FLOWHEAD

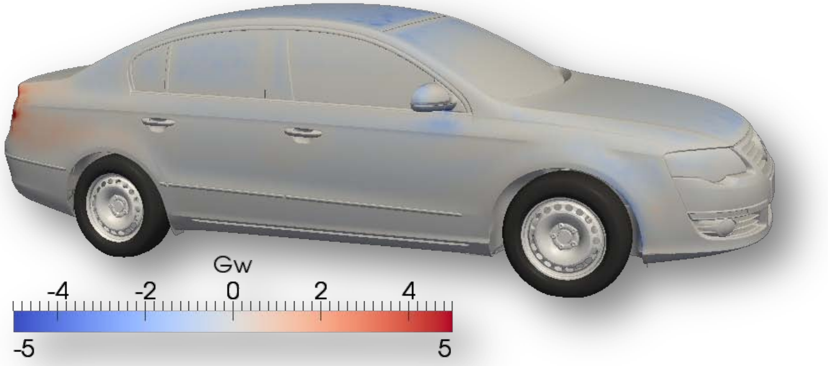
Fluid Optimisation Workflows for Highly Effective Automotive Development Processes

Adjoint Solver Advances, Tailored to Automotive Applications

Technology • Process • Consulting

www.iconCFD.com

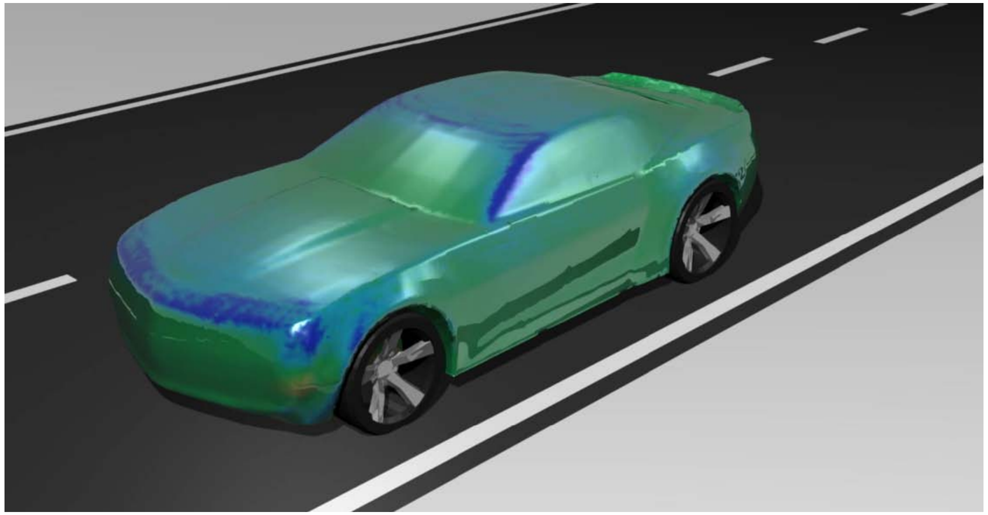
Stamatina Petropoulou
s.petropoulou@iconCFD.com



SEVENTH FRAMEWORK PROGRAMME

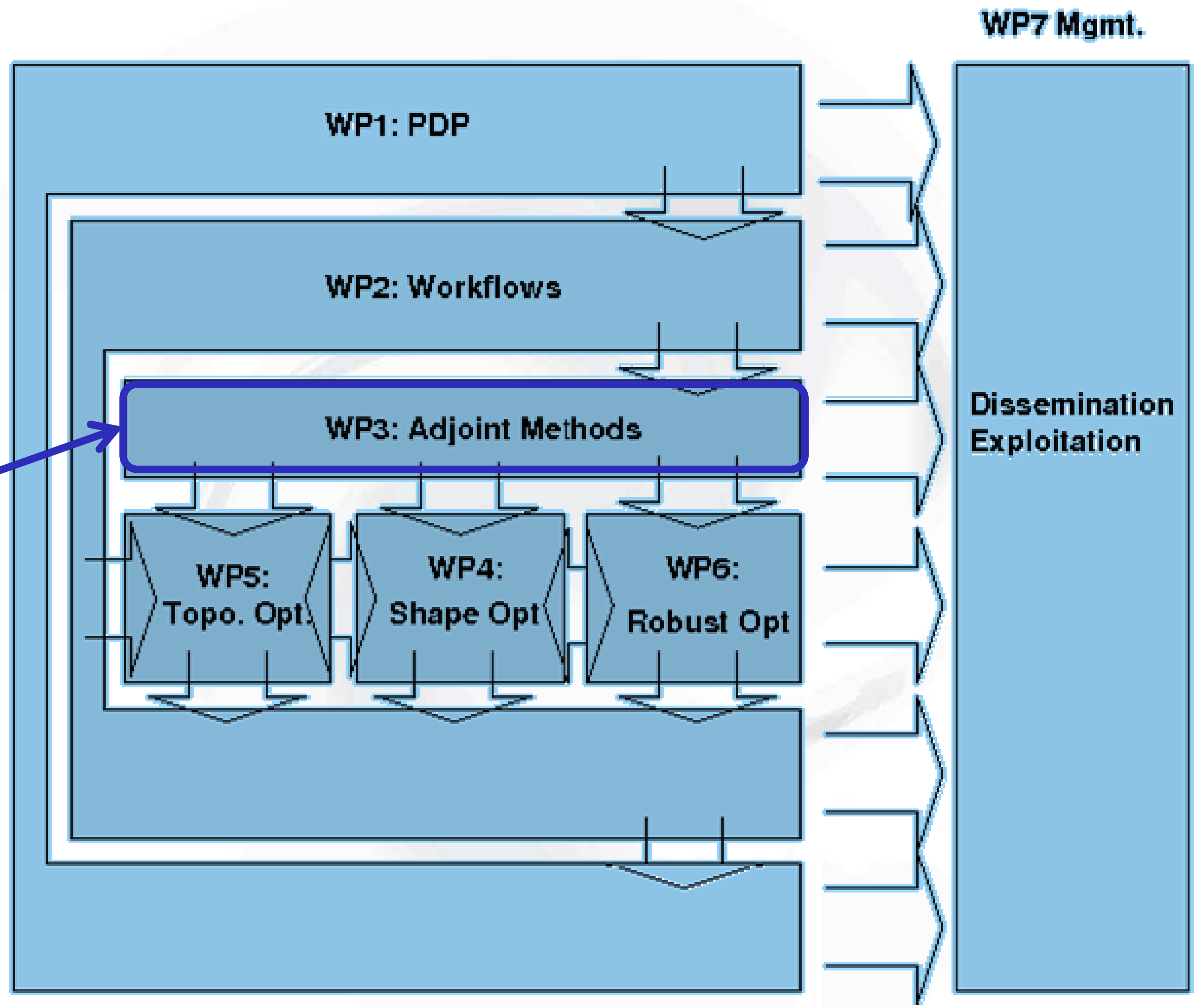
Contents

1. Icon's Principal Work in FlowHead
2. Demonstration Cases
3. Icon's Further Development Work
4. Conclusions/Future Work



FlowHead Overview

Technology • Process • Consulting



Icon's tasks are mainly on this work package

Work Package 3.1

- Stage 1: Adjoint code with enhanced BC and cost functions
- Stage 2: Adjoint code with differentiated turbulence model
- Stage 3: Adjoint code with optimised performance

Technology • Process • Consulting

Adjoint Solver

- Development of boundary conditions for specified cost functions
- Added volume cost functions to the solver
- Zonal treatment for volume cost functions

