Overview and Summary of the Third AIAA High Lift Prediction Workshop

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Overview

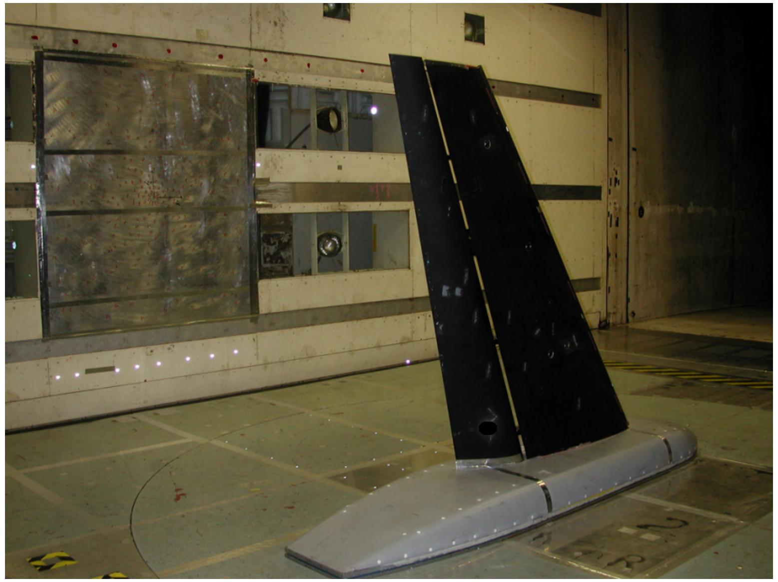
- General summary of HiLiftPW-3 results.
  - CFD comparisons against itself (consistency, verification).
  - CFD comparisons against experiment (validation).
- Have things improved since HiLiftPW-2?
- What have we learned?
- What should be done differently for HiLiftPW-4?

Outline

- Introduction
- High lift geometries and experimental data
- Grid systems
- Summary of entries
- Results
  - Turbulence modeling verification
  - HL-CRM
  - JSM
- Statistical analysis
- Conclusions

Where we've been (some highlights)

- HiLiftPW-1 (2010).
  - NASA Trapezoidal Wing-Body; including effect of flap deflection.
  - CFD tended to underpredict lift; big spread near stall.
  - No support brackets were included in the CFD (when they were, predicted lift was even lower).
  - Transition modeling seemed to help improve comparisons with experiment.
  - Flow near wing tip was very difficult to predict.



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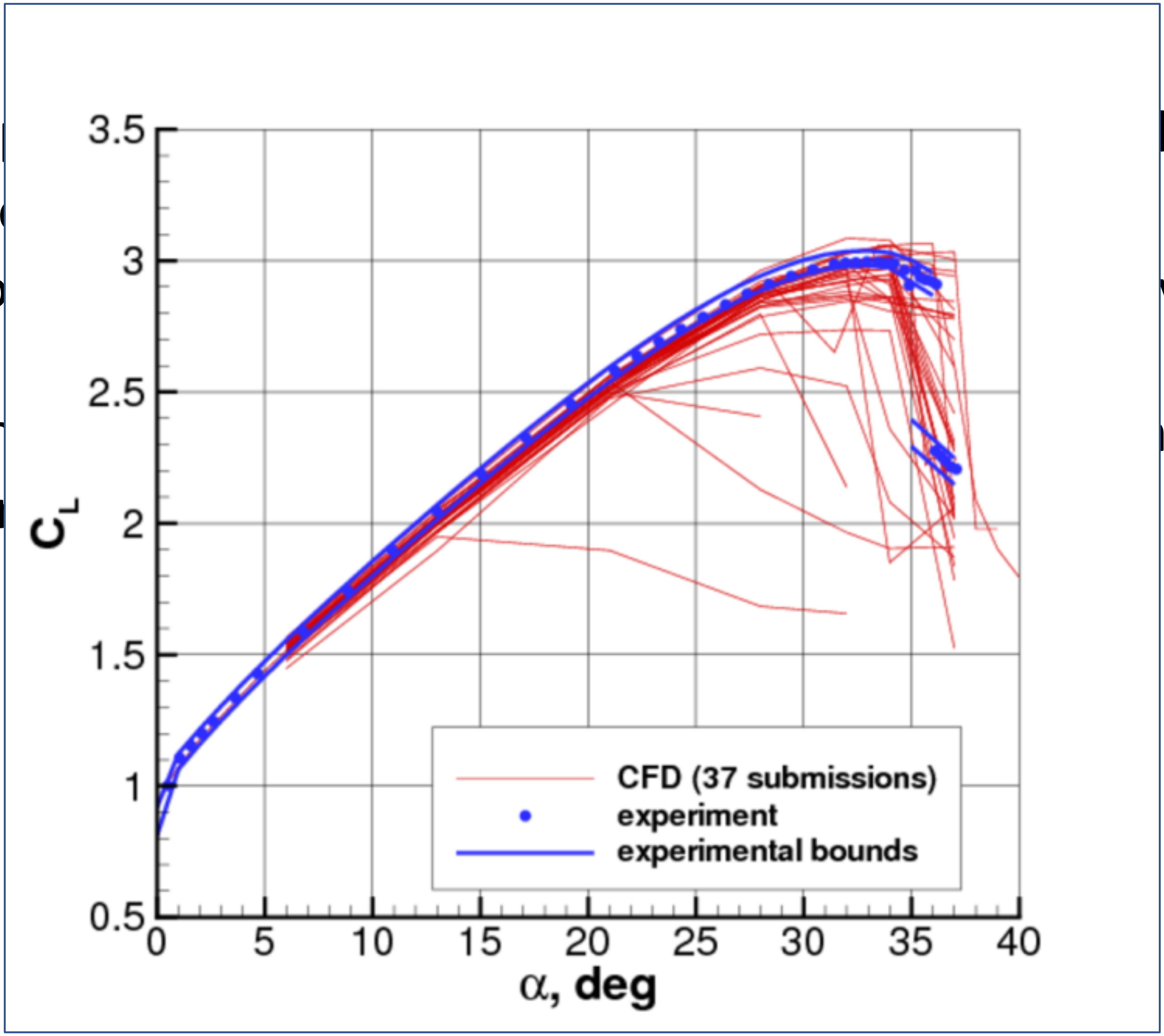
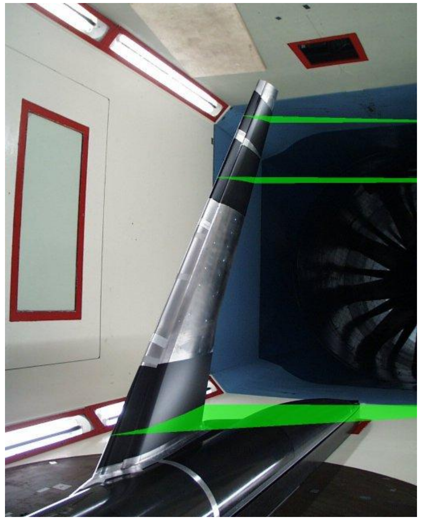
- HiLiftPW-1
  - NASA Tra[…] […]lection.
  - CFD tend[…]
  - No suppo[…] […]y were, predicted lift was even[…]
  - Transition[…] […]s with experiment.
  - Flow near[…]



Where we've been (some highlights)

- HiLiftPW-2 (2013).
  - DLR-F11 Wing-Body; including effect of Reynolds number.
  - CFD sometimes underpredicted, sometimes overpredicted lift; again showed bigger spread near stall.
  - Separation behind slat tracks was probably influential in initiating stall; even when including brackets, CFD usually got it wrong (e.g., separation behind wrong brackets).
  - No clear trends with transition modeling stood out.
  - Attaining steady-state convergence sometimes difficult.
  - Experimental oil flows were extremely useful for determining whether CFD was capturing the physics correctly or not.



Where we've been (some highlights)

- HiLiftPW-2
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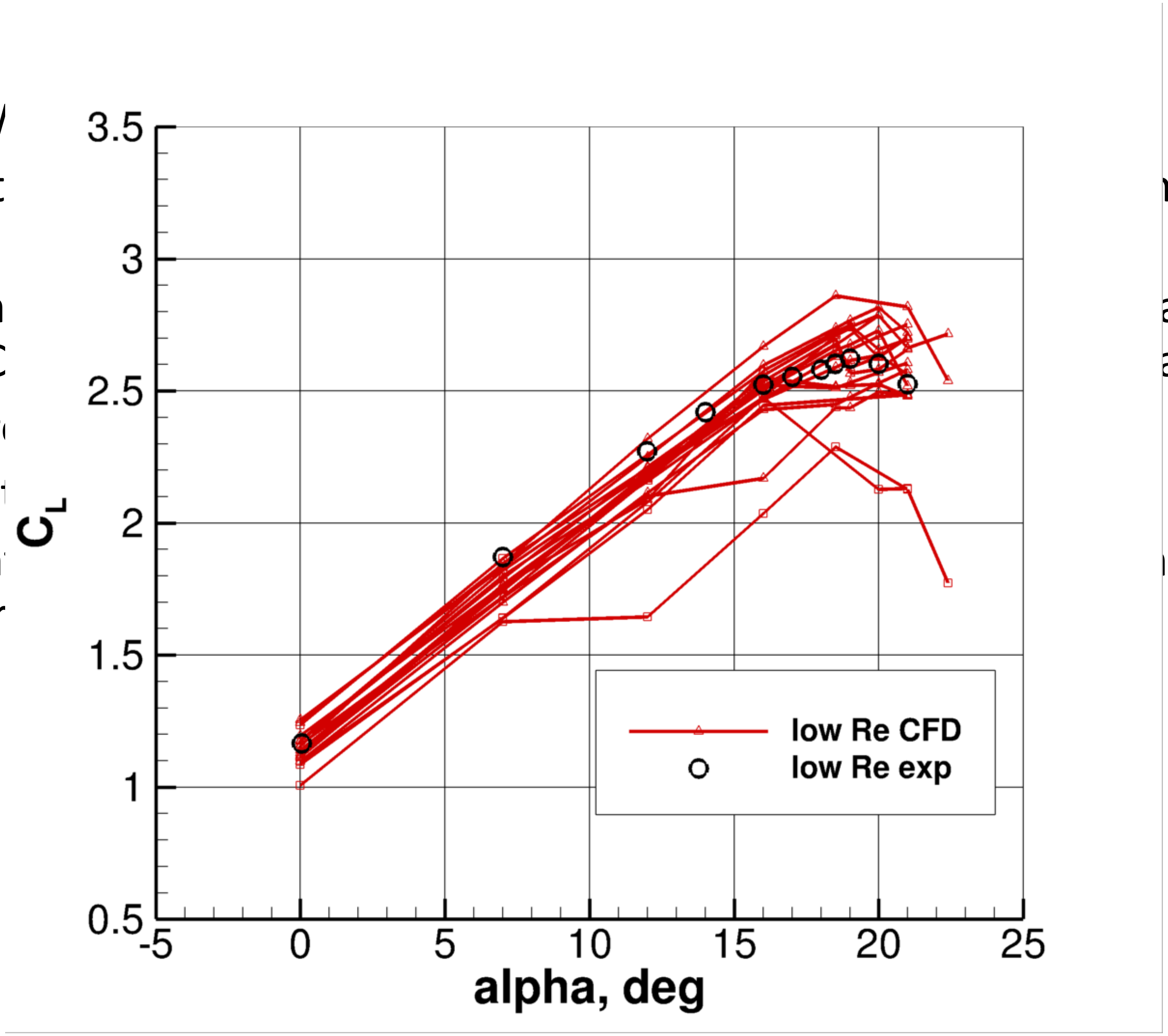
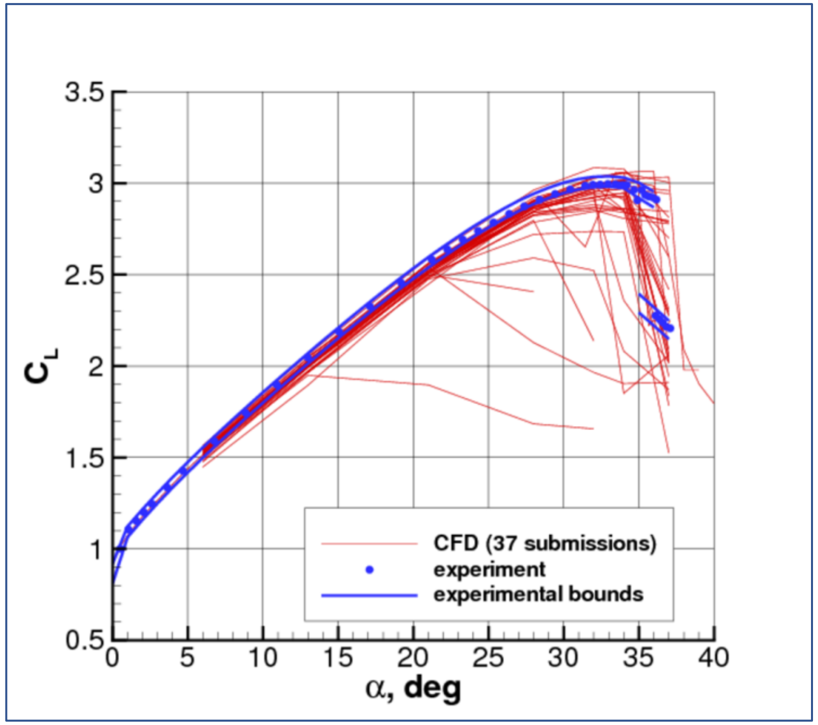


