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

by

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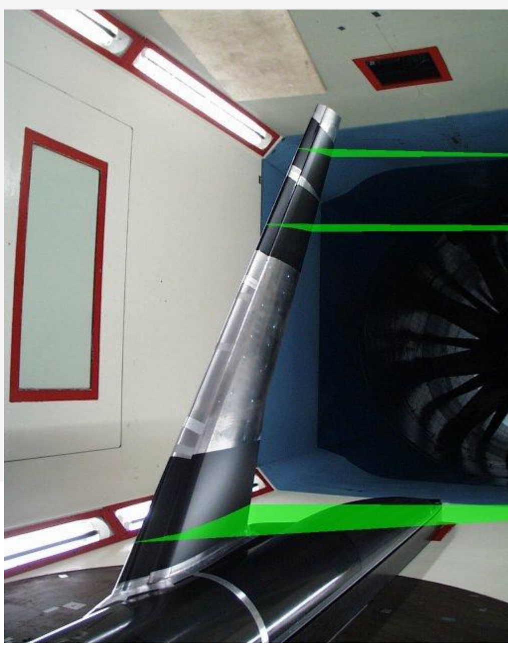
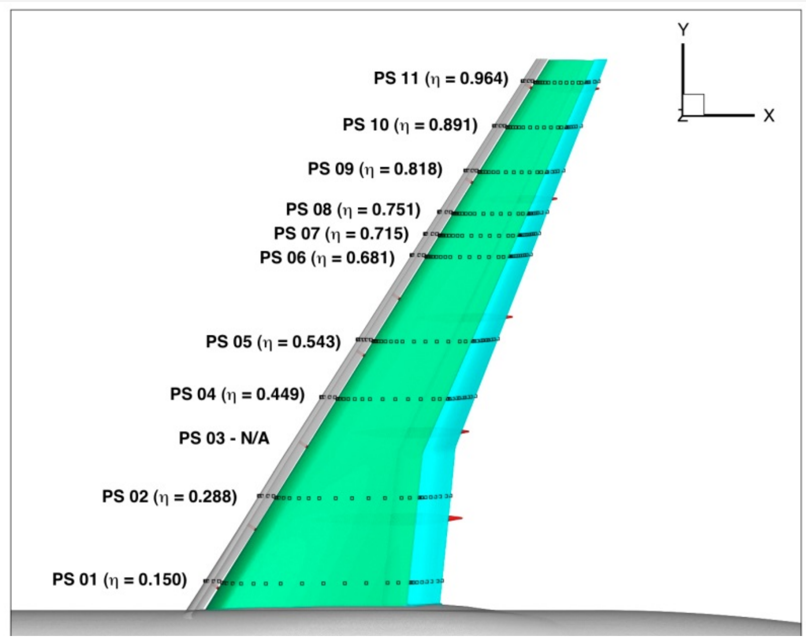
Scope

- 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

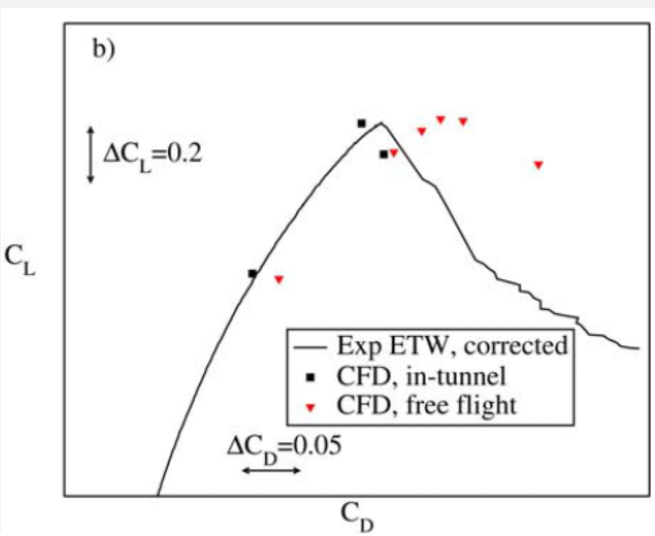
- Layout and geometry from Airbus Germany, denoted KH3Y
- WT model constructed by DLR, called DLR F11
  - 1.4 meter half span, fuselage 3 meters
  - Wing AR 9.353, taper ratio 0.3
- Experimental investigations at two tunnels, parts released to public
  - Low (1.35×10^6) and high (15.1×10^6) Reynolds numbers
- Integrated forces & moments, Cp 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
    - ✓ AIAA 2007-262; AIAA Journal 2008, Vol. 45, no. 1
  - ➢ Effects from WT instrumentation close to maximum lift



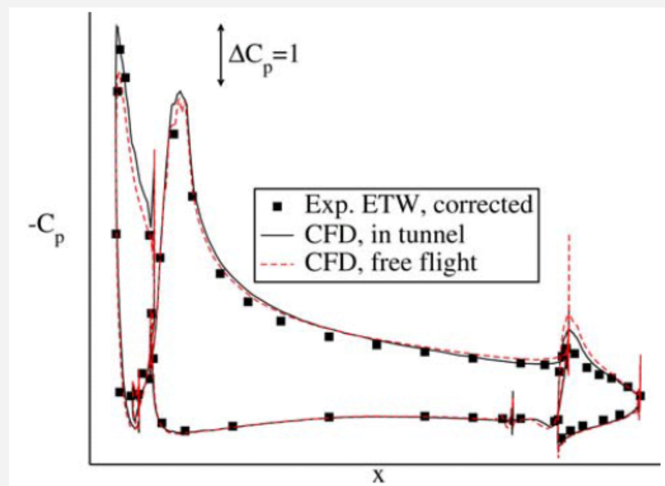


Figure 15. Pressure distributions, tunnel results corrected to free flight. *Angle at maximum lift α_2, 15% span.*

