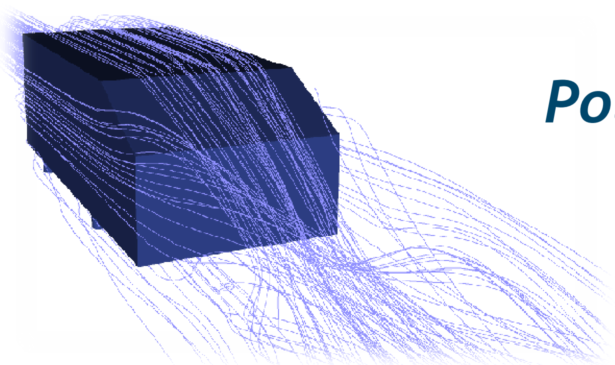

3rd OpenFOAM Workshop
Politecnico di Milano, Milan, ITALY
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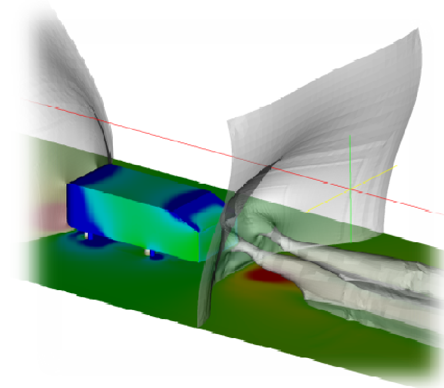

Investigation of the flow around the Ahmed body using RANS and URANS with various turbulence models

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ISW

K plus Kompetenzzentrenprogramm

Eine Förderinitiative des Bundesministeriums für Verkehr, Innovation und Technologie (BMVIT).
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Overview

Introduction

Test case definition

Numerical method

Results

Conclusions

Overview

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Introduction

Test case definition

Numerical method

Results

Conclusions

Introduction

Objective

- Simulation of flow around the bluff „Ahmed body“ as an example for the application of OpenFOAM in **industrial vehicle aerodynamics**

Method

- **Variation** of meshes, turbulence models, convection schemes and simulation methods (steady/unsteady) to find good overall settings
- Simulation of cases with various angles of attack
- Evaluation of the results against measurement data and results of calculations with other CFD programs
- Evaluation of different solver settings for optimal use of resources

Overview

Introduction

Test case definition

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Results

Conclusions

Ahmed body

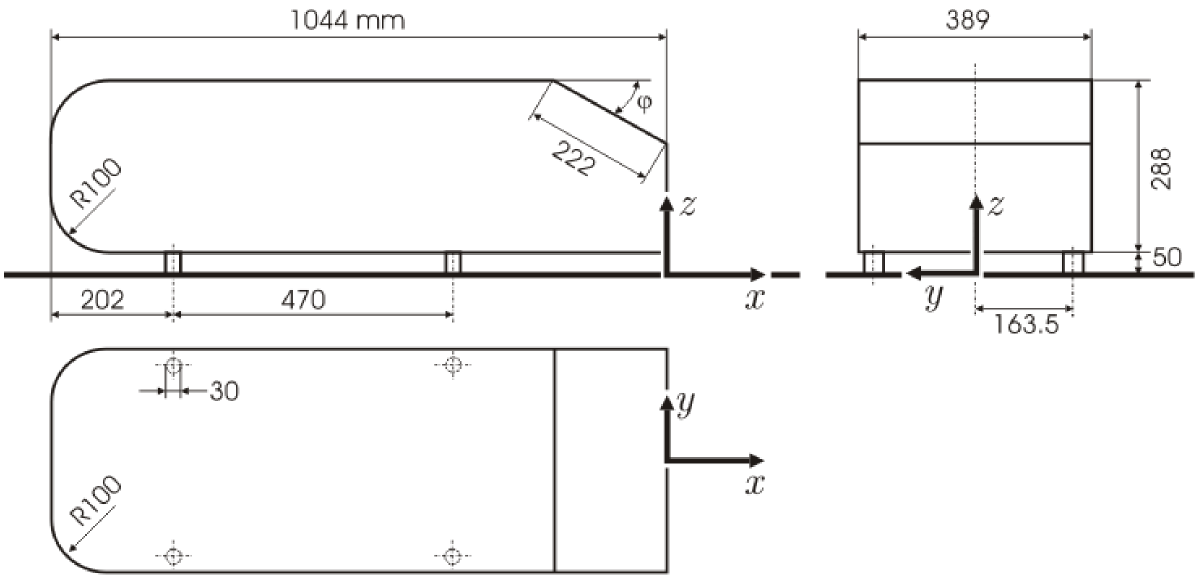
Bluff body for validation of measurements and simulations in vehicle aerodynamics

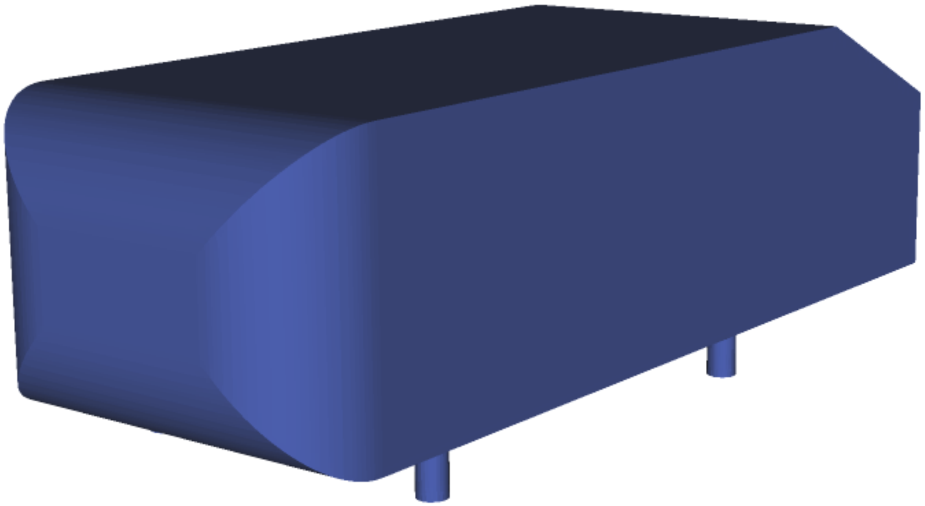
- simple geometry
- typical stream shapes
- experimental data exist, e.g.:

❖ S.R. Ahmed, SAE Paper 840300

❖ S. Becker, H. Lienhart,C. Stoots, ERCOFTAC workshop 9.4 (2000): LDA-Measurement

