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Optimization Procedures in a Car Design: CFD and Multibody applications

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Contents

BACKGROUND OF THE PROBLEM

THE INCREASING PERFORMANCE REQUIREMENTS AND THE ECONOMICAL PRESSURE TO INCREASE THE EFFICIENCY OF VEHICLES

Traditional design processes cannot longer be competitive

Current practice is to move the design of complex equipments away from a process involving a sequence of specialist departments

and

TO EMPHASIZE ITS MULTIDISCIPLINARY NATURE THROUGH THE USE OF *INTEGRATED PRODUCT TEAMS*

These commercial trends, together with the immense volume of design, manufacturing and maintenance data inherent to complex modern equipments

DEMAND FOR A HEAVILY COMPUTERIZED ENVIRONMENT

Aerodyamics

The aerodynamic design plays a crucial role in the development phase of new automotive configurations

The aerodynamics aspects are characterised by a strong intrinsic complexity, in particular for the strong interaction with the stylist group

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The aerodynamics designer needs as much aids as possible to strengthen the choices and discard unsuitable solutions

IN THIS CONTEXT, THE POSSIBILITY OF EVALUATING PERFORMANCES OF DIFFERENT CONFIGURATIONS IS OF UTMOST IMPORTANCE

PROBLEM:

THE HIGH NUMBER OF GEOMETRICAL PARAMETERS INVOLVED, WHICH ARE NECESSARY FOR DEFINING EACH CONFIGURATION

OPTIMISATION IN AERODYNAMICS

A systematic analysis taking into account the effects of all these parameters is very difficult, given the complexity related to

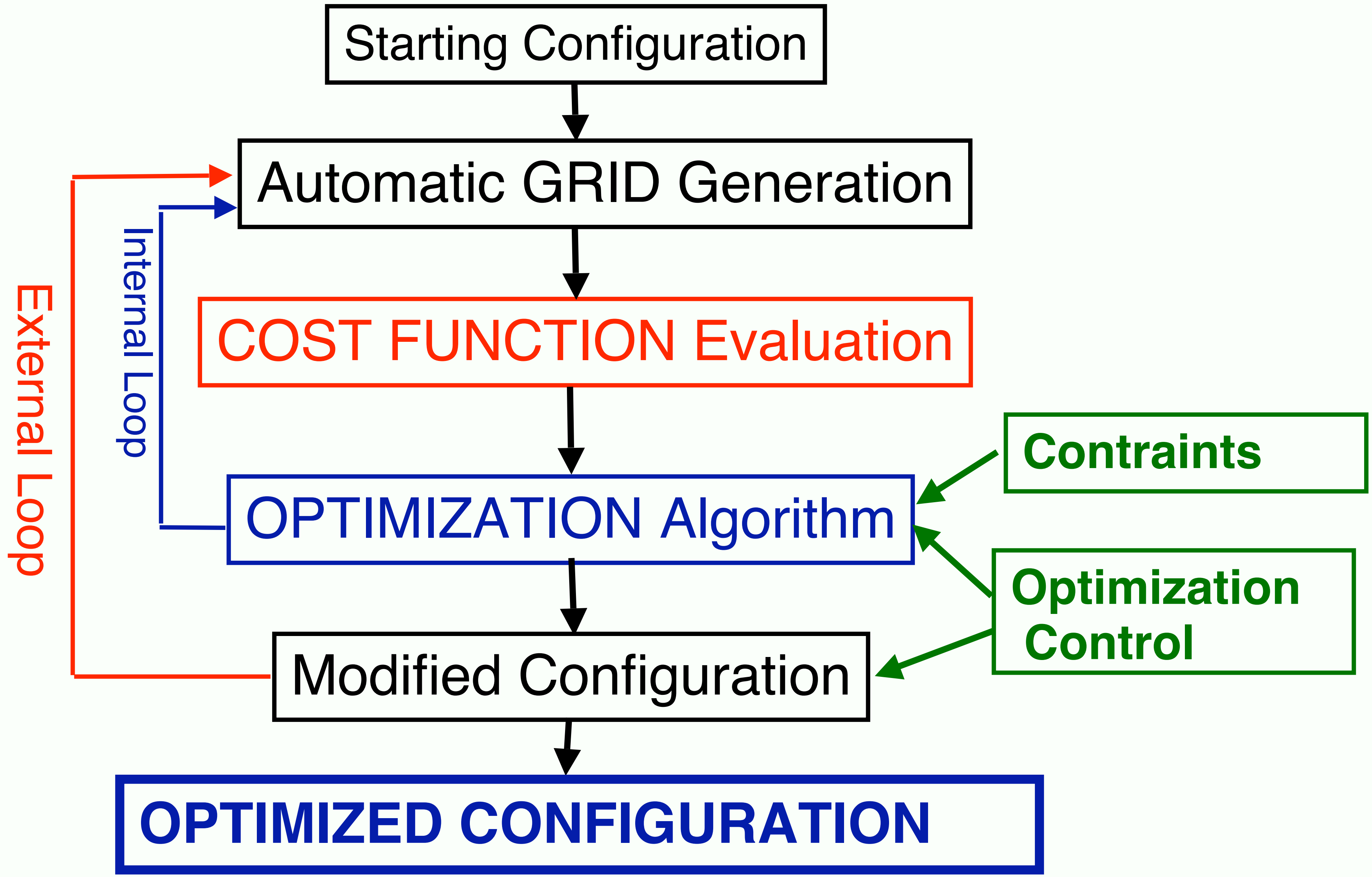
- **aerodynamic load evaluation**
- **assessment of mechanics, stylist, commercial and others requirements**

A direct numerical optimization technique may be satisfactorily used to find one's way through this complex survey

Whit this kind of aid the designer:

- **Has great flexibility in the choice of the design variables**
- **The problem may be addressed systematically**

Aerod. Optimisation: The Basic Scheme



The activity on the study of optimization has significantly increased over the last years, driven by:

- **Advances in computational methods**
- **Improvement in computer performances**

THIS IS PARTICULARLY SIGNIFICANT IN THE AERODYNAMIC DESIGN

Fundamental Aspects

From the analysis of the existing bibliography, in order to have:

- Improvement in the configuration performances
- Reduction in the "time to market"

TWO DIFFERENT ASPECTS can be highlighted

to improve the accuracy and the validity range of the results, to obtain a realistic representation of the aerodynamic flow

↓

Sophisticated flow solver

to obtain the results in short time

↓

Increased computational capabilities

Clearly, accuracy of the flow solutions and short computing time act in opposite directions

Fundamental Aspects (2)

In general we have procedures with:

- **High accuracy coupled to long processing time**

OR

- **Rapid time responses obtained with simplified aerodynamic solvers**

Different methodologies have been proposed to solve this classical accuracy-time dilemma, and analysed

- **“Mixed” optimisation algorithms**
- **Adjoint methods**

“Mixed” algorithms

They are discussed, for instance, in:

Lombardi G., Beux F., Carmassi S.
Aerodynamic Design of High Performance Cars: Discussion and Examples on the Use of Optimization Procedures
SAE transactions - Journal of Passengers cars: Mechanical System, 2002-01-2043, 2002, pp. 1950-1961.

where a description of the different optimisations algorithms are also presented

A good compromise between accuracy and time is obtained

Problem:
it is difficult and critical to define the criteria for the switch

Adjoint methods

They are discussed, for instance, in:

de' Michieli Vitturi M., Beux F., Lombardi G., Dervieux A.
Optimum Shape Design for Turbulent Viscous Flows Around Complete Configurations of 2D Flying Sails.
Journal of Computational Methods in Sciences and Engineering, Vol. 3, No. 3., 2003, pp. 347-359.

the technical strategy is to merge together CFD and numerical optimization

THIS PROCEDURE GIVES VERY GOOD RESULTS, BUT IT IS RELATED TO A SPECIFIC PROBLEM AND FLOW SOLVER

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NOT INDICATED FOR INDUSTRIAL APPLICATIONS

Aerodynamics Optimisation and the Car

The impact of aerodynamics optimisation procedures extends across many aspects of vehicle engineering

Fluid dynamic analysis, including heat transfer, is the basis of design for several aspects:

- **External shape**
- **Passenger comfort and climate control**
  - **noise reduction**
  - **Heating**
  - **ventilation and air conditioning**
- **Subsystems (such as windscreen de-icing)**

THE AERODYNAMICS OPTIMISATION IN FERRARI

General Aspects

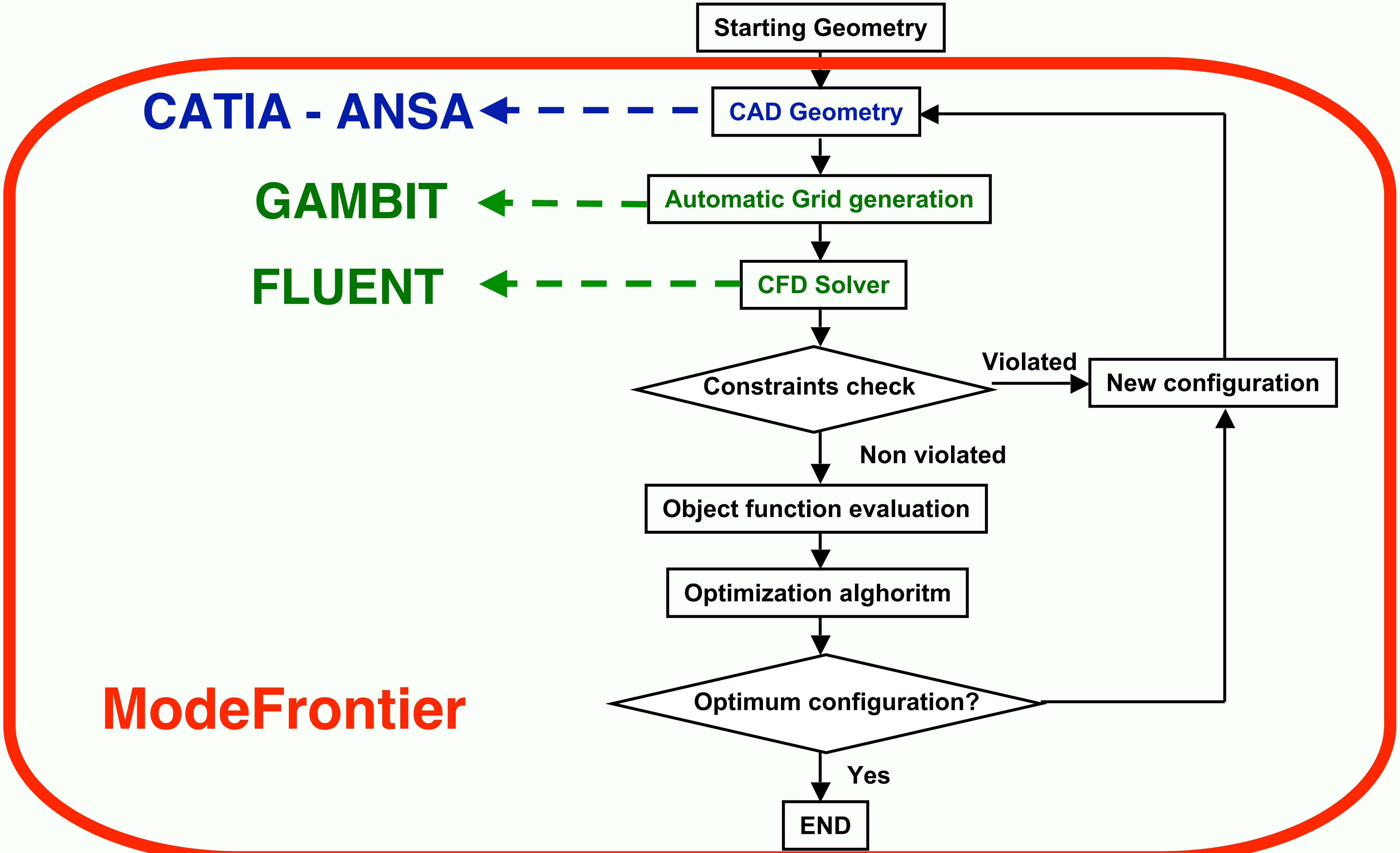
From the aerodynamic point of view the problem is related to the evaluation of lift and drag in incompressible flow, with a complex geometry characterized by extended zones of separated flow

In particular, the more important aspect is the capability to evaluate the small differences that occur in the aerodynamics forces for configurations characterized by small differences

an accurate method is necessary, and a RANS approach seems to be suitable

The SOFTWARE

Basically, a classic "black box" scheme is utilised



Geometry Representation

The optimisation procedure requires the geometry definition in a parametric form, in order to manage the geometry modification in an automatic way

but:

the number of parameters necessary for the car shape definition is very high (some thousand)

THIS IS ONE OF THE MORE CRITICAL POINTS OF THE OPTIMISATION PROCEDURE

Geometry Representation: Problems

the high number of parameters necessary for the car shape definition leads to two main problems:

1. **It is impossible to directly manage the geometrical parameters as design variables**
2. **The management of the parameters defining the general shape (the "volume" of the car) is completely different from the management of the parameters defining the "details" of the car**

