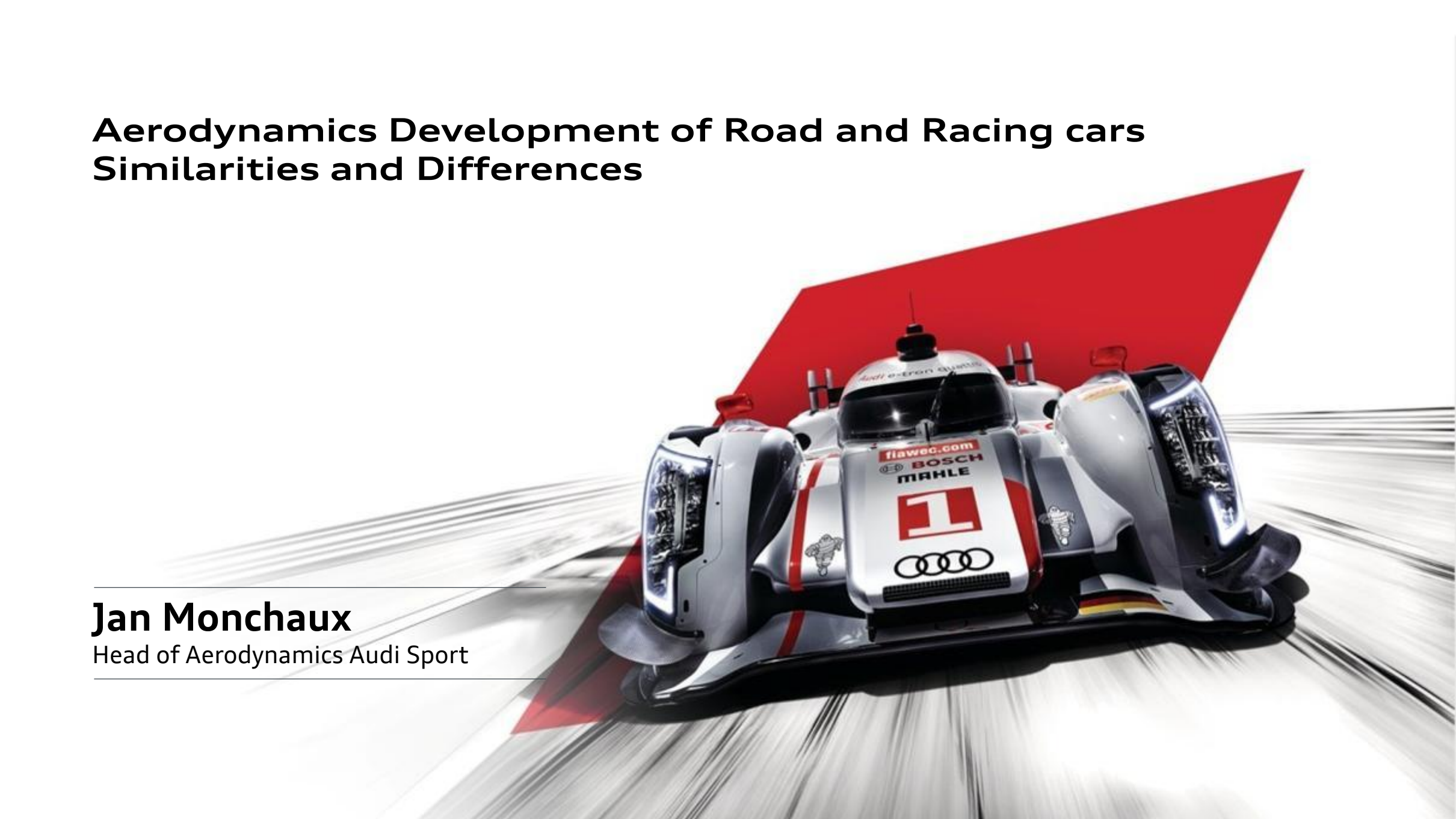
Aerodynamics Development of Road and Racing cars
Similarities and Differences



