Advanced Mesh Morphing for Automotive Applications using RBF Morph

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Tor Vergata

(rbf-morph)™

Outline

- RBF Morph tool presentation
- Industrial Applications
- Advanced features

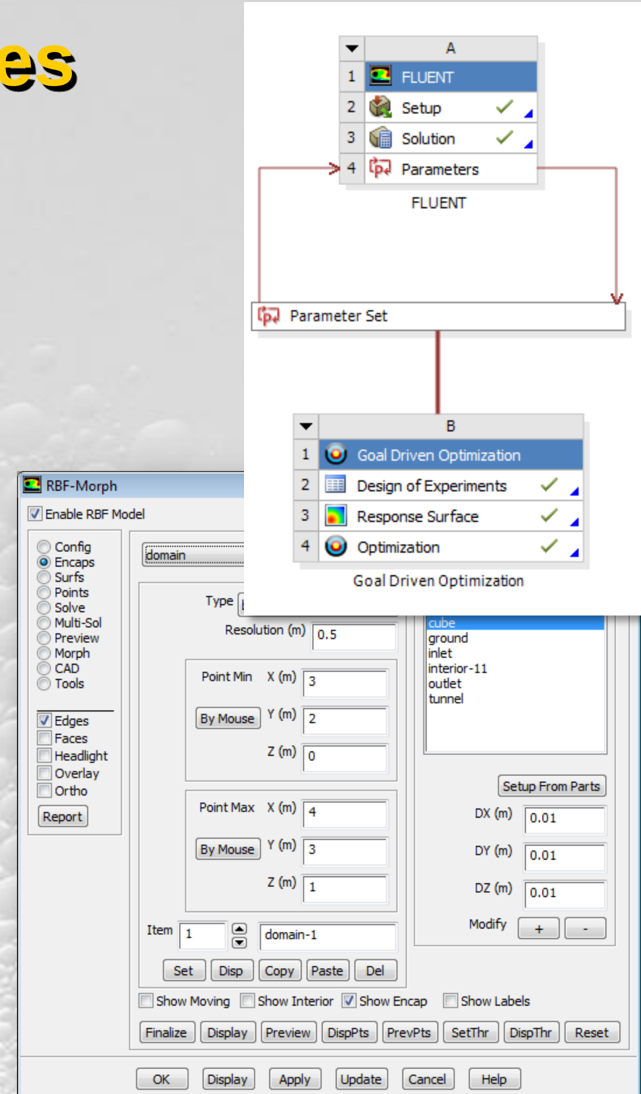
RBF Morph tool presentation

Morphing & Smoothing

- A mesh morpher is a tool capable to perform **mesh modifications**, in order to achieve arbitrary shape changes and related volume smoothing, without changing the mesh topology.
- In general a morphing operation can introduce a reduction of the **mesh quality**
- A **good** morpher has to minimize this effect, and maximize the possible shape modifications.
- If mesh quality is well preserved, then using the same mesh structure it's a **clear benefit** (remeshing introduces **noise**!).

RBF Morph Features

- **Add on** fully integrated within **Fluent** (GUI, TUI & solving stage) and **Workbench**
- **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**).



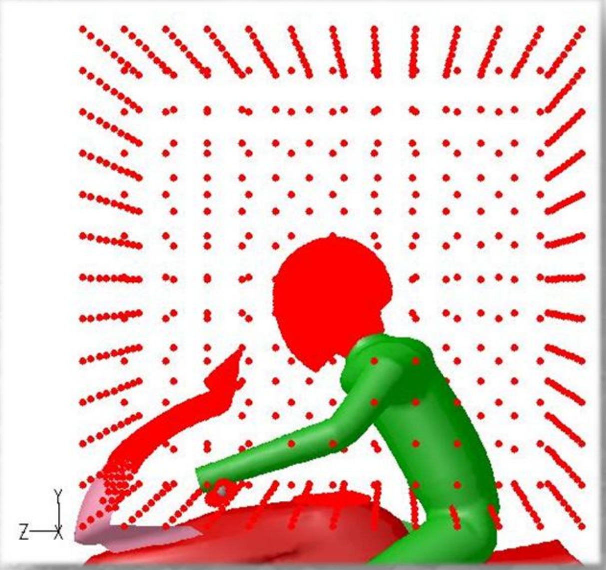
Mesh Morphing with Radial Basis Functions

- A system of **radial functions** is used to **fit** a **solution** for the mesh movement/morphing, from a list of **source points** and their **displacements**.

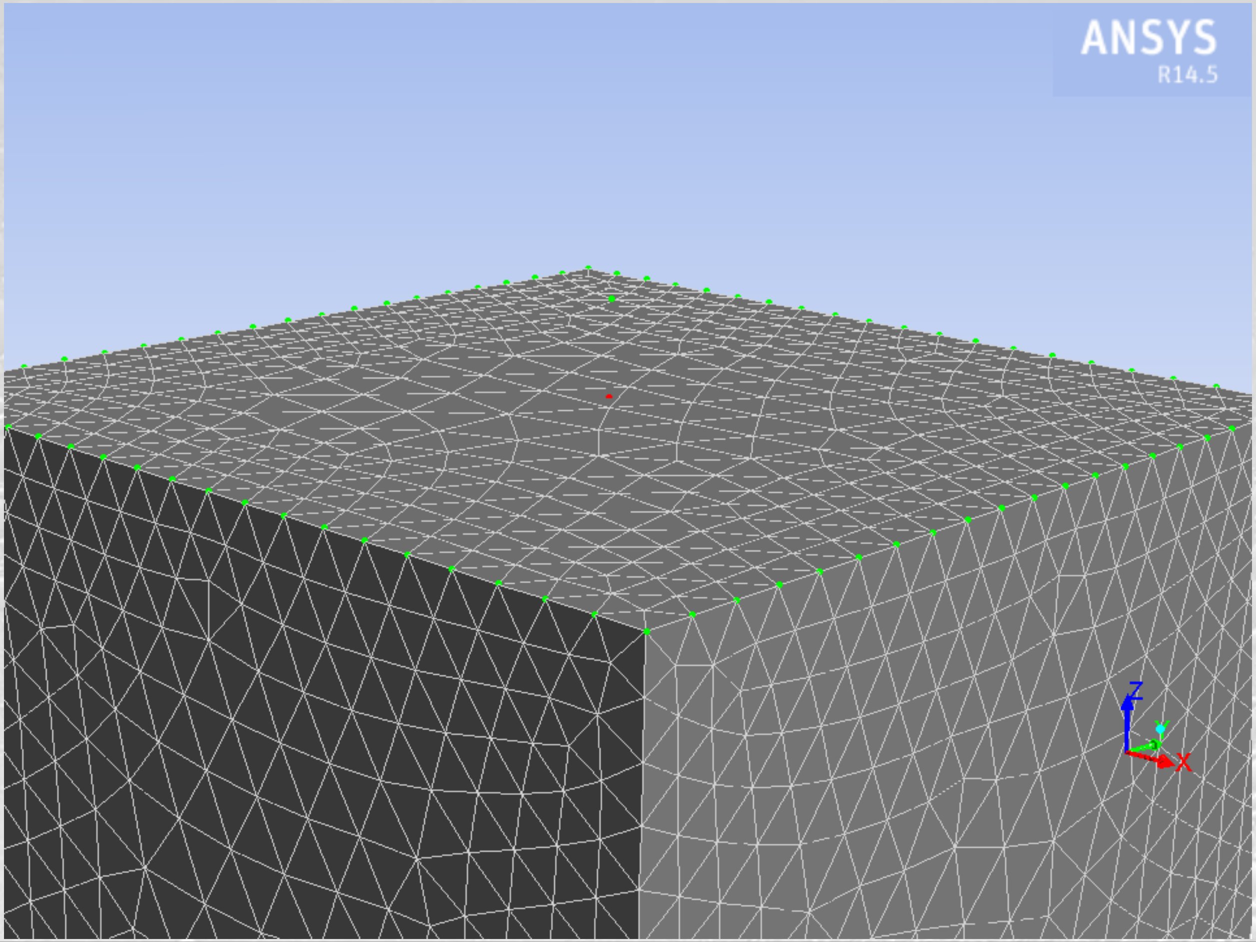
- The RBF problem definition does not depend on the mesh

- Radial Basis Function interpolation is used to derive the displacement in **any location** in the space, each component of the displacement is interpolated:

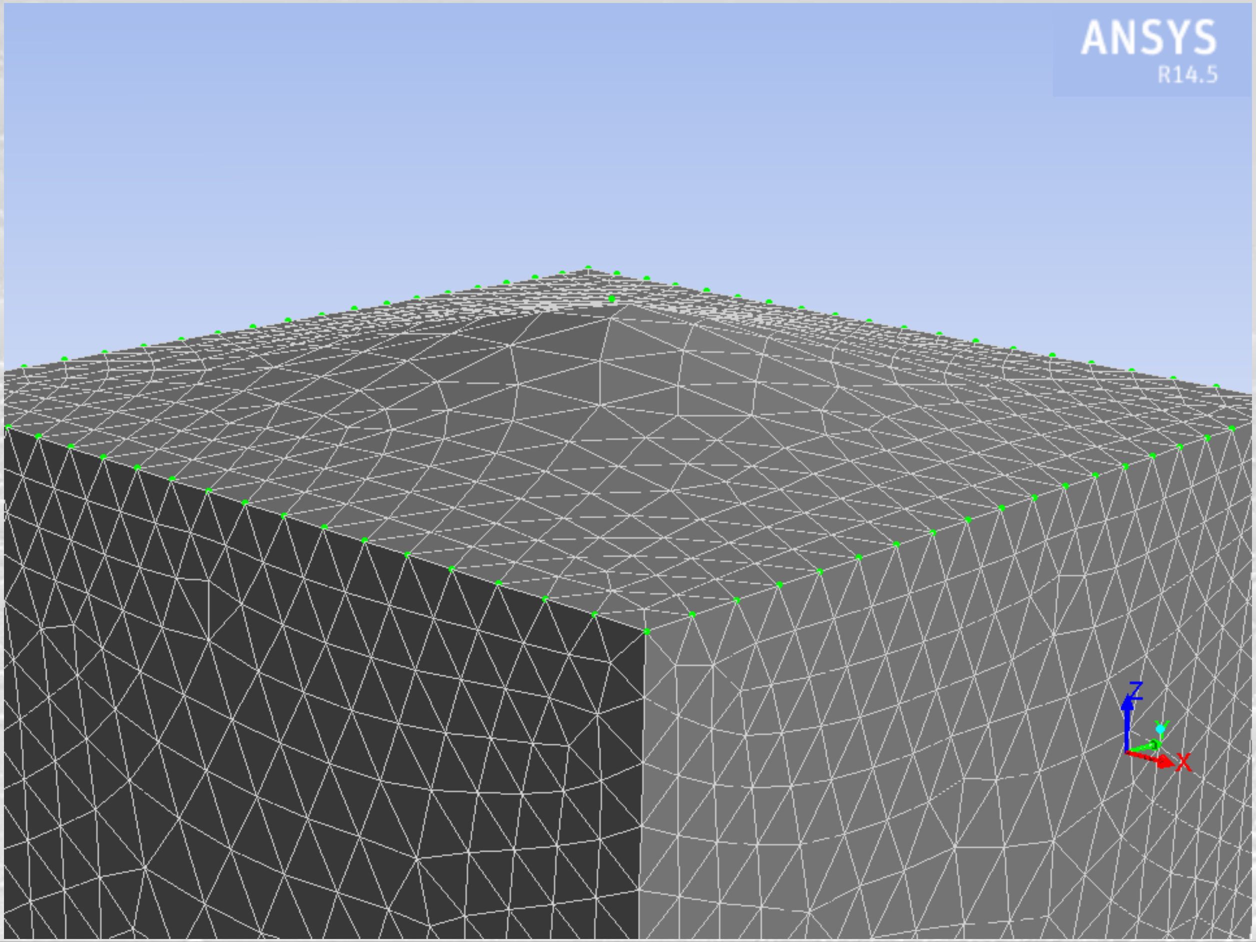
$$\begin{cases} v_x = s_x(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ v_y = s_y(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^y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



