DrivAer - Aerodynamic Investigations for a New Realistic Generic Car Model using ANSYS CFD

Thomas Frank(†), Benedikt Gerlicher(†), Juan Abanto(**)
(†) ANSYS Germany, Otterfing, Germany
(**) ANSYS Inc., Lebanon, NH, USA
Thomas.Frank@ansys.com
Contents

• The DrivAer Benchmark by TU Munich, Institute of Aerodynamics and Fluid Mechanics
  – Investigated DrivAer car model variants
• The meshing process
• CFD investigations for the DrivAer fastback car:
  – F_S_woM_wW
  – F_D_wM_wW
• Comparison to TU Munich wind tunnel data
• Cross-comparison of ANSYS CFX and ANSYS Fluent
• Summary & Outlook
Objectives

- **Automotive Aerodynamics Validation of ANSYS CFD**
- Generic reference model with modern car geometry
- Investigation of meshing process and technologies for contemporary and complex car body geometry
  - Including **wheels**
  - Including **mirrors**
  - Including **detailed floor** with exhaust system
- **Validation of ANSYS CFX & ANSYS Fluent**
- Comparison to TU Munich wind tunnel data
- Turbulence model validation and data comparison
  - steady/transient SST and SAS-SST
DrivAer Geometry
Development of the DrivAer model by TU Munich

BMW 3 Series
Limousine

Audi A4
Limousine

Courtesy by TU Munich, Inst. of Aerodynamics
DrivAer Geometry
Development of the DrivAer model by TU Munich

BMW 3 Series
Limousine

DriveAer Car Body

Audi A4
Limousine

Courtesy by TU Munich, Inst. of Aerodynamics
DrivAer Geometry
Development of the DrivAer model by TU Munich

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>4613mm</td>
</tr>
<tr>
<td>Total width</td>
<td>1820mm</td>
</tr>
<tr>
<td>Total height</td>
<td>1418mm</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2786mm</td>
</tr>
<tr>
<td>Track width front</td>
<td>1520mm</td>
</tr>
<tr>
<td>Track width back</td>
<td>1527mm</td>
</tr>
</tbody>
</table>

Courtesy by TU Munich, Inst. of Aerodynamics
Testcase Description - Geometry

Development of the DrivAer model by TU Munich

Naming conventions

- Rear end
- Underbody
- Mirrors
- Wheels

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Testcase Description - Geometry
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Naming conventions
- Rear end
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Testcase Description - Geometry
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Naming conventions

Rear end
Underbody
Mirrors
Wheels

Courtesy by TU Munich, Inst. of Aerodynamics
Testcase Description - Geometry

Development of the DrivAer model by TU Munich

Naming conventions

- Rear end
- Underbody
- Mirrors
- Wheels

Courtesy by TU Munich, Inst. of Aerodynamics
Experimental Facility and Data

- The experimental data is provided by the Institute of Aerodynamics and Fluid Mechanics, TU Munich
- Experiments are performed in a wind tunnel including a moving belt @ 1:2.5 model scale

Courtesy by TU Munich, Inst. of Aerodynamics
# Test Case Conditions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model Scale</strong></td>
<td>1:2.5</td>
</tr>
<tr>
<td><strong>Inlet velocity</strong></td>
<td>40 m/s</td>
</tr>
<tr>
<td><strong>Air Temperature</strong></td>
<td>20°C</td>
</tr>
<tr>
<td><strong>Air Pressure</strong></td>
<td>1.013 bar</td>
</tr>
<tr>
<td><strong>Air Density</strong></td>
<td>1.2047 kg/m$^3$</td>
</tr>
<tr>
<td><strong>Reference Length (Length of car model)</strong></td>
<td>1.84 m</td>
</tr>
<tr>
<td><strong>Resulting Reynolds number</strong></td>
<td>$4.87 \times 10^6$</td>
</tr>
<tr>
<td><strong>Ground velocity</strong></td>
<td>40 m/s</td>
</tr>
</tbody>
</table>

*Courtesy by TU Munich, Inst. of Aerodynamics*
Experimental Uncertainties

Also DrivAer experiments are carried out with care, the data are subject to the following uncertainties:

• Blockage of the TUM wind tunnel cross sectional area is rather high for the car model
• Existent pressure gradient over the length of the measurement section of the wind tunnel
• Efficiency of boundary layer scoop
• Necessity to take into account rolling friction and aerodynamic effects from rotating wheels and tire rim design; but tires are not connected to the weights (i.e. $C_D$ and $C_L$ measurement system)
• Disturbance from model support system (MSS) and wheel supports on car aerodynamics
• Influence from interaction of the rolling road system (RSS) with not moving side floor of the wind tunnel
• General measurement errors of applied measurement technologies (weights, pressure transducers)
Investigated DrivAer Car Models

