37th
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2021

HYBRID EVENT

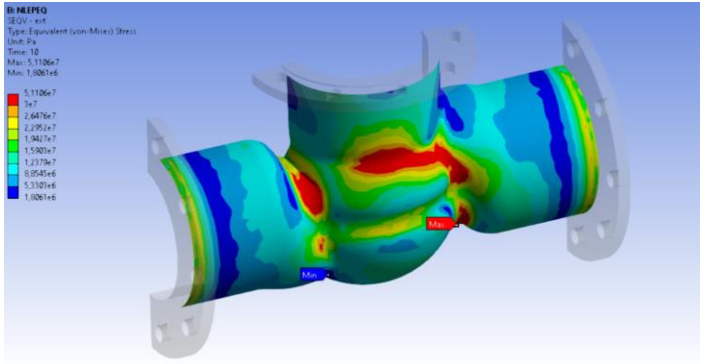
Simulation and mitigation of Vortex Induced Vibrations by means of high fidelity FSI simulation and advanced mesh morphing

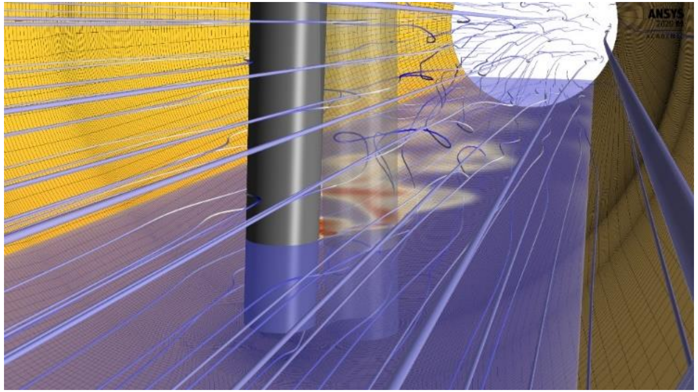
Marco E. Biancolini – marco.biancolini@rbf-morph.com
Stefano Porziani

RBF Morph srl, Monte Compatri (RM), Italy

Outline

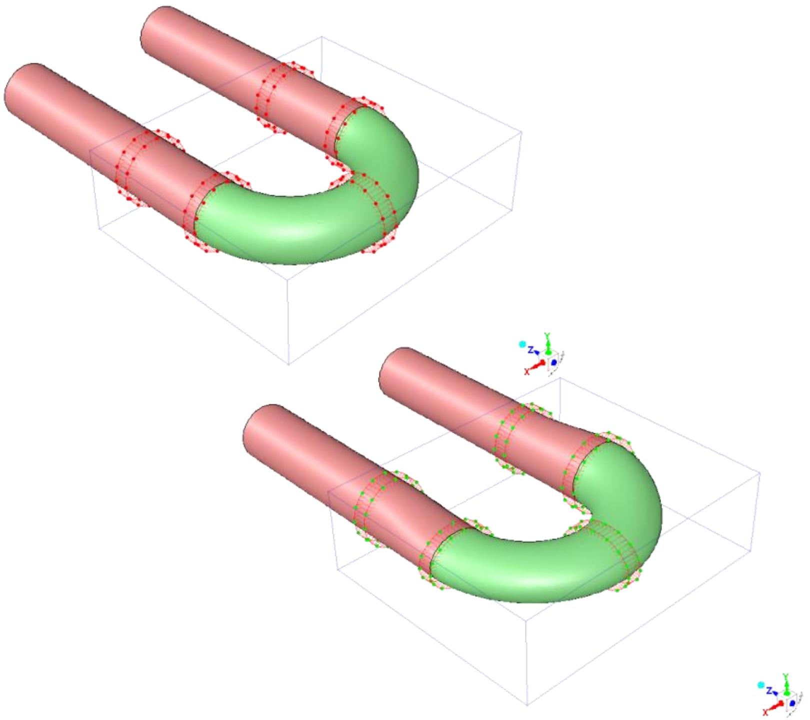
- A short introduction to RBF Morph and Radial Basis Functions (RBF) background
- Advanced mesh morphing solutions jointly offered with Ansys
- Oil & Gas Industry needs
- Detailed study of VIV of a thermo-well
- Conclusions





Shape parameterization strategy

- Geometric parameterization by **mesh morphing**
- The principle is to take the control on a set of point and to transfer the deformation to the whole mesh
- A new shape of the CAE model ready to run
  - for structural analysis in the FEA solver
  - for flow analysis in the CFD solver



Radial Basis Functions mesh Morphing

- We offer Radial Basis Functions (RBF) to drive mesh morphing (smoothing) from a list of source points and their displacements.
  - Surface shape changes
  - Volume mesh smoothing.
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing.

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

Radial Basis Functions mesh Morphing

(rbf-morph)™

Welcome to the World of Fast Morphing!

www.rbf-morph.com

- Main advantages
  - No re-meshing
  - Can handle any kind of mesh
  - Can be integrated in the CAE solver (FEM/CFD/FSI)
  - Highly parallelizable
  - Robust process
  - The same mesh topology is preserved (adjoint/ROM)
  - CAD morphing (iso-brep)

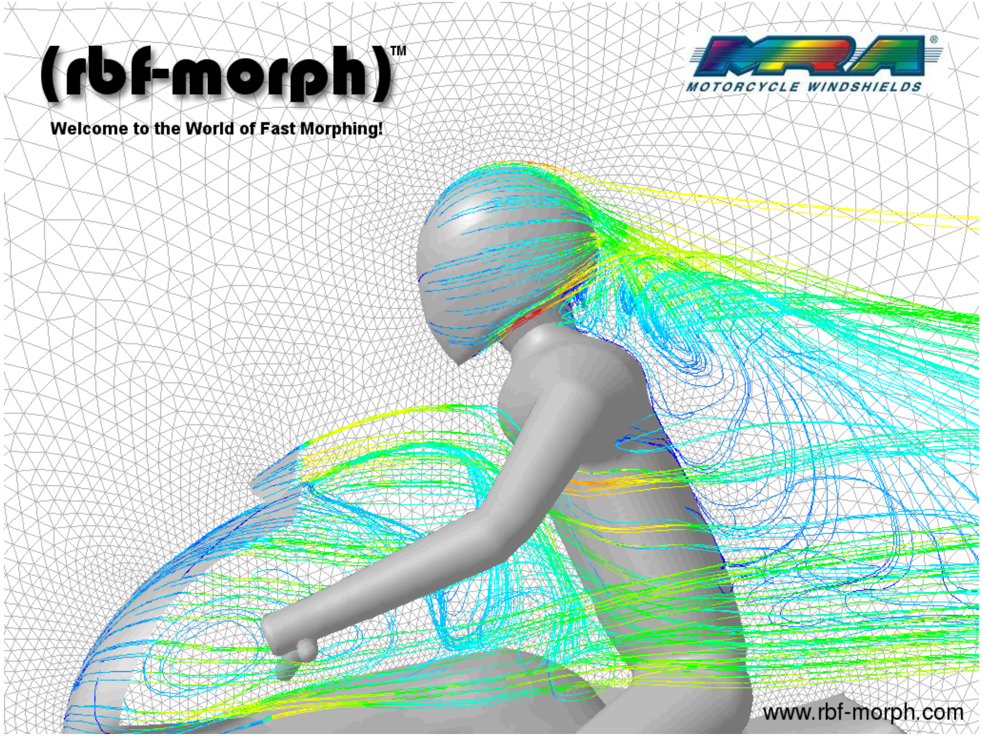
We make CAE models parametric

CAE models supported includes flow analysis (CFD) and structural analysis (FEM)

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.



