NASA Trapezoidal Wing Computations Including Transition and Advanced Turbulence Modeling

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NASA Langley Research Center

Computational AeroSciences Branch

30th AIAA Applied Aerodynamics Conference, High Lift Special Session

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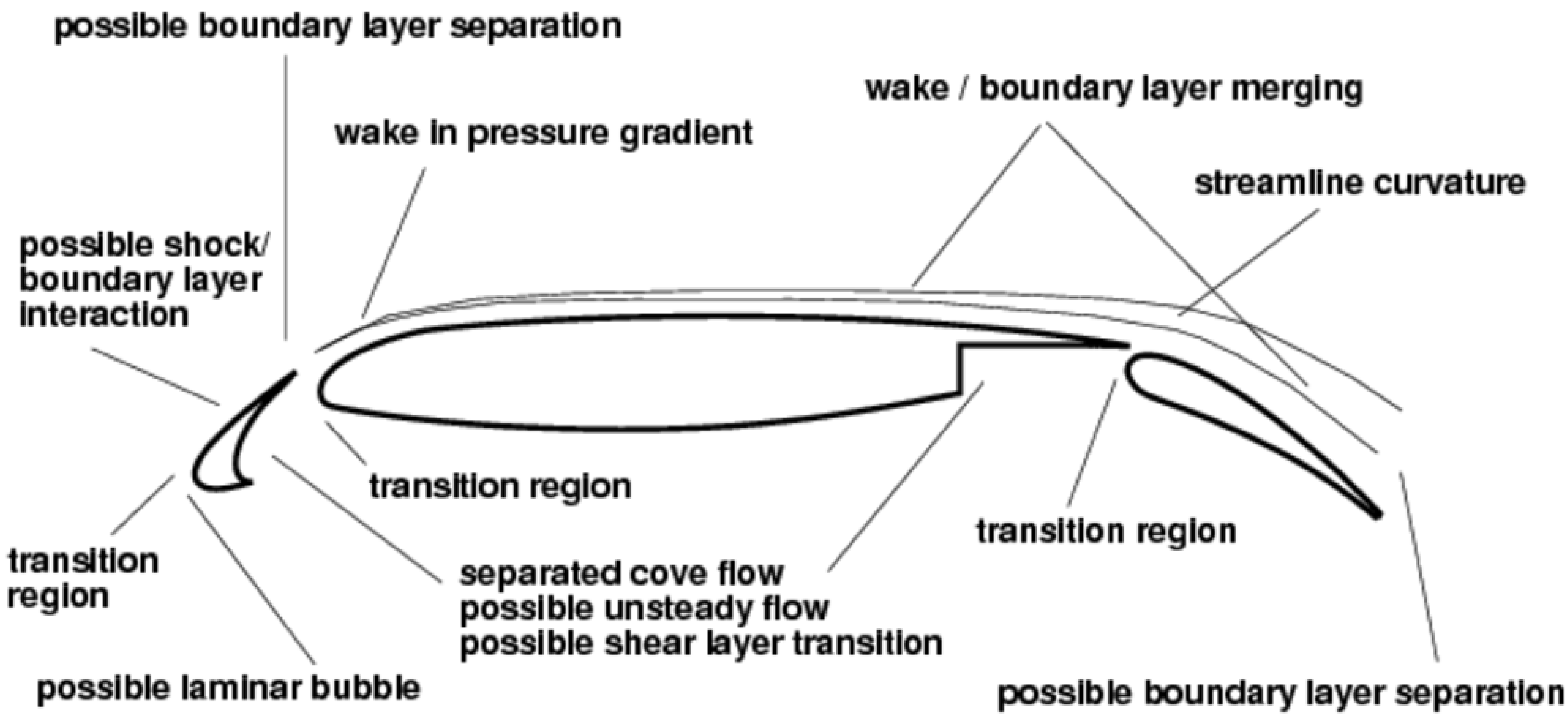
Introduction

Prediction of high-lift flows is challenging



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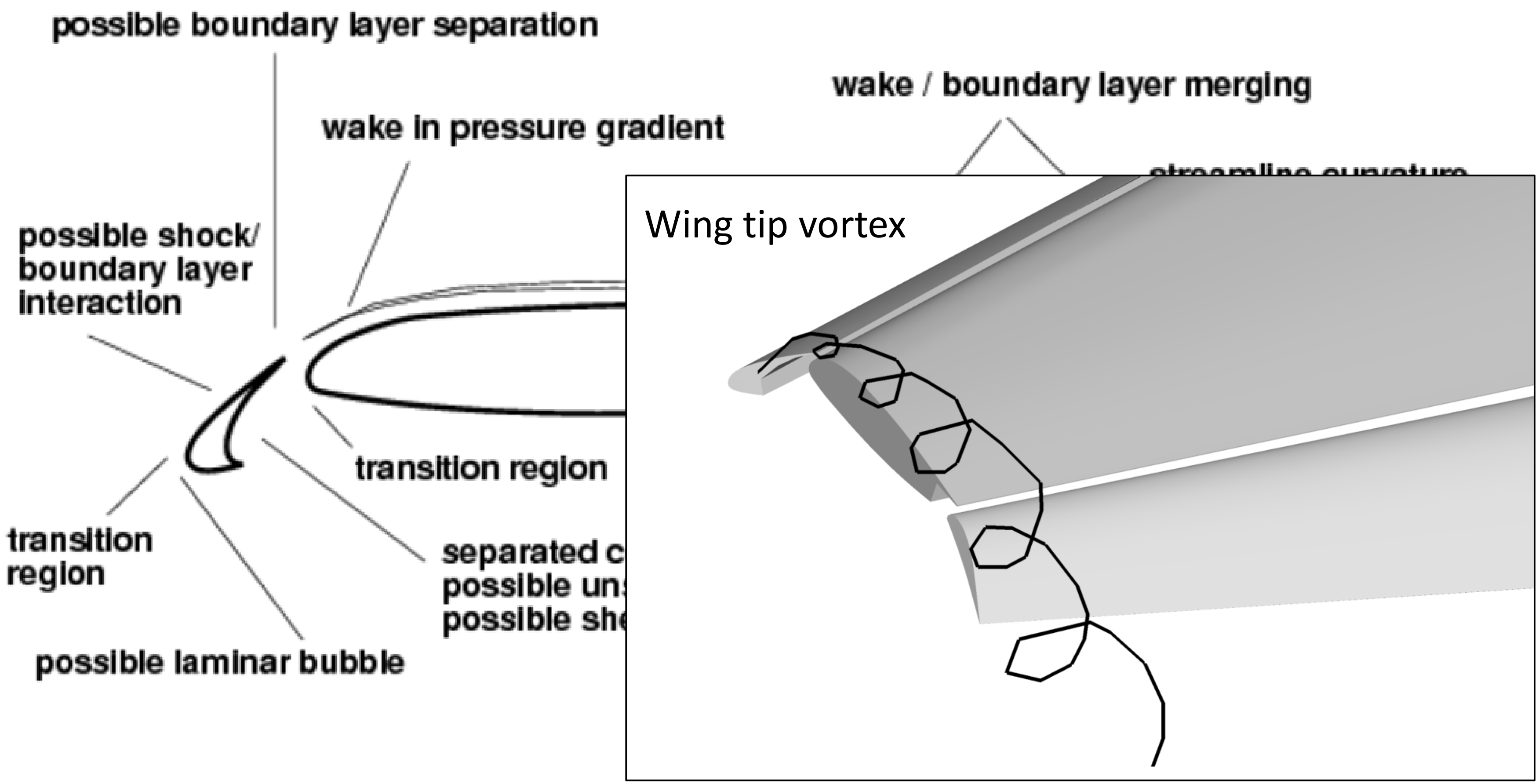
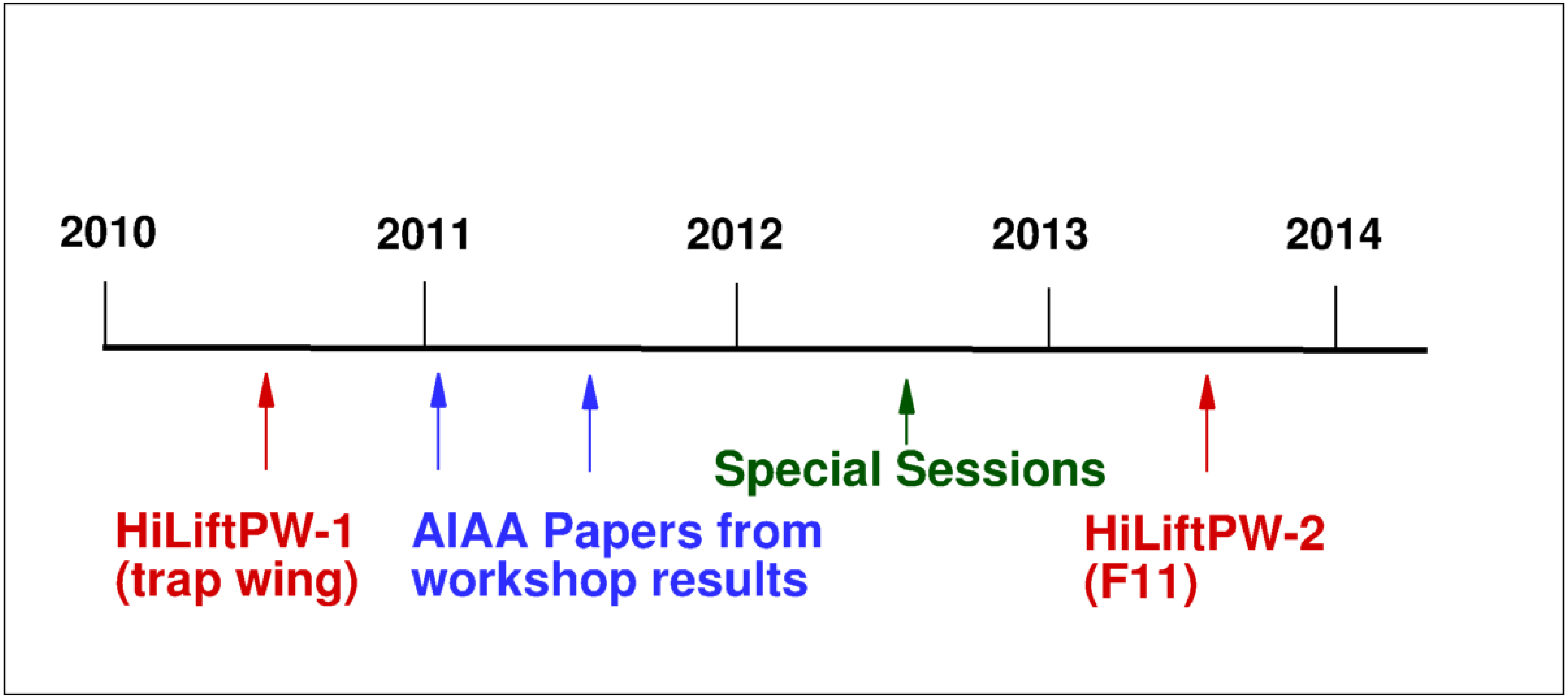


Two parts to this talk

- Brief summary of HiLiftPW-1
  - Serves as an overview to the Special Sessions
- Rumsey/Lee-Rausch recent work on Trap Wing
  - Corresponding to AIAA paper 2012-2843

Brief Summary of HiLiftPW-1

Timeline


2010
2011
2012
2013
2014
Special Sessions
HiLiftPW-1
(trap wing)
AIAA Papers from
workshop results
HiLiftPW-2
(F11)

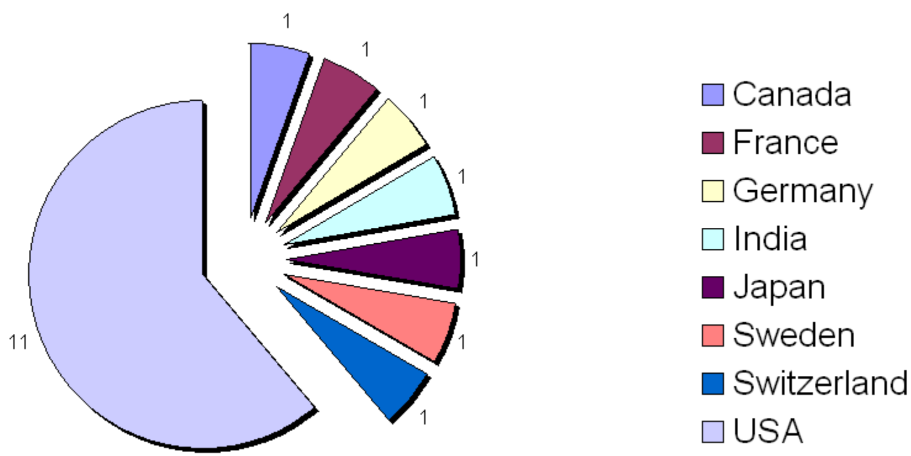
Summary of HiLiftPW-1

- Held Summer 2010
- Open series of international High Lift Prediction Workshops (HiLiftPW)
- Long-term objectives of workshop series
  - Assess current prediction capability
  - Develop modeling guidelines
  - Advance understanding of physics
  - Enhance CFD prediction capability for design and optimization
  - Provide impartial forum
  - Identify areas needing additional research & development
- **Looking for: overall collective results, trends, and outliers**