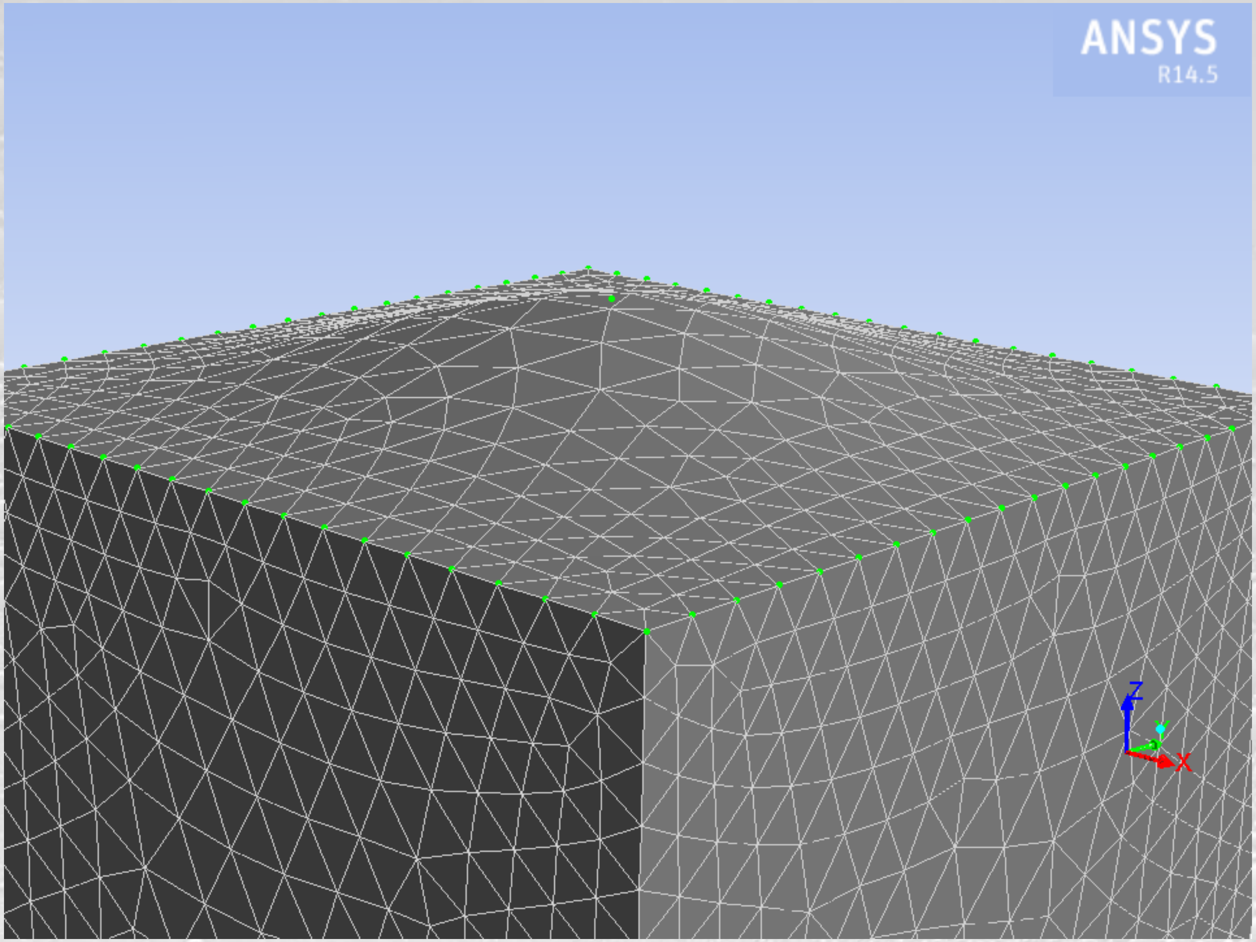
One pt at center and border (80 pts)



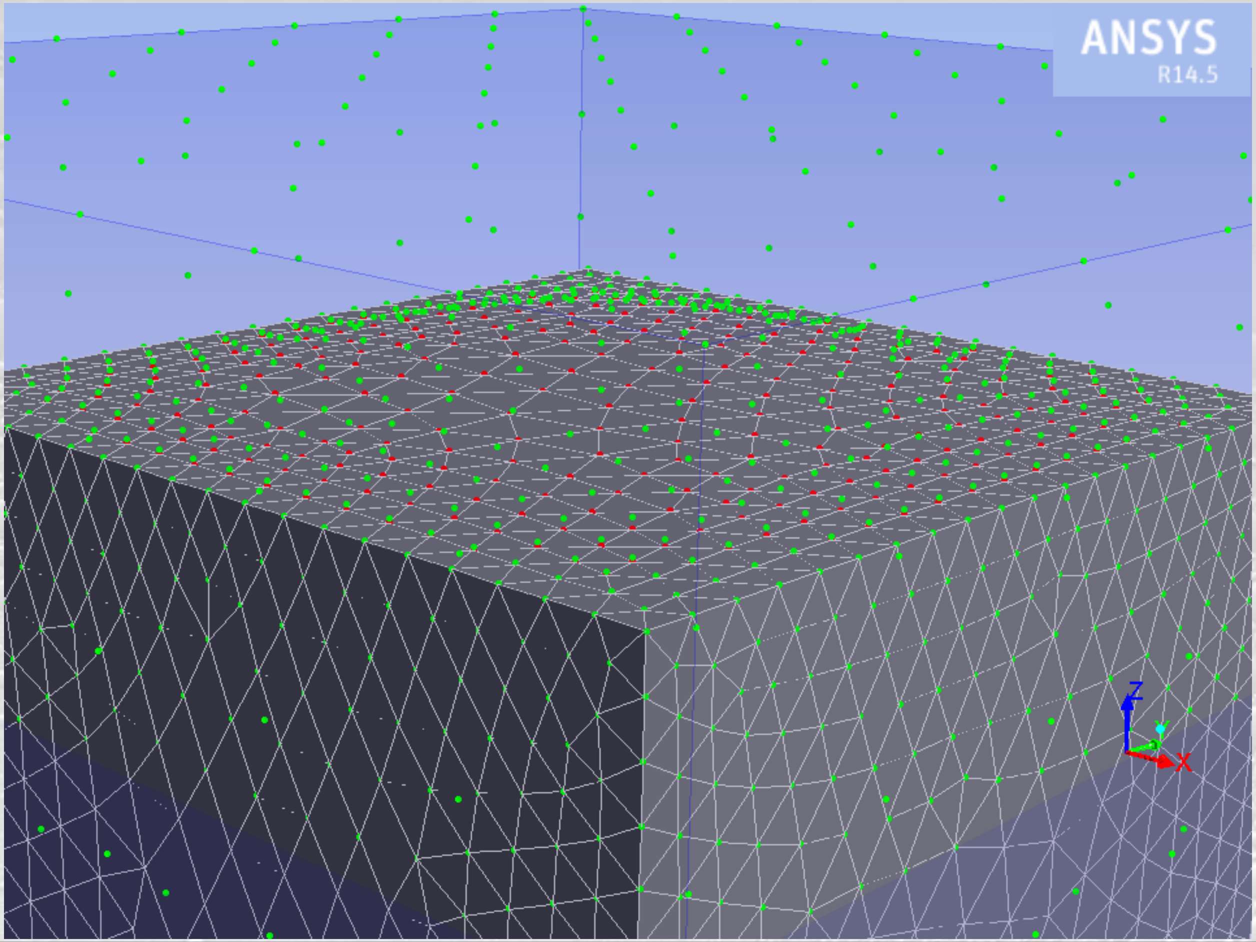
Effect on surface (gs-r)



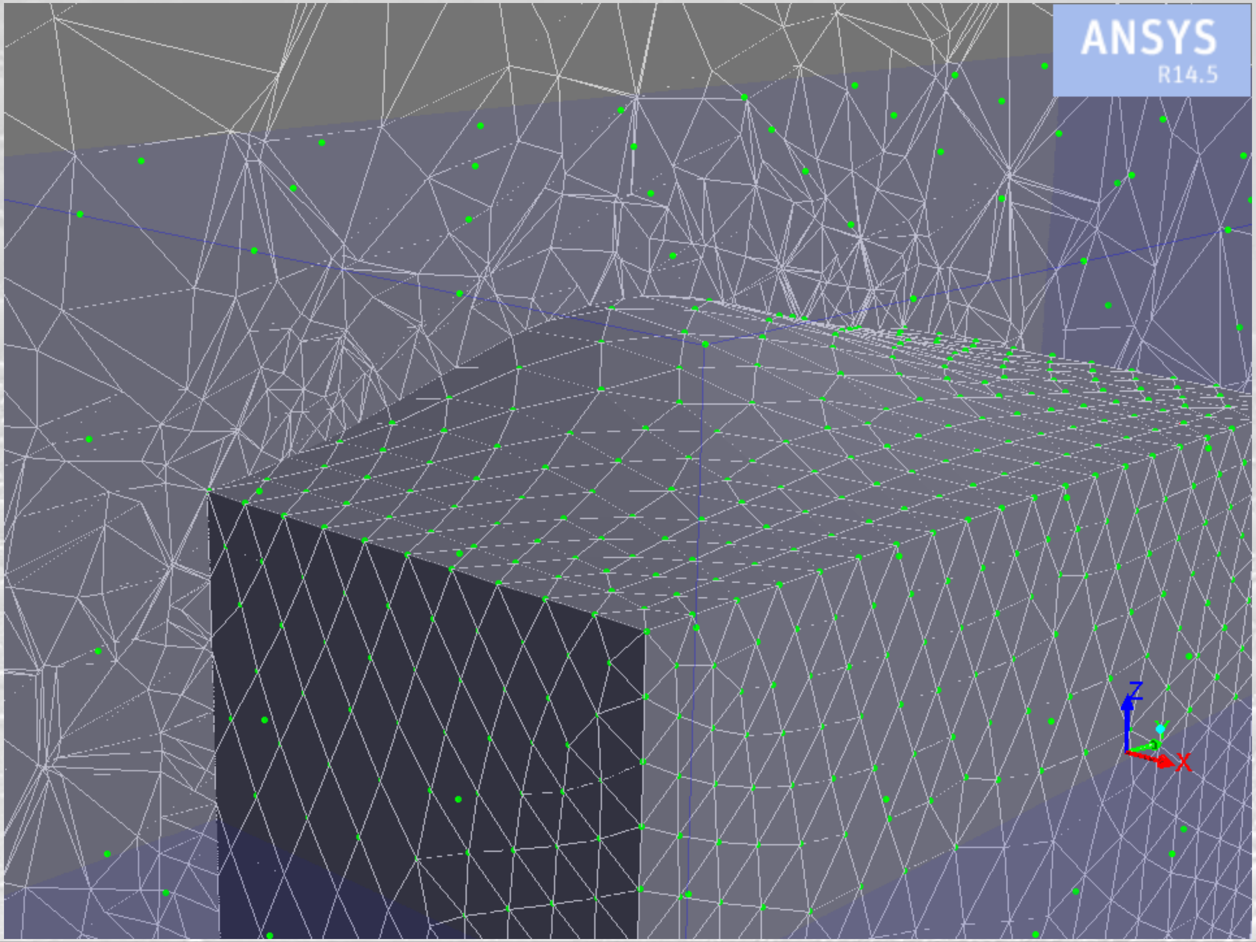
Effect on surface (cp-c4)



Control of volume mesh (1166 pts)

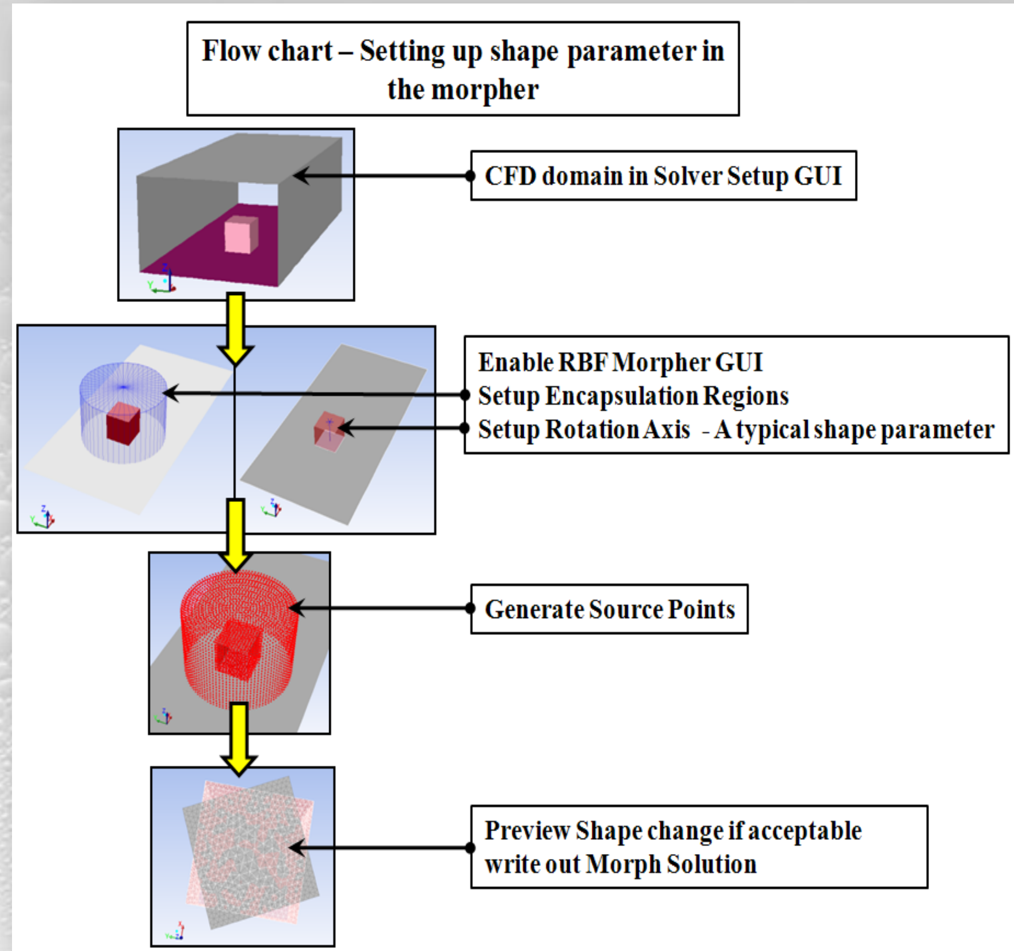


Morphing the volume mesh



How it Works: the problem setup

- The problem must describe correctly the **desired changes** and must **preserve exactly** the fixed part of the mesh.
- The prescription of the **source points** and their displacements fully defines the *RBF Morph* problem.
- Each problem and its fit define a mesh **modifier** or a **shape parameter**.