❖ W. Meile (ISW of Graz UT), 2007, forces and pressure distribution





Overview

Introduction

Test case definition

Numerical method

Results

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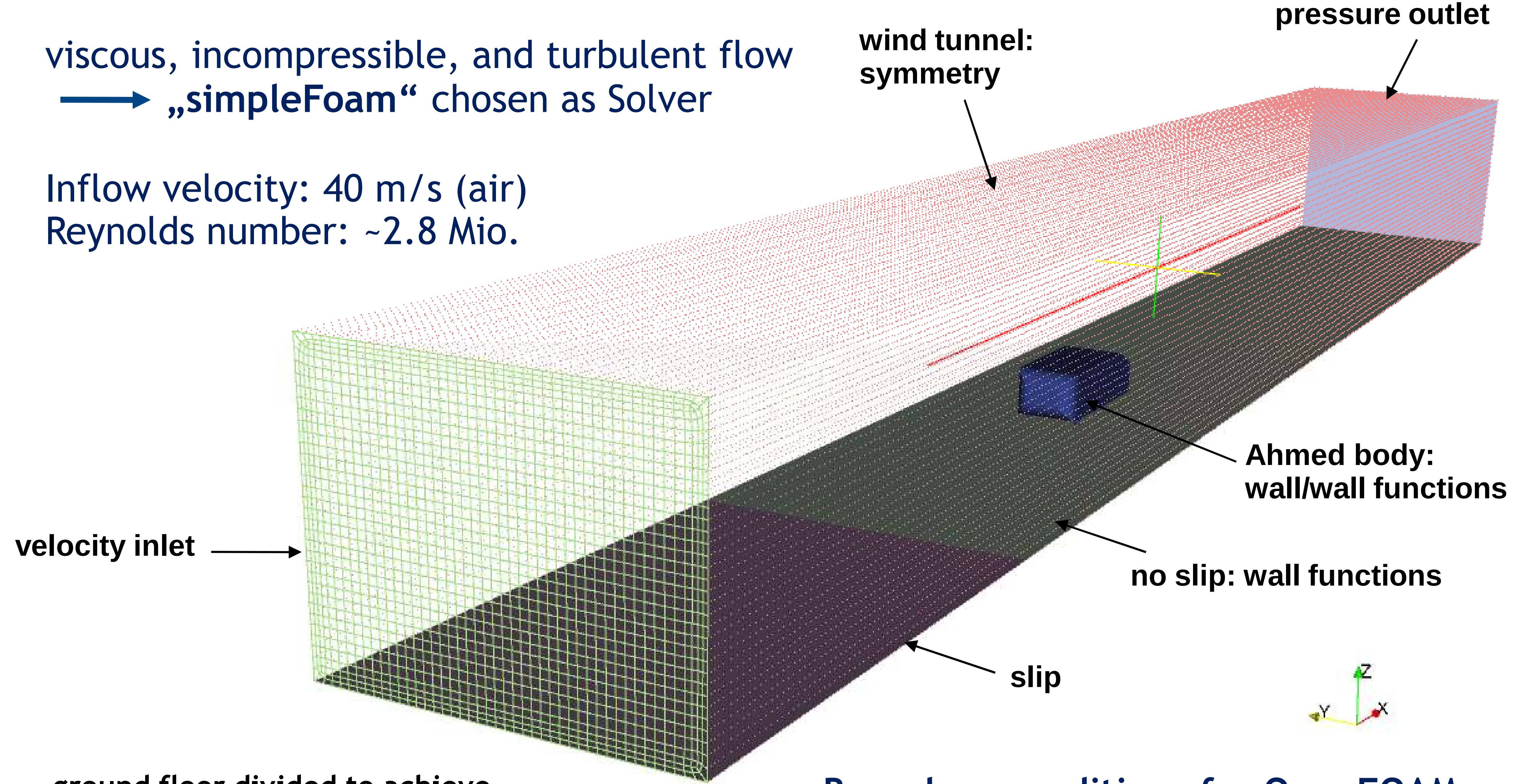
Simulation environment

Geometry of the wind tunnel is given by a recommendation of Ercoftac: 15 x 1.87 x 1.4 m^3

viscous, incompressible, and turbulent flow
→ **„simpleFoam“** chosen as Solver

Inflow velocity: 40 m/s (air)
Reynolds number: ~2.8 Mio.



ground floor divided to achieve correct boundary layer thickness

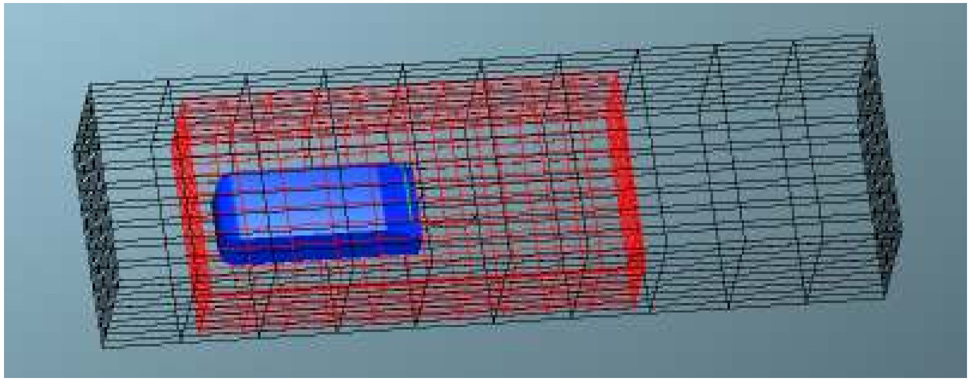
Boundary conditions for OpenFOAM

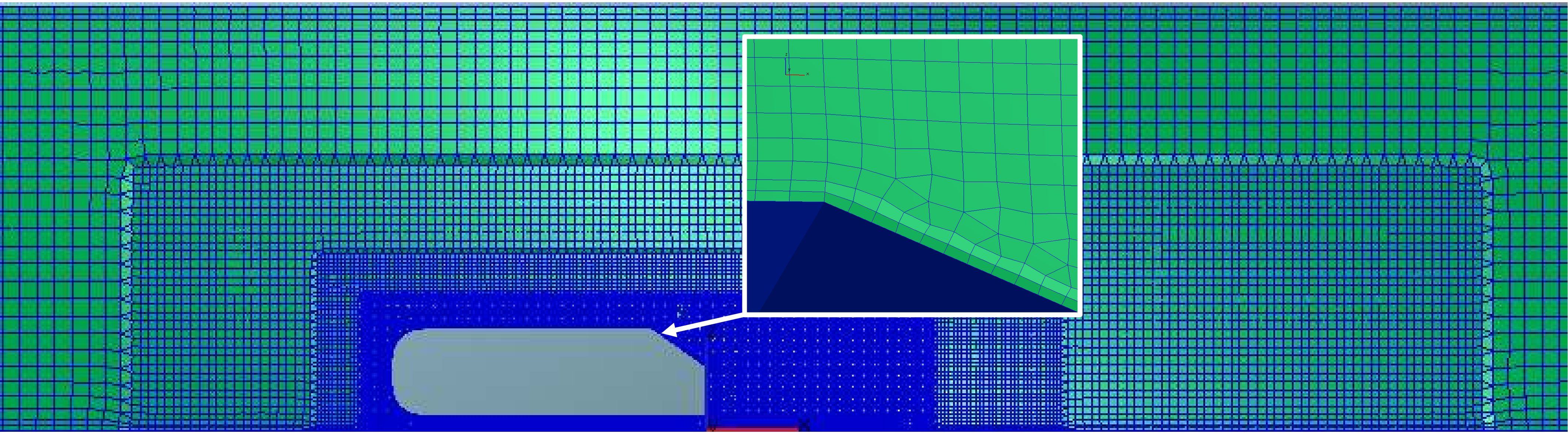
Meshes

Commercial meshing program SPIDER

→ hybrid, hexahedron-dominant meshes with prisms and tetrahedrons in the transition and boundary layers

→ stepwise refinement determined by geometrical boxes around the Ahmed body





Variations

Geometry	25° slant 35° slant	Simulation and comparison of all cases with straight inflow (0° angle of attack) → 12 variations *(only best results are presented)*
Meshes	very coarse (~1 Mio. cells) coarse (~2-2.5 Mio. cells) fine (~4.7 Mio. cells)	
Turbulence model	SST („kOmegaSST“) RKE („realizableKE“)	
Convection scheme	Upwind (1st order) Linear limited SFCD MUSCL	Simulations with different convection schemes only for a reference case → 4 variations
Angle of attack	0° 9° 15°	Simulations with different angles of attack only for a reference case → 3 variations

Personal "best practice" for the numerical settings

	OpenFOAM version 1.4.1
Flow solver	simpleFoam (modified)
Turbulence model	RKE
Schemes for discretization	• „Gauss SFCD" or „Gauss SFCDV" for convection • „Gauss linear" or „corrected" for other operators
Linear solver	• GAMG (Multigrid) for pressure with: smoother = GaussSeidel; nCellsInCoarsestMesh = number CPU's x 40-50 • PbiCG (conjugated gradients) for other variables
Solver tolerance	1.0e-07 for all variables
Relaxation coefficients	• 0.3 for pressure • 0.5 for other variables
Nonorthogonal correction	number of correctors for an iteration 1-3

Overview

Straight flow (1/2)

