



High Fidelity Adaptively Refined CFD and Reduced Order Models of a High Aspect Ratio Aeroelastic Wing Wind-Tunnel Model

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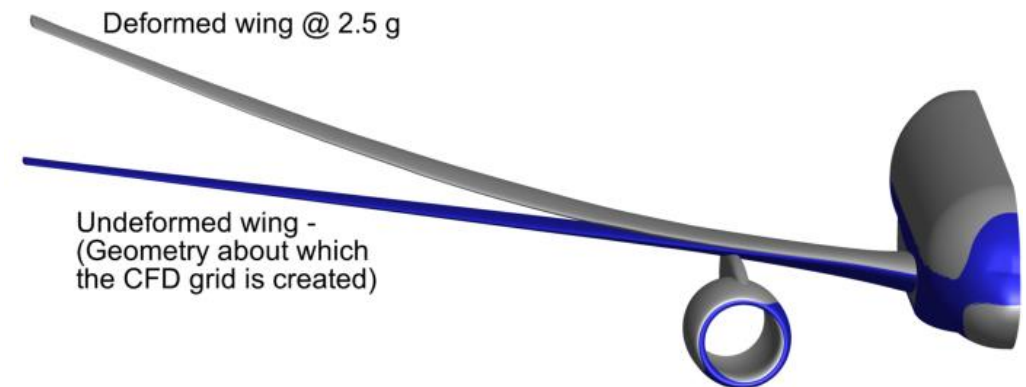
NASA Langley Research Center

Aeroelasticity Branch

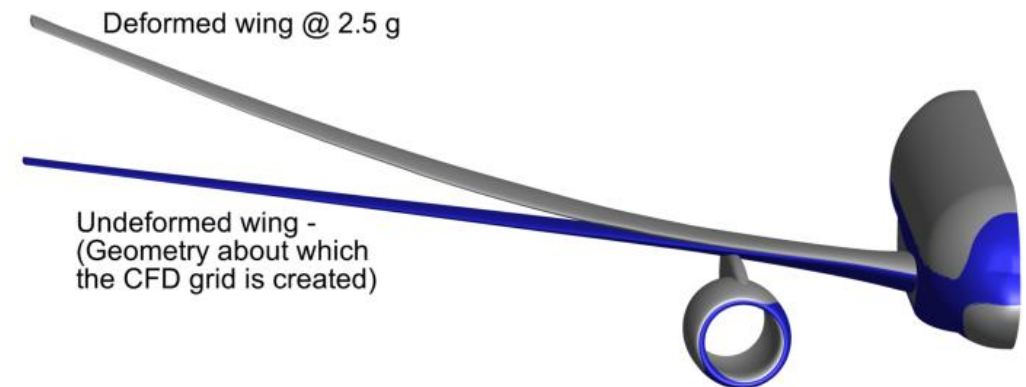
Introduction and Motivation for this Work



- This work uses the FUN3D v13.7 CFD code with the Spalart-Allmaras (SA) turbulence model to do a time-domain system identification of the aerodynamics for a high aspect-ratio aeroelastic wind tunnel model.
- This requires lengthy time histories over many cycles of motion to create repeatable data records in the presence of a nonlinear flow field. These solutions can be very expensive.
- Because of this, adaptive mesh refinement (AMR) will be used to reduce the size of the grid, reduce run times and hopefully enhance the accuracy of the flow solution.
- Actively adapting during an unsteady simulation is very expensive. For that reason, to maintain efficiency, the adaptation will be performed on the steady-state aeroelastically deformed wing.
- The transient fluid dynamics will be simulated with a grid that deforms with an adapted but fixed topology.

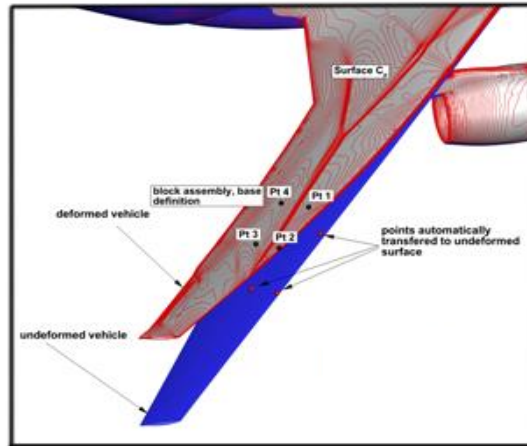


- This directly relates to the NASA CFD Vision 2030 study recommending AMR as part of CFD solution process.
- However, the present industrial scale application with large deformations is not being addressed by current AMR research.
- Frequently, AMR algorithms use strong mesh anisotropy to align a mesh with flow features to reduce grid count. This is acceptable for boundaries that move at most rigidly. This is not acceptable for highly deforming wings.
- Production aircraft experience sizable amounts of bending and torsion which limit the permissible aspect ratio of surface elements in order to maintain the integrity of the deformed surface.
- The present study will leverage the already advanced spacing and aspect ratio control, and mesh quality available in the commercial software HeldenMesh.

