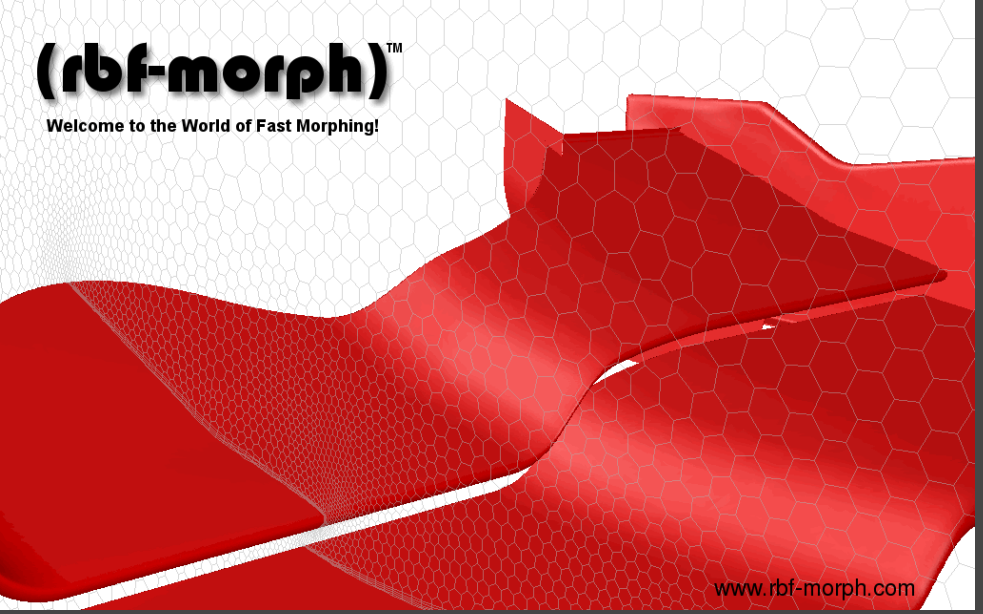


(rbf-morph)™

ANSYS PREFERRED SOLUTION PARTNER

RBF Morph and ROM

RBF mesh morphing and reduced order models (ROM) squeeze high fidelity CAE simulations into real time digital twins

Prof. Marco Evangelos Biancolini – RBF Morph CTO & Company Founder

Dr. Michel Rochette - ANSYS Systems Business Unit - Twin Builder

Outline

- A short introduction to RBF Morph
- Why RBF+ROM for Digital Twins?
- How RBF+ROM with ANSYS?
- Two detailed applications
  - ROM of stresses acting on a turbine blade
  - ROM of an aneurysm hemodynamics
- Conclusions

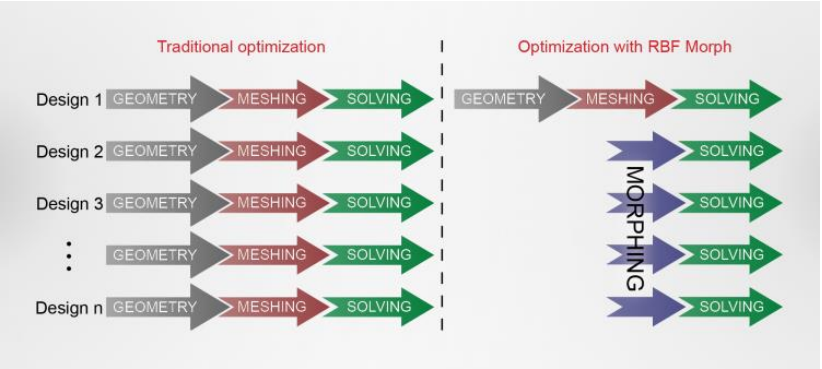
Parametric CAE models

CAE – Computer Aided Engineering

RBF Morph makes the CAE model **parametric** with respect to the **shape.**

Works for **any size of the mesh.**

Shape parameters can be steered with the **optimizer of choice.**

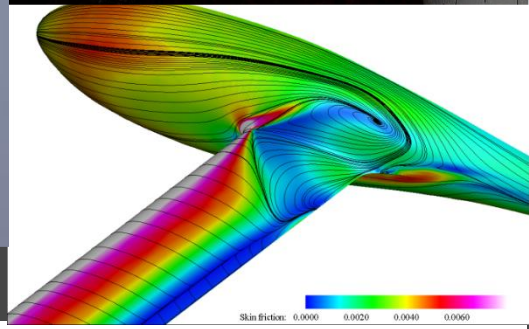


"RBF Morph is an ingenious morphing tool that allows engineers to mold the geometry like clay to very high precision"

Professional Motorsport Magazine
Issue April-June 2012

"State of the art morphing technology available with seamless integration to the ANSYS FLUENT community"

Shane Moeykens
Strategic Partnerships Manager
ANSYS Inc



Taurus glider optimization

RBF4AERO

Experiments show a separation at wing/fuselage junction occurring at an AoA of 8 deg. Fluent simulation can capture the issue.

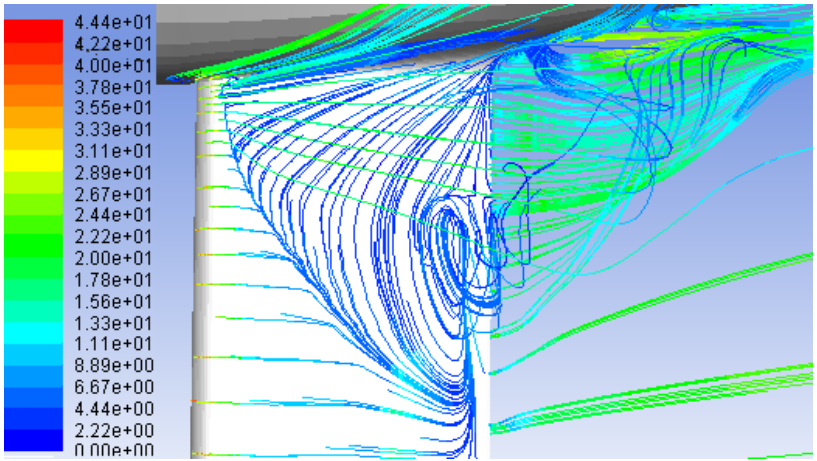
(rbf-morph)™

RBF Morph Fluent Add On

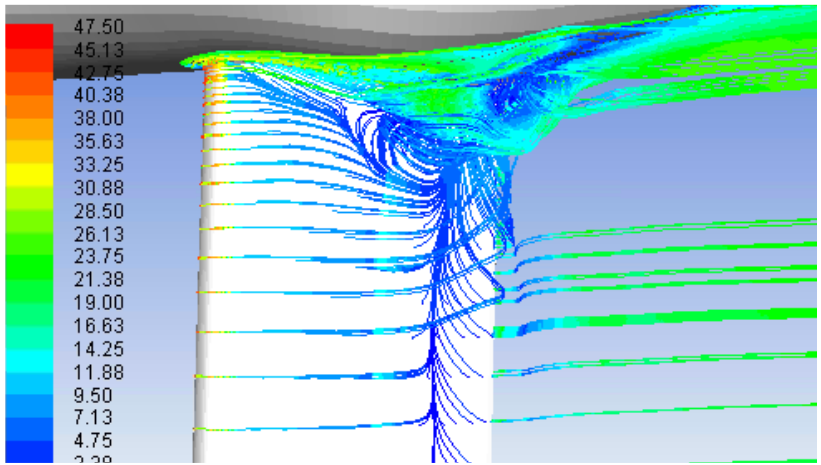
Our flagship product. Released in 2009, distributed by ANSYS since 2012.

Taurus glider optimization

Original design E=14.9



Optimal design E=20.1 (+35%)



(rbf-morph)™

WHO WE ARE?

My name is Marco Evangelos Biancolini and we offer…

…academic and CAE synergy…

Academic

- Associate Professor of Machine Design at the University of Rome "Tor Vergata" (**UTV**)
- Thesis and PhD students across **Italy** and **Europe**
- Students' project (FSAE, ARION)
- Coordinator/WP leader of **EC** projects (RBF4AERO, Fortissimo, RIBES, Cloudifacturing, MeDiTATe)

CAE business

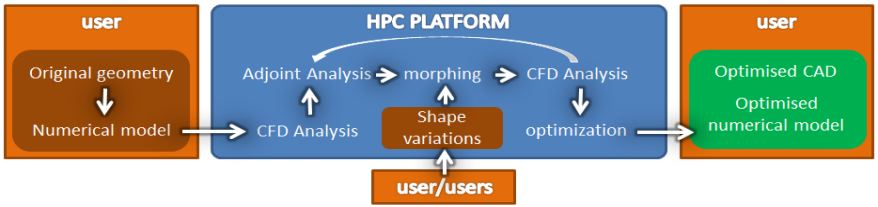
- Expert of advanced **CAE workflow** (vertical automations for shape optimization)
- Author and owner of **RBF Morph™** software
- Honorary member of **Technet Alliance** since 2013

…for better solutions!