Cost Functions

- Library for calculating cost functions during runtime

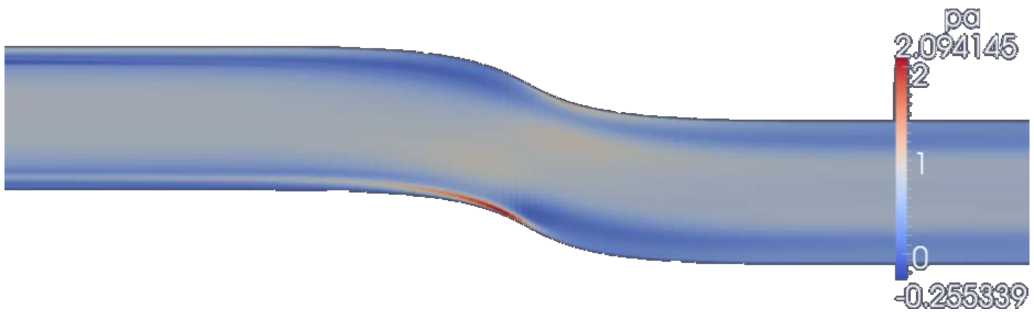
Sensitivity Derivatives

- Utility for calculating the sensitivities on the patches of interest

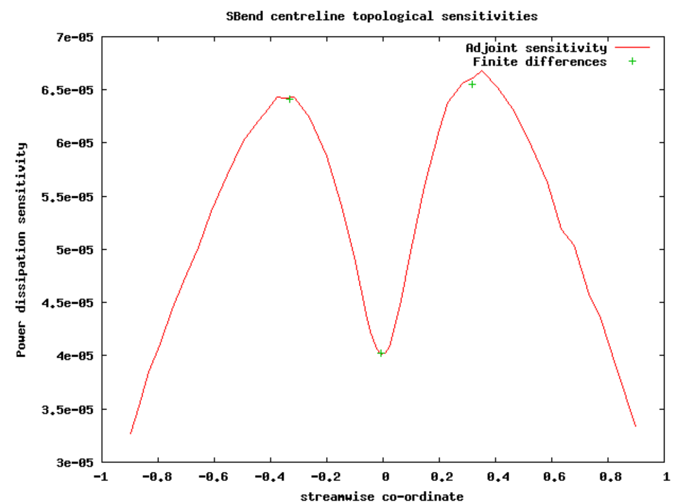
Application	Objective function(s)	Top. opt. possible	Shape opt. possible	Primal responsibility
External aerodynamics	▪ drag ▪ lift	No	yes	VW
Intake manifolds, intake ports	▪ mass flow rate ▪ swirl/tumble	Yes	yes	RSA
Air ducts	▪ pressure drop ▪ uniformity of flow at the outlet ▪ equal mass flow through different outlets ▪ turbulent kinetic energy (for assessment of noise generation) ▪ material cost (i.e. surface)	Yes	yes	VW
Exhaust manifolds	▪ uniformity of flow upon entering the catalytic converter ▪ pressure drop ▪ material cost (i.e. surface)	Yes	yes	RSA
Engine cooling (water jacket, intercooler etc)	▪ pressure drop ▪ heat transfer	(yes)	yes	RSA
Side mirror	▪ acoustic sources	No	yes	VW

- Power dissipation – Topological sensitivities validation
- A 2D Sbend geometry was used for the validation
- Laminar flow and “frozen” adjoint turbulence
- Finite differences in two points
- The agreement was really good

Adjoint pressure field for power dissipation



Power dissipation topology sensitivity
- comparison with finite differences



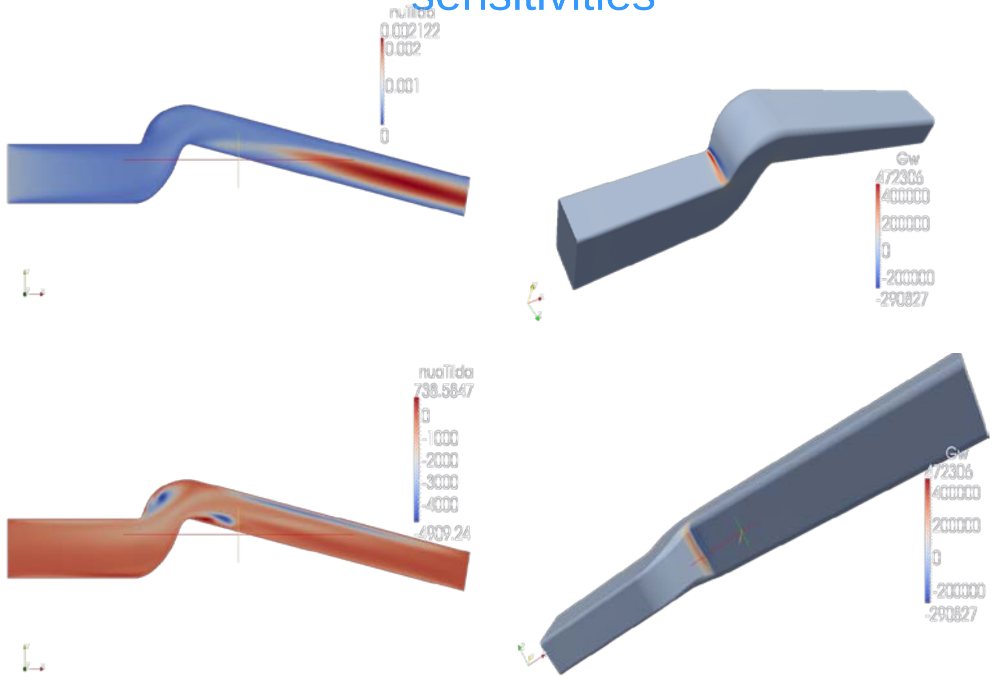
Work Package 3.1.2

- The Adjoint solver was enhanced with the differentiated Spalart-Allmaras one equation turbulence model [1]
- A new volume cost function for noise reduction was developed and validated
- The noise reduction is achieved by the minimisation of the turbulent content in a specified volume
- Zonal treatment for this cost function was implemented
- Validation and comparison with the “frozen” turbulence approach was performed.

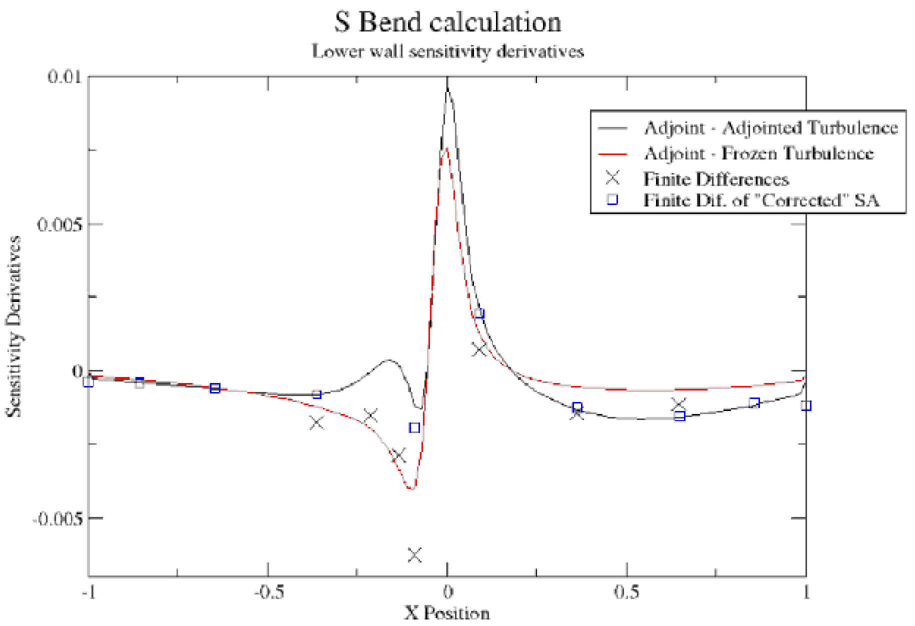
1. Zymaris, A, Papadimitriou, V, Giannakoglou, K, Othmer, C. Continuous Adjoint Approach to the Spalart-Allmaras Turbulence Model for Incompressible Flow, Computers & Fluids, 38(8):1528-1538, 2009.

- Power dissipation – Surface sensitivities validation
- An extended 3D Sbend geometry was used for the validation
- Comparison between “frozen” turbulence and differentiated turbulence model

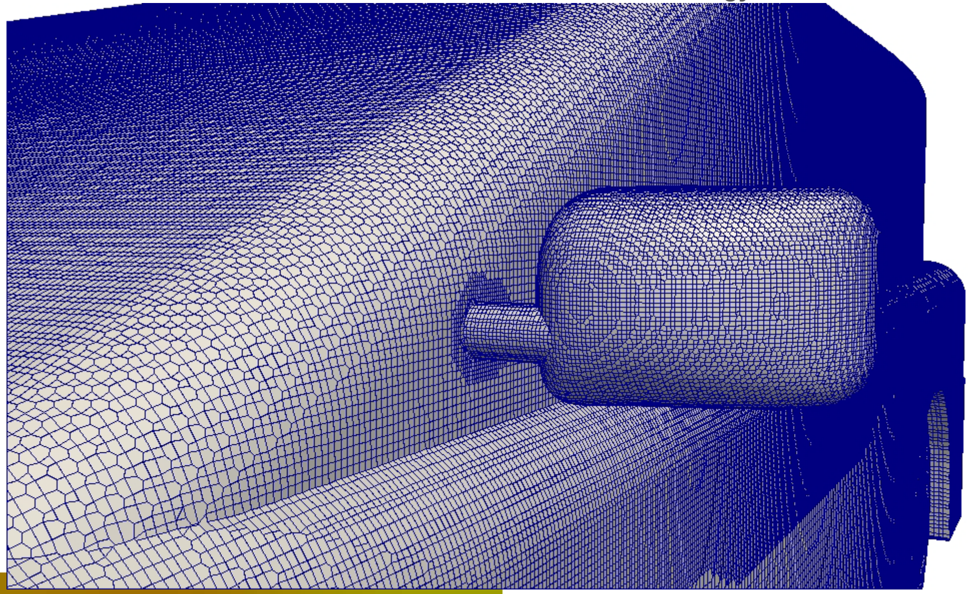
Primal and adjoint turbulent variables and surface sensitivities