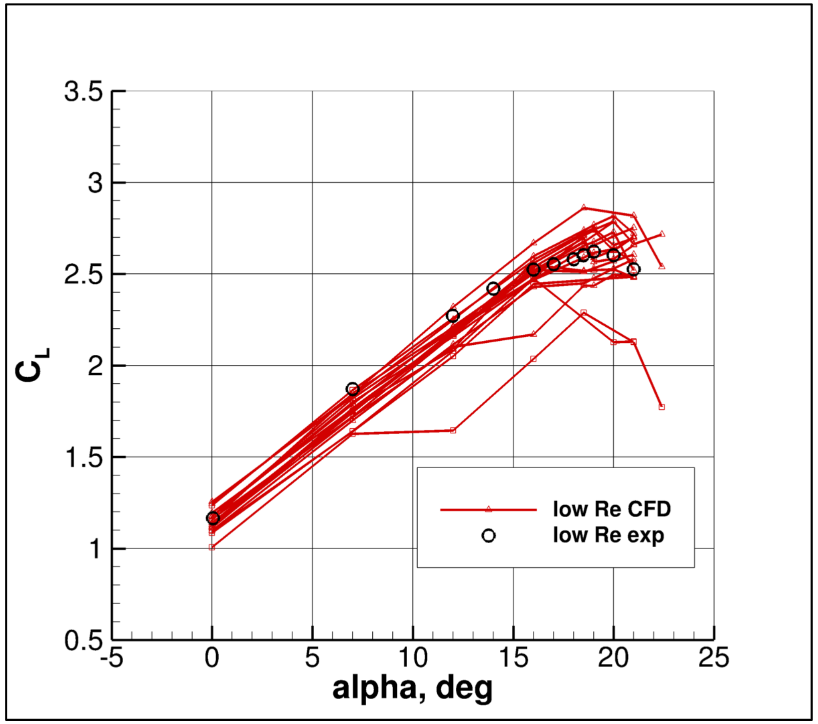
Quick comparison

HiLiftPW-1



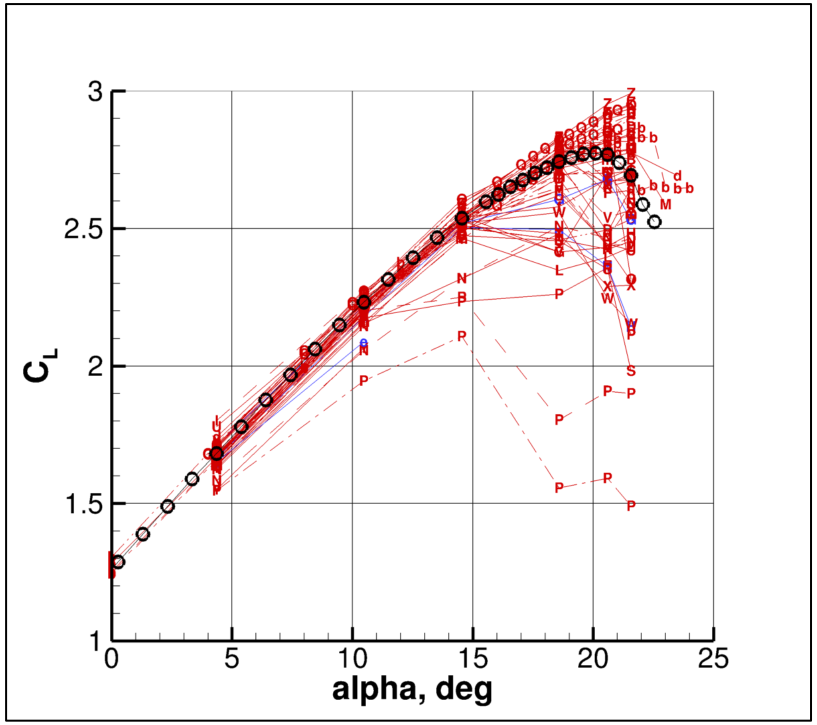
37 submissions

HiLiftPW-2



48 submissions

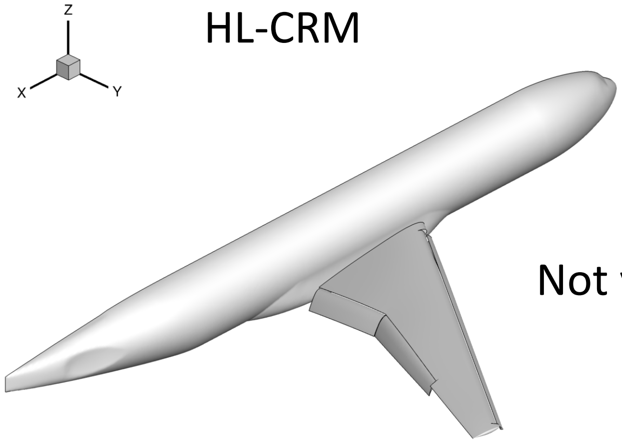
HiLiftPW-3



79 submissions

HiLiftPW-3 geometries and experimental data

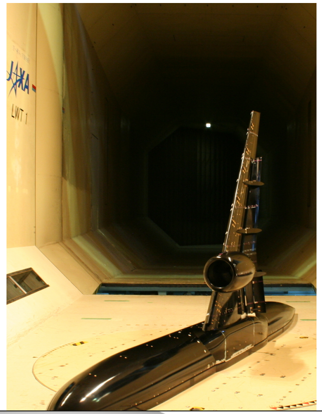
HL-CRM

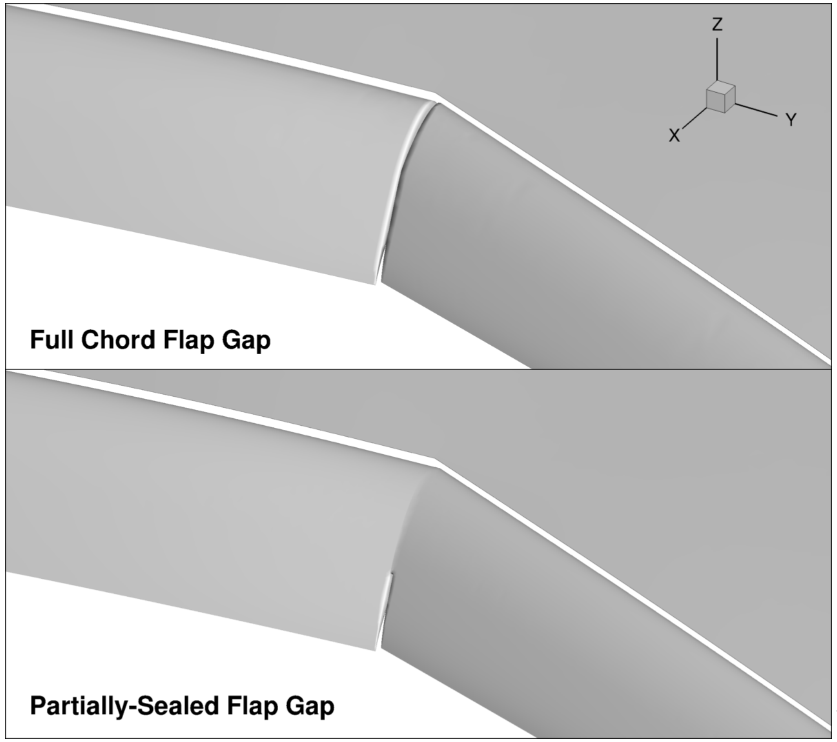


Not yet built

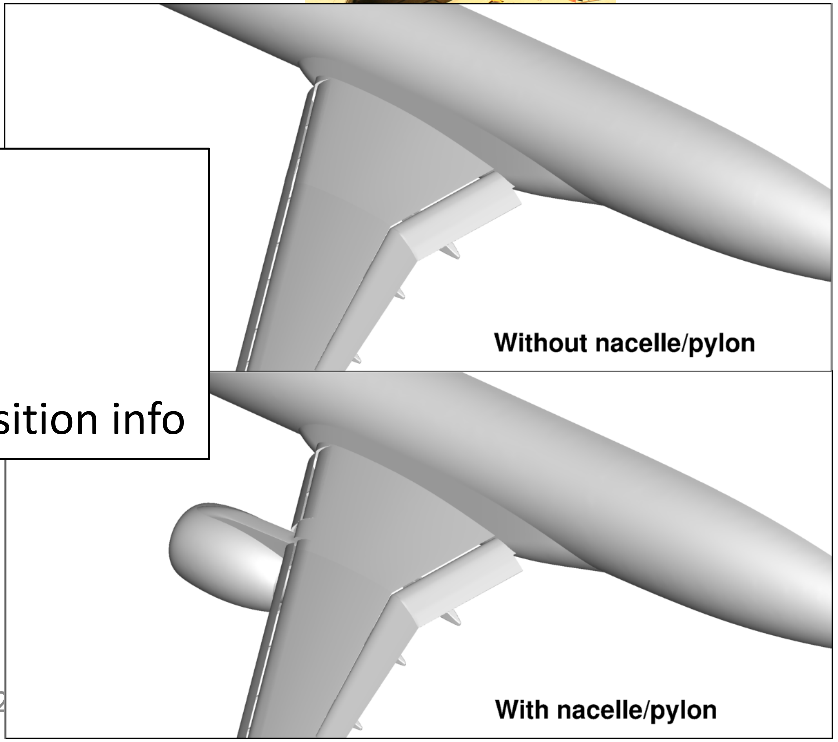
JSM

Tested in JAXA-LWT1 in early 2000s
- No tripping



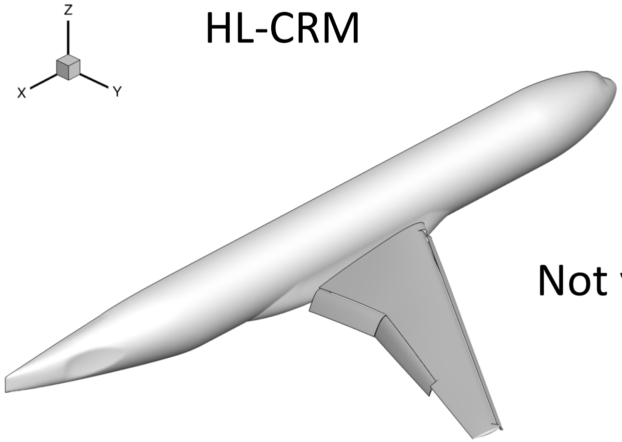


Forces
Moment
Cp
Oil flow
Some transition info



HiLiftPW-3 geometries and experimental data

HL-CRM



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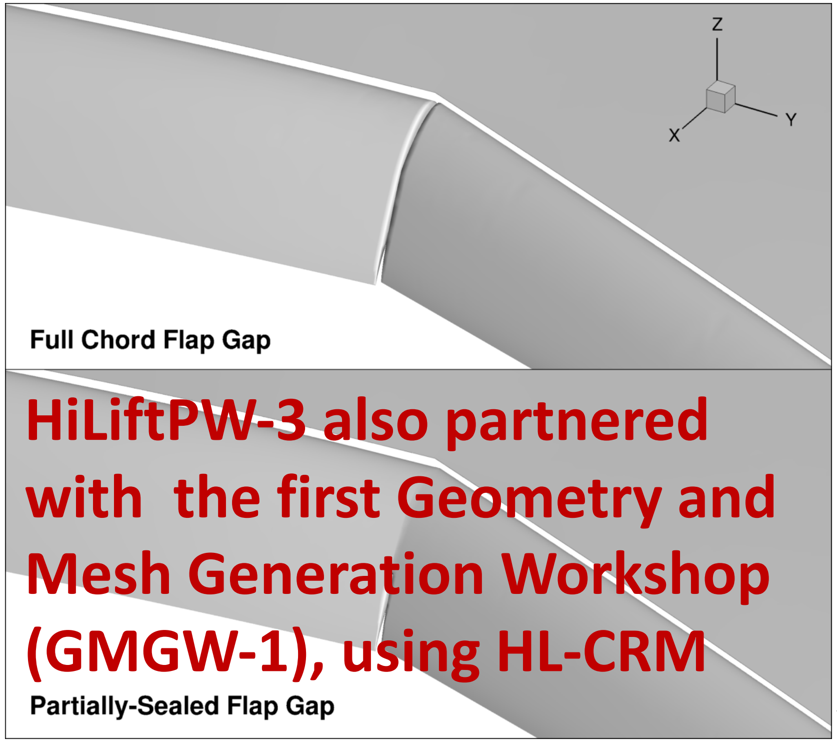

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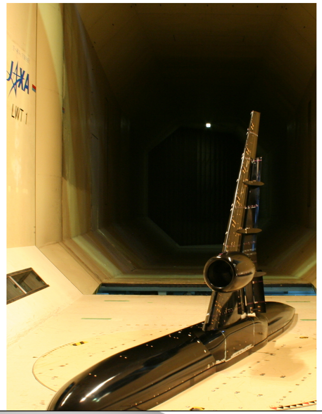

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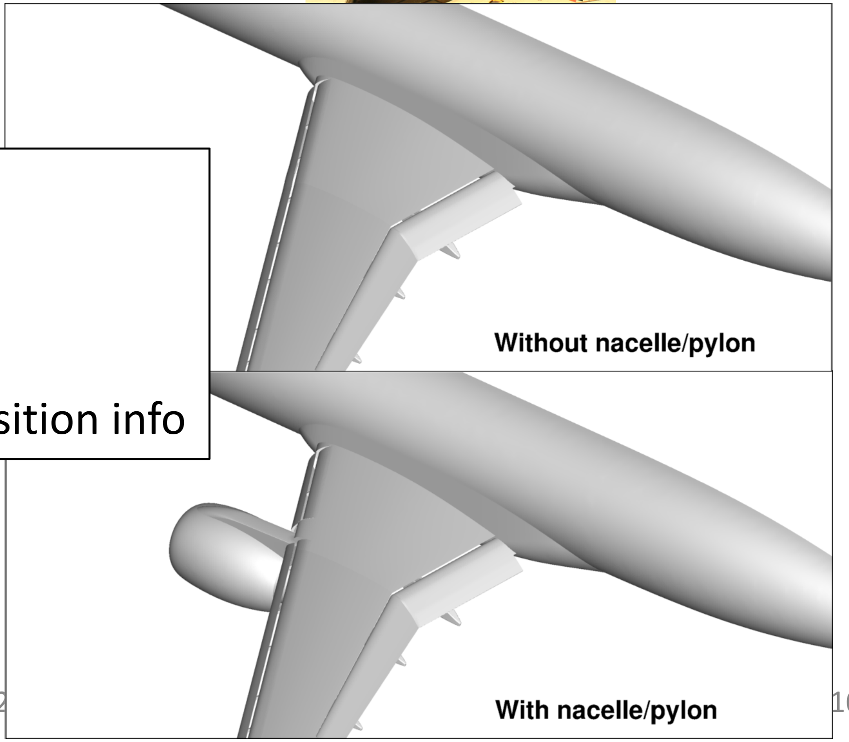
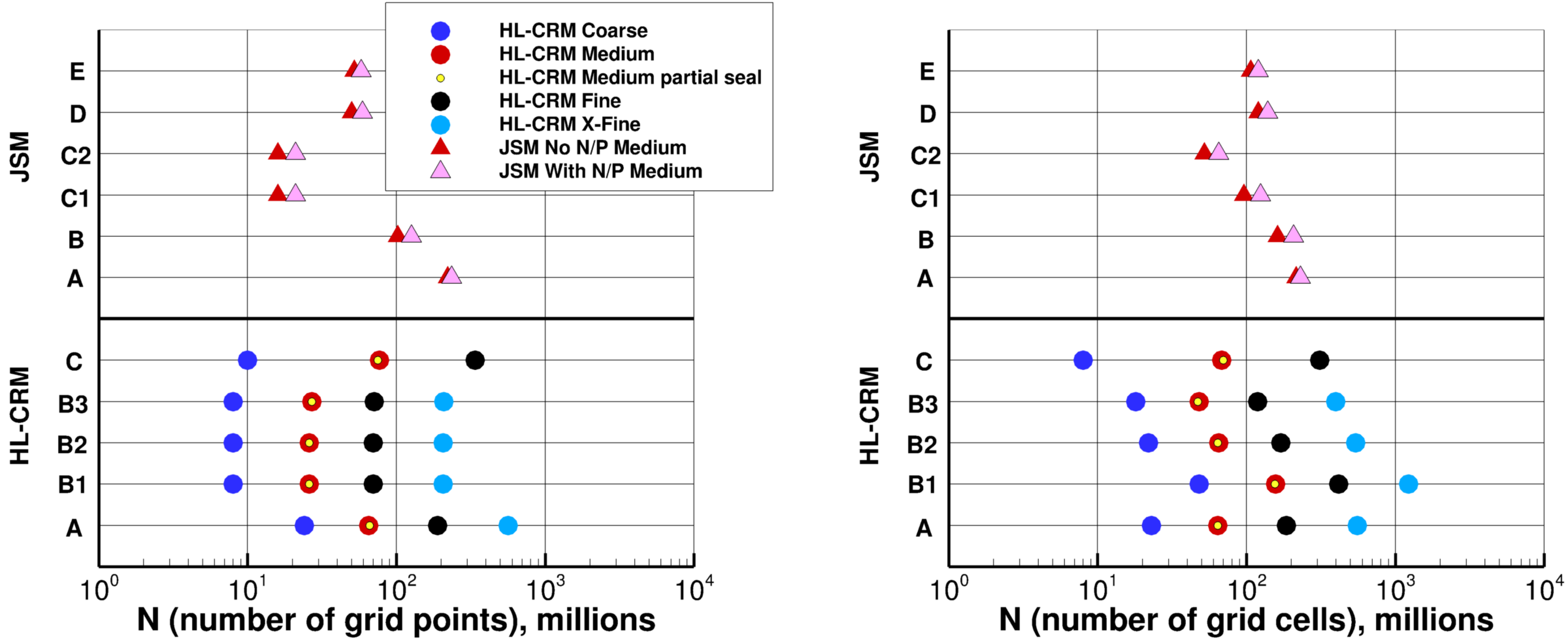


Committee-provided grid systems

For HL-CRM and JSM



Average medium grid: approx 71 M points and 120 M cells
Median medium grid: approx 52 M points and 107 M cells

Summary of entries

- 35 individuals/groups with 79 entries.
  - 14 different countries (40% U.S.).
  - Broad representation from industry, academia, CFD vendors, and government research labs.
- Turbulence models:
  - Most used SA or variant (RC, R, neg, QCR, noft2).
  - K-omega type: BSL, SST, SST-V, SST-V-sust, SST-2003, SST w mods, Wilcox1988, Wilcox1988CC.
  - Lag-EB-ke.
  - SSG/LRR-RSM-w2012.
- Transition models:
  - SST-gamma, AFT2017b, gamma-Ret-SST.
- Non-RANS:
  - Finite element with implicit SGS model.
  - LB with VLES wall model.
  - LB with WALE SGS model.
  - DDES.
- Not everyone submitted all requested cases.
- Details in paper.