Problem 1 (1)

Degrees of freedom for geometry update

The set of parameters is too large to be a good set of variables to be changed during optimization

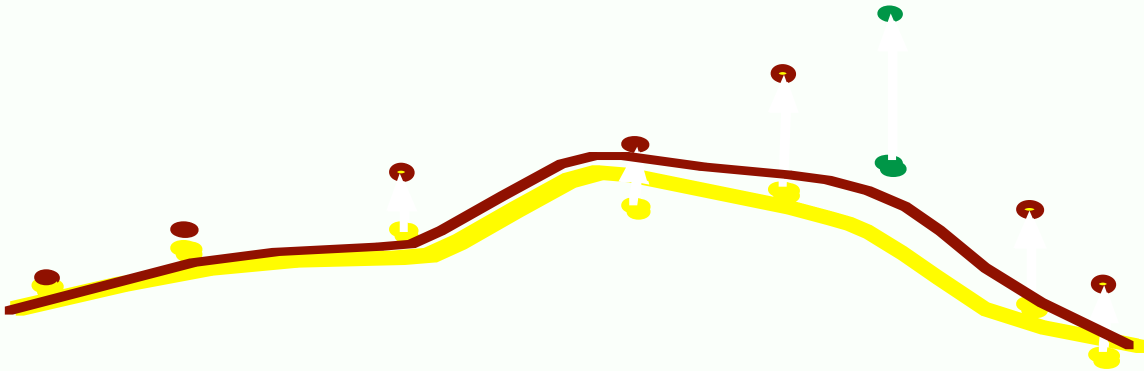
Moreover:

changing a single parameter induces modifications confined in local portions of the geometry, thus resulting in not acceptable shapes.

The solution has been the introduction of additional, fewer structures, which allow controlling the parameters and producing changes more extended over the car geometry

Problem 1 (2)

- Parameters
- Control point



The displacement of a control point produces different displacements of the parameters, depending on the relative distance

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- Reduced number of design variables
- Smooth surfaces

Problem 2

To solve these problems two different procedures are identified

the optimisation procedure is different when:

- **the optimisation of the "volumes" of the car is required**
- **the optimisation of a detail is required**

Optimisation of the "Volumes"

For the "volume" problem a procedure for the parametric definition of the car geometry was developed.
At the present, the external shape of the car, without details, can be satisfactory represented by means of some hundreds of parameters, and it is possible to make the optimisation procedure on the entire car, following the "standard" procedure

Lombardi G., Vannucci S., Ciampa A., Davini M.
The Aerodynamics of the Keel of America's Cup yachts: an Optimization Procedure
International Aerospace CFD Conference, Paris, June 2007.

The Optimisation of "Details"

In this case the problem appear quite different.
In fact, only a limited part of the geometry is involved in the modification

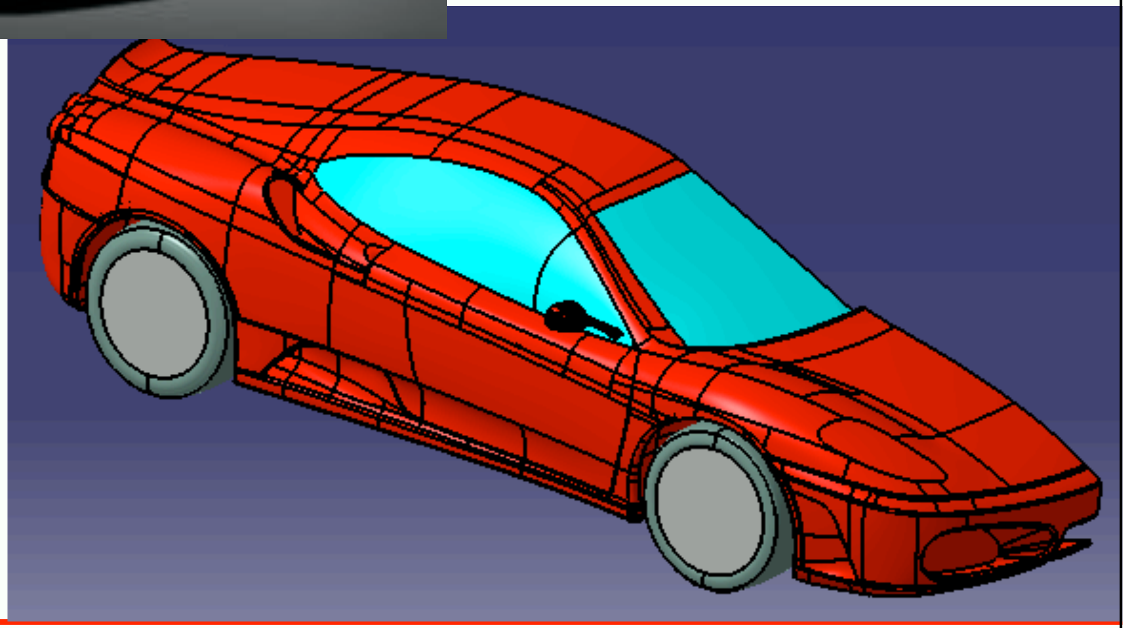
- **Only a small part of the geometry can be varied during the optimisation process**
- **Parameters defining the details under considerations can be usually used directly as design variables**

it was decided to approach the problem in a different way, following the procedure that will be described in the following example

EXAMPLE

Optimisation of the rear diffuser of the F430

The CAD model (general view)

