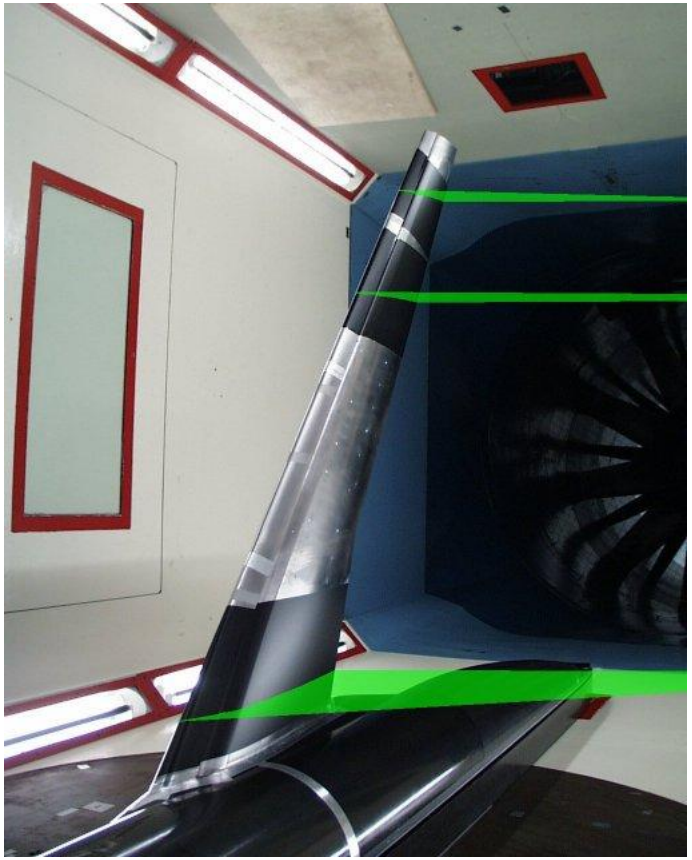
HiLiftPW-2 Summary



C. L. Rumsey

NASA Langley Research Center

Overview

- Main goals of this summary
  - learn trends
  - make note of outliers
  - perform statistical analysis
- Many participants did not complete their study by the deadline, so corrections & additions will no doubt be coming

Participants

ID	Code	Type	Grid	Turb	Other
002.1	FUN3D	uns	D	SA	
002.2	CFL3D	str	A	SA	
003.1	Overflow	ovr	E	SA	Incl trans
003.2	Overflow	ovr	E	SA-RC	
003.3	Overflow	ovr	E	SA-QCR2000	Incl trans
004	CFD++	uns	B + nc	SA-RC	
005.1	HIFUN	uns	A	SA	
005.2	HIFUN	uns	B	SA	
006	FUN3D	uns	D	SA-RC	
007.1	CFLOW	uns	C	SA	
007.2	UG3	uns	C	SA	
008	CRUNCH	uns	D	SST	
009	Overflow	ovr	E	SA	
010.1	CFD++	uns	A + C	SA	

Participants

ID	Code	Type	Grid	Turb	Other
010.2	CFD++	uns	A	SST	
010.3	CFD++	uns	A	K-e-Rt	
011.1	NSMB	str	A	SA	
011.2	NSMB	str	A	SA-Edwards	
012	PowerFlow	lb	nc	LBM-VLES	C3 only
013	UPACS	str	A	SA-noft2-R	
014	UNICORN	uns	nc	SGS	Adapt, C2b
015.1	CFX	uns	B (no brk)	SST/GRET	Incl trans
015.2	FLUENT	uns	B (no brk)	SST/GRET	Incl trans
016	ELSA	ovr	E	SA	
017	COBRA	str	nc	SA	
018	VULCAN	str	A	Wilcox1988	case4: SST
020	Overflow	ovr	E	SA-noft2-RC	
021	TAU	uns	B	SA	Incl C3

Participants

ID	Code	Type	Grid	Turb	Other
022	PHASTA	uns	nc	SA	
023	NSU3D	uns	D	SA	
024.1	EDGE	uns	B	EARSM	
024.2	EDGE	uns	B	SA	
025	NSU3D	uns	nc	Wilcox1988	
026	MFLOW	str	A	SA	Incl C3
028	FLUENT	uns	A + B	SA-RC	
029	XFLOW	lb	nc	WMLES	

str=structured
uns=unstructured
ovr=overset (str)
lb=lattice boltzmann

A,B,C,D,E = committee grids
nc=non-committee grid created by participant

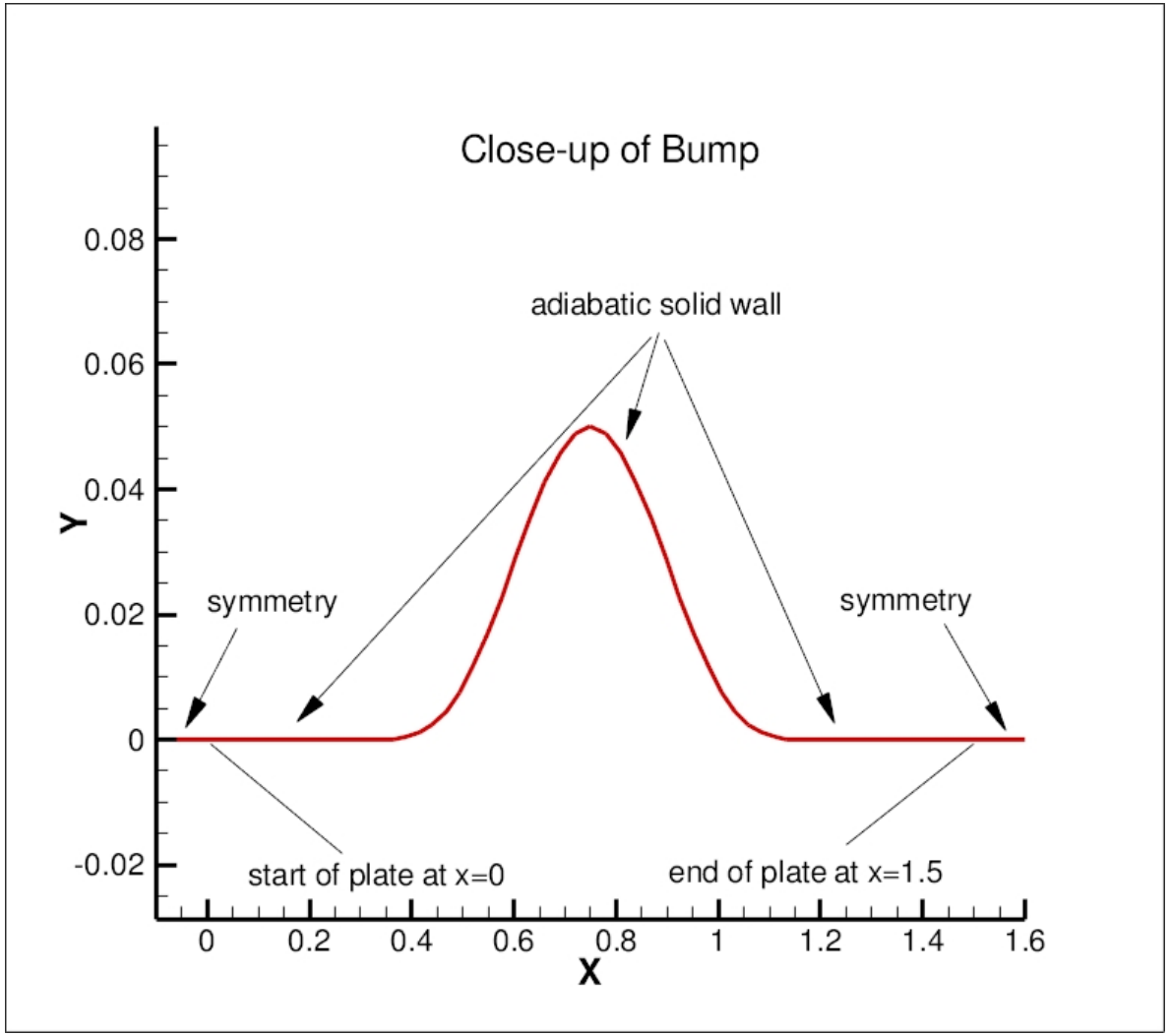
Summary

- Grid type:
  - 13 structured/overset
  - 21 unstructured
  - 2 Lattice-Boltzmann
- Grids:
  - 11 used A, 8 used B, 3 used C, 4 used D, 6 used E
  - 7 made their own
- Turbulence models:
  - 25 used SA or variant
  - 4 used SST or variant
  - 4 other RANS
  - 3 scale-resolving type

Cases

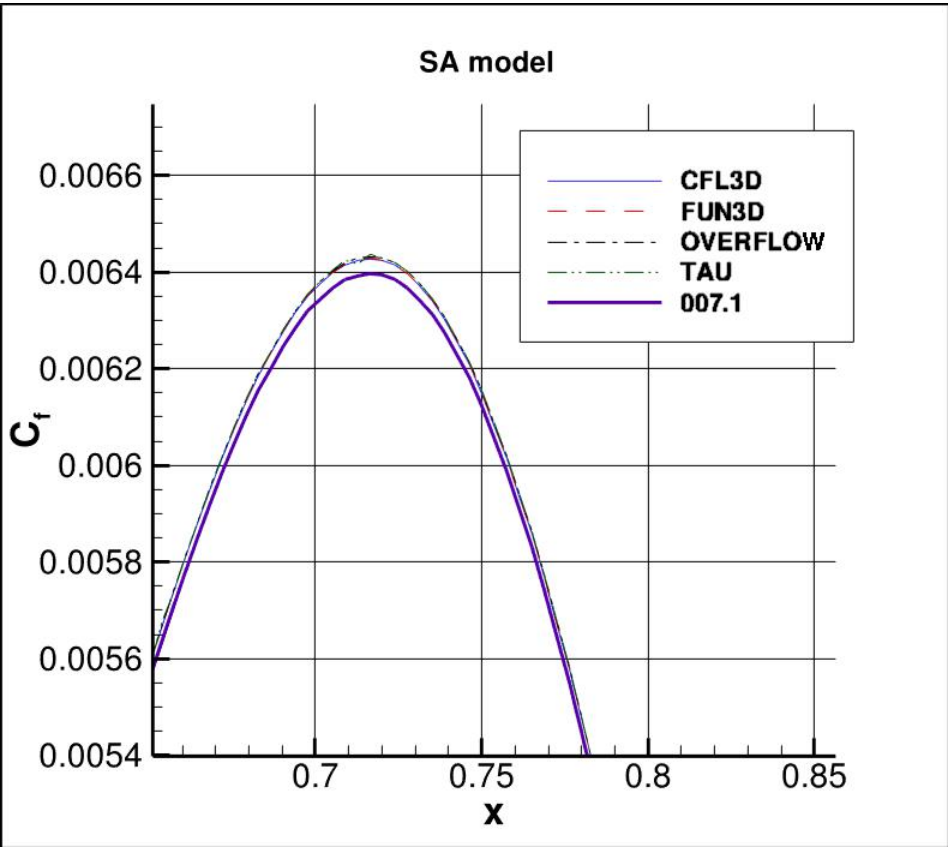
- Case 1
  - Re=15.1 M, fully turbulent, no brackets
- Case 2
  - a) Re=1.35 M, fully turbulent, w brackets
  - b) Re=15.1 M, fully turbulent, w brackets
  - c) Re=1.35 M, transitional w brackets
- Case 3
  - a) Re=1.35 M, w brackets+bundles
  - b) Re=15.1 M, w brackets+bundles
- Case 4
  - Turbulence model 2-D verification study

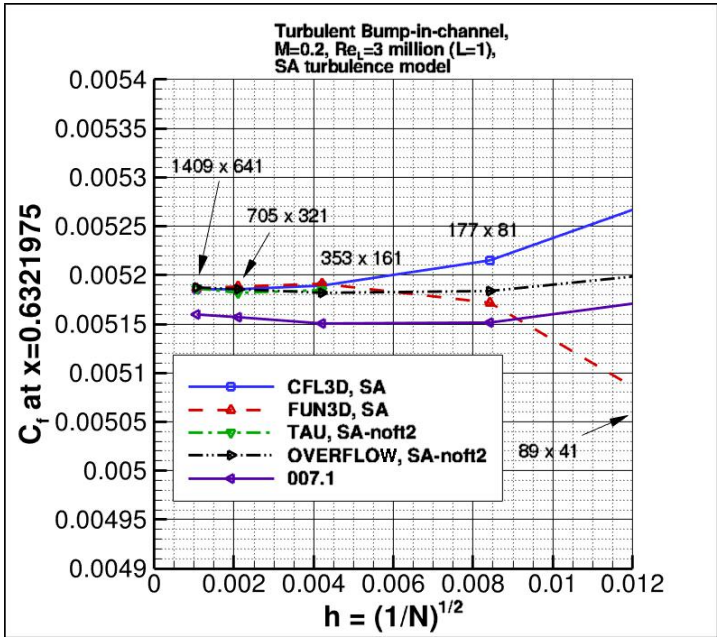
Case 4 Turb model verification

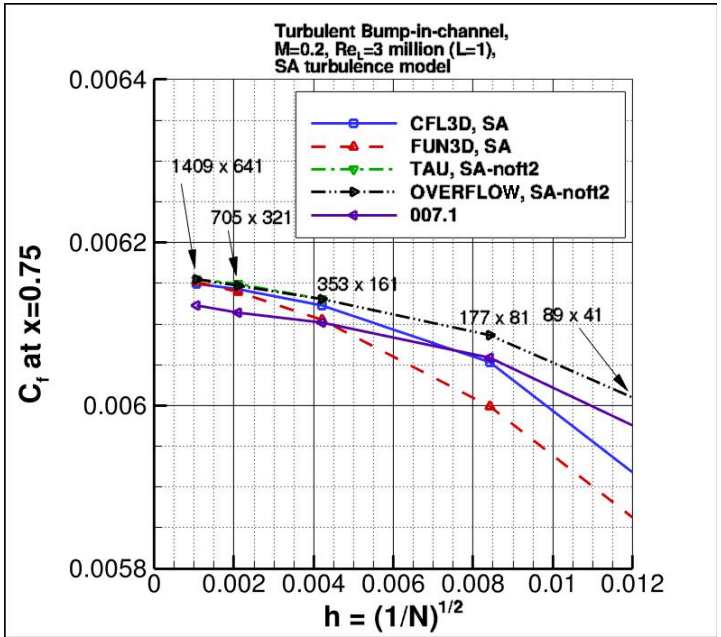


This case also used in DPW-5 (see AIAA-2013-0046)

Case 4 Turb model verification

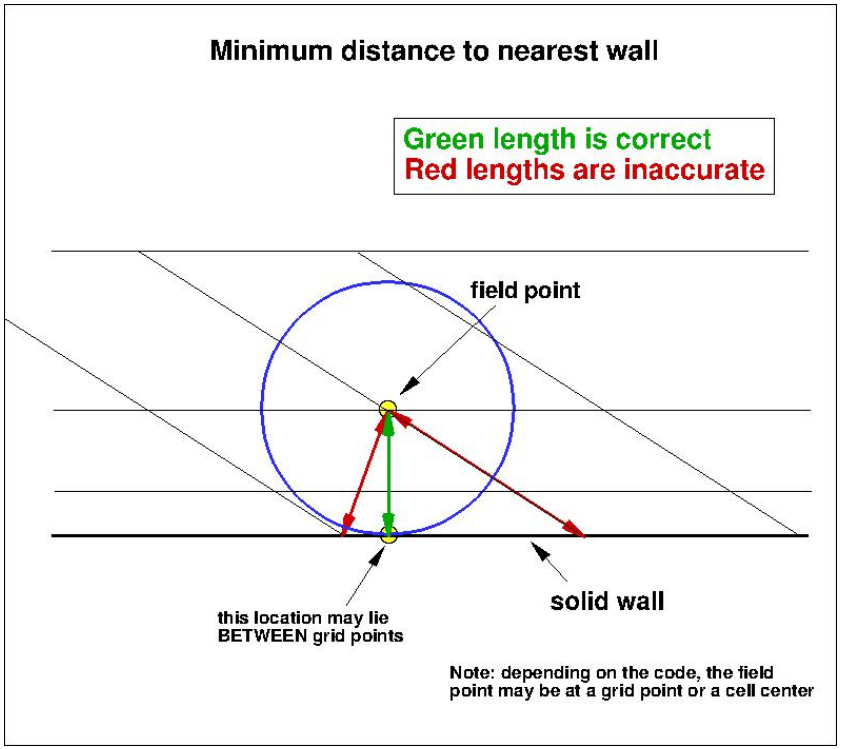


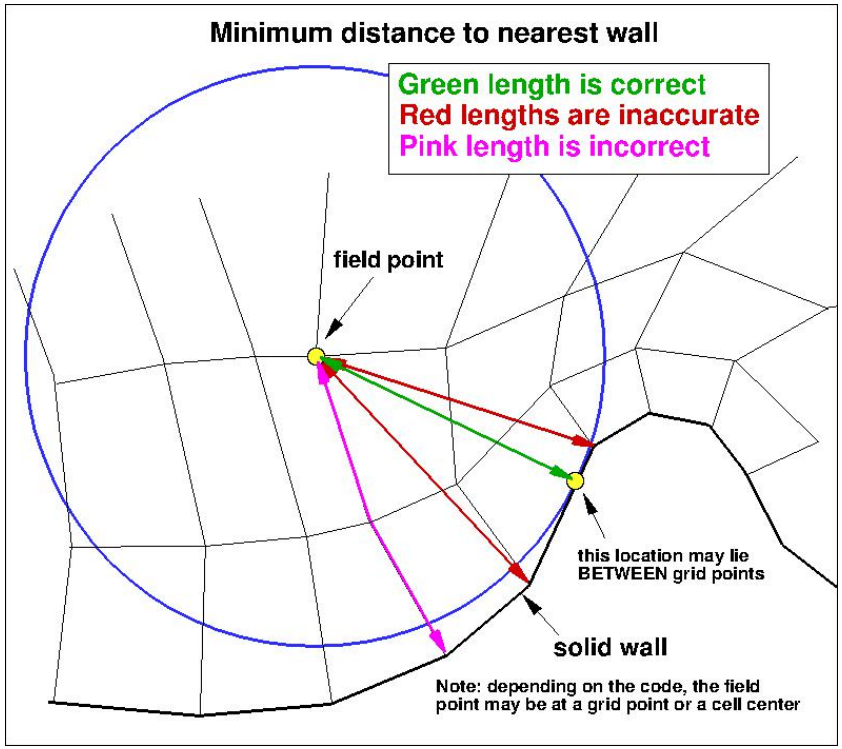




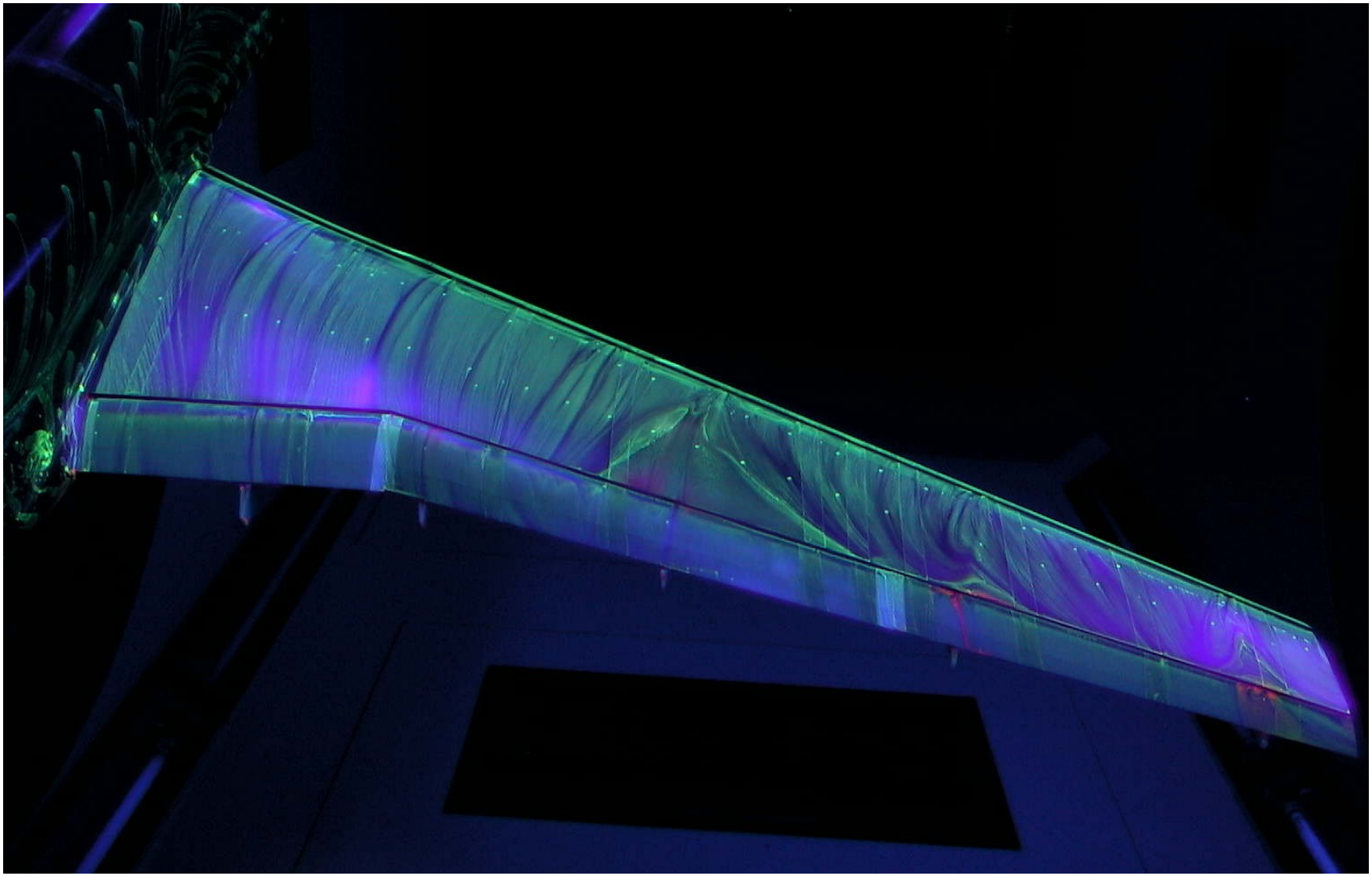
Very small difference between 007.1 result and TMR website; during talk, it was noted that BCs need to be corrected and results resubmitted

Accurate min distance is particularly important for SA model

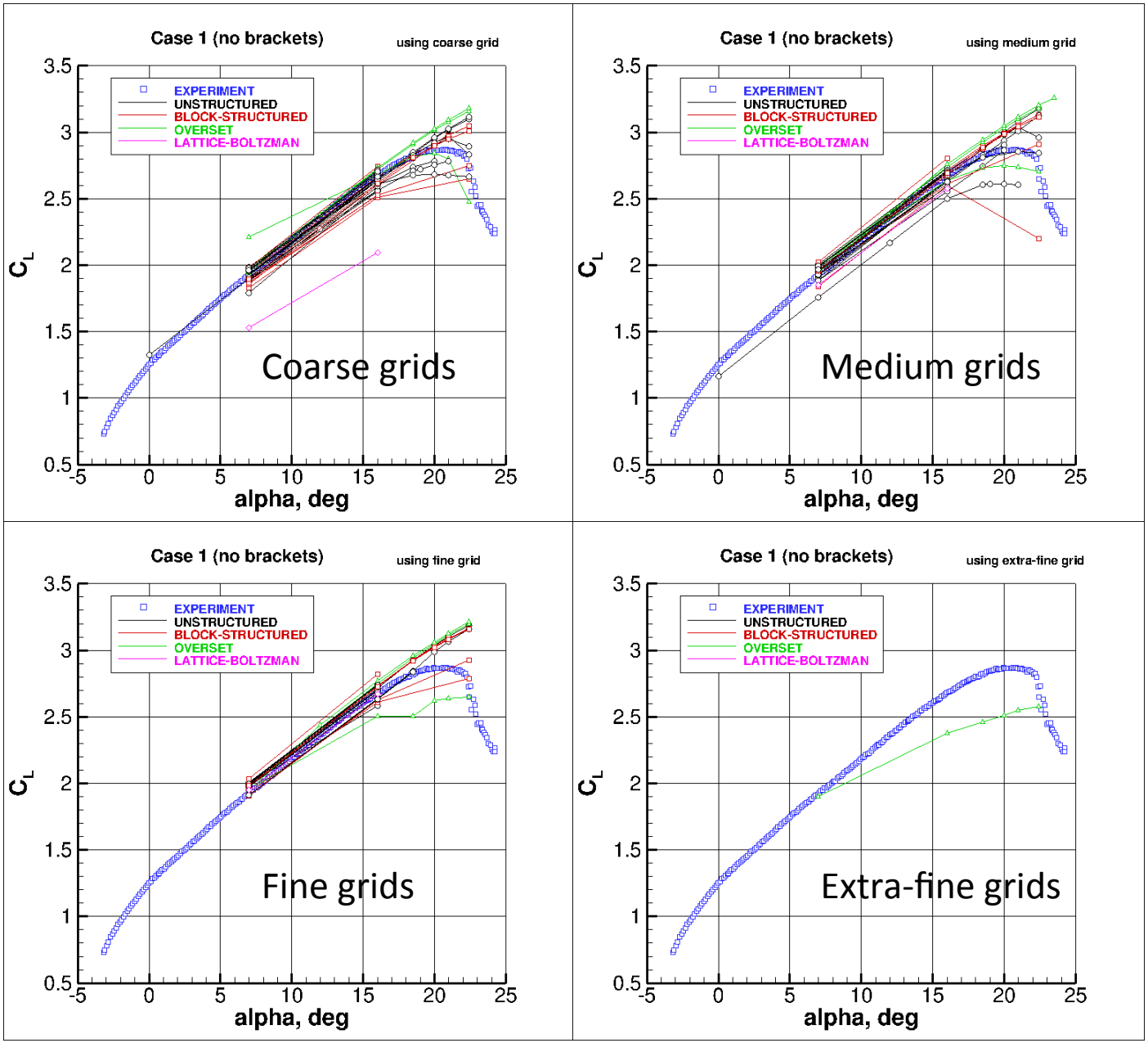




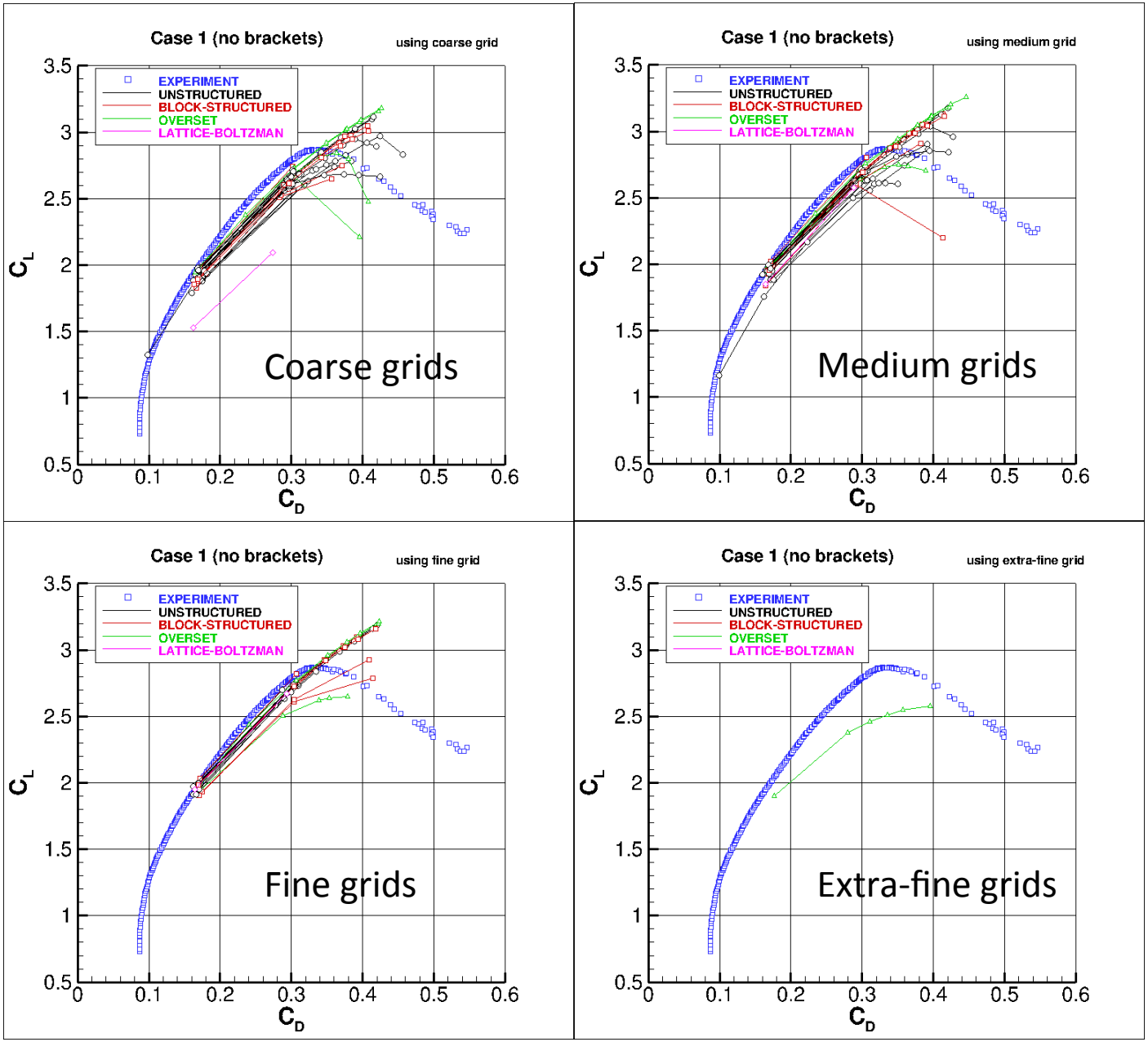
DLR F11 EUROLIFT landing configuration



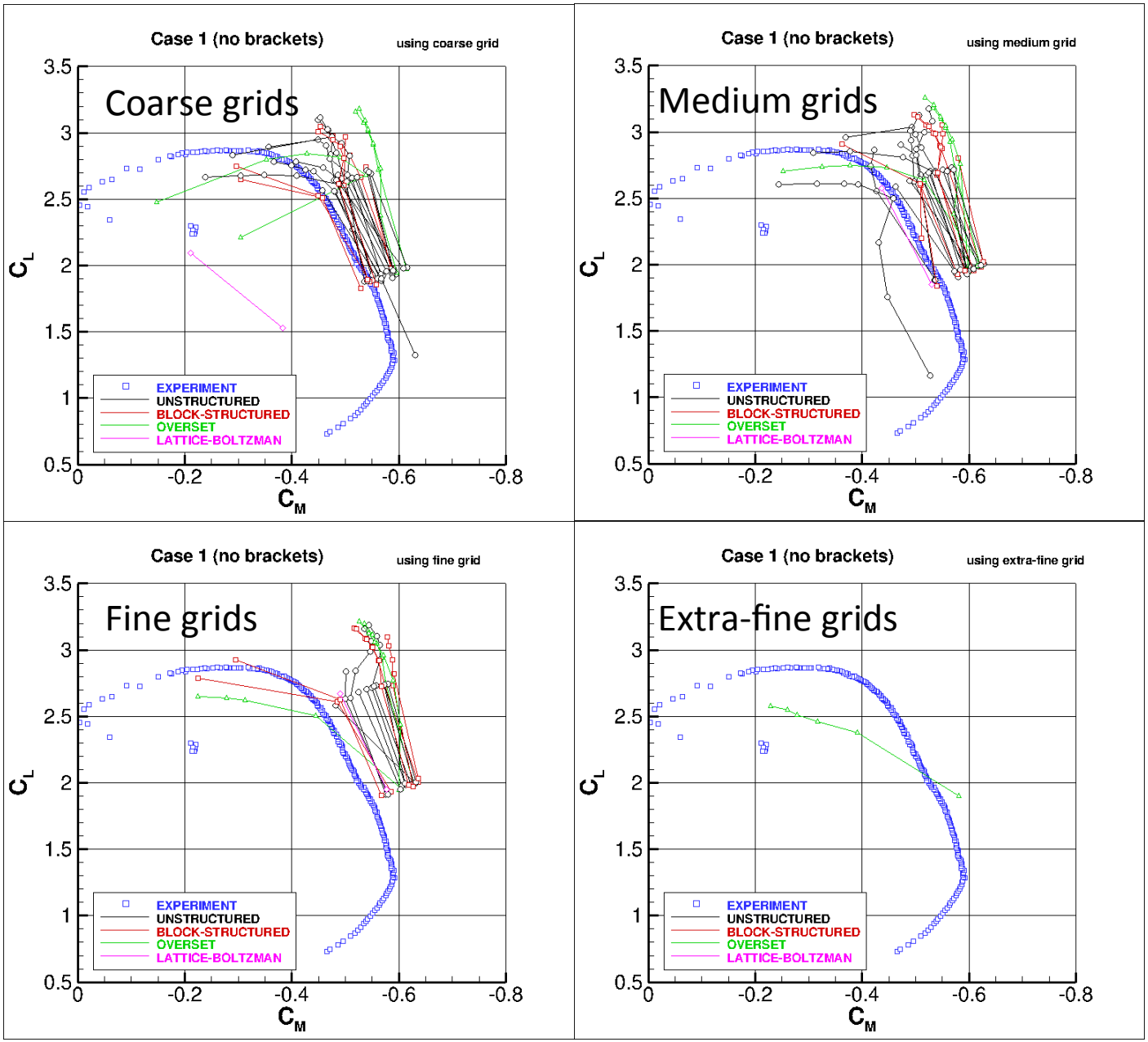
Case 1, Lift curve



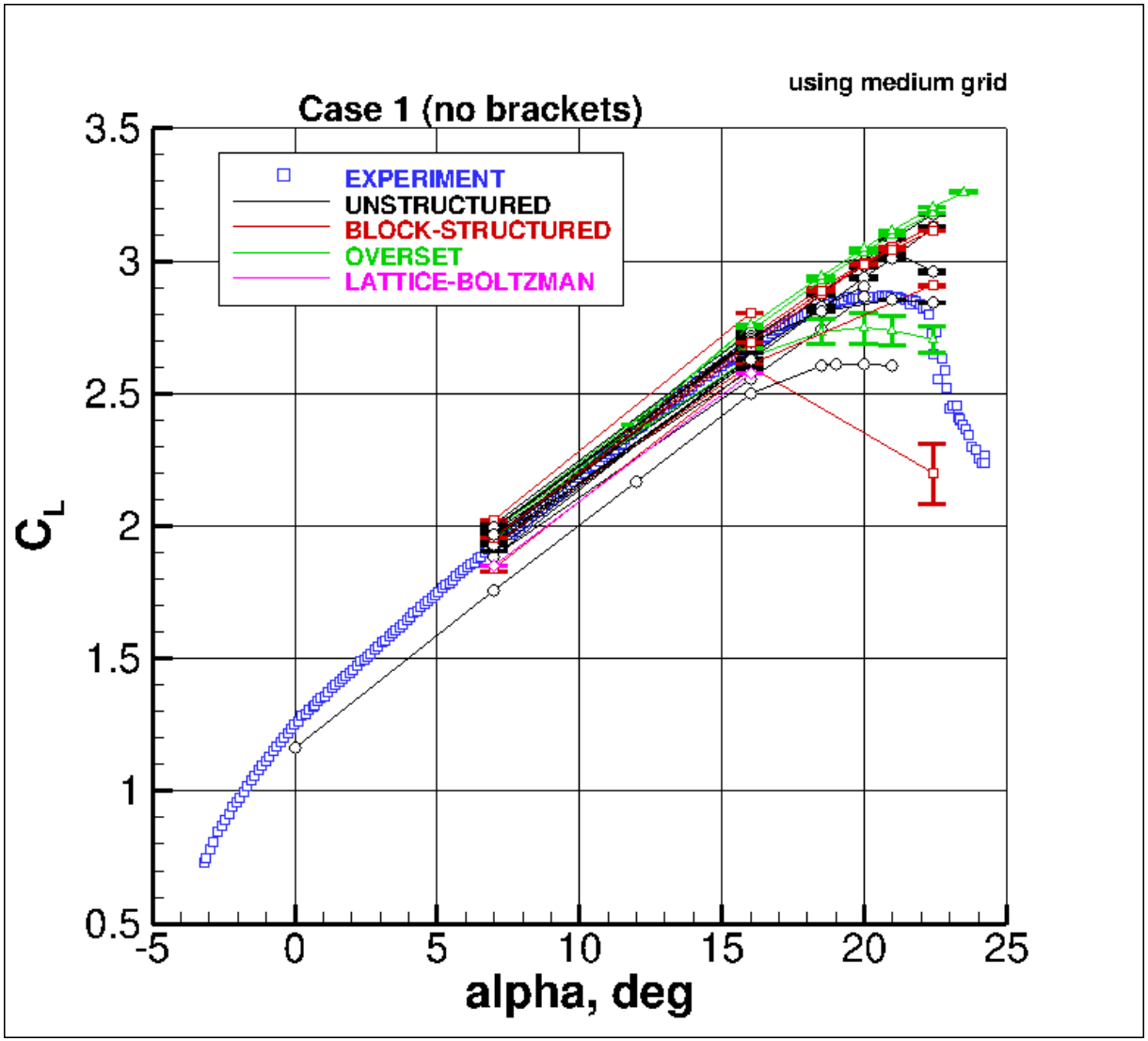
Case 1, Drag polar



Case 1, Moment polar

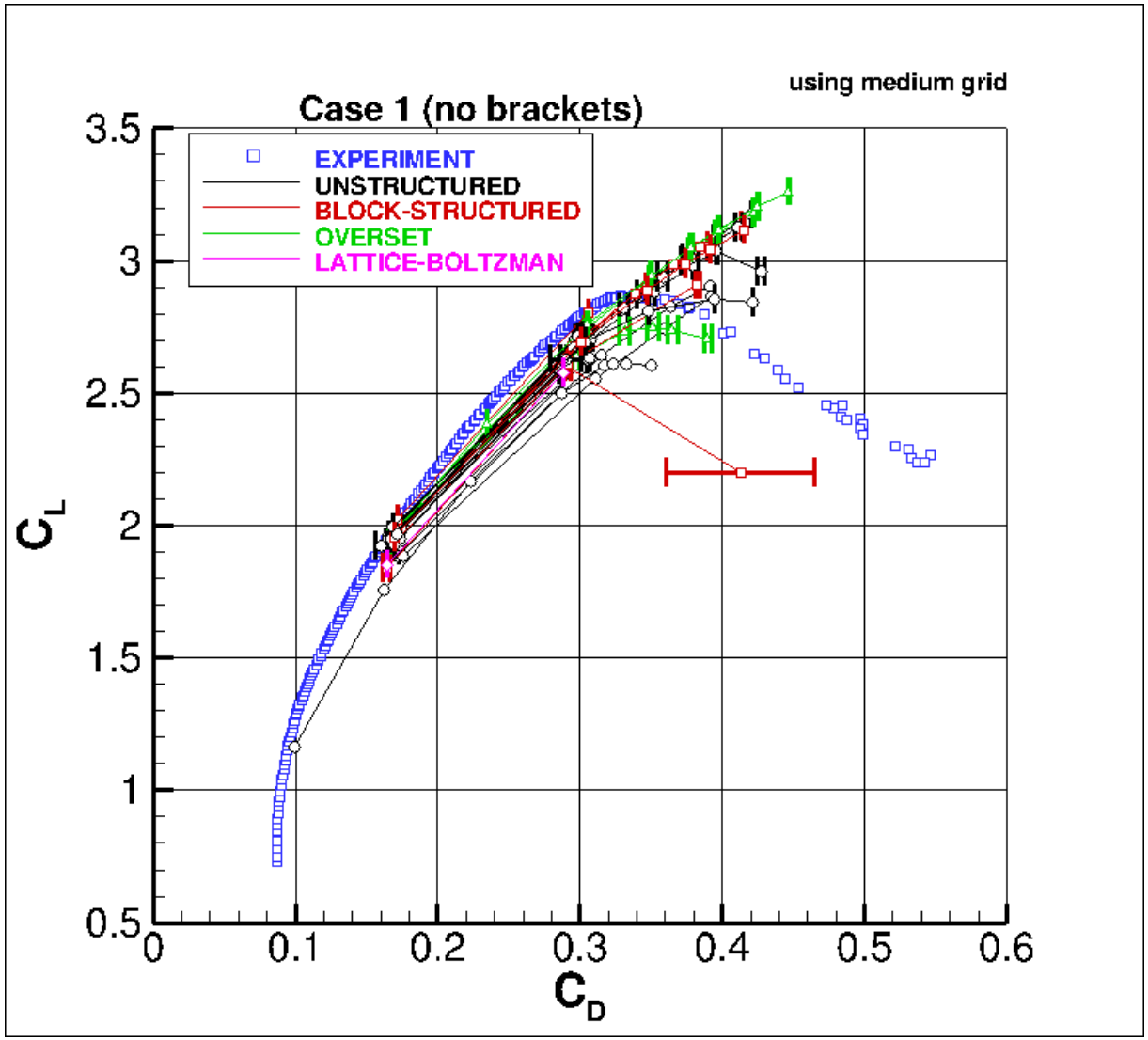


Case 1 Lift curve with variation, M

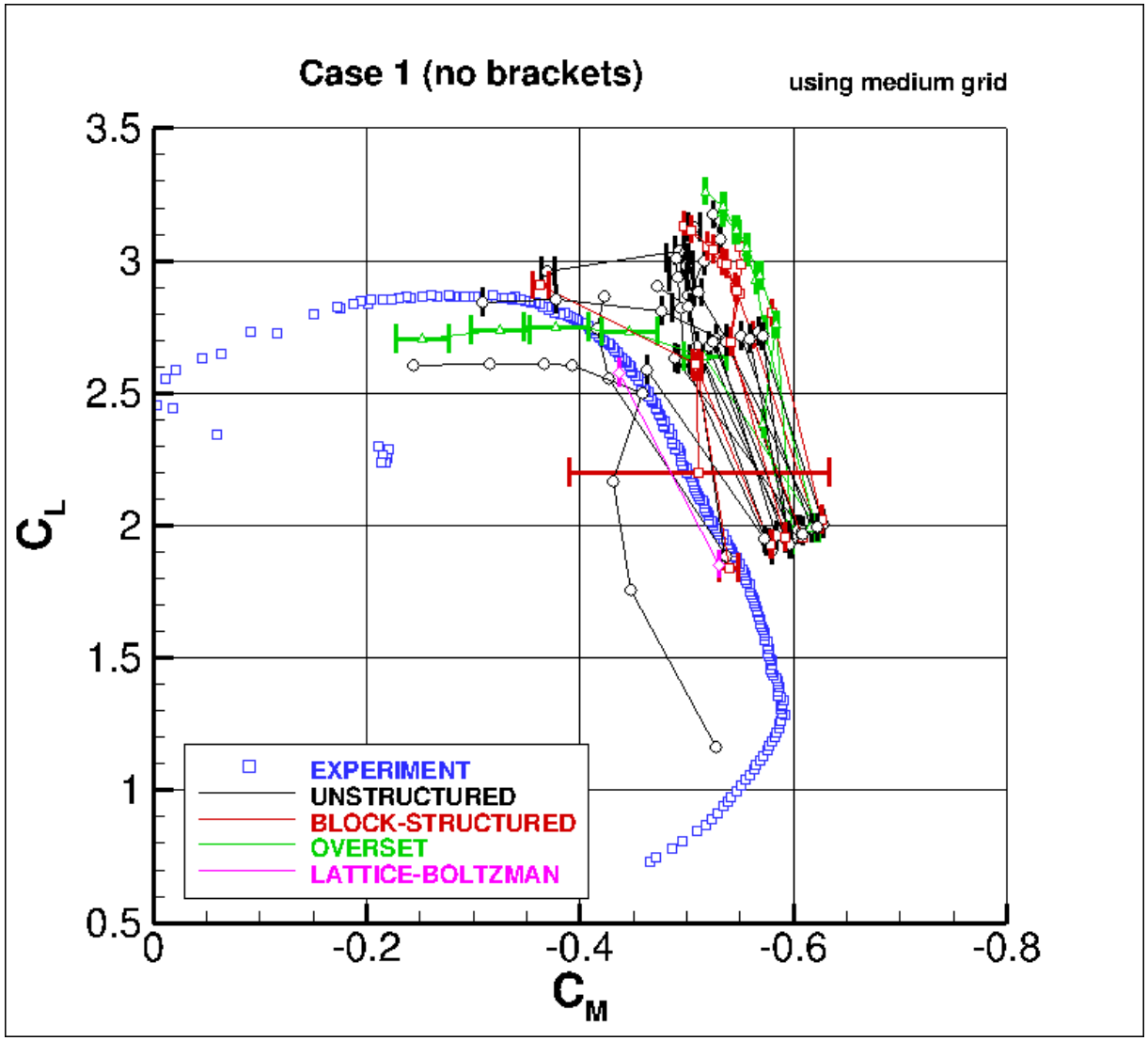


Those above exp lift curve reported very small variations; those below reported larger variations

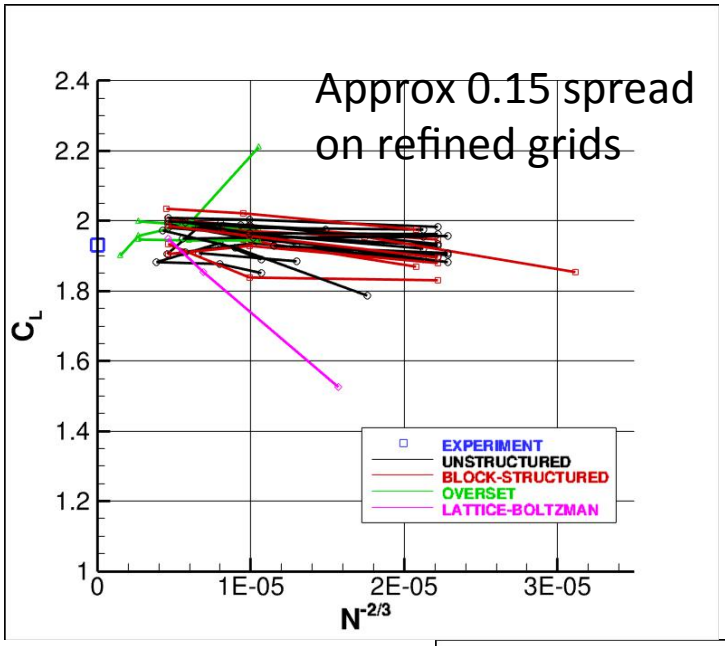
Case 1 Drag polar with variation, M

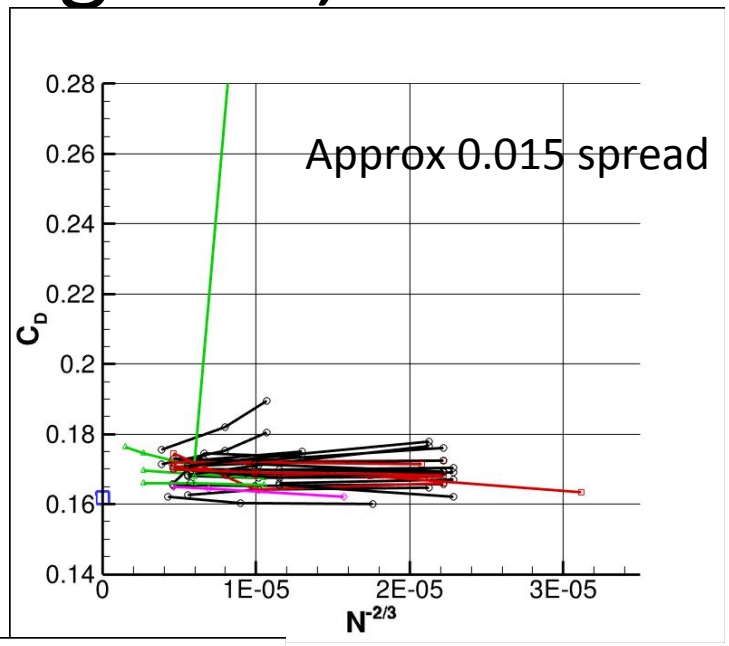


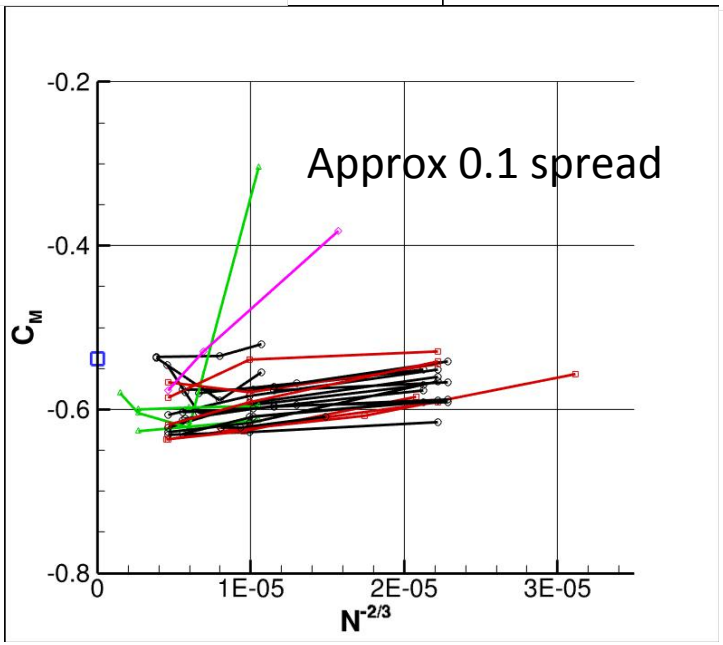
Case 1 Moment polar with variation, M



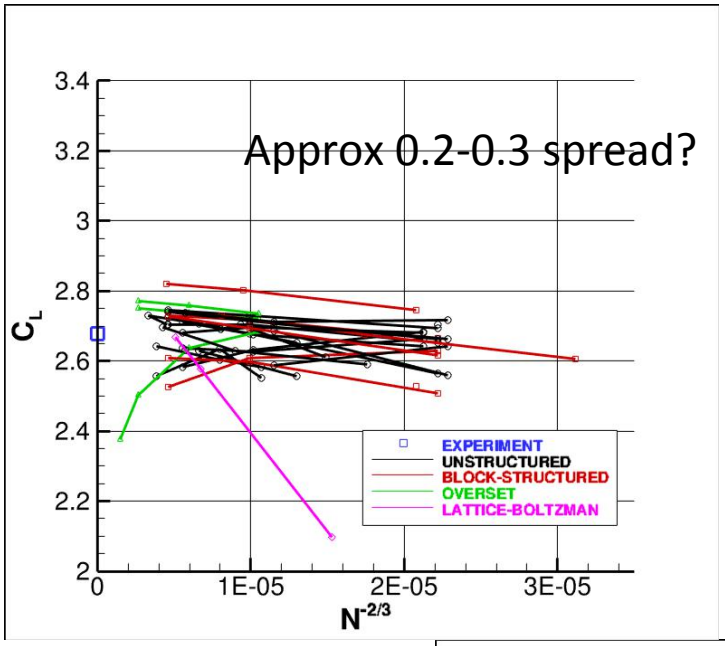
Case 1 Grid convergence, AoA=7

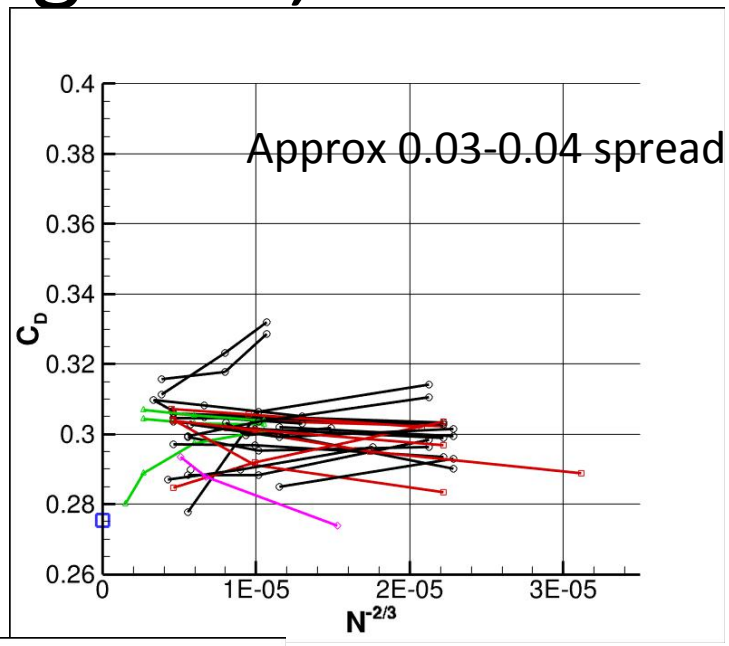


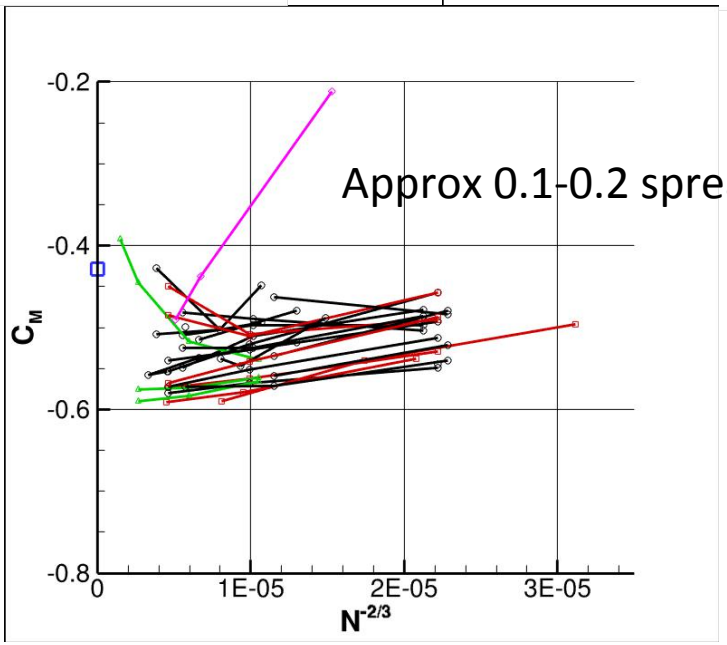




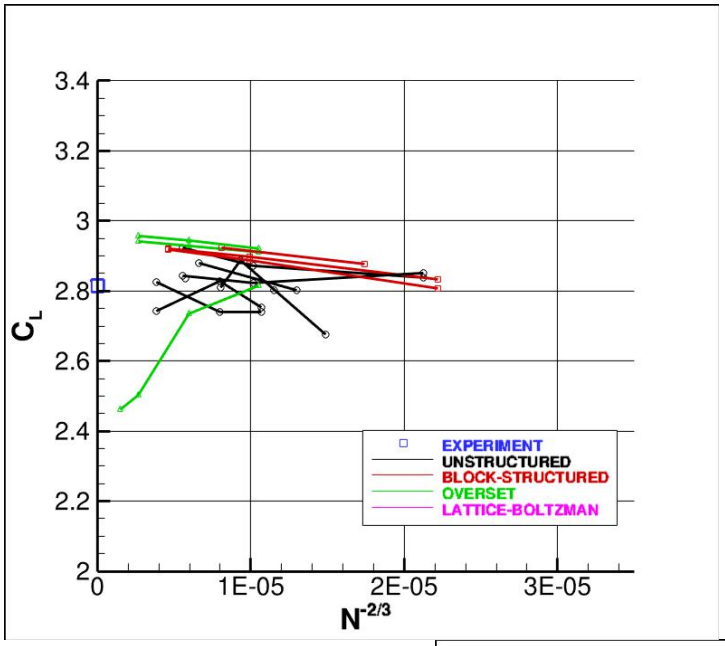
Case 1 Grid convergence, AoA=16

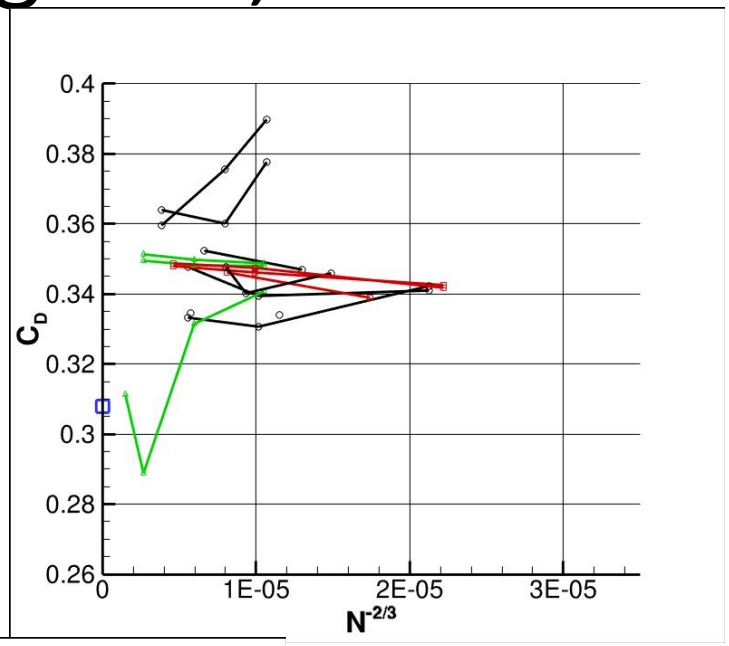


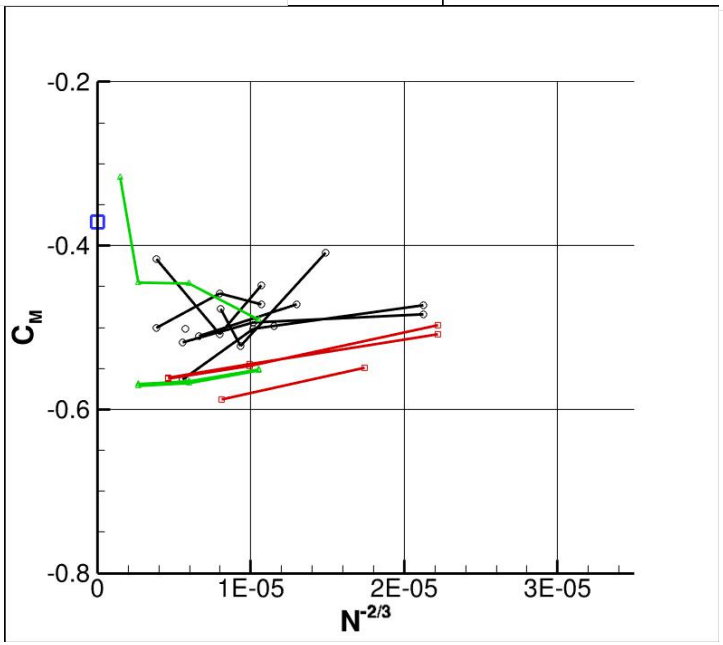




Case 1 Grid convergence, AoA=18.5



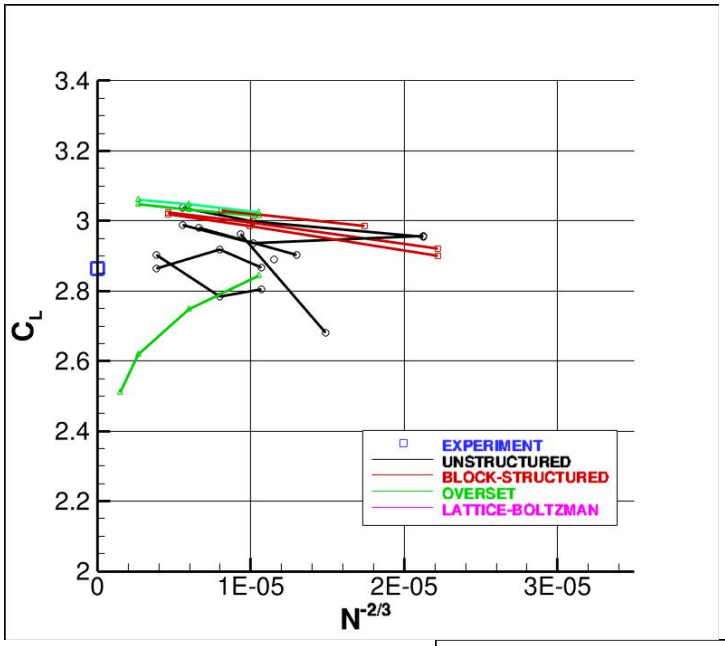


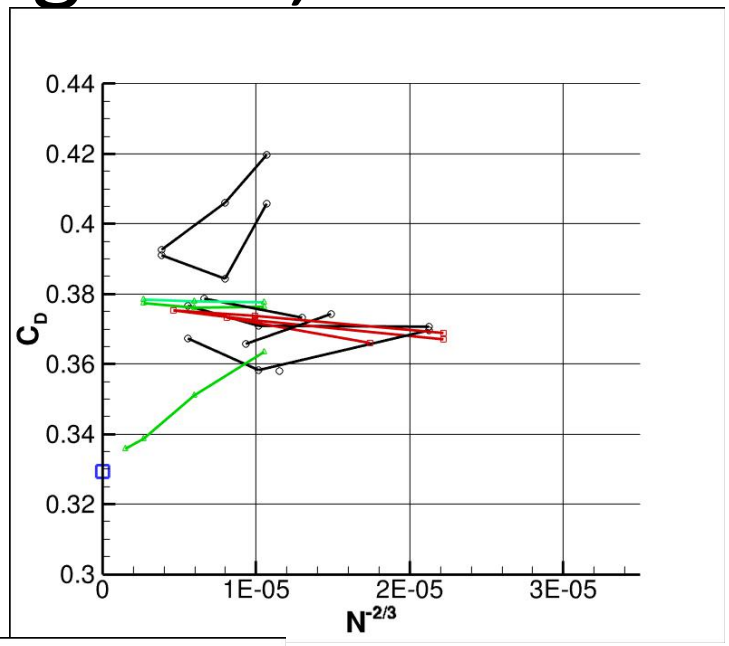


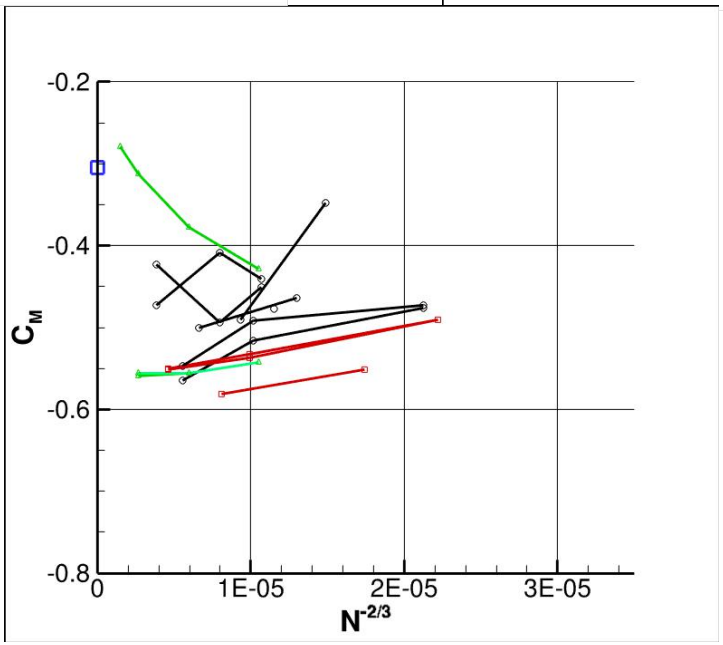
Much more difficult to tell where soln going at higher AoAs

