EMPIAS엠피어스
Innovative Engineering Systems

OpenFOAM 라이브러리 기반 솔루션인 ELEMENTS와 HELYX를 통한 CFD 최적화 해석

2016. 09. 30.

엠피어스 주식회사

http://www.empias.co.kr

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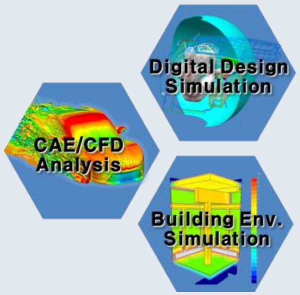

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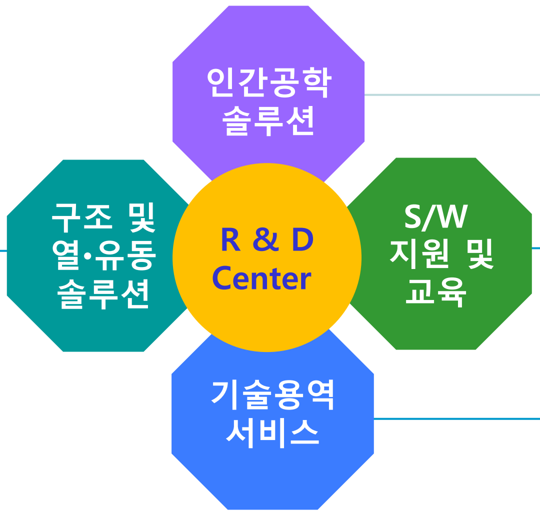
회사개요

- 회 사 명 엠피어스 주식회사
- 주 소 서울시 금천구 가산동 345-90 한라시그마밸리 1710
- 설 립 일 2004년 2월
- 홈 페이지 www.empias.co.kr
- 회사 연혁
  - 1998. 07. 씨엠에스테크㈜ 설립
  - 2004. 02. 엠피어스㈜ 사명 변경
  - 2008. 01. 전문화 엔지니어링 체제 구축
  - 2011. 06. 기업부설연구소 설립(한국산업기술진흥원)
  - 2012. 08. 벤처기업인증(기술보증기금)

회사전경

주 요 사 업



인간공학관련 해석소프트웨어
공급 및 설계, 평가, 용역

열유체(CFD) 및 구조해석
(FEA) 솔루션공급 및 기술지원

소프트웨어의 개발
유지보수, 교육 및
기술지원서비스

차량의 인간공학 설계평가
CFD 및 FEM Mesh Modeling
열,유체해석
환경 엔지니어링해석

개발사 소개 | ENGYS

- CAE products and services
- Focus on open-source solutions
- Solution platforms:
  - CFD → HELYX® (OpenFOAM®)
  - MDO → DAKOTA / HELYX - Adjoint
  - GUI → HELYX-GUI / HELYX-OS
- History:
  - 2009 → founded in the UK
  - 2010 – present → 5 offices worldwide (UK, Germany, Italy, USA, Aus.)
  - 2012 → Joint Venture with ARC (ELEMENTS)
  - 2013 → resellers Japan and Benelux
  - 2014 → resellers Korea and China



개발사 소개 | ENGYS 주요 고객

Automotive / Racing

DAIMLER, MIRA, FIAT, CRF CENTRO RICERCHE FIAT, Ferrari, VW, Audi, BMW, MITSUBISHI MOTORS, faurecia, SANDEN Delivering Excellence, CHRYSLER

Aerospace / Transportation / Military

FINCANTIERI, VOITH, BOMBARDIER TRANSPORTATION, Kawasaki, ARMSCOR Armaments Corporation of South Africa SOC Ltd, SCHOTTEL, DLR, BECHTEL

Building Environments

RAMBØLL, BMT, WOLFGANG SORGE INGENIEURBÜRO FÜR BAUPHYSIK GMBH Beratende Ingenieure VBI (IfB), Foster + Partners, 鹿島 KAJIMA CORPORATION, IES, SOM

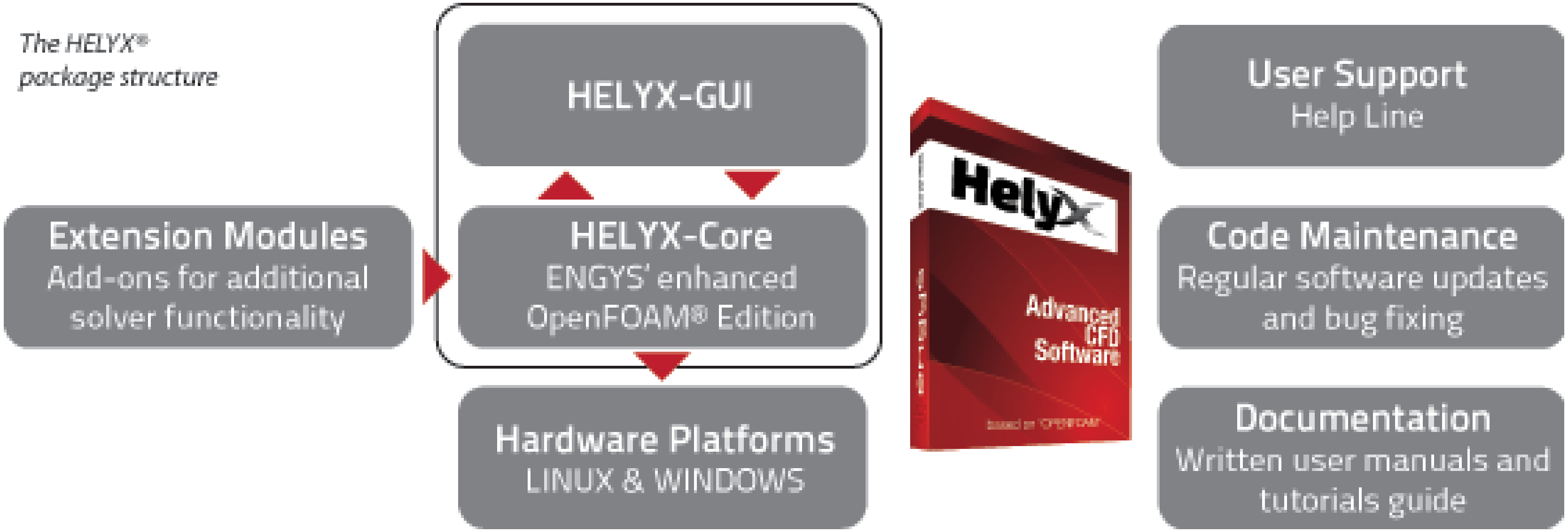
Process / Manufacturing

Panasonic, Fuji Electric, P&G, BASF The Chemical Company, SMS SIEMAG SMS group, BOSCH Invented for life, Whirlpool CORPORATION, IHI, NIPPON STEEL & SUMITOMO METAL

Oil & Gas / Energy / Turbo

NESTEJACOBS, HITACHI Inspire the Next, MEIDEN, VTT, GRUNDFOS, LEITWIND, OELTECHNIK ... the customer care company, ClearSign

