Improving the Prediction for the NASA High-Lift Trap Wing Model

by

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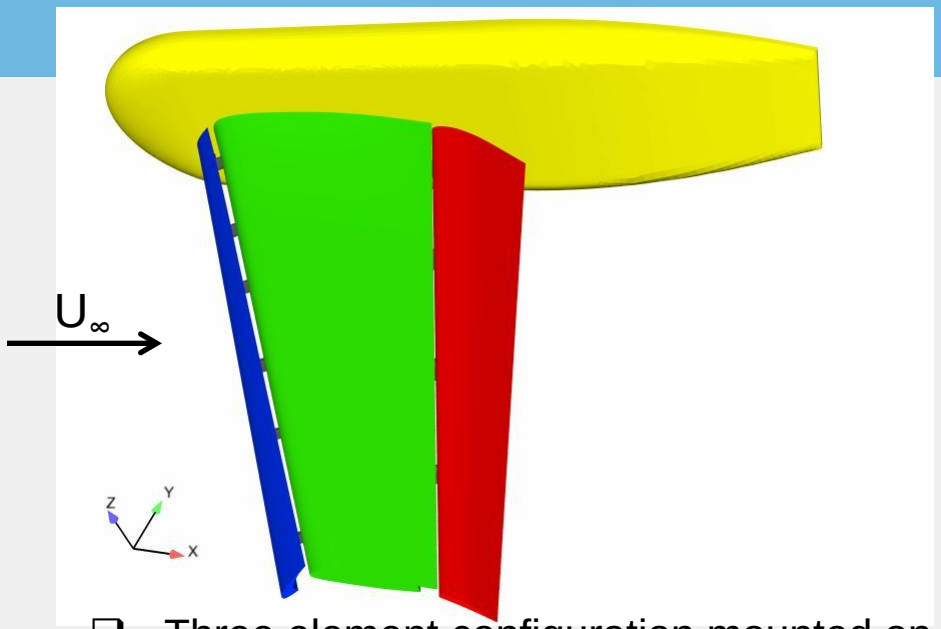
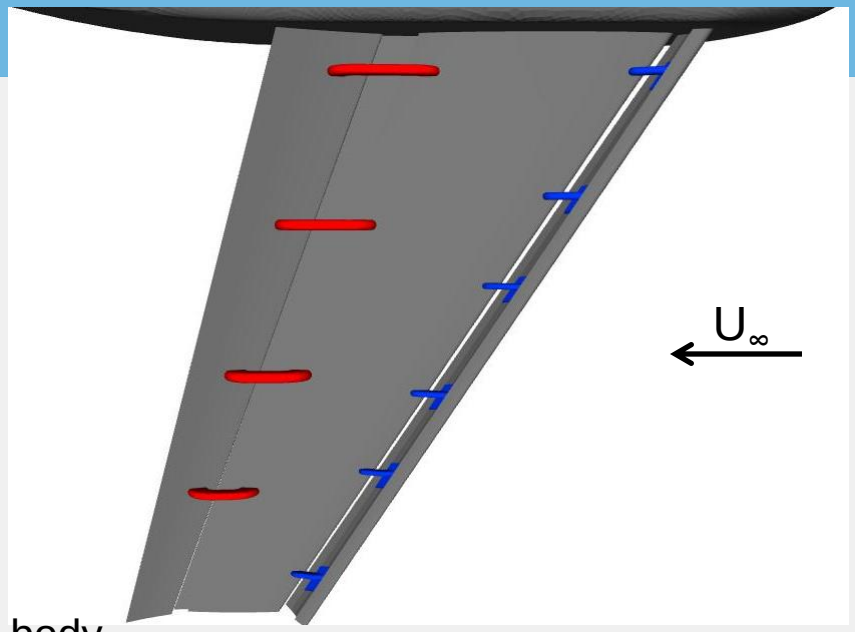
Layout of presentation

- Summary of results presented at the workshop in June
  - Grid convergence
  - Maximum lift predictions
  - Investigation of three turbulence models
- Improving the predictions
  - Sensitivity to artificial dissipation
  - Approximation of the viscous operator
  - Including the brackets (“real geometry”)
  - Transition prediction and specification
- Summary and conclusions

Model geometry and flow conditions





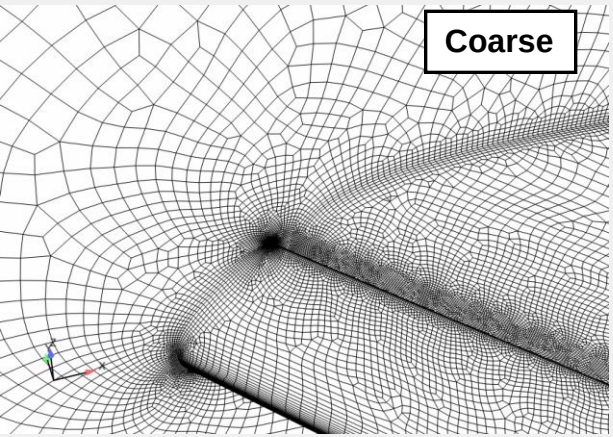
- Three element configuration mounted on a body
  - AR 4.56, taper ratio 0.4, leading edge sweep φ=33.9°
- Experimental data from NASA Langley
  - Flow conditions M_∞=0.2, Re=4.3 $\times$ 10^6
- Two flap settings
  - **Configuration 1**: flap deflection 25° (most computations for this deflection)
  - **Configuration 8**: flap deflection 20°
- Brackets
  - Part of the “real geometry” measured
  - Most calculations neglected these devices for the workshop

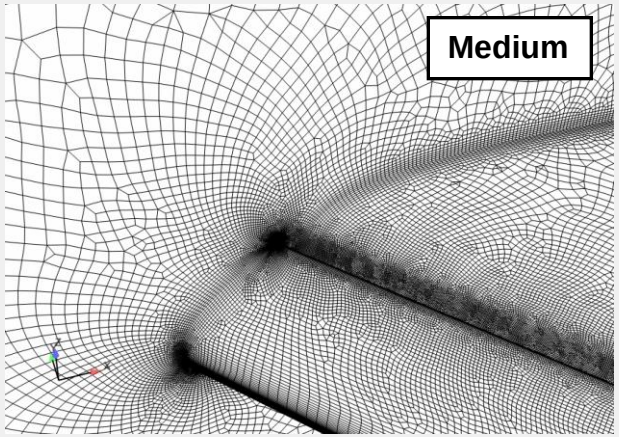
Grids

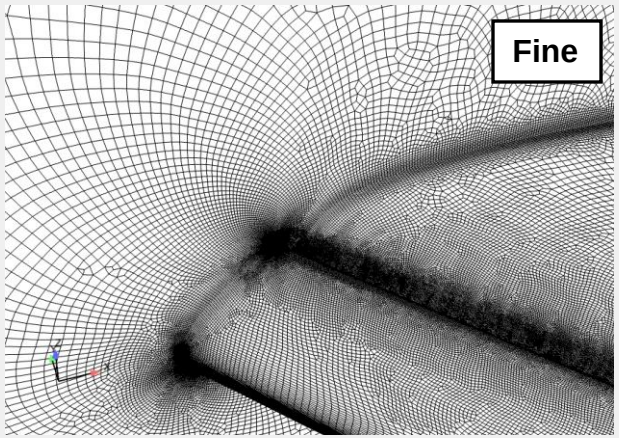
DLR grids, Configuration 1	Coarse	Medium	Fine
# nodes	12.3×10^{6}	37.0×10^{6}	110.7×10^{6}
# boundary nodes	328×10^{3}	683×10^{3}	1421×10^{3}
# hexahedral elements	11.2×10^{6}	34.1×10^{6}	103.3×10^{6}
# prisms	42×10^{3}	92×10^{3}	217×10^{3}
# tetrahedral elements	5.3×10^{6}	13.3×10^{6}	36.3×10^{6}

- DLR grids generated with SOLAR grid generator
- Unstructured hexahedral elements mainly in near field
  - Tetrahedral elements further away
- Configuration 8 similar in size as medium grid for Configuration 1
- Configuration 1 with bracket slightly finer than medium 1 grid without rackets
  - About 50 million nodes

Grids pictures

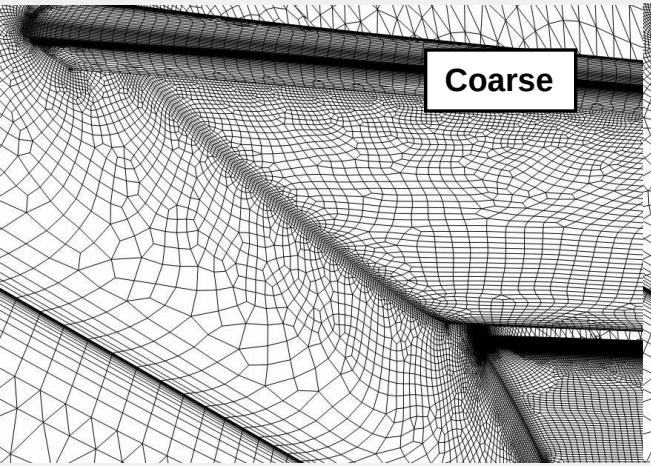


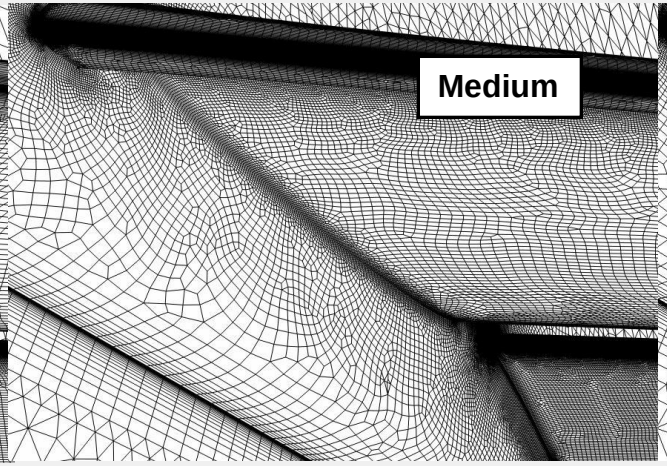


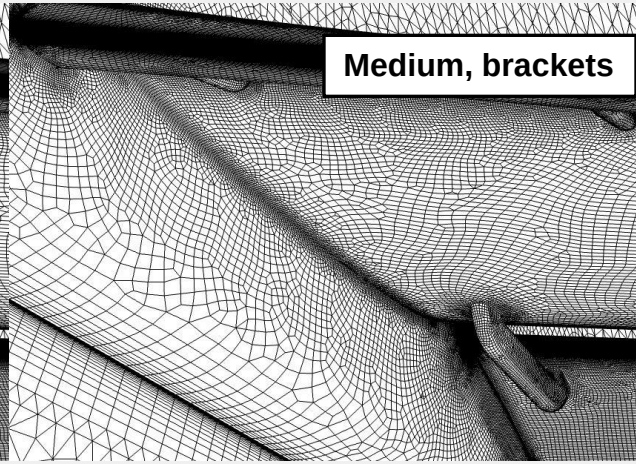


- Grids for grid refinement study
  - Configuration 1, no brackets

Grids pictures



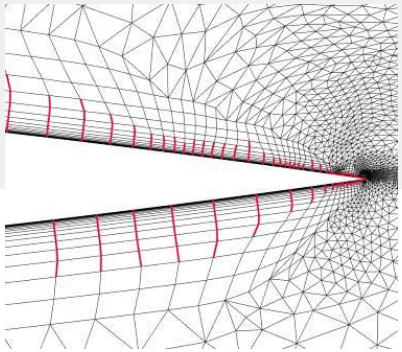




- Structured layer constant in size for all grids
- Very similar grid resolution with/without brackets

Computational information

- Edge in-house code for unstructured grids
- 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
- Central scheme with artificial dissipation for mean flow
  - Central or upwind for turbulence
- Linux cluster used, up to 128 processors
  - Computing time ~ (128*) 24 hours for finest grids (~110 M nodes)
- Weak boundary conditions on all variables including no-slip velocity
  - AIAA 2009-3551
- Line-implicit time integration in regions with stretched grids
  - AIAA 2009-163



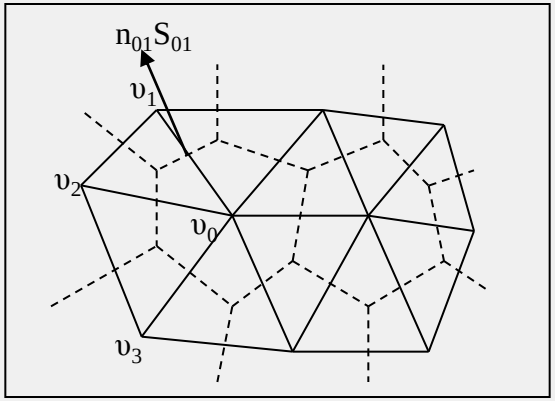
Approximation of viscous operator

Viscous stress tensor:

$$\tau = (\mu + \mu_T)\left(\nabla u + (\nabla u)^T - \frac{2}{3}(\nabla \cdot u)I\right)$$

Thin layer approximation of viscous flux:

$$\tau \cdot n \approx \mu\left(\frac{\partial u}{\partial n} + \frac{1}{3}\left(\frac{\partial u}{\partial n} \cdot n\right)n\right)$$



