Comparison of SA-QCR and RSM for an Angle of Attack Sweep on the NASA CRM-WB (TC 2a)

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DLR

Overview on DLR activities for DPW-7

Test case	Grid Levels	Mesh generation	Turb. Model	Team
1a	L1-L6	SOLAR, Common grids	RSM	DLR-Aerodynamics (Keye/Brodersen)
2a	L3	Centaur, Custom grids	RSM	DLR-Aeroelasticity (Friedewald/Fehrs)
	L3	Centaur, Custom grids	SA-QCR	DLR-Aeroelasticity (Friedewald/Fehrs)
6	L3	SOLAR, Common grids	RSM	DLR-Aerodynamics (Keye/Brodersen)

current presentation

Results of „Team DLR-Aerodynamics “ in presentations by Stefan Keye and Olaf Brodersen

CFD grids

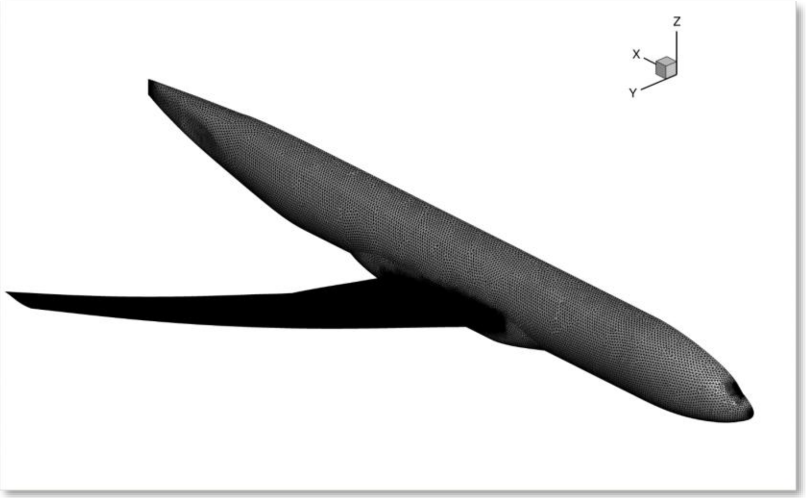
L3: Medium Grid Size

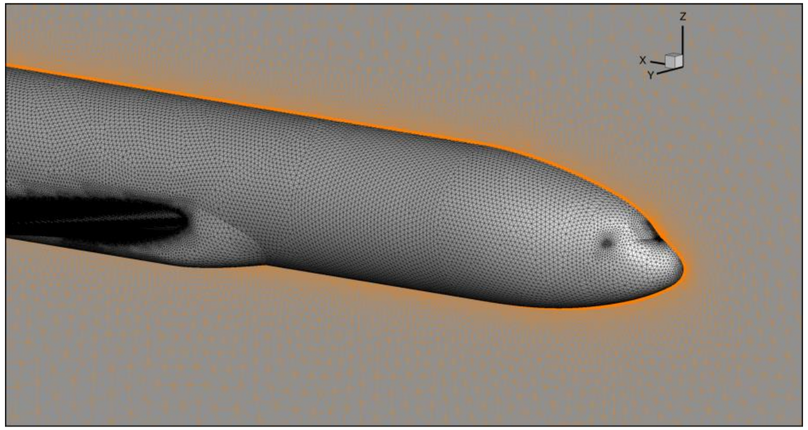
Overview

- Centaur grids
  - structured surface grid on wing
  - unstructured (triangles) surface grid on fuselage & wing tip
  - hexahedral (structured surf regions) / prismatic (unstructured surf regions) boundary layer grid
  - tetrahedral grid for remaining flow field
- one deformed geometry per AoA
- automatic, sequential grid generation with the same settings for all AoA

  →automatic grid generation results in minor differences in overall grid size

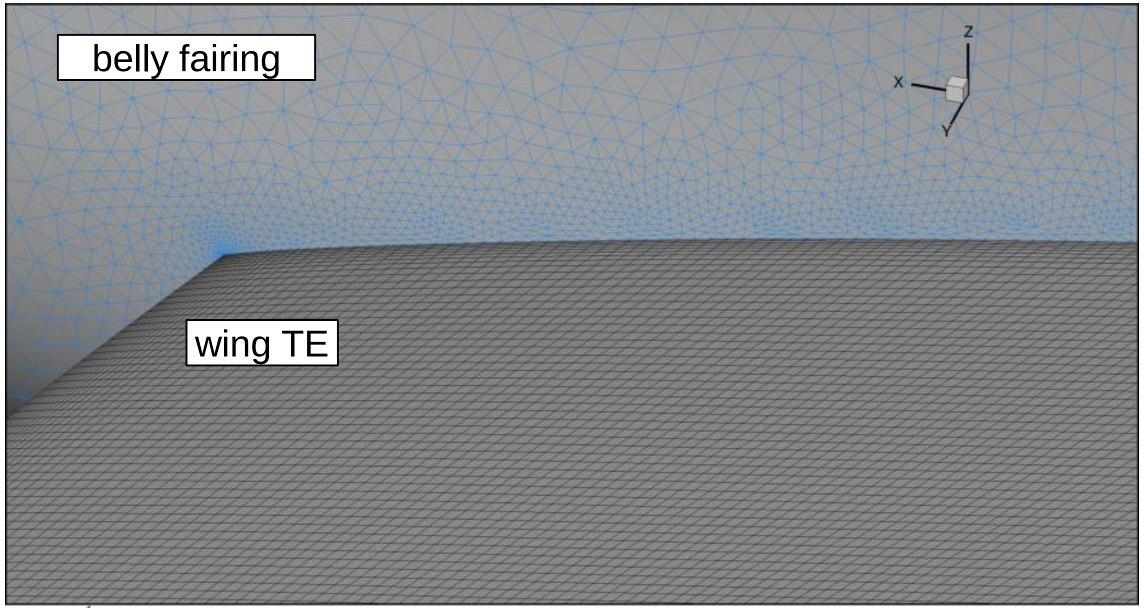
  →≈46 million mesh nodes for each grid

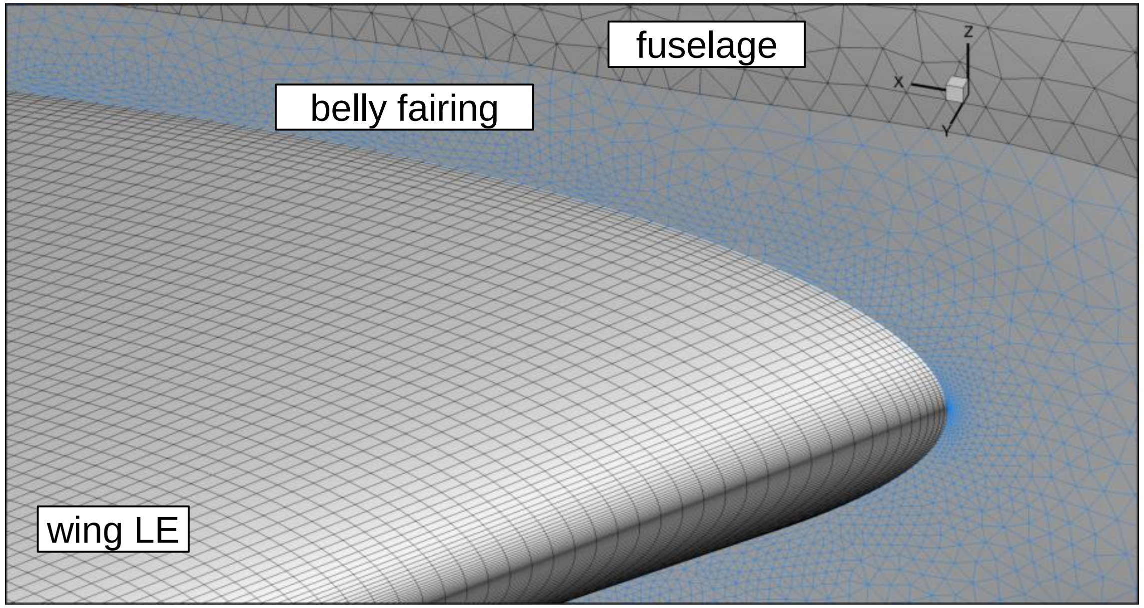




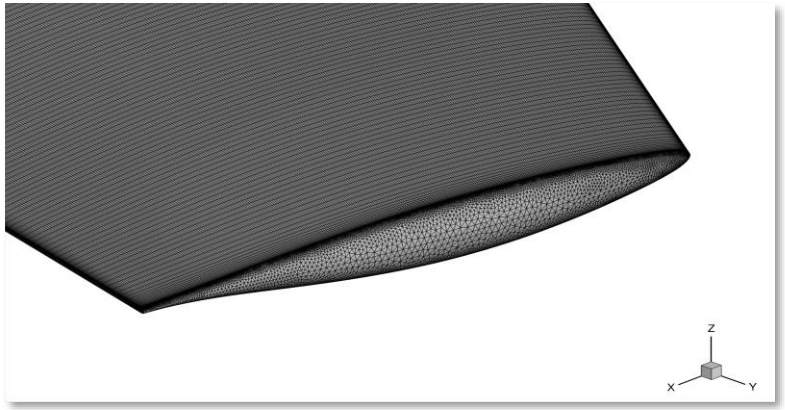
L3: Medium Grid Size
Wing body junction

- structured surface mesh on wing
- 350 nodes on upper and lower surface in chord direction
- 580 nodes on upper and lower surface in span direction





