RBF Morph software
External Aerodynamic Optimization Using ANSYS Mesh Morphing

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(rbf-morph)™

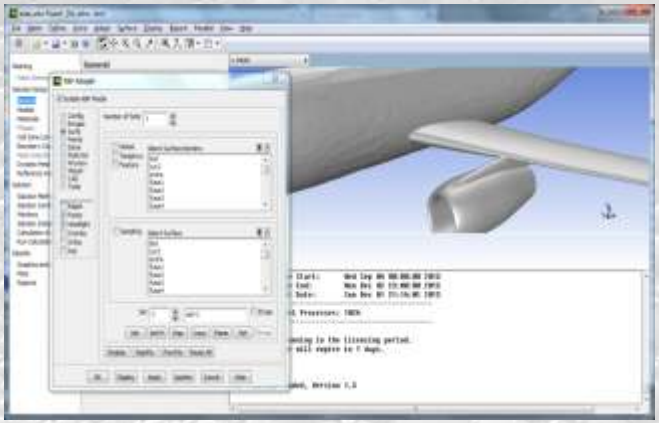
Outline

- Company Introduction
- RBF Morph Software Line
- Key benefits for the Automotive industry
- Automotive Applications

Company Introduction

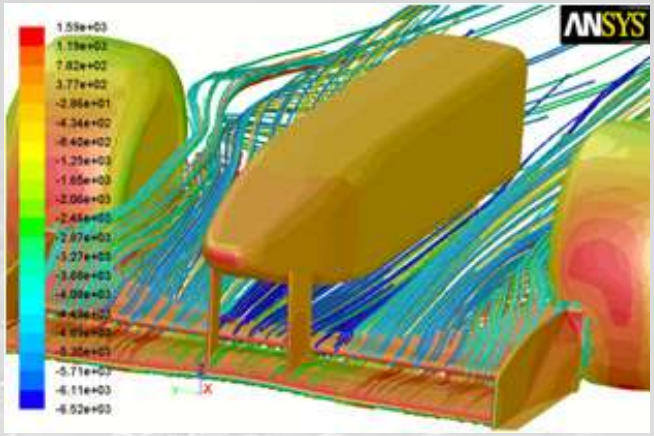
RBF Morph is a pioneer and world-leading provider of numerical morphing techniques and solutions conceived to efficiently handle shape optimization studies concerning most challenging industrial applications.
We are an independent software-house and vendor. Our main product is **RBF Morph**™, that is 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 as an add-on of the CFD commercial code ANSYS® Fluent®, as a stand alone product and as an ANSYS ACT Extension.



Company Introduction

The **RBF Morph** tool had its inception in 2008 as 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 deliver 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 FP7 Fortissimo

ANSYS

ENGIN SOFT

easc
EUROPEAN AUTOMOTIVE SIMULATION CONFERENCE

2013 Automotive Simulation World Congress

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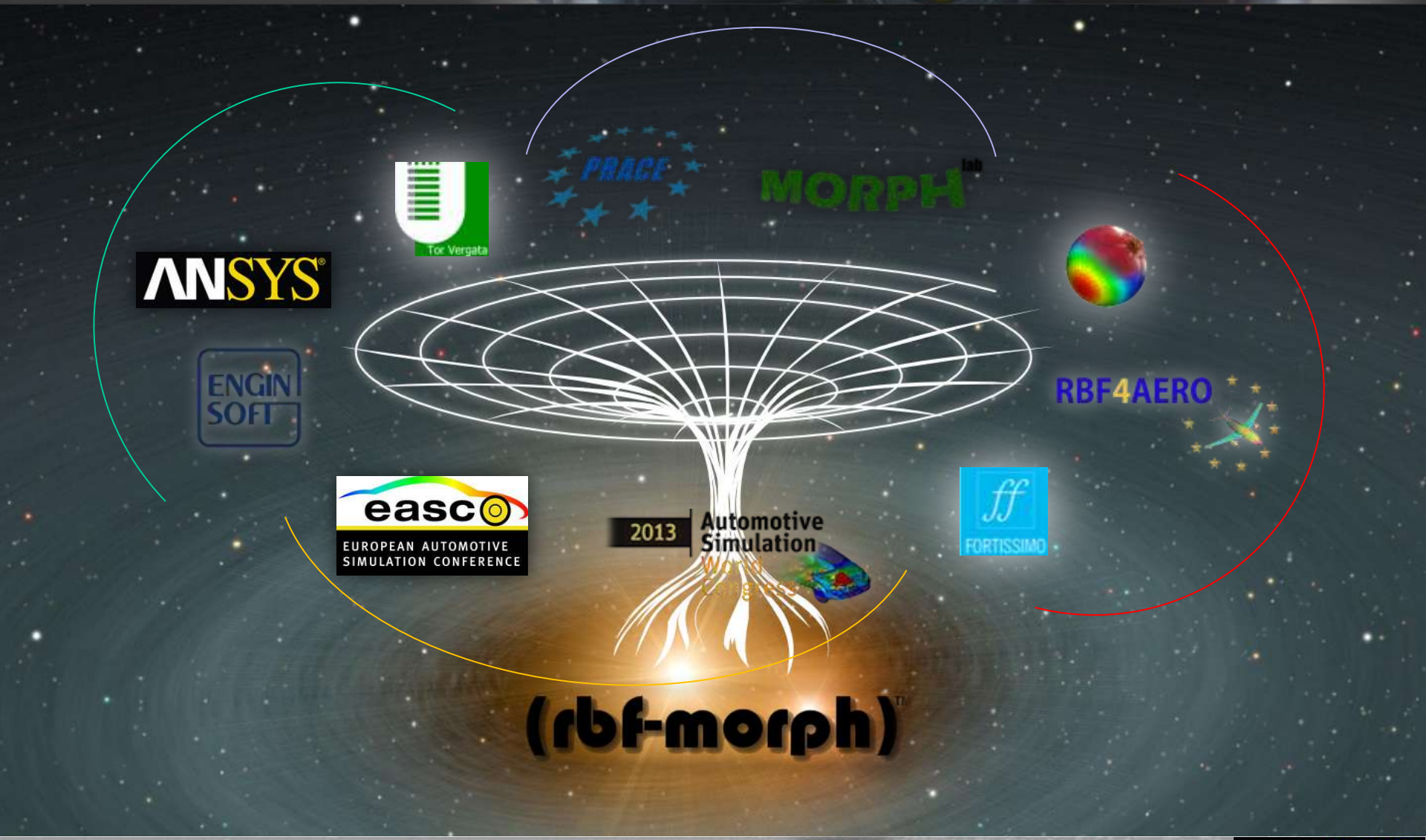
Knowledge Galaxy

2015 Automotive Simulation World Congress



ASWC 2015
June 2015 - Detroit, MI, USA

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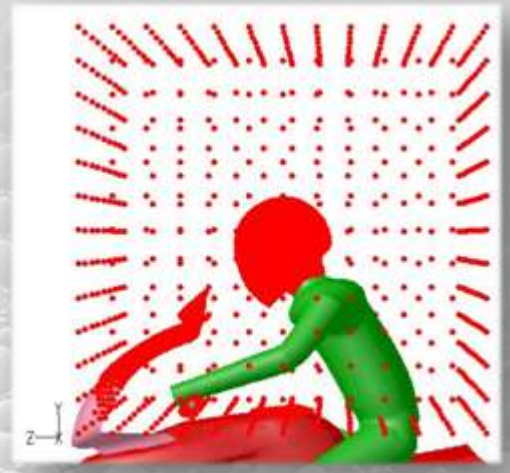
ANSYS

RBF Morph software line

Mesh Morphing with RBF

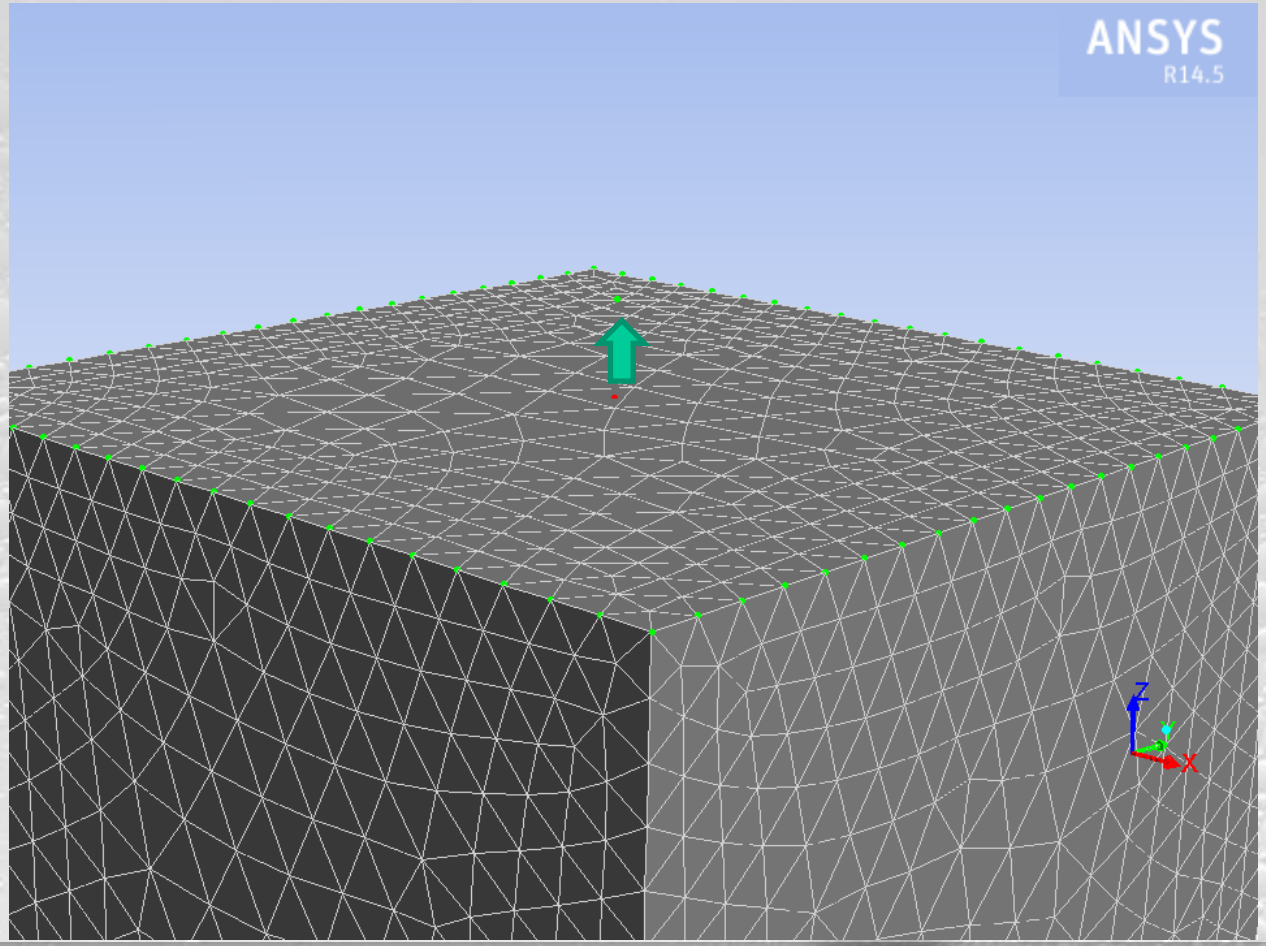
- A system of **R**adial **B**asis **F**unctions is used to **fit** a **solution** for the mesh movement/**Morph**ing, from a list of **source points** and their **displacements**.
- The RBF problem definition does not depend on the mesh
- Radial Basis Function interpolation is used to derive the displacement in **any location** in the space, each component of the displacement is interpolated:

