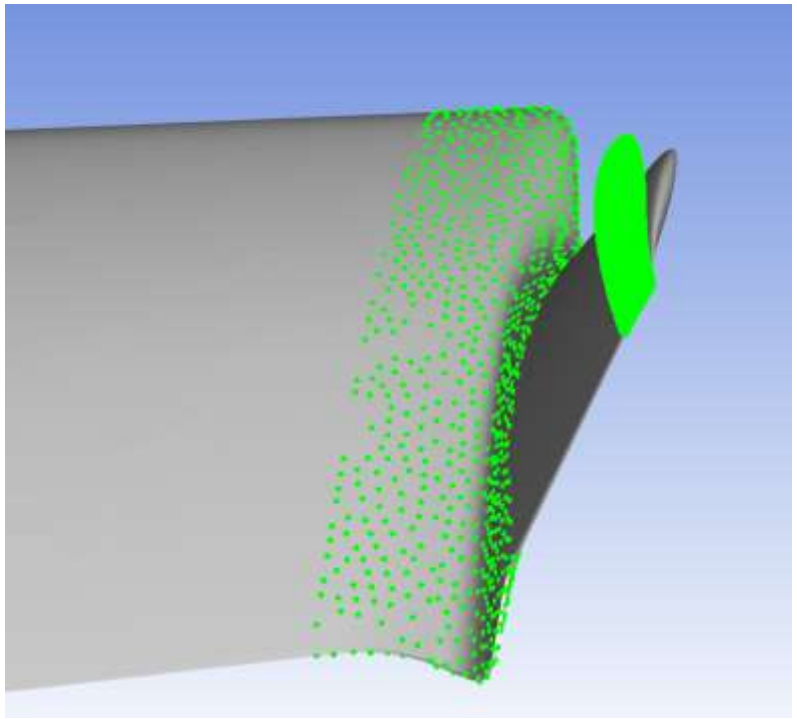
Optimal design E=20.1 (+35%)



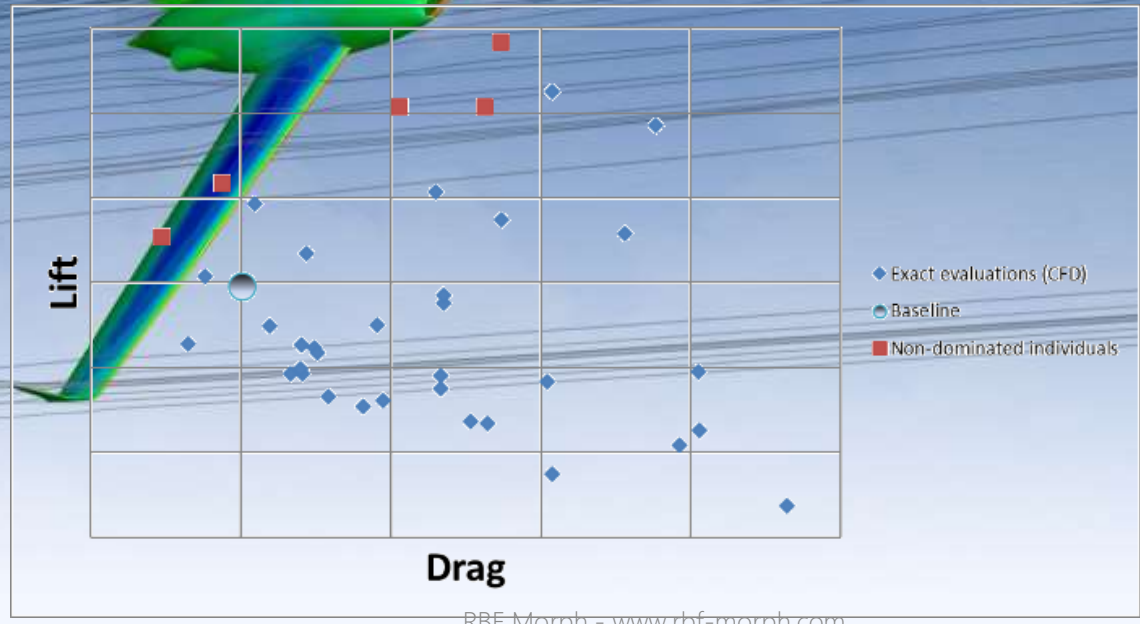
Mesh morphing examples for CFD and FEA applications

Aerospace

FSI winglet optimization



Range extended by 12%



RBF Morph - www.rbf-morph.com

RBF4AERO

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)**

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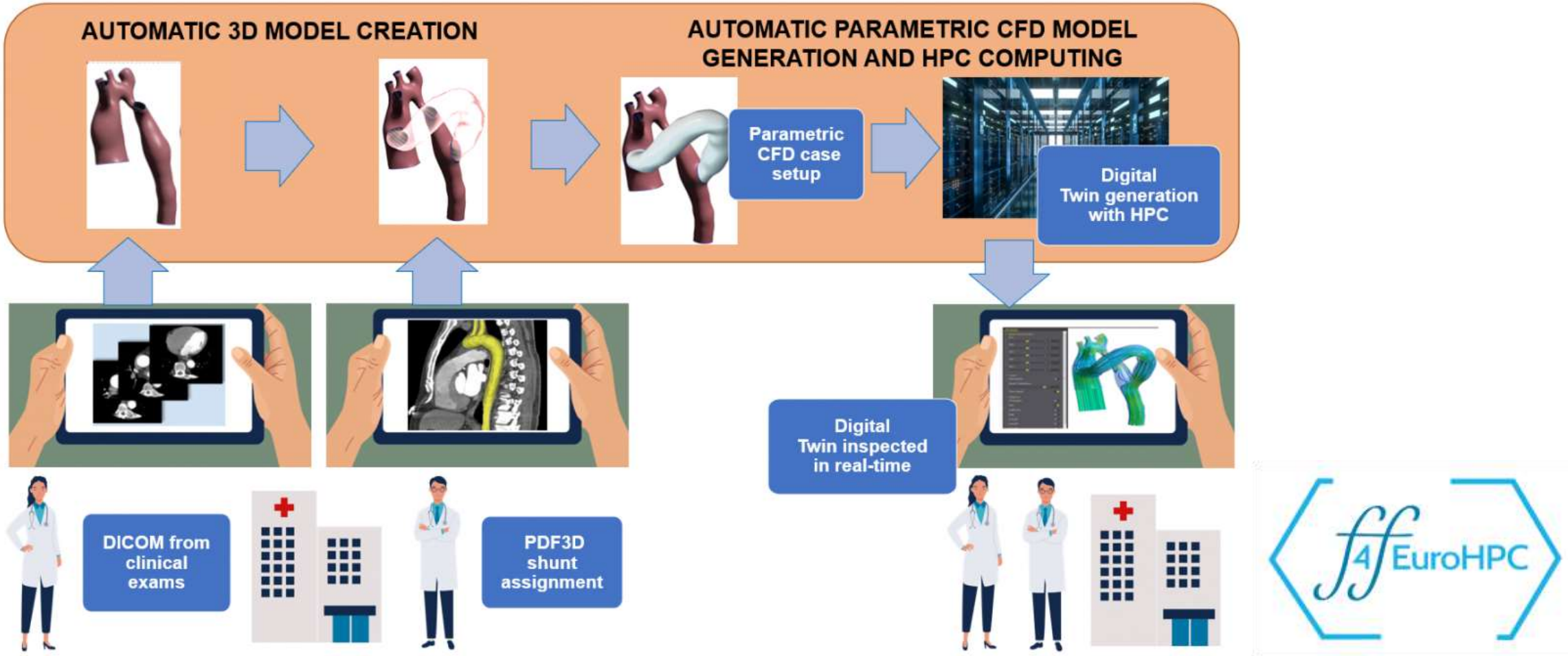
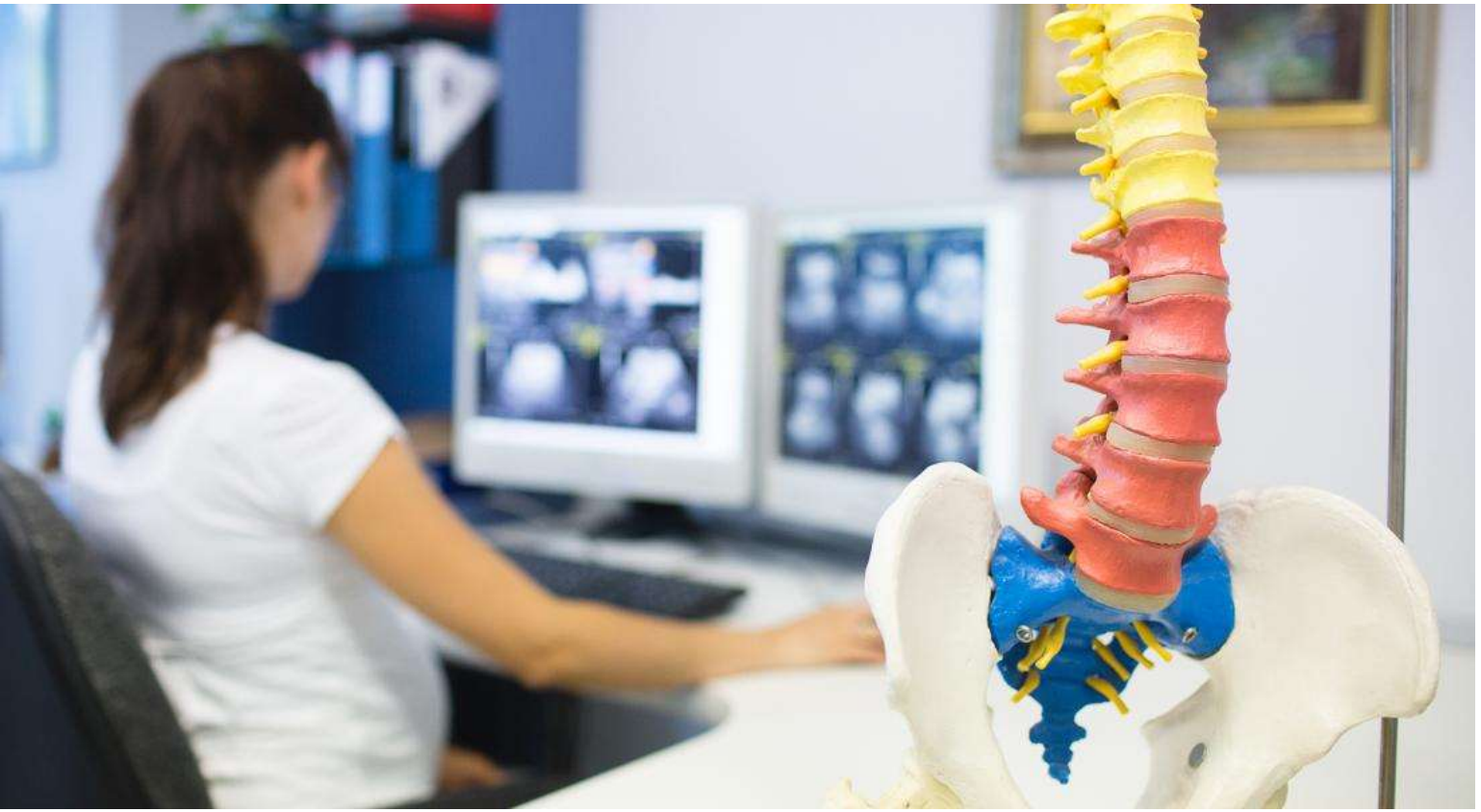
Healthcare

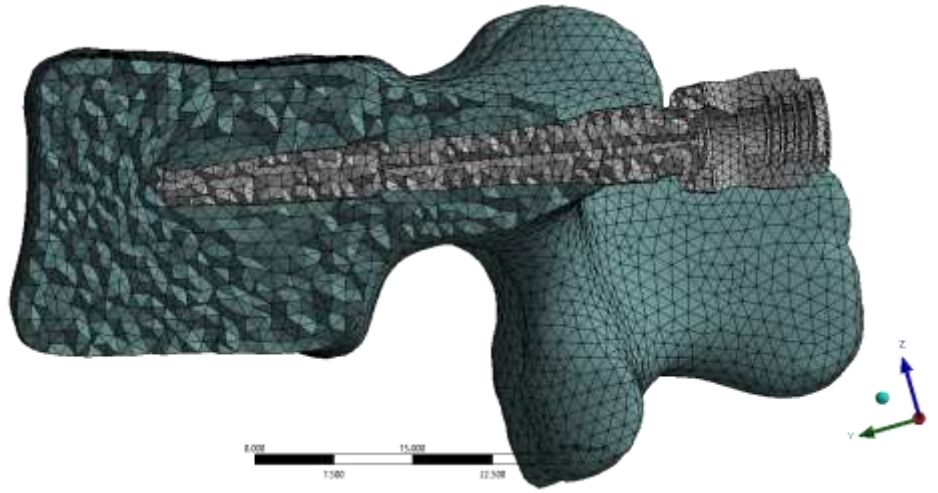
Medical Digital Twin Copernicus

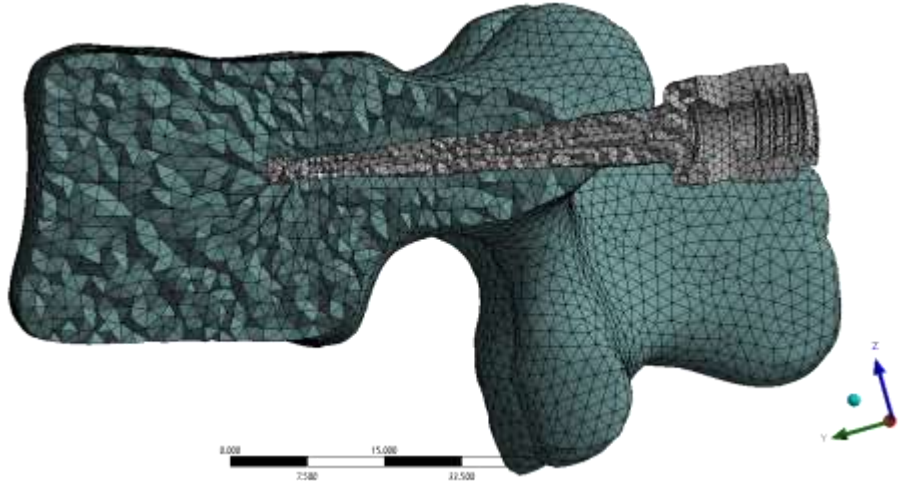


https://www.ff4eurohpc.eu/en/experiments/2021070910512579/cloudbased_hpc_platform_to_support_systemicpulmonary_shunting_procedures

Spine surgery Digital Twin







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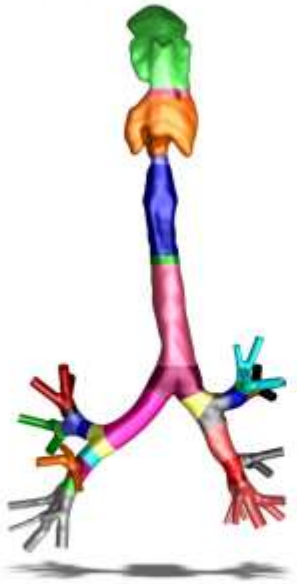
spinner
next generation spine experts

Medical Digital Twin DiTAiD

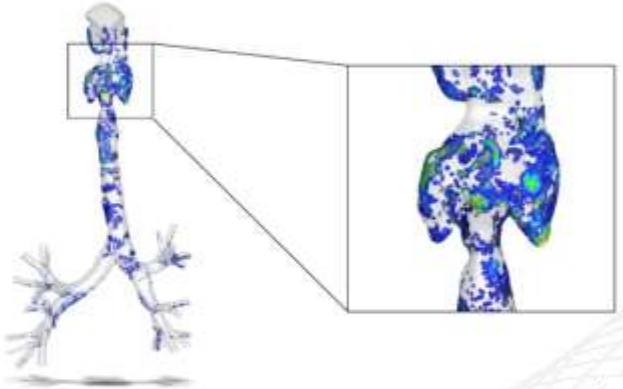
From lung scan to medical use

1) Scan of lungs



2) Extraction of lung shape parameters

3) Digital twin

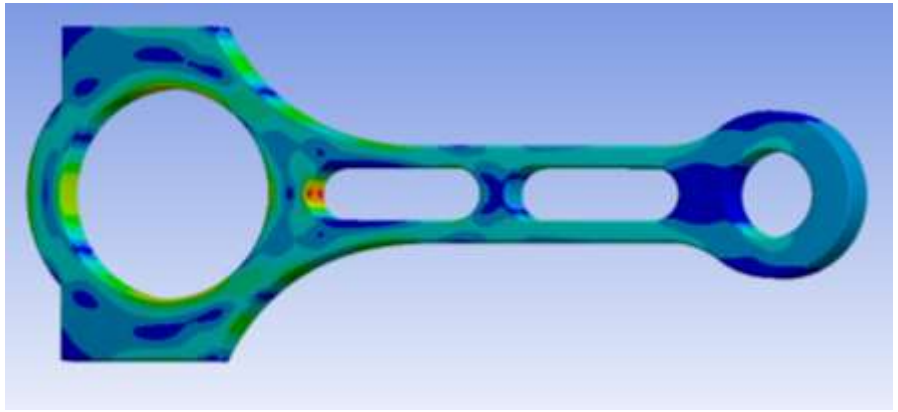


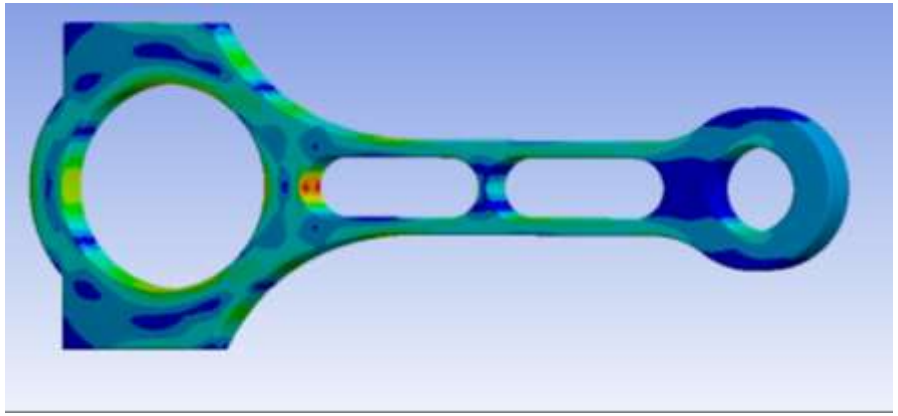
4) Visualization and interpretation for medical use

