(rbf-morph)™

ANSYS PREFERRED SOLUTION PARTNER

How RBF mesh morphing can boost multi-physics simulation of vehicle 4.0

Università di Roma Tor Vergata

Prof. Marco Evangelos Biancolini – University of Rome “Tor Vergata”

Outline

- A brief introduction of what we do
- RBF Morph UTV synergy
- Mesh morphing and vehicle 4.0?
- Parametric CAE
- RBF Morph software
- Shape optimization examples
- Running Research Projects
- FSI simulations
- Conclusions

Welcome to the World of Fast Morphing!

www.rbf-morph.com

Academic and CAE activities

Academic

- Associate Professor at the University of Rome "Tor Vergata" (**UTV**)
- Two courses: "Machine Design" and "Advanced Structural Mechanics"
- Thesis and PhD students in **Italy** and **Europe**
- Coordinator of the technical scientific committee of the journal "A&C Analisi e calcolo"

CAE business

- Expert of advanced **CAE workflow** (vertical automations for shape optimization)
- Author and owner of **RBF Morph™** software
- Professional experience as consultant (**FEM, CFD**)

Academic and CAE activities

Academic

- Coordinator/WP leader of 3 **EU FP7** projects (RBF4AERO, Fortissimo and RIBES)
- Coordinator of 3 national research projects at UTV (SmartBench, RBF4ARTISTS, RBF4CRACKS)
- Partner of ENEA (FEA of **DEMO** TF coil system, **DTT** magnets)
- External Expert of **F4E** (ITER)

CAE business

- Technical Partner of **ANSYS Inc.** since 2009 (OEM since 2012)
- Honorary member of **Technet Alliance** since 2013
- Partner of **CAE companies** worldwide (Enginsoft, ESSS, Ozen, Esteco)

A powerful synergy

Academic	CAE business

UTV + ISV RBF Morph

- A variety of applications ranging from **research** to **industrial** exploitation can be tackled
- **Technology transfer** is boosted (including personnel)
- **Funds** access is facilitated
- A **network** of **partners** (Industries, Universities, Research Institutes, CAE Companies)

FORTISSIMO

R.I.B.E.S.

RBF4AERO

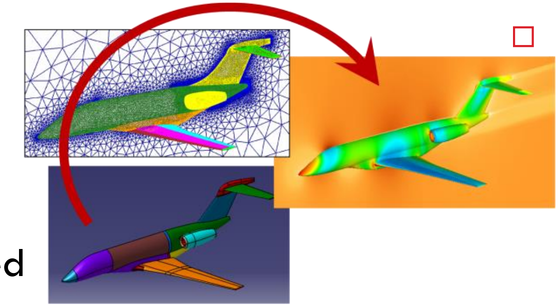
Mesh morphing and vehicle 4.0?

- Digital twins
- Shape parametric CAE
- Multi-physics
- Big Data
- 3d printing support
- Optimization
- HPC - cloud
- Reduced order models

Geometry - CAE link

RBF mesh Morphing

- Main advantages
  - No re-meshing
  - Can handle any kind of mesh
  - Can be integrated in the CAE solver
  - Highly parallelizable
  - Robust process
- Main disadvantages
  - Can't handle topology change
  - Back to CAD procedure required



CAD to mesh

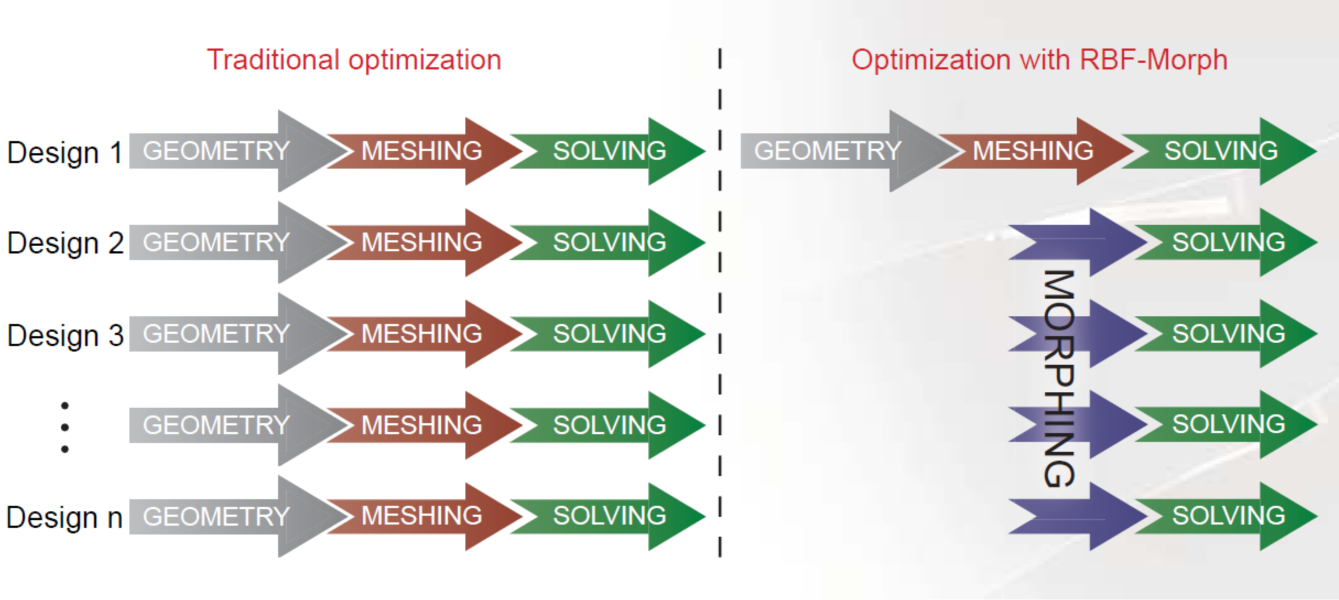
- Main advantages
  - Accurate geometry quality control
  - High constraints setup flexibility
  - No "back to CAD" required
- Main disadvantages
  - Complex setup
  - Highly skilled CAD user required
  - Robustness
  - Remesh required

Parametric CAE models

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

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

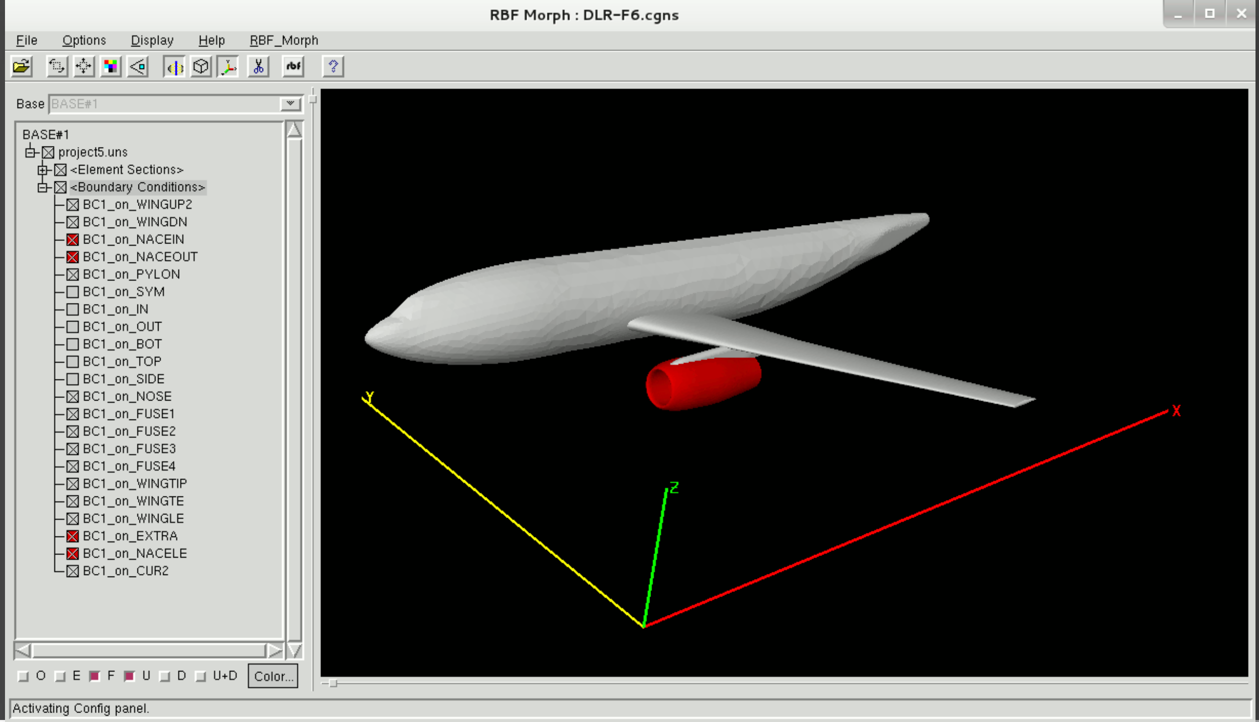
Shape parameters can be steered with the **optimizer of choice.**