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

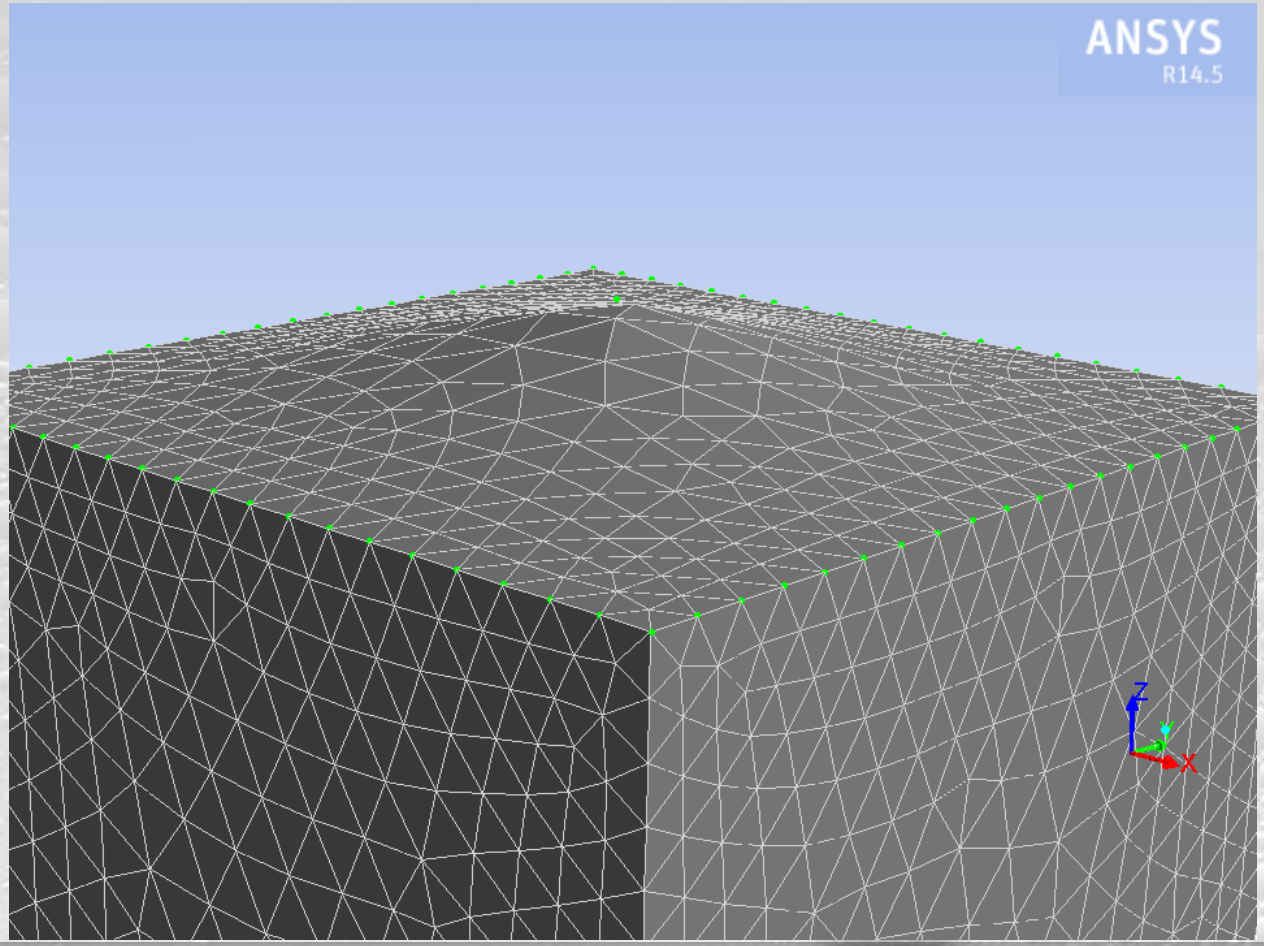


- RBF are recognized as on of the **best mathematical tool** for mesh morphing. The main issue is about performances required for the solution of **large dataset**.

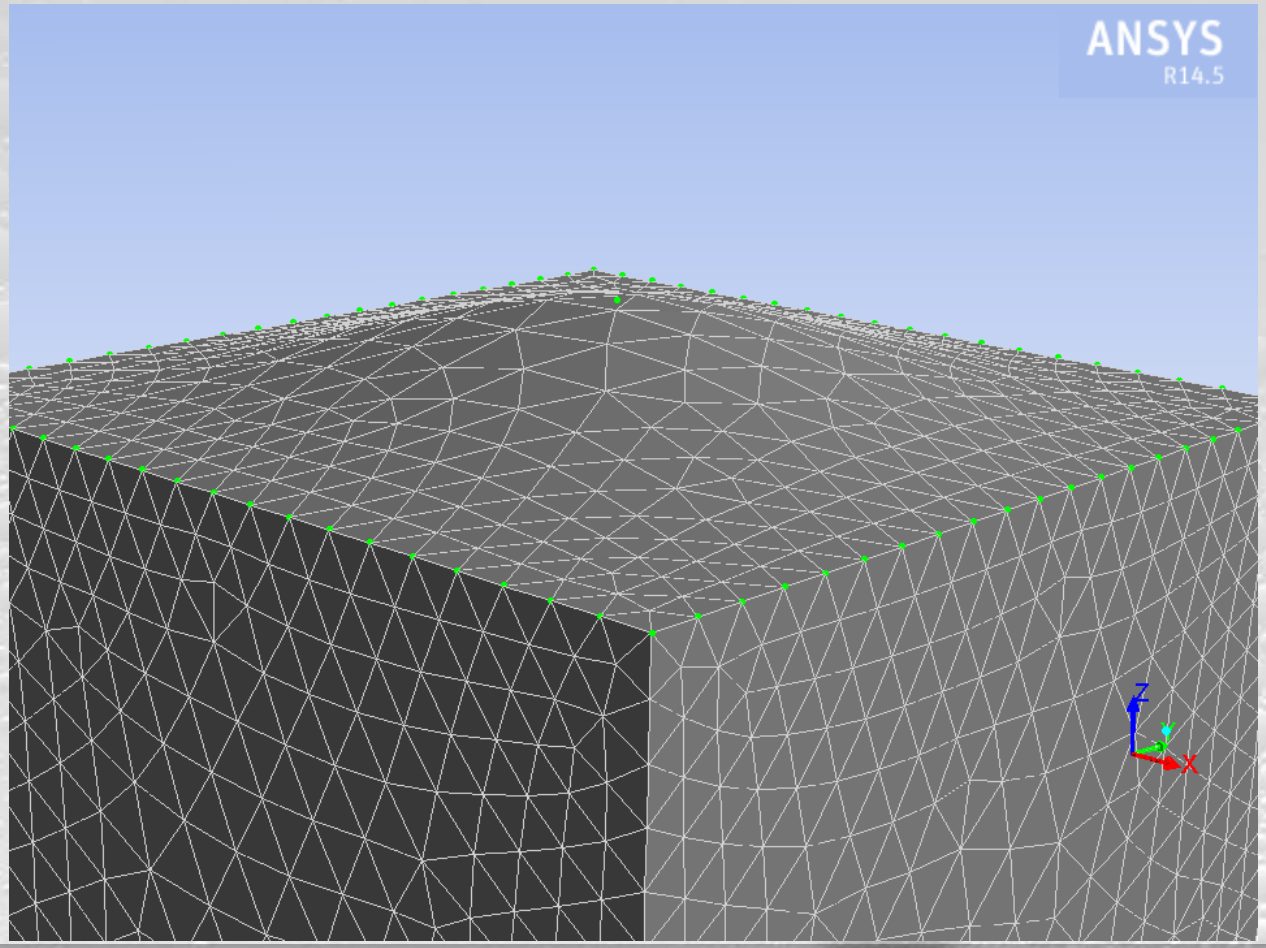
One pt at center and border (80 pts)



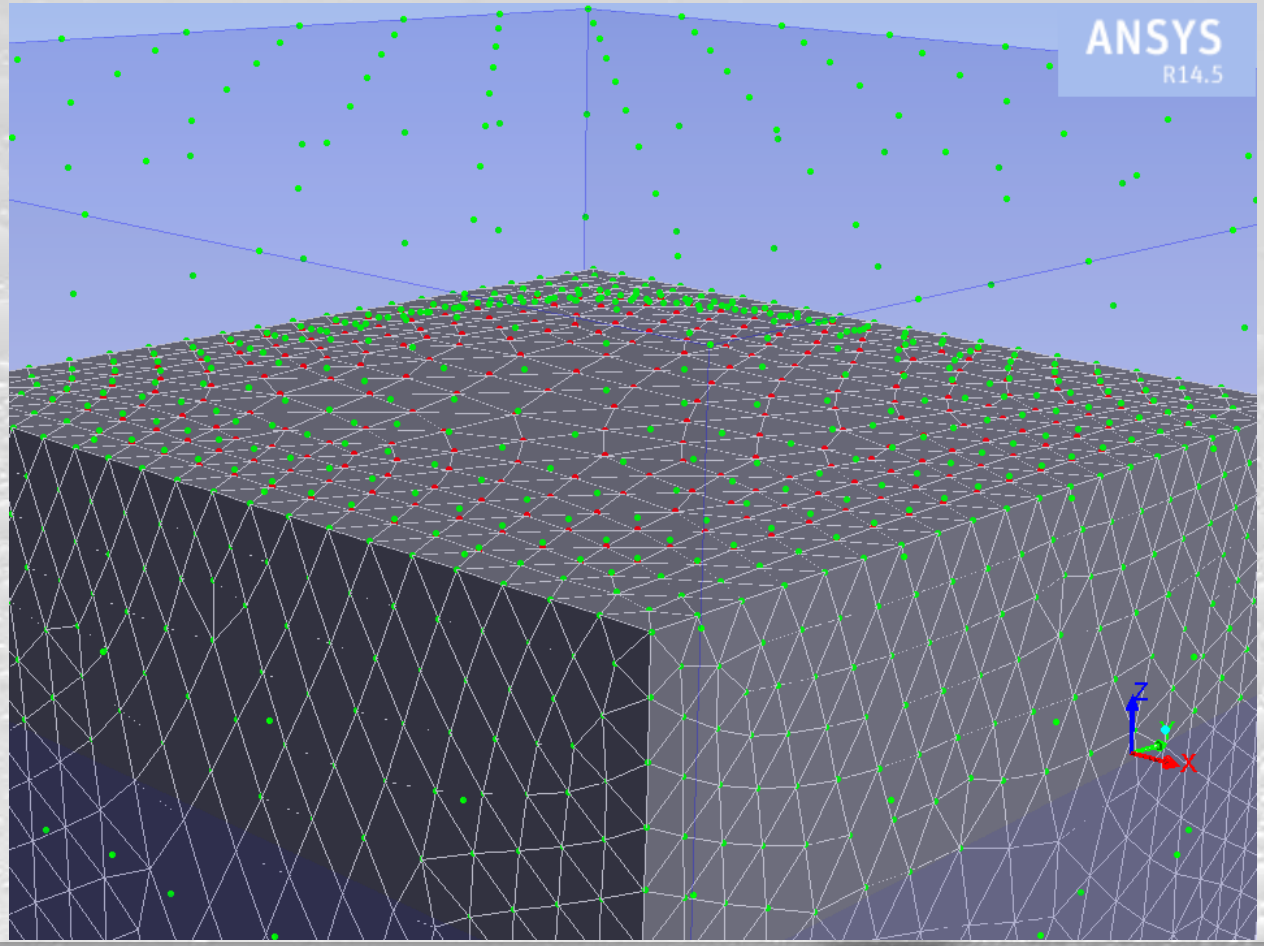
Effect on surface (gs-r)



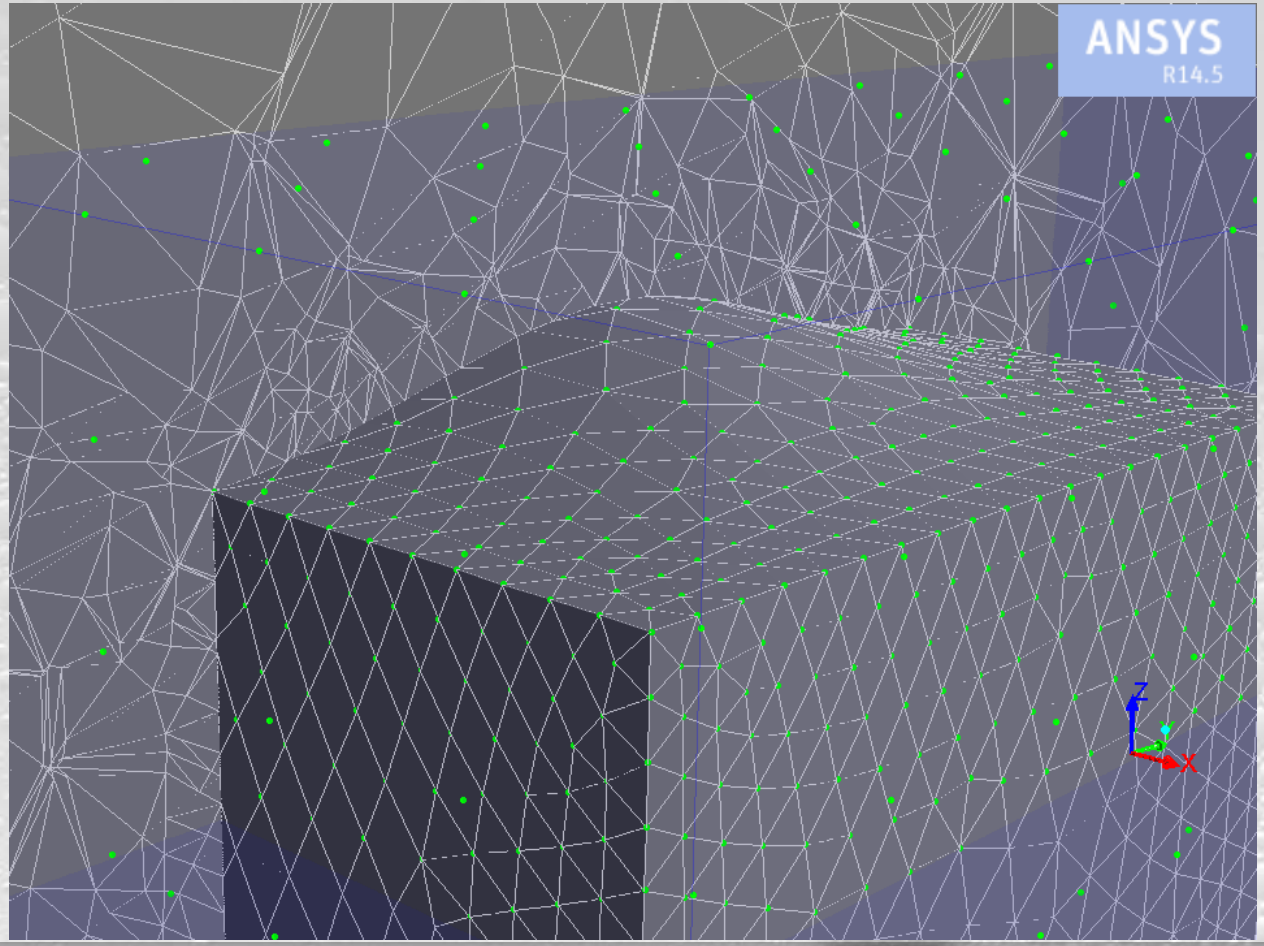
Effect on surface (cp-c4)



