An advanced CFD post-processing tool enabled by adjoint and RBF mesh morphing allows the fast exploration of an arbitrary number of shape parameters effect on performances

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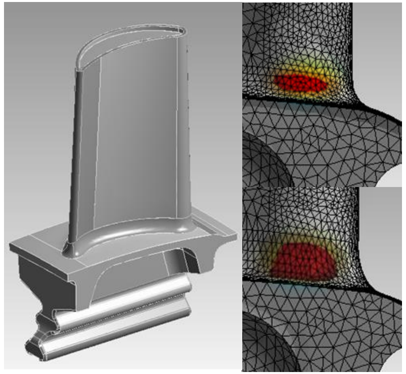
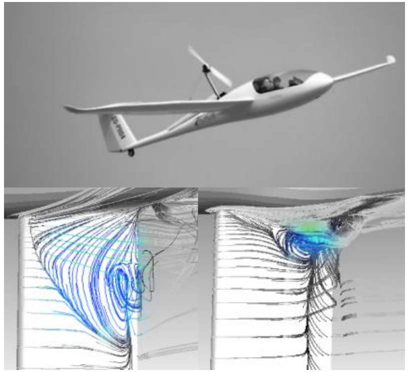
RBF Morph srl

rbf™

Outline

- RBF Morph technology and software solutions for **shape optimization**
- Gradient based examples based on **adjoint** solver
- Beyond (before) optimization: advanced **post processing**
- Industrial example: exploring the drag reduction of a **Formula Indy** car
- Conclusions





10+ years of RBF Morph

2007 – **Fluent Customization for a Formula One Top Team**

2008 – Technical Partner of Ansys Inc.

2009 – “Most Advanced Approach” recognition

2009 – **RBF Morph Module for Ansys Fluent released**

2010 – First industrial application combining modeFRONTIER and RBF Morph

2011 – **RBF Morph Stand Alone released**

2012 – Ansys OEM partner

2013 – Honorary member of Technet Alliance

2013 – **“Most Innovative Use of Simulation” recognition**

2014 – **RBF Morph ACT for Mechanical released**

2015 – RBF Morph ACT in the ANSYS App Store

2016 – **RBF Morph company founded**

2016 – Winner of ANSYS Hall of Fame (nautical field)

2017 – Ansys Preferred Solution Partner

2018 – EC Project Cloudifacturing

2019 – Ansys Advanced Solution Partner

2020 – EC SME instrument Phase 1 RBF2CAD

Industries served (100+ institutions)

- Automotive
- Aerospace & Defence
- Nautical & Marine
- Healthcare & Medical
- Energy
- Oil & Gas

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

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

Biancolini, M. E. (2017). *Fast radial basis functions for engineering applications*. Springer International Publishing.

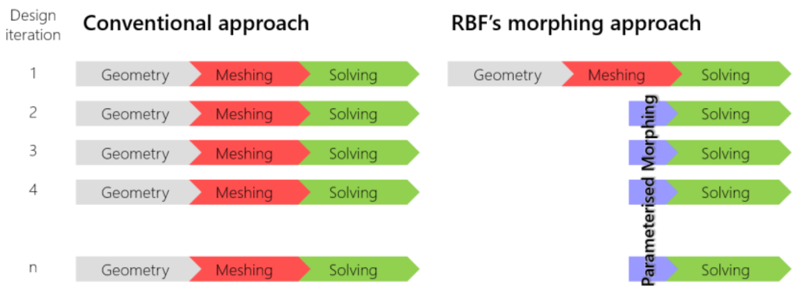
Parametric CAE models

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.

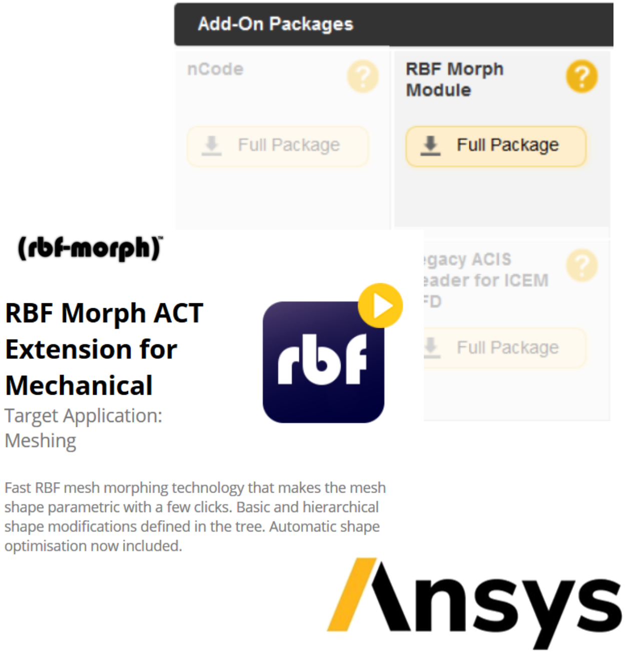


- It's **easy and fast**: shape parameters are defined in the CAE GUI. No need to iterate the CAD
- The turnaround time of the optimization is usually **reduced by a factor five** (weeks become days)

We offer Ansys integrated solutions…

ACT Extension (FEM)

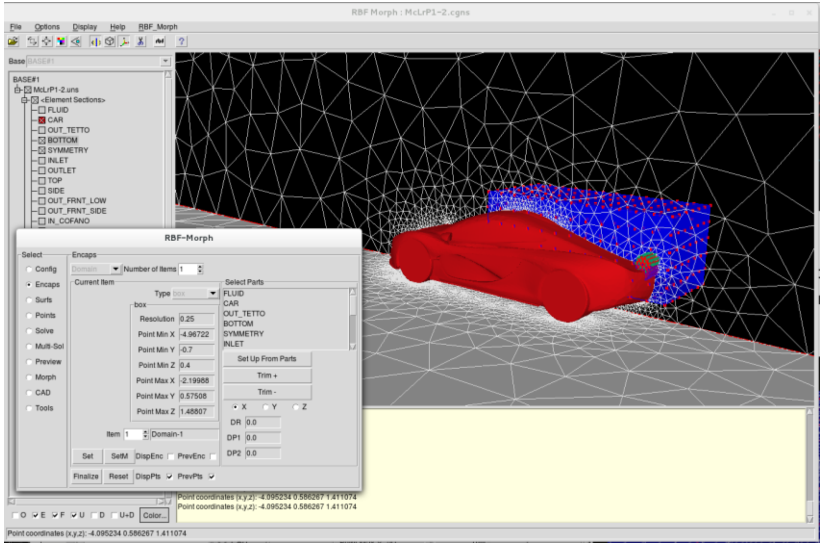
- Released in **2014**
- Fully embedded in ANSYS **Mechanical** (parametric)
- Benefits of **underlying geometry** (or aux geo with dead meshes)
- …**WB** Meshing



Fluent Module (CFD)