**E_S_woM_woW**
- **Estate**
  - Smooth underbody
  - without Mirrors
  - without Wheels

**F_S_woM_wW**
- **Fastback**
  - Smooth underbody
  - without Mirrors
  - with Wheels

**F_D_wM_wW**
- **Fastback**
  - Detailed underbody
  - with Mirrors
  - with Wheels
Investigated DrivAer Car Models

E_S_woM_woW
Estate_
  Smooth underbody_
    without Mirrors_
    without Wheels

F_S_woM_wW
Fastback_
  Smooth underbody_
    without Mirrors_
    with Wheels

F_D_wM_wW
Fastback_
  Detailed underbody_
    with Mirrors_
    with Wheels
# Geometry & Computational Domain

<table>
<thead>
<tr>
<th>Model Scale to Car Size</th>
<th><strong>1:1</strong></th>
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</thead>
<tbody>
<tr>
<td>Inlet velocity</td>
<td><strong>16 m/s</strong></td>
</tr>
<tr>
<td>Air Temperature</td>
<td>20°C</td>
</tr>
<tr>
<td>Air Pressure</td>
<td>1.013 bar</td>
</tr>
<tr>
<td>Air Density</td>
<td>1.2047 kg/m³</td>
</tr>
<tr>
<td>Reference Length (Car Length)</td>
<td>4.6</td>
</tr>
<tr>
<td>Resulting Reynolds number</td>
<td>$4.87 \times 10^6$</td>
</tr>
<tr>
<td>Ground velocity</td>
<td><strong>16 m/s</strong></td>
</tr>
</tbody>
</table>

## Dimensions of the Bounding Box

<table>
<thead>
<tr>
<th>Model scale</th>
<th>1 : 1</th>
<th>1 : 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>10L</td>
<td>46.13 m</td>
</tr>
<tr>
<td>Total width</td>
<td>11B</td>
<td>20.02 m</td>
</tr>
<tr>
<td>Total height</td>
<td>8H</td>
<td>11.34 m</td>
</tr>
</tbody>
</table>
Meshing Process

- Meshing process using:
  - ANSYS DesignModeler 14.5
  - ANSYS TGrid in Fluent 14.5
F_D_wM_wW: Computational Mesh2

- Full 3d model → SAS-SST
- ~110 Mill. Cells
- Four refinement zones
- 20 Inflations on the car
- 15 Inflations on the road
- y*<1 on the car body
- MRF-Zones for the rims (MRF=Moving Reference Frame)
Mesh Generation

Connection between road and wheels
Setup for Road & Wheels

- Road = Moving wall
- Rotational boundary condition on tire
- MRF-Zones at the rims (Moving Reference Frame)
## Simulation Matrix

<table>
<thead>
<tr>
<th>Timestep</th>
<th>Mesh 1</th>
<th>Mesh 2</th>
<th>Mesh 2 Full Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steady SST</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Δt = 0.1ms</td>
<td>•</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steady SST</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Δt = 1 ms</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Steady SST</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Δt = 10 ms</td>
<td>•</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transient SST</td>
<td>•</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Δt = 1 ms</td>
<td>•</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Transient SAS-SST</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Δt = 1 ms</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>Transient SAS-SST</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Δt = 0.2 ms</td>
<td>•</td>
<td>•</td>
<td></td>
</tr>
</tbody>
</table>

• – ANSYS CFX investigation
• – ANSYS Fluent investigation
Investigation Results F_S_woM_wW

F_S_woM_wW - Fastback_Smooth underbody_without Mirrors_with Wheels
F_S_woM_wW: Comparison of Drag

Comparison: Transient Runs

<table>
<thead>
<tr>
<th></th>
<th>Exp Results</th>
<th>Mesh 1 Transient 1ms</th>
<th>Mesh 2 Full Geometry Transient 1ms</th>
<th>Mesh 2 Full Geometry SAS-SST 1ms</th>
<th>Mesh 2 Full Geometry SAS-SST 0.2ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag Coeff</td>
<td>0.2519</td>
<td>0.2831</td>
<td>0.2745</td>
<td>0.2830</td>
<td>0.2834</td>
</tr>
</tbody>
</table>

Averaged over 60s 1500 time steps 1440 time steps 2000 time steps 6382 time steps

* - Simulation did not totally converge within the given coefficient loops
Experimental data by courtesy of TU Munich, Inst. of Aerodynamics

\[ C_D, \text{Experiment} = 0.2519 \]
\[ C_D, \text{mean, Fluent} = 0.2684 \]
\[ C_D, \text{mean, CFX} = 0.2834 \]
ANSYS CFD, SAS-SST –
$C_p$ at Symmetry Plane $y=0\text{mm}$ (top)

