OPEN SOURCE CFD SUCCESS IN EUROPEAN AND AMERICAN AUTOMOTIVE INDUSTRY SOLUTIONS

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- ICON overview
- iconCFD applications I
- iconCFD applications II
- Success stories

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ICON COMPANY

- Independent, Private
- CFD advisors since 1992
- Imperial College, London
- International
- Scalable
- Flexible

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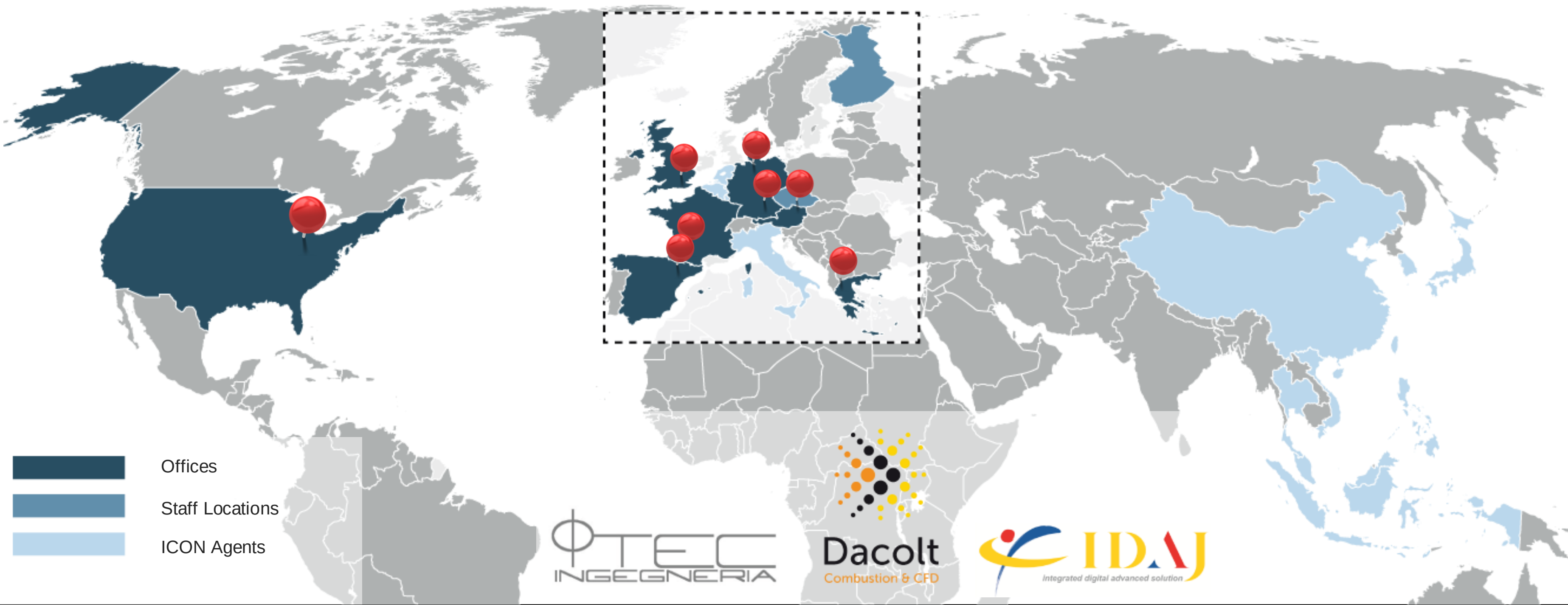

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ICON WORLDWIDE
HUMAN RESOURCES

- 100+ CFD-specialist Staff
- 15 developers dedicated to industrial support of open source CFD processes
- Collaboration network of specialist developers, consultants, academics
- 200+ staff in total
- Recruiting talent

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- CFD Consulting
- Training
- Integrated Technology/Process
- Proprietary & Open Source

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ICON CUSTOMER SAMPLE

Automotive

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SEAT Centro Técnico

Automotive supplier

BEHR

Oil & Gas

Shell

OMV

Rail transportation

SIEMENS

BOMBARDIER TRANSPORTATION

Aerospace

AIRBUS AN EADS COMPANY

DLR

Built environment

SL-RASCH GMBH

ARUP

Defence & Security

[dstl]

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ICON MOTO

Complete Process Framework

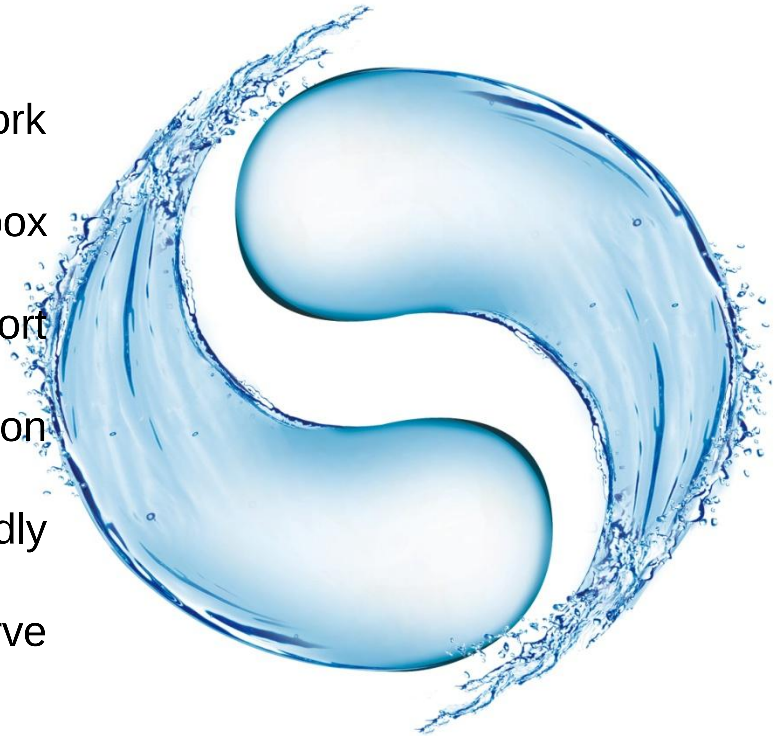
Interrelated Toolbox

Direct support

Documentation

User friendly

Steep learning curve



Low costs

Unlimited scalability

100% Customisable

Hands on exploration

Independence

"Best of both worlds"

Proprietary - Open Source

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AUTOMOTIVE APPLICATIONS

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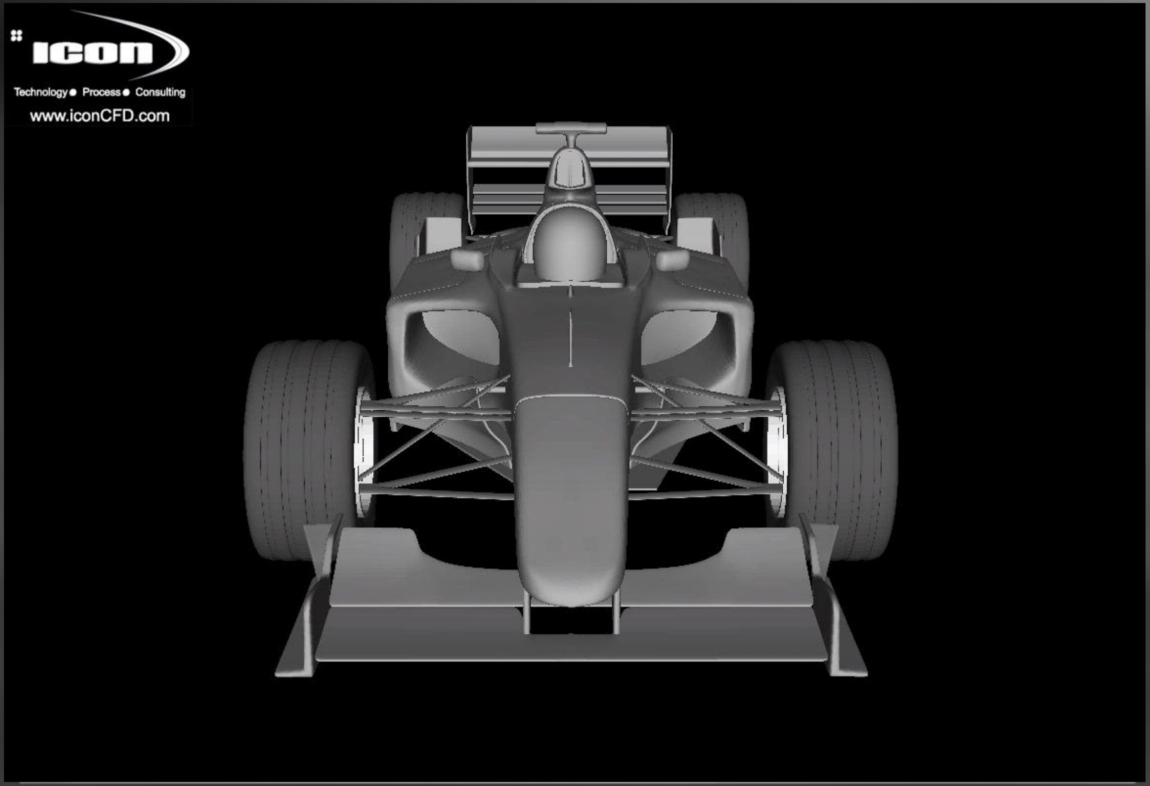
- Chemical
- Oil
- Paper
- Rail
- Consumer Products
- Defense