Accelerating the solver

- The evaluation of RBF at a point has a cost of order N
- The fit has a cost of order $\mathbf{N^3}$ for a direct fit (full populated matrix); this limit to ~10.000 the number of source points that can be used in a practical problem
- Using an iterative solver (with a good pre-conditioner) the fit has a cost of order $\mathbf{N^2}$; the number of points can be increased up to ~70.000
- Using also space partitioning to accelerate fit and evaluation the number of points can be increased up to ~**300.000**
- The method can be further accelerated using fast pre-conditioner building and FMM RBF evaluation…

Solver performances evolution

- 10.000 RBF centers FIT
  - 120 minutes Jan 2008
  - 5 seconds Jan 2010
- Largest fit **2.600.000** 133 minutes
- Largest model morphed **300.000.000** cells
- Fit and Morph a **100.000.000** cells model using **500.000** RBF centers within **15 minutes**

#points	2010 (Minutes)	2008 (Minutes)
3.000	0 (1s)	15
10.000	0 (5s)	120
40.000	1 (44s)	Not registered
160.000	4	Not registered
650.000	22	Not registered
2.600.000	133	Not registered

Coming soon: GPU acceleration!

- Single RBF complete evaluation
- Unit random cube
- **GPU**: Kepler 20 2496 CUDA Cores GPU Clock 0.71 GHz
- **CPU**: quad core Intel(R) Xeon(R) CPU E5-2609 0 @ 2.40GHz

#points	CPU	GPU	speed up
5.000	0,098	0,005	21,2
10.000	0,319	0,012	27,2
15.000	0,668	0,025	26,7
20.000	1,135	0,038	29,6
25.000	1,722	0,054	31,9
30.000	2,452	0,079	30,9
35.000	3,307	0,109	30,5
40.000	4,287	0,135	31,8
45.000	5,390	0,181	29,7
50.000	6,708	0,214	31,4
100.000	26,136	0,745	35,1
150.000	58,970	1,735	34,0
200.000	115,363	2,862	40,3

Complexity test GPU vs. CPU

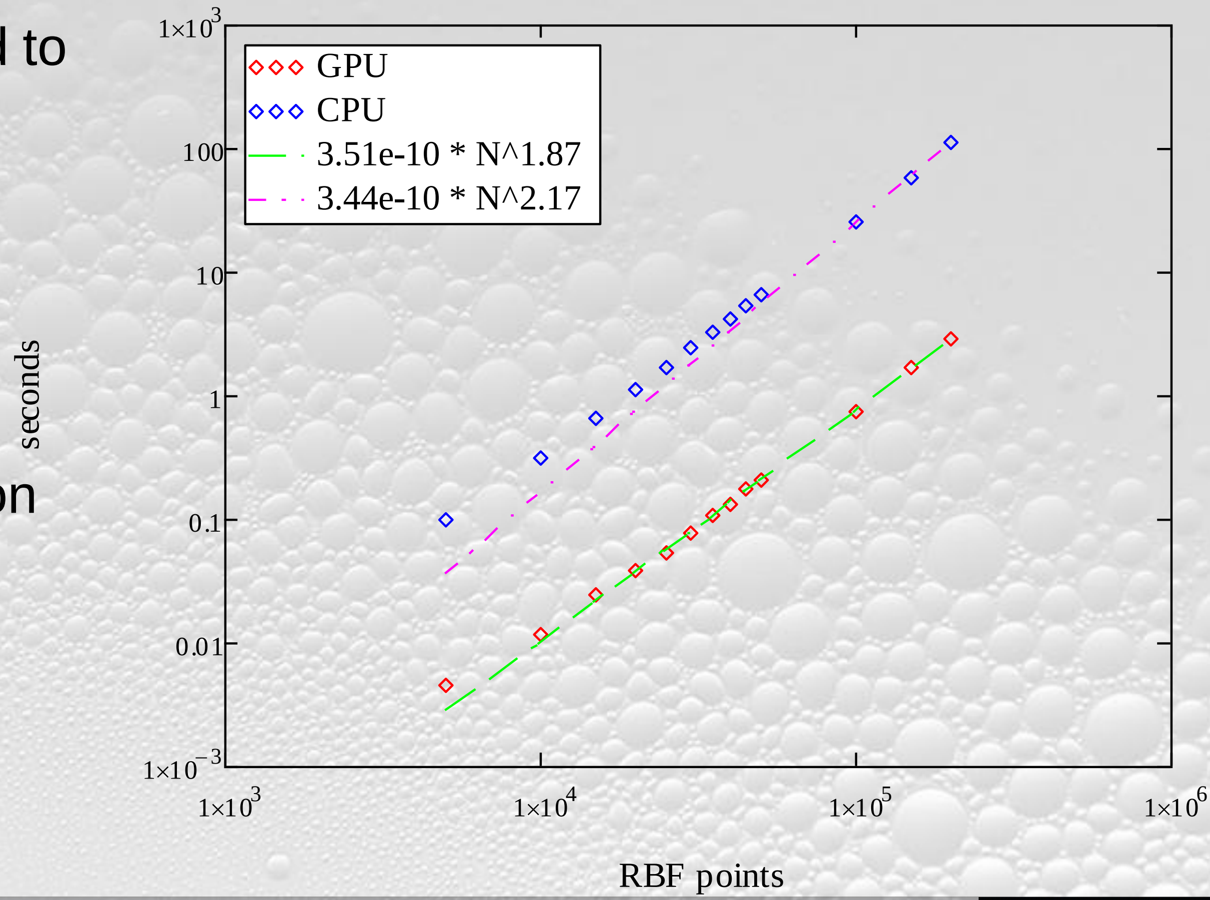
- Complexity is expected to grow as **N ^{2}**
- GPU observed as

  time(N) = k * N $^{1.87}$
- CPU observed as

  time(N) = k * N $^{2.174}$
- Estimation at one million points:

  GPU: 59 s

  CPU: 2783 s



HPC Workflows

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

Industrial Applications

Formula 1 Front Wing

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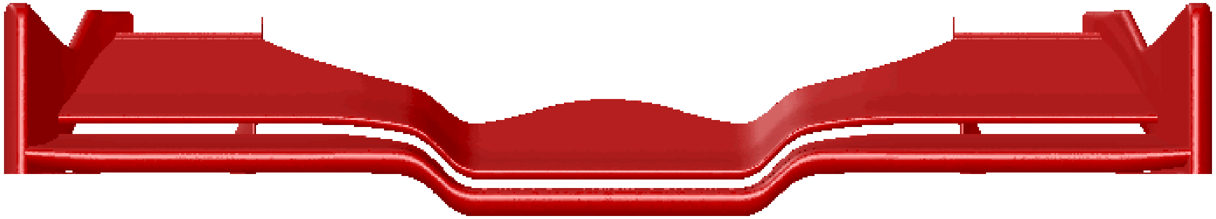
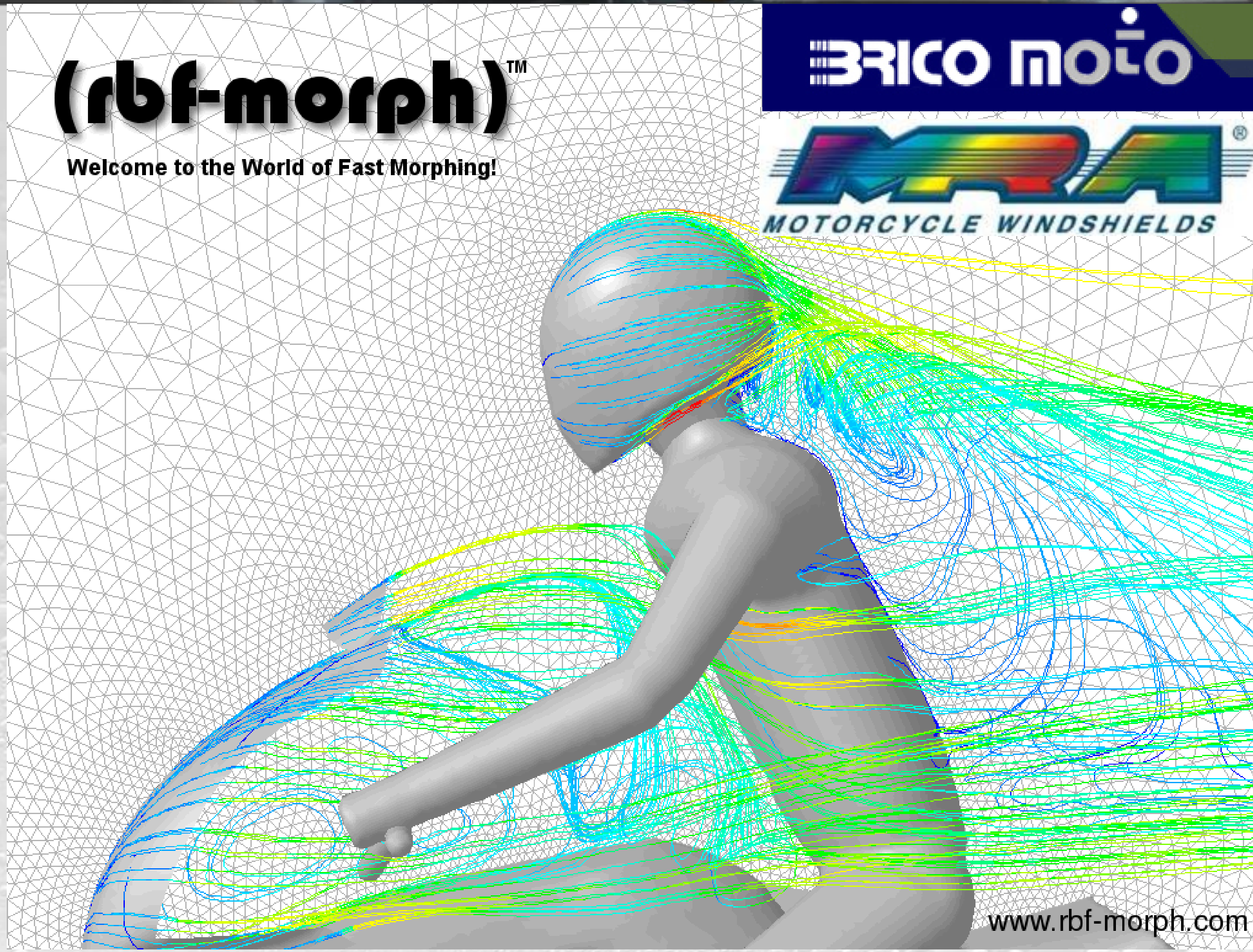
Welcome to the World of Fast Morphing!

