DALLARA AUTOMOBILI

Two-way coupled aeroelastic analysis of a Dallara Le Mans prototype car

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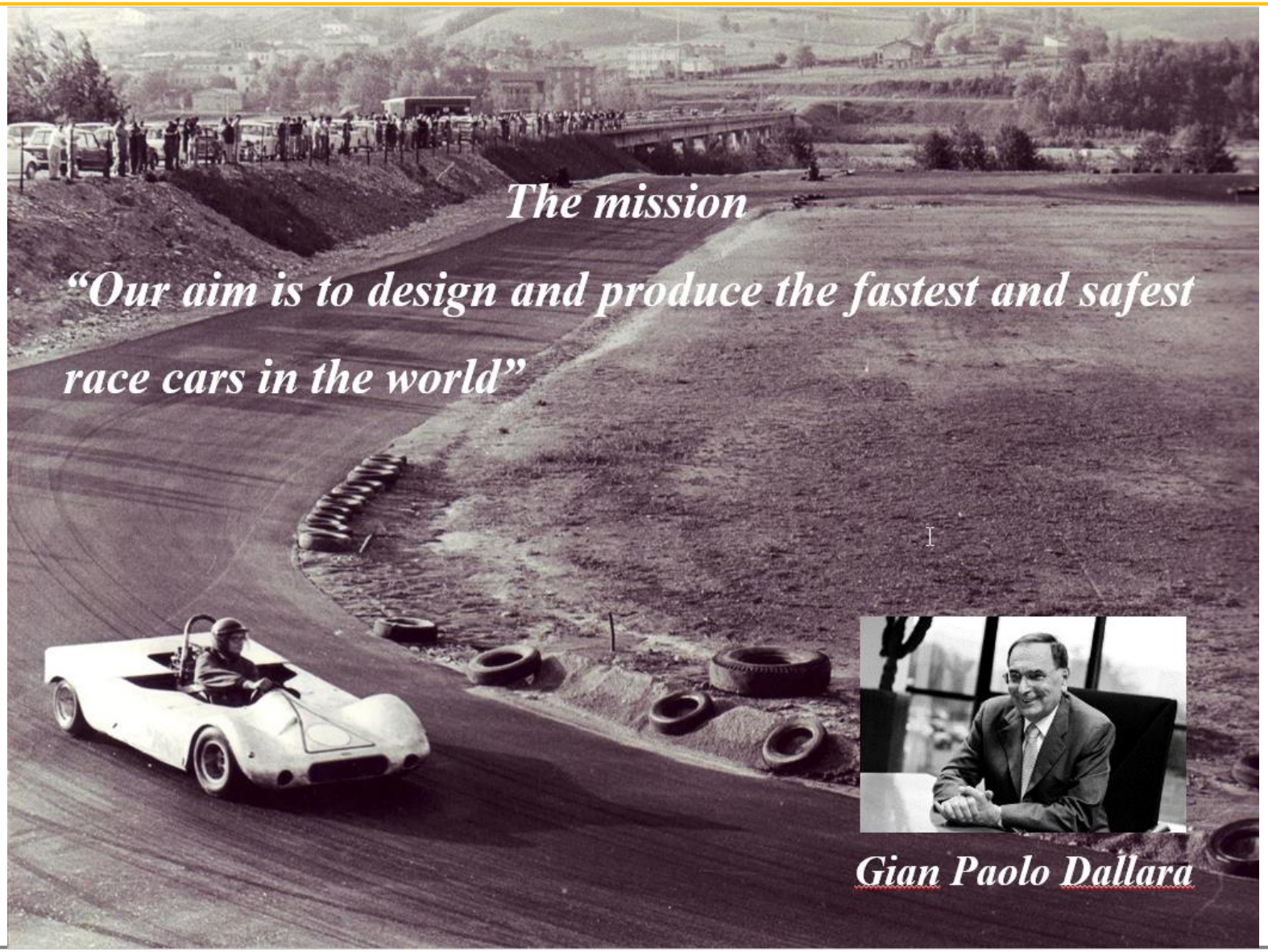

The mission
"Our aim is to design and produce the fastest and safest race cars in the world"
Gian Paolo Dallara

Dallara Group

dallara AUTOMOBILI

VARANO DE' MELEGARI, PR

TOTAL AREA: 12.000 SQM

ENGINEERING & MANUFACTURING

dallara FABBRICA

VARANO DE' MELEGARI, PR

TOTAL AREA: 2.300 SQM

MANUFACTURING

dallara ACADEMY

VARANO DE' MELEGARI, PR

TOTAL AREA: 2.700 SQM

EDUCATION & EXHIBITION

dallara COMPOSITI

COLLECCHIO, PR

TOTAL AREA: 7.000 SQM

MANUFACTURING

dallara USA

SPEEDWAY, INDIANA

TOTAL AREA: 11.200 SQM

ENGINEERING & MANUFACTURING

Products

Championship


IndyCar


LMP1


LMP2


Formula 2


Formula 3


Formula E


Super Formula


GP3


Indy Lights


RS01

Consultancy


Haas Formula 1 Team


Cadillac DPi


Bugatti Chiron


Lamborghini Aventador


Lamborghini Huracan GT3


Lamborghini Huracan Supertrofeo

Bugatti Vision Gran Turismo


Alfa Romeo 4C

Dallara Stradale

Core Competencies – Full Vehicle

LIGHTWEIGHT DESIGN & STRUCTURAL OPTIMIZATION

HOLISTIC PERFORMANCE SIMULATIONS

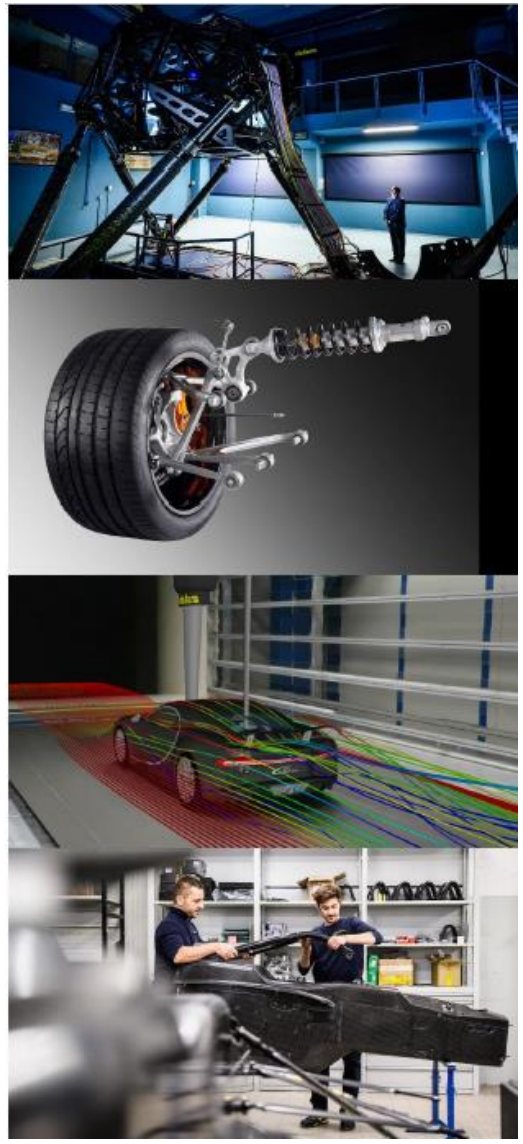
- Vehicle dynamics
- Passive and Active Cooling Systems
- ICE & Electric Power Train

