

Contribution to HiLiftPW-3

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Gulfstream Aerospace - 039

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Summary of cases completed: FUN3D, Committee Grids, SA

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Polar, Restarts, 19° - stall, Fully turb, grid study
1a (full gap)	yes	yes	yes
1b (full gap w adaption)	no	no	no
1c (partial seal)	no	no	no
1d (partial seal w adaption)	no	no	no
Other			

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Polar, Restarts, 6° - 18.5°, Fully turb
2a (no nacelle)	yes	no	no	yes
2b (no nacelle w adaption)	no	no	no	no
2c (with nacelle)	yes	no	no	yes
2d (with nacelle w adaption)	no	no	no	no
Other				

Case	2D Verification study	Other
3	no	
Other		

Summary of cases completed: FUN3D, Custom Grids, SA

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Polar, Restarts, 9° - stall, Fully turb, grid study
1a (full gap)	no	yes	yes
1b (full gap w adaption)	no	no	no
1c (partial seal)	no	no	no
1d (partial seal w adaption)	no	no	no
Other			

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Polar, Restarts, 6° - 18.5°, Fully turb
2a (no nacelle)	yes	no	no	yes
2b (no nacelle w adaption)	no	no	no	no
2c (with nacelle)	yes	no	no	yes
2d (with nacelle w adaption)	no	no	no	no
Other				

Case	2D Verification study	Other
3	no	
Other		

Solution Background

- Solver : FUN3D
 - Developed at NASA Langley
 - Finite volume RANS solver
 - Roe's flux difference splitting
 - Node-centered, unstructured, mixed-element
- Turbulence model: SA
- Convergence Criteria
 - CL and CD variation within $\pm 0.1\%$
 - JSM Grids required relaxed criteria to $\pm 1.0\%$, but could not meet this criteria at higher AOA
- Flow initialization
 - Cases were submitted from scratch (free-stream initialization) as well as with restarts (initialized from previously resolved solutions at lower AOA)
- References
 - Park, M. A., Laflin, K. R., Chaffin, M. S., Powell, N. A., and Levy D. W., "CFL3D, FUN3D, and NSU3D Contributions to the Fifth Drag Prediction Workshop", AIAA Journal of Aircraft, Vol. 51, No. 4, July-Aug 2014, pp.1268-1283.

Brief overview of grid systems

Grid System	Case(s)	Notes
Committee B2-HLCRM_UnstrPrismTet_PW	1a	Solutions converged well, but XFine grid is prohibitively expensive to run a full alpha sweep due to dense grid
Committee C2-JSM_UnstrMixed_VGRID	2a,2c	Experienced large amounts of separation along the wing which prevented FUN3D from obtaining converged solutions
User HLCRM_UnstPrismTet_HM	1a	Generated grid system in order to explore and compare GAC's gridding methodologies to the committee provided grids
User JSM_UnstPrismTet_HM	2a, 2c	These grids were created in an attempt to see if large regions of flow separation over the wing were unique to committee grids

GAC Custom Grid Generation

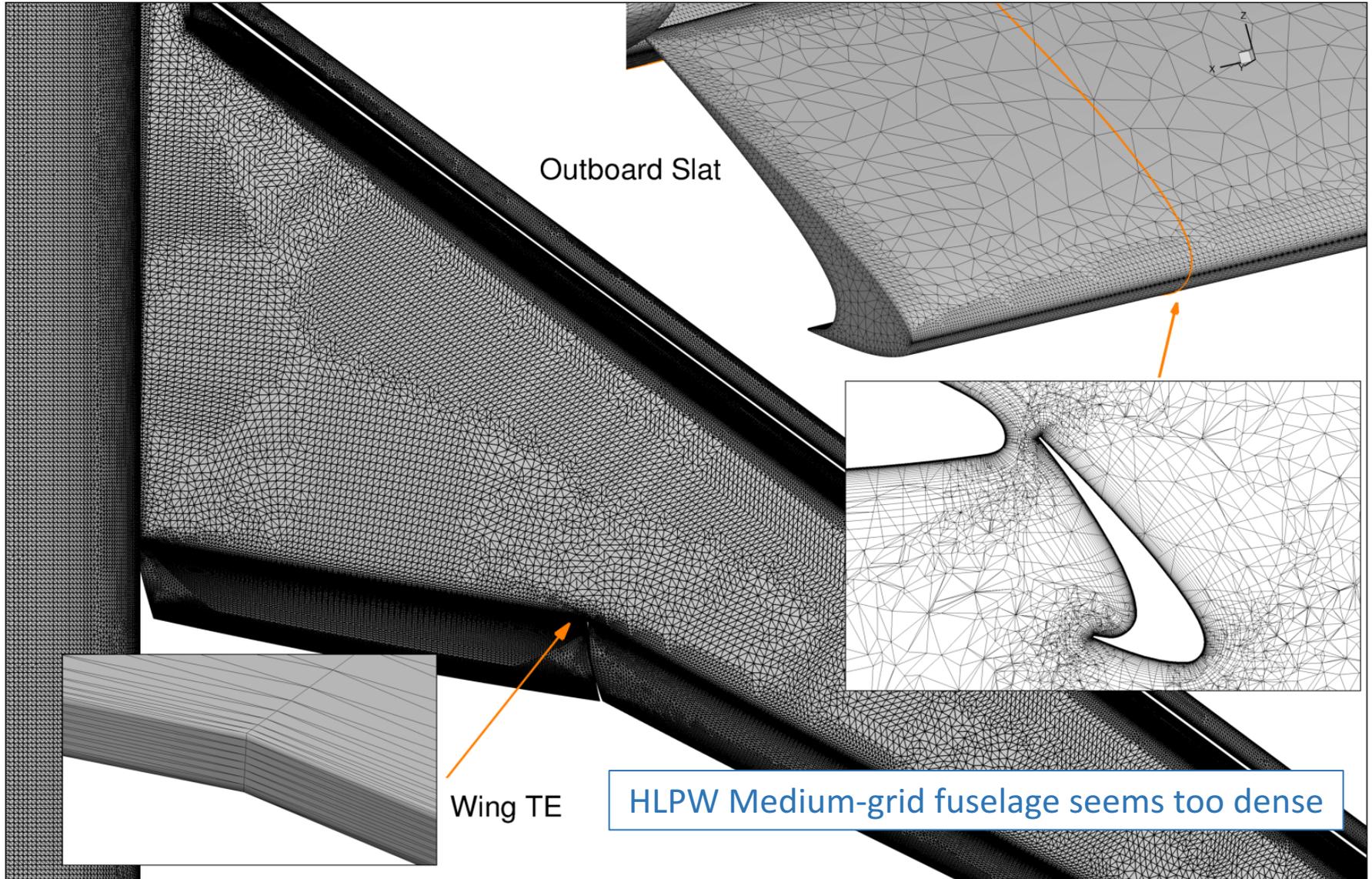
- Code: HeldenMesh
 - Commercial code similar to VGRID
 - Unstructured mixed element
 - Advancing front (inviscid grid) and advancing layers (viscous grid)
 - Capable of generating grids straight from IGES geometry with minimal user interaction
 - Surface sources enable user to set mesh resolution based on surface curvature
- Advancing front grid parameters
 - Geometric growth rate of 10%
 - Exponential growth rate of 7%
- Advancing layer grid parameters
 - Geometric growth rate of 15%
 - Exponential growth rate of ~2.0%
 - Height of the first grid point off of the surface:
 - 0.0016 for the HLCRM and 0.001 for JSM
- Geometries needed modification (small wedges) in order for HeldenMesh to create a grid without any invisible vectors

Custom HLCRM Grid Convergence Study

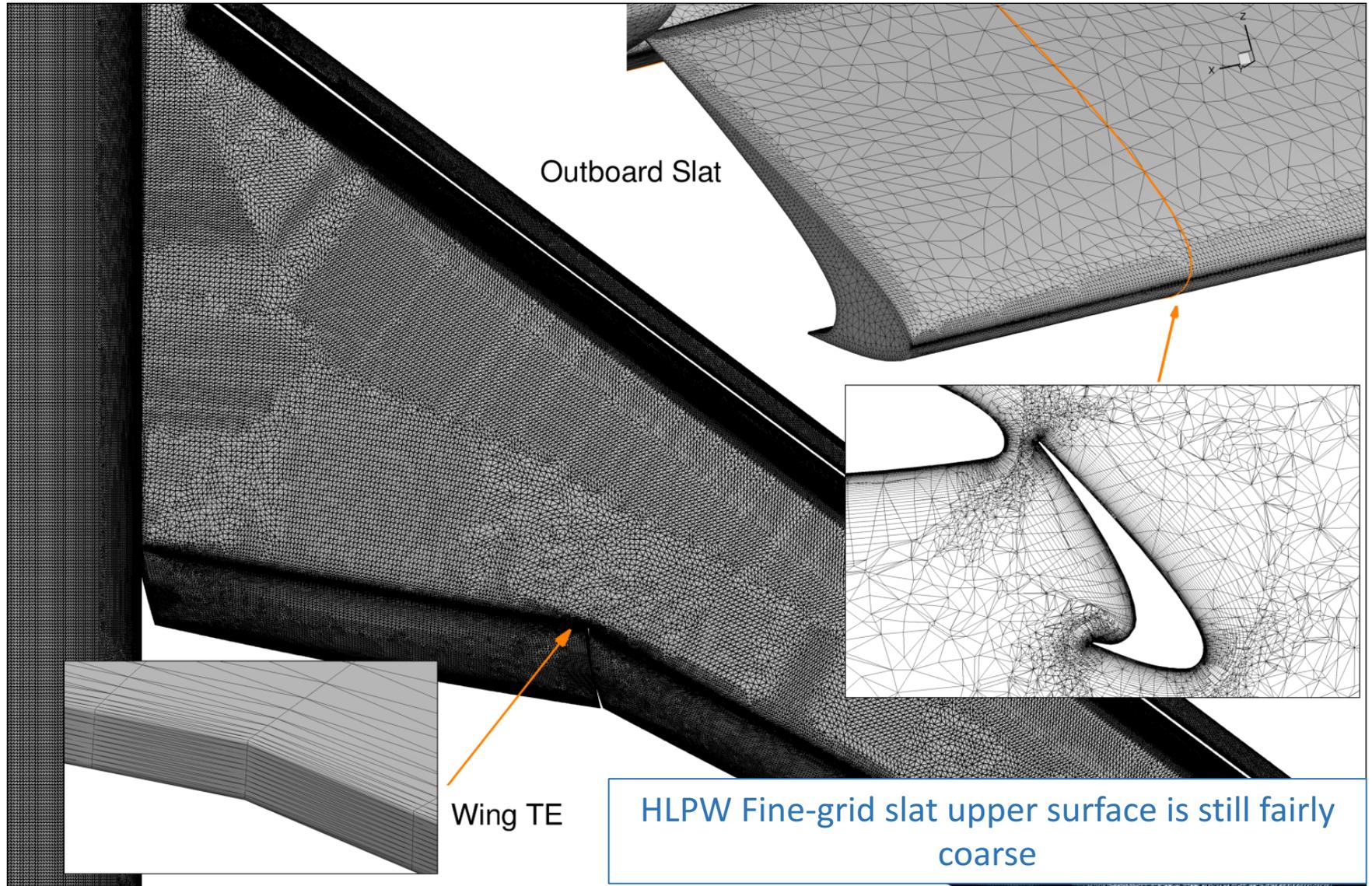
Refinement Level	Number of Points GAC Custom Grid	Number of Points B2-HLCRM Unstructured Prism Tet PW
Extra Coarse	27,797,836	NA
Coarse	33,317,931	8,088,820
Medium	41,392,107	26,491,099
Fine	54,451,571	69,890,916
Extra Fine	77,884,918	205,577,514

- Grid study conducted at $\alpha=16^\circ$ and $\alpha=19^\circ$
- Individual component forces plotted to understand which areas are most sensitive to grid refinement
- Departures from HLPW Gridding Guidelines
 - Chord wise spacing of LE between 0.3% and 0.7% local chord (sample from custom HLCRM slat)
 - Grid size does not grow 1.5X in all directions per grid level
 - Advancing front grid factored by 0.6, 0.8, 1.2 and 1.4
 - Advancing layer growth rate was not scaled with refinement
 - Viscous grid grows immediately (no constant cell spacing)

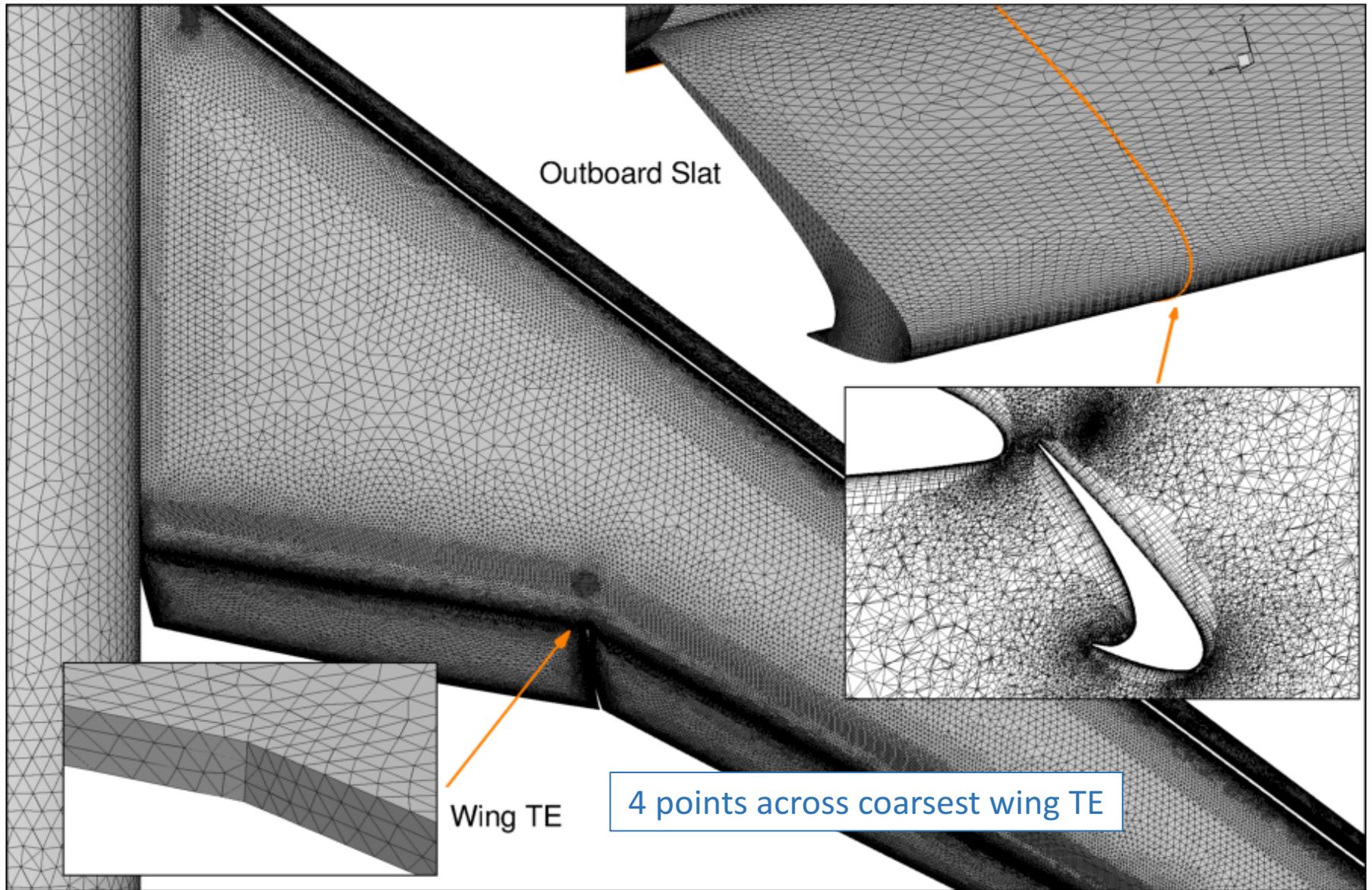
Workshop Provided Prism-Tet HLCRM Medium Grid



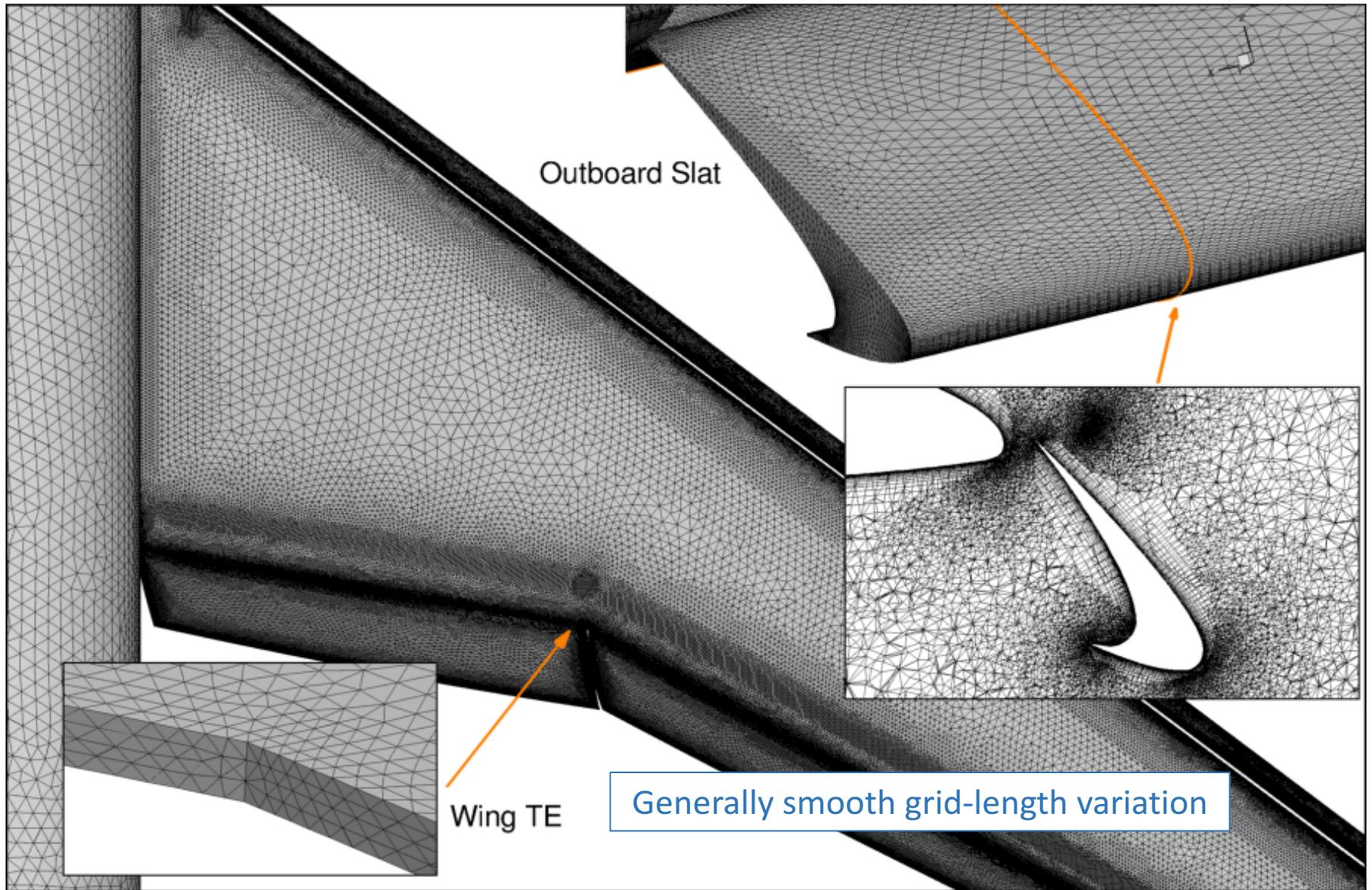
Workshop Provided Prism-Tet HLCRM Fine Grid