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AERODYNAMICS
APPLICATIONS

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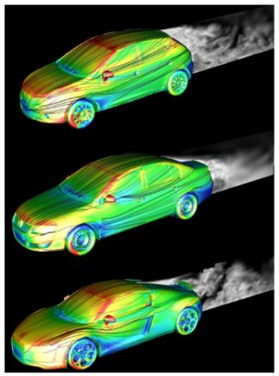
AERODYNAMICS
ACCURACY

the wheels — but the fine structures are not damped out.



	Δc_D [-]	Δc_{Lf} [-]	Δc_{Lr} [-]
SEAT Ibiza	0.018	-0.017	0.045
SEAT Leon	0.021	-0.005	0.030
VW Golf	0.003	0.034	0.024
VW Passat	0.011	-0.033	0.035
VW New Beetle	0.016	0.001	0.030
Audi A3	0.007	-0.018	0.034
Audi A5	0.011	-0.036	0.031
Audi A6	-0.004	0.002	0.026
Audi Q5	-0.001	-0.006	0.047
Audi TT	-0.001	-0.006	0.051
Audi R8	0.022	0.021	-0.012

Table 3: Comparison of predicted aerodynamic coefficients with experiment for range of vehicles

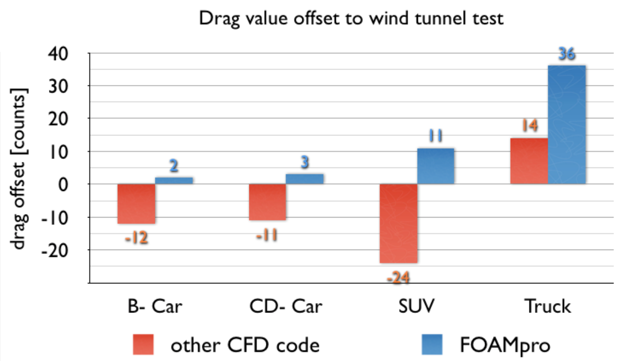
table shows that, on the whole, good accuracy is obtained for the prediction of drag coefficient over the whole range of vehicles. A few notable exceptions can be identified, however. Both SEAT vehicles suffer from a significant overprediction in drag that is not observed in the other squareback vehicles in the suite. Closer investigation of these particular cases is required to ascertain the source of the discrepancy, including a verification of the exact correspondence of all the details of the simulated geometry to that of the vehicle tested in the wind tunnel. At 16 counts, the error in the prediction for the Volkswagen New Beetle is also quite high. This result can likely be attributed to the fact that the aerodynamics of this particular vehicle are dominated by pressure–gradient driven separation at the round rear surface of the vehicle, always a particular challenge for any CFD methods that employ

Presented at SAE World Congress 2009

(SAE 2009-01-0333)

Efficient, high accuracy, robust simulation methodology for usage in production

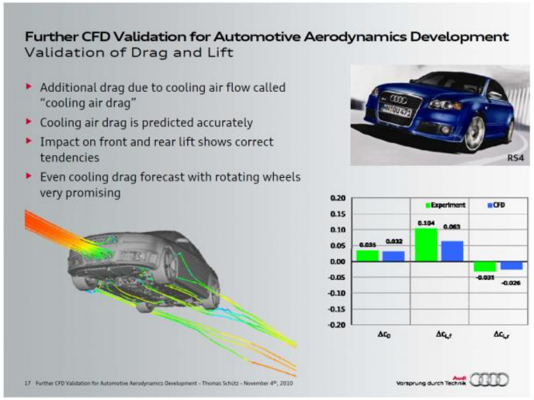
Robust and fast meshing of complex geometries



Presented at SAE World Congress 2011

(SAE 2011-01-0163)

DES validated with wind tunnel data, and compared to proprietary CFD codes.



Full presentation available online : https://www.opensourcecfd.com/conference2010/

"Further CFD Validation for Automotive Aerodynamics Development" – Thomas Schütz - AUDI

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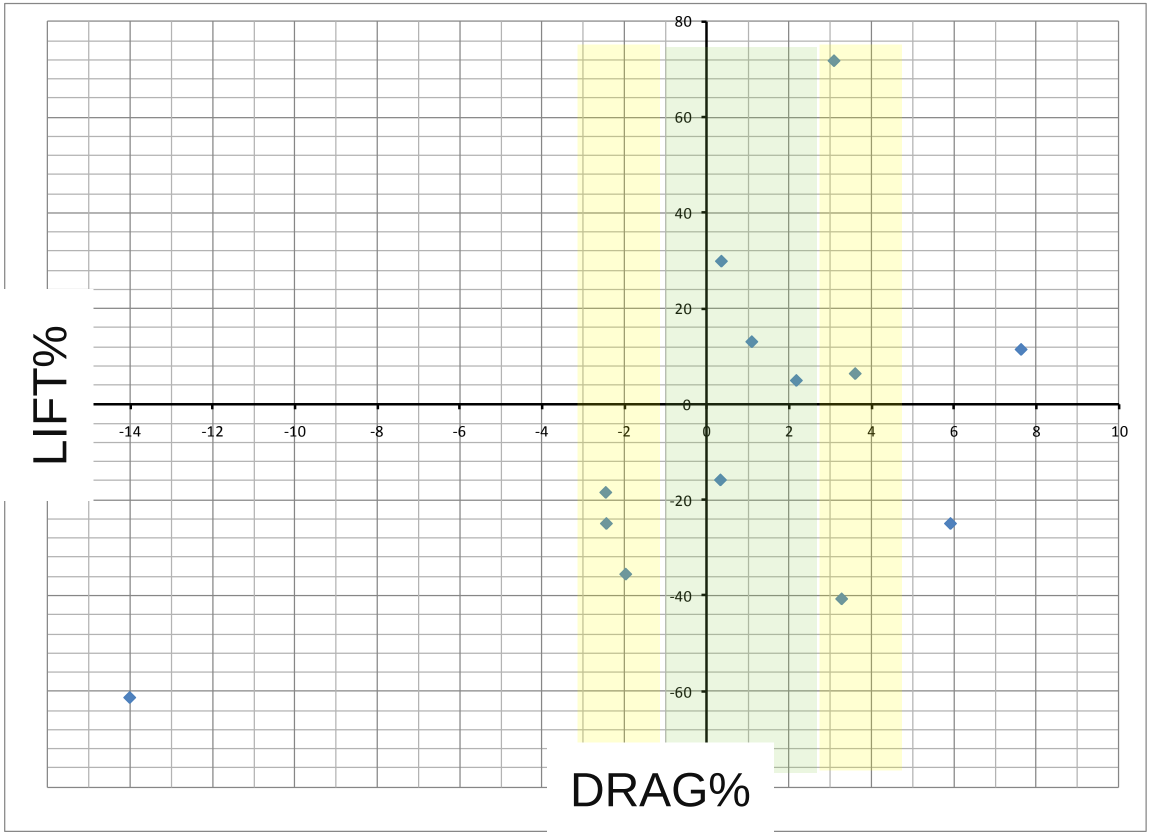
AERODYNAMICS
ACCURACY

About 40% of results are within 2% accuracy in Drag.

