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3rd High-Lift Workshop Summary Paper - OpenFOAM, STAR-CCM+ & LAVA Simulations on Unstructured grids

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- Introduction
- Solver setup
- HL-CRM
- JSM
- Conclusions

Introduction

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- Attempt to compare three unstructured grid submissions to the HLPW3 workshop
- Not possible for a true comparison because different grids/solvers/turbulence models were used.
- Attempt to look for trends and demonstrate performance of each code. No experimental data for HL-CRM
- Each author have been encouraged to publish a more detailed version of their results. Please see their presentations on HLPW3 for more details. Not fully representative of all of the work by participants

Motivation

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University of Oxford

- Assess OpenFOAM for a high-lift geometry for the first time
- First HLPW contribution – learn about the importance of the mesh, turbulence model, flow physics
- Look where future researched is needed

Siemens

- Assess the performance of STAR-CCM+ for a complex flow
- Assess different turbulence modelling options

LAVA group

- Assess the unstructured branch of the code
- Meshing best-practices for unstructured code
- Compare against other branches of the code

Solvers (Oxford)

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- OpenFOAM 4.0
  - Compressible segregated pressure-based scheme (rhoPimpleFoam)
  - Preconditioned Conjugate Gradient
  - 2nd order upwind for Momentum + Turbulence
  - SA Model
  - 1240 cores for 48hrs (longer for higher AoA)
  - Warm starts

- STAR-CCM+ v11.06 (used to provide a benchmark for OpenFOAM)
  - Compressible coupled implicit density based
  - AMG Multi-grid
  - Roe Scheme
  - Green-Gauss min-mod limiter
  - 2nd order upwind Momentum + Turbulence
  - SA Model
  - 640 cores for 40hrs (longer for higher AoA)
  - Warm starts

Solvers (Siemens)

- STAR-CCM+
  - Compressible coupled implicit density based
  - AMG Multi-grid
  - Roe Scheme
  - *Hybrid Least Squares / Green-gauss (Venkatakrishnan limiter)*
  - 2nd order upwind Momentum + Turbulence
  - Warm starts
  - SA/SST (a_1=1)/Lag k-E Elliptic blending model*

  - *Lardeau, S., and Billard F., "Development of an elliptic-blending lag model for industrial applications," 54th AIAA Aerospace Sciences Meeting, 2016

Solvers (LAVA)

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- LAVA Unstructured
  - Cell-centered
  - 2nd order accurate MUSCL scheme
  - Green-Gauss with min-mod limiter
  - GMRES
  - AUSMPW+ scheme
  - Warm starts
  - SA-RC-QCR Model
  - ~2200 cores for 48 hours (run extra long to ensure force convergence)

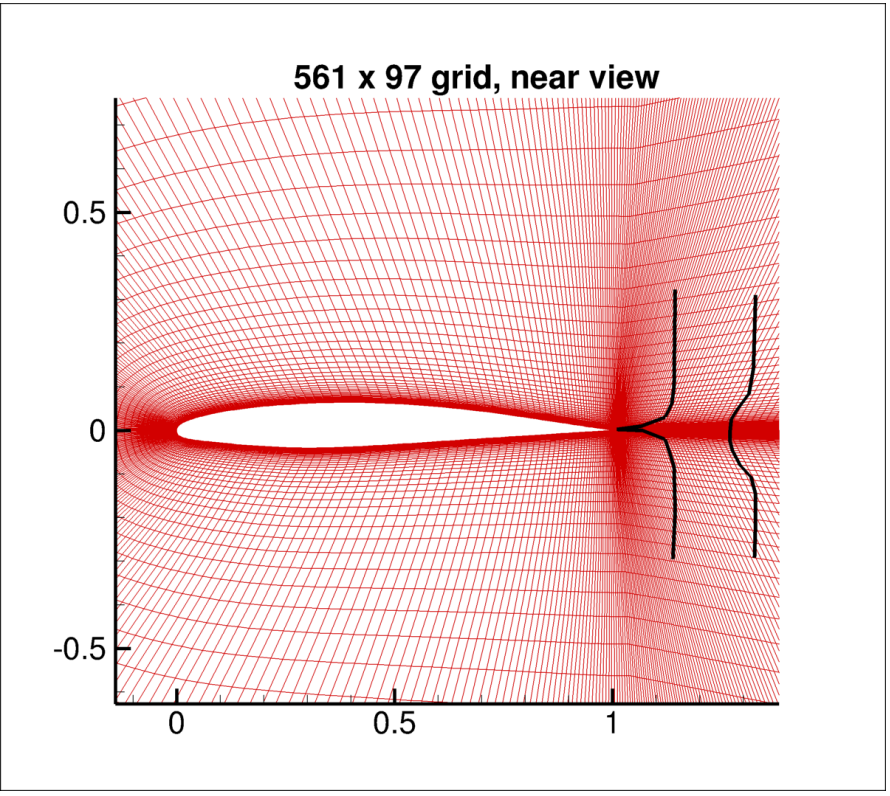
Other papers describing work:

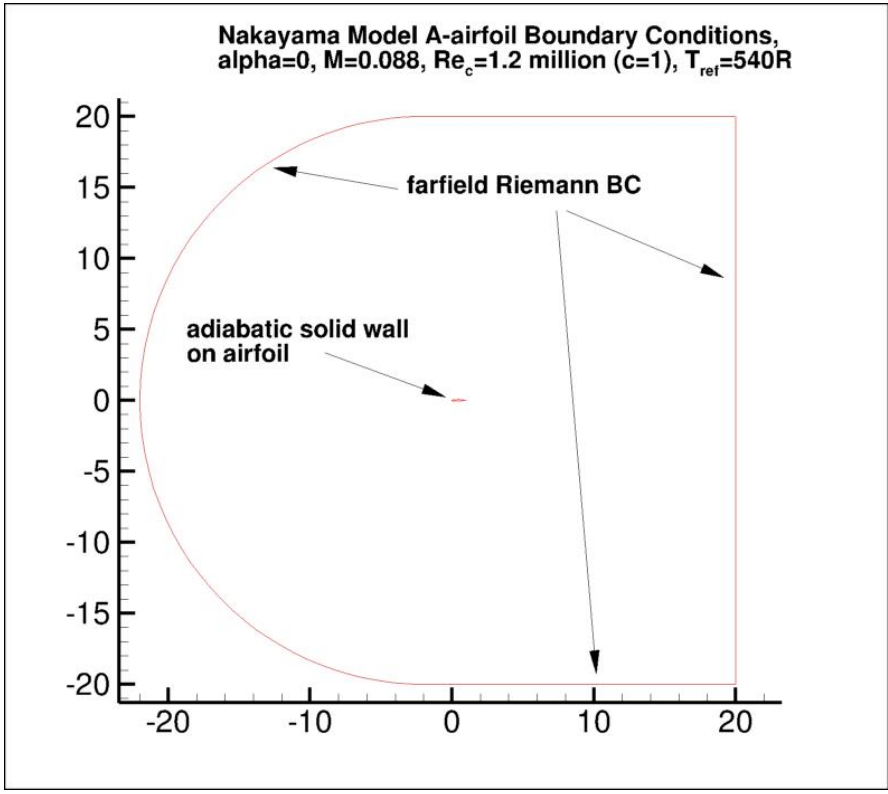
Jensen, J. C., Denison, M., Stich, G. D., Housman, J. A., and Kiris, C. C., "LAVA Simulations for the 3rd AIAA CFD High Lift Prediction Workshop using Body Fitted Grids," AIAA SciTech Forum, 2018.

Coder, J. G., Pulliam, T. H., and Jensen, J. C., "Contributions to HiLiftPW-3 using structured, overset grid methods," SciTech Forum, 2018.

DSMA661 Airfoil

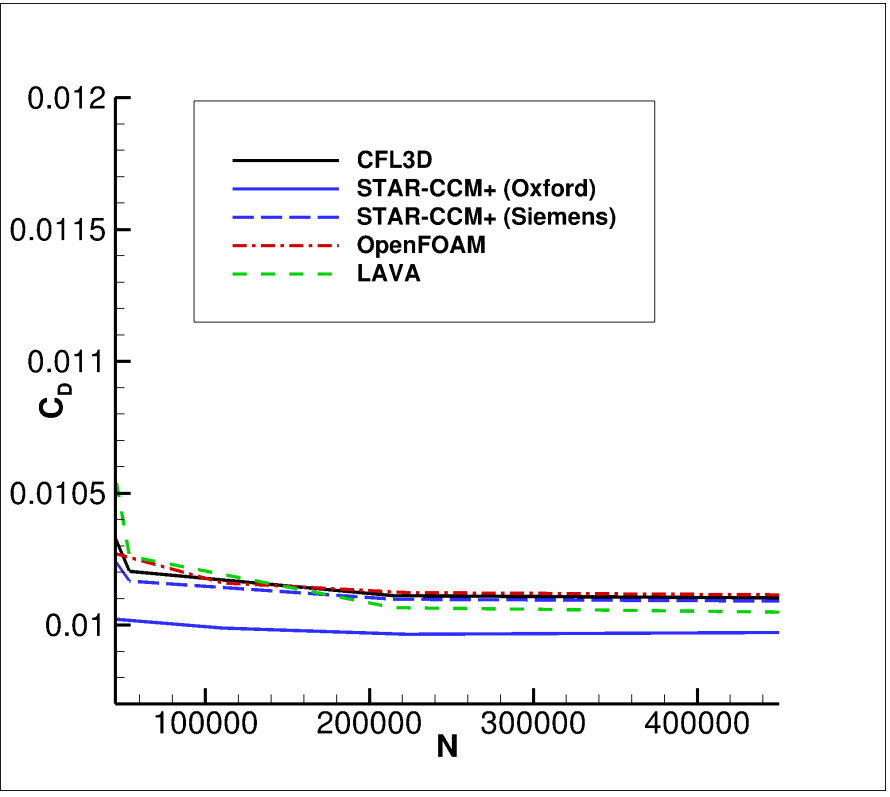
Simple 2-D case of near-wake behind DSMA661(MODEL A) airfoil from NASA TMR website.

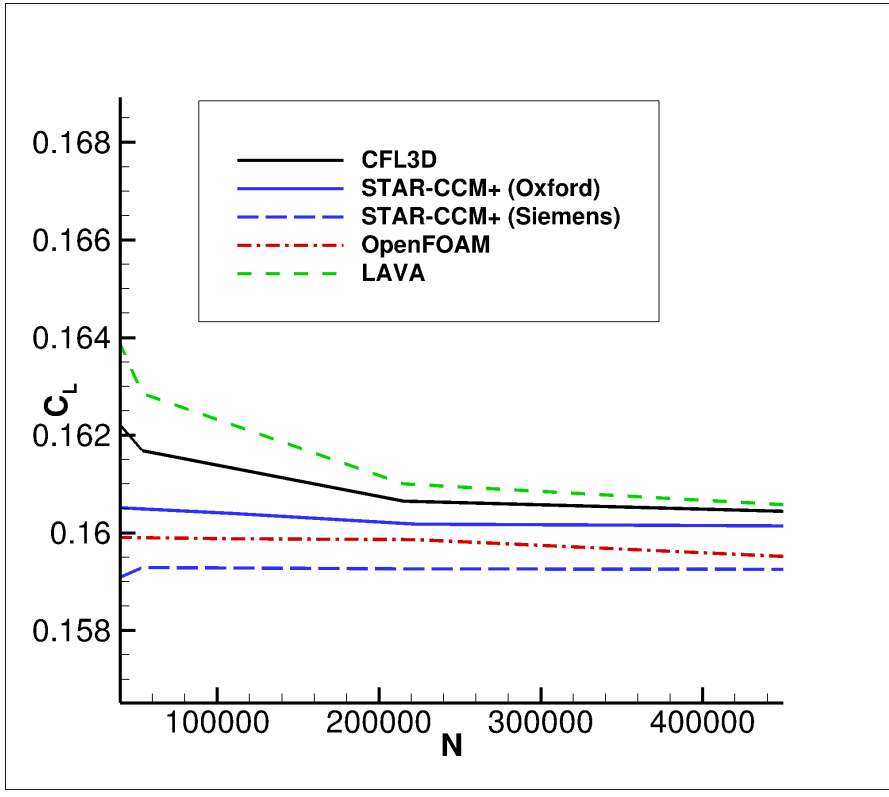




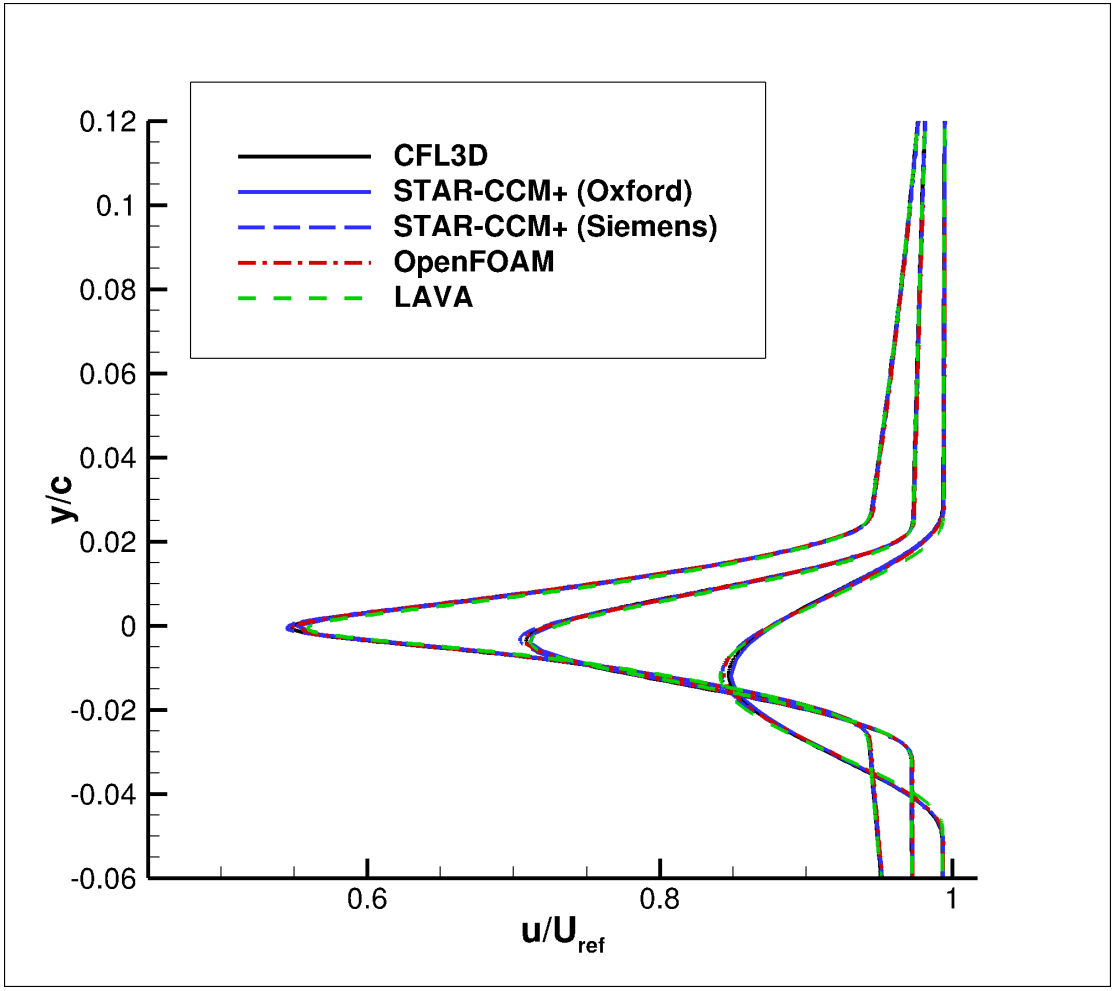
DSMA661 Airfoil

SA Model (RC-QCR for LAVA) results show a relatively tight coupling of the results for Cd but time variants for Cl.
Differences between STAR-CM+ results (on same mesh and turb models) highlights differences in user choice of gradient schemes





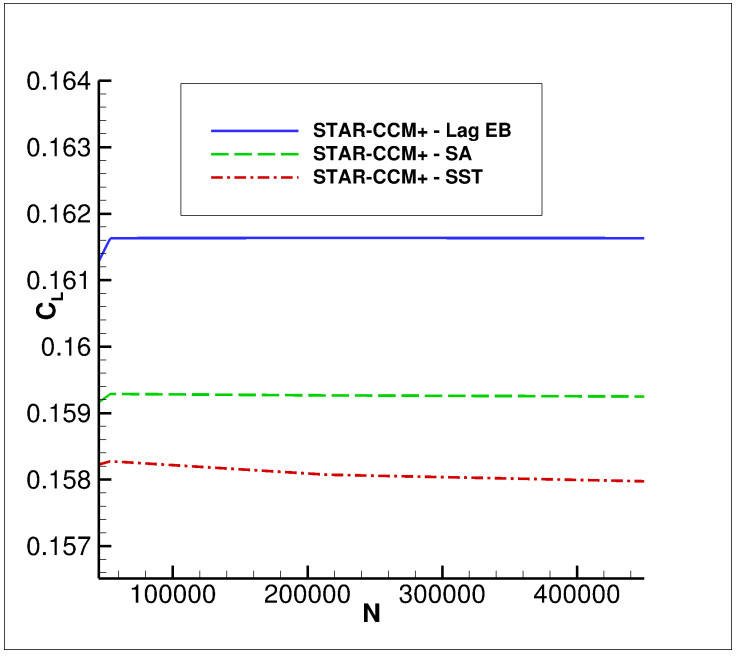
DSMA661 Airfoil

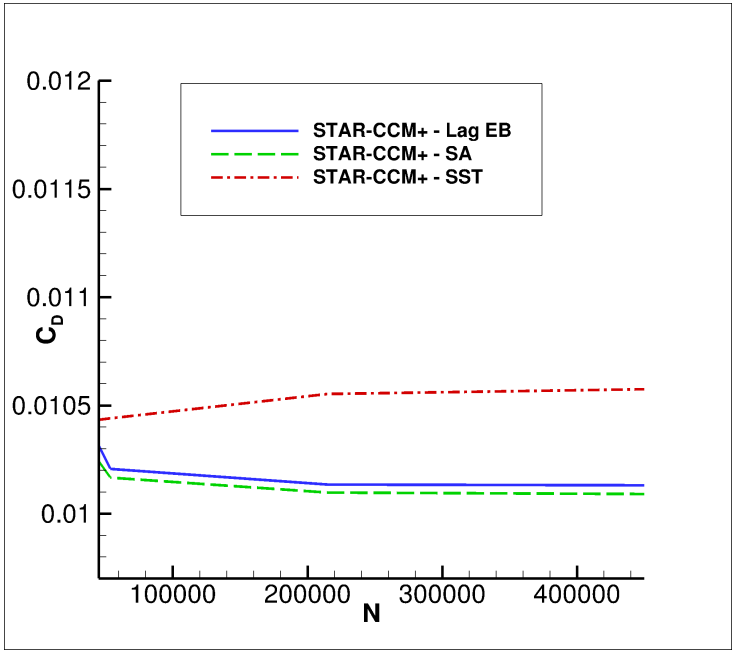


Off-body data to very close however with little to no difference between the results

DSMA661 Airfoil

Even for relatively simple geometry there is a noticeable difference between different turbulence models. No attempt to made on which is best





HL-CRM

- Results from Siemens and Oxford – LAVA group focused their effort on their curvilinear solver for this test case.
- Relatively clean wing (compared to JSM)

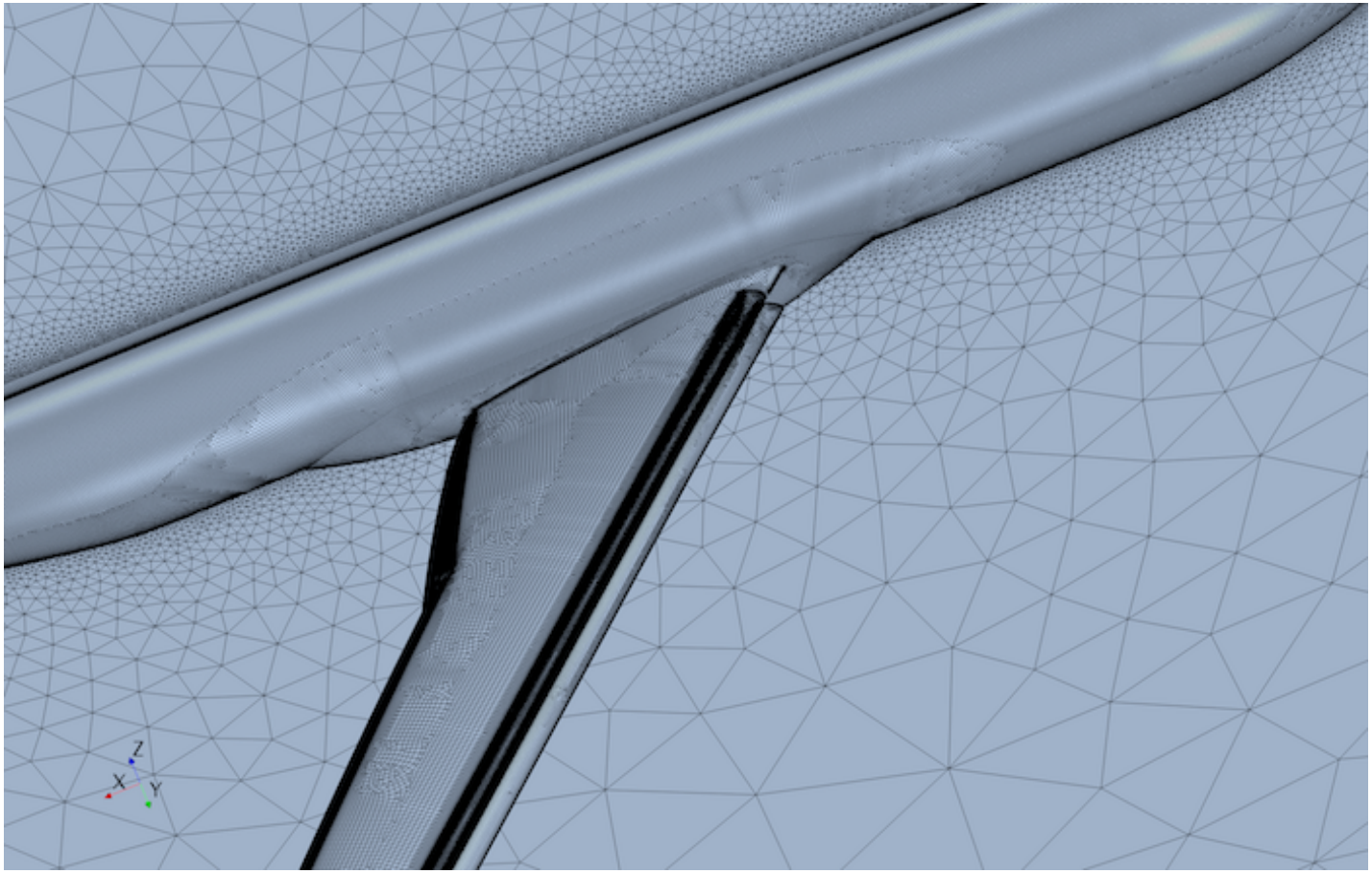
Case Parameters and Requirements

Case 1a: Full Chord Flap Gap (REQUESTED)

Mach Number	0.2
Alphas	8 and 16°
Reynolds Number based on MAC	3.26 million
Reference Static Temperature	518.67°R (=15.00°C=59.00°F)
Reference Static Pressure	760.21 mmHg (=14.700 PSI)
Mean Aerodynamic Chord (MAC)	275.8 inches full scale
Important Details:	• The intent here is to analyze the full-scale geometry at wind tunnel conditions. Instead of scaling the geometry down to 10% scale, we are analyzing the full-scale grid in a more viscous fluid. In other words, viscosity in this case is not sea level standard, but is scaled up appropriately, to achieve the desired Re of 3.26 million based on 275.8 inches for the full-scale model. • Run simulations FULLY TURBULENT. • This configuration is gapped approximately 1" full-scale between the inboard/outboard flaps and between inboard flap and side of body. • All simulations are "free air"; no wind tunnel walls or model support systems.

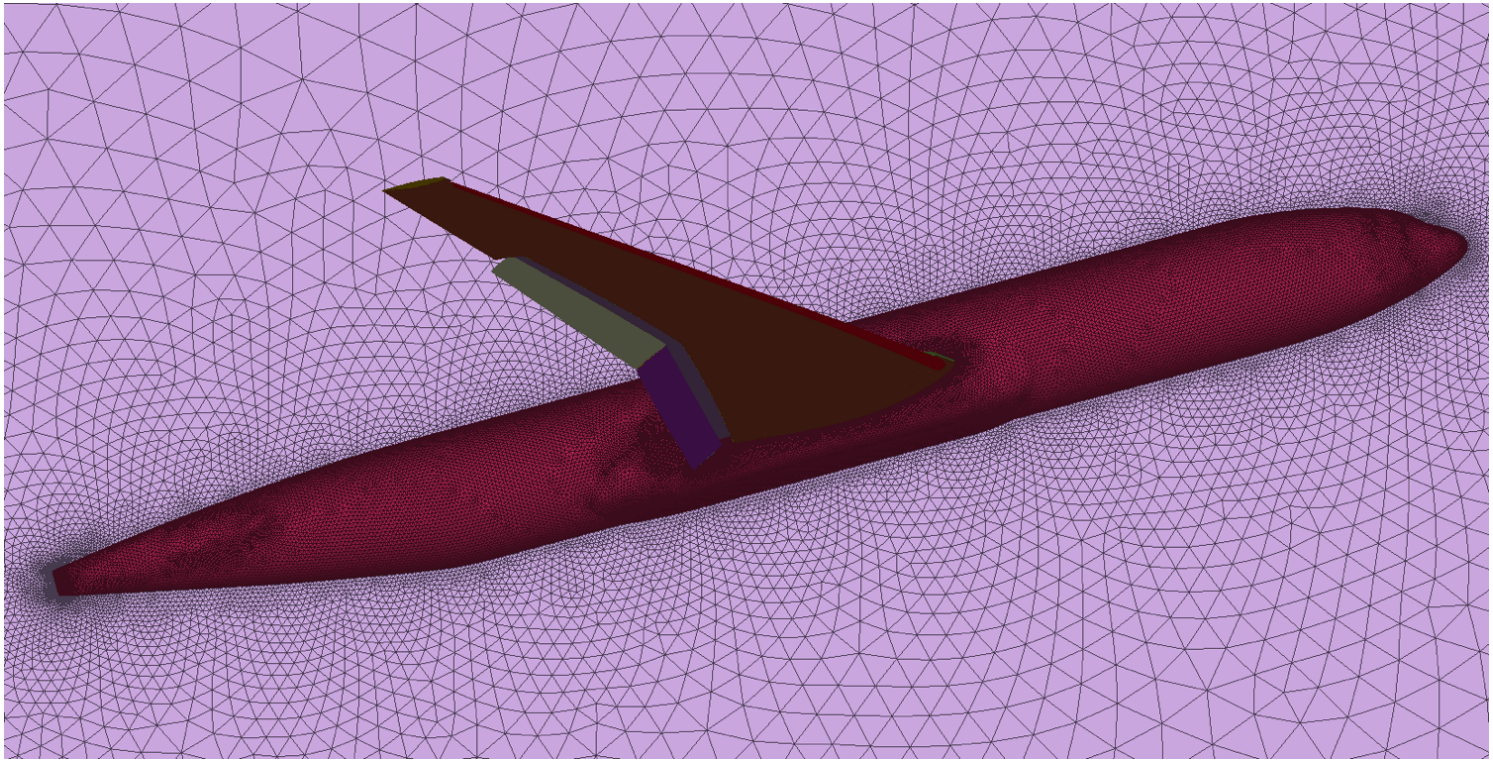
HL-CRM - Siemens

- Pointwise family of prism-tet grids – C/M/F = 18M,46M,118M cells



HL-CRM - Oxford

- OpenFOAM snappyHexMesh was too poor
- Developed meshes in ANSA (BETA-CAE Systems) – Adv. Front + tets
- Provided for other participants to use
- See Skaperdas, V, Ashton N – Development of high-quality hybrid unstructured meshes for the GMGW-1 workshop using ANSA *AIAA-2018-0660*



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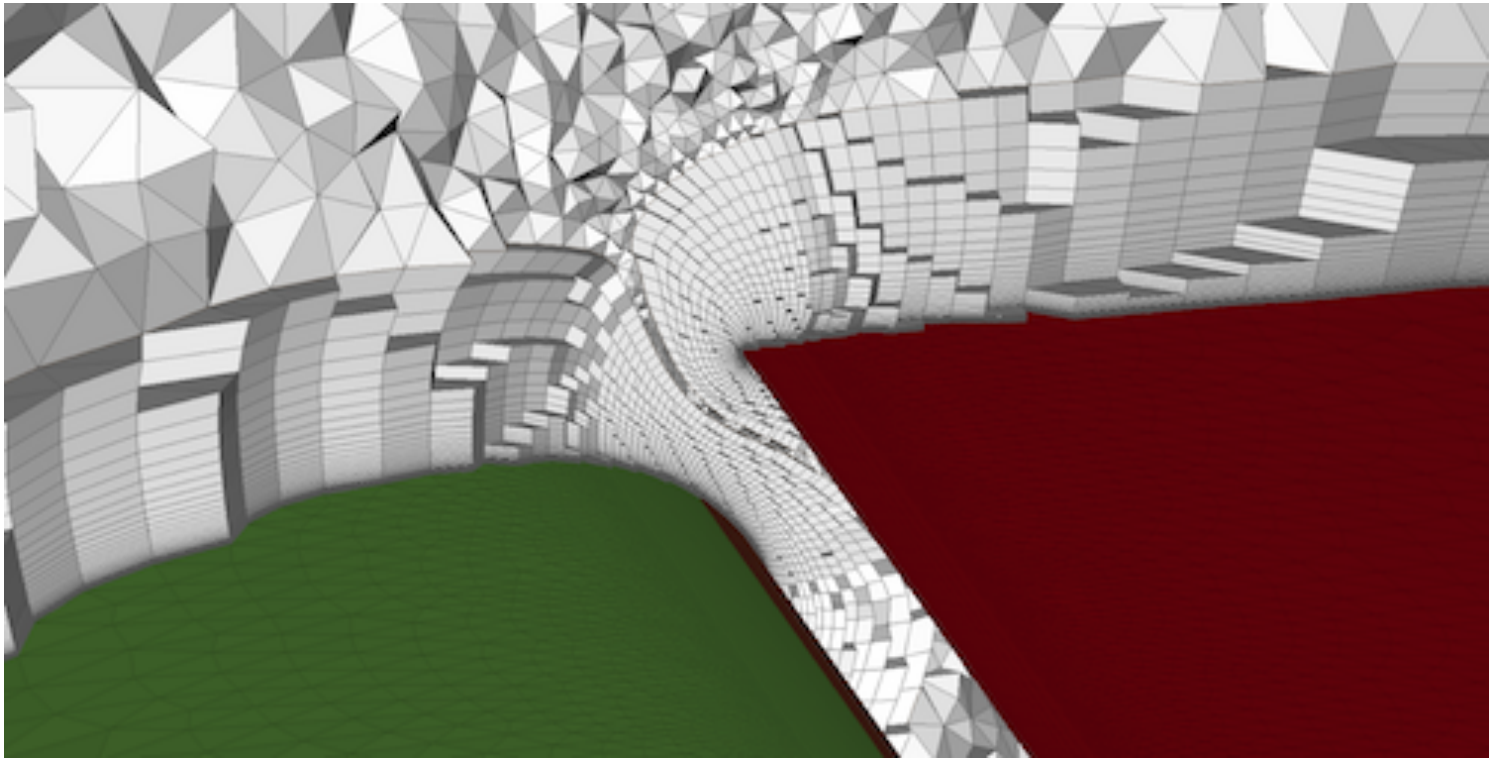
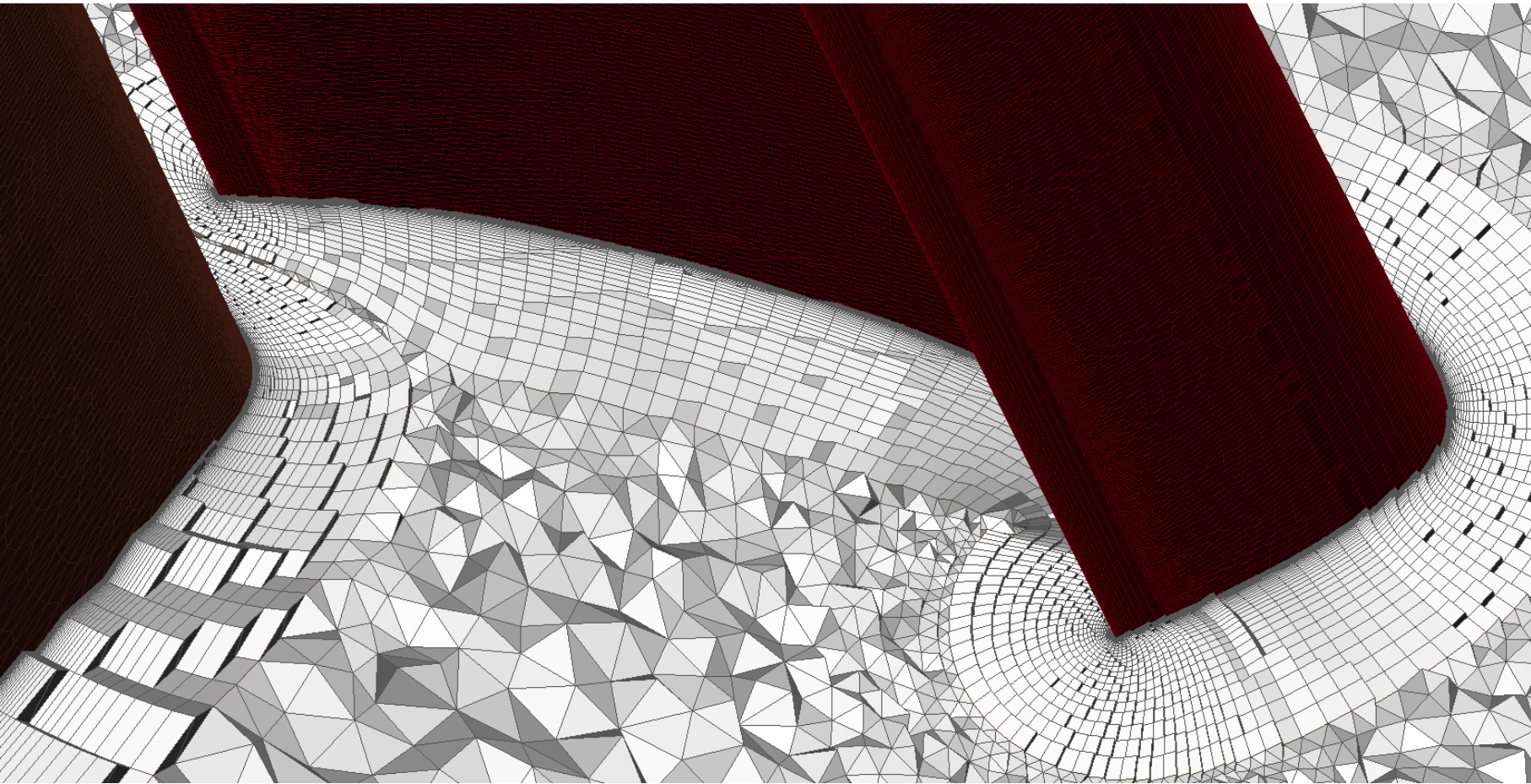