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

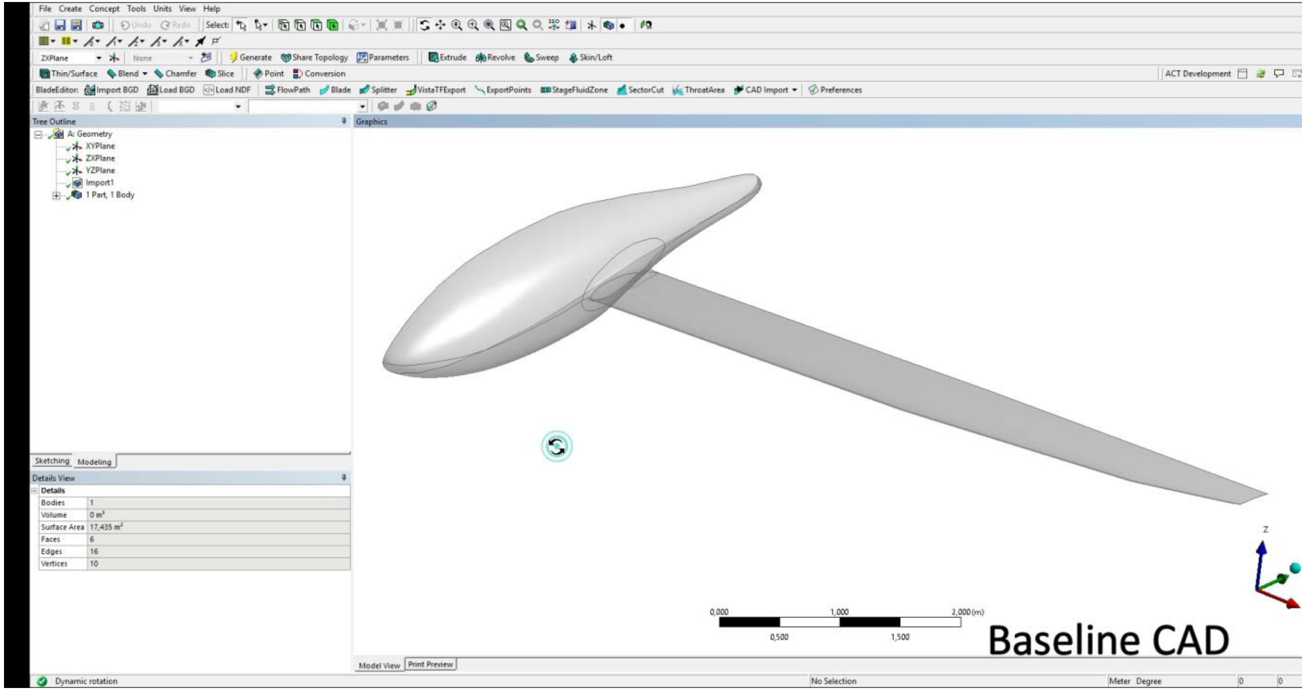
...and a Stand Alone software



- Released in 2011
- Read in **STL and CGNS file formats**
- Solver independent process that supports **many mesh formats**
- **Scriptable** via tcl

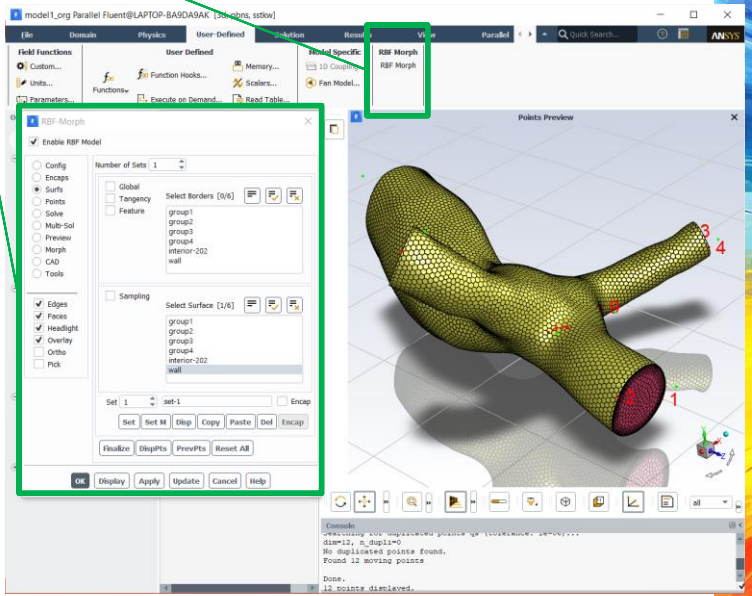
RBF Morph Fluent Module

https://youtu.be/EWsigyqByRg

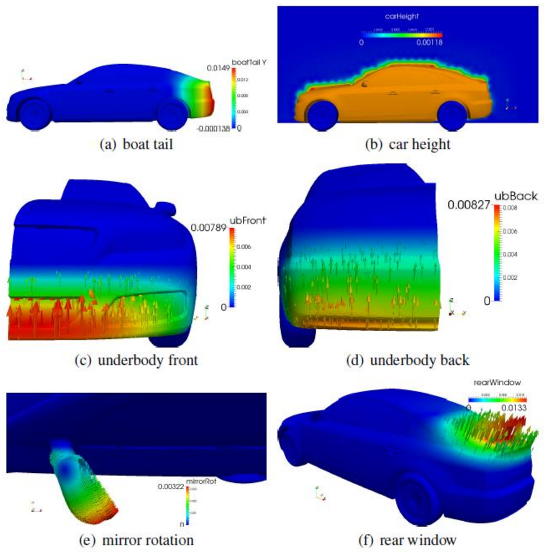


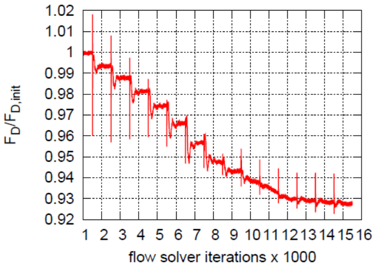
Fluent module

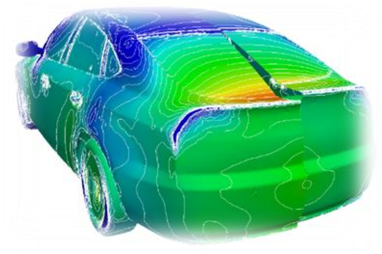
- Add on fully integrated within Fluent (GUI, TUI & solving stage), **Workbench** and **Adjoint Solver**
- Mesh-independent RBF fit used for **surface** mesh morphing and **volume** mesh smoothing
- **Parallel** calculation allows to morph large size models (many millions of cells) in a short time
-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



Gradient-based optimization (adjoint)