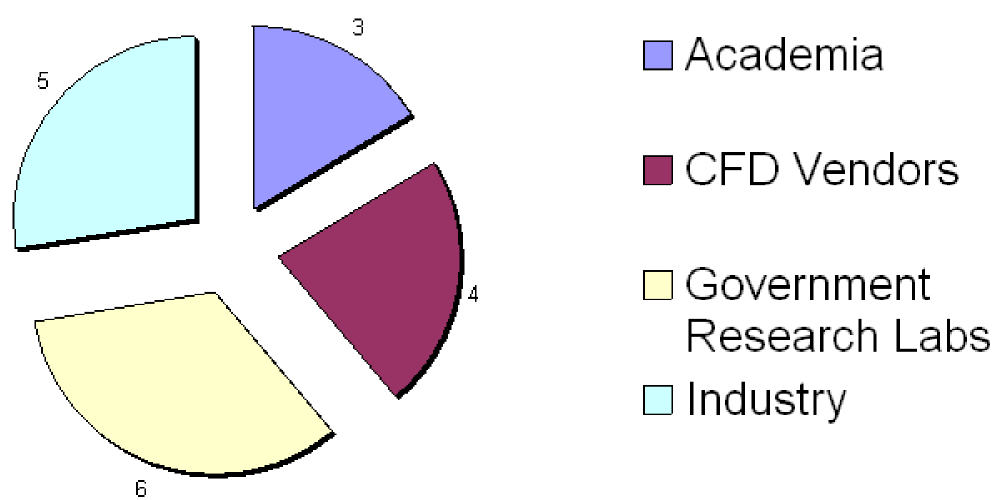
NASA Trapezoidal Wing

- In Langley 14x22 ft Wind Tunnel

HiLiftPW-1 participant statistics



21 groups
39 entries
15 different CFD codes



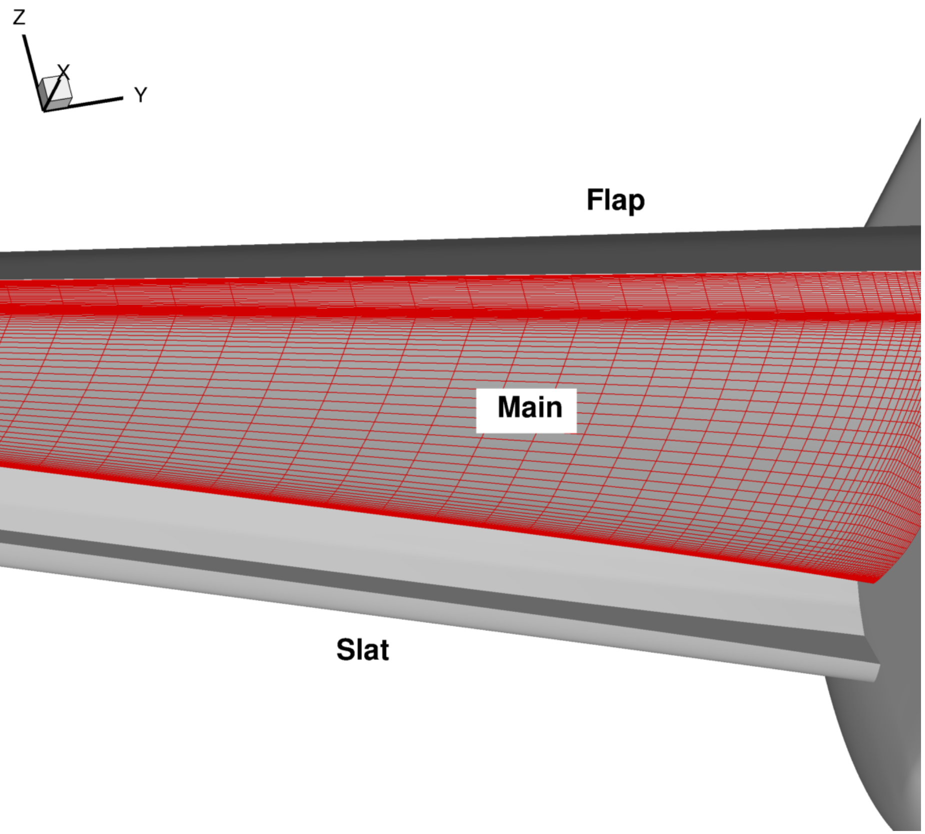
HiLiftPW-1 test cases

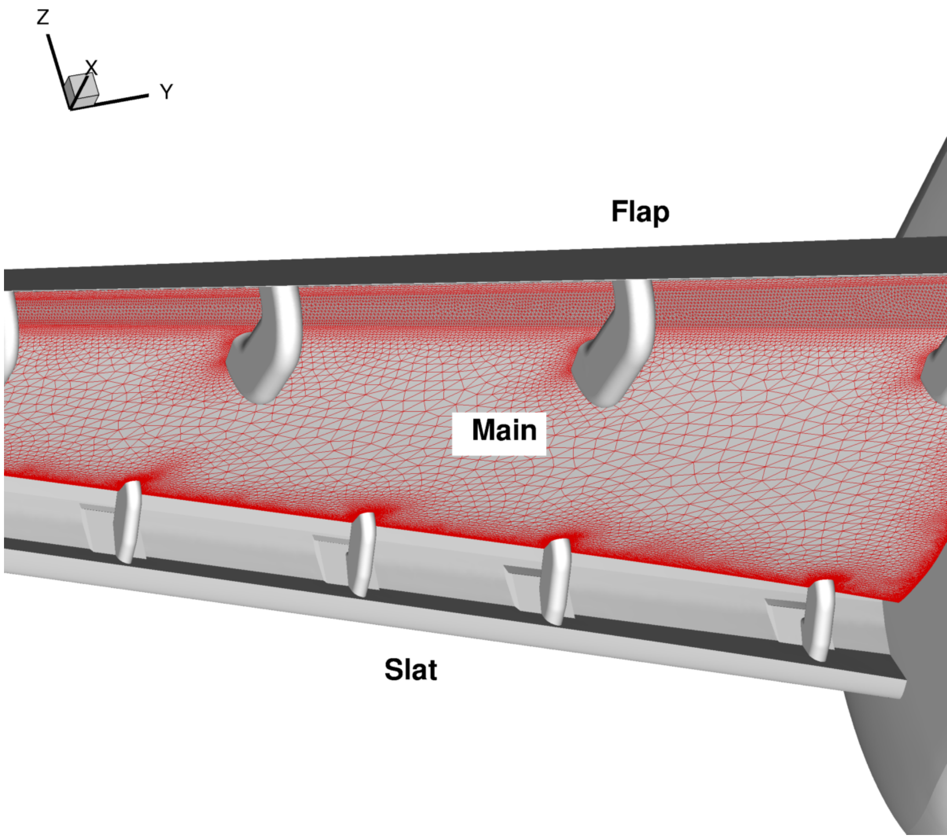
- Focused on two configurations:
  - Config 1 (slat 30 flap 25)
  - Config 8 (slat 30 flap 20)*
- Grid convergence studies
- Optional: effect of brackets

- All cases “free air”, fully turbulent
- Compared against 14x22 data corrected to free air conditions

*Note: Config 8 not discussed here; see J Aircraft 48(6):2068-2079, 2011

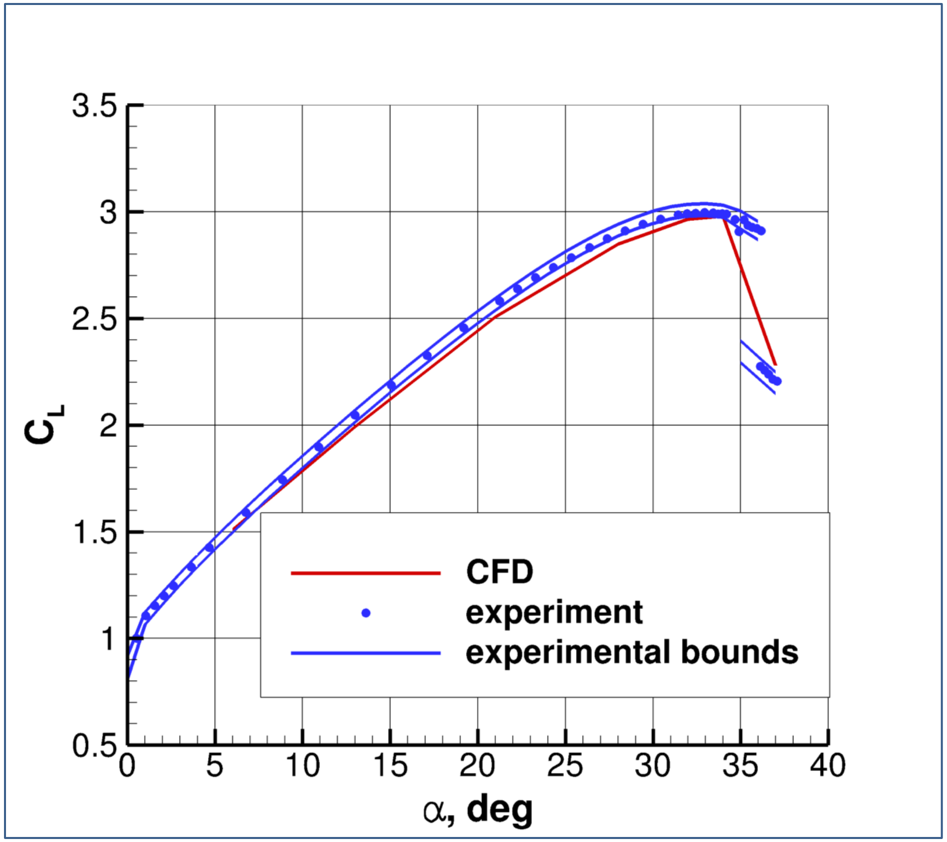
“Clean” vs. brackets

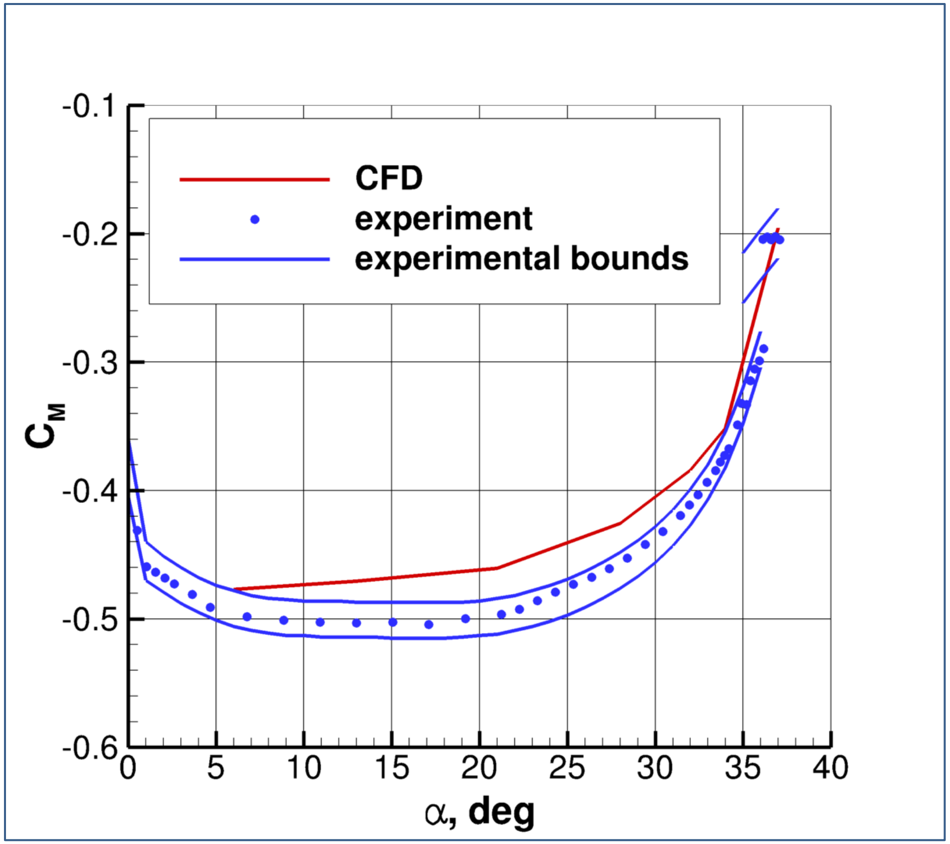




Typical result

Configuration 1, medium grid (no brackets)





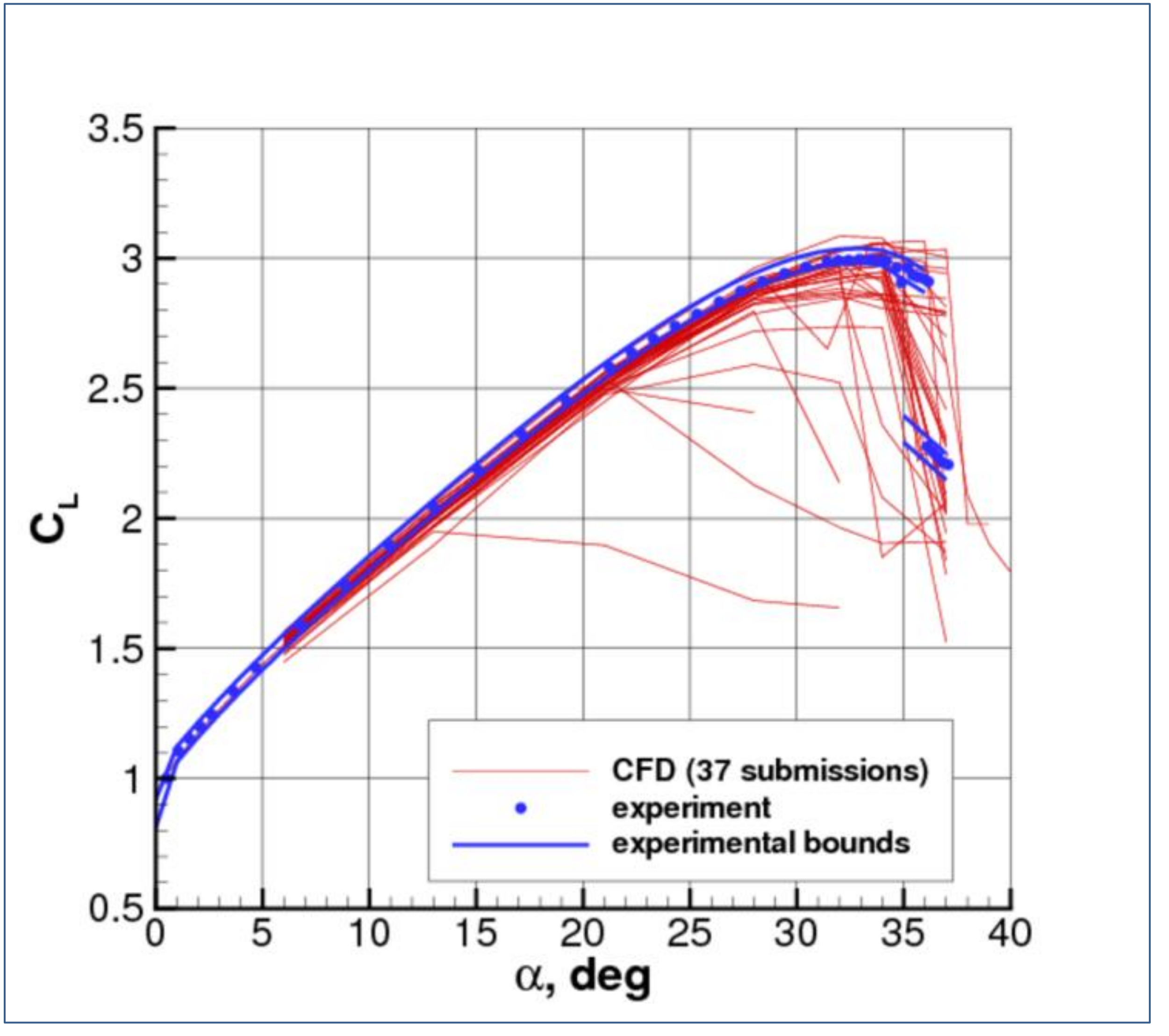
Including brackets makes comparisons worse

Summary of all results

Configuration 1, medium grid (no brackets)

-In the collective, CFD tended
to under-predict lift, drag,
and moment magnitude

-There were CFD outliers,
especially at higher alphas



Summary of all results

Configuration 1, medium grid (no brackets)

-In the collective, CFD tended
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-There were CFD outliers,
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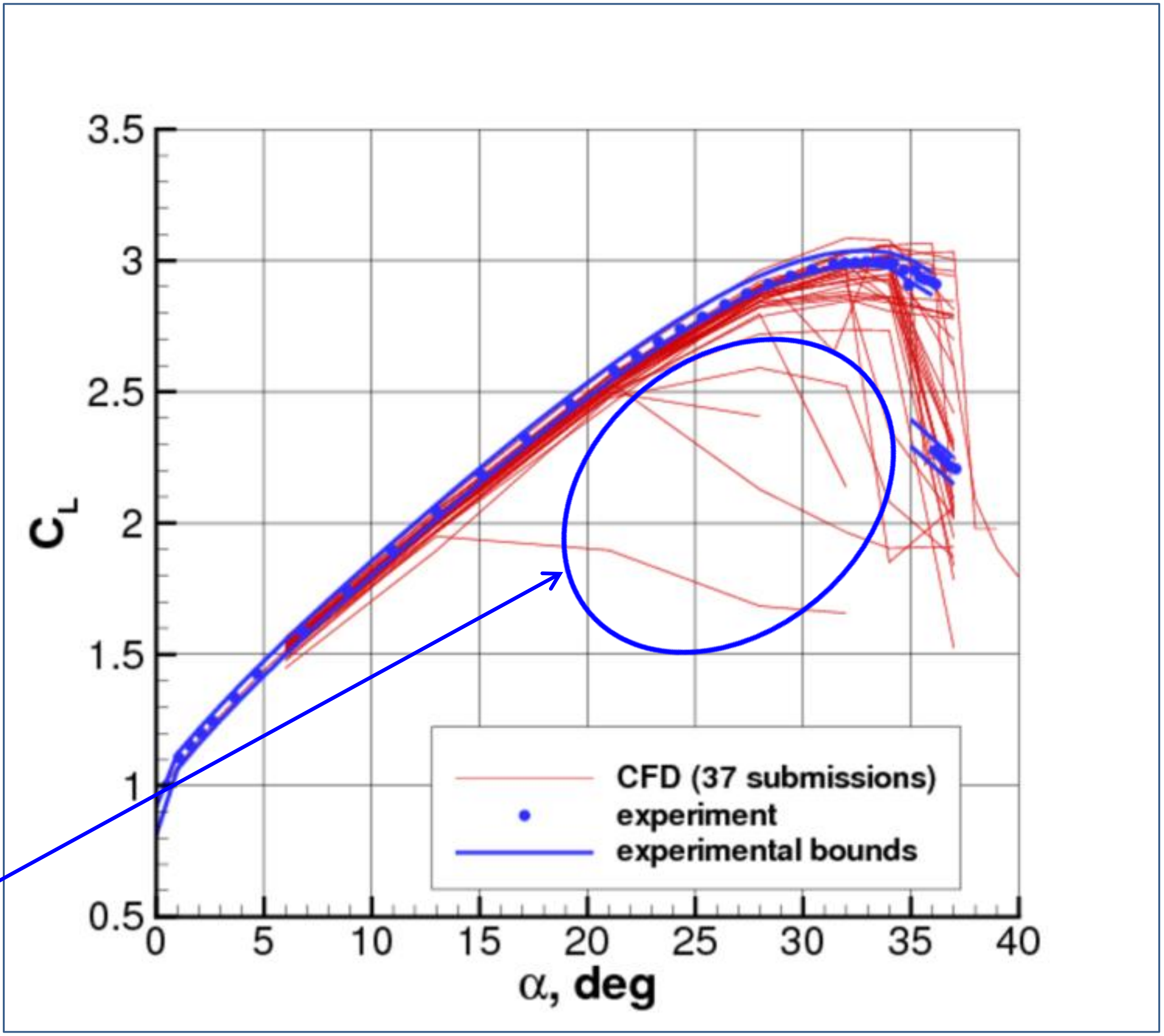
-Some problems at high alphas due to code sensitivity to initial conditions