HELYX | Overview

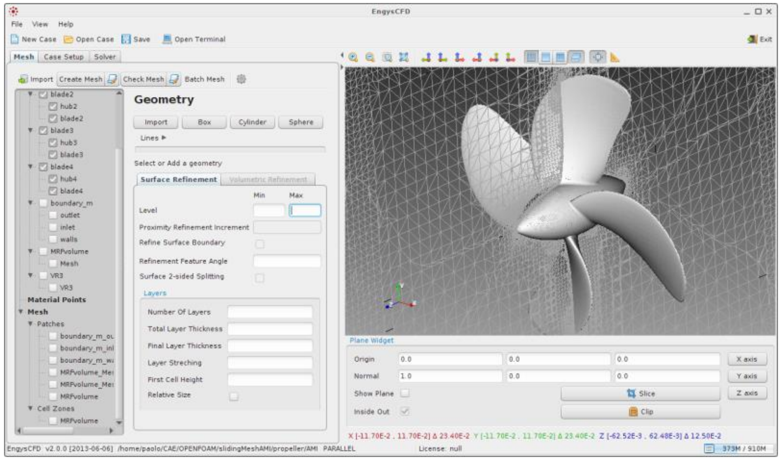


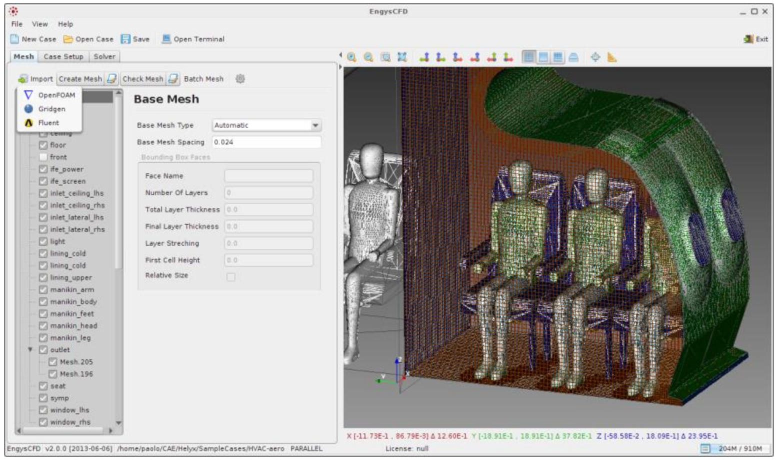
- General purpose CFD product
- Open-source CFD simulation engine developed by ENGYS
- Many enhancements over standard OpenFOAM
- Modular add-ons for extended solver capabilities

HELYX-Core | Overview

- HELYX-Core vs. OPENFOAM
  - HELYX-Core based on v3.0+
  - 2000+ files modified
  - 400+ new files

- Primary development goal → improve user experience and solver quality
  - Ease of Use
  - Application specific capability
  - Accuracy/Robustness/Speed

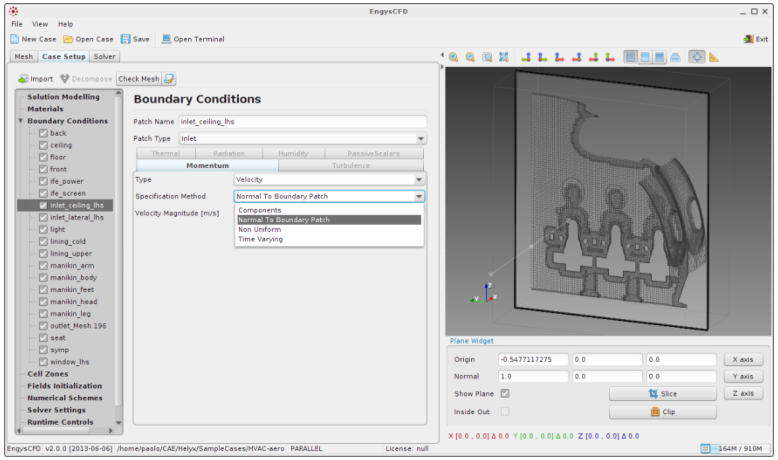


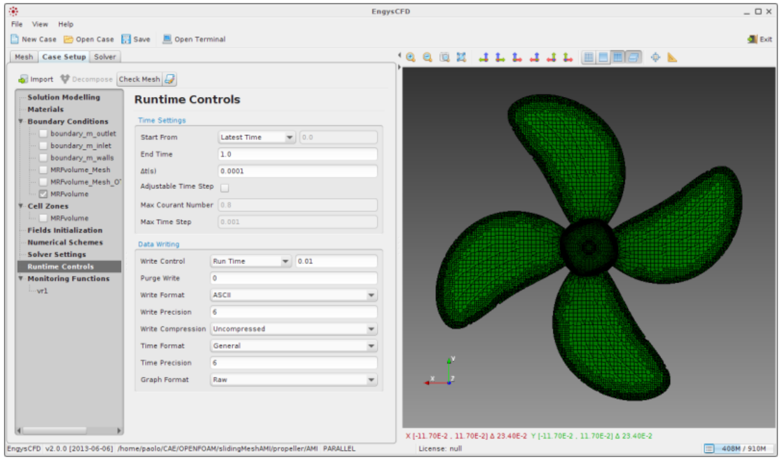


- Windows and Linux support
- Automatic hex-dominant parallel meshing with minimum CAD preparation
- Geometry, mesh & fields interactive 3D visualisation
- Comprehensive set of models and boundary conditions
- Sensible defaults for advanced parameters
- Advanced TUI (text user interface) for batch scripting

Key Features

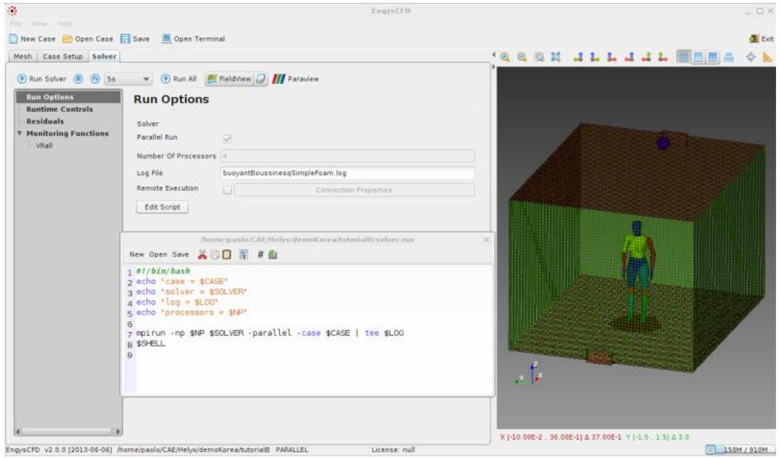
- Solvers in HELYX-GUI:
  - single phase
  - incompressible/compressible
  - turbulent/laminar
  - RANS, URANS, DES, LES
  - energy/buoyancy
  - thermal/solar radiation
  - multiphase (VOF/Euler)
  - passive scalar transport
  - humidity transport
  - moving rotating mesh
  - porous/MRF/sources