AERODYNAMICS

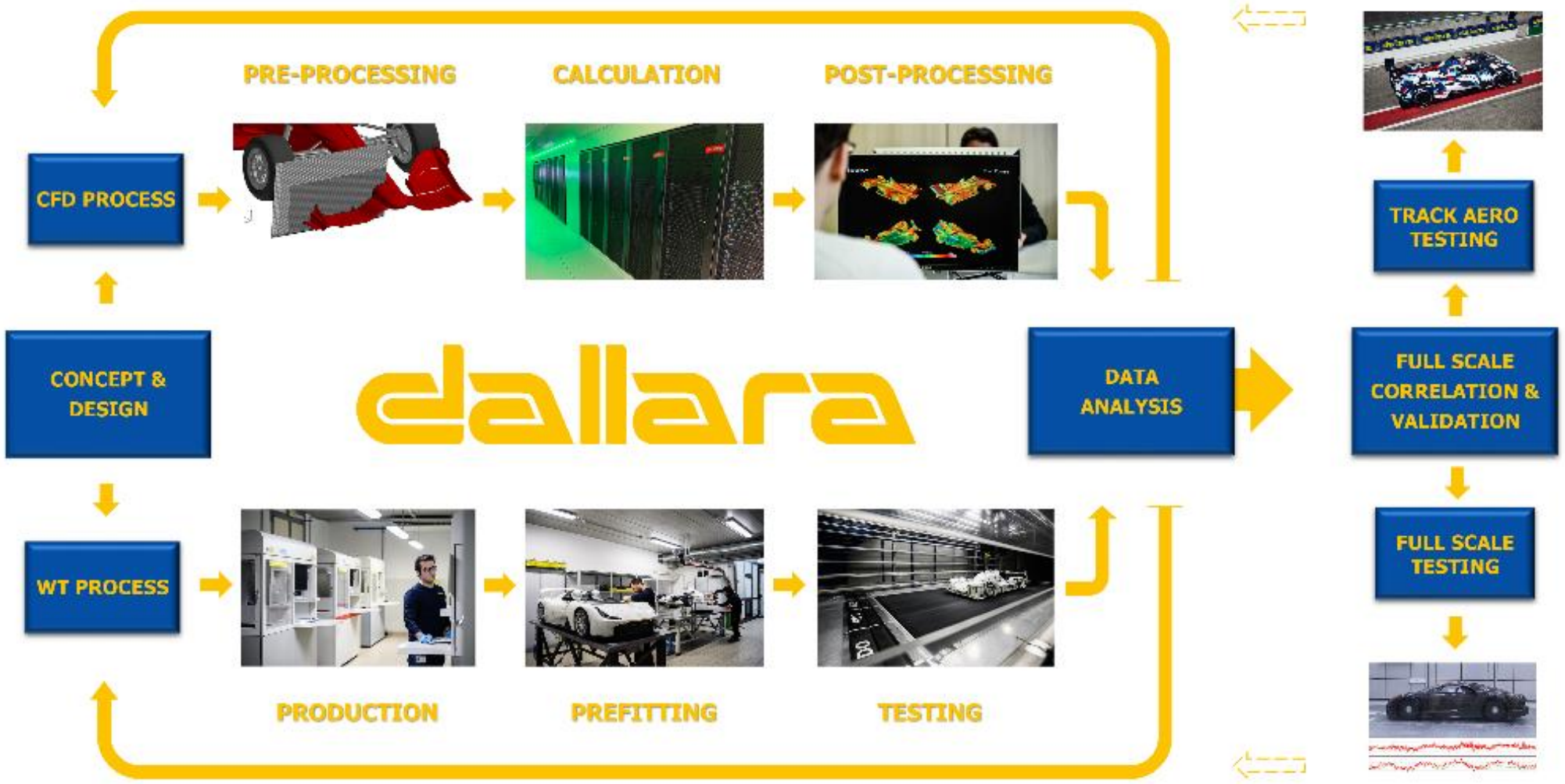
ELECTRONIC ARCHITECTURE & DEVELOPMENT

PRODUCTION & ASSEMBLY

INDOOR & FULL VEHICLE OUTDOOR TESTING



Dallara Aerodynamic Development Process



CFD Tools

The CFD tools are deeply involved in the aerodynamic application for racing car, automotive development, combining a great potential related to the HPC innovation and mathematical models evolution with time and cost control.

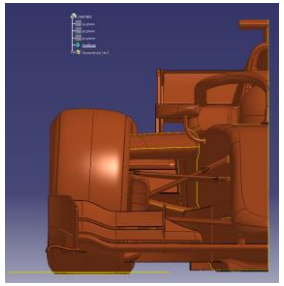
Fields of application: Racing Motorsport, Automotive, Motorbike and Bike, Aerospace, Food Engineering.

Overall Numbers:

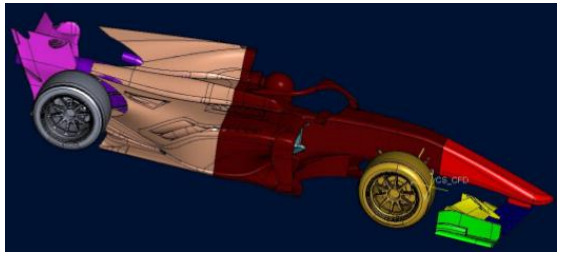
- **Over 500 Teraflops** of CFD computational capacity on premises.
- **14 Dedicated servers** for pre and post-processing phases.

CFD Fully Automated Process

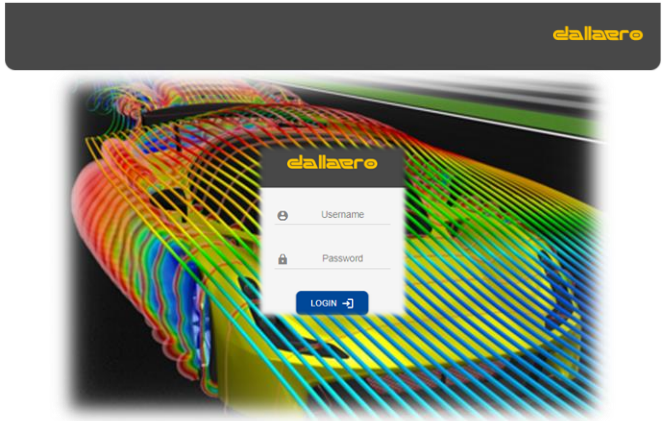
CAD Design

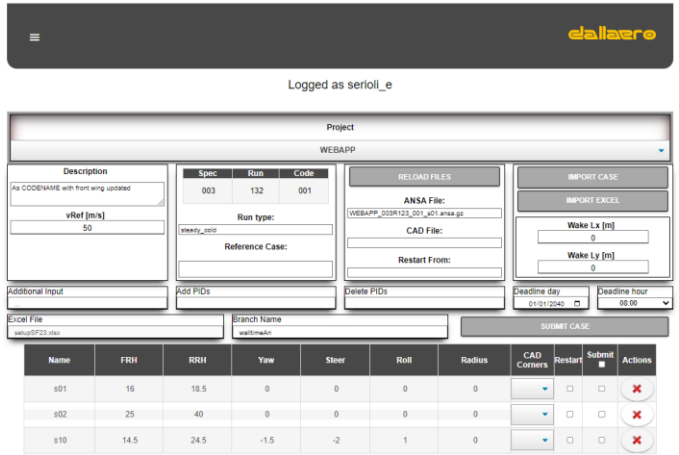


CONCEPT AND DESIGN
CREO PTC and CATIA,
PID splitting



CFD Process Management





CFD «As a Service» with a Dallara-made application web-based for:

- Automatic CFD process submission available for Aero Development
- Custom Post-Processing integrated tools

PRE – PROCESSING
Beta Cae ANSA + Ansys FLUENT MESHING

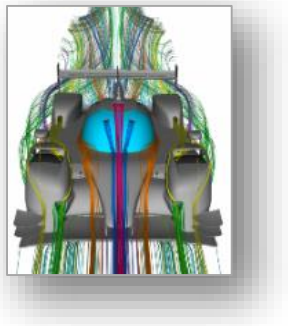
SET UP & RUN
Ansys FLUENT SOLVER

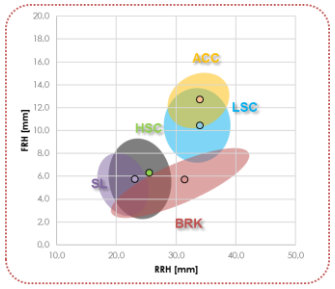
POST – PROCESSING
Kitware PARAVIEW / Tecplot Inc FIELDVIEW / Ansys ENSIGHT

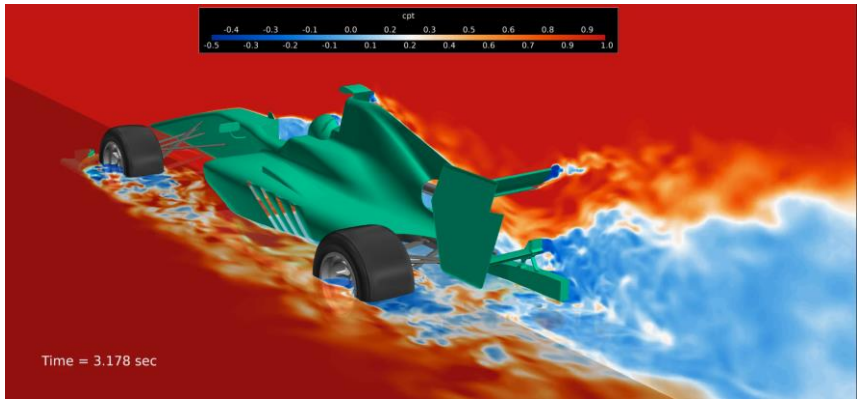
CFD Development and Applications

- **Aero performance development and Aero Map**

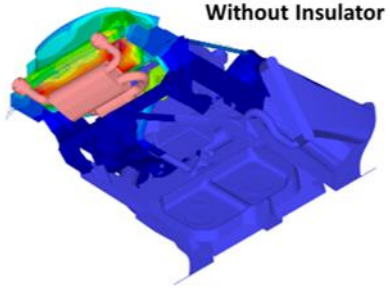
Aero performance development, Map points sensitivities (SL, CRN, BRK conditions etc), CRN in curved flow, steady and transient simulations.