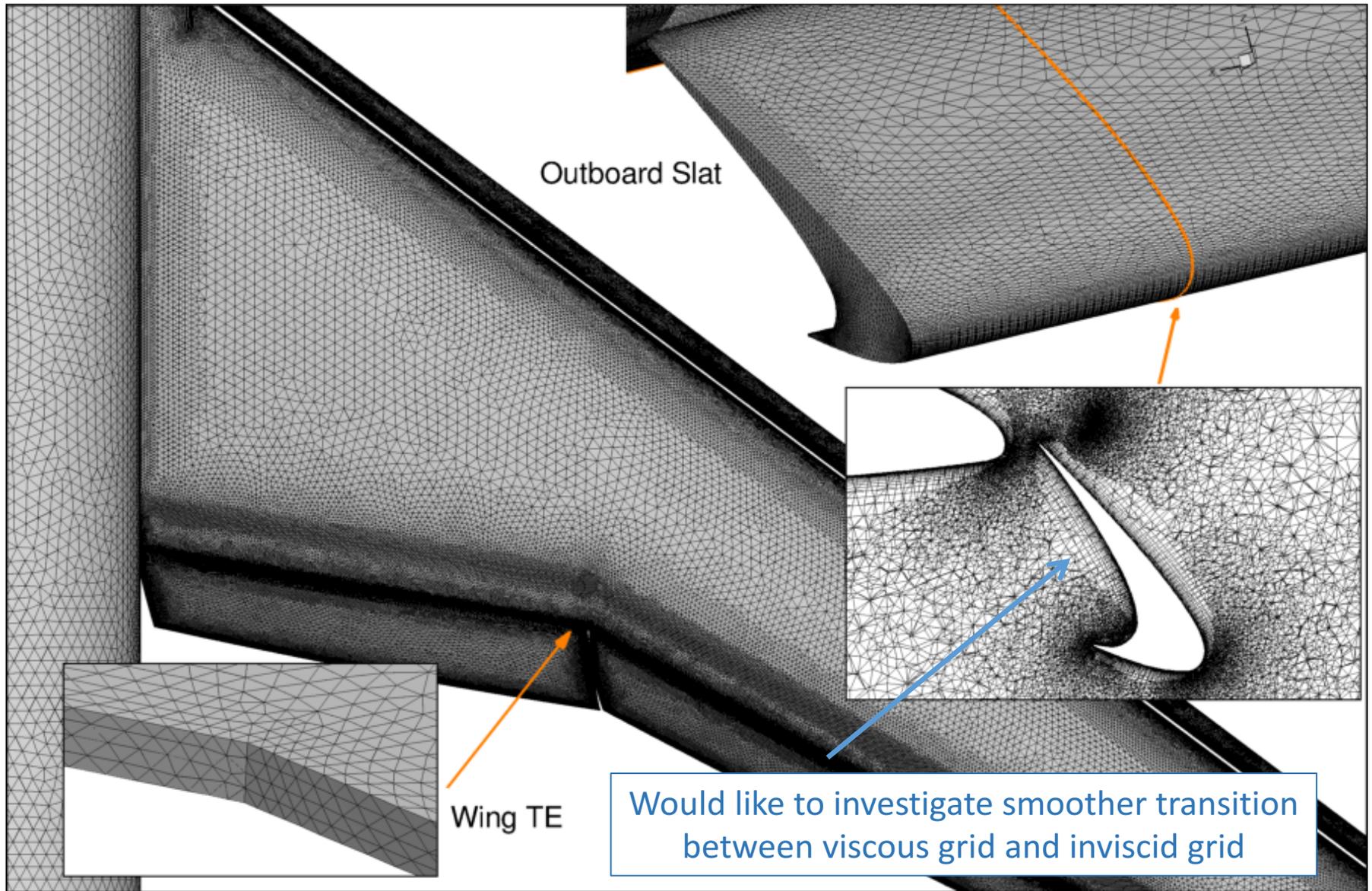
GAC Custom HLCRM XCoarse Grid



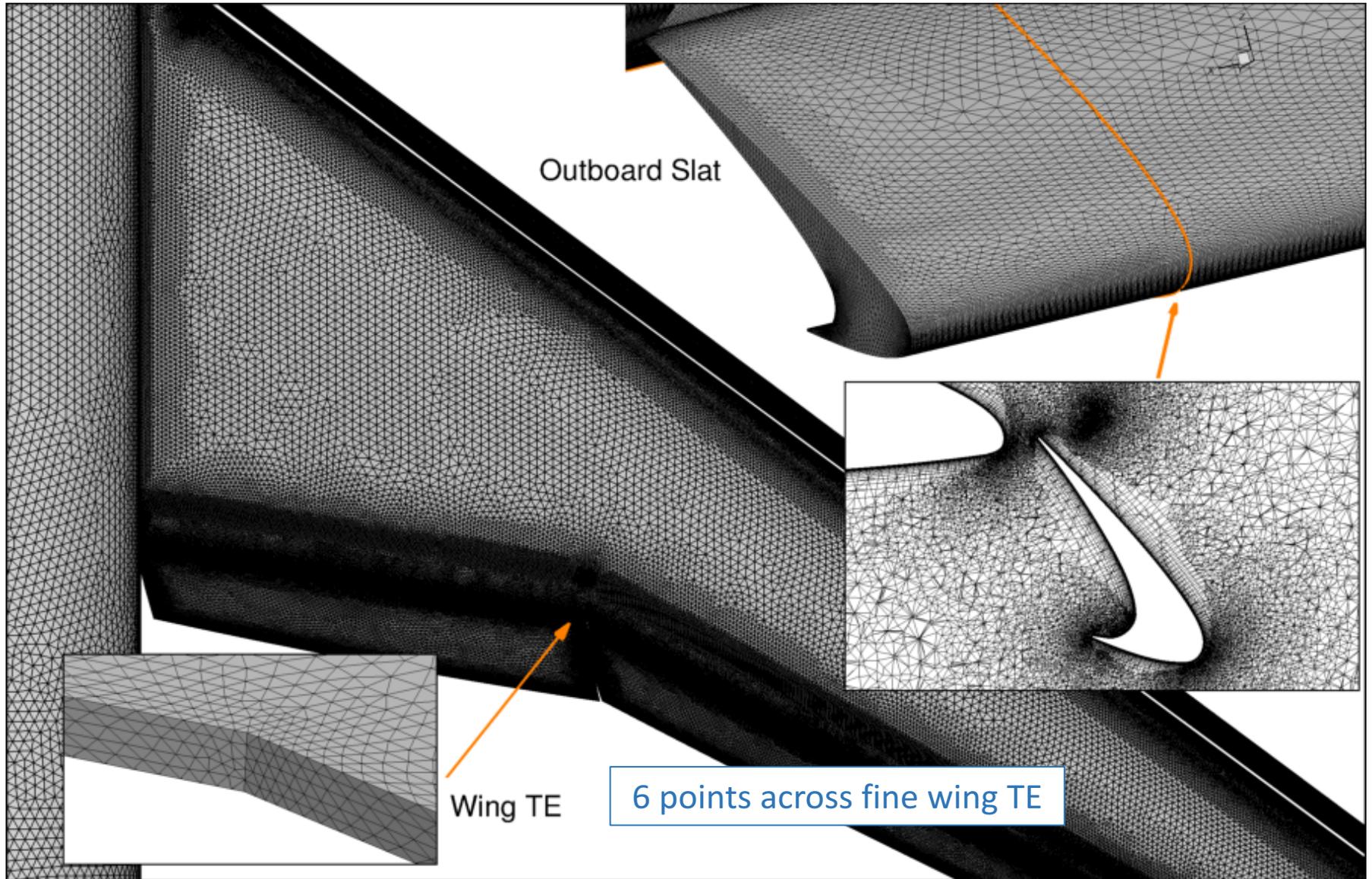
GAC Custom HLCRM Coarse Grid



GAC Custom HLCRM Medium Grid

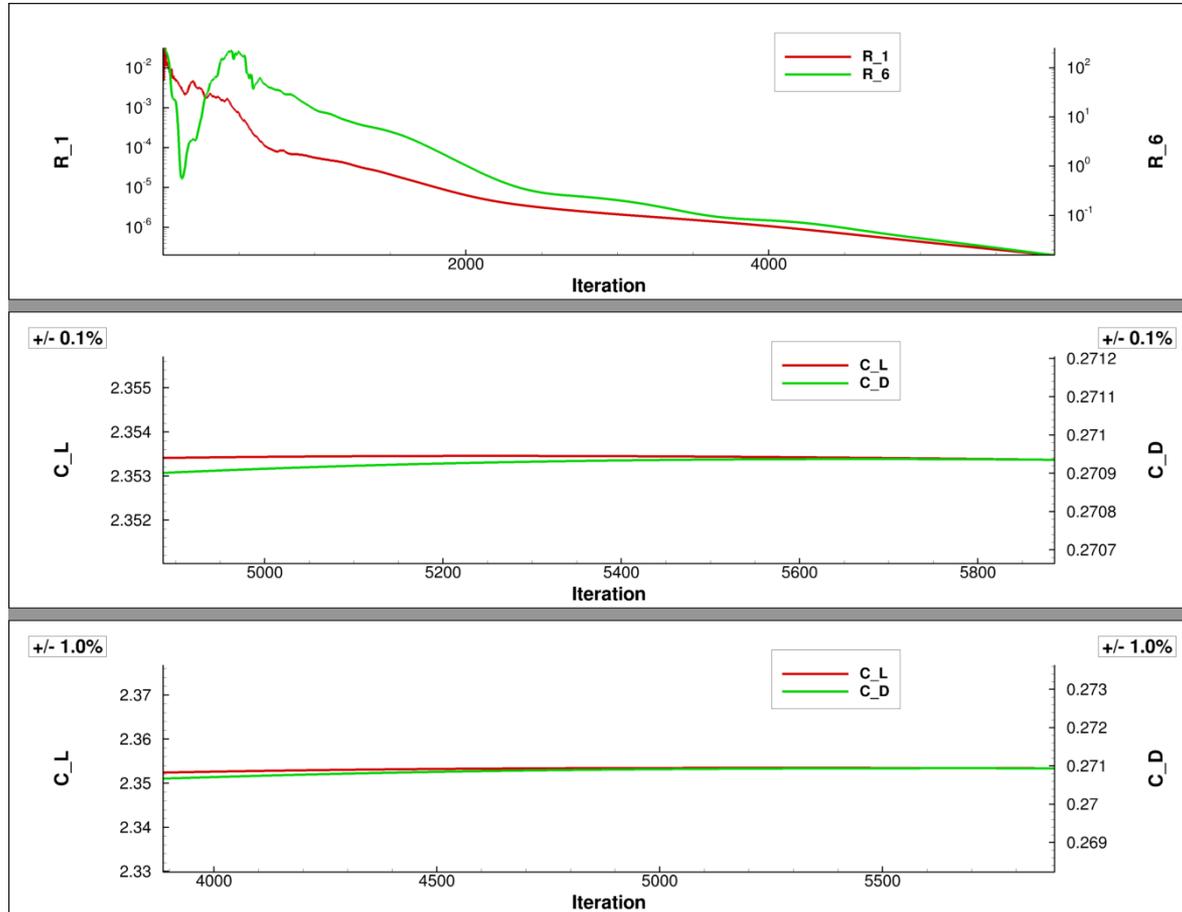


GAC Custom HLCRM Fine Grid



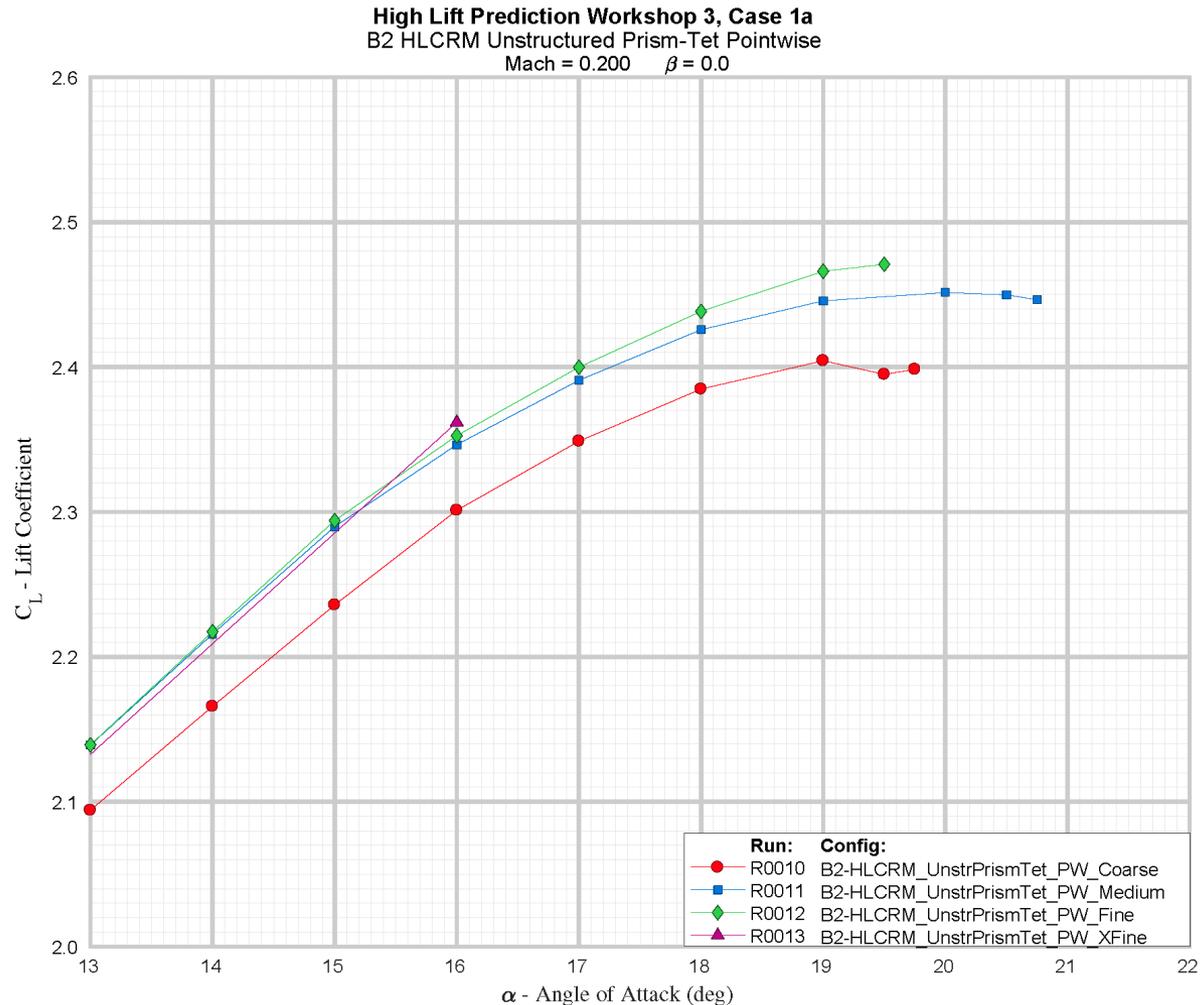
Convergence Histories

CRM – Committee Fine Grid at 16°



CRM demonstrates smooth convergence

Workshop Provided Prism-Tet HLCRM Grids

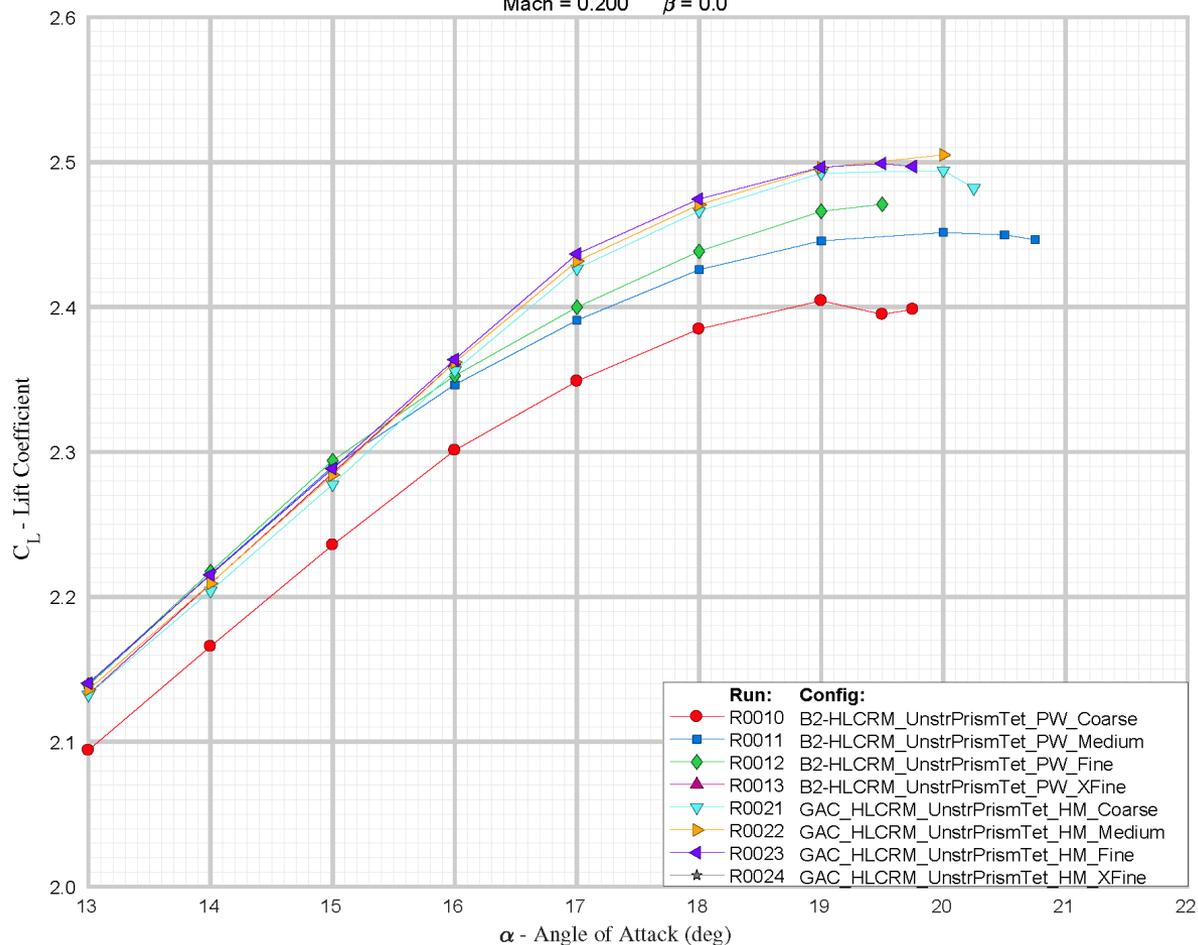


Grid refinement increases CL_{max}

All solutions restarted from previous solutions at lower AOA

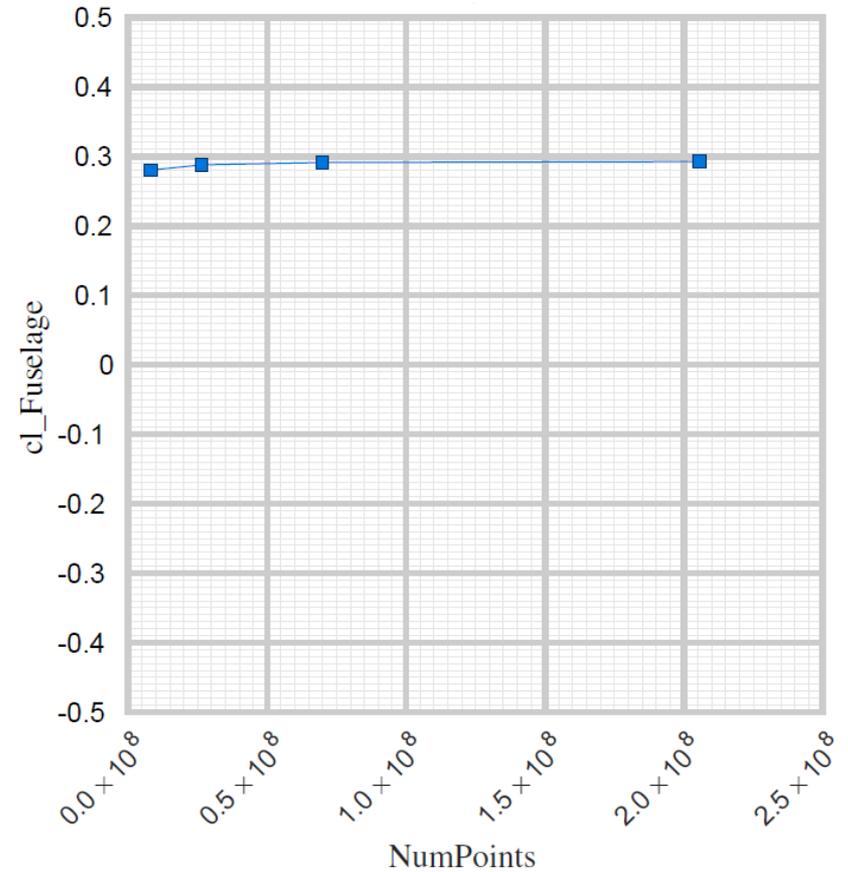
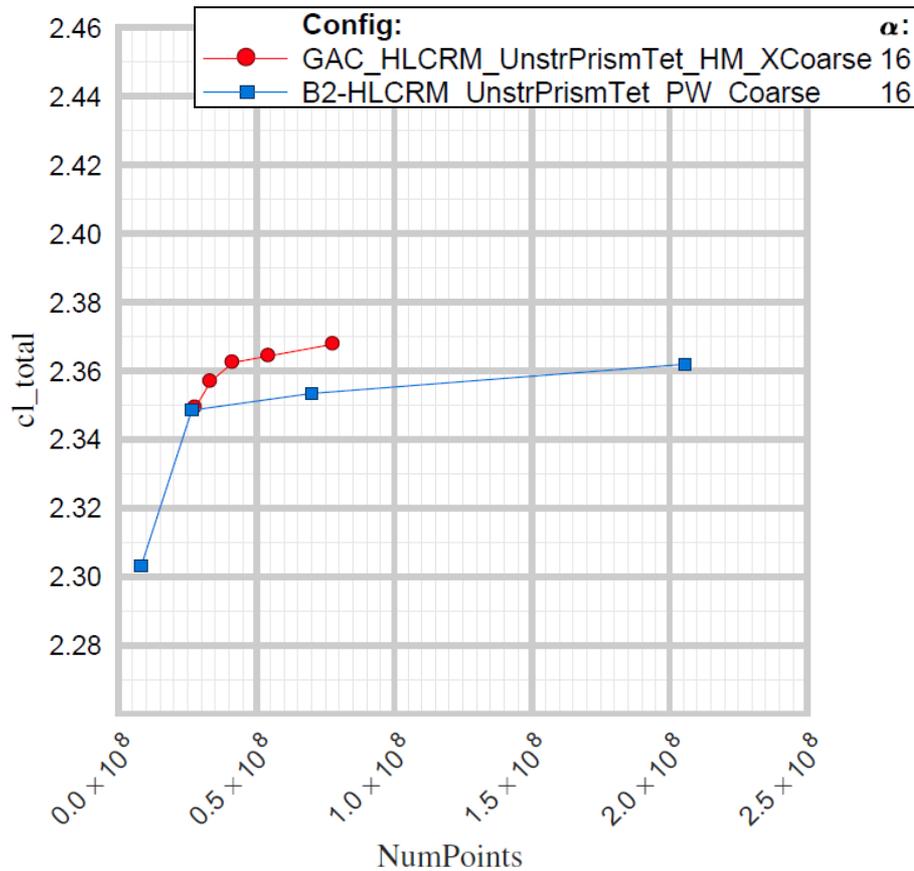
GAC Prism-Tet HLCRM Grids

High Lift Prediction Workshop 3, Case 1a
GAC Custom and Committee Provided Grids
Mach = 0.200 $\beta = 0.0$



Custom grids predict higher C_L after 16°
Custom results exhibit small variation in C_{Lmax}