Through powerful RBF methods

No re-meshing: 5x faster, even for complex shapes and any kind of mesh

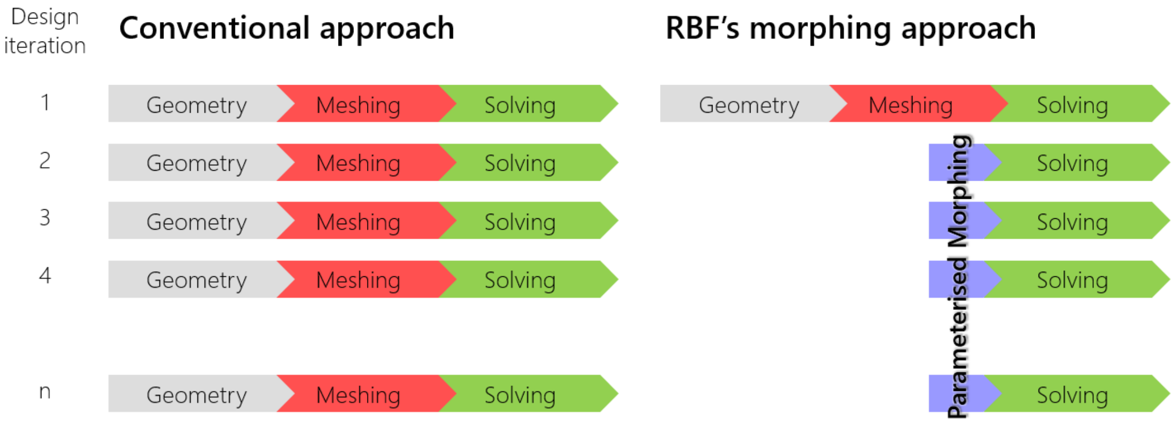
Very effective: up to 15% performance improvement

Can be integrated in CAE solvers (FEM/CFD/FSI)

Highly parallelizable

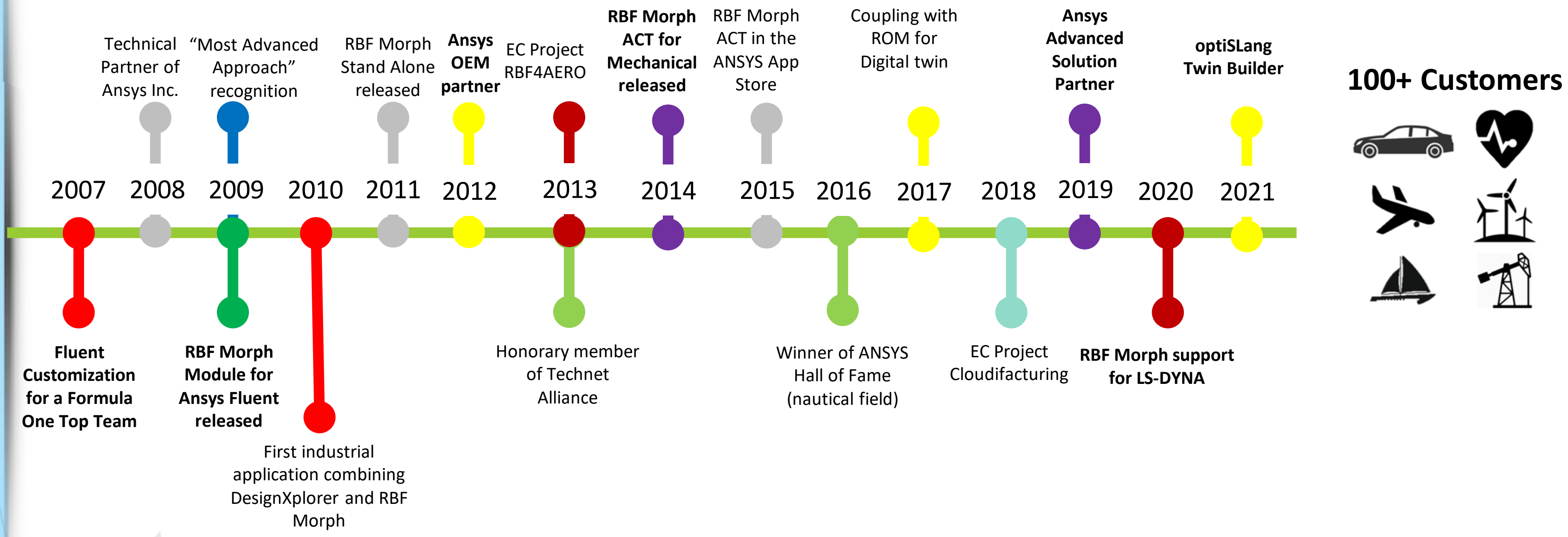
Robust process, proven in safety-critical industries

Saving time and money



- It's easy and fast: shape parameters are defined in the CAE GUI. No need to iterate the CAD.
- The turnaround time of the optimization is usually reduced by a factor five (weeks becomes days)

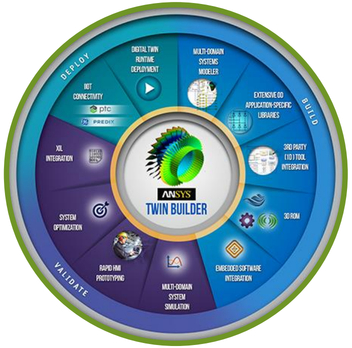
A solution based on 10+ years of experience

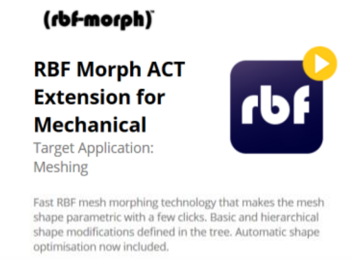


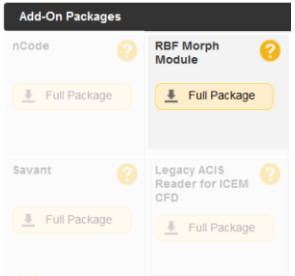
Ansys integrated solutions

ACT Extension (FEM)

- Released in **2014**
- Fully embedded in ANSYS **Mechanical** (parametric)
- Benefits of **underlying geometry** (or aux geo with dead meshes)
- ...**WB** Meshing





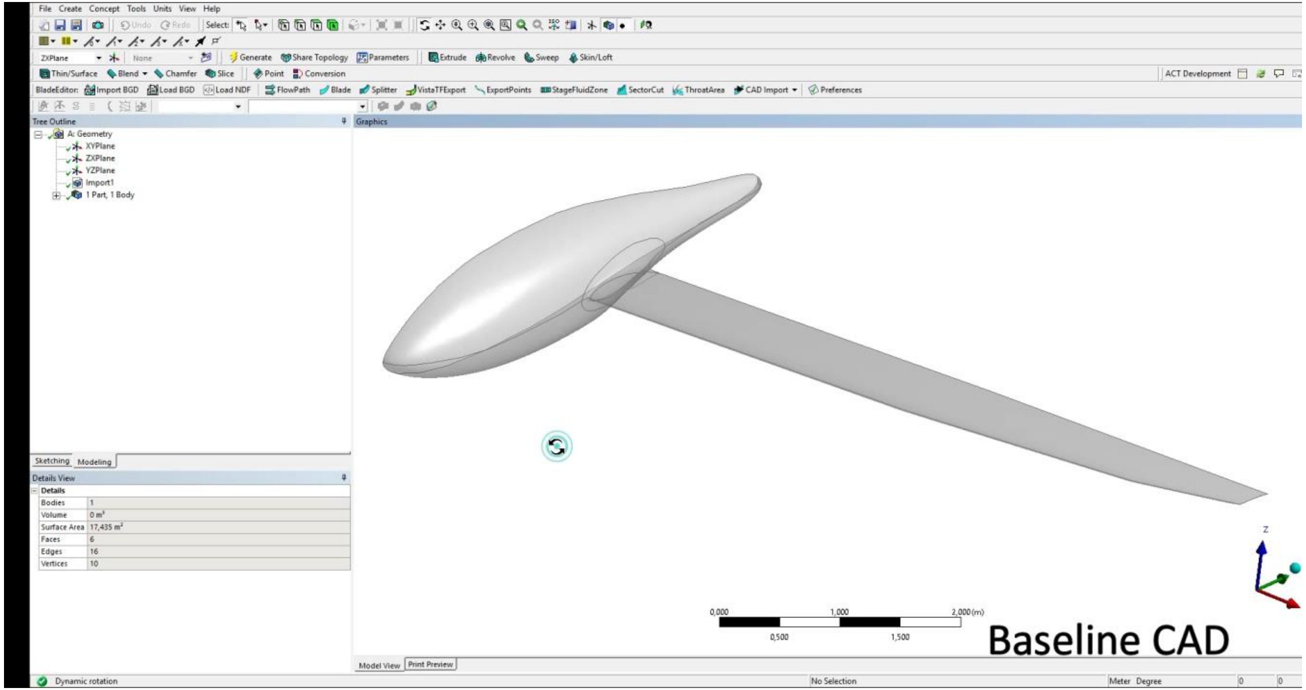


Fluent Module (CFD)

