BSCW AePW-2 Geometry and Grids

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AePW-2

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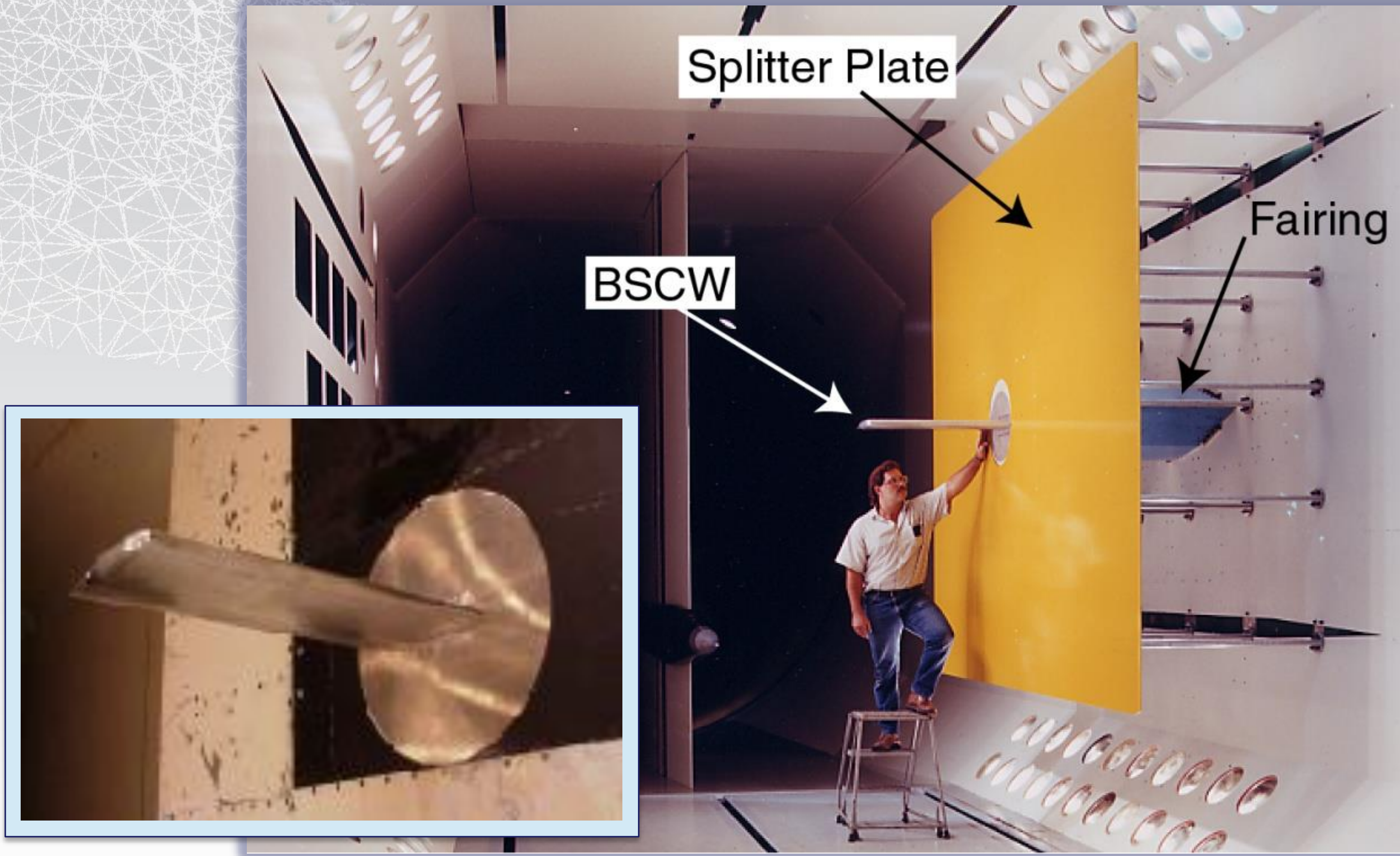
Outline

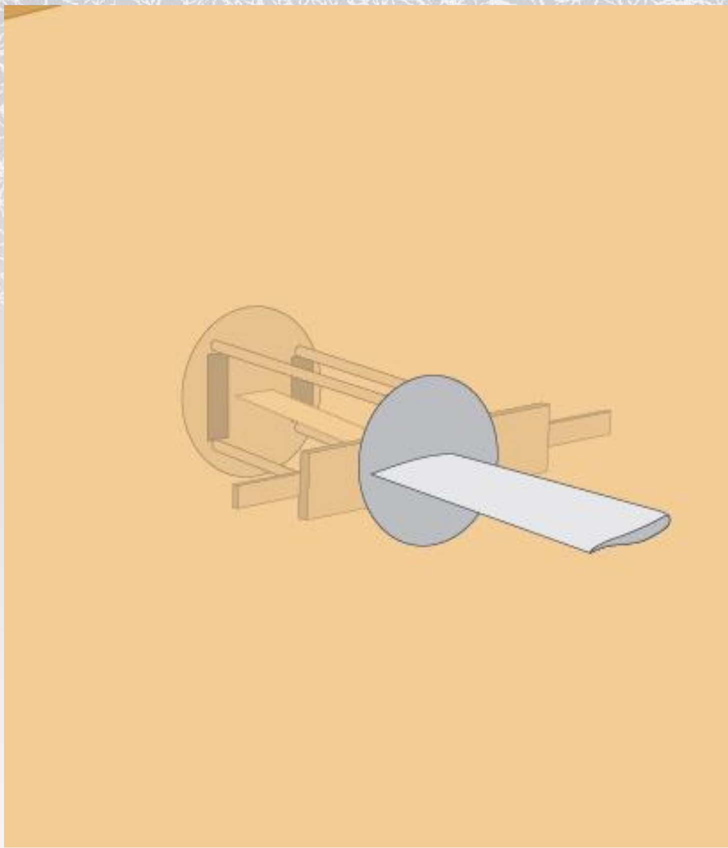
- BSCW Background Information
- Grids
- Assumptions
- Grid Motion
- FUN3D 8 grids study

Benchmark Supercritical Wing (BSCW)

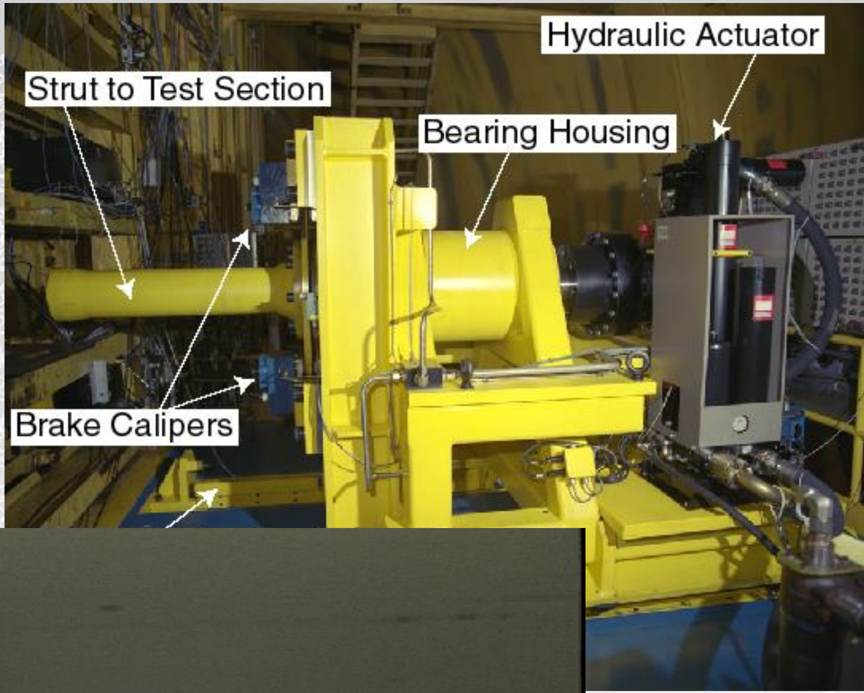


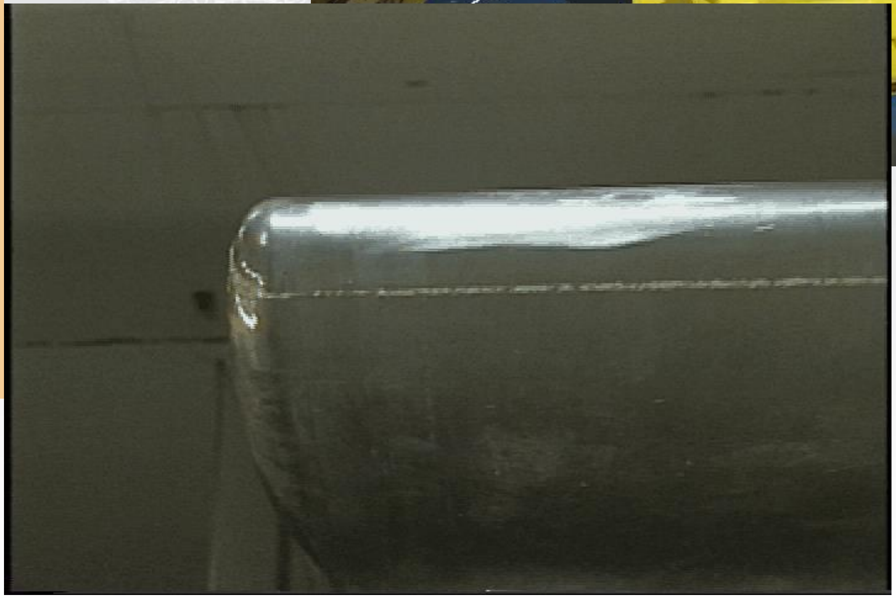
Experimental data from 2 wind tunnel tests are being used for comparison data

TDT Test 470:
Pitch And Plunge Apparatus (PAPA)

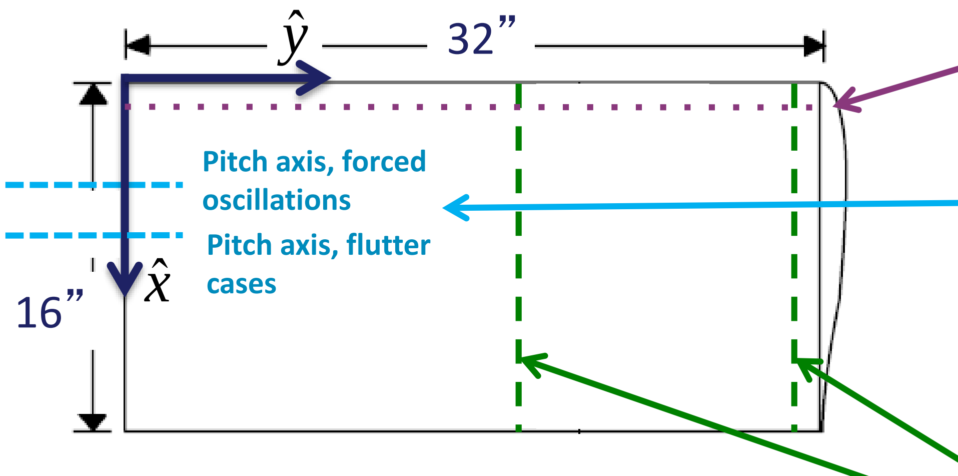


TDT Test 548: Oscillating TurnTable (OTT)





BSCW Test Configurations



Model planform. Dimensions are in inches.