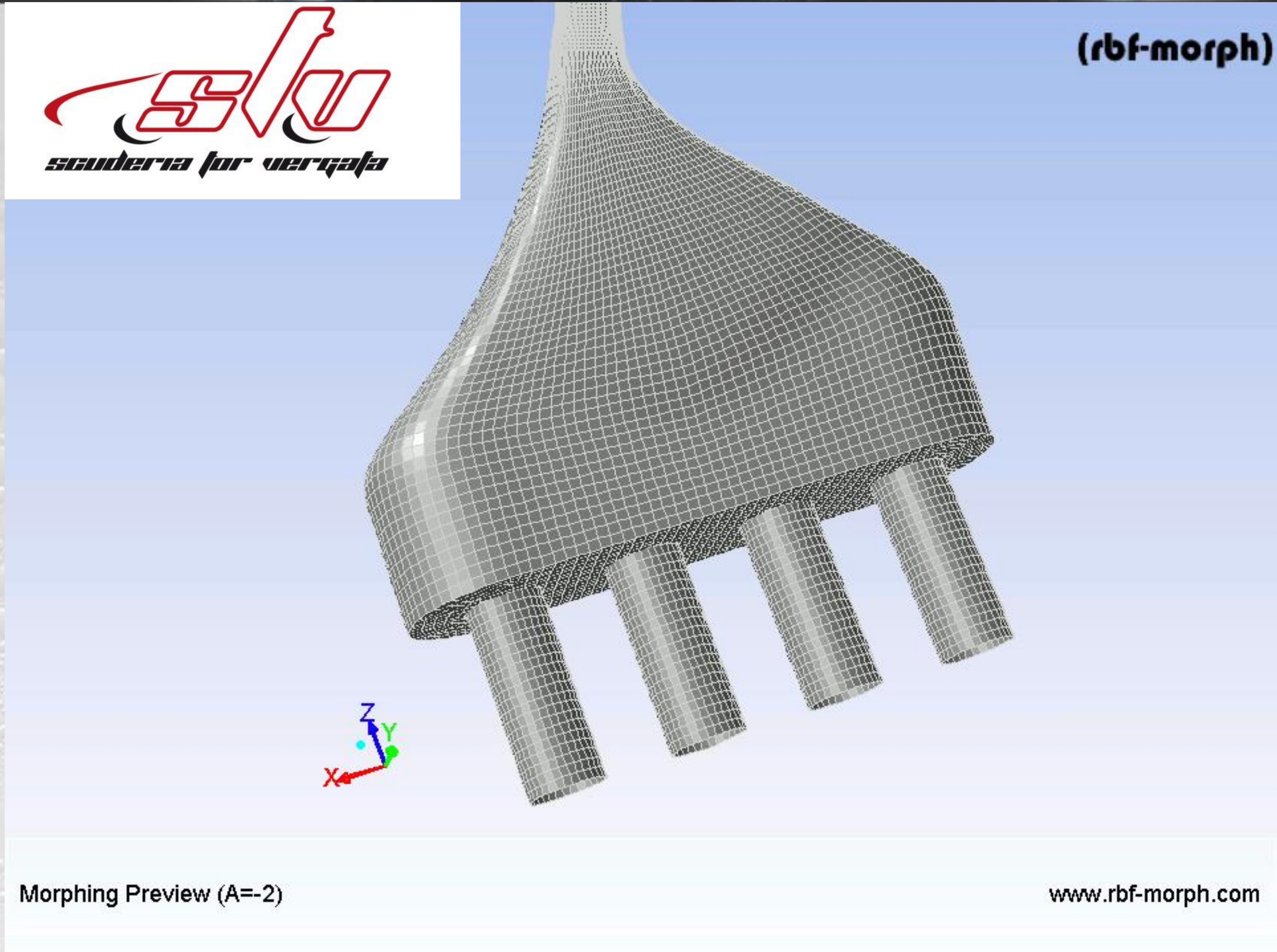


www.rbf-morph.com

Motorbike Windshield (Bricomoto, MRA)



Engine Air box shape (STV FSAE Team)



Exhaust manifold
Constrained Optimization
Adjoint Solver

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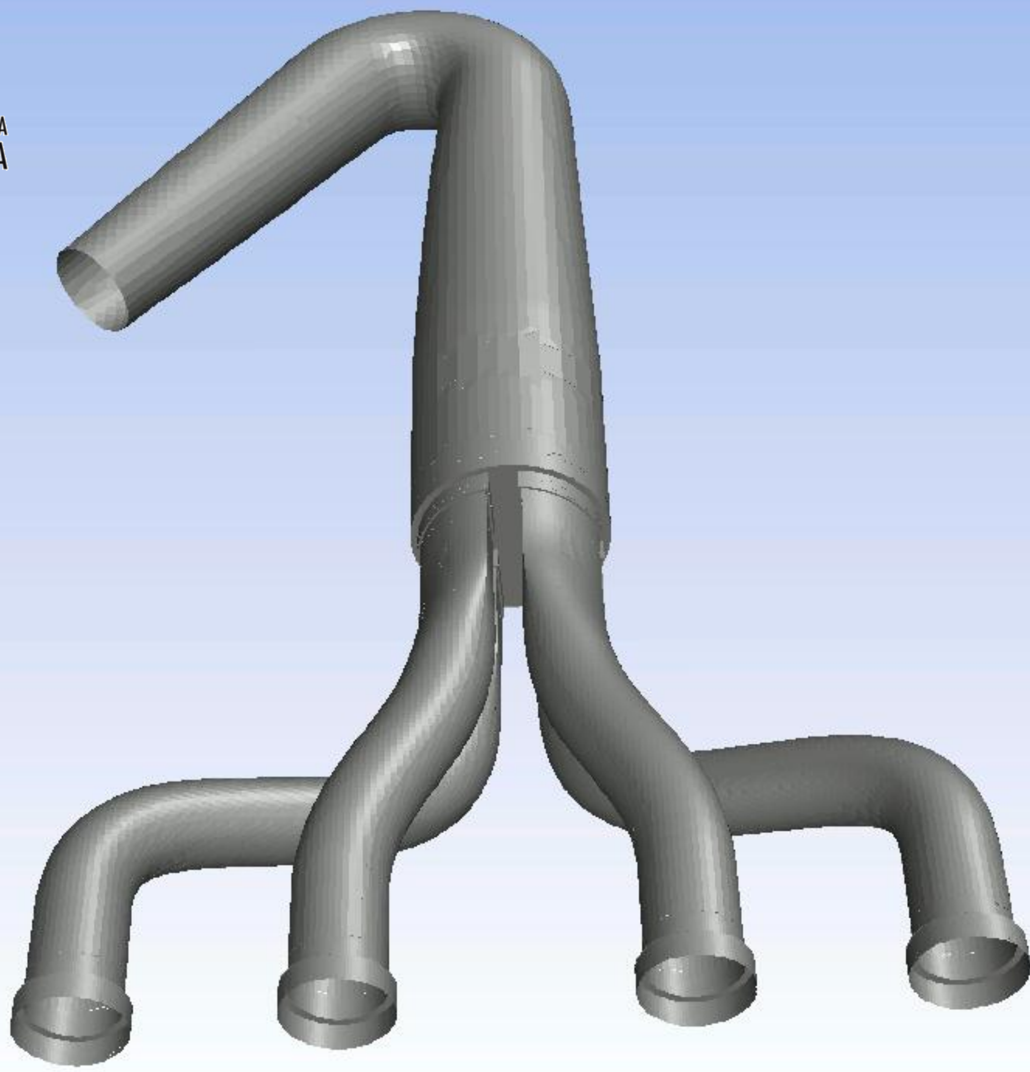
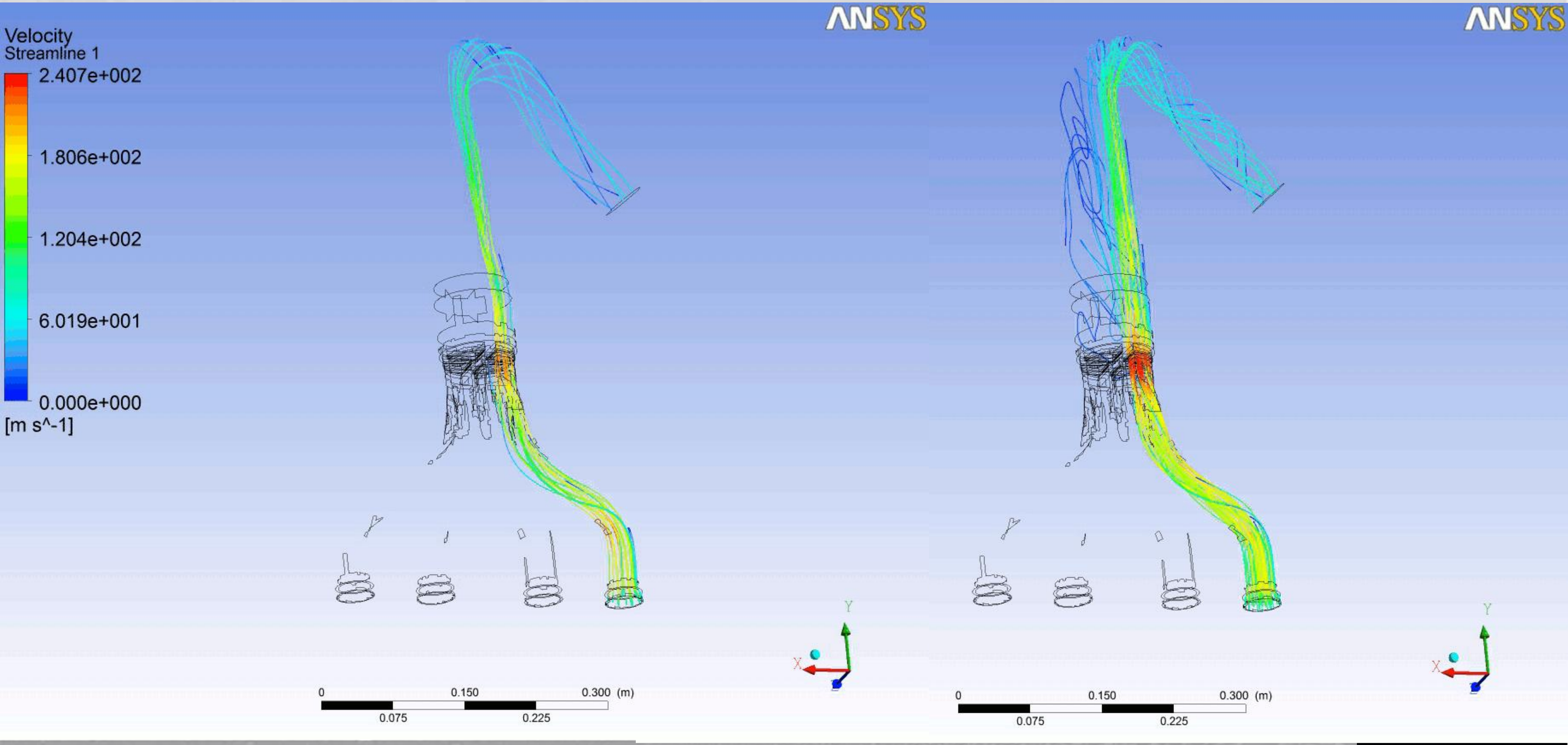


Name	P5 - Pipe1Curve1	P6 - Pipe2	P7 - Pipe4Curve1	P8 - Pipe3	P1 - PressureDrop1	P2 - PressureDrop2	P3 - PressureDrop3	P4 - PressureDrop4
					Pa	Pa	Pa	Pa
Current	4	4	4	4	12892	11366	13028	16619
DP 1	3	3	3	3	12882	11247	13487	16731
DP 2	2	2	2	2	12897	11546	13554	16911
DP 3	1	1	1	1	13403	11477	13920	17666
DP 4	0	0	0	0	13555	11750	13967	17718

Optimized vs. Original - Streamlines



MIRA Reference car (MIRA ltd)