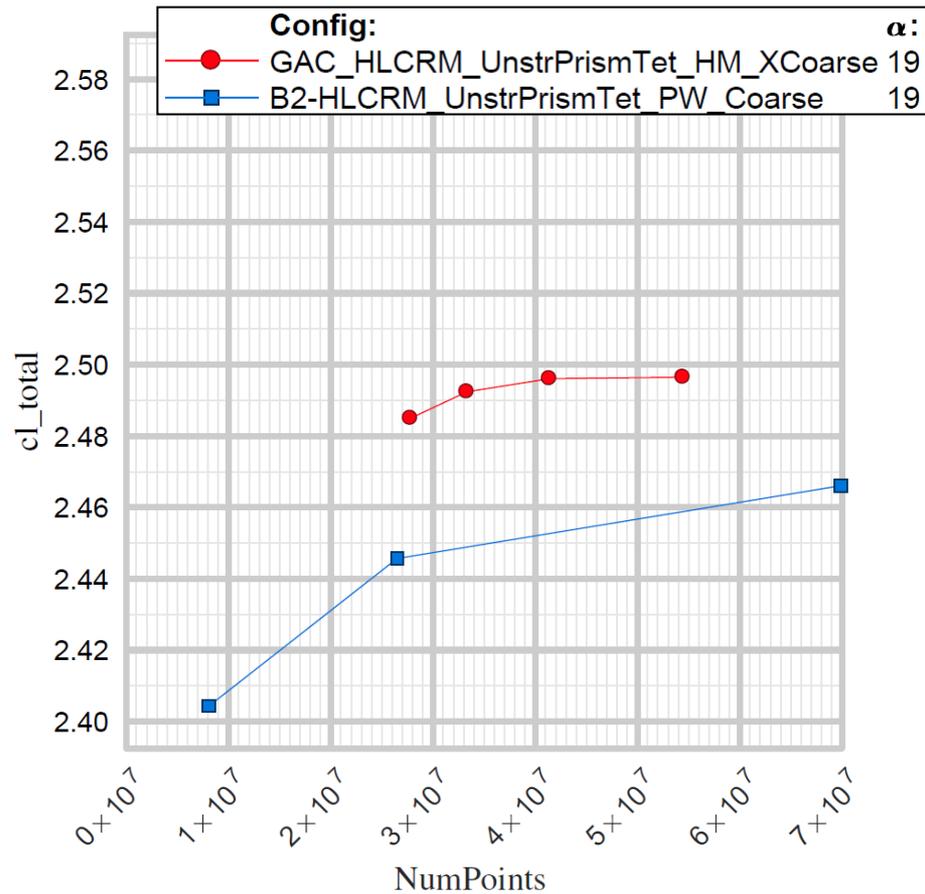
Grid Dependency at 16°



Committee and custom grids indicate grid independence at 16°

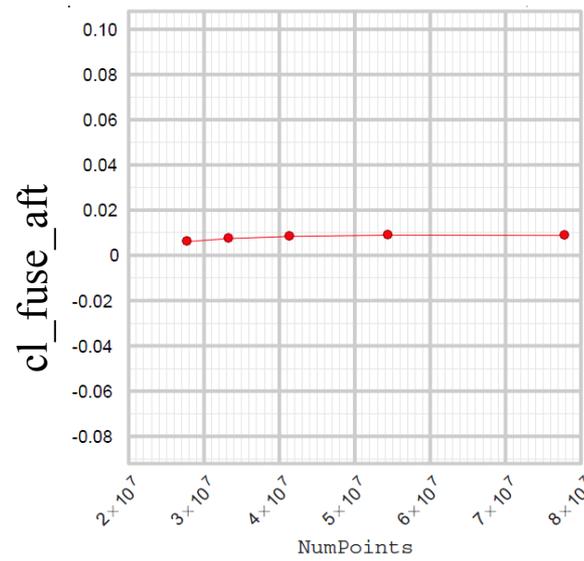
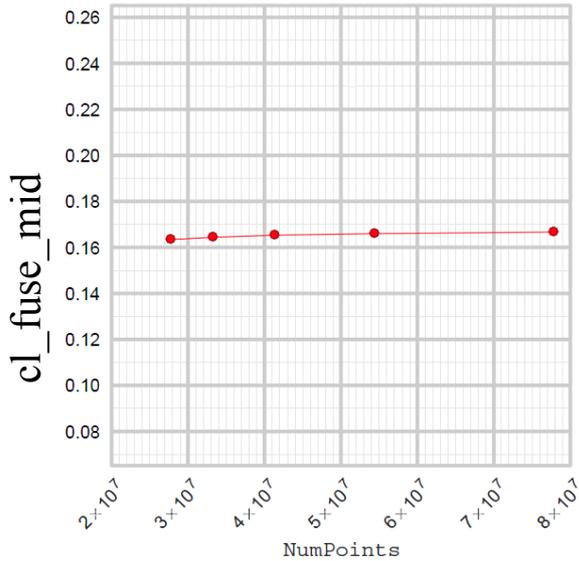
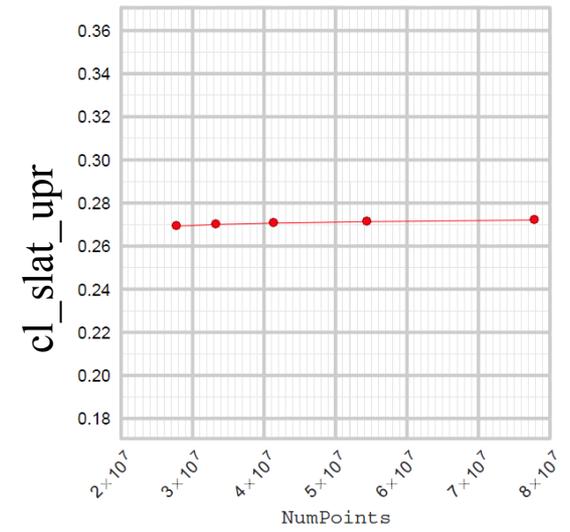
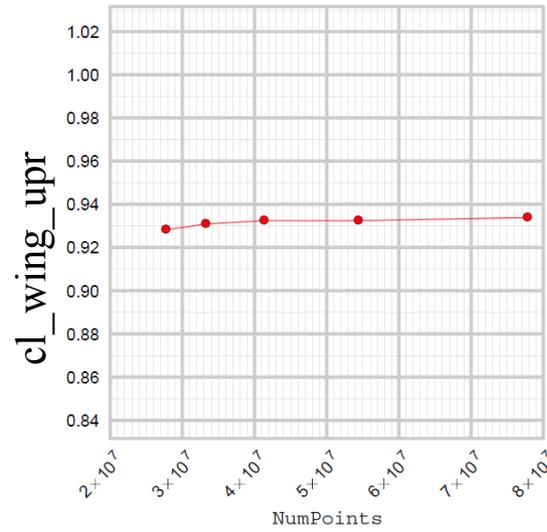
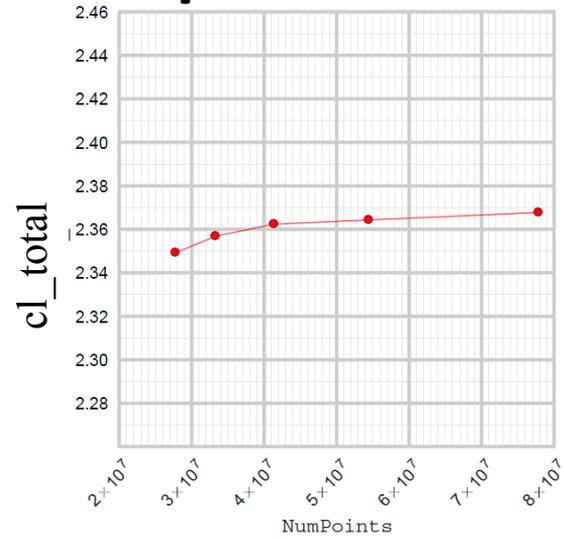
Committee fuselage exhibits very little grid dependency beyond medium grid

Grid Dependency at 19°



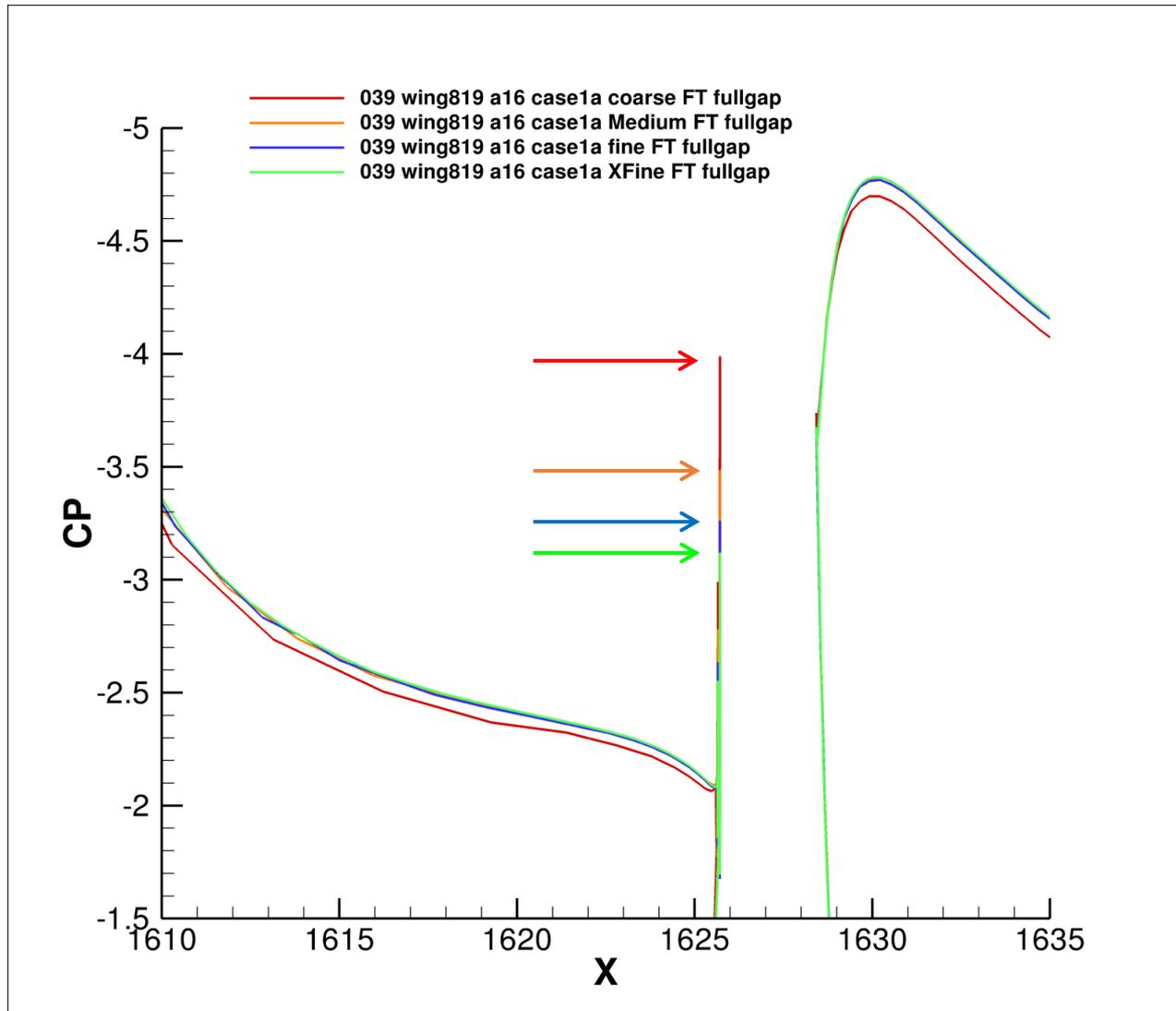
Committee and custom grids don't appear to converge on same CLmax
Custom medium grid seems to produce grid independent solution
Stall is important, hence the performance of a grid study at 19°

Component Level Grid Dependency Study of Custom Grids



Analyzed grid dependency for each aircraft component to determine local need for refinement

Slat TE Pressure Peak



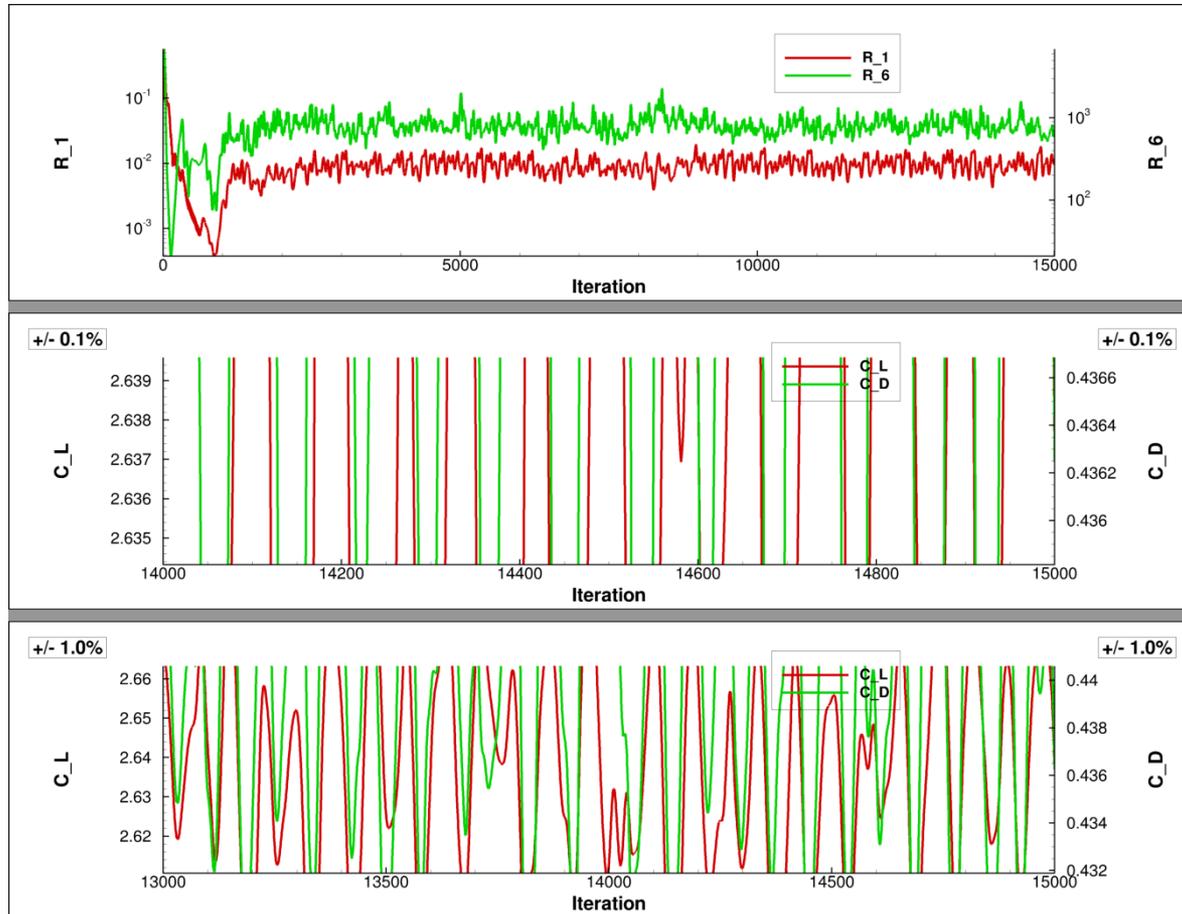
TE pressure peak decreases (minimum pressure increases) with grid refinement

HL-CRM Results

- Committee provided grids may not converge on a grid-independent CLmax within a usable range of grid resolution
 - Grid study results indicate that CL increases with increasing grid resolution
 - GAC grids converge on a CLmax that is 0.03 higher than the committee Fine grid
 - Committee XFine is prohibitively expensive to pursue CLmax
- Opportunities for improving grid efficiency were identified by analyzing local grid dependency
 - Committee grids showed little grid dependency on the fuselage, even for the coarse grid
- Increasing grid refinement on the slat TE reduced local suction peak
 - This may reduce the risk of grid-induced flow separation behind the slat; further analysis is needed