<u>Transition Strip</u>: 7.5% chord

<u>Pitch Axis:</u>
<u>Forced Oscillation, (OTT Test)</u>: Pitching motion about 30% chord
<u>Flutter, (PAPA Test):</u> Pitching motion about 50% chord

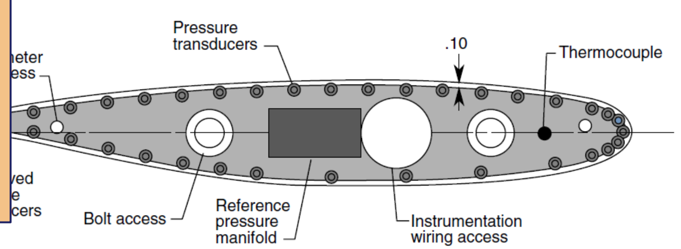
<u>Unsteady Pressure Measurements</u>:

- 1 chord fully-populated at 60% span for both tests
- Outboard chord at 95% span populated for the PAPA test only (not for forced oscillation cases)

<u>60% span station: 40 In-Situ Unsteady Pressure Transducers</u>:

- 22 upper surface
- 17 lower surface
- 1 leading edge

Airfoil section is SC(2)-0414

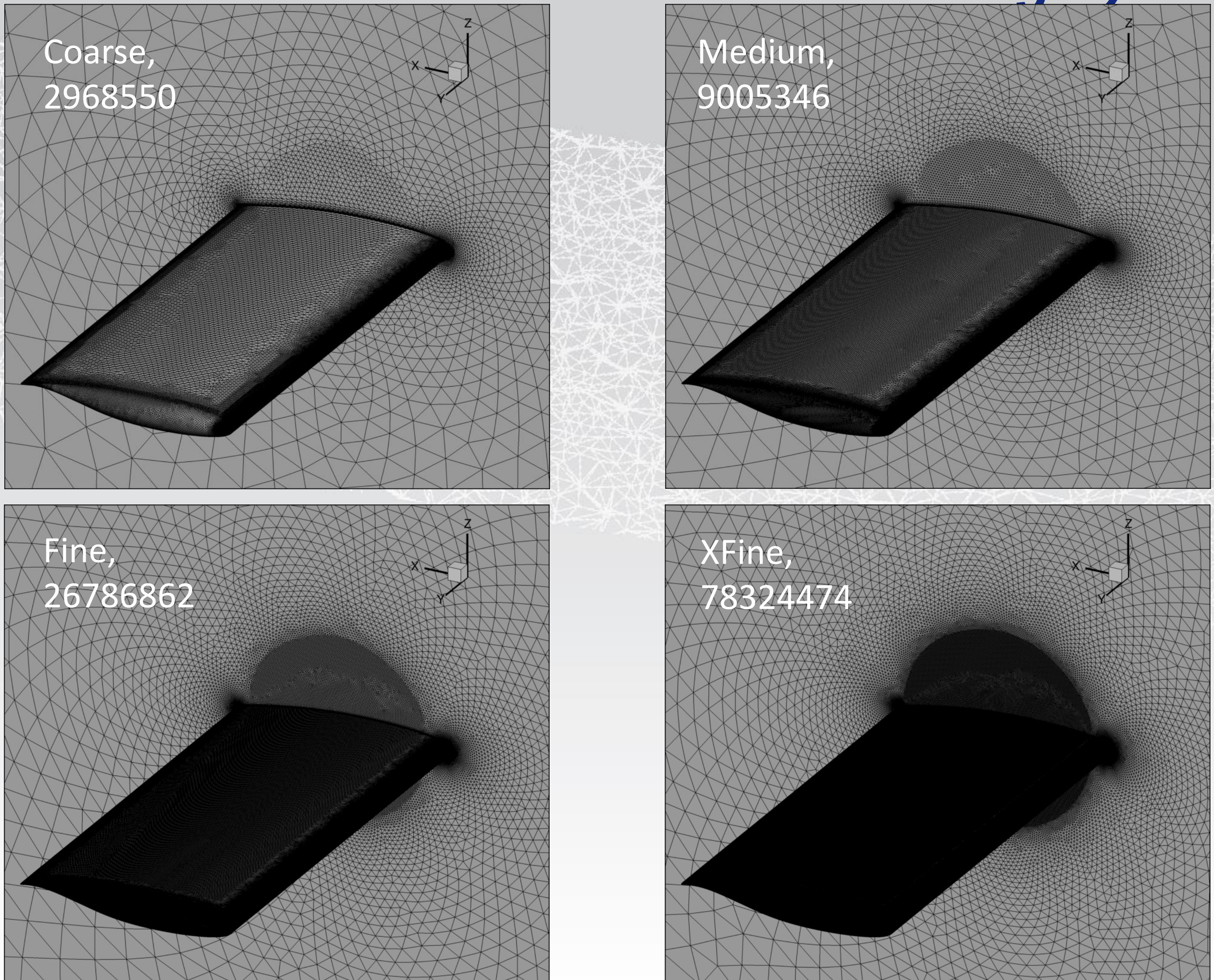


Cross-section at 60% span, showing the layout of the unsteady pressures.

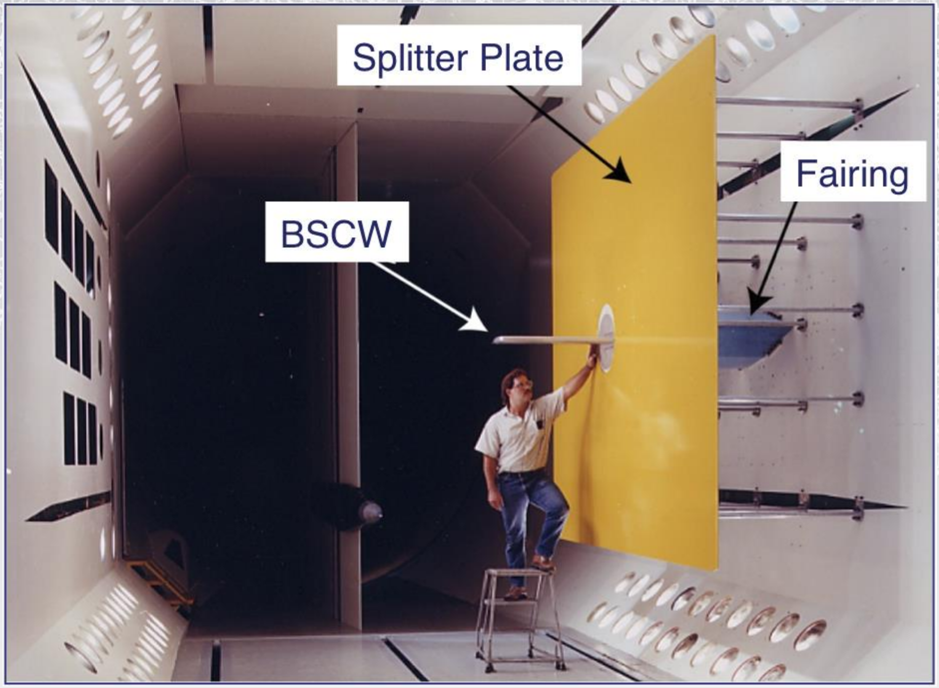
Notes….

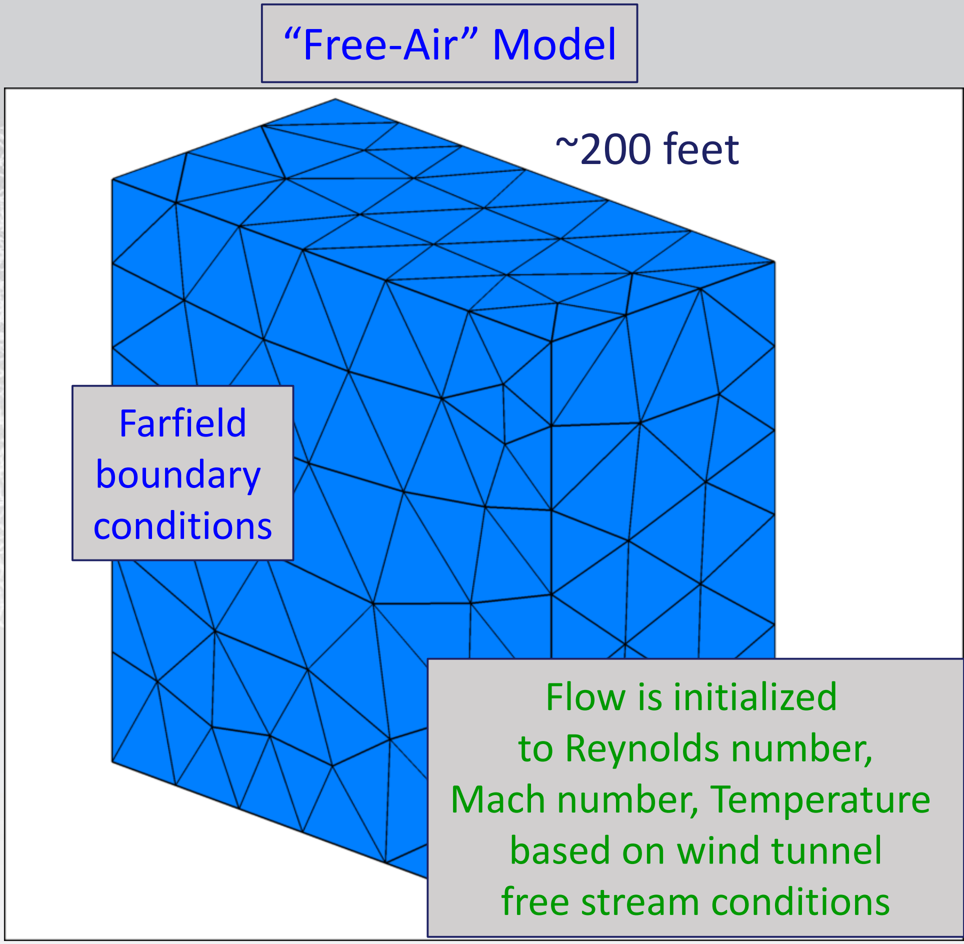
- Prior to AePW-1, we did not have CAD model of the BSCW wing.
- In 2011, CAD model and IGES files were constructed from the optically scanned data obtained 20 years ago.
- In 2011, unstructured grids for AePW-1 were constructed using VGRID software and structured grids using Gridgen software using gridding guidelines based on Drag Prediction Workshop recommendations.
- In 2014, a laser scan of the wing was conducted.
- Laser scan surface closely matched the optical scan: a small discrepancy was noted near the wing tip on the trailing edge.
- New grids were not constructed: AePW-1 grids are used in AePW-2.
- Workshop contributors are free to build their own grids.
- In 2014 a simplified FEM of the wing was built and preliminary computations completed by Organizing Committee.
- Assumptions….

Unstructured grids for AePW-1 were constructed VGRID software from NASA Langley



Benchmark Supercritical Wing (BSCW)





Ref: Chwalowski, P., Heeg J., "FUN3D Analyses in Support of the First Aeroelastic Prediction Workshop," AIAA 2013-0785.

