SUMAD Unsteady Analysis of the Benchmark SuperCritical Wing for the Aeroelastic Prediction Workshop 2

Eirikur Jonsson
Dr. Charles A. Mader
Dr. Joaquim R.R.A. Martins
http://mdolab.engin.umich.edu

Aeroelastic Prediction Workshop 2
AIAA SciTech 2016
Research in Multidisciplinary Design Optimization
Laboratory divided into two main thrusts

Fundamental MDO algorithms

Applications of MDO

\[
\frac{\partial R}{\partial u} \frac{du}{dr} = I = \left( \frac{\partial R}{\partial u} \right)^T \left( \frac{du}{dr} \right)^T
\]
SUMAD Solver Overview

- General, parallel, finite-volume, cell-centered, structured multi-block solver
- Solves Euler/RANS equation in steady, unsteady, time-spectral modes
- Central Scalar (JST), Central Matrix, Upwind dissipation schemes
- Multigrid with Full Multigrid startup. Arbitrary cycling scheme
- Smoothers (RK, DDADI and NK)
- Turbulence models (SA, SAE, k-w modified, k-w Wilcox, k-tau, SST, v2f)
- Time integration scheme, Implicit BDF2
- Deforming grids, GCL compliant ALE scheme
SUMAD models used for this work

- Solves RANS equation in steady, unsteady mode
- Central Scalar (JST) dissipation scheme
- DDADI and NK as smoothers
  - Switched to Newton-Krylov solver after partially converged solution to speed convergence
- Turbulence models
  - Spalart Allmaras (Standard) used exclusively for case 1
  - Menter SST used exclusively for case 3
- Time integration scheme, Implicit BDF2, GCL compliant ALE scheme
Grid information

- Structured Multi-block, hexahedral elements, face matched block
- DPW gridding guidelines used
- Surface mesh created in ICEM
- Volume mesh generated using in-house hyperbolic extrusion code
- Coarse mesh obtained by removing every other node in each direction

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Medium</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td># Nodes</td>
<td>23.4 x10^6</td>
<td>7.0x10^6</td>
<td>2.9 x10^6</td>
</tr>
<tr>
<td># Elements</td>
<td>22.7 x10^6</td>
<td>6.7x10^6</td>
<td>3.1 x10^6</td>
</tr>
<tr>
<td>Max Y+</td>
<td>0.425</td>
<td>0.759</td>
<td>1.015</td>
</tr>
<tr>
<td>First layer</td>
<td>1.067x10^-6 m</td>
<td>1.600x10^-6 m</td>
<td>2.388x10^-6 m</td>
</tr>
<tr>
<td>height</td>
<td>(42x10^-6 in)</td>
<td>(63x10^-6 in)</td>
<td>(94x10^-6 in)</td>
</tr>
<tr>
<td>Outer boundary</td>
<td>100c</td>
<td>100c</td>
<td>100c</td>
</tr>
<tr>
<td>Multigrid</td>
<td>5 levels</td>
<td>5 levels</td>
<td>4 levels</td>
</tr>
</tbody>
</table>
Computational domain is a semi-sphere. Grid wraps around the wing in a O-topology fashion.
Cases analysed

• Case 1
  – Steady State
  – Unsteady forced

• Case 3
  – Steady State
  – Unsteady Unforced
  – Unsteady Forced
Run criterion for all cases

<table>
<thead>
<tr>
<th></th>
<th>Case 1 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multigrid cycles</strong></td>
<td>4w/3w</td>
</tr>
<tr>
<td><strong>(Fine/Coarse)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Steady State convergence</strong></td>
<td>8 orders of magnitude (1e8)</td>
</tr>
<tr>
<td><strong>(rho)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Unsteady convergence</strong></td>
<td>30 inner iteration with MG (&gt;1.5 - 2 orders of magnitude at each timestep)</td>
</tr>
<tr>
<td><strong>(each timestep)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Unsteady # of periods</strong></td>
<td>6</td>
</tr>
<tr>
<td><strong>Unsteady total physical time</strong></td>
<td>0.6 s</td>
</tr>
</tbody>
</table>

- All steady state results converge well
- Time-accurate forces converged at each timestep
Unsteady post-processing for all cases

- Transients not present after 2 periods
- The last 4 periods are analyzed (0.4s)
- Only whole periods analyzed
- Rectangular window
- Block Overlap 80%
- 2 cycles per block
Cases analysed

- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady State
  - Unsteady Unforced
  - Unsteady Forced
Case 1 – Steady state, $C_p$ at $\eta = 0.6$
Cases analysed

- Case 1
  - Steady State
  - Unsteady forced

- Case 3
  - Steady State
  - Unsteady Unforced
  - Unsteady Forced
Case 1 Unsteady forced timestep size

- Forcing frequency $f = 10$ Hz
- Solution stated from freestream velocity

<table>
<thead>
<tr>
<th>Timestep $dt$ [s]</th>
<th># steps per period</th>
<th># cycles</th>
<th>Total # of steps</th>
<th>Total physical time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0015625</td>
<td>64</td>
<td>6</td>
<td>384</td>
<td>0.6</td>
</tr>
<tr>
<td>0.00078125</td>
<td>128</td>
<td>6</td>
<td>768</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Case 1 Smaller timestep has little effect on lift, drag and moment coefficients.