Jan Monchaux
Head of Aerodynamics Audi Sport

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

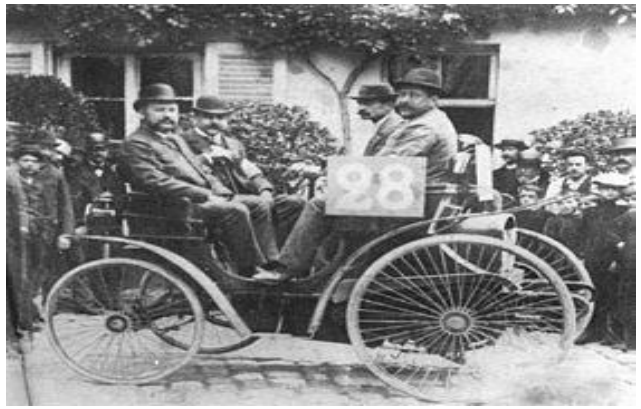
Contents

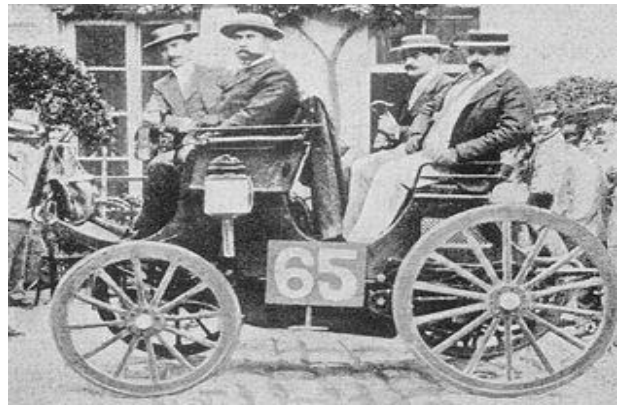
- Introduction
- Challenges and Targets
- Simulation (CFD)
- Wind Tunnel Testing
- Conclusions

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Introduction

- In the early days of the automotive industry…
  - Race cars were road cars.
  - Races were more a parade to demonstrate reliability & expertise of the car manufacturers.
  - Aerodynamic drag became rapidly of importance in order to increase $v_{max.}$



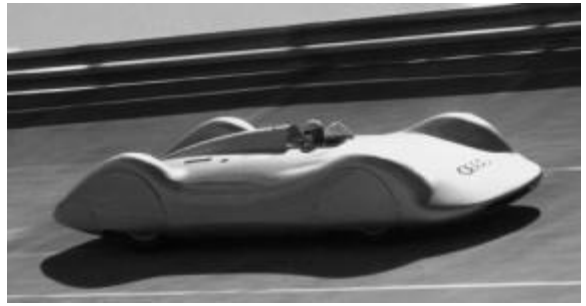


Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Introduction

- From the 30s until the 50s…
  - Manufacturers started to design and produce dedicated race cars reaching impressive top speeds.
  - A period in which the relationship between body shape and aerodynamic drag was intensively investigated.

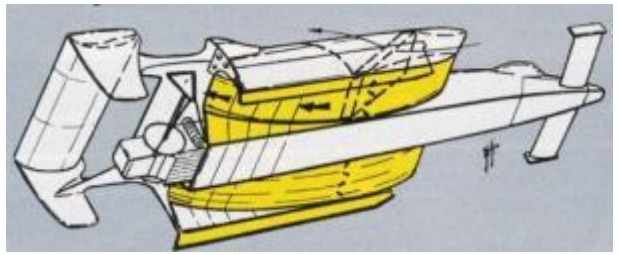




Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Introduction

- From the 60s onward…
  - Rear wings, front wings and ground effect concept all generating downforce and thus increasing tire grip and cornering speed implemented on race cars.
  - None of these solutions retained for road cars.
  - This period was the beginning of the divorce between the aerodynamics of road and racing cars even if drag reduction remained important in race cars.