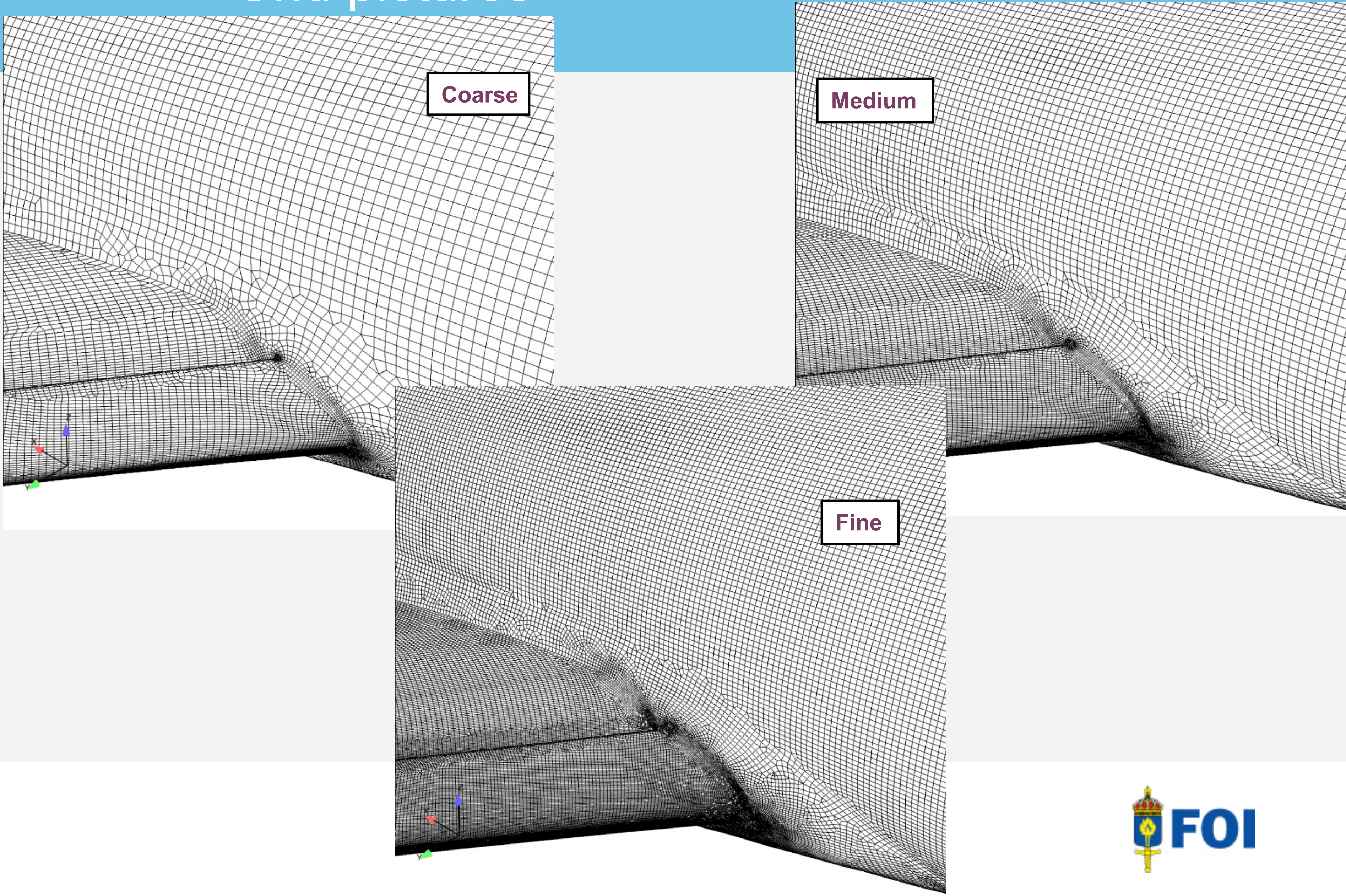
Grids from DLR

- Supplied grids from DLR used (B_uns_mix_Case1Config2_v1)

Grid	Case 1 coarse	Case1 medium	Case1 fine	Case 2 Low Re	Case 2 High Re
# nodes	9.2×10^6	25.6×10^6	73.4×10^6	37.3×10^6	32.3×10^6
# boundary nodes	0.42×10^6	0.86×10^6	1.77×10^6	1.10×10^6	1.10×10^6
# hexahedral elements	6.5×10^6	18.6×10^6	54.9×10^6	29.0×10^6	23.7×10^6
# prisms	34×10^3	96×10^3	195×10^3	245×10^3	197×10^3
# tetrahedral elements	14.4×10^6	39.5×10^6	108×10^6	46.7×10^6	48.7×10^6
# structured layers	~16	~22	~31	~27	~22

- 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



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

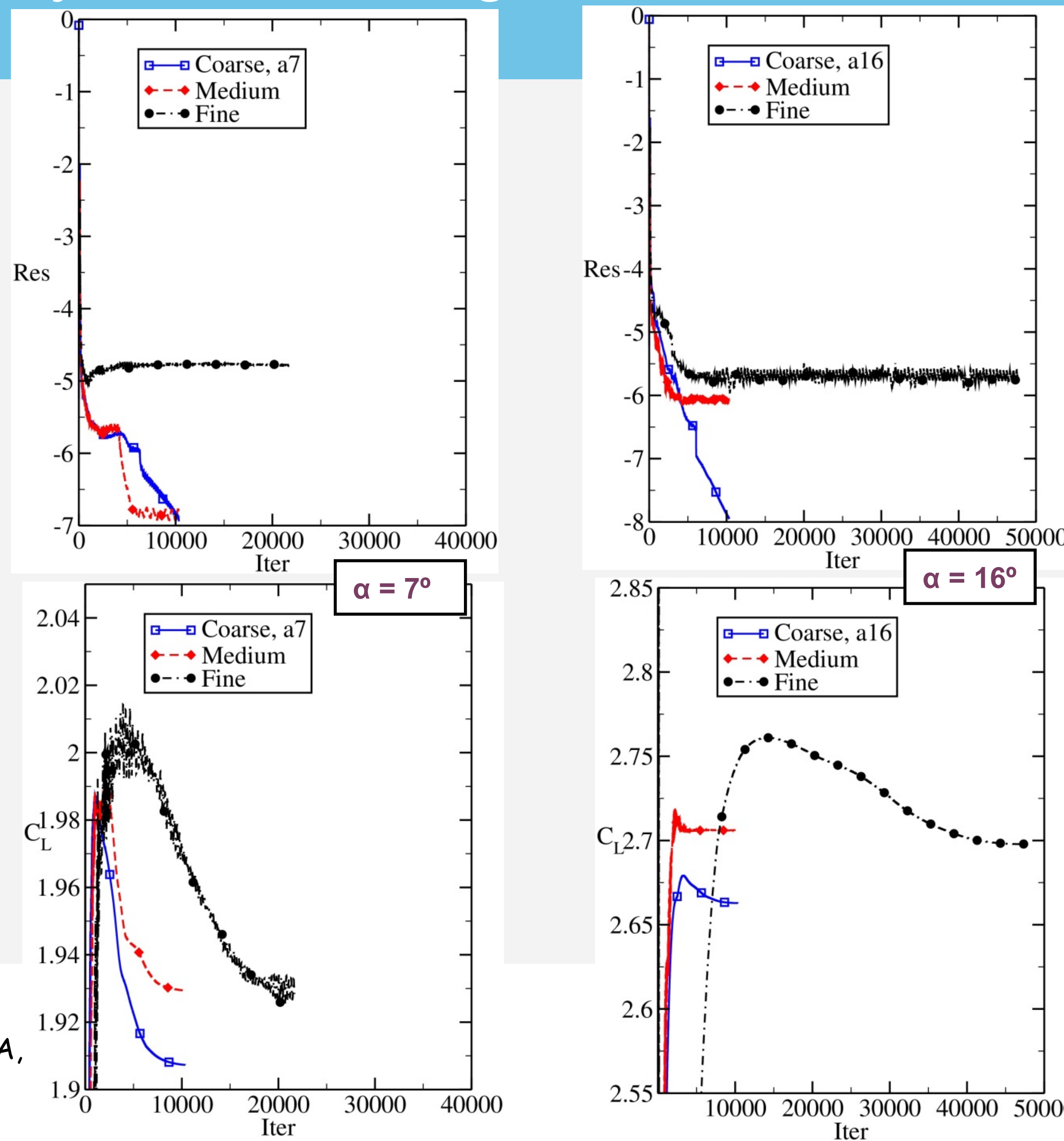
Turbulence models

- Explicit Algebraic Reynolds Stress Model (EARSM)
  - Wallin, S., Johansson, A. V., “An Explicit Algebraic Reynolds Stress Model for Incompressible and Compressible Turbulent Flows,” Journal of Fluid Mechanics, Vol. 403, 2000, pp. 89-132
  - Hellsten, A., “New Advanced k-ω Turbulence Model for High Lift Aerodynamics,” AIAA Journal, Vol. 43, No. 9, 2005, pp. 1857-1869
  - Standard implementation
- Explicit Algebraic Reynolds Stress Model with curvature correction (EARSM-CC)
  - Wallin, S & Johansson, A.V. “Modelling streamline curvature effects in explicit algebraic Reynolds stress turbulence models”, International, Journal of Heat and Fluid Flow, 23 (5), 2002, pp. 721-730
  - Standard implementation
- Spalart-Allmaras model
  - Spalart, P. R., and Allmaras, S. R., ”A One-Equation Turbulence Model for Aerodynamic Flows”, AIAA Paper 92-0439, 1992.
  - Standard implementation but cross diffusion written as diffusive and anti-diffusive term