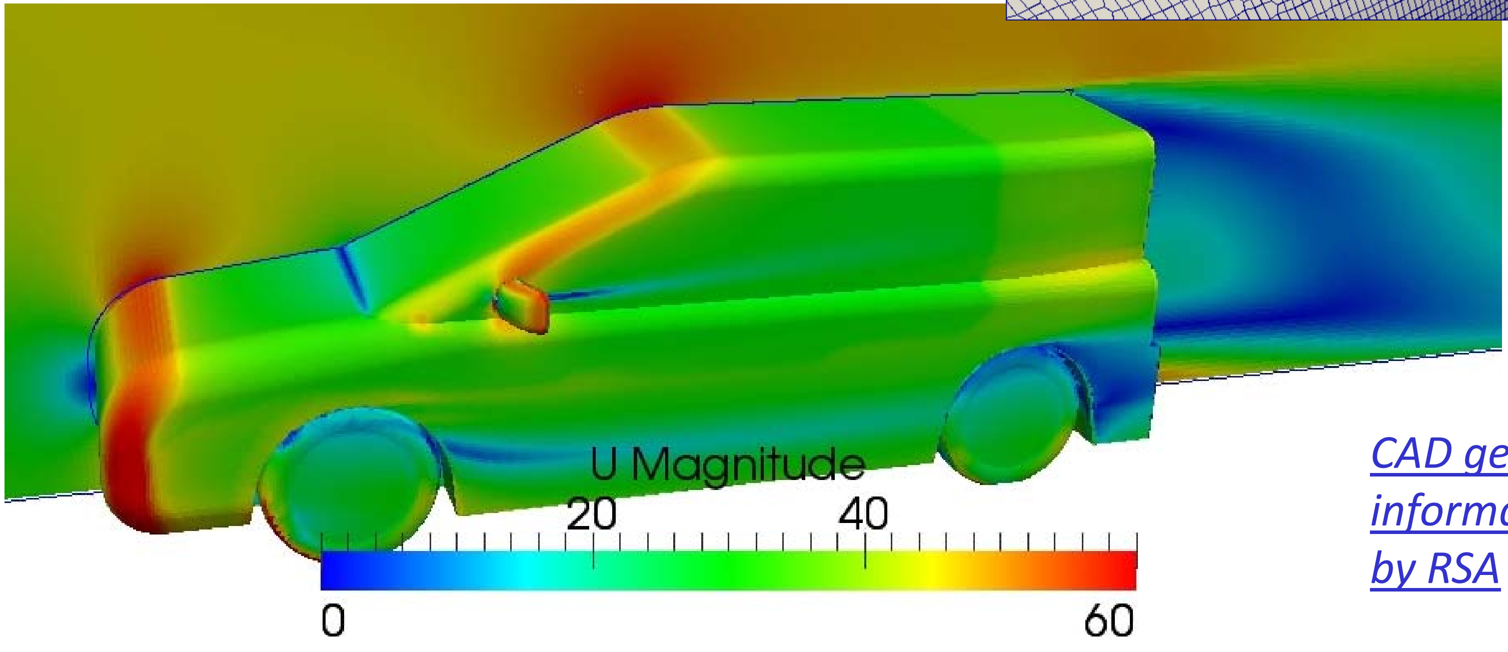


Power dissipation surface sensitivity - comparison with “frozen” turbulence



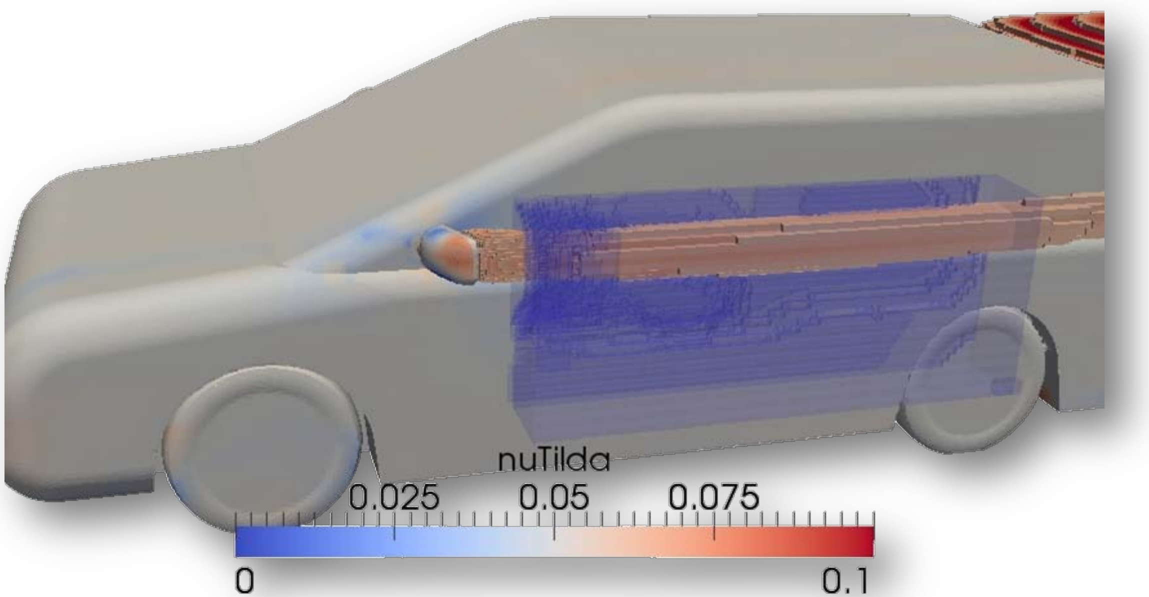
- Steady RANS calculation
- ~9.5m cells polyhedral mesh
- Small mesh but detailed for aero acoustics (mirror, window)

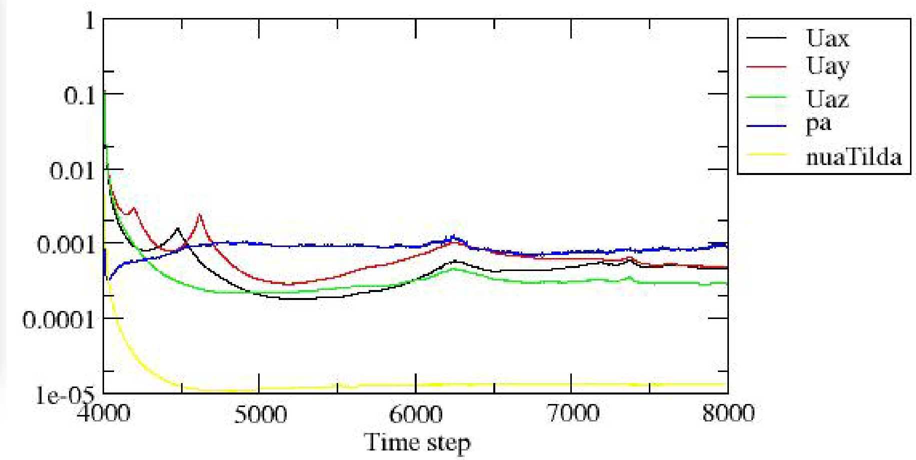




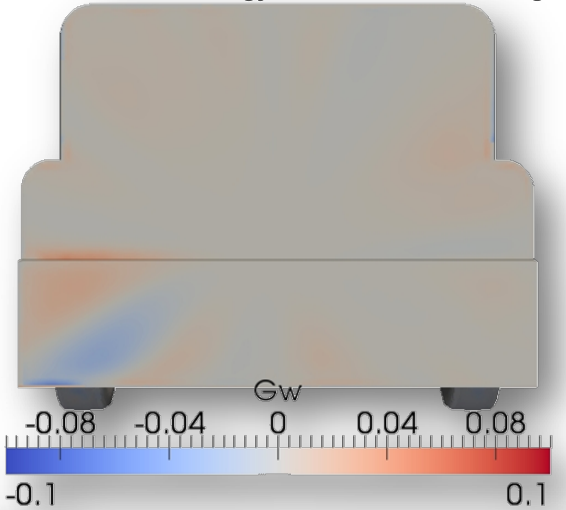
CAD geometry and flow information were provided by RSA

