THE INFLUENCE OF MESH CHARACTERISTICS ON OPENFOAM SIMULATIONS OF THE DRIVAER MODEL

Grigoris Fotiadis*, Vangelis Skaperdas, Aristotelis Iordanidis
BETA CAE Systems S.A., Greece

KEYWORDS – ANSA, μETA, meshing, pre-processing, post-processing, CFD, OpenFOAM, automotive aerodynamics

ABSTRACT –
In this study external aerodynamics CFD simulations are performed using OpenFOAM on the three variants of the DrivAer model, a realistic geometry with details representative of current automotive designs. A thorough examination of the effect of different meshes on the solution convergence and accuracy is performed. These meshes differ in terms of generation process and time involved, their density and their quality. Different meshing approaches are followed using the pre-processor ANSA, ranging from standard hybrid penta and tetra meshes to hexa dominant and polyhedral ones. Other factors considered are the steady or transient approaches, as well as the importance of including the wind tunnel in the simulations to exactly match CFD and experimental results. All post-processing steps are performed in μETA fully automatically in order to identify the differences in the above simulations. Conclusions are derived with respect to the importance of the mesh, and the optimum pre-processing strategy that ensures robust automation as well as high fidelity CFD simulations with OpenFOAM.
The influence of mesh characteristics on OpenFOAM simulations of the DrivAer model

Grigoris Fotiadis, Vangelis Skaperdas, Aristotelis Iordanidis
BETA CAE Systems S.A.
The DrivAer model of the Technical University of Munich

Experimental setup:
1:2.5 scale wind tunnel model
Re = 4.87 x 10^6
L = 1.84 m
U = 40 m/sec
Free stream turbulence = 0.4%

Acknowledgments to:
Institute of Fluid Mechanics and Aerodynamics of the Technical University of Munich for providing the model geometries in IGES and STEP formats

Reference
Previous related work of BETA CAE

Studies with Fluent and OpenFOAM simulations were presented at:
*ANSYS Automotive Simulation Congress Group, Frankfurt, October 2013*
*International Open Source CFD Conference, Hamburg, October 2013*

Model was scaled up to full size $L = 4.612$ m
Domain size $50 \times 20 \times 11.5$ m
blockage ratio= 1%
domain sides set to symmetry
Steady State RANS simulations
Re = $4.87 \times 10^6$
Turbulence model: k-omega SST
Cases with and without moving ground simulation with MRF modeling of rotating wheels

Presence of model support seems to decelerate the flow locally
Software and hardware used

- ANSA v15.3.0 for pre-processing
- OpenFOAM v2.3 for solving
- µETA v15.3.0 for post-processing

6 Linux Centos 6.6 PCs
Each one with
40 cores Xeon CPU E5-2660 at 2.6GHz
256 Gb RAM
Geometry preparation: STEP file input and property assignment

Geometries that included detailed underbody and mirrors were selected
Geometry preparation: Construction of wind tunnel geometry
Geometry preparation: Construction of wind tunnel geometry

Blockage ratio ≈ 8%
Flexible Size Boxes controlling mesh refinement aligned to the flow
Batch Meshing setup: automation and consistency in meshing

Batch Mesh provides:
- Automation
- Consistency
- Mesh spec traceability
Batch mesh generated surface mesh

Automatic curvature and sharp edge refinement, in combination with the use of Size Boxes ensure the efficient and accurate capturing of all details of the model. Quality according to Fluent skewness < 0.45
**Batch mesh generated surface mesh**

Automatic generation of models with variable resolution using batch meshing

- **Coarse** - 780 k trias on vehicle - 1.7 million in total
- **Medium** - 1.5 million trias on vehicle - 2.5 million in total
- **Fine** - 2.5 million trias on vehicle - 3.7 million in total
Boundary layer generation

First height 0.8 mm
Growth rate = 1.2
4 layers
+3 layers in aspect mode
Last aspect ratio 40% of length

Total layer height ≈ 12 mm
Boundary layer generation: local squeezing at proximities
Boundary layer generation: local exclusion of layers at problematic areas

Very confined area leading to excessive squeezing

Boundary layer scoop area with sharp leading edge

Trailing edge of aerofoil shaped model support
Batch mesh generated volume mesh

Automatic generation of layers and volume mesh for all variants and mesh densities (15 combinations)
Image below of medium size mesh with layers (50 million cells) generated in under 1 hour
Indicative mesh quality statistics: Notchback tetra medium with layers

Max Non orthogonality = 59.99

Maximum skewness = 3.99
Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing

- Coarse mesh - 1.7 million trias - 34.5 million cells
- Medium mesh - 2.5 million trias - 50 million cells
- Fine mesh - 3.7 million trias - 78.7 million cells
Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing

Coarse mesh - 1.7 million trias - 27.8 million cells

Medium mesh - 2.5 million trias - 40.6 million cells

Fine mesh - 3.7 million trias - 61.2 million cells
Mesh refinement study for HexaPoly with layers case