- All calculations assumed fully turbulent flow

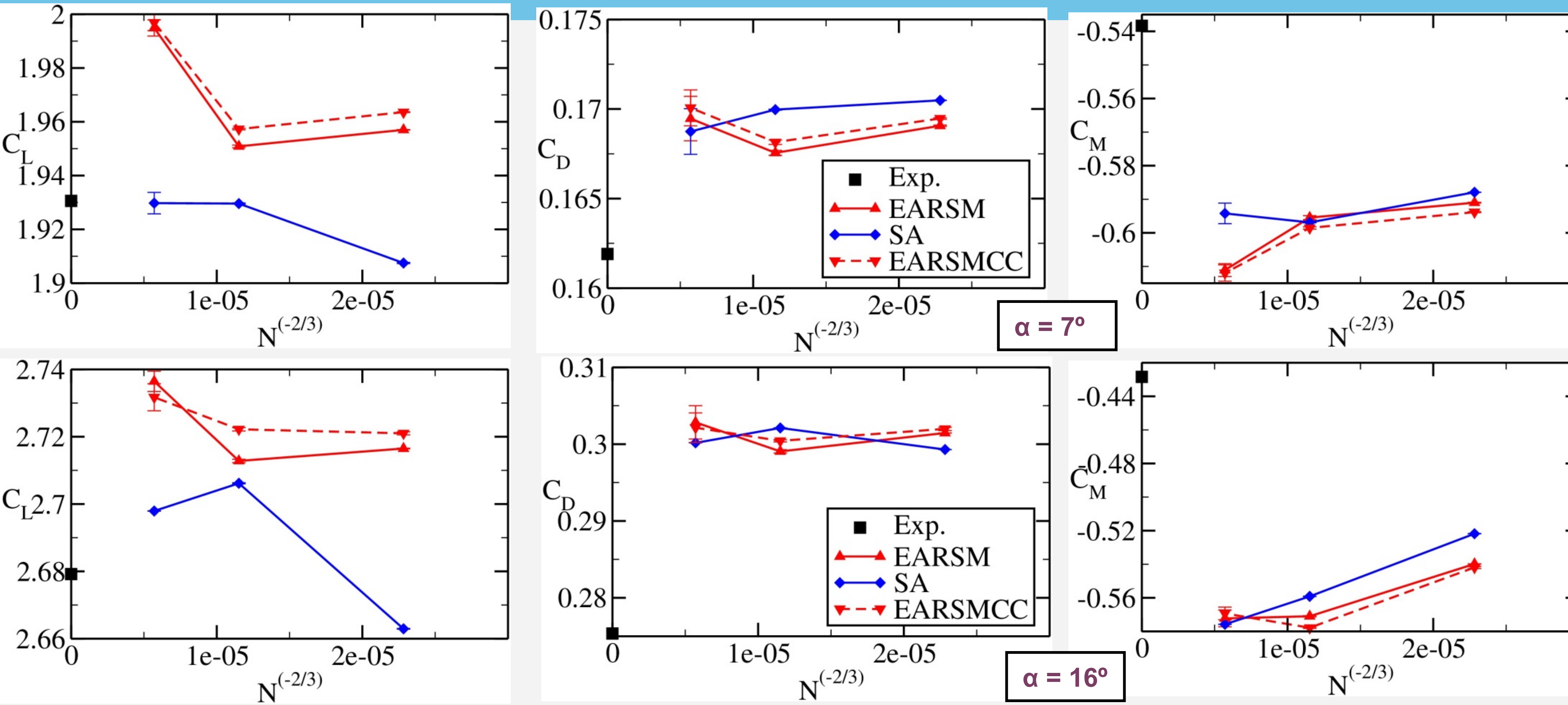
Case1, steady state convergence

- Steady state convergence rates
  - SA
  - EARSM(-CC) similar or worse
- Rather poor convergence
  - Compared to NASA trap wing
  - Unsteadiness ???