Summary of all results

Configuration 1, medium grid (no brackets)

-In the collective, CFD tended
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-There were CFD outliers,
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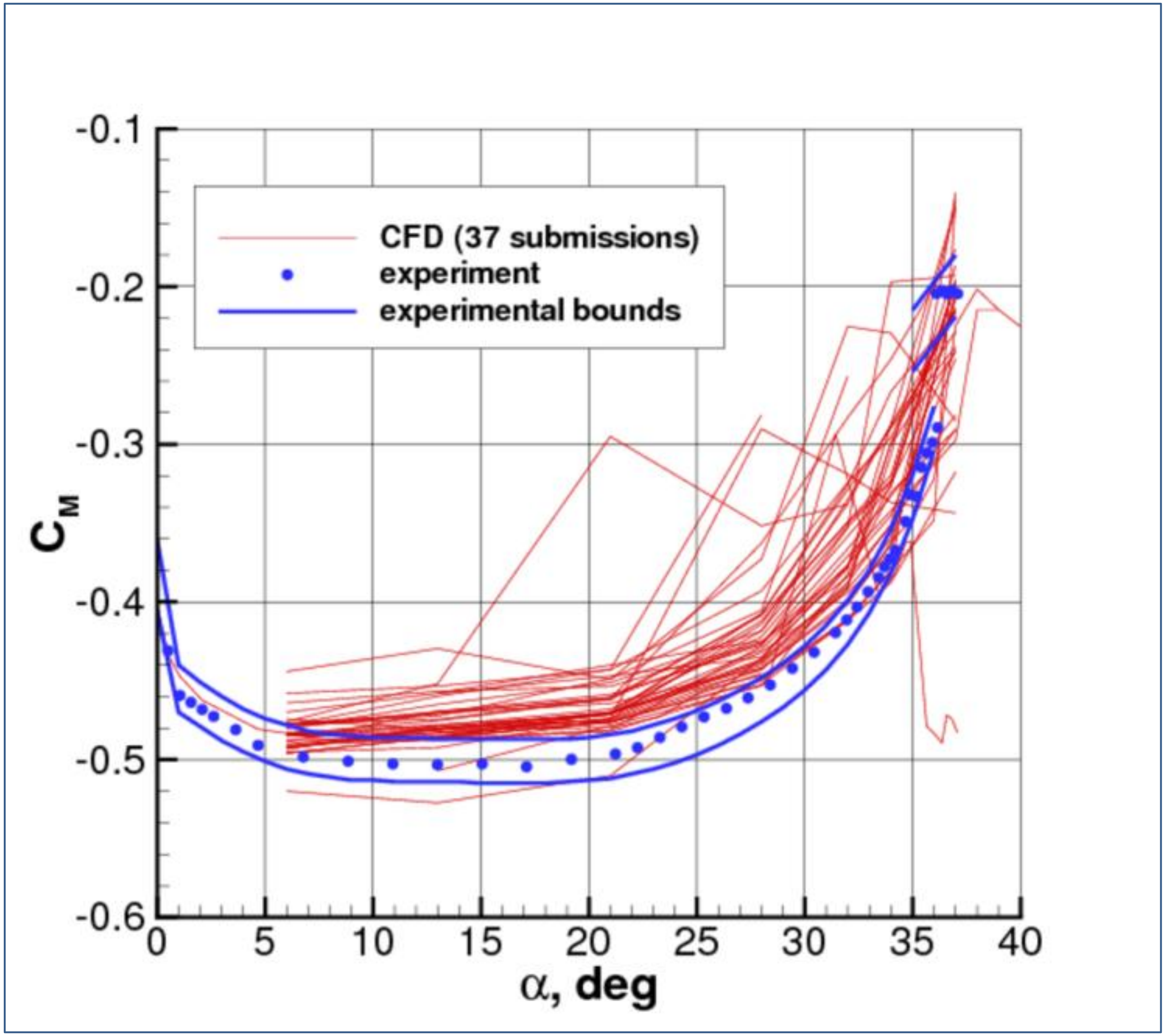
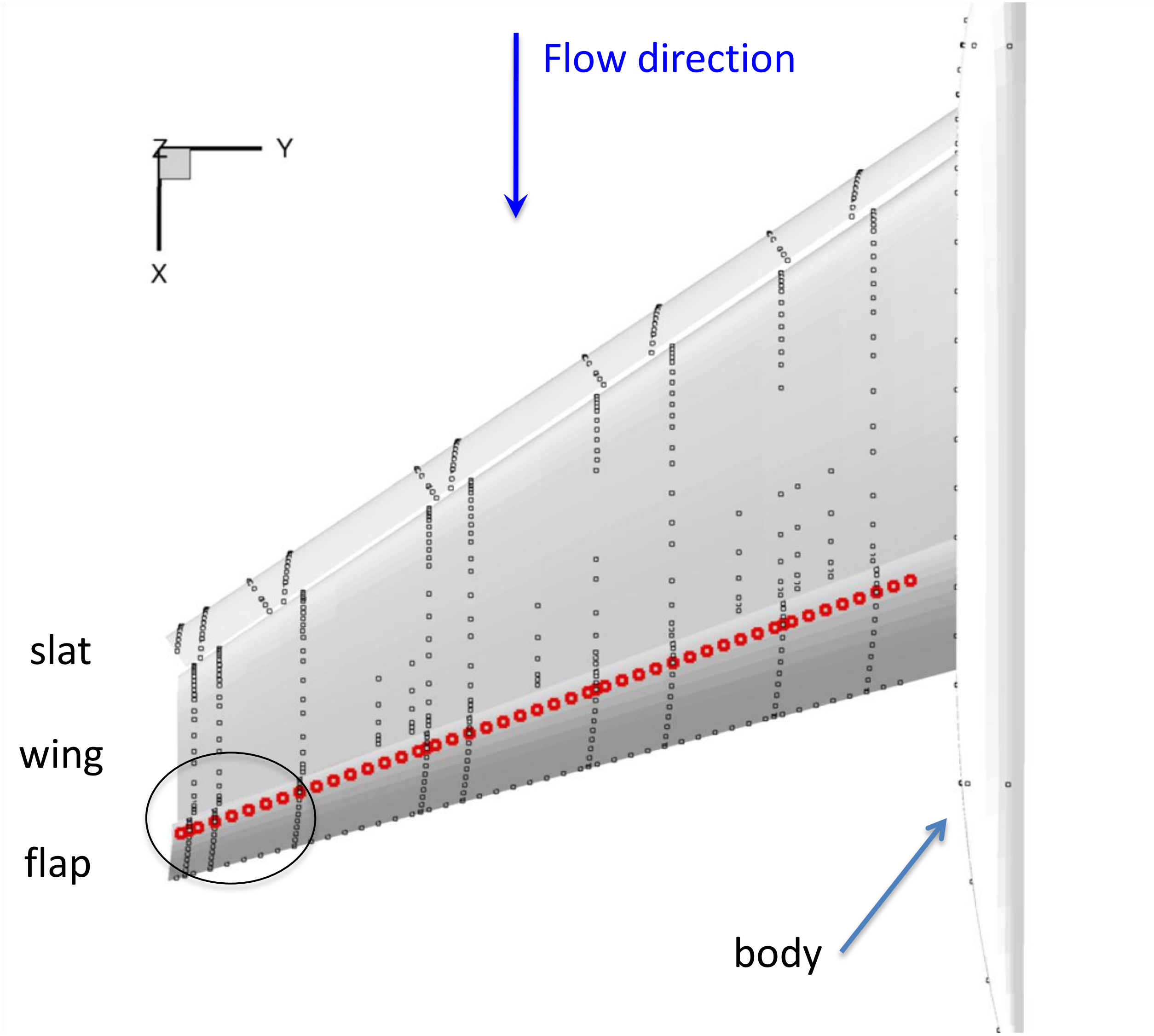
-We now think that including transition can have big effect on moment