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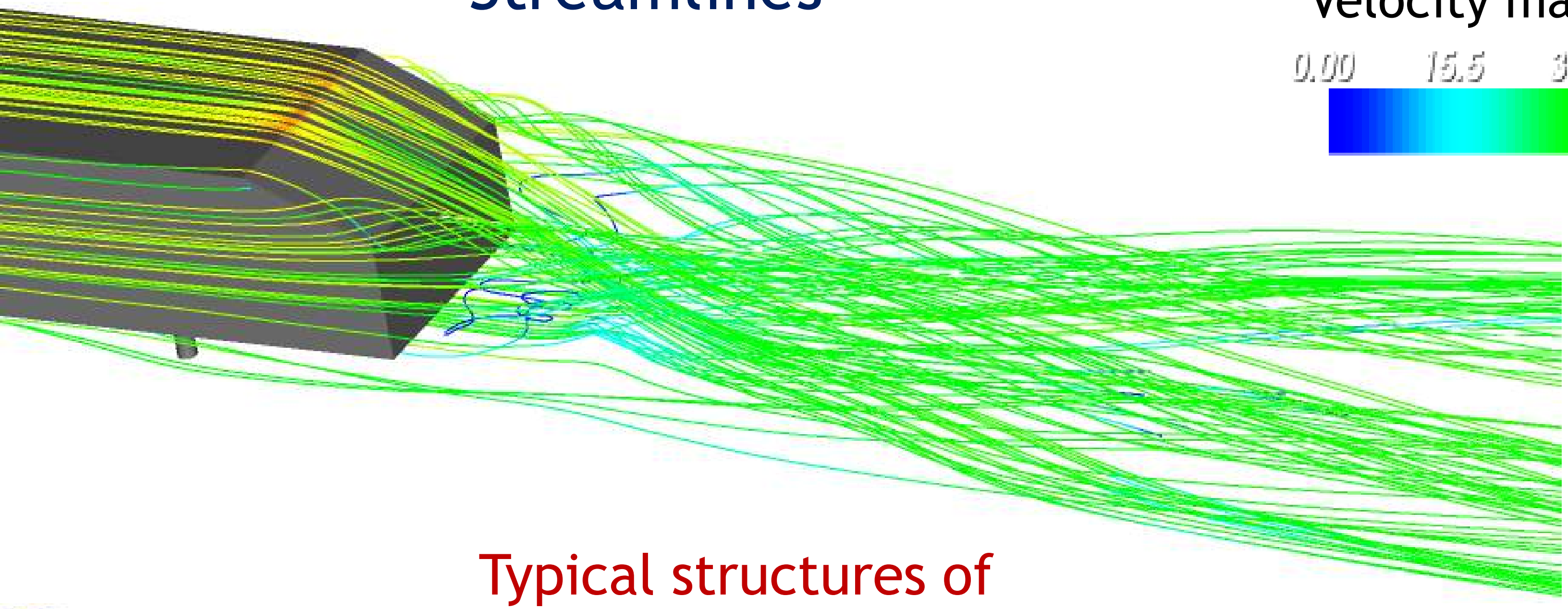
Streamlines

Velocity magnitude [m/s]

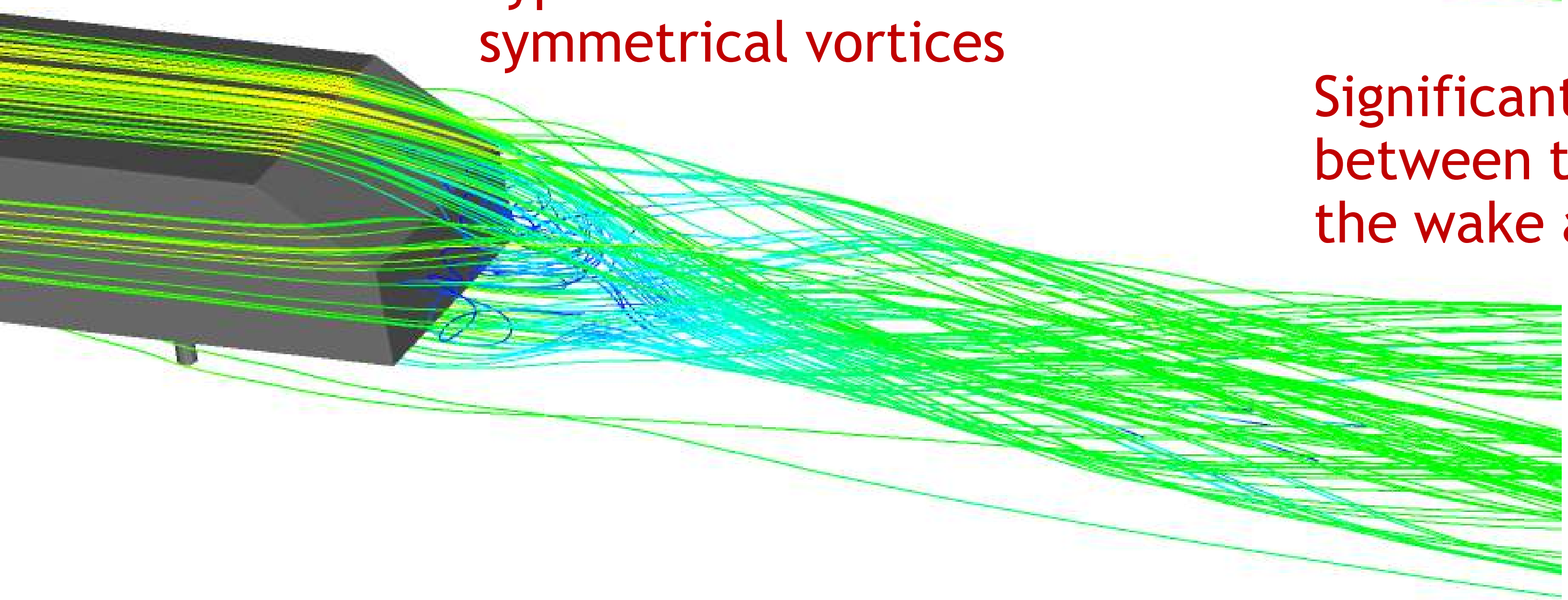
0.00 15.5 31.0 46.5 62.0



25° slant

Typical structures of symmetrical vortices

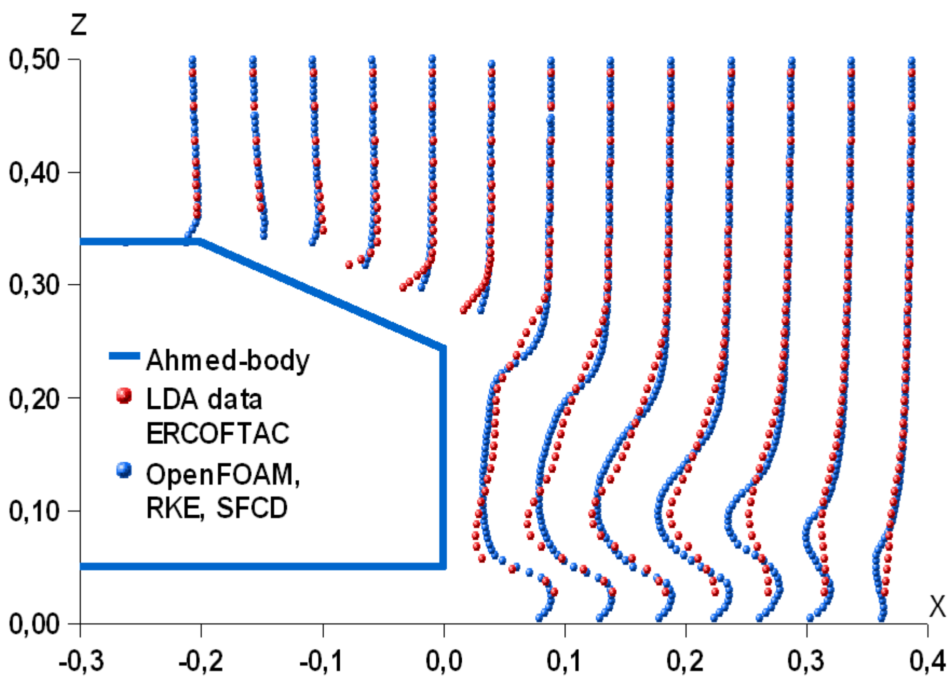
Significant differences between the two cases in the wake area