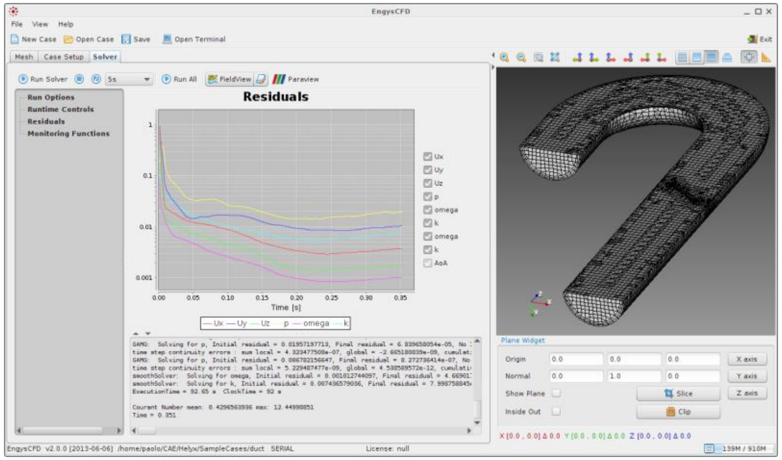




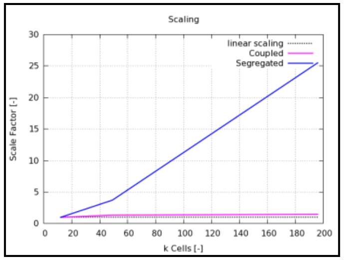
Key Features

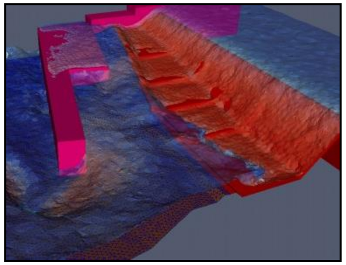
- Tools in HELYX-GUI:
  - IGES/STL import for meshing
  - Mesh import/merge/export from/to other tools
  - Mesh zone creation
  - Fields mapping/initialisation
  - Monitoring functions
  - Custom editor interface for user-defined entries
  - Multiple manipulation widgets (plane, measure, surface split)
  - Solution export to Paraview, Ensight, Fieldview

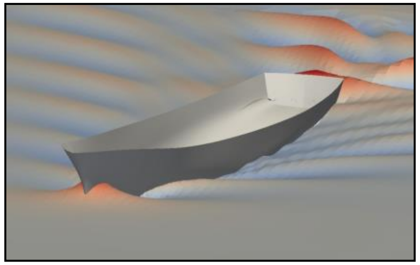


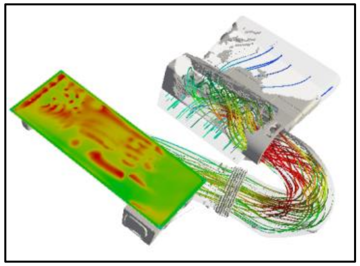


- Advanced add-on solver packages for HELYX®
- Extend capabilities beyond HELYX-Core feature list
- Developed by specialists → independent development partners
- Full GUI / user support
- Available at extra cost in addition to HELYX®



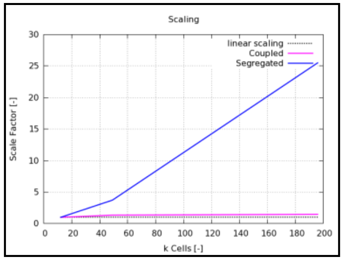


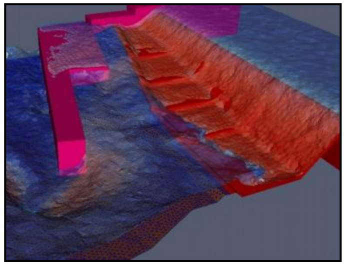


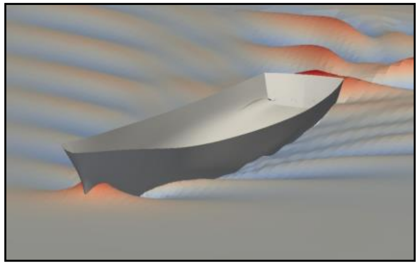


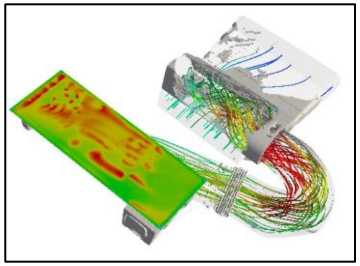
HelyX Modules | What is available?

- **Coupled** → fully implicit block coupled solvers
- **Adjoint → continuous CFD adjoint for topology and shape optimisation**
- **Hydro** → enhanced VOF multi-phase environment with thermal capabilities
- **EcoMarine** → ship hull hydrodynamics
- **PEM** → Polyhedral Element Method







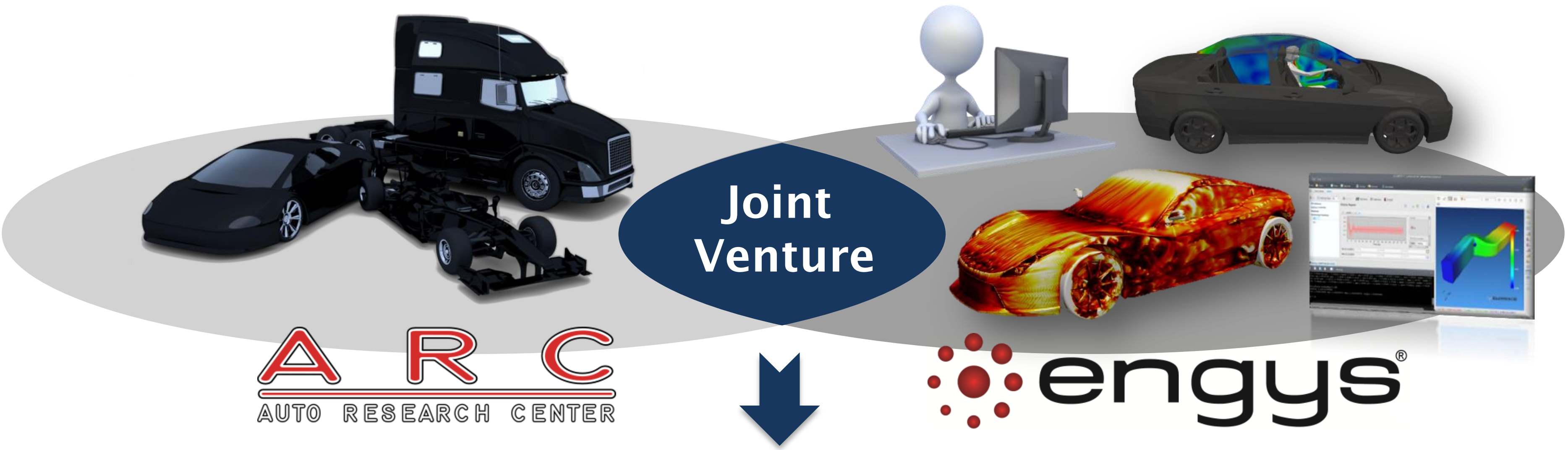


AUTO RESEARCH CENTER

Automotive Engineering R&D, Wind Tunnel, 7-Post & Gearbox Rig, CFD

ENGYS

Open-source CAE Software Engineering, CFD, MDO, Development, Support



STREAMLINE SOLUTIONS LLC

ARC and **ENGYS** unique combination of automotive engineering resources and CAE software development expertise to create ELEMENTS for CFD automotive analysis using open-source methods