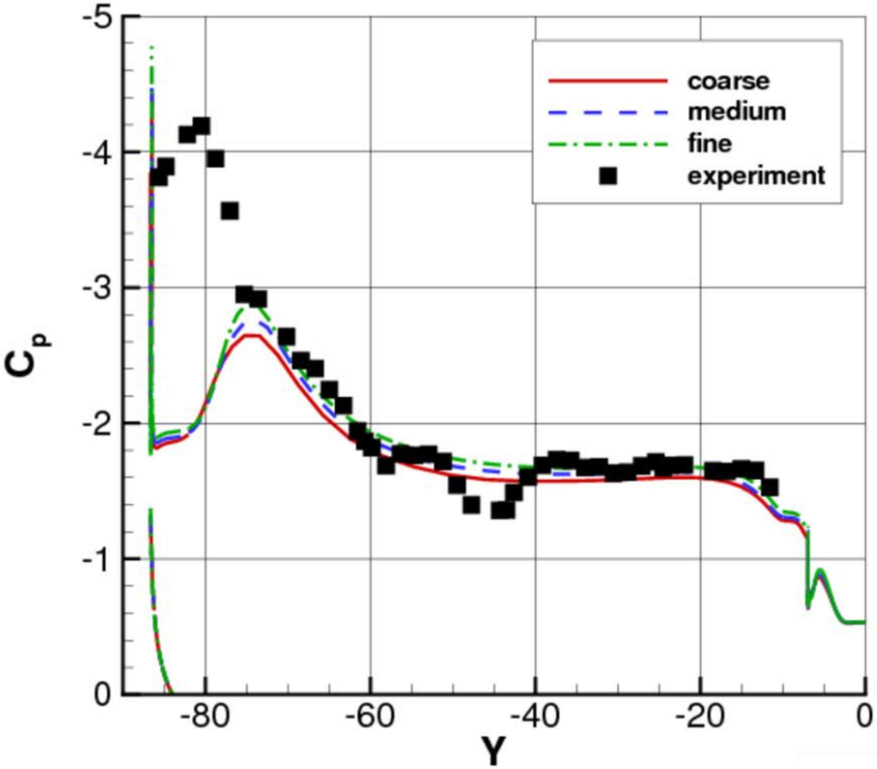
Predictions near the wing tip



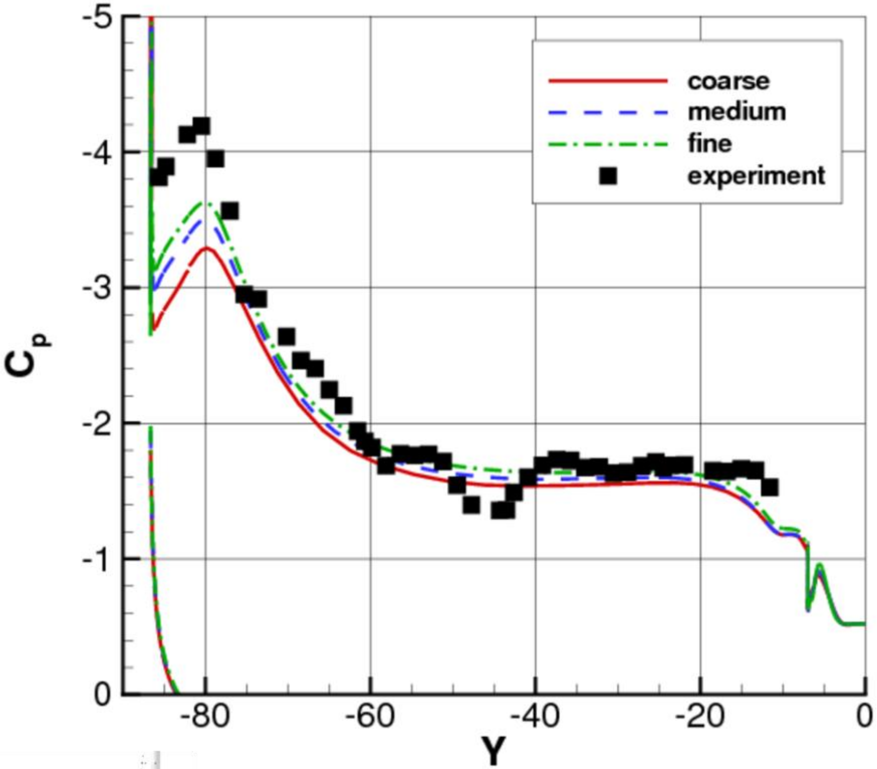
Predictions near the wing tip

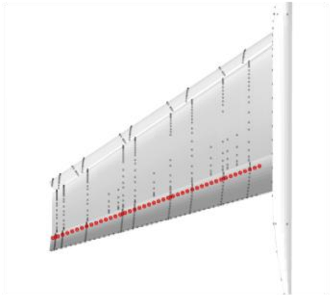
Alpha=28^0, configuration 1

Typical thin-layer N-S



Typical full N-S

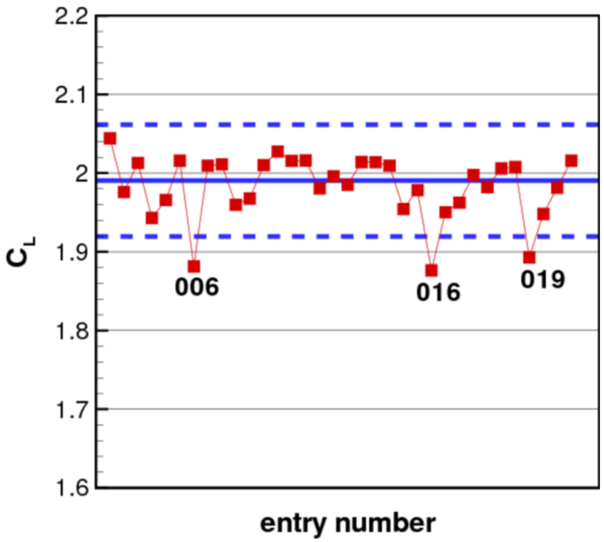




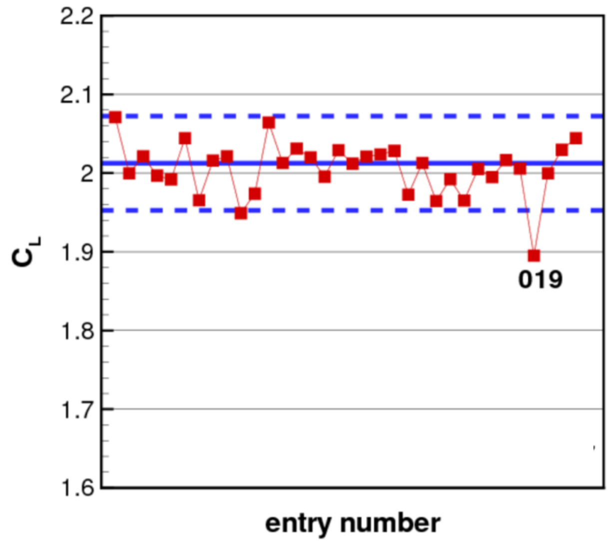
Statistical analysis

Helpful to identify outliers

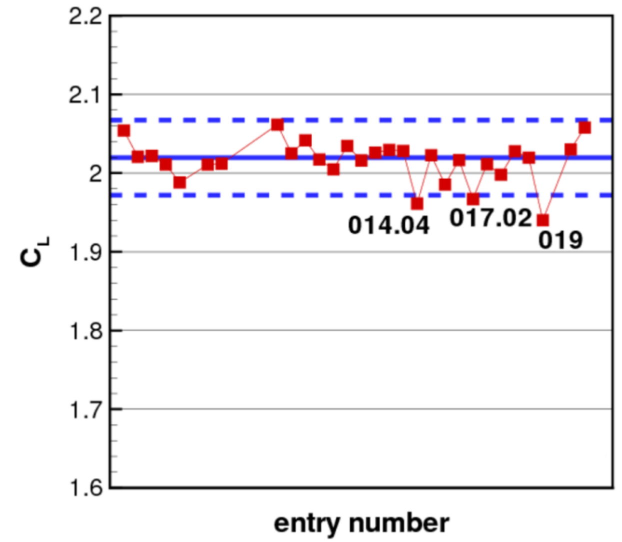
Coarse grid



Medium grid



Fine grid



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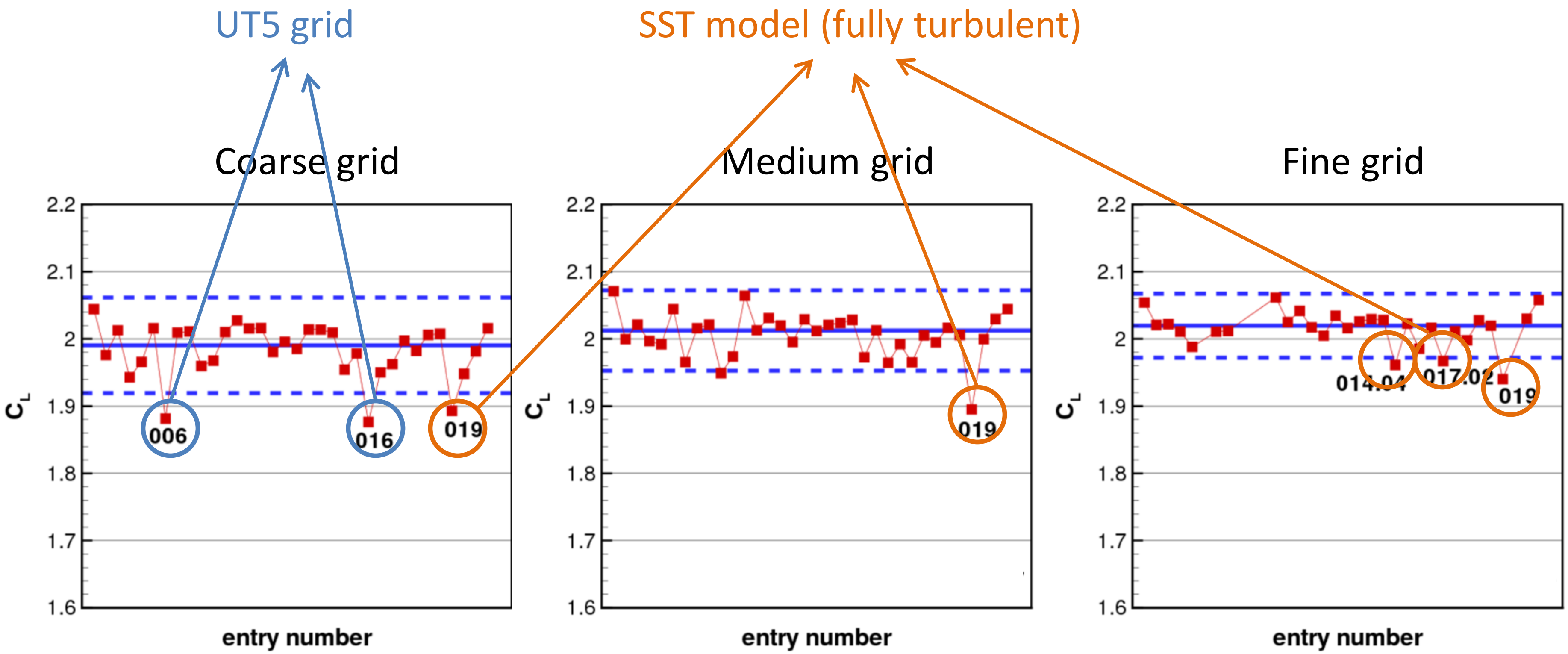
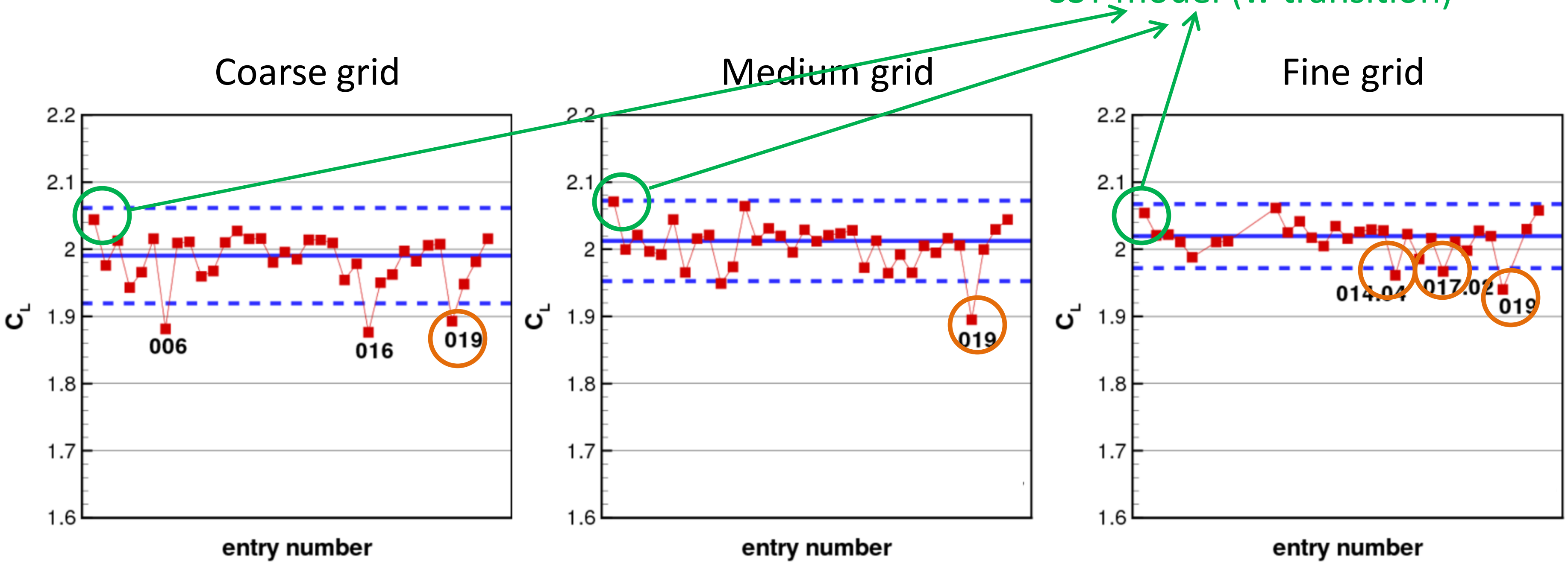


Statistical analysis

Helpful to identify outliers

SST model (fully turbulent)

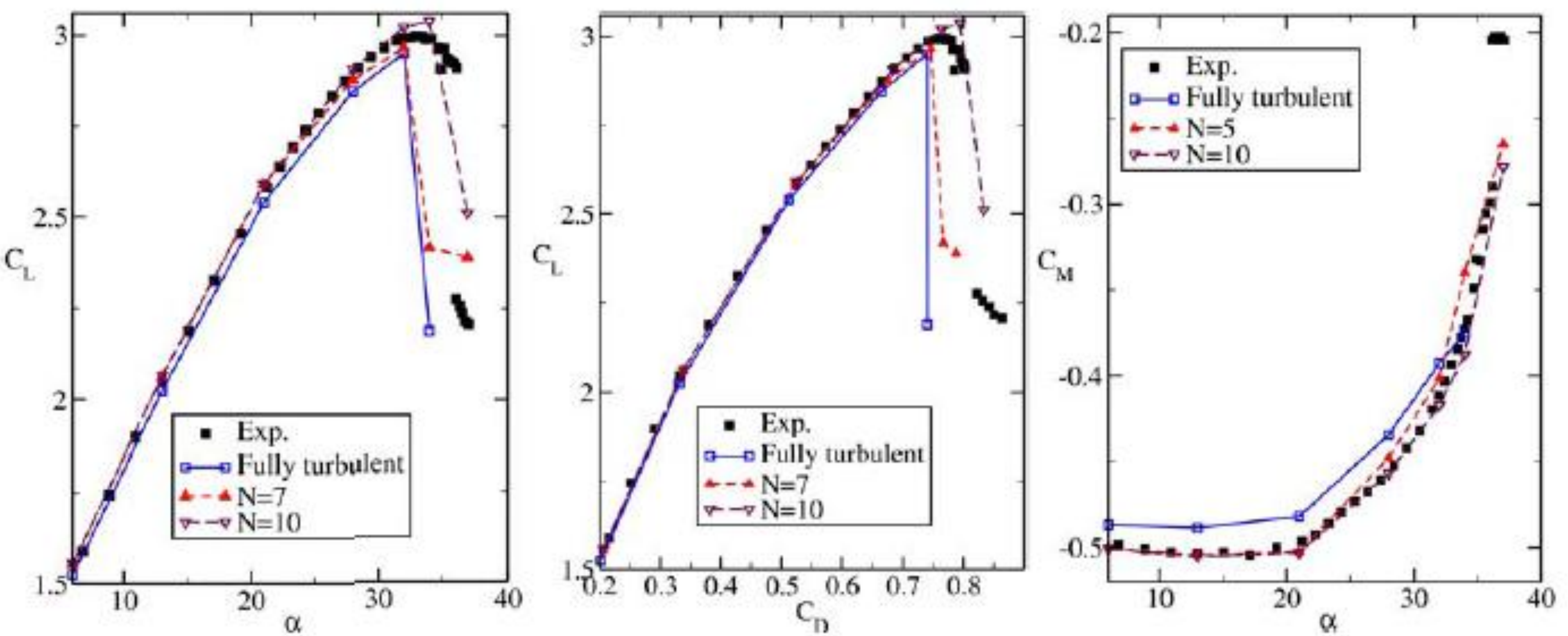
SST model (w transition)



Subsequent study at FOI

Including brackets and transition (SA model)

From AIAA-2011-3009 (Eliasson et al)

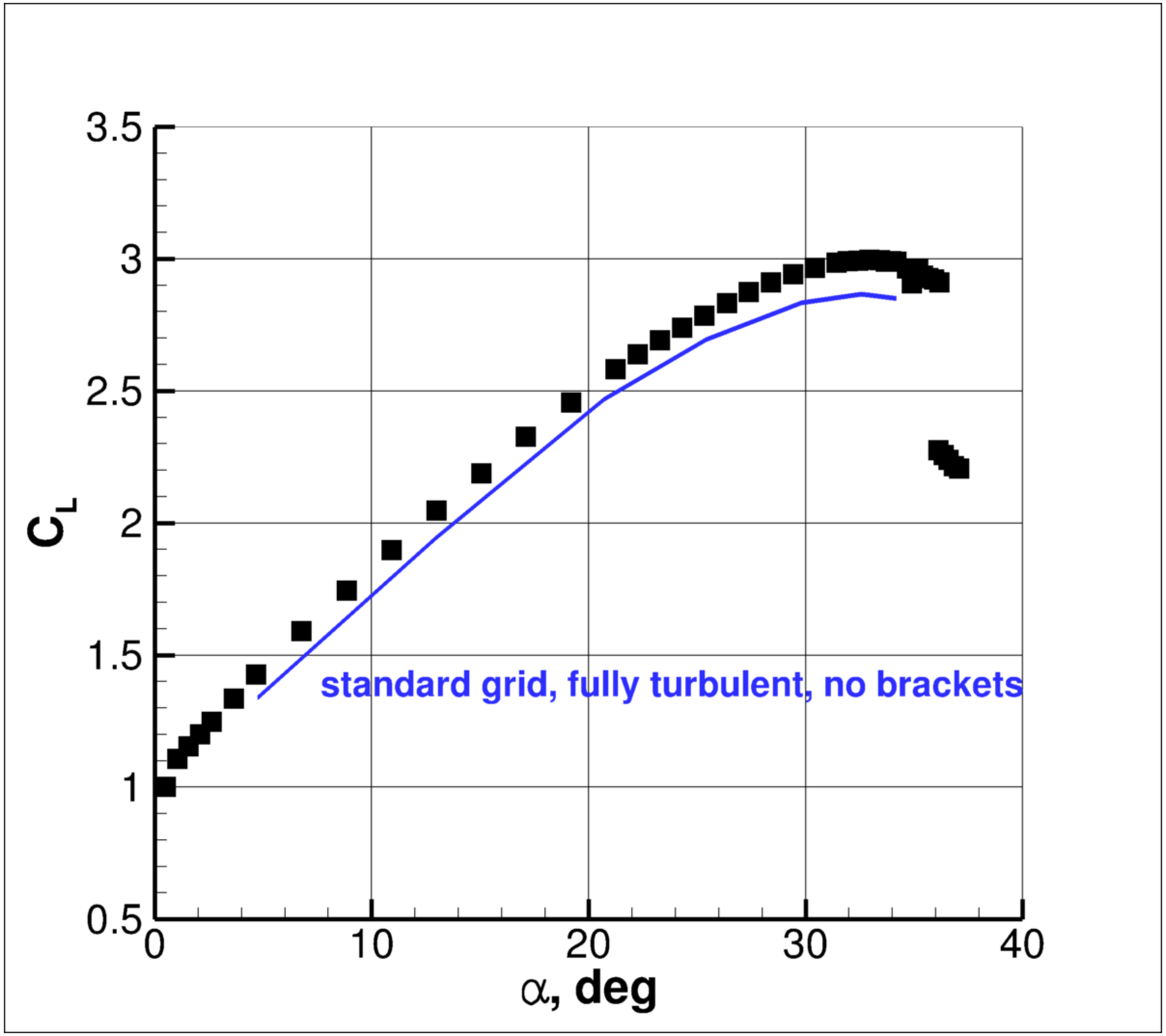


Including transition increases lift and decreases moment
(both in better agreement with experiment)

Some conclusions from Trap Wing studies to date

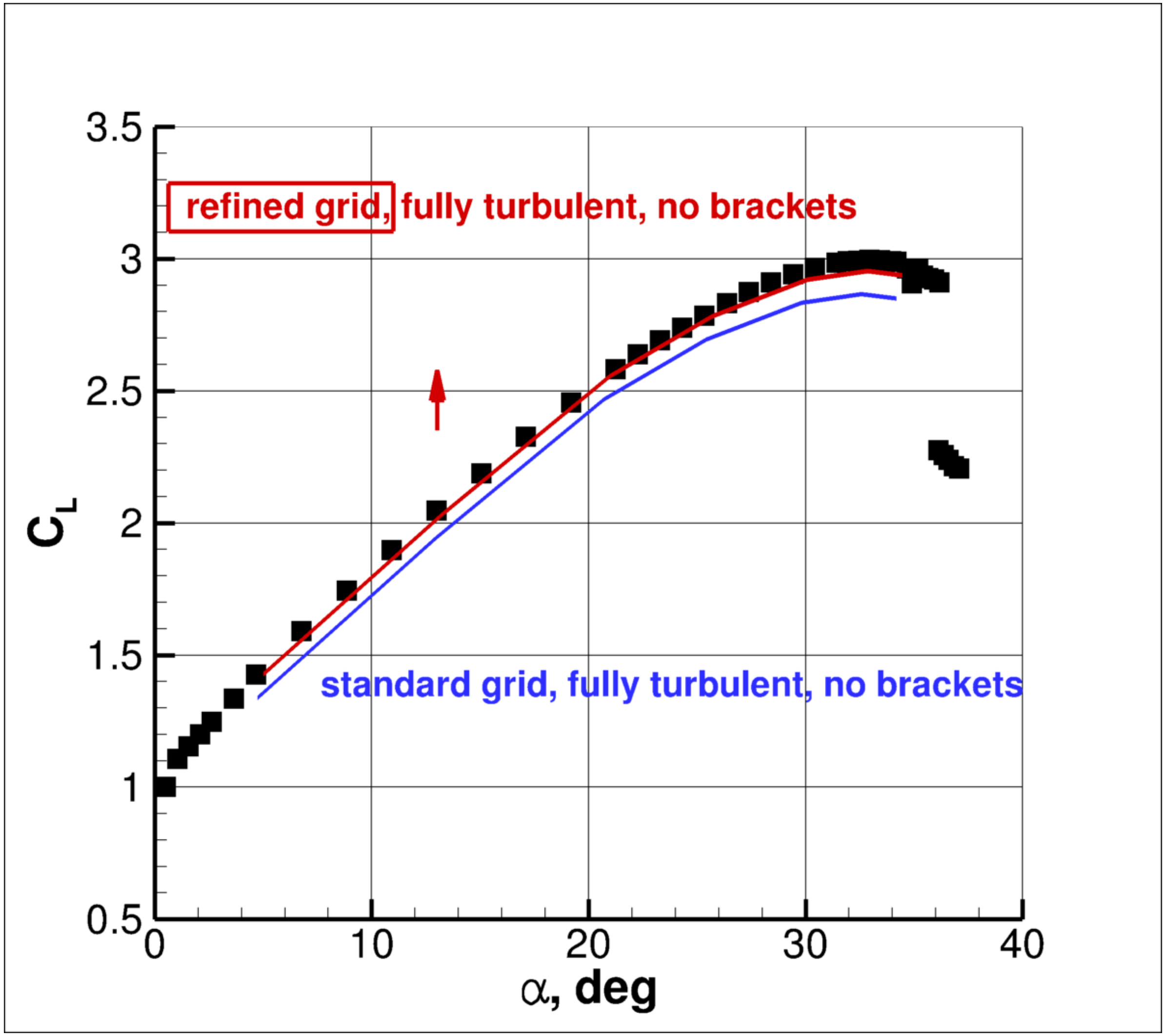
- Wing tip region difficult to predict
  - CFD codes have trouble agreeing with experiment
  - CFD codes have trouble agreeing with each other
  - Additional targeted grid refinement probably required
  - Thin-layer assumption is particularly poor
- Refining grid typically increases lift
- Including brackets decreases lift
- Accounting for transition is particularly important
  - Increases lift, decreases moment
  - Studies by Steed (ANSYS-CFX), Eliasson (FOI), Fares (Exa)