RBF Morph Fluent Add On

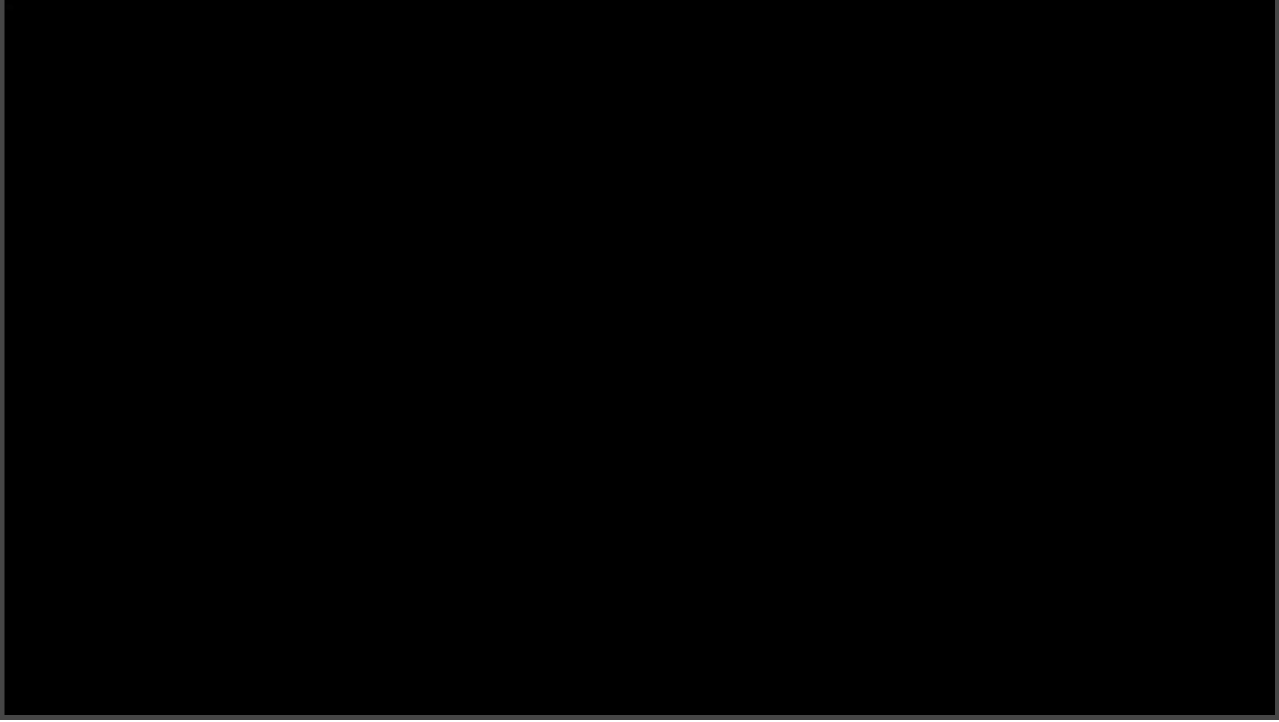
Our flagship product. Released in 2009, distributed also by ANSYS since 2012.

https://youtu.be/_geLbD-Be-k



RBF Morph Stand Alone

Released in 2012. The MT of the RBF4AERO project (www.rbf4aero.eu).



RBF Morph ACT Extension

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

https://youtu.be/TUOJGAG7Wtk

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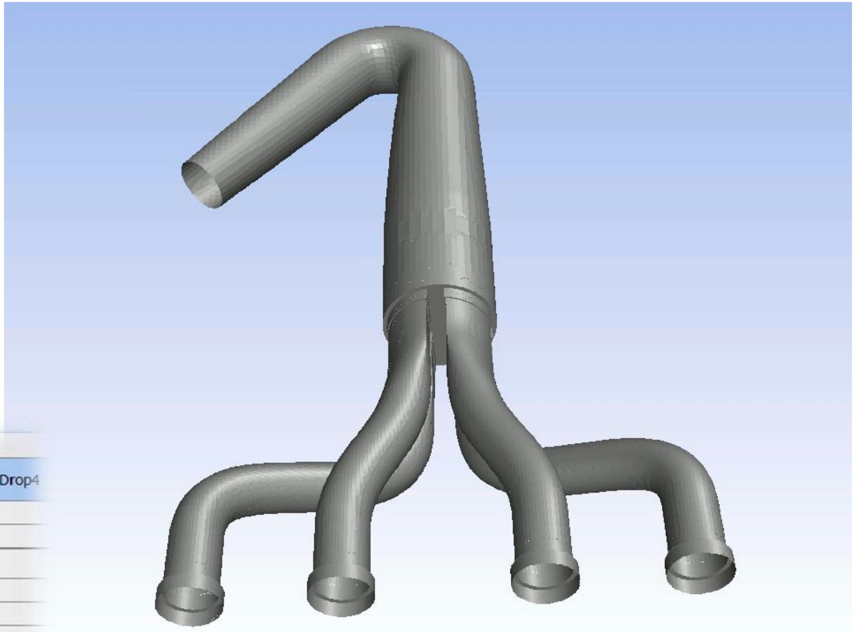
Exhaust manifold optimization

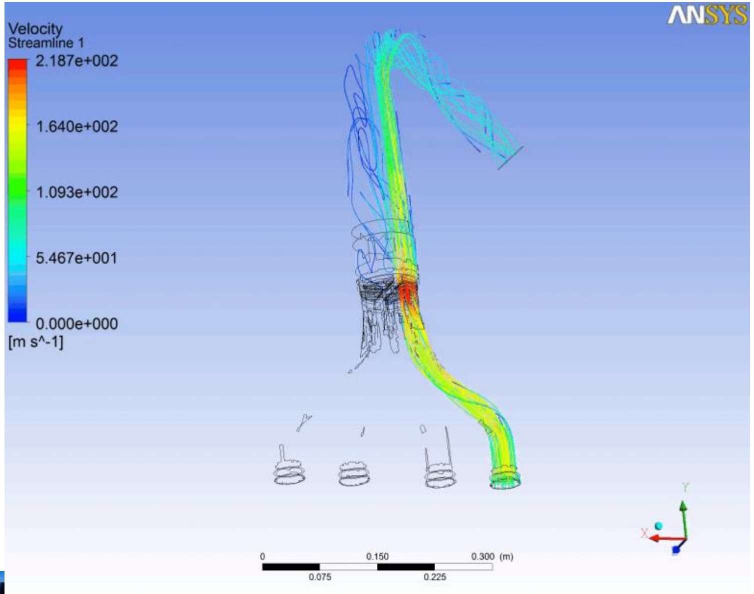
- Minimum average pressure drop
- Balancing pressure drop at the four runners
- 8% improvement with balanced pressures!



