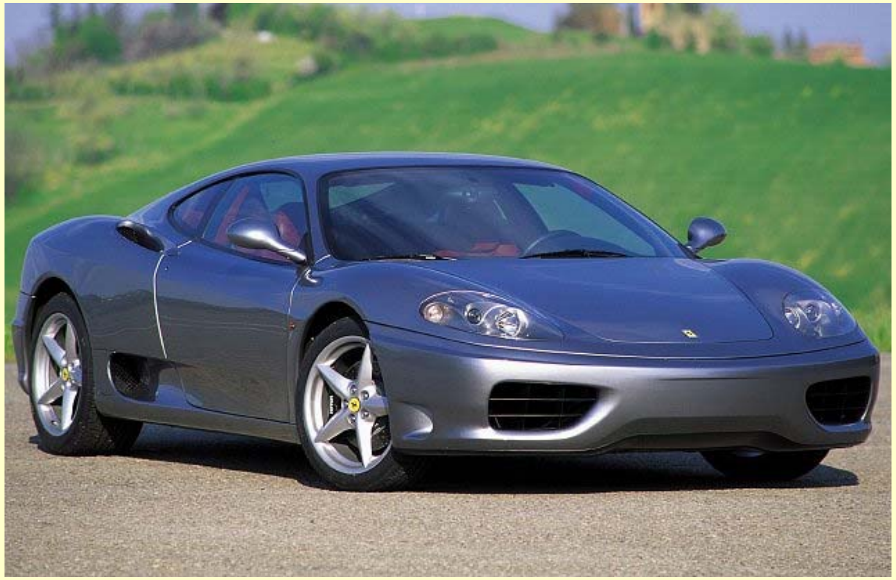
The Influence of Aerodynamics on the Design of High-Performance Road Vehicles - Part 2



Guido Buresti

Department of Aerospace Engineering

University of Pisa (Italy)

CONTENTS

- **ELEMENTS OF AERODYNAMICS**
- **AERODYNAMICS OF CARS**
- **AERODYNAMICS OF HIGH-PERFORMANCE CARS**
- **DESIGN TOOLS**
- **AERODYNAMICS AT FERRARI AUTO**
- **CONCLUSIONS AND FUTURE DEVELOPMENTS**

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Experimental techniques

Specific wind tunnels for automotive research

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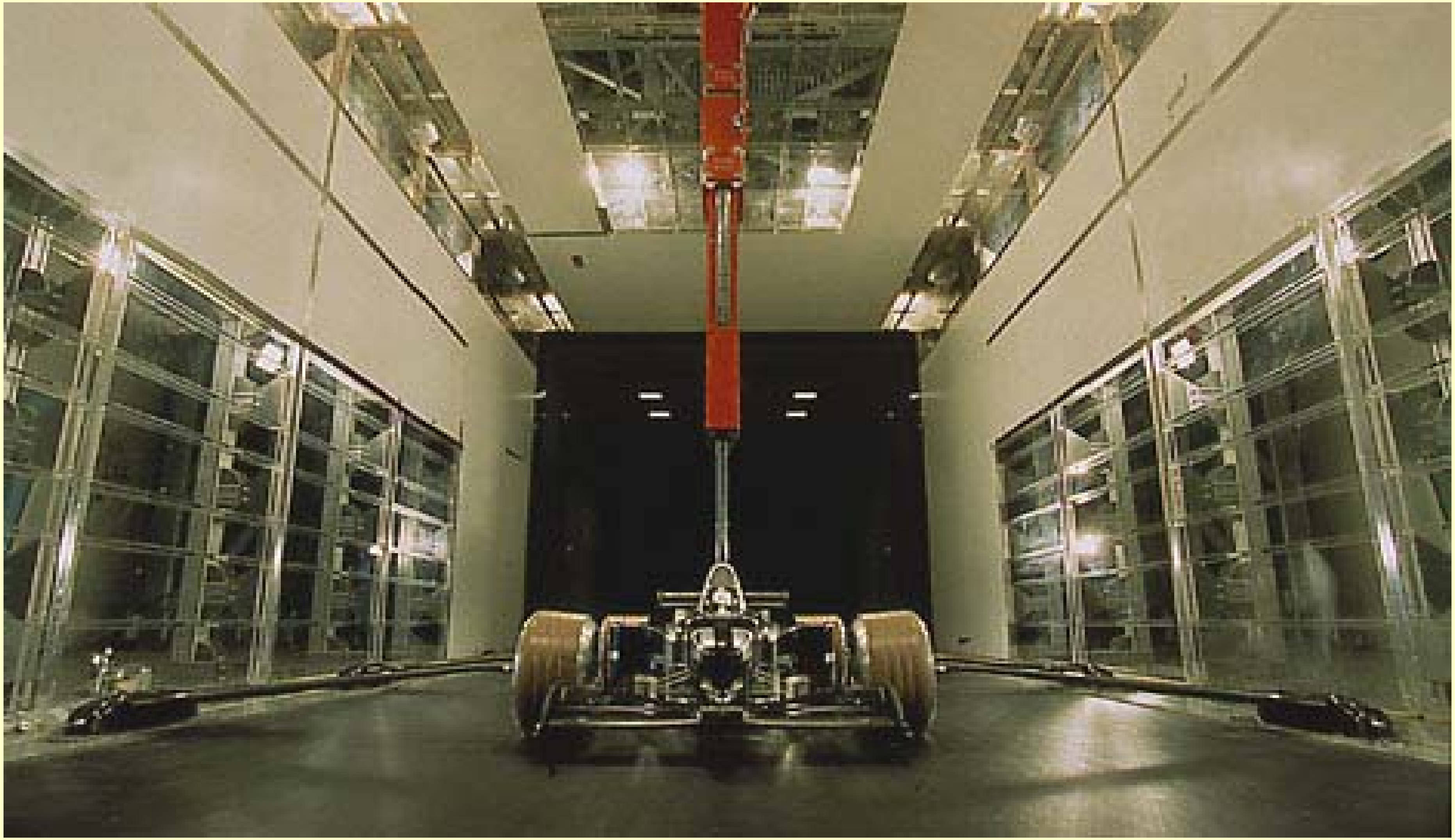
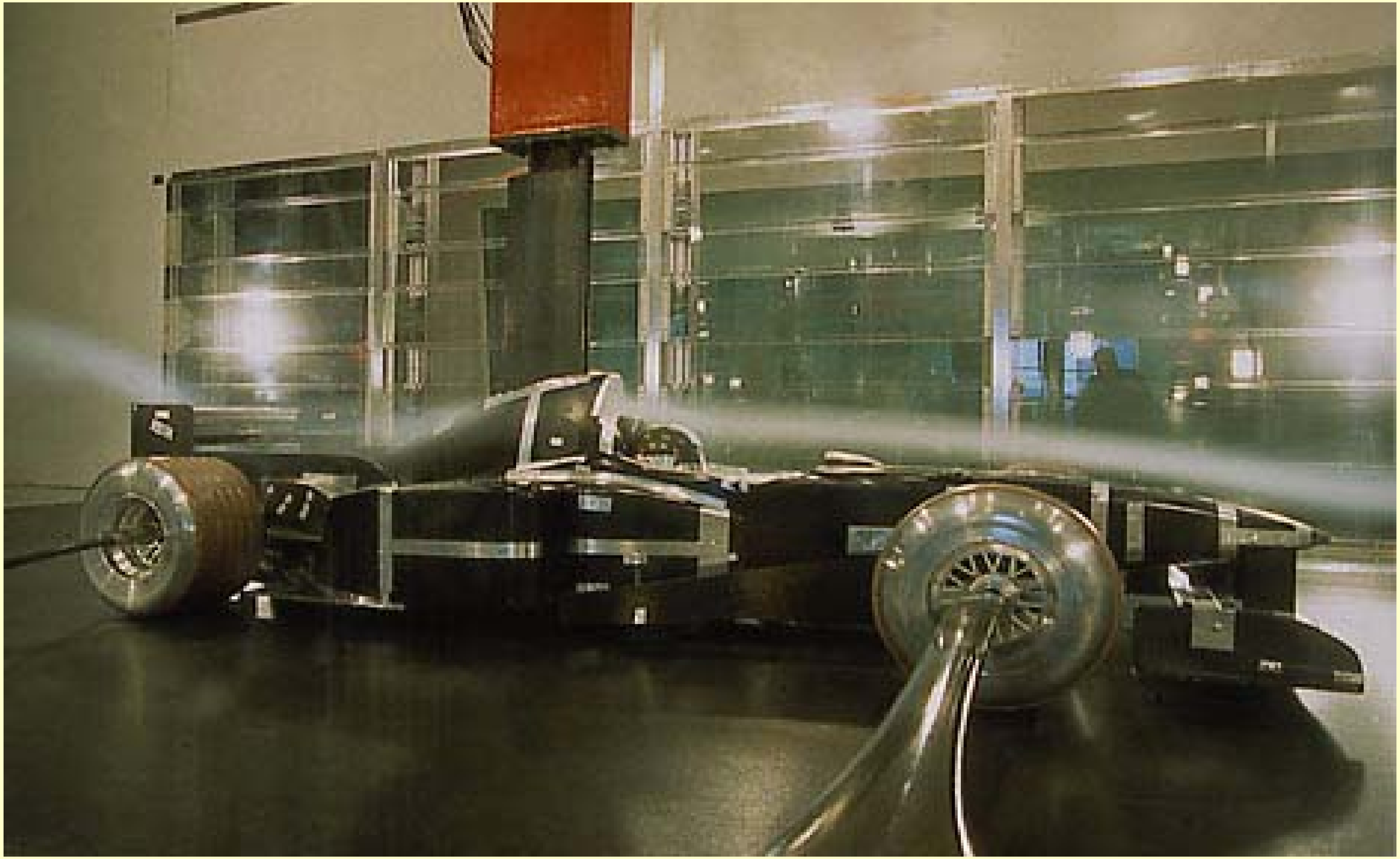
The Ferrari Gestione Sportiva wind tunnel



The Ferrari Gestione Sportiva wind tunnel



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The Ferrari Gestione Sportiva “small” wind tunnel

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Numerical techniques

Numerical solution of the equations of fluid dynamics (Navier-Stokes equations)

Basic method : Direct Numerical Simulation (DNS)

⇩

For typical application conditions DNS is not possible!

