Comparison of Fixed and Adaptive Mesh Results for HiLiftPW-3

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Summary of cases completed: GGNS, SA-QCR

Case (HL-CRM)	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	yes	yes	
1b (full gap w adaption)	yes	yes	
1c (partial seal)	yes	yes	
1d (partial seal w adaption)	yes	yes	

Case (JSM)	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	yes	no	no	
2b (no nacelle w adaption)	yes	no	no	
2c (with nacelle)	yes	no	no	
2d (with nacelle w adaption)	yes	no	no	

Case (DSMA661)	2D Verification study	Other
3	yes	
Other	adapted	

Summary of code and numerics used

GGNS[1] (General Geometry Navier-Stokes)

- Tet-only unstructured grids
- Stabilized finite-element SUPG, second order
- Exact Jacobians, Newton-Raphson algorithm
- Linesearch. Time marching to steady state
- PETSc framework for linear and non-linear solvers
- Machine-zero converged steady state solutions
- Fully turbulent solutions : SA-QCR turbulence model

EPIC[2] (Edge Primitive Insertion and Collapse)

- Anisotropic metric-based tetrahedral grid adaptation
- Utilizes edge based operators to coarsen/refine surface and volume mesh to match a target metric field
- Metric field derived from solver error estimate

1) Kamenetskiy, D. *et al.* , “Numerical Evidence of Multiple Solutions for the Reynolds-Averaged Navier–Stokes Equations,” AIAA Journal Vol. 52, No. 8 (2014), pp. 1686-1698
2) Michal, T. and Krakos, J., “Anisotropic Mesh Adaptation through Edge Primitive Operations," AIAA Paper 2012-159, 2012

Brief overview of grid system(s)

Grid System	Case(s)	If committee grid, report any problems/issues If user grid, reason for generating grid system
Committee (B1-HLCRM_UnstrTet_PW)	1a, 1c	No solver problems/issues
User (a-HLCRM_AdaptedTet_EPIC)	1b, 1d	Generated adapted grid system for each geometry/AOA
Committee (C1-JSM_UnstrTet_VGRID)	2a, 2c	No solver problems/issues
User (JSM_AdaptedTet_EPIC)	2b, 2d	Generated adapted grid system for each geometry/AOA

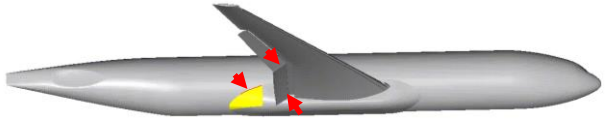
Committee Grids (B1-HLCRM and C1-JSM)

- B1-HLCRM – fixed grid family of grids (Pointwise)
- C1-JSM – single fixed grids for Nacelle on/off geometries (VGRID)

Adapted Grids

- Adapted to Mach Hessian, directly on IGES geometry
- Fully automated family of grids from initial grid and geometry

HLCRM Geometry Issues



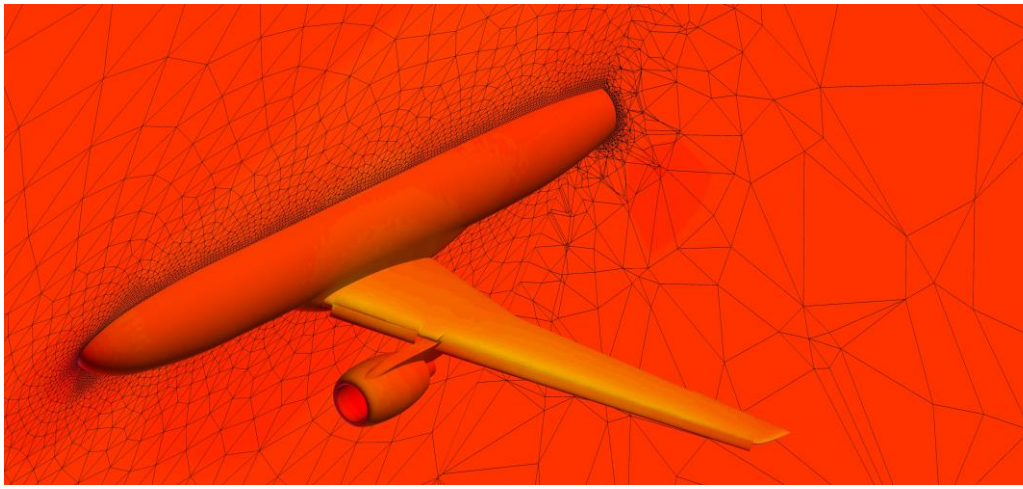
- Highly resolved definition of Wing/Body fairing – high computed curvature
- Trimming curve offset (0.02”) between
  - inboard flap lower surface and sides
  - slat trailing edge and slat upper/lower surfaces
- Offset issues were introduced during geometry prep, corrected and rerun

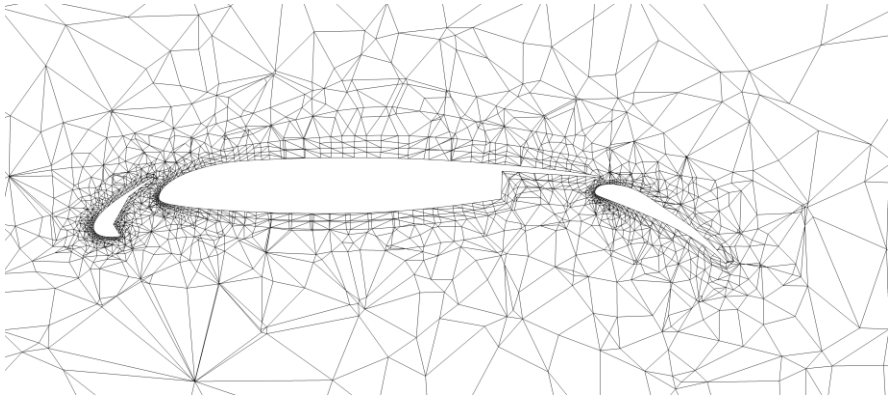
Example Adaptation Sequence

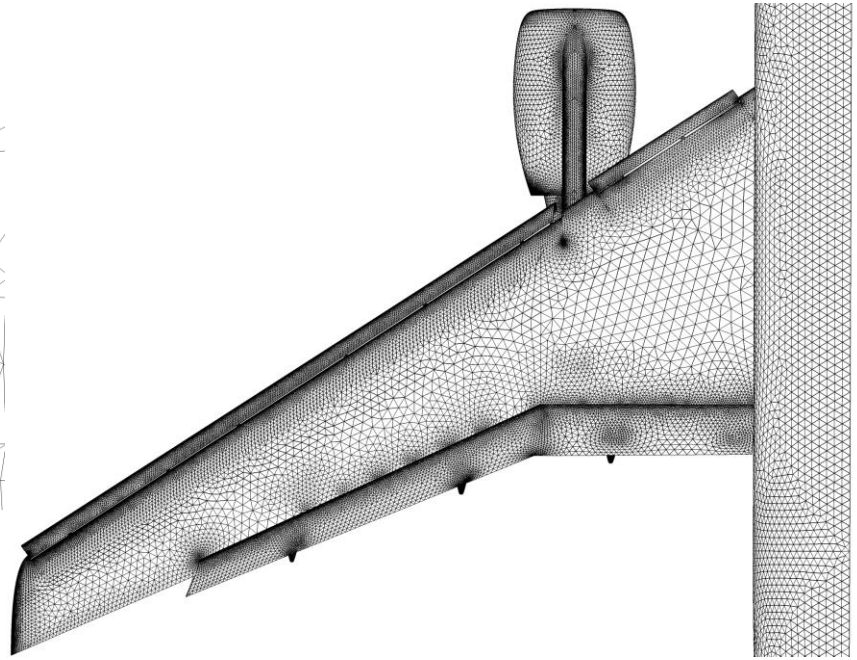
JSM case2d, Mach 0.172, Re=1.93M, α=14.54^o Grid Level 0

- Start with coarse initial grid
- Generate solution and error estimate
- Derive anisotropic sizing field that distributes mesh DOF to equilibrate error over domain