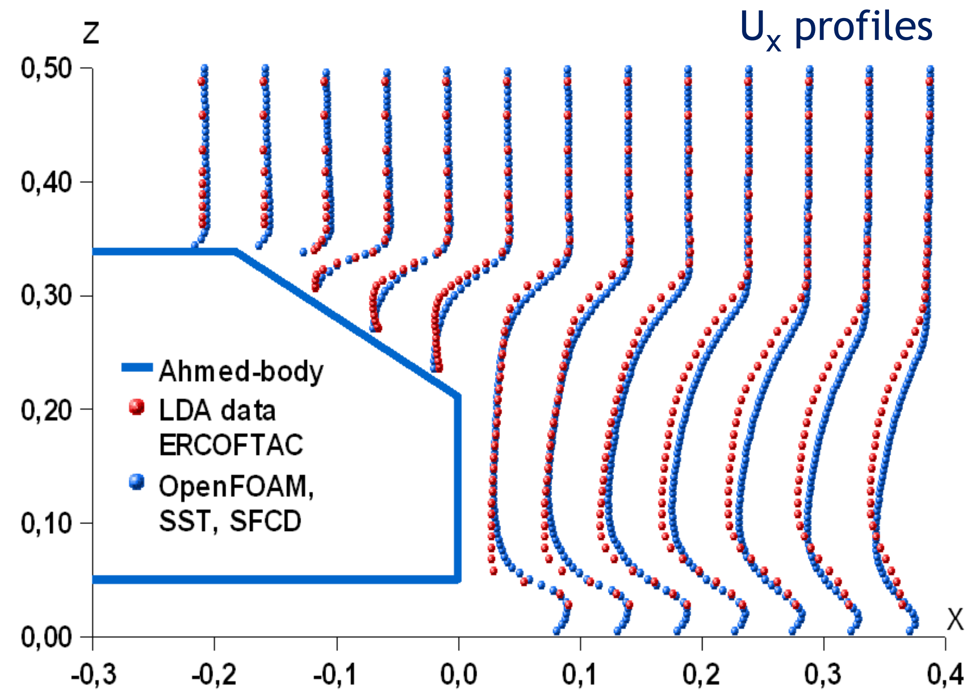


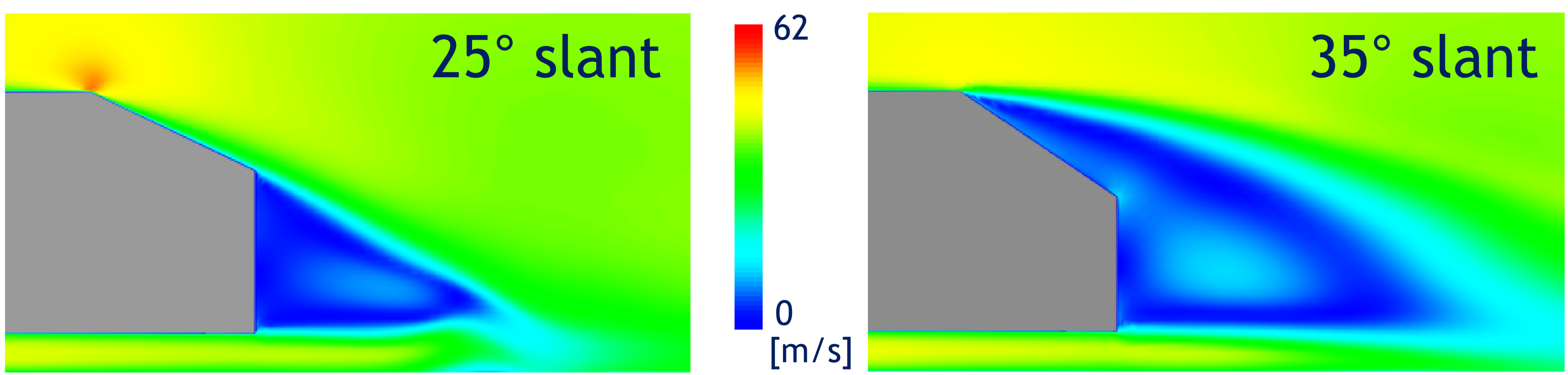
35° slant

Straight flow (2/2)

