Investigation of Grid Generation Strategies for Prediction of High Lift Flows

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Review of work during 2nd HILIFT Prediction Workshop

Focus of Current Studies

Grid Details
- Surface Grids
- Volume Grids

Simulation Details

Results: High Reynolds Number Study
- Lift Prediction & Stall Development
- Investigation of CL dip at $\alpha = 20^\circ$
- Comparison of Surface grid generation strategies
- Comparison of Volume grid generation strategies

Results: Low Reynolds Number Study
- Lift Prediction & Stall Development
- Comparison of Velocity Profiles

Observations & Conclusions
Simulation Details

Solver Name: CFD++ (by Metacomp Technologies)
Method: RANS Finite Volume Cell Centered Approach
Discretization: Second Order Upwind
Limiter: Minmod
Turbulence Model: Spalart Allamaras with Rotational Correction (SARC)

<table>
<thead>
<tr>
<th>High Reynolds Number Case</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reynolds Number</td>
<td>15.1M</td>
</tr>
<tr>
<td>Mach Number</td>
<td>0.175</td>
</tr>
<tr>
<td>Static Temperature</td>
<td>114K</td>
</tr>
<tr>
<td>Angles of Attack</td>
<td>16 - 22.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low Reynolds Number Case</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reynolds Number</td>
<td>1.35M</td>
</tr>
<tr>
<td>Mach Number</td>
<td>0.175</td>
</tr>
<tr>
<td>Static Temperature</td>
<td>298.6K</td>
</tr>
<tr>
<td>Angles of Attack</td>
<td>16 - 21</td>
</tr>
</tbody>
</table>
Config1 (No support brackets) Analysis

- Used following Mixed Unstructured Grids:
  - DLR Coarse, Medium, Fine, TATA 115M and TATA 104M
- Simulated $\alpha = 7^\circ$ to $22.4^\circ$ at High Re Conditions
### Config2 (with support brackets) Analysis

- Used Pointwise Mixed Unstructured Grids provided by AIAA
- Simulated $\alpha = 16^\circ$ to $22.4^\circ$ at High Re and $\alpha = 16^\circ$ to $21^\circ$ at Low Re Conditions
- Under prediction of Stall angle and Max. CL at High Re
- Sudden Dip at $\alpha = 20^\circ$
- Stall not predicted up to $\alpha = 21^\circ$ at Low Re

![Config2 Lift Predictions](image)
Focus of Current Studies

EuroLift Configuration with Support Brackets (Config2) is analyzed to:

- Investigate Surface and Volume Grid Generation Strategies to improve Lift Prediction at High Re
- Understand the reason for Dip at $\alpha = 20^\circ$ at High Re
- Assess Applicability of High Re Grids to the Analysis of order of magnitude lower Re Case
Surface Grids

**Grid 1:** Pointwise grid available from AIAA HiLIFTPW2

**Grid 2 & Grid 3:** In-house High Re grids

**Grid 4:** In-house Low Re grid

### Grid 1
- Stretched rectangular Tri elements leading to coarser leading edge resolution
- Finer resolution of mid-chord portions of lifting elements

### Grid 2, Grid 3 & Grid 4
- Identical Surface Grids
- Regular Tri elements leading to finer leading edge resolution
- Coarser resolution of mid-chord portions of lifting elements
**Volume Grids**

**Grid 1:** Higher Prism Layer Thickness compared to other grids

**Grid 2:** Lower Prism Layer Thickness than Grid 1

**Grid 3:** Prism Layers identical to Grid 2 and also has dense Tet around Lifting elements

**Grid 4:** Generated for Low Re using similar strategy as Grid 3

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**Table: Details of Grids Used for the Analysis**

<table>
<thead>
<tr>
<th>Grid Name</th>
<th>Grid Type</th>
<th>Tet+Prism+Pyramids</th>
<th>Tet+Prism+Pyramids</th>
<th>Tet+Prism+Pyramids</th>
<th>Tet+Prism+Pyramids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid 1</td>
<td>Grid Size</td>
<td>148M</td>
<td>156M</td>
<td>158M</td>
<td>121M</td>
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<tr>
<td></td>
<td>Surface Mesh Size</td>
<td>2.4M</td>
<td>3.64M</td>
<td>3.64M</td>
<td>3.64M</td>
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<tr>
<td></td>
<td>First Cell Height</td>
<td>0.00028mm</td>
<td>0.00055mm</td>
<td>0.00055mm</td>
<td>0.0061mm</td>
</tr>
<tr>
<td></td>
<td>Prism Growth Rate</td>
<td>1.15</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>No of Prism Layers</td>
<td>65</td>
<td>45</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Prism Layer Height</td>
<td>35mm</td>
<td>14mm</td>
<td>14mm</td>
<td>18mm</td>
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<td>Density Box*</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Software Used</td>
<td>Pointwise</td>
<td>ICEM CFD</td>
<td>ICEM CFD</td>
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<td></td>
<td>Created By</td>
<td>Pointwise Inc.</td>
<td>TATA</td>
<td>TATA</td>
<td>TATA</td>
</tr>
</tbody>
</table>