ELEMENTS | Current Deliverables

- ELEMENTS incorporates two CFD interfaces in one GUI:

External Aero GUI
External vehicle aerodynamics wizard

General purpose CFD interface
UHTM, HVAC, cabin comfort, powertrain, CAA…

Aero GUI | Wind Tunnel Validation

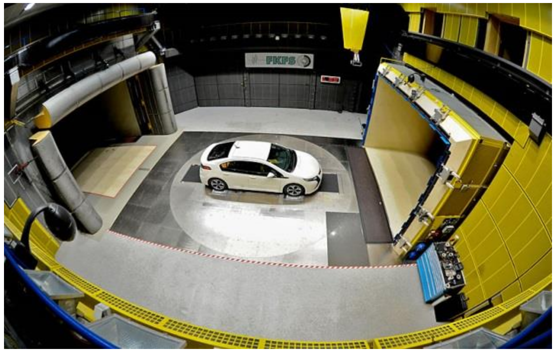
- Objectives:
  - Validate best-practices for external aerodynamics CFD
- Requirements:
  - Wind tunnel measurements (ARC)
  - Range of vehicle shapes
- Outcome:
  - Automated CFD process
  - Consistent drag prediction across multiple vehicle shapes
  - High accuracy within a specified confidence interval of error

Vehicle Types

- Sedan
- Hatchback
- Estate
- SUV
- Streamliner
- Nascar
- Indycar
- Light Duty Truck
- Heavy Duty Truck

200+ Test Configurations

- All vehicle types
- Fixed Ground
- 5-belt Moving Ground
- Single Belt Moving Ground
- Test Speed
- Yaw Angle
- Ride Height
- Vehicle Modifications (e.g. Cooling close/open, Spoiler on/off, Underbody Panels on/off)



Aero GUI | Wind Tunnel Validation

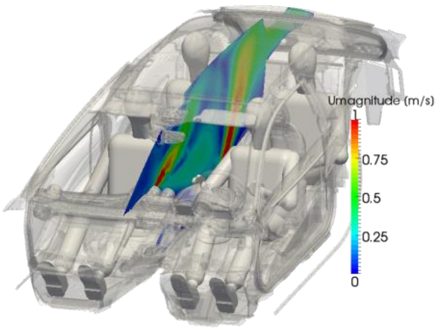
MPIAS 엠피어스 Innovative Engineering Systems

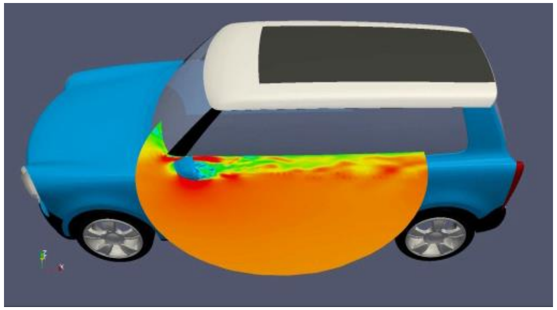
Vehicle No.	Vehicle Model	Grille (open, closed, blanked)	Wind Tunnel Data		Elements Coefficients			Notes (no. of cells, prism layers, run length, etc.)
			Scale	Ground Simulation	CD	CLF	CLR	
1	DRIVAER Estate	n/a	40%	Single Belt	2.40%			Scale Model, 29.5 Cells, 24 hrs, 3 body layers
2	DRIVAER Fast	n/a	40%	Single Belt	-0.41%			Scale Model, 29.7 Cells, 18.4 hrs, 3 body layers
3	DRIVAER Notch	n/a	40%	Single Belt	0.41%			Scale Model, 29 Cells, 24.3 hrs, 3 body layers
4	Sedan 1	open	100%	5 Belt	0.67%	-0.67%	-6.56%	Full Size Model, 49M Cells, 22.5 hrs, 3 body layers
		open	40%	Single Belt	0.00%	-7.19%	4.45%	Scale Model, 46M Cells, 23 hrs, 3 body layers
		closed	40%	Single Belt	1.74%	-2.48%	4.61%	Scale Model, 54.5M Cells, 25.8 hrs, 3 body layers
5	Sedan 2	open	100%	5 Belt	0.00%	-1.87%	-0.37%	45M Cells, 3 Body layers, 22 hrs, Open, Full Size
		blanked	100%	Fixed	1.57%	-26.38%	9.84%	
6	Sedan 3	closed	100%	Fixed	2.35%			42 M Cells, 3 Body Layers, 46 hrs, Full Size
		open	40%	Single Belt	0.32%	-2.27%	-2.27%	Perforated Plate Porous Zones, Simulated ARC tunnel Belt System
		closed	40%	Single Belt	2.03%	-1.35%	2.03%	Perforated Plate Porous Zones, Simulated ARC tunnel Belt System
7	Estate 1	open	40%	Single Belt	-0.32%	11.04%	26.62%	Scale Model In tunnel, 91.5 M Cells, 49.74 hrs, 3 body/belt layers.
8	Estate 2	open	100%	5 Belt	-0.95%	-3.81%	-3.17%	
9	Hatchback 1	open	40%	Single Belt	3.09%	7.21%	19.75%	Scale Model in Tunnel, 101.4M Cells, 25.65 hrs, 3 body/belt layers.
10	Hatchback 2	open	100%	5 Belt	2.18%	-22.55%	12.00%	
11	SUV 1	open	40%	Single Belt	0.81%	6.59%	-16.76%	Scale Model, 47.7M Cells, 13.4 hrs, 3 body layers
12	NASCAR 1		40%	Single Belt	2.22%			Scale Model, 53.4M Cells, 35.6 hrs, 3 body layers
13	NASCAR 2	open	40%	Single Belt	-1.25%	-32.67%	-10.47%	Scale Model
14	Semi-Truck 1	open	12.5%	Single Belt	0.19%			Tractor CD is 0.326/(0.320); trailer CD is 0.207/(0.214) Tunnel/(CFD)
15	Light Truck 1	open	20%%	Single Belt	-0.38%	-5.09%	-10.38%	63M Cells, ARC Moving Belt on Floor

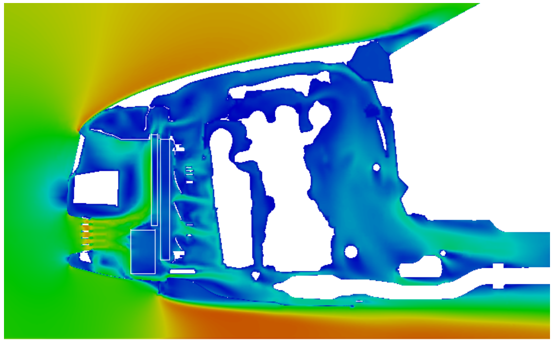
Cars → **Average Error Magnitude 1.2% 9.37% 9.24%**