Control of volume mesh (1166 pts)



Morphing the volume mesh

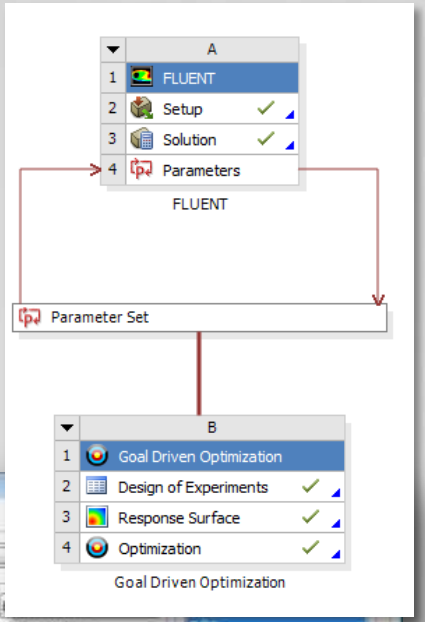


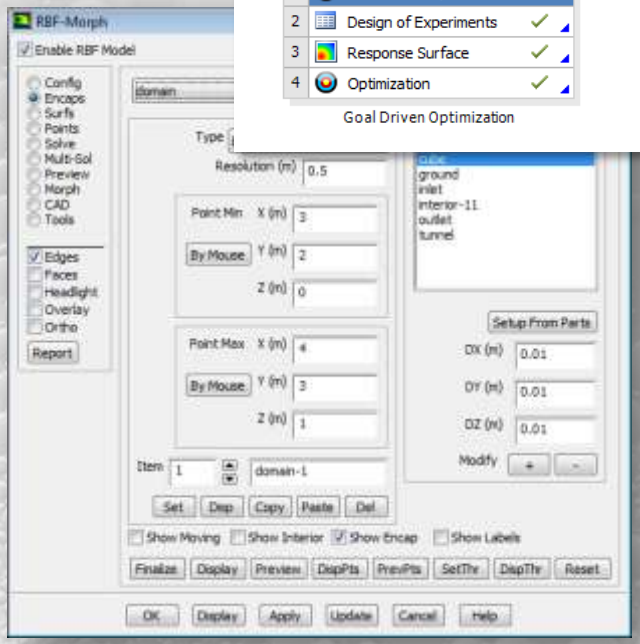
RBF Morph software line

- HPC RBF **general purposes** library (state of the art algorithms, parallel, GPU). This is the numerical kernel of our software. **Millions** of RBF centers can be fitted in a short time.
- Awarded mesh morphing software available as an add-on for **ANSYS Fluent** CFD solver
- **Stand alone** morphing software + smoothing commands for different mesh formats
- ANSYS Mechanical **ACT module** (Released in May 2015!).

Fluent add-on

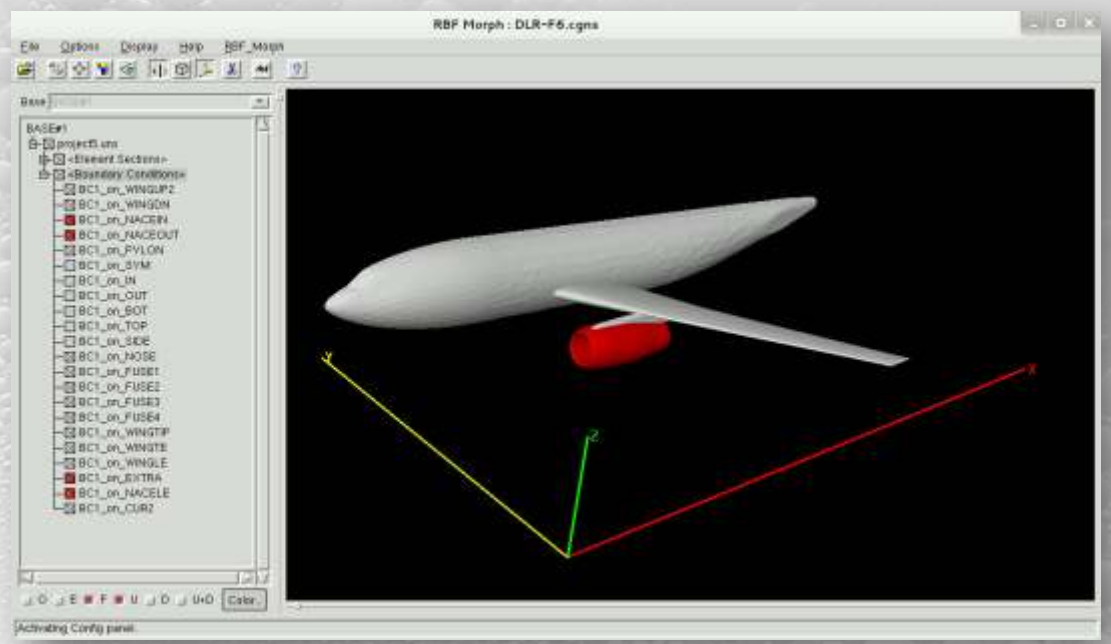
- **Add on** fully integrated within **Fluent** (GUI, TUI & solving stage), **Workbench** and **Adjoint Solver**
- **Mesh-independent** RBF fit used for surface mesh morphing and volume mesh smoothing
- **Parallel** calculation allows to morph **large size** models (many millions of cells) in a short 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**)





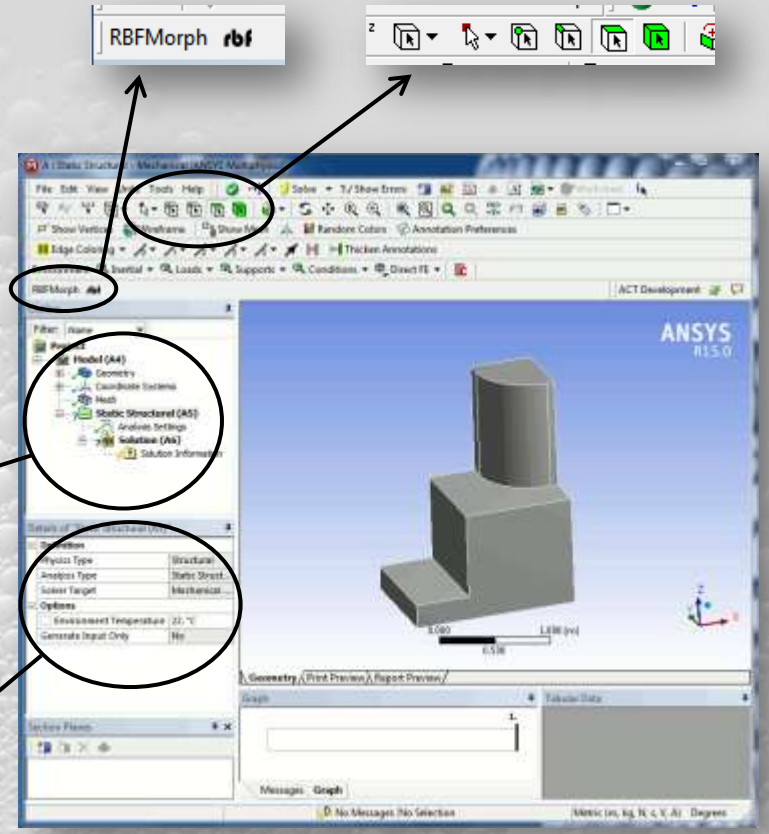
RBF Morph Stand Alone

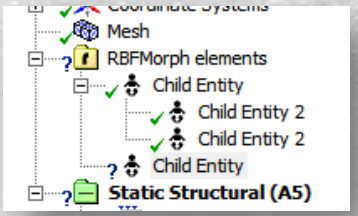
- RBF solutions are fully compatible and **exchangeable** between add-on and standalone versions
- Support for STL and CGNS file formats. Selected morphed surfaces can be exported in STL format and **back to CAD** is possible via STEP files
- **Add-on-like** interface
- **Solver independent** process 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

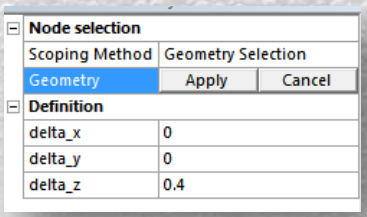


ACT module for Mechanical

- 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)



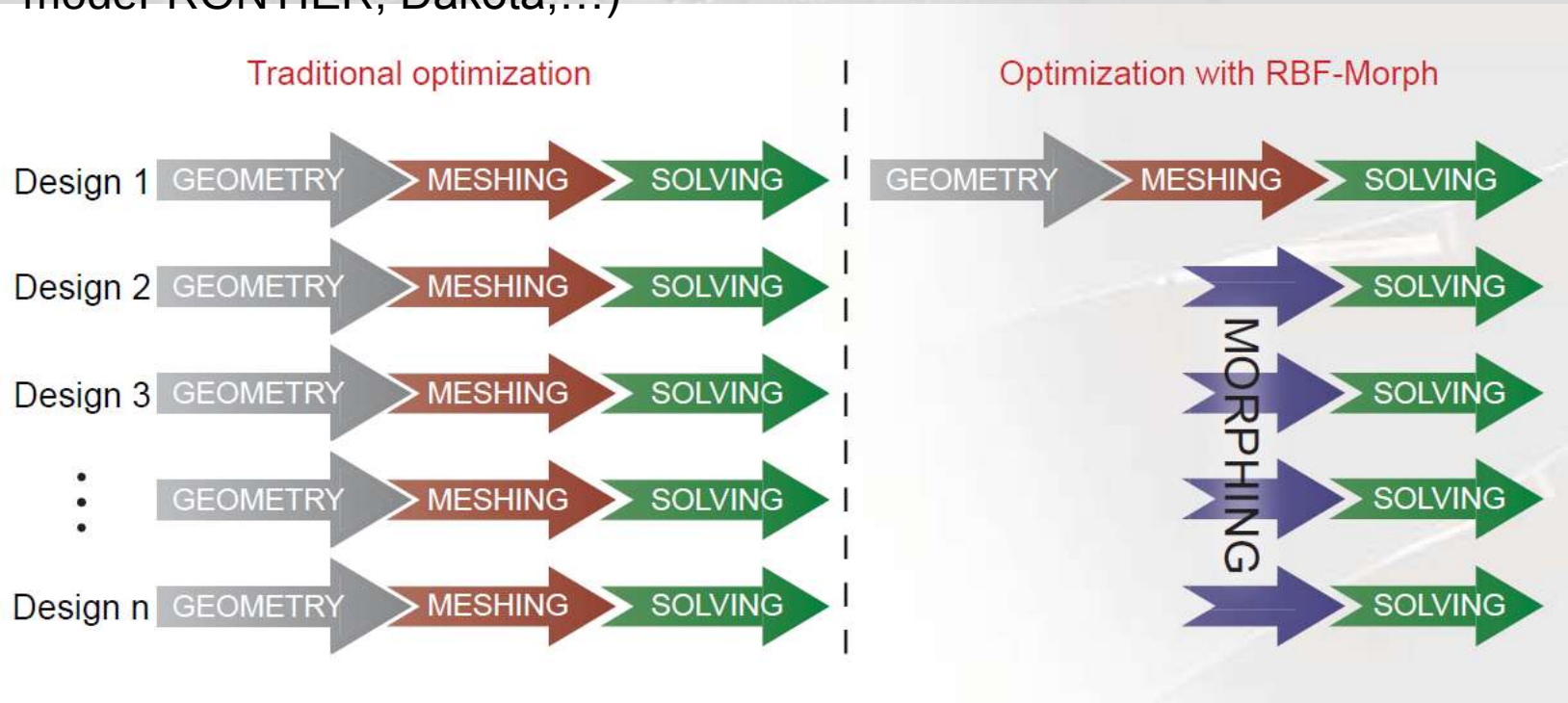




RBF Morph key benefits

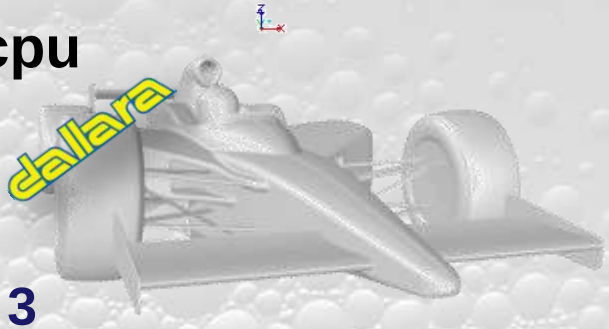
Key benefits: automated

- RBF Morph makes the Fluent model **parametric** with respect to the **shape**
- Works for **any size of mesh** (from small models managed with a WS up to huge Formula 1 meshes in an HPC environment)
- Exposed parameters can be steered with the **optimizer of choice** (DX, modeFRONTIER, Dakota,…)