Results

- Turbulence modeling verification
- HL-CRM
- JSM

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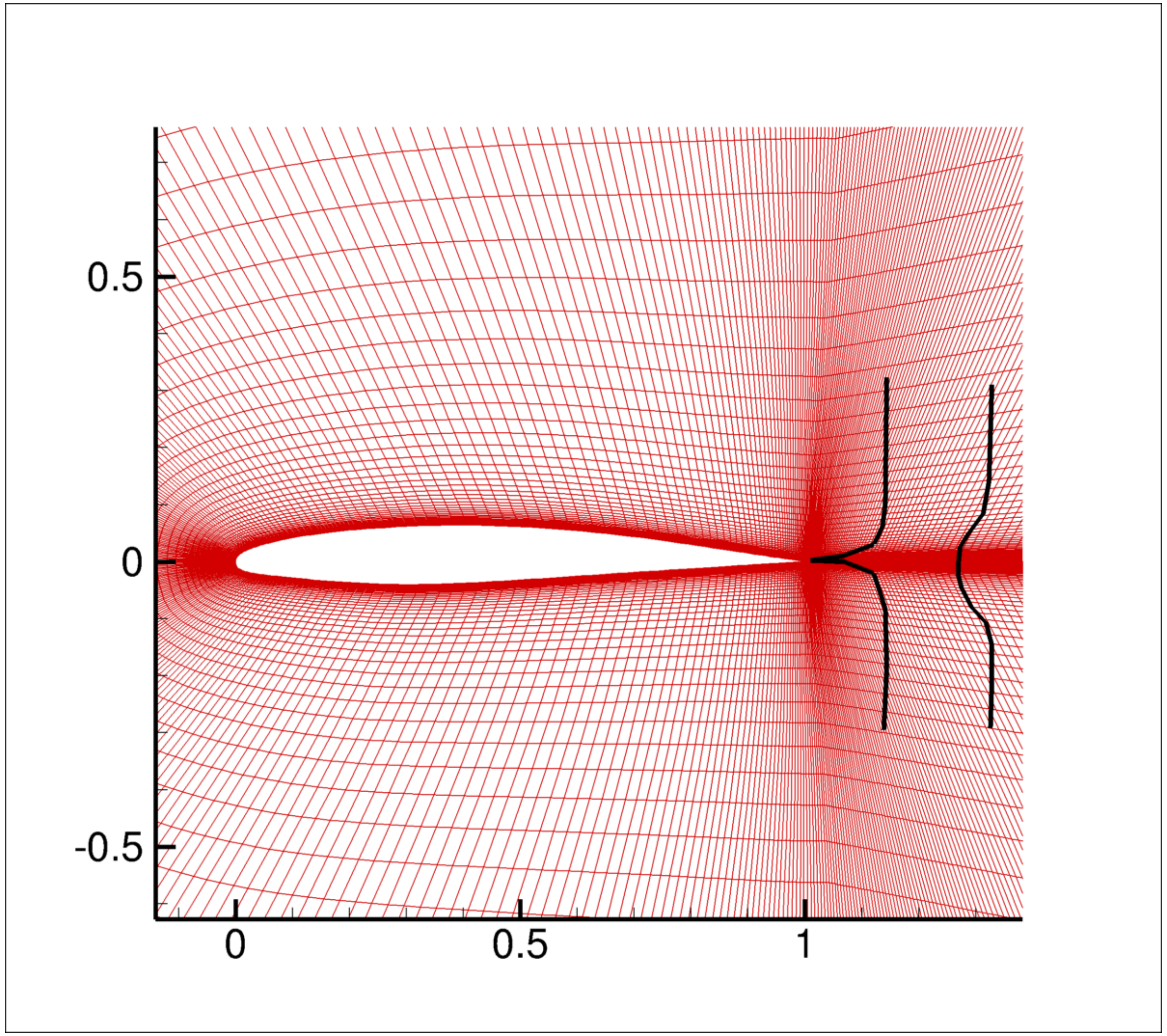
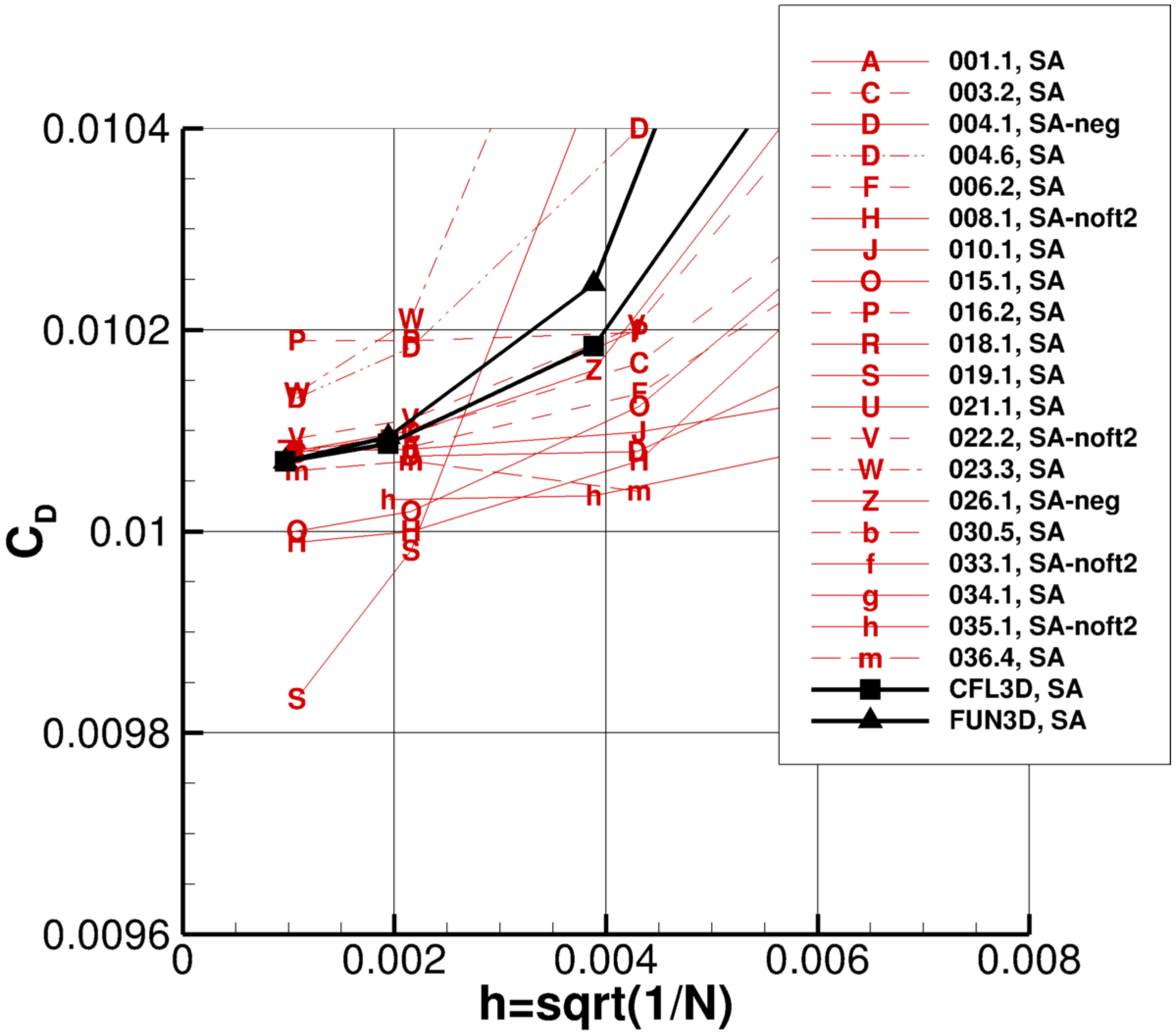
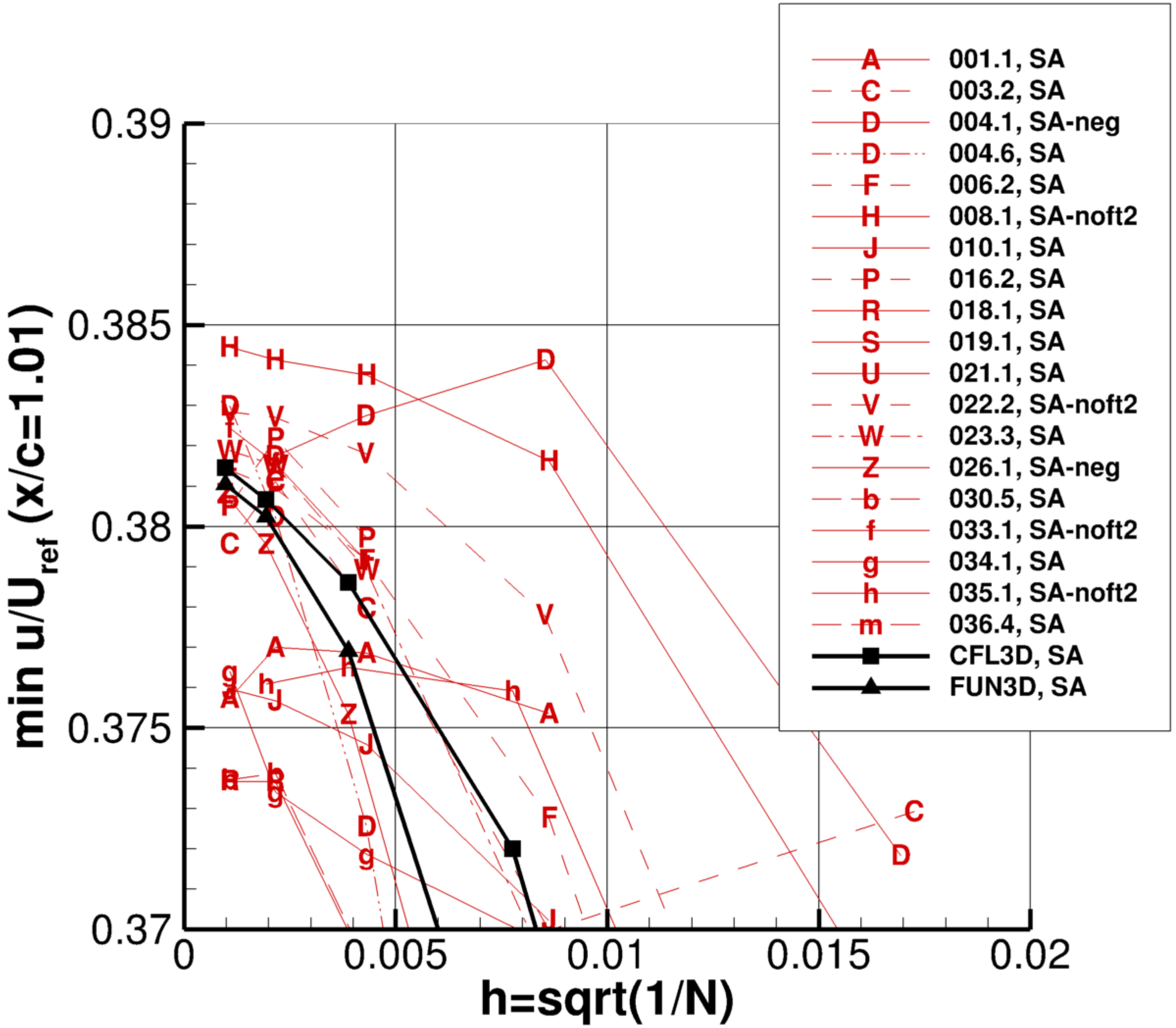
DSMA661(Model A) airfoil,
M=0.088, alpha=0 deg,
Re_C=1.2 million
(JFM 160:155-179, 1985)



Turbulence modeling verification

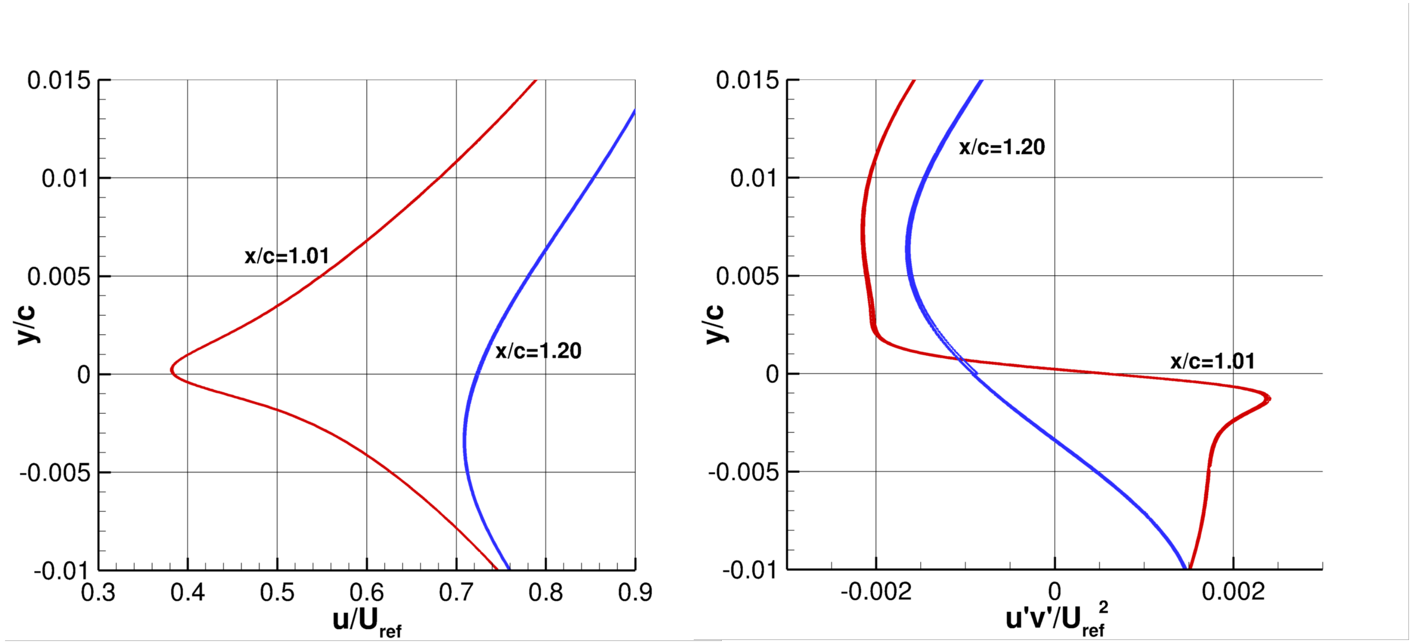
Only completed for SA model (SA, SA-neg, SA-noft2)





The important role of verification

2-D verification case
8 different codes produce nearly identical results for SA model
(CFL3D, FUN3D, Kestrel/COFFE, CFD++, OVERFLOW, BCFD, TAU, and LAVA)



Approximately 30% of the codes that ran the verification case were <u>fully verified</u> for the SA model

Additional verification exercises still needed for other models, including SA variants

VERIF/2DANW case from TMR website: https://turbmodels.larc.nasa.gov

Verification removes one possible source of CFD uncertainty, for a given model.
Other sources: grid (size, extent, adherence to geometry), BCs, iterative convergence.