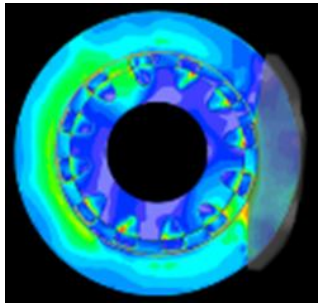






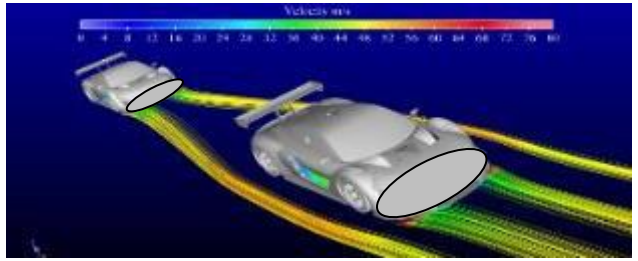
- **Thermal analysis: Cooling & Engine system** Radiator flow and under-hood simulations, Brake cooling

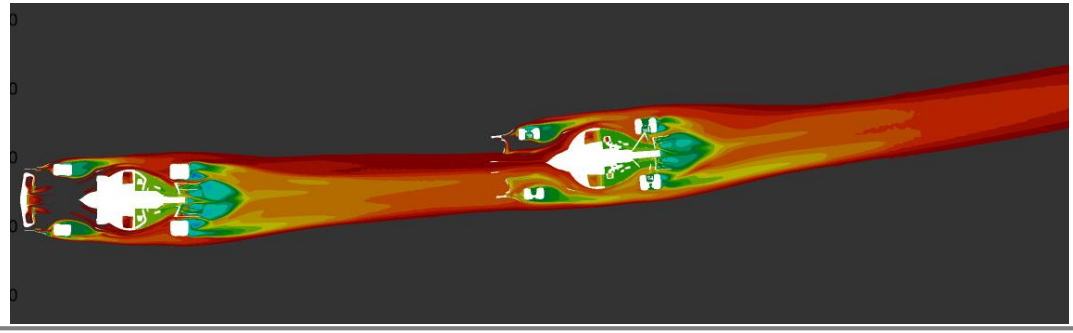




- **Wake Study: leading and following car**

Overtaking analysis (especially for mono-make series) and traffic situations in map points and curved flow layout



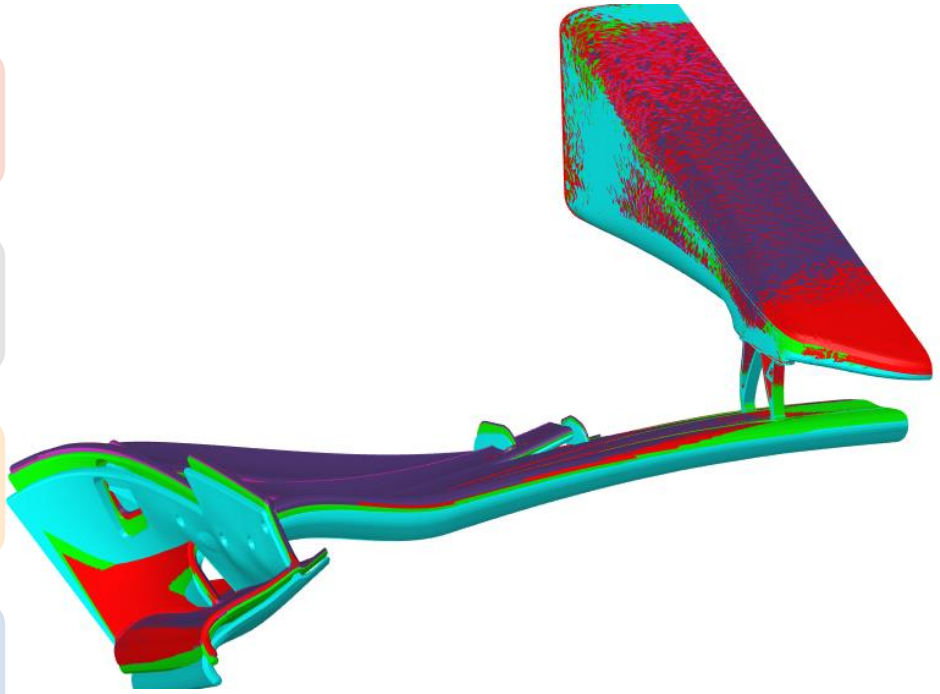


FSI – Fluid Structure Interaction

Looking for an extreme optimization of performance, Fluid Structure Interaction and multiphysics in general is a key achievement for car design and development.

FSI can lead the project in different stages:

Safety	guarantee the structural integrity with optimum weight, even with high loads levels experienced during the lap
Homologation	structural deformations are within the limits of regulation
Performance loss	deformation cycles can cause gradual degradation of performances (suspensions)
Performance development	developing aerodynamic performance by driving the structural deformation



FSI – Fluid Structure Interaction

Application SP1

Le Mans Prototype car is a challenging and up-to-date example to study FSI.

Activity targets:

1. Methodology investigation: POC on simplified geometry of SP1 for aero and detailed structural model
2. Industrial investigation: to be pursued once the method is been proven

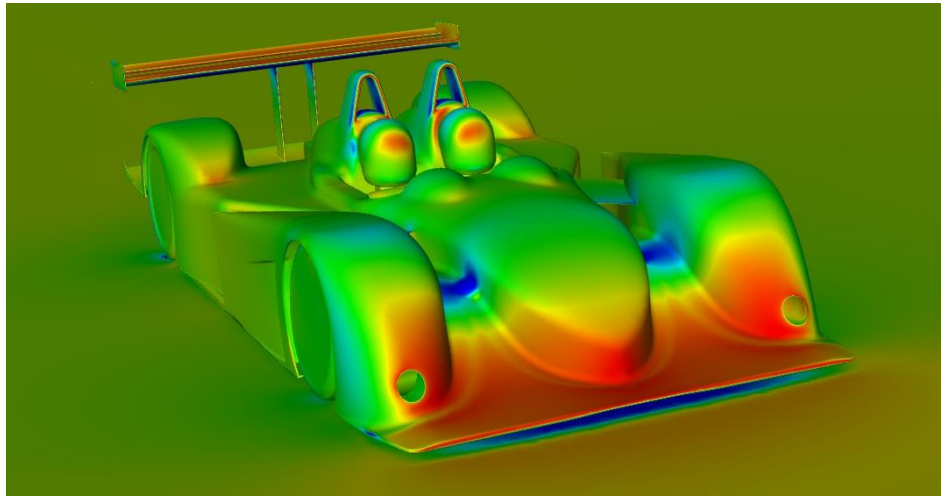
Current subject area: Front Splitter

The front splitter is one of the main driver of aerodynamic performance on LMP-like cars.