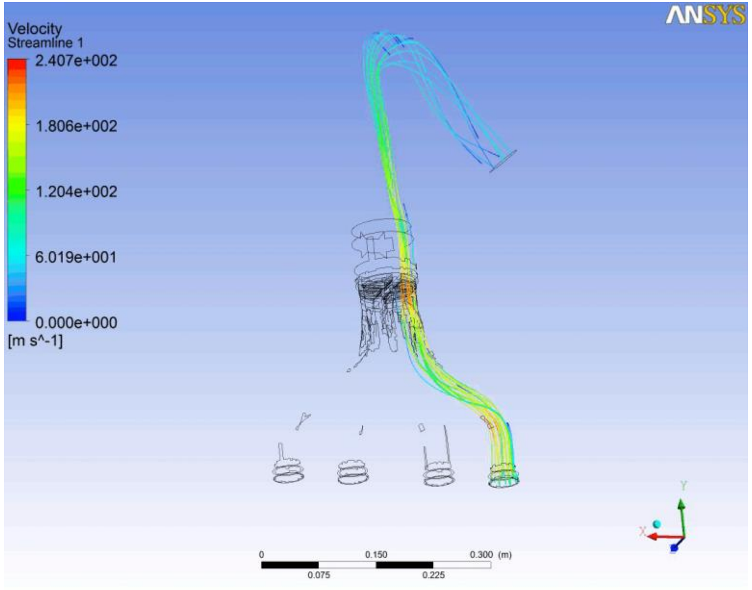
	A	B	C	D	E	F	G	H	I
1	Name	P5 - Pipe1Curve1	P6 - Pipe2	P7 - Pipe4Curve1	P8 - Pipe3	P1 - PressureDrop1	P2 - PressureDrop2	P3 - PressureDrop3	P4 - PressureDrop4
2						Pa	Pa	Pa	Pa
3	Current	4	4	4	4	12892	11366	13028	16619
4	DP 1	3	3	3	3	12882	11247	13487	16731
5	DP 2	2	2	2	2	12897	11546	13554	16911
6	DP 3	1	1	1	1	13403	11477	13920	17666
7	DP 4	0	0	0	0	13555	11750	13967	17718

Exhaust manifold optimization

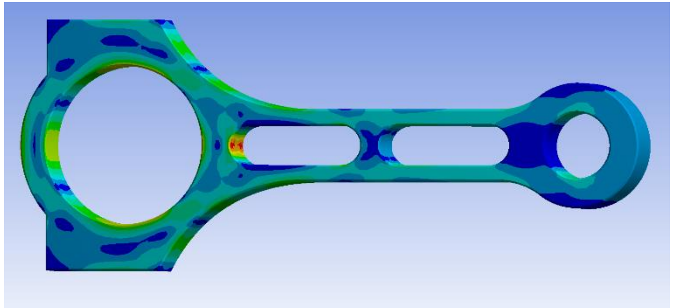
Original design

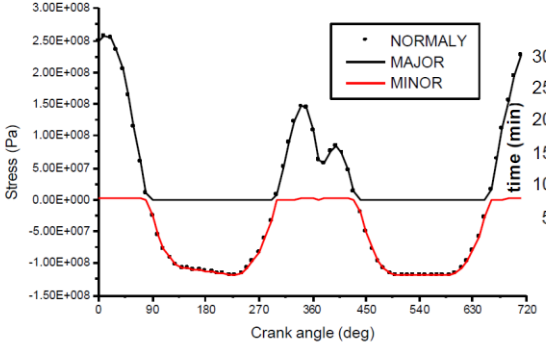


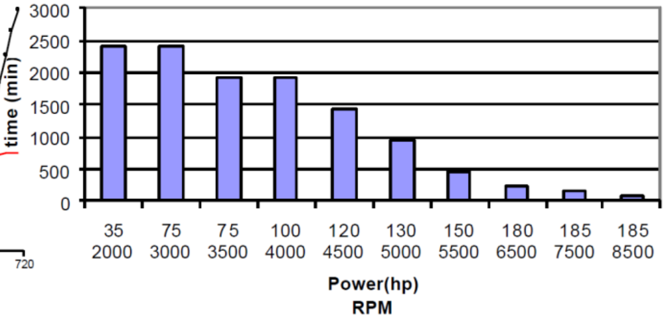
Optimal design

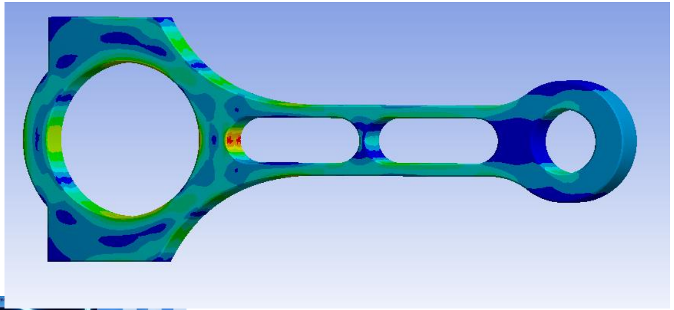


Connecting rod optimization



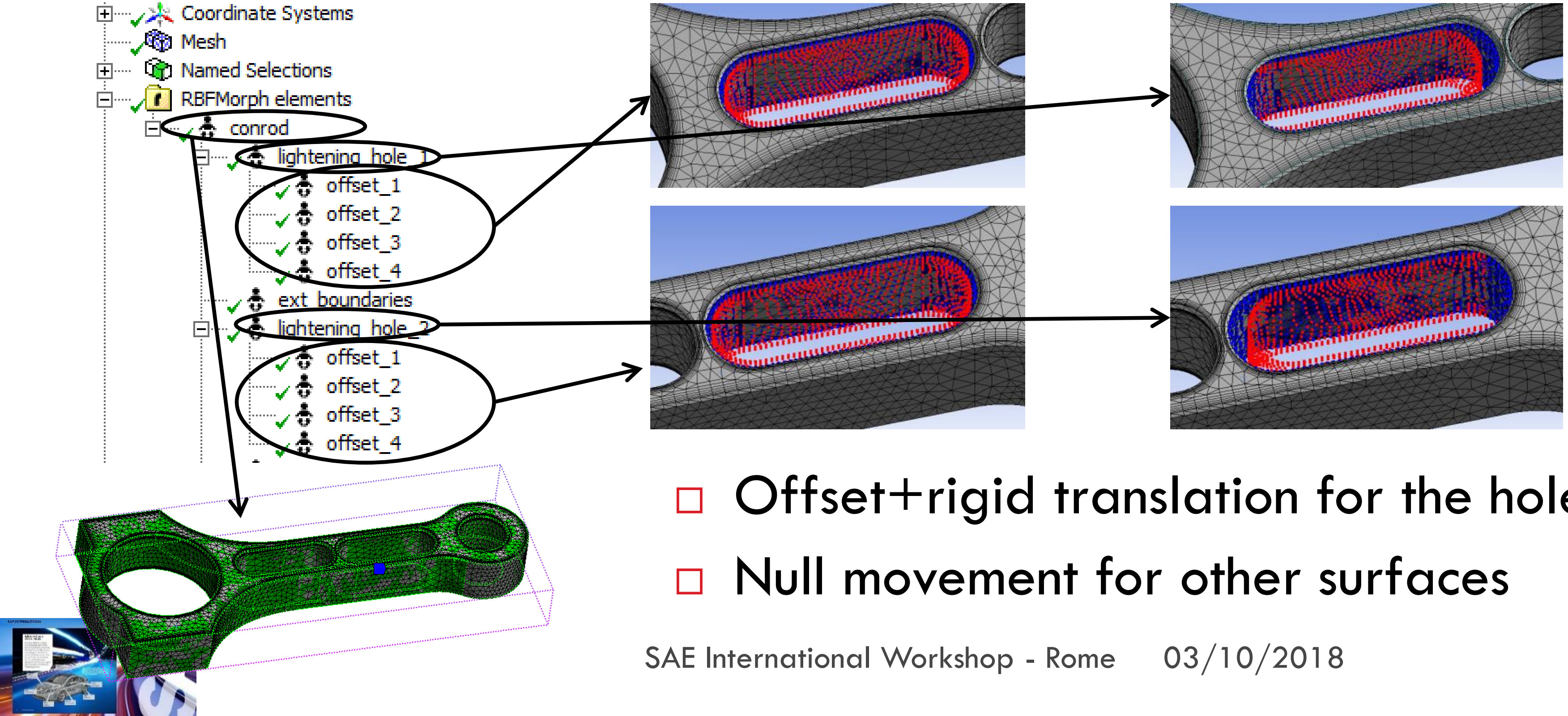






- Computed load history (kinematic analysis)
- Titanium Ti-6Al-4V (Grade 5)
- Cumulated damage map over the testing spectrum

