INTERNATIONAL CAE CONFERENCE

35th INTERNATIONAL CAE CONFERENCE AND EXHIBITION

THE ENGINEERING SIMULATION PATH TO DIGITAL TRANSFORMATION

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Vicenza Convention Centre @Fiera di Vicenza

CAE Up: digital twins at the service of manufacturing processes

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Summary

- RBF Morph Introduction
- Robust design concepts
- Radial Basis Functions mesh morphing and projection
- Test case
- CloudiFacturing project
- CAE^{Up} Experiment
- Conclusions

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RBF Morph: celebrating 10 years of mesh morphing!

- On demand ANSYS Fluent Add On conceived in 2007 for a F1 Top Team and launched on the market in 2009
- Offered today as
  - ANSYS Fluent Module
  - ANSYS Mechanical ACT Extension
  - Stand Alone software and **HPC RBF library**

(rbf-morph)™

Welcome to the World of Fast Morphing!

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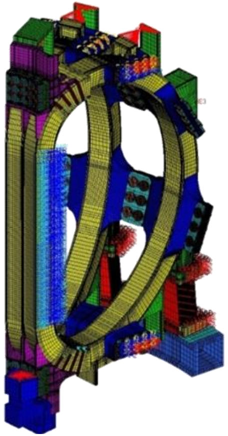
RBF Morph: celebrating 10 years of mesh morphing!

Robust design concepts

- The actual **manufactured shapes** represent the nominal geometry within a prescribed tolerance
- The effect on performances can be **predicted** in advance (mesh morphing and RS method are typically adopted)
- The effect on performances can be **evaluated after manufacturing** (an update of CAE models is required!)
- The same concepts can be applied to parts that passed QA (i.e. deviations within prescribed tolerances) as well to **off-design parts** (for instance repaired ones)
- According to the **Digital Twin** concept we want the CAE model to be individual part specific

Robust design concepts

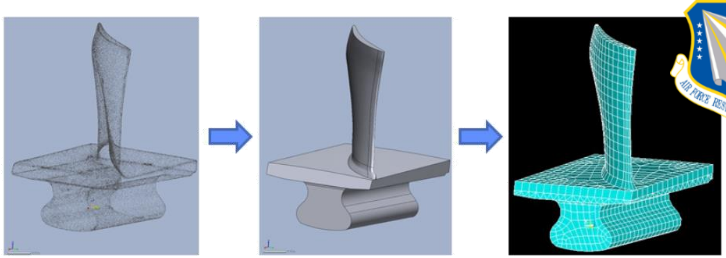
- A. Portone, A. Formisano, G. D'Amico, M. Jimenez, B. Bellesia Results on error fields simulation in ITER from the first EU TF coil manufacturing. 33rd Meeting of ITPA MHD 1-3 April 2019, Daejeon, South Korea.
- Biancolini, M.E., Cella, U., 2019. Radial basis functions update of digital models on actual manufactured shapes. Journal of Computational and Nonlinear Dynamics 14, 021013.
- Kaszynski, A. A., Beck, J. A., & Brown, J. M. (2014, June). Automated finite element model mesh updating scheme applicable to mistuning analysis. In ASME Turbo Expo 2014: Turbine Technical Conference and Exposition. American Society of Mechanical Engineers Digital Collection.



Clean Sky

RIBES

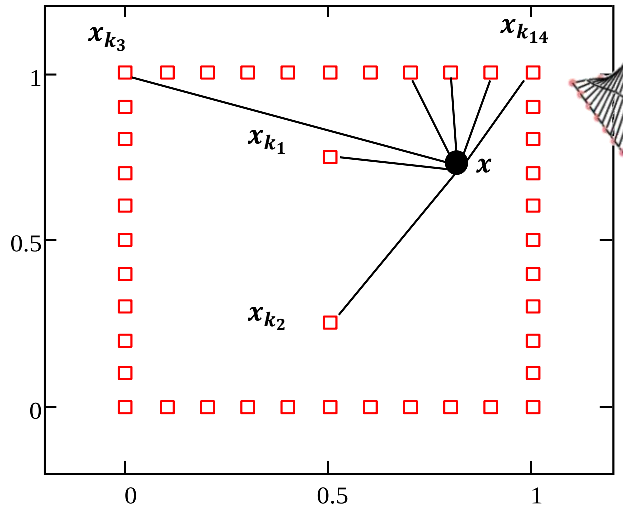
FUSION FOR ENERGY

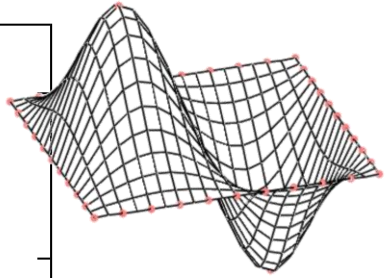


RBF Background

- RBFs are a mathematical tool capable to **interpolate** in a generic point in the space a function **known** in a discrete set of points (**source points**).
- The interpolating function is composed by a **radial basis** and by a **polynomial**.