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

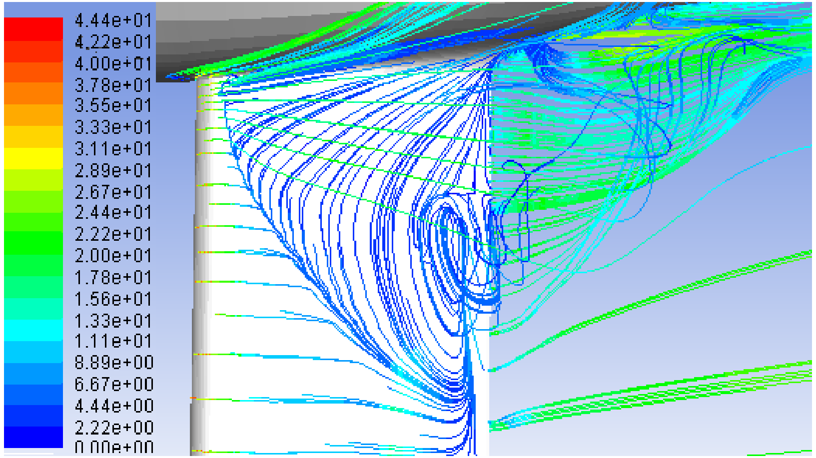
RBF Morph Fluent Module

https://youtu.be/EWsigyqByRg

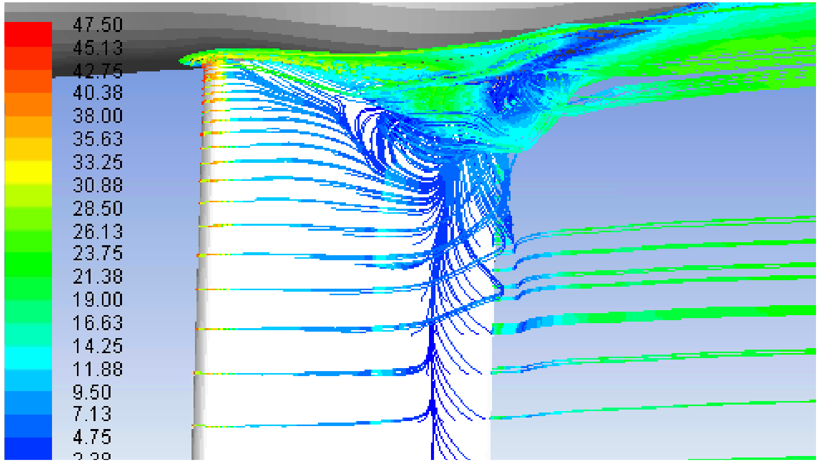


Glider optimization

Original design E=14.9

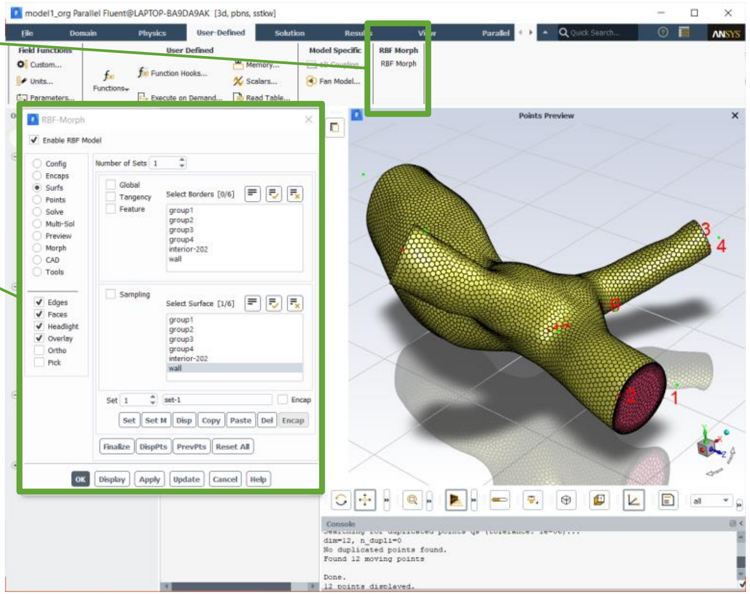


Optimal design E=20.1 (+35%)



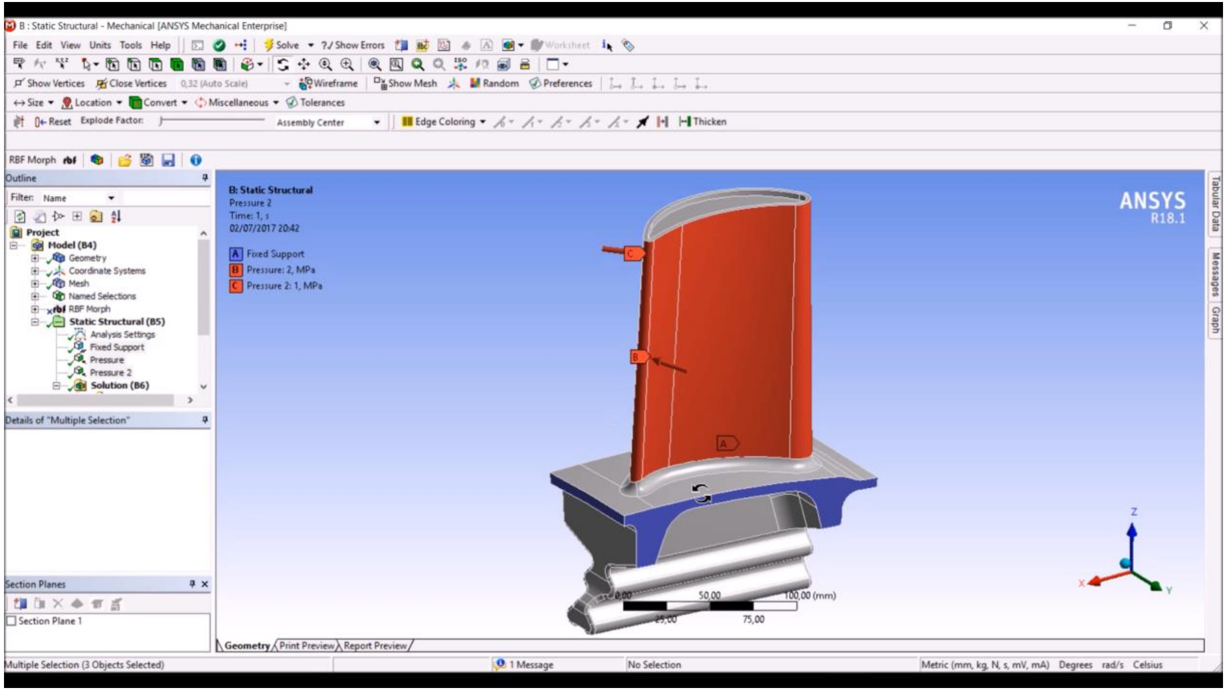
Fluent module

- 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**)