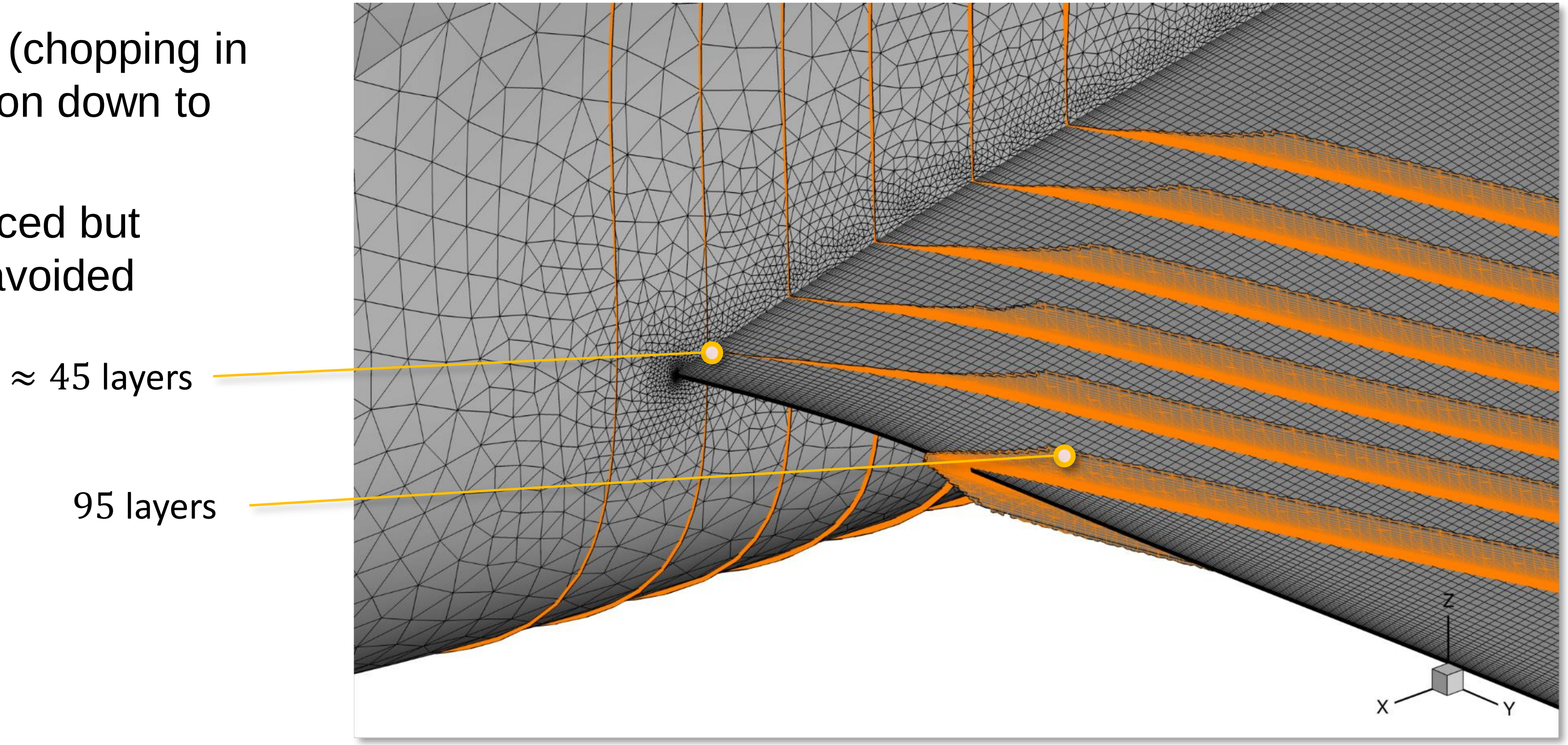
- triangular surface mesh on fuselage
- triangular surface mesh on wing tip



L3: Medium Grid Size

Example for 3.00deg

- Centaur chops boundary layer grid in some regions
- nominally 95 hex layers (chopping in fuselage-wing intersection down to ≈ 45 layers)
- chopping might be reduced but usually not completely avoided



Flow Solver TAU

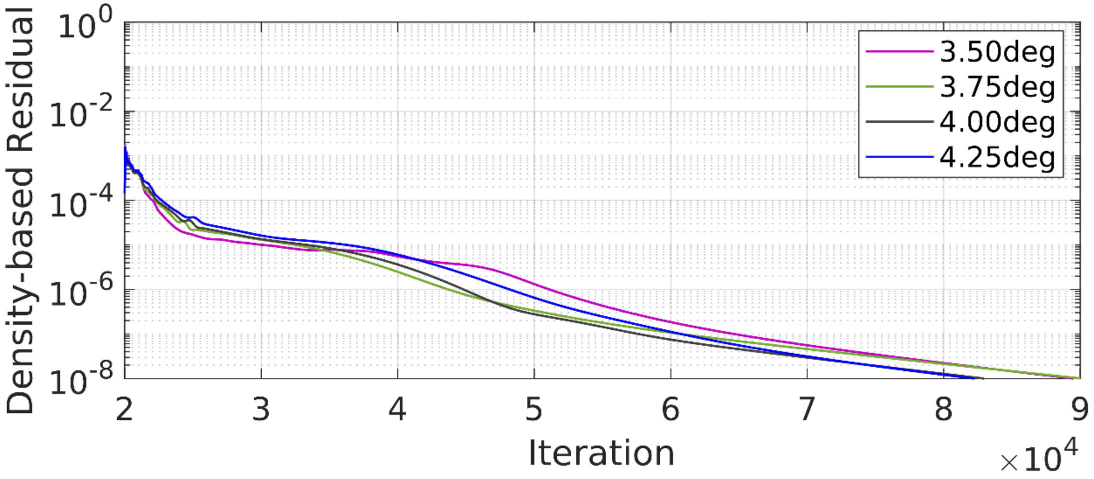
- Finite Volume
- Grid metric: Cell vertex
- Multigrid cycle: 3v, CFL 5
- Time Integration: Lower-Upper Symmetric Gauss-Seidel
- Spatial Discretization: Central scheme
- Numerical Dissipation: Scalar
- RANS + URANS
- TAU Release 2020.1.0

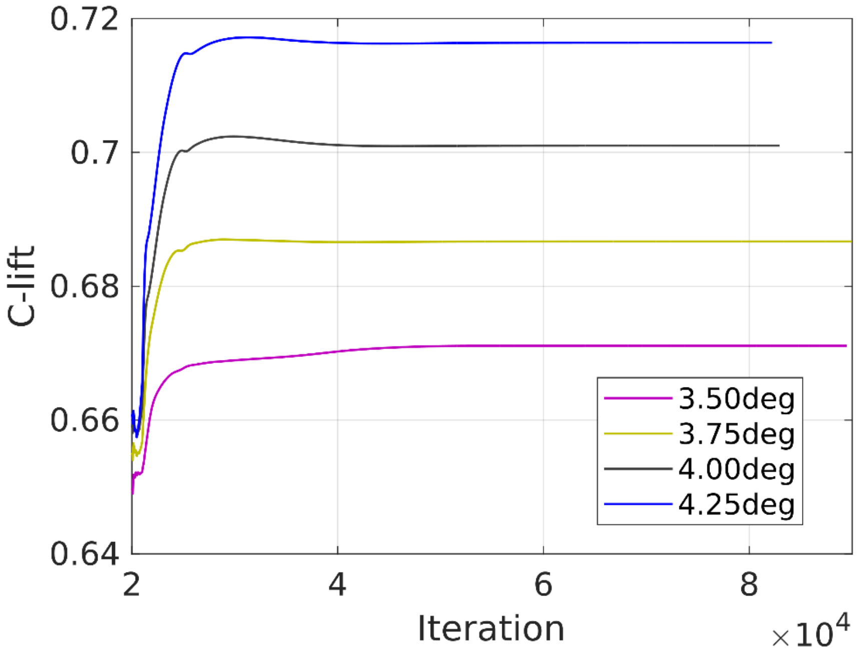
- Turbulence models used:
  - Negative formulation of Spalart-Allmaras with quadratic constitution relation (SA-QCR), (Togiti et al., 2014, DOI: 10.2514/1.C032609)

  - Reynolds-Stress model (RSM): Speziale-Sarkar-Gatski/Launder-Reece-Rodi (SSG/LRR) in combination with ln-omega formulation (Eisfeld et al., 2022, DOI: 10.2514/1.J060510)