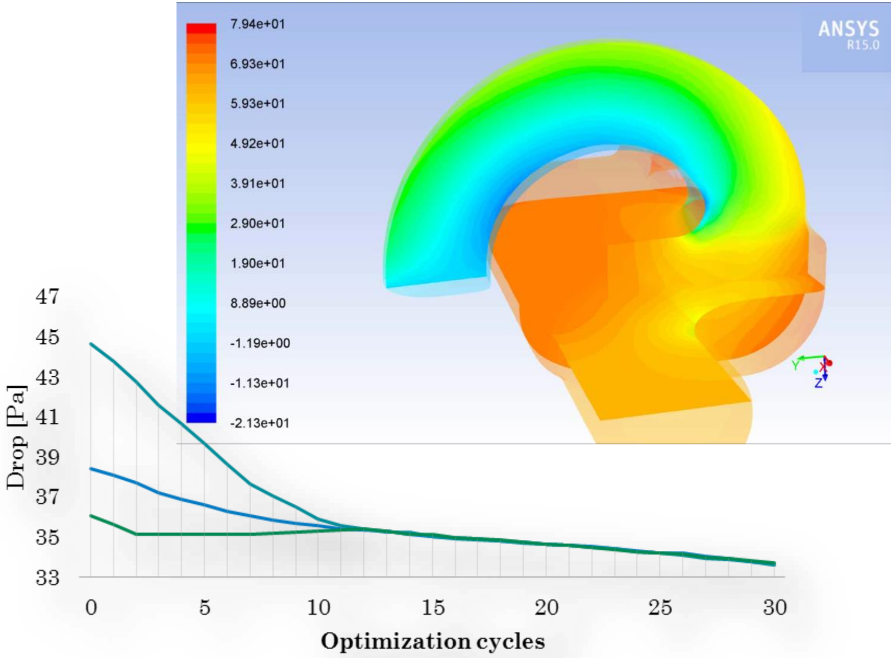
Optimization with parameters

- The adjoint formulation provides the **gradient** of an aerodynamic objective function **with respect to surface displacements**

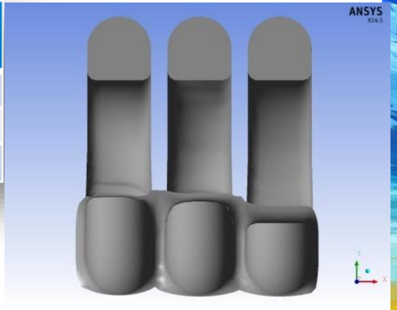
$$\frac{\delta F}{\delta \vec{b}} = \frac{\delta F}{\delta x_\kappa} \frac{\delta x_\kappa}{\delta \vec{b}}$$

- RBF Morph provides the **deformation velocity** (adjoint preview)

Engine Air box

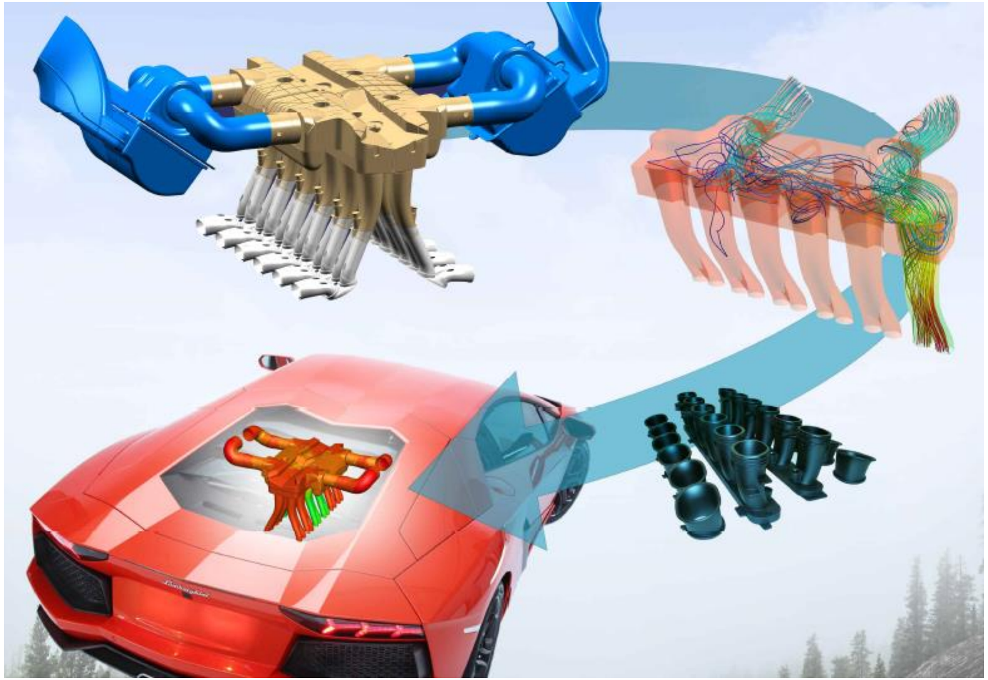


	Mean pressure Drop [Pa]	Unbalance
Baseline	39.7	12.45%
Optimized	33.635	0.12%
Reduction	15.3%	99.0%



- **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

Engine Air box



- V12 700Hp@8250RPM
- Obtained shape allows to get a **5.9%** reduction of pressure drop

Beyond (before) optimization: advanced adjoint based post-processing

- High fidelity CAE solver adopted in this study is **Ansys Fluent** (CFD+adjoint)
- Advanced mesh morphing is provided by combining the CFD solver with the **RBF Morph Fluent module**
- A new **interactive custom feature** defined to quickly explore new shapes without any additional solver calculations

(rbf-adjoint-interactive)

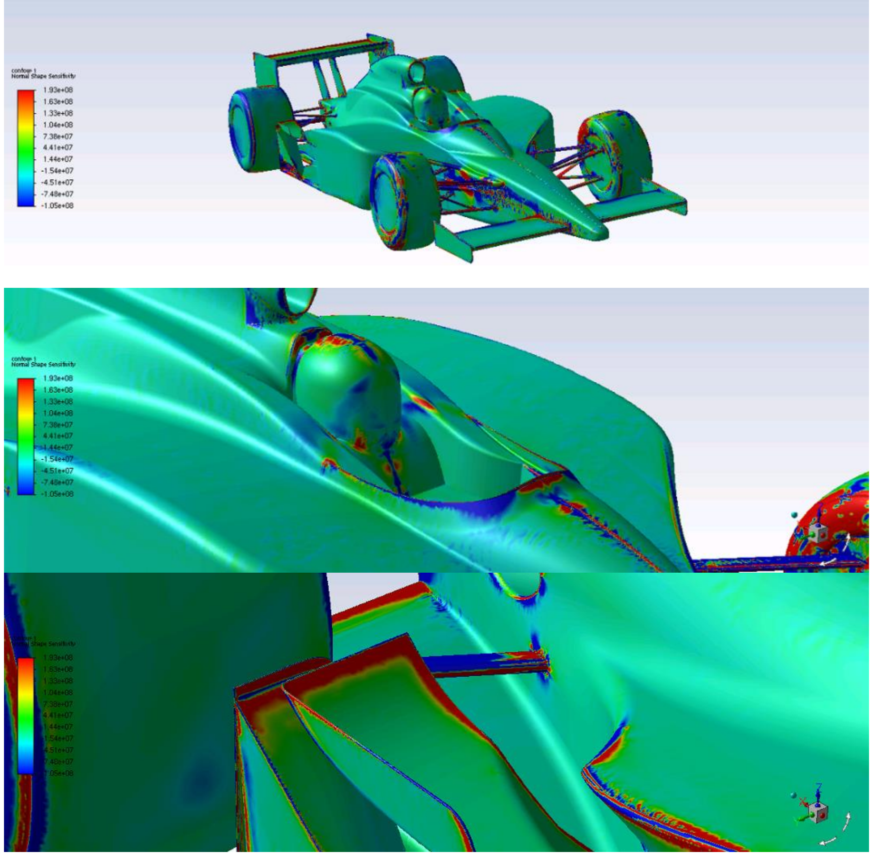
Beyond (before) optimization: advanced adjoint based post-processing

