FUN3D Analysis of DPW-IV
Common Research Model

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FUN3D Core Capabilities

- Solves 2D/3D steady and unsteady Euler and RANS equations on node-based mixed element grids for compressible and incompressible flows
- Used for numerous projects internal and external to NASA across the speed range
- General dynamic mesh capability: any combination of rigid/overset/morphing grids, including 6-DOF effects
- Aeroelastic modeling w/ mode shapes, full FEM, CC, etc
- Adjoint-based design optimization and mesh adaptation
- Linear scaling through 1000’s of cores
- Capabilities fully integrated, large support team, online documentation, tutorials, etc
FUN3D Unstructured Grid Code

- Full Navier-Stokes equations-node centered
- Parallel 3D compressible finite-volume RANS for mixed-element meshes
- Implicit time-stepping using multi-color point Gauss-Seidel relaxation for linear system
- UMUSCL 0.5 scheme (CD + Roe) for inviscid fluxes with Venkatakrishnan limiter
- Combined Green-Gauss and edge-based gradients for viscous fluxes
- Spalart-Allmaras turbulence model (loosely coupled)
FUN3D Unstructured Grid Code

• Parallel version - MPI
  – Old paradigm (multiple steps)
    * Sequential pre-processor using MeTiS domain decomposition or parallel pre-processor using ParMetis
    * Parallel flow solver (reads partition files)
    * Sequential post-processing for visualization
  – New paradigm (one step)
    * Solver loads grid file directly in parallel and performs domain decomposition using ParMetis
    * Global grid image not in-core at any time
    * Parallel co-processing for animation, slicing, etc
    * LaRC internal version
Summary of FUN3D Results

• Case 1:
  – Grid Convergence study at Mach = 0.85, CL = 0.500 ±0.001
    • Tail Incidence angle, \(i_H = 0^\circ\)
    • Coarse, Medium, Fine, and Extra-Fine Grids
    • Chord Reynolds Number \(Re_c=5\times10^6\), fully turbulent
  – Downwash Study at Mach = 0.85
    • Drag Polars for alpha = 0.0\(^\circ\), 1.0\(^\circ\), 1.5\(^\circ\), 2.0\(^\circ\), 2.5\(^\circ\), 3.0\(^\circ\), and 4.0\(^\circ\)
    • Tail Incidence angles \(i_H = -2^\circ, 0^\circ, +2^\circ\), and Tail off
    • Medium grid
    • Chord Reynolds Number \(Re_c=5\times10^6\), fully turbulent
    • Trimmed Drag Polar (CG at reference center) derived from polars at \(i_H = -2^\circ, 0^\circ, +2^\circ\)
    • Delta Drag Polar of tail off vs. tail on (i.e. WB vs. WBH trimmed)
**Computational Grids - CRM**

- Mixed-element versions of the workshop unstructured node-based LaRC grids
- Advancing layer tetrahedra are merged into prisms/pyramids

<table>
<thead>
<tr>
<th></th>
<th>Original Grid</th>
<th>Merged Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nodes</td>
<td>Cells Tet.</td>
</tr>
<tr>
<td>Coarse</td>
<td>3.7M</td>
<td>21.6M</td>
</tr>
<tr>
<td>Medium</td>
<td>10.2M</td>
<td>60.3M</td>
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<tr>
<td>Fine</td>
<td>36.0M</td>
<td>212.2M</td>
</tr>
<tr>
<td>Extra-Fine</td>
<td>105.6M</td>
<td>623M</td>
</tr>
</tbody>
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Residual Convergence Medium Grid for $C_L=0.5$

- During the convergence history, relaxation in alpha based on error in total lift (method from CFL3D as coded by Steve Allmaras)
Residual Convergence Fine Grid for $C_L=0.5$

- During the convergence history, relaxation in alpha based on error in total lift (method from CFL3D as coded by Steve Allmaras)
Residual Conv. Extra-Fine Grid for $C_L=0.5$

- From raw grid to solver iterations in ~20 minutes using fully parallel paradigm on 1024 distributed memory processors
- Output slices, surface flows, etc generated simultaneously
- Old paradigm: pre-processing grid would take 10-15 days and ~180GB on Columbia-class shared-memory machine
Grid Convergence of CRM Forces/Moment
Grid Convergence of CRM Wing Pressures
Grid Convergence of CRM Wing Pressures

- CRM Coarse Grid (3.5M)
- CRM Medium Grid (10M)
- CRM Fine Grid (35.0M)
- CRM Extra-Fine Grid (105M)

\[ C_p \]

\[ x/c \]

\[ \eta = 0.502 \]

\[ \eta = 0.950 \]
Grid Convergence of CRM Tail Pressures

DPW IV June 20-21, 2009

http://fun3d.larc.nasa.gov
Fine Grid SOB & Trailing-Edge Separation

Cf wing = cf\textsubscript{x}\cos(\Lambda_{c/4}) + cf\textsubscript{y}\sin(\Lambda_{c/4})
Grid Convergence of SOB Separation

- **Coarse**: BL_SOB=10.4% semi-span, BL_Bubble=10.9%
- **Medium**: BL_Bubble=11.4%
- **Fine**: BL_Bubble=11.8%
- **Extra-Fine**: BL_Bubble=12.1%
CRM Downwash Study

- Mach 0.85
- \( \text{Re}_c = 5 \times 10^6 \)
- Spalart-Allmaras
- Fully Turbulent
- Medium Grids
CRM Downwash Study

Lift

Idealized Drag

Pitching Moment
Summary

- **Grid convergence study**
  - Good residual convergence on 4 grid (up to 105 million nodes) with CL driver active
  - Linear variation in total drag on finest 3 grids (delta CD = 6 counts)
  - Small variations in wing/tail Cp with grid refinement
  - 1-2% chord wing TE separation (mid-span)
  - Small wing SOB separation
  - No tail SOB/TE separation

- **Downwash study (medium grid)**
  - Delta drag 27 counts at $C_L = 0.5$
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