VZLU/FOI joint contribution using the Edge solver
by
Aleš Prachař¹, Peter Eliasson², Petr Vrchota¹, Shia-Hui Peng²

¹) VZLU, Aerospace Research and Test Establishment (CZE)
²) FOI, Swedish Defence Research Agency
Overview

- Description of Team and Edge solver
- Calculations with Edge solver
  - Solver settings
  - Turbulence models
- Case 1: 2D Verification Study (NACA0012)
  - Common structured grids
- Case 2: Grid convergence studies
  - Common unstructured grids (NASA GeoLab, Rev00), deflection at 2.75°
  - All levels (Tiny → Ultra), both configurations (WB, WBNP)
- Case 3: Incidence sweep
  - AoA's 2.5° – 4.0° as specified, deformed grids
  - Common Medium grid (NASA GeoLab, Rev00)
- Conclusion
Description of Team and flow solver

- **VZLU**
  - Czech Aerospace Research and Test Establishment, founded 1922
  - Group of approx 10 people involved in CFD (Aerodynamics dept.)
  - New to DPW

- **FOI**
  - Swedish Research and Defence Agency
  - Support to Swedish industry with CFD and expertise (e.g., Saab)
  - Active in DPW's since DPW-2 (2003)

- **Edge**
  - CFD solver for unstructured grids
  - Developed at FOI, shared among collaborative partners (incl. VZLU)
Edge, setting

- **Edge**
  - Finite volume, node-based, dual grid
  - Agglomeration multi-grid, near wall semi coarsening 1:4
  - Line-implicit/explicit RK time stepping
  - Weak boundary conditions for all variables everywhere

- **Settings**
  - 3-4 grid levels, W-cycles, CFL 1.00-1.25 and 3 RK stages
  - Central scheme with artificial dissipation (JST) for mean flow
  - upwind for turbulence
  - Full NS, compact discretization of normal derivatives

- **Turbulence modeling**
  - SA, standard model (1992)
Computing platform and time

- Various resources
  - FOI and VZLU in-house clusters, external cluster
  - Difficult to compare wall clock time

- Medium grid (Case 3, VZLU cluster)
  - Computed on 48 cores
  - About 36 h wall clock time per case
  - By experience: Intel Xeon cores faster (as much as 3x)

- Grid convergence study
  - Computed on 48-256 cores
  - Steady state computations
  - Search for AoA ($C_L=0.5$) / 3-4 automatic adjustments
Case 1: NACA0012 verification study

- **Common (Family II) grid**
  - 7 grid levels, number of points doubles in each direction (x 4)
  - C-type, quadrilaterals, stretched elements aligned with x-axis
  - Grid not aligned with the wake

- **Flow conditions**
  - $M = 0.15; \text{Re} = 6 \text{ million}; \text{AoA} = 10^\circ$

- **Solver setting and flow solution**
  - Steady state stabilization
  - Line-implicit time integration
  - Slow convergence
  - SA, EARSM turbulence models
    - Similar grid convergence history
    - Slightly different values
Case 1: NACA0012 details

- **Grid assessment (1-fine, 7-coarse)**
  - No wall functions used in Edge
  - $y+$ sufficient from level 5 on ($y+>1$ only at LE)
  - $y+ \sim 0.05$ for level 2 (EARSIM case displayed)

- **Pressure distribution ($C_p$), skin friction ($C_{f,x}$)**
  - Good agreement with reference TAU solution
  - Lower negative pressure peak for EARSIM
Case 1: Forces and Moments

- **SA turbulence model**
  - Converged values comparable to reference data
  - TAU, FUN3D, CFL3D (website)

- **EARSM**
  - Total values differ from SA
    - Lower for coarse, higher for fine grids
  - $\Delta C_L \approx 2l_c$, $\Delta C_D \approx 10d_c$
  - Similar path
  - Grid convergence achieved
Case 2: Grid convergence studies

- **Wing-Body (WB) and Wing-Body-Nacelle-Pylon (WBNP)**
  - Common unstructured grids (NASA GeoLab, Rev00), deflection at 2.75°
  - All levels (Tiny → Ultra), both configurations (WB, WBNP)
    - Converted from .ugrid → cgns (cgns library program)
    - Converted from cgns → Edge internal binary format (in-house program)
    - WBNP Ultra – problems with conversion to cgns, size of data
    - Preprocessing – issues with size of integer ($2^{31} \approx 2.15e9$)