+85% of results are within 4% accuracy

Absolute drag value prediction

Consistent relative Aerodynamics predictions



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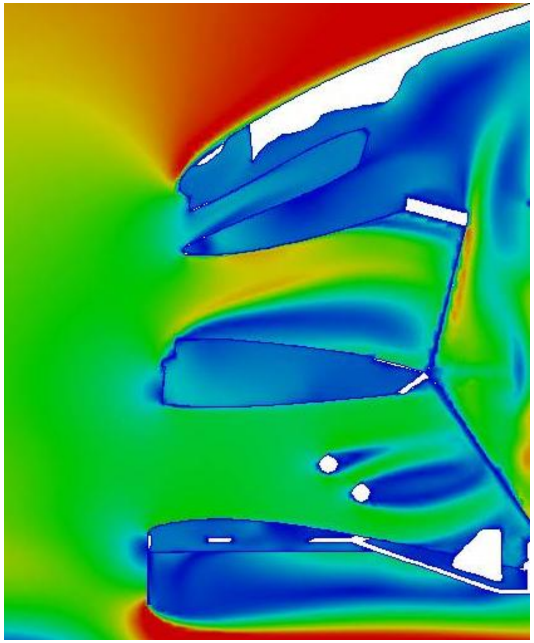
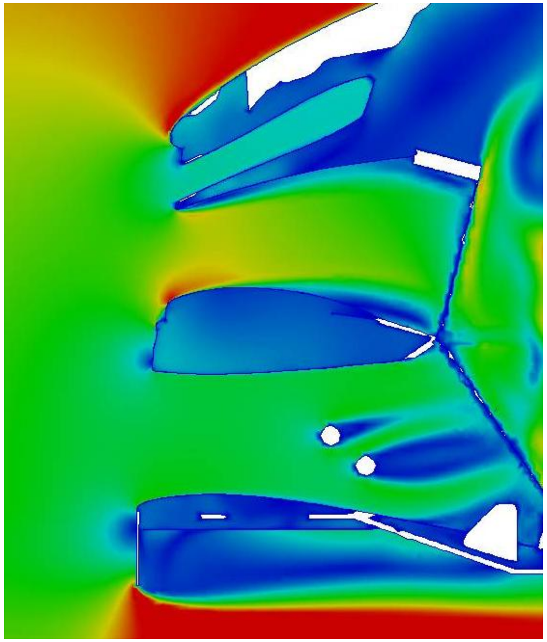
UHTM
ENGINE COLD FLOW





Underhood flow optimisation

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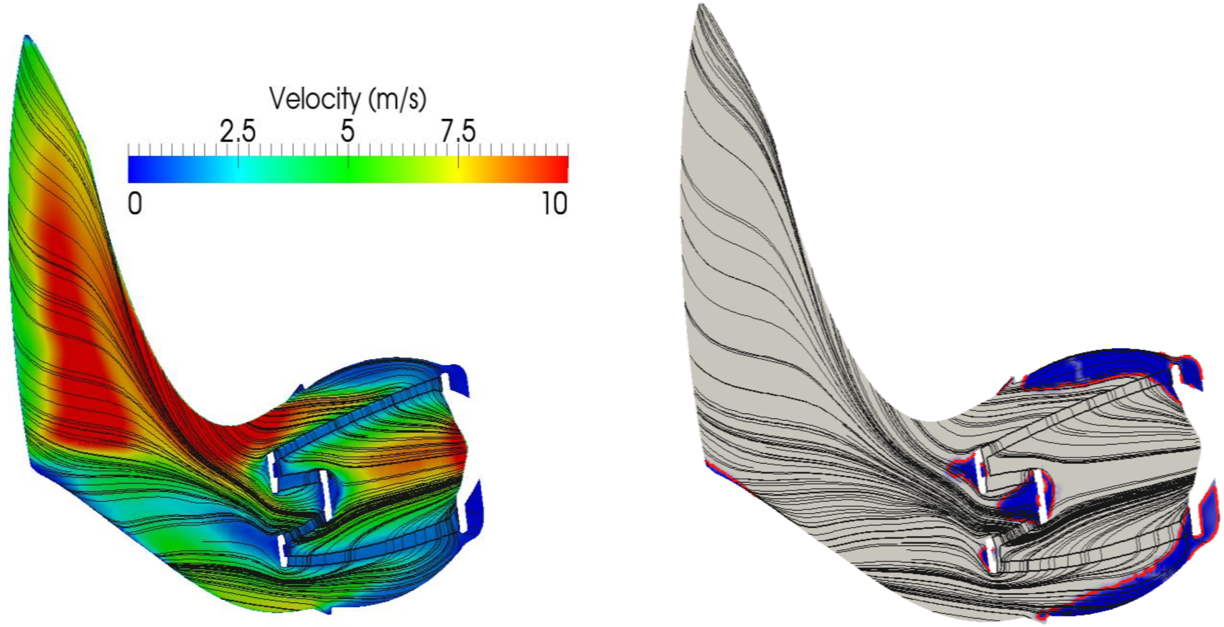
UHTM
ENGINE COLD FLOW - INTAKE



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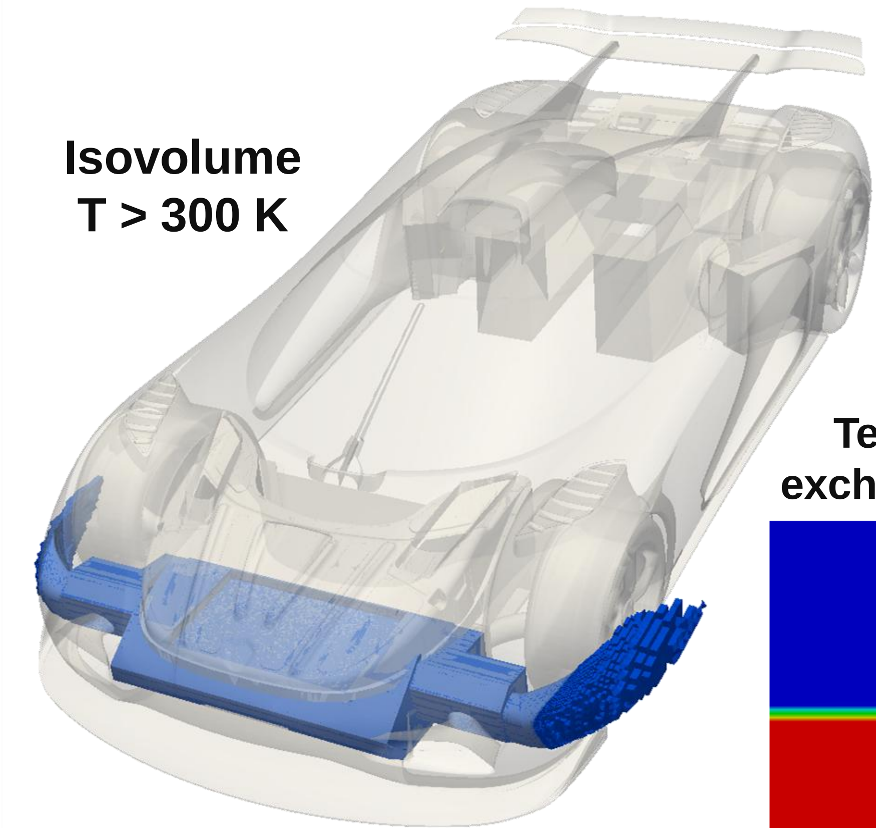
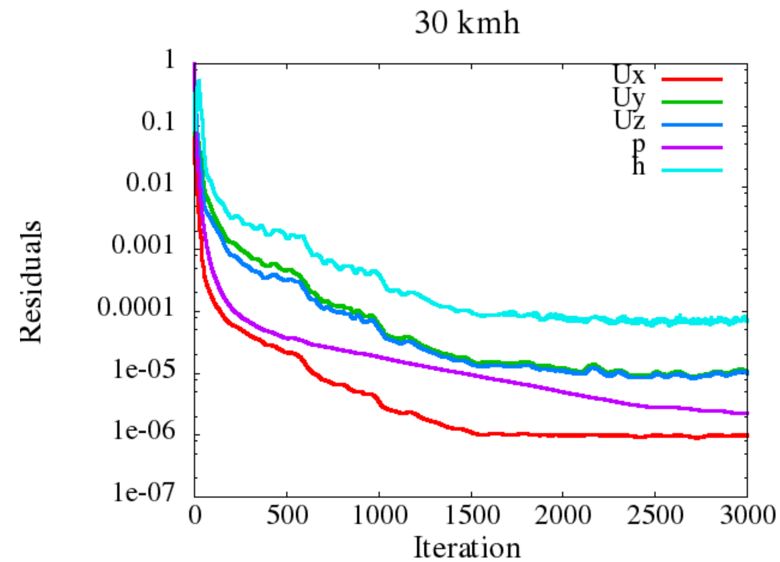
UHTM
HOT FLOW