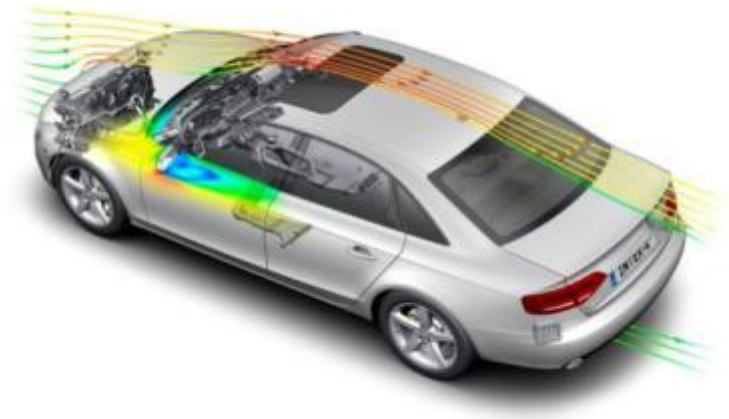
Aerodynamics Development of Road and Racing Cars
Similarities and Differences

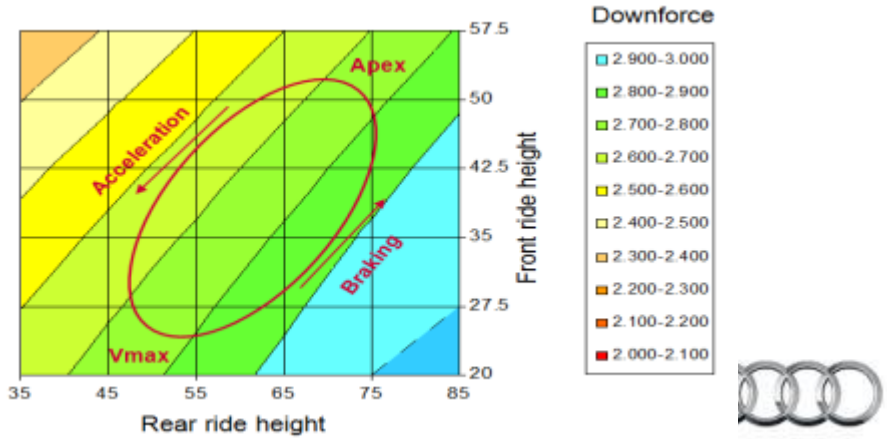
Introduction

- Today and tomorrow…
  - Similarities?
  - Insuperable differences?
  - Reunion possible? Needed?

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

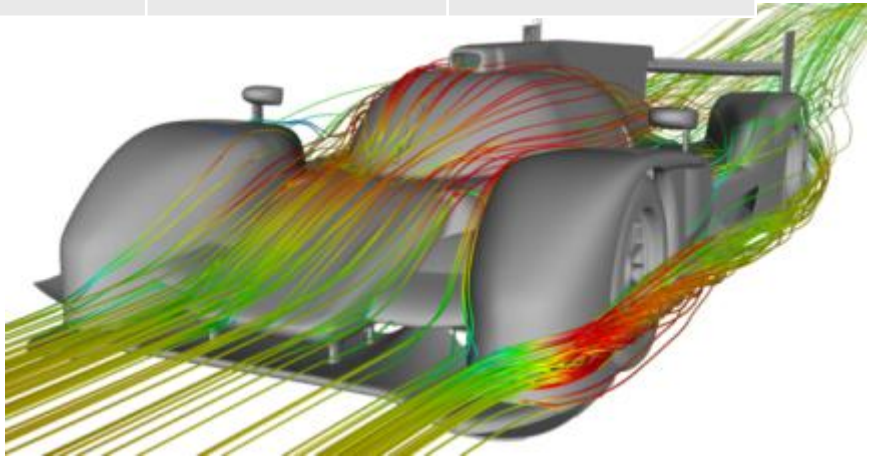
Challenges	Road cars	Racing cars
Flow topology highly 3D, asymmetric, separated & time dependant	++	+++
Strong interactions between inner & outer flow	++	+
Complex & large multidimensional motion of envelop (n>6)	+	+++
Aerodynamics mainly influence & restricted by stylist demands, packaging, law limitations…	+++	+
AeroD acoustics	+++	o
Cooling air & cabin conditioning to be ensured	+++	+
Extreme ground proximity	o	+++
Complex deformation of shape & contact patch of tires	o	+++





Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Targets	Road cars	Racing cars
Minimize Cx (→ reducing CO_2-emissions)	+++	+
Reducing noise (increases comfort)	+++	o
Improve stability (minimize lift & side forces)	++	+++
Minimize Cx variations between all car configurations (from the portfolio)	+++	o
Opimum Cz / Cx ratio	+	+++
Optimum „drivability“ & maximum cornering limit speed	+	+++
„just enough“ cooling & „just enough“ air for engine	++	+++
Stable, robust & safe solutions	+++	+++