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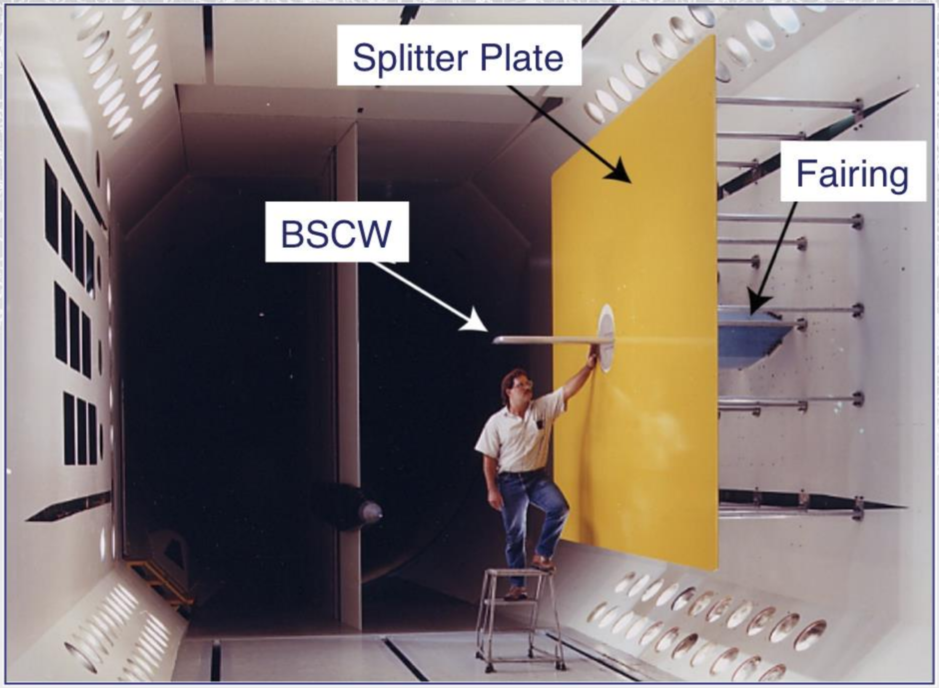
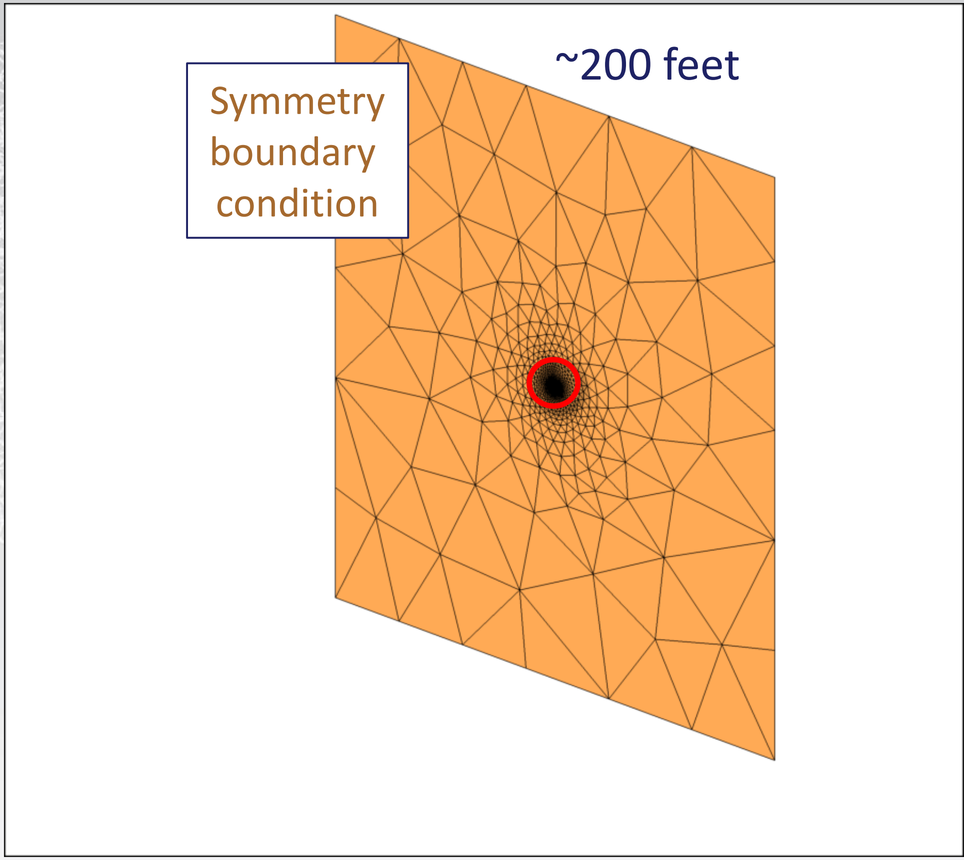


"Free-Air" Model



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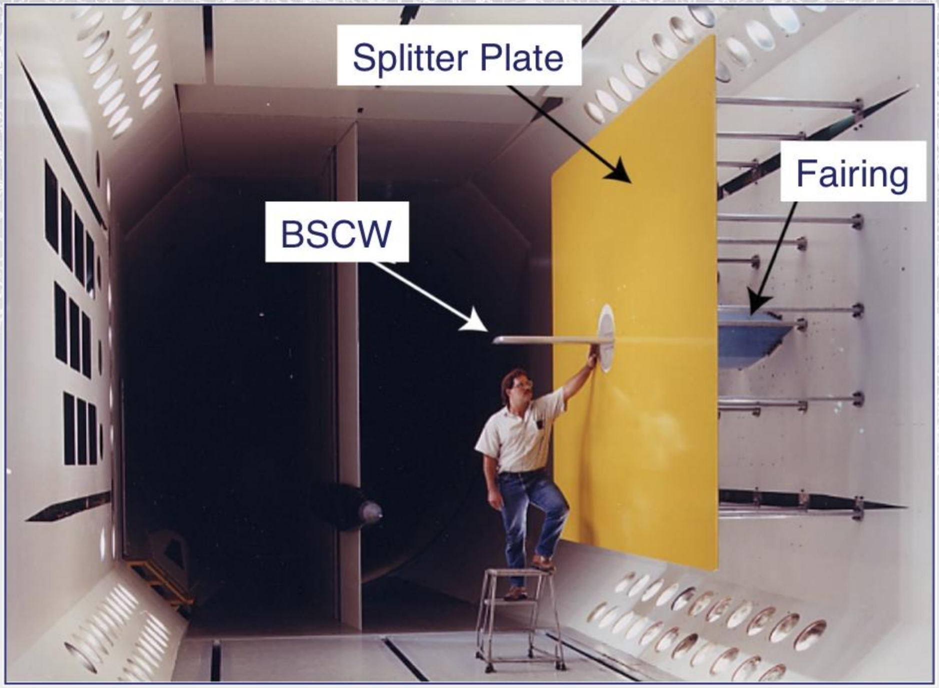
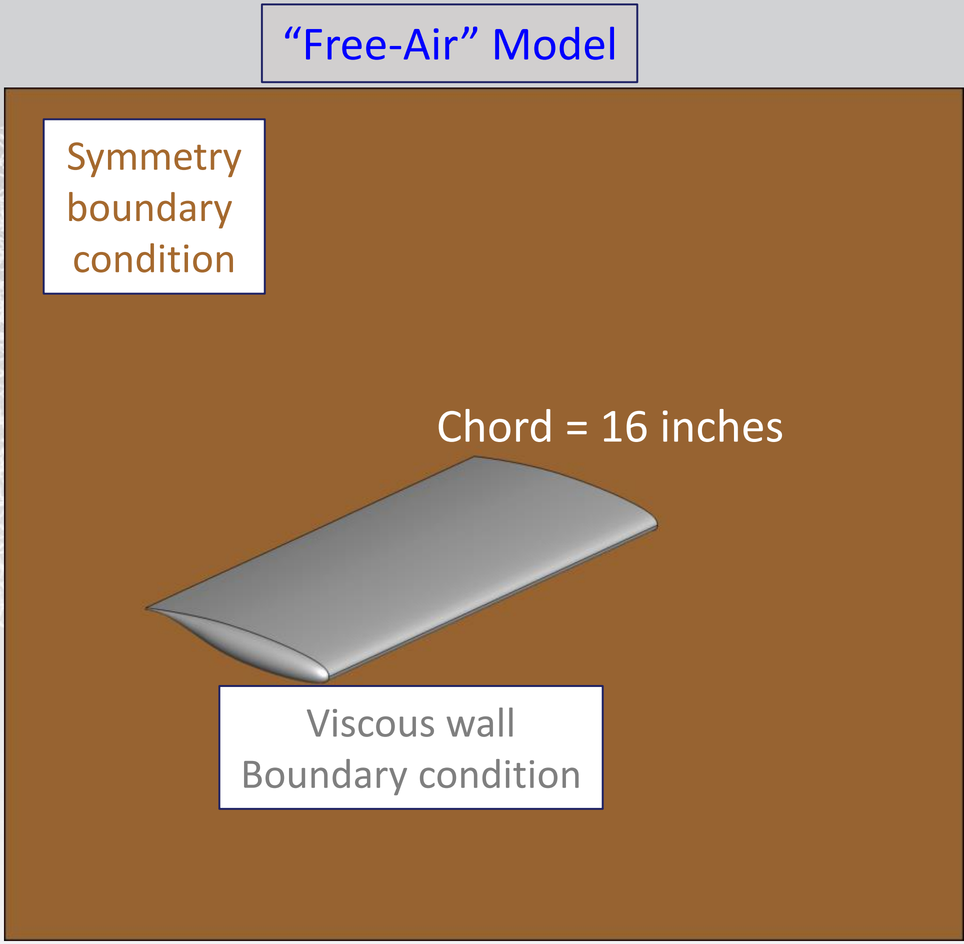




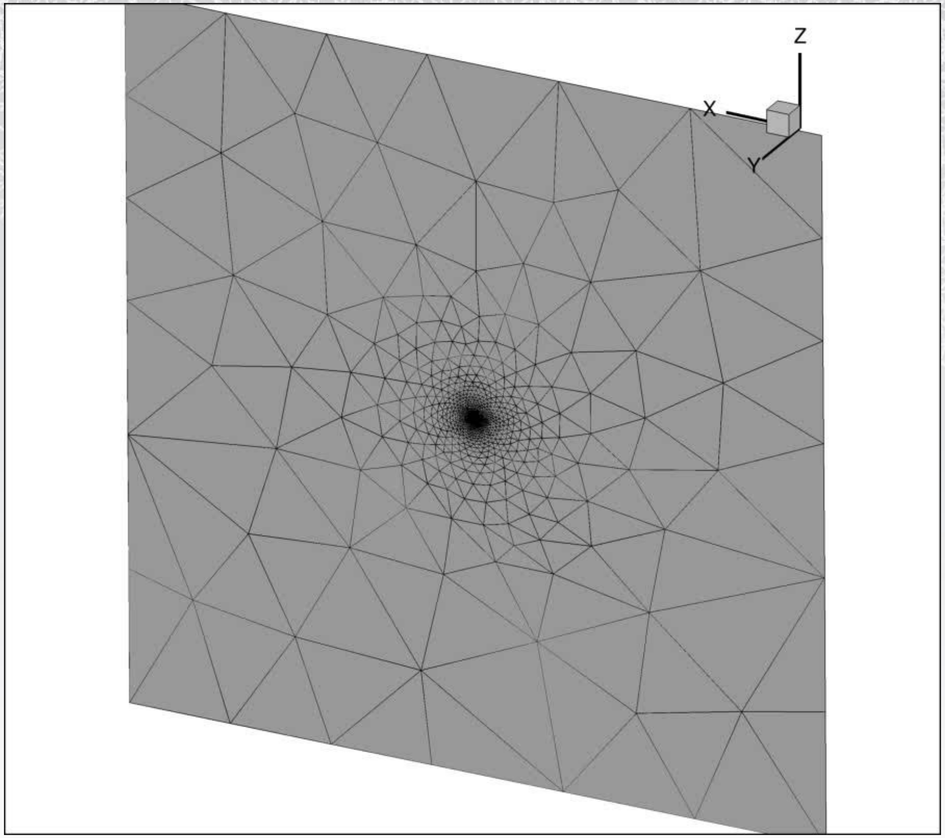
Ref: Chwalowski, P., Heeg J., "FUN3D Analyses in Support of the First Aeroelastic Prediction Workshop," AIAA 2013-0785.

Raveh, D. E., Yossef, Y. M., Levy, Y., "Flow Simulations for the First Aeroelastic Prediction Workshop Using the EZNSS Code," AIAA 2013-0787.

