RBF Morph software
How to boost Fluent Adjoint using RBF Morph

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Outline

• Company Introduction
• RBF Morph Software Line
• Ongoing Researches
• Industrial Applications
• Fluent Adjoint Coupling
RBF Morph is a pioneer and world-leading provider of numerical morphing techniques and solutions conceived to efficiently handle shape optimization studies concerning most challenging industrial applications. We are an independent software-house and vendor. Our main product is RBF Morph™, that is a unique morpher that combines a very accurate control of the geometrical parameters with an extremely fast mesh smoothing properly designed to be integrated in advanced computational optimization procedures.

The RBF Morph tool is currently available in the market mainly as add-on of the CFD commercial code ANSYS® Fluent®.
The **RBF Morph** tool had its inception in 2008 as an on-demand solution for a Formula 1 top team. The need was a novel technology able to change the shape of large CFD numerical models as fast as possible. The final result had been so good that the technology was packaged in a commercial software product and launched onto the market.

At present, Dr. Marco Evangelos Biancolini is the unique owner of the **RBF Morph** technology and, as Director, avails himself of the collaboration of several experts for the delivery of products and services.
Company Introduction

- Morphing-based numerical tools and services
- RBF Morph Milestones
  - 2008: tool implementation for Formula 1 top team consultancy activity
  - 2009: founded in Italy
  - 2009: Software Partner of ANSYS
  - 2009: at EASC RBF Morph won the Most Advanced Approach Award Most Innovative Approach using Simulation Methods
  - 2011: strategic partnership with Tor Vergata University (Rome)
  - 2012: OEM partner of ANSYS
  - 2013: beneficiary of an FP7 AAT Project RBF4AERO
  - 2013: at ASWC RBF Morph awarded for the Best use of HPC
  - 2013: Partner of Enginsoft
  - 2014: beneficiary of FP7 Project RIBES
  - 2014: beneficiary of FPT Fortissimo
• Awarded mesh morphing software available as an add-on for ANSYS Fluent CFD solver

• HPC RBF general purposes library (state of the art algorithms, parallel, GPU)

• Stand alone morphing software + smoothing commands for different mesh formats

• ANSYS Mechanical ACT module (first release planned in June 2014)
• **Add on** fully integrated within **Fluent** (GUI, TUI & solving stage), **Workbench** and **Adjoint Solver**

• **Mesh-independent** RBF fit used for surface mesh morphing and volume mesh smoothing

• **Parallel** calculation allows to morph **large size** models (many millions of cells) in a short time

• Management of **every kind of mesh** element type (tetrahedral, hexahedral, polyhedral, etc.)

• Support of the **CAD re-design** of the morphed surfaces

• **Multi fit** makes the Fluent case truly parametric (only 1 mesh is stored)

• **Precision**: exact nodal movement and exact feature preservation (**RBF** are better than **FFD**)
Deeply integrated in ANSYS Mechanical: same look & feel, same interaction logic

Nested in the usual Mechanical tree as an added object, shares its scoping tools for geometrical and mesh elements selections

Written in python and xml, uses external RBF Morph core libraries

Child hierarchical logic for complex morphings (two steps, three steps, ..., n steps setups)
• RBF solutions are fully compatible and **exchangeable** between add-on and standalone versions

• Support for STL and CGNS file formats. Selected morphed surfaces can be exported in STL format and **back to CAD** is possible via STEP files

• **Add-on-like** interface

• **Solver independent** process currently supports many mesh formats

• Functions **scriptable** via tcl

• Global supported bi-harmonic functions and $C^0$, $C^2$, $C^4$ compact supported functions available
Ongoing RBF Morph Researches
RBF Morph and Adjoint coupling: Adjoint sculpting, Adjoint preview, Augmented DOE

- **STL** targeting, **CAD** controlled surfaces
- **Mesh to CAD** features
- Mapping of **magnetic** and **pressure** loads
- Interpolation of **hemodynamic** flow fields acquired *in vivo*
- Strain and **stress** calculation (experimental data, coarse FEM, isostatic lines)
“Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimisation” –

ACP3-GA-2013-605396

www.rbf4aero.eu
• Radial basis functions at fluid Interface Boundaries to Envelope flow results for advanced Structural analysis

JTI-CS-2013-GRA-01-052
• Factories Of the Future Resources, Technology, Infrastructure and Services for Simulation and Modelling

• Approved experiment: “Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms”
Industrial Applications
Sails Trim (Ignazio Maria Viola, University of Newcastle)

Morphing Preview (A=0)

Yacht and superyacht consultancy and research
school of marine science and technology
ignazio.viola@ncl.ac.uk

2014 ANSYS USERS MEETING
May 2014 - Milano, Italy
Optimization of sweep angles
Optimization of nacelle
FSI analysis on a Indy race car
**FSI analysis on a Indy race car**

<table>
<thead>
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<th>Modes used</th>
<th>Maximum displacement (mm)</th>
<th>Maximum difference (mm)</th>
<th>Maximum error (%)</th>
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</tbody>
</table>

[2014 ANSYS USERS MEETING](#)  
May 2014 - Milano, Italy
Ice accretion morphing
3D accretion morphing

2014 ANSYS USERS MEETING
May 2014 - Milano, Italy

www.rbf-morph.com
RBF Morph, an ANSYS Inc. Partner
Fluent Adjoint Coupling
Design evolution
• An **adjoint solver** allows to compute the **derivatives** of an engineering quantity with respect to the positions of all the nodes of the mesh.

