Ansys part of Synopsys TRANSPORTATION SUMMIT 2025 and International LS-DYNA User Conference

Interactive Real-Time Design Exploration in VR Using RBF Morph and Twin Builder

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Agenda

- About us – past and running projects
- Radial Basis Functions – Data Science and Geometrical Intelligence
- Parameter-based and parameter-free shape optimization
- Interactive Real-Time Design Exploration
- Case Studies
- Conclusions

EU-funded research projects 2013-2025

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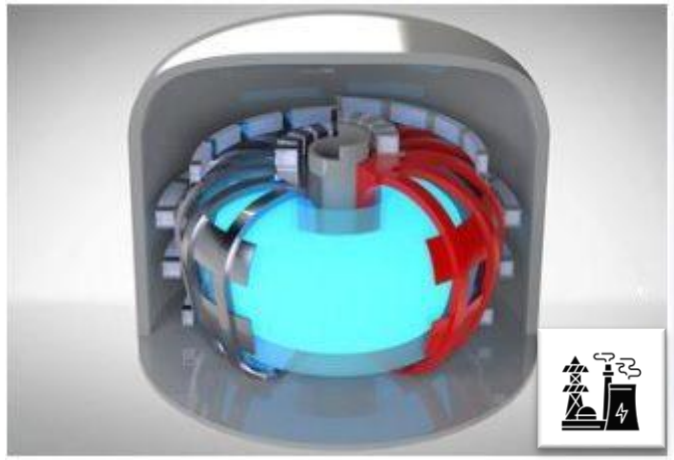
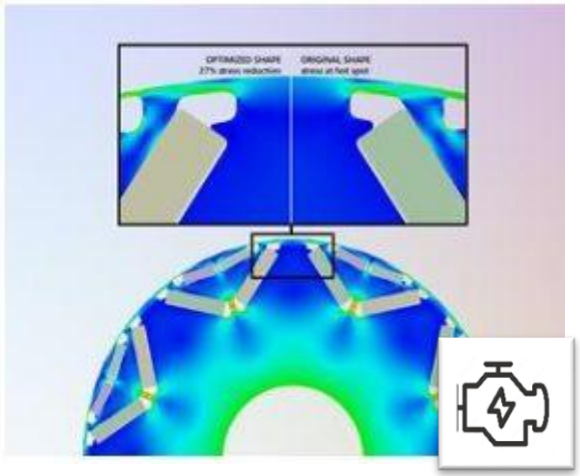
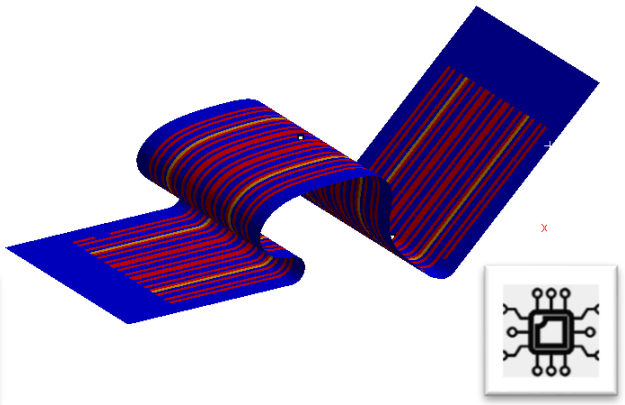
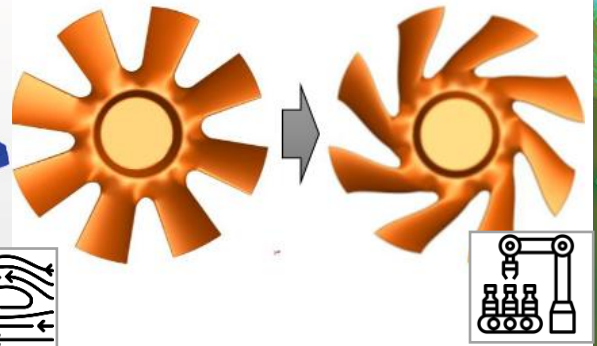
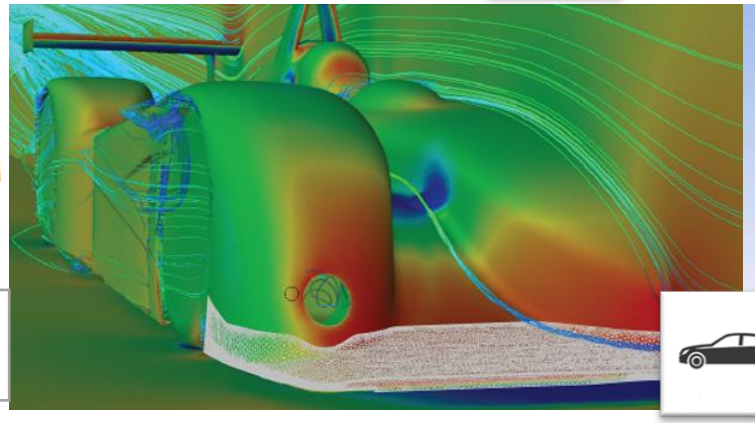
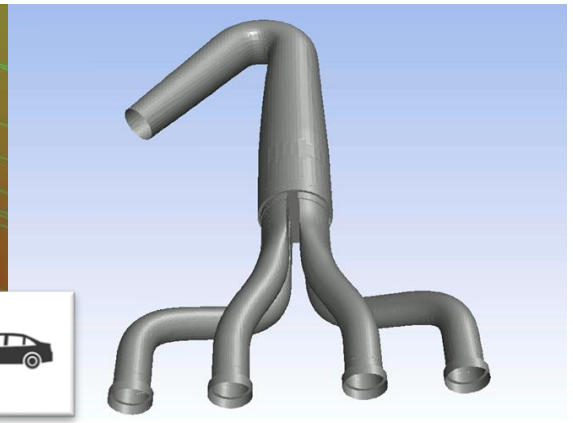








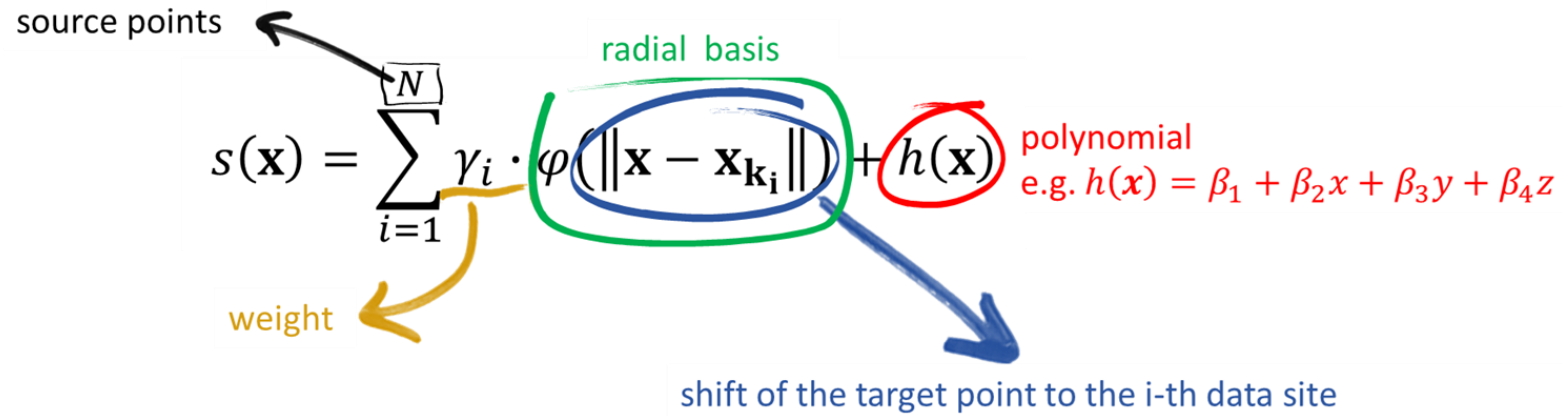




Radial Basis Functions

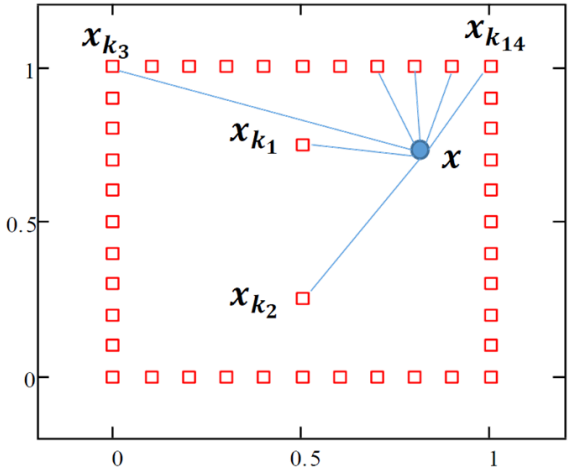
Data Science and Geometrical Intelligence

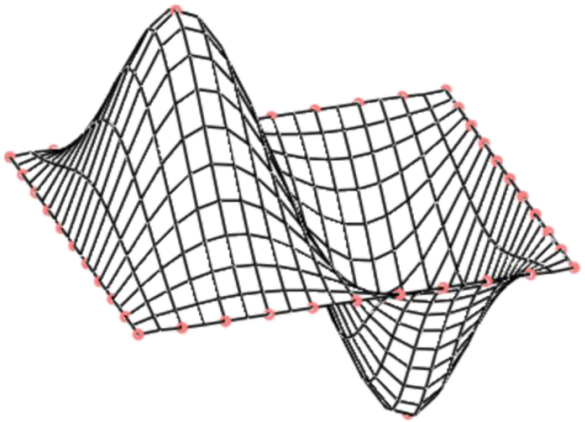
Radial Basis Functions (RBF) in a nutshell



RBF	φ(r)
Spline type (Rn)	r^n, *n odd*
Thin plate spline	$r^n \log(r)$ *n even*
Multiquadratic (MQ)	$\sqrt{1+r^2}$

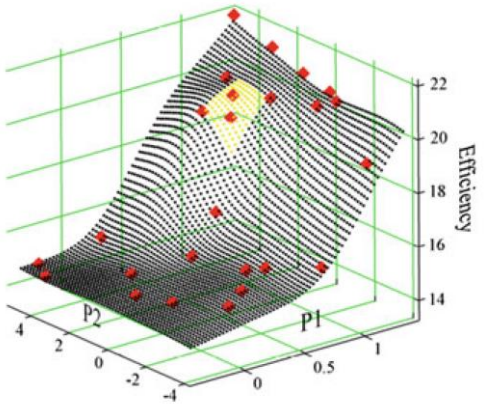
RBF are a very powerful mathematical tool able to interpolate **everywhere** in the $\mathbb{R}^n$ space a function given at scattered **source points**