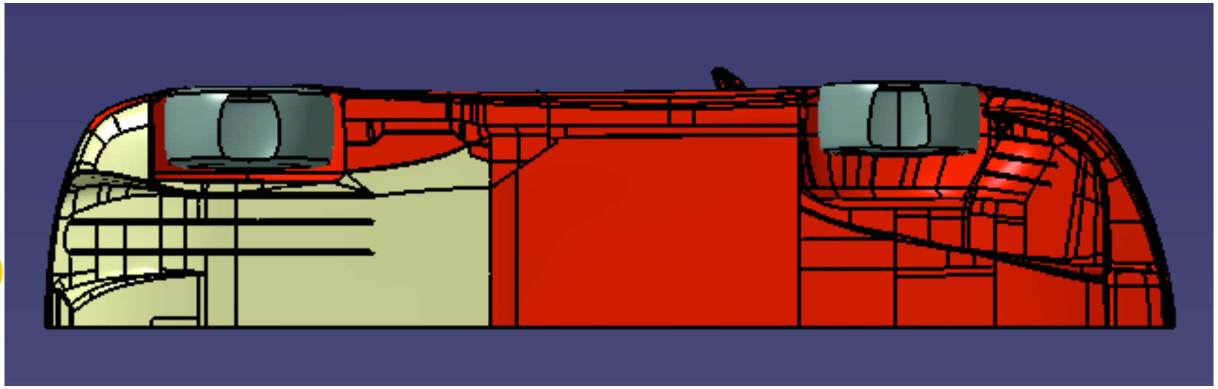


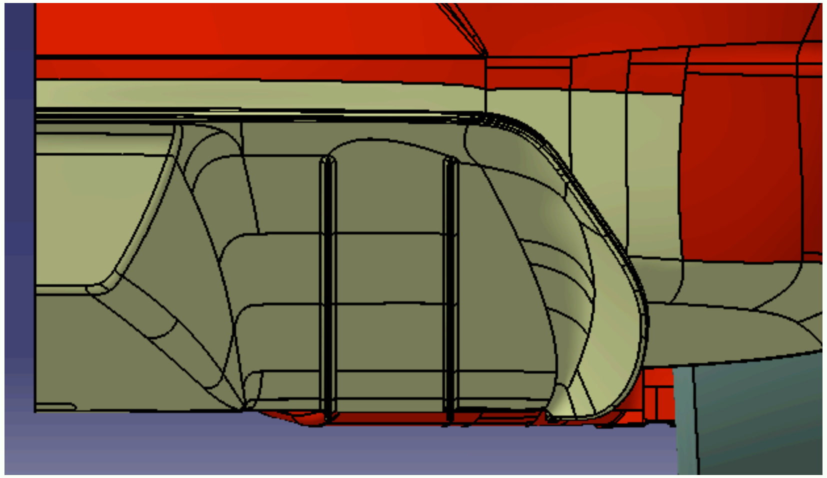
The CAD model (the lower side)

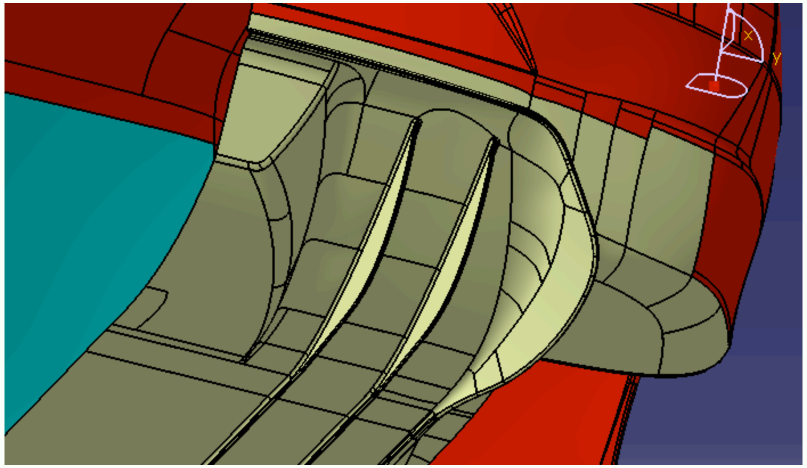
Because of the interest is focused on the rear diffuser, only a part of the geometry will be varied during the optimisation procedure

the CAD geometry is divided in two parts

- **the "fixed" part (red)**
- **the "detail" part (yellow)**







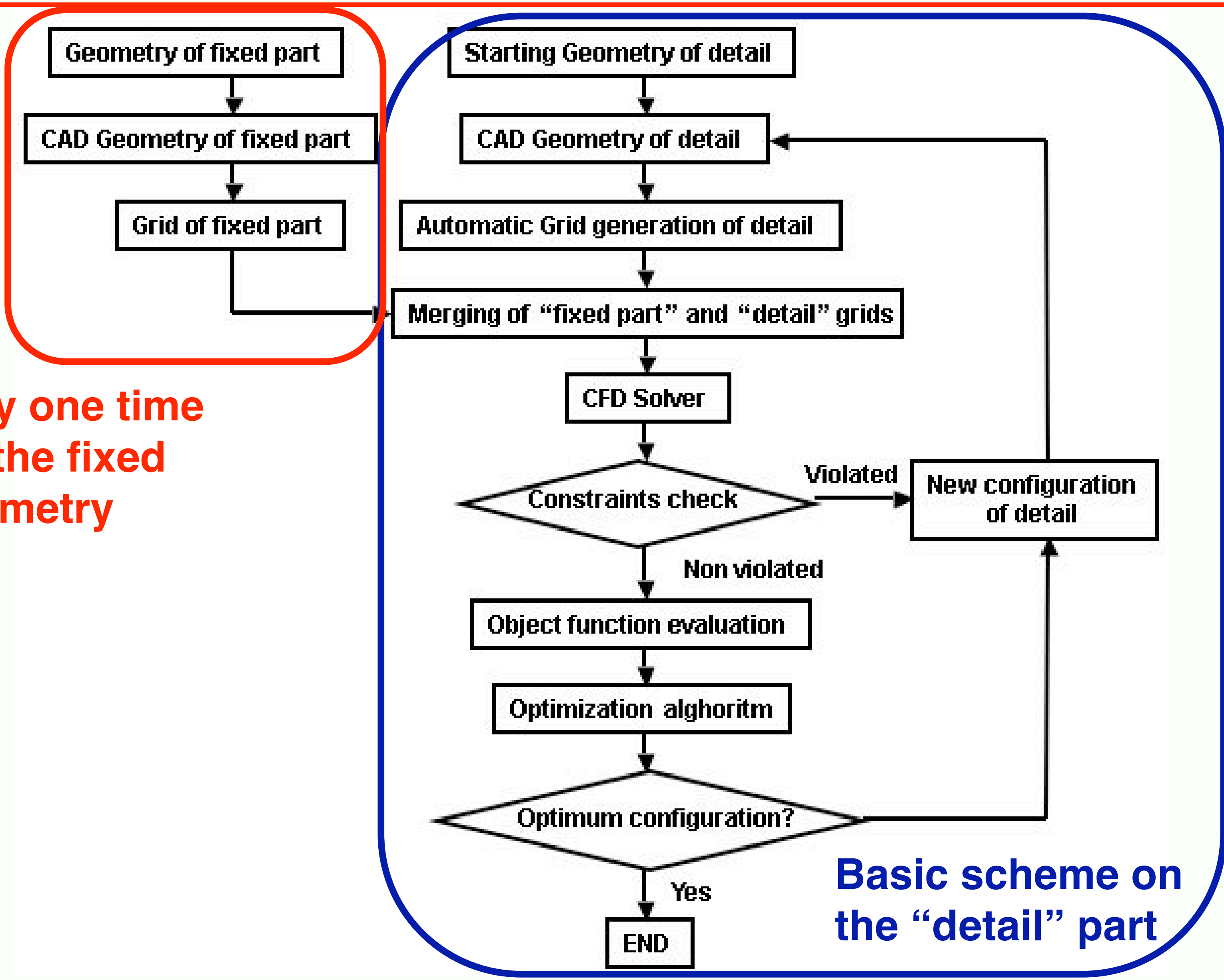
Only the "detail" part is parametric, and its geometry will change during the optimisation process