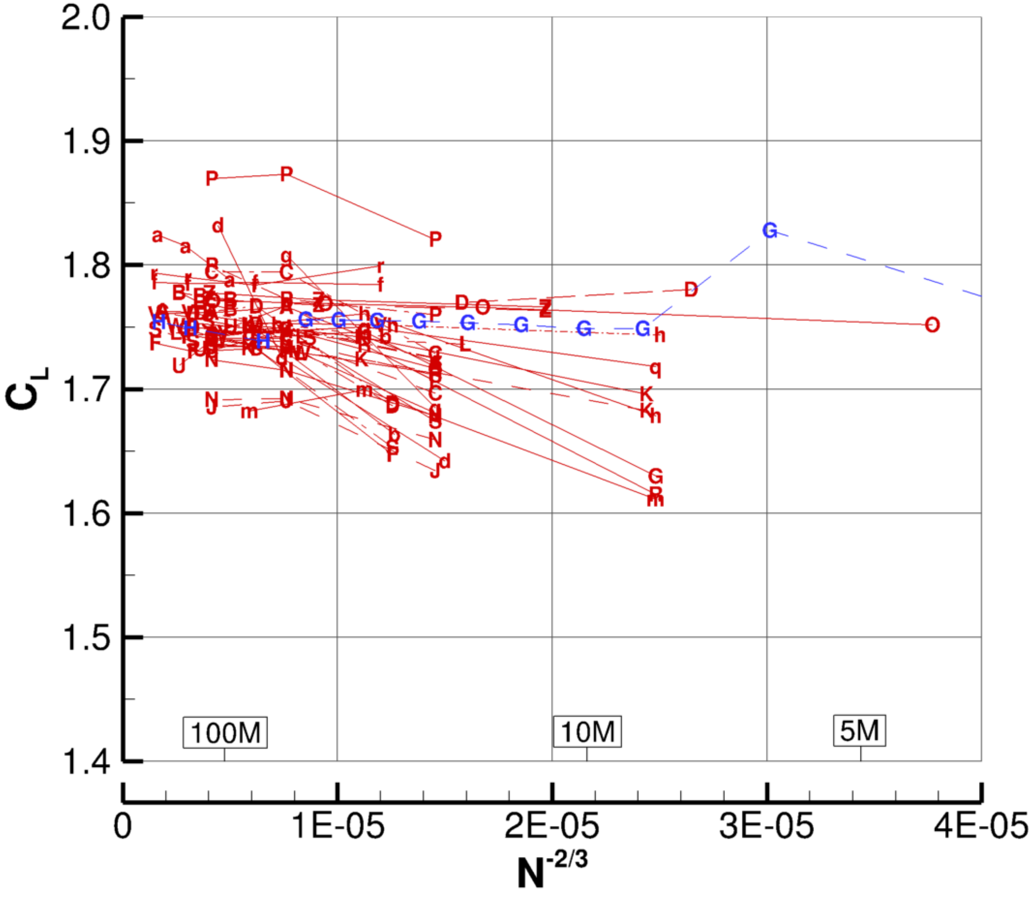
Results

- Turbulence modeling verification
- HL-CRM
- JSM

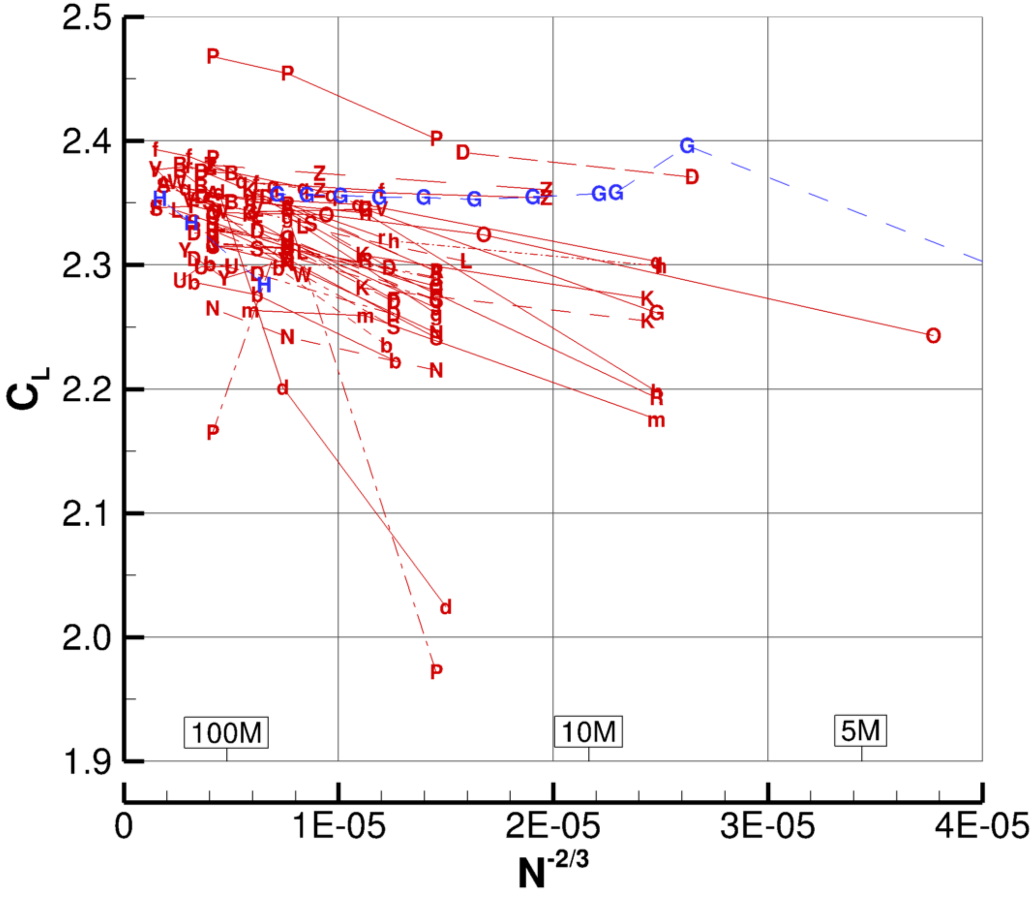
Focusing on only a few main points here; further details (such as effect of flap gap treatment) are given in the paper

HL-CRM grid convergence (all results)

alpha = 8 deg.



alpha = 16 deg.



Note: blue curves represent grid-adaption results

Drag and moment shown in paper

The important role of verification

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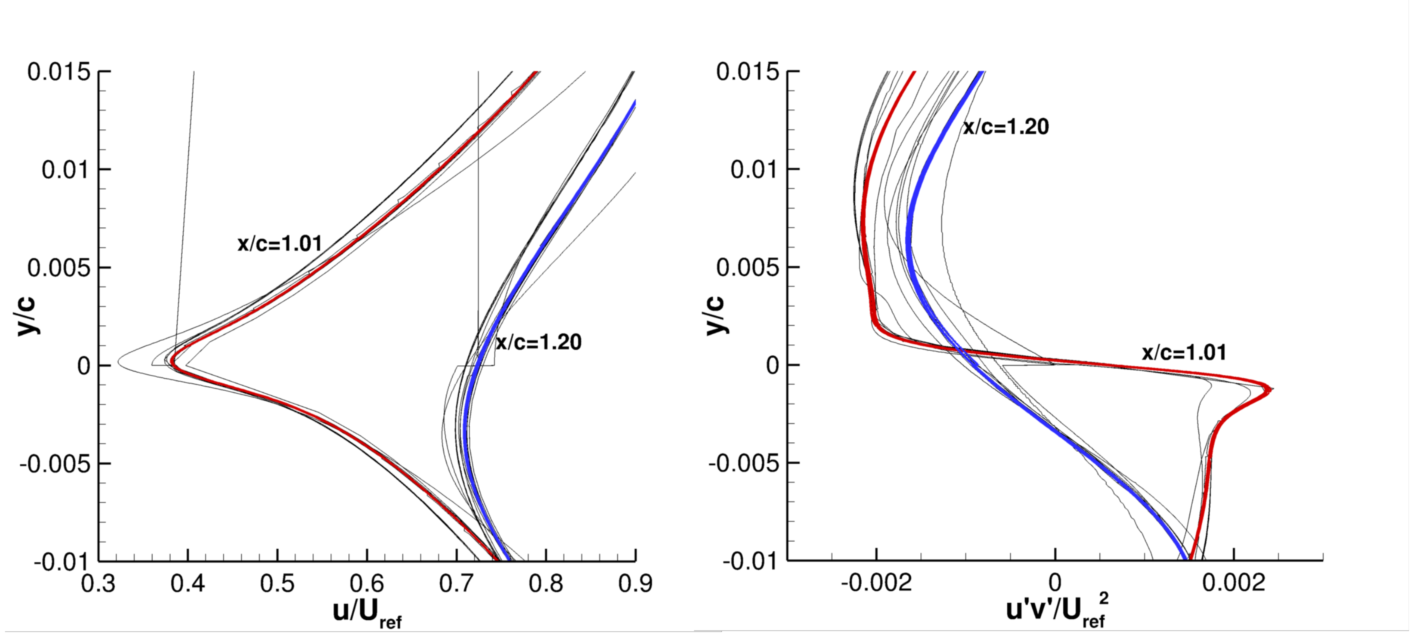
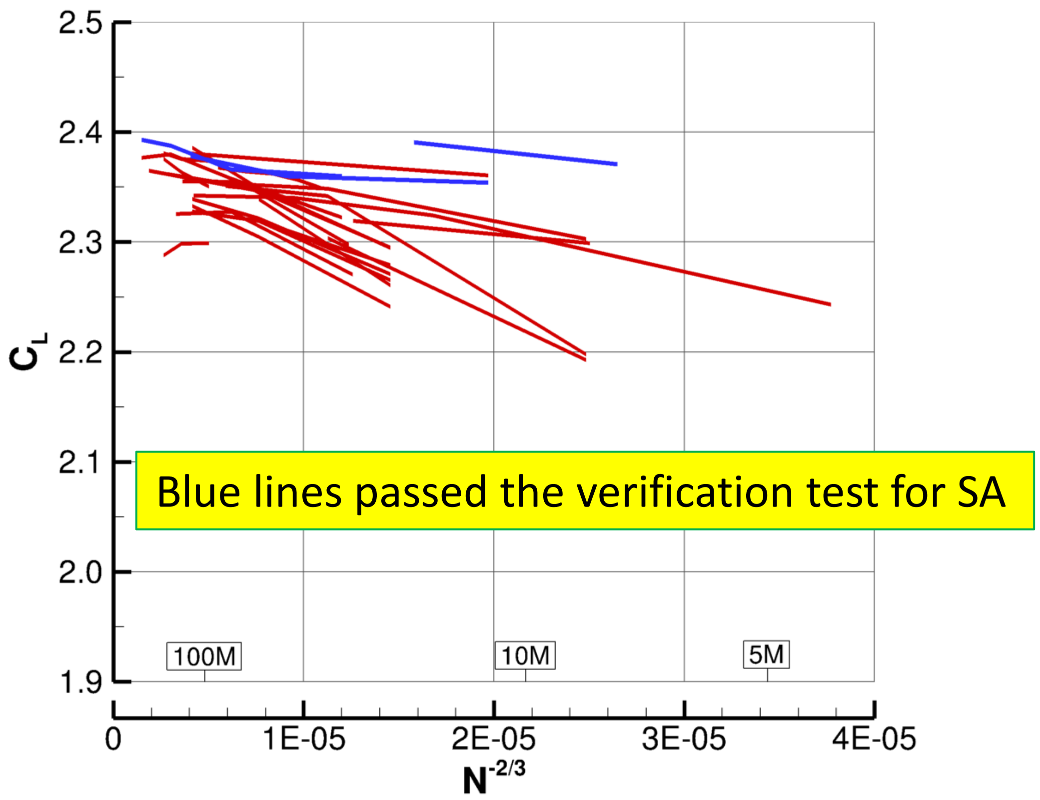


VERIF/2DANW case from TMR website: https://turbmodels.larc.nasa.gov

HL-CRM
SA models only



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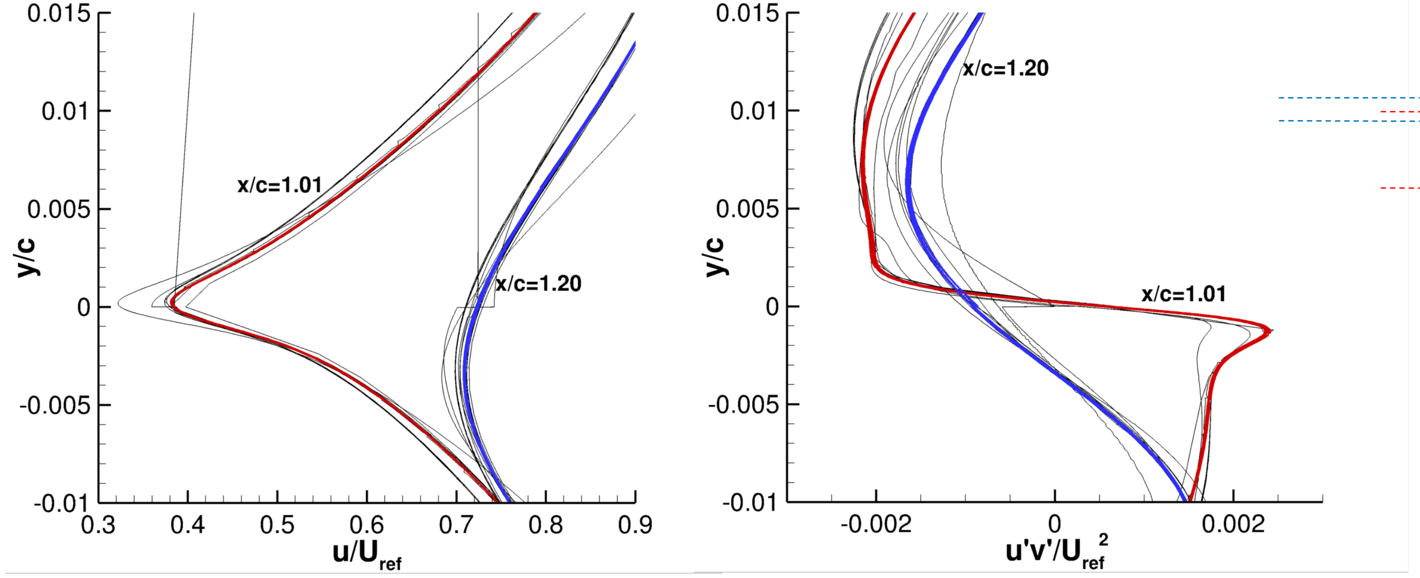
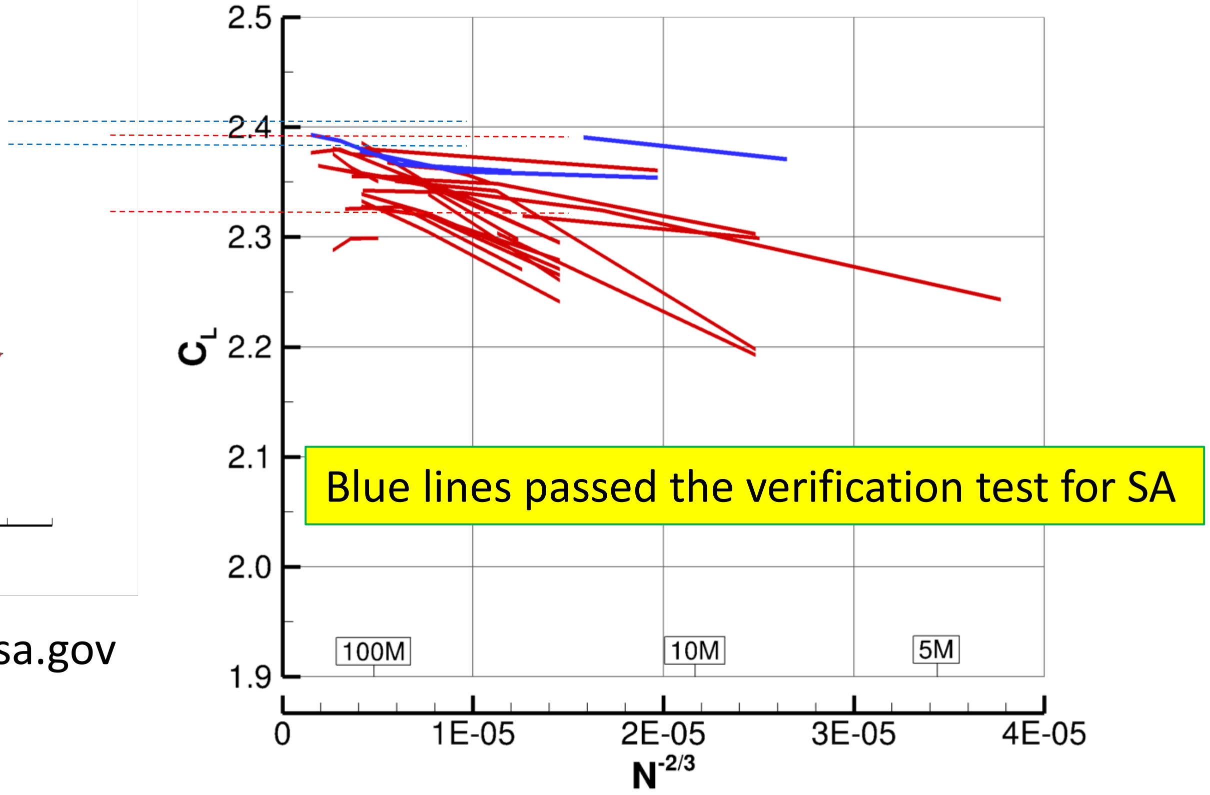
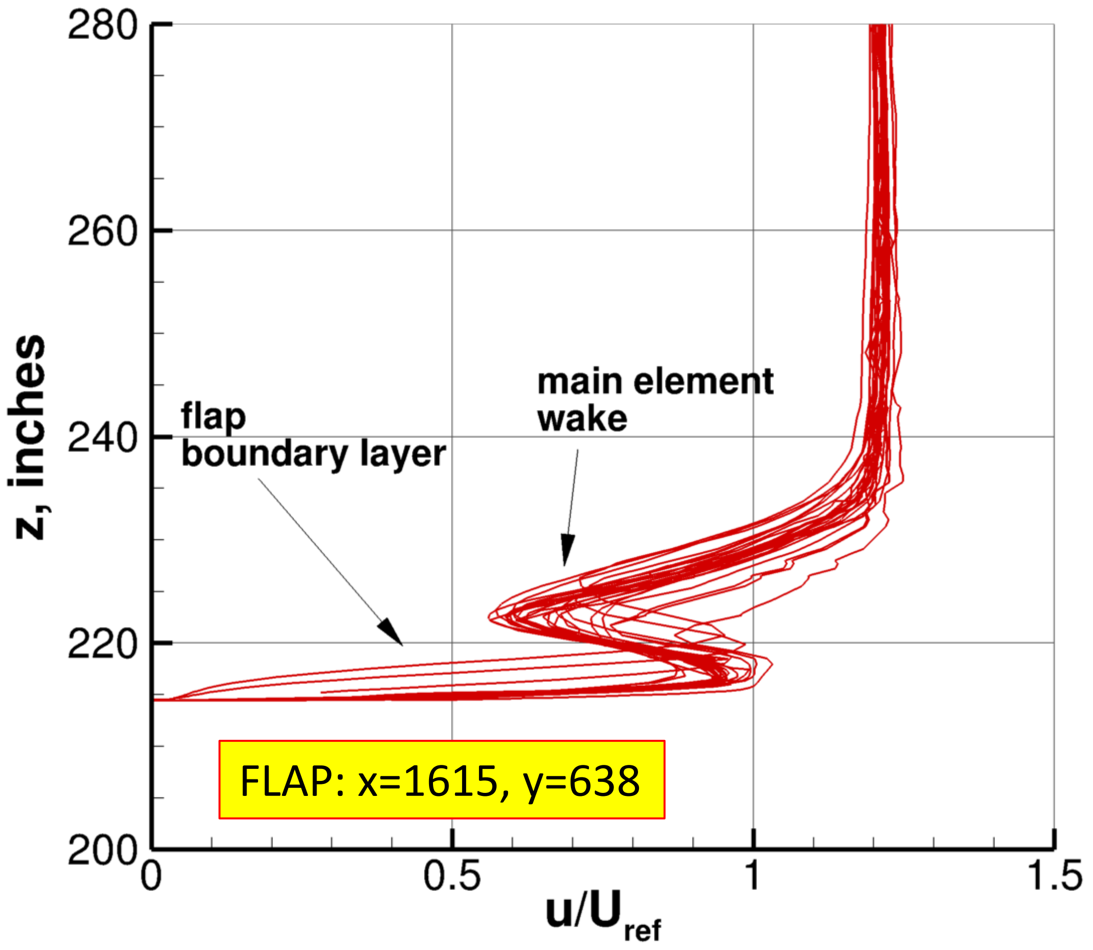
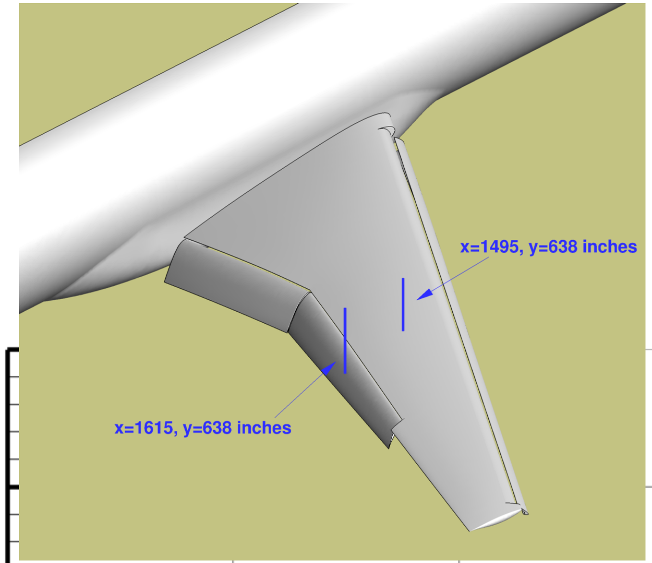