Isovolume
T > 300 K





Temperature evolution in the heat exchanger (RAD) – 2 rows x 4 columns

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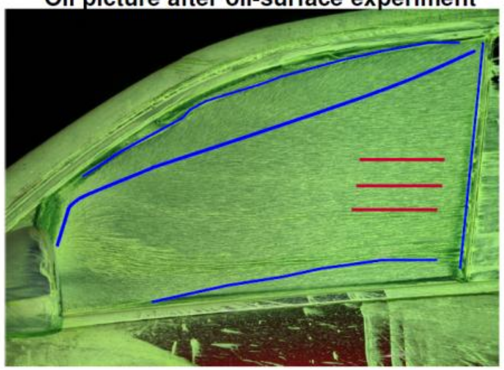
AERO ACOUSTICS

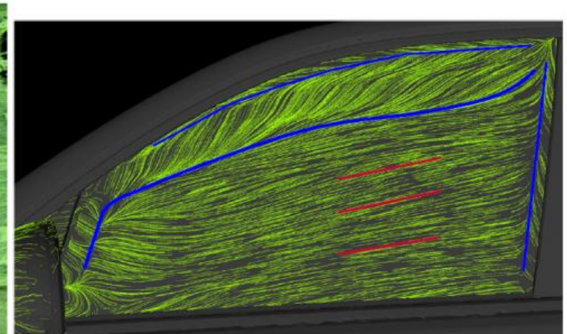
FLOW STRUCTURE

Status: Aeroacoustics - Comparison of Reality and Simulation at side window

Reality
Oil picture after oil-surface experiment



Simulation



Remarks:

- Vortices caused by the A-pillar coincide.
- Recirculation areas could be simulated well.
- Streamlines of simulation are not horizontal.

Seite 20

EK TECHNISCHE ENTWICKLUNG
Entwicklung Aufbau Funktionsauslegung Ausstattung und Methoden, EKAB

Presented by VW at ICON Open Source CFD International conference (OSCIC) in 2011
Full presentation available online : https://www.opensourcecfd.com/conference2011/
Applications Of OpenFOAM® In Automotive Industry – R. Sundermeier - VAG

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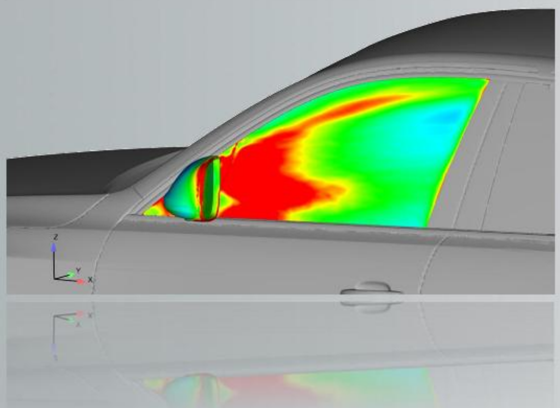
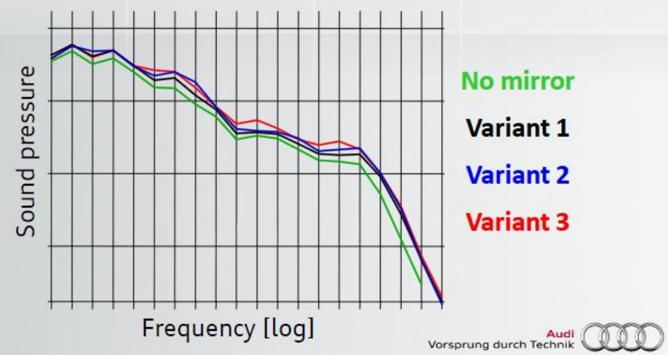
AERO ACOUSTICS PRACTICAL APPROACH

Case 2: Audi Q5



Variant	Intensity index	Ranking CFD	Ranking measurement
No mirror	0.049	1	1
Variant 1	0.059	2	2
Variant 2	0.061	3	3
Variant3	0.074	4	4



12 Dr. K. Zens, AUDI AG, OSCIC 2012

Audi Vorsprung durch Technik

Presented by AUDI at ICON Open Source CFD International conference (OSCIC) in 2012 Full presentation available online : https://www.opensourcecfd.com/conference2012/ Open Source CFD Applications for Aerodynamics at AUDI; Dr. Kentaro Zens AUDI AG.

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iconCFD
KEY TO SUCESS?

Low pre-processing effort

Fast setup

Parallel mesher and solver

Fast turnaround time

Body fitted mesh

Navier-Stokes numerics for attached flows

Cost-efficient

"Best of both worlds"

LBM like Process - Navier Stokes Solver

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iconCFD OPTIMISATION

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OPTIMISATION
CHANGE IN PARADIGM

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OPTIMISATION
CHANGE IN PARADIGM

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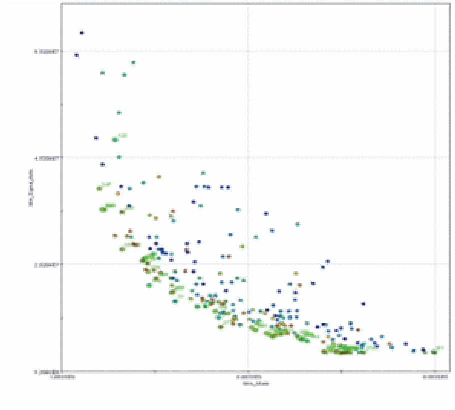
Multi-objective

Discrete & continuous parameters

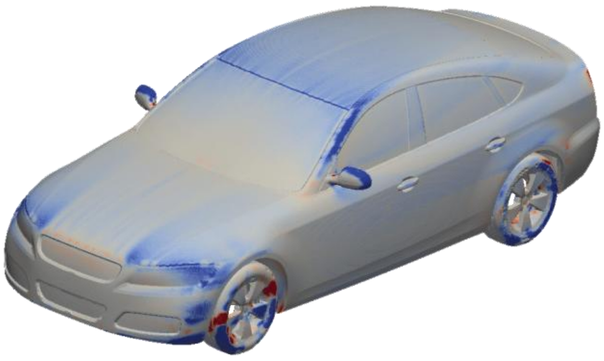
Ability to introduce construction constraints



Low Computational Cost

Continuous local sensitivity in every point of the domain

Feasibility to get to non-intuitive solutions



STOCHASTIC - ADJOINT

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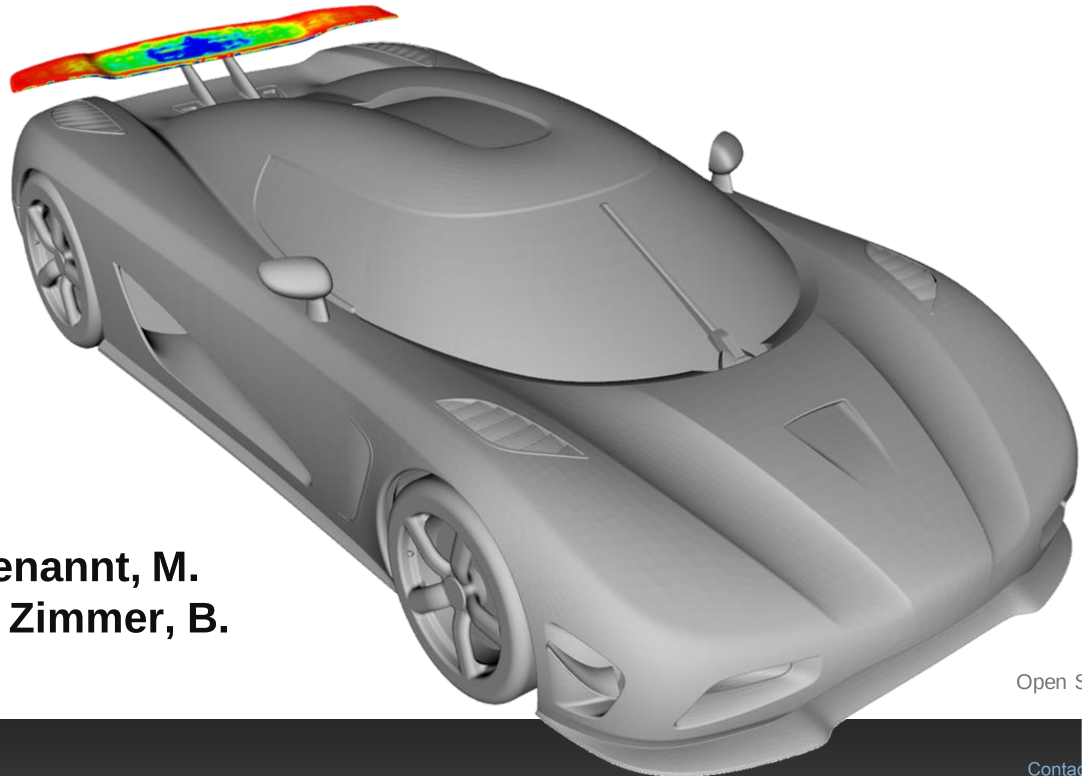
Mapping Adjoint Sensitivities to Geometry Parameters for Shape Optimization