3 block-structured (002.2, 017, and 026) are fairly tight

Case 1 Grid convergence, AoA=20



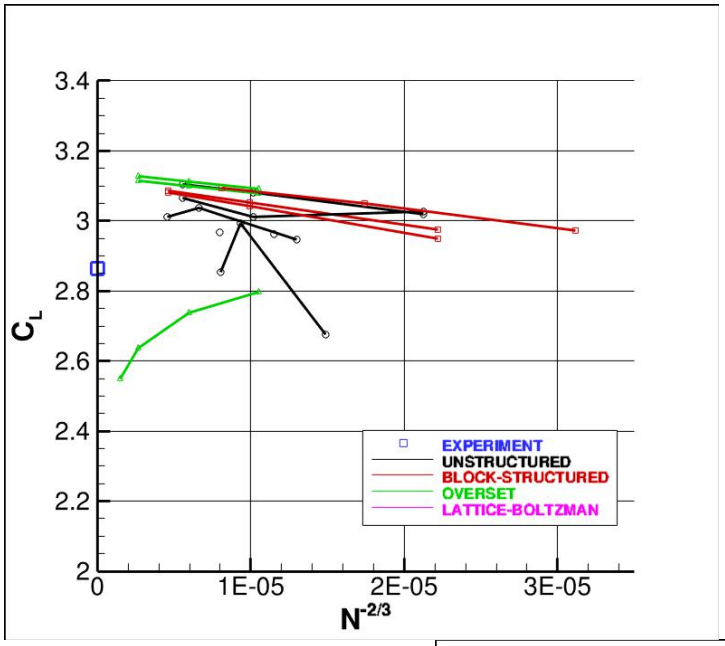


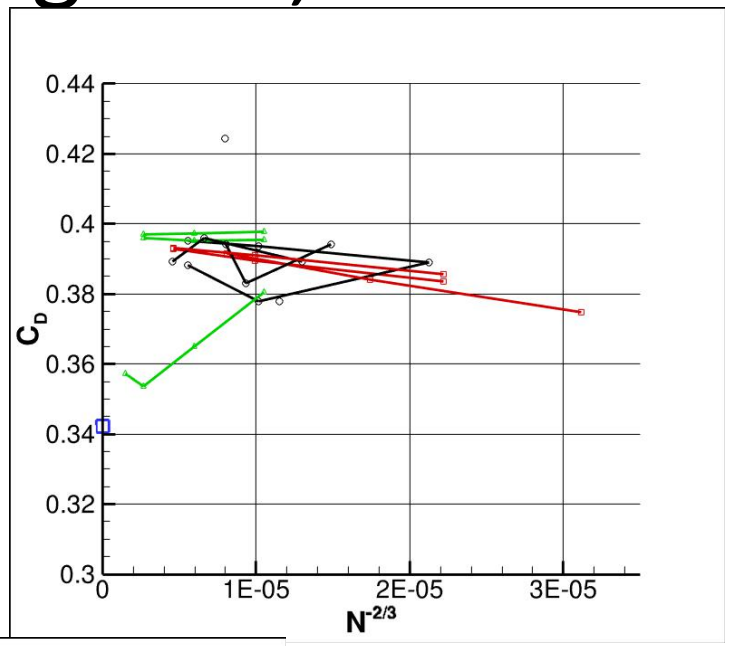


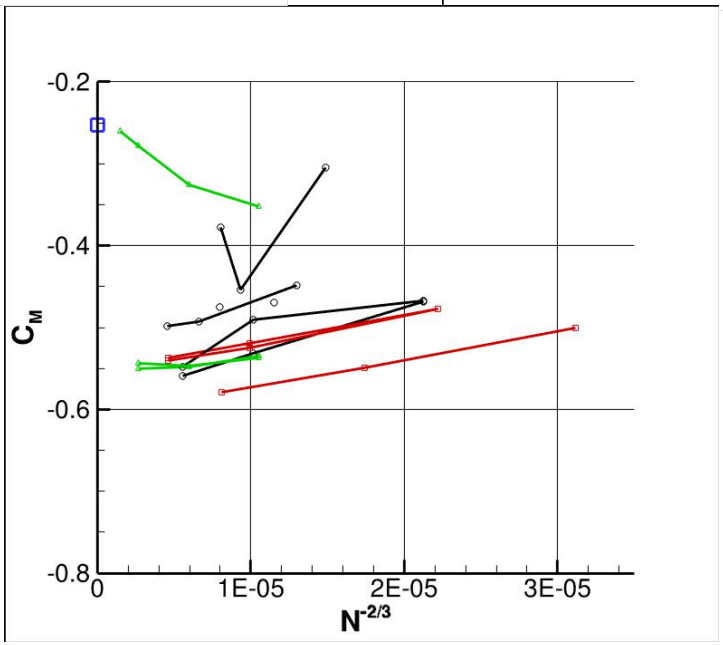
Much more difficult to tell where soln going at higher AoAs

3 block-structured (002.2, 017, and 026) are fairly tight

Case 1 Grid convergence, AoA=21



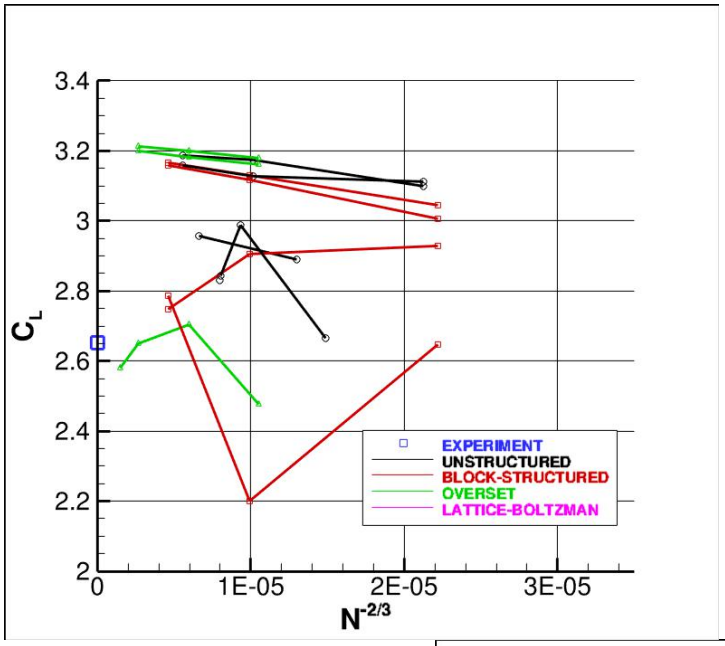


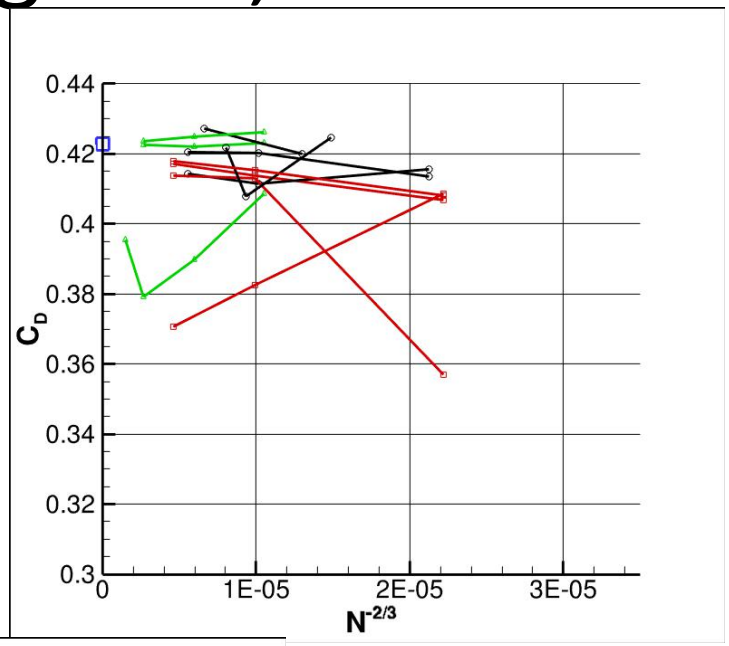


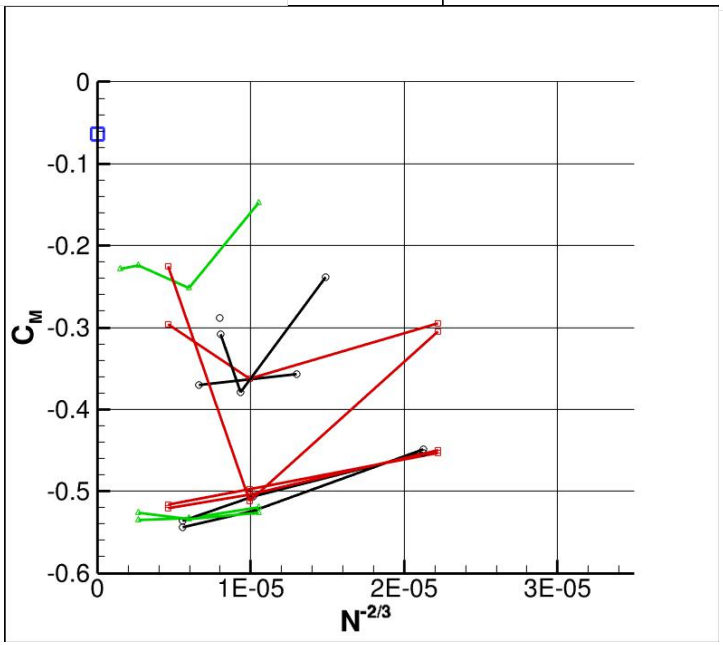
Much more difficult to tell where soln going at higher AoAs

3 block-structured (002.2, 017, and 026) are fairly tight

Case 1 Grid convergence, AoA=22.4



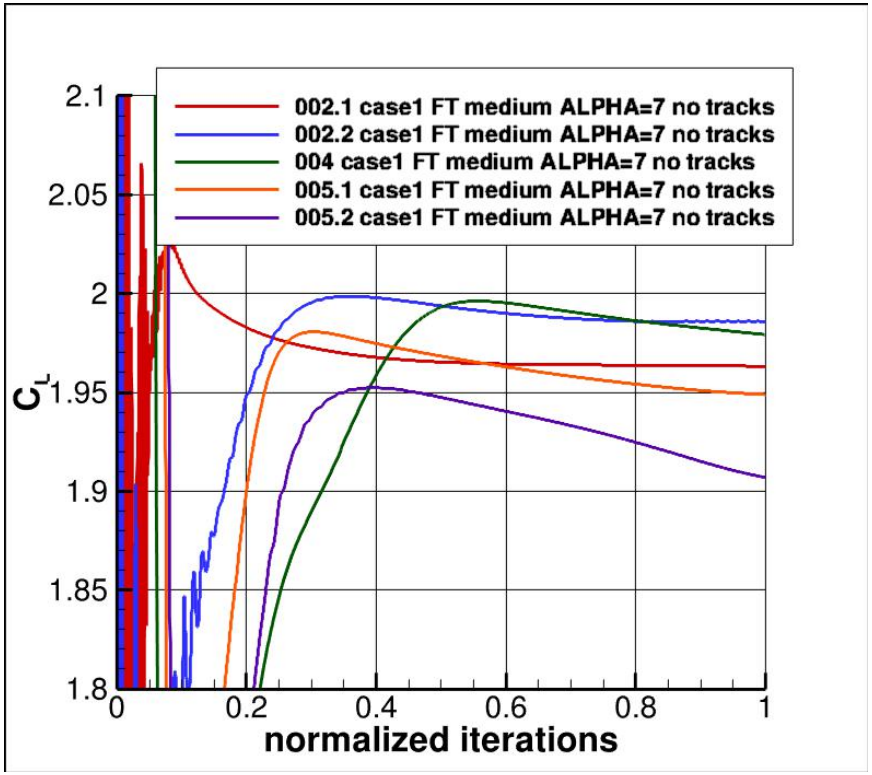


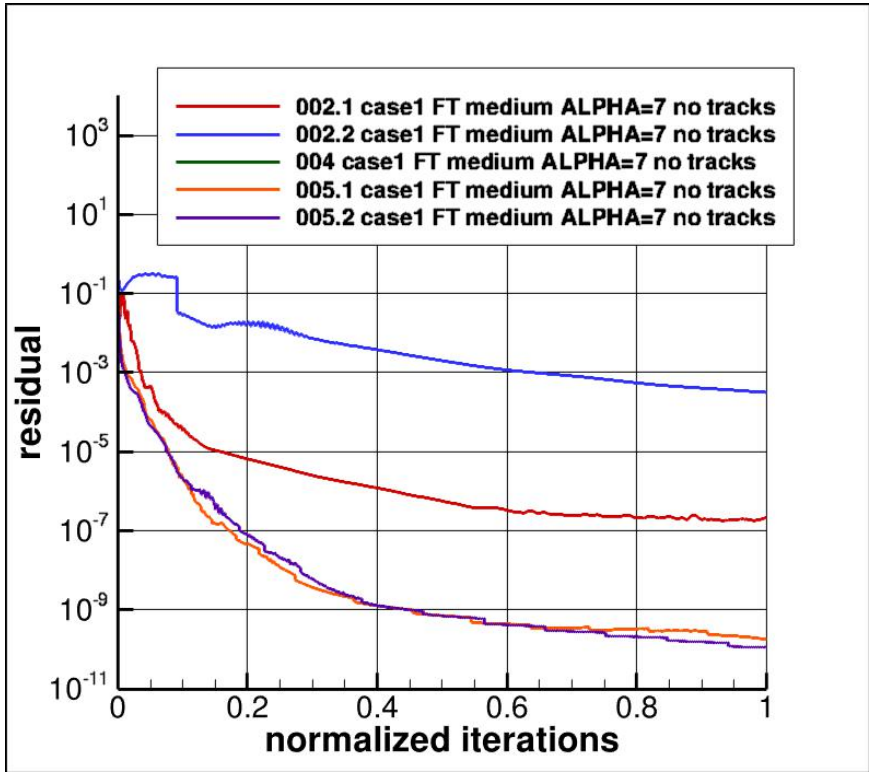


Much more difficult to tell where soln going at higher AoAs

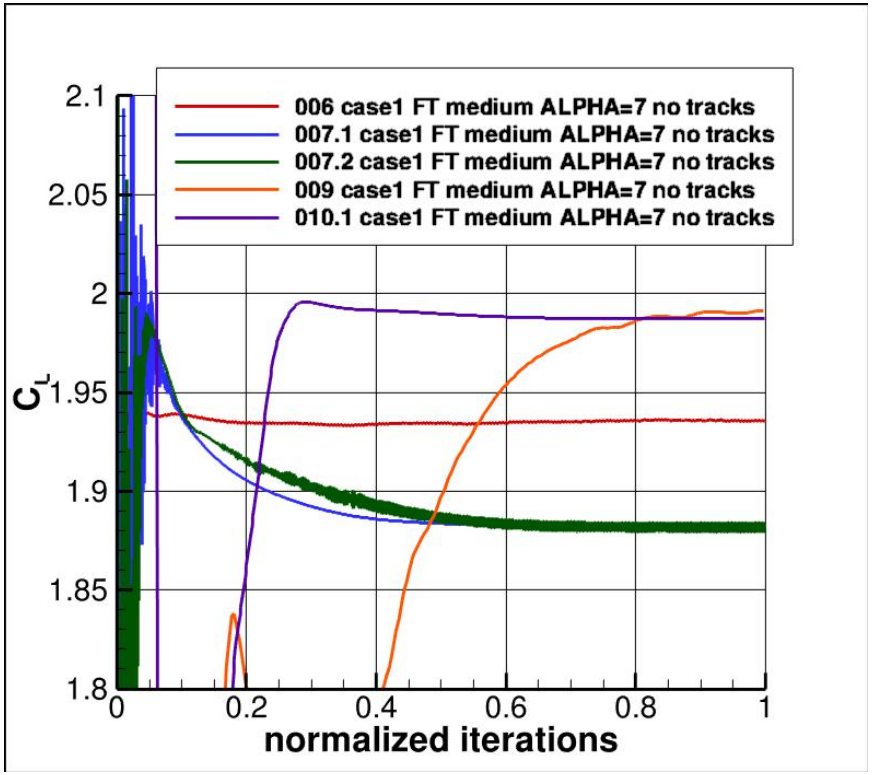
Block-structured 011.1 and 011.2 very different from 002.2 and 026

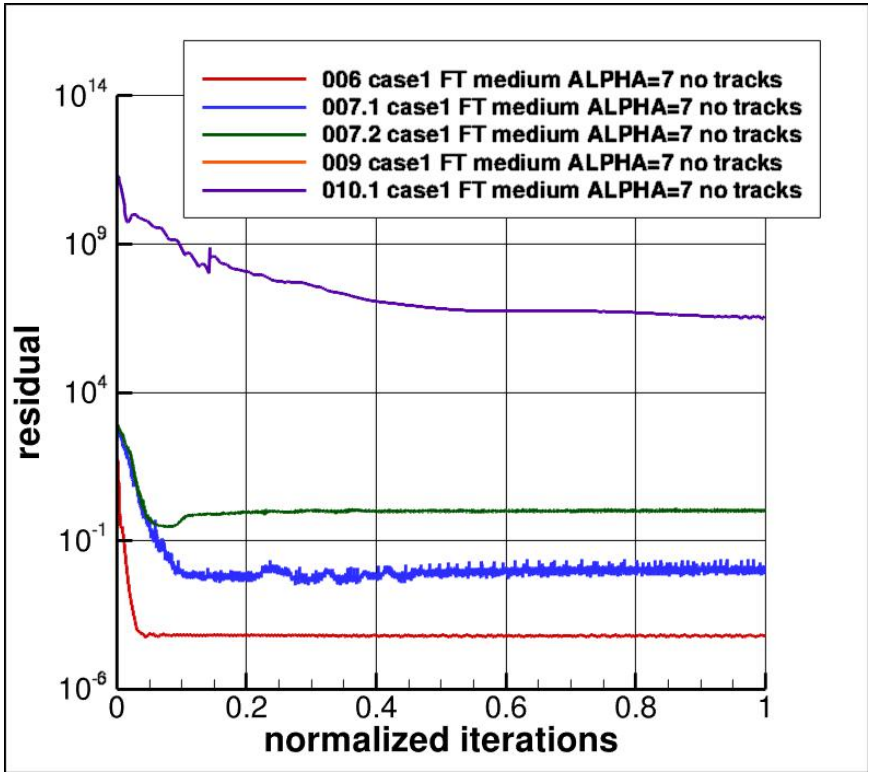
Case 1 Iterative convergence, AoA=7



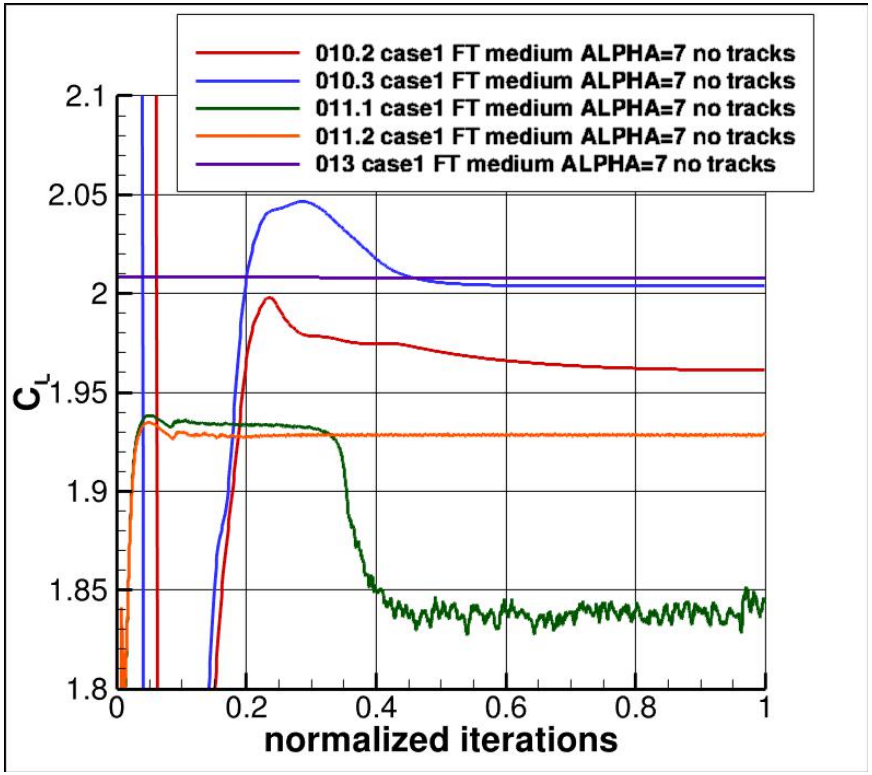


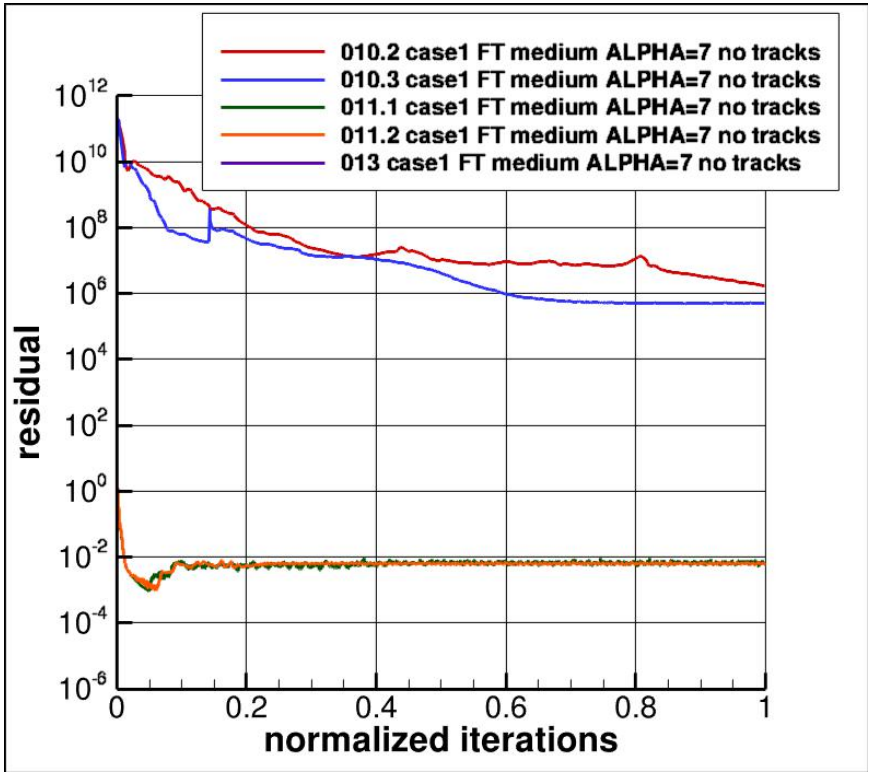
Case 1 Iterative convergence, AoA=7



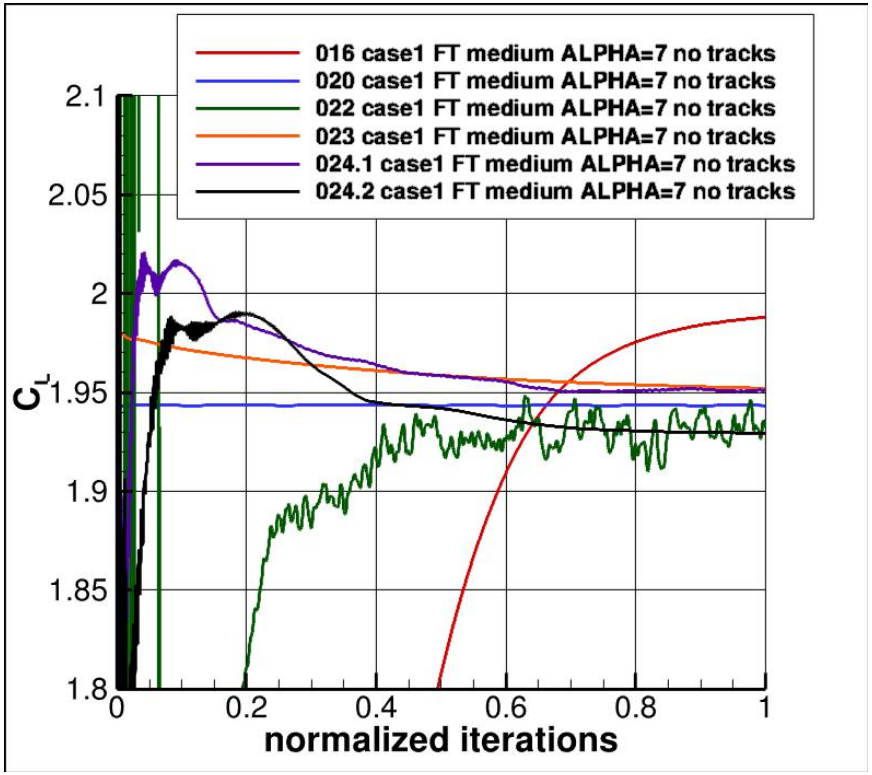


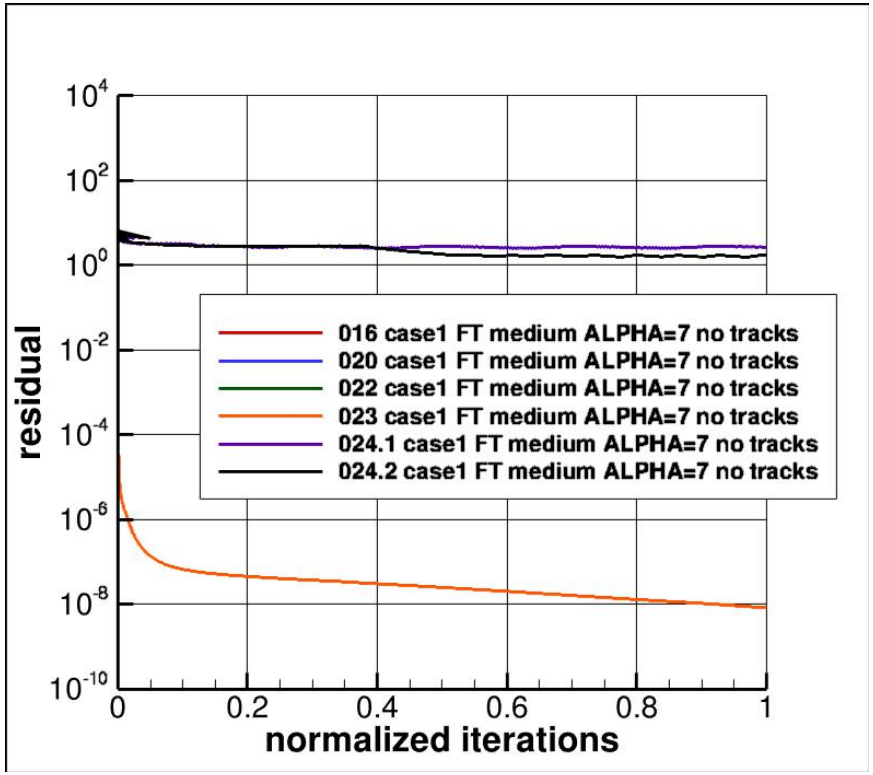
Case 1 Iterative convergence, AoA=7





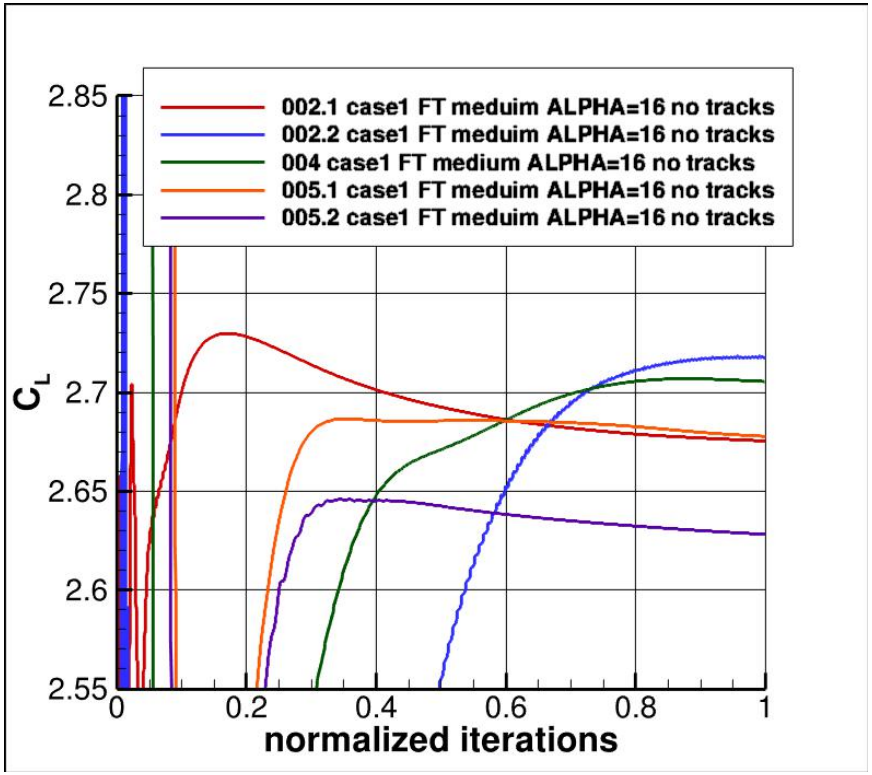
Case 1 Iterative convergence, AoA=7

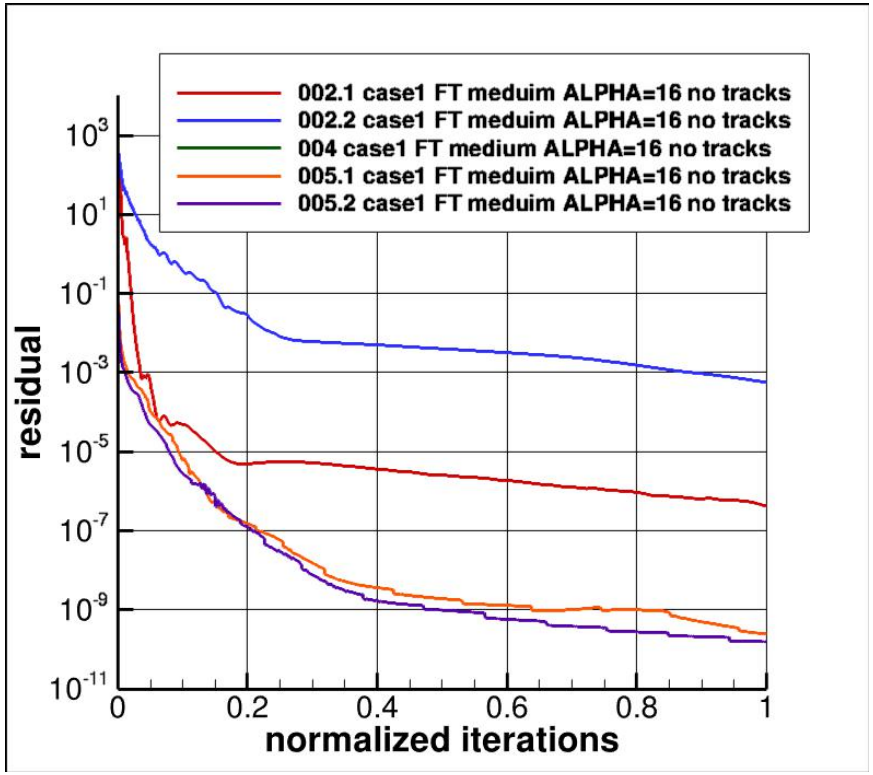




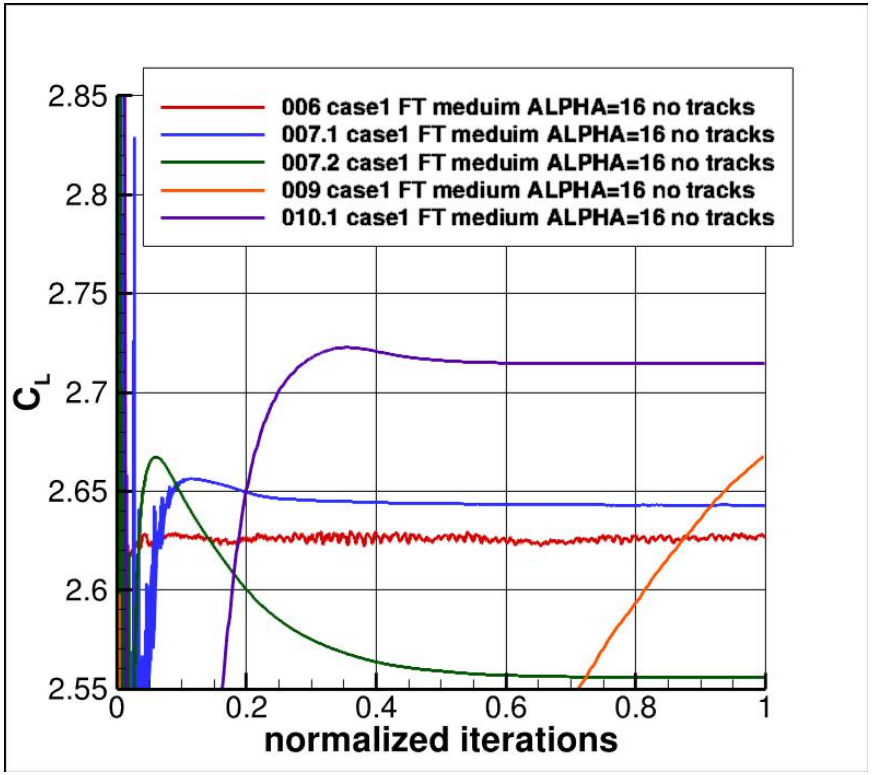
GREEN (022) – time accurate

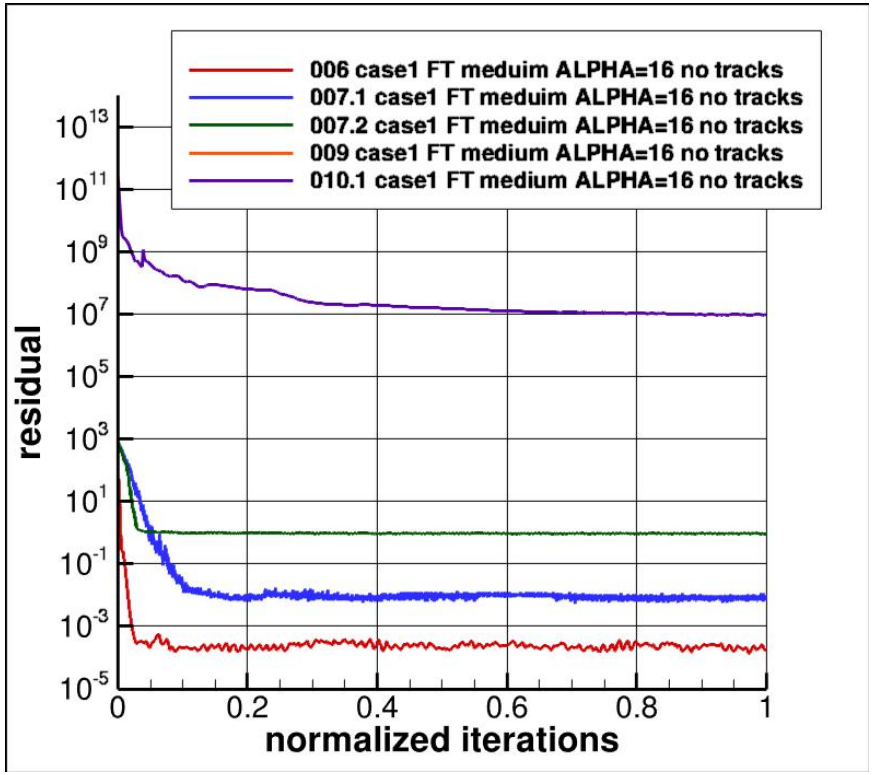
Case 1 Iterative convergence, AoA=16



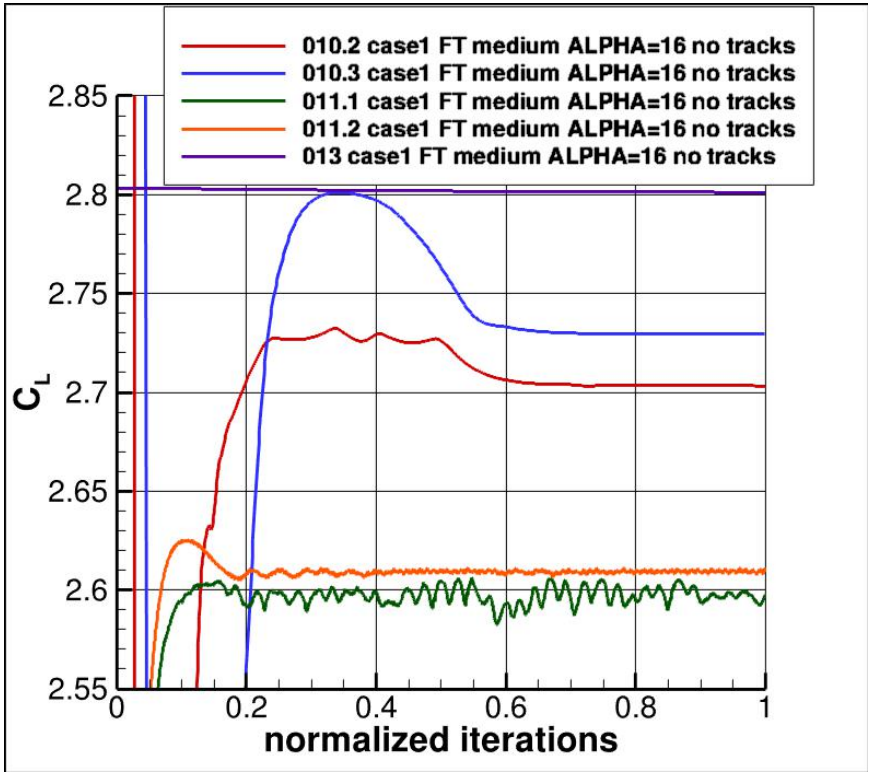


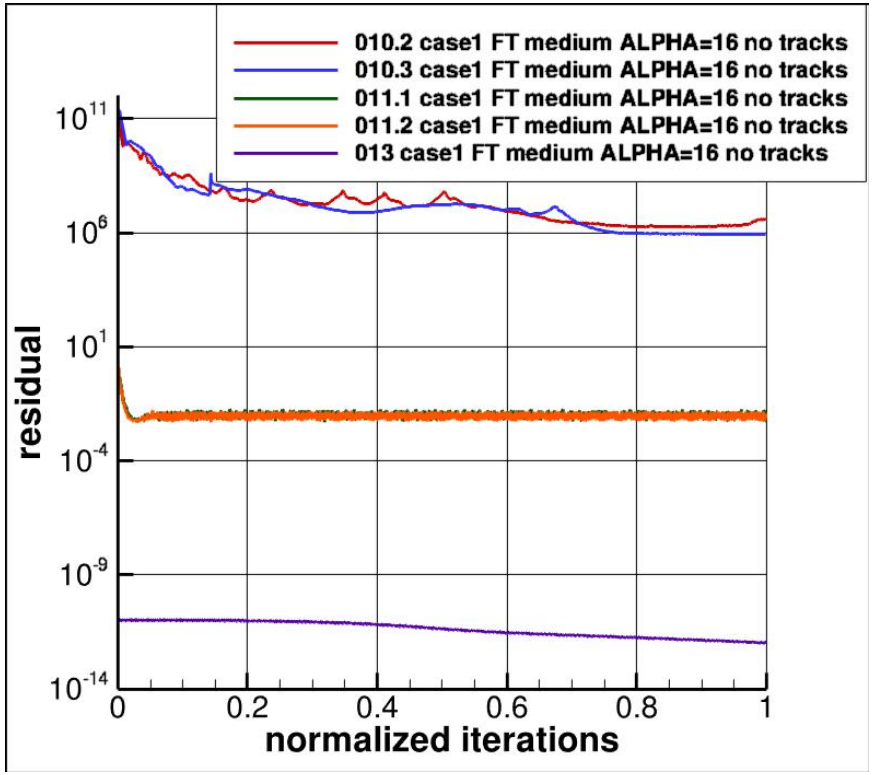
Case 1 Iterative convergence, AoA=16



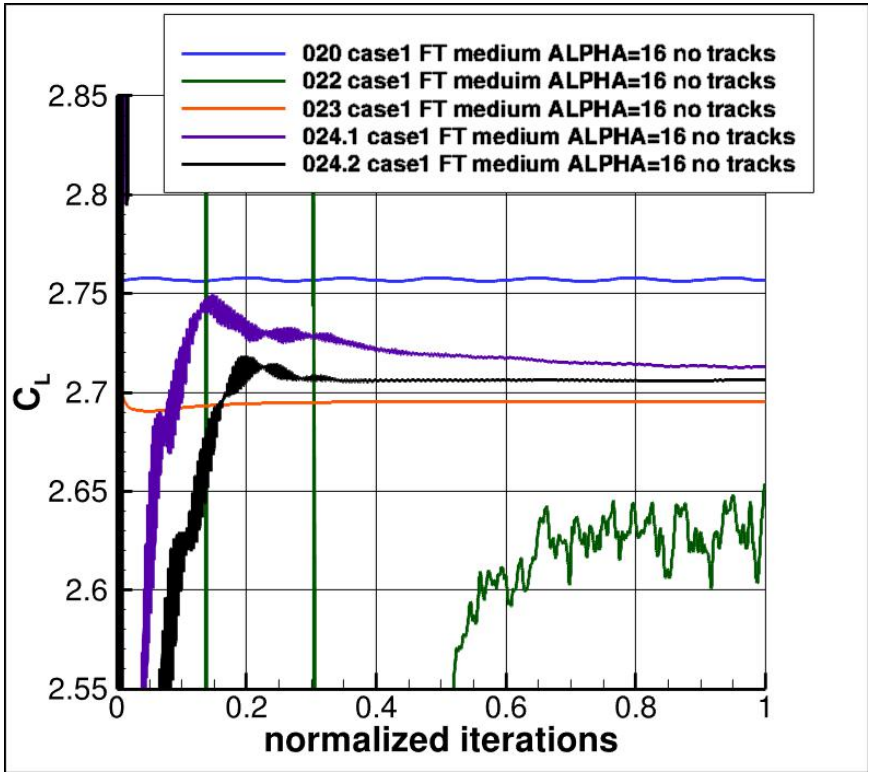


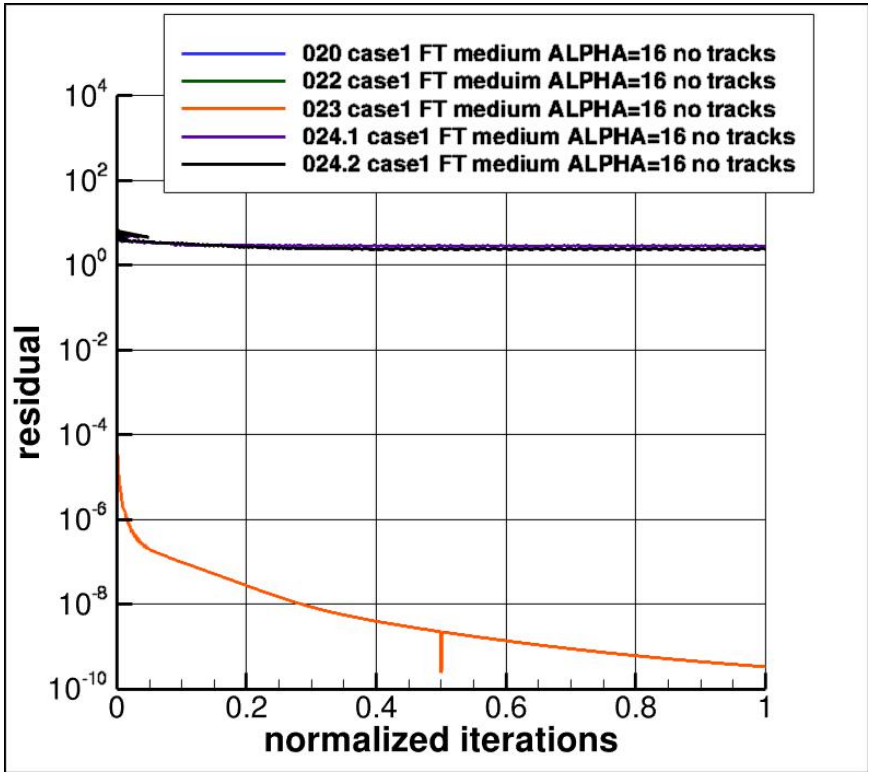
Case 1 Iterative convergence, AoA=16





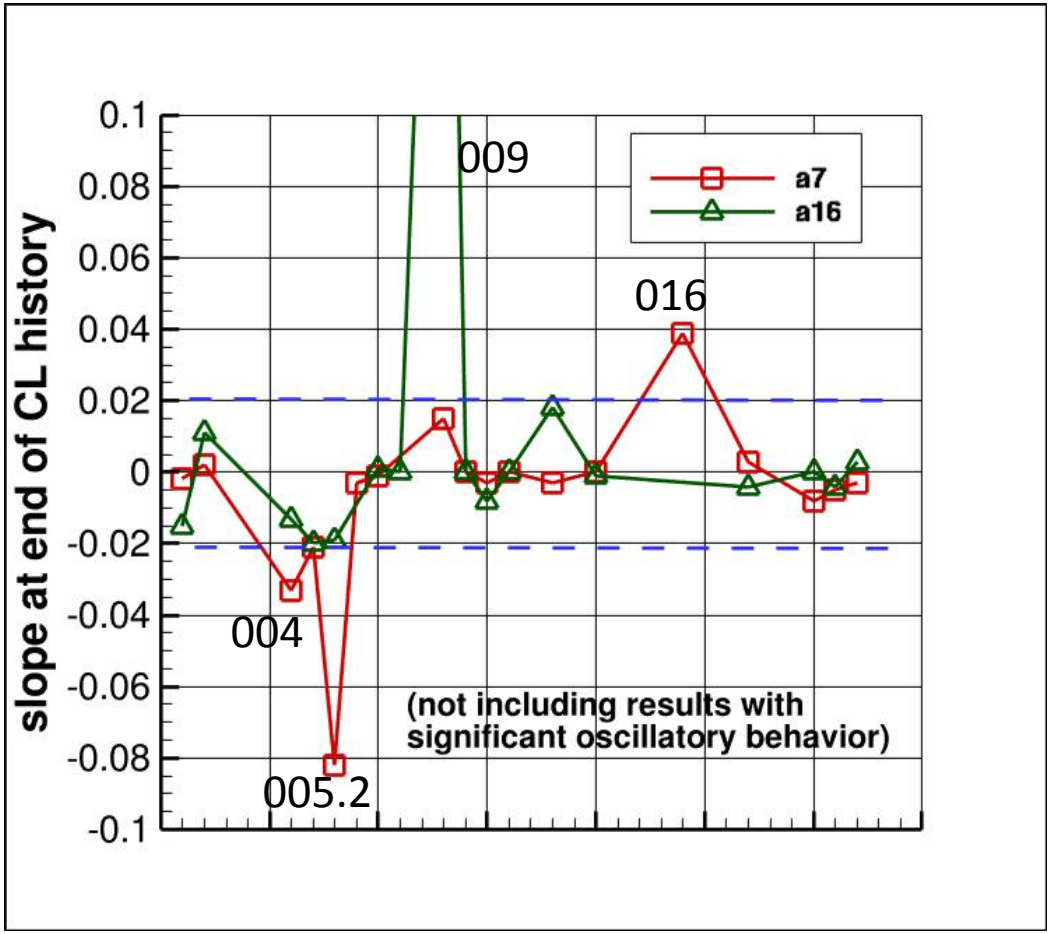
Case 1 Iterative convergence, AoA=16

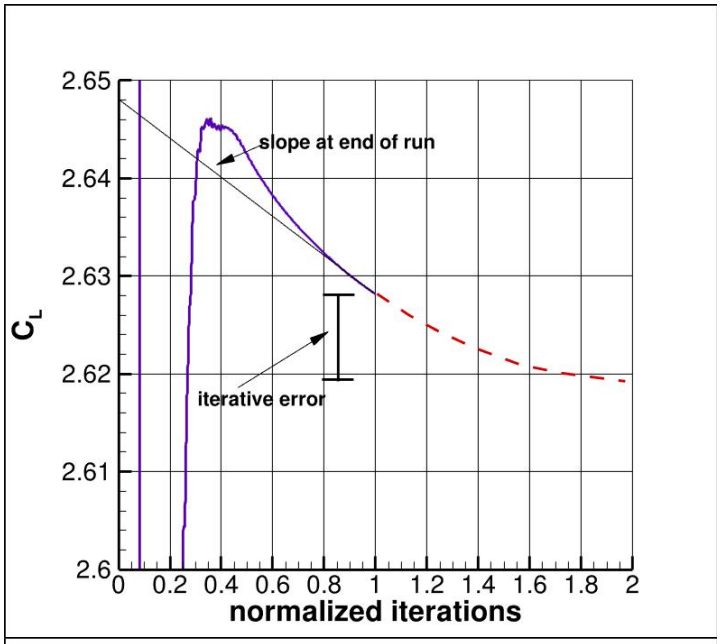


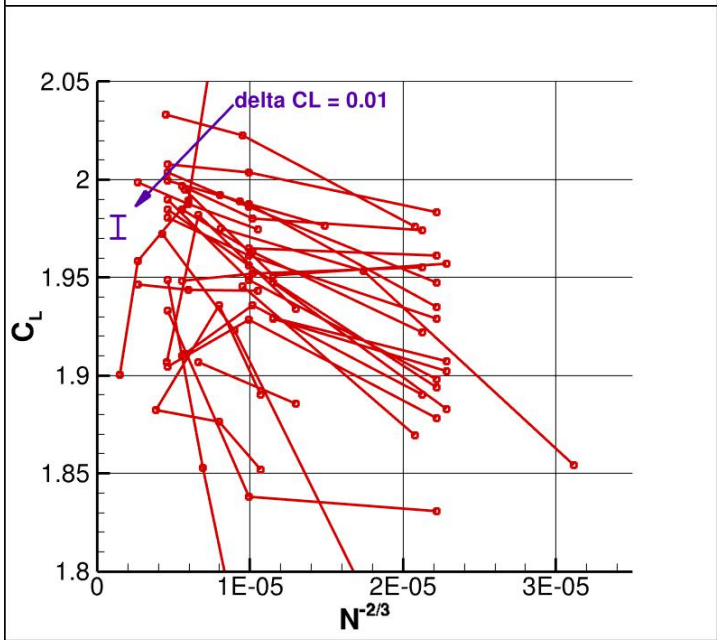


GREEN (022) – time accurate

Iterative convergence summary

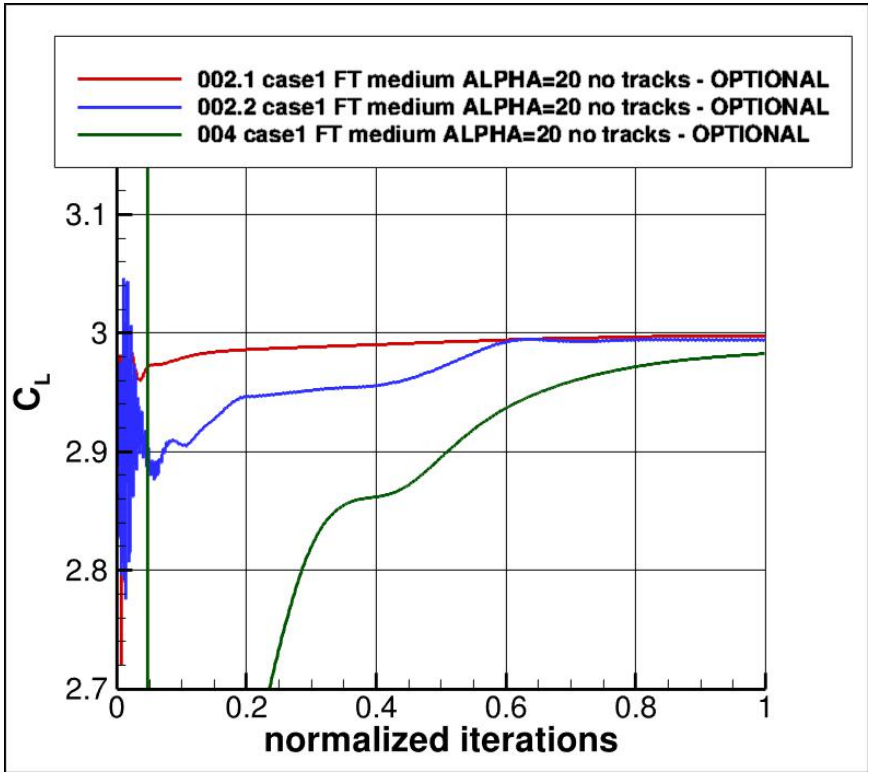


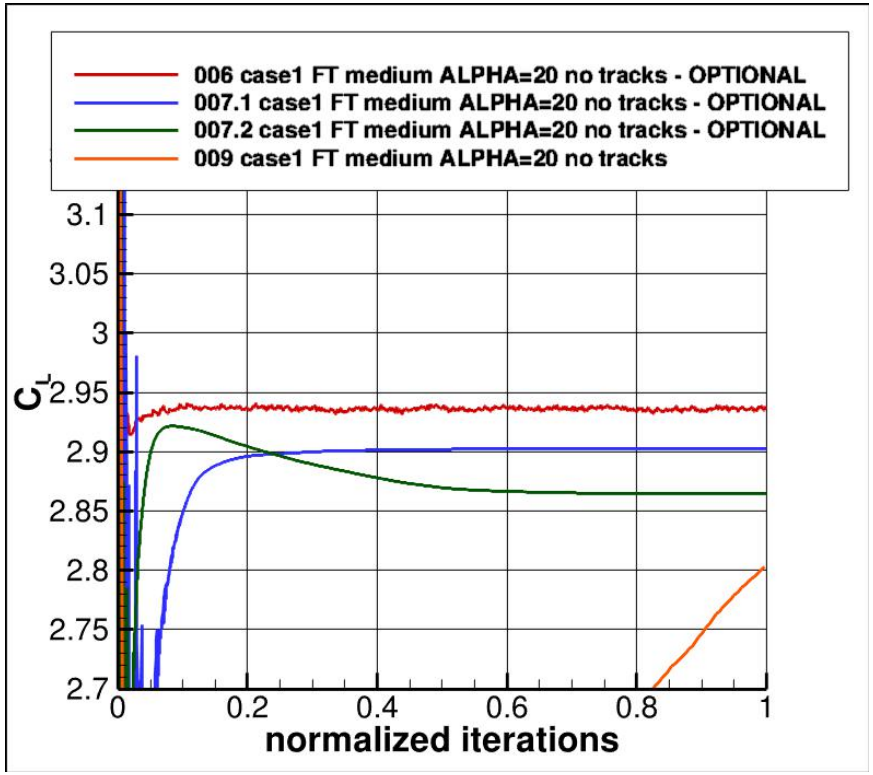




As a guess, a final slope of +-0.02 might yield an iterative error on the order of CL=0.01

Case 1 Iterative convergence, AoA=20

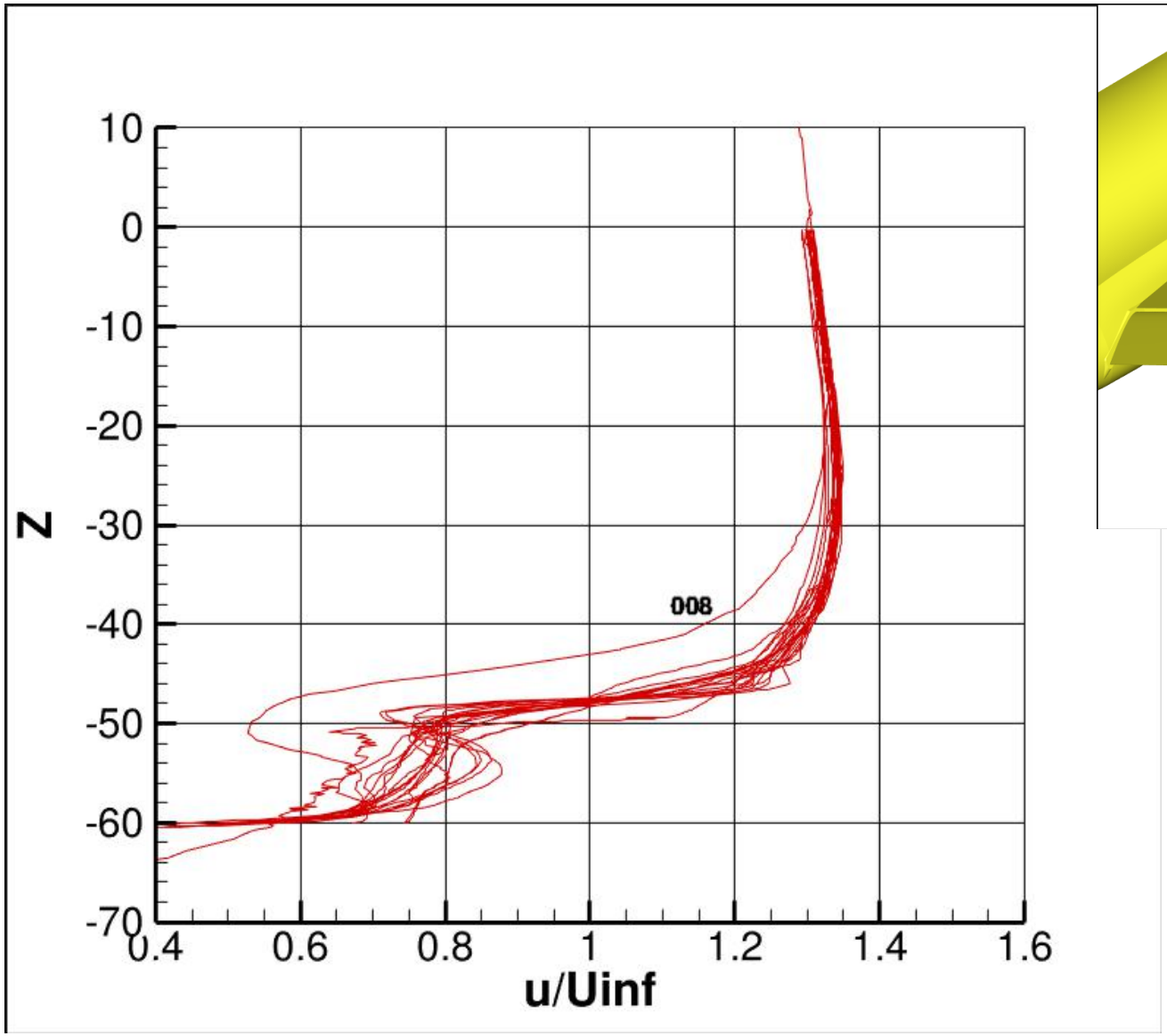


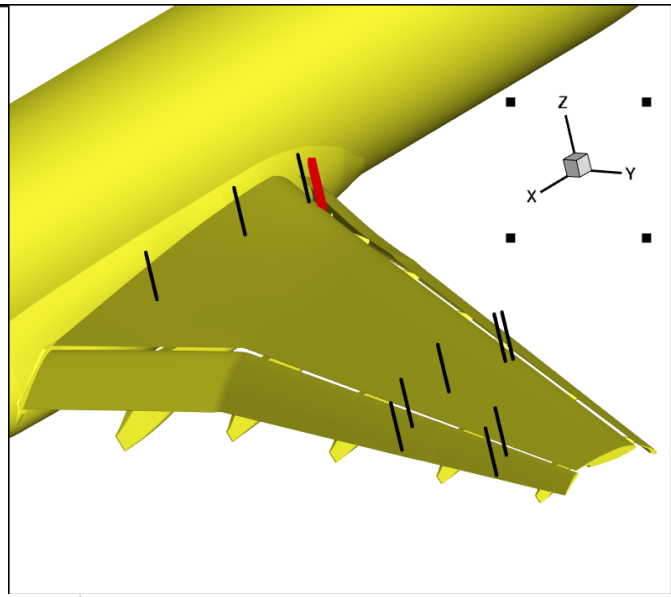


Case 1 Iterative convergence

- Some of the results for Case 1 may not have been converged sufficiently
  - 4 of 35 cases at AoA=7 and 16 are suspect
  - Most participants did not report iterative convergence for higher (optional) AoA's
- About half of participants' residuals "hang"

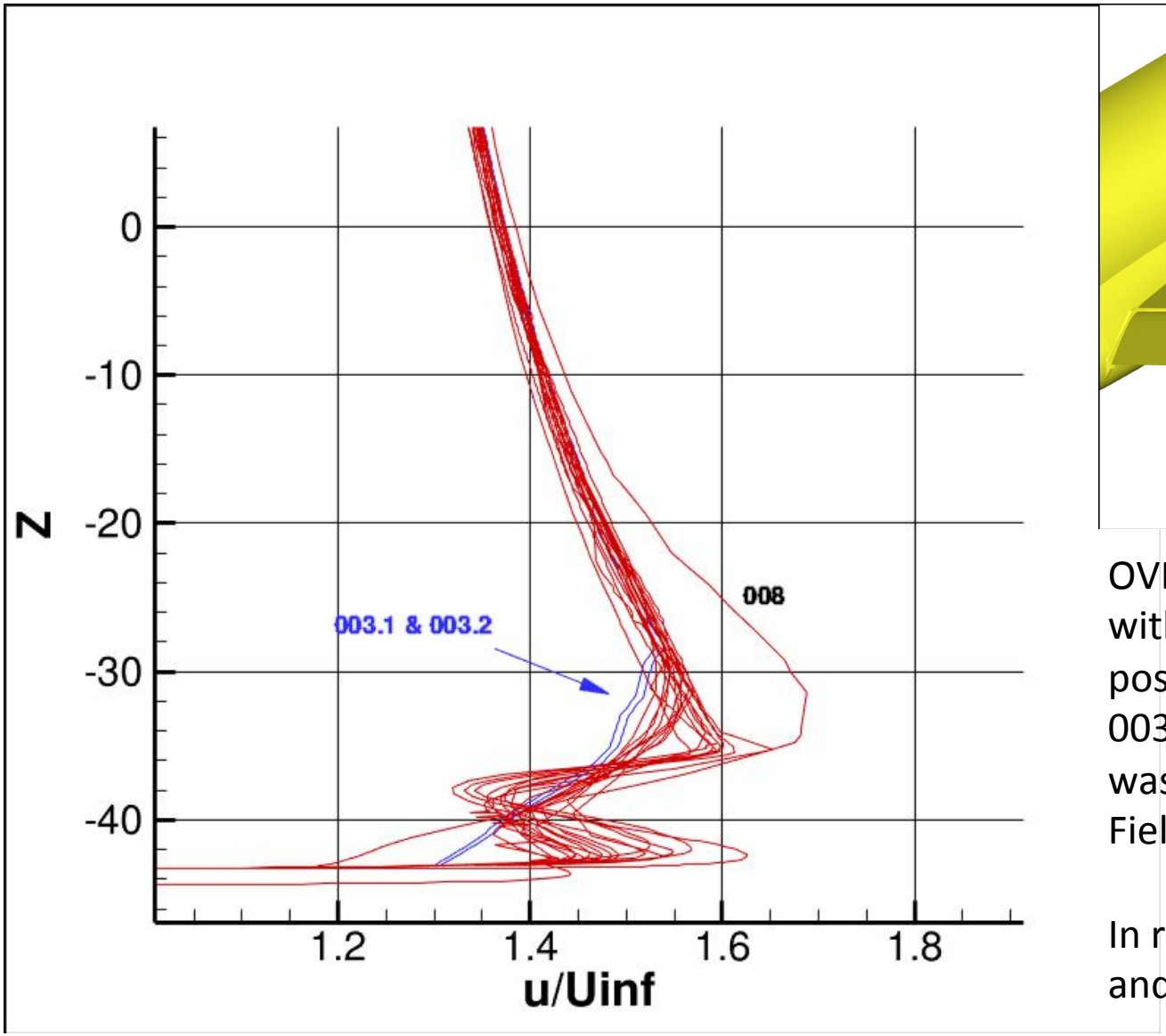
Case 1 Velocity, AoA=7, 1B1

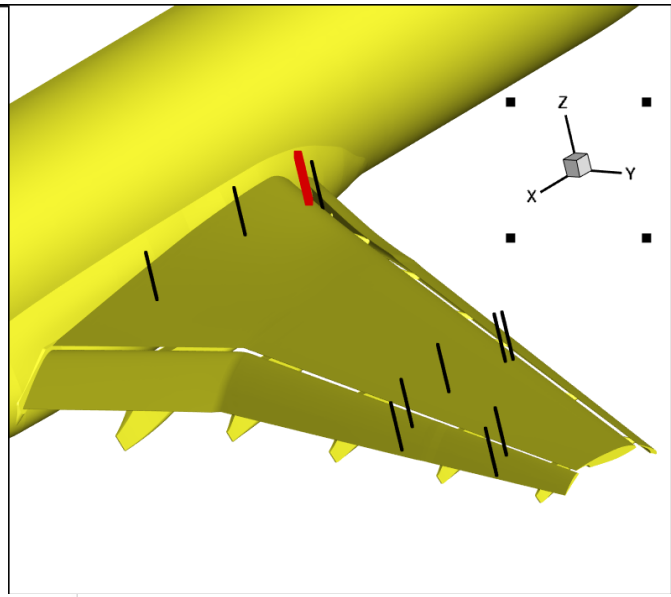




Note: All vel results on medium grids except 021, which only provided fine

Case 1 Velocity, AoA=7, 1B2

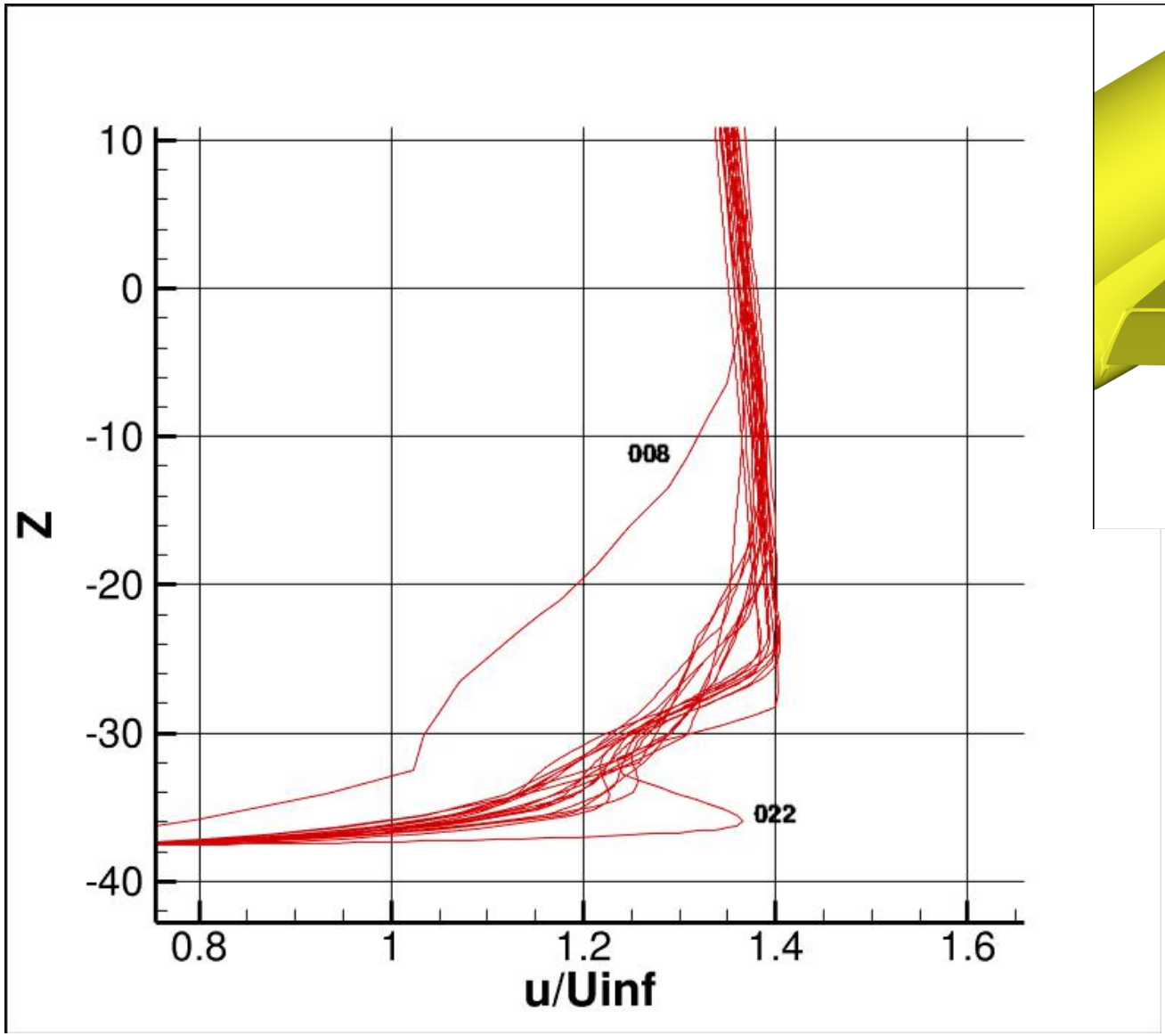


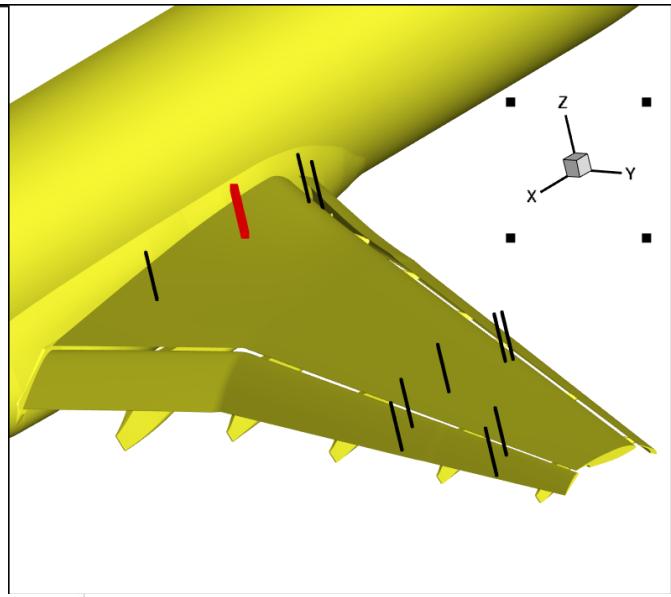


OVERFLOW files had issue with Tecplot's interpolation postprocessing. This affected 003.1 and 003.2. Problem was overcome in 020 using Fieldview.