⇩

Reynolds-averaged Navier-Stokes equations (RANS)

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Reynolds-averaged Navier-Stokes equations (RANS)

“Commercial” codes are used (FLUENT, STAR-CD)

Computing times: from a few hours to several days according to complexity of configuration and available computational resources

Good qualitative results, and even quantitative, if codes are validated with experimental data for the analysed class of bodies

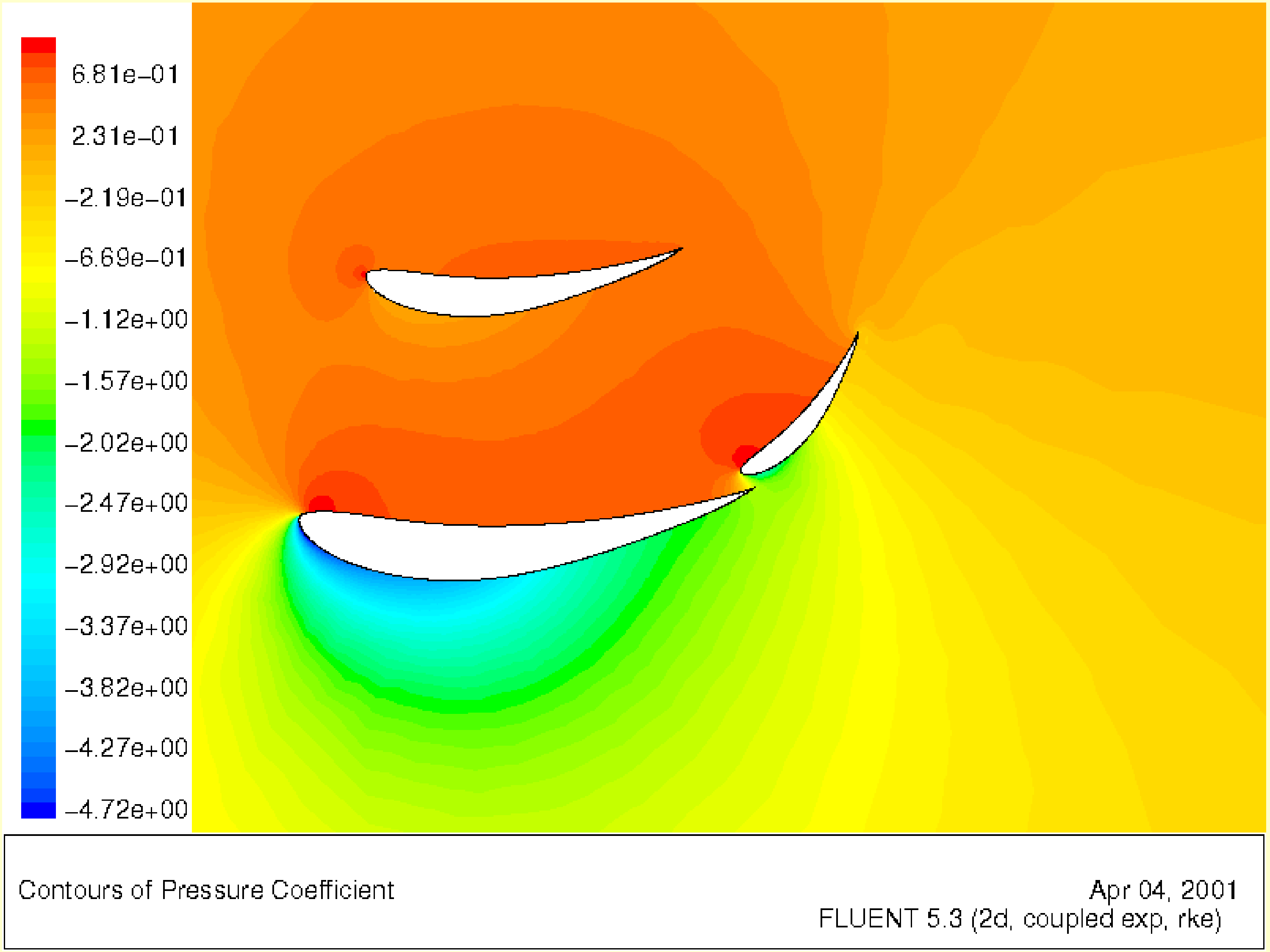
⇓

A good aerodynamic competence is necessary

Good for comparisons between different configurations

Good indications on physical phenomena

Examples of RANS numerical results



Examples of RANS numerical results

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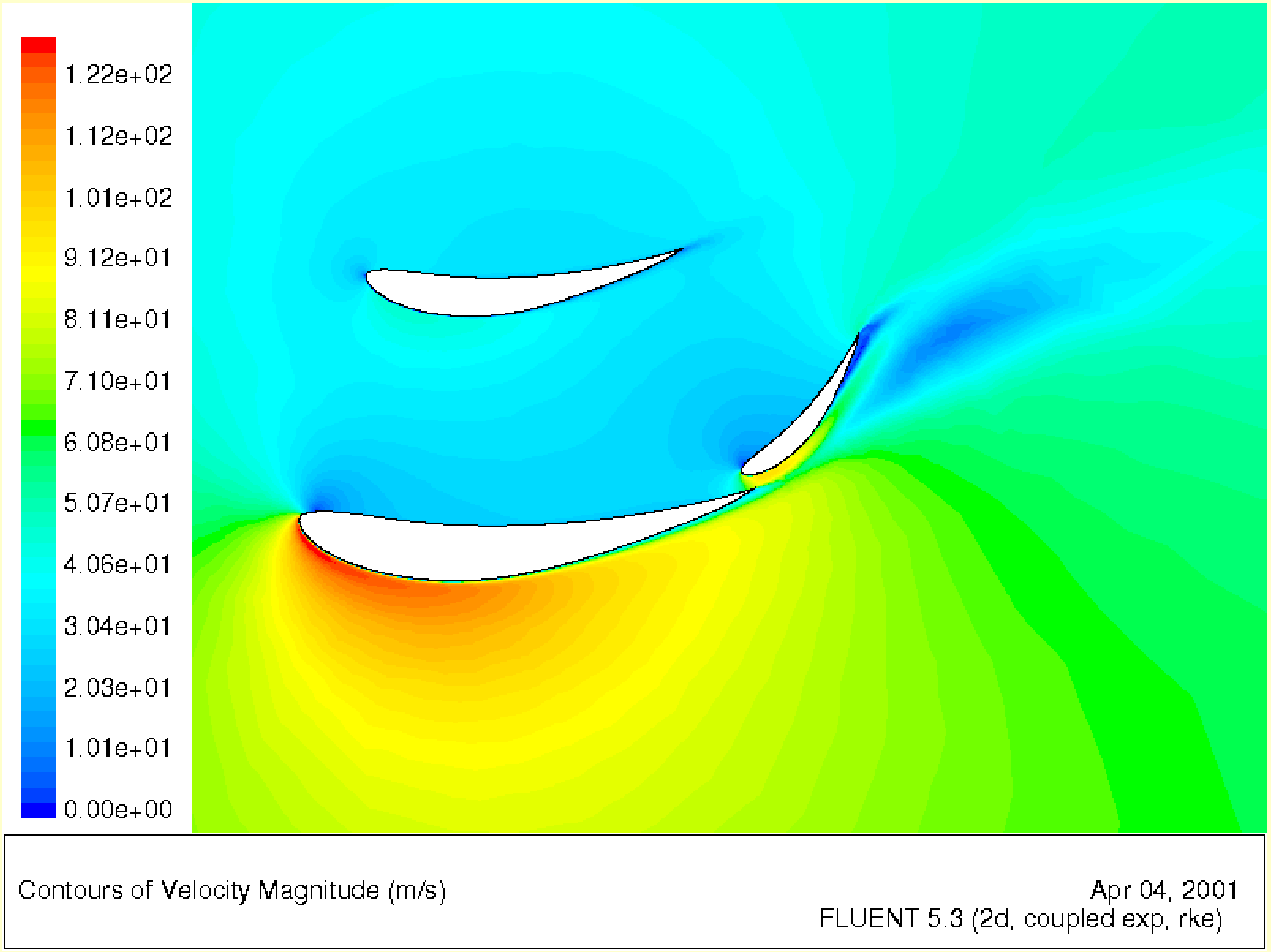

Examples of RANS numerical results

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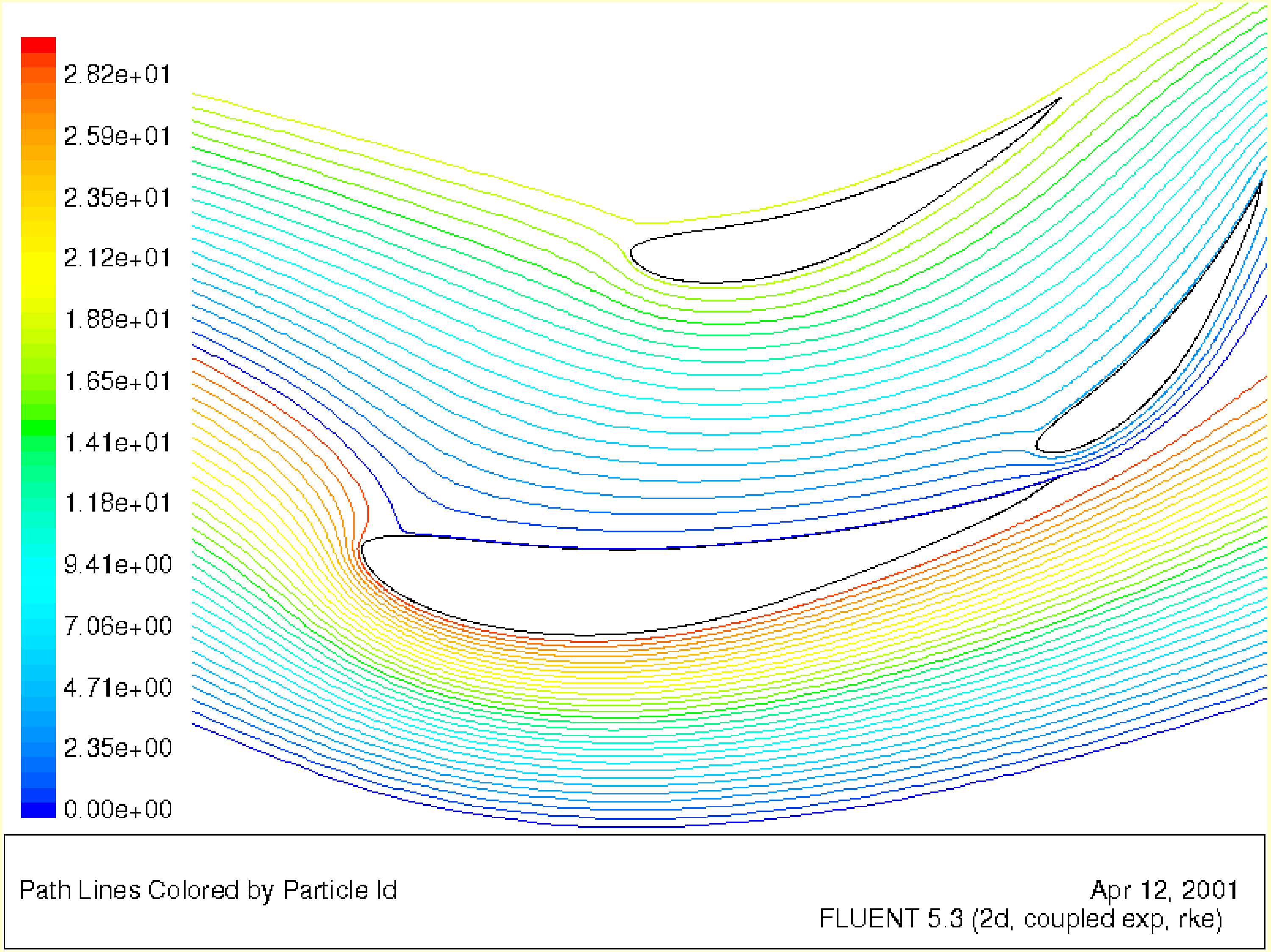