Key benefits: performances

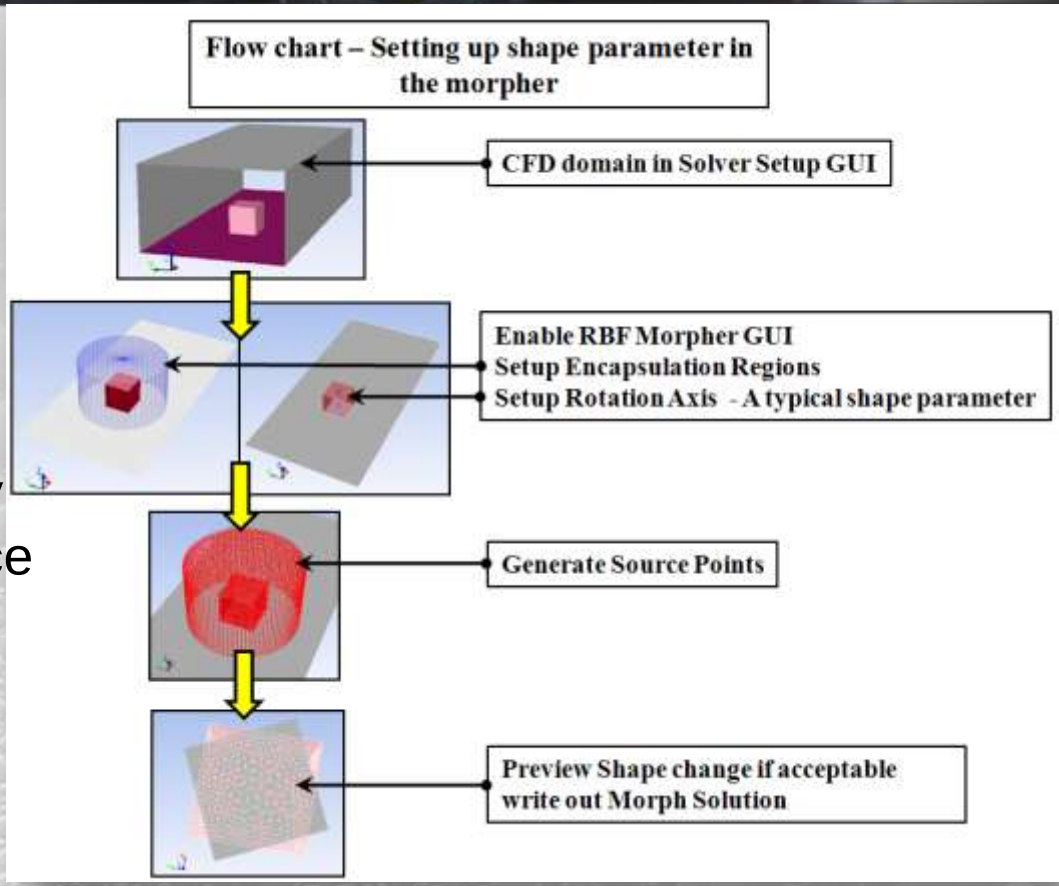
- **14 mill**. cells, 60.000 points, PC **4 cpu** 2.67 GHz
  - fitting time: **53 sec**. (serial)
  - smoothing: **3.5 min**.
- **50 mill**. cells, 30.000 points, HPC **140 cpu**
  - fitting time: **25 sec**. (serial)
  - smoothing: **1.5 min**.
- **100 mill**. cells, 200.000 points, HPC **256 cpu**
  - fitting time: **25 min**.
  - smoothing: **5 min**.



- Largest fitted cloud **2 mill**. points on **32 cpu** in **3 hours**.
- Largest model morphed (in our knowledge) **700.mill.** cells on **768 cpu** in **45 min**.

Key benefits: flexibility

- The integrated GUI allows to **carefully** control surface shape and volume morphing (2 steps option available)
- A **quick learning curve** guided by a rich Tutorial Collection
- The **CFD analyst** can act exactly where is needed (even in absence of a parametric CAD)

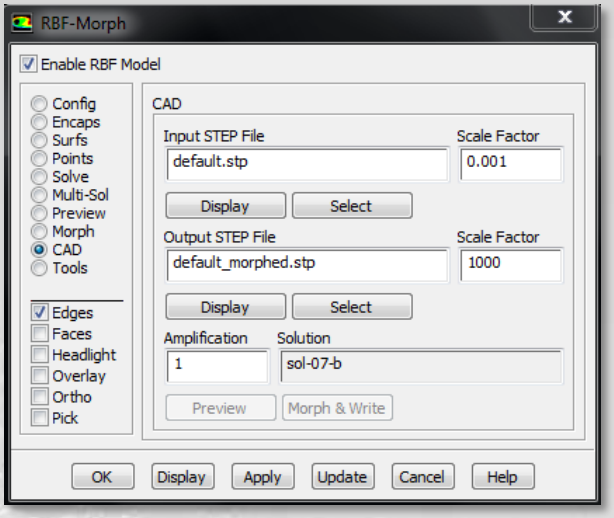


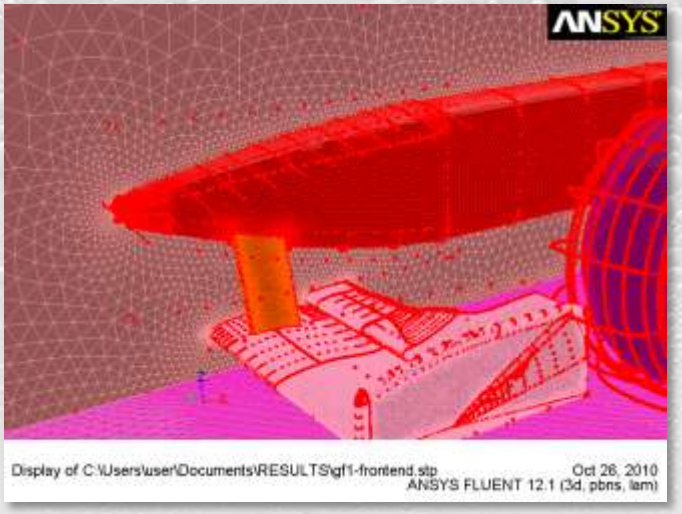
"RBF Morph is an ingenious morphing tool that allows engineers to mold the geometry like clay to very high precision"

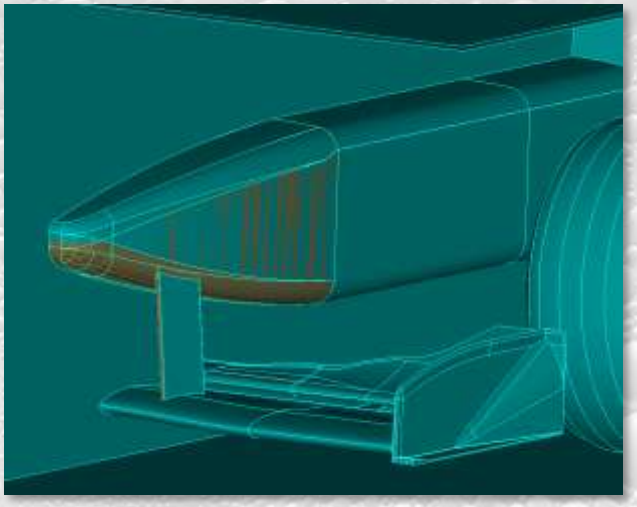
Professional Motorsport Magazine
Issue April-June 2012

Key benefits: back to CAD

- At the end of the automated optimization the optimal configuration is available as a **CFD model**
- Morphing the underlying CAD (NURBS conversion) makes the optimal configuration available as a **CAD model**







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HPC Workflows

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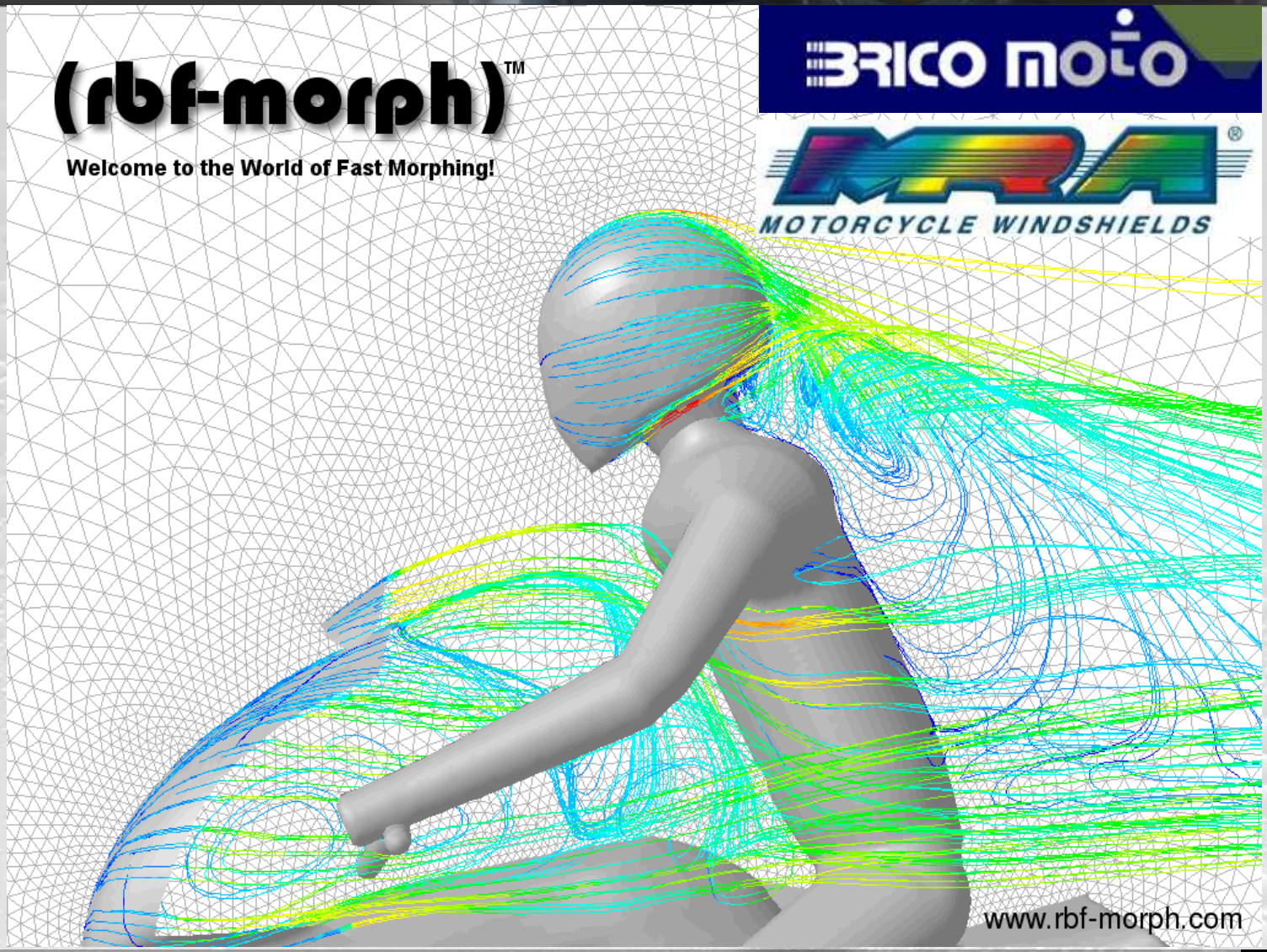
Case	Motorbike windshield	Reference car	Sedan	Hull	**Volvo XC60**	Sails	DLR-F6	IR5
Organization	MRA/UTV	MIRA	ANSYS	Leeds	**ANSYS**	New Castle / UTV	MorphLab/ UTV	Dallara
Year	2009	2010	2011	2011	**2012**	2013	2013	2013
#Mcells	1,5	5,2	6	0,3	**50**	1,5	14	80
mesh type	tets	poly	tets	hexa	**tets**	hexa	tets	tets
#par	3	3	2	8	**4**	4	8	5
#design	45	27	9	45	**50**	100	81	1
RS Tool	modeF	Mathcad	DX	DX	**DX**	DX/ Mathcad	DX	FSI
ncores	4	2	12	4	**240**	16	16	256
RUN (hr)	48	300	24	45	**50**	26	102	1
Time to set-up one par (hr)	1,5	2,5	2	1	**2**	2	1	2
Time to set-up (hr)	4,5	7,5	4	8	**8**	8	8	8
Serial time one design (hr)	4,27	22,22	32,00	4,00	**240,00**	4,16	20,15	256,00
Serial time one design (hr/Mcells)	2,84	4,27	5,33	13,33	**4,80**	2,77	1,44	3,2