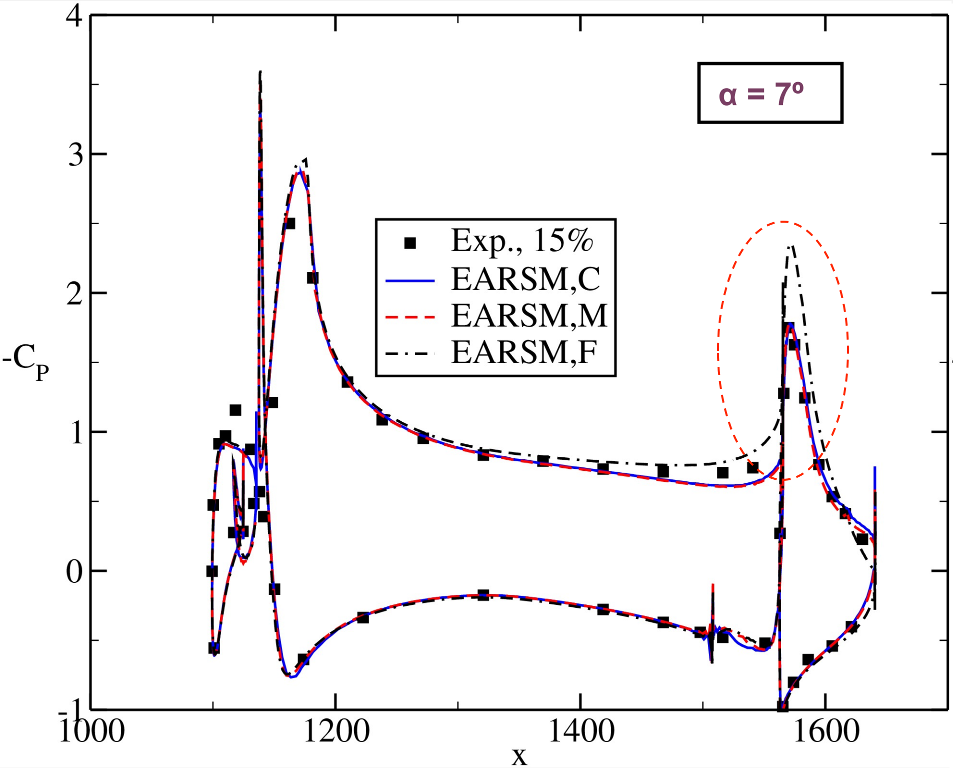
AIAA,

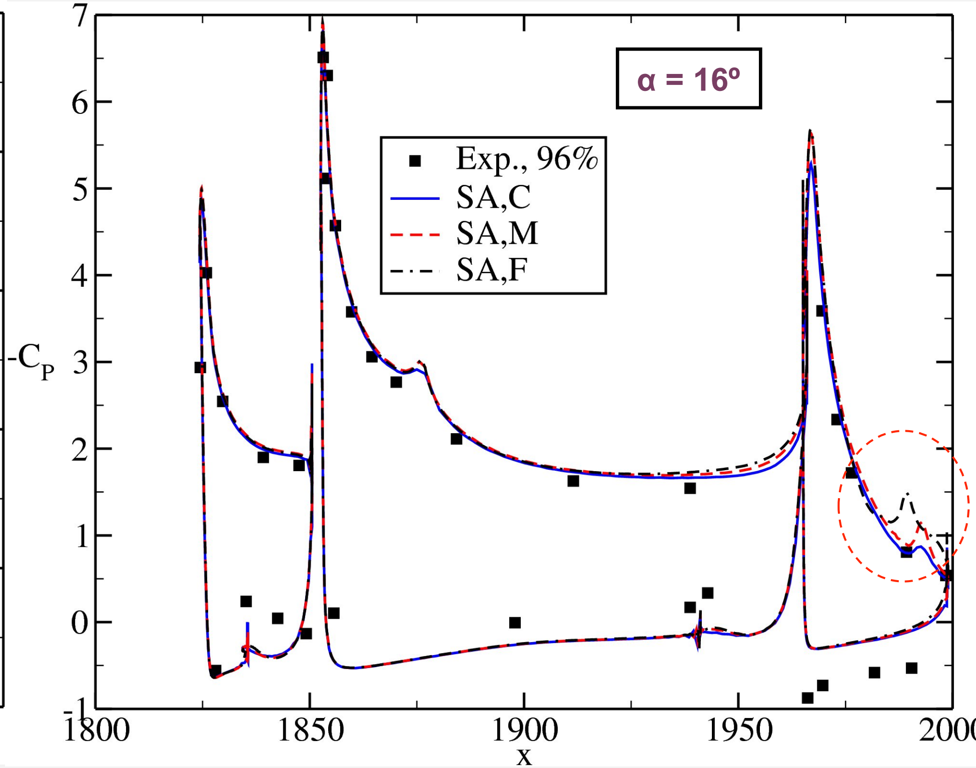
Case1, grid convergence



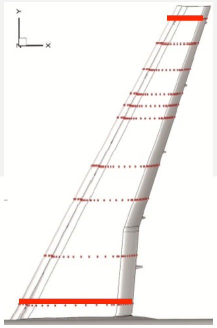
- ❑ (Unphysical) Variation in forces and moments indicated
- ❑ Variation between grids < 2%
  - ➢ Variations due to oscillation < 1%
  - ➢ Variation in C_L within 4 cts (HLPWS-1 within 2 cts)
  - ➢ Some deviation from experiments (in particular C_D)

Case1, Cp plots



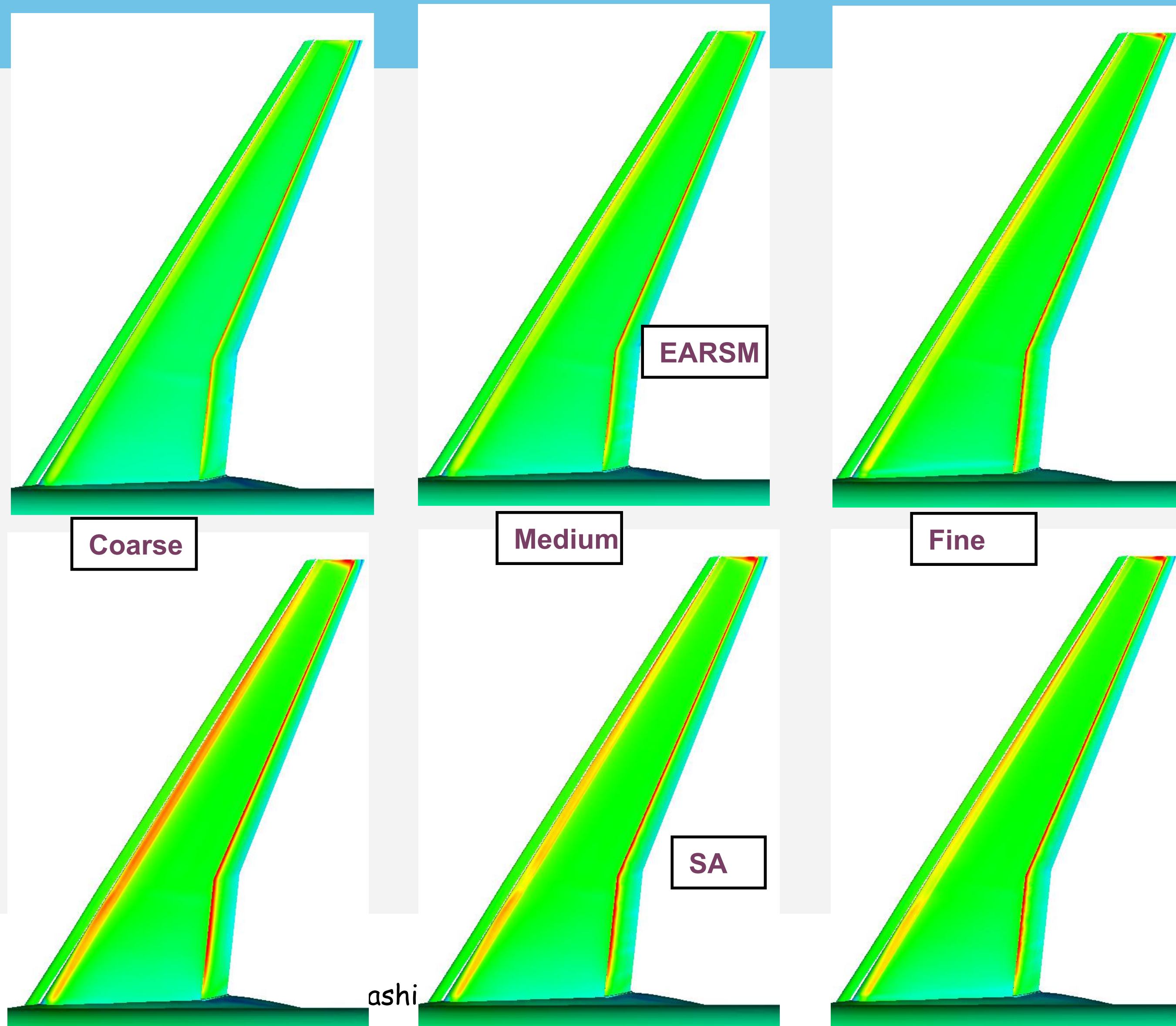


- Higher inboard suction on fine grid with EARSM
- Outboard variations at trailing edge for SA
- Very similar results EARSM and EARSM-CC



Case1, Skin friction (x-component)