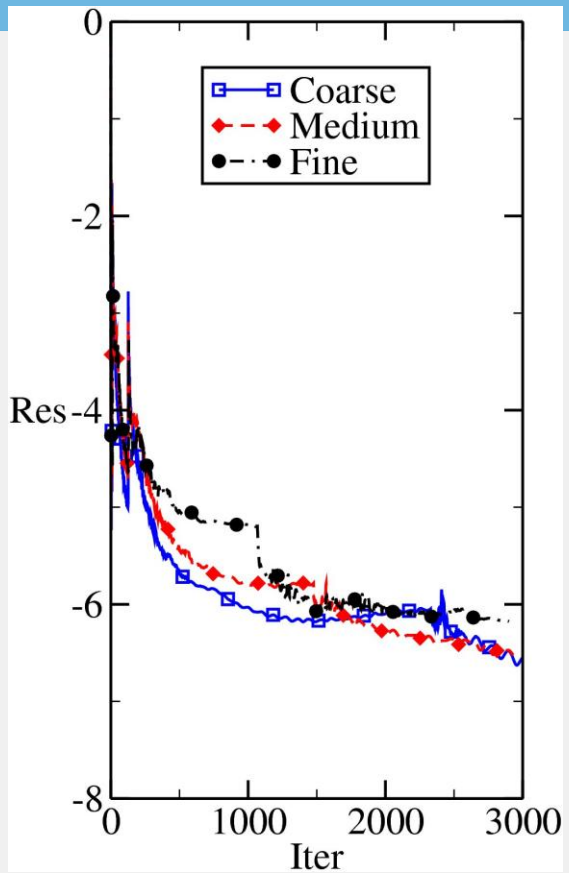
where τ is the stress tensor and n the unit normal between two nodes on an edge

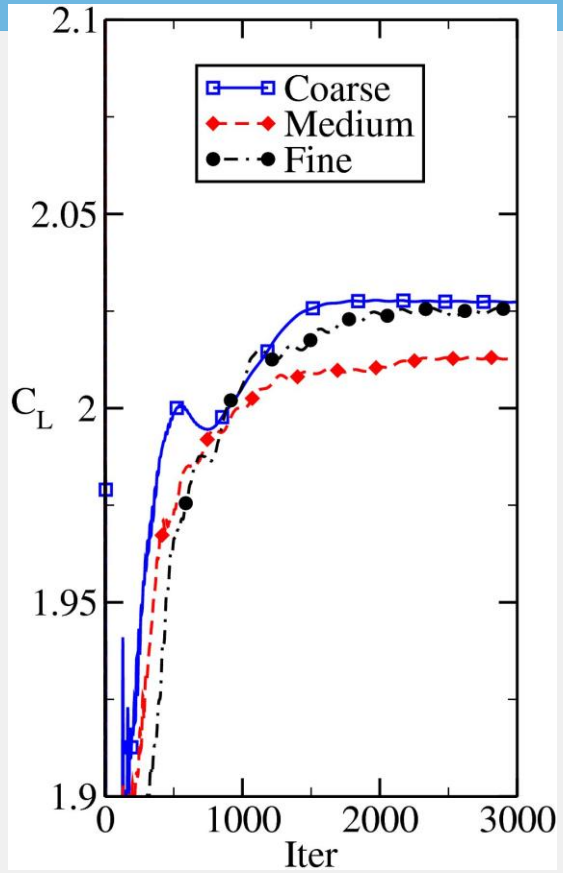
Approximation of normal derivatives: $$\frac{\partial \varphi}{\partial n_{01}} = \frac{q_1 - q_0}{|x_1 - x_0|}$$

For a full viscous operator: Remaining tangential derivatives added from nodal gradients:

$$\nabla \varphi_0 = \frac{1}{V_0}\sum_i \frac{(\varphi_i + \varphi_0)}{2} n_{i0} S_{i0}$$

Typical convergence rates





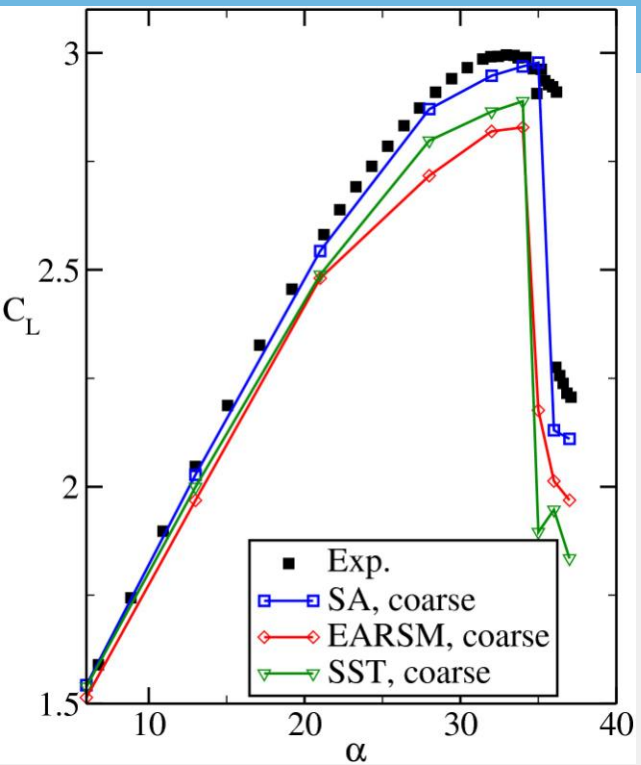
- Coarse, medium fine grids, α = 13°
- ~ 3000 iterations required

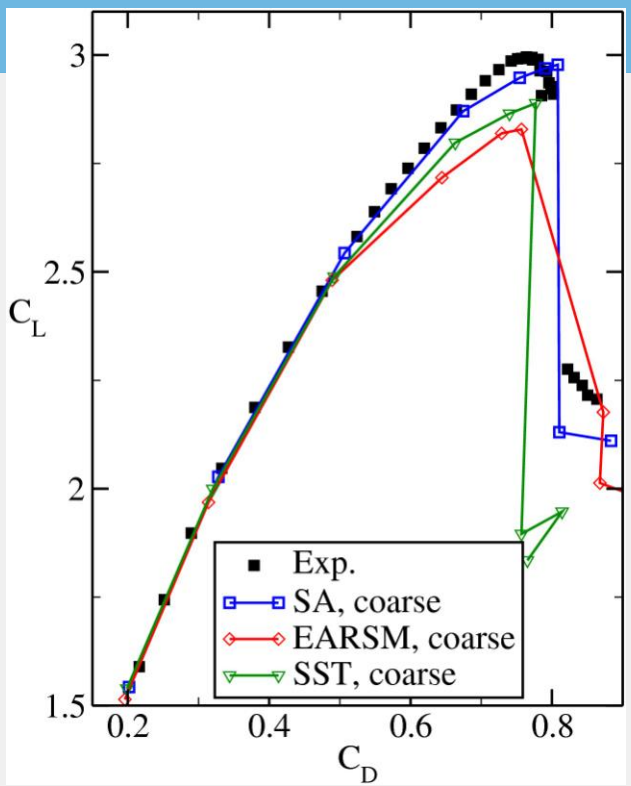
Summary of results from workshop in June 2010

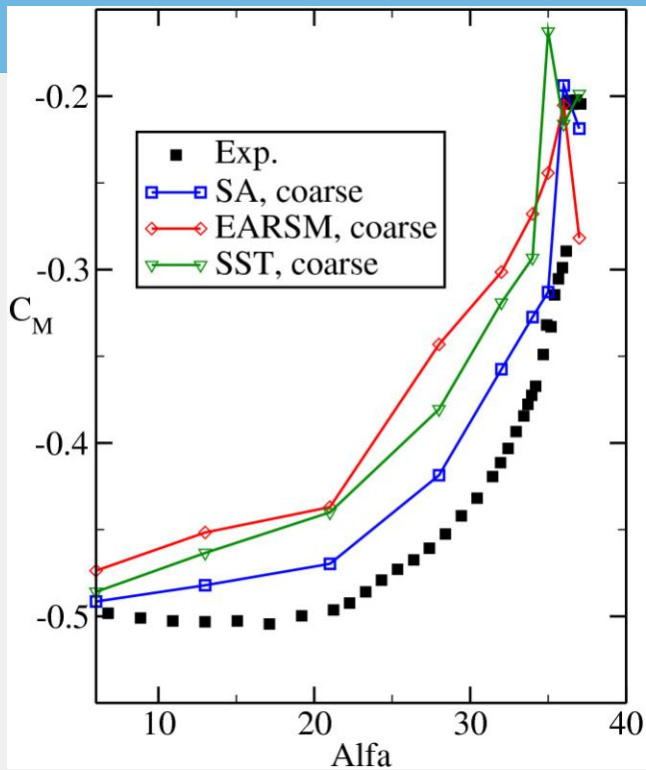
- Investigation of three turbulence models
- Grid convergence
- Maximum lift predictions

- Thin-layer approximation used
- Fully turbulent calculations

Turbulence model influence, Configuration 1

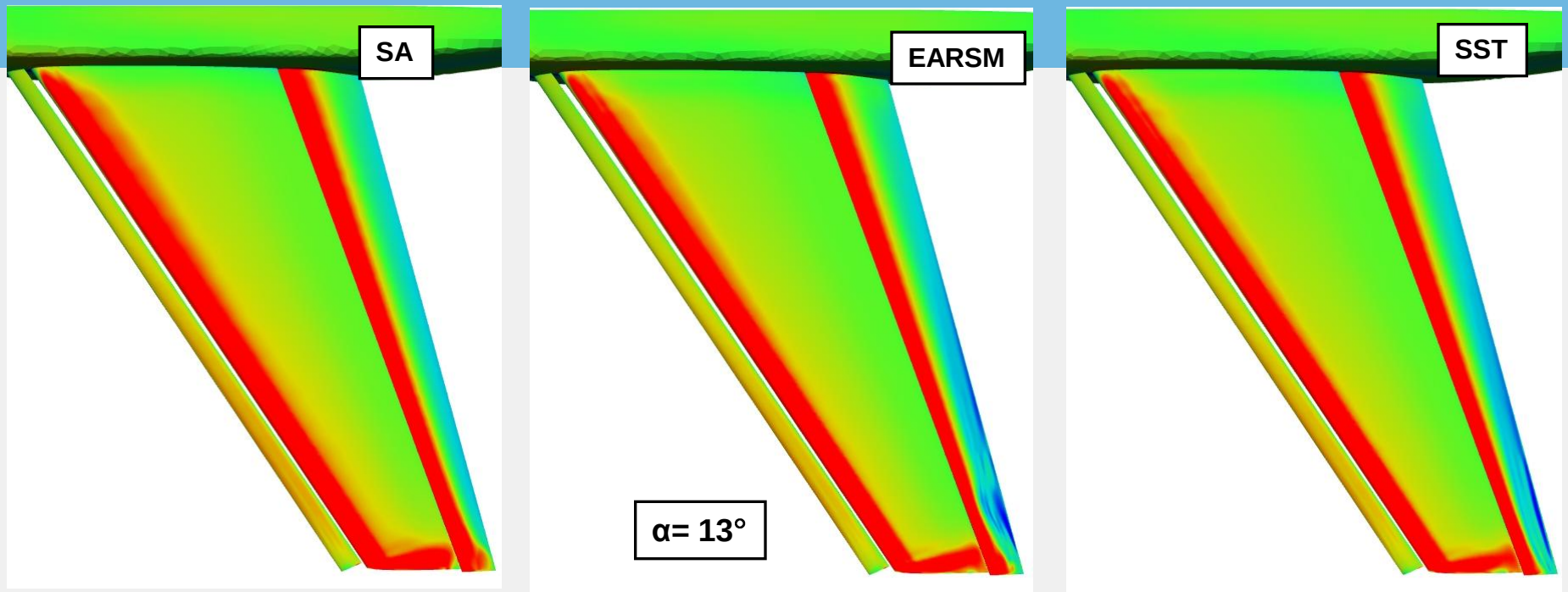






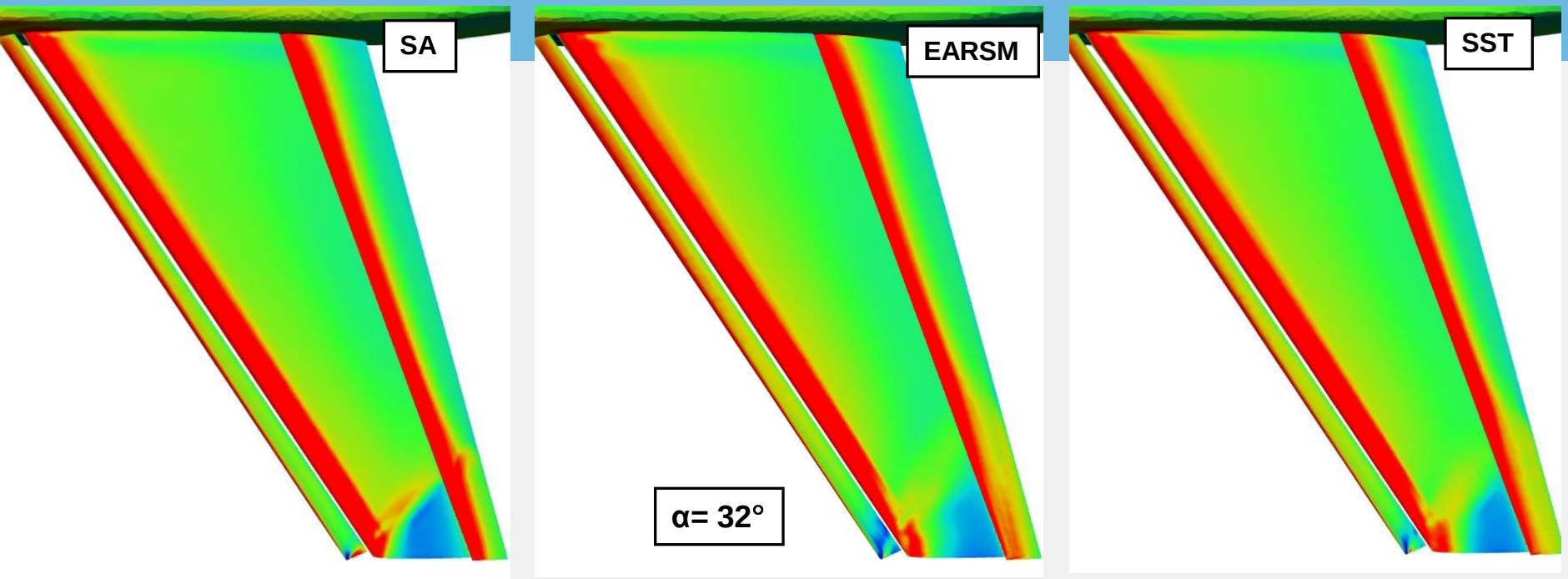
- Models: SA, EARSM, SST
- Lower lift with EARSM, SST
- Earlier lift break down with EARSM, SST

