6th Drag Prediction Workshop

VZLU/FOI joint contribution using the Edge solver

by

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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

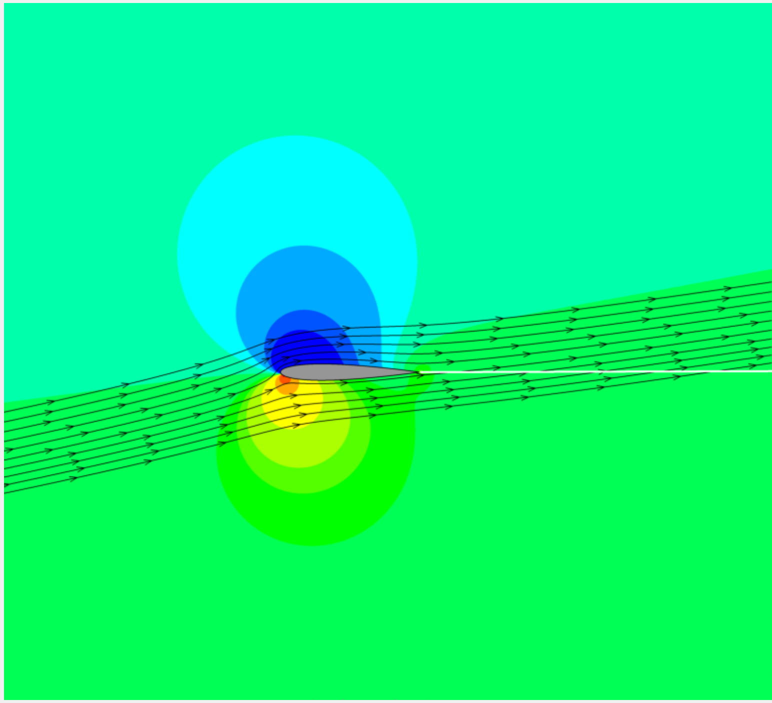
- Edge
  - Finite volume, node-based, dual grid
  - Agglomeration multi-grid, near wall semi coarsening 1:4
  - Line-implicit/explicit RK time stepping
  - Weak boundary conditions for all variables everywhere
- Settings
  - 3-4 grid levels, W-cycles, CFL 1.00-1.25 and 3 RK stages
  - Central scheme with artificial dissipation (JST) for mean flow
  - upwind for turbulence
  - Full NS, compact discretization of normal derivatives
- Turbulence modeling
  - SA, standard model (1992)
  - EARSM, Wallin & Johansson (2000), ω-equation by Hellsten (2005)

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

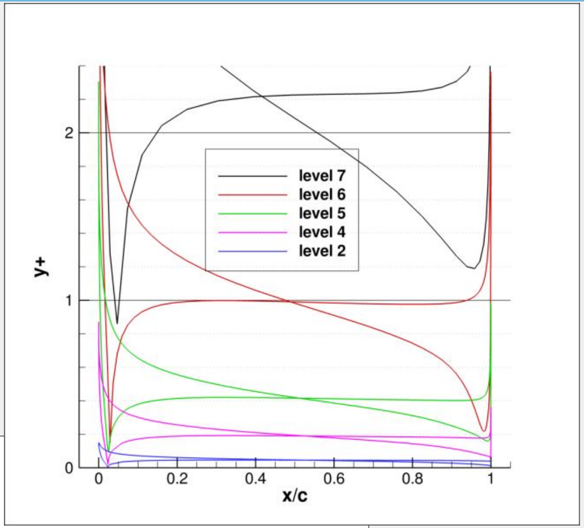
Case 1: NACA0012 verification study

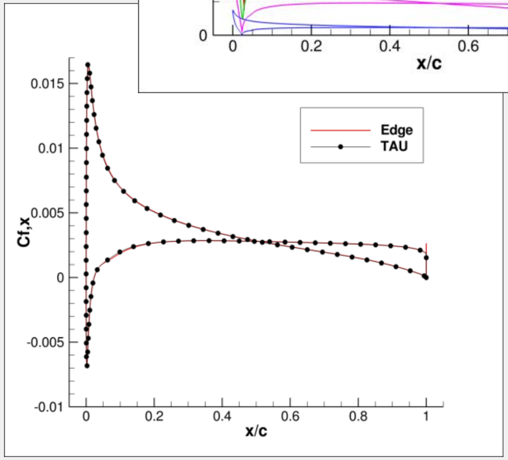
- ❑ Common (Family II) grid
  - ➢ 7 grid levels, number of points doubles in each direction (x 4)
  - ➢ C-type, quadrilaterals, stretched elements aligned with x-axis
  - ➢ Grid not aligned with the wake
- ❑ Flow conditions
  - ➢ M = 0.15; Re = 6 million; AoA = 10°
- ❑ Solver setting and flow solution
  - ➢ Steady state stabilization
  - ➢ Line-implicit time integration
  - ➢ Slow convergence
  - ➢ SA, EARSM turbulence models
    - ➢ Similar grid convergence history
    - ➢ Slightly different values

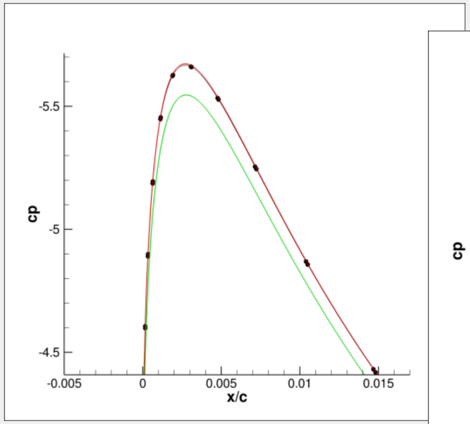


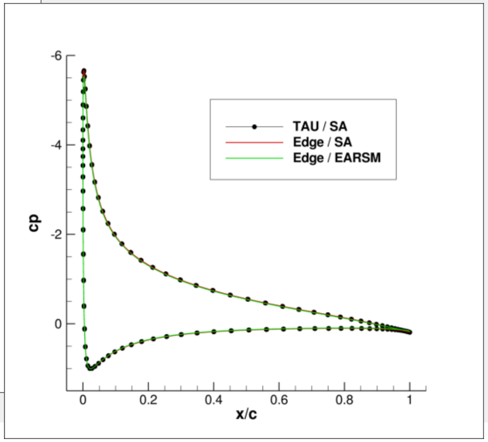
Case 1: NACA0012 details

- Grid assessment (1-fine, 7-coarse)
  - No wall functions used in Edge
  - y+ sufficient from level 5 on (y+>1 only at LE)
  - y+ ~ 0.05 for level 2 (EARSM case displayed)
- Pressure distribution (Cp), skin friction (Cf,x)
  - Good agreement with reference TAU solution
  - Lower negative pressure peak for EARSM



