

Rectangular Supercritical Wing Results using NSU3D

Dimitri Mavriplis

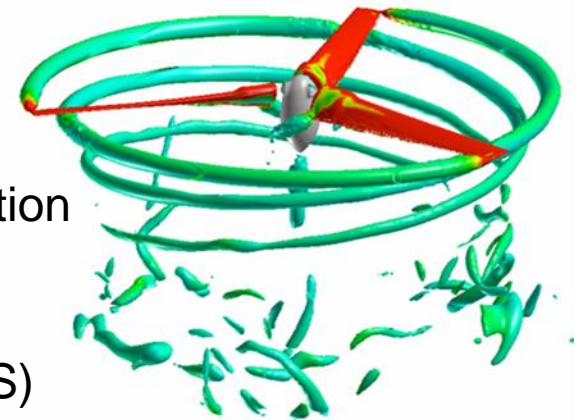
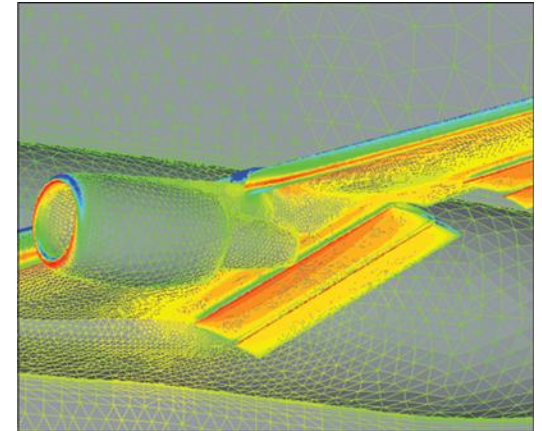
Mike Long

Zhi Yang

University of Wyoming

NSU3D Description

- Unstructured RANS solver
- Widely used for fixed wing (steady) and rotorcraft (unsteady)
 - Vertex-based discretization
 - Mixed elements (prisms in boundary layer)
 - Matrix artificial dissipation
 - Option for Roe scheme with gradient reconstruction
 - No cross derivative viscous terms
 - $\nabla(\mu\nabla v)$ (Similar to incompressible Full NS)
 - Option for full Navier-Stokes terms
 - Extended stencil with edge-based normal derivatives

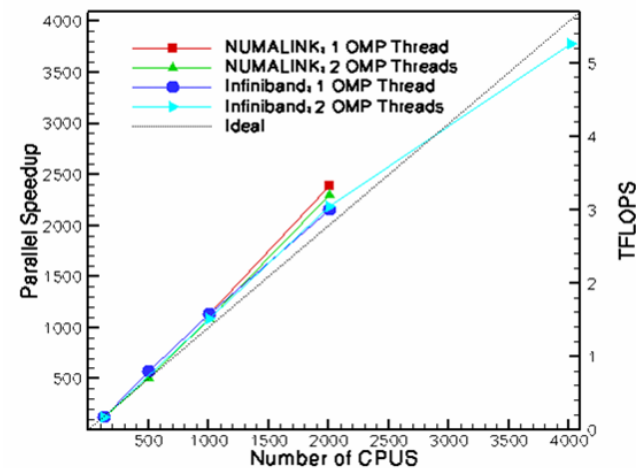
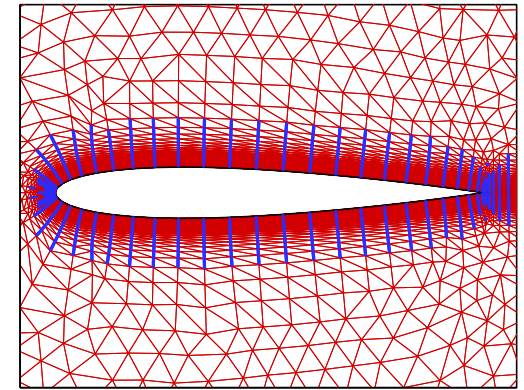


Solver Description (cont'd)