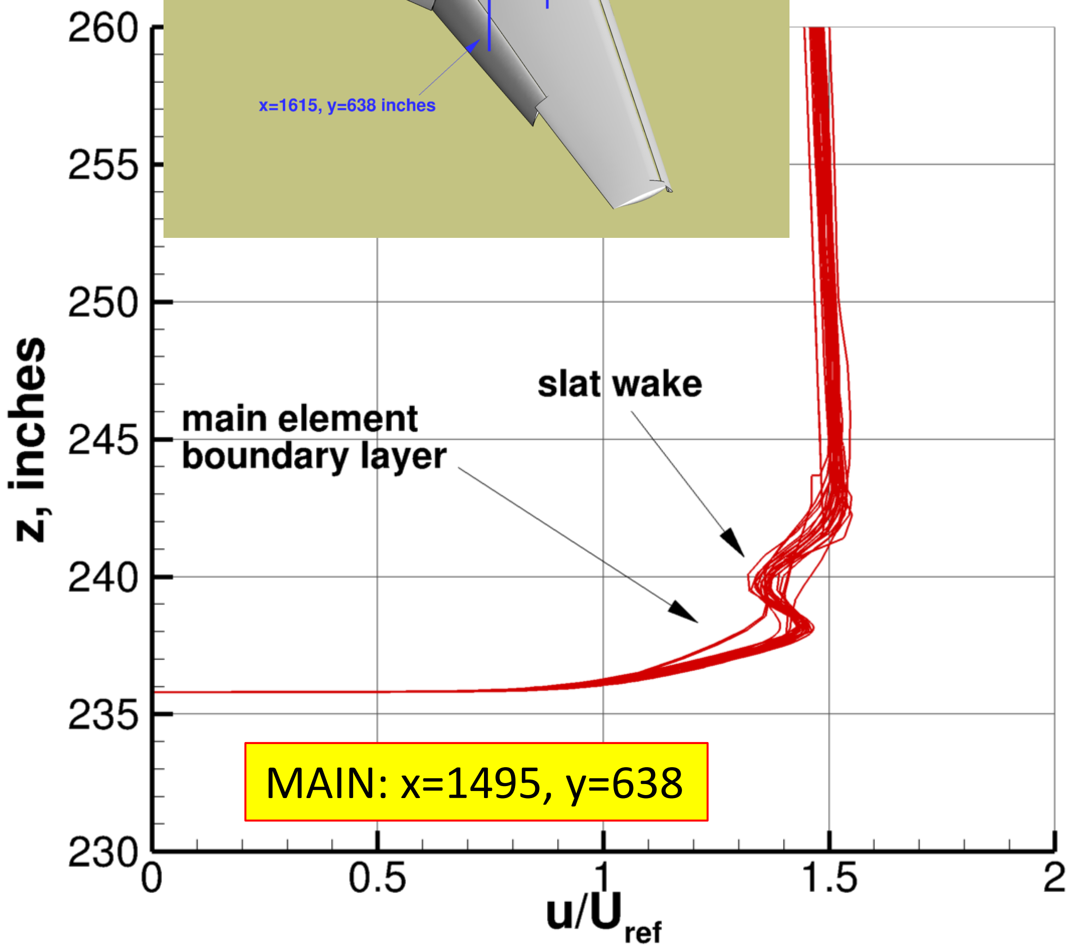


VERIF/2DANW case from TMR website: https://turbmodels.larc.nasa.gov

HL-CRM velocity profiles







Results

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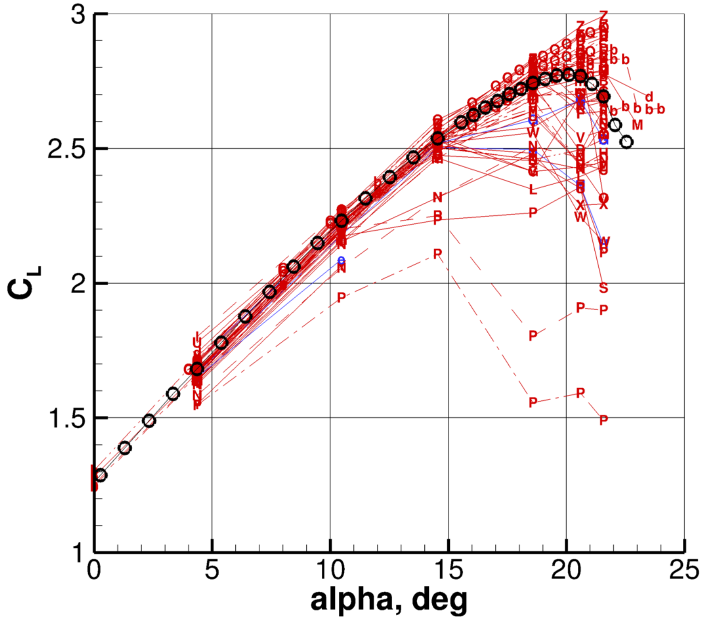
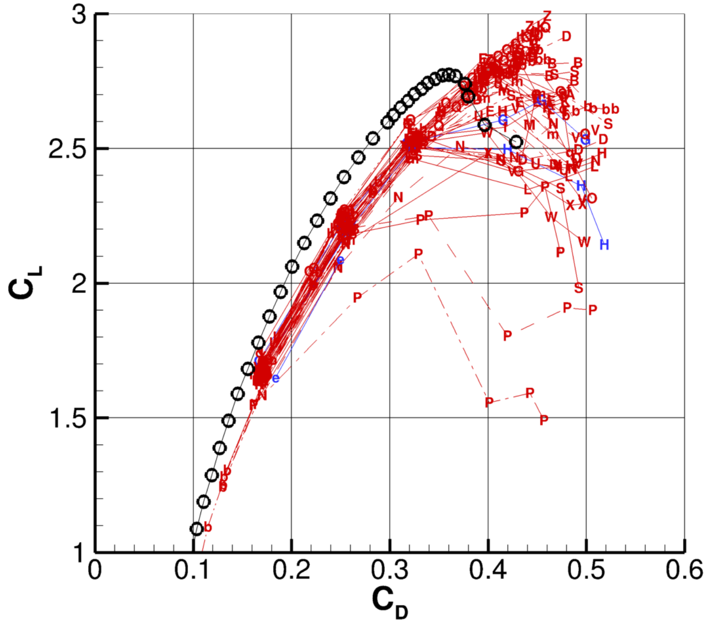
further details are given in the paper