Turbulence model influence, Configuration 1



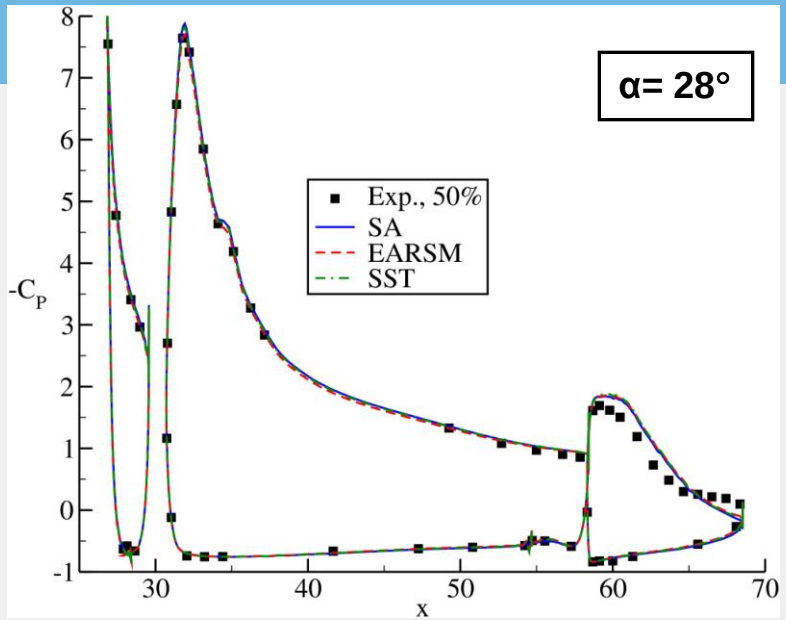
- Skin friction plot, x-component (blue = reversed flow)
- Larger trailing edge flap separation at lower incidences with EARSM, SST
- Very small trailing edge flap separation with SA

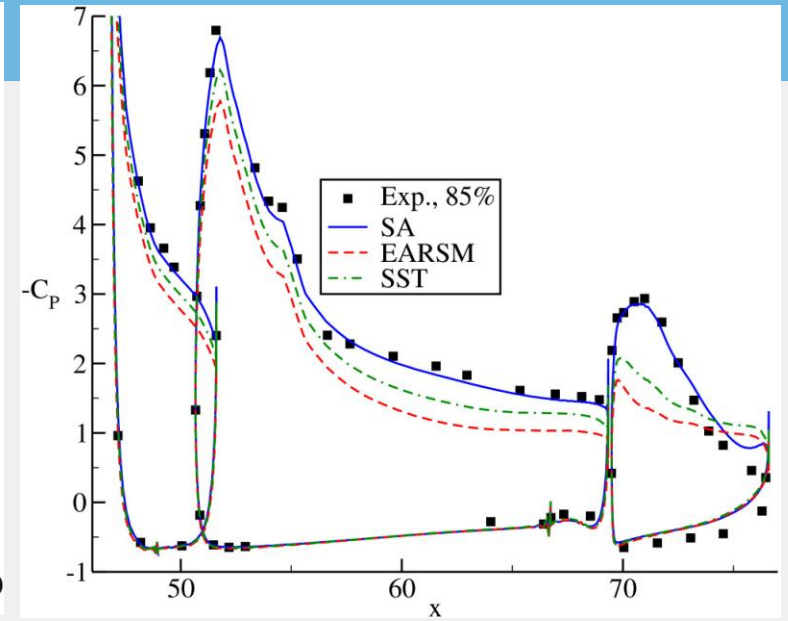
Turbulence model influence, Configuration 1

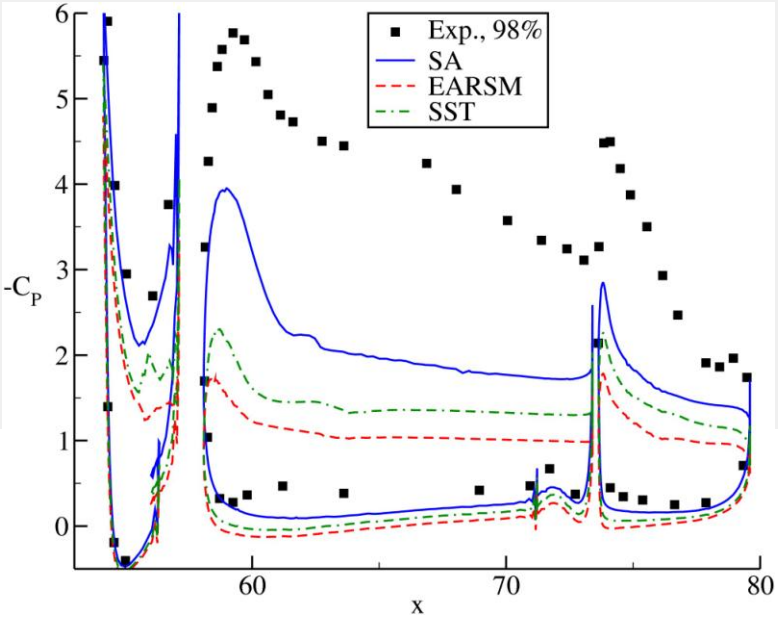


- Attached flap flow at higher incidences
- Differences on slat and main wing at higher incidences

Turbulence model influence, Configuration 1



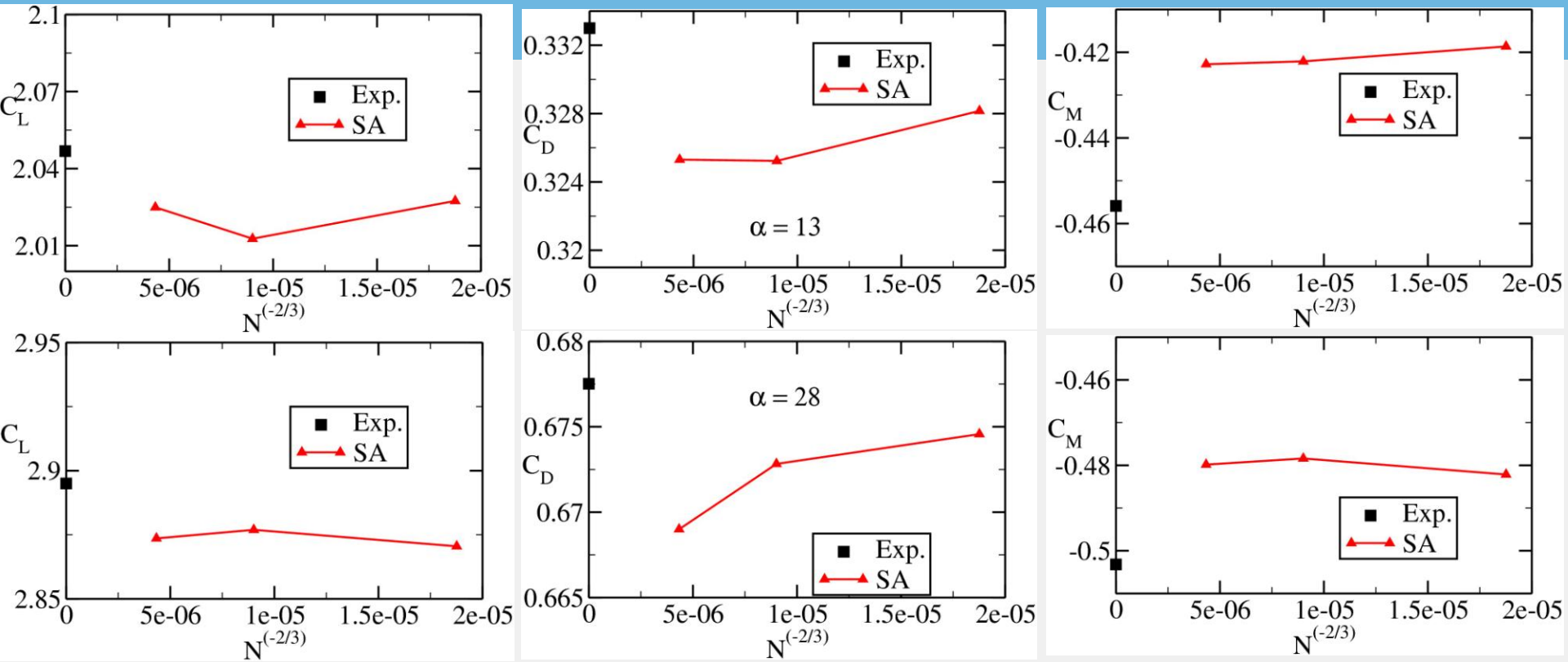




- ❑ Larger experimental discrepancies with EARSM ,SST
- ❑ Large deviations at the wing tip

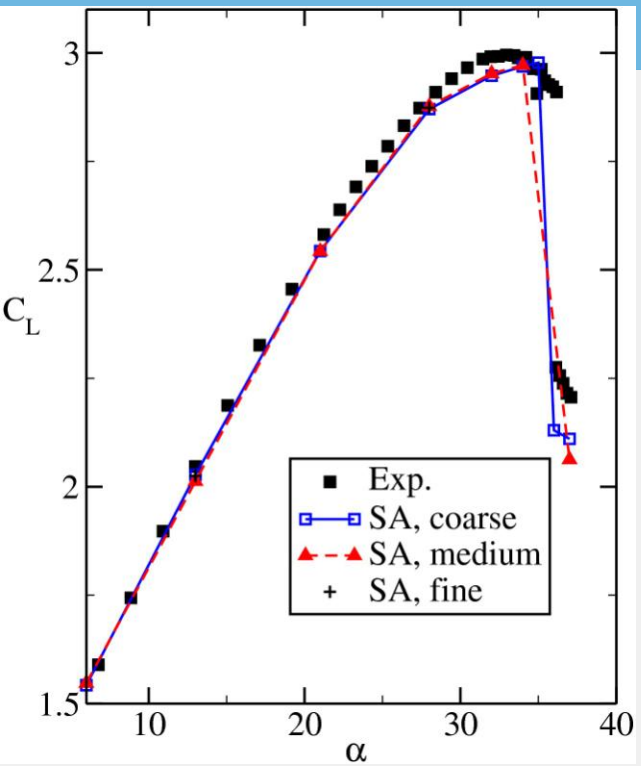
⇒ Stay with SA for the rest of the investigation