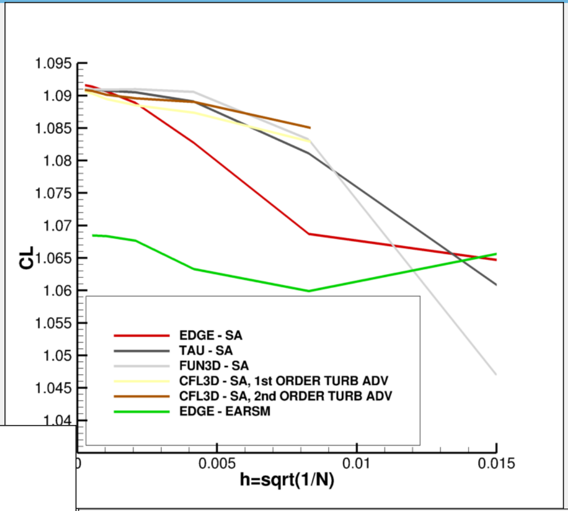


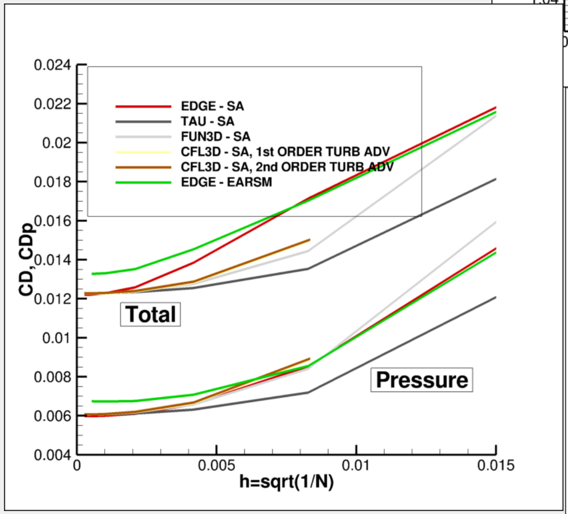


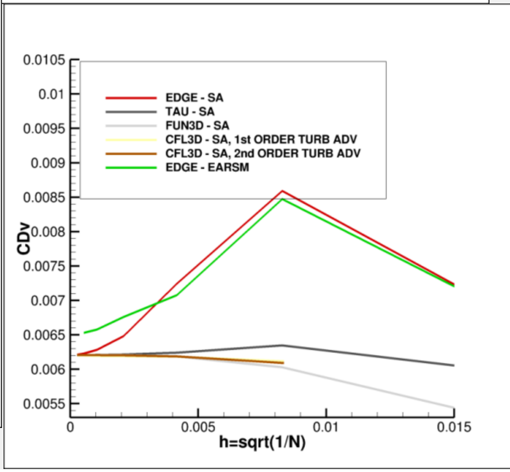


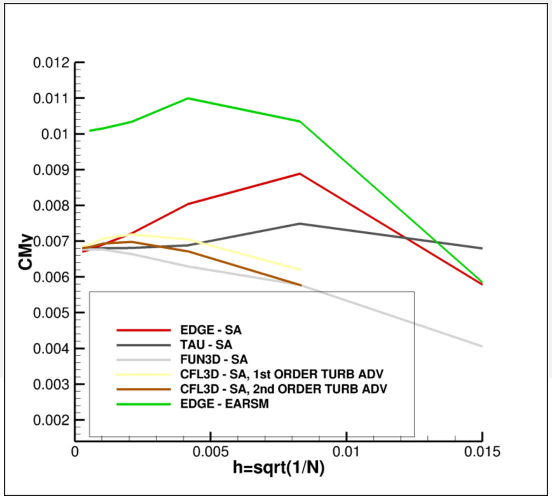
Case 1: Forces and Moments

- 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
  - $\Delta C_L \approx 2$lc, $\Delta C_D \approx 10$dc
  - Similar path
  - Grid convergence achieved









Edge

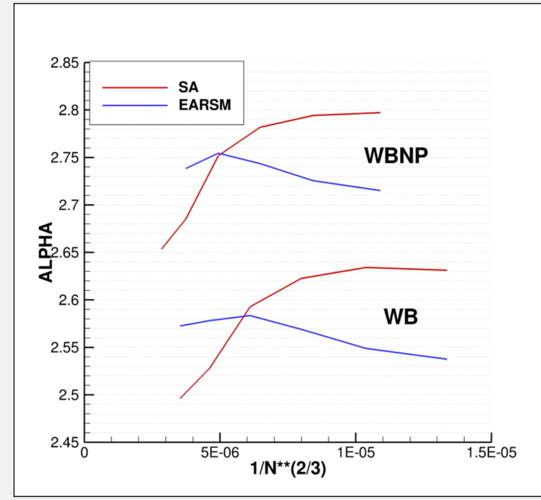
Case 2: Grid convergence studies

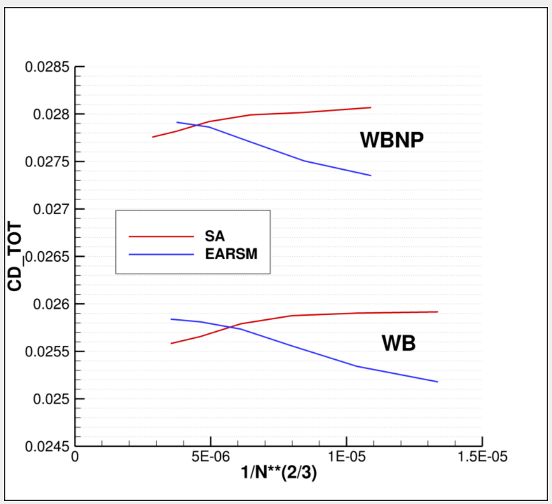
- Wing-Body (WB) and Wing-Body-Nacelle-Pylon (WBNP)
  - Common unstructured grids (NASA GeoLab, Rev00), deflection at 2.75°
  - All levels (Tiny → Ultra), both configurations (WB, WBNP)
    - Converted from .ugrid → cgns (cgns library program)
    - Converted from cgns → Edge internal binary format (in-house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