S. Weickgenannt, M. Saroch, A. Zimmer, B. Leroy

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Open Source CFD International Conference 2013

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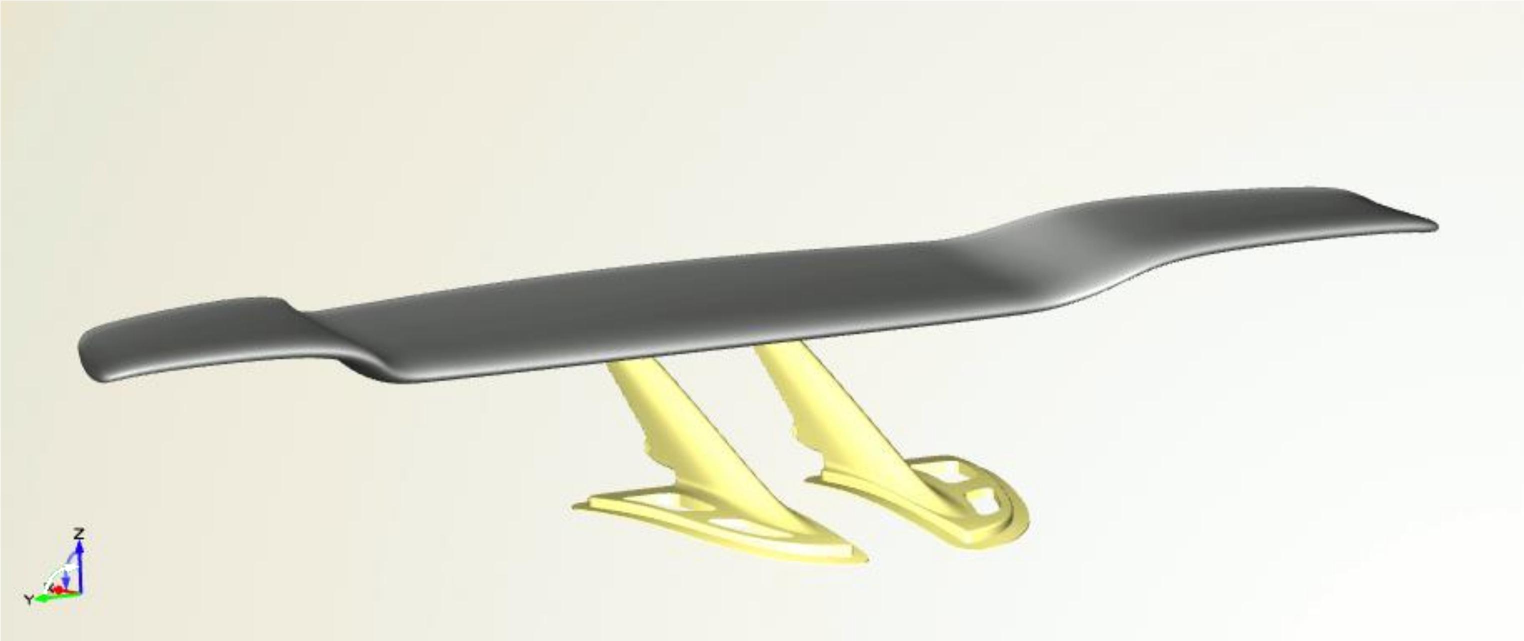
Parametric Model

19 design variables control the shape with the help of spanwise distributions of profile parameters

Geometry constraints regarding span and chord length are automatically met



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Linking Adjoint Sensitivities and parameters

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Adjoint shape sensitivity values can be used to displace the surface cells directly and to morph the shape, e.g. in a CAD independent approach

Downside is that the **shape changes cannot easily be fed back into the design workflow, geometry constraints may be violated**

→ **Solution**: connect shape sensitivities to CAD parameters

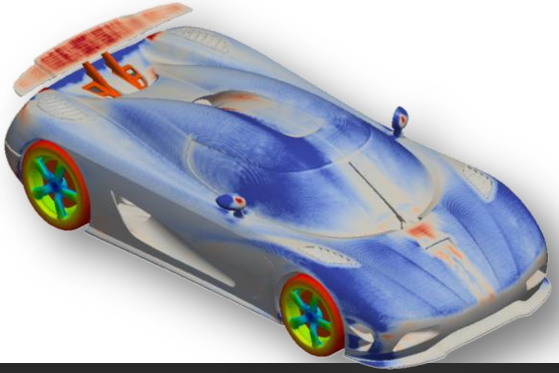
Parametric sensitivity

$$\frac{\partial J}{\partial \alpha_n} = \sum_k \frac{\partial J}{\partial n_k} \frac{\partial n_k}{\partial \alpha_n} \frac{A_k}{A_{avg.}}$$

Adjoint shape sensitivity ($\frac{\partial J}{\partial n_k}$)

Normal displacement of model boundary due to CAD parameter changes: „design velocity“ ($\frac{\partial n_k}{\partial \alpha_n}$)

Relative local cell size ($\frac{A_k}{A_{avg.}}$)



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Design Velocity Results

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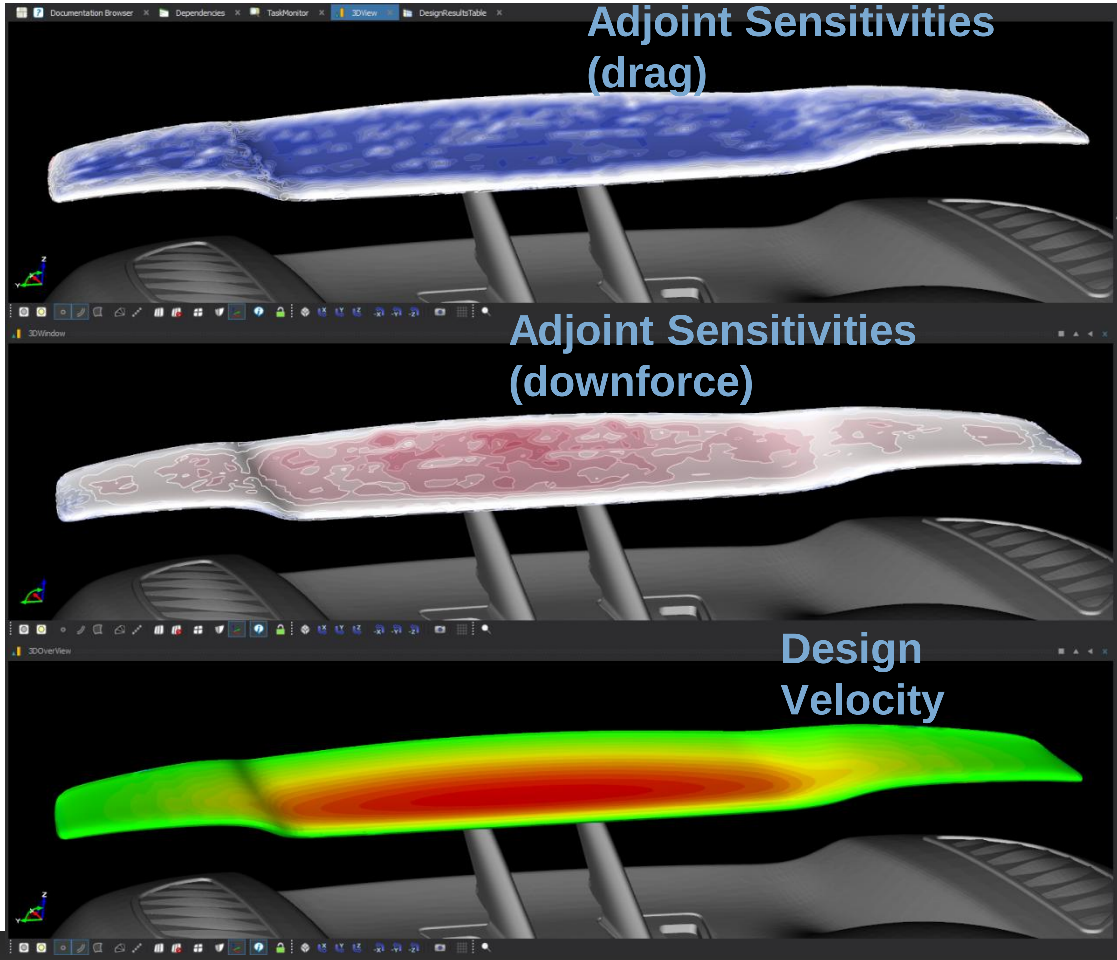
Thickness_pressCenter