Cartoon of general CFD behavior



(schematic representation)

Cartoon of general CFD behavior



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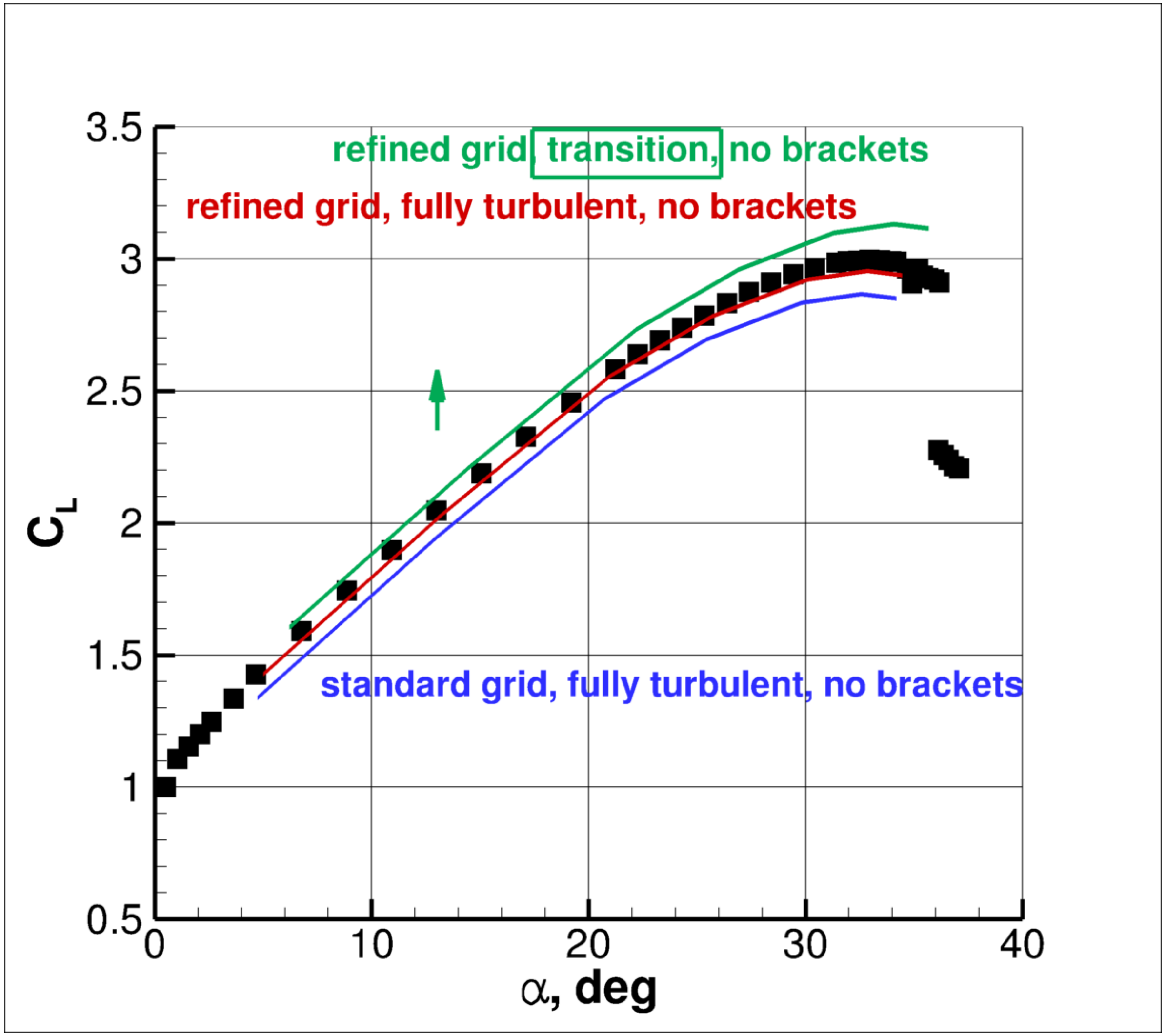

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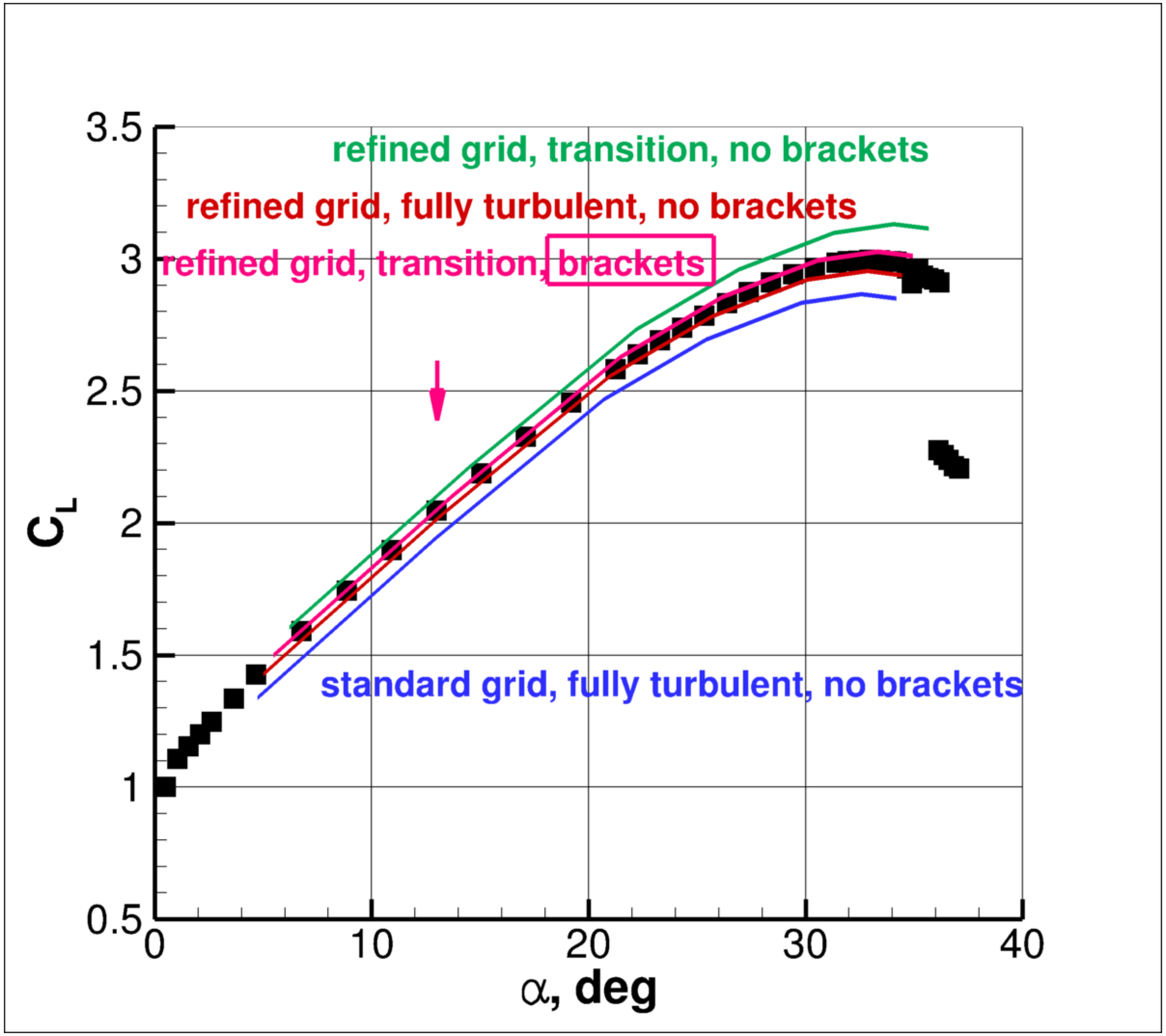


You may get the right answer for the wrong reason

(schematic representation)

Why Hold Special Sessions?

- Build on lessons learned from HiLiftPW-1
  - Same Trap Wing configuration
  - Is there more we can learn?
  - Can we do better?
  - Make use of new velocity probe information
- Provide forum for new groups to participate
  - Many of presenters are new to HiLiftPW

NASA Trapezoidal Wing Computations Including Transition and Advanced Turbulence Modeling

AIAA Paper 2012-2843

Current contribution

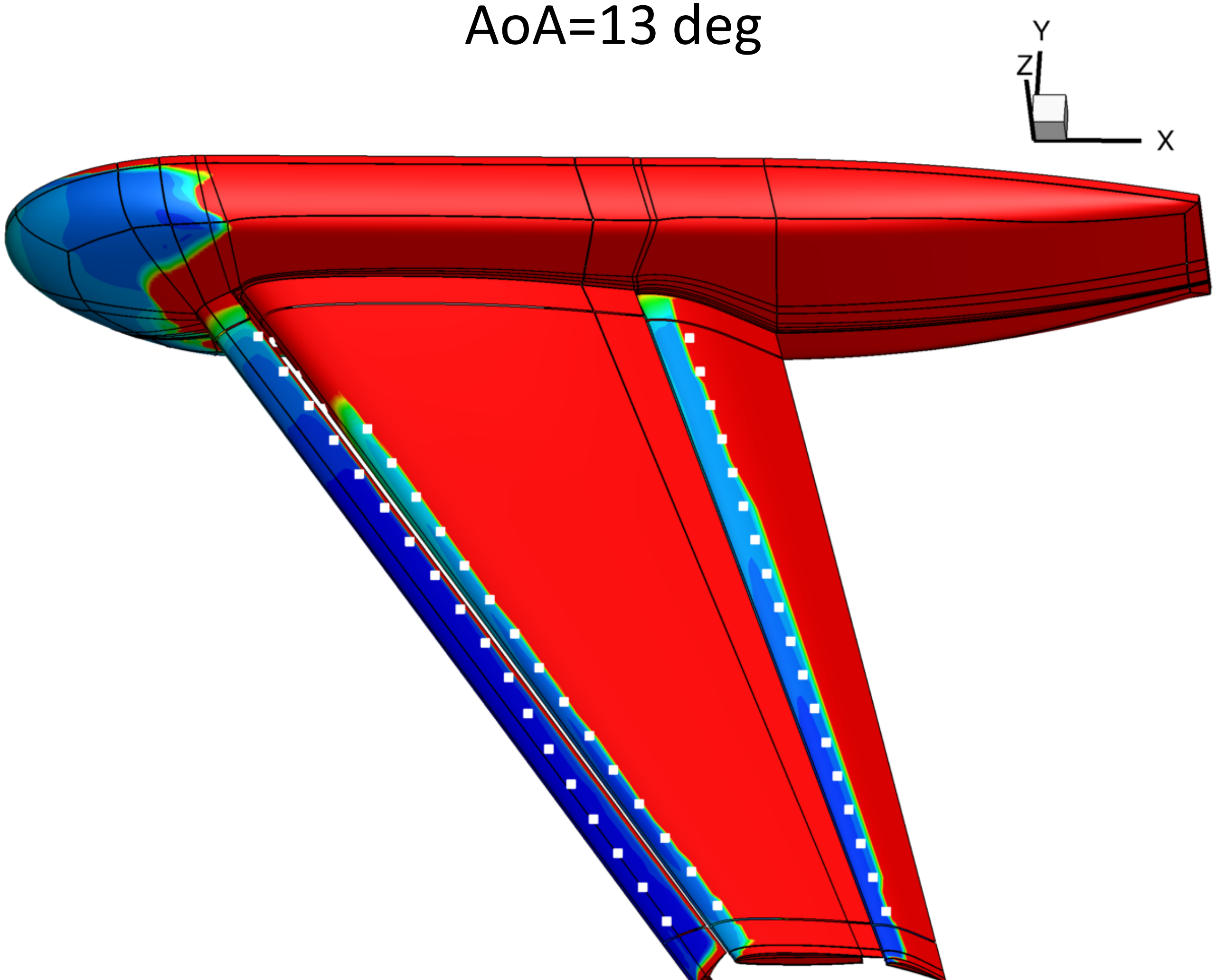
- Verification of transition influence
- Investigation of grid and model effect on wake velocity profile predictions
- Influence of turbulence model rotation and curvature corrections

Results

- Transition was implemented in CFL3D and FUN3D
  - Langtry-Menter $\gamma - \mathrm{Re}_\theta$ SST model (4-eqn model)
    - Very effective engineering tool; good results overall
    - Yielded transition regions similar to those from e^N method in most regions over the wing
    - Agreed best with experimental velocity profiles
    - Downside: transition equations can be difficult to converge
  - By zeroing out turbulent production in specified regions (FUN3D)
    - Effective at AoA=13 deg; early separation at high AoA
- Including transition improved predictions significantly
  - Reduced upper surface flap separation
  - Increased lift

Comparison of transition prediction

AoA=13 deg



Color contours: $\gamma - \mathrm{Re}_\theta$ SST model (blue laminar, red turbulent)

Dots: e^N method (Eliasson et al)