Aerodynamics Development of Road and Racing Cars
Similarities and Differences

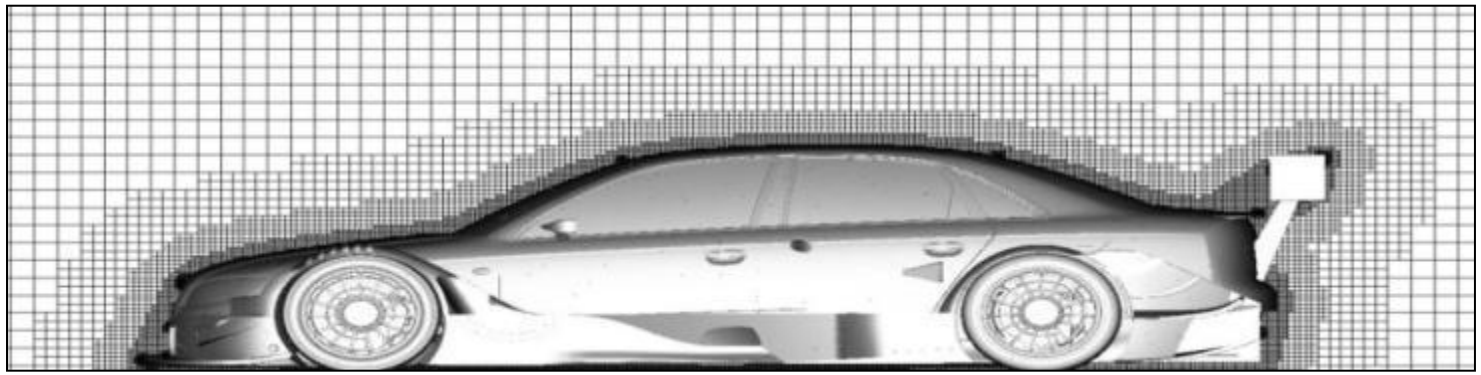
Simulation (CFD)

- **Road Cars**
  - Very early phase to develop the optimum body shape; later to analyze flow details
  - Primarily LES simulations
  - Mainly outer flow, detailed body and underbody, selectively with detailed under hood
  - Simulation of wind tunnel conditions:
    5 belt system, narrow center belt + rotating wheels
  - Still critical:
    - turbulence modeling
    - inner / outer flow
    - convergence
    - tire deformations and details

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Simulation (CFD)

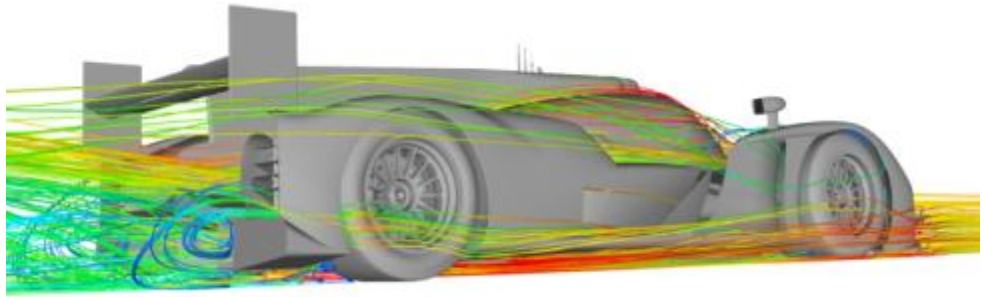
- **Racing Cars**
  - CFD for race cars is part of standard development process
  - Primarily SS RANS modelisation
  - Evaluation of concepts in early development phase
  - „Optimization“ of concepts before wind tunnel test
  - Additional information to wind tunnel data (pressure mappings, local forces, flow topology…)
  - Thermal management & optimization



Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Simulation (CFD)