Connecting rod optimization



- Offset+rigid translation for the holes
- Null movement for other surfaces

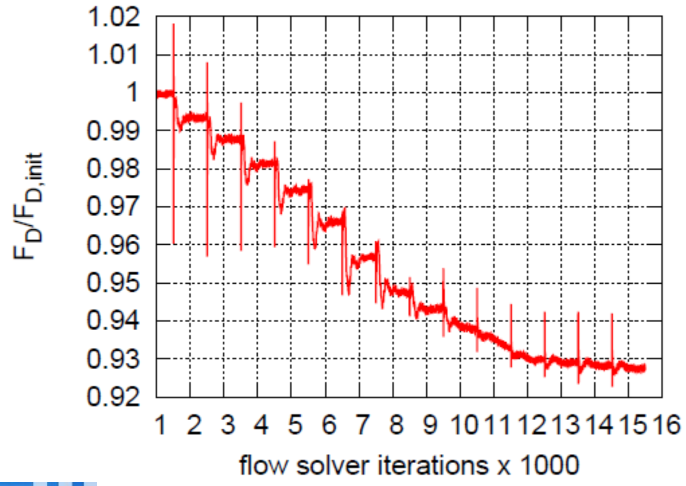
Connecting rod optimization

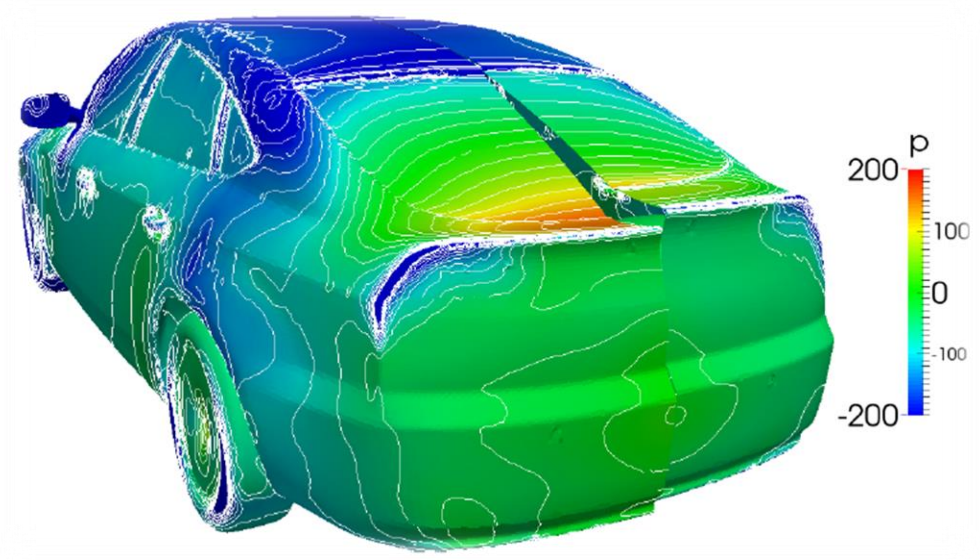
Original design 358.7g

Optimal design 334.4g (-6.7%)

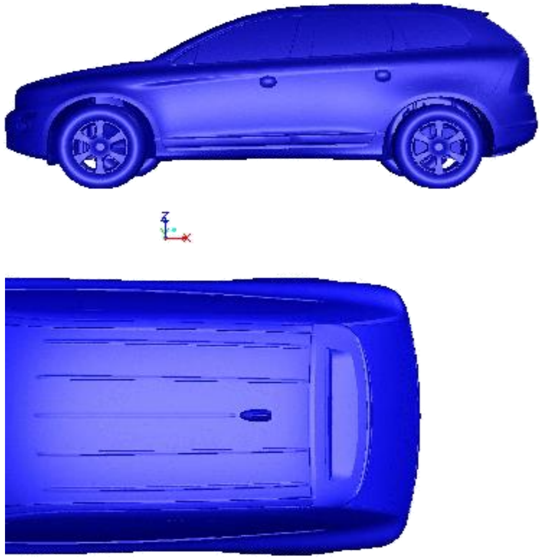
DrivAer (Open Foam)

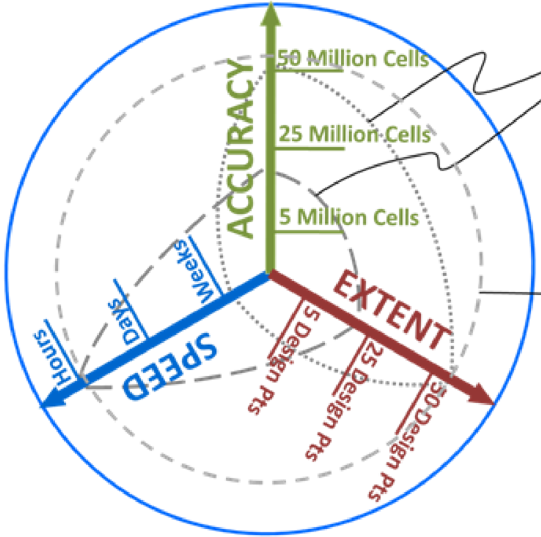
- A 7% drag reduction is observed after 15 cycles. Optimal (left) vs. original shape (right).





50:50:50 Project Volvo XC60

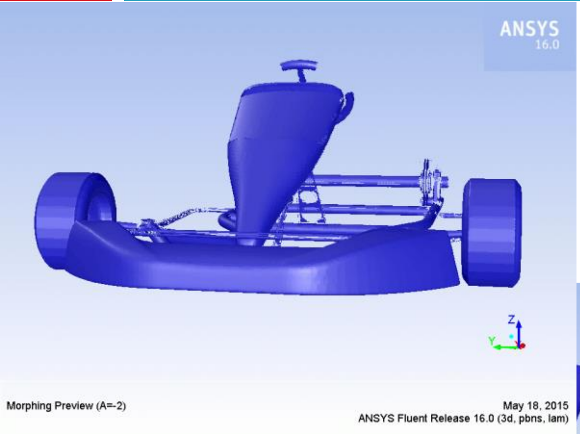


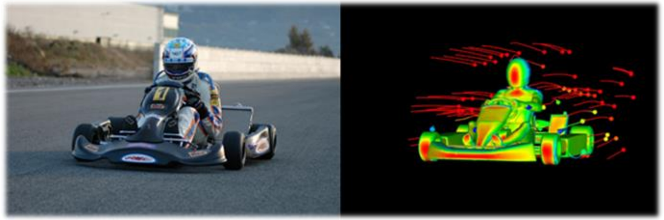


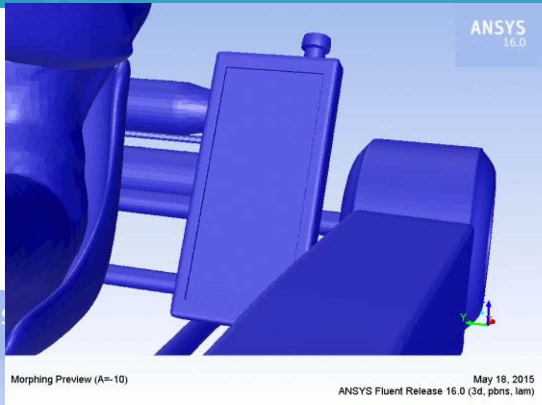
Prior aerodynamics optimization processes have either achieved speed at the expense of accuracy and extent or vice versa

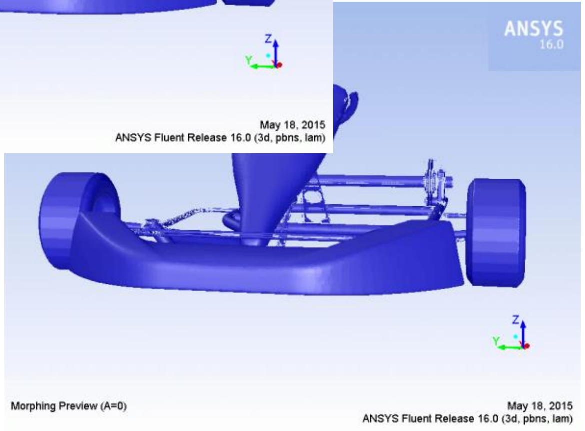
The goal of the current work is to achieve speed without compromising accuracy or extent

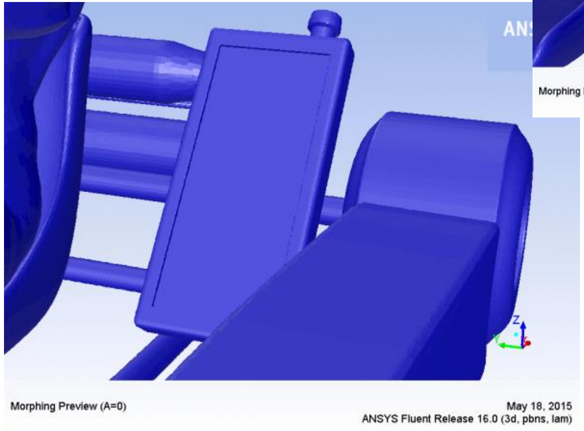
Parametric go kart











Vehicle mission simulation - FSAE

07APAC-229

Engine/vehicle matching for a FSAE race car

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In this paper a simple method to support the selection of the engine of a FSAE race car is presented. The rules impose to use a 4T engine with a maximum displacement of 610 cc breathing from a 20mm restrictor inserted downstream to the throttle body. The rules impose also the acceleration mission of the engine vehicle system: 75m acceleration test and 77m maximum length of straight lines if included between two 9m radius hairpins. An integrated model that consider restricted engine torque, drag and rolling losses and vehicle mass is presented and used to evaluate the system performances in the acceleration mission for several engines.

have joined the project with La Sapienza University of Rome for a common project within ATALazio structure, and the new team SPQRacing is born.