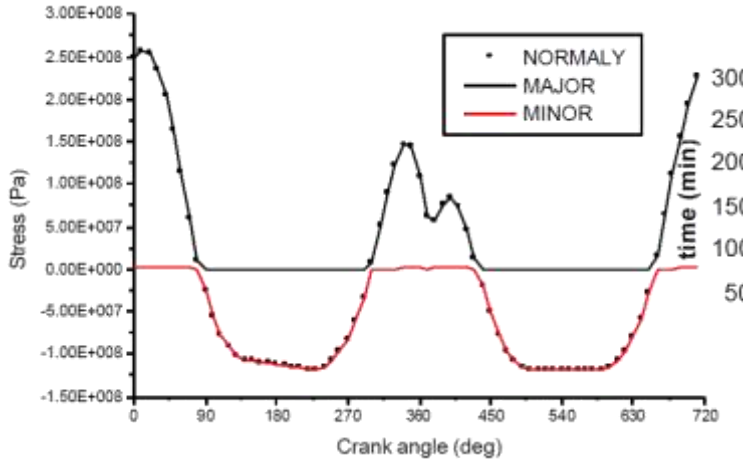
https://www.ff4eurohpc.eu/en/experiments/2022031514424665/digitaltwin_for_airflow_and_drug_delivery_in_human_airways

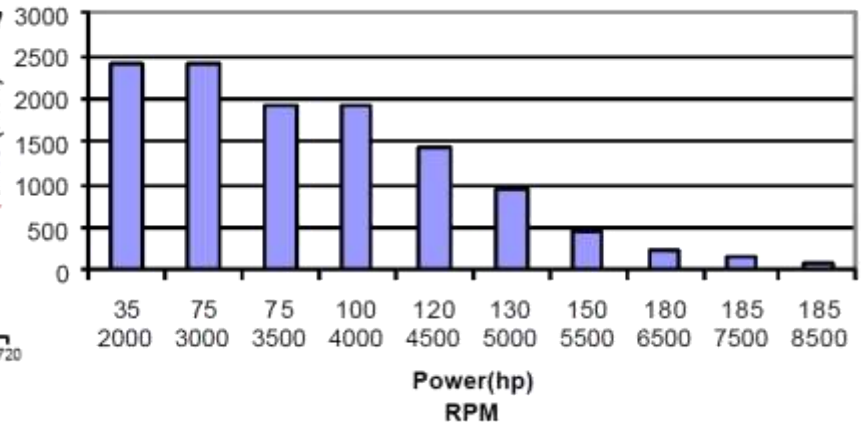
Automotive

Connecting rod optimization







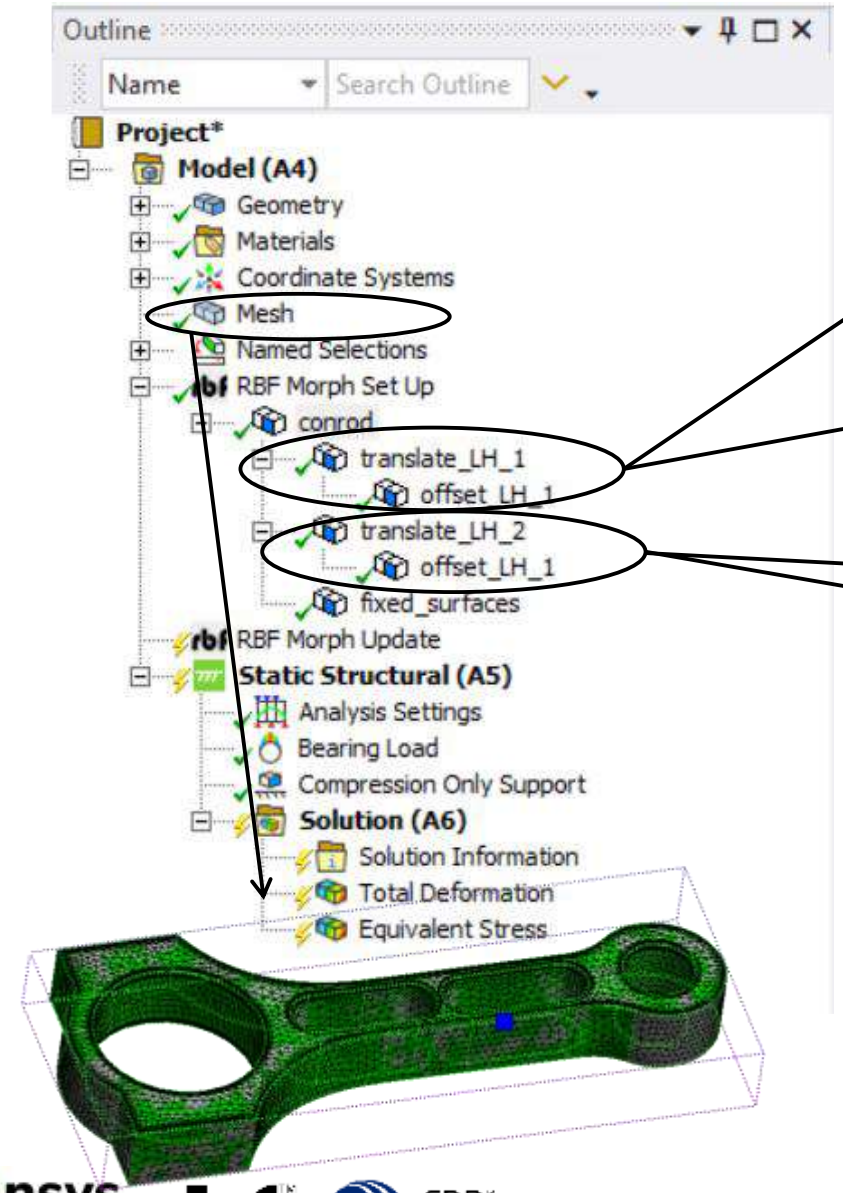


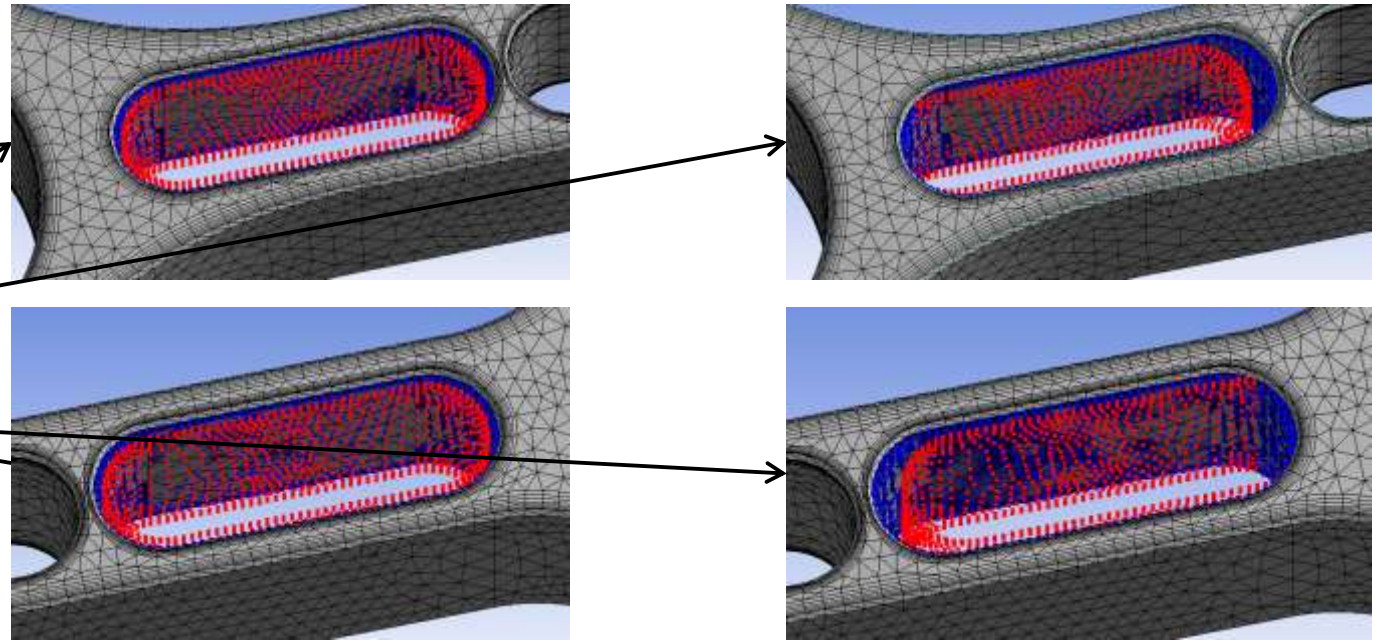
- Computed load history (kinematic analysis)
- Titanium Ti-6Al-4V (Grade 5)
- Cumulated damage map over the testing spectrum

https://www.rbf-morph.com/wp-content/uploads/2015/12/596_aias_2015_ottimizzazione-strutturale-mediante-mesh-morphing.pdf

Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

Connecting rod optimization





- Offset+rigid translation for the holes
- Null movement for other surfaces

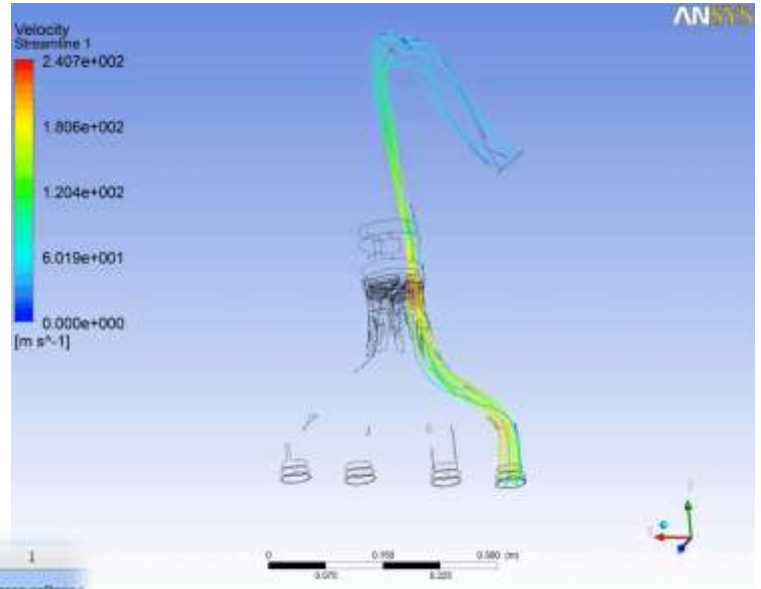
Connecting rod optimization

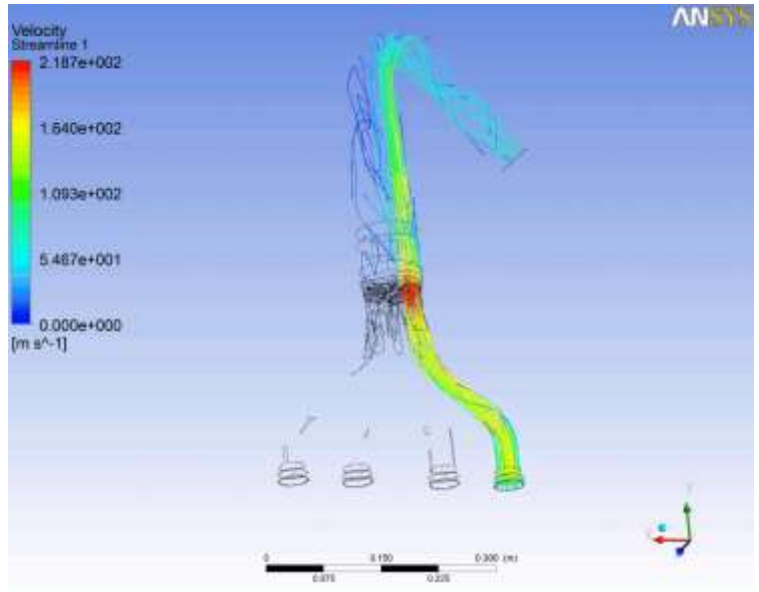
- Original design 358.7g

- Optimal design 334.4g (-6.7%)

Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

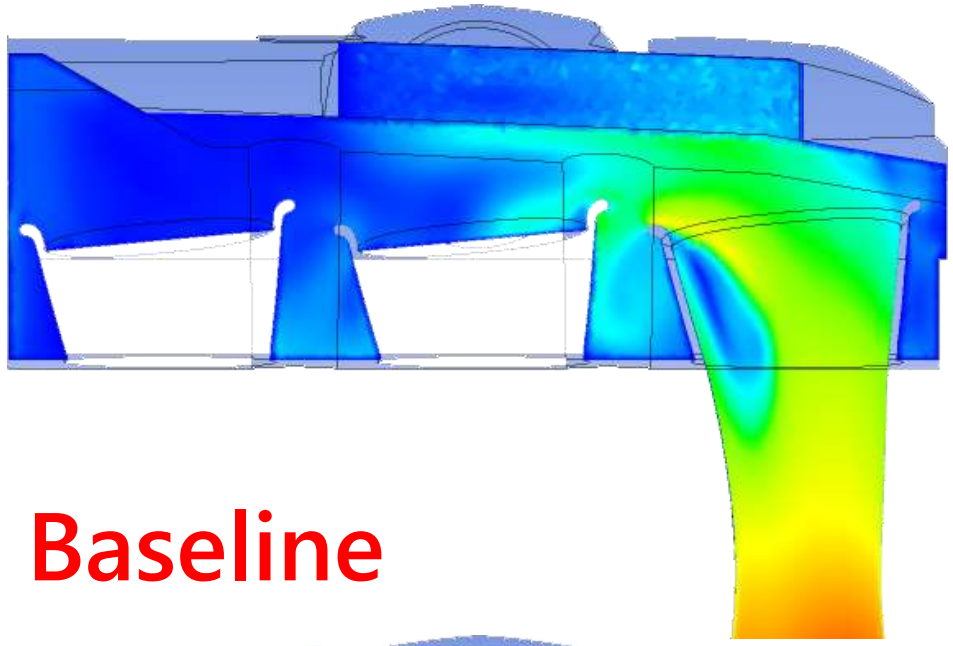
Exhaust manifold



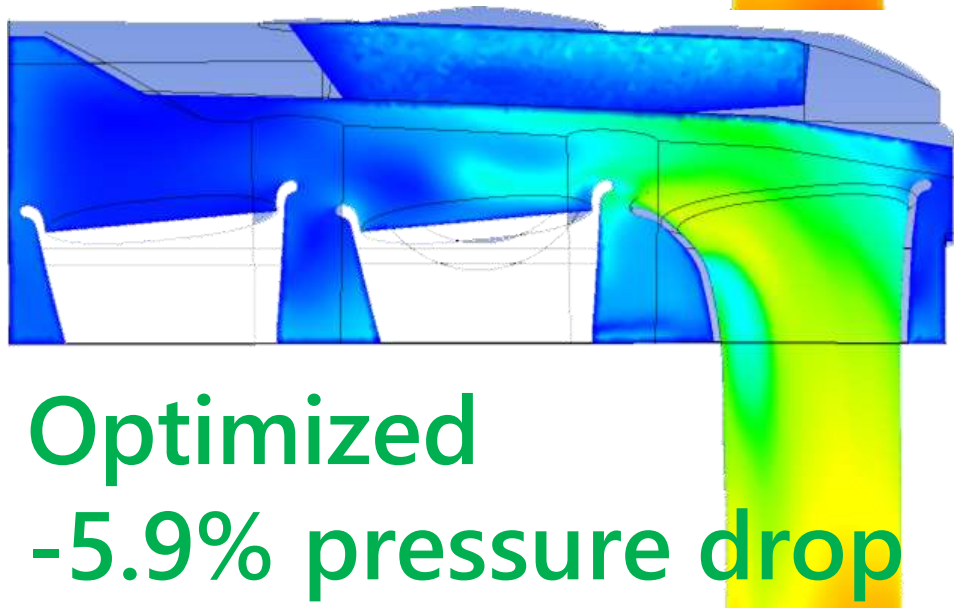


	A	B	C	D	E	F	G	H	I
1	Name	P5 - Ppe1Curve1	P6 - Ppe2	P7 - Pipe4Curve1	P8 - Ppe3	P1 - PressureDrop1	P2 - PressureDrop2	P3 - PressureDrop3	P4 - PressureDrop4
2						Pa	Pa	Pa	Pa
3	Current	4	4	4	4	12892	11366	13028	16619
4	DP 1	3	3	3	3	12882	11247	13487	16731
5	DP 2	2	2	2	2	12897	11546	13554	16911
6	DP 3	1	1	1	1	13403	11477	13920	17666
7	DP 4	0	0	0	0	13555	11750	13967	17718