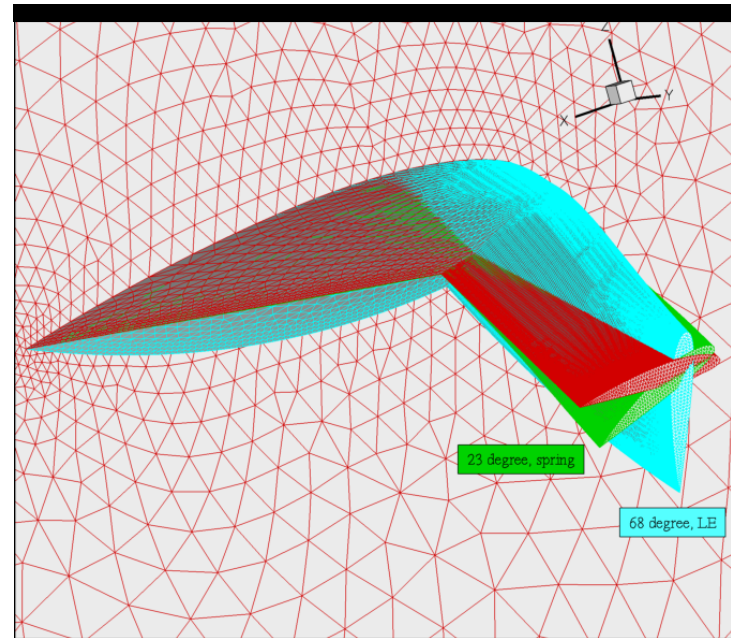
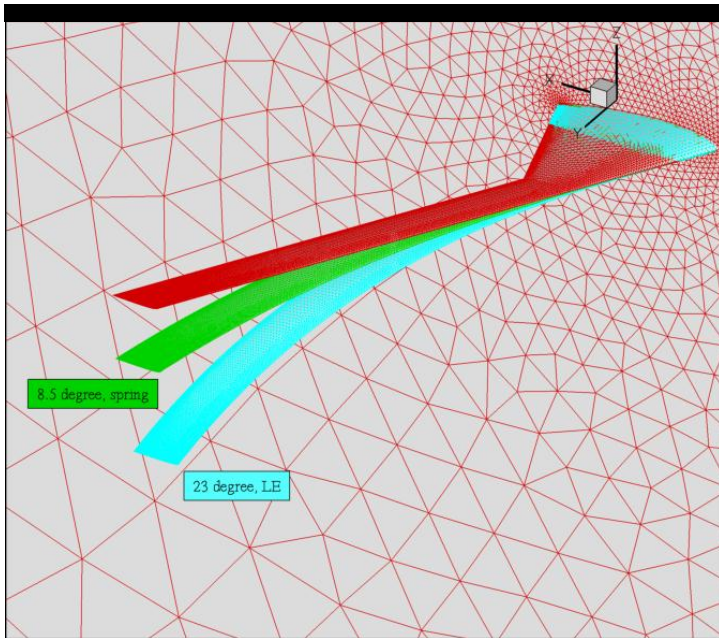
- Spalart-Allmaras turbulence model
 - (original published form)
 - Used exclusively in AePW calculations
- Options for
 - Wilcox k-omega model
 - Mentor SST Model
 - Not exercised in AePW

Solution Strategy

- Steady or BDF2 Implicit Time-stepping
- Jacobi/Line Preconditioning
 - Line solves in boundary layer regions
 - Relieves aspect ratio stiffness
- Agglomeration multigrid
 - Fast grid independent convergence
- Parallel implementation
 - MPI/OpenMP hybrid model
 - MPI only on local 512 core cluster
and on NASA Pleiades Supercomputer