Methodology approach for FSI

- Modal (or Classical) Approach
- Two-Coupled Way Approach

High fidelity Fluid Structure Interaction analyses



CFD

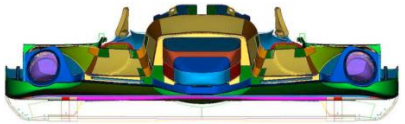
FEM

Main approaches for high fidelity FSI analysis:

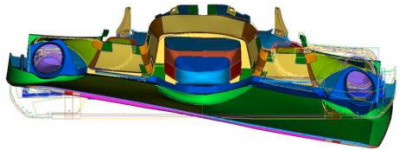
- **Modal approach** for aeroelastic analyses
- **2-way** (CFD-CSM) coupling

Modal approach for FSI

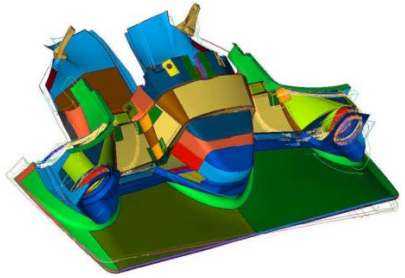
Mode 1



Mode 2



Mode 3



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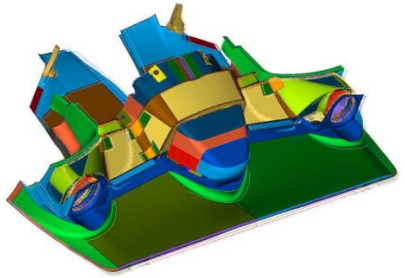
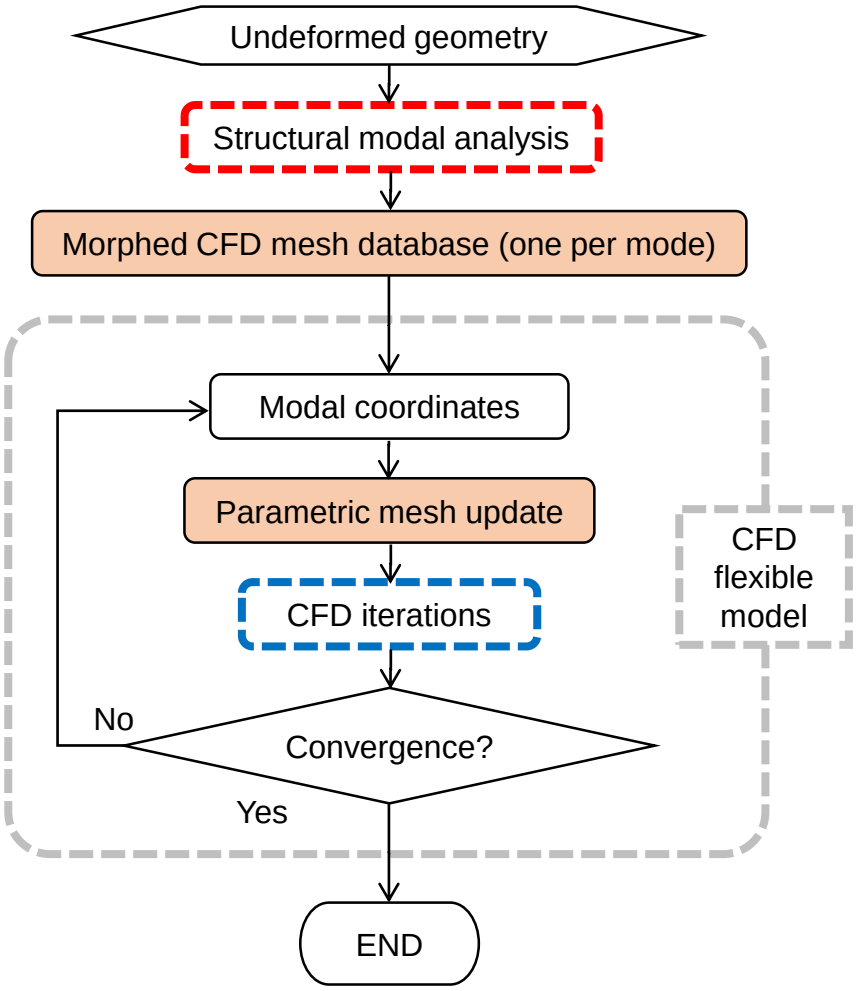
Mode k





Parametric mesh formulation

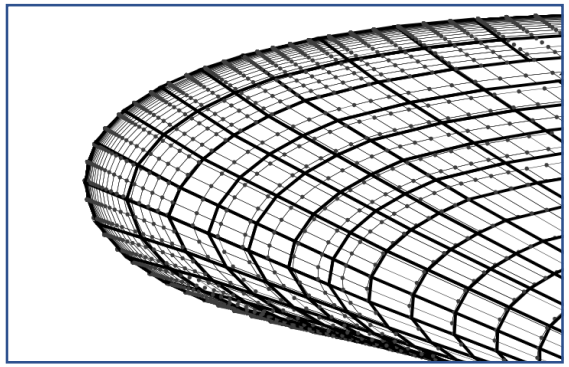
number of natural modes

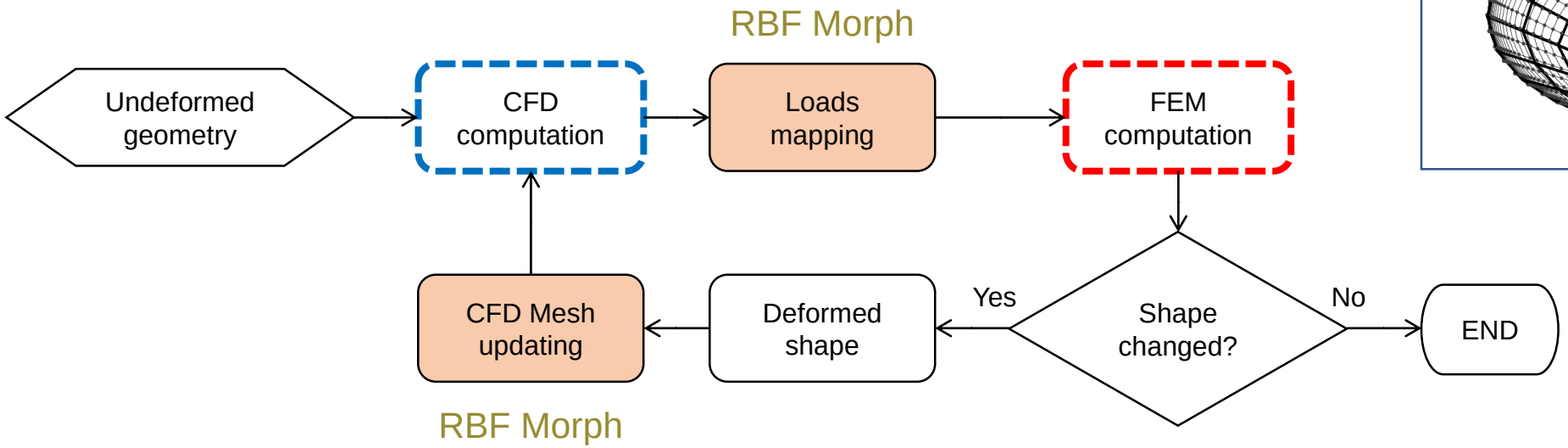
nodal modes displacement

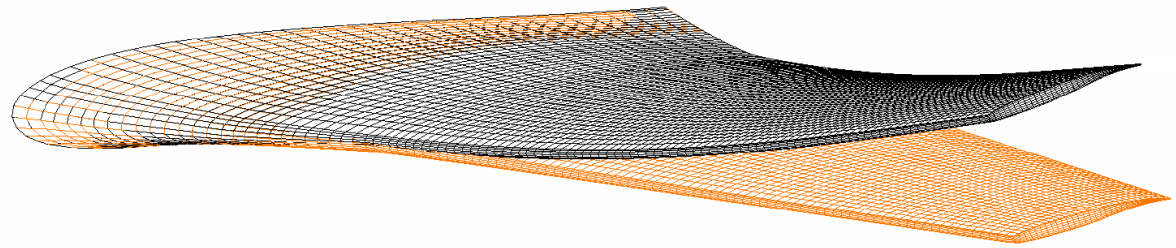
$$X_{CFD} = X_{CFD_0} + \sum_{i=1}^{k} q_i \Delta X_i$$