The grid volume is subdivided in two parts:

- the fixed part, representing the geometry of the car not changing in the optimisation
- the parametric part (yellow), defining the rear diffuser, and changing during the optimisation, following its parameters variations

At any step of the optimisation, the grid volume is obtained merging the fixed part with the parametric one

The scheme



Only one time for the fixed geometry

Basic scheme on the “detail” part

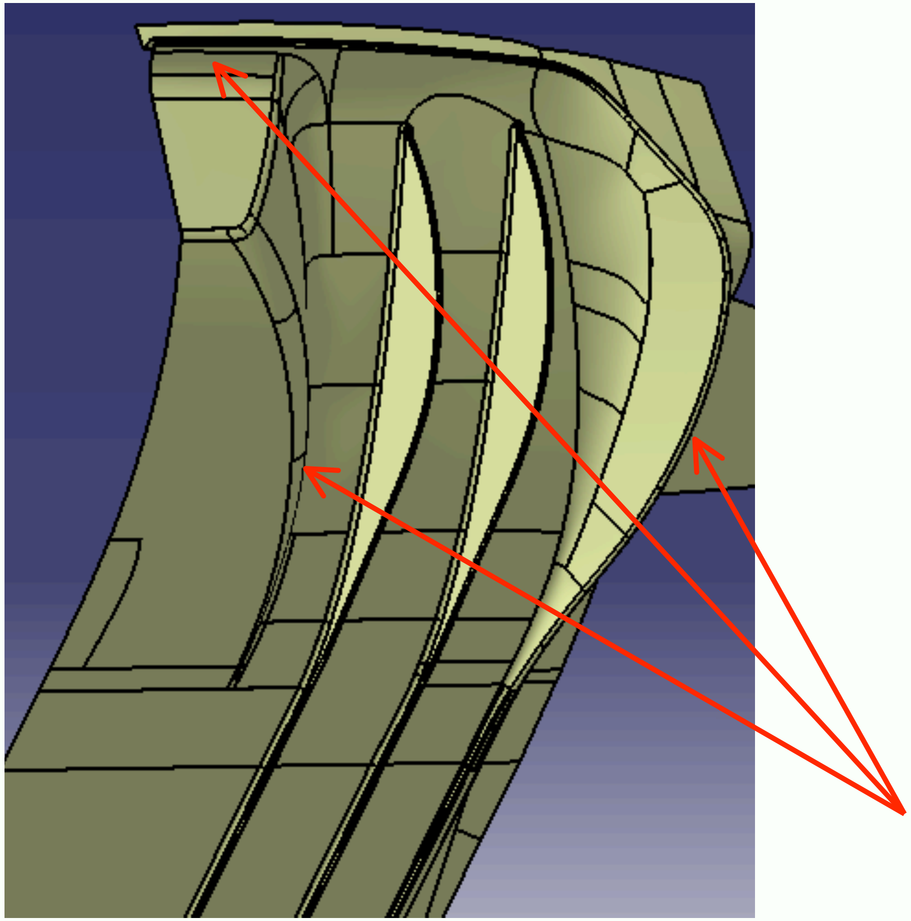
Advantages

- Reduced time for the CAD phase (in the optimisation procedure only for the rear diffuser)
- Reduced time for the grid generation
- Small dimensions for the file to manage
- Better representation of the geometry on respect to a global parametric scheme

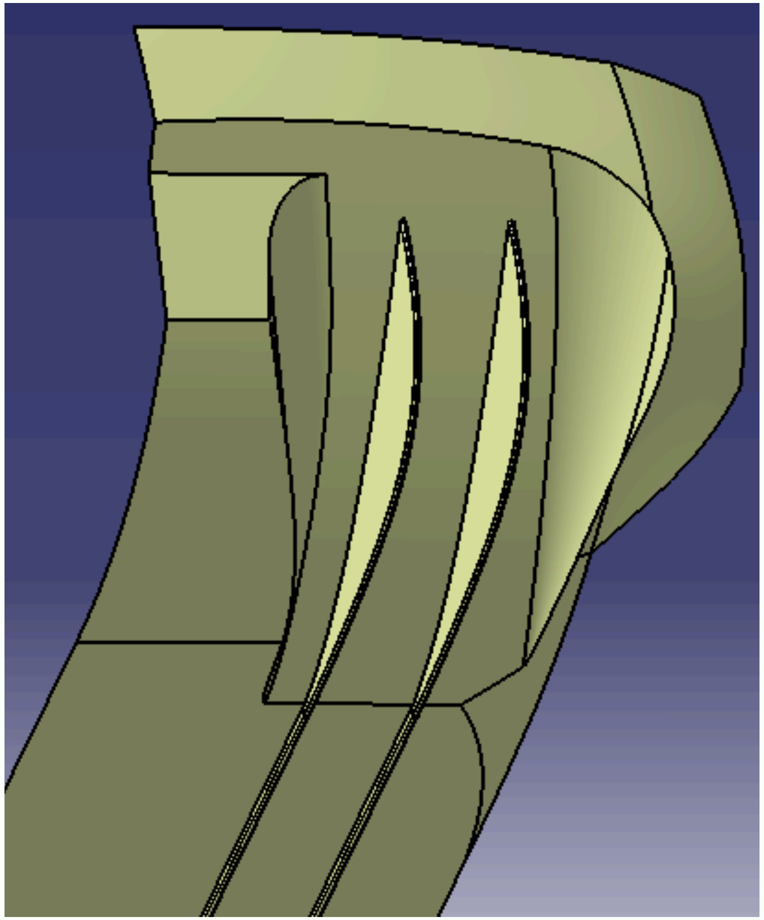
- Reduced time
- Reduced computational requirements
- Better Results

Geometric Representation of the Diffuser

Anyway, some geometrical simplifications of the smaller details are necessary to have a reasonable grid