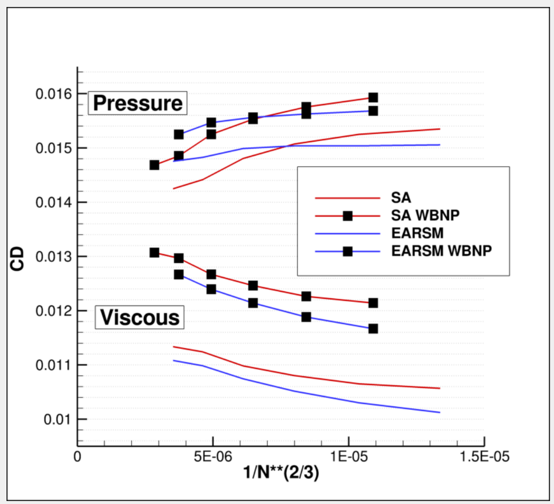
Grid	Wing-Body		Wing-Body-Nacelle-Pylon	
	Total # nodes	Wall nodes	Total # nodes	Wall nodes
Tiny	20×10^6	5.28×10^5	28×10^6	6.06×10^5
Coarse	30×10^6	6.92×10^5	41×10^6	7.94×10^5
Medium	44×10^6	9.09×10^5	61×10^6	1.04×10^6
Fine	66×10^6	1.19×10^6	91×10^6	1.37×10^6
eXtra	101×10^6	1.56×10^6	138×10^6	1.79×10^6
Ultra	151×10^6	2.05×10^6	209×10^6	2.35×10^6

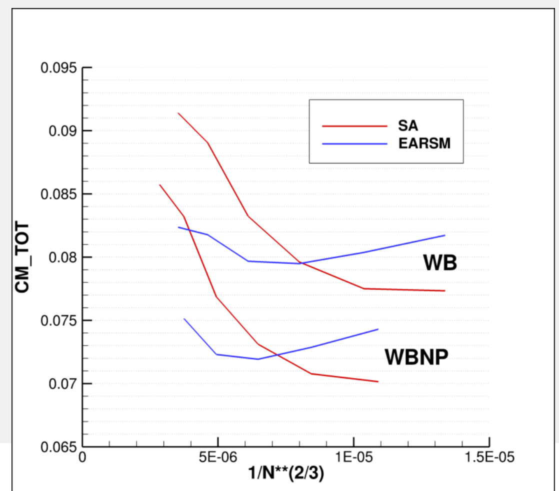
Case 2: Integral values

- SA and EARSM, WB and WBNP
  - ΔC_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)