(rbf-adjoint-interactive)

1. Inspect flow solution and adjoint sensitivity
2. Decide the regions to be modified
3. Create desired shape modifications (design parameters, FEA deflections, sculpted shapes)
4. Explore how shape modifications combines and get a (gradient based) estimation of the performance

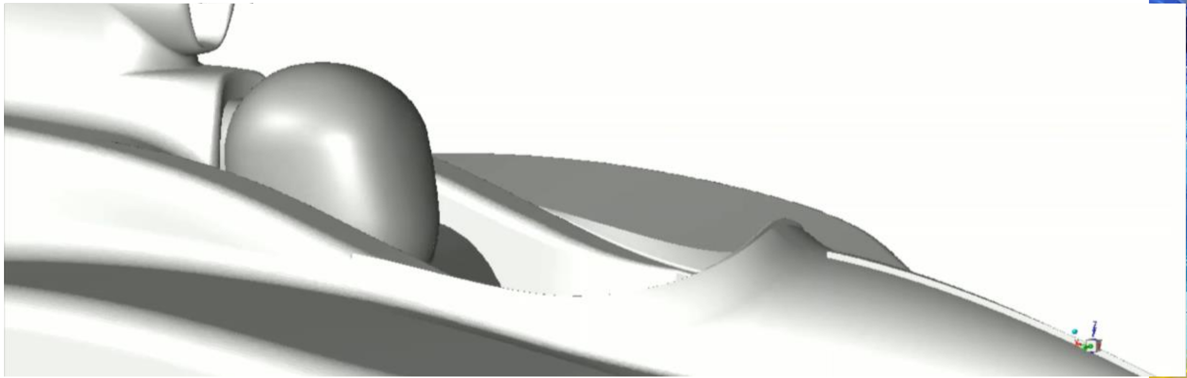
Drag analysis of a dallara Indy car

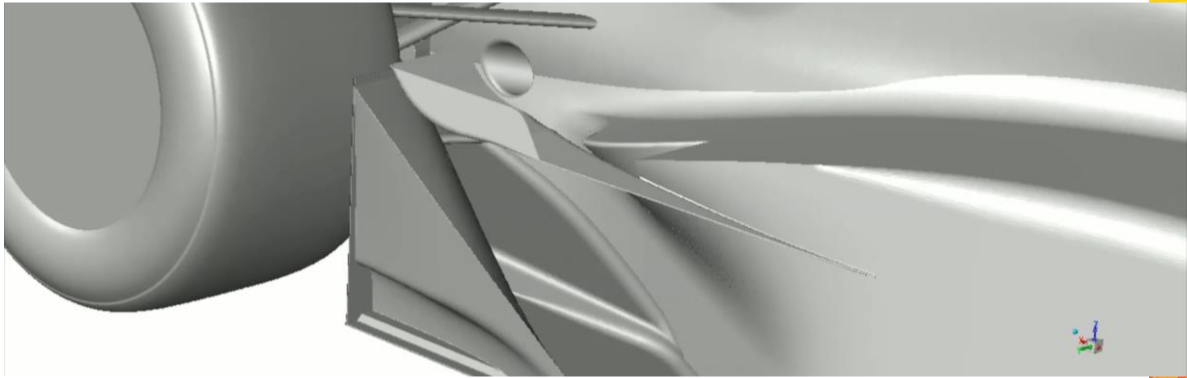
- Half car model comprised of about **80 millions cells**
- Drag sensitivity computed with adjoint solver
- Regions of interest:
  - Windshield
  - Rear wheel deflector



Drag analysis of a dallara Indy car

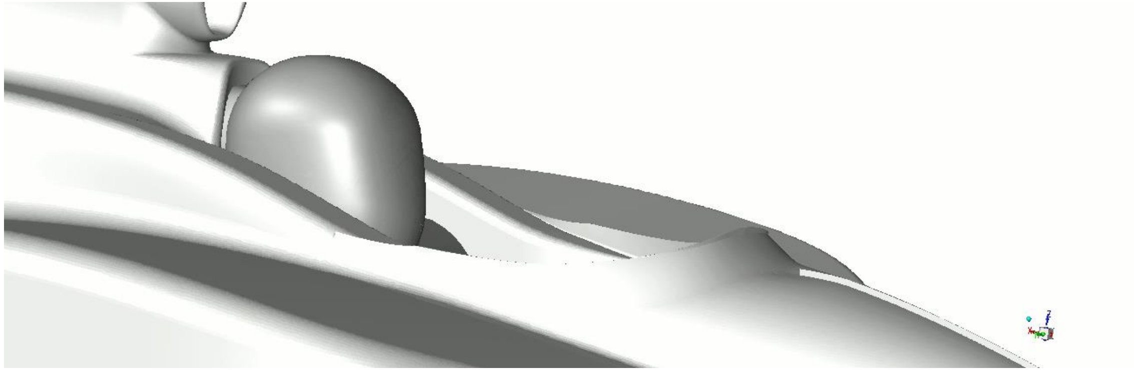
- Shape modifications are defined to get a variety of feasible new shapes
  - **Windshield** is controlled by 9 different actions
  - **Rear wheel deflector** is controlled by 3 different actions