Balanced flow and 8% less pressure drop



Baseline



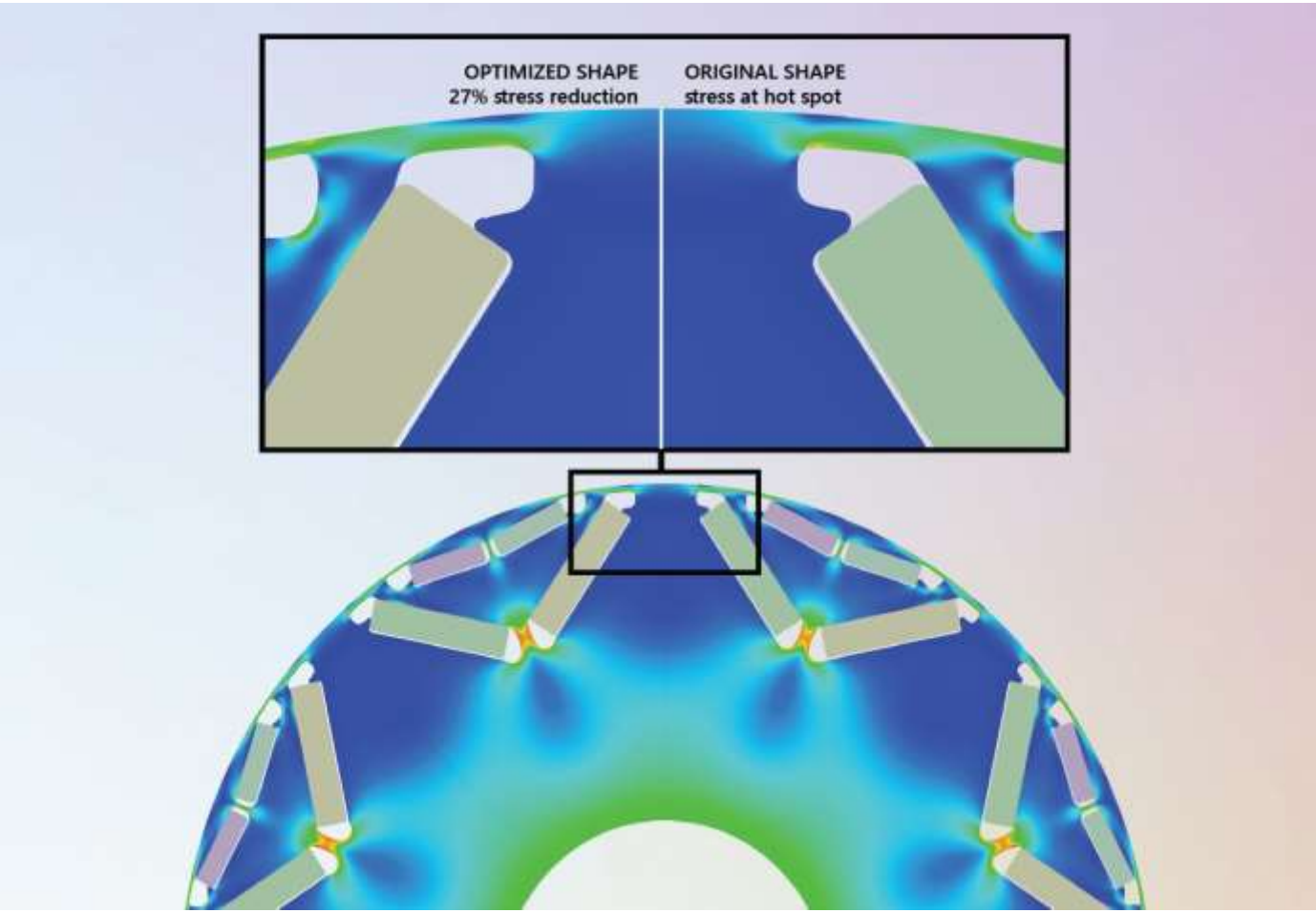
Optimized
-5.9% pressure drop

Lamborghini Aventador engine air box

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

Electric motor design

- Example of 2d shape optimization
- Hot spots mitigated after the EM calculation by Maxwell
- Biological Growth Method in Ansys Mechanical

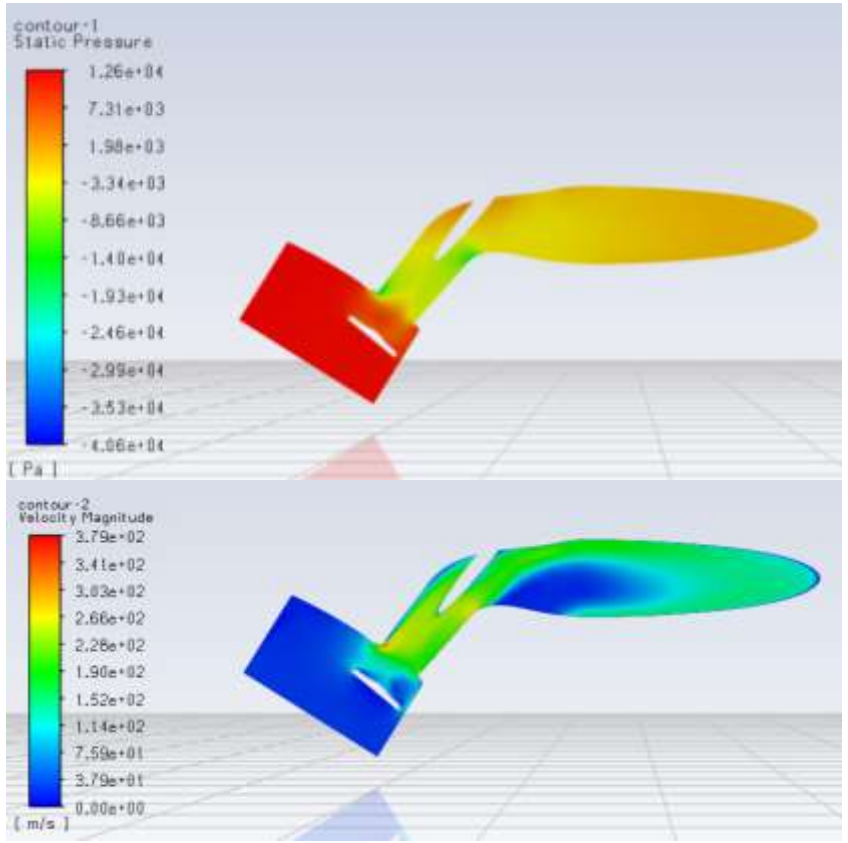


Engine head optimization

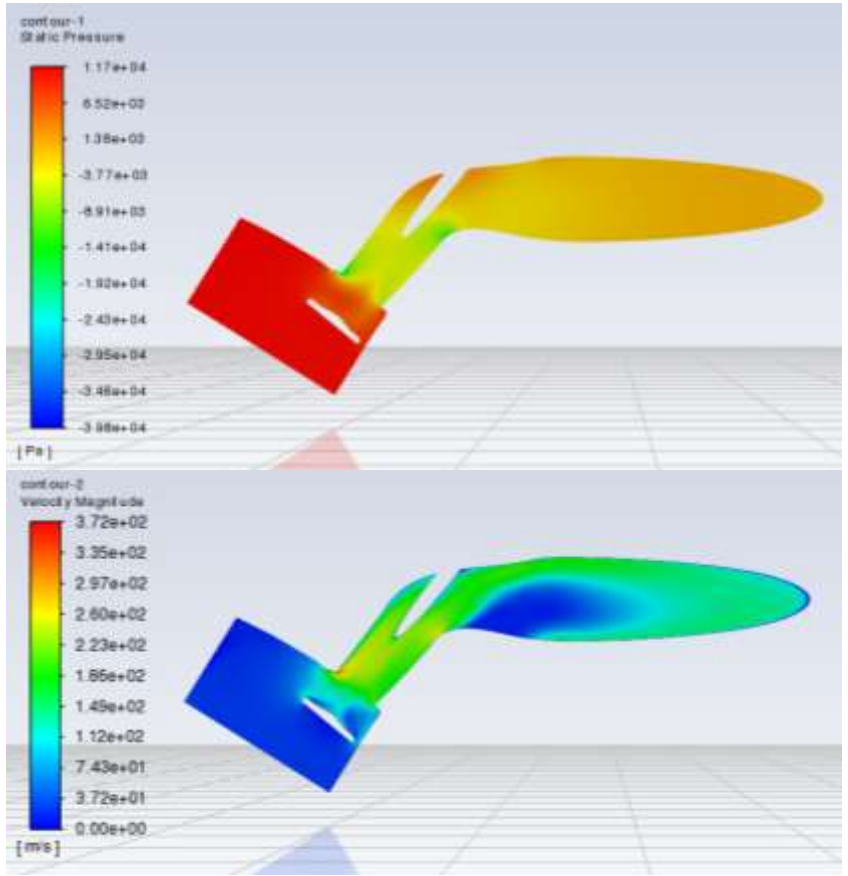
- Multi-physics problem
  - Thermal fatigue
  - Coolant circulation
  - Intake/exhaust ports
- KPI
  - Reliability – life
  - Engine performance

Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

Pressure drop at exhaust

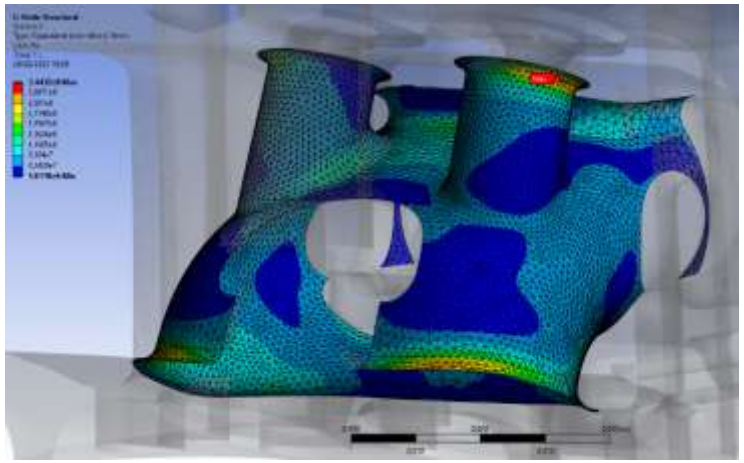


Baseline



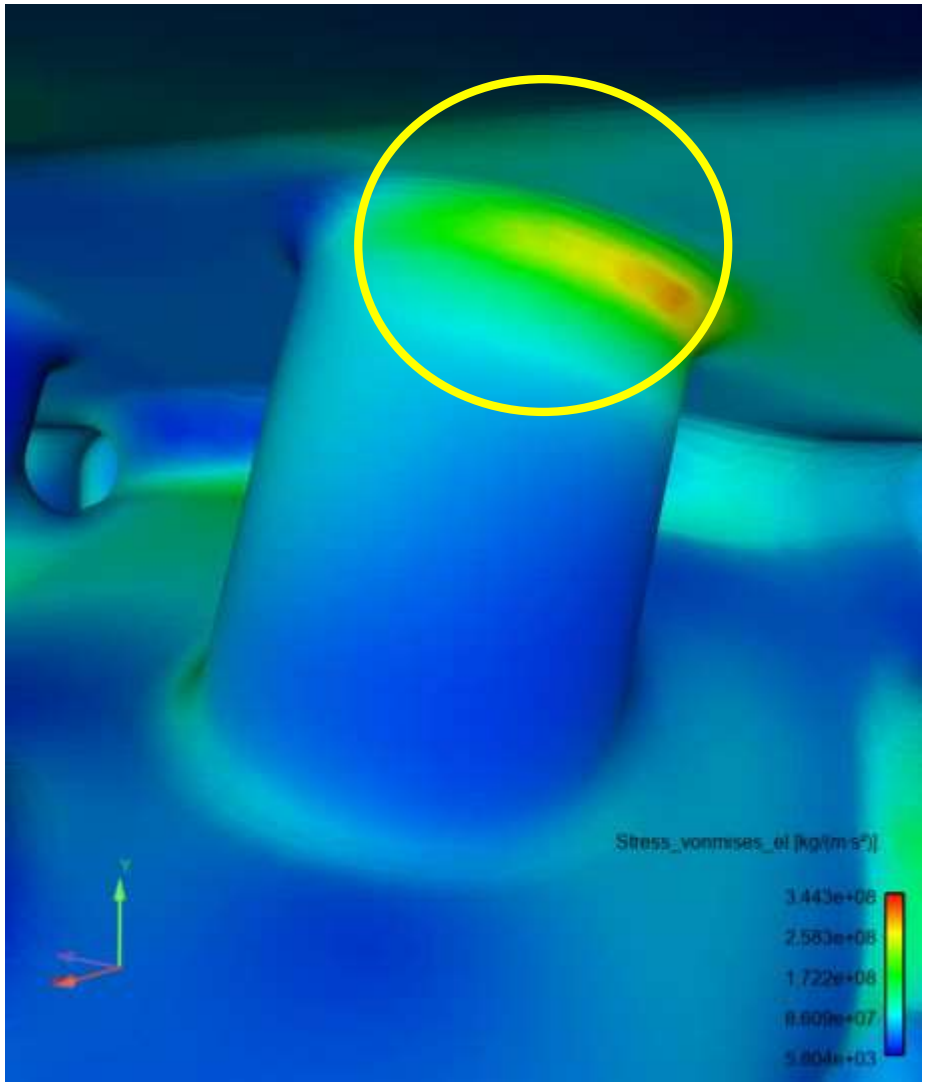
Optimized (-7.5%)

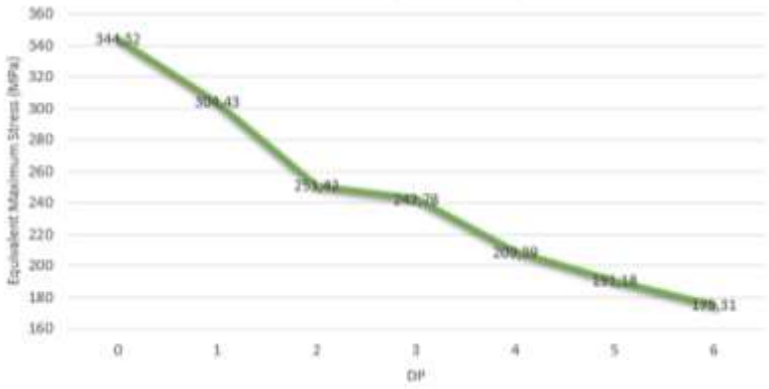
Hot spot stress at exhaust



Baseline

Optimized (-49%)





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Structural Optimization of a wheel hub

https://www.enginsoft.com/expertise/a-natural-remedy-for-hot-spot-stresses.html

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Reuse the LS-DYNA model of a different car