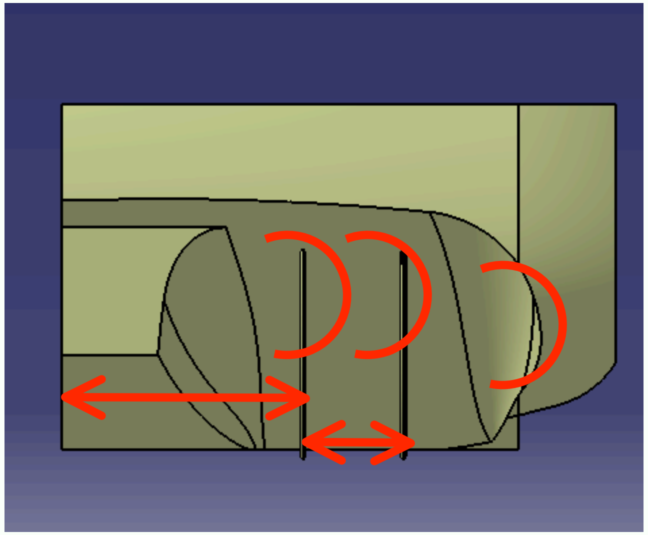
Real geometry

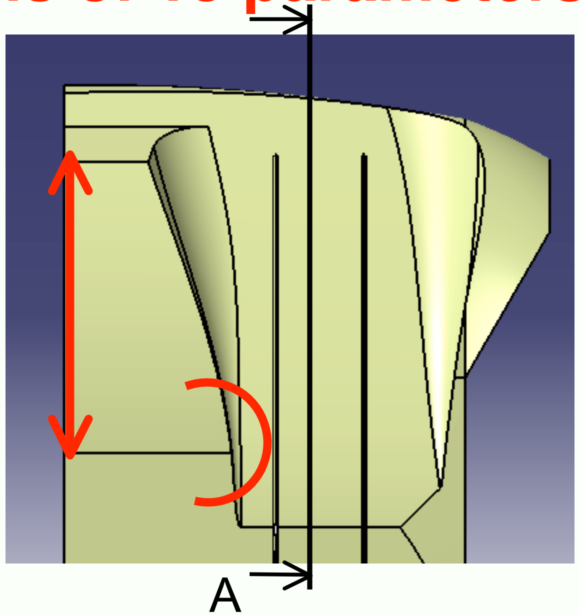


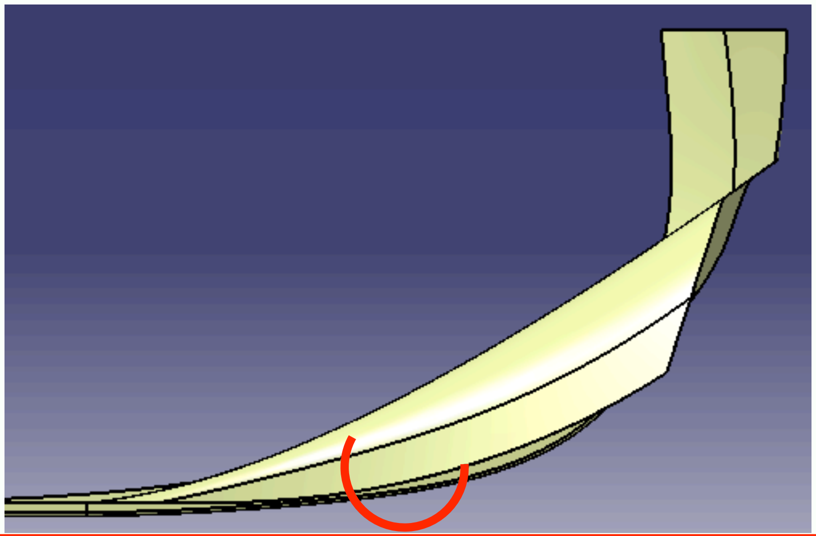
Represented geometry

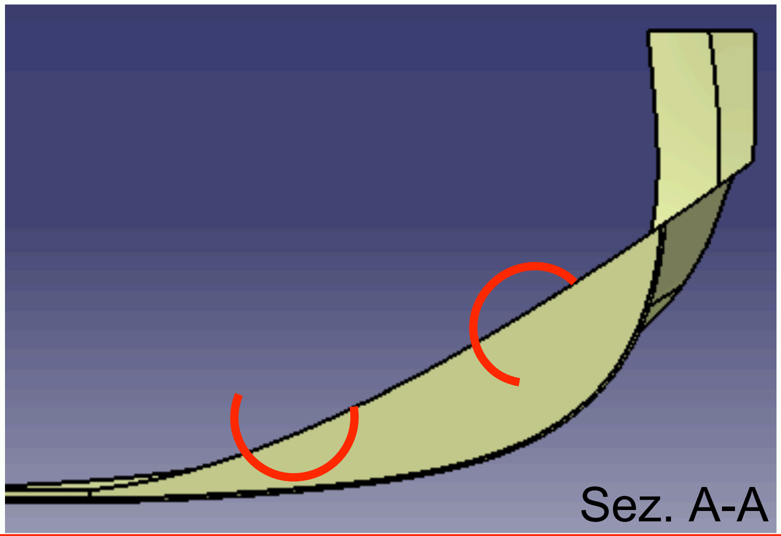
Parametric Representation of the Diffuser

The diffuser is represented by means of 13 parameters









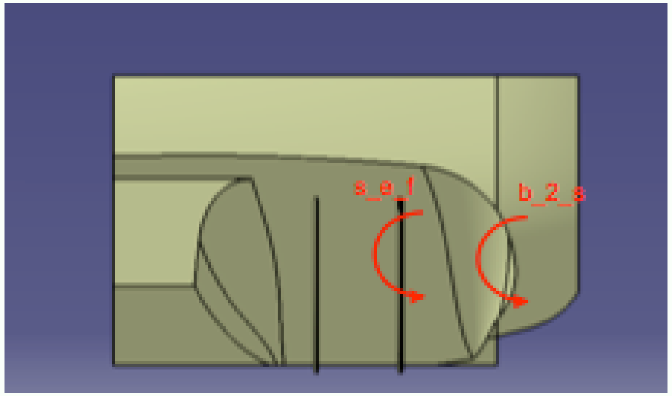
The RANS Evaluations (FLUENT)

- car speed: 35 m/s
- grid domain: 22 car lengths, 20 car widths, 15 car heights
- k-ε realizable turbulence model
- About 2.5 millions of cells on the half car (simmetry)