HL-CRM Meshes

CRM close up near slat lower side

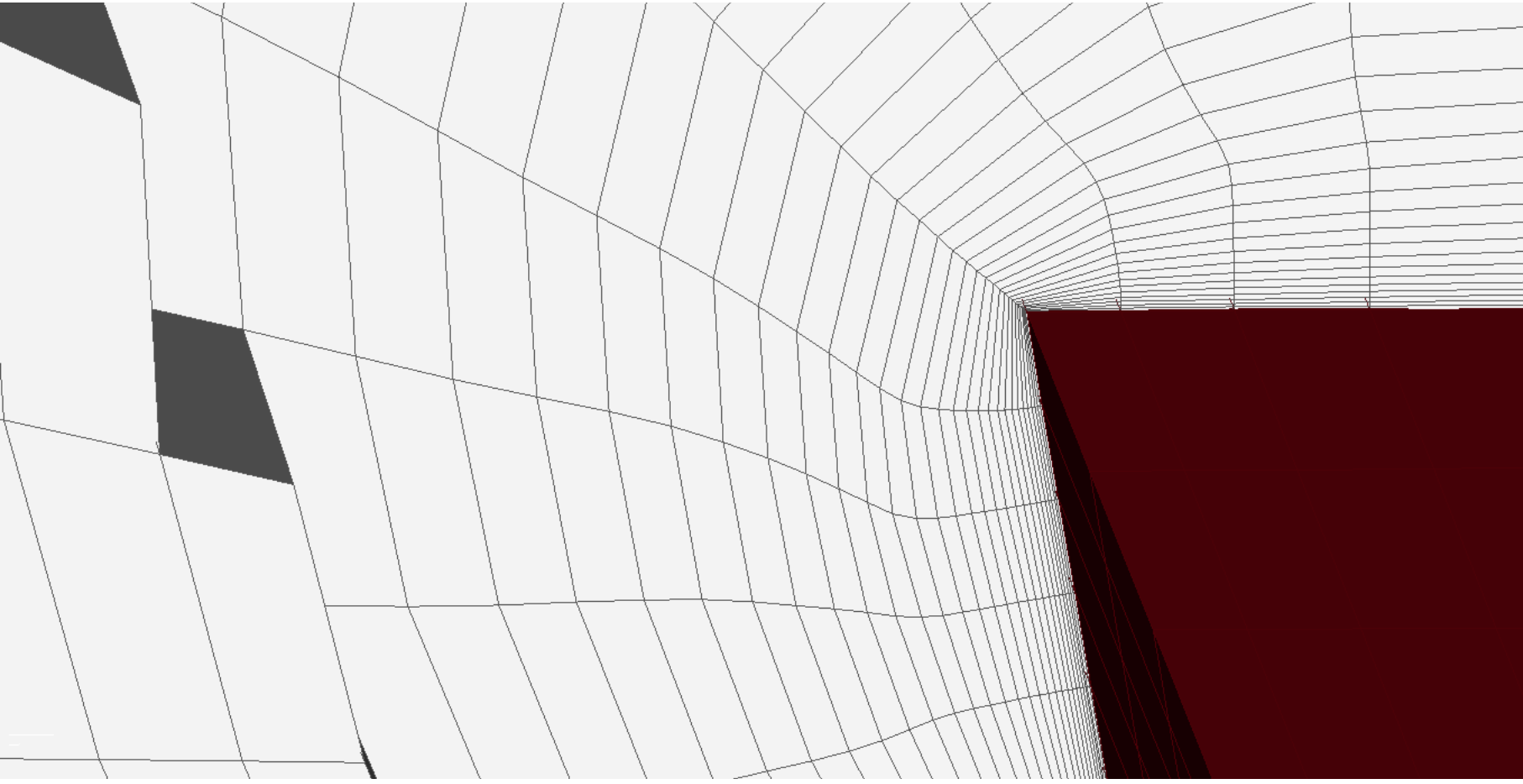


HL-CRM Meshes

	Coarse gapped flaps	Medium gapped flaps	Medium sealed flaps	Fine gapped flaps
Surface mesh size (millions)	1.8	2.4	2.3	2.8
Volume mesh size (millions)	89	147	143	237
Trailing edge rows of elements	4	6	6	8
Number of Layers	Wing:40 Fuselage:45	Wing:45 Fuselage:57	Wing:45 Fuselage:57	Wing:65 Fuselage:84
Layers growth	1.25	1.16	1.16	1.1
Layers first height (inches)	0.000787	0.000787	0.000787	0.000787

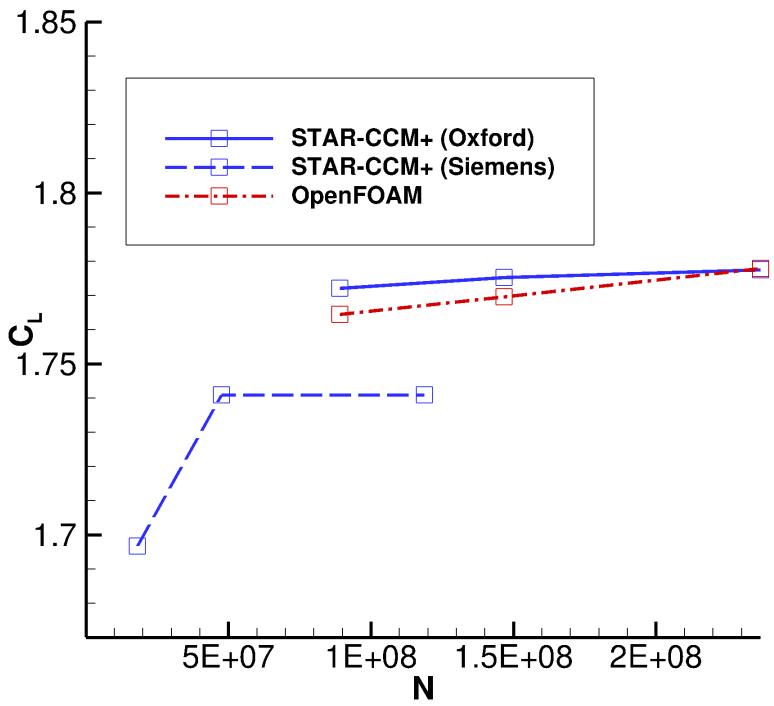
HL-CRM Meshes

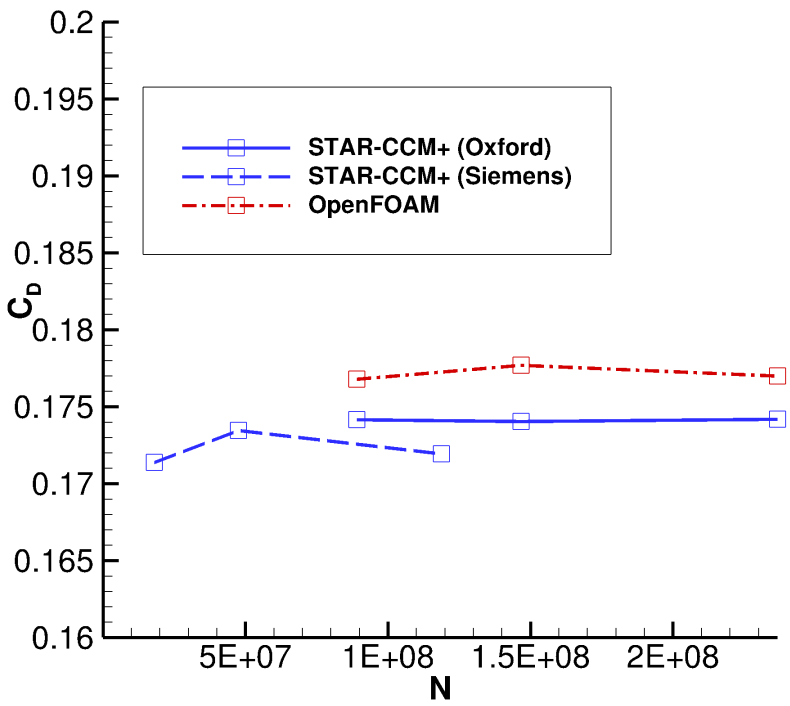
CRM imposed orthogonality of layers near the wall – will reduce OpenFOAM wall-distance problem



HL-CRM - 8

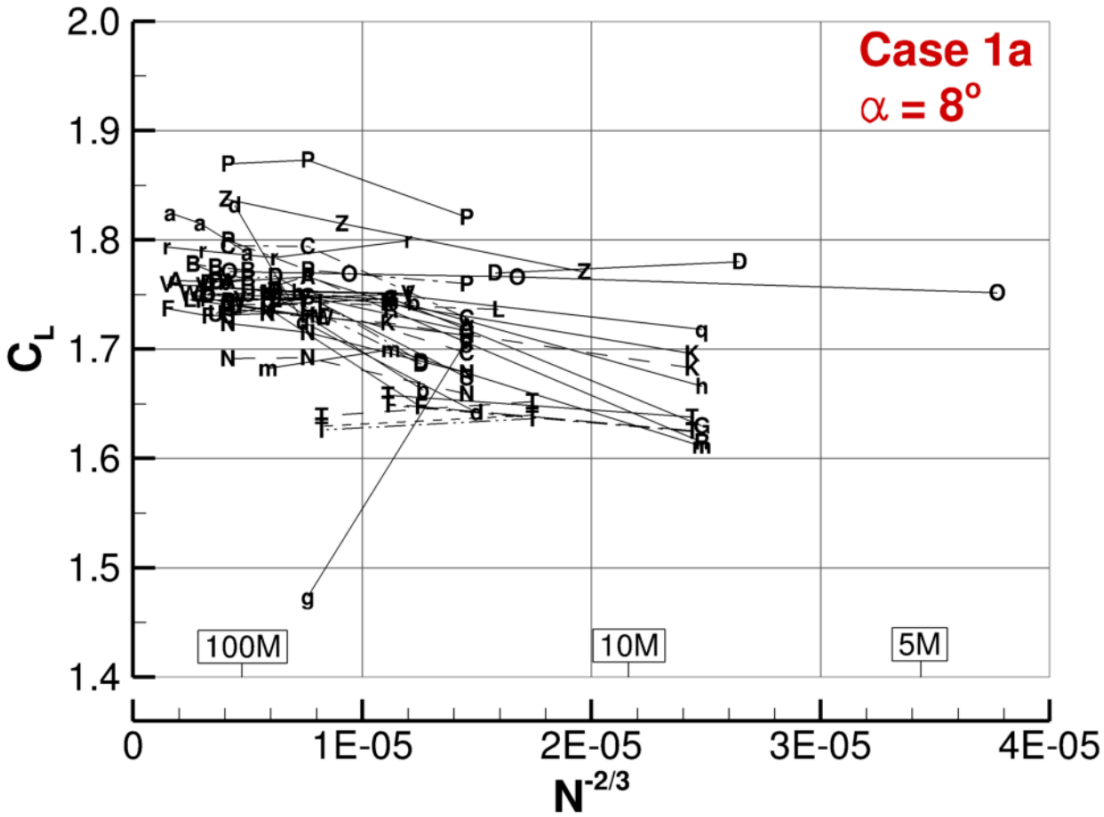
- Not reached mesh convergence by finest grid (236 million cells)
- STAR-CCM+ (Oxford) and OpenFOAM on the same grid towards to a than less 0.5% difference. Cd around a1.1% constant offset on the drag
- Siemens results on a different grid family lower Cl but a finer grid is needed to see the true mesh refinement trend





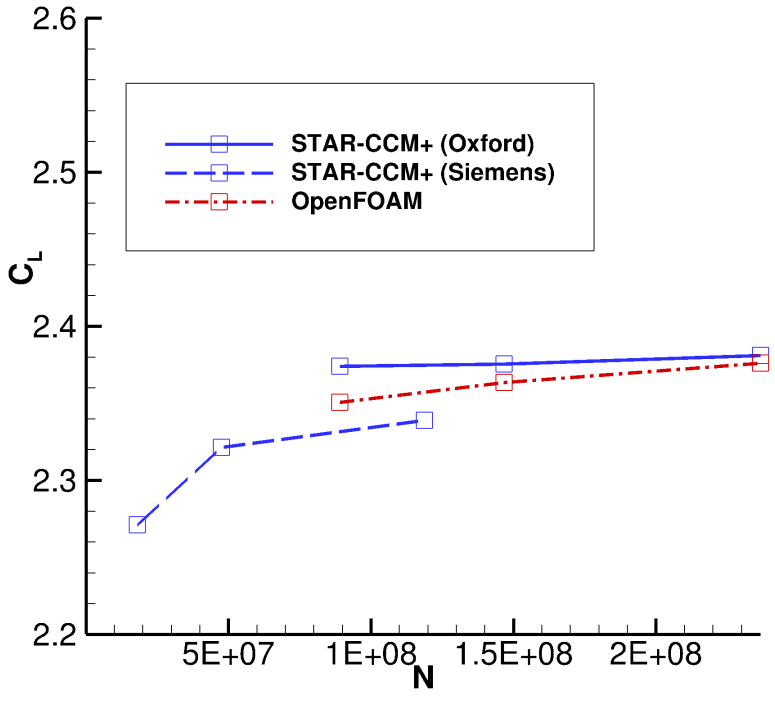
HL-CRM

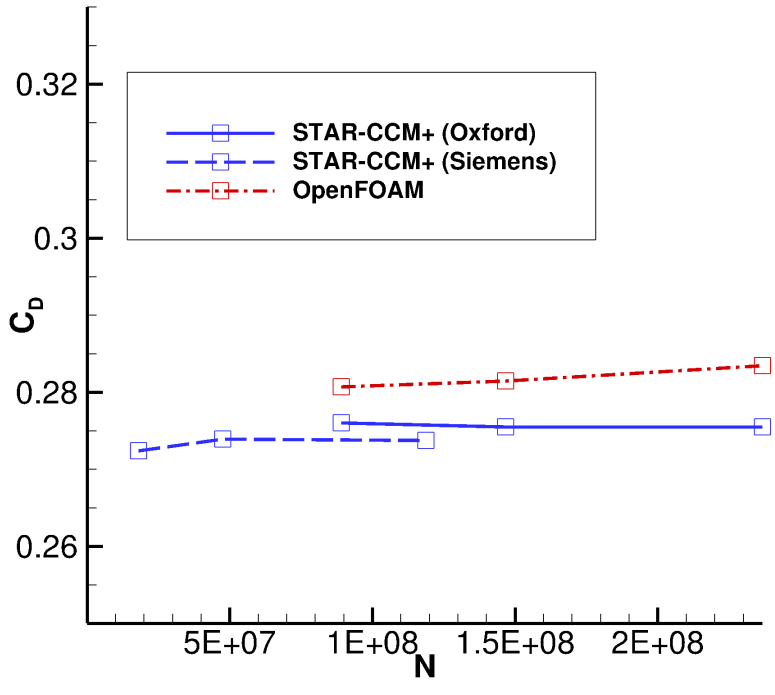
- All results within the pack but highlights the clear influence of the grid even within the same code



HL-CRM - 16

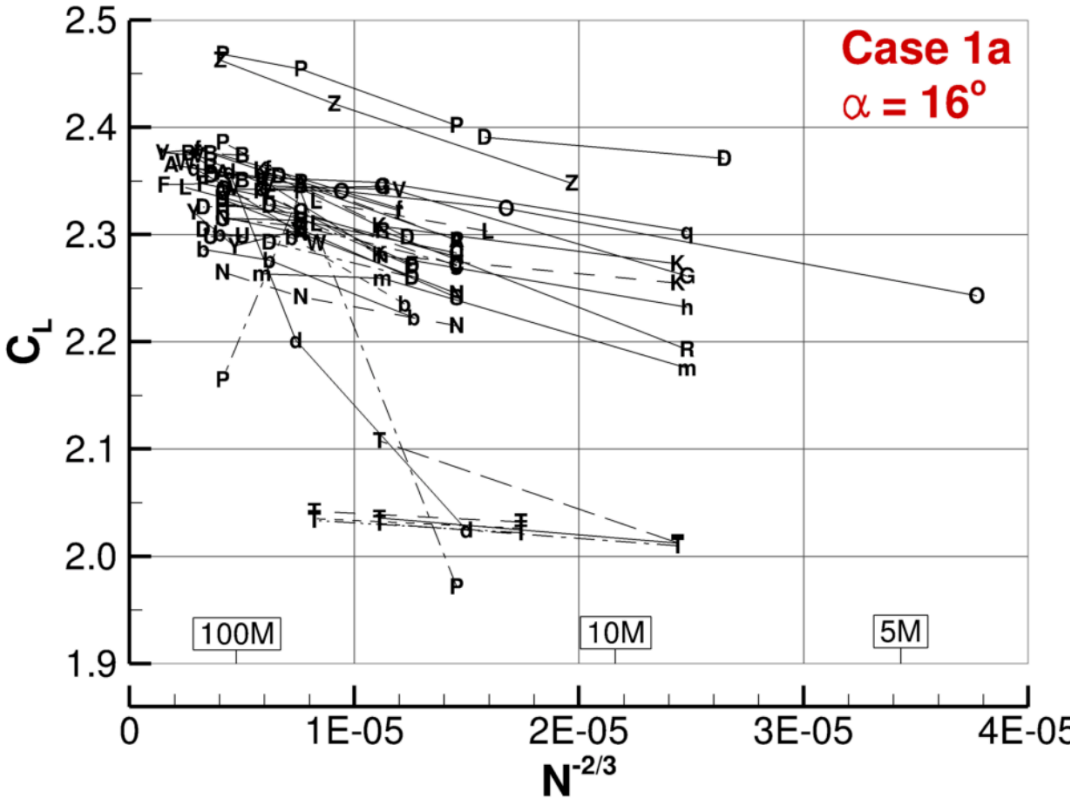
- Not reached mesh convergence by finest grid (236 million cells)
- Again OpenFOAM/STAR-CCM+ (Oxford) show very similar results – same mesh only way to make conclusions
- Similar differences between STAR-CCM+ Oxford and Siemens but finer grid needed





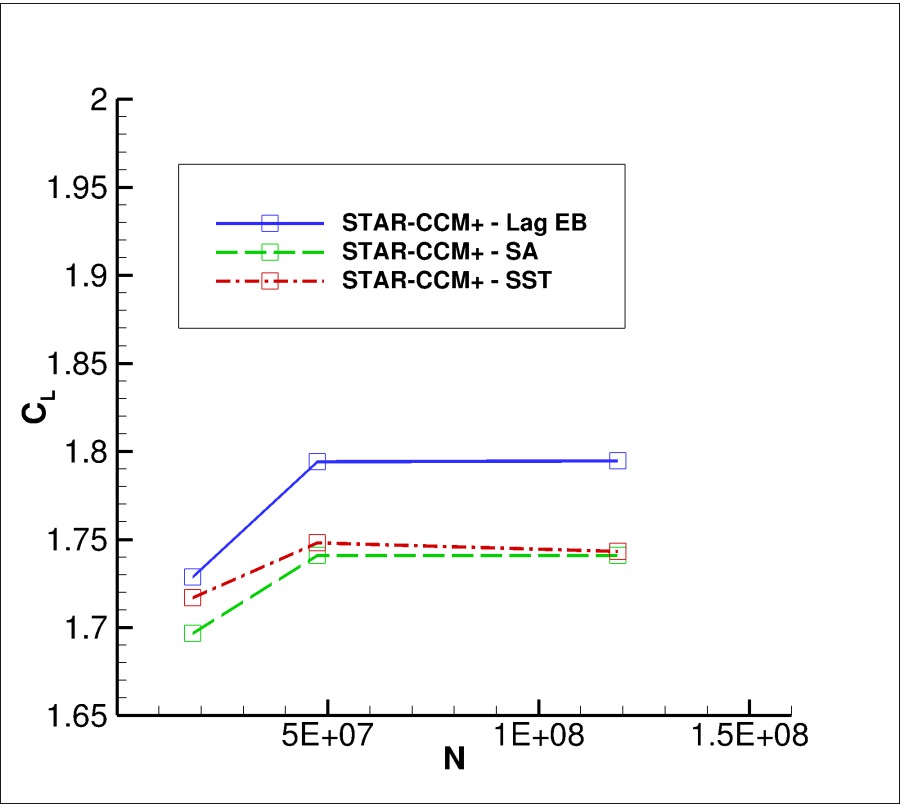
HL-CRM

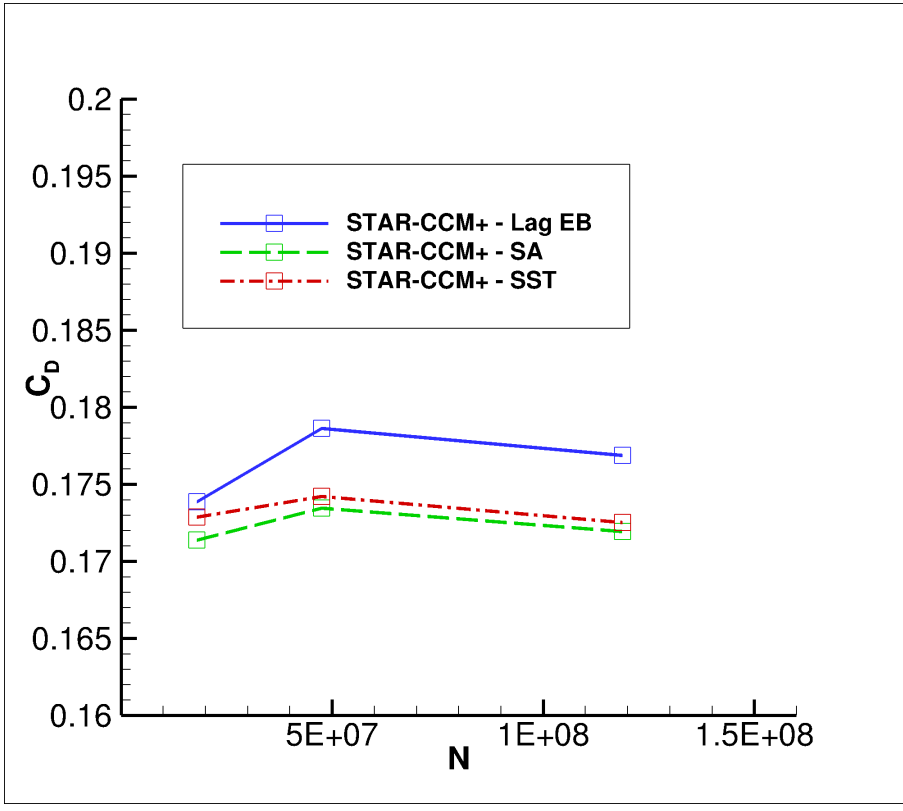
- Again good agreement with other codes – within the pack



HL-CRM - 8

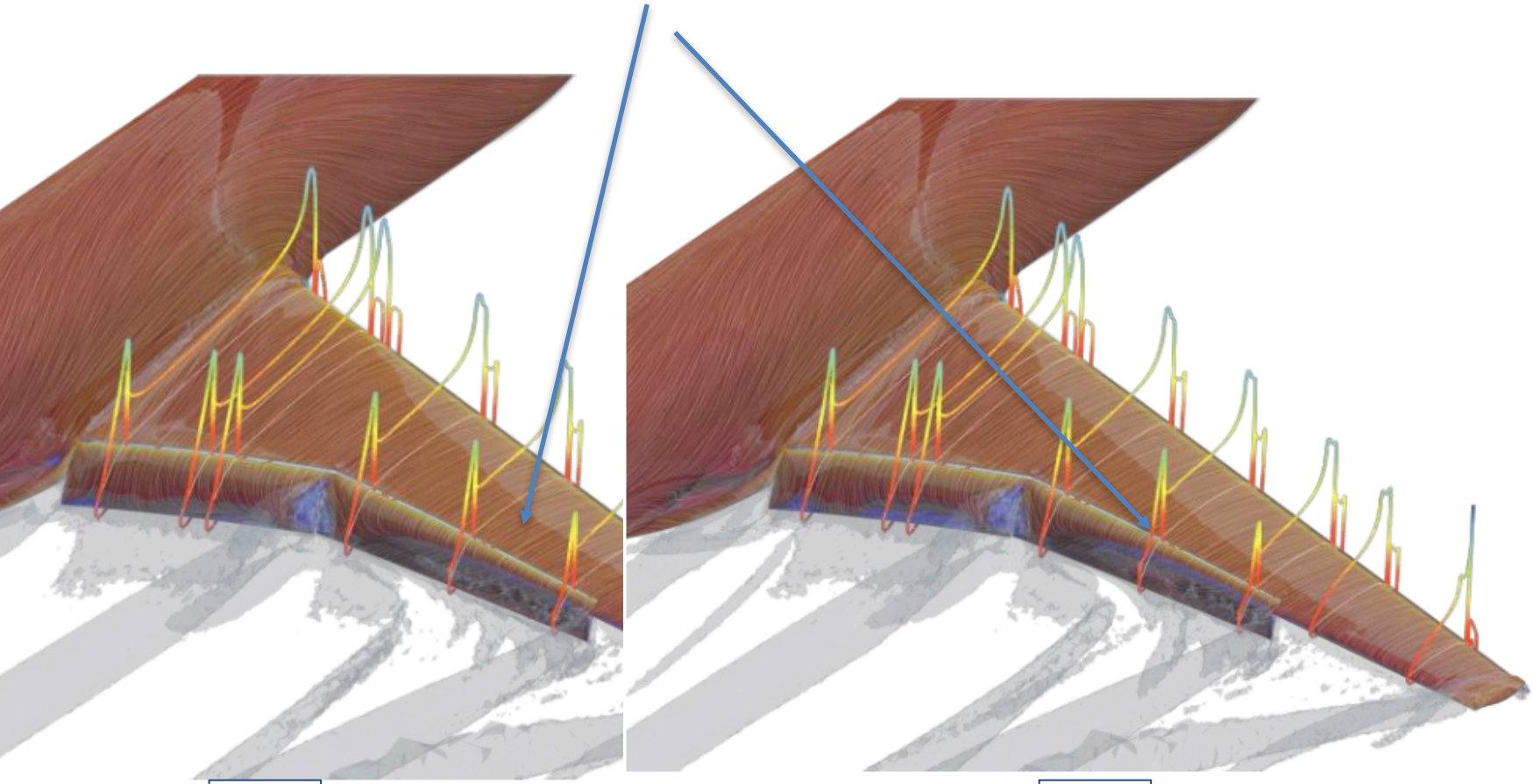
- All turbulence models follow the same trend for grid convergence. Given that this is a blind test, not possible to say which one is more accurate





HL-CRM – 8 - Siemens

- SA and SST models predicted the same outboard flat separation
- Lag EB predicts less outboard stall which gives higher lift (and likely more lift-induced drag)



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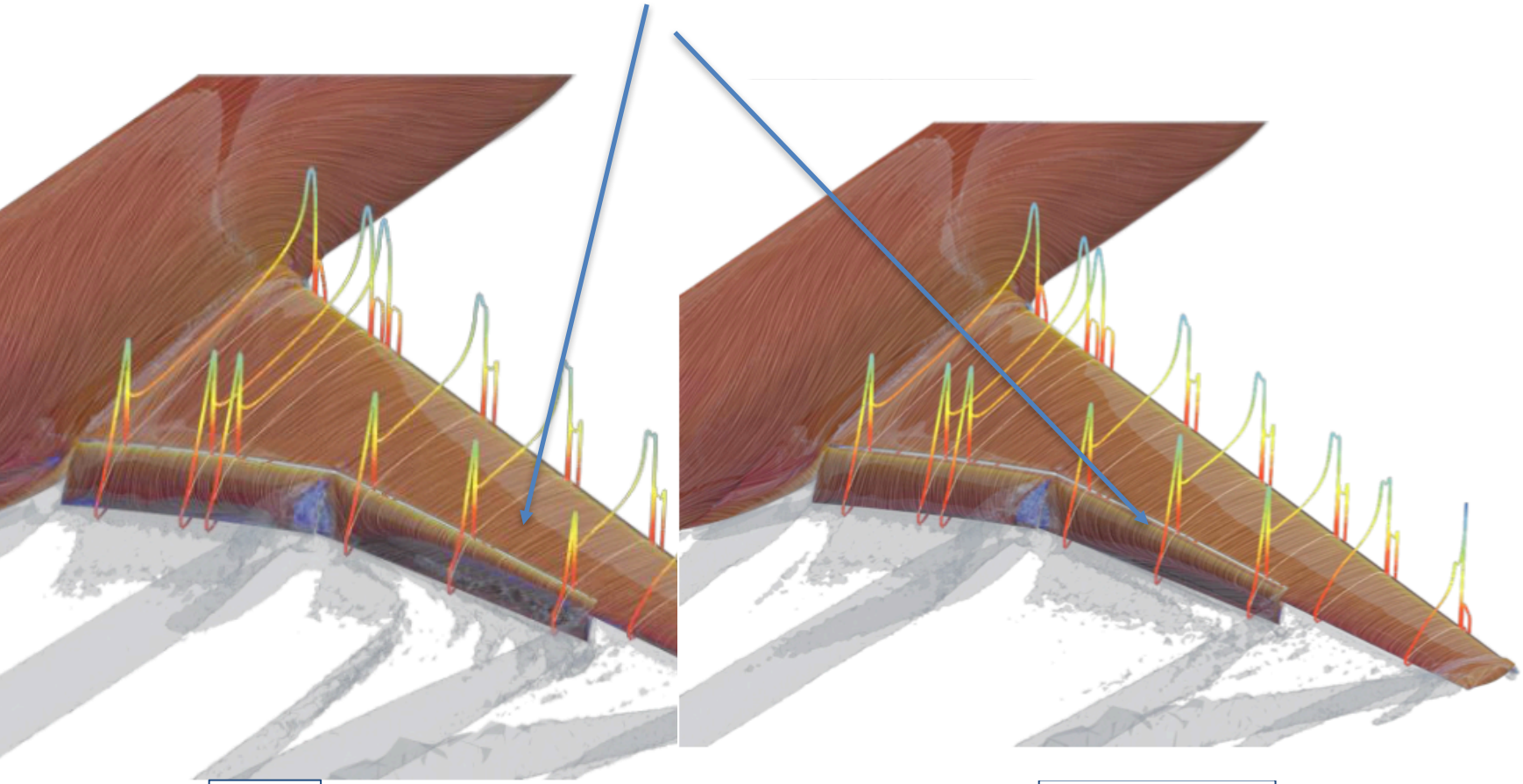
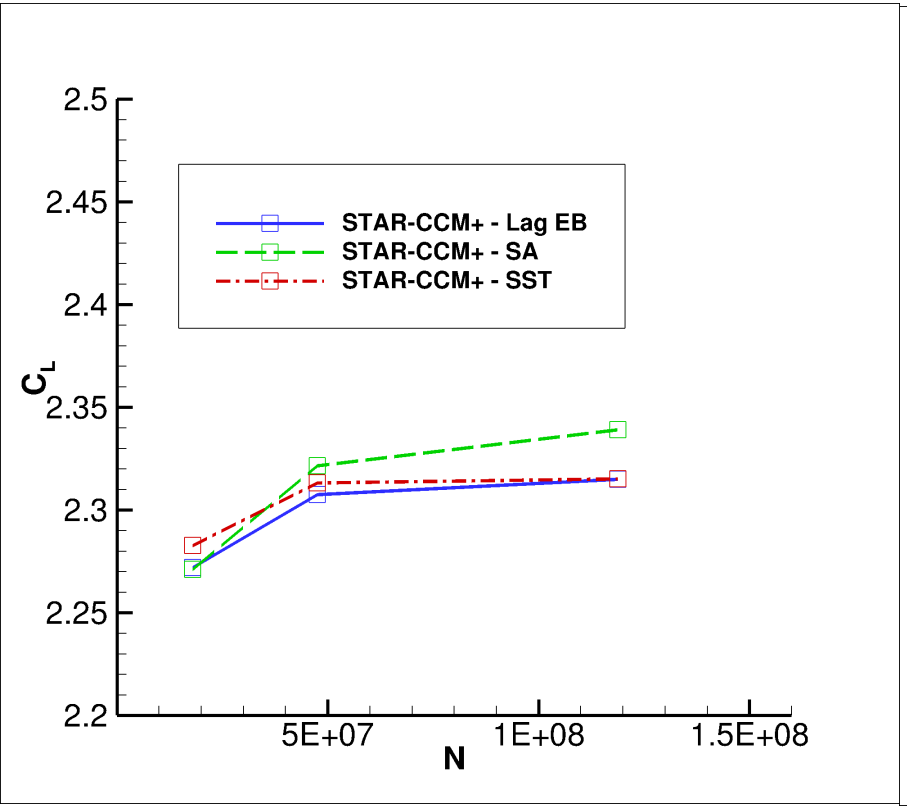