Convergence Behaviour
RANS + URANS

SA-QCR, RANS
Convergence

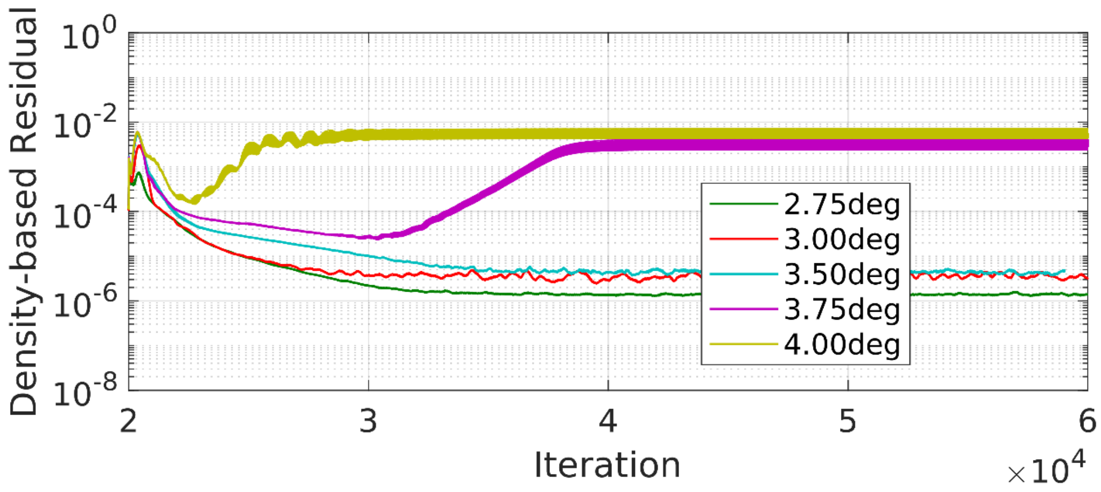


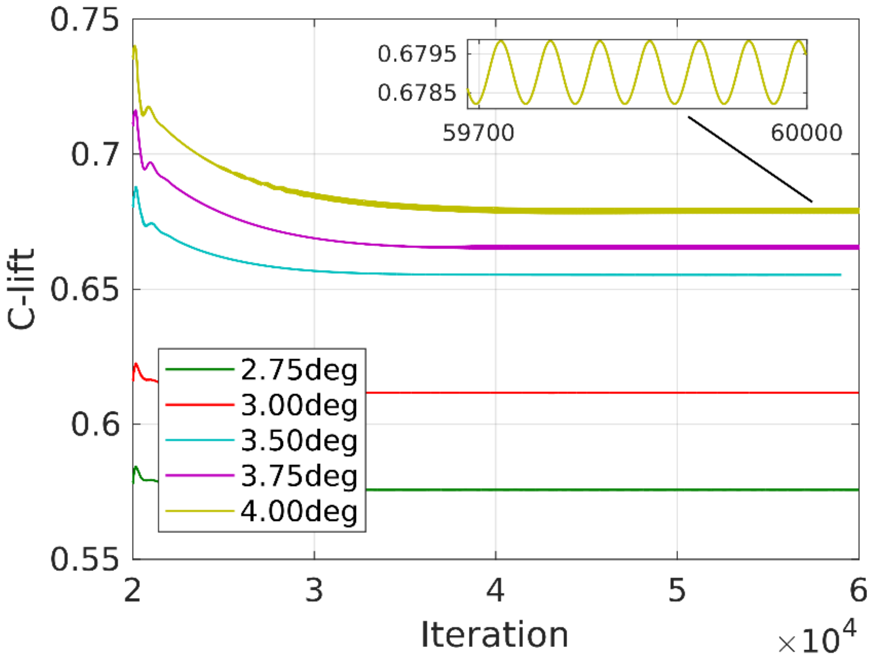


- all AoAs well converged with SA-QCR

RSM, RANS

Convergence



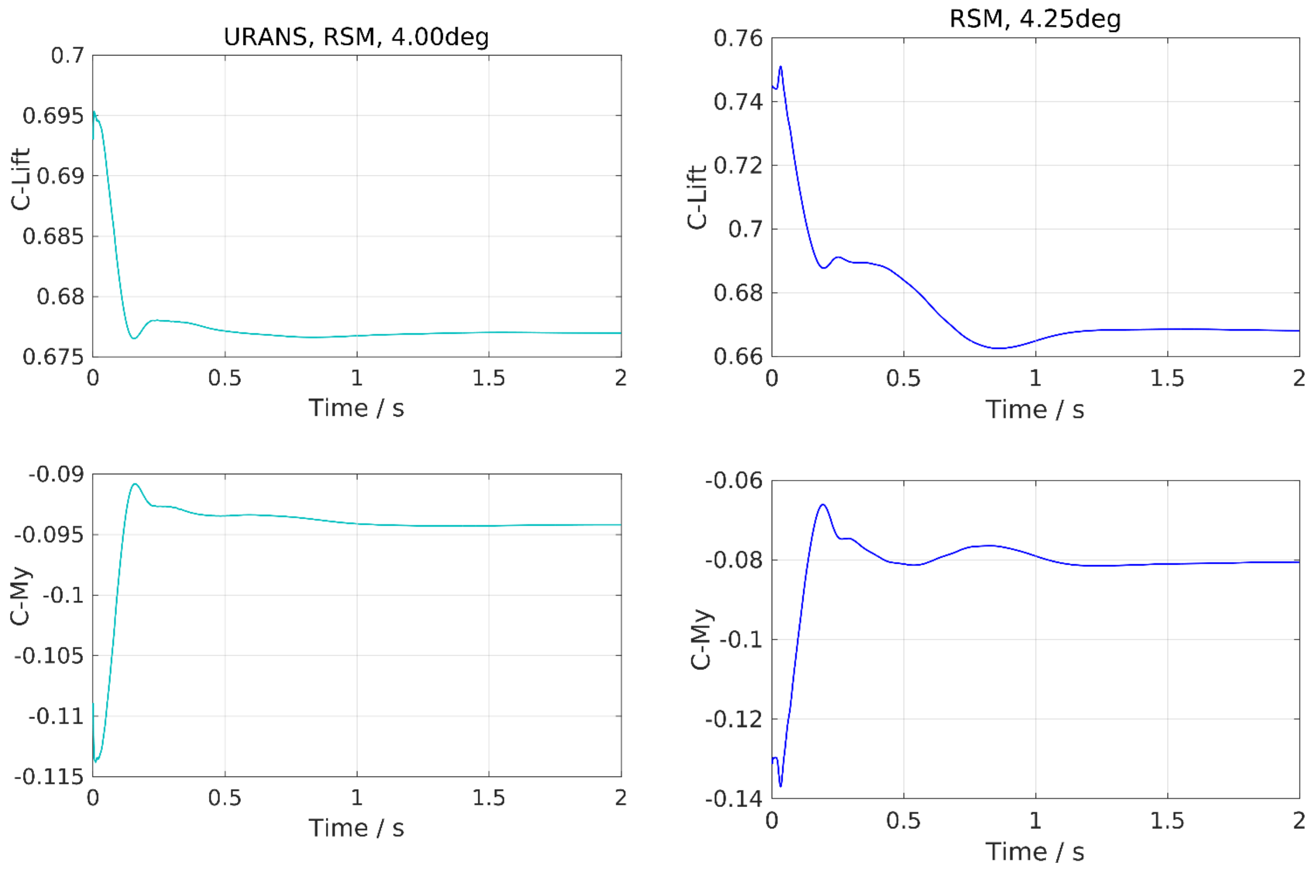


- Low AoA with reasonable convergence behaviour
- Convergence problems for higher AoA
  - also using different CFL numbers and types of multigrid/single grid

  → Switch to URANS

RSM, URANS

Convergence



AoA 4.00deg and 4.25deg

- well converged
- stable conditions

- different time steps and different Cauchy convergence criteria lead to identical results (not shown here)

Summary on TAU simulations: Ma 0.85, Re 20Mio, L3 Grids

Angle of Attack Sweep for TC2a

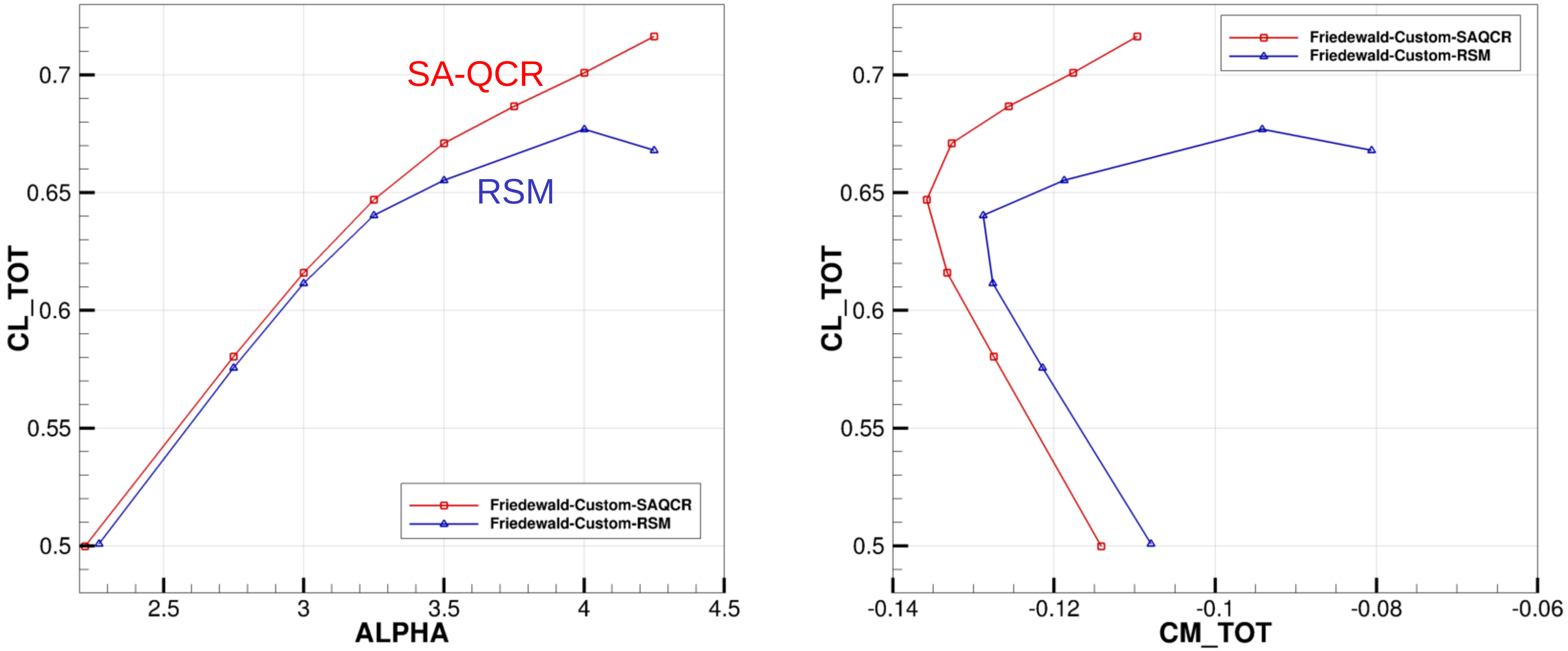
AoA / deg	SA-QCR	RSM
target-CL = 0.50	RANS, 2.22deg	RANS, 2.27deg
2.75	RANS	RANS
3.00	RANS	RANS
3.25	RANS	RANS
3.50	RANS	RANS
3.75	RANS	-
4.00	RANS	URANS, stable
4.25	RANS	URANS, stable