A	
1	External Model
2	Setup

Crash-test-with-wall

B	
1	LS-DYNA
2	Engineering Data
3	Model
4	Setup
5	Solution
6	Results

DYNA-Crash-Standard

C	
1	Mechanical Model
2	Engineering Data
3	Geometry
4	Model

Surface-Geometry-To-Morph

D	
1	LS-DYNA
2	Model
3	Setup
4	Solution
5	Results

DYNA-Crash-Morphed

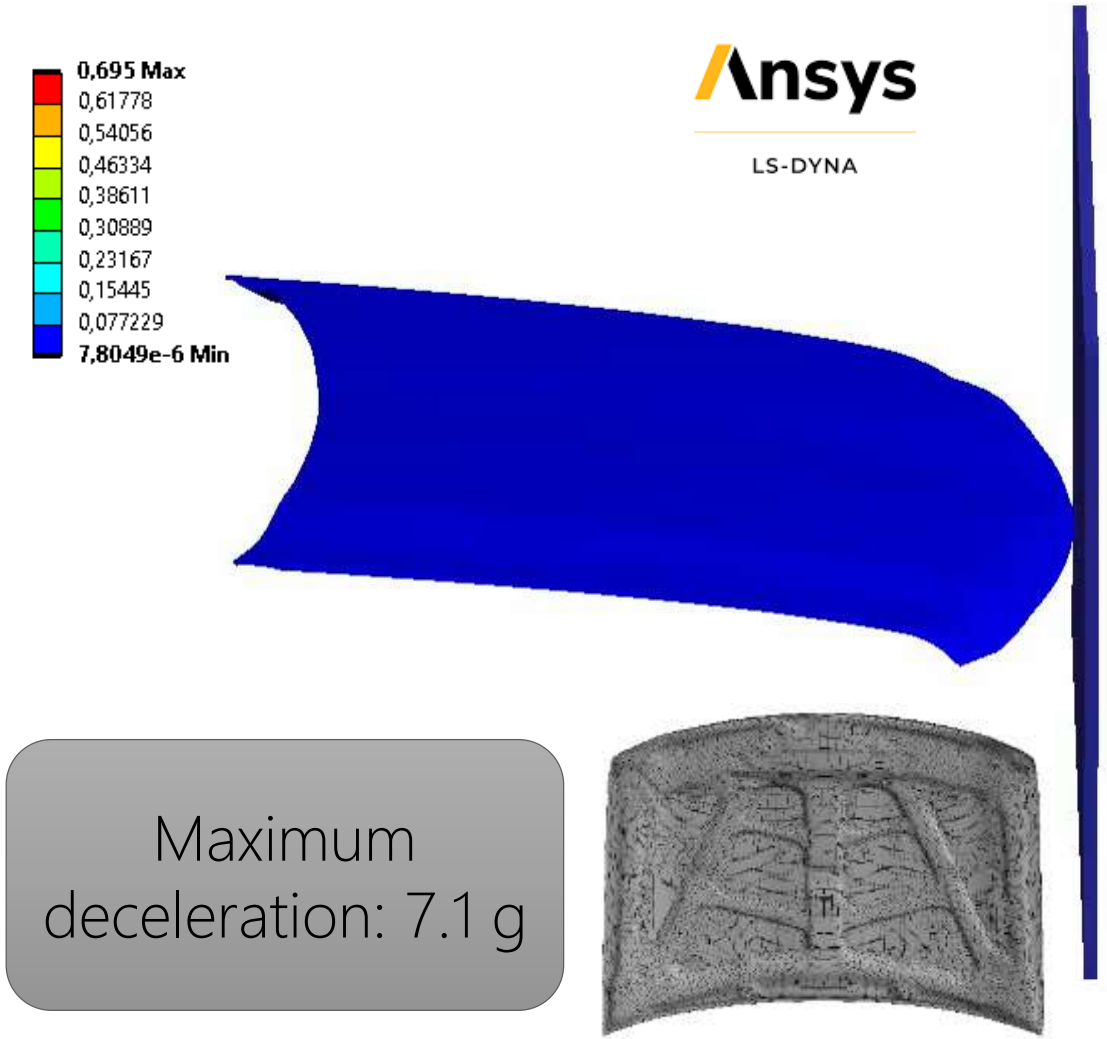
Ansys

LS-DYNA

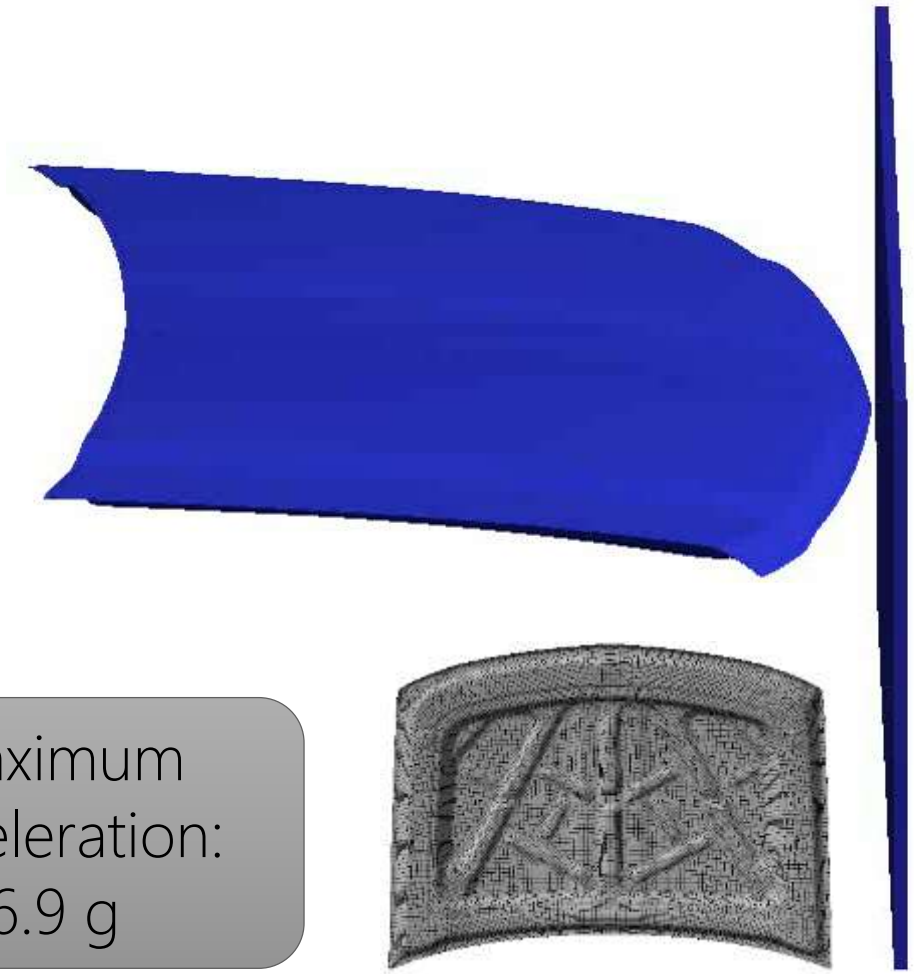
https://www.rbf-morph.com/wp-content/uploads/2021/04/RBF-Morphand-LSDYNAintoAnsysWorkbenchandMechanical.pdf

Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

Reuse the LS-DYNA model of a different car



Maximum deceleration: 7.1 g

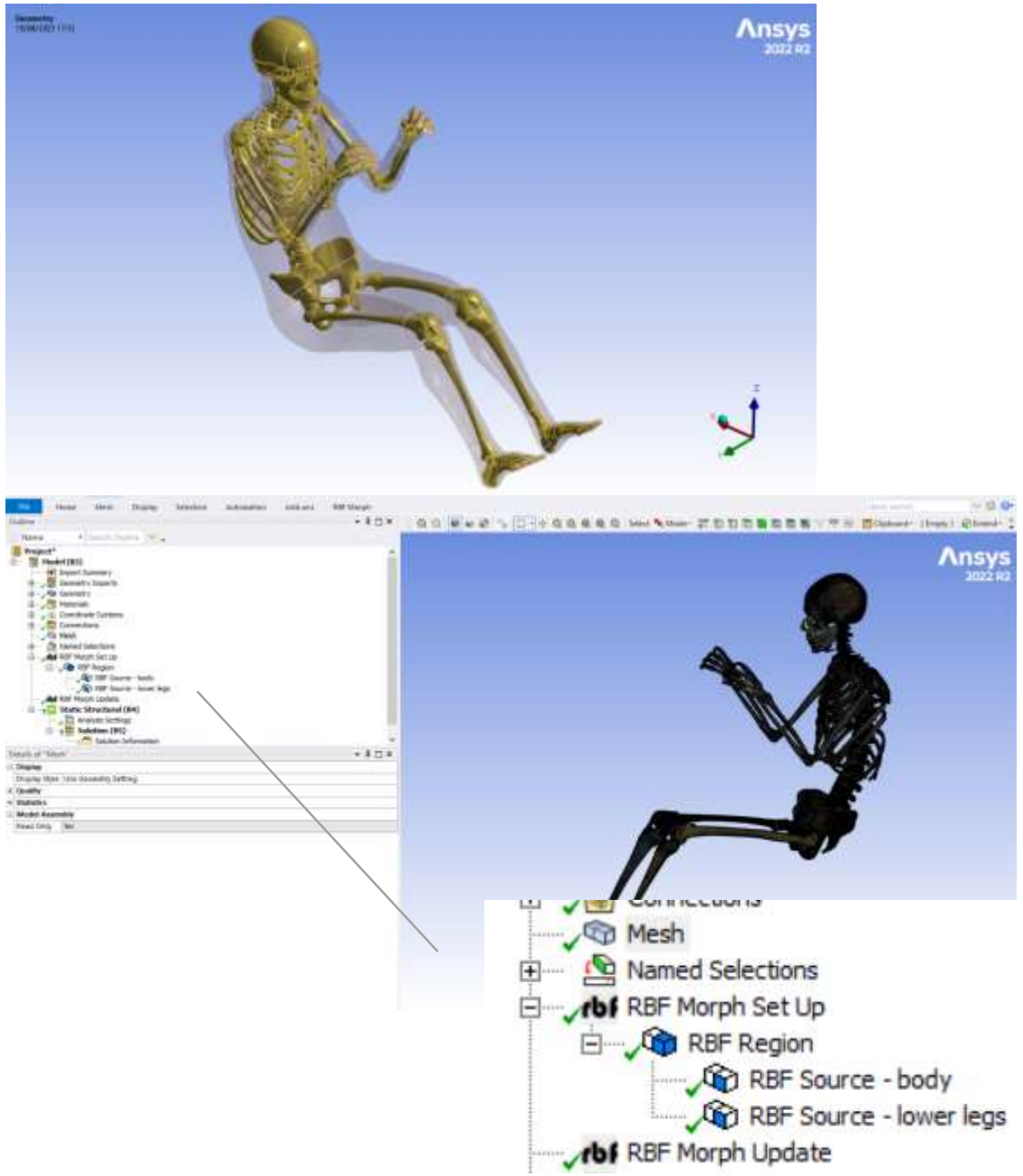


Maximum deceleration: 6.9 g

https://www.rbf-morph.com/wp-content/uploads/2021/04/RBF-Morphand-LSDYNAintoAnsysWorkbenchandMechanical.pdf

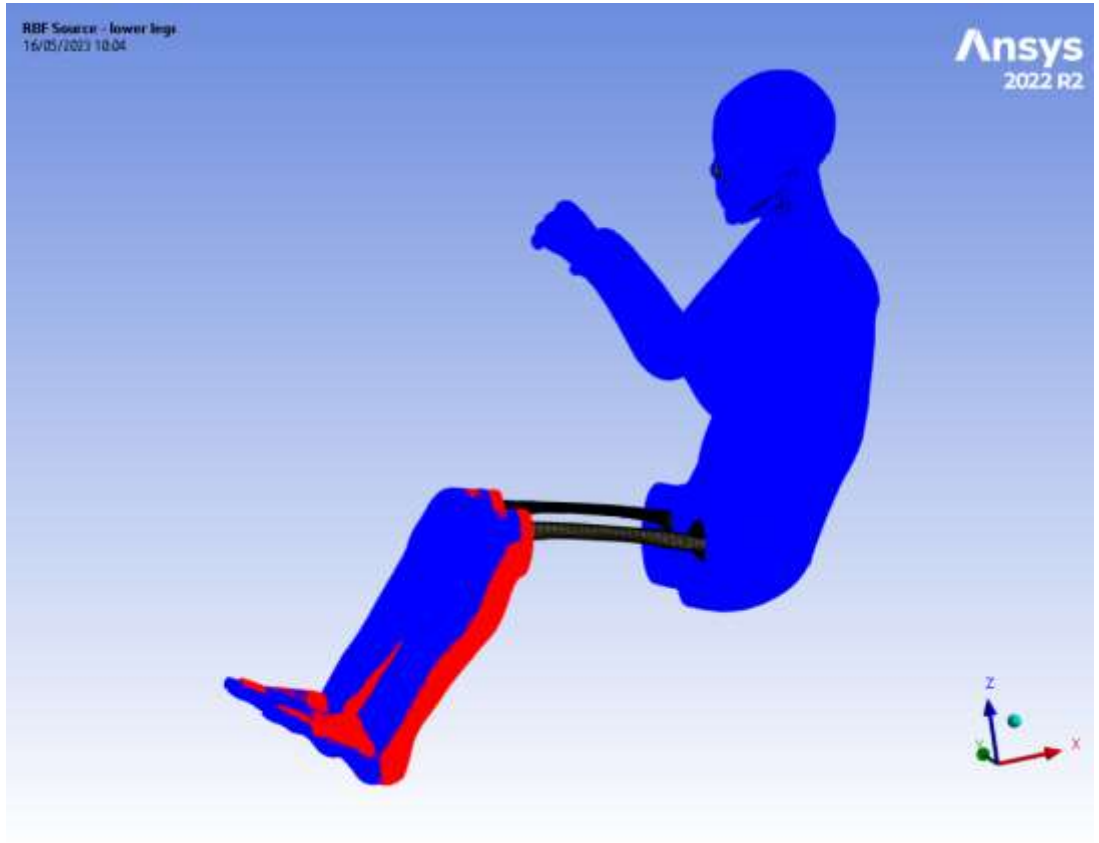
Parametric THUMS

- Total HUman Model for Safety (THUMS) https://www.toyota.co.jp/thums/
- RBF Sources (that could be nested) define the morphing action – we use here just the skin and the bones
- RBF Regions receive the final morphing (full .key file ready to run)



Parametric THUMS

- In this test we use the skin to control the morphing
- The lower legs and feet are moved along the upper legs direction
- Upper legs are shortened
- The process (66.000 RBF sources 273.000 nodes moved) takes less than 1 minute



Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

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Ansys SELECT TECHNOLOGY PARTNER rbf EDR MEDESO

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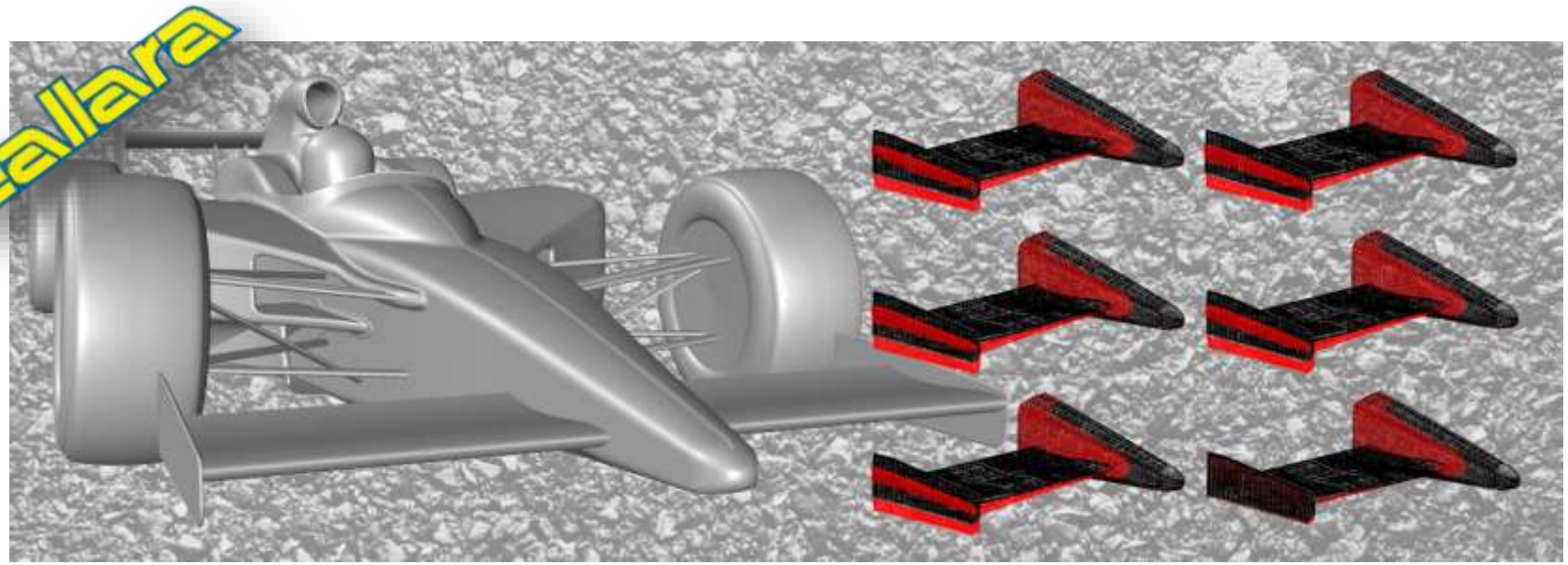
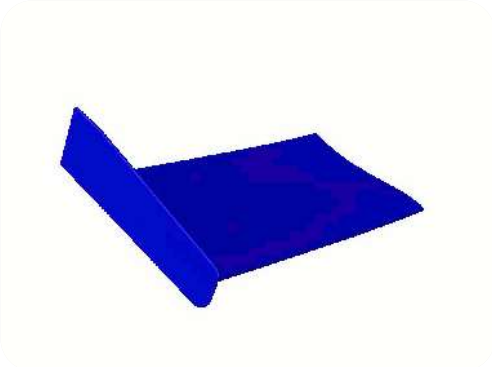
FSI Example: Indy Race Car





