Results from the 2nd AIAA CFD High Lift Prediction Workshop using Edge

by

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Scope

- **Motivation**
  - Assessment and validation of in-house flow solver Edge
  - Comparative study of three turbulence models
    - EARSM (Explicit Algebraic Reynolds Stress Model)
    - SA (Spalart Allmaras) models
    - EARSM + curvature correction (EARSM-CC)

- **High Lift work performed**
  - Grid convergence studies using DLR hybrid Solar grids (Case 1, conf. 2)
    - High Re, 2 incidences, 3 turb. models
  - Polar calculations using DLR hybrid Solar grids (Case2, conf. 4)
    - Low and high Re, spec. incidences up to maximum lift, 3 turb. models
DLR F11 Configuration

- Layout and geometry from Airbus Germany, denoted KH3Y
- WT model constructed by DLR, called DLR F11
  - 1.4 meter half span, fuselage 3 meters
  - Wing AR 9.353, taper ratio 0.3
- Experimental investigations at two tunnels, parts released to public
  - Low ($1.35 \times 10^6$) and high ($15.1 \times 10^6$) Reynolds numbers
- Integrated forces & moments, $C_p$ distributions, oil flow pictures, PIV data
Background

- Familiar test case from EUROLIFT I, II and DESIREH
- Example from EUROLIFT II
  - Investigation of installation effects on a take-off configuration
  - Wall/peniche caused some inboard effects
    - Leading to reduced drag
  - Effects from WT instrumentation close to maximum lift

![Graph](image1.png)

Figure 15. Pressure distributions, tunnel results corrected to free flight. Angle at maximum lift $\alpha_2$, 15% span.
Supplied grids from DLR (B_uns_mix_Case1Config2_v1)

<table>
<thead>
<tr>
<th>Grid</th>
<th>Case 1 coarse</th>
<th>Case1 medium</th>
<th>Case1 fine</th>
<th>Case 2 Low Re</th>
<th>Case 2 High Re</th>
</tr>
</thead>
<tbody>
<tr>
<td># nodes</td>
<td>9.2×10⁶</td>
<td>25.6×10⁶</td>
<td>73.4×10⁶</td>
<td>37.3×10⁶</td>
<td>32.3×10⁶</td>
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<td># boundary nodes</td>
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<td>0.86×10⁶</td>
<td>1.77×10⁶</td>
<td>1.10×10⁶</td>
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<td># hexahedral elements</td>
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<td>54.9×10⁶</td>
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<td>23.7×10⁶</td>
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<tr>
<td># prisms</td>
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<td>96×10³</td>
<td>195×10³</td>
<td>245×10³</td>
<td>197×10³</td>
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<td>39.5×10⁶</td>
<td>108×10⁶</td>
<td>46.7×10⁶</td>
<td>48.7×10⁶</td>
</tr>
<tr>
<td># structured layers</td>
<td>~16</td>
<td>~22</td>
<td>~31</td>
<td>~27</td>
<td>~22</td>
</tr>
</tbody>
</table>

Case1, configuration 2
- Simplification: No slat and flap track fairings
- Grid convergence studies

Case2, configuration 4
- Polar calculations

Case3
- Pressure tube bundles added to conf. 4
- Optional case, not computed
Grid pictures

Coarse

Medium

Fine
Edge flow solver

- Only steady state calculations

- Finite volume, node centered, edge-based
- 3-4 level W-cycles, full multigrid
  - Semi coarsening, 1:4
- 3-stage Runge-Kutta scheme, CFL=1.25
- Line-implicit time integration in regions with stretched grids
- Central scheme with artificial dissipation for mean flow and turbulence
- Full NS, compact discretization of normal derivatives
- Weak boundary conditions on all variables including no-slip velocity

- All solutions started from free stream
- Linux cluster used, up to 128 processors
  - Computing times up to 10 days for finest grids and 40,000 iterations
Turbulence models

- Explicit Algebraic Reynolds Stress Model (EARSM)
  - Standard implementation

- Explicit Algebraic Reynolds Stress Model with curvature correction (EARSM-CC)
  - Standard implementation

- Spalart-Allmaras model
  - Standard implementation but cross diffusion written as diffusive and anti-diffusive term

- All calculations assumed fully turbulent flow
Case 1, steady state convergence

- Steady state convergence rates
  - SA
  - EARSM(-CC) similar or worse

- Rather poor convergence
  - Compared to NASA trap wing
  - Unsteadiness ???

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Case 1, grid convergence

- (Unphysical) Variation in forces and moments indicated
- Variation between grids < 2%
  - Variations due to oscillation < 1%
  - Variation in $C_L$ within 4 cts (HLPWS-1 within 2 cts)
  - Some deviation from experiments (in particular $C_D$)
Higher inboard suction on fine grid with EARSM
Outboard variations at trailing edge for SA
Very similar results EARSM and EARSM-CC
Case 1, Skin friction (x-component)

\[ \alpha = 7^\circ \]
Case1, Skin friction (x-component)

$\alpha = 16^\circ$

- Coarse
- Medium
- Fine
- EARSM
- SA
Case2a (low $Re=1.35 \times 10^6$), Forces and moments

- Lift underestimated at lower incidences
- Drag over predicted
- SA over predicts max $C_L$, EARSM(CC) under predict
- Moment better predicted with EARSM(CC) models
- EARSM and EARSM-CC very similar (except $\alpha=12^\circ$)
Case2a, Cf, SA

- Inboard separation at $\alpha = 12^\circ$
- Lift break down at outer part of wing

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Case2a, Cf, EARSM + EARSM-CC

- Similar patterns
  - EARSM-CC inboard separation at $\alpha=12^\circ$
  - Inboard separation at $\alpha=16^\circ$
- Lift break down at outer part of wing
Case2a, Cp plots

- Inboard separation with EARSM(-CC) models
- High outboard suction for SA

\[ \alpha = 16^\circ \]
Case2a, velocity magnitude

- Velocity vs. PIV
- Lower velocity magnitude with EARSM(-CC)
  - Station close to flow separation
- Slat wake not captured
Case2b (Re=15.1×10^6), forces and moments

- Closer agreement between models
  - Brackets reduce lift, drag over estimated
- Maximum lift over predicted
  - No lift break down with SA
- $C_M$ not well captured at higher incidences

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Case2b, Cf

- Mainly attached flow up to maximum lift
  - Brackets visible
- Similar lift break down as for low Re at outer part of wing
Case2b, Cp, alfa 7, 12

Good experimental agreement
Similar results between all models
   Higher inboard suction with SA
Summary

- Steady state convergence rates reasonable
  - Some oscillations in global forces/moments
- Grid convergence reasonable
  - Variation in $C_L < 2\%$, oscillations $< 1\%$
  - Higher than for 1st workshop (4 lift cts vs. 2 cts)
- Larger deviation from experiments at lower Re
  - Transition not taken into account
- Good agreement at higher Re
  - Max $C_L$ over estimated
  - $C_D$ over predicted
- Similar results between the 3 models at higher Re
  - Effect from curvature correction insignificant
- Conclusions for lower Re require transition pred./spec.