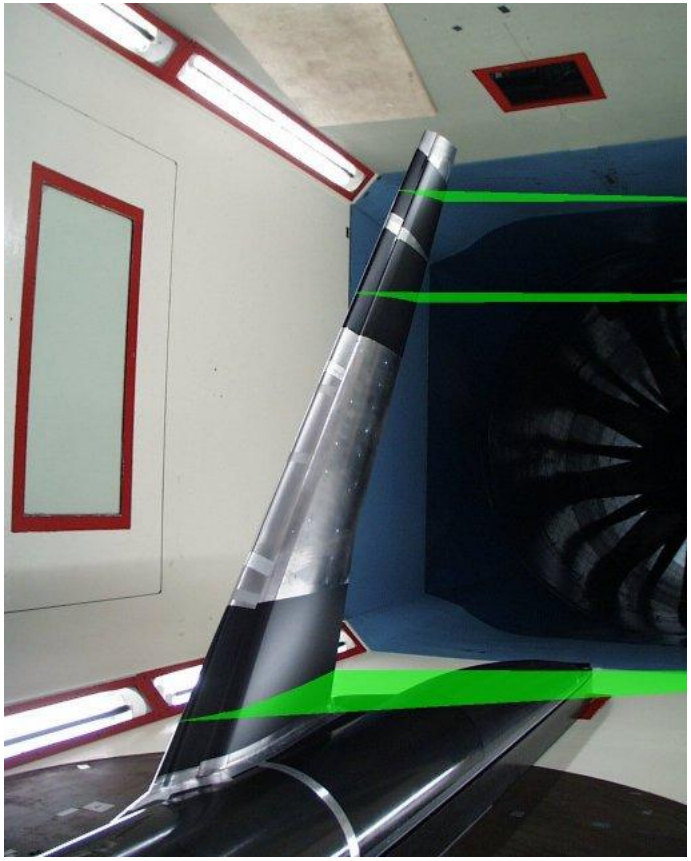


Overview and Summary of the Second AIAA High Lift Prediction Workshop

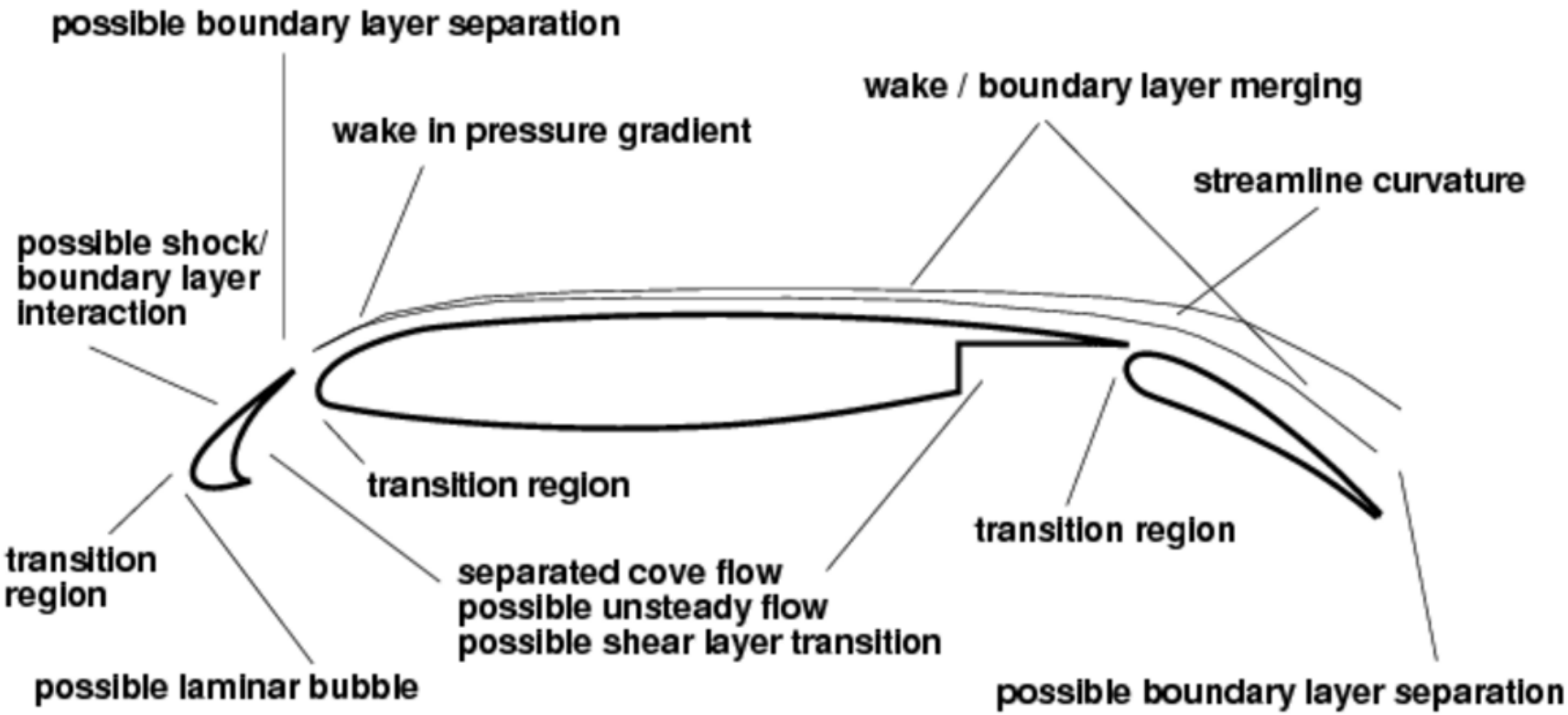
C. L. Rumsey
NASA Langley Research Center
J. P. Slotnick
The Boeing Company

Overview

- Main goals of this summary
  - Describe the HiLiftPW-2 workshop
  - Summarize the results
  - Discern trends
  - Make note of outliers
  - Perform statistical analysis
  - Draw conclusions
  - Briefly discuss next steps

Introduction

- Prediction of high lift flows is challenging



Introduction

- HiLift Prediction Workshop series
  - Patterned after the successful DPW series
  - HiLiftPW-1 held in Chicago in Summer 2010
    - NASA trapezoidal wing (3-element wing + body)
    - Subsequently led to 17 AIAA papers of workshop result, and 13 AIAA papers on follow-up research
    - Brief summary on next slides
  - HiLiftPW-2 held in San Diego in Summer 2013
    - DLR-F11 (3-element wing + body)
    - Papers of workshop results today and at AIAA conference in June 2014 (Atlanta)

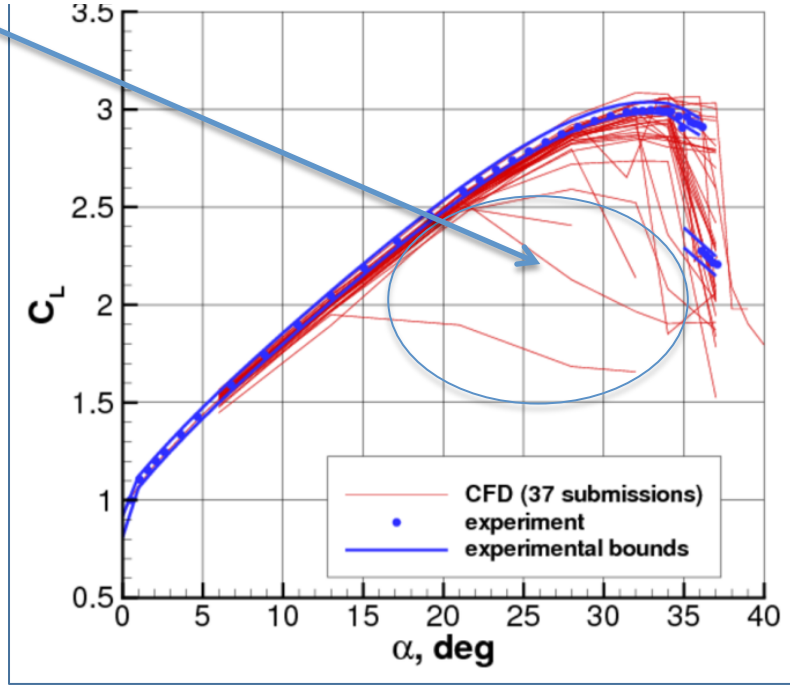
HiLiftPW-2 workshop committee

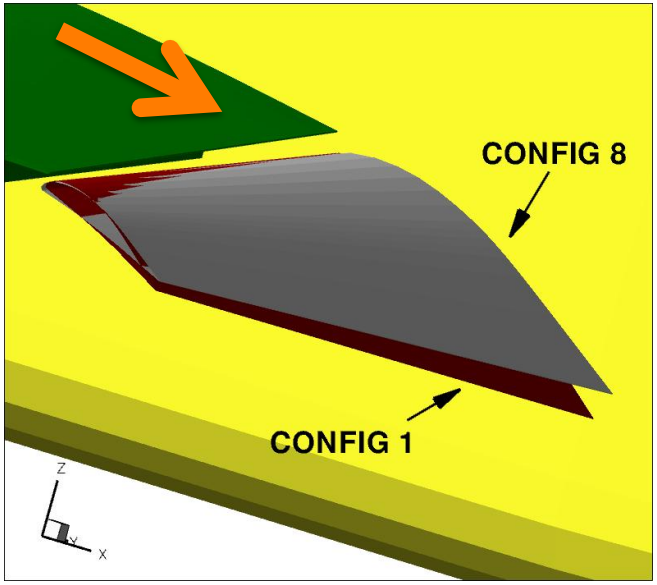
- Jeff Slotnick & Tony Sclafani (Boeing)
- Mark Chaffin & Dave Levy (Cessna)
- Ralf Rudnik & Kerstin Huber (DLR)
- Tom Wayman (Gulfstream)
- Judi Hannon & Chris Rumsey (NASA LaRC)
- Carolyn Woeber (Pointwise)
- Dimitri Mavriplis & Mike Long (U Wyoming)
- Tom Pulliam (NASA Ames)

HiLiftPW-1

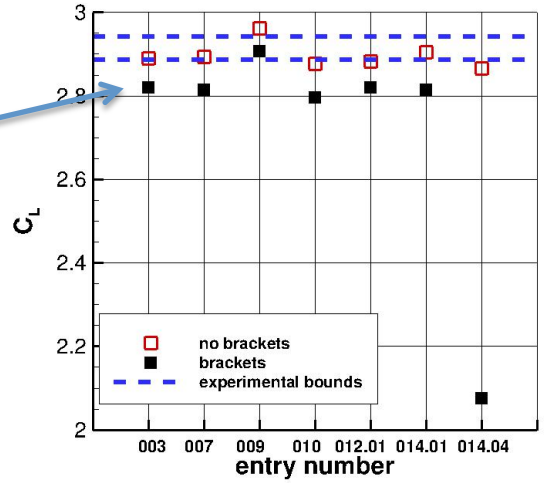
Config 1 results

Some problems at high alphas due to code sensitivity to initial conditions





Including brackets lowered the predicted lift



HiLiftPW-1

- Summary in Journal of Aircraft 48(6):2068-2079, 2011
- Two different flap setting configurations at Re_c=4.3 x 10^6
- CFD tended to under-predict CL, CD, and magnitude of CM compared to experiment
- More spread among CFD near CLmax than at lower alphas
- Trends with grid refinement were in right direction
  - But no refinement studies done with support brackets
- Including support brackets yielded lower lift; was important for capturing particular details in surface pressures
- Transition was important; including it in the CFD tended to increase predicted lift
- Unstructured coarse grid with tets in BL was worse than same grid with tets merged into prisms in BL
- Flow field near wing tip was very difficult to predict
- Deltas between 2 configurations only predicted qualitatively

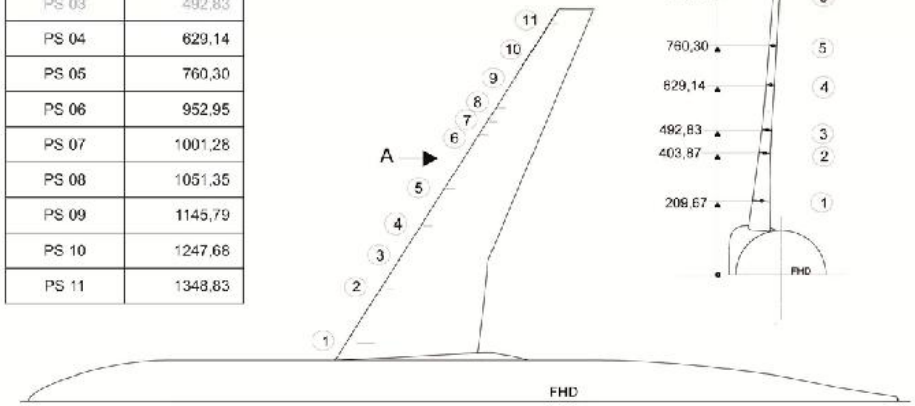
HiLiftPW-2

- DLR-F11 configuration
  - Used for EUROLIFT research program
  - More representative of realistic aircraft configuration than NASA trapezoidal wing
  - Tested over wide range of Reynolds numbers
  - Landing configuration chosen
  - Exp details in AIAA 2012-2924 (including short & medium term repeatability, and facility effects)

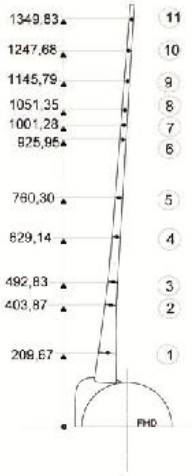
HiLiftPW-2

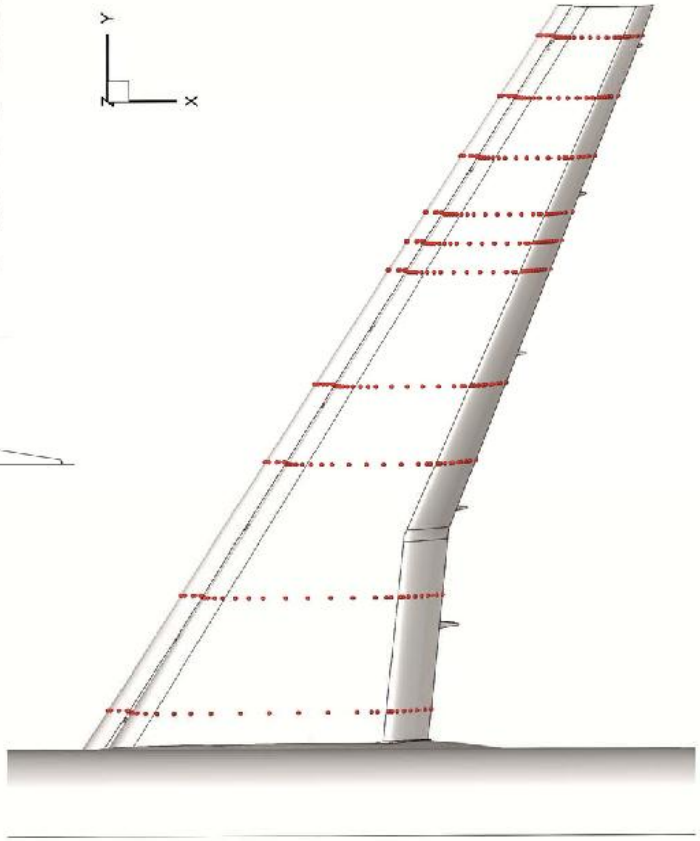
Pressure Section Locations for the Fixed Wing

Sections	y-coordinate
PS 01	209,67
PS 02	403,87
PS 03	492,83
PS 04	629,14
PS 05	760,30
PS 06	952,95
PS 07	1001,28
PS 08	1051,35
PS 09	1145,79
PS 10	1247,68
PS 11	1348,83



View on arrow A

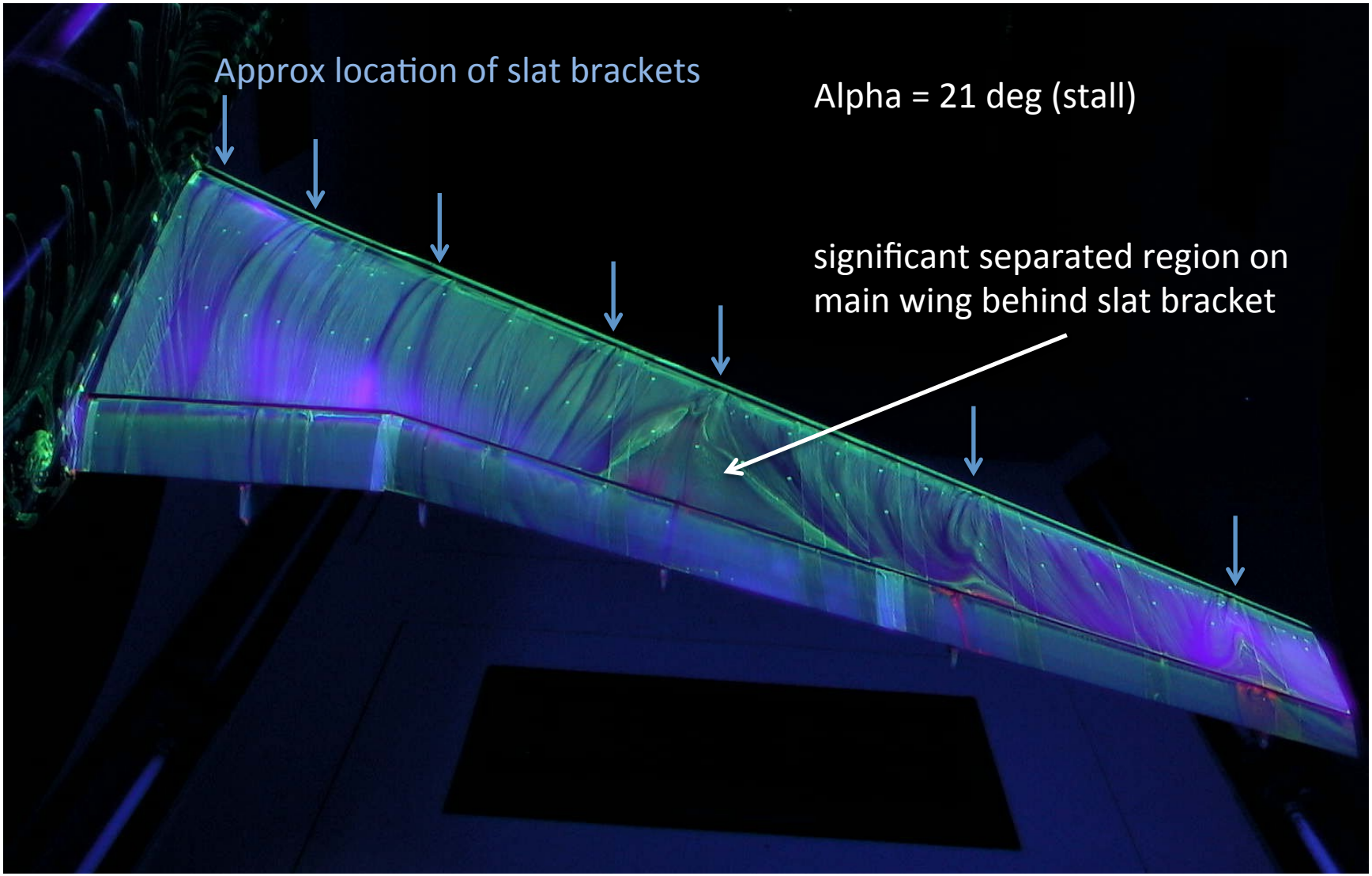




- B-LSWT results at $Re_c=1.35x10^6$
- ETW results at $Re_c=15.1x10^6$
- Focus here: forces, moments, surface pressures, PIV

B-LWST = Bremen low speed wind tunnel
ETW = European transonic wind tunnel

DLR-F11 oil flow visualization at low Re



Test Cases

- Geometry was approximated in series of configurations that built up the model for improved geometric fidelity
  - Config 2 – wing/body/high lift system
  - Config 4 – same as Config 2 plus slat and flap support brackets
  - Config 5 – same as Config 4 plus slat pressure tube bundles (simplified to approximately account for blockage)

Photos from AIAA 2012-2924

Test cases, no brackets

- Case 1 (required)
  - Grid convergence study on Config 2 at high Re
  - Alpha = 7, 16, (optional 18.5)
  - Fully turbulent
  - Coarse, Med, Fine grids (optional XFine)

Test cases, brackets

- Case 2
  - Reynolds number study on Config 4 using Med grid
  - Case 2a (required)
    - Low Re, fully turbulent
    - Alpha = 0, 7, 12, 16, 18.5, 20, 21, 22.4
  - Case 2b (required)
    - High Re, fully turbulent
    - Alpha = 0, 7, 12, 16, 18.5, 19, 20, 21
  - Case 2c (optional)
    - Low Re, with transition prediction
    - Alpha = 0, 7, 12, 16, 18.5, 20, 21, 22.4

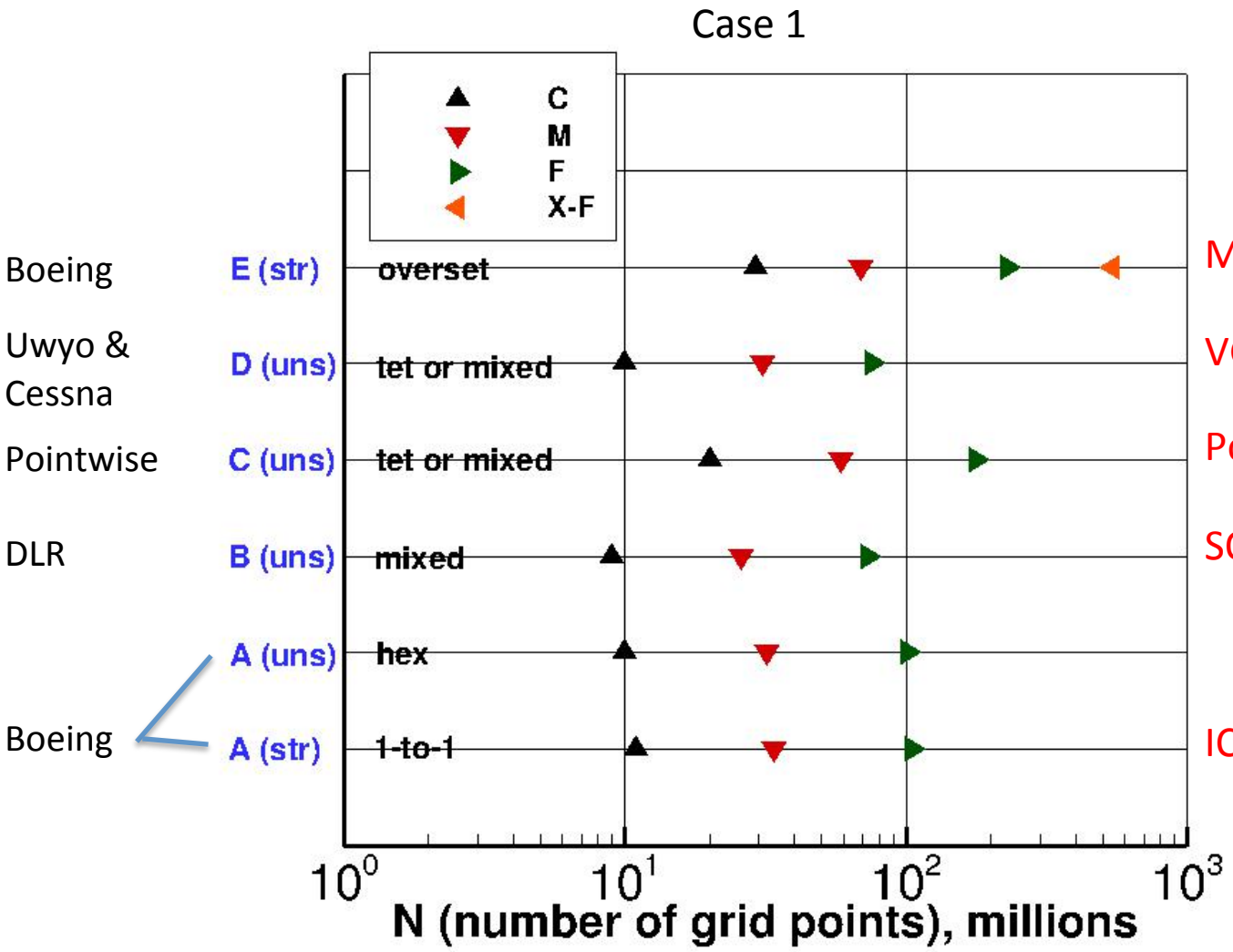
Test cases, brackets+bundles

- Case 3 (optional)
  - Reynolds number study on Config 5 using Med grid
  - Case 3a
    - Low Re, fully turbulent or transitional
    - Alpha = 0, 7, 12, 16, 18.5, 20, 21, 22.4
  - Case 3b
    - High Re, fully turbulent or transitional
    - Alpha = 0, 7, 12, 16, 18.5, 19, 20, 21

Test cases, verification

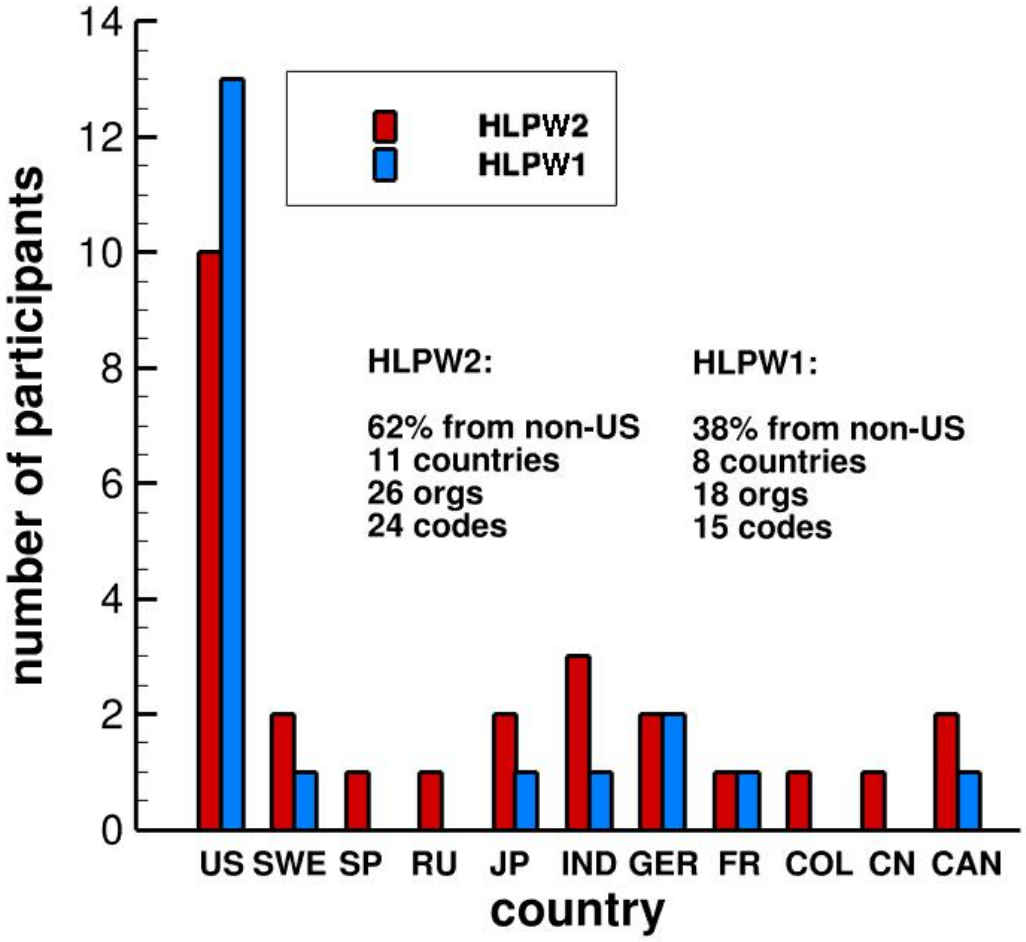
- Case 4 (optional)
  - 2-D turbulence model bump case from http://turbmodels.larc.nasa.gov
  - Includes grid convergence study

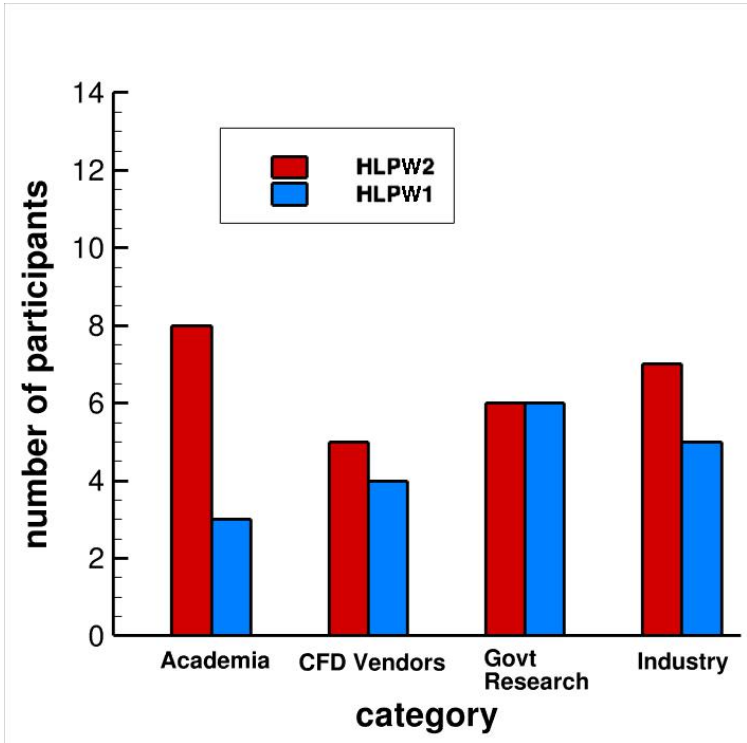
Grid systems



	Case 2	Case 3
Misc	Y	Y
VGRID	Y	Y
Pointwise	Y	N
SOLAR	Y	Y
	N	N
ICEM CFD	N	N

Participation





Participant	Grid Type	Solver	Turb	Case 1	Case 2a	Case 2b	Case 2c	Case 3a	Case 3b	Case 4
002.1	Uns	FUN3D	SA	x	x	x				x
002.2	Str-blocked	CFL3D	SA	x						x
003.1+	Str-overset	OVERFLOW	SA, SA+AFT	x	x	x	x			
003.2	Str-overset	OVERFLOW	SA-RC	x	x	x				
003.3+	Str-overset	OVERFLOW	SA-QCR+AFT				x			
004.1	Uns	CFD++	SA-RC	x						
004.2*	Uns	CFD++	SA-RC			x				
005.1	Uns	HiFUN	SA	x						
005.2+	Uns	HiFUN	SA	x	x	x				
006	Uns	FUN3D	SA-RC	x						
007.1+	Uns	CFLOW	SA	x	x	x				x
007.2+	Uns	UG3	SA	x	x	x				x
007.3*	Uns	CFLOW	SA	x						
008	Uns	CRUNCH CFD	SST	x	x	x				
009.1+	Str-overset	OVERFLOW	SA	x	x	x				
009.2*	Str-overset	OVERFLOW	SST		x					
009.3*	Str-overset	OVERFLOW	SST-GRET				x			
010.1+	Uns	CFD++	SA	x	x	x				
010.2+	Uns	CFD++	SST	x						
010.3+	Uns	CFD++	k-e-Rt	x						x
011.1+	Str-blocked	NSMB	SA	x						x
011.2+	Str-blocked	NSMB	SA-Edwards	x						x
011.3*	Str-blocked	NSMB	SA-salsa	x						x
012.1	Lattice-Boltz	PowerFLOW	LBM-VLES					x	x	
012.2*	Lattice-Boltz	PowerFLOW	LBM-VLES+trans					x		
013.1+	Str-blocked	UPACS	SA-noft2-R	x						x
013.2*	Str-blocked	UPACS	SA-noft2-R-QCR	x						
013.3*	Str-blocked	UPACS	SST-V	x						
013.4*	Str-blocked	UPACS	SST-V-QCR	x						
013.5*	Uns	TAS	SA-noft2-R	x						
013.6*	Uns	TAS	SA-noft2-R-QCR	x						
014	Uns	UNICORN	SGS			x				
015.1+	Uns	CFX	SST	x	x	x				
015.2+	Uns	Fluent	SST	x	x	x				
016.1+	Str-overset	elsA	SA	x						
016.2*	Str-blocked	elsA	SA	x						
017+	Str-blocked	COBRA	SA	x	x	x				
018	Str-blocked	VULCAN	Wilcox1988	x						x
020	Str-overset	OVERFLOW	SA-noft2-RC	x	x	x				
021+	Uns	TAU	SA	x	x	x		x	x	
022+	Uns	PHASTA	SA	x	x	x				
023	Uns	NSU3D	SA	x	x	x				
024.1	Uns	EDGE	EARSM	x	x	x				
024.2+	Uns	EDGE	SA	x	x	x				
025	Uns	NSU3D	Wilcox1988	x	x	x				
026	Str-blocked	MFLOW	SA	x	x	x		x	x	
028	Uns	Fluent	SA-RC	x						
029+	Lattice-Boltz	XFlow	WMLES	x	x	x			x	

Incl transition

SA type

Unstructured

Lattice-Boltz

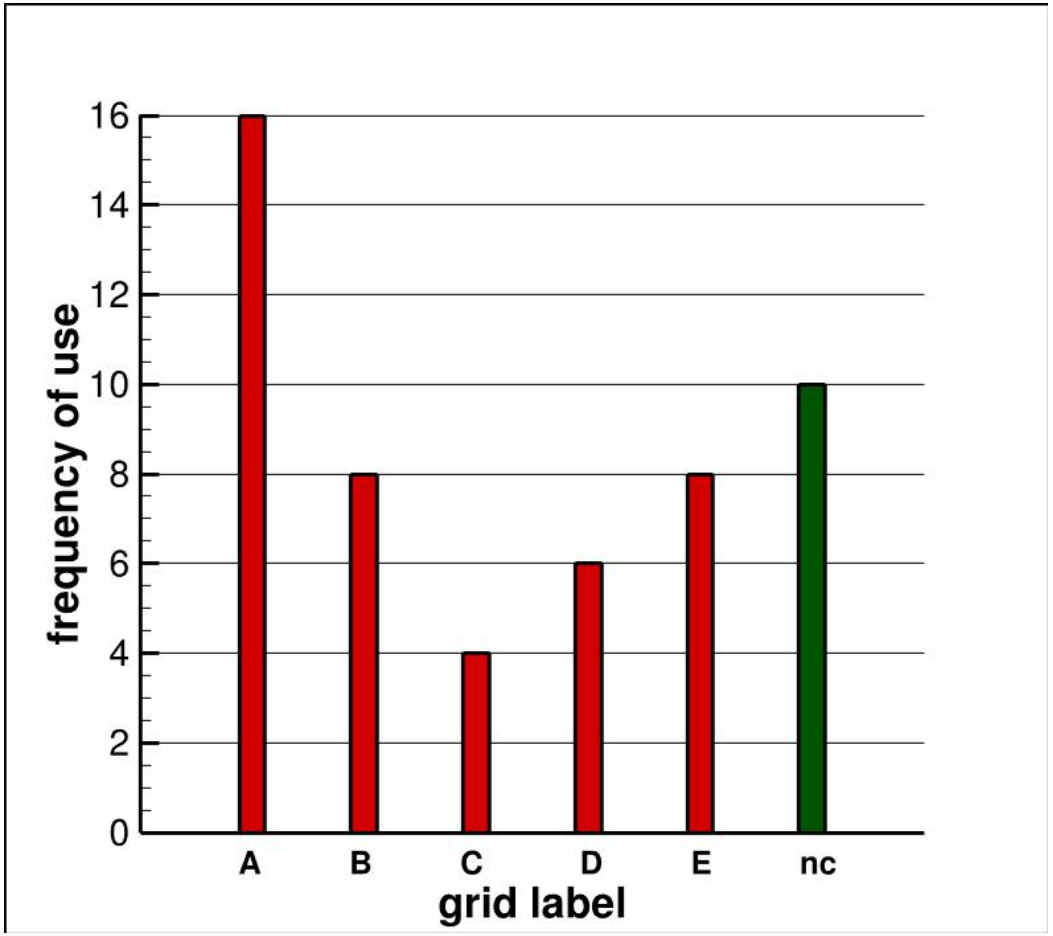
Adaptive

Summary of entries

- Grid type:
  - 20 structured/overset
  - 25 unstructured
  - 3 Lattice-Boltzmann
- Turbulence models:
  - 32 used SA or variant
  - 8 used SST or variant
  - 4 other RANS
  - 4 scale-resolving type
- Transition:
  - 4 accounted for it