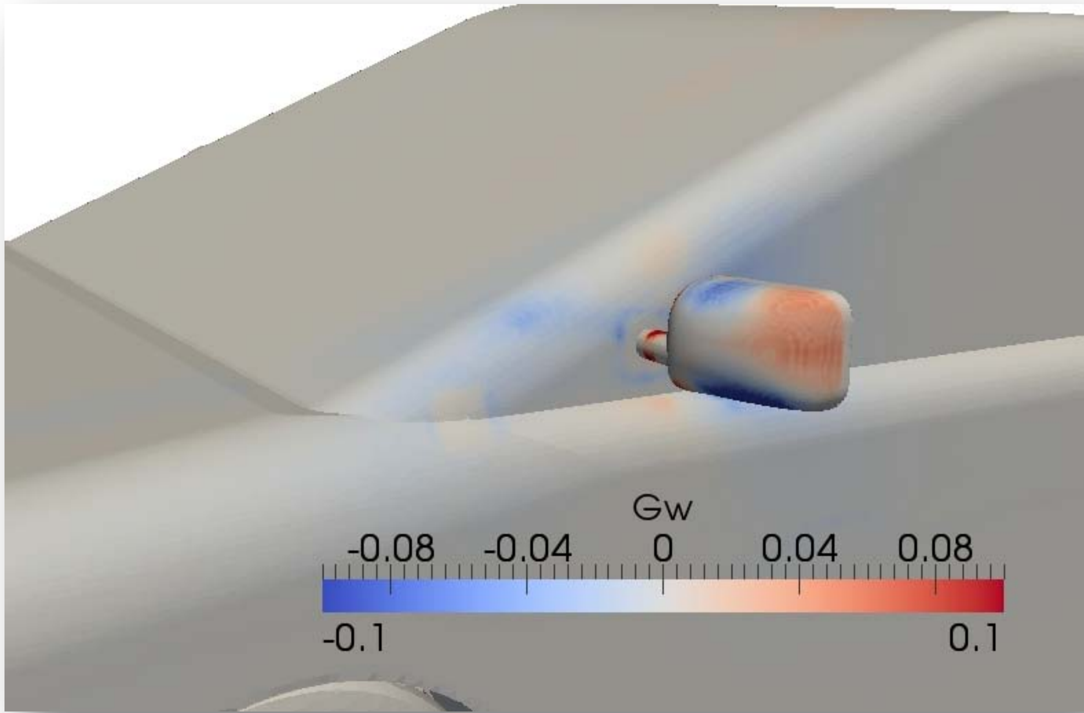
- A volume was defined to enclose the turbulent effect from the mirror
- The turbulent energy minimisation cost function was defined only in the specified volume
- Convergence of the adjoint variables was achieved in ~3000 iterations

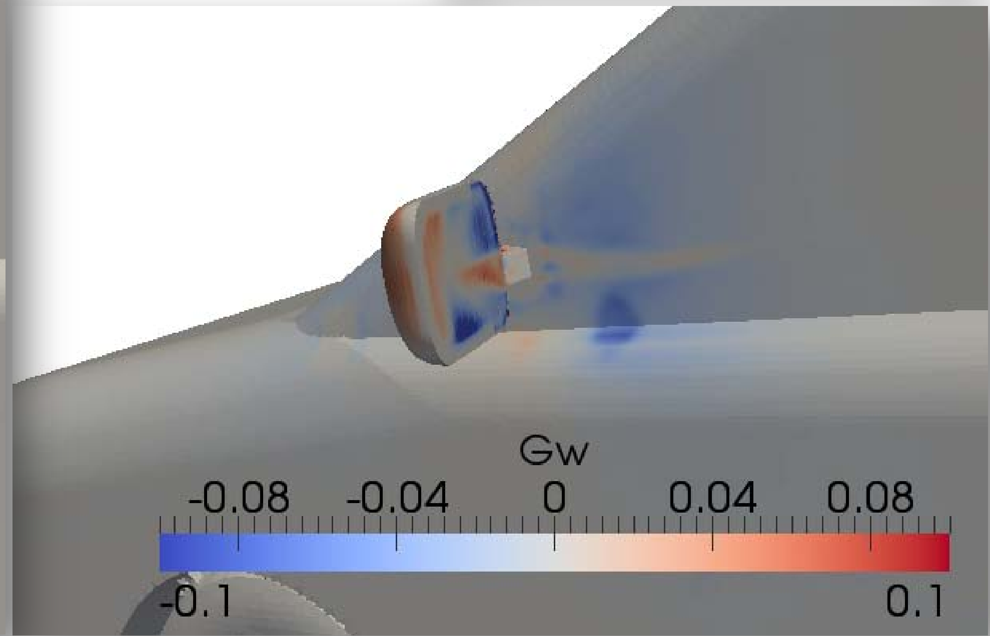




- Detailed results from the turbulent energy minimisation case where the cost function is defined on a specified volume
- The sensitivities at back of the car are also affected