each AoA with a separate L3 grid

Results
Comparison of SA-QCR and RSM

Angle of Attack Sweep: Ma 0.85, Re 20Mio

Lift and Moment Coefficients

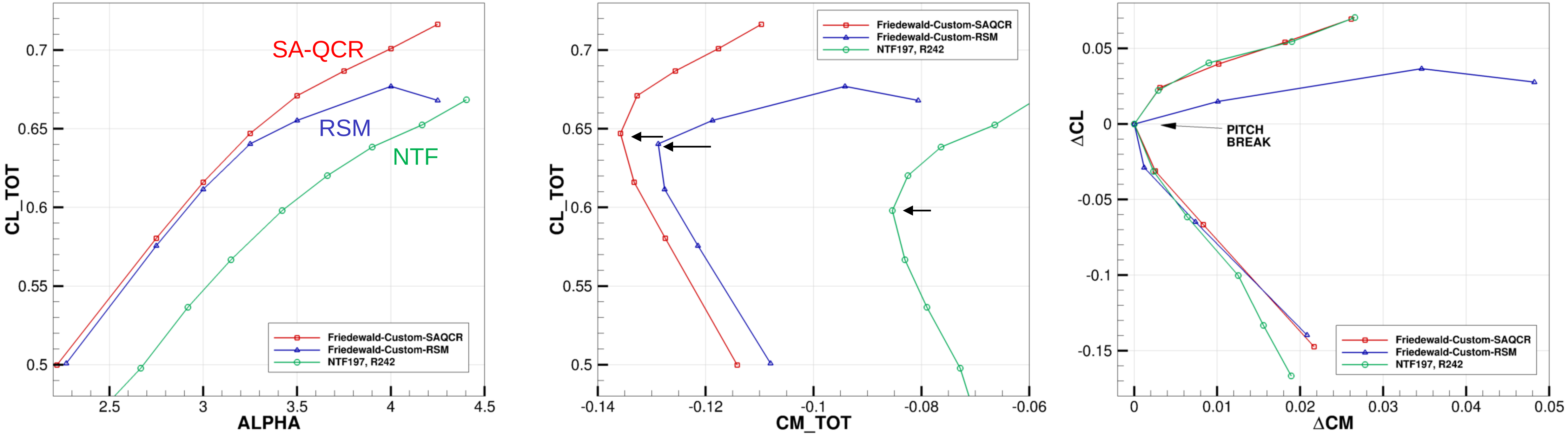


- RSM comparable to SA-QCR for lower AoA
- At higher AoA: lift breaks down for RSM, whereas SA-QCR lift increases

Angle of Attack Sweep: Ma 0.85, Re 20Mio

Lift and Moment Coefficients

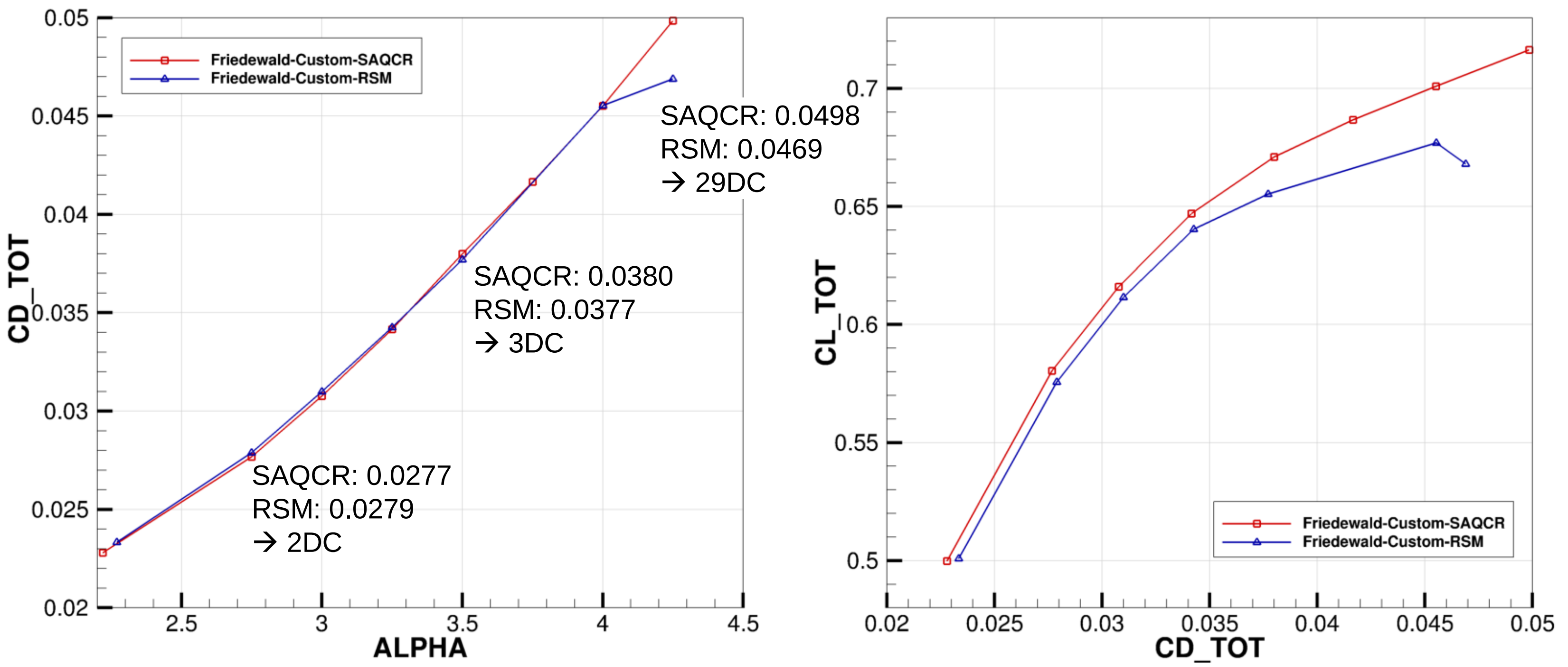
shift in lift and moment
to match pitch break