*Note: Density box is a dense region of tetrahedral elements in the vicinity of aircraft lifting surfaces.
Results: High Reynolds Number Study
Lift Prediction

- Grid 2 and Grid 3 improved prediction of Stall angle and Max. CL
- Grid 3 Results demonstrated highest improvement at $\alpha = 20^\circ$ where CL Dip is observed
- Abrupt stall for Grid 2 and Grid 3, typical of SA model
- Grid 2 and Grid 3 indicated unsteadiness in the solution from 20° onwards
Stall Development

Grid 2 & Grid 3 have indicated fluctuations in Lift Coefficients and separation extent varies accordingly. The stall pattern depicted here corresponds to last iteration value which is mentioned in the figure.

Similar stall development but with varying degree of separation
Investigation of CL dip at $\alpha = 20^\circ$

Good Agreement of surface pressures compared to Steady analysis especially on Wing followed by Slat, however Flap still needs improvement

Improvement in Lift Prediction

Over prediction of Separation over Wing Surface by Steady run

Good Agreement of surface pressures compared to Steady analysis especially on Wing followed by Slat, however Flap still needs improvement
Comparison of Surface grid generation strategies

Leading edge Pressure distribution at section y/b = 0.68, $\alpha = 16^\circ$

This trend consistently observed throughout the analysis

Leading edge pressure is sensitive to chord-wise and span-wise grid resolution
Comparison of Volume grid generation strategies

Vorticity Contours at section y/b = 0.68, α = 16°

Prism most efficient in resolving wake vorticity

Reduction in tetrahedral size showed small improvement in the wake resolution

Trend consistent throughout the analysis
Results: Low Reynolds Number Study
Lift Prediction

- All the grids over predicted stall angle and corresponding Max. CL
- Grid 1 prediction are closer to experiment up to $\alpha = 19^\circ$
- However, over prediction of CL is higher and no stall was observed up to 21°. Further angles of attack were not simulated due to time constraints
Stall Development

$\alpha = 18.5^\circ$

$\alpha = 21^\circ$

CFD predicted development of single outboard separation while experiment shows two small regions of separations out of which inner one grows causing mid span stall.
Comparison of Velocity Profiles

Sample Velocity Profile comparison at $\alpha = 18.5^\circ$ and $21^\circ$

- Overall trends for Entire Low Re analysis
  - Experimental trends matched well for Plane 1 and Plane Wing Sections but agreement on flap remained poor
  - Overall predictions of Grid 1 showed closer agreement to experiment at different span locations for both $\alpha = 18.5^\circ$ and $21^\circ$
  - No considerable difference in the predictions of Grid 3 and Grid 4
  - Most probable reason for better predictions by Grid 1 is slower prism layer growth rate

PIV Plane Locations

<table>
<thead>
<tr>
<th>Plane 1 Window C</th>
<th>Plane 1 Window B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane 2 Window D</td>
<td>Plane 2 Window B</td>
</tr>
<tr>
<td>Plane 3 Window E</td>
<td>PIV Plane Locations</td>
</tr>
</tbody>
</table>

Expt. : Black  
Grid 1 : Red  
Grid 3 : Blue  
Grid 4 : Pink
High Reynolds Number Study

- Stall angle and CLmax prediction using Steady RANS has been satisfactory

- Unsteady analysis indicated that the cause of CL dip at $\alpha = 20^\circ$ was over prediction of separation on Wing by Steady Analysis

- Leading edge pressure distribution indicates sensitivity to spanwise grid distribution

- Faster dissipation rate of multi-element wake vorticity observed for tetrahedral elements compared to prisms

- Vorticity dissipation rate reduced with reduction of tetrahedral size
Observations and Conclusion

**Low Reynolds Number Study**
- All grids predicted higher CLmax and Stall Angle than experiment
- CFD predicted outboard stall contrary to mid span stall in Wind Tunnel Tests
- All grids under-predicted fullness of velocity profiles and indicated inadequate wake resolution
- High Re grids may be usable for Low Re analysis as long as sufficient prism layer height is present to resolve wake regions
- It may be possible to improve velocity profile prediction with smaller stretching ratio but further investigations are needed in this direction

**Observations Common to both studies**
- Flow prediction over flap needs improvement
- Efforts in this direction can improve not only Lift but Drag Predictions as well
Thank You