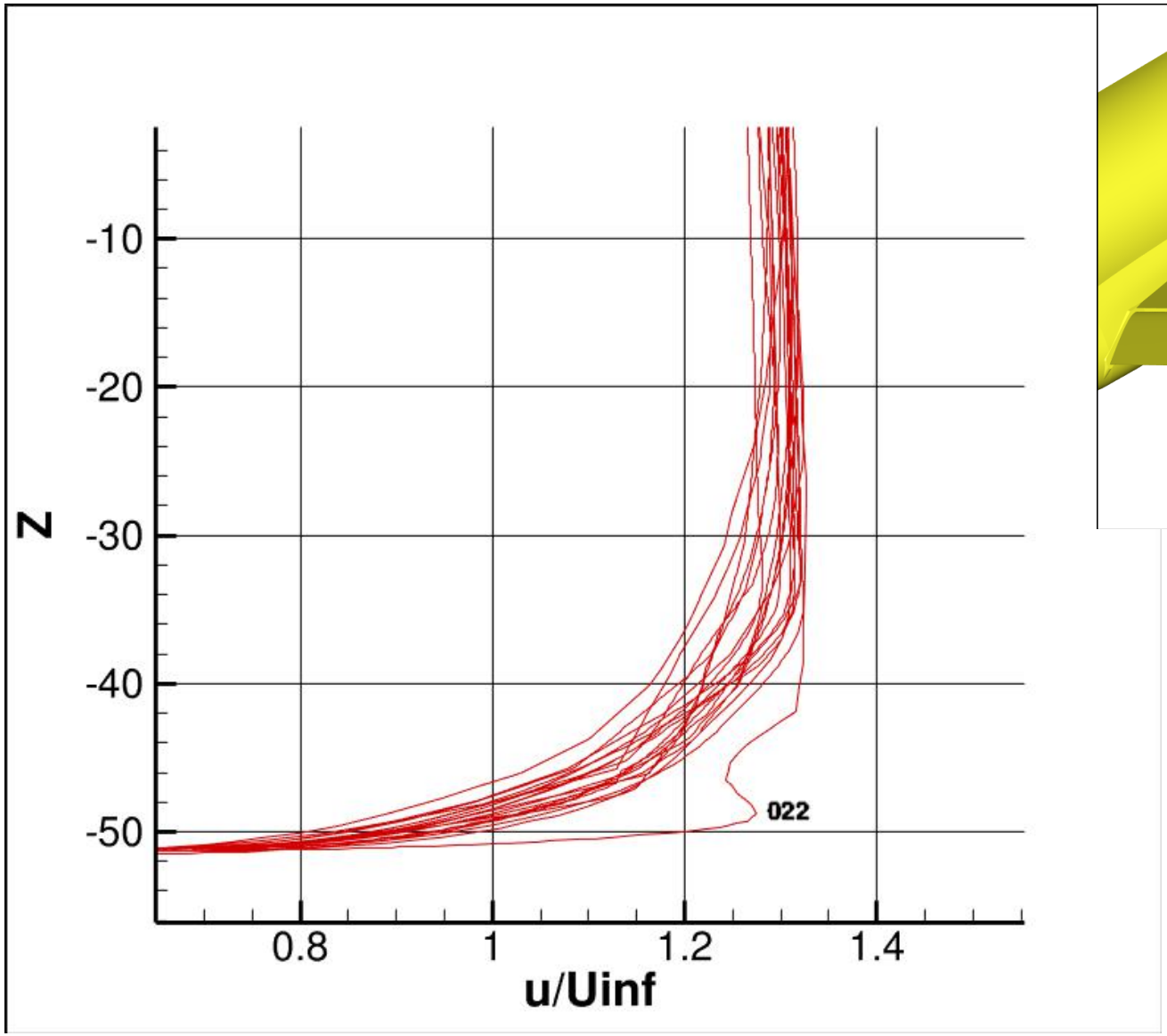
In remaining vel figures, 003.1 and 003.2 not plotted.

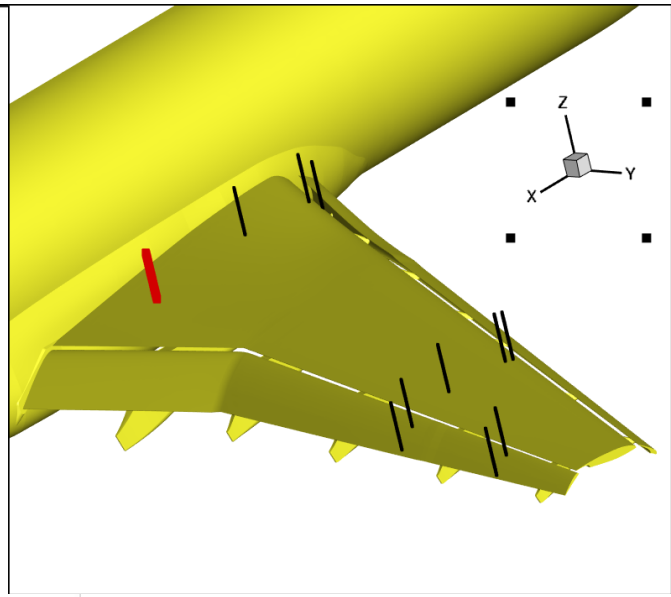
Case 1 Velocity, AoA=7, 1C1



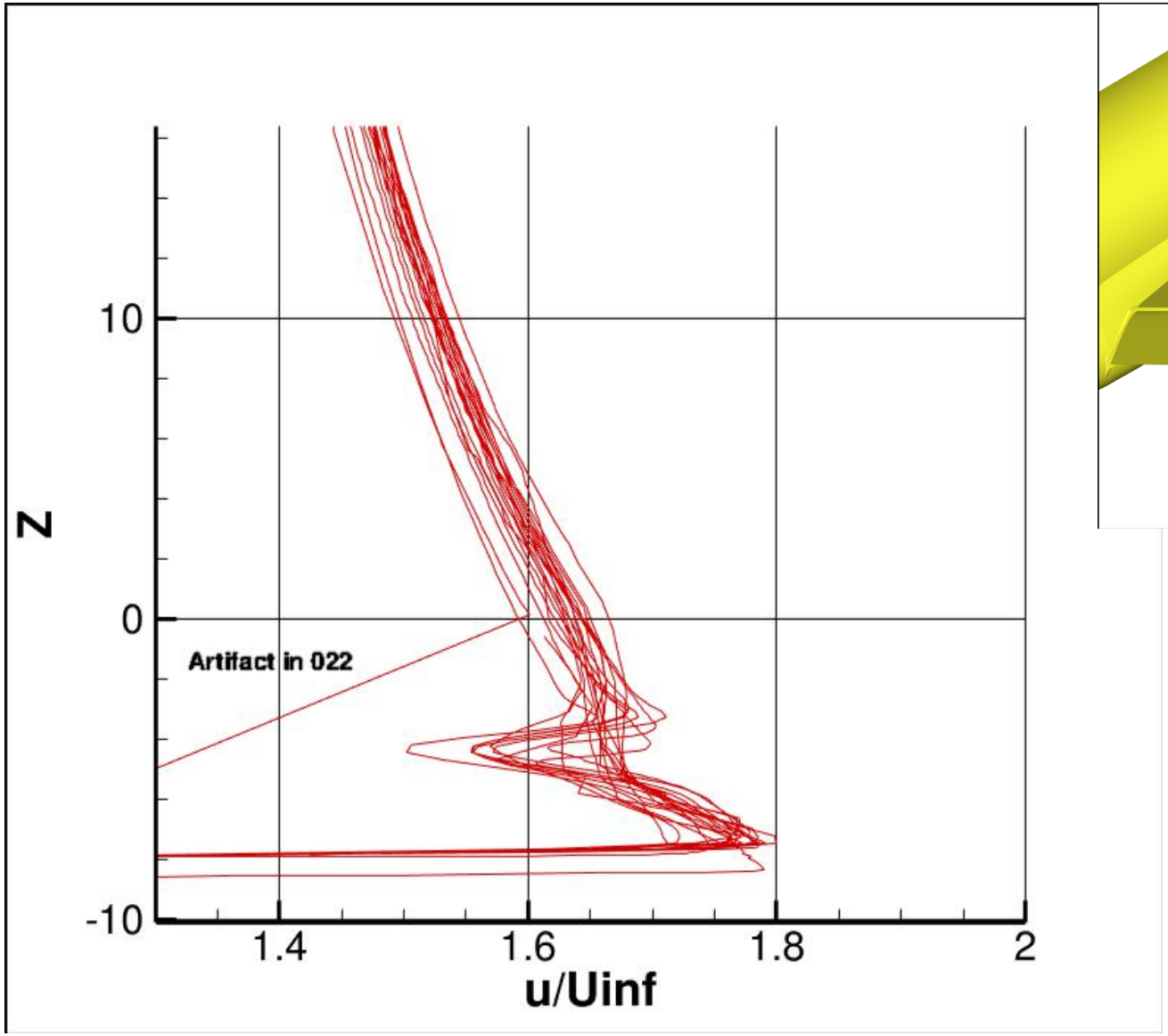


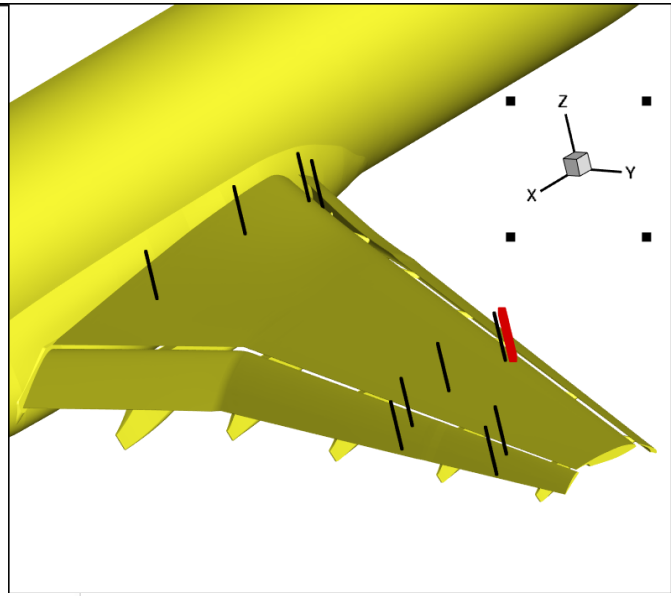
Case 1 Velocity, AoA=7, 1D1



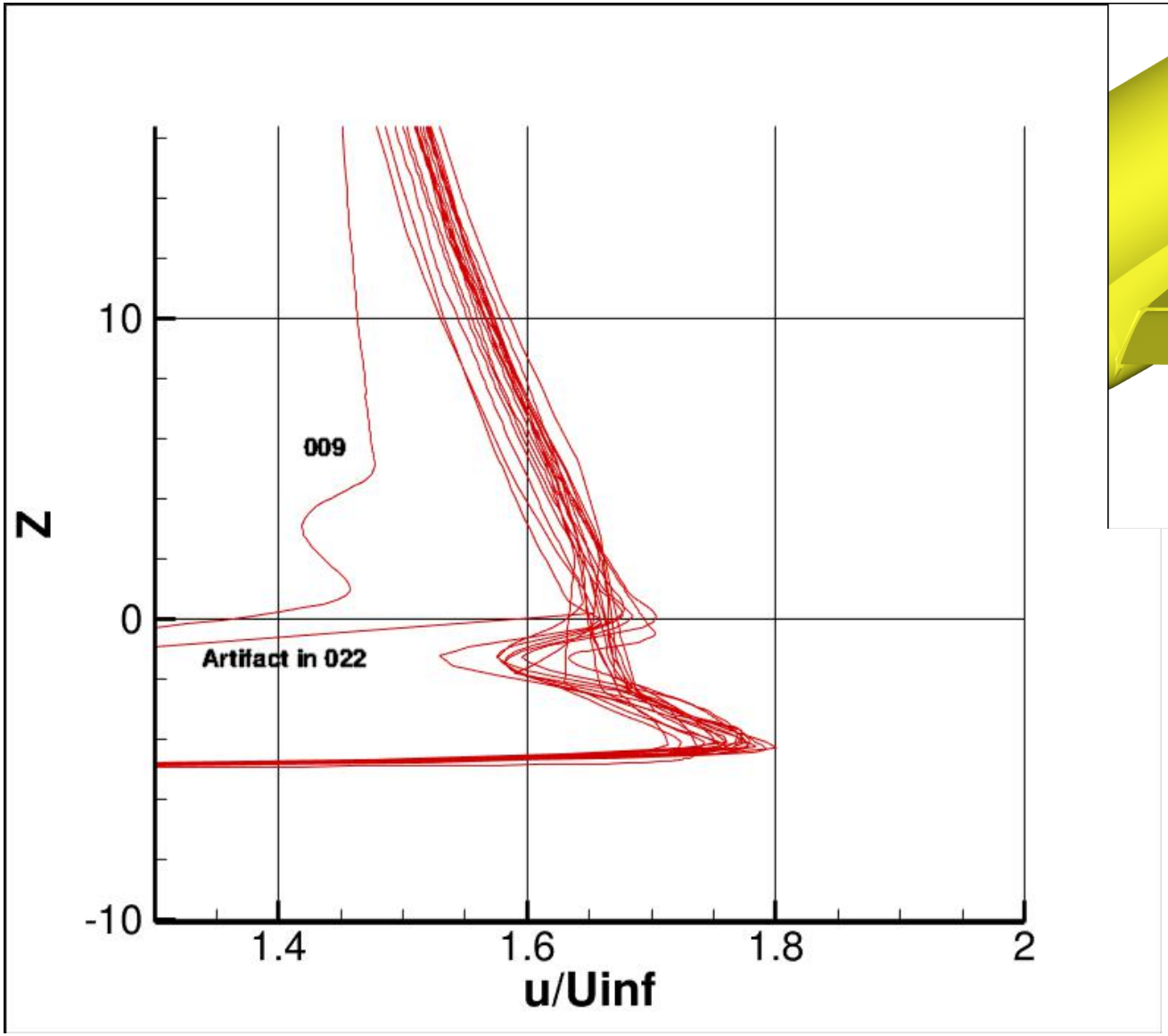


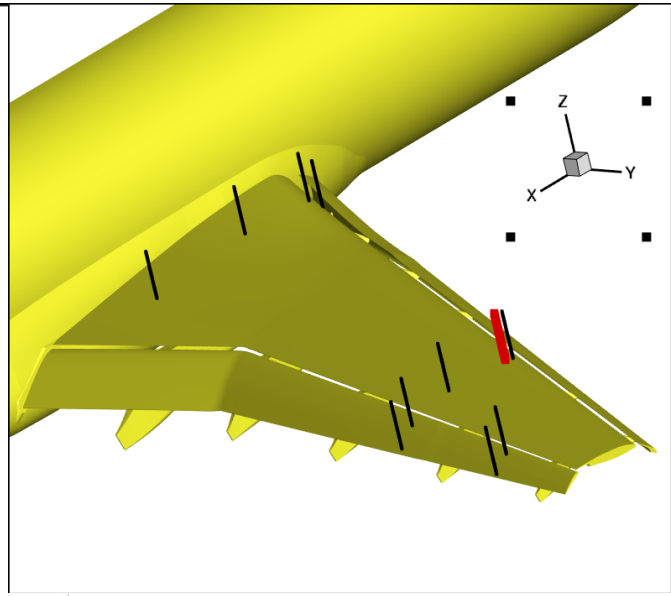
Case 1 Velocity, AoA=7, 2B1



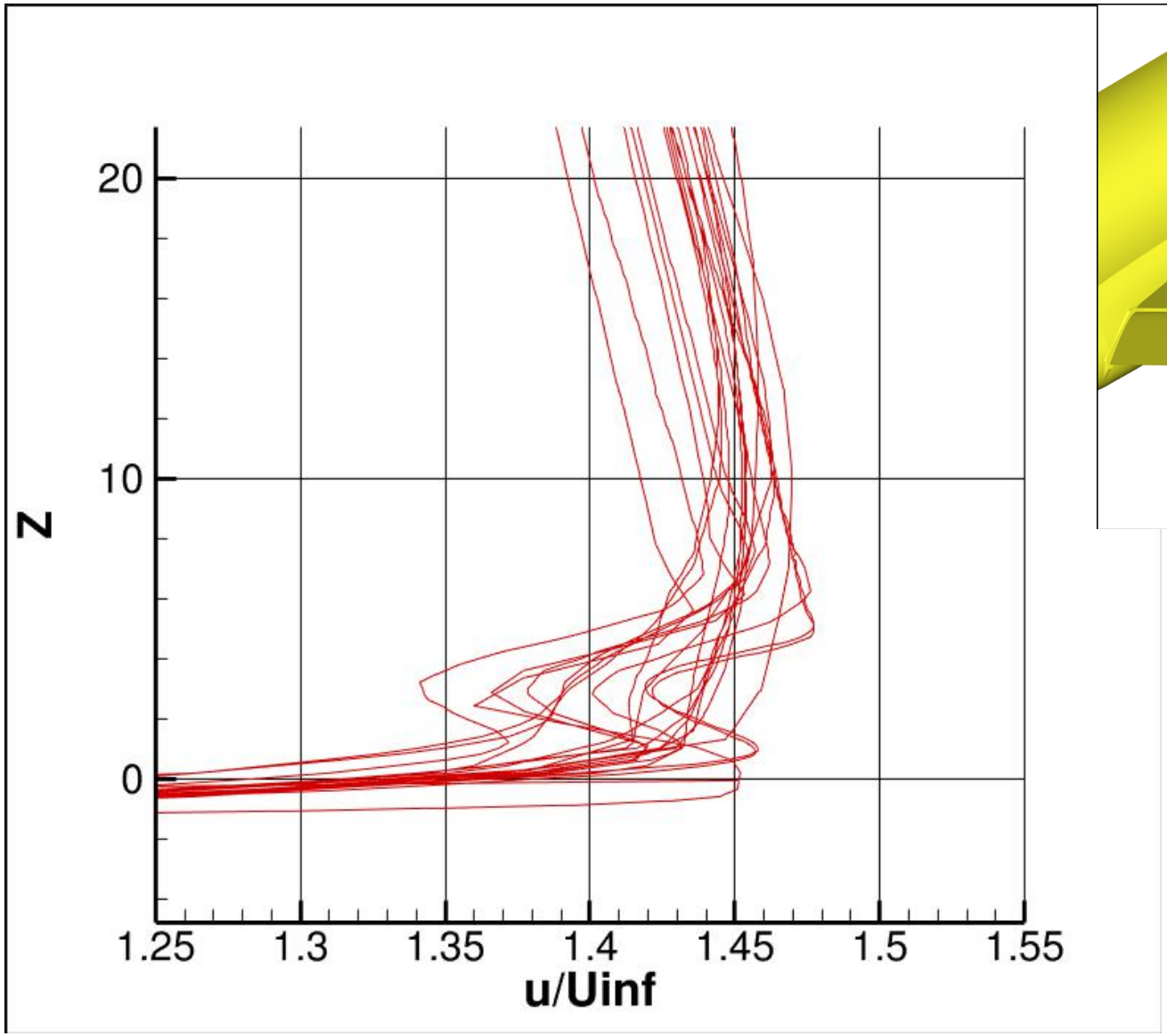


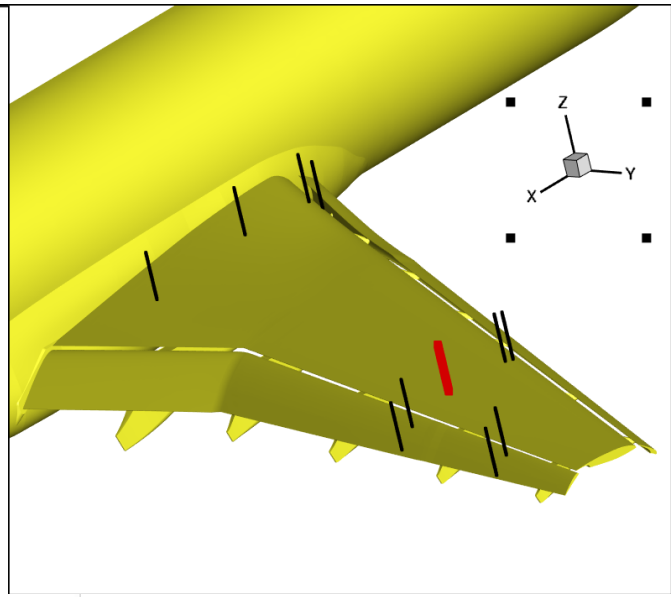
Case 1 Velocity, AoA=7, 2B2



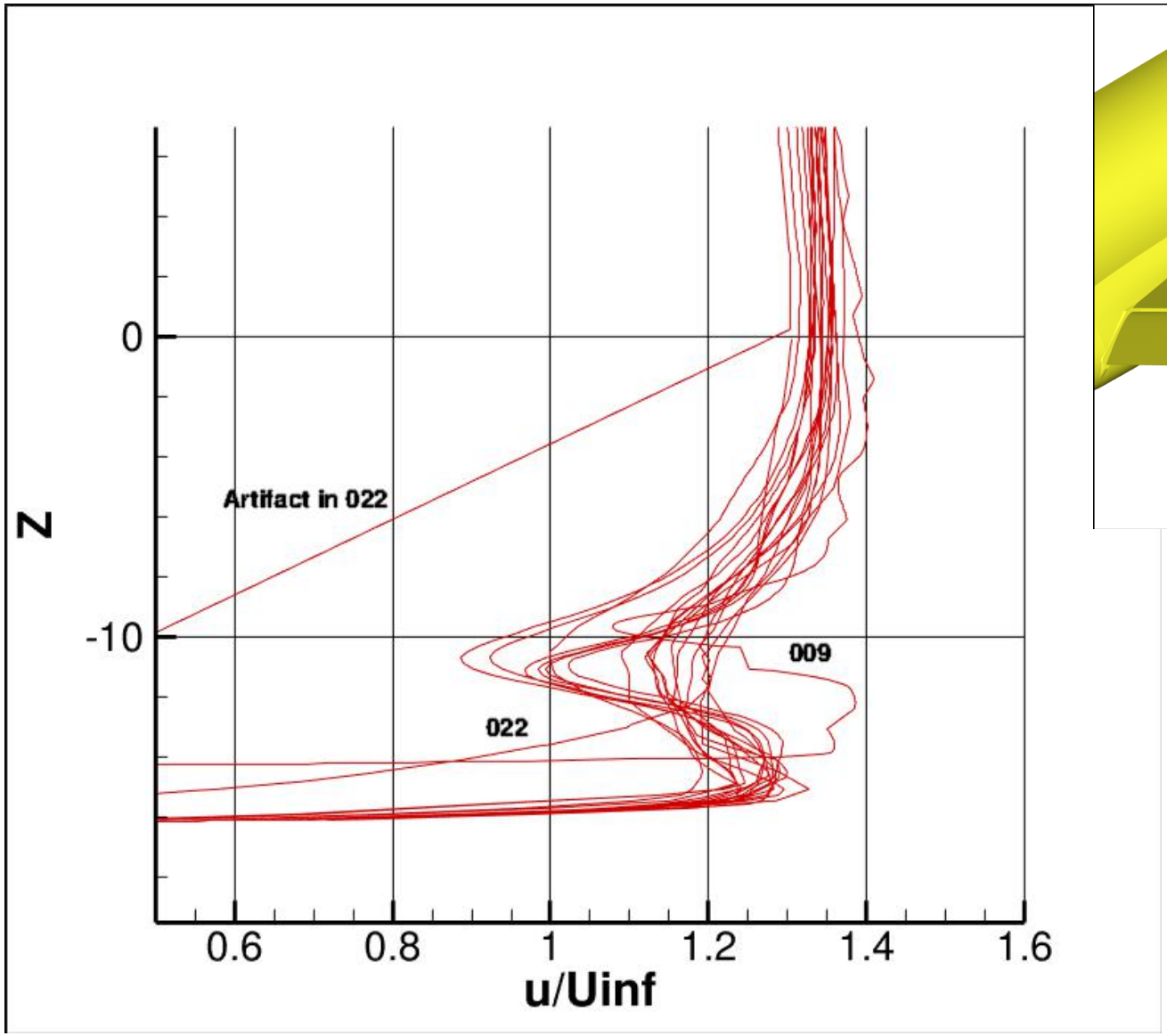


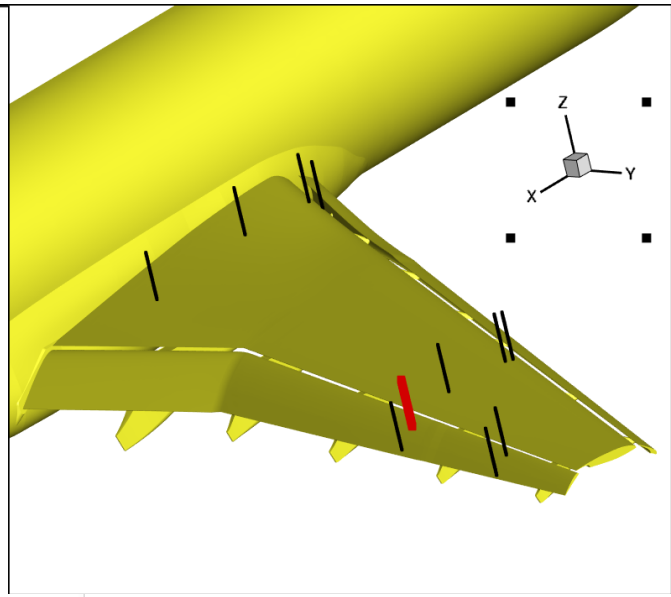
Case 1 Velocity, AoA=7, 2D1



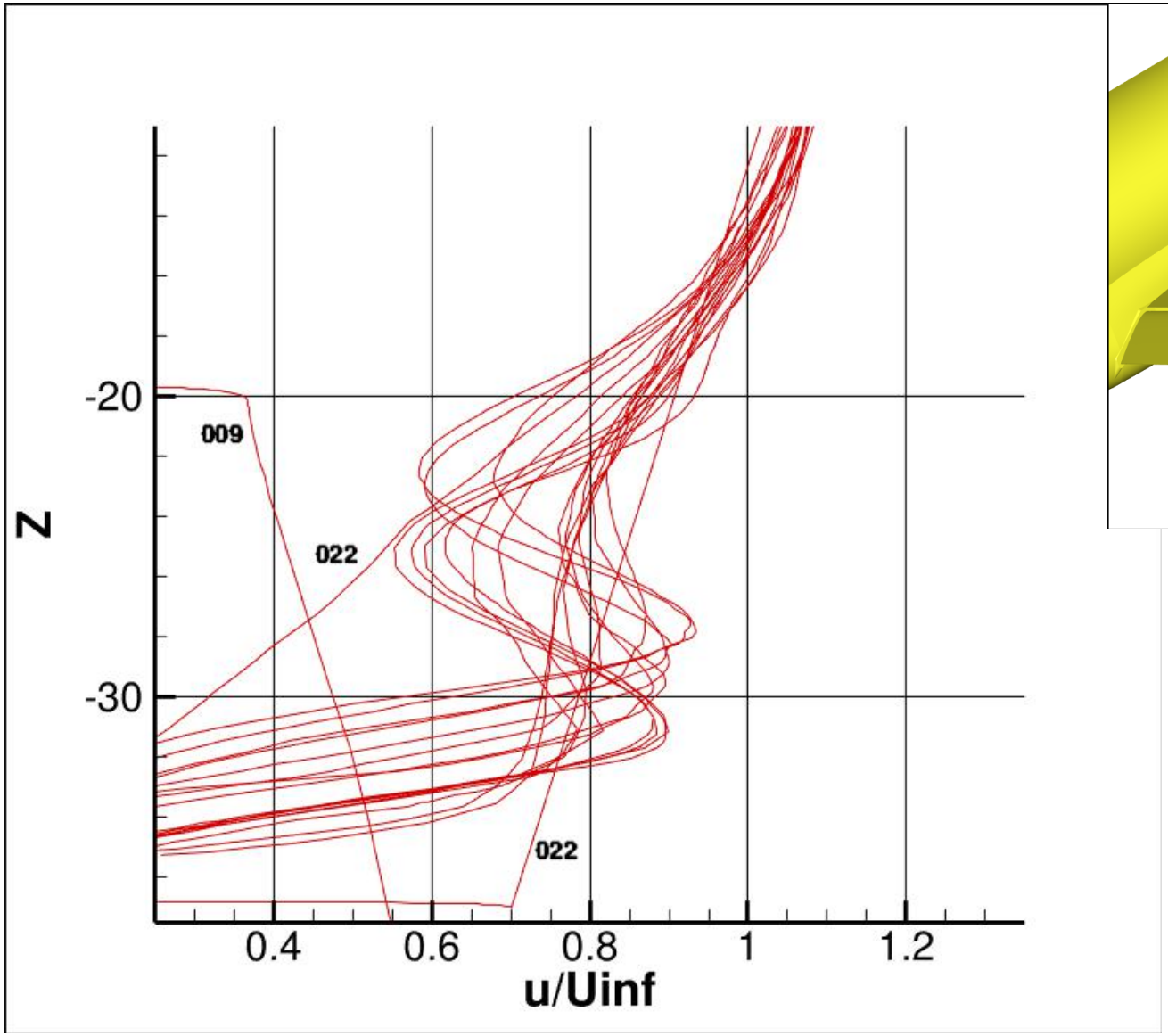


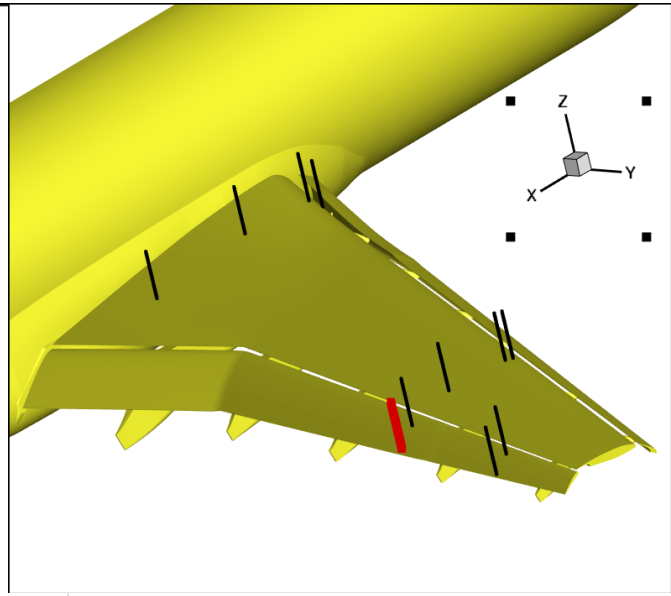
Case 1 Velocity, AoA=7, 2E1



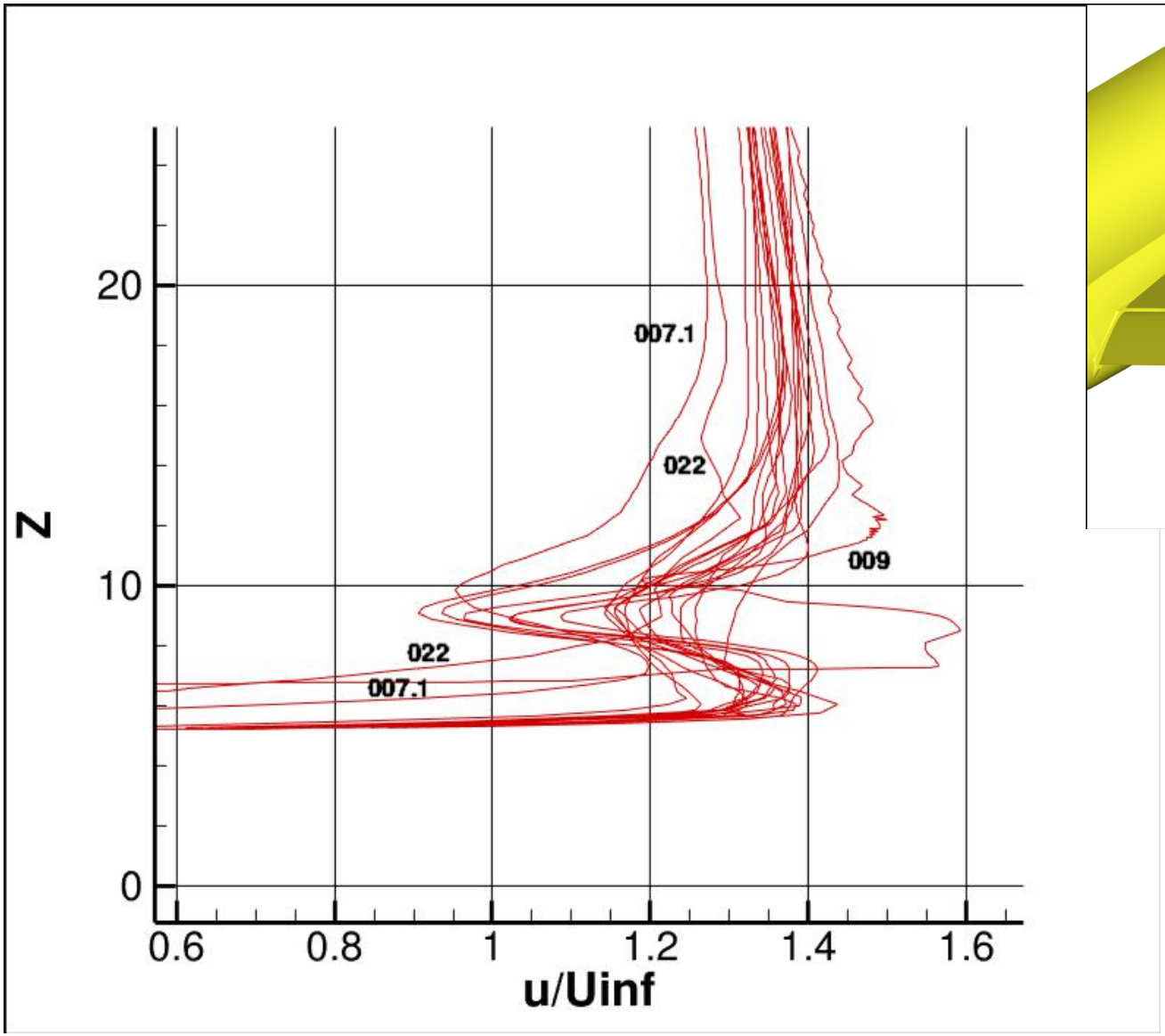


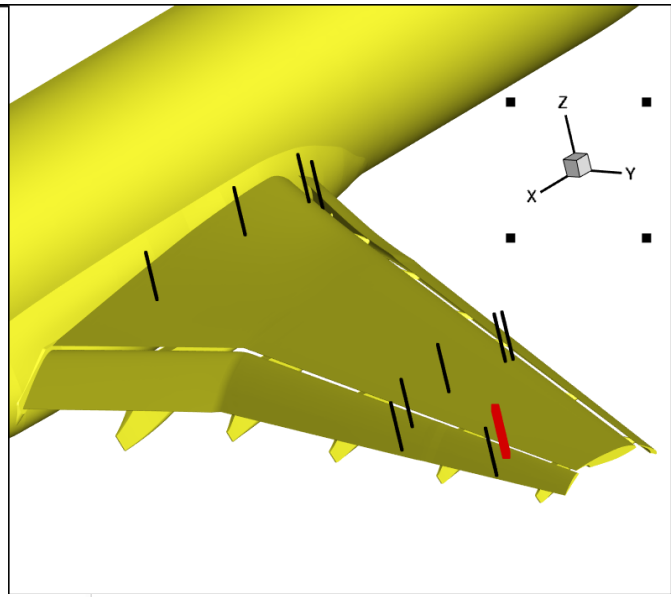
Case 1 Velocity, AoA=7, 2E2



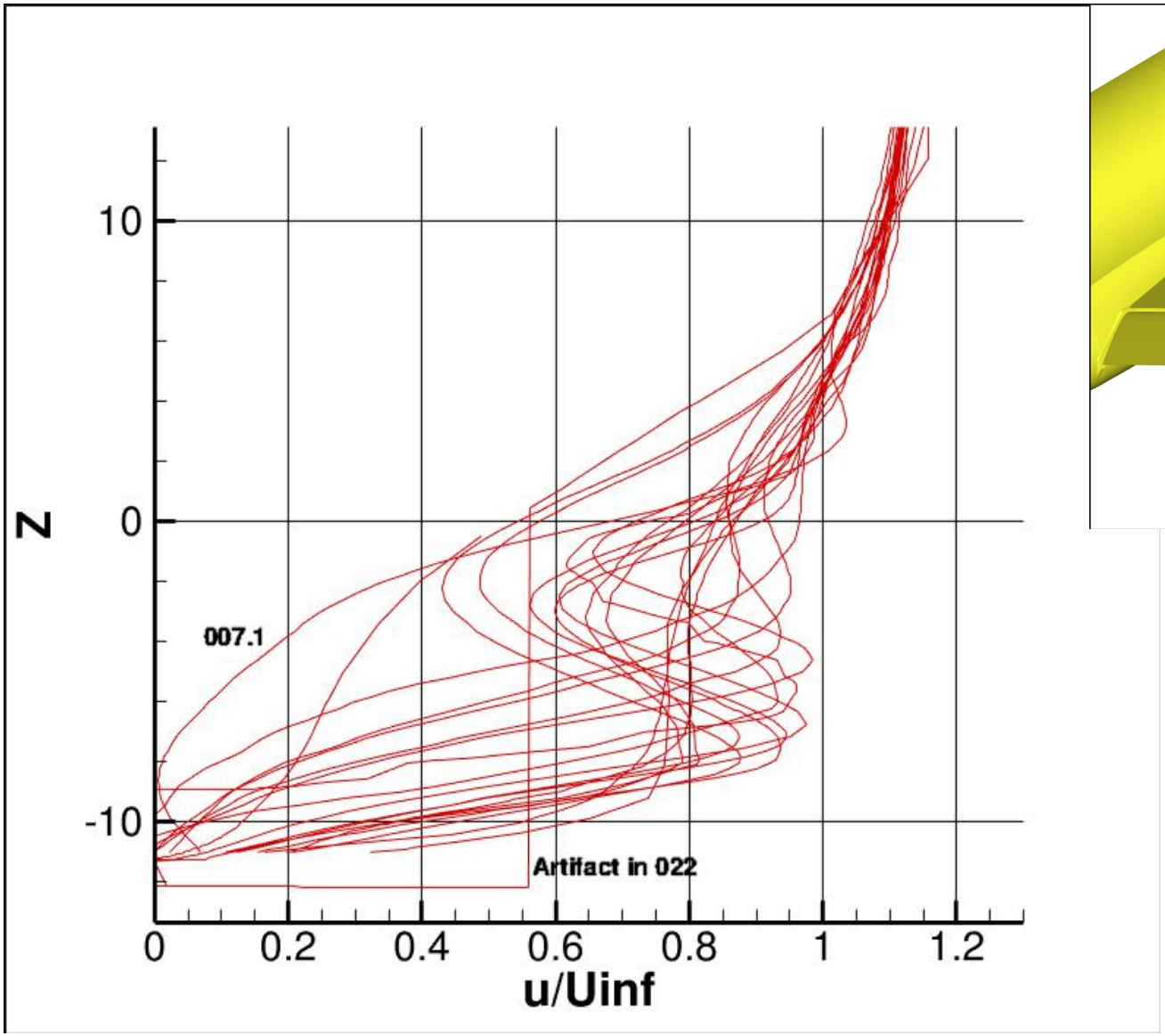


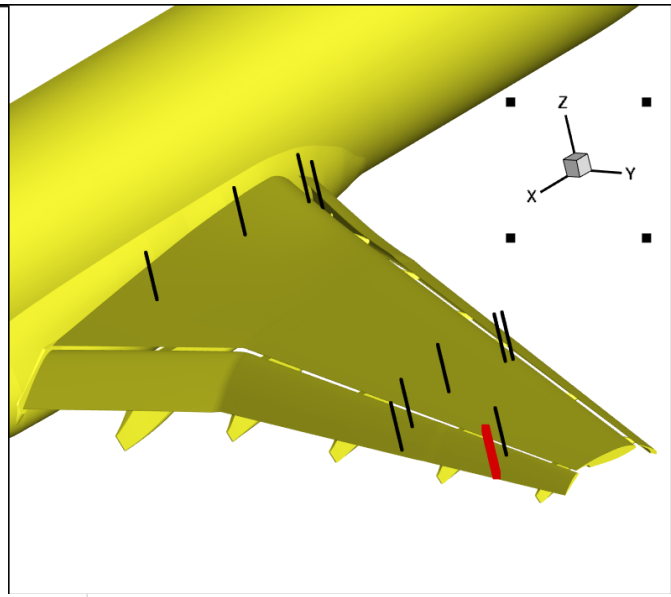
Case 1 Velocity, AoA=7, 3E1



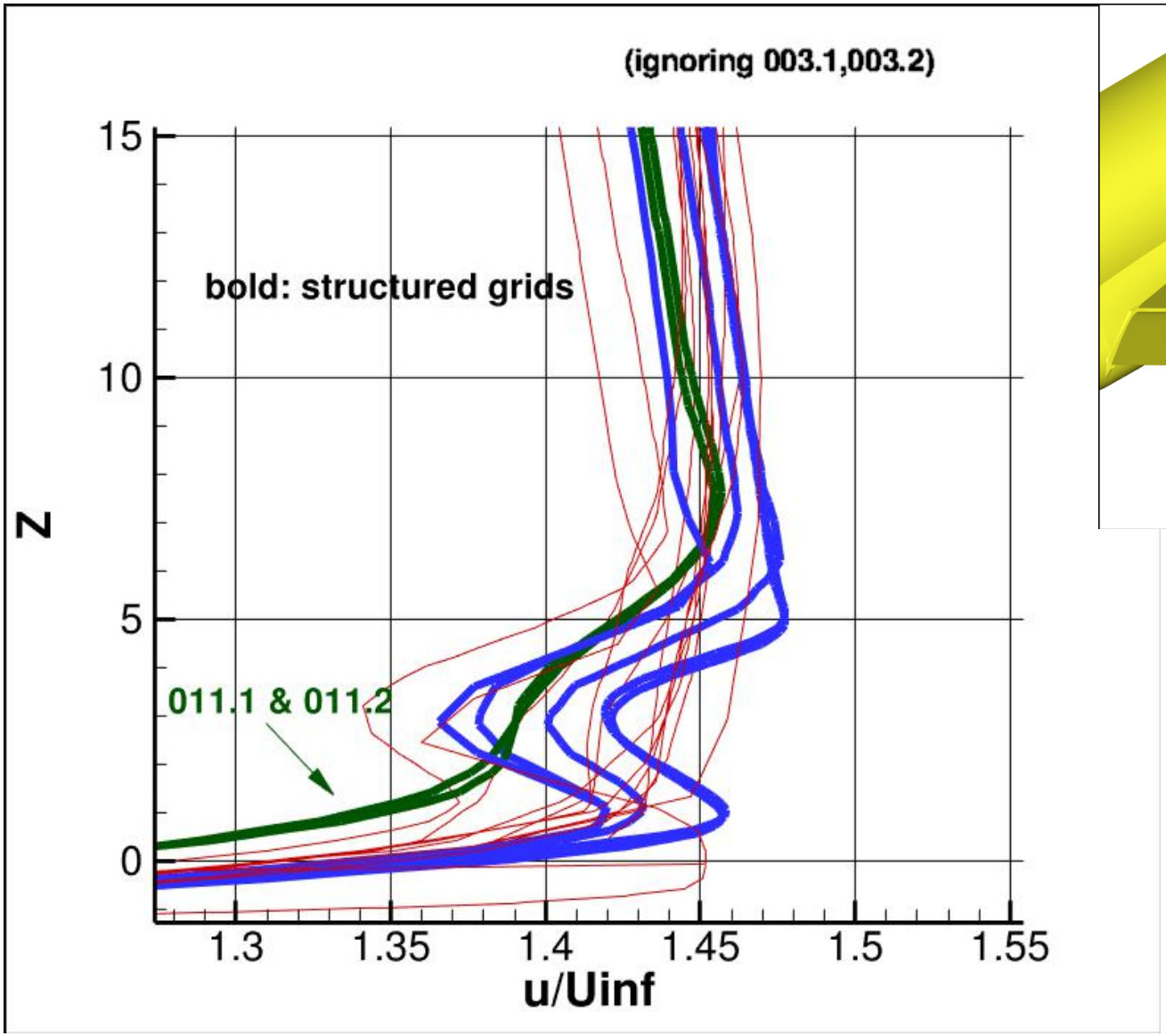


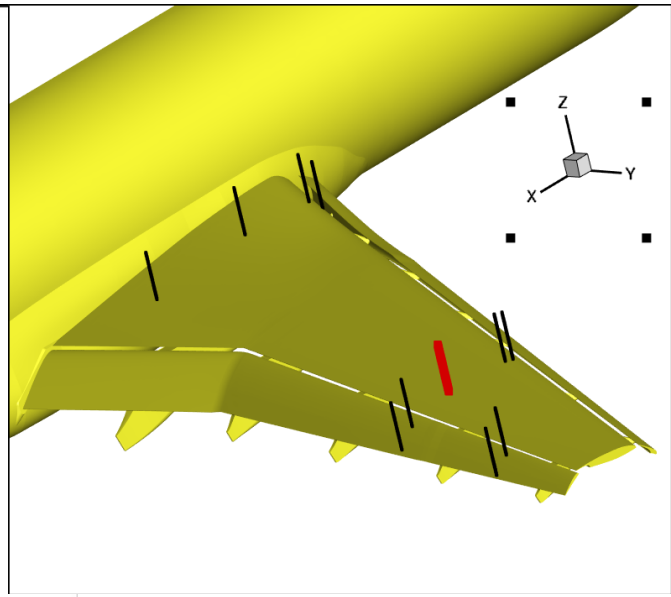
Case 1 Velocity, AoA=7, 3E2



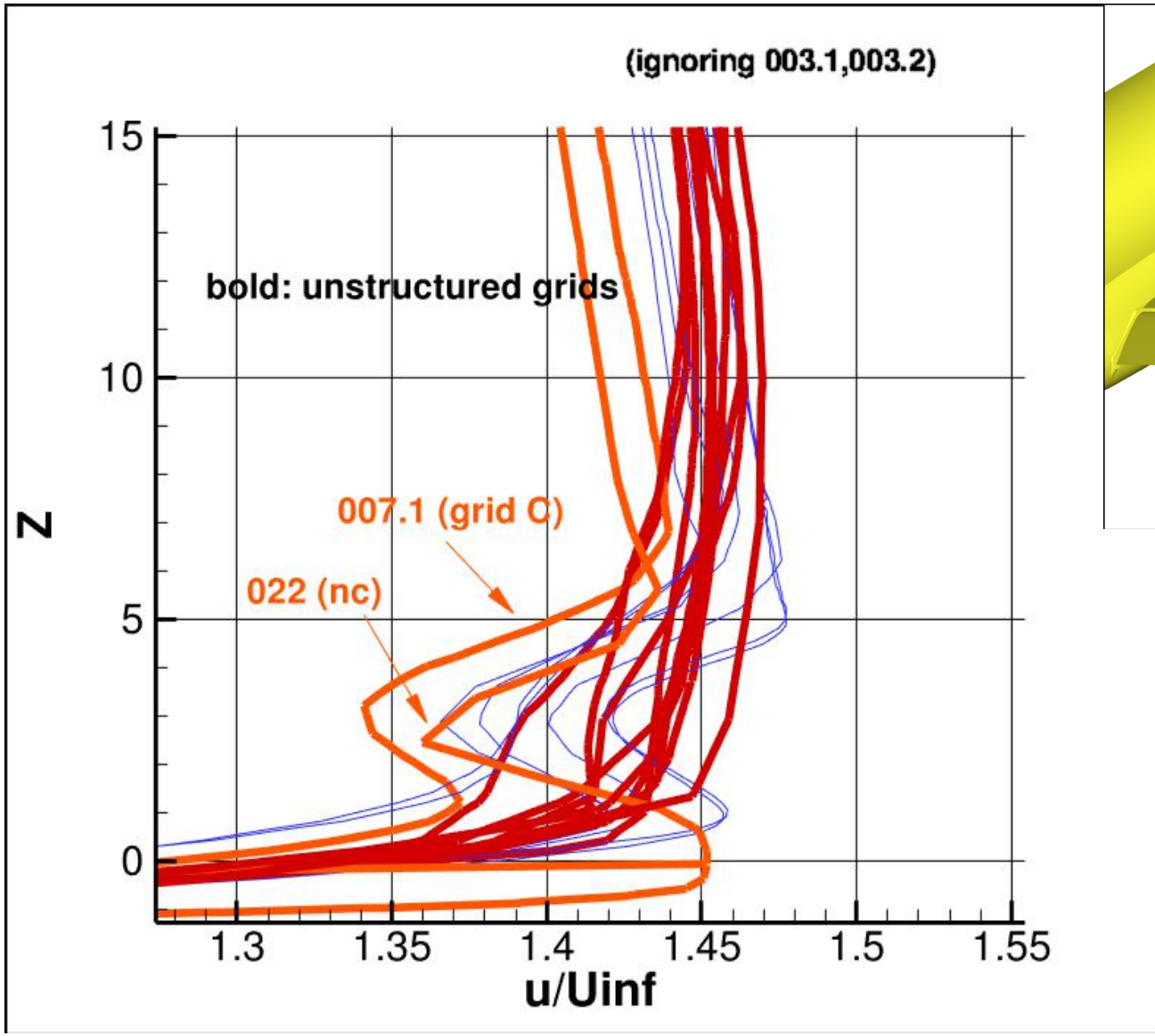


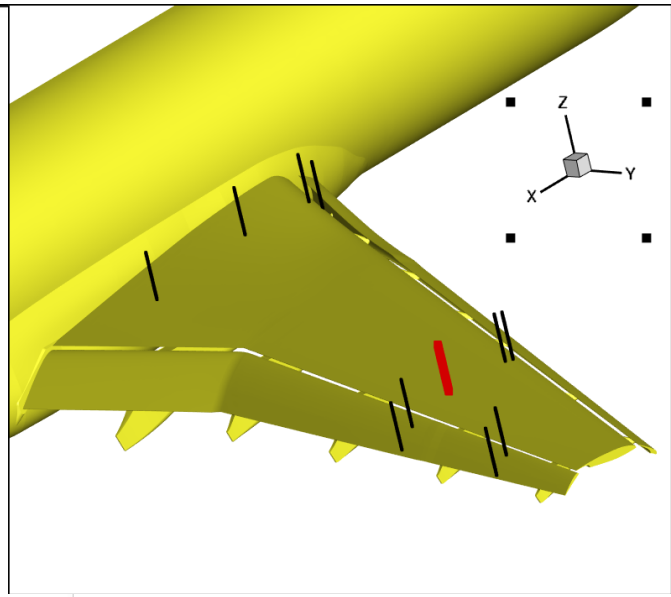
Grid type effect on velocity, AoA=7, 2D1



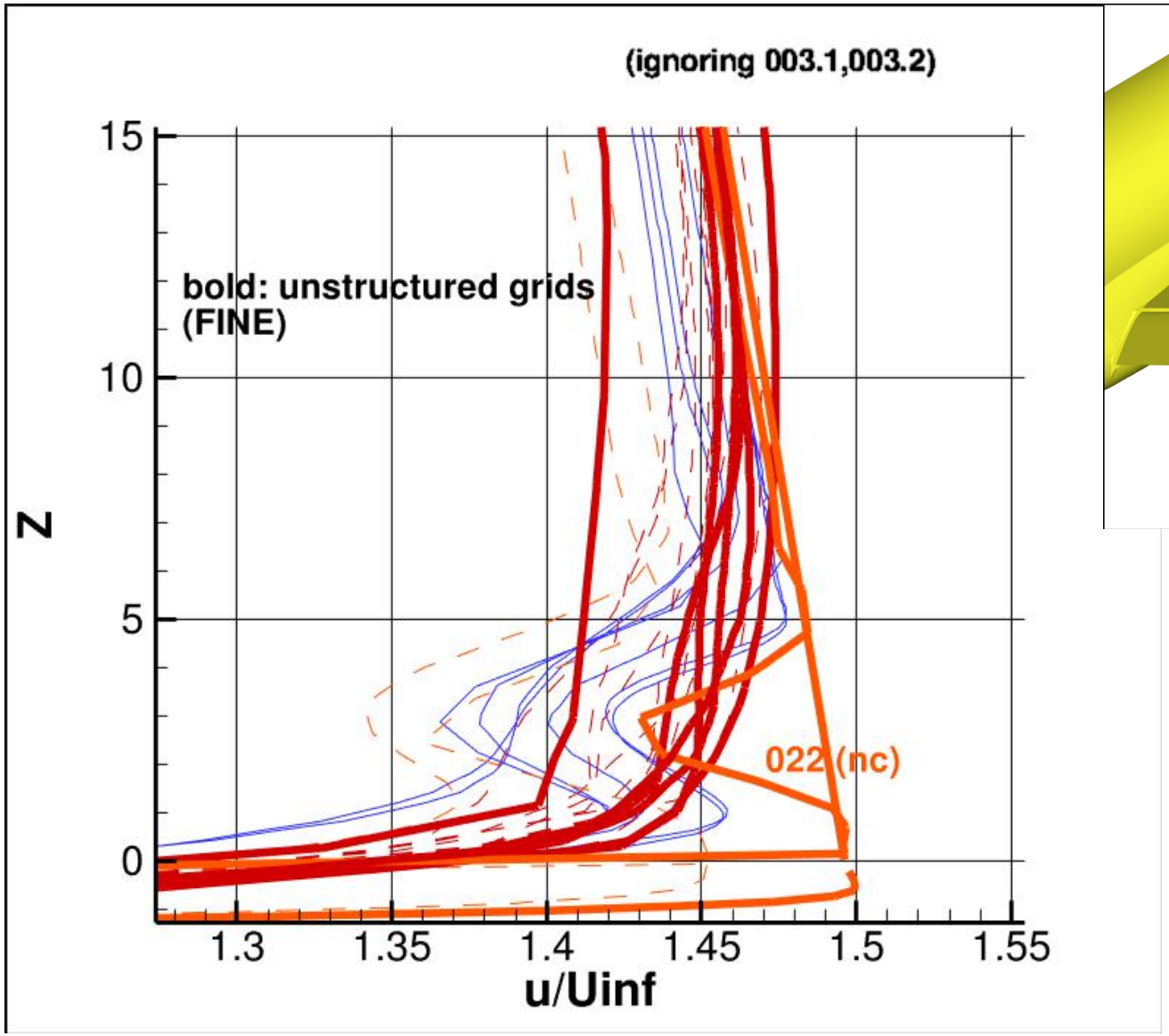


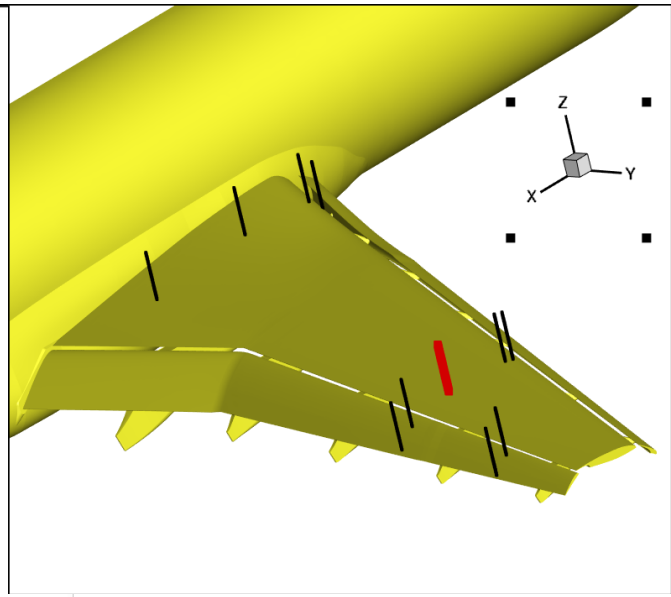
Grid type effect on velocity, AoA=7, 2D1





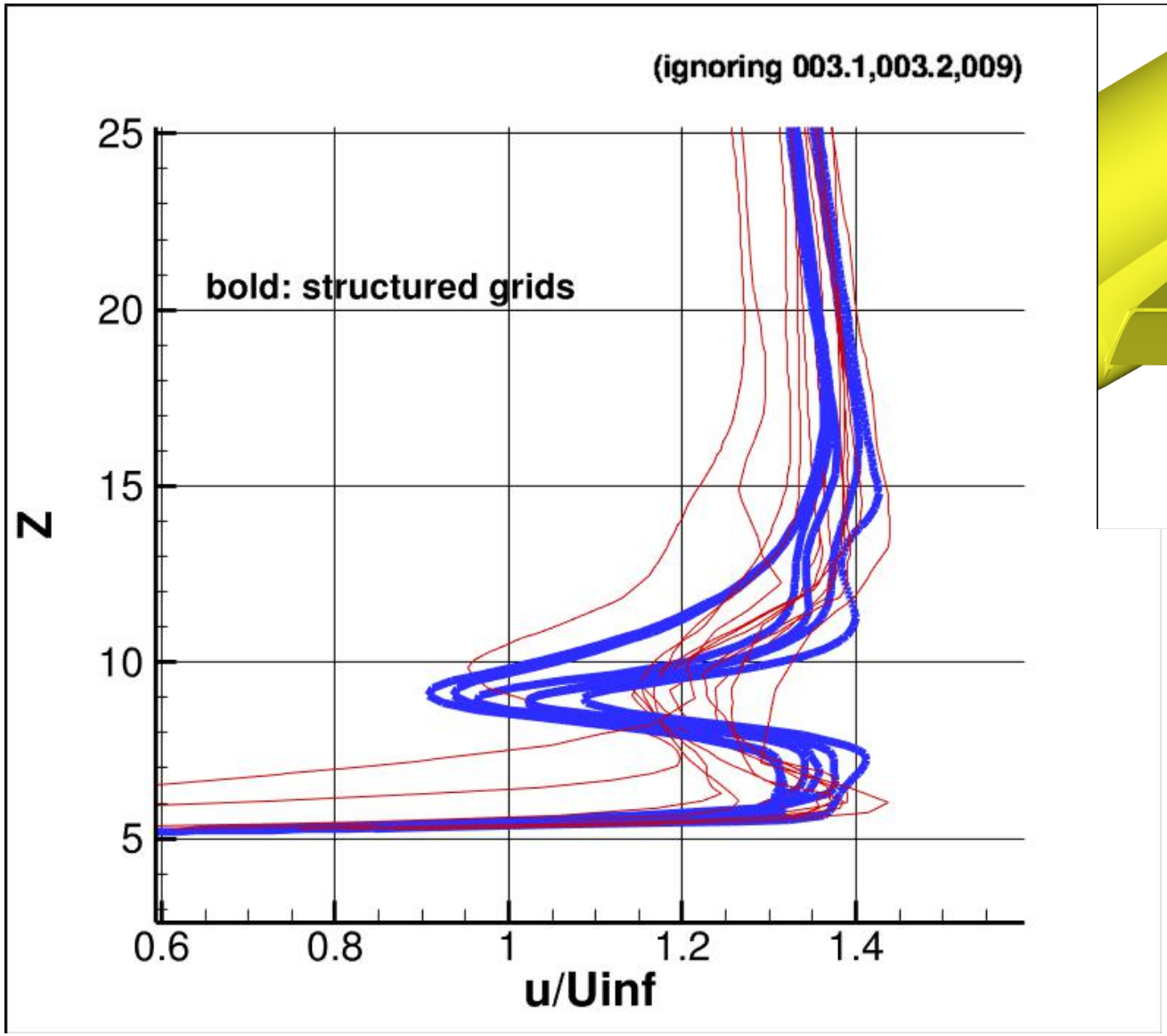
Grid type effect on velocity, AoA=7, 2D1

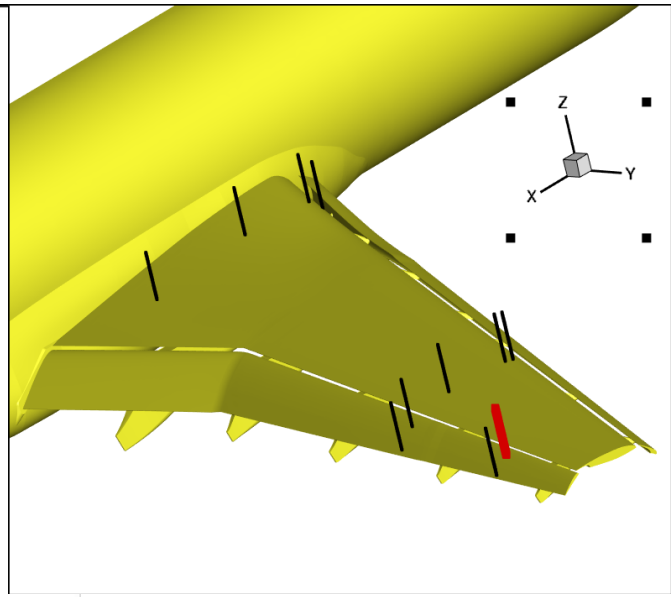




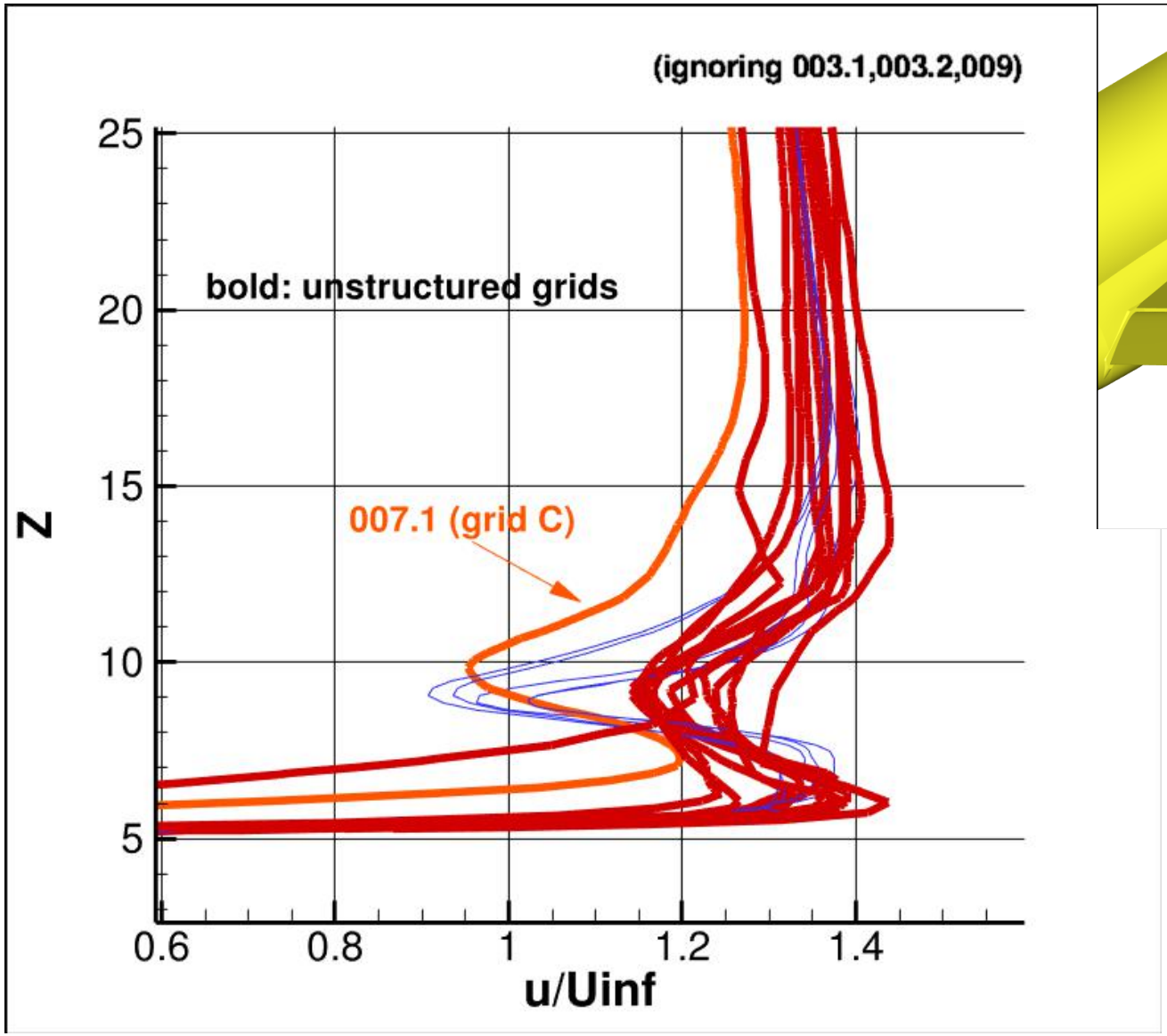
Most FINE unstructured grids still do not resolve wake