$$s(\boldsymbol{x}) = \underbrace{\overbrace{\sum_{i=1}^{N} \gamma_i \varphi\left(\left\| \boldsymbol{x} - \boldsymbol{x}_{k_i} \right\|\right)}^{\text{radial basis}}}_{\text{distance from the i-th source point}} + \overbrace{h(\boldsymbol{x})}^{\text{polynomial}}$$





RBF Mesh Morphing

- Once solved the RBF problem each displacement component is interpolated

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

- Several different radial function (kernel) can be employed

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 Implicit Surface

- Let's consider the RBF of a scalar field (cubic radial function)

$$s(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i \left(\sqrt{(x - x_{s_i})^2 + (y - y_{s_i})^2 + (z - z_{s_i})^2} \right)^3 + h(\mathbf{x})$$

- It can be differentiated in closed form

$$\frac{\partial s(\mathbf{x})}{\partial x} = 3 \sum_{i=1}^{N} \gamma_i \,(x - x_{s_i}) \sqrt{(x - x_{s_i})^2 + (y - y_{s_i})^2 + (z - z_{s_i})^2} + \beta_1$$

$$\frac{\partial s(\mathbf{x})}{\partial y} = 3 \sum_{i=1}^{N} \gamma_i \,(y - y_{s_i}) \sqrt{(x - x_{s_i})^2 + (y - y_{s_i})^2 + (z - z_{s_i})^2} + \beta_2$$

$$\frac{\partial s(\mathbf{x})}{\partial z} = 3 \sum_{i=1}^{N} \gamma_i \,(z - z_{s_i}) \sqrt{(x - x_{s_i})^2 + (y - y_{s_i})^2 + (z - z_{s_i})^2} + \beta_3$$

RBF implicit surface

- The analytic gradient

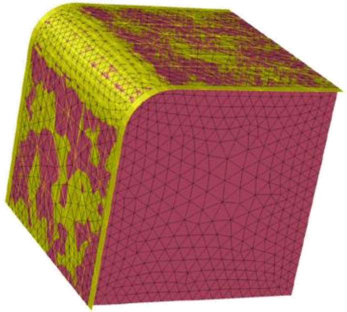
$$\nabla s(\mathbf{x}) = \left\{ \frac{\partial s(\mathbf{x})}{\partial x} \quad \frac{\partial s(\mathbf{x})}{\partial y} \quad \frac{\partial s(\mathbf{x})}{\partial z} \right\}^T$$

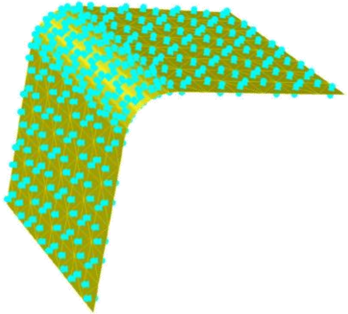
- can be used to project a point on iso-surfaces of the scalar field

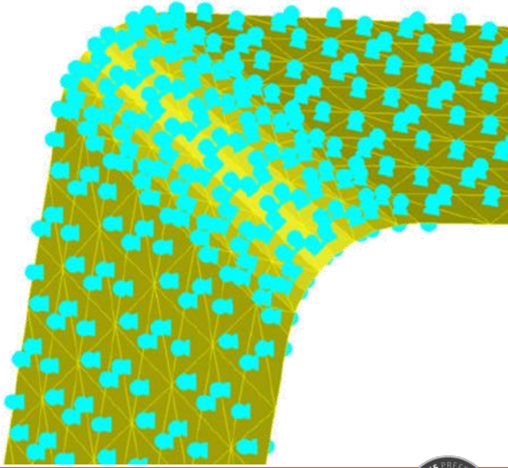
$$\mathbf{x}_{k+1} = \mathbf{x}_k + \frac{s(\mathbf{x}_k)}{||\nabla s(\mathbf{x}_k)||^2} \nabla s(\mathbf{x}_k)$$