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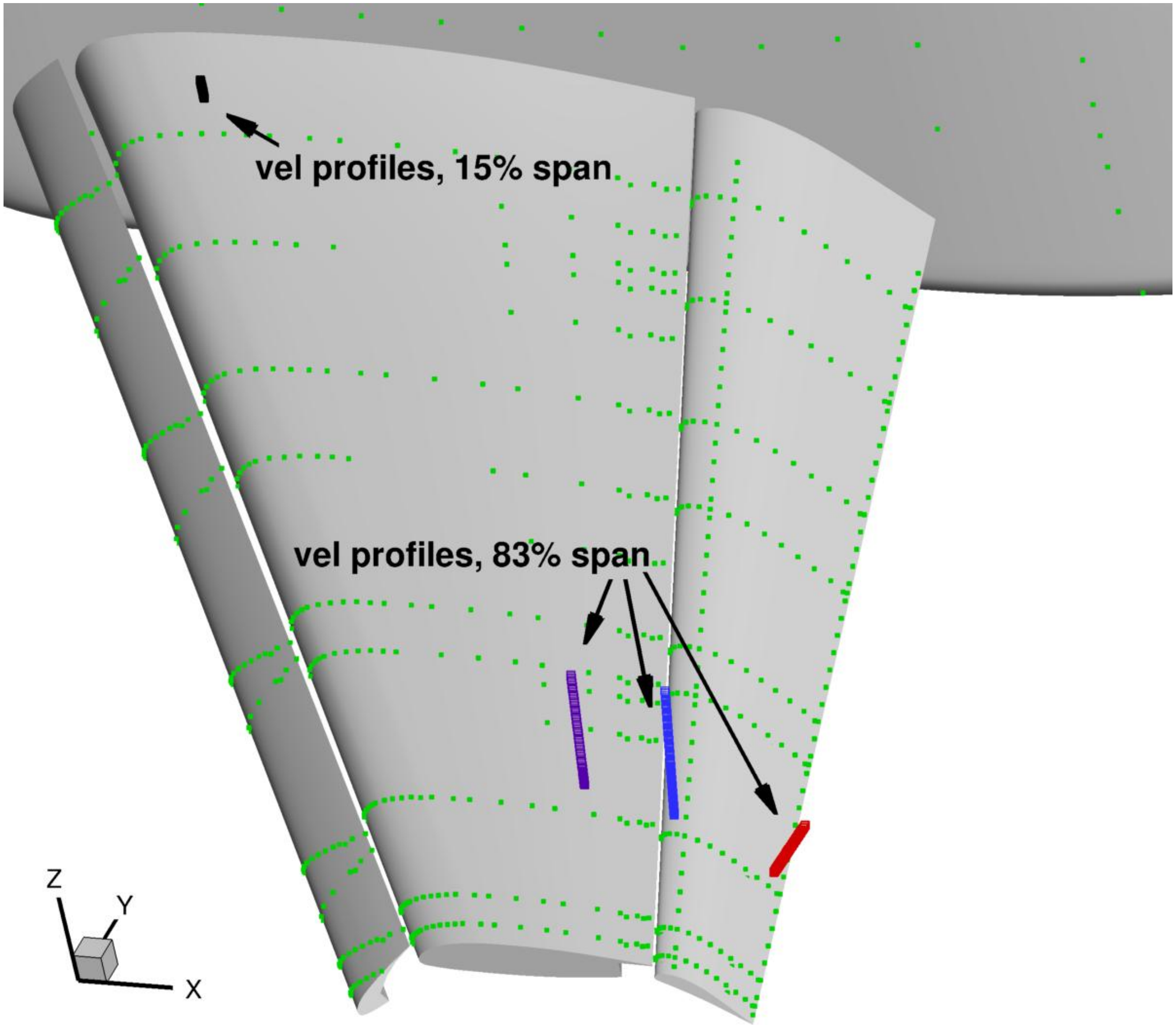
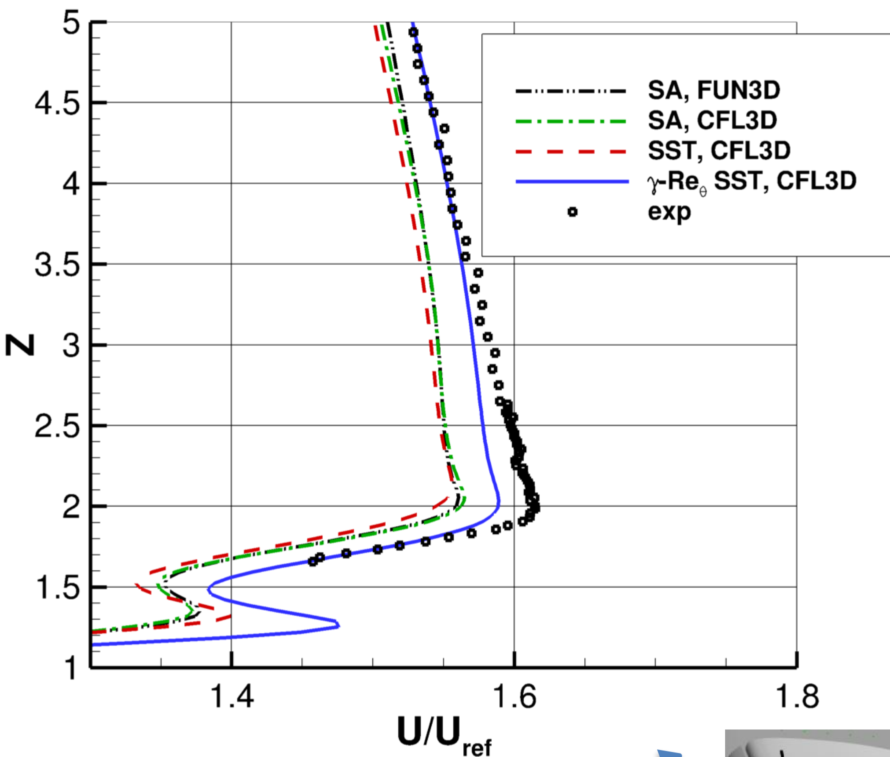
Velocity profiles



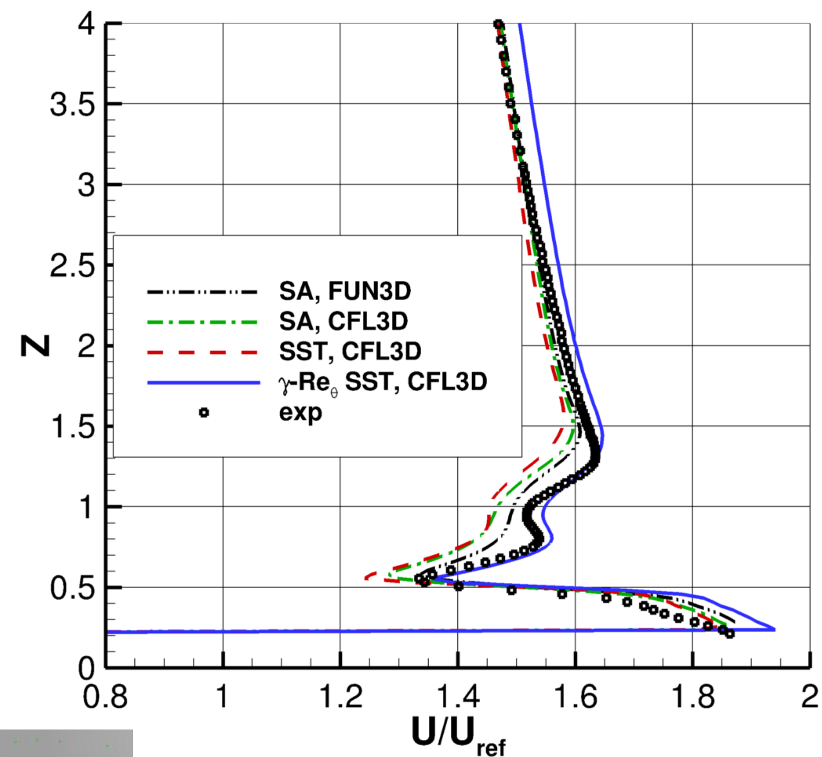
Effect of transition on velocity profiles

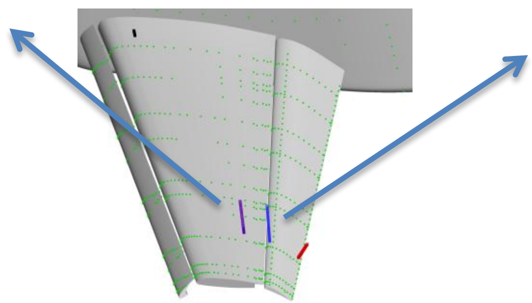
AoA=28 deg, structured SX1/UX9 grid (no brackets)

Main element, 83% span



Flap forward element, 83% span





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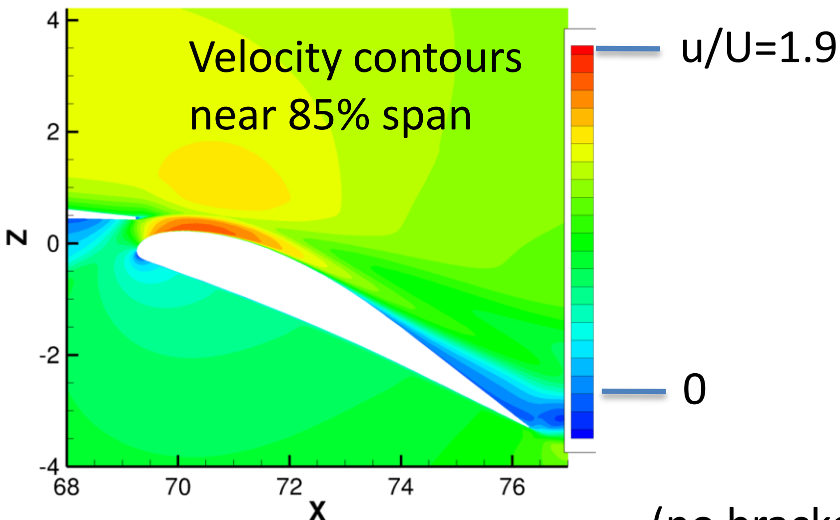
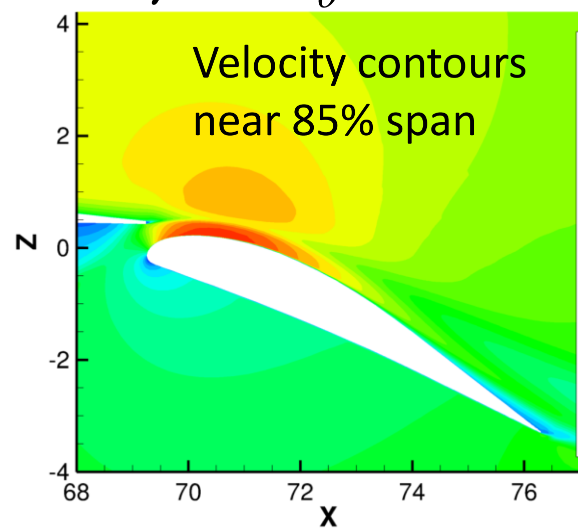
AoA=13 deg

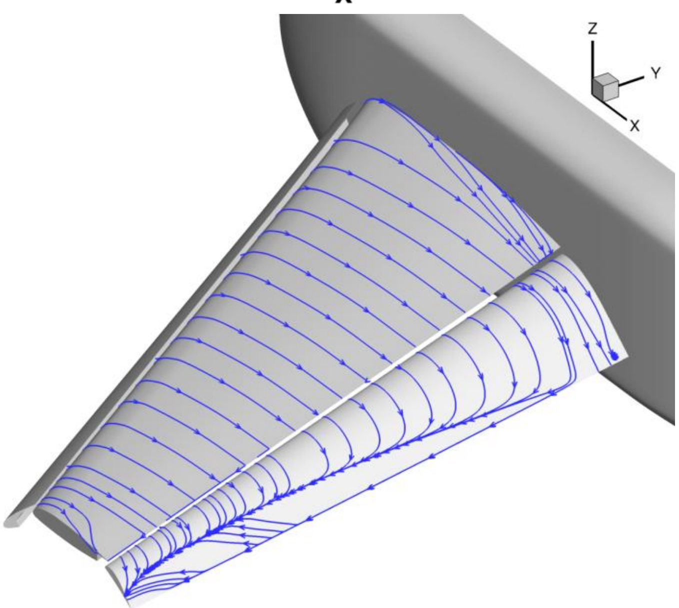
SST

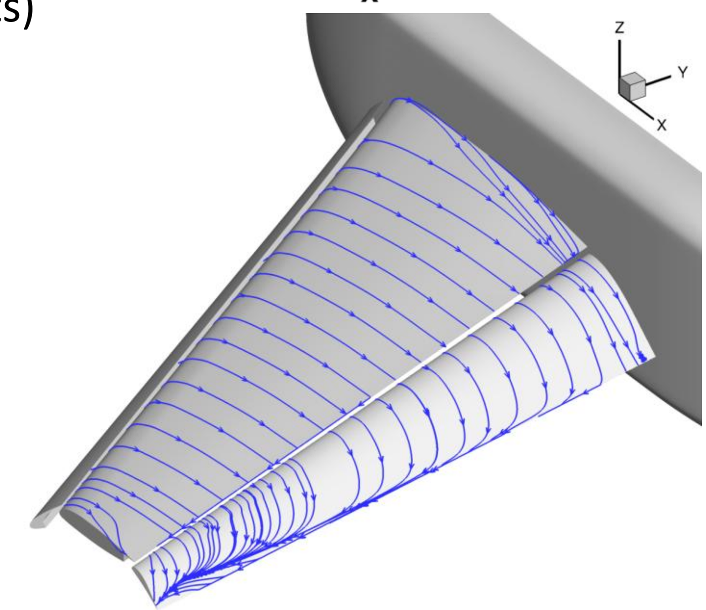


$\gamma - \mathrm{Re}_\theta$ SST



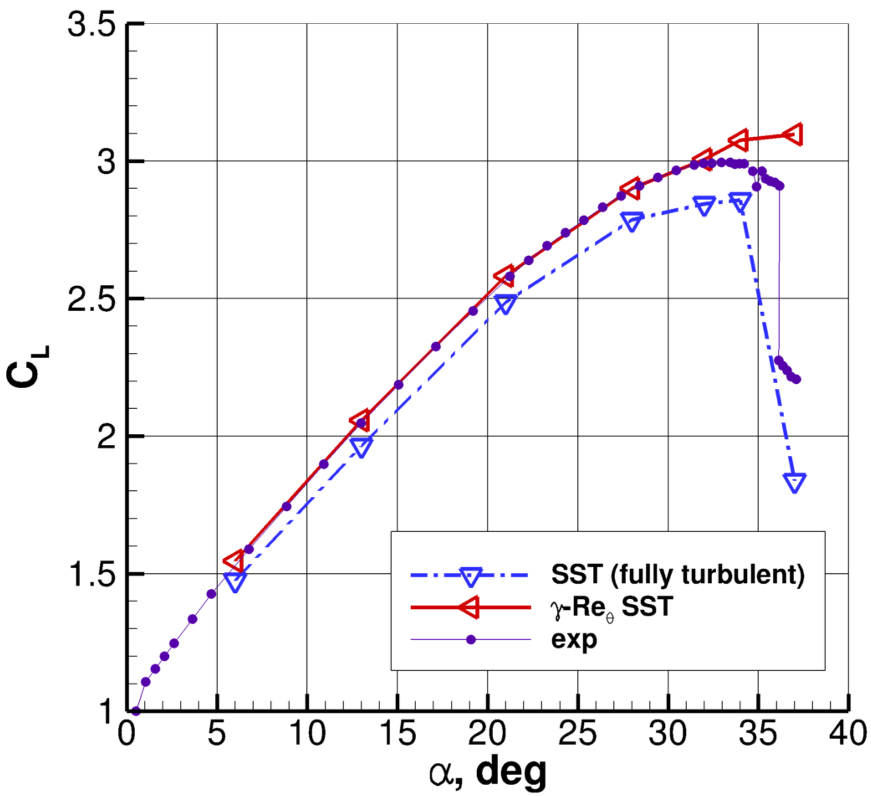
(no brackets)

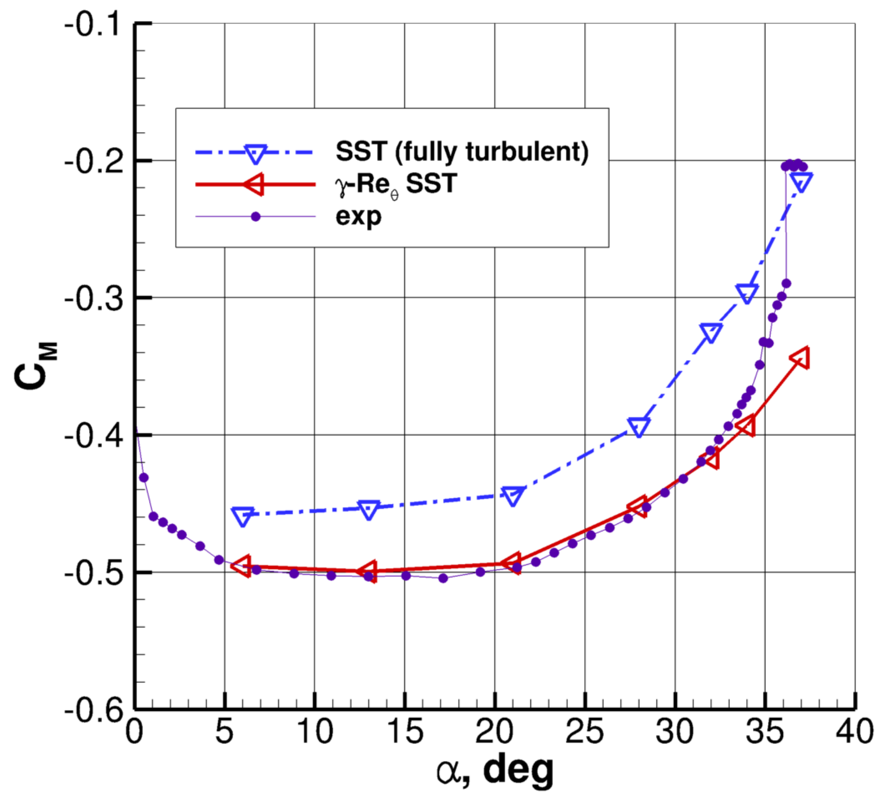




Lift and moment predictions

CFL3D results (no brackets)