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
ANSYS CFD, SAS-SST – $C_p$ at Symmetry Plane $y=0$mm (bottom)

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
ANSYS CFD, SAS-SST – $C_p$ at $z=0.15m$

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics

![Graph showing $C_p$ vs. $x$ for different cases: Experiment: F_S_woM_wW, ANSYS Fluent SAS-SST, ANSYS CFX SAS-SST. The graph includes a representation of a vehicle with a red line indicating $z=0.15m$.](image-url)
Comparison of Q-Criterion

**URANS SST**
\[ \Delta t = 0.001 \text{s} \]
2,942 Timesteps
\[ \Rightarrow 2.942 \text{s} \]

**SAS-SST**
\[ \Delta t = 0.001 \text{s} \]
High Resolution
1,000 Timesteps
\[ \Rightarrow 1 \text{s} \]
Comparison of Q-Criterion

**ANSYS Fluent**

Fluent, SAS-SST
Δt=0.2 ms
15000 time steps
3.0 s total time

Q criterion level = 0.0005

**ANSYS CFX**

CFX, SAS-SST
Δt=0.2 ms
14419 time steps
2.884s total time
Vortex Structure from Transient Simulation, SAS-SST, Δt=0.2ms
Vortex Structure from Transient Simulation, SAS-SST, $\Delta t=0.2\text{ms}$
Investigation Results F_D_wM_wW

F_D_wM_wW - Fastback Detailed underbody with Mirrors with Wheels
Experimental data by courtesy of TU Munich, Inst. of Aerodynamics

- $C_D$, Experiment = 0.2927
- $C_D$, mean, Fluent = 0.3114
- $C_D$, mean, CFX = 0.3158

**Diagram Description:**

The diagram illustrates the history of $C_D$ (drag coefficient) over time. The data is represented by different lines corresponding to various simulations and experimental results:

- **Red line:** Experiment
- **Blue line:** ANSYS CFX, URANS SST
- **Dashed blue line:** ANSYS CFX, URANS SST, Mean $C_D$
- **Green line:** ANSYS Fluent, SAS-SST
- **Dashed green line:** ANSYS Fluent, SAS-SST, Mean $C_D$

The plot covers a time range from 8000 to 15000 time steps, with $C_D$ values ranging from 0.1500 to 0.3500.
ANSYS CFD, SAS-SST – $C_p$ at Symmetry Plane (top)

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
ANSYS CFD, SAS-SST – $C_p$ at Symmetry Plane (bottom)

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
Better agreement between CFD and data for $C_p$ extracted from the left side of the car

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
ANSYS CFD, SAS-SST – $C_p$ at $z=0.15m$ (right)

Experimental data by courtesy of TU Munich, Inst. of Aerodynamics
ANSYS CFX, URANS SST, $\Delta t=0.2\text{ms}$

– Asymmetric wake –
ANSYS CFX, URANS SST, $\Delta t=0.2\text{ms}$
– Asymmetric wake –
ANSYS CFX, URANS SST, $\Delta t=0.2\text{ms}$
– Asymmetric wake –
October 31, 2013
2013 Automotive Simulation World Congress

ANSYS Fluent SAS-SST, $\Delta t=0.2\text{ms}$

Lambda-2 criterion level = 0.01
Bottom view of F_D_wM_wW
Lambda-2 criterion level = 0.001
Bottom view of F_D_wM_wW
Summary & Conclusions
• Simulating the DrivAer car is first of all a meshing challenge!
• Established a meshing process, where ANSYS TGrid in Fluent 14.5 and direct CAD model tessellation was applied
• Three different DrivAer cars meshed and simulated → (U)RANS SST and SAS-SST comparison
• Applied feasible amount of CFD best practice related investigations:
  – mesh and timestep dependence
  – iteration error → convergence
  – steady vs. transient
  – (U)RANS vs. scale-resolving turbulence modeling
• Reasonable good agreement for $C_p$ value comparison to data
• Influence from the model support system (MSS) on $C_p$ on the top of the car roof observable
• Differences at point of vortex impingement in the rear of the car

• CFD predicted slightly higher $C_D$ values in comparison to data
  – Influence from wind tunnel geometry
  – Quite high blocking ratio for this large model in TUM wind tunnel
  – Influence from road simulator vs. entirely moving road (CFD)

  \[ \text{Desirable to have PIV data for flow field comparison} \]

• Good and very consistent comparison between ANSYS CFX and ANSYS Fluent for investigated DrivAer car models
• Further streamlining and refinement of the ANSYS TGrid in Fluent based meshing process possible

  \[ \rightarrow \text{e.g. longer extension of refined zones behind the car} \]
Questions?
References