Mesh Motion Approach

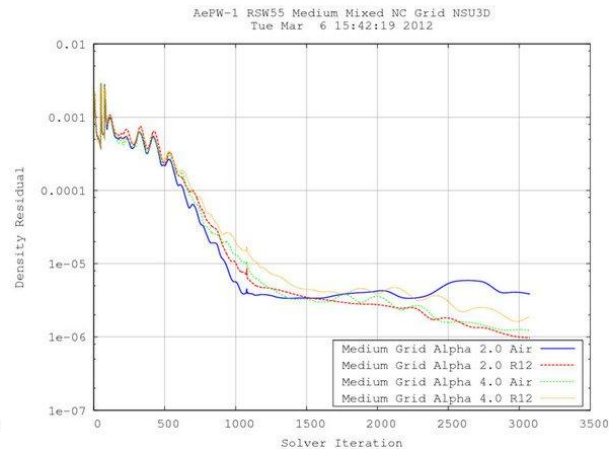
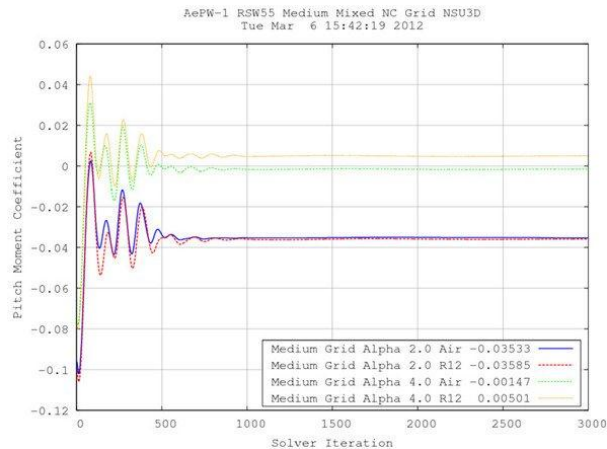
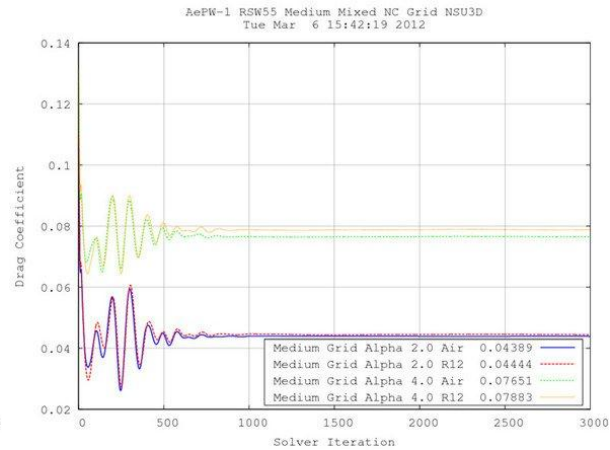
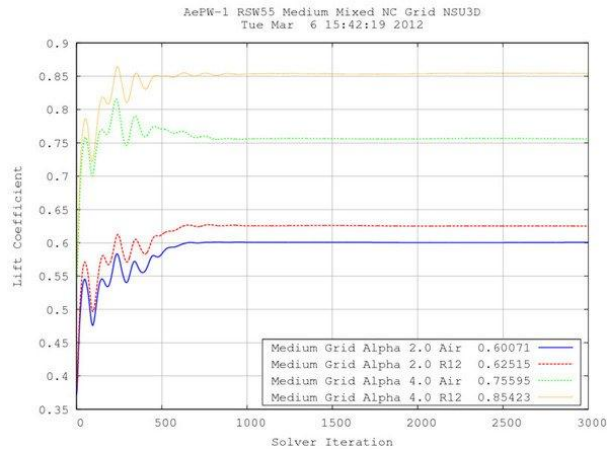


- Linear elasticity analogy with prescribed modulus E
 - More robust than simple mesh-spring analogy
 - Solved using line-implicit multigrid algorithm
 - Similar to CFD flow solver
 - Grid independent convergence rates including highly stretched boundary-layer type grids
 - Generally converged 10 orders of magnitude at each time step

Cases Run

- Steady State Runs
 - Coarse, Medium, Fine meshes: (Solid Mesh, Mixed NC)
 - Incidence=2° and 4°
- Time Dependent Runs
 - Coarse and medium meshes
 - $f=10\text{Hz}$ and $f=20\text{Hz}$
 - 64 time step per period
 - 50 multigrid cycles per time step
 - Determined by study on coarse grid as sufficient
 - Full time step and convergence study planned as follow up
 - Coarse grid: 0.93 secs/cycle on 128 cores
 - Medium grid: 1.35 sec/cycle on 256 cores