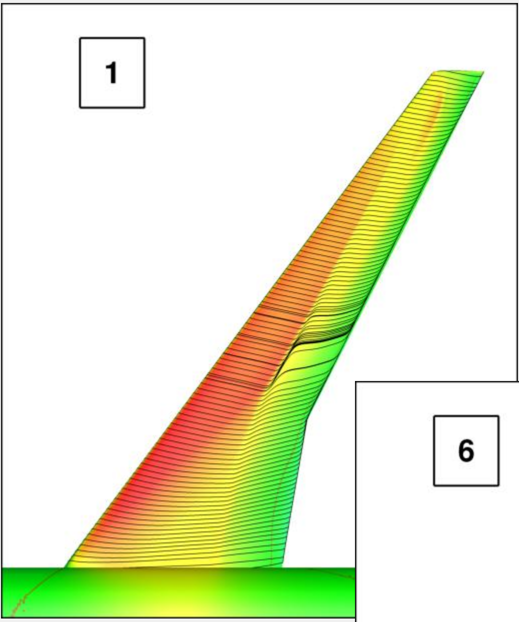


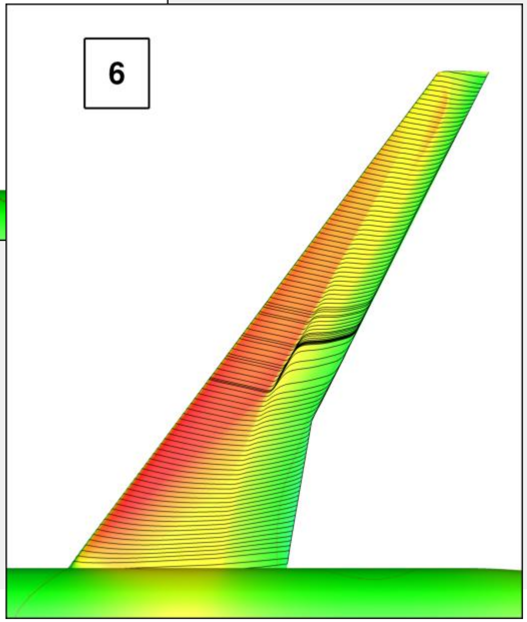


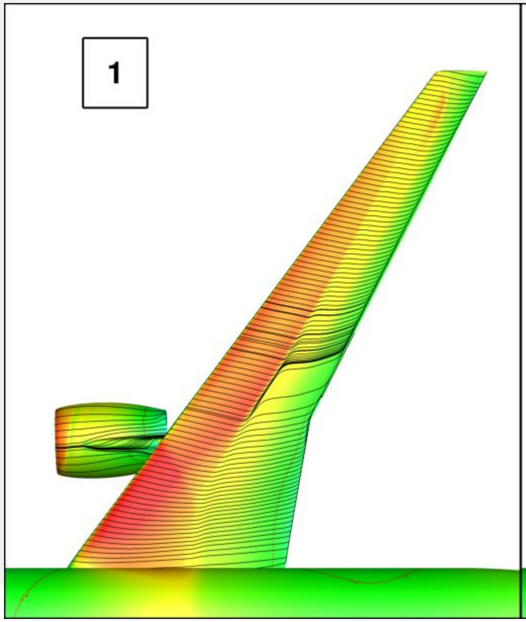
Edge

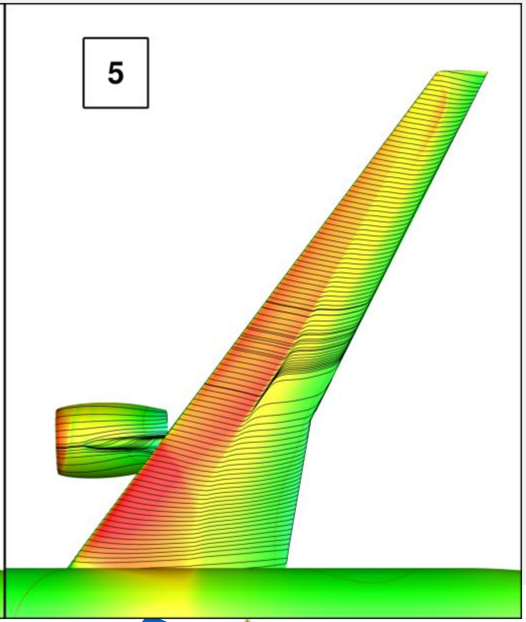
Case 2: Skin friction and Cp

- 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





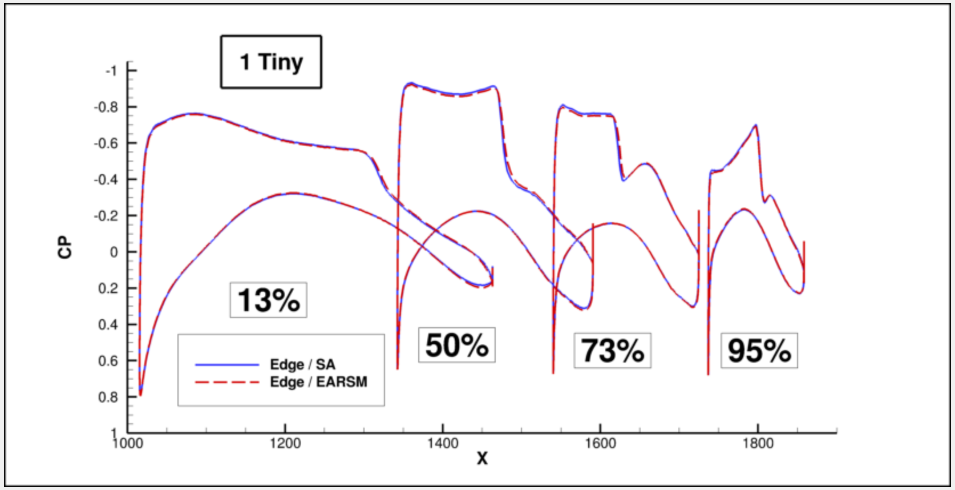


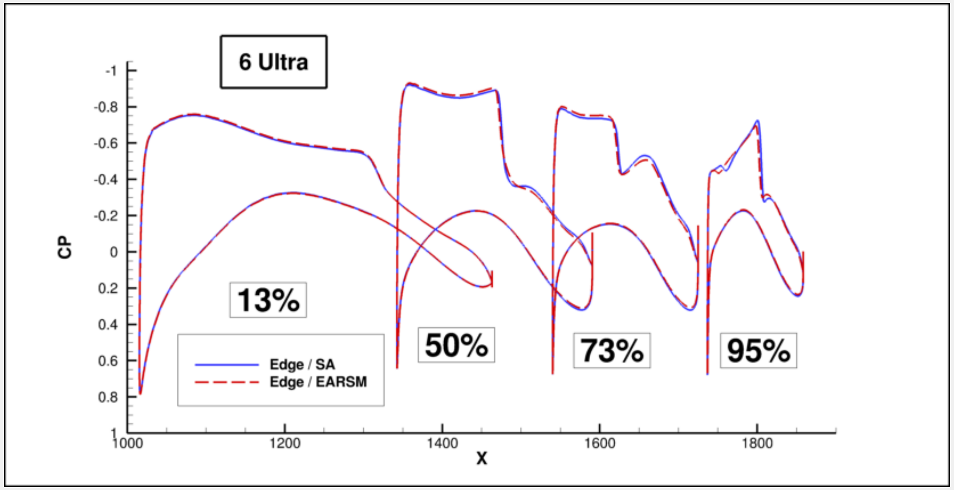


Edge

Case 2: Cp at cuts, turbulence models

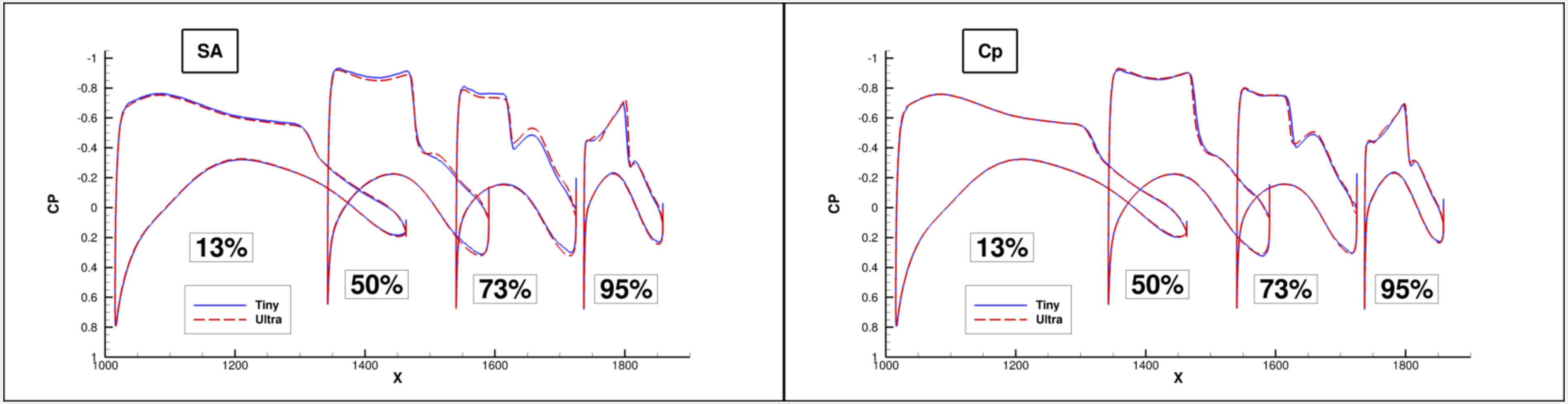
- Small differences between models (SA, EARSM)
  - Differences in the outer wing region
  - More visible for fine grids (Ultra)