JSM, no nacelle/pylon

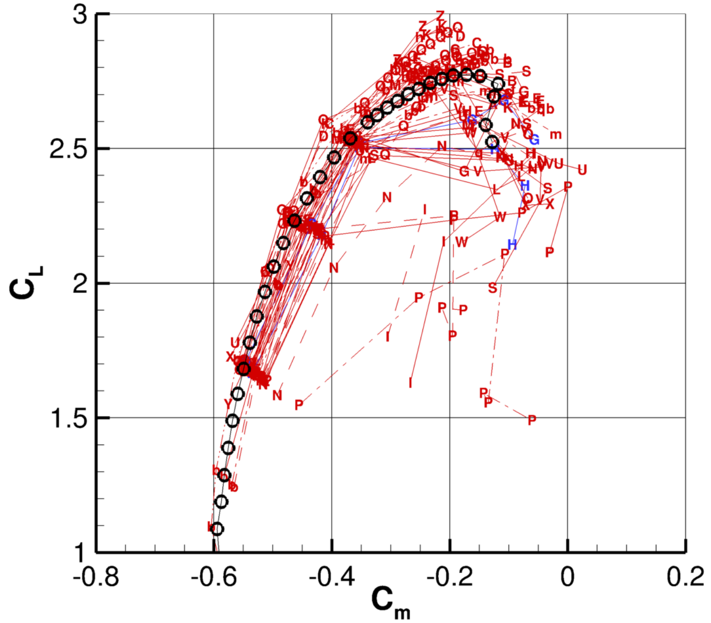
Lift coefficient



Drag coefficient

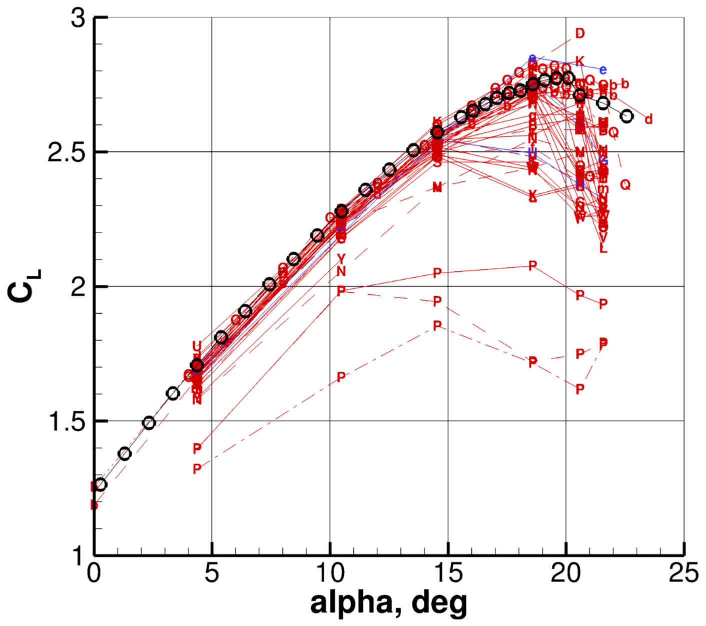


Moment coefficient

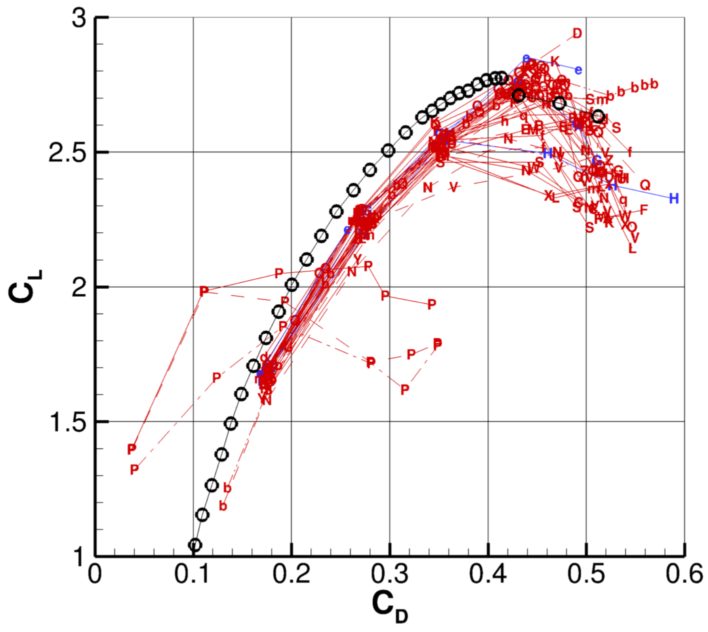


JSM, with nacelle/pylon

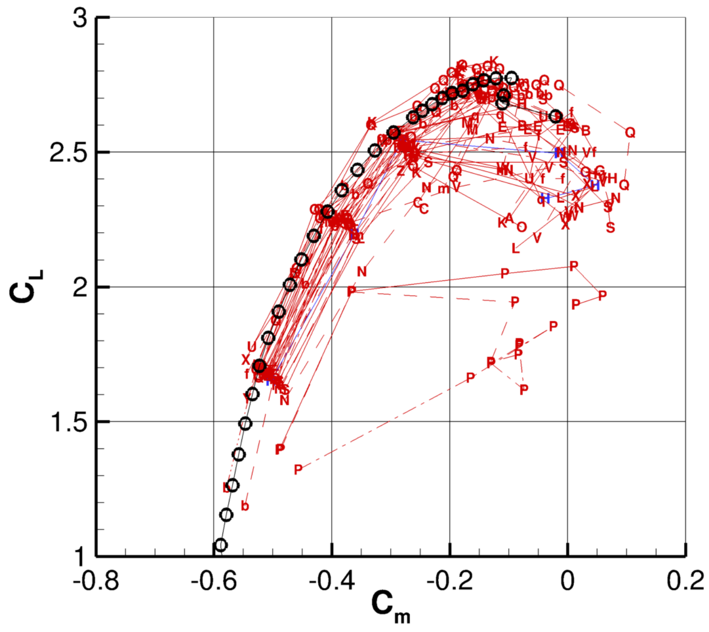
Lift coefficient



Drag coefficient

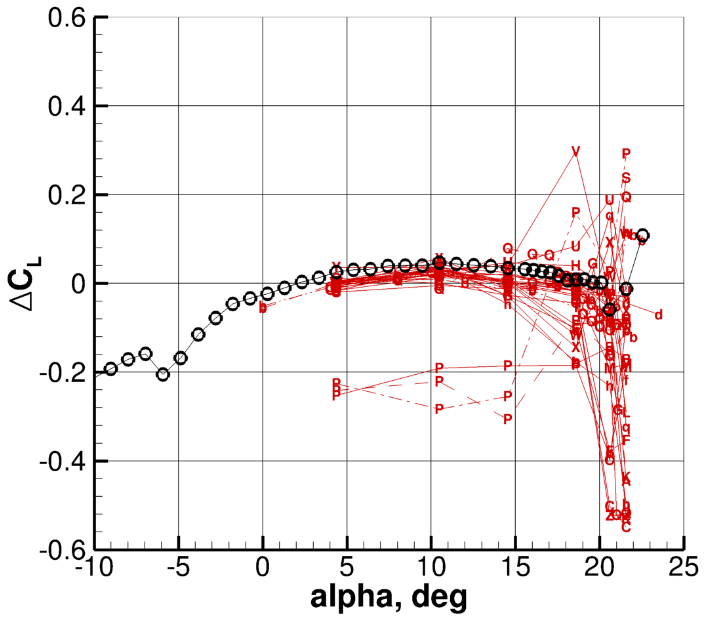


Moment coefficient

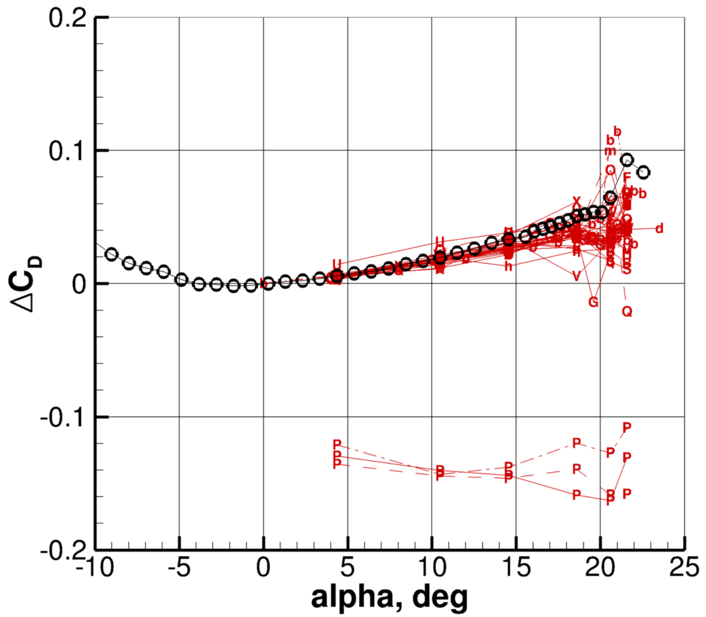


JSM, deltas between nacelle/pylon on and off

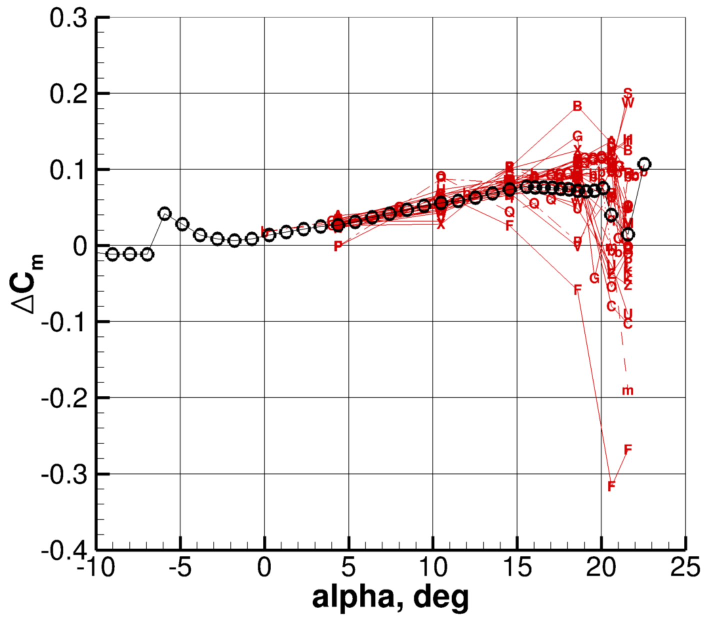
Lift coefficient



Drag coefficient



Moment coefficient



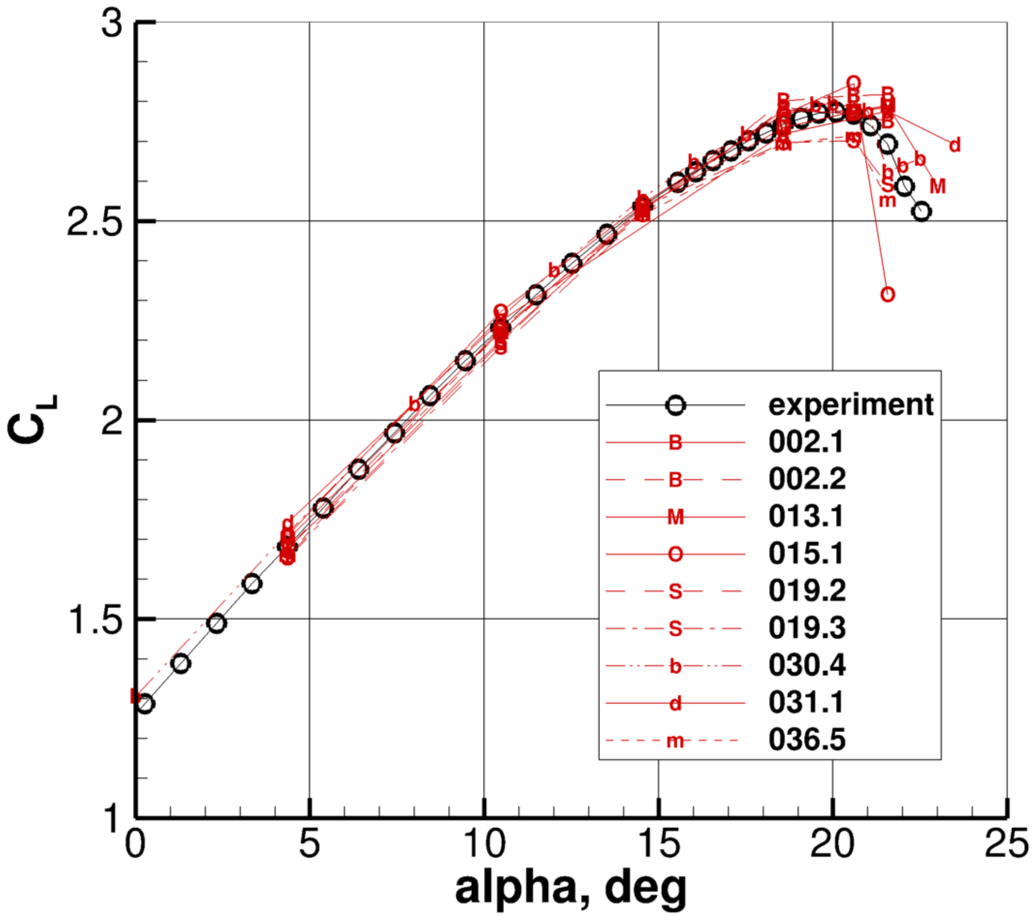
Except for one outlier, participants predicted deltas well (albeit large scatter near max lift)

CFD results that agreed "best" with JSM C_L data

Minimize $\frac{1}{N}\Sigma(C_{L,\ CFD}\ \_\ CL_{,\ exp})^2$

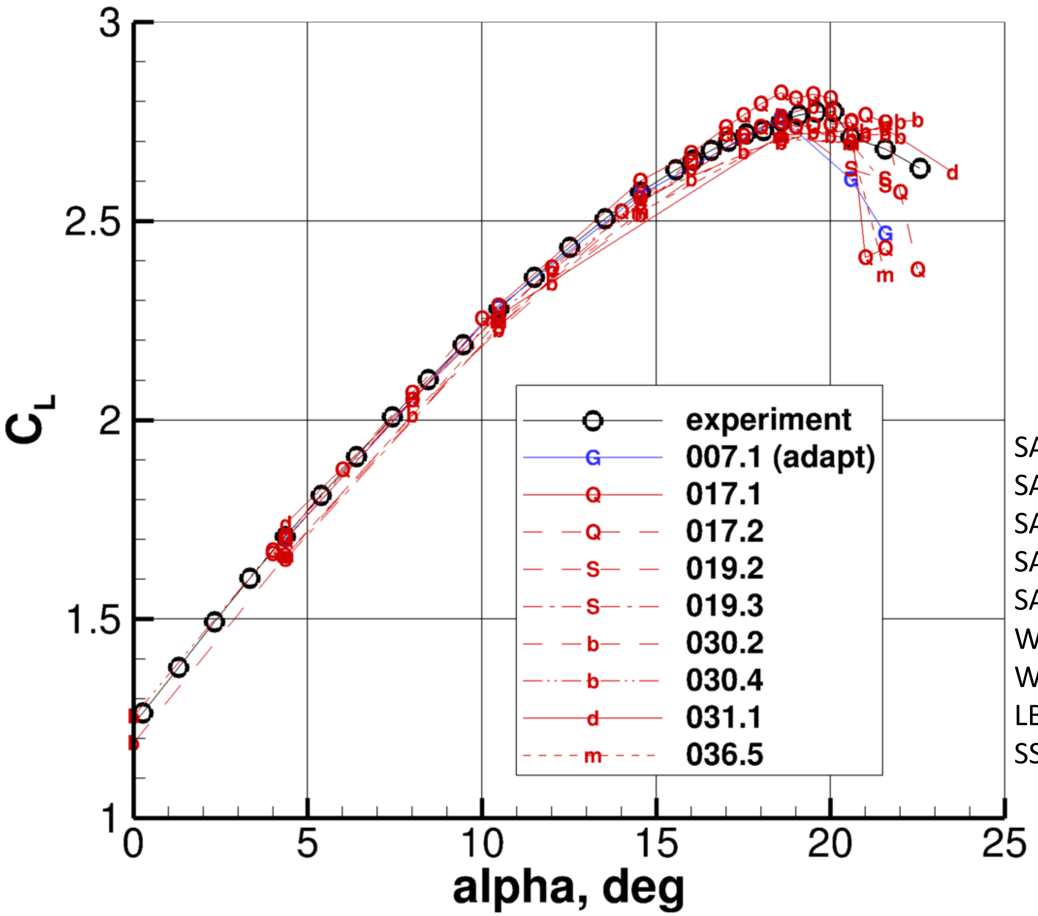
(ignoring results with no/late $C_{L,max}$)

No nacelle/pylon



SA
SA
LB VLES
SA
SA-RC-QCR
SA-RC-QCR
W98CC+trans
LB WALE
SST[mod]

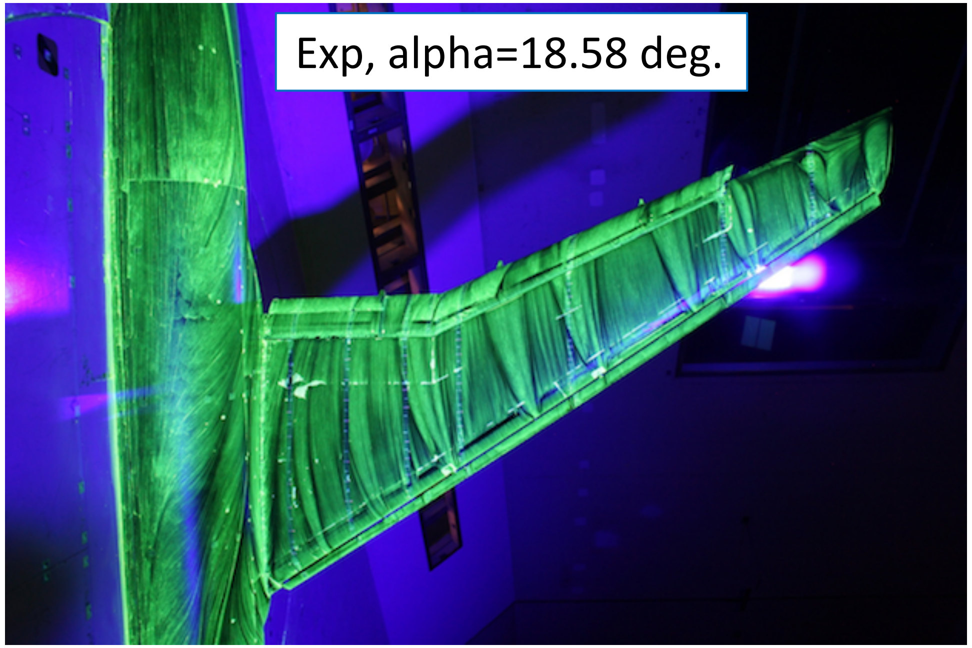
With nacelle/pylon

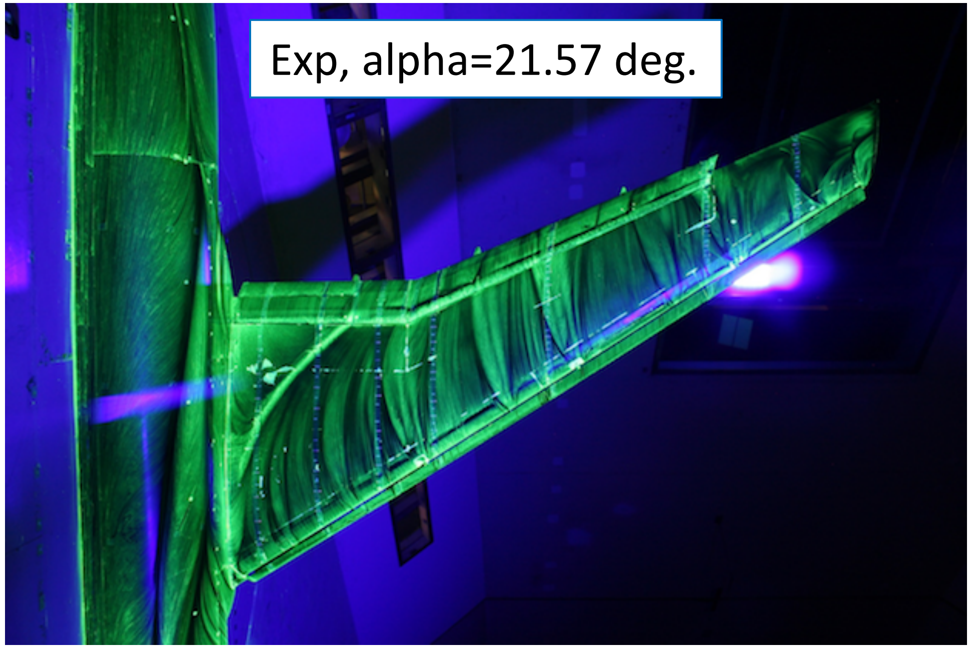


SA-QCR
SA-neg
SA-neg
SA-RC-QCR
SA-RC-QCR
W98CC
W98CC+trans
LB WALE
SST[mod]

General observation from the workshop

- Most of the RANS codes produced surface flows that had too much separation near the wing tip compared to the experiment and not enough separation near the wing root at and beyond max lift.
  - Notable exceptions: scale-resolving methods (like LB).