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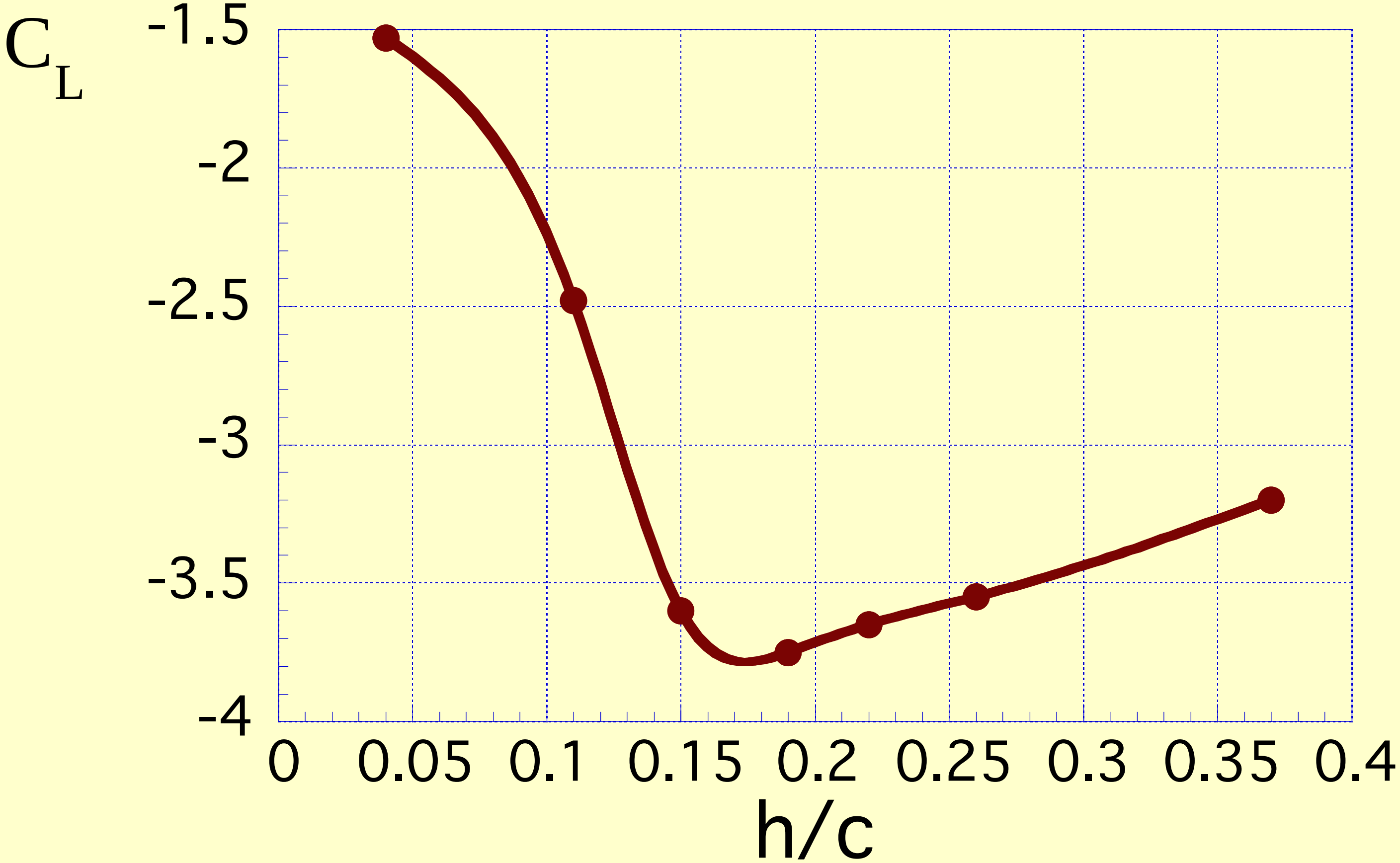
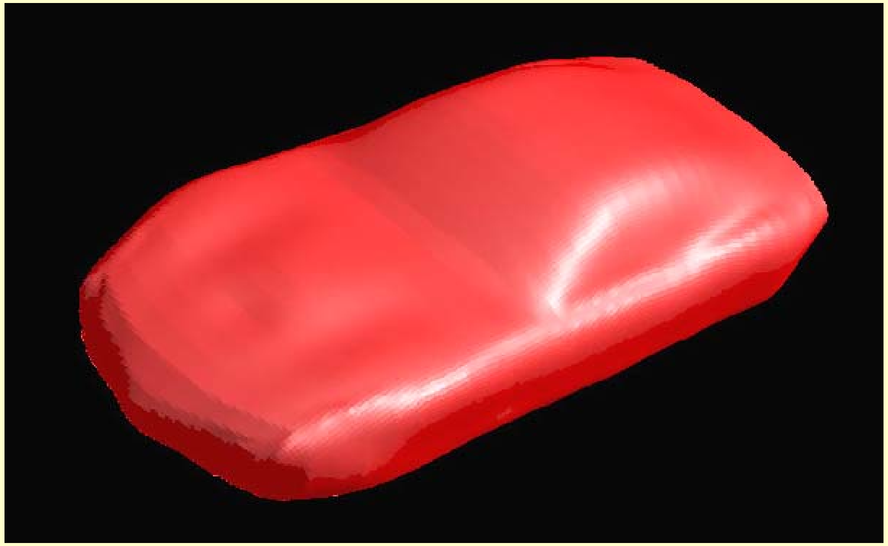
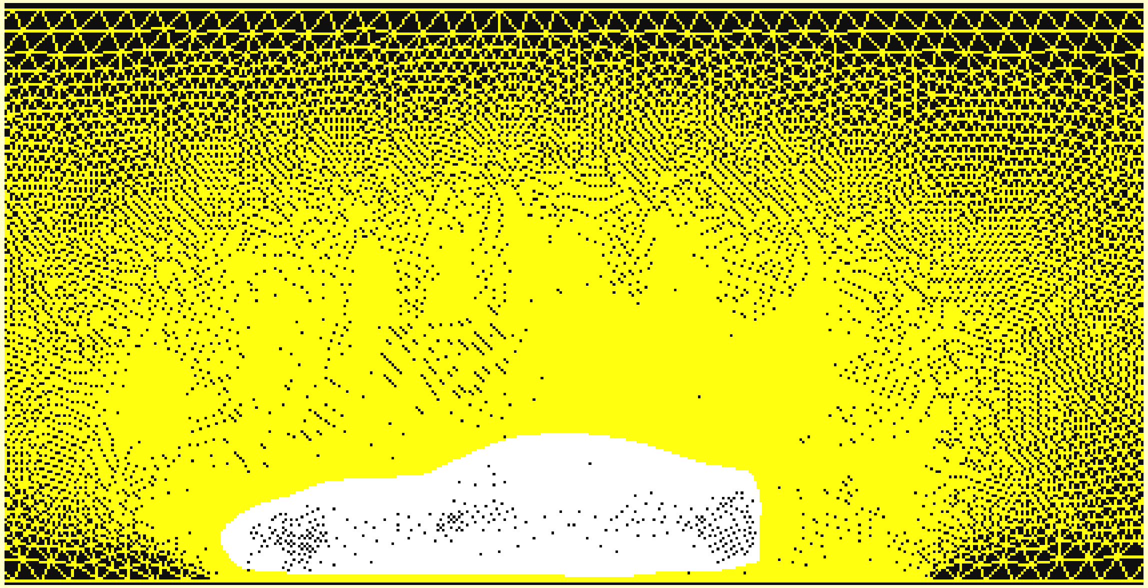
Analysis of download of a front F1 airfoil with varying distance from the ground

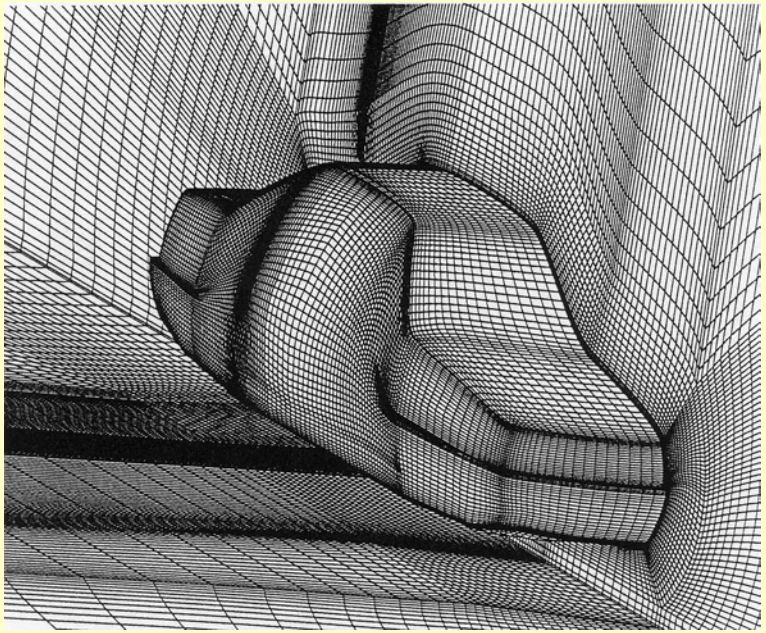


Examples of RANS numerical results

Discretization of vehicle and computational grid







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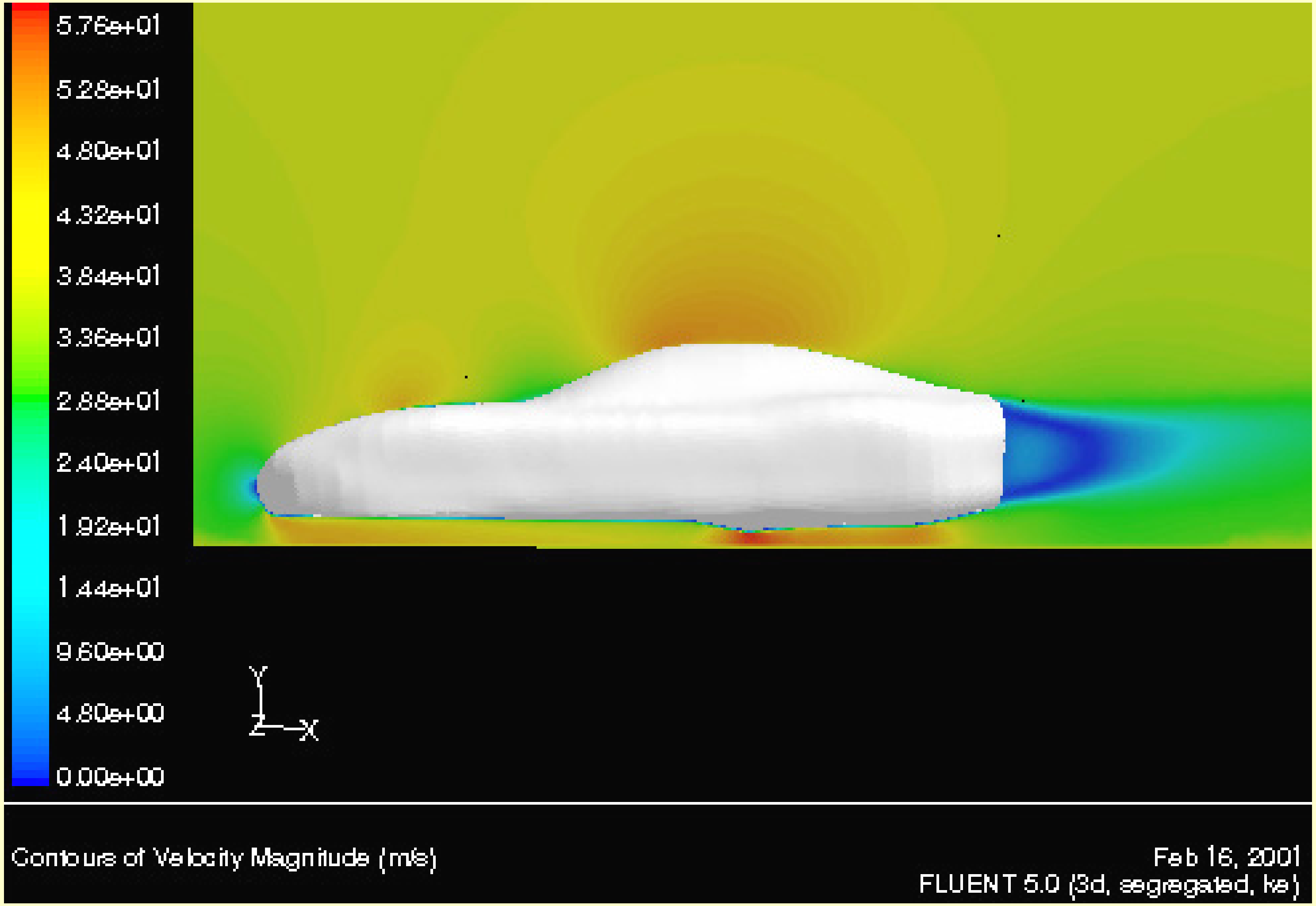
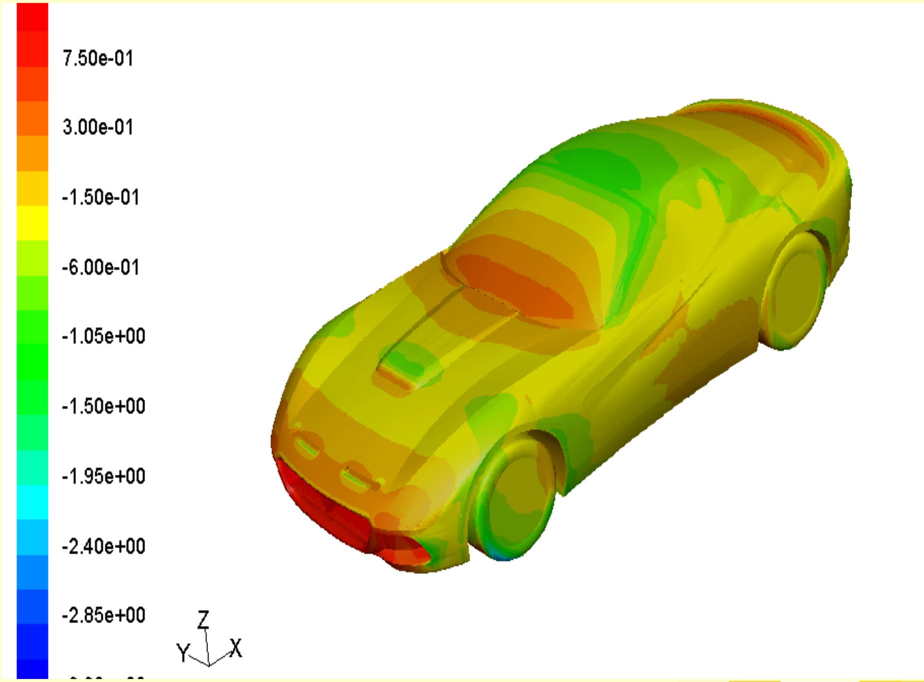
Velocity magnitude