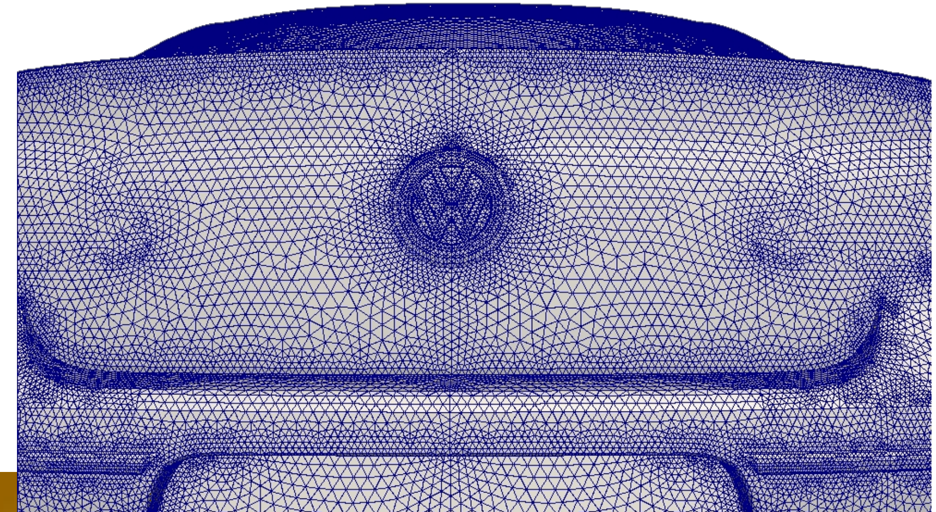


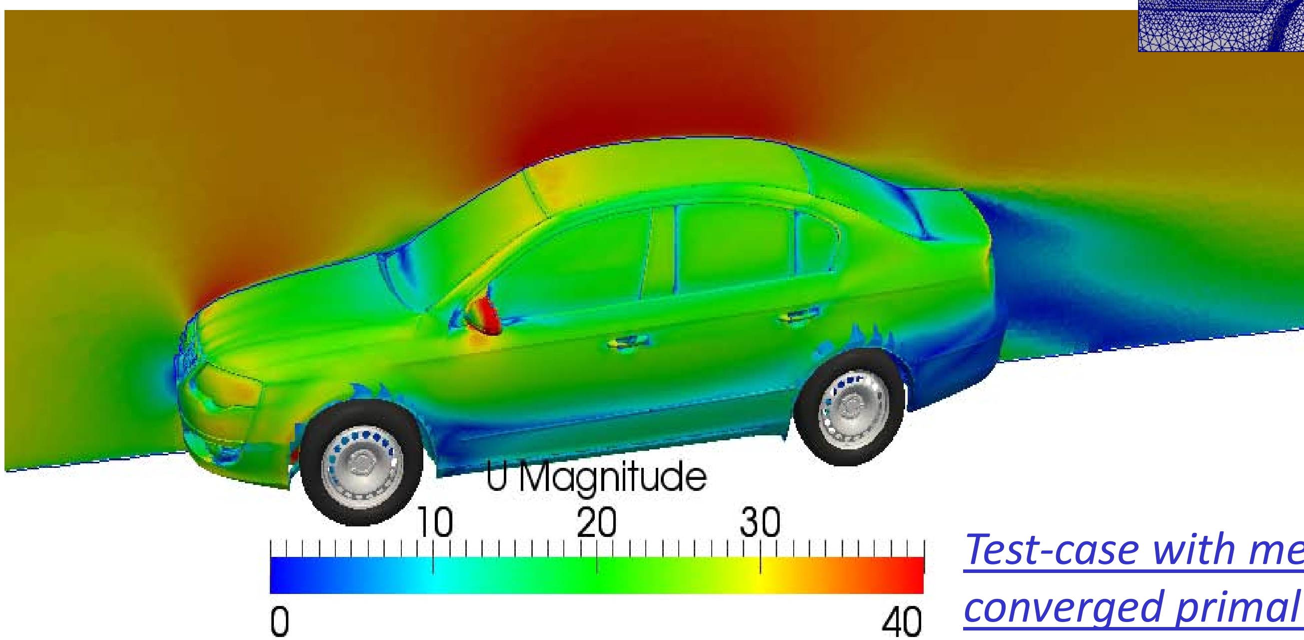


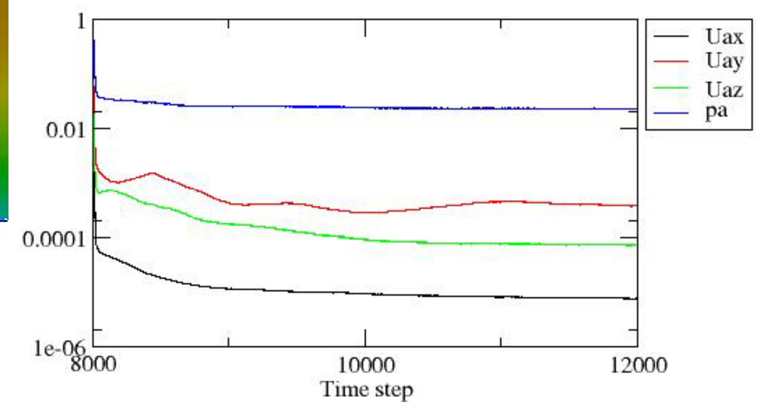
Work Package 3.1.3

- Based on the user's experiences some performance issues were addressed to achieve the efficiency for the required turnaround time
- Test cases for this task were provided by the industrial partners
  - *VW: External Aerodynamics - Drag minimisation*
  - *VW: Duct - Power Dissipation minimisation (Topology)*
  - *VW: Aero-acoustics – shear stress velocity minimisation*
  - RSA: *Mirror Aero-acoustics -Turbulent energy minimisation (demonstrated)*
- Convergence on those cases was achieved and the quality of the results was assessed
- A best-practices guide was established and delivered

- B6 test case - Drag minimisation
- Steady RANS calculation
- ~17.5m cells tetra mesh - 5 surface layers
- Adjoint solver convergence

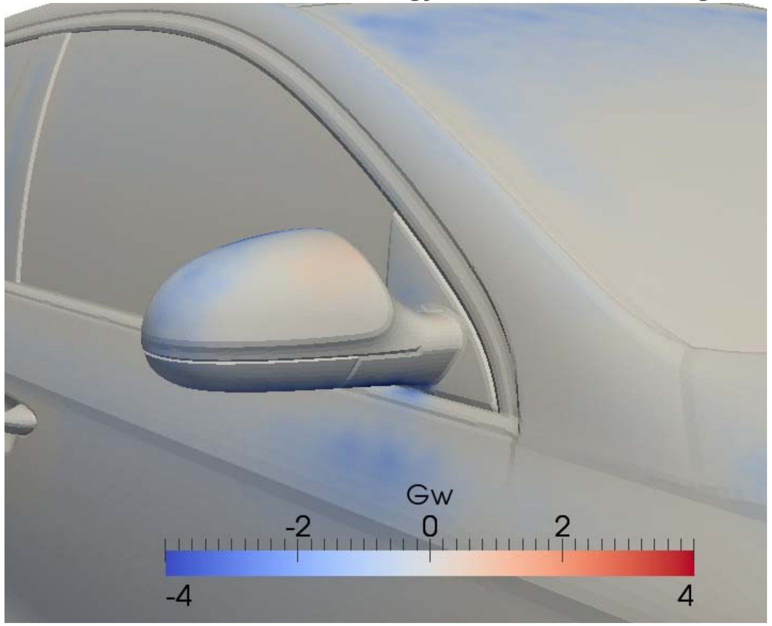


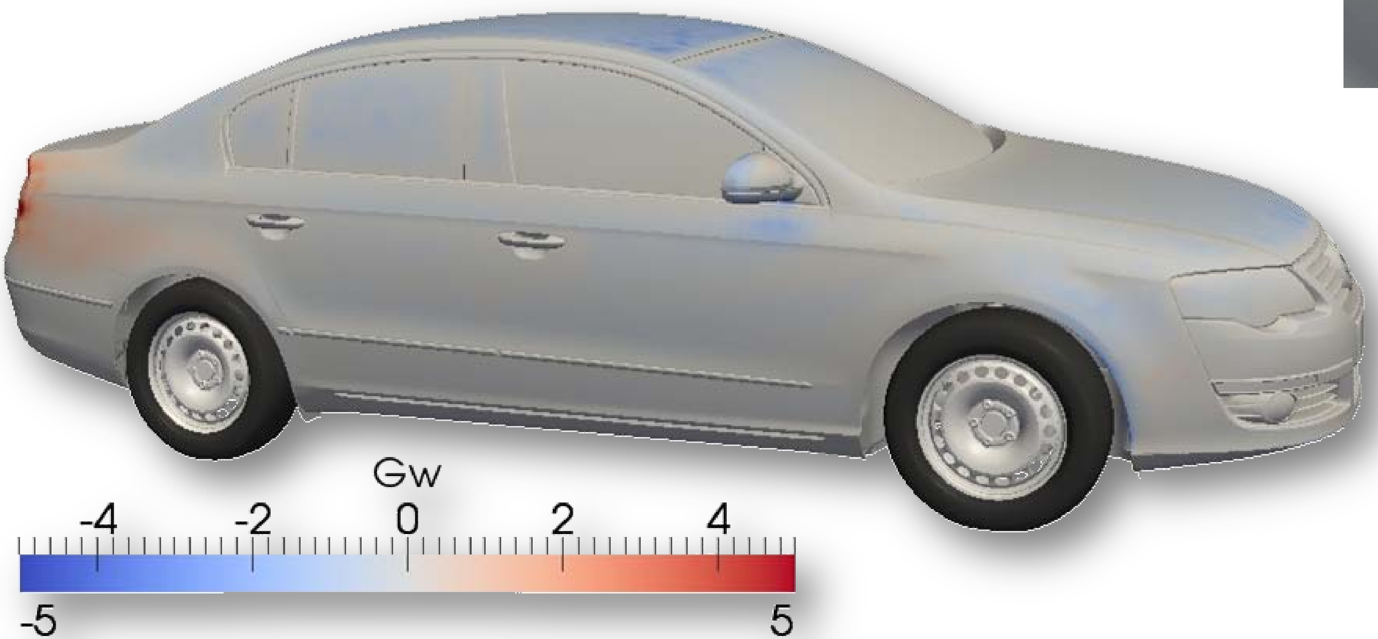




Test-case with mesh and converged primal solution was provided by VW

- Results with Face Limiter
- Sensitivities on the car body
- The non-symmetric results on the the back are due to the non-symmetric under-body geometry