modal coordinate

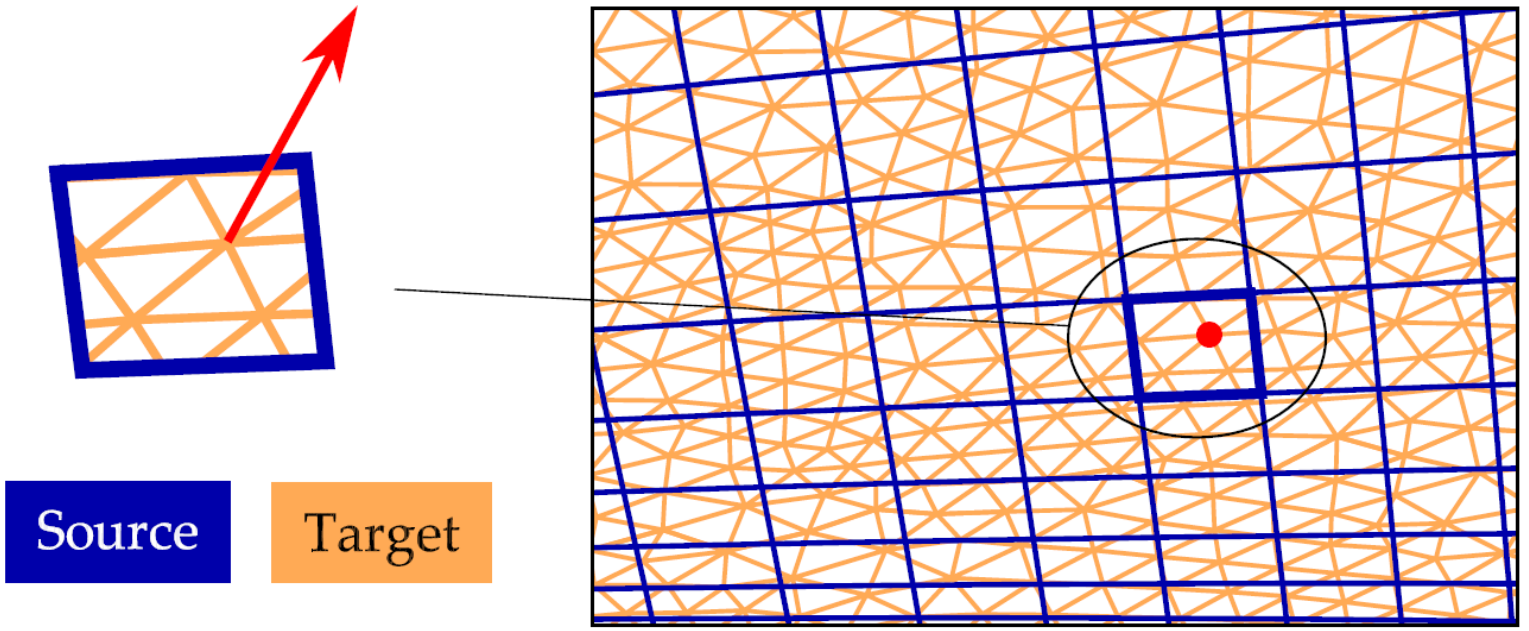
2 ways FSI procedure







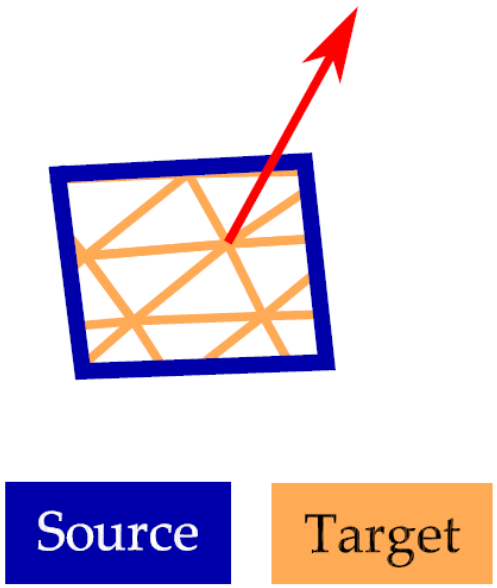
Loads mapping problem



Transfer solutions (scalar and vectorial) between non conformal discretization of a common domain

Solution mapping

- Source and target points sets are organized into **overlapping subdomains** using the Partition Of Unity (POU) method
- In each subdomain the **interpolation/extrapolation** problem is locally solved by **RBF** and local solutions combined using **blending functions**
- For each pair of corresponding subdomains a set of **correction coefficients** that locally force the **equivalence between the resultants** of the source and target subdomains are defined
- In the overlap regions correction coefficients from different subdomains are combined by using **blending functions**



Reference:
Biancolini, ME, Chiappa, A, Giorgetti, F, Groth, C, Cella, U, Salvini, P. A balanced load mapping method based on radial basis functions and fuzzy sets. *Int J Numer Methods Eng*. 2018; 115: 1411– 1429. doi: 10.1002/nme.5850

Load mapping errors

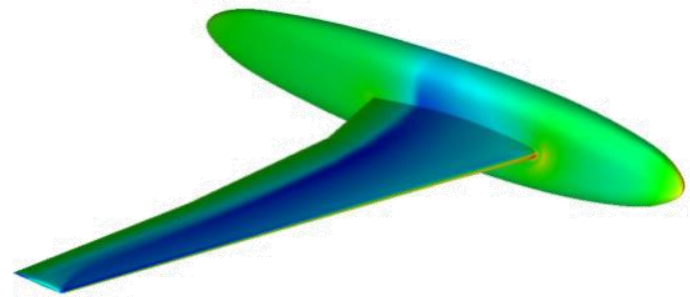
% errors on forces resultants components

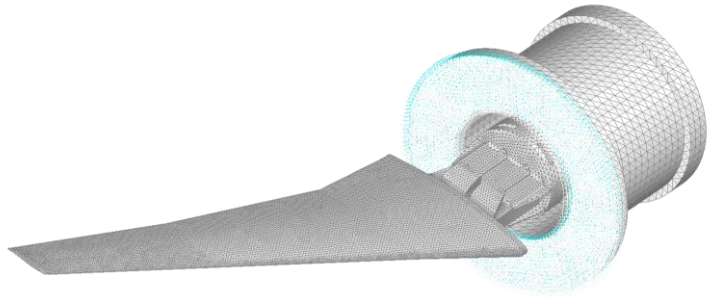
% ERROR	R_X [N]	R_Y [N]	R_Z [N]
NO CORRECTION	47.3%	6.6%	1.0%
CORRECTION	0%	0%	0%

% errors on moments resultants components

% ERROR	M_X [Nm]	M_Y [Nm]	M_Z [Nm]
NO CORRECTION	13.1%	13.8%	27.8%
CORRECTION	0.8%	0.11%	0.38%

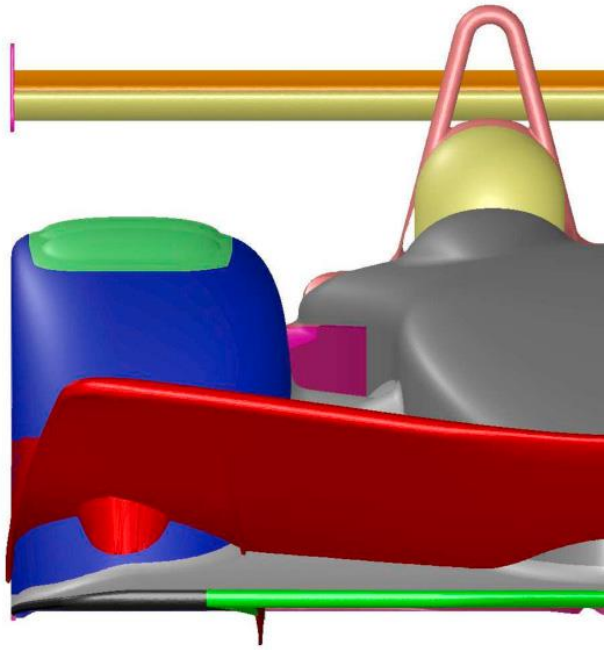
HiReNASD wing test case



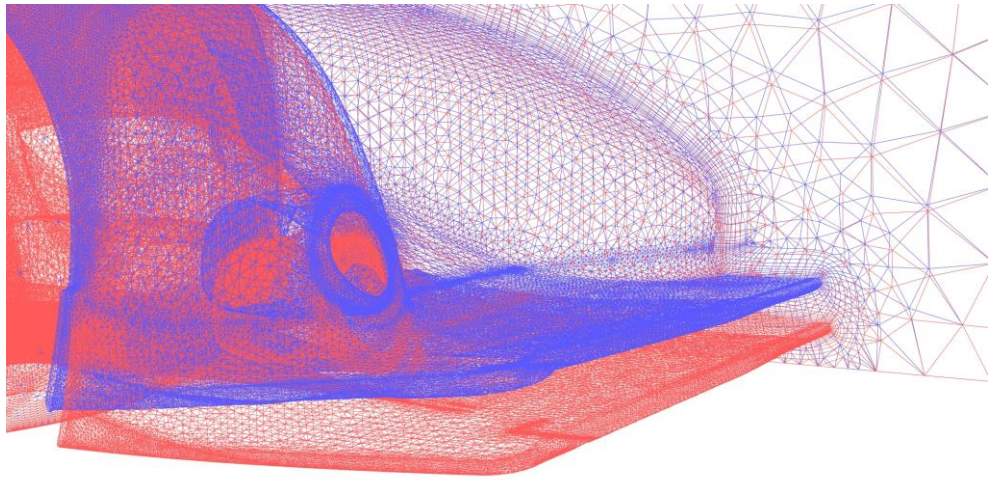


CFD Mesh updating by RBF mesh morphing

- **RBF mesh morphing setup acquiring the FEM nodes displacements as source points displacement**



Geometric deformation



CFD model

- RBF are recognized to be the **best mathematical tool** for mesh morphing.

