An Assessment of the Unstructured-Grid Software TetrUSS for Drag Prediction on DLR-F4 Configuration

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Unstructured Grid Solver USM3Dns

- Developed at the NASA LaRC  (Frink, 1992, 1996)
- Tetrahedral cell-centered, finite volume Euler and N-S solver
- Specifications:
  - Roe’s flux-difference splitting
  - spatial discretisation through an analytical reconstruction scheme
  - implicit backward-Euler time stepping
  - Spalart-Allmaras one-equation turbulence model
  - optional modeling of viscous sub-layer with a wall function
  - memory requirement: 1400 bytes/cell
  - speed: 34 µsec/cell/cycle on CRAY C90
  - runs on UNIX and Linux platforms

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### DLR-F4 Wing-Body Configuration

CASE 1 (single point): $M_\infty = 0.75$, $C_L = 0.5$, $Re = 3.0 \times 10^6$

<table>
<thead>
<tr>
<th>Data</th>
<th>$\alpha$ (degrees)</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$C_M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ONERA</td>
<td>0.192</td>
<td>0.50</td>
<td>0.0290</td>
<td>-0.126</td>
</tr>
<tr>
<td>NLR</td>
<td>0.153</td>
<td>0.50</td>
<td>0.0290</td>
<td>-0.130</td>
</tr>
<tr>
<td>DRA</td>
<td>0.179</td>
<td>0.50</td>
<td>0.0279</td>
<td>-0.137</td>
</tr>
<tr>
<td>USM3Dns$^1$</td>
<td>-0.300</td>
<td>0.50</td>
<td>0.0277</td>
<td>-0.158</td>
</tr>
<tr>
<td>USM3Dns$^2$</td>
<td><strong>0.175</strong></td>
<td>0.56</td>
<td>0.0303</td>
<td>-0.156</td>
</tr>
</tbody>
</table>

$^1$ USM3Dns computation at $C_L = 0.5$

$^2$ USM3Dns computation at $\alpha = 0.175^\circ$ (average of experimental values)
DLR-F4 Wing-Body Configuration

CASE 1: $M_\infty = 0.75$, $\alpha_{\text{avg.}} = 0.175^\circ$, $C_L = 0.5$, $Re = 3.0 \times 10^6$

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>ONERA Data</th>
<th>DRA Data</th>
<th>NLR Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0.185$</td>
<td>$0.185$</td>
<td>$0.185$</td>
</tr>
<tr>
<td>2</td>
<td>$0.238$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$0.331$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$0.409$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$0.512$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$0.636$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>$0.844$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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DLR-F4 Wing-Body Configuration

**CASE 2**
Drag Polar

\( M_\infty = 0.75, \, Re = 3.0 \times 10^6 \)

\[ C_D - C_L \]

\[ \alpha \]

- ONERA Data
- DRA Data
- NLR Data
- USM3Dns

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DLR-F4 Wing-Body Configuration

CASE 3&4
Constant $C_L$ Mach Sweep
Drag Rise Curves
$Re = 3.0 \times 10^6$

- ONERA Data
- DRA Data
- NLR Data
- USM3Dns

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Concluding Remarks

- **TetrUSS** is a practical unstructured grid software system suitable for prediction of aircraft forces and moments
- A salient feature of the system is ease of grid generation for complex configurations with **VGRIDns**
  - N-S grids were generated for DLR-F4 configuration in days
- **USM3Dns** is a robust unstructured grid solver
  - Current DLR-F4 cases were computed with the *wall-function* (WF) option of USM3Dns on a grid similar to the standard (provided) grid with fewer number of cell layers in the boundary layer
    - The WF grid contains 2.4 million cells
  - All computations were performed “smoothly” with fast convergence (on average 1500 cycles per solution)
  - **Flux limiter** in USM3Dns was recently isolated as cause of over-prediction of wing pressure drag by 35 to 50 counts on advanced subsonic transport configurations
  - Current solutions on DLR-F4 were computed *without* limiter
DLR-F4 Wing-Body Configuration

Effect of Flux Limiter on USM3Dns Computed Drag

\[ M_\infty = 0.75, \ \alpha = 0.93^\circ, \ Re = 3.0 \times 10^6 \]

Experimental Data

- \( \eta_2 = 0.238 \)
- \( \eta_3 = 0.331 \)
- \( \eta_4 = 0.409 \)
- \( \eta_5 = 0.512 \)
- \( \eta_6 = 0.636 \)
- \( \eta_7 = 0.844 \)

USM3Dns (with limiter)

- \( \eta_2 = 0.238 \)
- \( \eta_3 = 0.331 \)
- \( \eta_4 = 0.409 \)
- \( \eta_5 = 0.512 \)
- \( \eta_6 = 0.636 \)
- \( \eta_7 = 0.844 \)

USM3Dns (without limiter)

\[ \eta = y/s \]

<table>
<thead>
<tr>
<th>Data</th>
<th>( C_L )</th>
<th>( C_D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experim.</td>
<td>0.602</td>
<td>0.0352</td>
</tr>
<tr>
<td>USM3Dns</td>
<td>0.650</td>
<td>0.0412</td>
</tr>
<tr>
<td>USM3Dns (no limiter)</td>
<td>0.653</td>
<td>0.0364</td>
</tr>
</tbody>
</table>

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