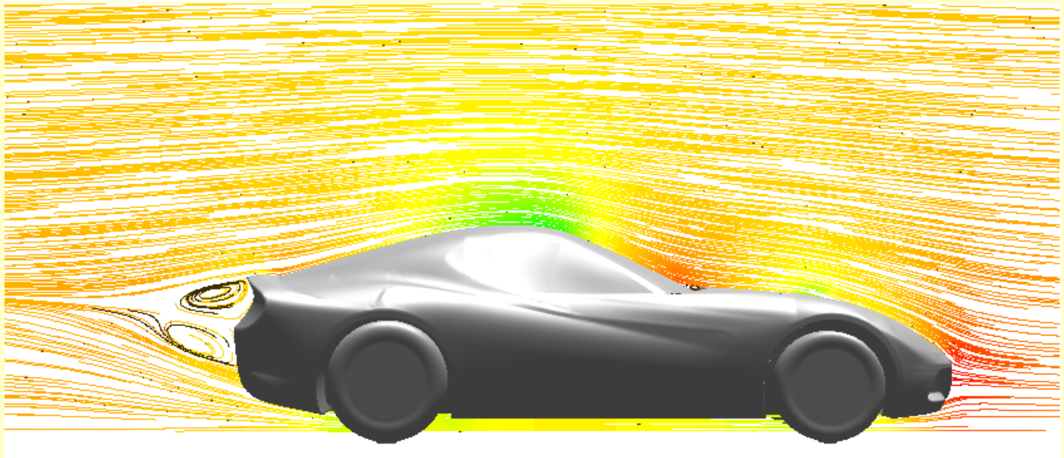


Examples of RANS numerical results



Pressures

Streamlines



Examples of RANS numerical results

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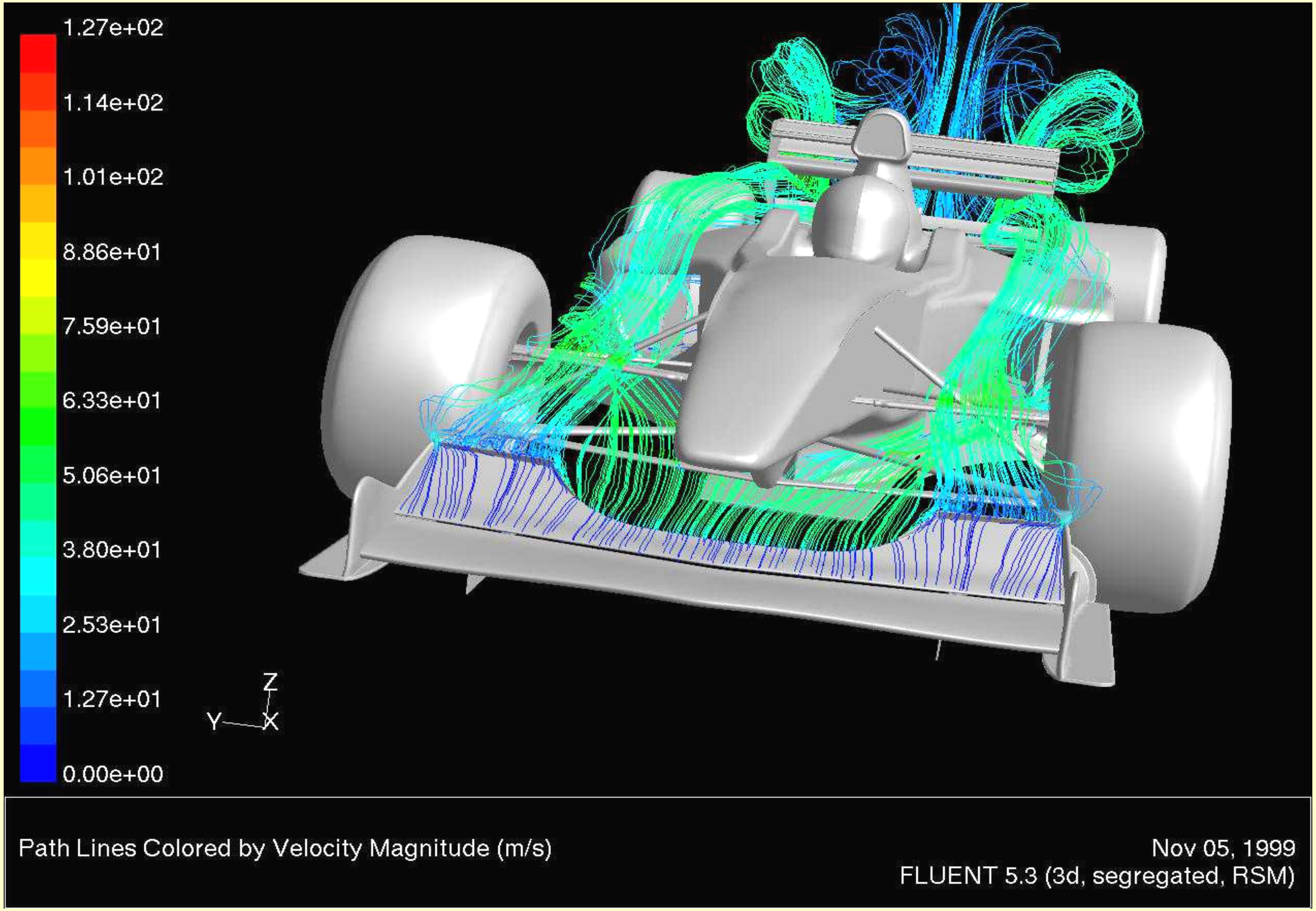

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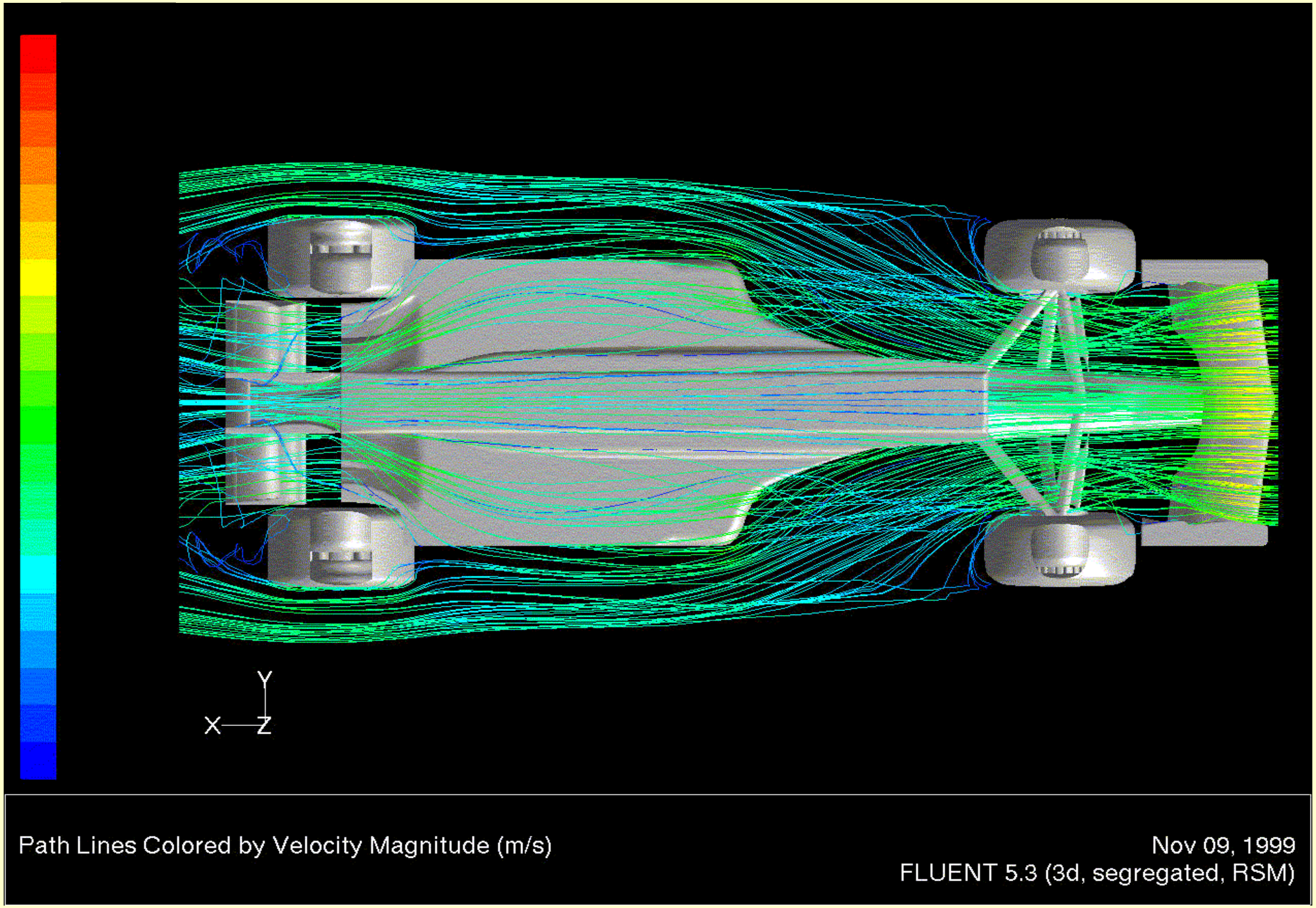