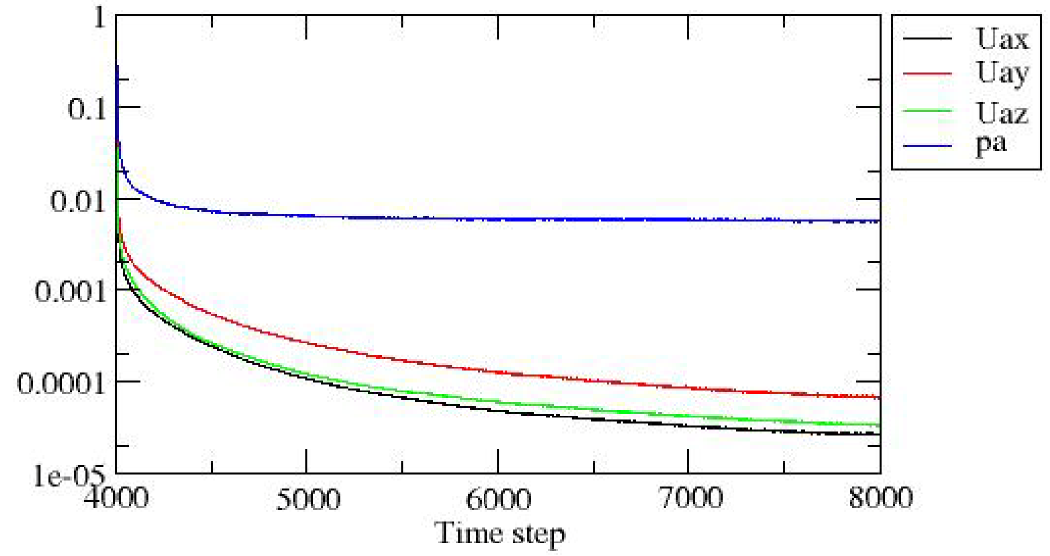


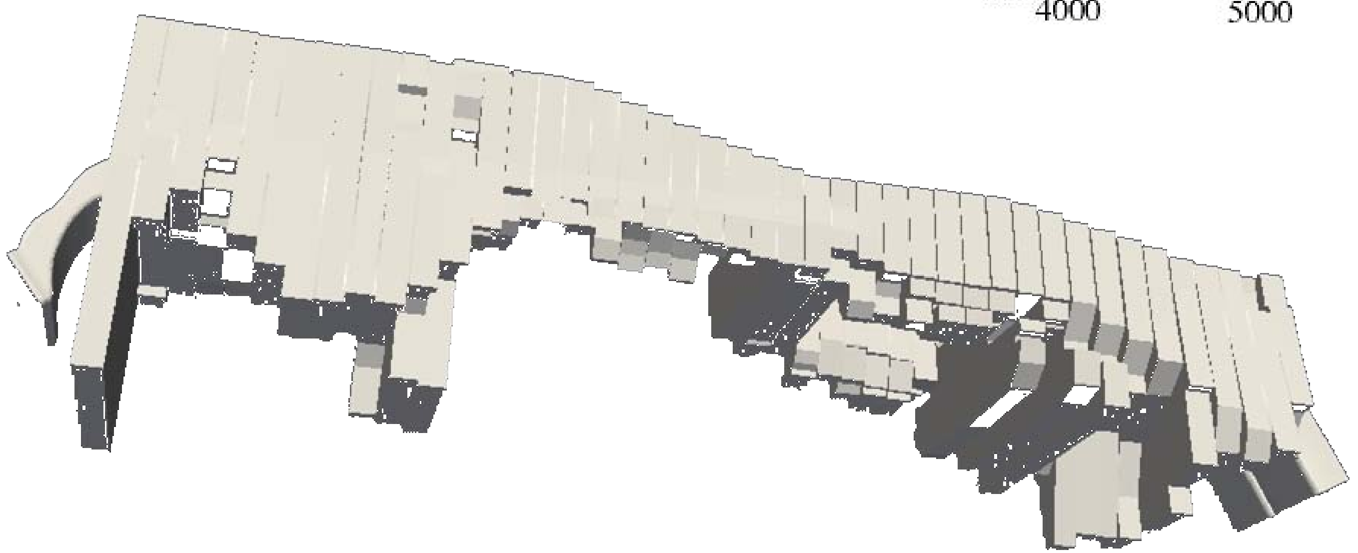


Duct - Power Dissipation (Topology)

- Duct Topology - Power Dissipation minimisation
- Steady RANS calculation
- ~5.5m tetra cells
- Limiters were used but are not essential

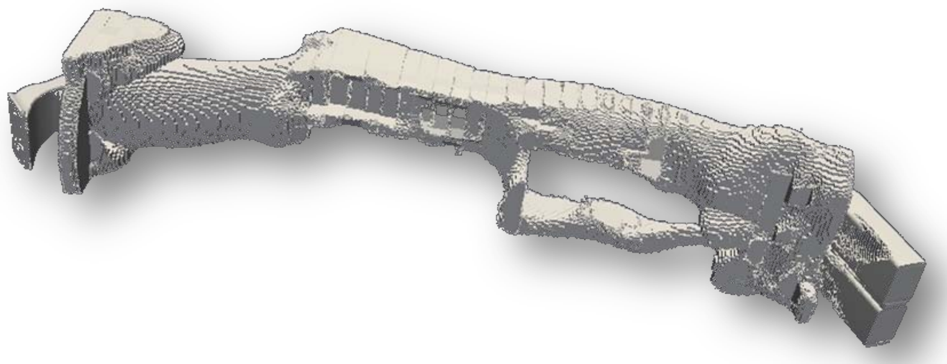
Convergence of adjoint variables

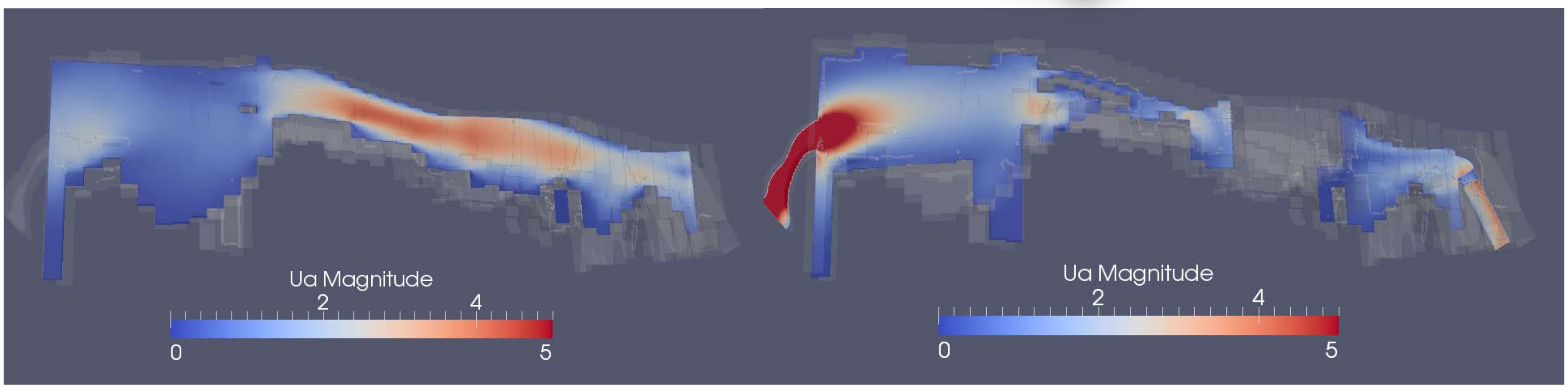




Test-case with mesh and converged primal solution was provided by VW

- Duct Topology - Pressure Drop minimisation
- Resulting geometry after topology optimisation
- Two y-cut of the Ua velocity