Figure 1. Ohio State University FSAE Car 2006.

Steering wheels – lap time optimization

Track by Track Robust Optimization of a F1 Front Wing Using Adjoint Solutions and Radial Basis Functions

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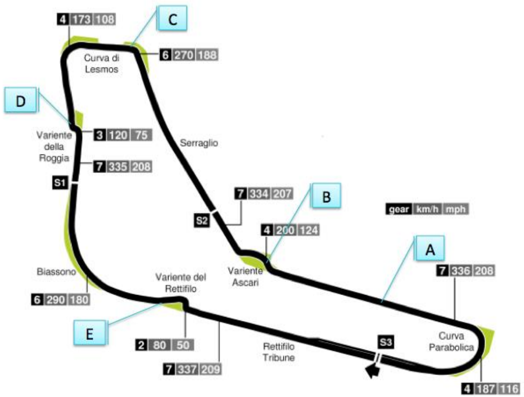
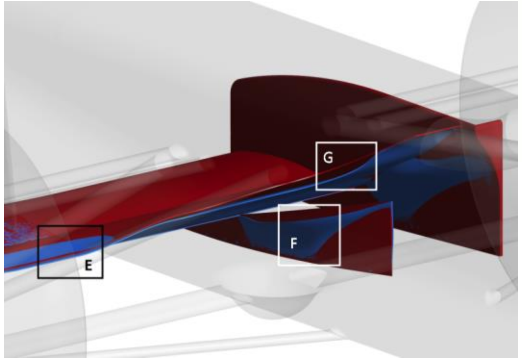
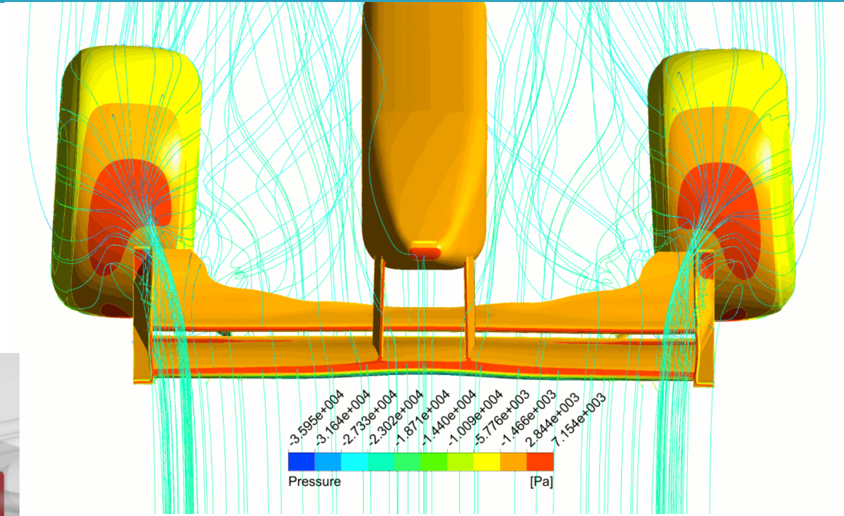
10.2514/6.2014-3174







Land Speed Record – BB2

Int. J. Vehicle Design, Vol. 44, Nos. 3/4, 2007 379

Design of a lightweight chassis for the land speed record vehicle Buckeye Bullet 2

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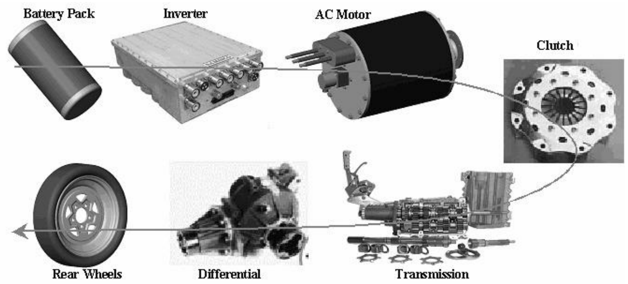

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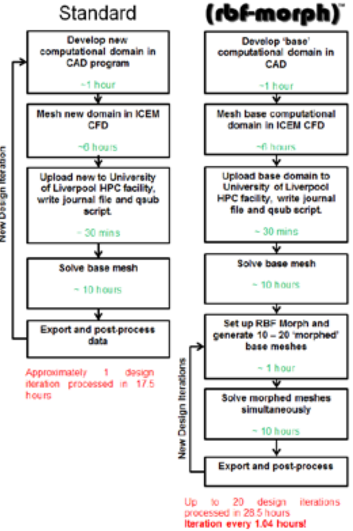
Land Speed Record – ARION1

ANALISI E CALCOLO



VOGLIA DI RECORD: IL PROGETTO "ARION1 LAND SPEED BICYCLE" DELL'UNIVERSITÀ DI LIVERPOOL

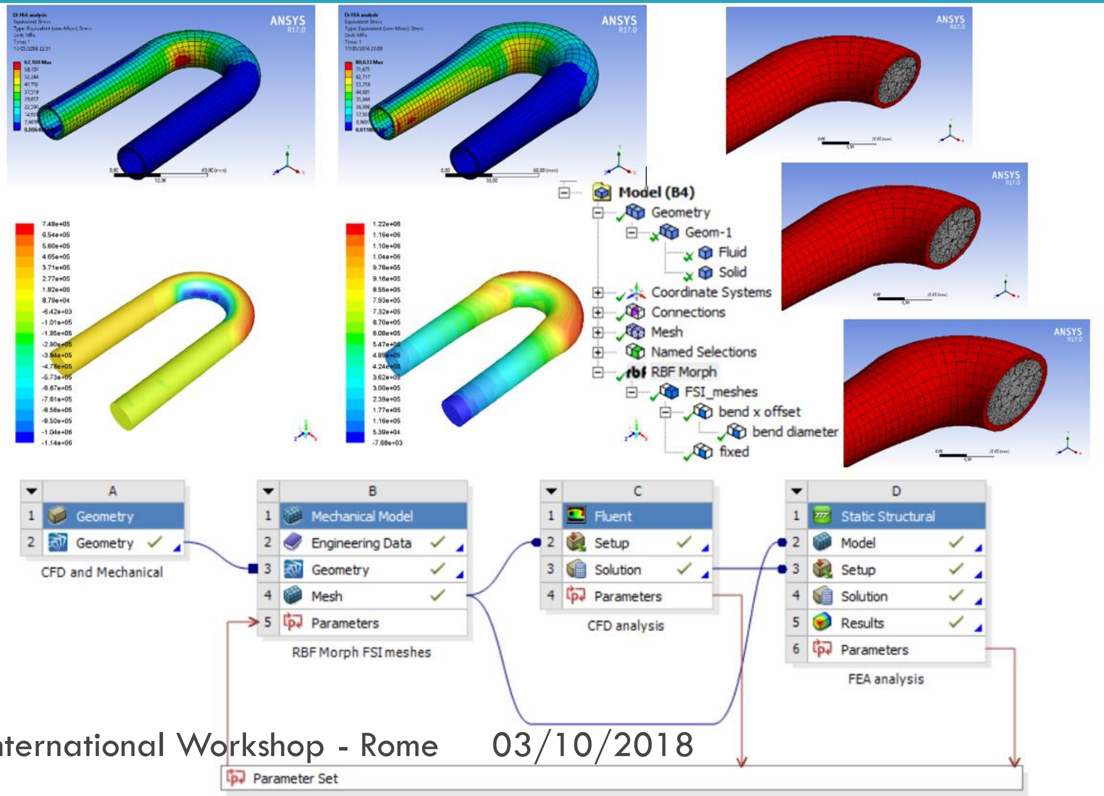
MARCO EVANGELOS BIANCOLINI

Università di Roma - Dipartimento di Ingegneria dell'Impresa "Mario Lucertini".

L'obbiettivo è battere il record di velocità utilizzando una bicicletta dove la sola potenza disponibile è quella dell'atleta. Sedici studenti del Masters of Mechanical Engineering lavorano intensamente alla progettazione dell'ARION1, il mezzo con il quale contano di battere record mondiali maschili e femminili, rispettivamente 133.78 km/hr (2013) e 121.81 km/hr (2010).