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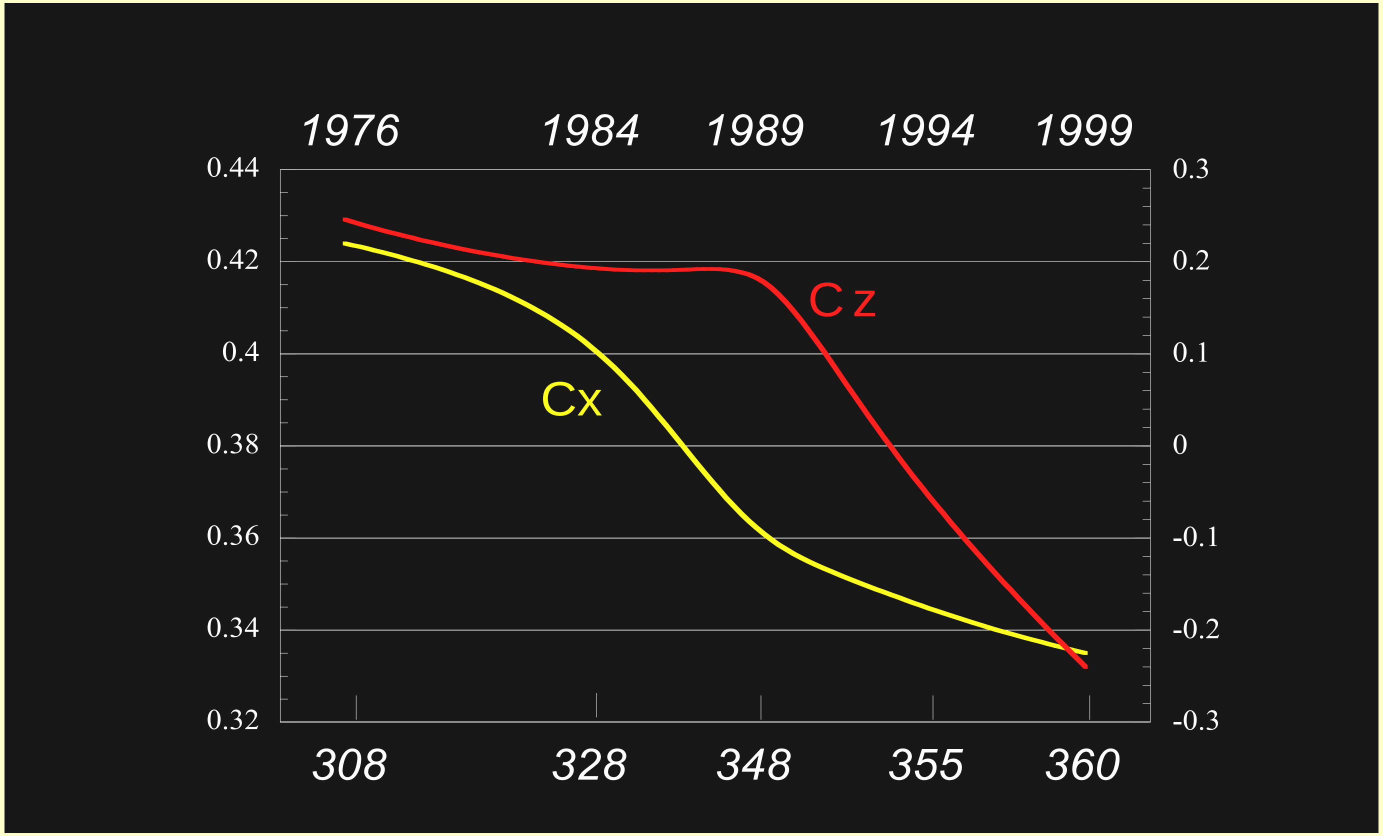
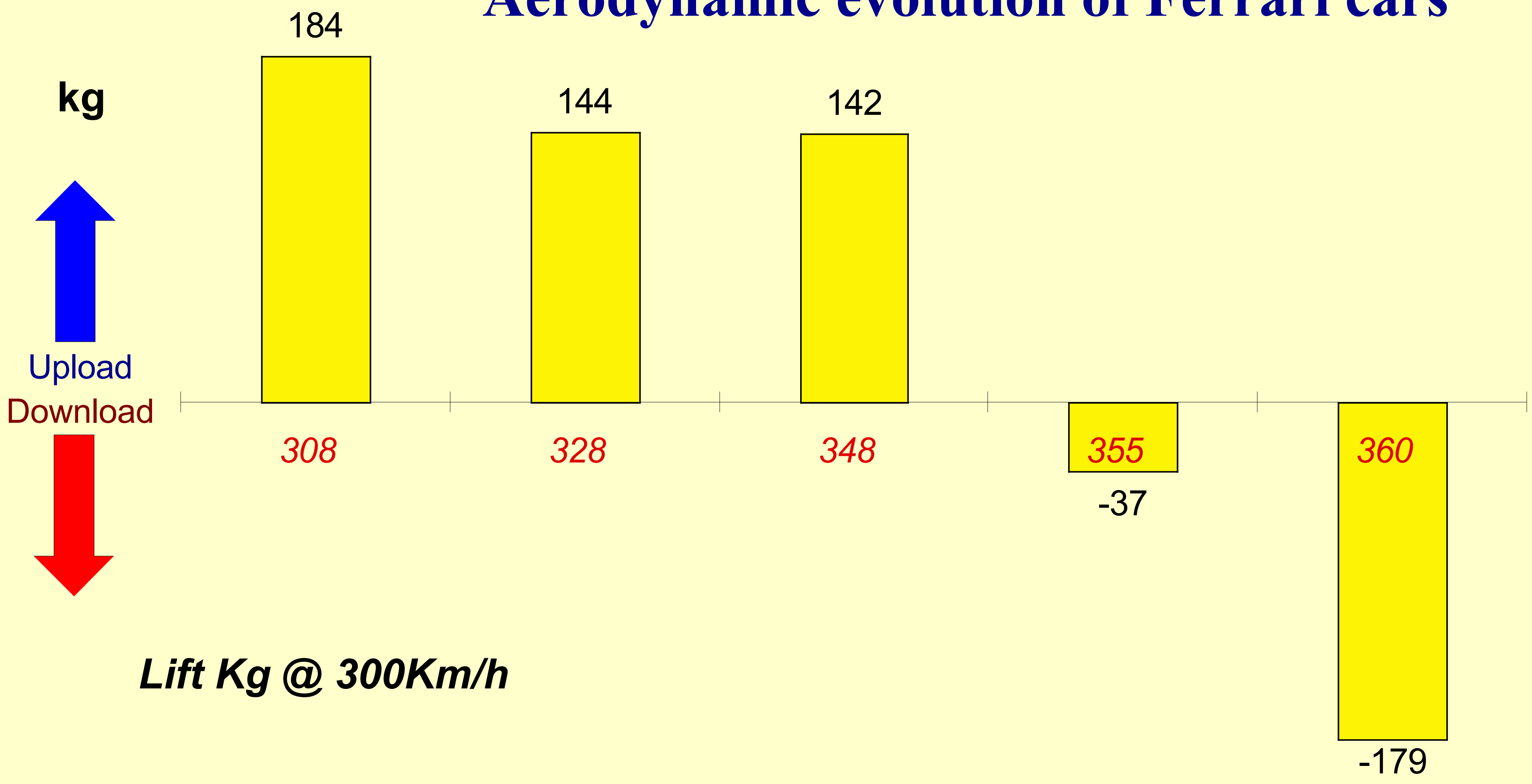
Aerodynamic evolution of Ferrari production cars



Aerodynamic evolution of Ferrari cars

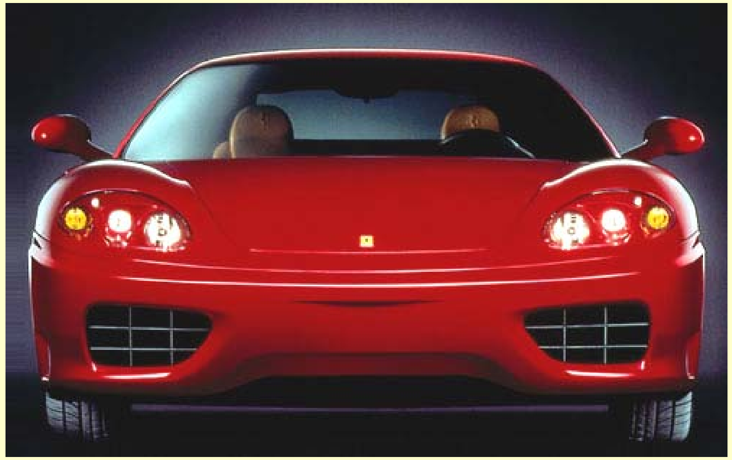


Lift Kg @ 300Km/h

Underbody and aerodynamic coefficients of F360 Modena

Ant: - 0.11

Post: - 0.13



C_z = - 0.240

C_x = 0.335

Since 1989

- Characterization of new wind tunnel
- Solution of specific design problems
- Involvement of DIA in the development and utilization of new design tools

Since 2000 - General agreement DIA - Ferrari:

- DIA is reference for research and innovation in aerodynamics
- DIA directly cooperates in the design of new cars

Working tools:

- Graduation theses on research topics of interest for Ferrari
- Research contracts on specific problems

DIA cooperated in the aerodynamic design of:

550

360

Enzo

612

...

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Some topics:

Particular measurement methods

Direct measurement of vorticity

Surface visualization

Basic investigations of common interest

Wall effects in wind tunnels

Effects of afterbody rounding

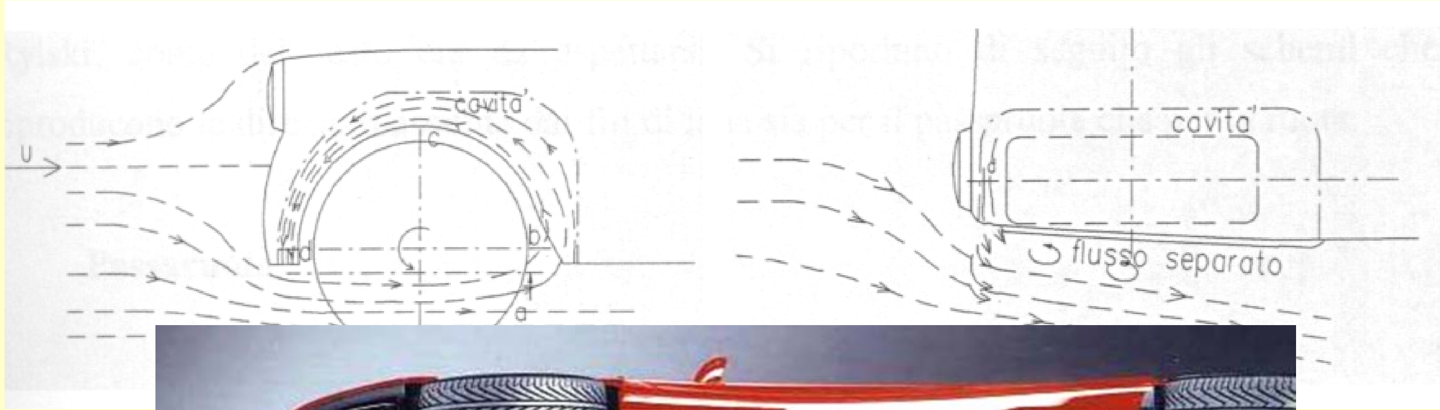
- Aerodynamics of wheelhouses

Common research project

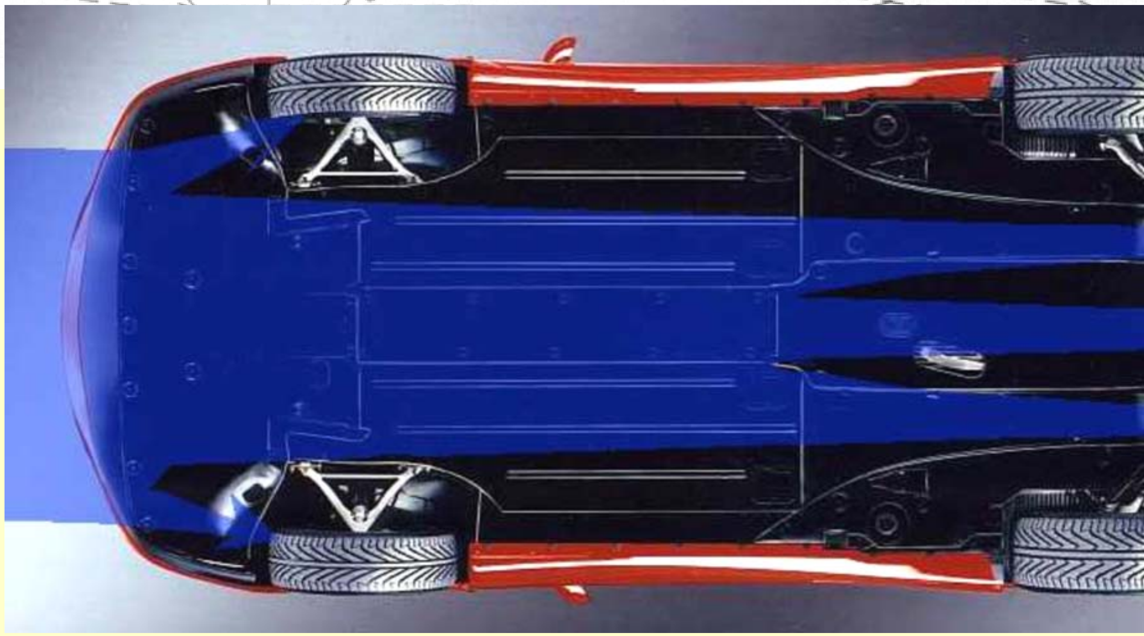
- Development of a numerical procedure for the optimized preliminary aerodynamic design of new cars