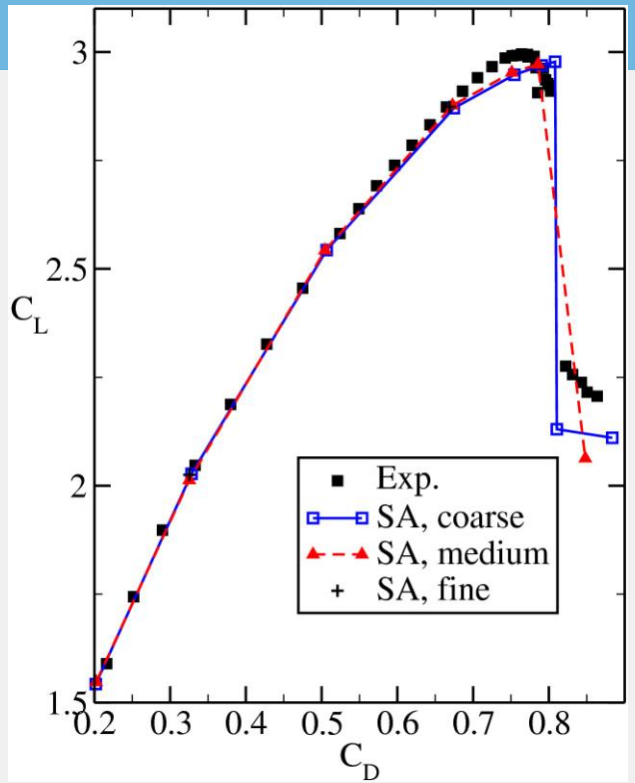
Grid convergence, Configuration 1

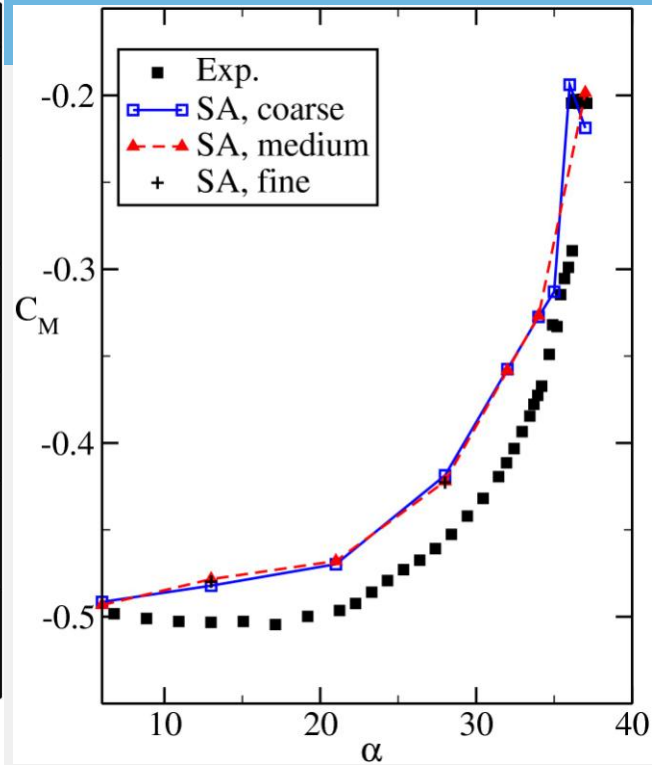


- Reasonable grid convergence
  - Small differences between grids, not monotonic though

Grid convergence, Configuration 1



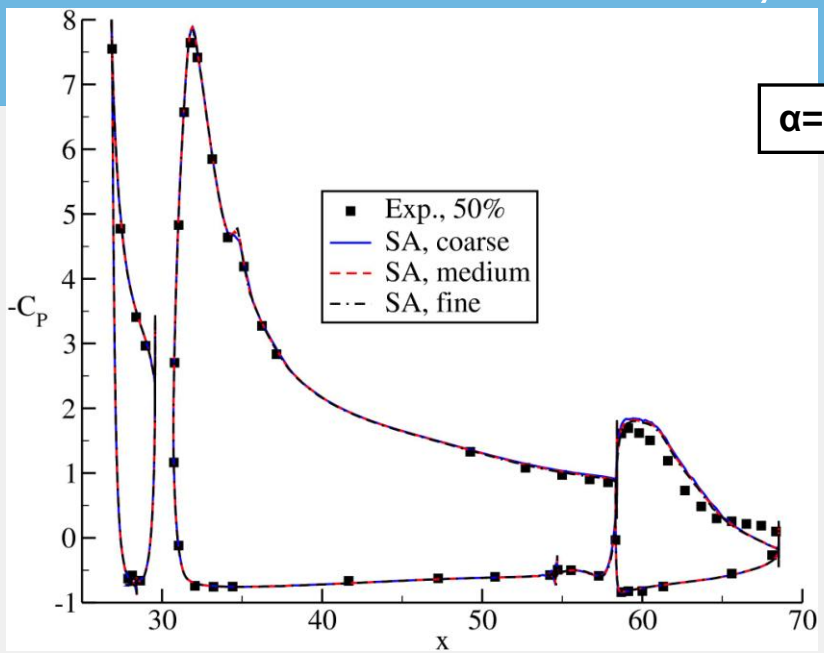


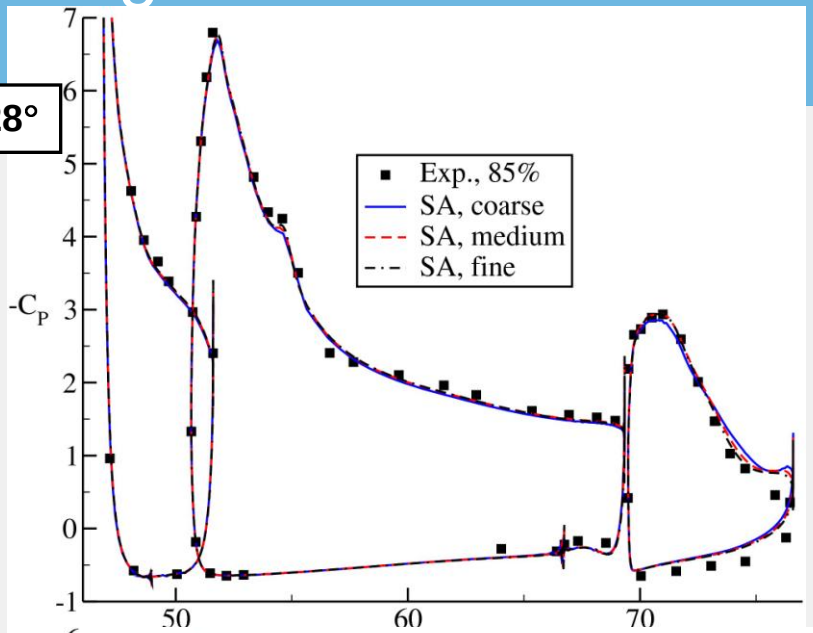


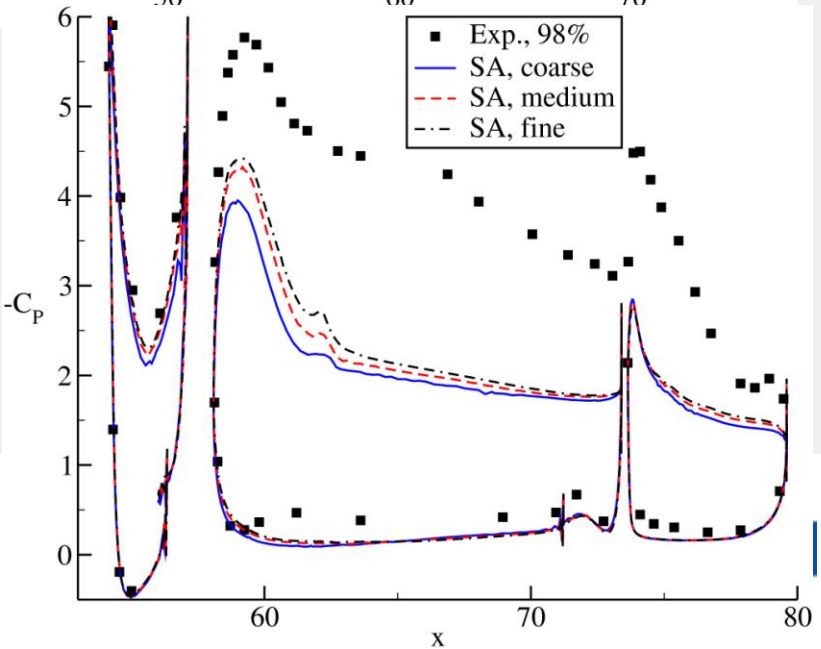
- Polars on coarse medium and fine grids
  - Only 2 incidences on finest grid (α=13º, α=28º)
- Small differences between results on different grids
  - Small under prediction of C_L, higher incidences
  - Lift break down at about α=36º
  - Over-prediction of C_M

Pressure distributions, Configuration 1

α= 28°

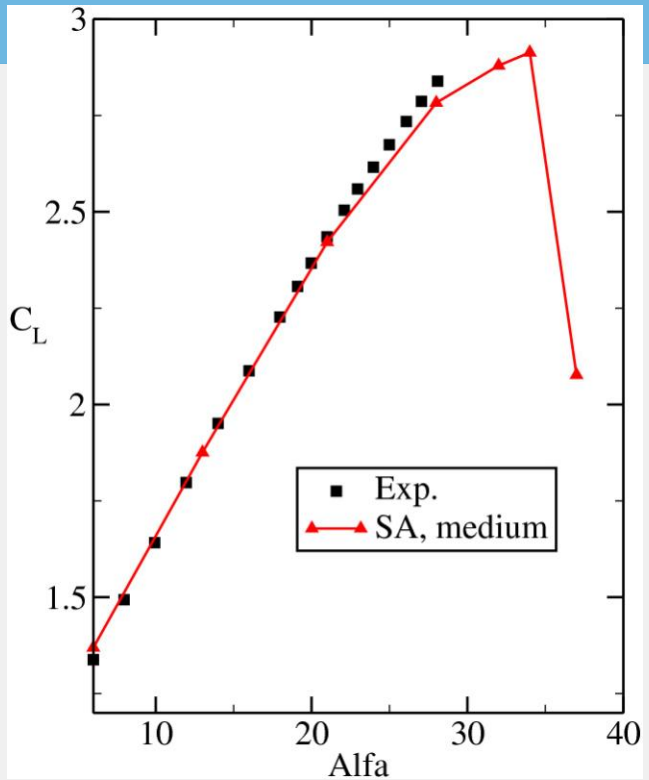






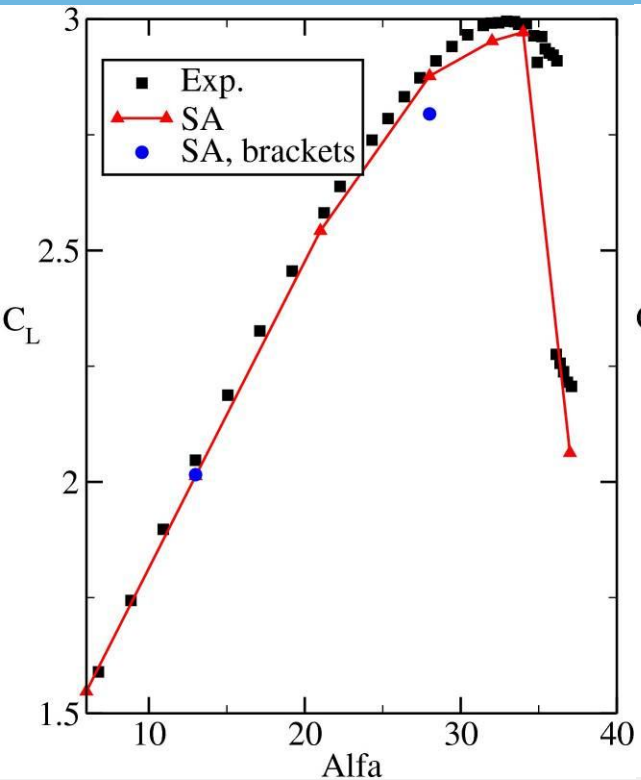
- Coarse, medium fine grids
- Small variations
- Large deviations at the wing tip
  - Not due to grid resolution

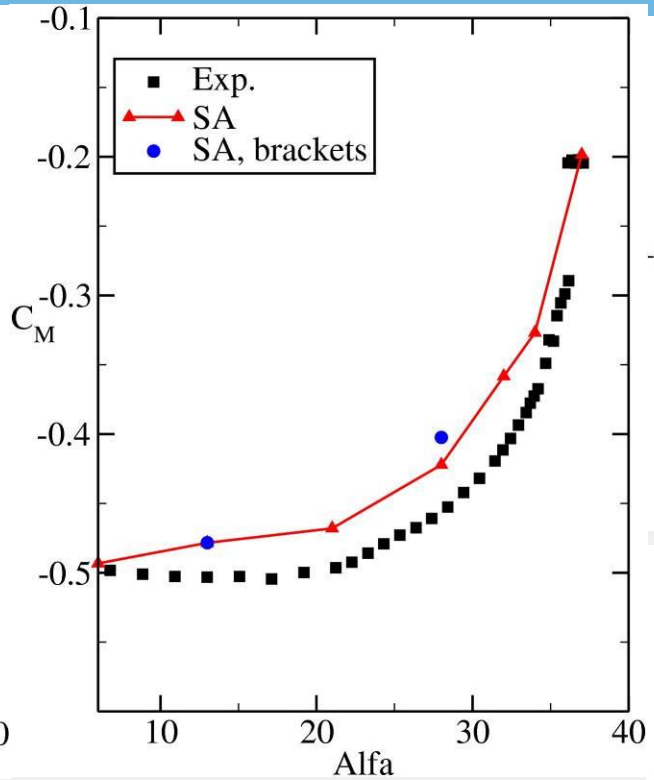
Configuration 8

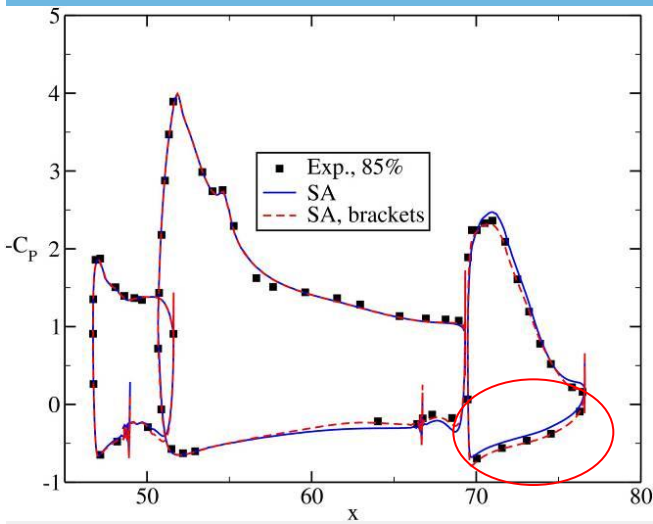


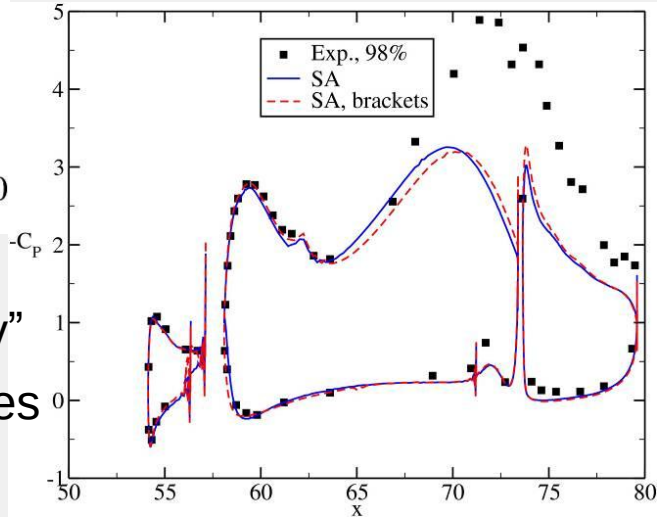
- Configuration 8 – smaller flap deflection angle 20º (reduced from 25º)
- Slightly lower lift
- Same behavior as Configuration 1 ⇒ no added value