- Trends of experiment seem to be better captured using SA-QCR

Angle of Attack Sweep: Ma 0.85, Re 20Mio

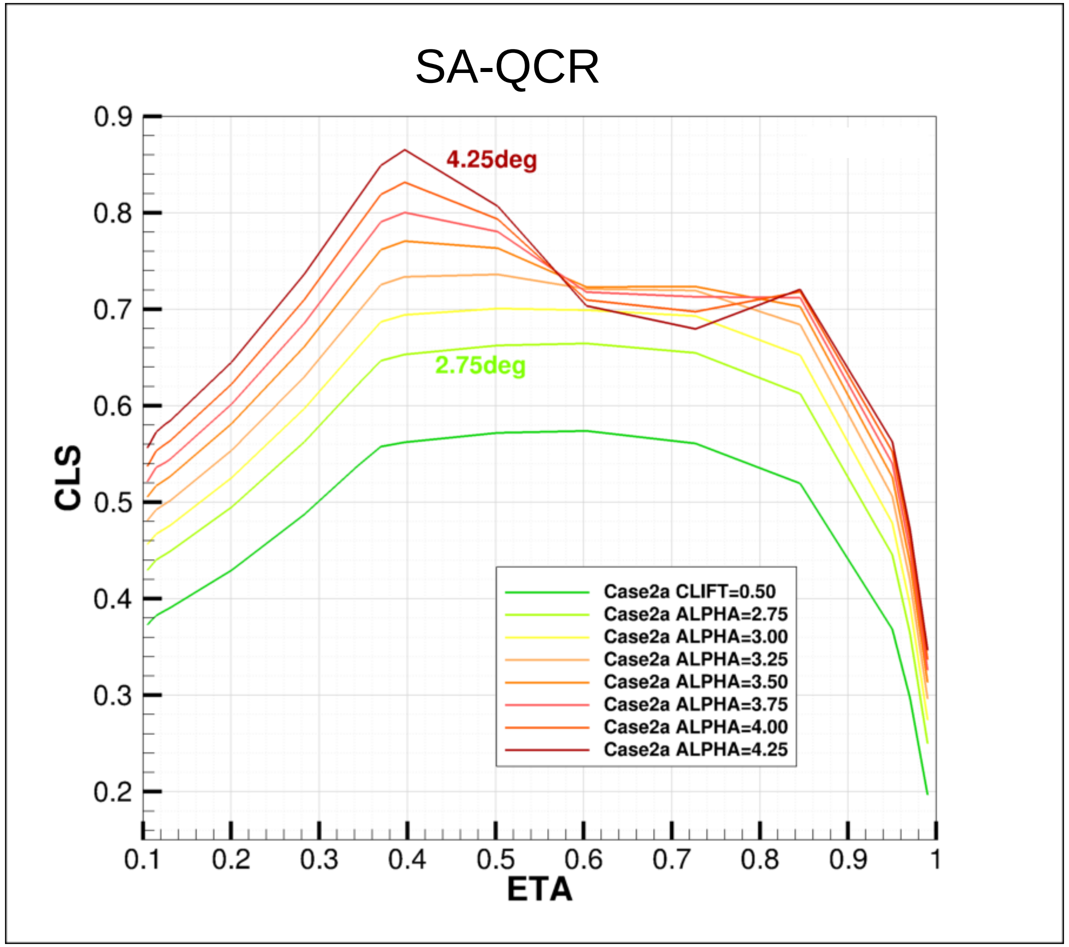
Drag coefficient

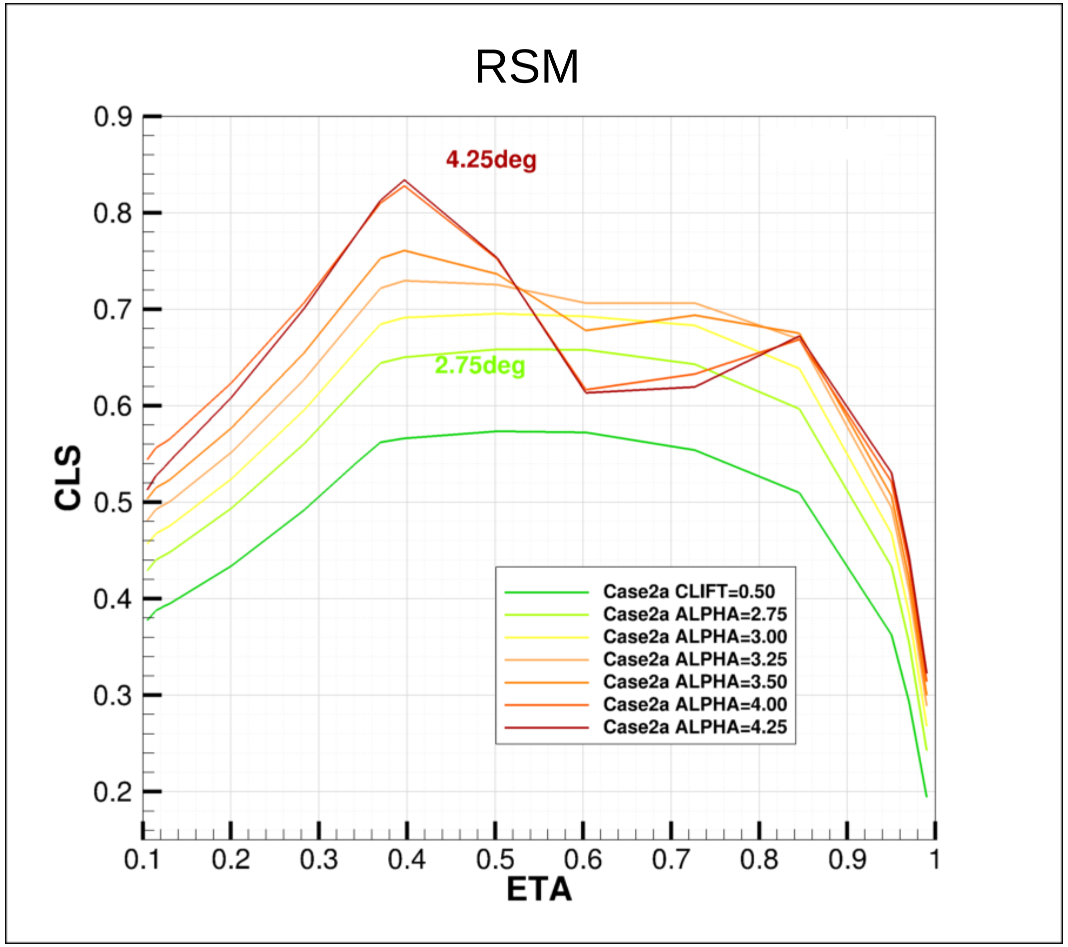


- total drag matches up to 4deg
  → Loss of lift-induced drag seems to be compensated by profile drag
- large discrepancy at highest AoA