Automotive Applications

Motorbike Windshield



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Exhaust manifold

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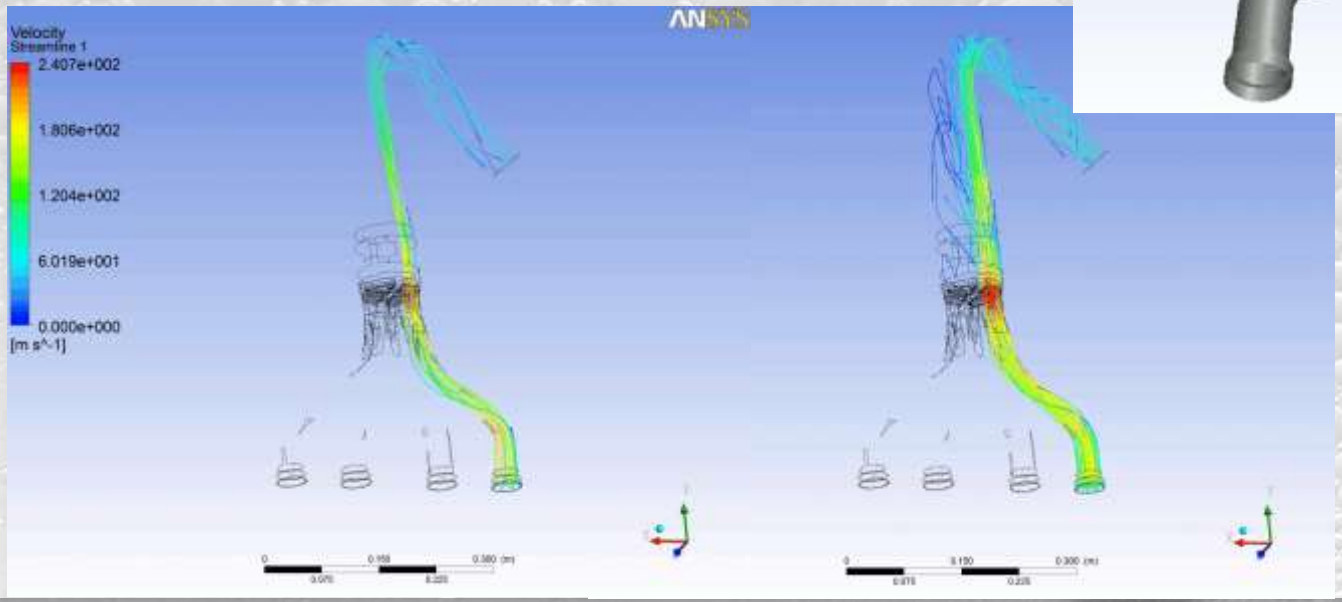
	A	B	C	D	E	F	G	H	I
1	Name	P5 - Pipe1Curve1	P6 - Pipe2	P7 - Pipe4Curve1	P8 - Pipe3	P1 - PressureDrop1	P2 - PressureDrop2	P3 - PressureDrop3	P4 - PressureDrop
2						Pa	Pa	Pa	Pa
3	Current	4	4	4	4	12892	11366	13028	16619
4	DP 1	3	3	3	3	12882	11247	13487	16731
5	DP 2	2	2	2	2	12897	11546	13554	16911
6	DP 3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



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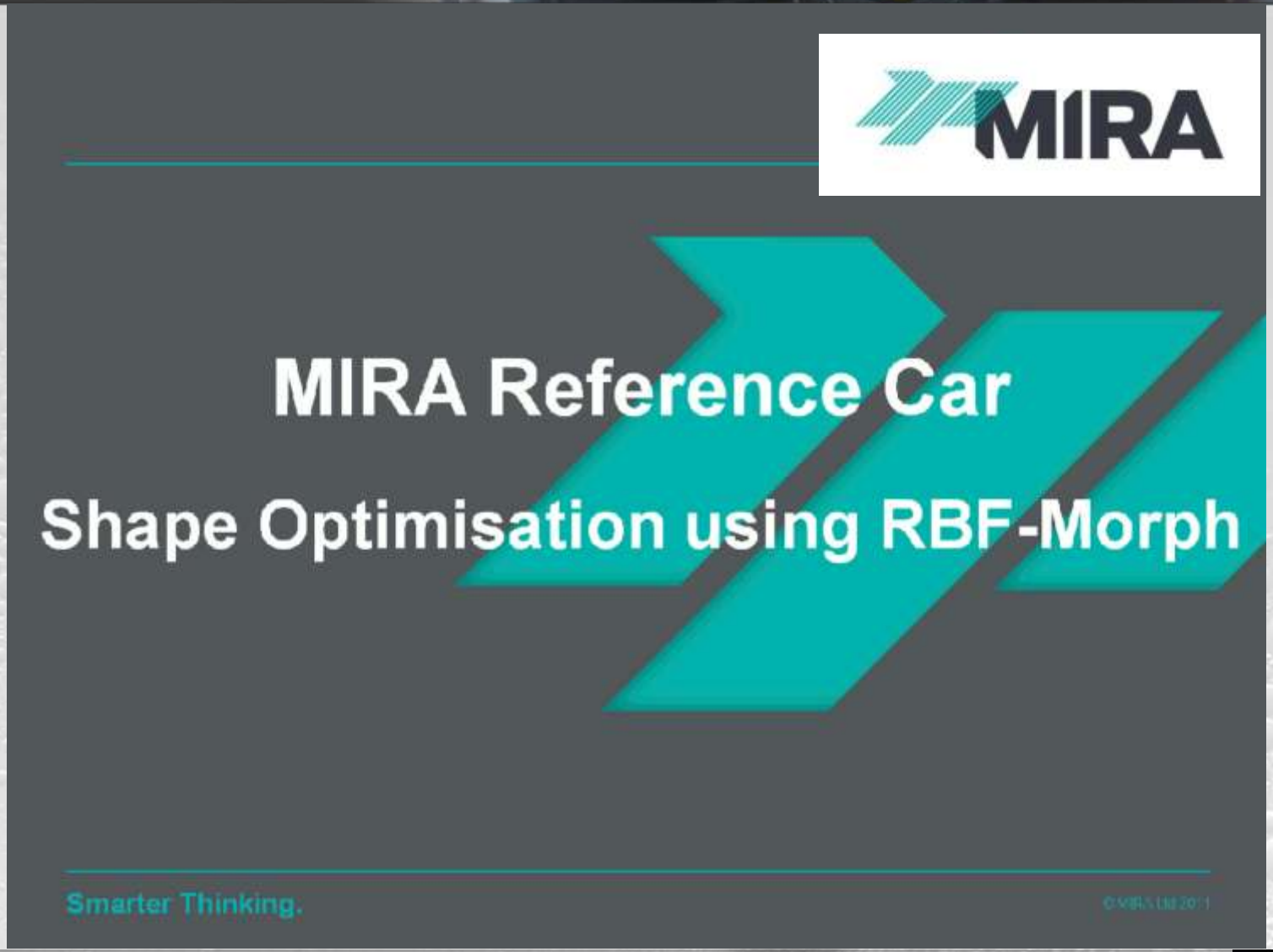
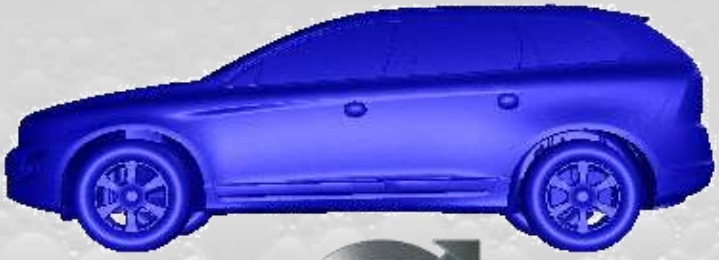
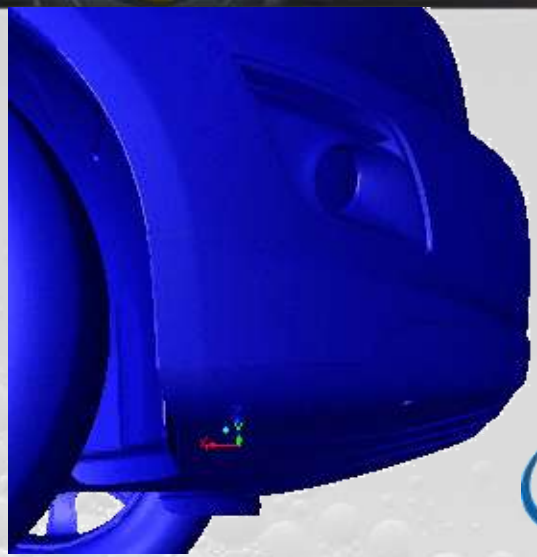
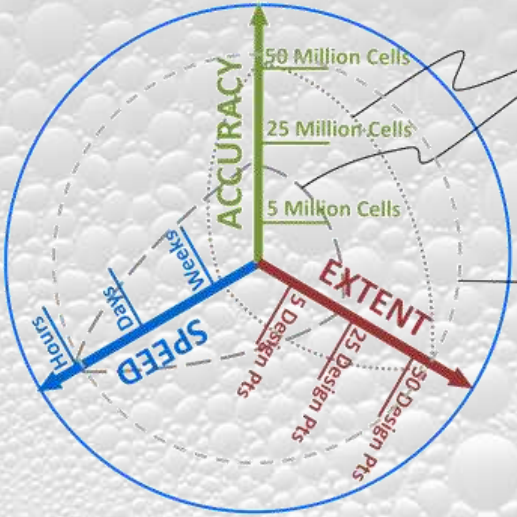
MIRA Reference car



50:50:50 Project Volvo XC60



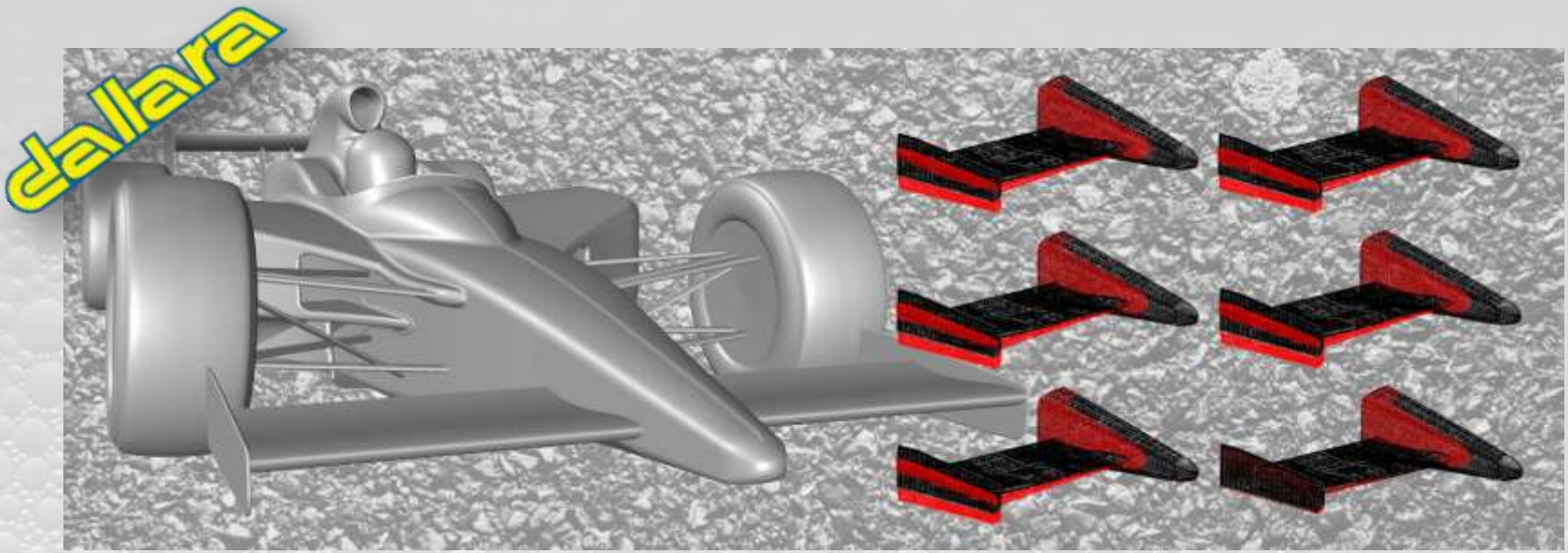




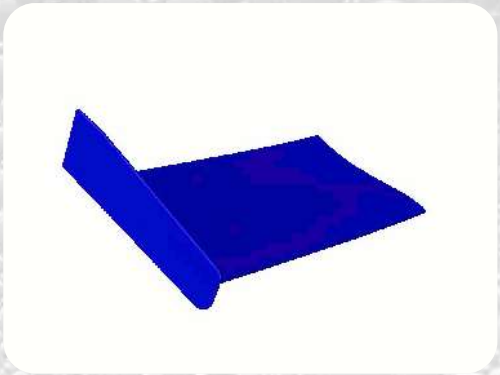
Prior aerodynamics optimization processes have either achieved speed at the expense of accuracy and extent or vice versa