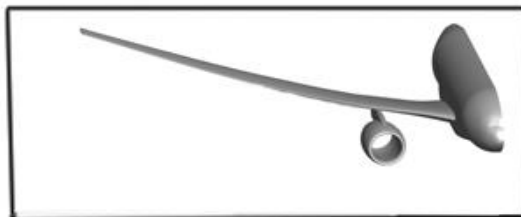


Current Methodology

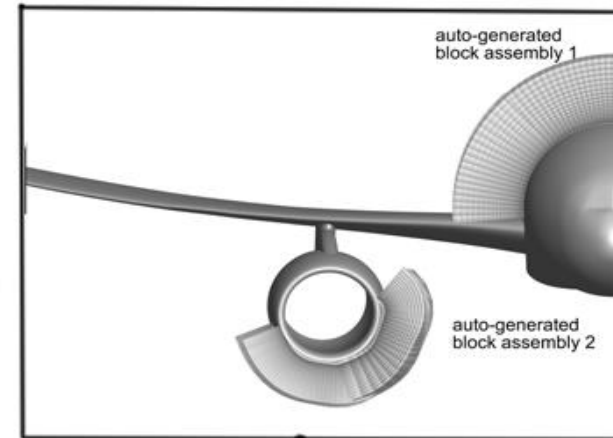
Identify features, frame. Points projected back to original shape



Compute static aeroelastic solution on starting grid

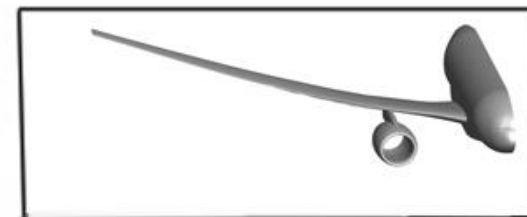


Block assemblies auto generated



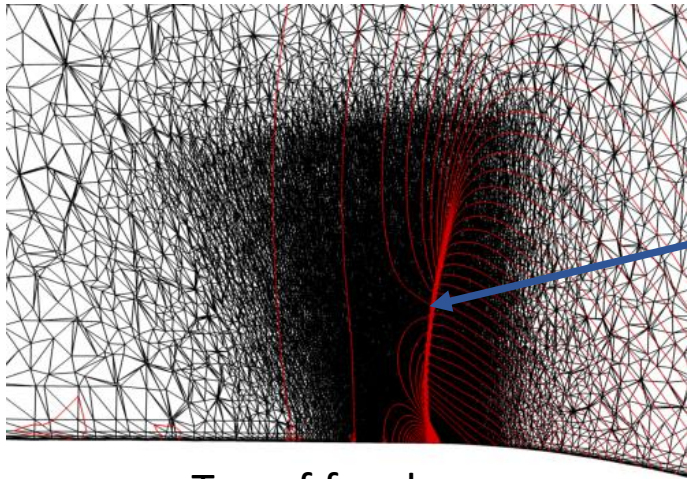
Heldenmesh grid regenerate
refine interpolate

Restart static aeroelastic solution



Current Methodology

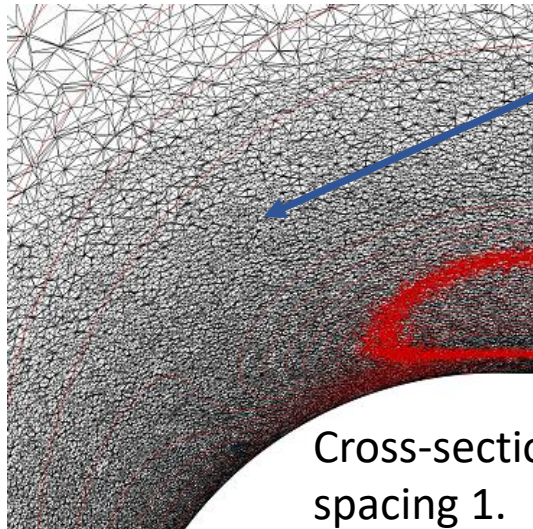
Streamwise



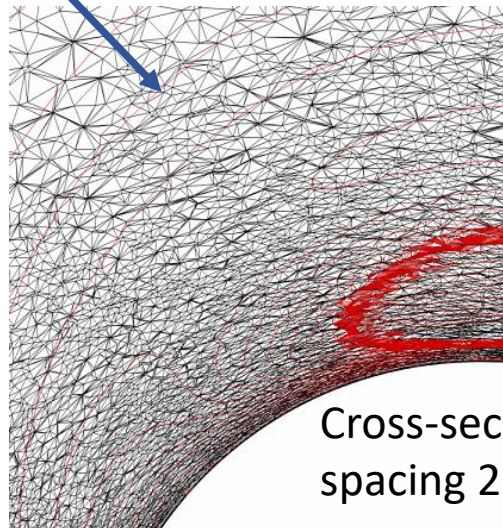
Top of fuselage

Grid spacing de-refines smoothly away from feature.