Angle of Attack Sweep: Ma 0.85, Re 20Mio

Sectional Lift

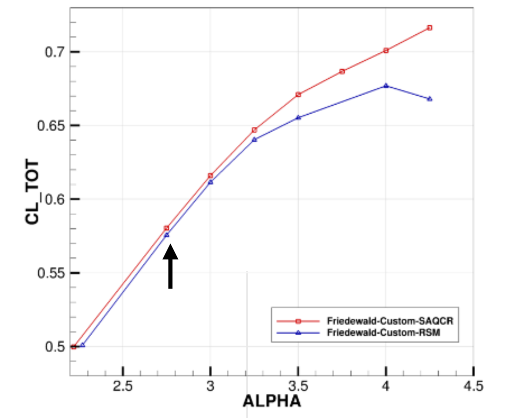


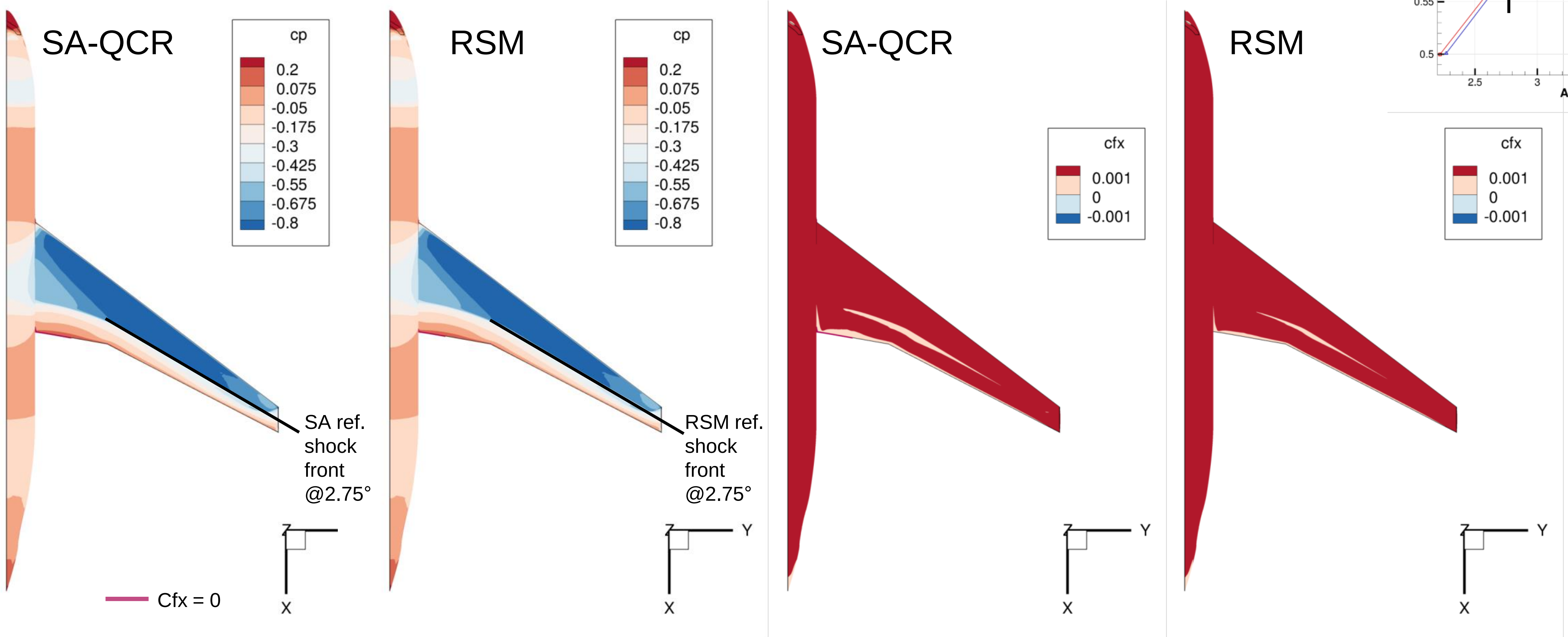


- RSM with significantly larger breakdown in lift

Pressures and skin friction

AoA 2.75deg

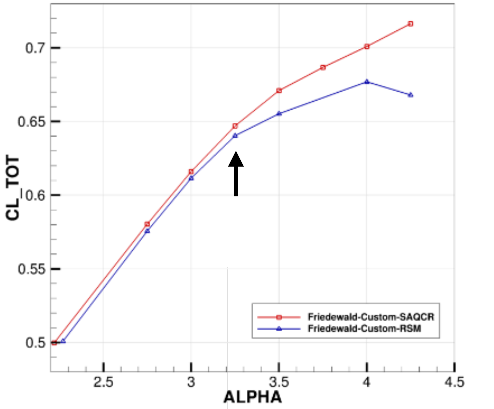


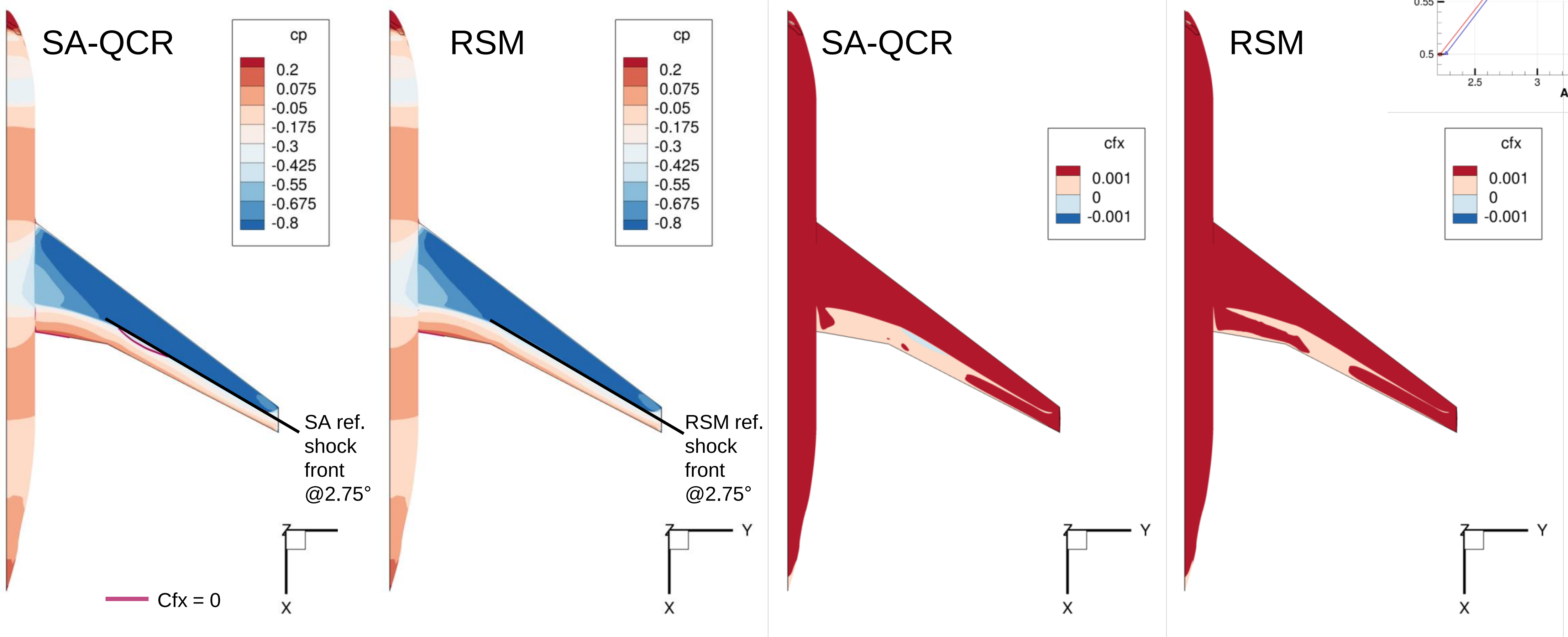


- Turbulence models are comparable to each other

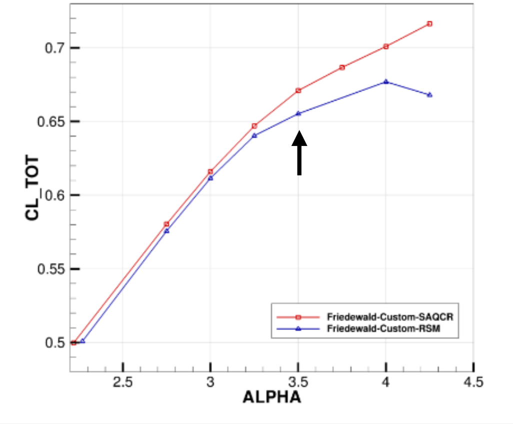
Pressures and skin friction

AoA 3.25deg



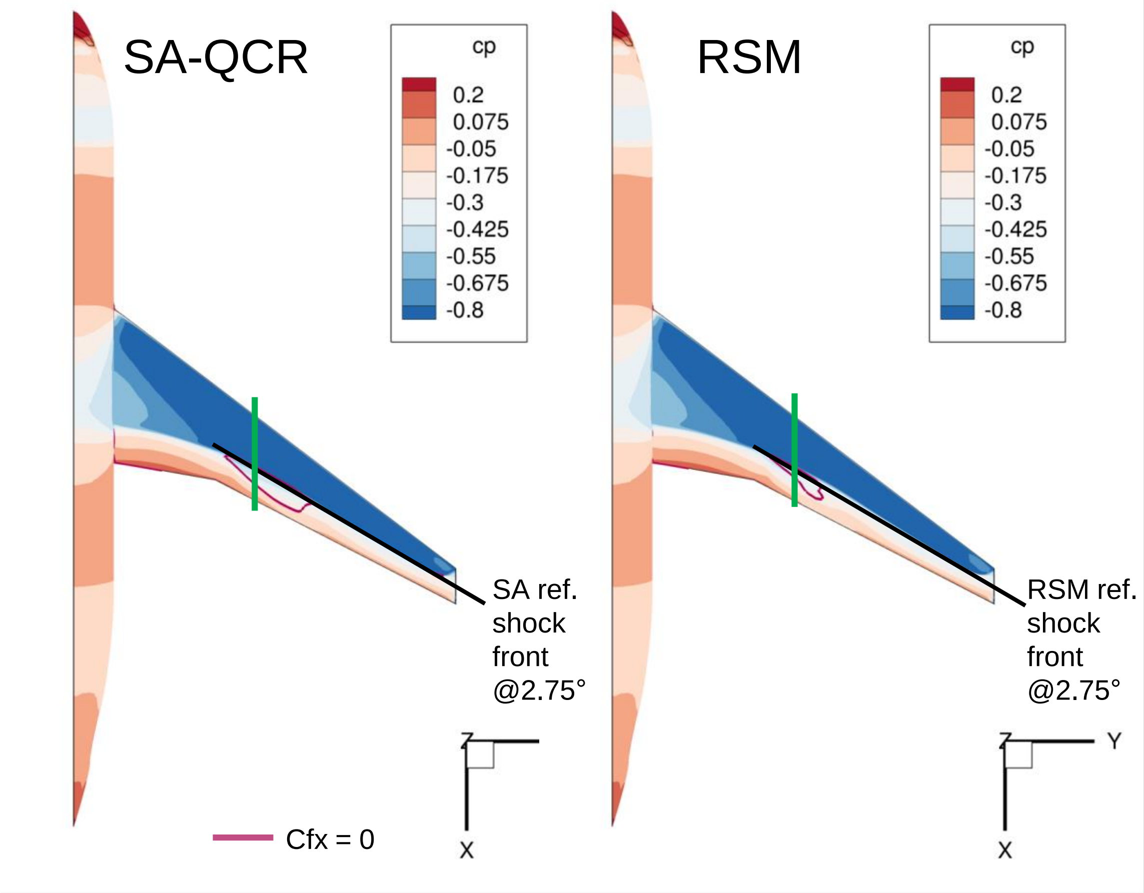


- SA-QCR: separation set in, shock front did not move

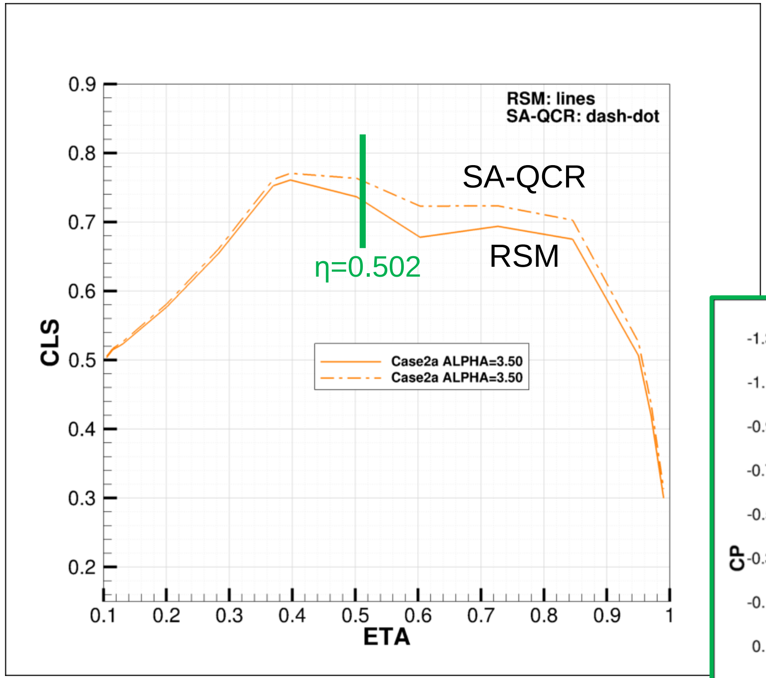


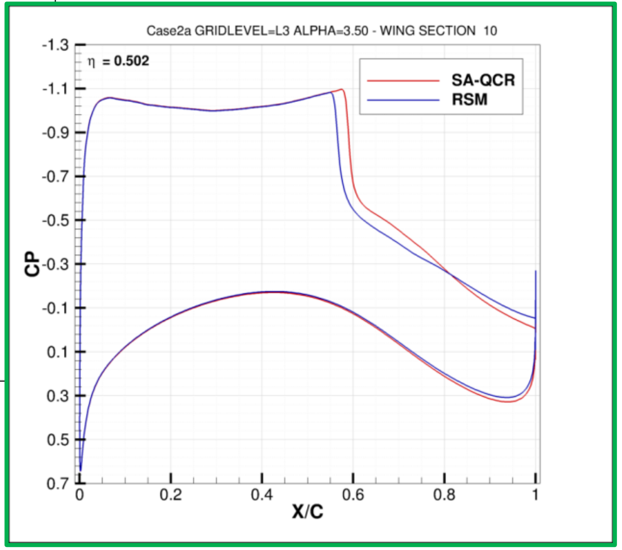
Pressures and skin friction

AoA 3.50deg



Sectional lift

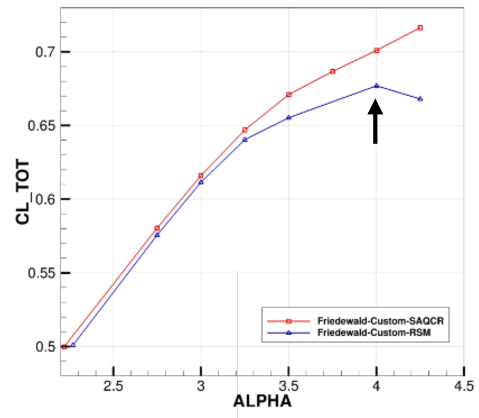


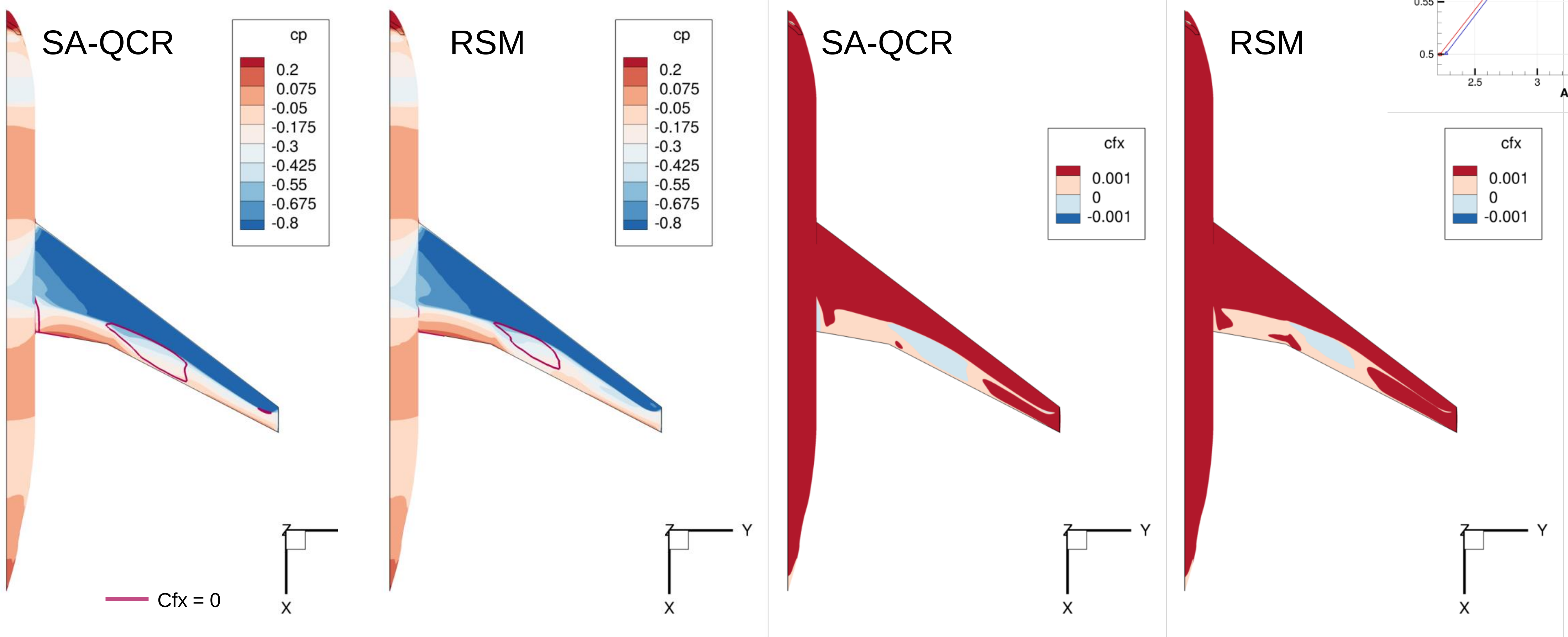