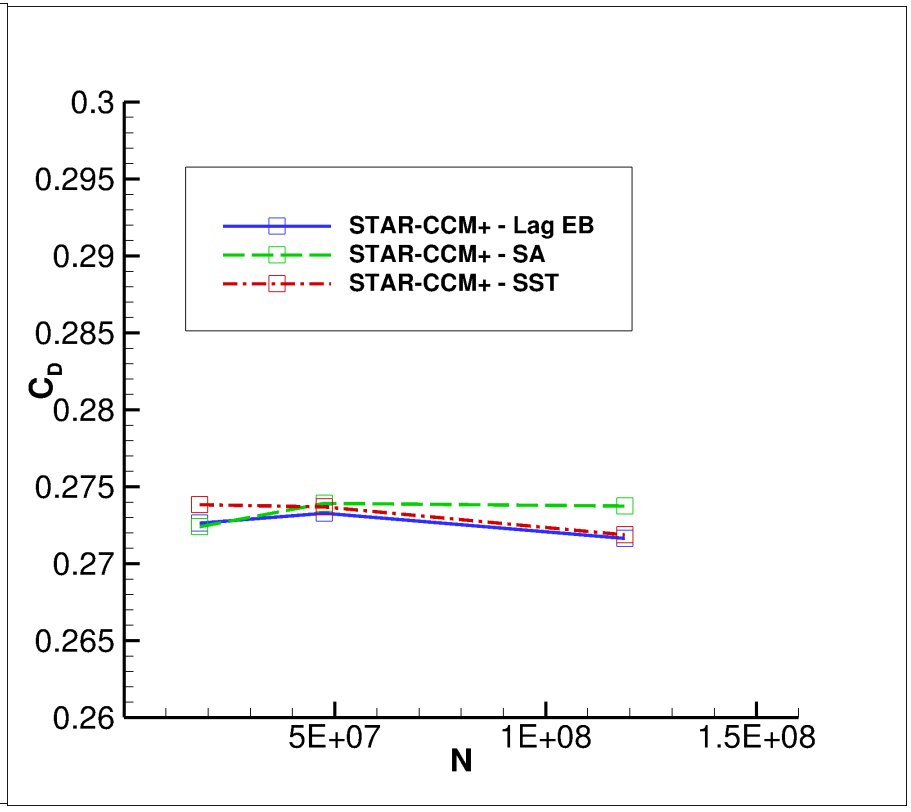
SA

Lag EB

HL-CRM - 16

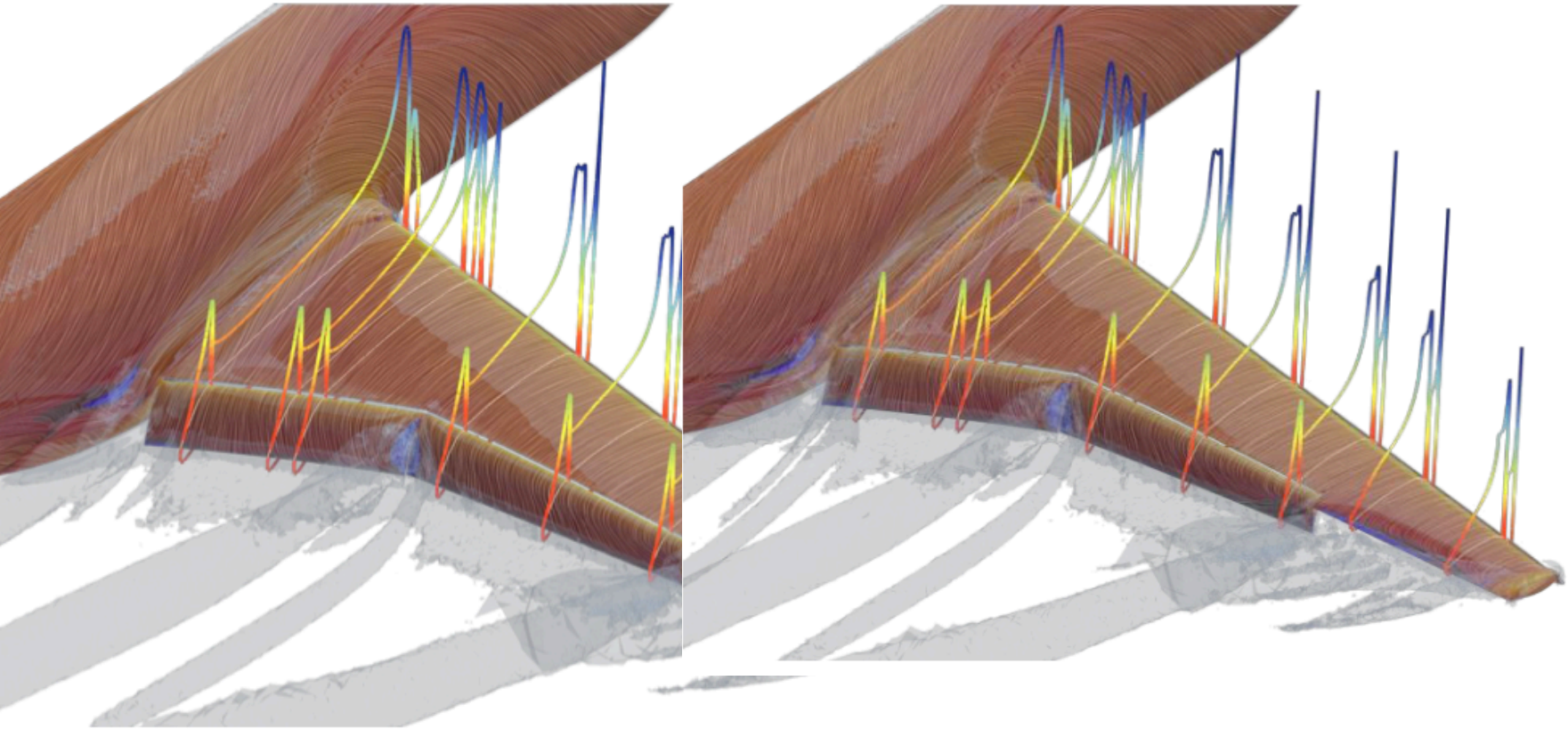
- Differences reduce by 16 AoA, again useful information for when





HL-CRM – 16 – Siemens

- At the higher angle of attack all agree well, although less outboard separation than Oxford results (shown later)
- Exp data would be useful here



SA

SST

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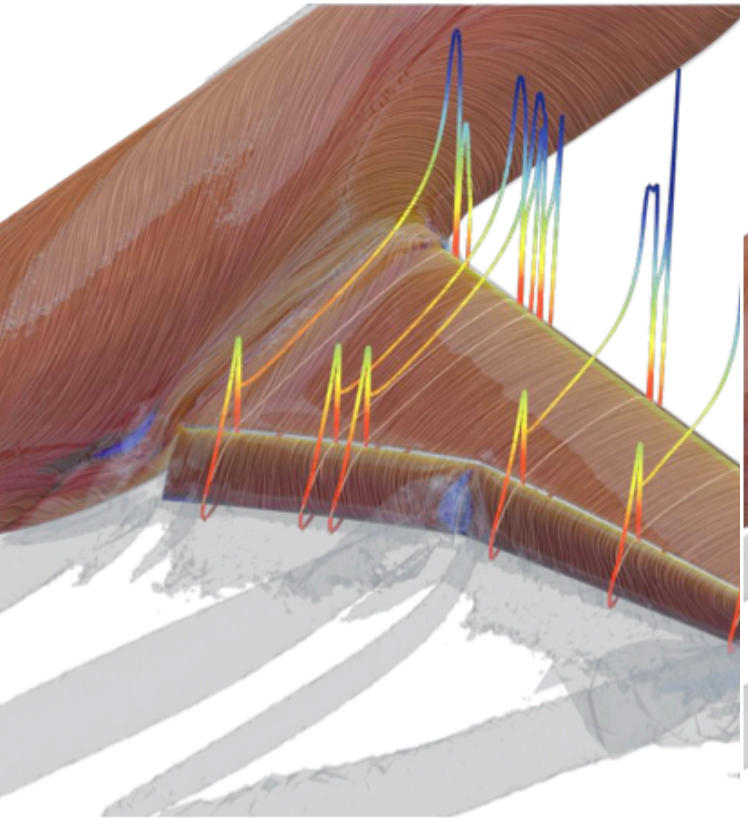
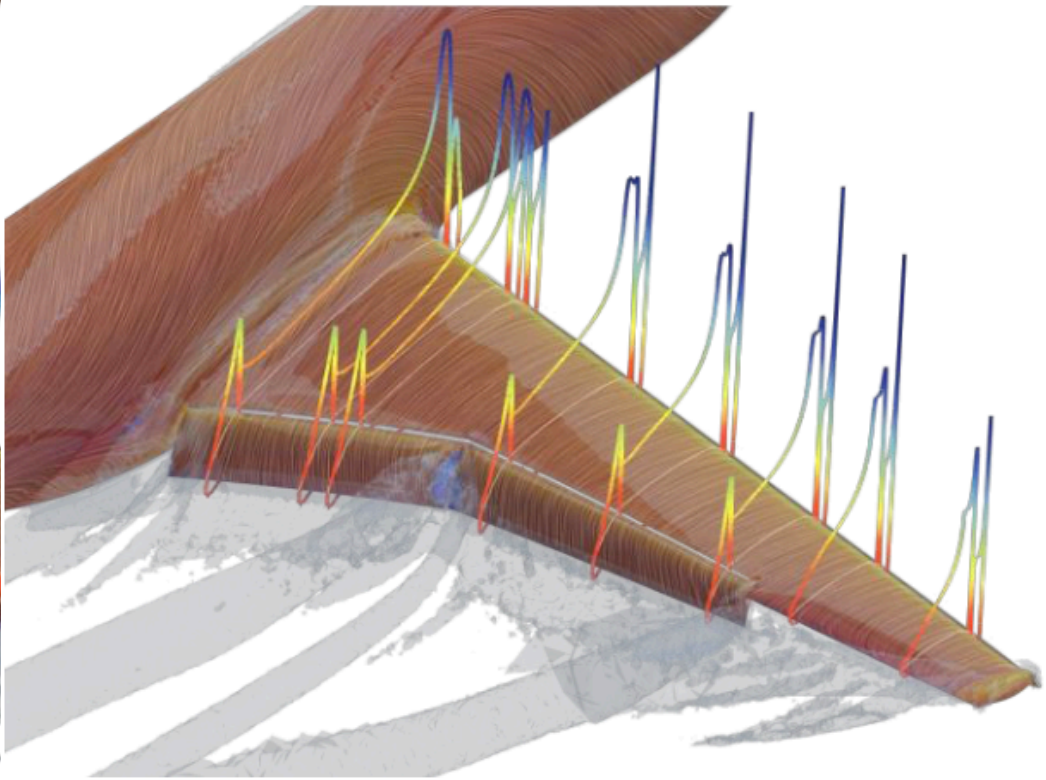
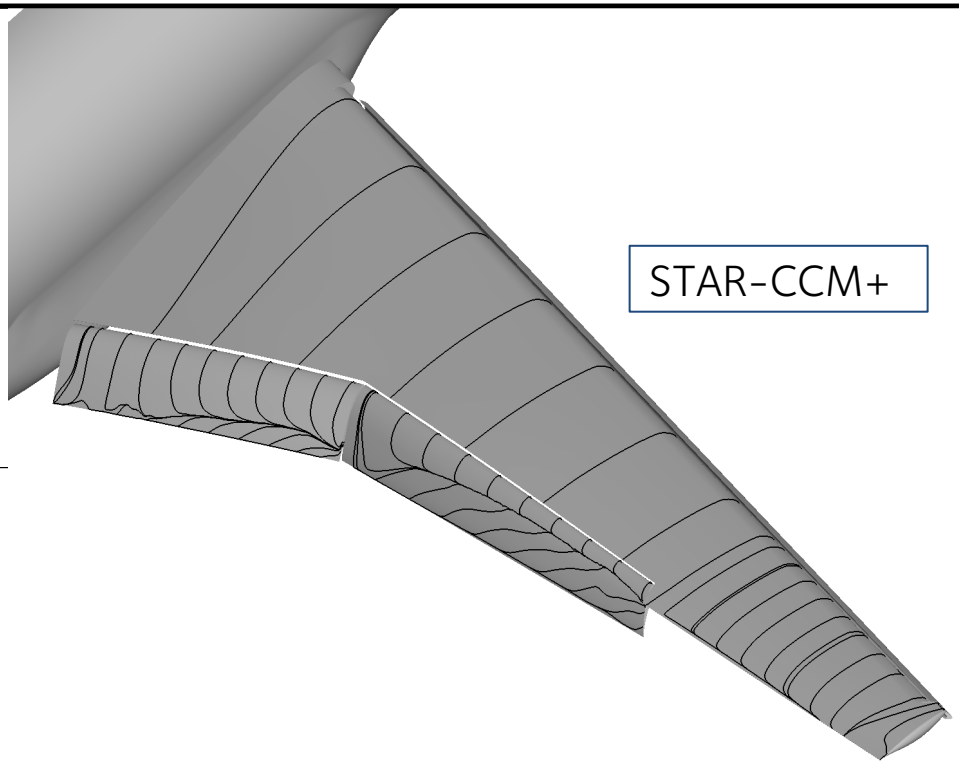


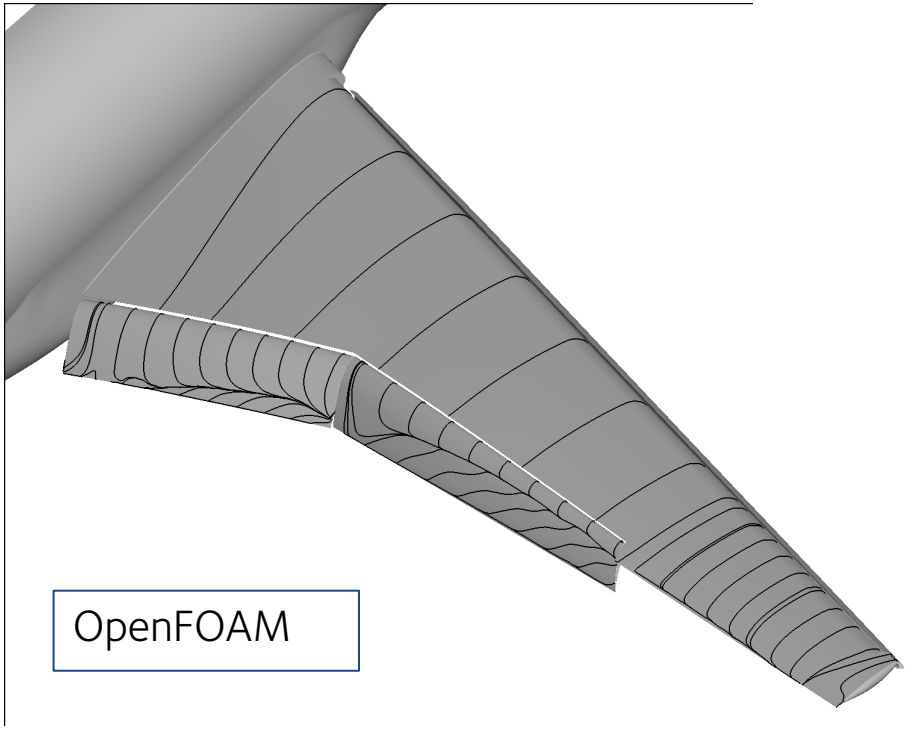
SA



Lag EB

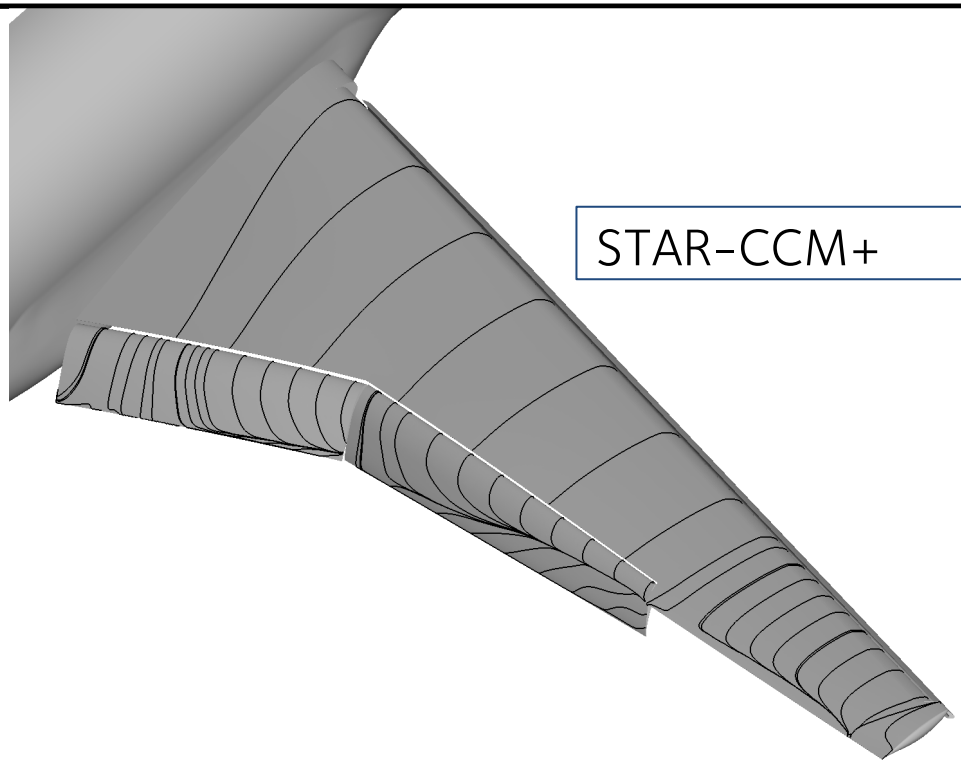
HL-CRM 8°

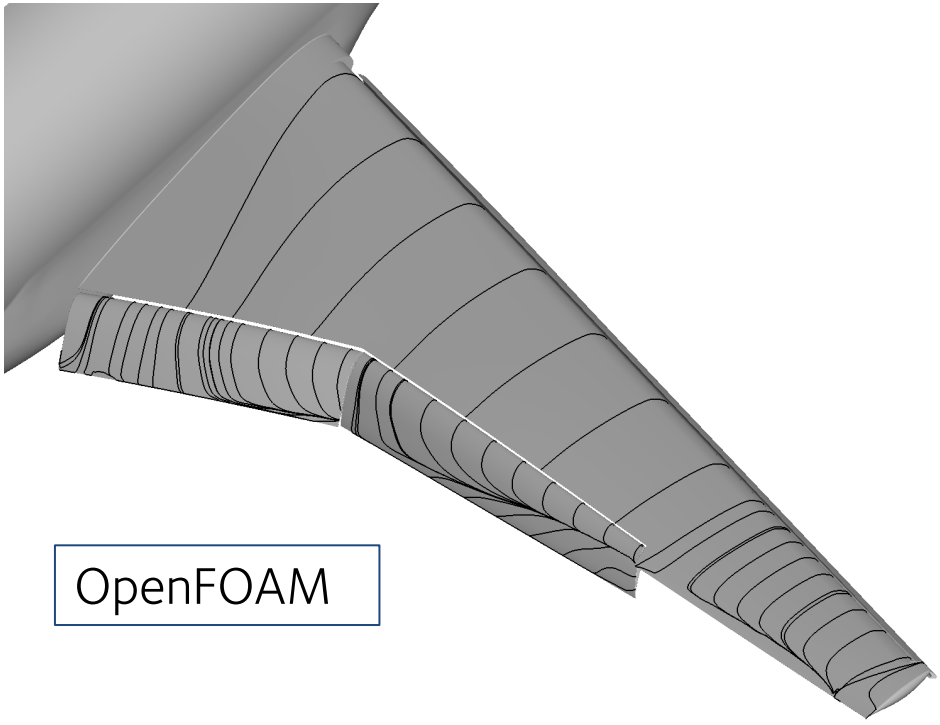




- Inboard & Outboard flap separation is very similar between the codes

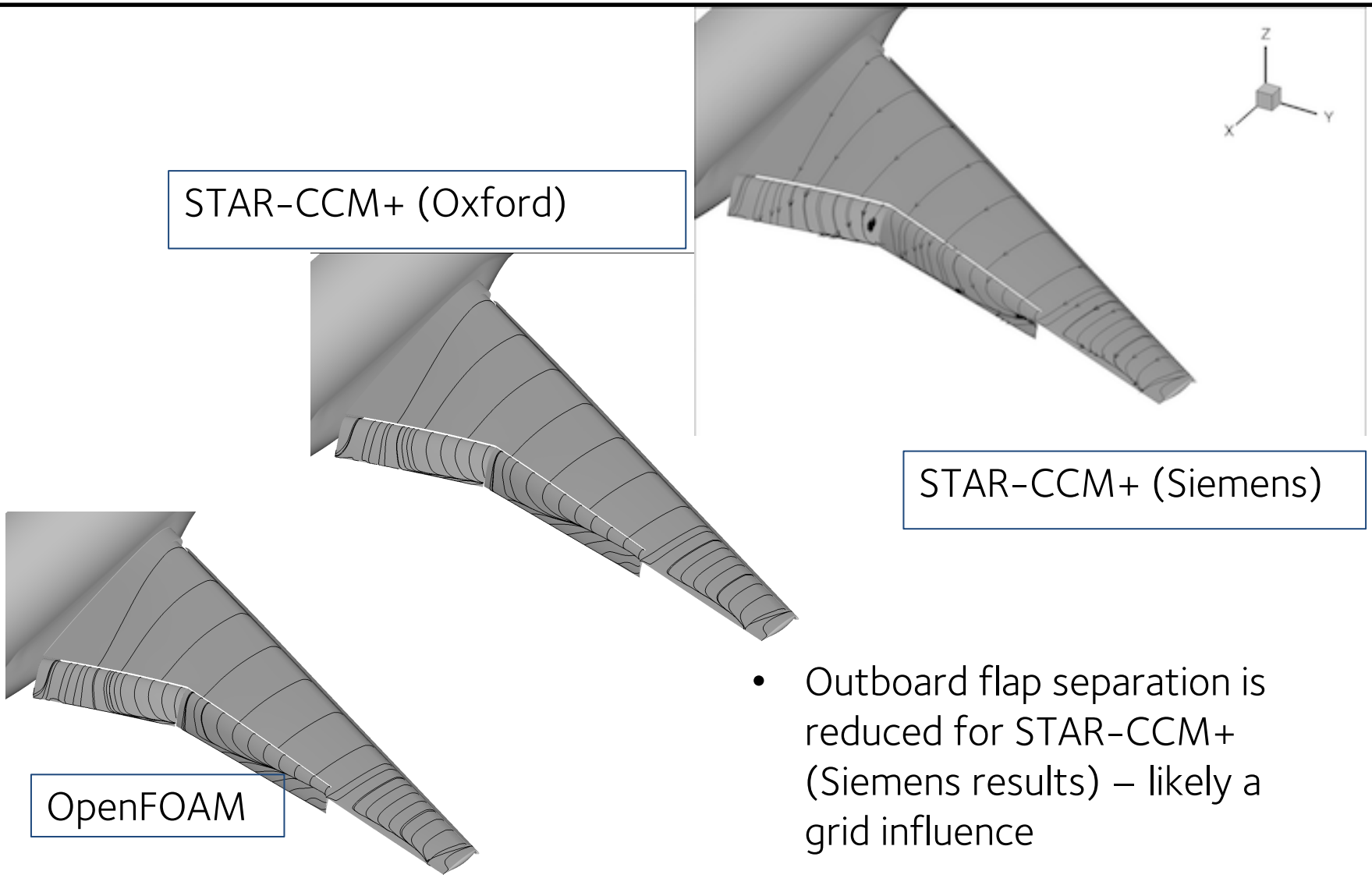
HL-CRM 16°





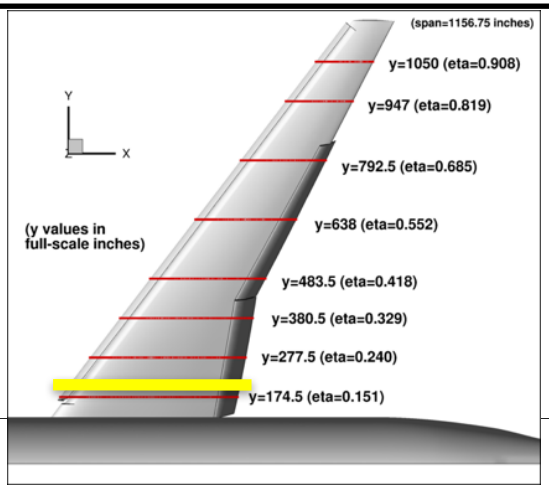
- Outboard flap separation only – very similar between codes

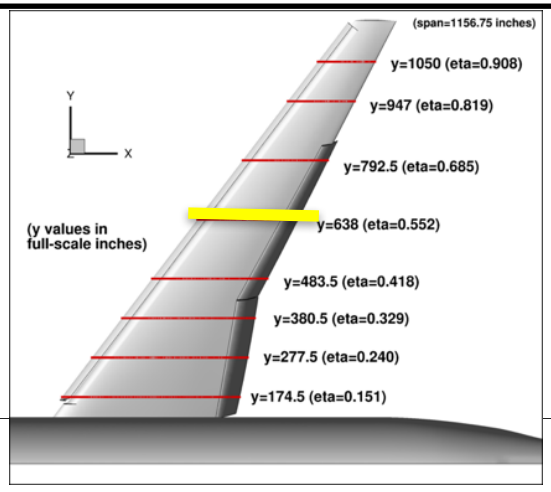
HL-CRM 16°

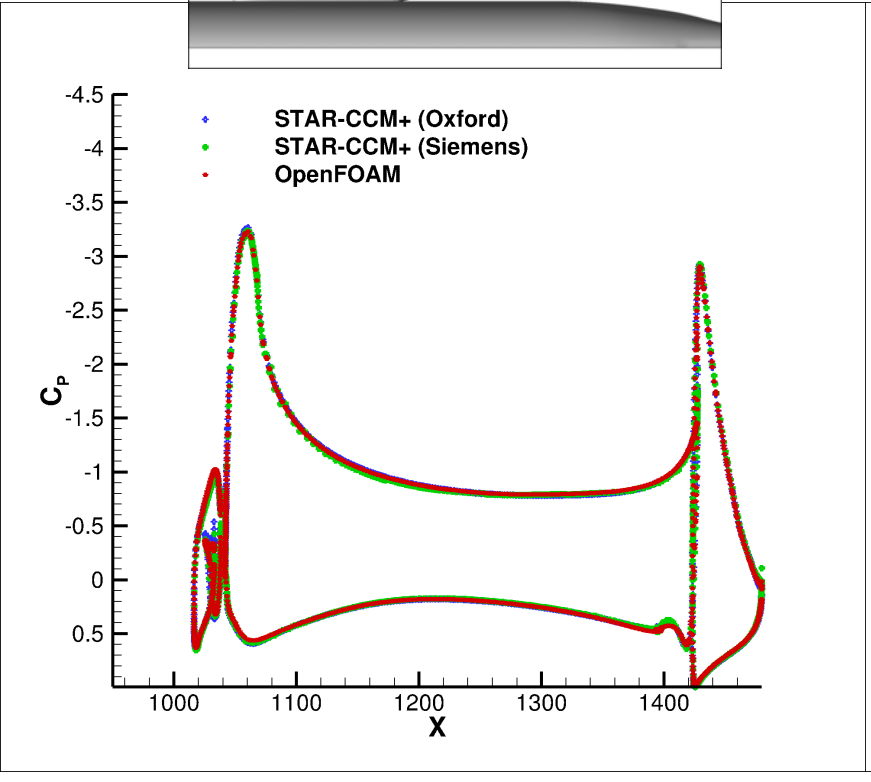


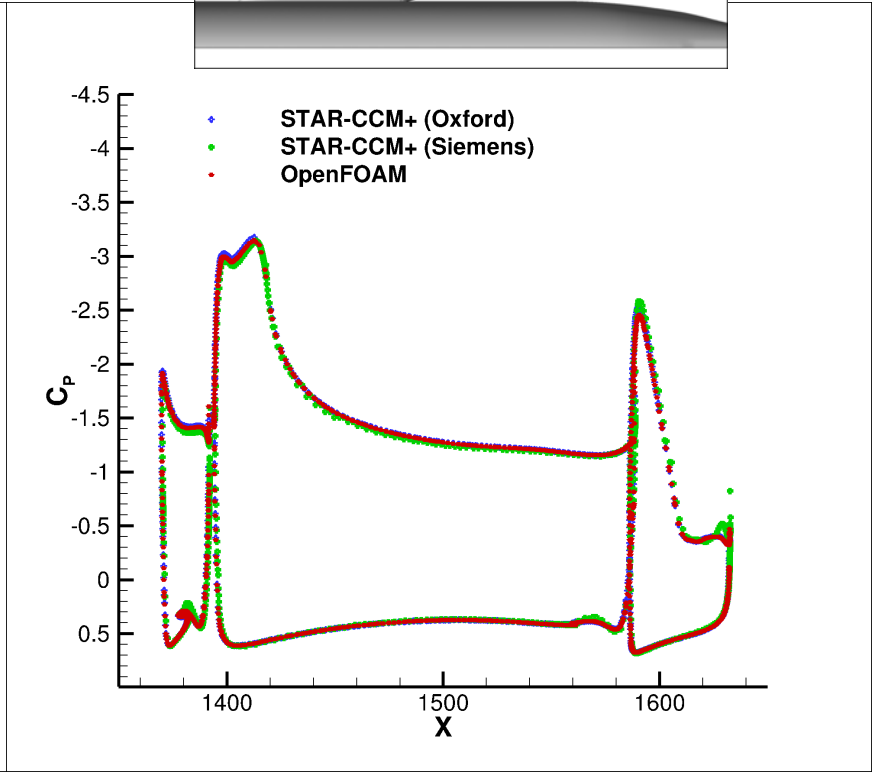
- Outboard flap separation is reduced for STAR-CCM+ (Siemens results) – likely a grid influence