Lateral spacing expands smoothly away from the surface, and grid lines wrap around the body.

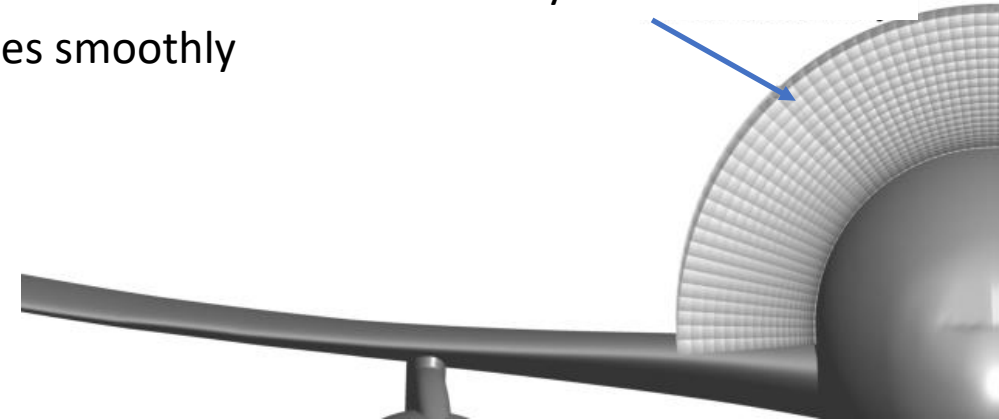


Cross-section spacing 1.

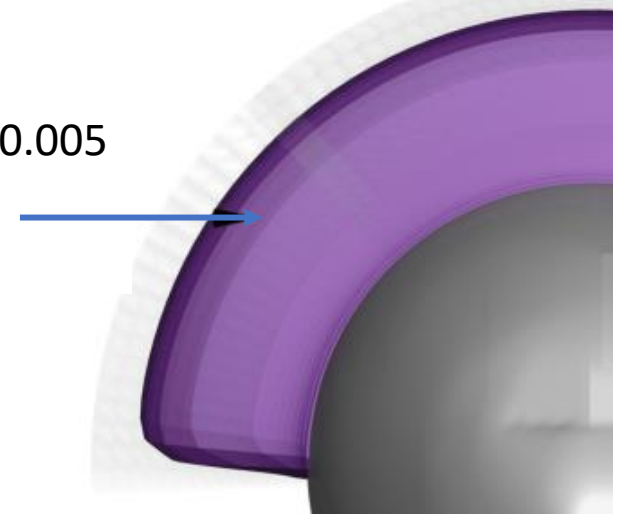


Cross-section spacing 2.

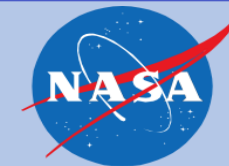
Auto-generated block assembly 1



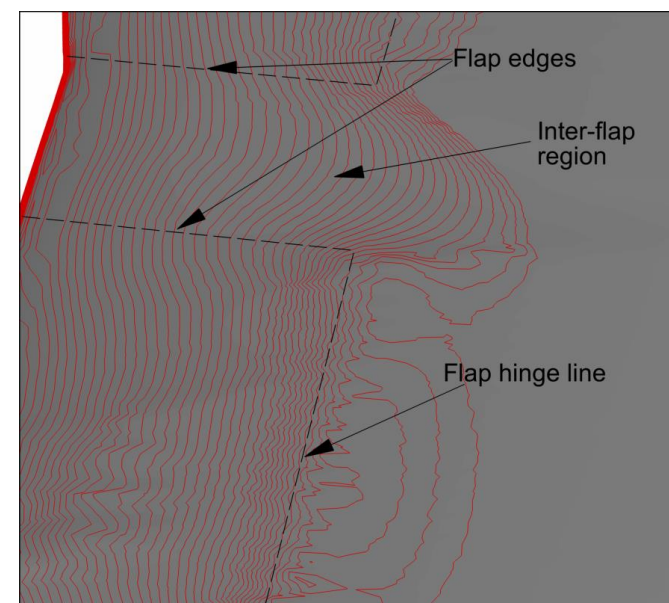
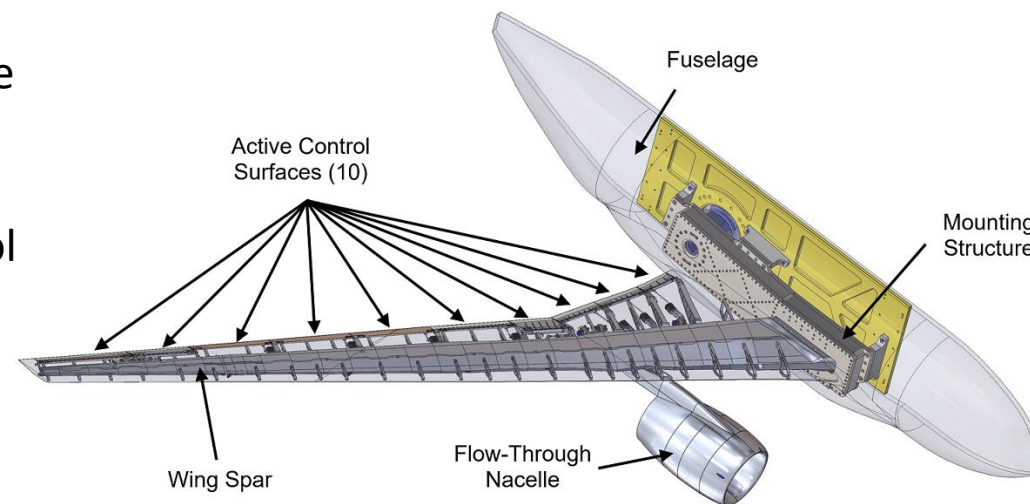
Iso-surface of 0.005 streamwise Spacing.