RBF implicit surface

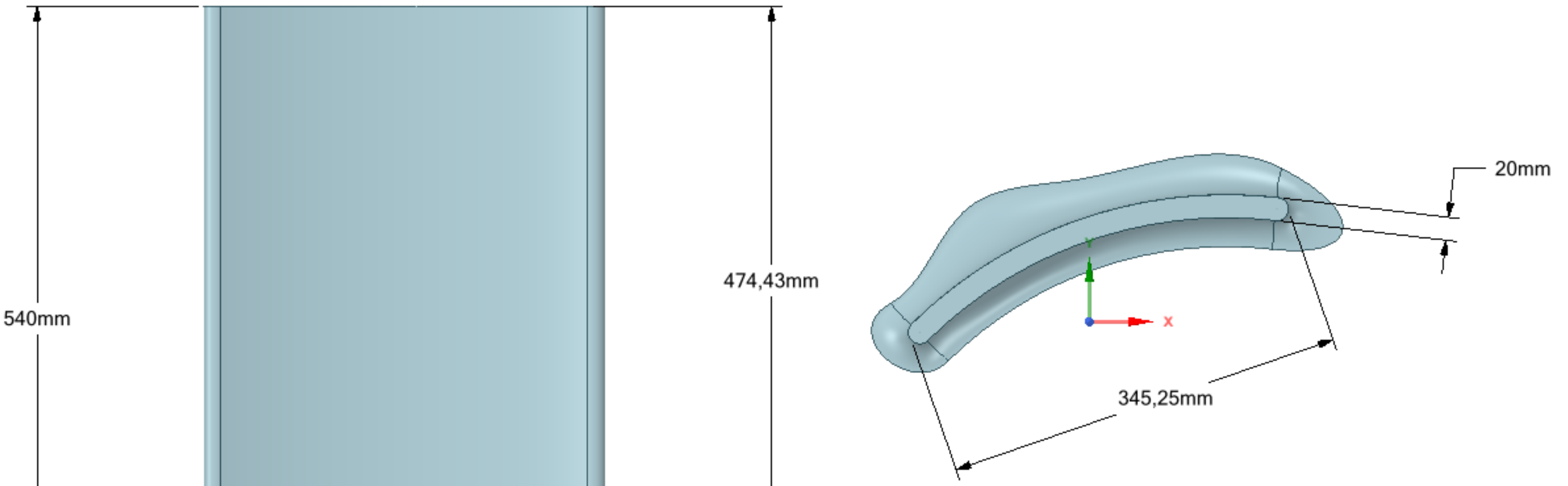
- **Source** points of the RBF are defined:
  - On centroids (f = 0)
  - On inner offset points (f = -1)
  - On outer offset points (f = 1)
- The gradient projects onto the 0 iso-surface
- Offset **distance** (uniform along the normal direction) should be tuned to **avoid clash** of offset points