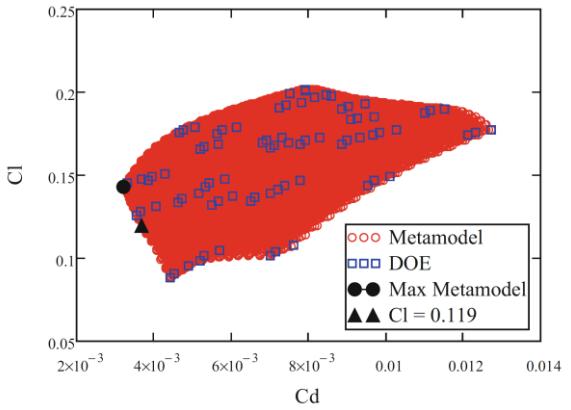




Interpolators in multi-dimensional spaces

- **Data science** problems
  - **Inference** $\mathbb{R}^n \Rightarrow \mathbb{R}^m$
  - Gaussian RBF is recognized as the "RBF neural network"
  - Useful for **surrogates** in **optimization**
- 3D space manipulation (shape deformation, data mapping)
  - Field manipulation is a key enabler for **geometric intelligence**
  - RBF mapping for multi-physics interfaces and as a "morphing extender"



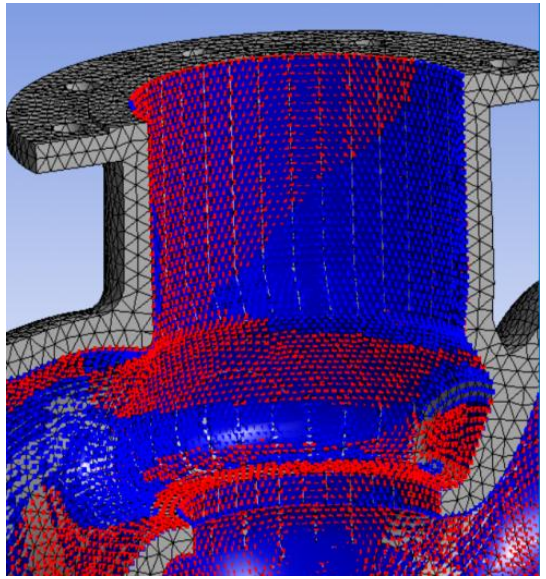


Shape optimization

Parameter-based and parameter-free workflows

RBF Mesh Morphing

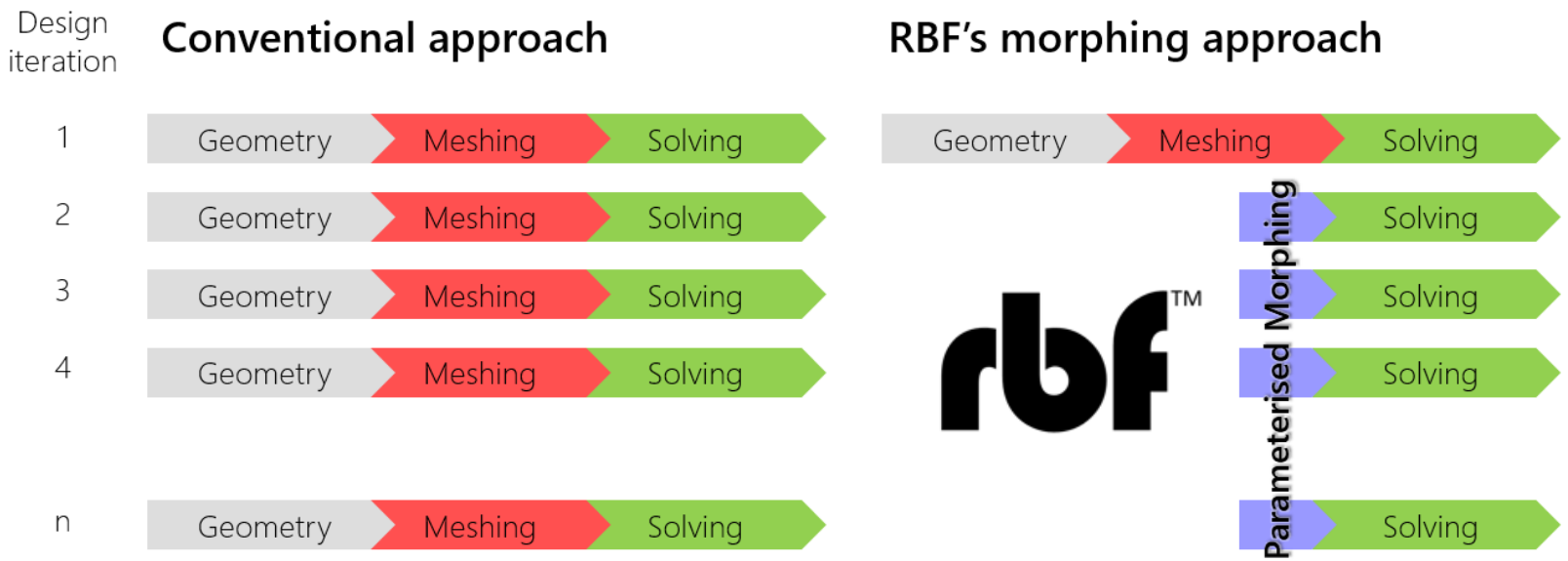
- We adopt **Radial Basis Functions** (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements
  - Surface shape changes
  - Volume mesh smoothing
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing



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

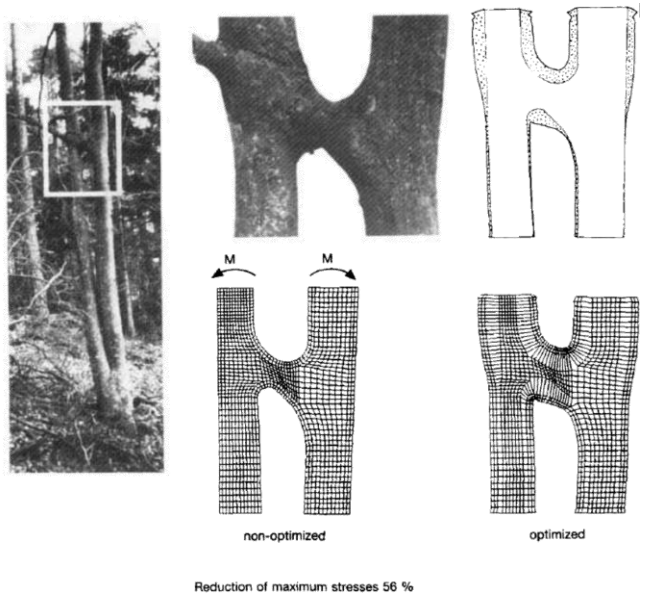
Parameter-based shape optimization

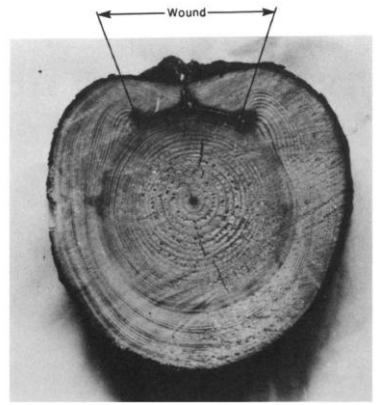
- Morphing is a **key enabler** for optimization and Digital Twins
- The turnaround time of the optimization is usually **reduced by a factor five** (weeks becomes days)

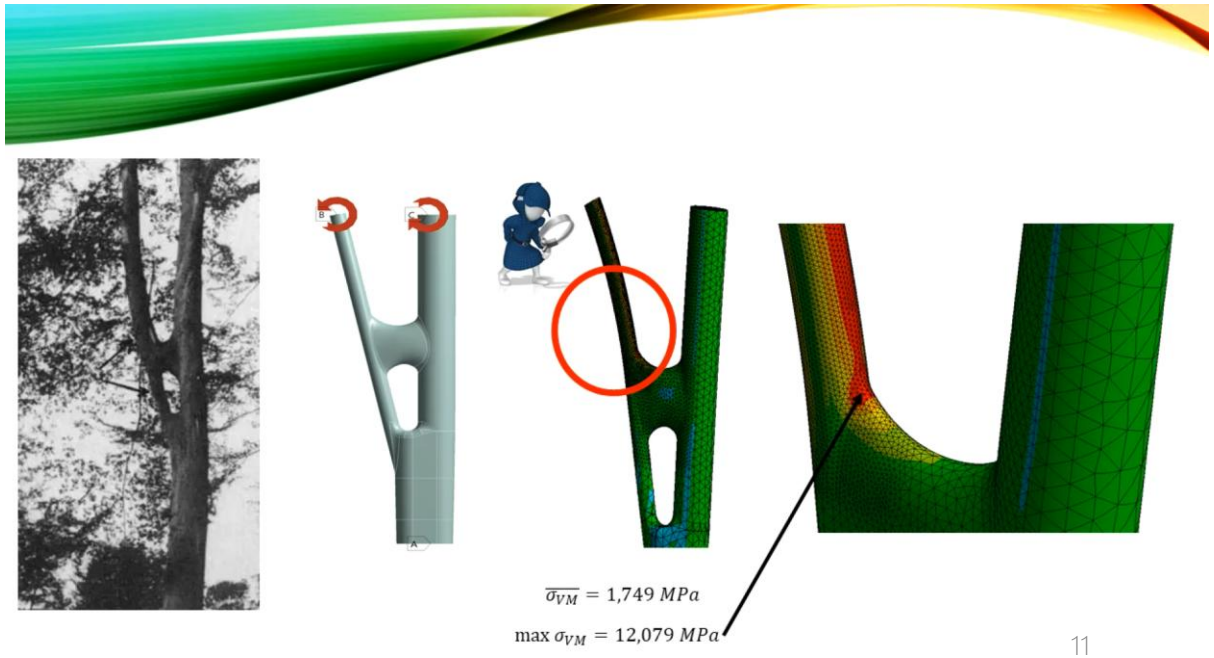


BGM Background

- BGM approach is based on the observation that biological structures growth is driven by local level of stress.
- Bones and trees' trunks are able to adapt the shape to mitigate the stress level due to external loads.
- The process is driven by stress value at surfaces. Material can be added or removed according to local values.
- Was proposed by Mattheck & Burkhardt in 1990







Parameter-free shape optimization

- The BGM idea is that surface growth can be expressed as a **linear law** with respect to a given threshold value:

$$\dot{\varepsilon} = k\left(\sigma_{Mises} - \sigma_{ref}\right)$$

- Waldman and Heller refined this first approach proposing a **multi peak** one:

$$d_i^j = \left(\frac{\sigma_i^j - \sigma_i^{th}}{\sigma_i^{th}}\right) \cdot s \cdot c\,, \qquad \sigma_i^{th} = max(\sigma_i^j) \text{ if } \sigma_i^j > 0 \quad \text{or} \quad \sigma_i^{th} = min(\sigma_i^j) \text{ if } \sigma_i^j < 0$$

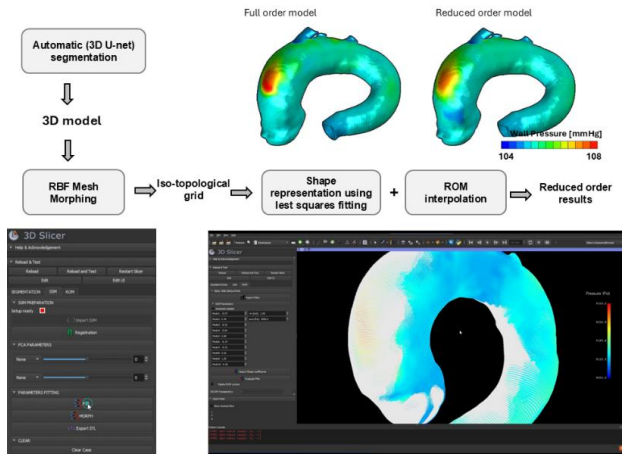
- A different implementation is present and different **stress types** can be used to modify the surface shape:

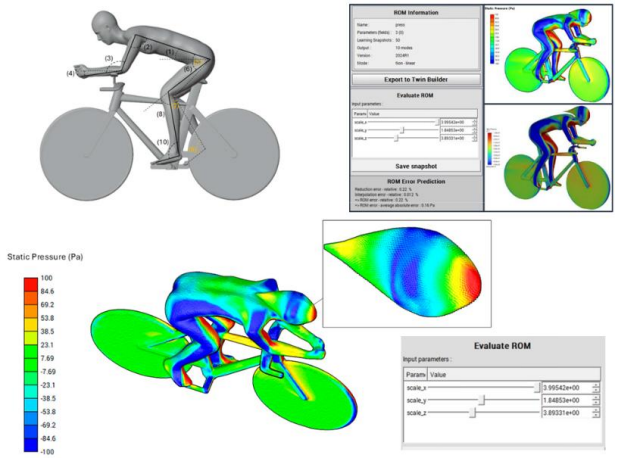
$$S_{node} = \frac{\sigma_{node} - \sigma_{th}}{\sigma_{max} - \sigma_{min}} \cdot d$$

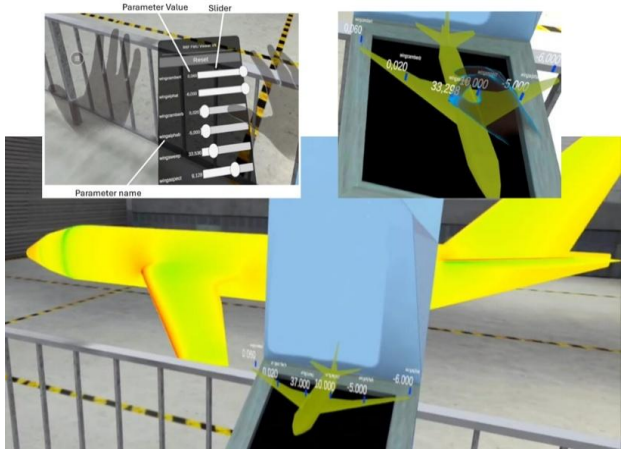
Interactive Real-Time Design Exploration

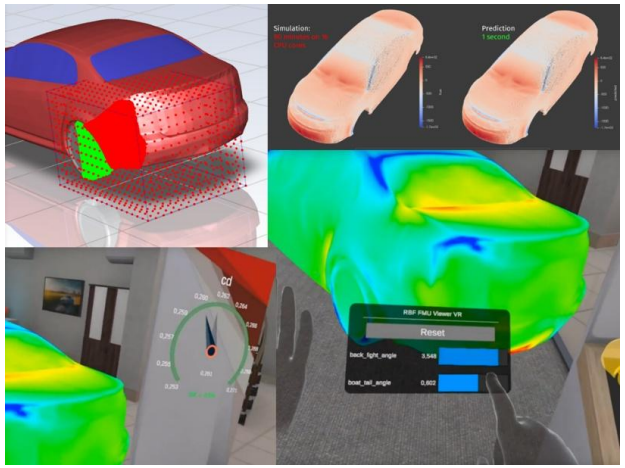
From Advanced Simulation to VR

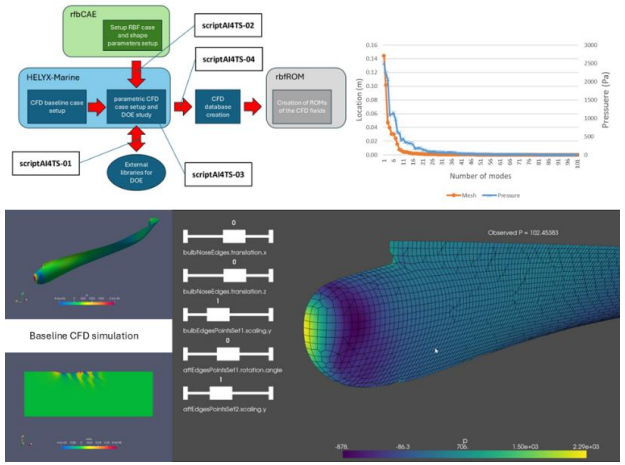
Interactive Real-Time Design Exploration: Applications

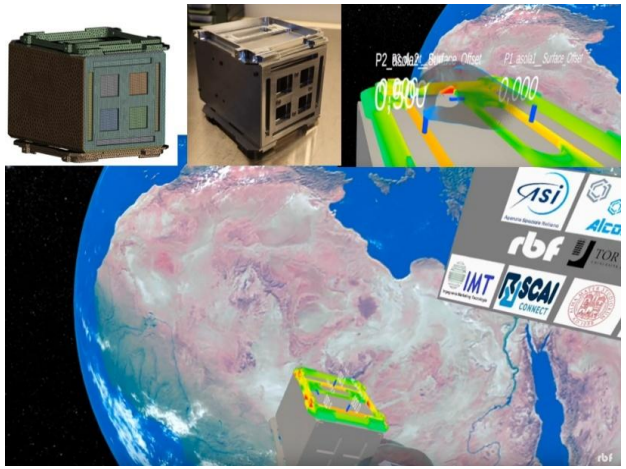












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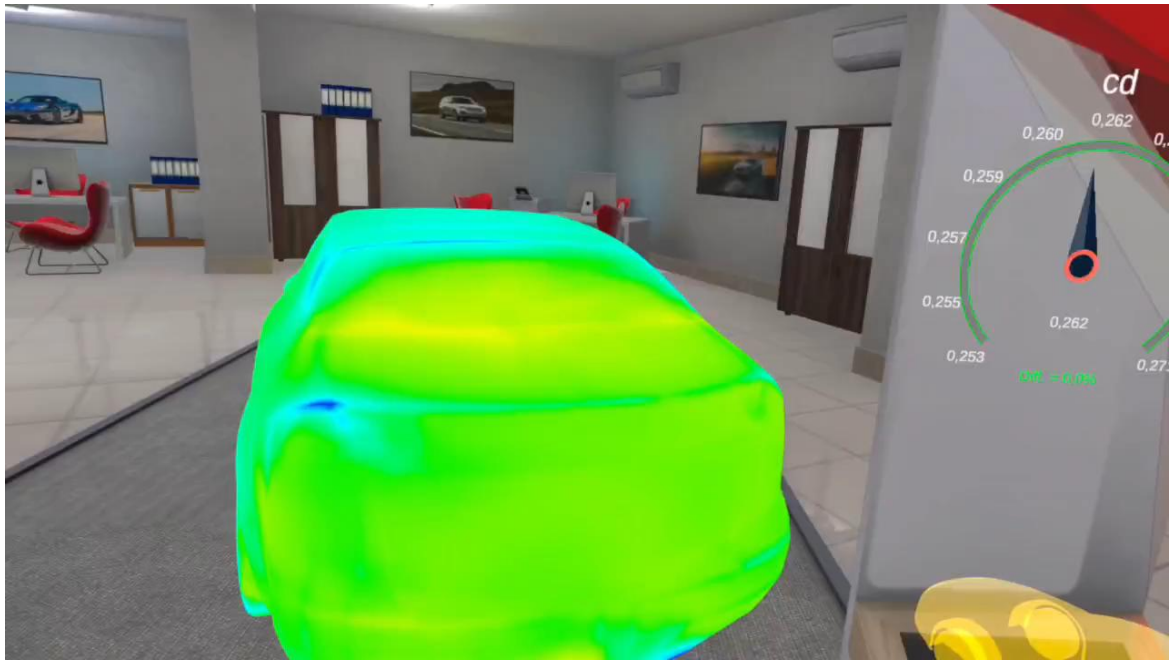
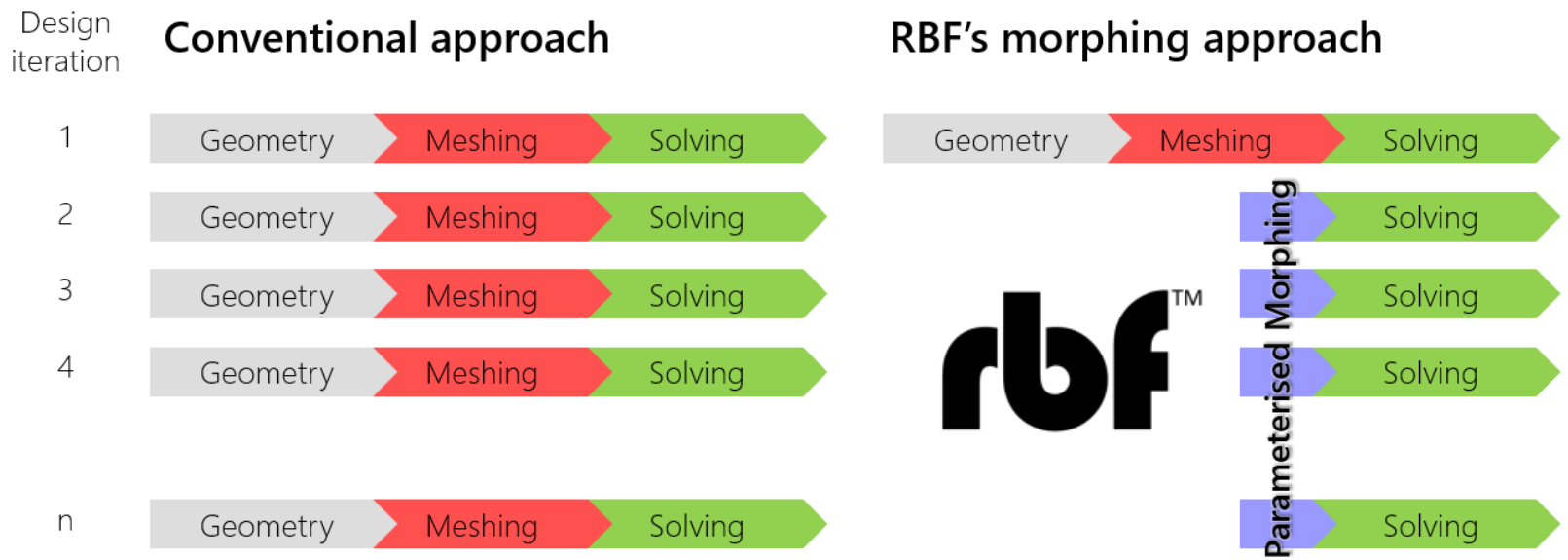
Interactive Digital Twins?