FORTISSIMO

(rbf-morph)™

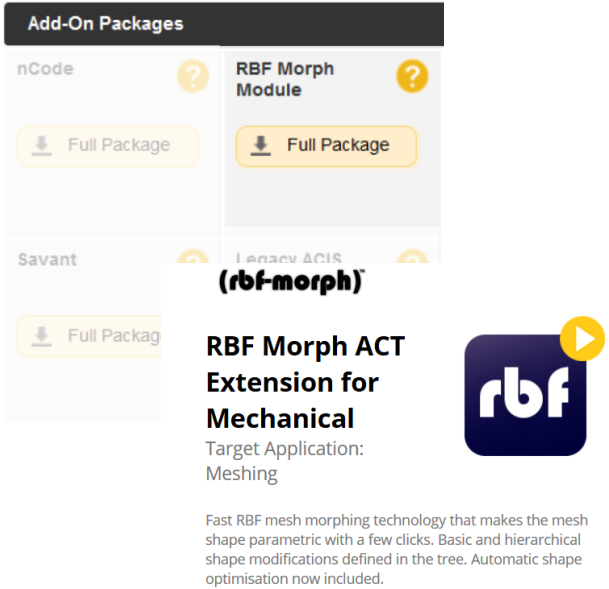
- **F**actories **O**f the Future **R**esources, **T**echnology, **I**nfrastructure and **S**ervices for **SI**mulation and **MO**delling
- WP515: **"Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms"**
- **HSL srl, Trento; University of Rome "Tor Vergata"; CINECA**



ANSYS integrated solutions

Fluent Add On

- Released in **2009**
- Fully integrated within Fluent (GUI, TUI & solving stage), Workbench and **Adjoint Solver**
- Multi physics features (**FSI**)

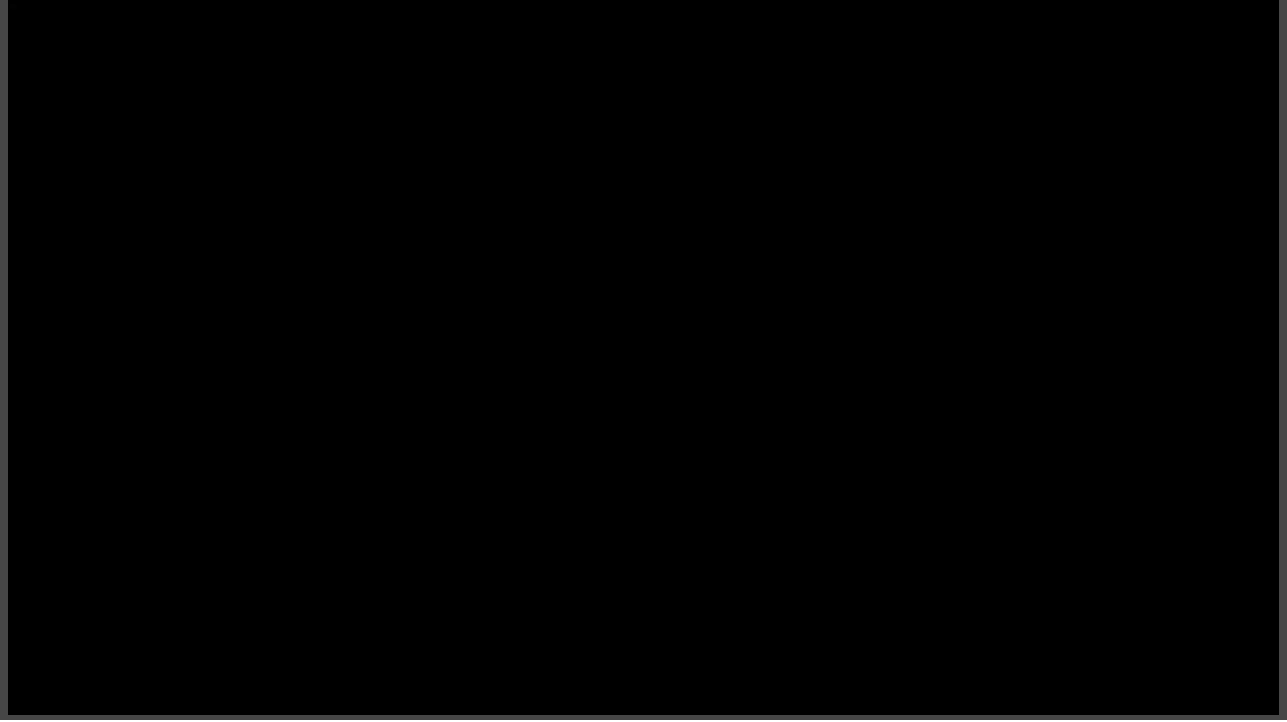


ACT Extension

- Released in **2015**

SACMI

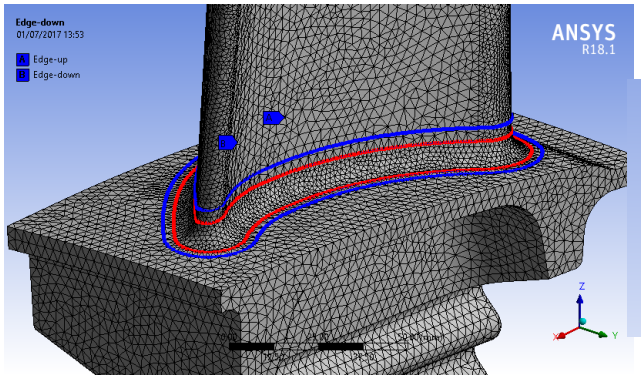
- Fully embedded in ANSYS **Mechanical** (parametric)
- Benefits of **underlying geometry** (or aux geo with dead meshes)
- …**WB** Meshing

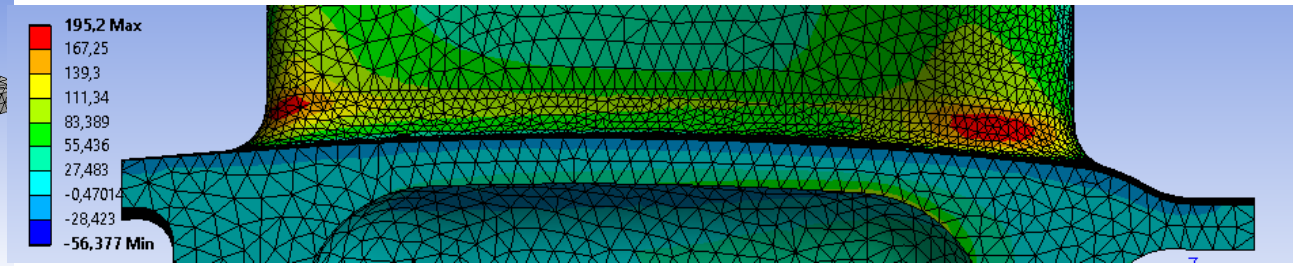


RBF Morph ACT Extension

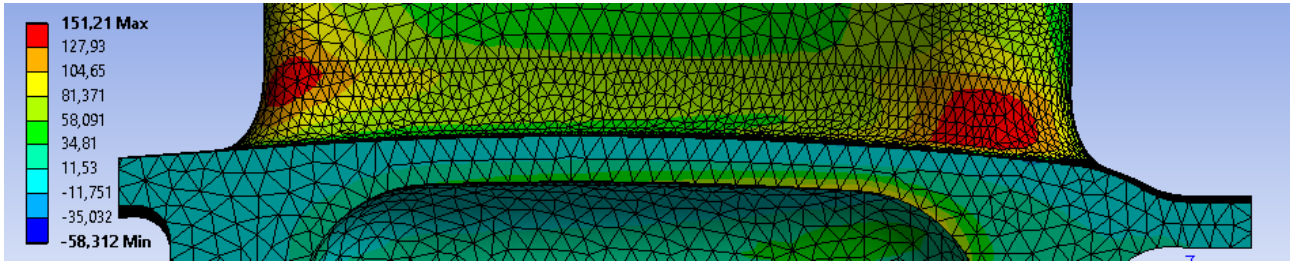
Released in 2015. Available also on the ANSYS App Store.

Blade fillet stress reduction





- Two parameters allow to get a 22.5% stress **reduction**



New market drivers for mesh morphing

Additive Manufacturing

- Is emerging as a mainstream technology
- Offers a great potential for new complex shapes
- Topological and shape optimization allows to have the design driven by the physics (adjoint, BGM)

Digital Twins

- Mesh morphing allows to adapt on **actual manufactured shapes**
- CAE Up
- Cloudi Facturing
- Mesh morphing is a key enabler for shape parameters in ROM
- We are offering this feature starting from ANSYS v19.2

Digital Twin or Virtual Prototyping?

PRIMO PIANO

DIGITAL TWIN
O PROTOTIPAZIONE VIRTUALE?

Prof. Marco Evangelos Biancolini
Dipartimento di Ingegneria dell'Impresa "Mario Lucertini" Università di Roma Tor Vergata

«Se con l'approccio della prototipazione virtuale l'intento era quello della progettazione, ovvero simulazione numerica mirata a comprimere i tempi di sviluppo di un nuovo prodotto, con il passaggio al digital twin si mira all'uso della simulazione durante la vita del prodotto stesso.

Nel mondo del CAE vediamo evolvere il nome delle tecnologie anche se nella sostanza i metodi numerici alla base non differiscono poi così tanto. In tempi recenti per parlare di simulazione numerica si è usato tanto il termine "prototipazione virtuale". Oggi troviamo sempre più spesso il termine *digital twin*. Il nuovo nome non è solo legato a una moda passeggera o a scelte di comunicazione dettate dal marketing. Il passaggio al "gemello digitale" segna infatti un nuovo modo di utilizzare le stesse analisi. Se con l'approccio della prototipazione virtuale l'intento era quello della progettazione, ovvero simulazione numerica mirata a comprimere i tempi di sviluppo di un nuovo prodotto, con il passaggio al *digital twin* si mira all'uso della simulazione durante la vita del prodotto stesso. Una rappresentazione digitale della fisica che modella un sistema risulta infatti molto utile per prevederne il comportamento e per interagire con il sistema reale aiutati dall'evoluzione delle informazioni disponibili grazie al gemello digitale.