Advantages and limits of the two approaches

Modal approach

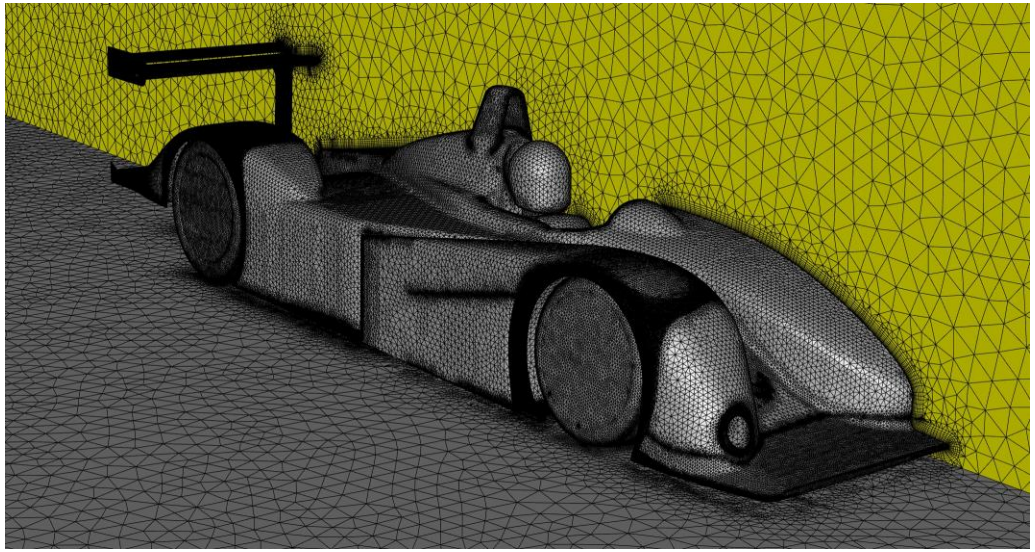
- Main advantages
  - simpler numerical
  - Higher robustness
  - Mesh adaptation during computation (faster solution)
- Limits
  - Linear problems only (small displacements)
  - Uncertainness on the modal base dimension

Coupled CFD-CSM

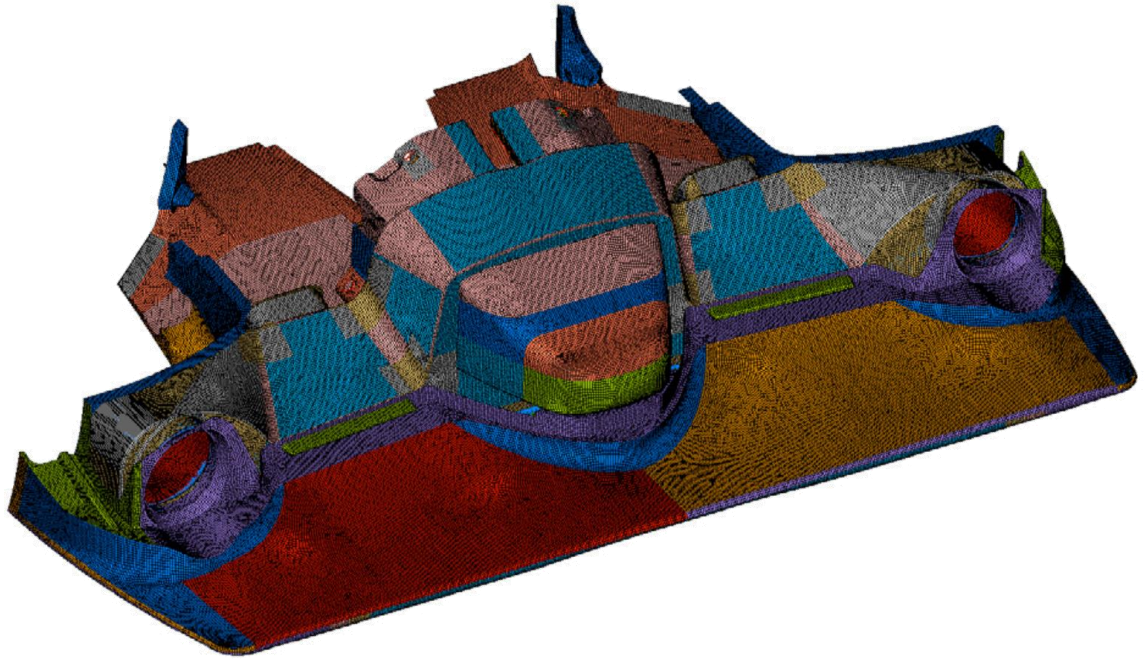
- Main advantages
  - High accuracy
  - Limitation of the problem to solve related only to the solvers capability
- Limits
  - More complex to setup
  - Computationally more expensive (extra costs related to the FEM analysis)

2-way FSI analysis of the Dallara LMP1

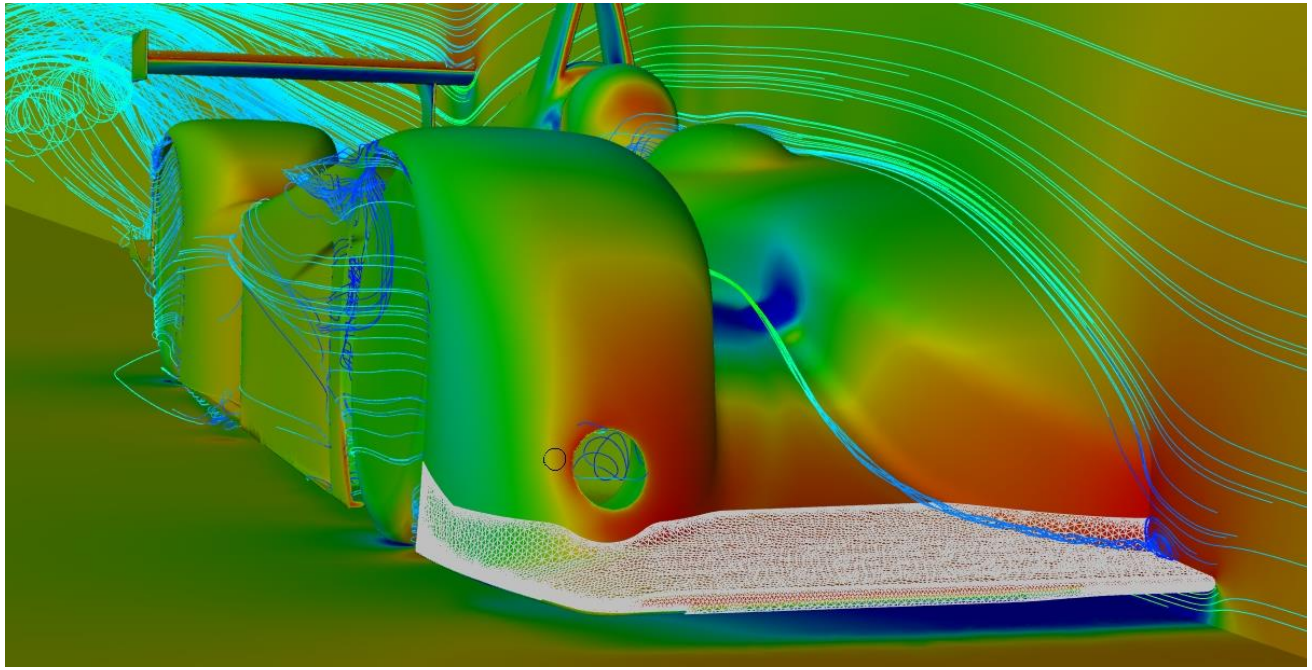
- 13 mill. hybrid unstructured CFD Computational
- half domain based on a simplified geometric model (no internal fluxes and no dynamic inlets)
- Domain 20 m height, extended 20 m upstream and 30 m downstream