Steady Results

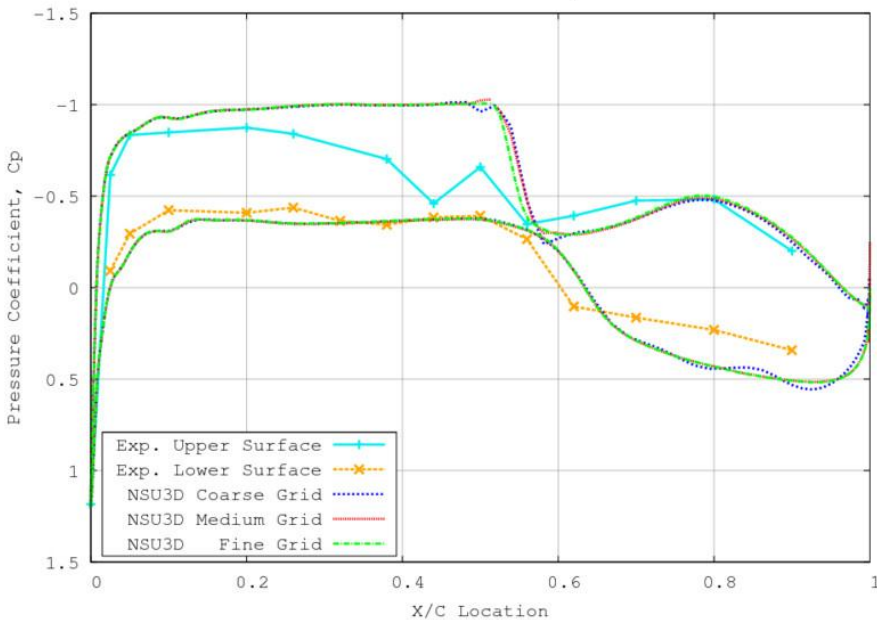


- Large difference between air and heavy gas γ

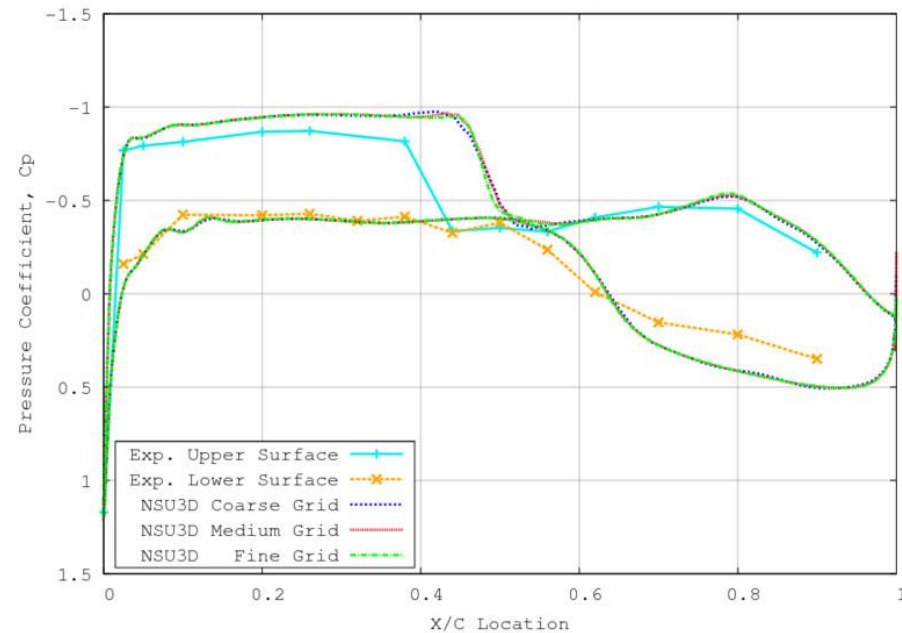
RSW Steady-State Results

Incidence=2°

RSW55 Mixed Element Node Centered Grids - Case 6E23
Eta=0.309 Mach=0.825 Alpha=2.0



