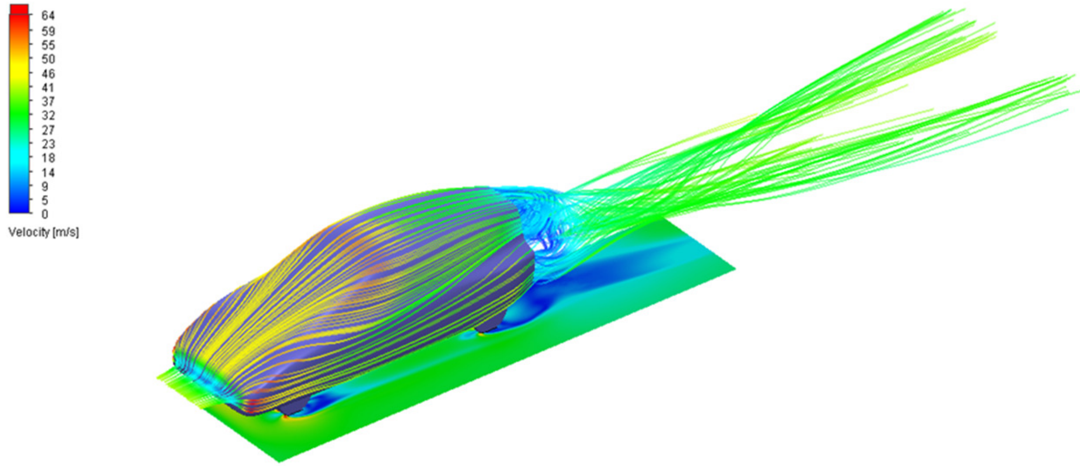
Comparison of the ASMO Car Model with Experimental Data and Simulations

Mike Gruetzmacher, Mentor Graphics

NAFEMS

Content

- Introduction
- Physical Engineering Models
- The ASMO example
- Conclusion



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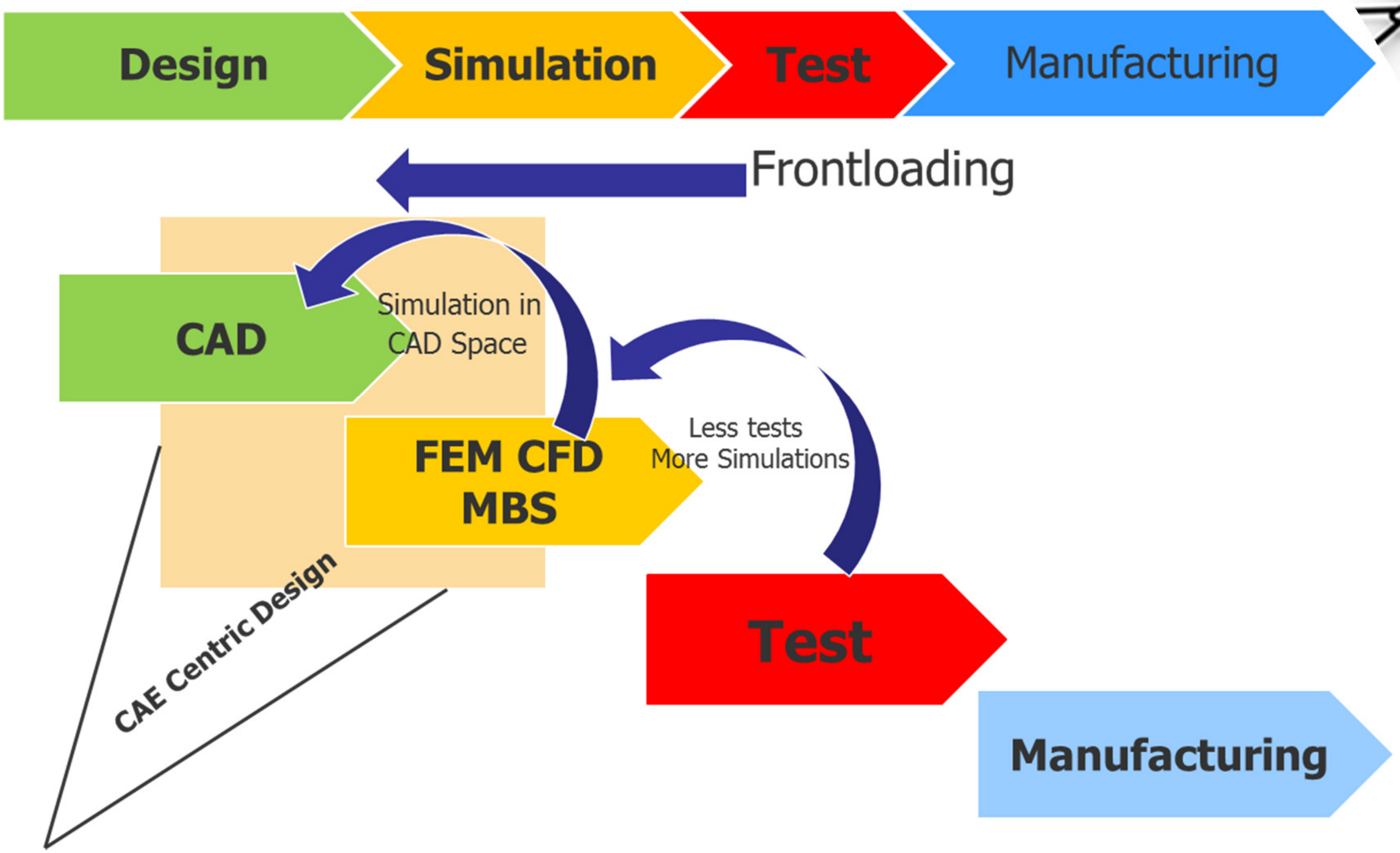
Introduction



Introduction

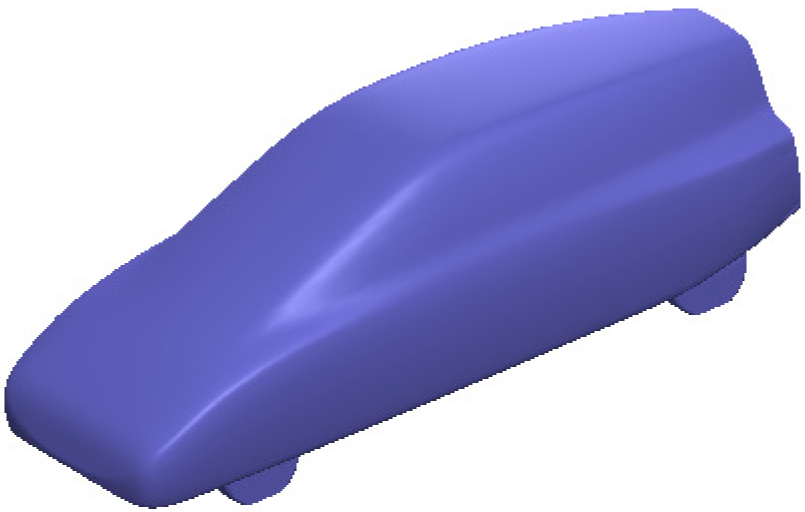
- Early development phase
- Aerodynamics car analysis
  - Wind tunnel experiments
  - CFD analysis
- Increasing flexibility, cost reduction, design modifications
- Impact of components (e.g. radiator grill, rear wing, mirrors)

Introduction

- Real car models: very complex geometry
- Simplified reference bodies for
  - Basic investigations
  - Code validations

Introduction

- ASMO example: „Aerodynamisches Studienmodell“
- Wind tunnel tests by Daimler Benz and Volvo