Initial Mesh Nodes=678K

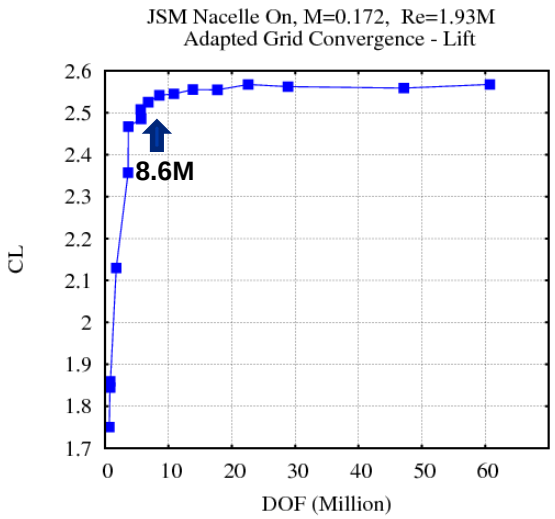


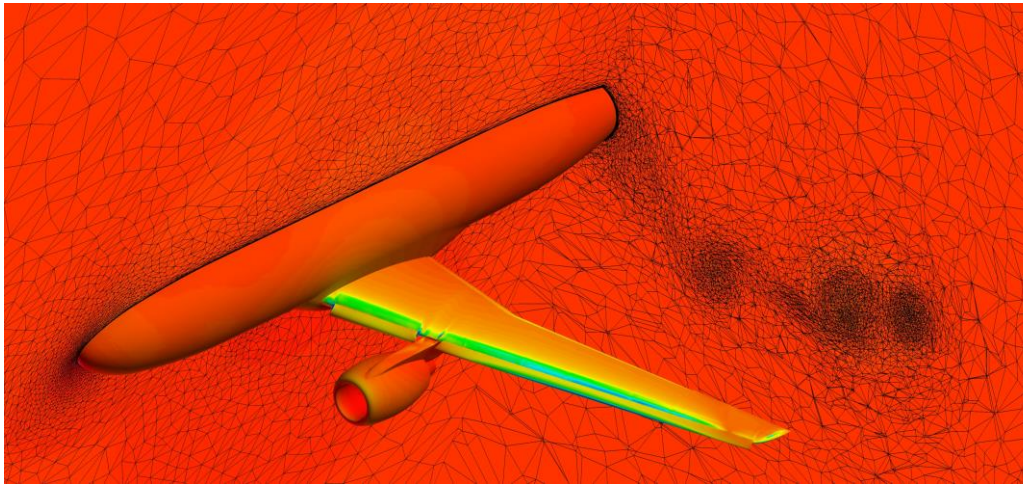


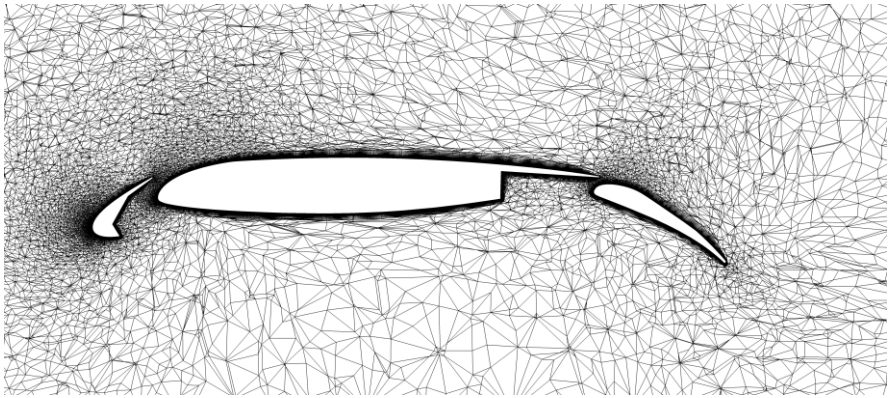


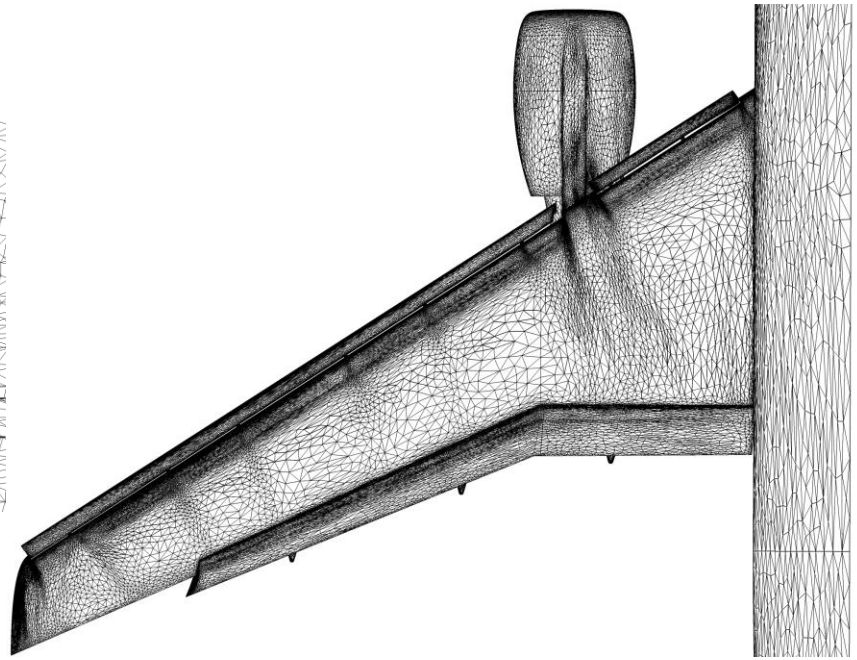
Example Adaptation Sequence

JSM case2d, Mach 0.172, Re=1.93M, α=14.54º Grid Level 9



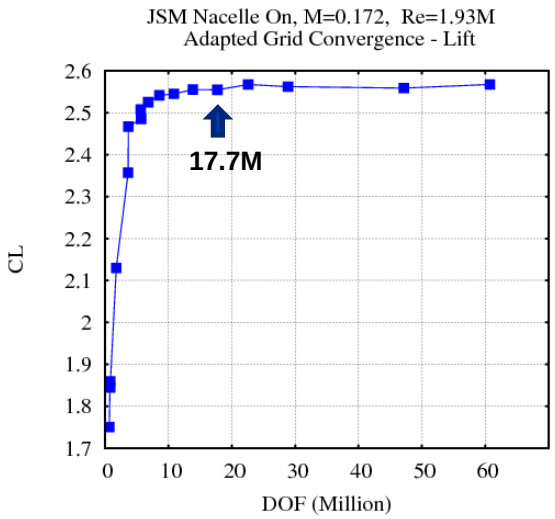


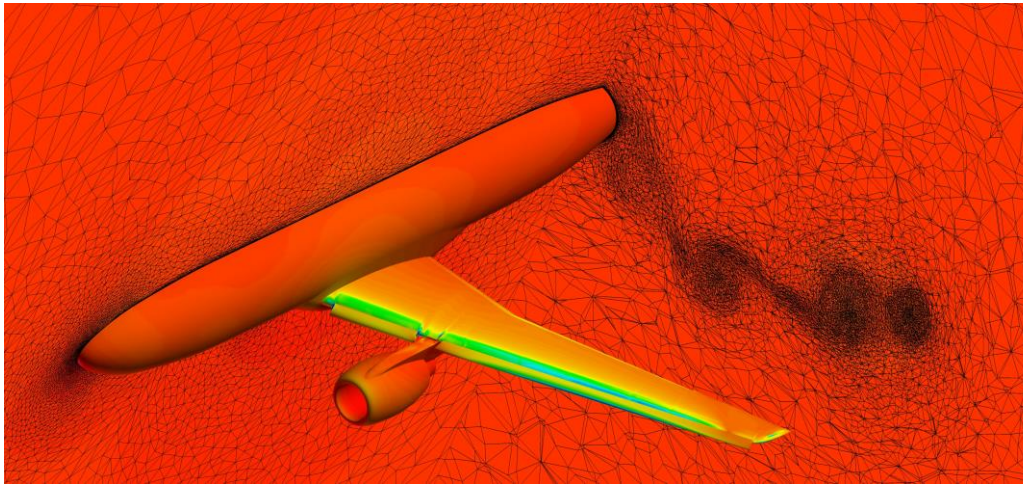


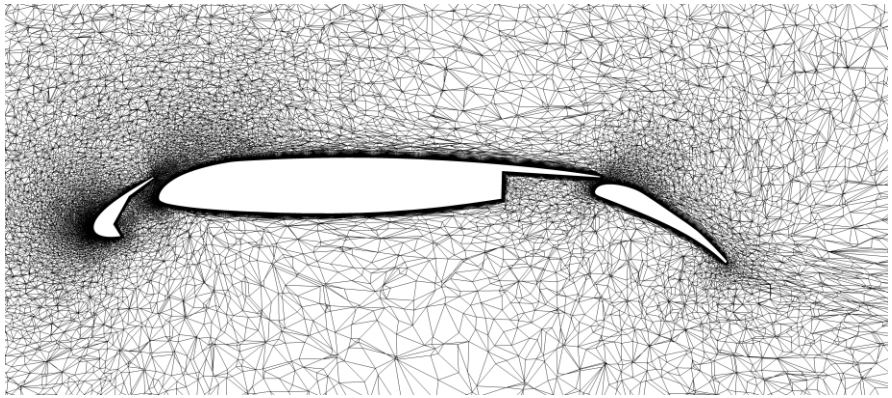


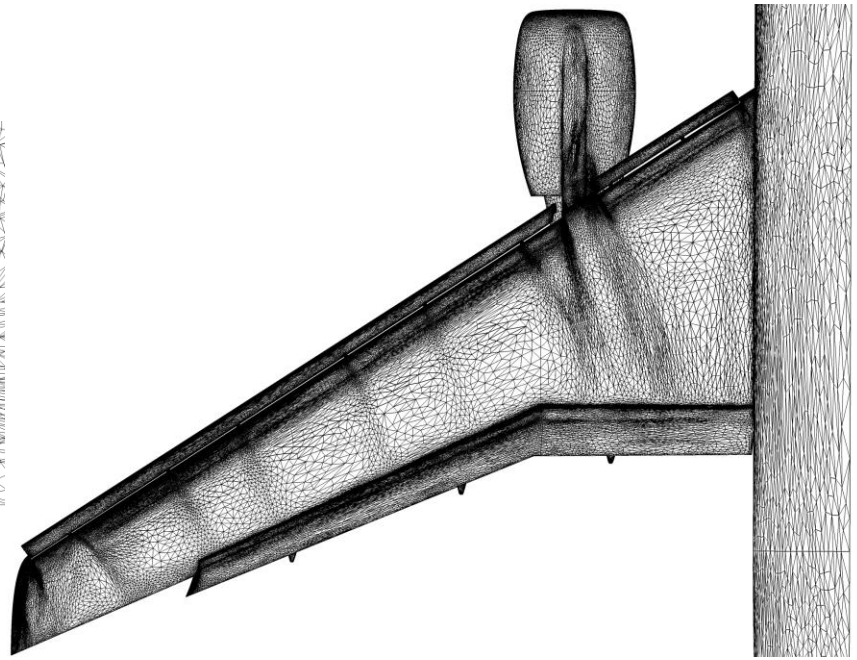
Example Adaptation Sequence

JSM case2d, Mach 0.172, Re=1.93M, α=14.54º Grid Level 12



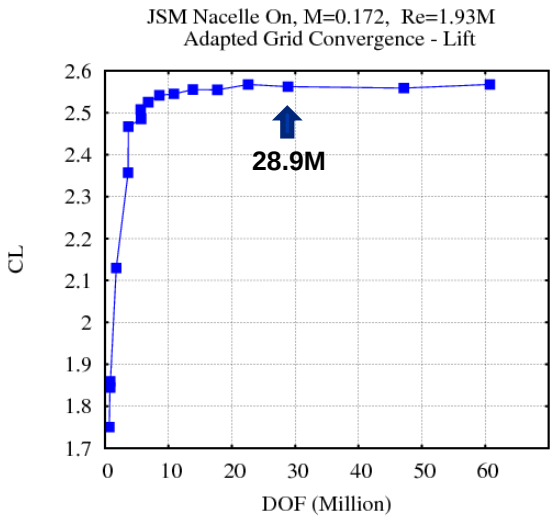


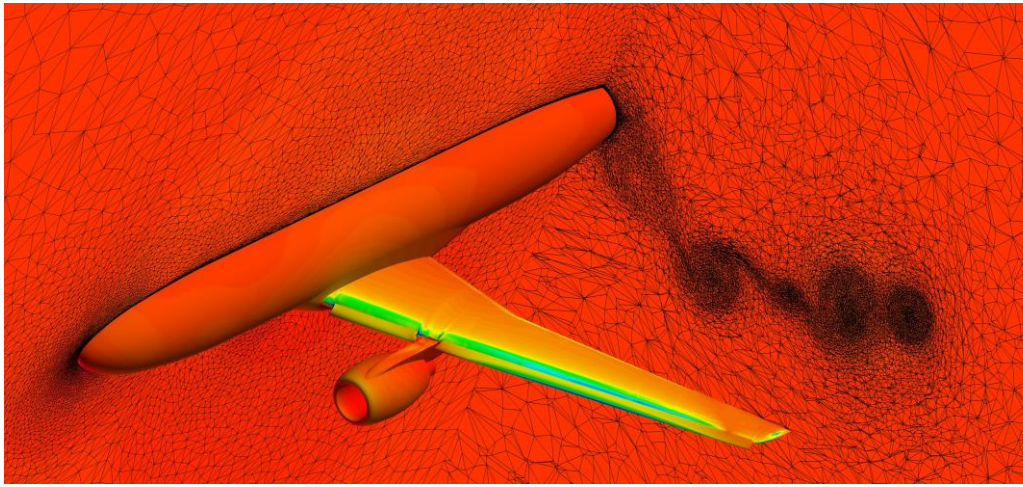


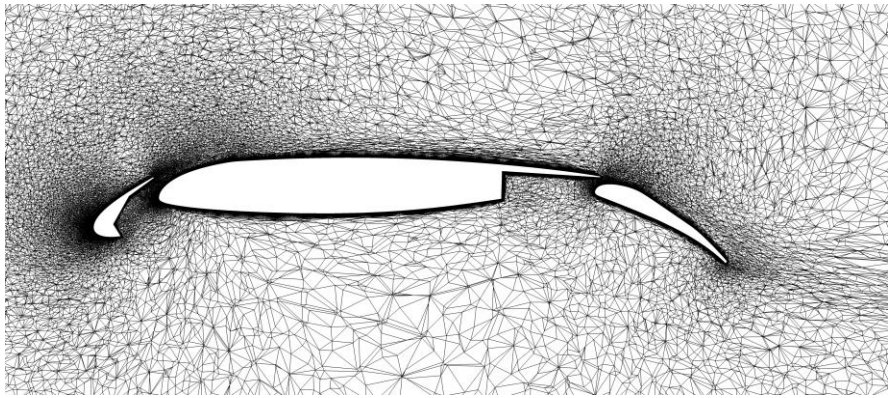


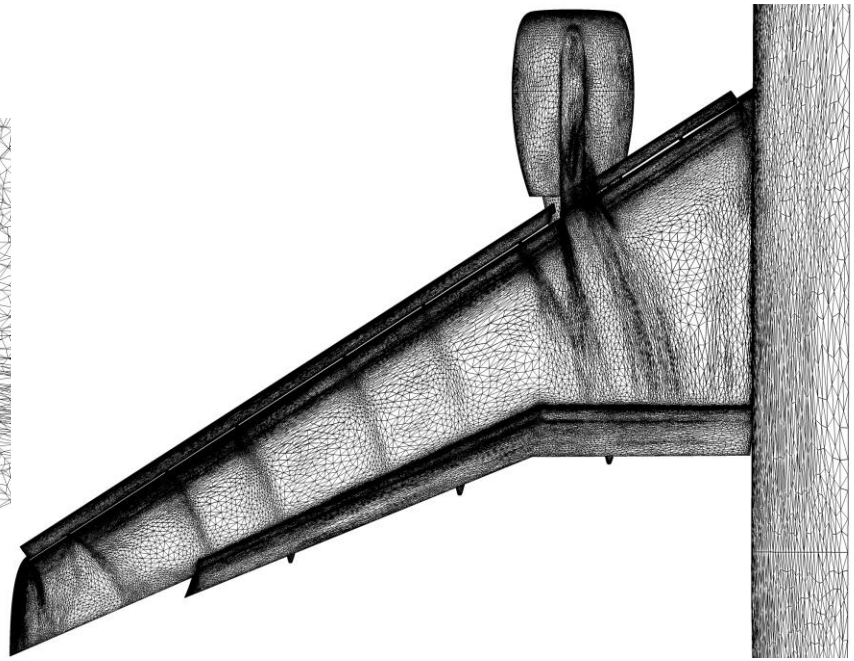
Example Adaptation Sequence

JSM case2d, Mach 0.172, Re=1.93M, α=14.54º Grid Level 14



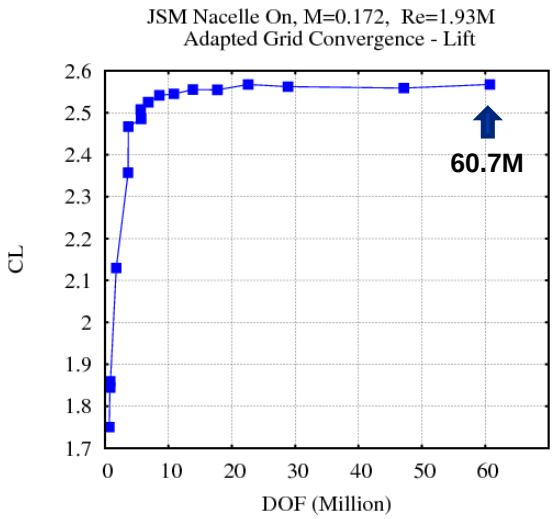


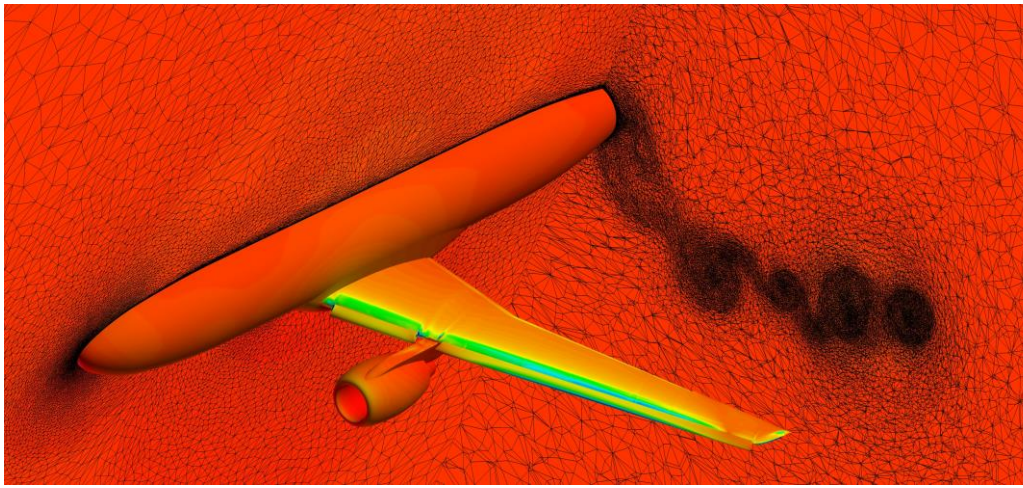


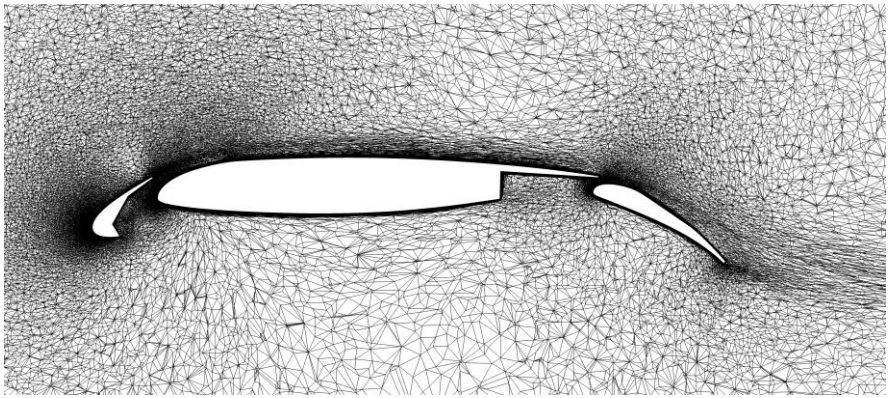


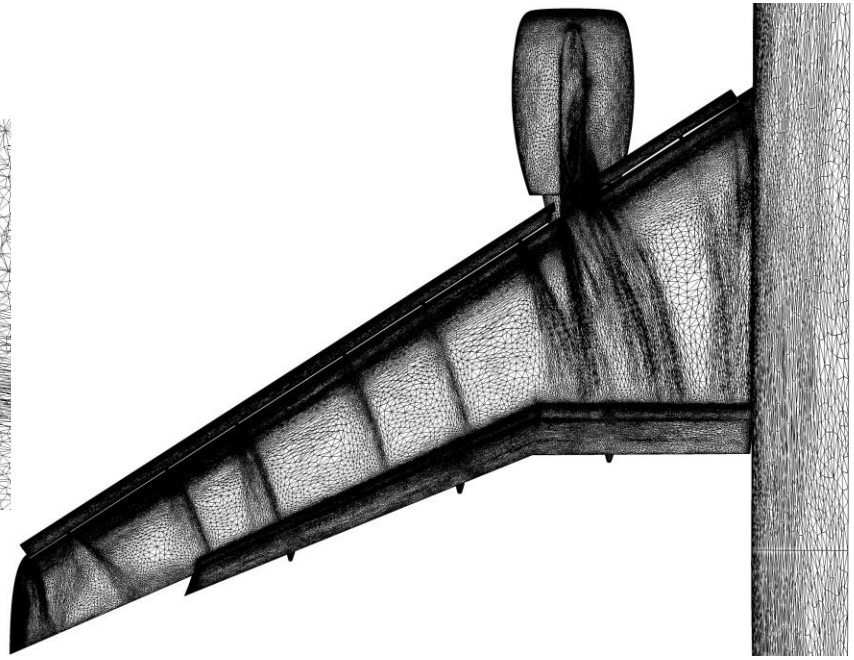
Example Adaptation Sequence