Application to the IAWTM Model



- The configuration under investigation is the Integrated Adaptive Wing Technology Maturation (IAWTM) wind-tunnel model.
- This model has a highly flexible wing, as well as movable control surfaces.
- Control surfaces are modeled with continuous mold-line.
- An example of an area that will attract mesh clustering in an automated AMR algorithm is shown.
 - The deformed wing hinge lines and interpolated region between the two flaps are shown.
- When these features have already been refined for unsteady system ID purposes, it is not best to have an automated AMR additionally refine them.



- This leads to assumptions in this work:
 - Leading edges, corners, geometric discontinuities or attached boundary layer flows have already been sufficiently resolved by the automated feature resolving capability in Heldenmesh.
 - Flap edges and hinge lines have already been refined.
- The remaining flow features to be resolved are shock surfaces, separated boundary layers, wake or shed vorticity.
- Heldenmesh already has volume shapes to refine features, e.g. hexahedral blocks, cylinders, annular regions, tetrahedra, prisms, spheres and ellipses. Hexahedral blocks will be used here.
- Currently the process is only semi-automated. Future work will try to fully automate this process.

- Maneuver load alleviation (MLA) conditions at Mach 0.85 are considered.
- Two angles of attack: 0 degrees (C_1) and 2 degrees (C_2).
- Three grid levels (L_1 , L_2 , L_3).
- Levels (L_1 , L_2 , L_3) for condition 1 (C_1) have been globally refined by halving surface element areas with each new grid level (13, 28 63 million node grids).
- Levels (L_1 , L_2) for condition 2 (C_2) have been refined in a similar way, however, level 3 (L_3) has used a slightly improved (later version of the process) mesh distribution with more highly anisotropic volumes away from the surface that allows a smaller grid count.

Table 2 . Grid details.

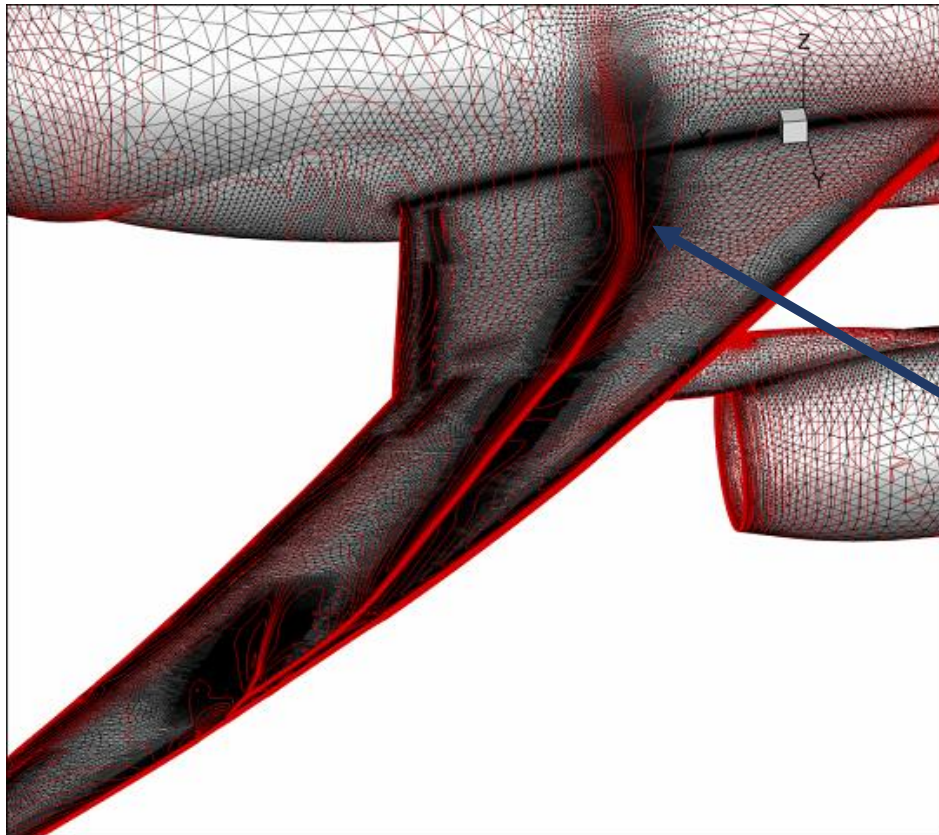
designation	angle of attack (Deg)	number of grid points (millions)
C_1L_1	0	63
C_1L_2	0	28
C_1L_3	0	13
C_2L_1	2	34
C_2L_2	2	15
C_2L_3	2	14