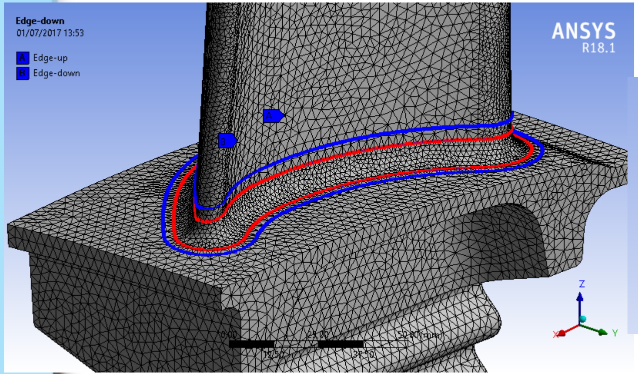


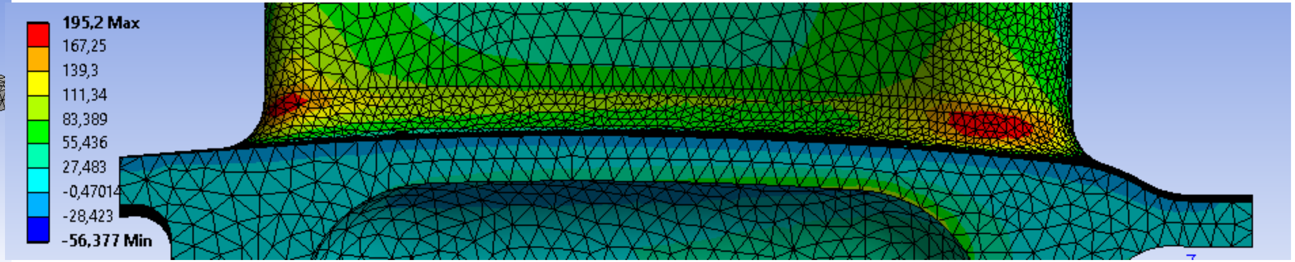
RBF Morph ACT Extension

https://youtu.be/TUOJGAG7Wtk

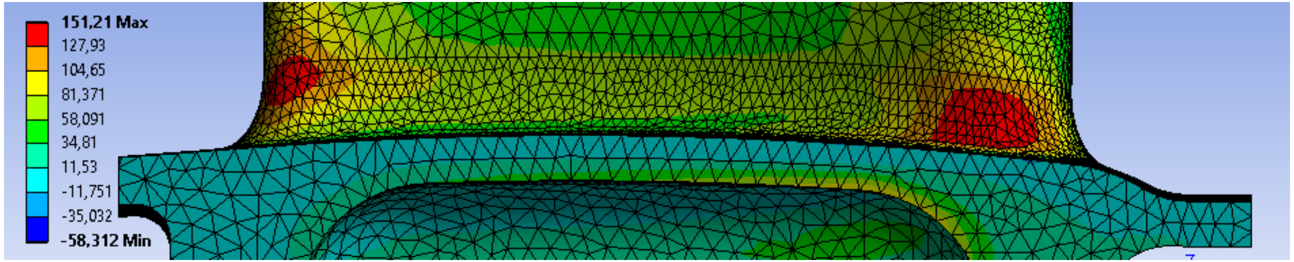


Blade fillet stress reduction



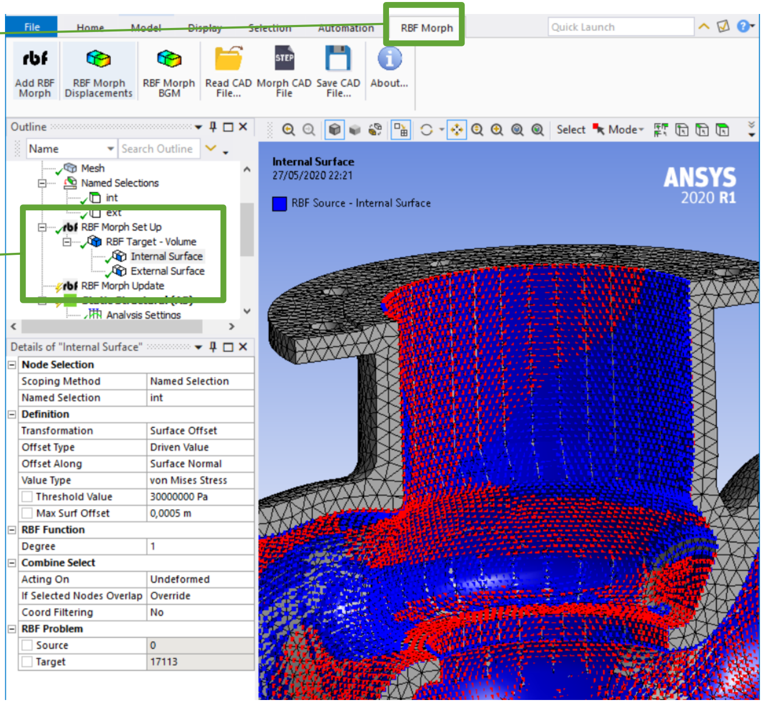


Two parameters allow to get a 22.5% stress **reduction**



ACT Extension for Mechanical

- Deeply integrated in ANSYS Mechanical: same **look & feel**, same interaction logic, **same parameters!**
- 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 library** (OpenMP and CUDA powered)
- Child **hierarchical** logic for complex morphing (two steps, three steps, …, n steps setups)



Structural optimization case study at ICC2021

Visit the **RBF Morph** booth at the International CAE Conference and Exhibition 2021.

Energy Session

November 17 | 14:30 - 17:50

Break: 16:00 – 16:30

Language: English

16:30 - 16:50

UNIVERSITY OF ROME TOR VERGATA | CORRADO GROTH

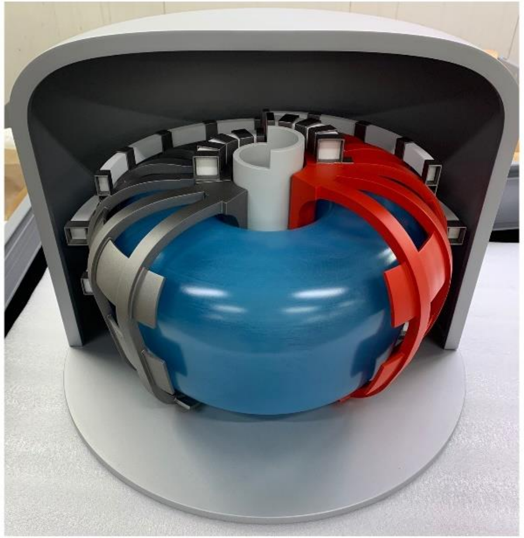
Reshaping the Tokamak TF Coil of DEMO with high fidelity multi physics CAE and advanced mesh morphing

The DEMO Tokamak represents a major challenge under the technical and technological points of view. It is evident that such a race can be won only with an effort up to the challenge at each step of the roadmap, starting with the design stage. This entails the deployment of the most effective design tools available in the CAE environment. This paper shows the optimisation strategy adopted for the TF coils of the ADCs, searching for the best compromise between electromagnetic (EM) and structural compliances. A continuous transformation, based on mesh morphing enabled by the tool RBFMorph, turns the baseline FE model into its bending-free counterpart, with a series of intermediate configurations available for EM and structural investigations as output. A candidate coil is determined for each configuration as the one experiencing an acceptable stress level. Static membrane stress levels during magnetization could be reduced significantly from more than 700 MPa to below 450 MPa.