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

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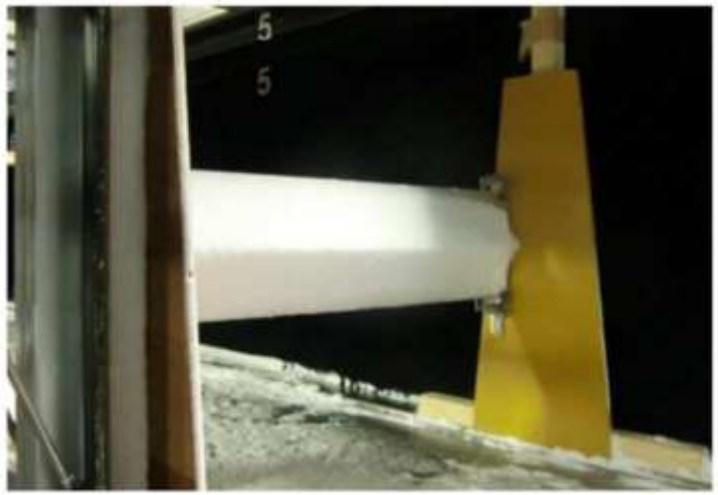
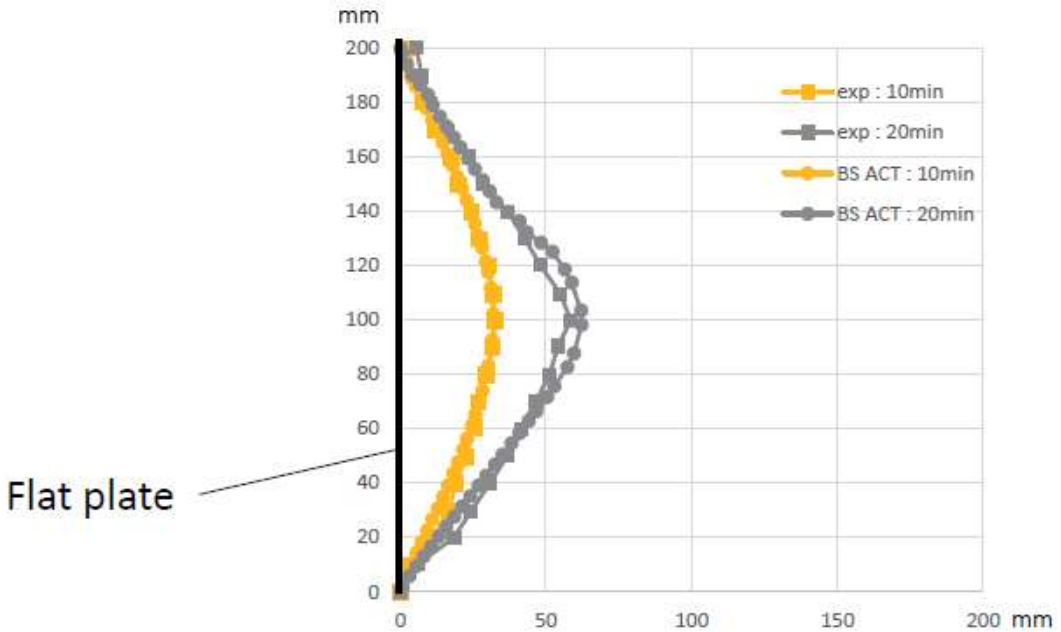
Transient pitching simulation - porpoising

Snow accretion blowing

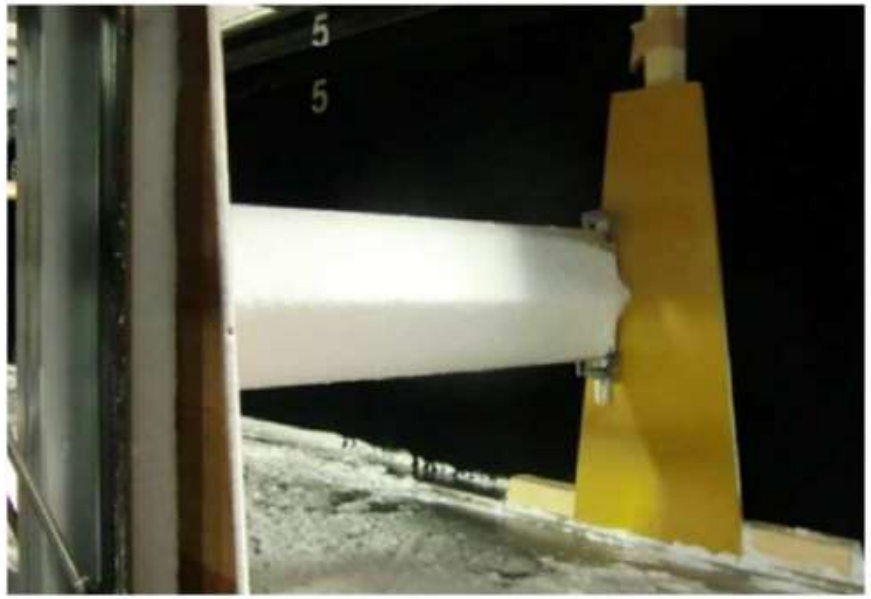
- Snow melting agent may be sprayed to prevent roads from freezing in cold regions
- Snow salt damage can lead to corrosion and rust on vehicle body and underbody
- The ability to predict snow adhesion patterns in CFD without field testing provides decision support for design changes early in the project



Snow accretion blowing



Temporal changes in cross section during snow accretion

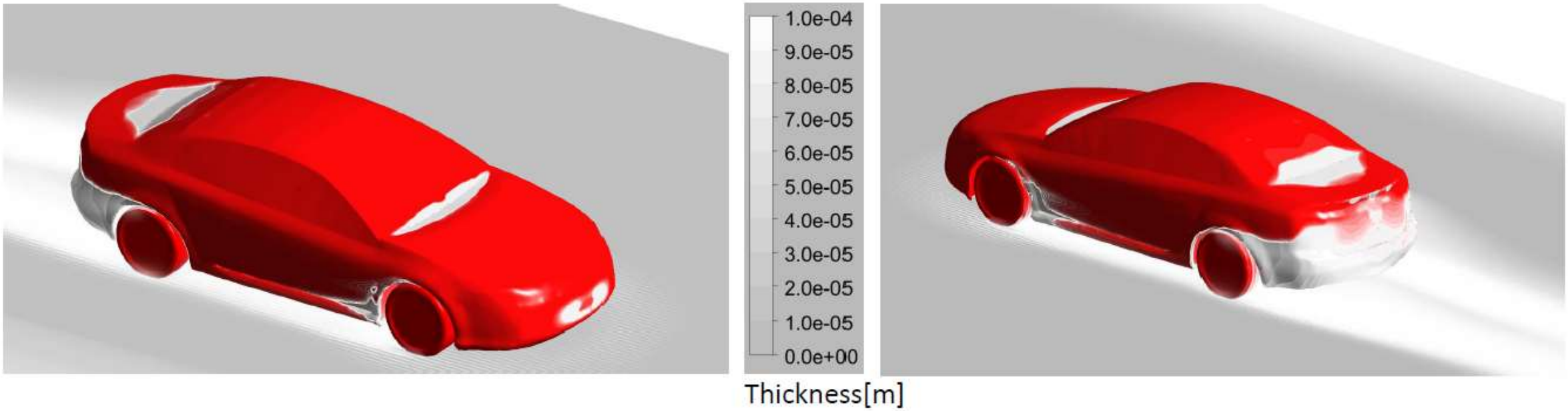


Experiment: snow accretion on flat plate

Snow accretion blowing

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

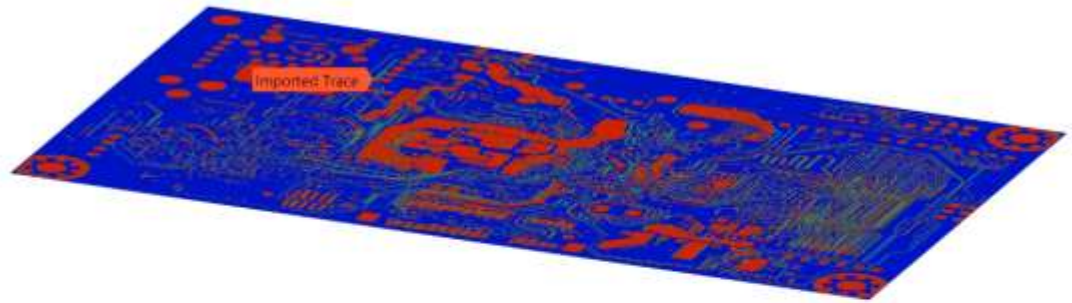
- Snow contamination pattern after 15-minute solo driving

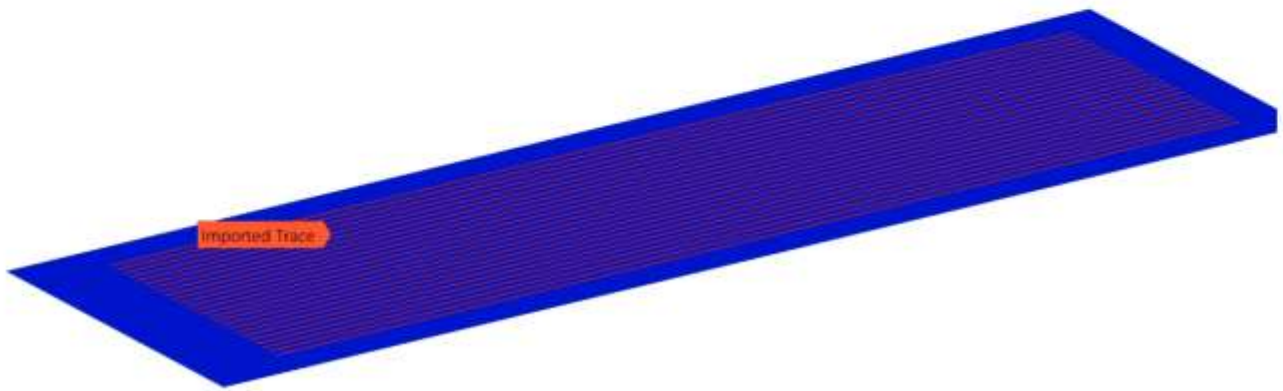


Electronics

Morph onto CAD shapes

RBF Morph & Ansys Mechanical allow fast adaption of Flexible PCBs onto the installation shape

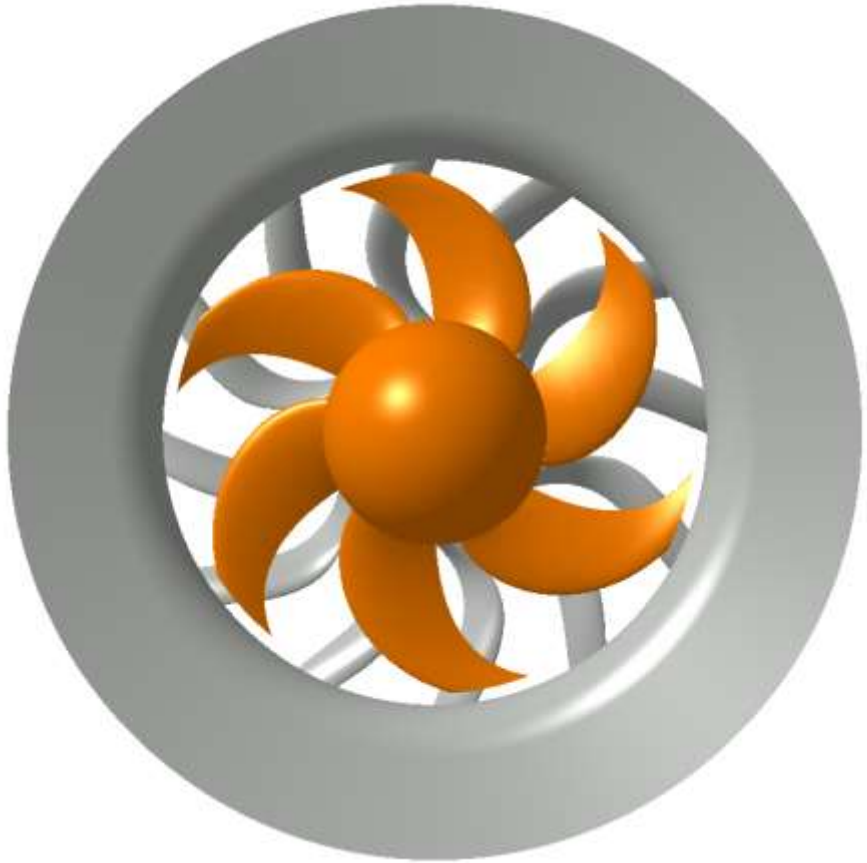




https://iopscience.iop.org/article/10.1088/1757-899X/1038/1/012084

Optimization of a propeller

- **Noise reduction** achieved thanks to the improved design
- Morphing in **cyclic symmetry**
- Set-up defined on a reference blade (6 shape parameters)
- Rotating surface interface preserved



RBF mesh morphing for noise reduction

Ansys Fluent

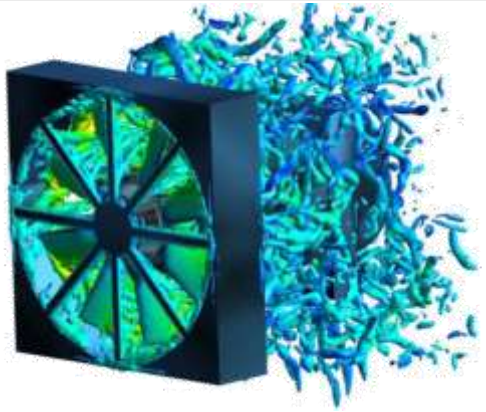
- High fidelity modeling of Fan aerodynamics
- Direct and Integral methods for sound propagation
- Inbuilt Post-processing for Aeroacoustics

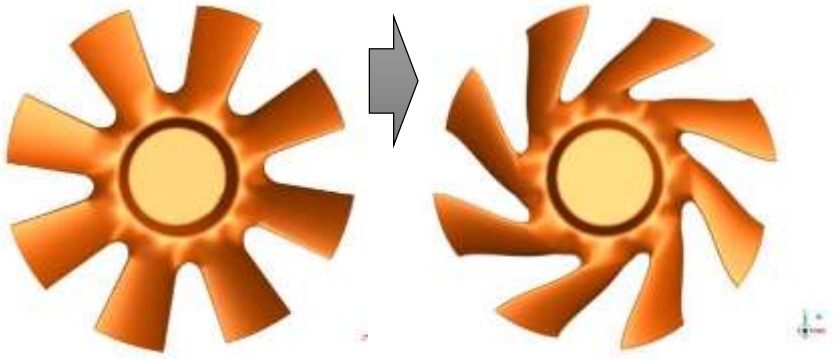
RBF Morph

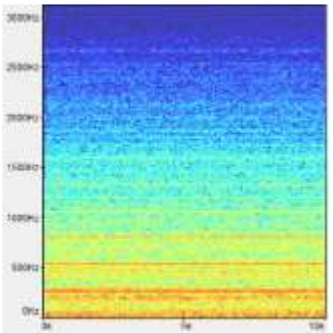
- Parametric studies of blade shapes and positions including Design Of Experiments (DOE) and shape optimization
- Fast mesh deformation fully integrated in the solving process

Ansys VRXPERIENCE Sound

- Signal duration extension
- Psychoacoustic analysis
- Sound Design
- Characterization