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

FSI analysis on a 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



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Parametric go kart

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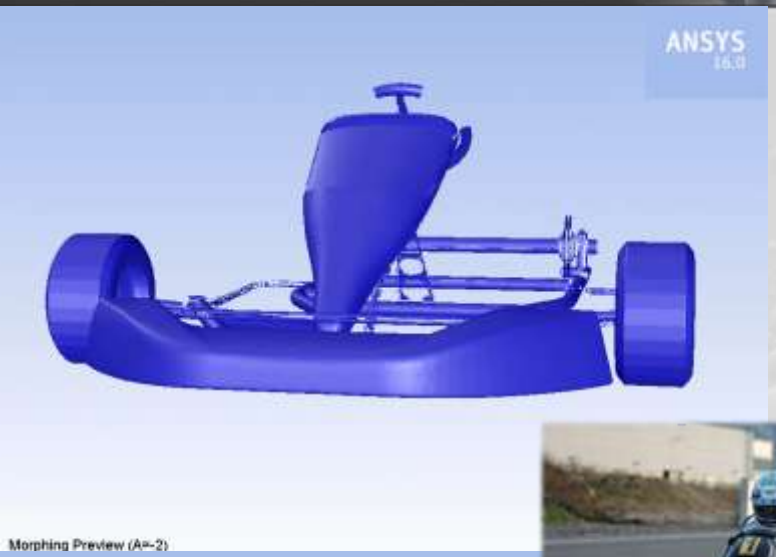

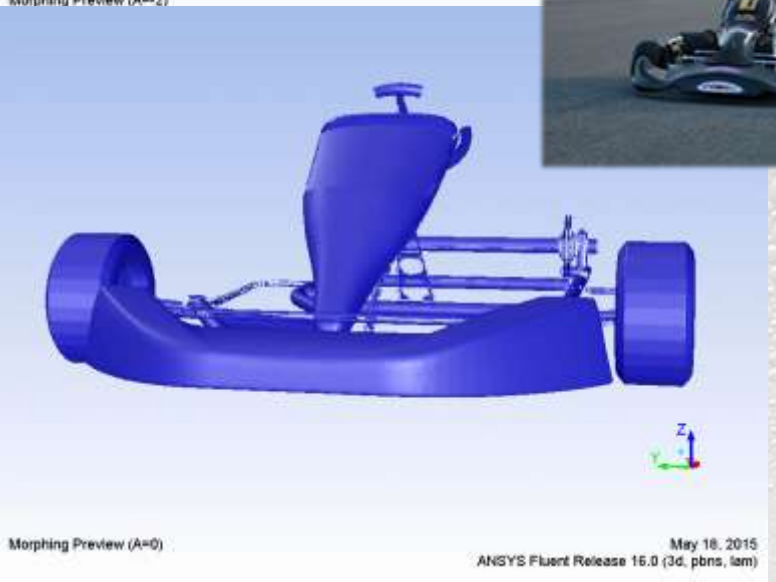

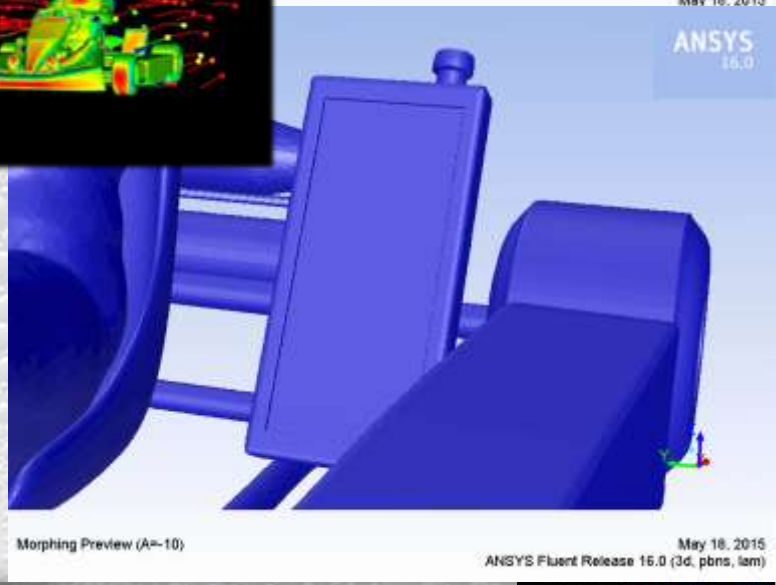

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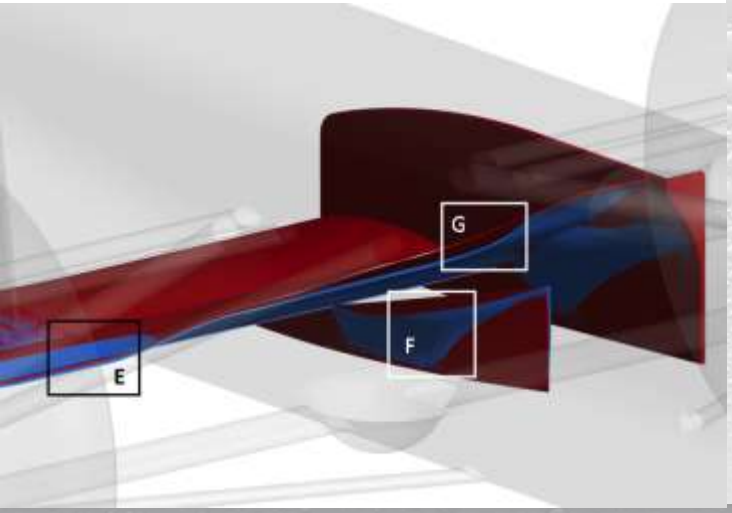
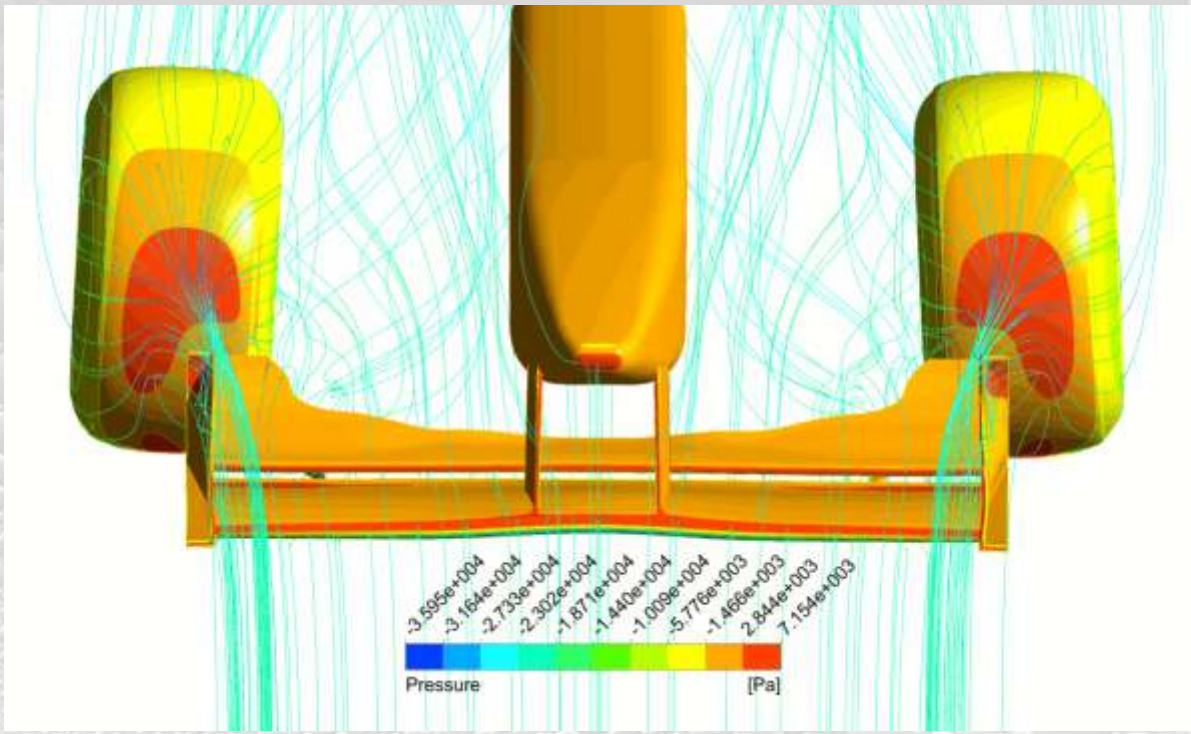
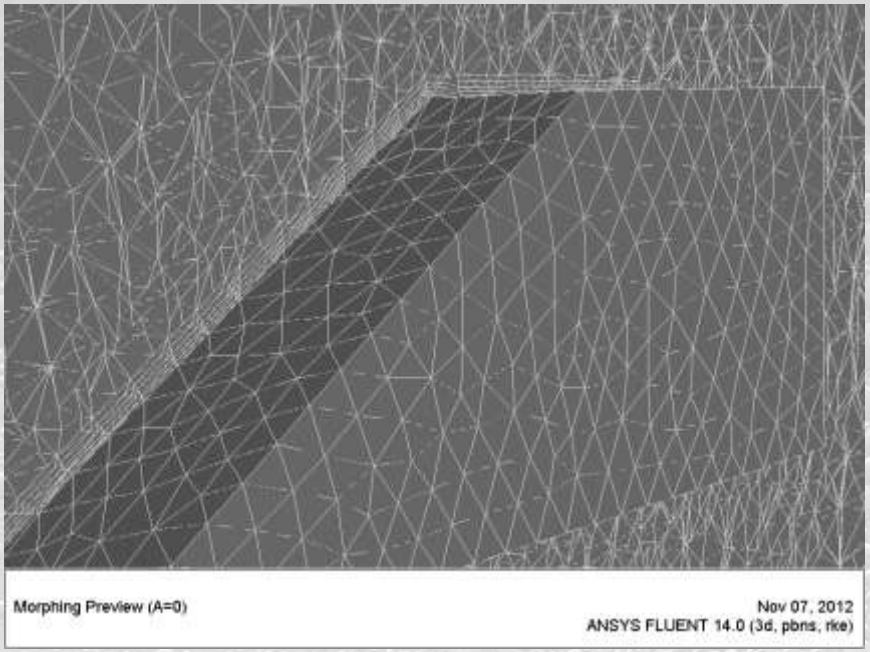
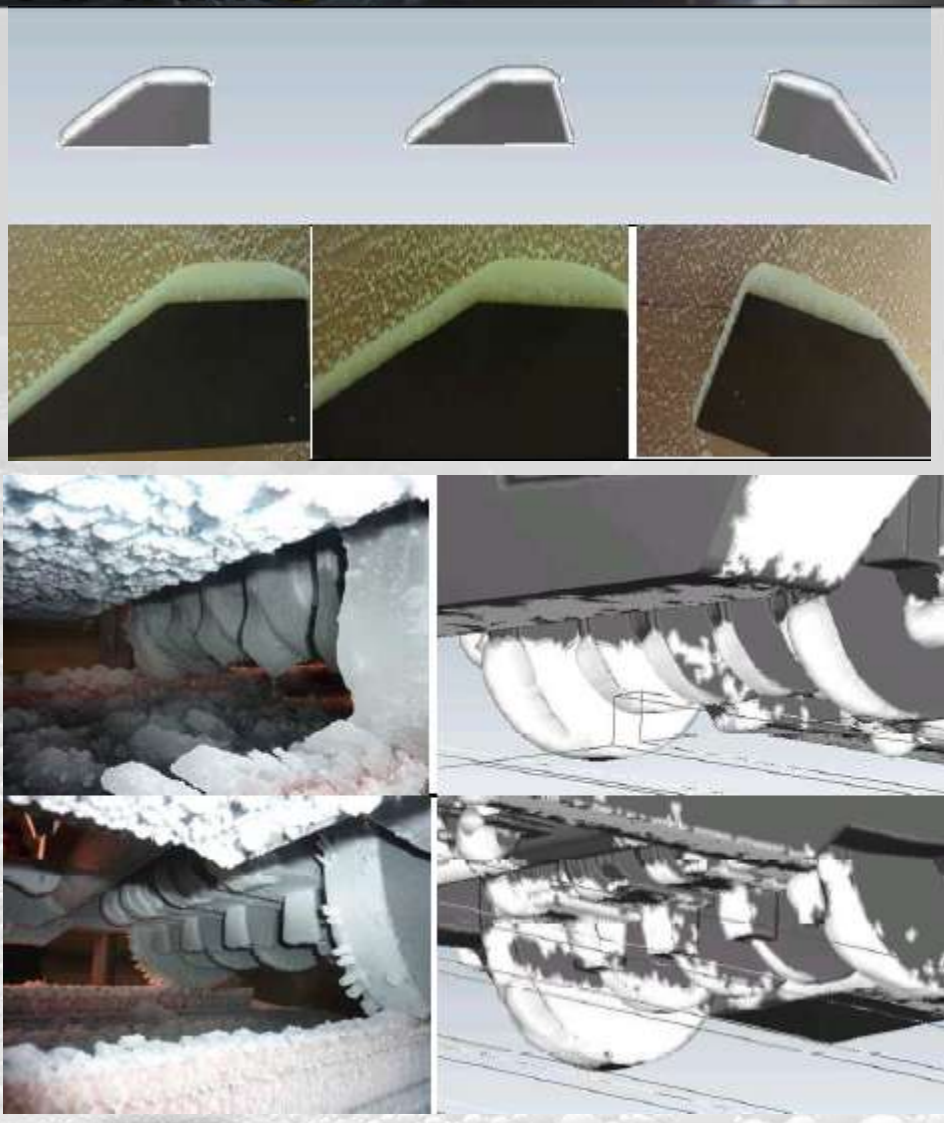
Steering wheels – lap time optimisation