- **General Requirements for „successful“ usage of CFD (Racing + Road Cars)**
  - Highly detailed CAD model (external surfaces & internals)
  - Adequate deformed tire shape & contact patch
  - Modeling of radiators (porous medias), air inlet for engine (outlet) & exhaust gas (inlet), correct boundary conditions when needed (temperatures, density)
  - Ground simulation & rotating wheels (MRF-Model)
  - Mesh quality & size: Typically 50 – 100 Mio Cells (racing cars half model, road cars full model)
  - Adequate solver choice:
    Usually stationary incompressible RANS with adequate turbulence model (racing) or LES (road cars)
  - Short turn around & high accuracy of results (good correlation to experiment)



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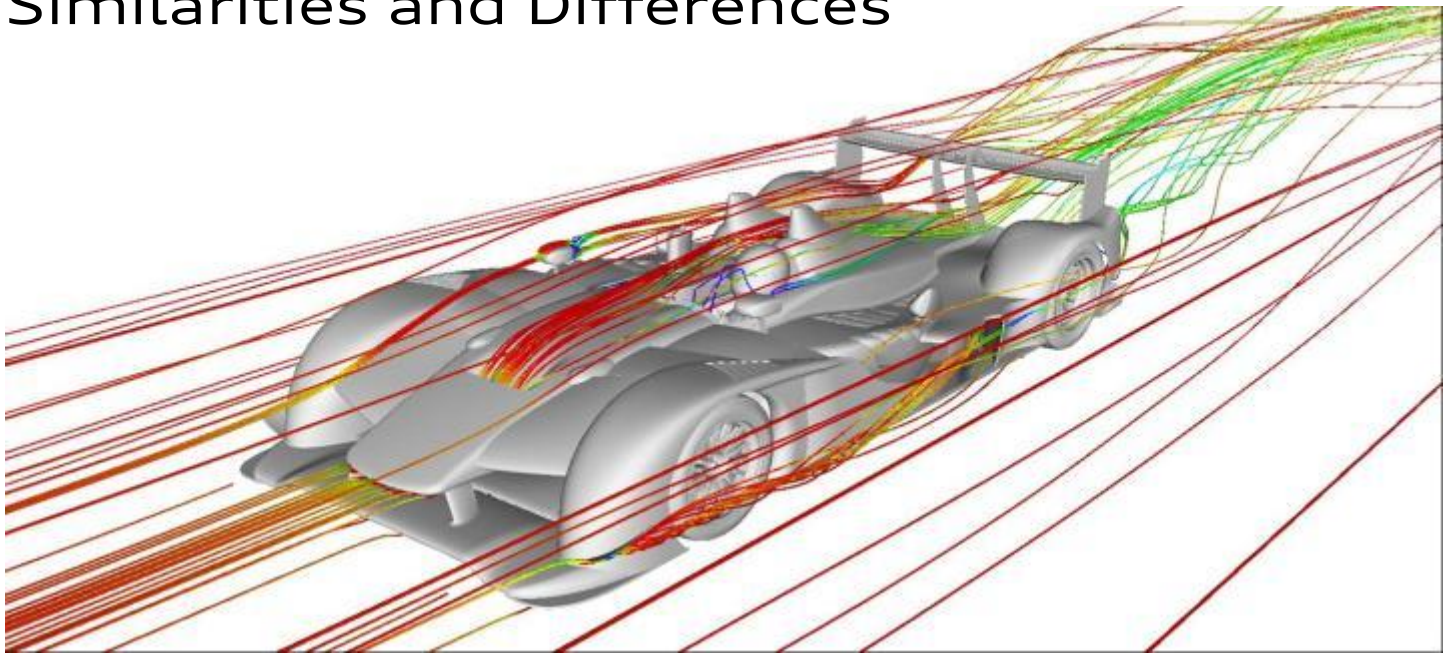
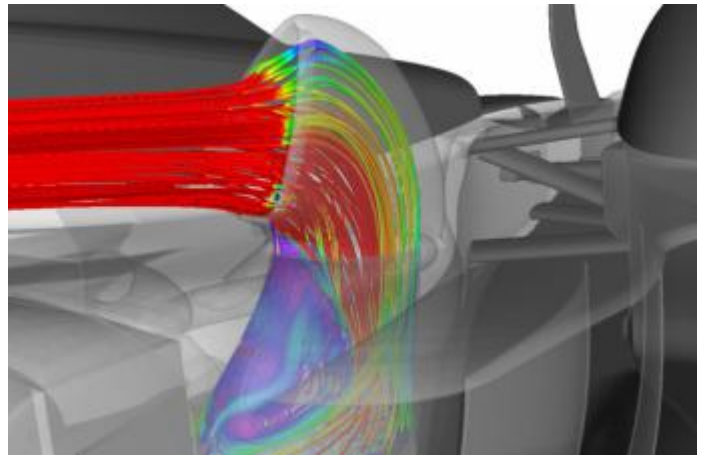
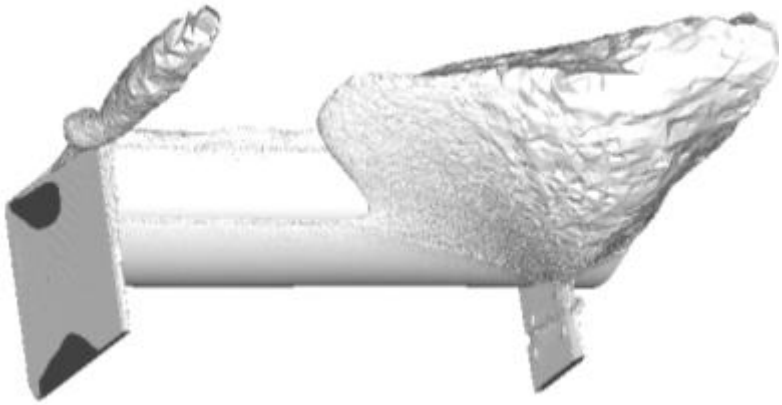