Application to IAWTM

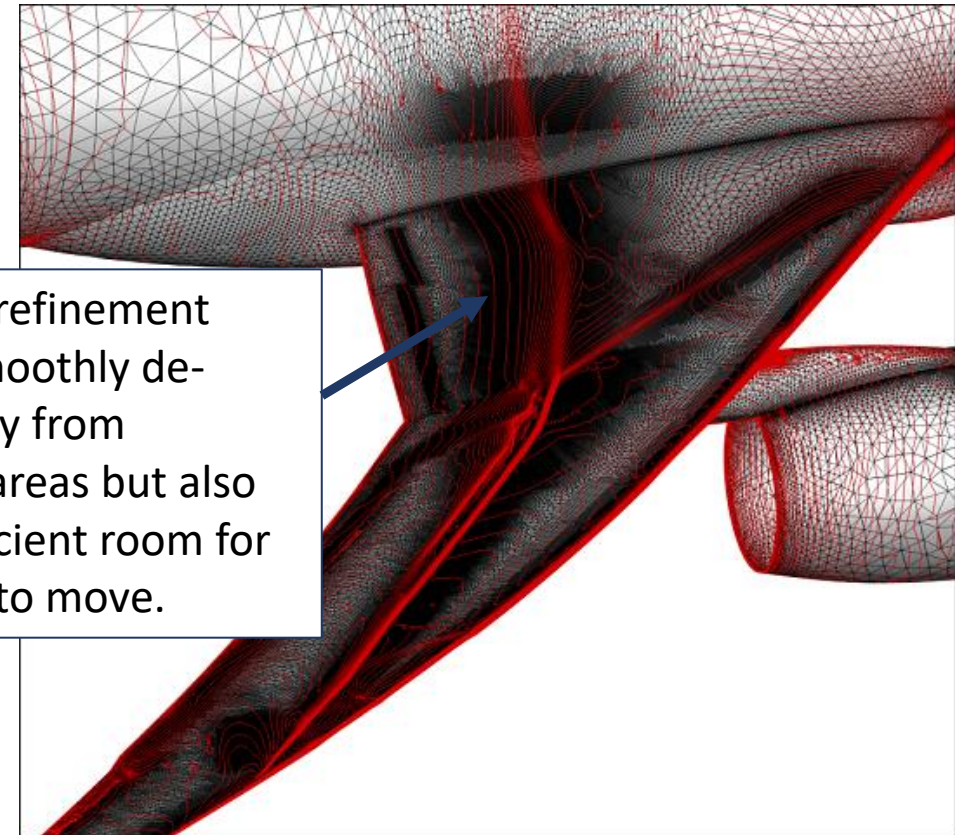


Mach 0.85 Cases for Maneuver Load Alleviation

C_1L_3



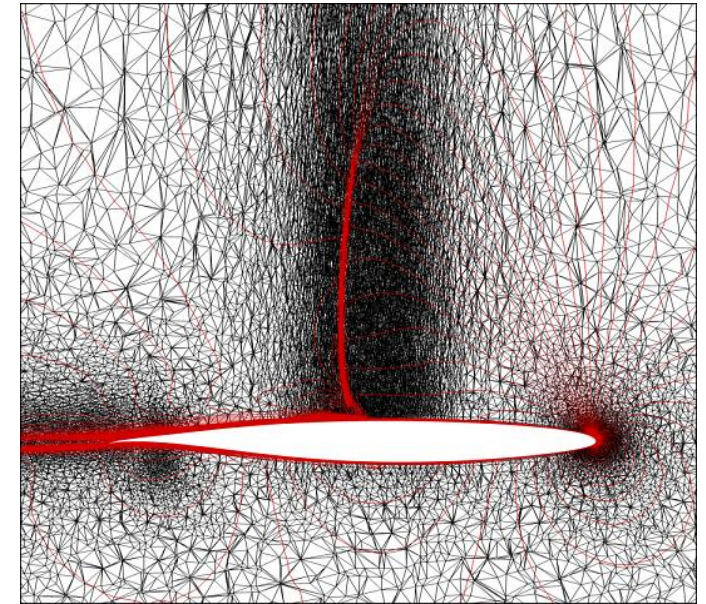
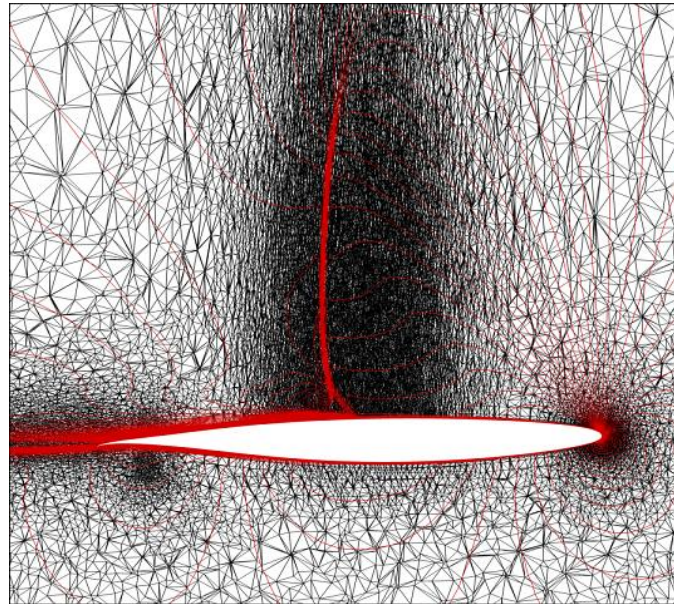