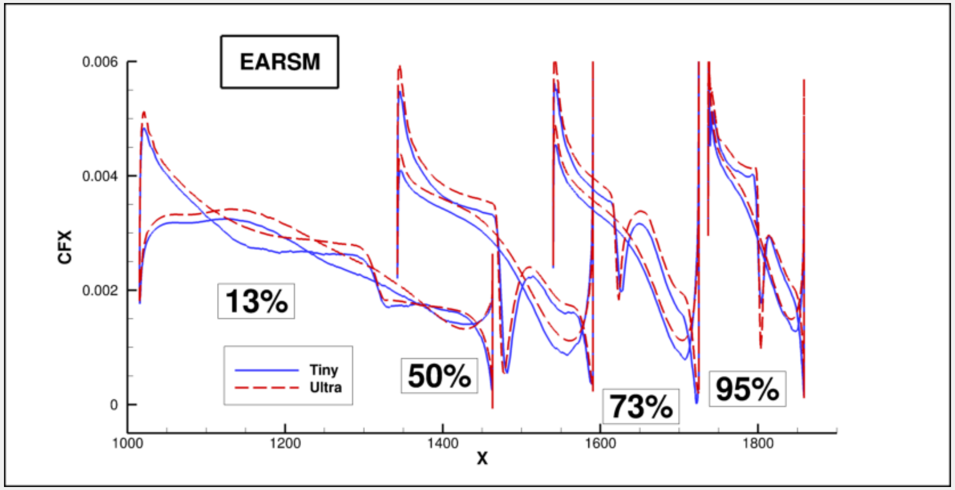
Case 2: Cp at cuts, grid refinement

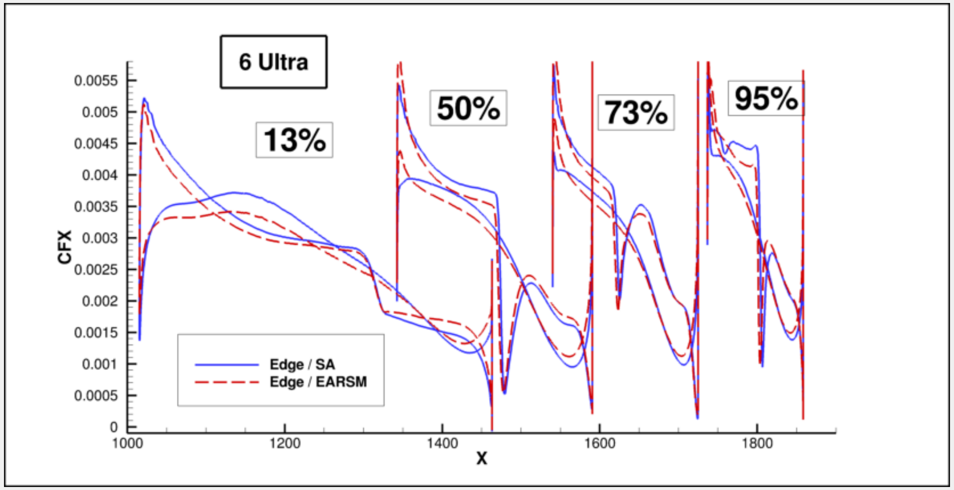
- Comparison of Tiny and Ultra fine grids (WB)
- Some differences at outer wing region
  - More visible with SA model
  - Similar behaviour also for WBNP



Case 2: Skin friction at cuts

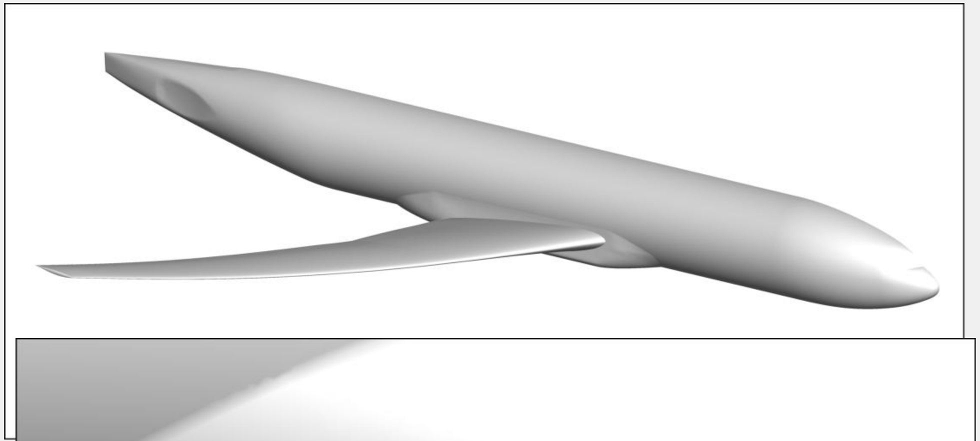
- Differences in Cf,x
  - Higher for finer grids
    - Consistent with integral values (viscous drag increases)
  - Higher for SA model
    - Consistent with integral values