Un aspetto molto importante relativo all'interazione con il *digital twin* è la compressione dell'informazione basata su modelli ridotti ROM *(Reduced Order Models)*. La messa a punto dei modelli previsionali è solitamente basata su previsioni high fidelity a campo intero come ad esempio analisi strutturali con il metodo degli elementi finiti o analisi fluidodinamiche con il metodo dei volumi finiti. Tali analisi richiedono grandi risorse di calcolo e, in molti casi, l'uso del supercalcolo. La grande accuratezza e affidabilità delle analisi numeriche si paga quindi con una mancanza di "reattività". L'aggiornamento dello stato del sistema dovuto al cambiamento del sistema reale può richiedere diverso tempo qualora sia necessaria una nuova esecuzione del calcolo high fidelity. La definizione del ROM *(ROM building)* richiede molto tempo, specialmente se si considera un numero elevato di parametri che cambiano lo stato del sistema; la fase di uso *(ROM consumption)* avviene in tempo reale.

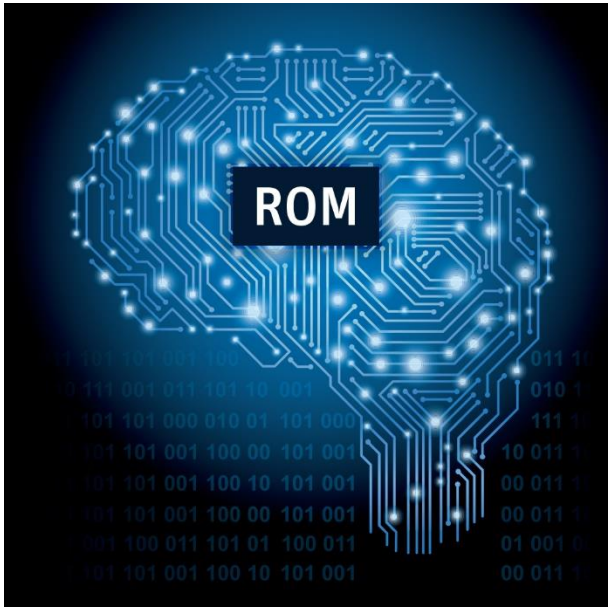
Le nuove tecnologie ROM, separando la fase di preparazione del *digital twin* da quella di utilizzo, stanno consentendo di mettere a punto approcci basati sulla realtà aumentata pensati per la fruizione da parte di operatori specializzati sul particolare sistema, come ad esempio nelle applicazioni medicali, ma non necessariamente esperte di CAE. Questo cambiamento apre la strada a sistemi interattivi, dispositivi aptici, grafica realistica e immersiva e rende necessaria una forte integrazione con la simulazione che potrà essere "distillata" in un ROM molto compatto.

DIGITAL TWIN
O PROTOTIPAZIONE VIRTUALE?

Nel mondo del CAE vediamo evolvere il nome delle tecnologie anche se nella sostanza i metodi numerici alla base non differiscono poi così tanto. In tempi recenti per parlare di simulazione numerica si è usato tanto il termine "prototipazione virtuale". Oggi troviamo sempre più spesso il termine *digital twin*. Il nuovo nome non è solo legato a una moda passeggera o a scelte di comunicazione dettate dal marketing. Il passaggio al "gemello digitale" segna infatti un nuovo modo di utilizzare le stesse analisi. Se con l'approccio della prototipazione virtuale l'intento era quello della progettazione, ovvero simulazione numerica mirata a comprimere i tempi di sviluppo di un nuovo pro-

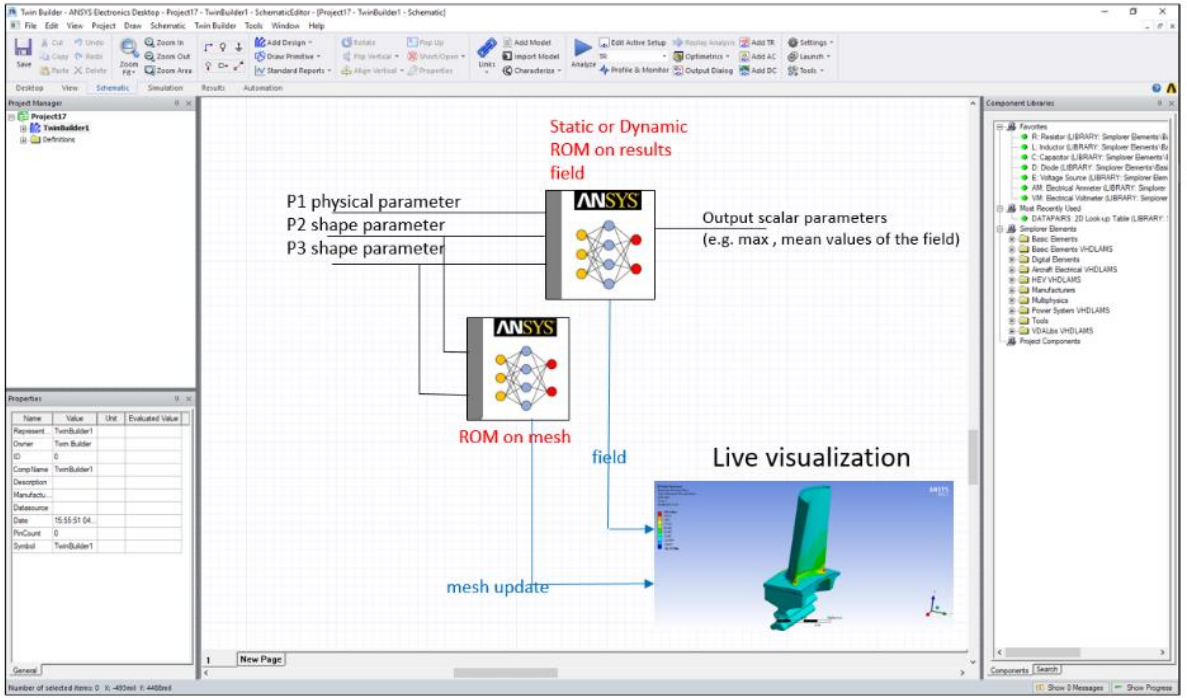
Why ROM for Digital Twins?

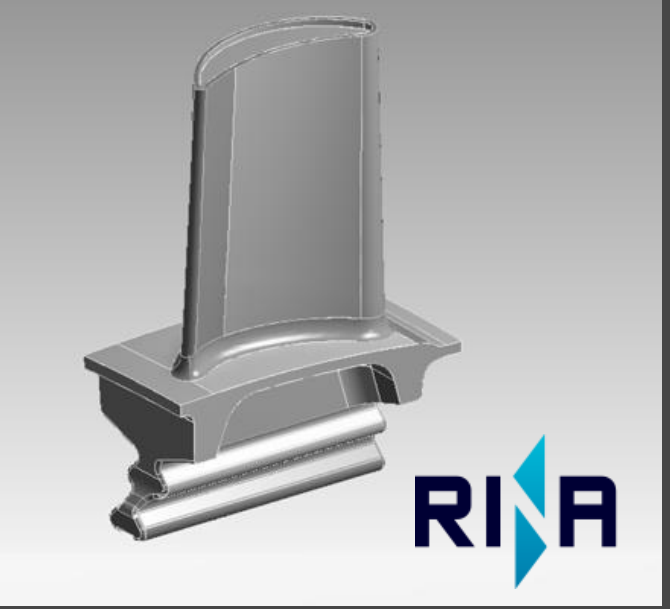
- High fidelity CAE simulations requires HPC and time to be computed
- The results of a parametric CAE study can be compressed into a ROM
- The ROM delivers the same detail level of the high fidelity simulations in real time
- IP stays safe and the ROM can be deployed to create the digital twin (.romz, .fmu)
- https://www.ansys.com/blog/how-to-build-reduced-order-model-cfd-simulations



ROM with shape parameters?