- High-fidelity simulations big data for training AI models:
  - Design stage: steer new projects more effectively
  - Operation stage: **real-time** interactions are key enablers of digital twins
- Challenges:
  - High level of automation required
  - Replicable, easily deployable workflow
- We present a comprehensive solution based on Ansys CAE tools powered by **Unity rendering** and exported to **Meta Quest 3** AR/VR



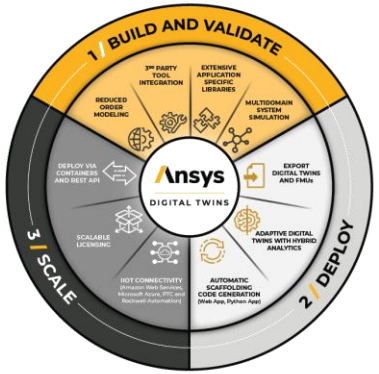
Interactive Digital Twins Challenge #1

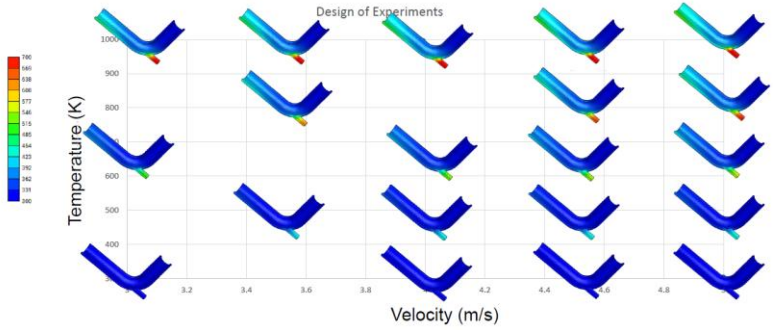
- High level of automation to create snapshots is needed
- Geometrical parameters require mesh topology preservation
- **Ansys RBF Morph** combined with **Ansys CAE solvers**

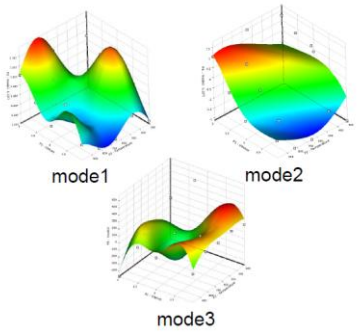


Interactive Digital Twins Challenge #2

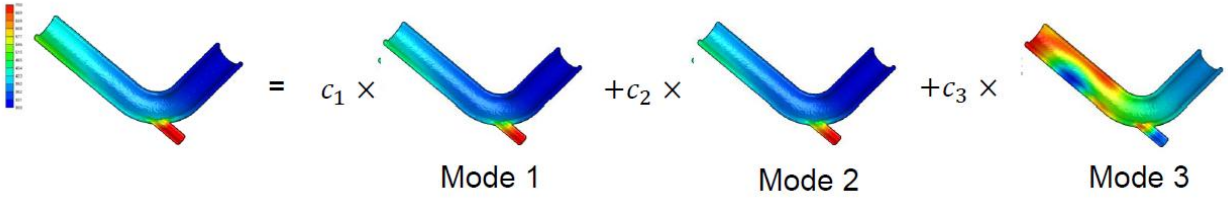
- Replicable, easily deployable workflow?
- **Reduced Order Models** (ROM) are compressed (POD) ready to be inferred (GARS)
- **Ansys Twin Builder**
- Unity rendering
  - Meta Quest 3 AR/VR
  - Apple VisionPro?





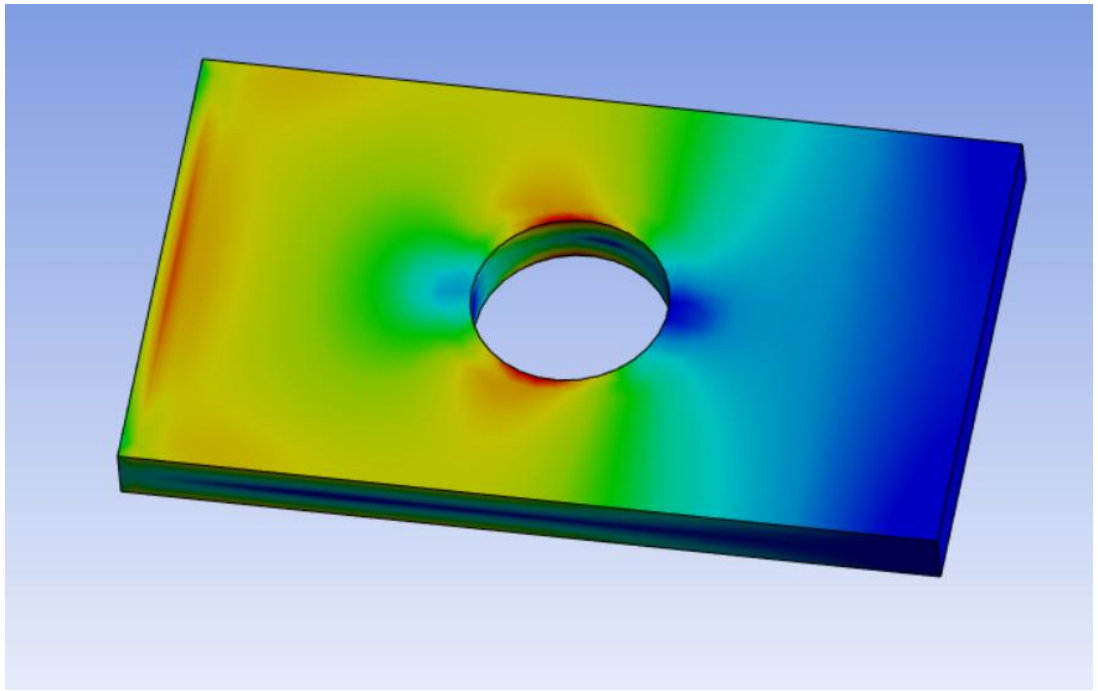


POD+GARS = ROM

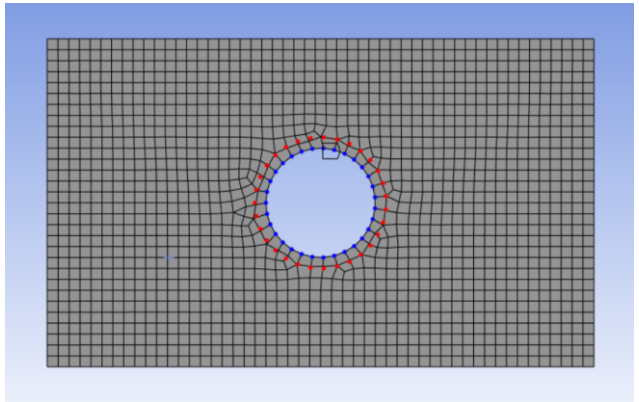


A simple FEA model – ROM - FMU

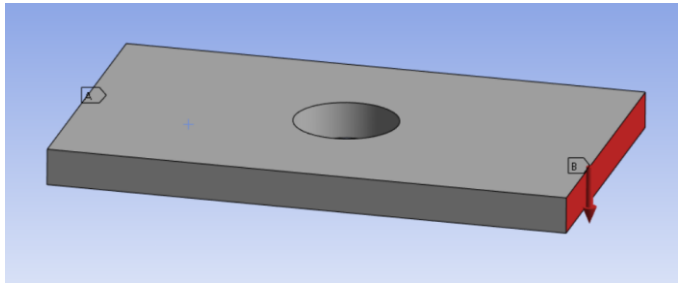
- Solid model created by CAD
- The notch effect is accurately captured by Mechanical
- RBF Morph allows to create **one geometrical parameter** to change the diameter of the hole
- The applied loads is the **physical parameter**
- Snapshots are exported and the FMU created by Twin Builder



Workflow

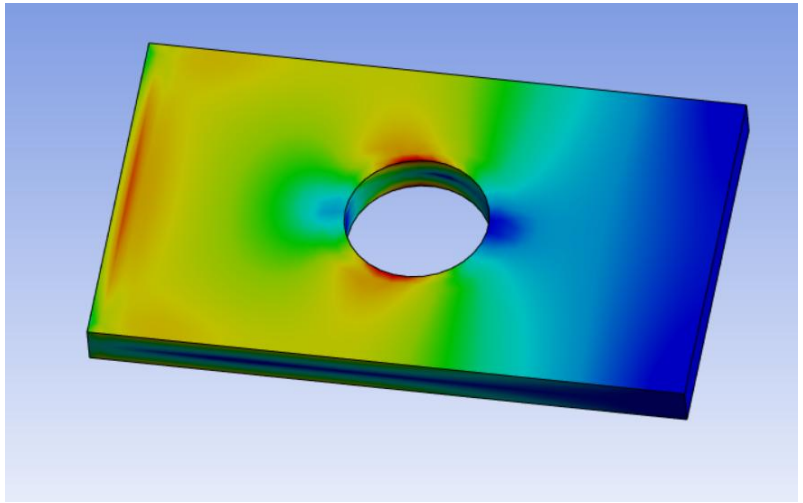


Shape parameter: radius offset

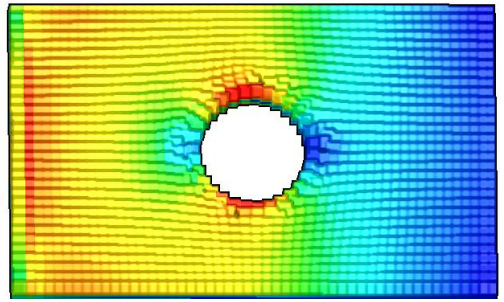


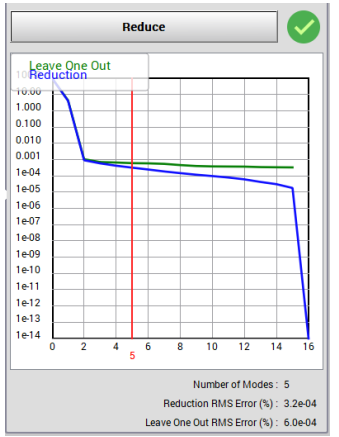
Physical parameter: Force

Step 1: Geometry and mesh → Step 2: Setting → Step 3: Parameters → Step 4: DOE: 30 DPs → Step 5: ROM