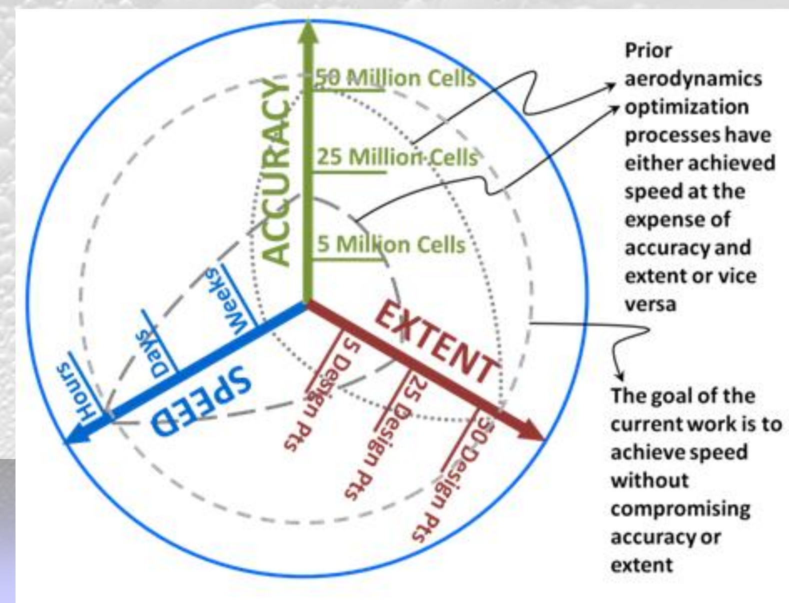
MIRA

MIRA Reference Car

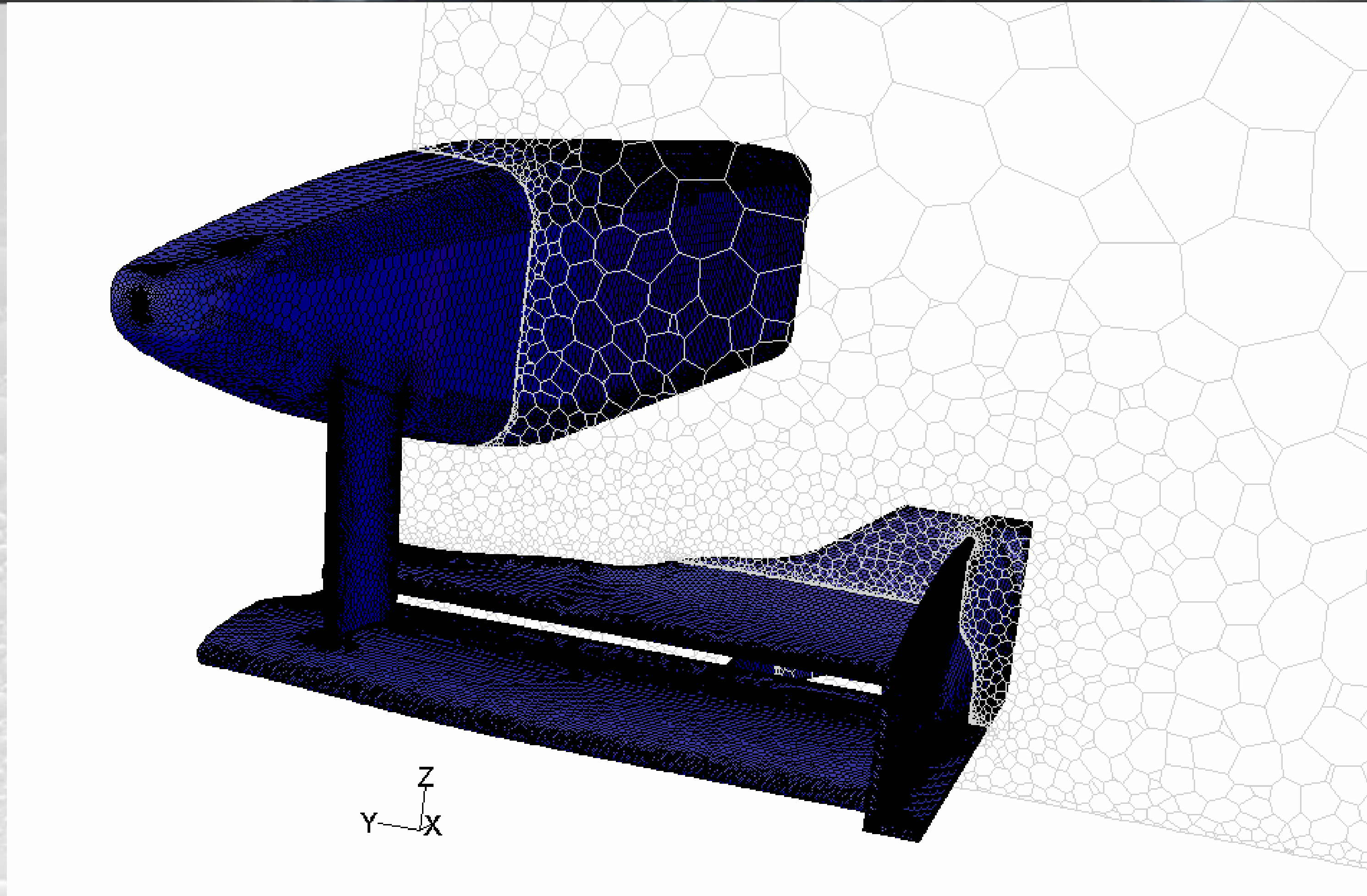
Shape Optimisation using RBF-Morph

Smarter Thinking.

50:50:50 Project Volvo XC60 (Ansys, Intel, Volvo)