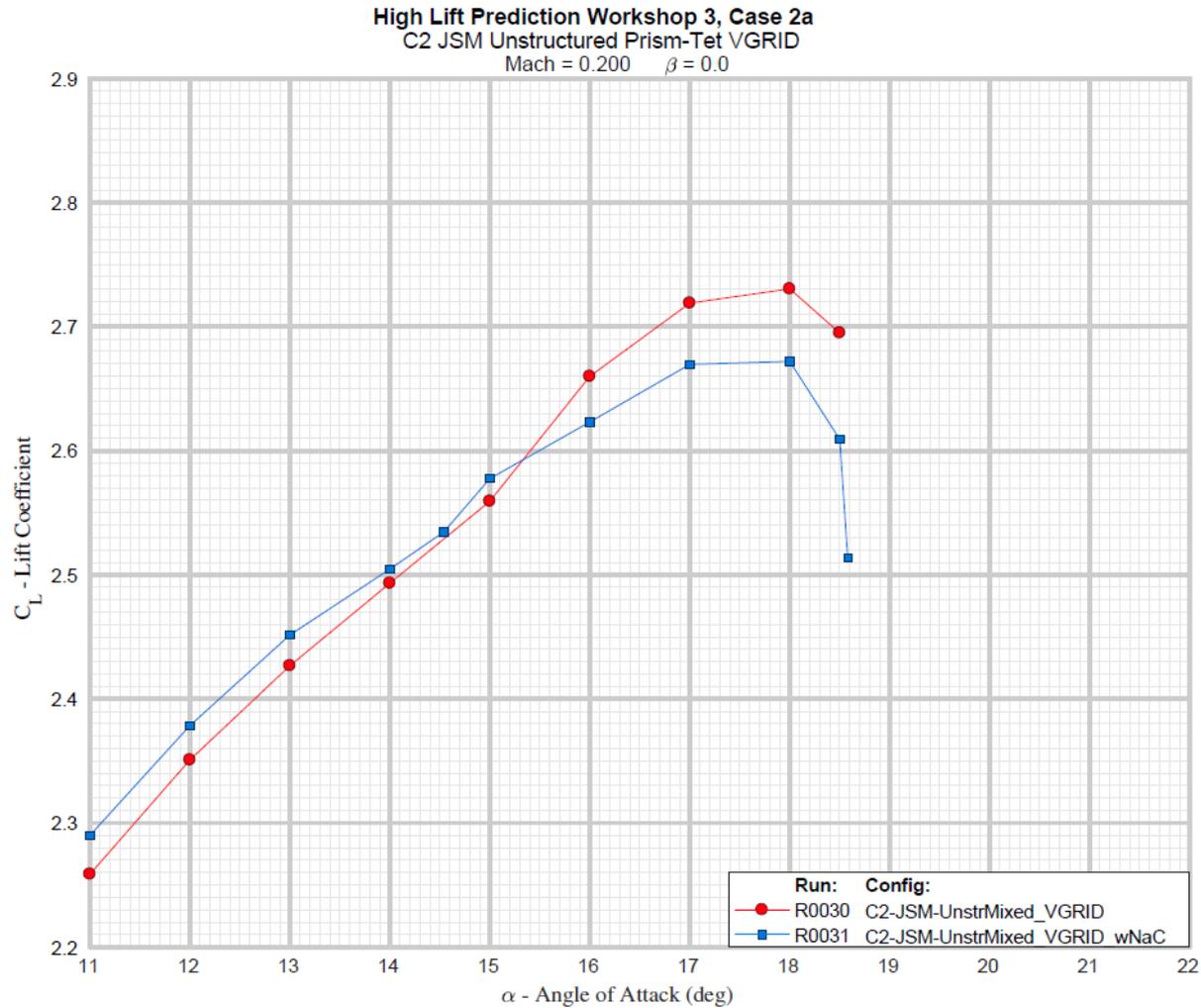
Convergence Histories

JSM – Committee w/out Nacelle at 18.58°



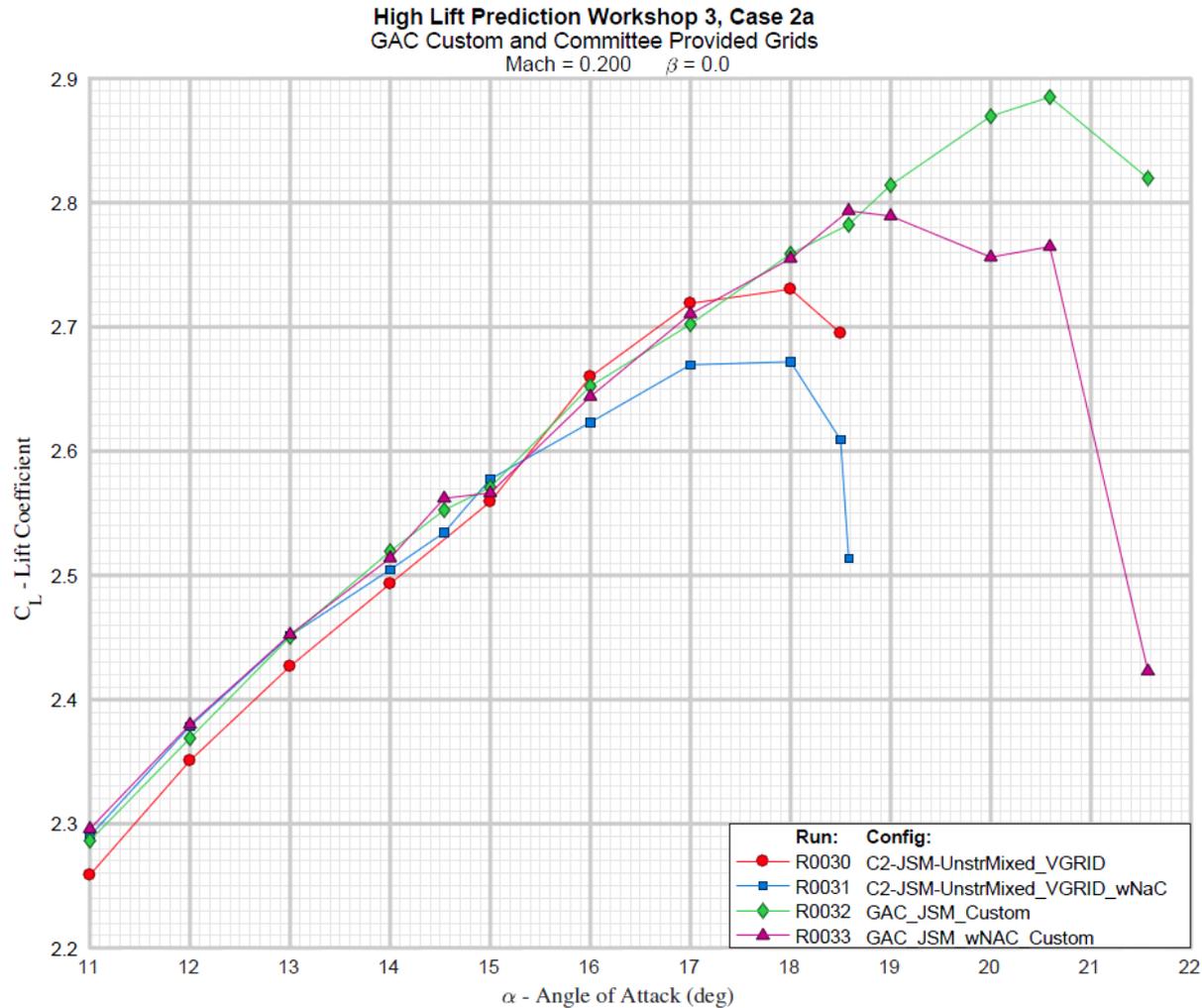
JSM shows unsteady convergence

Workshop Provided Prism-Tet JSM Grids



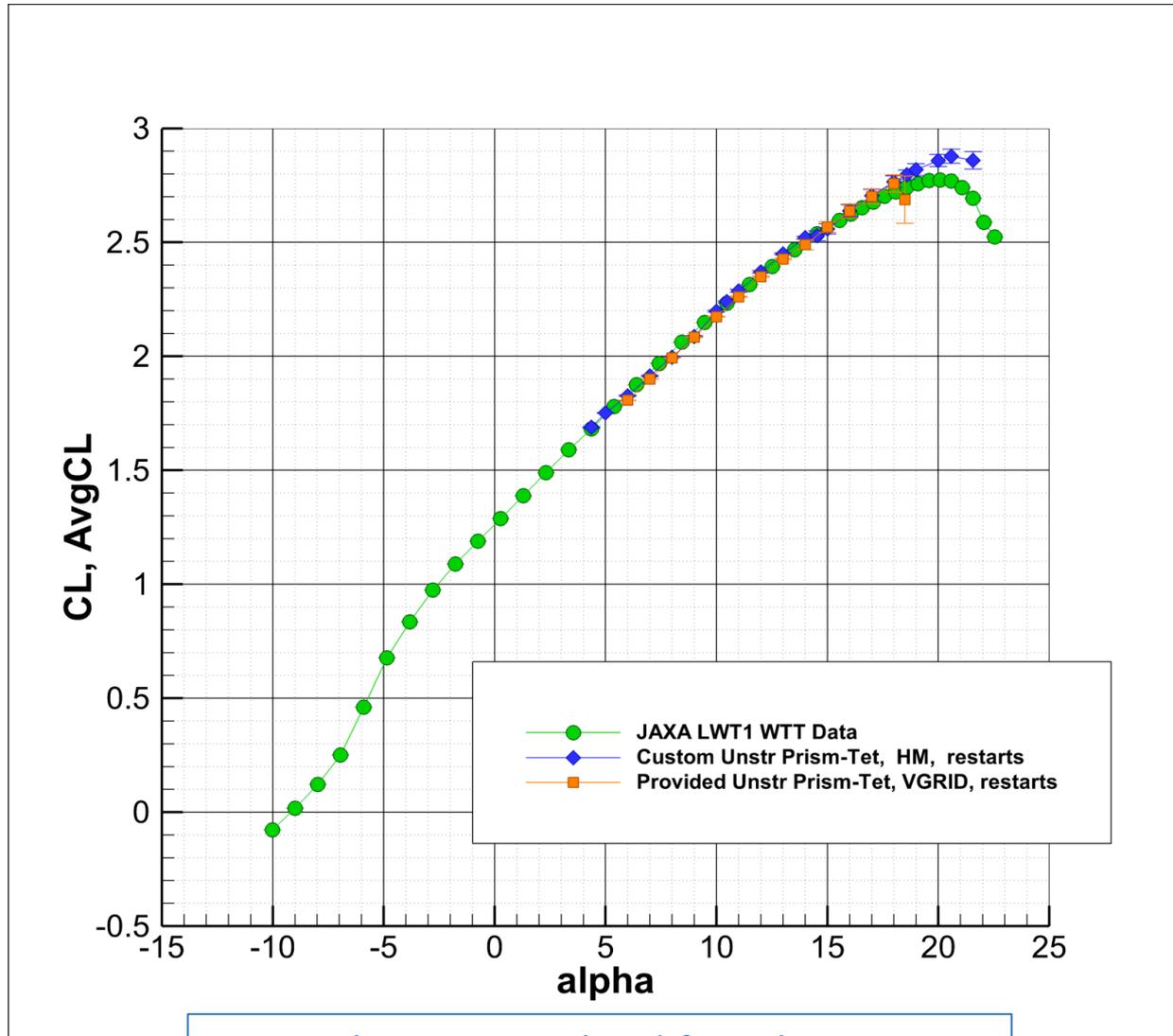
Significant level of noise in solution

GAC Prism-Tet JSM Results



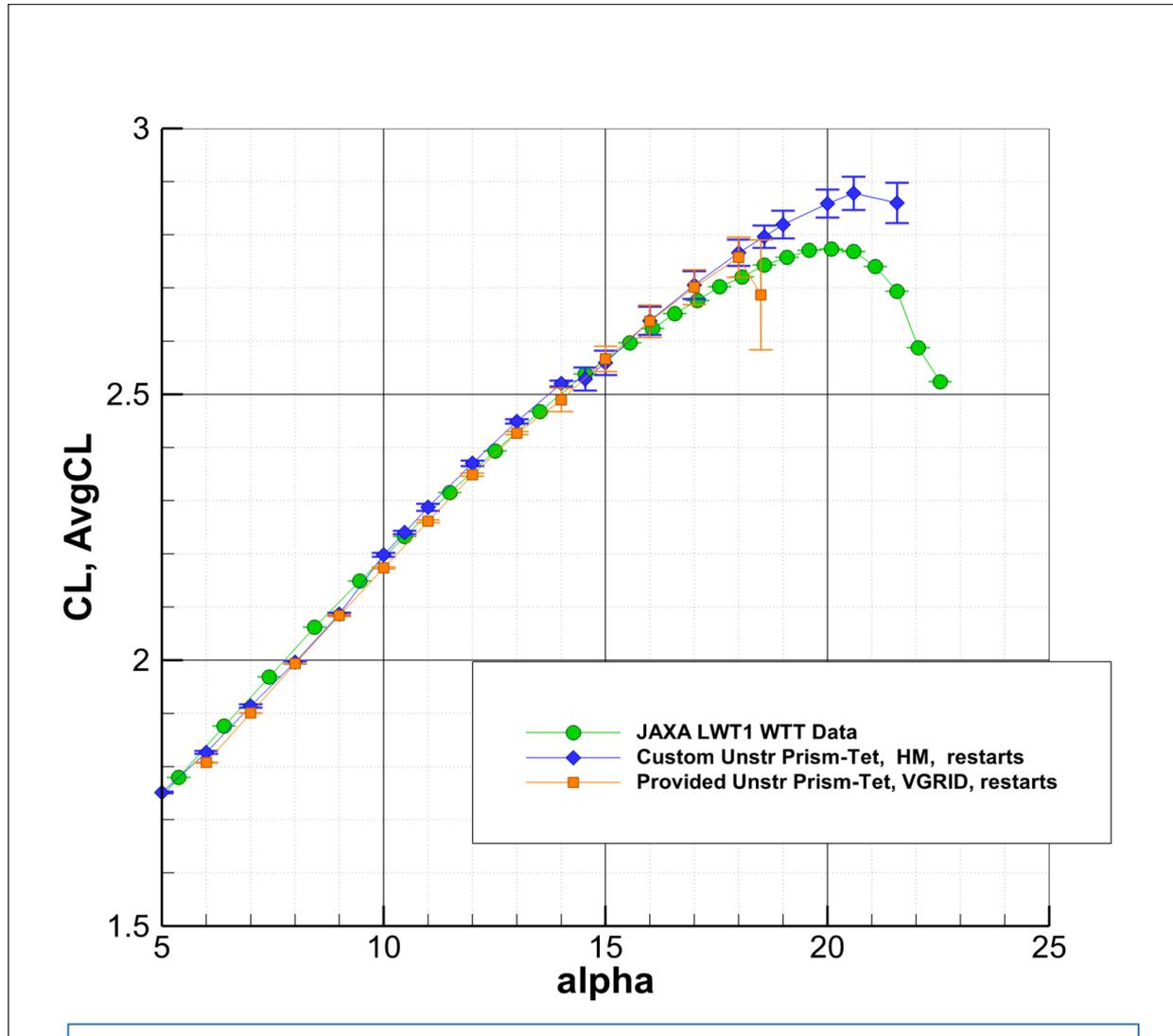
Custom grids indicate larger alpha max and greater CLmax

JSM Comparison to Wind Tunnel



CFD solutions initialized from lower AOA
CFD CL averaged over last 1000 iterations

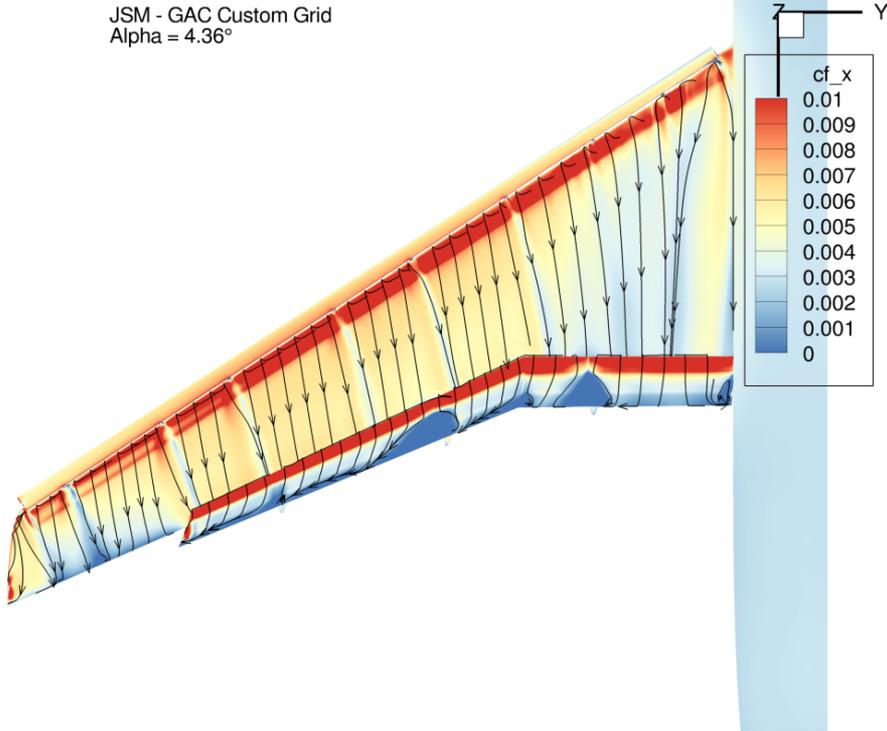
JSM Comparison to Wind Tunnel



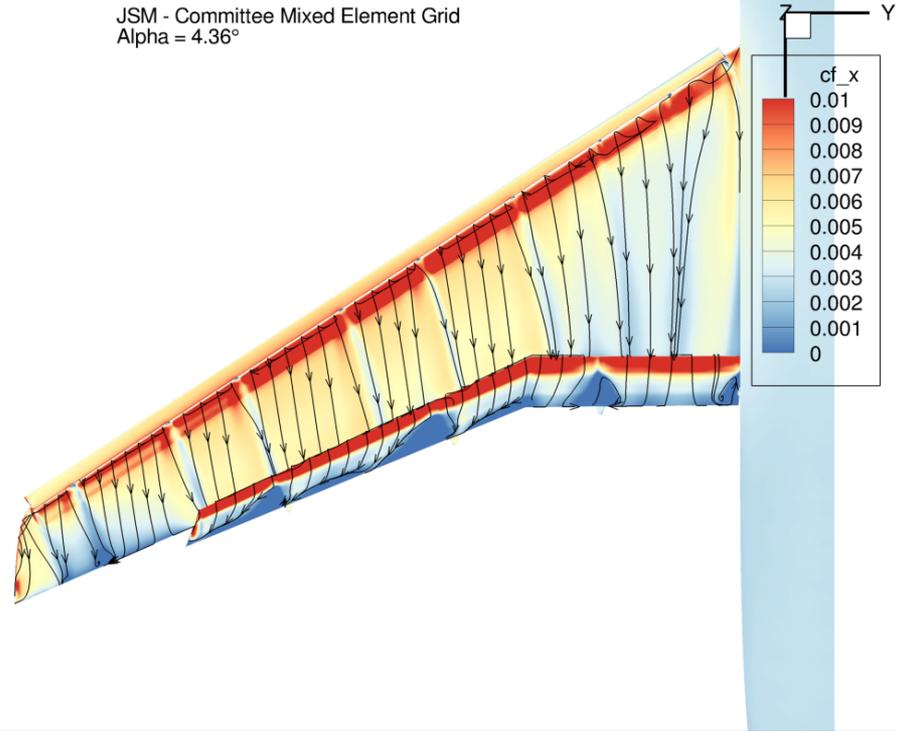
Initialized solutions compare well between 15° and 18°
but neither grid predicts CLmax

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 4.36°



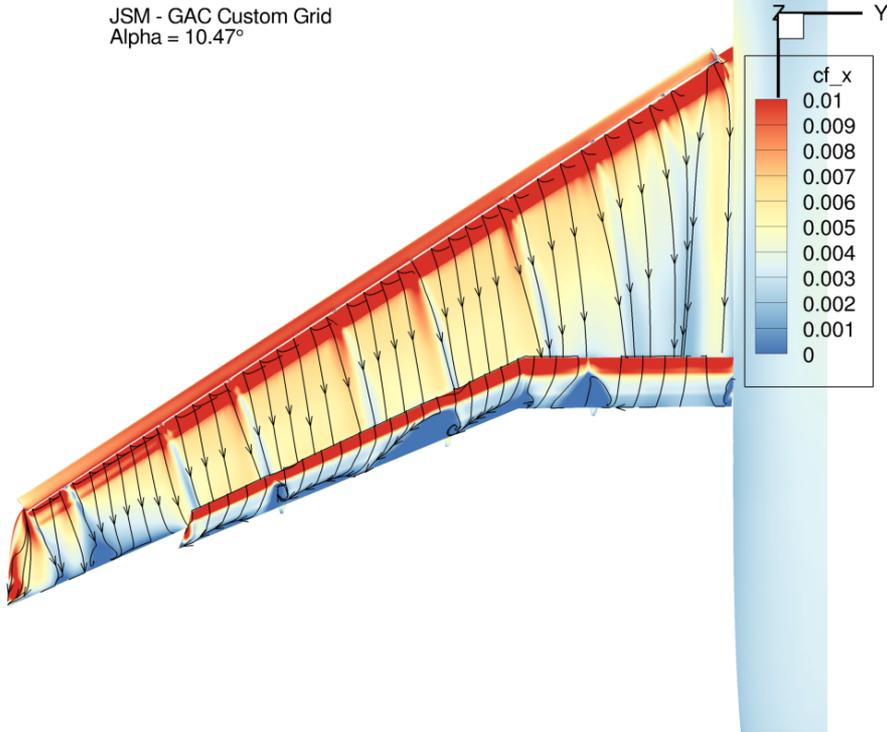
JSM - Committee Mixed Element Grid
Alpha = 4.36°



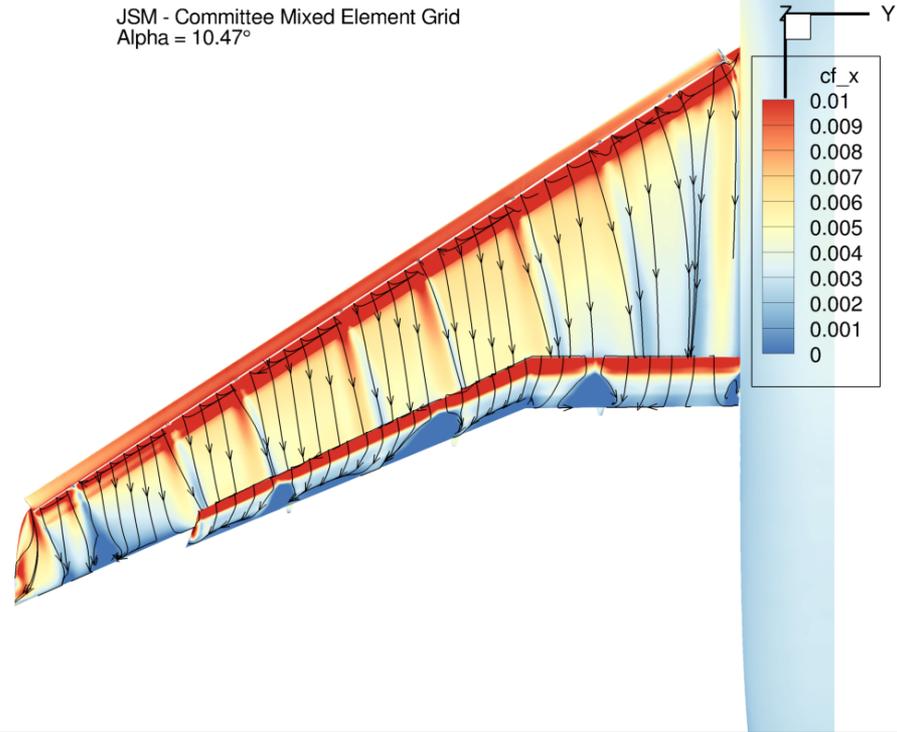
Similar solutions at 4.36°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 10.47°



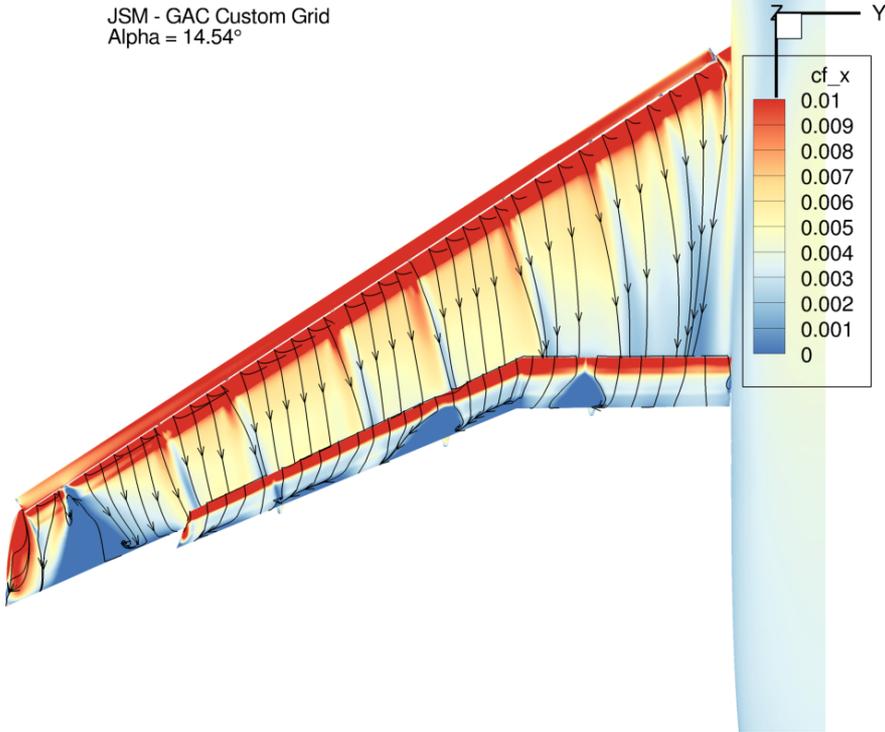
JSM - Committee Mixed Element Grid
Alpha = 10.47°



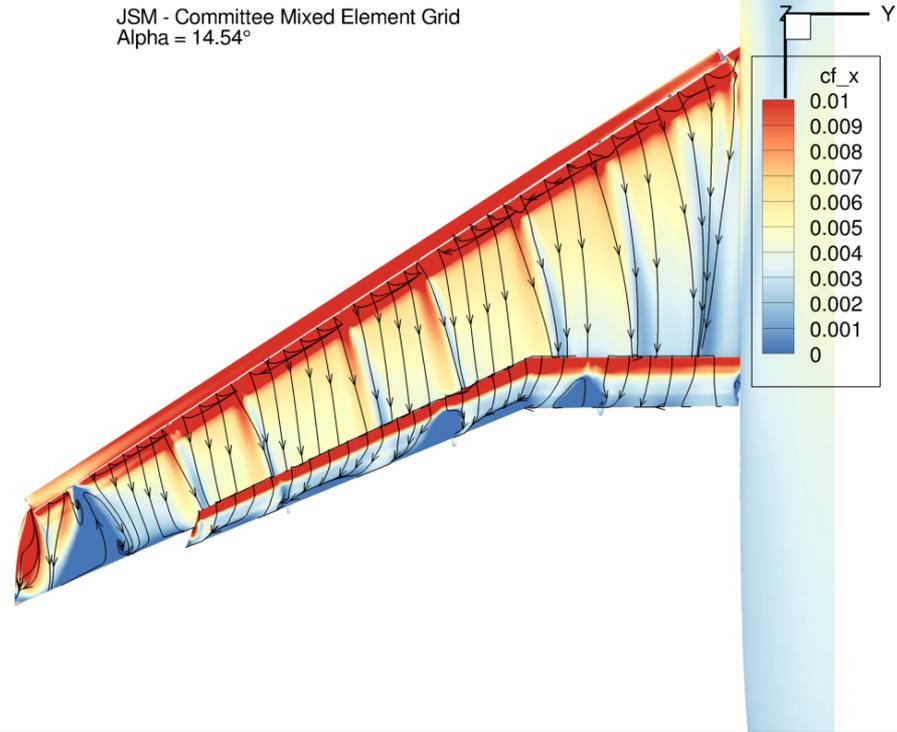
Similar solutions at 10.47°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 14.54°



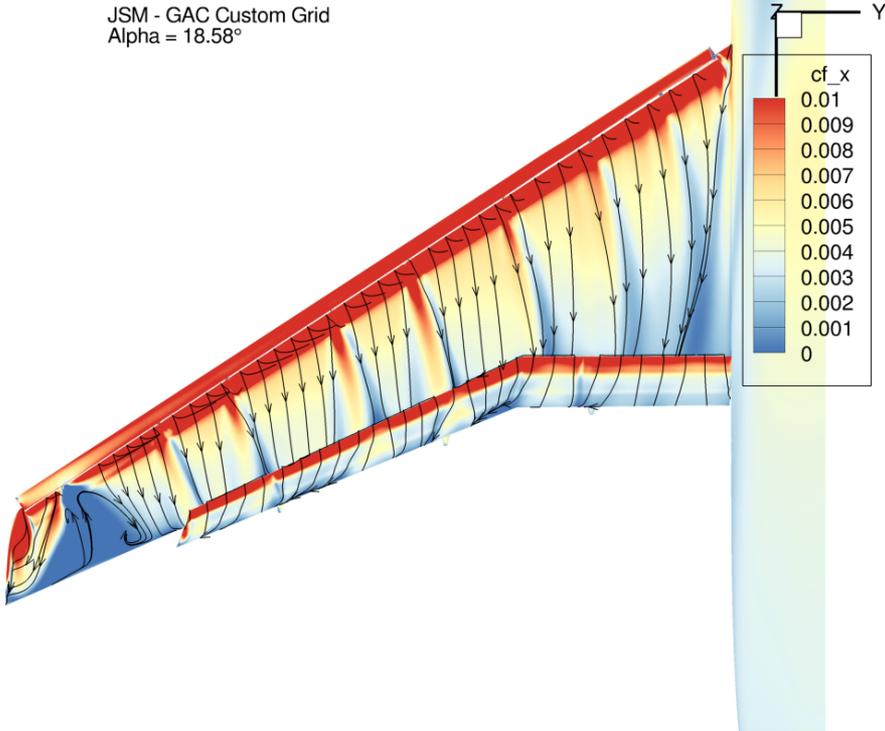
JSM - Committee Mixed Element Grid
Alpha = 14.54°



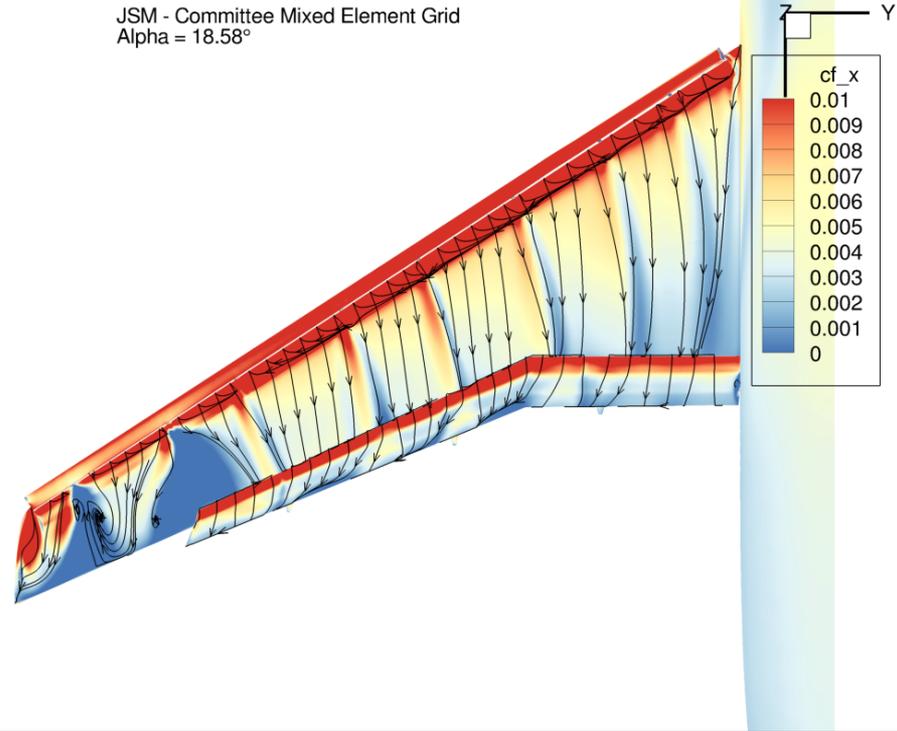
Similar solutions 14.54°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 18.58°