- Shape parameters are often required in a Digital Twin
- The ROM of the mesh joined with the ROM of the CAE solution is an effective answer
- RBF mesh morphing allows to create the ROM of the mesh

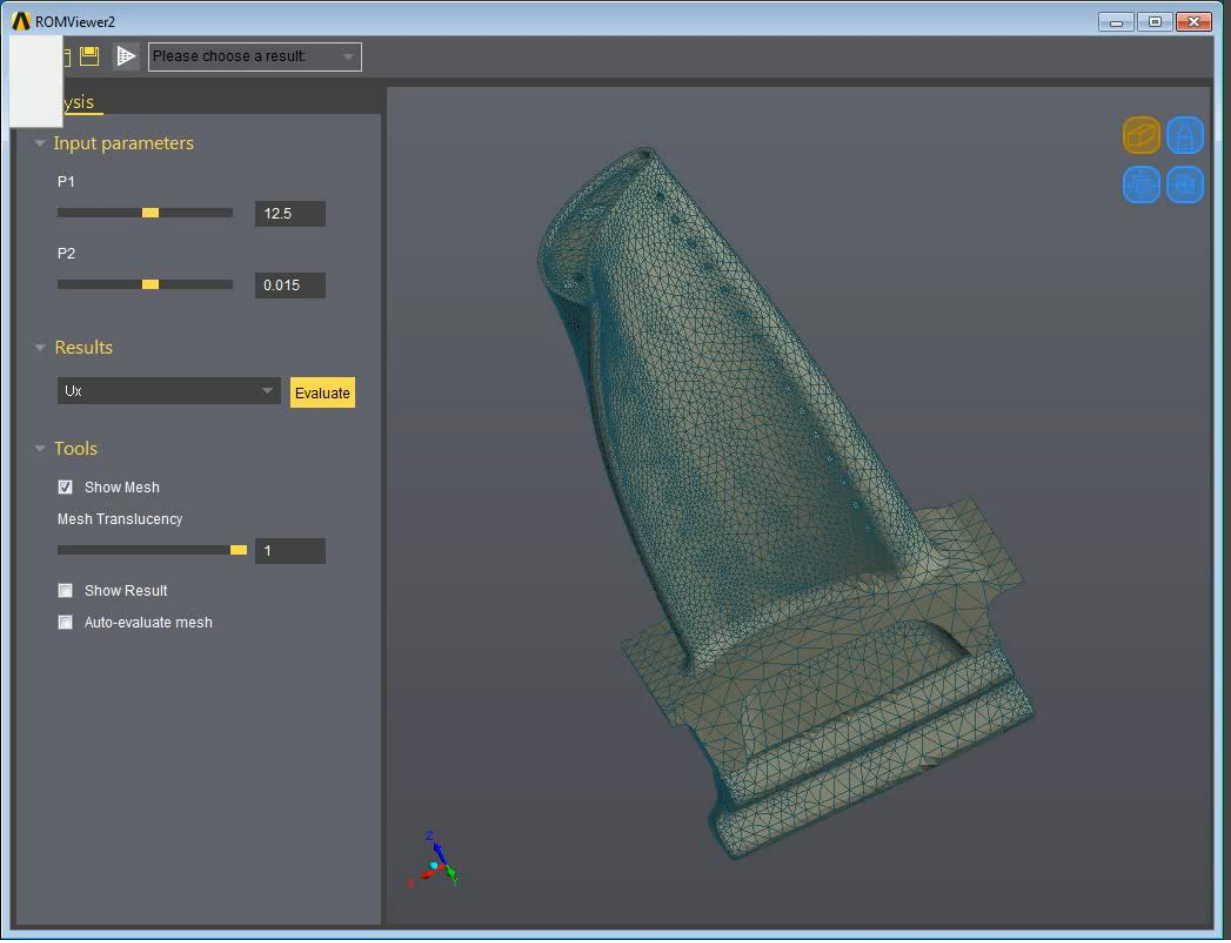




(rbf-morph)™

ROM OF STRESSES ACTING ON A TURBINE BLADE

ACT Extension based workflow



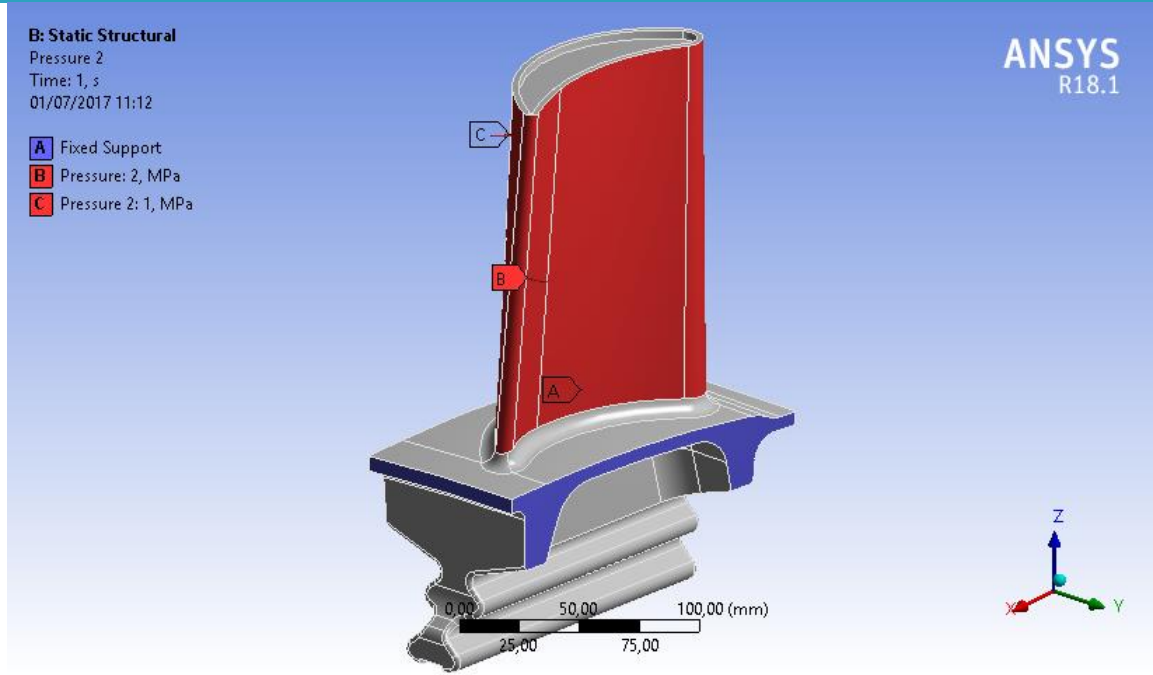
(rbf-morph)™

ANSYS PREFERRED SOLUTION PARTNER

ACT Extension based workflow

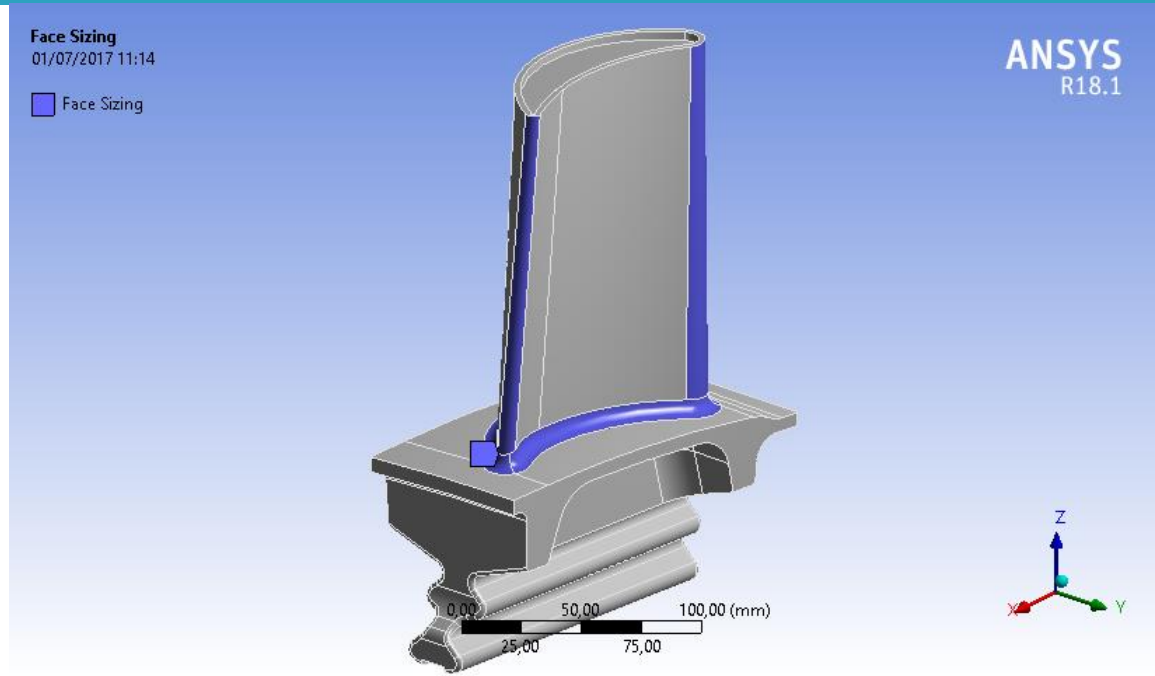
Problem description

- The study is focused on the stress at the root fillet
- Simplified boundary conditions
- Mesh refinement areas
- Baseline stress solution