HL-CRM 8° – ETA 151,552

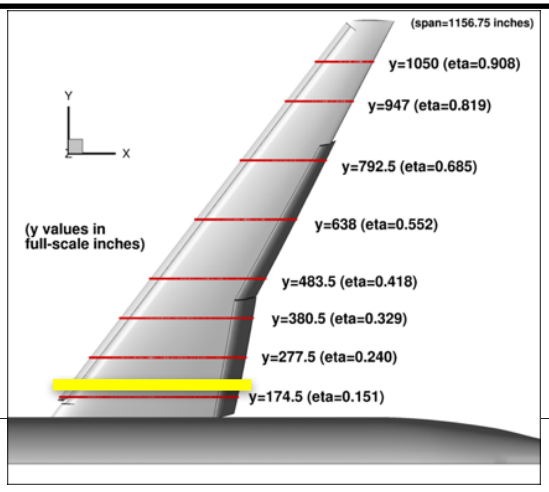


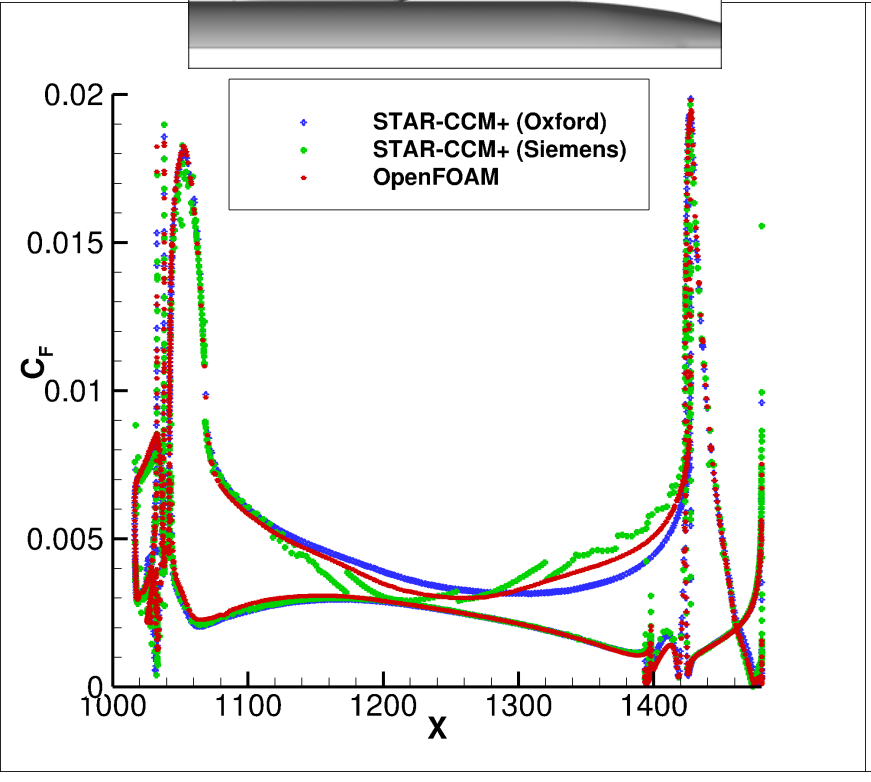


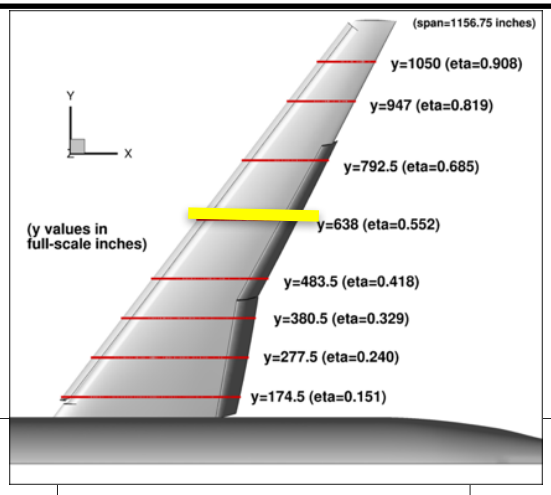


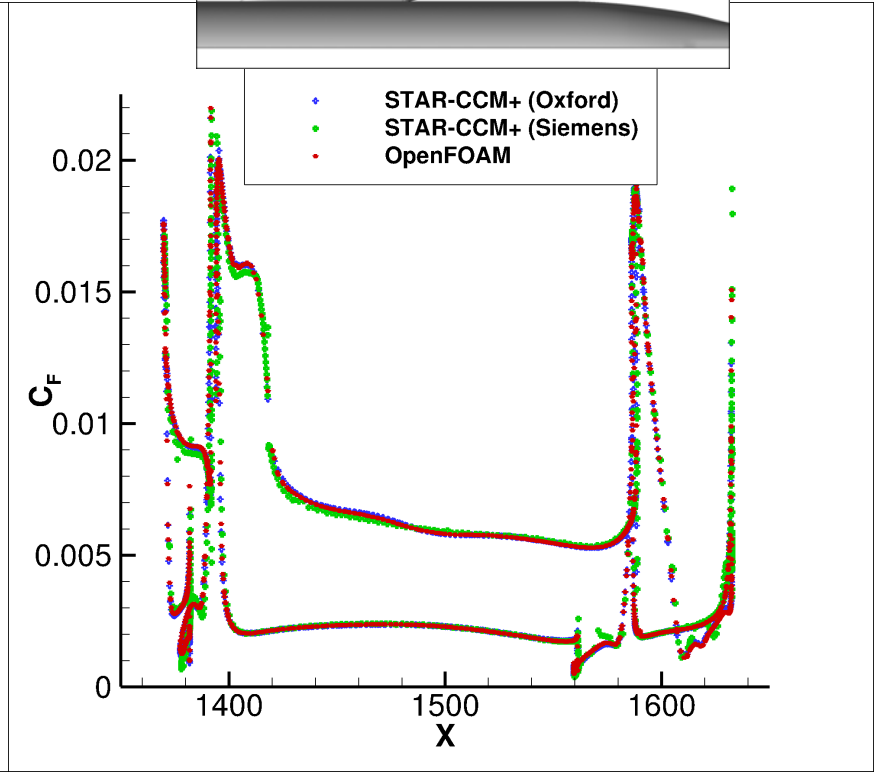


HL-CRM 8° – ETA 151,552 – C_F

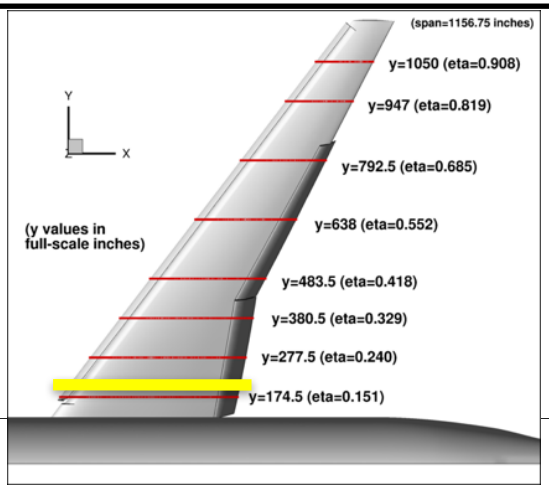


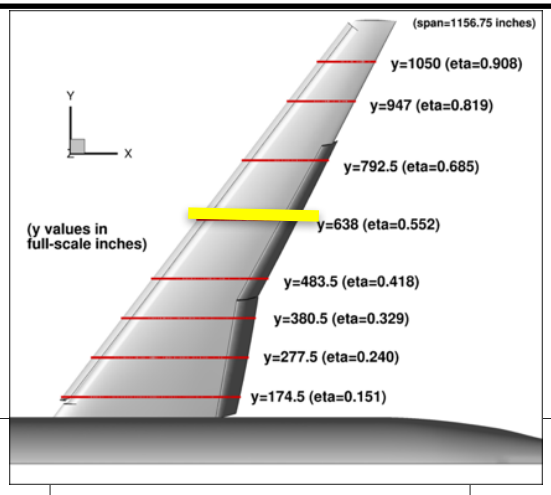


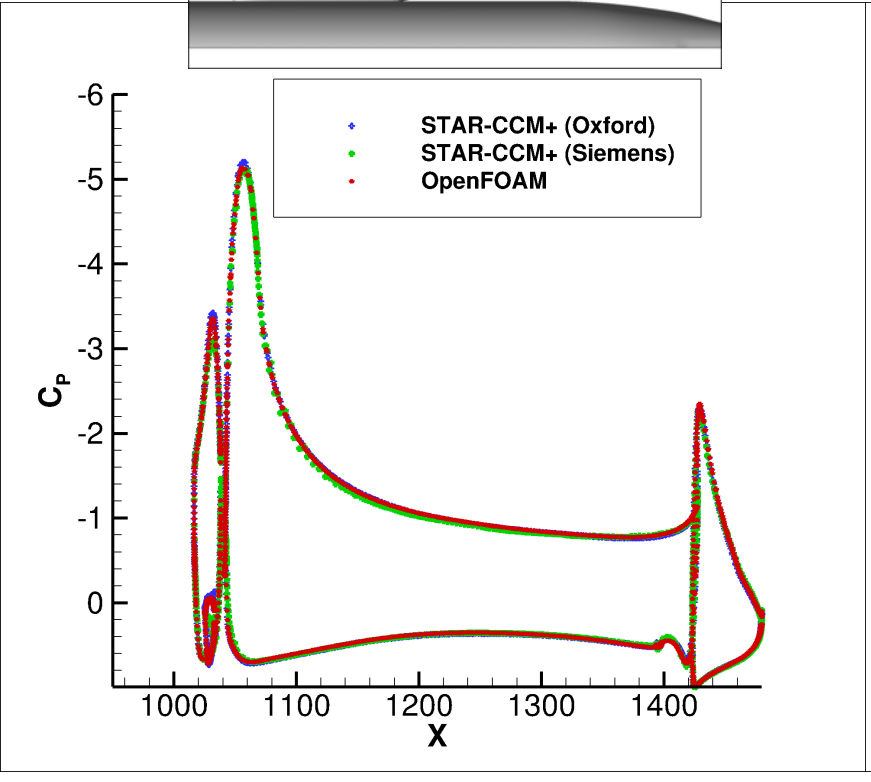


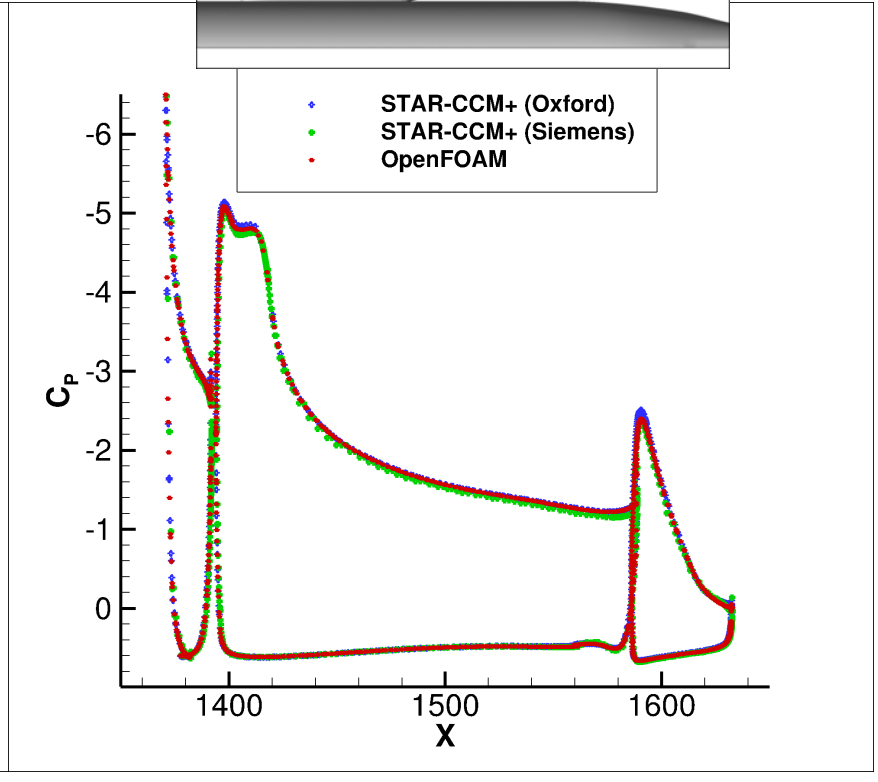


HL-CRM 16° – ETA 151,552

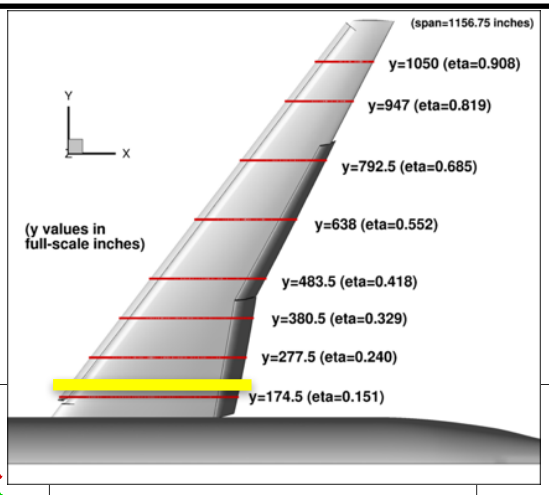


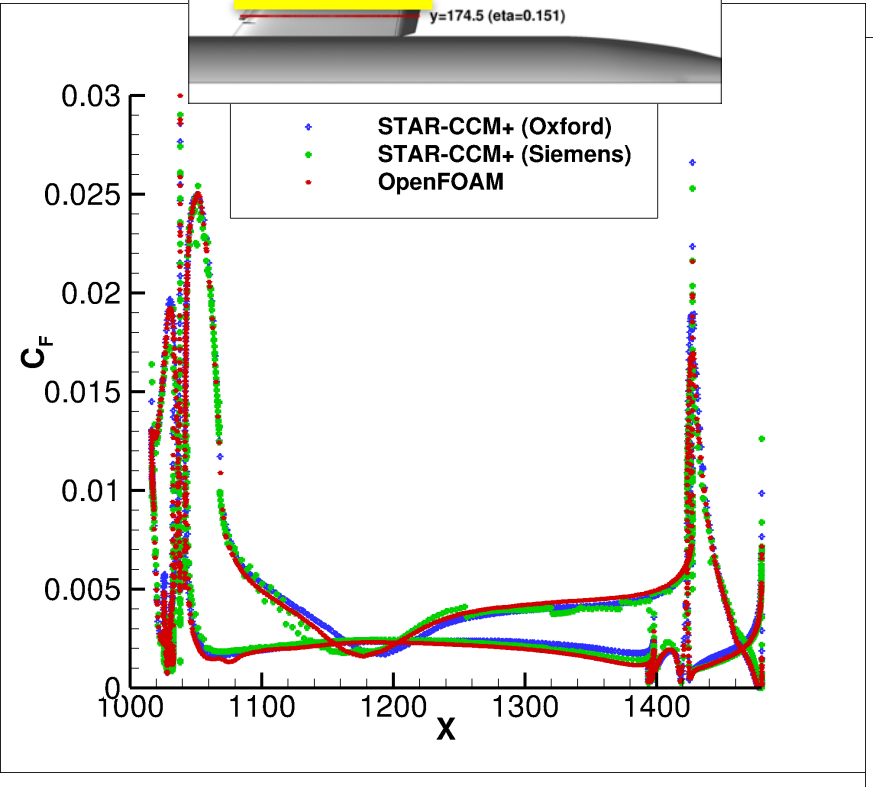


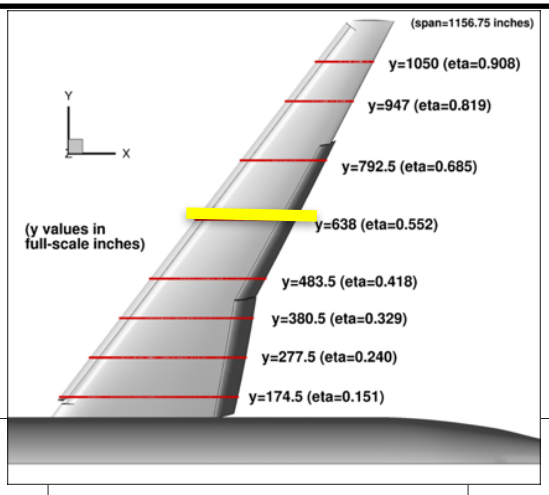


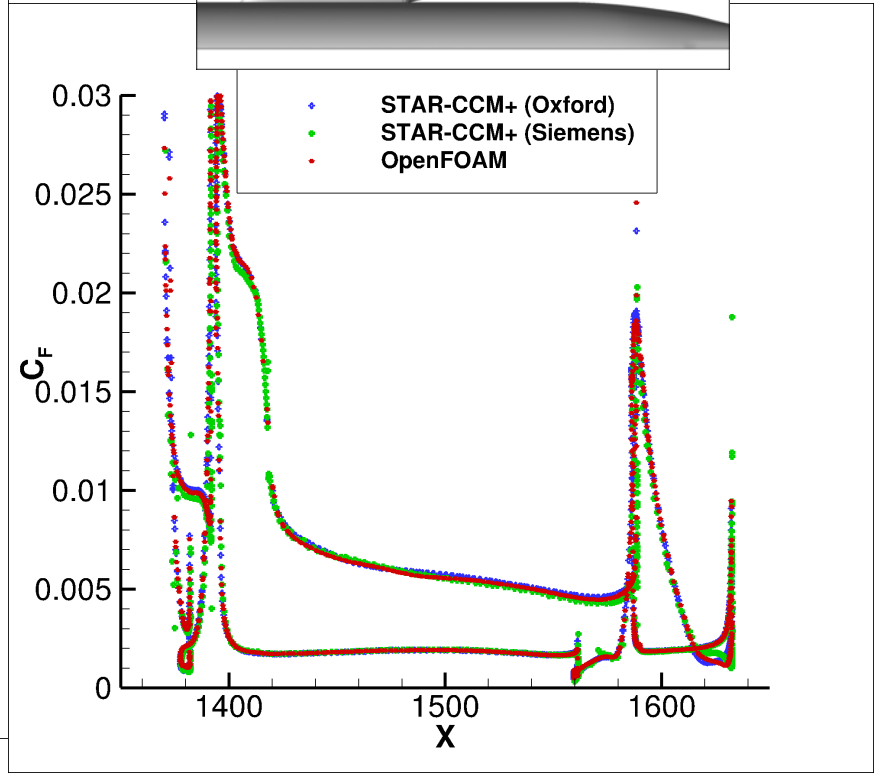


HL-CRM 16° – ETA 151,552 – C_F



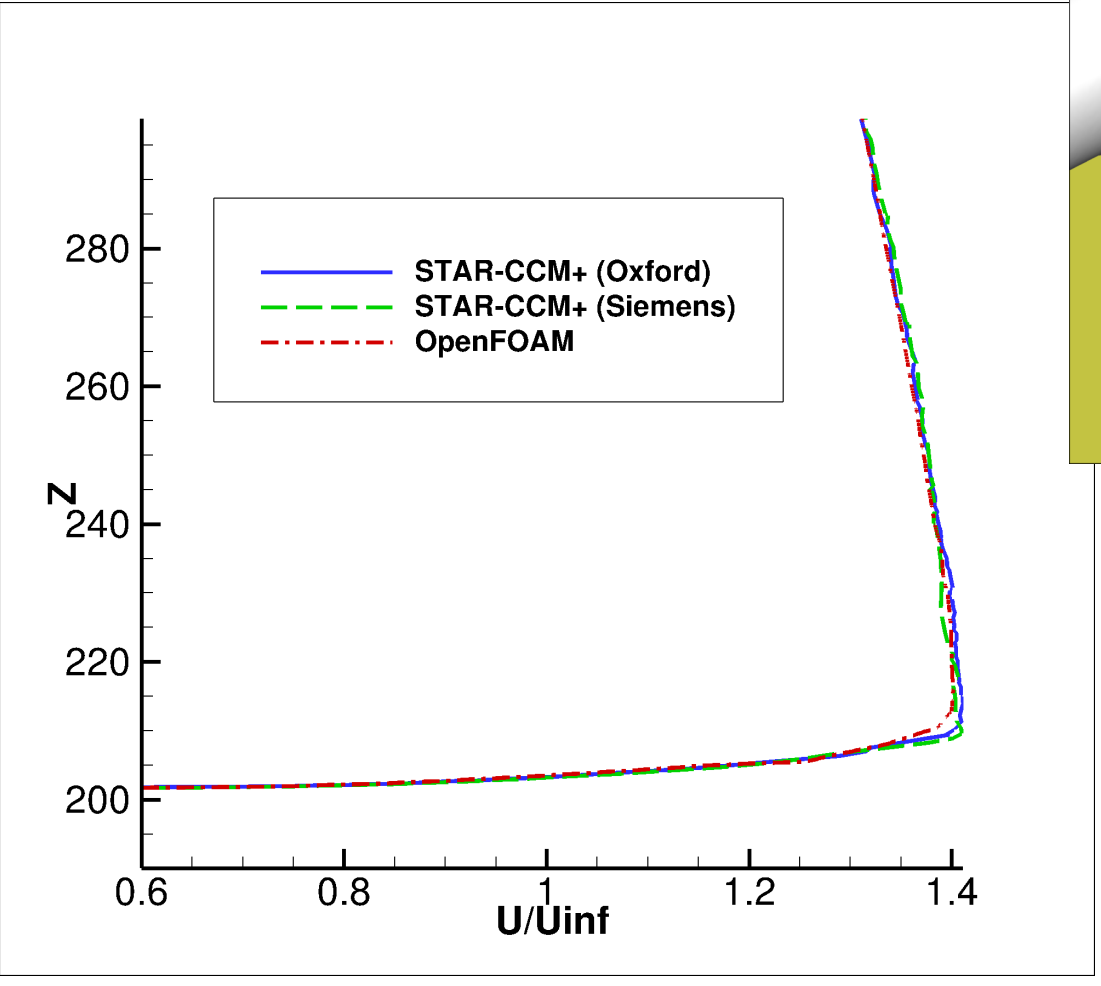


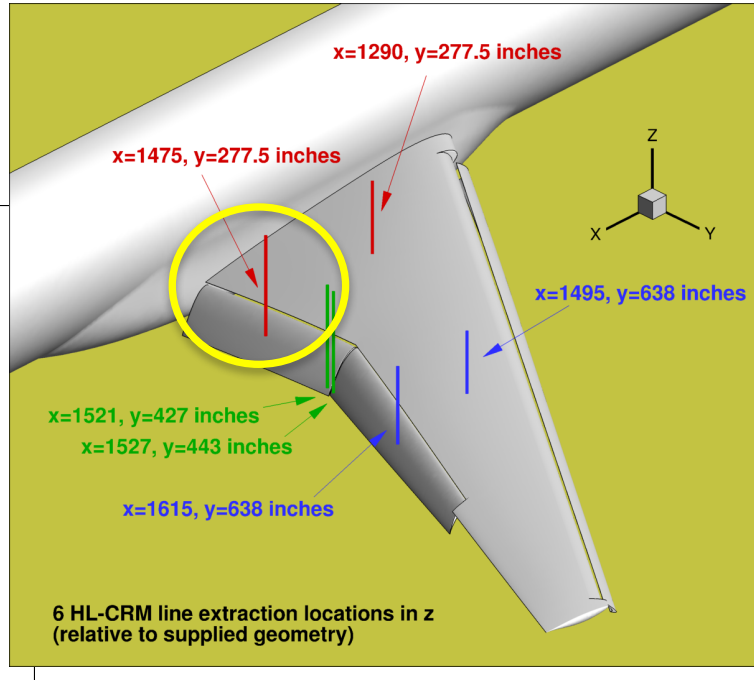




HL-CRM 16° – Velocity profiles

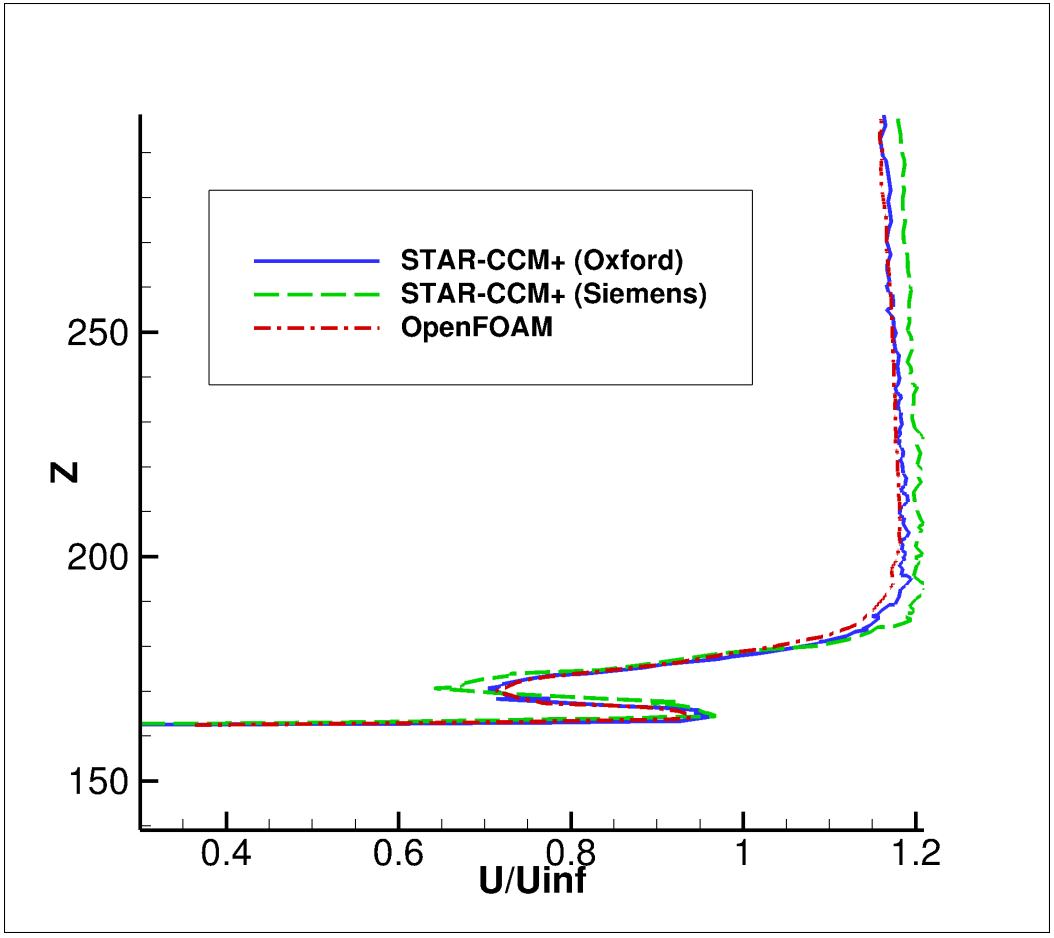
- Inboard off body is similar between codes

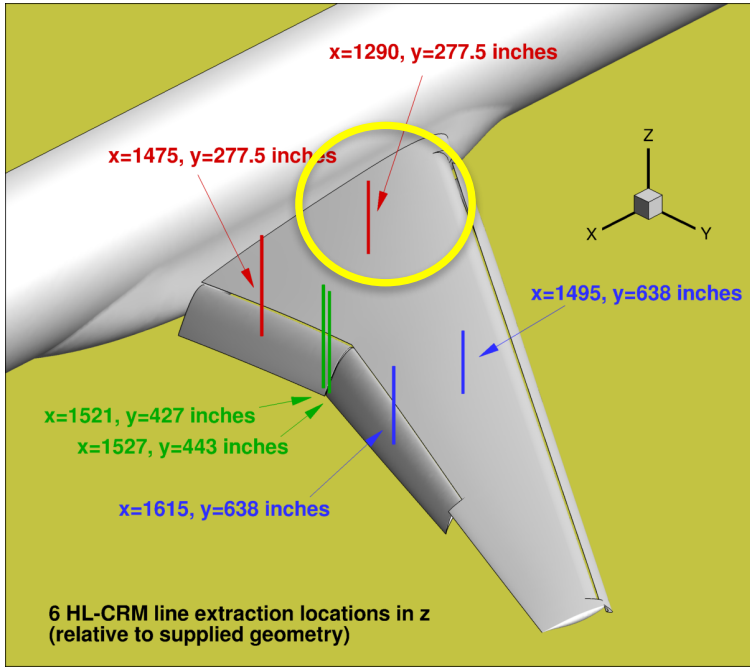




HL-CRM 16° – Velocity profiles

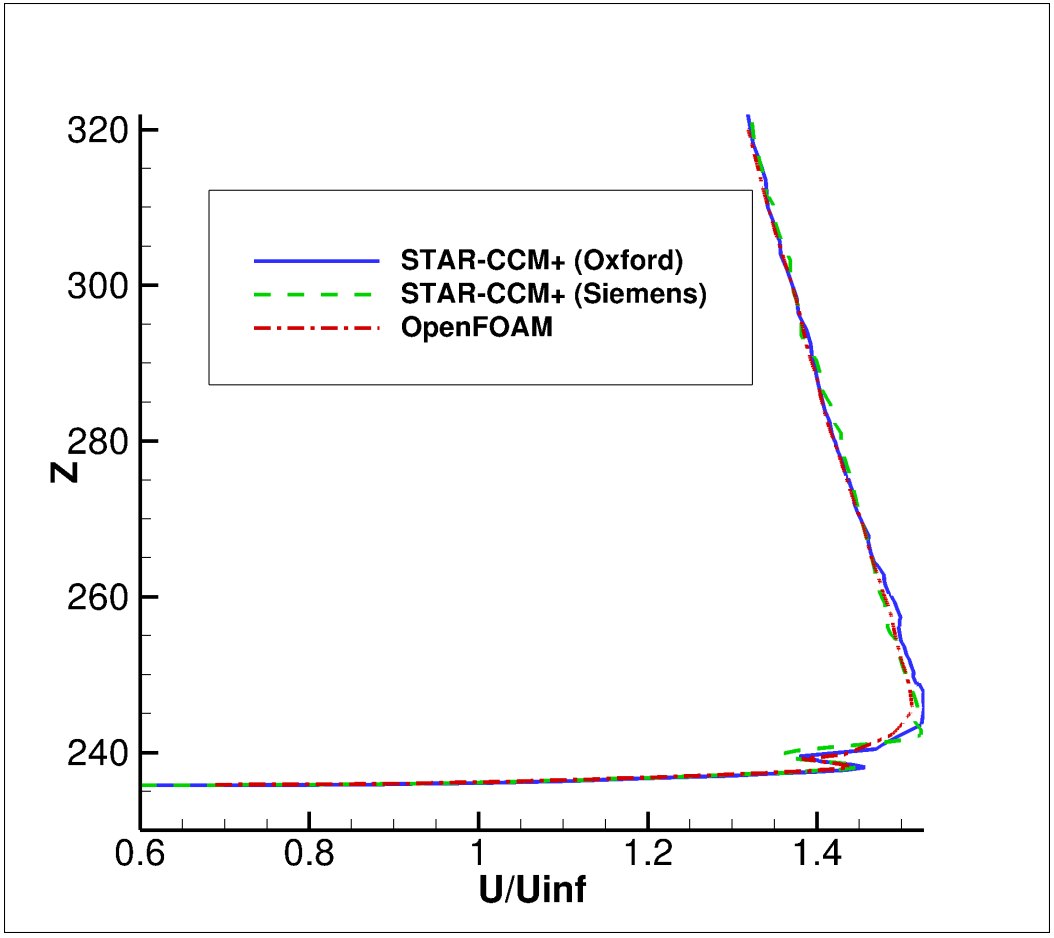
- Slight differences between approaches – will be useful when we have this exp. data