α = 7º



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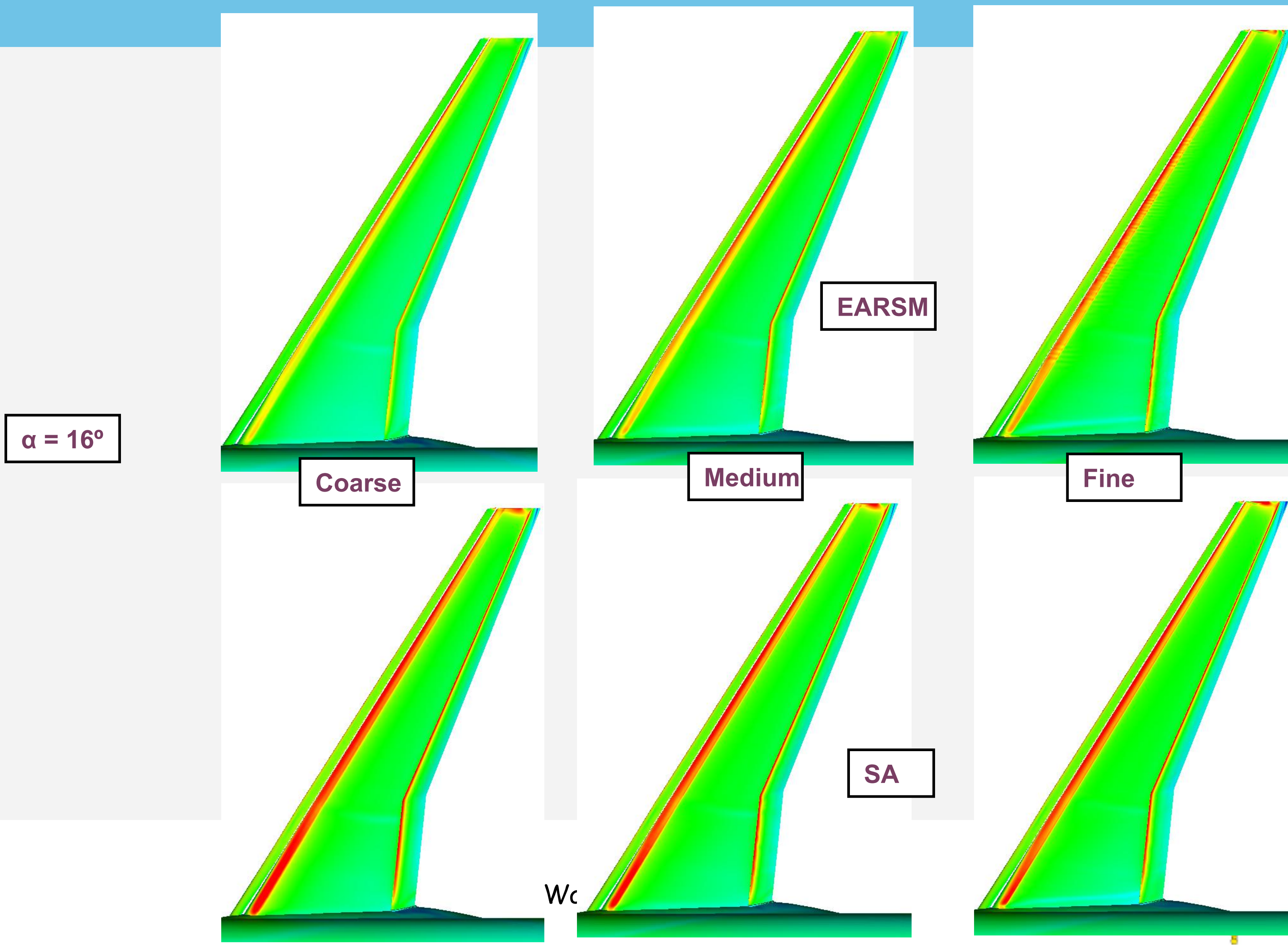
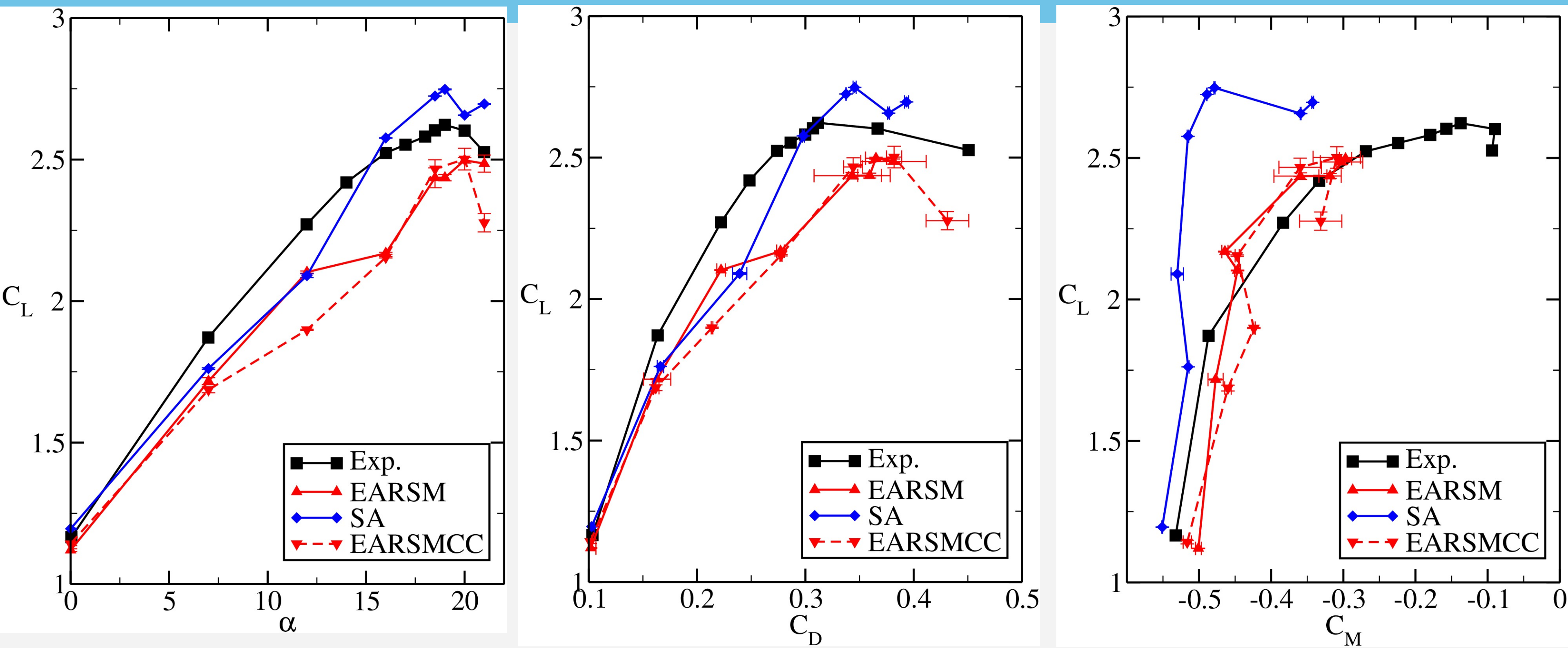
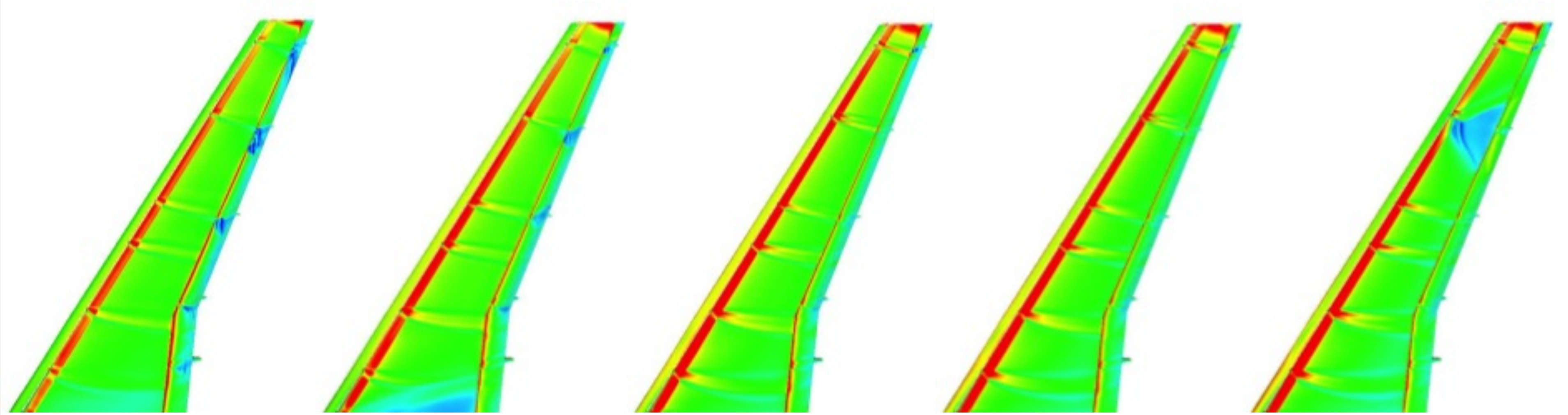