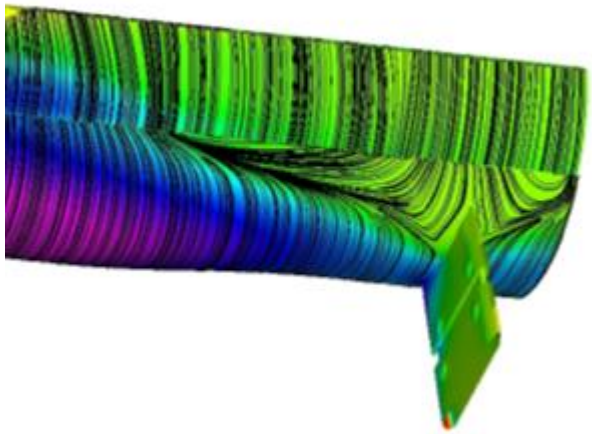
Typical flow visualisation based on CFD calculations

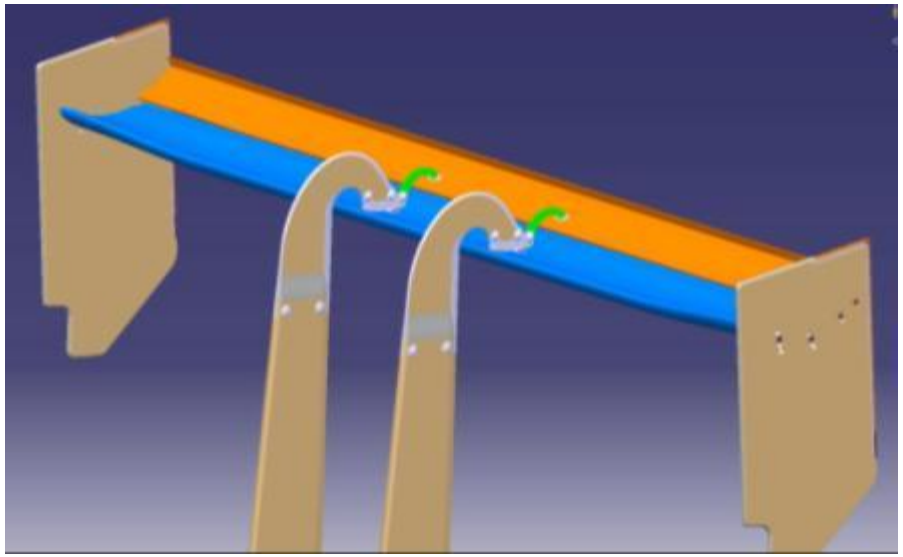


Engine air inlet optimisation

Aerodynamics Development of Road and Racing Cars
Similarities and Differences







Rear wing separation induced by pillar on the suction side of the profiles
-> solved with the Swan pillars