Ansys SELECT TECHNOLOGY PARTNER

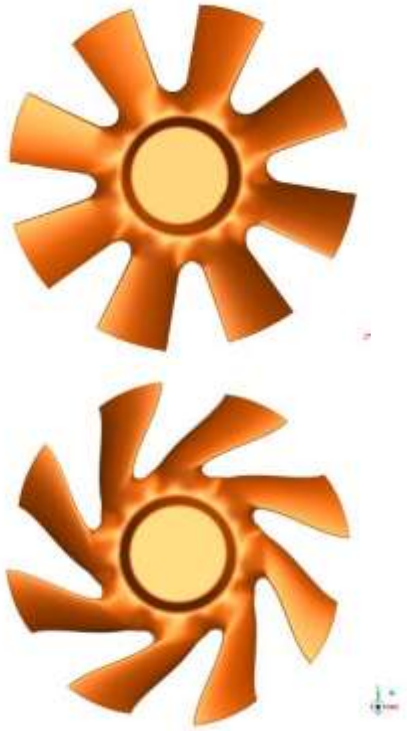
rbf

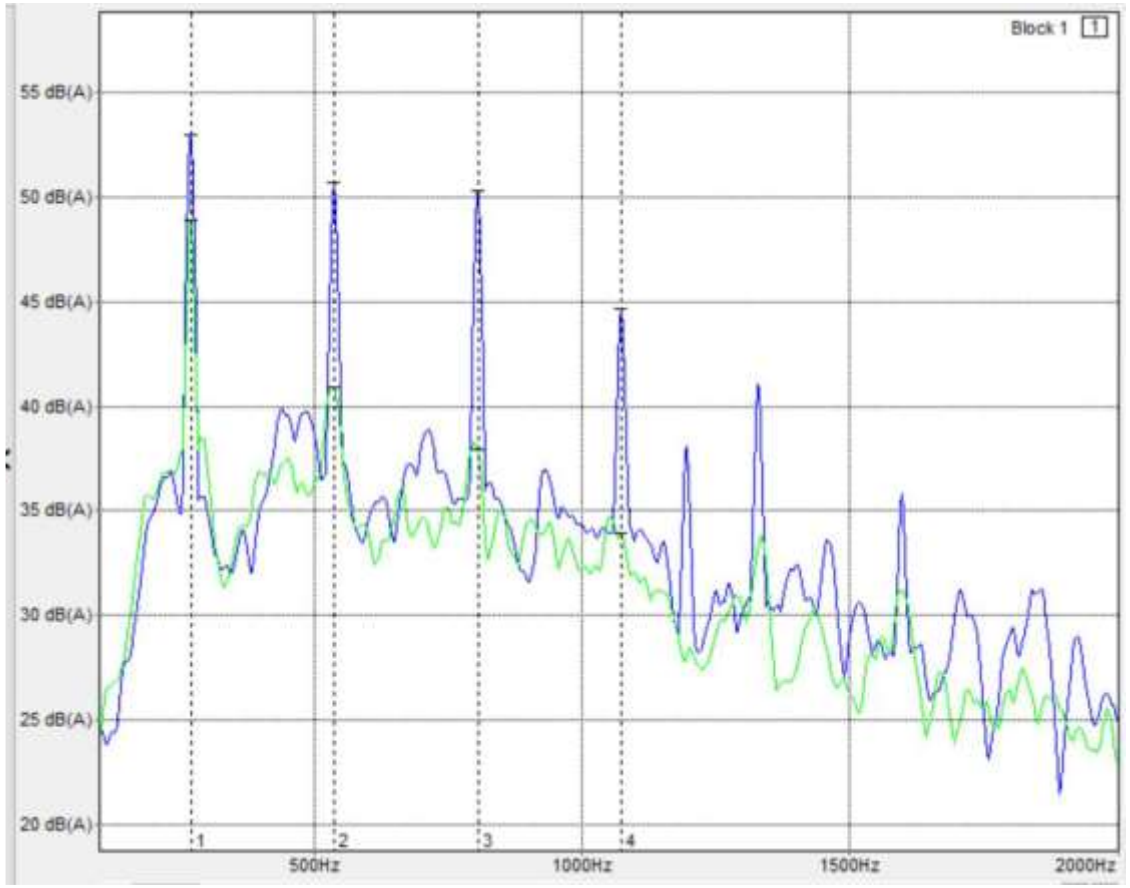
EDR MEDESO

Noise reduction

Baseline

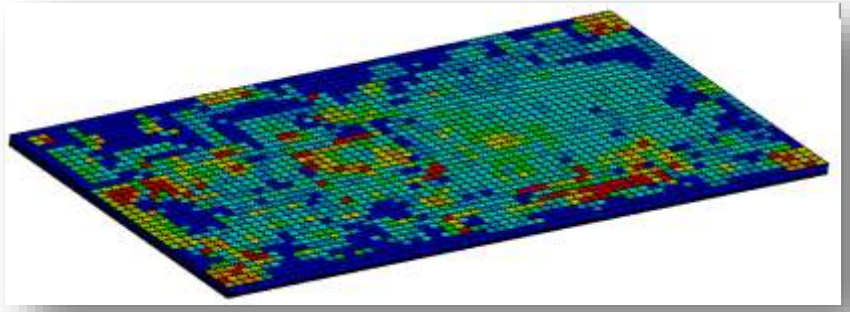
Optimized



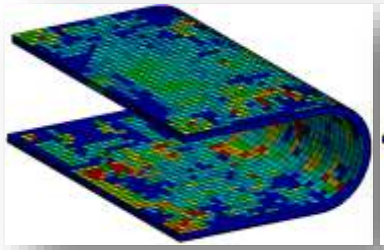


Flex/RigidFlex PCB

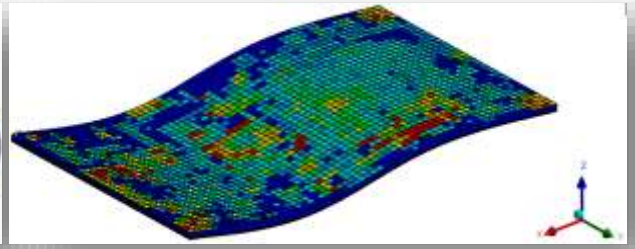
- Flex/RigidFlex PCB FEA model (shell, 3d, trace mapping) can be updated onto the **installation shape** and then used for subsequent structural analysis
- Full 3d models and layered shells are supported
- Trace mapping is properly updated



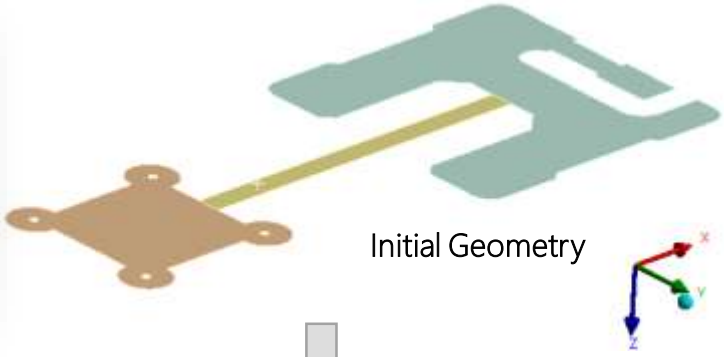
RBF Morph



Wrap Geometry

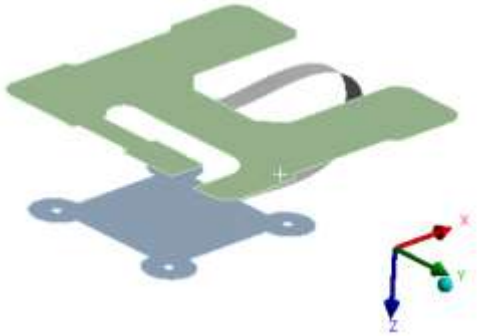


Wavy Geometry



Initial Geometry

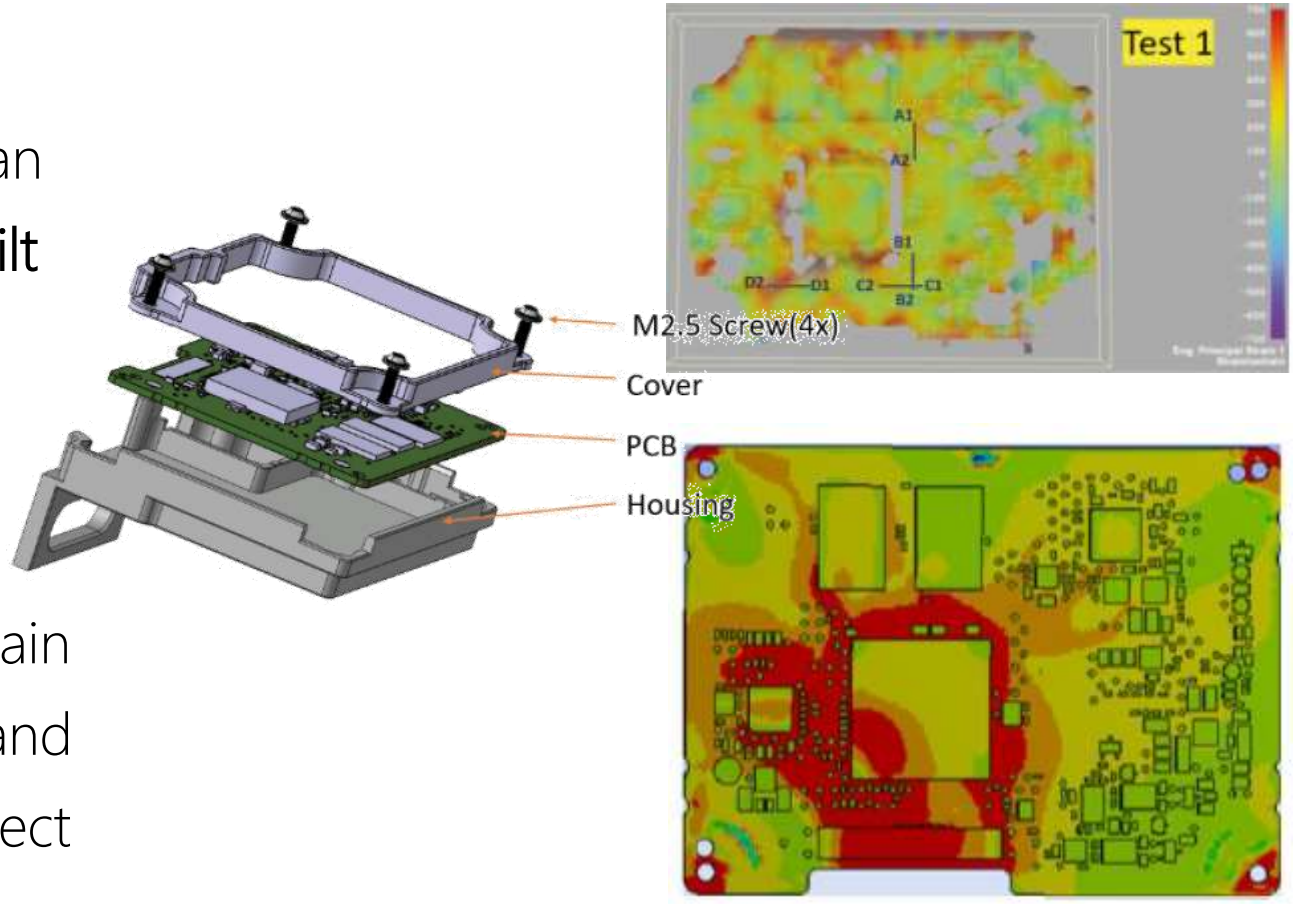
RBF Morph



Target Geometry

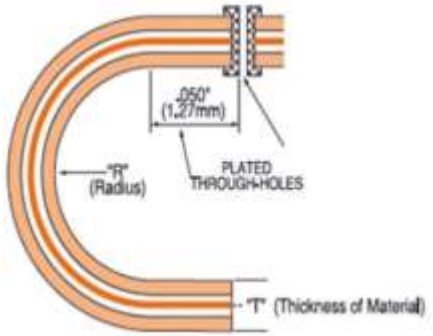
Flat PCB with planarity deviations

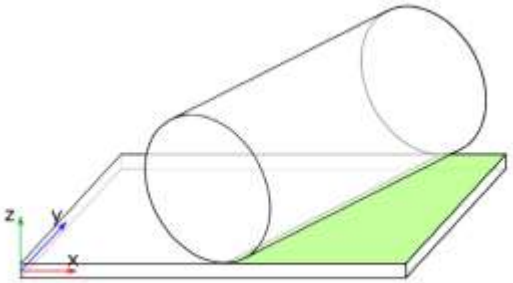
- Flat PCB with planarity deviations can be morphed to represent the **as built** shape and then mounted in the housing to assess the shape error induced loads
- Once the screws are tightened a strain (and stress) distribution is induced and predicted by FEA thanks to the correct representation of acquired board shape

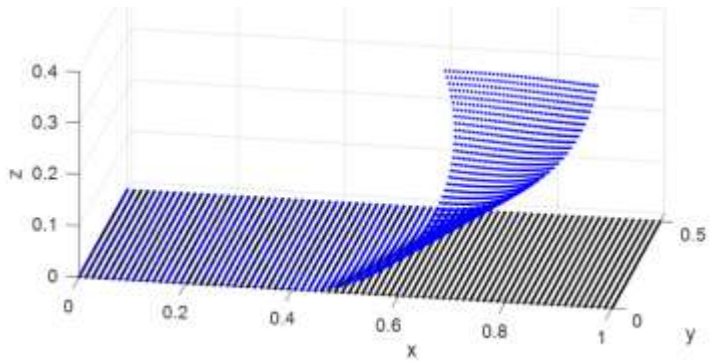


Fast evaluation of low-cycle fatigue

- Fast evaluation of **low-cycle fatigue** (plasticity included) of prescribed radius FCB bend
- A full 3d model with all the layers is controlled by CAD
- The evolution is imported in MAPDL to accurately evaluate the stress-strain cycles in the material



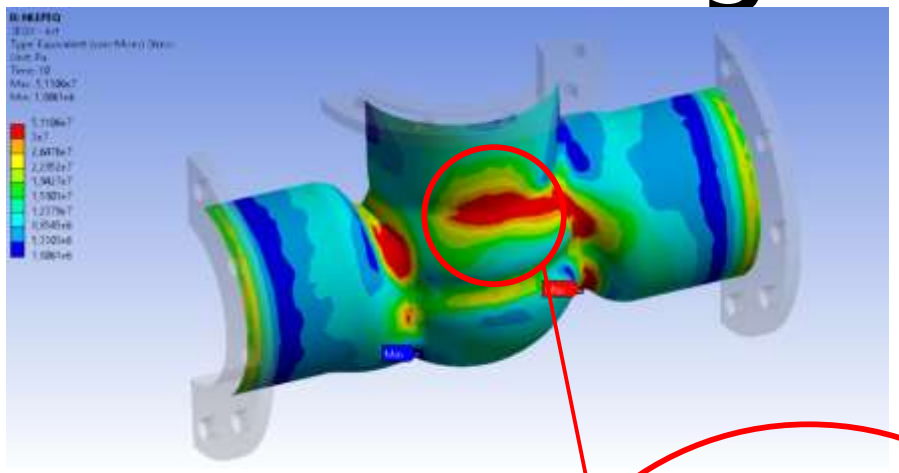




An RBF Meshless Approach to Evaluate Strain Due to Large Displacements in Flexible Printed Circuit Boards

Oil & Gas

Thermal fatigue of a valve



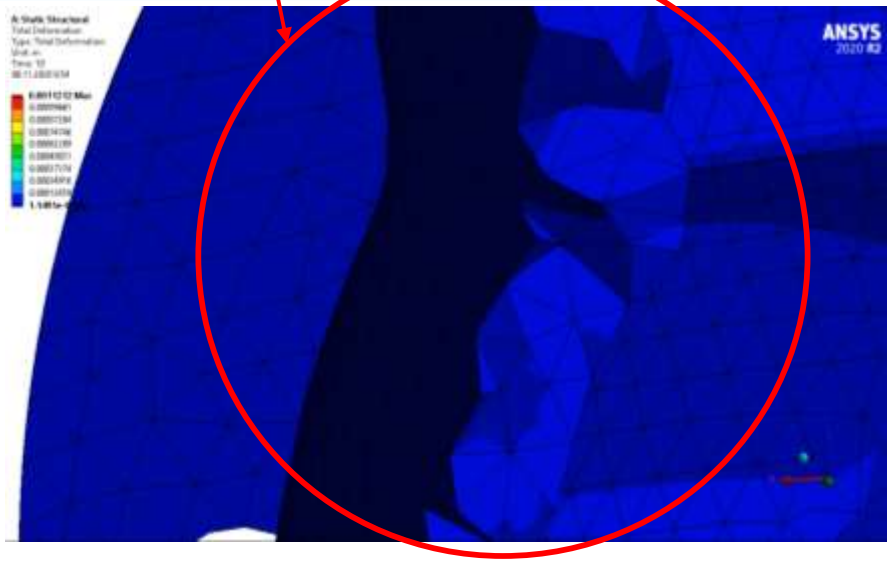
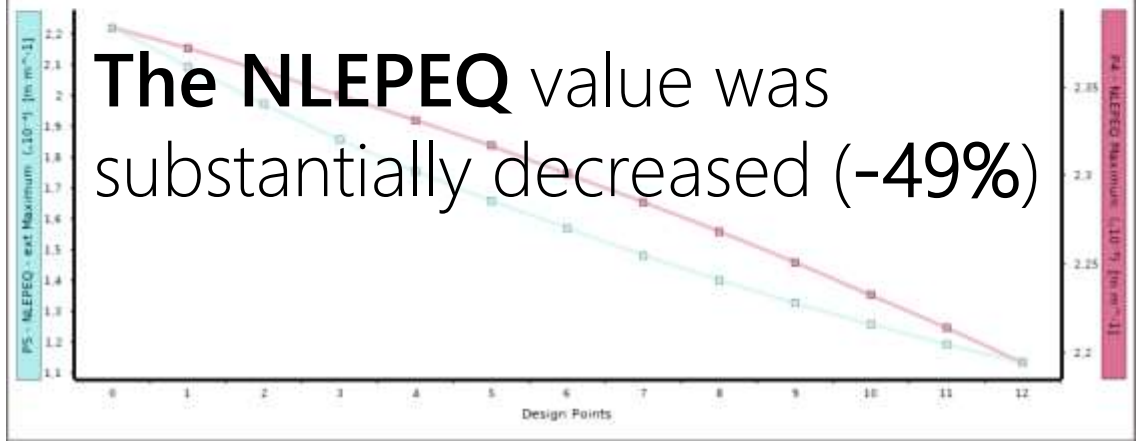


Table of Design Points

	A	B	C	D	E	F	G	H	I	I
1	Name	Update Order	P1 - RBF Morph Set Up Shape ID	P2 - SEQV Maximum	P3 - SEQV - ext Maximum	P4 - NLEPEQ Maximum	P5 - NLEPEQ - ext Maximum	Ret...	Retained Data	Note
2	Units			Pa	Pa	m m^-1	m m^-1			
3	DP 0 (Current)	1	0	1,5402E+08	5,363E+07	0,0023835	0,00022191	✓	✓	
4	DP 1	2	1	1,542SE+08	5,356E+07	0,0023718	0,00020926	✓	✓	
5	DP 2	3	2	1,5325E+08	5,2605E+07	0,0023588	0,00019708	✓	✓	
6	DP 3	4	3	1,5285E+08	5,25E+07	0,0023452	0,00018557	✓	✓	
7	DP 4	5	4	1,5243E+08	5,2377E+07	0,0023311	0,00017529	✓	✓	
8	DP 5	6	5	1,5266E+08	5,2267E+07	0,0023166	0,00016586	✓	✓	
9	DP 6	7	6	1,5293E+08	5,2144E+07	0,0023008	0,00015691	✓	✓	
10	DP 7	8	7	1,5322E+08	5,2022E+07	0,0022849	0,00014824	✓	✓	
11	DP 8	9	8	1,535E+08	5,1888E+07	0,0022683	0,00014026	✓	✓	
12	DP 9	10	9	1,5378E+08	5,1748E+07	0,0022509	0,00013278	✓	✓	
13	DP 10	11	10	1,5407E+08	5,1598E+07	0,0022324	0,00012589	✓	✓	
14	DP 11	12	11	1,5435E+08	5,1443E+07	0,0022139	0,00011936	✓	✓	
15	DP 12	13	12	1,5463E+08	5,1265E+07	0,0021941	0,00011347	✓	✓	
*								☐		