General CFD Interface | Overview

- General purpose CFD interface for automotive applications:
  - UHTM (CHT, fans, porous media)
  - CAA (LES/DES turbulence)
  - HVAC (thermal flows, radiation)
  - Soiling (Lagrange DPM)
  - Water management (VOF, multiphase)
  - Others
- Automatic hex-dominant mesh
- Easy setup and usage
- Open-source simulation engine



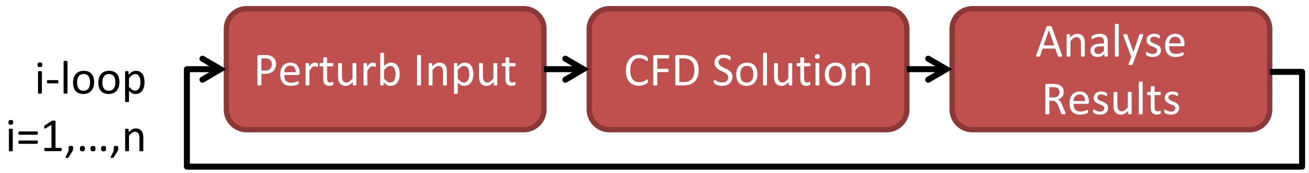




HELYX / ELEMENTS – Adjoint | Key Features

- Unique continuous adjoint formulation for topology and shape optimisation developed by ENGYS
- Multi-objective (> 10 different objective functions)
  - forces & moments, uniformity, pressure loss, massflow split, swirl, wall shear stress…
- Fast gradient based optimization
- 2nd order accuracy for advection
- Immersed boundary for interface tracking
- Incompressible and compressible flow support
- RANS and time-averaged DES/LES support
- MRF and porous media support
- No expert knowledge required
- Employed to calculate sensitivities w.r.t. user defined objective functions
- Cost of simulation independent from the number of design parameters
- Calculation of the sensitivity derivatives is approximately equivalent with the solution time of one traditional CFD simulation
- Fully validated and deployed in industrial settings for several years (VW, BMW, etc.)

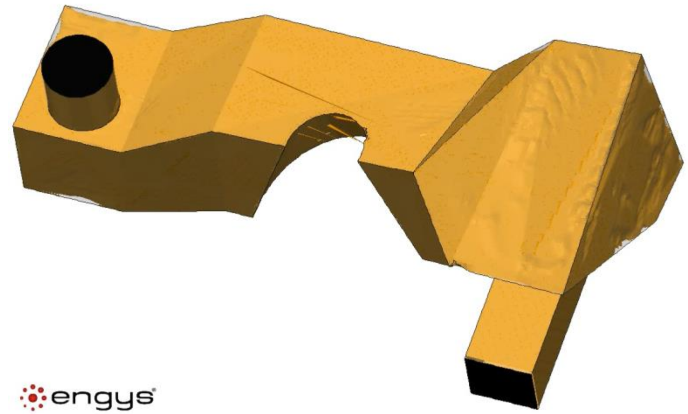
- Optimise large number of design variables in the shortest possible time
- Typical approaches to calculate sensitivities w.r.t. a specific objective cost function:
  - **Finite Differences** → *n* design variables require *n*+1 flow calculations



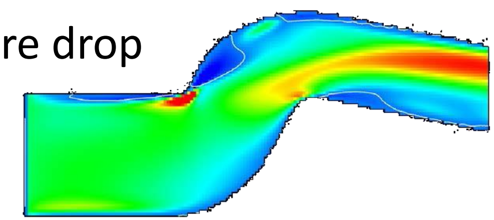
  - **Adjoint Method** → *n* design variables require 1 flow + 1 adjoint calculation independent of No. of design variables

Adjoint | Topology Optimization

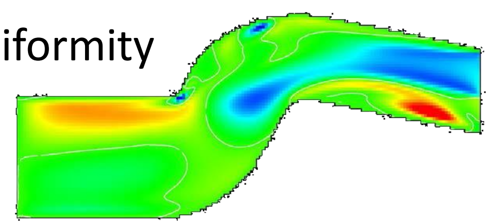
- Specify design space and inlet/outlet interfaces
- Define optimisation objectives
- Calculate volume sensitivities
  - Volume cells penalised according to objective function
  - Track "optimum" interface with immersed boundary
- Output "smooth" surface optimised shape
- Single flow simulation