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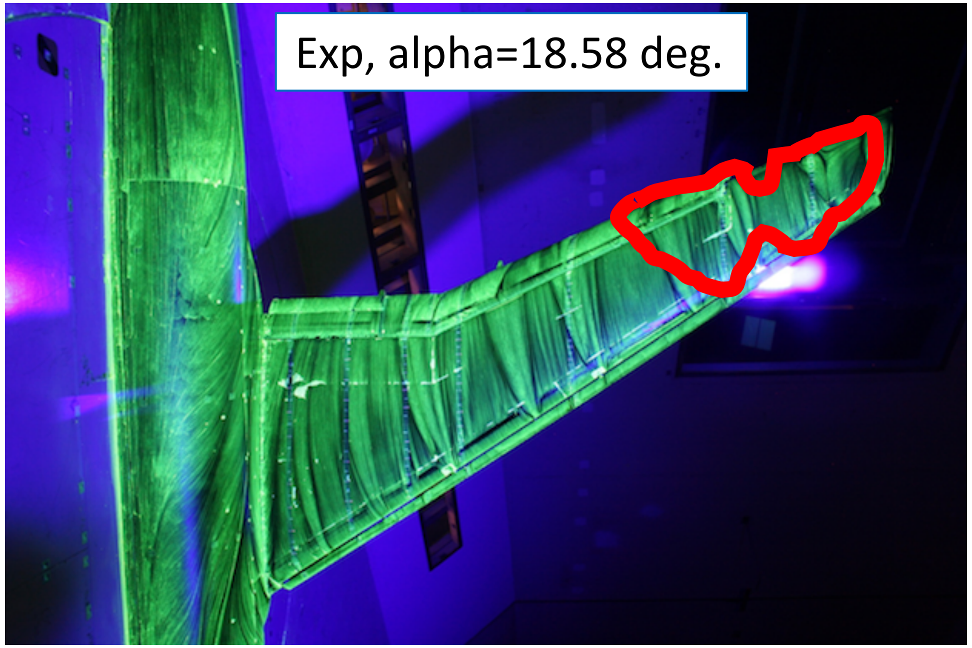
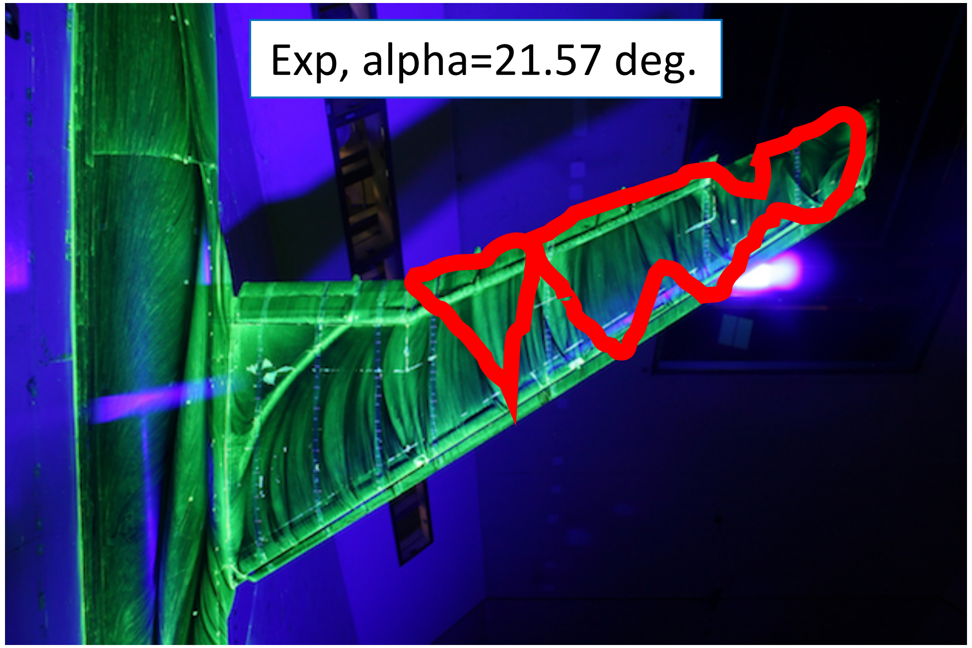
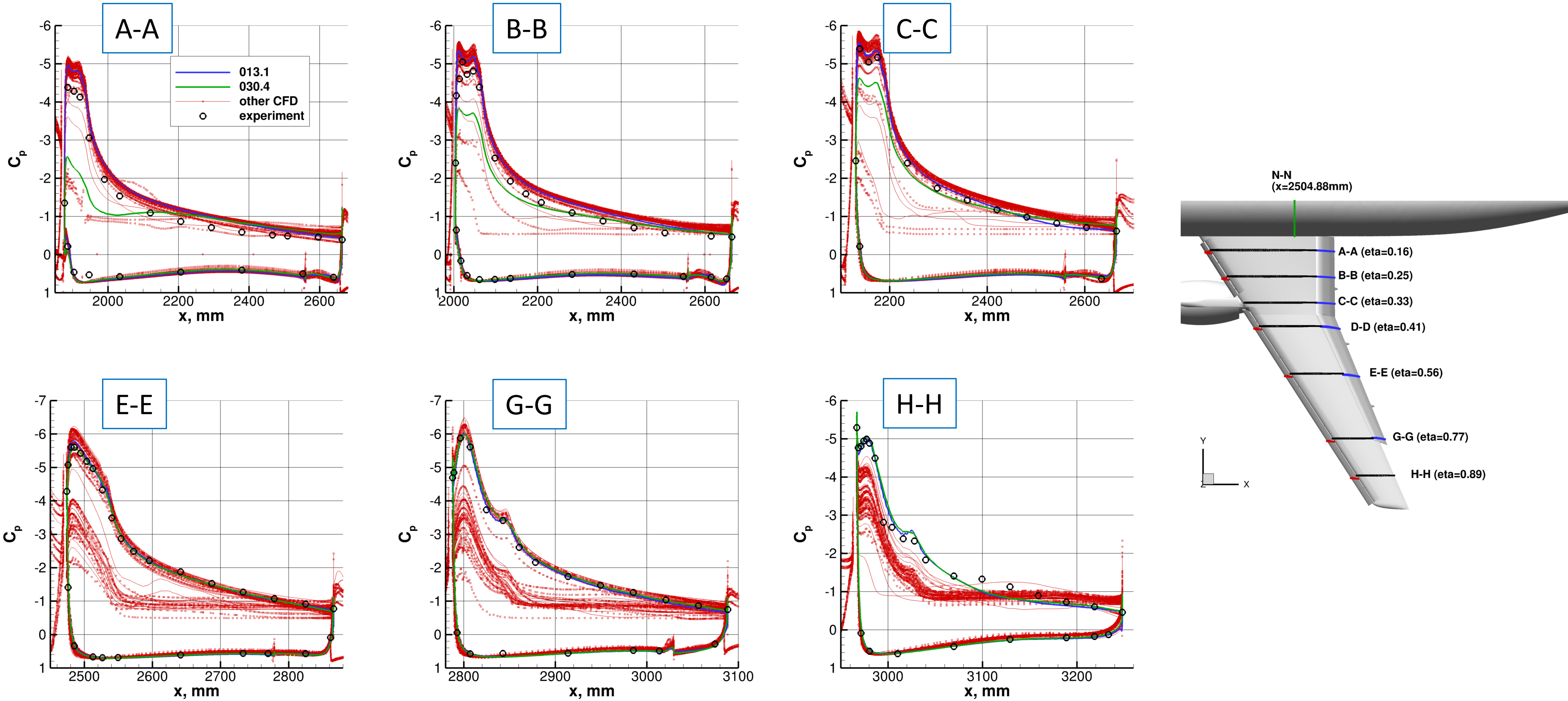




(notional typical RANS)

JSM: surface pressure coefficients

Main element, alpha=21.57 deg., no nacelle/pylon



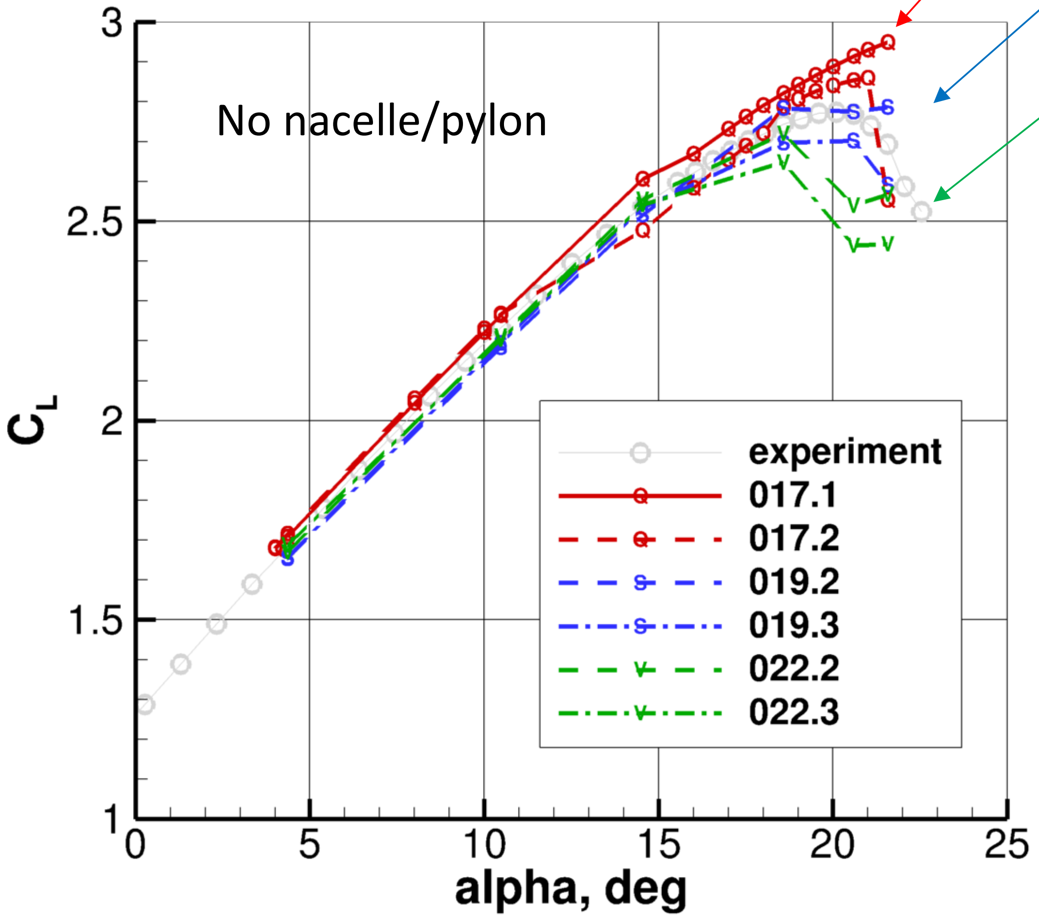
JSM: issues near $C_{L,max}$

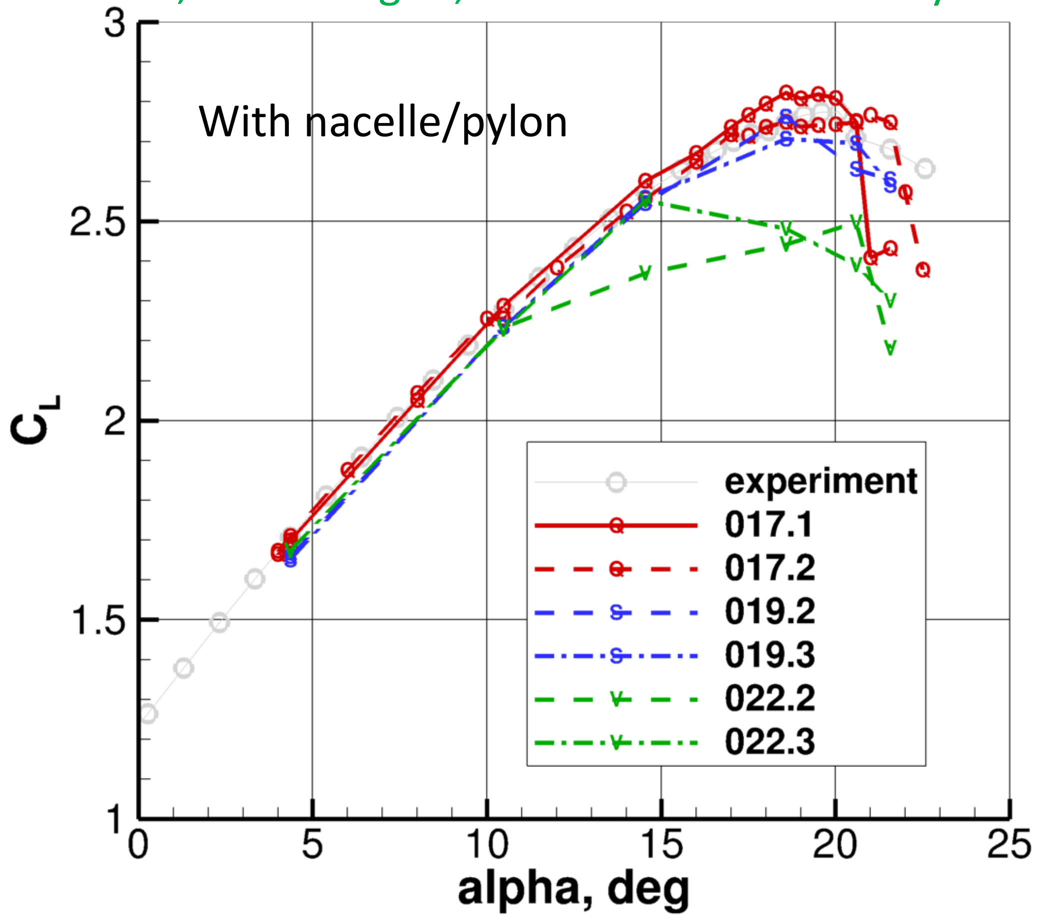
Grid and temporal treatment both have big influence

Same code & model, different grid

Same code & model, different grid

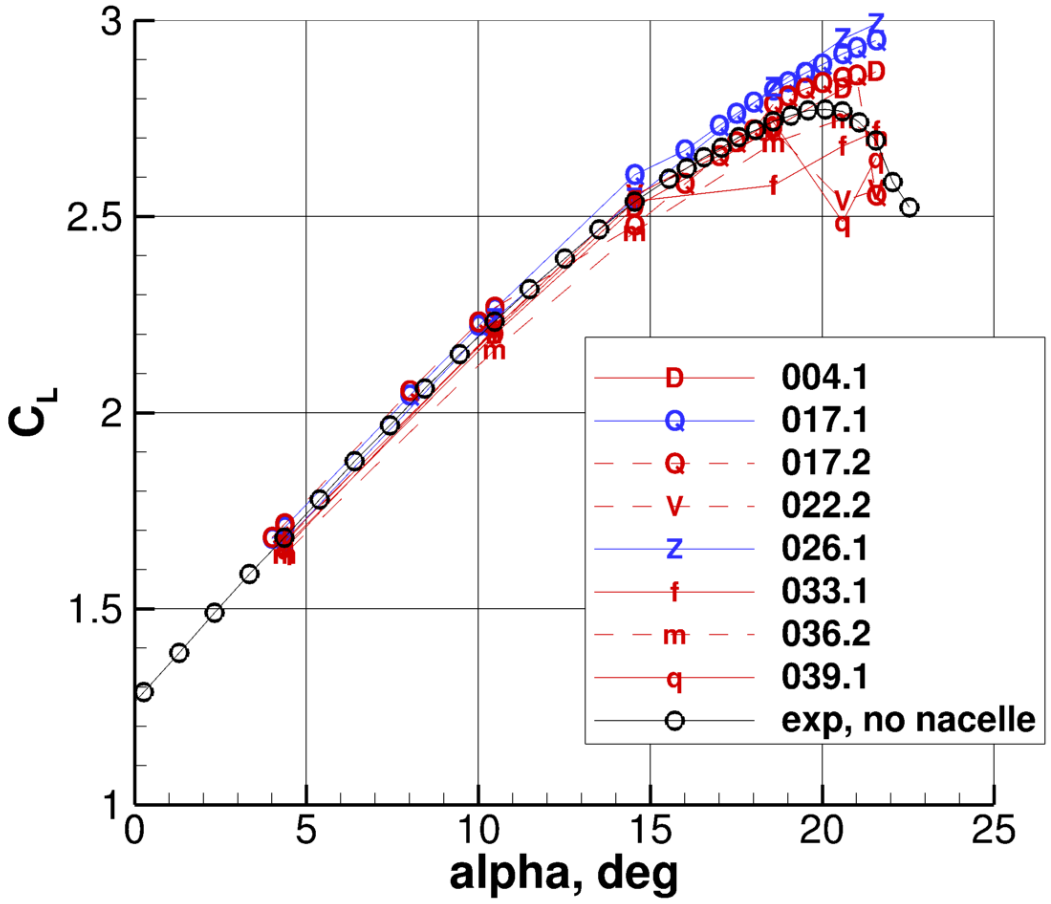
Same code, model & grid, time-accurate vs. steady-state