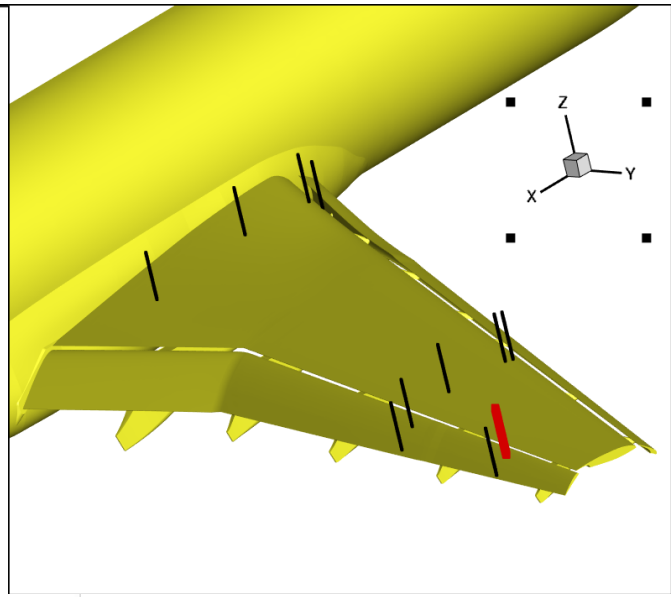
Grid type effect on velocity, AoA=7, 3E1





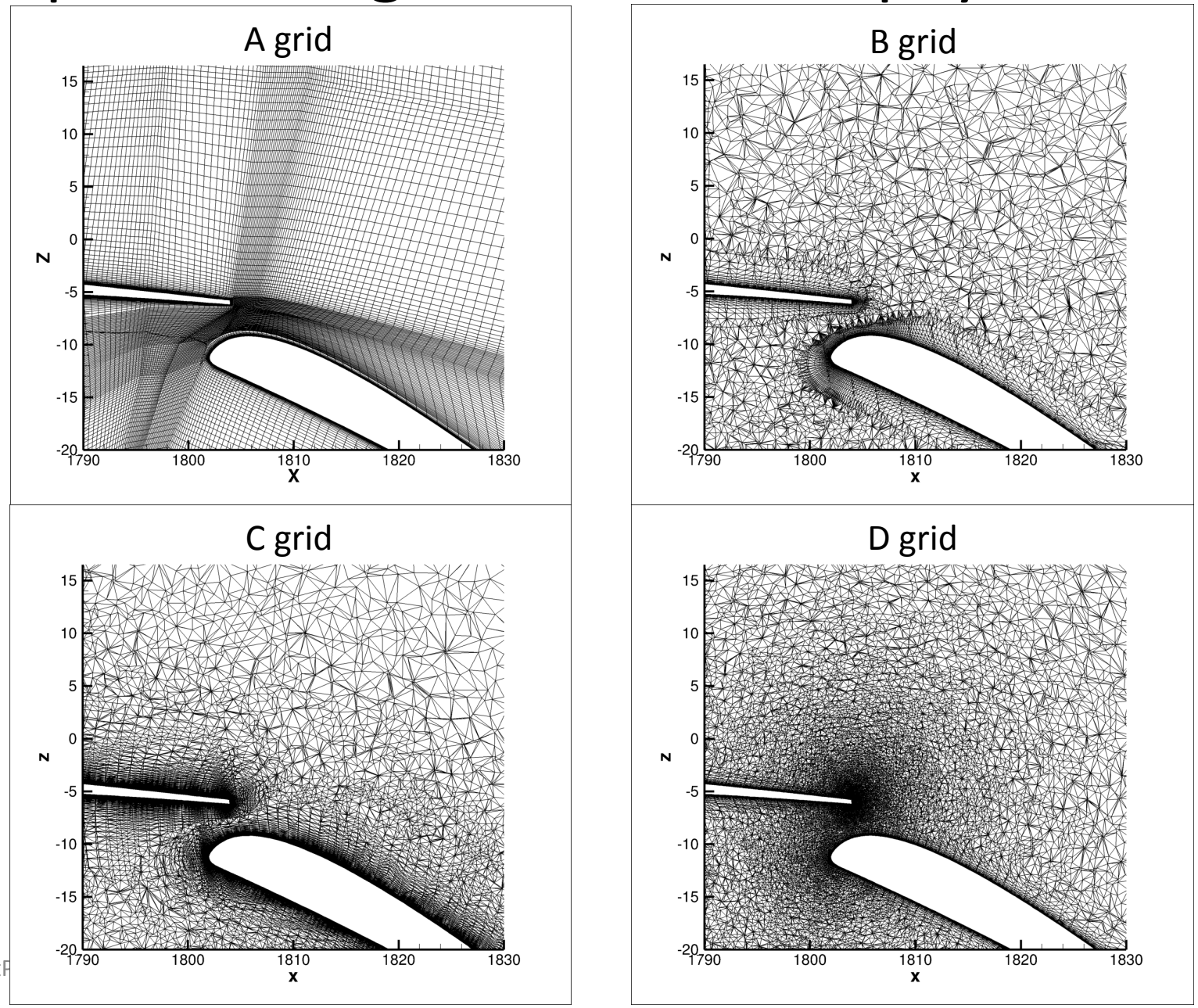
Grid type effect on velocity, AoA=7, 3E1



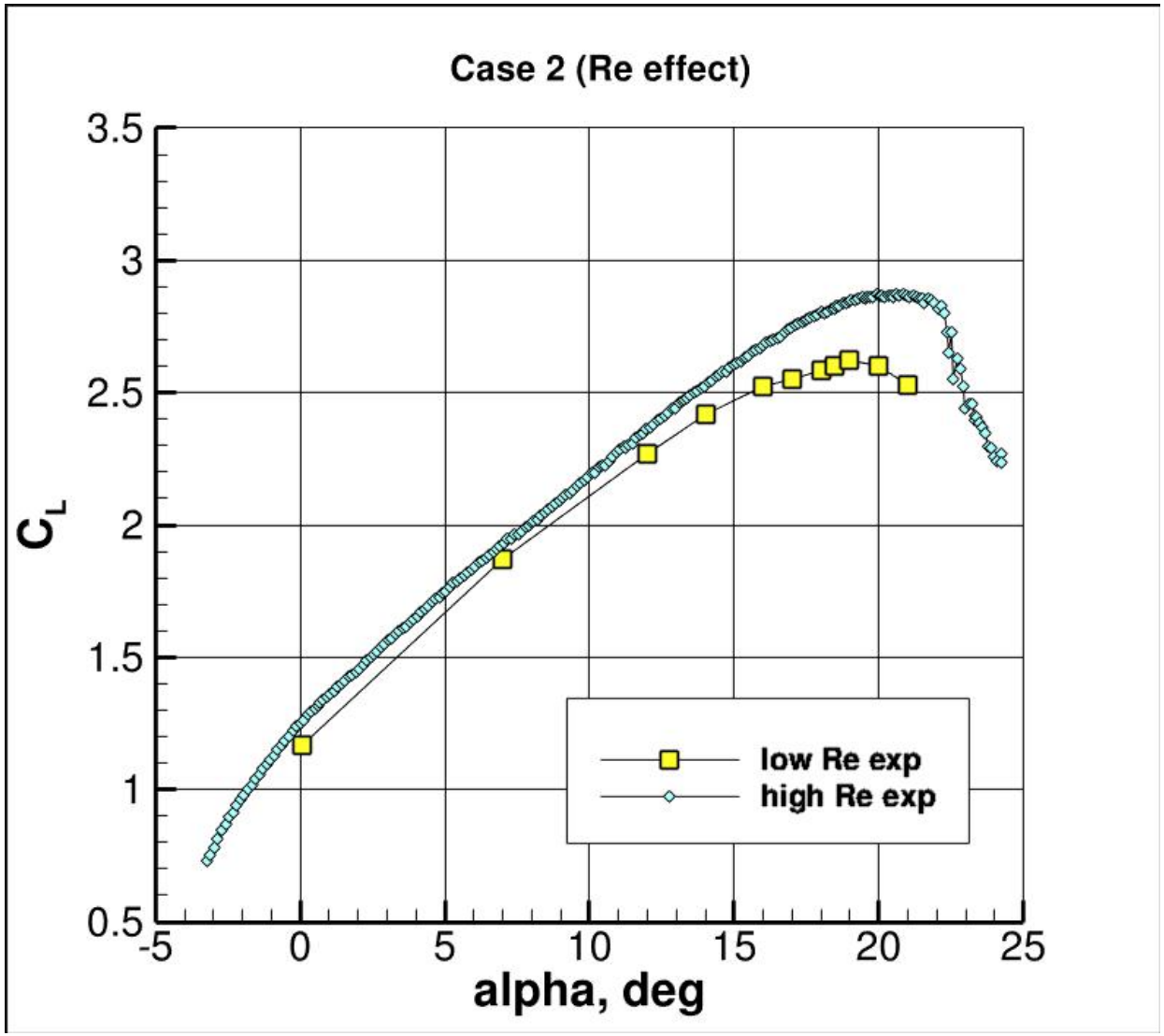


Comparison of grid cuts over flap, y=979.596

Fine grids

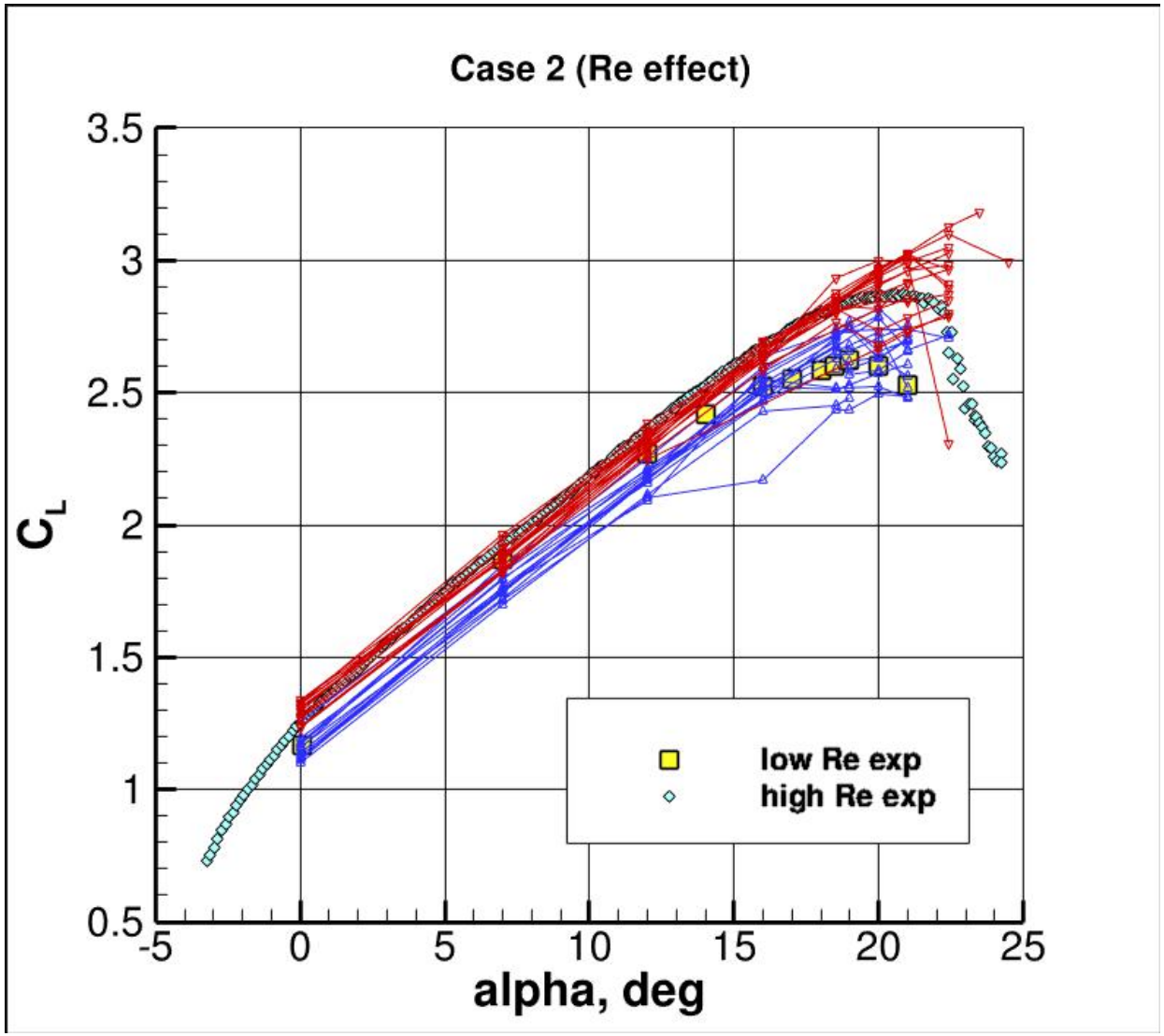


Case 2 Reynolds number effect



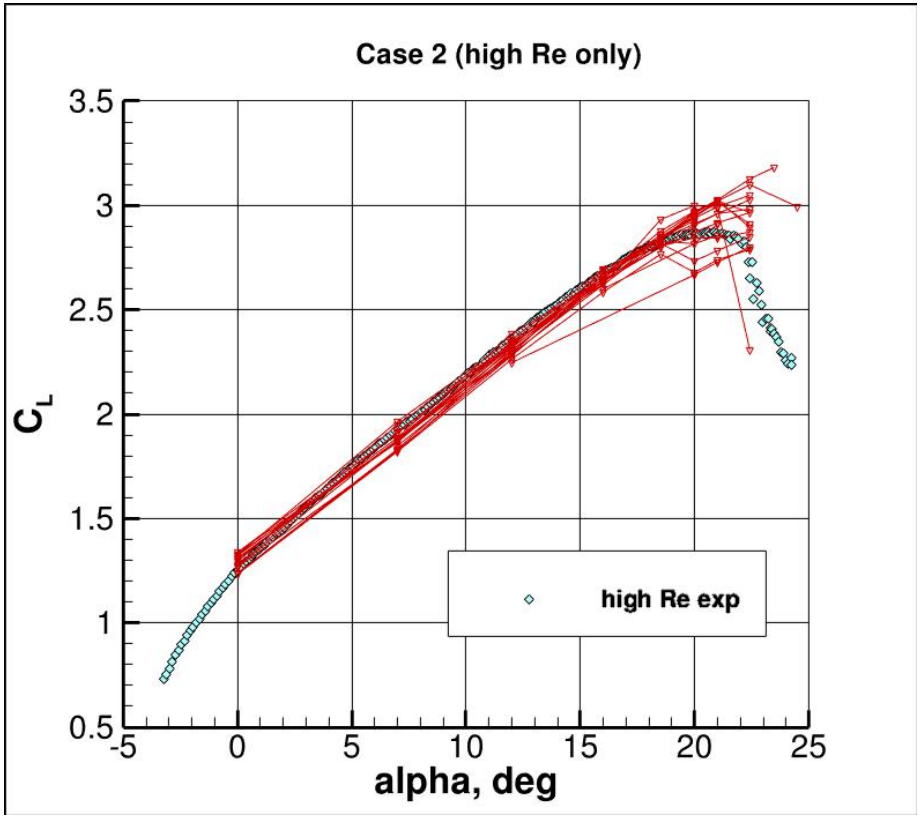
Case 2 Reynolds number effect

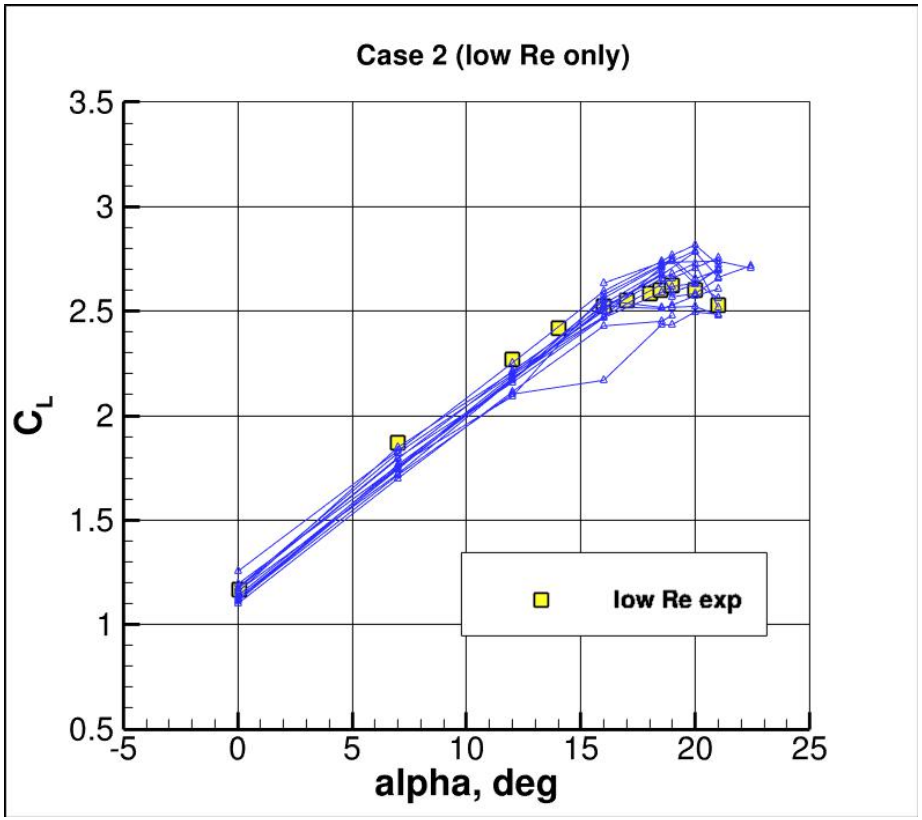
Including brackets



Case 2 Reynolds number effect

Including brackets

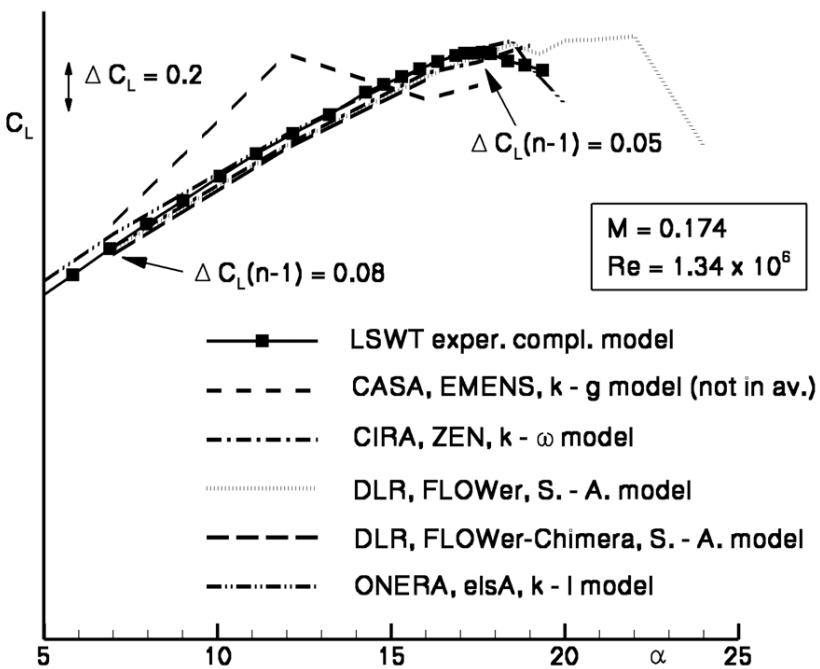


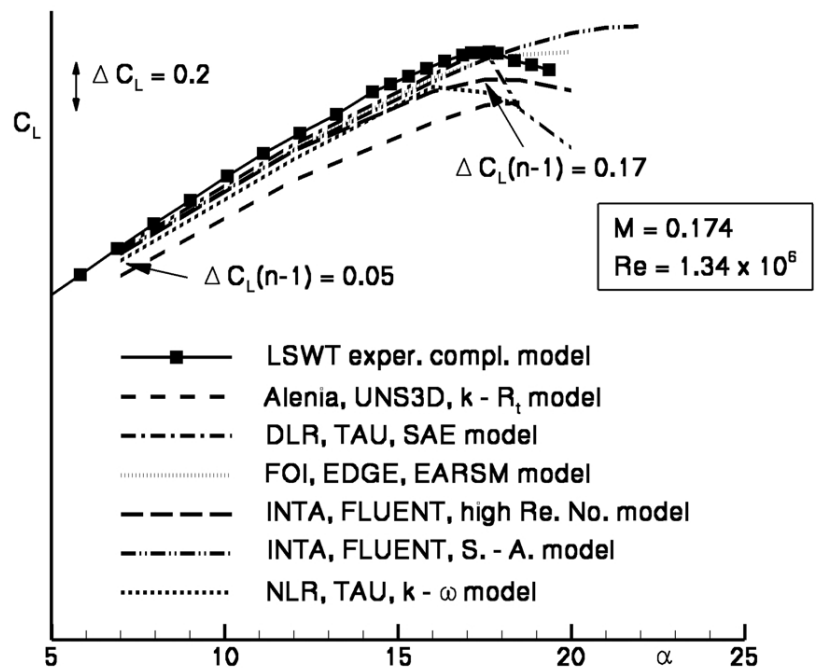


Collectively, how well is CFD capturing the stall breaks?

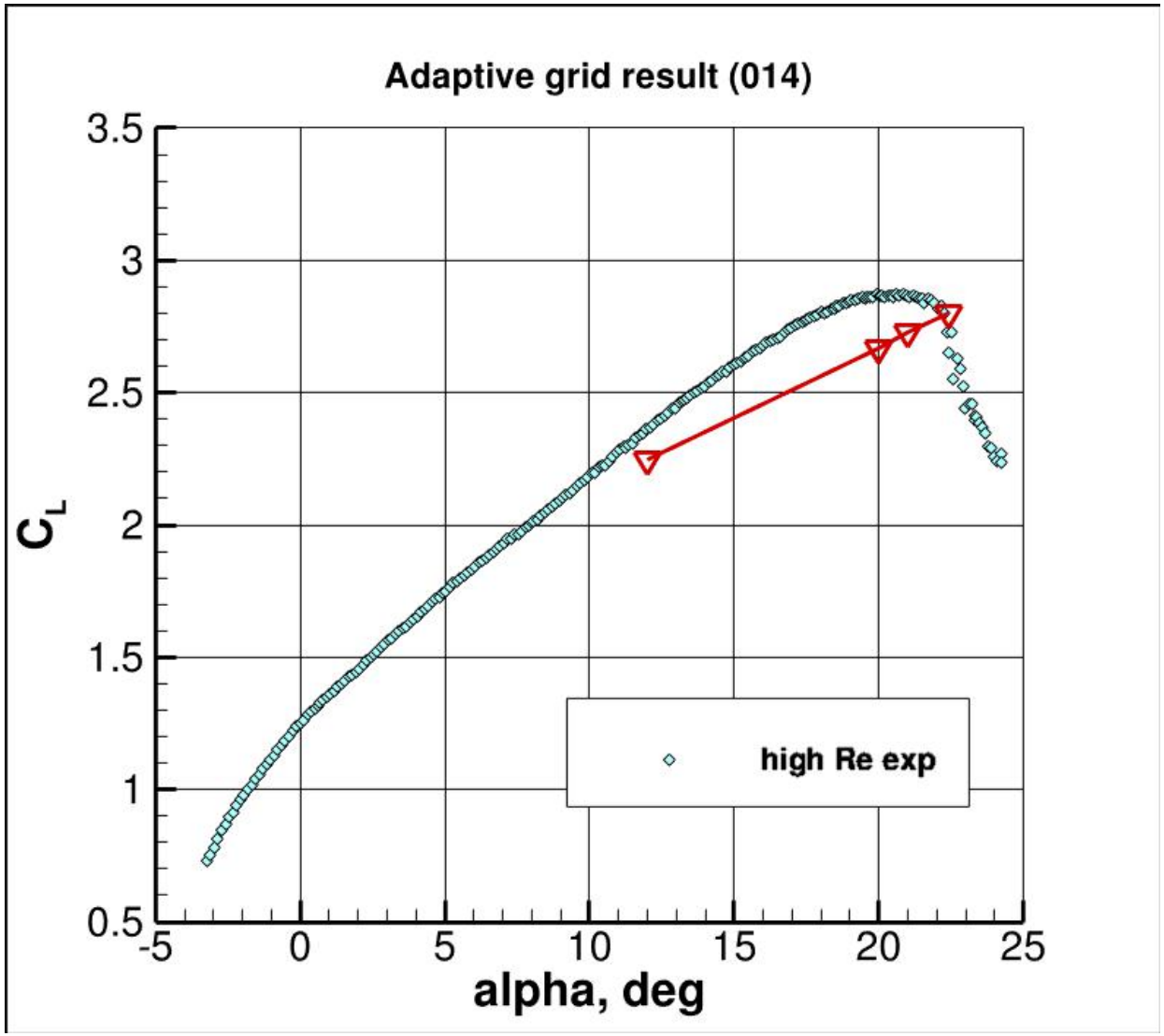
Comparison to EUROLIFT

- EUROLIFT (AIAA-2003-3794) looked at slightly different DLR F11 configuration (take-off)
  - Low Re only (1.34 million)
  - Grid sizes of order 3 million points

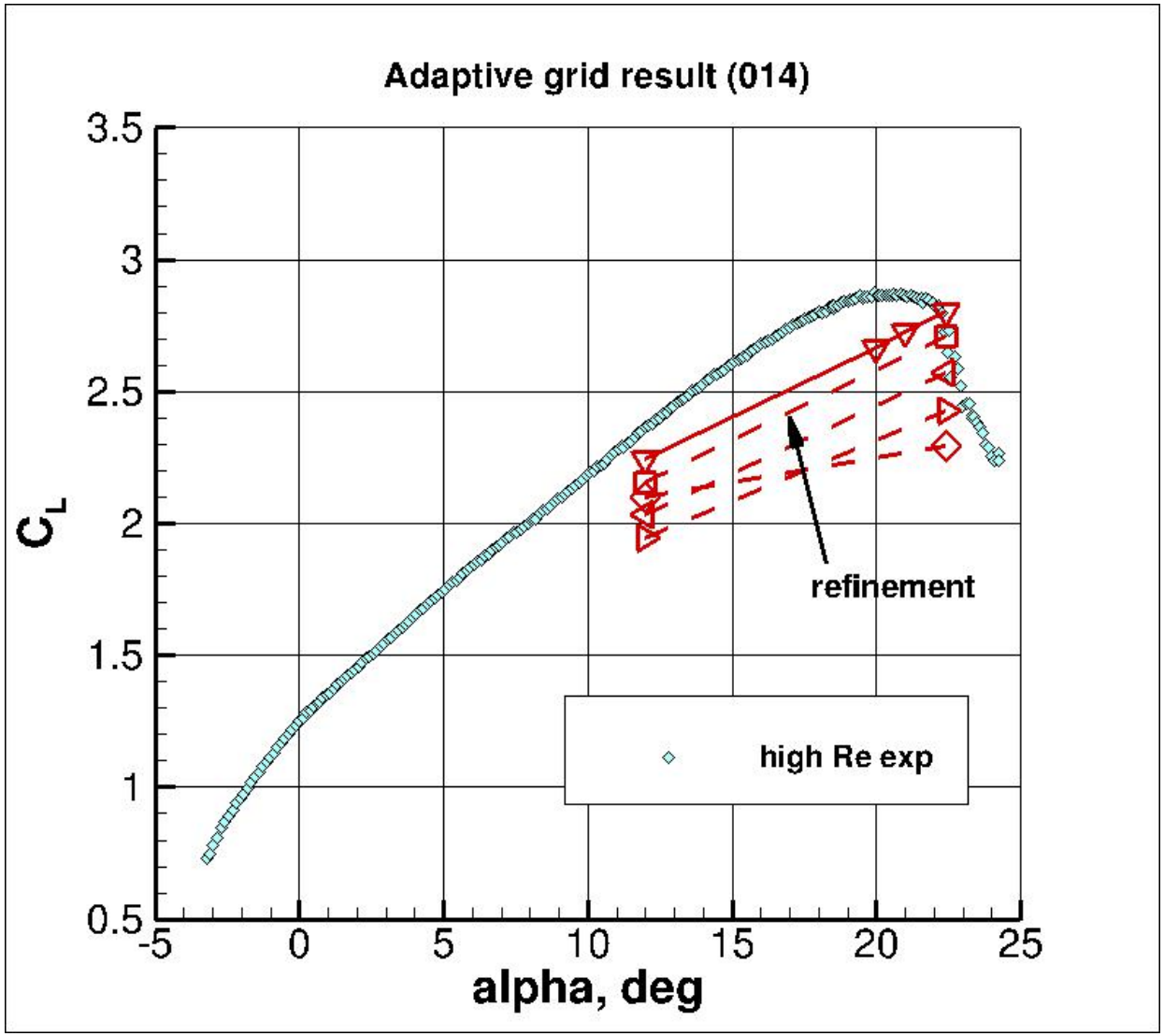




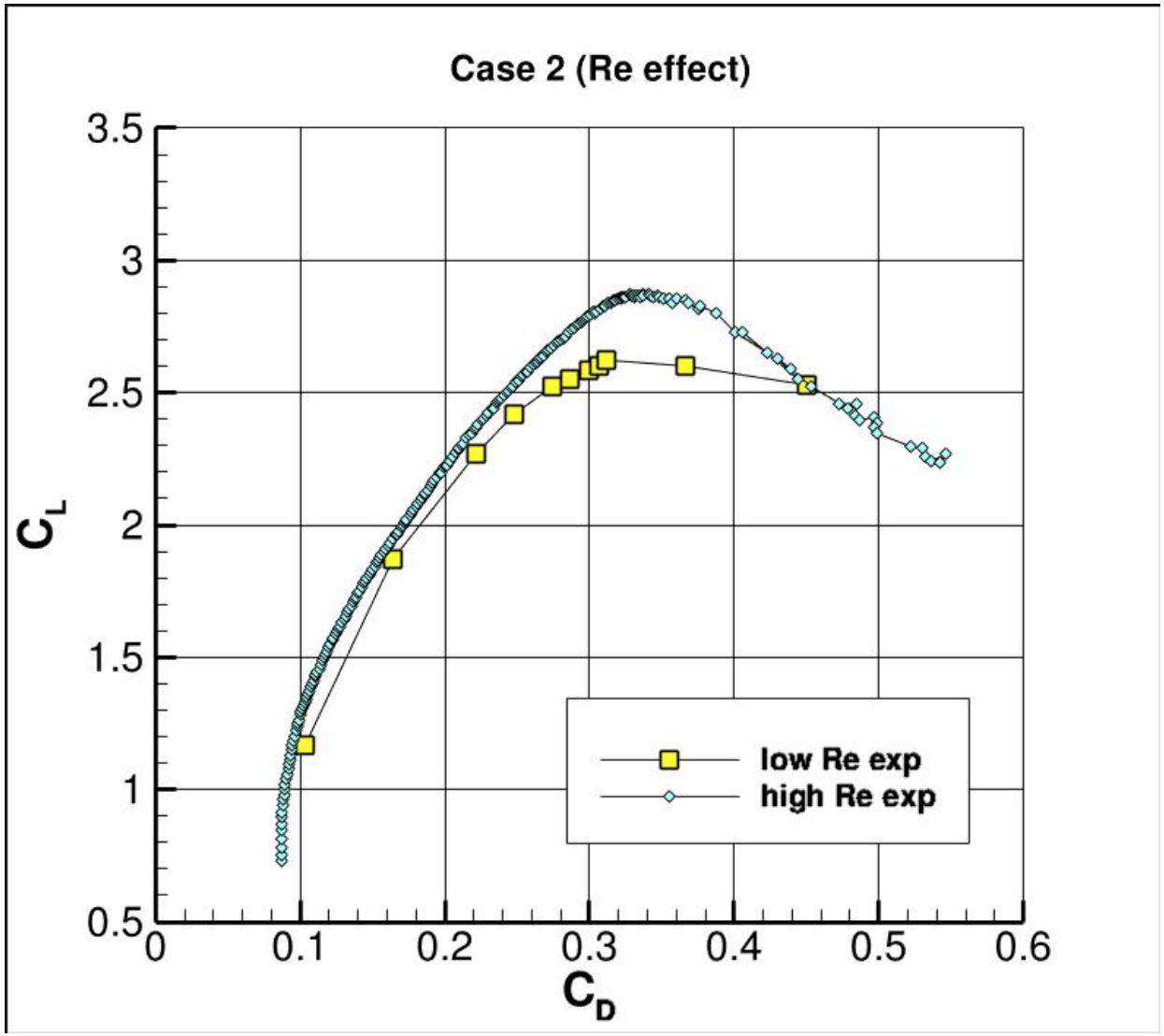
Case 2b adaptive result at high Re



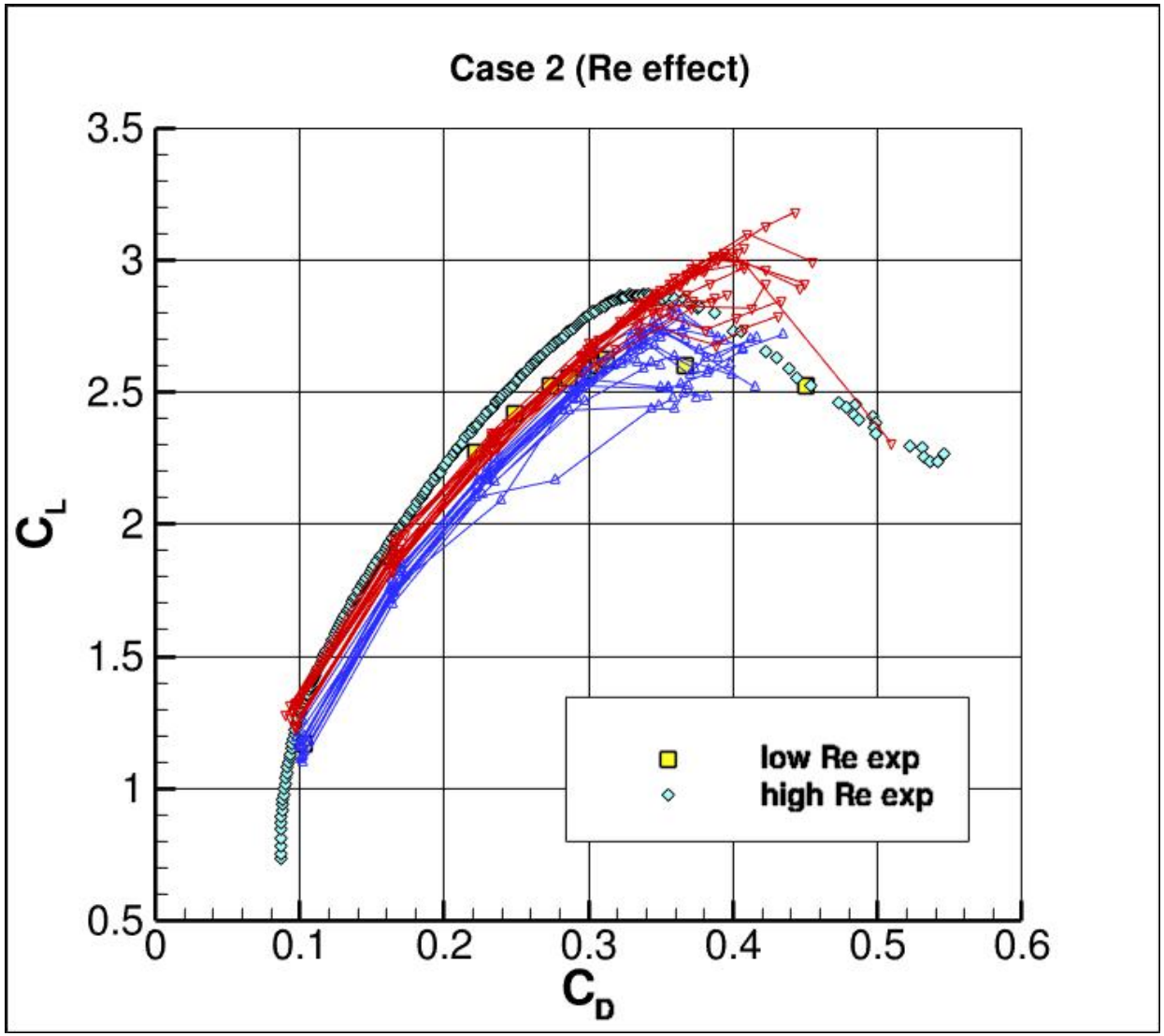
Case 2b adaptive result at high Re



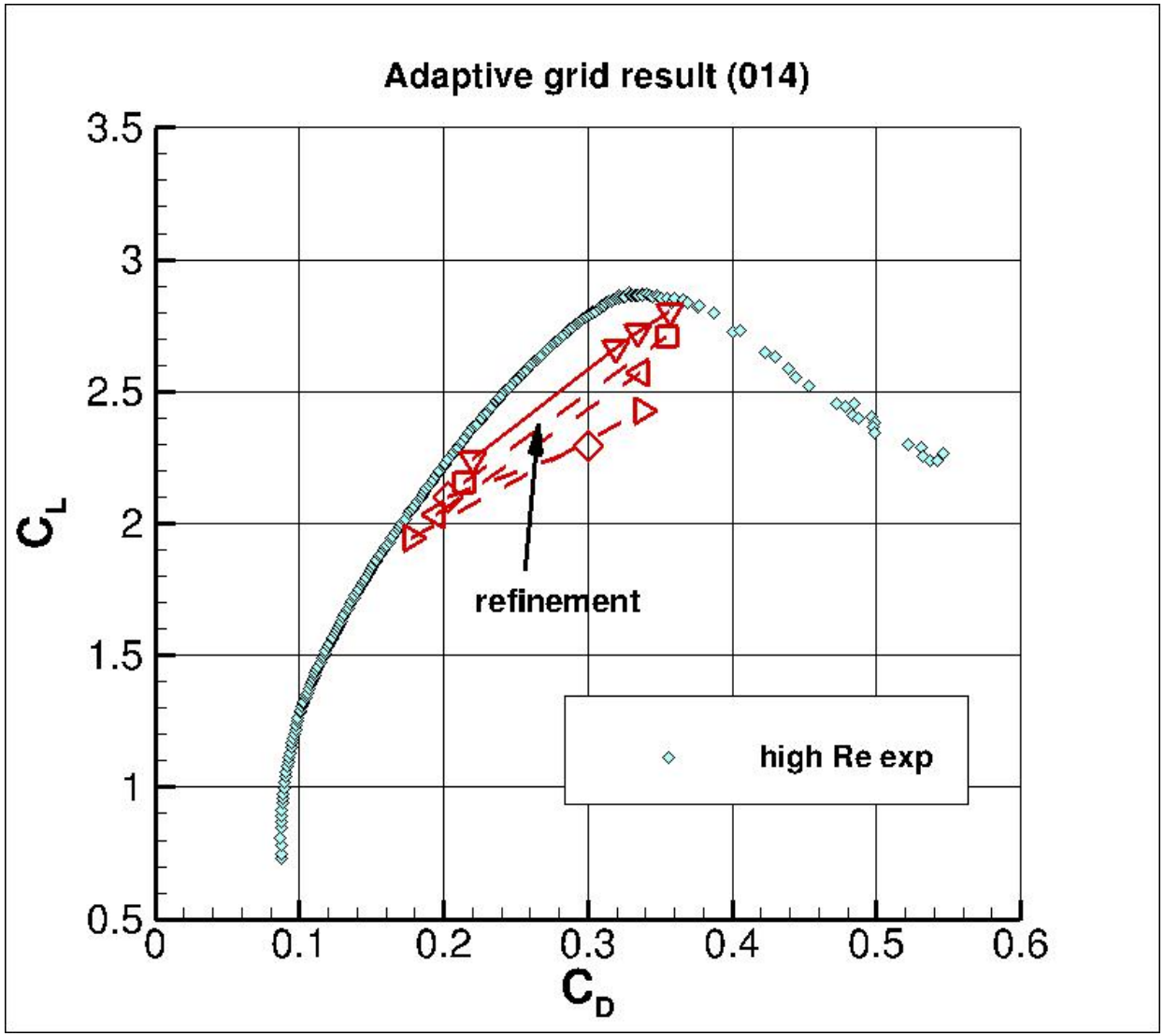
Case 2 Reynolds number effect



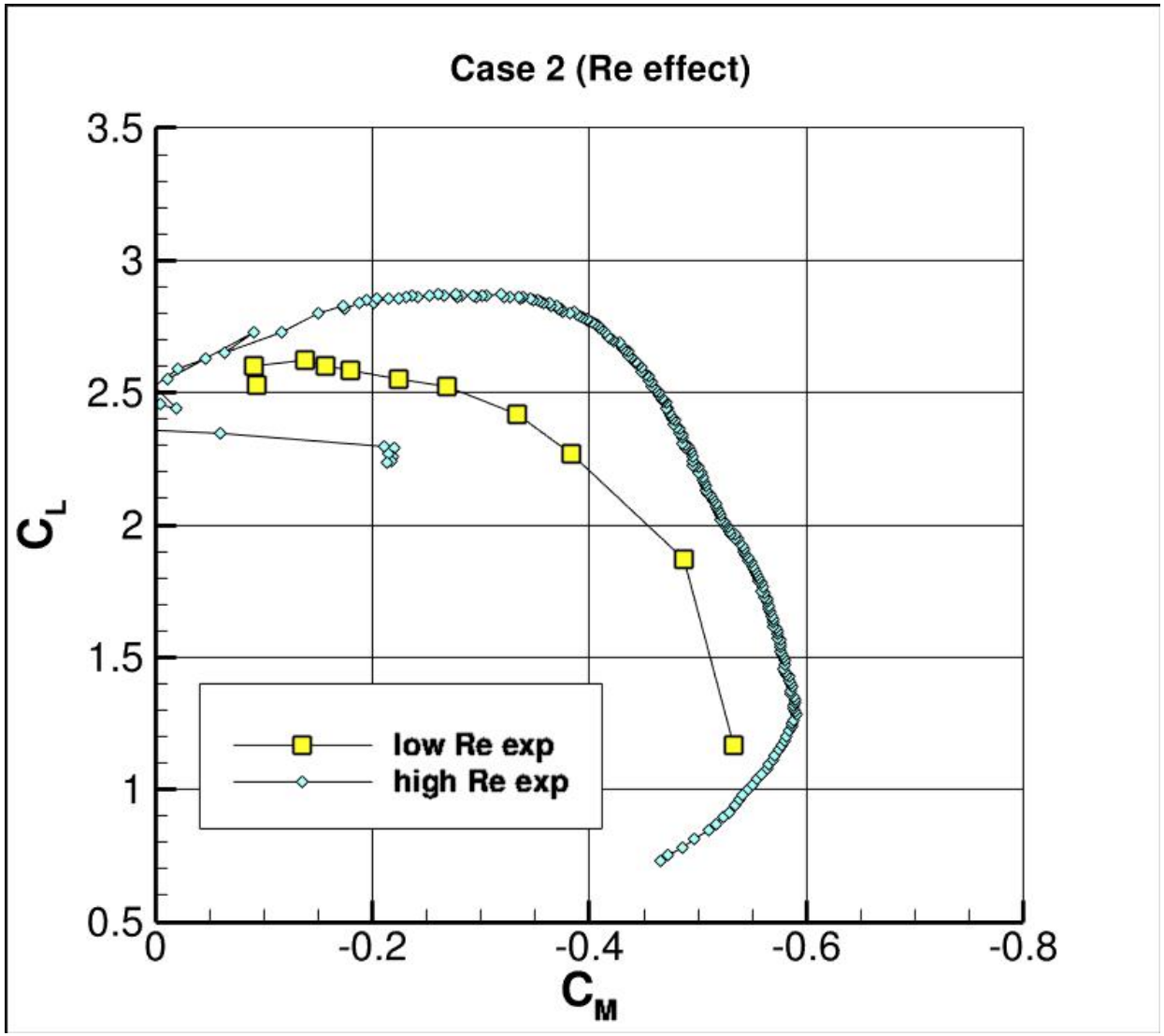
Case 2 Reynolds number effect



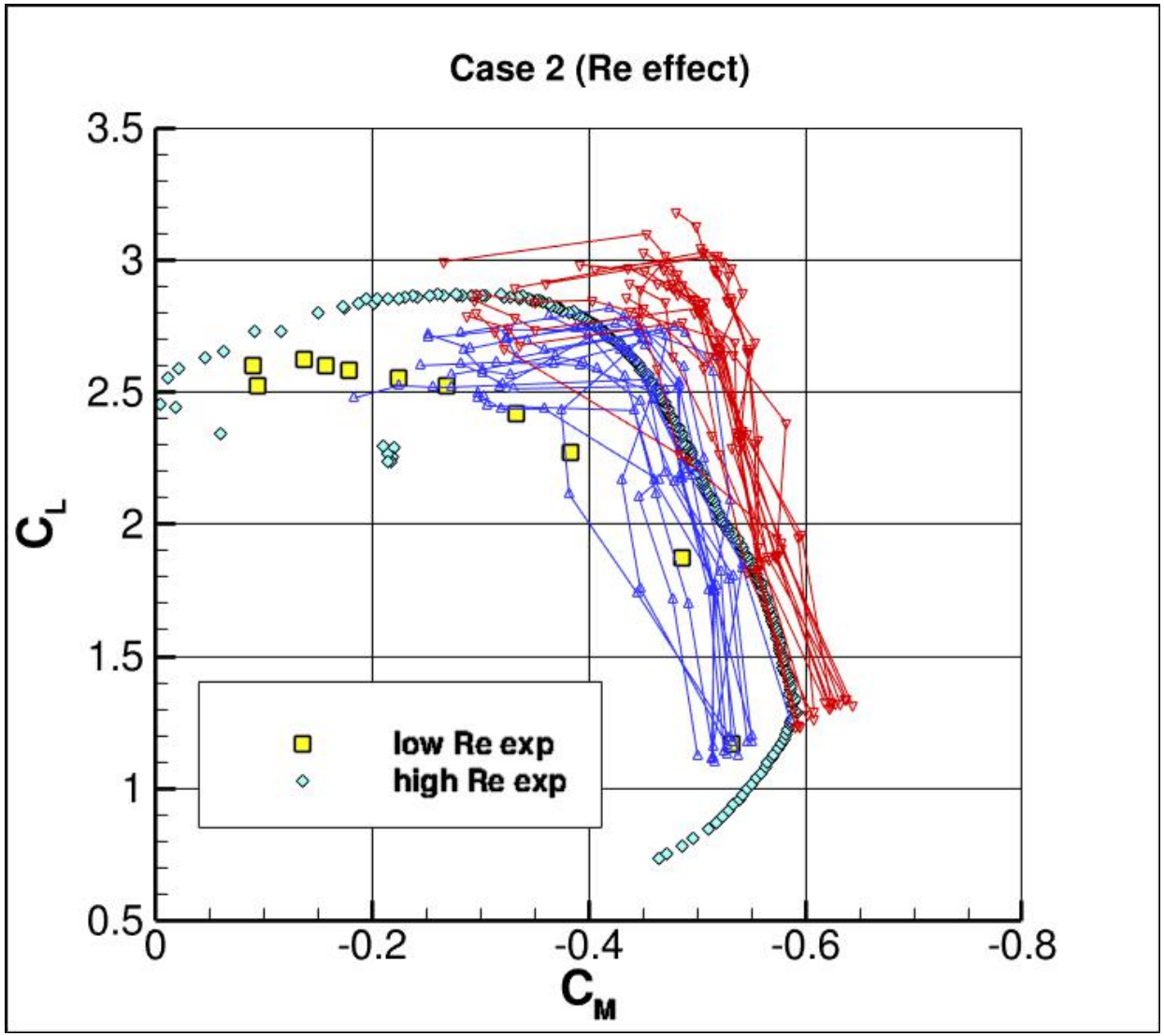
Case 2b adaptive result at high Re



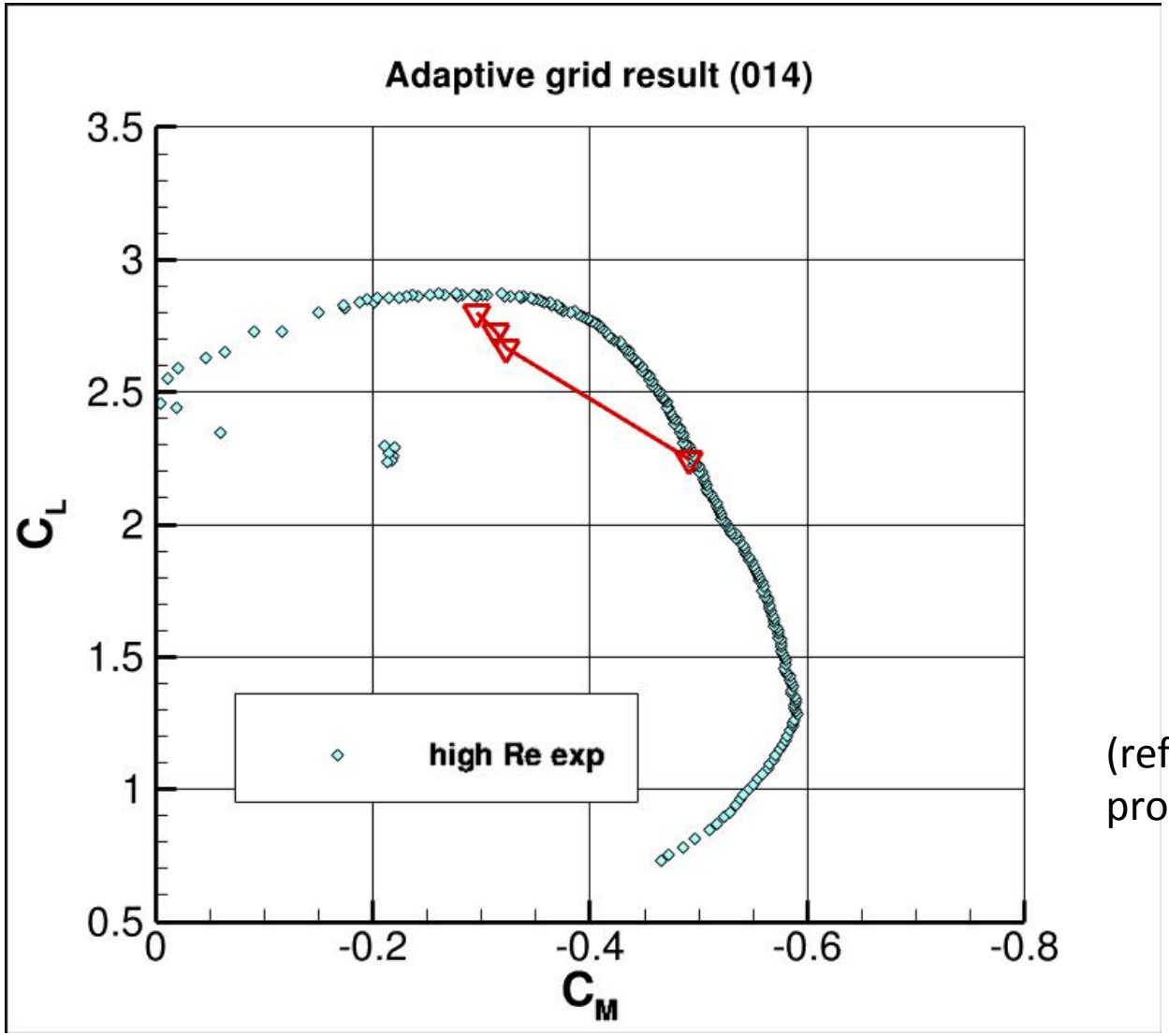
Case 2 Reynolds number effect



Case 2 Reynolds number effect

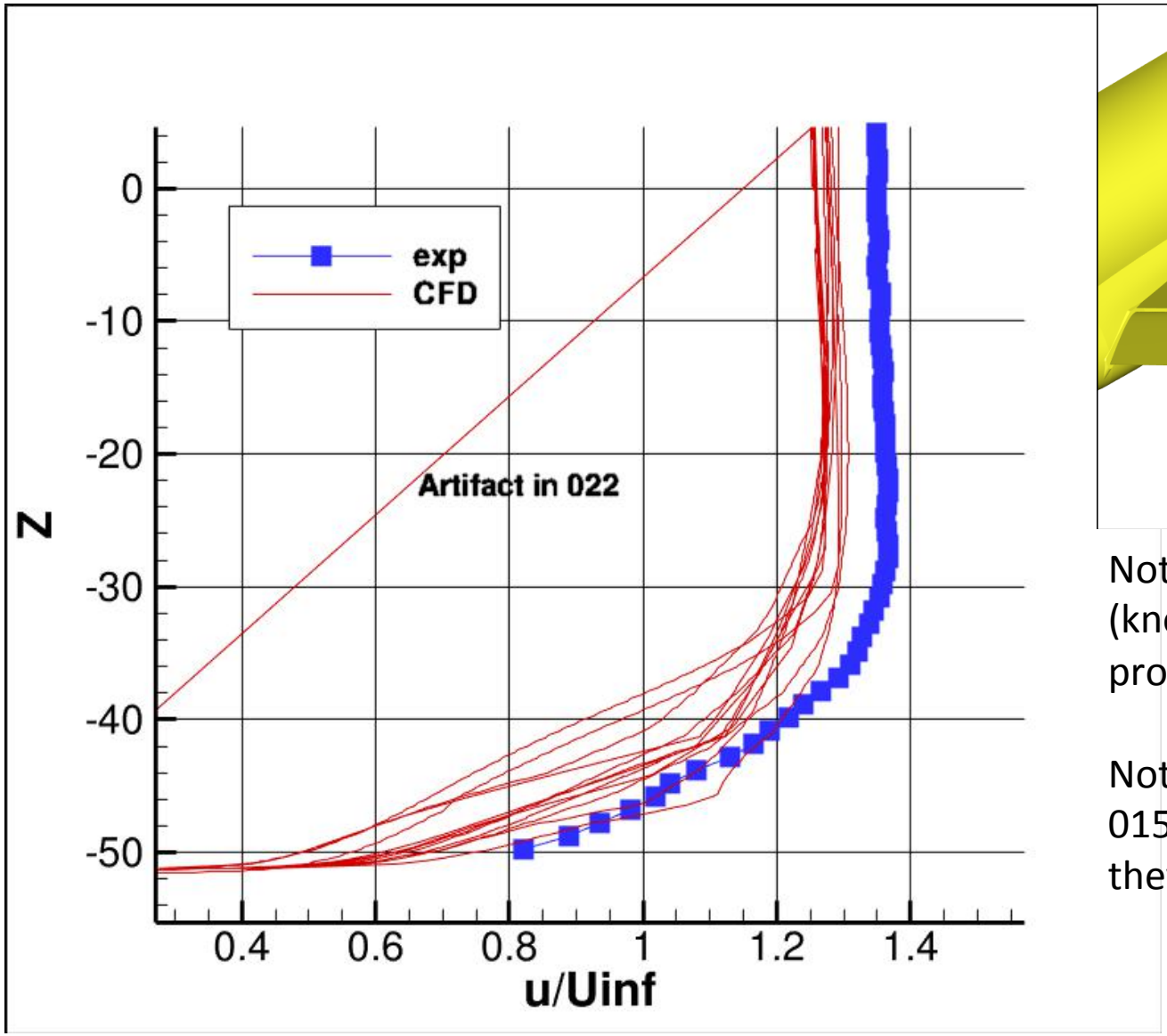


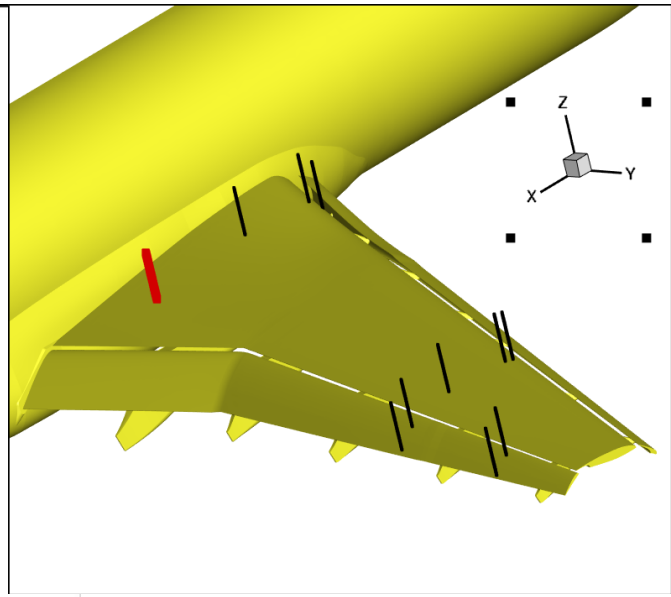
Case 2b adaptive result at high Re



(refinement not provided)

Case 2a (low Re w brackets), AoA=7, 1D1

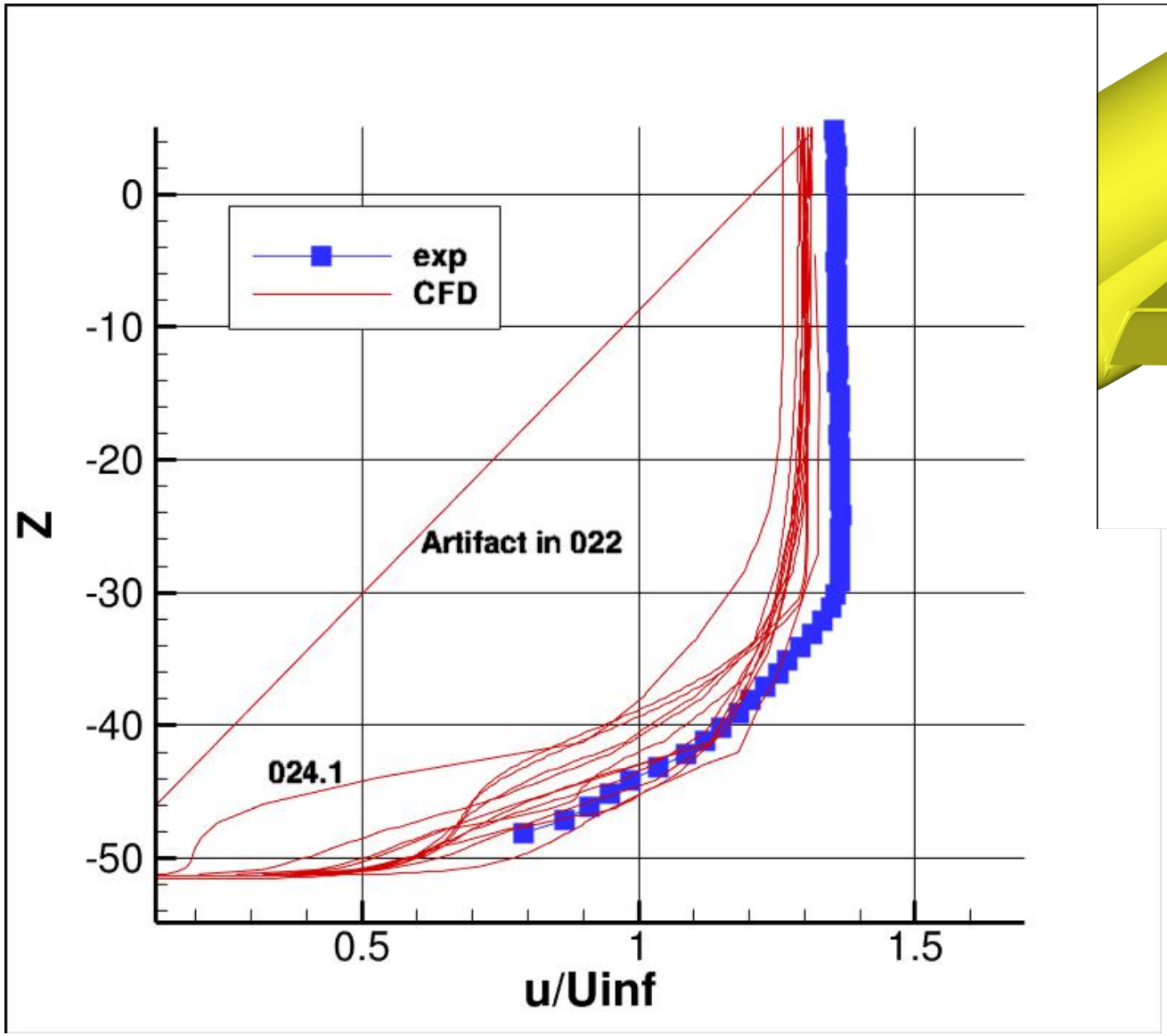


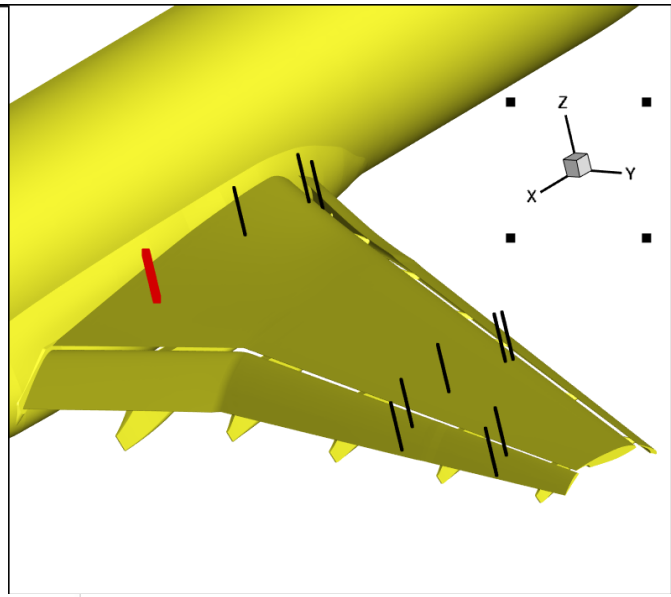


Not plotting 003.1, 003.2 (known incorrect post-processing)