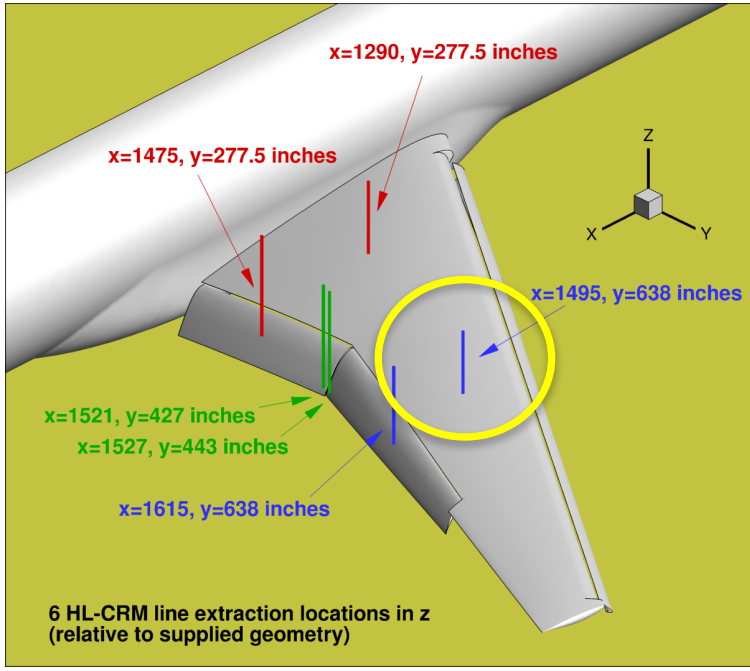




HL-CRM 16° – Velocity profiles

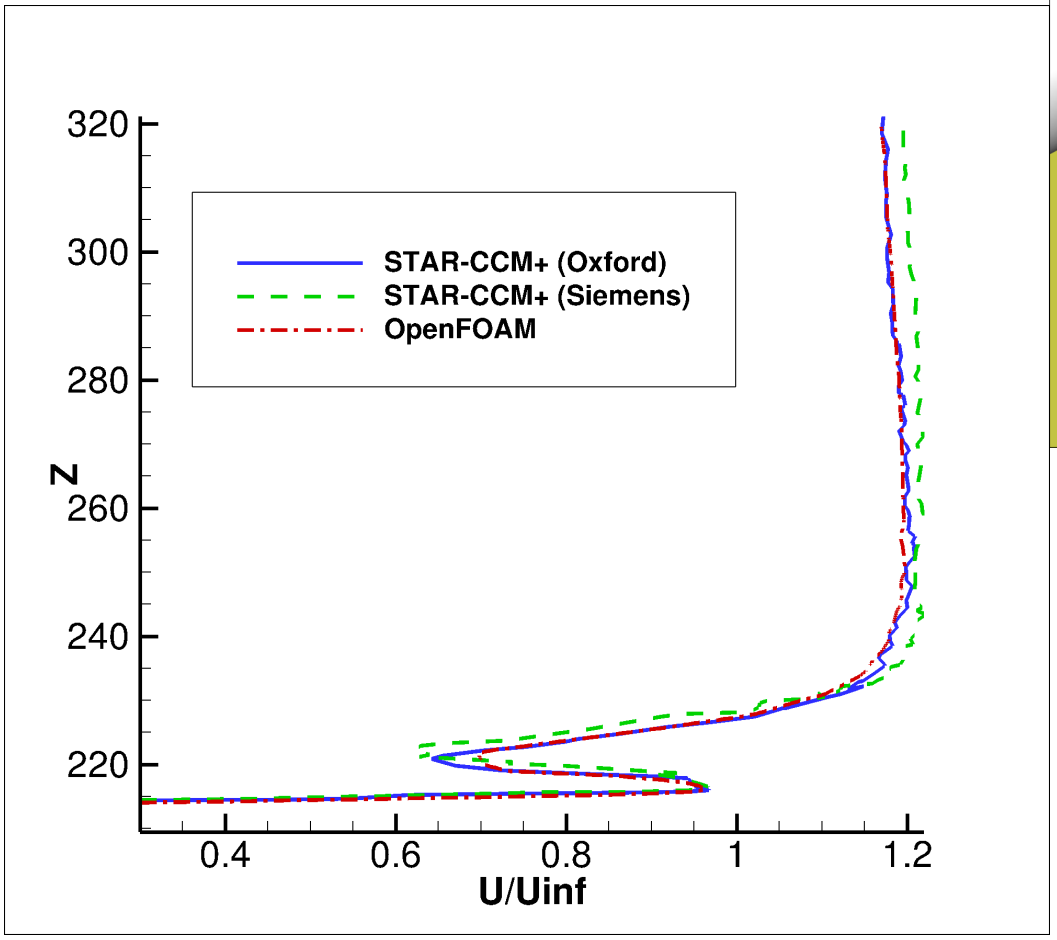
- Pretty close agreement

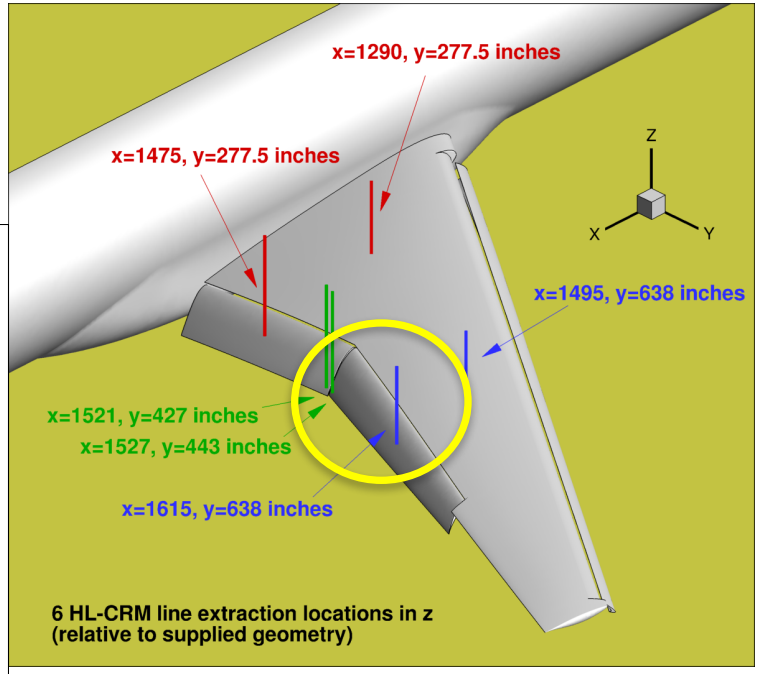




HL-CRM 16° – Velocity profiles

- More differences – illustrated in surface streamlines





HL-CRM conclusions

UNIVERSITY OF OXFORD

- < 0.5% difference between STAR-CCM+ (Oxford) and OpenFOAM on Lift, ~1-2% different in Drag – As controlled as possible with same grid and turb model
- Visually very similar flow structure and Cp distribution
- Siemens using Pointwise family show slightly lower Cl but grids were coarser and of a different design. Suspect that a finer grid would bring them closer
- Main flow physics change was outboard flap separation

- We can revisit these simulations once we have exp. data

JSM Results

JAXA JSM

- Nacelle-off cases were Siemens and Oxford, whereas all submitted results for Nacelle-on
- Experimental data is available to compare models more closely
- Caution that the flow is transitional and we're running free-air rather than tunnel
- More complex with slat-brackets

Case Parameters and Requirements

Case 2a: Nacelle/Pylon OFF (REQUESTED)

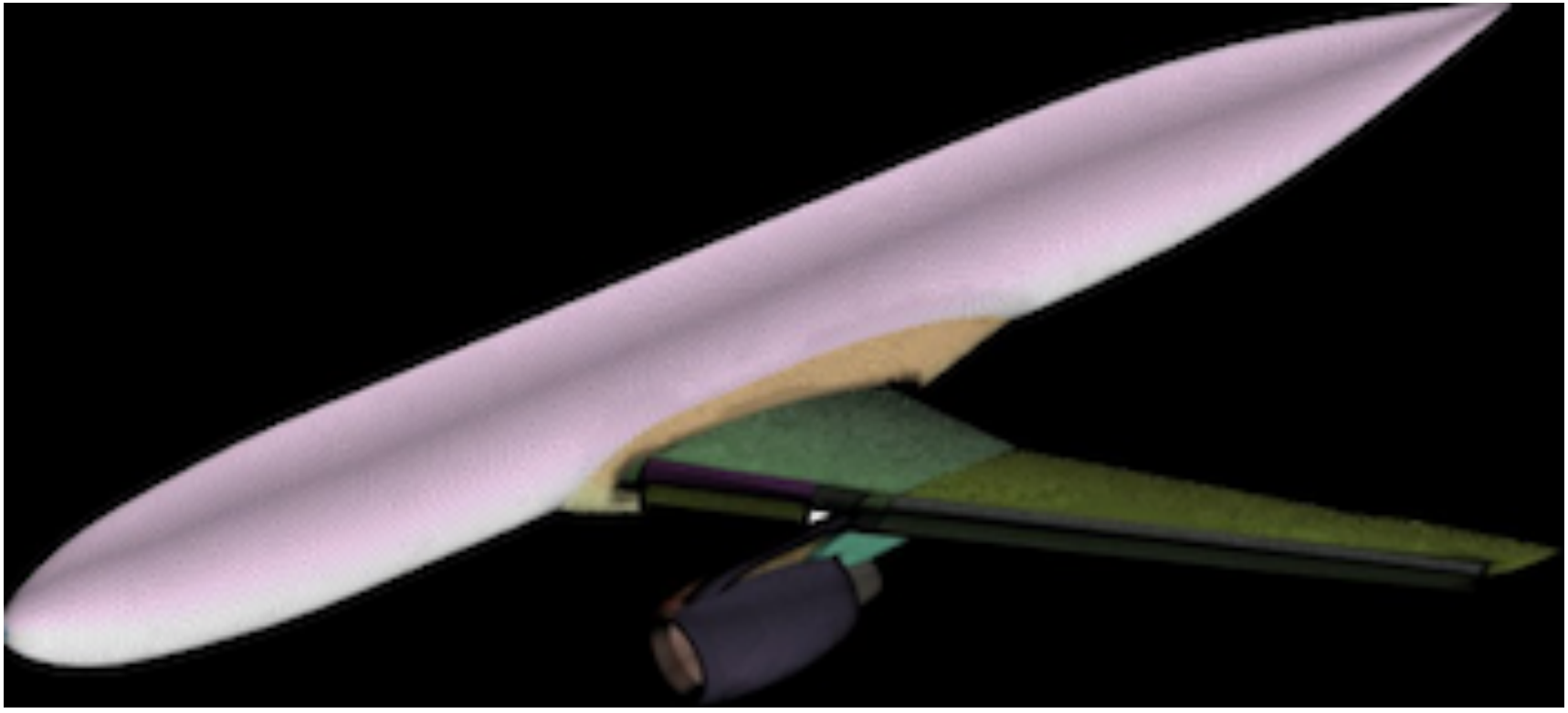
Mach Number	0.172
Alphas	4.36, 10.47, 14.54, 18.58, 20.59, and 21.57°
Reynolds Number based on MAC	1.93 million
Reference Static Temperature	551.79°R (=33.40°C=92.12°F)
Reference Static Pressure	747.70 mmHg (=14.458 PSI)
Mean Aerodynamic Chord (MAC)	529.2 mm model scale
Important Details:	• Run simulations FULLY TURBULENT and/or WITH SPECIFIED TRANSITION and/or WITH TRANSITION PREDICTION METHODS. • All simulations are "free air"; no wind tunnel walls or model support systems.

Case 2b: Nacelle/Pylon OFF with Adaptation (OPTIONAL)
Use grid refinement based on automatic solution adaptation and/or solution-guided grid regeneration to provide the required flow solutions using the parameters from Case 2a.

Case 2c: Nacelle/Pylon ON (REQUESTED)
Using the parameters from Case 2a, provide flow solutions for high lift configuration with the nacelle/pylon assembly ON.

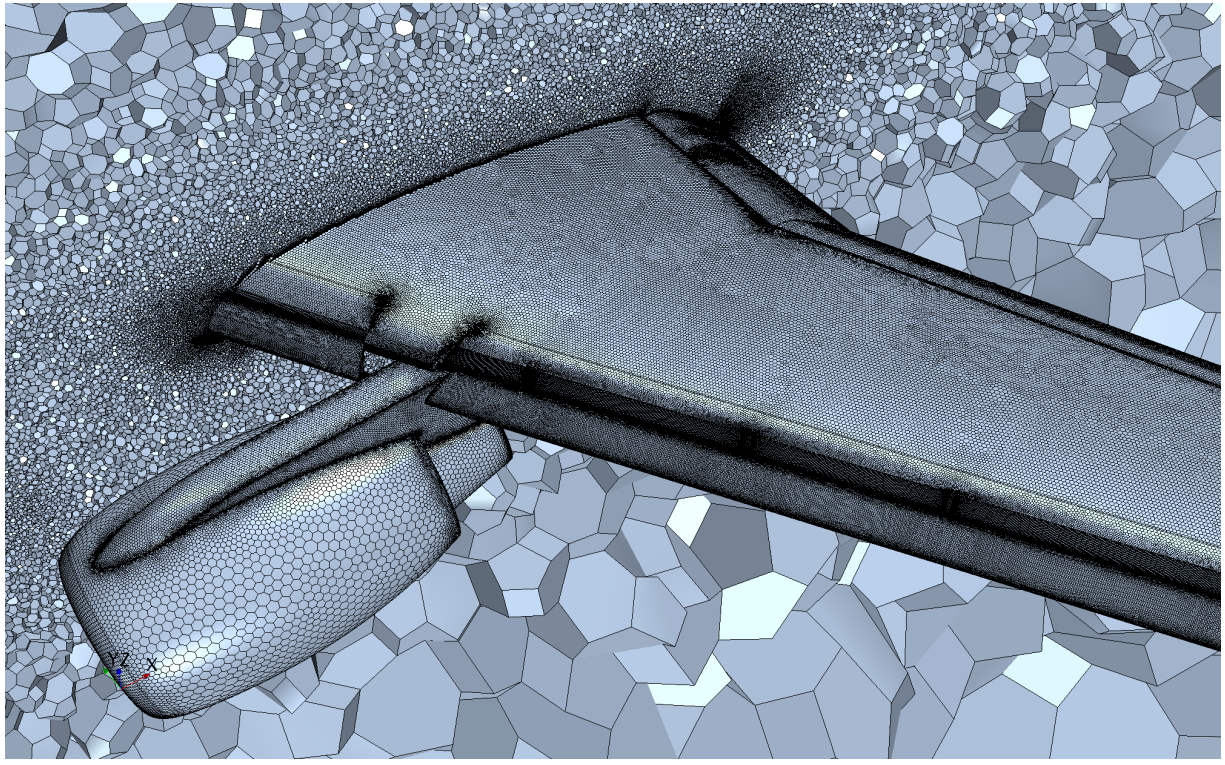
JAXA JSM – Siemens

- Siemens used the committee supplied hybrid prism-tet JAXA grid of 120M cells for nacelle-off and 138M cells for nacelle-on case.



JAXA JSM - LAVA

- ANSA for initial surface meshing and STAR-CCM+ for surface grid optimization and volume meshing.
- Prism layers were grown over the aircraft surface using STAR-CCM+ Advancing Layer Mesher with a near-wall cell layer thickness such that y+ = 1, stretching ratio of 1.2 and aspect ratio of the last prism layer to the first polyhedral layer height of 0.5.
- The grid includes 1.61M surface faces and 69.9M polyhedral cells



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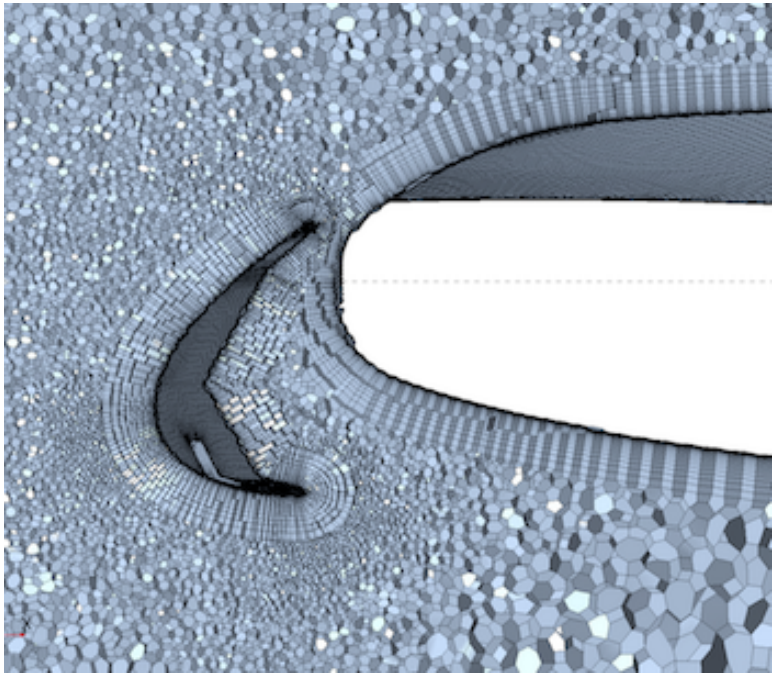
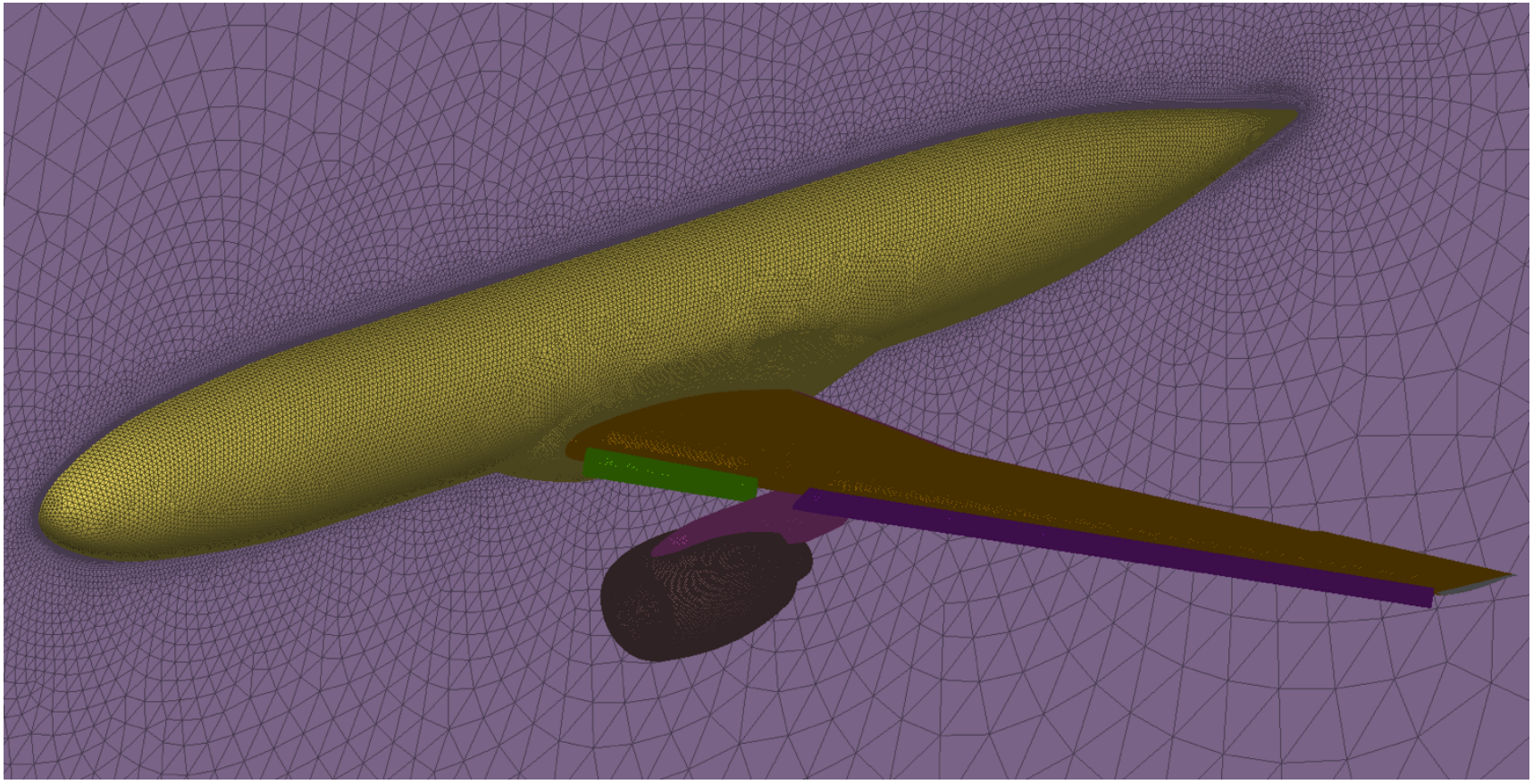


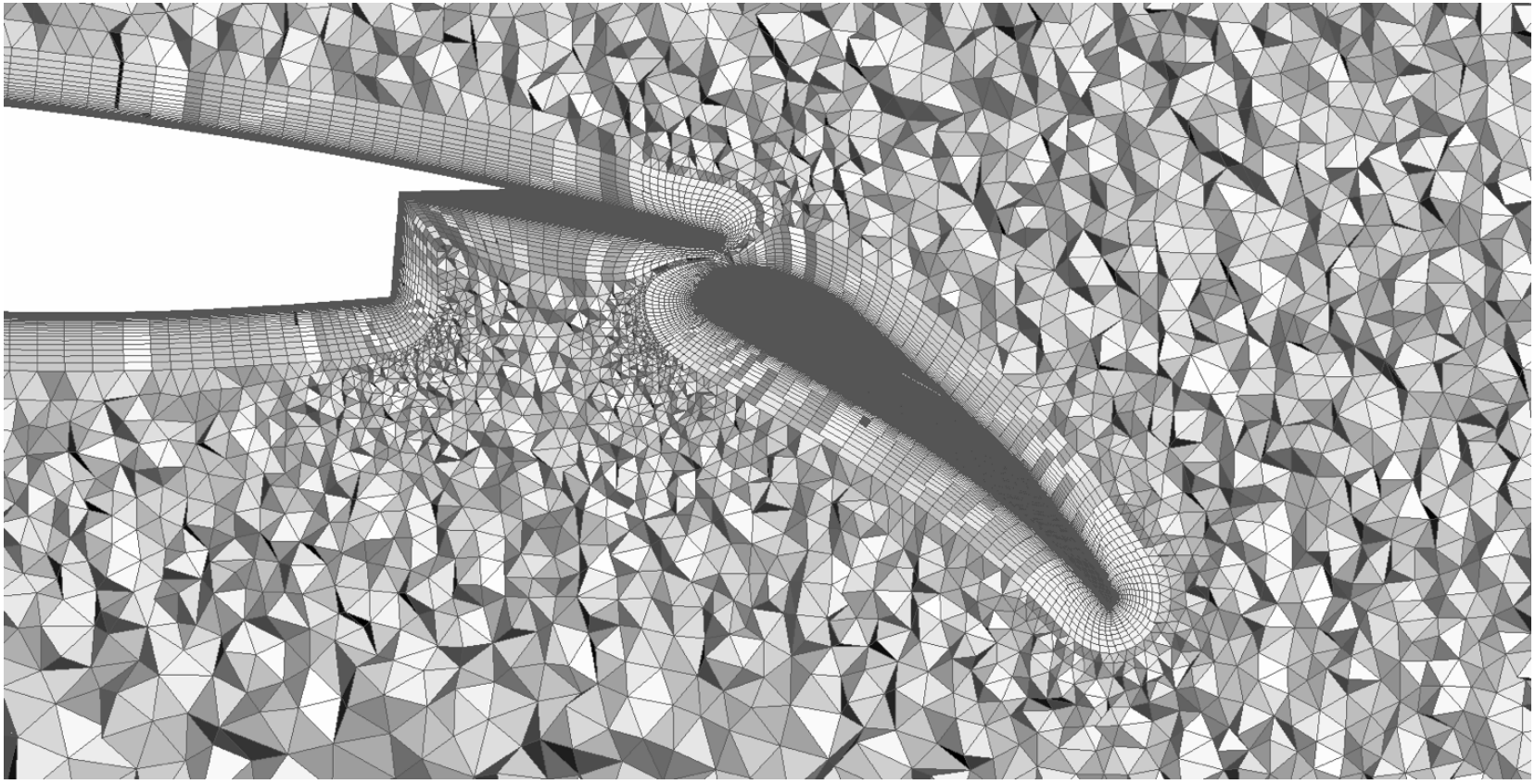
JAXA JSM – Oxford

Same approach take as to HL-CRM. Additional fine mesh created but not run



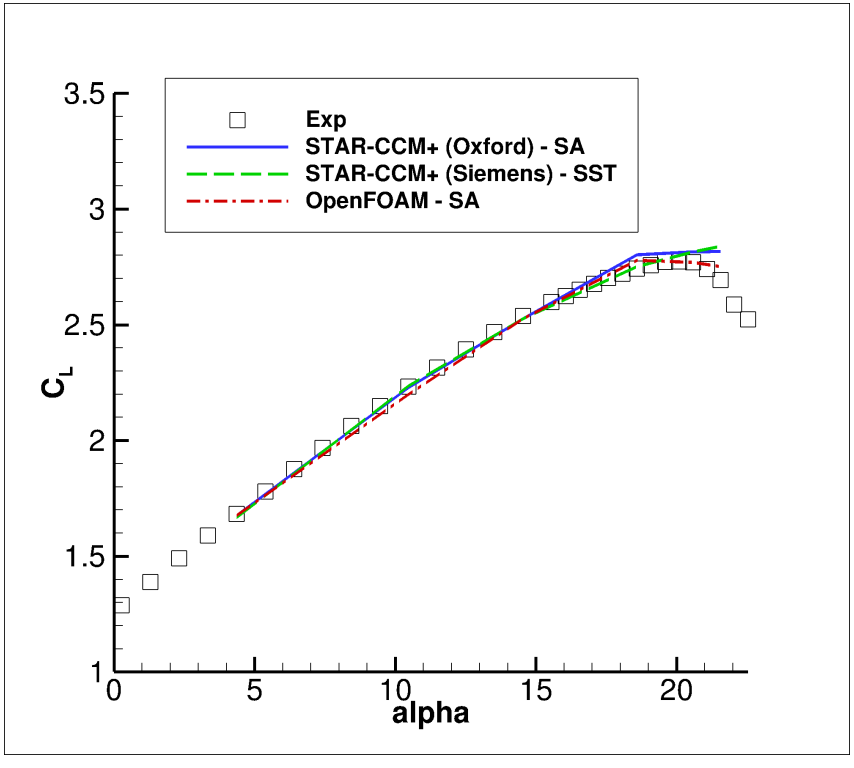
JAXA JSM – Oxford

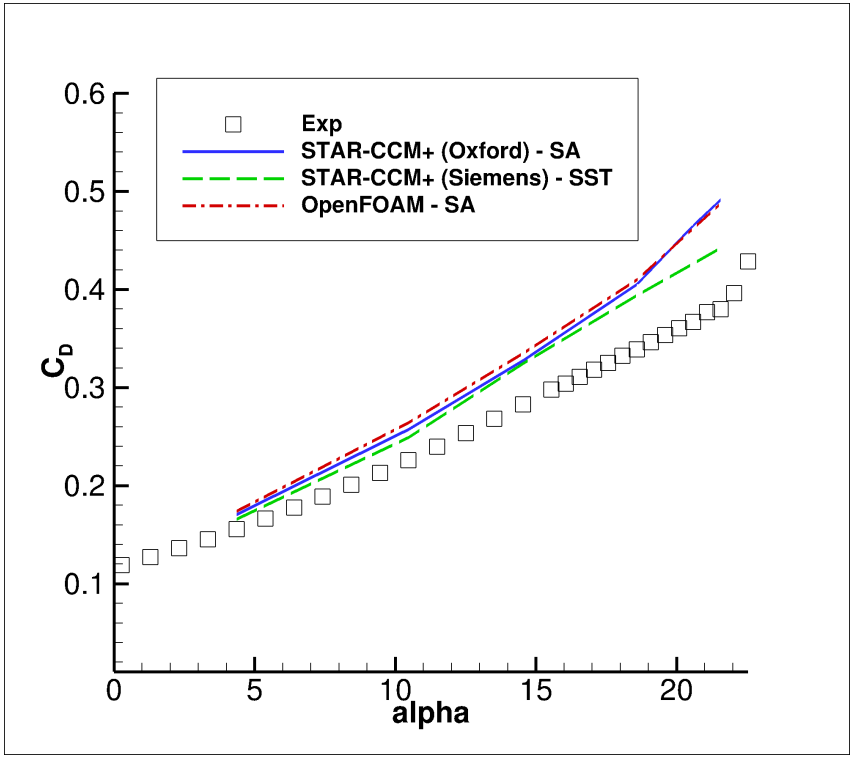
Same approach take as to HL-CRM. Additional fine mesh created but not run



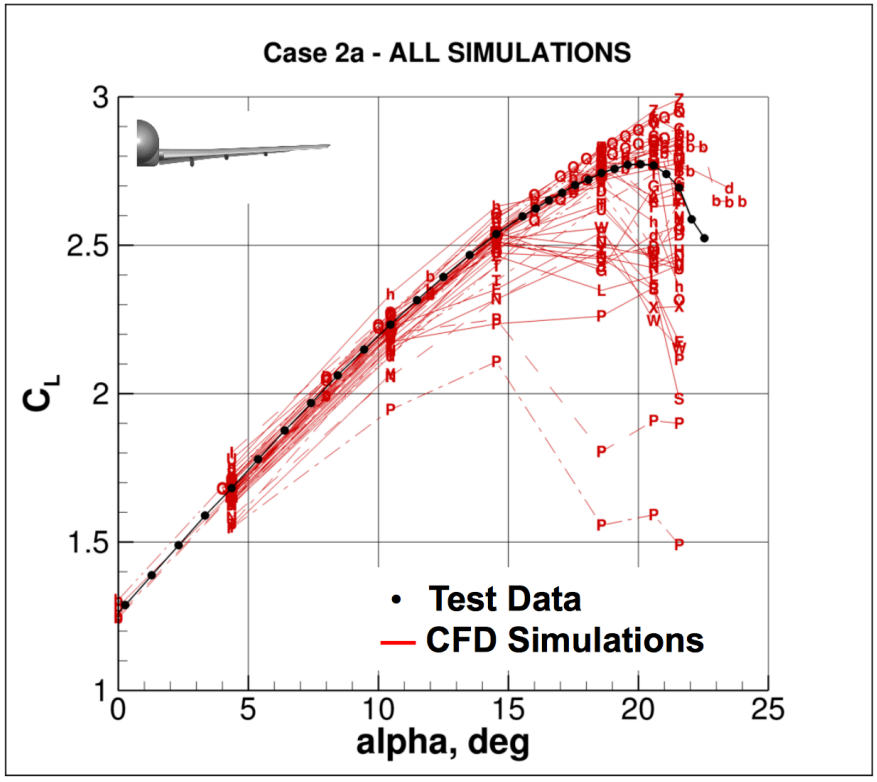
Same approach take as to HL-CRM. Additional fine mesh created but not run

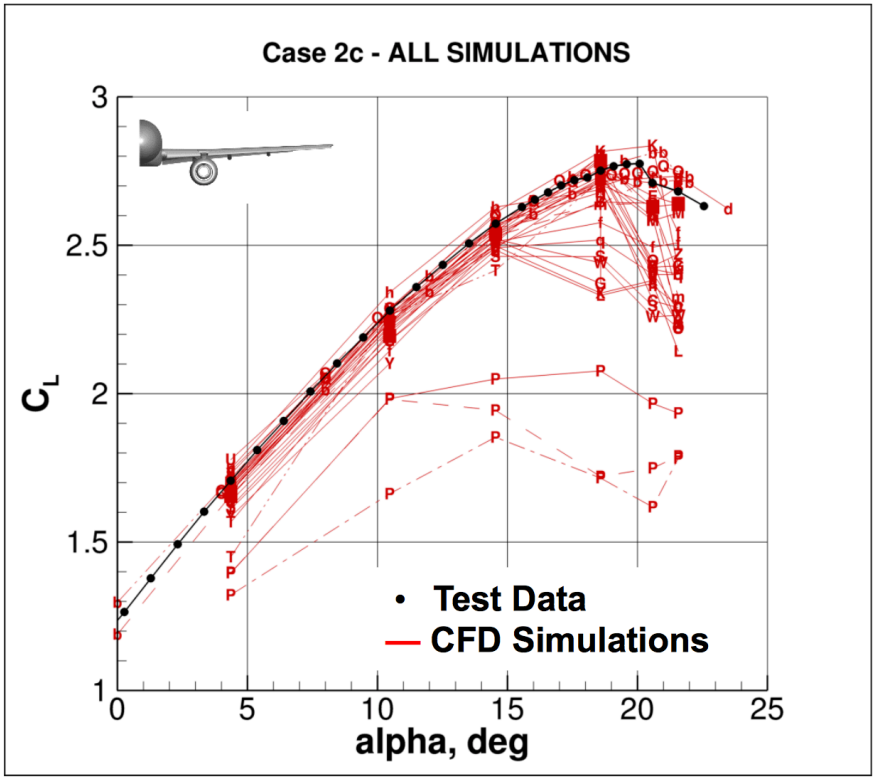
	Medium Case 01 (w/o nacelle)	Medium Case 02 (with nacelle)
Surface mesh size (millions)	1.7	1.8
Volume mesh size (millions)	109	120
Trailing edge rows of elements	8	8
Number of Layers	Wing:49 Fuselage:57	Wing:49 Fuselage:57
Layers growth	1.16	1.16
Layers first height (mm)	0.0015	0.0015





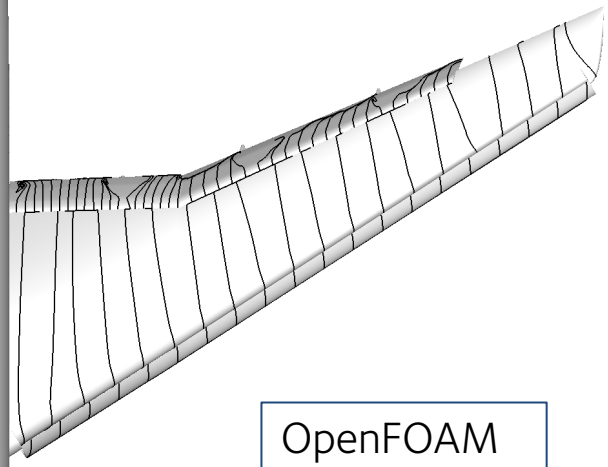
- Average difference between OpenFOAM & STAR-CCM+ = 1.0% for Lift and 1.1% for Drag
- Difference turb model for Siemens but agreement is very close up until stall (different grids though..)