Case2a (low Re=1.35×10^{6}), Forces and moments



- 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 α=12º)

Case2a, Cf, SA



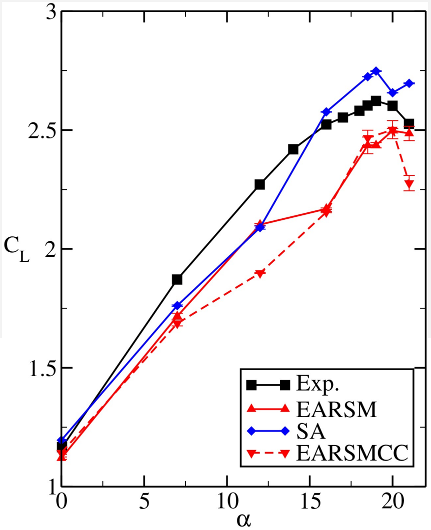
α = 7º

α = 12º

α = 16º

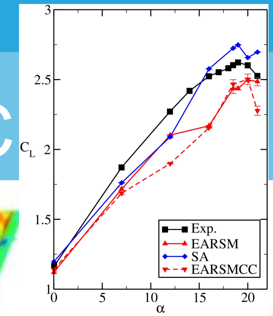
α = 18.5º

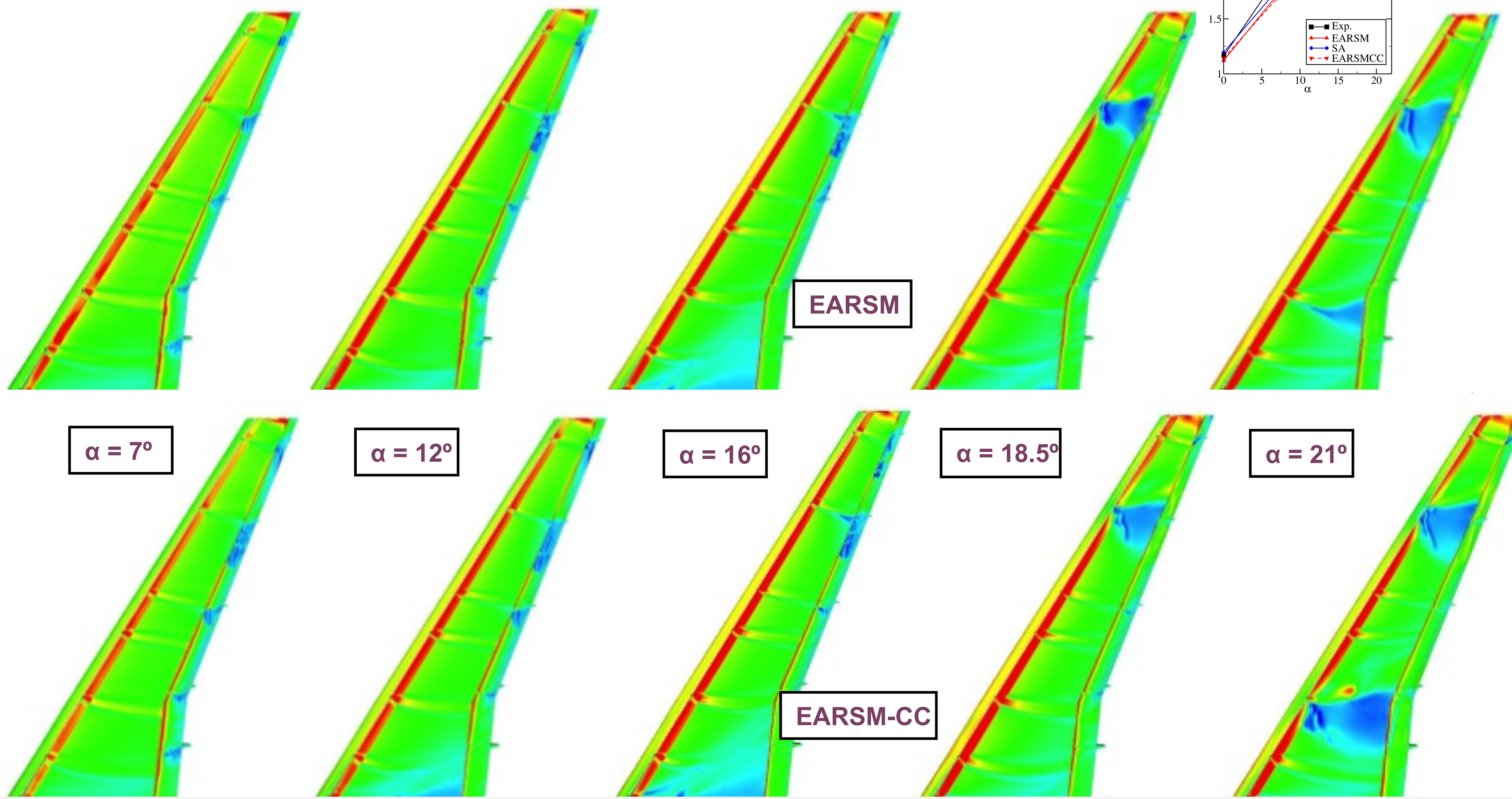
α = 21º



- ❑ Inboard separation at α=12º
- ❑ Lift break down at outer part of wing

Case2a, Cf, EARSM + EARSM-CC

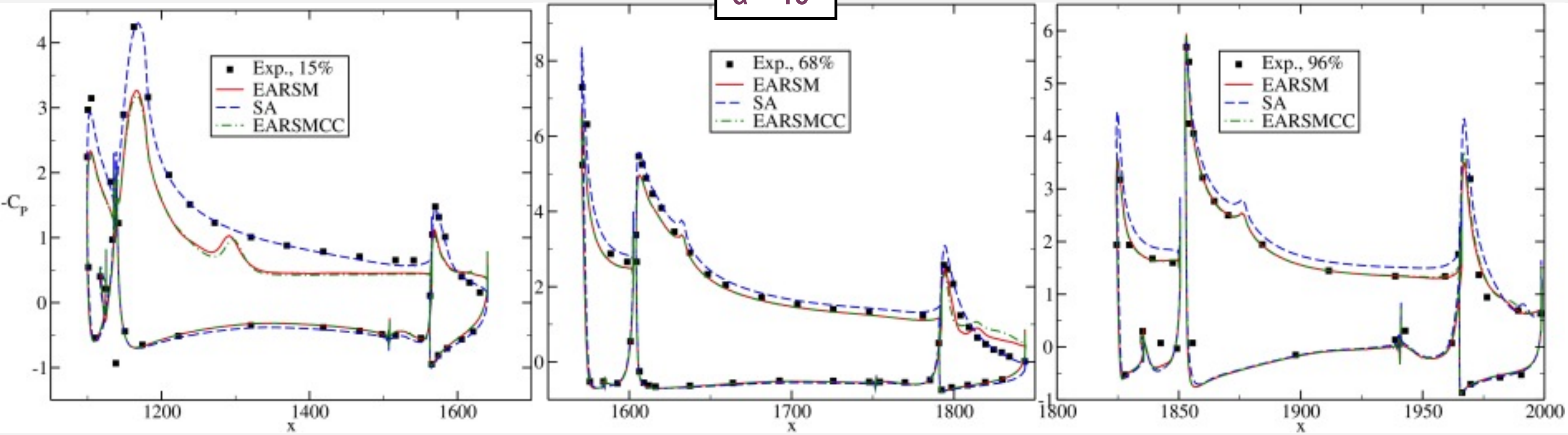




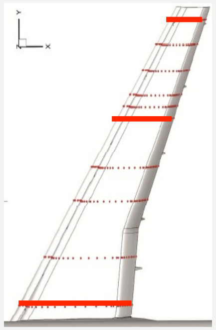
- Similar patterns
  - EARSM-CC inboard separation at α=12º