Aerodynamics of wheelhouses

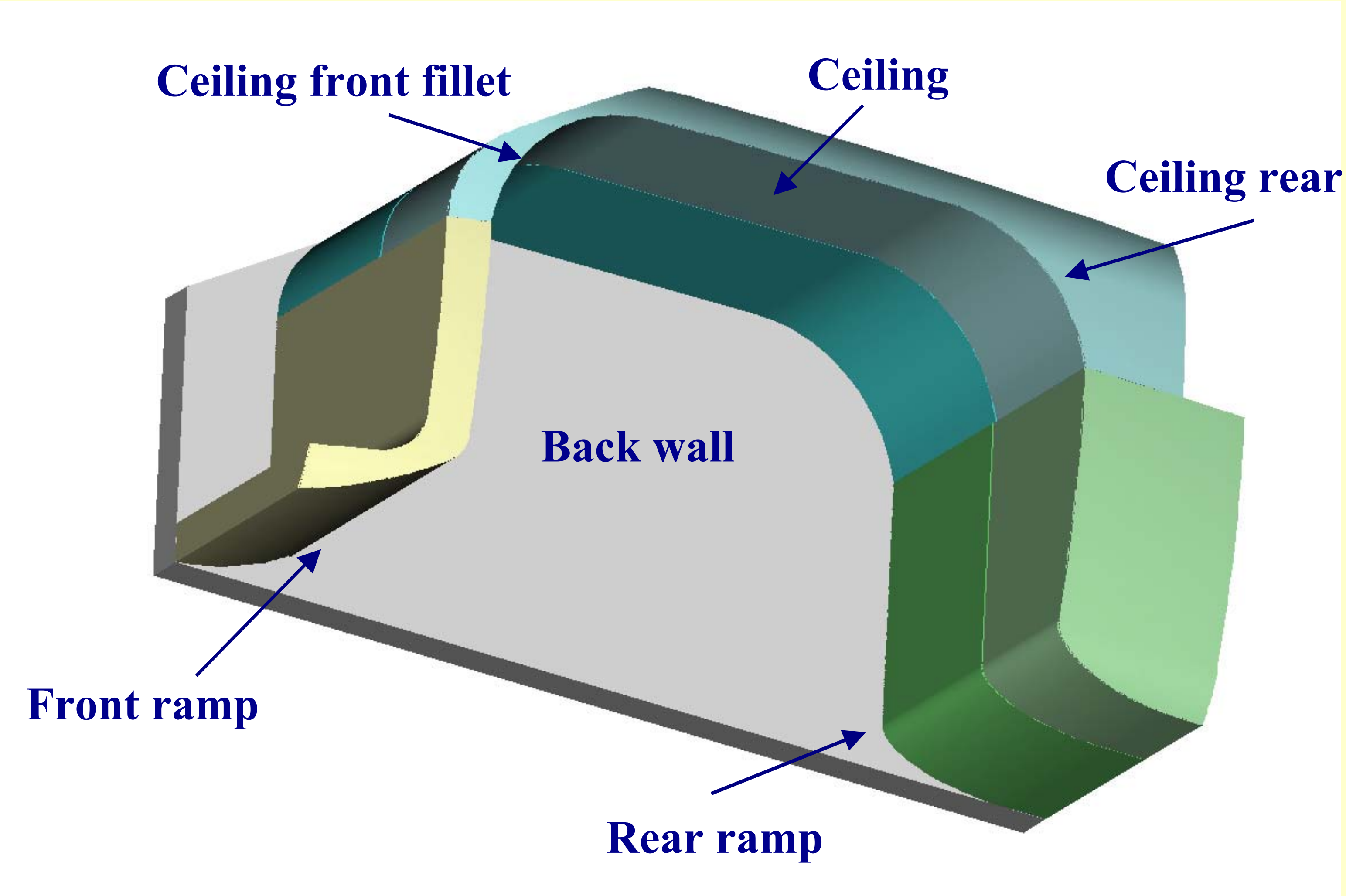
Type of Flow



Strong coupling with underbody



Nomenclature



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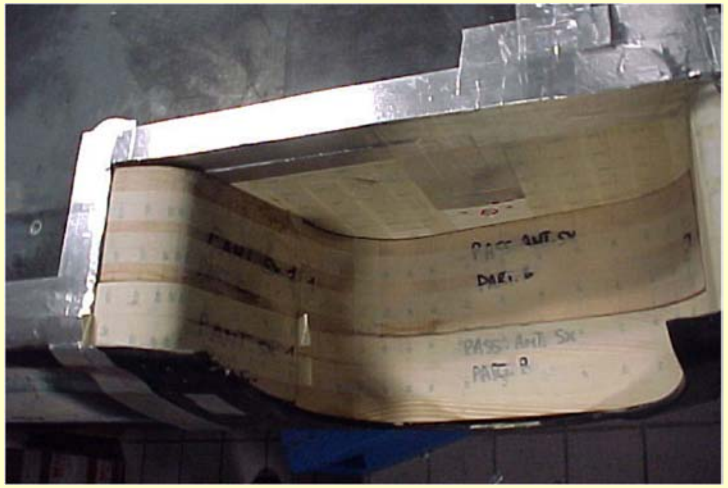
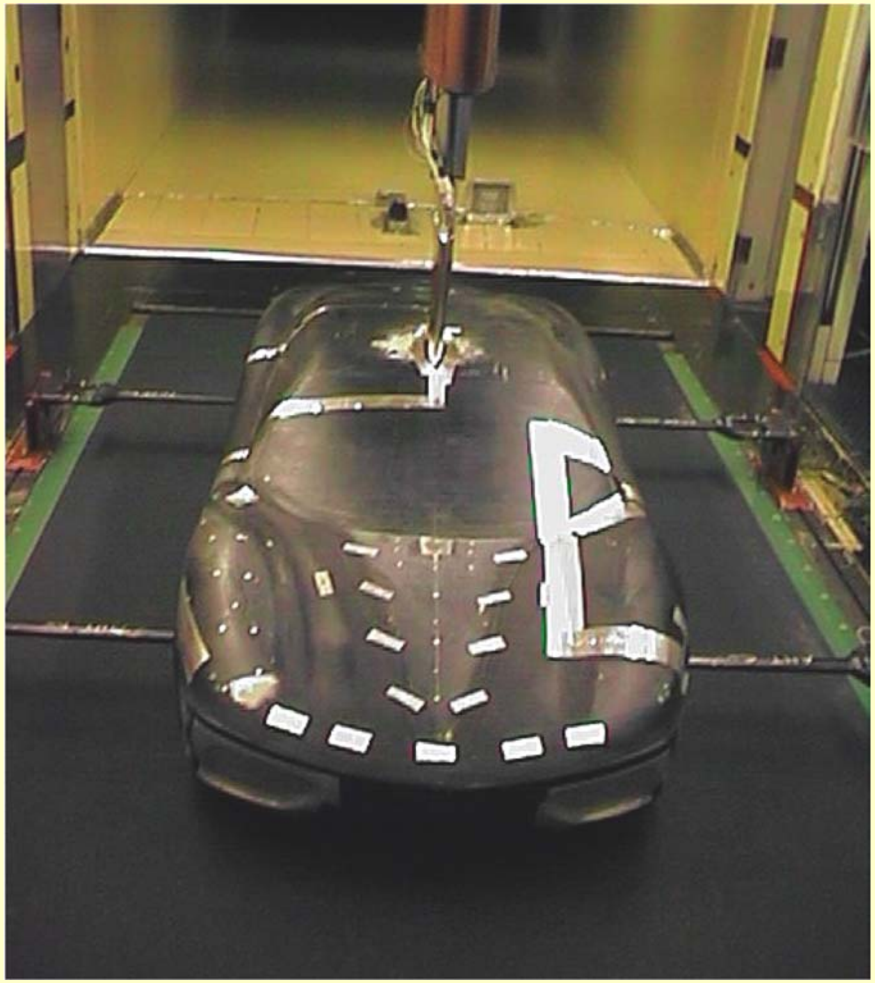
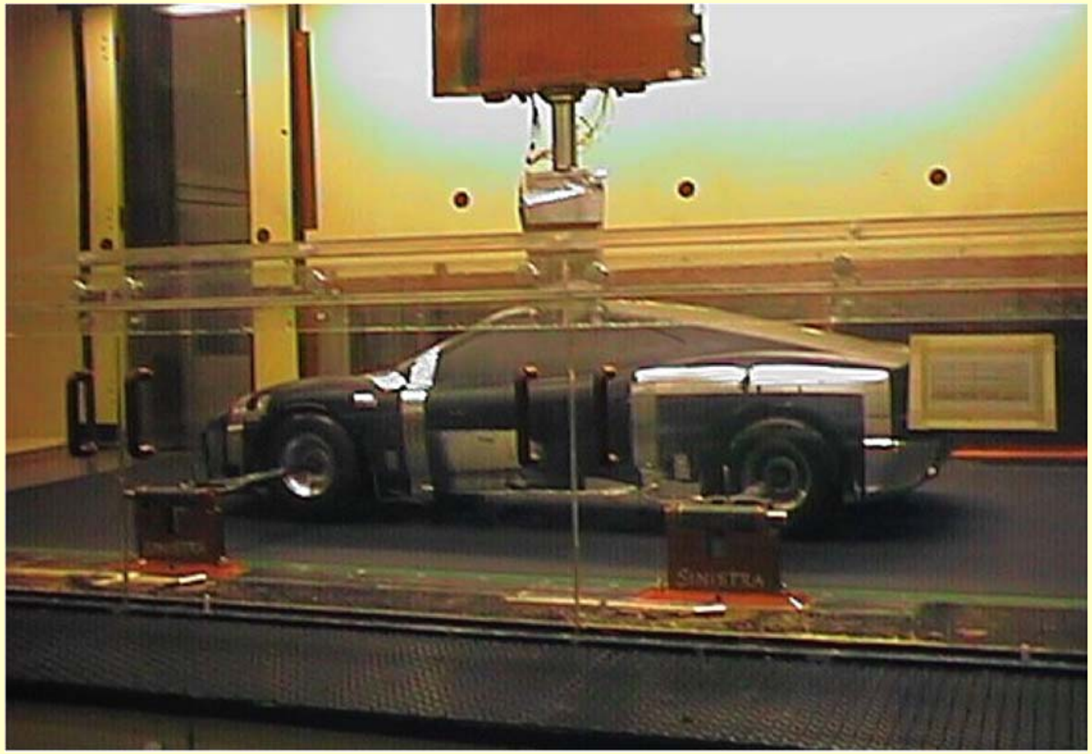
Different types of wheelhouse were analysed for different car attitudes relative to the ground



Wind tunnel test campaign





RESULTS

Modifications to the geometry of wheelhouses were devised which provided significant improvements

A strong correlation exists between wheelhouse geometry and underbody aerodynamics

⇓

An improvement of the wheelhouses implies a careful analysis of the flow on the car underbody, specially of the outflow from the front wheelhouse

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Objective of an aerodynamic optimization procedure:

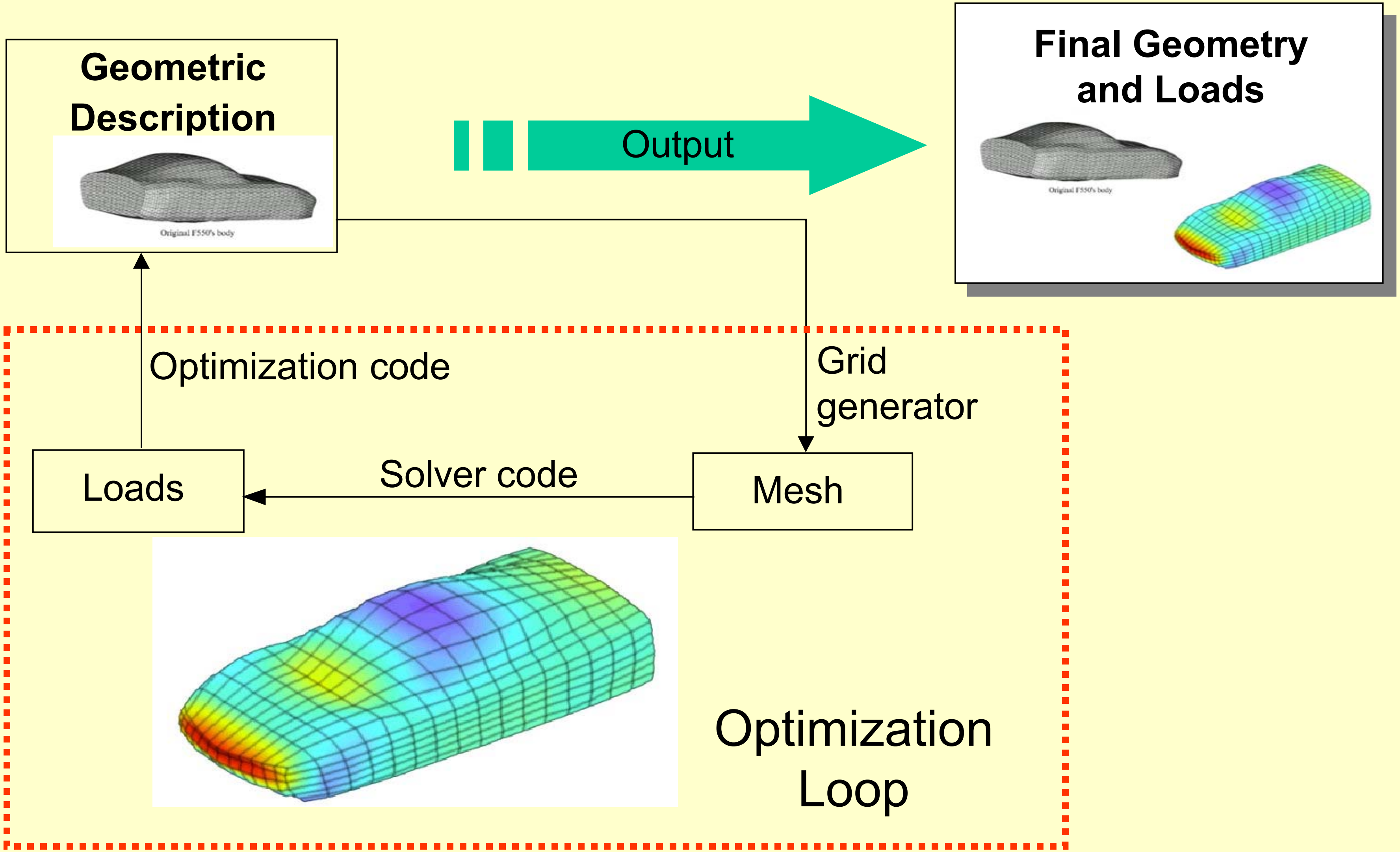
To devise a
NEW GEOMETRY OF THE CAR

MINIMIZING AN OBJECTIVE FUNCTION
linked to the car aerodynamic performance

TAKING A SERIES OF "CONSTRAINTS" INTO ACCOUNT:

- **Geometrical (style)**
- **Aerodynamic**
- **Technological**

Scheme of an optimization procedure



The evaluation of the aerodynamic loads must be repeated many times

⇓

The aerodynamic solver must be "unexpensive" as regards computational time, but sufficiently accurate

⇓

It is impossible (for the moment) to use codes for the solution of the Navier-Stokes equations (even RANS)

⇓

Modified "potential" methods

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"Potential" methods

Are much less expensive than RANS methods, but in principle may be applied only to "aerodynamic" bodies

However…

Investigations carried out by DIA showed that they may be used also for car shapes if the flow is attached until the body rear base and if the effect of the separated wake is adequately taken into account

⇓

The wake is modelled as a suitable continuation of the body

(wake model)

Optimized aerodynamic design

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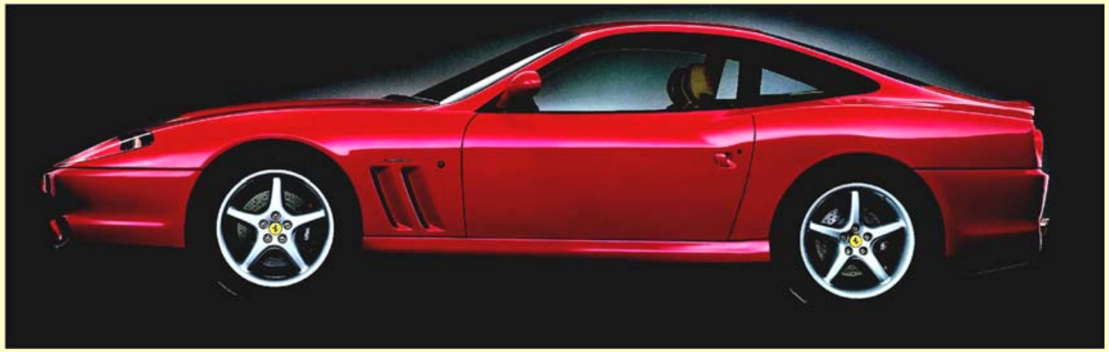

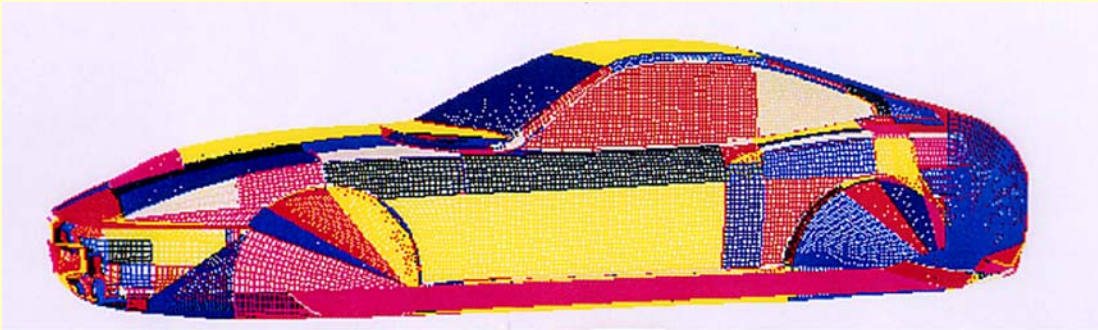

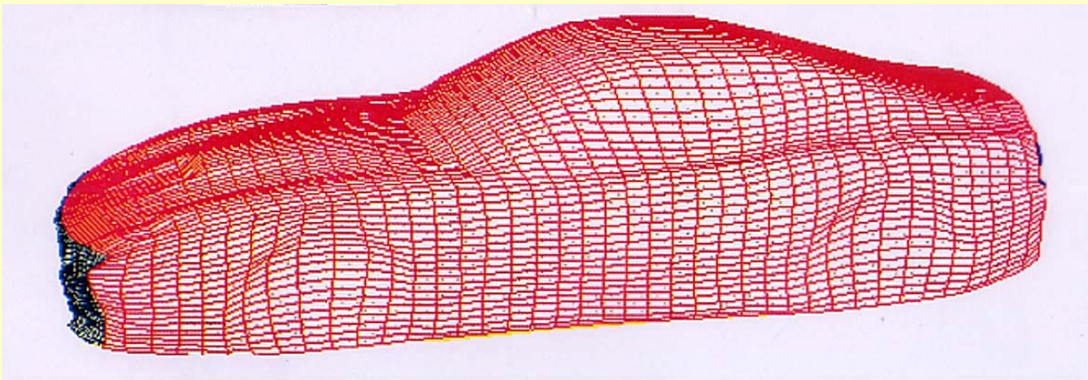

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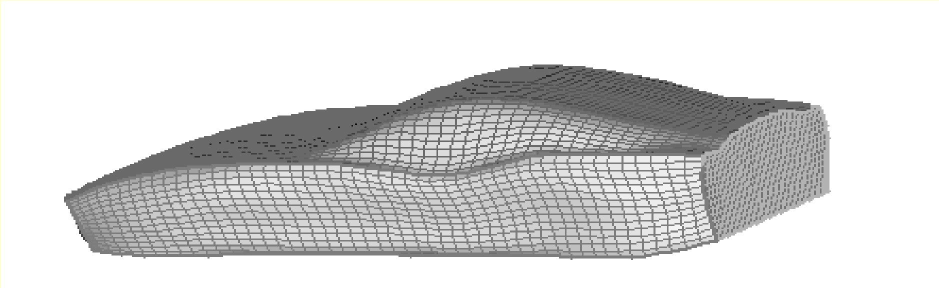
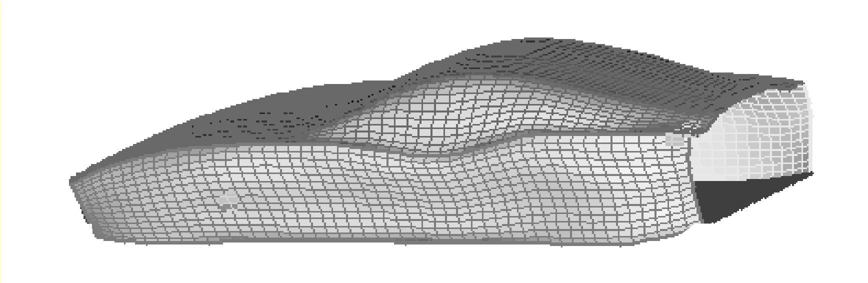
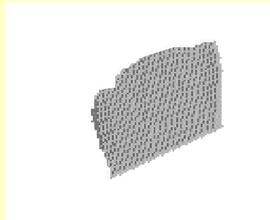
Optimized aerodynamic design



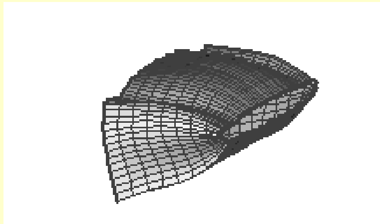
The car surface is divided in two parts



forebody

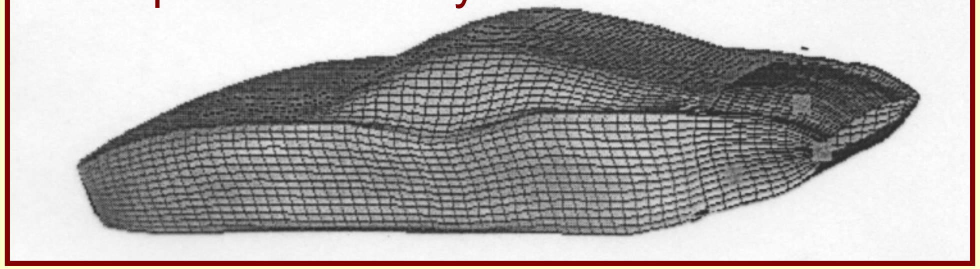


base



A "fictitious afterbody" is evaluated, using the "wake model"

Computational body



The "computational body" is:
the forebody +
the "fictitious afterbody"