JSM: further evidence of insufficient grid density

All “SA-verified” codes do not agree well using SA on (different) medium grids

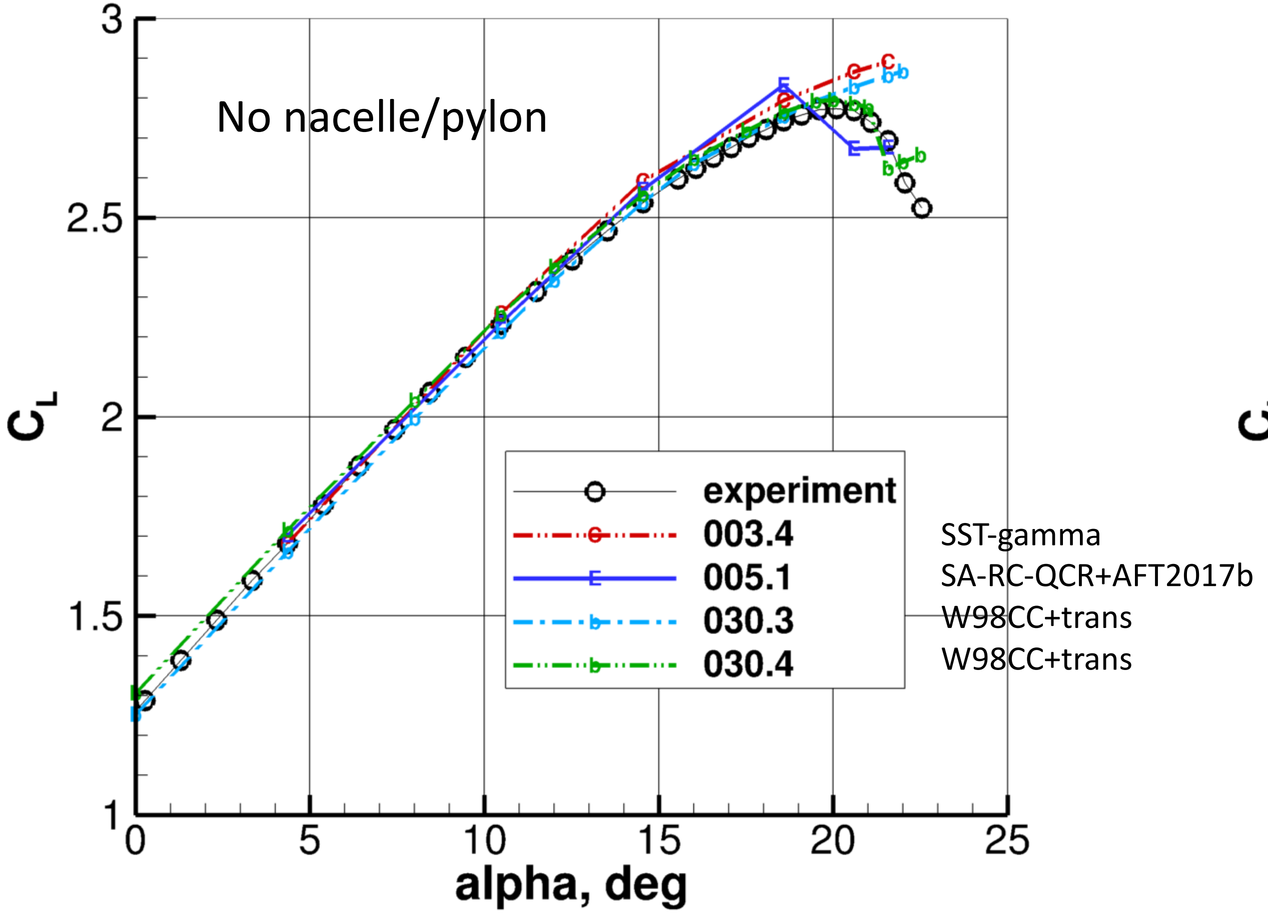


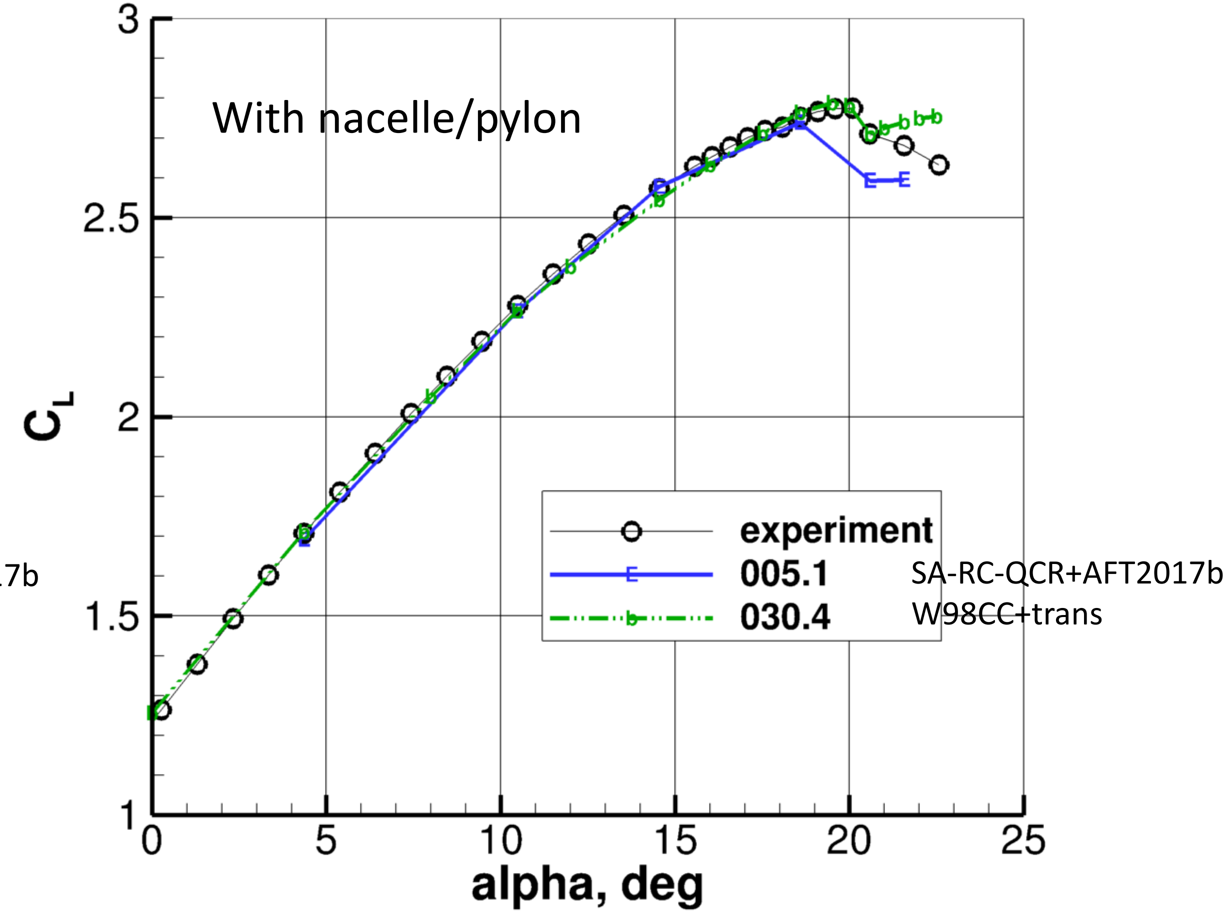
COFFE, grid C1
TAU, grid B
TAU, grid f(nc)
OVERFLOW, grid A
TAU, grid B
LAVA, grid A
FUN3D, grid C1
FUN3D, grid C2

And blue curves point to minor issues with insufficient iterative convergence and/or code setting/version differences

JSM: effect of transition models

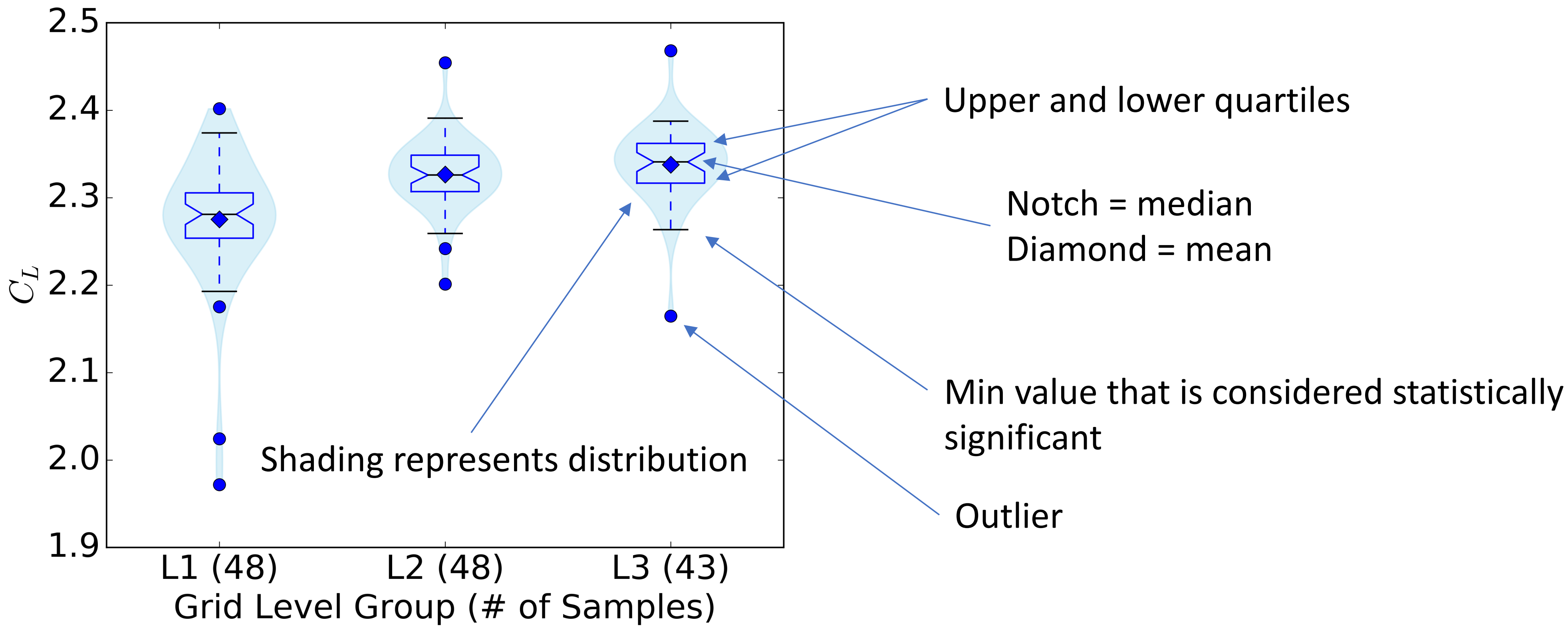
- Transition definitely present at this Re
- For 030.1 vs. 030.3 (committee grid E), little influence of transition noted
- For 030.2 vs. 030.4 (participant grid b), transition caused higher CL in the linear range and an earlier stall, in better agreement with experiment





Statistical analysis: HL-CRM

- Main conclusion: general scatter did not always decrease between the medium and fine grids, as would be expected if numerical error due to grid resolution was the primary source of variation.



Statistical analysis: JSM

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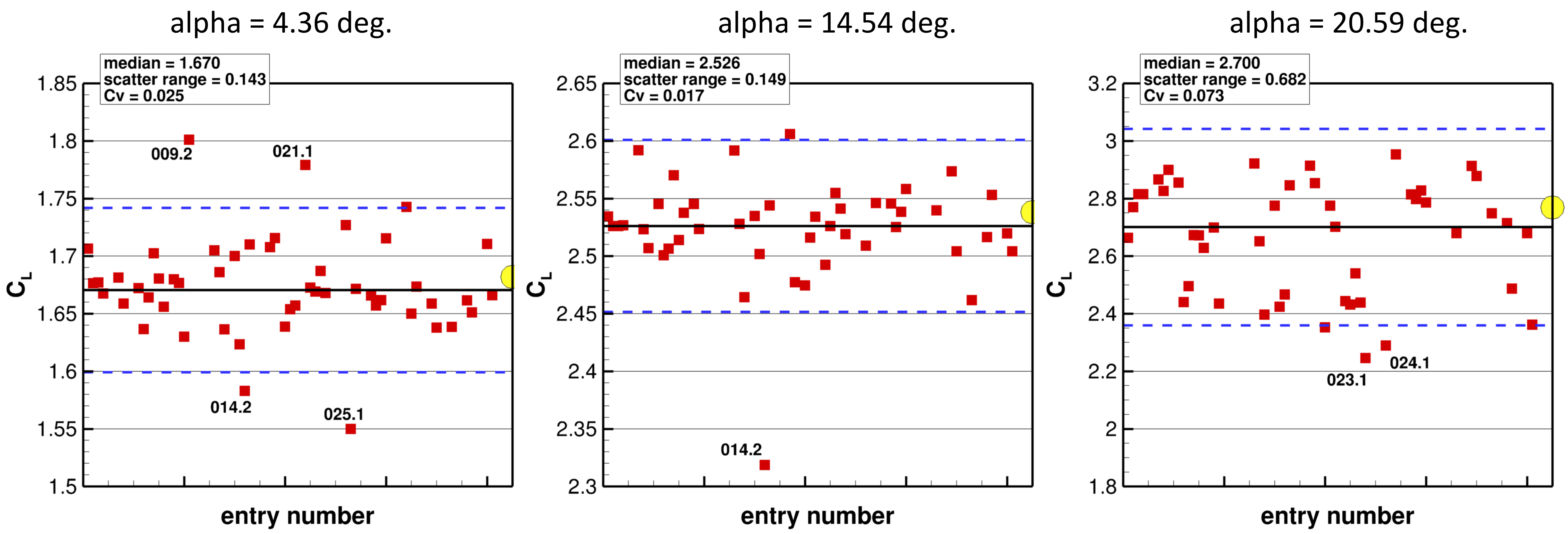

Cv = σ/μ = standard deviation / median

Scatter limits = $\mu \pm K\sigma\ (K = \sqrt{3})$

Has CFD gotten any tighter since HiLiftPW-2?

Low Re, with brackets, medium grids

Cases	Cv, low alpha	Cv, mid alpha	Cv, high alpha
HiLiftPW-2, alpha=7, 16, 20 deg.	0.038	0.057	0.060
HiLiftPW-3, alpha=4.36, 14.54, 20.59 deg.	0.025	0.017	0.073

YES YES NO

Conclusions

- In the verification case, only 30% of the CFD codes that participated with the SA turbulence model were fully verified.
- HL-CRM case explored grid convergence.
  - Spread between CFD results did not diminish on fine grids (similar to HiLiftPW-2).
  - Lack of verification in some codes may explain part of the spread.
- JSM explored effect of nacelle/pylon installation.
  - Use of “medium” grid only; deltas were generally well predicted.
  - Large spread in CFD results near $C_{L,max}$ (similar to HiLiftPW-1 and 2).
  - Significant influence of grid near $C_{L,max}$, so ”medium” grid probably not fine enough.
  - Transition should be important for this case, but transition models were not always better (grid influence?).
  - Many individual results compared very well with experimental lift curve; but we do not know why.
  - It was possible to get integrated quantities right for the wrong reasons.
  - Scale-resolving methods appeared to predict separation patterns better than RANS.
  - Participants were more consistent (compared to HiLiftPW-2) predicting complex high-lift configuration at low Re with all mounting bracket hardware at low alphas – BUT NOT NEAR $C_{L,max}$.

HiLiftPW-4 status and other questions/thoughts

- What should be done differently in HiLiftPW-4, so that we learn more?
  - Proposal: require the use of one or more specific (verified) models.
    - Identify the "best" (publicly-available) RANS model(s) from this workshop, and request that all RANS participants verify it in their code and use it.
    - Allow additional results using any model or model variant.
  - Near $C_{L,max}$: encourage larger grids, more grid adaption, higher order, time-accurate, more use of scale-resolving methods.
  - No more free-air CFD runs; try to match the wind tunnel semispan testing geometry and BCs.

End

Backup

Introduction

- Specific workshop series focused on the prediction of swept, medium/high-aspect ratio wings in landing/takeoff (high lift) configurations.
- Goals of HiLift workshop series:
  - Assess the numerical prediction capability of current-generation CFD technology.
  - Develop practical modeling guidelines for CFD prediction of high lift flow fields.
  - Advance the understanding of high lift flow physics to enable development of more accurate prediction methods and tools.
  - Enhance CFD prediction capability for high lift aerodynamic design and optimization.
  - Provide an impartial forum.
  - Identify areas needing additional research and development.

Test cases

- Case 1 - Grid Convergence Study on the NASA HL-CRM (free air, fully turb).
  - 1a: Full chord flap gap, M=0.2, Re_{MAC}=3.26 M, alpha=8, 16 deg.
  - 1b: Same as 1a, with grid adaption.
  - 1c: Same as 1a except partially-sealed flap gap.
  - 1d: Same as 1c, with grid adaption.
- Case 2 - Nacelle Installation Study on the JSM (free air, fully turb or with transition).
  - 2a: Nacelle/pylon off, M=0.173, Re_{MAC}=1.93 M, six alphas.
  - 2b: Same as 2a, with grid adaption.
  - 2c: Same as 2a except Nacelle/pylon on.
  - 2d: Same as 2c, with grid adaption.
- Case 3 - Turbulence Model Verification Study (fully turb).
  - VERIF/2DANW from http://turbmodels.larc.nasa.gov

Black=requested
Blue=optional

Grid systems

HL-CRM "committee grids"

Label	Grid tool	Org	Type	Coarse	Medium	Fine	Extra-fine	Notes
A-HLCRM	ANSA+ Chimera	NASA	str	24/23	65/64	189/185	564/554	Overset
B1-HLCRM	Pointwise	Pointwise	unstr	8/48	26/157	70/416	206/1228	Tet
B2-HLCRM	Pointwise	Pointwise	unstr	8/22	26/65	70/170	206/541	Mixed prism/tet
B3-HLCRM	Pointwise	Pointwise	unstr	8/18	27/48	71/119	208/397	Mixed
C-HLCRM	GridPro	GridPro	str	10/8	77/68	338/311	n/a	One-to-one

Points/cells

Grid systems

JSM “committee grids”

Label	Grid tool	Org	Type	Medium, no N/P	Medium, with N/P	Notes
A-JSM	Chimera	NASA	str	221/216	235/230	Overset
B-JSM	DLR-SOLAR	DLR	unstr	102/162	126/207	Mixed
C1-JSM	VGRID	Spaceship & Gulfstream	unstr	16/97	21/124	Tet
C1-JSM	VGRID	Spaceship & Gulfstream	unstr	16/52	21/65	Mixed
D-JSM	JAXA tools	JAXA	unstr	50/120	59/139	Mixed
E-JSM	ANSA	U Oxford & BETA-CAE	unstr	52/107	58/120	Mixed