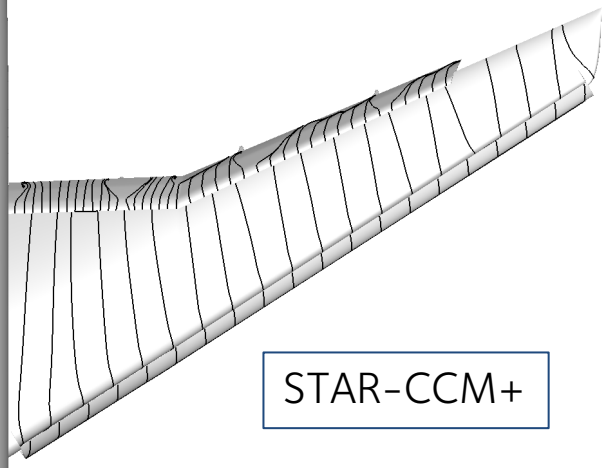


- Within the other participants results band (a pretty wide band!)

JSM NO-NACELLE 4.36°

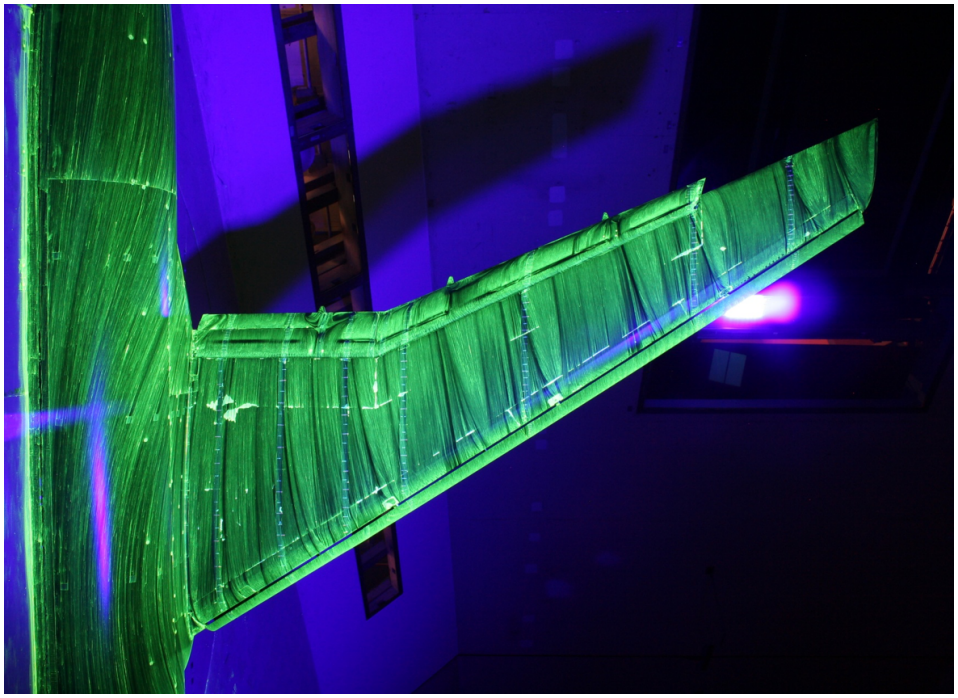


OpenFOAM

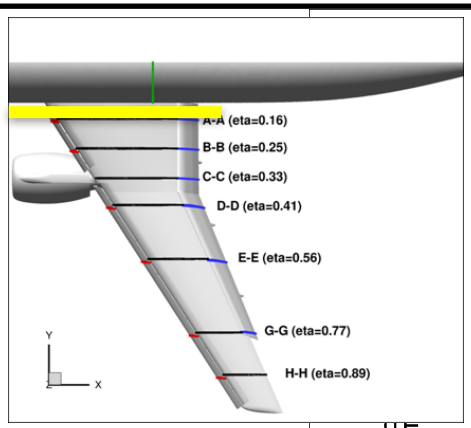


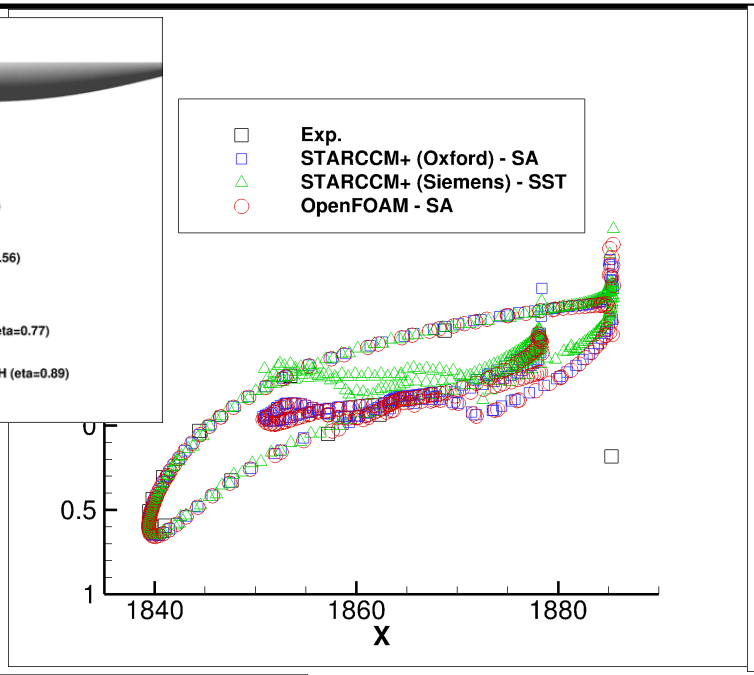
STAR-CCM+

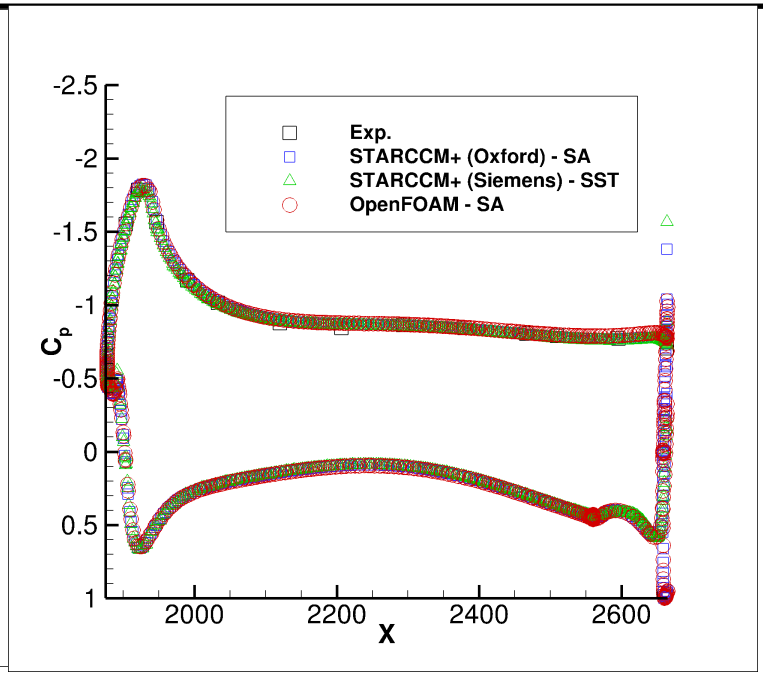
- Good agreement between CFD and Exp.

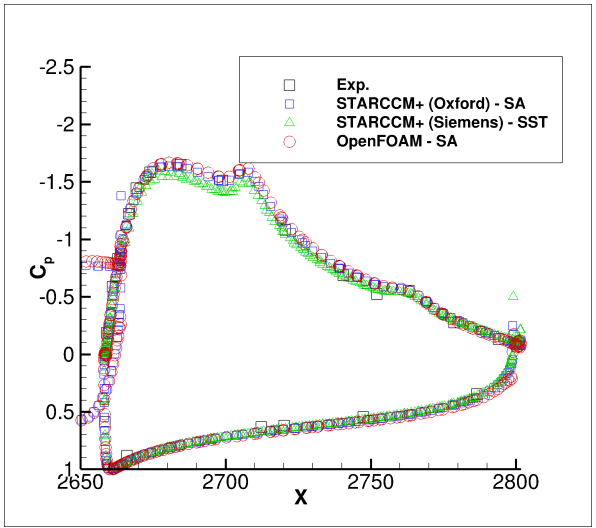


JSM NO-NACELLE 4.36° – A-A



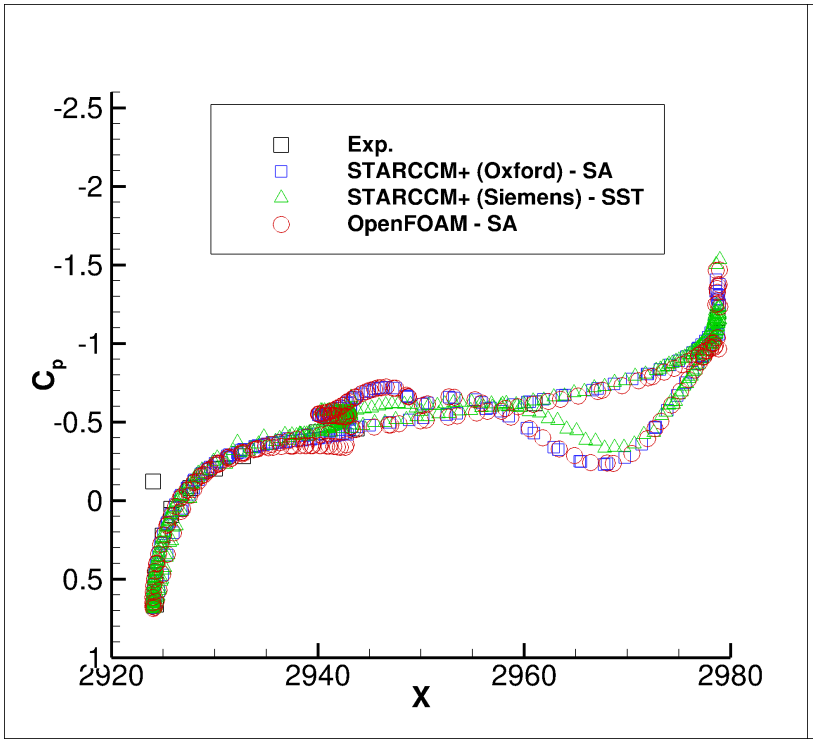


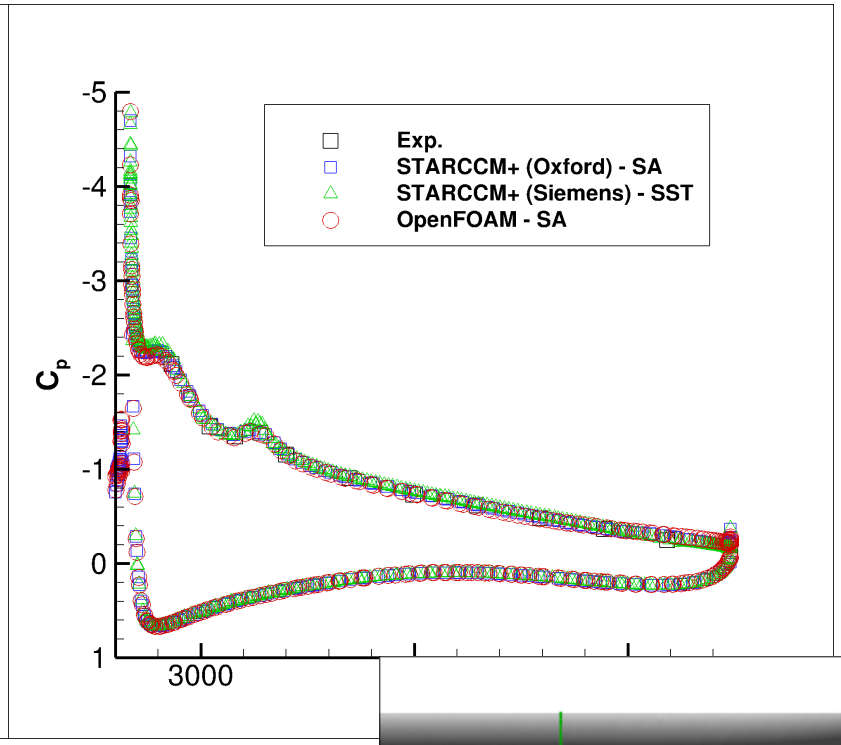


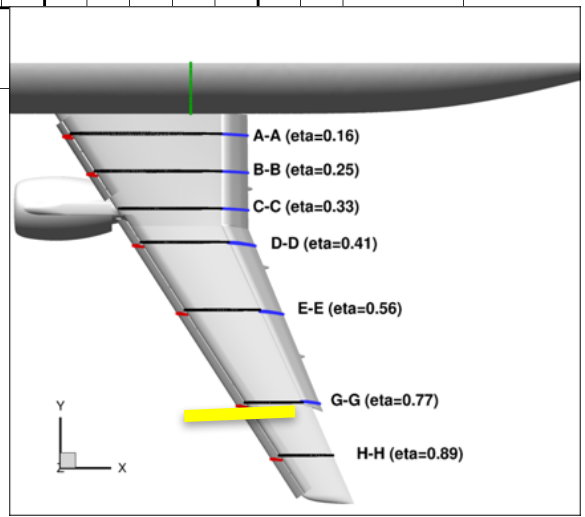


- Slightly more losses in the flap for SST (tends to be more sensitive to separation) but overall close agreement

JSM no-nacelle 4.36° – H-H

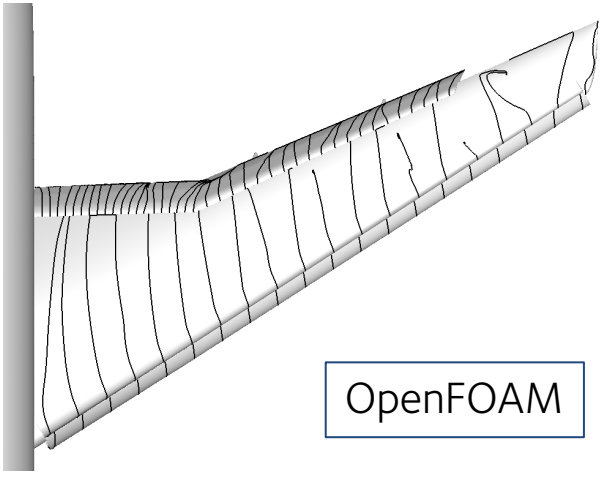




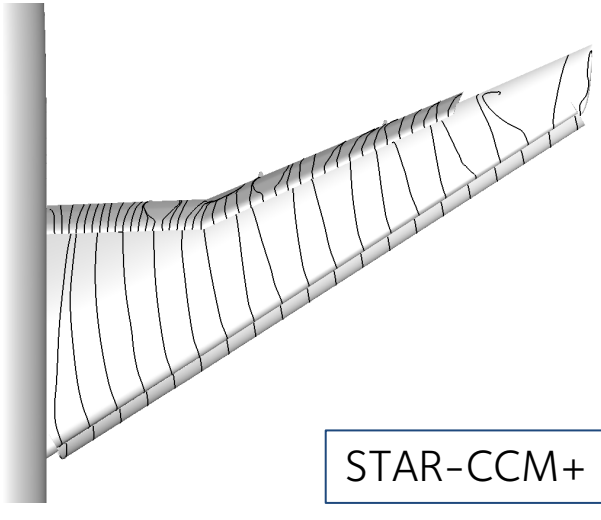


- Both codes and models agree with experimental data at the outboard

JSM NO-NACELLE 18.58°

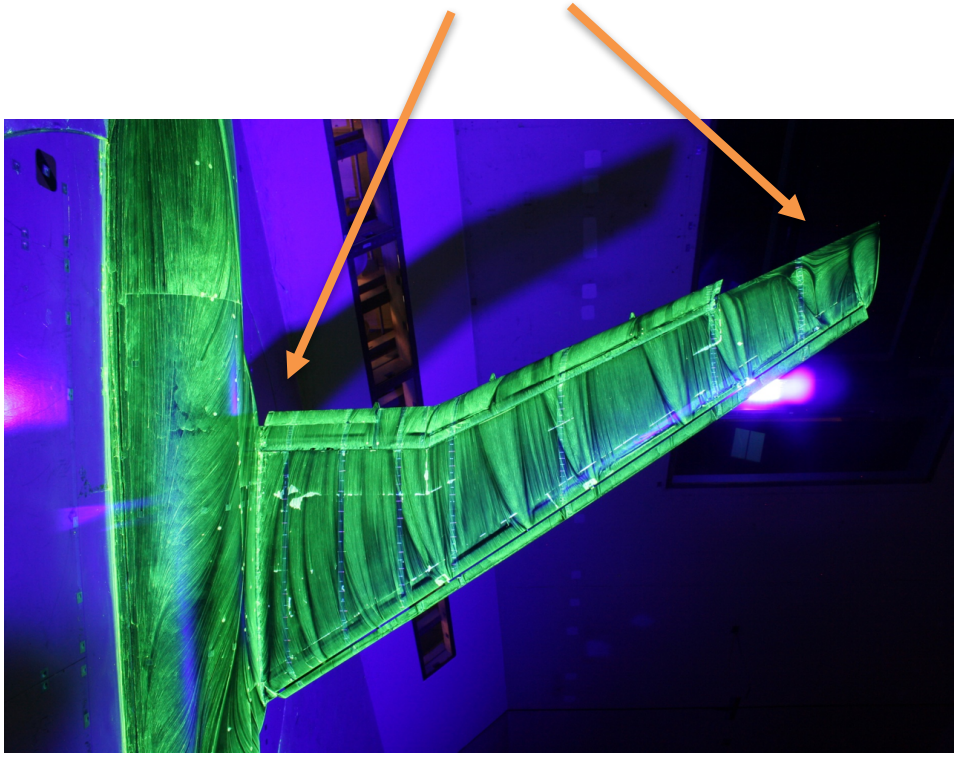


OpenFOAM

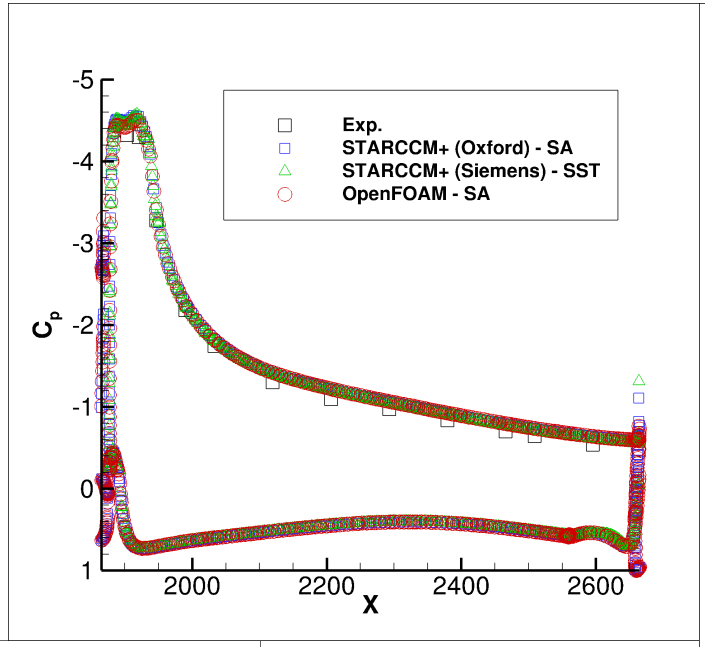


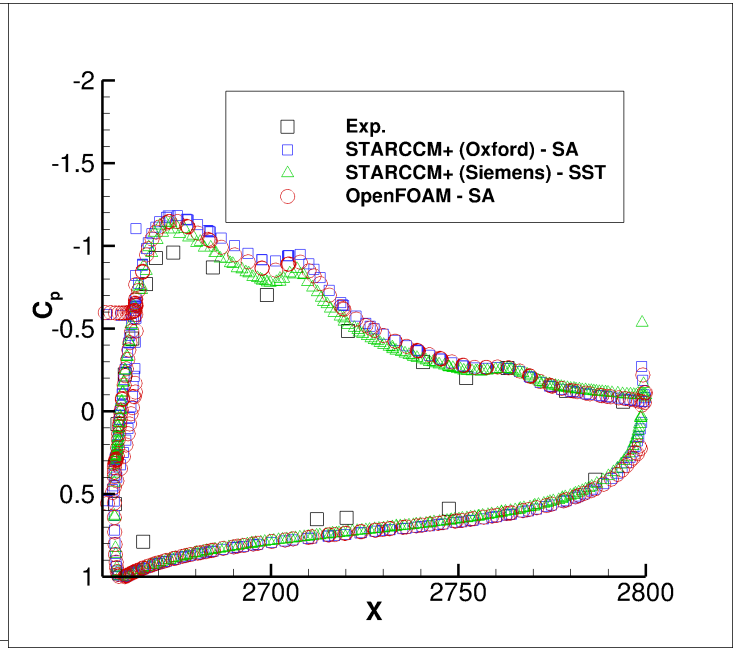
STAR-CCM+

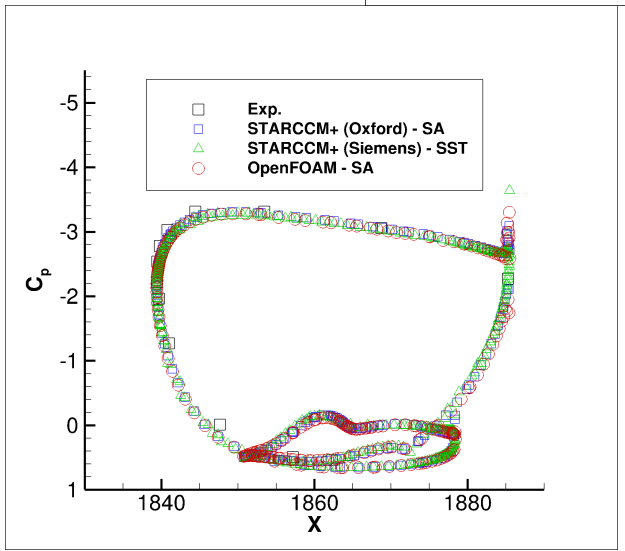
- Missing the start of the in-board separation
- Slight over-prediction of outboard losses



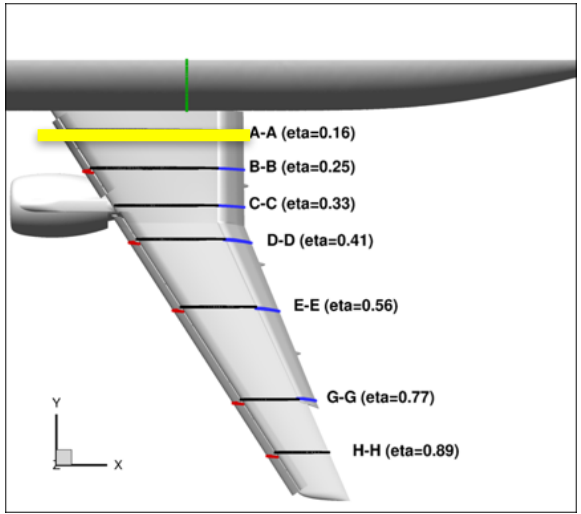
JSM NO-NACELLE 18.58° – A-A



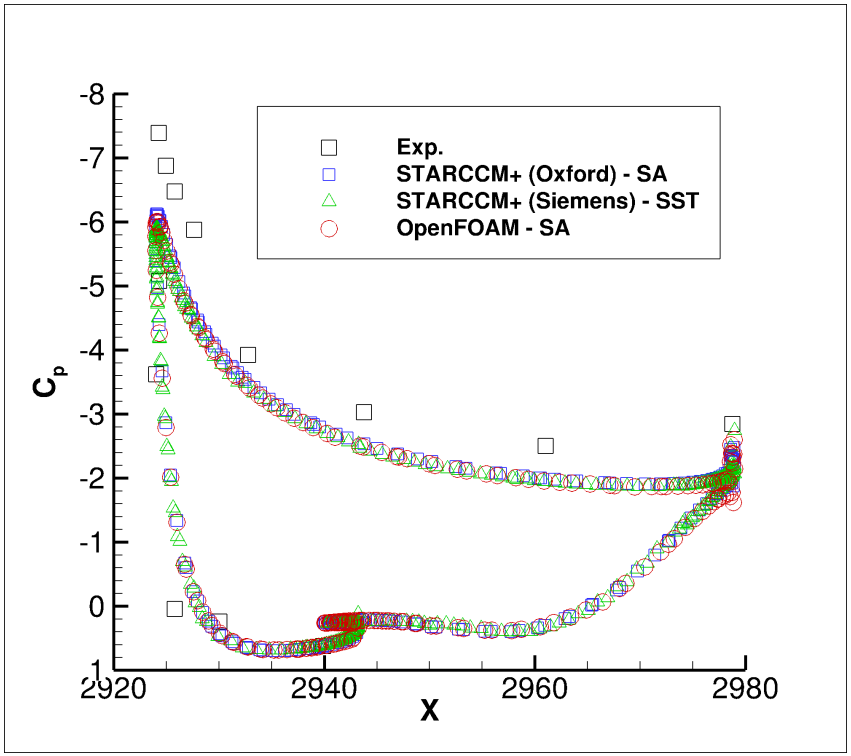


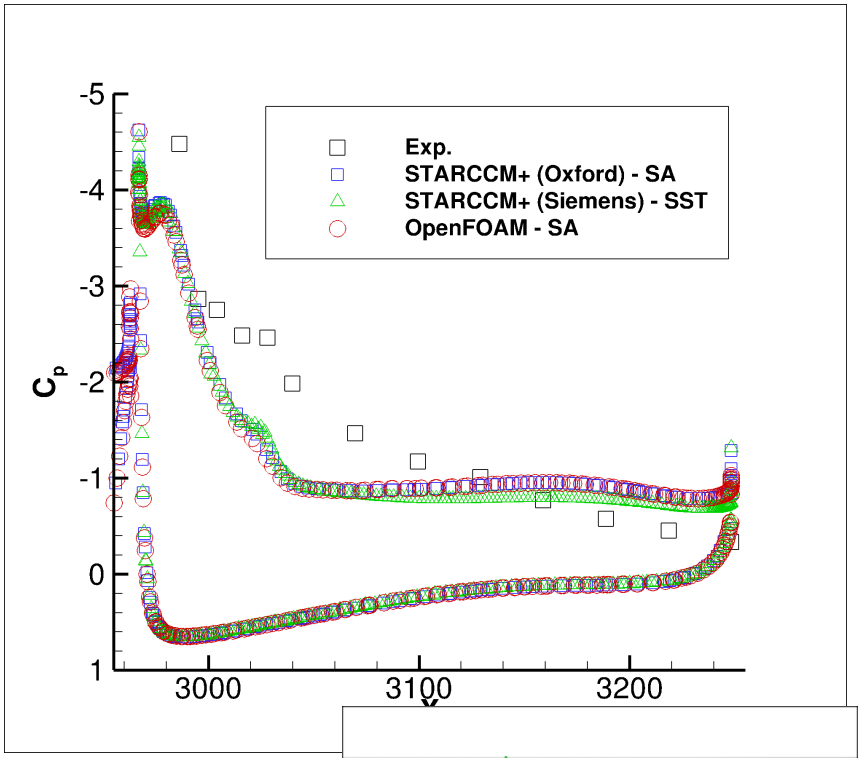


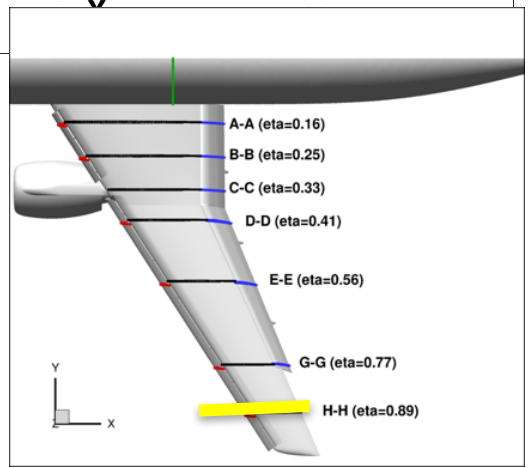
- Slightly under-predicting loses in the inboard flap



JSM no-nacelle 18.58° – H-H

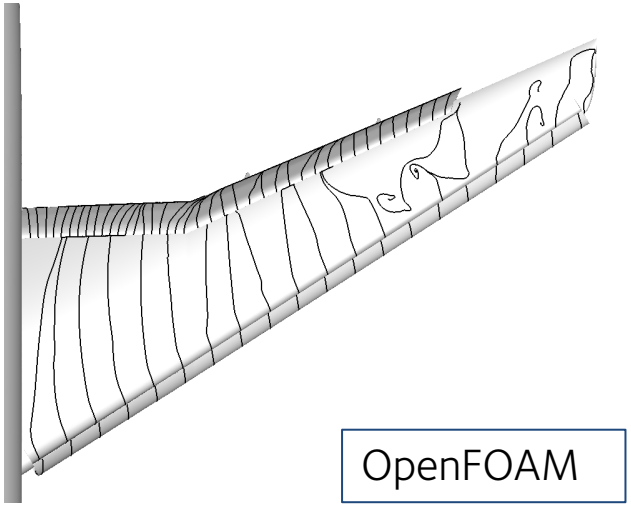




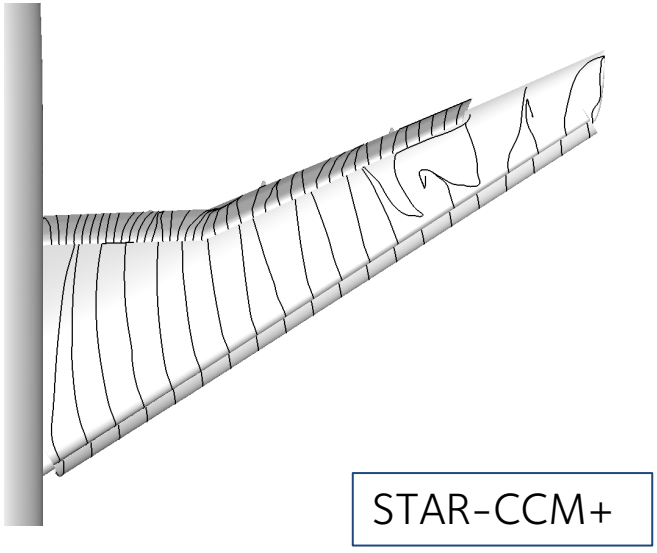


- More noticeable in the outboard flap section. Clear over-prediction of the loses here