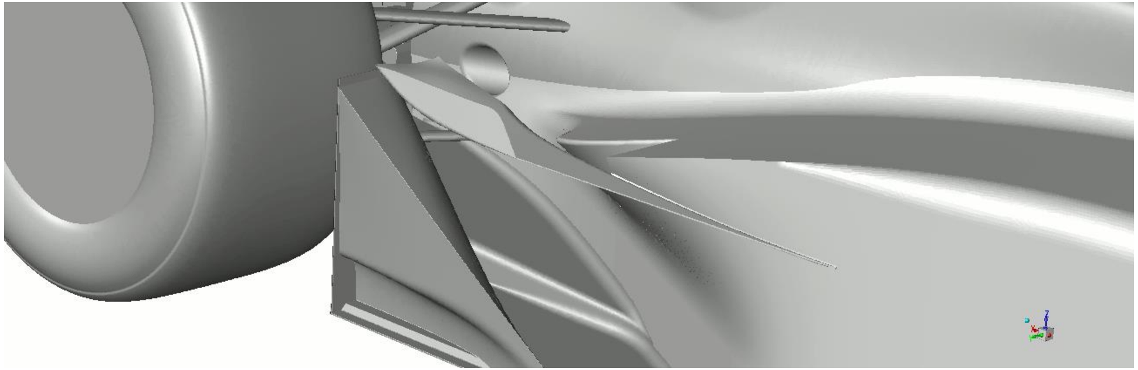




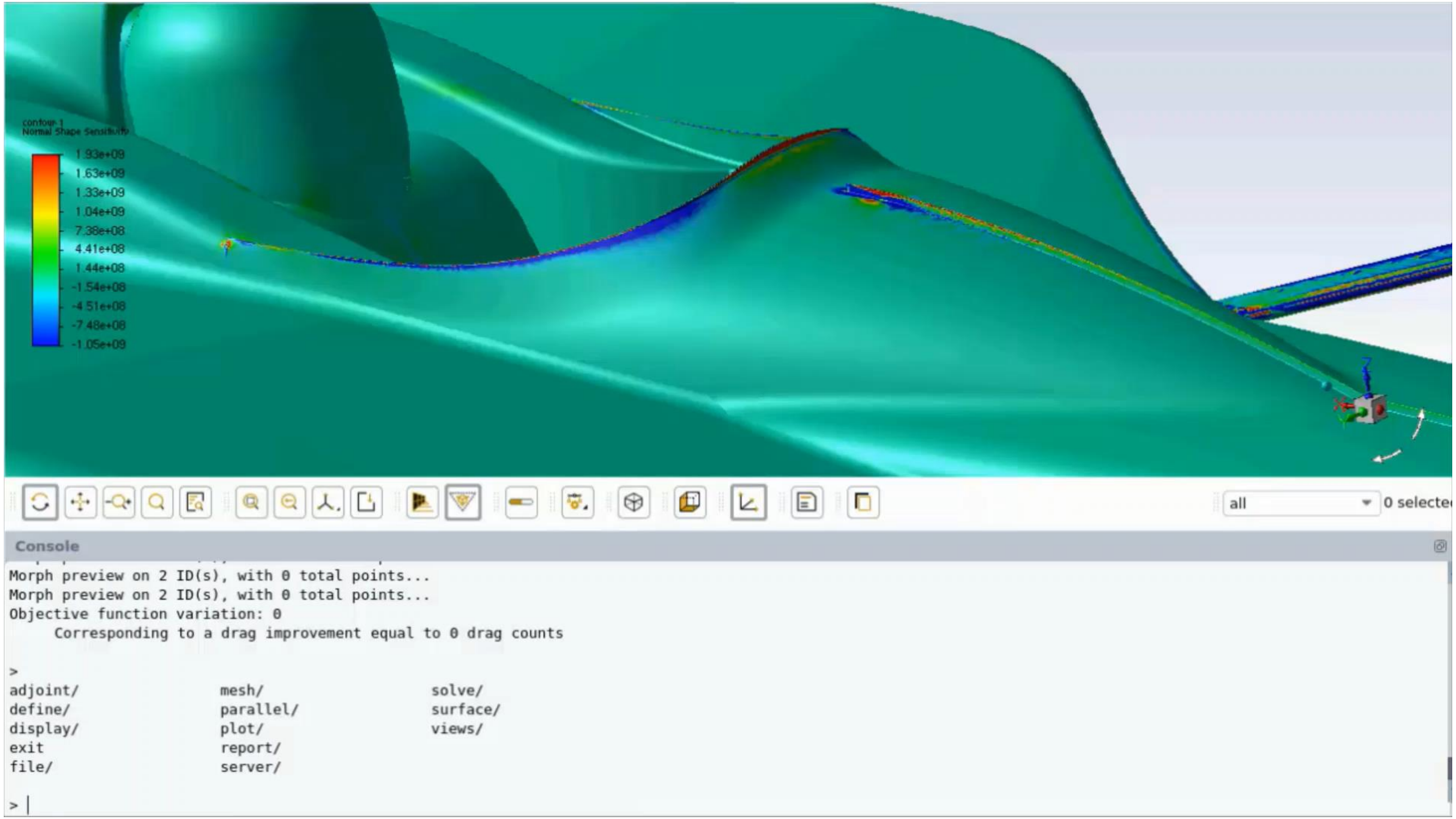
Drag analysis of a dallara Indy car

- Shape modifications are defined by **filtering adjoint** sensitivity field that allows to get a new optimal shape for
  - Windshield
  - Rear wheel deflector





Drag analysis of a dallara Indy car



Drag analysis of a dallara Indy car

The challenge

- Well, now we have a **quantitative estimation** of the effect of shape parameters
- Automatic methods are based on the **gradient** and can converge toward an optimum
- Can the **engineer** get a better shape in a single shot?