$\frac{\partial J}{\partial \alpha} \rightarrow$ pressure drop

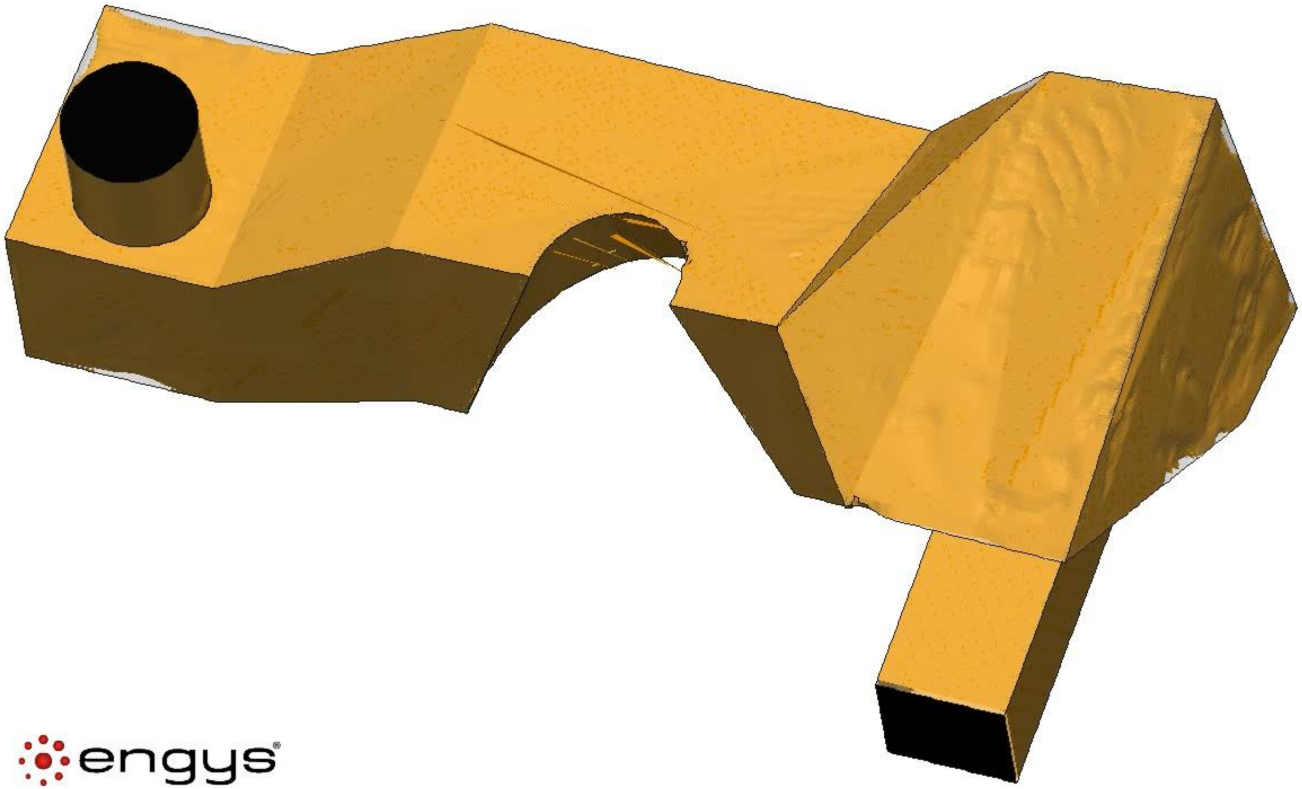


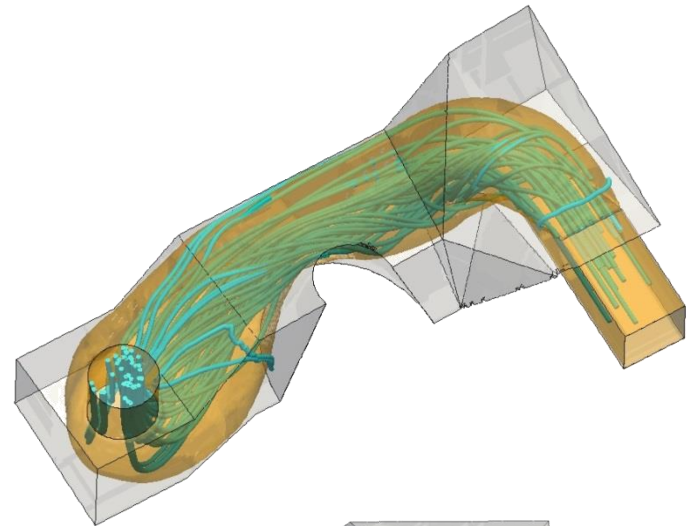
$\frac{\partial J}{\partial \alpha} \rightarrow$ flow uniformity

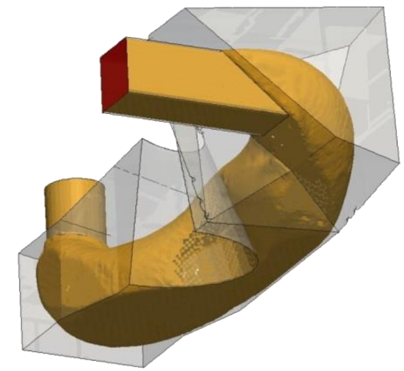


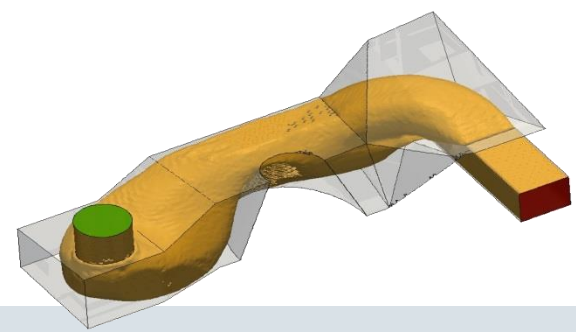
Adjoint | Topology Optimization

- 50% Pressure Loss improvement
- Optimized shape:





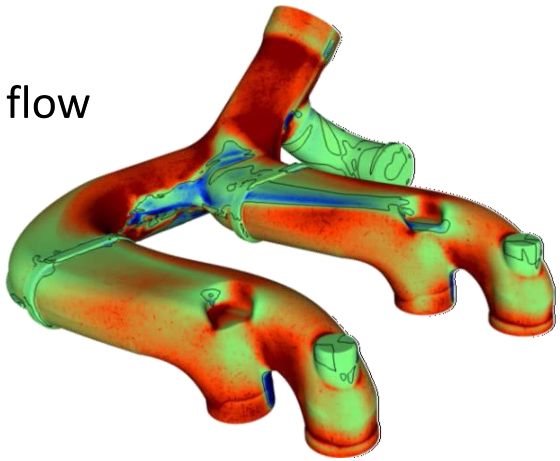




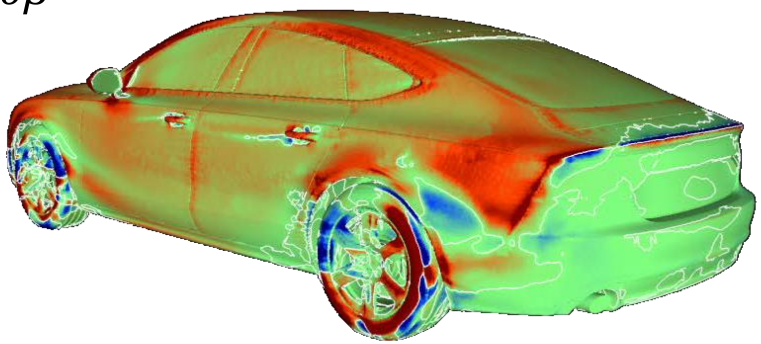
engys

- Based on RANS or time-averaged DES/LES results
- Define optimisation objectives
- Compute <u>surface</u> sensitivities
- Morph mesh/surface to reach optimal solution (neutral state)

$\frac{\partial J}{\partial \beta}$ → mass flow

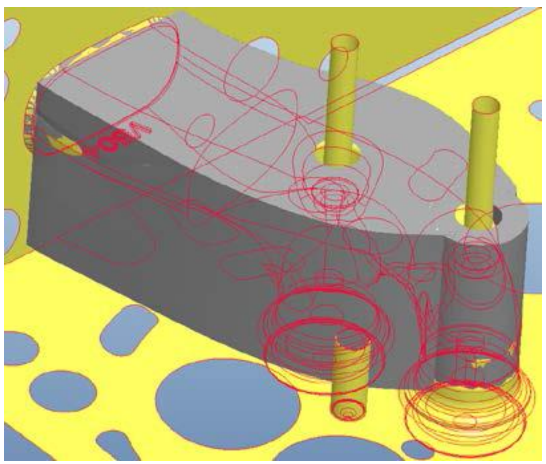


$\frac{\partial J}{\partial \beta}$ → drag



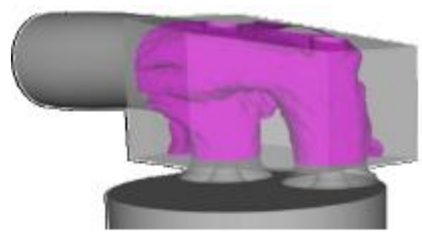
Engine Ports Design

Packaging space definition



[F. Kunze and R. Niederlein]