FSI shape optimization in ANSYS WB

- The fluid mesh and
- The solid mesh
- Morphed at the same time
- Solid is loaded with fluid pressure



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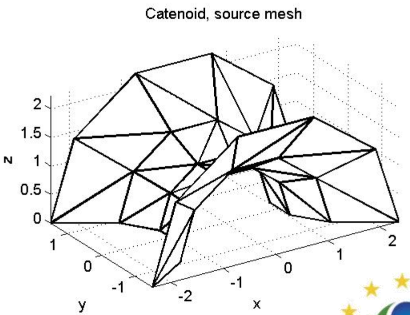
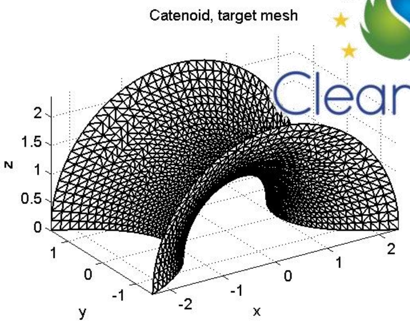
OUR RESEARCH PROJECTS

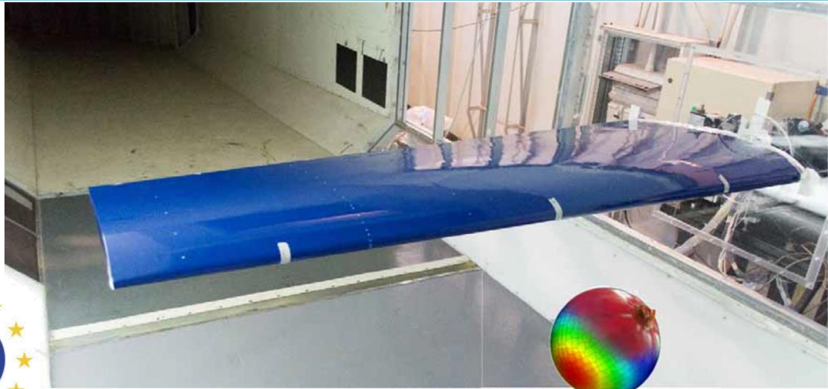
Funded projects currently running

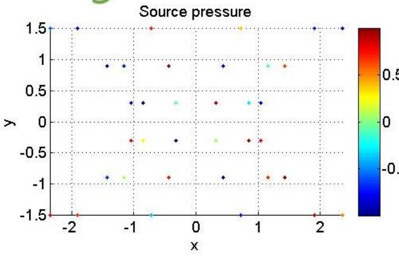
RIBES EU Project

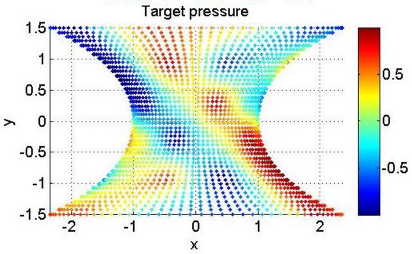
- **R**adial basis functions at fluid **I**nterface **B**oundaries to **E**nvelope flow results for advanced **S**tructural analysis
- **JTI-CS-2013-GRA-01-052**
- **www.ribes-project.eu**
- **RBF mapping**
  - Pressure field computed on surface (CFD) onto structure (FEA)
  - Temperature field mapped in the volume









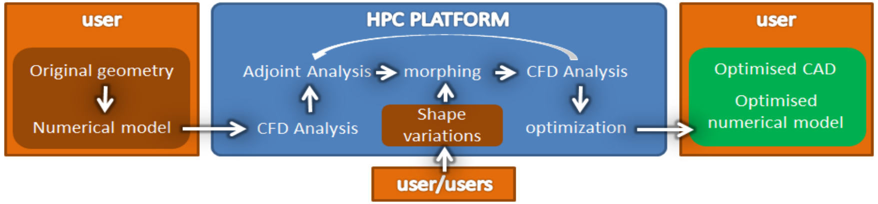


RBF4AERO EU Project

- Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimisation
- **ACP3-GA-2013-605396**
- **www.rbf4aero.eu**

Fortissimo EU Project

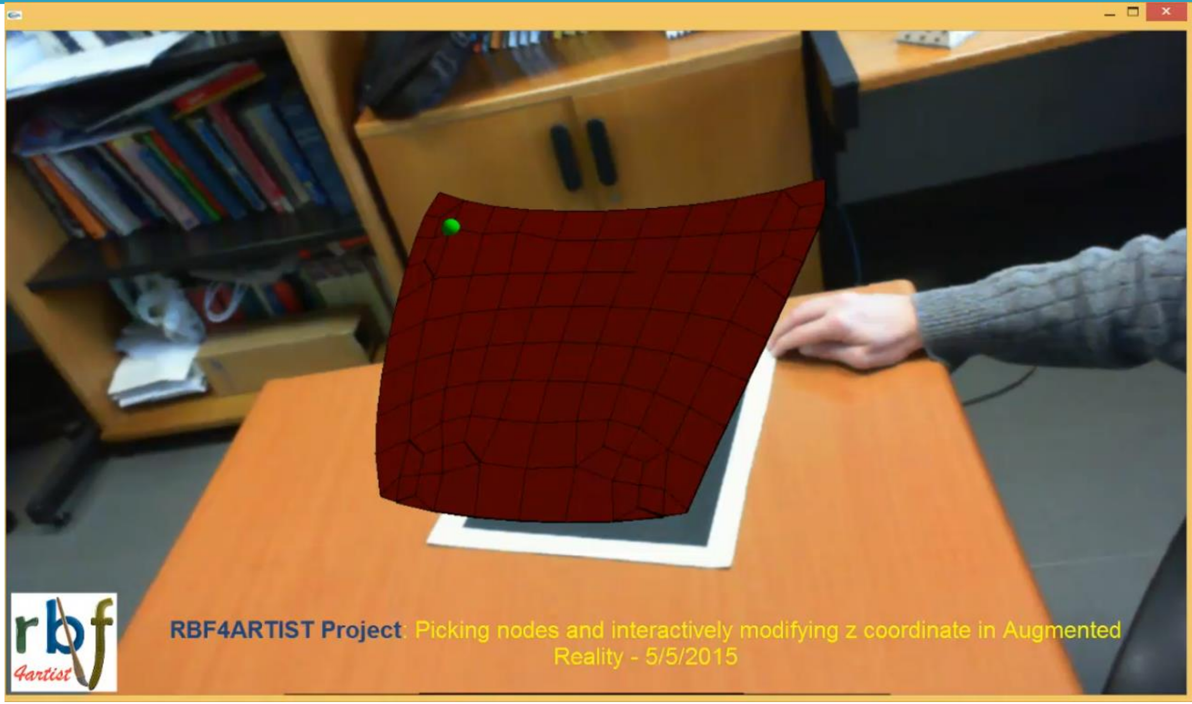
- **F**actories **O**f the Future **R**esources, **T**echnology, **I**nfrastructure and **S**ervices for **SI**mulation and **MO**delling
- WP515: **"Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms"**
- **HSL srl, Trento; University of Rome "Tor Vergata"; CINECA**



RBF4ARTIST

Uncovering the excellence UTV programme

- **Interactive sculpting**
  - Augmented reality
  - Force feedback system
  - Real time reactivity requires high performances!
  - youtu.be/74yjd7ZWcNk



Fortissimo 2 EU Project

FORTISSIMO

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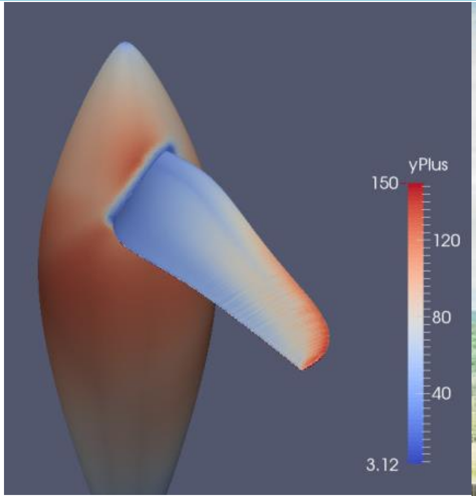
- **FSI optimisation (RBF4AERO now on FF2)**
  - Mesh morphing for shape parametrization of numerical grids
  - FSI based on mapping and modal superposition
  - Optimisation run on the flexible model
  - www.rbf4aero.eu/
  - youtu.be/eThibFzEPNI
  - youtu.be/A0WPDyhIr8Q