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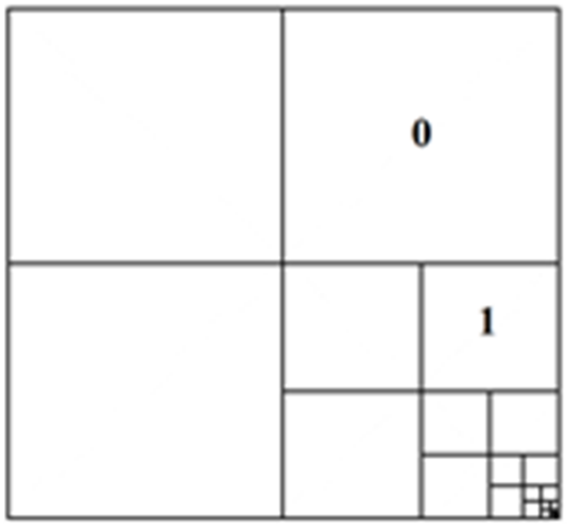
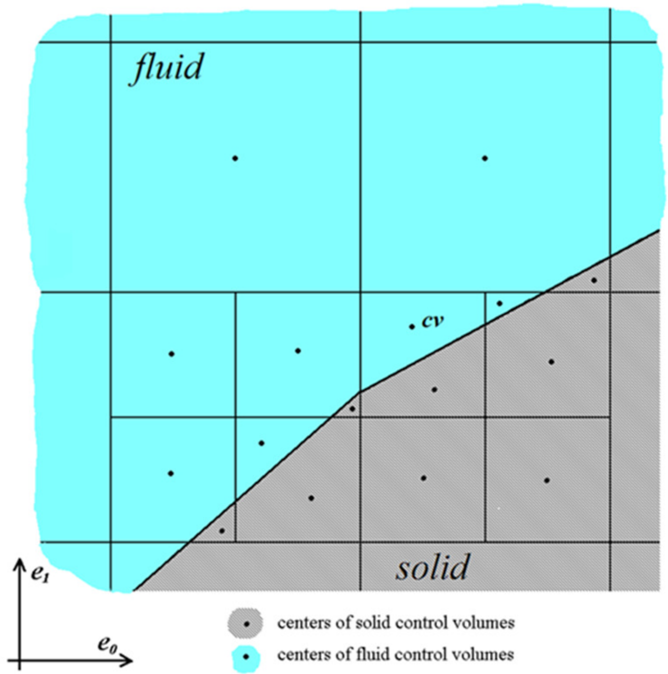
Meshing

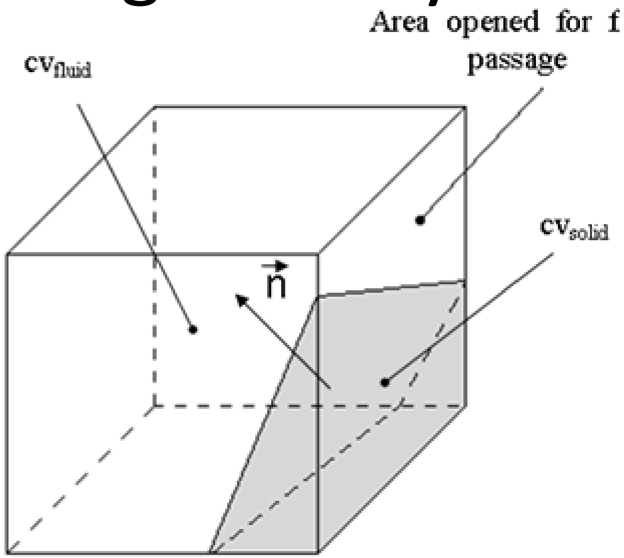
- Mesh: Rectangular Grid
- Refinements by cutting parallelepipeds

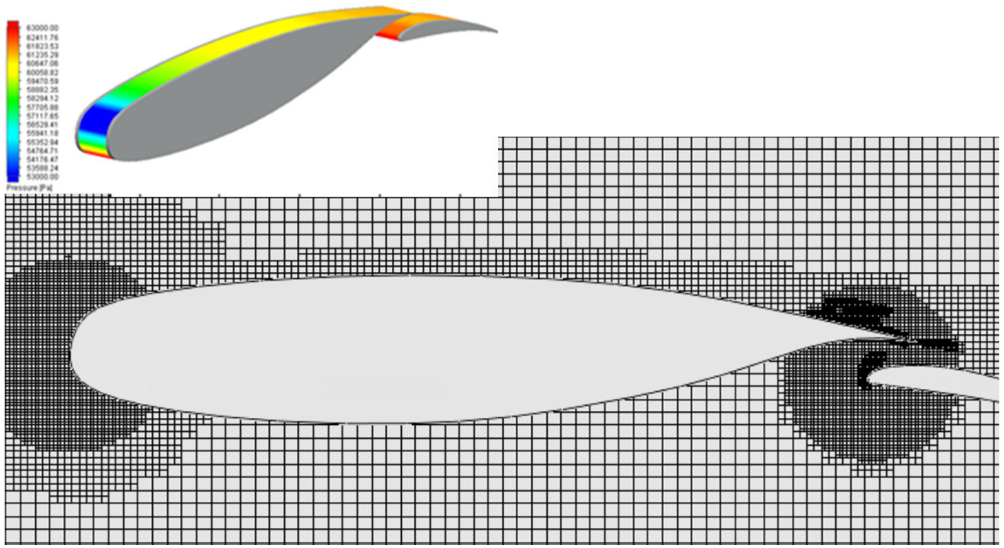




Meshing

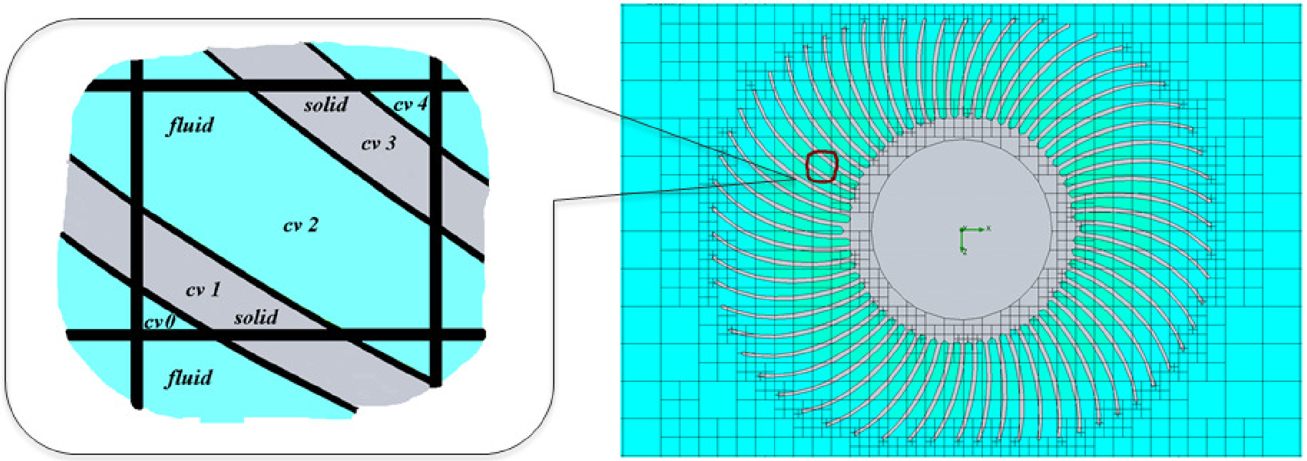
- Model body splits the cell into two or more sub-control volumes (polyhedrons) to represent the geometry





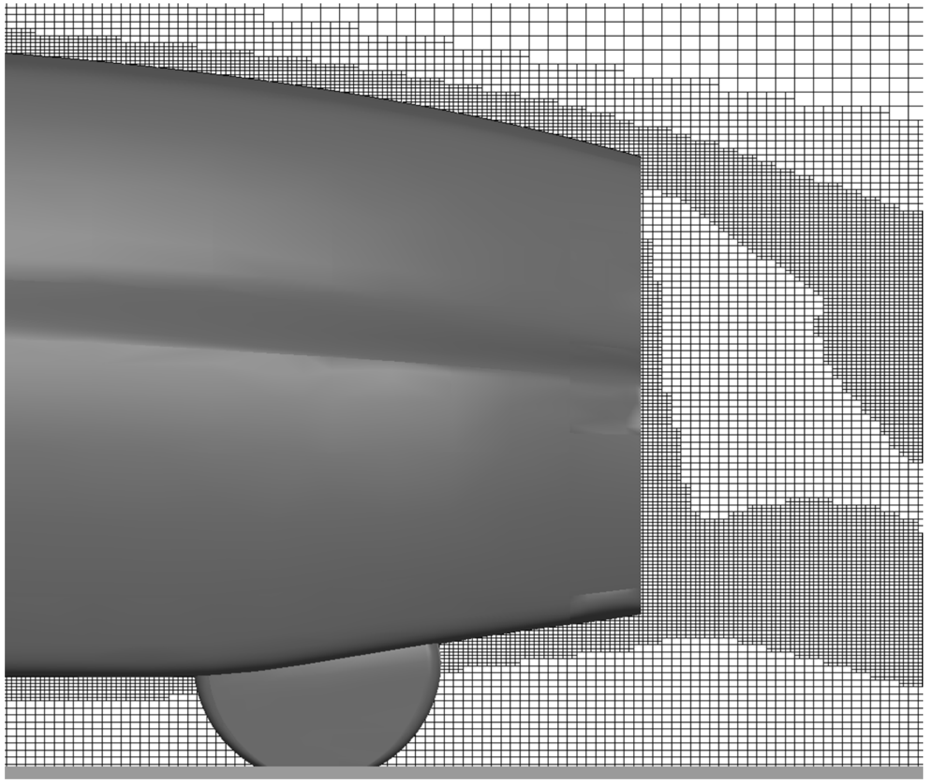
Meshing

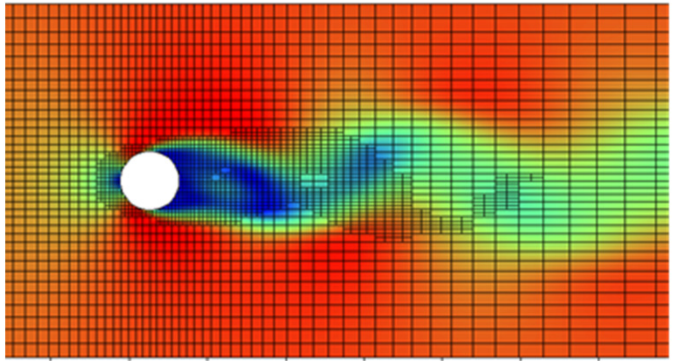
- Several sub-control volumes for very small features, f.i. thin layers