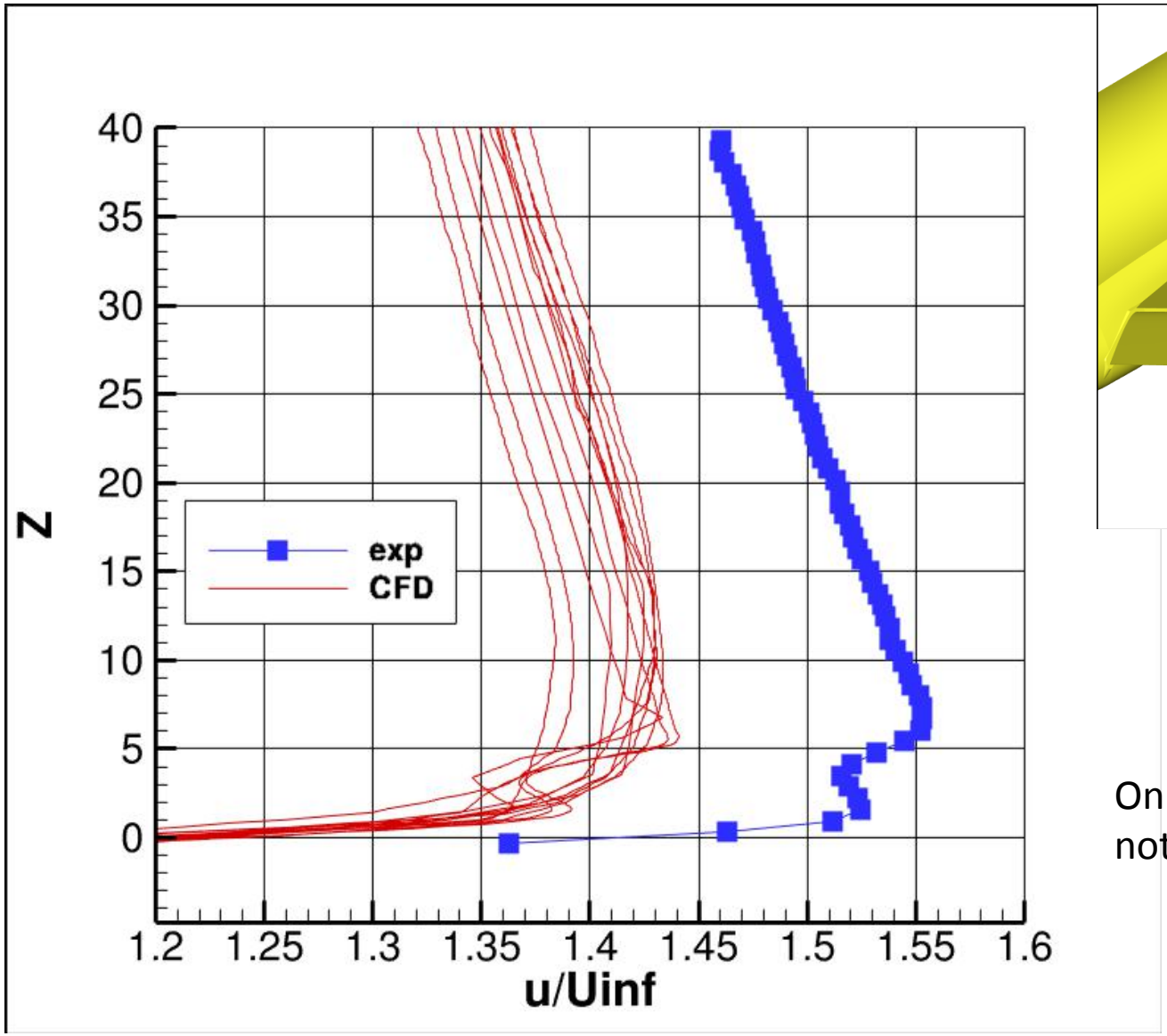
Note: including 015.1 and 015.2 results, even though they ran with no brackets

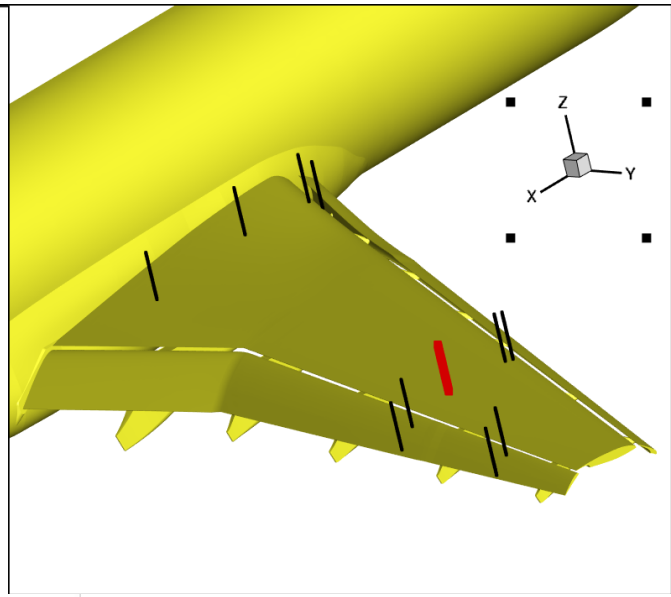
Case 2a (low Re w brackets), AoA=18.5, 1D1





Case 2a (low Re w brackets), AoA=7, 2D1

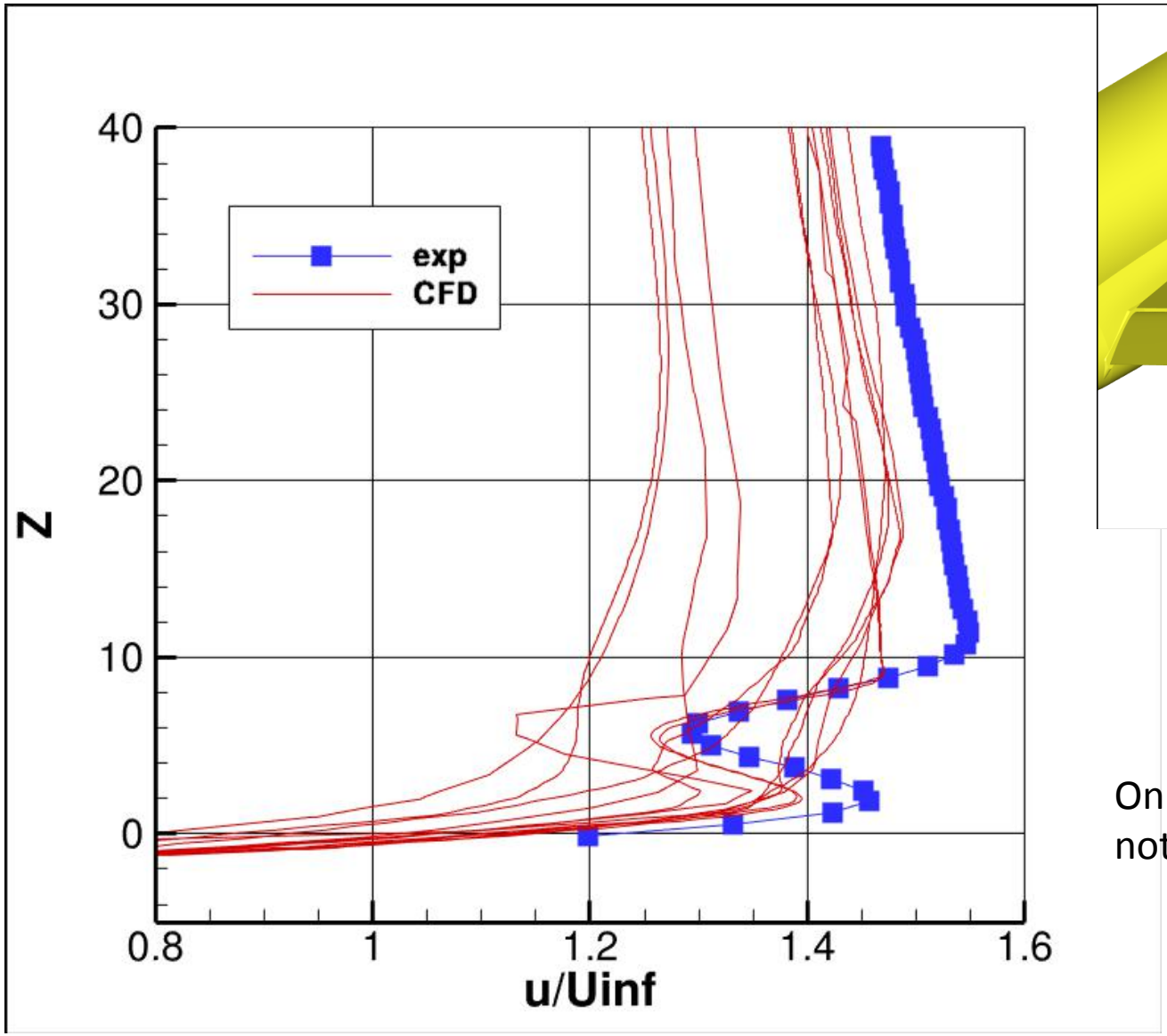


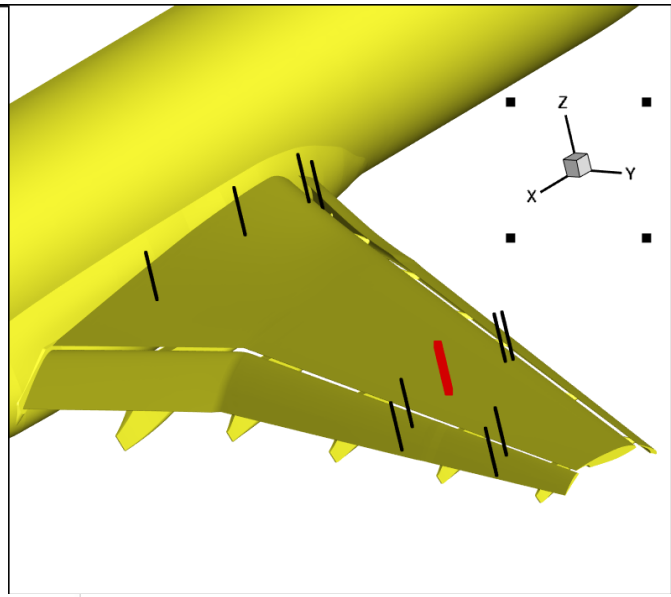


Only 009, 020, and 022 show noticeable slat wake

- -009 Str-Overset (E)
- -020 Str-Overset (E)
- -022 Uns (nc)

Case 2a (low Re w brackets), AoA=18.5, 2D1

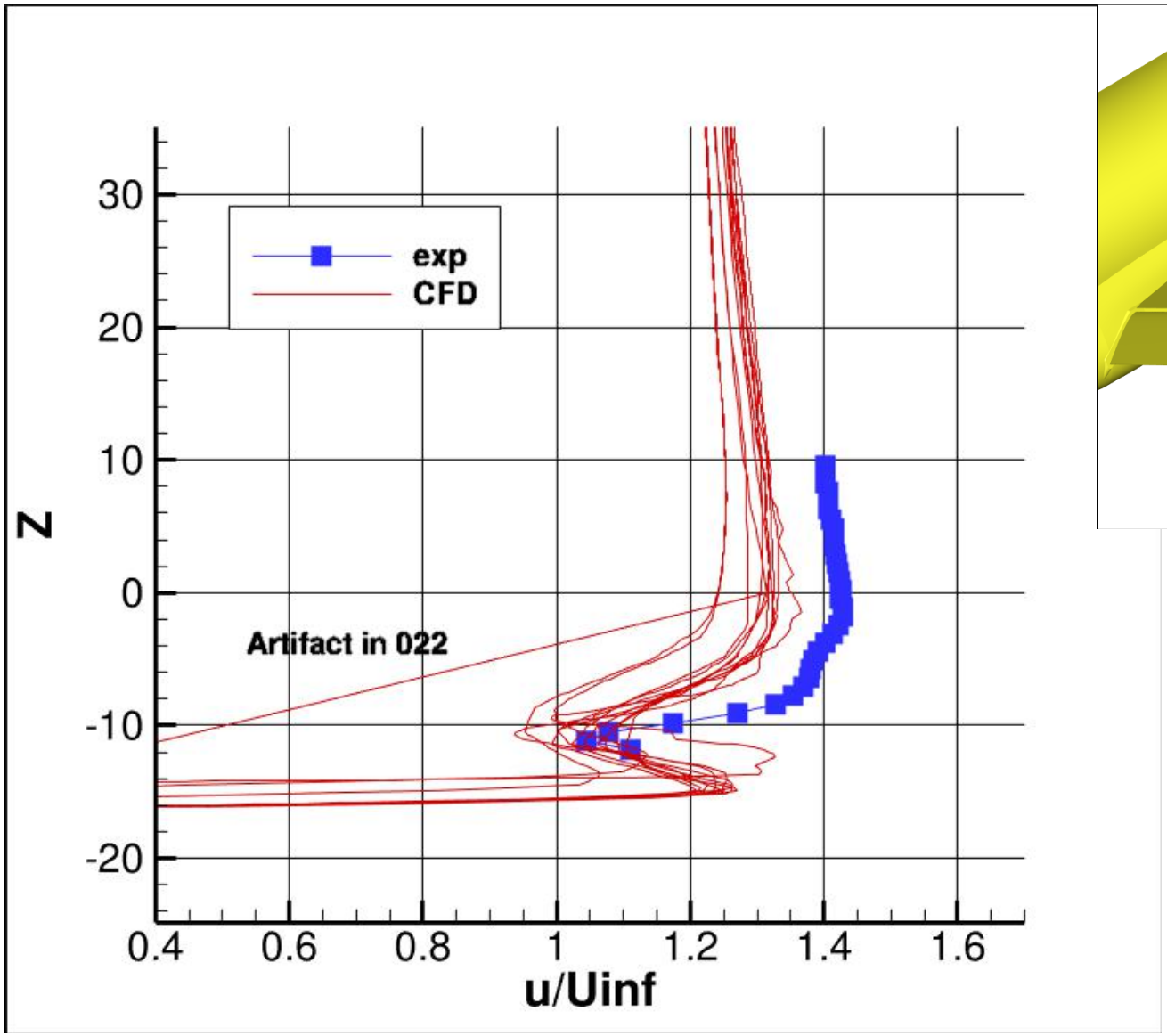


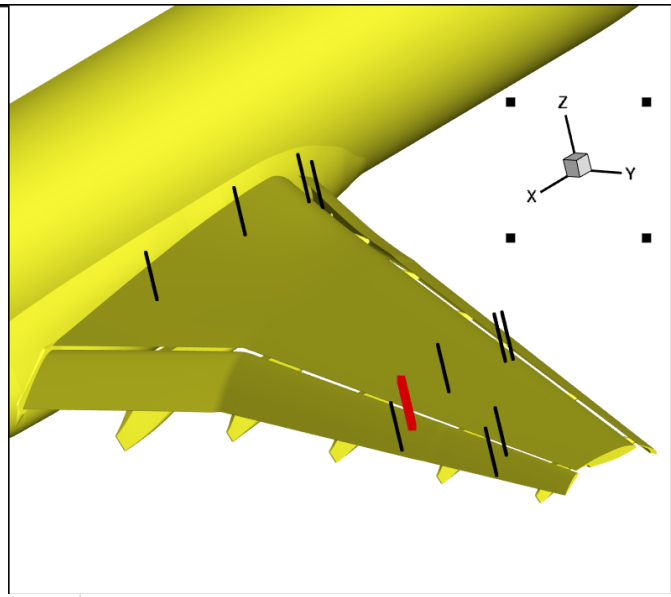


Only 009, 020, and 022 show noticeable slat wake

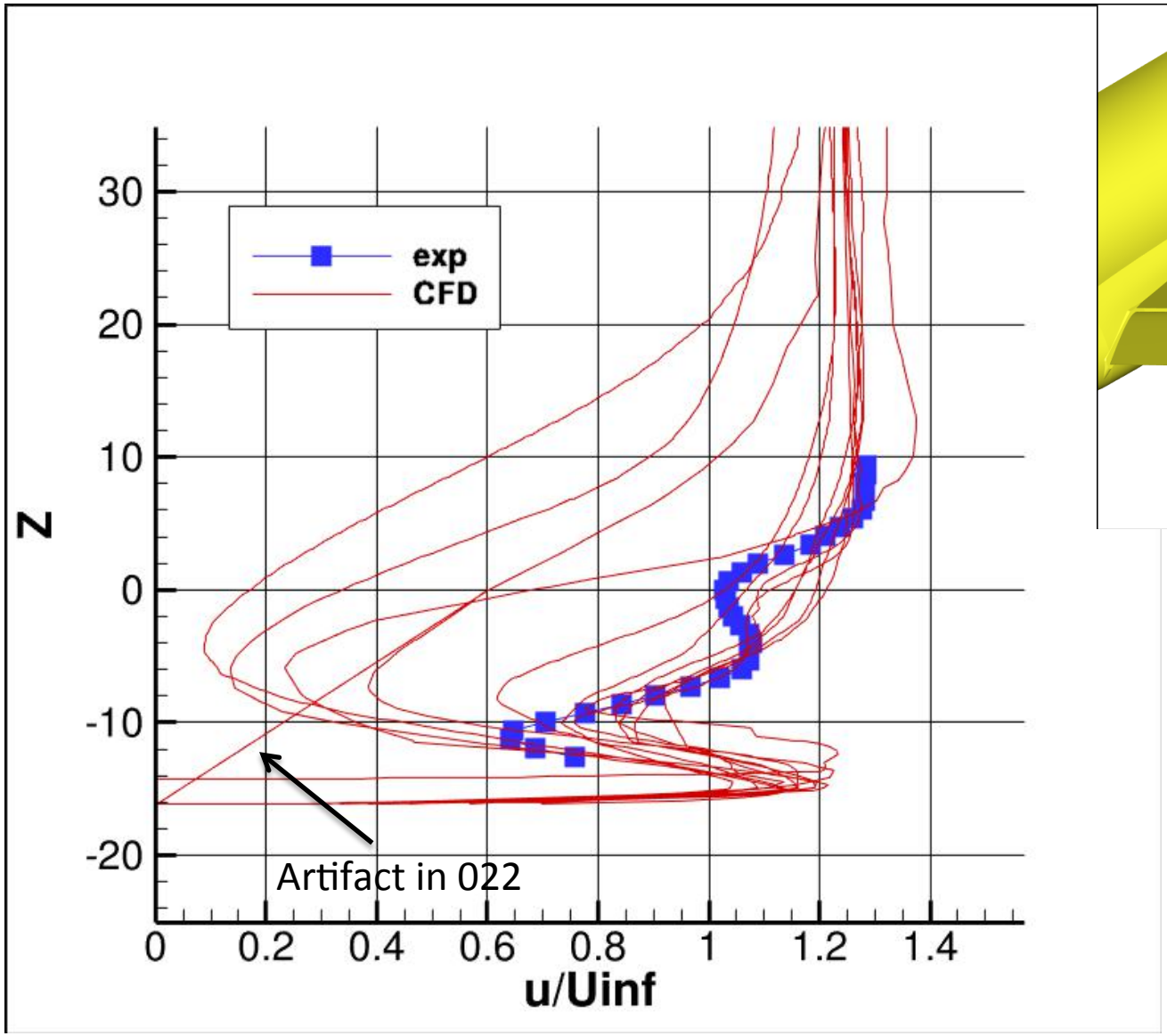
- -009 Str-Overset (E)
- -020 Str-Overset (E)
- -022 Uns (nc)

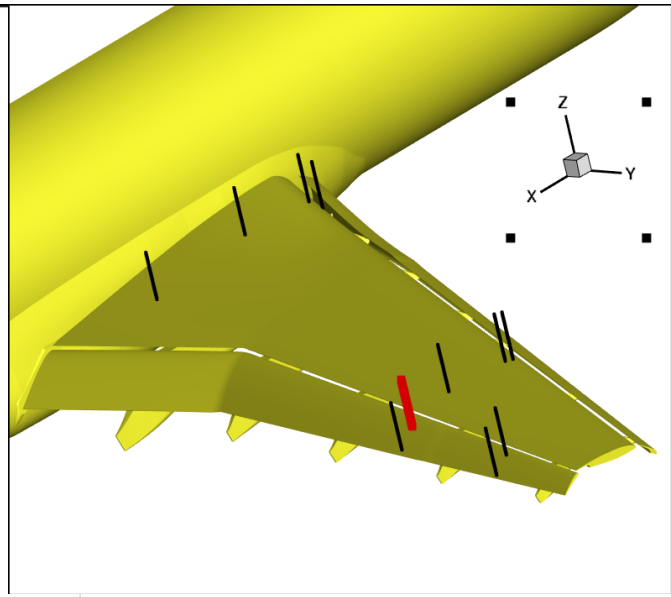
Case 2a (low Re w brackets), AoA=7, 2E1



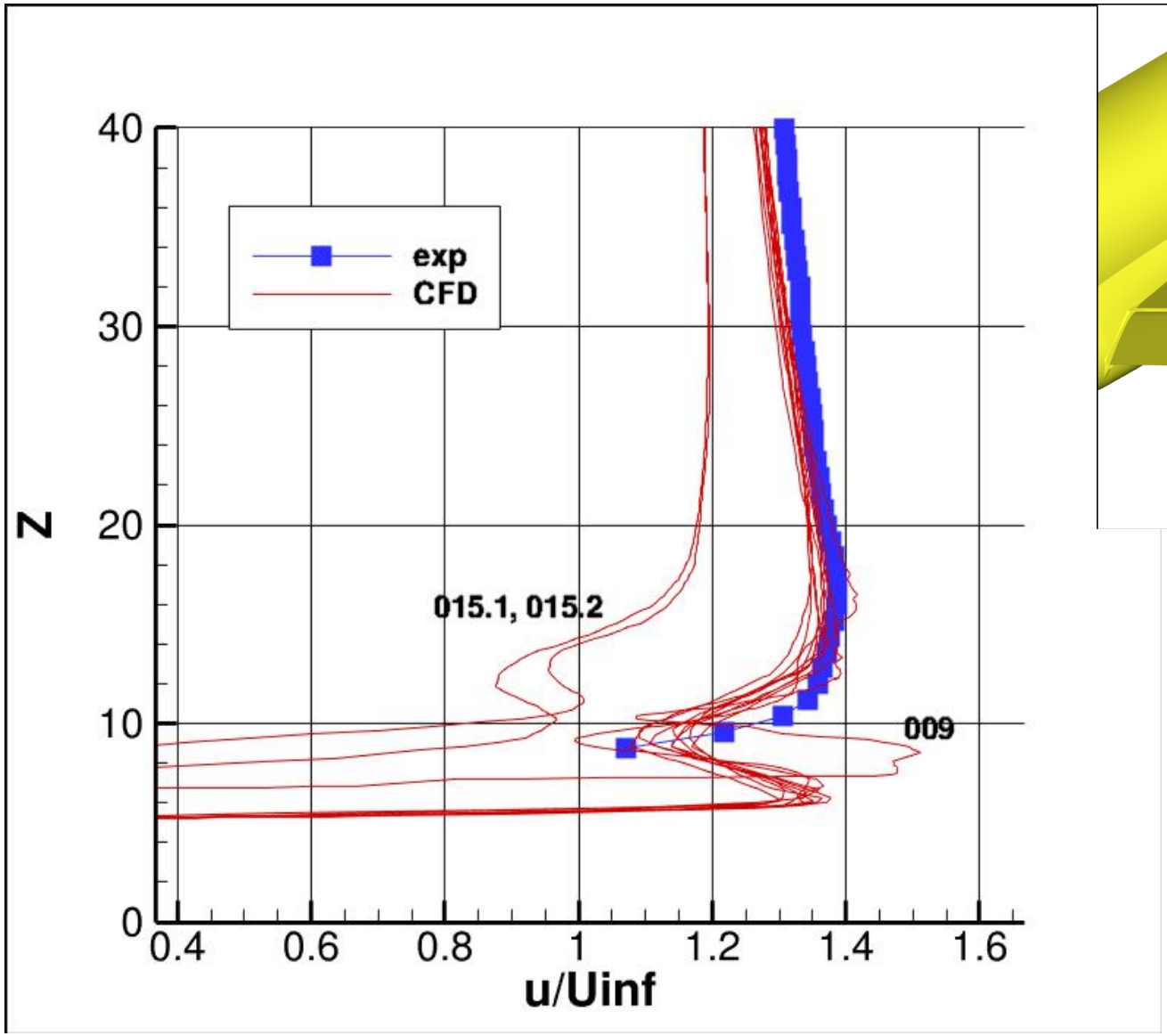


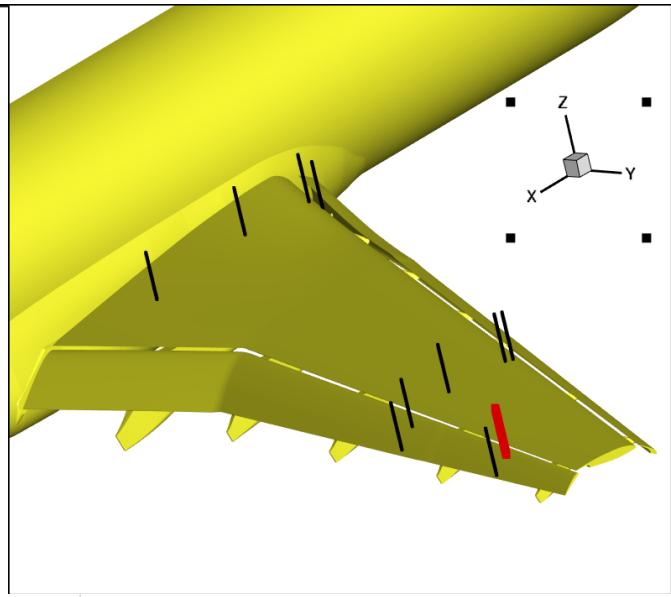
Case 2a (low Re w brackets), AoA=18.5, 2E1



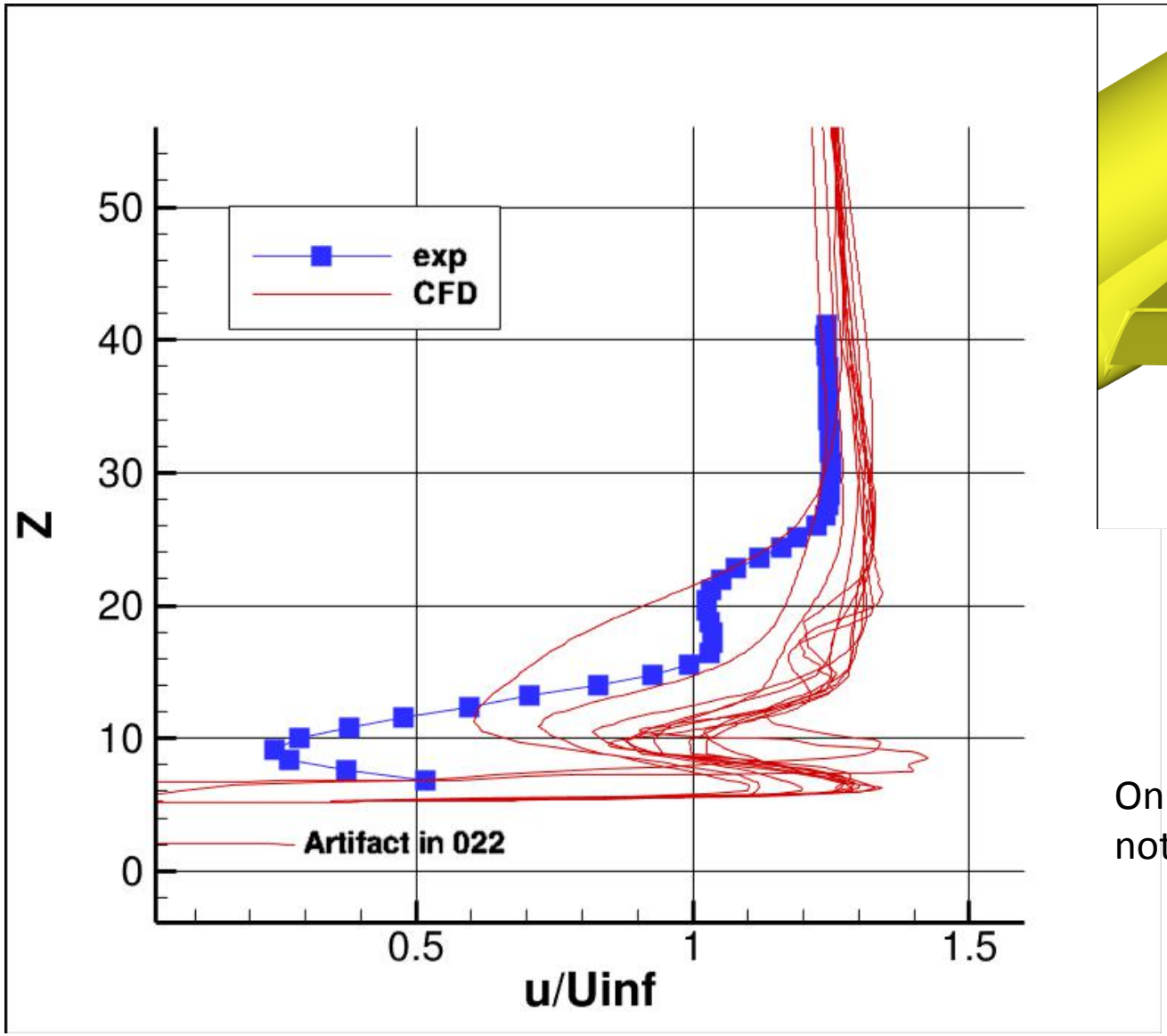


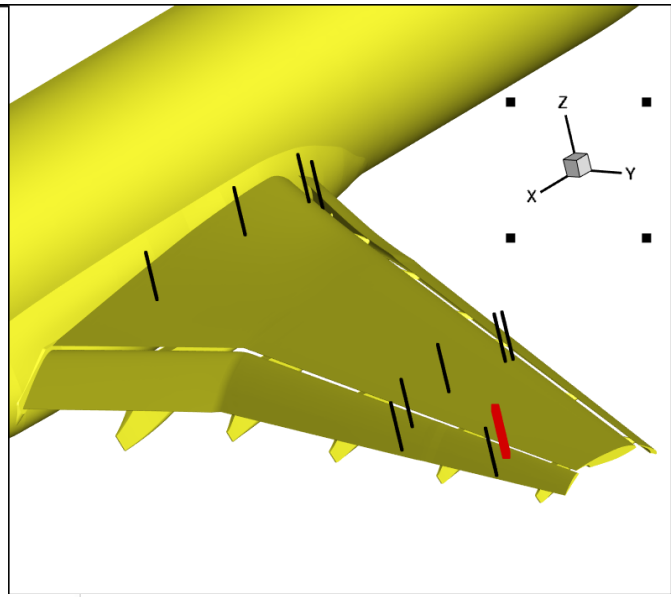
Case 2a (low Re w brackets), AoA=7, 3E1





Case 2a (low Re w brackets), AoA=18.5, 3E1

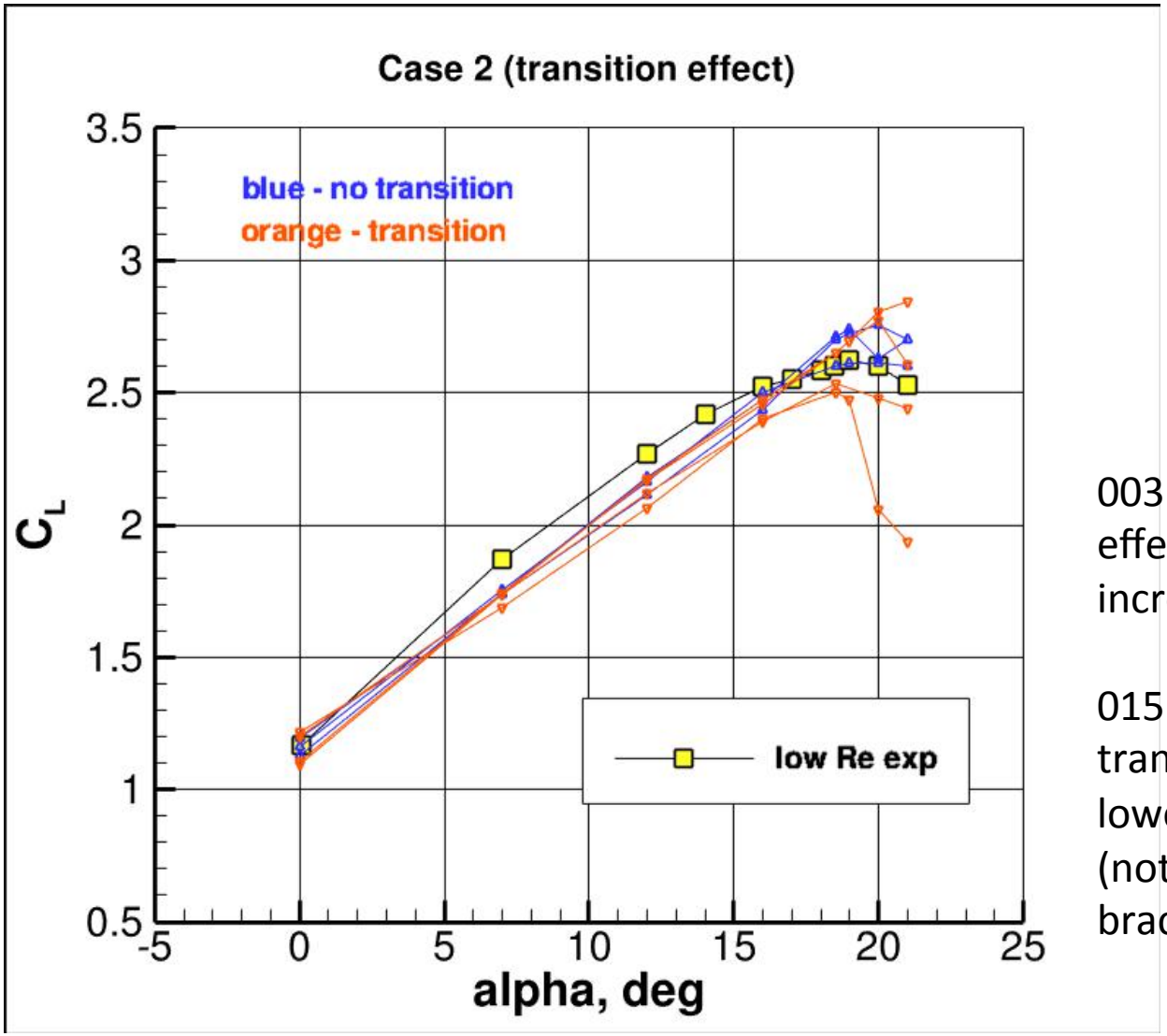




Only 009, 020, and 022 show noticeable slat wake

- -009 Str-Overset (E)
- -020 Str-Overset (E)
- -022 Uns (nc)

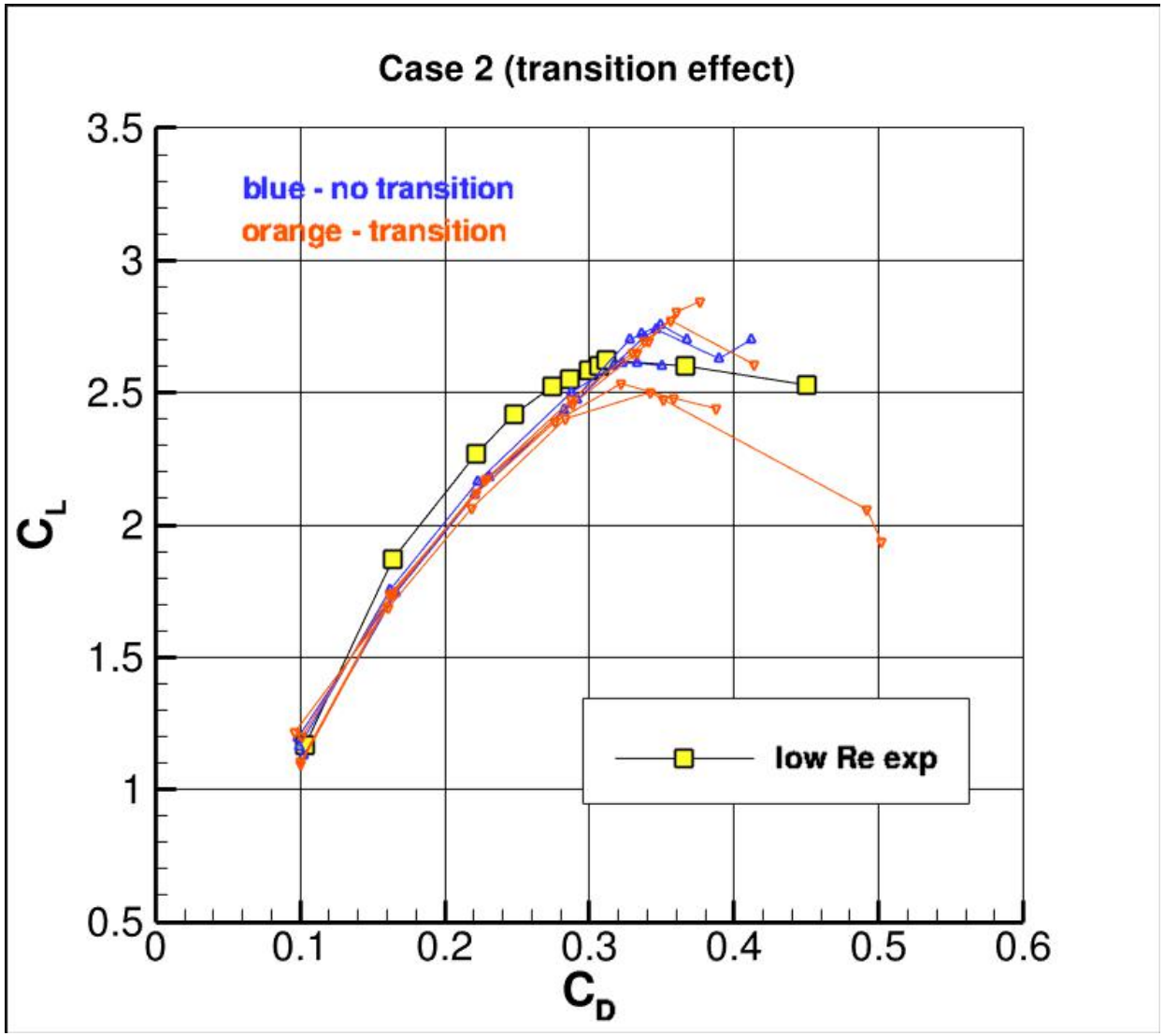
Case 2 Transition effect



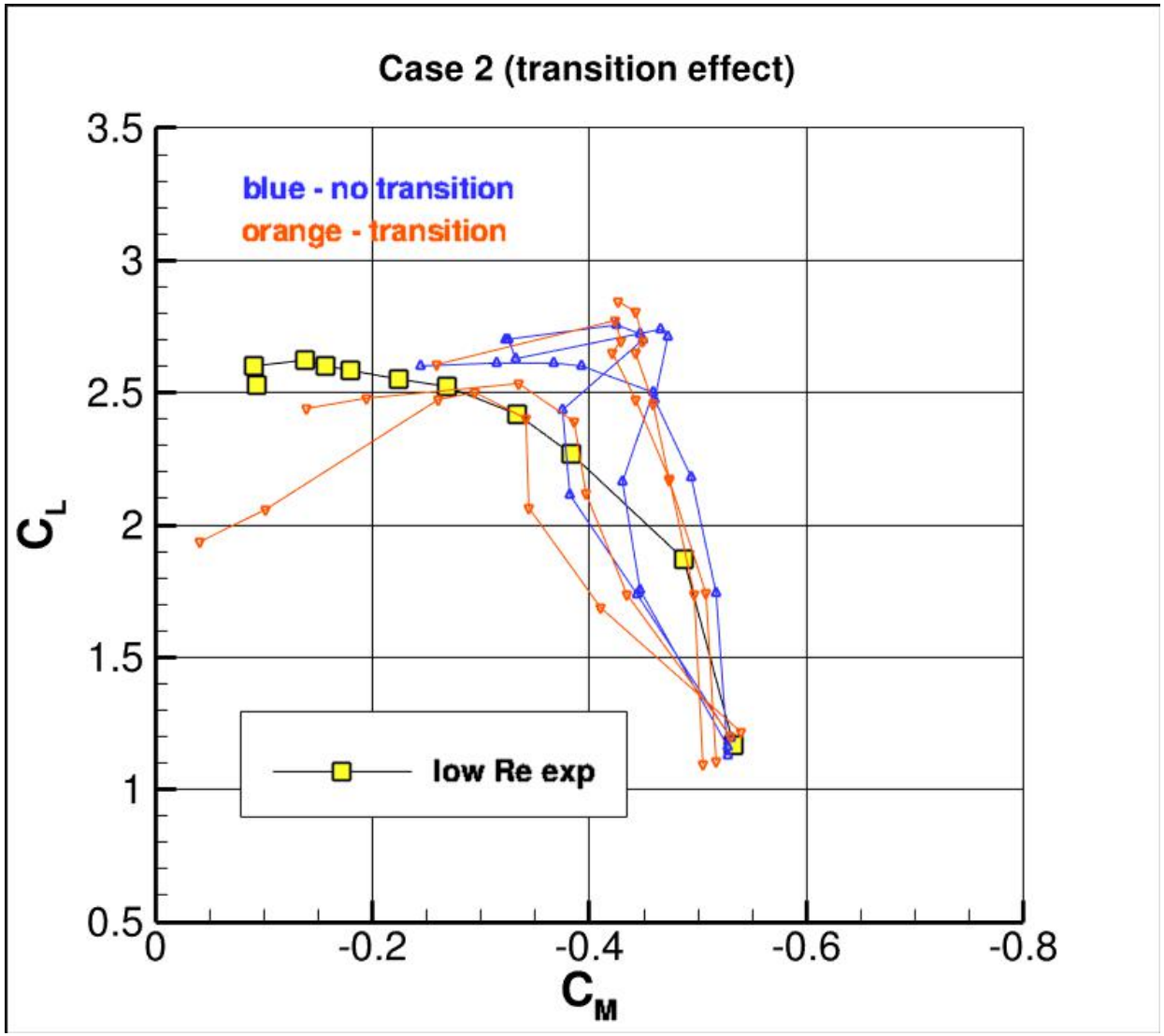
003.1: transition had little effect over most of curve, increased CLmax

015.1 and 015.2: transition generally lowered CL and Clmax (note: run without brackets)

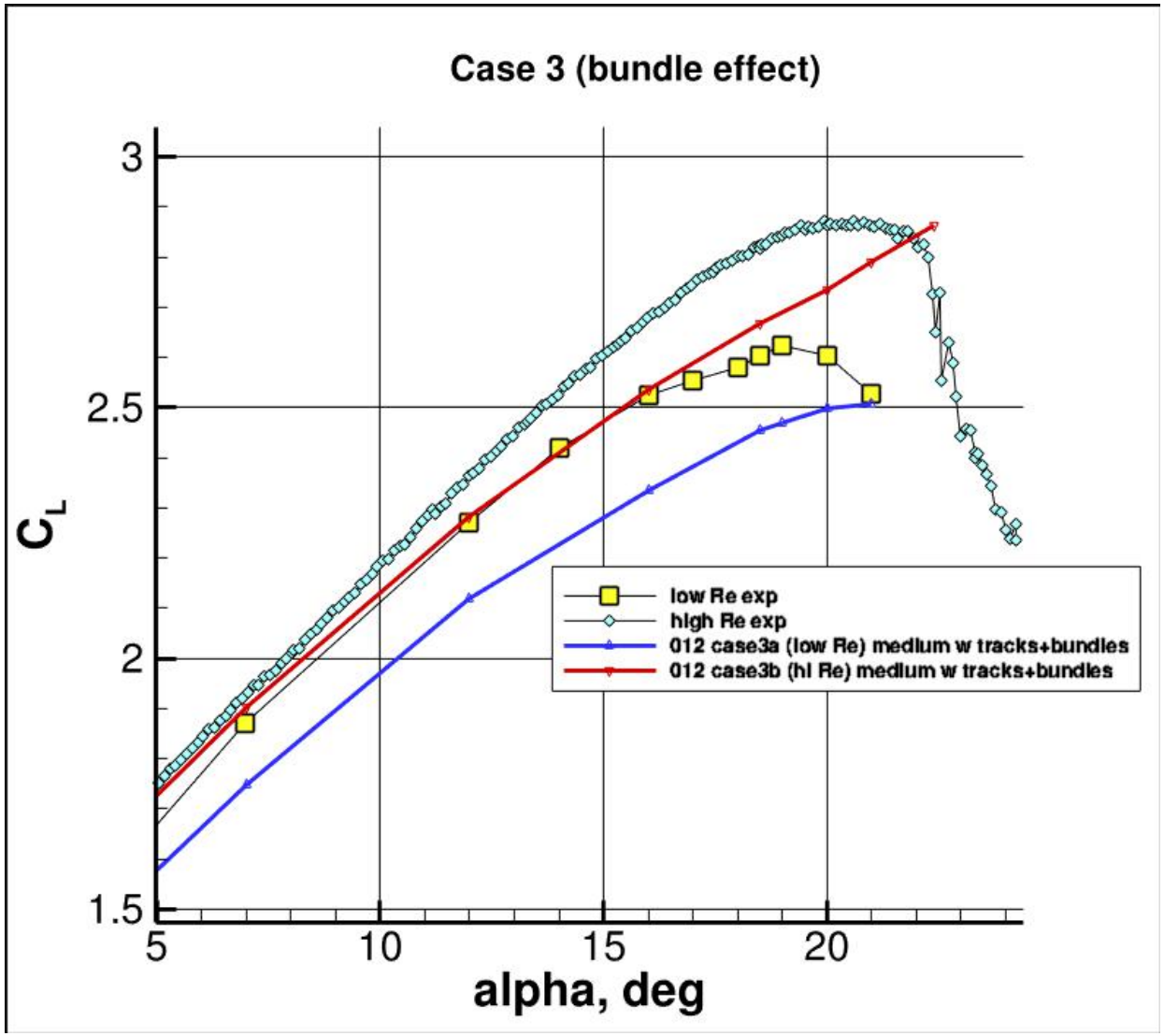
Case 2 Transition effect



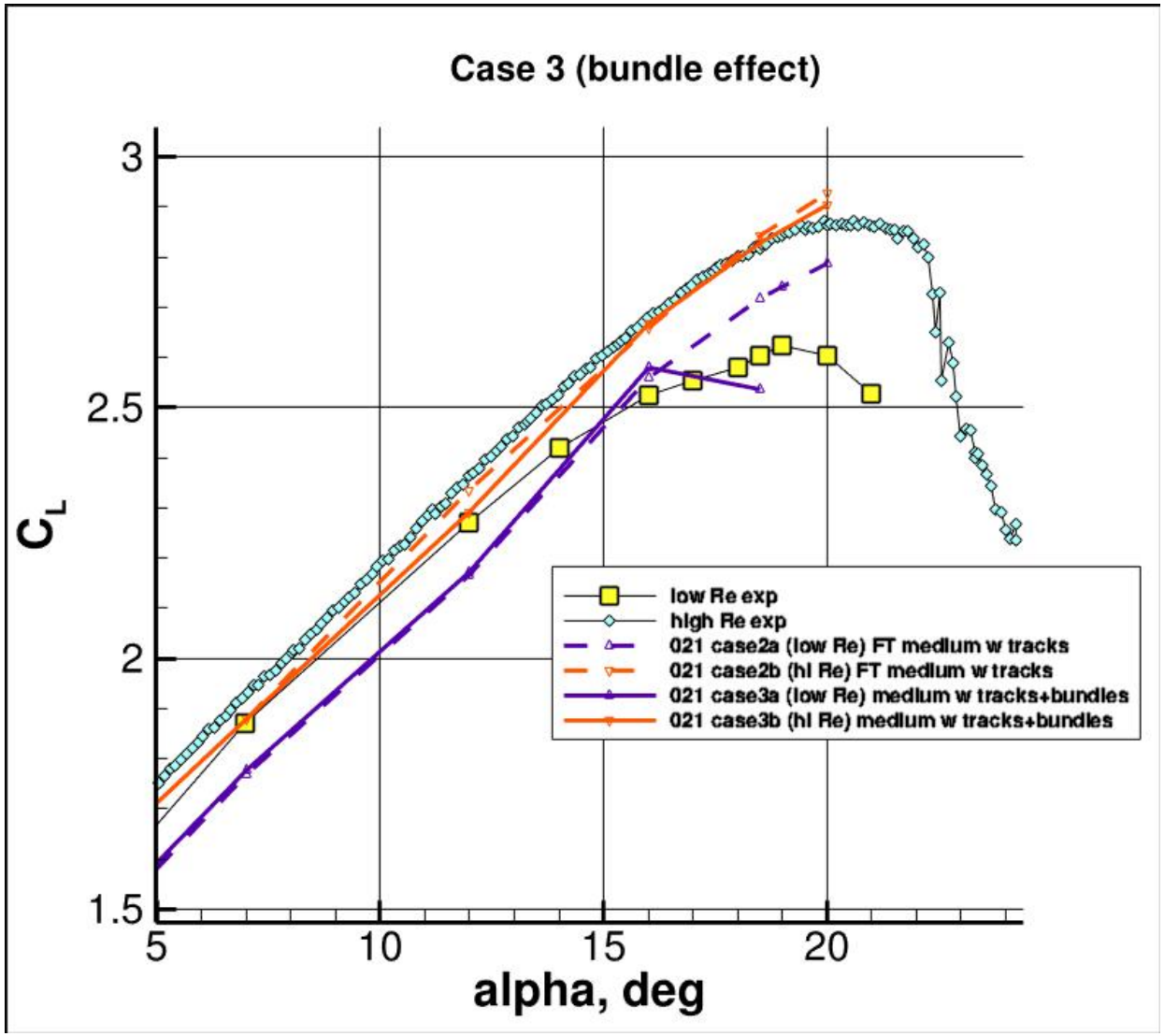
Case 2 Transition effect



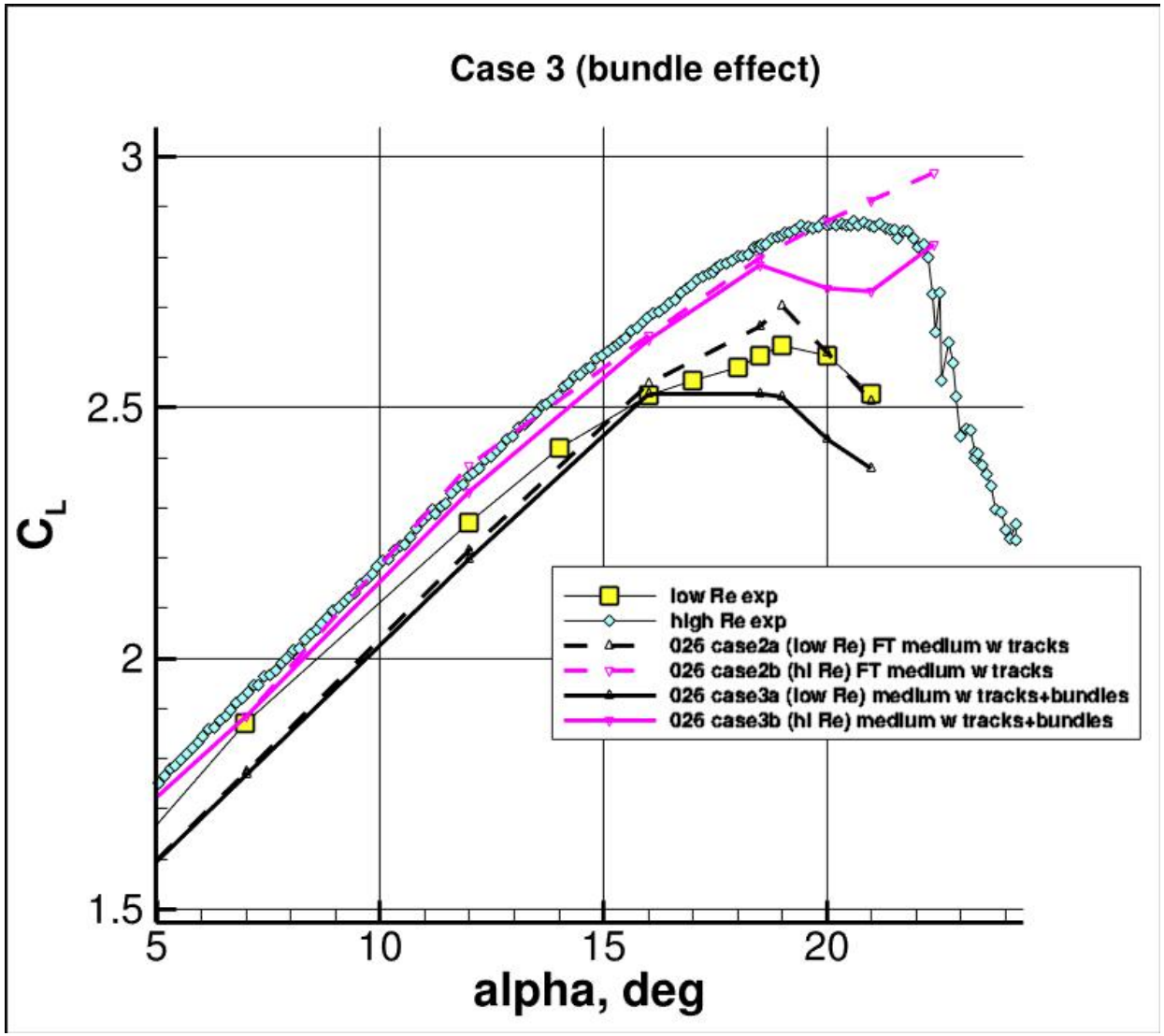
Case 3 Bundle effect



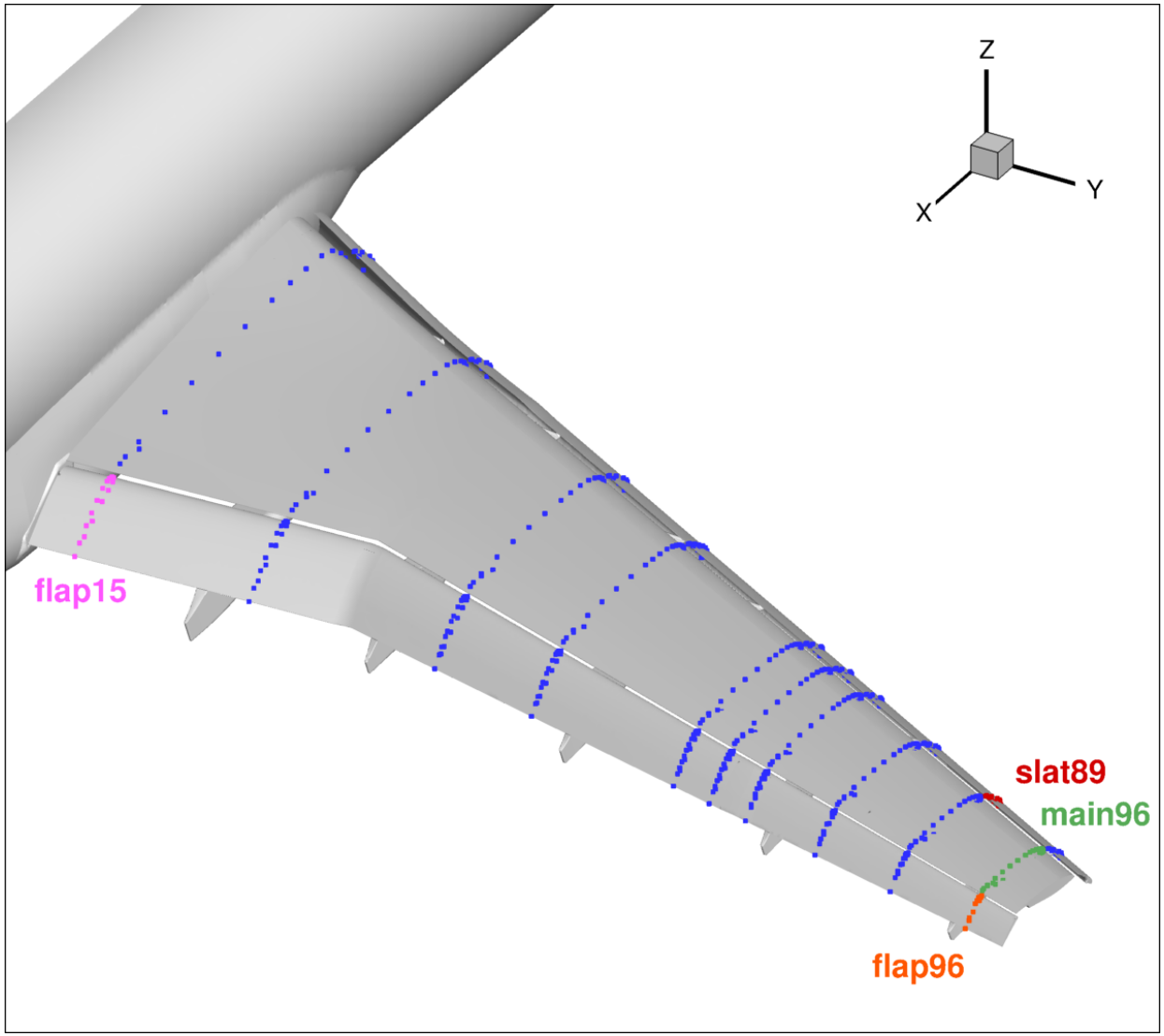
Case 3 Bundle effect



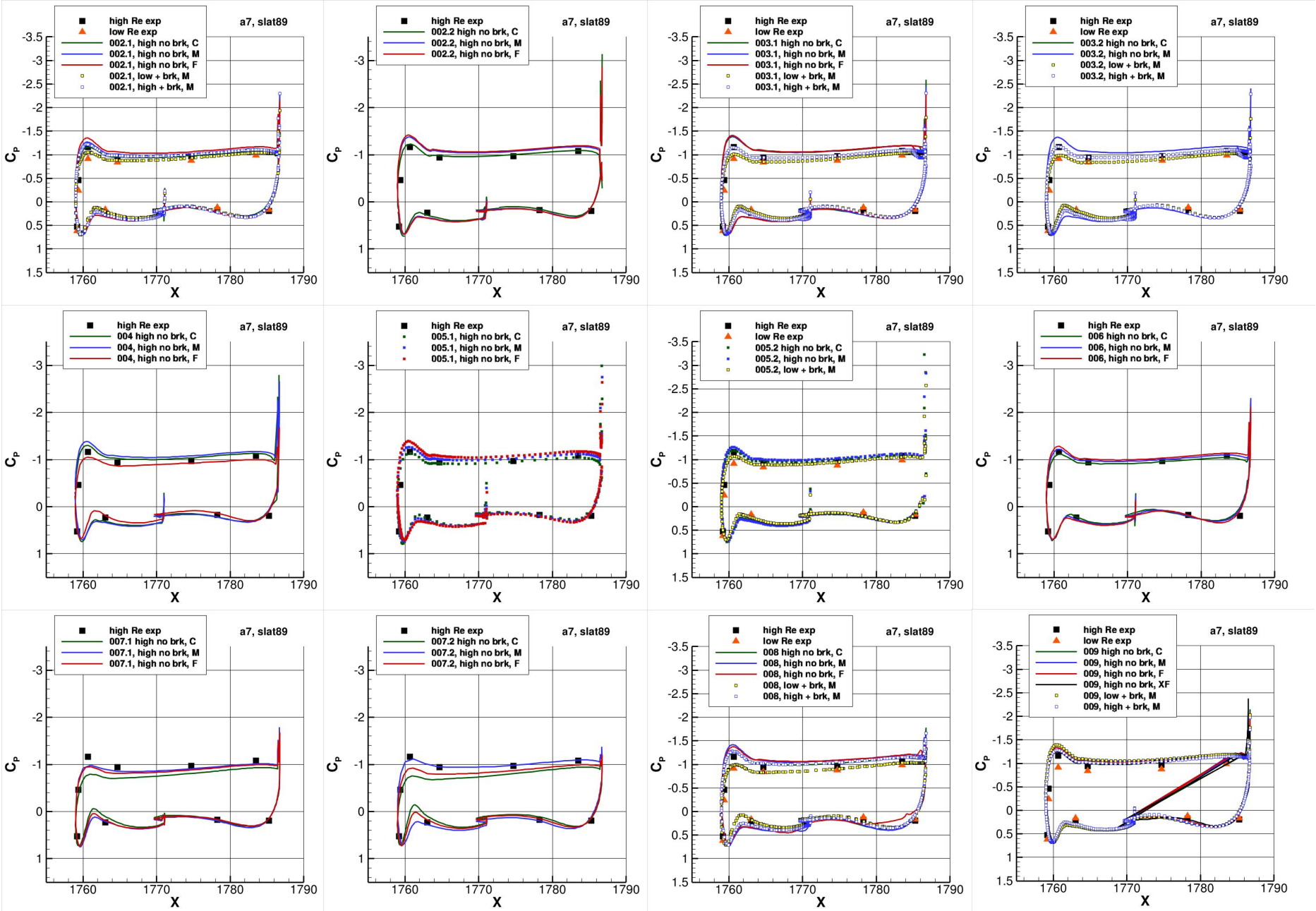
Case 3 Bundle effect



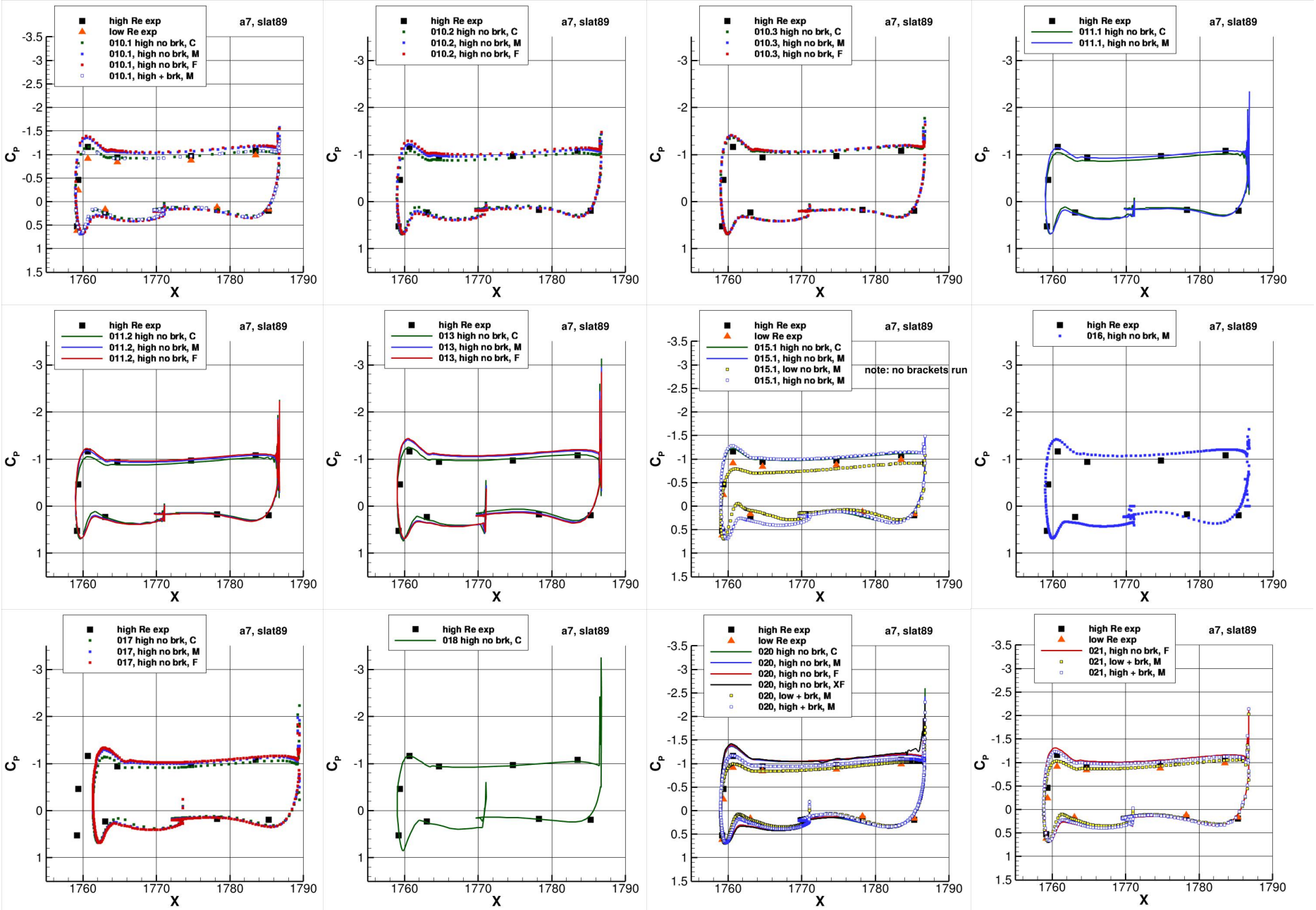
Surface pressure coefficients, AoA=7



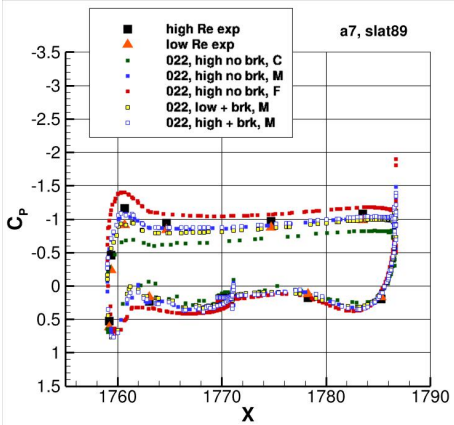
Cps at AoA=7, slat89

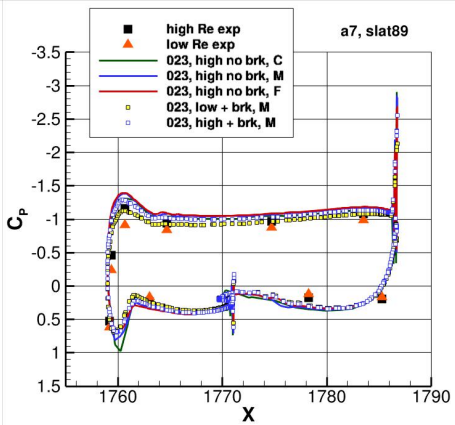


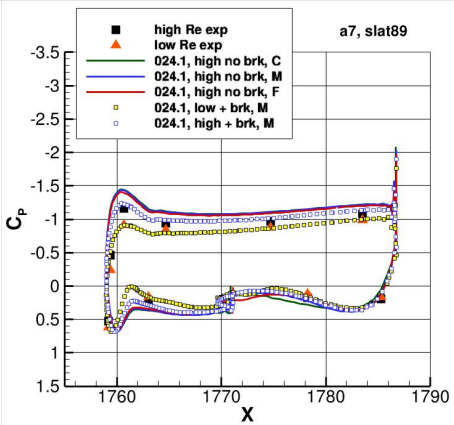
Cps at AoA=7, slat89

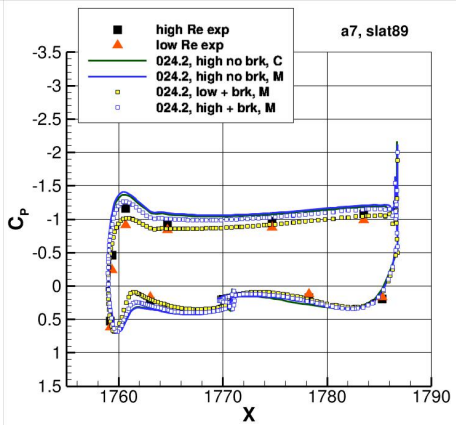


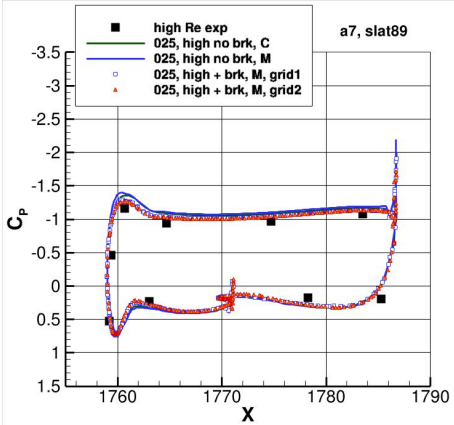
Cps at AoA=7, slat89

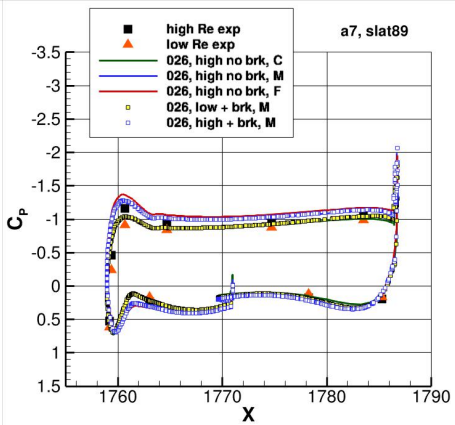






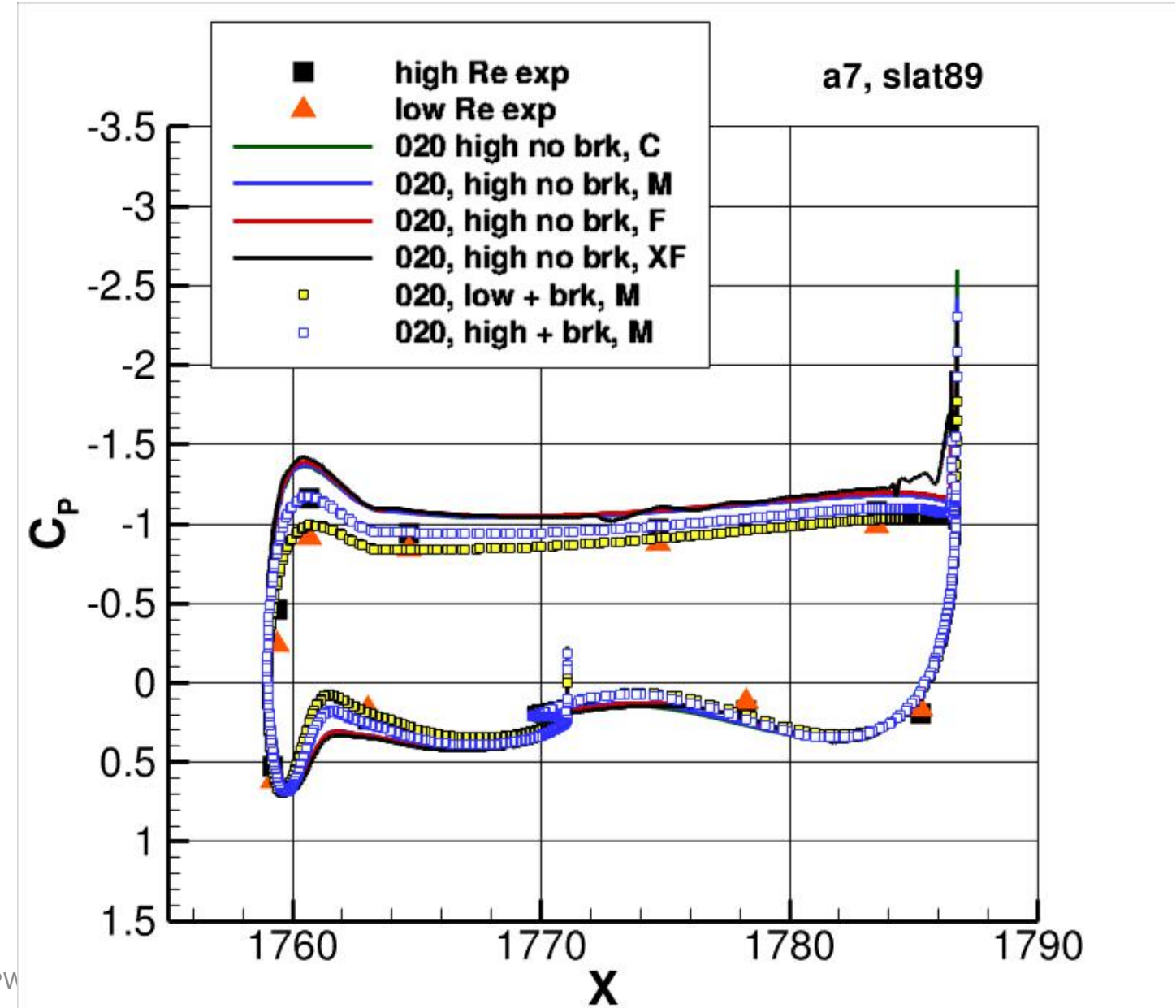




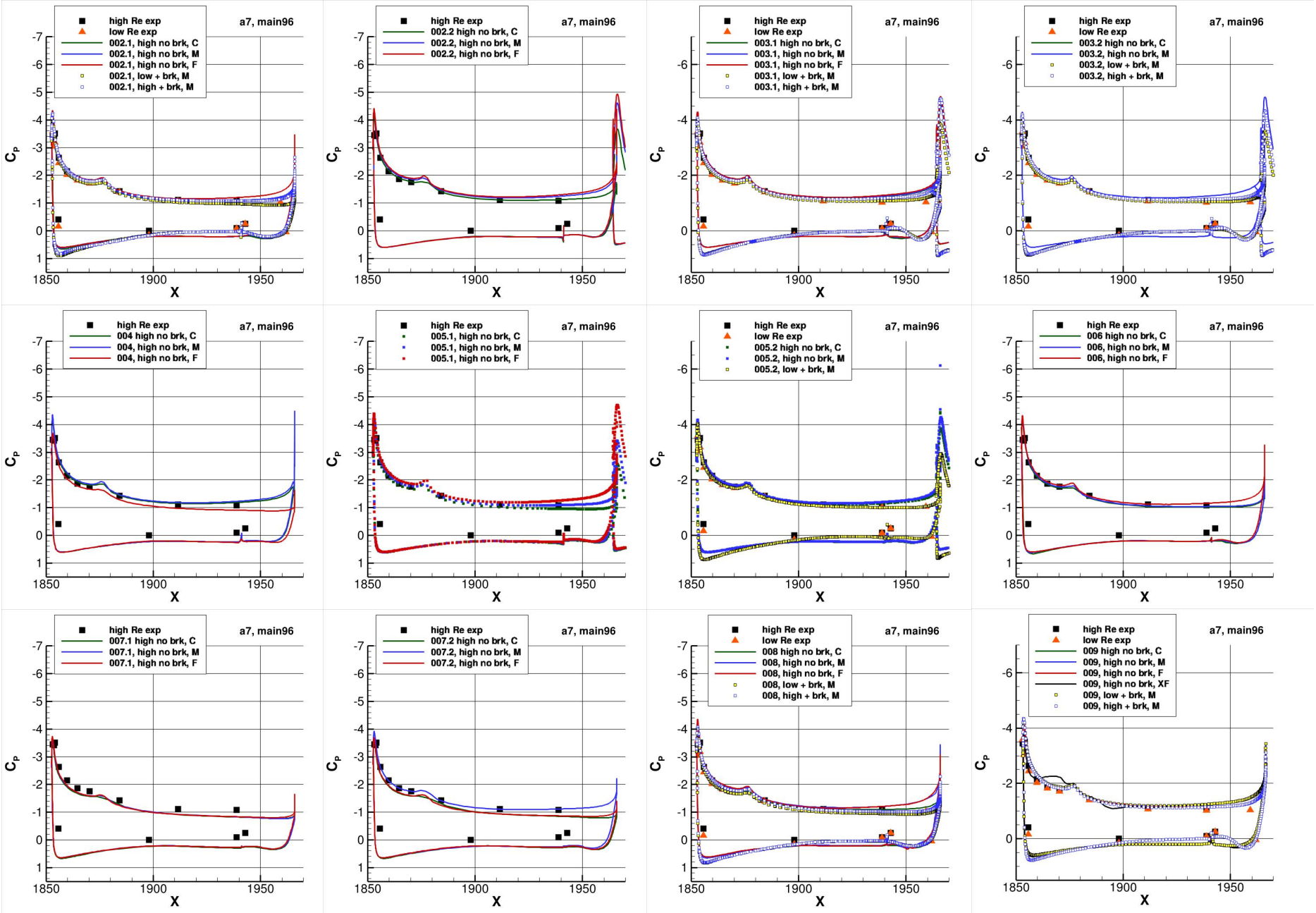


Runs w brackets tend to do better
Re effect qualitatively captured
Some results show more grid-dependence
017 used shifted geometry (for all)
-they were notified and this will be corrected for final data