Parameter Chart 0

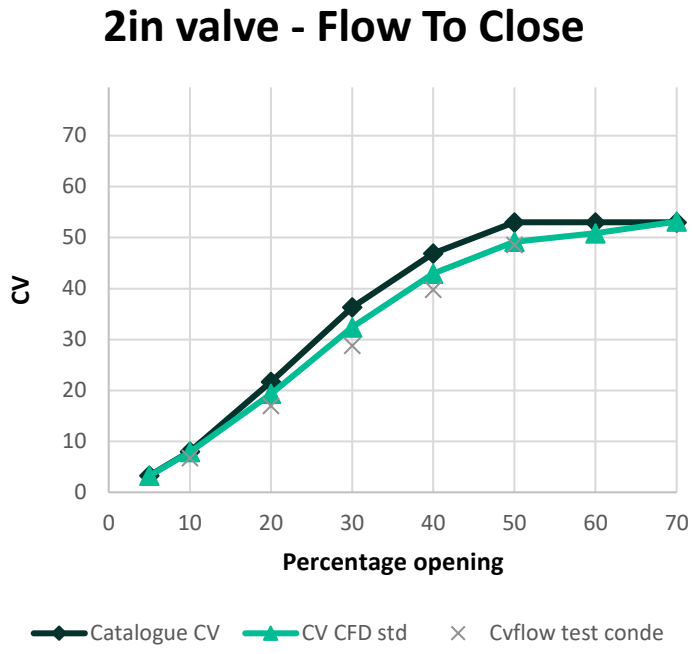


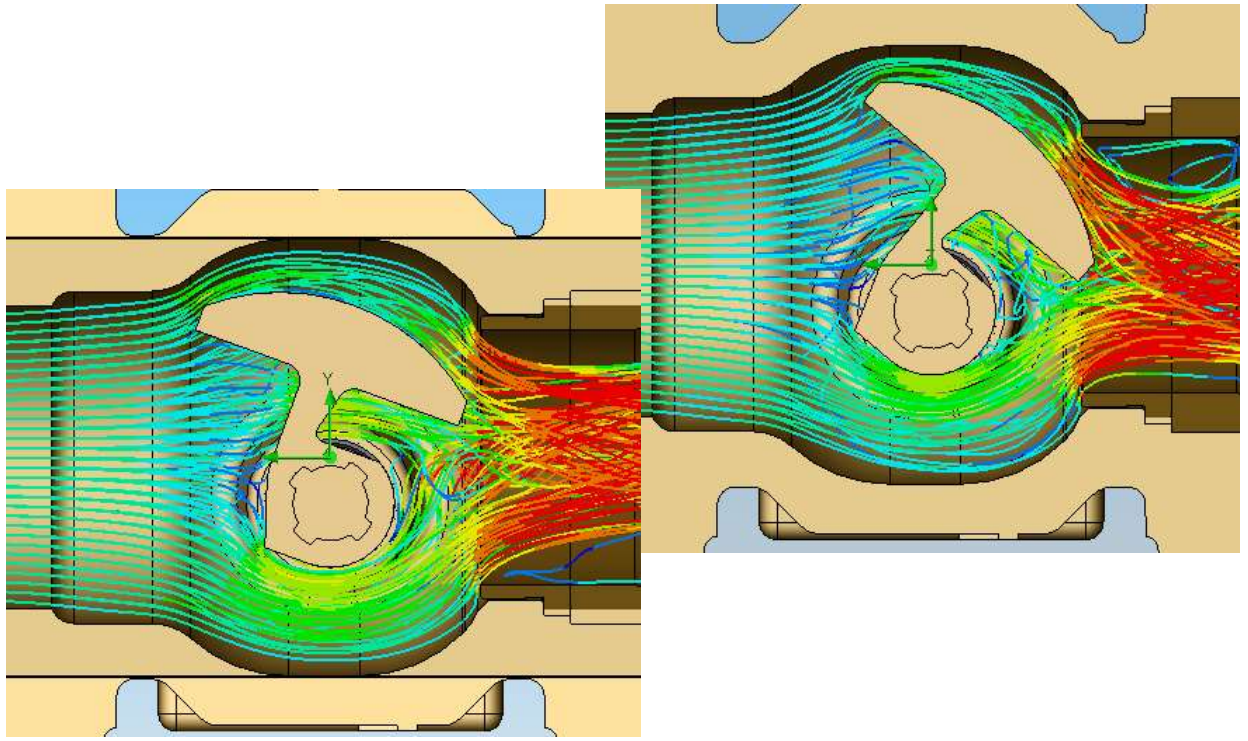
The NLEPEQ value was substantially decreased (**-49%**)

https://www.rbf-morph.com/wp-content/uploads/2020/12/CAE2020Aparameterlessshapeoptimizationprocessallowstoextendfatiguelifeof-structuralpartssubjectedtothermalfatigue.pdf

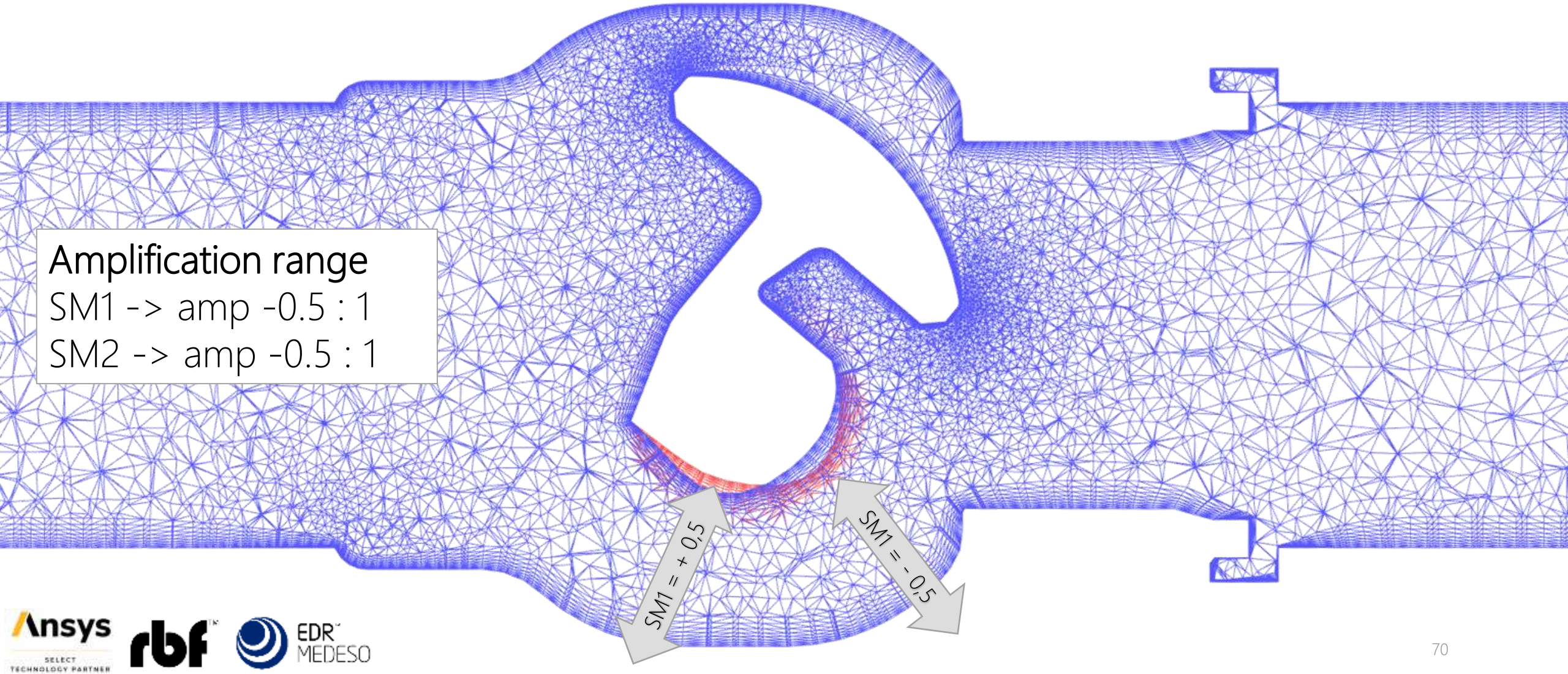
Problem

- The main object is the linearization of the Valve Coefficient with the opening angle