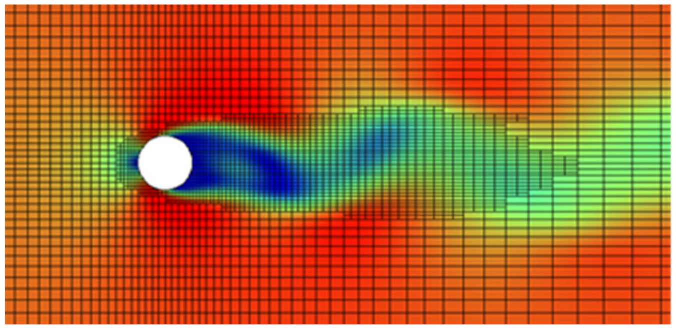


Meshing

- Solution adaptive refinement for regions with high flow gradients



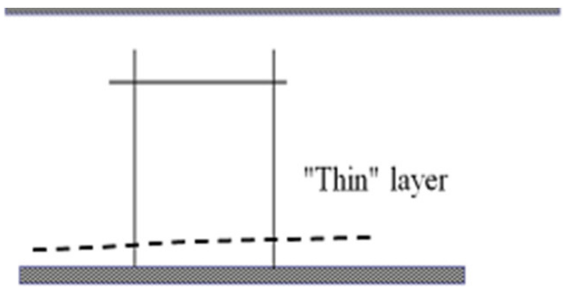




Boundary Layer

- FloEFD seperates the boundary layer treatment into:
  - „Thin“ Boundary Layer
  - „Thick“ Boundary Layer

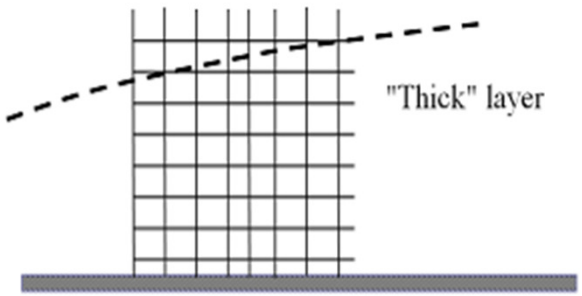
$\delta < 3$ cells



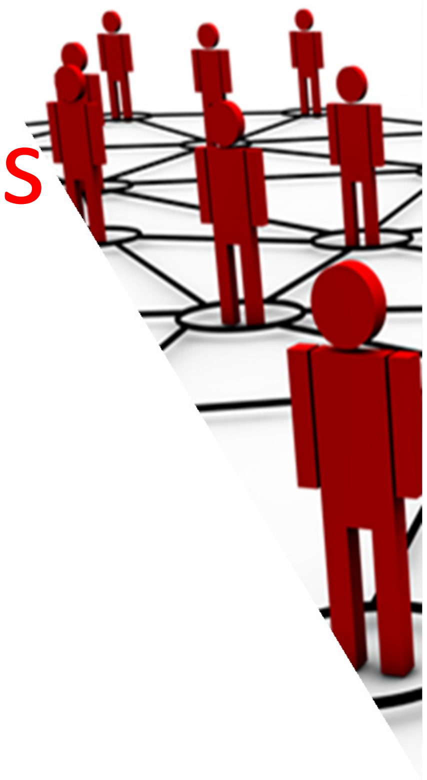
$3 < \delta > 6$ cells

Interpolated
between both
Types automatically

$\delta > 6$ cells



Physical Engineering Models



- One modified k-ε turbulence model

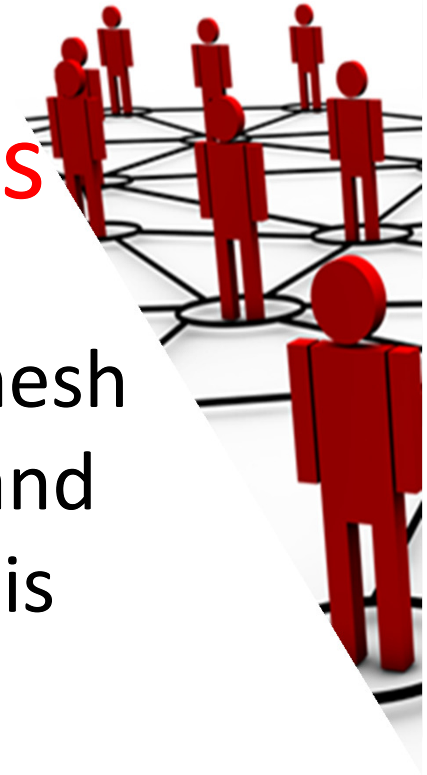
$$\frac{\partial \rho k}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_i k\right)=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right)+S_k$$

$$\frac{\partial \rho \varepsilon}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_i \varepsilon\right)=\frac{\partial}{\partial x_i}\left(\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right)+S_\varepsilon$$

$$S_k=\tau_{ij}^R\frac{\partial u_i}{\partial x_j}-\rho\varepsilon+\mu_t P_B$$

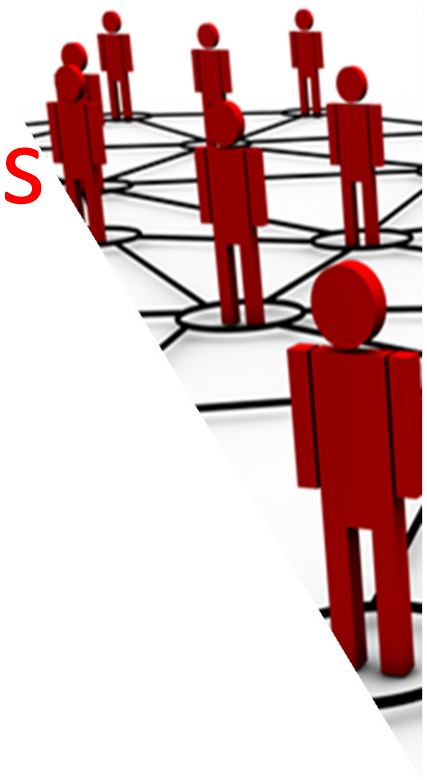
$$S_\varepsilon=C_{\varepsilon 1}\frac{\varepsilon}{k}\left(f_1\tau_{ij}^R\frac{\partial u_i}{\partial x_j}+\mu_t C_B P_B\right)-C_{\varepsilon 2}f_2\frac{\rho\varepsilon^2}{k}$$

Physical Engineering Models



- Algebraic solver is adapted to the mesh and the boundary layer treatment and includes the turbulence model in this approach
- high convergence stability and accuracy