von Mises stresses

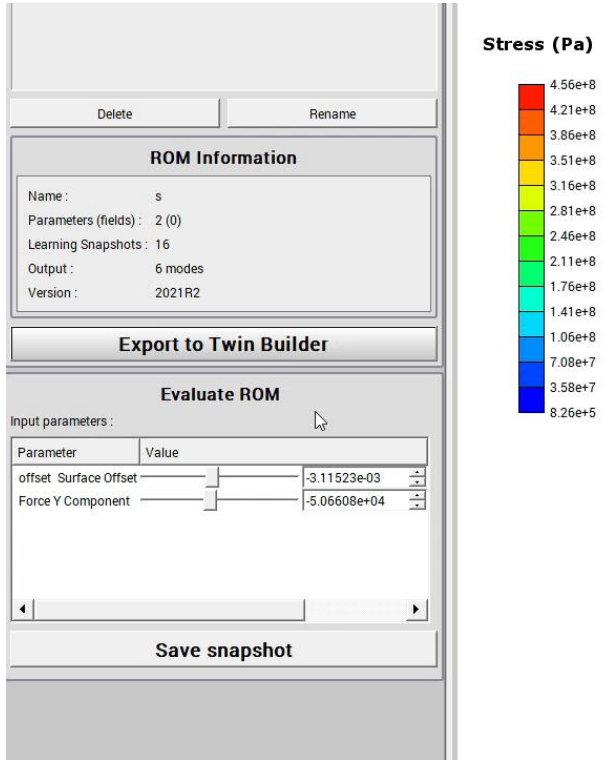


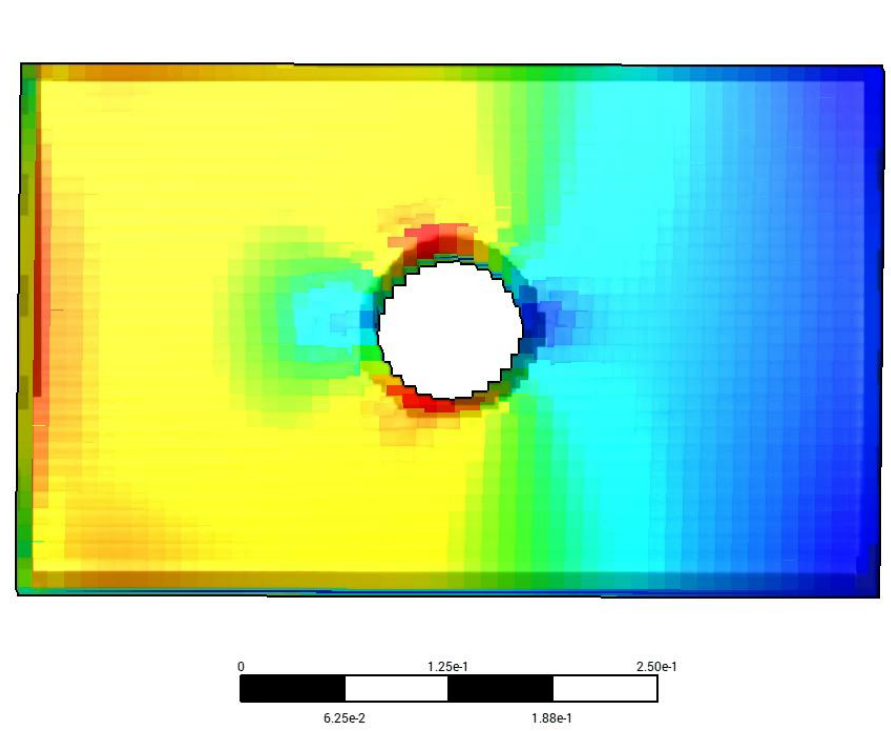


Ansys TB interface

Twin Builder

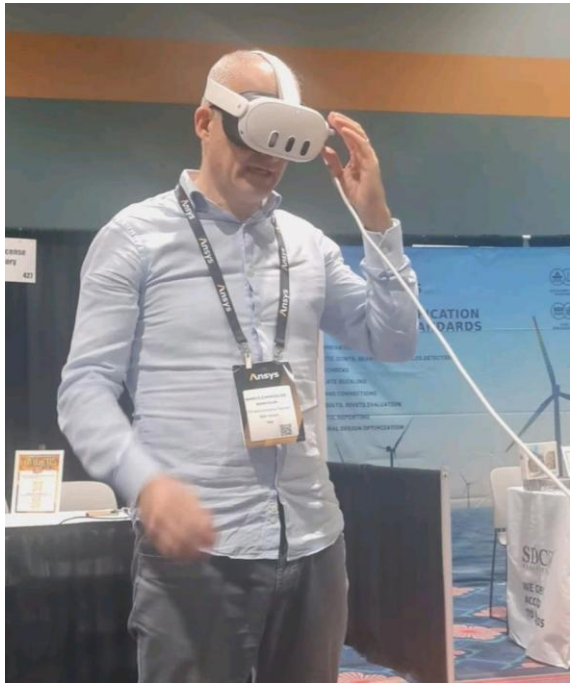
- ROM Builder
- Input parameters are controlled by the sliders
- **Point-based** rendering

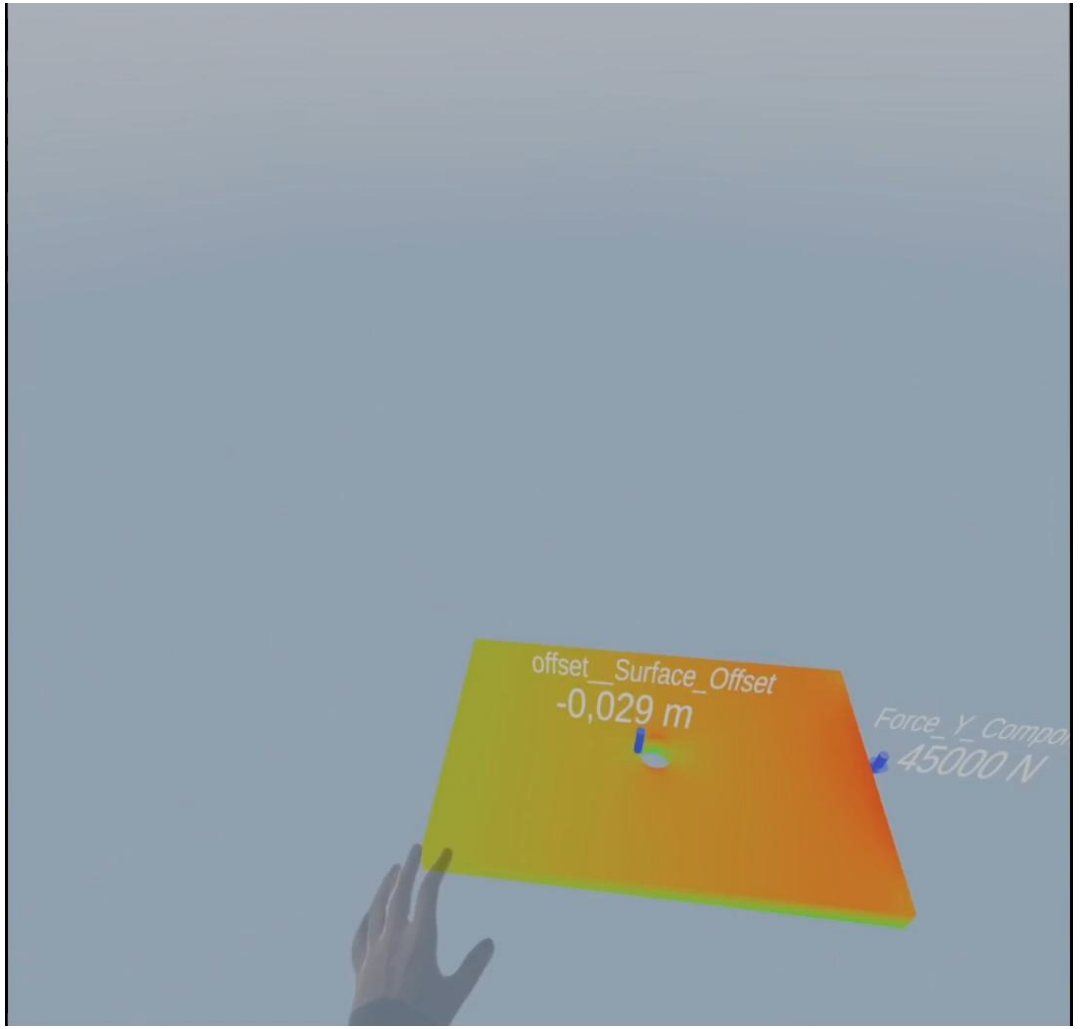




RBF Morph exported VR

- FMU are translated to ARM
- Meta Quest 3
- Input parameters are controlled by hands
- We can add an **immersive scene**
- Wireless AR/VR



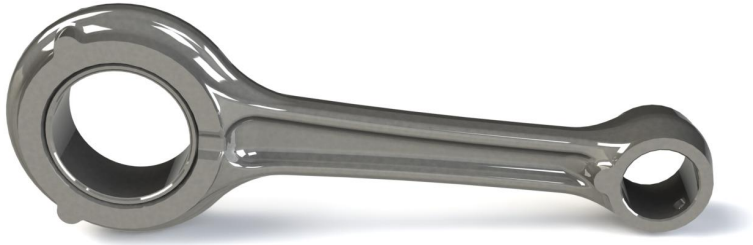


Interactive Digital Twins? Yes!

- Examples
  - **Motorsport** – interactive aero design of a Formula 3 car in the RBF Auto salon (Fluent)
  - **Automotive** – fatigue life optimization of a connecting rod (Mechanical)

Interactive Real-Time Design Exploration: Connecting Rod

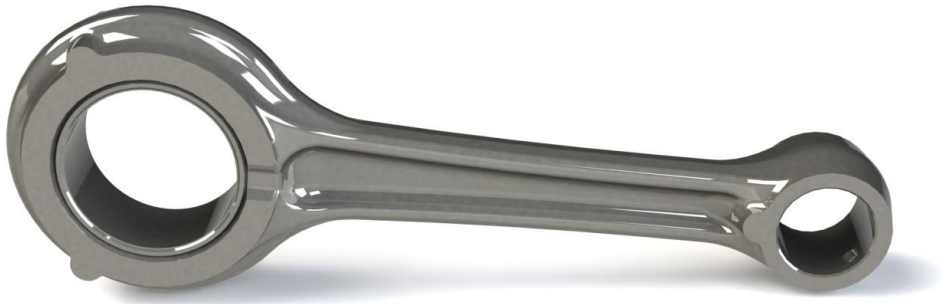
- Fatigue life optimization of a Piaggio 4-stroke engine **connecting rod**
- **Parametric mesh morphing** within an Ansys-based workflow
- A quick tool intended for interactive **hotspots mitigation**

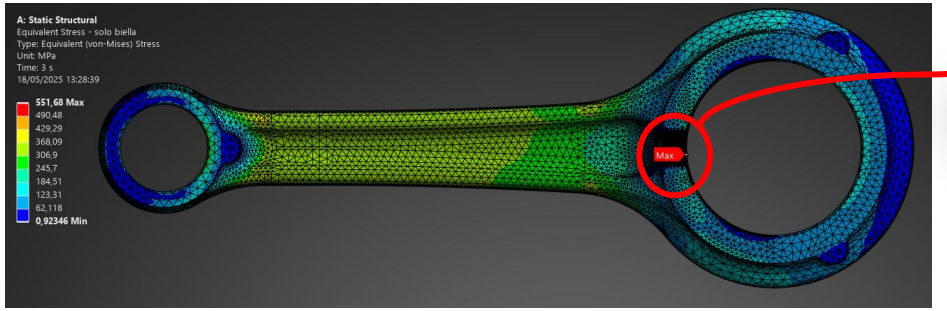


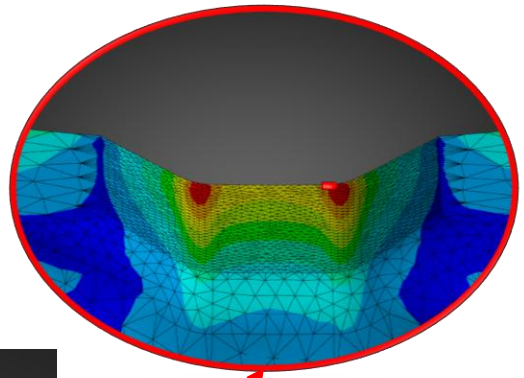
PIAGGIO

Interactive Real-Time Design Exploration: Connecting Rod

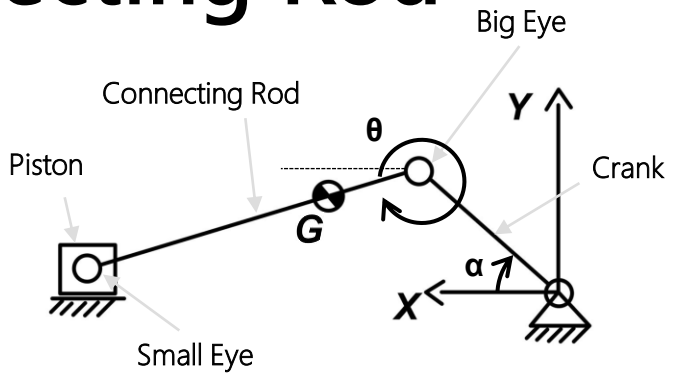
- Lower peak stress at constant mass — or same stress with less mass
- Increase safety factors and fatigue life and getting lower emissions
- Fast, reliable evaluations through a static ROM
- FEA (Ansys Workbench): stress/modal/fatigue checks
- Shape update: RBF-based mesh morphing