JSM case2d, Mach 0.172, Re=1.93M, α=14.54º Grid Level 17



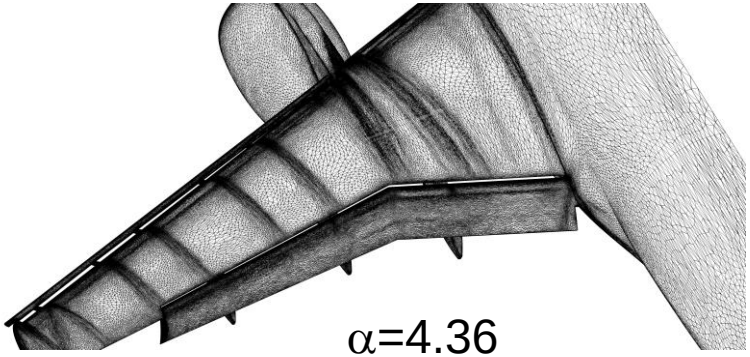


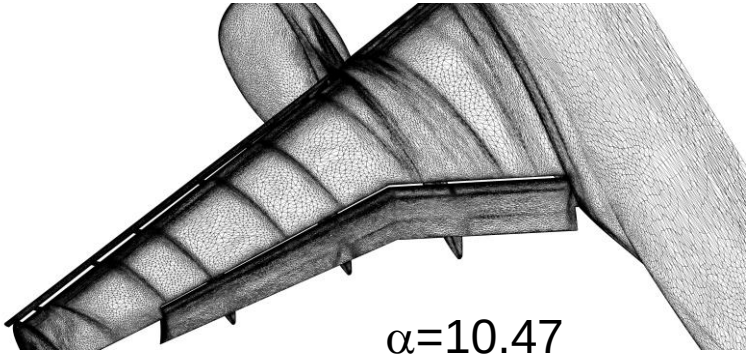


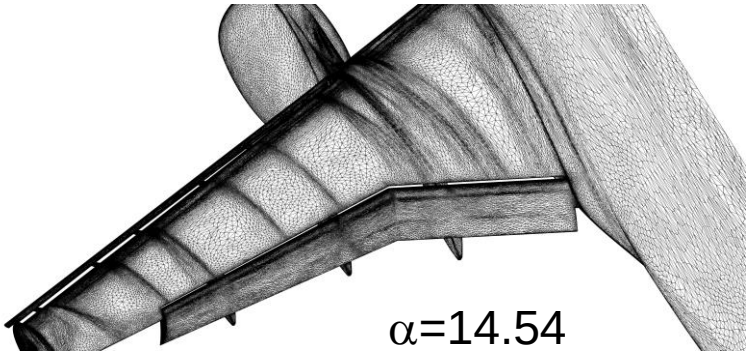


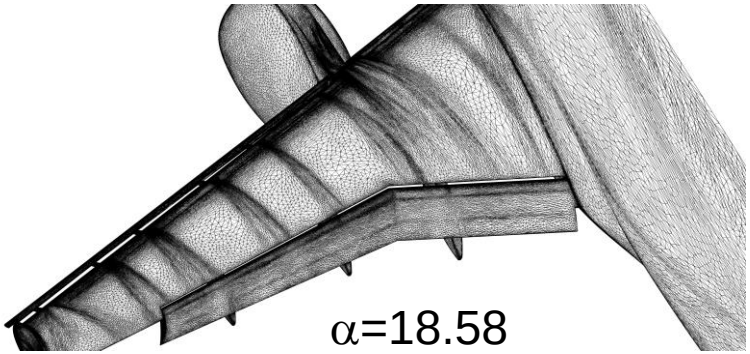
Adaptive Grid Generated at Each Solution Point

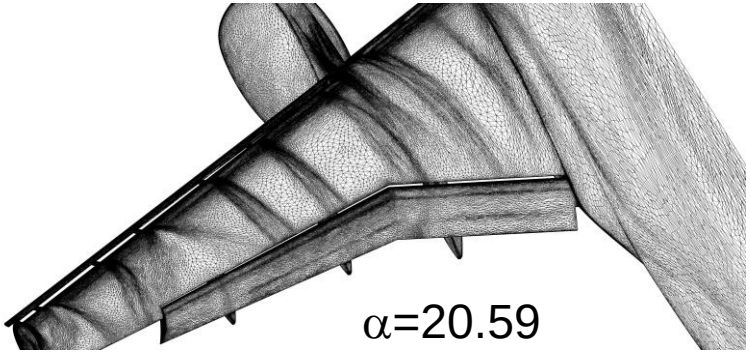
JSM Adapted Surface Grids for Angle of Attack Sweep

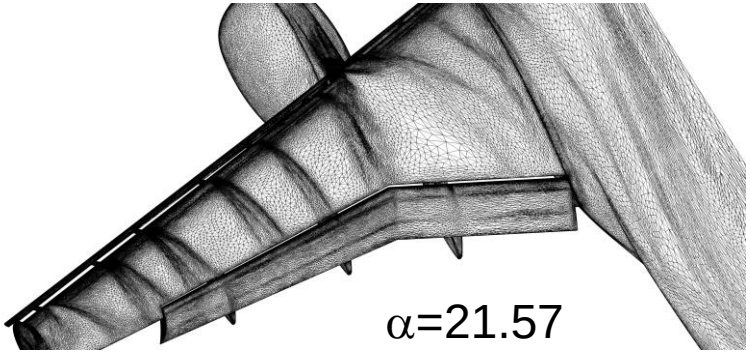






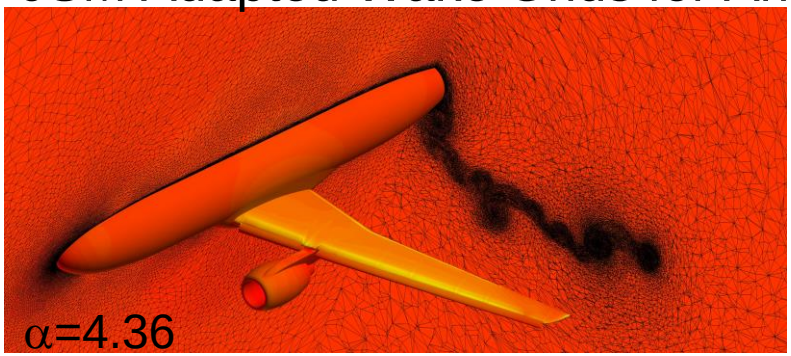


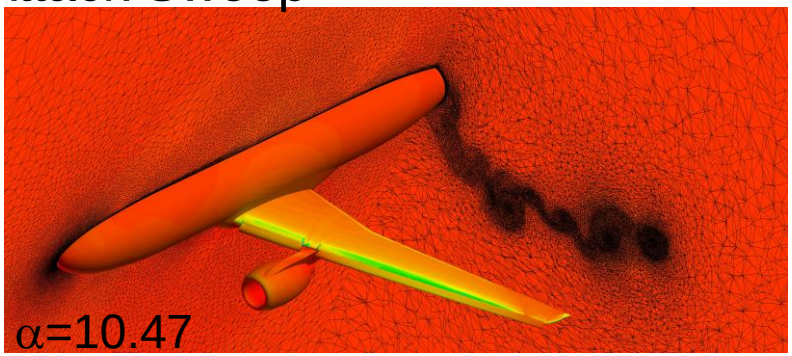


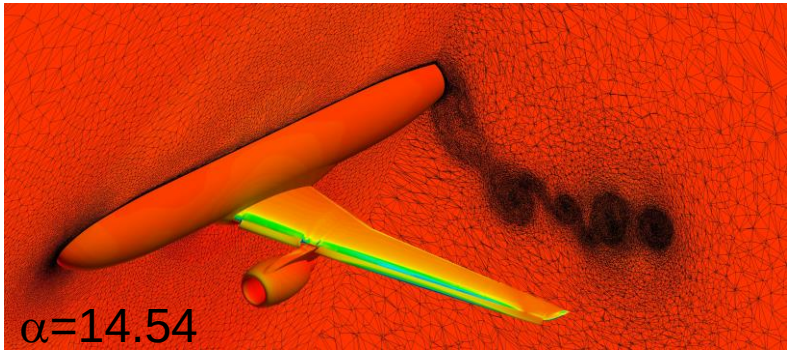


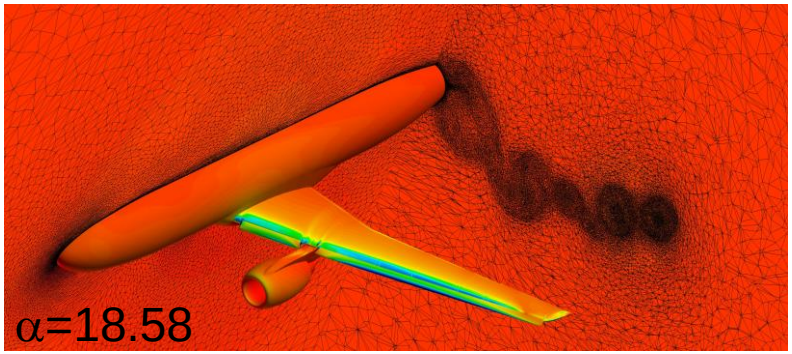
Adaptive Grid Generated at Each Solution Point

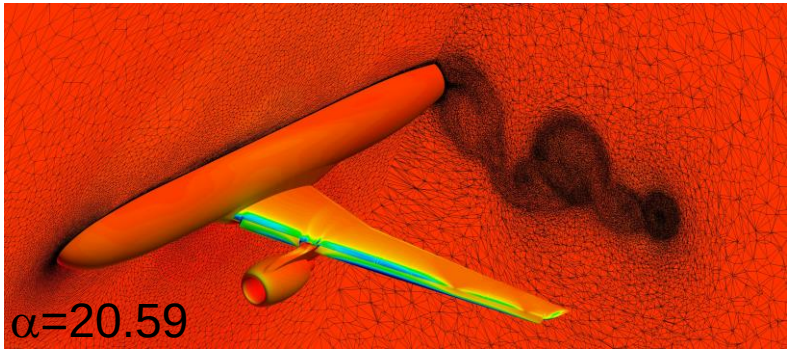
JSM Adapted Wake Grids for Angle of Attack Sweep

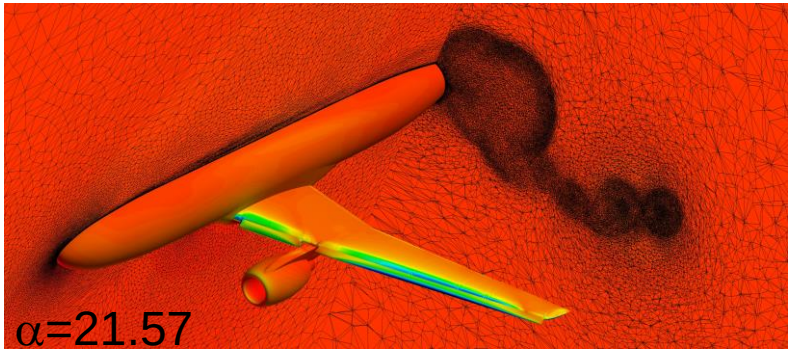










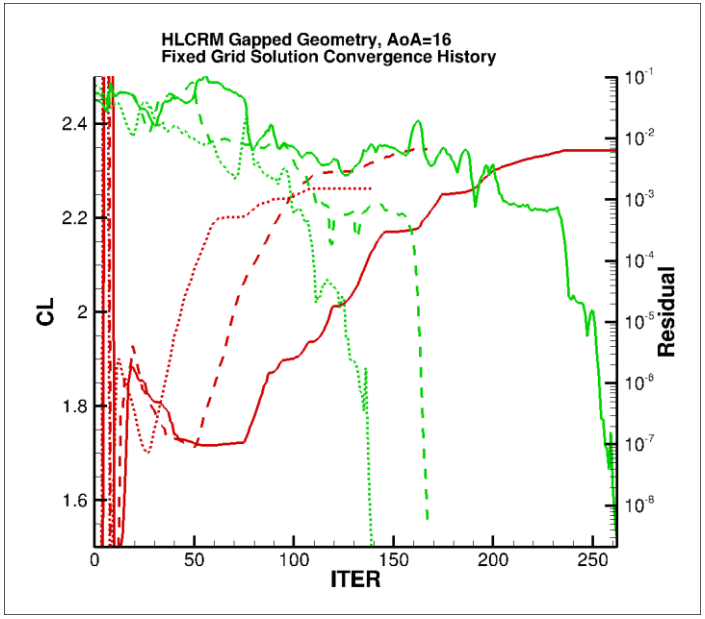


HL-CRM Cases (Gapped and Partially Sealed)

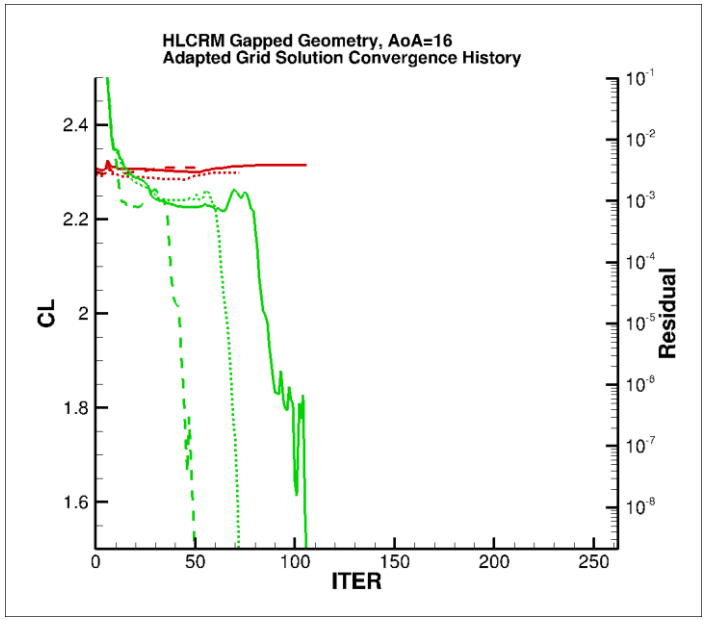
- Objective: Compare adapted and fixed grid solutions
- Fixed grid family: B1-HLCRM_UnstrTet_PW
- Adapted grid family: a-HLCRM_AdaptedTet_EPIC