Configuration 1 + brackets









- Configuration 1 + brackets = “real measured geometry”
- Lift becomes more under-predicted at higher incidences
- Pressure distributions improved at some stations

Conclusions of results from workshop in June 2010

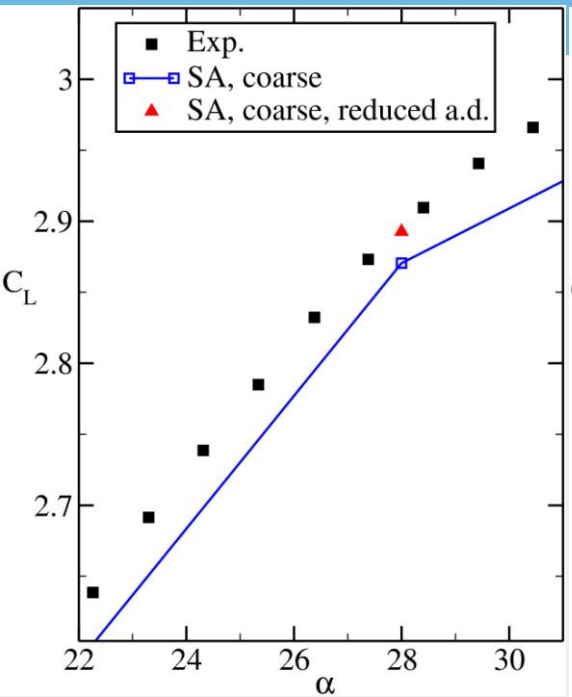
- SA model provides better results than other models
- Influences from grid resolution small
- Small under prediction of C_L, over-prediction of C_M
- Introducing brackets increased distance to experiments

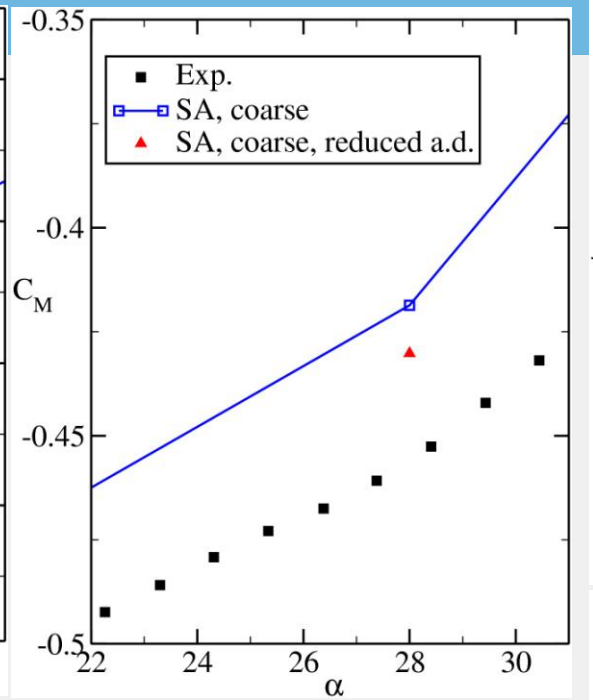
- Similar results to many other participants
- FOI results denoted as “fair”

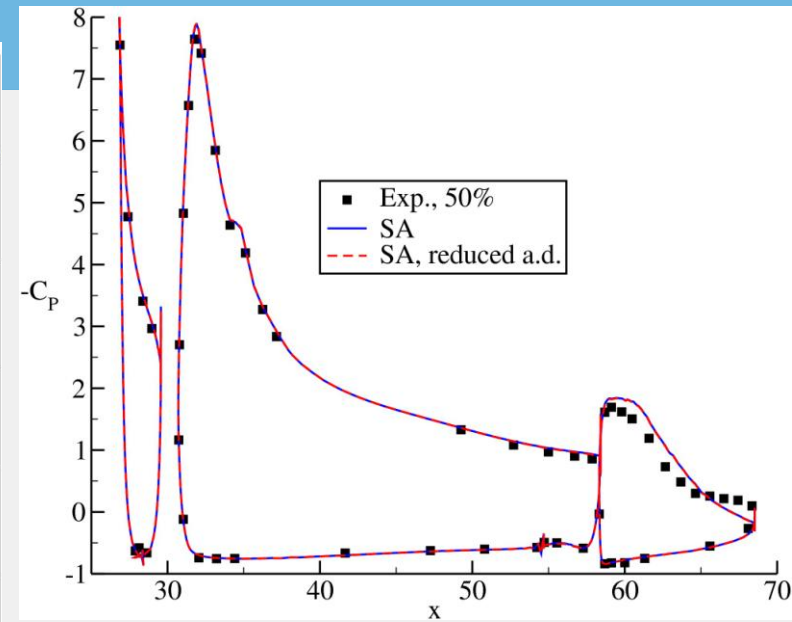
Further investigations after workshop

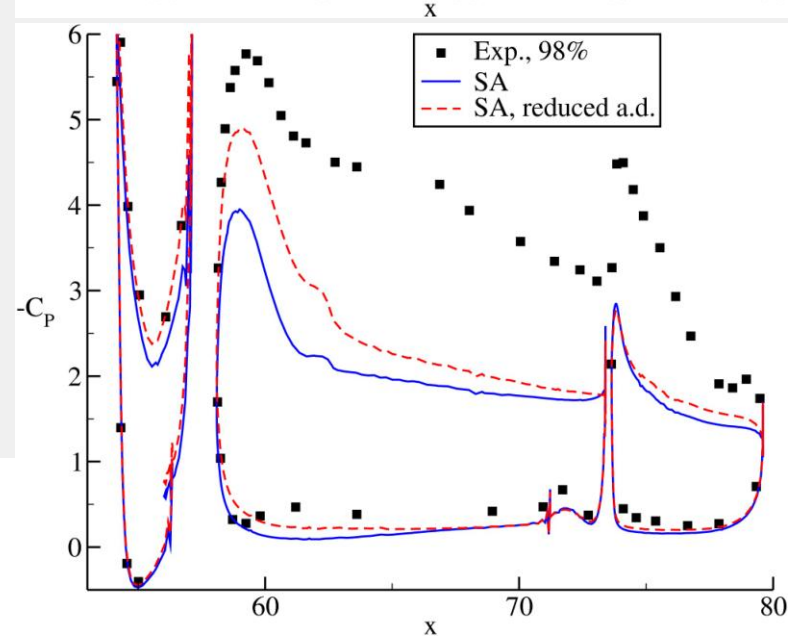
- Reducing artificial dissipation
- Full viscous operator
- Laminar-turbulent transition
- Geometry with brackets used mostly

Effect of reducing artificial dissipation





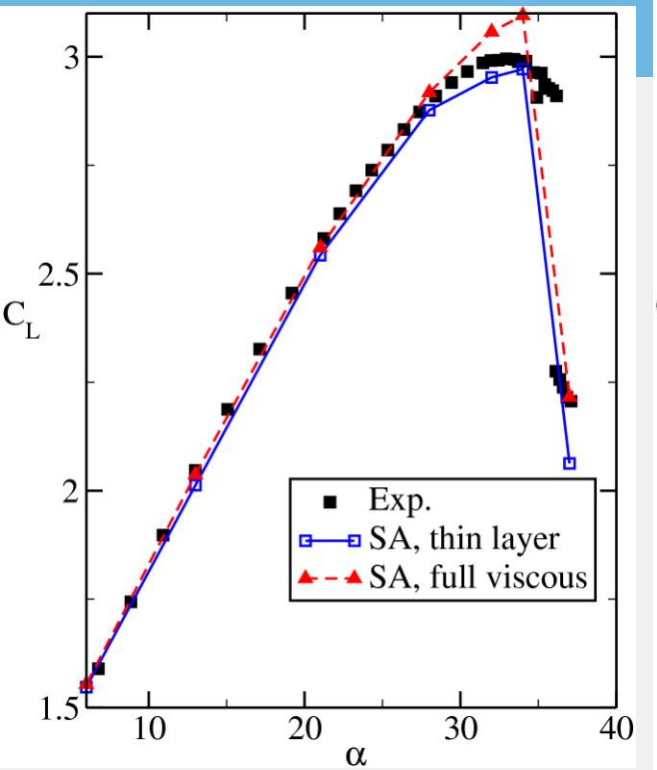


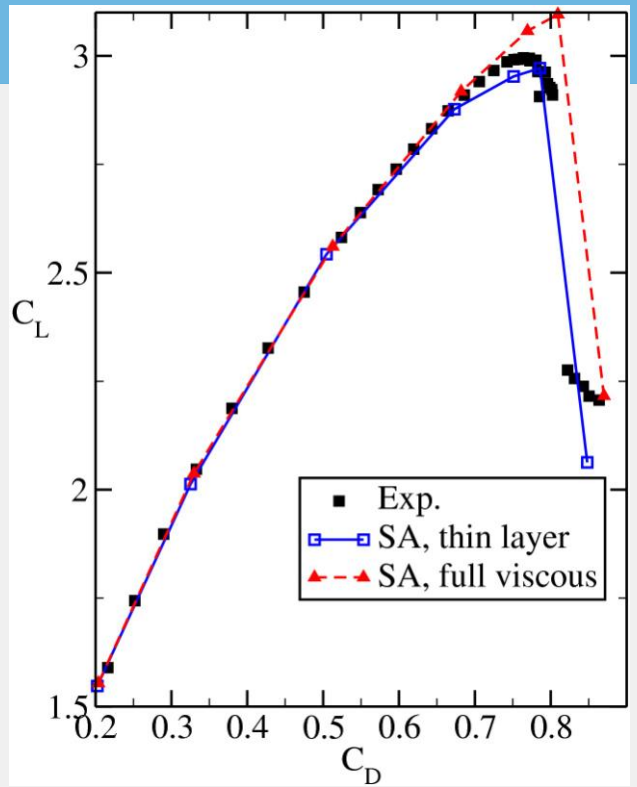


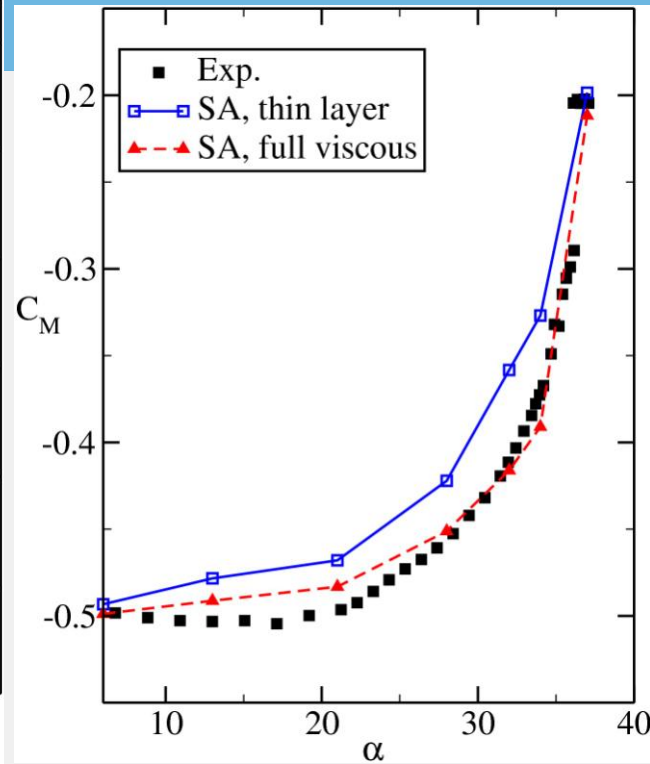
- Configuration 1, α=28º, no brackets
- Only reduction of artificial dissipation on turbulence eq. possible
  - Central scheme introduced with very small coeff.
- No inboard influence
  - Some influence at wing tip