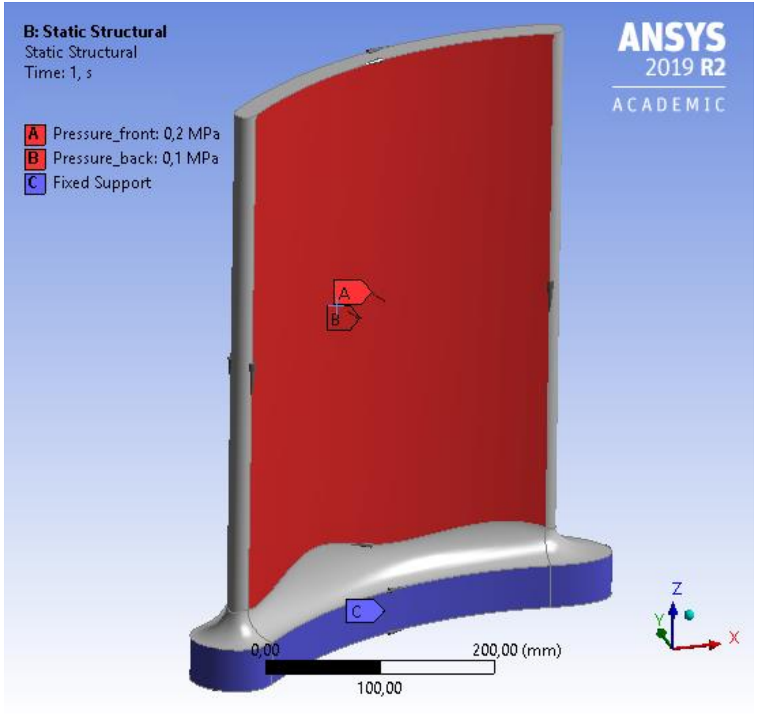


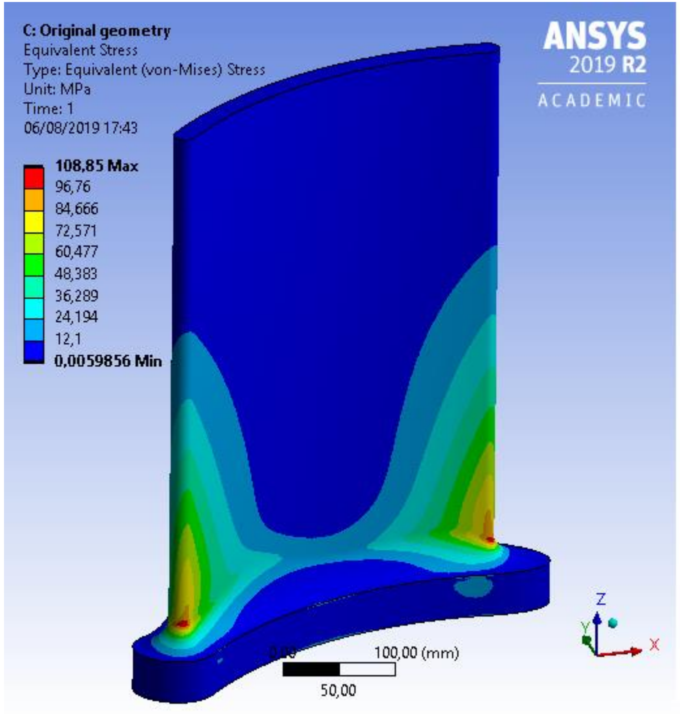


Test case – mock up of a turbine blade



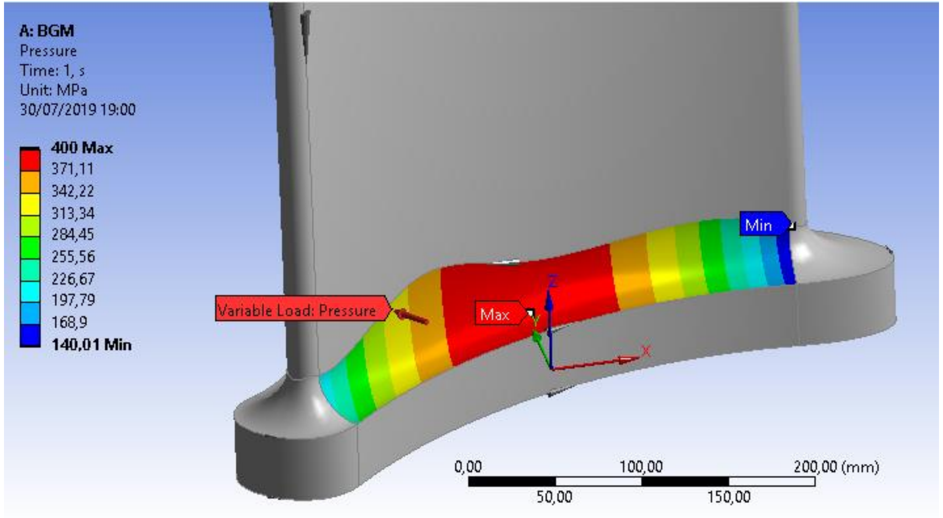
Test case – baseline stress





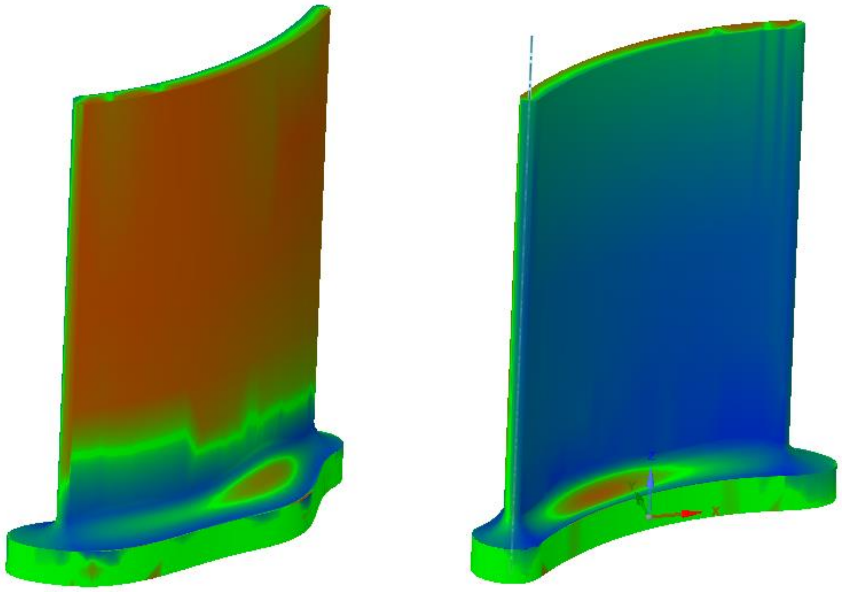
Test case – shape deviation

- The example examines the effects of manufacturing errors on a simplified **turbine blade** model
- A scan of the manufactured shape was not available and so a synthetic 3d scanned shape was generated by the application of a variable pressure field on the pressure side fillet and then by updating the shape according to local stress (BGM). A **maximum deviation of 0.4 mm** was applied.
- The shape perturbation was created adopting a **fictitious loading condition** (root clamped + constant pressure on the airfoil surface)