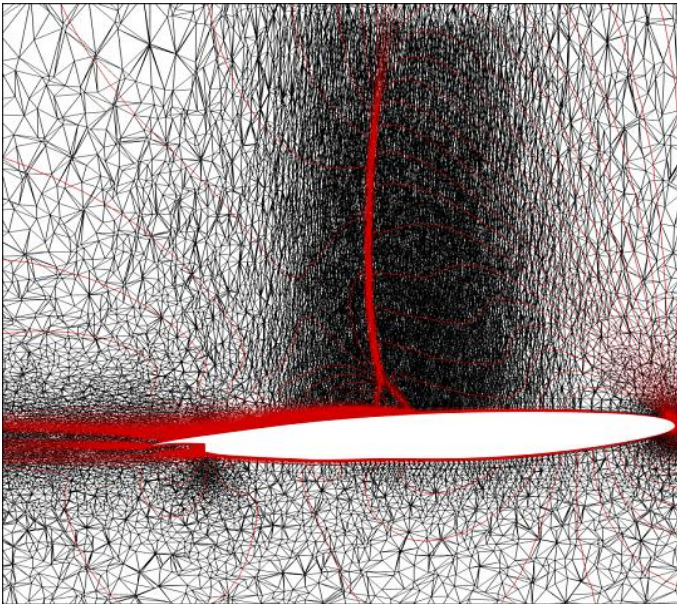
C_2L_3



Note that refinement regions smoothly de-refine away from clustered areas but also leave sufficient room for the shock to move.