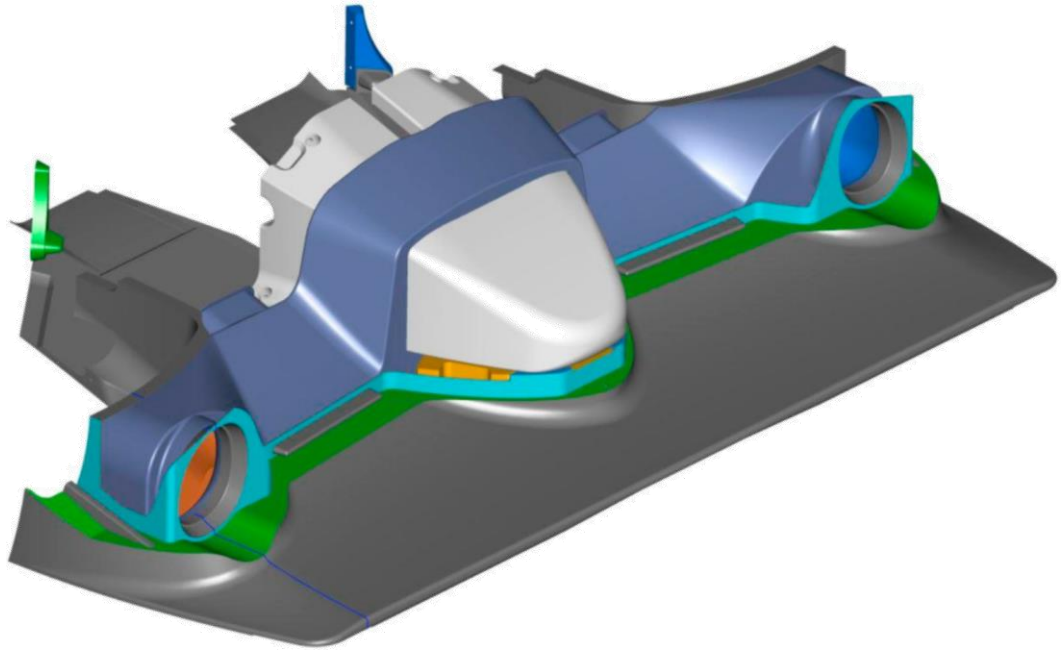
- FEM mesh composed of 400.000 shell elements