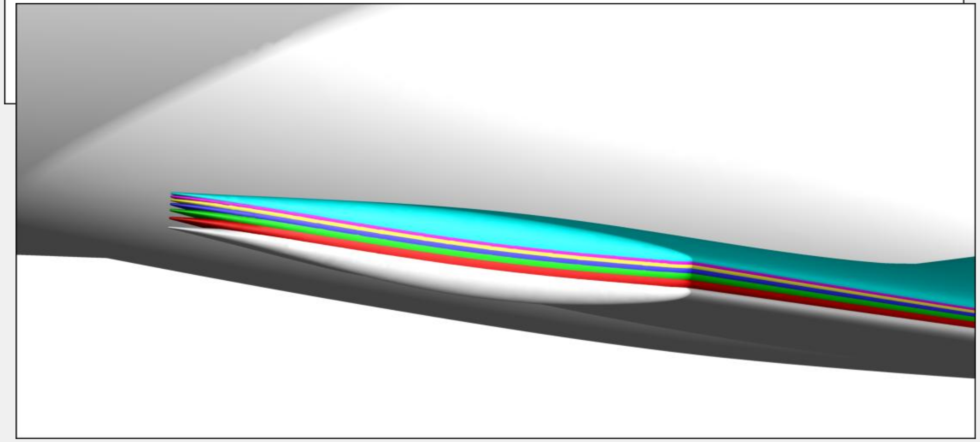




Case 3: CRM WB Static Aero-Elastic Effect

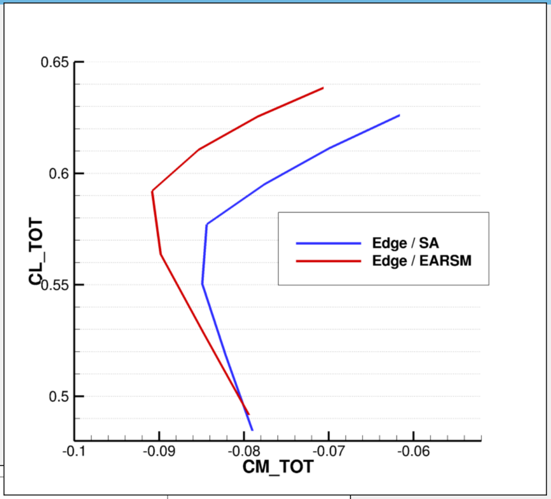
- Medium grids with aero-elastic deflections according to ETW measurement
  - Wing bend
    - Visible – Figure
  - Wing twist (lower AoA at wing tip)
    - Major Influence to the flowfield
- Flow conditions
  - AoA 2.5° to 4° (step 0.25°)
  - M = 0.85; Re = 5 million
  - SA and EARSM turbulence models
  - Otherwise identical solver setting
    - Also with Case 2
- CFD solution
  - Steady state achieved
  - Converges within 3000-4000 MG cycles

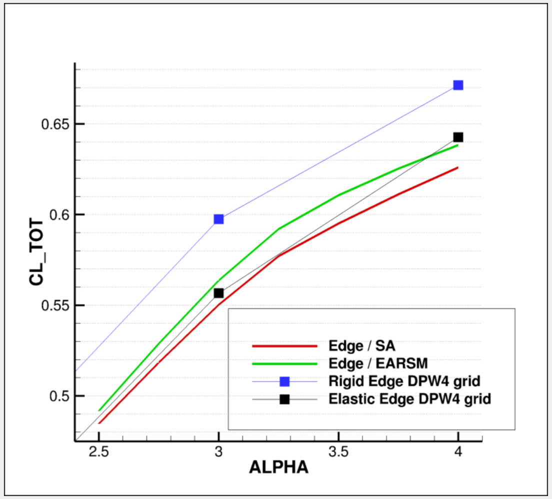


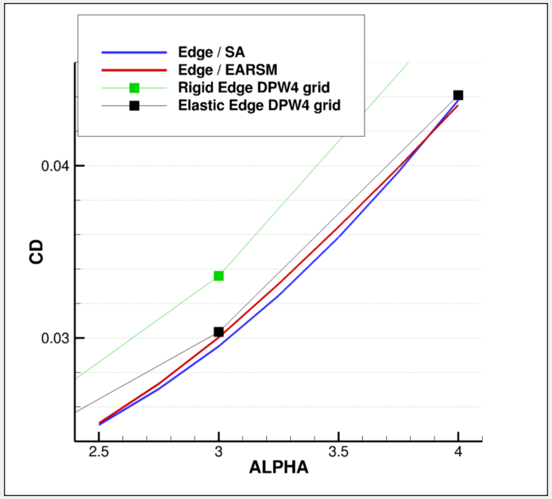


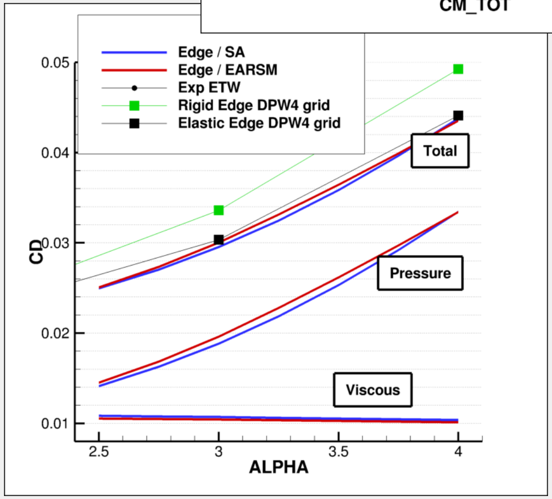
Case 3: Integral values

- SA vs. EARSM
  - ΔCL ≈ 1-1.5 lc, slightly increasing with AoA
  - ΔCD < 6 dc
  - Compared with rigid and elastic computation
    - DLR grid from DPW-4, rigid and elastic wing
    - Method AIAA 2015-3153 (HTP)
  - ΔCM < 0.01, increasing with AoA