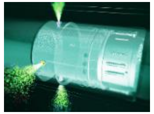
rbf™ TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA hSL Hic Sunt Leones EUROfusion

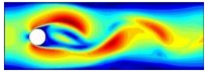
I have heard that with fusion we can have our own stars

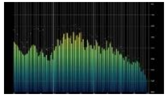
Come and have a look at the 3D printed prototype showing the effect of shape optimization



Oil & Gas Industry Needs



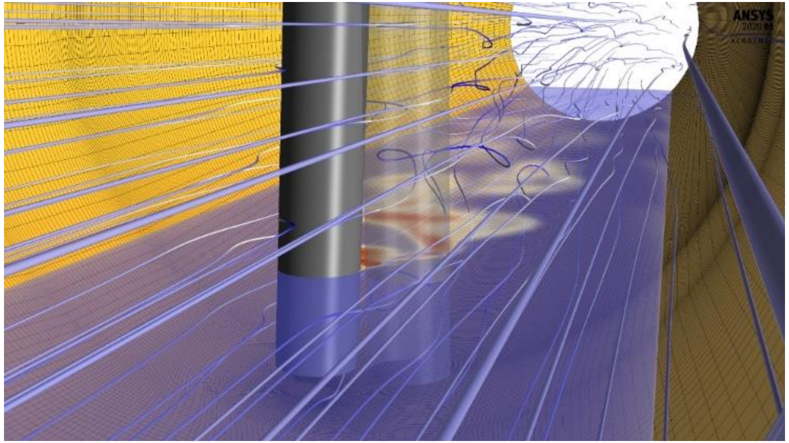




- Valve design with linear response with respect to position and flow resistance
- Resistance evaluation for downhole flow control devices
- Resistance reduction through drill bits and wells
- **Flow Induced Vibration of Oilfield Equipment inside flowlines**
- Noise reduction of fluid dynamic devices

Analysis of Vortex Induced Vibration of a thermowell by high fidelity FSI numerical analysis based on RBF structural modes embedding

- Introduction
- Vortex shedding phenomenon
- Theoretical background
- Proposed workflow
- Vortex induced vibration analysis
- Conclusions



Introduction and motivation

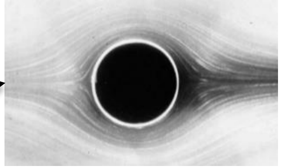
- Today the need for developing multi-physics approaches in order to address modern and complex design challenges is rising. A typical multi-physics phenomenon is the interaction between a **fluid and a structure**.
- The Fluid Structure Interaction is the interaction of a movable or deformable structure with an internal or a surrounding fluid flow.
- The proposed FSI modal approach allows the adaptation of the shape of the deformable structure according to **modes superposition.**
- The modal superposition FSI method is demonstrated on an industrial problem: the **vortex induced vibration of a thermowell**.

Vortex shedding phenomenon

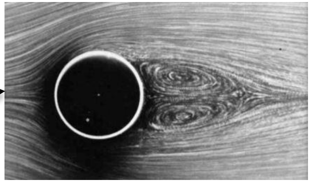
Vortex shedding is an oscillating flow that occurs when a fluid flows past a bluff body at specific Reynolds number. In this flow vortices detach periodically and alternately from the body generating a Von Kármán vortex street.

$$Re = \frac{\rho U D}{\mu}$$

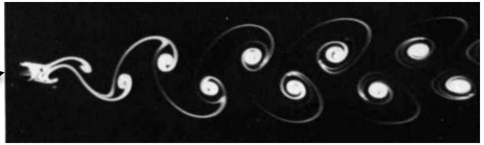
- *Re*<4 → Creeping laminar flow



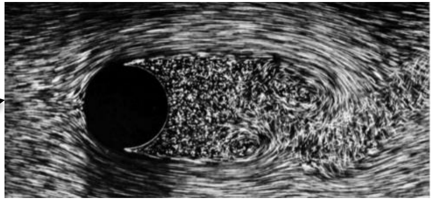
- 5<*Re*<49 → Symmetric and steady wake



- 49<*Re*<140-194 → Laminar vortex shedding

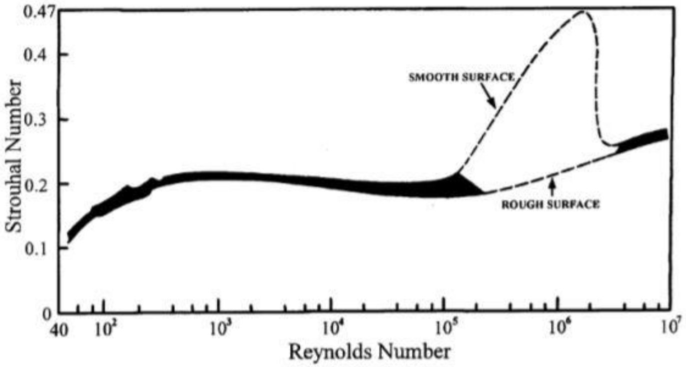


- 1000<*Re*<200000 → Sub-critical regime



Vortex shedding phenomenon

To describe the vortex shedding frequency, the **Strouhal** number is introduced: $St = \frac{fL}{U}$

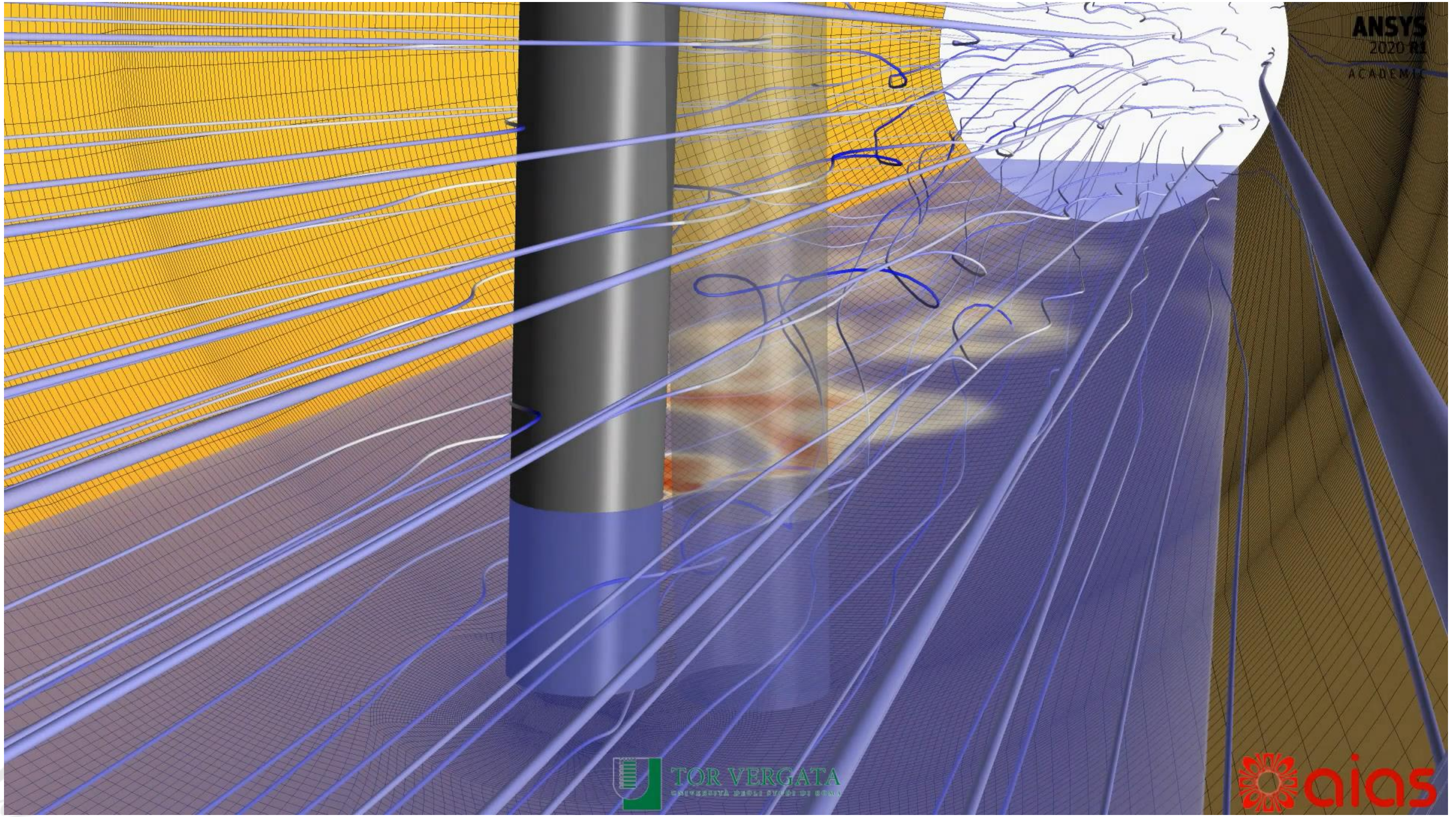


The alternating detachment of vortices an unsteady cross-flow force with the same **frequency** as the vortex shedding and a streamwise unsteady force with a frequency about doubled.