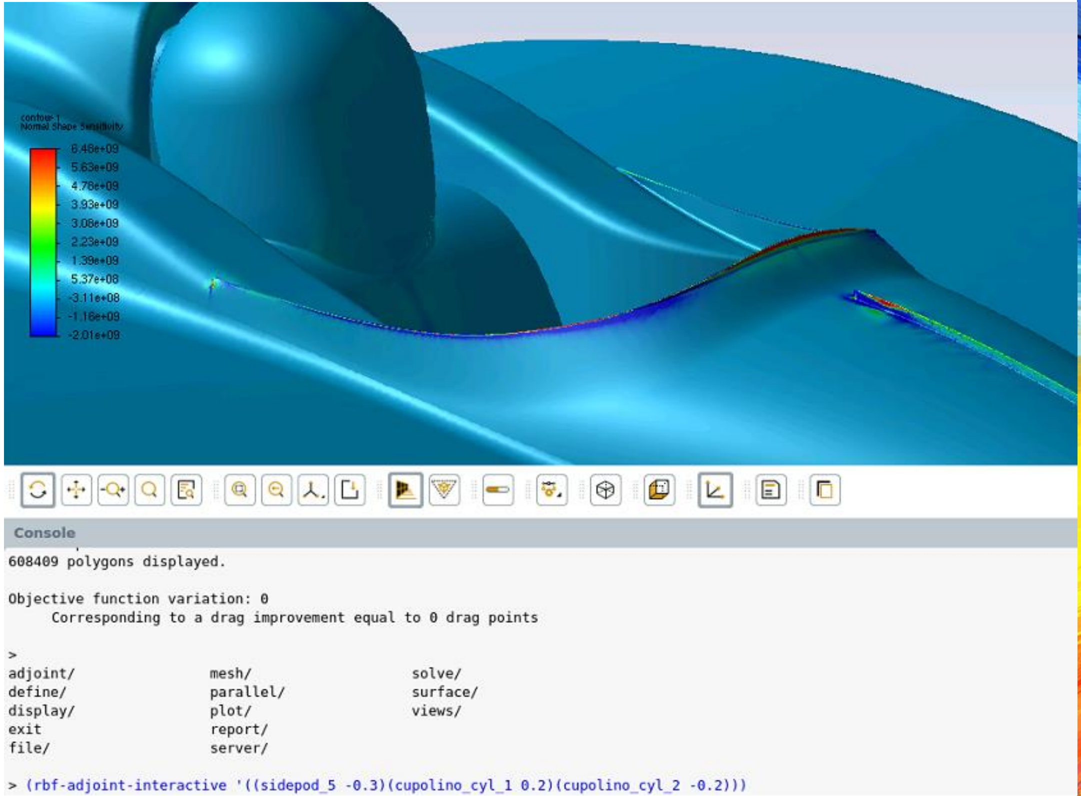
…to answer…

- *Sensitivities are valid only around the baseline*
- *Too much variation could be risky*
- *A small variation is safer… but predicts a small gain!*
- *(challenge posed on Friday to get the answer after the week end)*

Drag analysis of a dallara Indy car

Predicted result

- The new shape was defined combining the 3 parameters (2 on the windshield, 1 on the rear wheel deflector) that show most promising results
- A **0.5% reduction** of the drag force has been predicted
- The new model has been generated and submitted for a full CFD run



Drag analysis of a dallara Indy car

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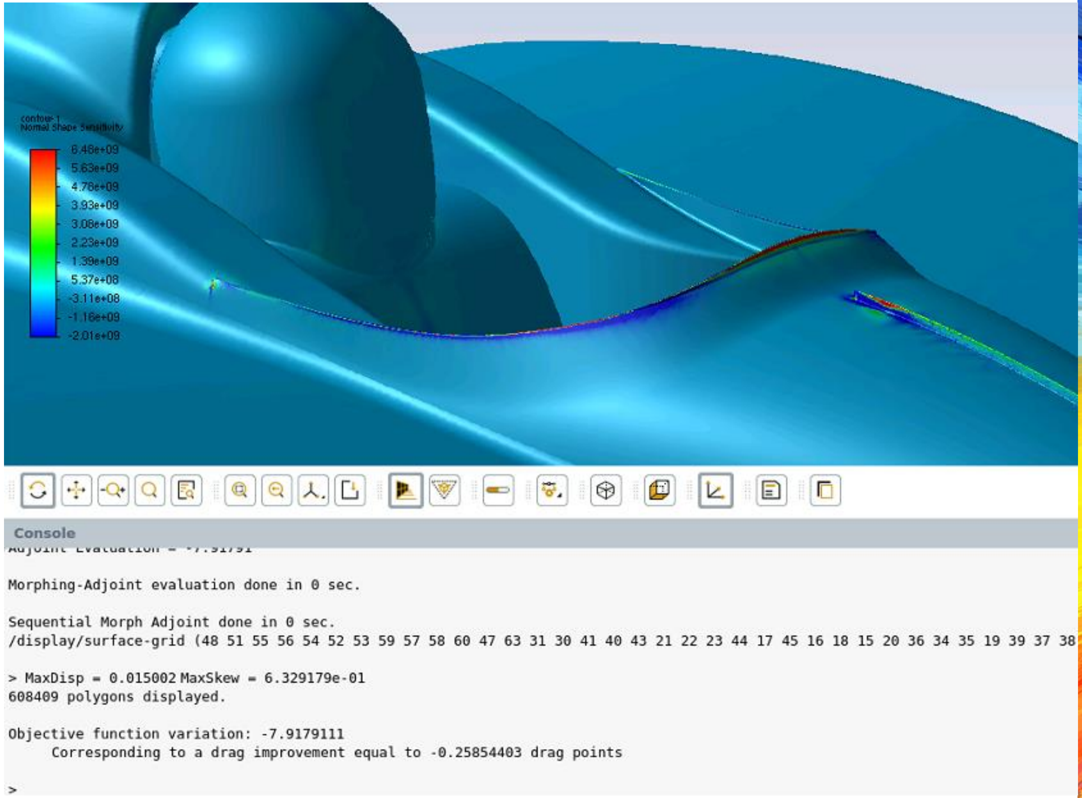


Drag analysis of a dallara Indy car

zone	Cd baseline	Cd modified	difference
w01aa-bw-chassis	0.050395574	0.049522977	-0.0008726
w01aa-bw-driver	-0.028866122	-0.027914999	0.00095112
w01aa-bw-engine-cover	0.00513905	0.005075394	-6.366E-05
w01aa-bw-sidep			
w01ab-mech-er			
w01ab-mech-ex			
w01ab-mech-ra			
w01ab-mech-ra			
w01ab-mech-ra			
w01ba-fuw-skid			
w01ba-fuw-step			
w01bb-ruw-diff			
w01bb-ruw-skid			
w01bb-ruw-top			
w01bb-ruw-tyre			
w02-fw-endplat			
w02-fw-main			
w03-rw-endplat			
w03-rw-main			
w03-rw-pylon			
w04-fs-inf			
w04-fs-pull			
w04-fs-sup			
w04-fs-track			
w05-rs-drivesha			
w05-rs-inf			
w05-rs-push			
w05-rs-sup			
w05-rs-track			
w06a-fwls-plate			
w06b-fwlr-rim			
w06b-fwlr-tyre-			
w06b-fwlr-tyre-			
w07a-rwls-plate			
w07b-rwlr-rim			
w07b-rwlr-tyre-			
w07b-rwlr-tyre-			
total			

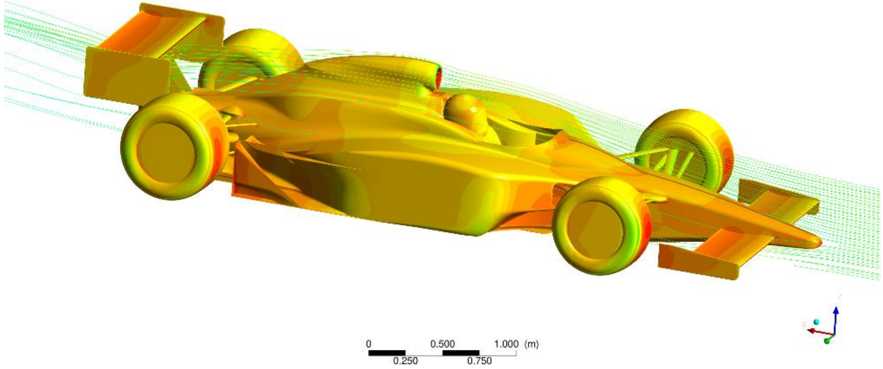
Obtained result

- A **1% reduction** of the drag force has been obtained!
- A **0.49 drag points** reduction (0.5392 → 0.5343) achieved
- The breakdown of **drag distribution** has been inspected