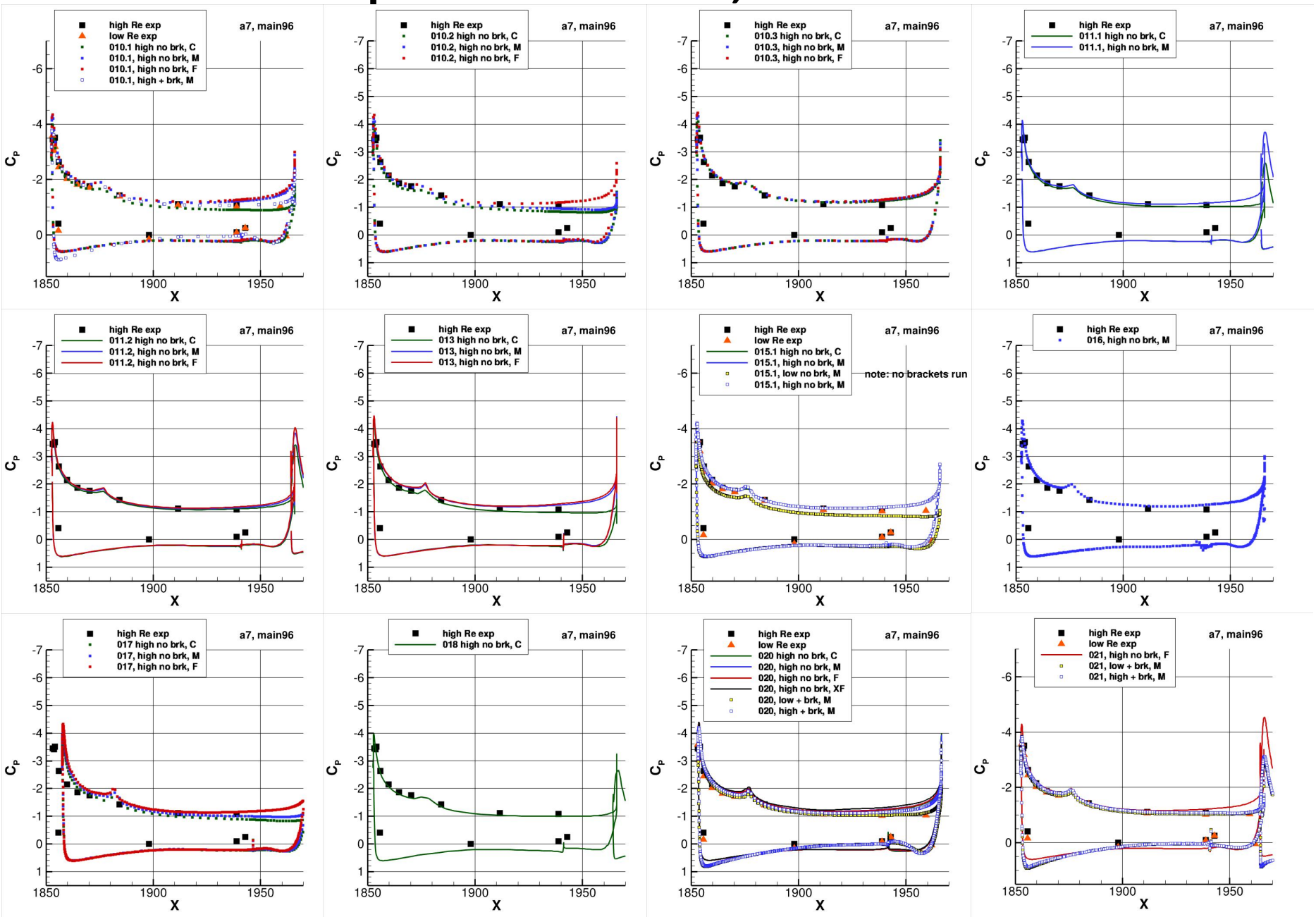
Cps at AoA=7, slat89 (example)



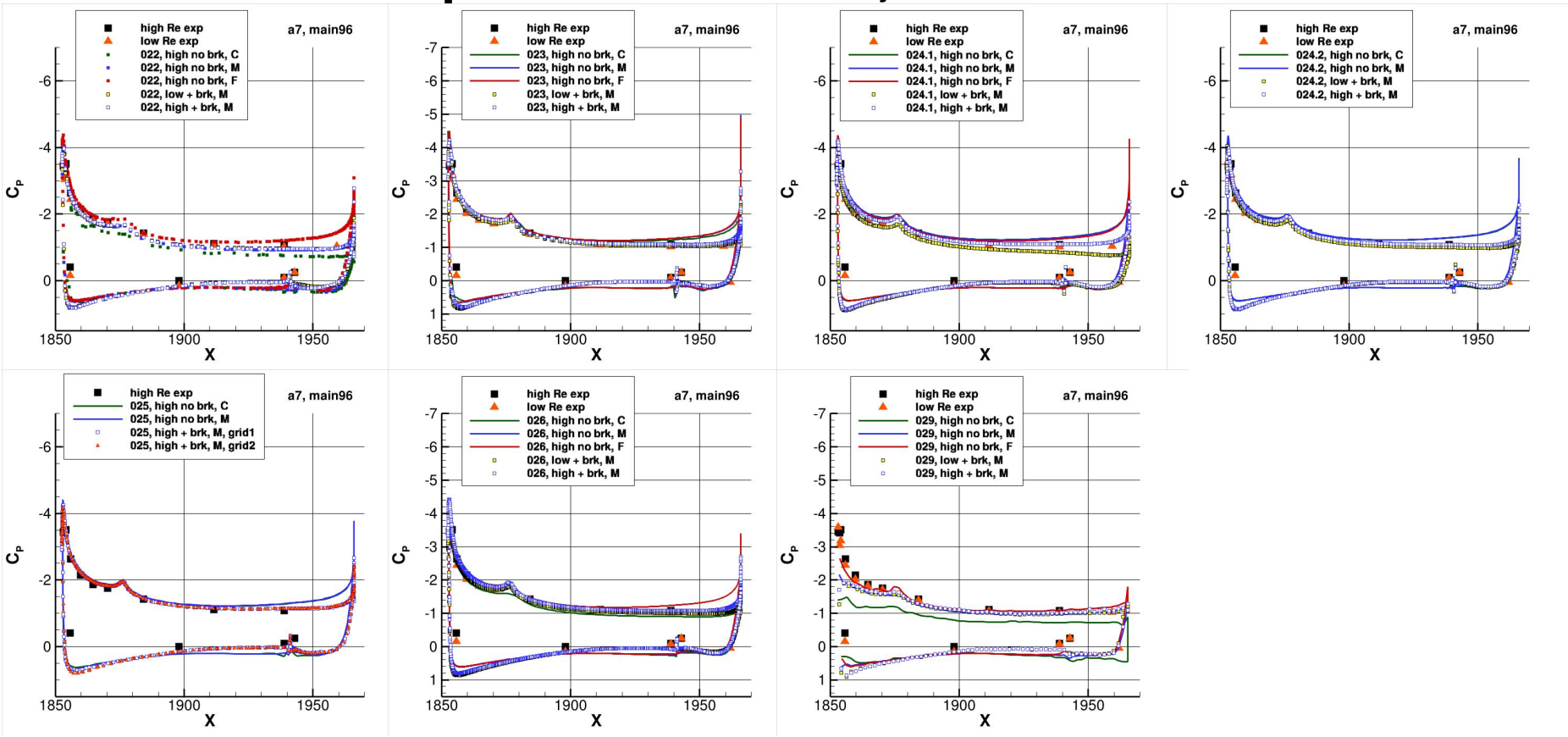
Cps at AoA=7, main96



Cps at AoA=7, main96

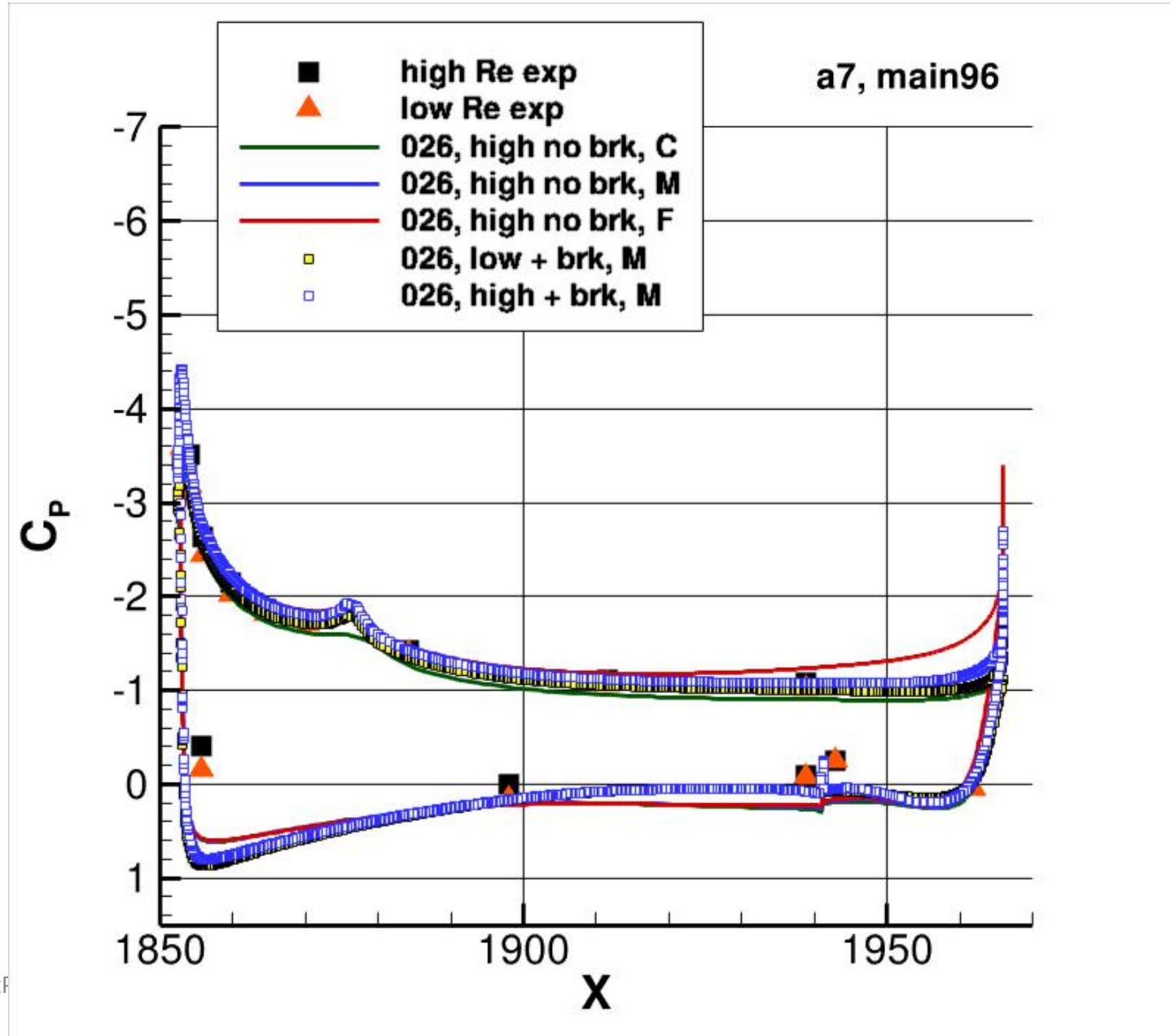


Cps at AoA=7, main96

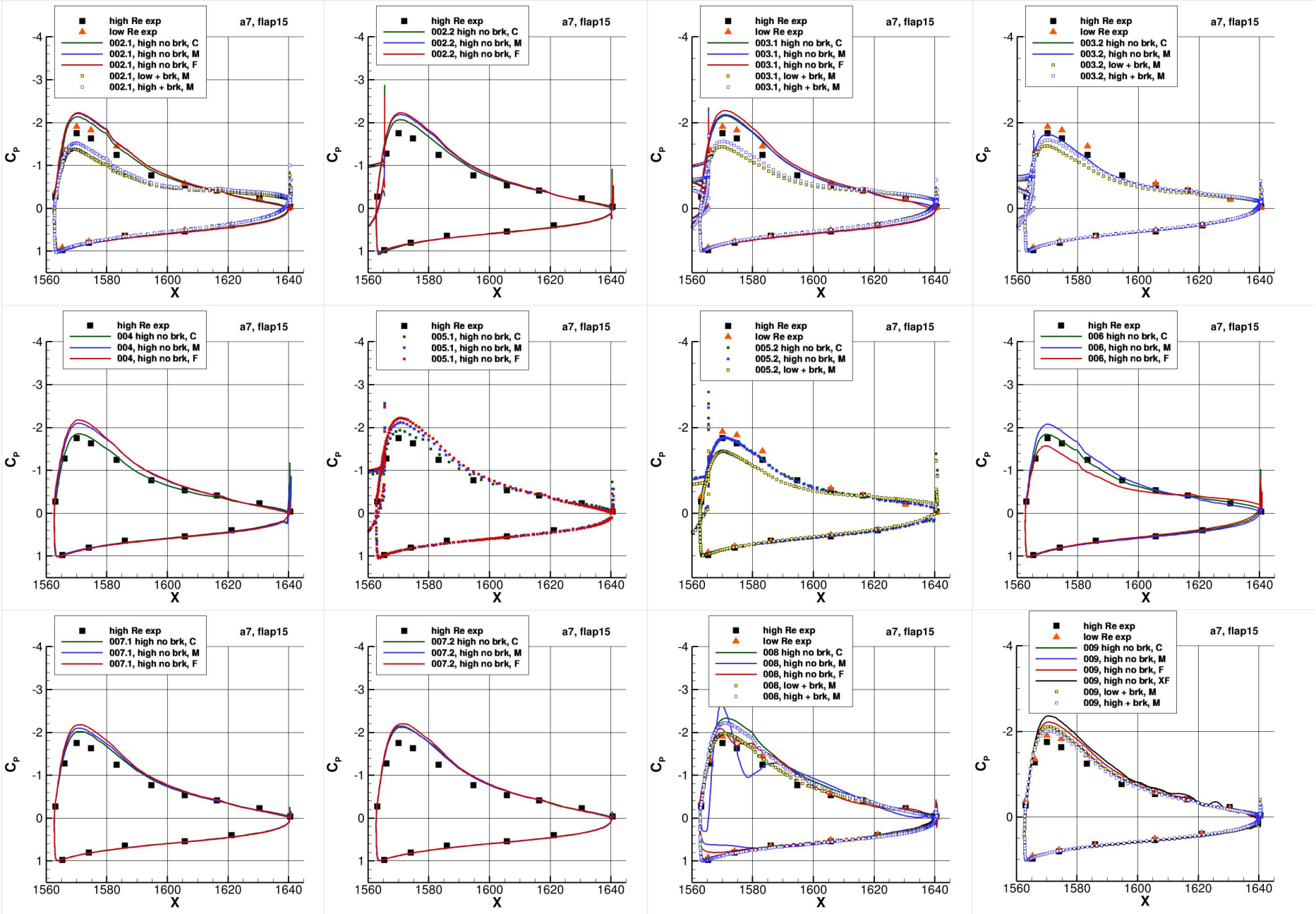


Runs w brackets tend to do better (rear)
Less Re effect

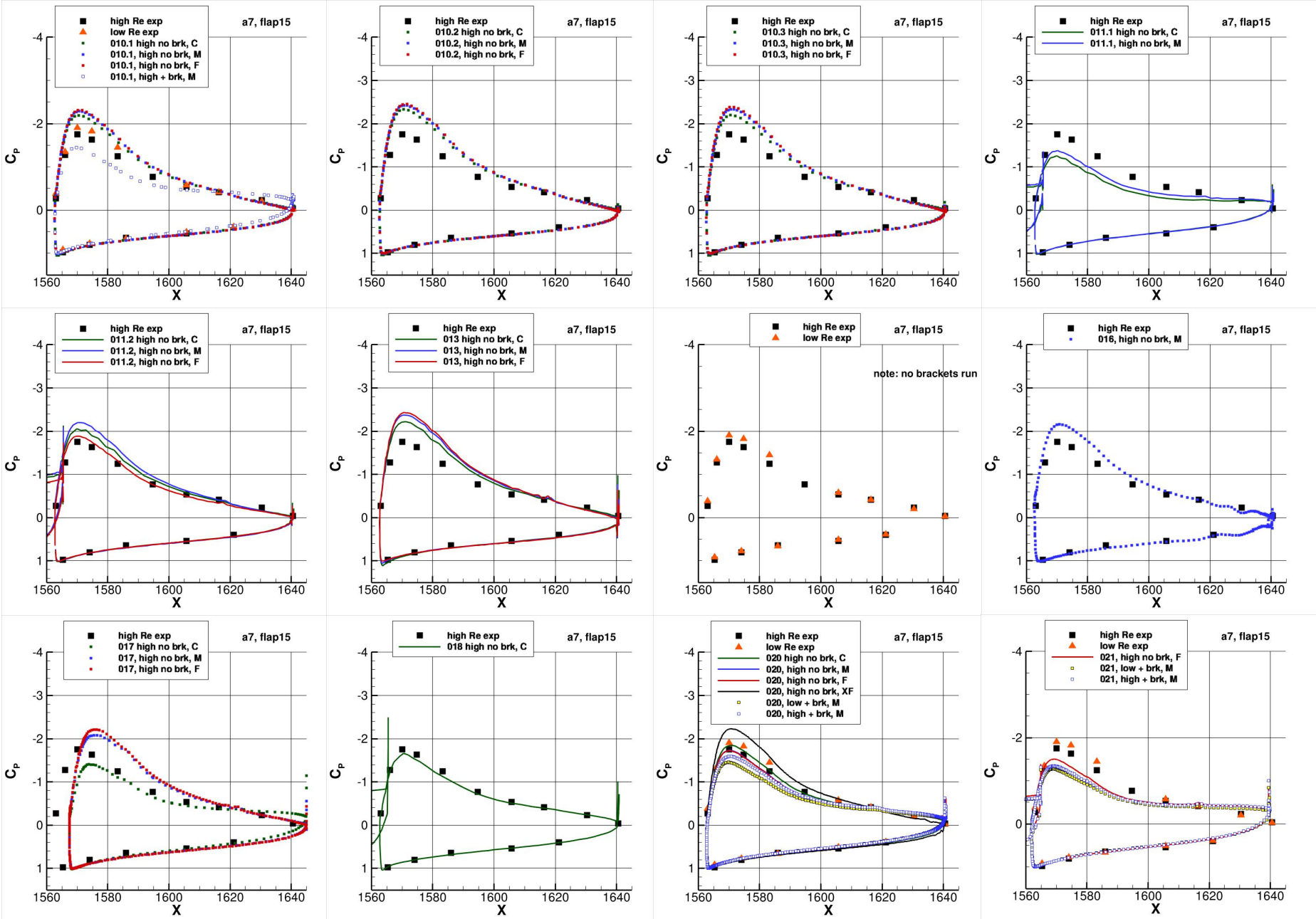
Cps at AoA=7, main96 (example)



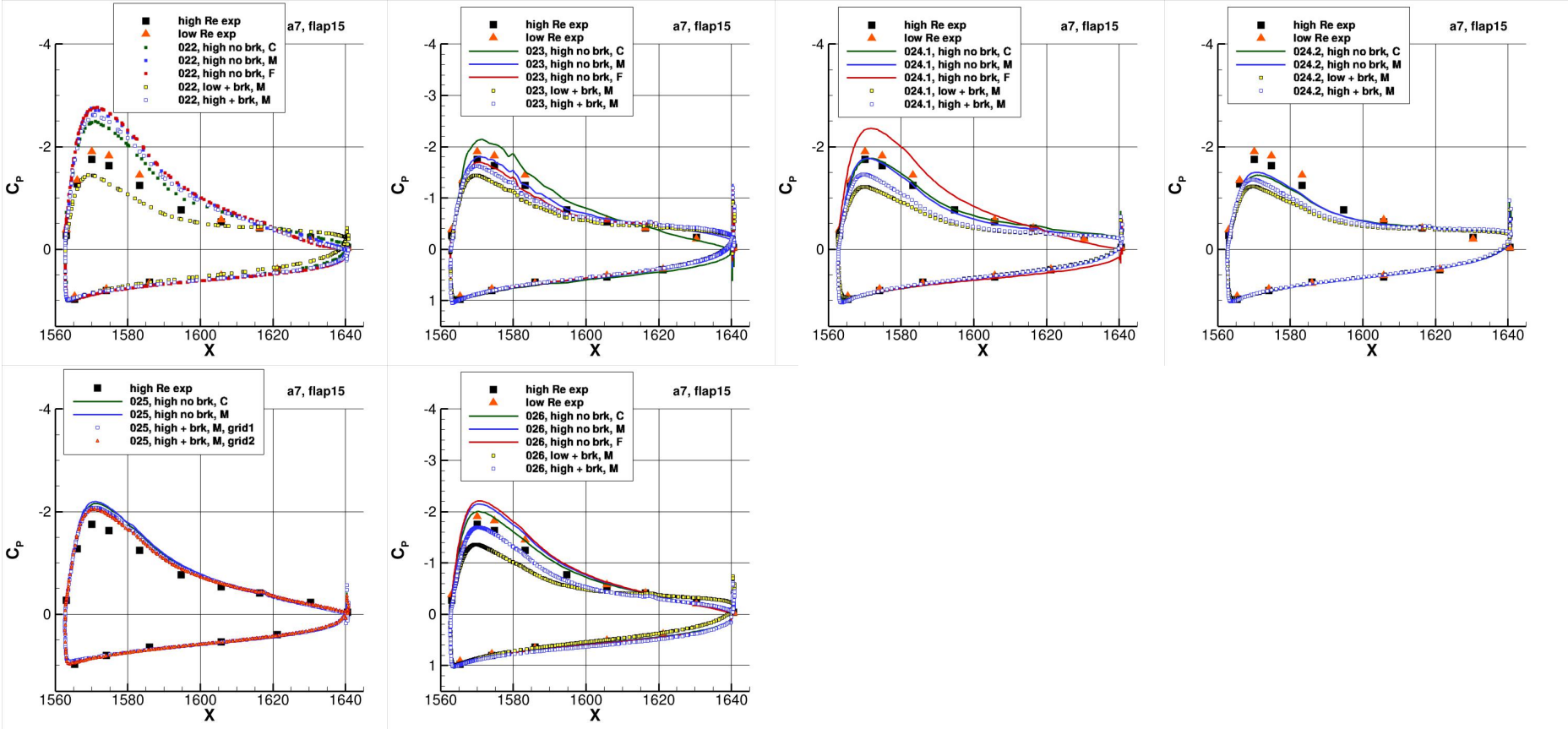
Cps at AoA=7, flap15



Cps at AoA=7, flap15

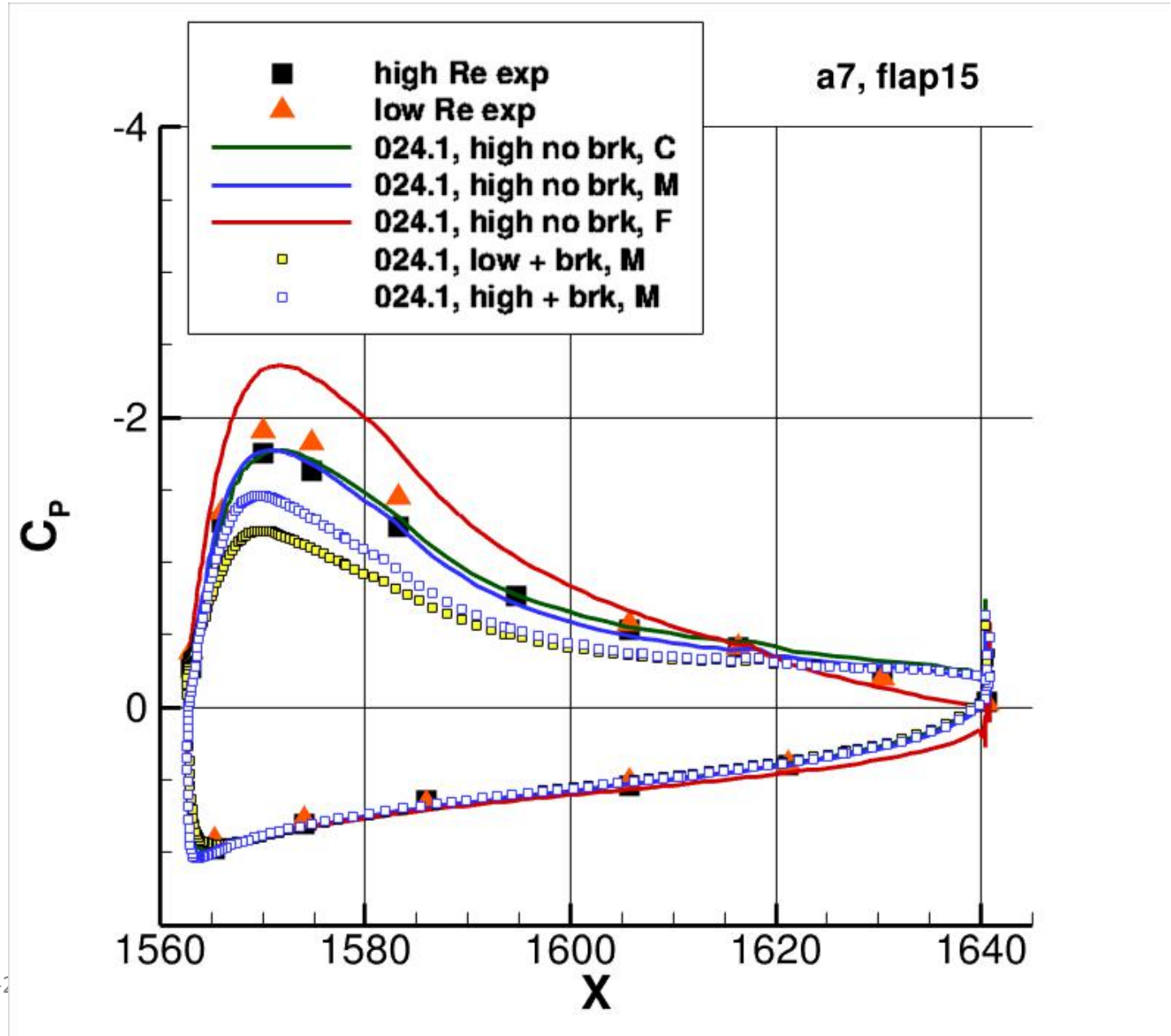


Cps at AoA=7, flap15

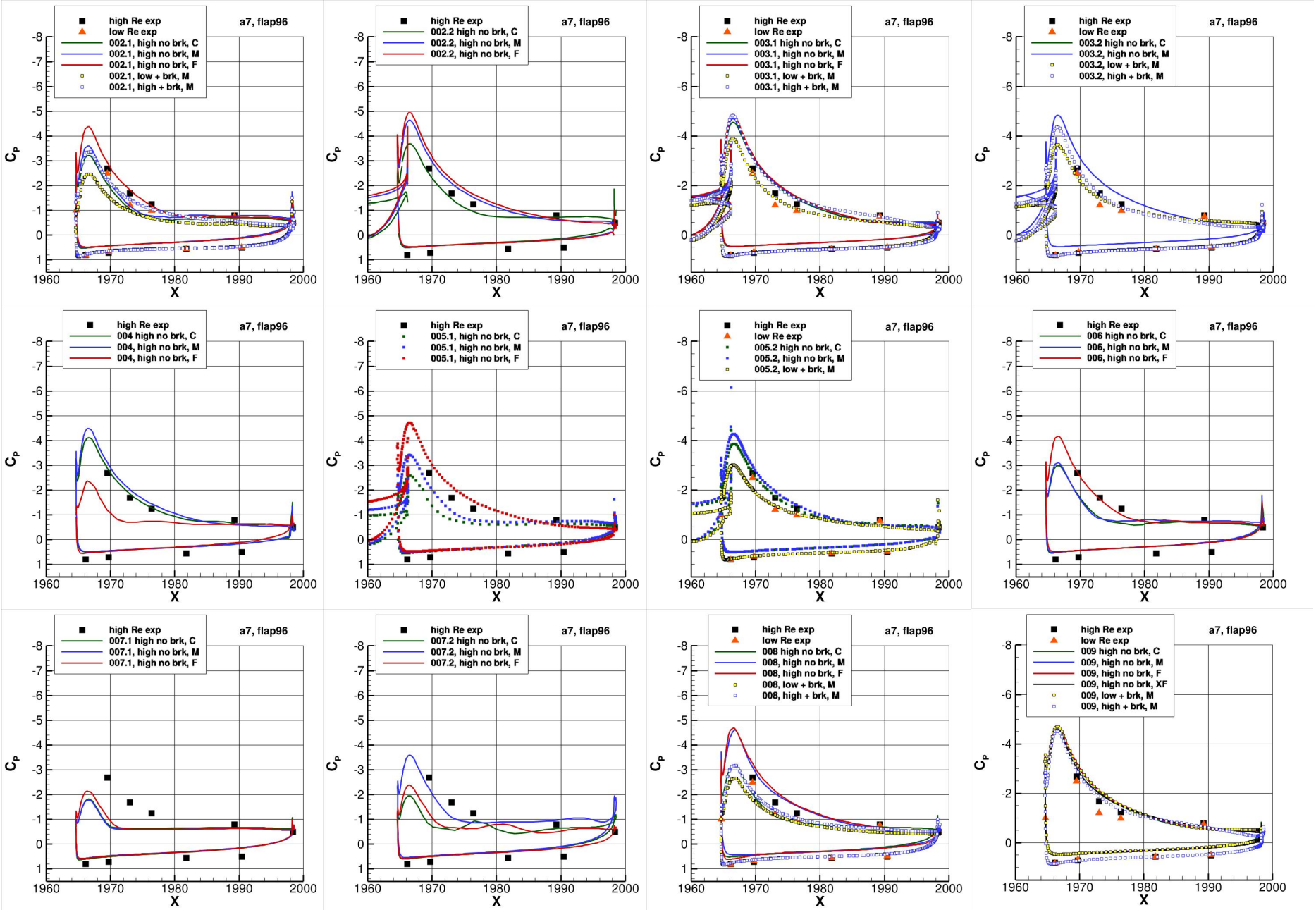


This station difficult to capture
Peak tends to be too great w/o brackets
… too low with brackets

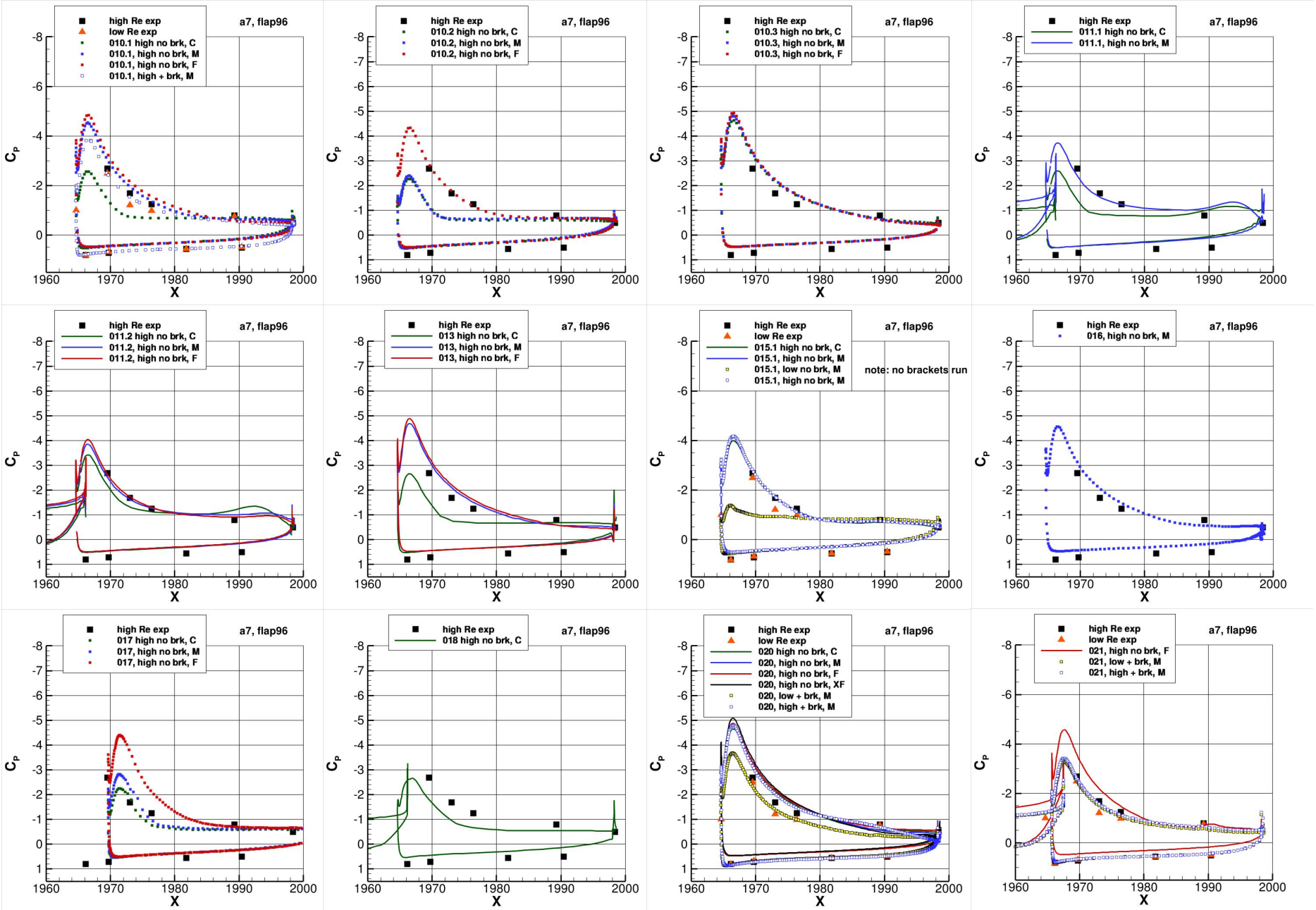
Cps at AoA=7, flap15 (example)



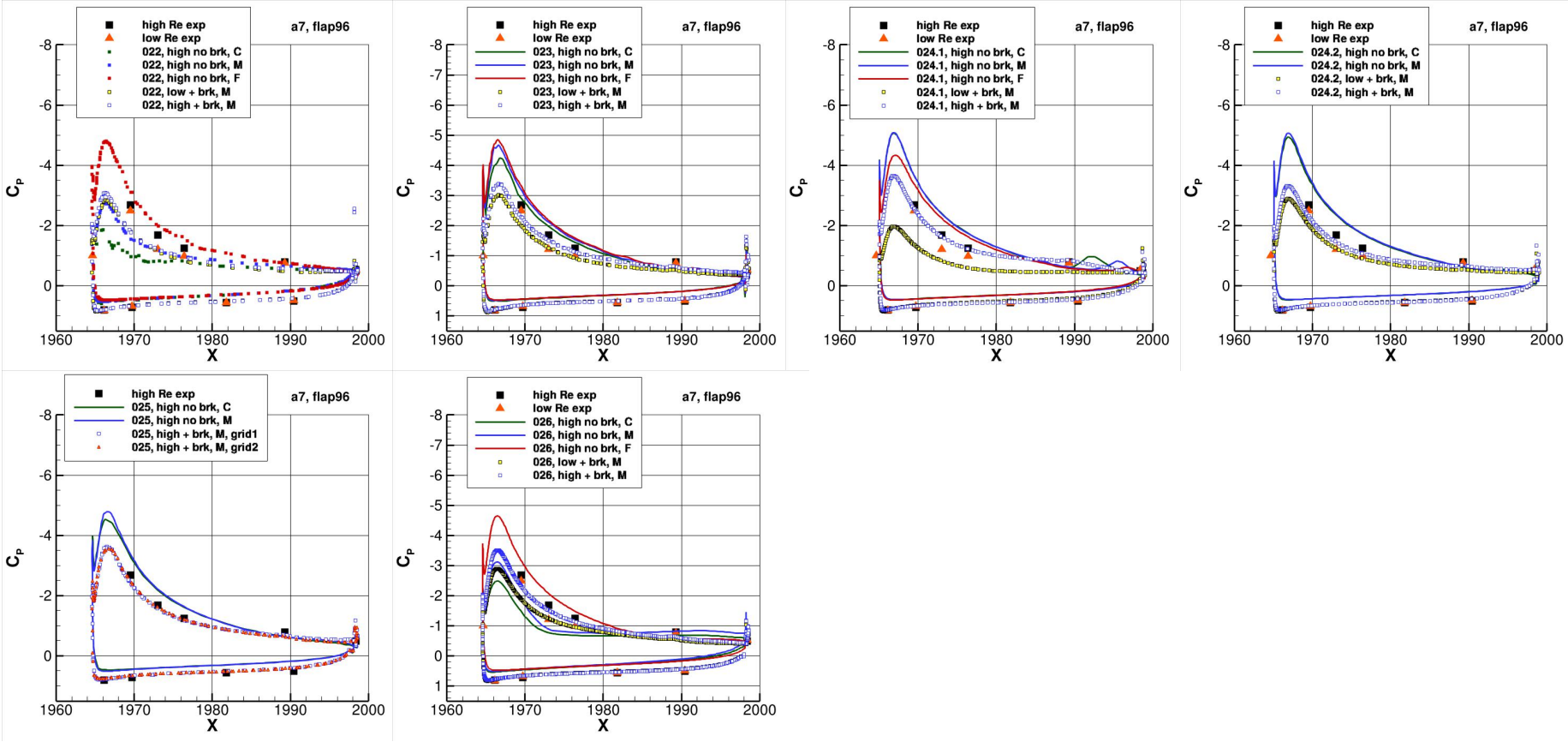
Cps at AoA=7, flap96



Cps at AoA=7, flap96

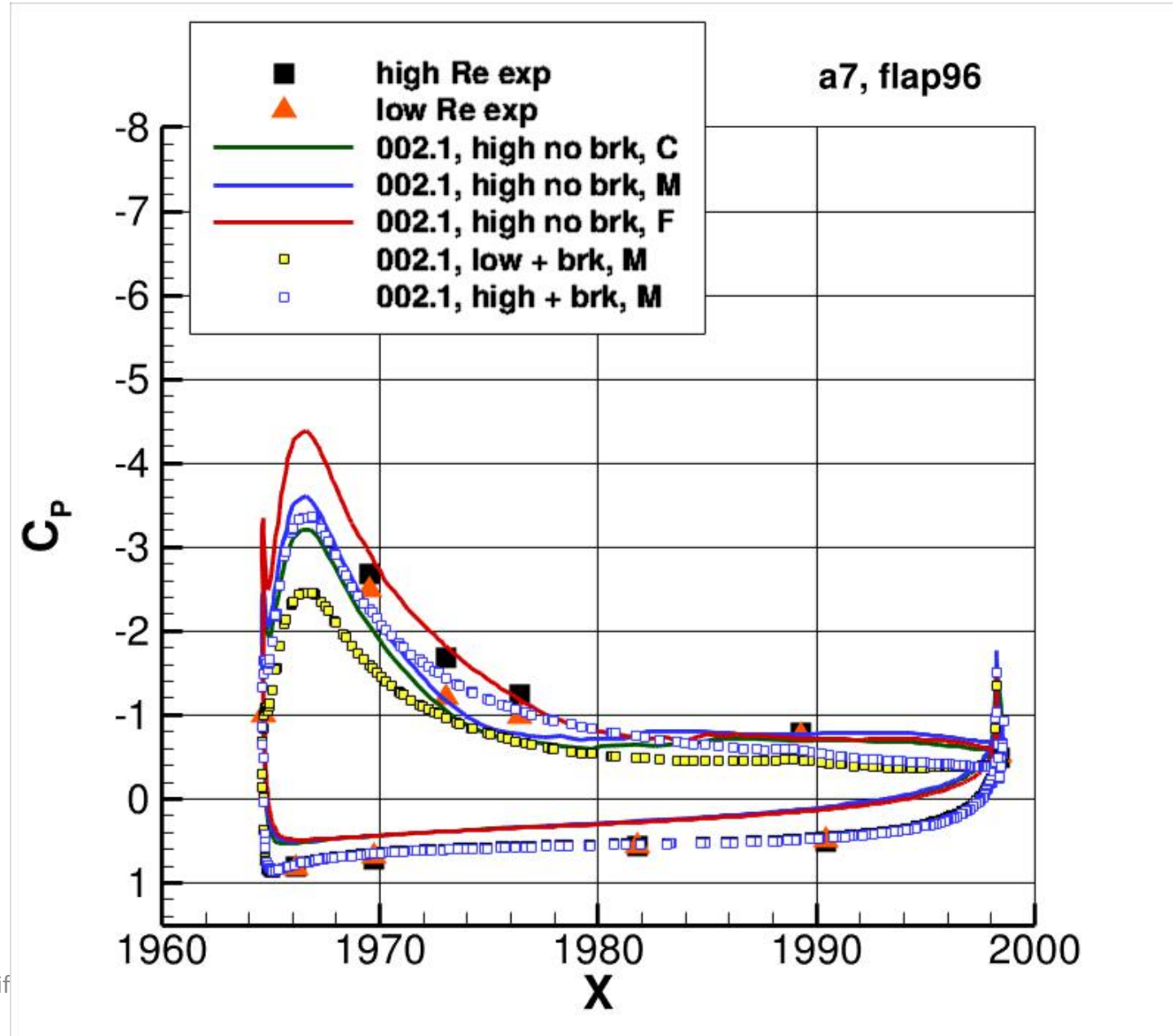


Cps at AoA=7, flap96



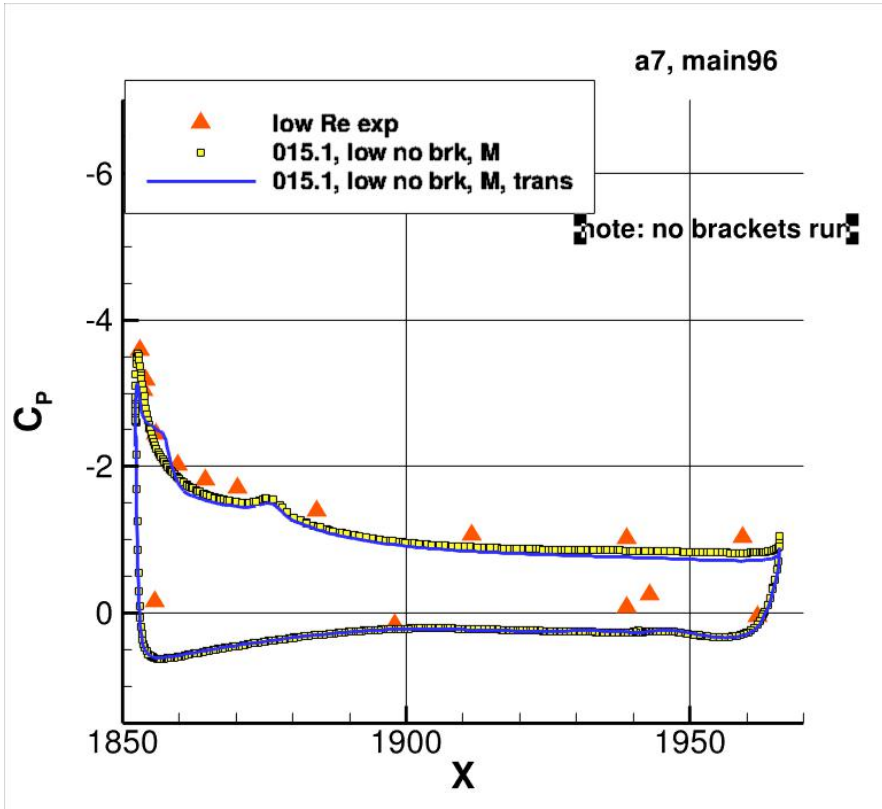
This station difficult to capture
More variation between results here
Runs w brackets tend to do better (esp lower surface)
Re effect qualitatively captured by some
Several results: massive separation

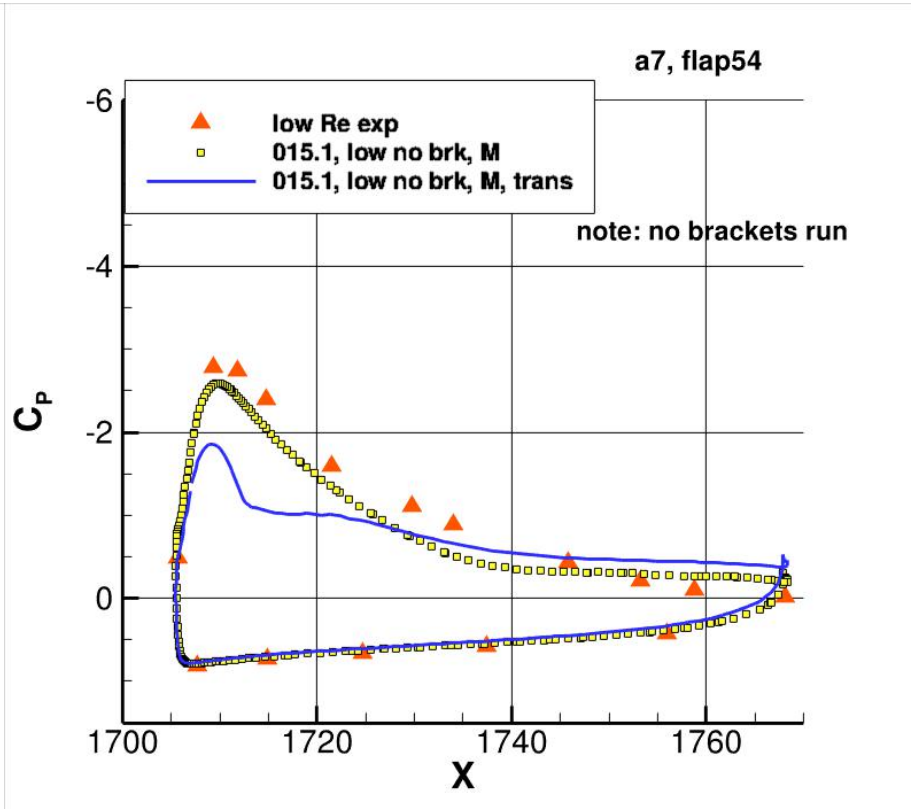
Cps at AoA=7, flap96 (example)



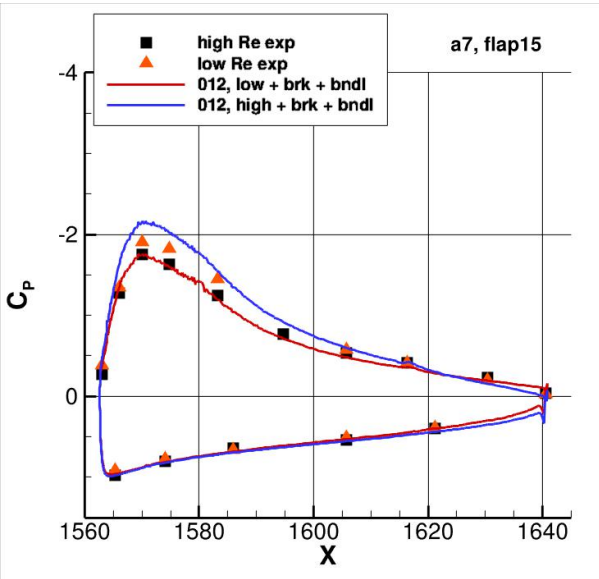
Transition effect at AoA=7

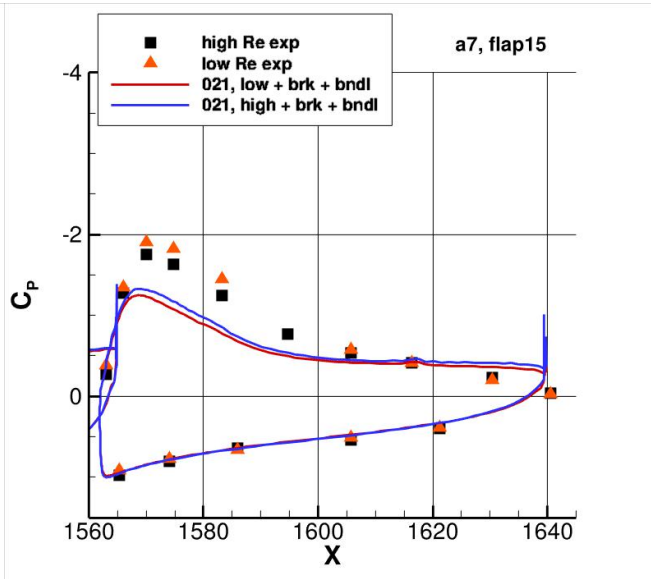
(Only one participant with readable Cp file at AoA=7)

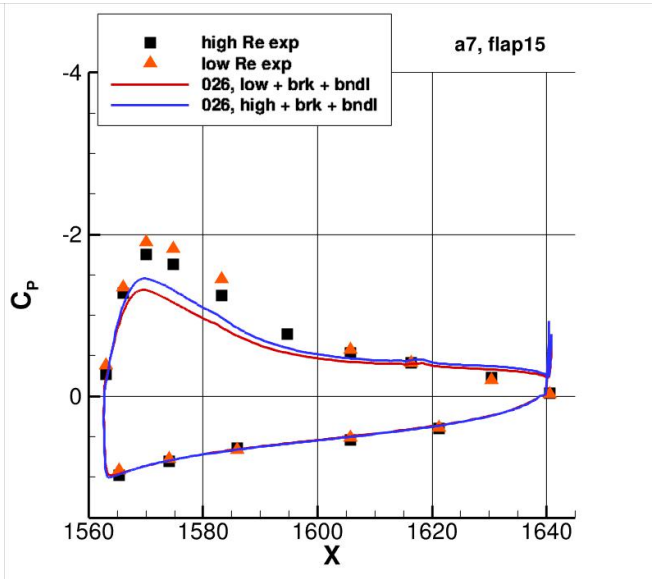




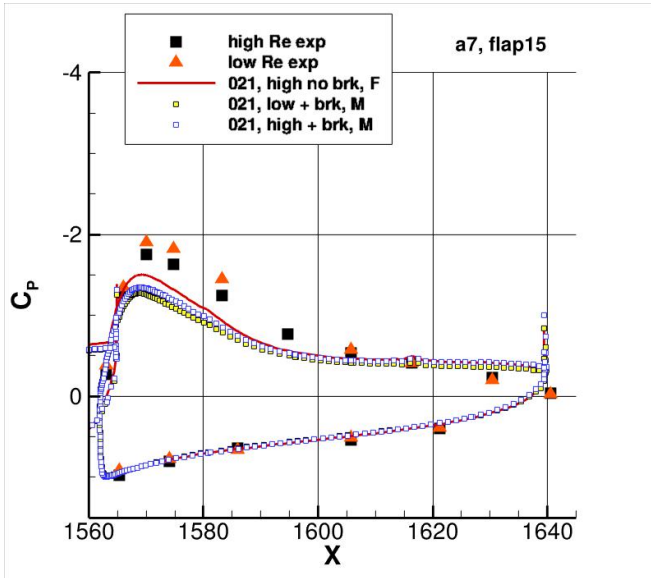
Results with brackets and bundles, AoA=7

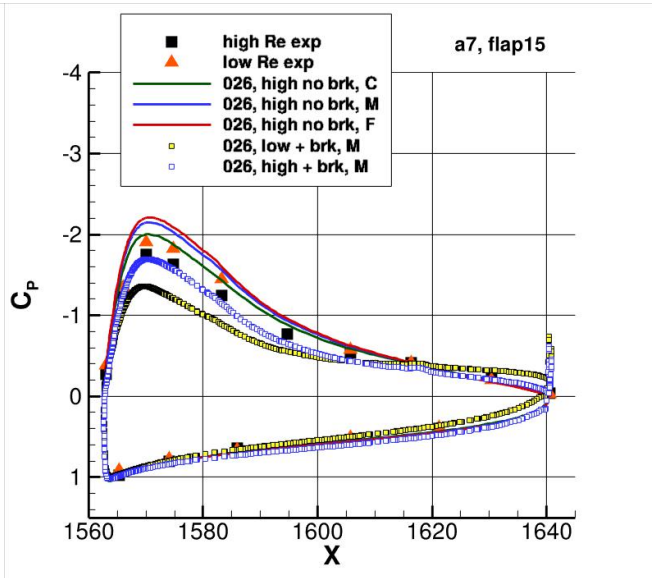




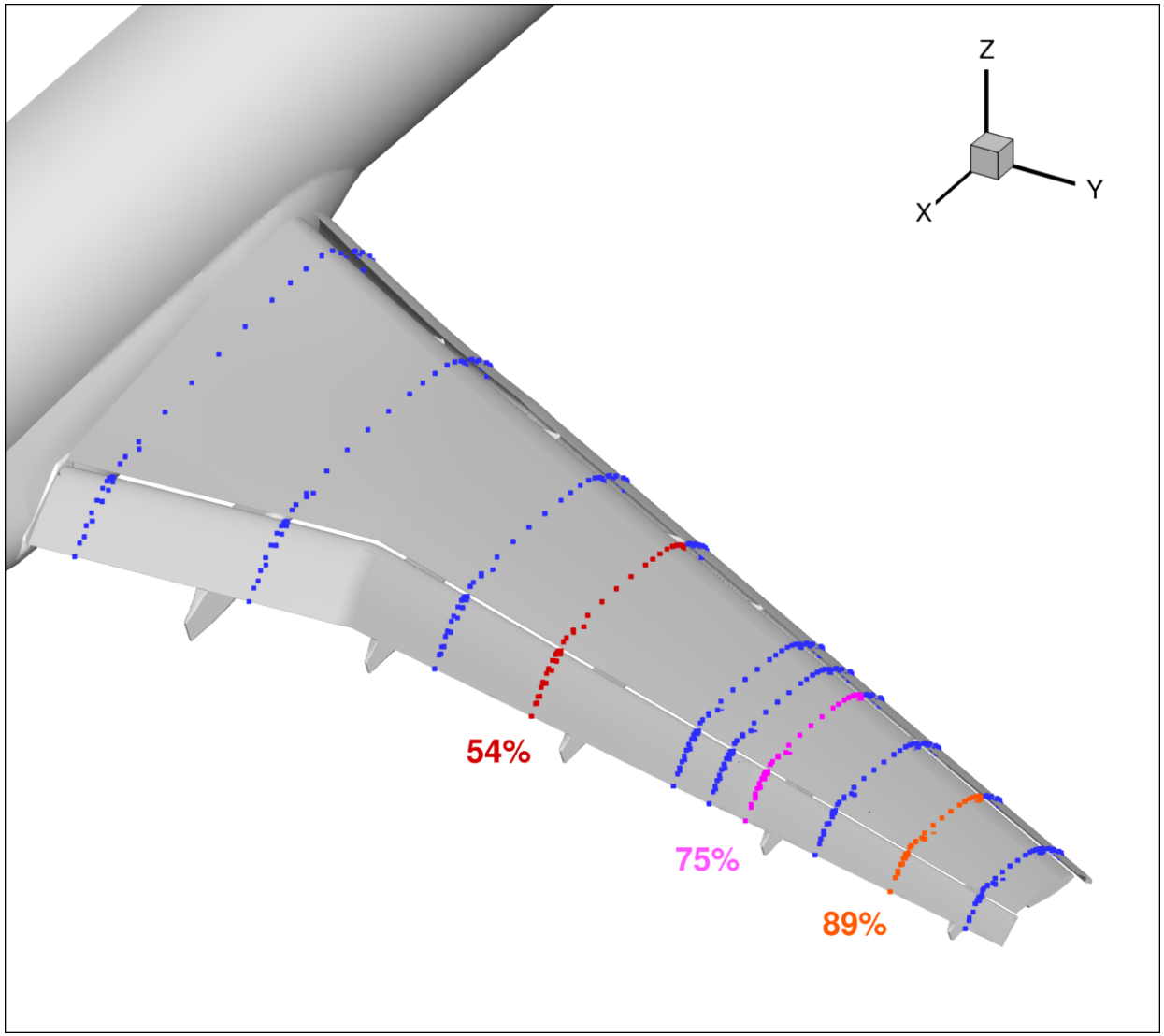


Results cases 1 and 2 (no bundles):