If the **Strouhal frequency approaches a natural frequency** of the flexible body around which the vortex shedding appears, an oscillatory response may occur ⇒ **lock-in**.

The full story in a nutshell…

https://youtu.be/At4LpQhk4OM



Theoretical background

***<u>Unsteady FSI using modal superposition</u>*:**

Hypothesis: modal force *F* can be considered constant within every time-step of integration

$$\Downarrow$$

$$q(t) = e^{-\varsigma\omega_n t}\left[q_0 \cos(\omega_d t) + \frac{\dot{q}_0 + \varsigma\omega_n q_0}{\omega_d}\sin(\omega_d t)\right] +$$

$$+e^{-\varsigma\omega_n t}\left\{\frac{F}{\omega_d}\left[\frac{4\omega_d}{\varsigma^2\omega_n^2 + 4\omega_d^2} - e^{-\varsigma\omega_n t}\frac{2\varsigma\omega_n \sin(\omega_d t) + 4\omega_d \cos(\omega_d t)}{\varsigma^2\omega_n^2 + 4\omega_d^2}\right]\right\}$$

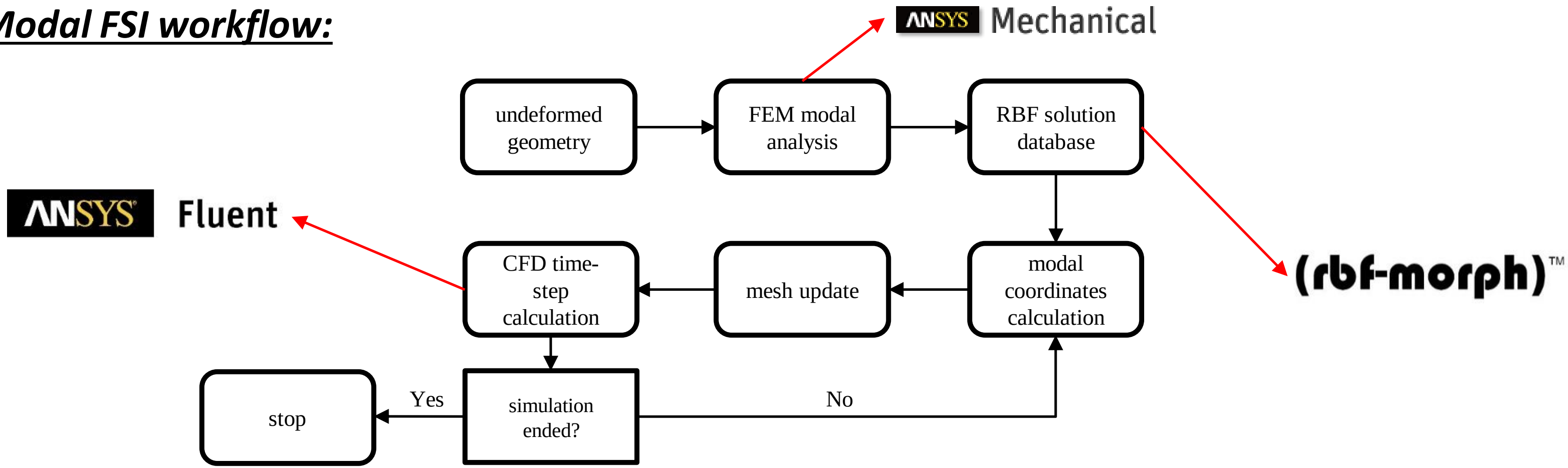
$$\Downarrow$$

$$\boldsymbol{y} = \sum_{i=1}^{\boldsymbol{n}} \boldsymbol{v}_{\boldsymbol{i}} q_{\boldsymbol{i}}$$

Not all the frequencies are excited ⇒ modes truncation.

Proposed workflow

Modal FSI workflow:



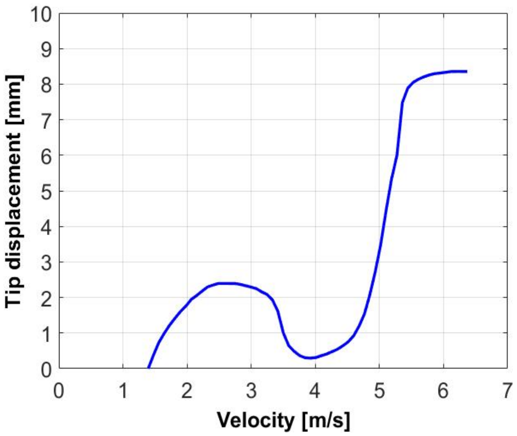
To speed up the mesh morphing step, the deformations associated with each modal shape are stored in memory. This is possible because the mesh deformations are obtained by linearly superimposing the action of each modal shape amplified by its modal coordinate:

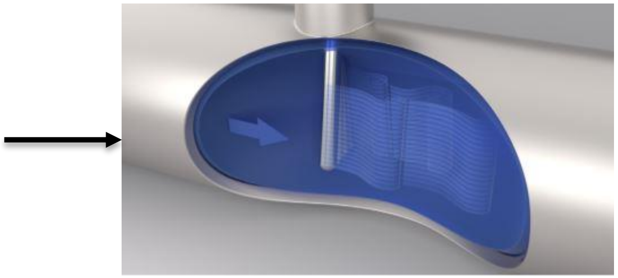
$$x_{CFD}(t) = x_{CFD_0} + \sum_{i=0}^{k} q_i(t)\Delta\mathbf{x}_i$$

Vortex induced vibration analysis

The tested thermowell, 470.219 mm in length, was equipped with accelerometers in the tip and immersed in a water flow loop evolving inside a 152.4 mm diameter pipe. To evaluate the flow induced vibrations, the water velocity ranged from 0 m/s to 8.5 m/s.

Results:



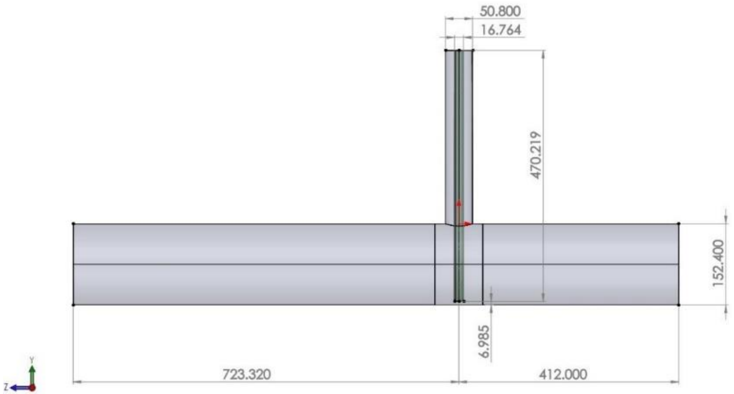


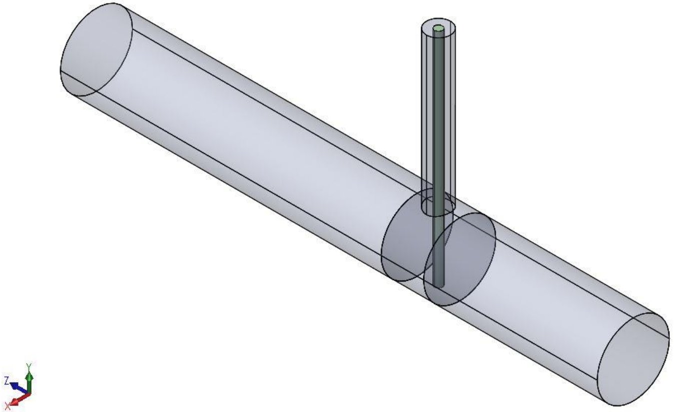
Two lock-in regions:

- In-line vibration: 2.33 mm maximum rms tip displacement at 2.44 m/s fluid velocity;
- Transverse vibration: 8.3mm maximum rms tip displacement at 6.4 m/s fluid velocity.