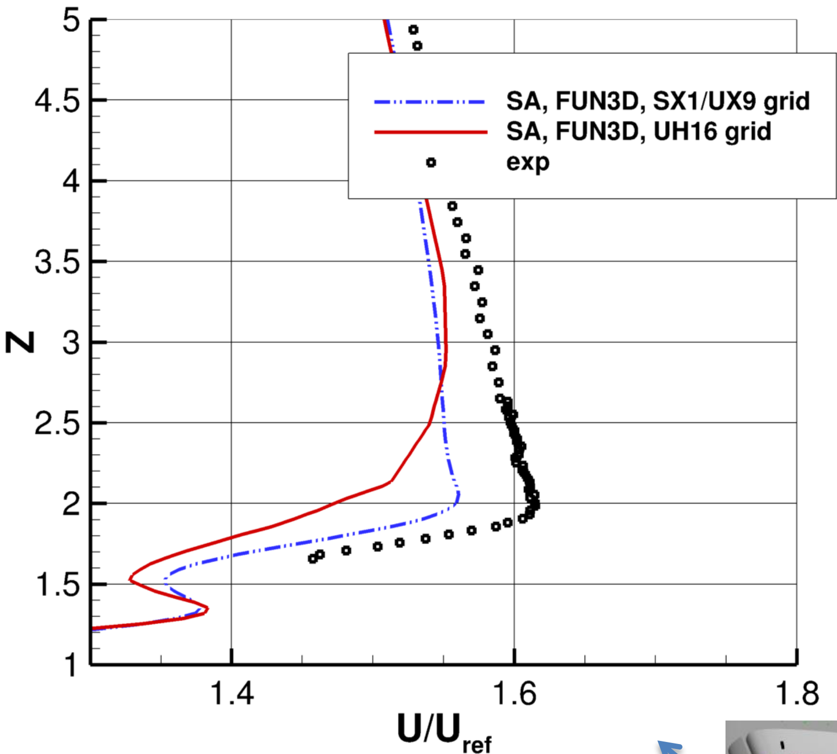
Results

- Grid resolution issues
  - Unstructured grids mis-predicted wake profiles (too diffused)
  - Automatic grid adaption would be helpful
- Rotation and curvature corrections in turbulence models helped
  - Increased lift (reduced upper surface pressures)
  - Improved resolution of wing tip vortex

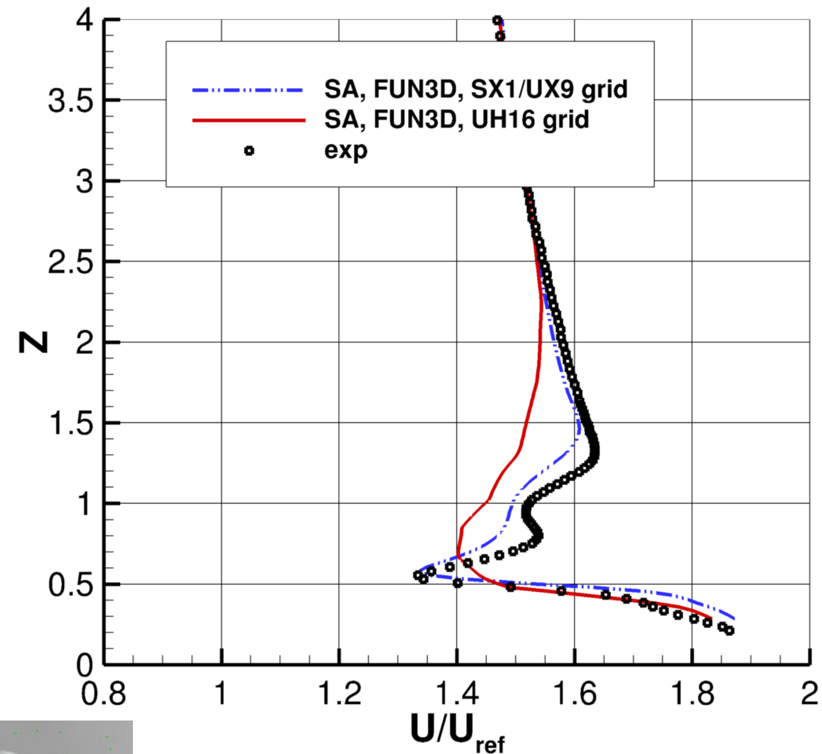
Effect of grid on velocity profiles

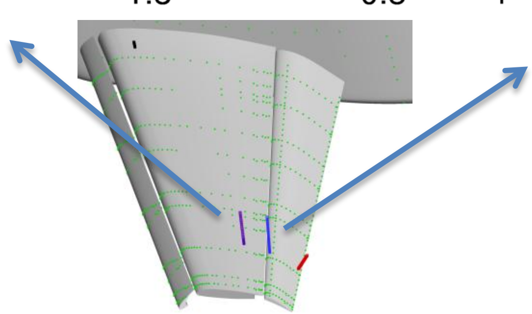
AoA=28 deg (no brackets)

Main element, 83% span



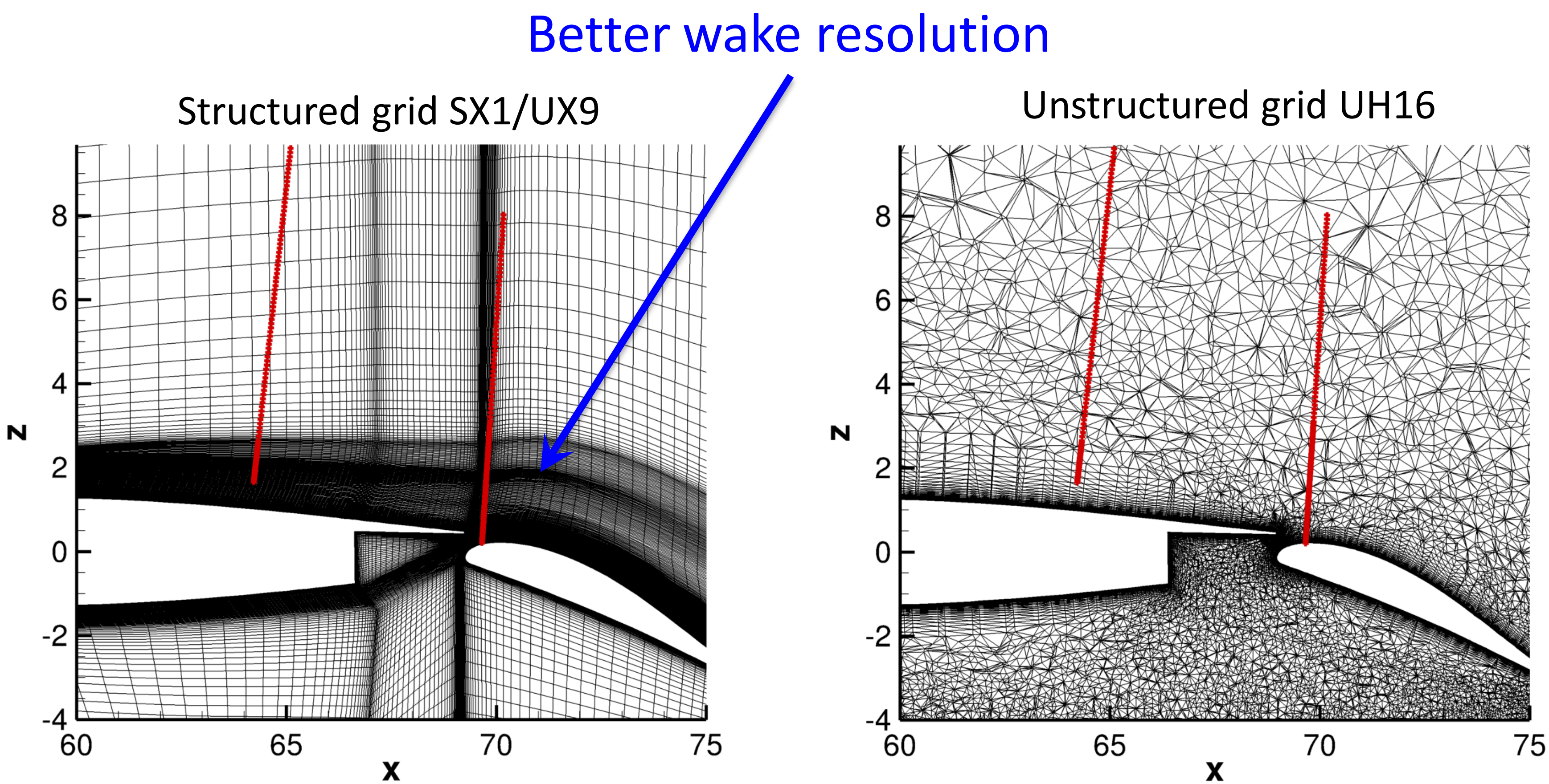
Flap forward element, 83% span





Comparison of grid section cuts

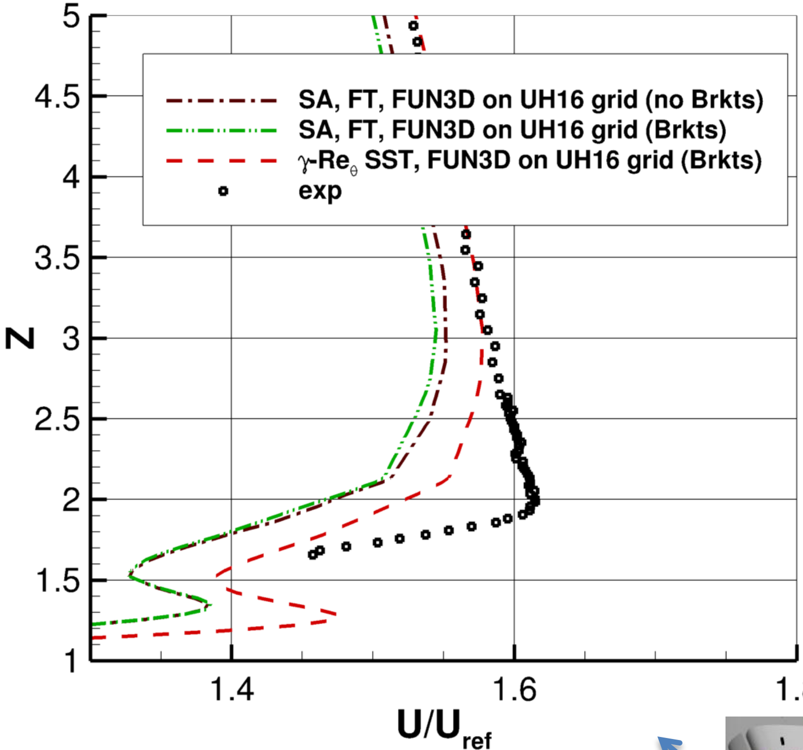
Near 85% span



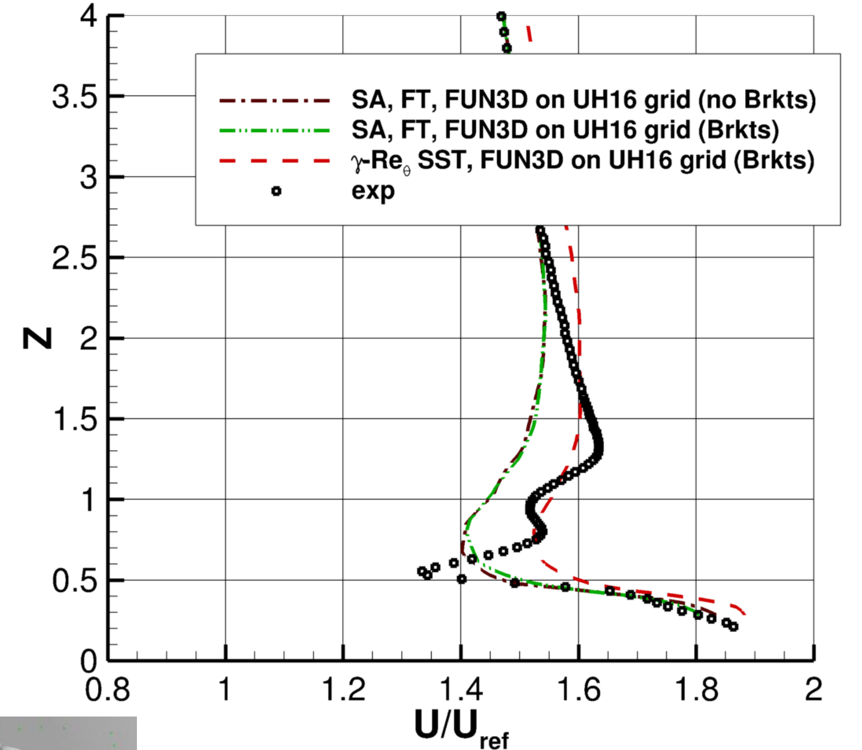
Effect of brackets and transition on velocity profiles

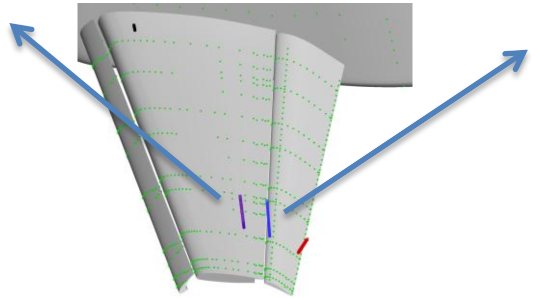
AoA=28 deg, unstructured UH16 grid

Main element, 83% span



Flap forward element, 83% span





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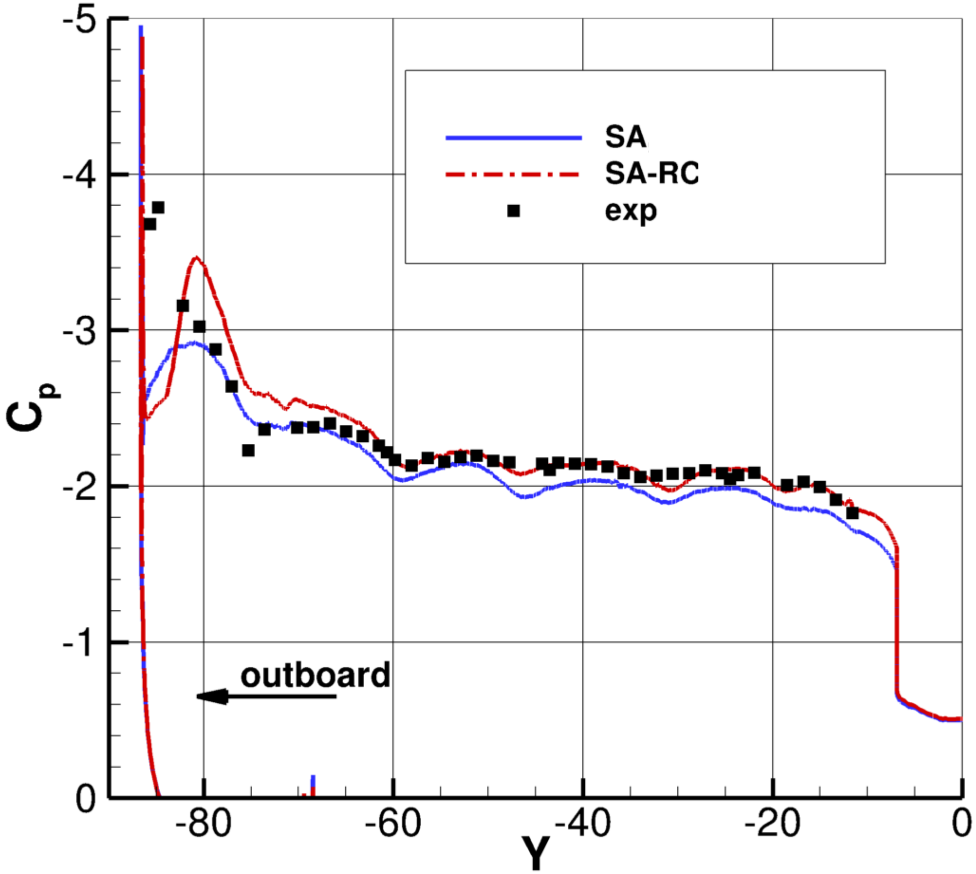
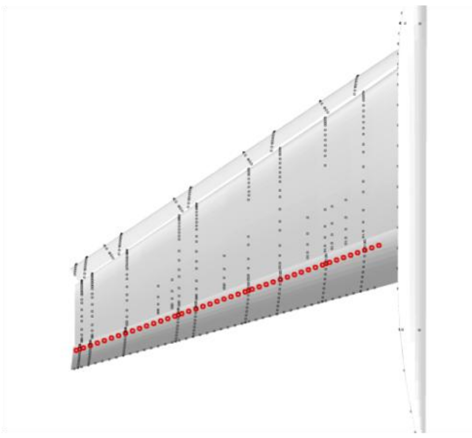
Rotation/curvature corrections