Physical Engineering Models



- Advanced Meshing Technology in FloEFD™

  http://go.mentor.com/2gogl

- Enhanced Turbulence Modelling in FloEFD™

  http://go.mentor.com/2glzd

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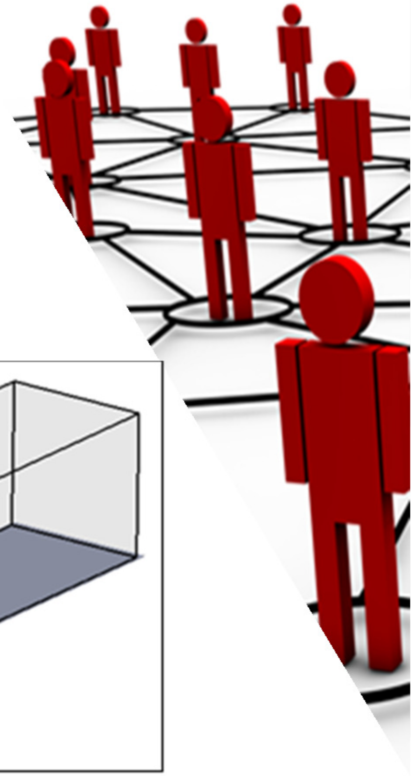
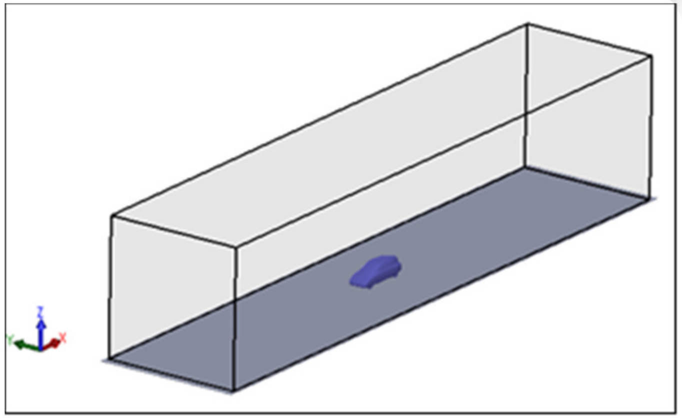
The ASMO example

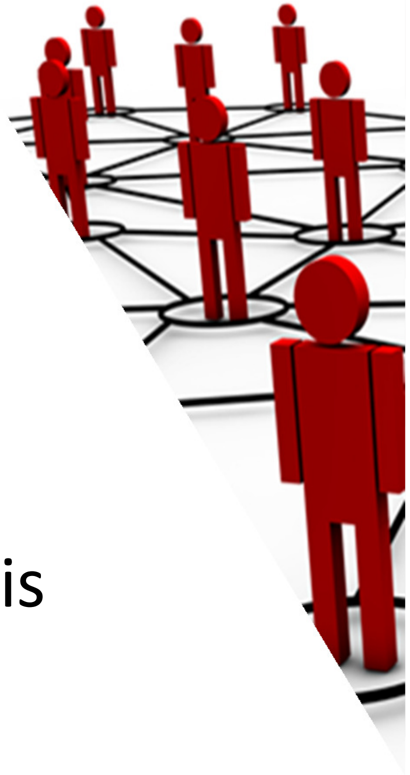


- Boundary Conditions
  - Velocity 50 m/s
  - Medium Air
  - Temperature 20 °C
  - Pressure 101,325 Pa
  - Reynolds Re=2,700,000 (vehicle length as reference)



- No movement applied to the floor surface (as in experiment)

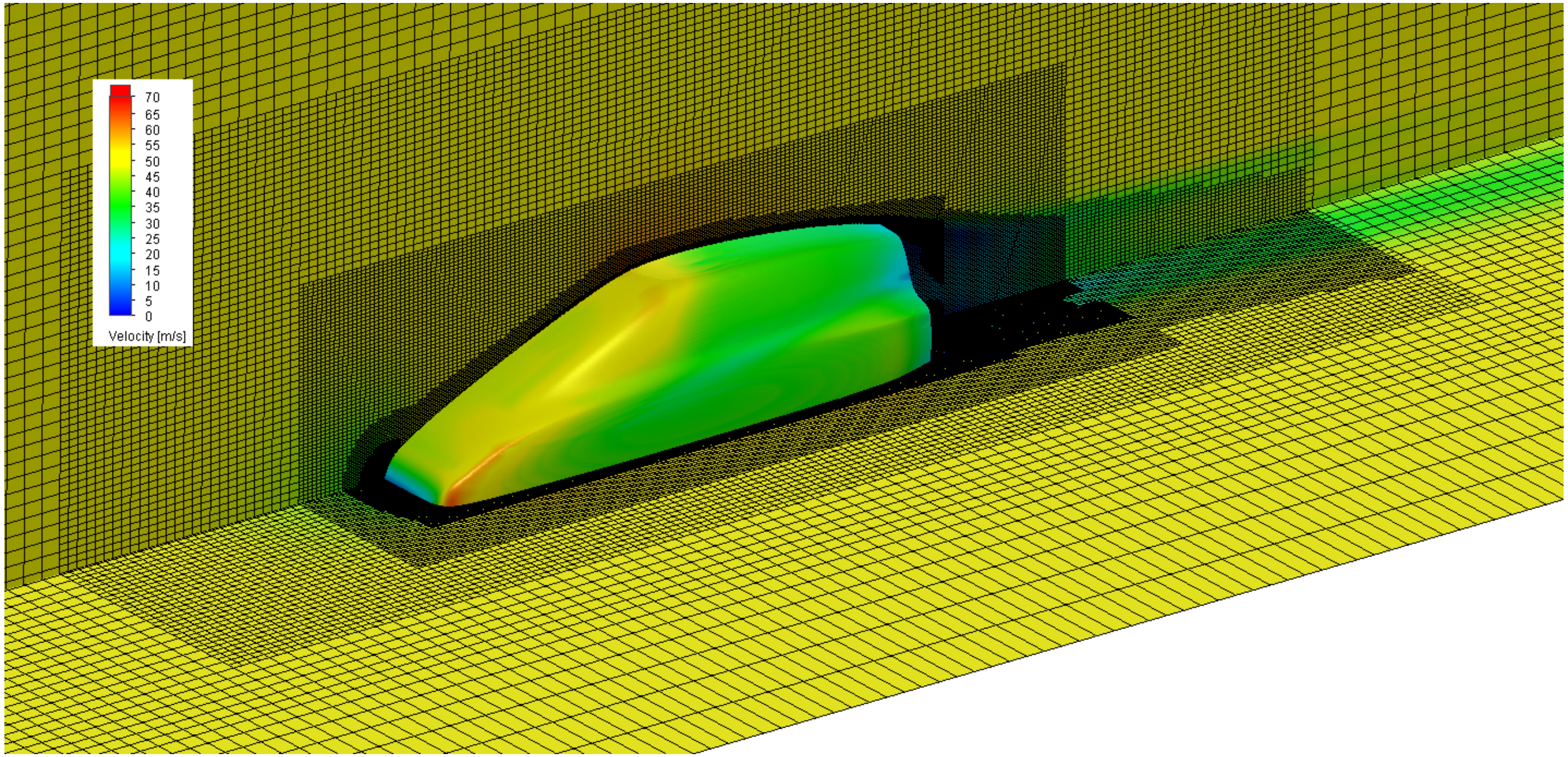
The ASMO example



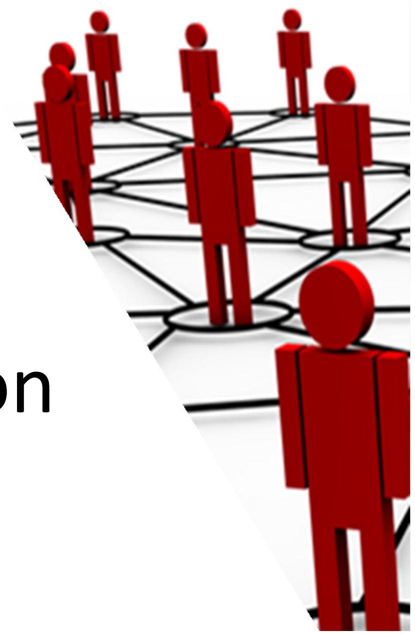
- Mesh:
  - Solution adaptive refinement used (two refinements are performed for this calculation)
- Number of cells:
  - Initial: 3.6 M
  - After the 2nd refinement: 13.5 M

The ASMO example

- Calculated Mesh:



The ASMO example



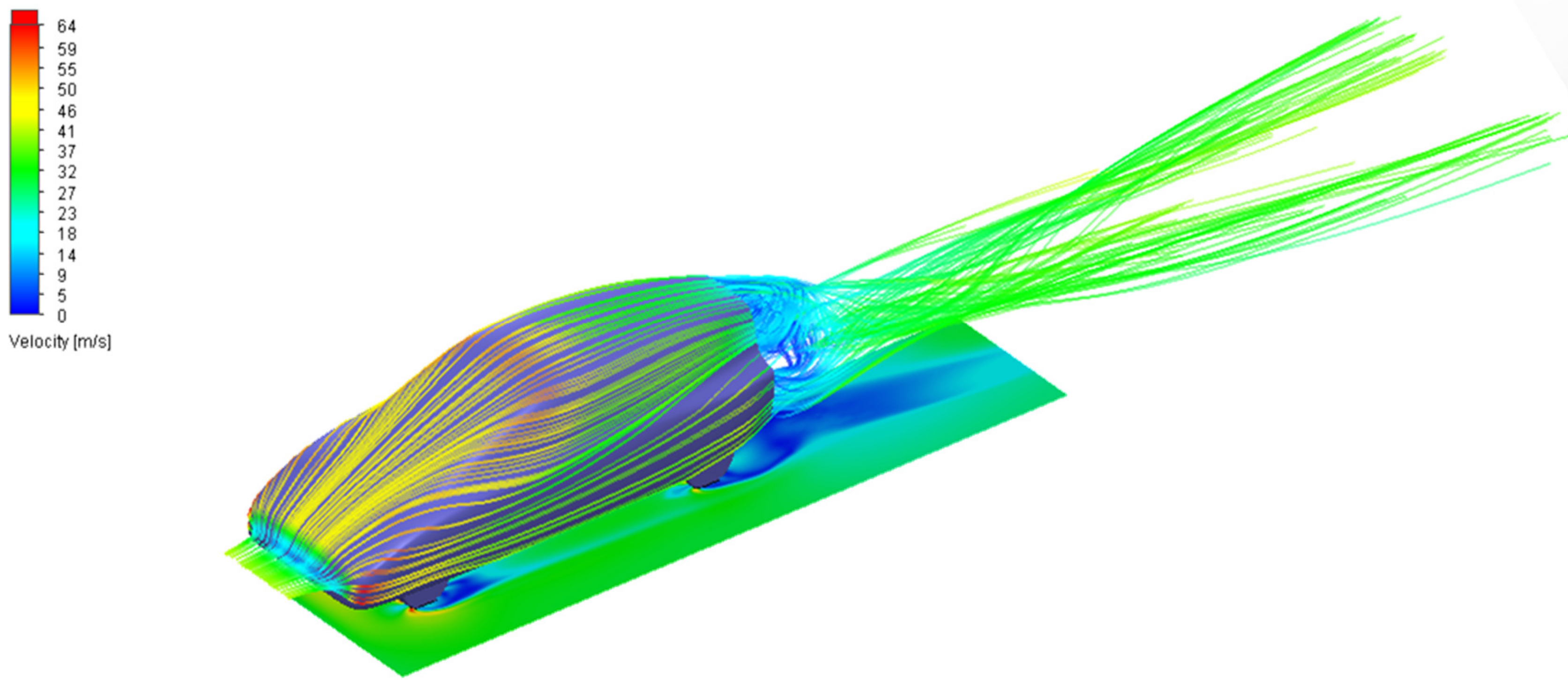
- Time Overhead Across the Simulation Workflow

Time Overhead Across the Simulation Workflow	in h
Setup Calculation project definition, pre-processing	1
Solving time (including meshing and refinements)	18*
• Initial 1st automatic meshing time	0,03 (1,5 min)
Results processing	4
Total	**23**
User time, approximately	5

* Intel(R) Xeon(R) CPU E5-2630 v3 @ 2.40GHz (2 CPU)

The ASMO example

Result discussion



The ASMO example

- Drag Coefficient

$$C_d = \frac{2F_d}{\rho u^2 A}$$

F_d = drag force in flow direction

ρ = fluid density

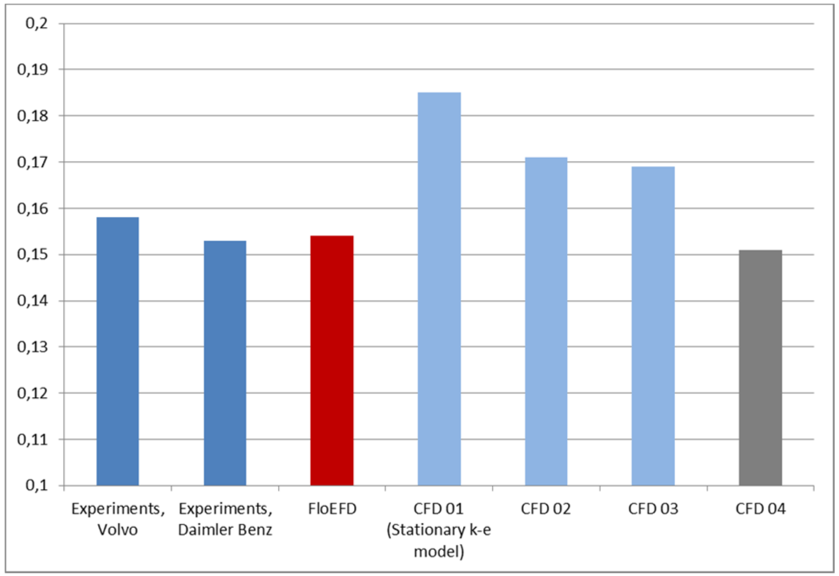
u = fluid velocity

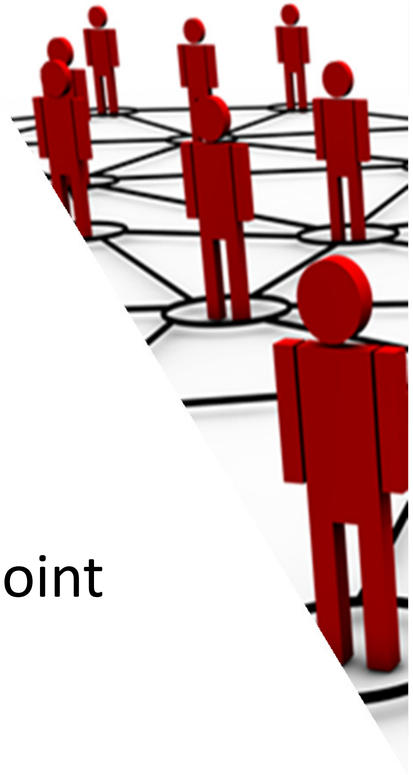
A = projected surface

The ASMO example

- Results: Drag Coefficient

Drag coefficient	
Experiments, **Volvo**	0,158
Experiments, **Daimler Benz**	0,153
FloEFD	**0,154**
CFD 01 (Stationary k-e model)	0,185
CFD 02	0,171
CFD 03	0,169
CFD 04	0,151





The ASMO example

- Pressure Coefficient $$C_P = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty v_\infty^2}$$