JSM NO-NACELLE 21.57°

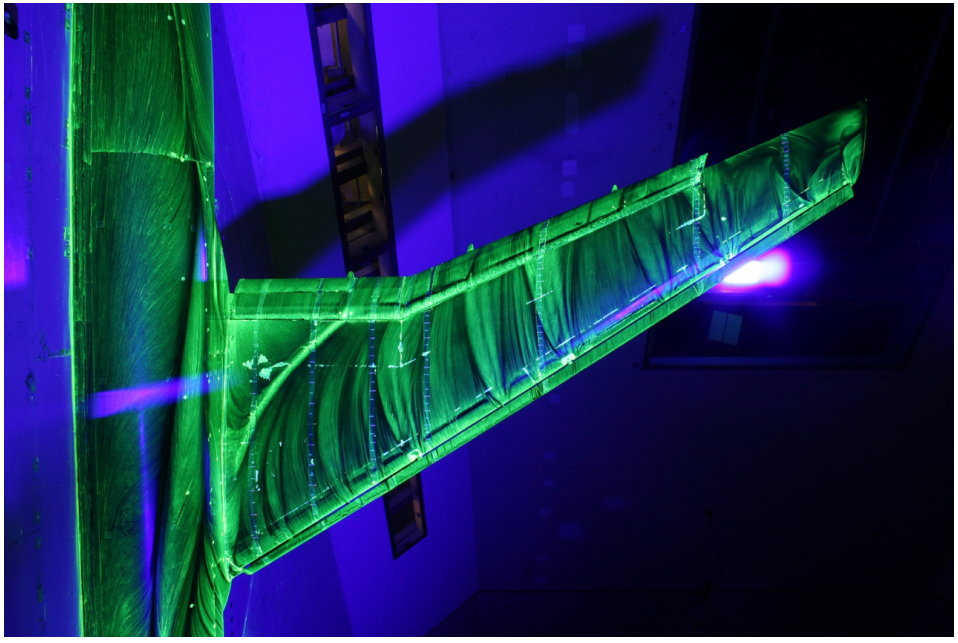


OpenFOAM

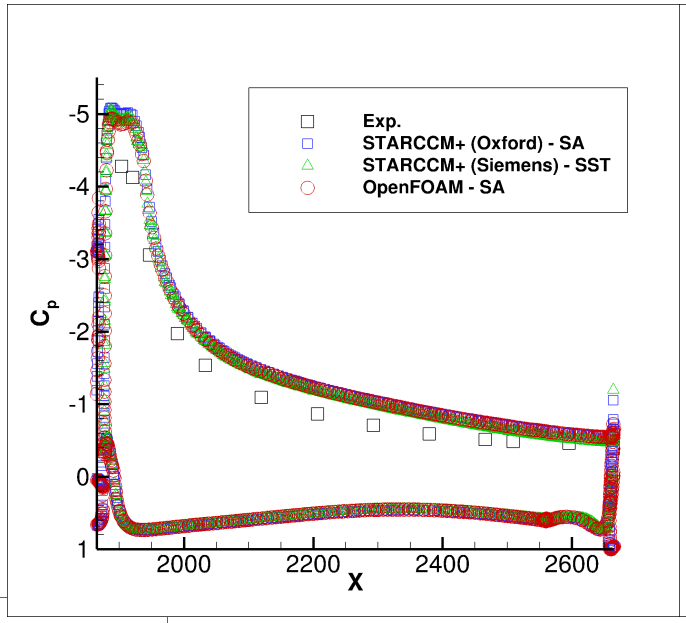


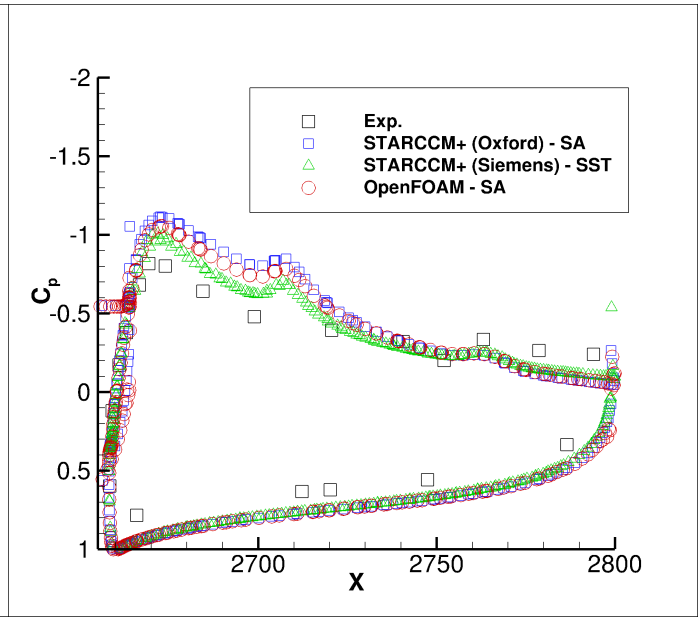
STAR-CCM+

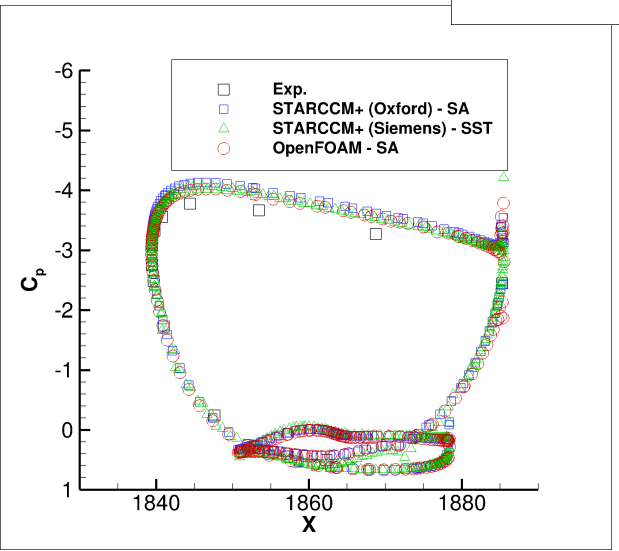
- In-board separation completely under-predicted (SA Turb)
- Over-prediction of outboard losses
- Error cancellation!



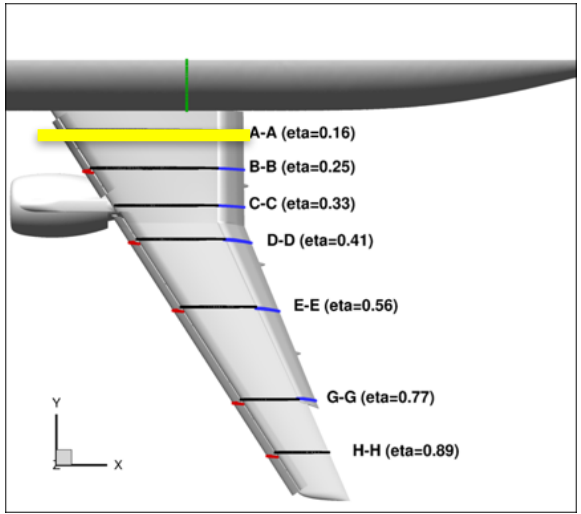
JSM NO-NACELLE 21.57° – A-A



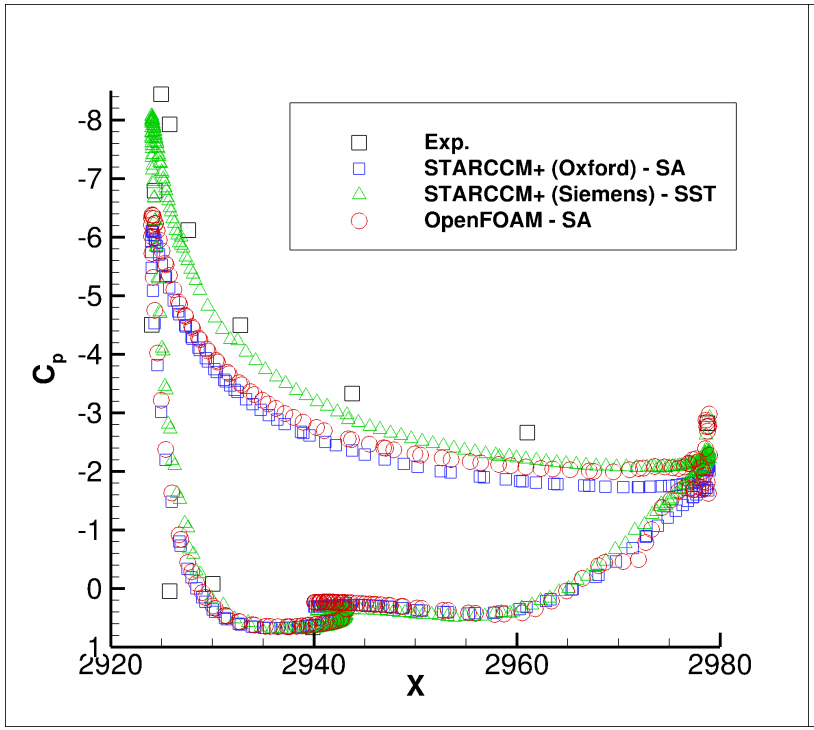


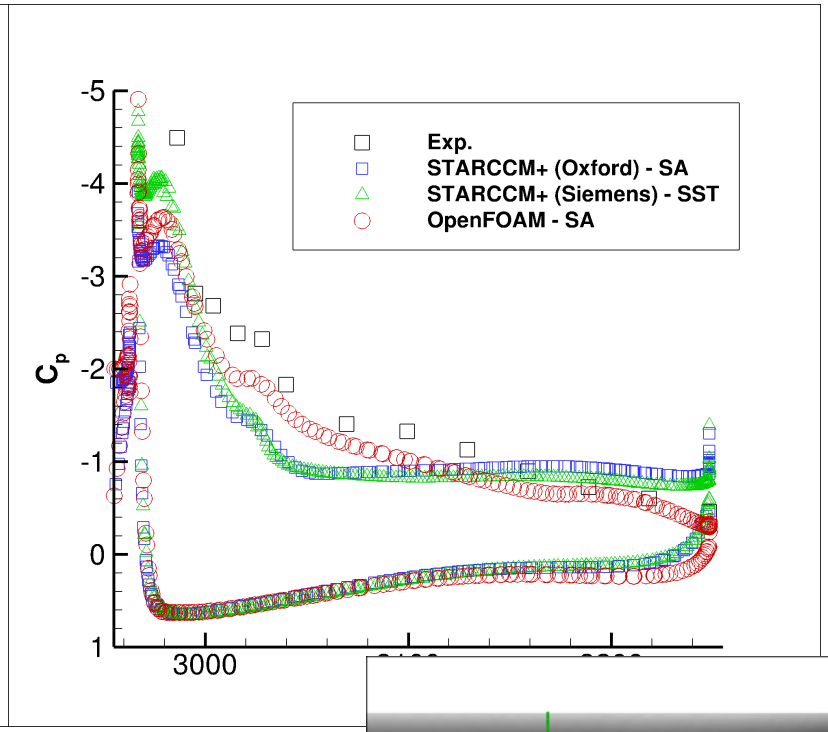


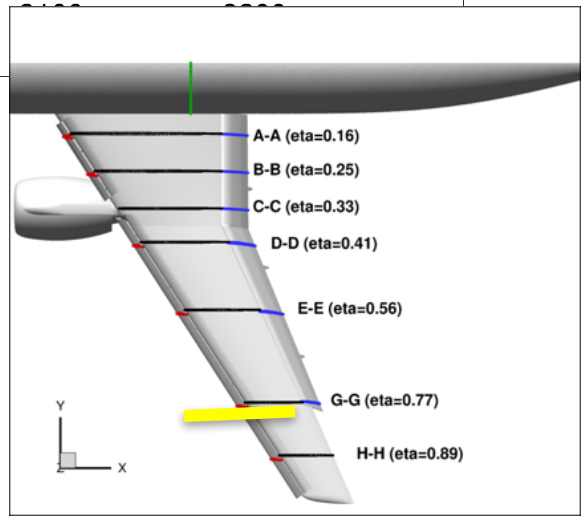
- In board losses against under-predicted



JSM NO-NACELLE 21.57° – H-H

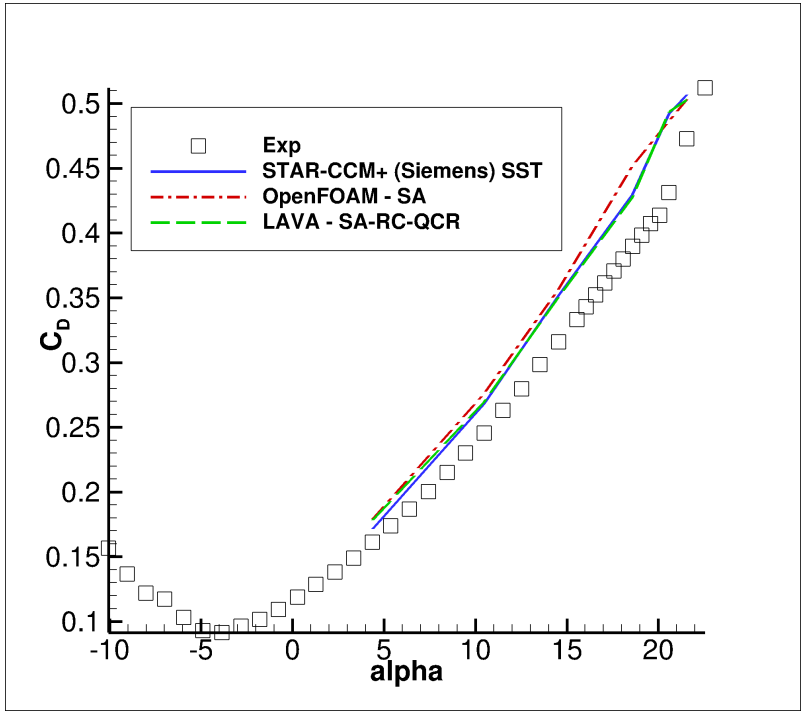


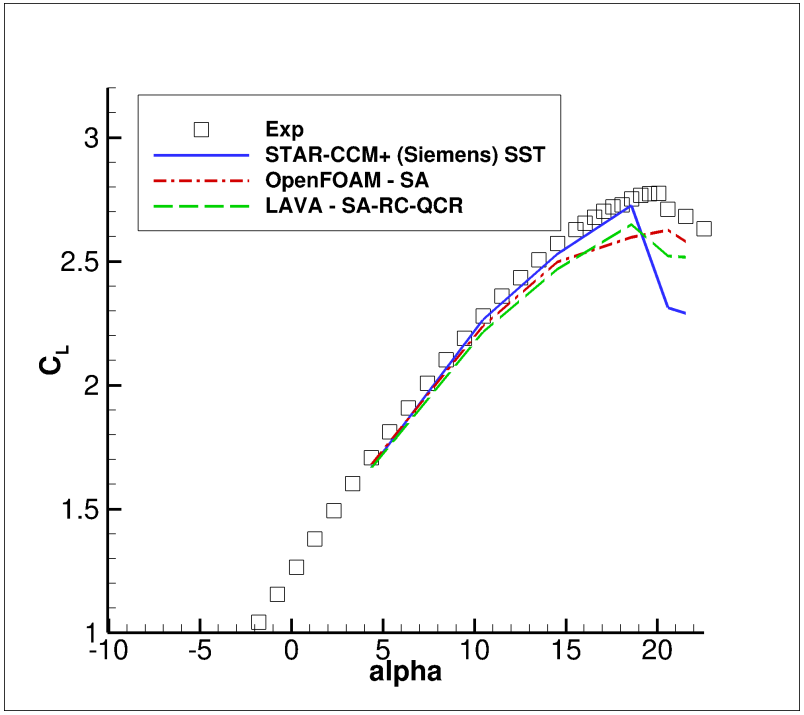




- Again too much lose. Agreement between codes/models start to break down

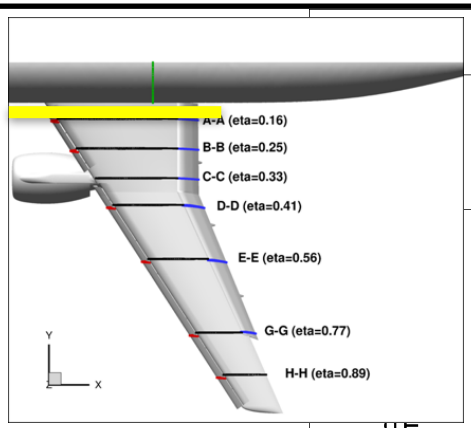
Nacelle-on

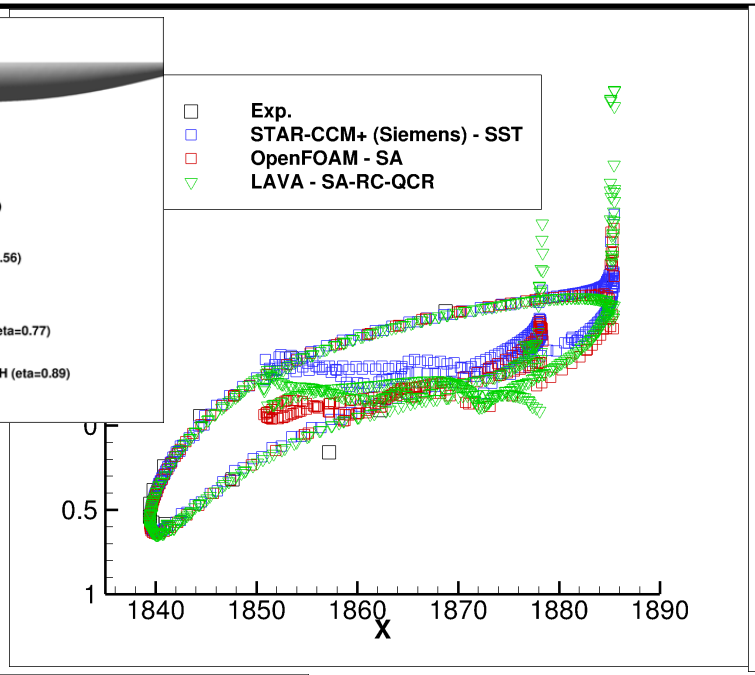


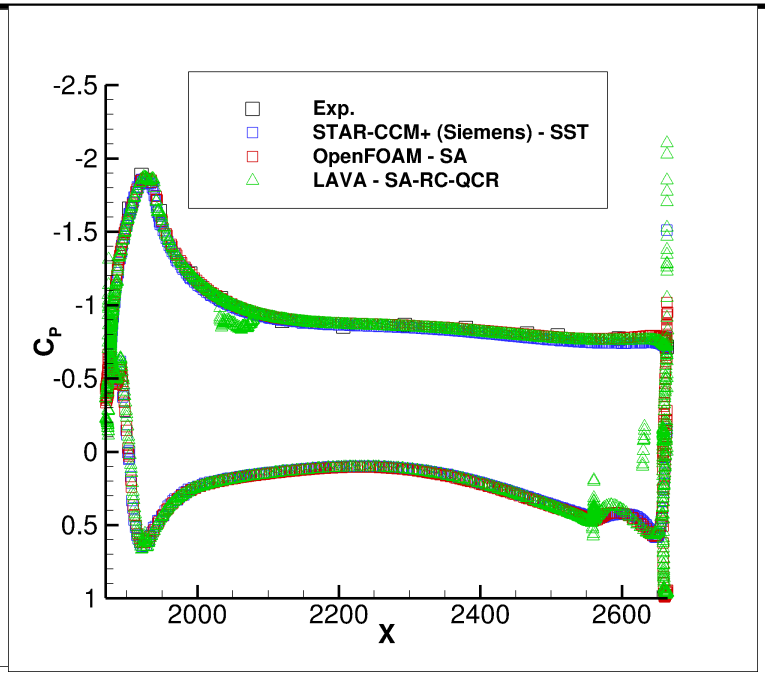


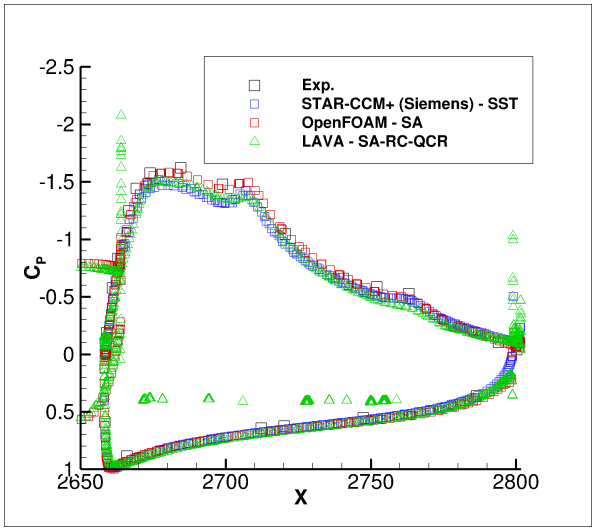
- Early stall compared to experiment
- Similar over-prediction of Drag
- All different turb and meshes – difficult to compare directly
- Given mesh refinement trends with HL-CRM, finer grids are needed here

JSM NACELLE 4.36° – A-A



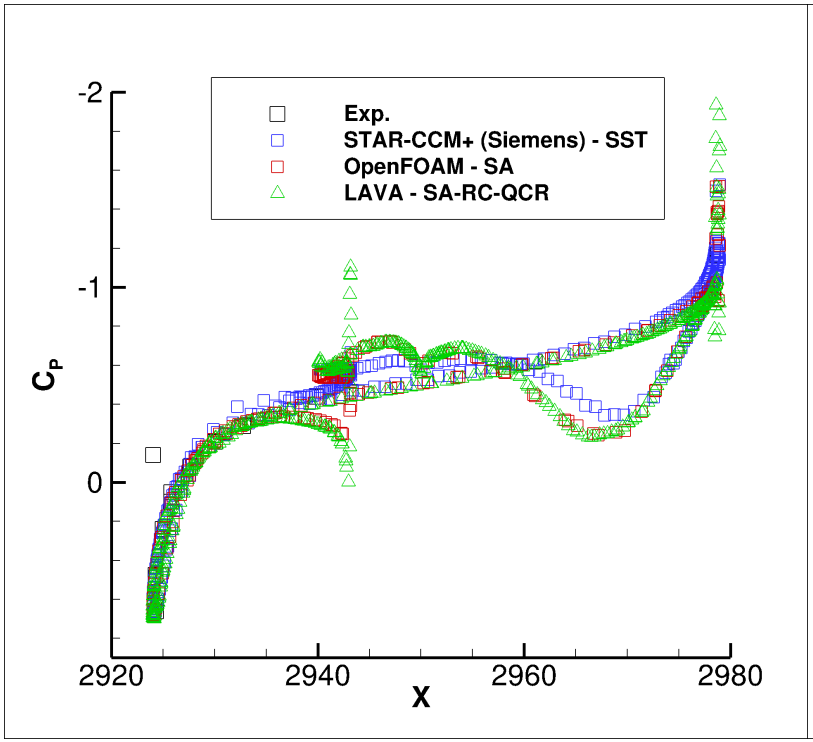


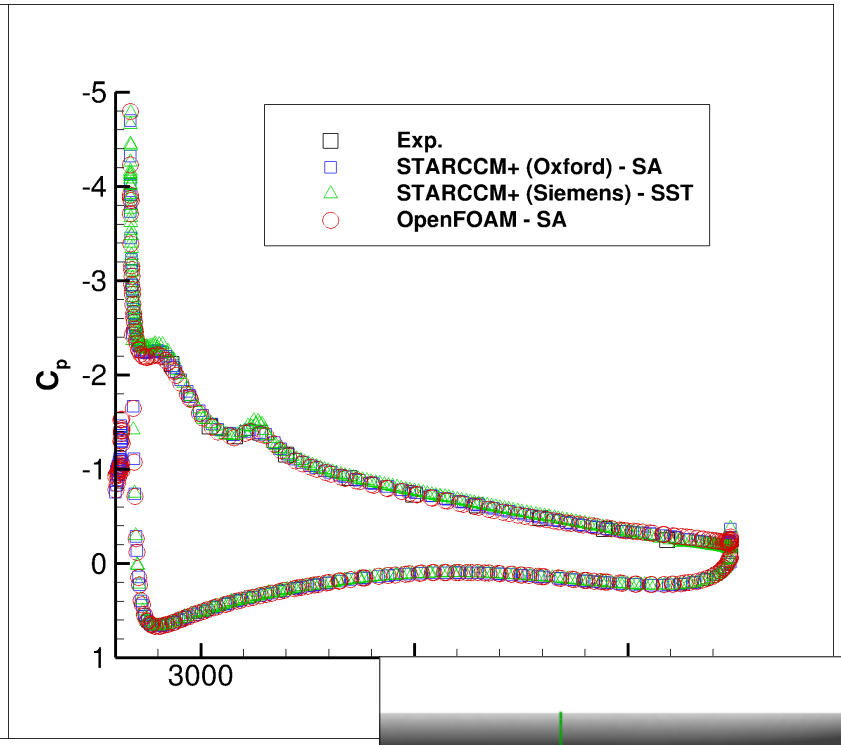




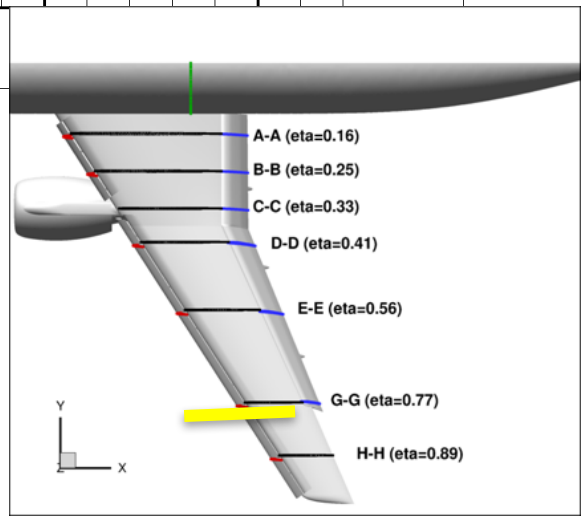
- Wing & flap agree well
- Slightly more losses in the flap for SST (tends to be more sensitive to separation)

JSM NACELLE 4.36° – H-H

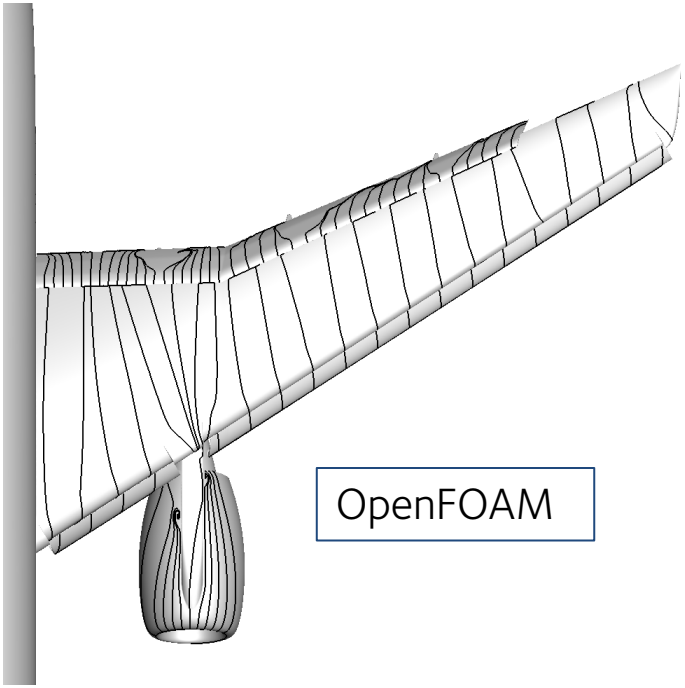


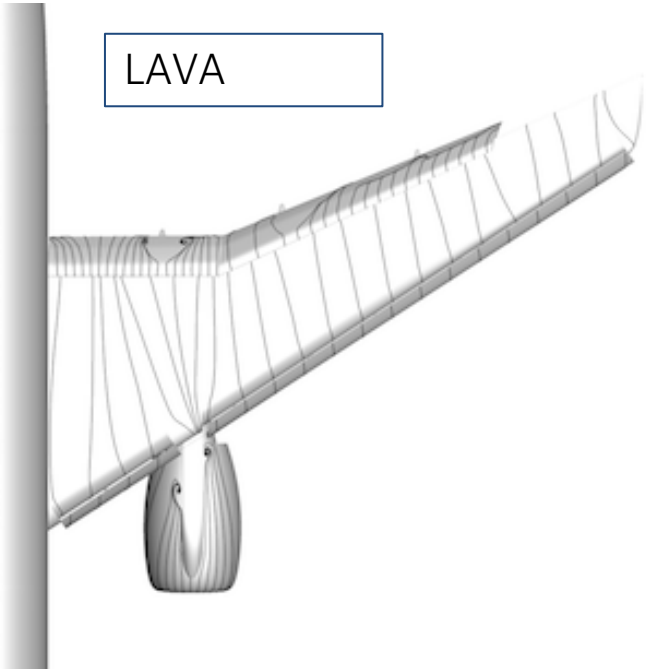


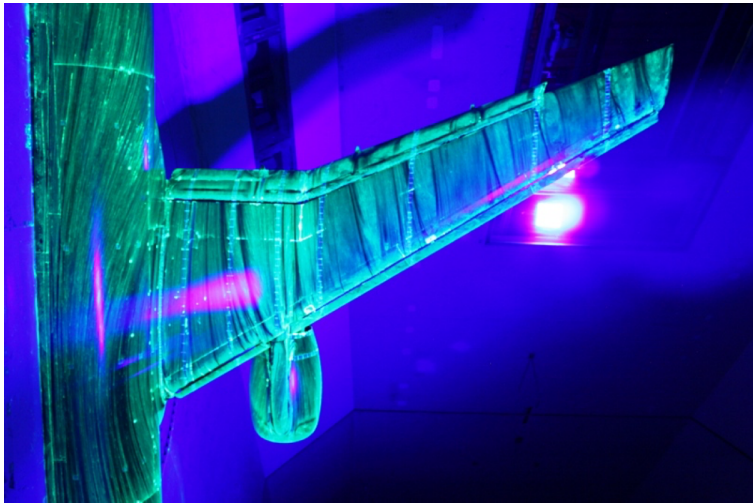
- Both codes agree with experimental data at the outboard