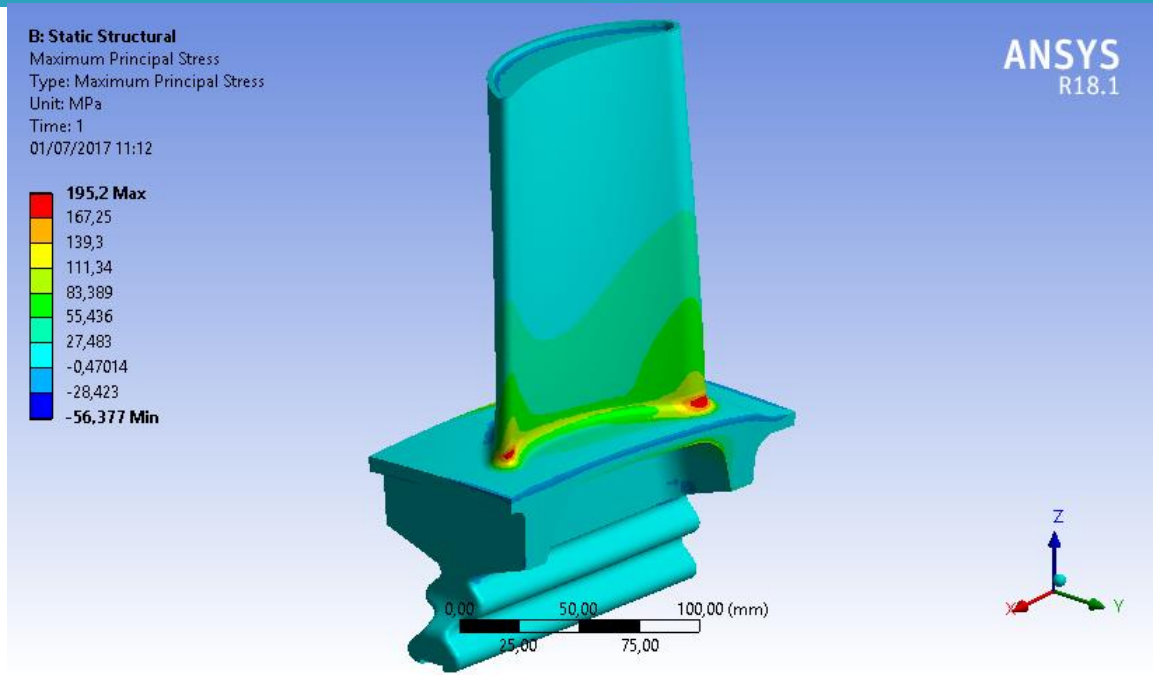
Problem description

- The study is focused on the stress at the root fillet
- Simplified boundary conditions
- Mesh refinement areas
- Baseline stress solution



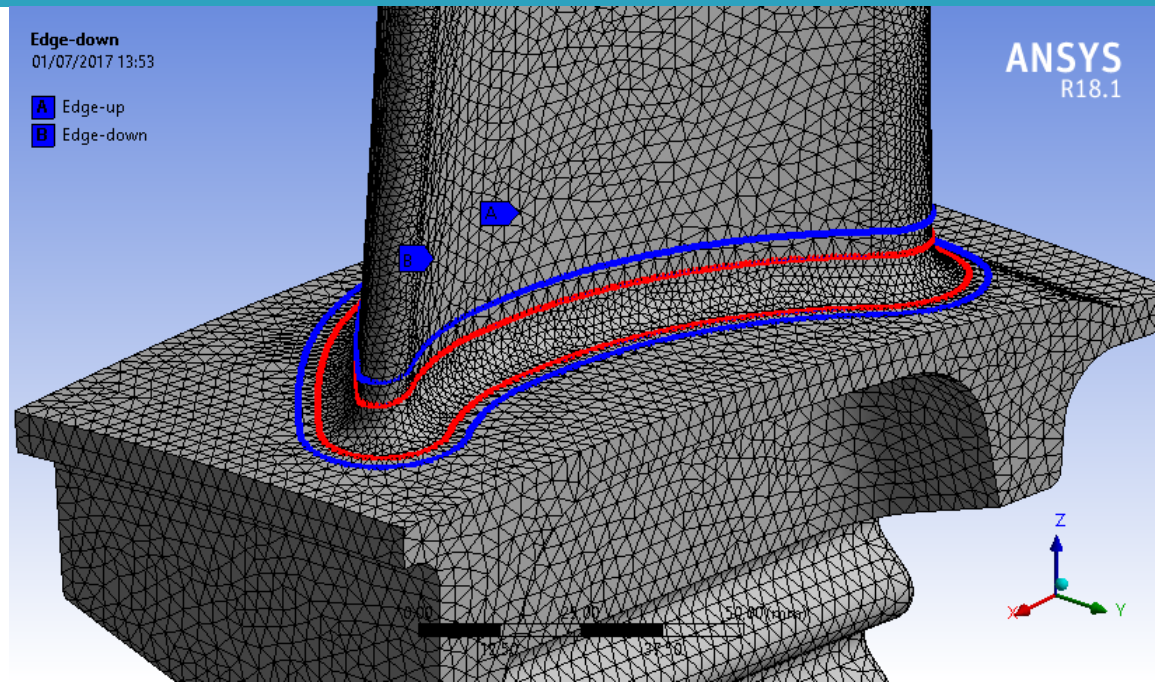
Problem description

- The study is focused on the stress at the root fillet
- Simplified boundary conditions
- Mesh refinement areas
- Baseline stress solution

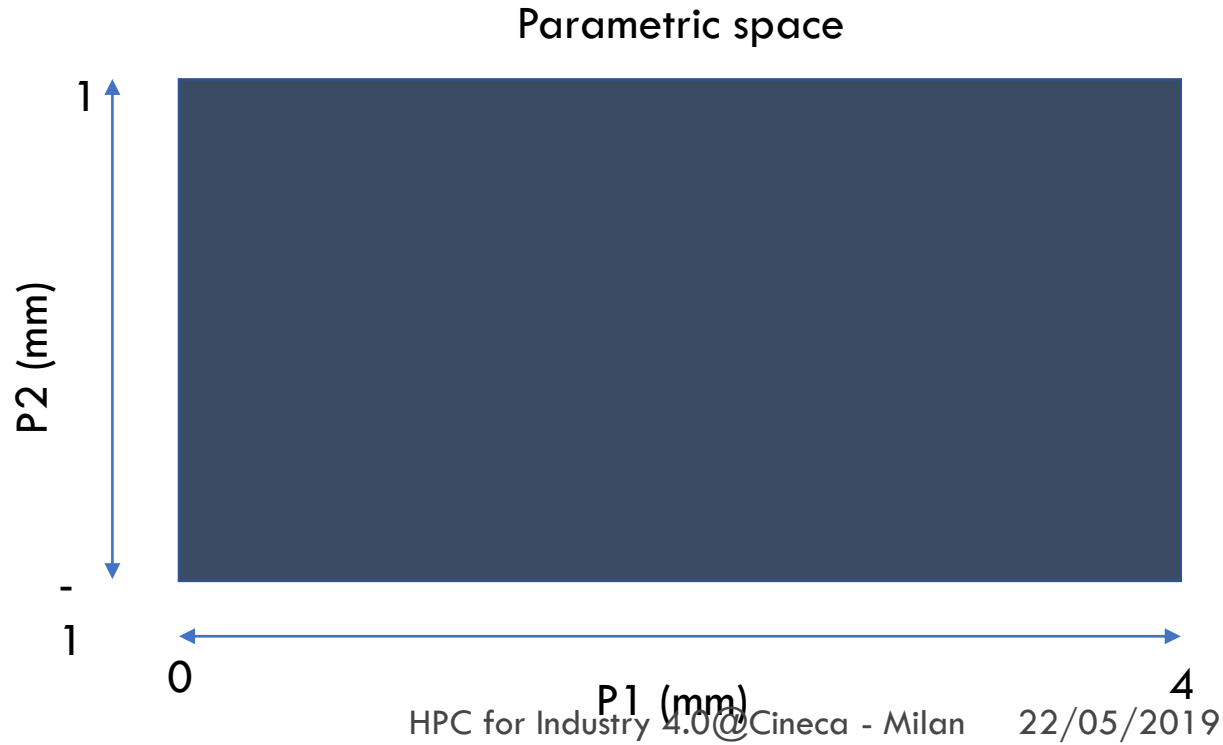


Advanced design approach for a notch

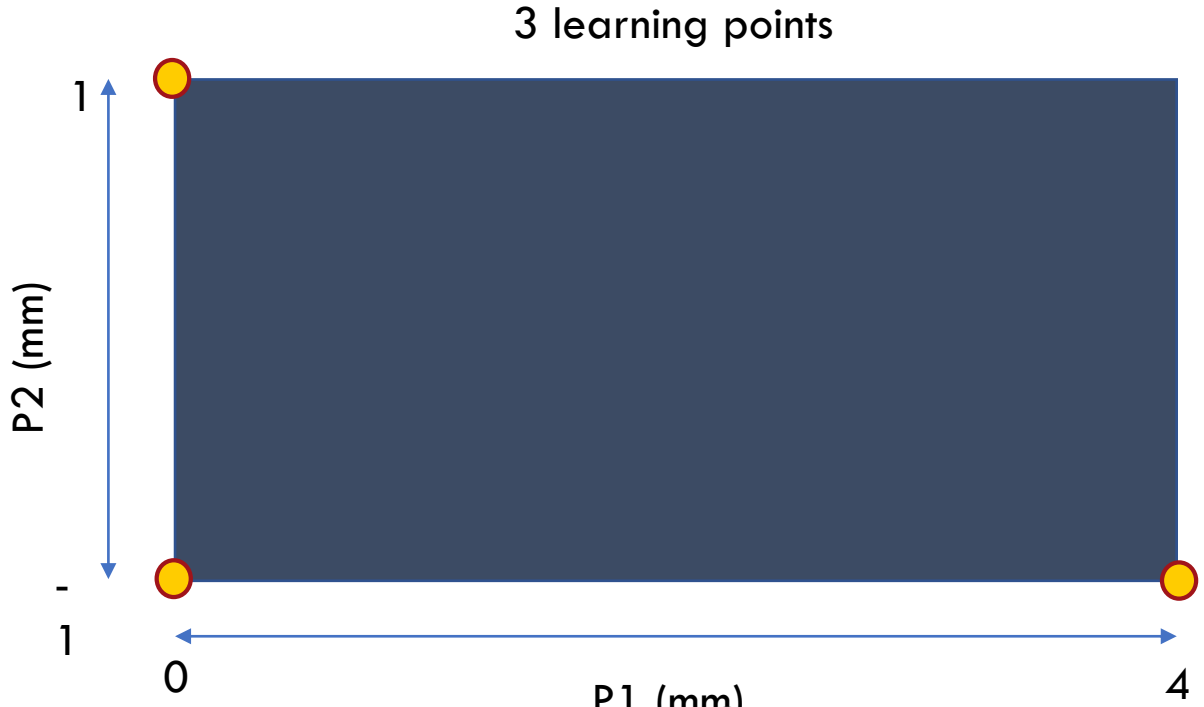
- We need to preserve the complex fillet shape
- This is achieved by controlling the curve at the beginning (P1)and at the end (P2) of the notch
- The fillet geometry is deformed accordingly
- The morphing action is propagated to the volume mesh