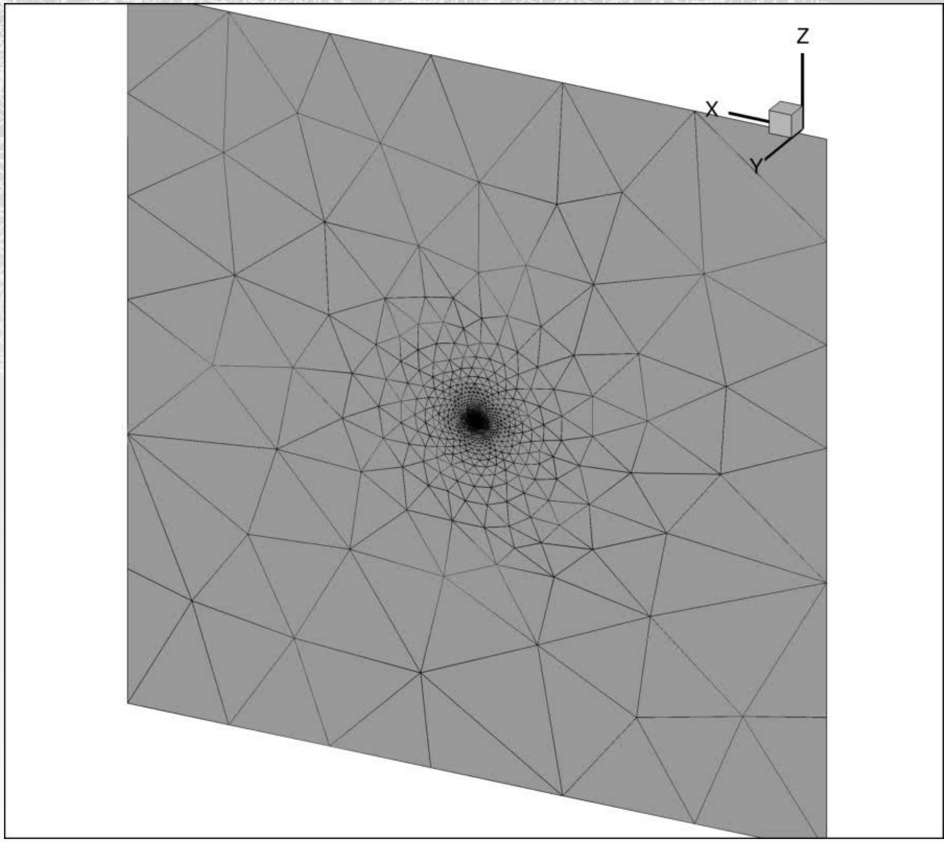
Schuster, D. M., "Aerodynamic Measurements on a Large Splitter Plate for the NASA Langley Transonic Dynamics Tunnel," NASA/TM-2001-210828.

Benchmark Supercritical Wing (BSCW) Grid Motion: wing motion vs. entire computational volume motion (forced oscillation cases)

Volume motion



Wing motion



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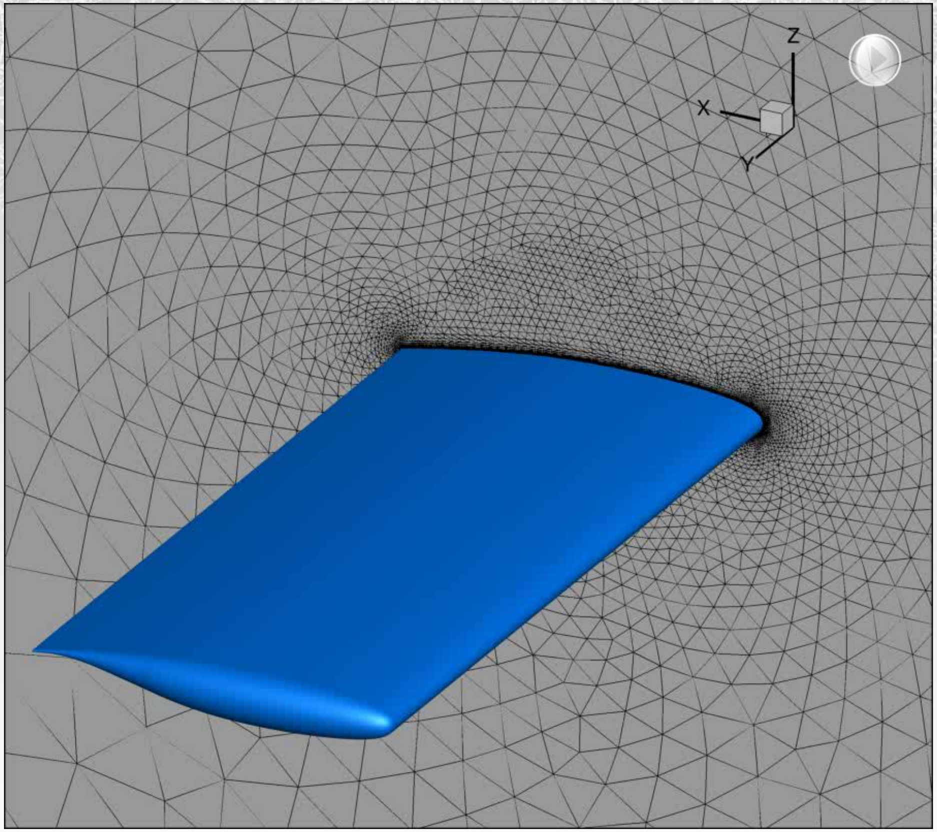
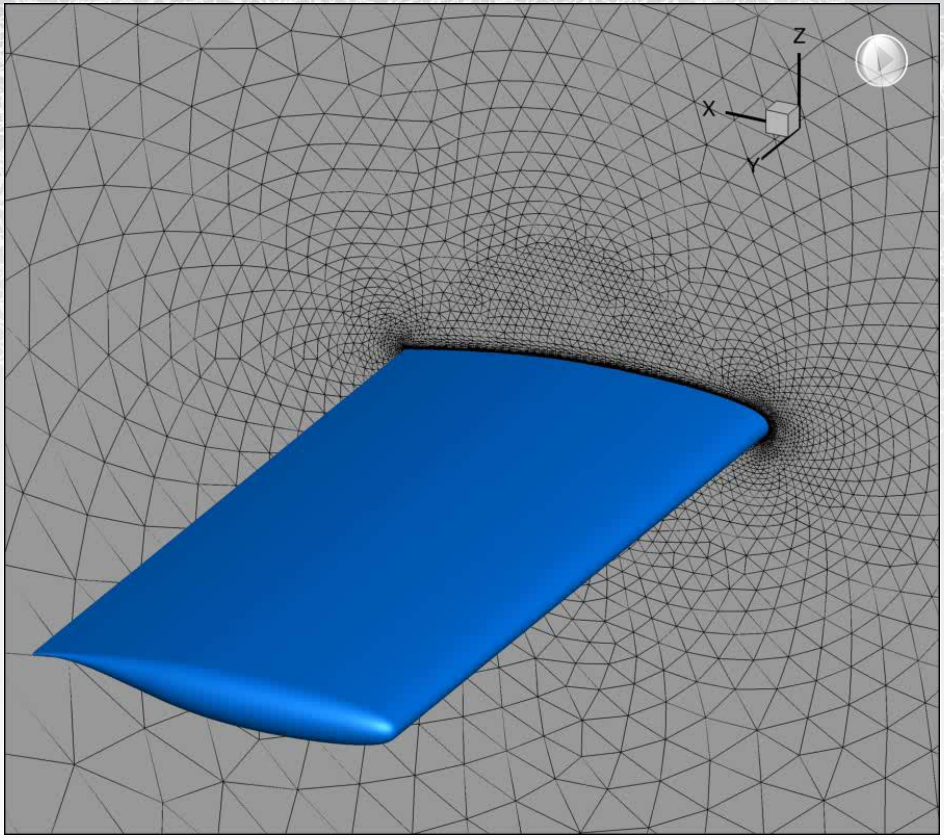


Wing motion



AePW-2 Case2 FUN3D study using 8 grids

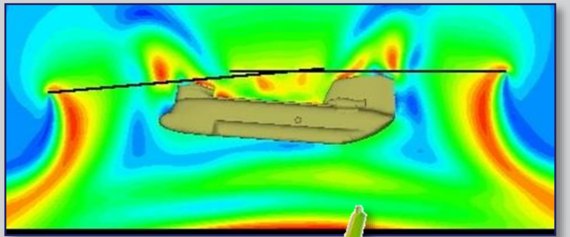
- FUN3D Analysis
  - Computational results obtained using the different grids being used by the AePW-2 teams, using a single code with all possible parameters identical
  - Grids are from FOI, Technion, U of Michigan, DLR and NASA
  - Five unstructured grids
  - Three structured grids: FUN3D utility converts a PLOT3D structured grid to a hexahedral unstructured grid
  - Case2: Mach 0.74, alpha = 0°, Experimental q = 169 psf
  - Spalart-Allmaras turbulence model
- Results
  - Unforced steady aerodynamic coefficients
  - Convergence
  - Static aeroelastic aerodynamic coefficients and pitch angle
  - Dynamic solution: damping values

Case #2: Low Mach number Flutter Simulations

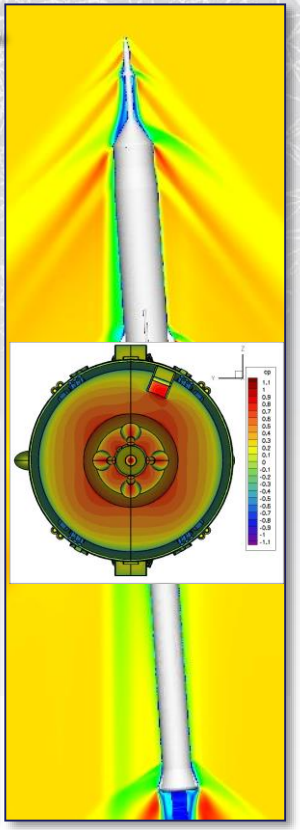
	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	0.85	0.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced Oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution • Oscillating Turn Table (OTT) exp data	• Unknown flow state • Pitch and Plunge Apparatus (PAPA) exp data	• Separated flow effects • Oscillating Turn Table (OTT) experimental data	• Separated flow effects • Oscillating Turn Table (OTT) experimental data	• Separated flow effects on aeroelastic solution • No experimental data for comparison

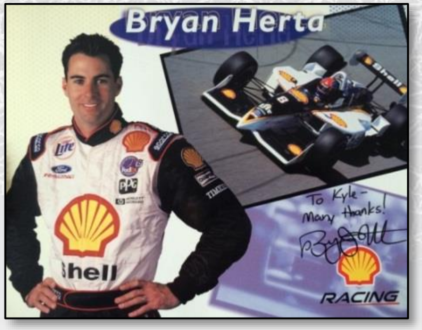
FUN3D Core Capabilities

- Established as a research code in late 1980s; now supports numerous internal and external efforts across the speed range
- Solves 2D/3D steady and unsteady Euler and RANS equations on node-based mixed element grids for compressible and incompressible flows
- General dynamic mesh capability: any combination of rigid / overset / morphing grids, including 6-DOF effects
- Aeroelastic modeling using mode shapes, full FEM, etc.
- Constrained / multipoint adjoint-based design and mesh adaptation
- Distributed development team using agile/extreme software practices including 24/7 regression, performance testing
- Capabilities fully integrated, online documentation, training videos, tutorials