Grid usage

- 16 used A, 8 used B, 4 used C, 6 used D, 8 used E
- 10 made their own (nc = non-committee)



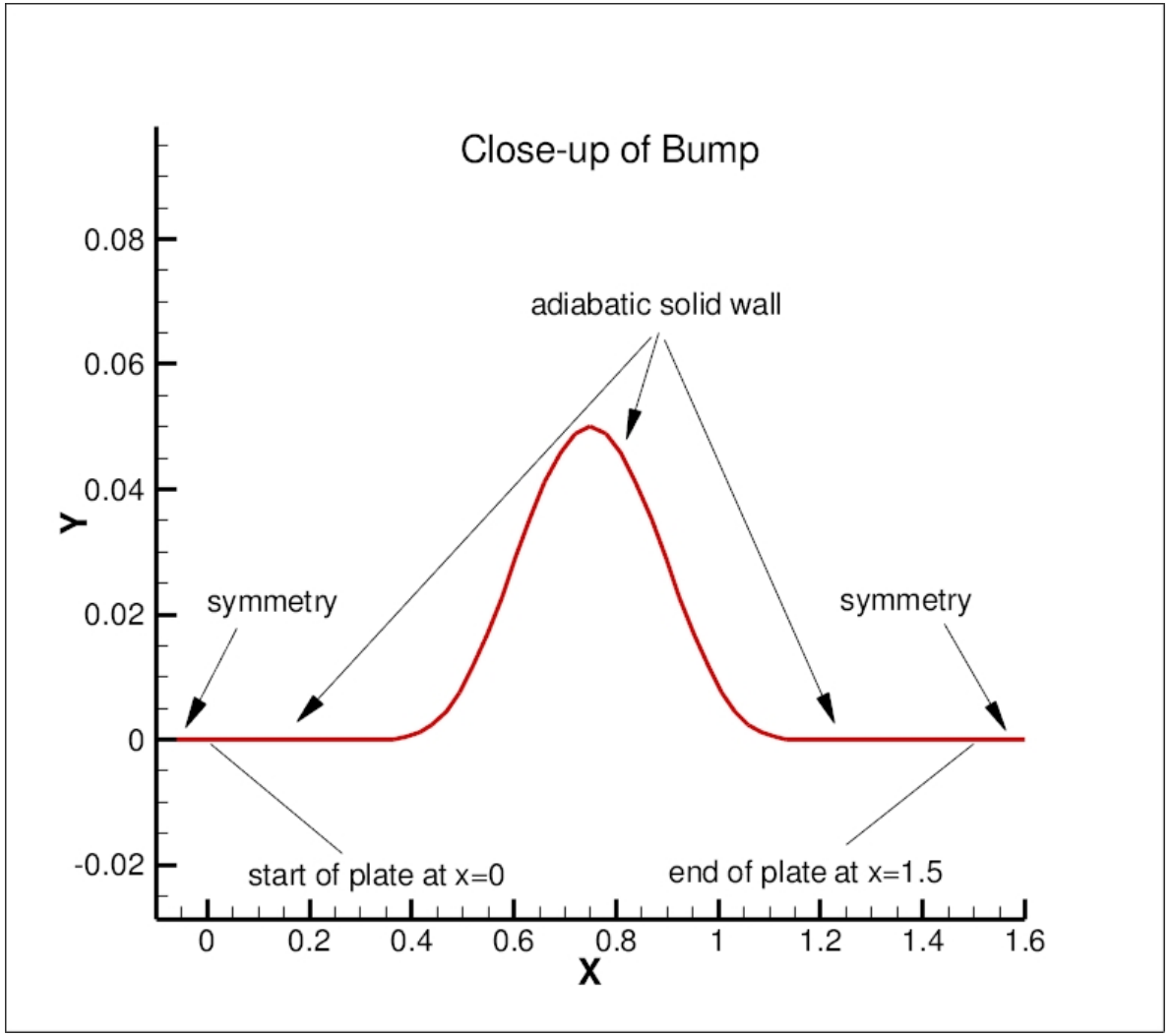
Cases

- Case 1
  - Re=15.1 M, fully turbulent, no brackets (41 datasets)
- Case 2
  - a) Re=1.35 M, fully turbulent, w brackets (22 datasets)
  - b) Re=15.1 M, fully turbulent, w brackets (21 datasets)
  - c) Re=1.35 M, transitional w brackets (3 datasets)
- Case 3
  - a) Re=1.35 M, w brackets+bundles (4 datasets)
  - b) Re=15.1 M, w brackets+bundles (4 datasets)
- Case 4
  - Turbulence model 2-D verification study (10 datasets)

Note: not all datasets were complete

Turbulence model verification (Case 4)

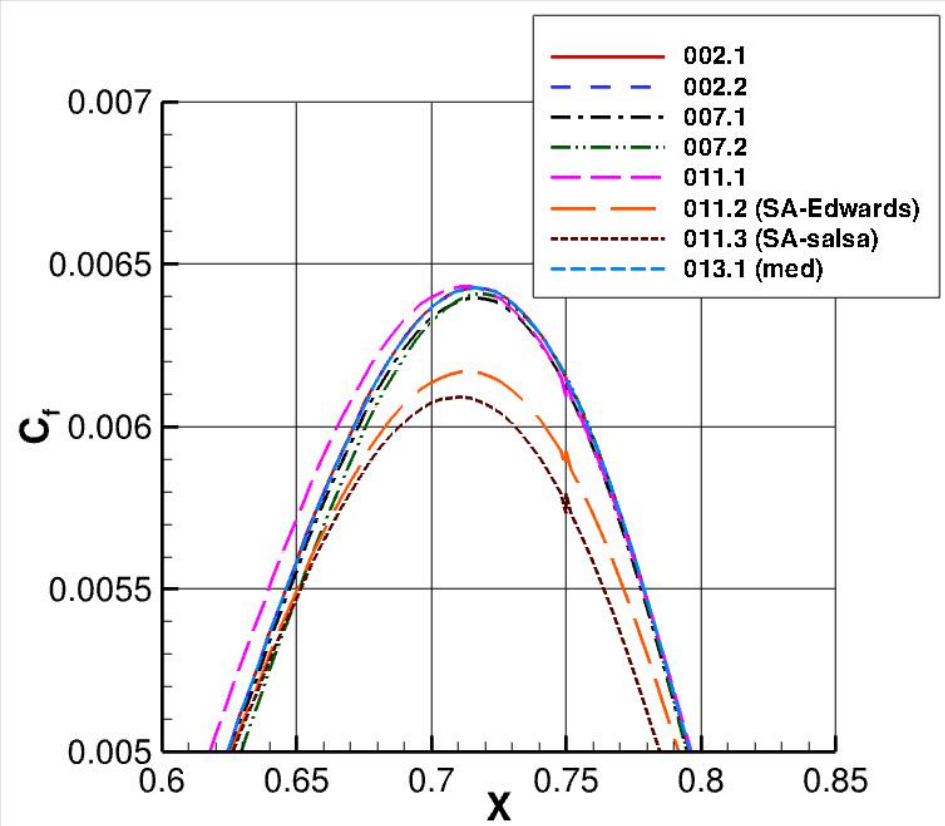
Case 4 Turb model verification

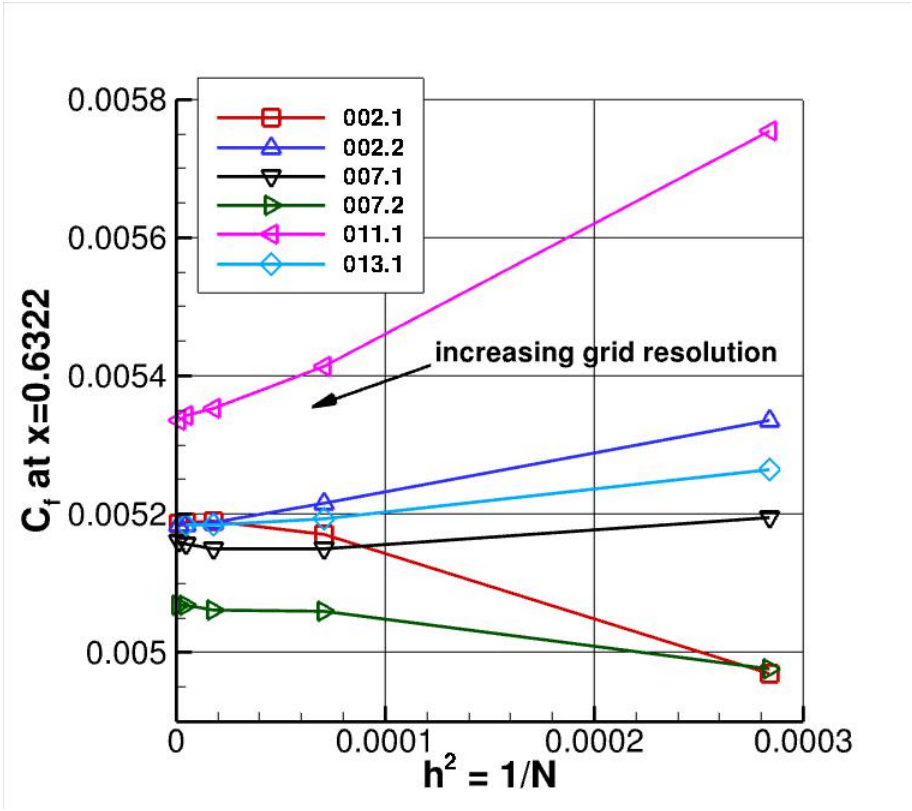


This case was also used in DPW-5 (see AIAA-2013-0046)

Case 4 Turb model verification

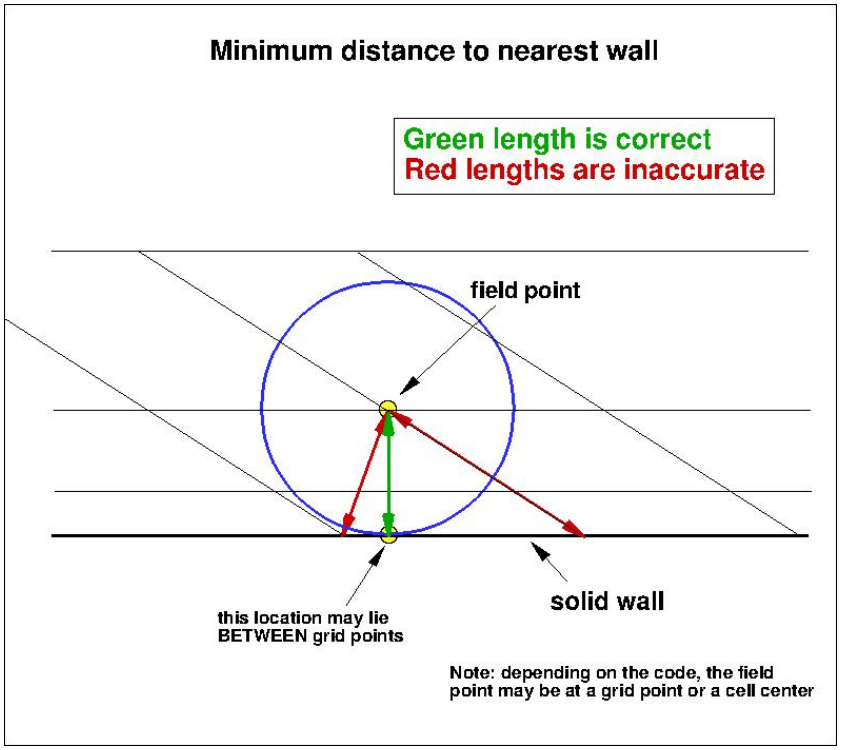
SA model and variants

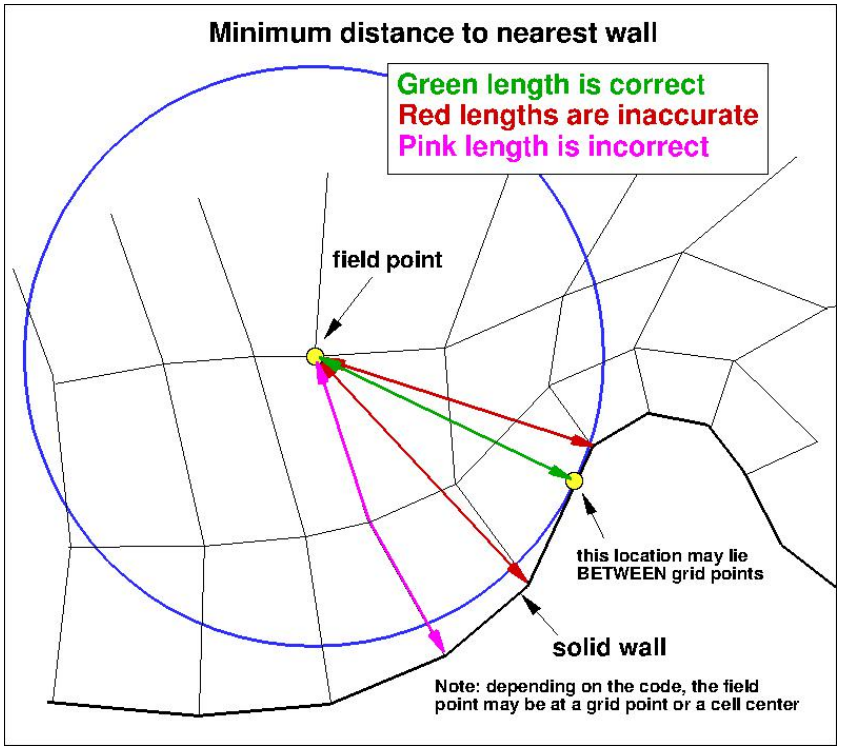




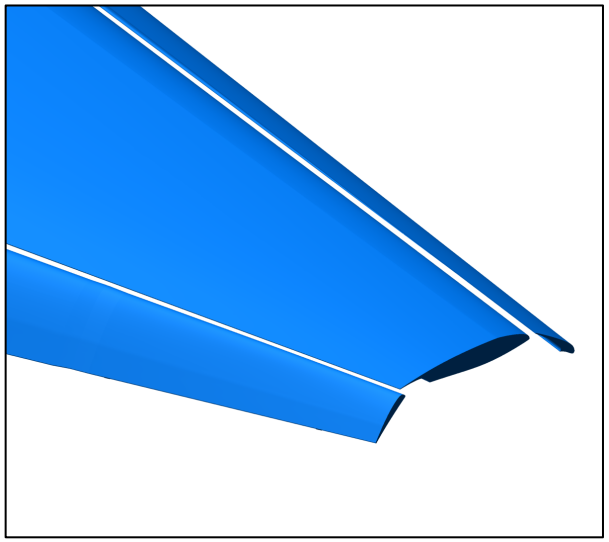
- SA-Edwards and SA-salsa significantly different from SA
- 007.2 and 011.1 do not agree with “accepted” SA results as grid is refined
- 007.1 just slightly off

Accurate min distance is particularly important for SA model



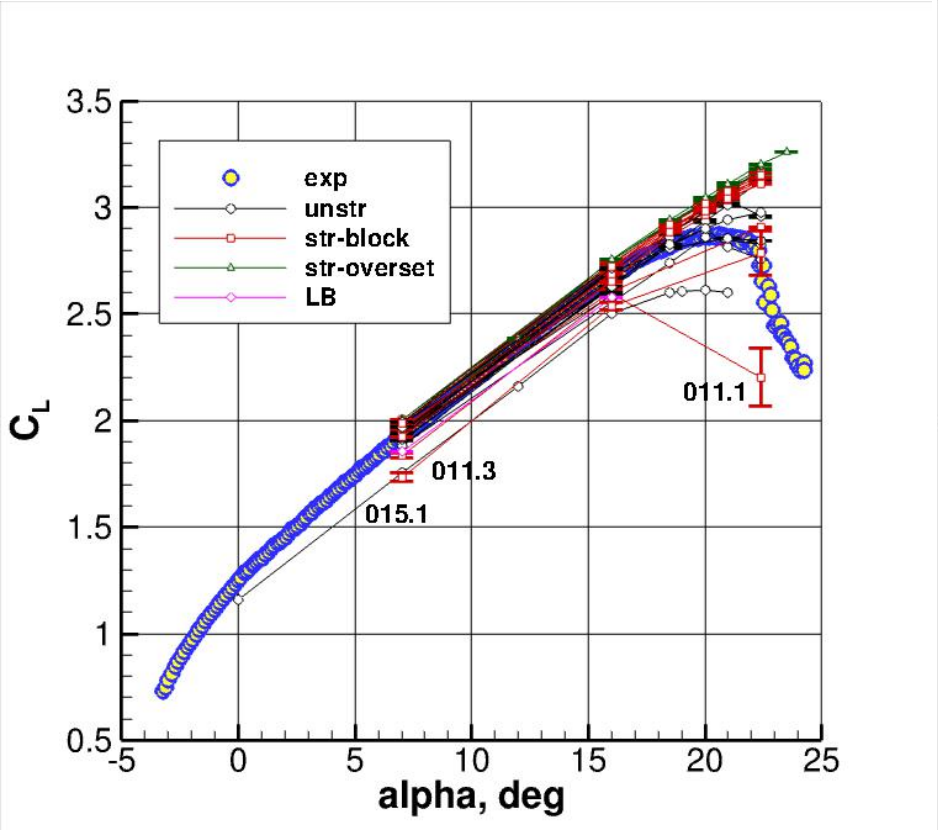


DLR-F11 Force & moment predictions
Case 1

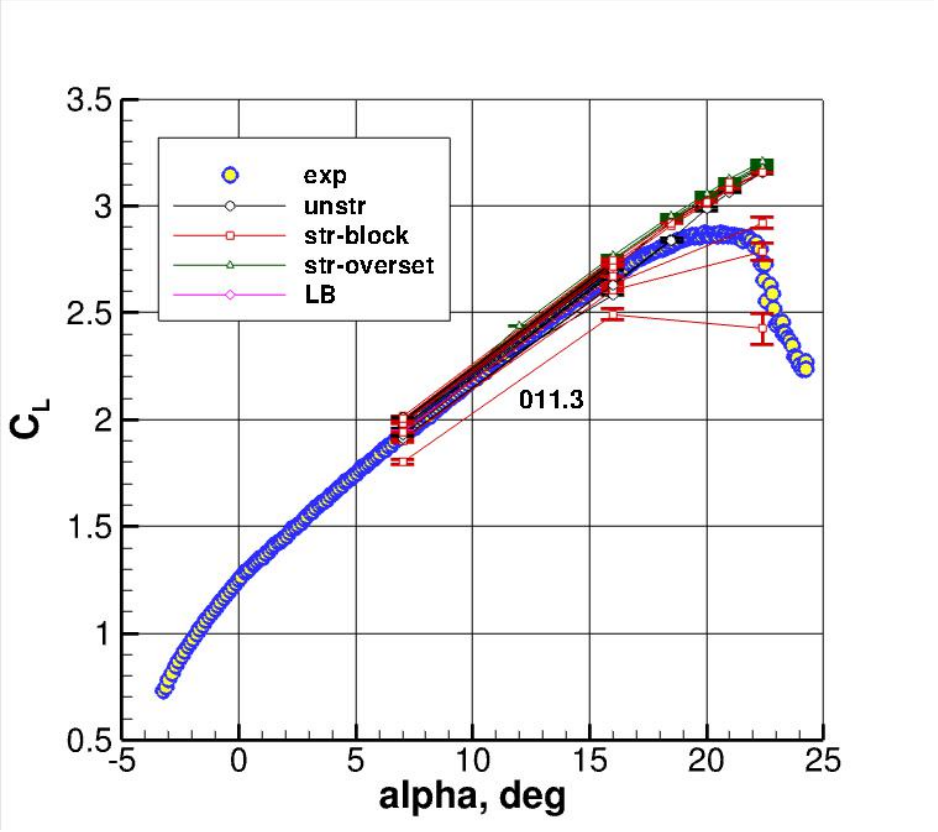


Case 1, Lift curve

Medium grids



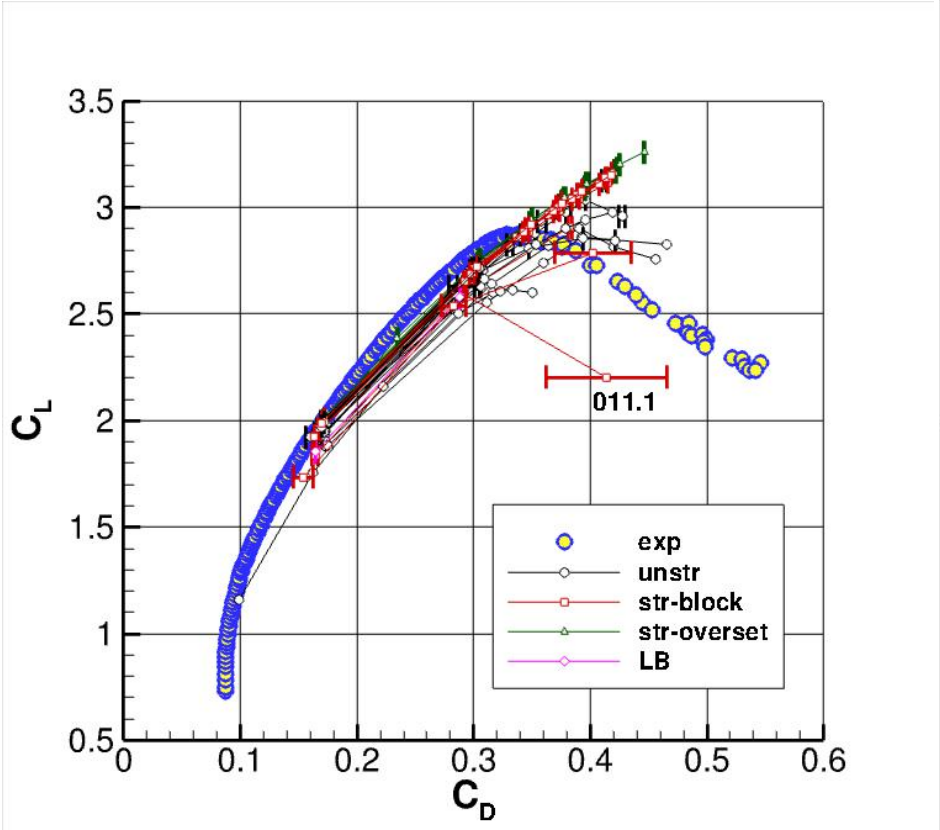
Fine grids



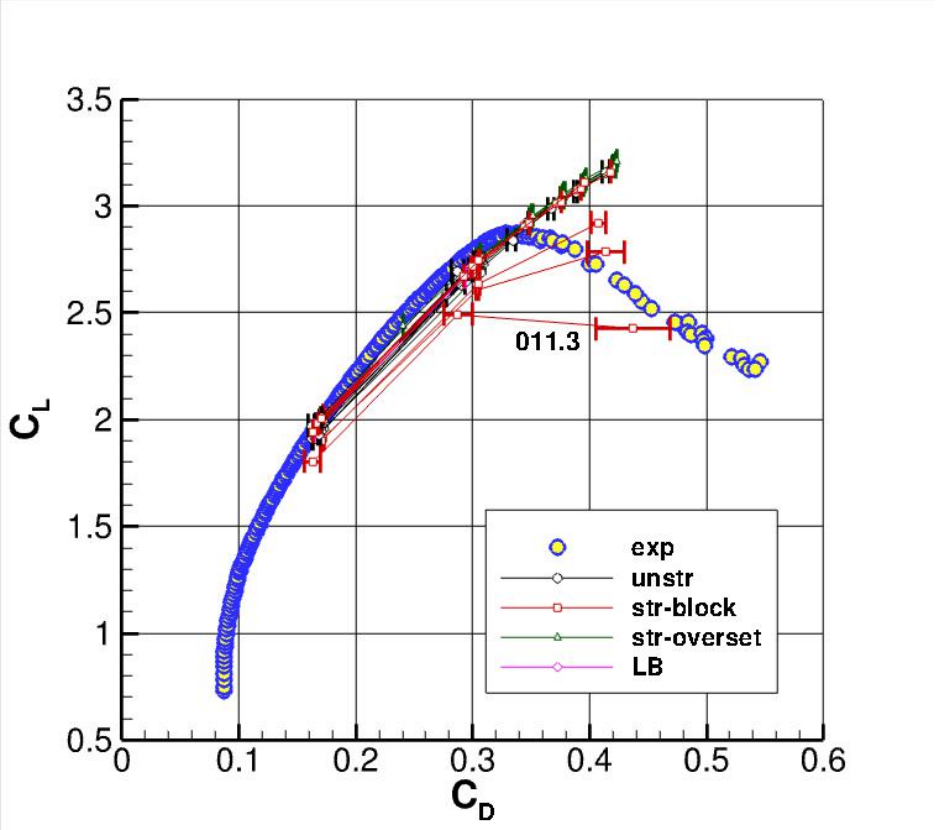
One grouping of CFD is fairly tight and over-predicts CLmax
Those with lower lift report higher uncertainties

Case 1, Drag polar

Medium grids

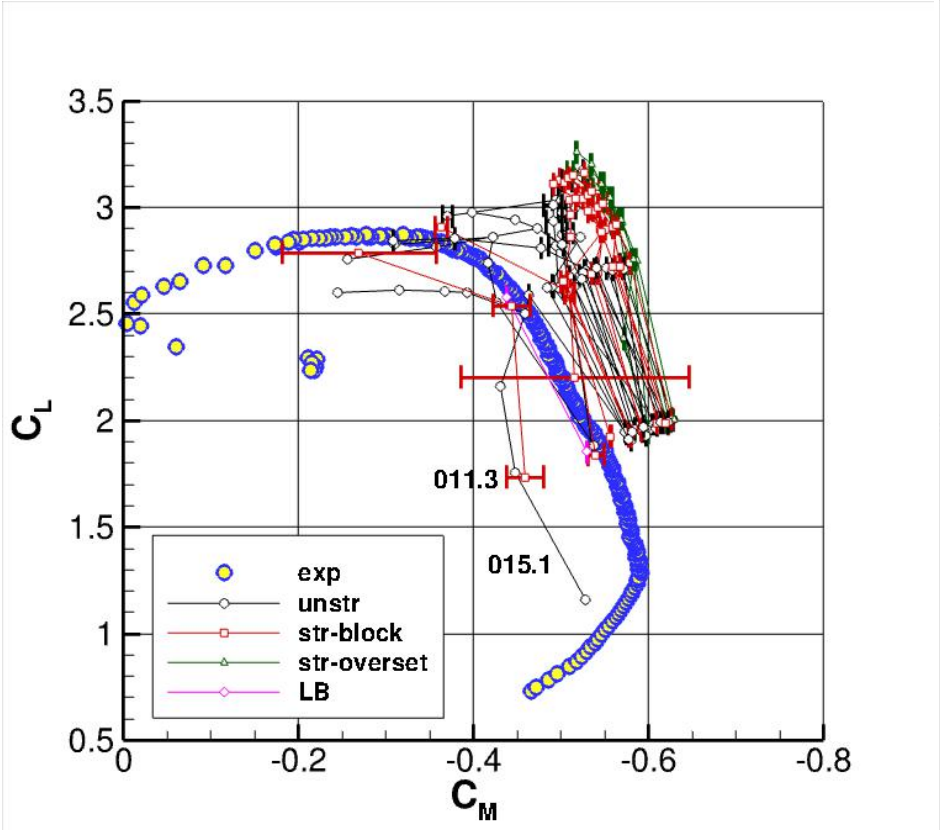


Fine grids

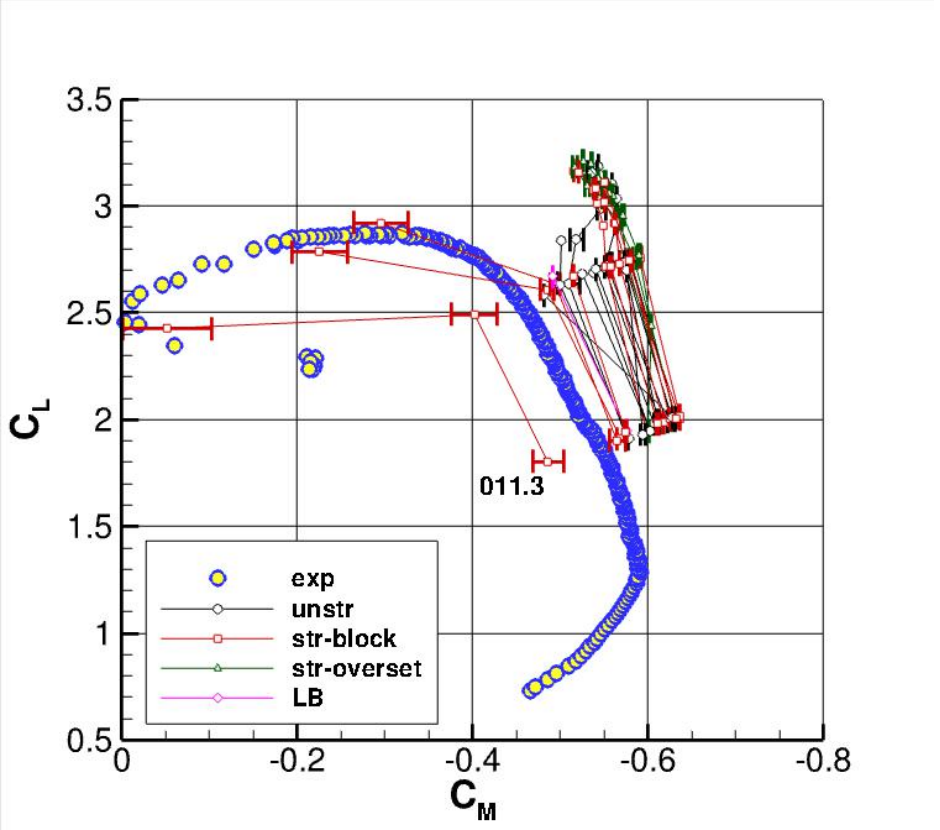


Case 1, Moment polar

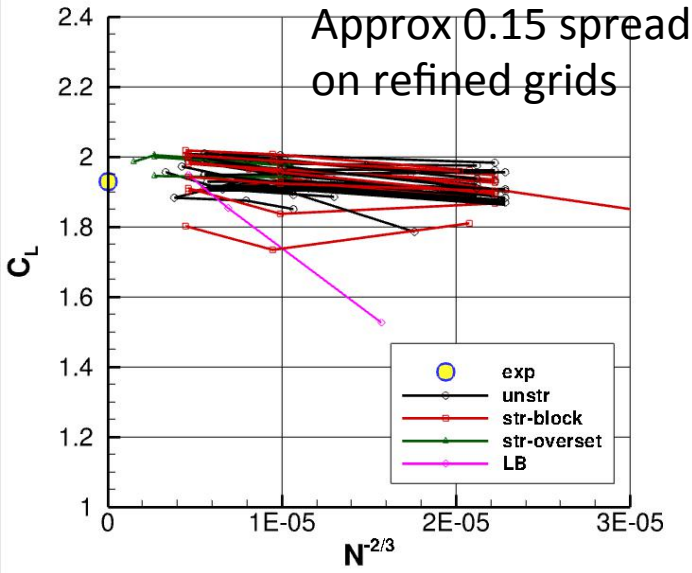
Medium grids

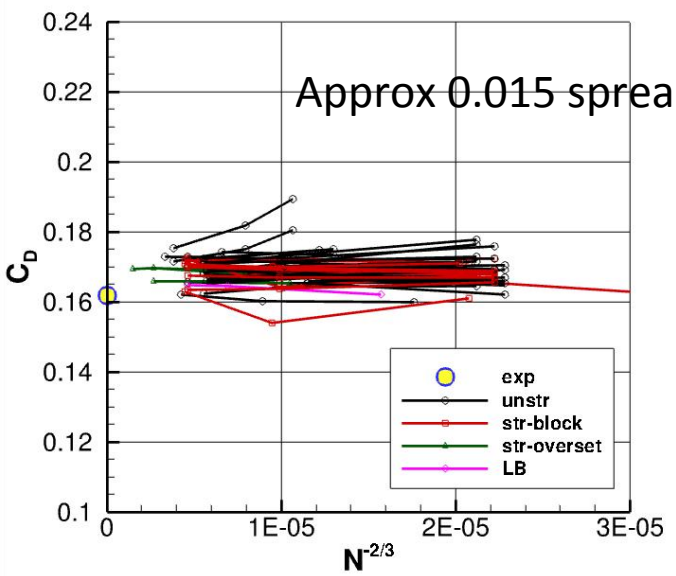


Fine grids



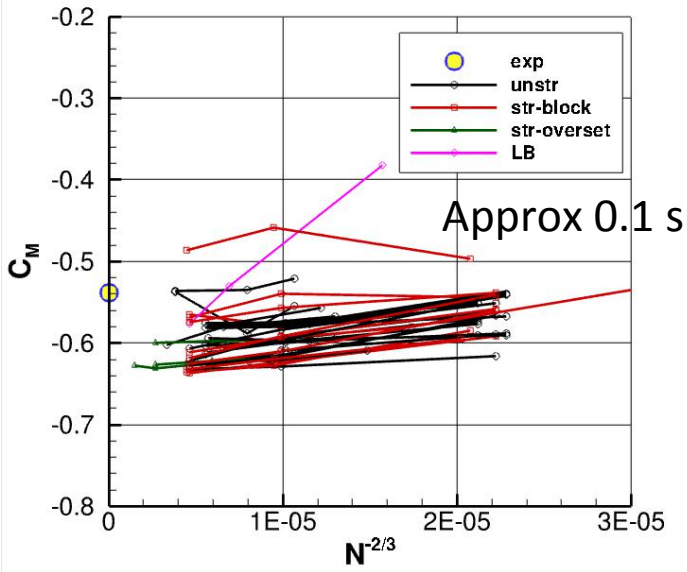
Case 1 Grid convergence, AoA=7



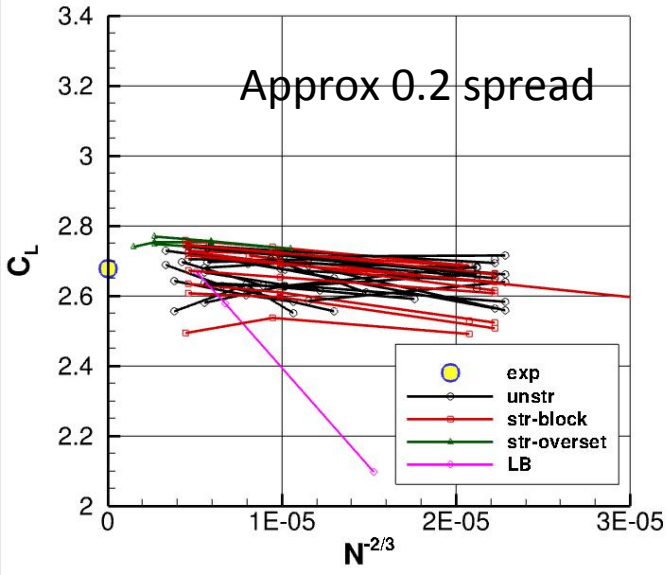


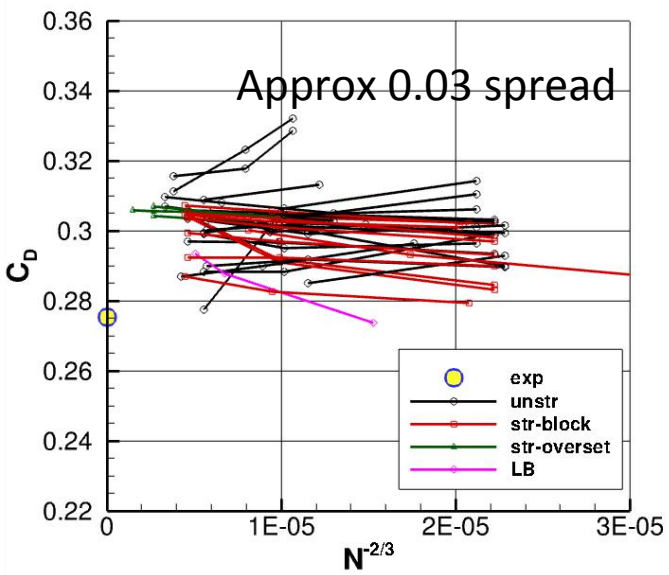
We are looking for CFD to "come together" as grid is refined ($N^{-2/3}$ -> 0)