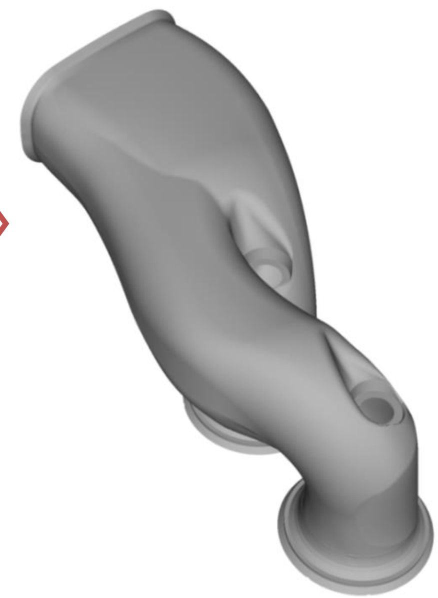
Drafting with HELYX-Adjoint



HELYX-Adjoint + manual CAD iterations

Fine tuning with HELYX-Adjoint

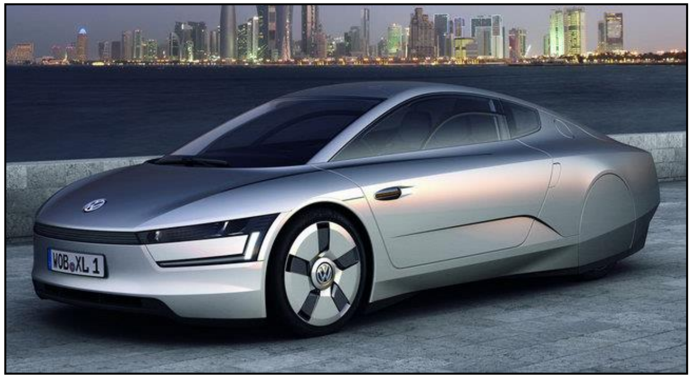
Final (hand-made) CAD Geometry

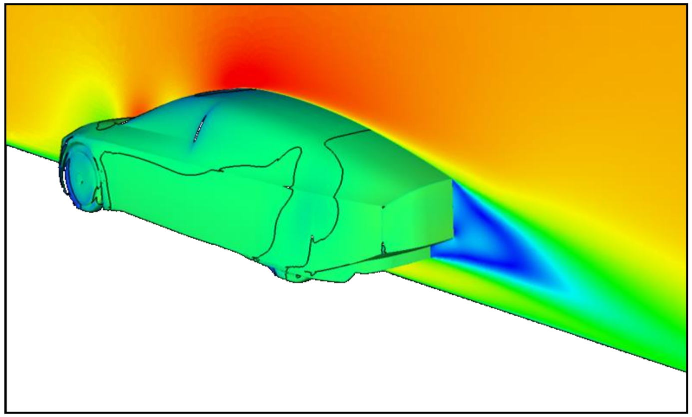


Taken from “The Adjoint Method Hits the Road” by C. Othmer [2014]

Adjoint Shape Optimisation | VW XL1

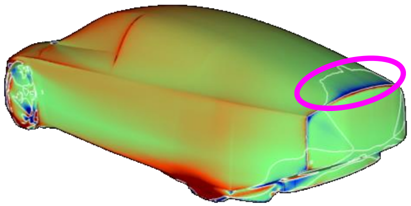
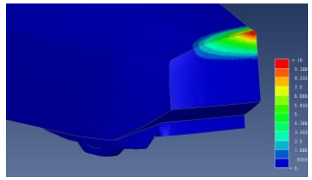
- Objective → Minimise drag
- Low-Reynolds mesh (y+ ~ 1)
- Primal
  - RANS with Spalart-Allmaras
- Adjoint:
  - Adjoint Spalart-Allmaras
- 4 cases tested by morphing different areas of the car
- 2 of the cases verified in the wind tunnel





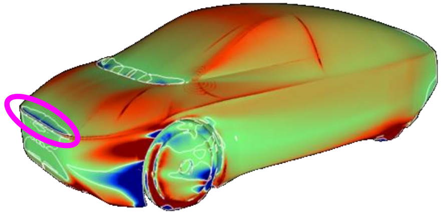
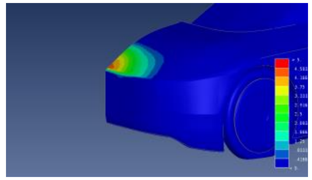
Adjoint Shape Optimisation | VW XL1

Morphing **according to** / **opposite to** sensitivities

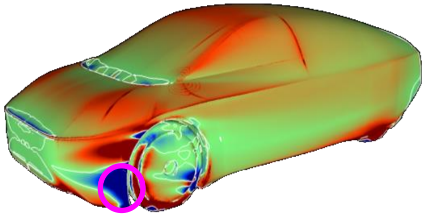
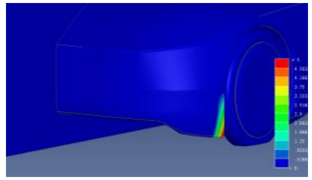
1  

-0,9% / +1,2% for 10mm displacement

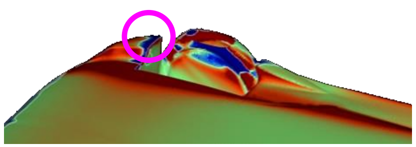
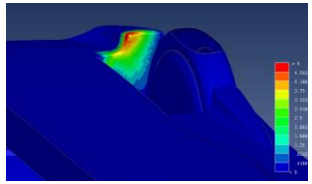
Confirmed in wind tunnel

2  

-0,13% / +0,14% for 5mm displacement

3  

-0,6% / +0,8% for 5mm displacement

4  

-0,8% / +1% for 10mm displacement

Confirmed in wind tunnel

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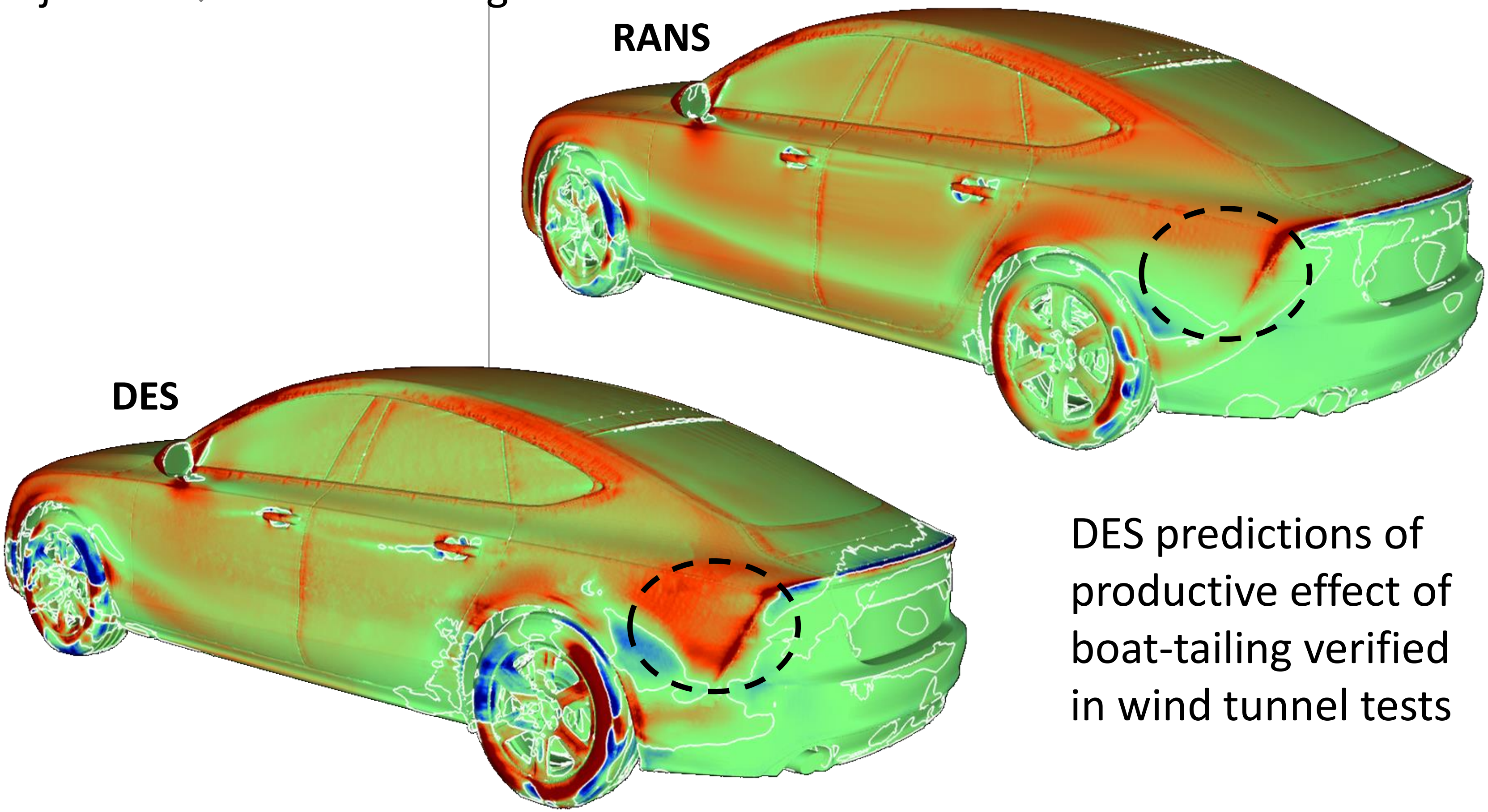
Adjoint Shape Optimisation | Audi A7