- Tested: SA-R, SA-RC, SST-RC, $\gamma - \mathrm{Re}_\theta$ SST-RC
- Example of effect of SA vs. SA-RC:

AoA=13 deg (with brackets)



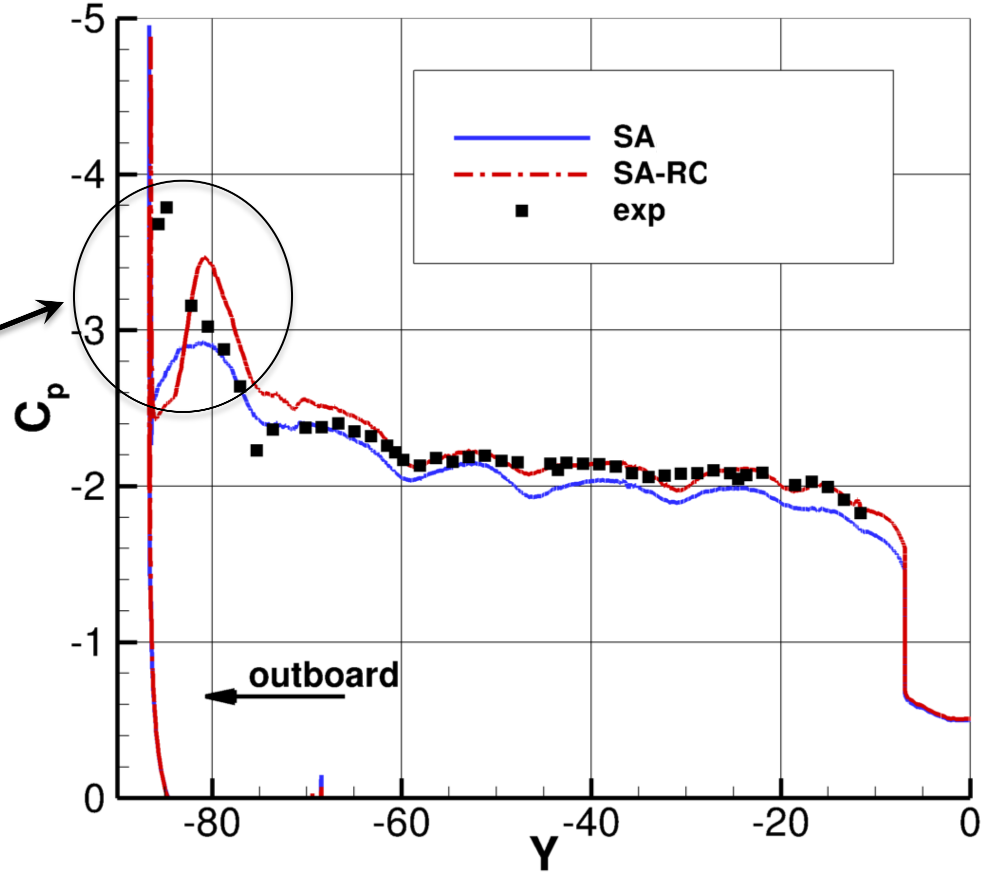


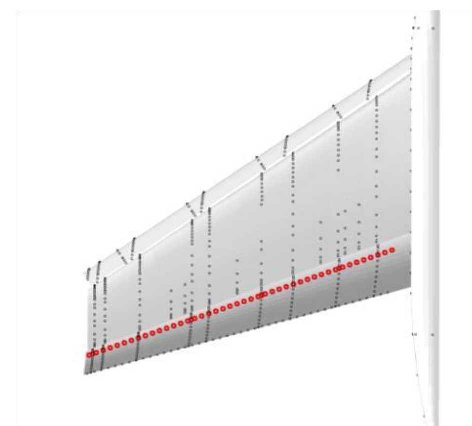
Rotation/curvature corrections

- Tested: SA-R, SA-RC, SST-RC, $\gamma - \mathrm{Re}_\theta$ SST-RC
- Example of effect of SA vs. SA-RC:

AoA=13 deg (with brackets)

Still getting poor predictions near the wing tip

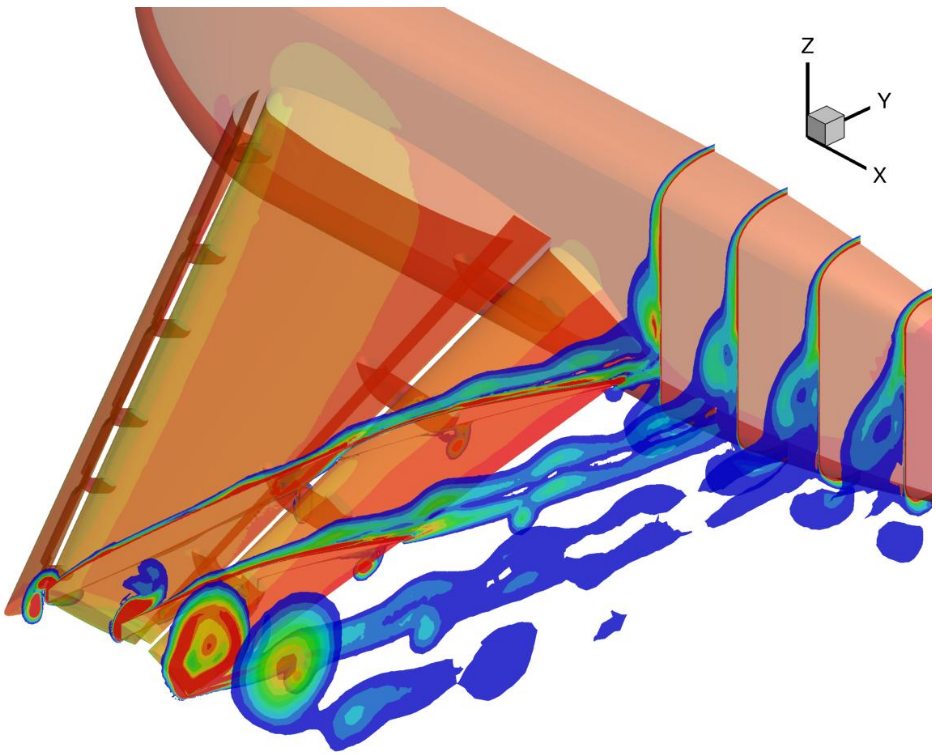




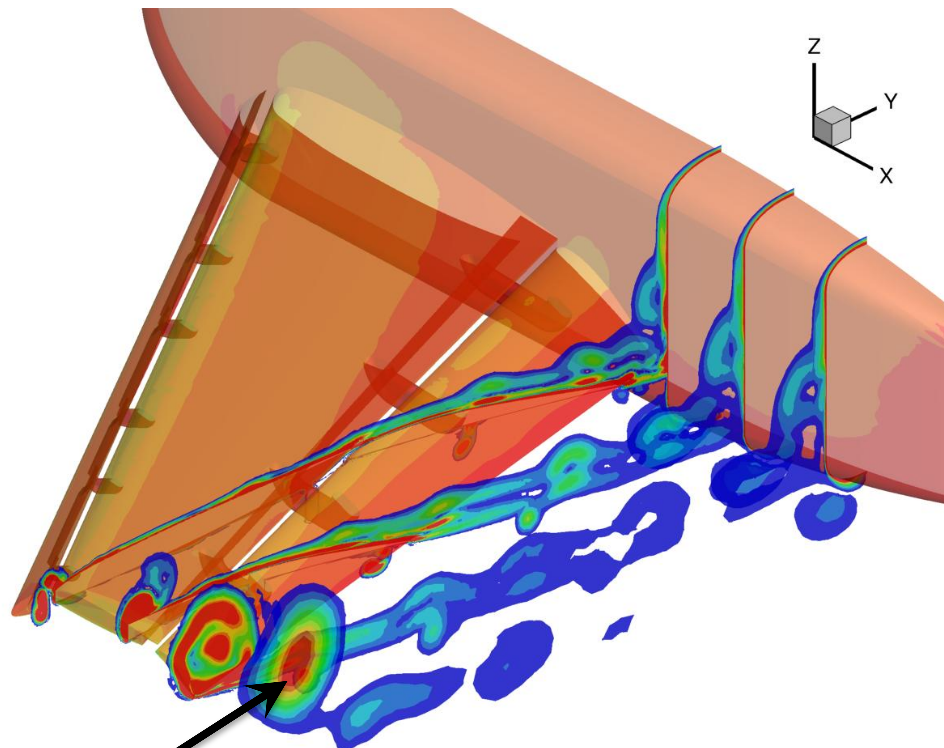
Rotation/curvature corrections

Vorticity contours

SA



SA-RC



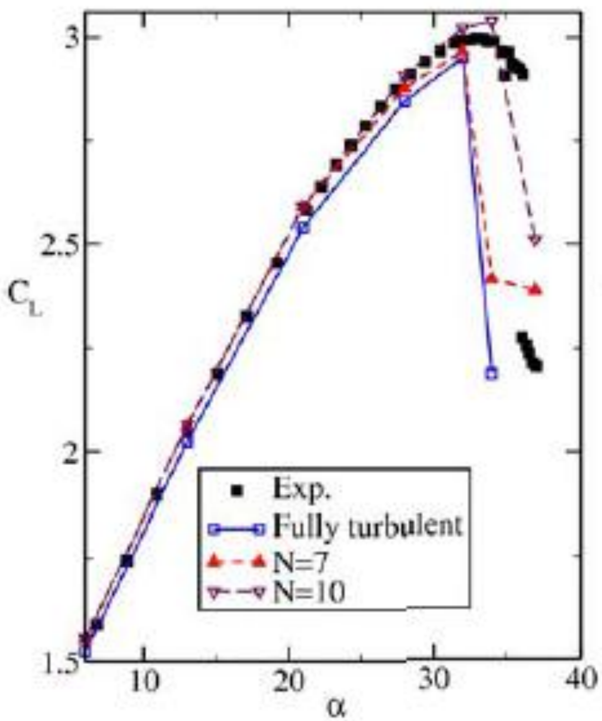
Peak vortex strength increased over 20%

Conclusions

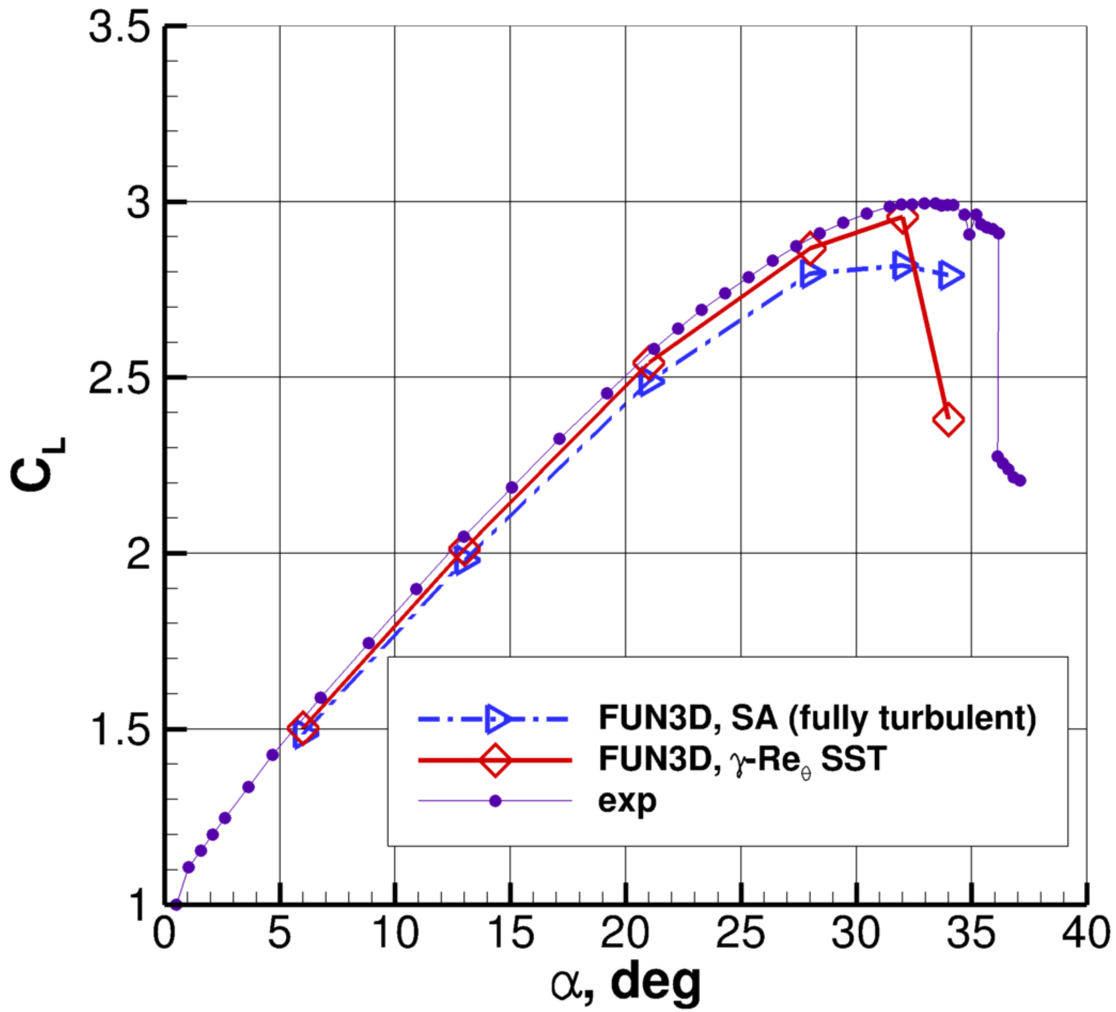
- Brief summary of HiLiftPW-1 given
- Brief summary of recent NASA LaRC results given
- Predicting $C_{L,max}$ accurately for the "right" reasons is still a challenge for CFD
- Many pieces have influence:
  - Transition
  - Turbulence modeling (e.g., RC effects)
  - Geometric fidelity (e.g., brackets)
  - Grid resolution, both global and local (e.g., tip vortex and wake regions)
- Upcoming talks this session and tomorrow AM
  - Many Trap Wing studies: including transition, separation, unsteady, adaptive, and uncertainty quantification

Comparison with brackets

FOI study (SA)



Current FUN3D results



Conclusions

- Brief summary of HiLiftPW-1 given
- Brief summary of recent NASA LaRC results given
- Predicting $C_{L,max}$ accurately for the "right" reasons is still a challenge for CFD
- Many pieces have influence:
  - Transition
  - Turbulence modeling (e.g., RC effects)
  - Geometric fidelity (e.g., brackets)
  - Grid resolution, both global and local (e.g., tip vortex and wake regions)
- Upcoming talks this session and tomorrow AM
  - Many Trap Wing studies: including transition, separation, unsteady, adaptive, and uncertainty quantification