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine (128)</td>
<td>0.370921</td>
<td>0.533943</td>
<td>0.452059</td>
</tr>
<tr>
<td>Fine (64)</td>
<td>0.370736</td>
<td>0.534137</td>
<td>0.452051</td>
</tr>
<tr>
<td>Coarse (128)</td>
<td>0.372832</td>
<td>0.536309</td>
<td>0.454168</td>
</tr>
<tr>
<td>Coarse (64)</td>
<td>0.372610</td>
<td>0.536608</td>
<td>0.454167</td>
</tr>
</tbody>
</table>
Case 1 FRF magnitude at $\eta = 0.6$

Upper Surface

Lower Surface
Case 1 FRF phase at $\eta = 0.6$
Cases analysed

- **Case 1**
  - Steady State
  - Unsteady forced

- **Case 3**
  - Steady State
  - Unsteady Unforced
  - Unsteady Forced
Case 3 – Steady state, $C_p$ at $\eta = 0.6$. Turbulence model SA predicts shock further aft than SST.
Case 3 – Steady state, $C_p$ at $\eta = 0.6$
Cases analysed

• Case 1
  – Steady State
  – Unsteady forced

• Case 3
  – Steady State
  – Unsteady Unforced
  – Unsteady Forced
Case 3 Unsteady unforced timestep

- Unforced (frequency $f = 0$ Hz)
- Solution stated from freestream velocity

<table>
<thead>
<tr>
<th>Timestep dt [s]</th>
<th># steps per period</th>
<th># cycles</th>
<th>Total # of steps</th>
<th>Total physical time [s]</th>
</tr>
</thead>
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<tr>
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<td>6</td>
<td>384</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Case 3 Unsteady unforced converge to steady state values for respective grid

| Coefficient | Steady | Unforced | $|\Delta| \times 10^5$ |
|-------------|--------|----------|-----------------------|
| $C_L$       | 0.39159| 0.39159  | 0                     |
| $C_D$       | 0.07312| 0.07312  | 0                     |
| $-C_M$      | 0.02095| 0.02094  | 1.06E-5               |
| $C_L$       | 0.38493| 0.38485  | 8.07E-5               |
| $C_D$       | 0.07251| 0.07250  | 1.01E-5               |
| $-C_M$      | 0.01737| 0.01734  | 3.01E-5               |

Fine Grid

Coarse Grid
Cases analysed

- Case 1
  - Steady State
  - Unsteady forced

- Case 3
  - Steady State
  - Unsteady Unforced
  - Unsteady Forced
Case 3b timestep size

- Forcing frequency $f = 10$ Hz
- Solution stated from freestream velocity

<table>
<thead>
<tr>
<th>Timestep $dt$ [s]</th>
<th># steps per period</th>
<th># cycles</th>
<th>Total # of steps</th>
<th>Total physical time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0015625</td>
<td>64</td>
<td>6</td>
<td>384</td>
<td>0.6</td>
</tr>
<tr>
<td>0.00039</td>
<td>256</td>
<td>6</td>
<td>1536</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Case 3b Smaller timestep has little effect on lift, drag and moment coefficients

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine (256)</td>
<td>0.302953</td>
<td>0.481044</td>
<td>0.392352</td>
<td>0.062902</td>
</tr>
<tr>
<td>Fine (64)</td>
<td>0.300794</td>
<td>0.484105</td>
<td>0.392751</td>
<td>0.064783</td>
</tr>
<tr>
<td>Coarse (256)</td>
<td>0.295979</td>
<td>0.476621</td>
<td>0.386582</td>
<td>0.063838</td>
</tr>
<tr>
<td>Coarse (64)</td>
<td>0.292924</td>
<td>0.479955</td>
<td>0.386835</td>
<td>0.066237</td>
</tr>
</tbody>
</table>
Case 3b FRF magnitude at $\eta = 0.6$
Case 3b FRF phase at $\eta = 0.6$

Upper Surface

Lower Surface
Questions?

More information available at:

http://mdolab.engin.umich.edu

This work was mostly completed on the Stampede cluster, using the Extreme Science and Engineering Discovery Environment (XSEDE).