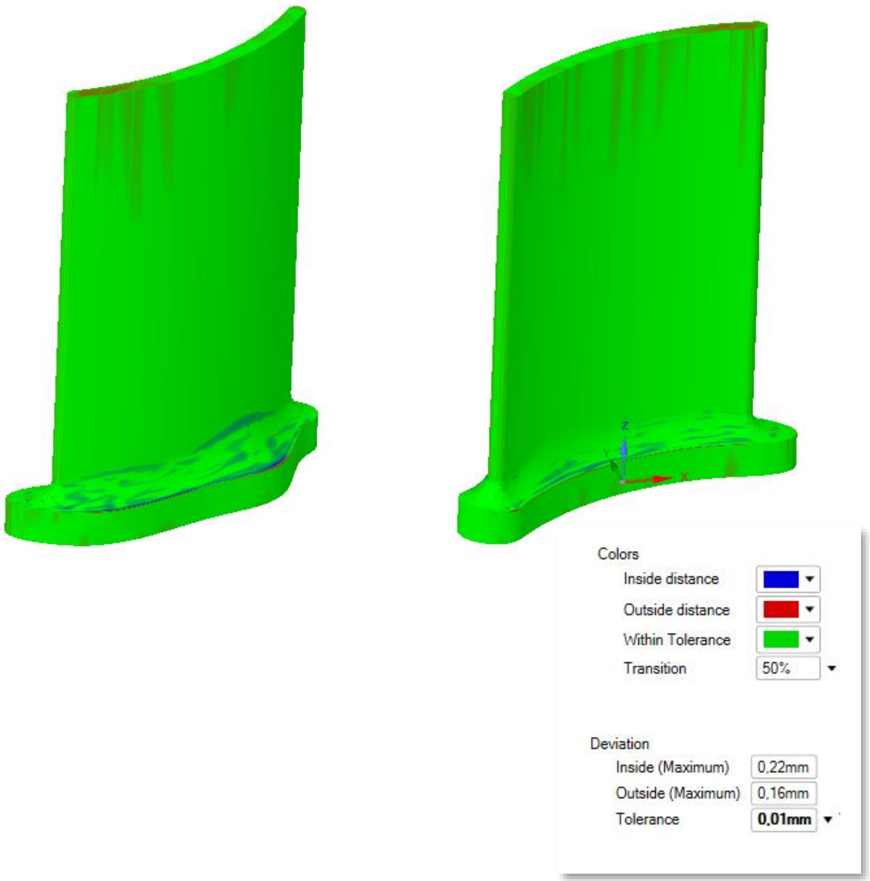
Test case - shape deviation

- A colour map is used to show the **deviation** between the two geometries
- The largest differences are in the fillet area, and the **maximum deviation** values are 0.38 mm for the inside area and 0.28 mm for the outside area



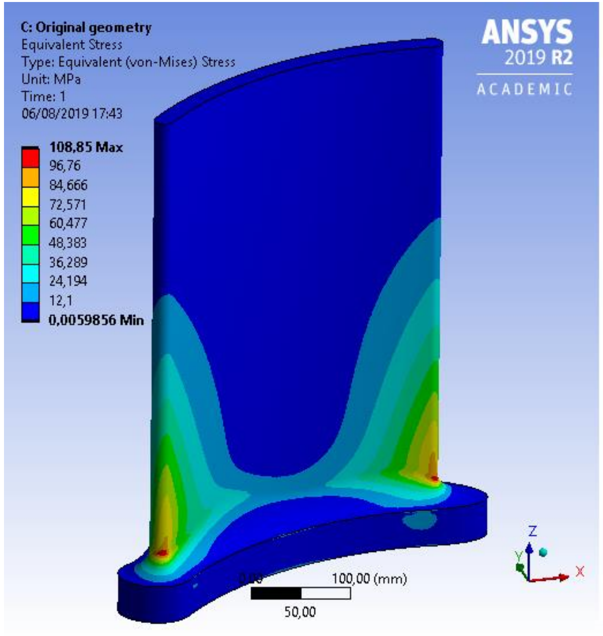
Results

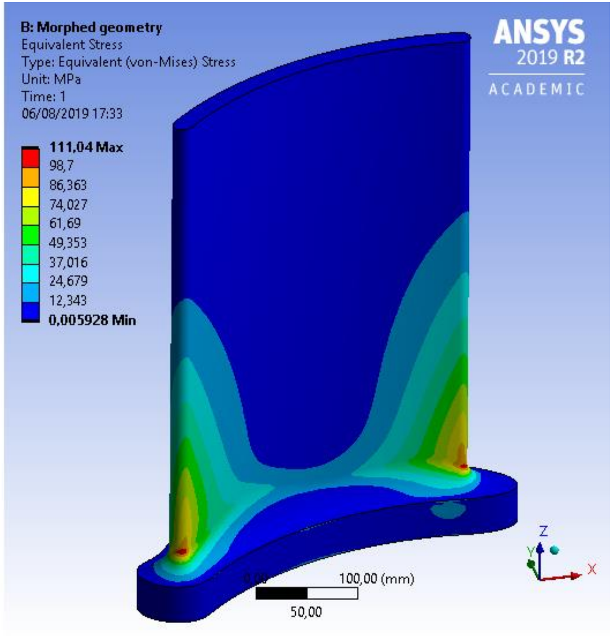
- The **morphed mesh** matches almost perfectly the target model
- The distance of almost all the sample points of the morphed body from the target one is **less than 0.01mm**
- The **measured difference** between the two geometries is contained within an interval of 0.03mm, that means less than 8% of the manufacturing tolerance



Results

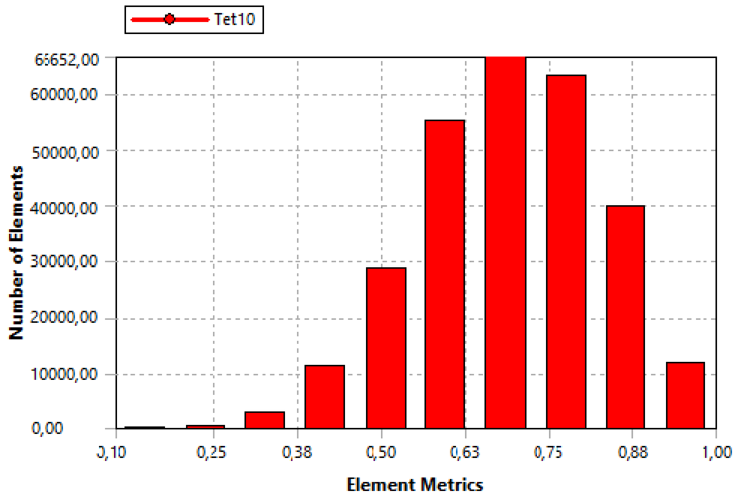
- The numerical solution shows a little increase of the maximum equivalent stress that changes from 109 MPa to 111 MPa approximately, namely below 2% in absolute terms