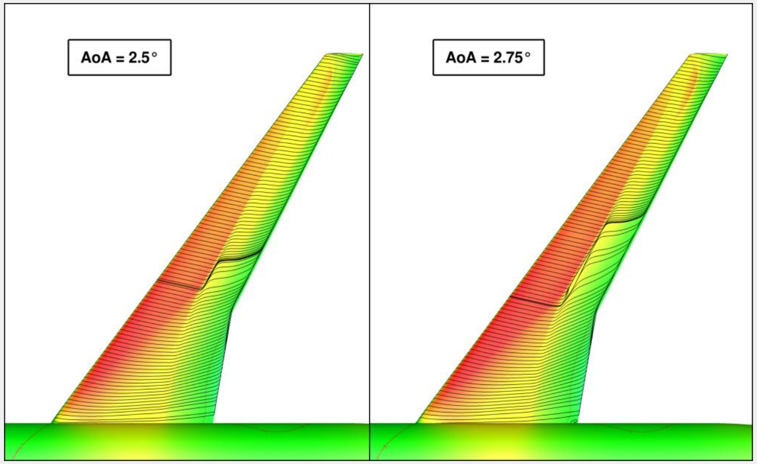




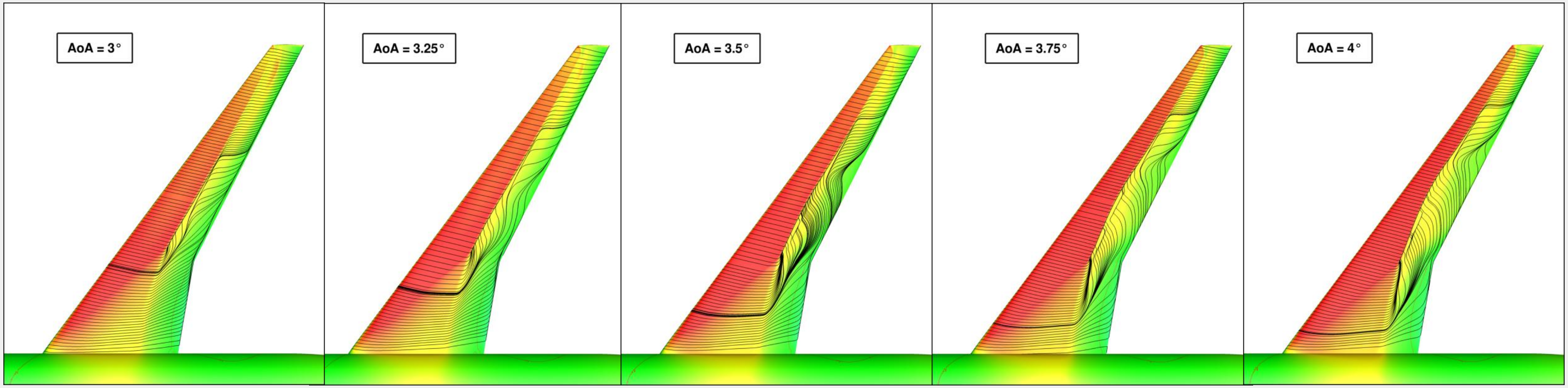




Case 3: Skin friction and Cp, SA

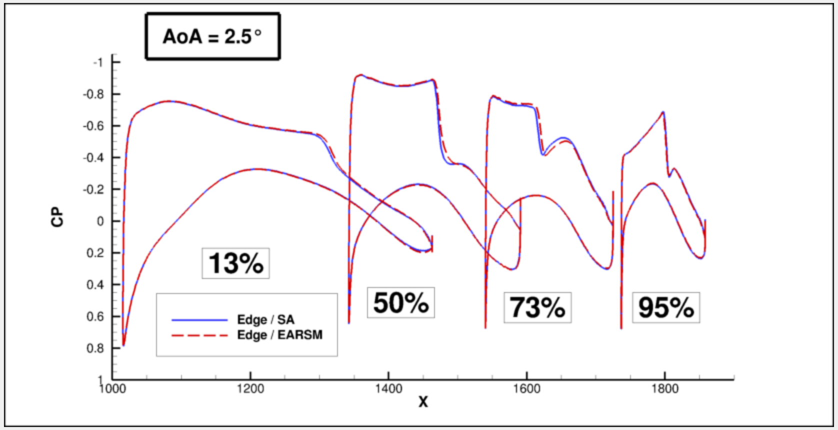


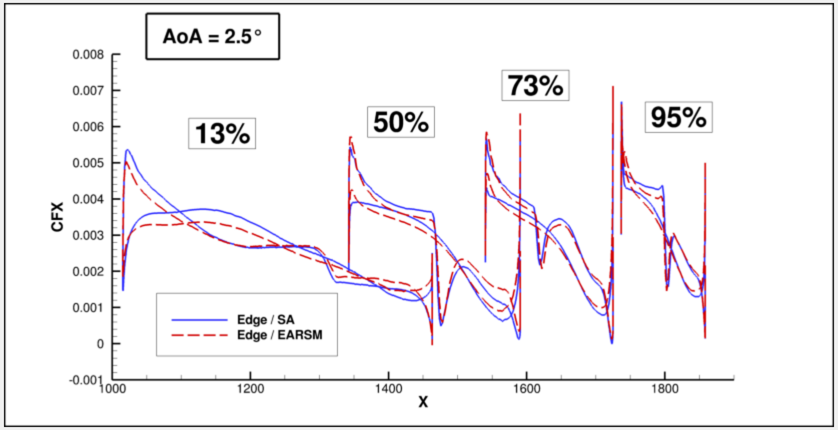
- Shock grows in strength as alpha increases
  - Moves upstream
- Trailing edge separation with increasing alpha
  - Downstream the shock wave
  - Mid span



Case 3: Cp and Skin friction at cuts, α = 2.5°

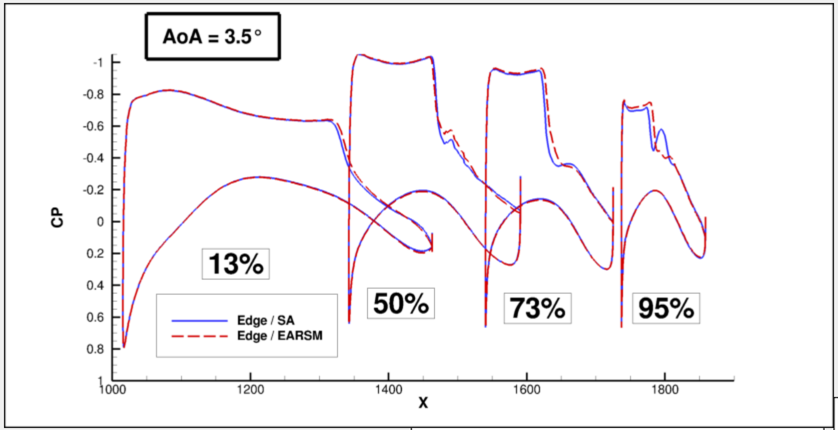
- Small differences between models (SA, EARSM)
  - Differences in shock location, slightly upstream for SA
  - Cf,x higher for SA
    - Consistent with higher viscous drag for SA model
    - Except after the shock