<table>
<thead>
<tr>
<th>Grid</th>
<th>Wing-Body</th>
<th></th>
<th>Wing-Body-Nacelle-Pylon</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total # nodes</td>
<td>Wall nodes</td>
<td>Total # nodes</td>
<td>Wall nodes</td>
</tr>
<tr>
<td>Tiny</td>
<td>$20 \times 10^6$</td>
<td>$5.28 \times 10^5$</td>
<td>$28 \times 10^6$</td>
<td>$6.06 \times 10^5$</td>
</tr>
<tr>
<td>Coarse</td>
<td>$30 \times 10^6$</td>
<td>$6.92 \times 10^5$</td>
<td>$41 \times 10^6$</td>
<td>$7.94 \times 10^5$</td>
</tr>
<tr>
<td>Medium</td>
<td>$44 \times 10^6$</td>
<td>$9.09 \times 10^5$</td>
<td>$61 \times 10^6$</td>
<td>$1.04 \times 10^6$</td>
</tr>
<tr>
<td>Fine</td>
<td>$66 \times 10^6$</td>
<td>$1.19 \times 10^6$</td>
<td>$91 \times 10^6$</td>
<td>$1.37 \times 10^6$</td>
</tr>
<tr>
<td>eXtra</td>
<td>$101 \times 10^6$</td>
<td>$1.56 \times 10^6$</td>
<td>$138 \times 10^6$</td>
<td>$1.79 \times 10^6$</td>
</tr>
<tr>
<td>Ultra</td>
<td>$151 \times 10^6$</td>
<td>$2.05 \times 10^6$</td>
<td>$209 \times 10^6$</td>
<td>$2.35 \times 10^6$</td>
</tr>
</tbody>
</table>
Case 2: Integral values

- SA and EARSM, WB and WBNP
  - $\Delta C_D < 5$ dc between grids for each turb. model
  - Each turb. model different monotonic behaviour ($C_D$)
  - SA: large variation of AoA on fine grids
  - EARSM: less grid sensitive (AoA, $C_M$)
Case 2: Skin friction and Cp

- Similar flow patterns between Tiny and Ultra (eXtra) grid
  - EARSM displayed

- No visible TE separation (Cf,x < 0)
  - EARSM
    - Identified only within 1% from TE, root and mid span
  - SA
    - TE separation < 5% from TE, reduced for finer grids
Case 2: Cp at cuts, turbulence models

- Small differences between models (SA, EARSM)
  - Differences in the outer wing region
  - More visible for fine grids (Ultra)
Case 2: Cp at cuts, grid refinement

- Comparison of Tiny and Ultra fine grids (WB)
- Some differences at outer wing region
  - More visible with SA model
  - Similar behaviour also for WBNP
Case 2: Skin friction at cuts

- Differences in $C_f,x$
  - Higher for finer grids
    - Consistent with integral values (viscous drag increases)
  - Higher for SA model
    - Consistent with integral values
Case 3: CRM WB Static Aero-Elastic Effect

- Medium grids with aero-elastic deflections according to ETW measurement
  - Wing bend
    - Visible – Figure
  - Wing twist (lower AoA at wing tip)
    - Major Influence to the flowfield

- Flow conditions
  - AoA 2.5° to 4° (step 0.25°)
  - M = 0.85; Re = 5 million
  - SA and EARSM turbulence models
  - Otherwise identical solver setting
    - Also with Case 2

- CFD solution
  - Steady state achieved
  - Converges within 3000-4000 MG cycles
Case 3: Integral values

- **SA vs. EARSM**
  - $\Delta C_L \approx 1-1.5 \, l_c$, slightly increasing with AoA
  - $\Delta C_D < 6 \, d_c$
  - Compared with rigid and elastic computation
    - DLR grid from DPW-4, rigid and elastic wing
    - Method AIAA 2015-3153 (HTP)
  - $\Delta C_M < 0.01$, increasing with AoA
Case 3: Skin friction and Cp, SA

- Shock grows in strength as alpha increases
  - Moves upstream
- Trailing edge separation with increasing alpha
  - Downstream the shock wave
  - Mid span
Case 3: Cp and Skin friction at cuts, $\alpha = 2.5^\circ$

- Small differences between models (SA, EARSMD)
  - Differences in shock location, slightly upstream for SA
  - $C_{f,x}$ higher for SA
    - Consistent with higher viscous drag for SA model
    - Except after the shock
Case 3: Cp and Skin friction at cuts, $\alpha=3.5^\circ$

- Local differences between models (SA, EARSM)
  - Outer wing region
  - Higher AoA

![Graph showing Cp and Skin friction at cuts](image-url)
Case 3: Spanwise distributions

- Sectional lift Influenced by the separation
  - Detected as $C_{f,x} < 0$, measured from TE
  - Mid span
- EARSM: More compact region and lift slightly less influenced
Summary and conclusion

- **2D NACA0012 Case**
  - Slow convergence
  - SA results comparable with reference codes
  - EARSM slightly different values, grid convergence achieved

- **Grid convergence**
  - Good steady state convergence
  - SA: larger variation of AoA to match $C_L=0.5$
  - EARSM: smaller differences between grid levels

- **Alpha sweeps**
  - Turbulence models
    - Increasing difference as incidence is increased ($C_L$, $C_M$)
    - Difference in shock locations, wing tip region
    - TE separation stronger for SA model
  - Consistent with elastic wing computation