- Objective → Minimise drag



DES predictions of productive effect of boat-tailing verified in wind tunnel tests

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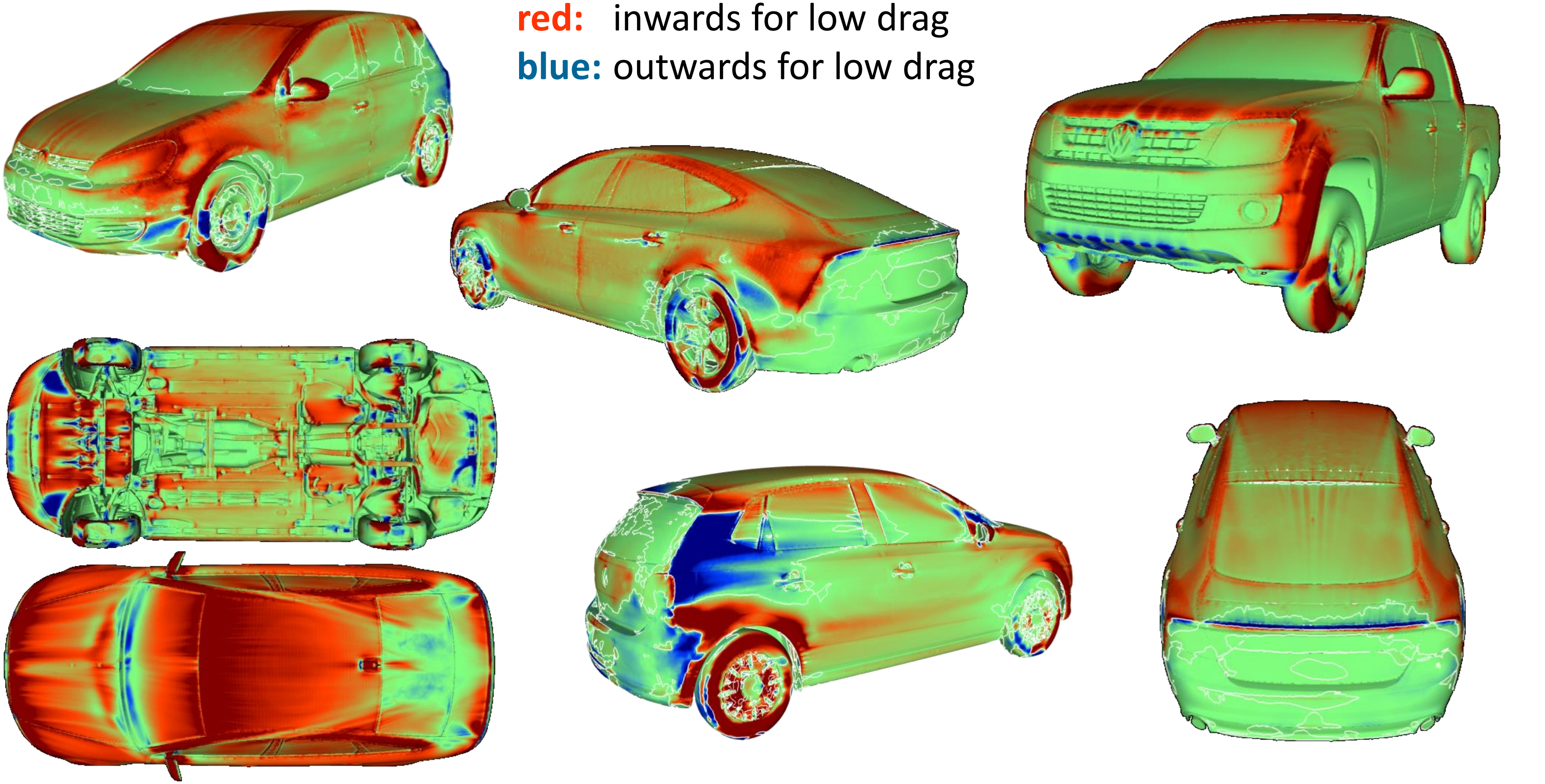
Adjoint Shape Optimisation | Other Examples

red: inwards for low drag
blue: outwards for low drag



HELYX | Conclusions and Benefits

- Unified off-the-shelf product
- Accountability
- Developed and maintained by FOAM/OpenFOAM® experts (developing FOAM since 1999)
- Best-in-class support
- Linux and Windows ports
- Fully validated solvers
- Entirely customisable (in-house methods, solvers…)
- Highly scalable (no HPC licenses)
- Open to 3rd party developers (plug-ins)
- **Great value for money!**

ELEMENTS | Conclusions and Benefits

- Open-source methods for maximum scalability and efficiency
- Dedicated interfaces for aerodynamics and other CFD applications
- Minimal CAD cleanup requirements → hours, not weeks
- Fully automatic meshing → improved speed and quality
- Embedded best practices in GUI → decades of experience
- Significantly reduced solution times → benchmarked against PowerFLOW and other CFD solvers
- Automated parallel post-processing → generate custom reports
- Highly accurate transient solutions → average drag errors of 1.2%
- Heavily validated results → access to own wind tunnel (ARC)
- Unique 2nd order continuous adjoint add-on solver for shape and topology optimisation

Thank You !

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