RBF4AERO

MODAL FSI APPROACH

Fluent Add On based workflows

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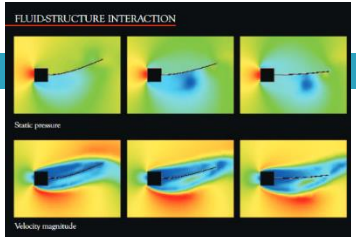
Transient FSI Example (with ANSYS France)

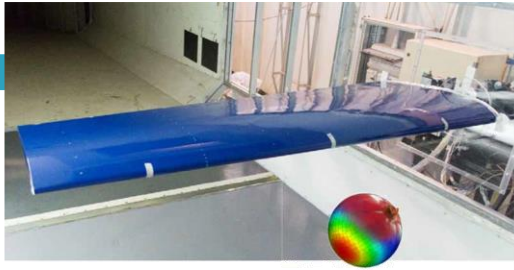
Simulation captures the instability observed at 0.35 m/s

https://youtu.be/A0WPDyhlr8Q

Research path

- The first UDF in 2005 (2D and 3D) for **time marching solutions.**
- RBF for **mesh morphing** and pressure mapping was introduced in 2009 with RBF Morph Fluent Add On.
- RBF Morph Stand alone for FSI with **OpenFoam** released in 2012.
- RBF4AERO (www.rbf4aero.eu) implementation (**cross solvers**, steady, 2-way and modal) 2013-2016
- RIBES (www.ribes-project.eu) implementation
- RBF Morph Fluent Add On **advanced FSI module** (steady and transient, HPC)
- 3 Awards! (2005, 2011, 2013)

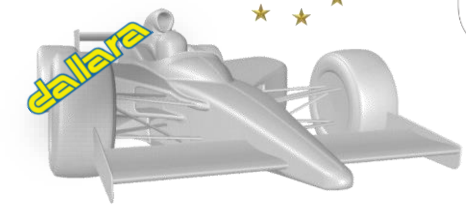




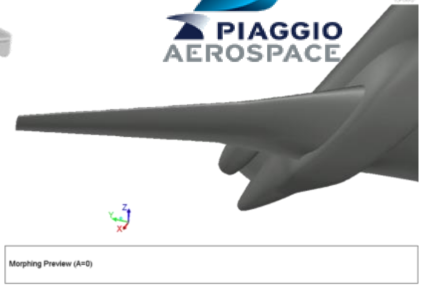
RIBES

RBF4AERO

Università di Roma Tor Vergata



PIAGGIO AEROSPACE



ANSYS

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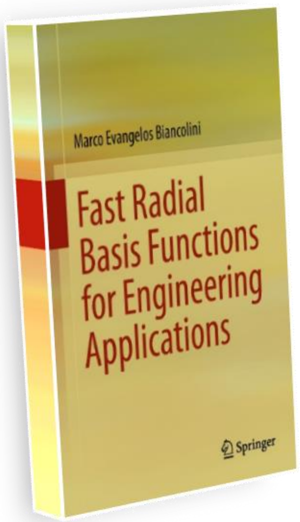
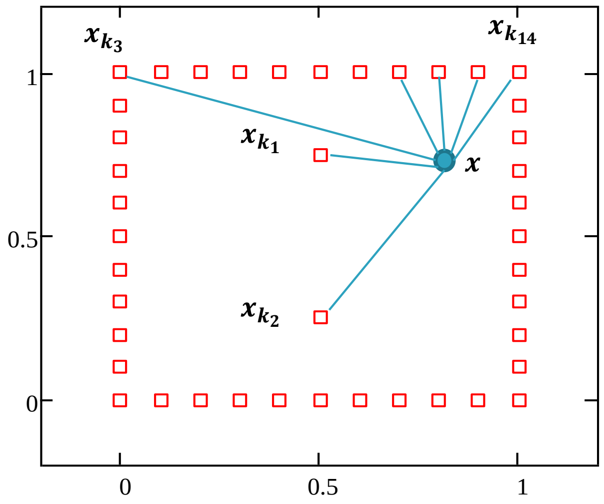
RBF Background



- 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**.

$$s(\mathbf{x}) = \sum_{i=1}^{N} \overbrace{\gamma_i \varphi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right)}^{\text{radial basis}} + \overbrace{h(\mathbf{x})}^{\text{polynomial}}$$



Structural modes embedding

- A certain number of **modes** is computed using FEA.
- An **RBF solution** is computed for each mode (constraining far field conditions and rigid surfaces, mapping FEA field on deformable surfaces). Modes on CFD mesh are stored.
- At initialization the CFD solver loads the modes and then:
  - the mesh deformation can be **amplified** prescribing the value of **modal coordinates**
  - **modal forces** are computed on prescribed surfaces by projecting the nodal forces (fluid pressure and shear) onto the modal shape

number of natural modes

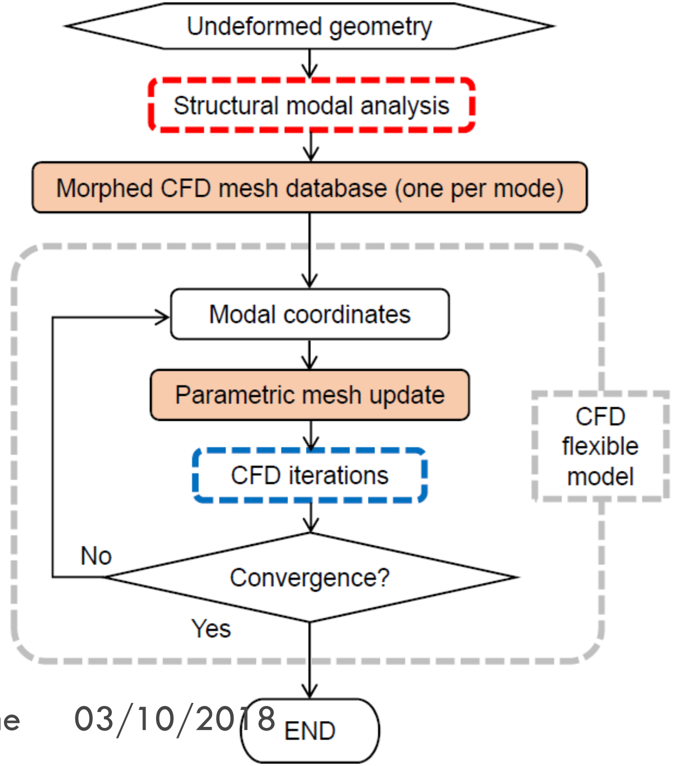
nodal modes displacement

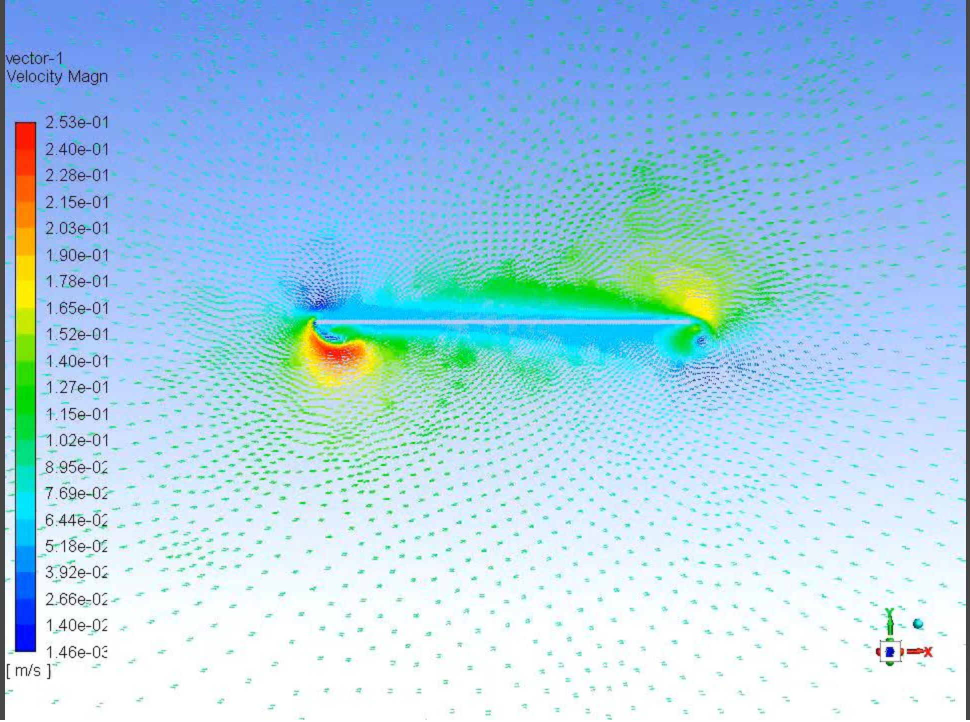
$$X_{CFD} = X_{CFD_0} + \sum_{i=1}^{k} q_i \Delta X_i$$