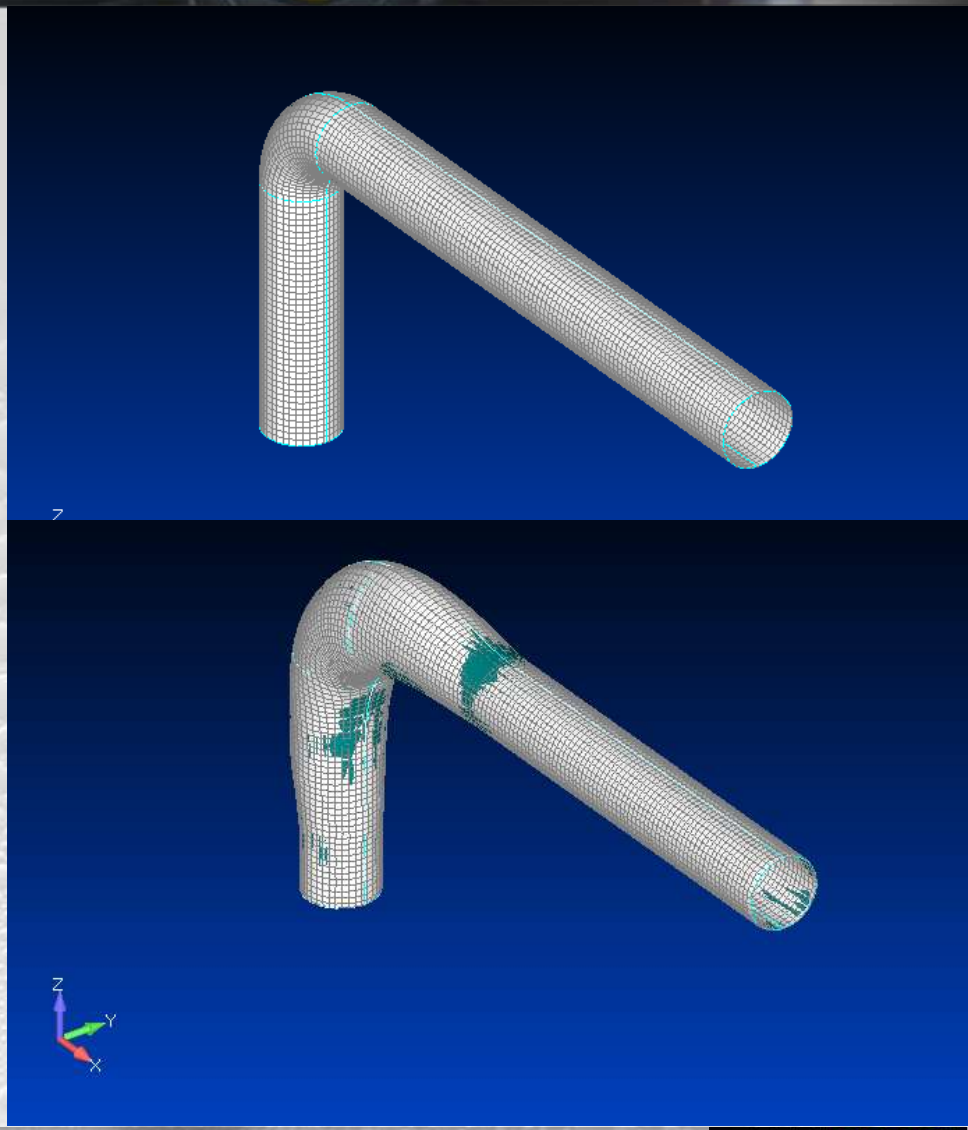
Snow accumulation on high-speed trains





Adjoint Self Sculpting

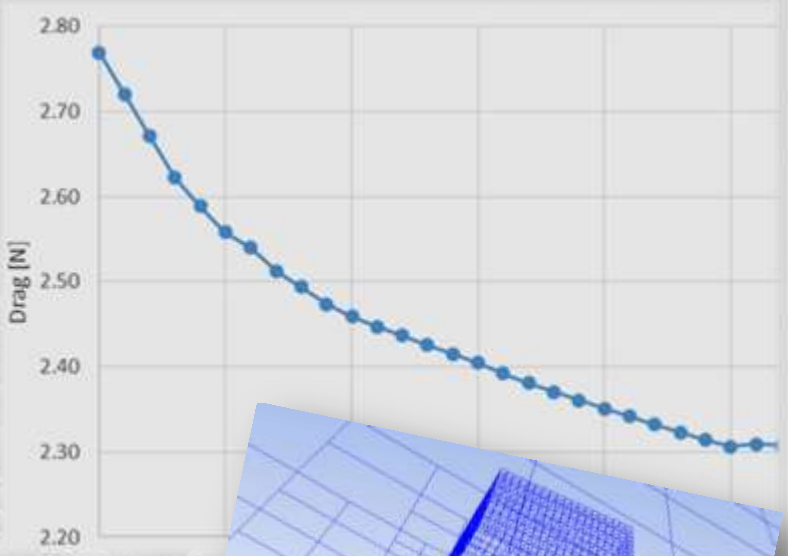
- 90 deg bend optimization
- New shape is sculpted using **adjoint data**
- Original geometry (2 cylinders and a torus) is transformed in **NURBS**
- **NURBS** are morphed using the **back to CAD** tool of RBF Morph

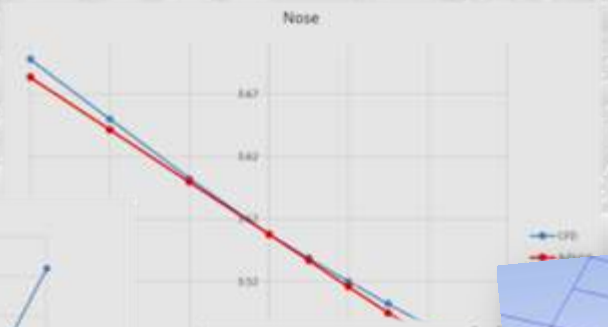


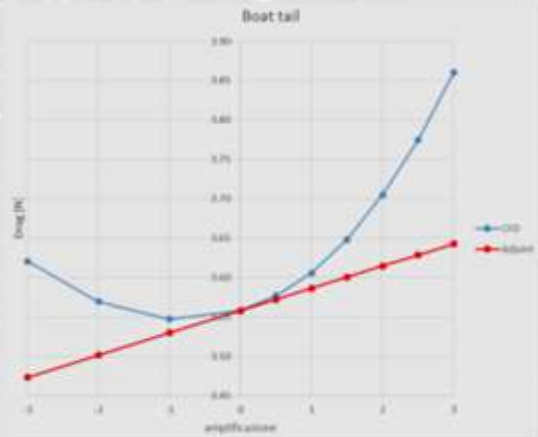
Adjoint preview

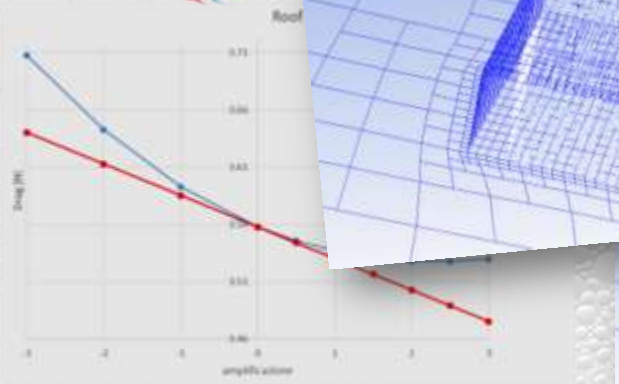
- A cube immersed in a wind tunnel is made parametric using **3 shapes**
- Steepest descent gradient method allows to reduce **drag** by **16.7%**

$$\alpha_j = -\beta \frac{dI}{dx_j}$$



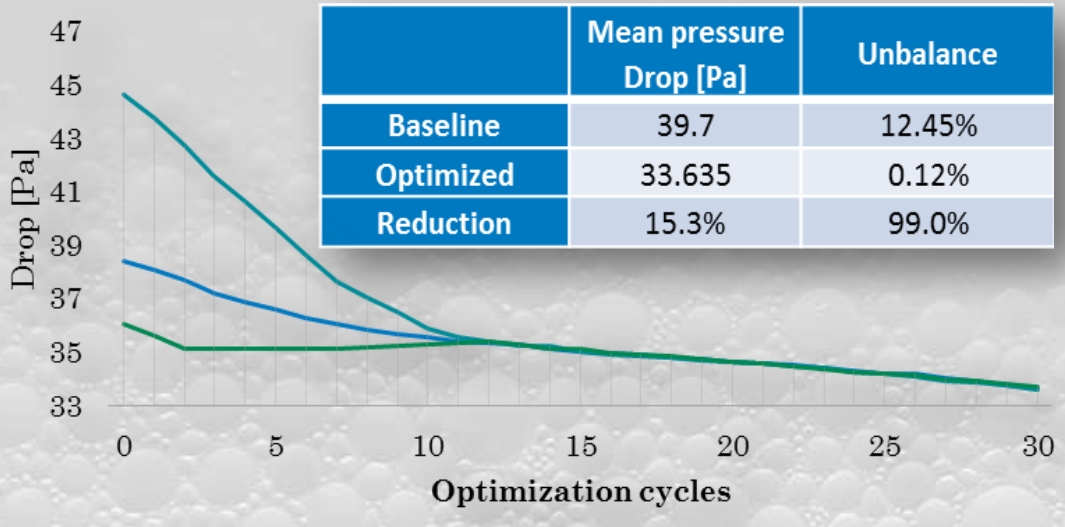




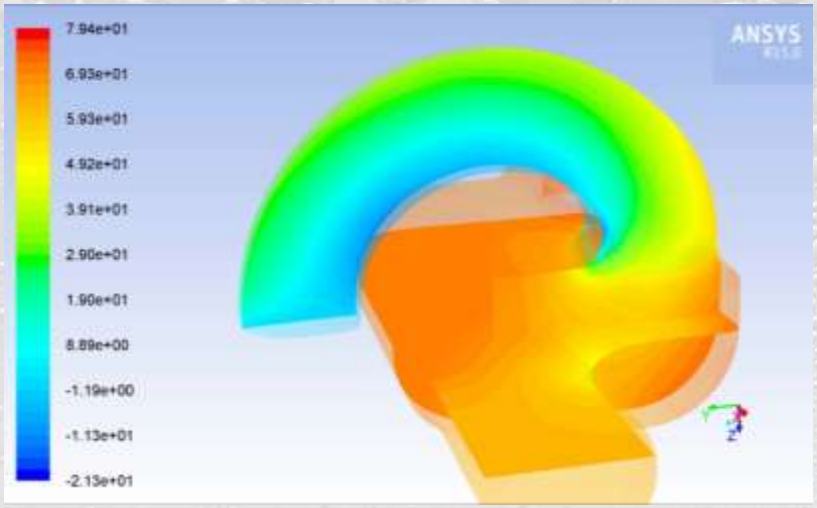


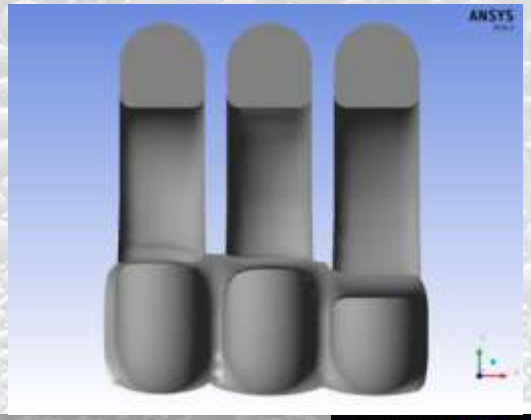
Engine Air box

	Mean pressure Drop [Pa]	Unbalance
Baseline	39.7	12.45%
Optimized	33.635	0.12%
Reduction	15.3%	99.0%



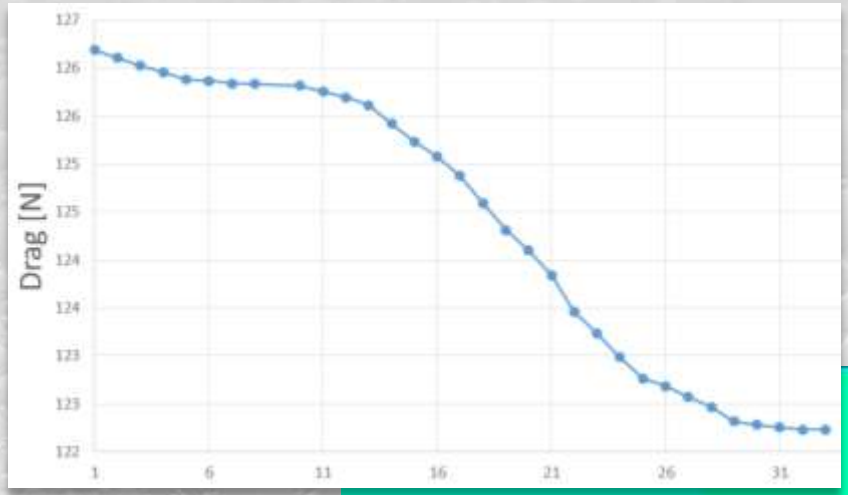
- **32 shape parameters** are used to control the geometry of the plenum and of the three runners
- Obtained shape allows to get a **15.3%** reduction of pressure drop and uniform distribution.