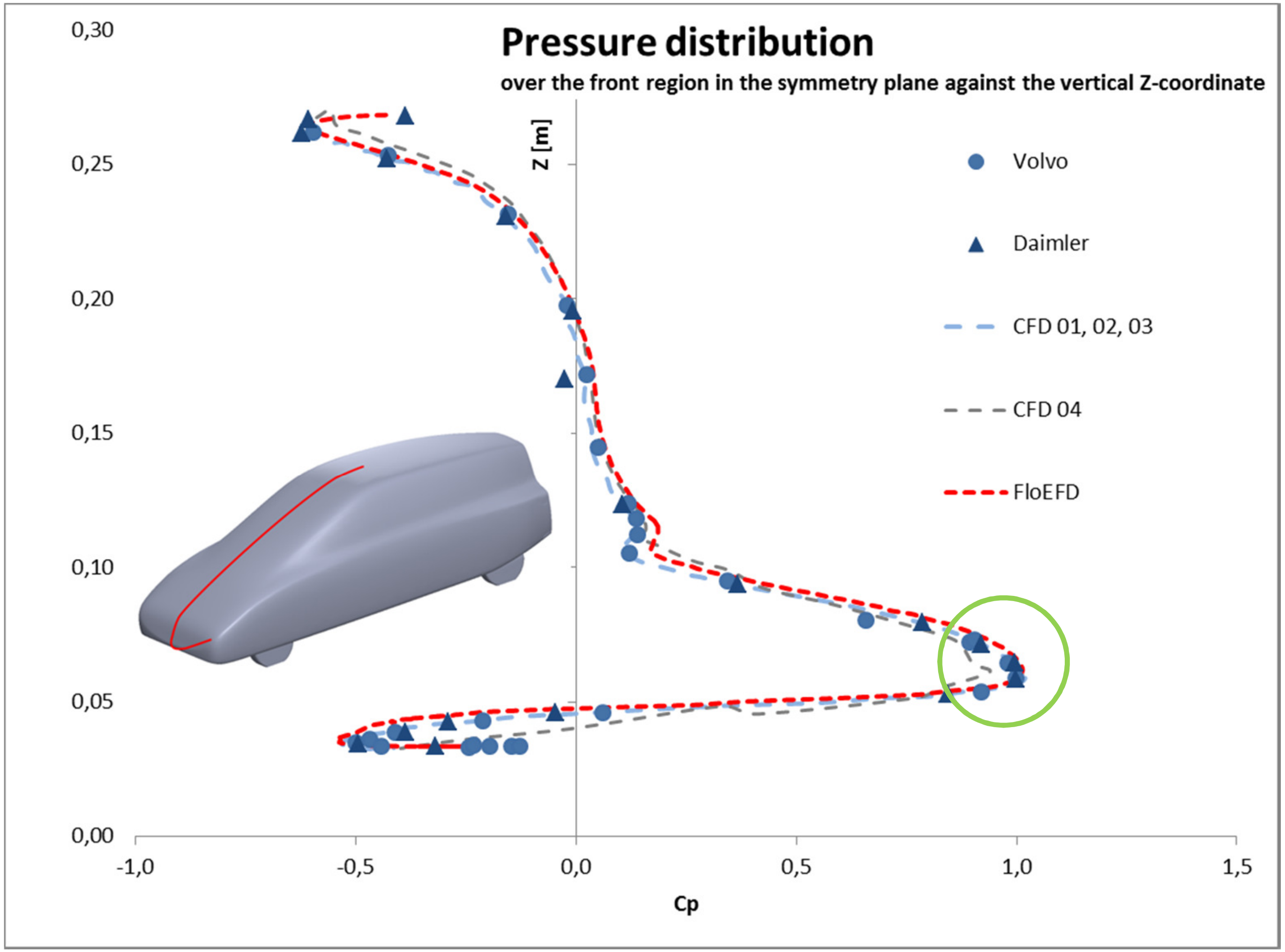
p = pressure at the corresponding point

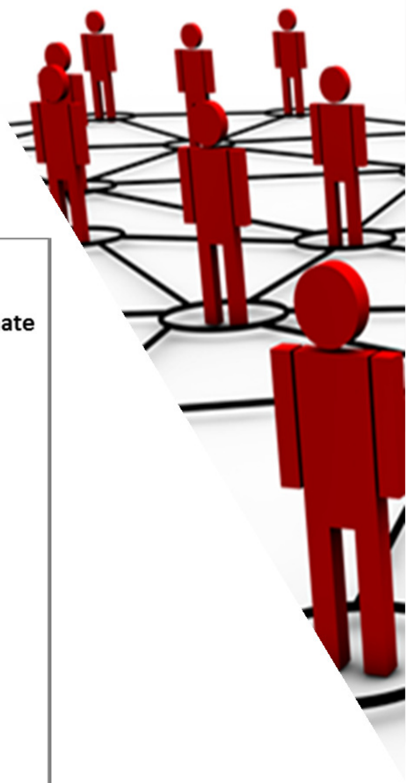
p_∞ = pressure in the freestream

ρ_∞ = fluid density in the freestream

v_∞ = freestream velocity

The ASMO example





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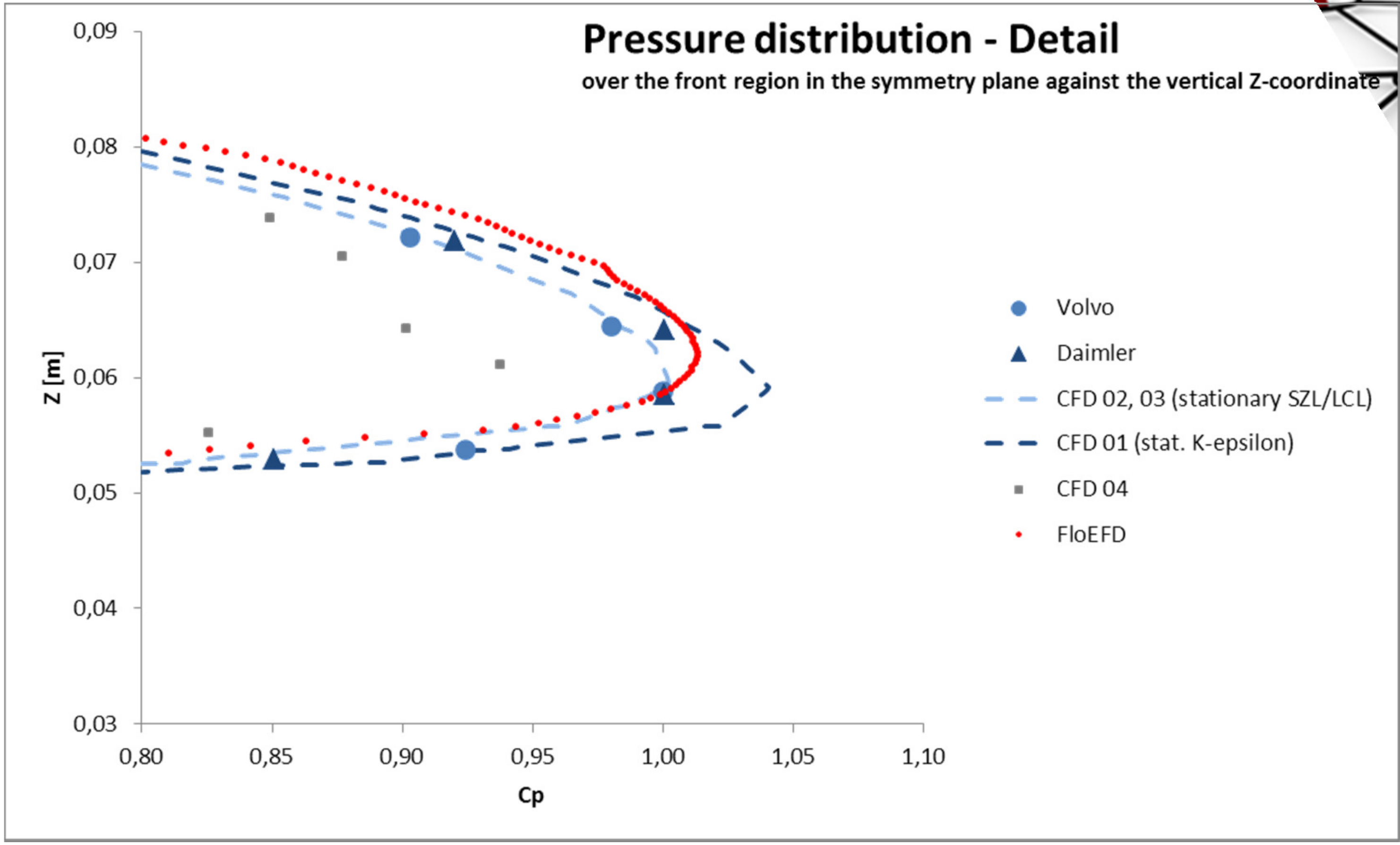

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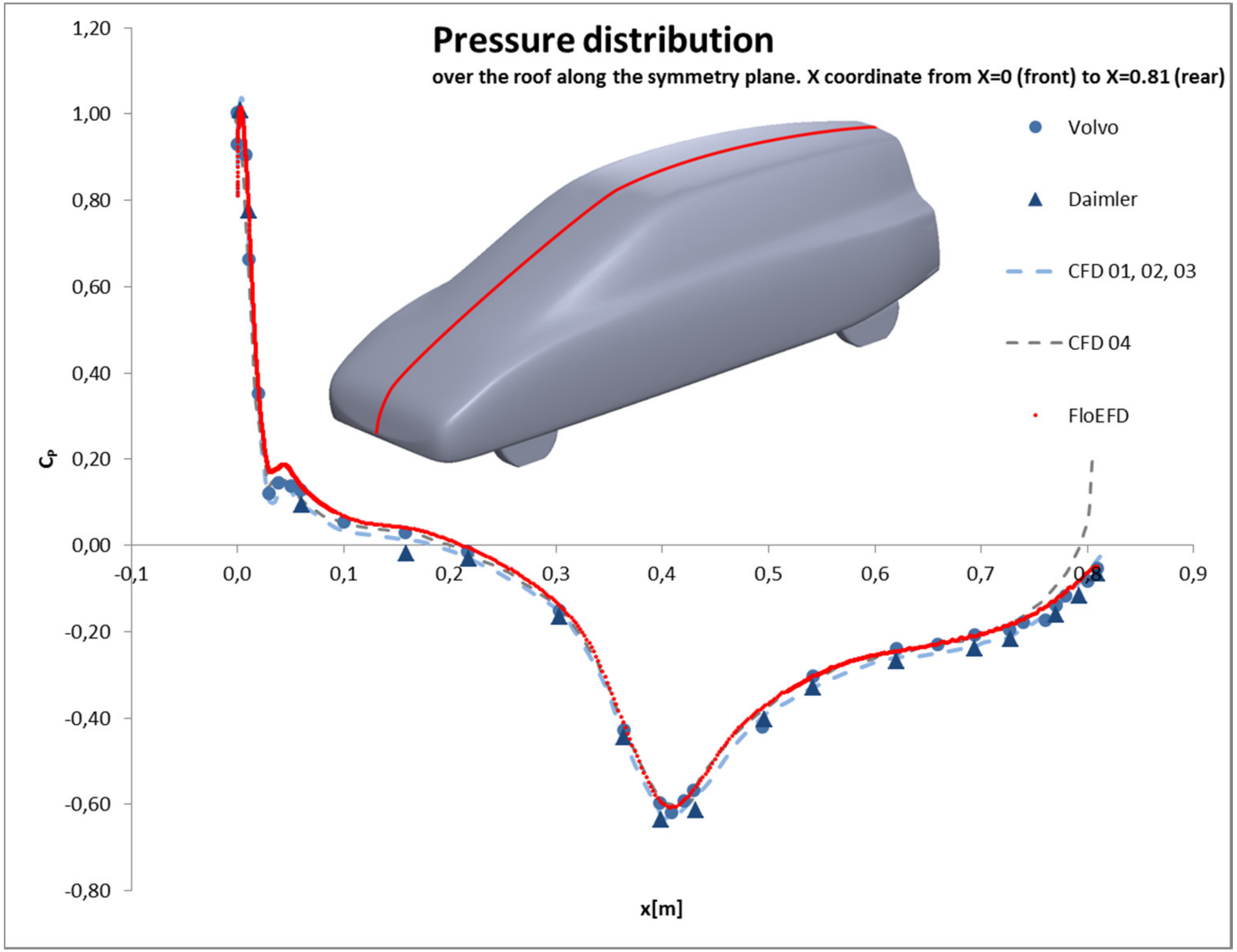