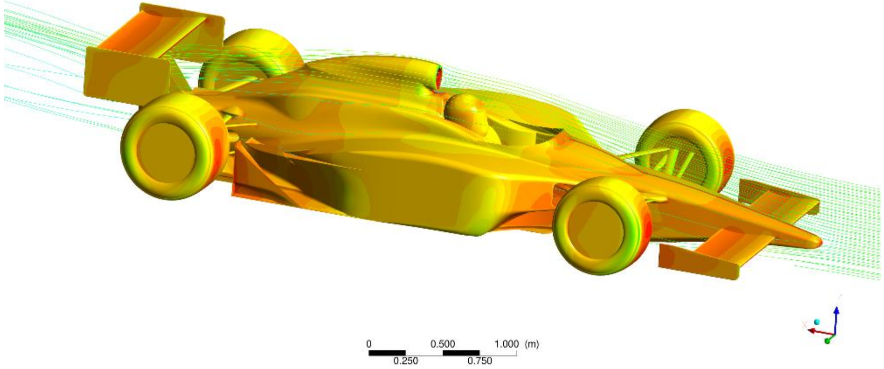
zone	Cd baseline	Cd modified	difference
w01aa-bw-chassis	0.050395574	0.049522977	-0.0008726
w01aa-bw-driver	-0.028866122	-0.027914999	0.00095112
w01aa-bw-engine-cover	0.00513905	0.005075394	-6.366E-05
w01aa-bw-sidepod	-0.001937374	-0.006622437	-0.0046851
...	0.036997341	0.038567107	0.00156977
w07b-rwlr-tyre-rear	0.14861484	0.14882451	0.00020967
total	0.5391928	0.53432232	-0.0048705

Drag analysis of a dallara Indy car

Original shape (Cd= 0.5392)

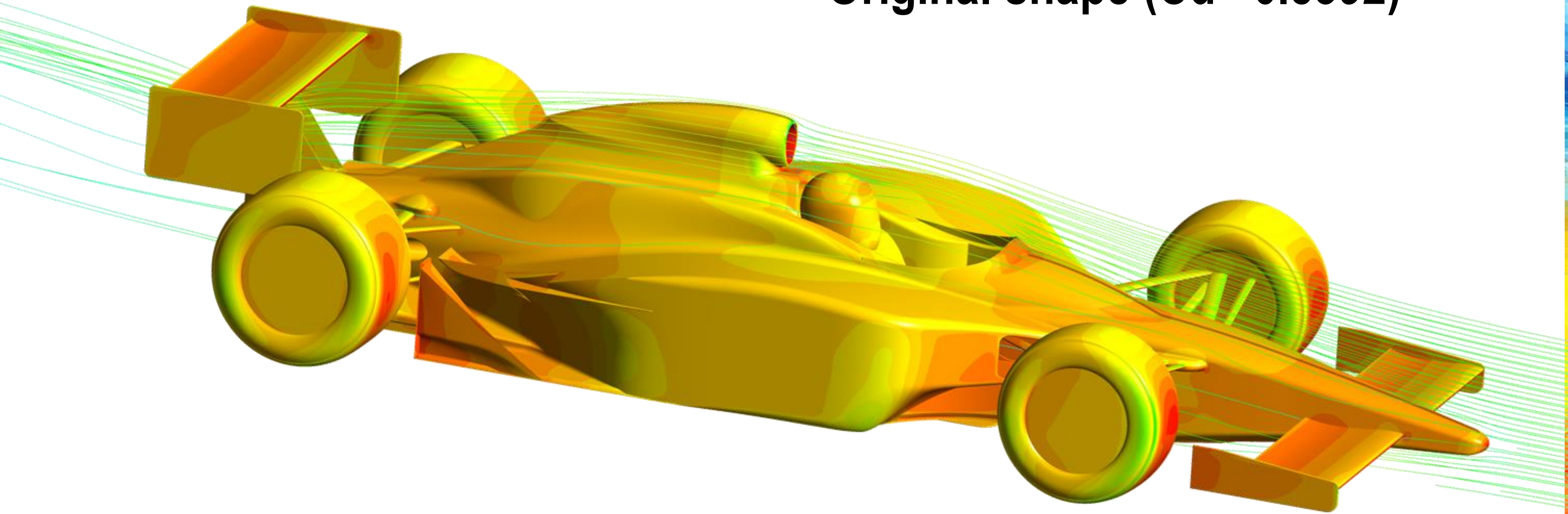


Optimized shape (Cd= 0.5343)



Drag analysis of a dallara Indy car

Original shape (Cd= 0.5392)



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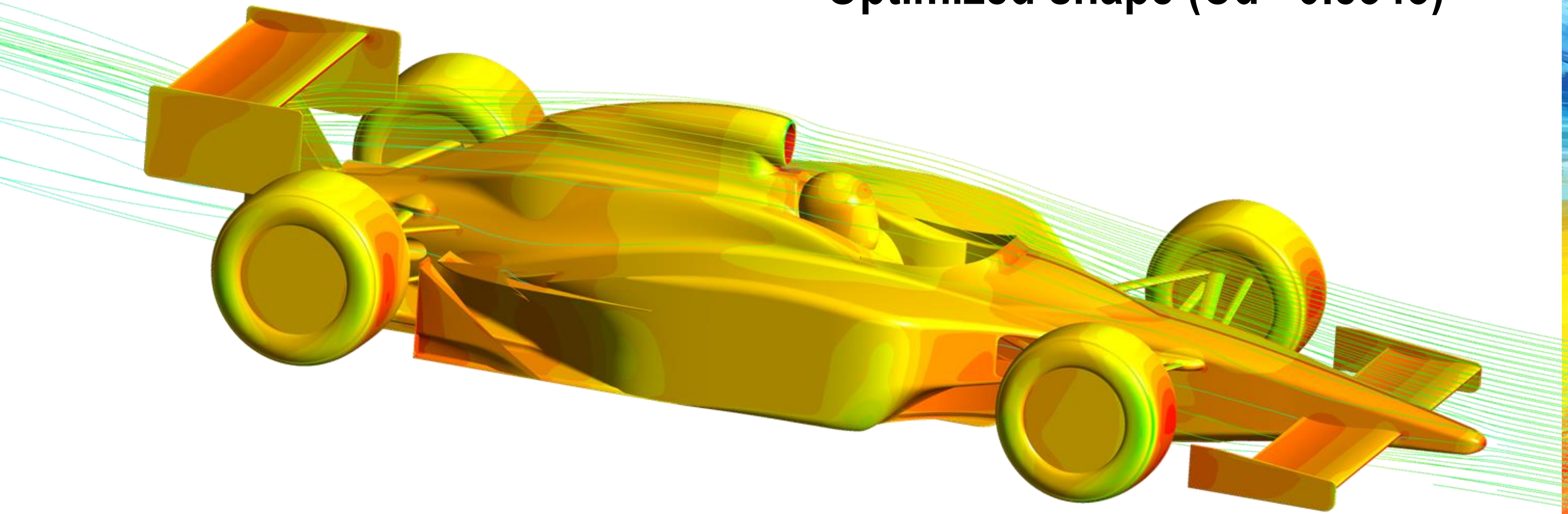