Vortex induced vibration analysis

Geometry:





Modal analysis:

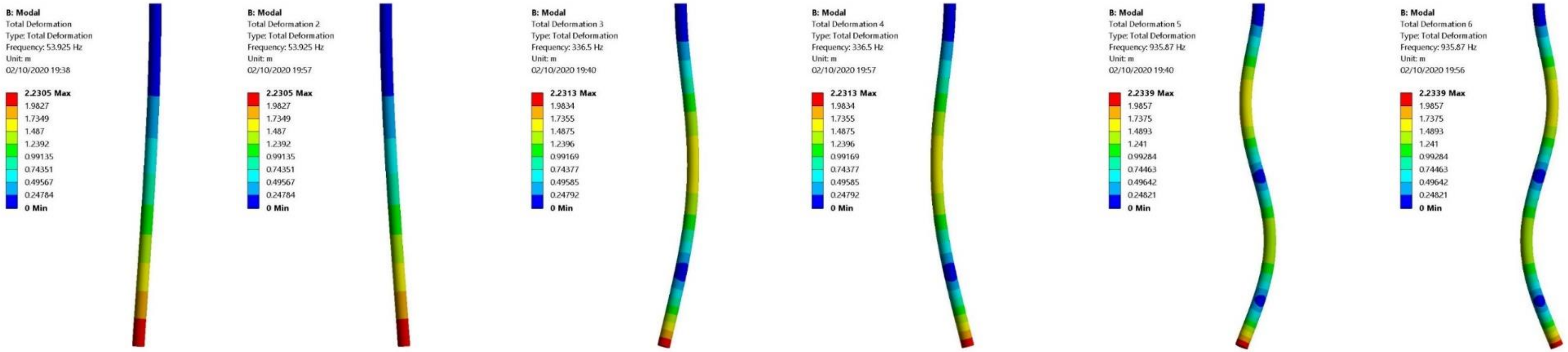
The first step needed to setup a FSI analysis based on the modal superposition method is to carry out a modal analysis of the deformable structure.

Material: 304/304L dual rated steel with a density of 7750 kg/m3, a Young's modulus of 200 GPa and a Poisson's ratio of 0.3.

Vortex induced vibration analysis

Modal shapes:

Algebraic multiplicity of two of the bending modes ⇒ six computed natural modes, correspond to only three distinct bending modes.



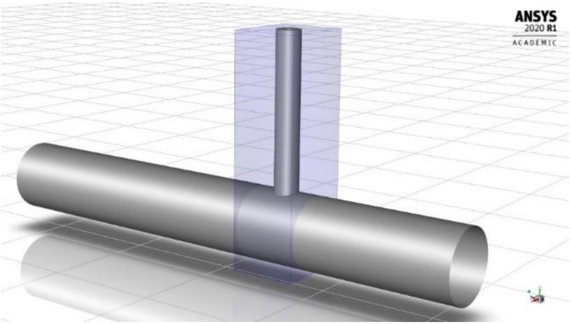
Analytical results: $\omega_{n,i} = \alpha_i^2 \sqrt{\frac{EI_B}{\rho A_B L_B^4}} \quad i = 1,2,3$

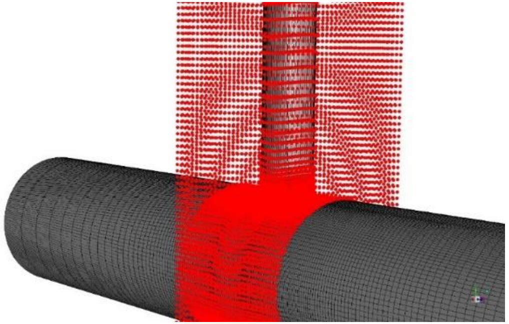
Mode	Analytical natural frequency [Hz]	FEM natural frequency [Hz]	Relative error [%]
1	53.883	53.925	-0.0779
2	337.681	336.499	0.34999
3	945.523	935.872	1.0207

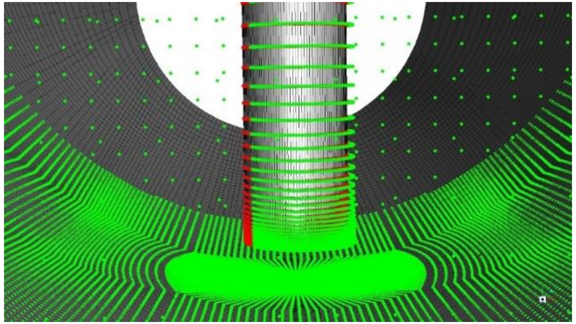
Vortex induced vibration analysis

RBF Morph set up:

the modal shapes computed by FEM are imposed as a motion law to the thermowell surface and a domain encapsulation is introduced to delimit the action of the morphing.





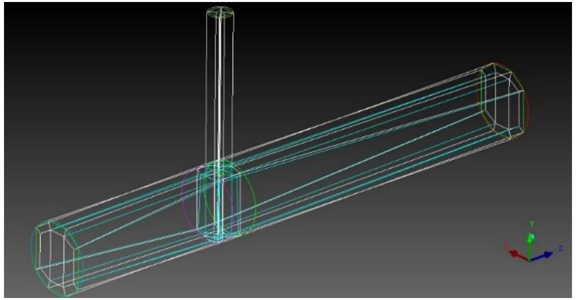


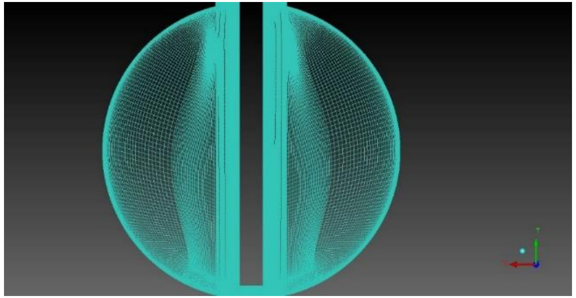
Vortex induced vibration analysis

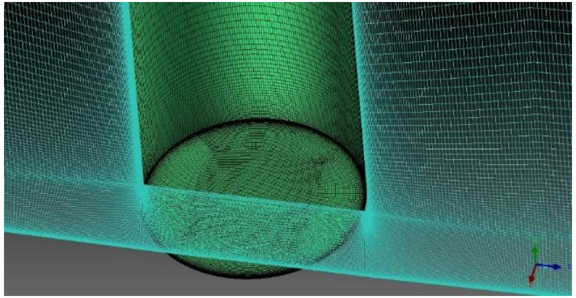
3-D computational grid:

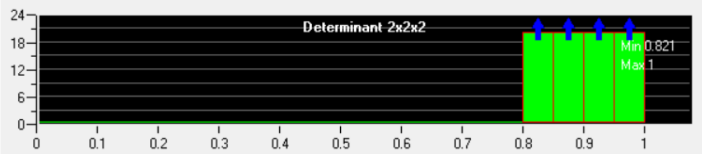
The geometry has been discretized into a computational domain through ANSYS® ICEM CFD™ using the setup validated in the 2-D analysis. The obtained mesh is structured, multiblock and composed of hexahedrons.

Key features: $y^+<1$ for the first row of cells near the walls, 1.2 growth factor after the first row, refinement in the wake, 3158640 hexahedral cells.