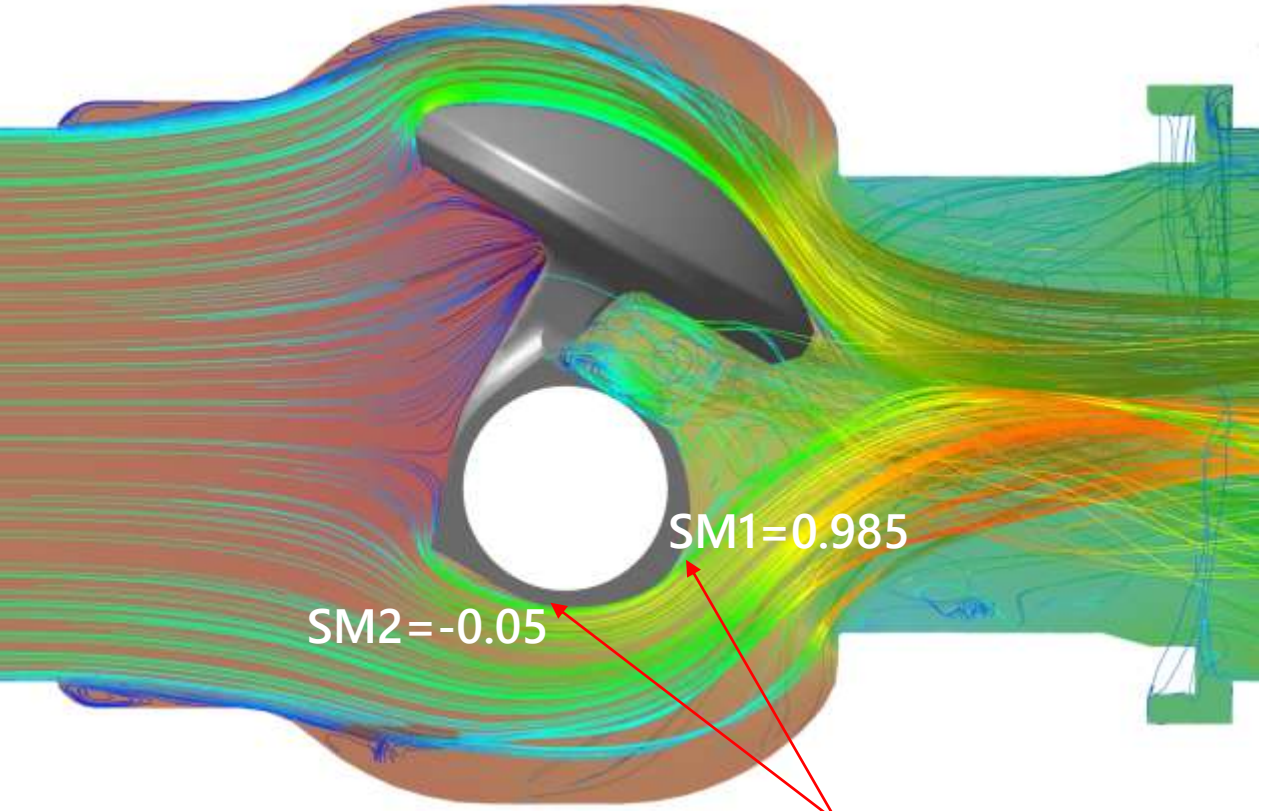




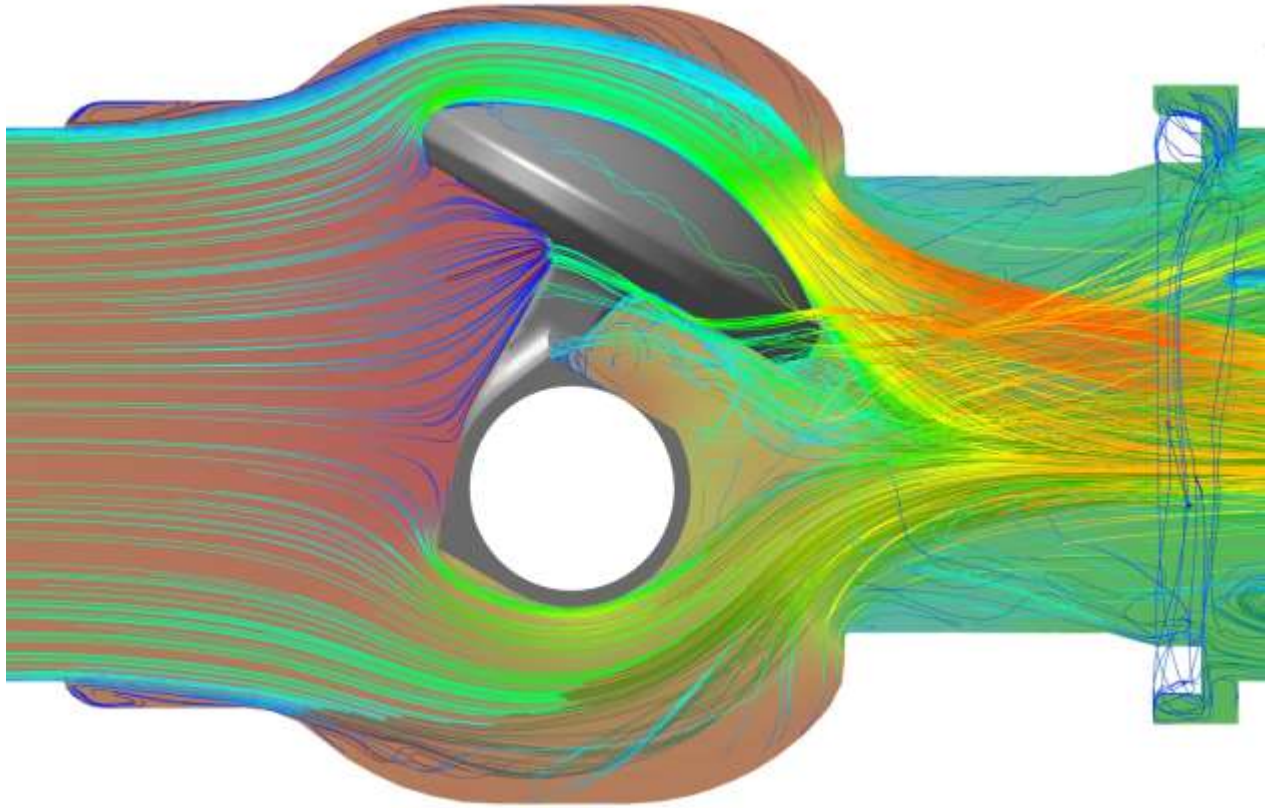
Example of morphing action



Solution of the optimization orchestrated by optiSLang

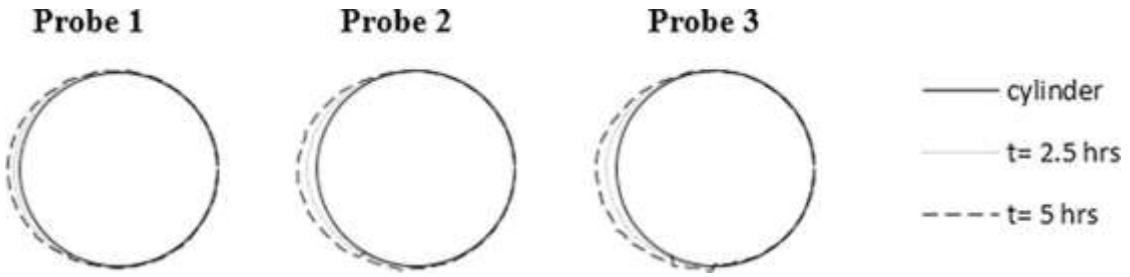


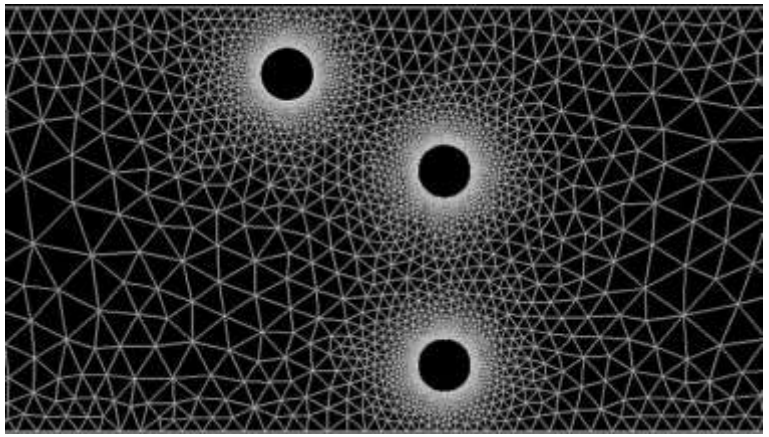
Optimized cam cross section

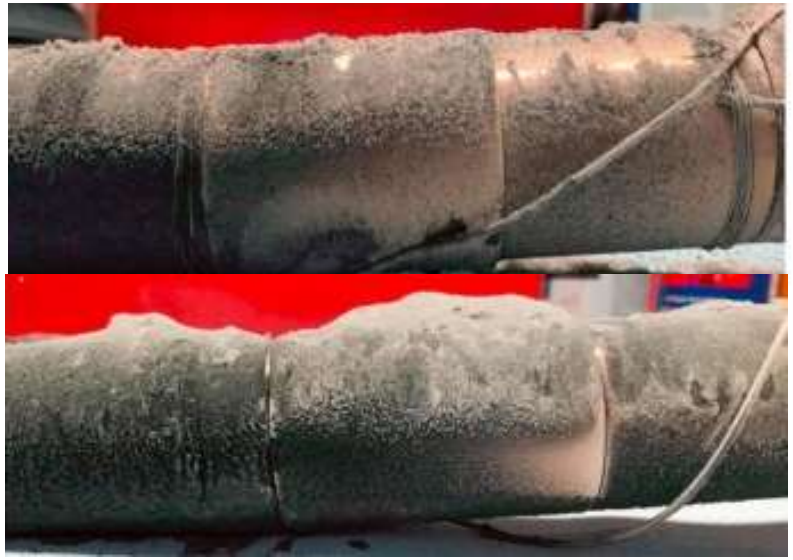


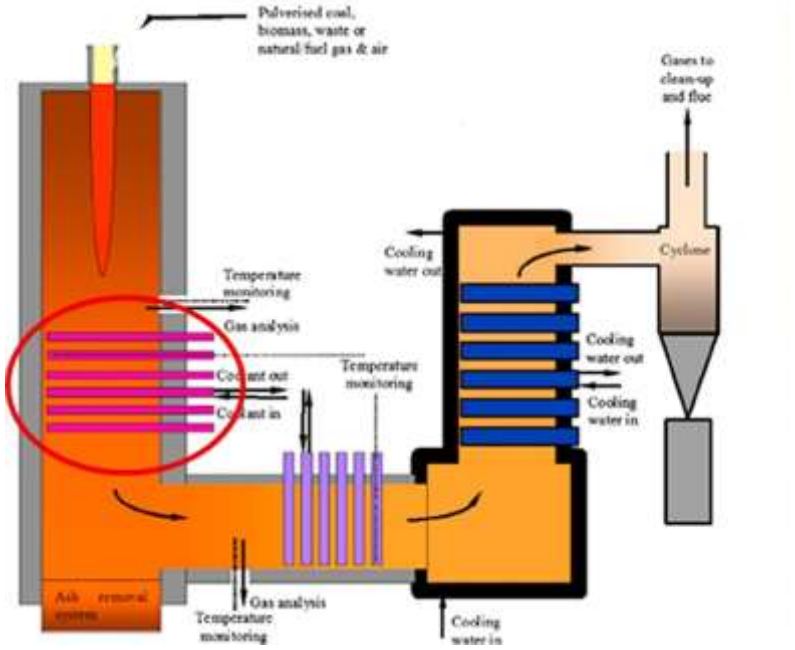
Original cam surface

Fouling of pipes in a pulverized fuel-fired combustor

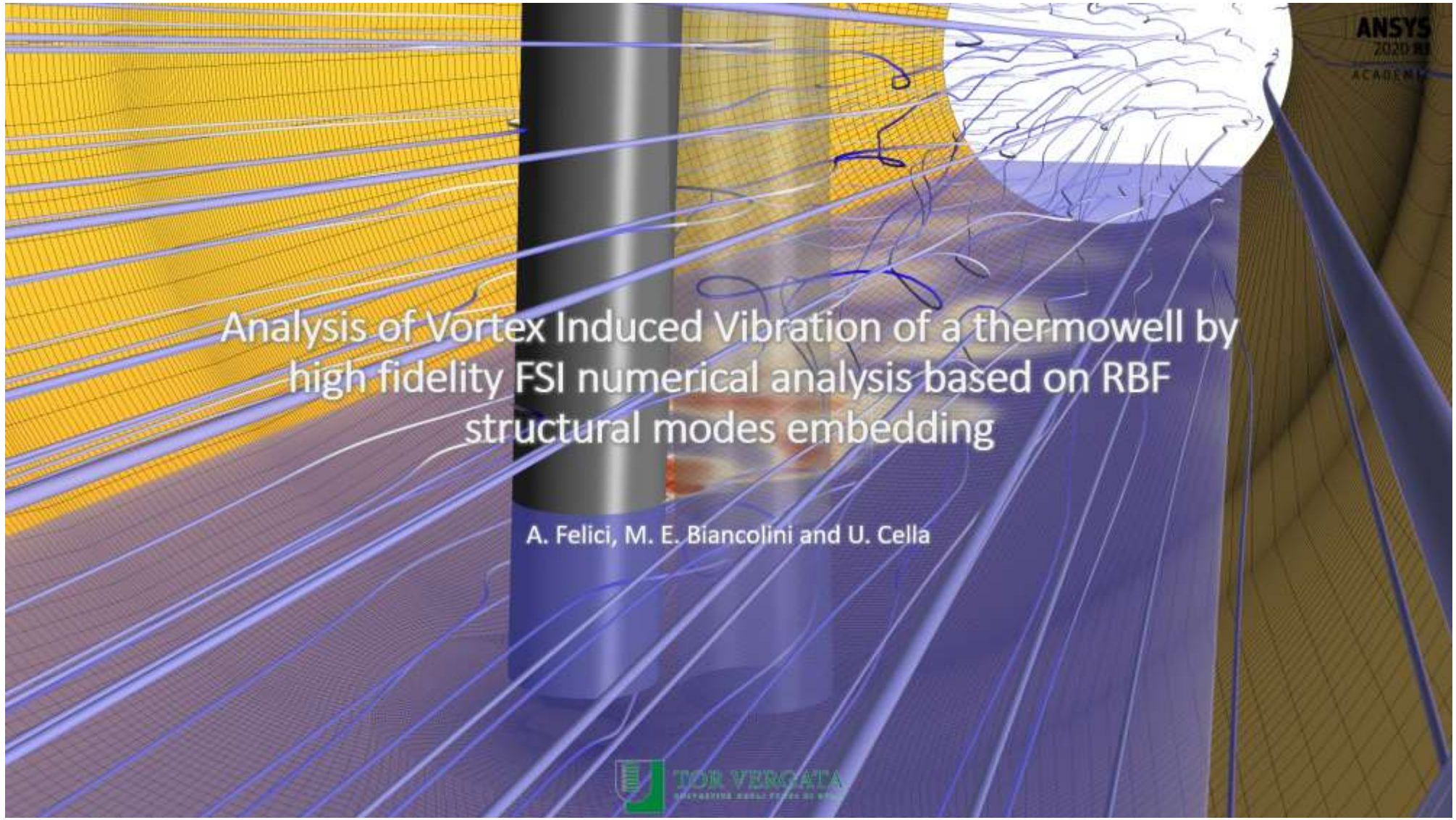








https://youtu.be/At4LpQhk4OM



Conclusions

- Advanced **mesh morphing** with RBF Morph has been demonstrated for Structural and Fluids applications
- Shape optimization, **parameter based or parameter free**, is available within Mechanical (MAPDL, LS-DYNA) and Fluent
- Snapshots for **reduced order models** and digital twin definition can be easily generated using as input shape parameters
- Mesh morphing can also be used for **morphing onto a prescribed target** (a new CAD variation, the actual manufactured shape captured by 3d scan)
- To learn more about the technology and how it can help your design visit our website
  - www.rbf-morph.com

Additional Resources

Additional Resources

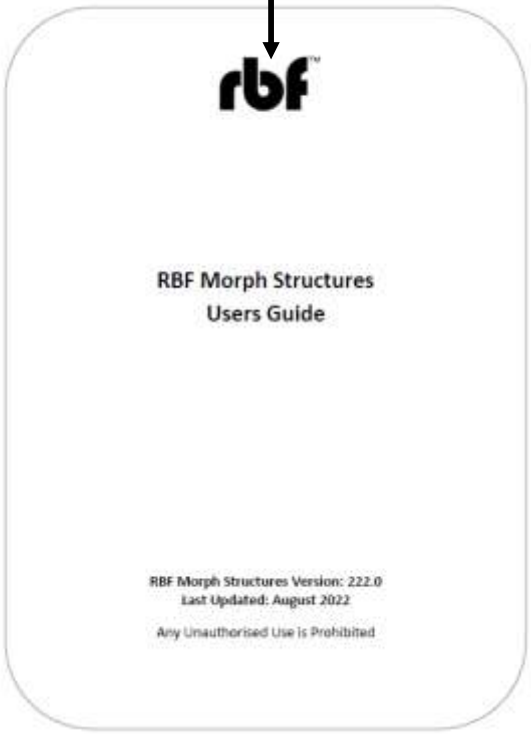
- In addition to the examples in this presentation, RBF Morph has comprehensive User Guide and extensive set of tutorials included in the download packages

Tutorials-V222.0

RBF-Morph-Structures-Release-Notes-V222.0.pdf

RBF-Morph-Structures-Tutorials-Guide-V222.0.pdf

RBF-Morph-Structures-Users-Guide-V222.0.pdf



Tutorial-01-conrod-V222.0.zip

Tutorial-02-optimization-automation-V212.0.zip

Tutorial-03-T-beam-V222.0.zip

Tutorial-04-bracket-V212.0.zip

Tutorial-05-CAD-projection-V212.0.zip

Tutorial-06-tapered-plate-V212.0.zip

Tutorial-07-BGM-V222.0.zip

Tutorial-08-ADPLSolve-V222.0.zip

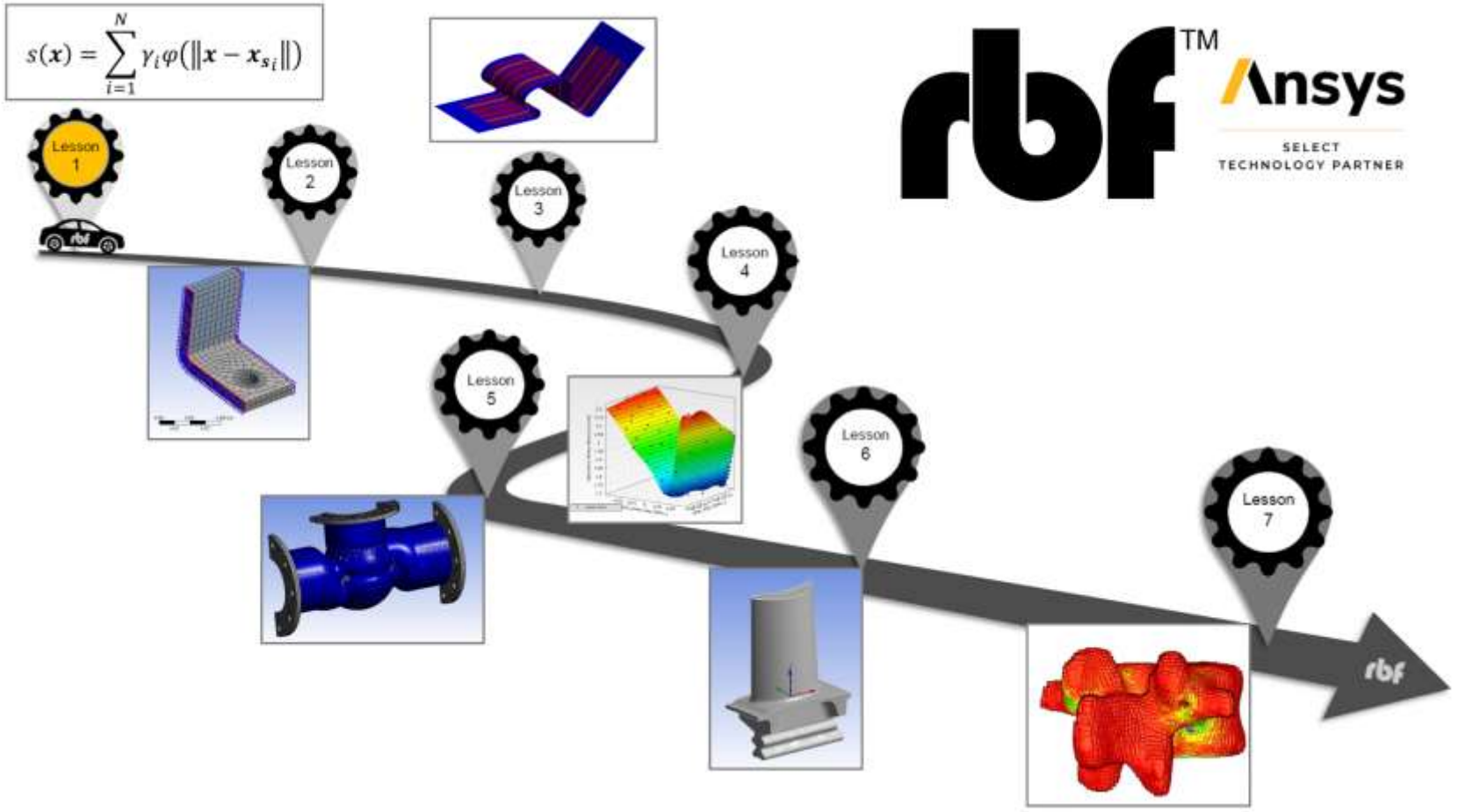
Tutorial-09-BGM-valve-optimization-V212.0.zip

Tutorial-10-APDL-BGM-V212.0.zip

Tutorial-11-Static-ROM-V221.0.zip

Additional Resources

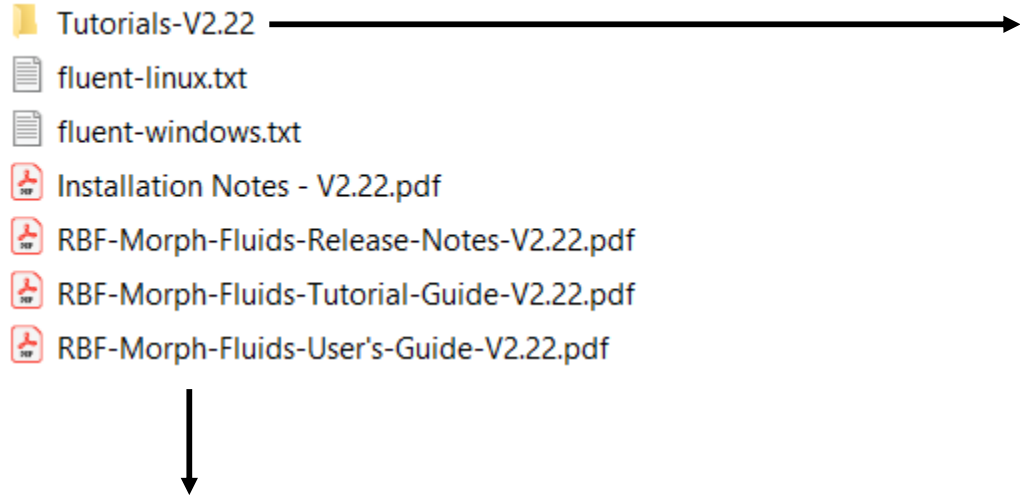
- Ansys Learning Hub: **Ansys RBF Morph Structures Getting Started (Self-paced Learning Available)**
- https://www.ansys.com/training-center/course-catalog/structures/ansys-rbf-morph-structures-getting-started

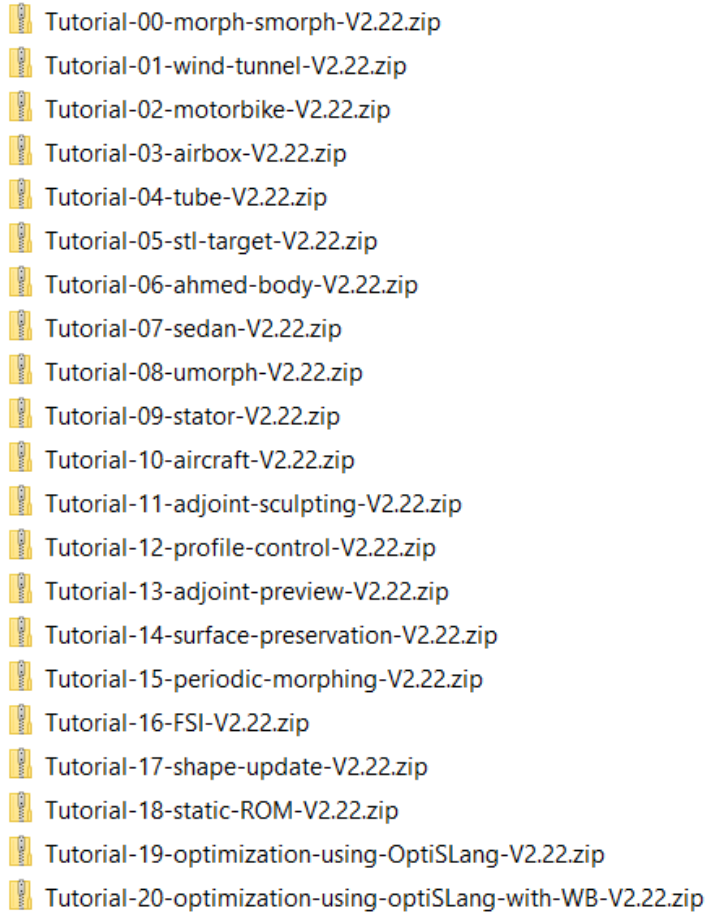


Ansys SELECT TECHNOLOGY PARTNER rbf™ EDR MEDESO

Additional Resources

- In addition to the examples in this presentation, RBF Morph has comprehensive User Guide and extensive set of tutorials included in the download packages (ALH coming soon!)





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