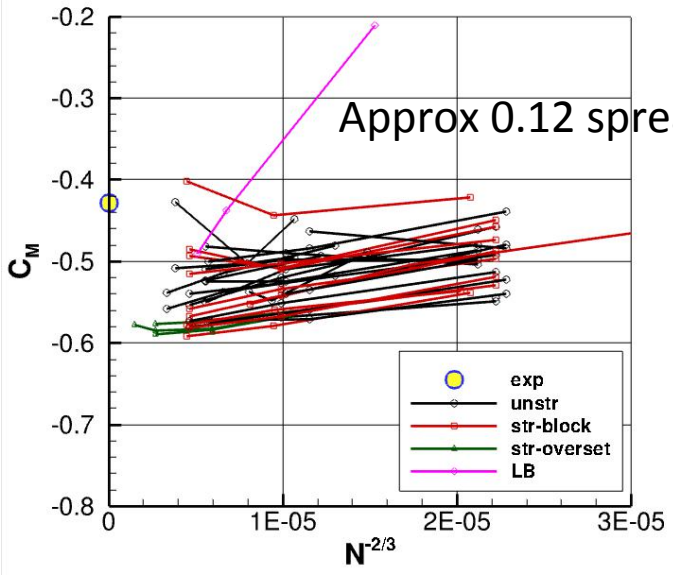
The spread can be thought of as CFD uncertainty



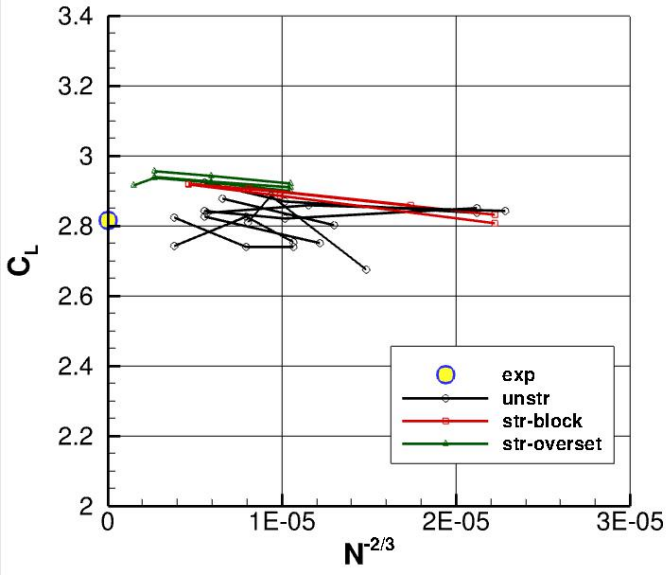
Case 1 Grid convergence, AoA=16

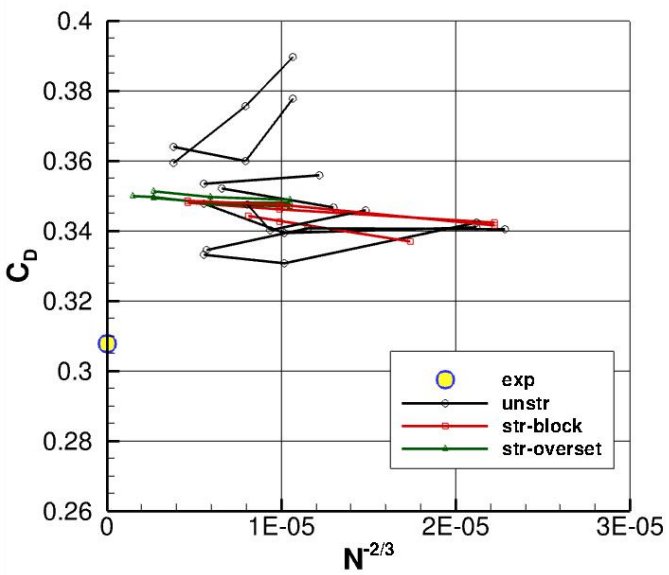


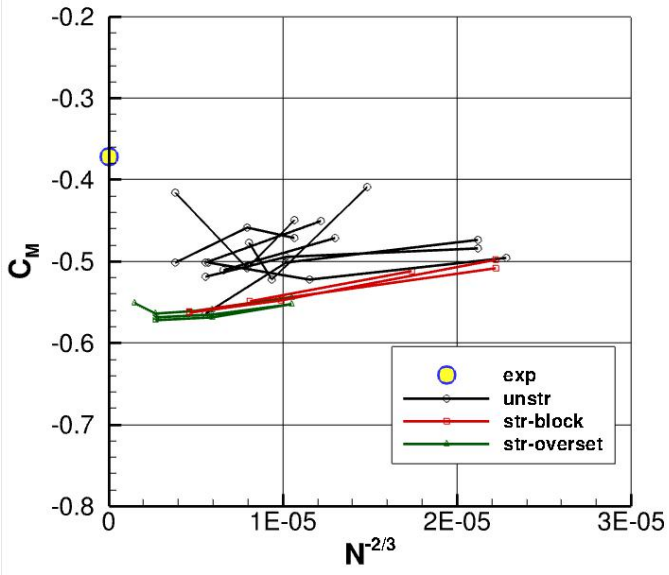




Case 1 Grid convergence, AoA=18.5



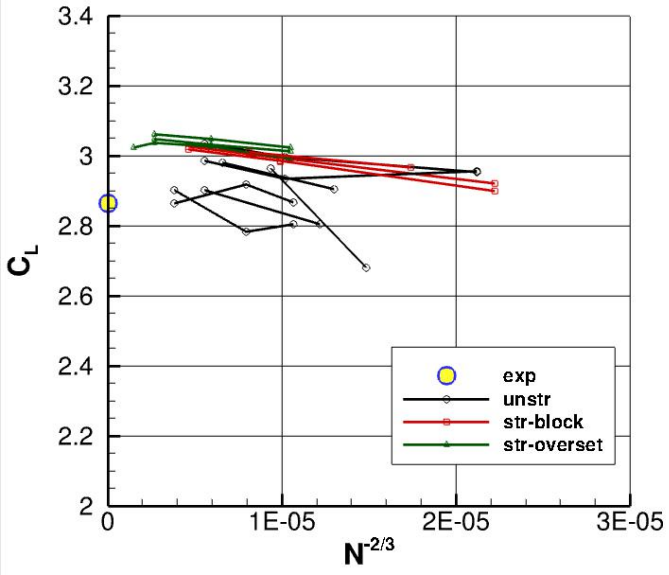


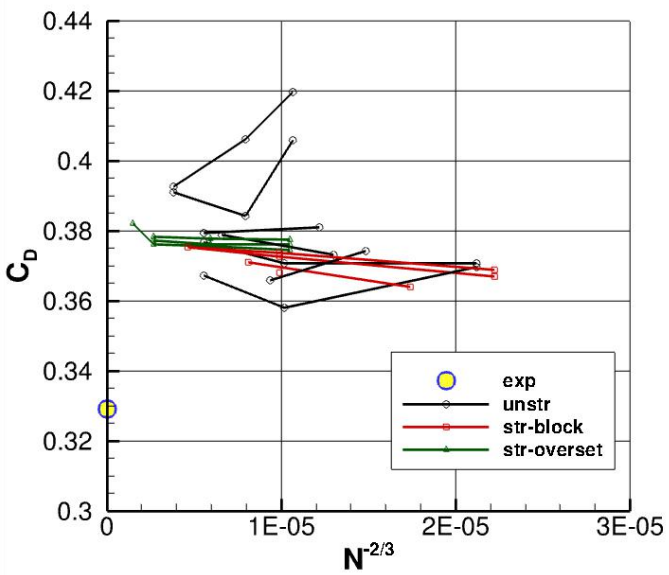


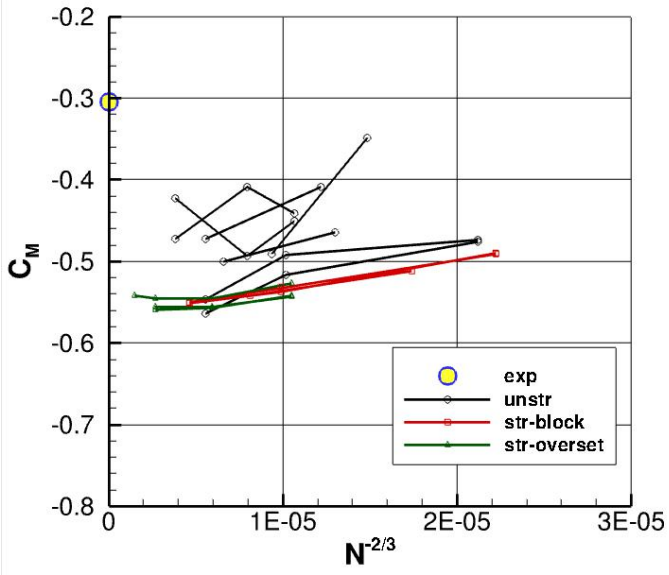
More difficult to tell where soln going at higher AoAs

Structured results are fairly tight

Case 1 Grid convergence, AoA=20



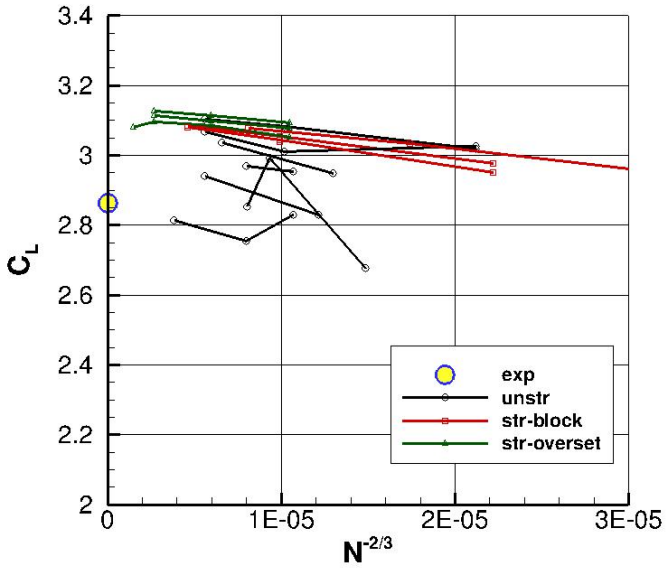


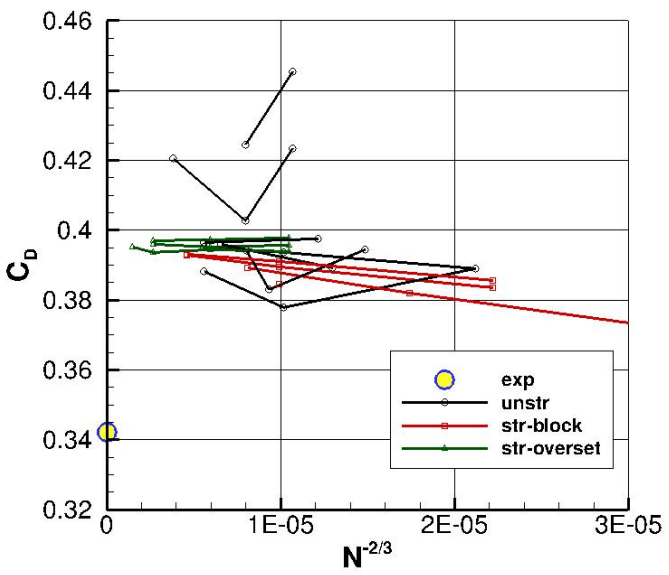


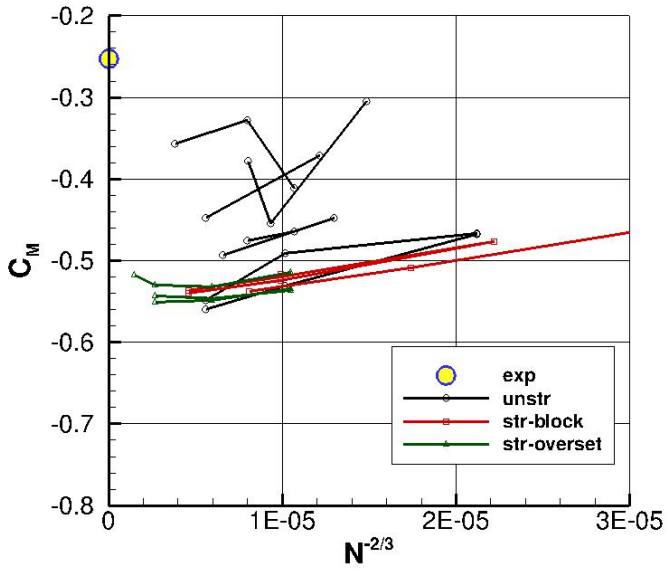
More difficult to tell where soln going at higher AoAs

Structured results are fairly tight

Case 1 Grid convergence, AoA=21



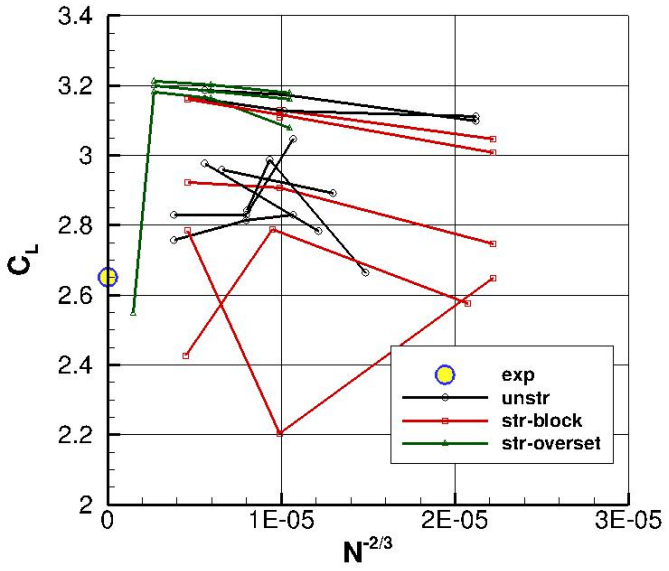


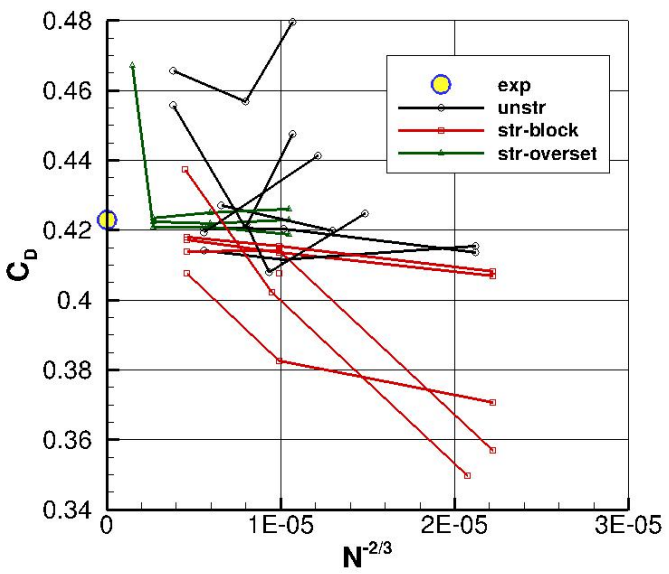


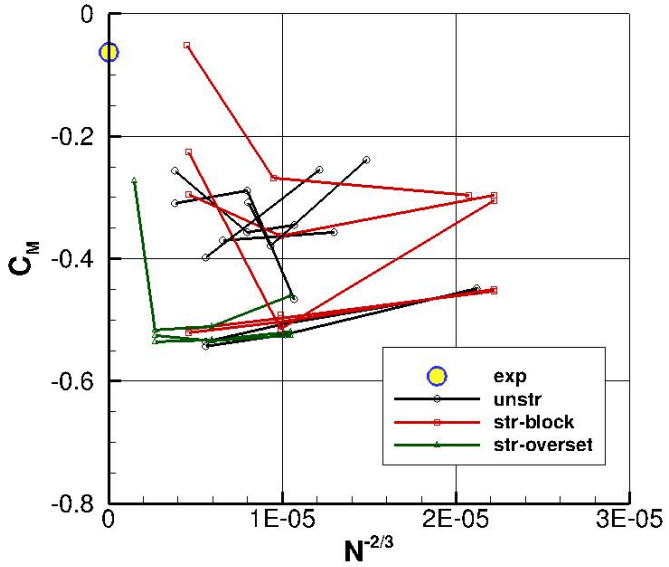
More difficult to tell where soln going at higher AoAs

Structured results are fairly tight

Case 1 Grid convergence, AoA=22.4



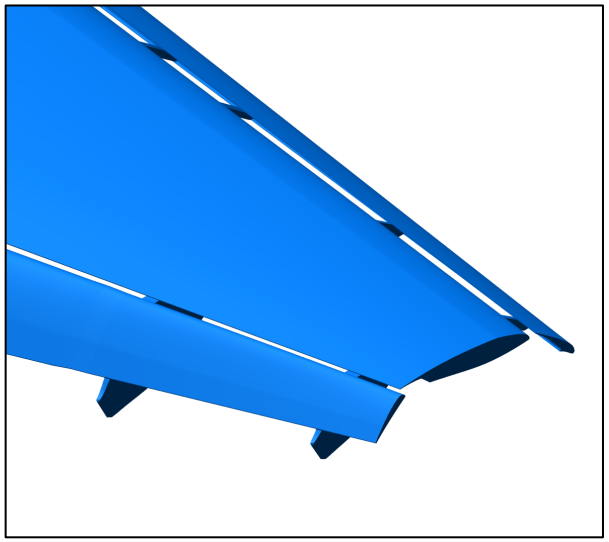




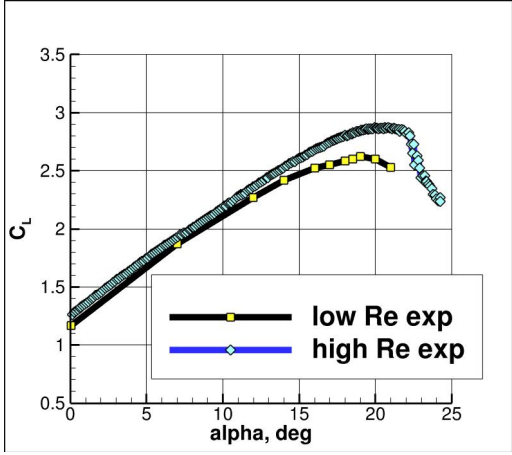
More difficult to tell where soln going at higher AoAs

All results show big spread

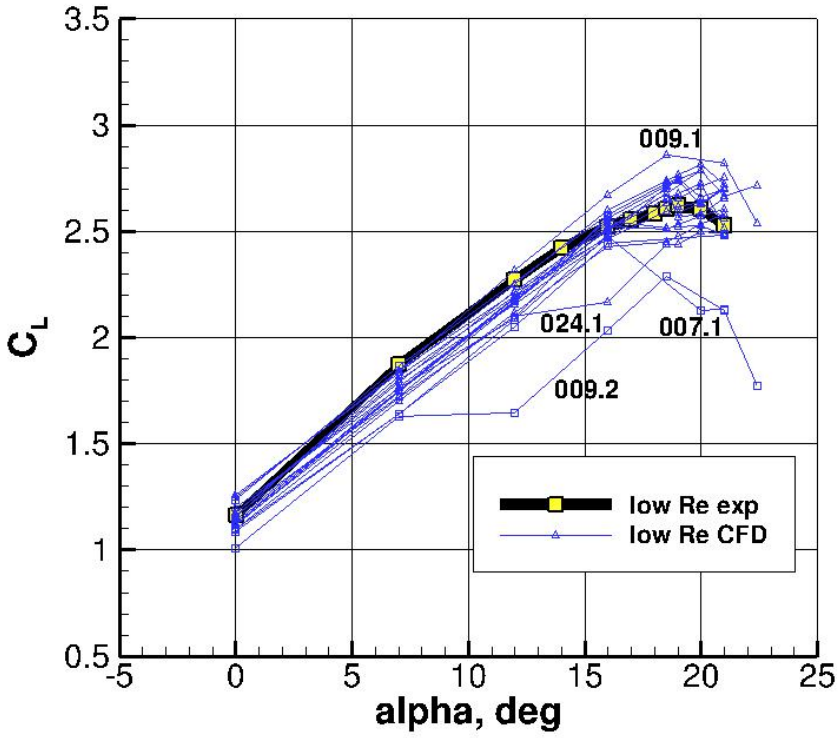
DLR-F11 Force & moment predictions
Cases 2 and 3