Rank 1 for drag

Rank 2 for downforce



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OPTIMIZATION
RESULTS

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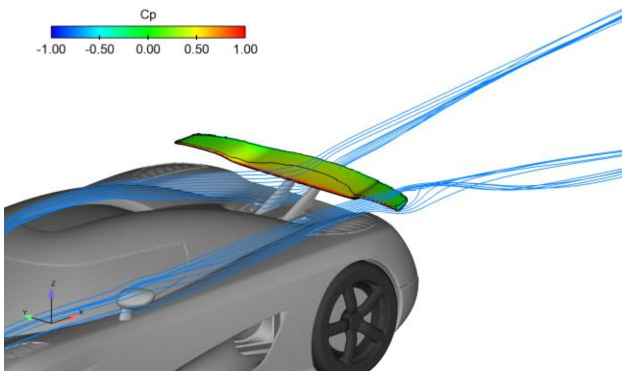
DRAG

parameter	*sensitivity*
thickness_pressCenter	247.23
stepPos_yShift	-92.83
thickness_sucCenter	-73.96
thickness_sucInner	-63.82
camber_pressCenter	-45.61

DOWNFORCE

parameter	*sensitivity*
stepPos_yShift	1123.71
thickness_pressCenter	-817.81
thickness_pressTip	-197.45
camber_pressCenter	176.49
thickness_sucCenter	-128.99

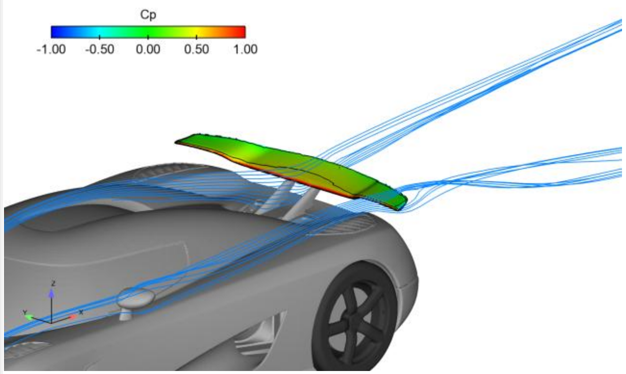
Baseline Results



Drag optimized

-0.96% drag

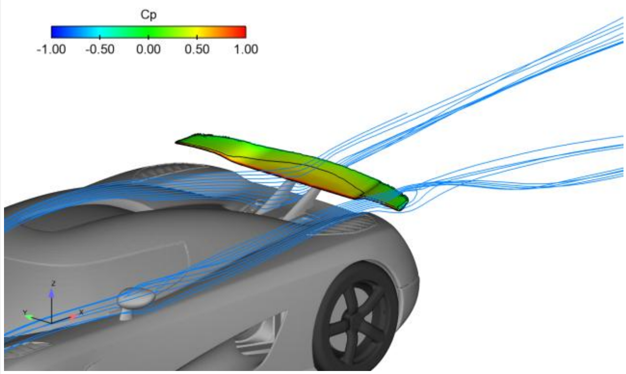
-3.75% downforce



Lift optimized

-0.03% drag

+3.86% downforce



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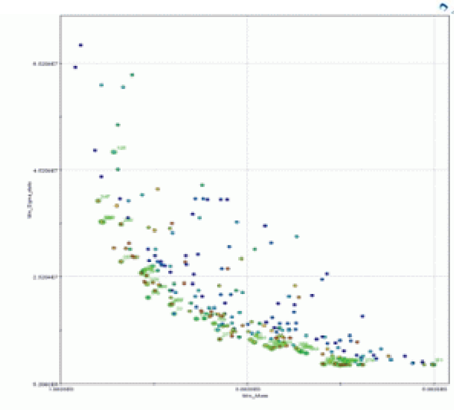
Multi-objective

Discrete & continuous parameters(High number)

Ability to introduce construction constraints



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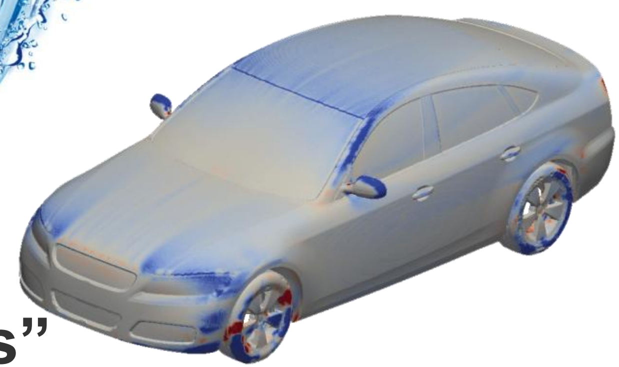

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VOLKSWAGEN GROUP CASE STUDY

Results First Presented at SAE World Congress 2009

(Full Paper SAE 2009-01-0333 :

"Application of Detached-Eddy Simulation for Automotive Aerodynamics")

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AeroFOAM PROJECT

- Multi-year development project
- Basic requirements:
  - Efficient and robust simulation methodology
  - Higher level of accuracy than previous tool required
  - Increased number of vehicle projects and reduced development times
  - Validation using experimental data from Audi and VW wind tunnels
  - Productive use for vehicle development from January 1, 2009
- Fast meshing process is a key factor
- Use of LES or DES – high accuracy

Ref: SAE 2009-01-0333

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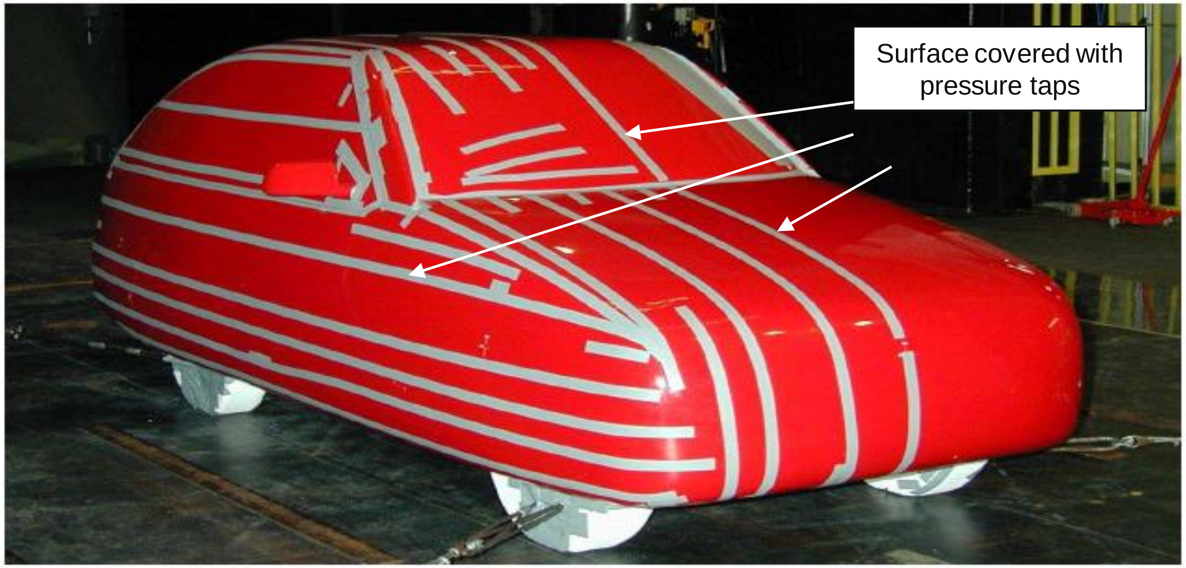
RESULTS FOR A GENERIC MODEL (VW RED MODEL)



	c_D [-]	c_{Lf} [-]	c_{Lr} [-]
Experiment	0.249	-0.052	0.128
Simulation	0.265	-0.048	0.118