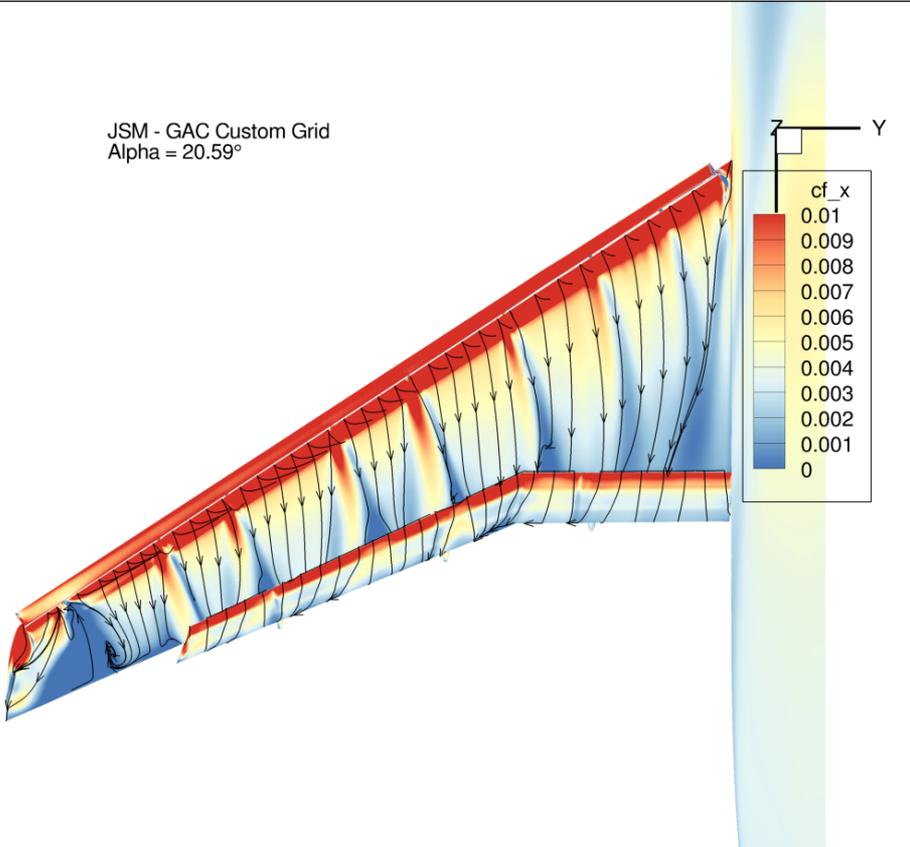
JSM - Committee Mixed Element Grid
Alpha = 18.58°



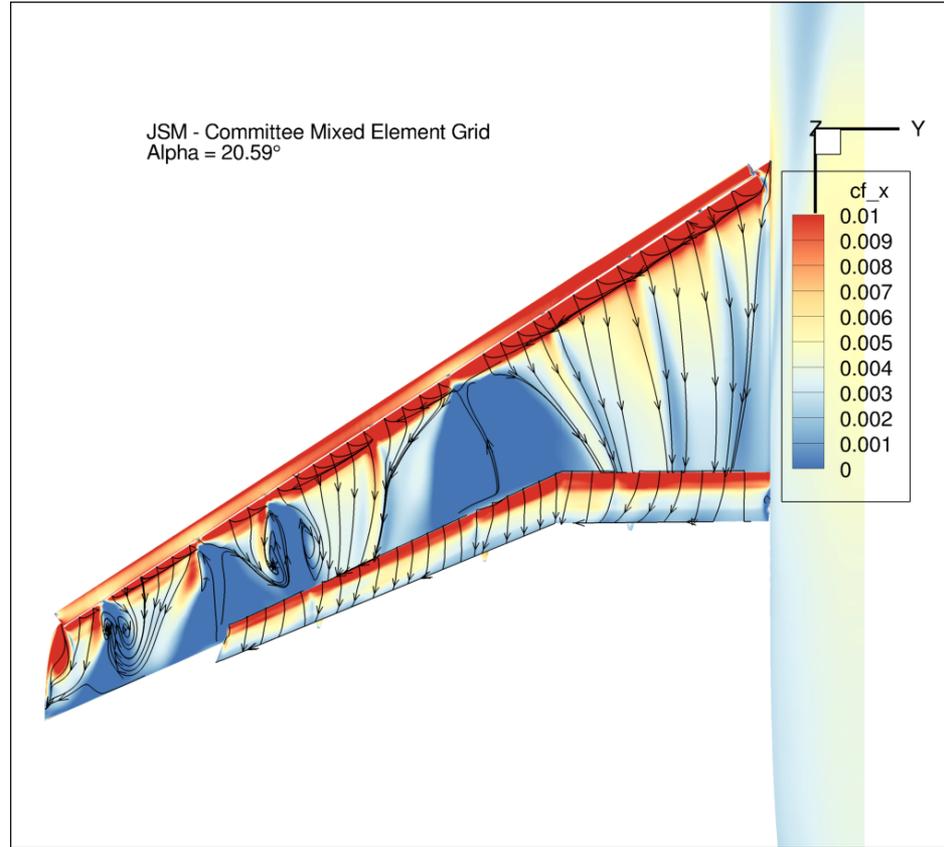
Second outboard separation appears at 18.58° on the committee grid

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 20.59°



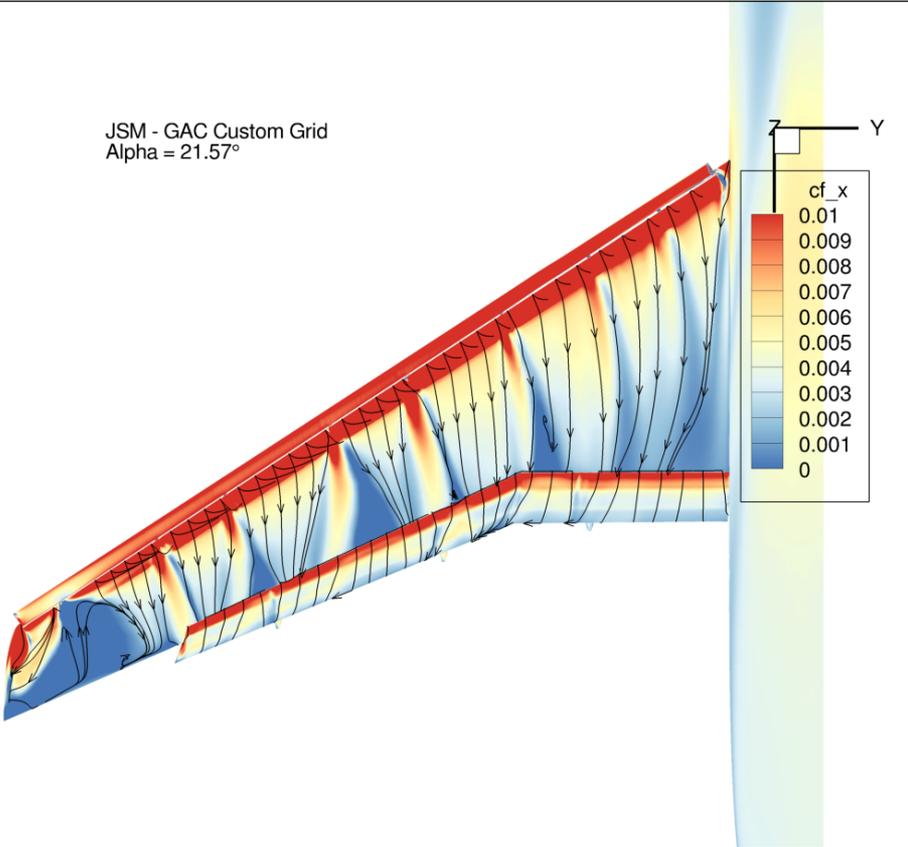
JSM - Committee Mixed Element Grid
Alpha = 20.59°



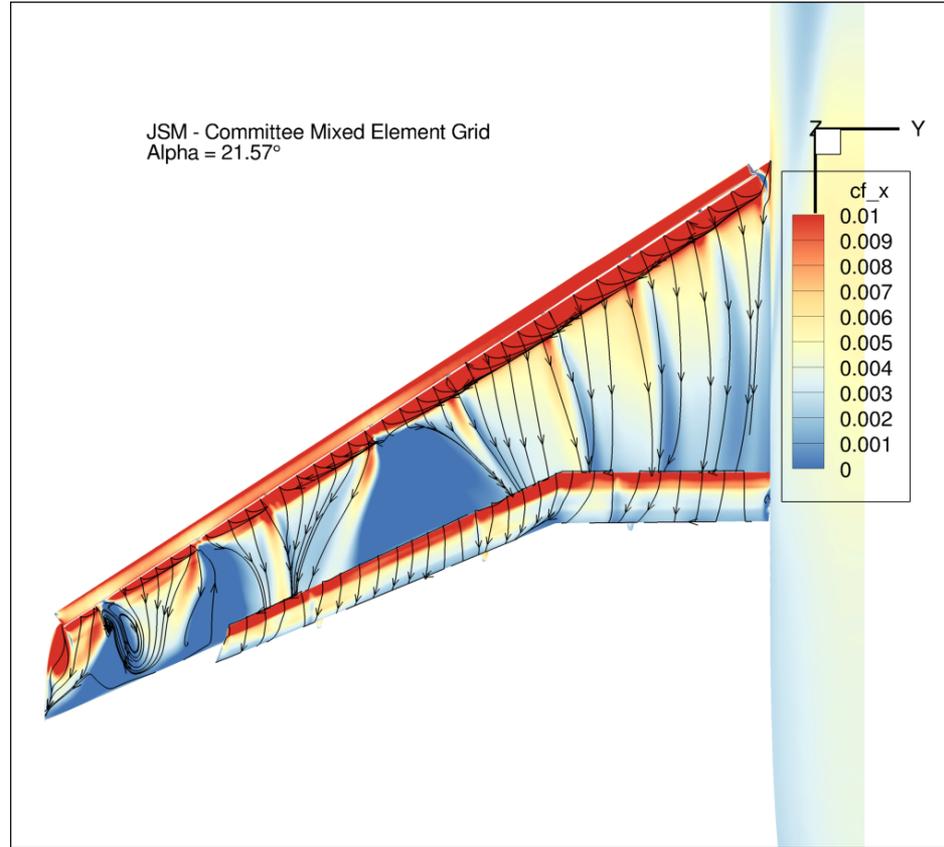
Custom grid with exhibits less separation at 20.59°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 21.57°



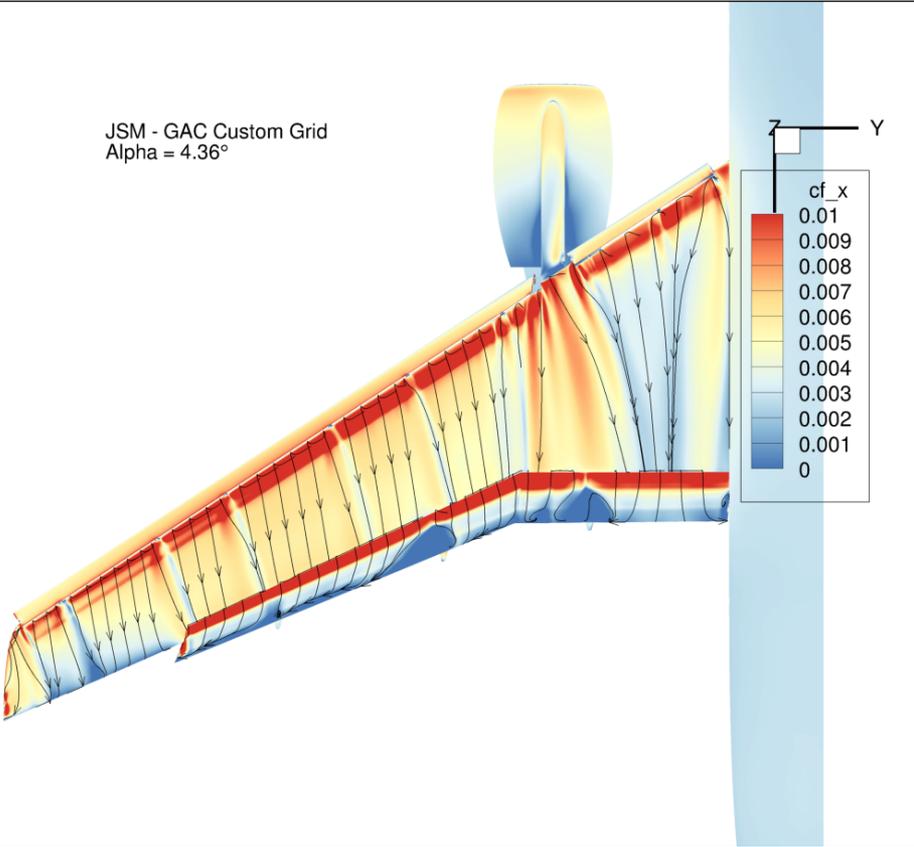
JSM - Committee Mixed Element Grid
Alpha = 21.57°



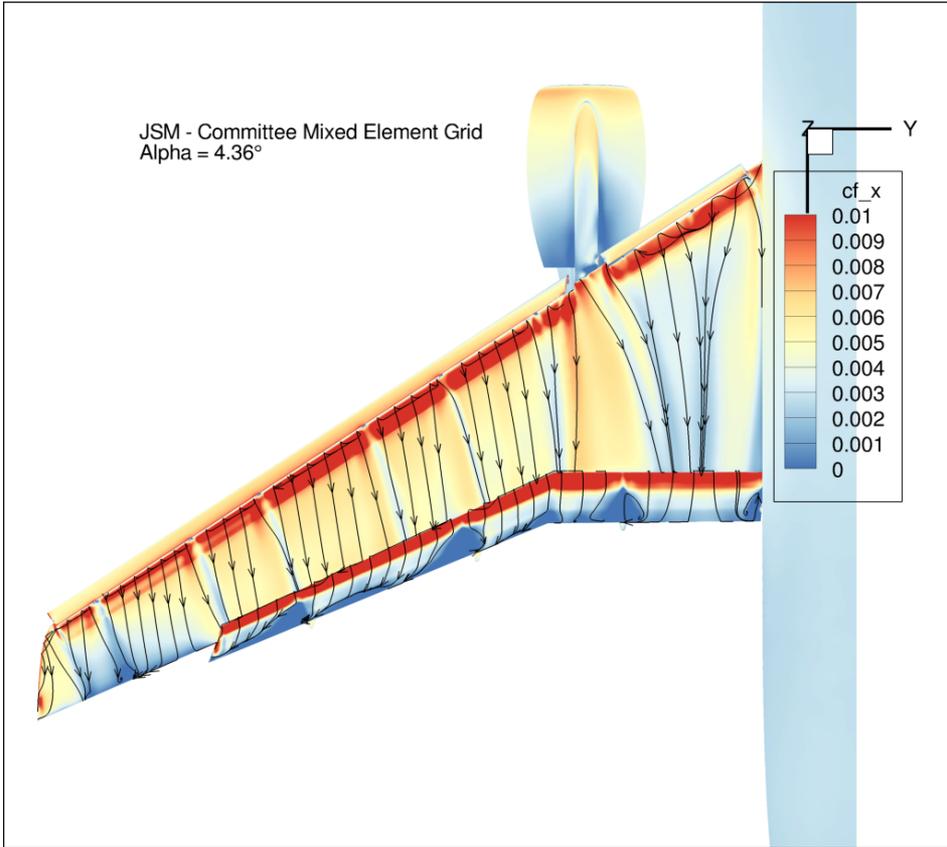
Additional separations appear in custom grid but are still more pronounced on committee grid

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 4.36°



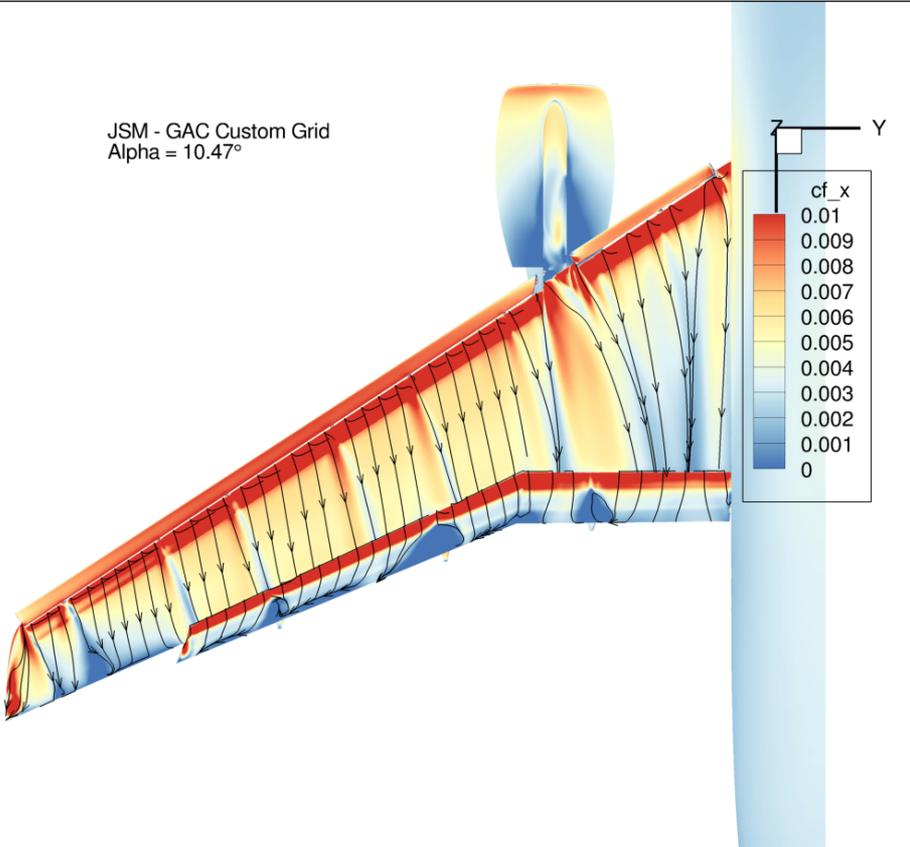
JSM - Committee Mixed Element Grid
Alpha = 4.36°



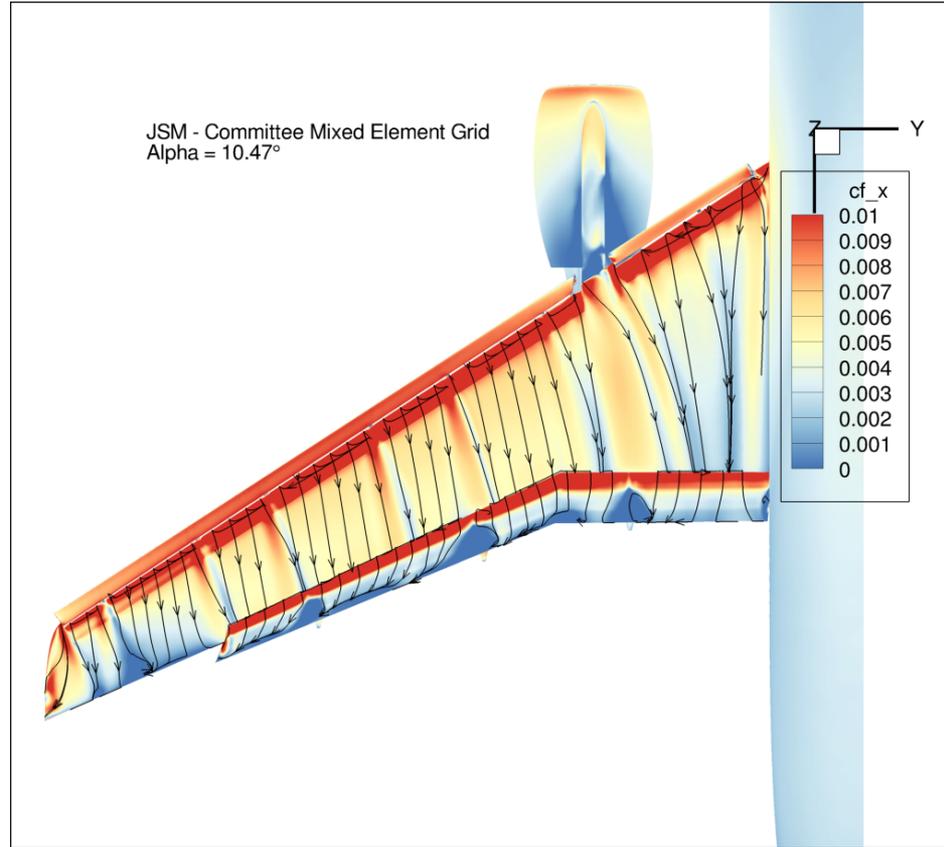
Similar solutions at 4.36°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 10.47°



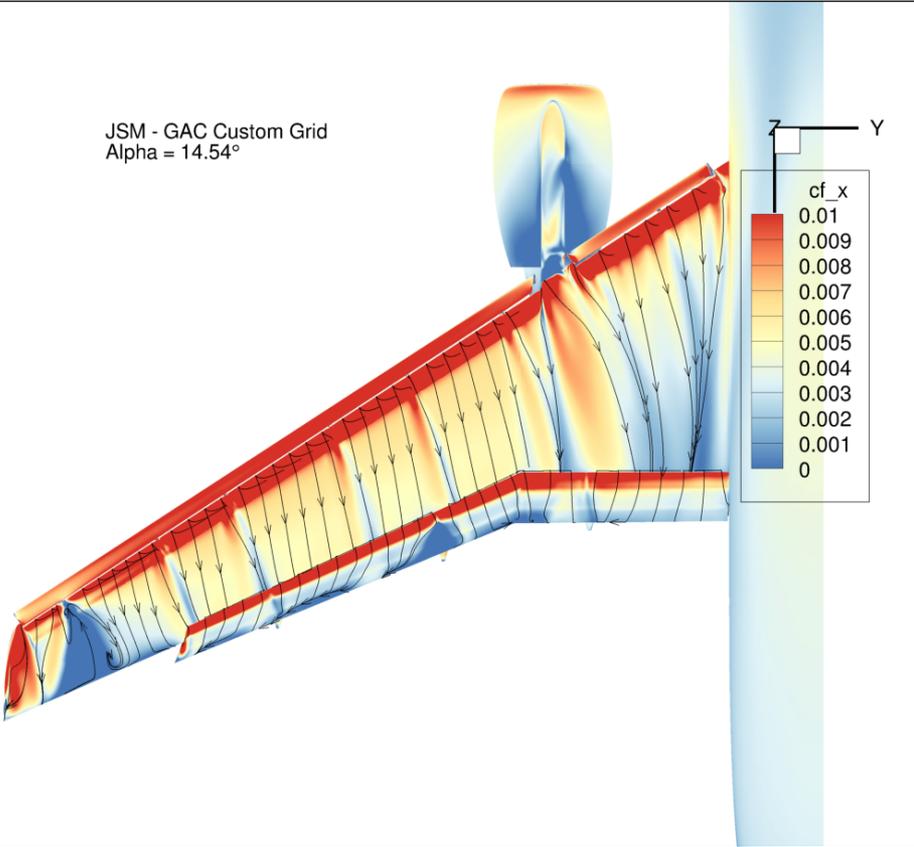
JSM - Committee Mixed Element Grid
Alpha = 10.47°