Sample Solution Convergence

Fixed Grid

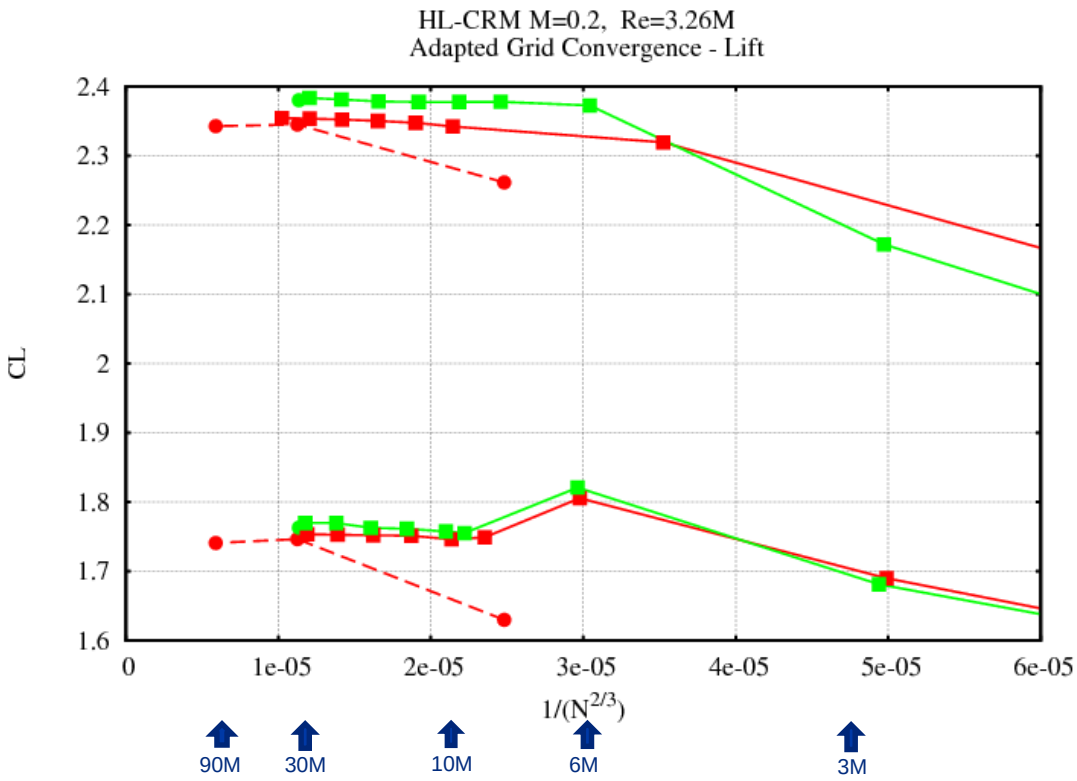


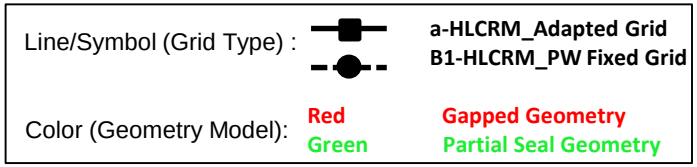
Adapted Grid



- Machine zero residual convergence achieved for nearly all solutions
- Adapted grid solutions converge in fewer iterations (better initial guess)

HL-CRM - Fixed and Adapted Grid Convergence





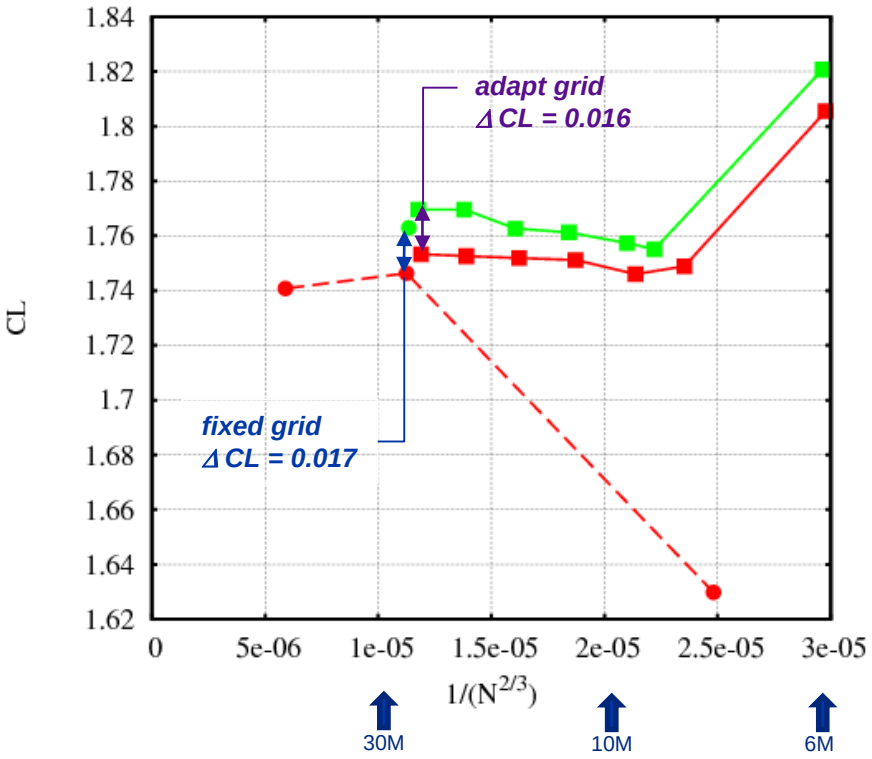
- Adapted solutions converge to near constant lift (~ 10M DOF)
  - Slight increase in CL with grid resolution continues
  - Consistent seal-gap increment with increasing grid resolution

- Insufficient data to evaluate fixed grid convergence
  - Non-asymptotic convergence for the gapped geometry
  - One data point for increment

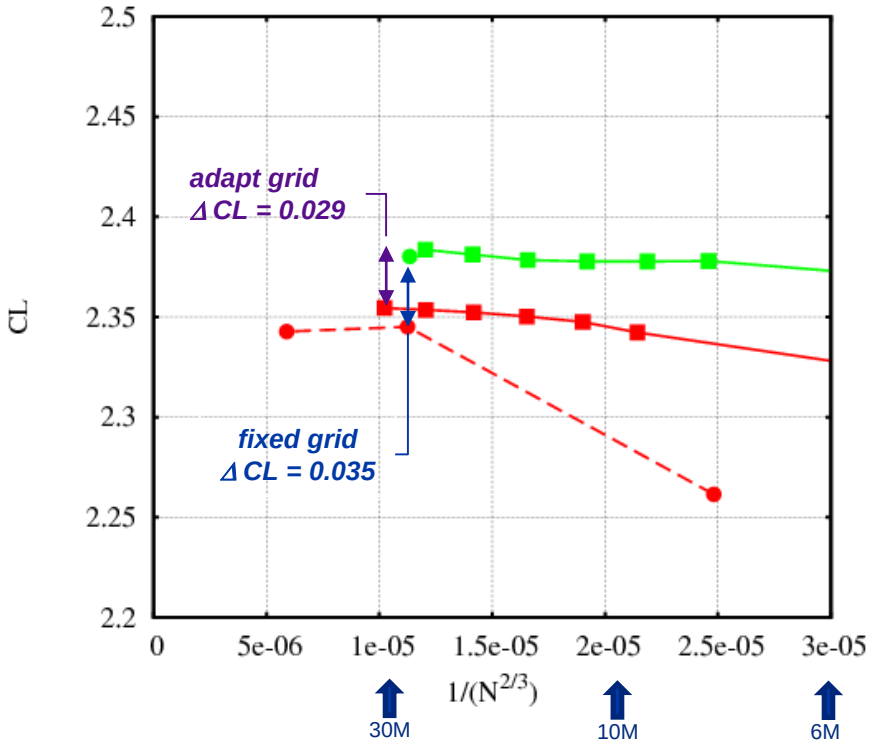
HL-CRM Computed Increment Sealed-Gapped

Line/Symbol (Grid Type) :		a-HLCRM_Adapted Grid B1-HLCRM_PW Fixed Grid
Color (Geometry Model):	Red Green	Gapped Geometry Partial Seal Geometry

Lift Convergence, α=8°



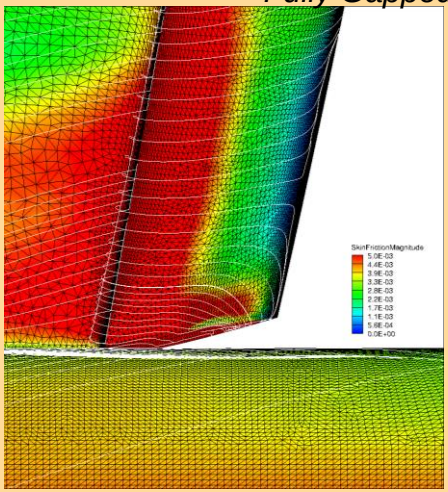
Lift Convergence, α=16°



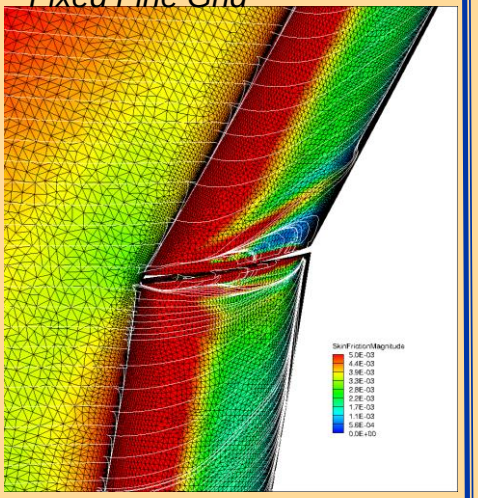
- Adaptive results provide richer data set for measuring increment (less uncertainty)

Solution Comparison in Flap Gaps, HLCRM AoA=16 degrees

Fully Gapped - Fixed Fine Grid

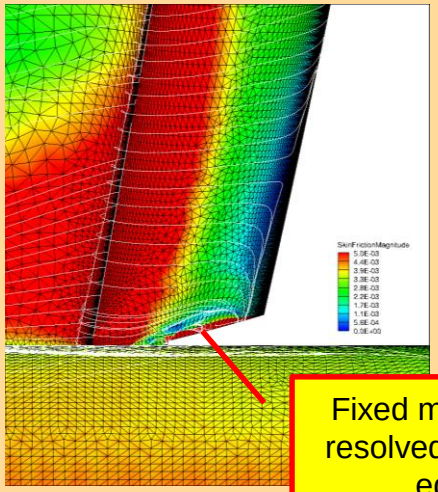


flap/body gap

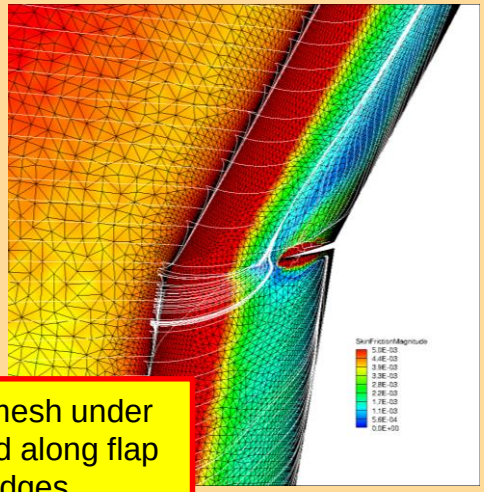


flap/flap gap

Partially Sealed - Fixed Fine Grid



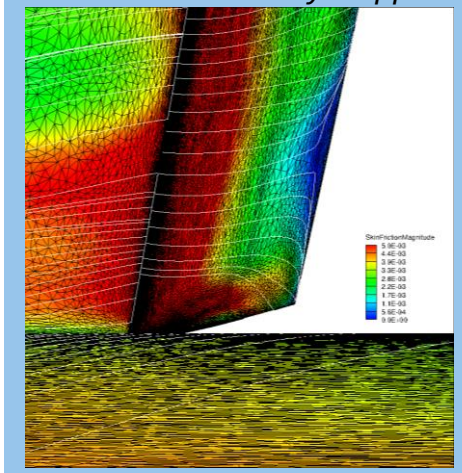
flap/body gap

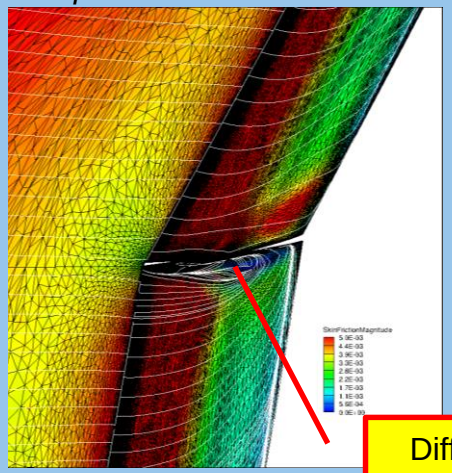


flap gap

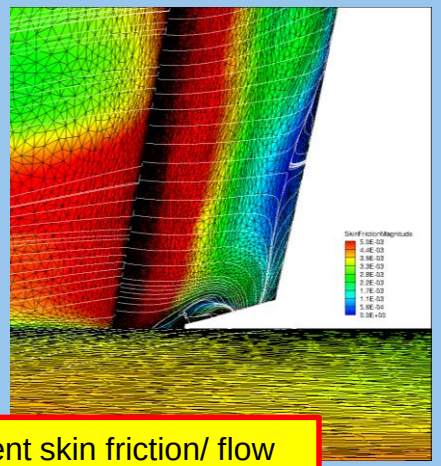
Fixed mesh under resolved along flap edges

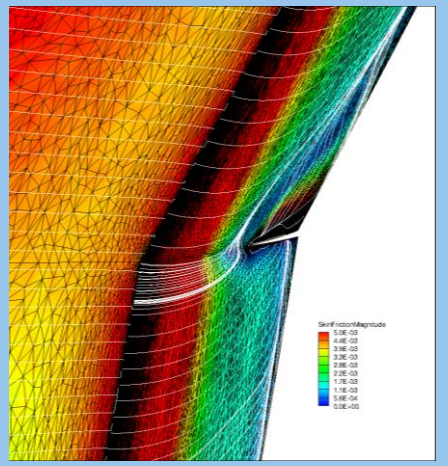
Fully Gapped - Adapt Fine Grid





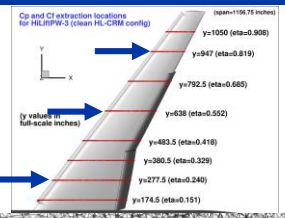
Partially Sealed - Adapt Fine Grid

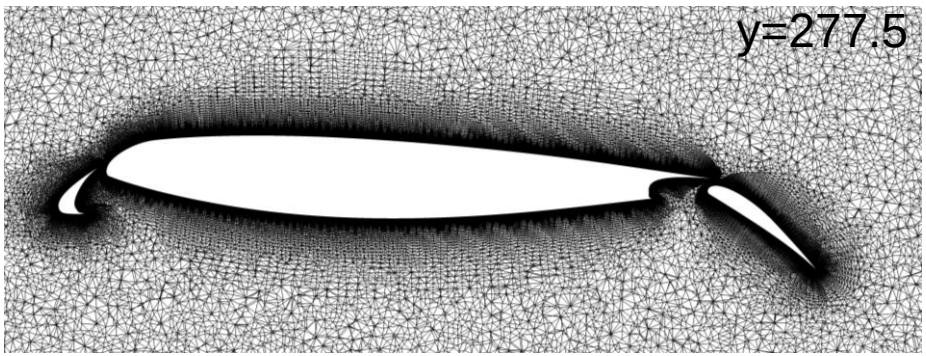


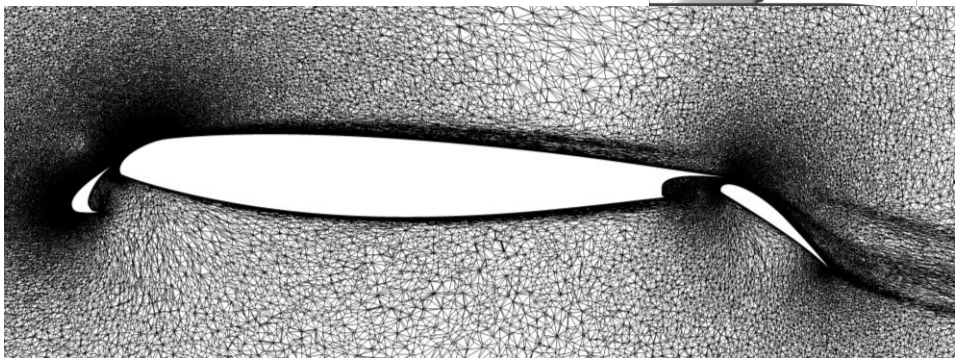


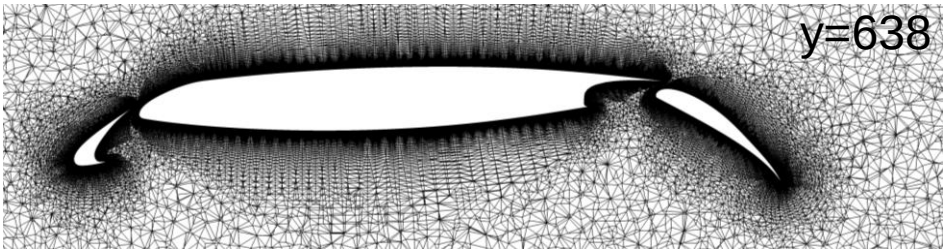
Different skin friction/ flow separation patterns between fixed/adapted solutions