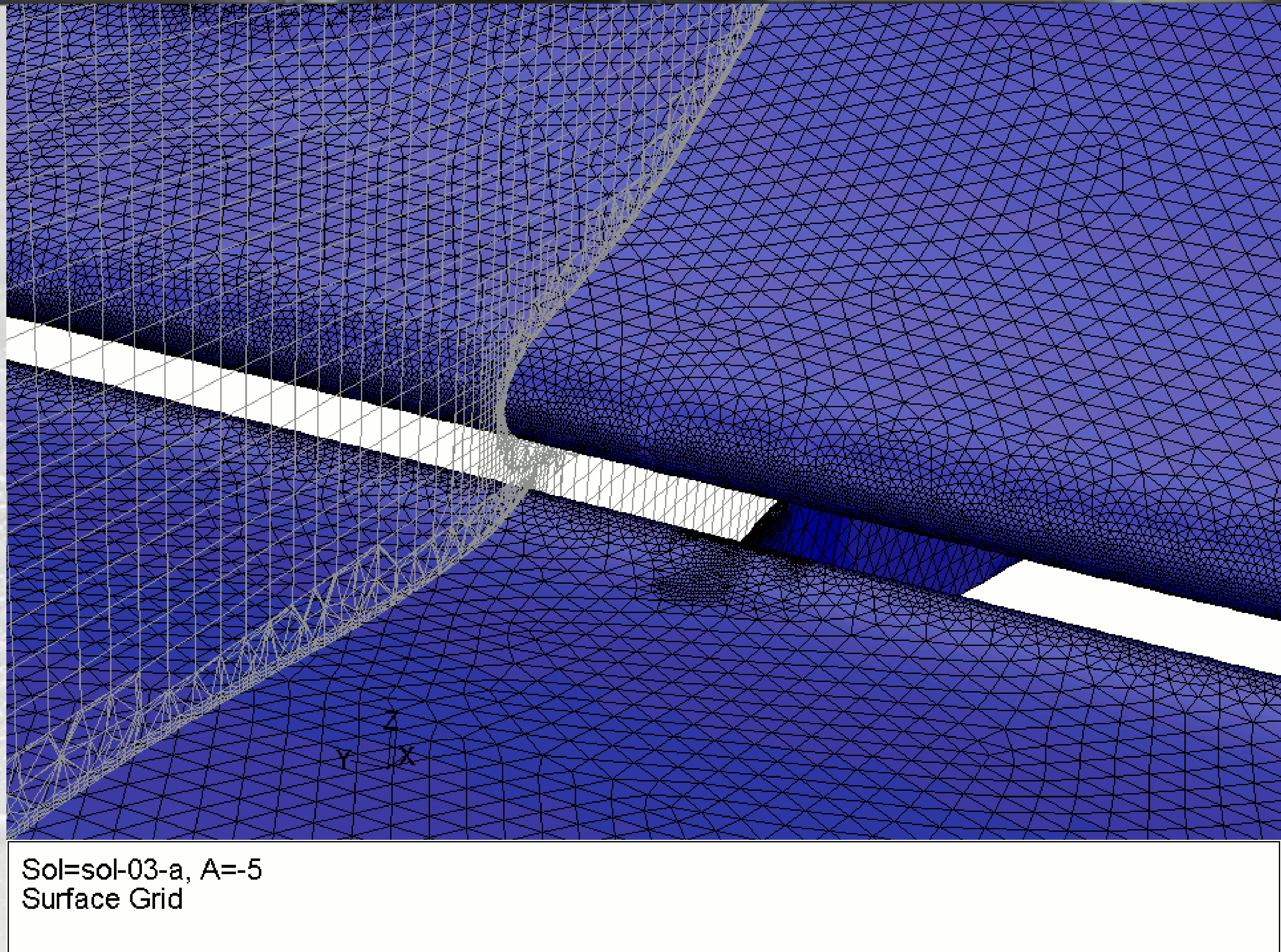


Generic Formula 1 Front End

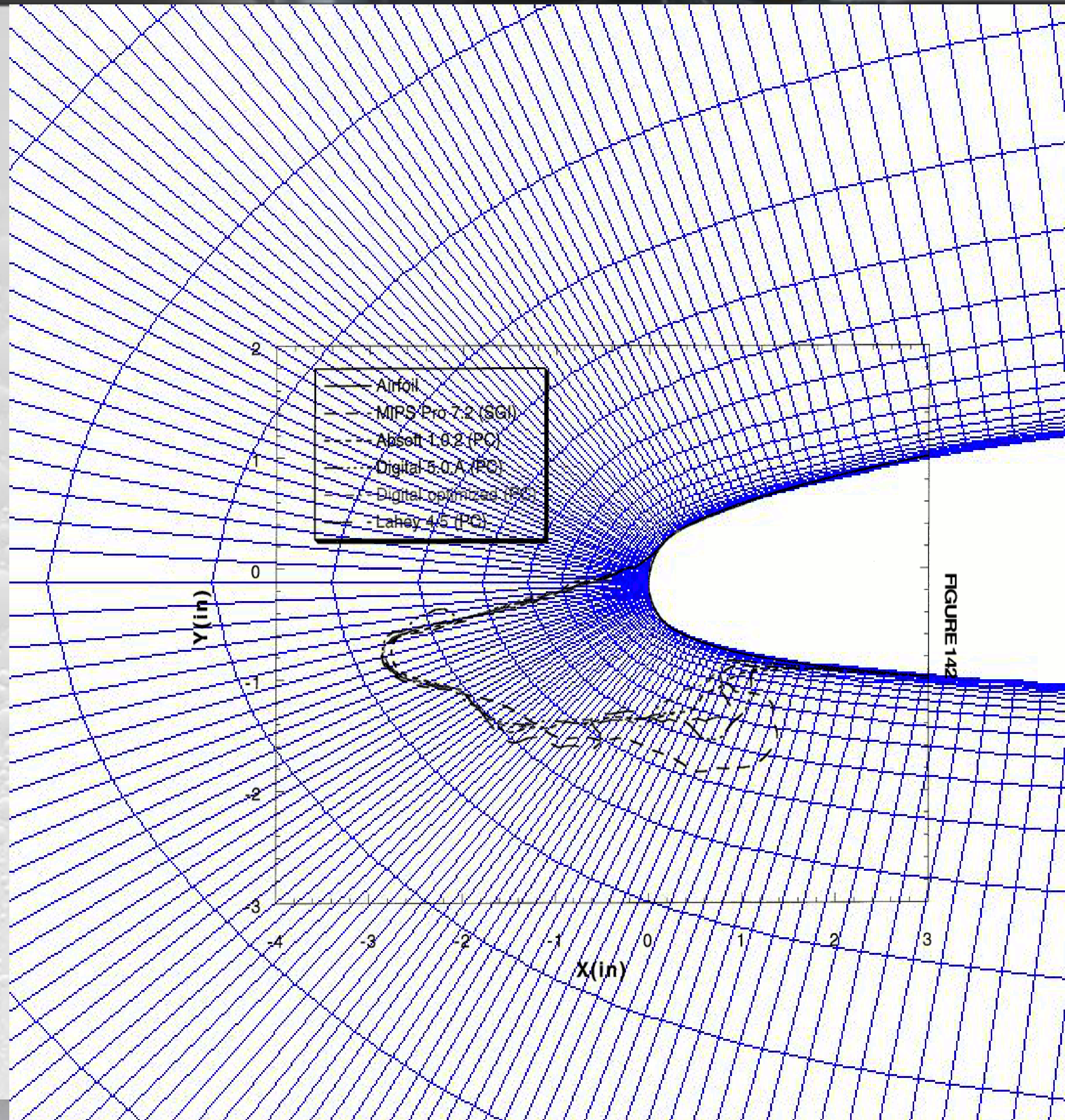


Sol=sol-01-c, A=0
Surface Grid

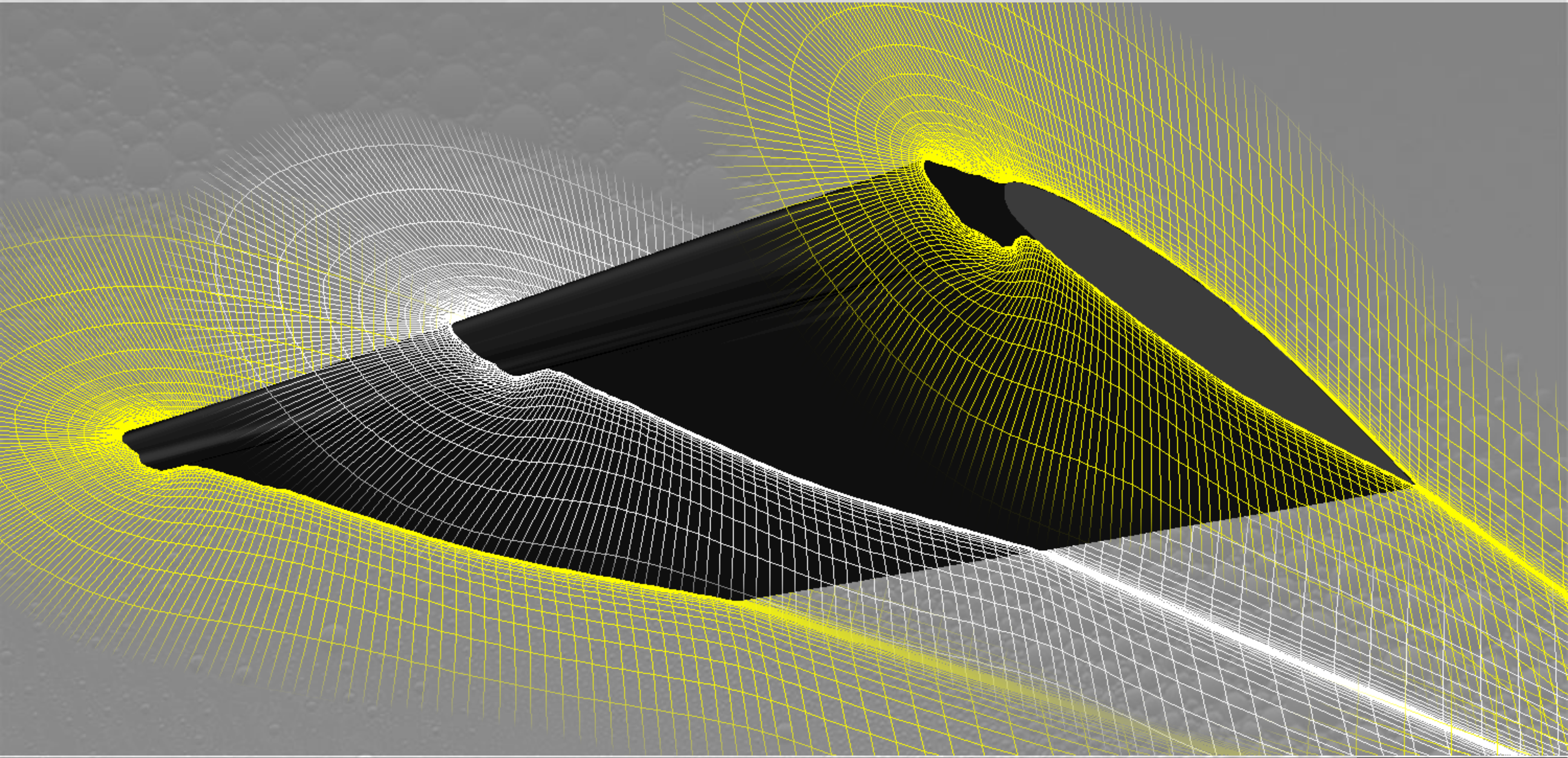
Generic Formula 1 Front End



Ice accretion morphing

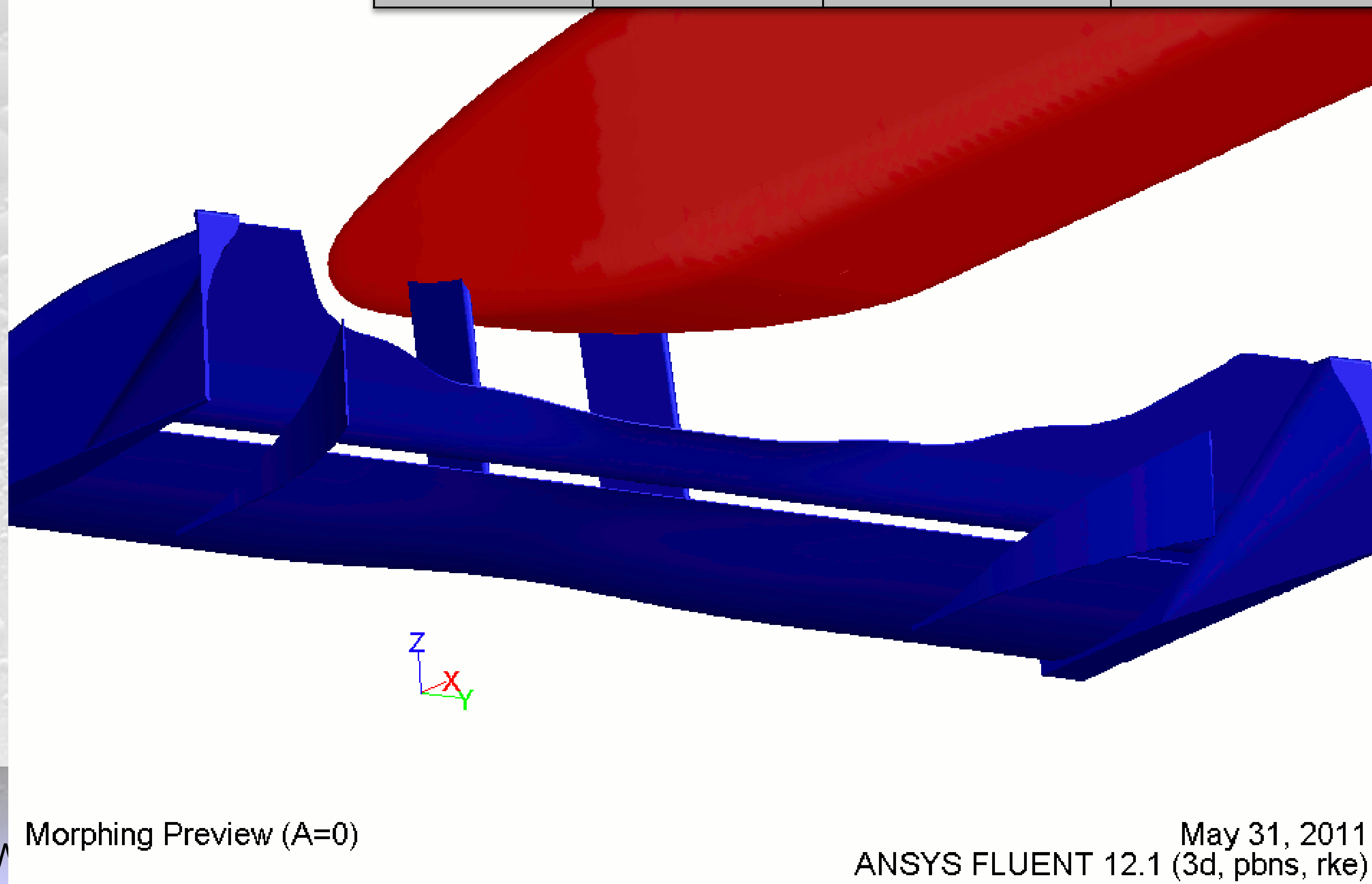


3D accretion morphing

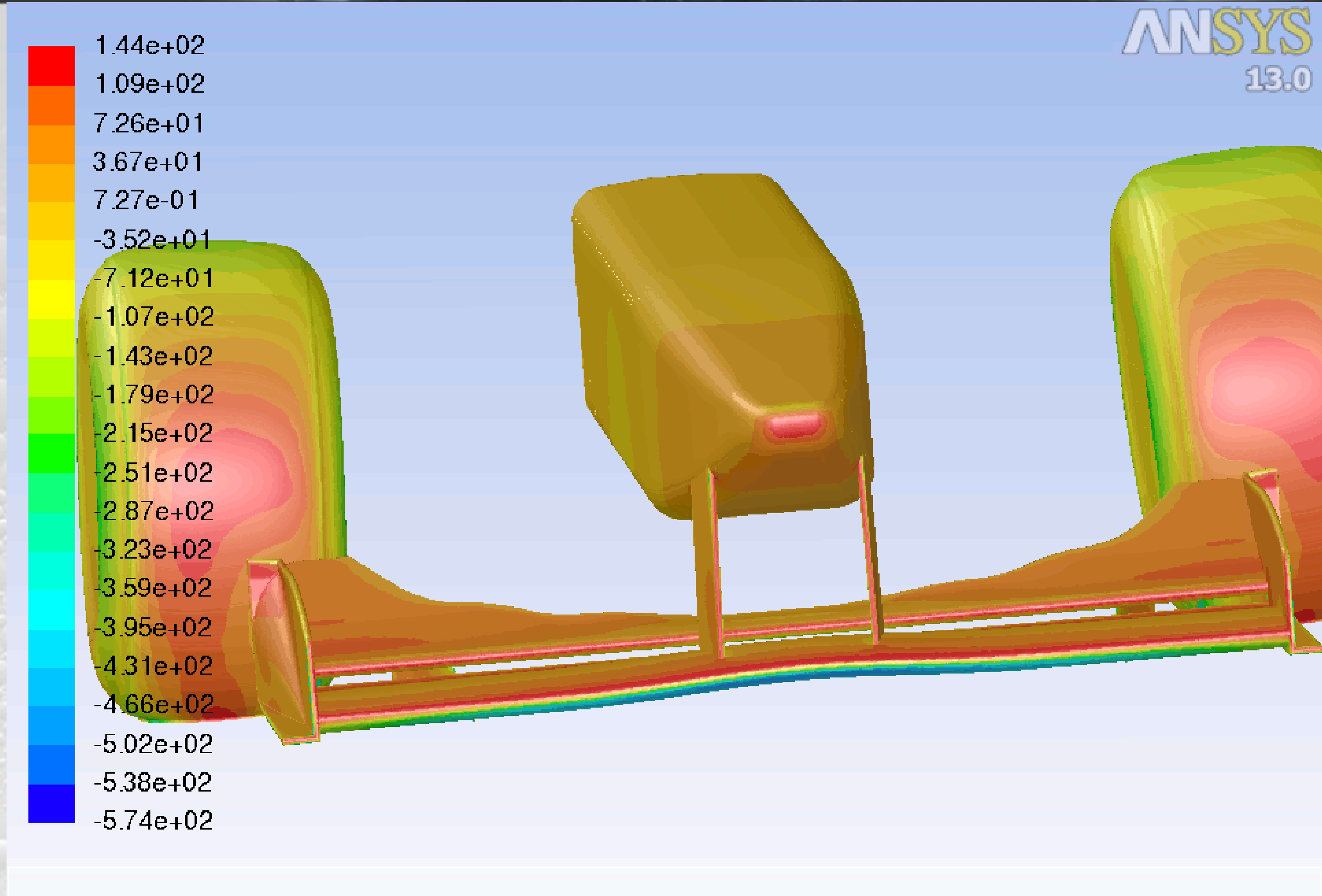


Aeroelastic Analysis of Formula 1 Front Wing

Mode	Disp(mm)	Max err(mm)	Max err (%)
1	7,19	1,61	22,39
2	7,19	0,86	12,00
3	6,98	0,85	12,15
4	6,90	0,66	9,50
5	6,85	0,19	2,76
2 Ways FSI	6,98	0,00	0,00