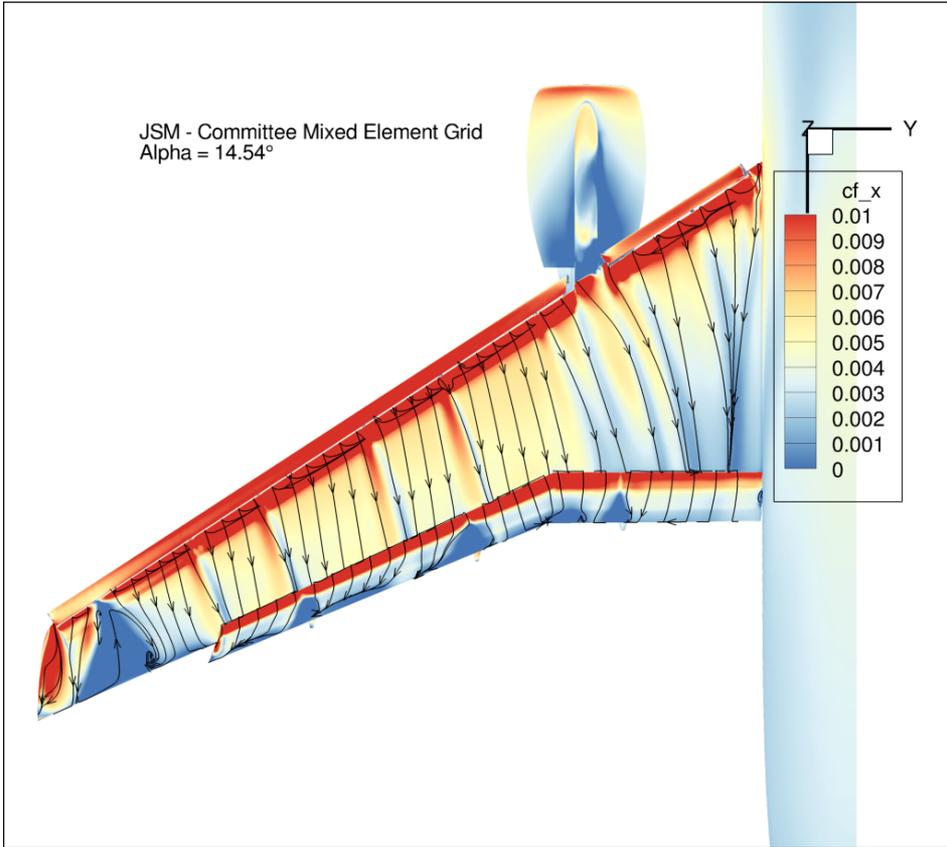
Similar solutions at 10.47°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 14.54°



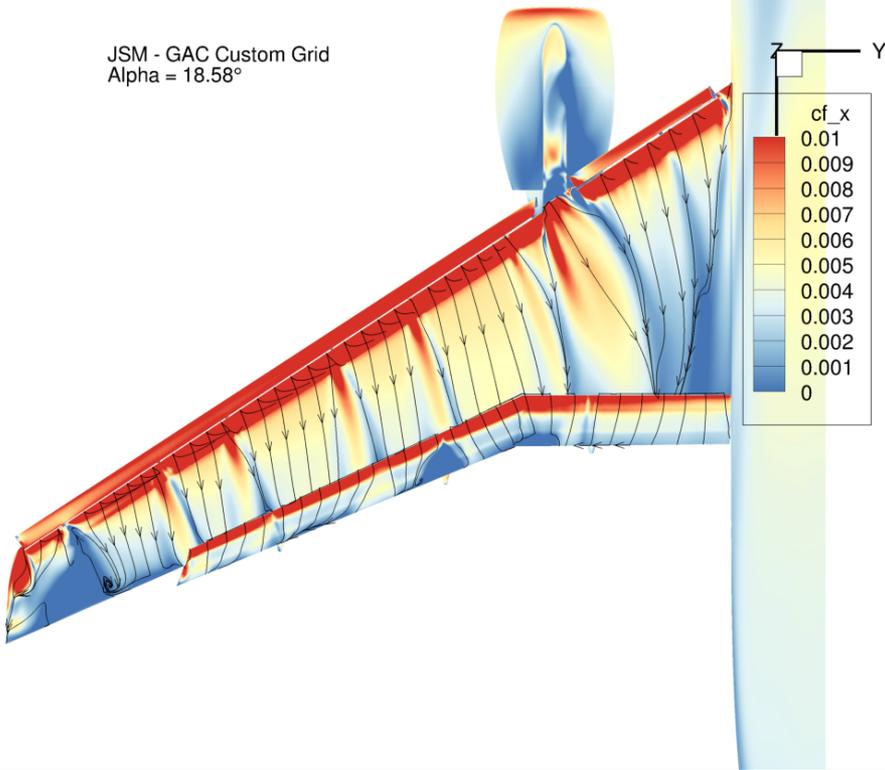
JSM - Committee Mixed Element Grid
Alpha = 14.54°



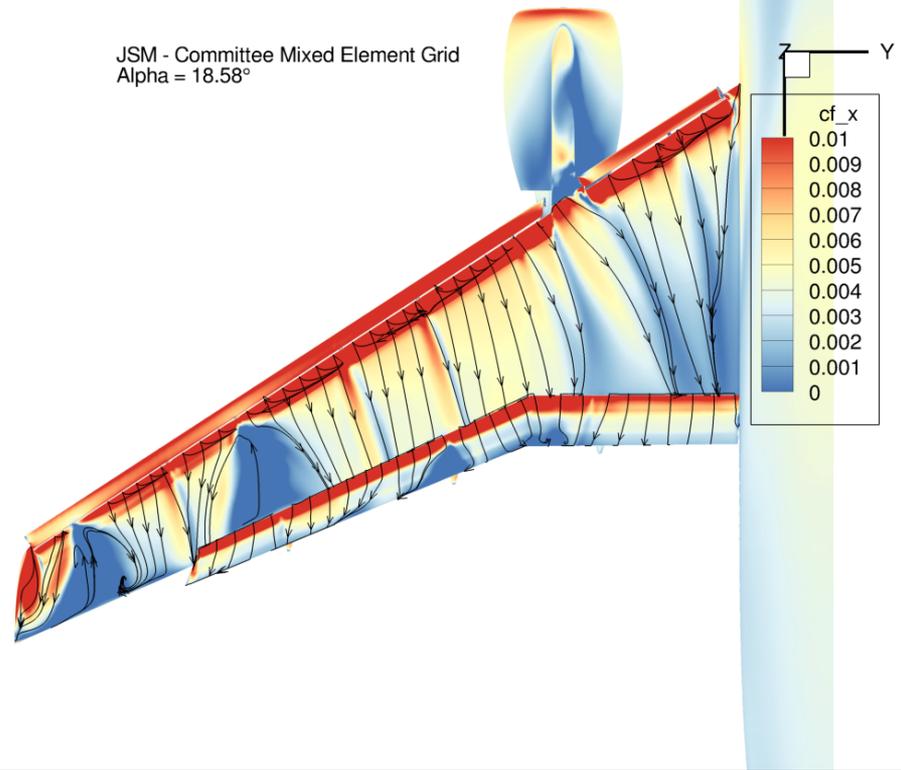
Similar solutions at 14.54°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 18.58°



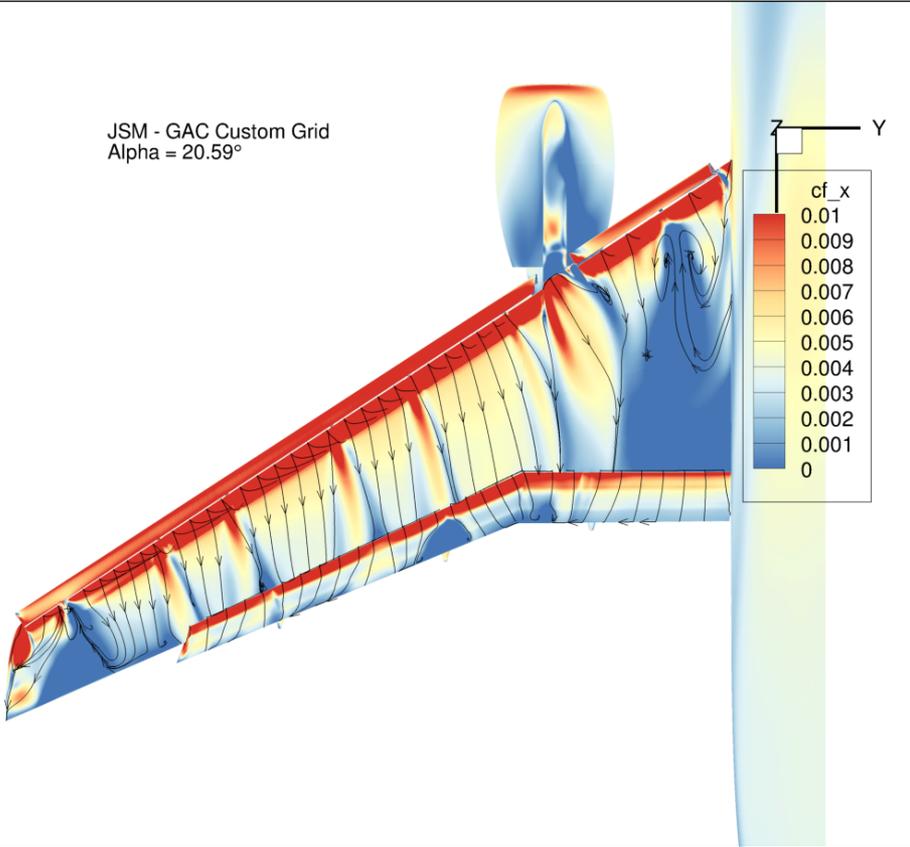
JSM - Committee Mixed Element Grid
Alpha = 18.58°



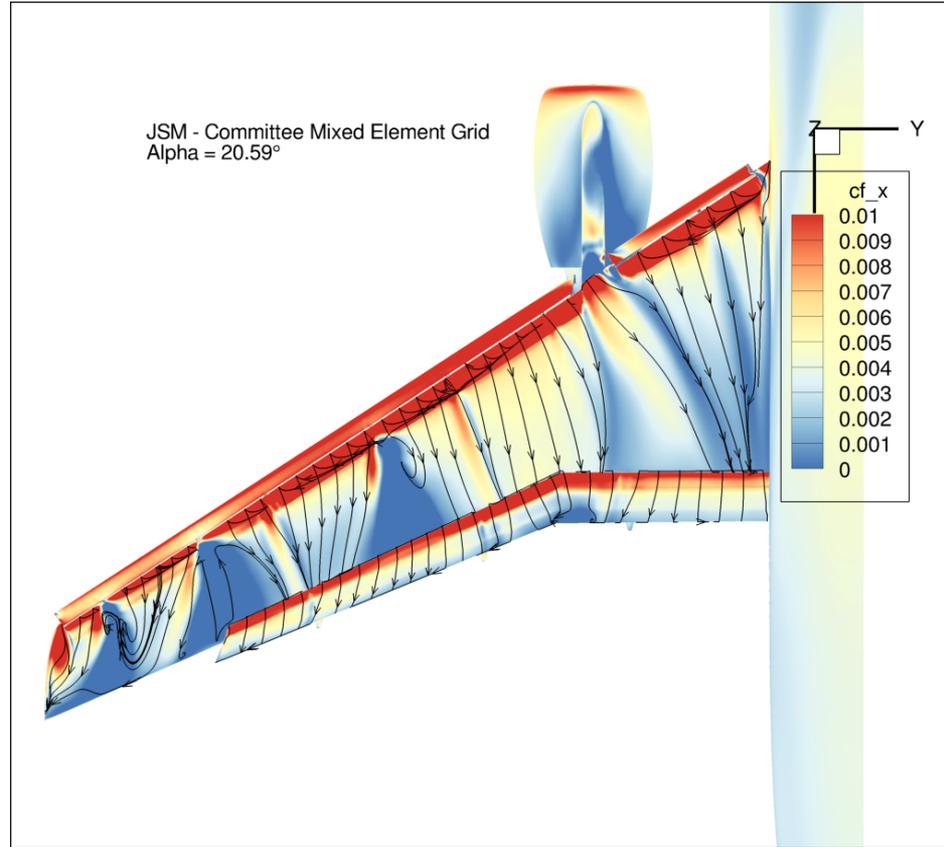
Second outboard separation appears at 18.58° on the committee grid

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 20.59°



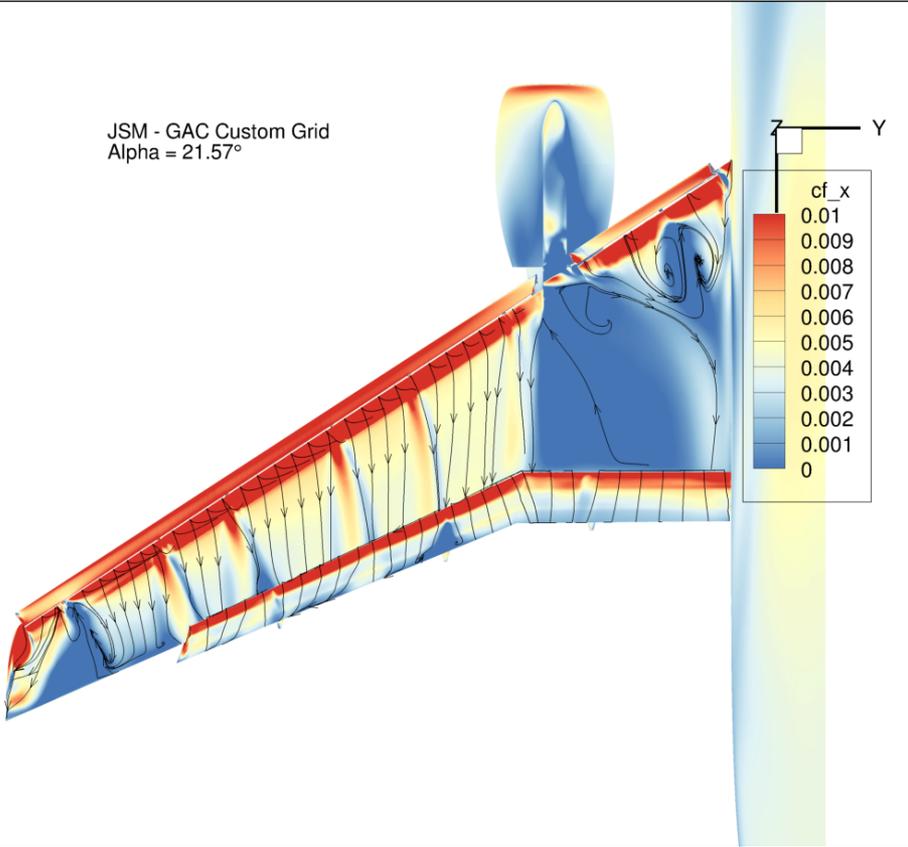
JSM - Committee Mixed Element Grid
Alpha = 20.59°



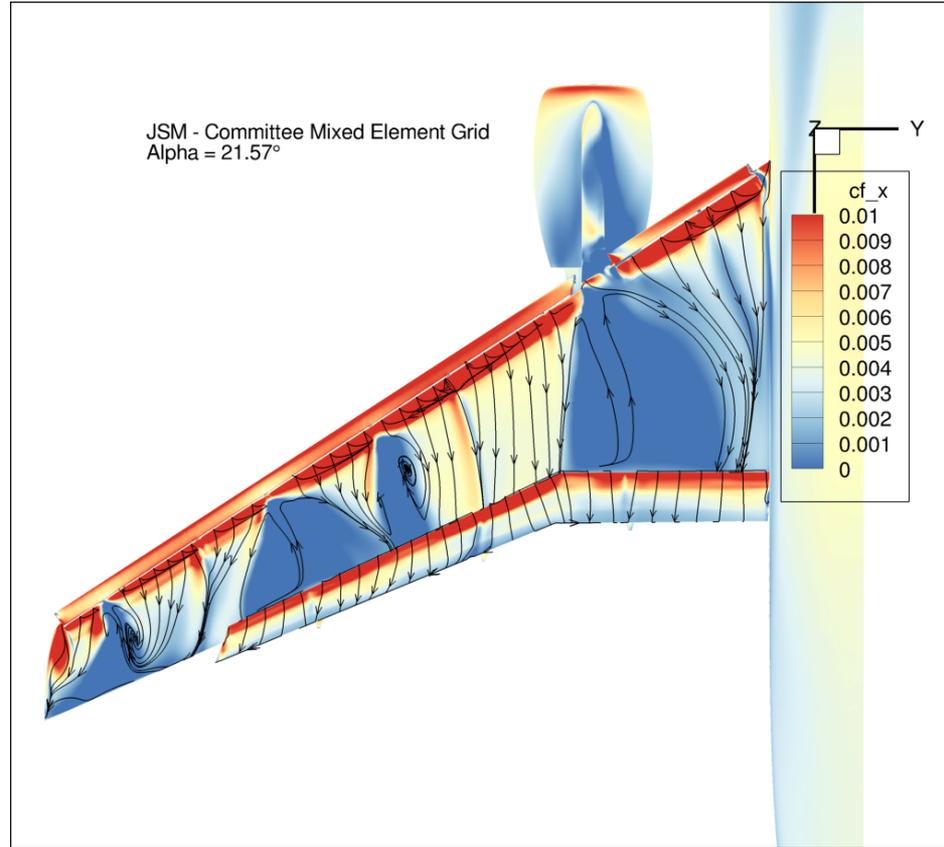
Large inboard separation on custom grid

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 21.57°

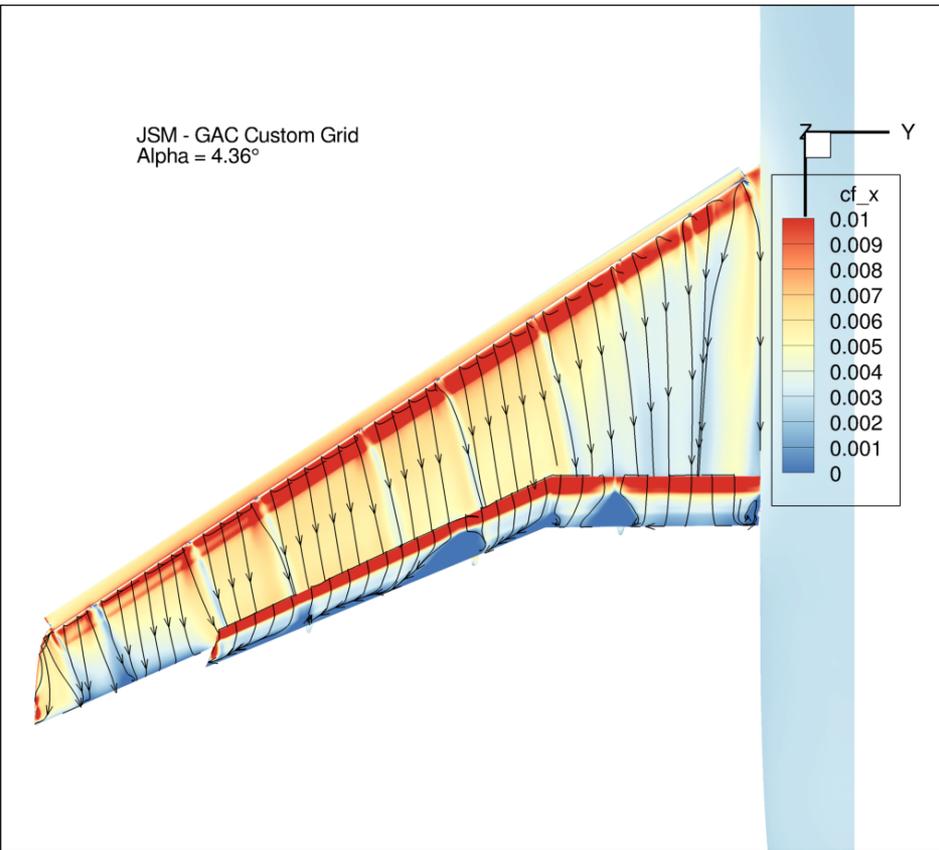


JSM - Committee Mixed Element Grid
Alpha = 21.57°



Large inboard separation on both solutions
Custom grid shows additional separation near LE

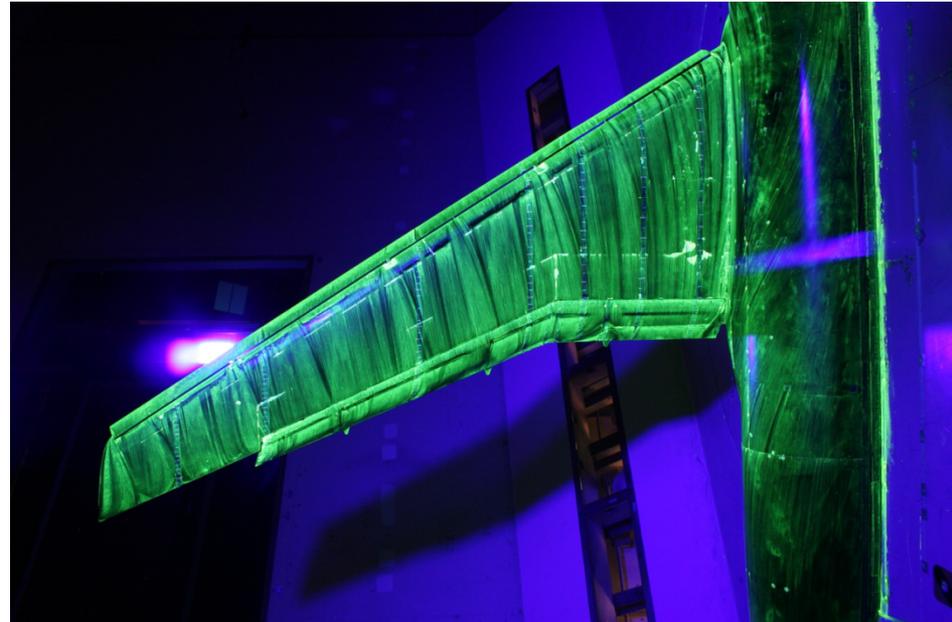
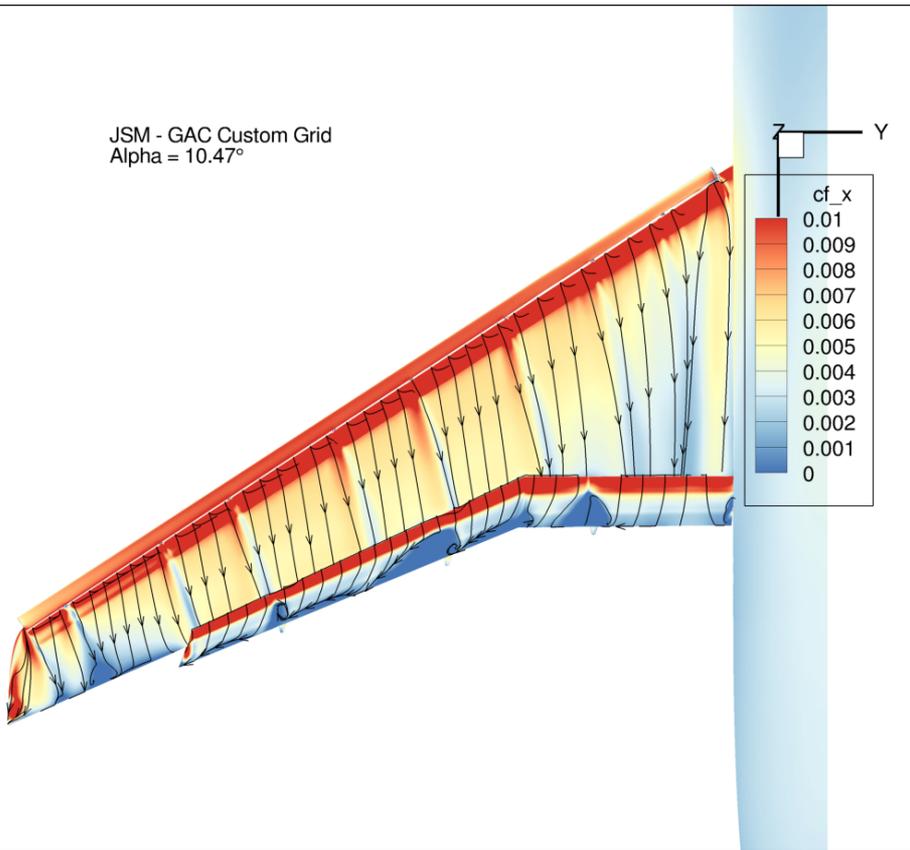
JSM Streamlines