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Wind Tunnel Testing

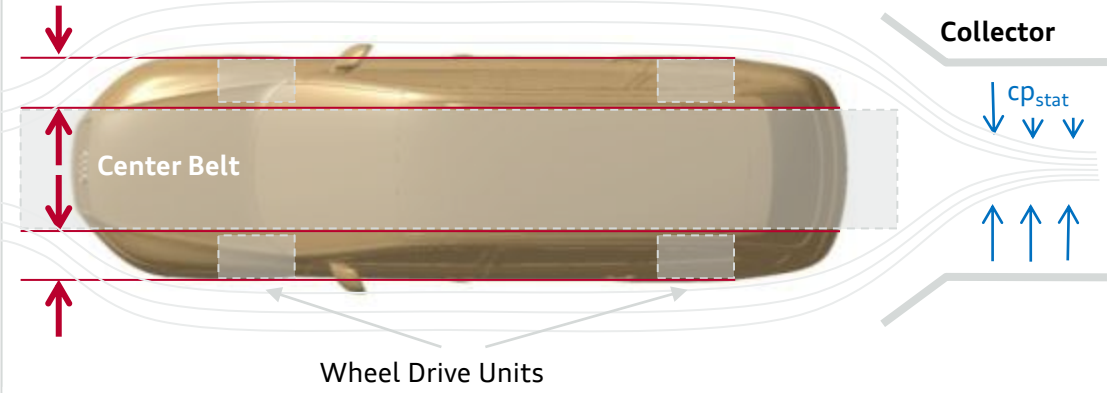
Model with or w/o wheel arms

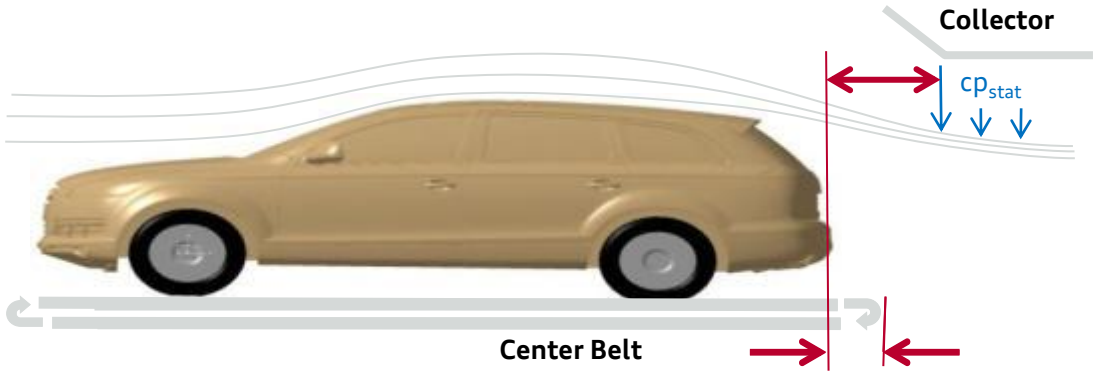
Clay model

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

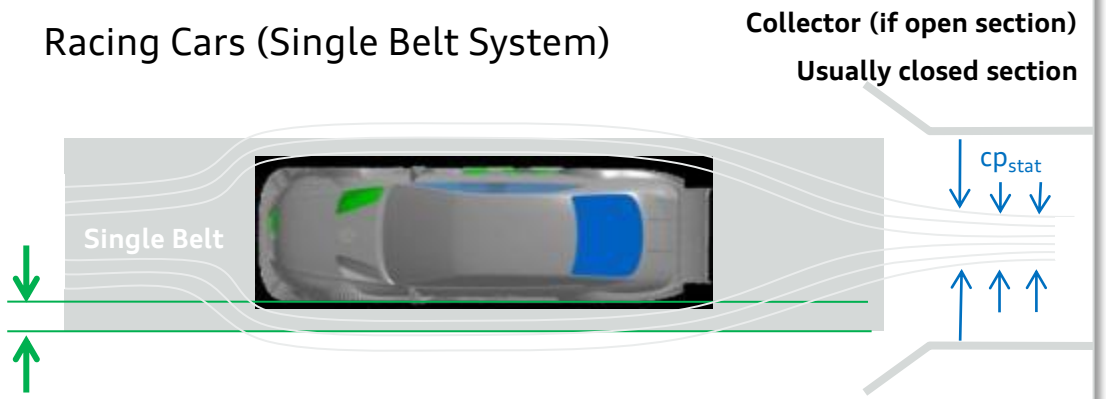
Wind Tunnel Testing

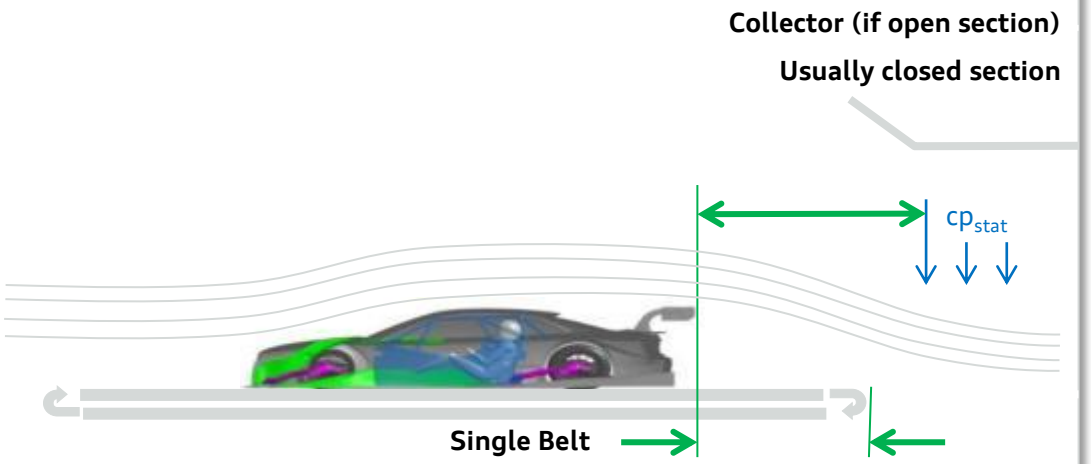
- Road cars (5 belt system)





- Racing Cars (Single Belt System)





Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Windtunnel testing	Road cars	Racing cars
25% or full scale clay models	+++	o
50% or 60% models	o	+++
Highly detailed model (external & internal flow, radiators, brake discs...)	+	+++
5 belt system with open test section	+++	o
Single belt rolling road with rotating wheels	o	+++
Easy and fast car change (simple fixation)	+++	+
Easy and fast change of parts	+	+++
Parametric approach for optimization („puzzle“ principle) with intensive usage of rapid prototype (rest of model out of carbon, steel and aluminium)	o	+++
Improvisation on the „fly“	+++	+
Development at fixed speed	++	+++
Highly detailed motion envelop to properly cover „real“ attitudes of car	+	+++
Advanced measurement equipment in model (pressure, local loads...)	+	+++
High overall repeatability	+++	++

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Wind Tunnel Testing

- **Road and Racing Cars wind tunnels**

  - Full scale (FS) testing in wind tunnel less frequent (blockage issues, modifications too late in development)
    → aerodynamic mapping possible
  - Climatic FS testing even less frequent
    → verification of sealing, wiper…

Aerodynamics Development of Road and Racing Cars
Similarities and Differences

Conclusions

- Motorsport aerodynamics made impressive improvements over the last 10 years thanks to enormous budget in F1
- Many methods commonly used in F1 & LMP1 could be partially transferred to the road car development
    - Intense usage of steady state calculations in CFD (without neglecting the transient ones)
    - Extremely detailed CAD models for CFD
    - More accurate WT models (including internals, tyres, suspensions)
    - Detailed & accurate modeling of the tyres for CFD & WT
    - Usage of rapid prototype in WT (reducing the %tage of clay)
    - Single belt testing in WT with underbelt load cells
    - WT strategy (simulation of all critical phases seen by the car)
    - ...
- Huge potential to speed up and improve the processes provided the engineers in charge open their mind
- These synergies will then on mid / long term have positive impacts on motorsport development (LES calculations for instance)

Thank you !