- separation onset for RSM → shock front more curved → shock moves more upstream
- less lift on mid-wing → growing difference in lift coefficient between SA-QCR and RSM

Pressures and skin friction

AoA 4.00deg

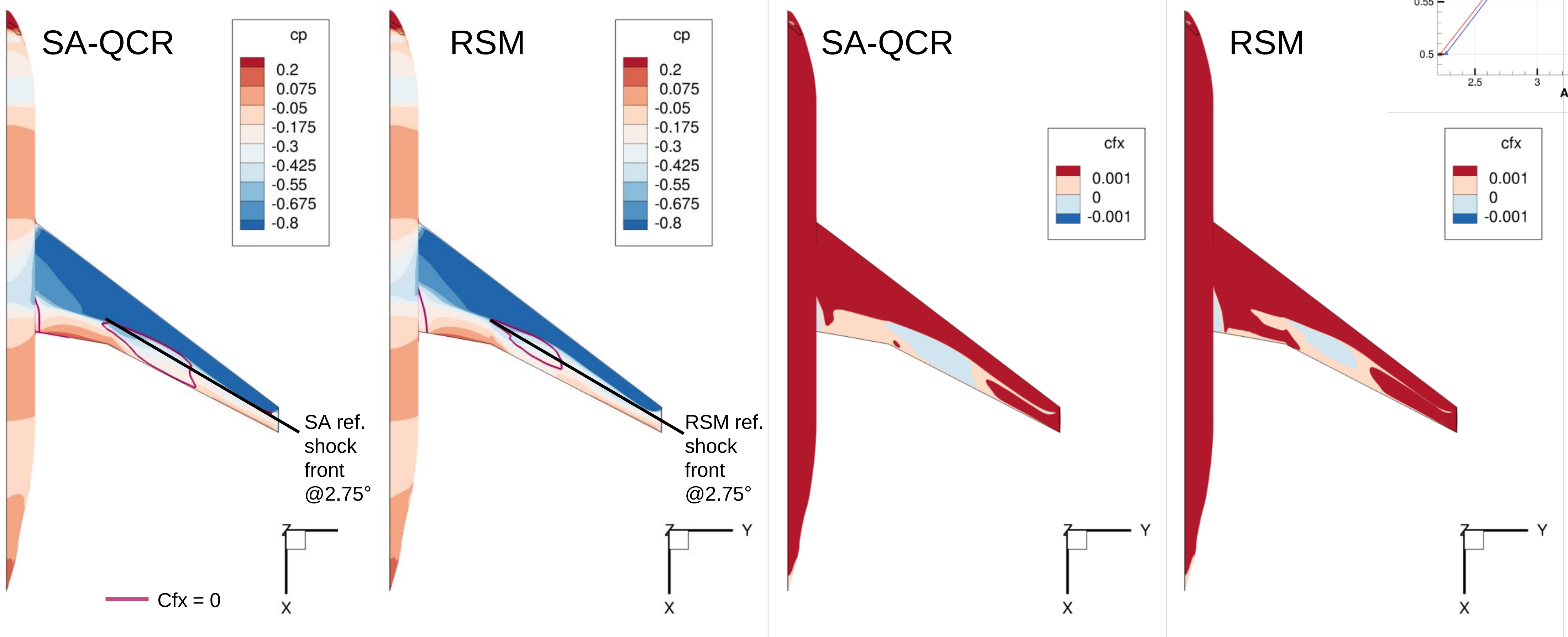


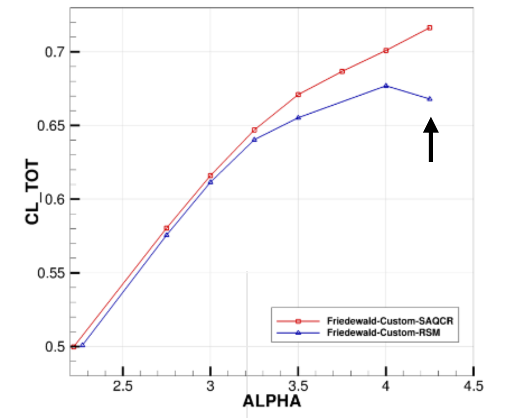


- SOB + small tip separation with SA-QCR
- significant upstream shock position with RSM → Lift largely reduced compared to SA-QCR

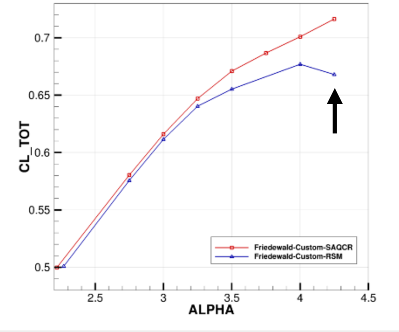
Pressures and skin friction

AoA 4.25deg



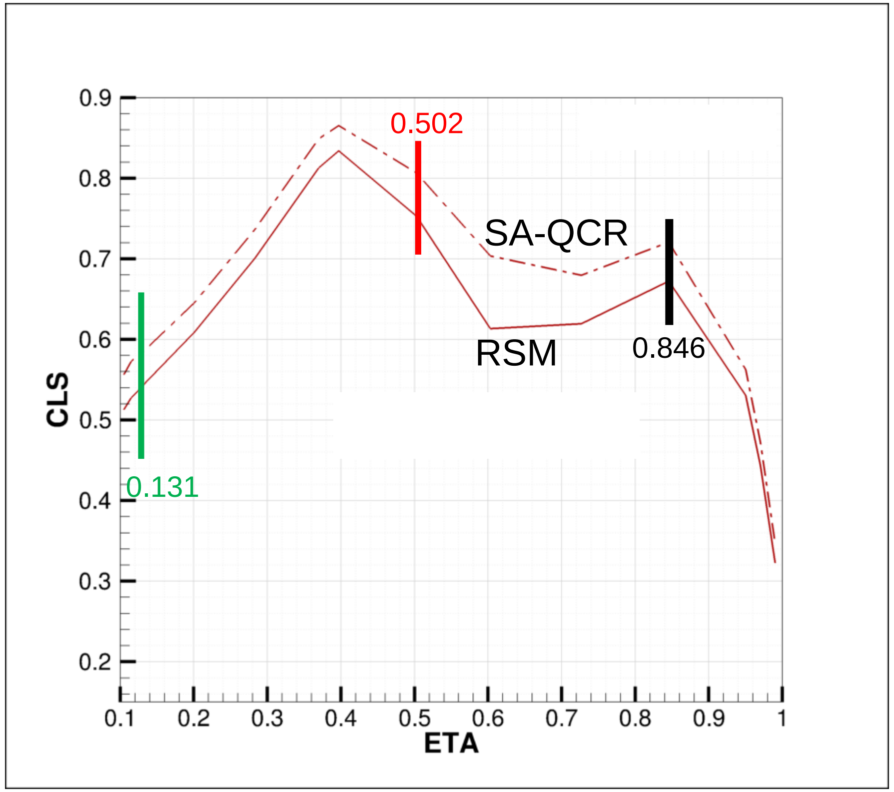


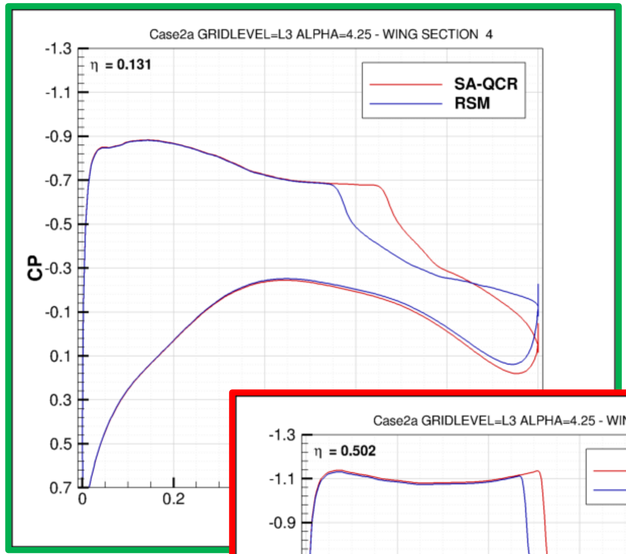
- sudden, large SOB separation with RSM + note different skin friction pattern
- less separation with RSM on mid-wing, but shock more upstream than with SA-QCR