Automatic generation of models with variable resolution using batch meshing

Coarse mesh - 1.7 million trias - 21.7 million cells

Medium mesh - 2.5 million trias - 32.1 million cells

Fine mesh - 3.7 million trias - 47.9 million cells
Generation of Polyhedral mesh from hybrid mesh conversion

- Coarse mesh - 3.7 million polys - 17.4 million cells
- Medium mesh - 5.5 million polys - 26.2 million cells
- Fine mesh - 7.7 million polys - 38.3 million cells
Overview of final volume mesh

Medium tetra model
## Summary of mesh models for different variants

<table>
<thead>
<tr>
<th>Variant</th>
<th>Open Domain</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notchback</td>
<td></td>
<td>Tetra (34.5 million)</td>
<td>Tetra (30.6 million)</td>
<td>Tetra (78.7 million)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hexa Interior (27.8 million)</td>
<td>Hexa Interior (40.6 million)</td>
<td>Hexa Interior (61.2 million)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hexa Poly (21.7 million)</td>
<td>Hexa Poly (32.1 million)</td>
<td>Tetra (47.9 million)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polyhedral (17.4 million)</td>
<td>Polyhedral (26.2 million)</td>
<td>Polyhedral (38.3 million)</td>
</tr>
<tr>
<td>Fastback</td>
<td></td>
<td>-</td>
<td>Tetra (50.1 million)</td>
<td>-</td>
</tr>
<tr>
<td>Estate</td>
<td></td>
<td>-</td>
<td>Tetra (51.6 million)</td>
<td>-</td>
</tr>
</tbody>
</table>
Setting up the OpenFOAM case in ANSA
**OpenFOAM simulations: setup**

**Numerical settings**
- LinearUpwindV scheme for velocity
- Upwind scheme for turbulence
- GAMG solver for pressure, tolerance $10^{-10}$, relTol 0.05
- smoothSolver for velocity and turbulence, tolerance $10^{-10}$, relTol 0.1

**Steady State simulations**
- simpleFoam
- Turbulence model: k-omega SST
- Stationary ground
- All runs started from potentialFoam initialization

**Transient simulation**
- pisoFoam
- time step $10^{-4}$ sec
- run for 3.5 sec real time
- Turbulence model: IDDES Spalart Almaras model for near wall
- Run starting from converged steady state solution
OpenFOAM simulations: Steady state simpleFoam convergence

Indicative convergence history of residuals and drag and lift coefficients for Notchback TetraRapid medium model.
Post-processing in μETA: $y^+$ results

Tetra with layers $20 < y^+ < 50$

Post-processing was performed manually for one CFD run and then META run in batch mode for the other 14 simulations producing automatically the same images.
Velocity field at symmetry plane of notchback

Tetra medium mesh

RANS

Transient IDDES (55msec animation)

RANS – Averaged field

Transient IDDES – Averaged field
Cut-plane of velocity magnitude

Steady RANS

Transient IDDES (55msec animation)
Velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

Transient IDDES (55 msec animation)
Averaged velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

Transient IDDES (55 msec animation)
Averaged velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

Transient IDDES (55 msec animation)
Velocity field at symmetry plane of fastback model

Averaged Velocity

RANS k-omega SST (Tetra Medium Mesh)

Experiment
Pressure loss regions: Iso-surface of total pressure = 0

Tetra medium mesh

Transient IDDES (55msec animation)

Steady RANS
Pressure loss regions: Total pressure at symmetry plane of notchback

Tetra medium mesh – Iteration / Time averaged values

Steady RANS

Transient IDDES
Open section wind tunnel corrections

Correction is applied on $U_{ref}$ based on the Plenum Method described by B. Nijhof, G. Wickern SAE 2003-01-0428 and R. Kuenstner, K. Deutenbach, J. Vagt SAE 920344

\[ k \cdot (P_{\text{inlet}} - P_{\text{plenum}}) = \frac{1}{2} \rho \cdot U^2 \]

\[ U_{ref} = \sqrt{\frac{2 \cdot k \cdot (P_{\text{inlet}} - P_{\text{plenum}})}{\rho}} \]
Convergence of Drag Coefficient: Tetra case - Notchback

Drag coeff

Drag coeff – Moving Average

Drag coeff – Moving Average

Time (hours)

Iterations

ANSA & μETA
INTERNATIONAL CONFERENCE
2015
THE MET HOTEL
Thessaloniki, Greece

βBETA
CAE Systems M
Averaging of fluctuating forces: Tetra medium mesh - Notchback
Mesh refinement study for Tetra and Hexa Interior meshes: $C_D$ & $C_L$ convergence

Coefficients calculated based on notchback projected frontal area = 0.3475 m$^2$
Comparison with experimental $C_D$ value of 0.272 for notchback model