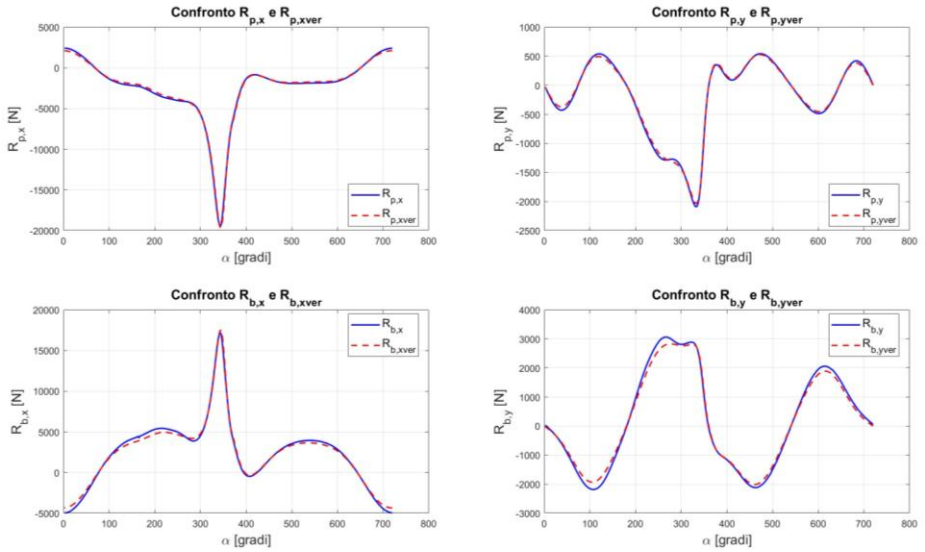


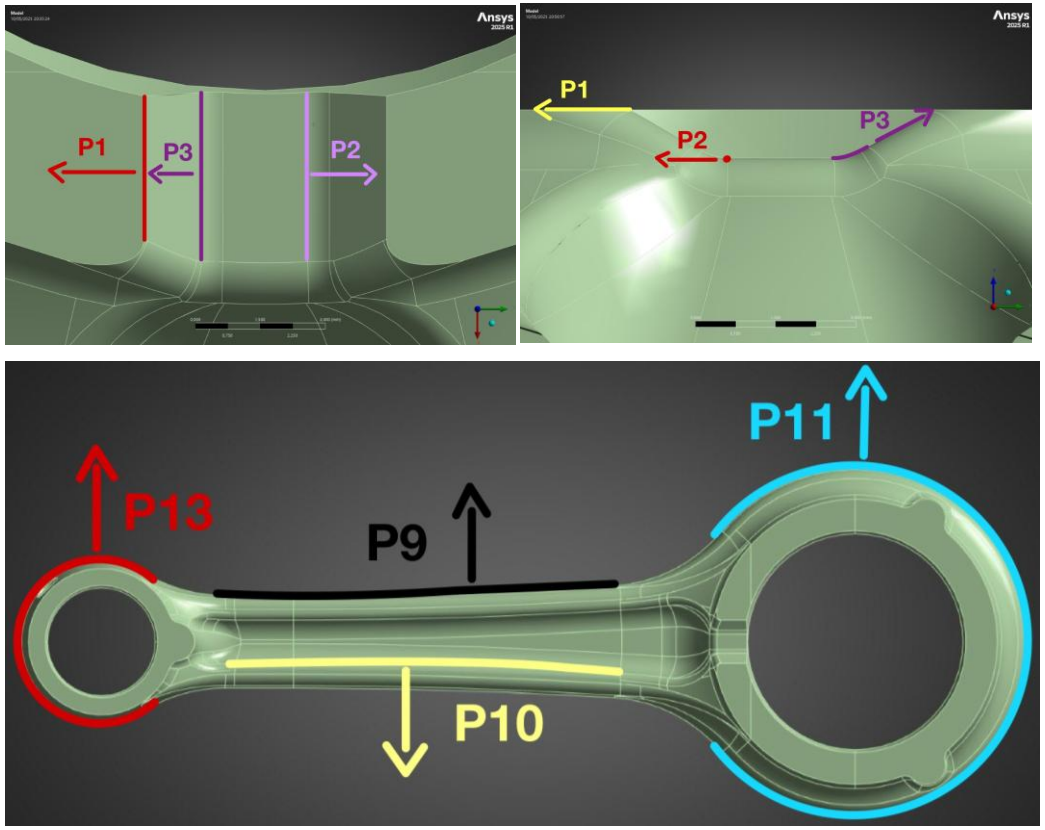




Interactive Real-Time Design Exploration: Connecting Rod

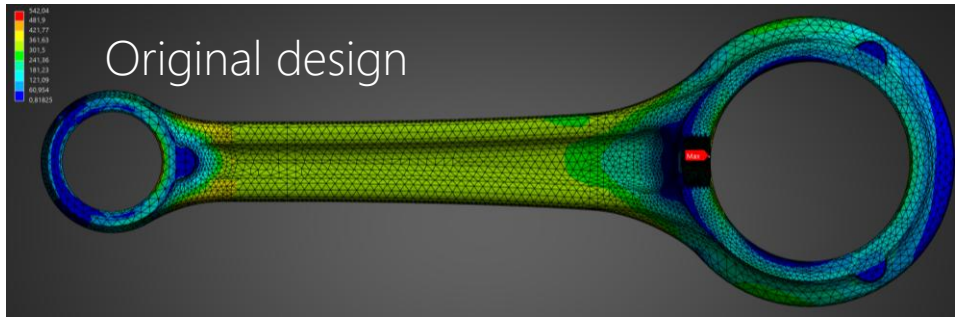






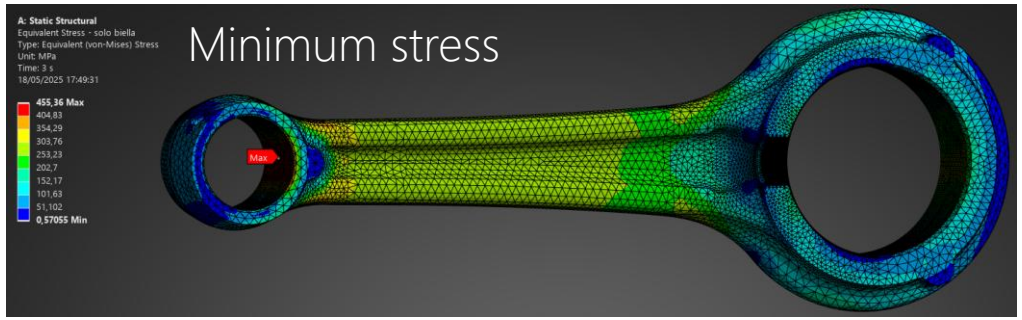
Interactive Real-Time Design Exploration: Connecting Rod

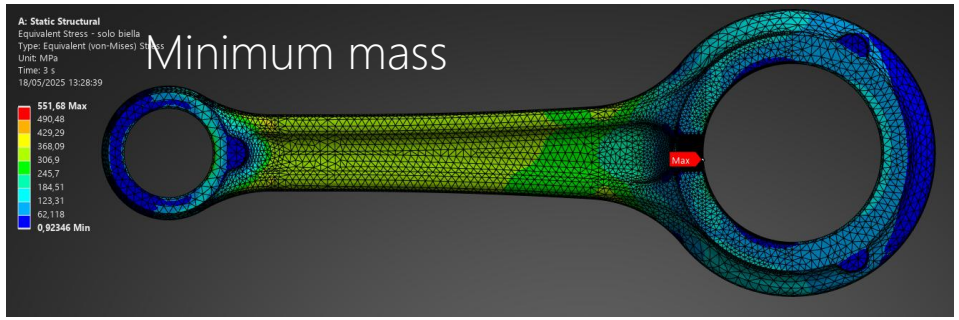
Worst load case:6500 RPM, α=344.7°, θ=-4.5°
DP113: minimum stress (-17,4%)
DP119: minimum mass (-21,0%)



DP	P1	P2	P3	P9	P10	P11	P13
113	1.239	0.787	-0.087	1.102	0.781	0.995	0.954
119	1.218	0.765	-0.146	1.003	0.900	0.903	0.952

DP	σ_{VM} [MPa]	V_{tot} [mm^3]	$\Delta\sigma$ [MPa]	$\Delta\sigma$ [%]	ΔV [%]	Δx_{G} [mm]
113	455.4	18016.4	-95.6	-17.4	0.9	-0.6
119	542.0	14110.9	-9.0	-1.6	-21.0	4.4