modal coordinate

Possible Simulation Scenario

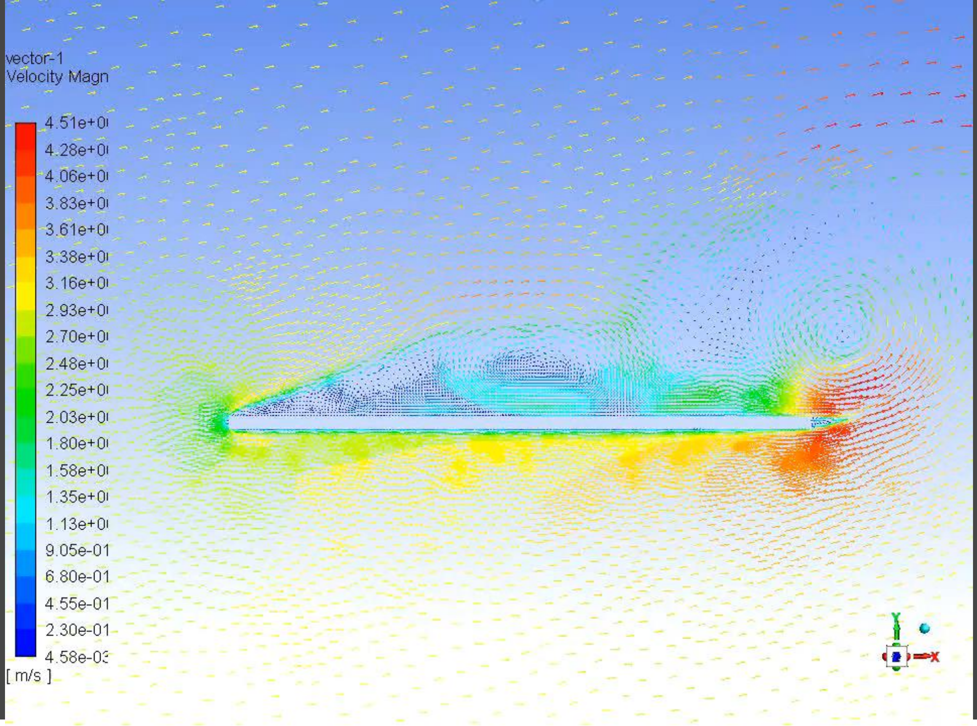
- Steady FSI to account for structure elasticity (aircraft wings, propeller blades, racing)
- Transient simulations with prescribed motions
  - flapping devices
  - structural modes acceleration for Reduced Order Models in flutter analysis
- Transient simulation with vibrations excited by the flow
  - forced response
  - computation of damped frequencies
- https://www.ansys-blog.com/rbf-morph-clean-sky/





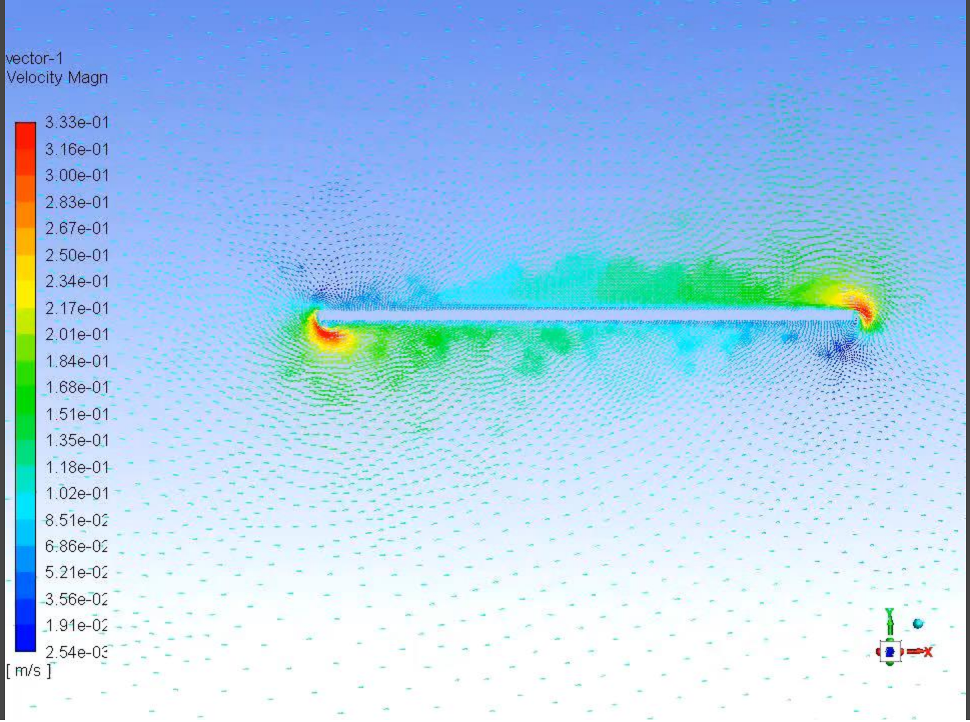
Possible Simulation Scenario - rigid

Rigid movement assigned – mesh deformation controlled with RBF



Possible Simulation Scenario - flexible

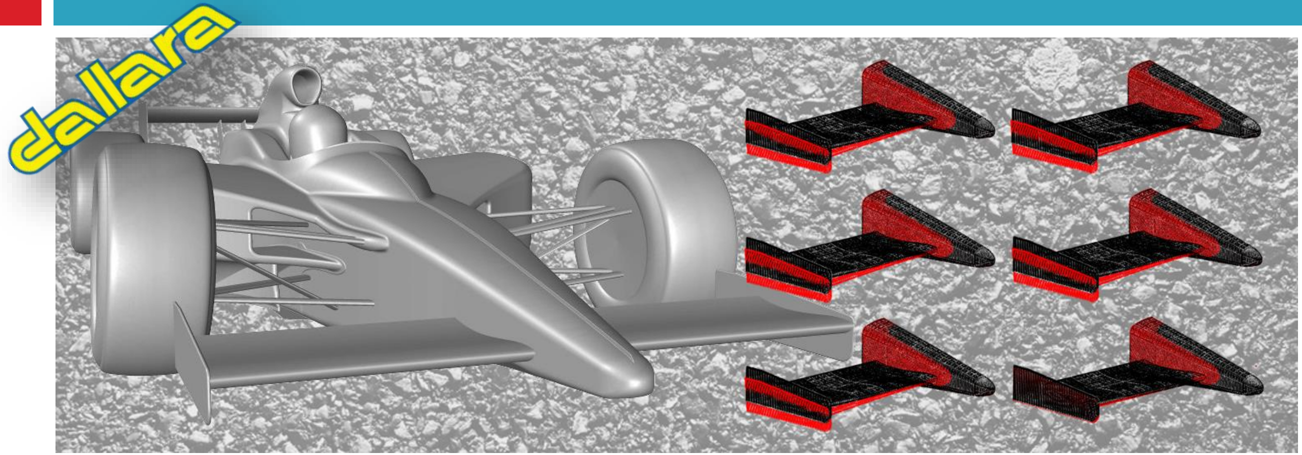
Deflection computed with 4 structural modes – vertical speed component added

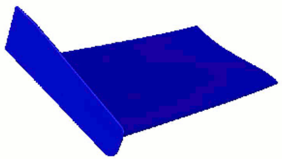


Possible Simulation Scenario - flapping

4 structural modes – ground vibration inertial forces added

Examples: Indy Race Car





Modes used	Maximum displacement (mm)	Maximum error (%)
1	5.941	8.3
2	5.898	6.5
3	5.584	2.7
4	5.56	1.4
5	5.555	0

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. **Modal shapes can be embedded as well!**
- Strong integration in **ANSYS products**: an Add On for Fluent & ACT Extension for Mechanical (and more…)
- FSI capabilities of RBF Morph Fluent Add on are today demonstrated for steady and transient simulations
- Many advanced industrial applications can be faced. Visit our web site www.rbf-morph.com to learn more.

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Many thanks for your kind attention!

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