<table>
<thead>
<tr>
<th></th>
<th>Run</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Domain</td>
<td>RANS k-omega</td>
<td>-</td>
<td>Tetra 0.284 (+4%)</td>
<td>-</td>
</tr>
<tr>
<td>Wind tunnel</td>
<td>RANS k-omega</td>
<td>Tetra 0.268 (-1%)</td>
<td>Tetra 0.274 (+1%)</td>
<td>Tetra 0.272 (0%)</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Hexa Int 0.258 (-5%)</td>
<td>Hexa Int 0.265 (-3%)</td>
<td>Hexa Int 0.265 (-3%)</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Hexa Poly 0.258 (-5%)</td>
<td>Hexa Poly 0.258 (-5%)</td>
<td>Hexa Poly 0.265 (-3%)</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Polyhedral 0.284 (+4%)</td>
<td>Polyhedral 0.301 (+11%)</td>
<td>Polyhedral 0.283 (+4%)</td>
</tr>
<tr>
<td>DES S-A</td>
<td>-</td>
<td>Tetra 0.281 (+3%)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Plenum method corrected values presented (correction can be as high as 15%)
<table>
<thead>
<tr>
<th></th>
<th>Run</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open Domain</strong></td>
<td>RANS k-omega</td>
<td>-</td>
<td>Tetra 0.078 (+95%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Tetra 0.054 (+35%)</td>
<td>Tetra 0.051 (+28%)</td>
<td>Tetra 0.067 (+68%)</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Hexa Int 0.094 (+135%)</td>
<td>Hexa Int 0.082 (+105%)</td>
<td>Hexa Int 0.088 (+120%)</td>
</tr>
<tr>
<td><strong>Wind tunnel</strong></td>
<td>RANS k-omega</td>
<td>Hexa Poly 0.116 (+190%)</td>
<td>Hexa Poly 0.087 (+118%)</td>
<td>Hexa Poly 0.096 (+140%)</td>
</tr>
<tr>
<td></td>
<td>RANS k-omega</td>
<td>Polyhedral 0.096 (+140%)</td>
<td>Polyhedral 0.133 (+233%)</td>
<td>Polyhedral 0.116 (+190%)</td>
</tr>
<tr>
<td></td>
<td>DES S-A</td>
<td>-</td>
<td>Tetra 0.031 (-23%)</td>
<td>-</td>
</tr>
</tbody>
</table>

Comparison with experimental $C_L$ value of 0.04 for notchback model.

Plenum method corrected values presented (correction can be as high as 15%).
Summary of $C_D$ and $C_L$ values for three variants

Tetra medium meshes RANS simulations

<table>
<thead>
<tr>
<th>Variant</th>
<th>$C_D$ Experiment</th>
<th>$C_D$ CFD</th>
<th>$C_L$ Experiment</th>
<th>$C_L$ CFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notchback</td>
<td>0.272</td>
<td>0.274 (+1%)</td>
<td>0.04</td>
<td>0.050 (+25%)</td>
</tr>
<tr>
<td>Fastback</td>
<td>0.274</td>
<td>0.271 (-1%)</td>
<td>0.05</td>
<td>0.058 (+16%)</td>
</tr>
<tr>
<td>Estate</td>
<td>0.314</td>
<td>0.279 (-11%)</td>
<td>-0.07</td>
<td>-0.050 (+29%)</td>
</tr>
</tbody>
</table>

Plenum method corrected values presented (correction can be as high as 15%)
Comparison with experiment: $C_p$ along upper symmetry line

Notchback medium tetra
Pre-processing and Simulation Times

Simulation times for 20,000 iterations

Mesh refinement

Time (mins)

<table>
<thead>
<tr>
<th>Mesh refinement</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Improvement</td>
<td>10</td>
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<td>17</td>
</tr>
<tr>
<td>Volume Mesh</td>
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<td>9</td>
<td>24</td>
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<tr>
<td>Layers Generation</td>
<td>12</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Surface Mesh</td>
<td>13</td>
<td>17</td>
<td>24</td>
</tr>
</tbody>
</table>
Concluding remarks

- In order to extract more accurate conclusions from this and from future studies we need to have the exact experimental setup specifications, like, velocity correction method, k factor, reference pressure measurement and of course accurate geometry of the problem.

- The correction method for Open Test Section Wind Tunnels significantly affects the results.

- The addition of the wind tunnel to the simulation significantly improved the agreement of the results with the experiment.

- Interpretation of results is of utmost importance. Averaging of forces must be performed with great caution and should consider several thousands of iterations.

- Tetra mesh proved to be the most accurate (Spot-on drag coefficient prediction, 28% deviation for lift coefficient), while polyhedral meshes seem to deviate a lot.

- Mesh refinement study showed that acceptable mesh independence can be reached at medium size.

- ANSA and µETA pre and post-processing for OpenFOAM was demonstrated with key points like:
  - High quality automated surface and volume meshing allowing quick mesh alternatives
  - Fully automated post-processing for multiple simulation results
Thank you

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website
www.beta-cae.gr

support
ansa@beta-cae.gr

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