Similar streamlines in CFD and wind tunnel

JSM Streamlines

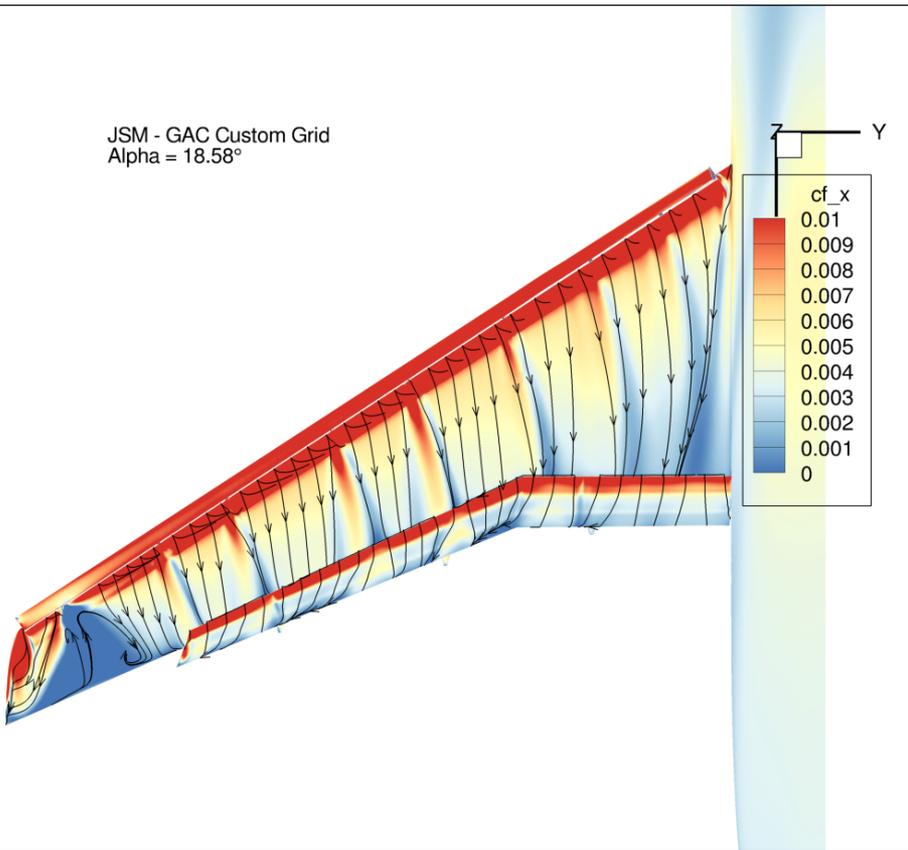
JSM - GAC Custom Grid
Alpha = 10.47°



Similar streamlines in CFD and wind tunnel

JSM Streamlines

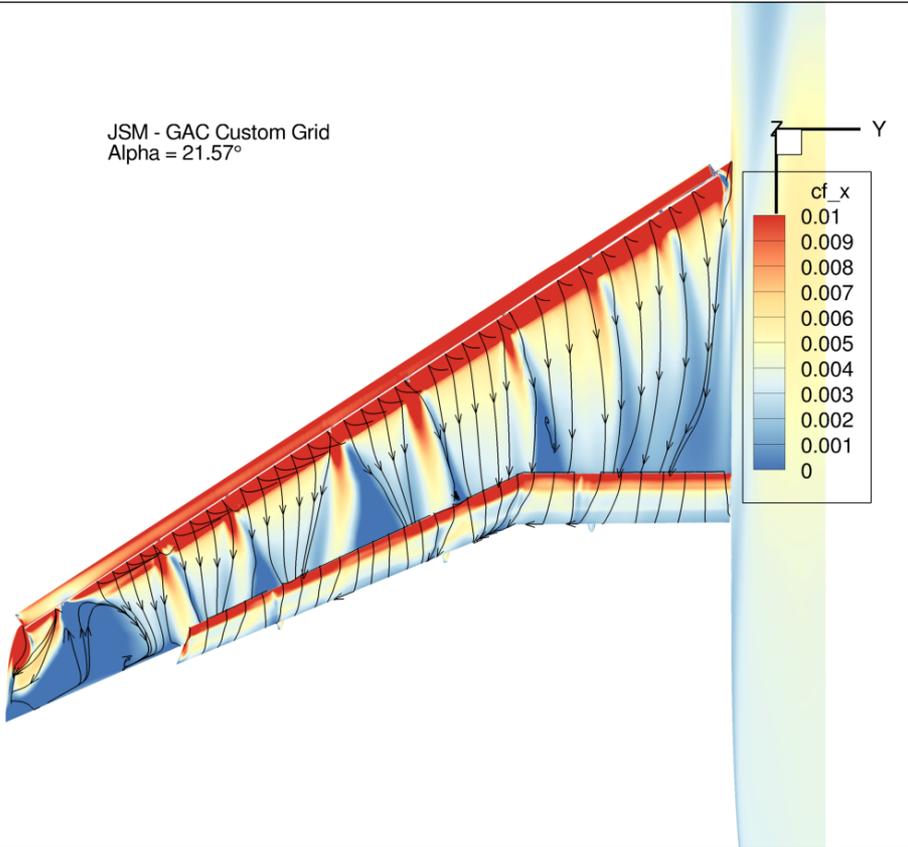
JSM - GAC Custom Grid
Alpha = 18.58°



Outboard wing separation present in CFD and wind tunnel

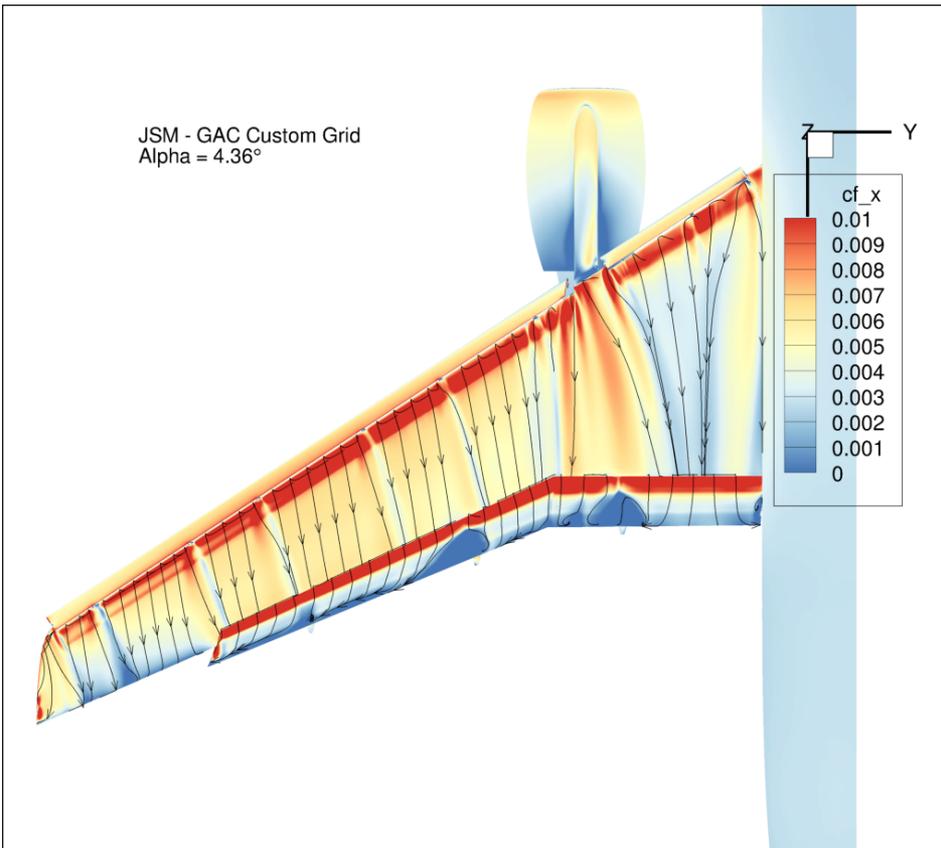
JSM Streamlines

JSM - GAC Custom Grid
Alpha = 21.57°



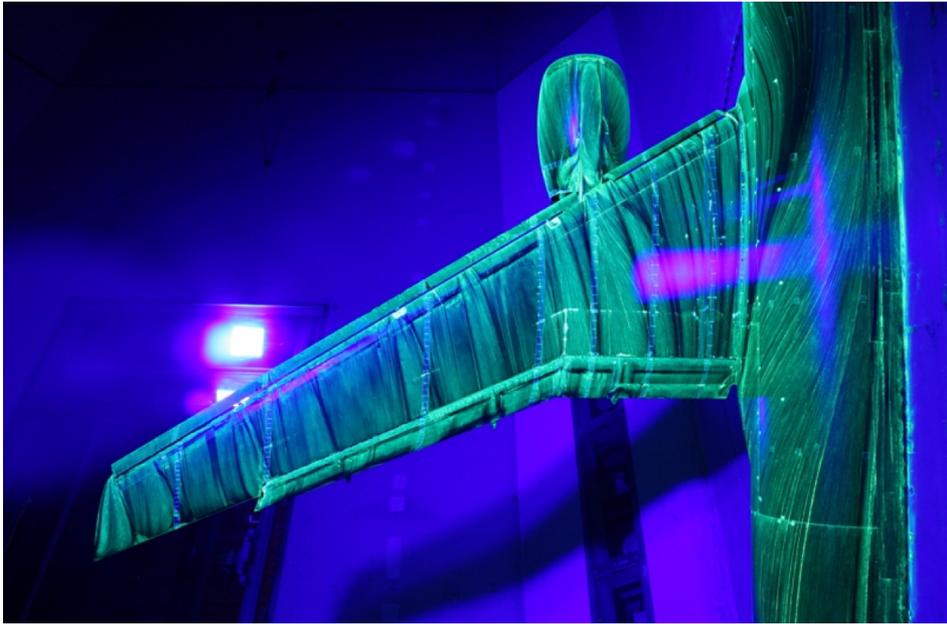
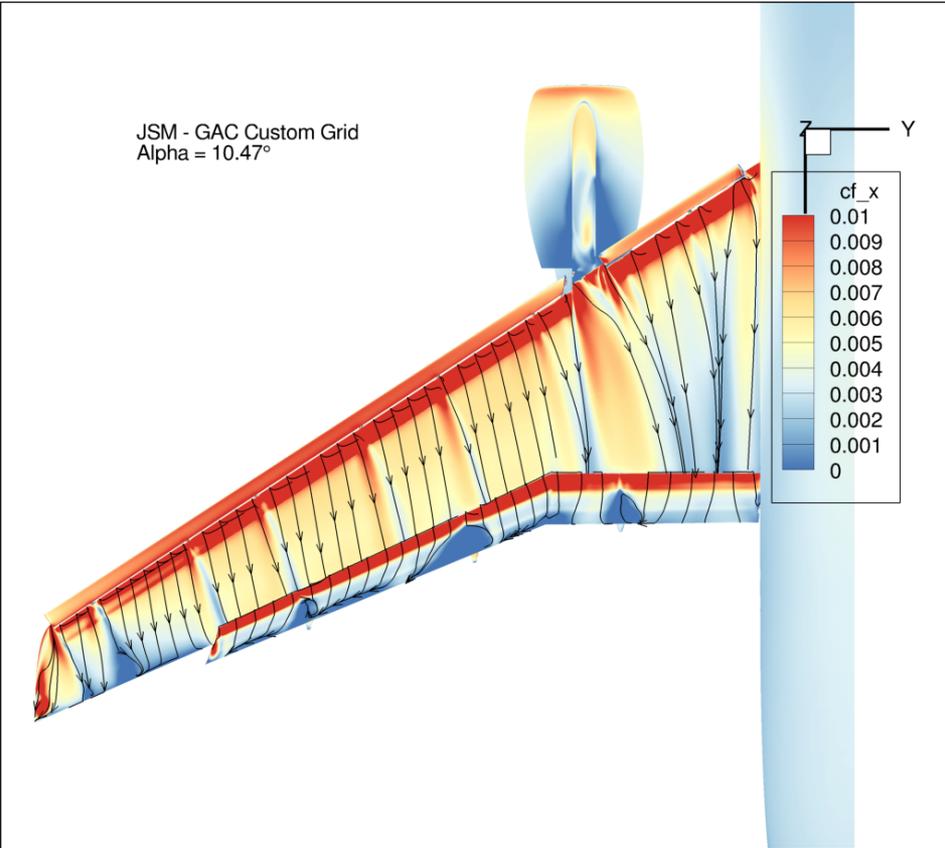
Somewhat similar flow patterns on wing root

JSM Streamlines



Similar streamlines in CFD and wind tunnel

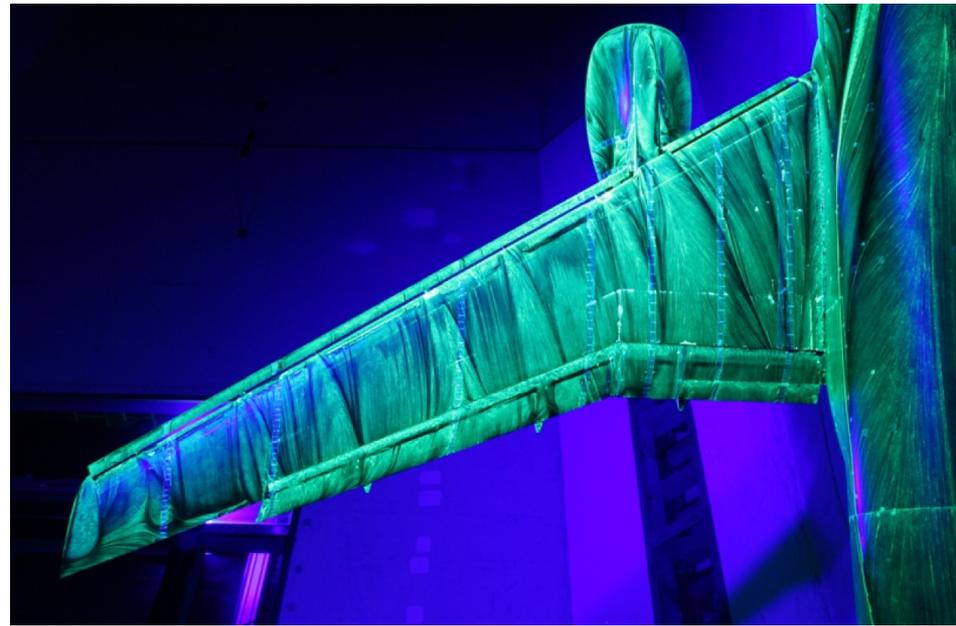
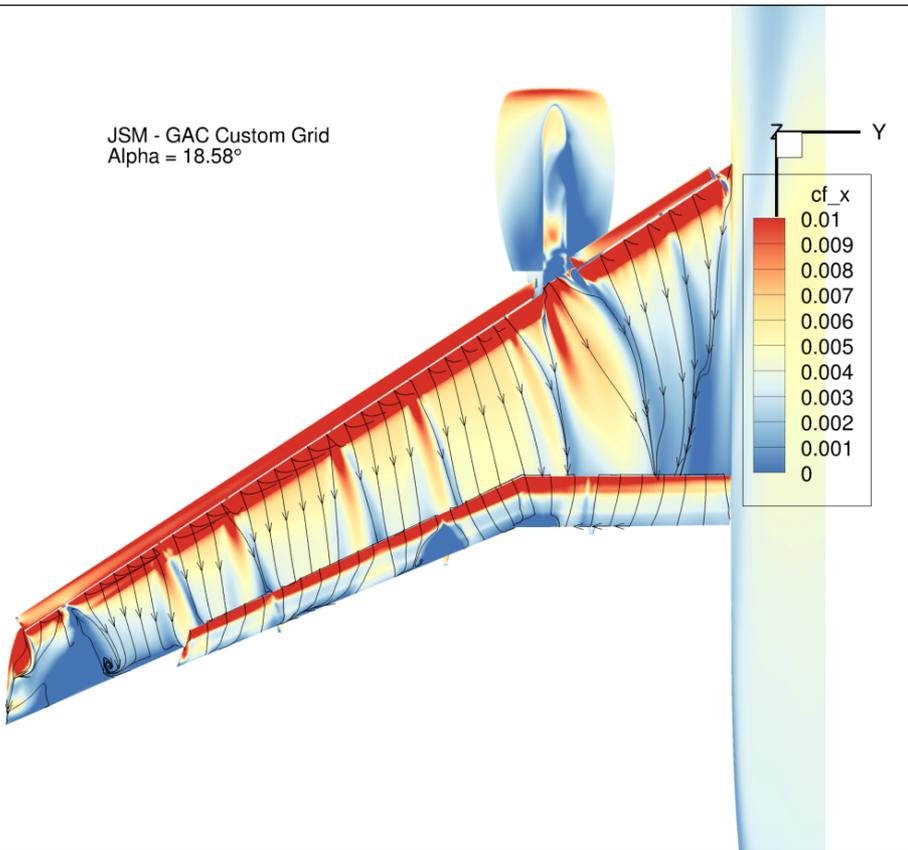
JSM Streamlines



Similar streamlines in CFD and wind tunnel

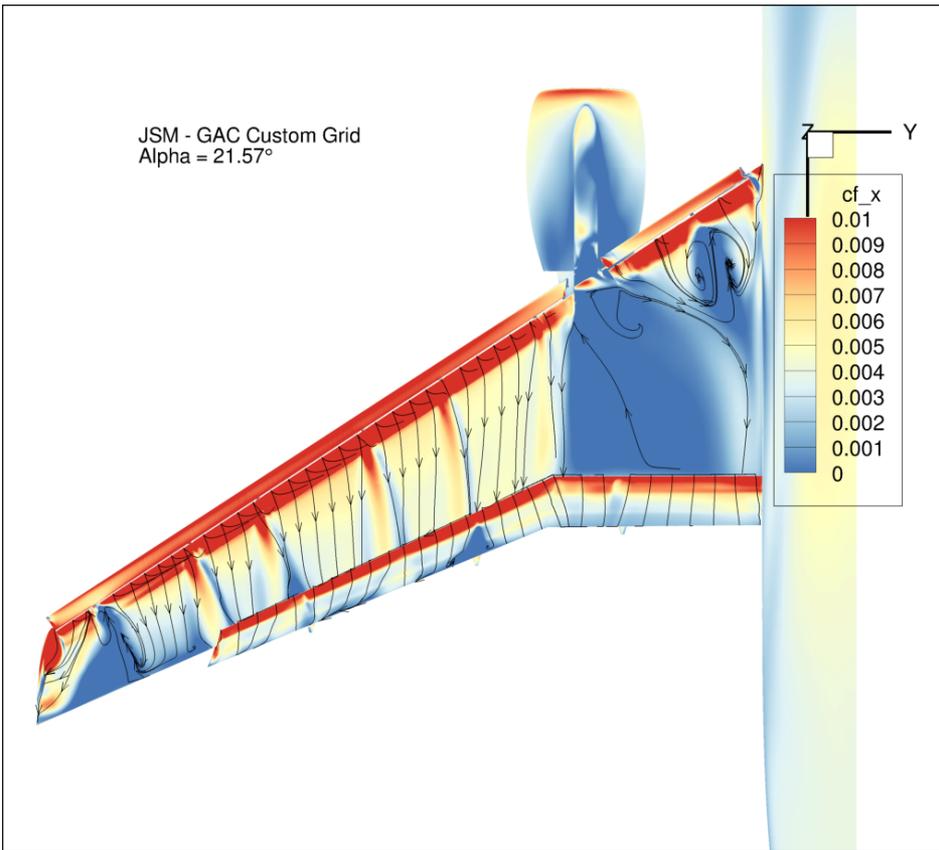
JSM Streamlines

JSM - GAC Custom Grid
Alpha = 18.58°



Outboard wing separation present in CFD and wind tunnel

JSM Streamlines



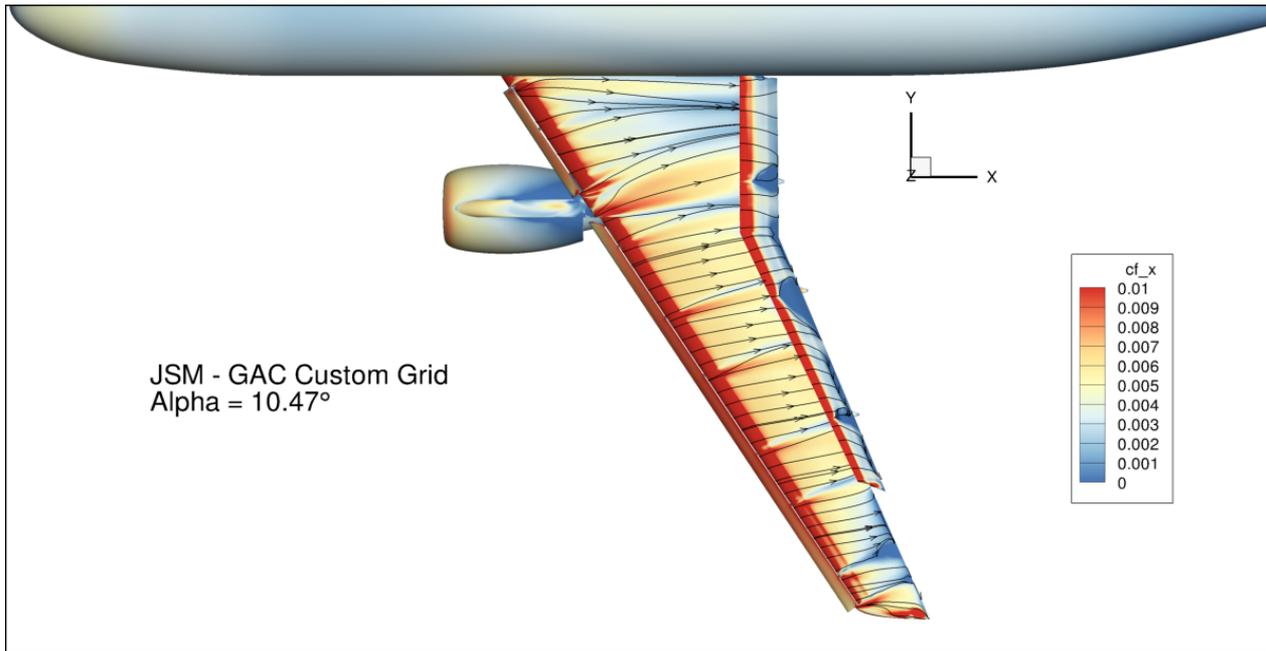
Inboard wing separation significantly different in CFD than in wind tunnel

JSM Results

- There appears to be a significant dependency upon the grid for both committee provided JSM grids and GAC custom JSM grids
 - Committee provided JSM grids show outboard separation where GAC custom grids do not
 - GAC custom grid with nacelle shows early and more pronounced inboard separation than committee grid