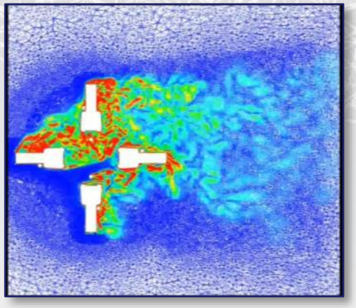


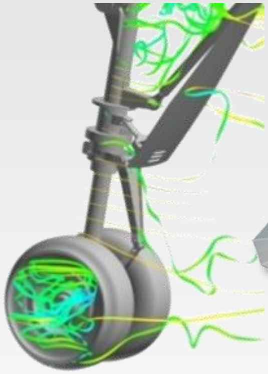
US Army

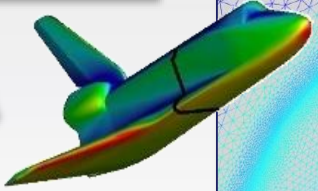


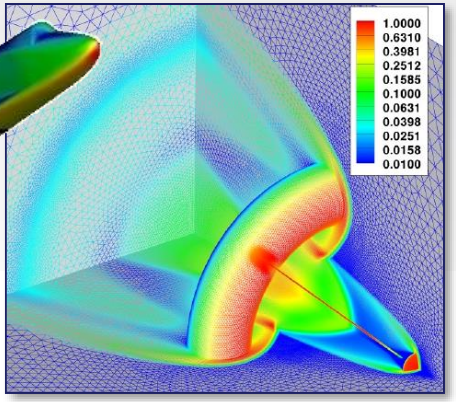


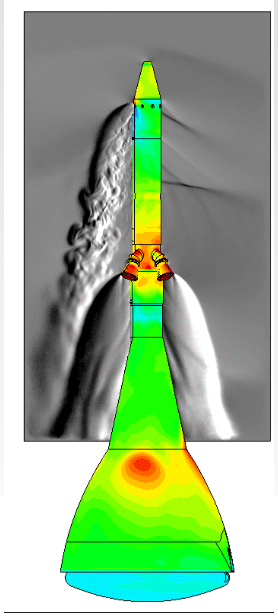
Georgia Tech











FUN3D Aeroelastic Capabilities

- Built upon elasticity PDE-based mesh deformation
- Built in modal structural solver, same as in CAP-TSD, CFL3D, Overflow
  - Typically uses mode shapes from NASTRAN normal modes analysis
- Coupling to external FEM/CSD codes
  - Read surface displacements obtained from FEM
  - Write aerodynamic loads (C_p, C_{fx}, C_{fy}, C_{fz}) for FEM
  - Requires CFD/CSD transfer middleware
  - Special case: rotorcraft comprehensive CSD codes, CAMRAD, DYMORE

FUN3D Mesh Deformation

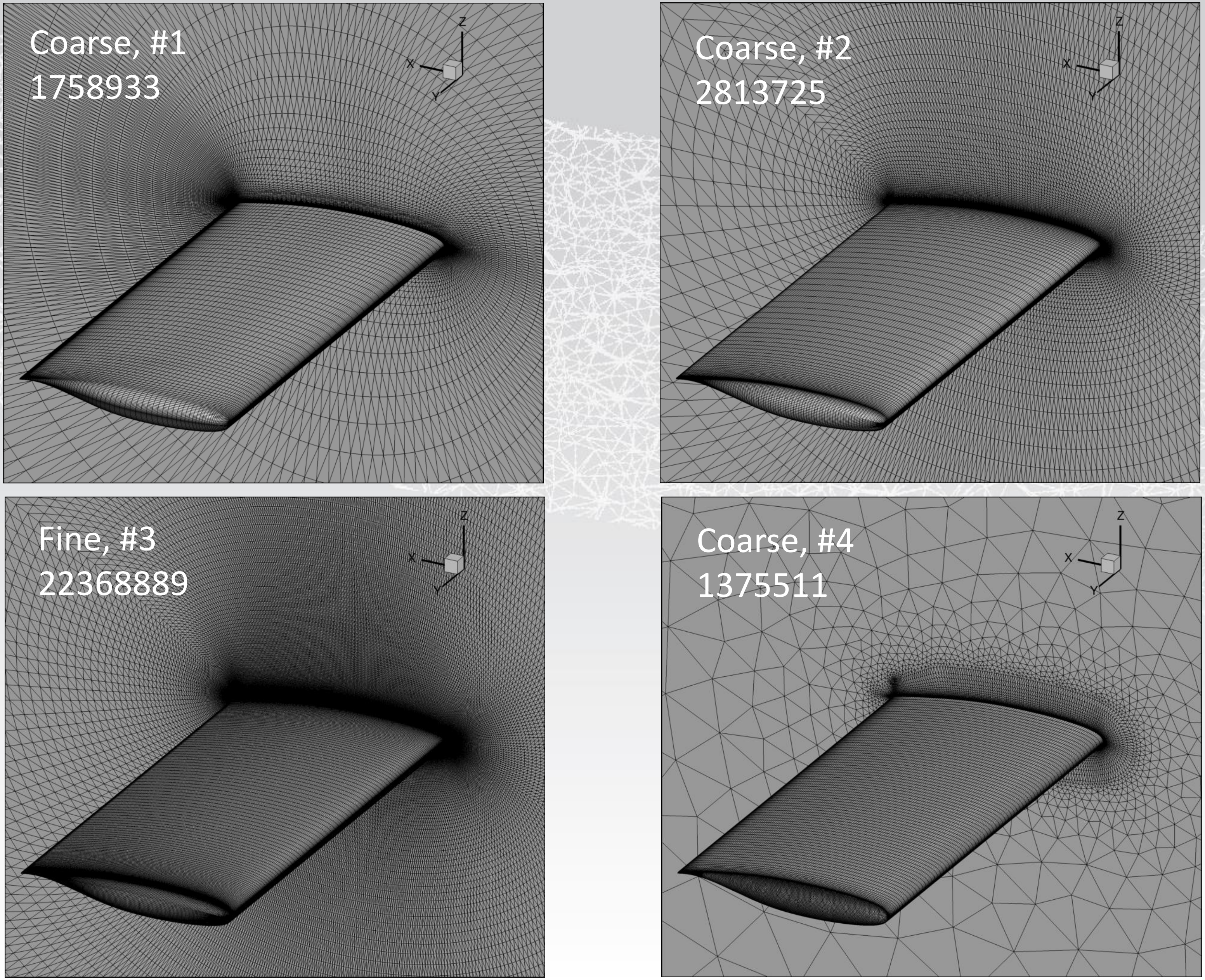
- Model the mesh as a linear elastic solid governed by

$$\nabla \cdot [\mu(\nabla u + \nabla u^T) + \lambda(\nabla \cdot u)I] = f = 0$$

$$l = \frac{Eu}{(1+u)(1-2u)} \qquad m = \frac{E}{2(1+u)}$$

- Choose Poisson’s ratio and Young’s modulus to close system
  - $u = const, E = E(1/V) \ or \ E(1/d)$
  - Smaller cells or cells closer to surface are stiffer
- Solve linear PDE
  - Large fraction (typ. 30% or more) of cost of flow-solver step
  - Eventually will employ multigrid to speed up solution
- Geometric Conservation Law (ALE formulation) accounted for
  - Essential for free stream preservation on deforming meshes
  - Appears as a source term in flow equation residuals