  - Inboard separation at α=16º
- Lift break down at outer part of wing

Case2a, Cp plots

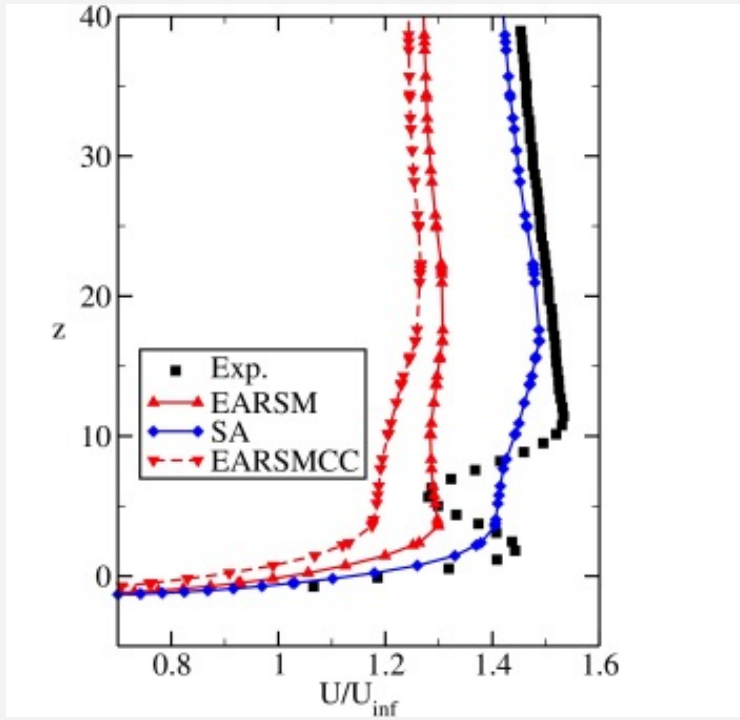
α = 16º

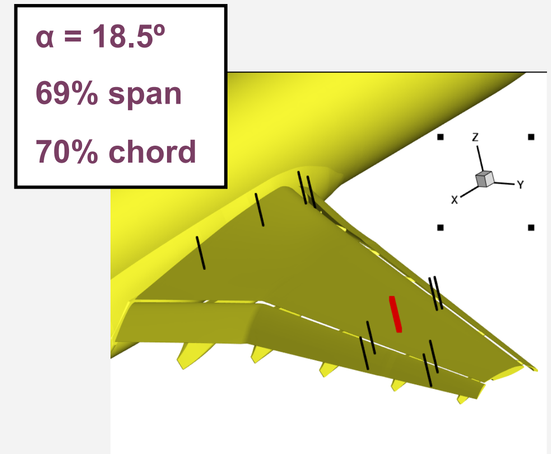


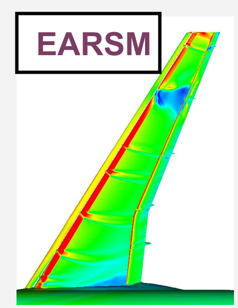
- ❑ Inboard separation with EARSM(-CC) models
- ❑ High outboard suction for SA

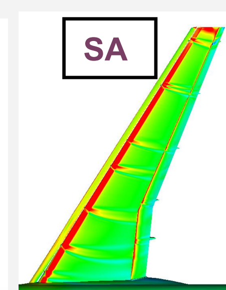


Case2a, velocity magnitude



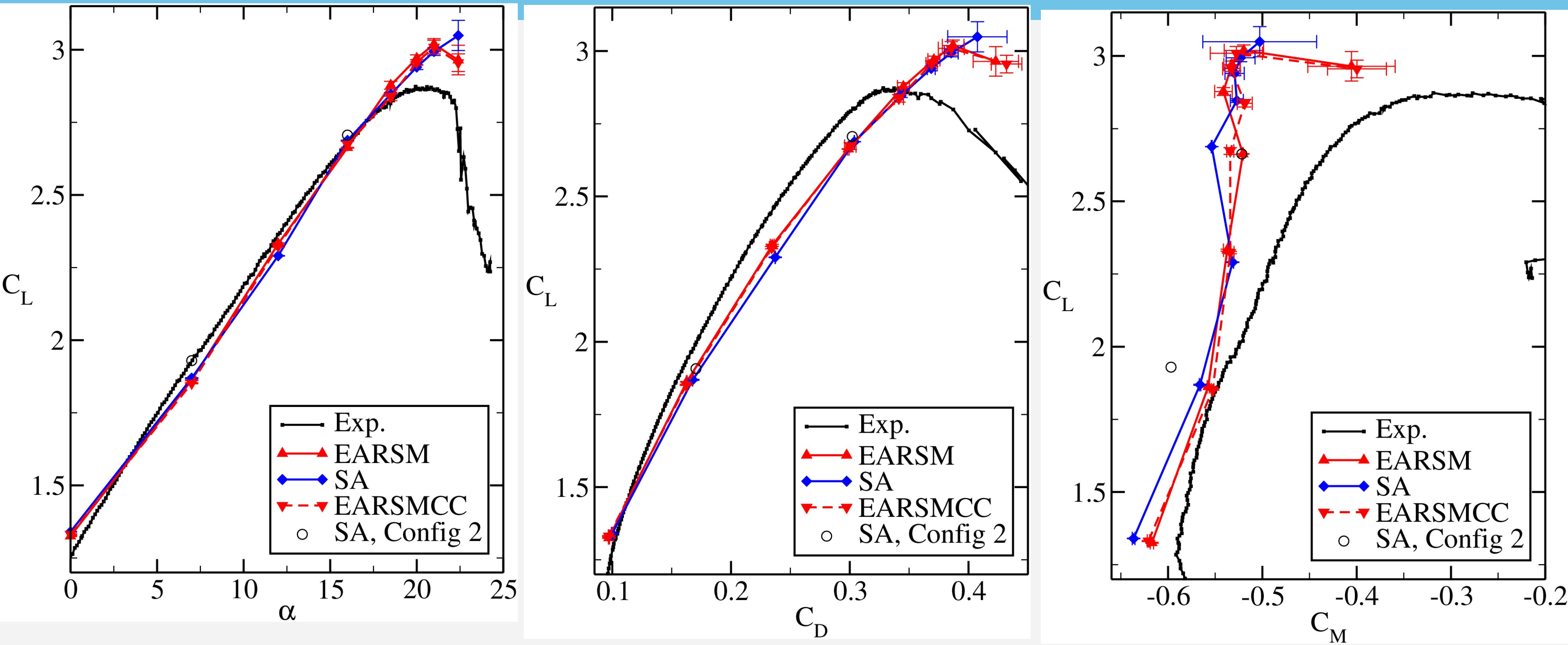






- ❑ Velocity vs. PIV
- ❑ Lower velocity magnitude with EARSM(-CC)
  - ➢ Station close to flow separation
- ❑ Slat wake not captured