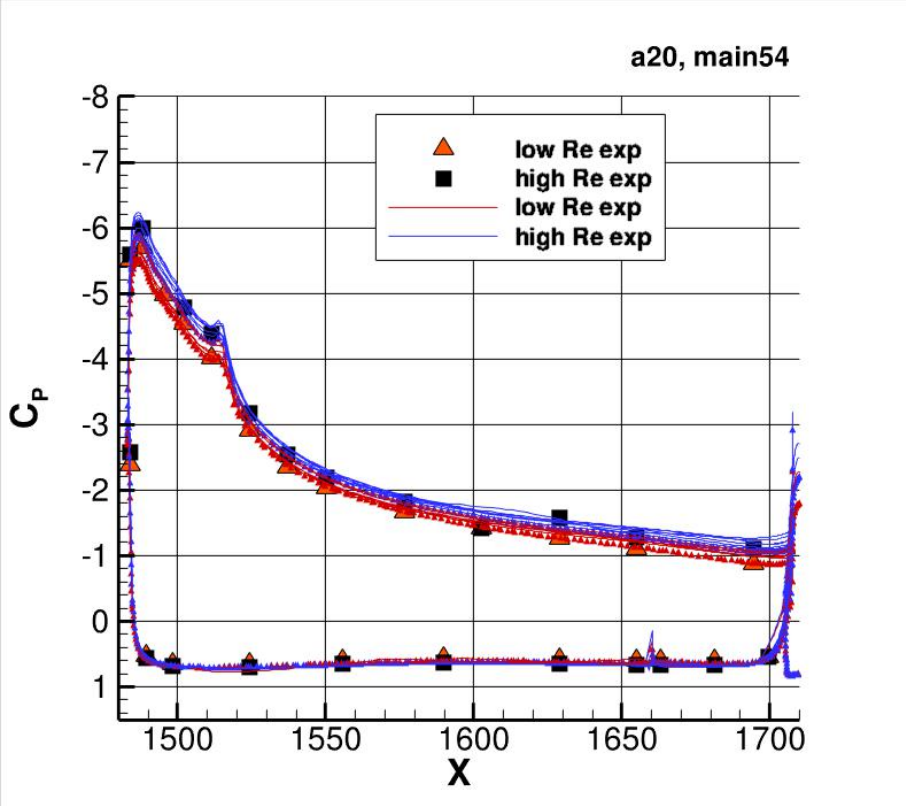


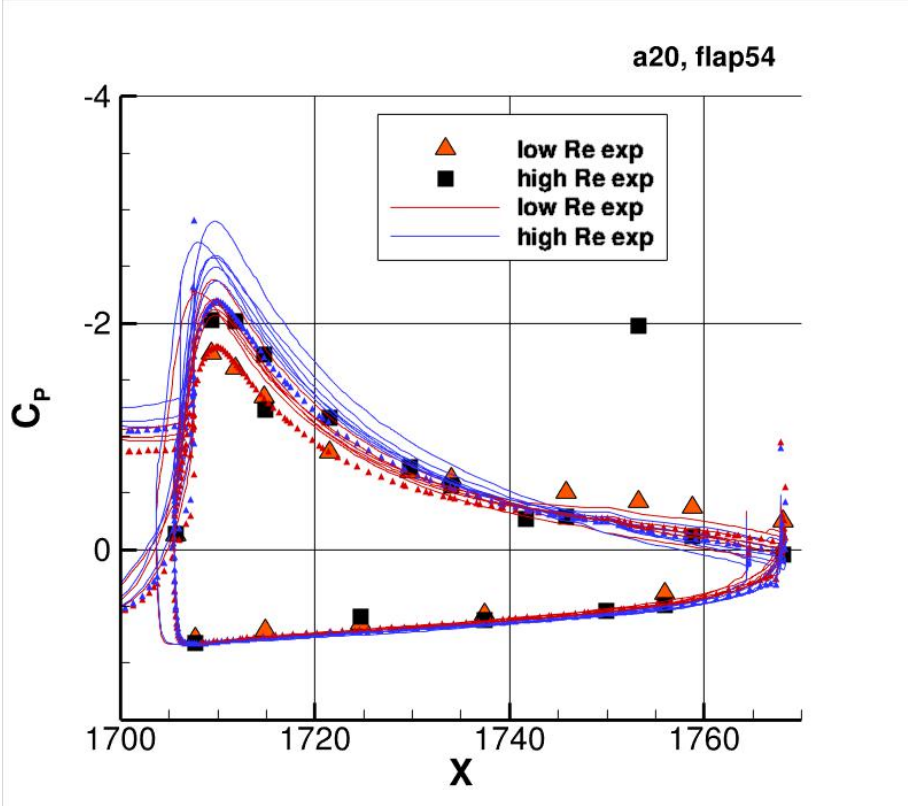
Surface pressure coefficients, AoA=20



Cps at AoA=20, 54%

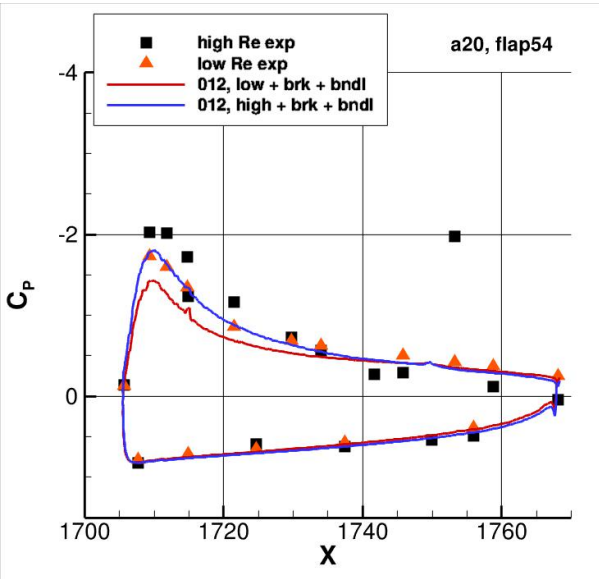
Trend with Re seen
Consistent results on main; more spread in CFD results on flap

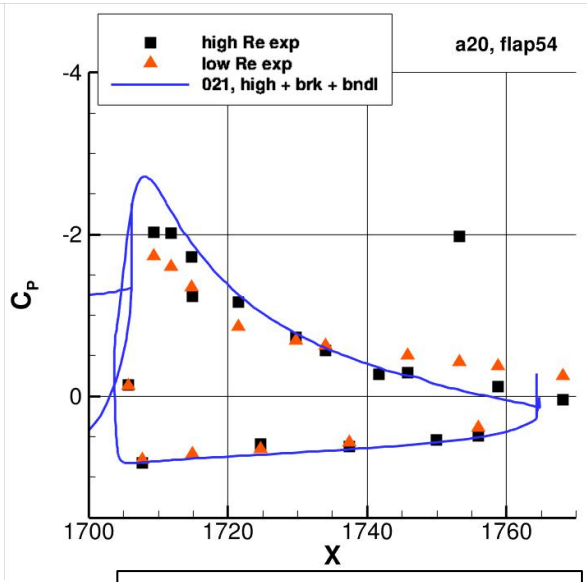


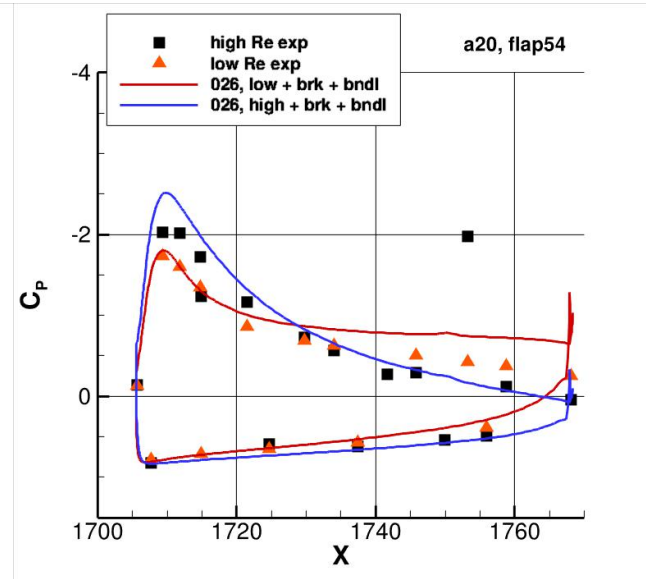


Note: only a sampling of CFD solutions w brackets taken

Results with brackets and bundles, AoA=20, 54%

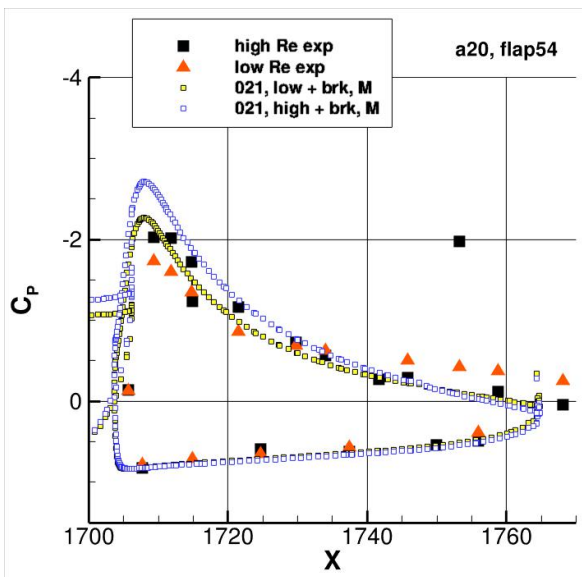


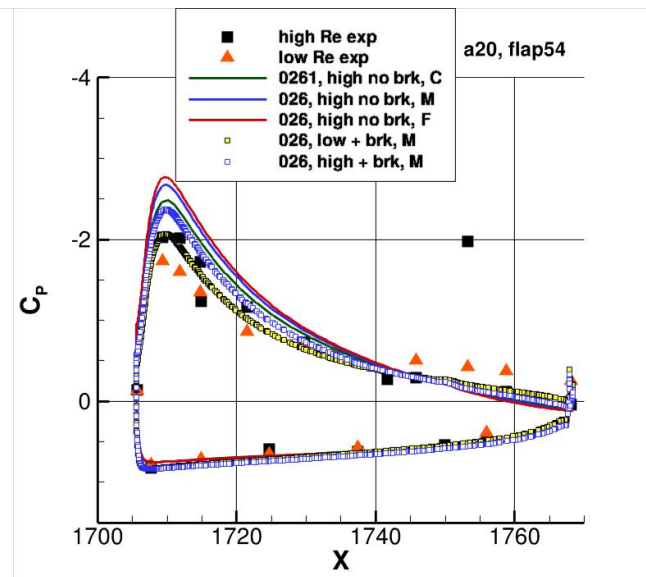




Shift in 0021's x here!

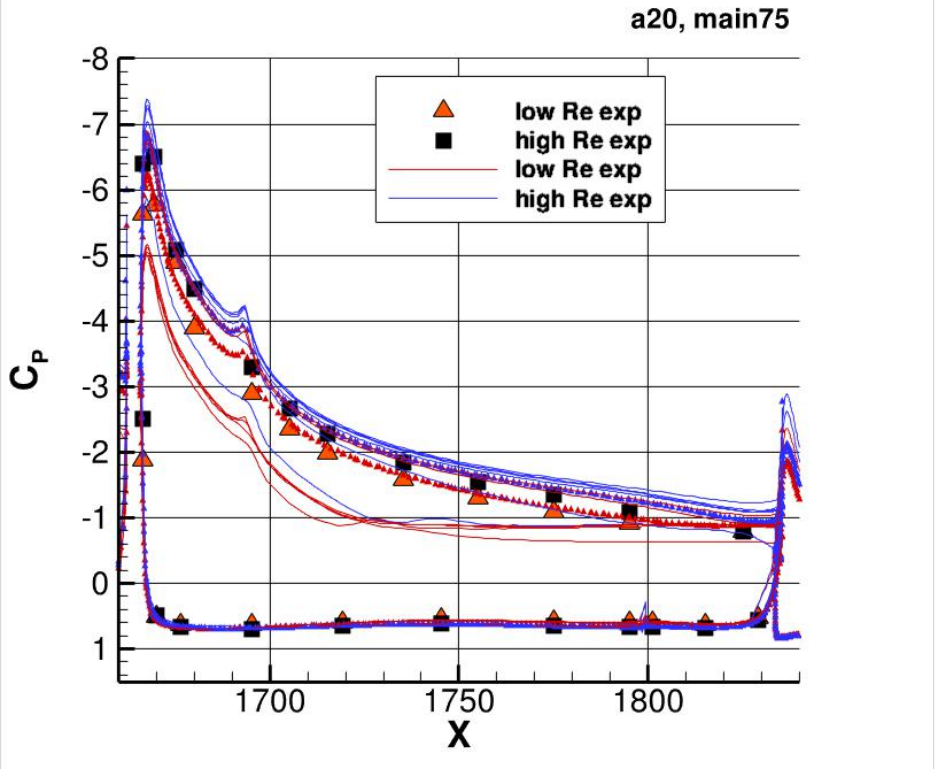
Results cases 1 and 2 (no bundles):

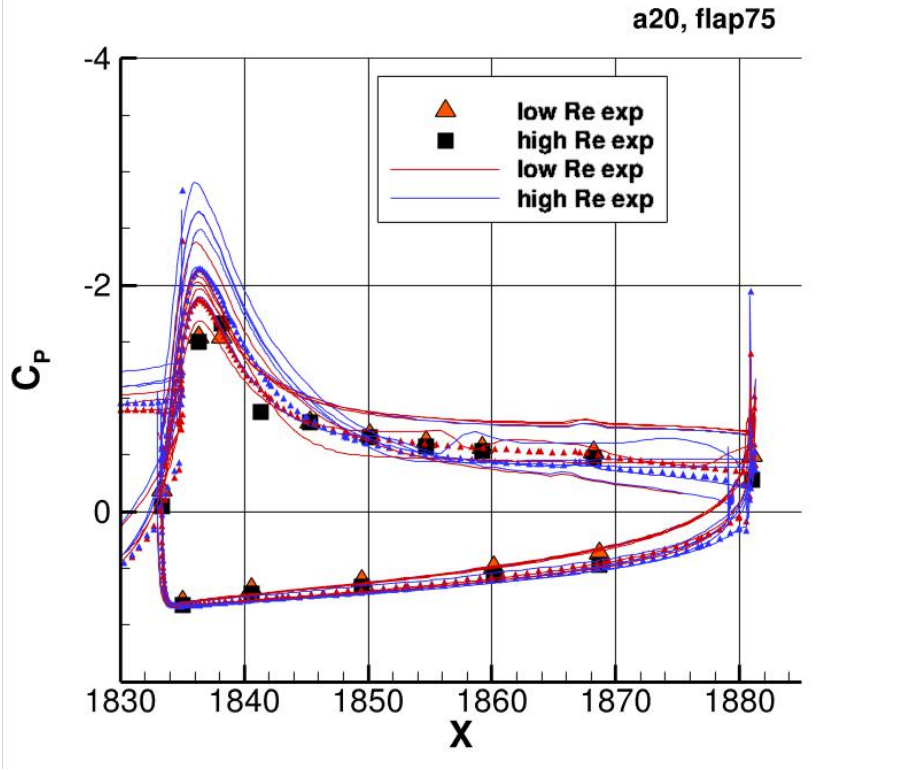




Cps at AoA=20, 75%

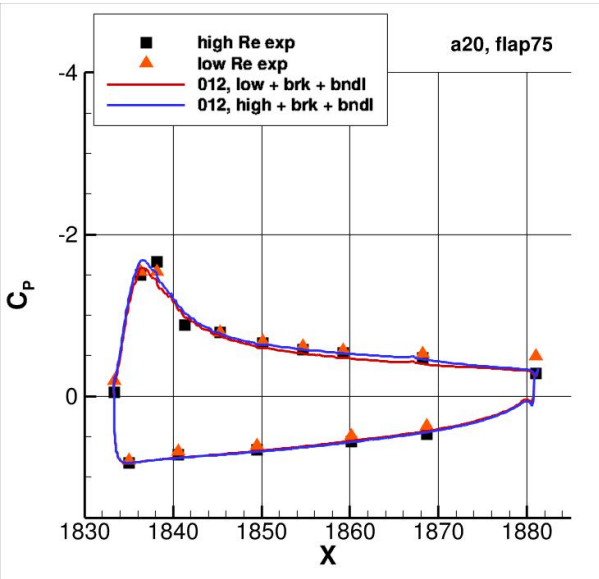
Trend with Re seen
Inconsistent results on main; some CFD shows massive separation
Considerable spread in CFD results on flap

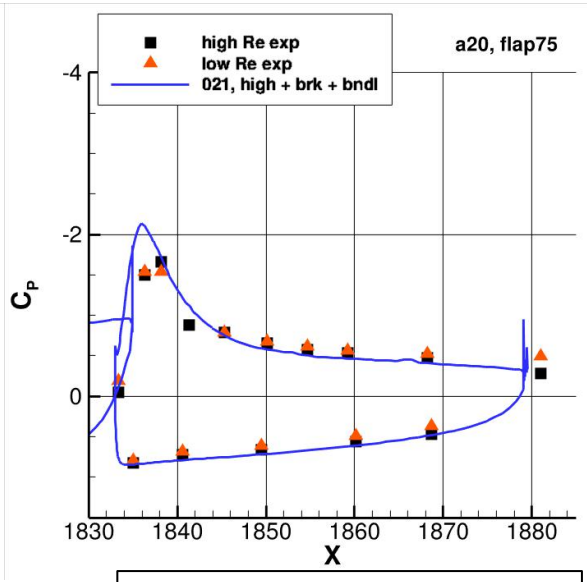


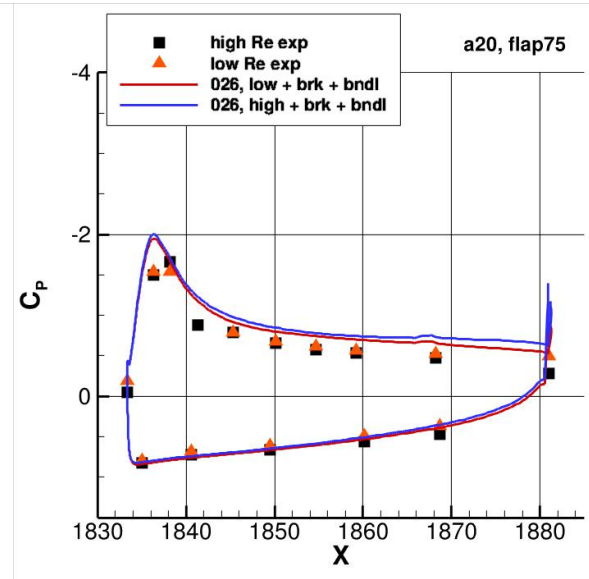


Note: only a sampling of CFD solutions w brackets taken

Results with brackets and bundles, AoA=20, 75%

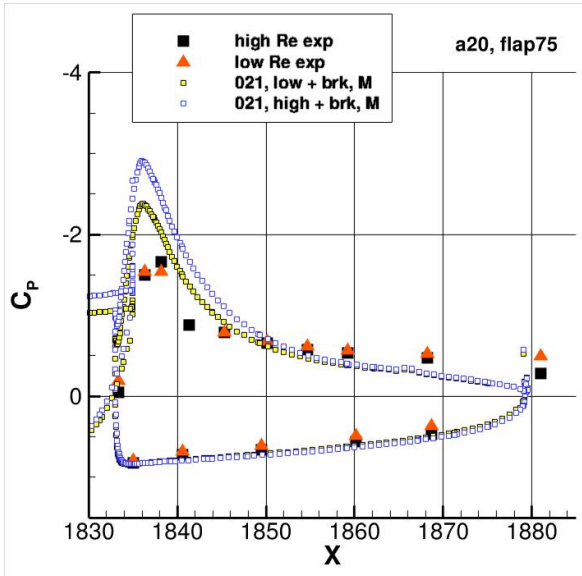


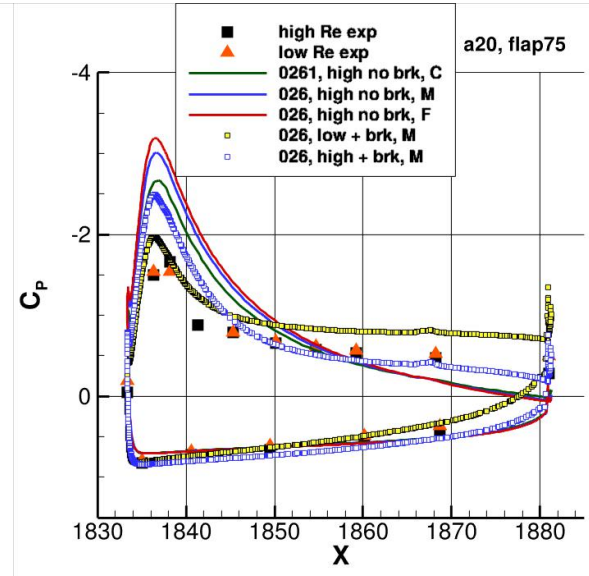




Shift in 0021's x here!

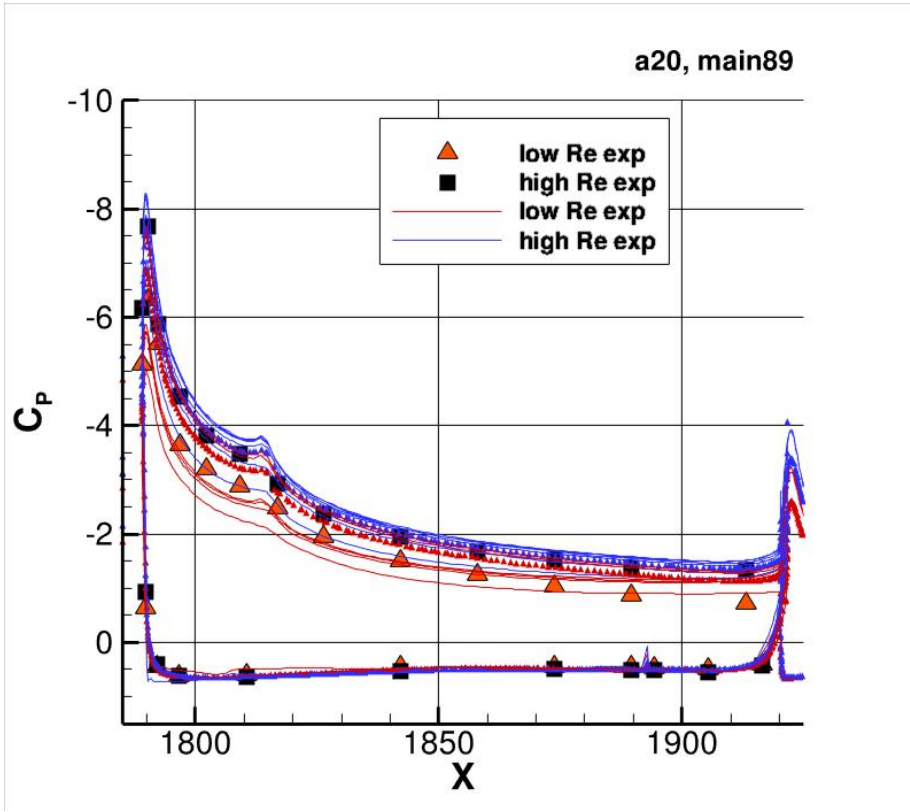
Results cases 1 and 2 (no bundles):

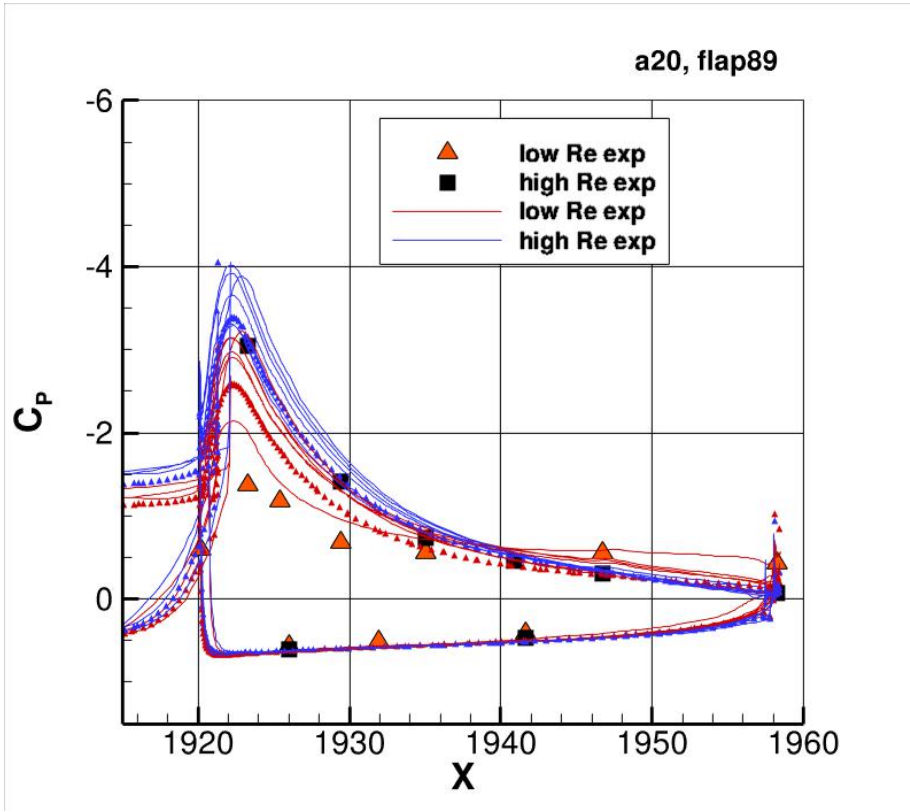




Cps at AoA=20, 89%

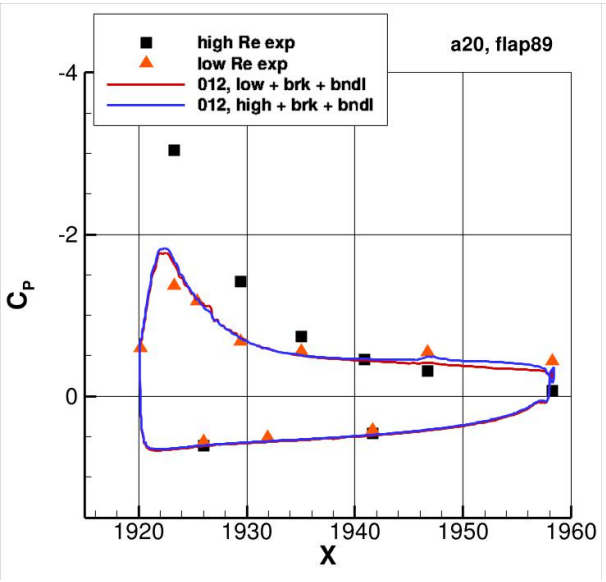
Trend with Re seen
Considerable spread in CFD results, especially at low Re

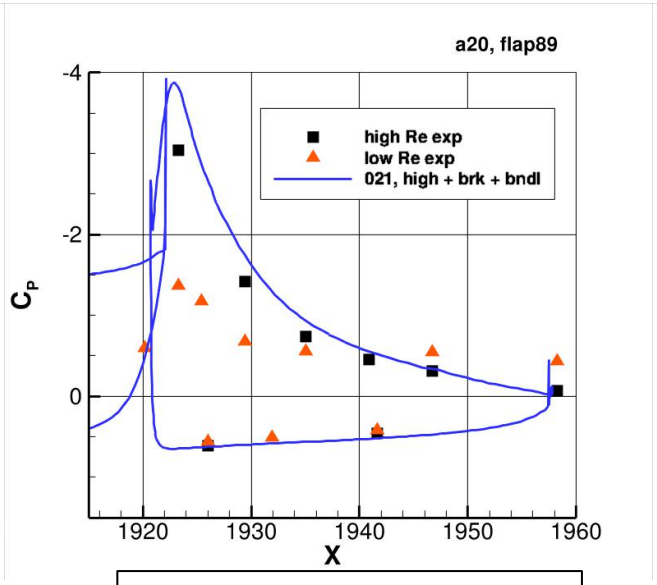


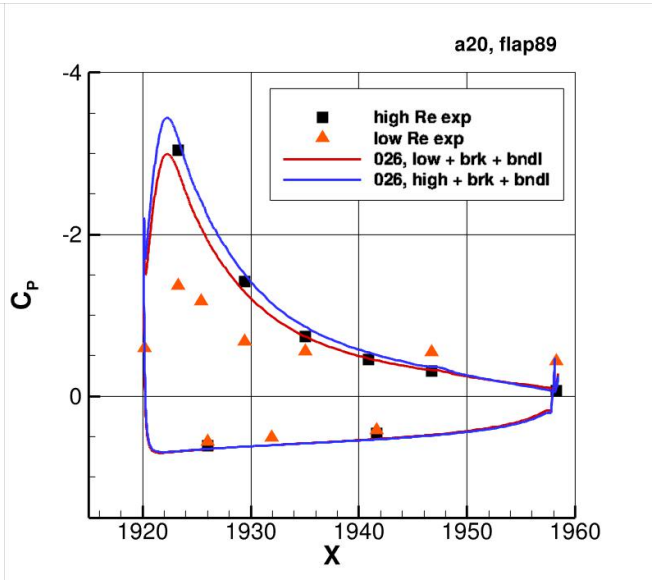


Note: only a sampling of CFD solutions w brackets taken

Results with brackets and bundles, AoA=20, 89%

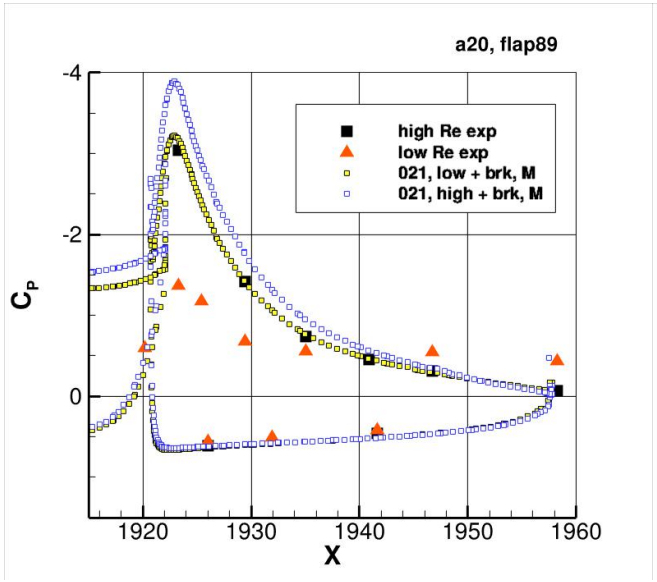


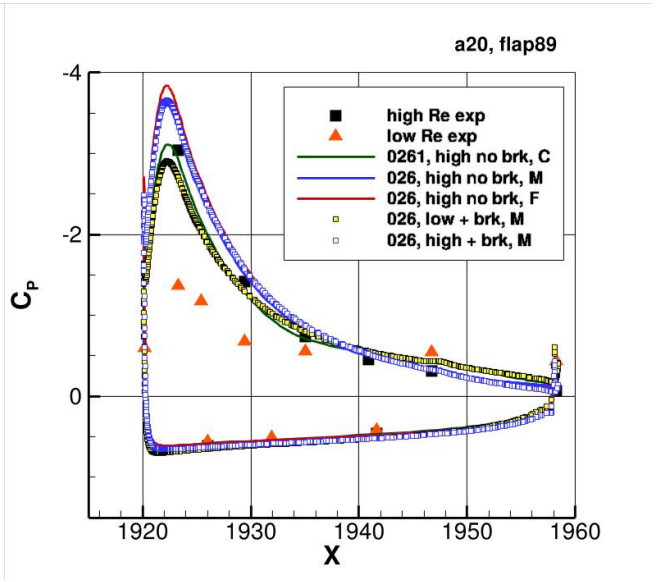




Shift in 0021's x here!

Results cases 1 and 2 (no bundles):



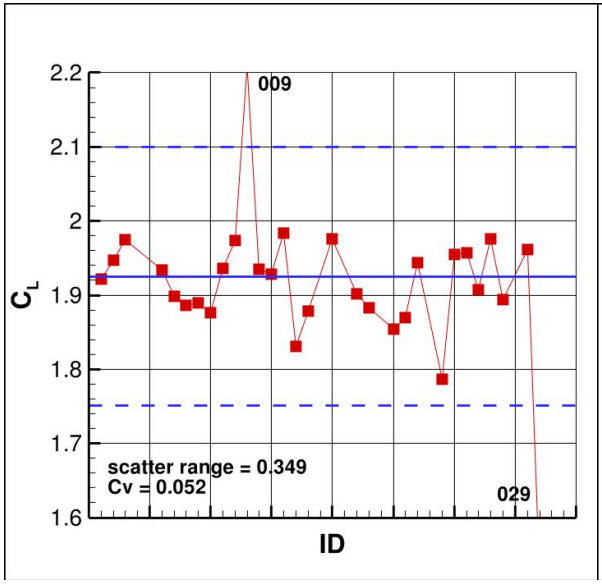


Force/moment statistics

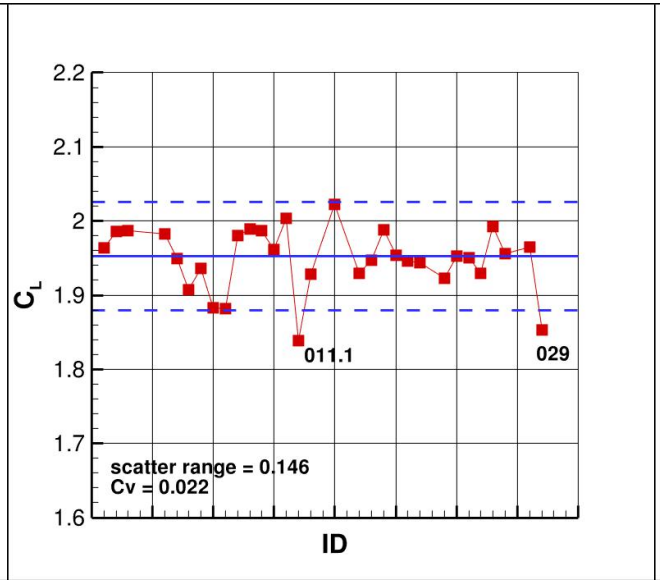
- Used basic method from DPW (see AIAA 2010-4673)
- Limits $\hat{\mu} \pm K\hat{\sigma}$
  - $\hat{\mu}$ = median of sorted data
  - $\hat{\sigma}$ = sample standard deviation
  - $K = \sqrt{3}$ = coverage factor
- Coefficient of variation Cv = $\hat{\sigma} / \hat{\mu}$

Case 1 C_L statistics, AoA=7

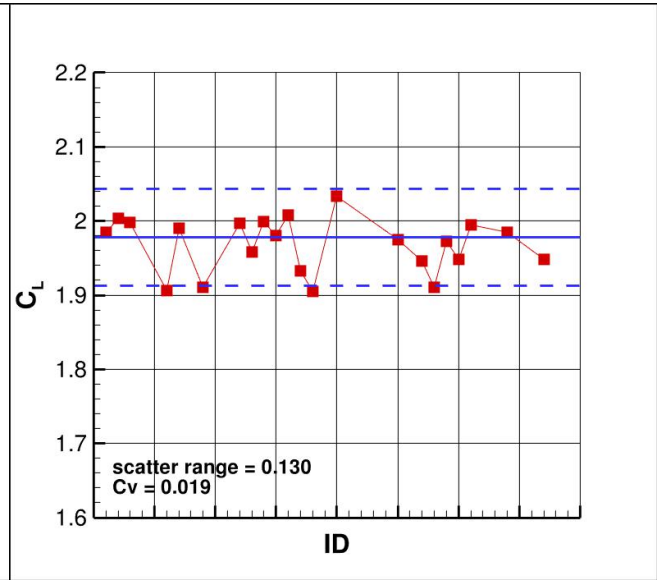
COARSE



MEDIUM



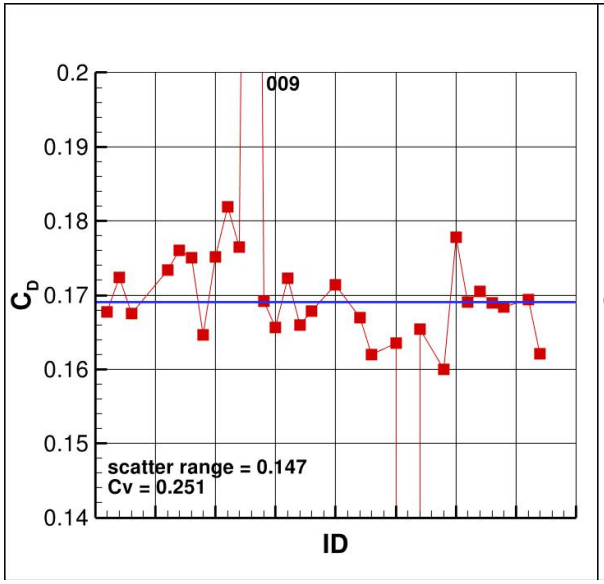
FINE



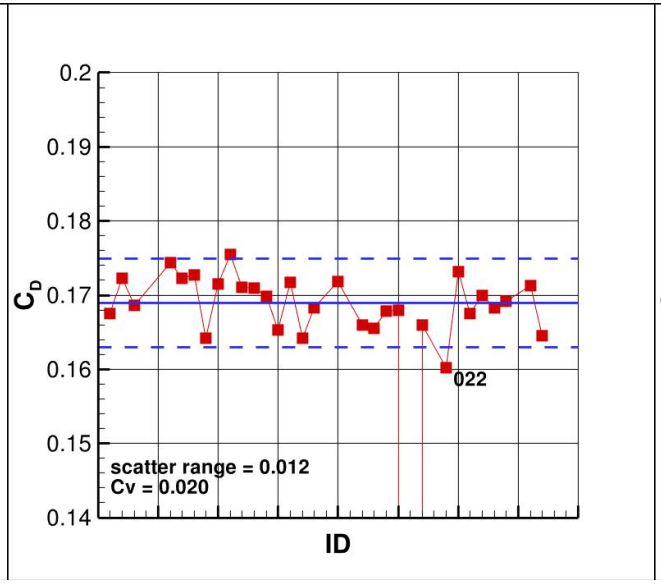
Scatter range decreases as grid is refined

Case 1 C_D statistics, AoA=7

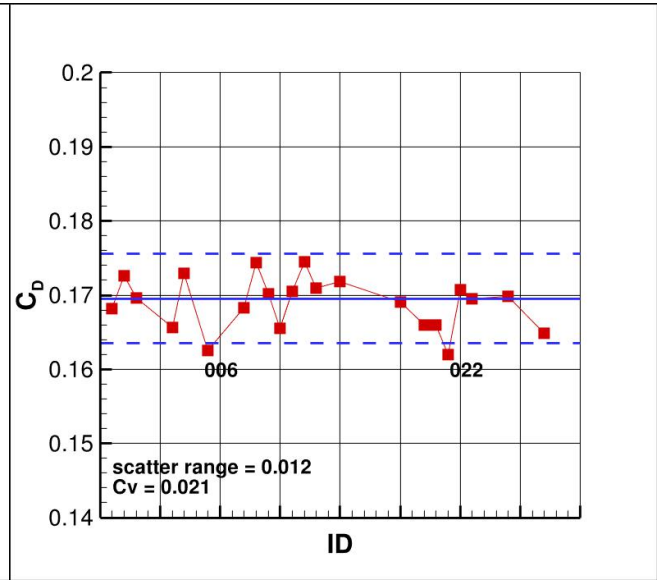
COARSE



MEDIUM



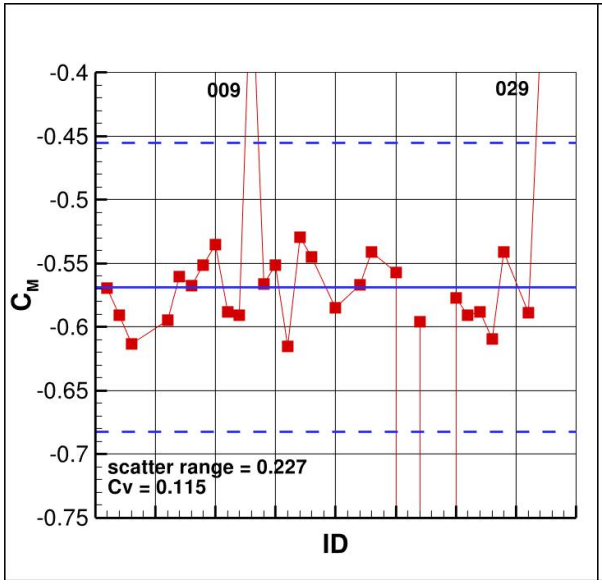
FINE



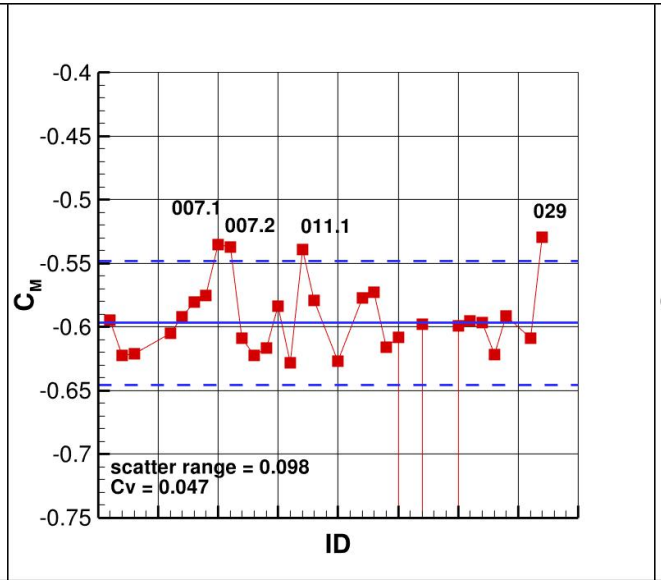
Scatter range is the same on medium and fine grids

Case 1 C_M statistics, AoA=7

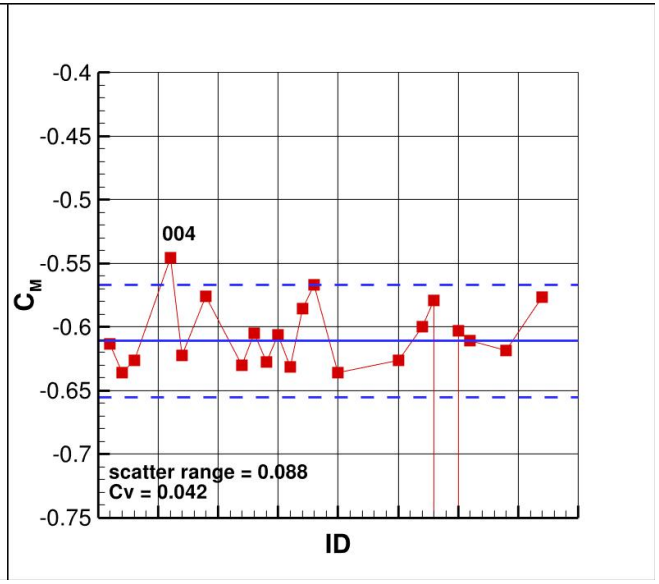
COARSE



MEDIUM



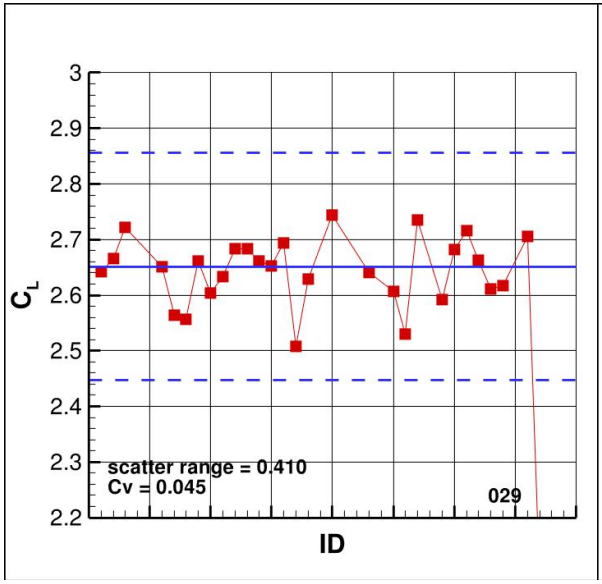
FINE



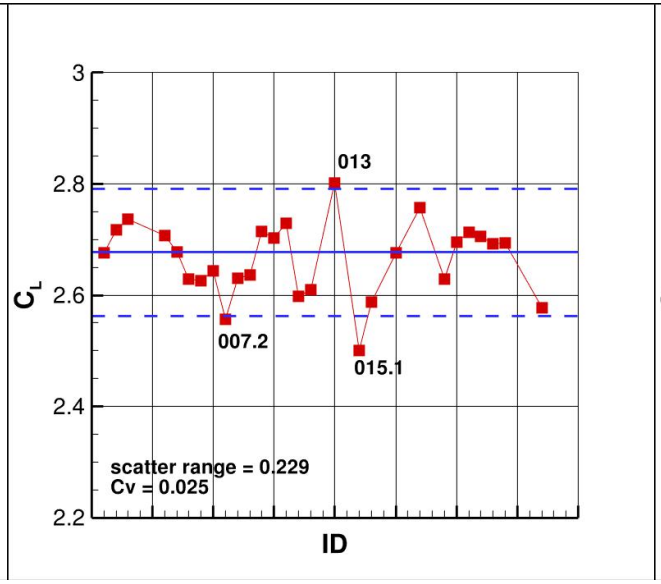
Scatter range decreases as grid is refined

Case 1 C_L statistics, AoA=16

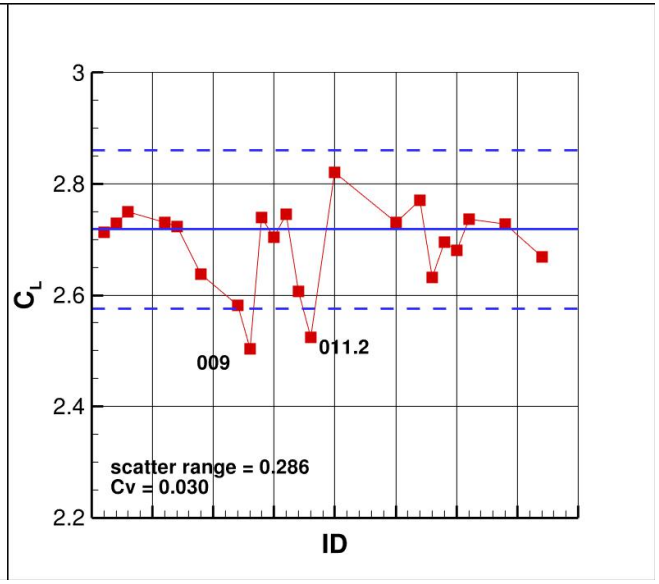
COARSE



MEDIUM



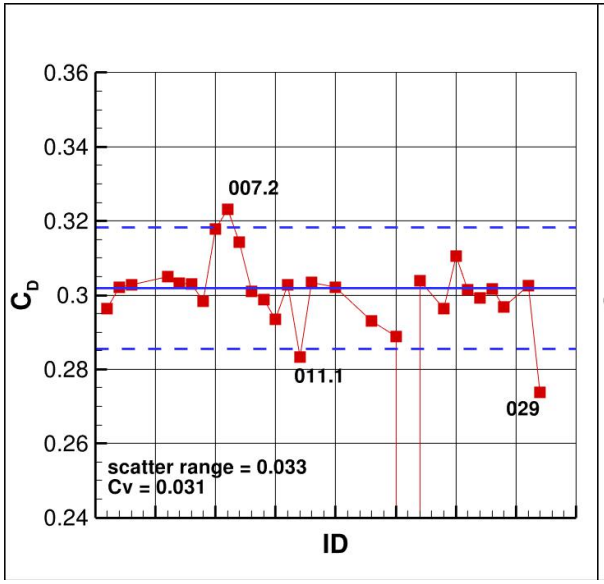
FINE



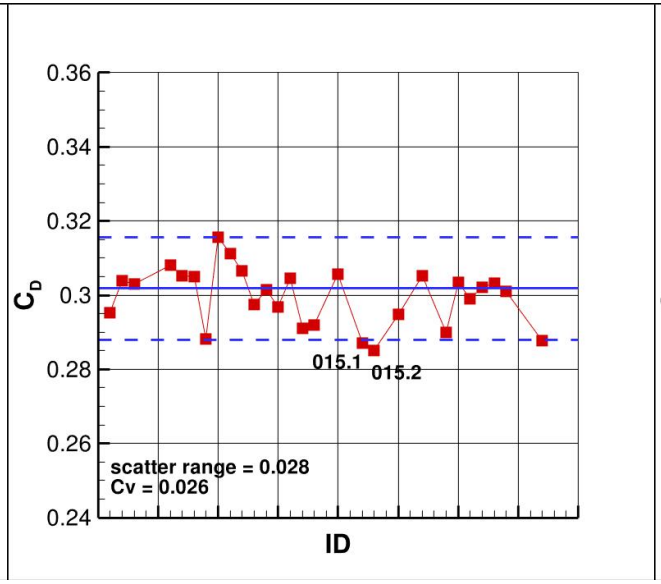
Scatter range decreases then increases as grid is refined

Case 1 C_D statistics, AoA=16

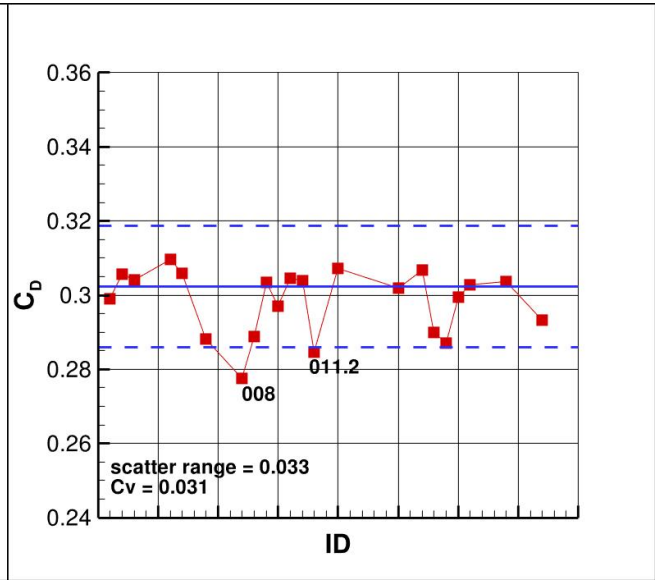
COARSE



MEDIUM



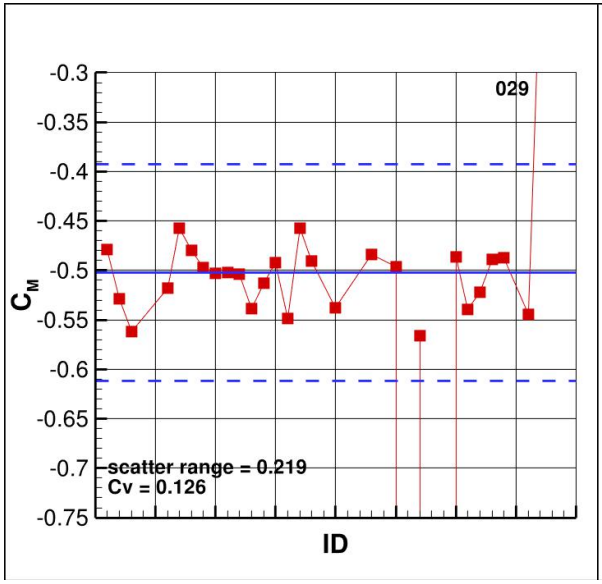
FINE



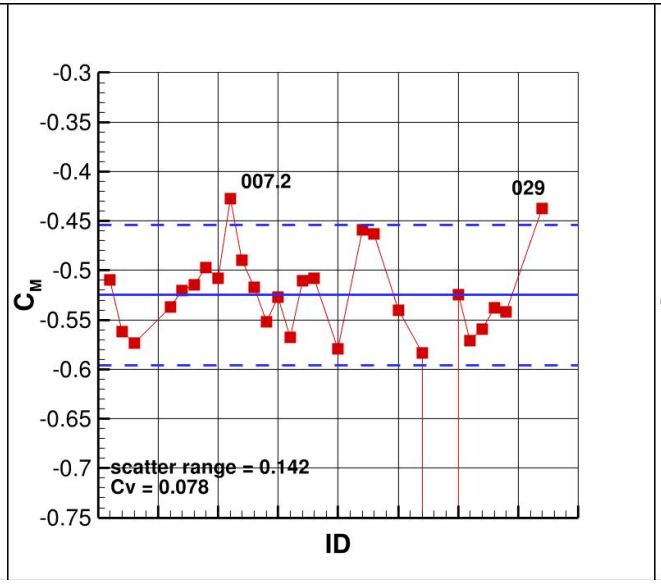
Scatter range decreases then increases as grid is refined

Case 1 C_M statistics, AoA=16

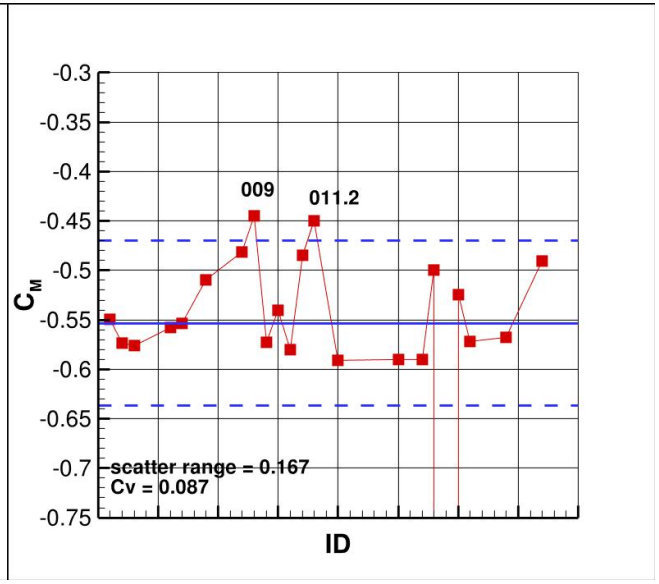
COARSE



MEDIUM



FINE



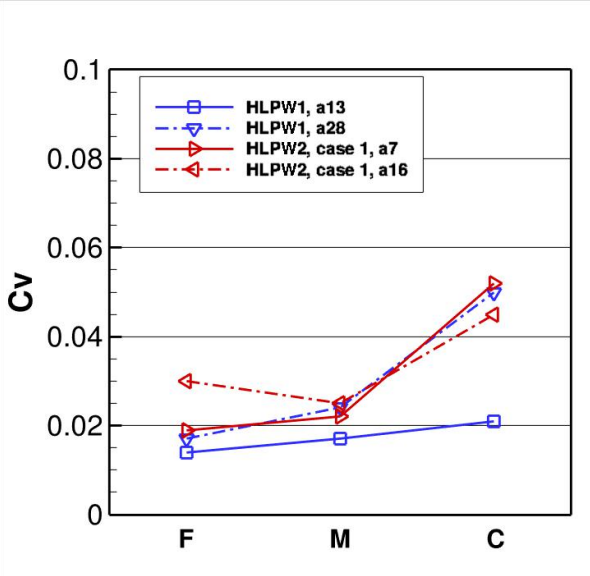
Scatter range decreases then increases as grid is refined

Coefficient of variation summary (F)

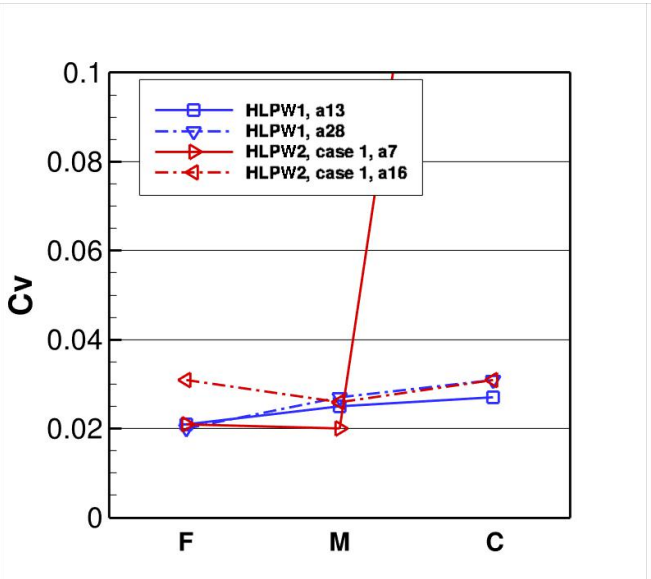
Case	Cv for lift	Cv for drag	Cv for moment
DPW II & III	n/a	0.02 – 0.025	0.045 – 0.06
DPW IV	n/a	0.022	0.157
HLPW1, a=13	0.014	0.021	0.031
HLPW1, a=28	0.017	0.020	0.049
Case 1, Alpha=7	0.019	0.021	0.042
Case 1, Alpha=16	0.030	0.031	0.087