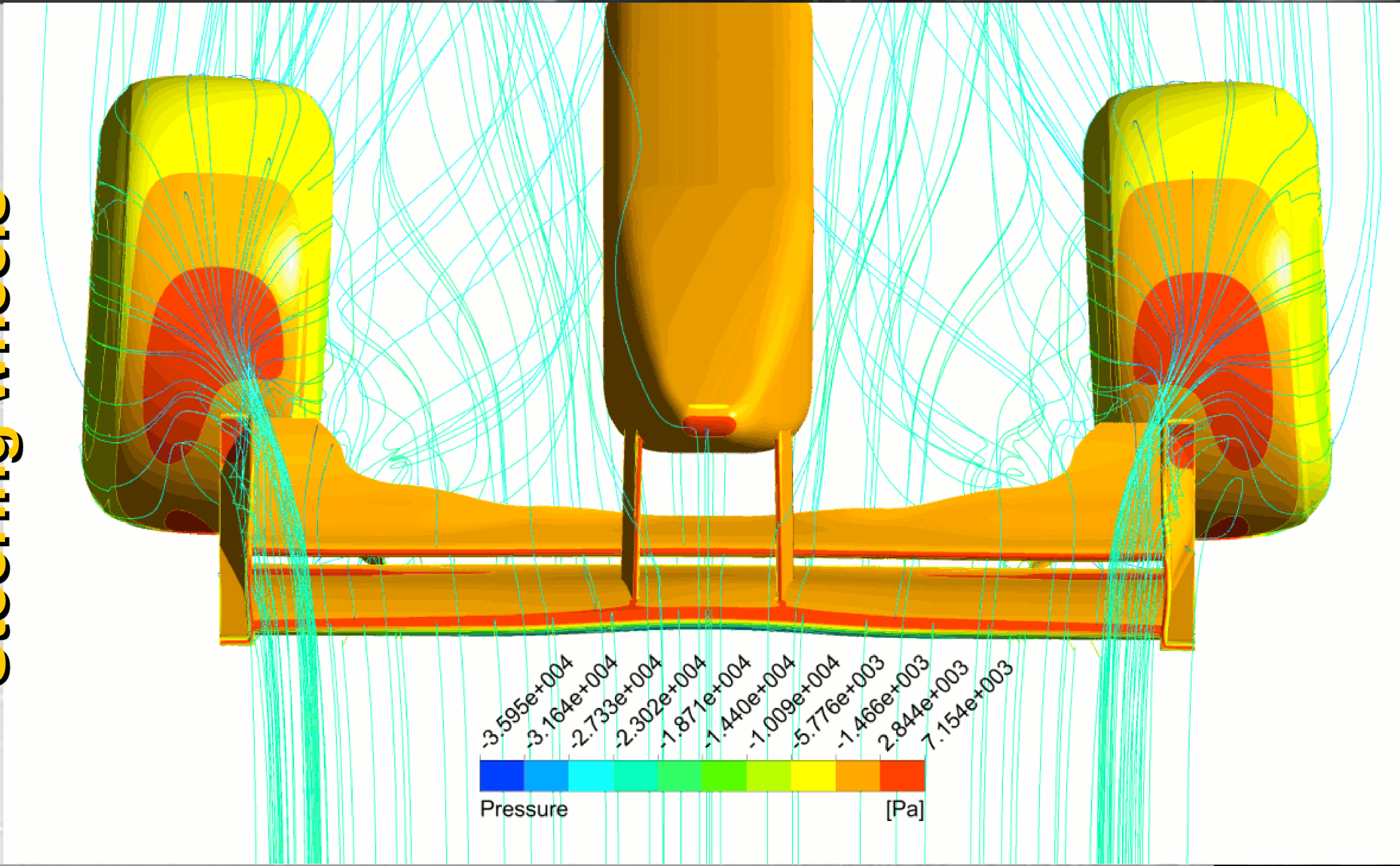


Aeroelastic Analysis of Formula 1 Front Wing

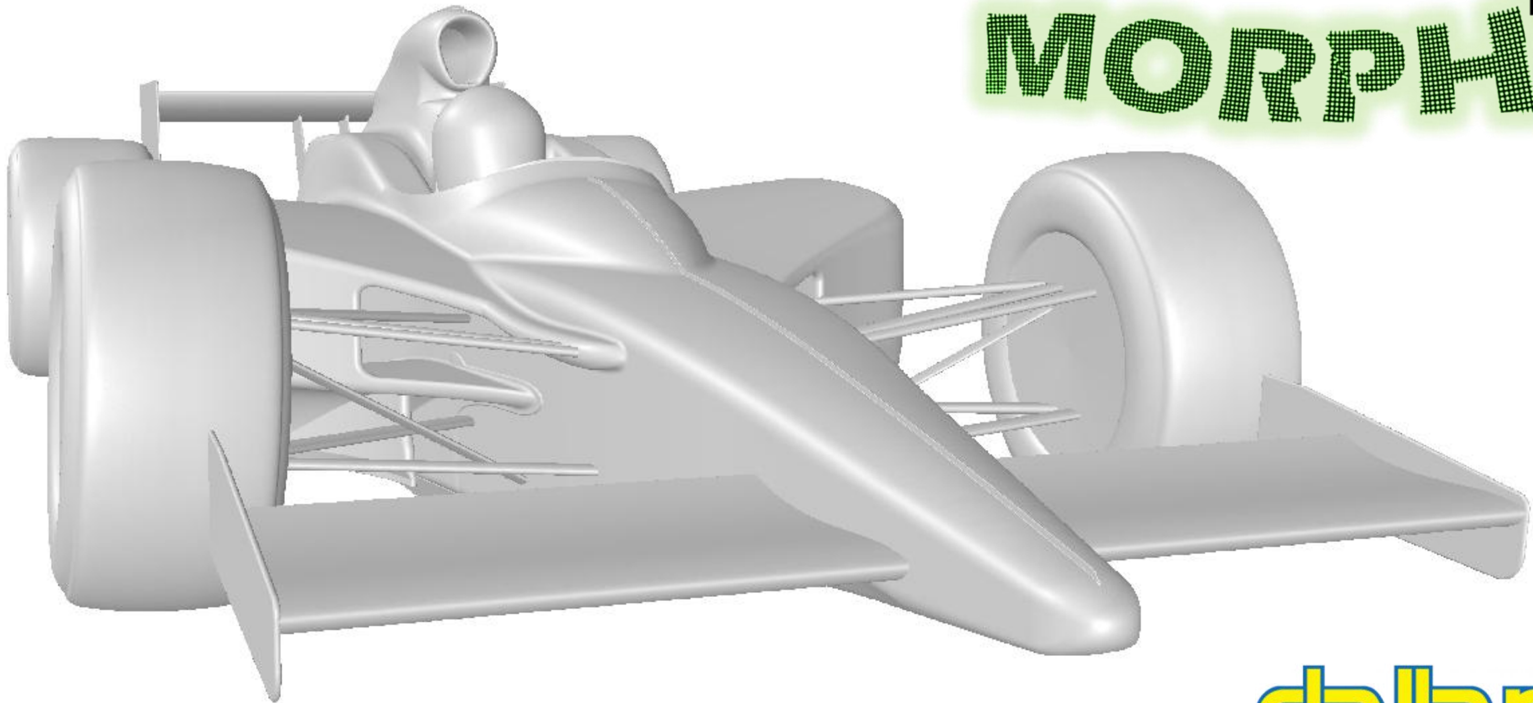


Contours of Static Pressure (pascal)
54kph

Steering wheels



MORPH lab



dallara

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PIAGGIO AERO

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CINECA SCAI
SuperComputing Applications and Innovation

D'APPOLONIA

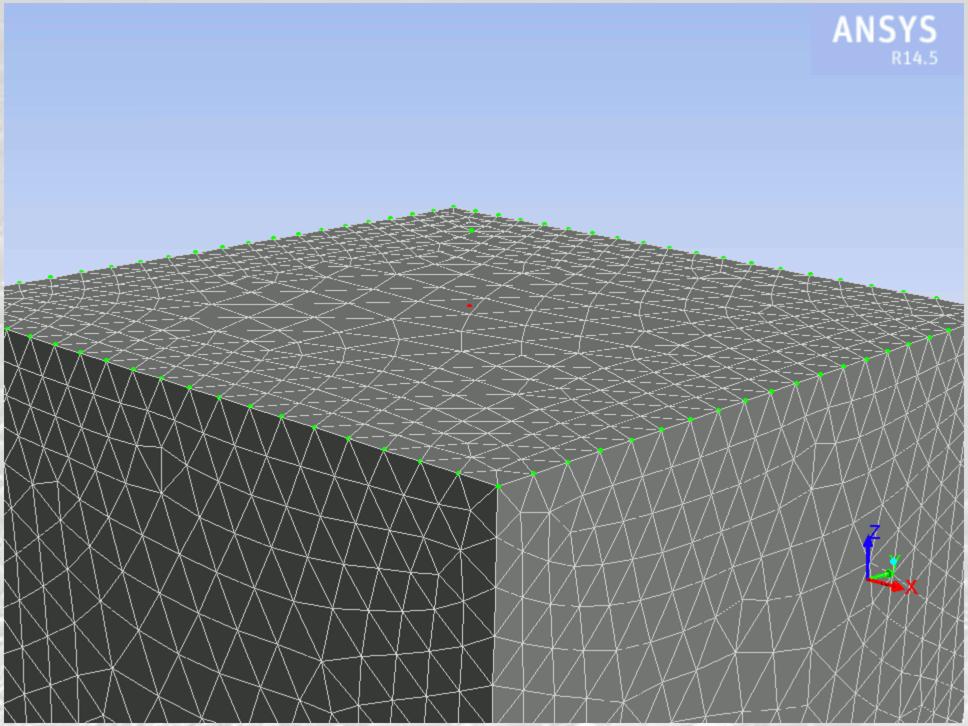
EU Project RBF4AERO – FP7Transport

- *"Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimisation"* – **GA no. ACP3-GA-2013-605396**

Advanced features

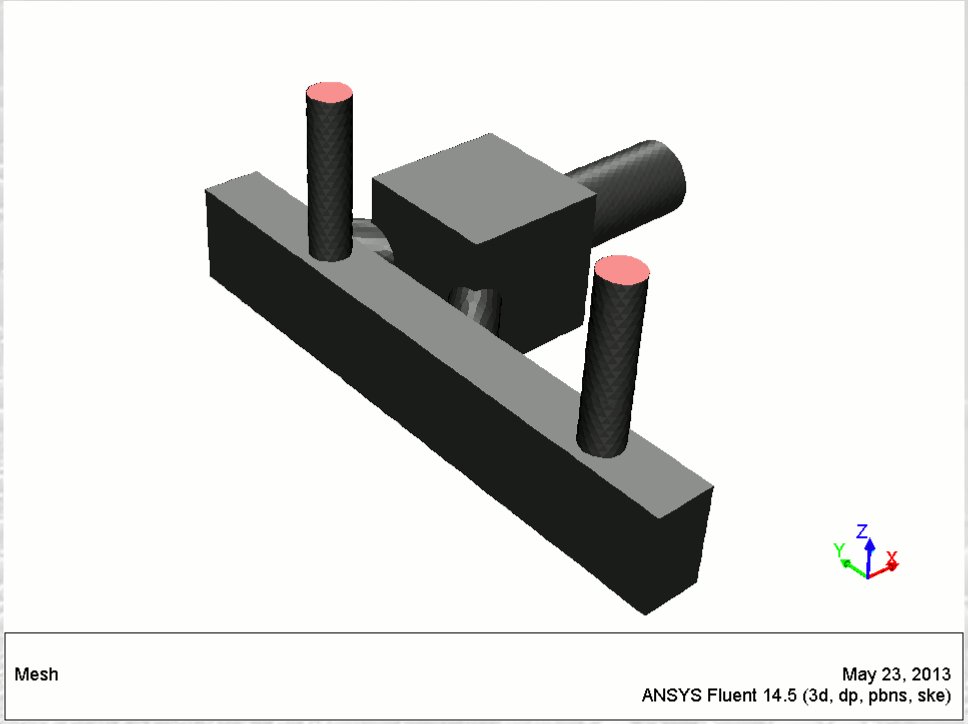
Two steps method

- **STEP-1** Specific set-up can be defined for accurate **surface control** (high order RBF)
- **STEP-2** Resulting shape can be used in the final set-up to control the **volume mesh** (preservation of other surfaces, fast and smooth bi-harmonic function)



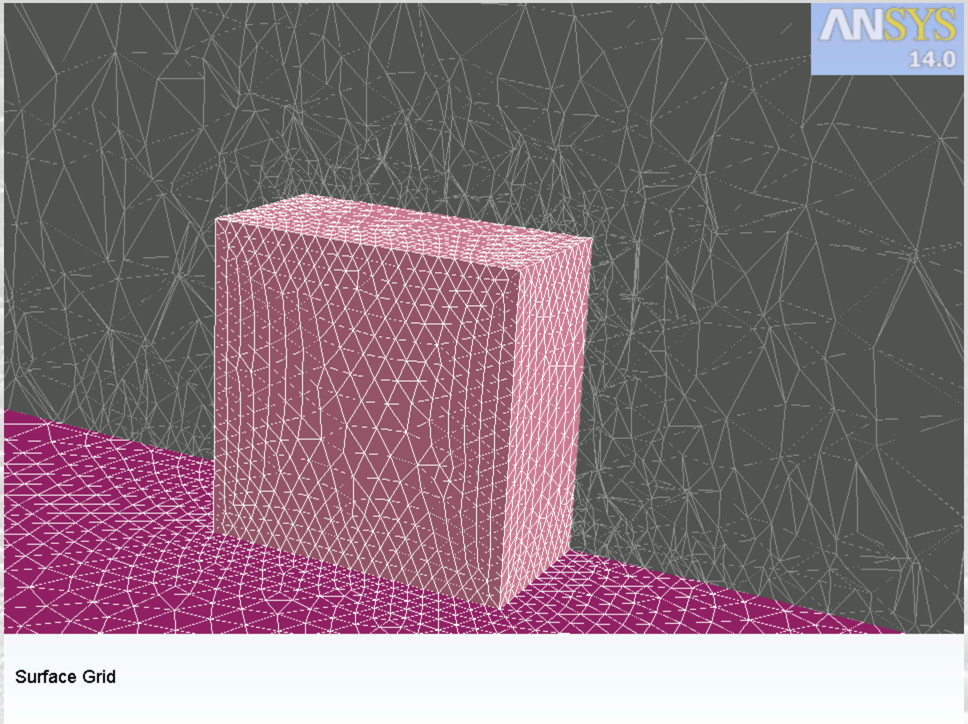
Adjoint sculpting

- Shape information coming from the **Fluent Adjoint** morpher can be used to control a surface
- A single adjoint (baseline shape) is used to define shape modifications in **multiple locations**
- New shape modifications can be **combined** as usual