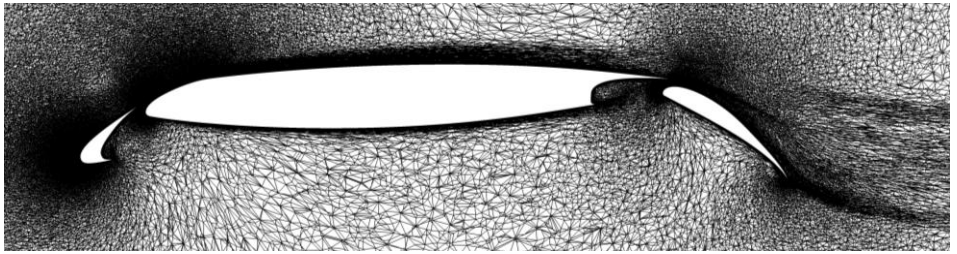
Comparison of Fixed and Adapted Volume Grids HLCRM Gapped AoA=16 degrees

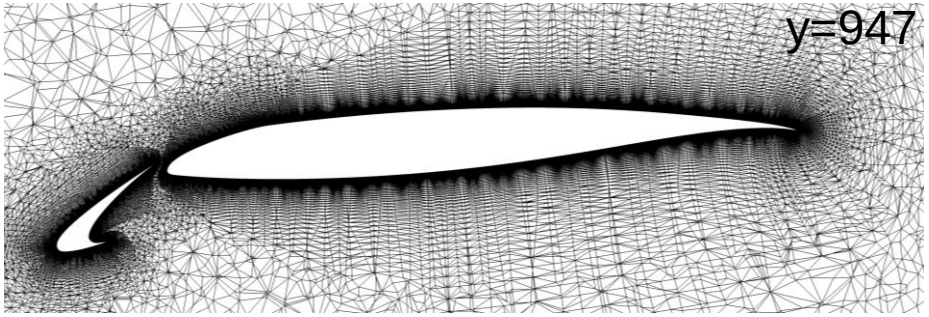


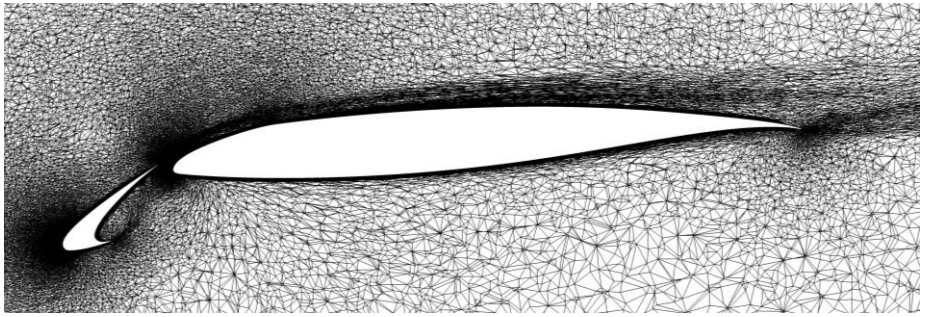










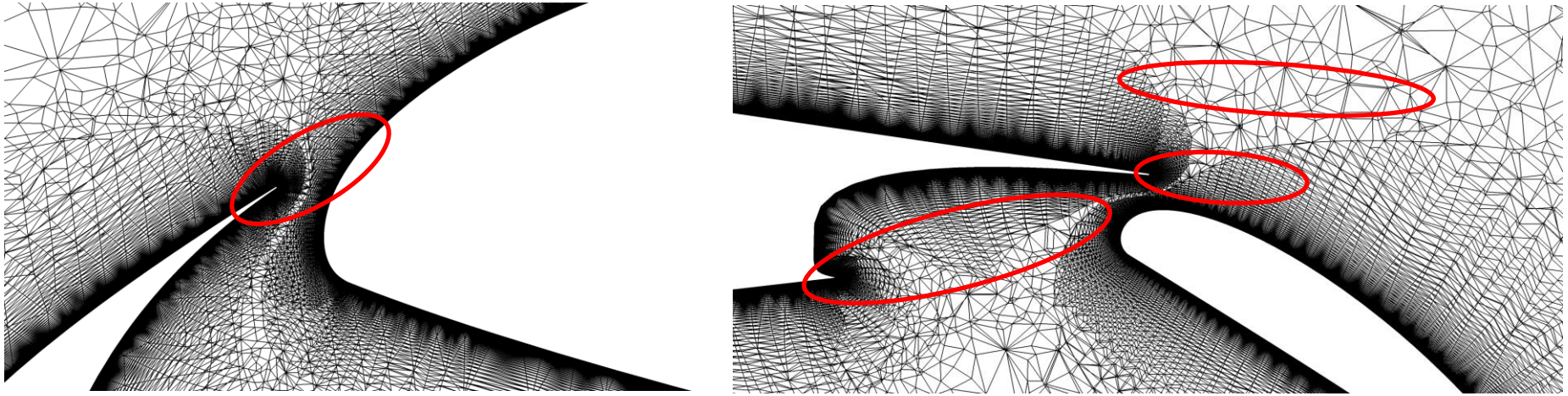


Fixed Fine Grid, 69.9 M Nodes

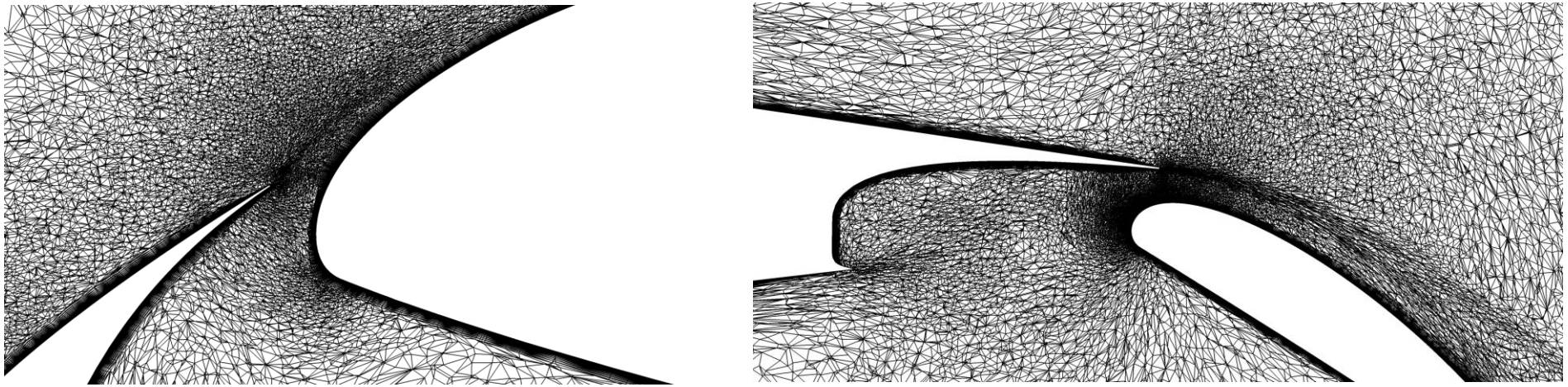
Adapt Fine Grid, 38.9 M Nodes

Fixed and Adapted Grid Slat and Wing Wakes y=638 HLCRM Gapped AoA=16 degrees

Fixed Fine Grid, 69.9 M Nodes

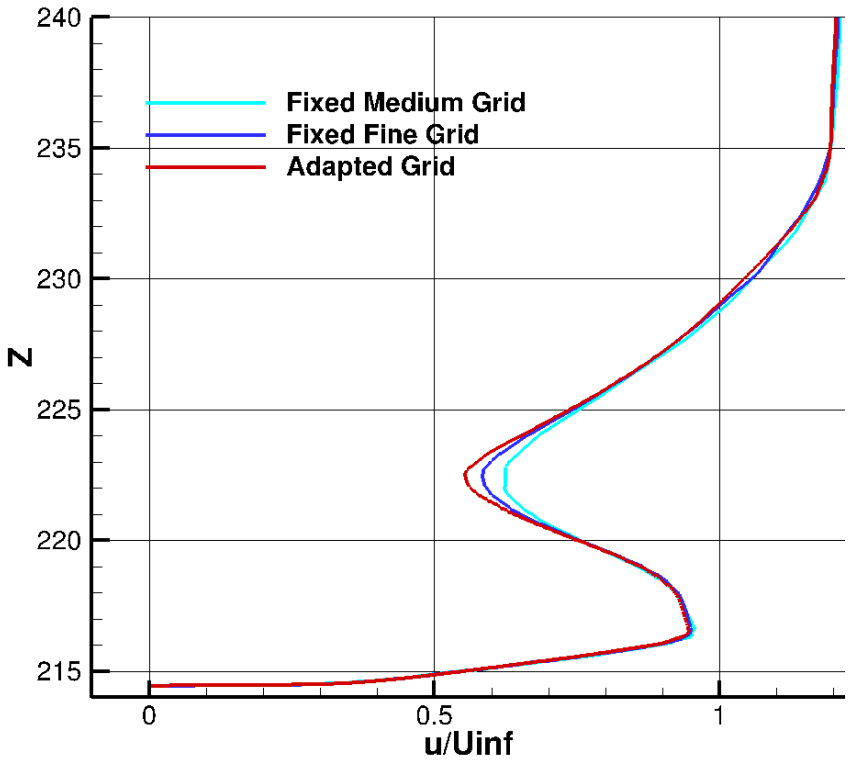


Adapt Fine Grid, 38.9 M Nodes

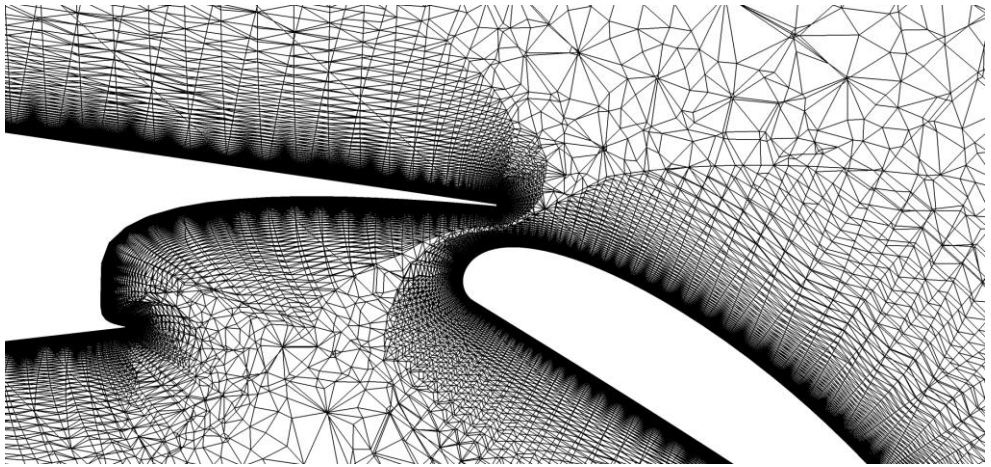


Adapted Grids Maintain Wake Resolution Near Merging Shear Layers

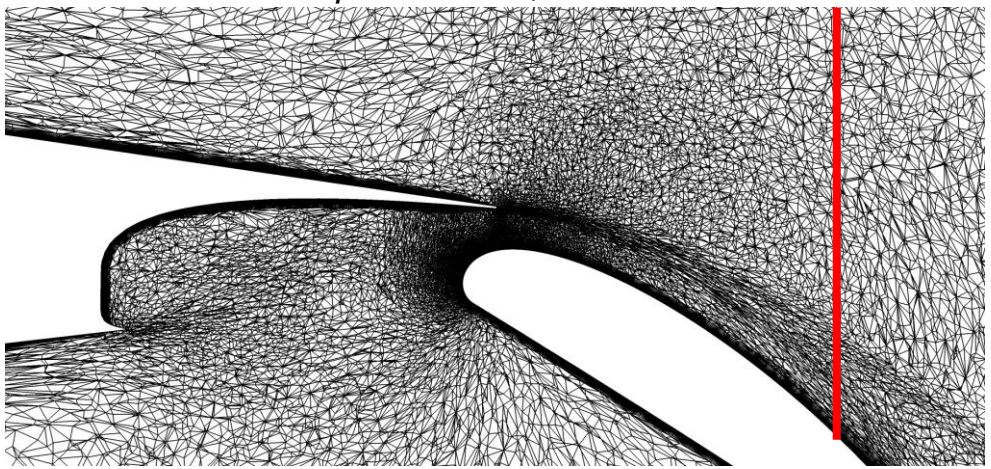
Fixed and Adapted Grid Velocity Profile x=1615, y=638 HLCRM Gapped AoA=16 degrees



