Case 2
DrivAer Fastback and Estate

1st Automotive CFD Prediction Workshop
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Petter Ekman
Linköping University
Content

• Background about chosen Method
  – Time-Step Size Sensitivity Study *
  – Turbulence Model Study **

• Chosen Method Case 2
• Simulation Results Case 2


Method – Sensitivity Study

- DrivAer Reference Model – Notchback
  - Smooth Underbody
- \( Re_L = 3.12 \cdot 10^6 \)
- 5° of yaw
- Test section included in the simulations
  - GroWiKa WT at TU Berlin
- Stationary ground and wheels

Method – Sensitivity Study

- ANSYS Fluent
- Stress Blended Eddy Simulation (SBES)
  - $k-\omega$ SST RANS model
  - Dynamic Smagorinsky SGS Model

- $\Delta t = 1.4 \cdot 10^{-6}s$
  - $CFL < 1$

- Mesh
  - 15-20 prisms layers
  - 61, 102 and 158 million cells

<table>
<thead>
<tr>
<th>Mesh size</th>
<th>$C_D$</th>
<th>$C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>61 million cells</td>
<td>0.268</td>
<td>-0.120</td>
</tr>
<tr>
<td>102 million cells</td>
<td>0.266</td>
<td>-0.136</td>
</tr>
<tr>
<td>158 million cells</td>
<td>0.269</td>
<td>-0.137</td>
</tr>
</tbody>
</table>

Method – Sensitivity Study

Comparison to Wind Tunnel Measurements – Following Best Practice

<table>
<thead>
<tr>
<th>Method</th>
<th>$C_D$</th>
<th>$C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFD</td>
<td>0.268 ± 0.002</td>
<td>-0.136 ± 0.001</td>
</tr>
<tr>
<td>Wind Tunnel</td>
<td>0.272 ± 0.003</td>
<td>-0.119</td>
</tr>
</tbody>
</table>

Measurements performed by TU Berlin

Method – Sensitivity Study

- Time-Step Size Investigation

<table>
<thead>
<tr>
<th>CFL</th>
<th>Time-step size [s]</th>
<th>( \frac{L}{(\Delta t \cdot U_\infty)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( 1.4 \cdot 10^{-6} )</td>
<td>20850</td>
</tr>
<tr>
<td>10</td>
<td>( 1.4 \cdot 10^{-5} )</td>
<td>2085</td>
</tr>
<tr>
<td>20</td>
<td>( 2.8 \cdot 10^{-5} )</td>
<td>1042.5</td>
</tr>
<tr>
<td>50</td>
<td>( 7.0 \cdot 10^{-5} )</td>
<td>417</td>
</tr>
<tr>
<td>100</td>
<td>( 1.4 \cdot 10^{-4} )</td>
<td>208.5</td>
</tr>
</tbody>
</table>

Results – Sensitivity Study

Forces - Difference against CFL1

- Drag forces relative insensitive
- Lift forces more sensitive
Results – Sensitivity Study

Total Pressure and Skin Friction Differences Against CFL1

Results – Sensitivity Study

Results – Sensitivity Study

SBES vs DDES and IDDES

**Notchback**

**Fastback**


Results – Sensitivity Study

SBES vs DDES and IDDES

Drag difference when increasing yaw angle for 0°

Measurements performed by TU Berlin

Results – Sensitivity Study

SBES vs DDES and IDDES

Skin Friction Coefficient $Y$

-0.0025  |  0  |  0.0025

Experiment  |  DDES SST $k$-$\omega$  |  IDDES SST $k$-$\omega$  |  SBES DSM SST $k$-$\omega$

$\beta = 0^\circ$

Results – Sensitivity Study

SBES vs DDES and IDDES

Chosen Method – Case 2

- ANSYS Fluent 2019R1
- Stress Blended Eddy Simulation (SBES)
  - Dynamic Smagorinsky SGS model
  - $k-\omega$ SST RANS model

- $\Delta t = 1.375 \cdot 10^{-4}$ s (corresponding to CFL10)
- 5 Inner Iterations
- Simulation Time: $5+20$ Convective Flow Units ($t \cdot U_\infty / L$)

- Mesh = Medium Hexapoly
- Boundary Conditions according to Case 2 description

### SBES is ~25% more expensive than DDES for the same mesh and numerical settings

- Simulation Cost on 1920 cores
  - Fastback = 133 658 corehours
  - Estate = 125 429 corehours
Results - Forces

- **Absolute Forces**

<table>
<thead>
<tr>
<th>Car Body/Method</th>
<th>$C_D$</th>
<th>$C_L$</th>
<th>$C_{LF}$</th>
<th>$C_{LR}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastback – SBES</td>
<td>0.229</td>
<td>-0.035</td>
<td>-0.120</td>
<td>0.086</td>
</tr>
<tr>
<td>Fastback – WT*</td>
<td>0.243</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Estate - SBES</td>
<td>0.279</td>
<td>-0.198</td>
<td>-0.154</td>
<td>-0.044</td>
</tr>
<tr>
<td>Estate – WT*</td>
<td>0.292</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- **Force Difference: Estate - Fastback**

<table>
<thead>
<tr>
<th>Method</th>
<th>$\Delta C_D$</th>
<th>$\Delta C_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBES</td>
<td>0.050</td>
<td>-0.163</td>
</tr>
<tr>
<td>WT*</td>
<td>0.049</td>
<td>-</td>
</tr>
</tbody>
</table>

Results - Pressure

- Comparison to Heft, A., et al. * and

Results - Pressure

- Comparison to Avadiar, T., et al. *
- Offset of $C_p = 0.05$

Conclusions

• Possible to be aggressive with time-step size
  – Drag relative insensitive
  – Lift more sensitive

• High accuracy achieved with SBES
  – Able to capture the complex flow over the rear window
  – Base pressure correlate well with measurements
  – Good drag prediction for different yaw and car configurations
  – Excellent trend prediction
  – ~25% more expensive than DDES $k$-$\omega$ SST
Acknowledgements

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Thank you!

Petter.ekman@liu.se
**Extra Material**

**Total Pressure and Skin Friction**