Ref: SAE 2009-01-0333

aeroFOAM

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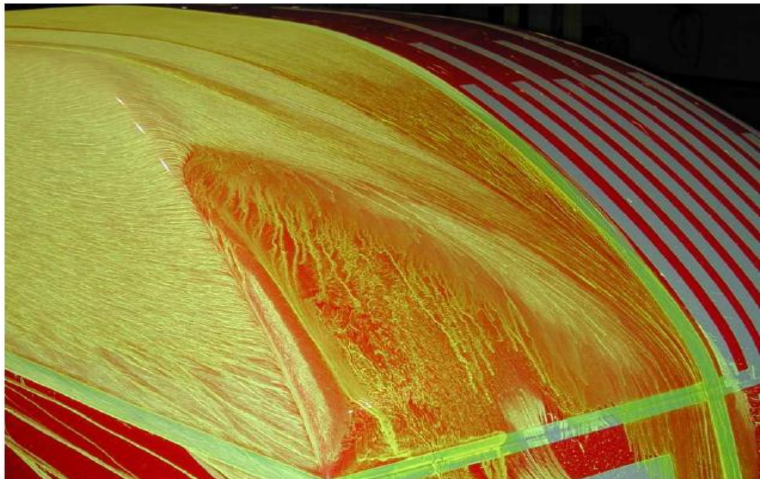
RESULTS FOR A GENERIC MODEL (VW RED MODEL)

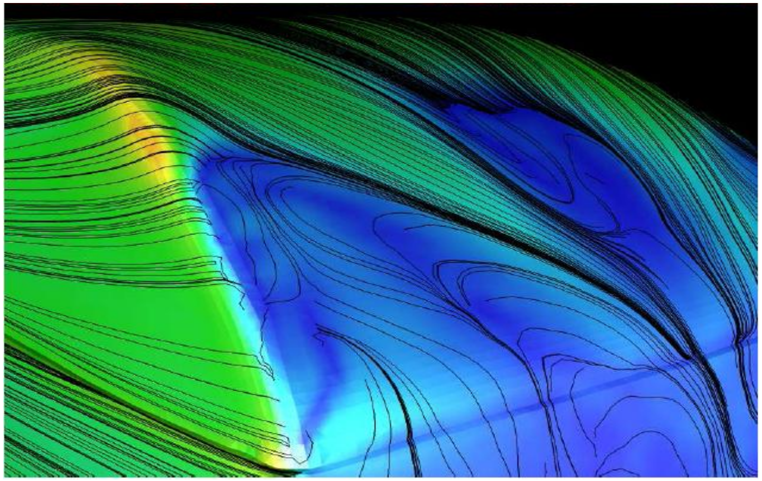
Oil-flow visualisation



Experiment

Ref: SAE 2009-01-0333

Numerical surface streamlines



Simulation

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RESULTS FOR A PRODUCTION CAR (AUDI A6)

no cooling flow,
no ground
simulation

	c_D [-]	c_{Lf} [-]	c_{Lr} [-]
Experiment	0.271	0.068	0.116
Simulation	0.267	0.070	0.142

Ref: SAE 2009-01-0333

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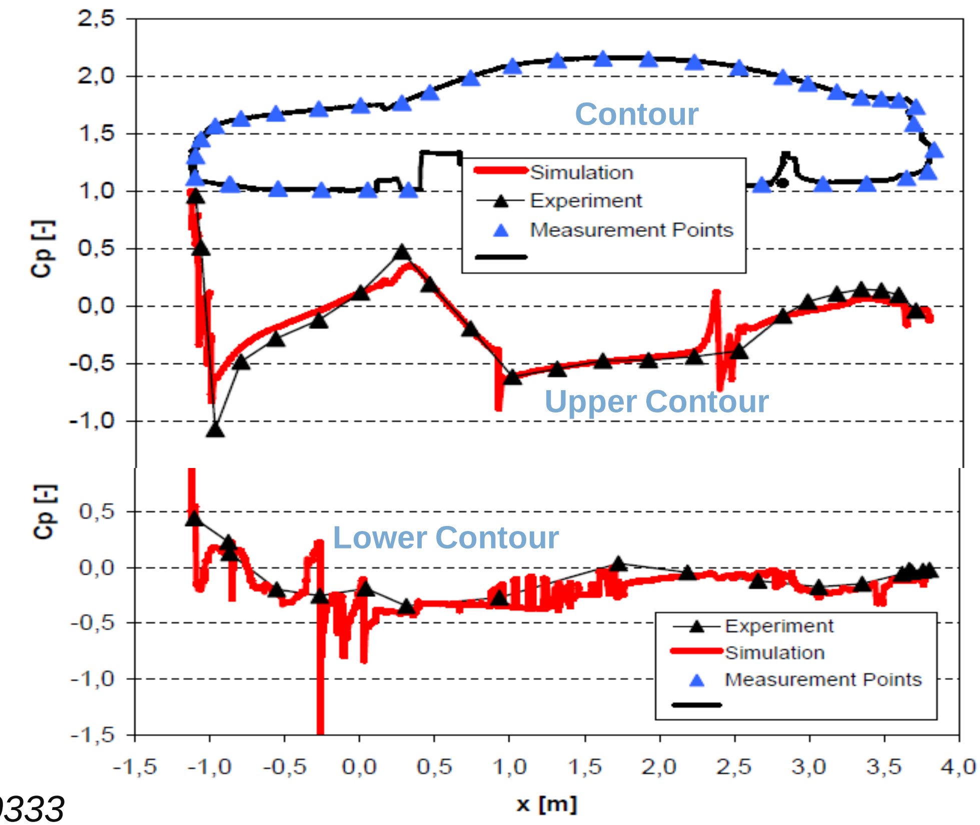
RESULTS FOR A PRODUCTION CAR



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RESULTS FOR A PRODUCTION CAR

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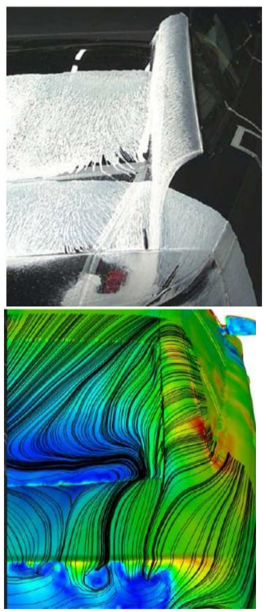
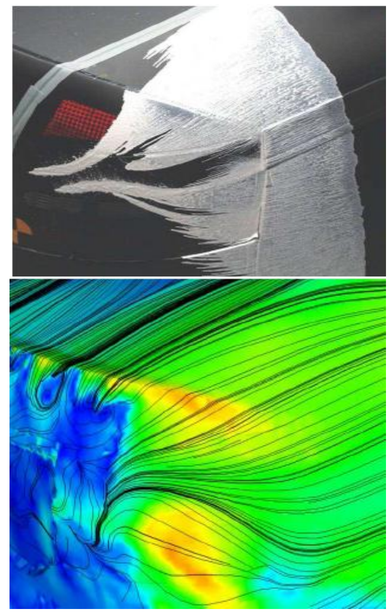
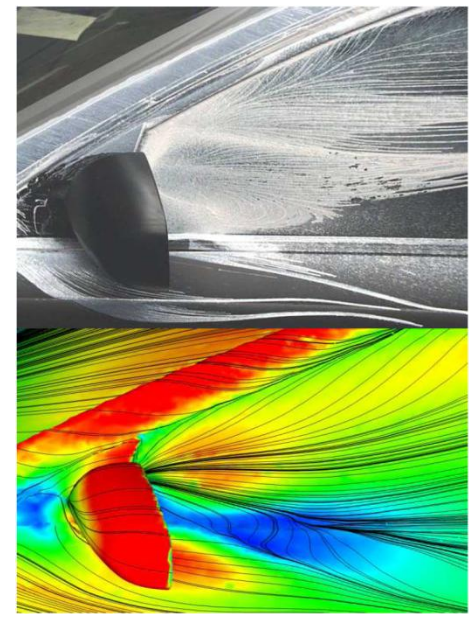
C-pillar region