RSW55 Mixed Element Node Centered Grids - Case 6E23
Eta=0.588 Mach=0.825 Alpha=2.0

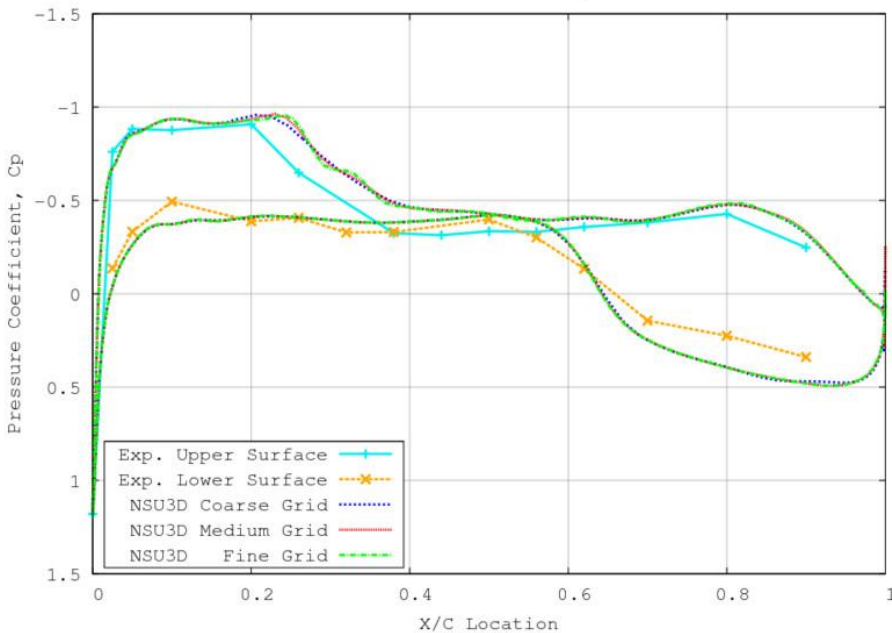


- Overprediction of lift at inboard stations
- Possible wall boundary layer effects (too thin)

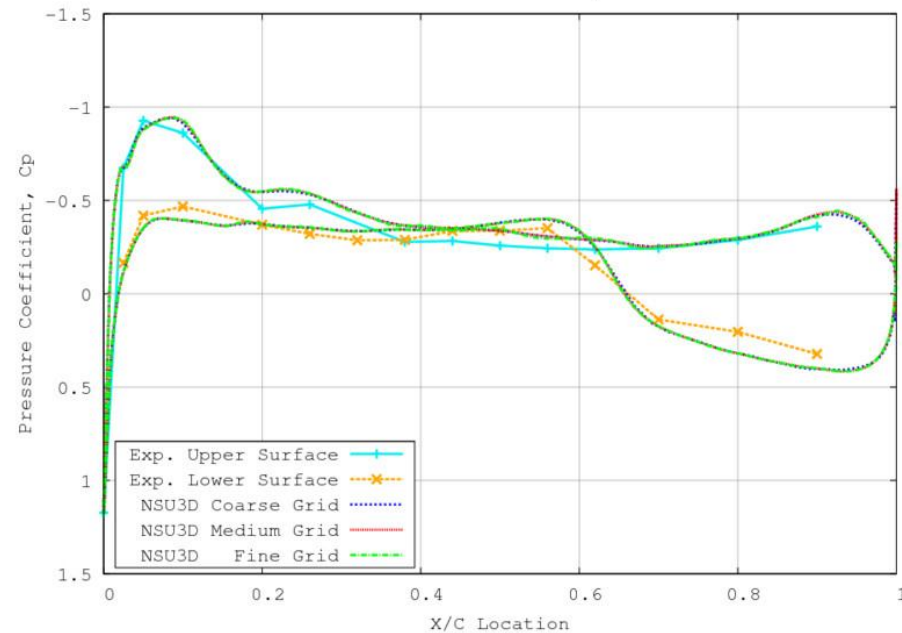
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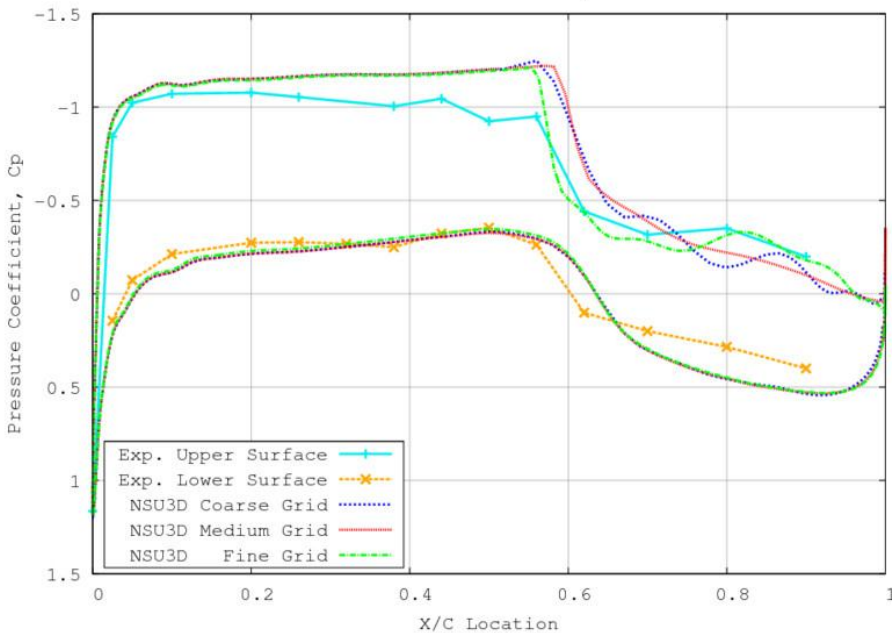


