Drag Prediction for the CRM model using the Edge solver

by

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Overview

- Calculations with Edge solver
  - Hybrid unstructured grids

- Two families of grids computed
  - Provided by DLR, results delivered to DPW
  - In-house grids generated, not delivered yet
    Grid generation delayed, results only just finalized

- Mandatory Case1
  - Grid convergence study
  - Downwash study
Selected grids

- Two families of unstructured grids used, from DLR and FOI
- DLR grids generated with SOLAR grid generator

<table>
<thead>
<tr>
<th>DLR grids, tail 0</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td># nodes</td>
<td>$4.1 \times 10^6$</td>
<td>$11.7 \times 10^6$</td>
<td>$34.1 \times 10^6$</td>
</tr>
<tr>
<td># boundary nodes</td>
<td>$108 \times 10^3$</td>
<td>$226 \times 10^3$</td>
<td>$470 \times 10^3$</td>
</tr>
<tr>
<td># hexahedral elements</td>
<td>$3.1 \times 10^6$</td>
<td>$9.2 \times 10^6$</td>
<td>$72.7 \times 10^6$</td>
</tr>
<tr>
<td># prisms</td>
<td>$1.8 \times 10^3$</td>
<td>$3.4 \times 10^3$</td>
<td>$3.4 \times 10^3$</td>
</tr>
<tr>
<td># tetrahedral elements</td>
<td>$5.3 \times 10^6$</td>
<td>$14.3 \times 10^6$</td>
<td>$38.6 \times 10^6$</td>
</tr>
</tbody>
</table>

- FOI grid generated with in-house grid generator Tritet

<table>
<thead>
<tr>
<th>FOI grids, tail 0</th>
<th>Coarse</th>
<th>Medium</th>
<th>Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td># nodes</td>
<td>$3.2 \times 10^6$</td>
<td>$10.1 \times 10^6$</td>
<td>$32.1 \times 10^6$</td>
</tr>
<tr>
<td># boundary nodes</td>
<td>$153 \times 10^3$</td>
<td>$336 \times 10^3$</td>
<td>$734 \times 10^3$</td>
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<tr>
<td># hexahedral elements</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
</tr>
<tr>
<td># prisms</td>
<td>$5.5 \times 10^6$</td>
<td>$18.3 \times 10^6$</td>
<td>$59.1 \times 10^6$</td>
</tr>
<tr>
<td># tetrahedral elements</td>
<td>$1.7 \times 10^6$</td>
<td>$4.1 \times 10^6$</td>
<td>$10.9 \times 10^6$</td>
</tr>
</tbody>
</table>
Grid pictures

- DLR medium grid, tail 0
- FOI medium grid, tail 0
Grid pictures, WB junction

DLR grids, tail 0

FOI grids, tail 0
Grid pictures, nose

DLR grids, tail 0

FOI grids, tail 0
Grid pictures, wing tip

DLR grids, tail 0

FOI grids, tail 0
Grid pictures, tail

DLR grids, tail 0

FOI grids, tail 0
Edge solver

Edge – a Navier-Stokes solver for unstructured grids
- Solves the compressible NS equations
- RANS/RANS-LES/LES solver
- Node-centered/ finite-volume formulation
- Edge based formulation with median dual grids
- Runge-Kutta time integration
- Agglomeration multigrid
- Parallel with MPI
- Dual time stepping for unsteady extension
- High temperature extension
- Low speed preconditioning
- Aeroelastic capability
- Grid adaptation
- Adjoint solver for shape optimization
Computational information

Computational settings

- Hellsten k-ω EARSM for the turbulence (AIAA Journal, Vol. 43, 2005)
  - Grid convergence calculations with k-ω SST
- 3-4 level W-cycles, full multigrid
  - Semi coarsening, 1:4
- 3-stage Runge-Kutta scheme, CFL=1.25
- Central scheme with artificial dissipation for mean flow and turbulence
- Full NS, compact discretization of normal derivatives
- Linux cluster used, up to 64 processors
  - Computing time ~ (64*) 6 hours for finest grids (~33 M nodes)

New since previous workshop

- Line-implicit time integration
- Weak boundary conditions on all variables including no-slip velocity
  - AIAA 2009-3551, presented on Monday June 22, 9.30
- Central discretization of turbulent equations
Steady state convergence

- Convergence (density res. and lift) on DLR medium grid, tail 0, $C_L=0.5$
- 3 levels full multigrid W cycles
- Convergence $|\Delta C_L| < 0.1\%$ requires:
  - $\leq 600$ fine grid iterations line implicit
  - $\leq 2000$ fine grid iterations explicit
  - Specified $C_L$ requires some extra iterations
Grid convergence, $C_L=0.5$

- Comparison between DLR and FOI grids
- Excellent grid convergence with DLR grids
  - Acceptable with FOI grids
- Grid converged drag: DLR grids $C_D=278.3$, FOI grids $C_D=280.3$
Comparison between EARSM and k-ω SST, DLR grids
Good grid convergence, slightly worse grid convergence with SST
Converged drag: EARSM $C_D=278.3$, SST $C_D=271.6$
Grid convergence, $C_L=0.5$

<table>
<thead>
<tr>
<th></th>
<th>EARSM</th>
<th>$k-\omega$ SST</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLR grids</td>
<td>$0.18\times10^{-4}$</td>
<td>$0.93\times10^{-4}$</td>
</tr>
<tr>
<td>FOI grids</td>
<td>$5.0\times10^{-4}$</td>
<td>-</td>
</tr>
</tbody>
</table>

- Measure of Merit, as defined in DPW3
  - Measures the linearity of the slope of drag grid convergence
  - Based on Richardson extrapolation from coarse-medium and medium-fine grids
  - Low value = good value
Skin friction, tail $0^\circ$, $C_L=0.5$

- DLR grid, EARSM
- Attached flow on wing and tail
- Separation on fuselage behind and below tail
Polars, $C_L$

DPW4/NASA CRM Effect of Stabilizer Angle on $C_L$

- Tail $ih = -2$
- Tail $ih = 0$
- Tail $ih = +2$
- Tail Off
- Trimmed

DLR grids, EARSM

FOI
Polars, $C_D$

- DLR grids, EARSM
- $\Delta C_D = 26$ cts at $C_L = 0.5$ (trimmed vs. tail off)
Polars, $C_M$

**DPW4/NASA CRM Effect of Stabilizer Angle on $C_M$**

- Tail $\phi = -2$
- Tail $\phi = 0$
- Tail $\phi = +2$
- Tail Off

- DLR grids, EARSM
C\textsubscript{p} on wing, tail 0°

- 4 span wise cuts
- DLR grids, EARSM, 5 angles of attack
- Attached flow although small area with C\textsubscript{fx}<0 at about 40% span
C_p on tail, tail 0°

- 4 span wise cuts
- DLR grids, EARSM, 5 angles of attack
- Attached flow
Summary

- **Grid convergence**
  - Very good results with DLR grids
  - Acceptable with FOI grid, 2 cts difference
  - $k$-$\omega$ SST gives slightly lower drag than EARSM, 7 cts difference
  - $\Delta C_M = 1.9 \times 10^{-3}$ DLR-FOI grids, $\Delta C_M = 1.0 \times 10^{-3}$ EARSM - SST
  - Attached flow on wing and tail, fuselage separation behind/below tail

- **Downwash study**
  - Linear lift increase up to about $\alpha = 3^\circ$
  - Tendency to separate at highest $\alpha = 4^\circ$