AePW-2 Case2 FUN3D study using 8 grids



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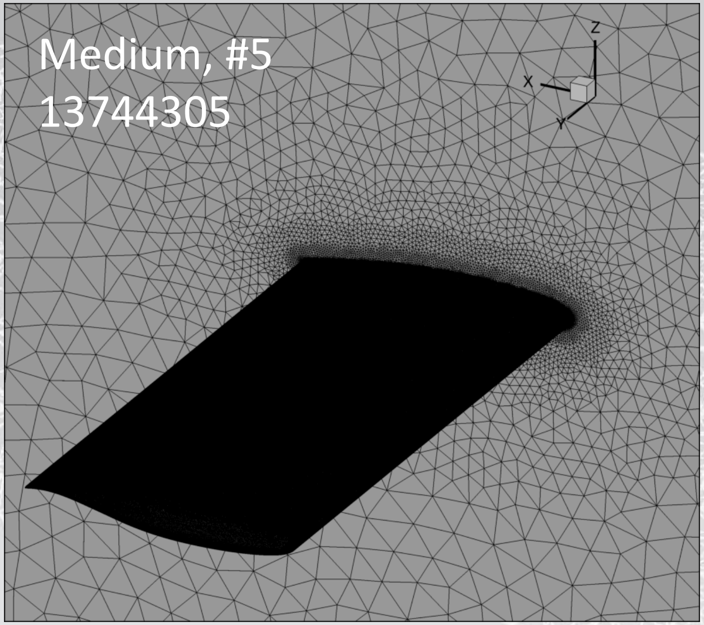
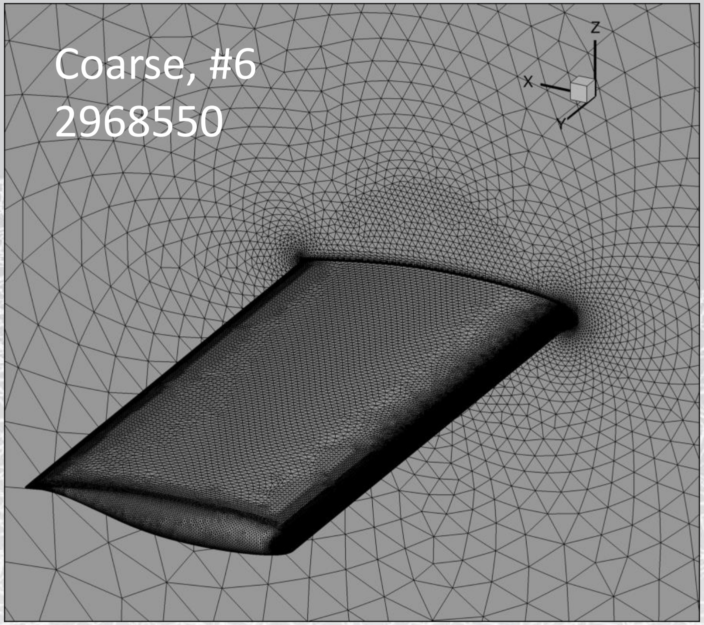
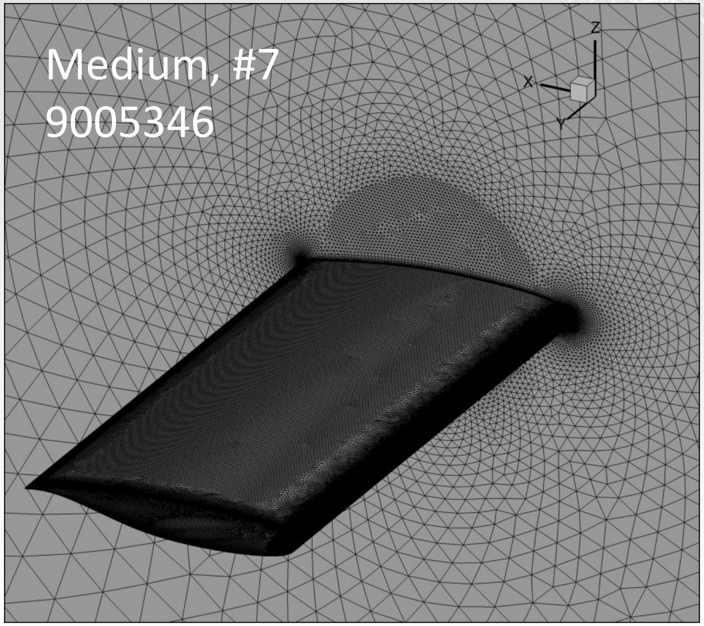
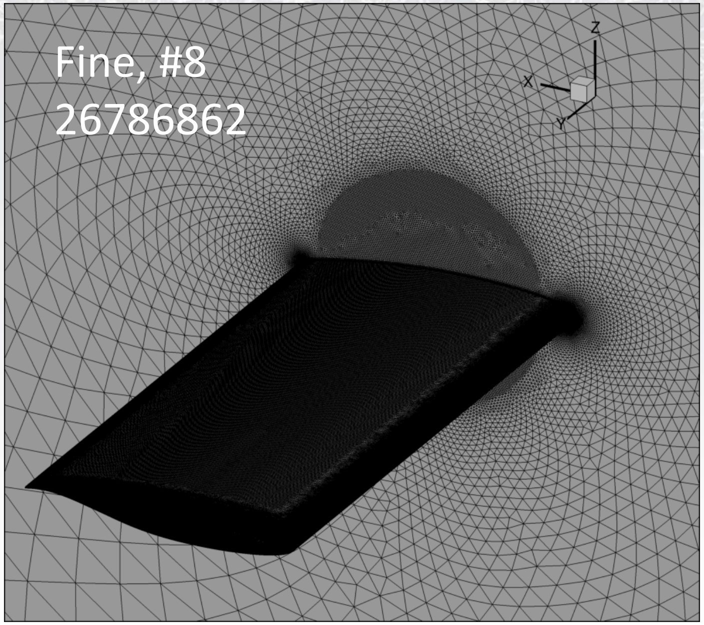
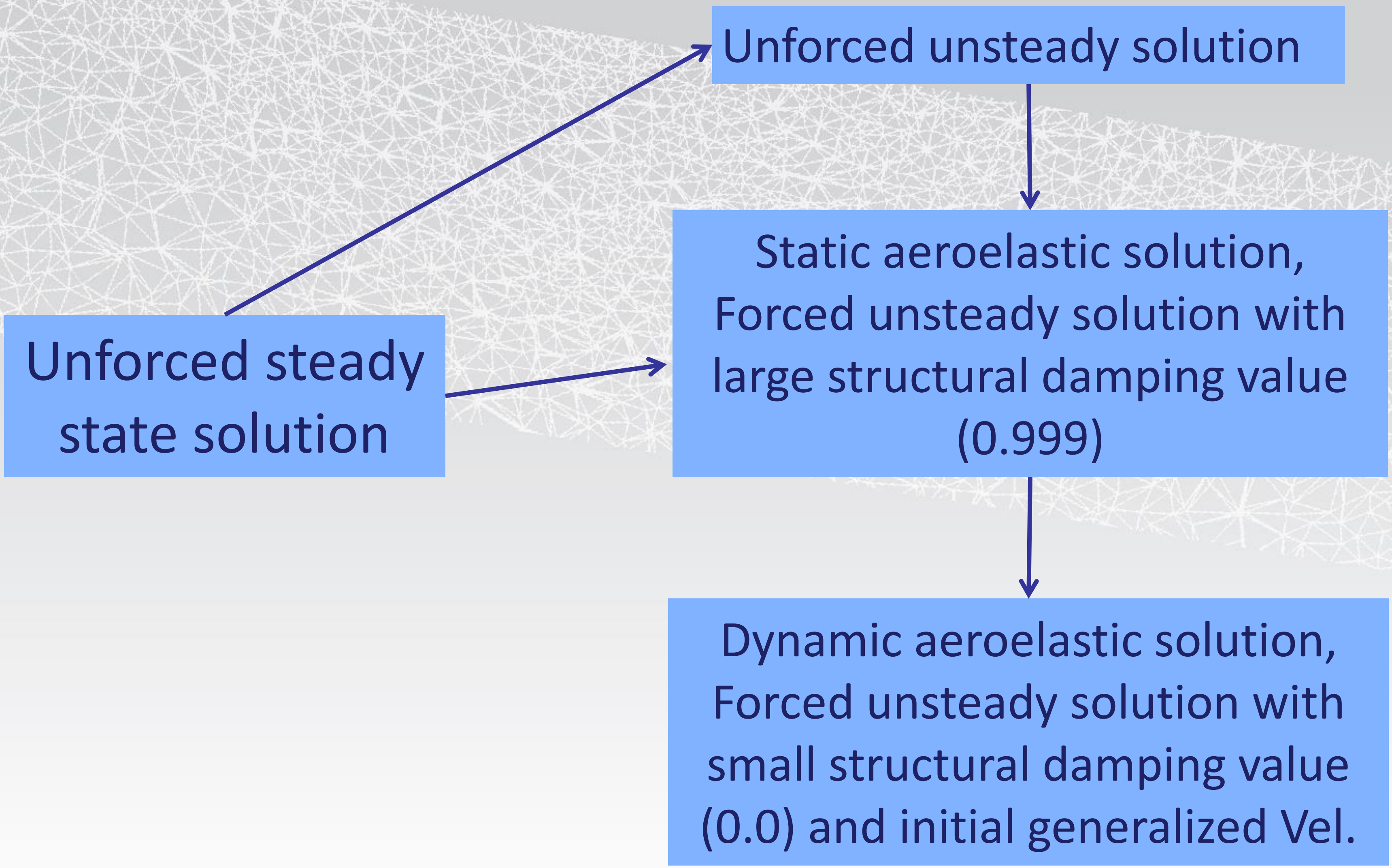








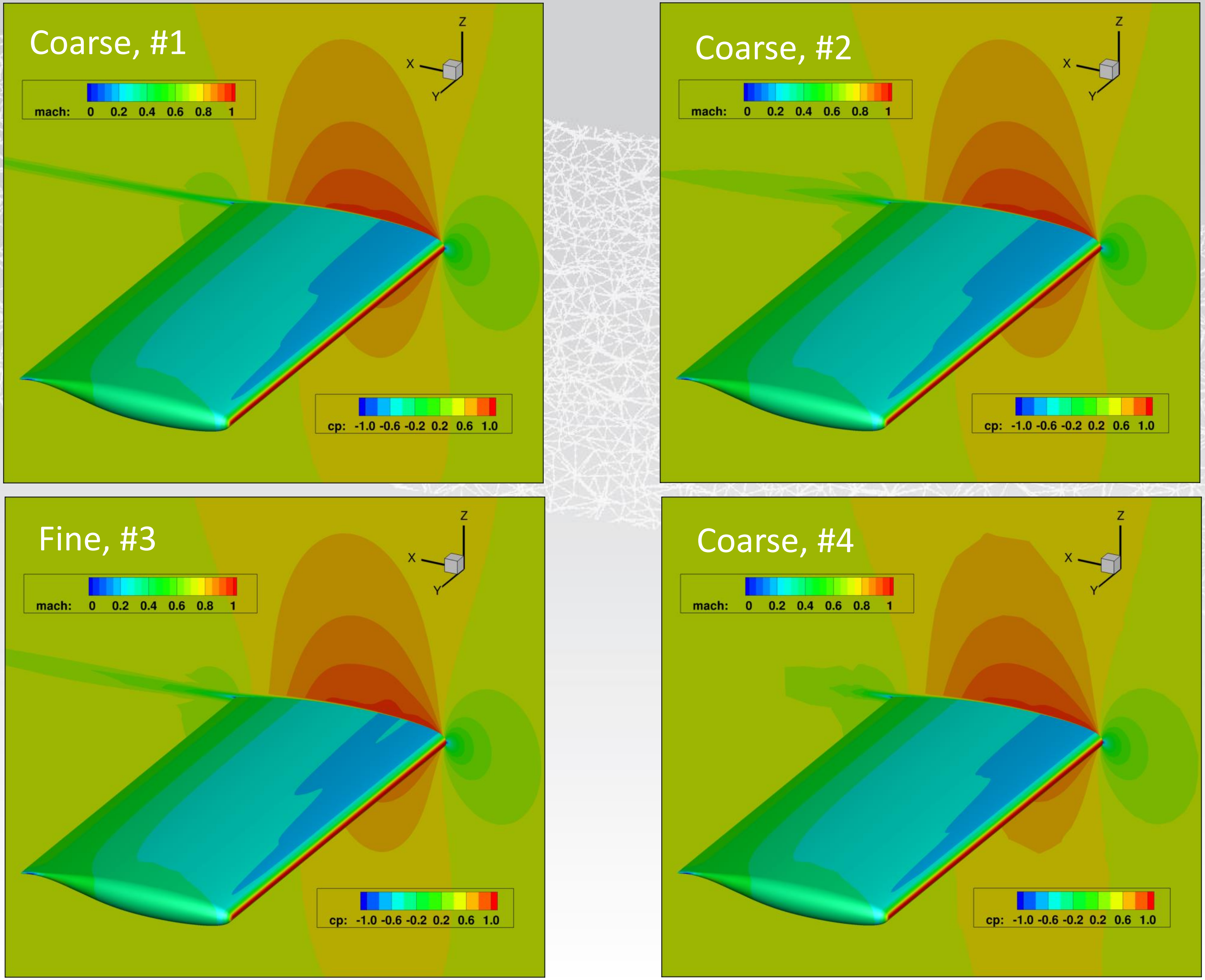
FUN3D Analysis Process



AePW-2 Case2 FUN3D study using 8 grids

Grid #	# nodes	Resolution
1	1758933	Coarse
2	2813725	Coarse
3	22368889	Fine
4	1375511	Coarse
5	13744305	Medium
6	2968550	Coarse
7	9005346	Medium
8	26786862	Fine