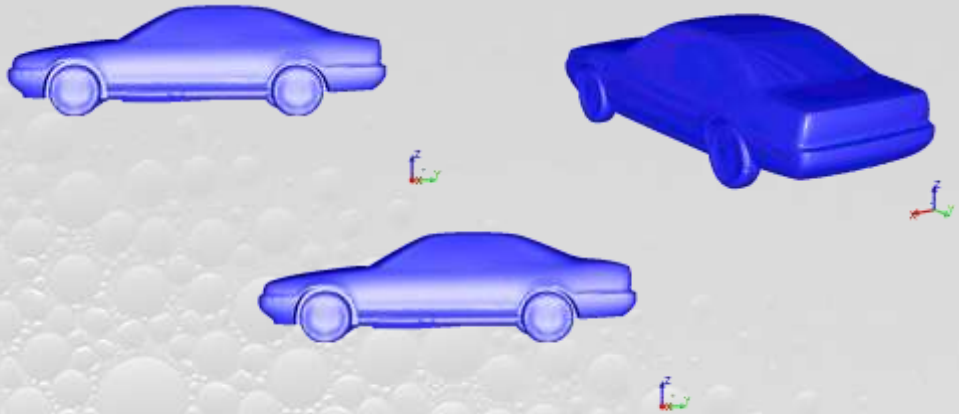




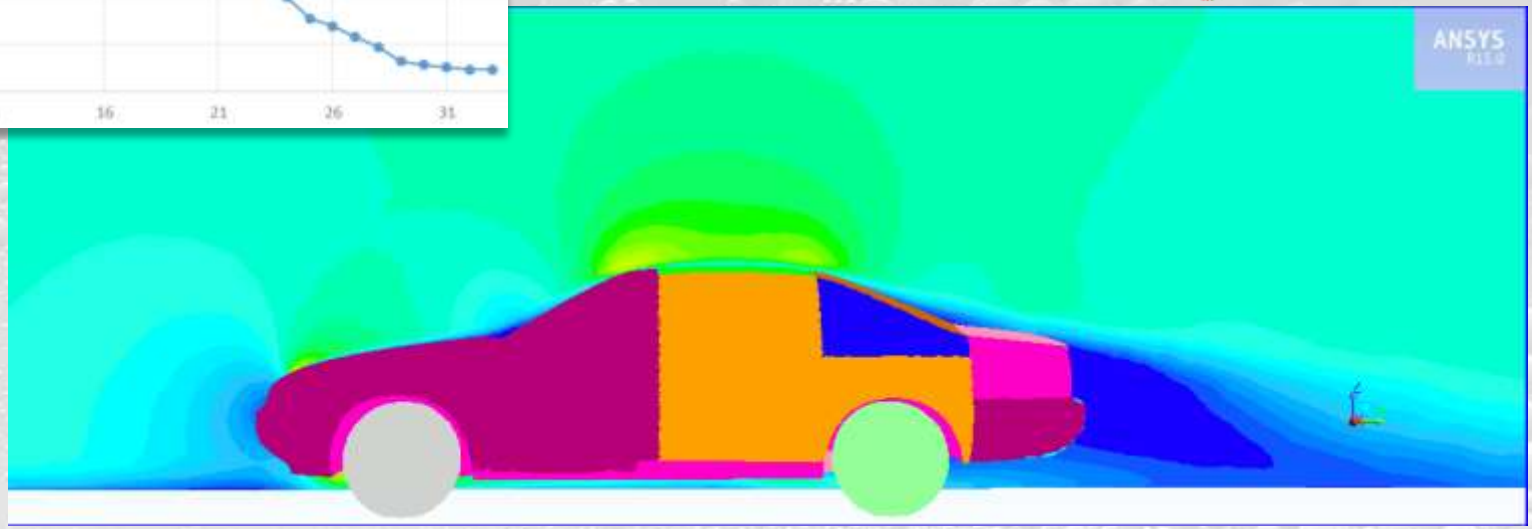
Sedan car

- A **3.13%** drag reduction is achieved after 33 cycles



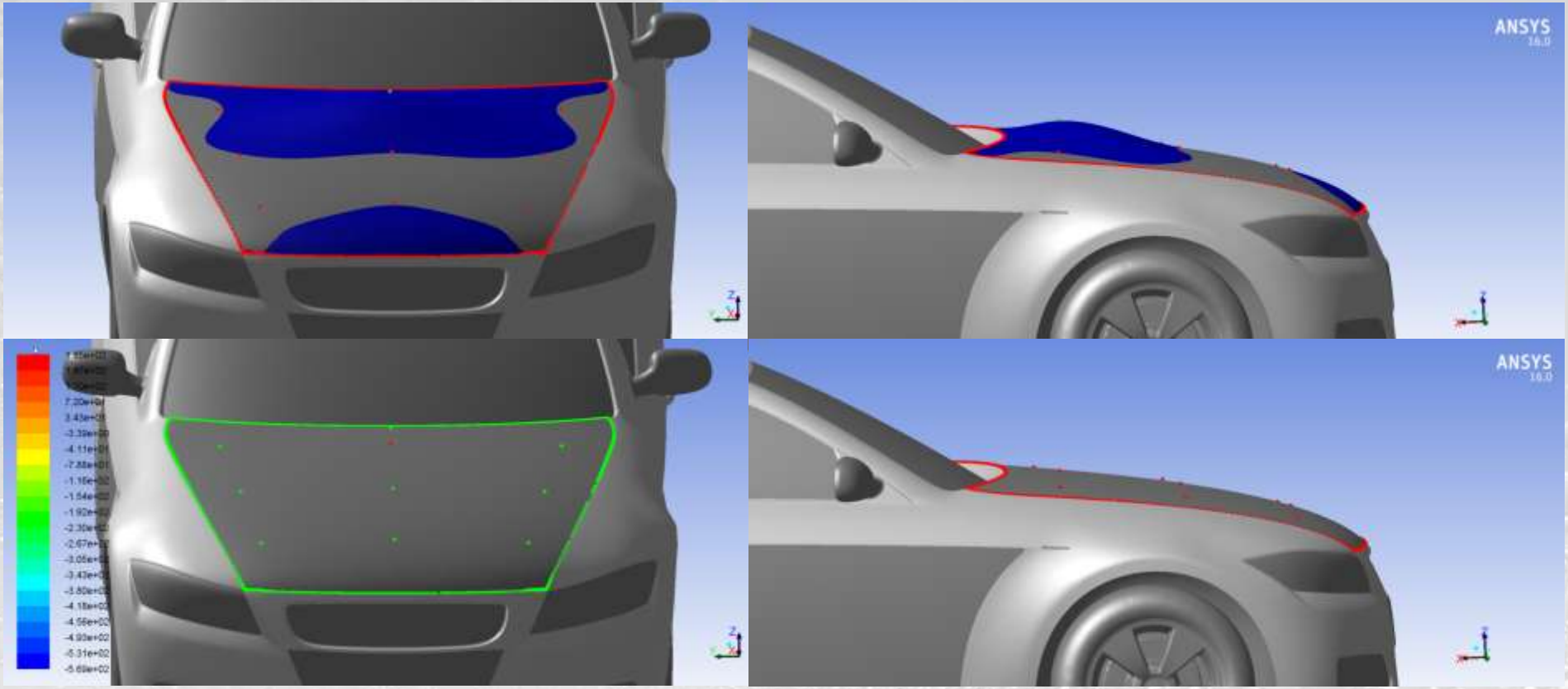


$$\alpha_j = -\beta \frac{dI}{dx_j}$$



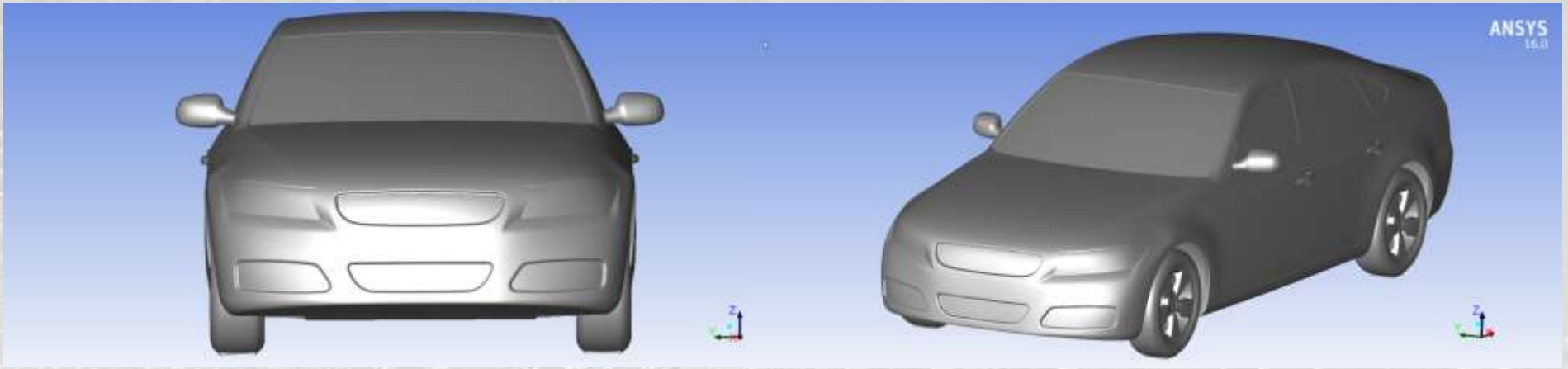
DrivAer adjoint sensitivity

- Hood is reshaped using 9 control points, constraining the edge, using 2 steps (high order RBF surface sculpting)



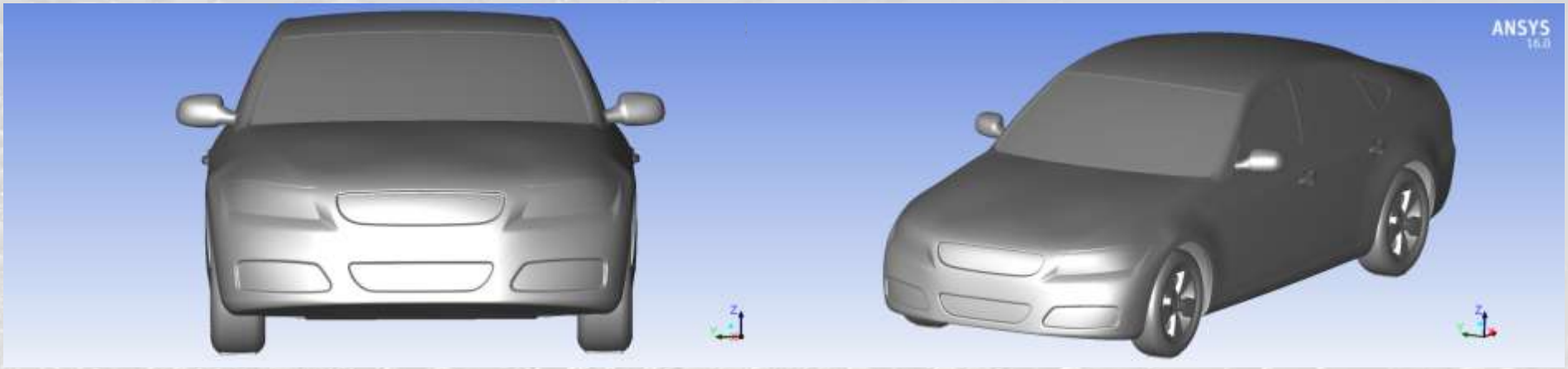
DrivAer adjoint sensitivity

- Adopting a maximum displacement of 5 mm and updating the surface according to gradient data a 0.5% drag reduction is expected.



DrivAer adjoint sensitivity

- Adopting a maximum displacement of 5 mm and updating the surface according to gradient data a 0.5% drag reduction is expected.



Conclusions

- An overview of **RBF Morph products** is given.
- **Key benefits** of the mesh morphing technology of RBF Morph are: automation, performances, flexibility and ability to bring back to CAD the optimal result.
- The **effectiveness** of RBF Morph in the automotive industry are proven by **7 years** of applications.
- Both **internal** and **external** flows studies can benefit of mesh morphing.
- **Advanced morphing** techniques allows to deal with: adjoint solution, FSI and snow accretion.

Many thanks for your kind attention!

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