• Post-process the **adjoint solution allows** to get:
  - **Shape Sensitivity**
  - **Contour & Vector plots of sensitivities**

• Coupling with a **mesh morpher** allows to fully exploit sensitivity data
  - An **FFD morpher** comes with the adjoint solver
  - **RBF Morph** is an excellent companion to take advantage of adjoint sensitivity data!
Possible strategies

- Adjoint self sculpting
- Adjoint preview (Sensitivity analysis with imposed shapes)
- Augmented-DOE
• **Adjoint shape** can be captured by RBF Morph

• The morphing action can be **accurately** controlled (Box, Surfs, Points...)

• Multiple “sculpted” shape modifications can be **combined**

• Optimized shape can be exported back to CAD

• Shape data can be transferred to a different model (the method is meshless)
• **Nodal sensitivities** are used to compute the sensitivity with respect to **shape parameters**

• A **single adjoint** solution can be used to analyze the observable change introduced by **many** imposed shape variations

• The **computational cost** is unaffected by the number of shape variations analyzed!

• **Shape variations** can be easily defined and blended together using **RBF Morph**

• Derivatives are available at a **given state** of shape parameters (i.e. after morphing)
Augmented DOE

• Adjoint derivatives with respect to shape parameters allows to **enrich** the **response surface** with tangent data

• Each full computed points of DOE (CFD+adjoint) comes with the value of the **response** and all the **local derivatives**

• **Example**: with 9 shape parameters 10 augmented DOE runs produce the same information of 100 CFD runs. The cost of the adjoint update is twice of simple CFD so a 5x speed-up can be achieved.
Fluent Adjoint Coupling Examples
Adjoint Self Sculpting

- Manifold system
- Shape information coming from the **Fluent Adjoint** morpher are used to control the shape
- A single adjoint (baseline shape) is used to define shape modifications in **two locations**
- New shape modifications can be **combined** as usual
Adjoint Self Sculpting

- Obtained shapes are used to update the original CAD
- Both runners are sculpted using the same solution data
Adjoint Self Sculpting

- 90 deg bend optimization
- New shape is sculpted using adjoint data
- Original geometry (2 cylinders and a torus) is transformed in NURBS
- NURBS are morphed using the back to CAD tool of RBF Morph
Adjoint preview

- A cube immersed in a wind tunnel is made parametric using 3 shapes.
- Steepest descent gradient method allows to reduce drag by 16.7%.

\[ \alpha_j = -\beta \frac{dI}{dx_j} \]
Engine Air box

- **32 shape parameters** are used to control the geometry of the plenum and of the three runners.
- Original **packaging** constraints are preserved.
- Each complete run consists in 3 CFD + adjoint simulation (one for pressure drop of each runner).
- Design **objectives**: minimum pressure drop, uniform pressure drop.
- Design **constraints**: regular shape of runners.
Engine Air box
Engine Air box

Obtained shape allows to get a **15.3%** reduction of pressure drop and uniform distribution.

<table>
<thead>
<tr>
<th></th>
<th>Mean pressure Drop [Pa]</th>
<th>Unbalance</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>39.7</td>
<td>12.45%</td>
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<tr>
<td>Optimized</td>
<td>33.635</td>
<td>0.12%</td>
</tr>
<tr>
<td>Reduction</td>
<td>15.3%</td>
<td>99.0%</td>
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</tbody>
</table>
• **3 shape parameters** are used to control the shape of the rear part (tail, roof, back window)

• Each complete run consists in a **CFD + adjoint** simulation (drag and its 3 derivatives are obtained)

• The **steepest descent** method is used to update the 3 shape parameters at each design cycle.

• Mesh size **3.6 millions** cells.

\[ \alpha_j = -\beta \frac{dI}{dx_j} \]
Sedan car
Sedan car
Sedan car
Sedan car

- A 3.13% drag reduction is achieved after 33 cycles
- With just 3 parameters a standard DOE has comparable costs.
Conclusions

• RBF Morph has been successfully coupled with *adjoint solver* of Fluent.
• Advanced mesh morphing allows to effectively enable *adjoint self sculpting*. Flow solution is used to define new shapes.
• RBF Morph allows to **pick, mix and reuse** self sculpted shapes.
• RBF Morph allows to **bring back to CAD** sculpted shapes.
• A *shape parametric* CFD model can be defined using ANSYS Fluent and RBF Morph (standard shapes or self sculpted ones can be mixed)
• Local **derivatives** with respect to shape parameters can be readily computed using the *adjoint preview* tool of RBF Morph.
• The effectiveness of RBF Morph + Fluent adjoint coupling has been demonstrated facing **challenging industrial applications**
Grazie per l’attenzione!

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