- Better agreement at outboard stations
- Possible wall boundary layer effects (too thin)

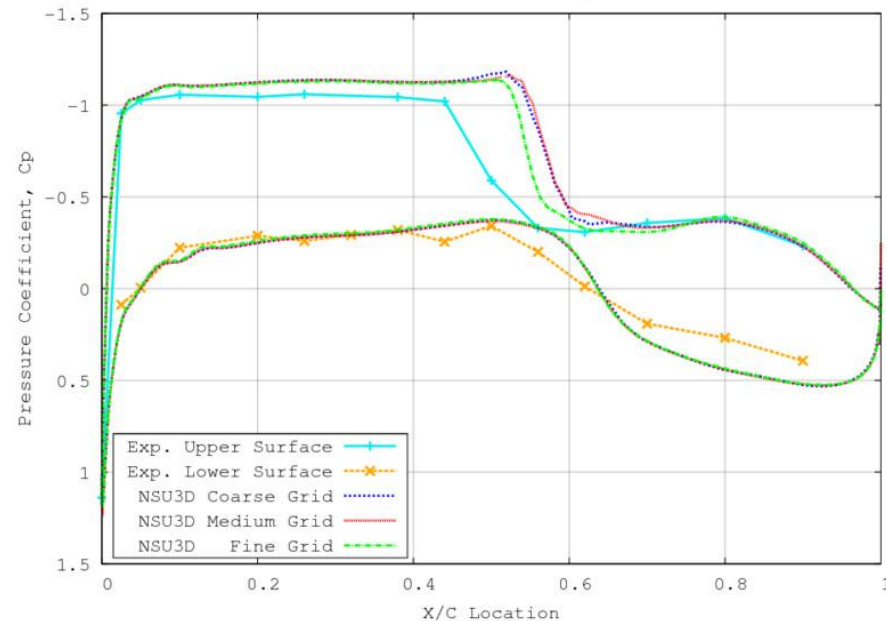
RSW Steady-State Results

Incidence=4°

RSW55 Mixed Element Node Centered Grids - Case 6E24
Eta=0.309 Mach=0.825 Alpha=4.0



RSW55 Mixed Element Node Centered Grids - Case 6E24
Eta=0.588 Mach=0.825 Alpha=4.0