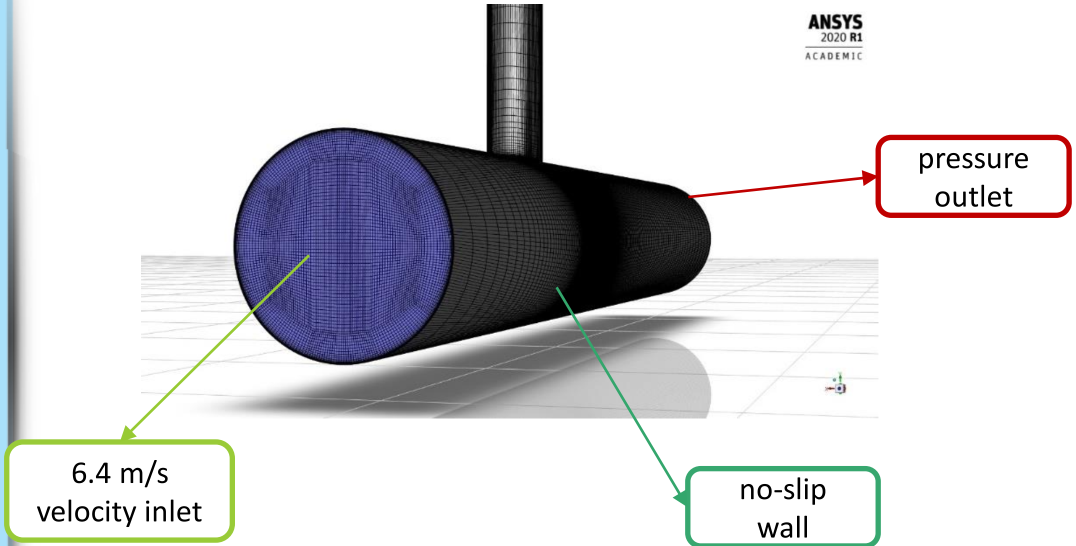






Vortex induced vibration analysis

CFD setup:



Key features:

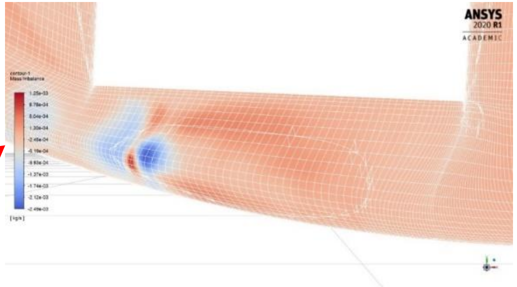
- Water density: 998 kg/m^3;
- Water viscosity: 0.001002 kg/(m·s);
- *Re*: 100000;
- Pressure-based solver;
- Constant density;
- URANS with SST k-ω;
- SIMPLE pressure-velocity coupling;
- Second order scheme for pressure;
- Second order upwind scheme for momentum and turbulence parameters;
- Lest squares cell based scheme for gradient;
- First order implicit transient formulation;
- Time-step size: 10^{-4} s;
- Computer-controlled convergence criterion: 10^{-5} residual of the continuity equation.

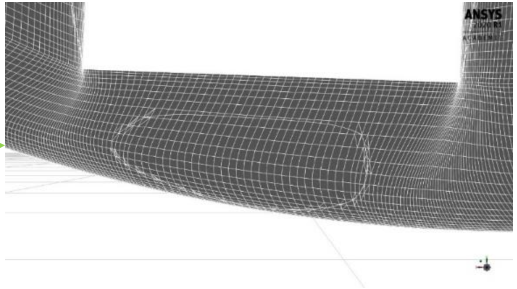
Vortex induced vibration analysis

Parametric study of structural damping effect:

The simulations ran on a HPC node equipped with 256 GB of RAM and four Intel® Xeon® Gold 6152 CPU, each featuring 22 cores @ 2.1 GHz. Out of the overall 88 cores, 30 were used to run the simulations.

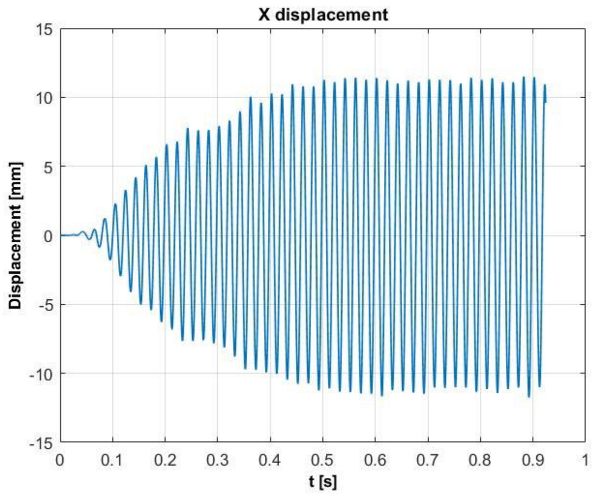
Damping ratio	Maximum RMS transverse tip displacement at dynamic steady state [mm]	Relative error [%]
0.01	Not reached	-
0.02	Not reached	-
0.05	6.45	22.3
0.04	8.48	-2.17
0.041	8.304	-0.048

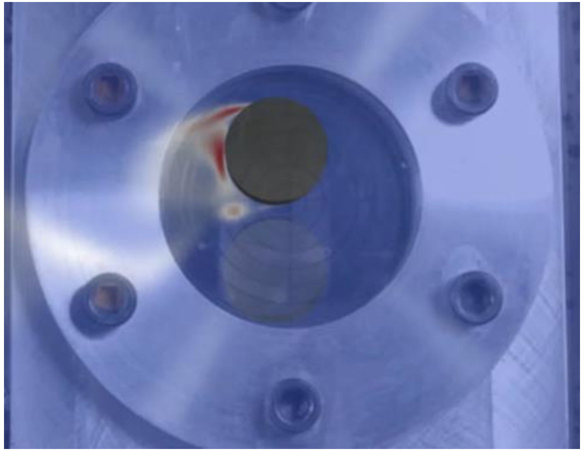




Vortex induced vibration analysis

FSI analysis results:

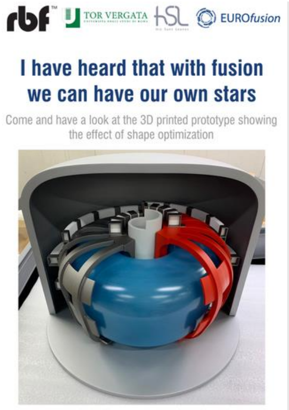


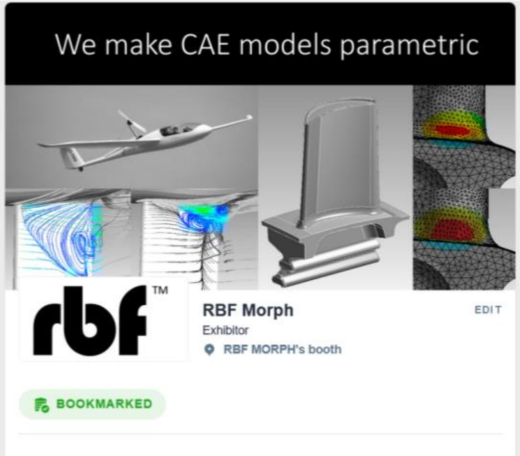


Synchronization between the vortex shedding and the thermowell oscillation ⇒ lock-in ⇒ vortex induced vibration.

Conclusions

- The RBF Morph technology integrated with Ansys has been introduced
  - A Fluent module capable to support shape optimisation and complex mesh deformations occuring during CFD run
  - An ACT Extension for Mechanical and LS-DYNA
  - Strong integration with Ansys platform (WB, DX, optiSLang, TwinBuilder)
- The objective of the VIV industrial study was successfully achieved
  - Modal superposition FSI analysis accurately simulates the vortex induced vibration observed in the thermowell
  - Thanks to RBF mesh morphing a reliable and robust FSI transient solver has been implemented
  - The approach is fast and can be adopted to tackle complex industrial problems
- For more information visit our **RBF Morph booth**





Many thanks for your kind attention!

marco.biancolini@rbf-morph.com

linkedin.com/company/rbf-morph

youtube.com/user/RbfMorph

rbf-morph.com