RBF Morph and ROM

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

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

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…for better solutions!

- Factories Of the Future Resources, Technology, Infrastructure and Services for SImulation and MOdelling
- WP515: “Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms”
- HSL srl, Trento; University of Rome “Tor Vergata”; CINECA

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ANSYS integrated solutions

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

- Released in 2015
- Fully embedded in ANSYS Mechanical (parametric)
- Benefits of underlying geometry (or aux geo with dead meshes)
- …WB Meshing

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RBF Morph ACT Extension

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

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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**
- 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?**

**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 passaggera 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 comprendere i tempi di sviluppo di un nuovo prodotto, con il passaggio al digital twin si mira all’uso della simu-

laione durante la vita del prodotto stesso. Una rappresentazione digitale della fisica che modello un sistema reale infatti molto più utile per procedere al comportamento e per interagire con il sistema reale anziché dell’evoluzione delle informazioni disponibili grazie al gemello digitale.

Un aspetto molto importante relativo all’interazione con il digitale è la possibilità di interagire con i dati di progettazione e lo sviluppo di un nuovo prodotto. Con il passaggio al digital twin si mira all’uso della simulazione durante la vita del prodotto stesso.
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](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
ROM OF STRESSES ACTING ON A TURBINE BLADE

ACT Extension based workflow
ACT Extension based workflow
The study is focused on the stress at the root fillet.

- Simplified boundary conditions
- Mesh refinement areas
- Baseline stress solution
Problem description

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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

Parametric space

P1 (mm)

P2 (mm)
ROM of the morphed mesh

3 learning points

P1 (mm)  P2 (mm)

0  1

1  4

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ROM of the morphed mesh

4 learning points

P1 (mm)

P2 (mm)
ROM of the morphed mesh

9 learning points
ROM of the morphed mesh

6 validation points

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ROM of the morphed mesh: Results

Singular values (SV) \[ \text{Ratio of square sums of SVs} = \frac{\sqrt{\sum_{j=1}^{N} SV_j^2}}{\sqrt{\sum_{j=1}^{N} SV_j^2}} \]

[Graph showing the logarithm of the ratio of square sums of singular values versus the number of modes, with three lines representing 9, 4, and 3 learning points, and a date of 22/05/2019.]
ROM of the morphed mesh: Results

Number of modes = 3

<table>
<thead>
<tr>
<th>N° learning points</th>
<th>$\varepsilon = \max_{6 \text{ val. points}} \left( \max_{\text{all mesh nodes}} \left( \text{dist}(X_{RBF}, X_{ROM}) \right) \right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>$6.09 \cdot 10^{-3} , mm$</td>
</tr>
<tr>
<td>4</td>
<td>$5.66 \cdot 10^{-3} , mm$</td>
</tr>
<tr>
<td>9</td>
<td>$3.32 \cdot 10^{-2} , mm$</td>
</tr>
</tbody>
</table>

$P_1 \equiv (0; 4) \, mm$

$P_2 \equiv (-1; 1) \, mm$
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}}

- Log (Ratio of square sums of SVs)
- Number of modes
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ROM of the maximum principal stress: Results

\[
\frac{\|\sigma_{\text{RBF}} - \sigma_{\text{ROM}}\|_2}{\|\sigma_{\text{RBF}}\|_2} < 1\%
\]

<table>
<thead>
<tr>
<th>N° learning points</th>
<th>( \varepsilon = \max_{6 \text{ val.points}} \left( \max_{\text{all mesh nodes}} \left( \sqrt{ (\sigma_{\text{RBF}} - \sigma_{\text{ROM}})^2 } \right) \right) )</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>( \max_{6 \text{ val.points}} \left( \max_{\text{all mesh nodes}} \left( \sqrt{ (\sigma_{\text{RBF}} - \sigma_{\text{ROM}})^2 } \right) \right) )</td>
<td>14.669 MPa</td>
</tr>
<tr>
<td>4</td>
<td>( \max_{6 \text{ val.points}} \left( \max_{\text{all mesh nodes}} \left( \sqrt{ (\sigma_{\text{RBF}} - \sigma_{\text{ROM}})^2 } \right) \right) )</td>
<td>6.230  MPa</td>
</tr>
<tr>
<td>9</td>
<td>( \max_{6 \text{ val.points}} \left( \max_{\text{all mesh nodes}} \left( \sqrt{ (\sigma_{\text{RBF}} - \sigma_{\text{ROM}})^2 } \right) \right) )</td>
<td>4.253  MPa</td>
</tr>
</tbody>
</table>

Order of magnitude of Maximum principal stress Maximum: \( 10^2 \) MPa
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 existing 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.

Digital Twin and mesh morphing application

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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)
Many thanks for your kind attention!

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