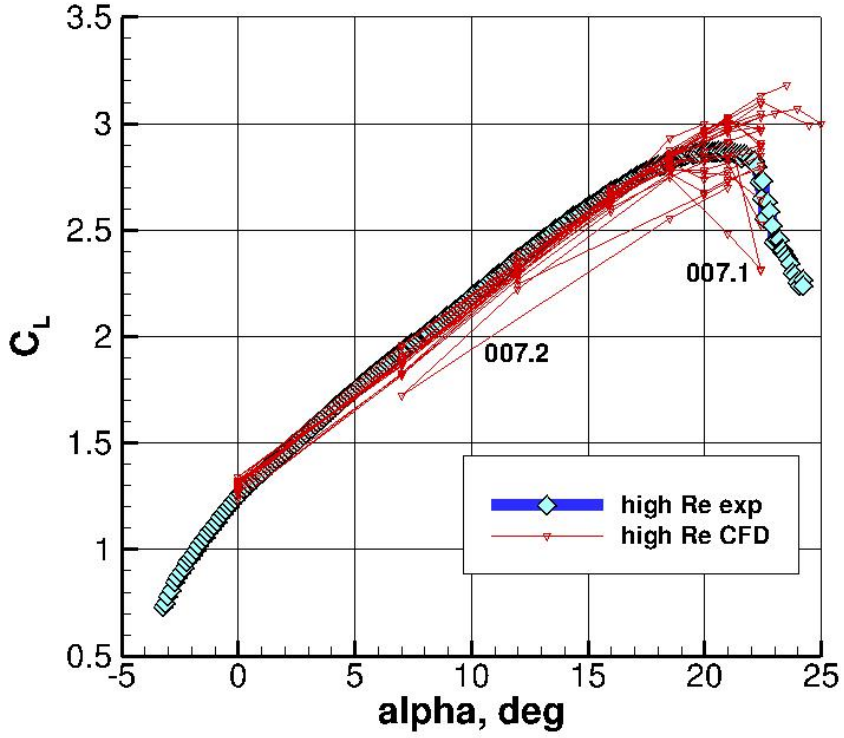
Case 2, Lift curve



Re = 1.35 x 10^6

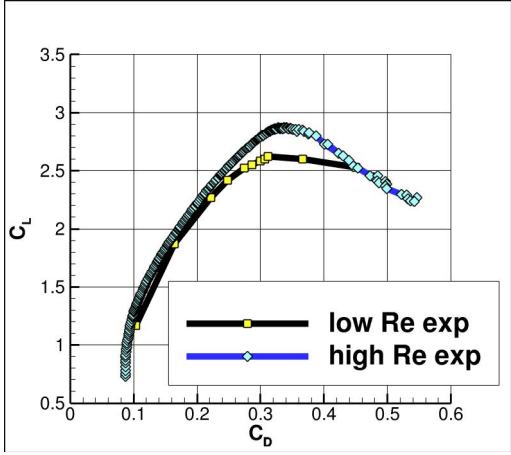


Re = 15.1 x 10^6

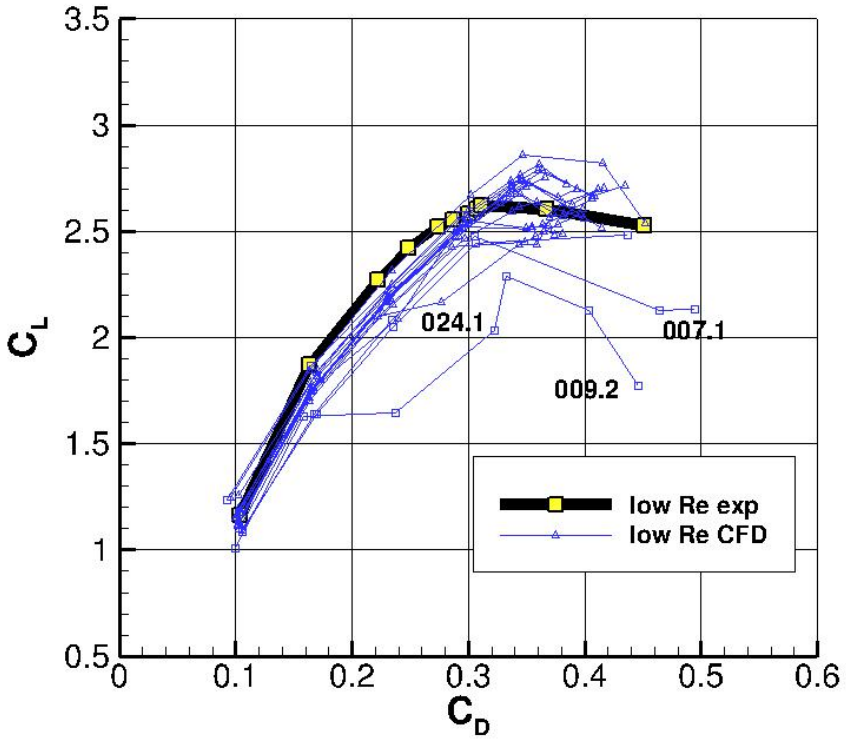


results on medium grids

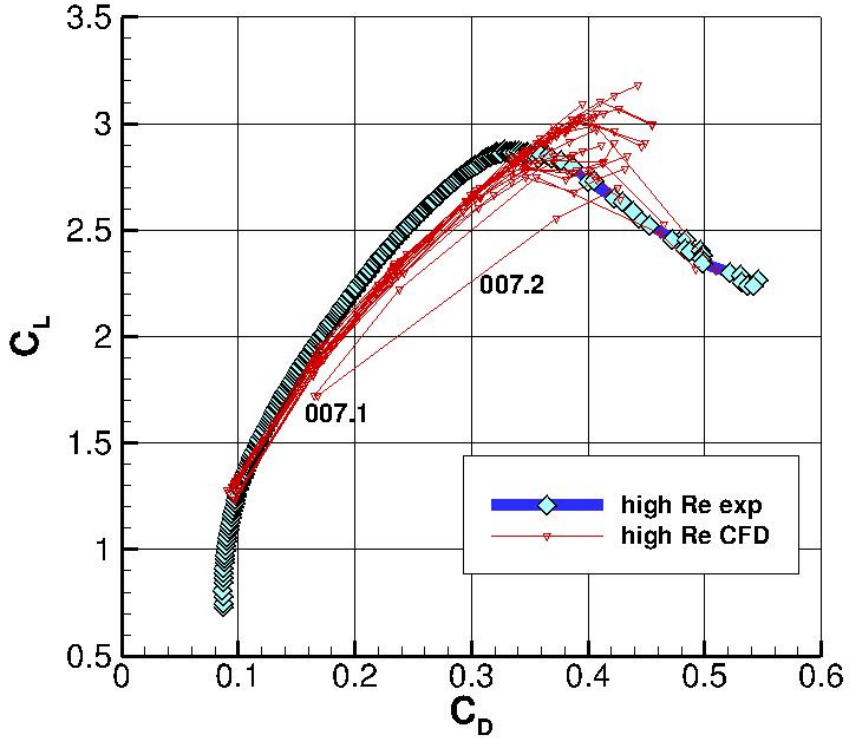
Case 2, Drag polar



Re = 1.35 x 10^6

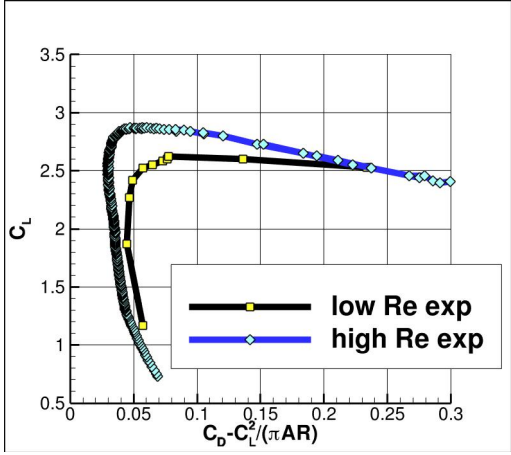


Re = 15.1 x 10^6

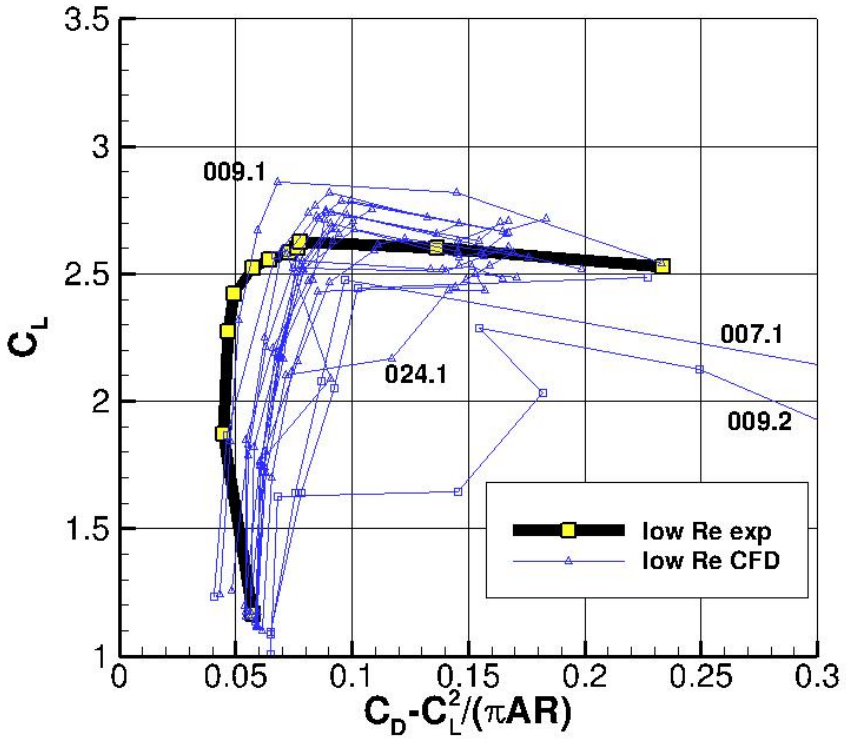


results on medium grids

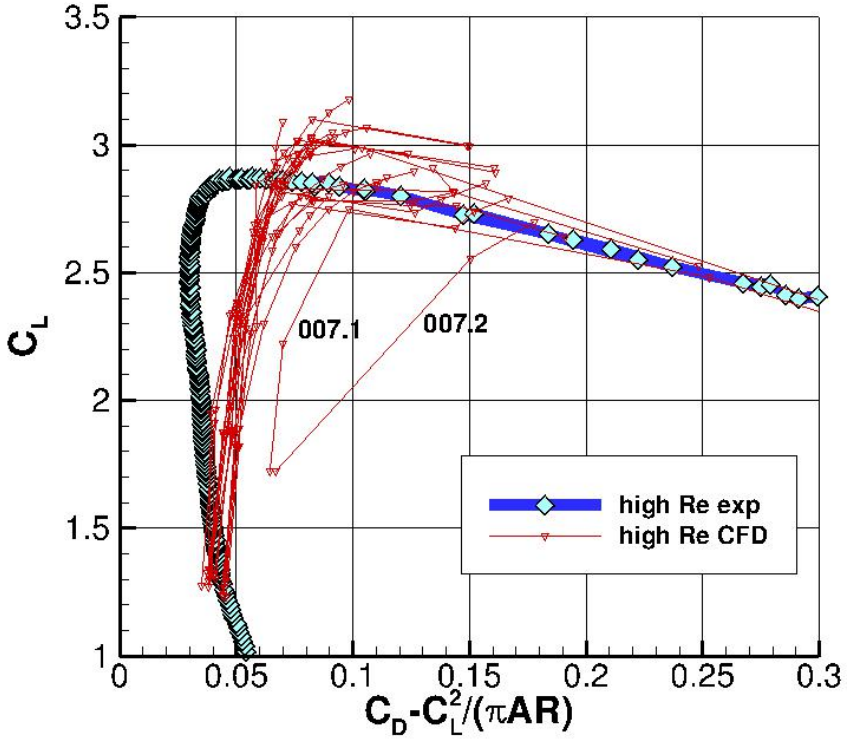
Case 2, Idealized drag polar



Re = 1.35 x 10^6

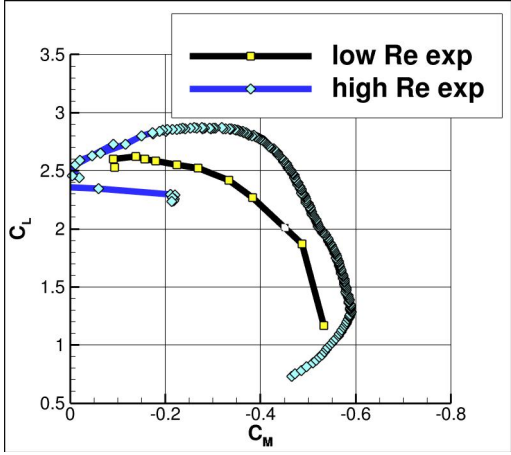


Re = 15.1 x 10^6

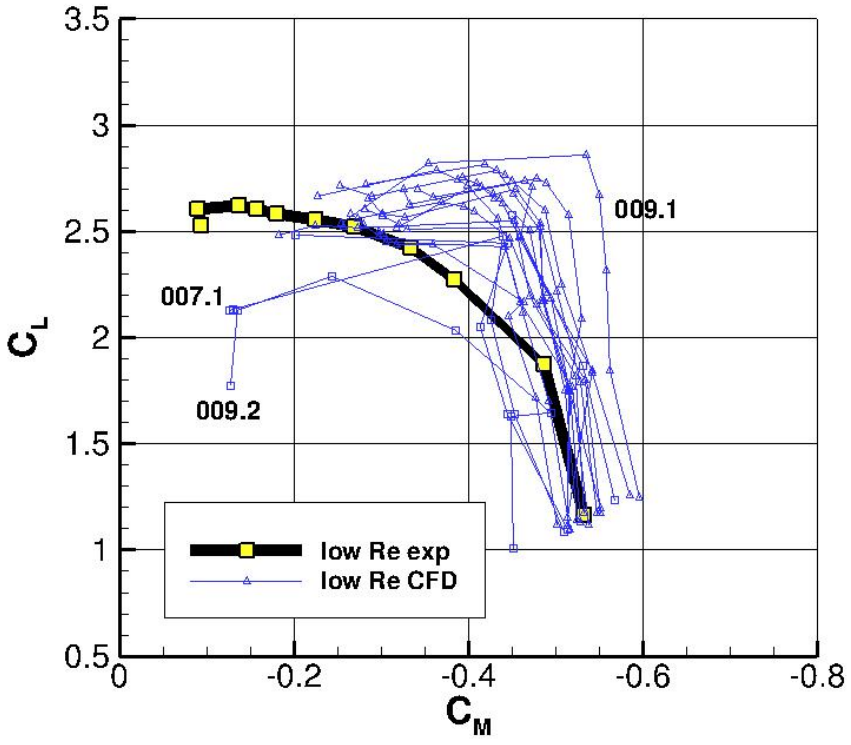


results on medium grids

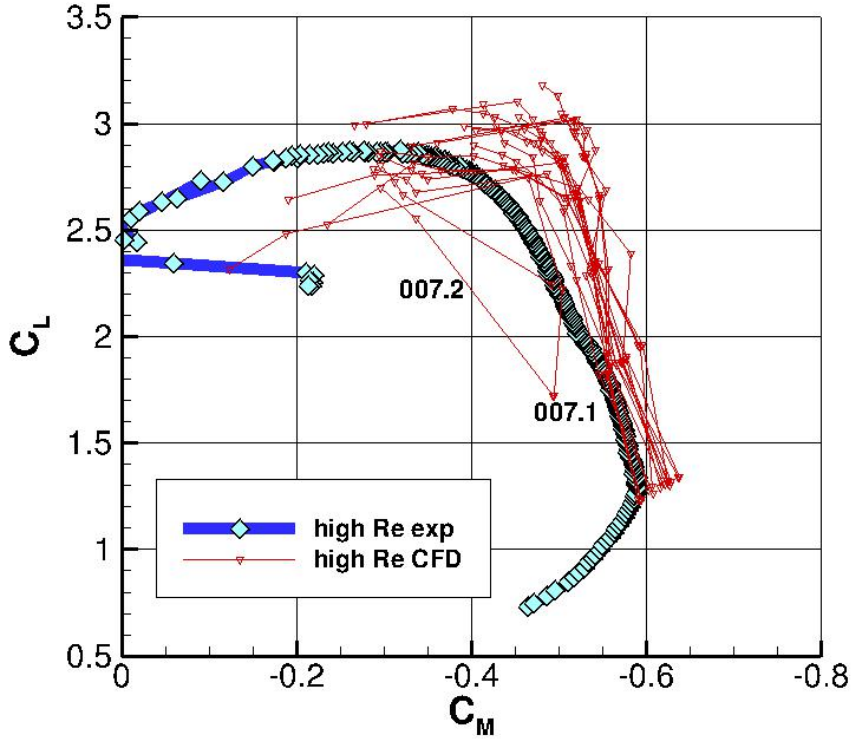
Case 2, Moment polar



Re = 1.35 x 10^6

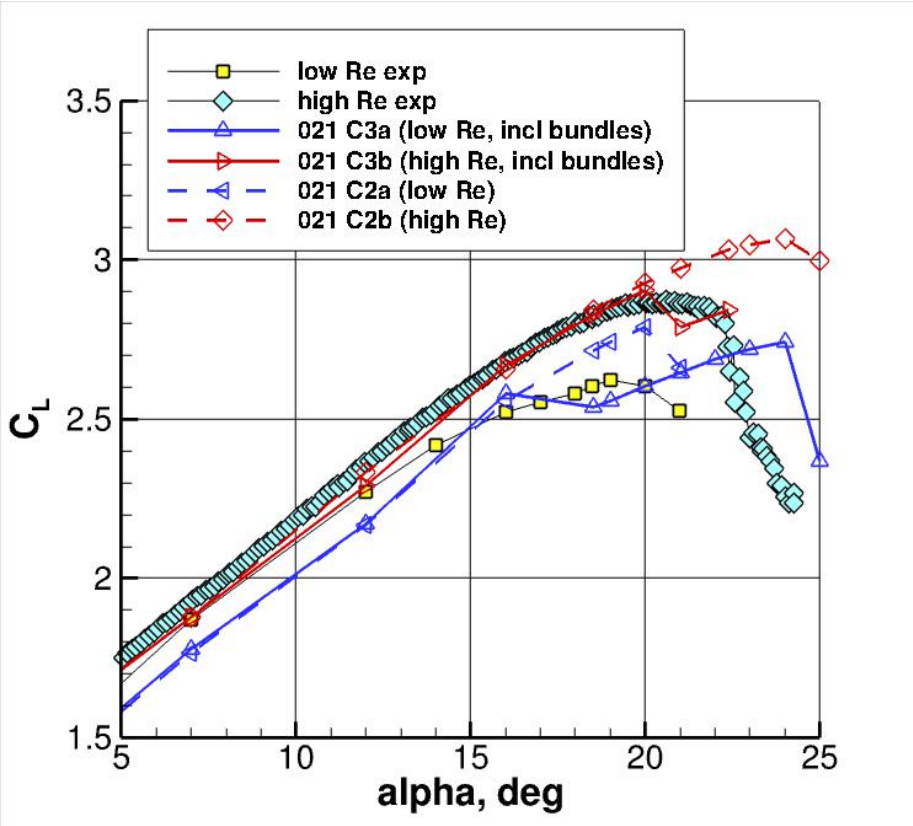


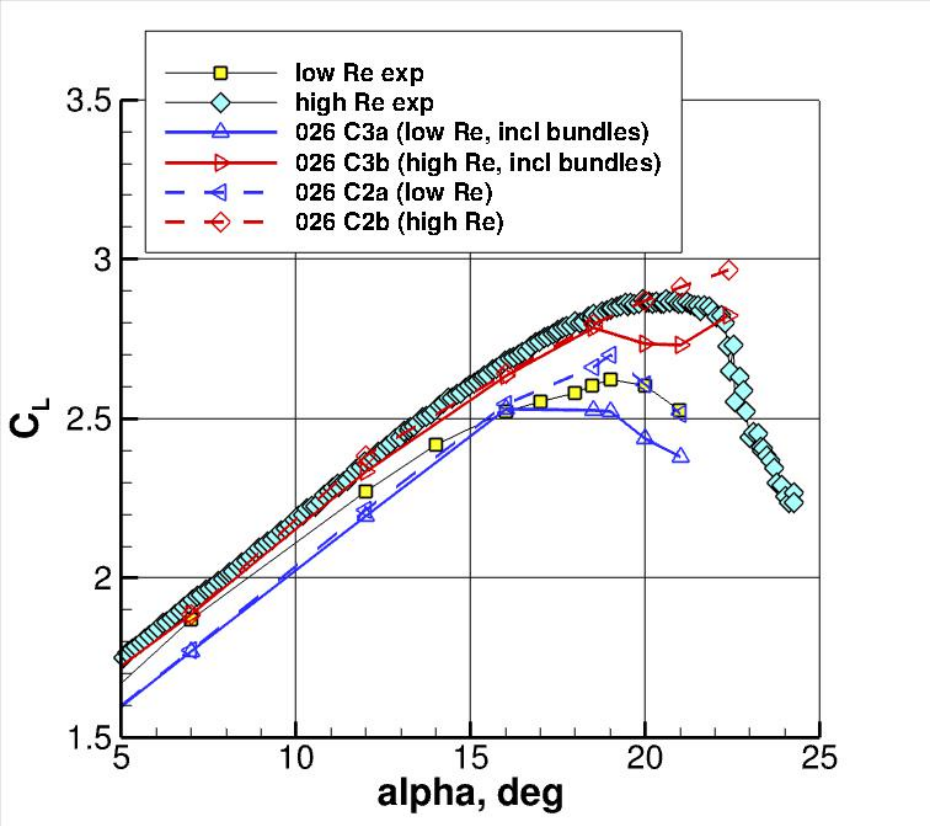
Re = 15.1 x 10^6



results on medium grids

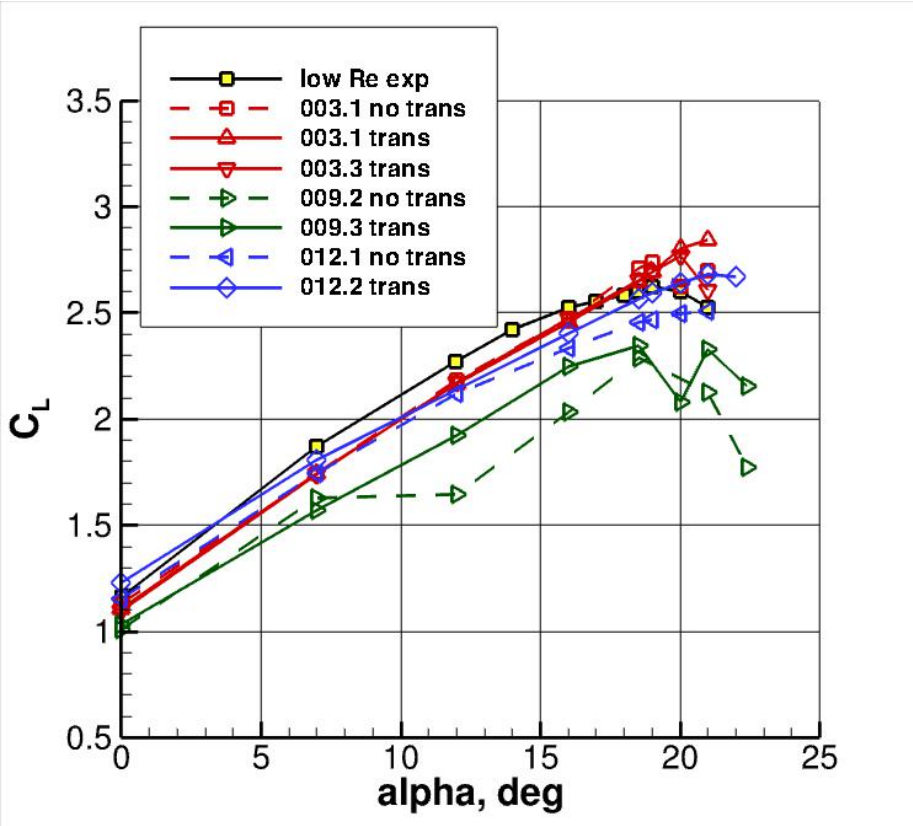
Effect of including pressure tube bundles

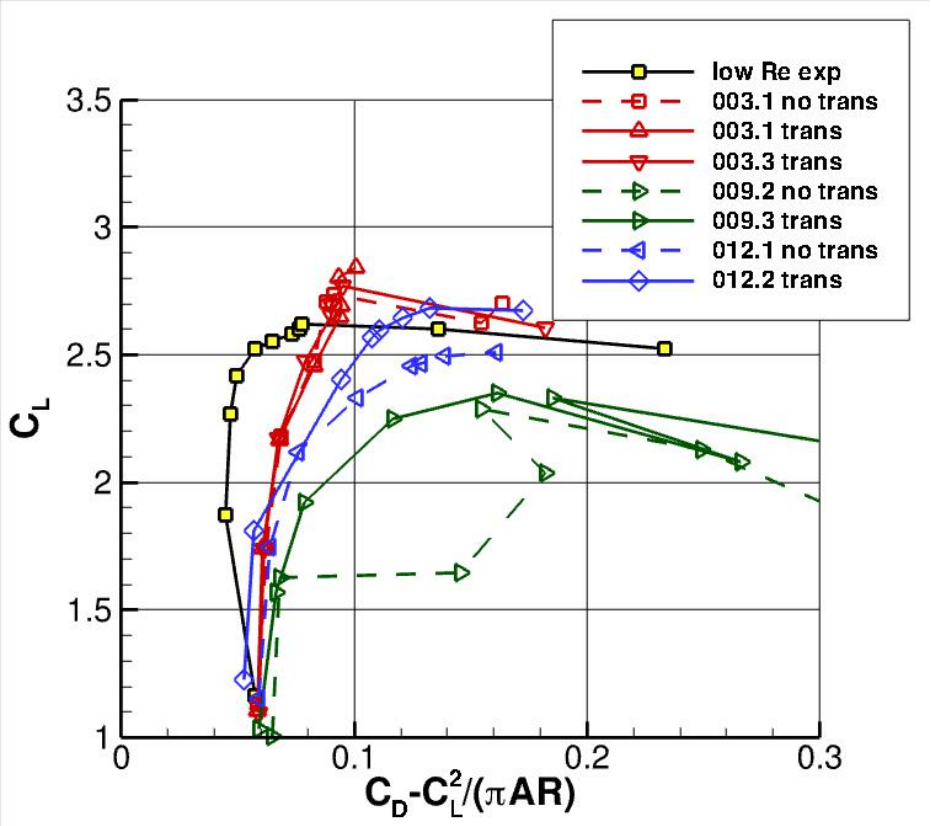




Some influence near CLmax

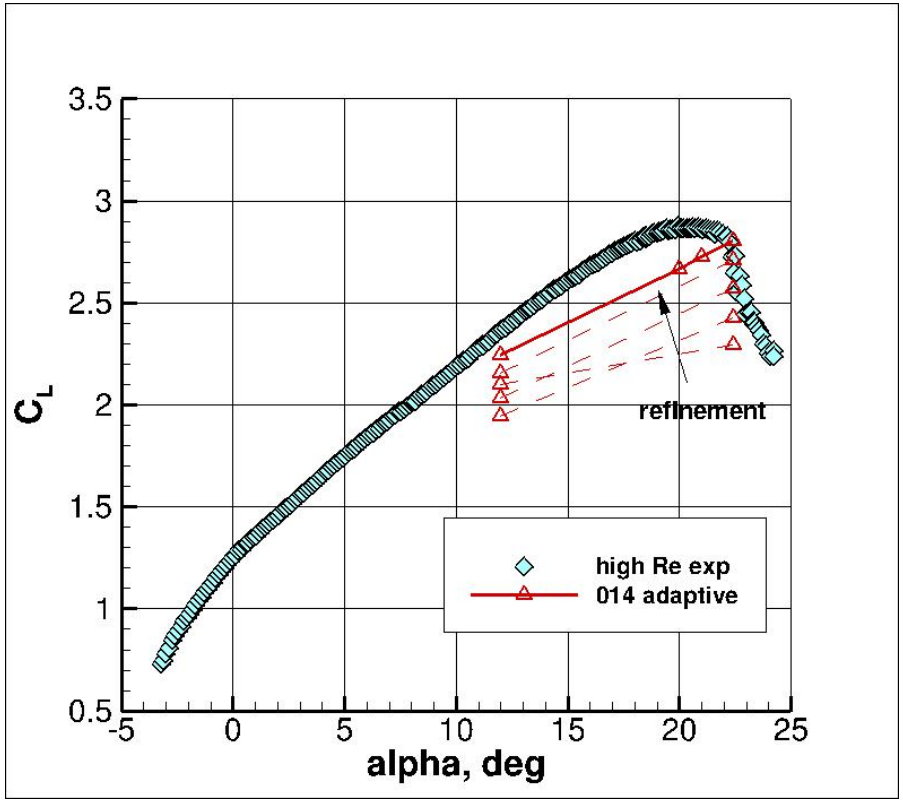
Effect of including transition

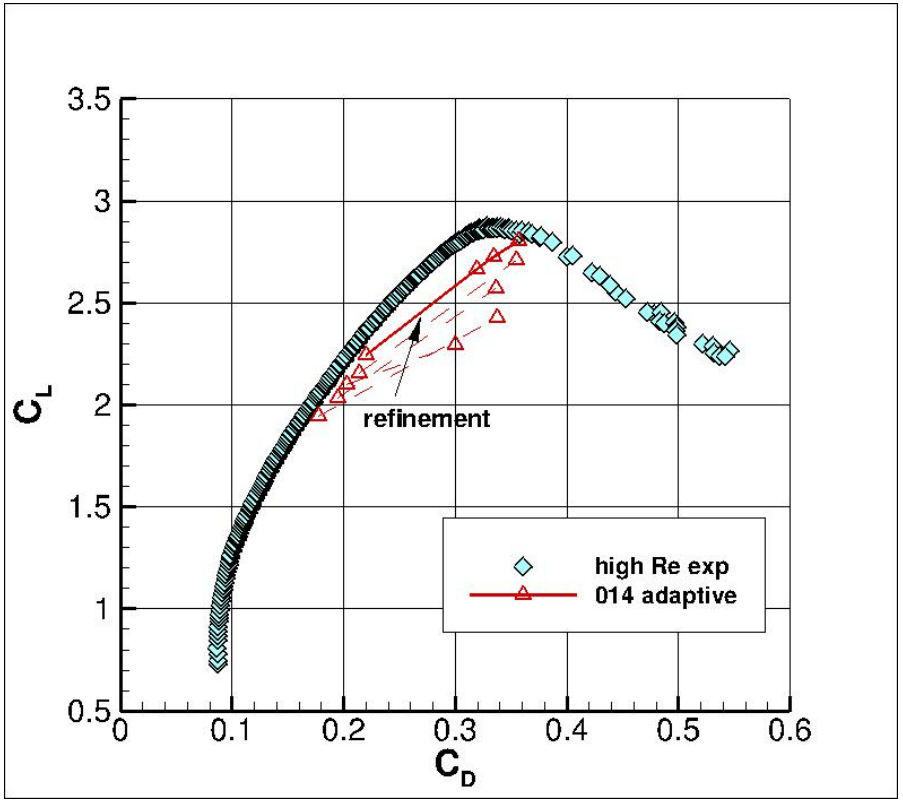




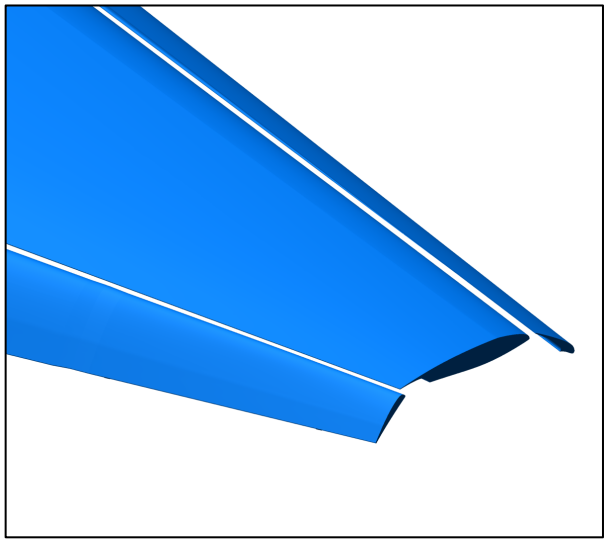
Inconclusive!

Case 2b adaptive result at high Re



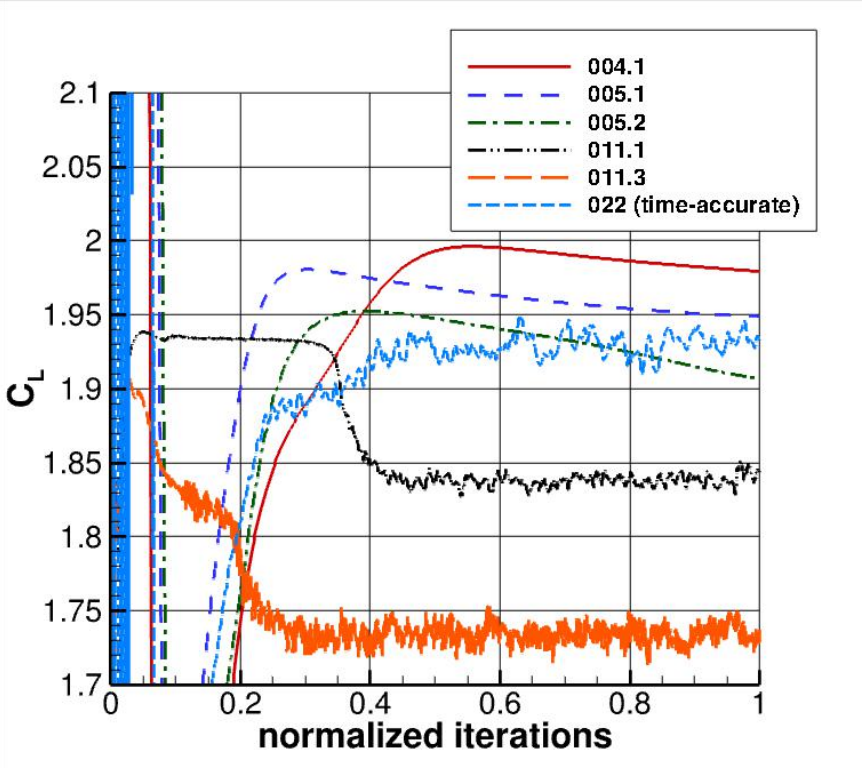


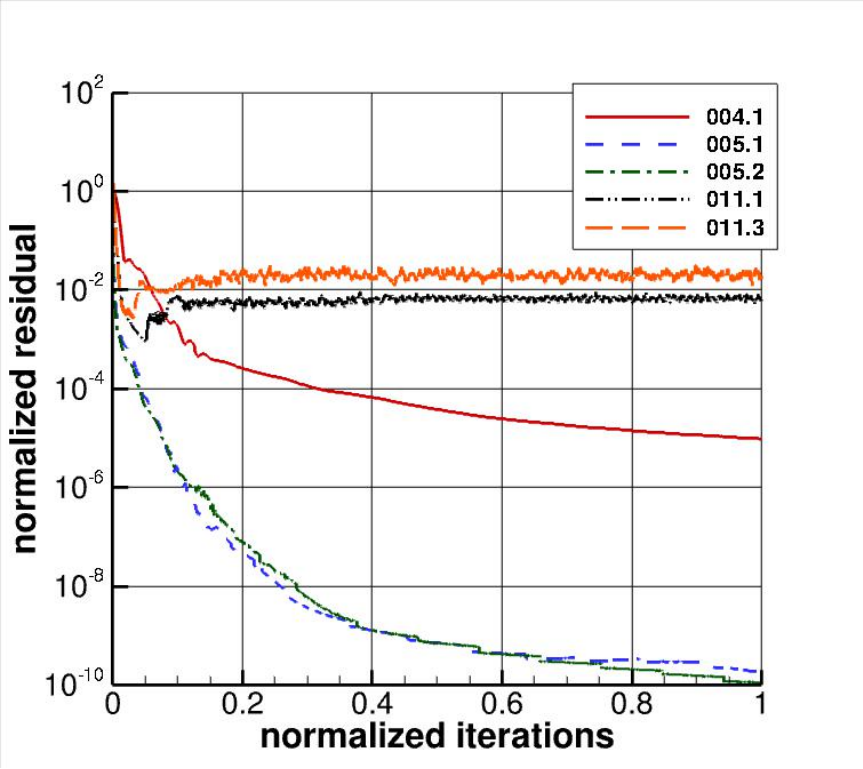
Iterative convergence
Case 1



Case 1 Iterative convergence, AoA=7

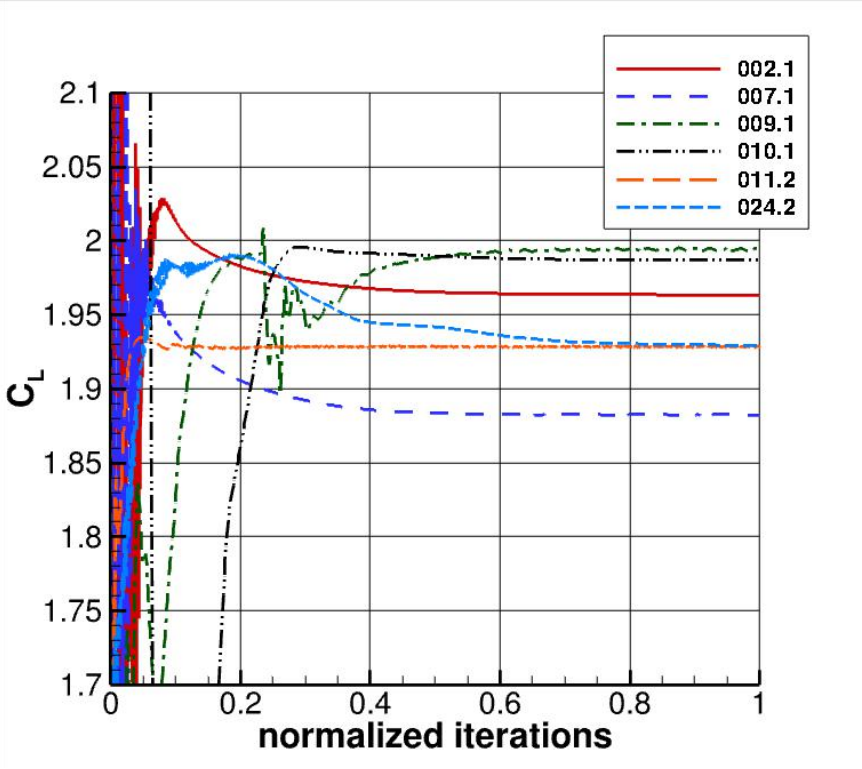
Entries with CL still changing at final iteration