Velocity fields in symmetry plane





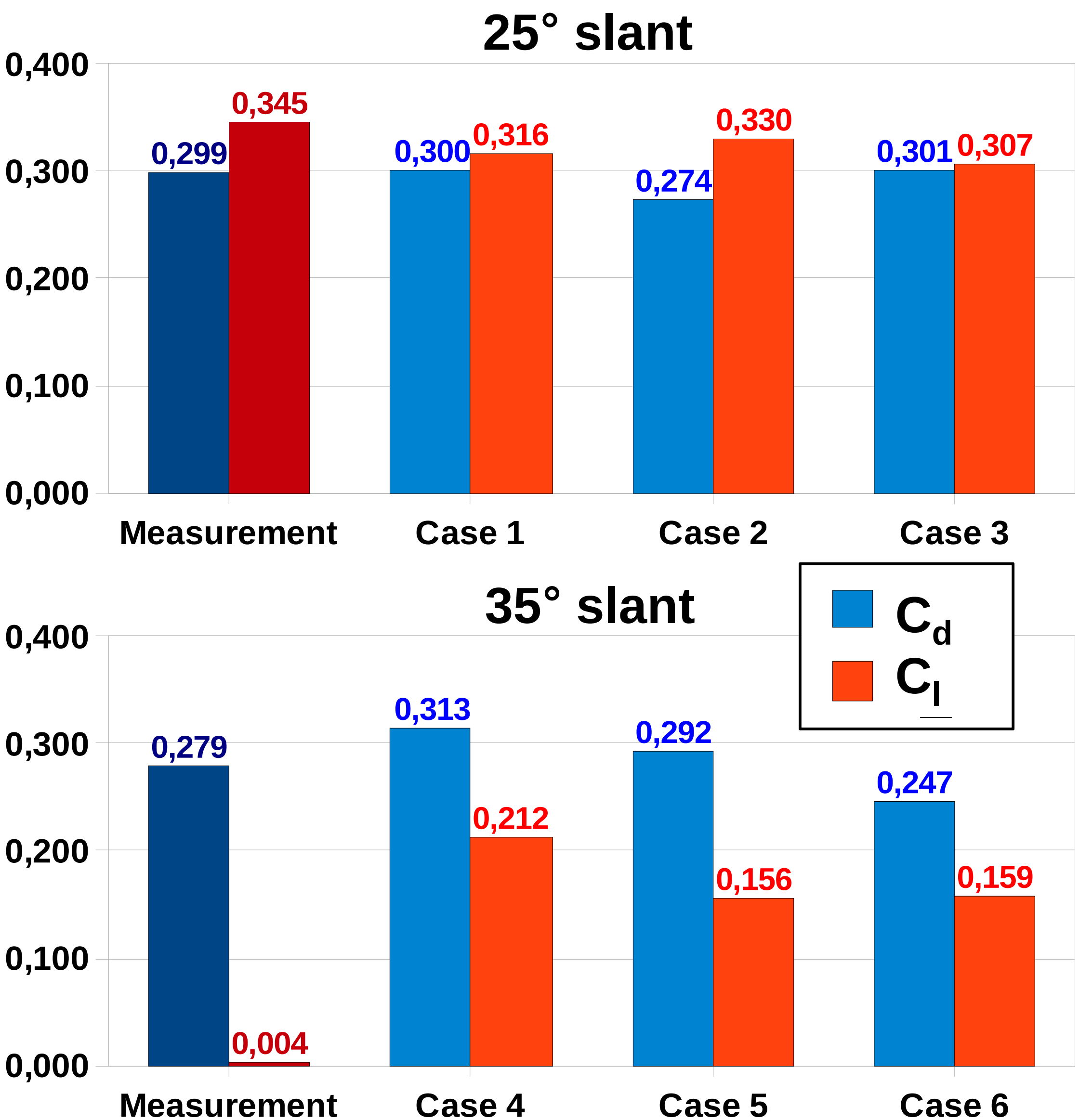


⇨ Attached flow over the slant

⇨ Detached flow over the slant

Mesh variation

Integral drag and lift coefficients



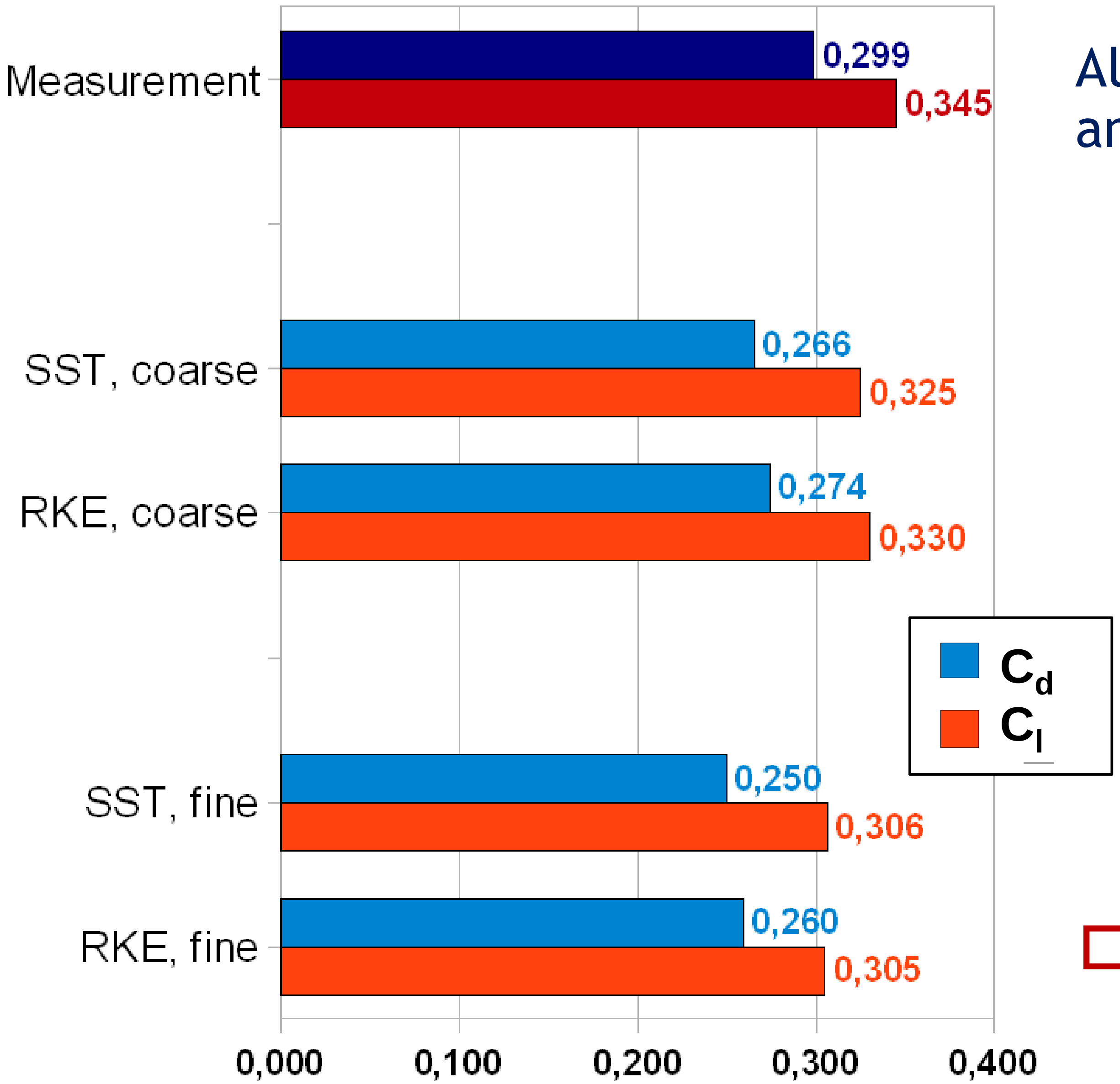
Best results for the following cases:

Ahmed 25°			
Case 1	~1.1 Mio. cells	SST	SFCD
Case 2	~2 Mio. cells	RKE	SFCD
Case 3	~4.7 Mio. cells	SST	upwind
Ahmed 35°			
Case 4	~1.2 Mio. cells	SST	SFCD
Case 5	~2.4 Mio. cells	SST	SFCD
Case 6	~4.6 Mio. cells	SST	limited linear

⇨ Strong deviations from measurements for the lift coefficient in all cases with 35° slant

Turbulence model variation

Integral drag and lift coefficients



All calculations for 25° slant and SFCD Scheme

Turbulence models:

- <u>RKE</u>: realizable-k-ε
- <u>SST</u>: k-ω-SST

Meshes:

- <u>Coarse</u> (~2 Mio. cells)
- <u>Fine</u> (~4.7 Mio. cells)

⇨ In most cases the RKE model provides slightly higher drag and lift values than the SST model

Convection scheme variation

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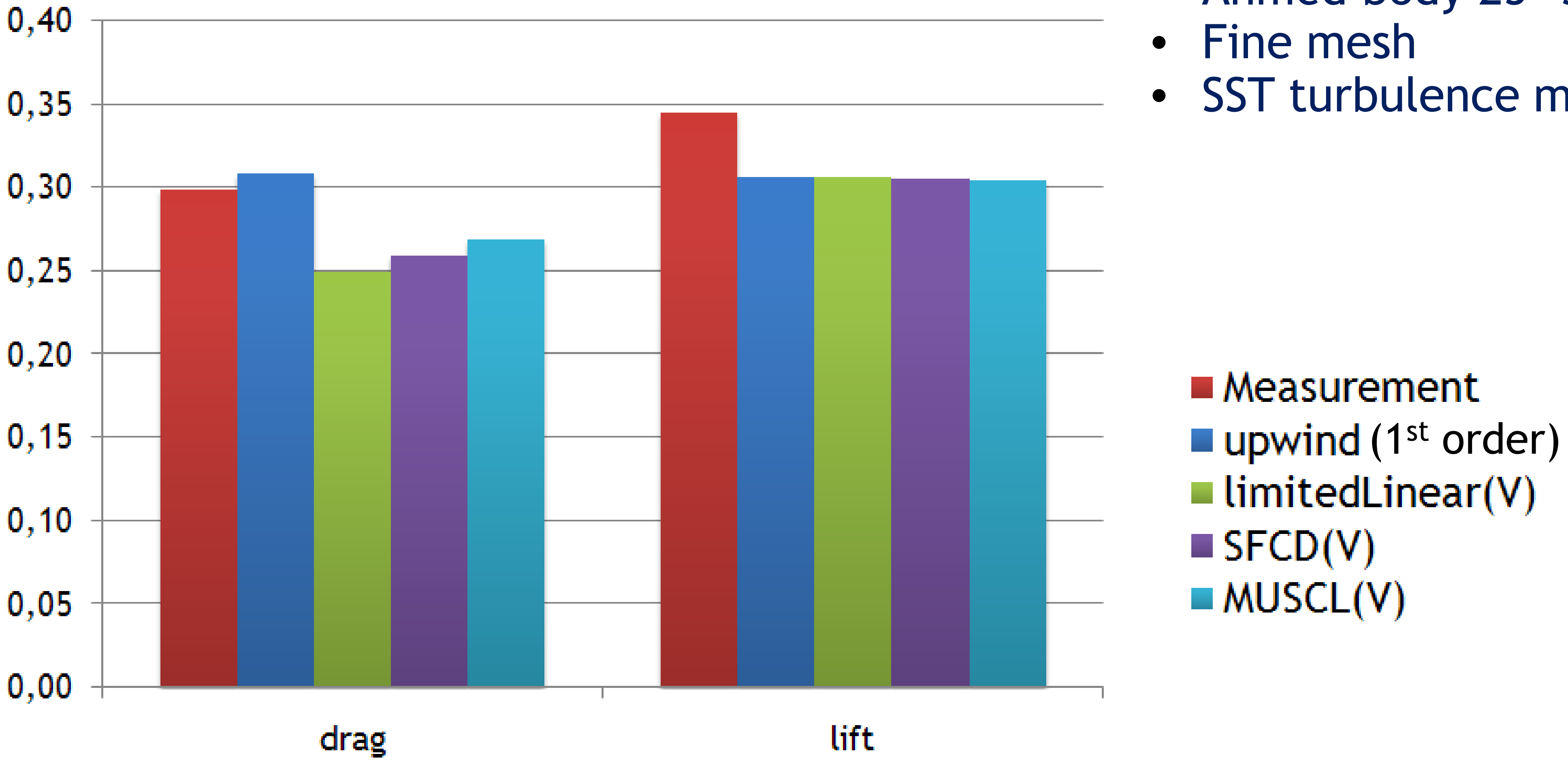
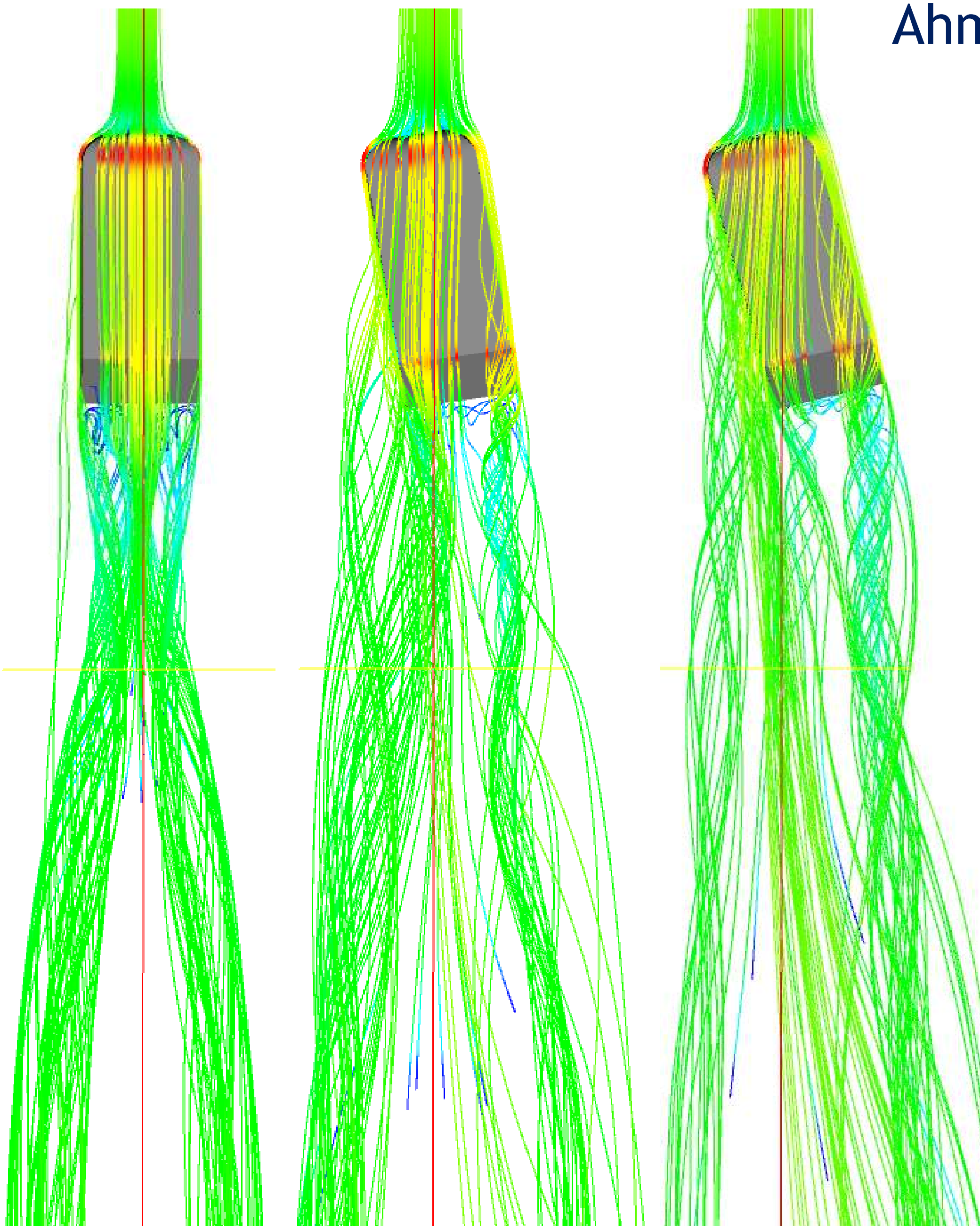
Integral drag and lift coefficients