Fixed Fine Grid, 69.9 M Nodes



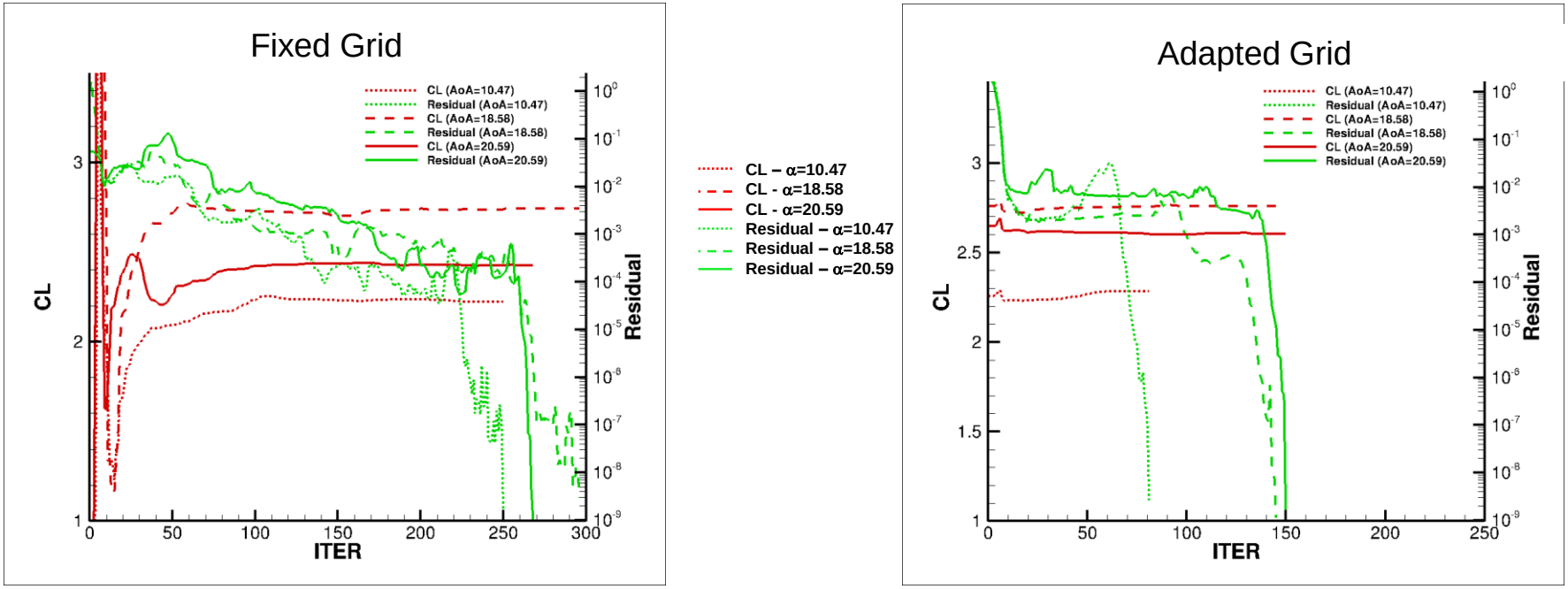
Adapt Fine Grid, 38.9 M Nodes



JAXA JSM Cases with and without Nacelle

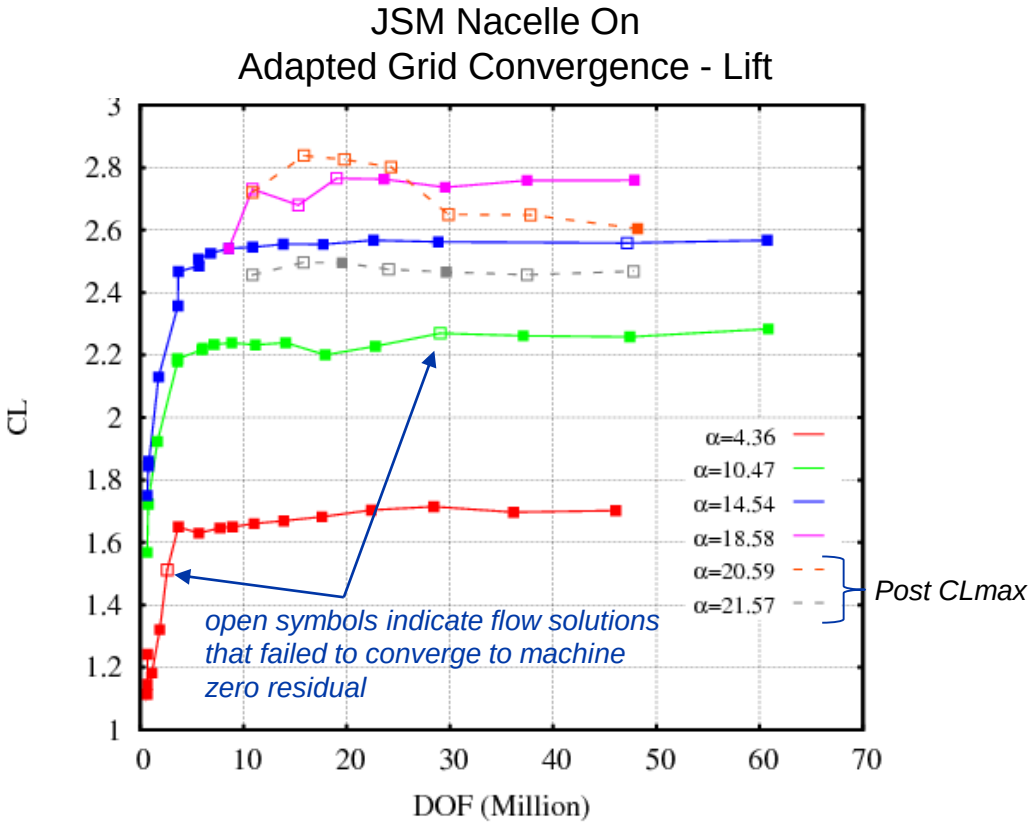
- **Objective: Compare adapted and fixed grid solutions**
- **Fixed grid family: C1-JSM_UnstrTet_VGRID**
- **Adapted grid family: JSM_AdaptedTet_EPIC**

Sample Solution Convergence (JSM with Nacelle)



- **Almost all solutions converge to machine zero residuals at pre-stall angle of attack**
- **Post stall solutions do not converge as well**
- **Adapted grid solutions converge in fewer iterations compared to fixed grid**

JAXA JSM – Adapted Grid Convergence



- **Rapid convergence to ~ 10M DOF followed by slow convergence to final lift**
- **Pre stall solutions convergence to near constant lift**
- **Post stall solutions not as close to grid converged**
- **Multiple solution branches complicate adaptive process**

JSM Nacelle On/Off - Forces and Pitching Moment

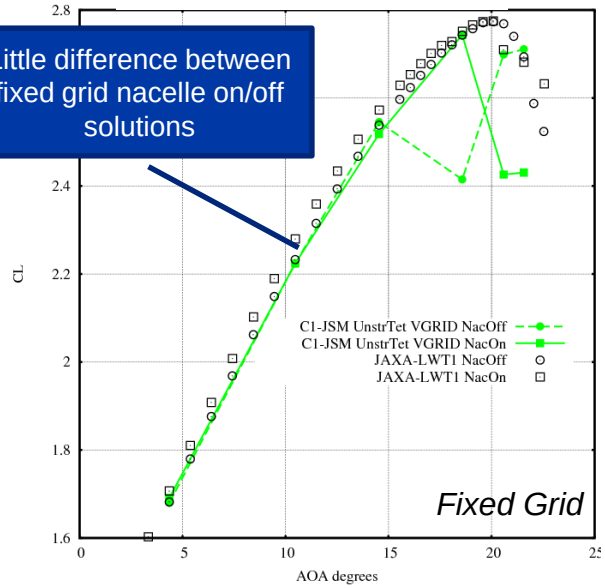
Lift Curve

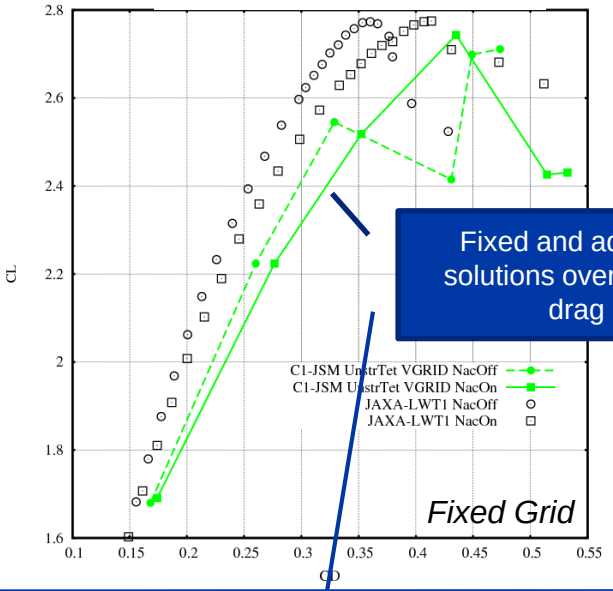
Drag Polar

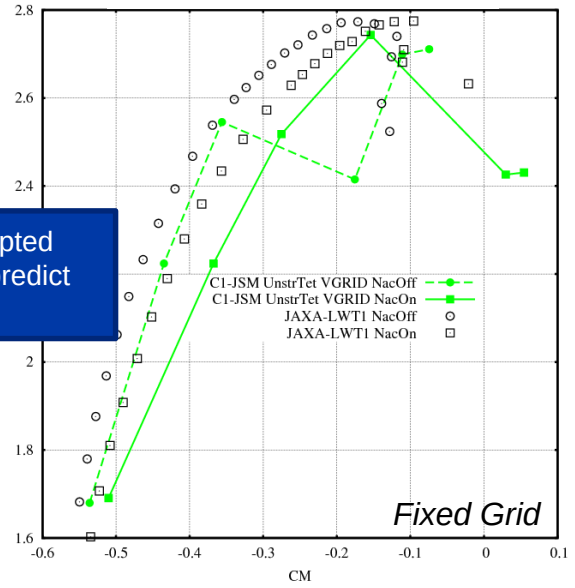
Pitching Moment

Little difference between fixed grid nacelle on/off solutions

Fixed and adapted solutions over predict drag

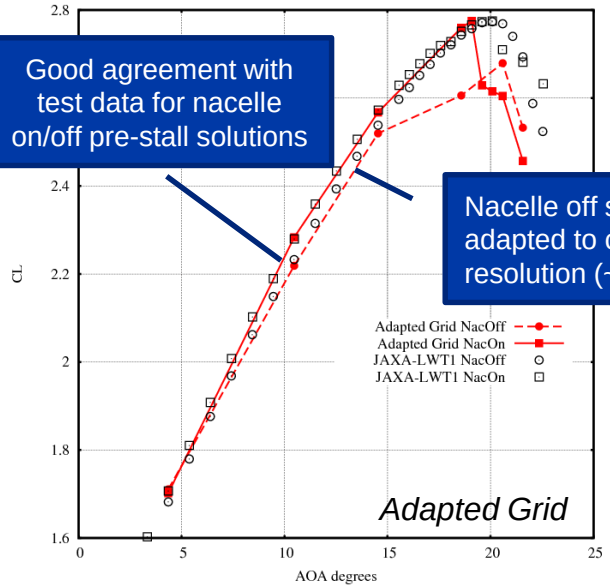


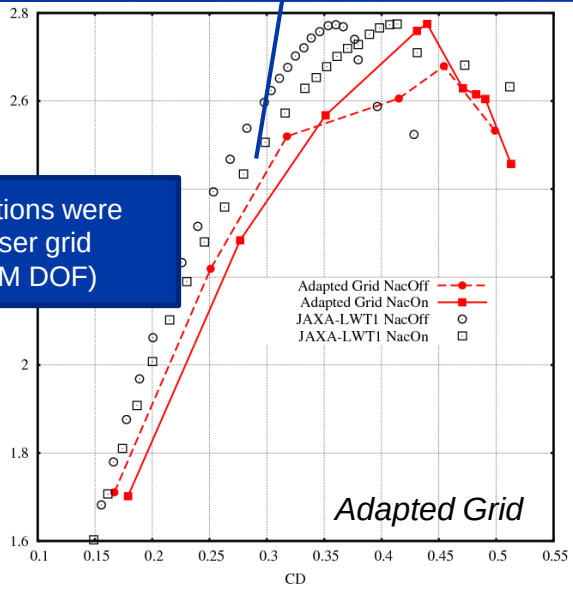


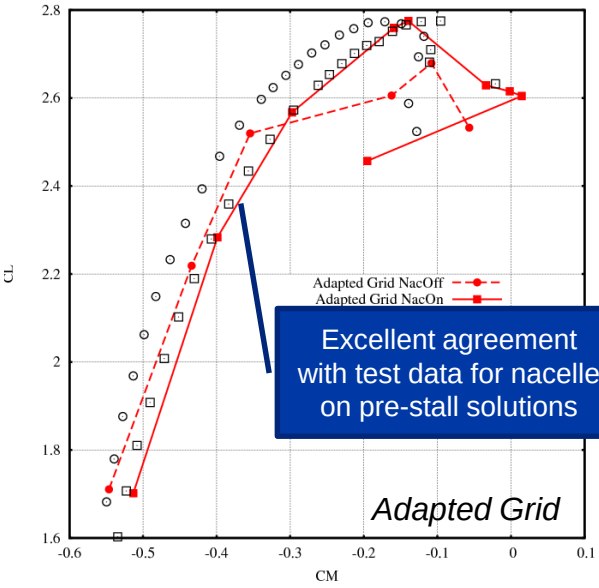


Good agreement with test data for nacelle on/off pre-stall solutions

Nacelle off solutions were adapted to coarser grid resolution (~ 20M DOF)