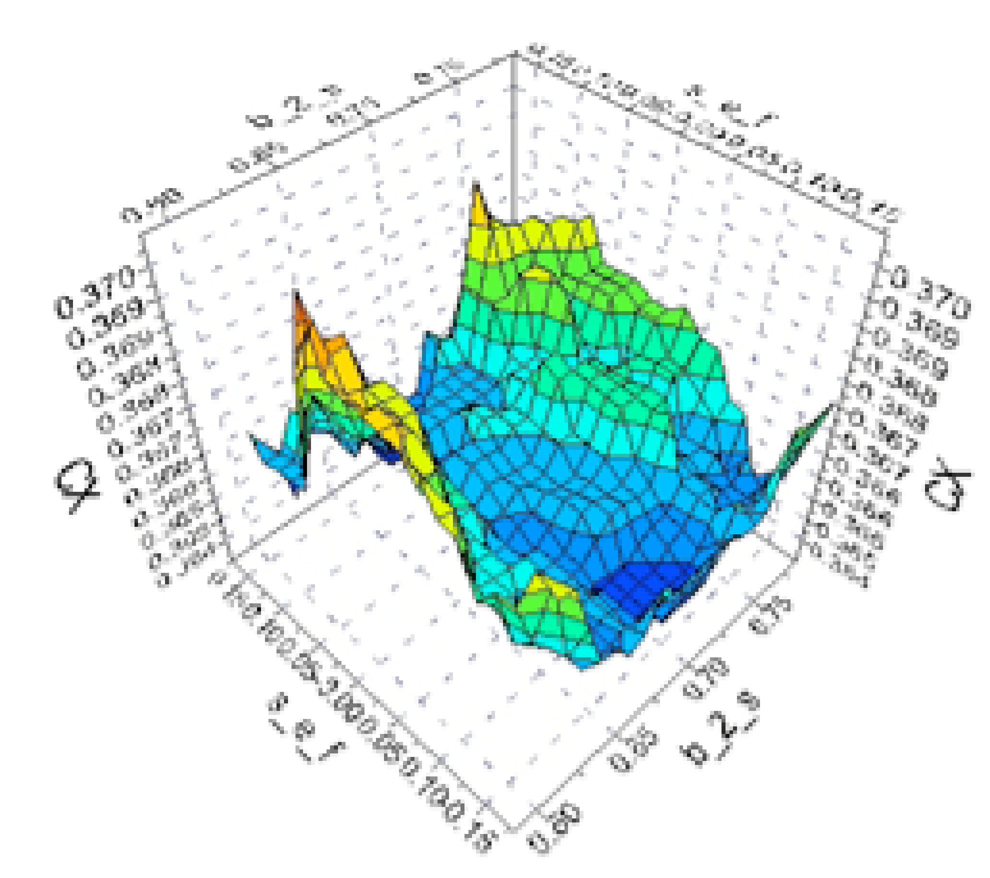
- Linux Cluster
- 16 nodes “AMD OPTERON 285” Dual Core (64 processors)
- Each node with 8 Gb di RAM
- Time for a single step: 26 minuti

  with a CFD time: 13 minuti

Example of Parametric Analysis



Analysed parameters



The optimisation Procedure

The optimisation procedure was driven by ModeFronter

As ALGORITHM was chosen the genetic algorithm Moga-II (Multiple – Objective Genetic Algorithm II)

The OBJECT FUNCTION was related to both the total drag and the vertical download of the car

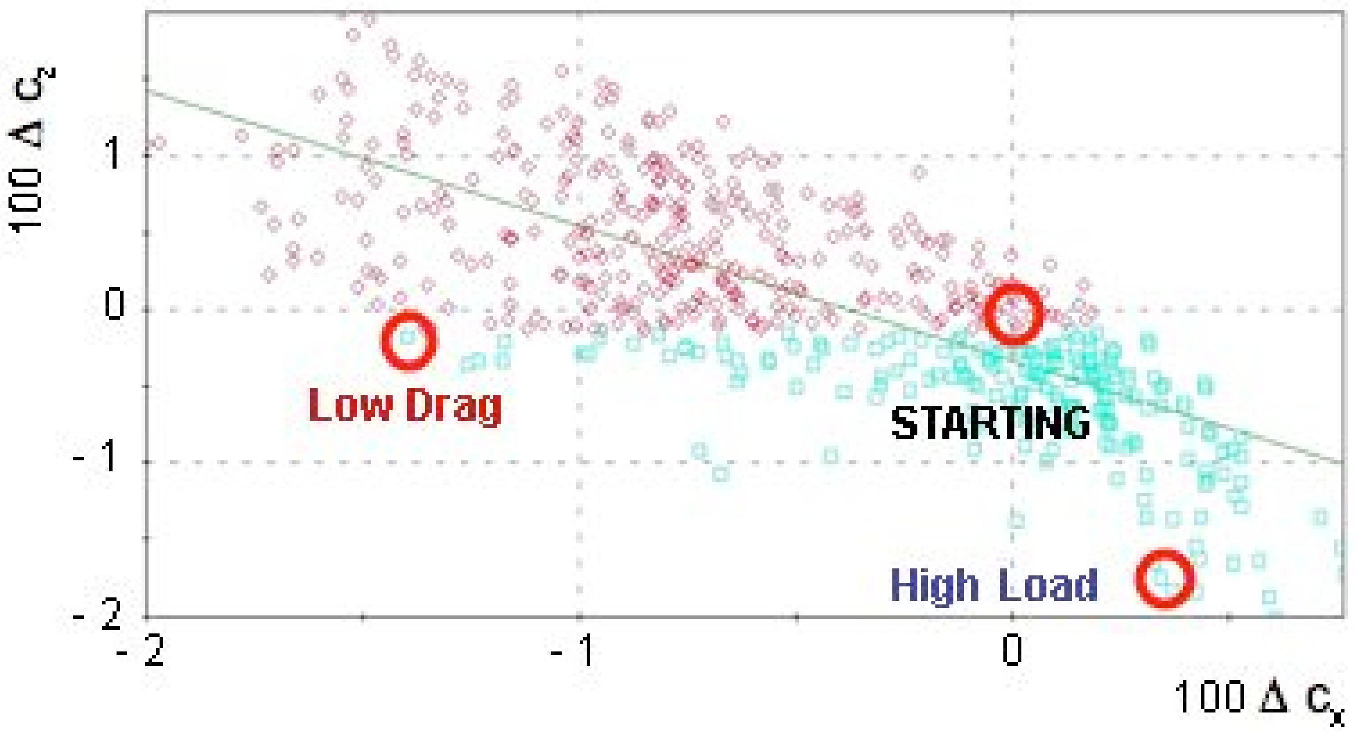
CONSTRAINTS:

- **minimum volume of the gearbox**
- **Maximum span of the lateral side of the diffuser**
- **The vertical download cannot be reduced ($C_Z \leq C_{Zref}$)**

STRATEGY:

- **42 initial base data (DOE, Design Of Experiments) were used, with 16 new populations**
- **570 different geometries were evaluated**