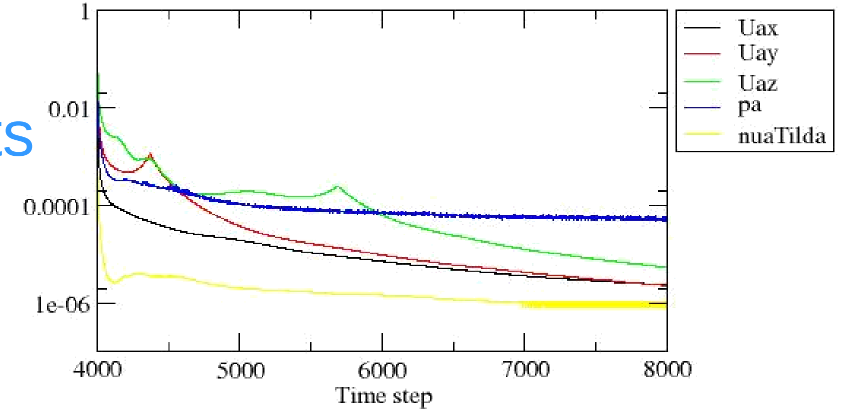




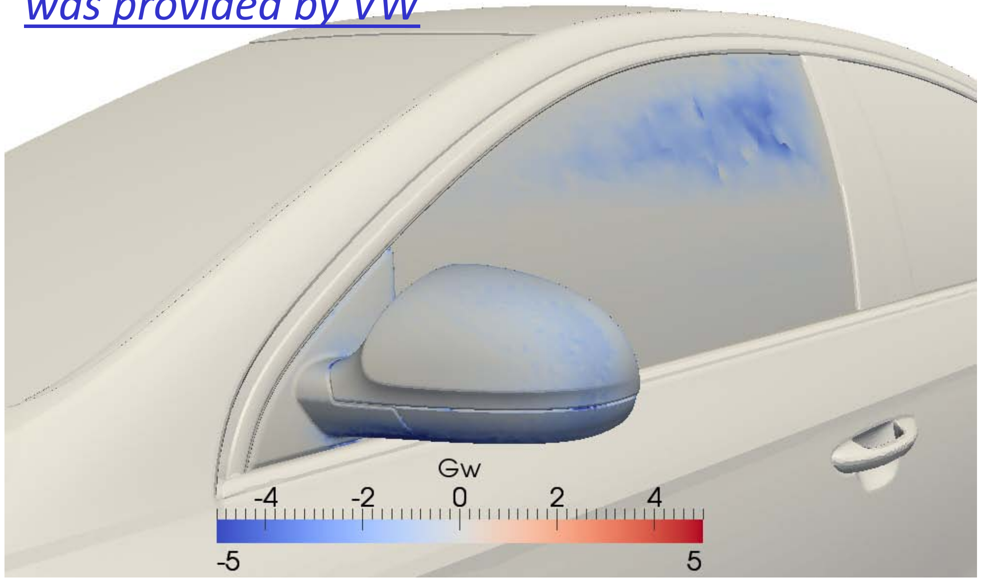
Aero-acoustics - adjointShearVelocity

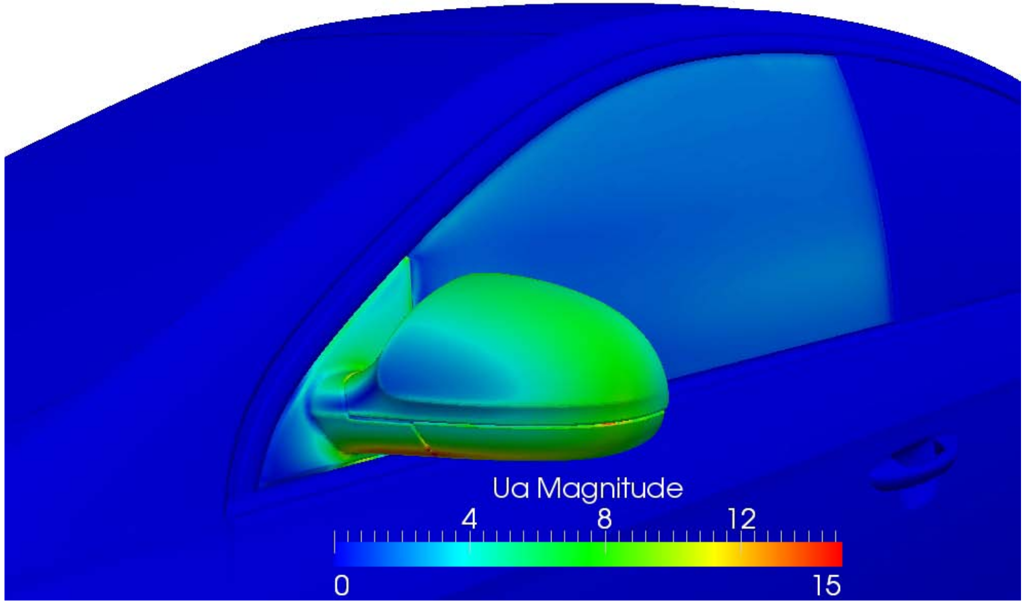
Technology • Process • Consulting

- Quarter model that does not include under-body
- ~22.5 m cells tetra mesh – $y^+=1$
- Turbulent adjointShearVelocity case results
- The adjoint turbulence model was used



Test-case with mesh and converged primal solution was provided by VW





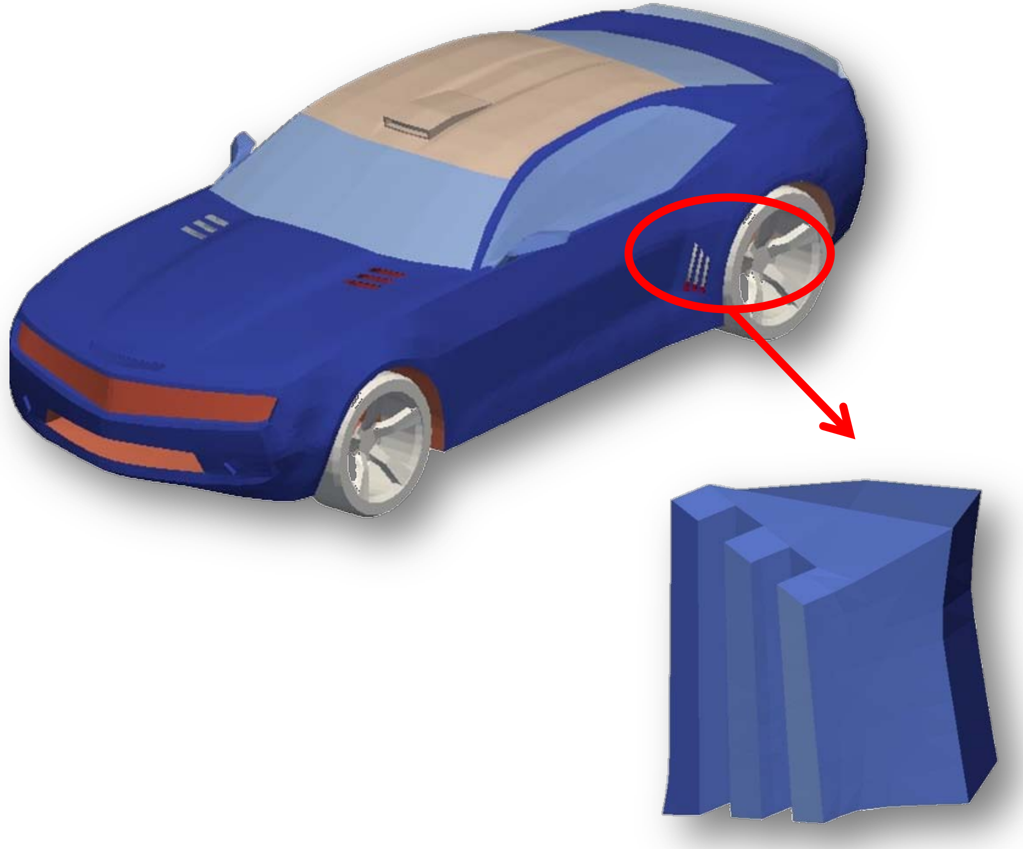
ICON FOAMpro Optimize SubCase

- In the past we were using topology optimisation for improving the performance of stand alone ducts.
- A fully automated process was developed in order to allow the user to easily setup a case where the flow on the complete geometry is simulated while only a component of the car is optimised.
- The creation and initialisation of the sub case and the topology optimisation are automatically incorporated in the process.
- The definition of the subdomain can be done via an STL with additional specifications for the inlets and outlets.
- The porosity on the sub case cells is updated at the end of each Adjoint cycle and mapped back to the base case in order to be accounted in the flow solution of the whole domain.