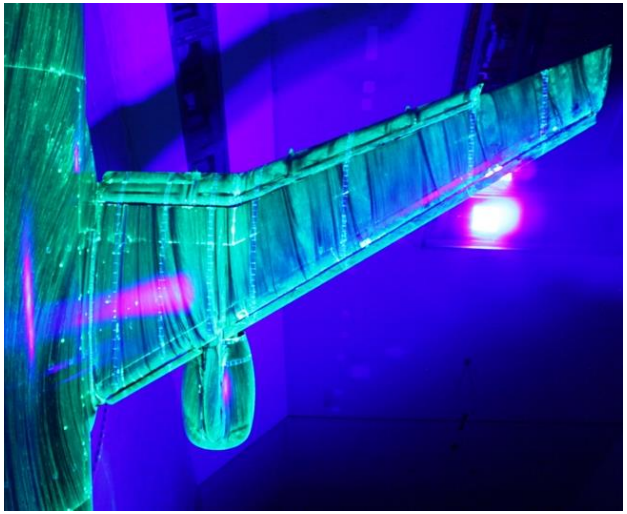




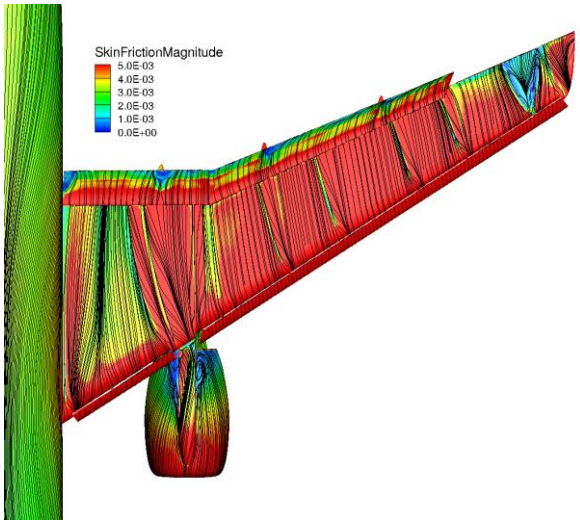


Excellent agreement with test data for nacelle on pre-stall solutions

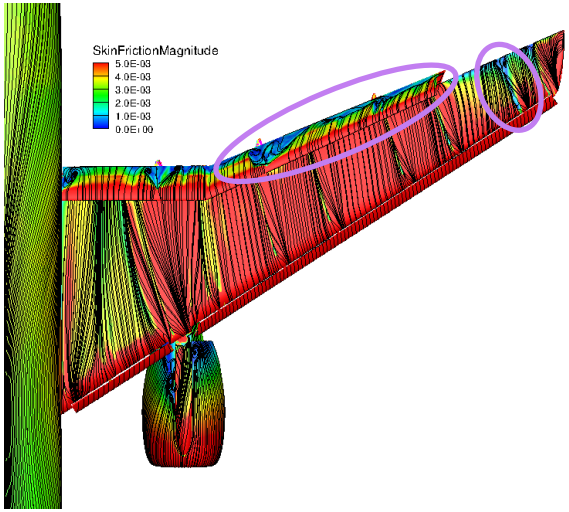
JSM Oil Flows AoA=4.36º



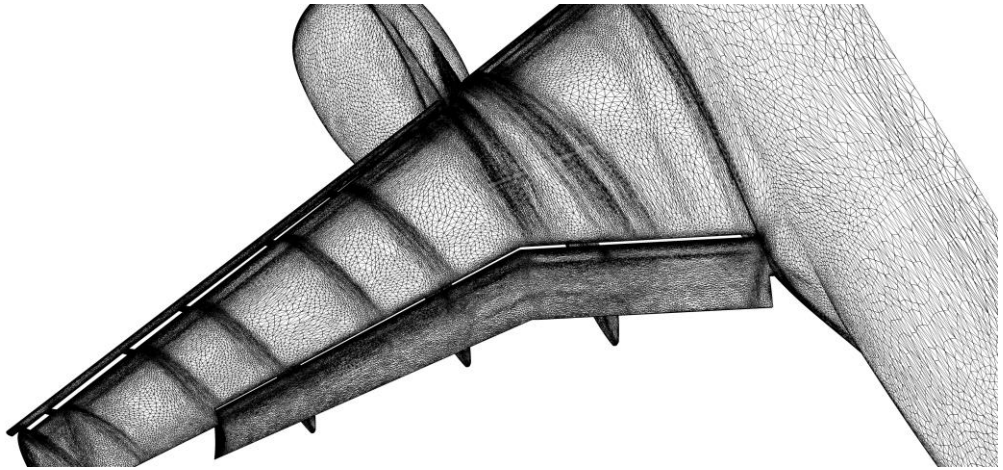
Test



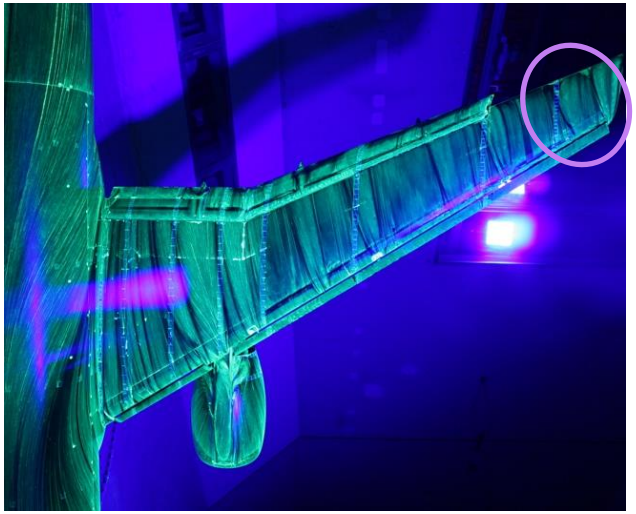
Adapted Grid



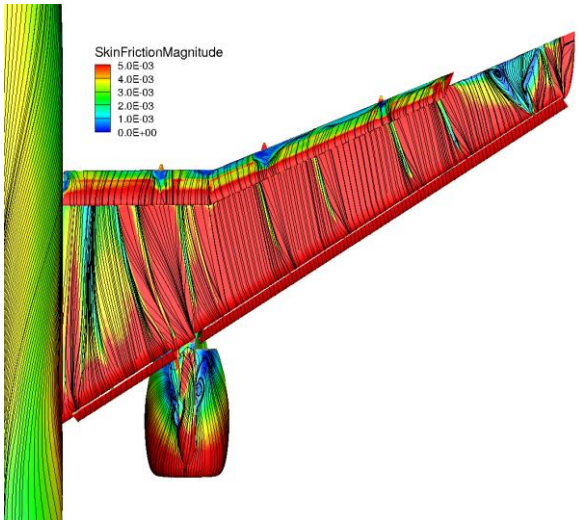
Fix Grid



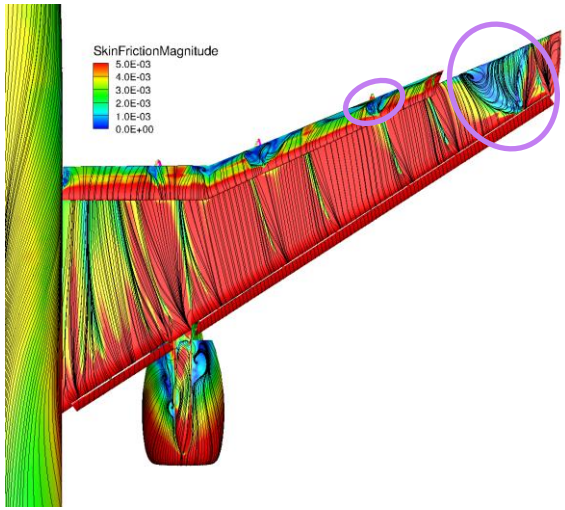
JSM Oil Flows AoA=10.47º



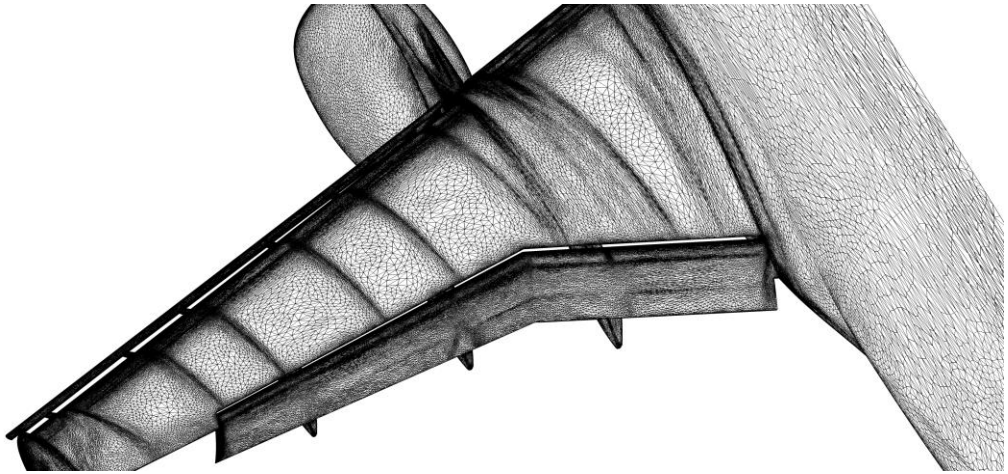
Test



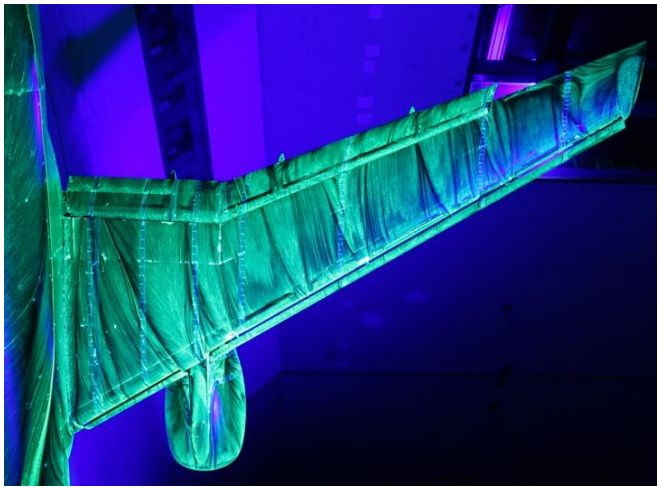
Adapted Grid



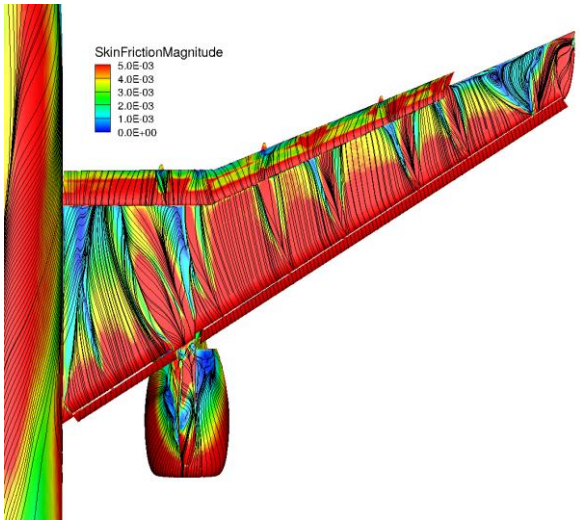
Fix Grid



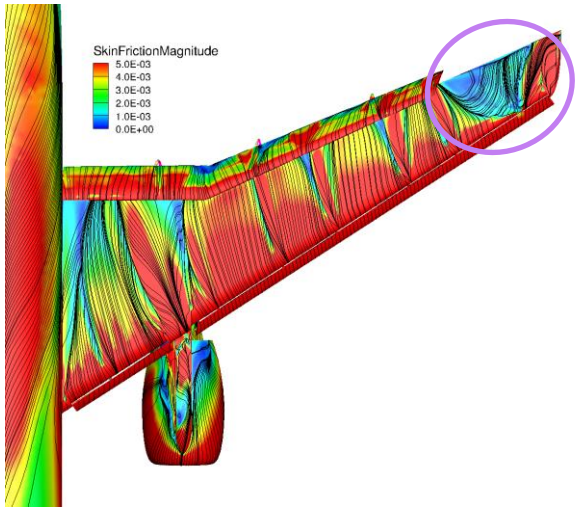
JSM Oil Flows AoA=18.59^{o}



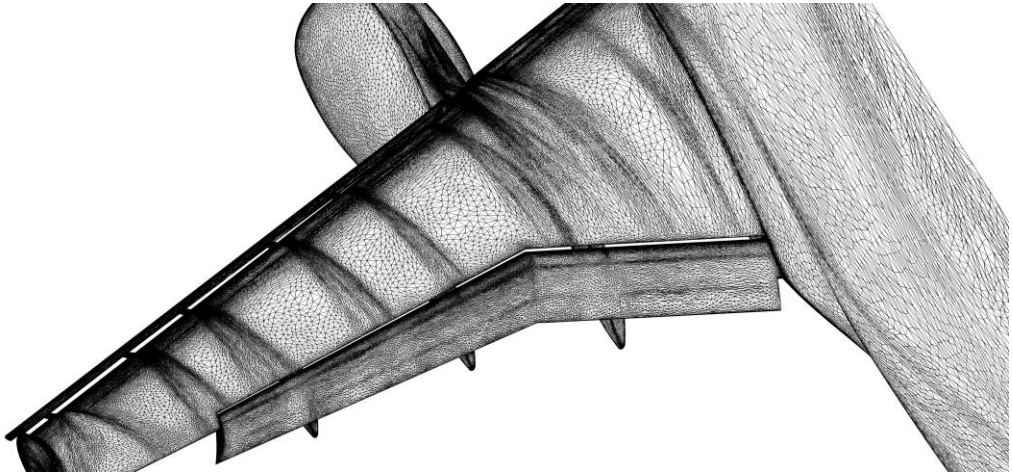
Test



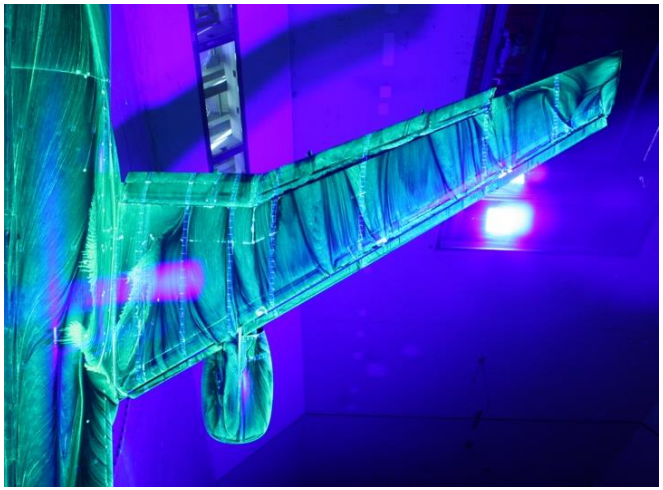
Adapted Grid



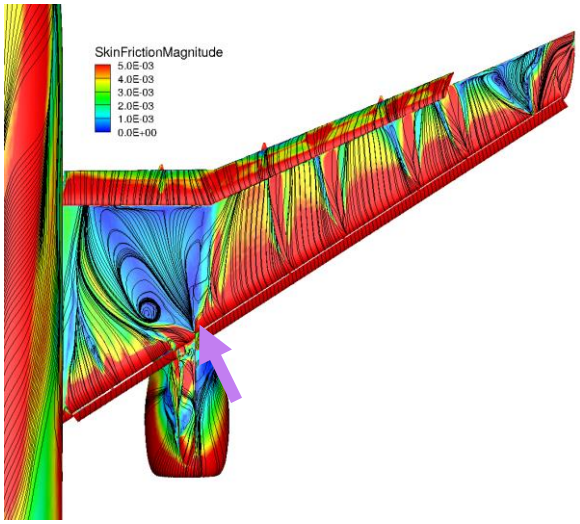
Fix Grid



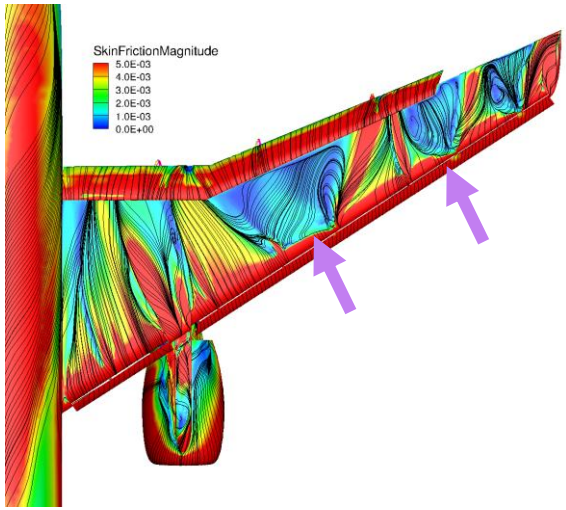
JSM Oil Flows AoA=21.57º



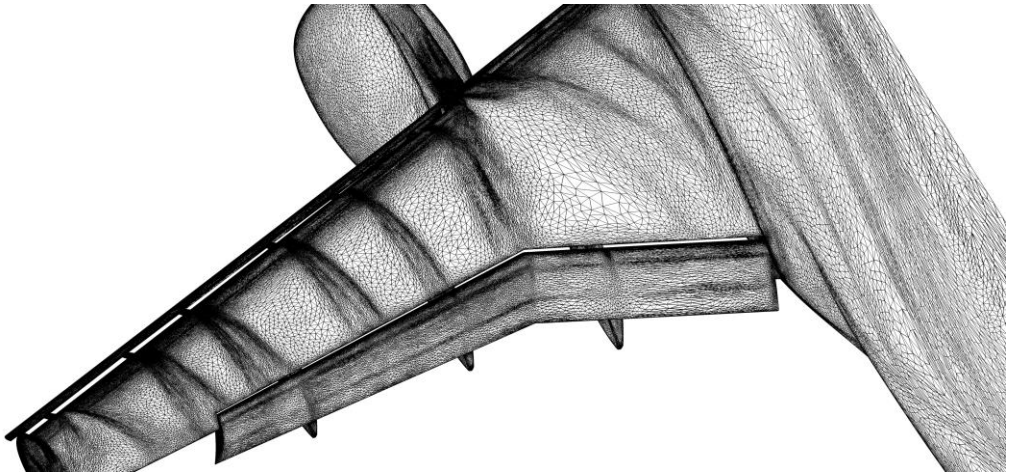
Test



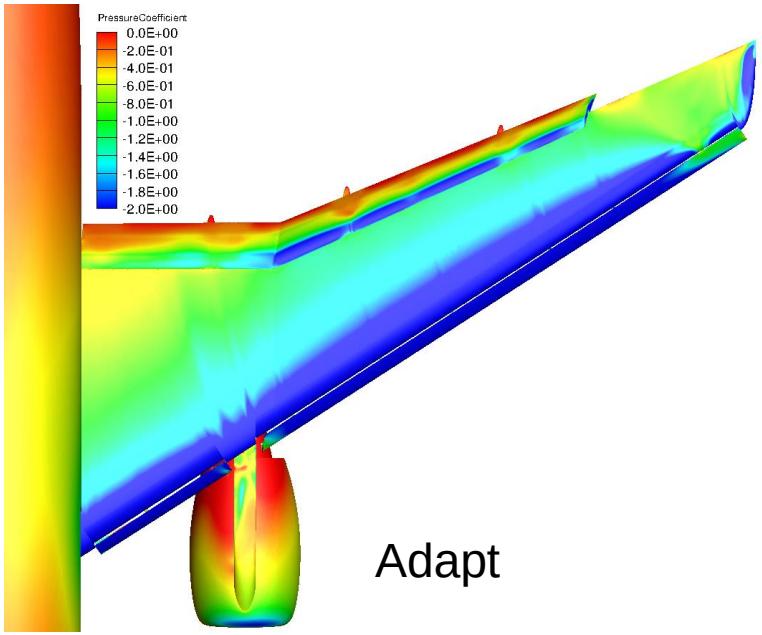
Adapted Grid



Fix Grid



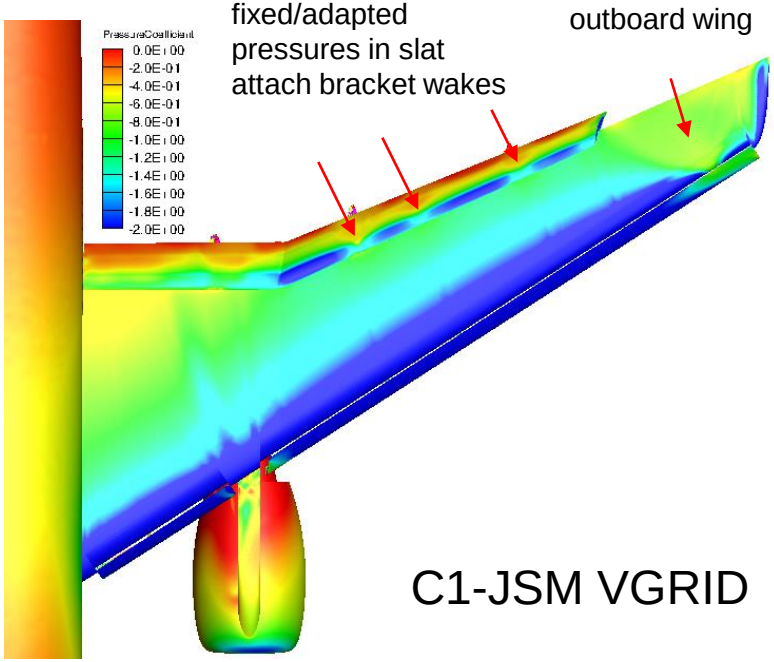
JSM with Nacelle AoA=14.54



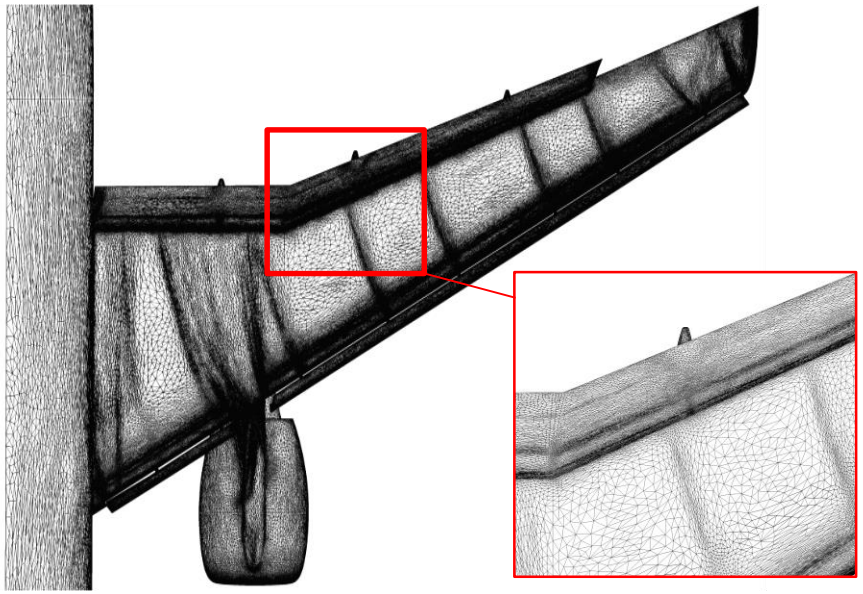
Adapt

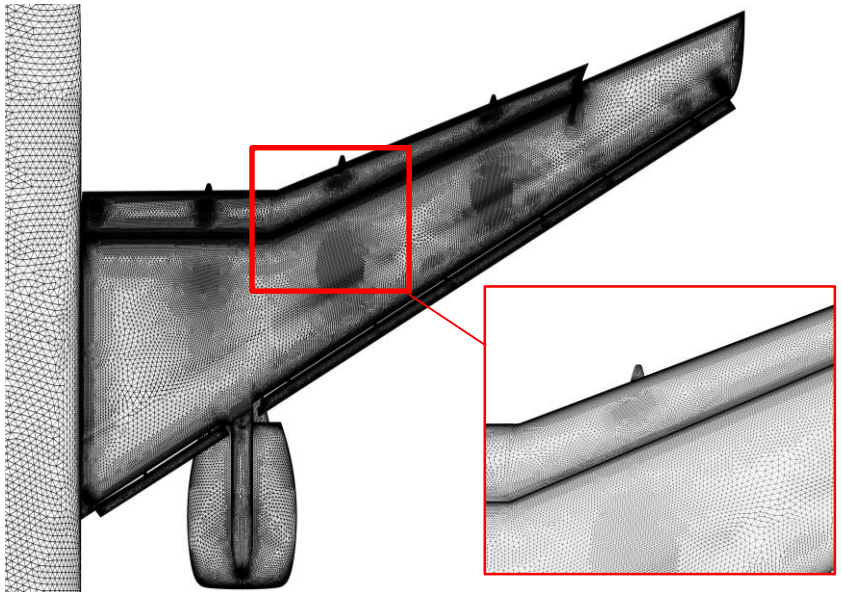
Different fixed/adapted pressures in slat attach bracket wakes

Larger separation on outboard wing

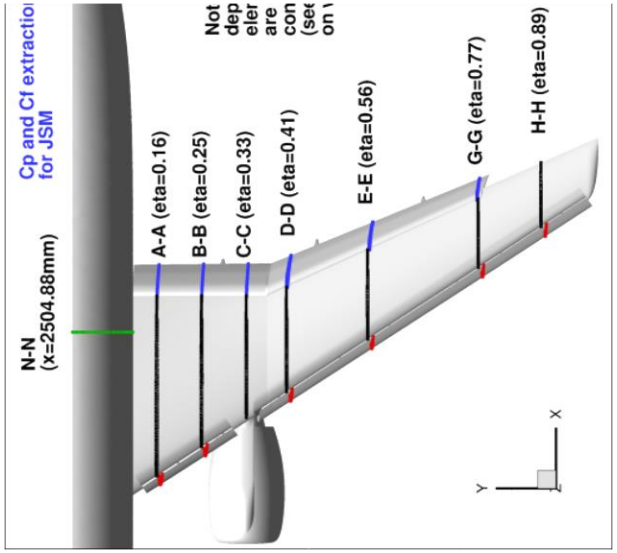


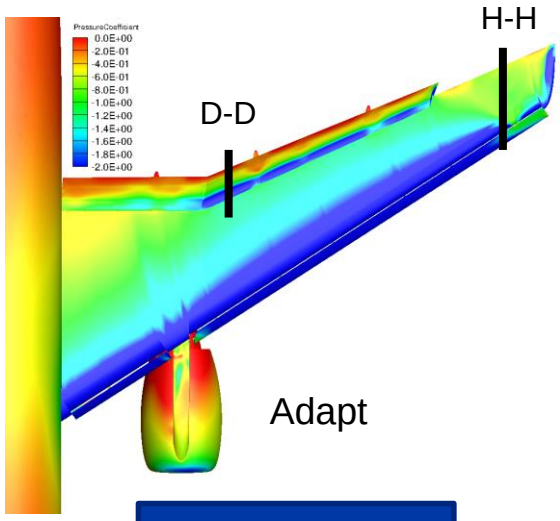
C1-JSM VGRID

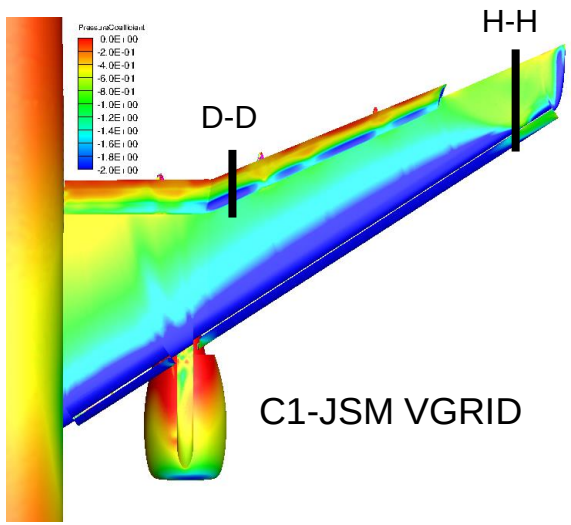




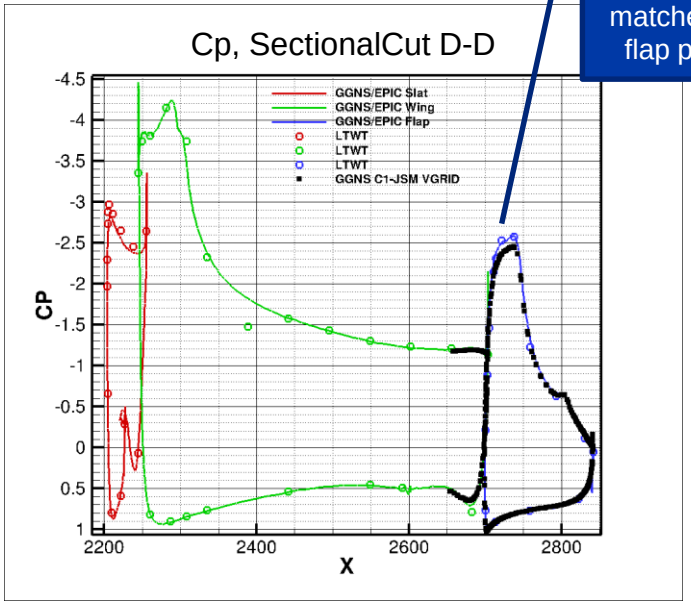