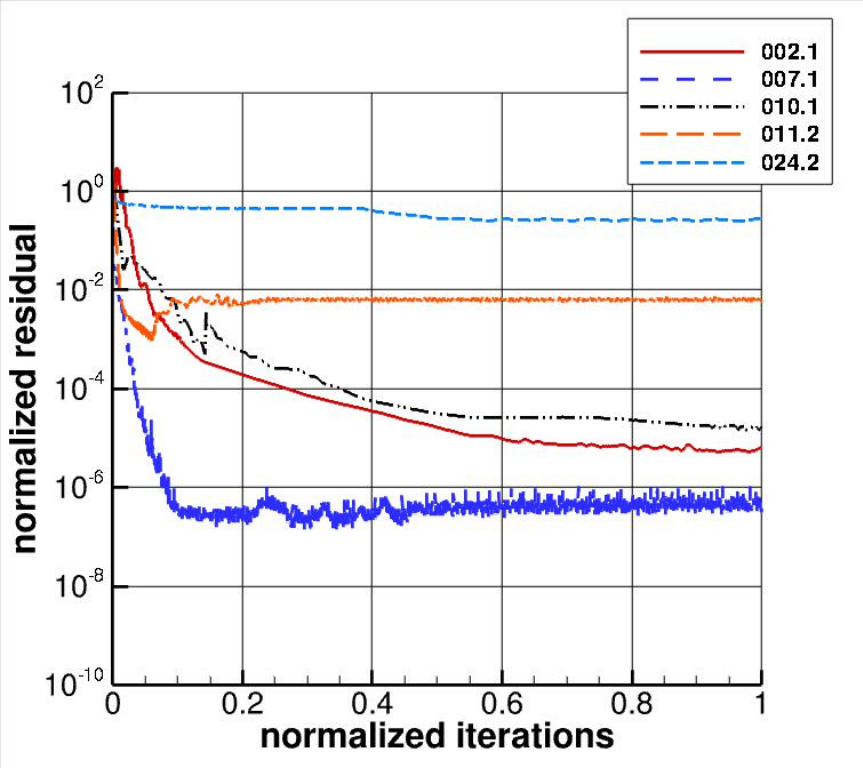




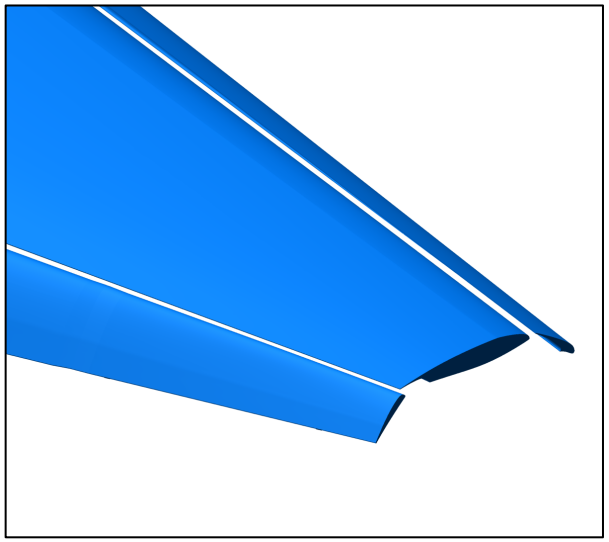
Case 1 Iterative convergence, AoA=7

Representative entries with CL relatively flat at final iteration

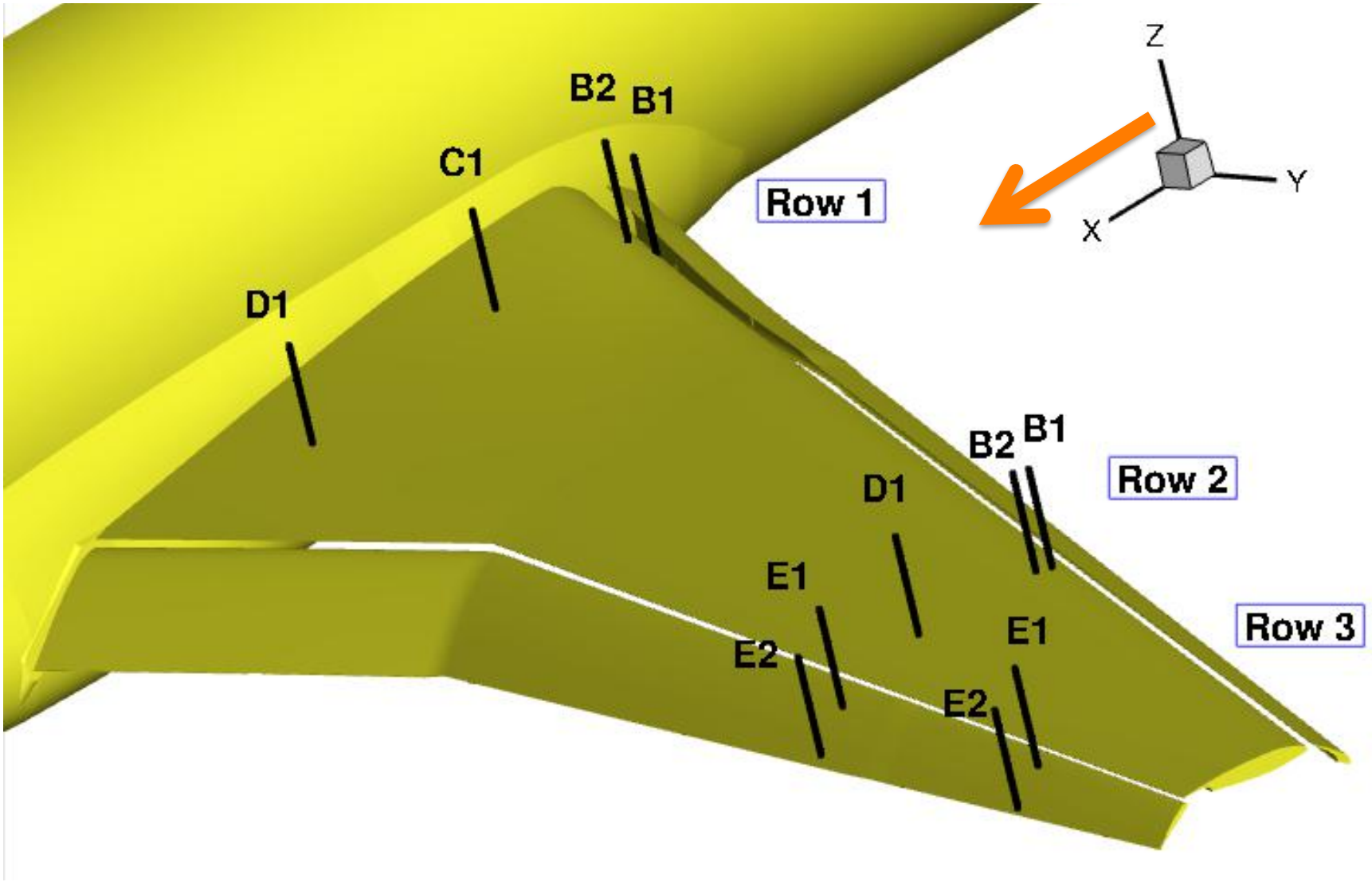




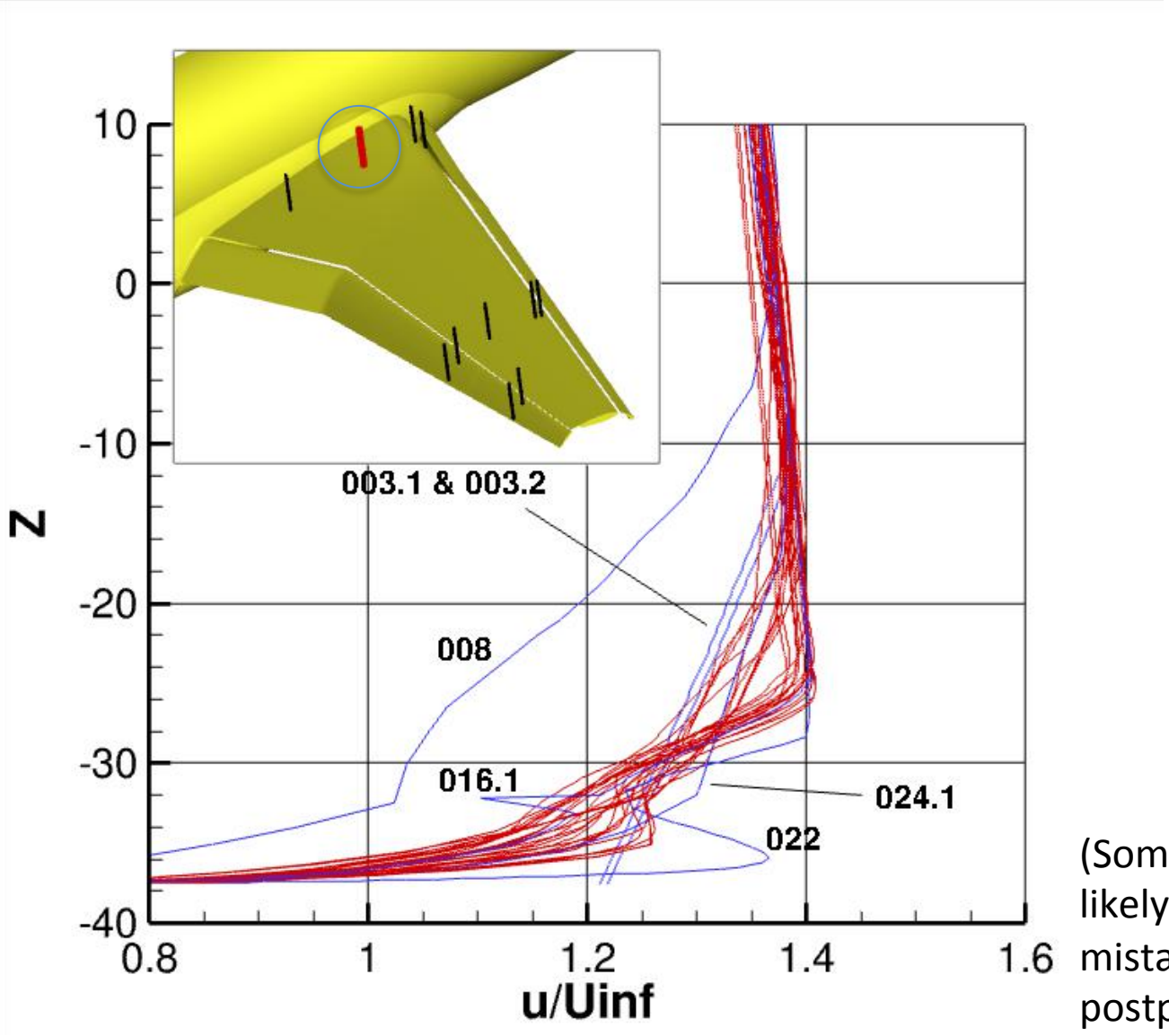
Velocity profiles
Case 1



Velocity extraction locations

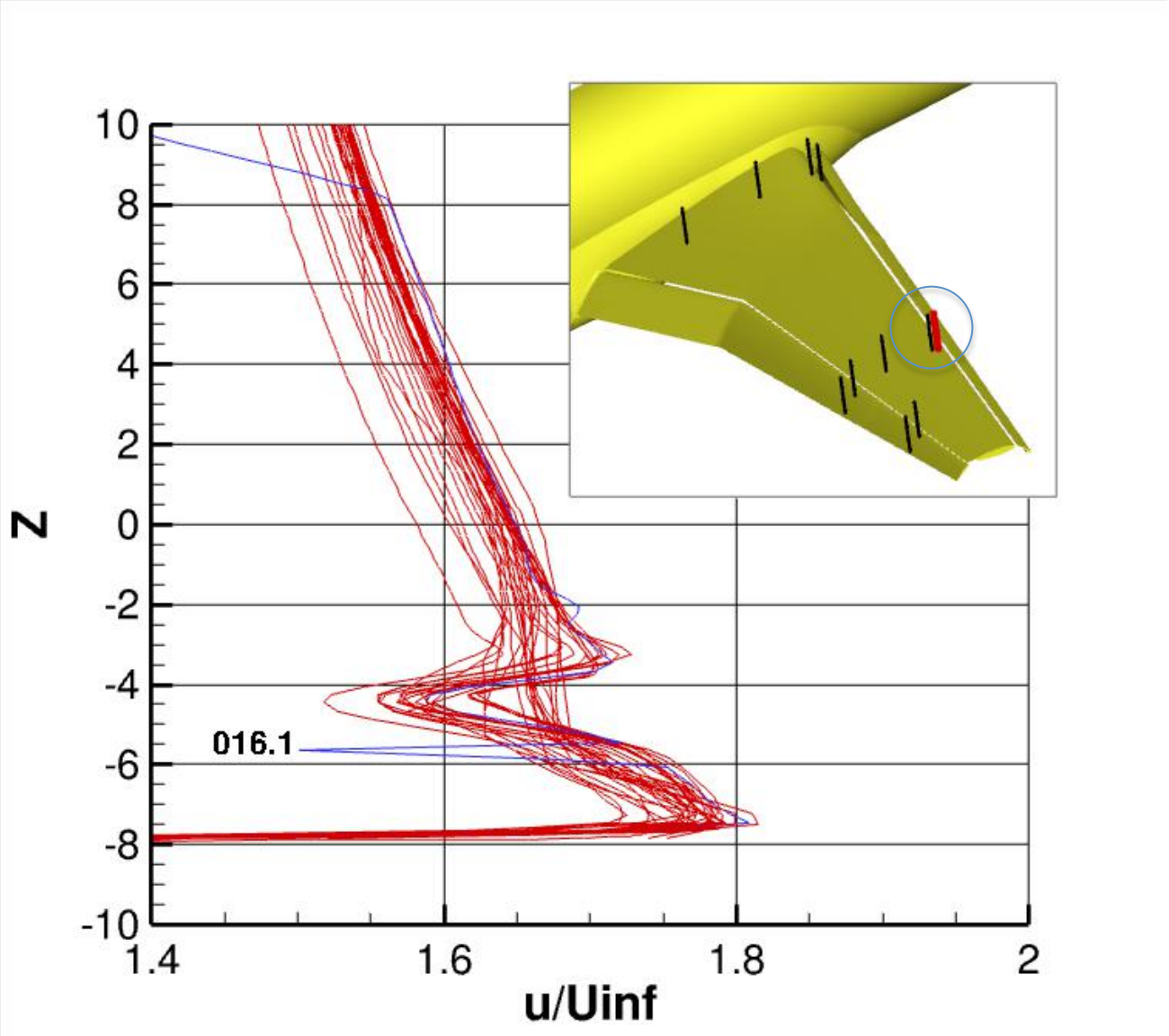


Case 1 Velocity, AoA=7, 1C1

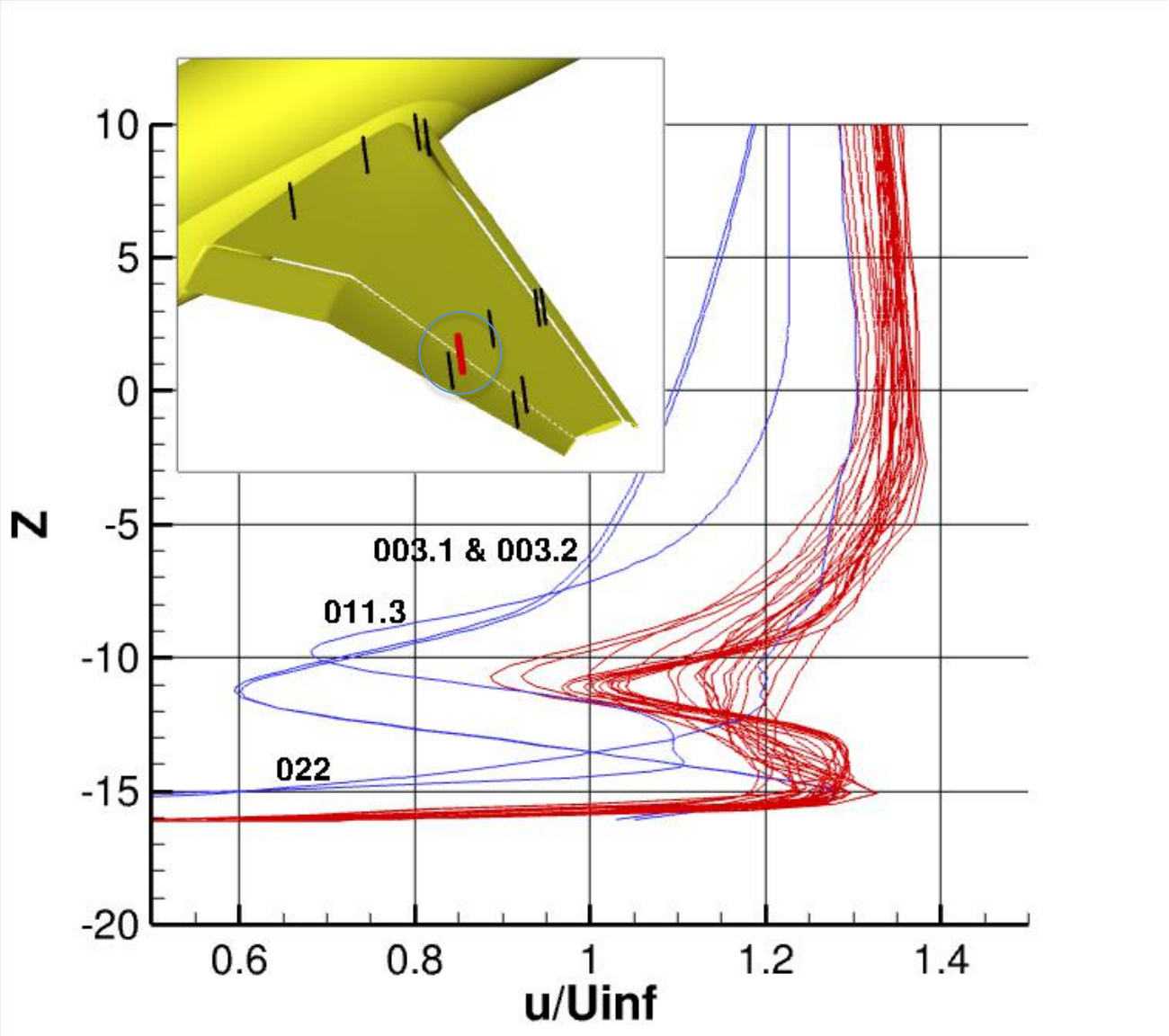


(Some participants likely made mistakes postprocessing)

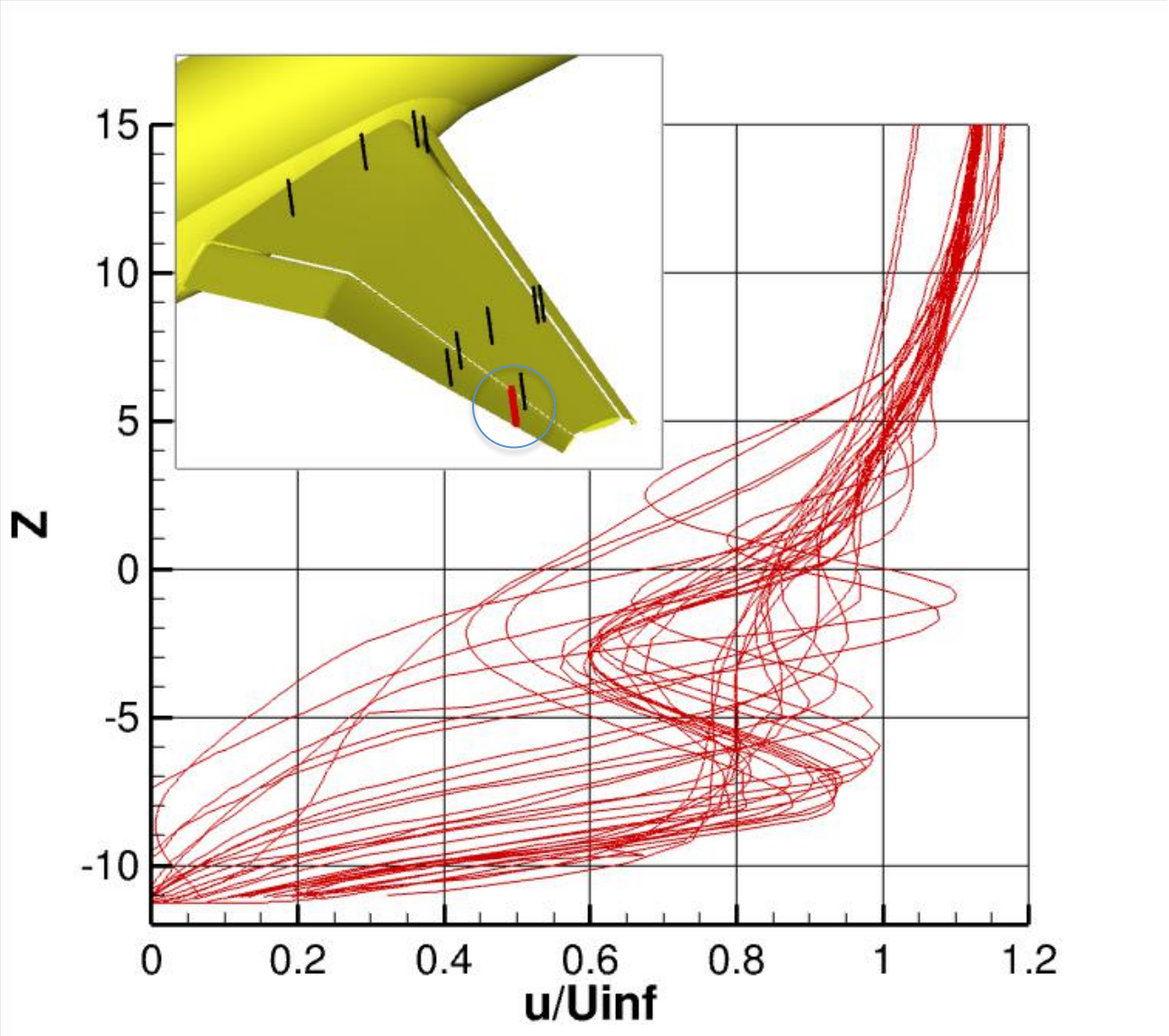
Case 1 Velocity, AoA=7, 2B1



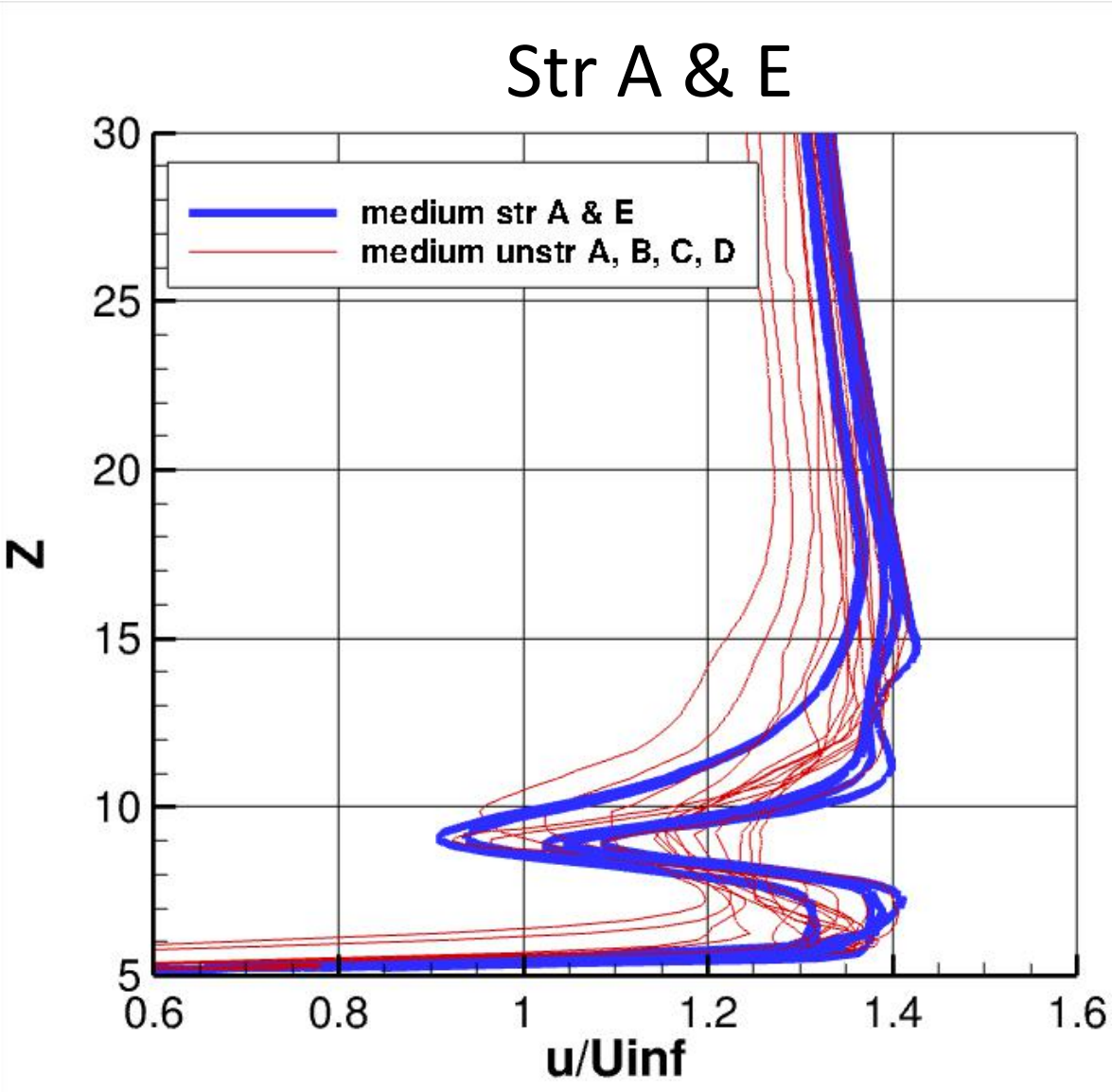
Case 1 Velocity, AoA=7, 2E1

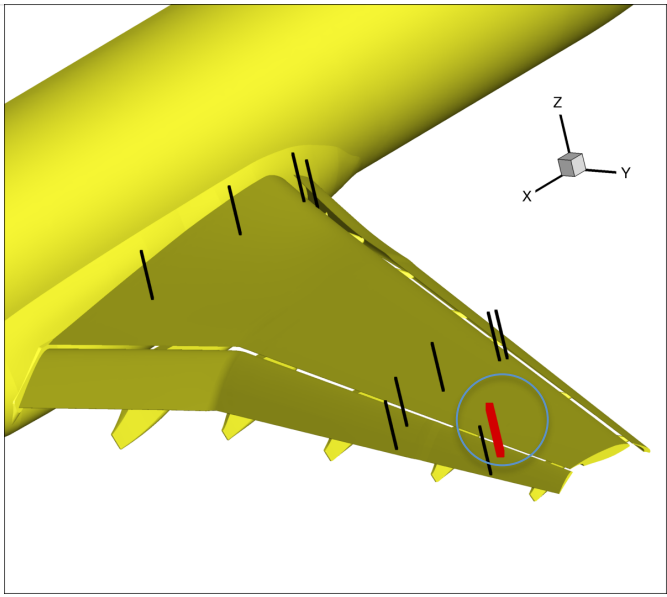


Case 1 Velocity, AoA=7, 3E2



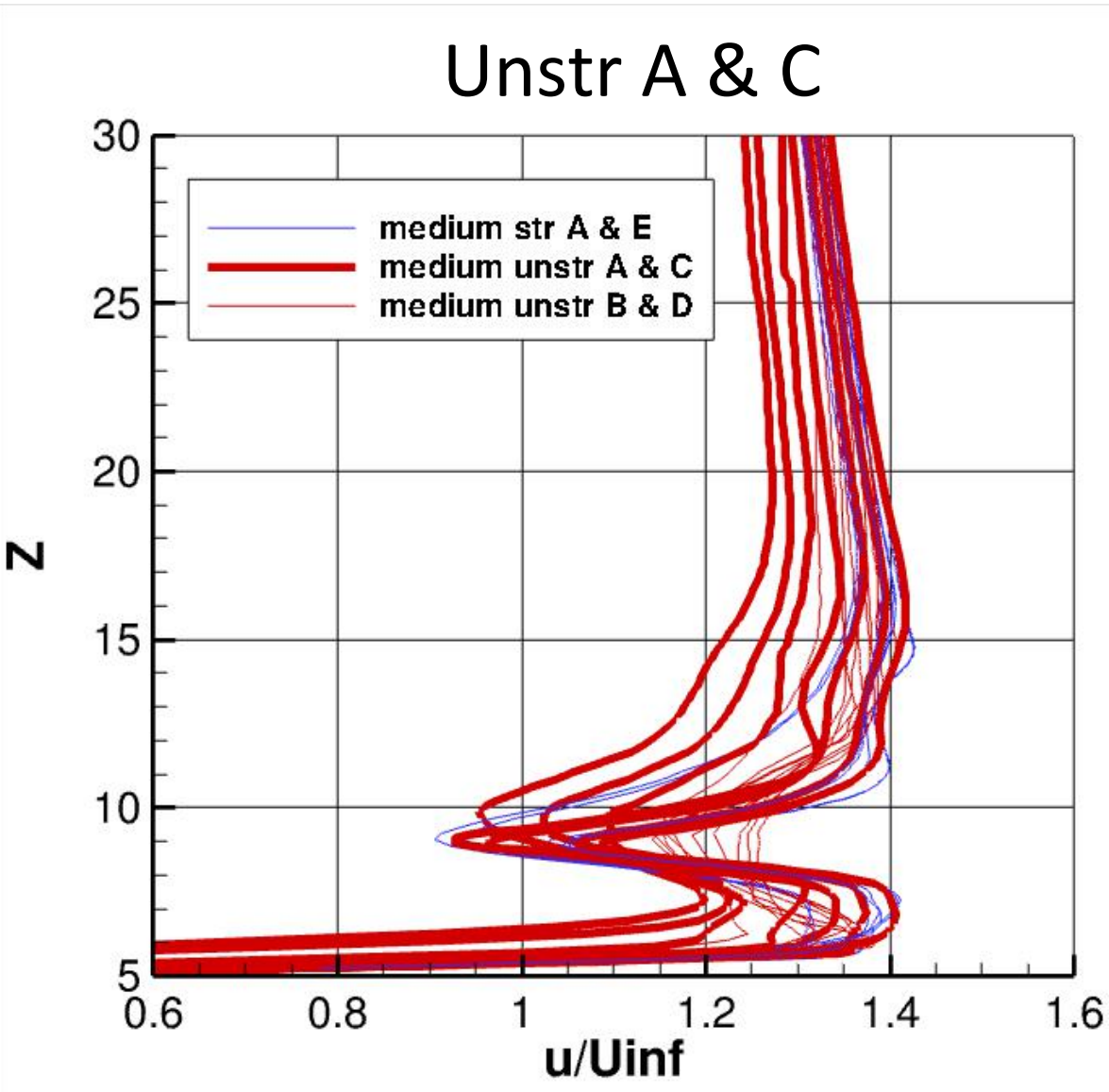
Grid type effect on velocity, AoA=7, 3E1

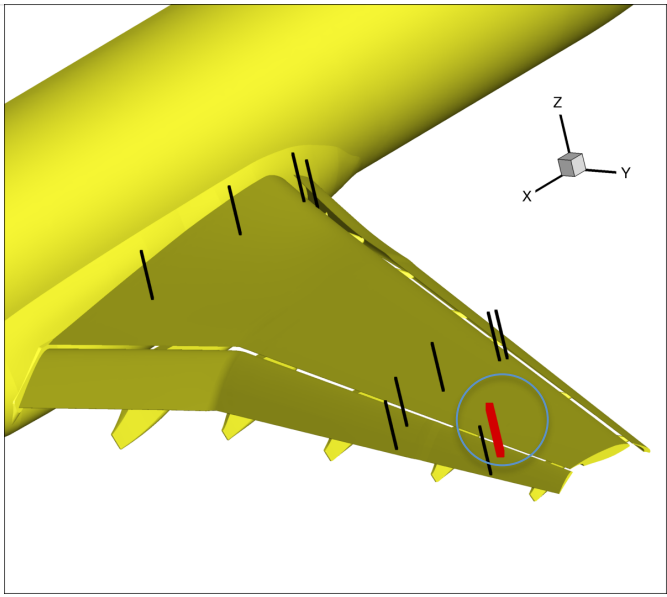




outliers removed

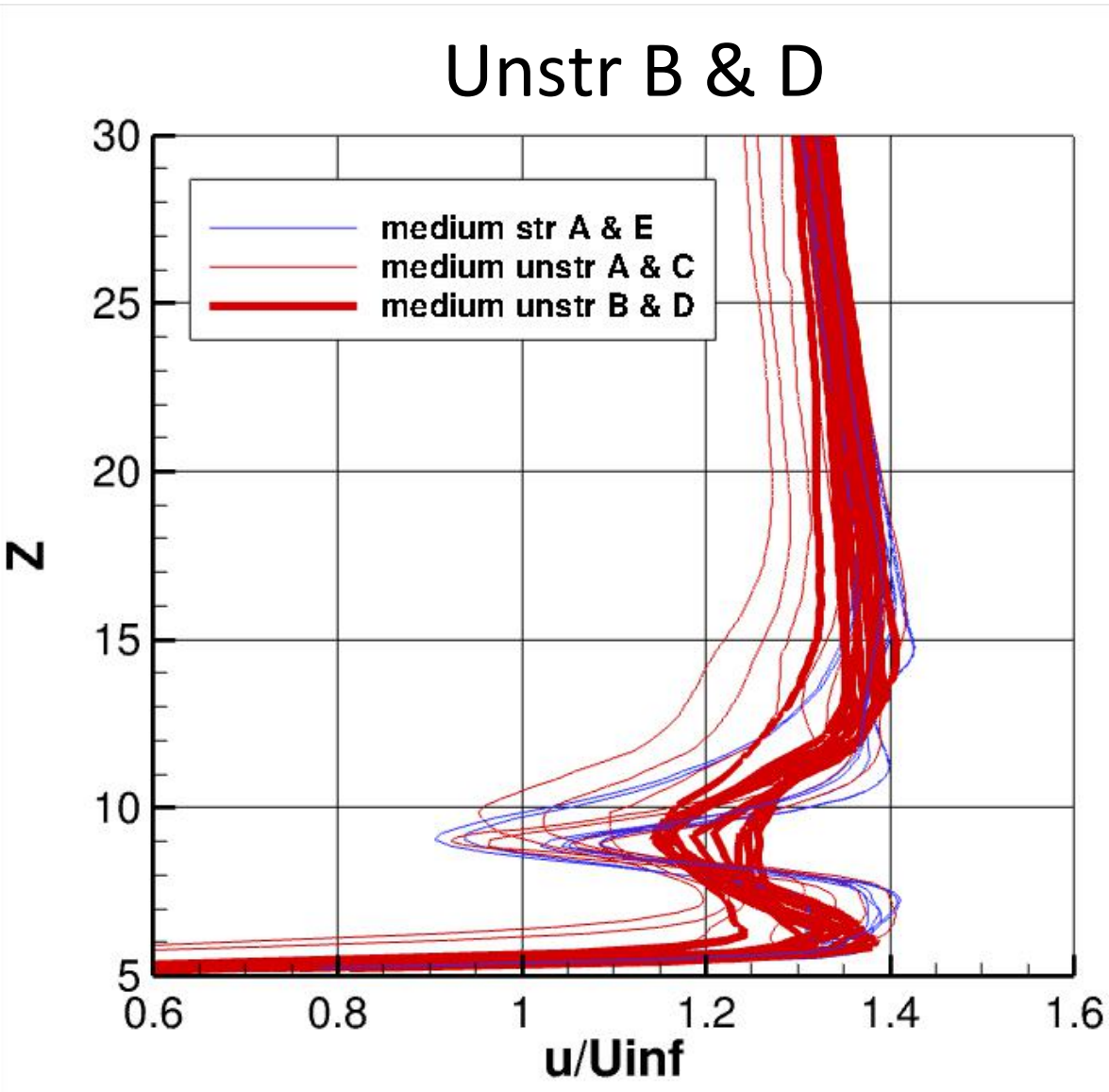
Grid type effect on velocity, AoA=7, 3E1

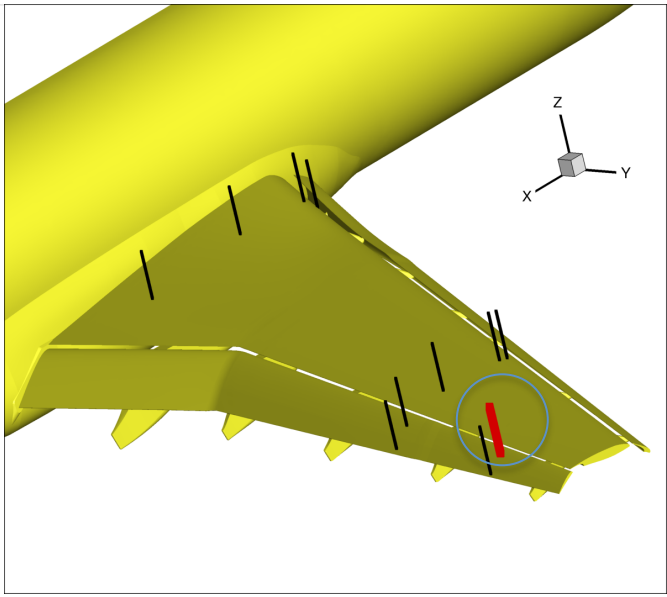




outliers removed

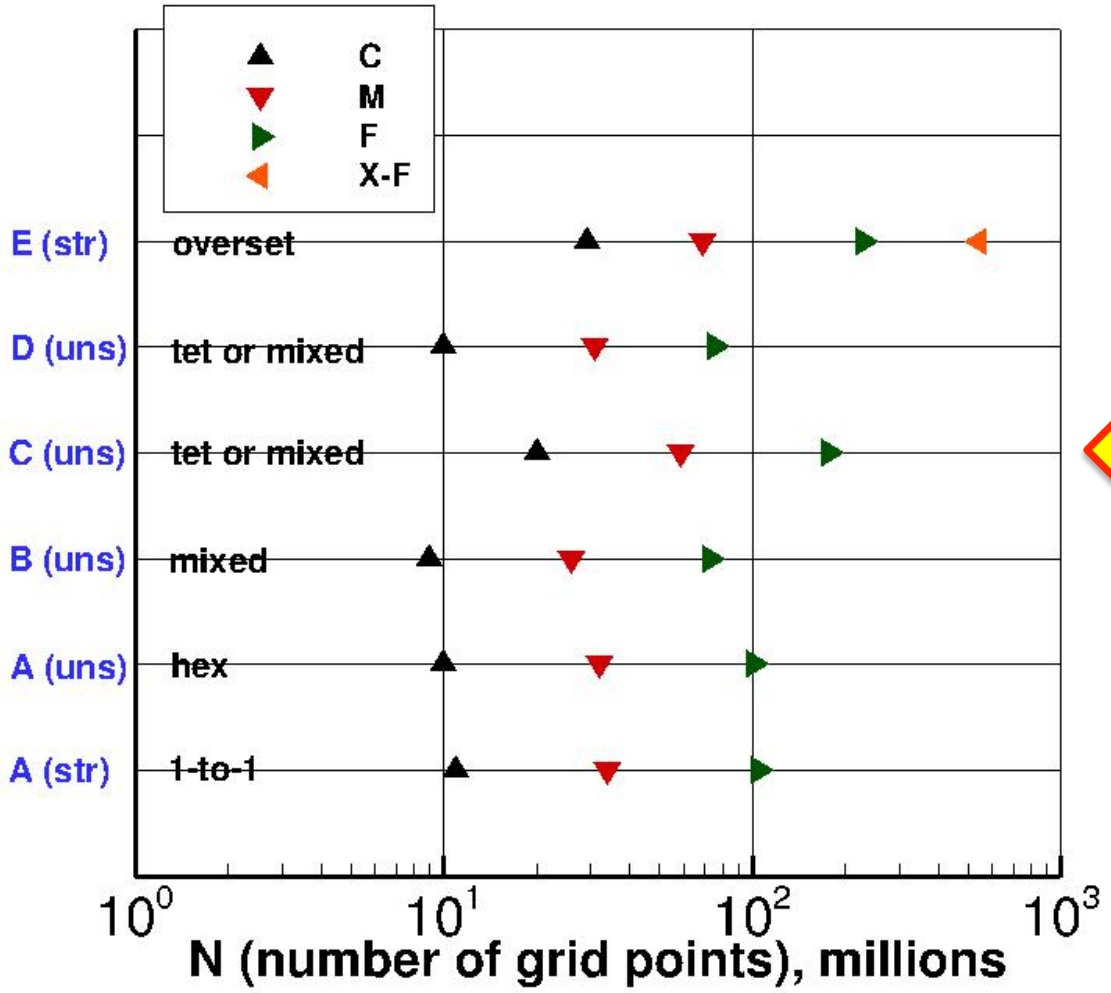
Grid type effect on velocity, AoA=7, 3E1