⇒ Limited influence

Effect of Viscous Operator

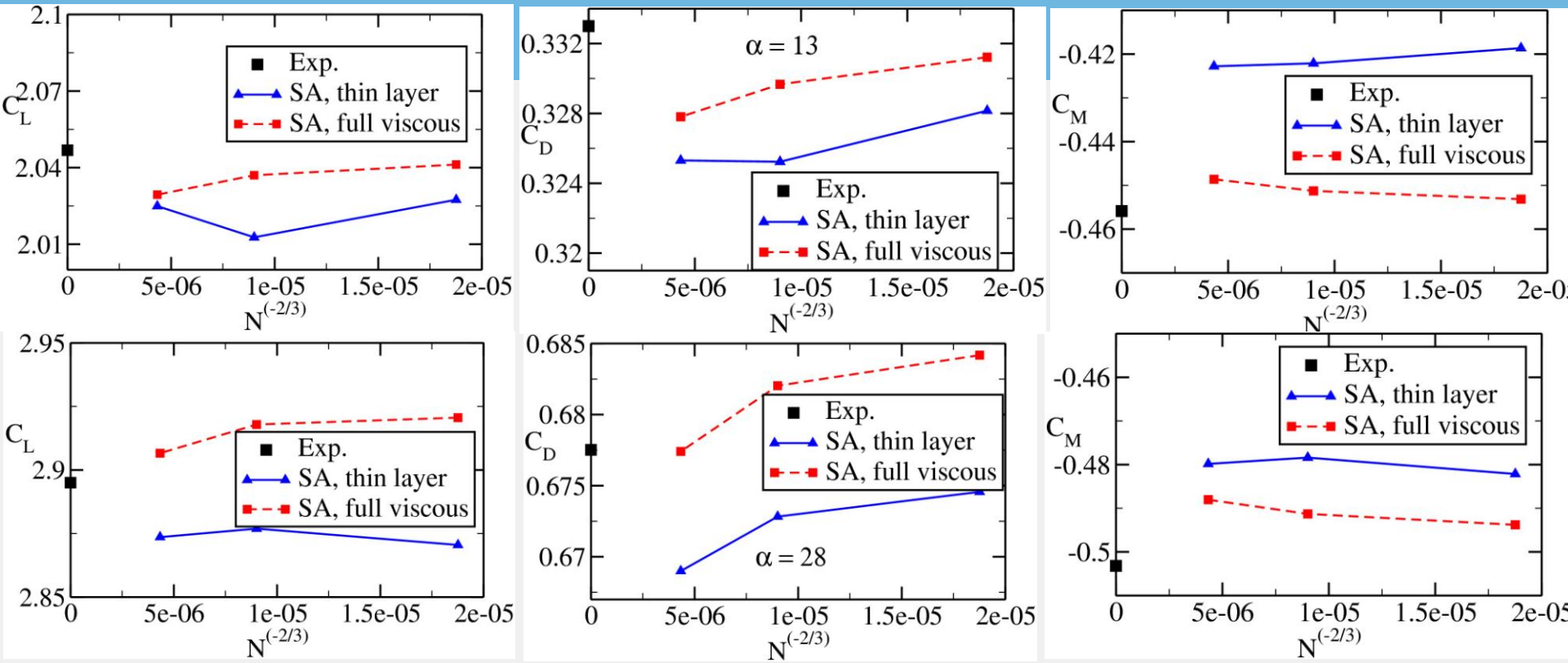






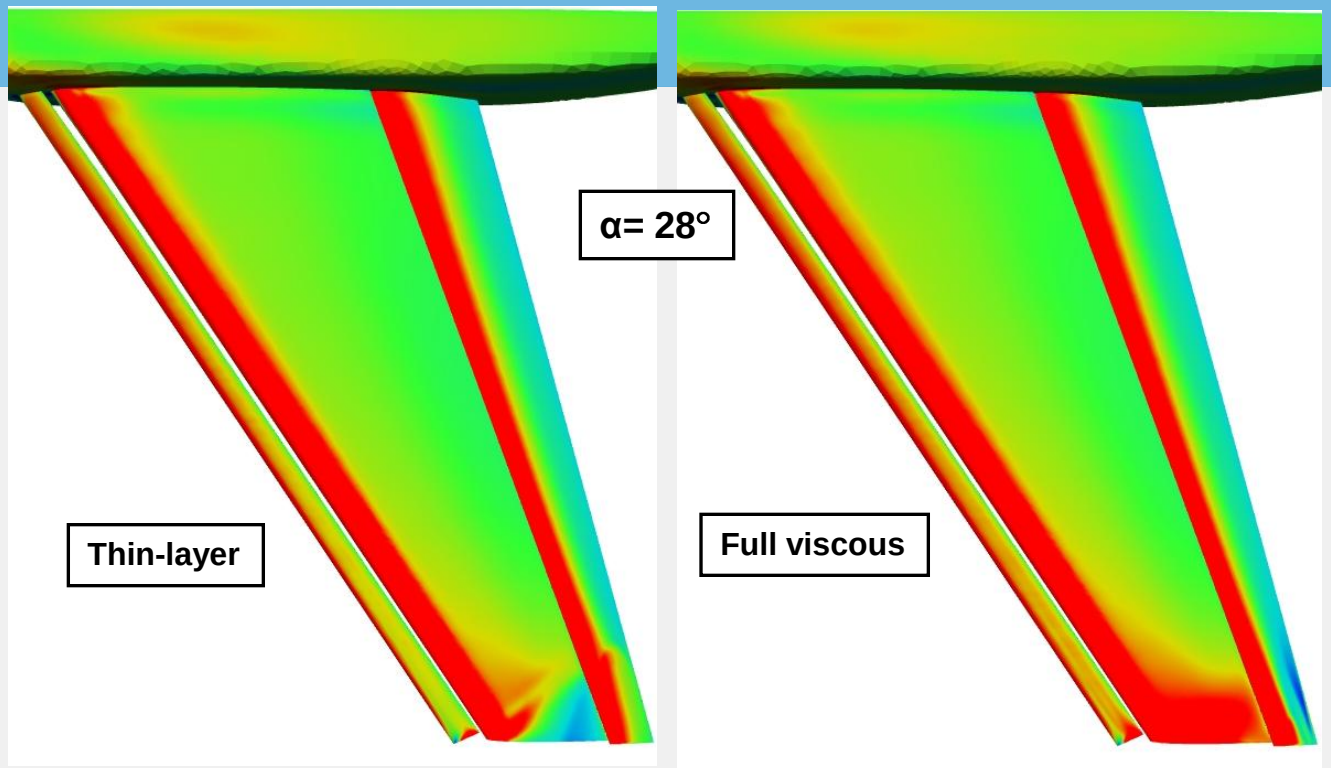
- Comparison thin-layer vs. full viscous operator
- Configuration 1, no brackets, medium grid
- Larger influence
  - Small over-prediction of C_L with full operator
  - Improved prediction of C_M

Effect of Viscous Operator, Grid Convergence



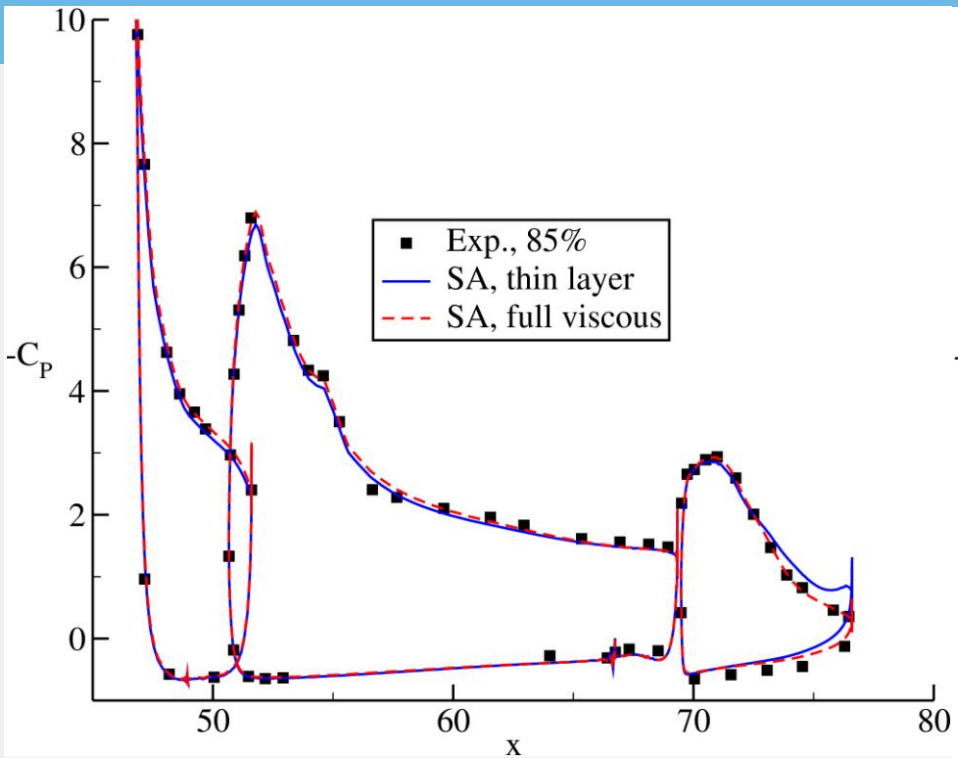
- Small differences due to different grids and operators
- Monotonic convergence with full operator
- Higher C_L + C_D and lower C_M, closer to experiments

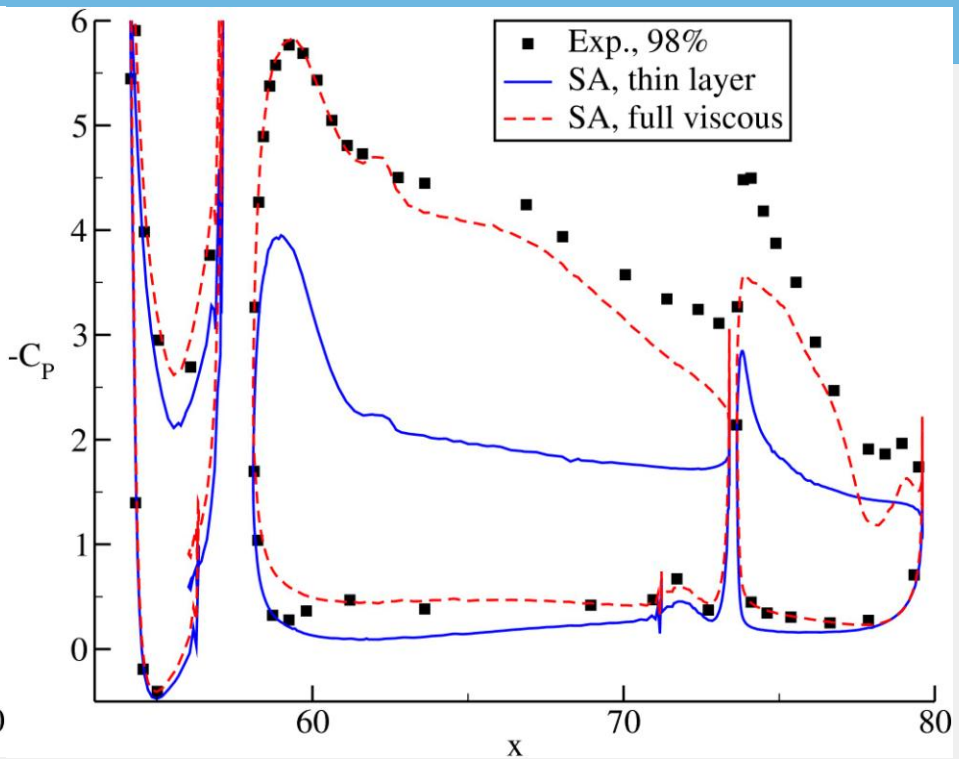
Effect of Viscous Operator



- Comparison thin-layer vs. full viscous operator
- Cf distribution, x-component
- No inboard influence
- Large influence on wing-tip flow