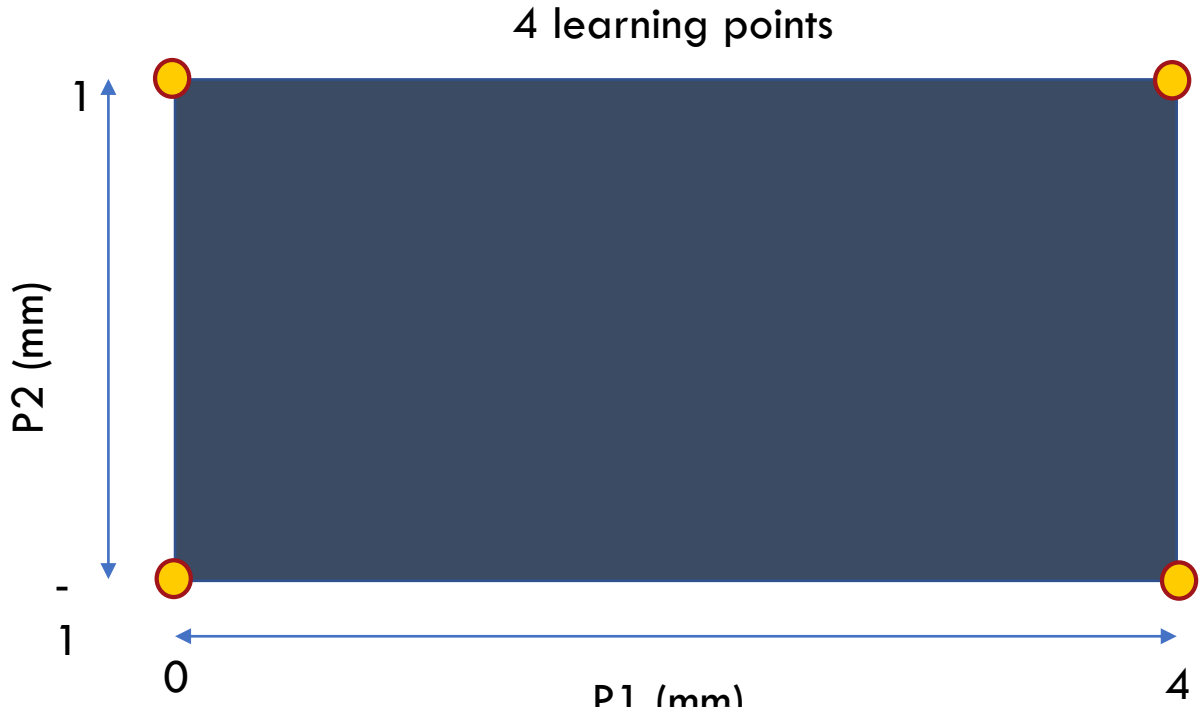
ROM of the morphed mesh



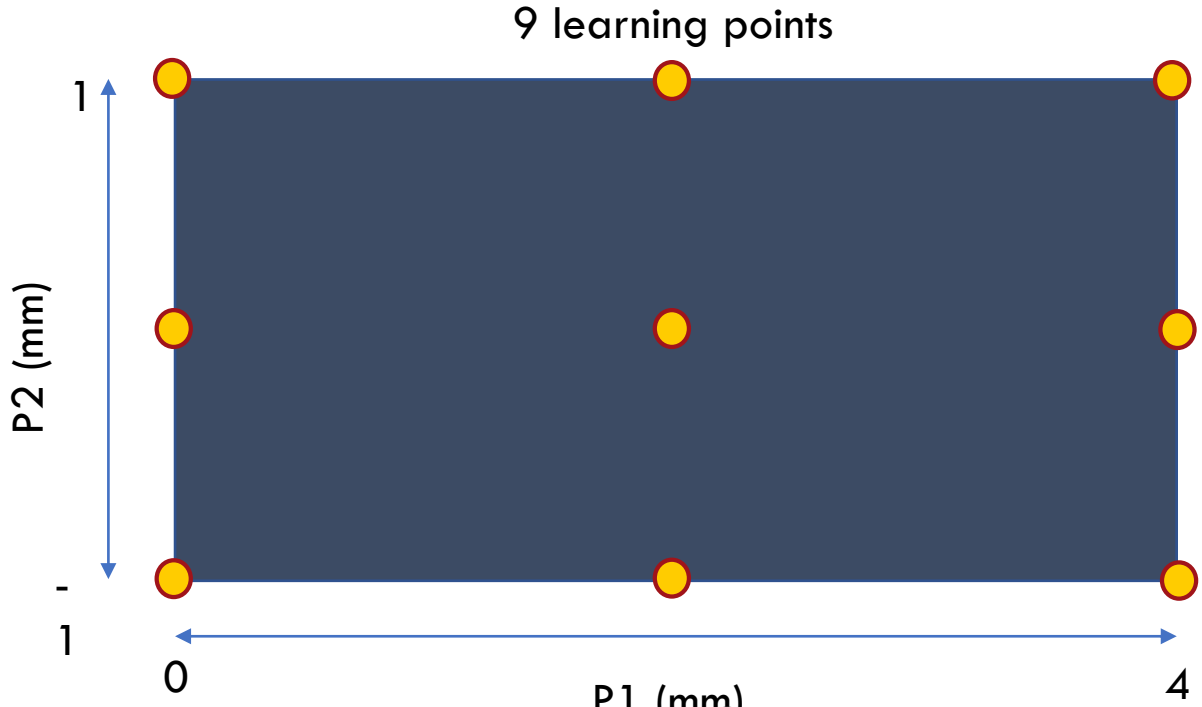
ROM of the morphed mesh



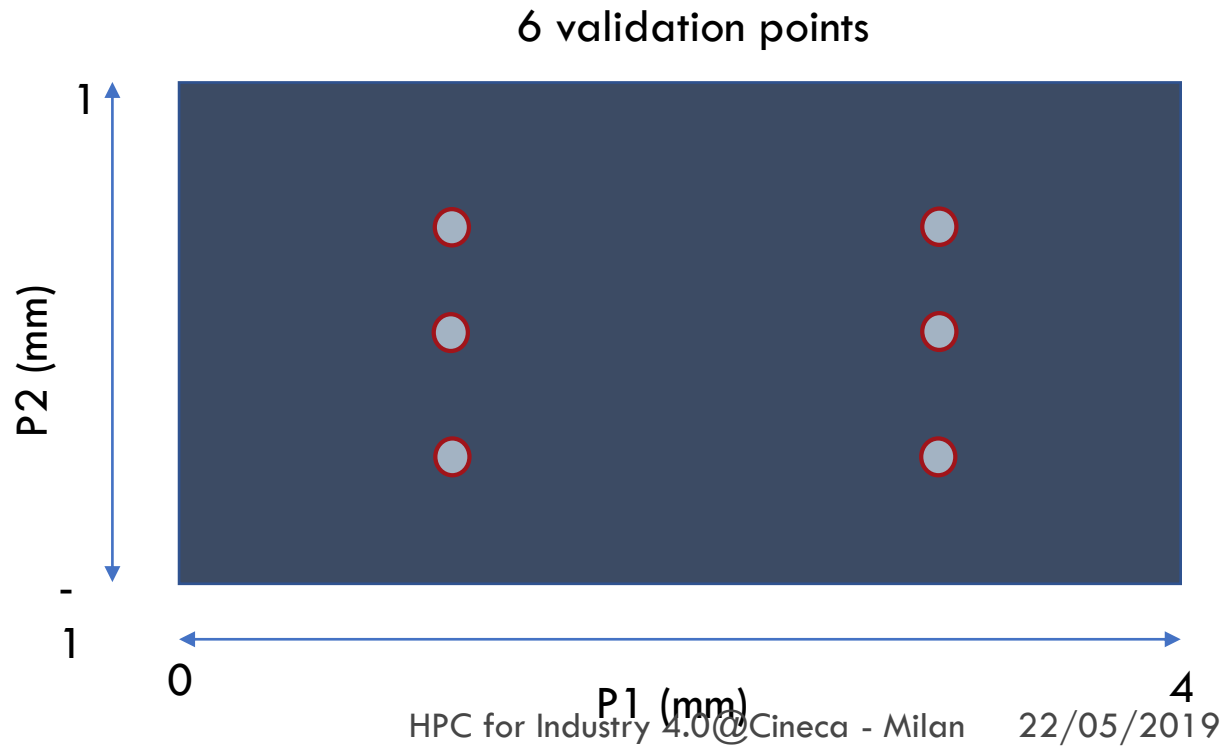
ROM of the morphed mesh



ROM of the morphed mesh

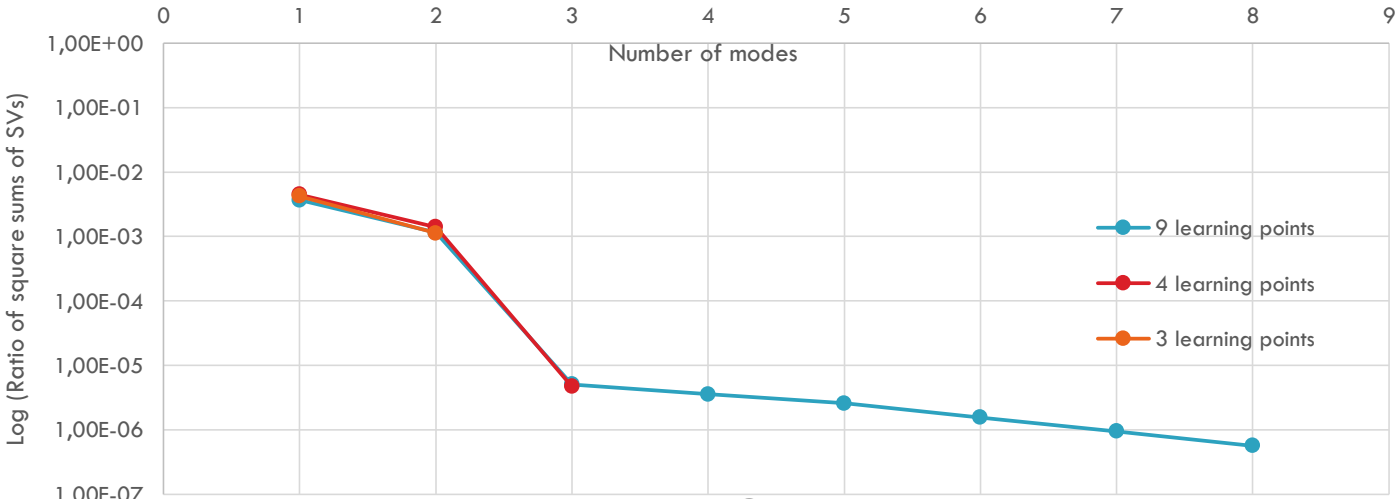


ROM of the morphed mesh



ROM of the morphed mesh: Results

Singular values (SV) → Ratio of square sums of SVs $= \frac{\sqrt{\sum_{j=i}^{N} SV_j^2}}{\sqrt{\sum_{j=1}^{N} SV_j^2}}$



ROM of the morphed mesh: Results

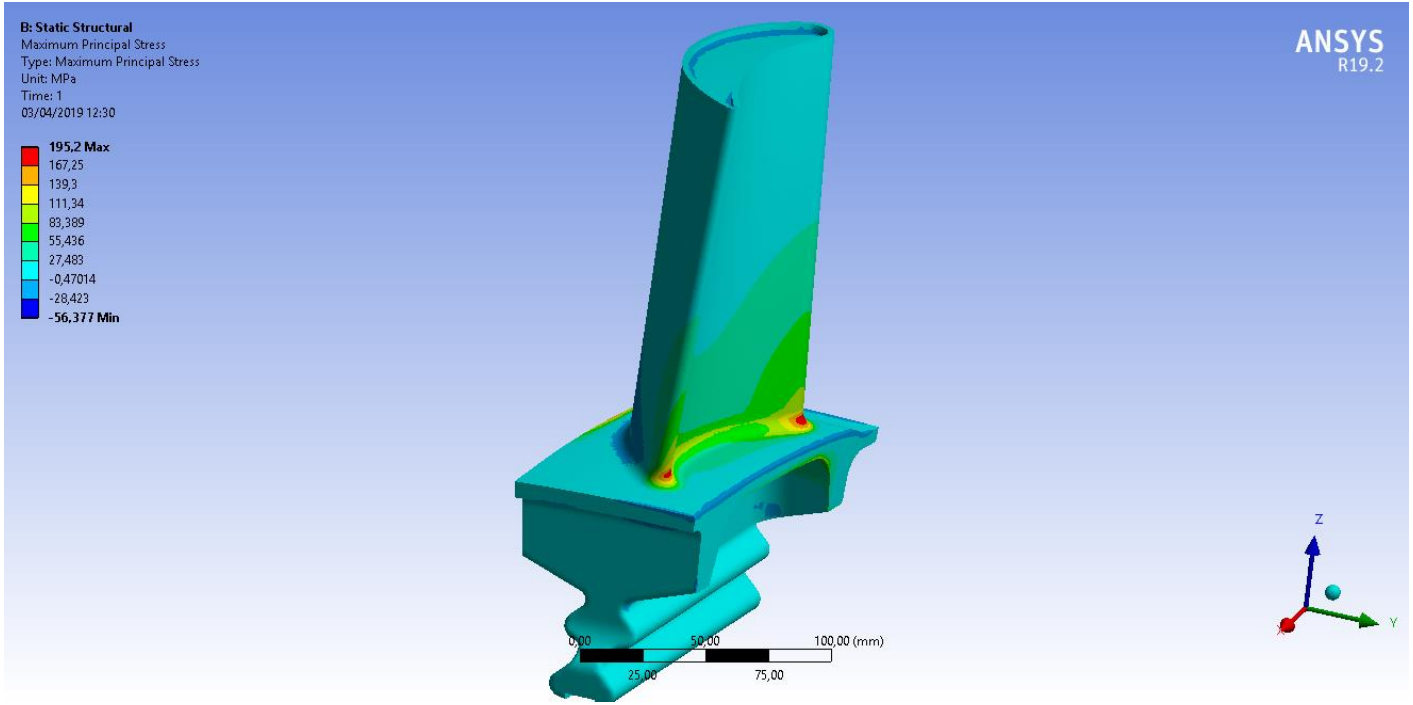