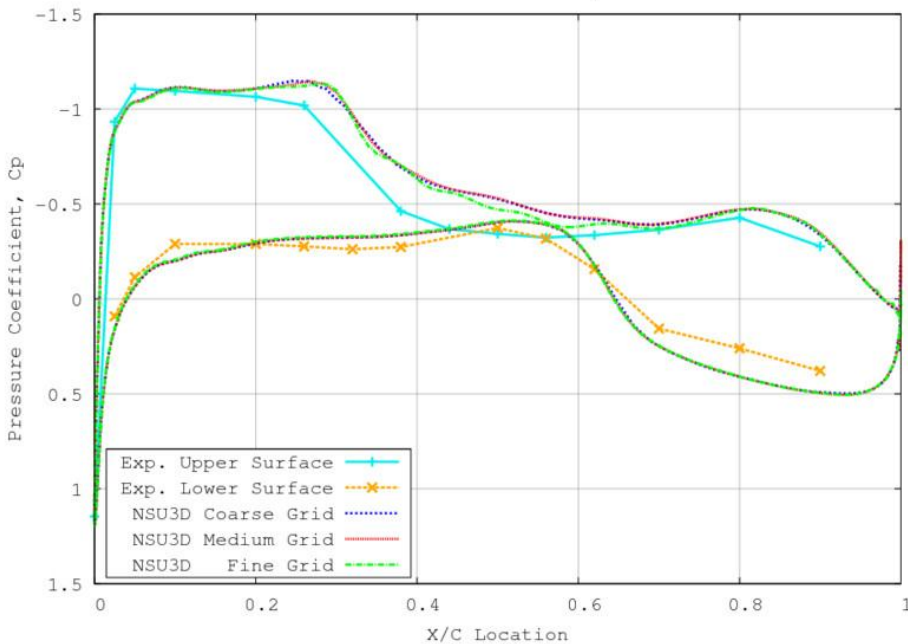


- Overprediction of lift at inboard stations
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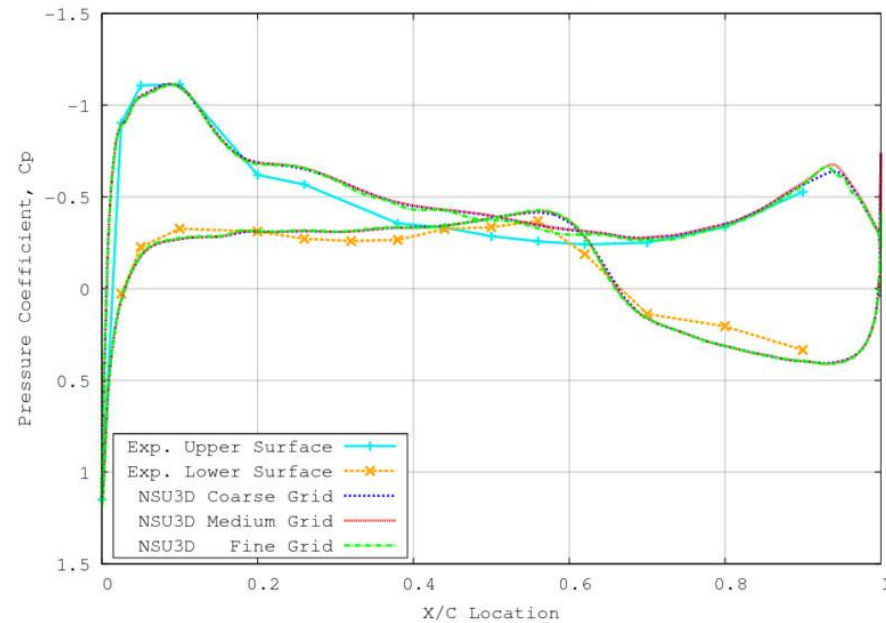
RSW Steady-State Results

Incidence=4°

RSW55 Mixed Element Node Centered Grids - Case 6E24
Eta=0.809 Mach=0.825 Alpha=4.0