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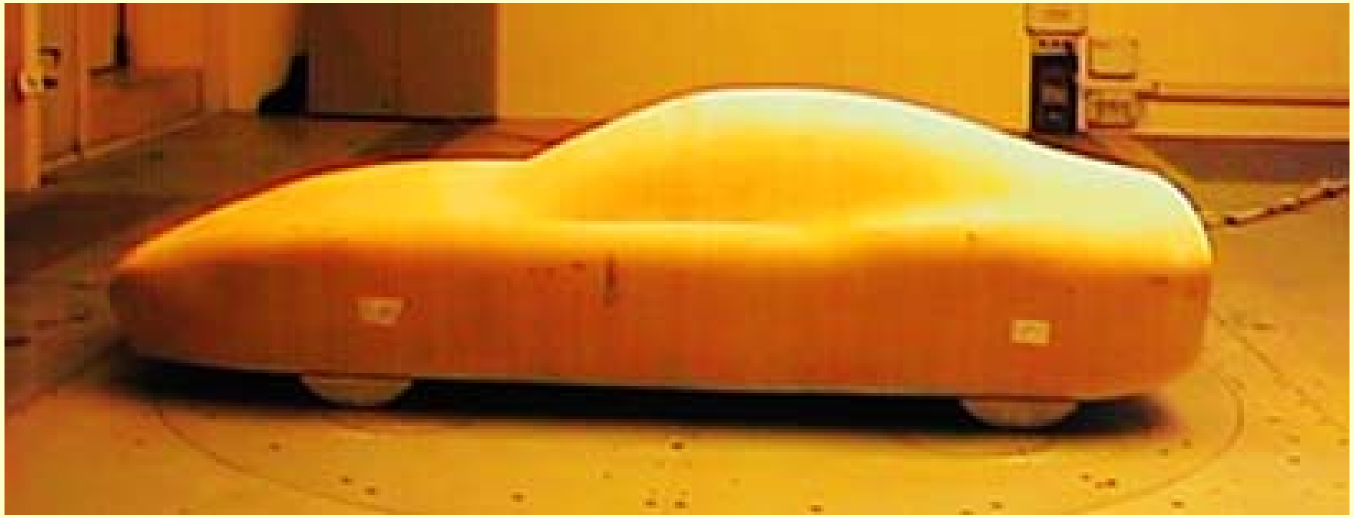
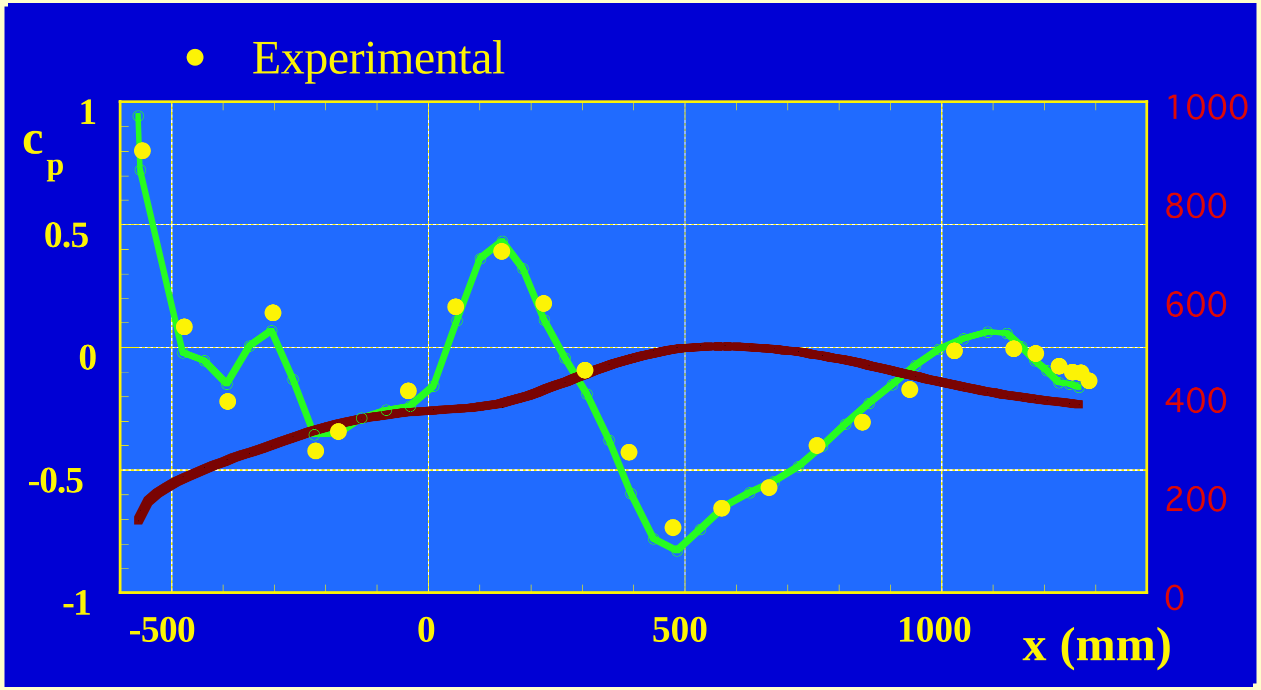
A WIND TUNNEL EXPERIMENTAL CAMPAIGN WAS CARRIED OUT TO VALIDATE THE PROPOSED SIMPLIFIED LOAD EVALUATION PROCEDURE

The shape and dimensions of the model were such that it could be considered a normal production car in 1:2.5 scale



Validation of the computational code



- **The comparison is very good**
- **The agreement extends to the end of the body, showing that the wake model works adequately**

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Validation of the optimization procedure

OBJECTIVE FUNCTION : VERTICAL LOAD

CONSTRAINTS:
- **Maximum aerodynamic drag**
- **Maximum displacement (3 cm in real scale)**

The "potential" code with wake model was used

THE WHOLE OPTIMIZATION PROCEDURE REQUIRED A ONE DAY WORK

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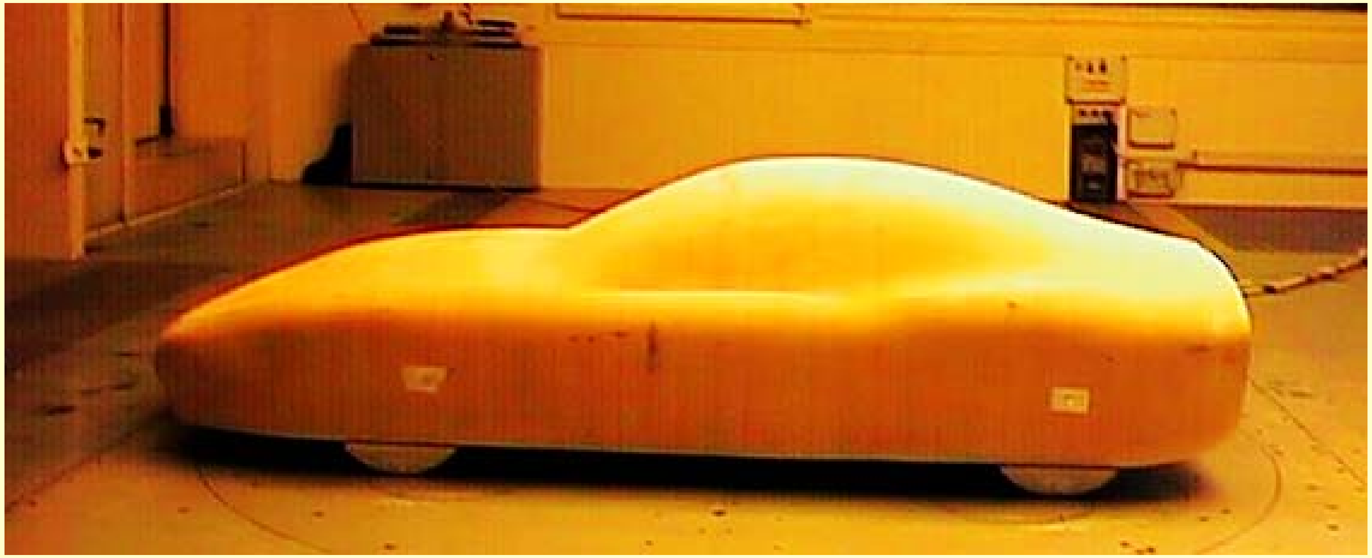
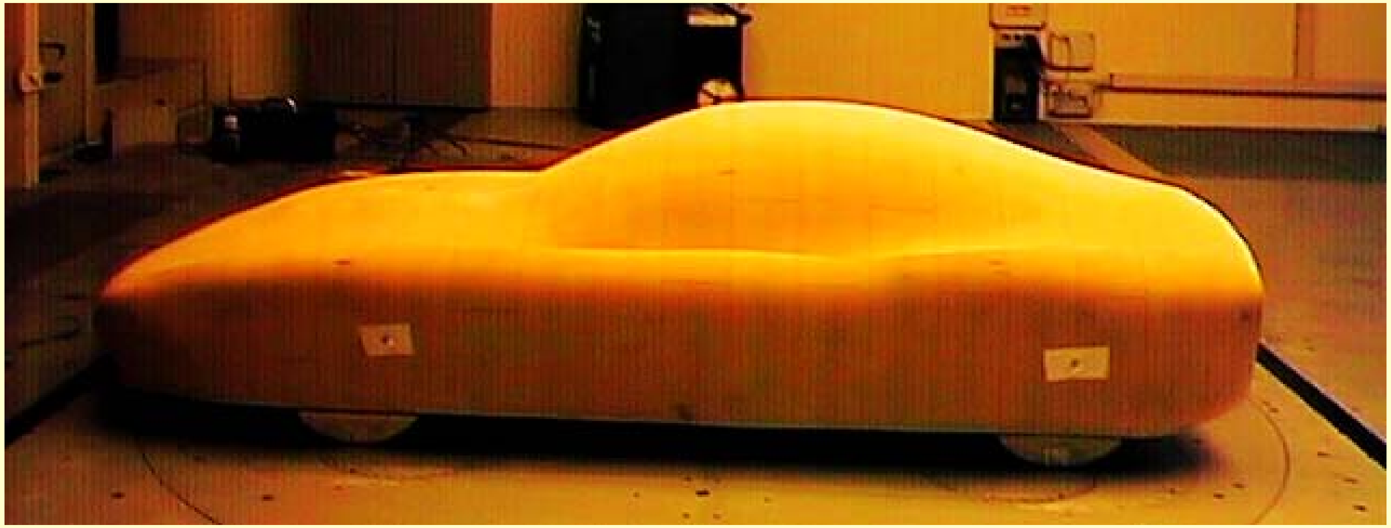
Comparison between original and optimized models

Original Model



Optimized Model



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Validation results

Wind tunnel experimental data

	Basic Geometry		Optimized Geometry
C_z	0.176	→	0.141
C_x	0.185	→	0.181

Load variations @ 280 Km/h

F_z = - 28 kg

16 cm x 1.5 m
Wing

F_x = - 3.5 kg

3 HP

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The aerodynamic optimization procedure has been introduced in the standard design process of the new Ferrari production cars

Style proposal (Pininfarina)

↓

Analysis with optimization procedure (Ferrari)

↓

Modification proposals

↓

New style proposal

↓

Model construction and wind tunnel tests

↓

Approval

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The synthesis of all the Ferrari aerodynamic know-how …

Ferrari Enzo

$C_z \cong -1.0$

Conclusions

The cooperation between DIA and Ferrari has produced:

- Increase in the Ferrari internal know-how and consequent direct involvement of Ferrari in the styling process of the new production cars
- Introduction at DIA of new basic aerodynamic research activities with applications in the automotive industry
- Opening of new occupational perspectives for graduated students

The expected future:

- Increased direct involvement of DIA in the design process of new production cars
- New interesting research topics

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A good aerodynamic design requires:

- **High basic and specific aerodynamic competence**
- **Search for physical comprehension**
- **Capitalization of acquired know-how**
- **Integrated design (team work):**

Clear and "realistic" definition of the aerodynamic specifications and of the technological and style constraints

Strong interaction between aerodynamic, style and production departments since the initial stages of the design process

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Some future research topics:

- **Increased know-how on the use of CFD (Navier-Stokes solvers) and their introduction in the optimization process**
- **Aerodynamics of cooling systems**
- **Increased understanding of and development of methods for the useful management of:**
  - **base flows (base drag)**
  - **locally-separated flows and vortical structures**
  - **interference effects**

  } **to produce know-how to be used when needed for new styles**
- **Study of “non-conventional configurations”**

THANK YOU FOR YOUR ATTENTION!