Mapping interface

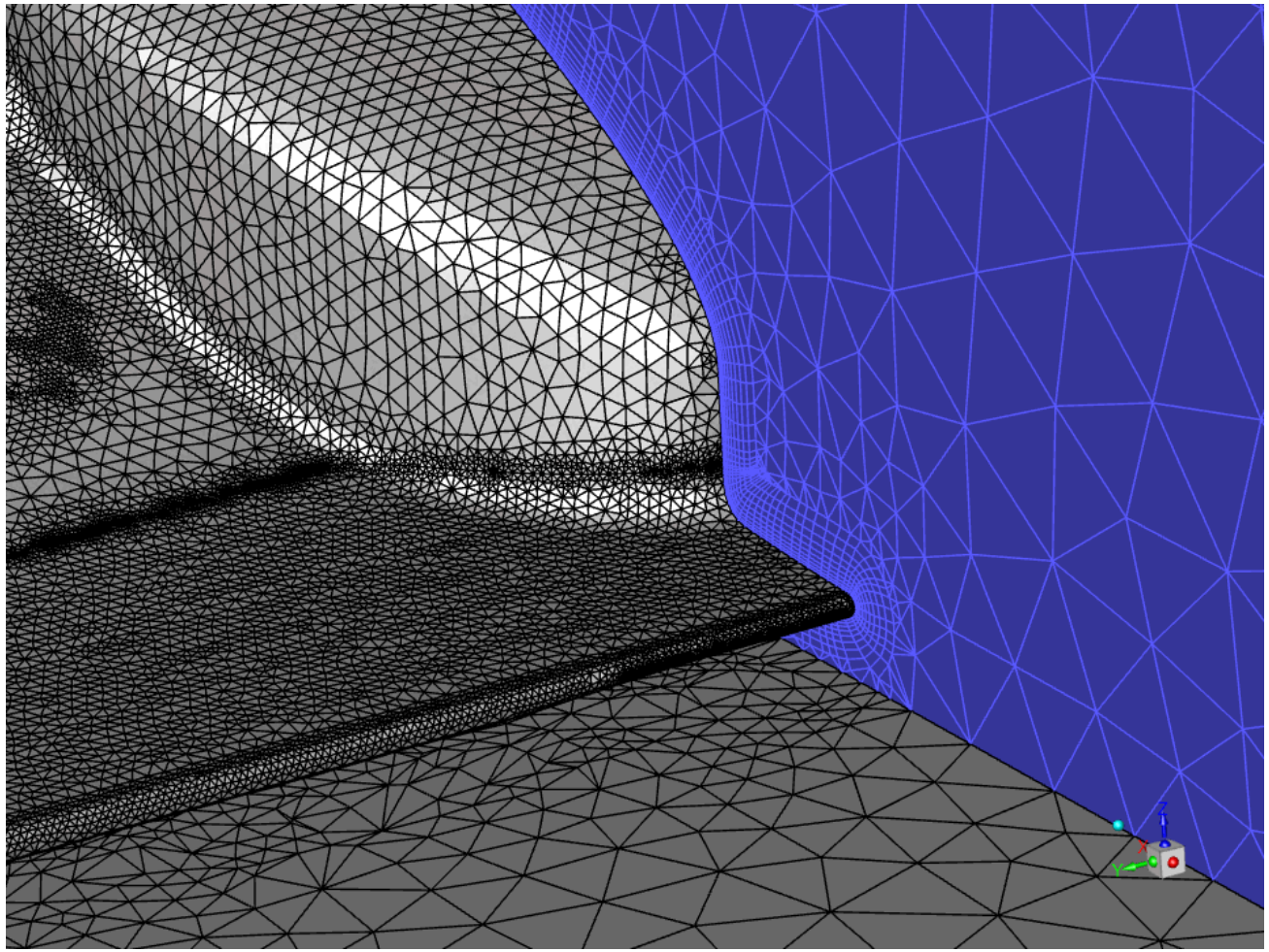


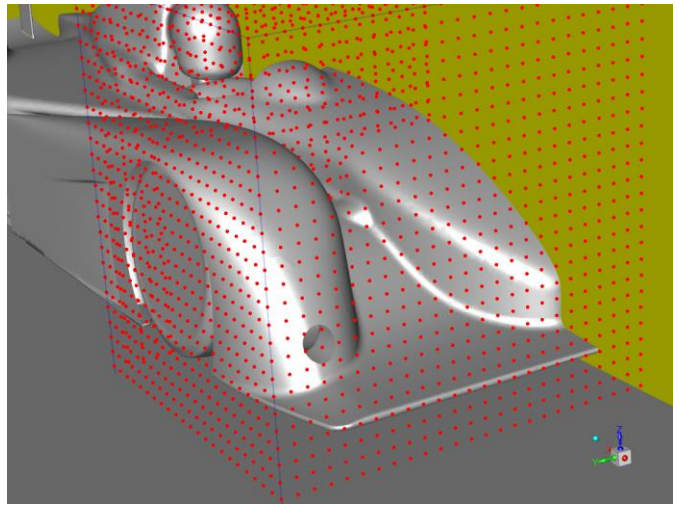
CFD model

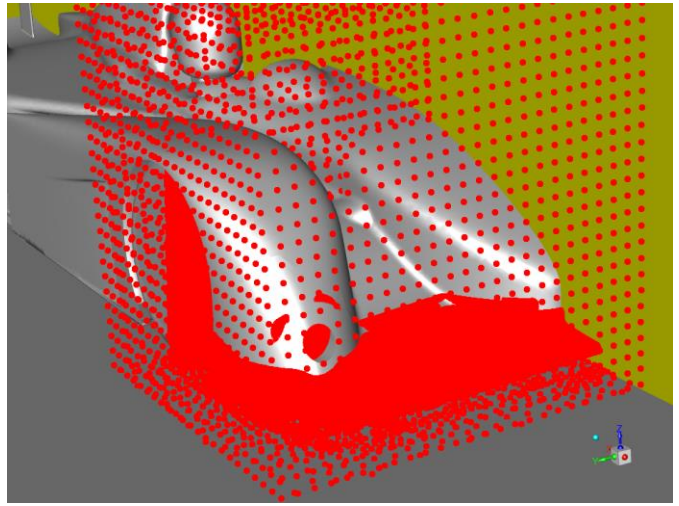


FEM model

RBF setup

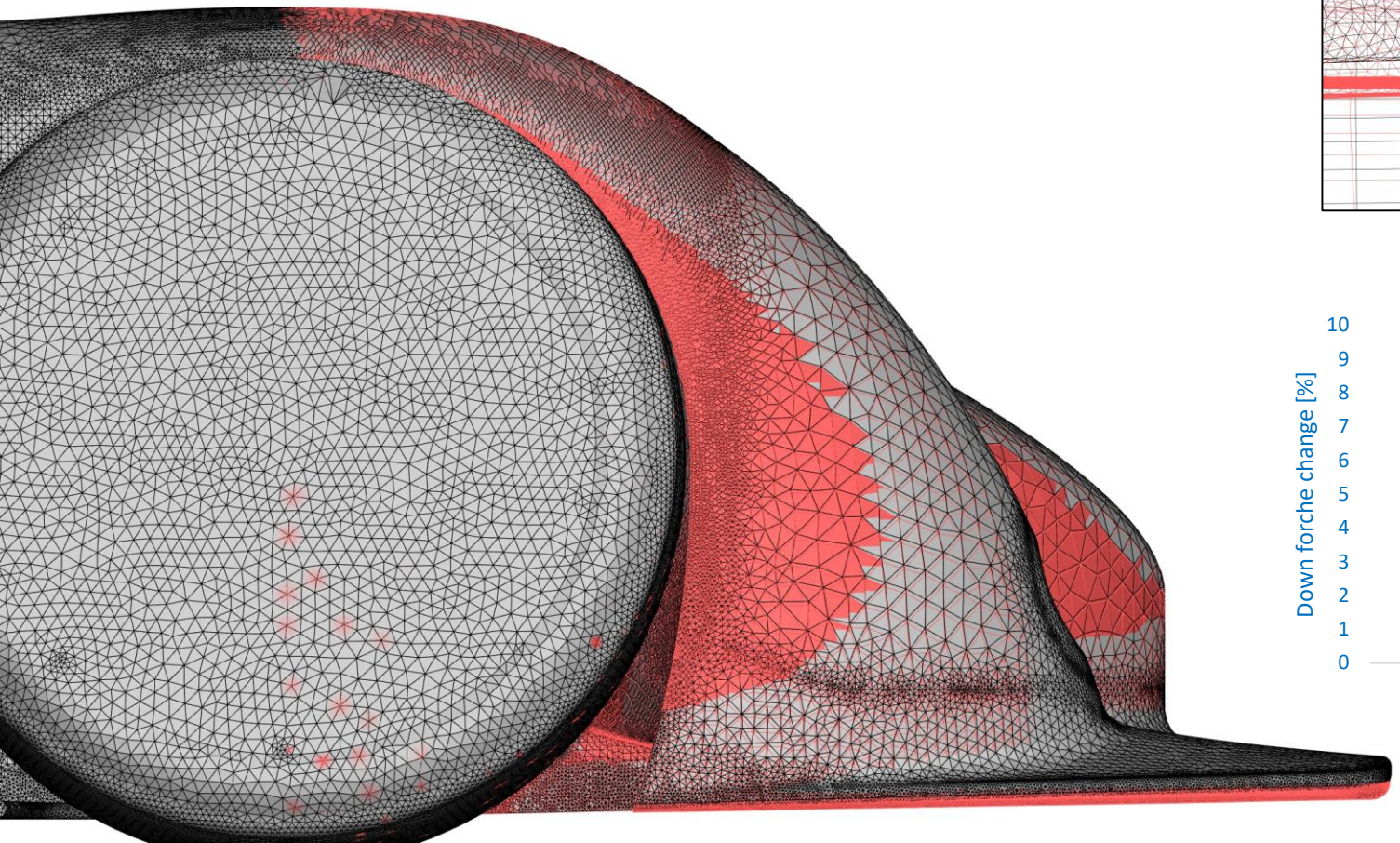


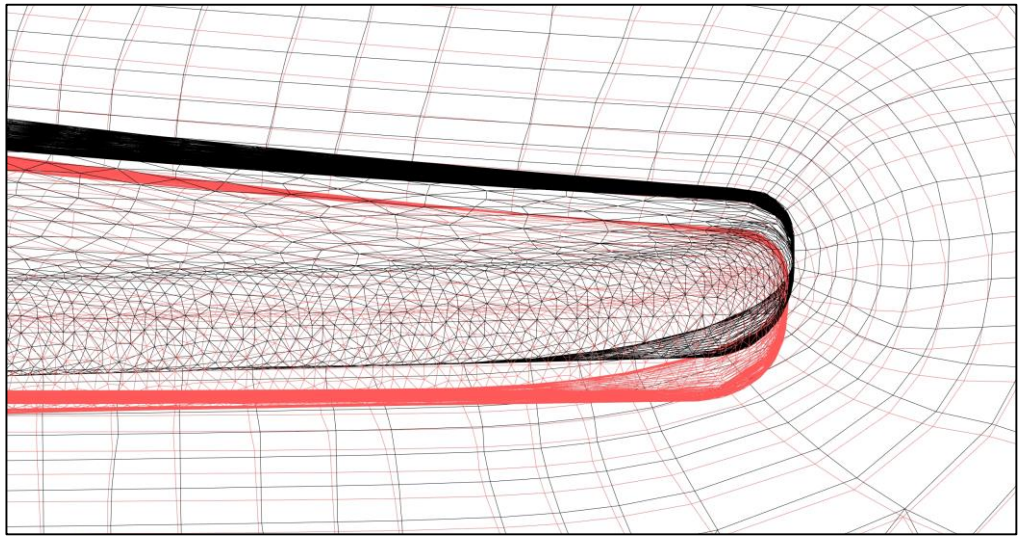


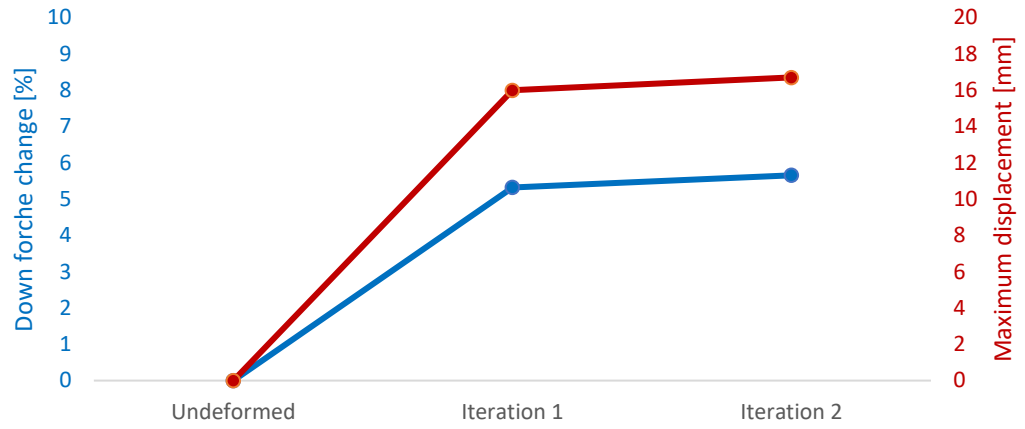


Solution of the CFD-CSM coupling

- Velocity = 250 Km/h







Conclusion

- FSI and Multiphysics in general is a key achievement for modern racing car development, where geometries are very complex, models are high demanding, solution should be highly accurate.
- In this study we presented RBF Morph as driving tool for the FSI two-way coupled approach, with the already proved effectiveness of RBF Morph for the FSI modal approach.
- RBF Morph proved to face the automotive challenge of FSI two-way coupled from a methodology aspect, matching the FEM model displacement with the Aero loads mapping.
- The proposed method was successfully applied to study the maximum displacement and performance deterioration of a Dallara Le Mans Prototype car (SP1), simplified Aero model, showing 17mm maximum displacement and 5% loss in front splitter downforce.
- Next step: *Industrial investigation: to be pursued once the method is been proven*

Many thanks for your kind attention!

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