Case 1 Coefficient of variation

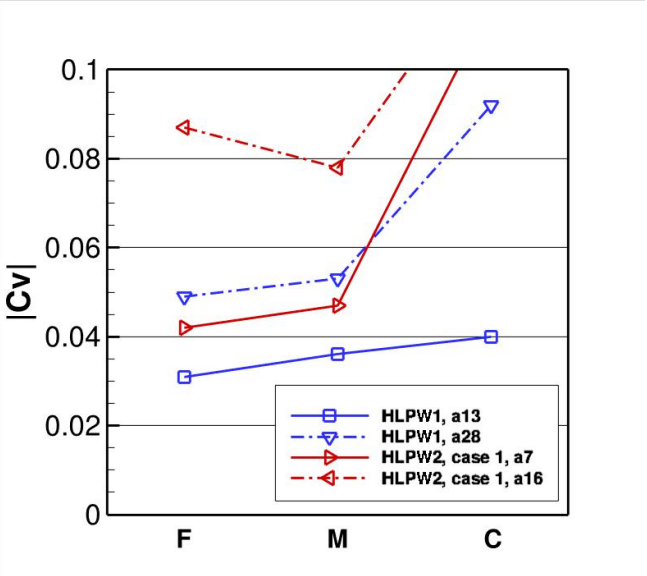
LIFT



DRAG

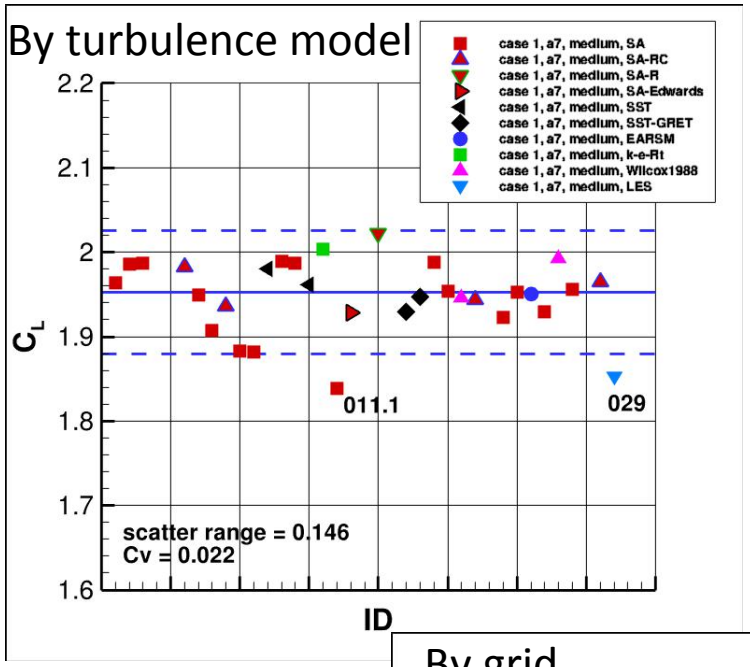


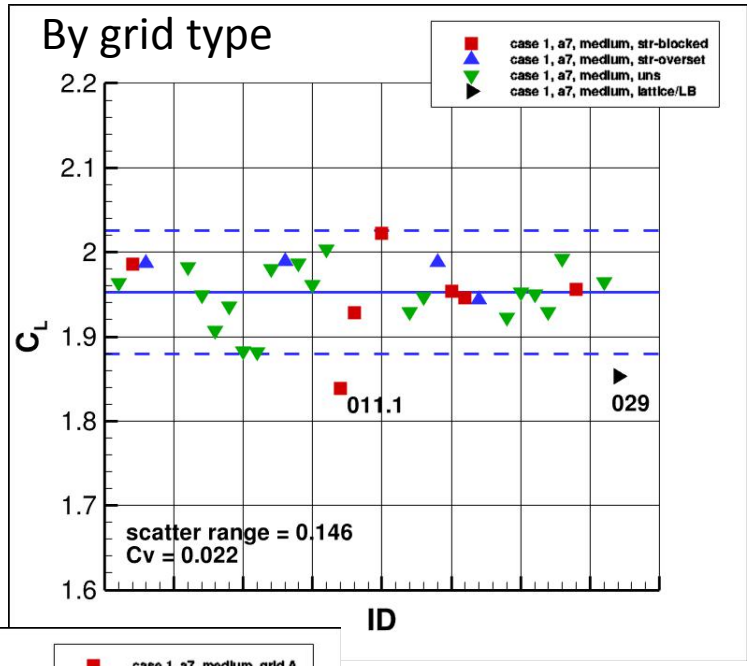
MOMENT

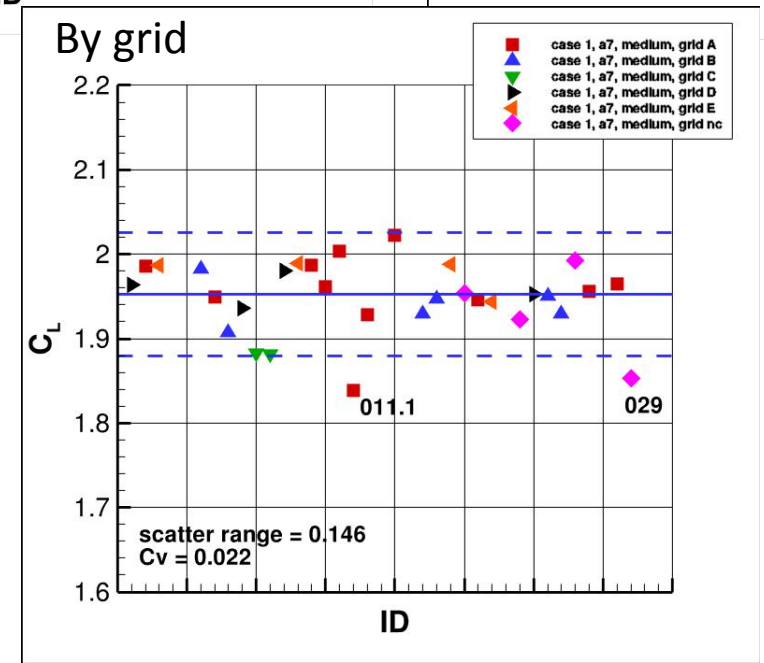


Cv's somewhat higher than HiLiftPW-1

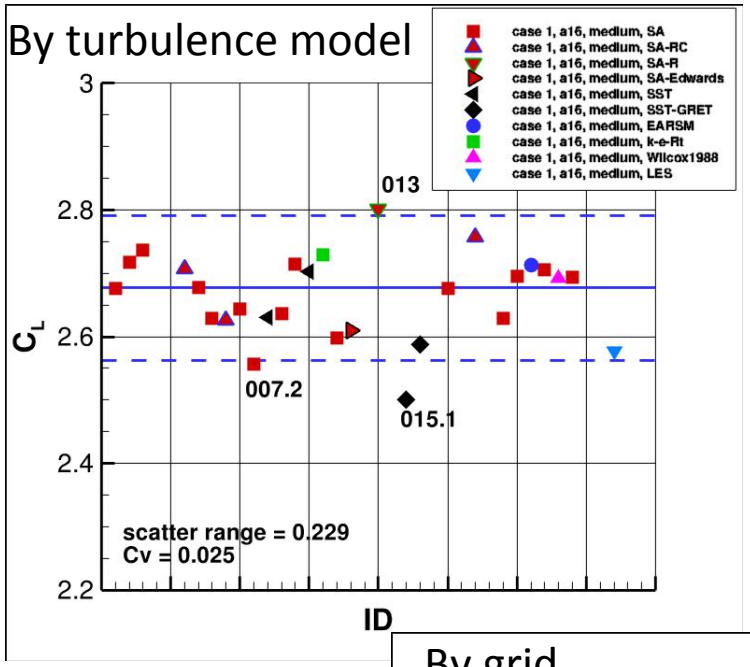
Looking for trends, AoA=7

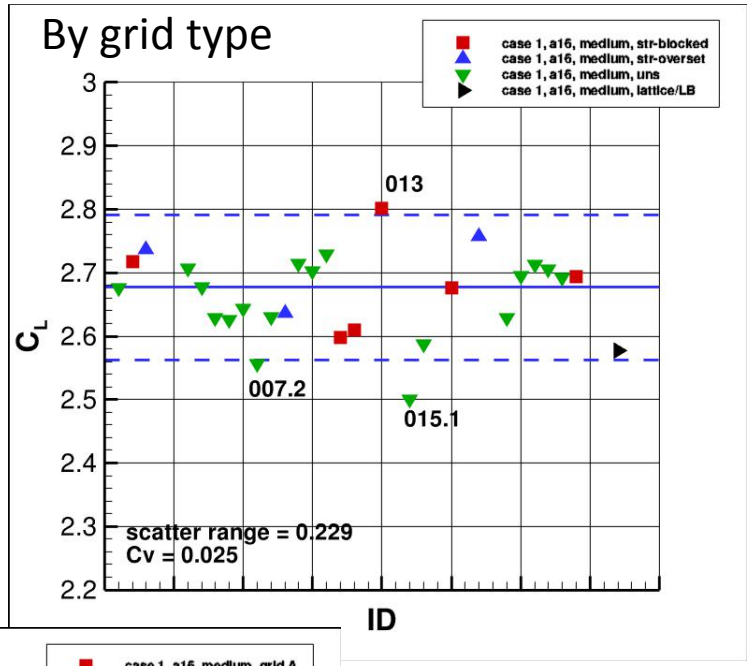


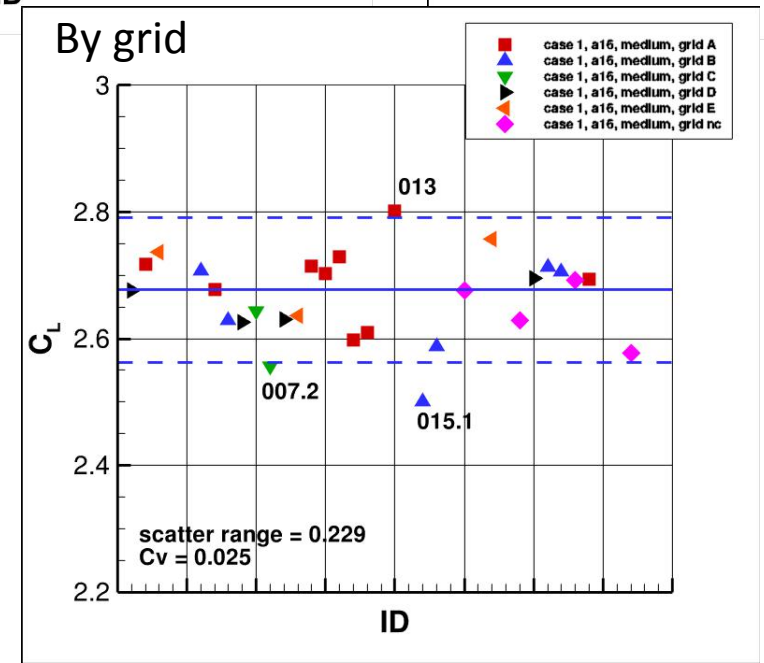




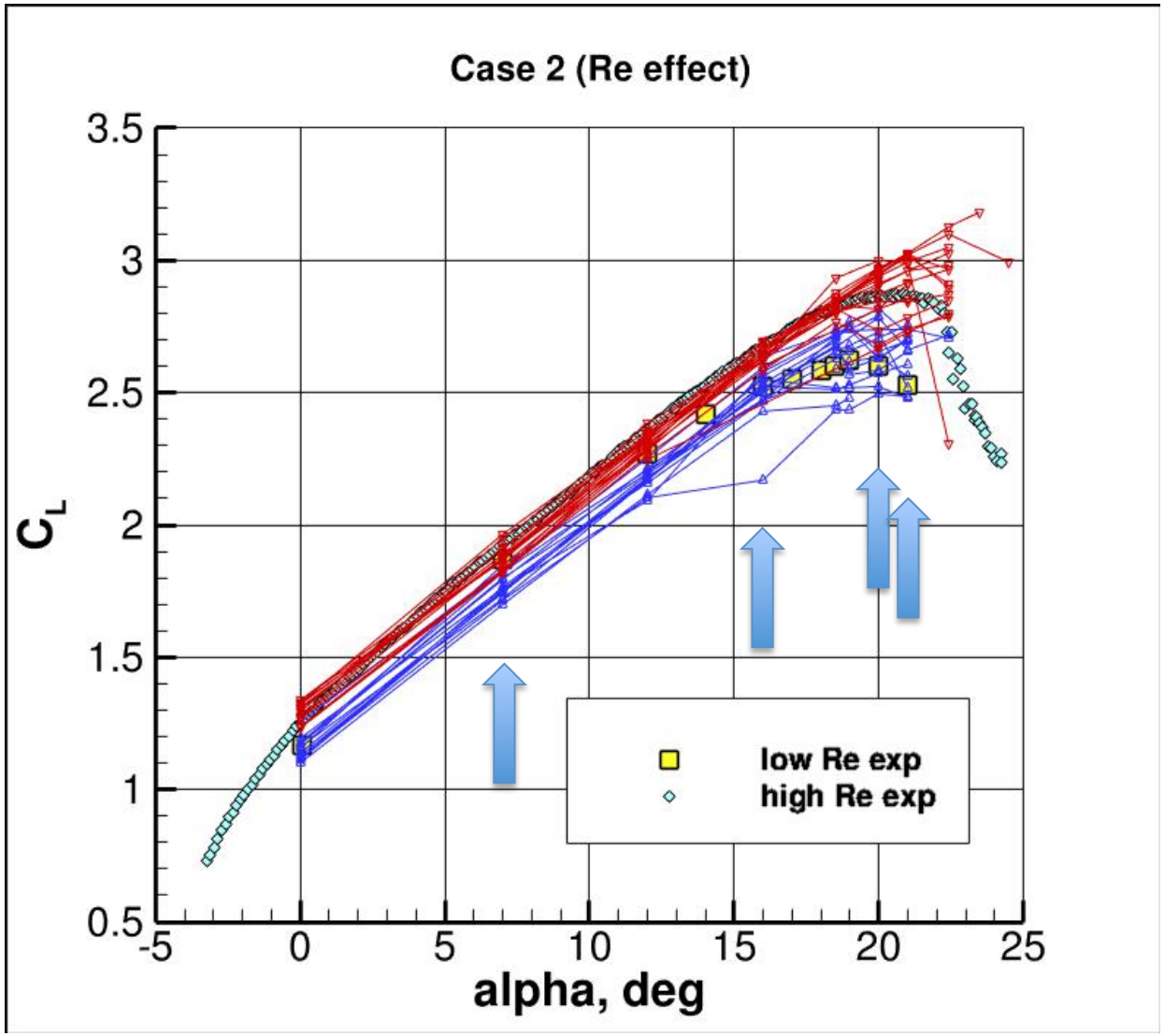
Looking for trends, AoA=16







Case 2 Reynolds number effect

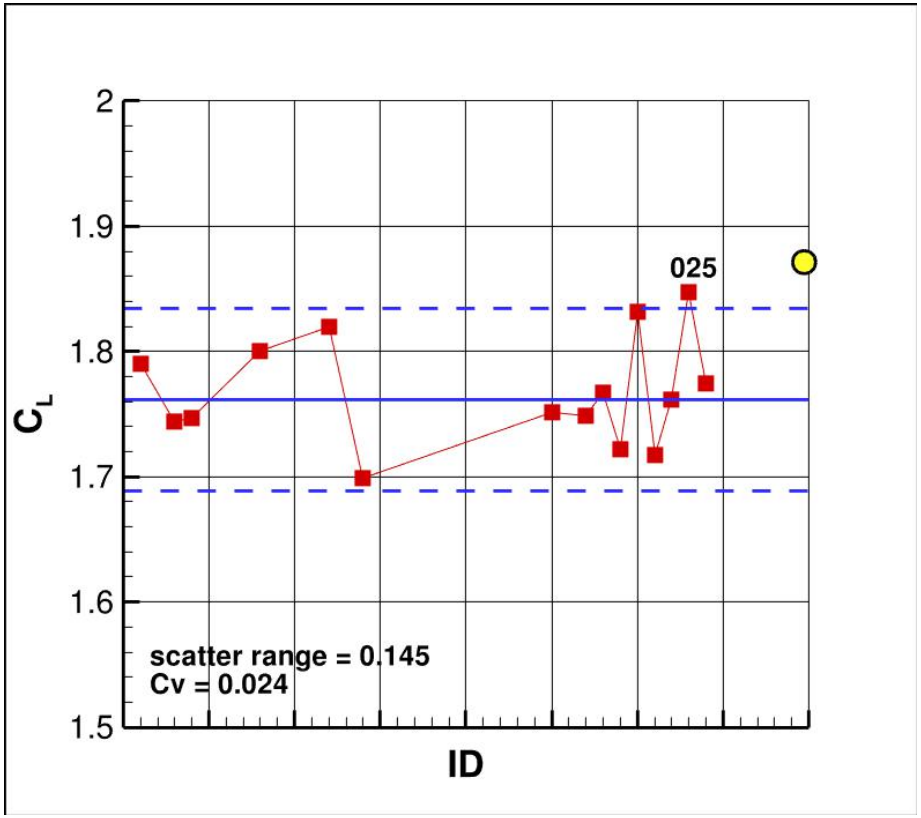


Including brackets

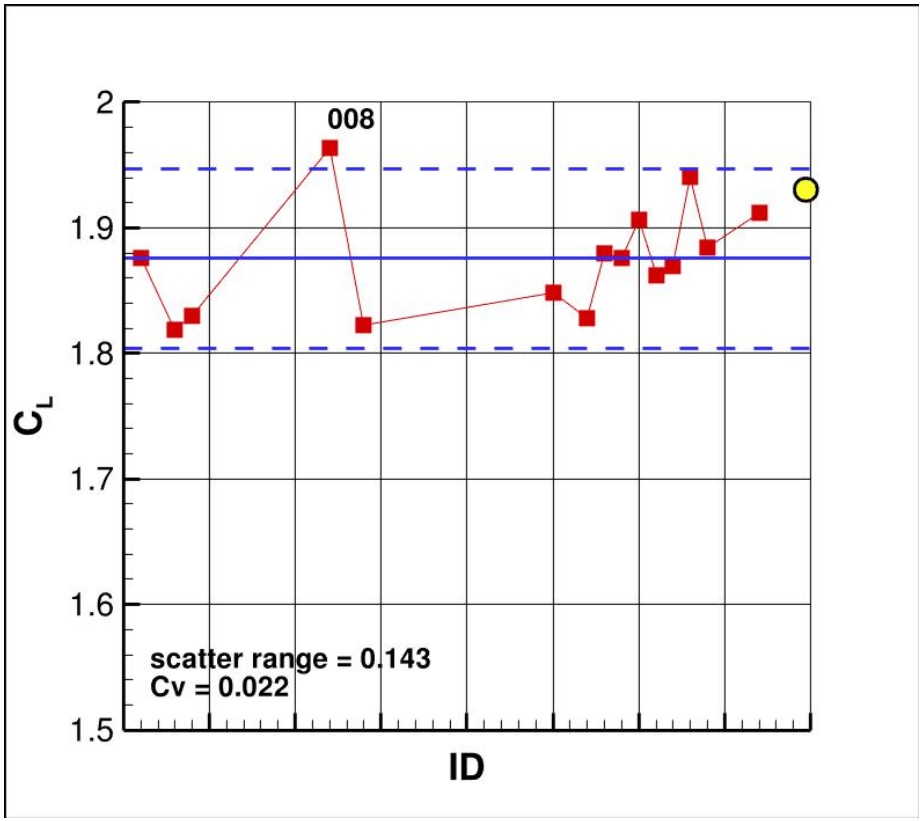
Case 2a/b C_L statistics, AoA=7

Including brackets

Low Re



High Re

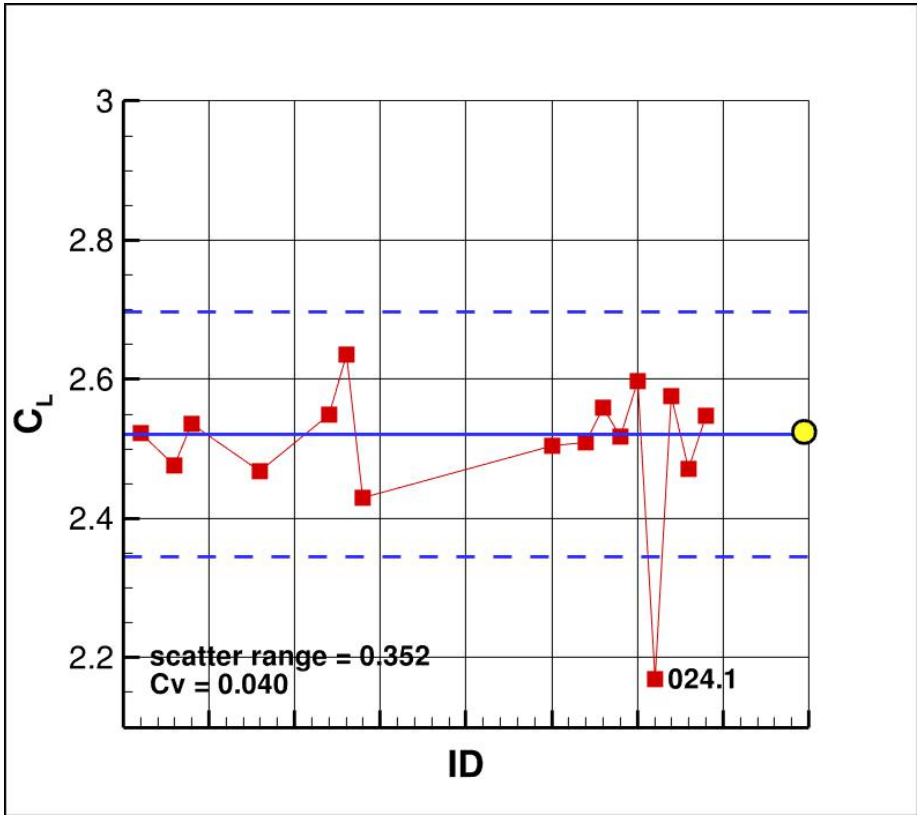


Low Re lift predicted too low

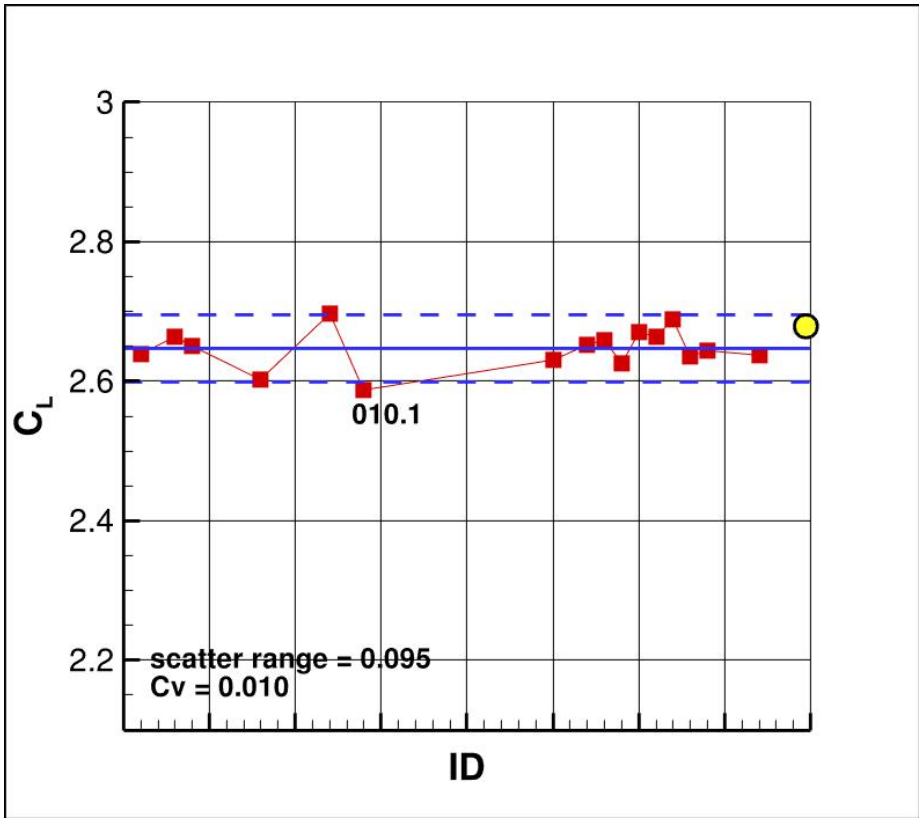
Case 2a/b C_L statistics, AoA=16

Including brackets

Low Re



High Re

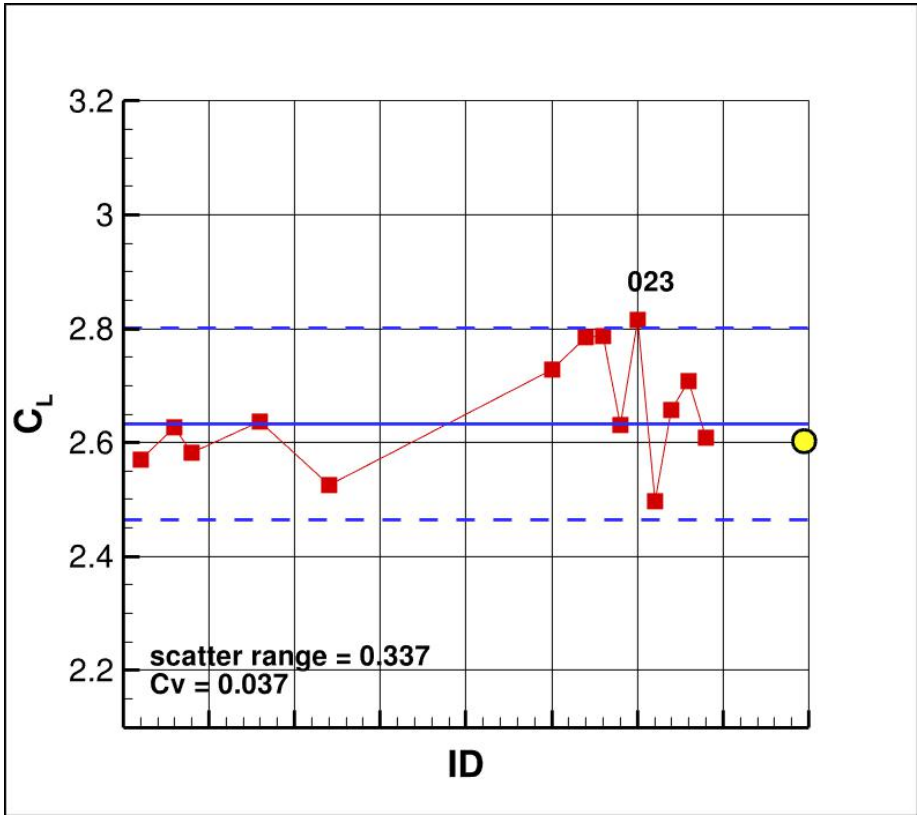


Re levels and trend captured well

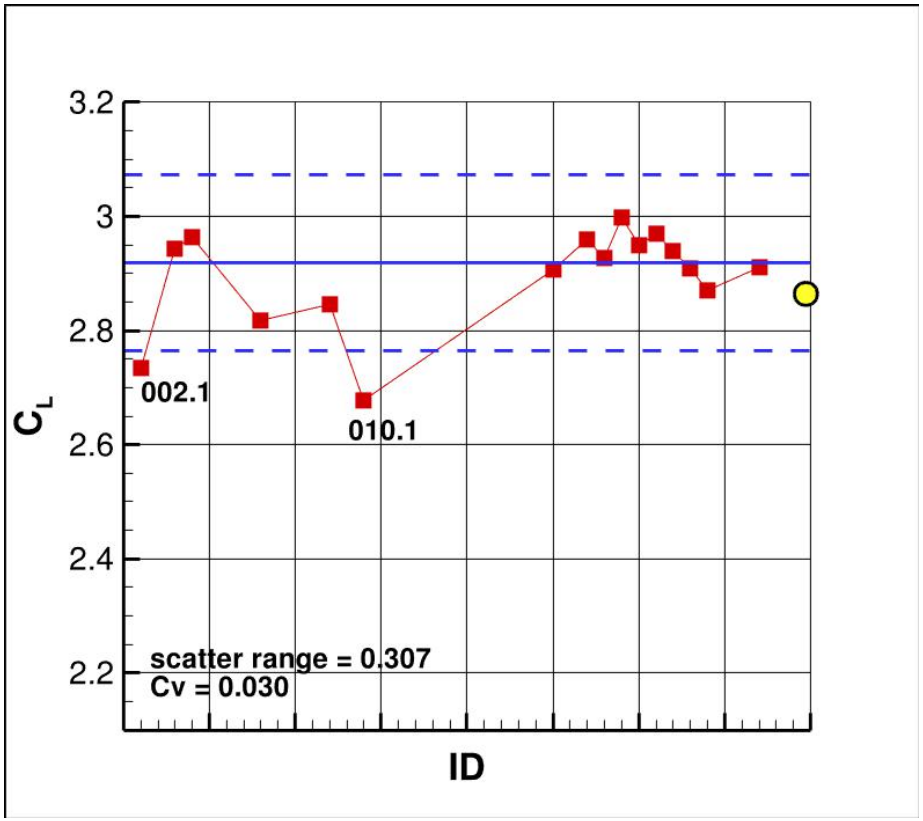
Case 2a/b C_L statistics, AoA=20

Including brackets

Low Re



High Re

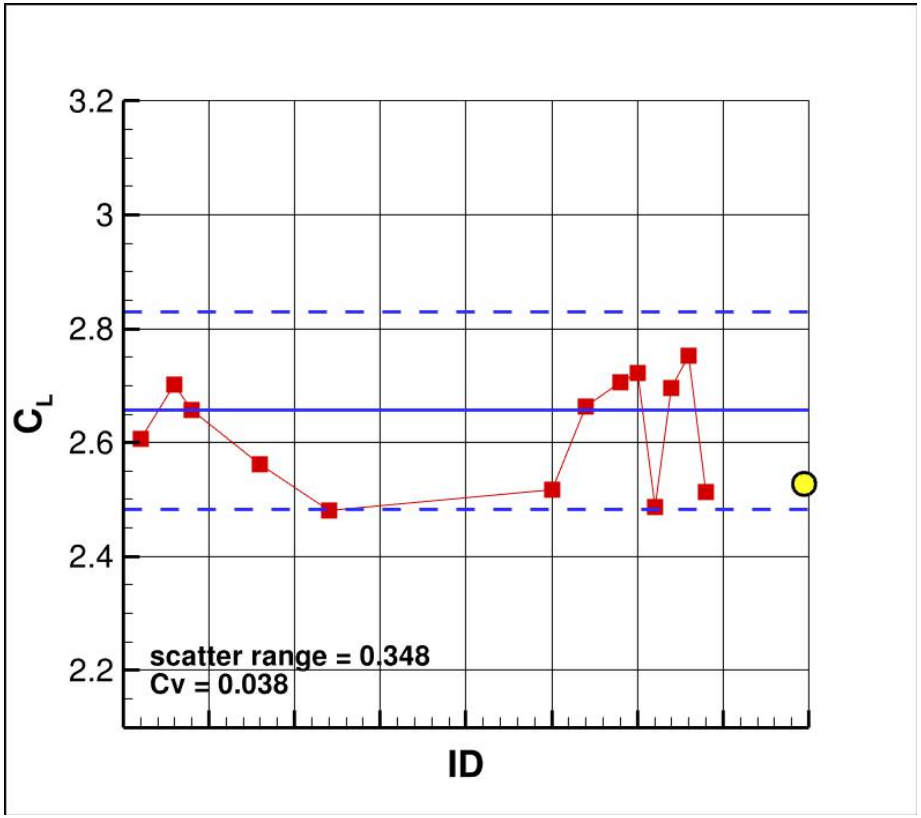


Re levels and trend captured well

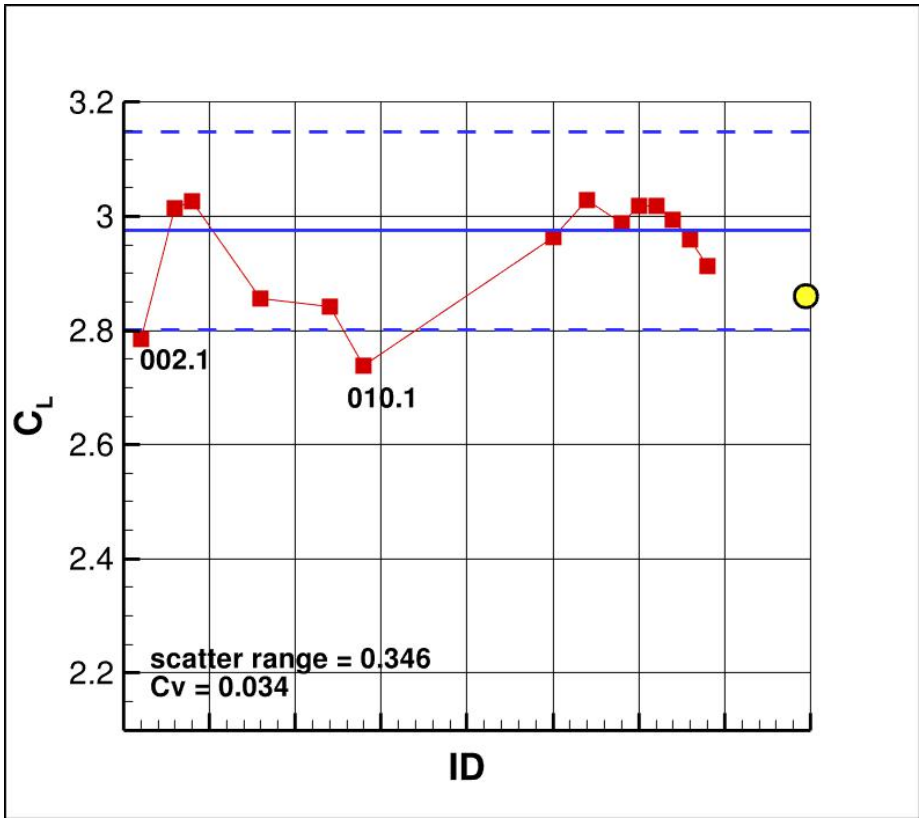
Case 2a/b C_L statistics, AoA=21

Including brackets

Low Re



High Re

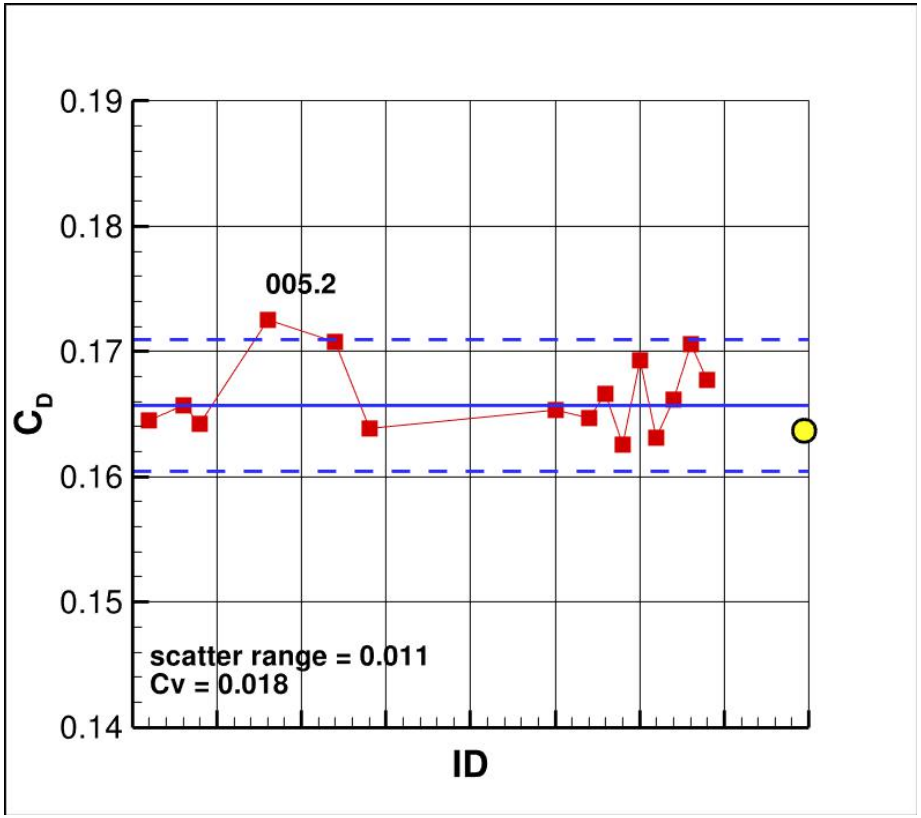


Collectively, CFD's CL still increasing (not capturing max CL)

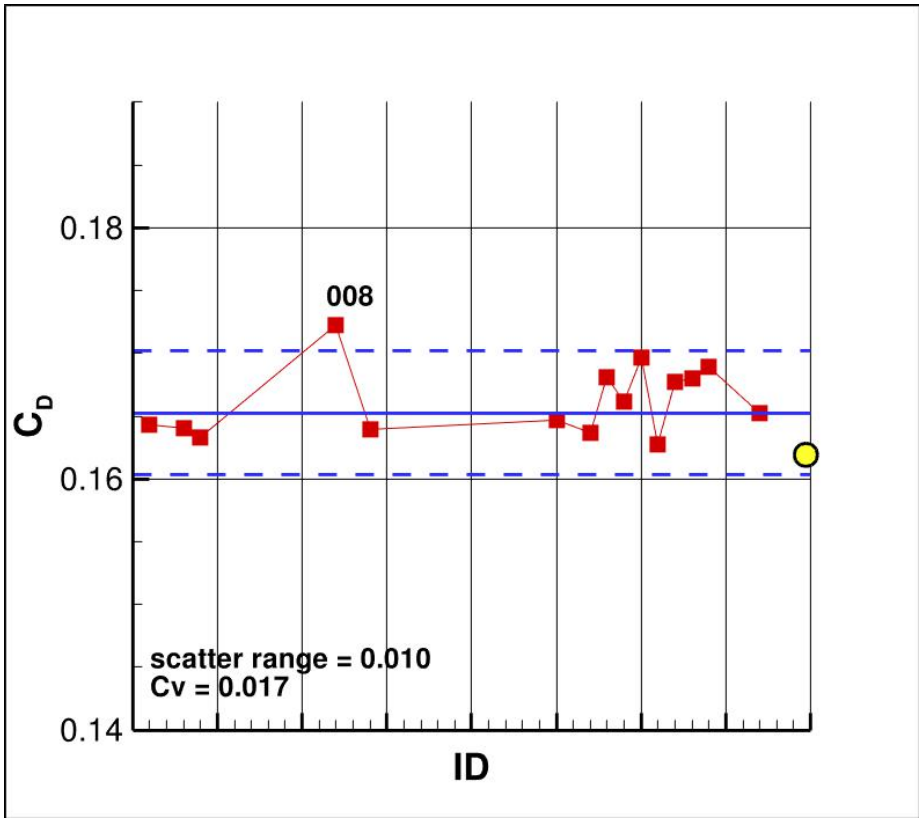
Case 2a/b C_D statistics, AoA=7

Including brackets

Low Re



High Re

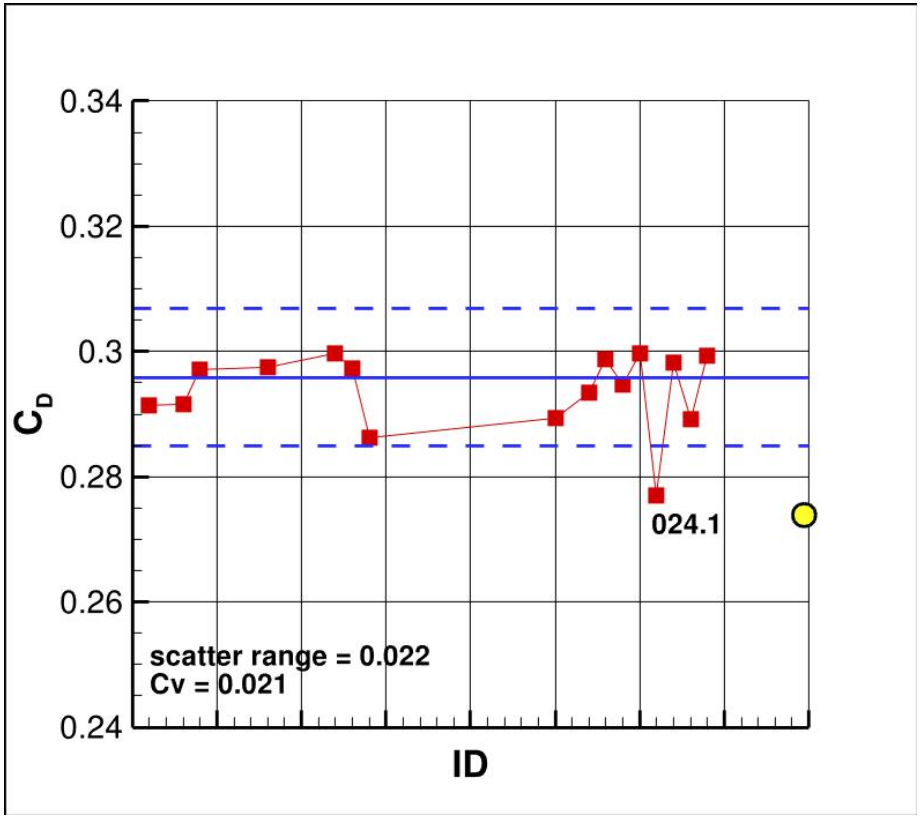


Drag levels predicted well; not much change with Re

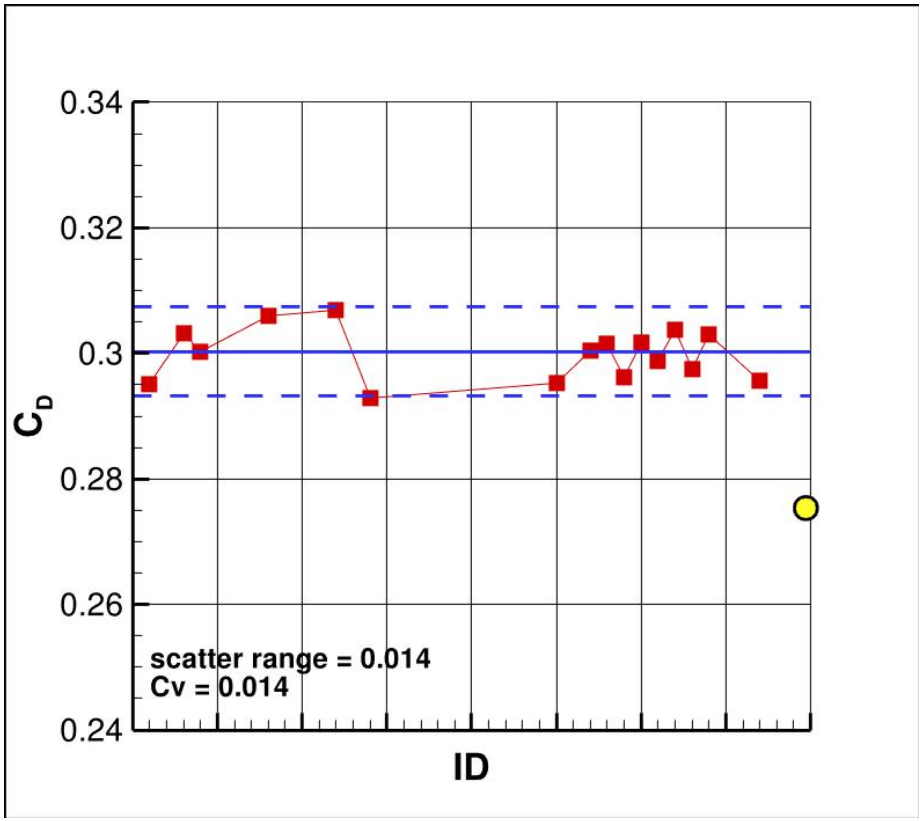
Case 2a/b C_D statistics, AoA=16

Including brackets

Low Re



High Re

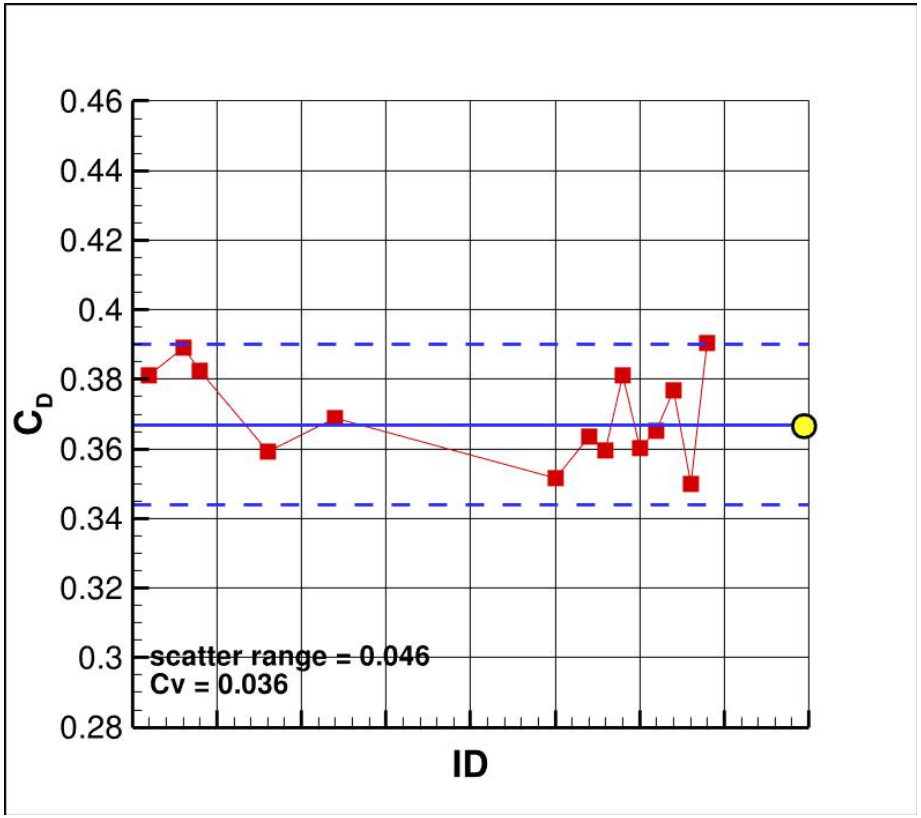


Drag computed too high

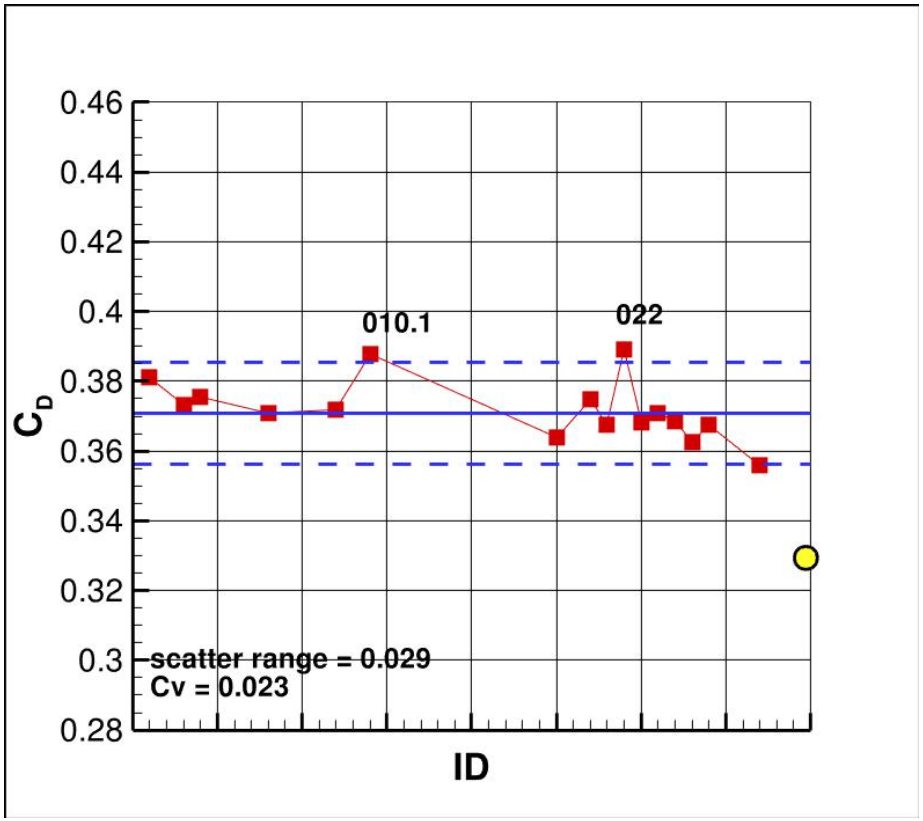
Case 2a/b C_D statistics, AoA=20

Including brackets

Low Re



High Re

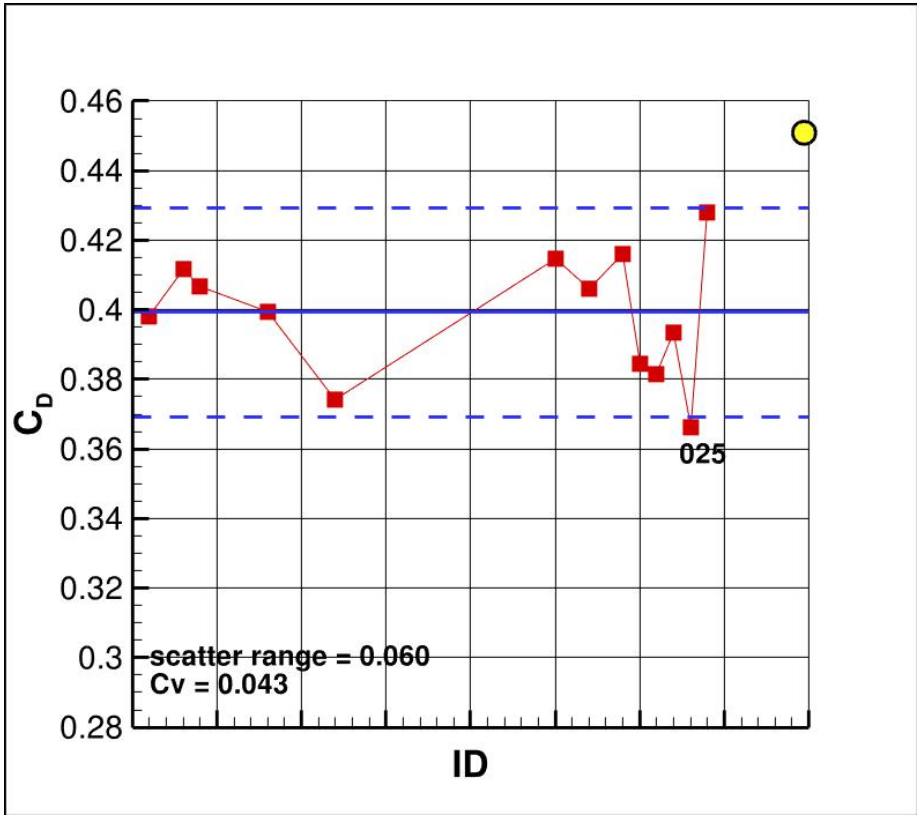


High Re drag computed too high

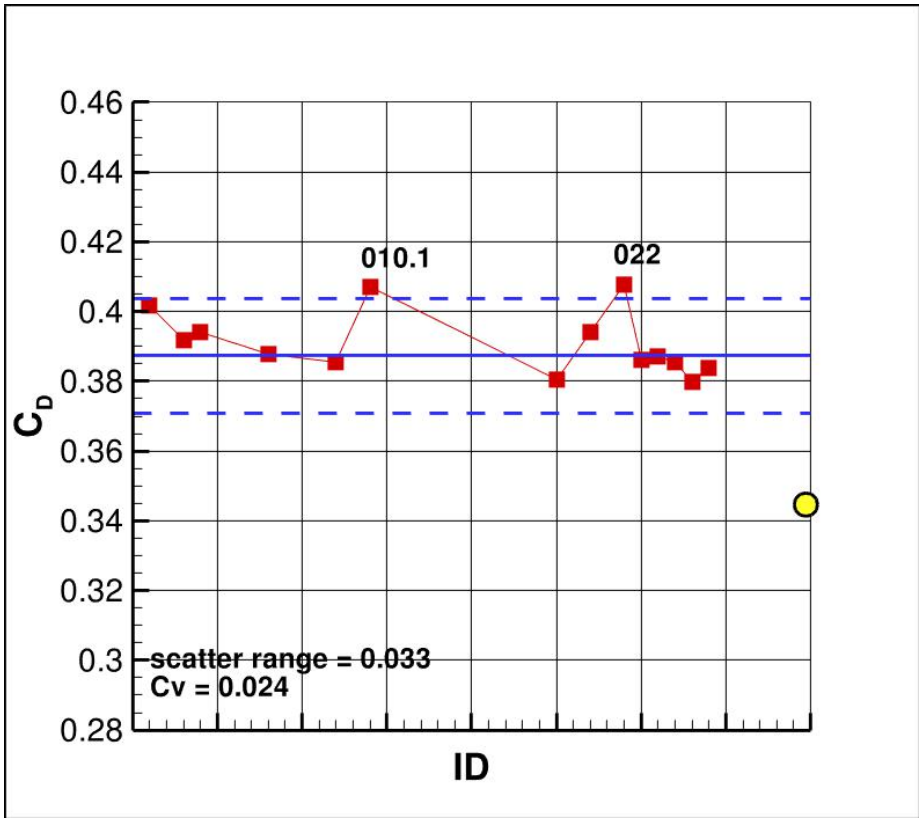
Case 2a/b C_D statistics, AoA=21

Including brackets

Low Re



High Re

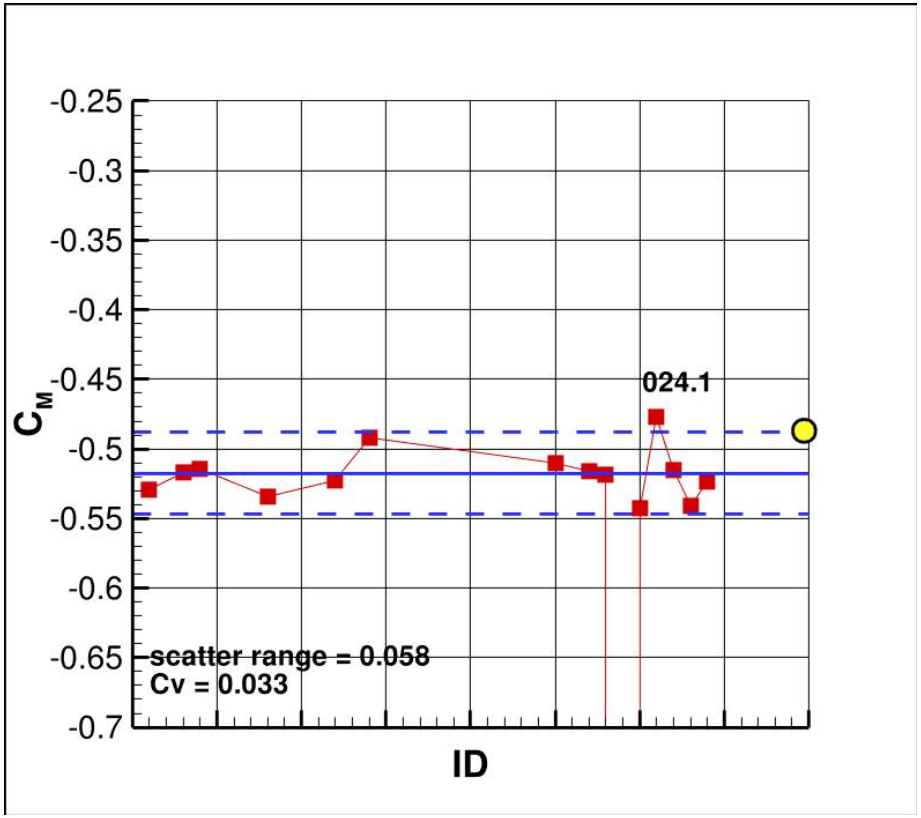


Low Re drag too low; high Re drag too high

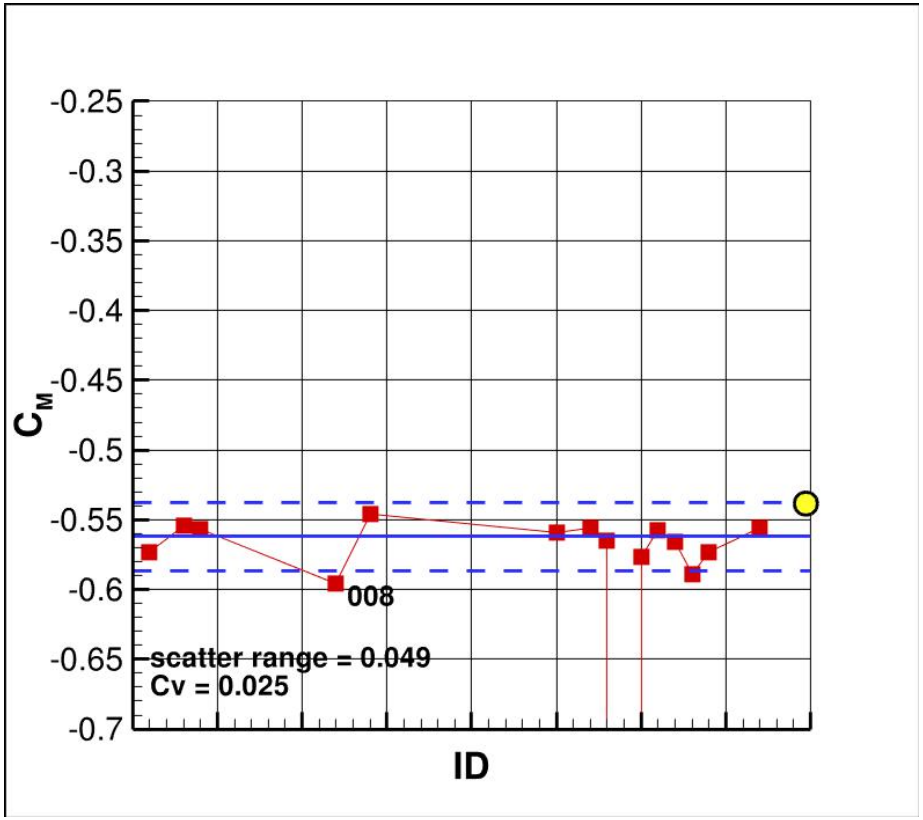
Case 2a/b C_M statistics, AoA=7

Including brackets

Low Re



High Re

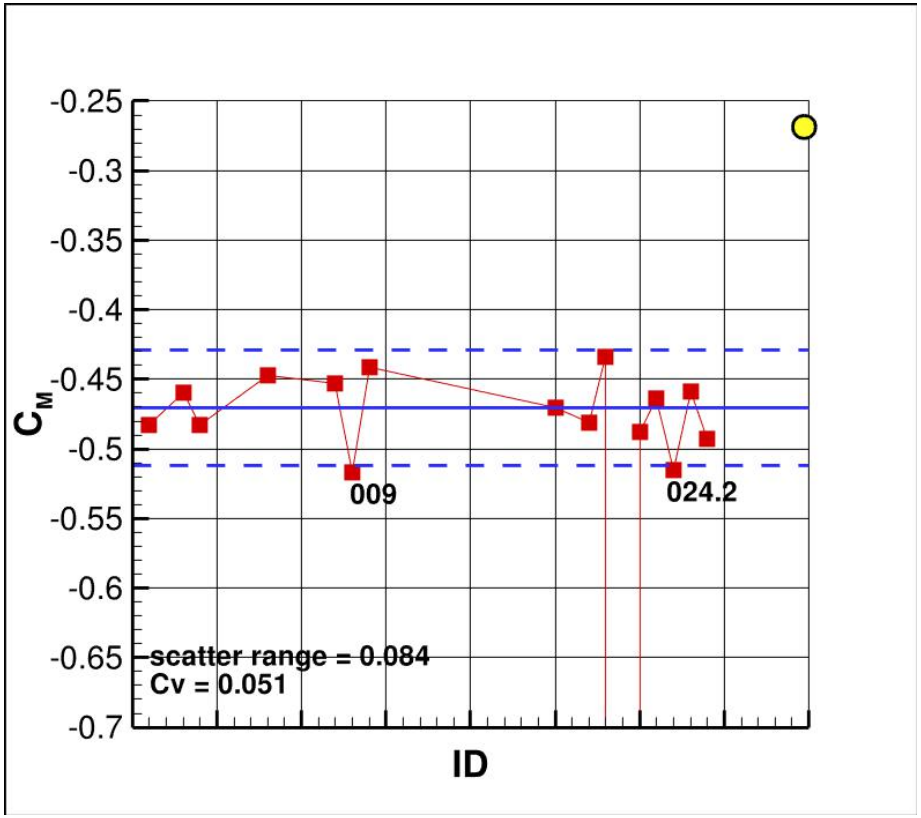


Moment computed reasonably well; trend with Re followed

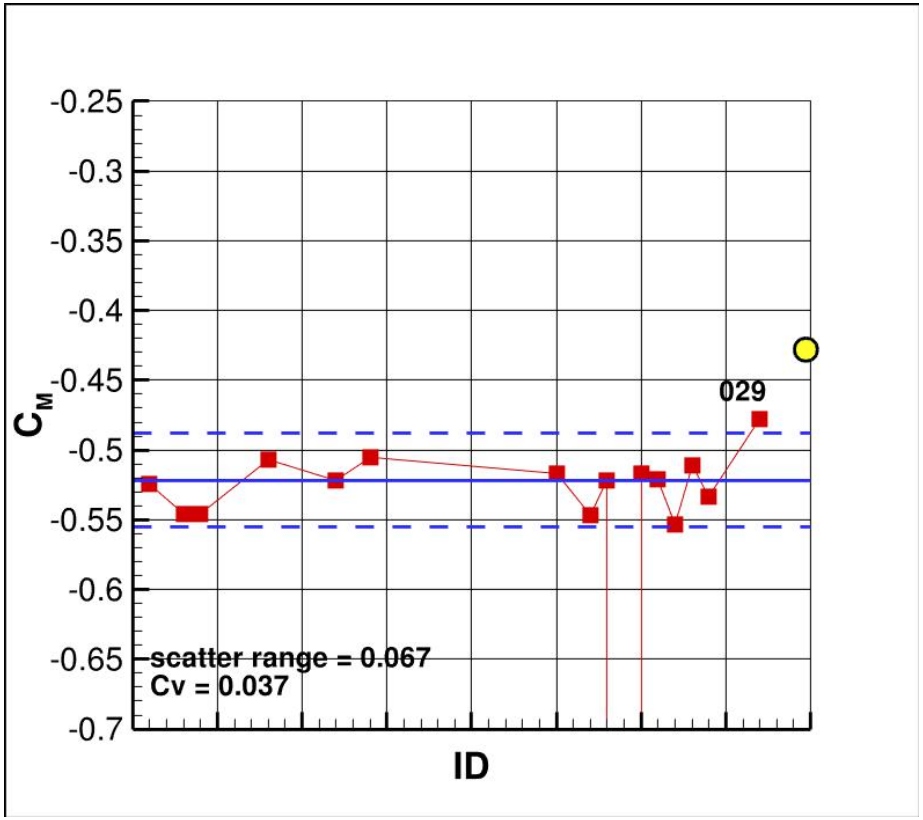
Case 2a/b C_M statistics, AoA=16

Including brackets

Low Re



High Re

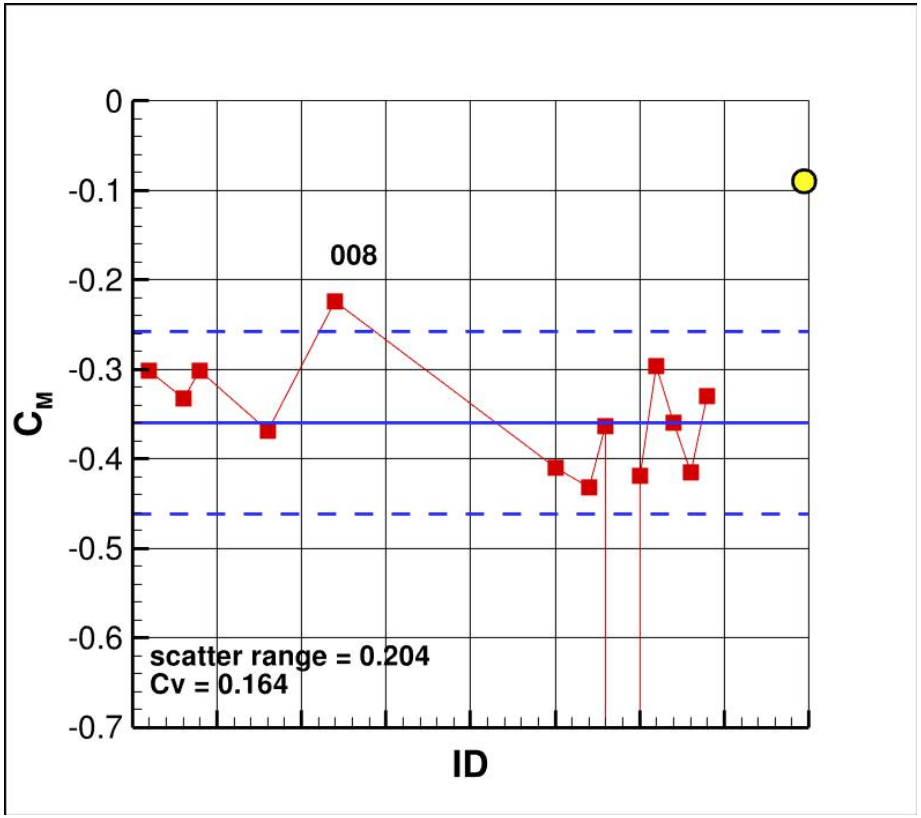


Moment computed too negative (pitch down)

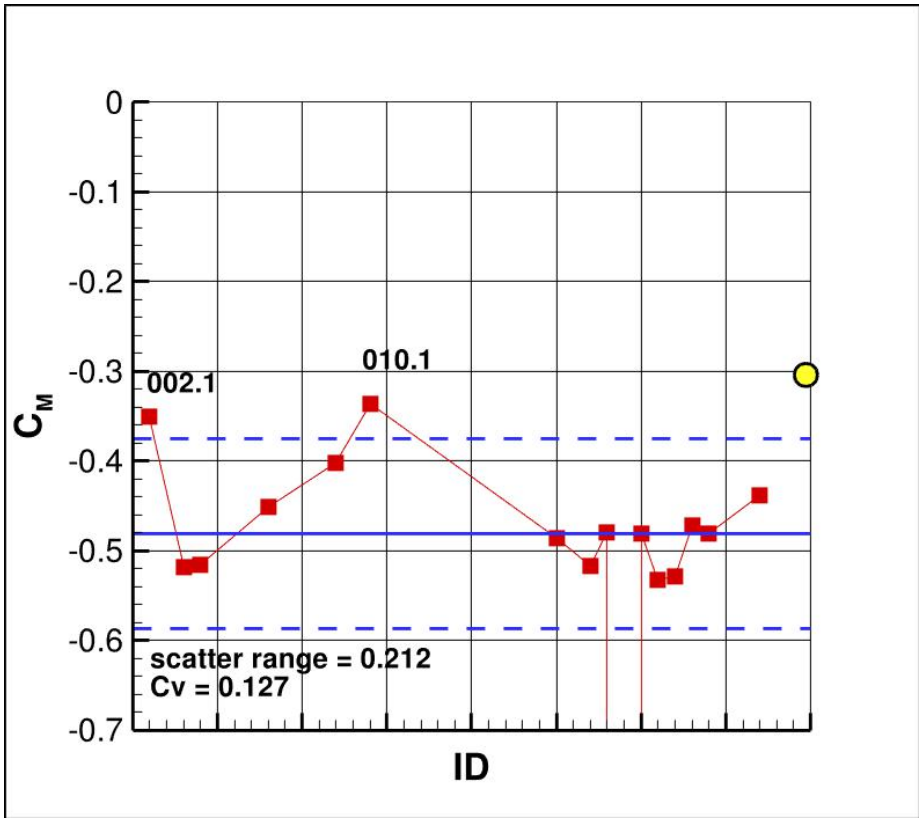
Case 2a/b C_M statistics, AoA=20

Including brackets

Low Re



High Re

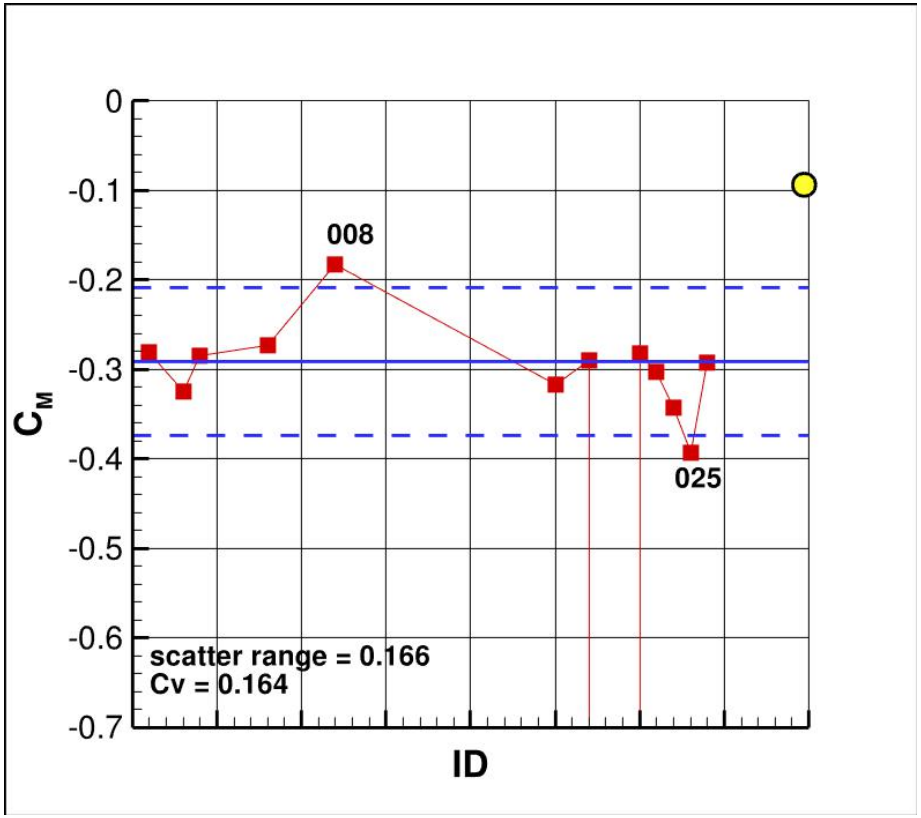


Moment computed too negative (pitch down)

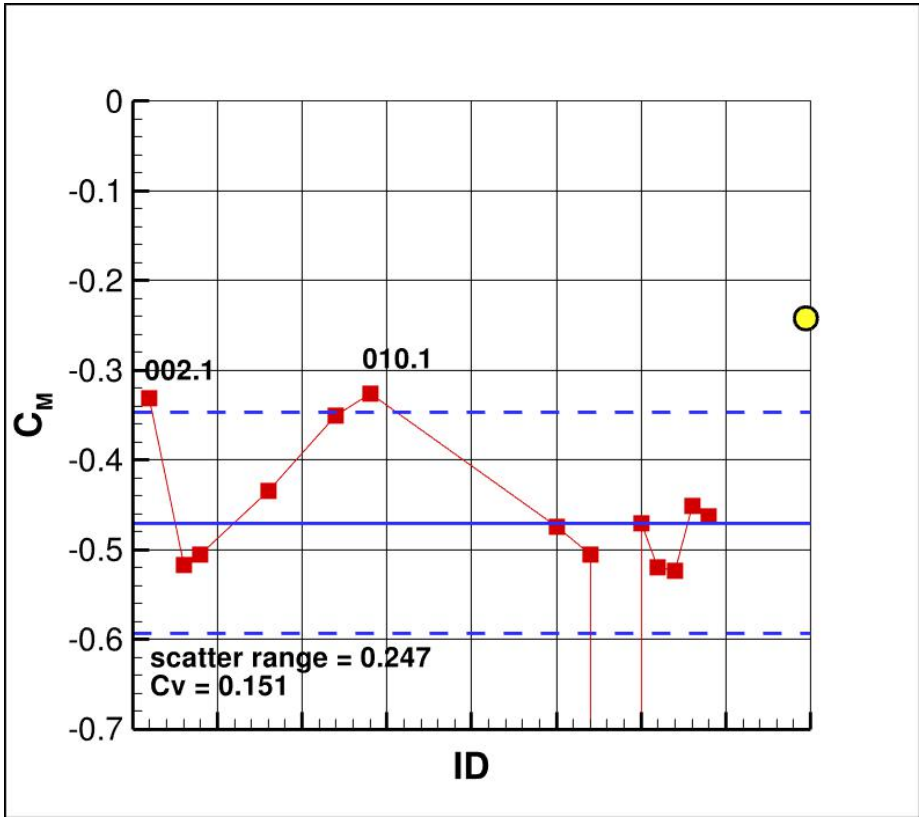
Case 2a/b C_M statistics, AoA=21

Including brackets

Low Re



High Re



Moment computed too negative (pitch down)

Summary

- Only two participants submitted Case 4 turb model verification
  - But one needs minor revision and the other was labeled incorrectly
  - And a few other participants say they still plan to do it
  - TBD
- High lift grid-convergence trends: only so-so
  - Coefficient of variations somewhat higher than previous workshops
  - At AoA=16, scatter gets worse on fine grid
- No definitive trends noted with turbulence model or grid type
- Velocity profiles show that structured grids usually capture wakes better
  - Exceptions: Unstructured Grid C series and 022's grid
- Including brackets is clearly important when comparing to experiment
- Importance of transition not clearly established by the results submitted to date
- Iterative convergence an issue with some submitted results