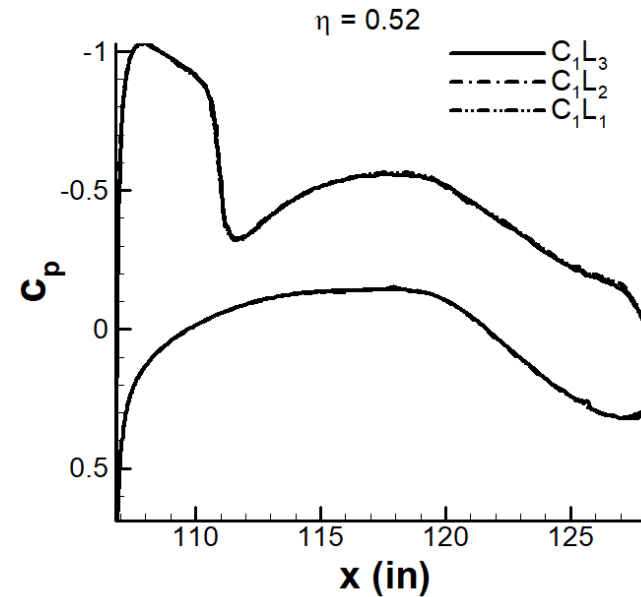
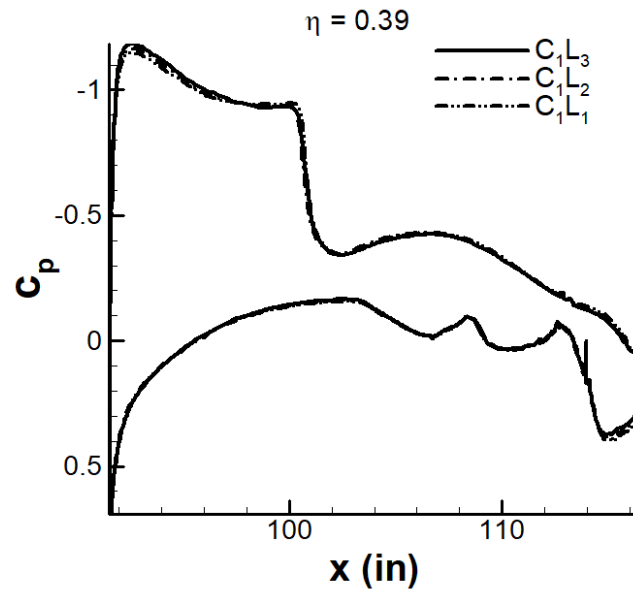
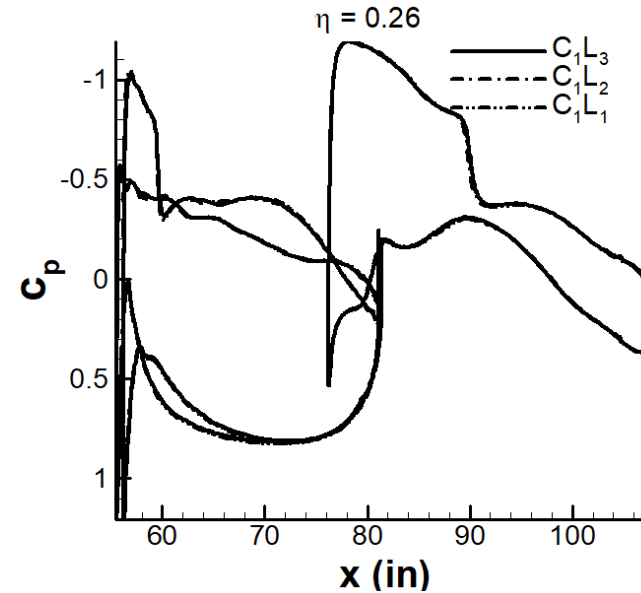
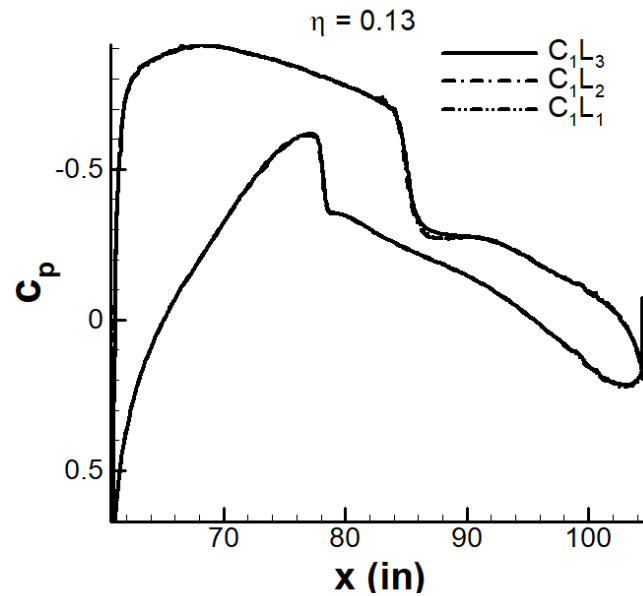
Mach 0.85 Cases for Maneuver Load Alleviation

C_2L_3



- Mesh is resolved well ahead of and behind flow feature.
- Vertical spacing around shock increases upward away from shock.
- Shock separation and wake are resolved, wake streamwise spacing increases away from wake.