Rear of car



A-pillar / side region



Ref: SAE 2009-01-0333

aeroFOAM

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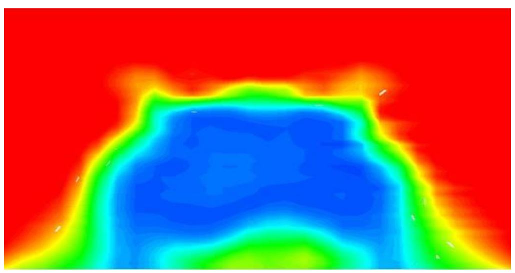
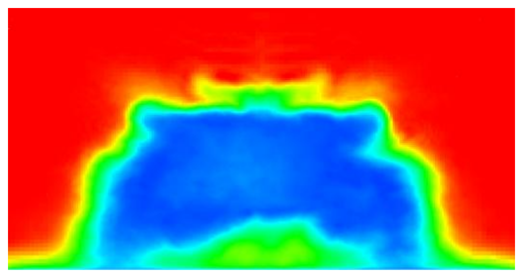
RESULTS FOR A PRODUCTION CAR

total pressure behind the car: plane at x = 3.90 m

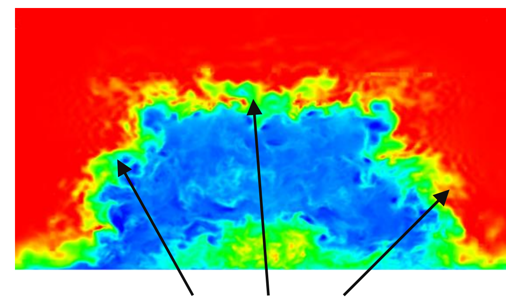
Experiment:
time averaged



Simulation:
time averaged



Simulation:
instantaneous



small-scale turbulent structures

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VOLKSWAGEN GROUP CASE STUDY

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Dr. Moni Islam; Head of Aerodynamics and Aeroacoustic Development

Presented at IDAJ CAE Solutions Conference 2013, Japan

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FORD MOTOR COMPANY CASE STUDY

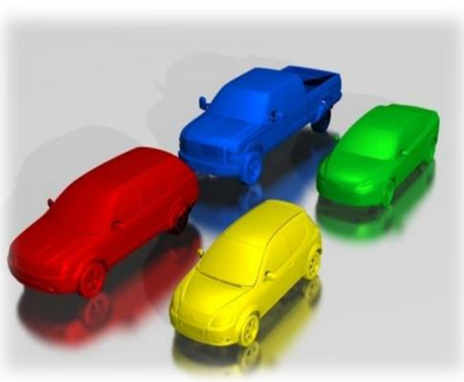
- Presented at SAE World Congress 2011 (SAE 2011-01-0163)
- DES validated with wind tunnel data, and compared to proprietary CFD codes.
- Robust and fast meshing of complex geometries (up to 80 millions cells)

B- Car

CD- Car

SUV

Truck



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GOAL OF THE BENCHMARK

- Understand capability of an **Open Source CFD** based process
- Accurate simulation of the **physics** of the flow field
- Predict effects of **geometry variations** on **aerodynamic lift** & **drag**
- Data compared and validated with existing CFD data and test data by **Ford Motor Company**.

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COMMON SETUP

- A common setup is designed **to reduce turn around time**
  - Consistent position of the vehicles

- **Different wind tunnels** for the vehicles
  - Tunnel setups adjusted to meet conditions
  - Reproduce the **boundary layer development**
  - Setup the **boundary patches** for the **tunnel geometry**
  - Mesh requirements steady state RANS vs. Transient DES simulation

- Common **meshing strategy**

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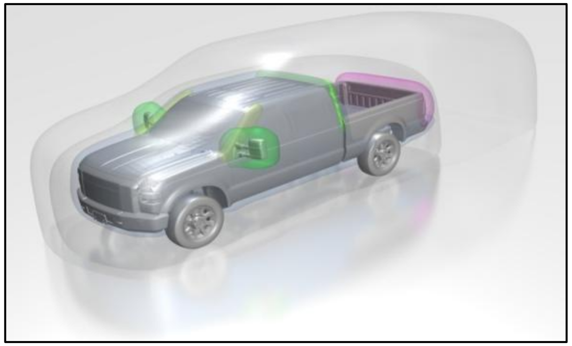
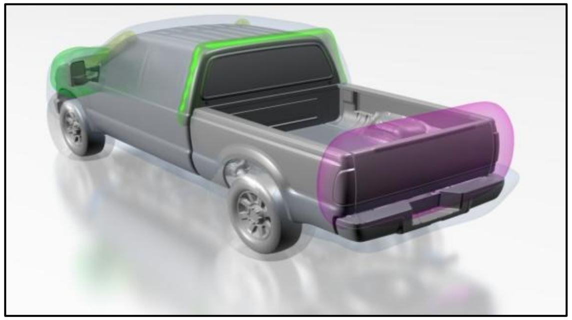
COMMON MESH STRATEGY

- Volume refinement zones based on offset of vehicle shape
  - Extended to include wake regions
- Local refinement zones (Pillars, Tires, Mirrors, Under body, etc.) to resolve separation and vortex structures more accurately
- Surface mesh refinement based on feature angles
- All meshes created fully automatically in parallel
  - Range of mesh sizes (25 to 120 million cells hex-dominant)





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DRAG RANKING OF THE BASE MODELS

- **Lift** & **drag** predicted with **DES simulation** based on mesh sensitivity analysis
- **DES** requires a **different mesh resolution** than steady state RANS (mesh sizes ~45 million cells)
- Mesh/Setup/Solver/Post processing completed in **parallel mode**, using up to 128 CPUs
- Flow field averaged for the last 40% of the simulation to extract the **time averaged information**
- Free stream velocities 35 – 40 m/s
- 3-4 iterations run per vehicle shape

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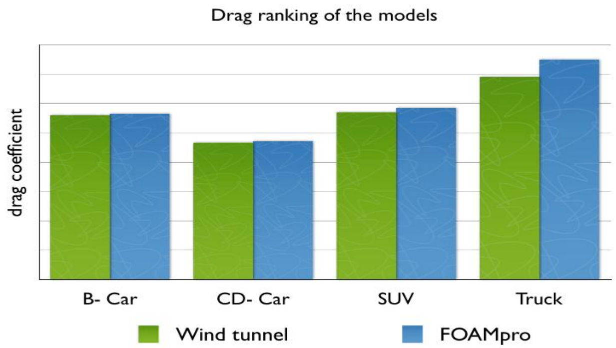
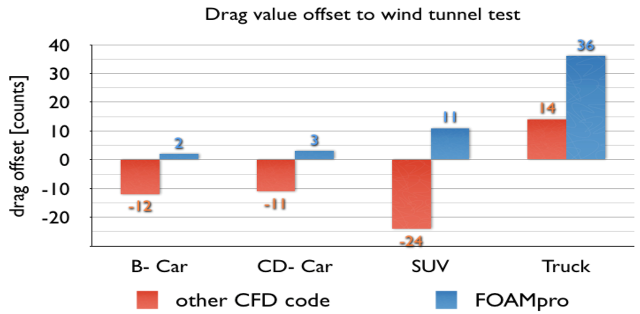
DRAG RANKING OF THE BASE MODELS

- SUV, B- and CD- car prediction within 3% to test data

  B- and CD- Car less than 5 drag counts
- Truck is showing higher difference to test data (8%)
- Consistent over prediction of drag throughout all performed DES simulations





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AGENDA

- ICON overview
- iconCFD applications I
- iconCFD applications II
- Success stories

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CONCLUSIONS

- A sample of automotive related applications have in Europe and America has been presented
- Open Source based CFD offers a real alternative which brings a massive increase of productivity to industrial users.
- Industrial use of adjoint optimisation technology is positively impacting automotive product design
- Aerodynamics will be of increasing importance in car development projects in the future.
- Open Source success stories have been presented for European and American OEM's

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THANK YOU

谢谢

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MORE INFORMATION?

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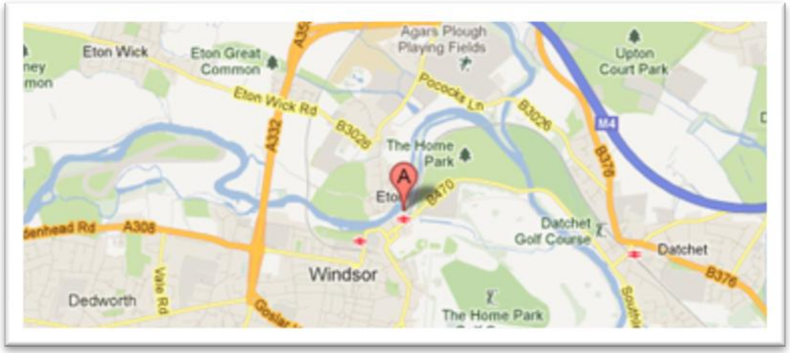

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