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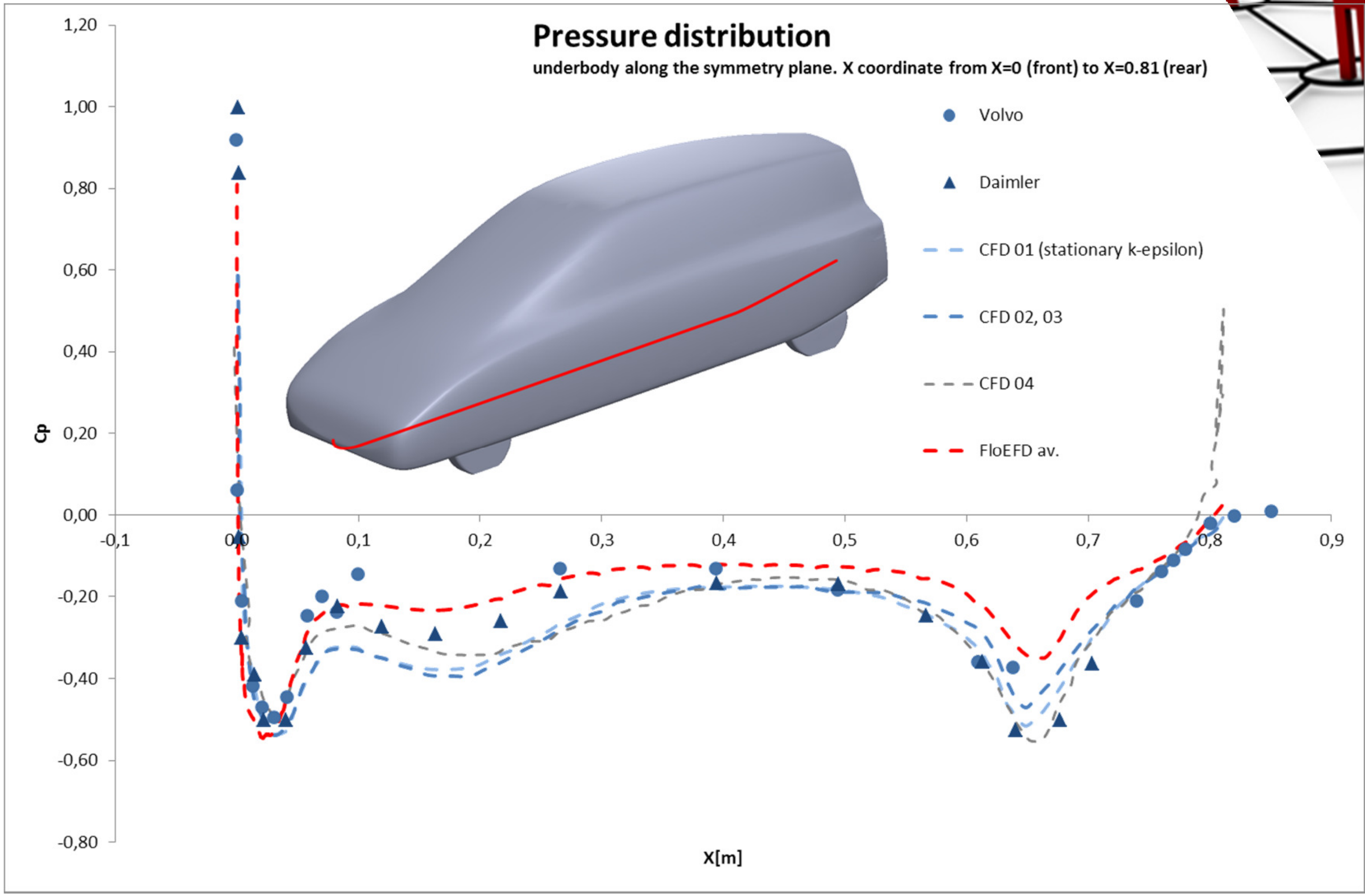

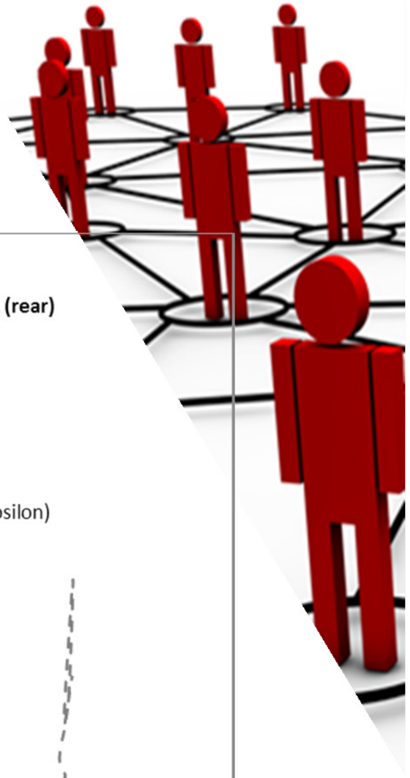

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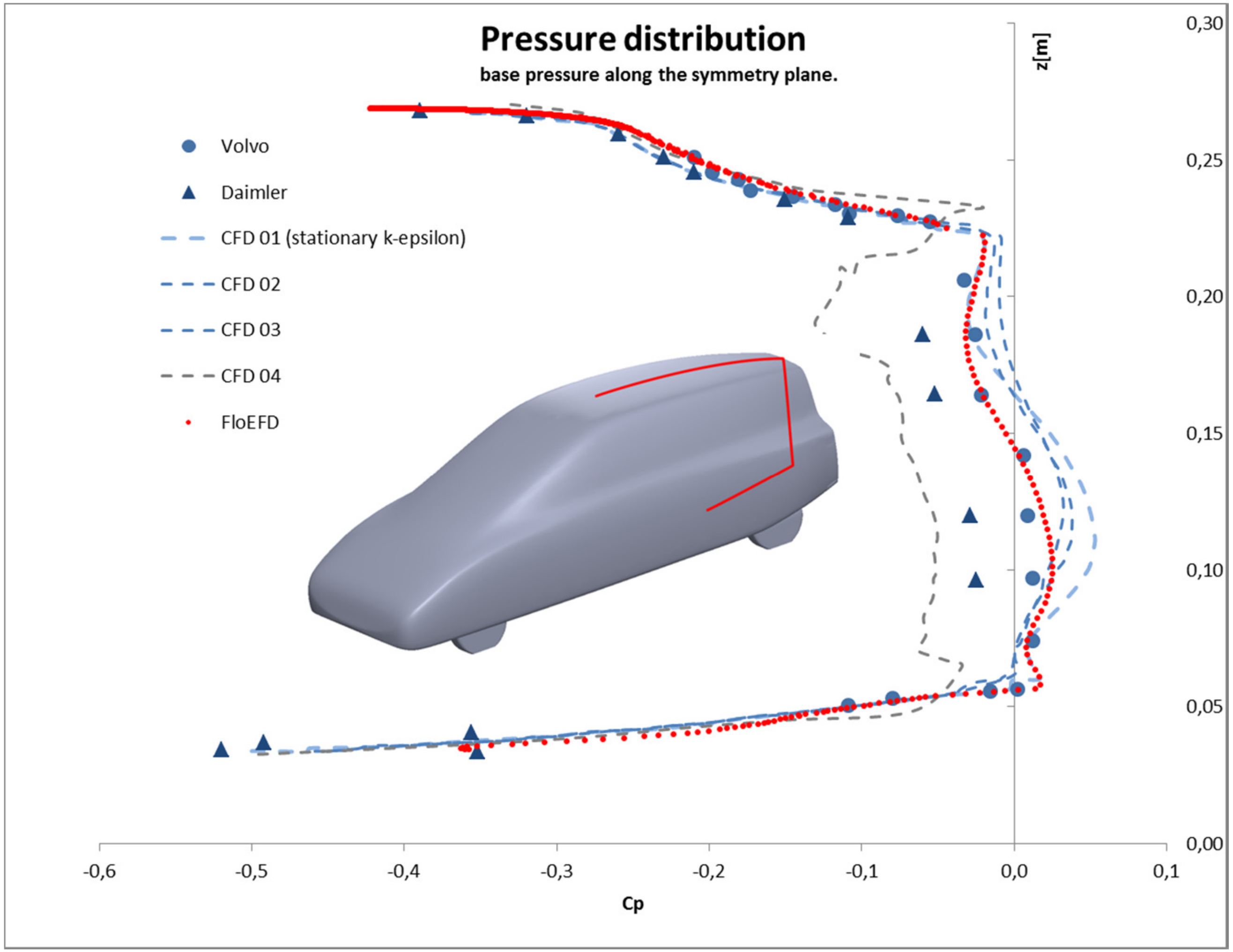