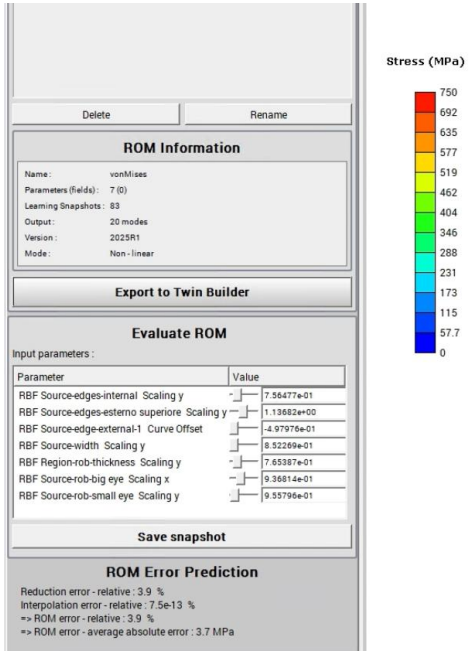


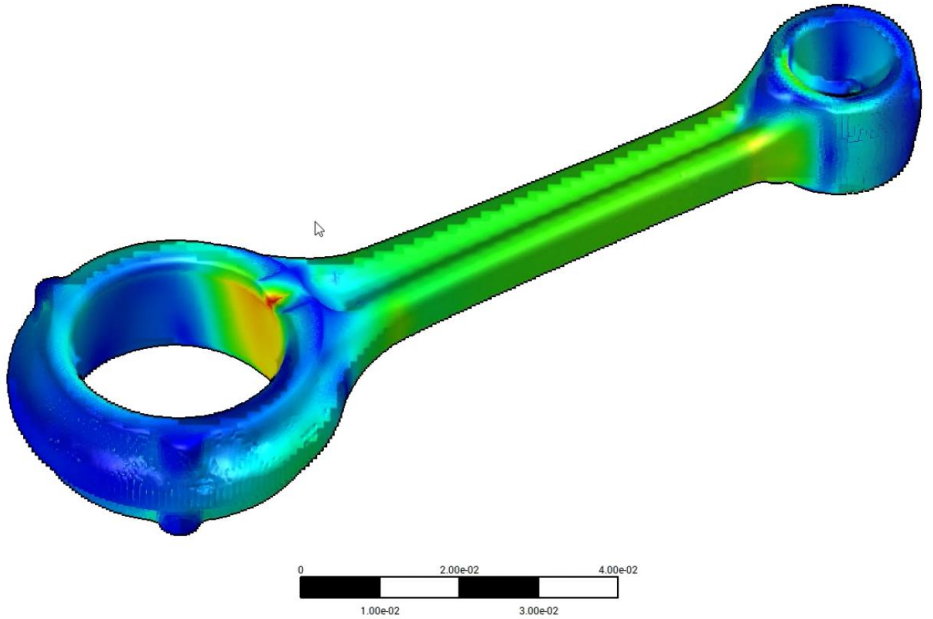
Interactive Real-Time Design Exploration: Connecting Rod

ROM building and validation

- 20 modes
- 80% training set, 20% validation set
- Maximum ROM error: 7%

	σ_{VM} FEM (N)	σ_{VM} ROM (N)	$\Delta\sigma_{VM}$ [%]
DP113	455.36	456.52	-0.26
DP119	542.04	566.00	-4.42

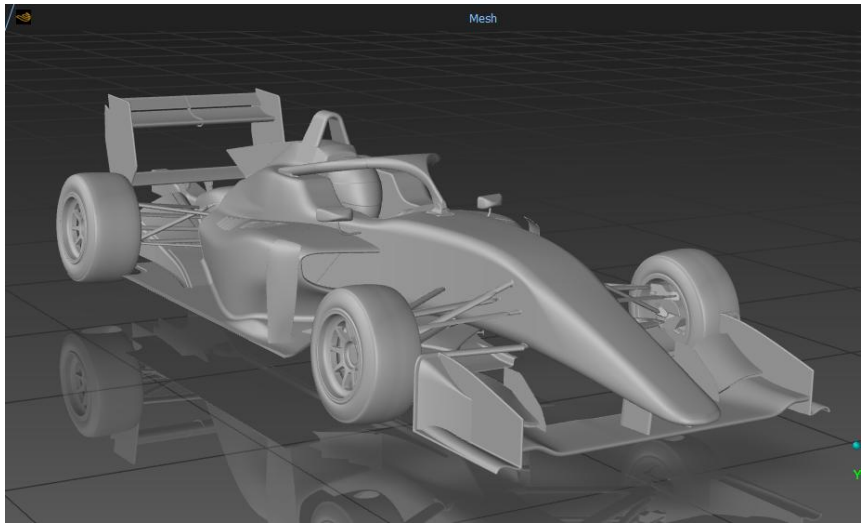




Interactive Real-Time Design Exploration: Connecting Rod

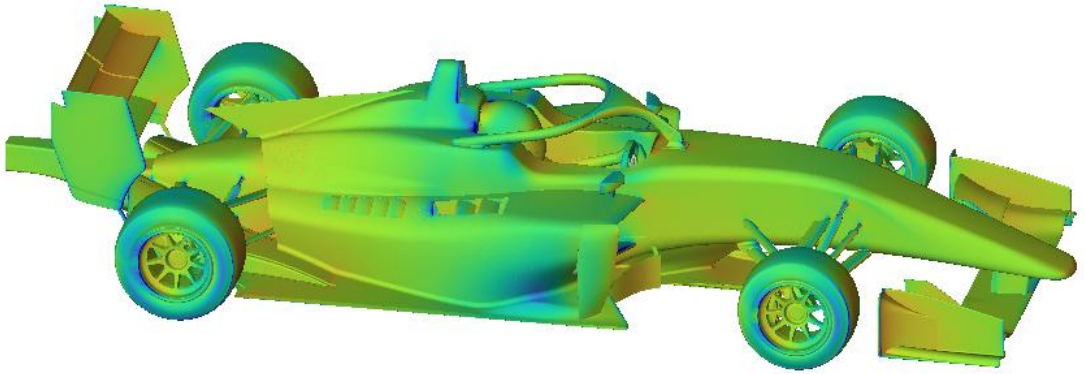
Interactive Real-Time Design Exploration: Dallara Formula 3 Single-Seater Front Wing

- Aero optimization of the **front wing**
- **Parametric mesh morphing** within an Ansys-based workflow
- A quick tool intended for interactive, field-aware, **lift and drag optimization**

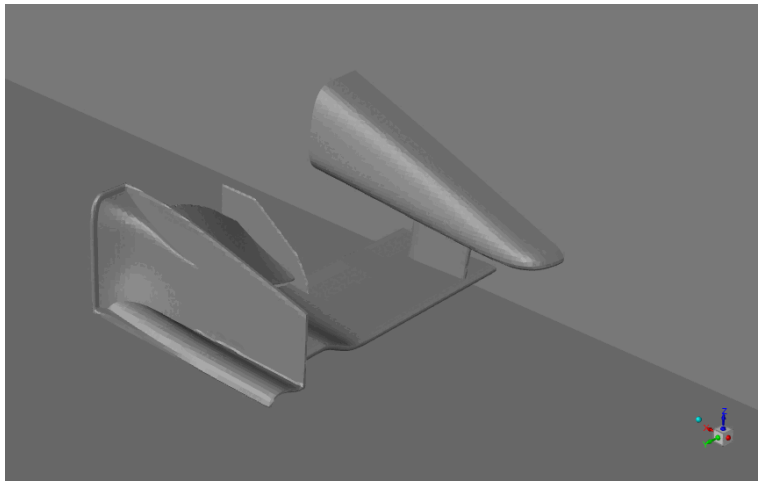


Interactive Real-Time Design Exploration: Dallara Formula 3 Single-Seater Front Wing

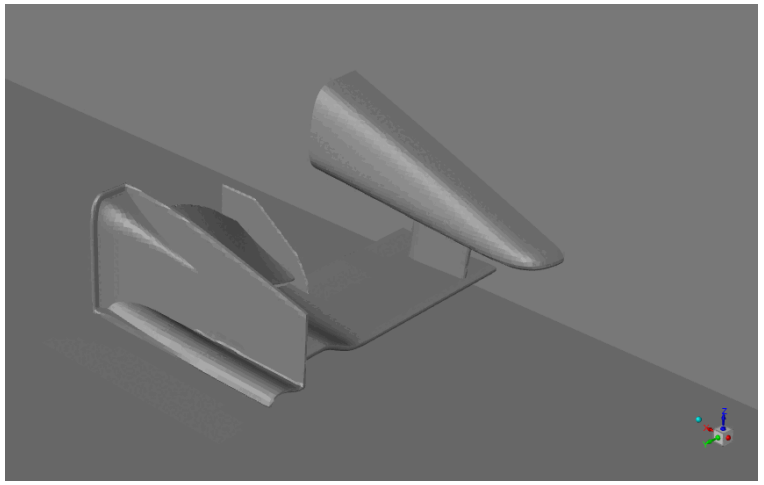
- Half car model mosaic mesh comprised of about 50 millions cells
- Drag reduction acting on front wing
- Fast, reliable evaluations through a static ROM
- Steady RANS CFD (Ansys Fluent)
- Shape update: RBF-based mesh morphing



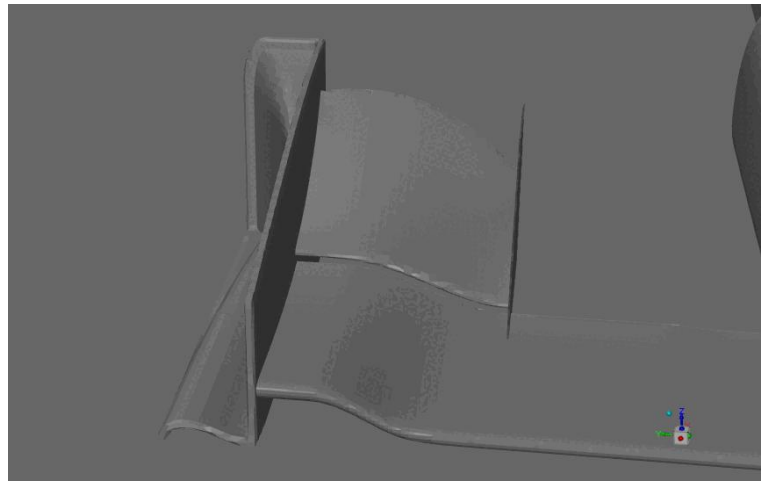
Interactive Real-Time Design Exploration: Mesh morphing – front wing end plate and flap