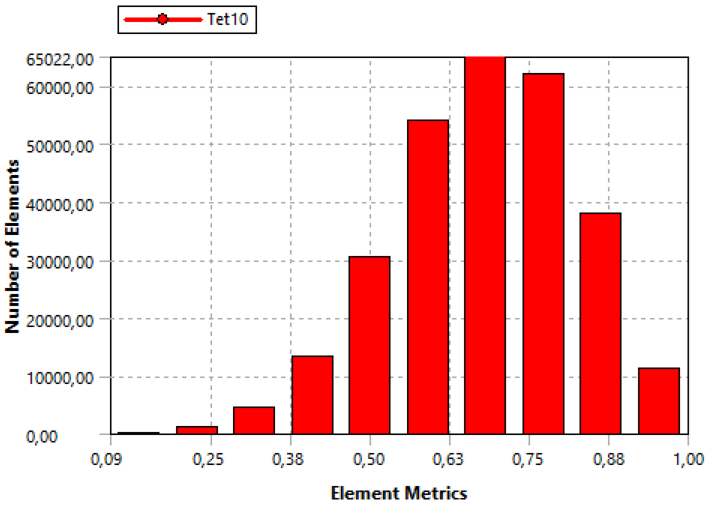




Results

- To test the goodness of the mesh morphing process, it was also made a comparison between element quality of the original mesh and the morphed mesh





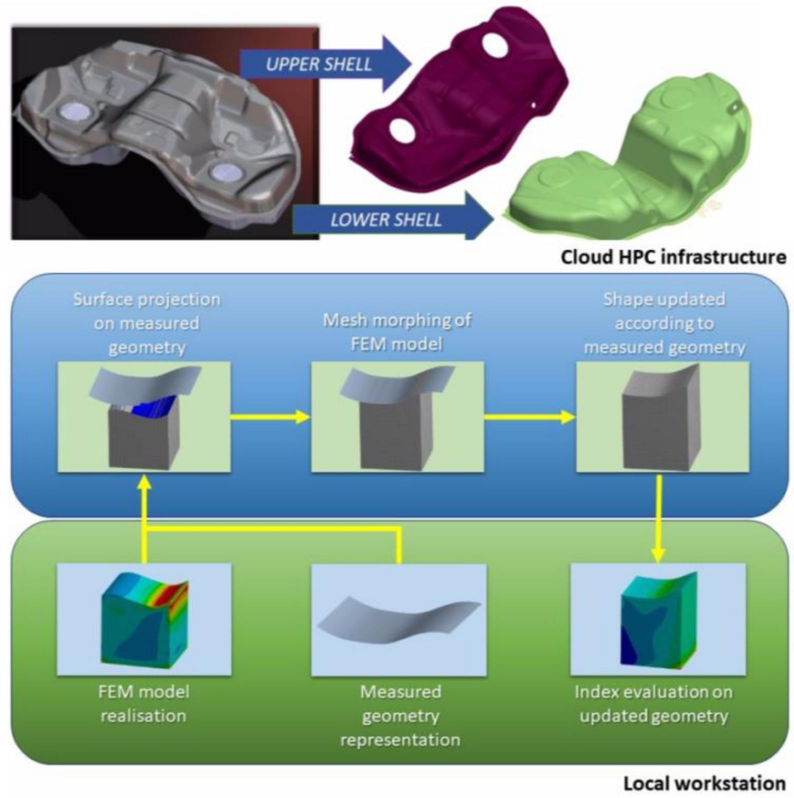
CloudiFacturing project (https://www.cloudifacturing.eu)

- The mission of **CloudiFacturing*** is to optimize production processes and producibility using **Cloud/HPC-based** modelling and simulation. By leveraging online factory data and advanced data analytics, the project contributes to the competitiveness and resource efficiency of **manufacturing SMEs**, ultimately fostering the vision of **Factories 4.0** and the **circular economy**.

(*) The project Cloudifacturing receives funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 768892.

CAE^{Up} Experiment – Overview

- **CAE^{Up}** succeeded the II call and aims to solve an important need of industrial design and optimization in a reliable and cost-effective way
- The need consists of the **verification** of the actual geometry of manufactured parts, adopting the **Digital Twin** approach
- The digital representation consists in **updating the numerical models** in the respect of the real shape of the manufactured products using **RBF mesh morphing**



CAE^{Up} Experiment – Consortium

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CAE^{Up} - Update of CAE models on actual manufactured shapes