outliers removed

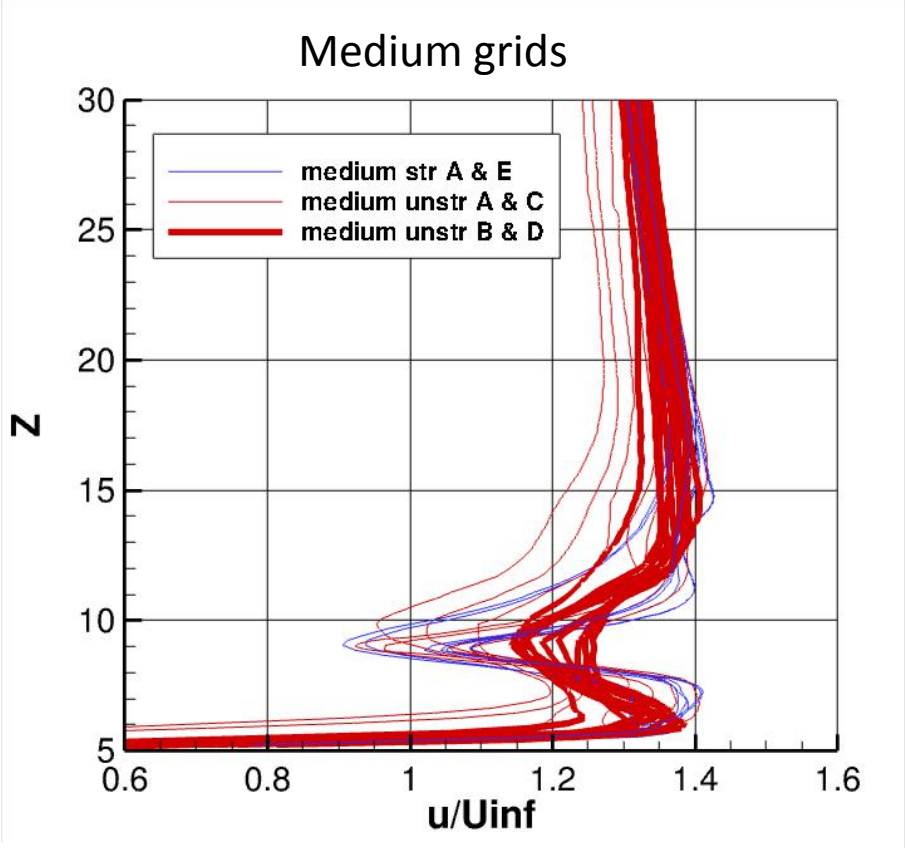
C grids capture wakes better

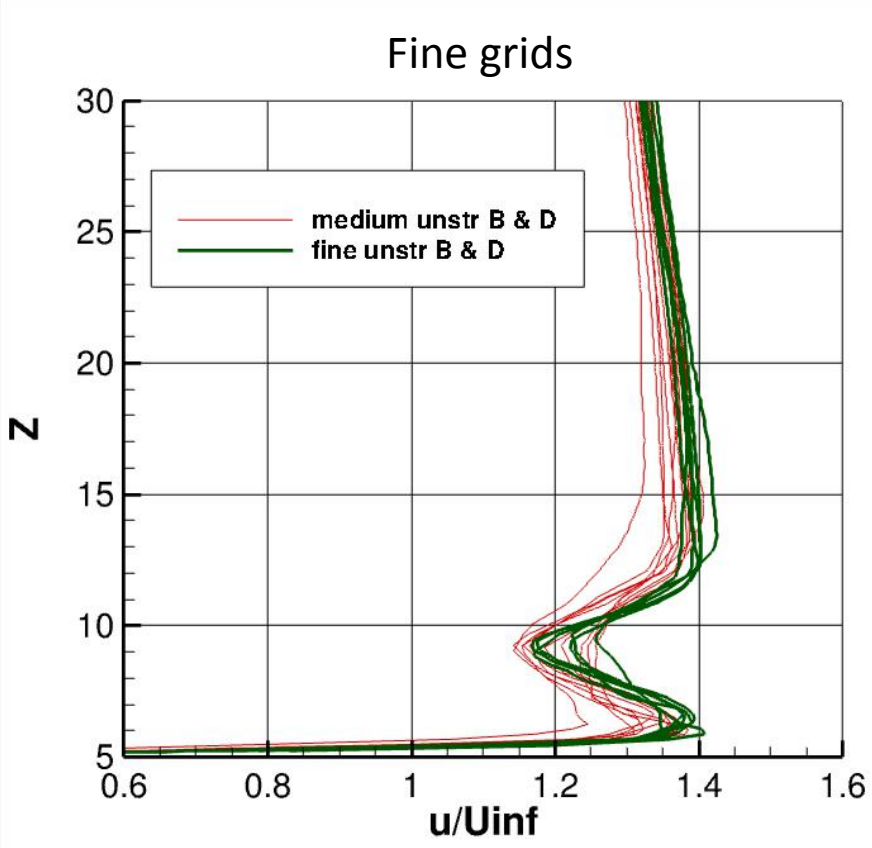


C grid is significantly finer than B & D unstructured grids

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

Unstr B & D

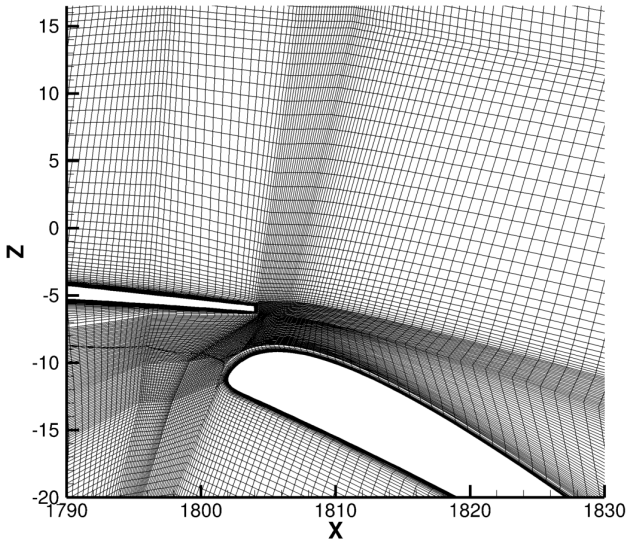




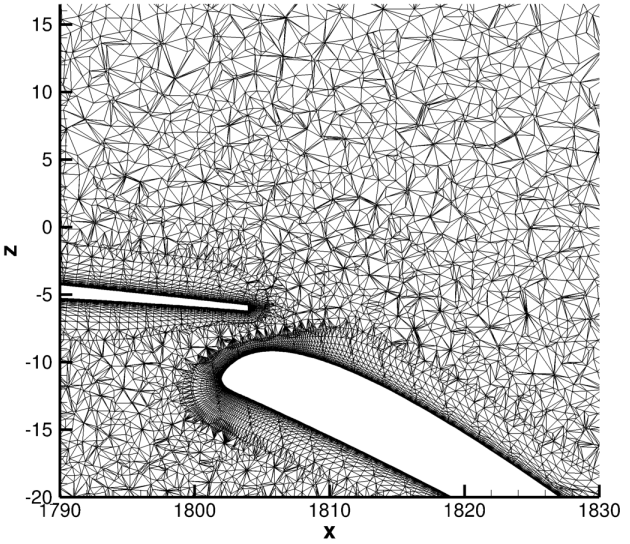
Comparison of flap grid cuts, y=979.596

Fine grids

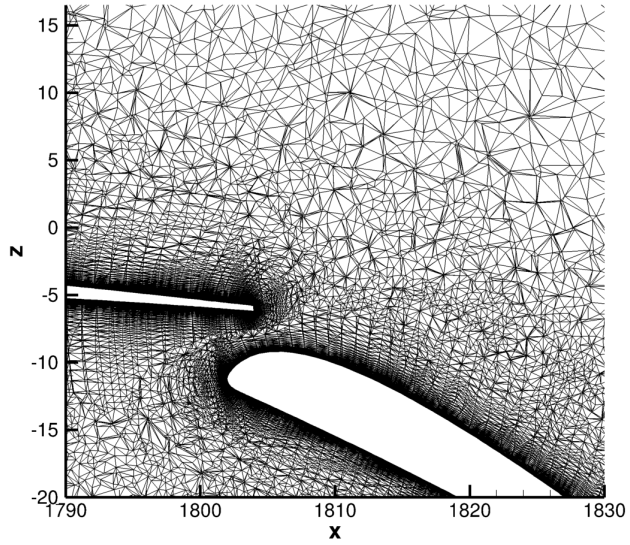
A grid



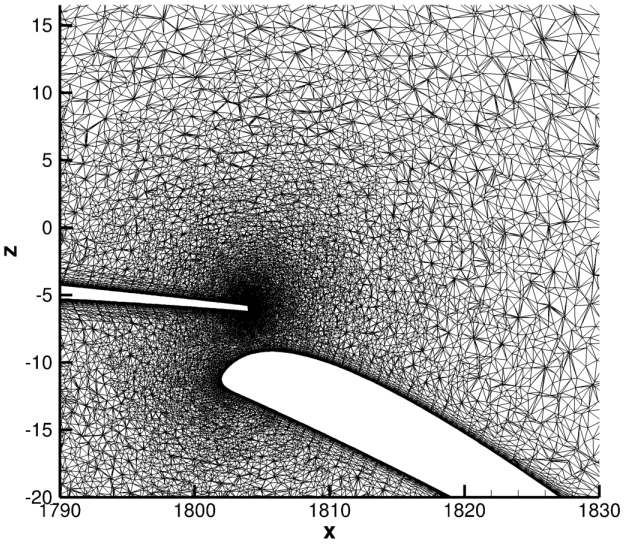
B grid



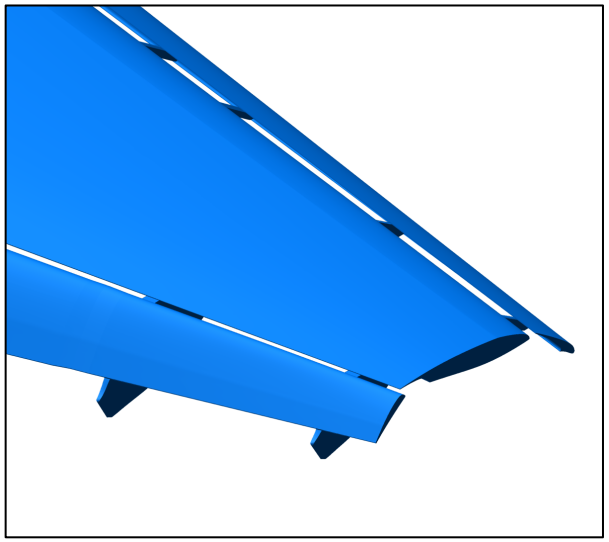
C grid



D grid

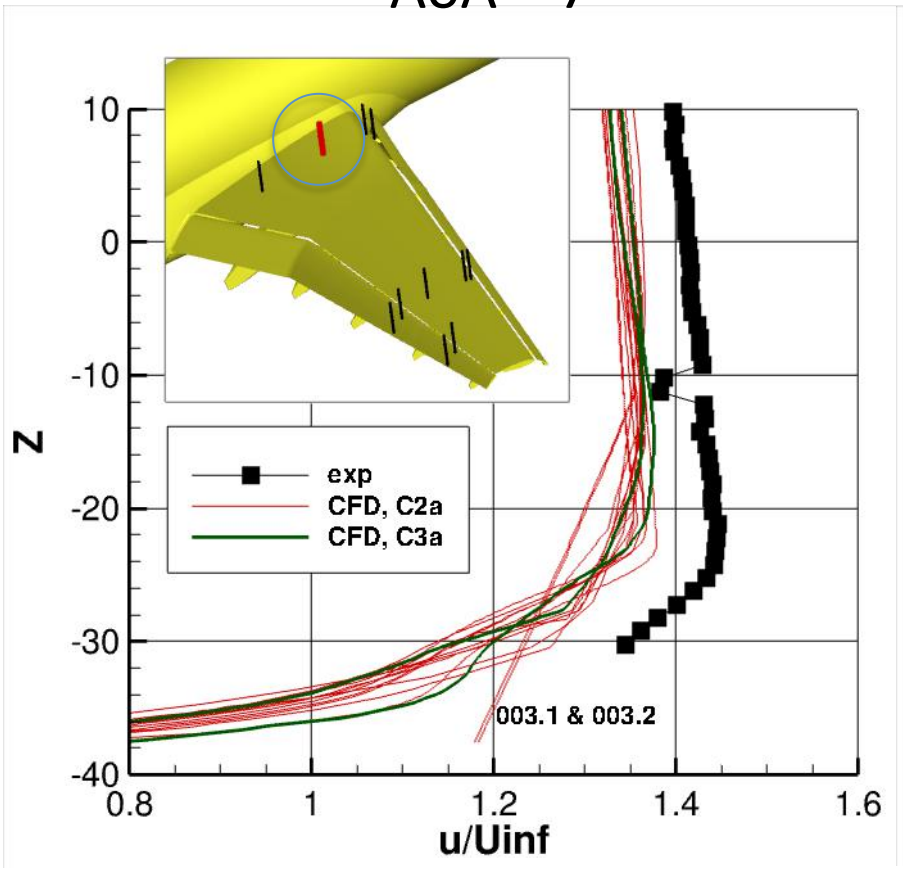


Velocity profiles
Cases 2 and 3

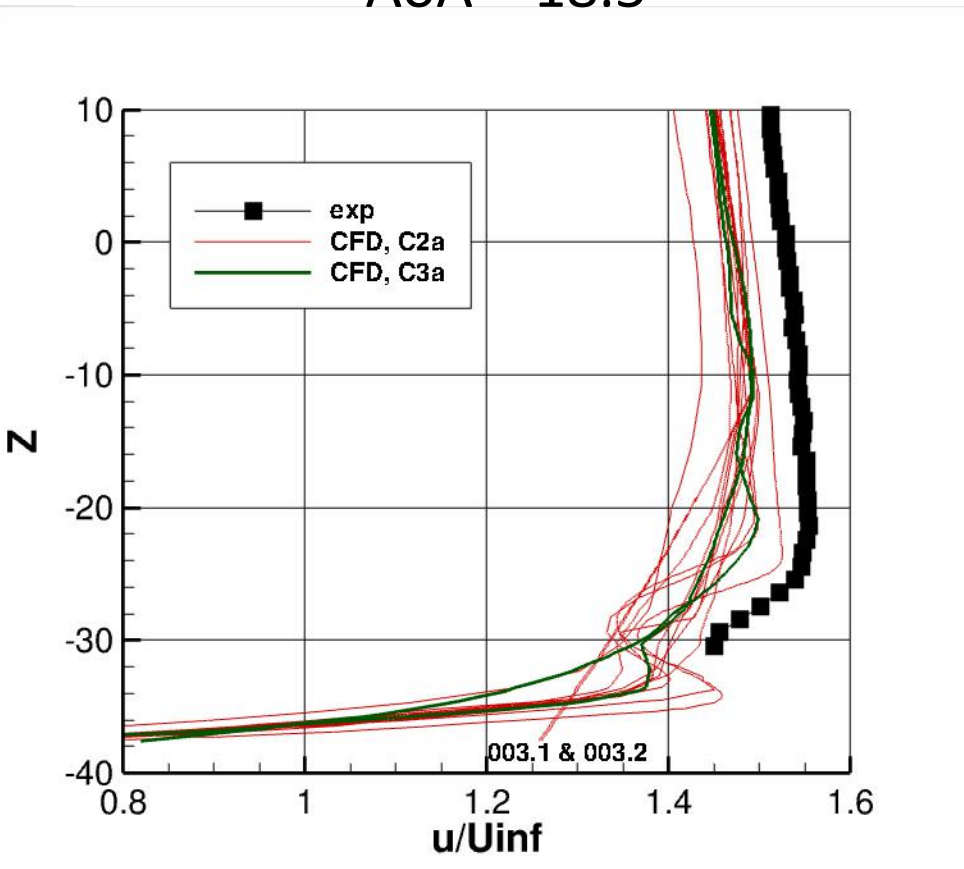


Cases 2a & 3a (low Re w brackets), 1C1

AoA = 7

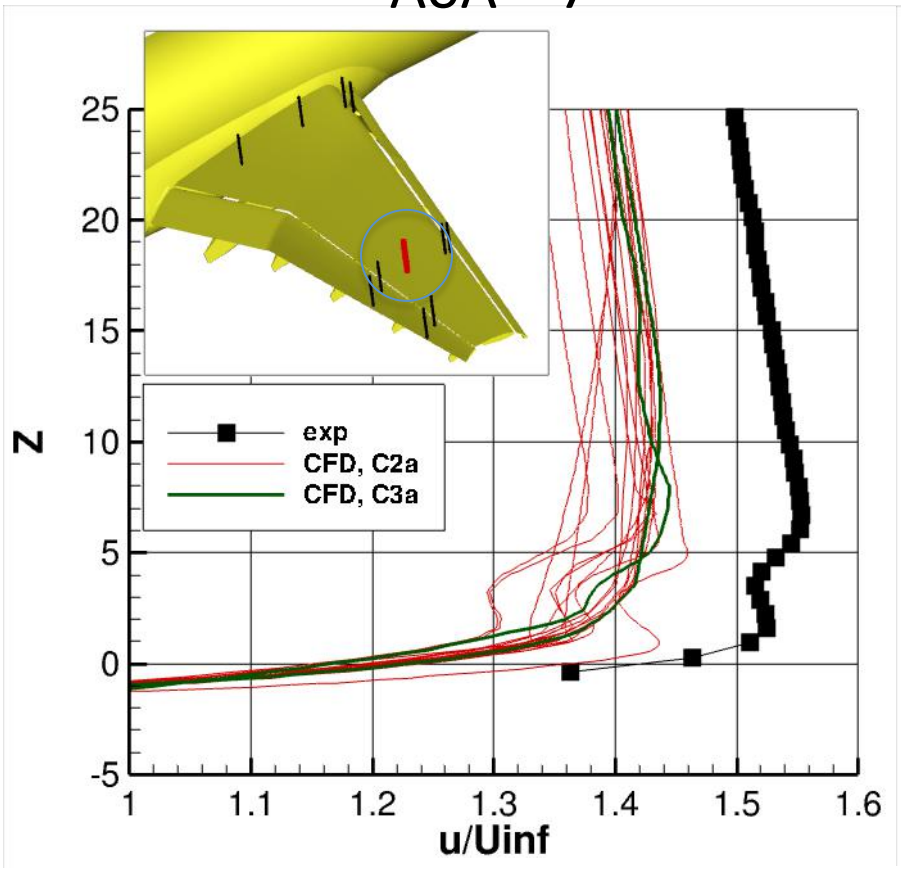


AoA = 18.5

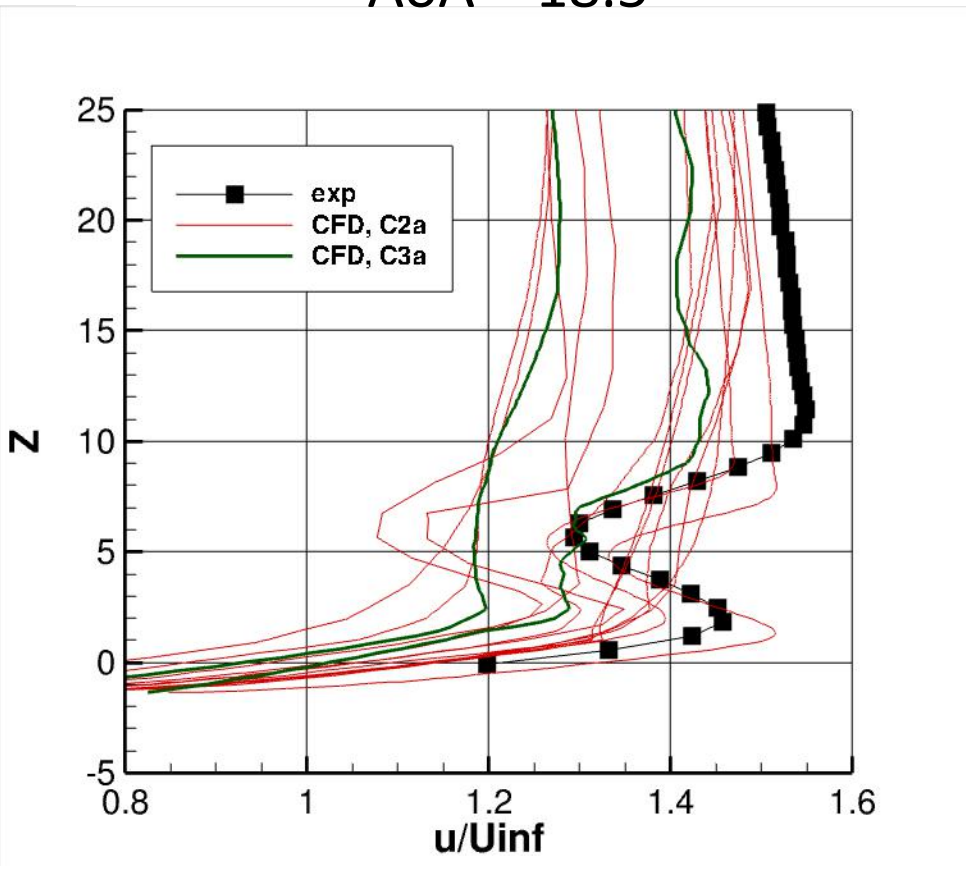


Cases 2a & 3a (low Re w brackets), 2D1

AoA = 7

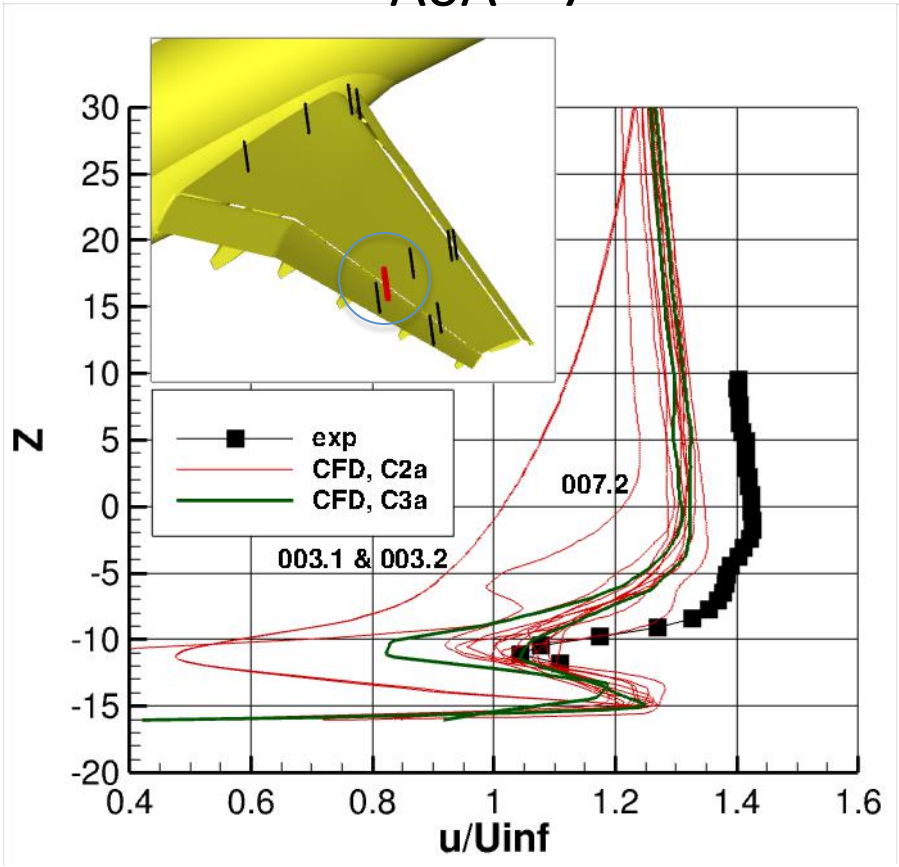


AoA = 18.5

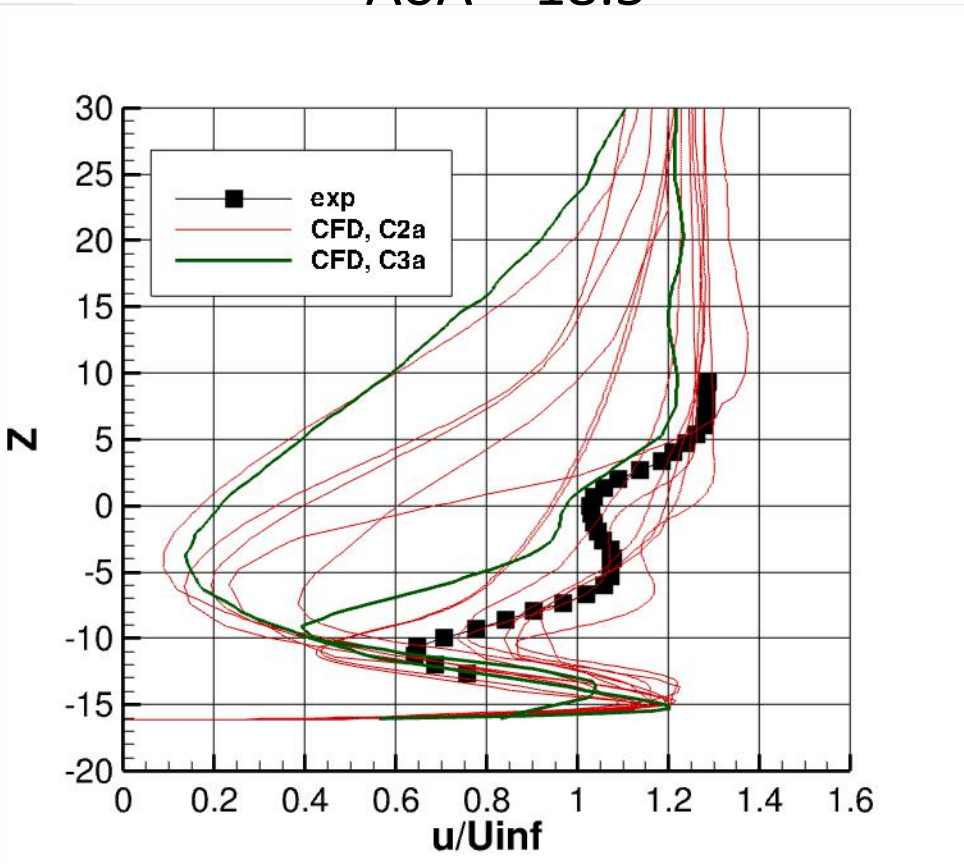


Cases 2a & 3a (low Re w brackets), 2E1

AoA = 7



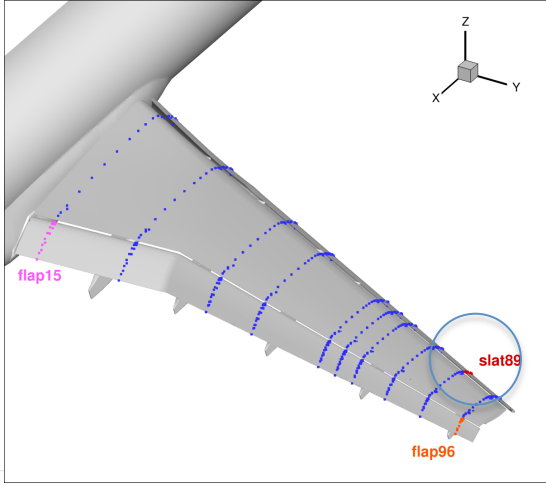
AoA = 18.5



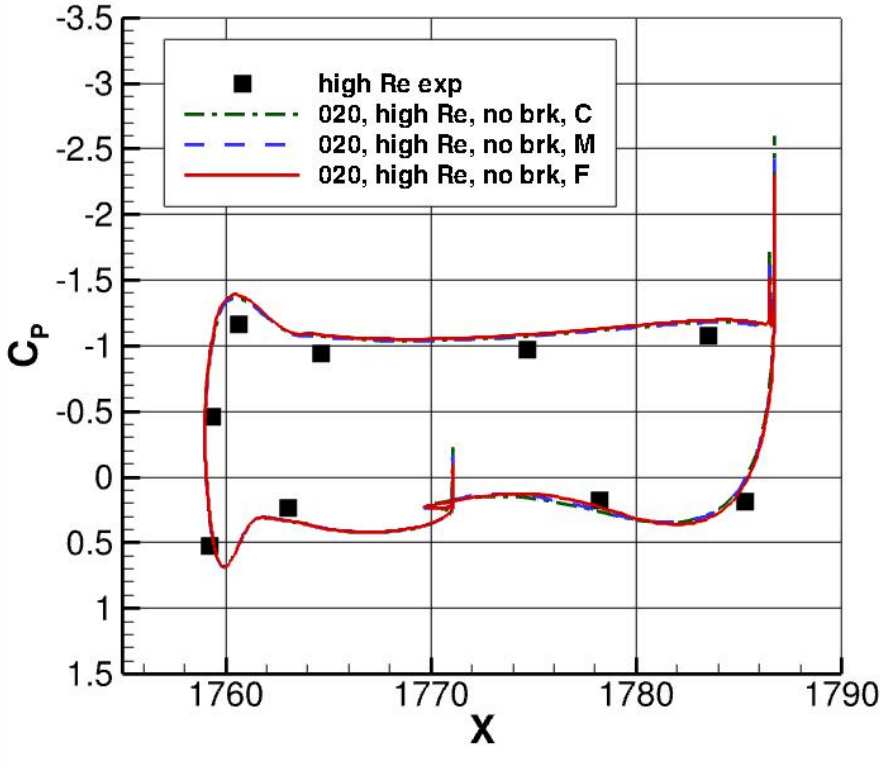
Sampling of surface pressure and skin friction coefficients