Summary

- High lift solutions are dependent upon adequate grid resolution and distribution
 - Provided HLCRM grids seem to converge on a lower CLmax than GAC custom grids
 - Grid resolution should be focused where the solution will experience the highest density gradients
 - Leading edges of wing, slat, flap, and fuselage
 - Grid resolution should also be focused where one would expect to have adverse pressure gradients
 - Upper surfaces of wing, flap, and slat
- Analyzing component level grid convergence can improve grid efficiency
 - Committee HLCRM model could be improved by redistributing grid density from fuselage to wing
- There is significant grid dependency for both committee provided JSM grids and GAC custom JSM grids as they both exhibit characteristics of grid dependent solutions
 - Convergence error was beyond the acceptable limits for accuracy
 - Separation along the wing that was inconsistent with wind tunnel oil flow results

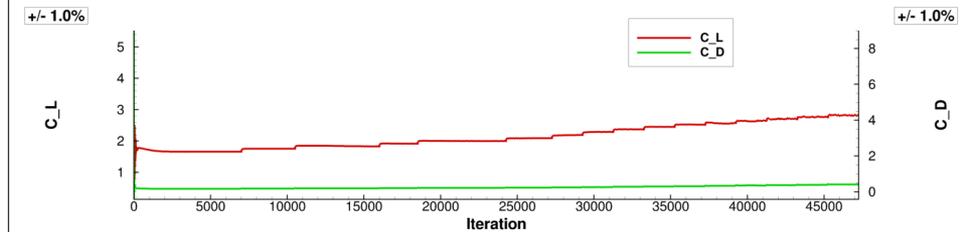
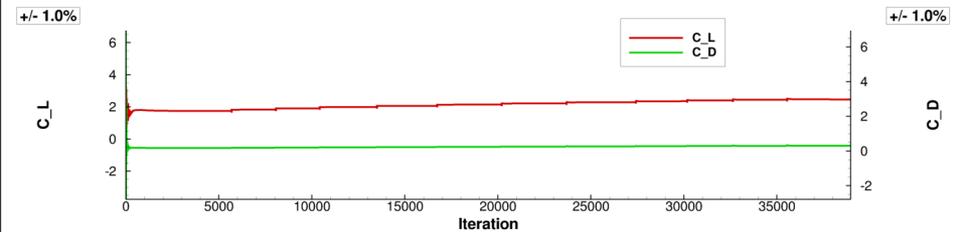
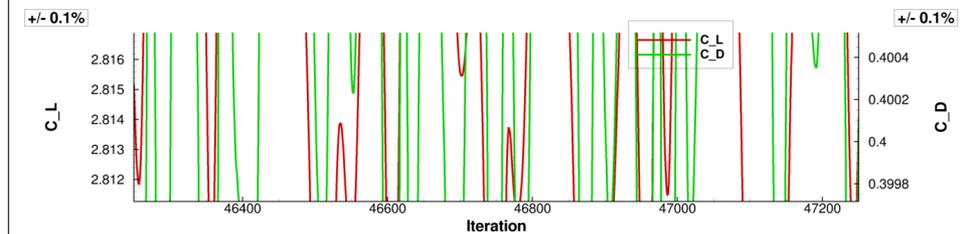
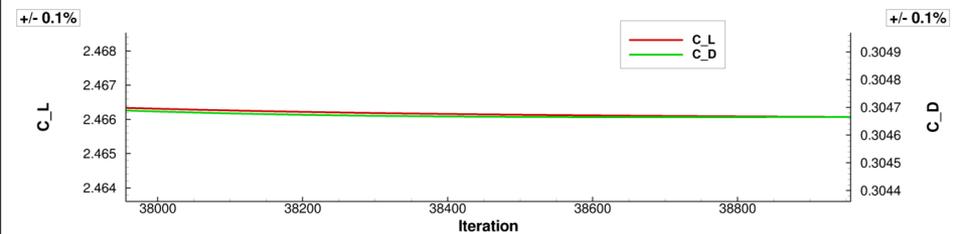
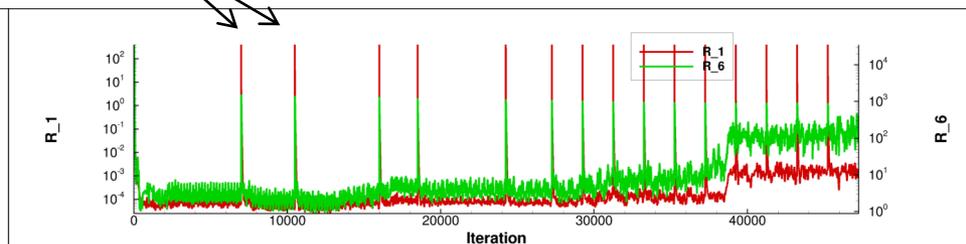
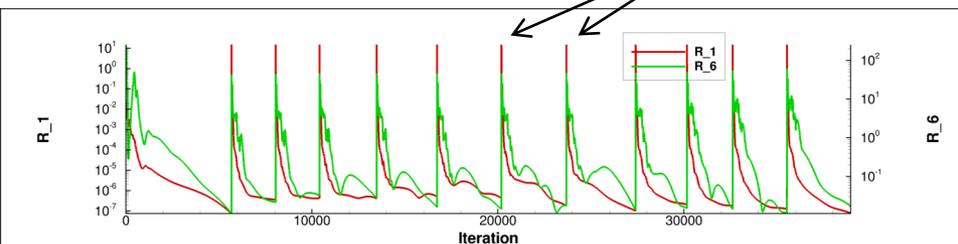


Questions?

BACKUP

Convergence Histories

Restart locations

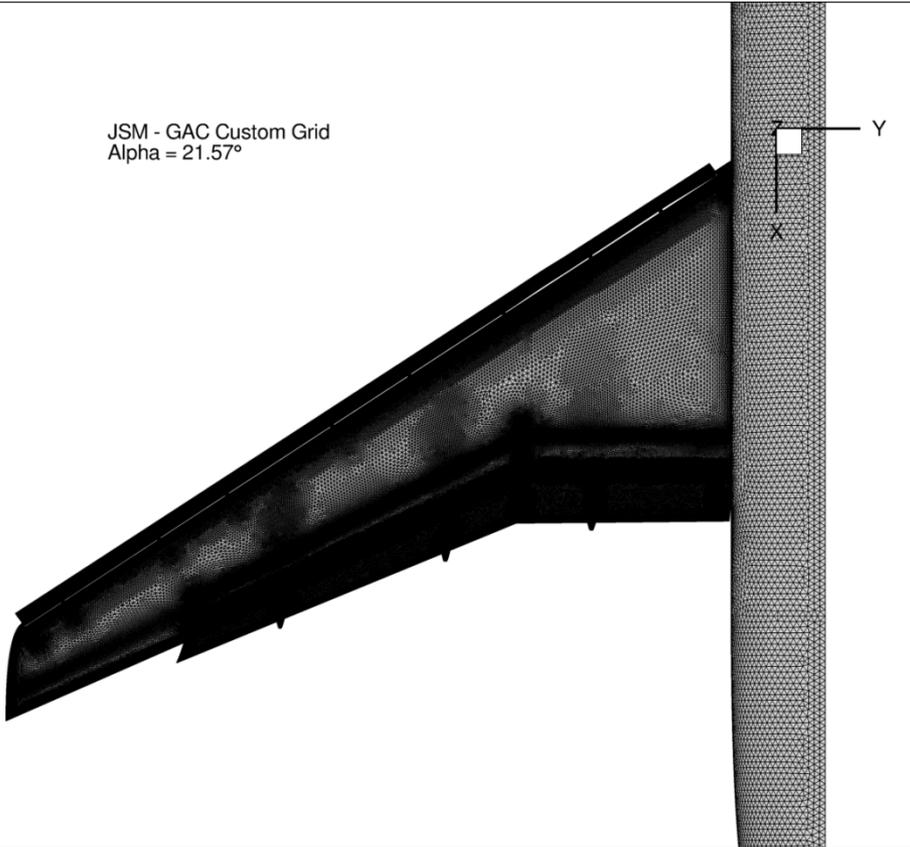


CRM – Committee Fine Grid 19°

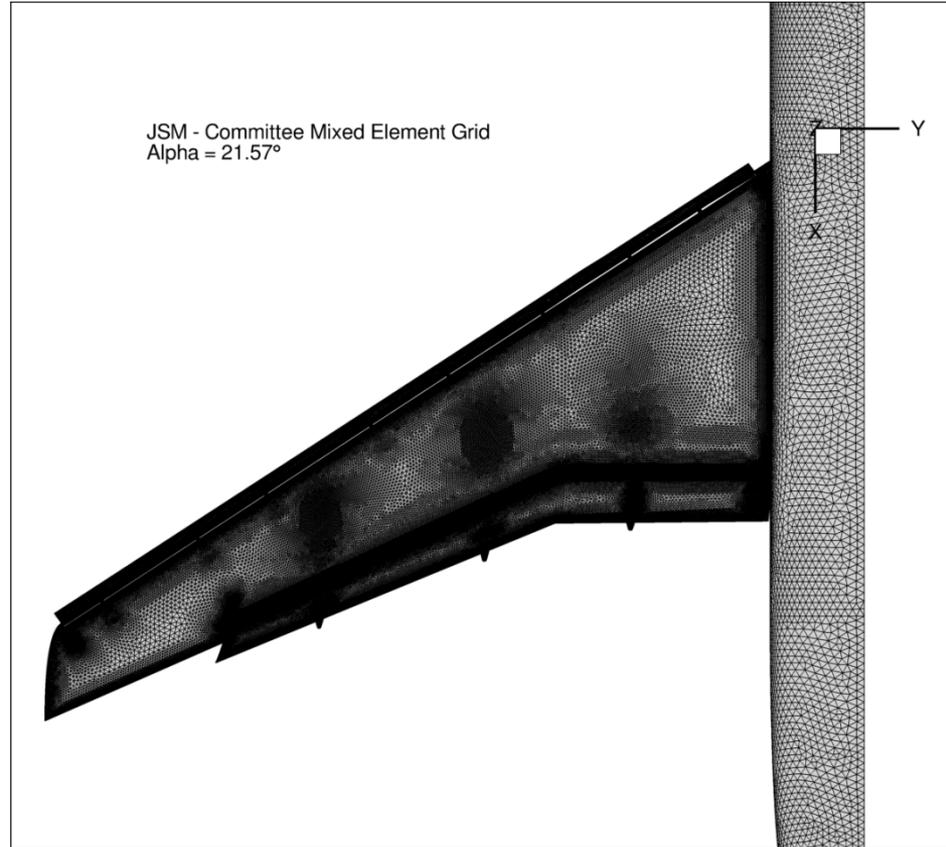
JSM – GAC Custom w/out Nacelle 19°

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 21.57°



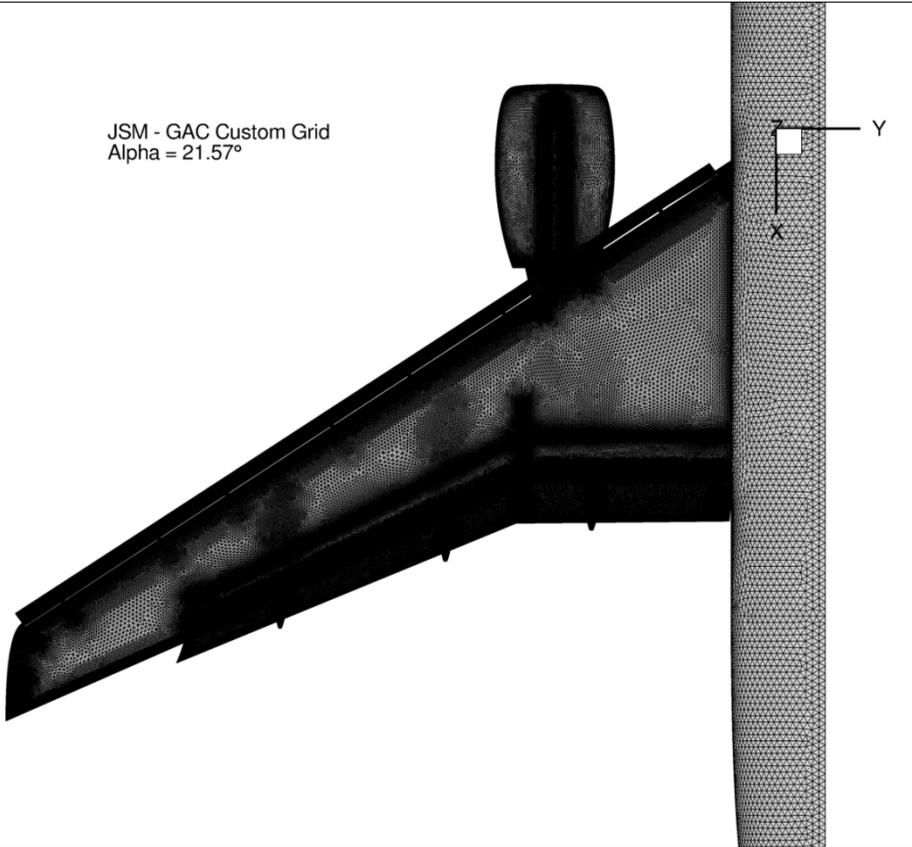
JSM - Committee Mixed Element Grid
Alpha = 21.57°



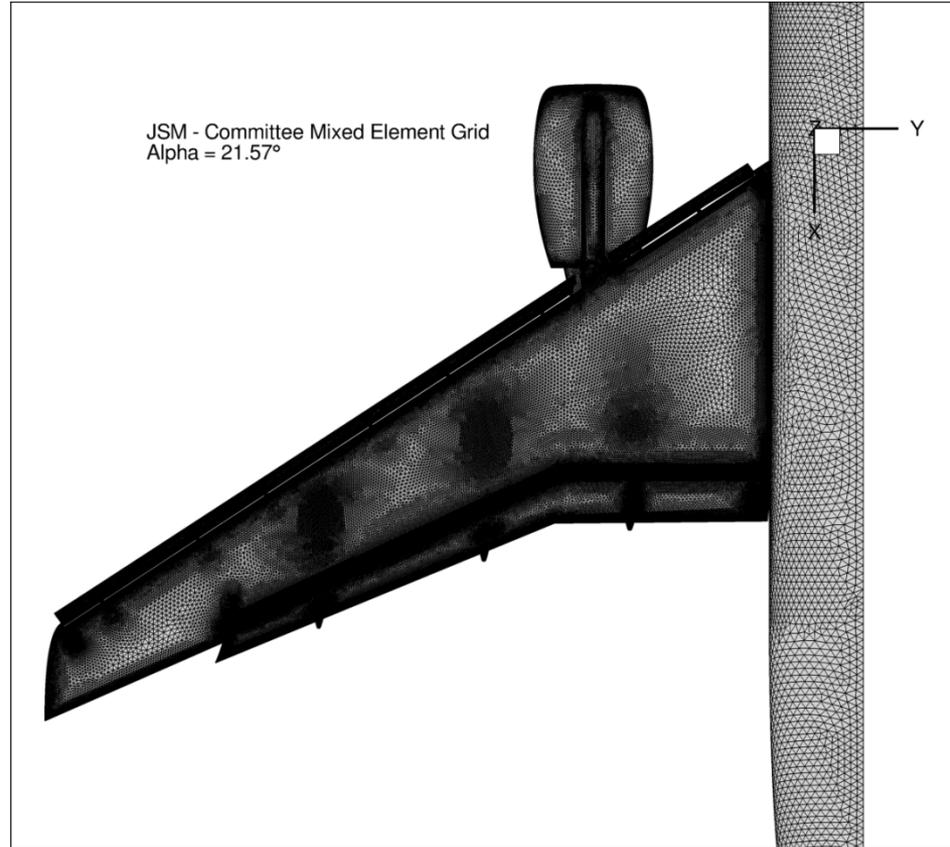
Similar grid density except at wingtip, GAC grid has greater density

JSM Streamlines

JSM - GAC Custom Grid
Alpha = 21.57°

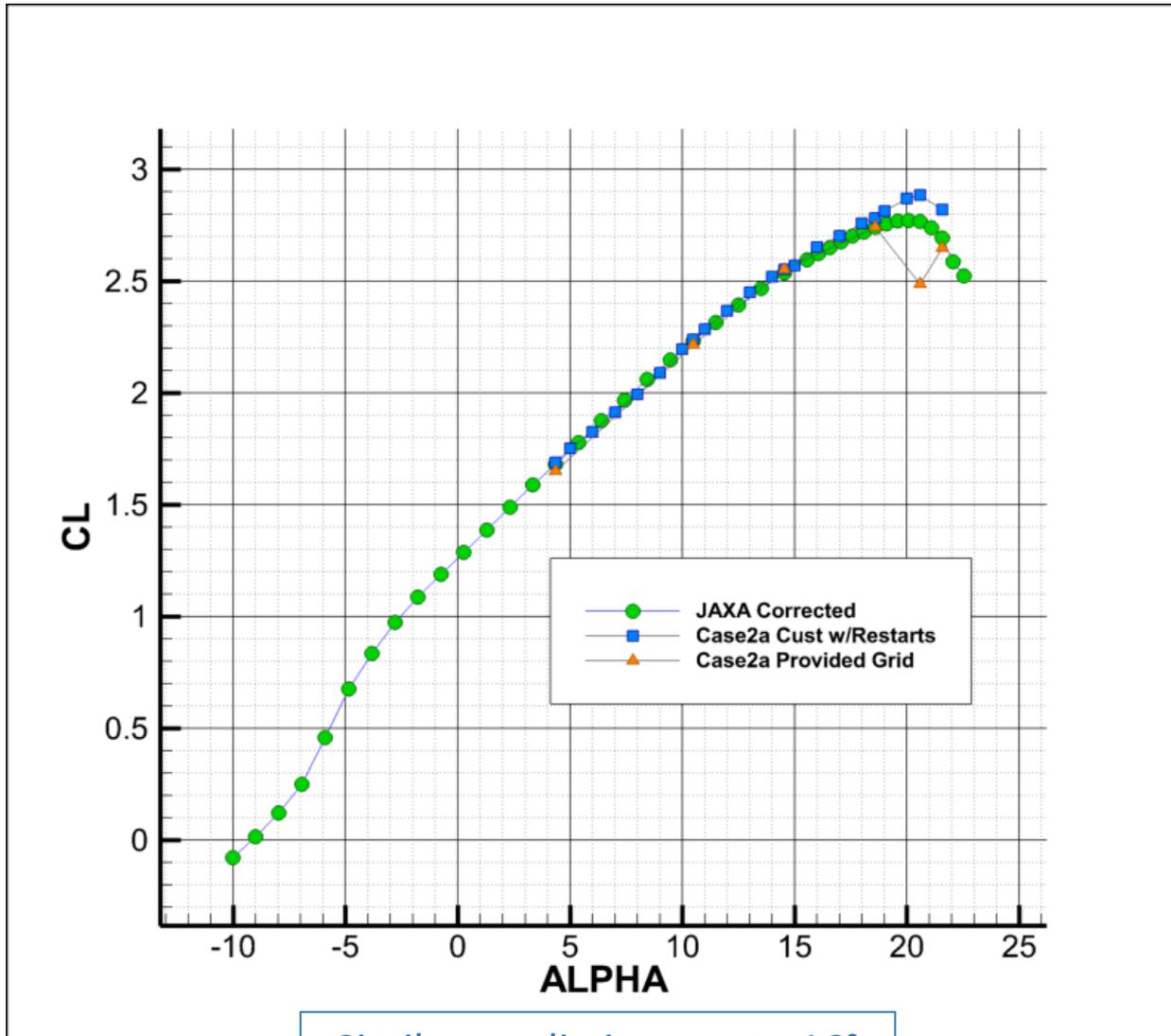


JSM - Committee Mixed Element Grid
Alpha = 21.57°



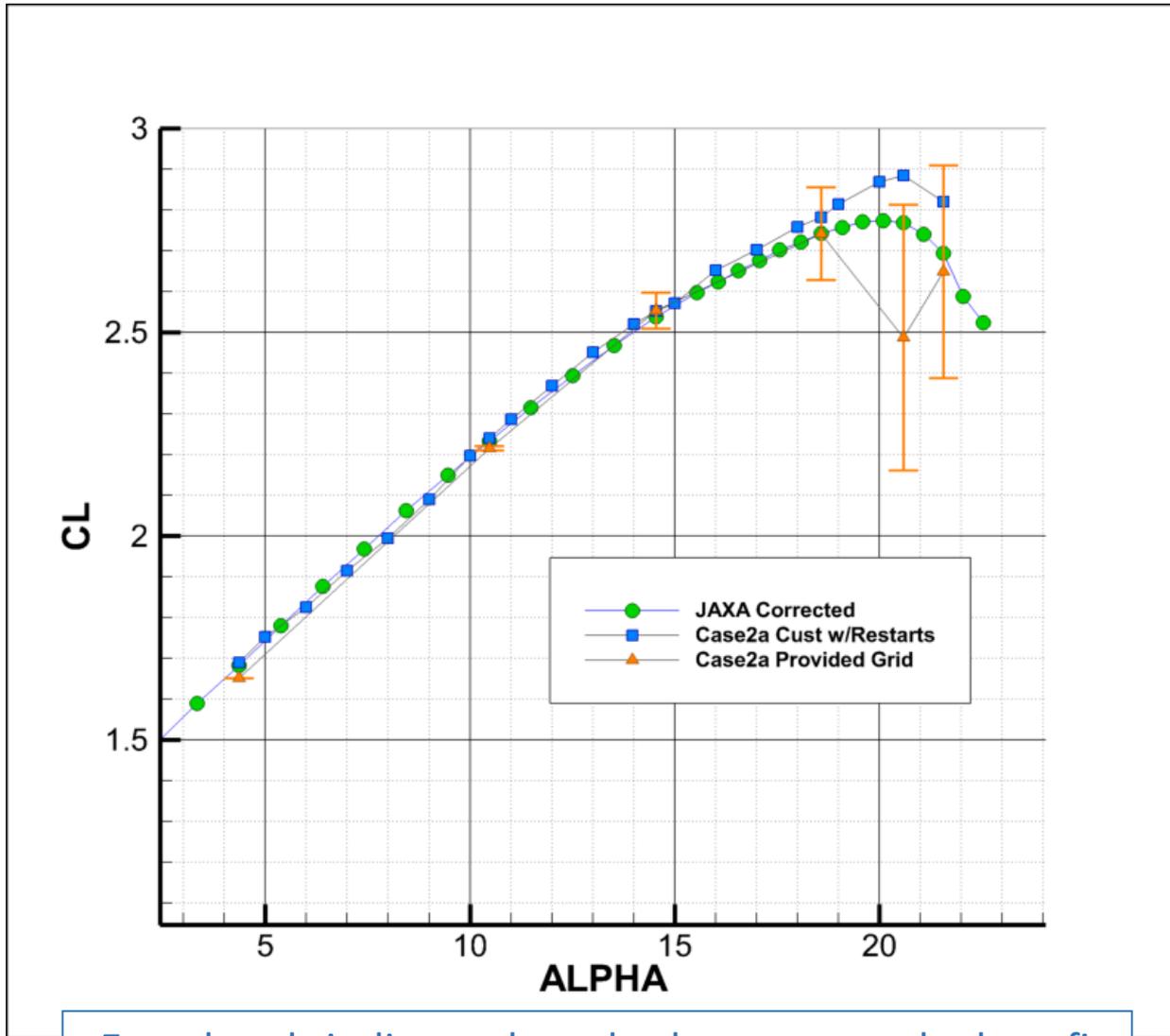
Similar grid density except at wingtip where custom grid has greater density

JSM Comparison to Wind Tunnel



Similar predictions up to 16°

JSM Comparison to Wind Tunnel



Error bands indicate plotted values may not be best fit