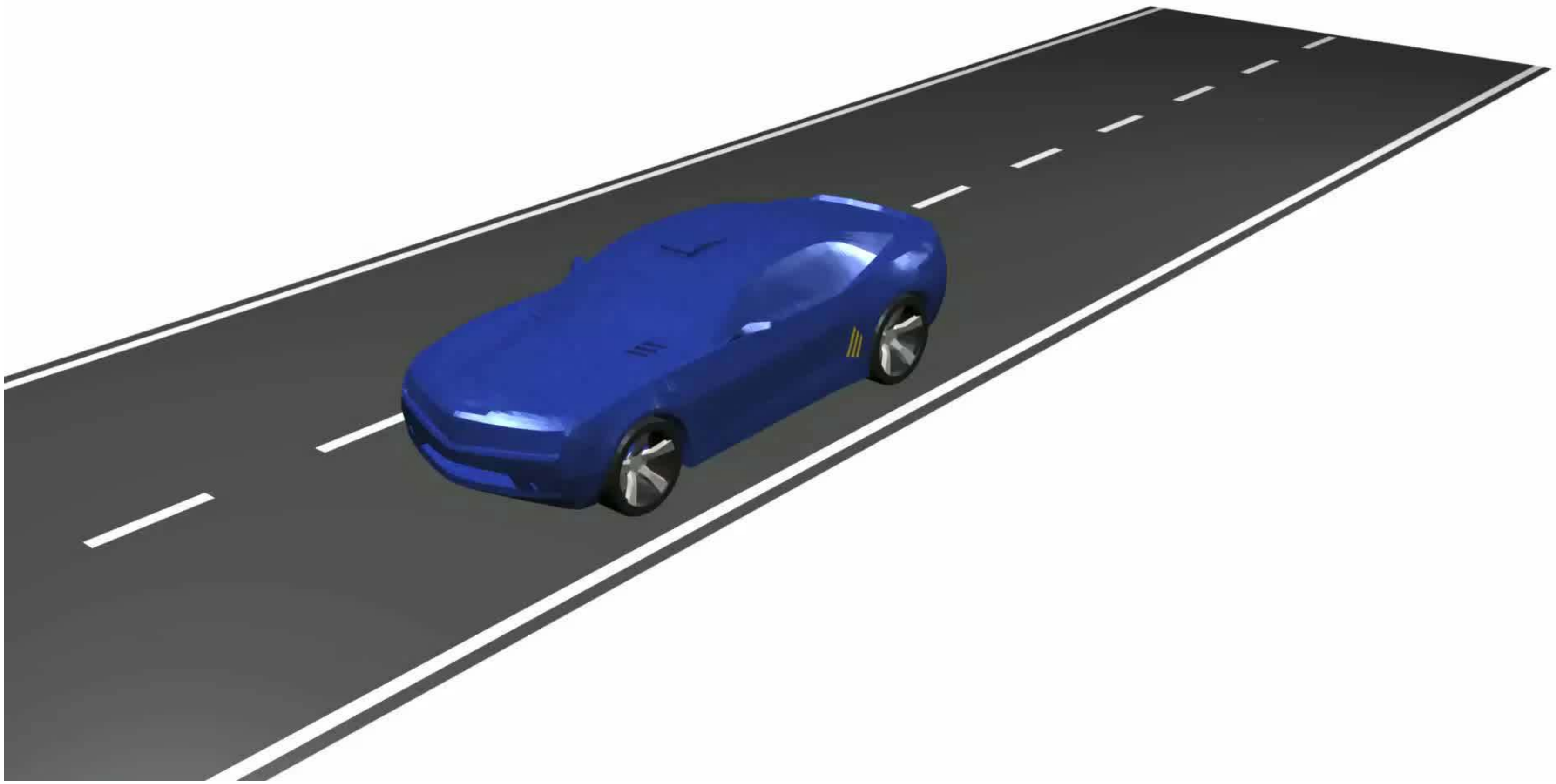
Duct optimisation – Reduction of losses

Technology • Process • Consulting

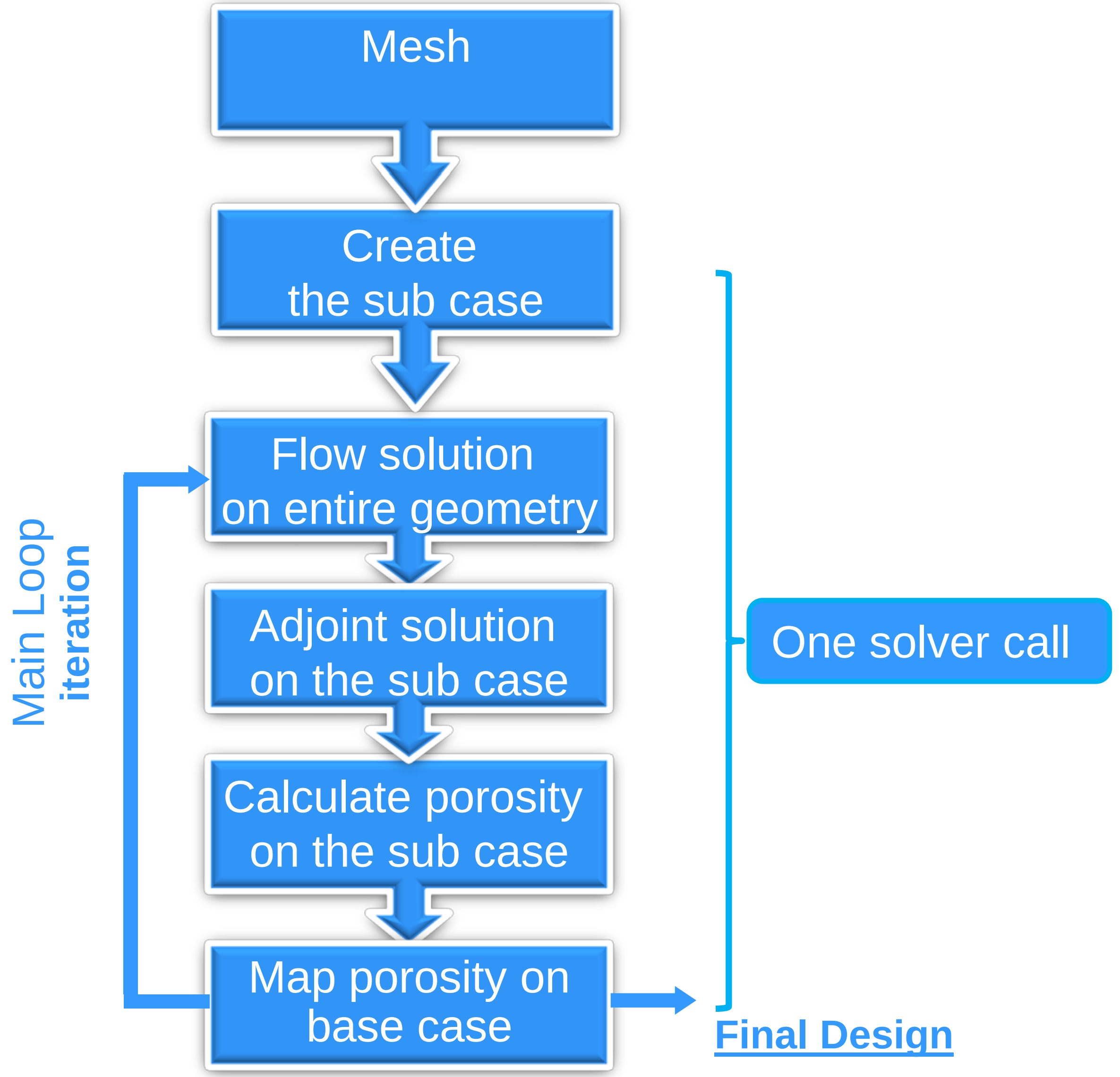
- The envelope used is the space between the grill and the rear wheel
- The flow around the whole geometry is calculated in order to specify the boundary conditions for the optimisation process.
- Adjoint topology optimisation is used to optimise the duct



Adjoint Sub Case



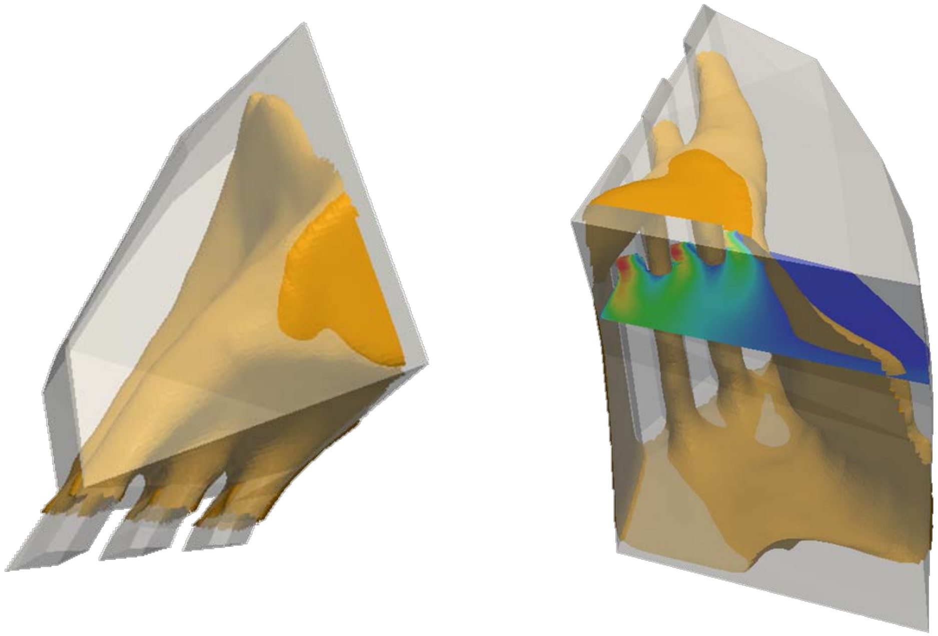
Duct Optimisation – Reduction of Losses



Optimisation Process

- The adjoint flow solver works as a plugin
- Any incompressible RANS flow solver can be used with small modifications
- Can be extended for LES
- The sub case is automatically created at the start of the solver

Resulting geometry after extracting the STL and wrapping



The process has been successfully implemented on a Lamborghini motorsport vehicle in early stages of design with an overall gain in pressure losses of about 16% compared to the original cooling duct. The resulting duct is currently being used to manufacture the cooling duct for the car.

supported the development
of ICON FOAMpro Optimize SubCase

Conclusions - Future Work

Technology • Process • Consulting

- Icon's work in the FlowHead project was advances of the adjoint solver to tailor industrial applications.
- Several boundary and volume cost functions were added to the solver and validated.
- A differentiated adjoint turbulence model was implemented and validated
- The solver robustness and stability were assessed and improved for the provided industrial cases.
- Exploitation and dissemination of the FlowHead work through further developments and several worldwide presentation of the results.
- Icon is continuously developing further processes on adjoint based optimisation
- An example was shown in the adjoint sub case process.
- The adjoint sub case process has already been successfully implemented on a Lamborghini motorsport vehicle with an overall gain of 16% in power losses.
- Icon's goal is creating an automated environment for inclusion of the optimisation in the vehicle production cycle.
- ICON FOAMpro GUI and ICON FOAMpro MultiCase to include setup for the adjoint solvers and utilities.

The contents of this archive are the property ICON.

It is supplied in confidence, and commercial security on its contents must be maintained. It must not be used for any purpose other than for which it is supplied, nor may any information be disclosed to unauthorised persons. It must not be reproduced in whole or in part without permission in writing from ICON.

www.iconCFD.com

Technology • Process • Consulting

www.iconCFD.com