Unforced Steady Solution



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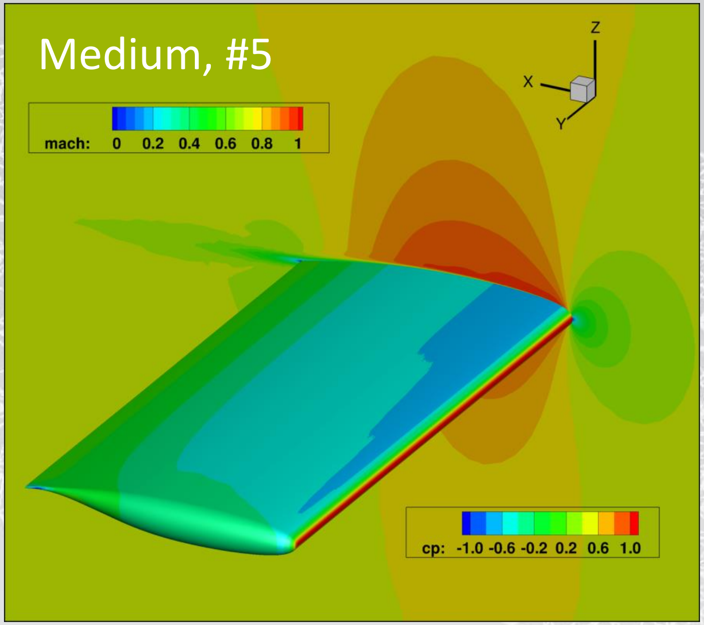
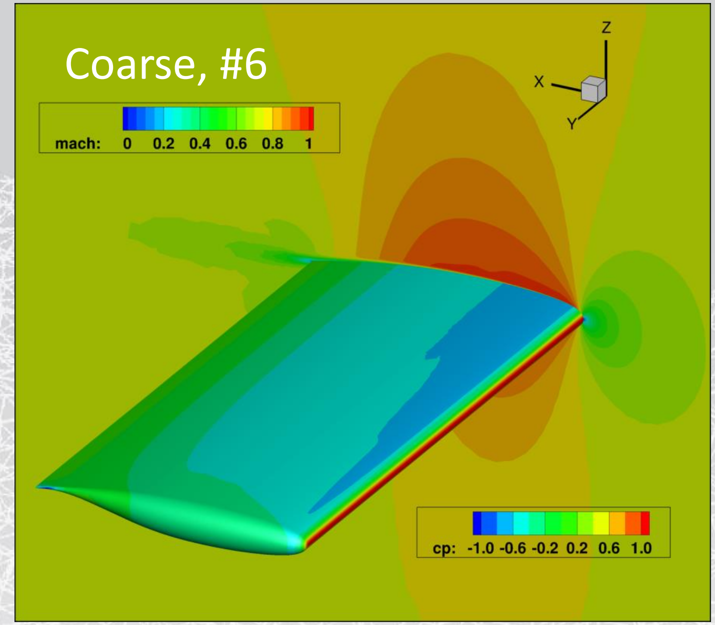
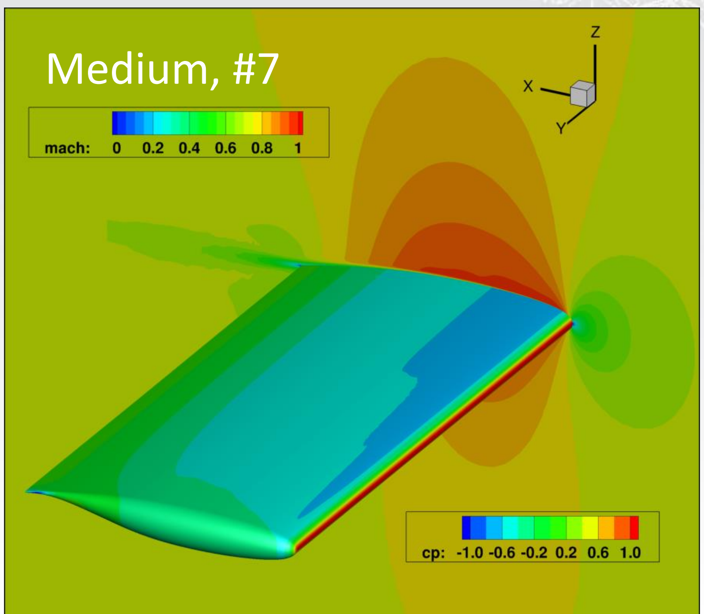
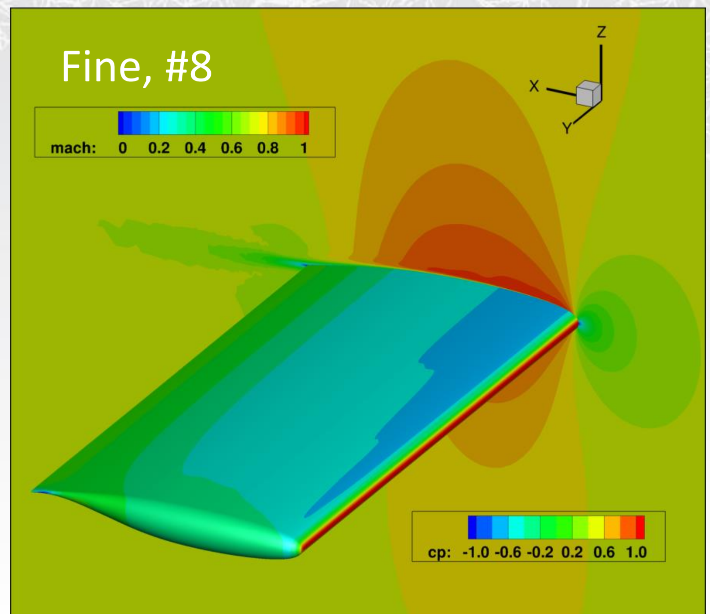
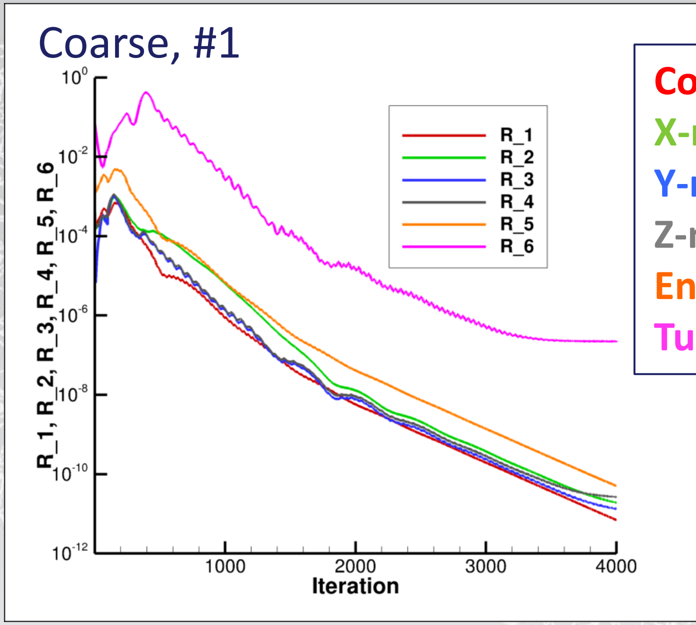