JSM with Nacelle AoA=14.54

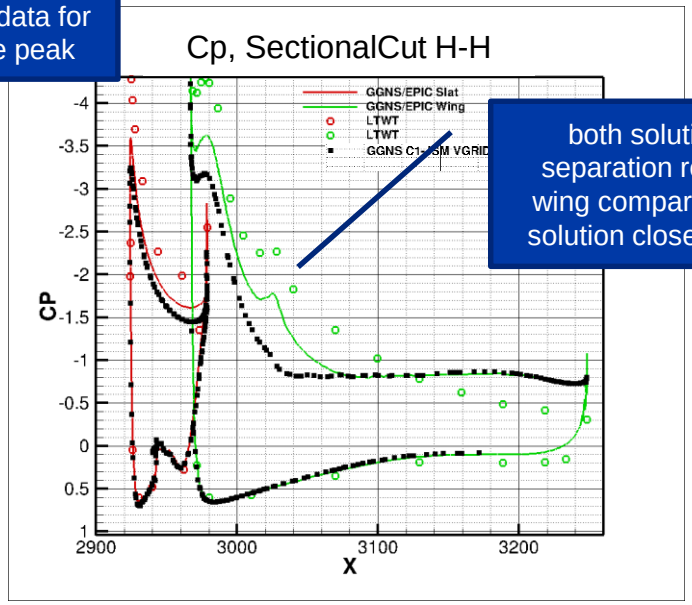






adapted grid solution matches test data for flap pressure peak





both solutions have larger separation region on outboard wing compared to test (adapted solution closer to test than fixed)

Summary

- **Adaptive Mesh Solutions**
  - ✓ Machine zero solution residual convergence obtained for most pre-stall solutions
  - ✓ Results approach constant lift with grid size for all cases
- **HLCRM Fixed/Adapted Grid Comparison**
  - ✓ Adapted grids better at resolving merging shear layers and details of flap gaps
  - ✓ Better grid convergence achieved for adapted grid results even at coarse grid sizes
  - ✓ Adaptive approach provided richer data set for measuring gap/seal increment
- **JSM Fixed/Adapted Grid Comparison**
  - ✓ Adapted results better at predicting slat attach wake impact on flap surface pressure and outboard wing separation
  - ✓ Adapted results predict nacelle on/off CL increment accurately compared to fixed grid
  - ✓ Adaptation did not improve CLmax prediction, both approaches predicted angle of attack at CLmax ~ 1^o early with nacelle and > 2^o early without nacelle
- **Adaptive Meshing Provided Several Advantages**
  - ✓ Automatic generation of consistent mesh family saved weeks of labor by an expert user compared to fixed grid approach
  - ✓ No a priori solution knowledge required
  - ✓ Reduced solution uncertainty due to mesh