- Ahmed body 25° slant
- Fine mesh
- SST turbulence model

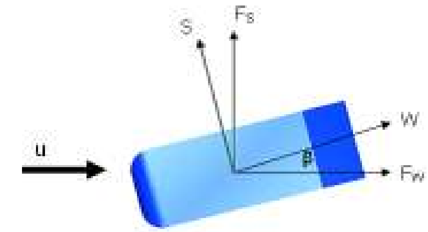
⇨
- The first-order solution provides better results !?
- The MUSCL scheme appears to be the best second order one.

Angle of attack variation

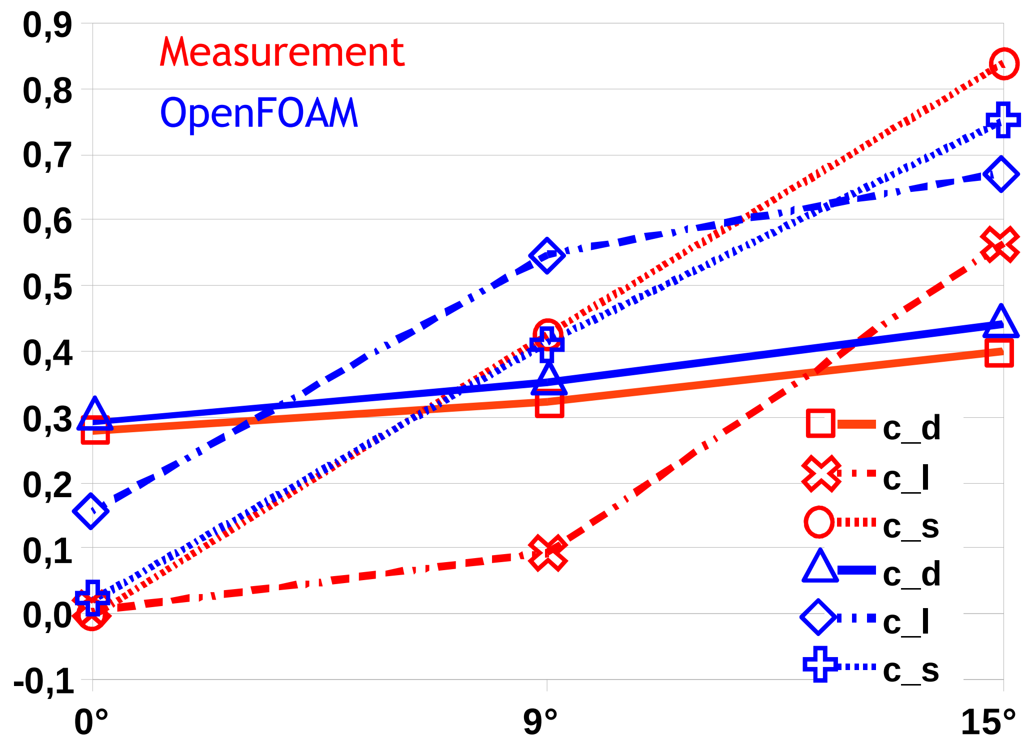


Ahmed body, 35° slant, ~2.5 Mio. cells, SST

	0°	9°	15°
c_d	0,279	0,323	0,400
c_l	0,004	0,093	0,565
c_s	-0,003	0,426	0,838
c_d	0,292	0,354	0,442
c_l	0,156	0,547	0,673
c_s	0,020	0,414	0,751