Number of modes = 3

N° learning points	$\varepsilon = \max_{6\ val.points} \left(\max_{all\ mesh\ nodes} (\mathrm{dist}(\boldsymbol{X}_{RBF}, \boldsymbol{X}_{ROM})) \right)$
3	$6.09 \cdot 10^{-3} mm$
4	$5.66 \cdot 10^{-3} mm$
9	$3.32 \cdot 10^{-2} mm$

P1 ≡ (0; 4) mm

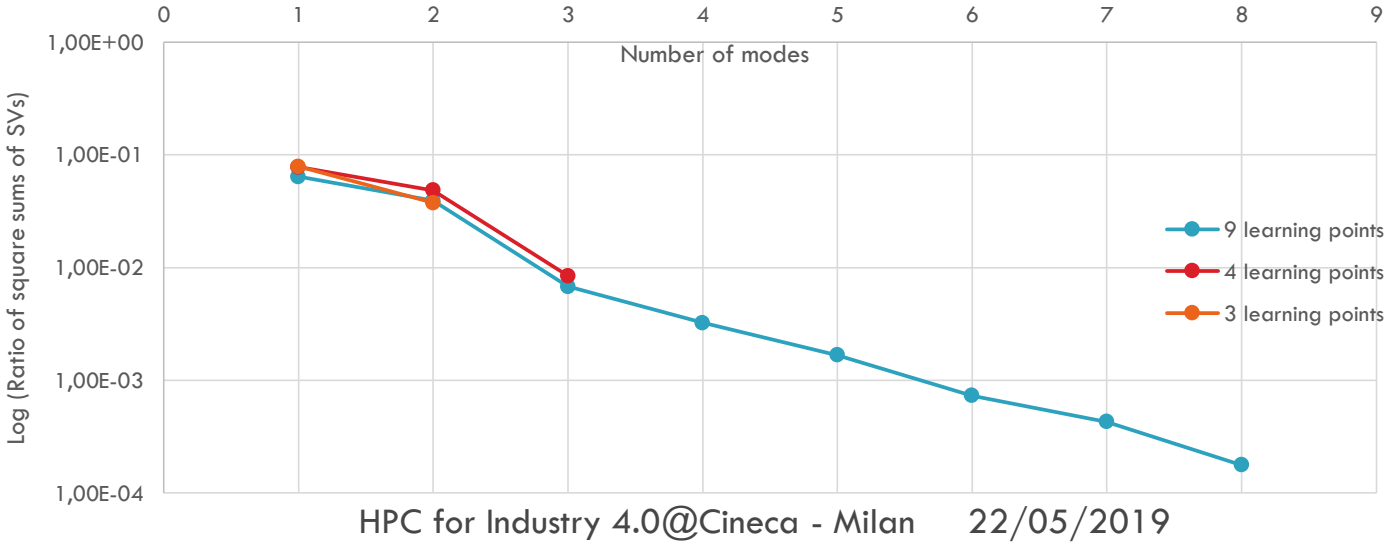
P2 ≡ (-1; 1) mm

ROM of the maximum principal stress



ROM of the maximum principal stress: Results

Singular values (SV) → Ratio of square sums of SVs $= \frac{\sqrt{\sum_{j=i}^{N} SV_j^2}}{\sqrt{\sum_{j=1}^{N} SV_j^2}}$