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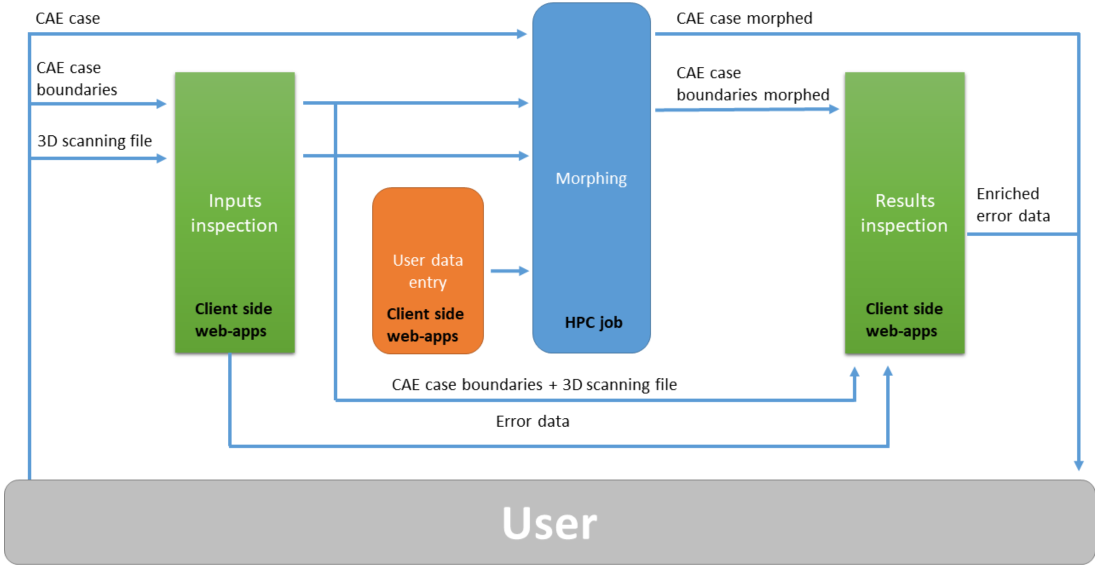
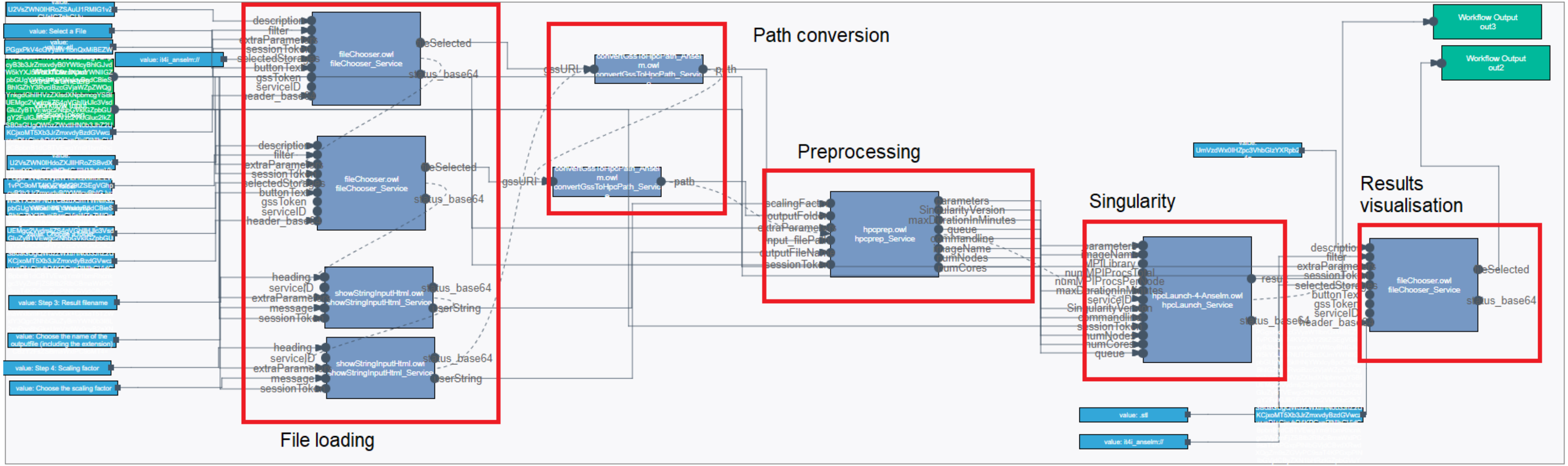
CAE^{Up} Experiment – Service benefits and features

- **effective tool**, that can be run through web, characterized by a high level of automation;
- **increased accuracy** in numerical prediction through CAE computing;
- **reduced production costs** obtained by quality assessment related to actual local shape;
- **high level of security** for the data.



SemWES workflow development

- The first stage of the workflow was finalized (docker).
- Singularity creation and management was set (HPC computing).
- Already tested (simple scaling operation through python).



SemWES workflow development

- Step 1 – 2 of the first testing

Experiment12 Demo

Welcome! This workflow takes a boundary STL surface file and scales it by a factor specified by the user,using a HPC service. The resulting STL scaled file can be accessed inside the Anselm storage

Workflow steps

1. **Select input STL boundary surface model file**
2. Select output folder
3. Select results filename
4. Select scaling factor
5. Results visualization

STL file selection

Select the .STL model file.