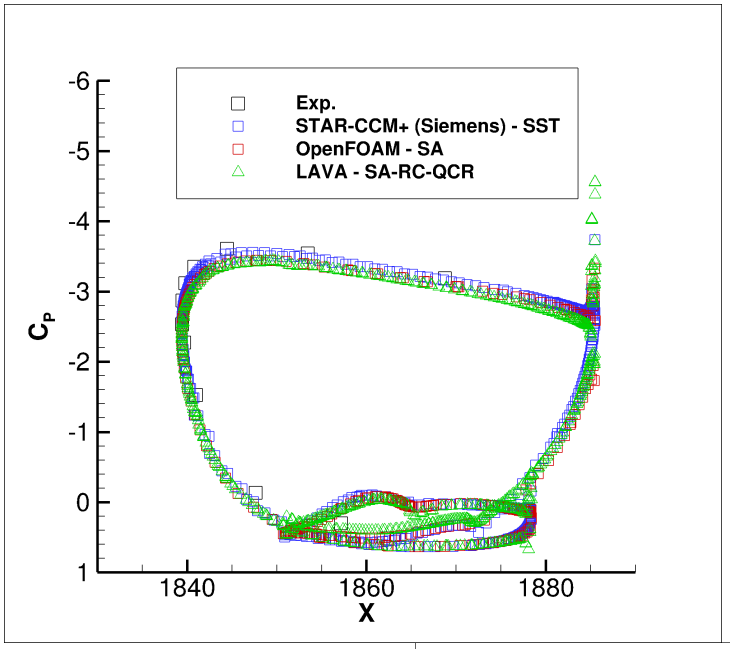
JSM NACELLE-ON 4.36°

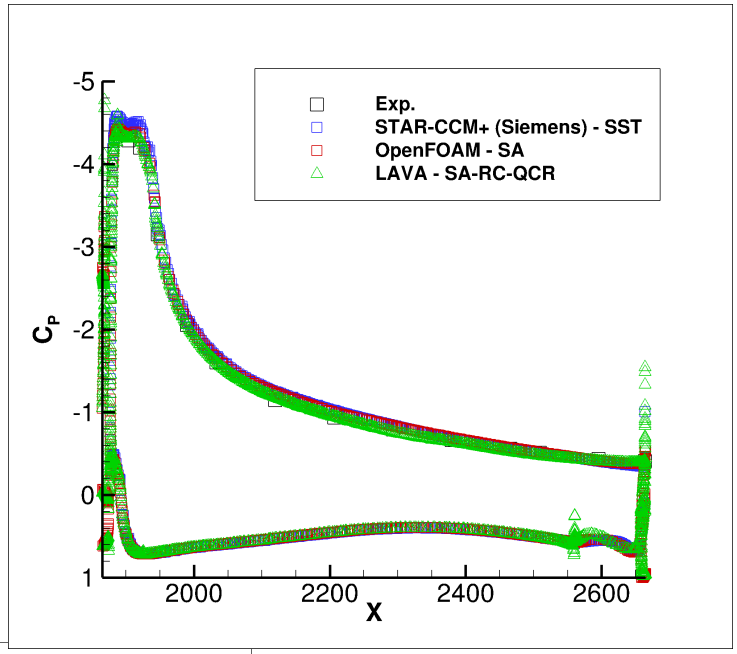


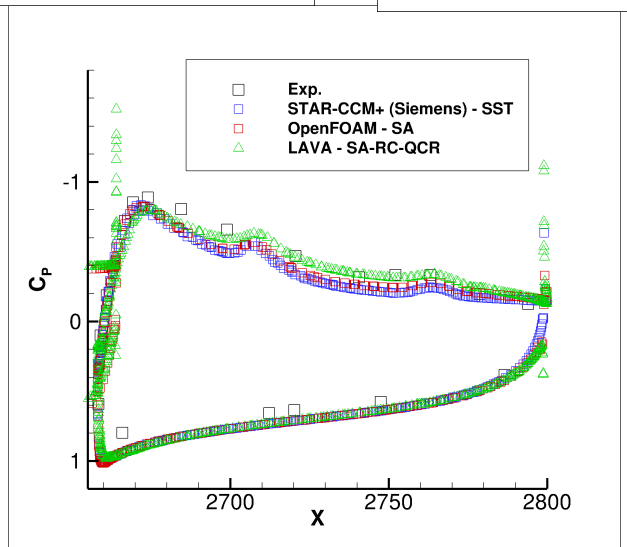


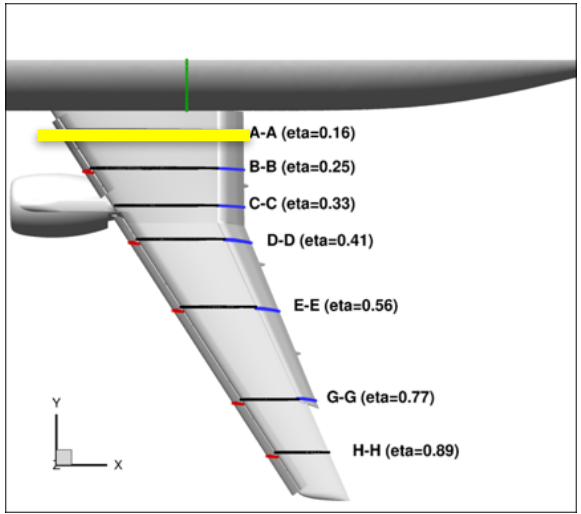


JSM NACELLE 18.58° – A-A

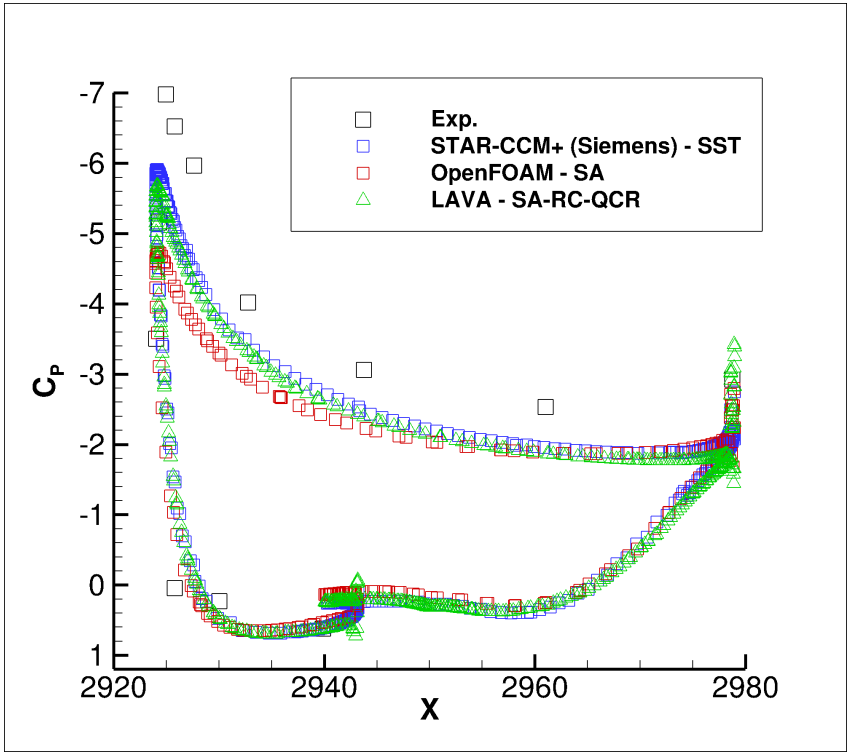


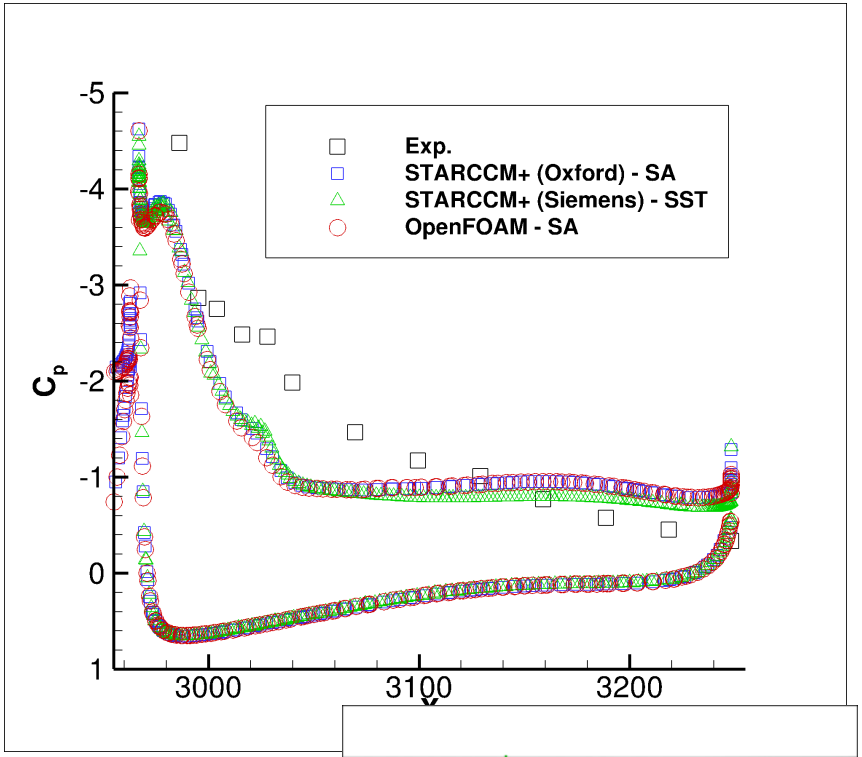


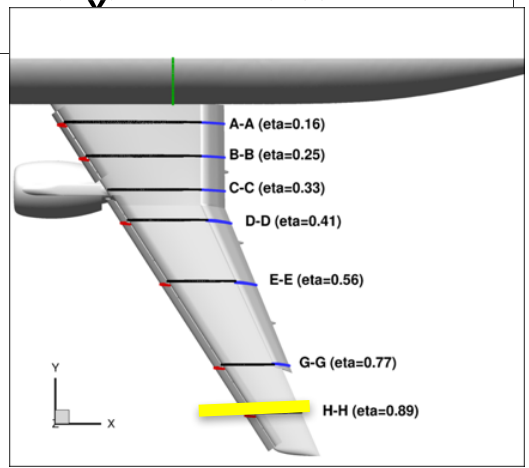




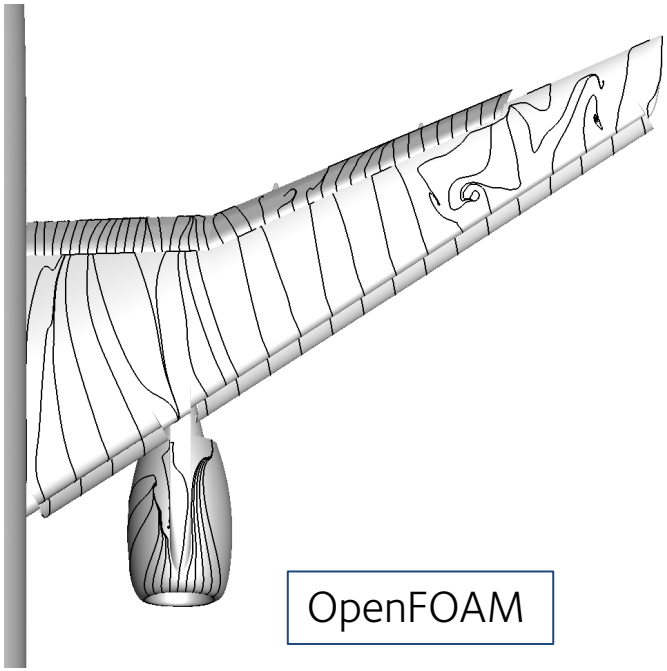
JSM NACELLE 18.58° – H-H

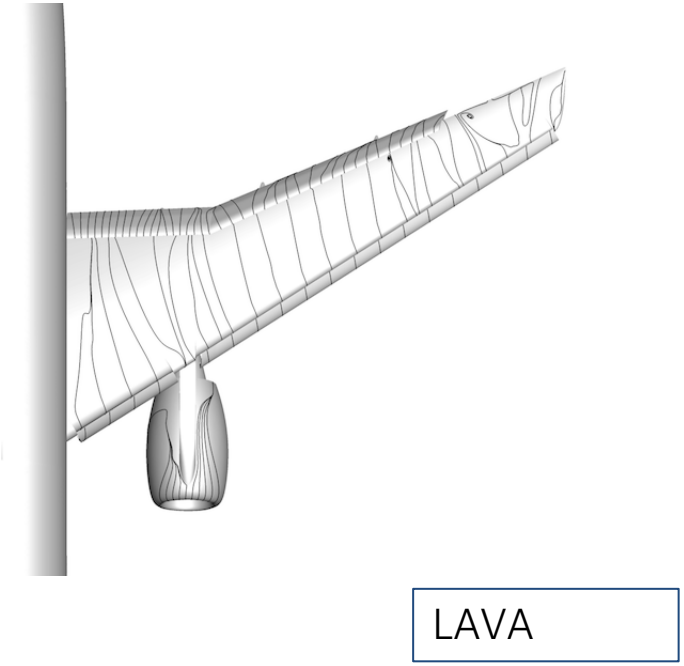




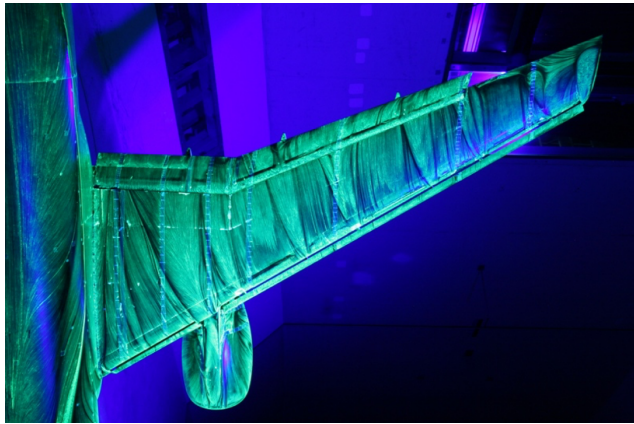


JSM NACELLE-ON 18.58°

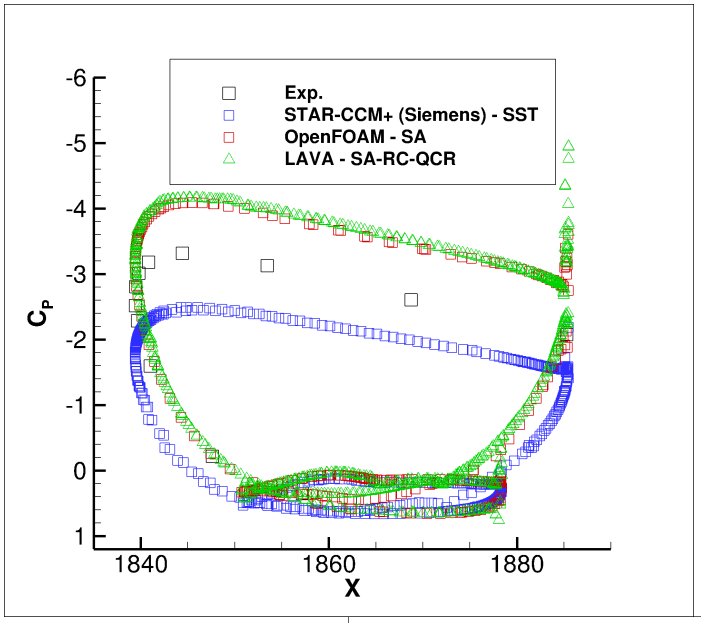


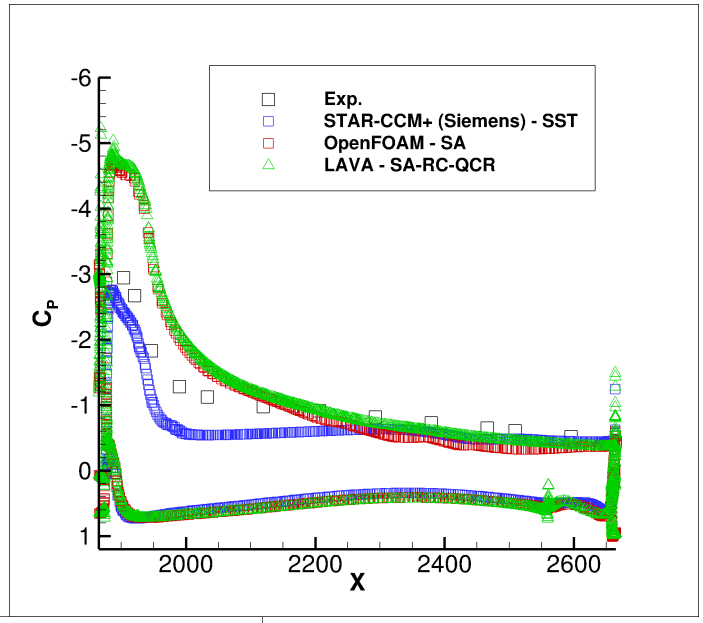


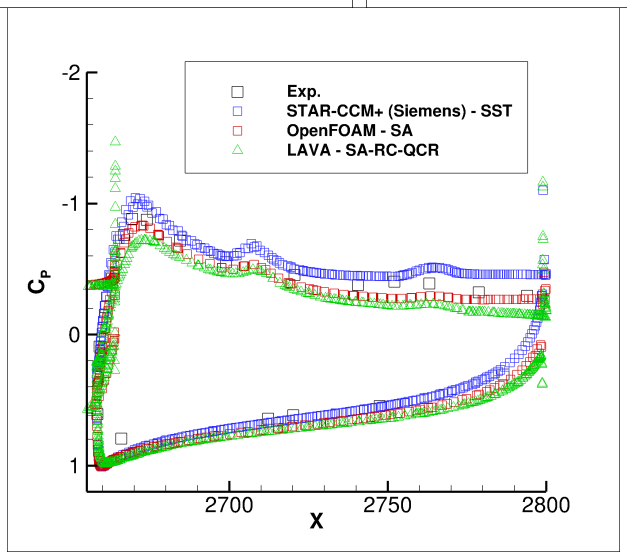
- Over-predicting outboard stall

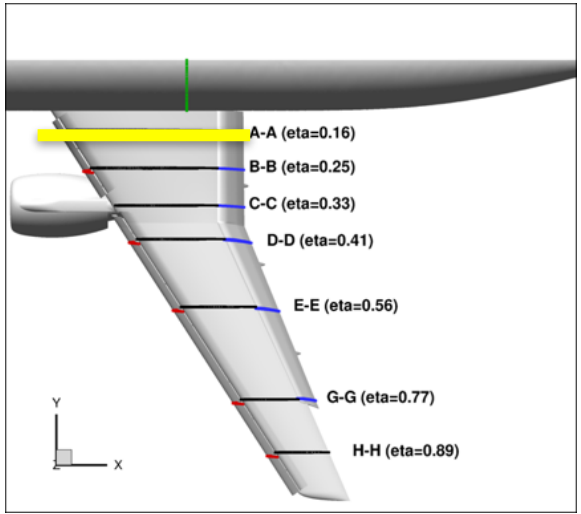


JSM NACELLE 21.57° – A-A



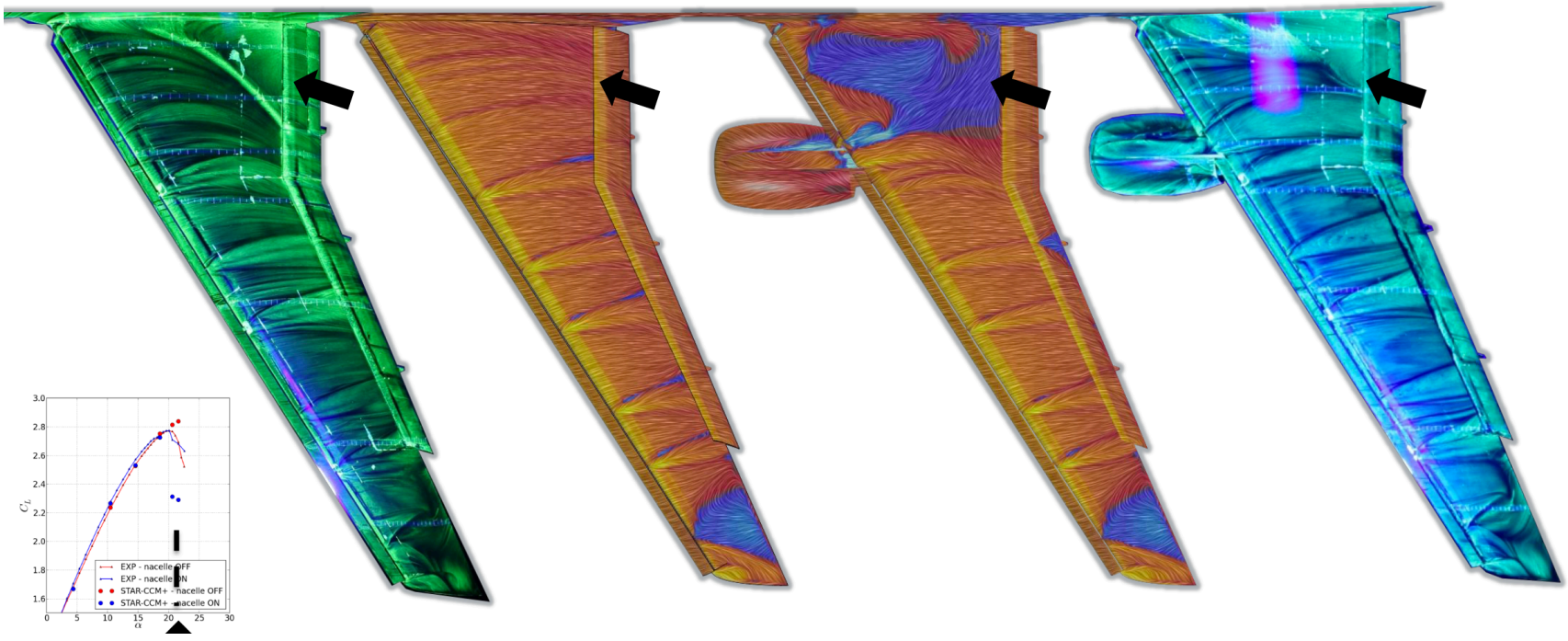




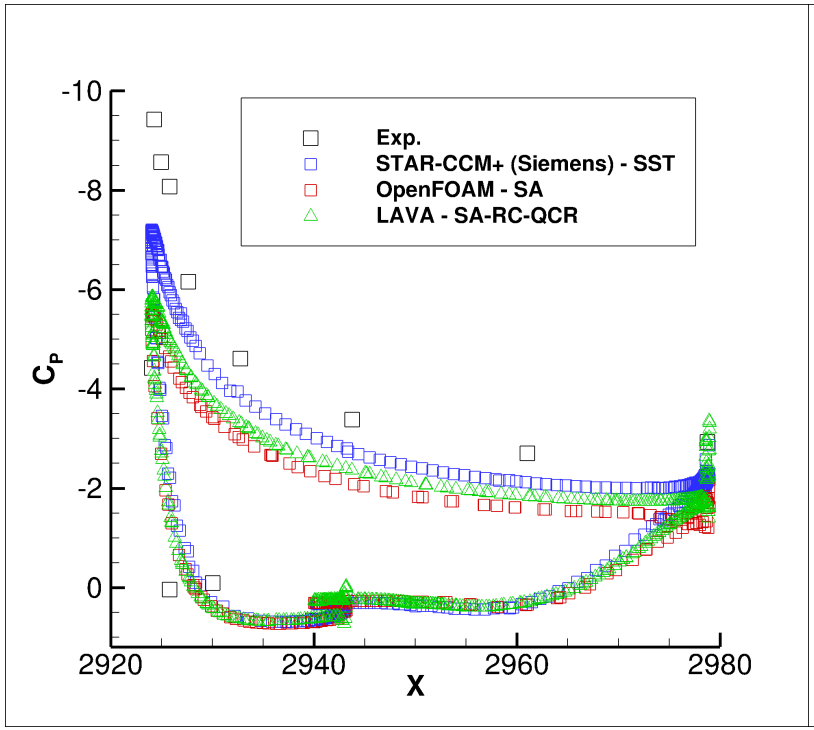


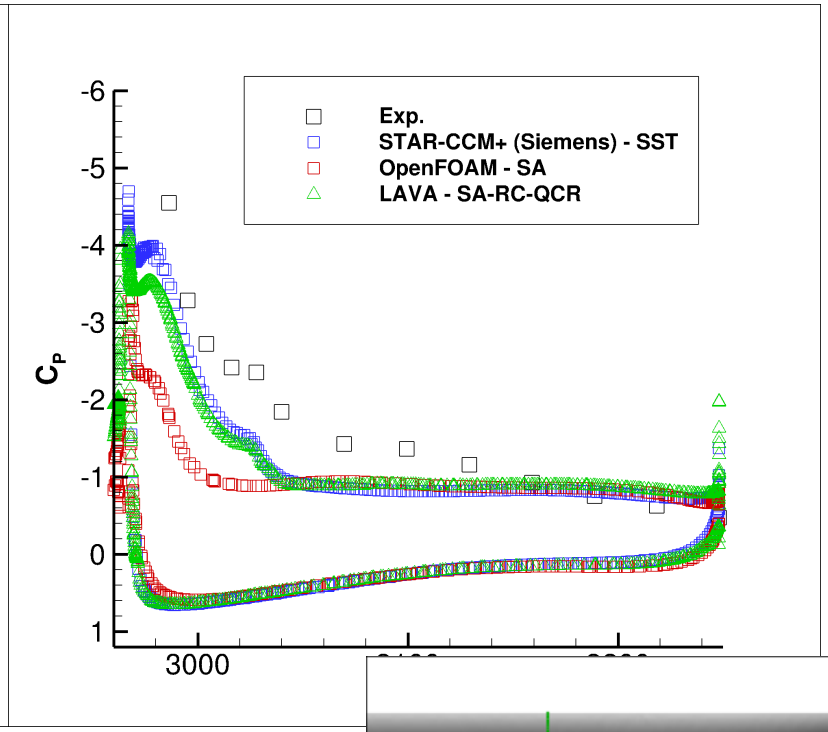
JSM NACELLE 21.57° – A-A

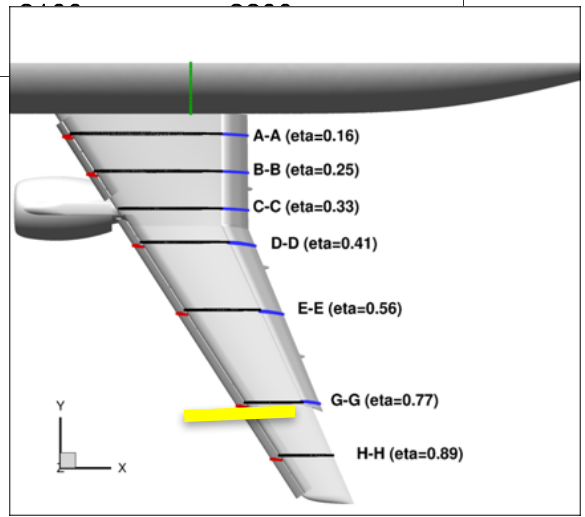
- Whilst Siemens (SST) gives inboard loses for nacelle-on, it looks more like nacelle influences and isn't present for the nacelle-off



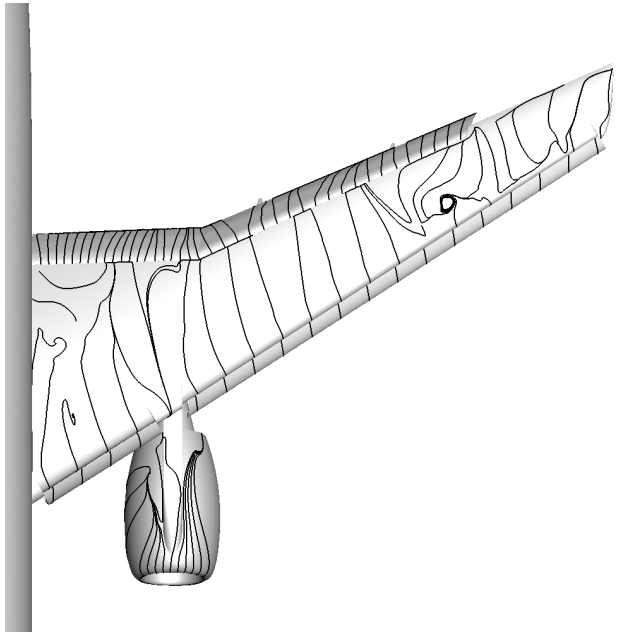
JSM NACELLE 21.57° – H-H



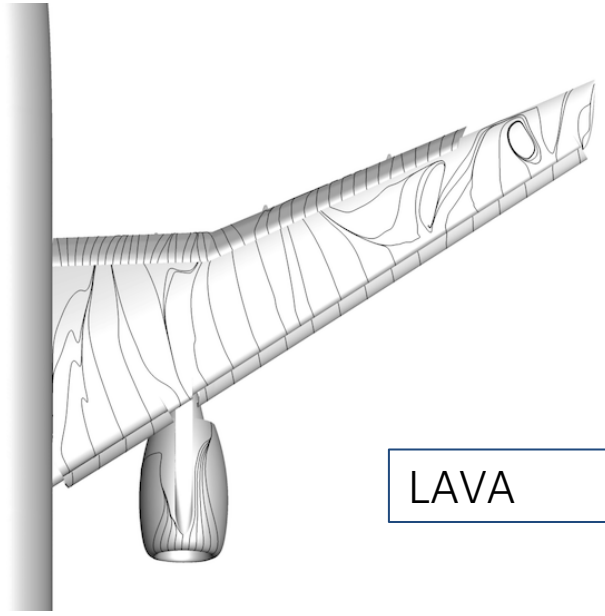




JSM NACELLE-ON 21.57°

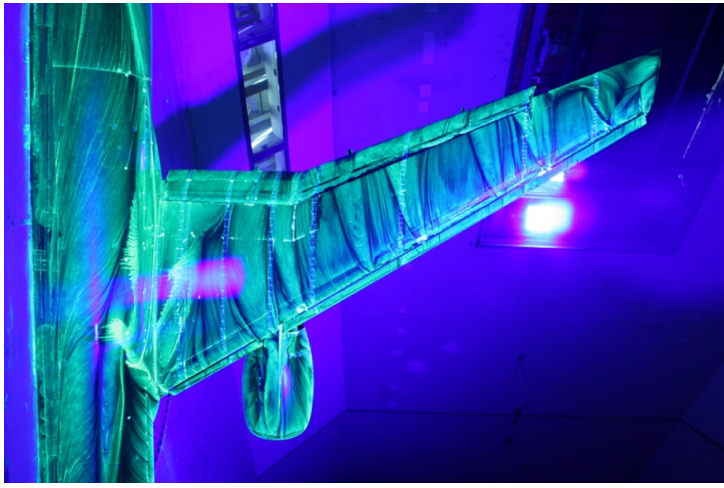


OpenFOAM



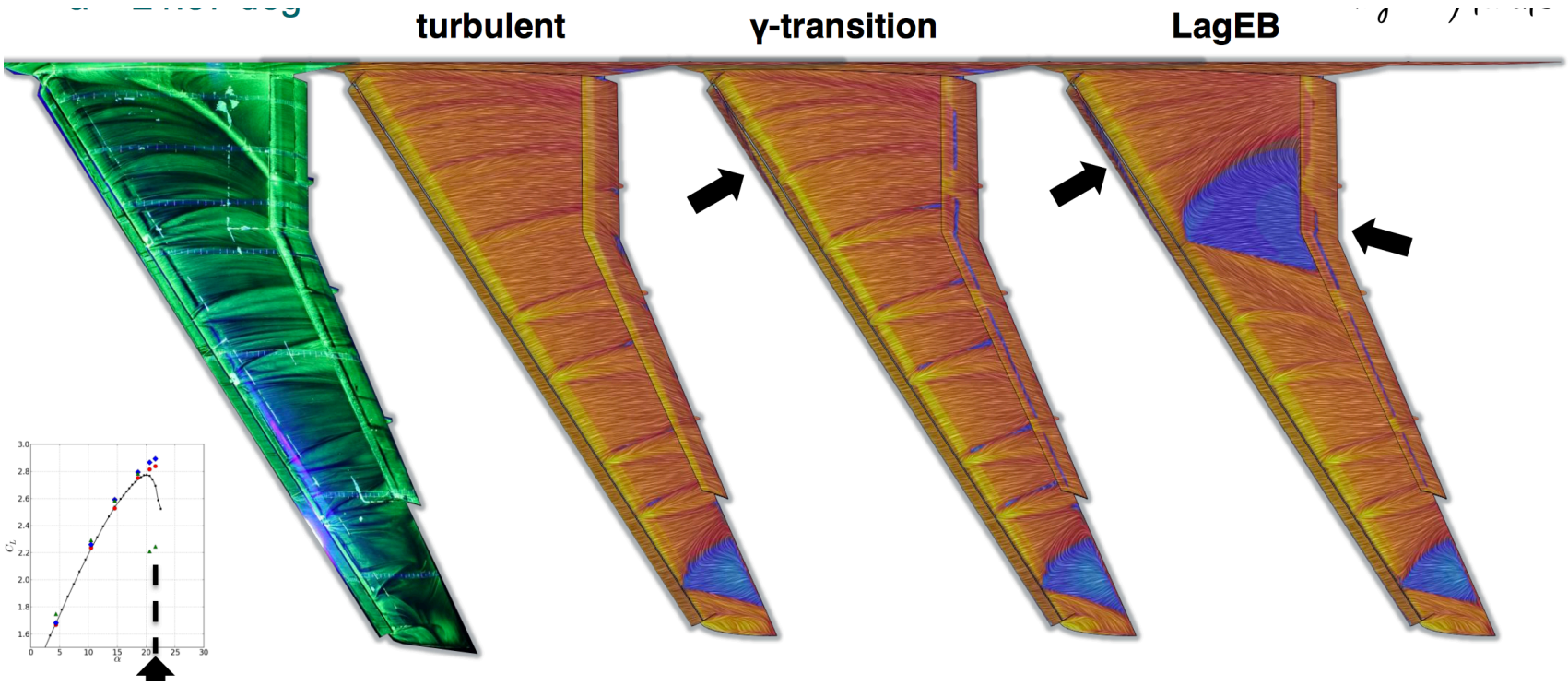
LAVA

- Over-predicting outboard stall
- Capturing in-board separation (unlike no-nacelle case)



JSM NACELLE-ON 21.57°

- Siemens ran gamma transition model with SST but did not see an influence on the inboard separation



Summary (1)

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- Fantastic learning experiences, many things to learn for HLPW4
- Assessment of three unstructured codes
  - Clear that meshing is a large variable – not just cell count but design
  - User settings clearly make a different
- OpenFOAM performed well (against prior expectations) matching STAR-CCM+ within 2% for the force coefficients
- STAR-CCM+ was found however to be more robust than OpenFOAM when using the same mesh/turb model. OpenFOAM still has some robustness issues

Summary (2)

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- Good results from LAVA with 70M but SA-RC-QCR doesn't seem to offer any improvements over SA in capturing the inboard stall
- Transition is still an open question – Siemens have started to investigate this but results do not appear to fix inboard stall.
- Transient methods may help but I'm not sure if this is why the inboard separation is wrong. Should be model the WT walls and take another look at meshing in this region?

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Thank you

- EPSRC for UK's National HPC Facility, ARCHER
- BETA-CAE Systems for ANSA licenses
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- The collaboration with and support from the 3rd AIAA High Lift Prediction Workshop organizing Committee are also greatly appreciated.
- The authors would also like to thank Sylvain Lardeau and Steve Evans from Siemens