Cp at slat89, AoA=7

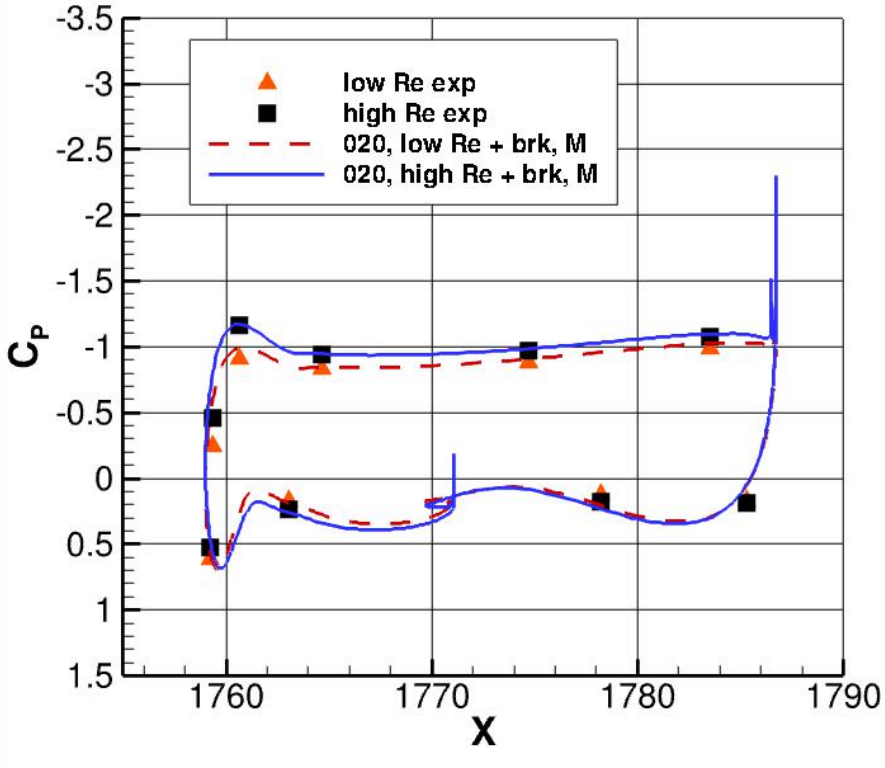
Typical result



No brackets

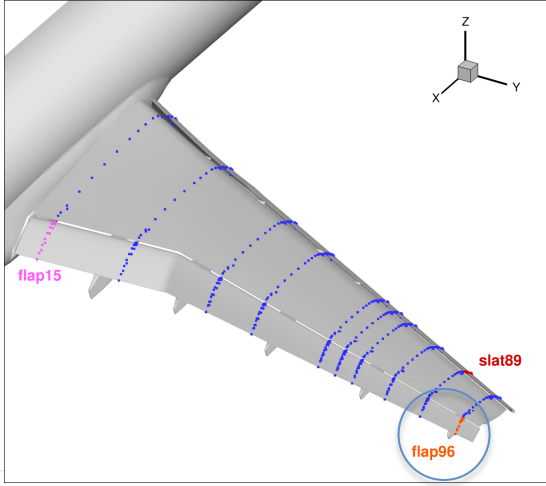


Brackets

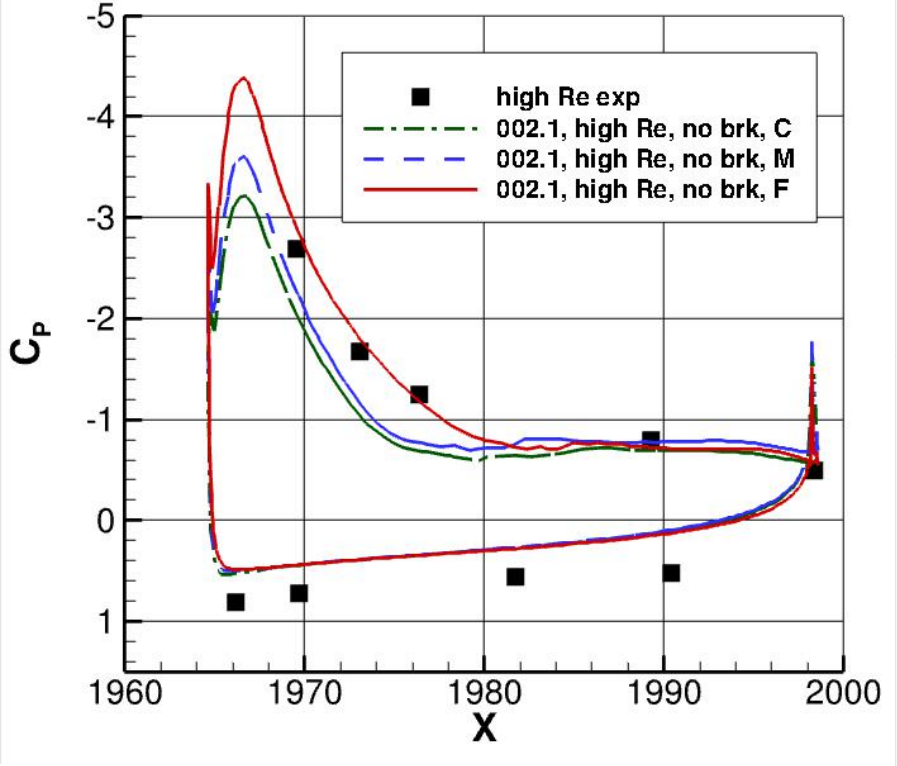


Cp at flap96, AoA=7

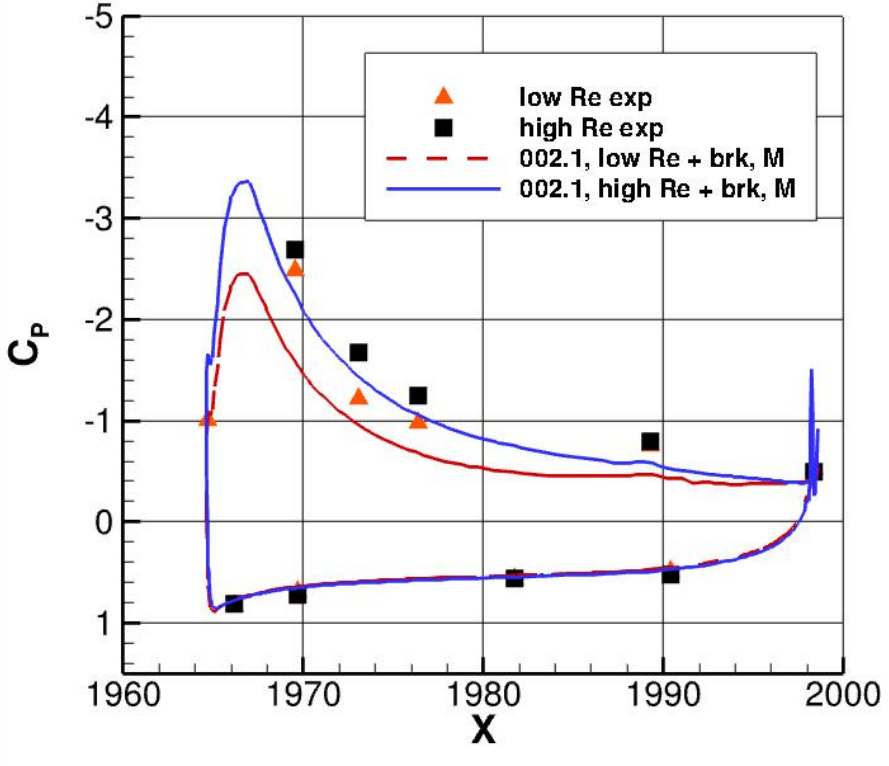
Typical result



No brackets

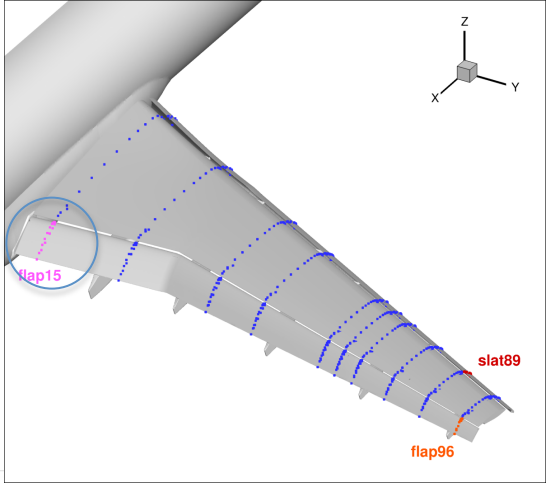


Brackets

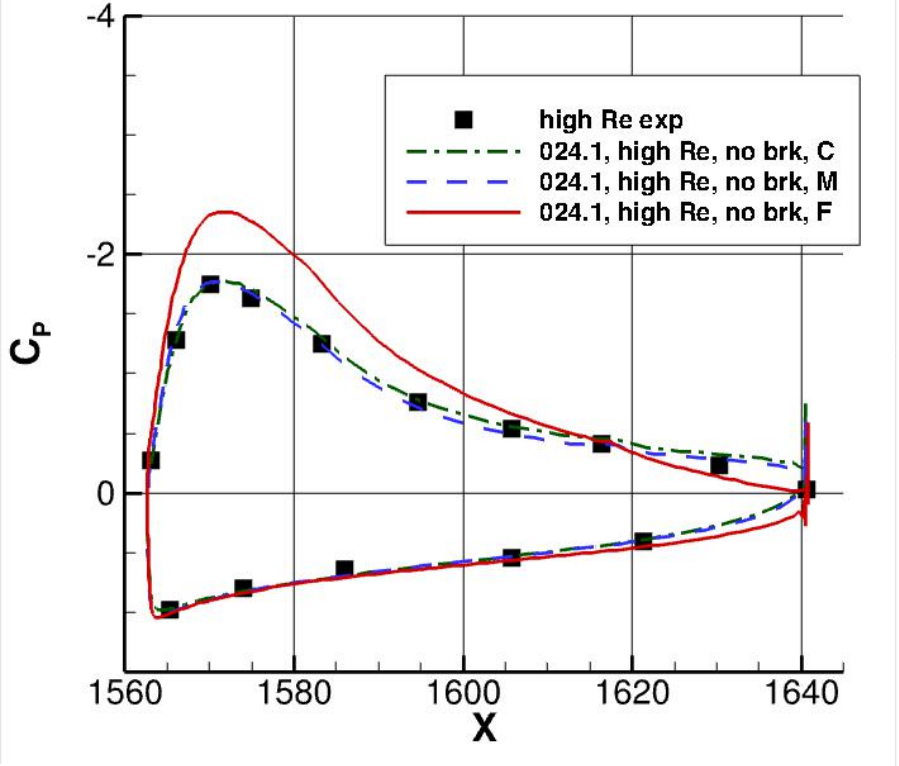


Cp at flap15, AoA=7

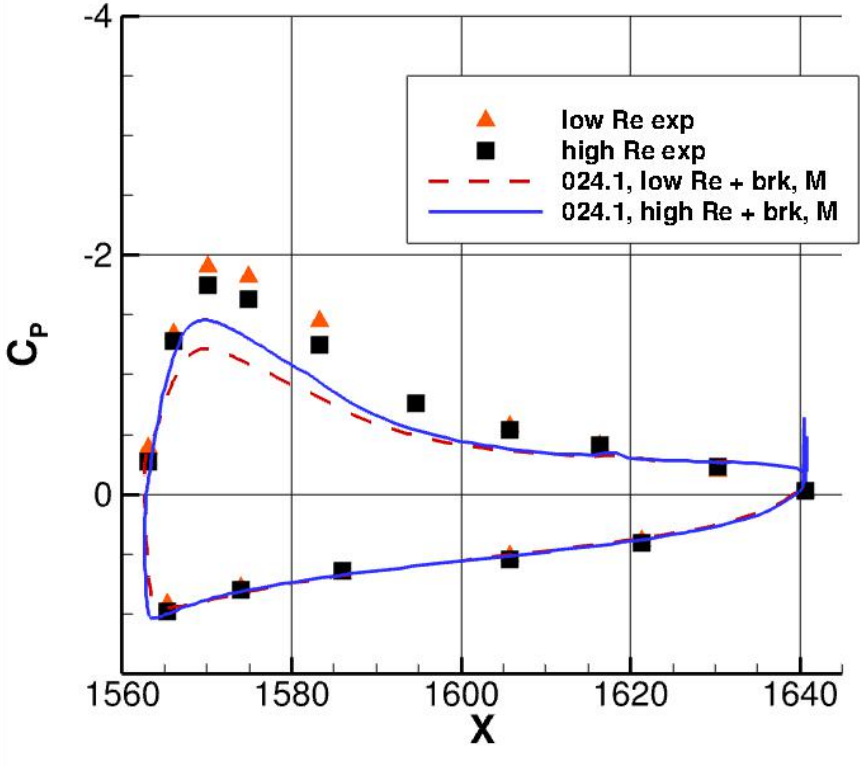
Typical result



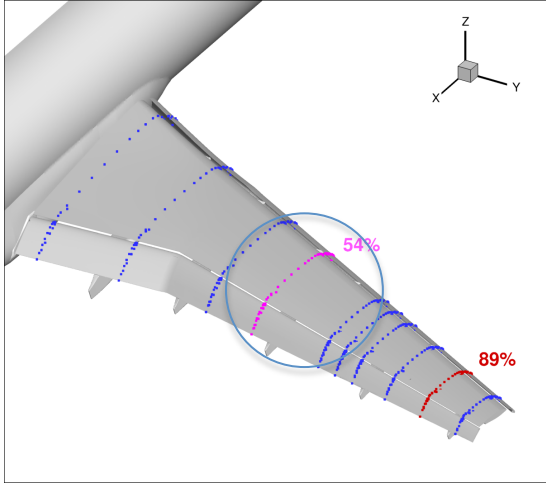
No brackets



Brackets

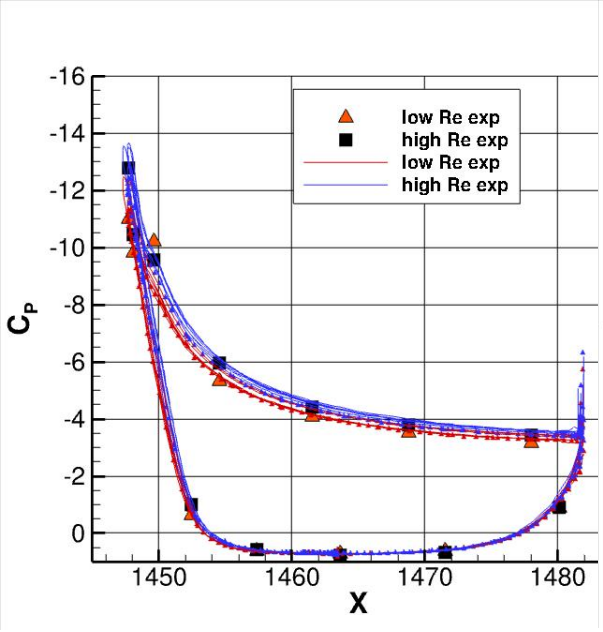


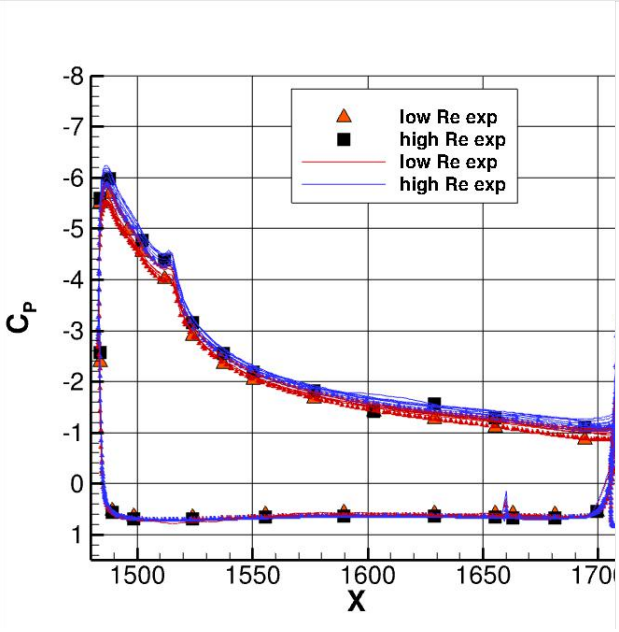
Cp at 54% span, AoA=20

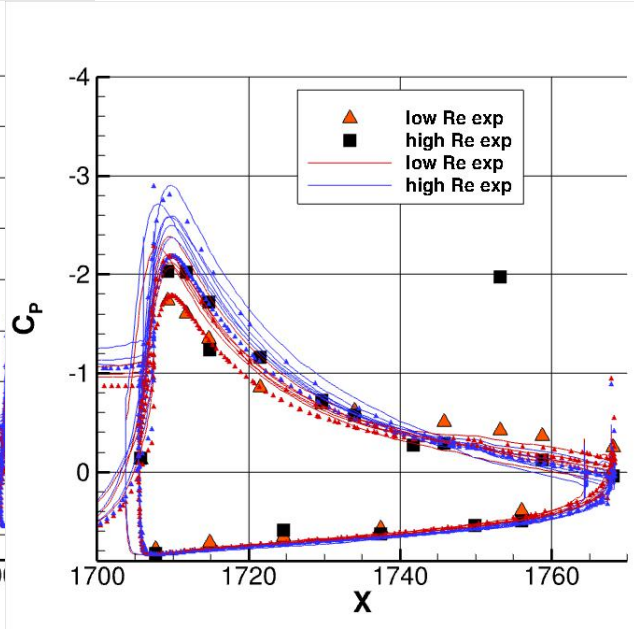


All results plotted

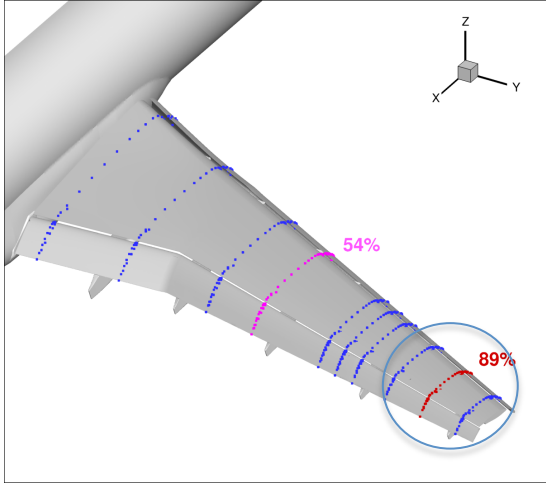
With brackets





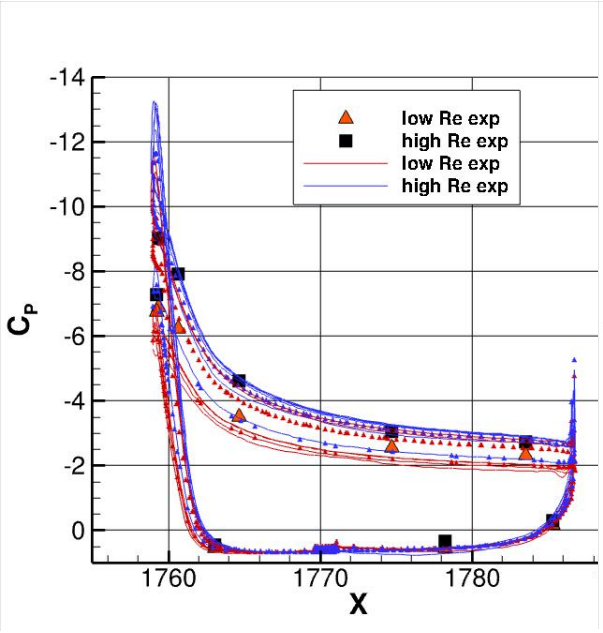


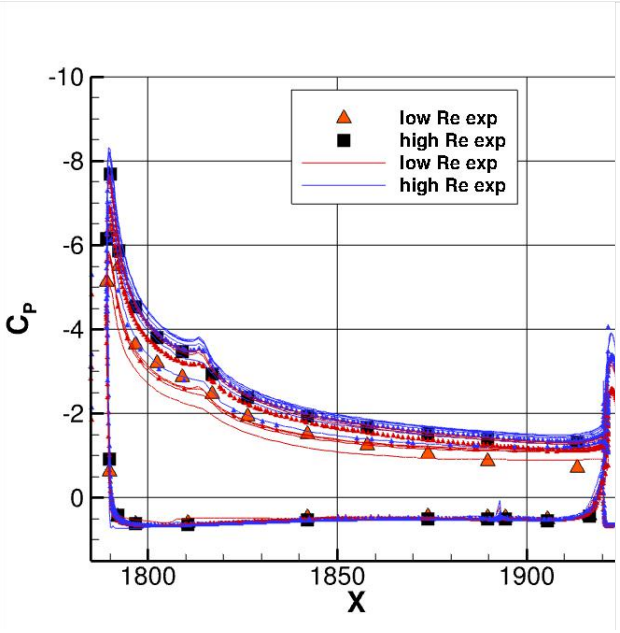
Cp at 89% span, AoA=20

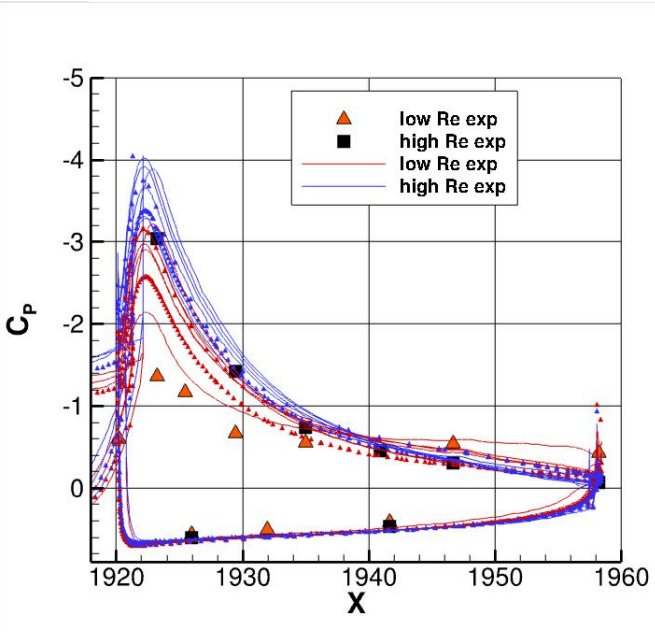


All results plotted

With brackets

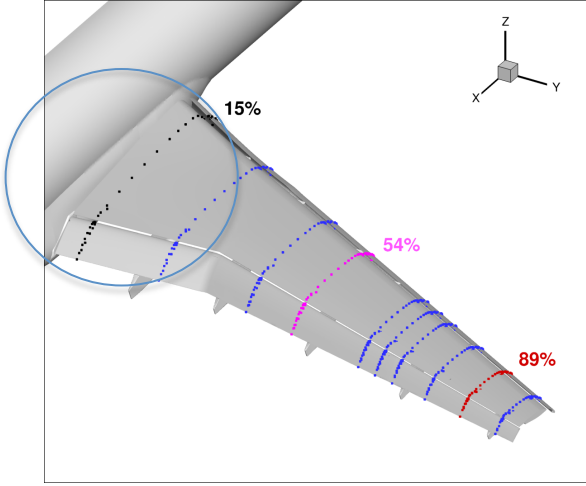






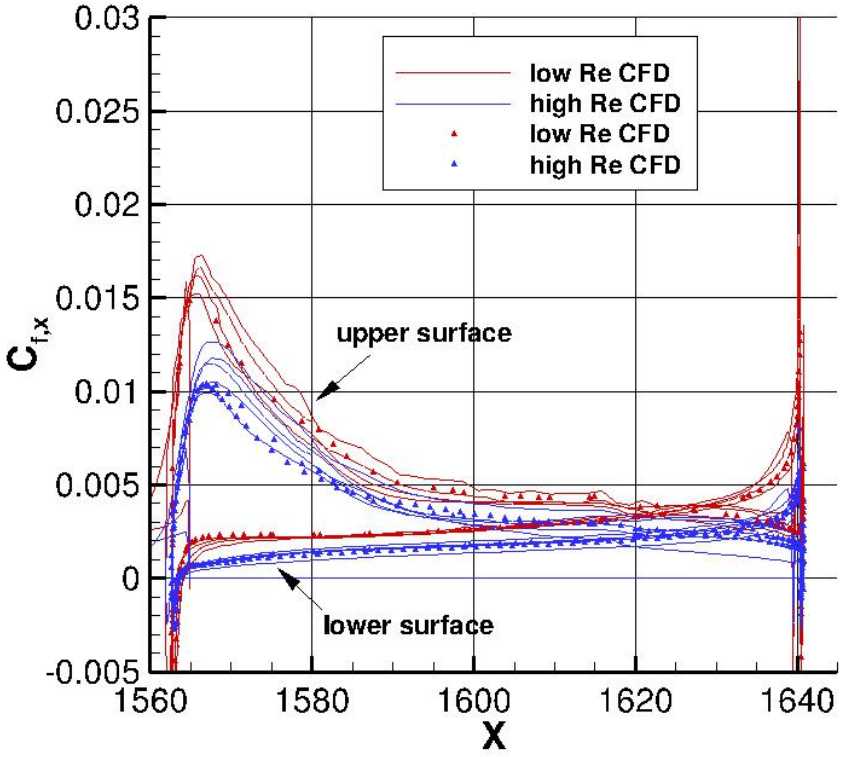
Cf,x at 15% span

All results plotted

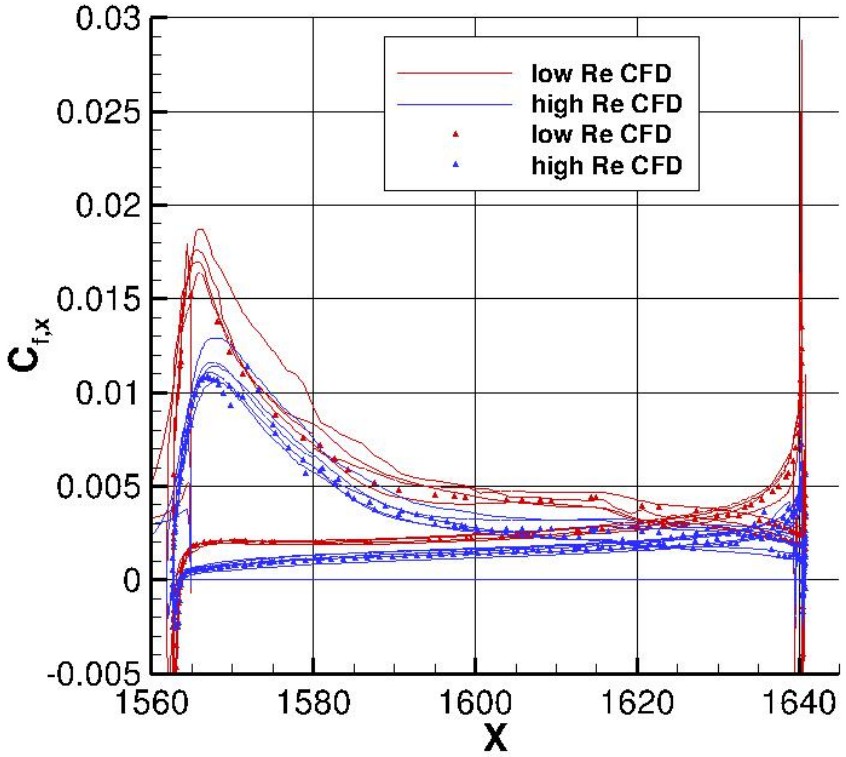


With brackets

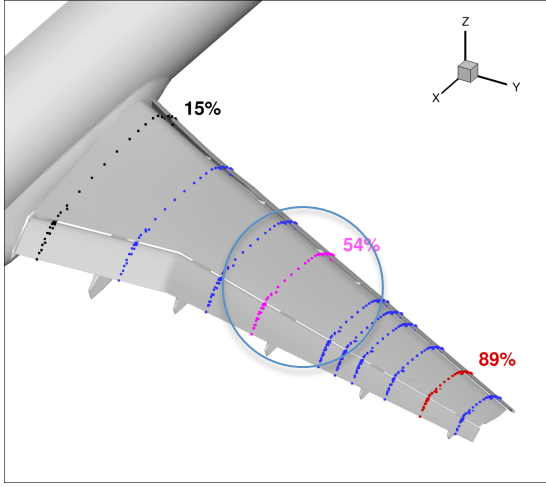
AoA=7 deg



AoA=16 deg



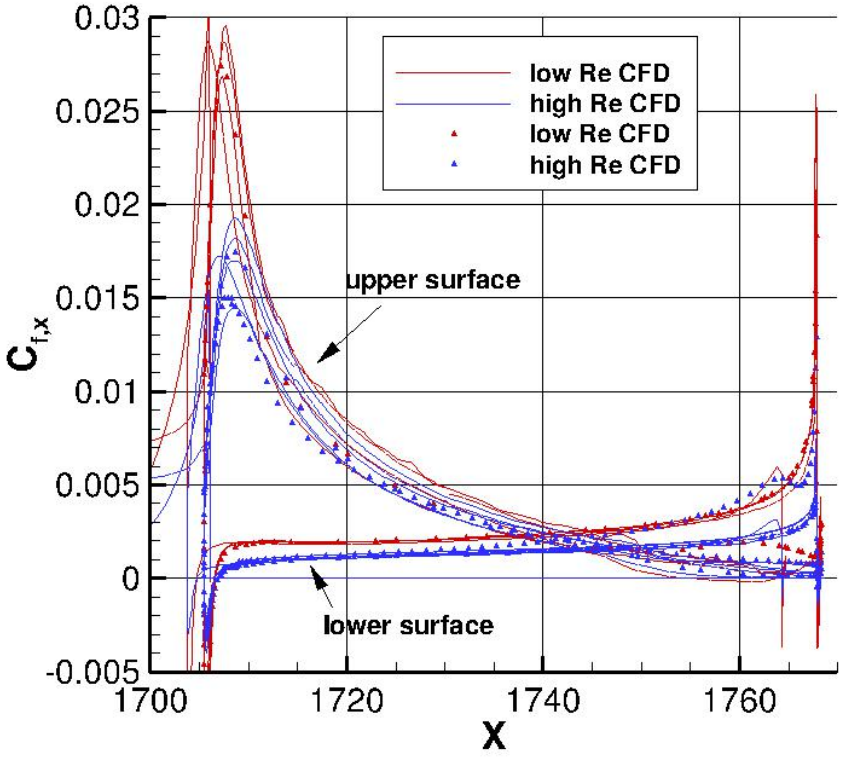
Cf,x at 54% span



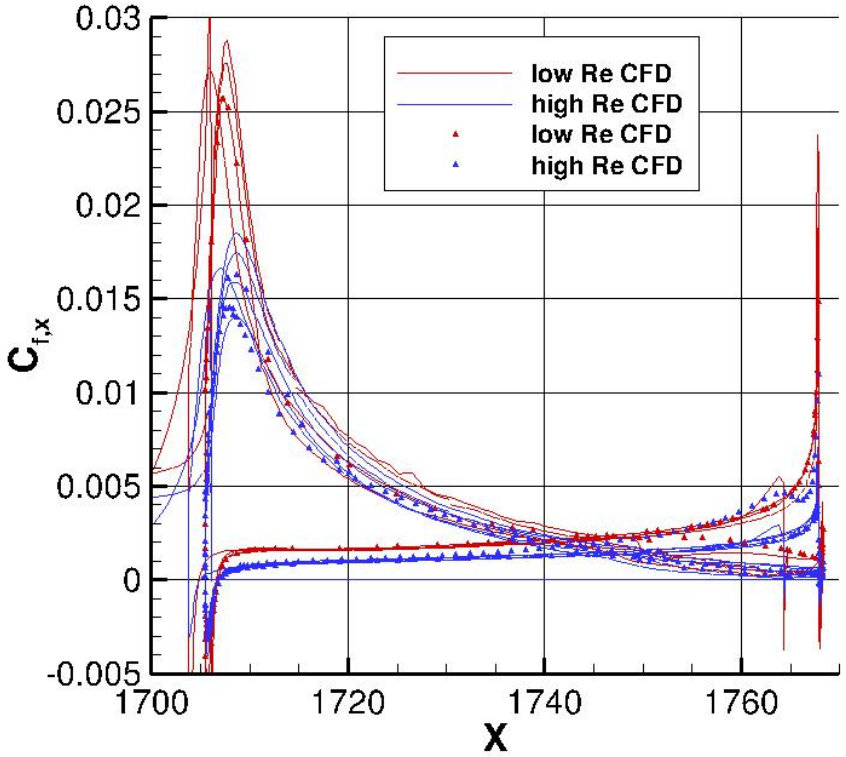
All results plotted

With brackets

AoA=7 deg

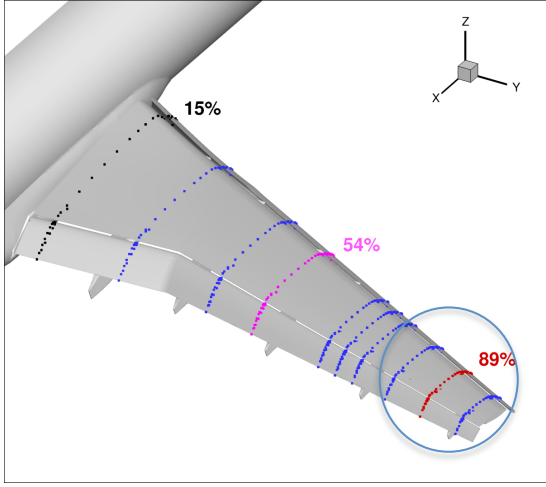


AoA=16 deg



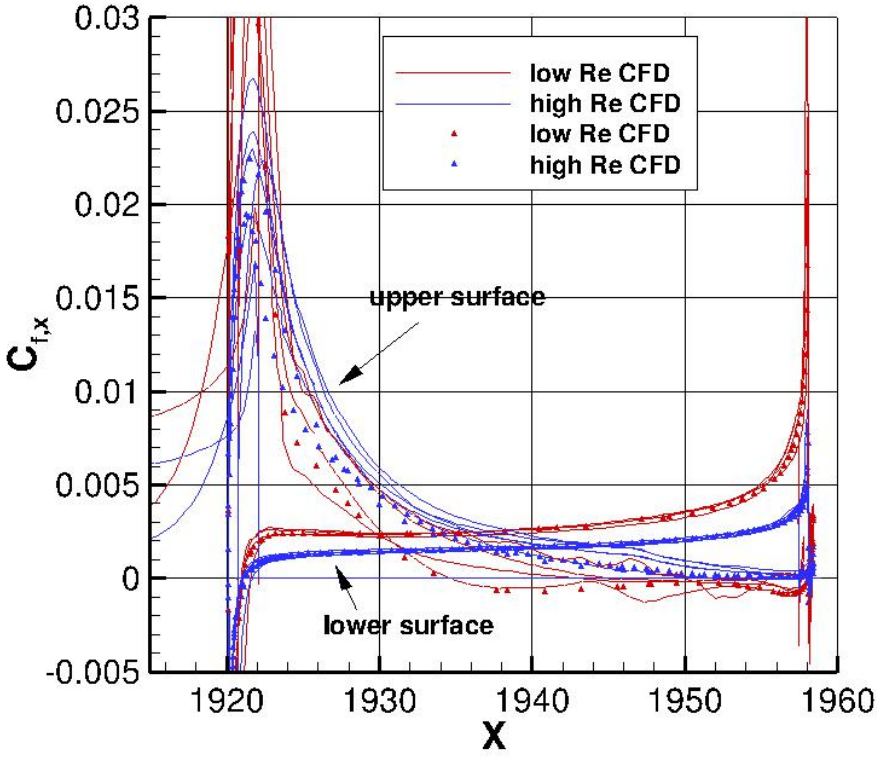
Cf,x at 89% span

All results plotted

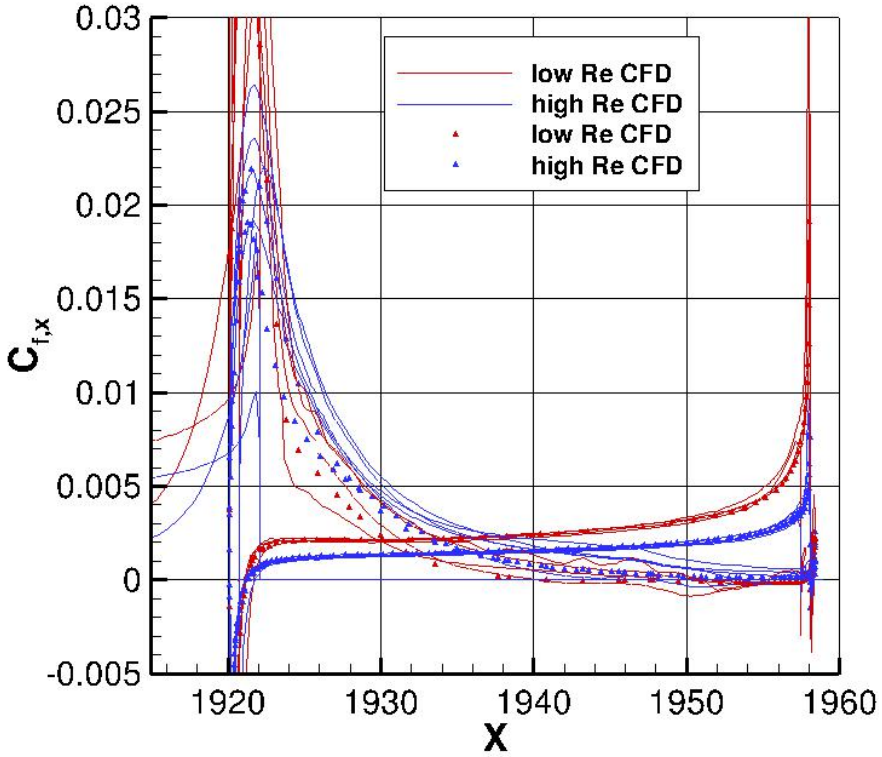


With brackets

AoA=7 deg



AoA=16 deg



Force/moment statistics

- Method of Morrison adopted
  - AIAA 2010-4673 (DPW analysis)
- Scatter limits

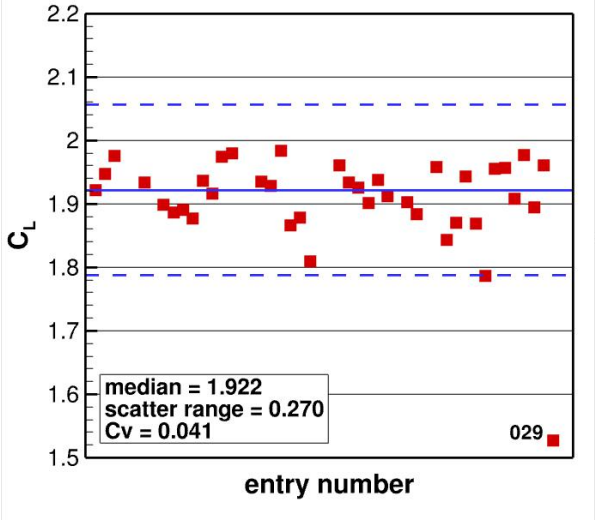
$$\hat{\mu} \pm K\hat{\sigma}$$

  - $\hat{\mu}$ is the median of sorted data (median is robust in presence of outliers)
  - $\hat{\sigma}$ is standard deviation
  - K is confidence interval coverage factor
    - Taken to be $\sqrt{3}$ (chosen based on assumed uniform distribution)
  - "Outliers" are submissions that reside outside of the scatter limits
    - Indication of potentially significant CFD difference
    - May need to be investigated, to understand the cause
- Coefficient of variation

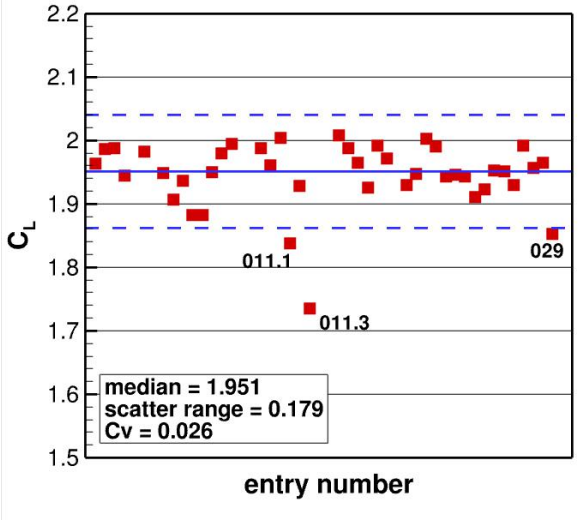
$$C_v = \hat{\sigma} / \hat{\mu}$$

Case 1 C_L statistics, AoA=7

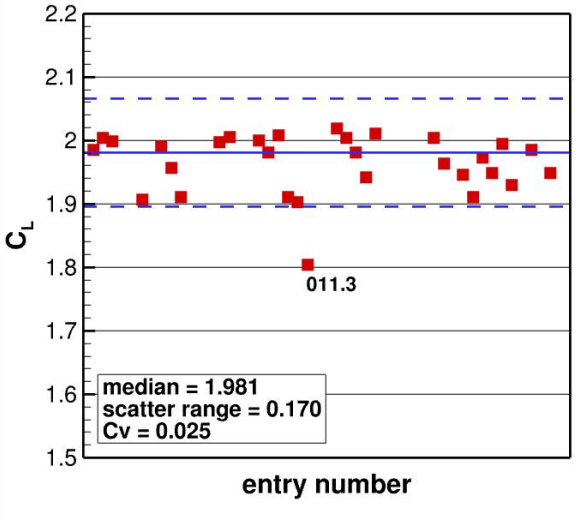
COARSE



MEDIUM



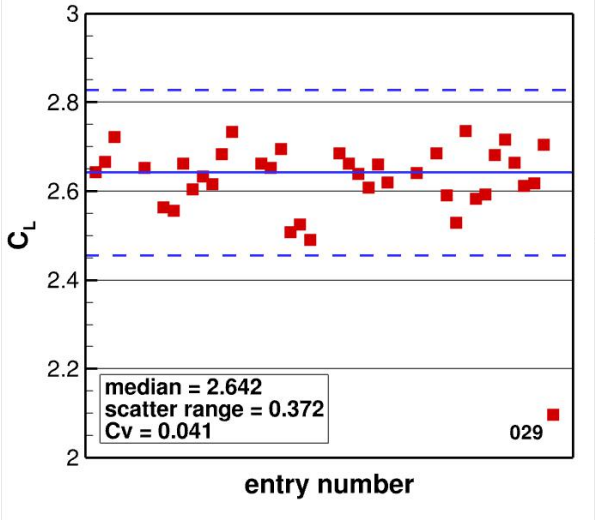
FINE



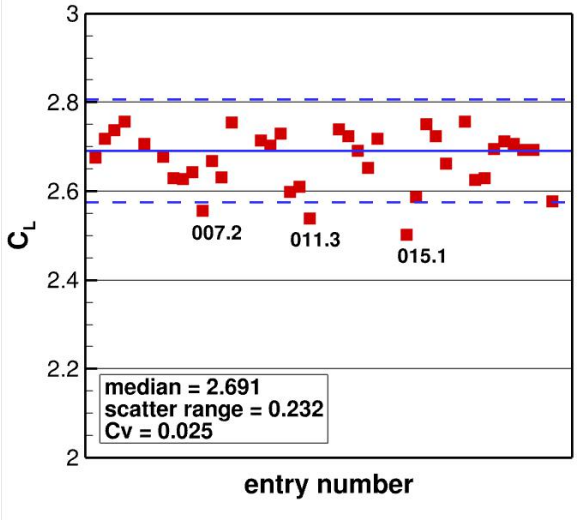
Scatter range decreases as grid is refined, but little change between M and F

Case 1 C_L statistics, AoA=16

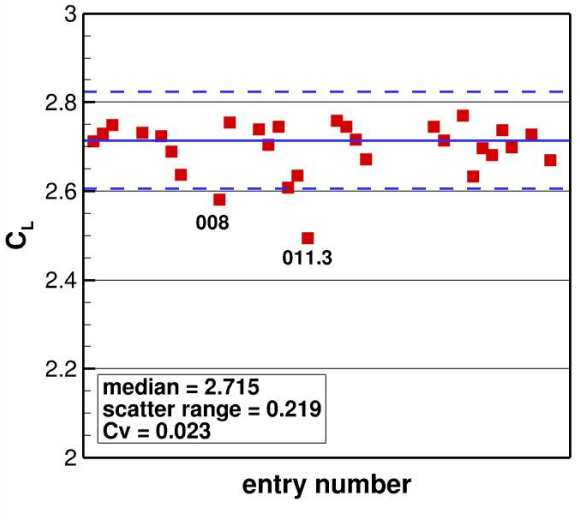
COARSE



MEDIUM



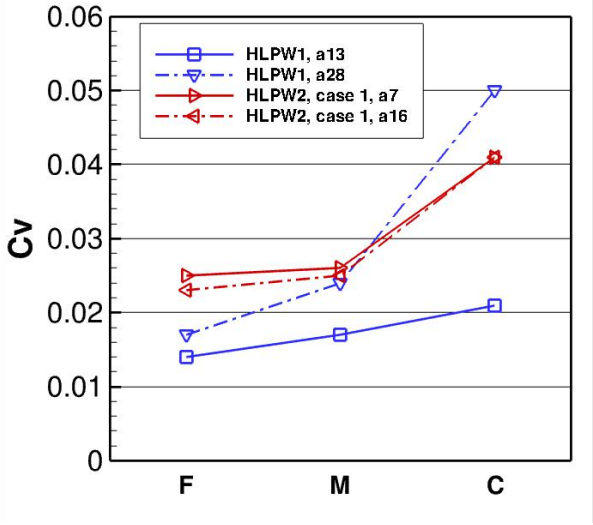
FINE



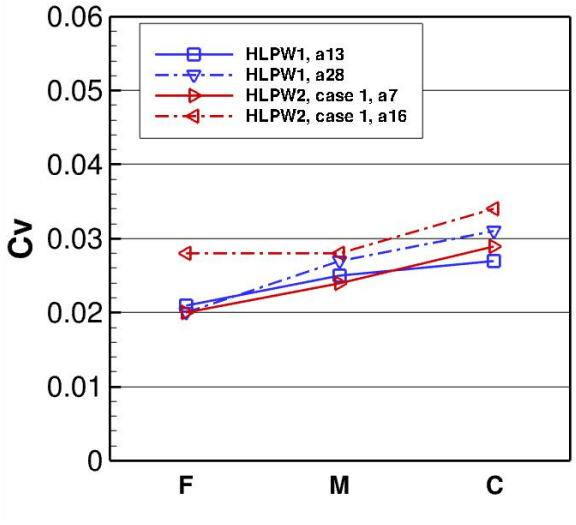
Scatter range decreases as grid is refined, but little change between M and F

Case 1 Coefficient of variation

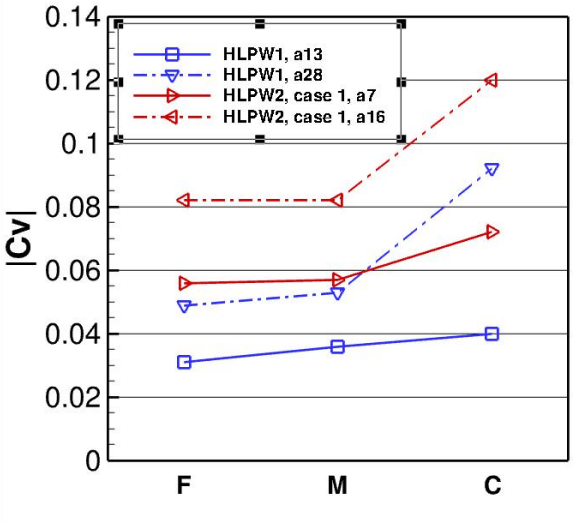
LIFT



DRAG



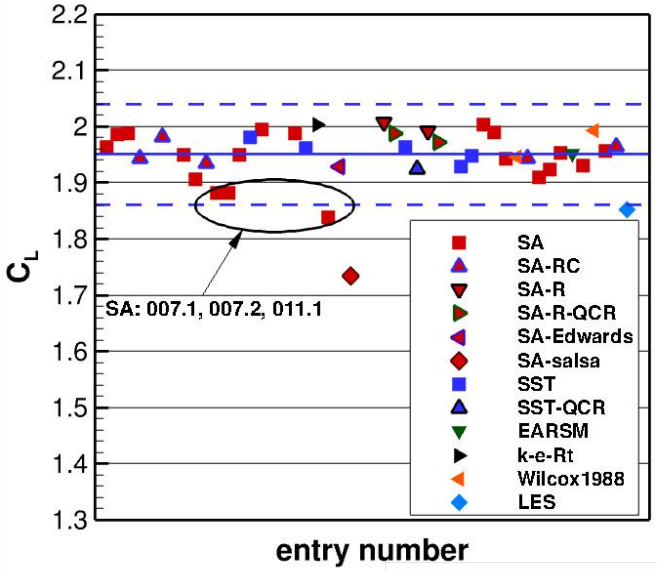
MOMENT



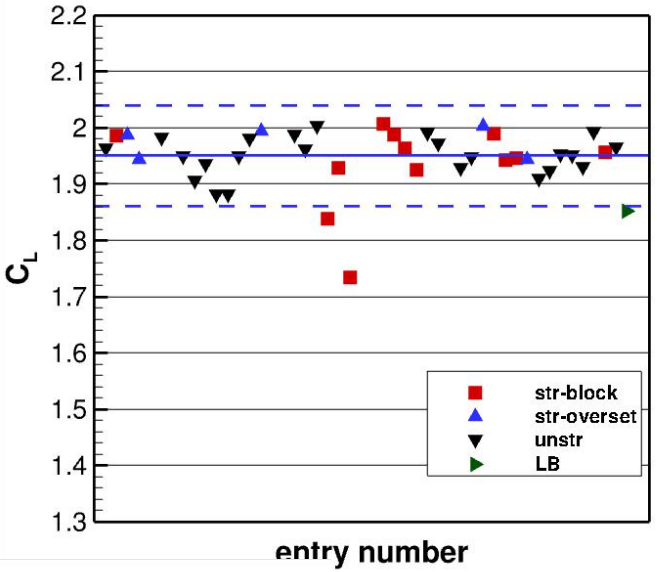
Cv's somewhat higher than HiLiftPW-1
Tend to flatten between M and F grids