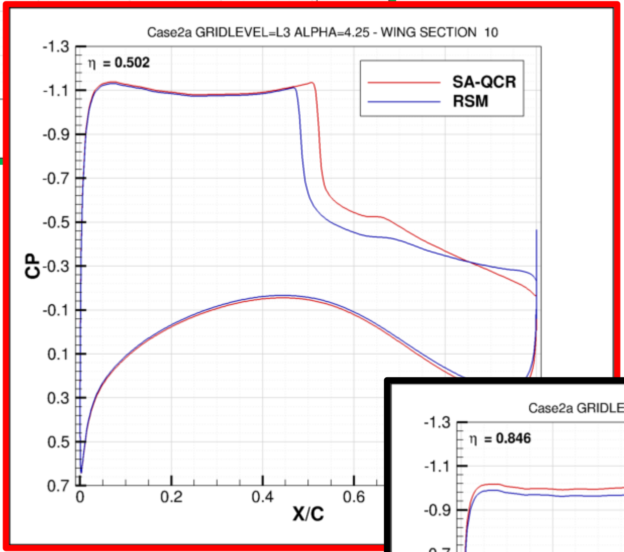


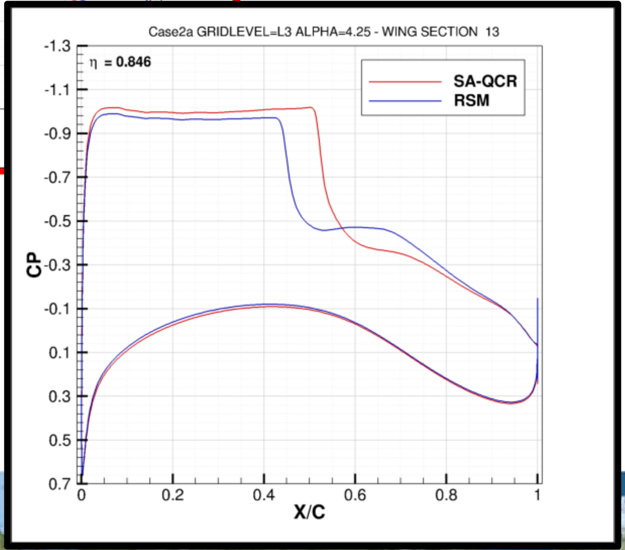
Pressures and skin friction

AoA 4.25deg





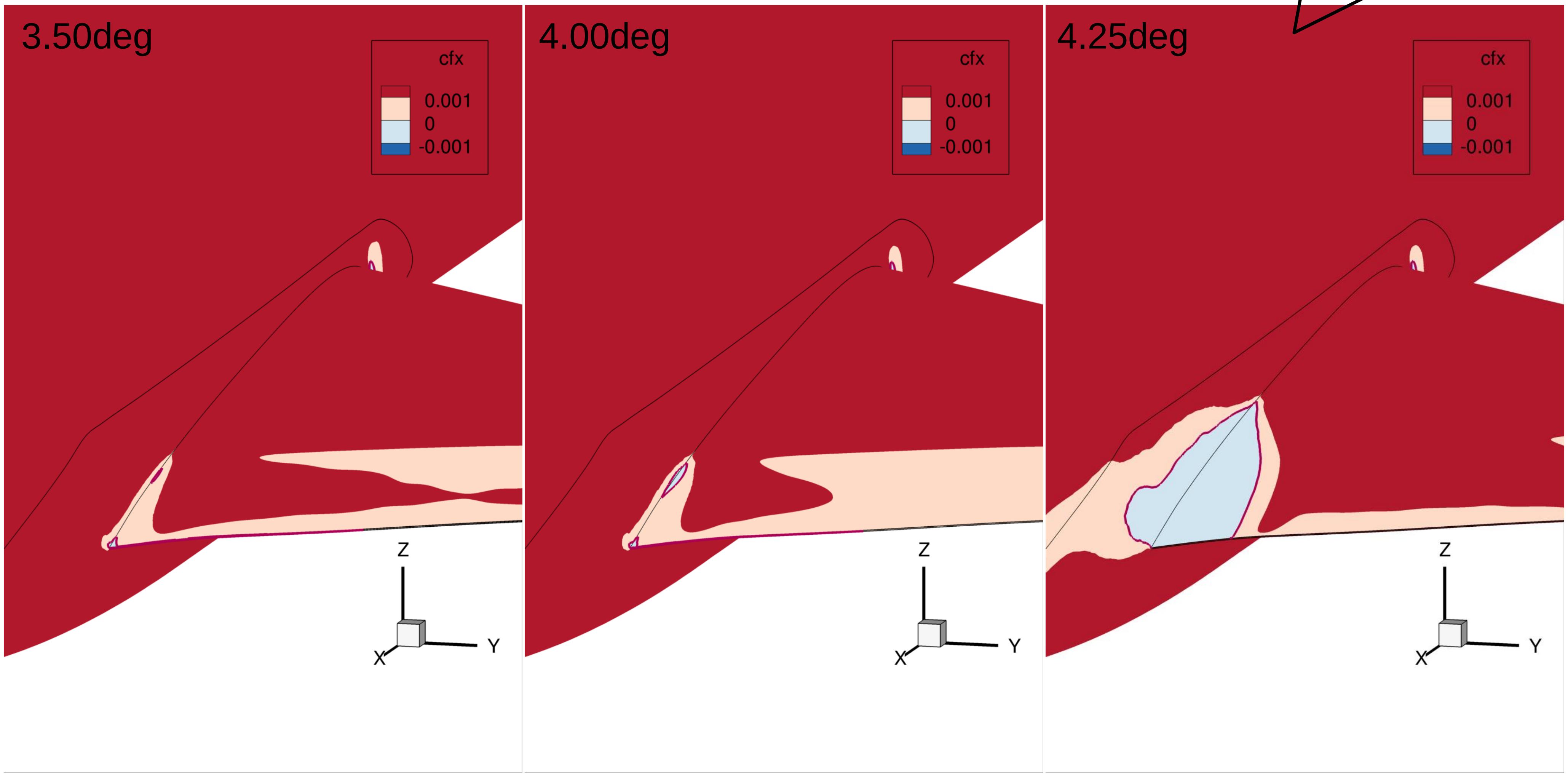




- RSM with constantly lower sectional lift
- significant reduction on mid-wing

Side-of-body separation with RSM

sudden appearance of large SOB separation



Summary

- angle of attack sweep at Mach 0.85 and Re 20Mio for the CRM-WB configuration
- medium grid size for each AoA: ≈46 Mio mesh nodes
- comparison of SA-QCR and RSM (SSG/LRR with an ln-omega formulation)

- for attached flow:
  SA-QCR with shock position more downstream than RSM → higher lift, but similar drag

- SA-QCR
  - with an early onset of separation on mid-wing (3.00deg) and side-of-body separation (3.75deg)
  - separated areas are smoothly growing in size
  - BUT comparable little effect on the shock position along the wing

- RSM
  - attached flow up to an AoA of 3.50deg, side-of-body separation with a sudden onset at 4.25deg
  - separated area stays comparably small, BUT has a significant effect on the shock position
  - lift is reduced significantly on the mid-wing due to the more upstream shock position

Outlook

- Why does RSM lead to such a large SOB separation?
- Check numerical robustness of the results
  - Variation of grid size
  - Reduce chopping of boundary layer in wing-body junction
- Try to improve convergence for RSM at high angles of attack using RANS
- URANS: Buffet / flow instabilities not found → increase AoA beyond 4.25deg at Re 20Mio

Thank you for your attention!

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L3: Medium Grid Size, LoQ Geometry

Requirements and Actual Settings

requirements	DPW-7, Medium (M)	DLR Göttingen
# points	$\approx 40 \cdot 10^6$	$\approx 46 \cdot 10^6$
Δy_1 / m	$\approx 2.96 \cdot 10^{-6}$	$2 \cdot 10^{-6}$
y^+	≈ 0.5	≈ 0.4
$\# \, \Delta y_1 s$	4	4
growth rate normal to wall		1.1
wing spanwise spacing	$< 0.05\% \cdot \frac{b}{2}$ at root & tip	LE root: 0.034 % LE tip: 0.0068 %
wing chordwise spacing	$< 0.05\% \cdot c_{local}$ at LE & TE	LE: 0.0168 % TE: 0.0435 %
wing TE Base	$>> 8$	**6**
spacing near fuselage nose & end of body	$< 0.5 \, \% \, c_{ref}$	nose: 0.66 % end of body: 1.38 %
farfield	$> 100 \cdot \frac{b}{2}$	3000 m

L3: Medium Grid Size, LoQ Geometry

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# $\Delta y_1 s$	4	
growth rate normal to wall		
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wing chordwise spacing		LE: 0.0168 % TE: 0.0435 %
wing TE Base		6
spacing near fuselage nose & end of body	$< 0.5\ \%\ c_{ref}$	nose: 0.66 % end of body: 1.38 %
farfield	$> 100 \cdot \frac{b}{2}$	3000 m

to allow smoother transition in local grid size

invalid hex-layers for smaller surface elements (could probably be fixed by adjusting CAD tolerances)