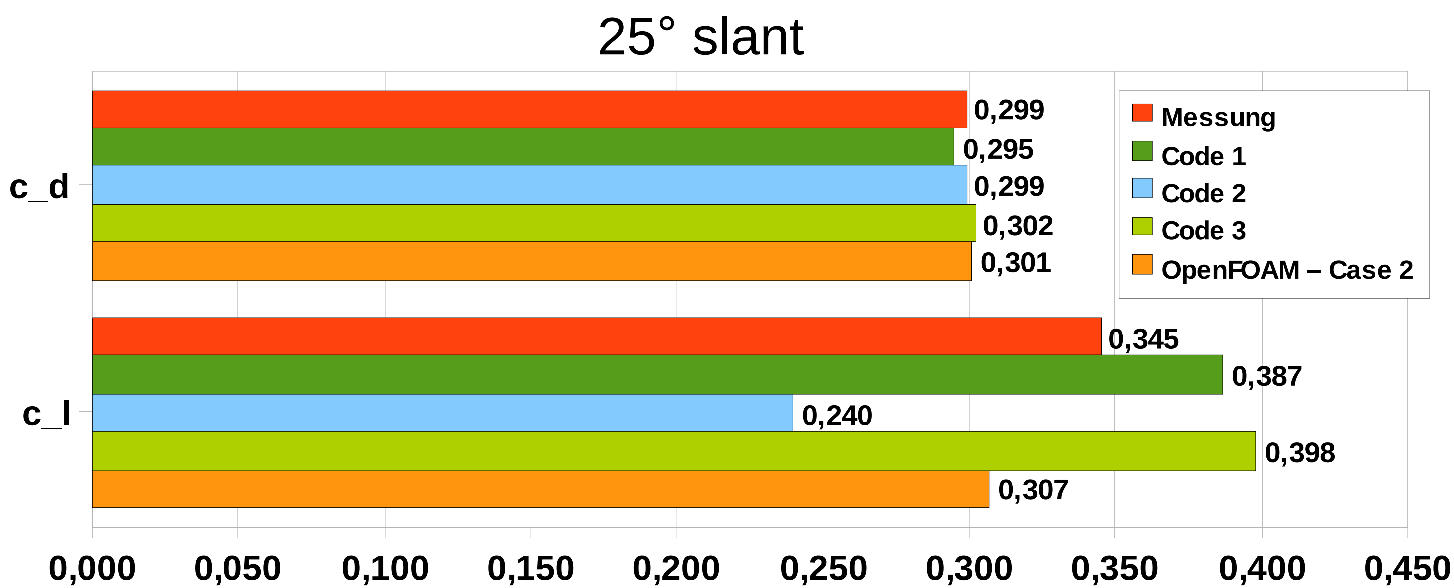


Coefficients referring to Ahmed-body coordinate system



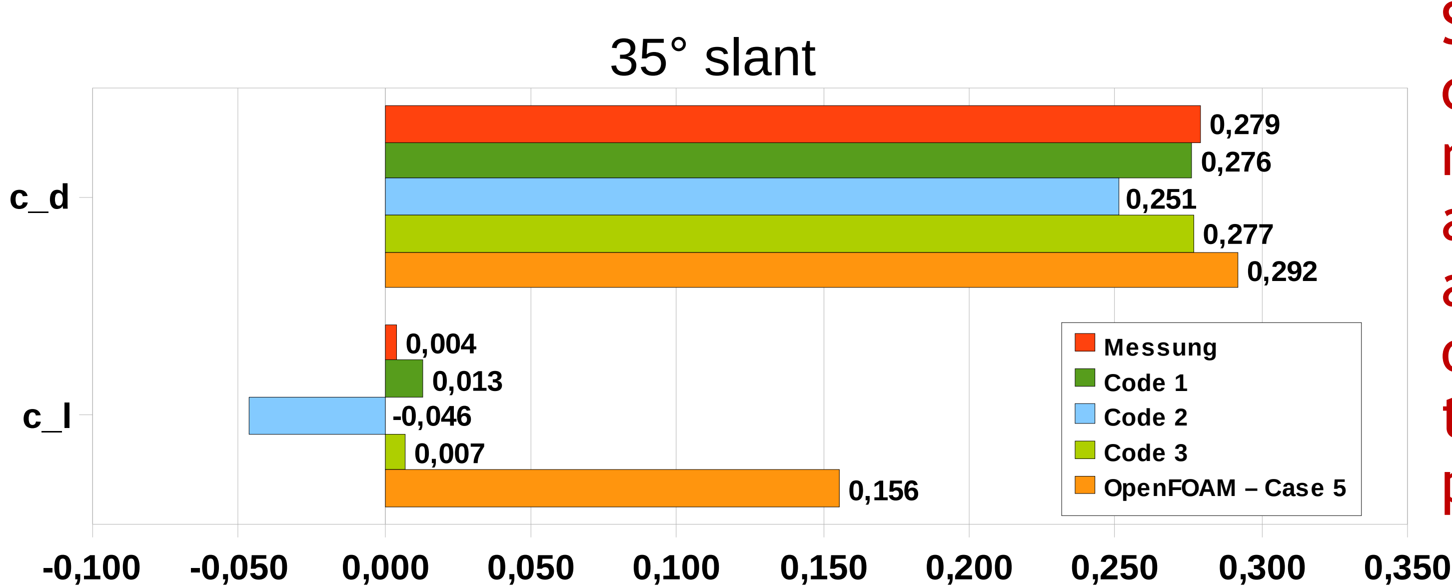
Results from other CFD programs

Integral drag and lift coefficients from different CFD codes



- Internal benchmarks
- steady state

⇩

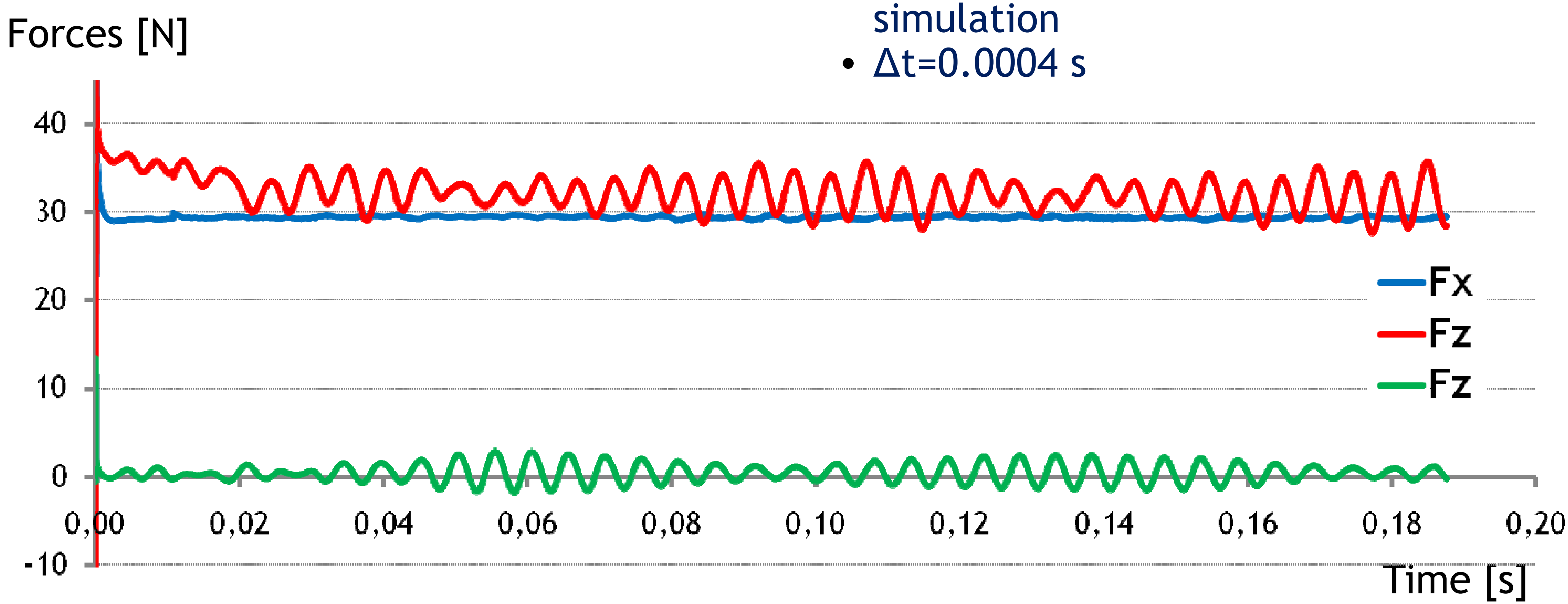


Strong deviation of lift coefficients from measurement data in all cases with 35° slant; apart from this, quality of results is similar to the results from other programs

Unsteady flow simulation (1/2)

Time development of forces on the Ahmed body

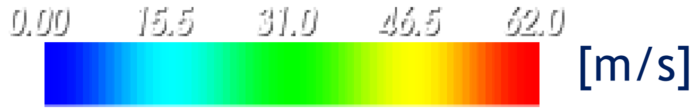
Numerics
- Calculation for 25° slant, 2 Mio. cells, RKE, MUSCL, Crank-Nicolson
- Initialised by the steady state simulation
- $\Delta t = 0.0004$ s



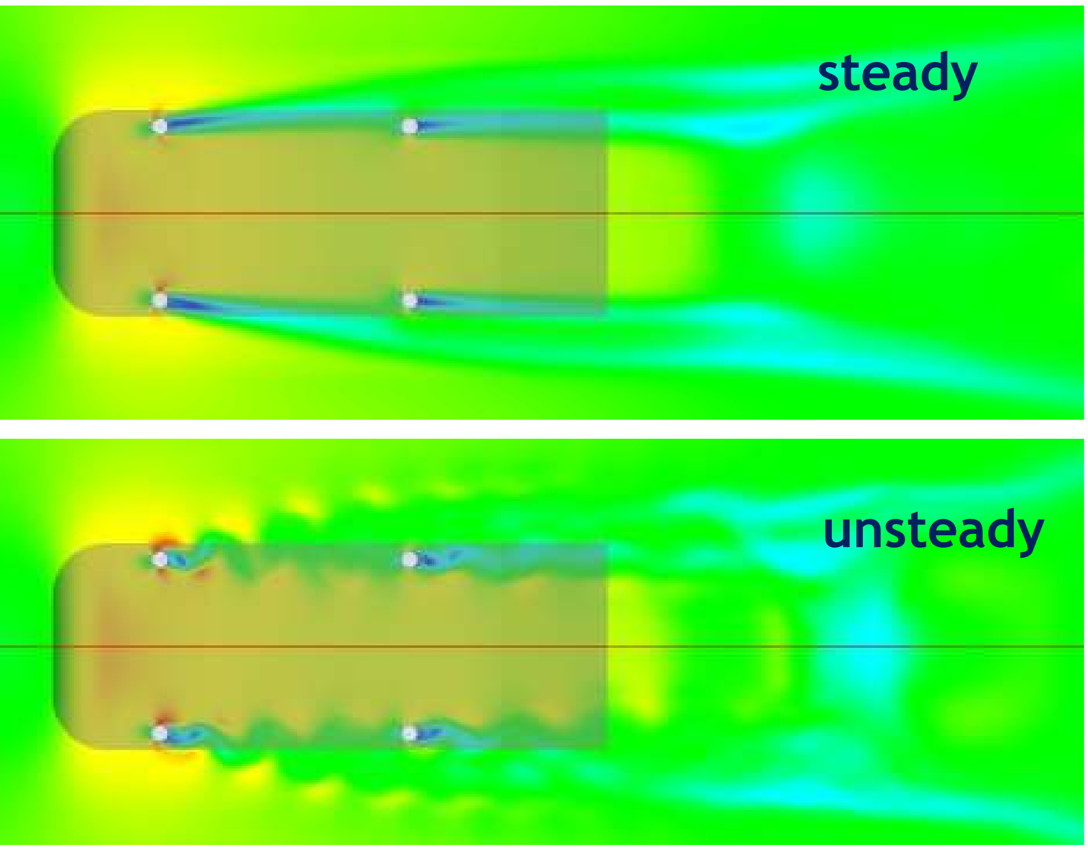
- The simulation reaches a quasi stationary behaviour
- Drag and lift forces are too small compared to the measurements and to the results of steady state simulation with the same mesh