Looking for trends, AoA=7

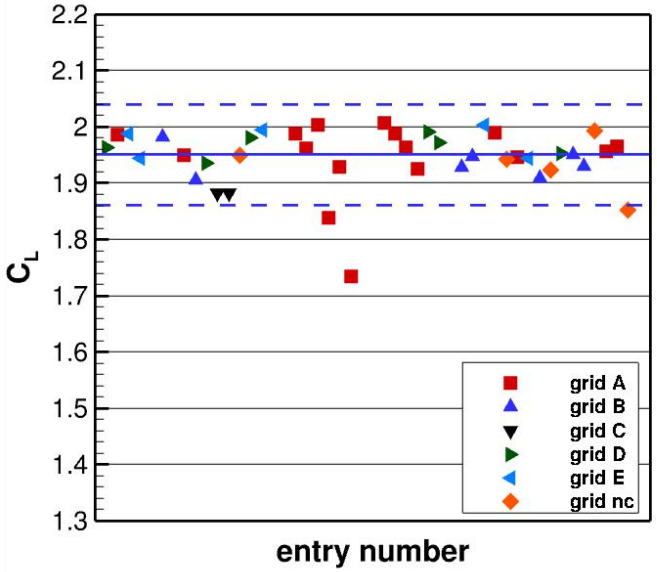
By turbulence model



By grid type



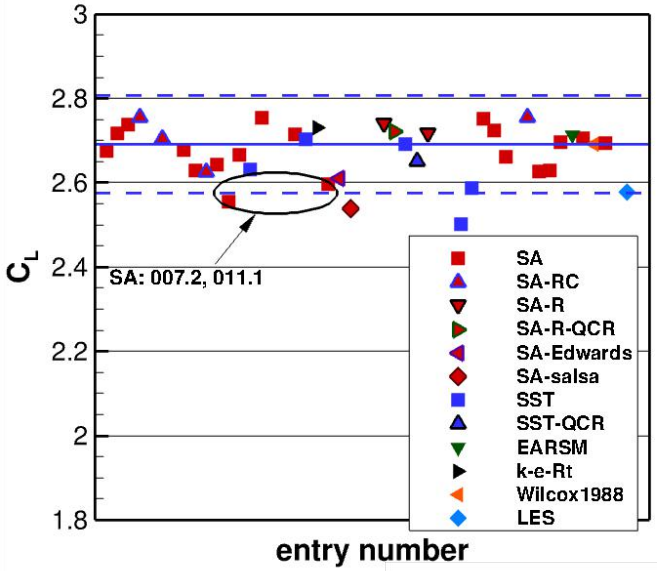
By grid



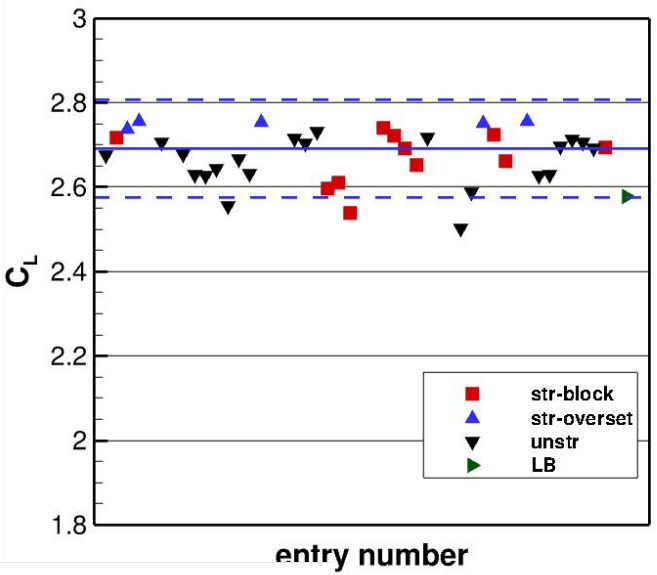
On medium grids

Looking for trends, AoA=16

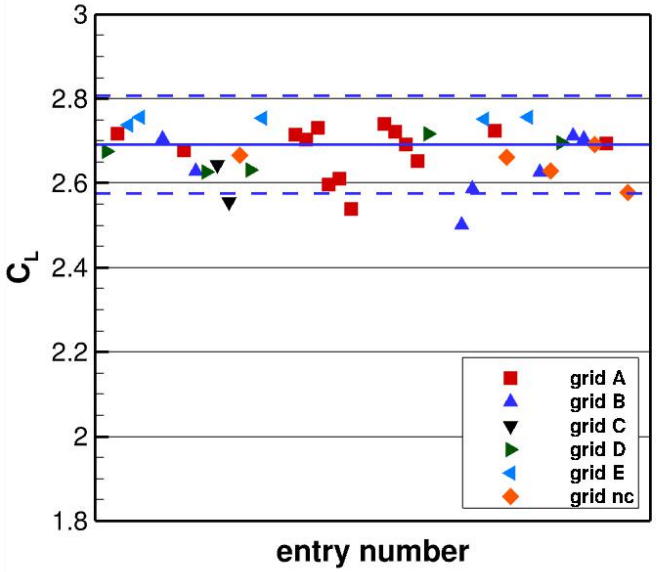
By turbulence model



By grid type



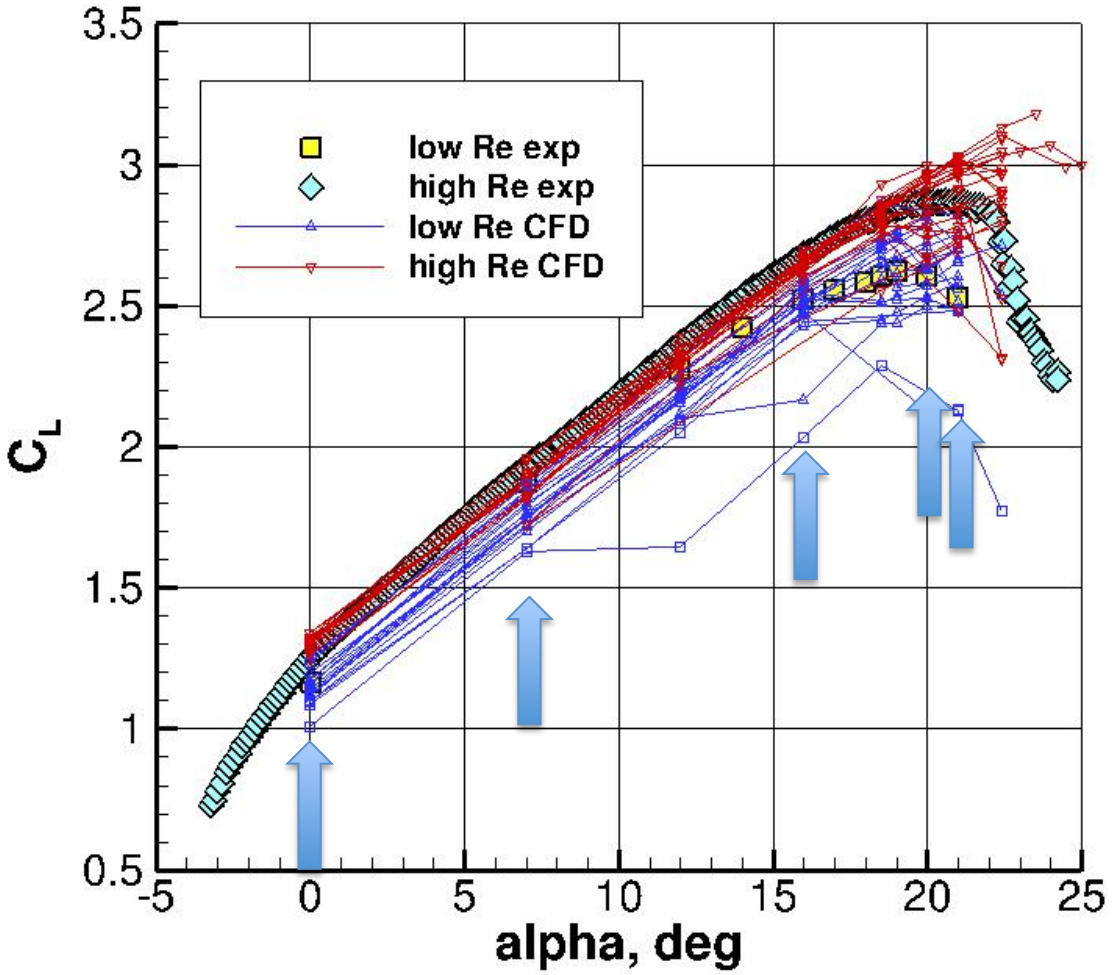
By grid



On medium grids

Case 2 Reynolds number effect

Including brackets

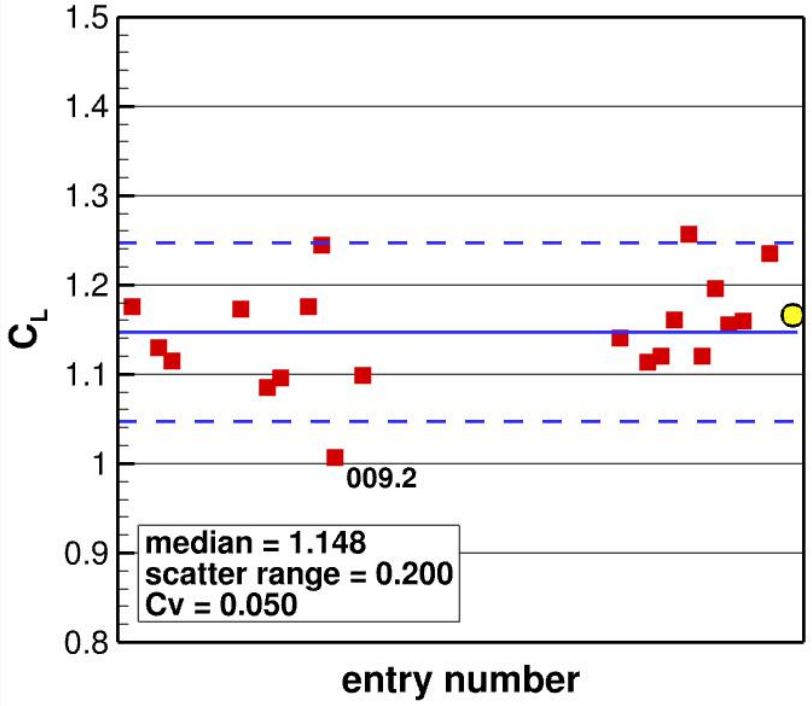


Not shown here: drag and moment mostly mis-predicted by CFD above AoA=7 deg. (see paper)

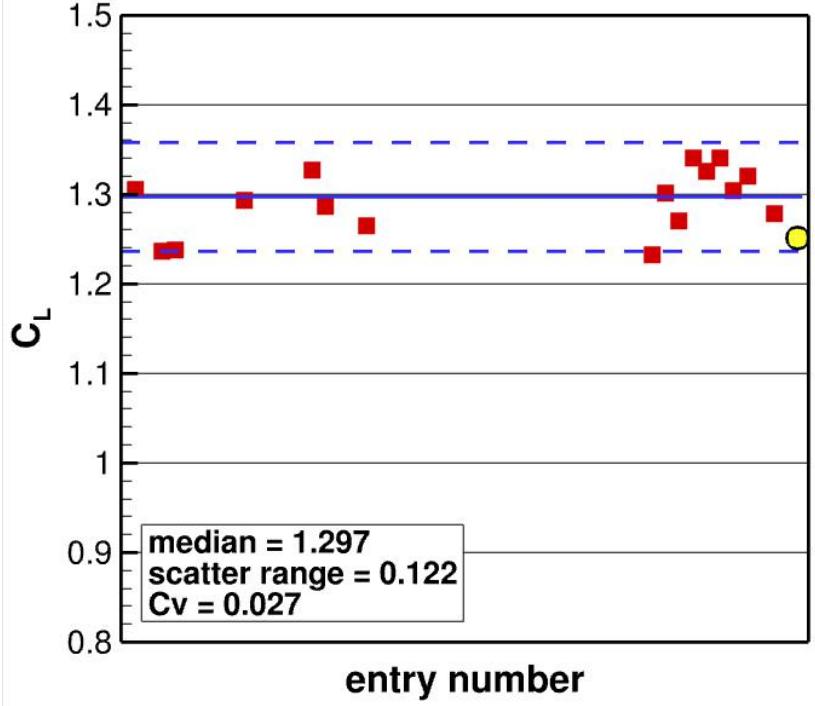
Case 2a/b C_L statistics, AoA=0

Including brackets

Low Re



High Re



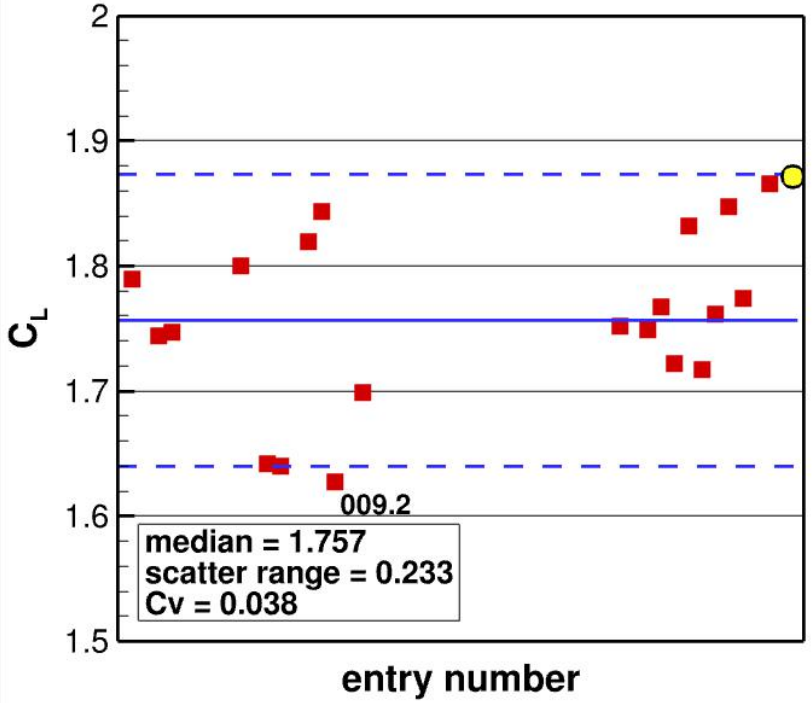
Yellow circle represents experiment

High Re lift predicted slightly too high by median CFD

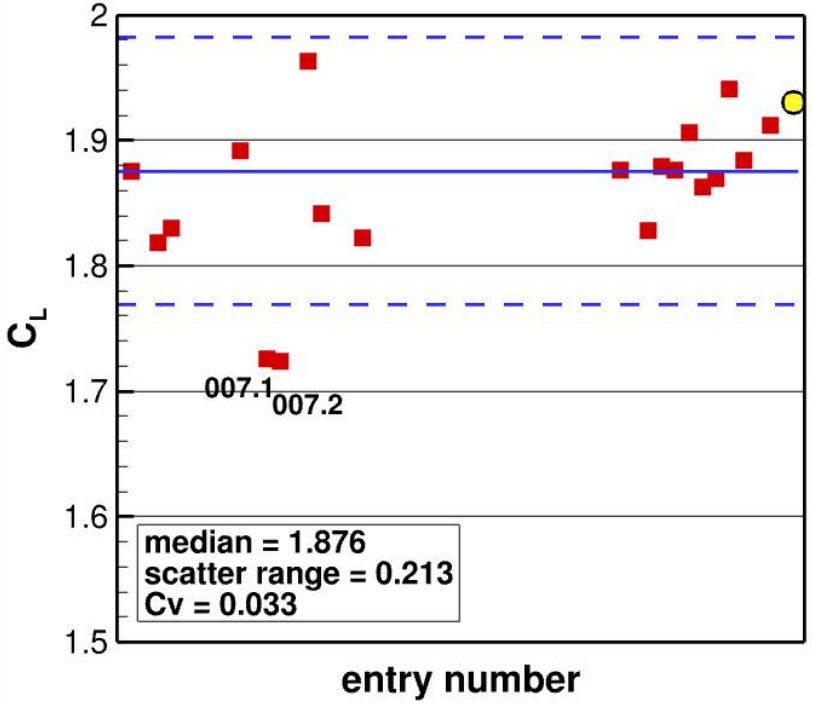
Case 2a/b C_L statistics, AoA=7

Including brackets

Low Re



High Re

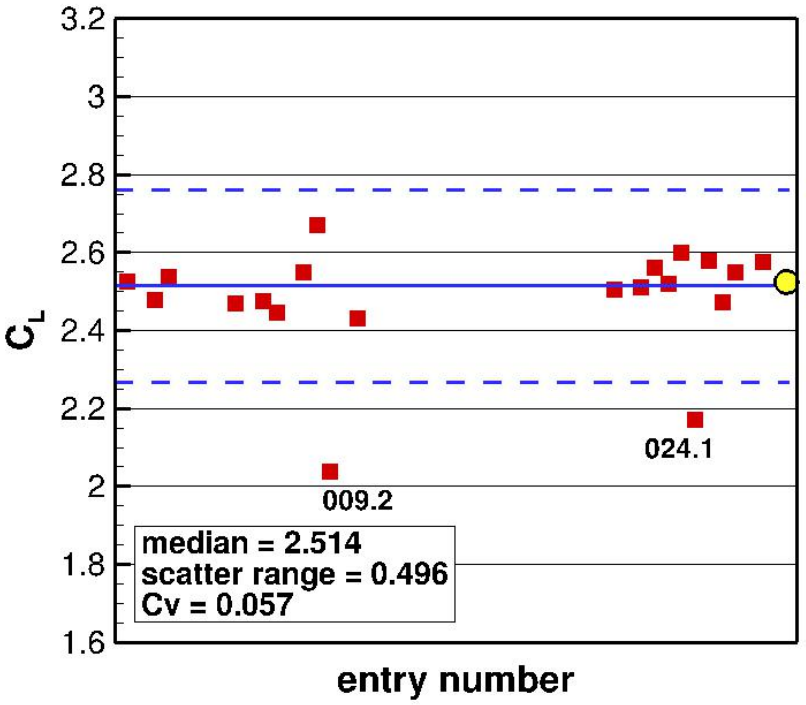


Low and high Re lift predicted too low by median CFD

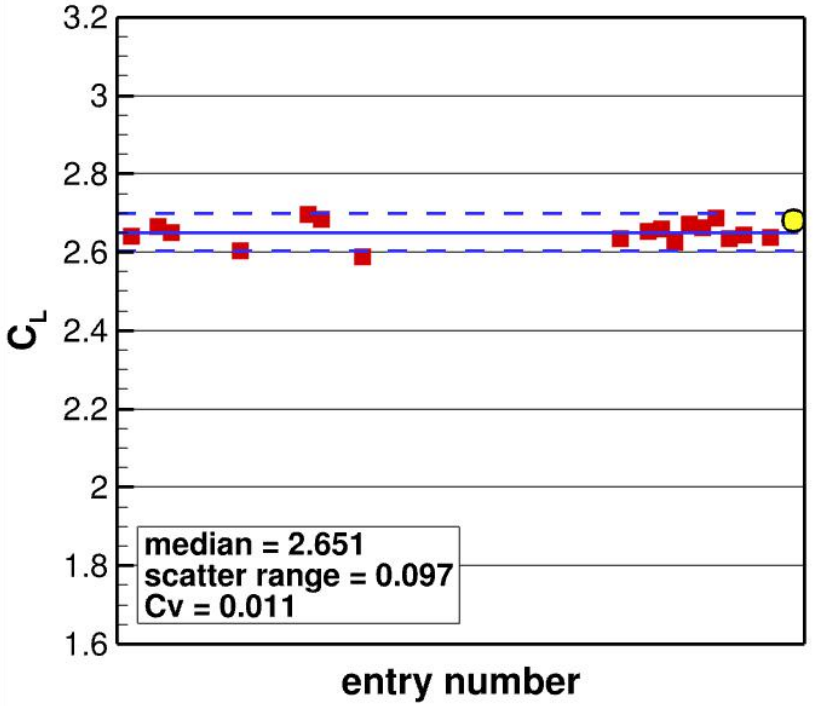
Case 2a/b C_L statistics, AoA=16

Including brackets

Low Re



High Re



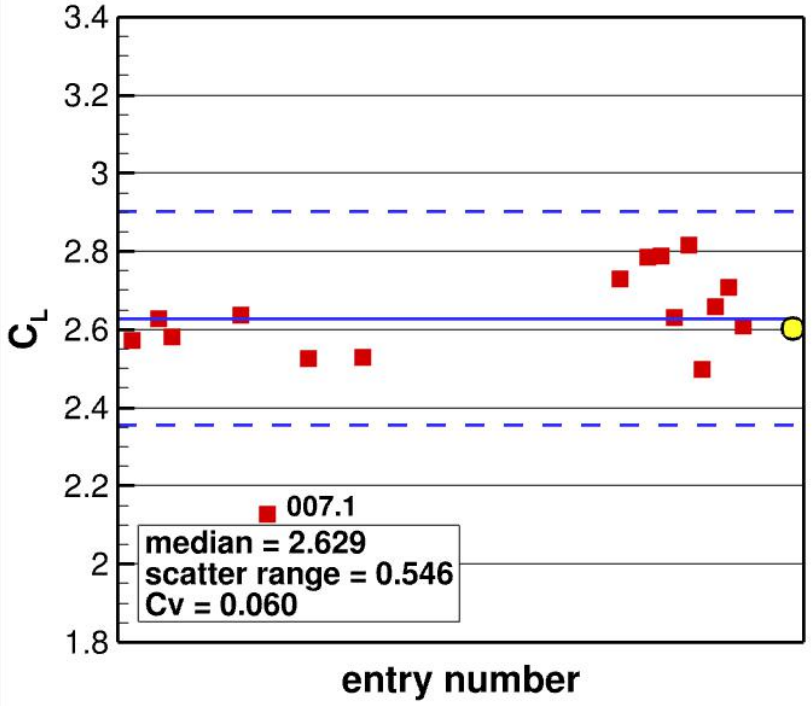
CL levels and Re trend captured well by median CFD

CFD remarkably tight at high Re

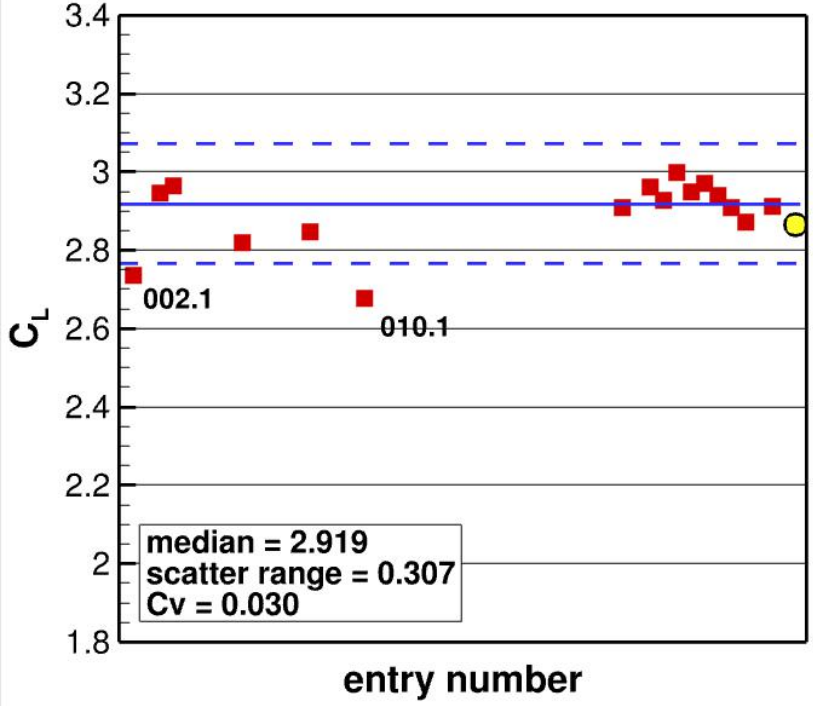
Case 2a/b C_L statistics, AoA=20

Including brackets

Low Re



High Re

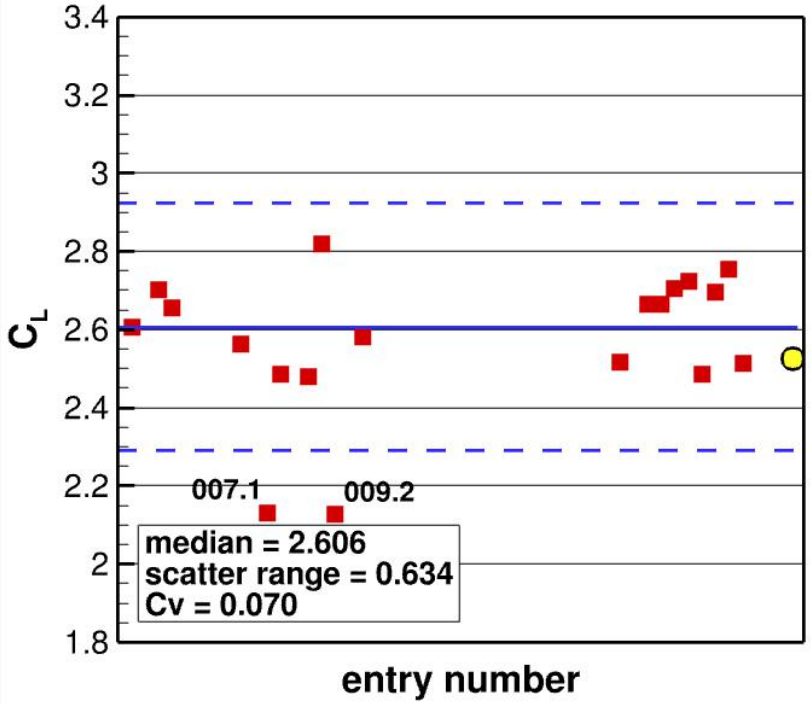


CL levels and Re trend captured well by median CFD

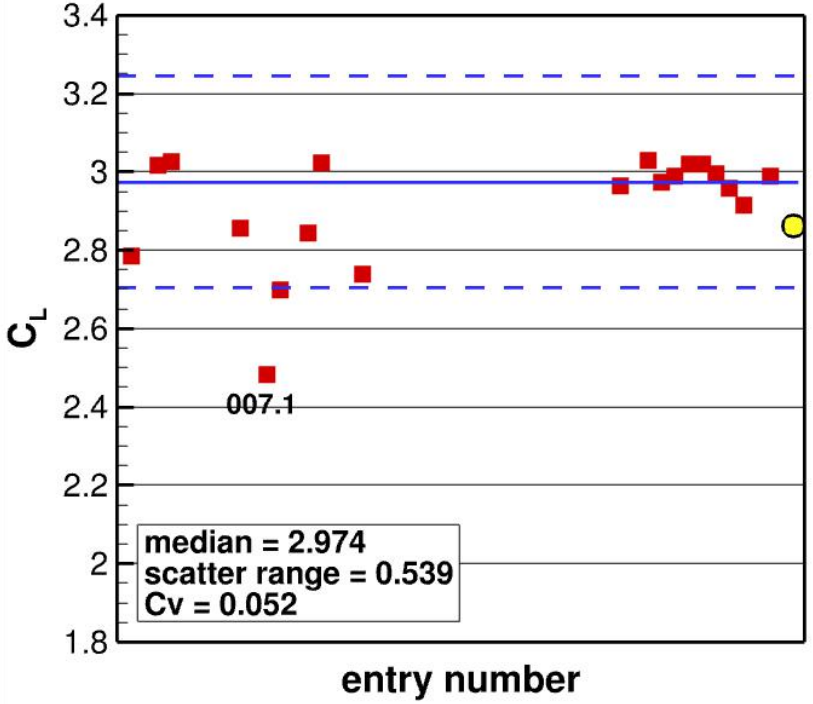
Case 2a/b C_L statistics, AoA=21

Including brackets

Low Re



High Re



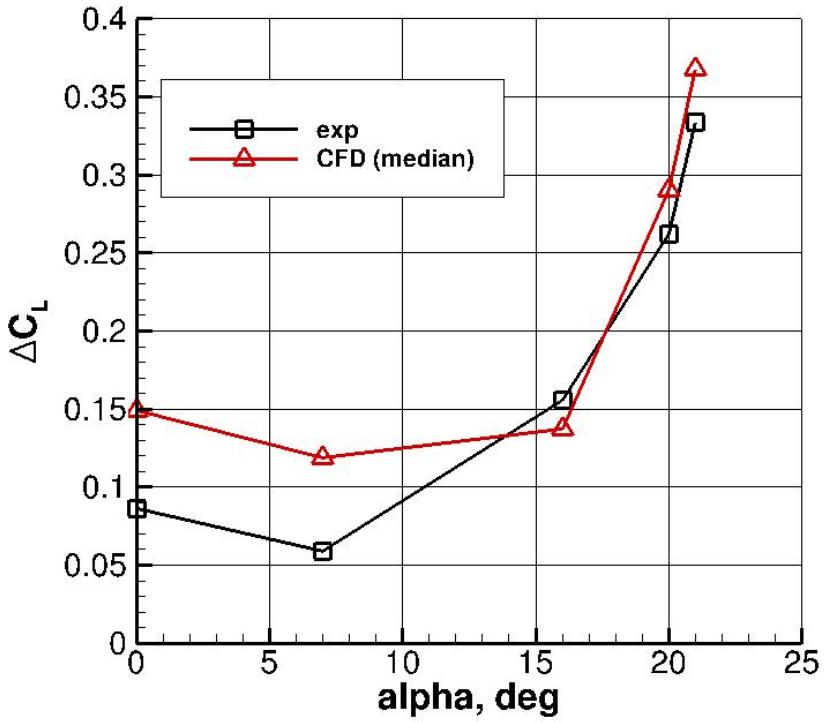
CFD's median CL still increasing (not capturing max CL)

Deltas due to Reynolds number

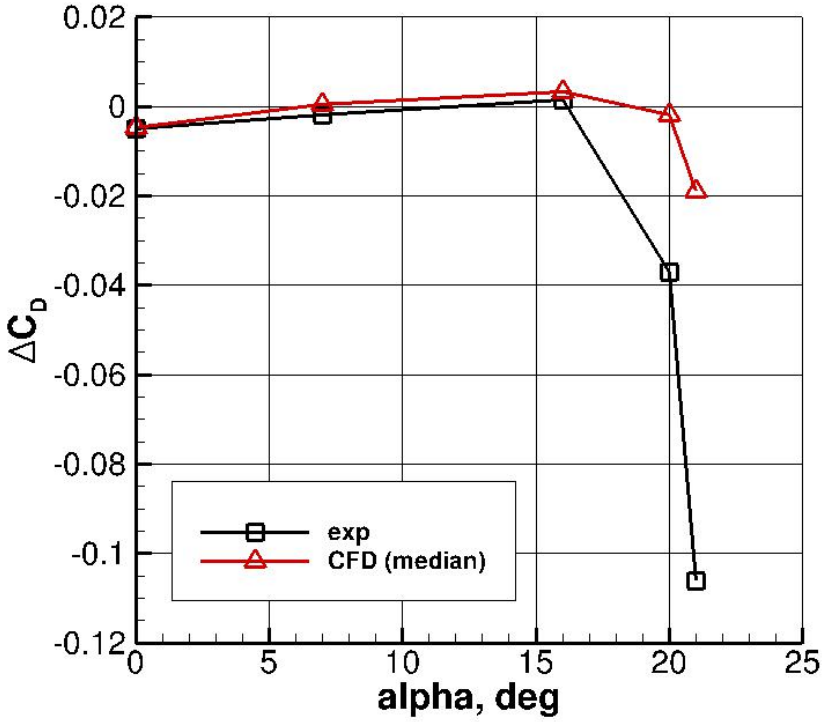
Including brackets

by MEDIAN CFD

Lift Coefficient



Drag Coefficient

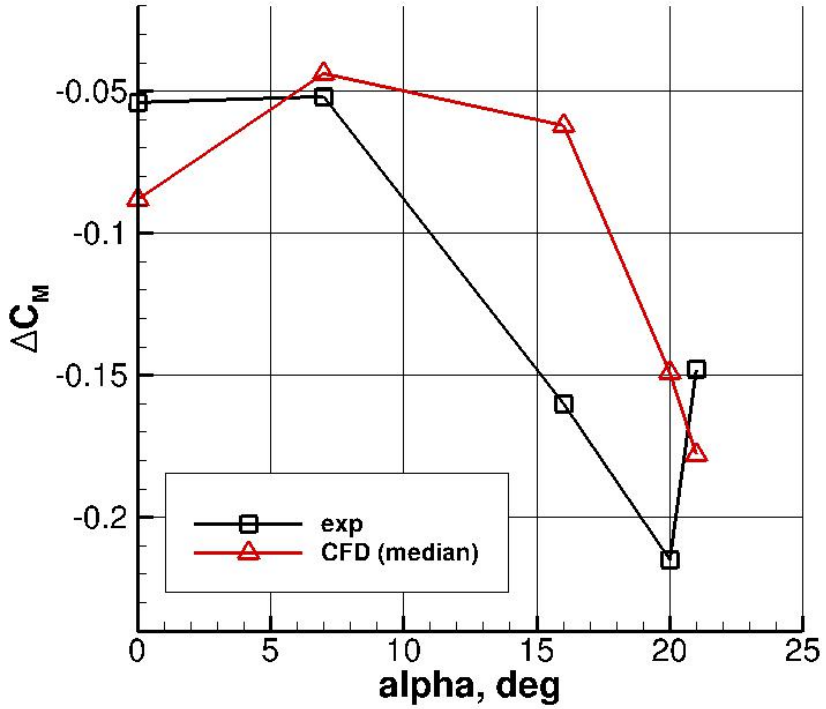


Deltas due to Reynolds number

Including brackets

by MEDIAN CFD

Moment Coefficient



Summary

- Turbulence modeling verification:
  - 8 of 10 submissions were SA or SA variant
  - The SA variants yielded different results
  - Among standard SA results:
    - 3 agreed “perfectly”
    - 1 very close
    - 2 showed notable differences
      - For DLR-F11, these also gave lowest lift of all SA submissions

Summary

- CFD consistency for DLR-F11:
  - Scatter among results did not decrease much between the medium and fine grid levels
    - Coefficient of variations somewhat higher than previous HiLift workshop
  - Insufficient iterative convergence may have played a small role
  - Scatter larger near CLmax
  - Inconsistencies between CFD results were largest on flap and at outboard stations

Summary

- Trends:
  - No definitive trends noted with turbulence model or grid type
  - But 2 of the 3 unstructured grids were poor for capturing wakes from upstream elements
  - Importance of transition was not clearly established by the results submitted
  - Median CFD results only qualitatively captured experimental Reynolds number trends
    - Median lift coefficient levels were similar to experiment
      - Scatter range around 0.2 at low AoAs
      - Scatter range around 0.3 – 0.6 at high AoAs
      - Exception: CFD very tight for AoA=16 at high Re
    - CFD mostly mis-predicted the drag and moment above AoA=7 deg.

Summary

- General:
  - Important to include slat & flap brackets, especially as oil flow experiment showed slat bracket influence near stall
  - Pressure tube bundles likely had influence near CLmax
  - The DLR-F11 cases were difficult for most codes to converge “fully”

Next steps

- Two AIAA special sessions on HiLiftPW-2 today with invited workshop participant results
- More HiLiftPW-2 AIAA special sessions at the AIAA June 2014 conference
- Brief discussion of possible future directions/ workshops at end of today's afternoon session