Effect of Viscous Operator



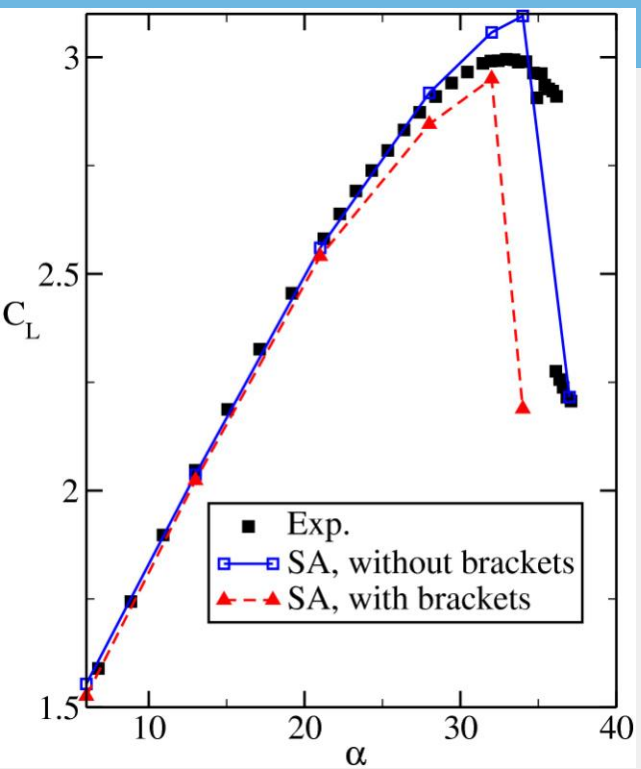


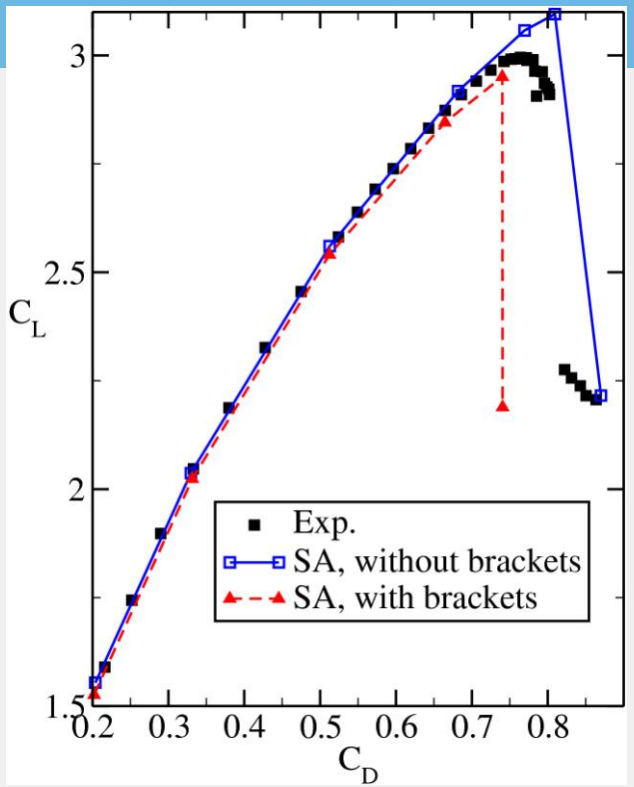
- No inboard influence
- Large influence on wing-tip flow ≥ 85% span

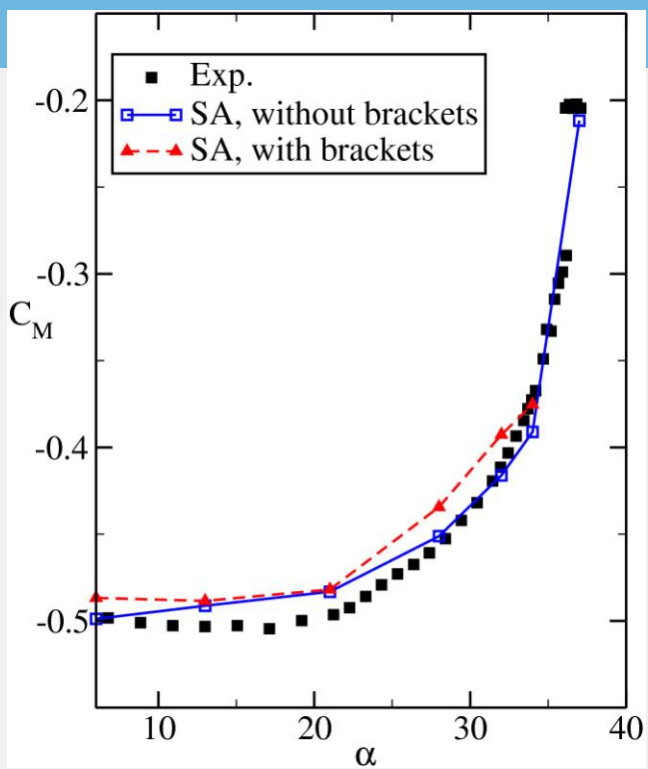
⇒ Full viscous operator gives improved prediction

- Note: brackets not included !

Effects of brackets

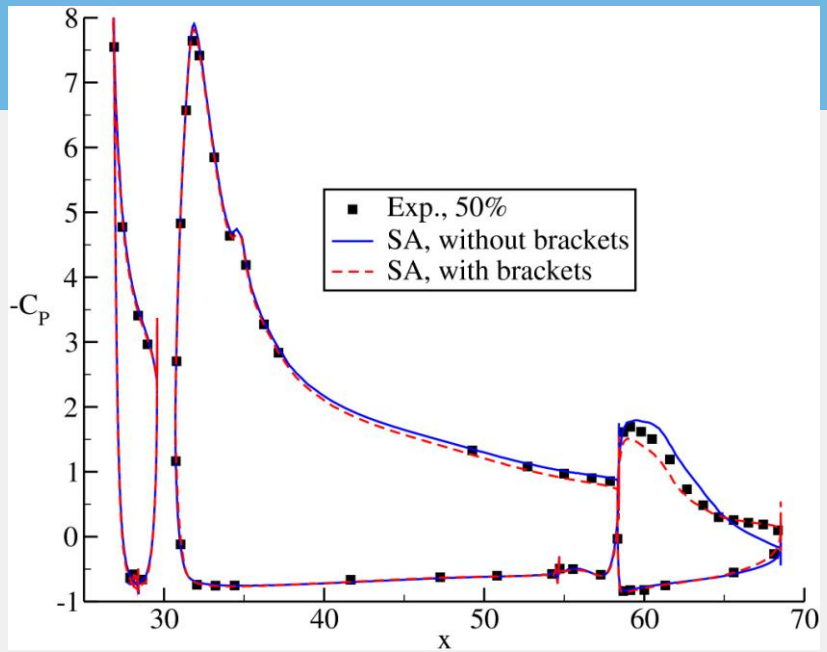


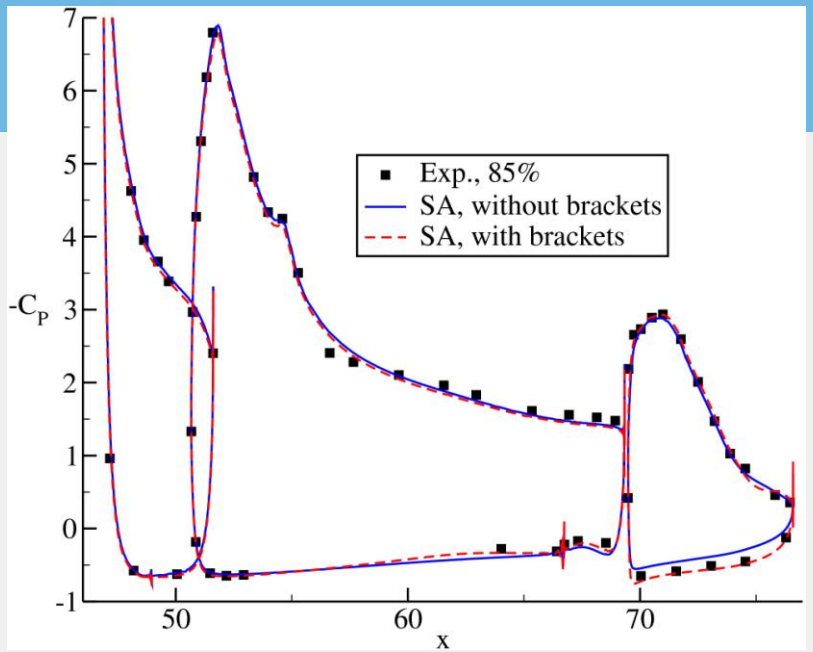


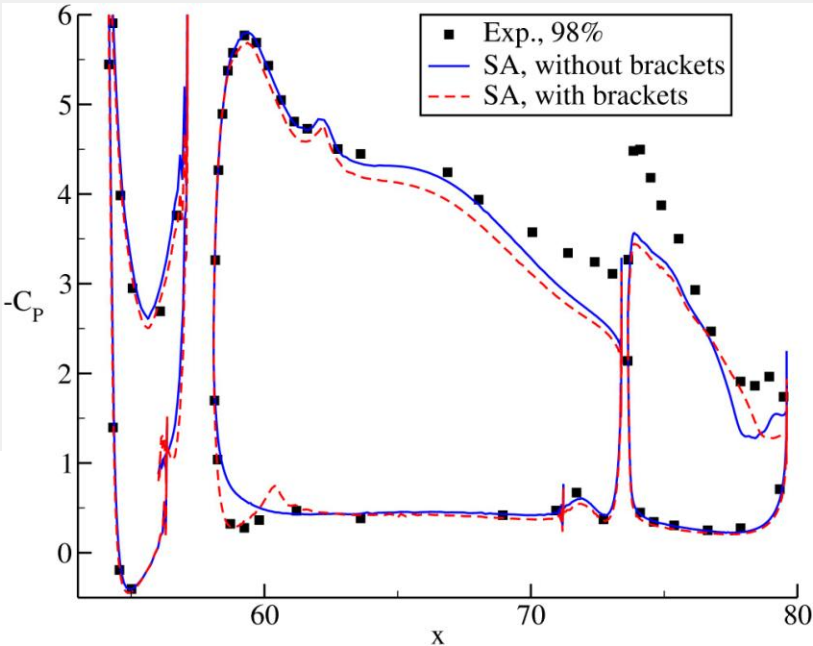


- Configuration 1, medium grids, with/without brackets
- Full viscous operator
- Brackets lead to
  - Lower lift at higher incidences, maximum lift 5% lower
  - Earlier lift (34º) break down (at 37º with brackets)
  - Larger values of C_M with larger discrepancies to experiments

Effects of brackets







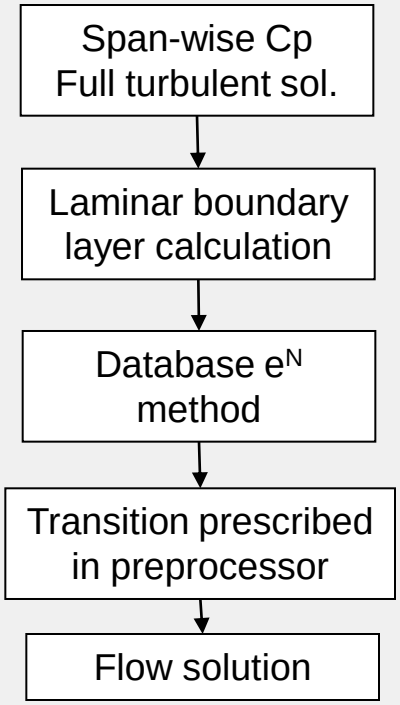
- C_P with/without brackets, α=28º
- Some improved predictions
  - Mainly at flap and rear wing

⇒ C_P improved but lift too low

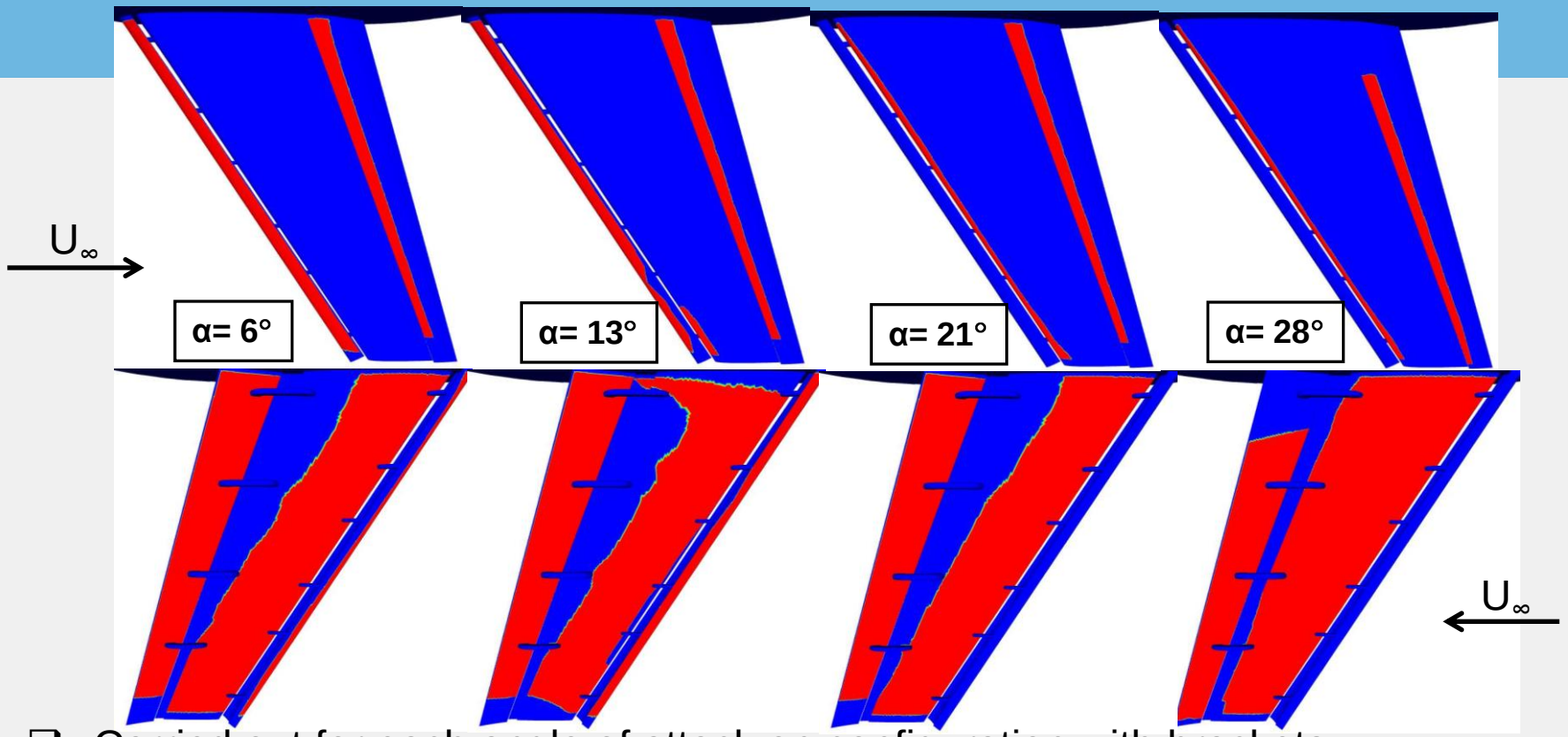
- So far fully turbulent calculations

Influence from transition

- Influence from transition investigated by transition prediction
- Data base method applied in 20 span–wise sections
  - Infinite local sweep assumed of each element
  - TS and cross-flow waves
  - Data based method with e^N with an envelope method
  - Transition assumed where N=15 or where laminar separation detected
- Pressure distribution from RANS
  - Input to boundary layer code and transition prediction
  - Cp from configuration without brackets
- Output used to prescribe turbulent/laminar parts CFD
  - Turbulent production switched off in laminar parts
  - Applied to configuration with brackets