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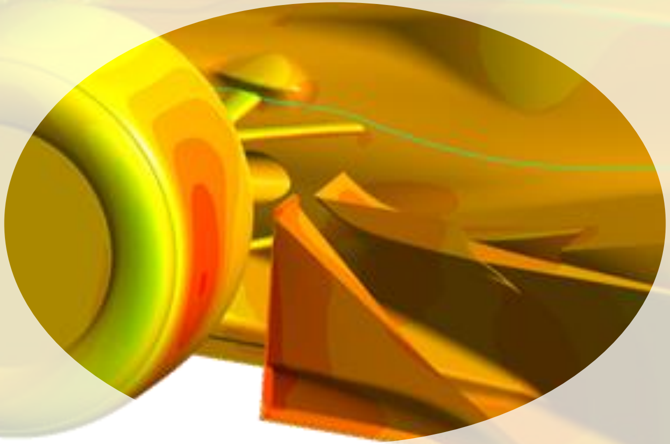

Drag analysis of a dallara Indy car

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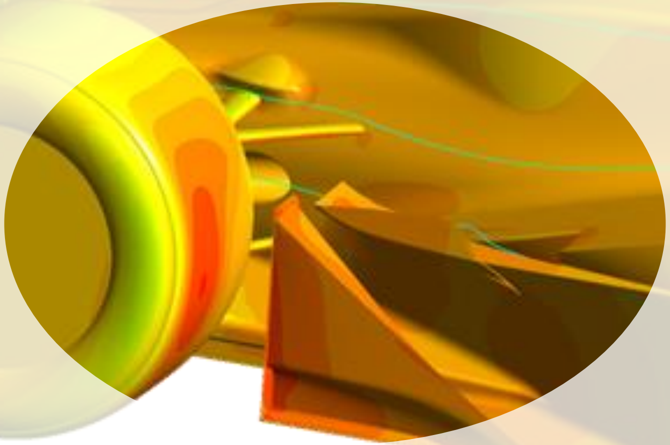

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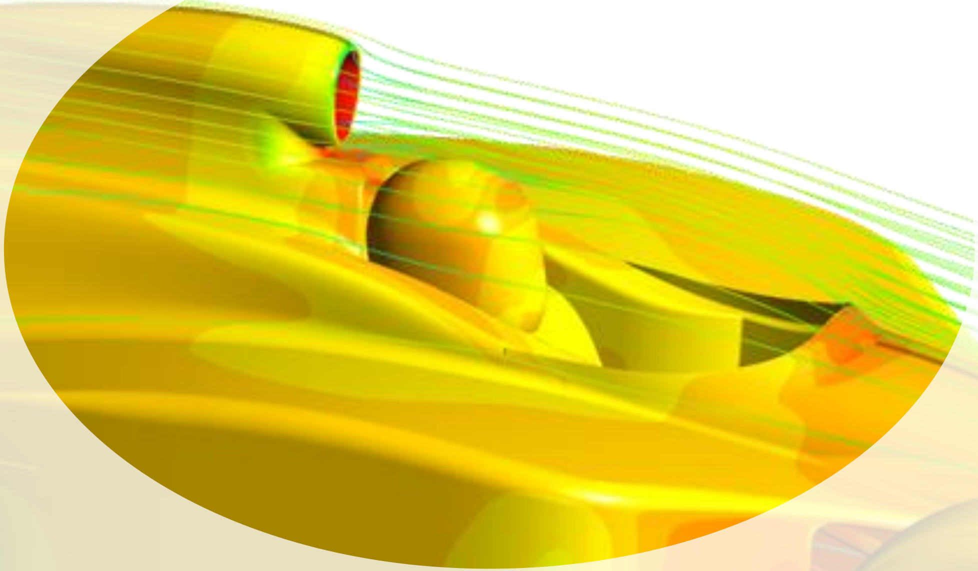

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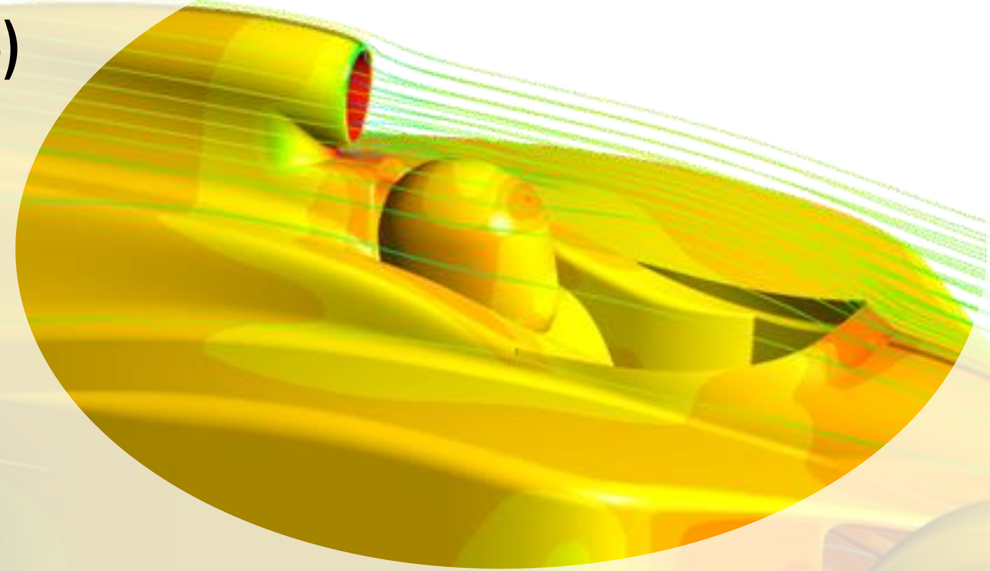

Conclusions

- There is a need for advanced tools to get as more information as possible from high fidelity CFD
- When **shape sensitivities** are available (adjoint solution) we can compute derivatives of performance vs. parameters
- In this study we presented **(rbf-adjoint-interactive)** a new tool based on Ansys Fluent, and RBF Morph that allows to predict the effect of shape on performance **without** the need of a new **CFD computation**
- The proposed method was applied to reduce the aerodynamic drag of a **Dallara Indy Car** acting on the windshield and on the rear wheel deflector gaining a **0.49 drag points**

Thank you!

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