Unsteady flow simulation (2/2)

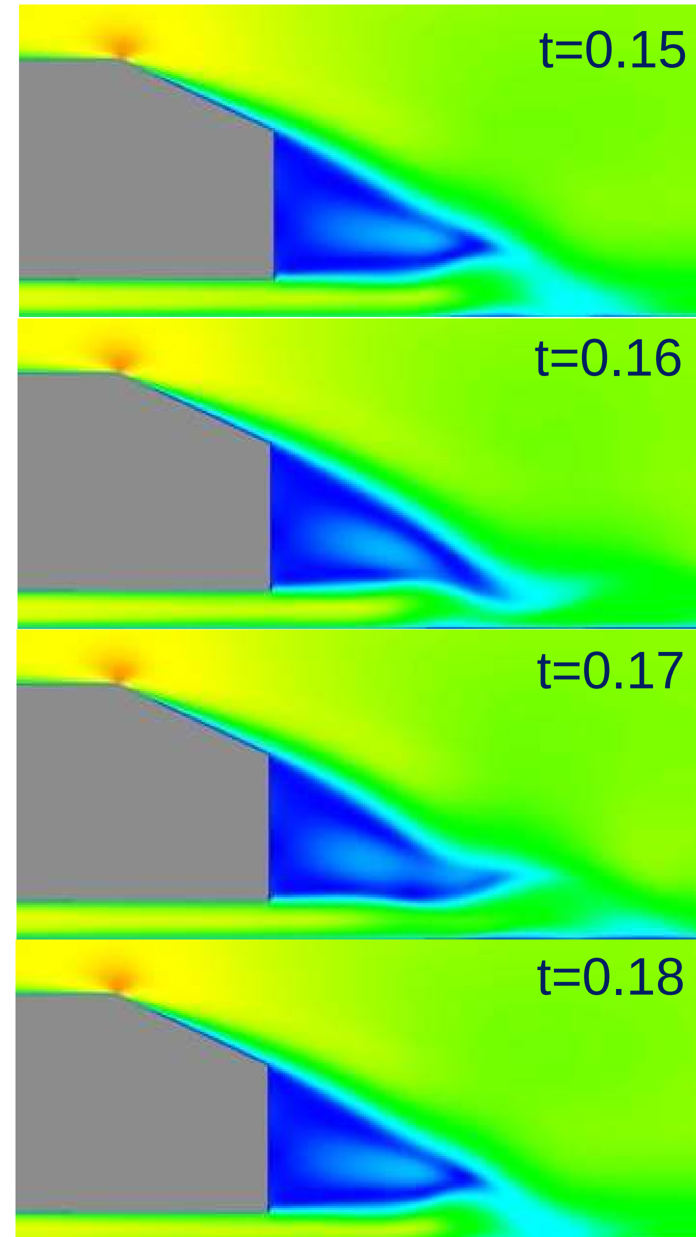
Velocity fields



Plane parallel to the ground



Symmetry plane – wake area



⇨ The local velocity field of the URANS simulation appears more realistic than the one of the steady state result

Overview

Introduction

Test case definition

Numerical method

Results

Conclusions

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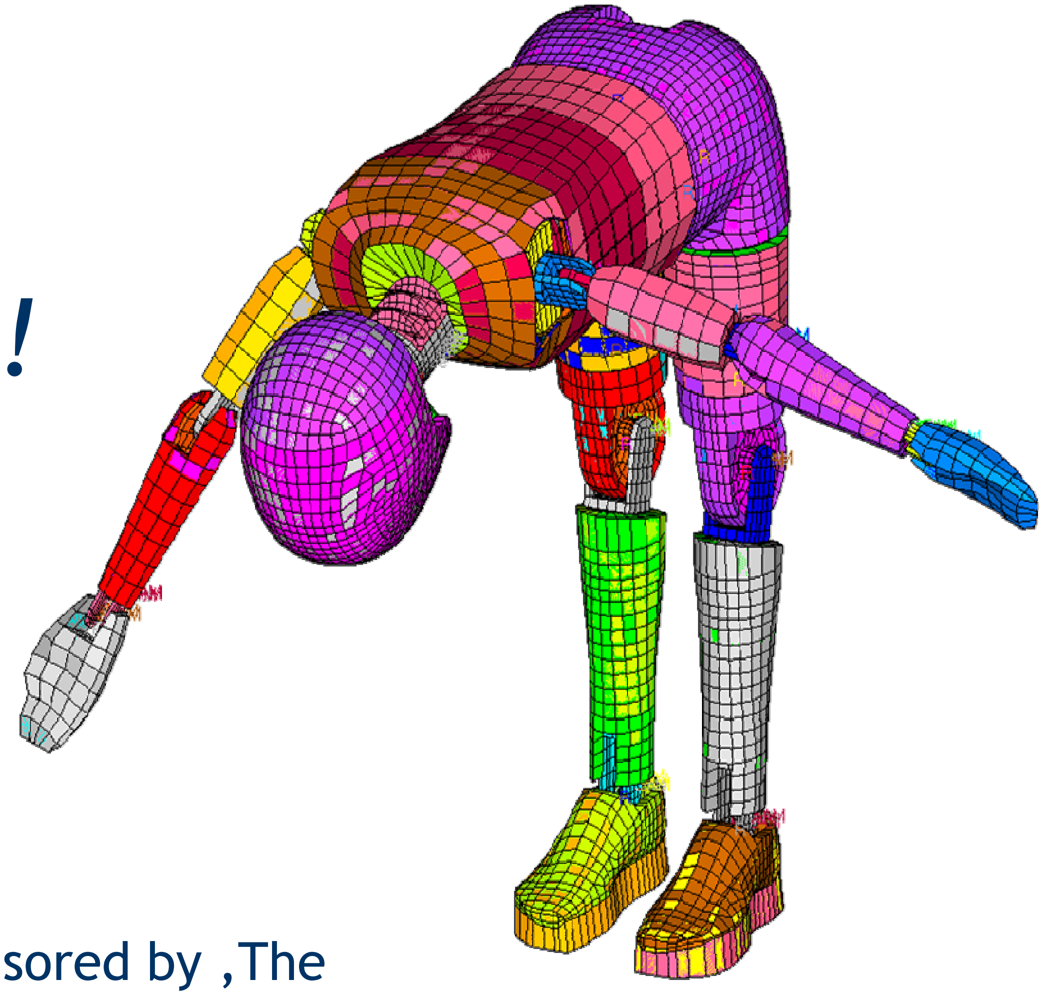
- **Good simulation results**, except for the lift coefficients in the 35° slant cases
- Full flexibility in modelling and numerics, but
  → good CFD knowledge and user experience are needed;
  → for industrial applications, a unified wall treatment for the whole range of y^+ down to the wall is needed;
  → the graphical interface has still to be enhanced for industrial applications.
- User guides and tutorials are good for the first steps in OpenFOAM, but
  → consistent and complete documentation for the use of components contained in the distribution are needed

⇨ OpenFOAM appears to be a reasonable **supplement** to commercial CFD programs in **industrial applications** with a **high potential of improvement**

Thank you
for your attention!



Questions?

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