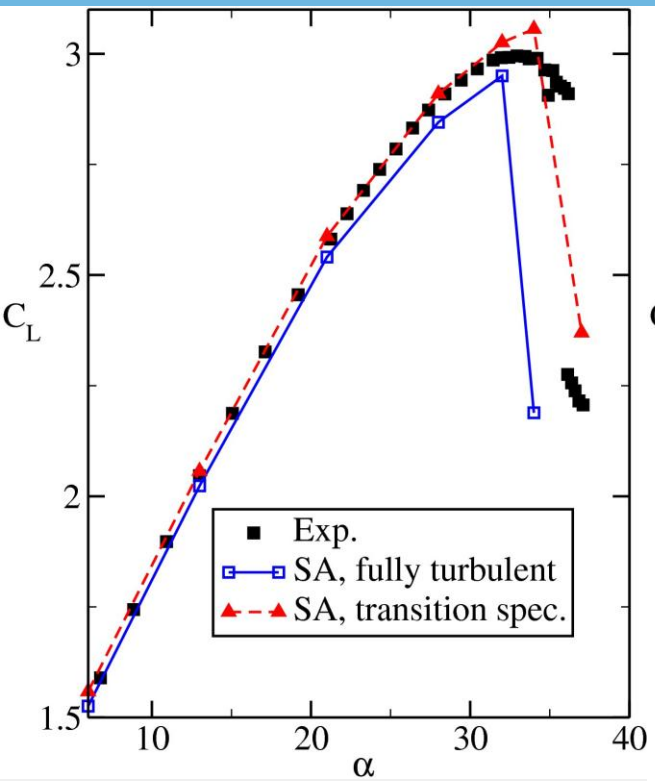


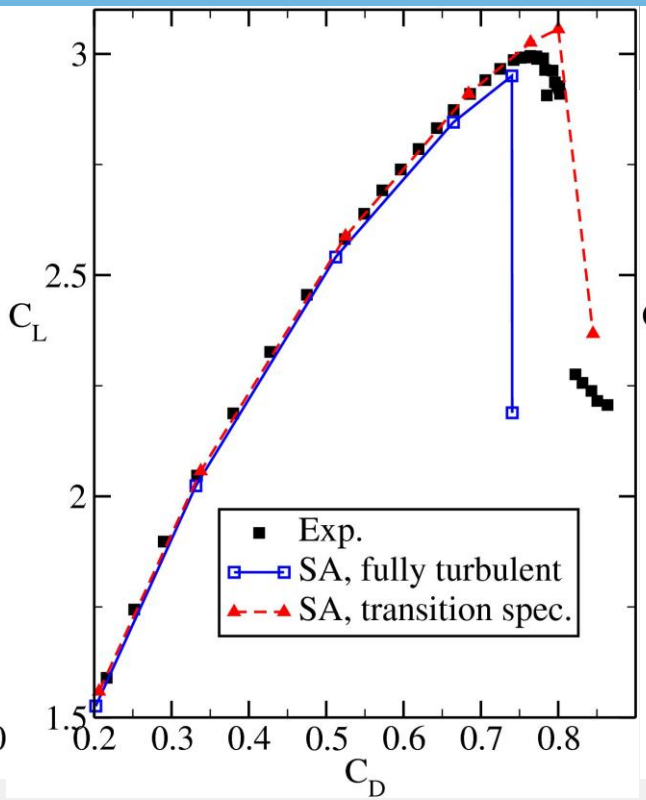
Laminar/turbulent areas, upper and lower sides

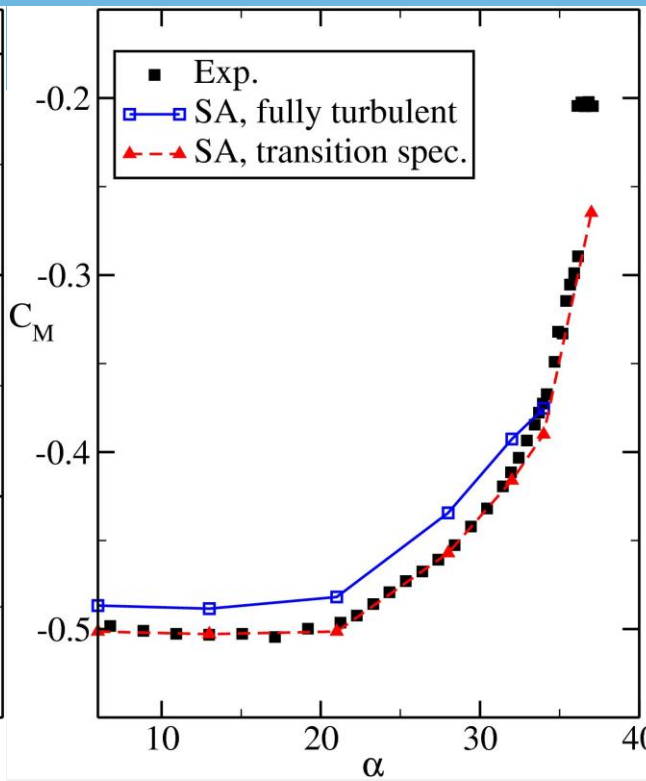


- Carried out for each angle of attack on configuration with brackets
  - α > 28º use same areas as for α = 28º
- Upper side of slat laminar α ≤ 13º
- Leading edge of main wing and flap laminar
- Lower side of wing and flap partly laminar
- Similarities and differences compared to AIAA 2005-5148 (McGinley *et al.*)

Influence from transition

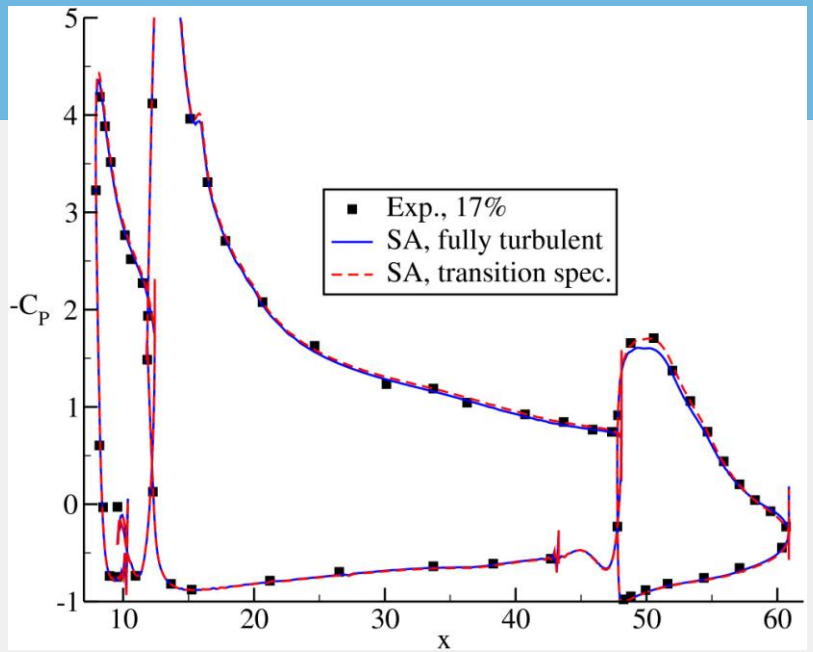


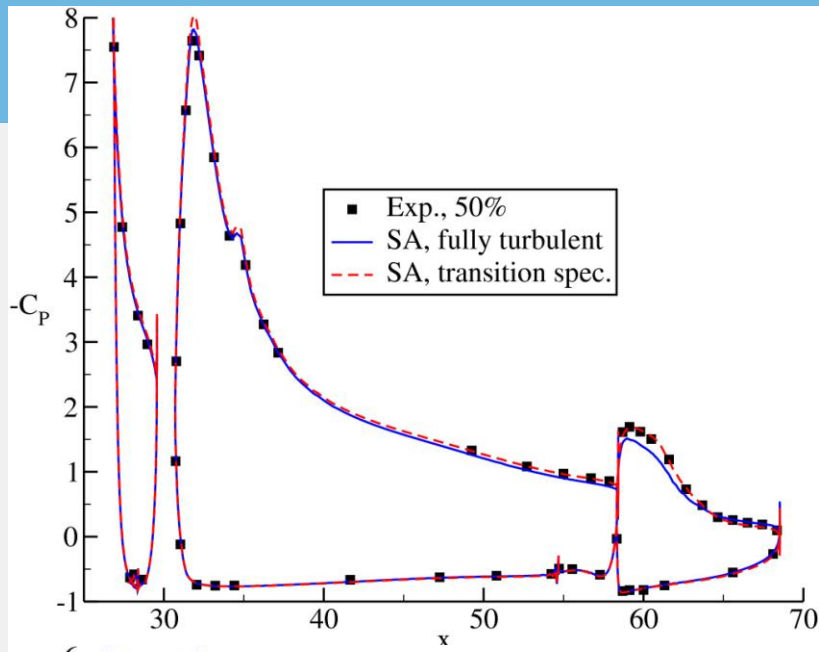


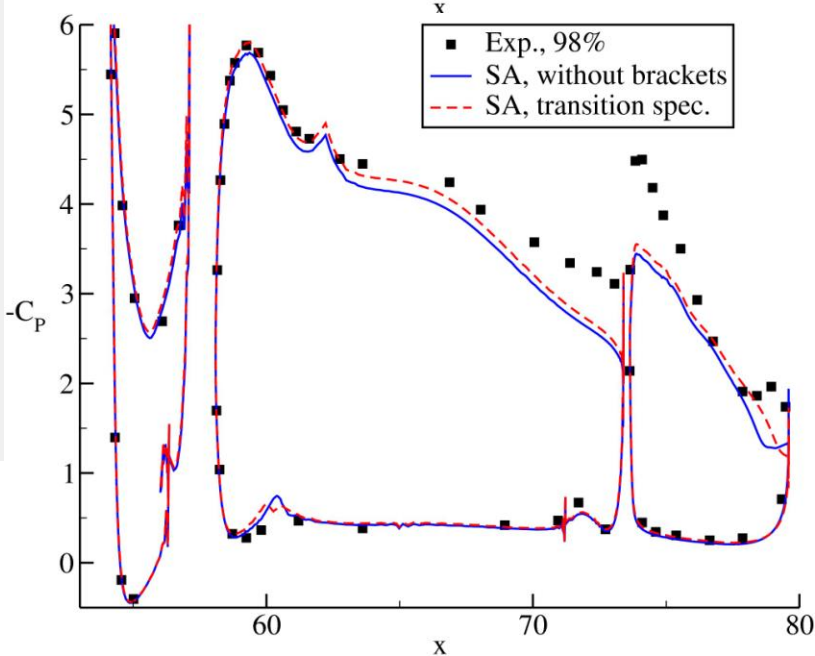


- Configuration 1, medium grids, with brackets
- Improved prediction with laminar areas prescribed
  - Higher lift at all angles
  - Later lift break down
  - Very good match of C_M with experiments

Influence from transition







- C_P with/without transition, α=28º
- Improved predictions
  - At flap and rear main wing
  - Along entire span
- Flap suction still under predicted

Summary of CFD investigation of HL trap wing

- SA model provides better predictions than other models
  - Why ?
- Grid convergence show small differences between results
  - Much smaller than those from turbulence model

Improved CFD predictions from

- Full viscous operator
- Using “real geometry” including brackets
- Including predicted/prescribed transition
  - Some open issues: N-factors, brackets influence …
- Combining the above