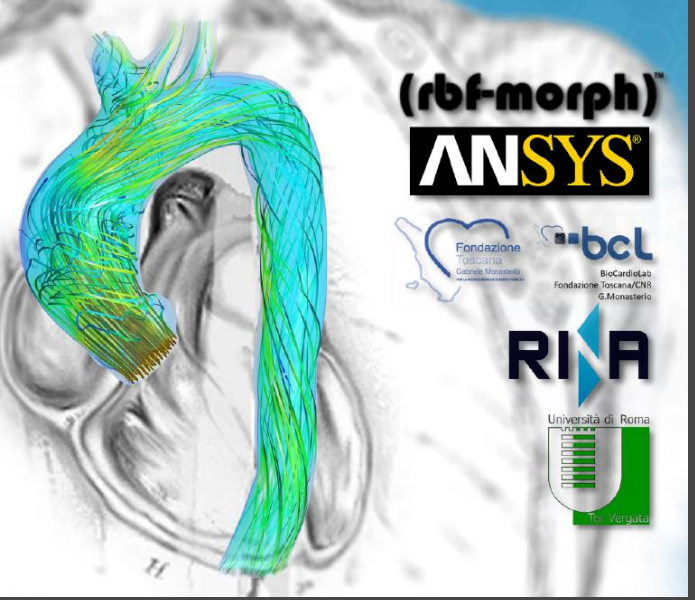


ROM of the maximum principal stress: Results

$$\frac{\|\boldsymbol{\sigma}_{RBF}-\boldsymbol{\sigma}_{ROM}\|_2}{\|\boldsymbol{\sigma}_{RBF}\|_2} < 1\%$$

N° learning points	$\boldsymbol{\varepsilon} = \max_{6\ val.points}\left(\max_{all\ mesh\ nodes}\left(\sqrt{(\sigma_{\boldsymbol{RBF}}-\sigma_{ROM})^2}\right)\right)$
3	14.669 MPa
4	6.230 MPa
9	4.253 MPa

Order of magnitude of Maximum principal stress Maximum: 10^2 MPa



(rbf-morph)™

ANSYS PREFERRED SOLUTION PARTNER

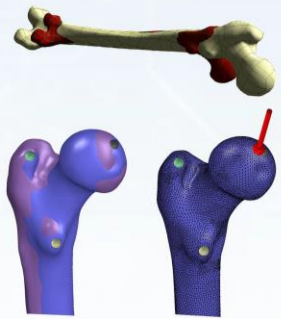
ROM OF AN ANEURYSM HEMODYNAMICS

Fluent Add On based workflow

Medical digital twin

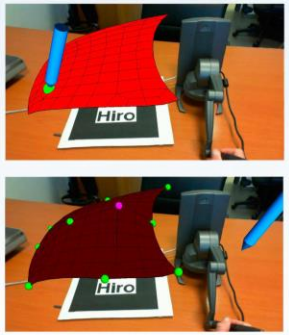
RBF MESH MORPHING

Radial Basis Functions (**RBF**) based Mesh Morphing allows to easily and rapidly adapt exhisting meshes to new shapes.



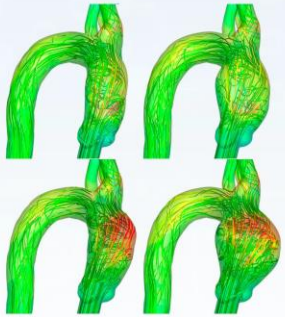
INTERACTIVE SCULPTING

Augmented Reality environment together with **Haptic Devices** allow to use fingers to interactively modify and sculpting model surfaces.



FAST RESULT ACCESS WITH ROM

Thanks to ANSYS® Reduced Order Model (**ROM**) technology, CFD and CSM results on morphed models can be inspected in real time.



RBF4ARTIST

Digital Twin and mesh morphing application

Fondazione Toscana Gabriele Monasterio

bcl BioCardioLab Fondazione Toscana/CNR G.Monasterio

ANSYS

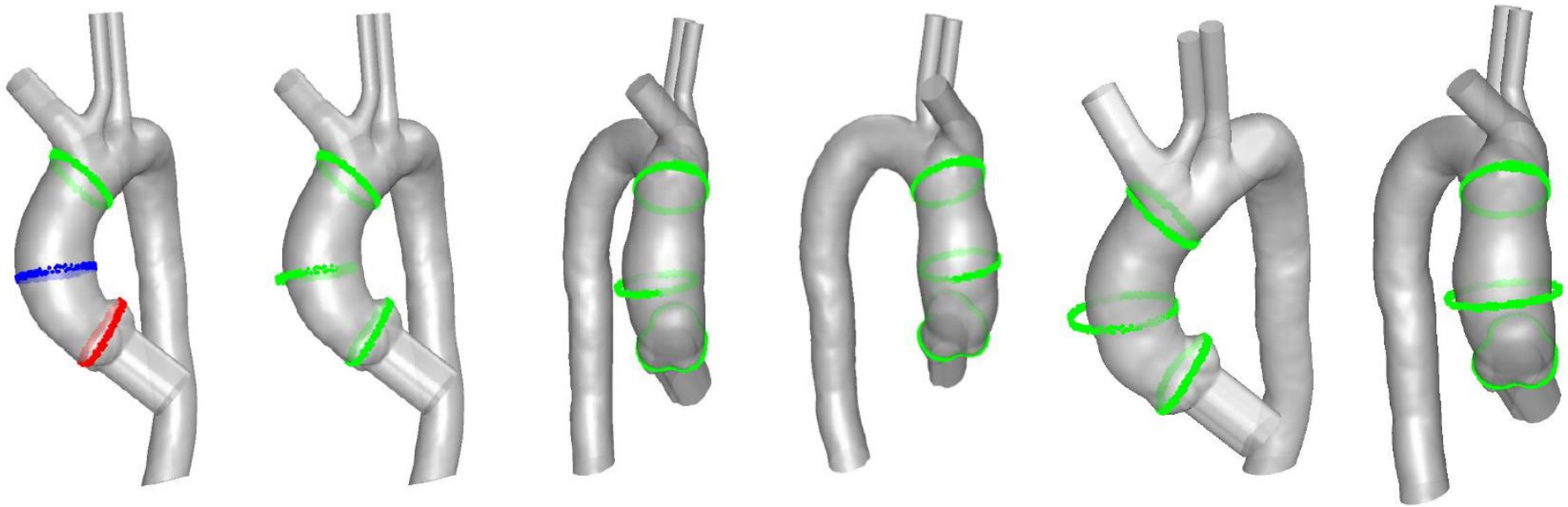
Università di Roma Tor Vergata

(rbf-morph)™

RINA

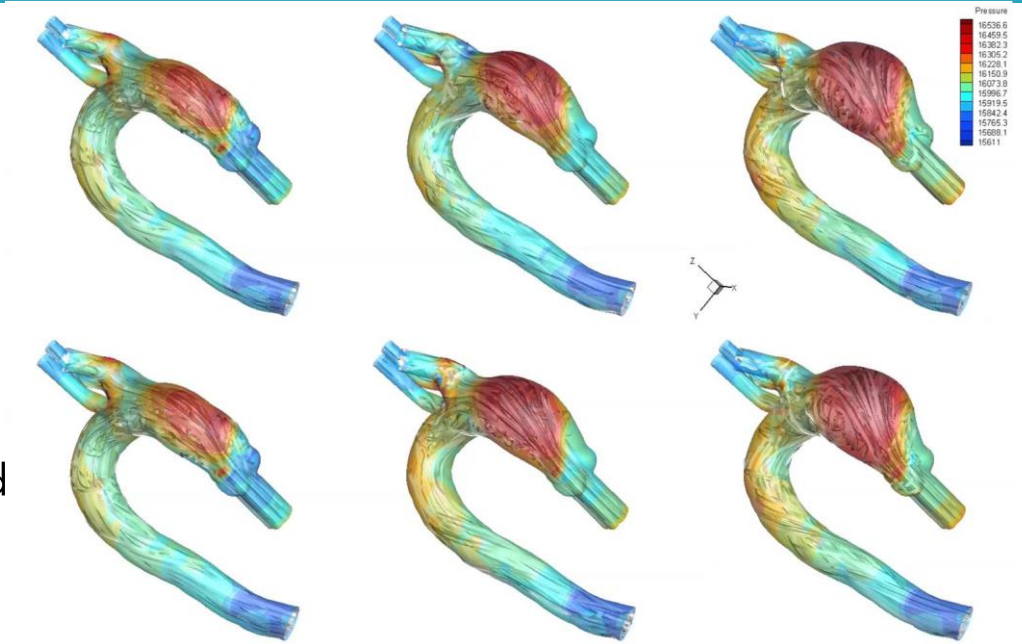
Me Di TA Te

Parametric shape of the bulge



Bulge evolution predicted using ROM

- 5 shape parameters: 40 snapshots in the design space
- 5 orthogonal modes extracted
- Error with respect to 10 modes below 1%
- Each DP requires 30 mins on a 128 GB, 20 cores Intel Xeon
- A grow of the bulge is inspected acting on the shape parameters
- Max error registered (ROM vs. full) 2.5%



Conclusions

- RBF Morph is an advanced **mesh morphing** technology based on Radial Basis Functions
- A **shape parametric** mesh is obtained. Parameters can be steered using standard optimization tools
- The strong integration with **ANSYS products** allows to **create ROM** accounting for shape effect
- A real time interaction with ROM is feasible using the **ROM of the mesh** combined with the ROM of the CAE solution
- The integration with ANSYS Twin Builder has been demonstrated with two detailed examples
- Shape parametric **digital twins** can be deployed (.romz, .fmu)

goo.gl/1svYd

twitter.com/RBFMorph

linkedin.com/company/rbf-morph

youtube.com/user/RbfMorph

rbf-morph.com

(rbf-morph)™

Many thanks for your kind attention!

marco.biancolini@rbf-morph.com