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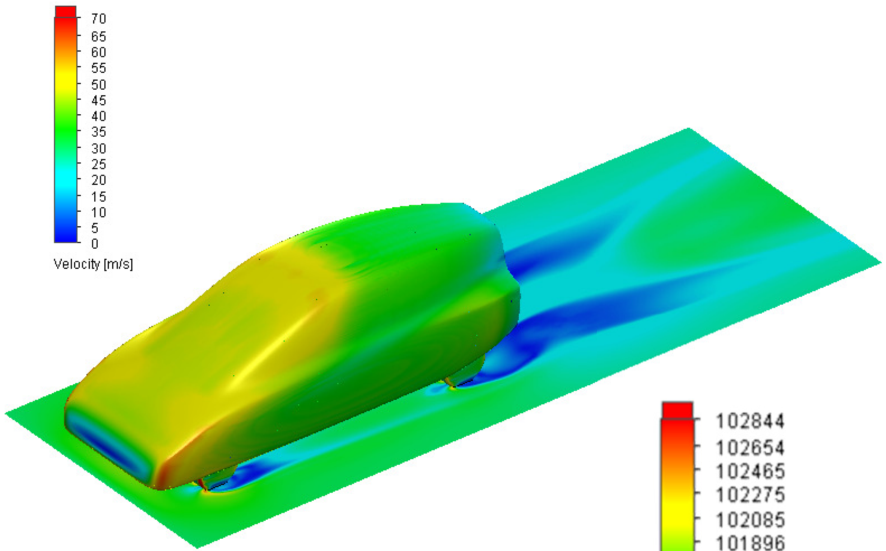

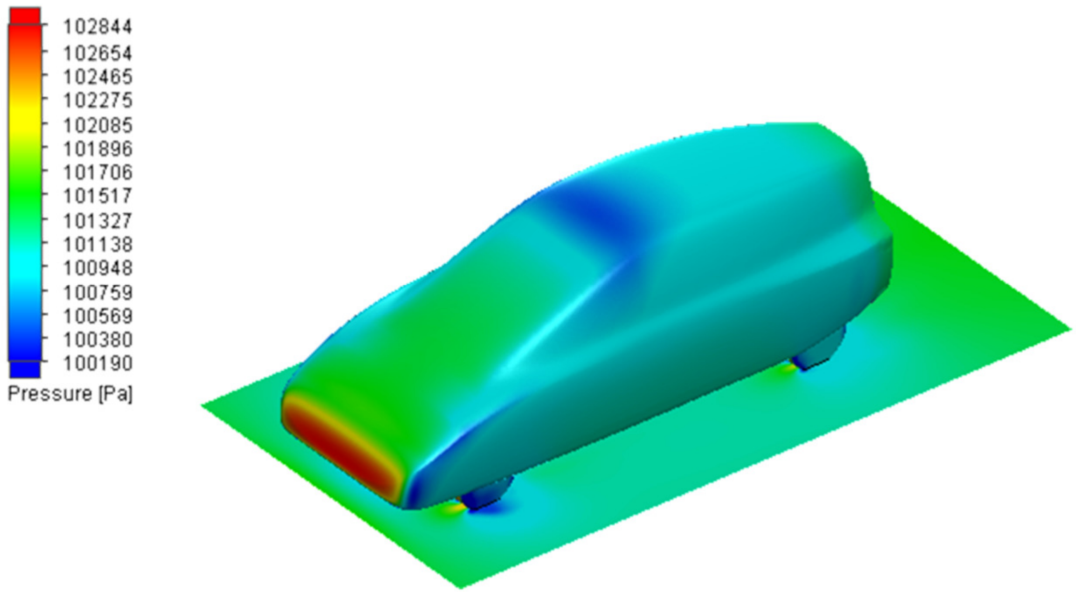

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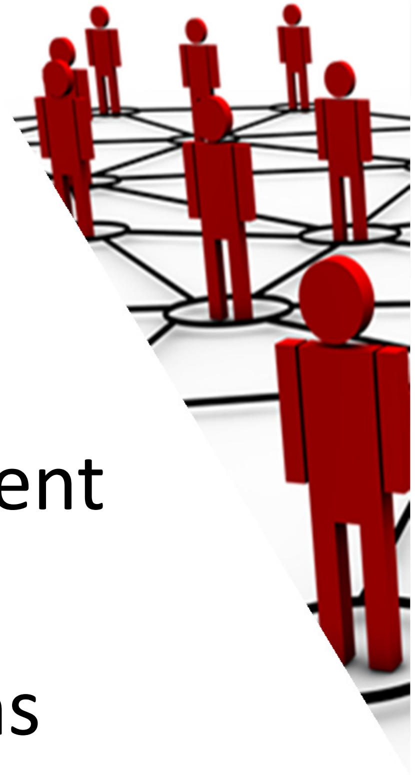

- Good agreement for the drag coefficient and the pressure coefficient curves
- Strong pressure coefficient variations due to turbulent wake influencing the diffuser area
- The CAD embedded CFD tool FloEFD shows reliable results

Conclusion

Accurate and Fast Complex Geometry Handling

Easy-of-Use by a non CFD expert

» **Frontloading**

Innovative Turbulence Model

Robust Cartesian Meshing
Avoid manual mesh creating,
Extremely fast meshing,
Complex geometry capture

Engineering Models
“Real Geometry”,
“Thin Walls”,
“Thin Channels”

High Automation
Automatic convergence,
Laminar-turbulent transition,
Grid independent near wall modelling

CAD Embedded

Effective Geometry Handling
No translation step necessary,
Design and Analysis stay synchronized,
Automatic fluid volume detection,
Automatic change recognition

Short Learning Curve
Easy to use by a designer,
Fast learning,
Multi CAD Ready

Conclusion

NAFEMS European Conference:

Computational Fluid Dynamics (CFD) – Beyond the Solve

The complete CFD activity chain across all industries from geometry to final conclusions – best practice methods and tools, automation, optimisation, verification and validation.

2 - 3 December, Munich, Germany

- CAD embedded simulation enables “Frontloading”
- Same level of accuracy compared to traditional, well established CFD tools and experimental results

Thanks for your attention !

References

[1] Whitepaper “Enhanced Turbulence Modeling In FloEFD”, Mentor Graphics Corporation, 2011, http://go.mentor.com/2glzd

[2] Perzon S., Davidson L.: "ON TRANSIENT MODELING OF THE FLOW AROUND VEHICLES USING THE REYNOLDS EQUATION", ACFD 2000 Beijing, 2000

[3] http://www.xflowcfd.com/pdf/Project01-ASMO.pdf, "Aerodynamic analysis involving moving parts with XFlow", 2010

[4] Marovic B., “CAD Embedded CFD vs. Traditional CFD Codes in a Blind JSAE Benchmark”, NAFEMS World Congress 2015