Grid Convergence – C_p Distributions for Static Deflected Wing

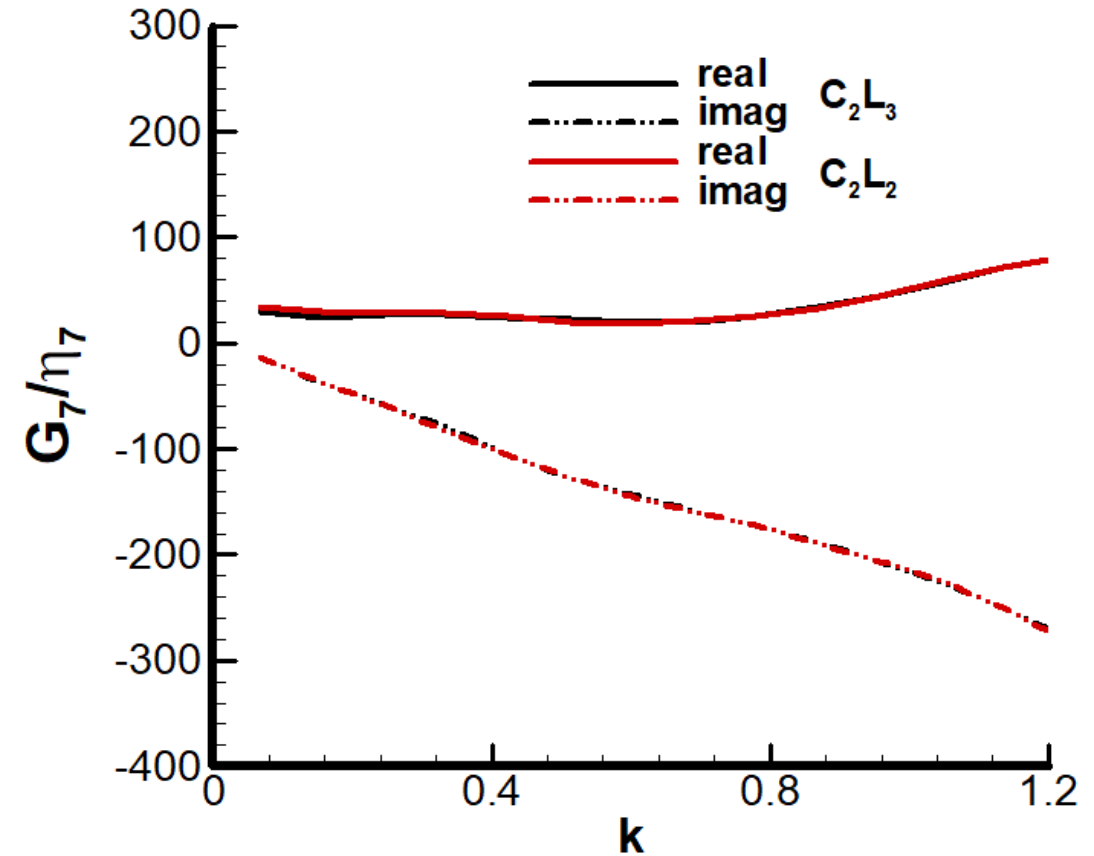
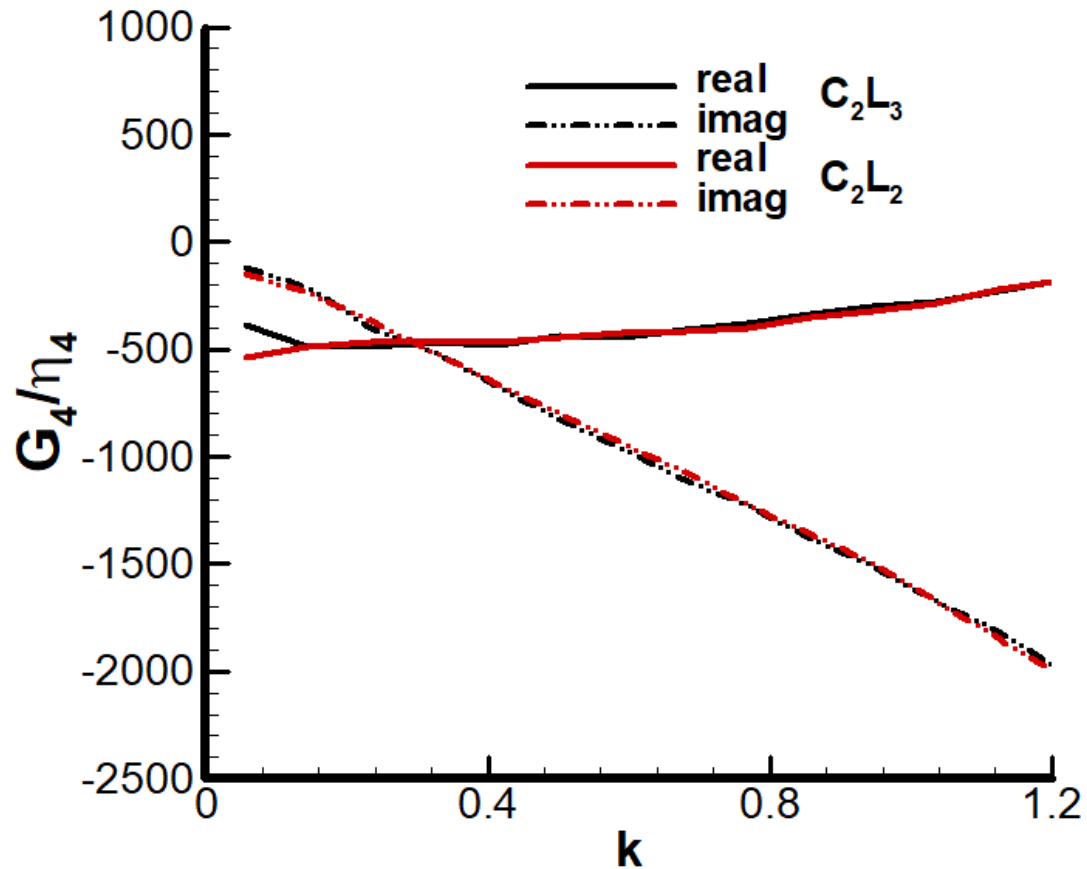


Grid Convergence – Unsteady Forces



- C_2L_2 and C_2L_3 having slightly different mesh refinement processes. Generalized aerodynamic forces are nearly identical.

Mach 0.85, AoA = 2 degrees



- Production aircraft undergoing large deformation having anomalous surface features are a difficult challenge for adaptive mesh refinement.
- A semi-automated method of selectively refining flow features using the HeldenMesh software and the CFD code FUN3D has been presented.
- Currently no error estimation is included.
- System identification of the flexible structure using multimodal multisine time-marching solutions has been performed.
- Both spatial and time convergence is demonstrated for the present application.
- Future work will investigate how to automate the entire process and include error estimation.