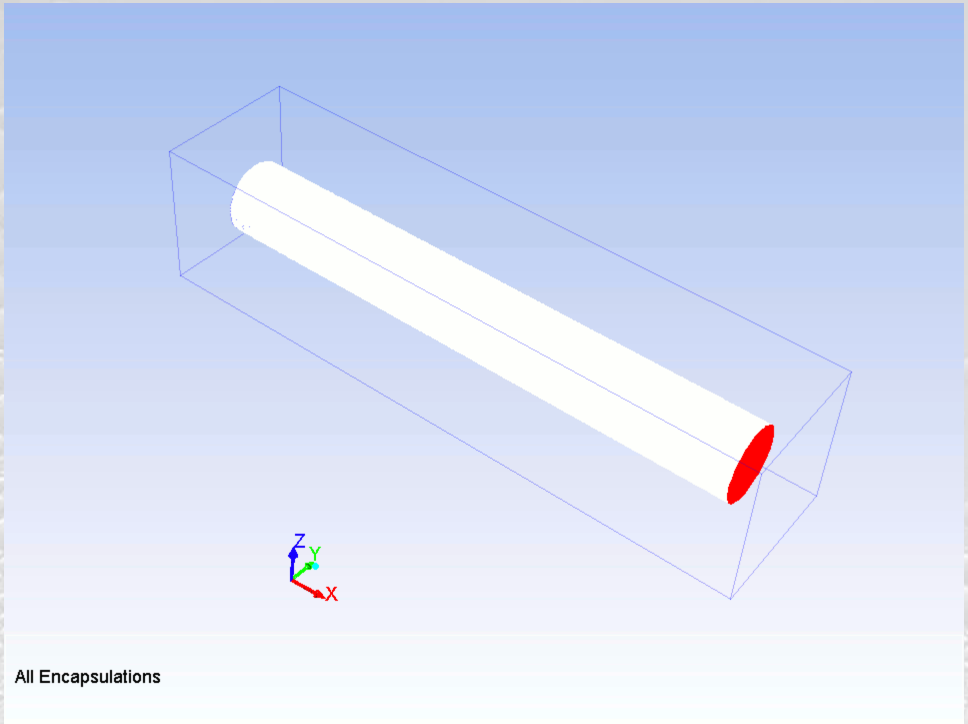
CAD controlled surfaces

- A new shape known in advance can be inserted using an **STL target**
- In the example a **fillet** with radius in the range 20-30 mm is applied to one edge of the 1000 mm side cube
- Shape **blending** allows a continuous variation



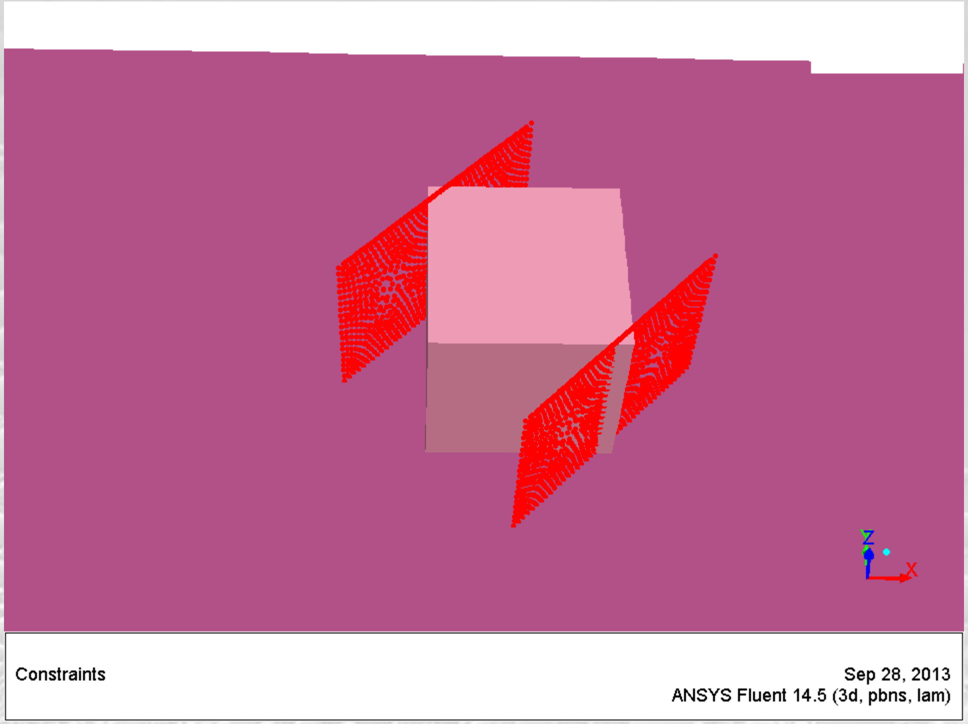
Box sculpting

- **Arbitrary points distribution** can be used to control surfaces
- Effect typical of **FFD boxes** can be obtained using special shapes to generate control points
- In the example a **tube** is **reshaped** using 20 points computes on a box (SP → Points command)



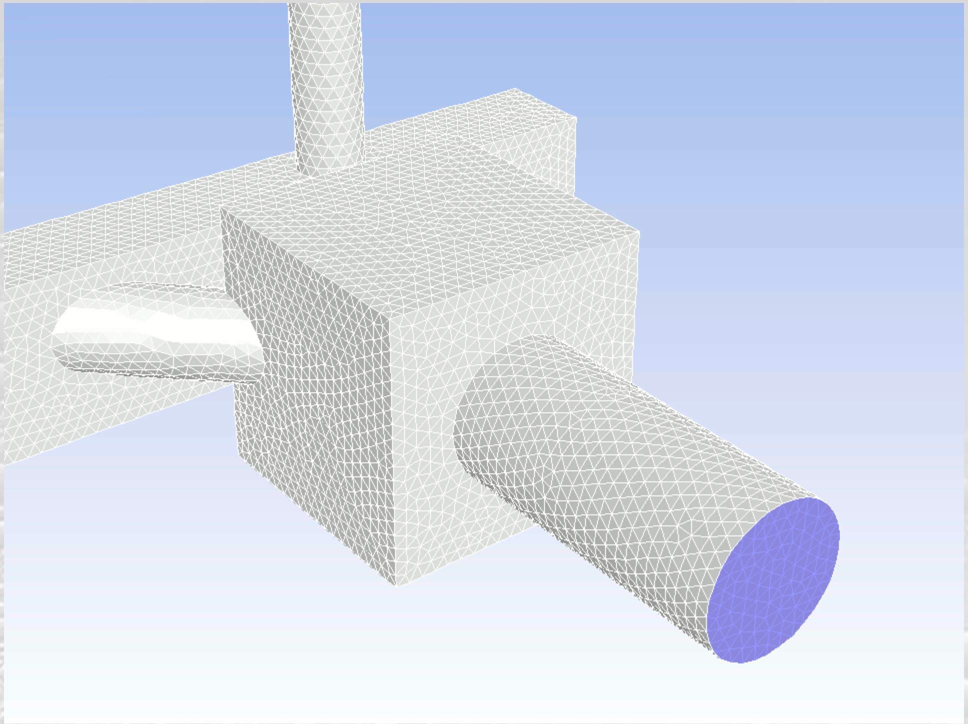
Constrained optimization

- When several shape parameters are combined it's difficult to control the **final position** of morphed shape
- RBF Morph allows to defined **list of planes** and to control the minimum distance of **monitored surfaces** with respect to all the plane in the list (**value exposed to WB**)
- Constraints are shown projecting the points of monitored threads



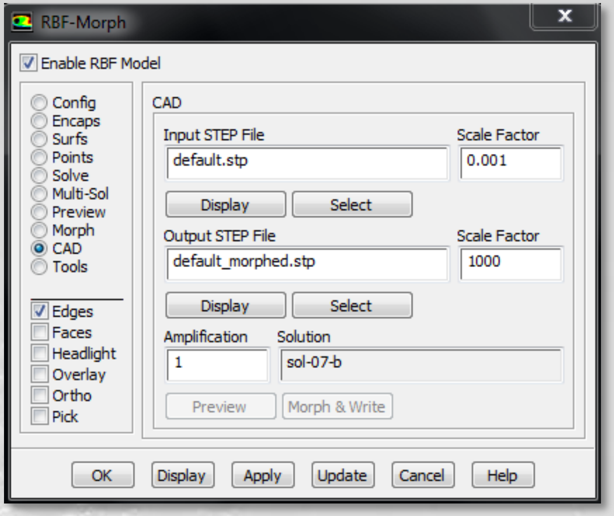
Surfaces intersection

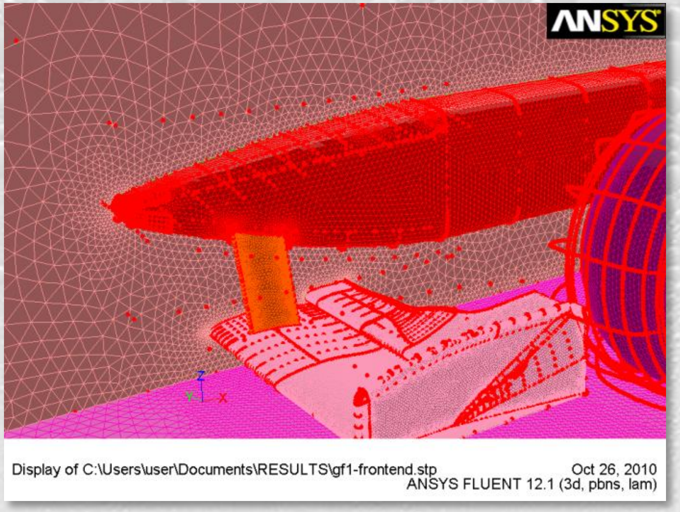
- Some times to accommodate morphing some undesired **deformations** are introduced
- Re-projection onto original surfaces (using **STL target** or self-projection) is then required
- In the example a multi step RBF sequence is used to **preserve** the shape of the flat surface

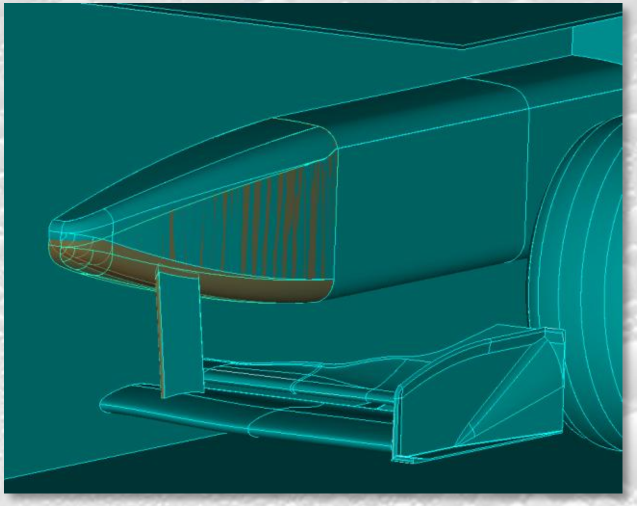


Importing in the CAD the new design

- Solution 07-b with ampli = 1 has to be reversed (**nose rotation** 1 deg)
- STEP file of original shape is loaded (points overlap within **Fluent GUI**)
- **Morphed STEP** file is generated







Conclusions

- A **shape parametric** CFD model can be defined using ANSYS Fluent and *RBF Morph*.
- Such **parametric CFD model** can be easily coupled with preferred optimization tools to steer the solution to an **optimal design** that can be imported in the preferred **CAD** platform (using **STEP**)
- Proposed approach **dramatically** reduces the man time required for set-up widening the CFD calculation capability (**50:50:50**).
- ***M.E. Biancolini****, Mesh morphing and smoothing by means of Radial Basis Functions (RBF): a practical example using Fluent and RBF Morph* in Handbook of Research on Computational Science and Engineering: Theory and Practice (http://www.cse-book.com/).

Thank you for your attention!

Dr. Marco Evangelos Biancolini

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