Case2b (Re=15.1×10⁶), 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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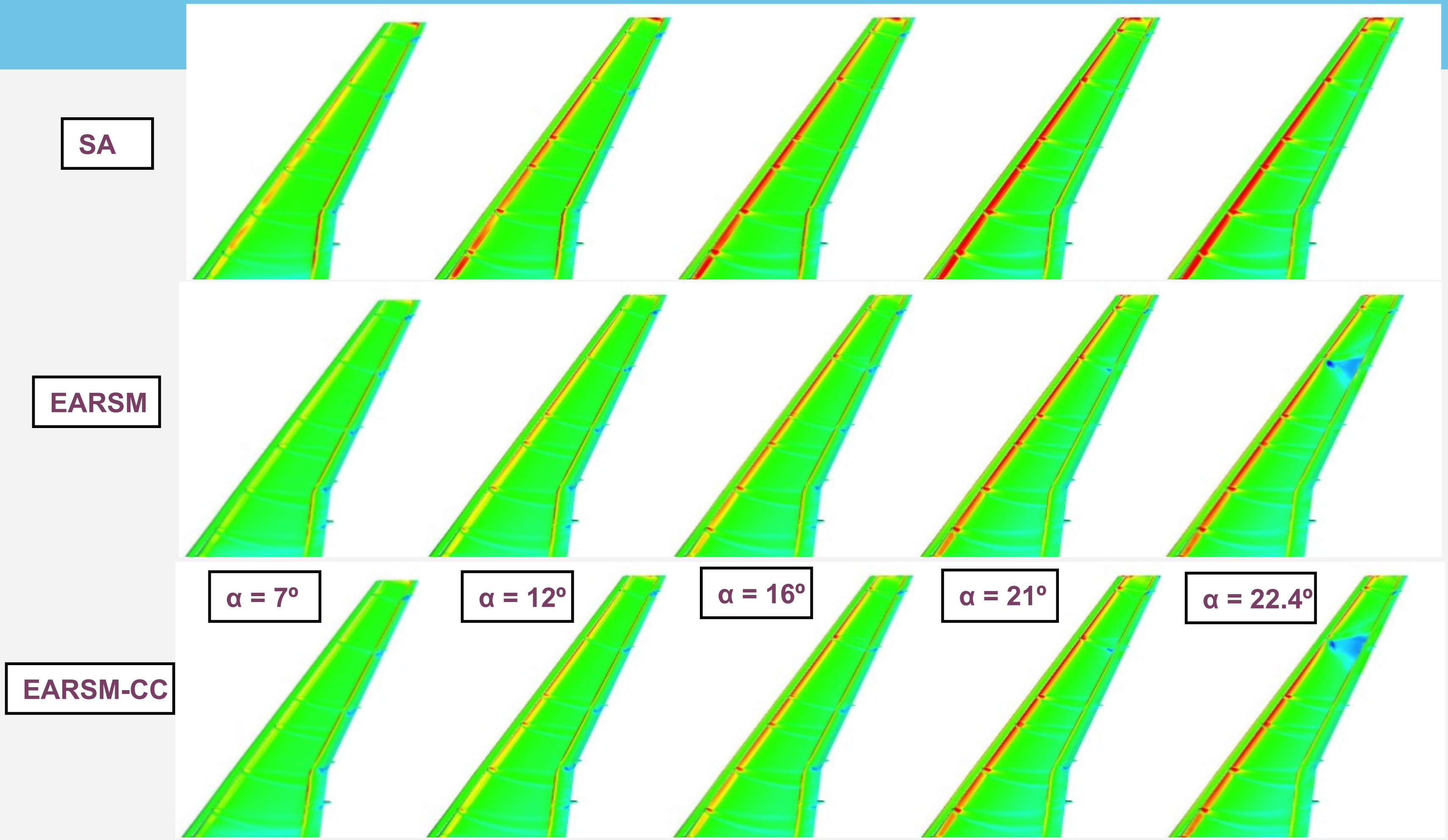
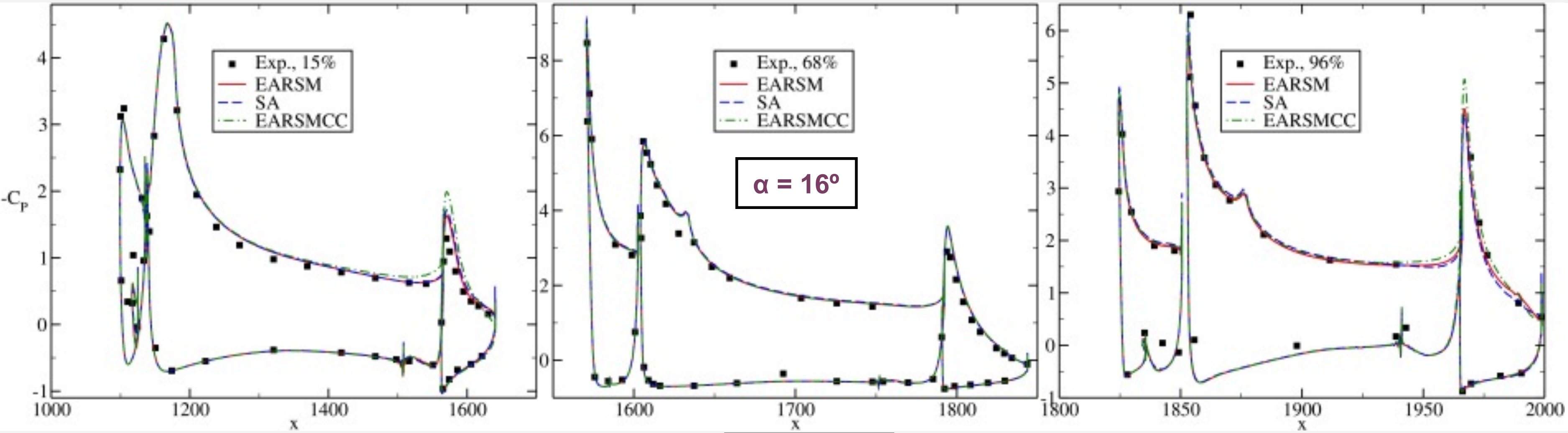
Case2b, Cf



- ❑ Mainly attached flow up to maximum lift
  - ➢ Brackets visible
- ❑ Similar lift break down as for low Re at outer part of wing

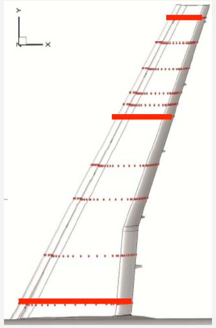
Case2b, Cp, alfa 7, 12



15% span

68% span

96% span



- ❑ Good experimental agreement
- ❑ Similar results between all models
  - ➢ Higher inboard suction with SA

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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.

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