Results - SCATTER CHART

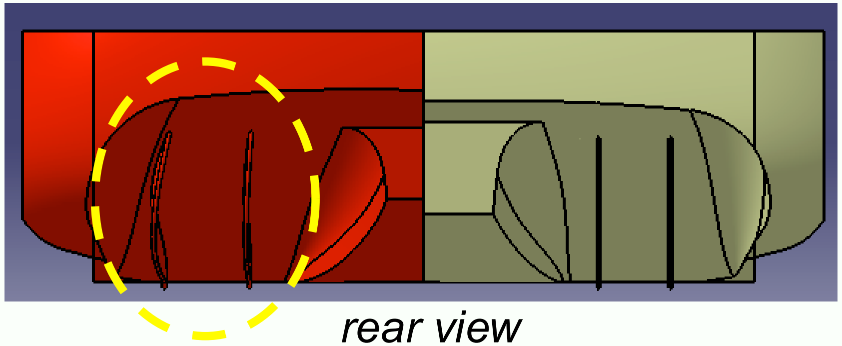


Two interesting configuration can be identified:

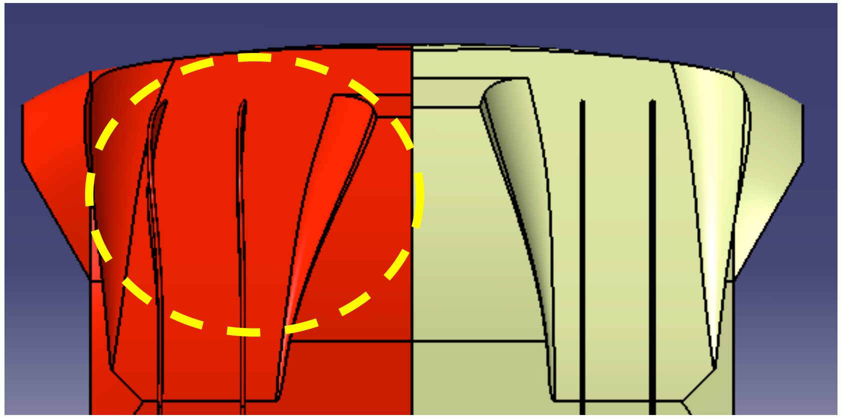
- **"Low Drag", characterised by a drag as lower as possible (without increase in vertical down-load)**
- **"High Load", characterised by a high value of the vertical download, with a low increase in drag**

“Low Drag” Configuration

Yellow original



rear view

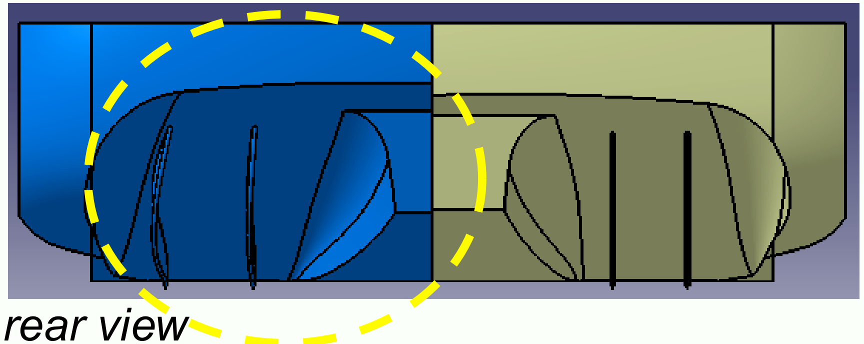


bottom view

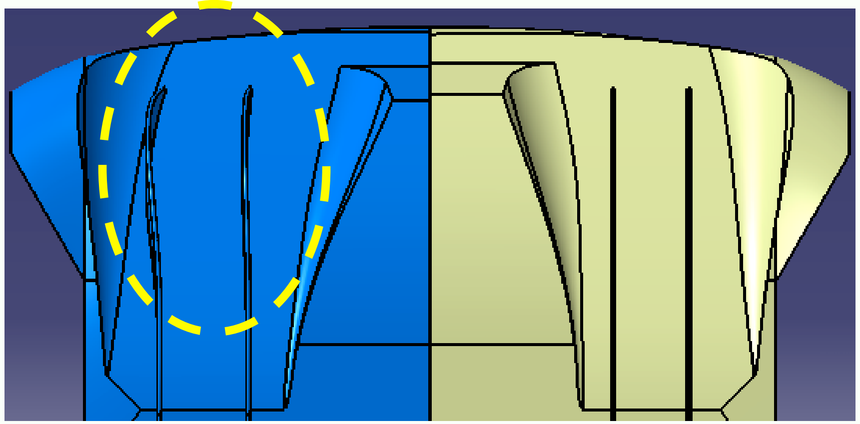
$100\ \Delta\ c_x$	$-100\ \Delta\ c_z$	Efficiency
-1.52	0.30	5.1

“High Load” Configuration

Yellow original



rear view



bottom view

$100\ \Delta\ c_x$	$-\ 100\ \Delta\ c_z$	Efficiency
0.26	1.94	7.5

Verification of the Results

A verification of the optimisation results with a refined grids, taking into account the details simplified in the optimisation, was carried out

The RANS evaluation were carried out with the same settling, with a grid of 15 millions of cells (on the half car)

	Optimisation		Refined grid	
	100 Δ c_x	- 100 Δ c_z	100 Δ c_x	- 100 Δ c_z
Low Drag	-1.52	0.30	-0.67	0.51
High Load	0.26	1.94	0.42	1.47

From results it is evident a not negligible difference, related to the sensitive to the geometrical details representation, but the tendency is clearly maintained

Final Comparison

The results obtained with the refined grid are used

	100 Δ c_x	- 100 Δ c_z
Low Drag	- 0.67	0.51
High Load	0.42	1.47

The effects are completely different for the two configurations. It is possible to make a choice between:

- **To increase the vertical load, but with an increased drag**
- **To reduce the drag, with also a (small) increase in vertical load**

Clearly, the choice depends on considerations regarding the actual aerodynamics performances of the car

CONCLUSIONS

- The developed project has demonstrated the applicability of optimization procedures in the context of automotive industry by using CFD for the aerodynamics solver
- The integration of the aerodynamic optimization in the design phase allows engineers to interact with the other design groups without excessive delays
- It becomes possible to search for solutions that do not negatively affect car style or performance, while providing a high degree of efficiency and safety
- The reduction of industrial costs is significant: in principle it is no longer needed to build many different models, to be subject to wind tunnel measurements: it is sufficient to test the final optimized ones

ACKNOWLEDGEMENTS

Thanks are due to AMD for the availability of an extremely powerful computing system.

Thanks are also due to A. Ciampa and E. Mazzoni (INFN of Pisa) to render the computing system very efficient and easy to use, resulting from their research activities on computing networks, applied to our cluster.