Endplate outward



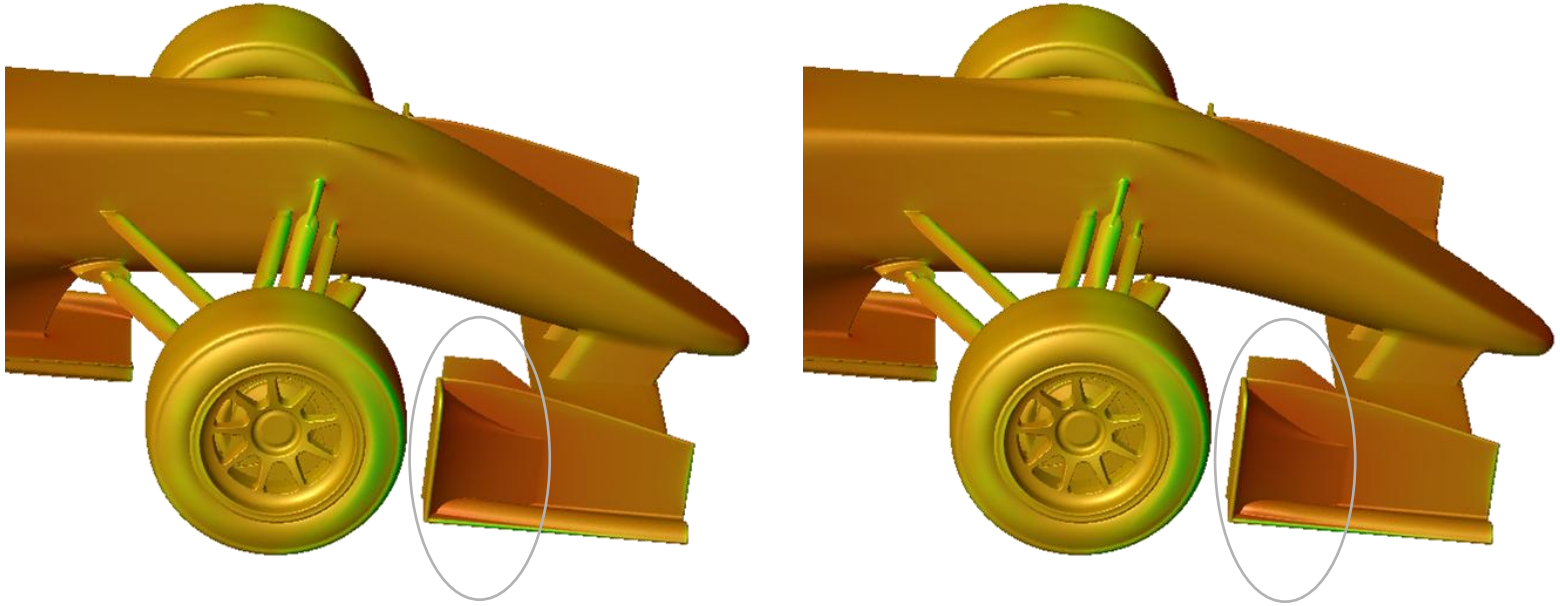
Endplate upward



Flap inclination

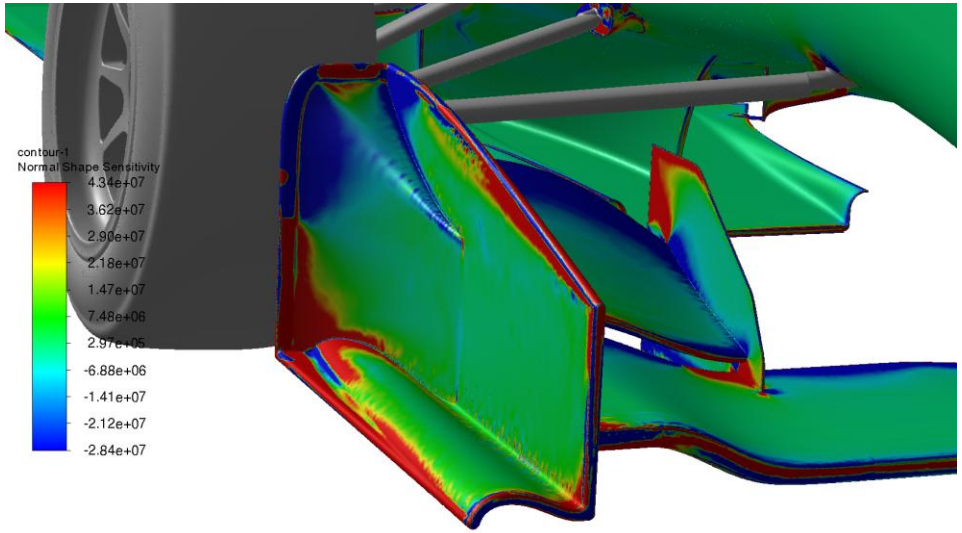
Interactive Real-Time Design Exploration: Front wing end plate and flap – optimized design

- Automated “standard” optimization
- -0,43 drag points gain achieved

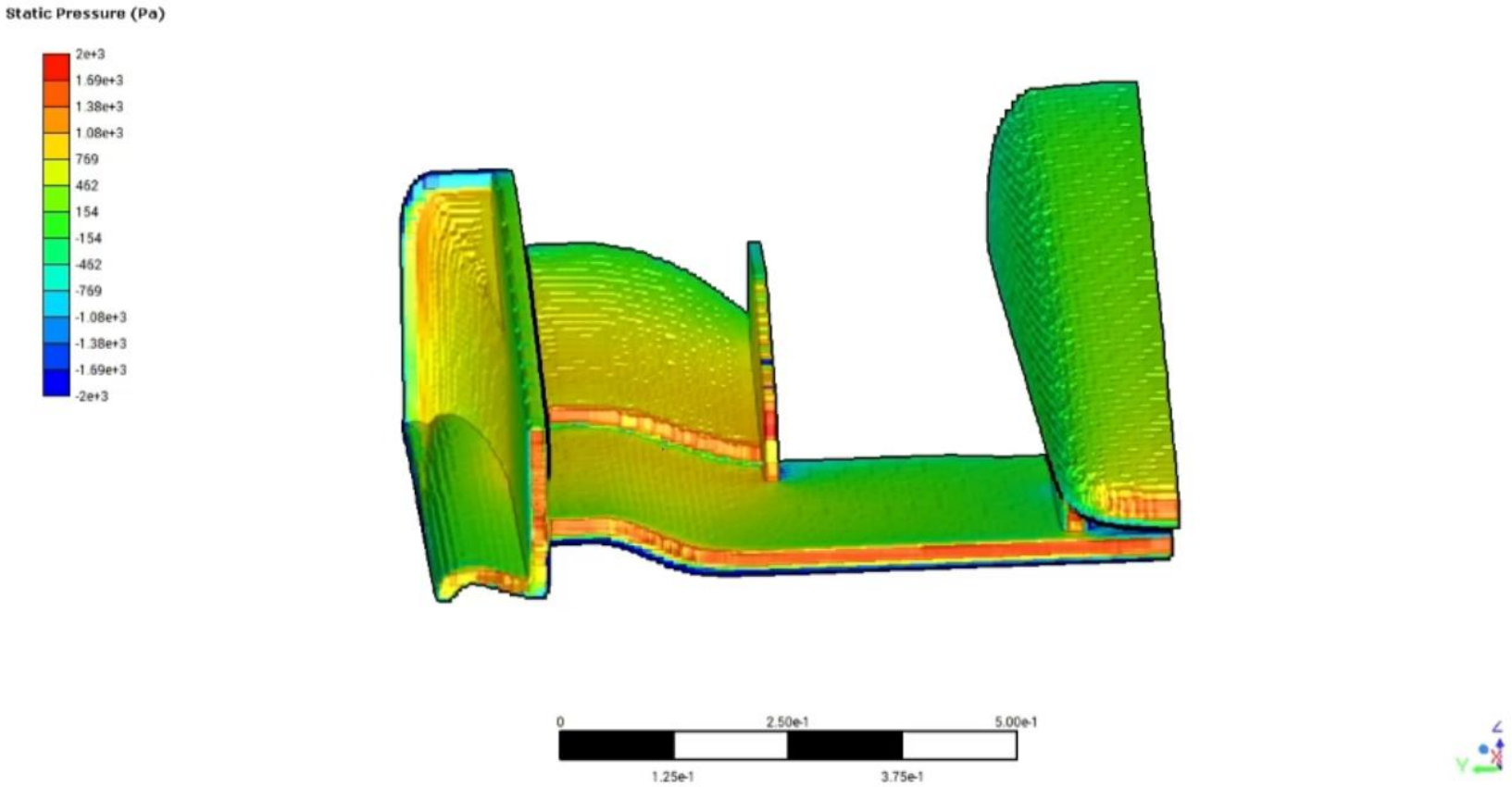


Interactive Real-Time Design Exploration: Dallara Formula 3 Single-Seater Front Wing

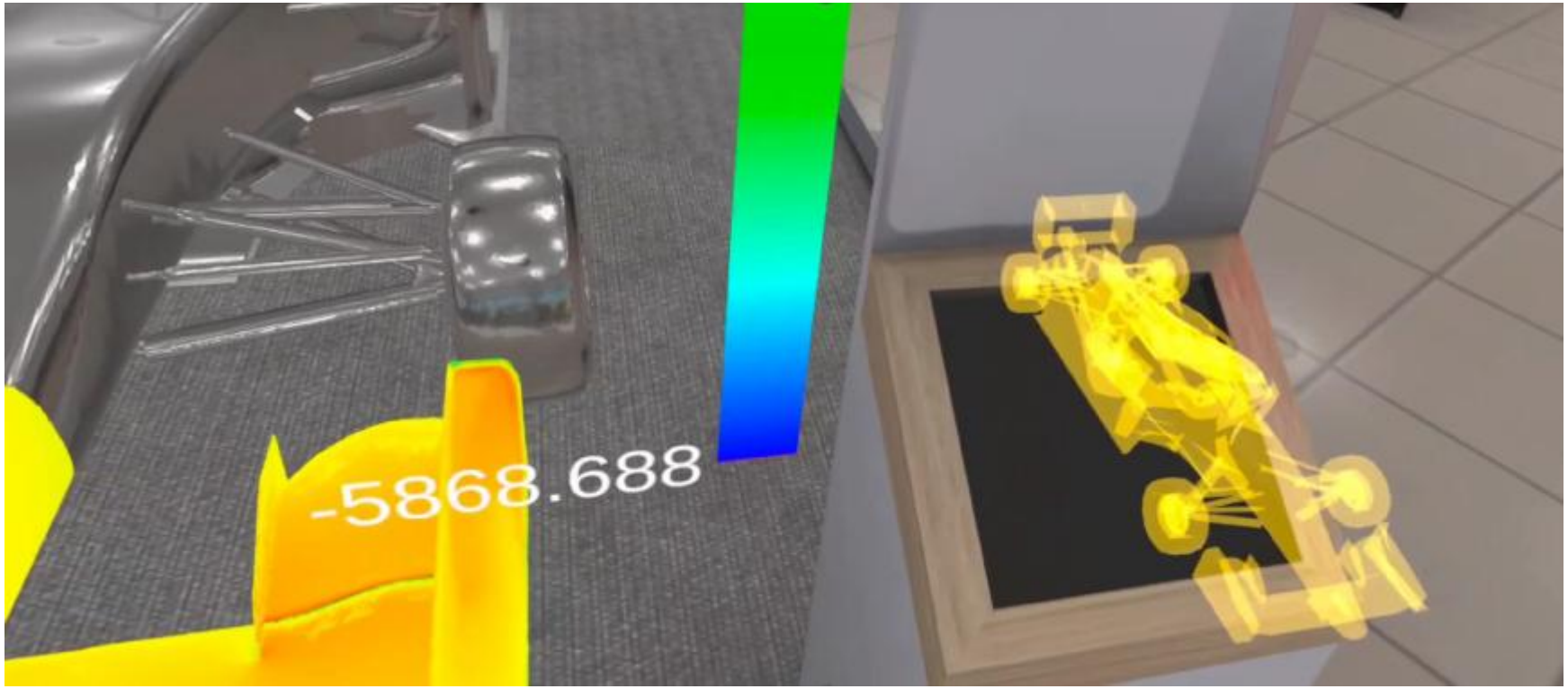
- The four parameters are explored generating 100 DPs
- Snapshots are collected and compressed
- FMUs exported by Twin Builder
- Interactive VR Experience featuring
  - Shape and Cp contour update
  - Lift and Drag gauges in the scene



Interactive Real-Time Design Exploration: Dallara Formula 3 Single-Seater Front Wing



Interactive Real-Time Design Exploration: Dallara Formula 3 Single-Seater Front Wing



Conclusions

- Interactive Digital Twins? **Yes!**
- We have a complete workflow based on Ansys products:
  - High fidelity solvers (Mechanical, APDL, LS-DYNA, Fluent)
  - Twin Builder
  - RBF Morph
- Two industrial examples, fatigue optimization of a connecting rod and a **scooter engine**, and aero optimization of a **single-seater front wing** have been demonstrated
- We support Meta Quest 3 & Pro (ARM), we are now considering Apple VisionPro

Many thanks for your attention!

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