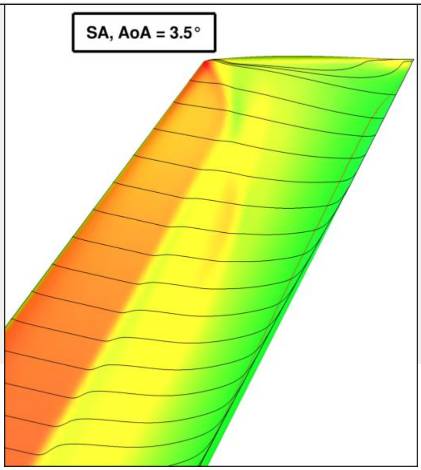


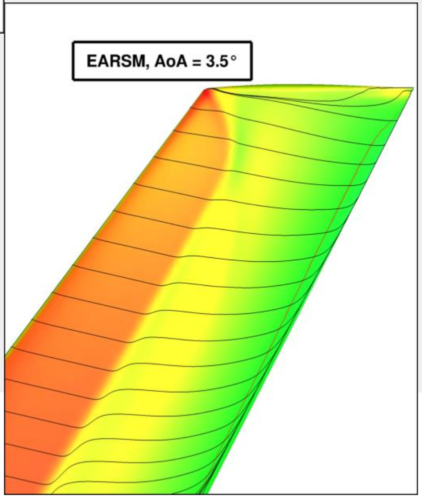


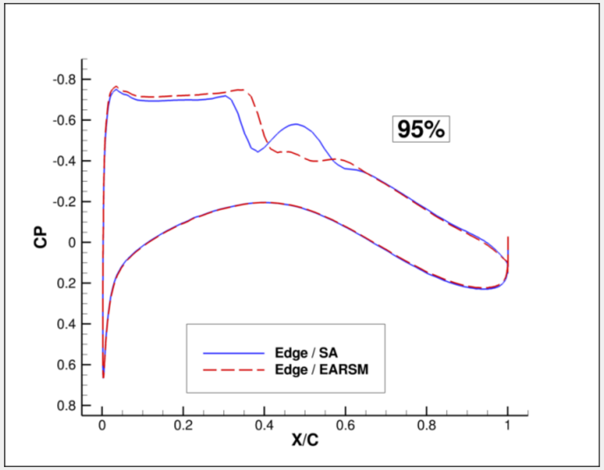
Case 3: Cp and Skin friction at cuts, α=3.5°

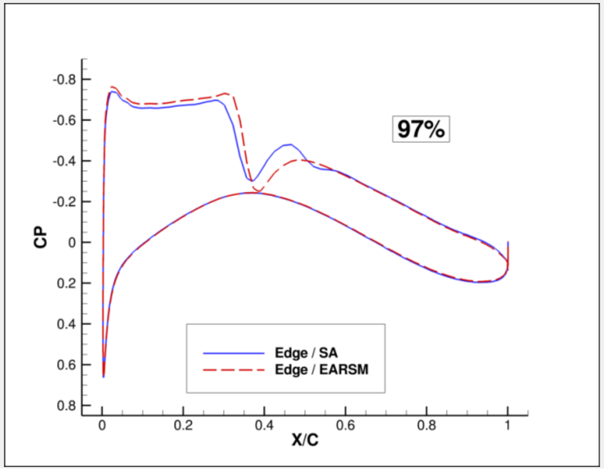
- Local differences between models (SA, EARSM)
  - Outer wing region
  - Higher AoA







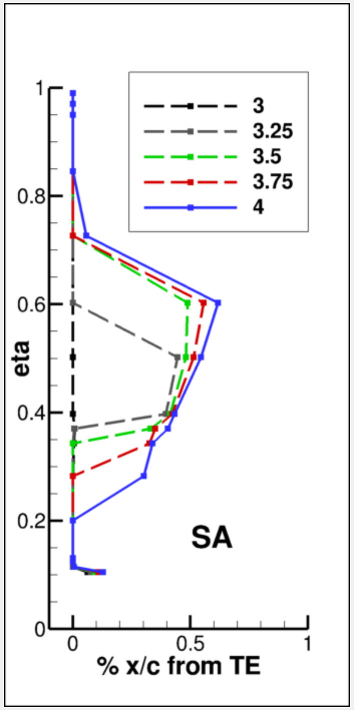


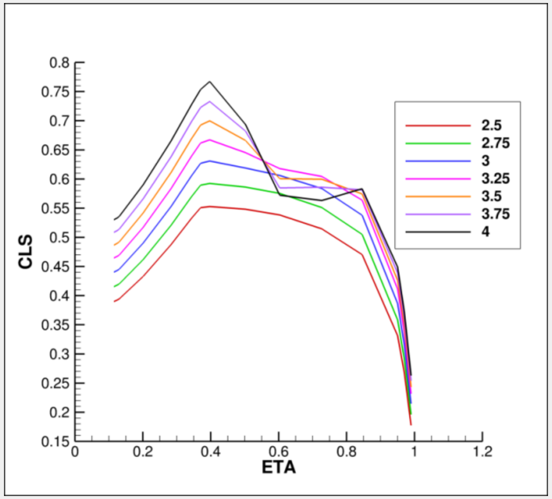


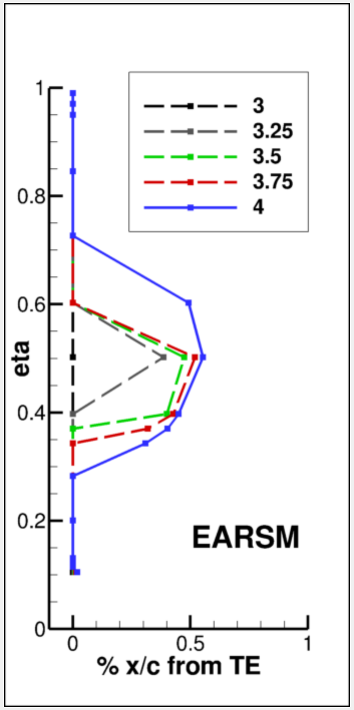
Edge

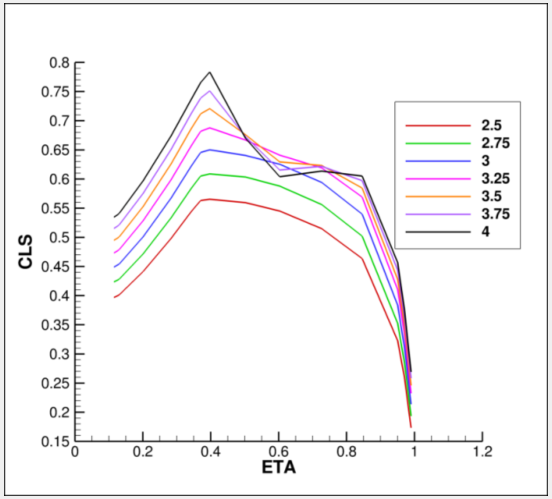
Case 3: Spanwise distributions

- Sectional lift Influenced by the separation
  - Detected as Cf,x < 0, measured from TE
  - Mid span
- EARSM: More compact region and lift slightly less influenced









Summary and conslusion

- 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 (CL, CM)
    - Difference in shock locations, wing tip region
    - TE separation stronger for SA model
  - Consistent with elastic wing computation