Select a File | Reset tree

- IT4I storage (Anselm cluster)
  - scratch
  - home
    - hpc_logs
    - rina
      - CAEBoundaries-ASCII.stl
      - 3dScanning-ASCII.stl
      - boundary.stl

Experiment12 Demo

Welcome! This workflow takes a boundary STL surface file and scales it by a factor specified by the user,using a HPC service. The resulting STL scaled file can be accessed inside the Anselm storage

Workflow steps

1. Select input STL boundary surface model file
2. **Select output folder**
3. Select results filename
4. Select scaling factor
5. Results visualization

Outout folder selection

Select where the output has to be saved

Choose a folder | Reset tree

- IT4I storage (Anselm cluster)
  - scratch
  - home
    - hpc_logs
    - rina

SemWES workflow development

- Step 3 – 4 and HPC computing.

Step 3: Result filename

Choose the name of the outputfile (including the extension)

boundaryscaled.stl | OK

Step 4: Scaling factor

Choose the scaling factor

10 | OK

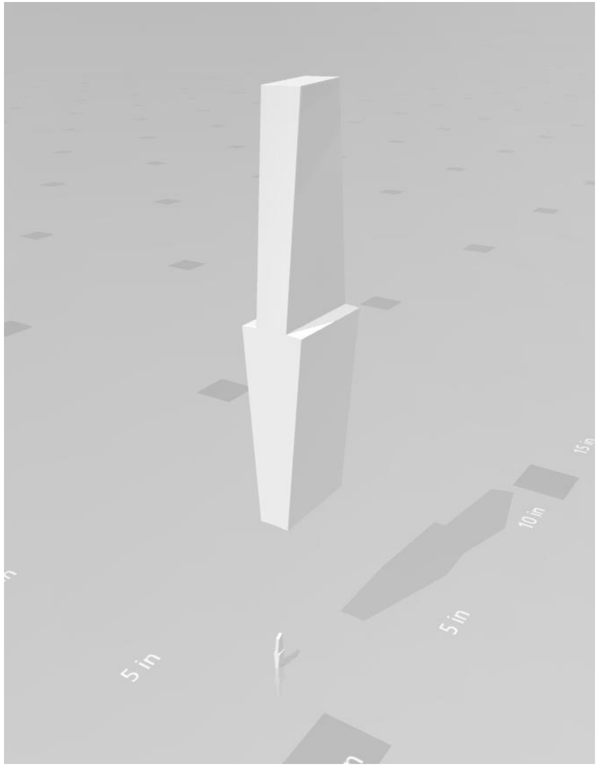
HPC job progress

This is a scaler. It's scaling a STL file on the HPC cluster.

(Status from Scaling.)

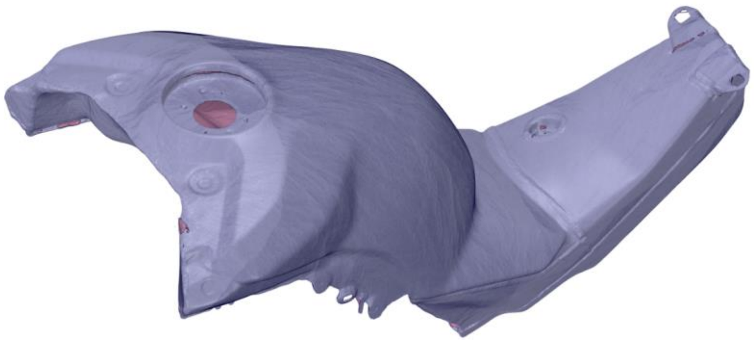
Click the Abort button to stop the waiter early. Please click only once, it will take a while until the request is processed. (The status might even update once more before the job is aborted.)

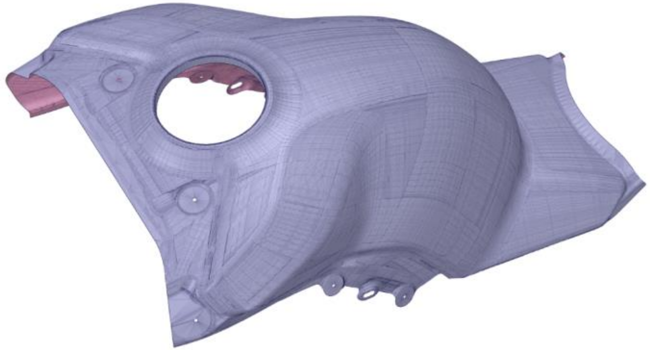
Abort



Test case – Ducati motorbike tank

- The tank was digitalized (left) and the FEM model is ready (CAD on the right)





Conclusions

- The adoption of the described procedure, based on the use of **RBF mesh morphing**, was showcased using a test case of a simplified blade
- Surface **projecting** technique based on the use of **RBF implicit surface** confirmed to guarantee high accuracy and flexibility in tackling **geometrical reconstruction** problems providing the capability to significantly reduce the effort if compared to a model reconstruction procedure adopting CAD systems.
- The workflow today demonstrated for **structural (FEA)** example is adopted for **multi-physics simulation** (including CFD) and the service of CAE^{Up} is designed to accept different mesh formats to accommodate multiple physics

Thank you!

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