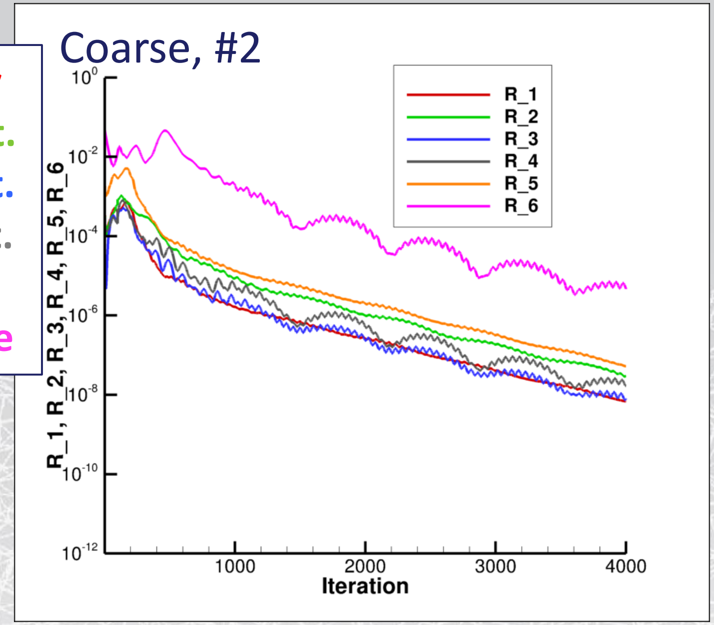


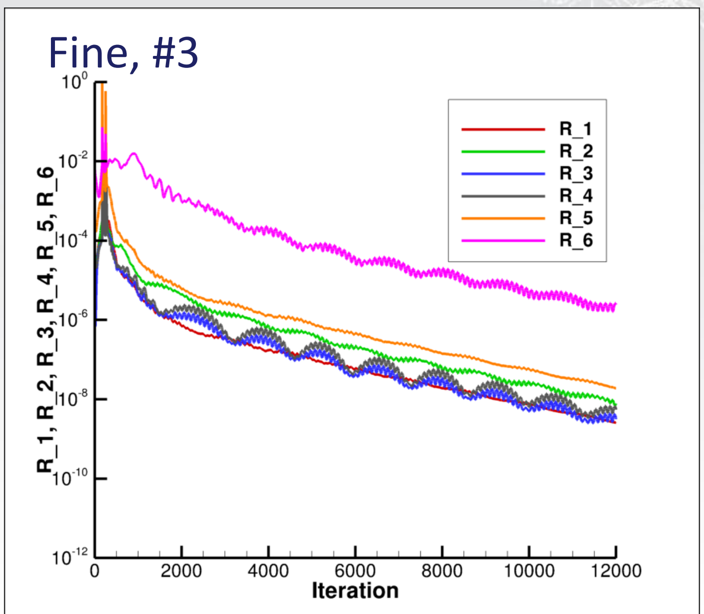


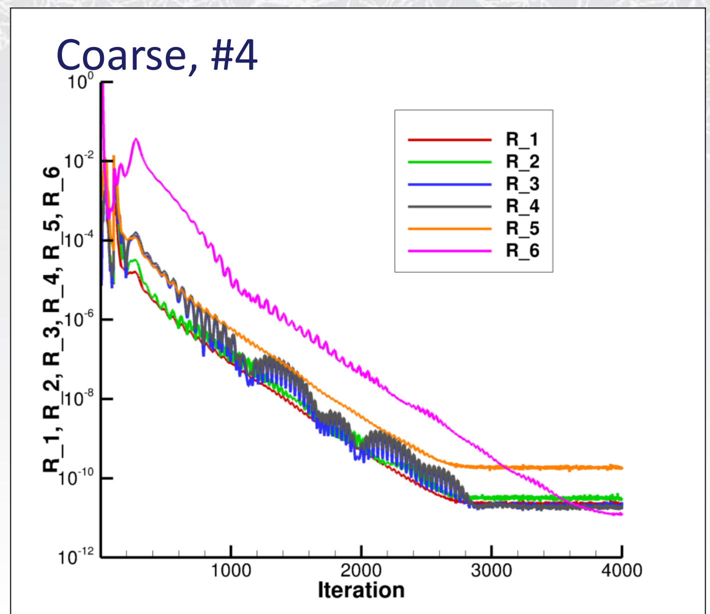
Convergence Rates: Unforced Steady



Continuity
X-moment.
Y-moment.
Z-moment.
Energy
Turbulence

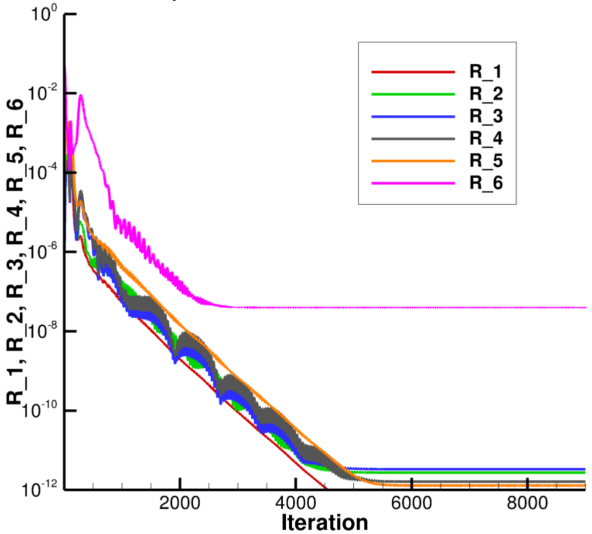






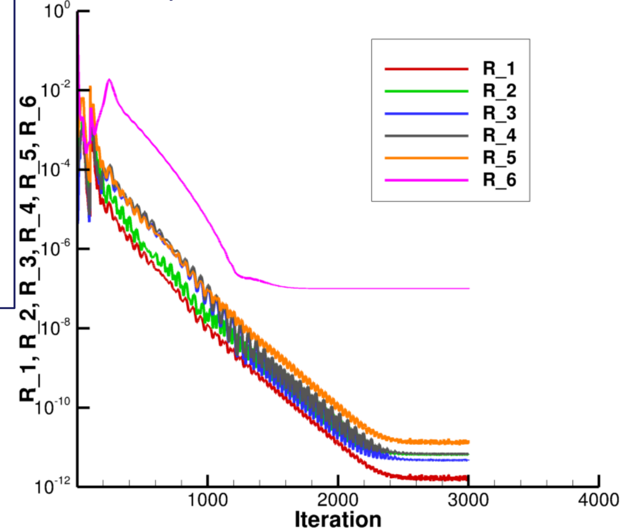
Convergence Rates

Medium, #5

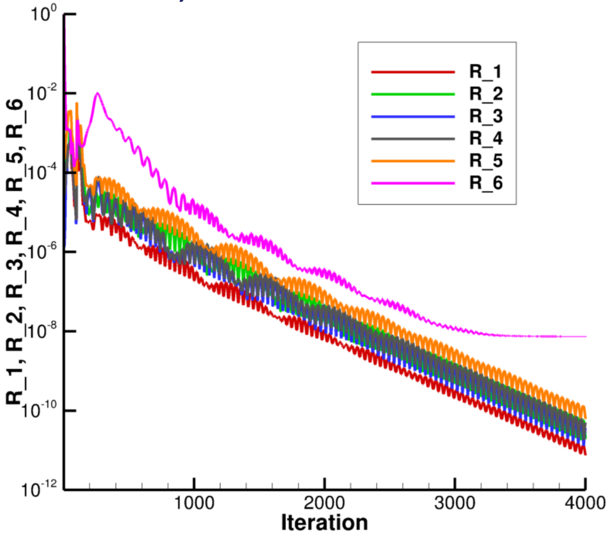


Continuity
X-moment.
Y-moment.
Z-moment.
Energy
Turbulence

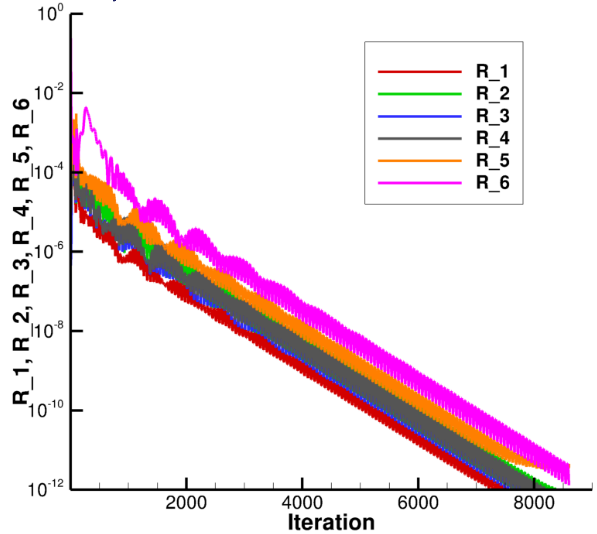
Coarse, #6



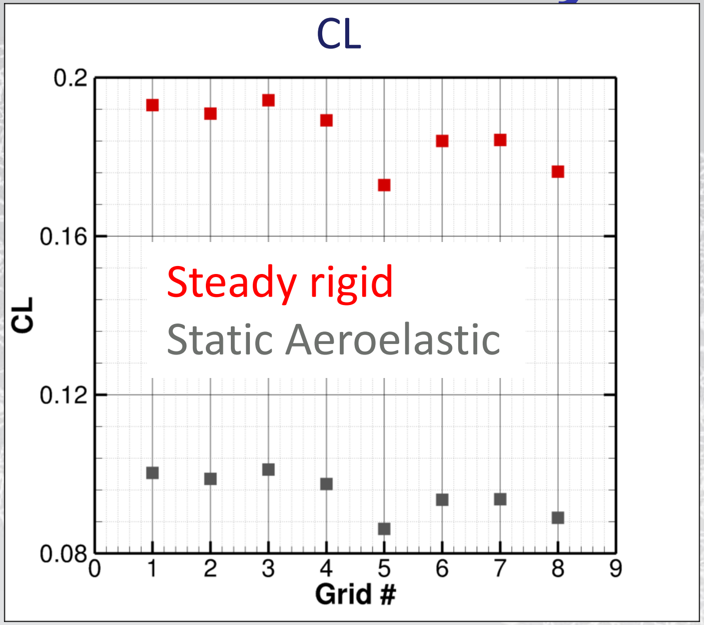
Medium, #7

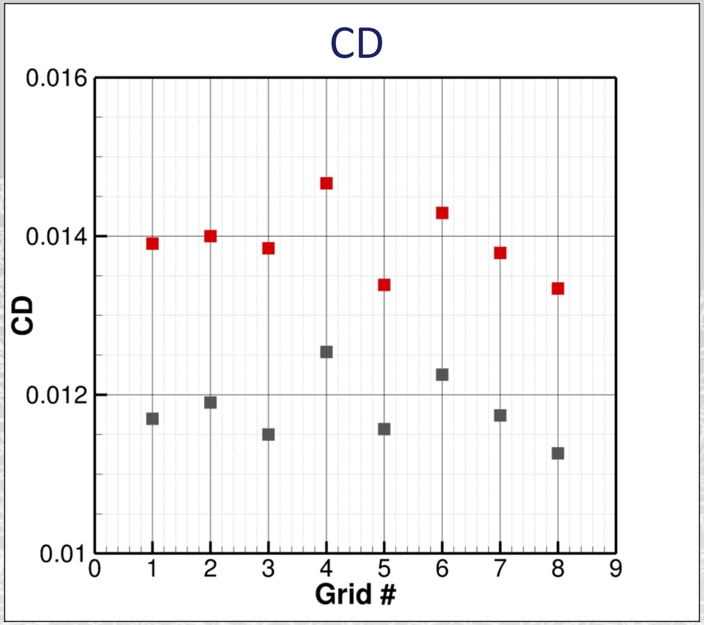


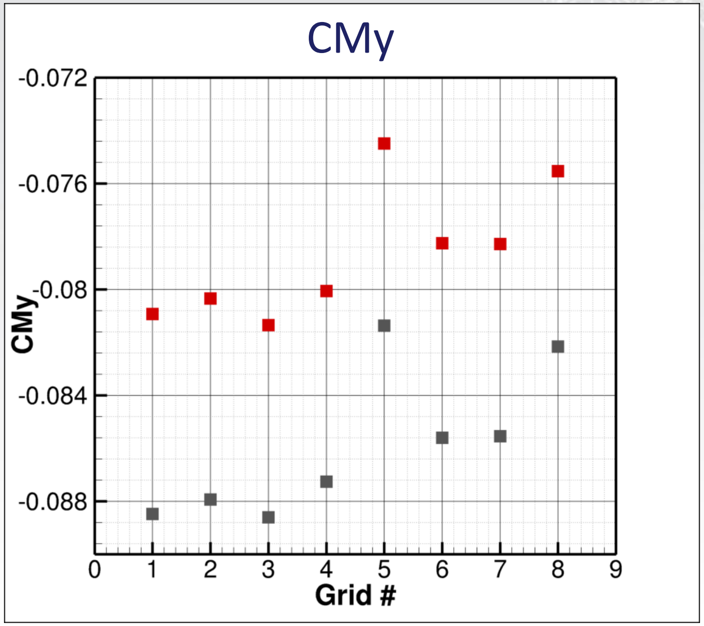
Fine, #8

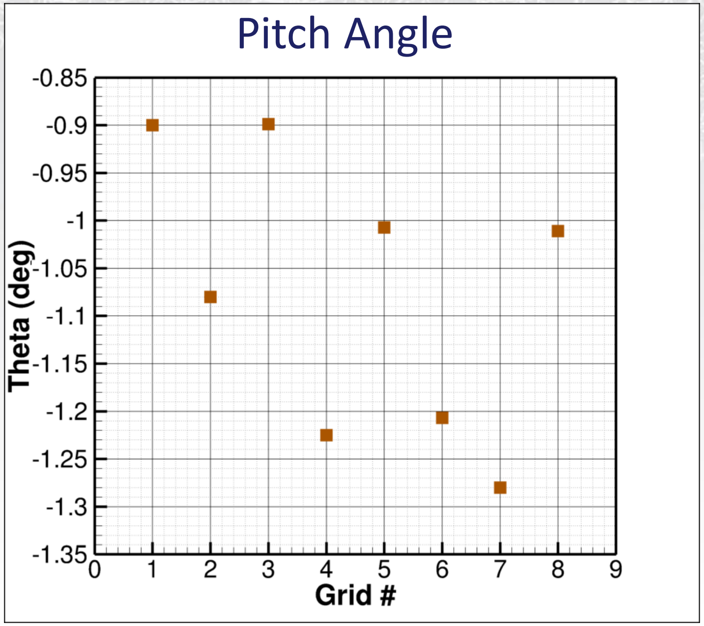


Unforced Steady and Static Aeroelastic Aerodynamic Coefficients



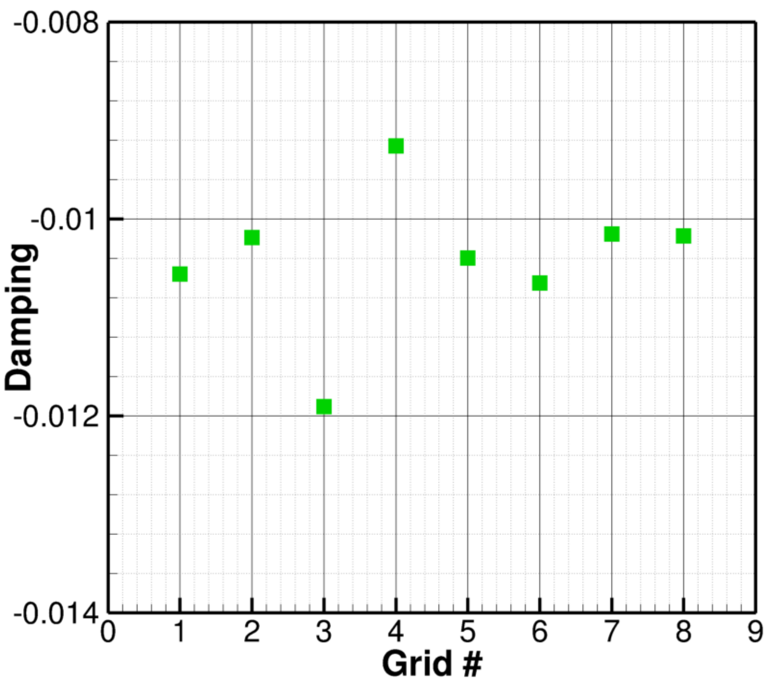




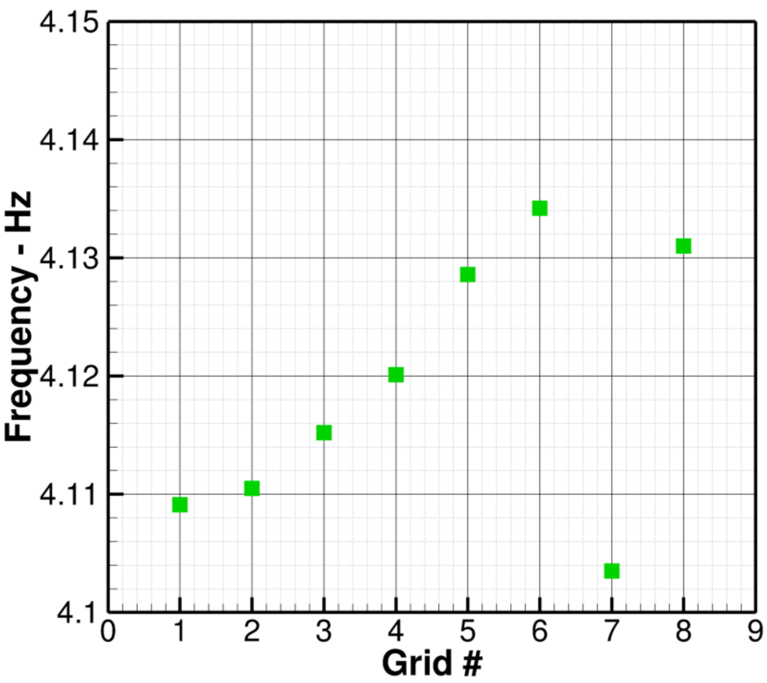


Dynamic Aeroelastic Results
Case 2: Mach 0.74, alpha = 0°, Experimental q = 169 psf

Damping



Frequency



Summary

Results from this study will be added to the AePW-2 database