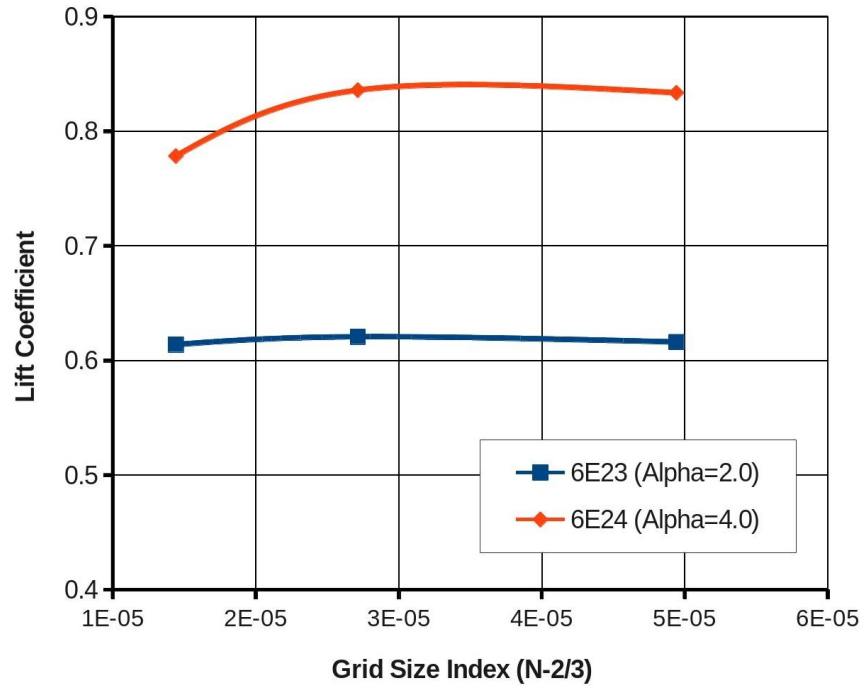
RSW55 Mixed Element Node Centered Grids - Case 6E24
Eta=0.951 Mach=0.825 Alpha=4.0



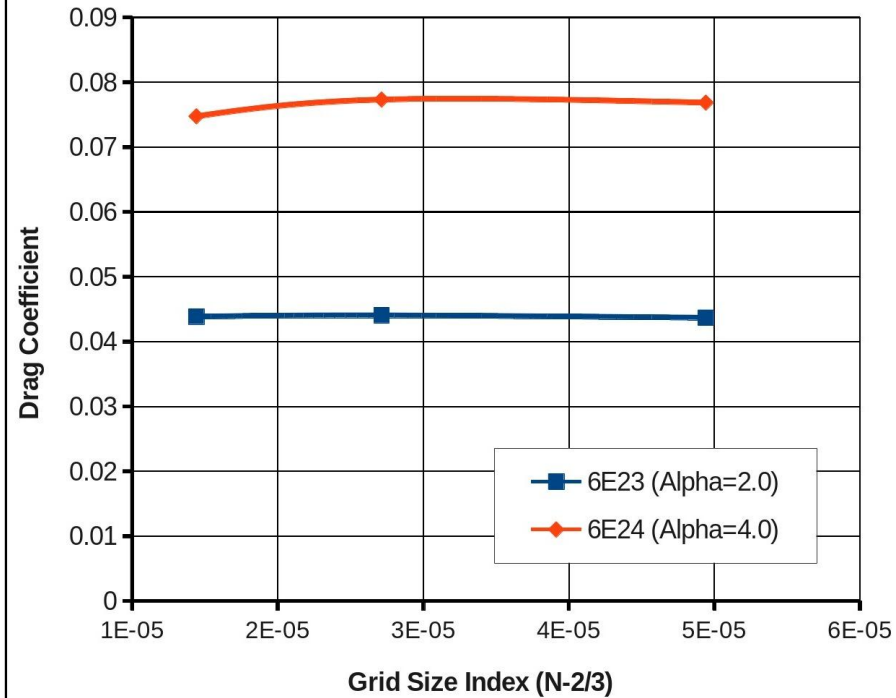
- Better agreement at outboard stations
- Possible wall boundary layer effects (too thin)

Grid Convergence

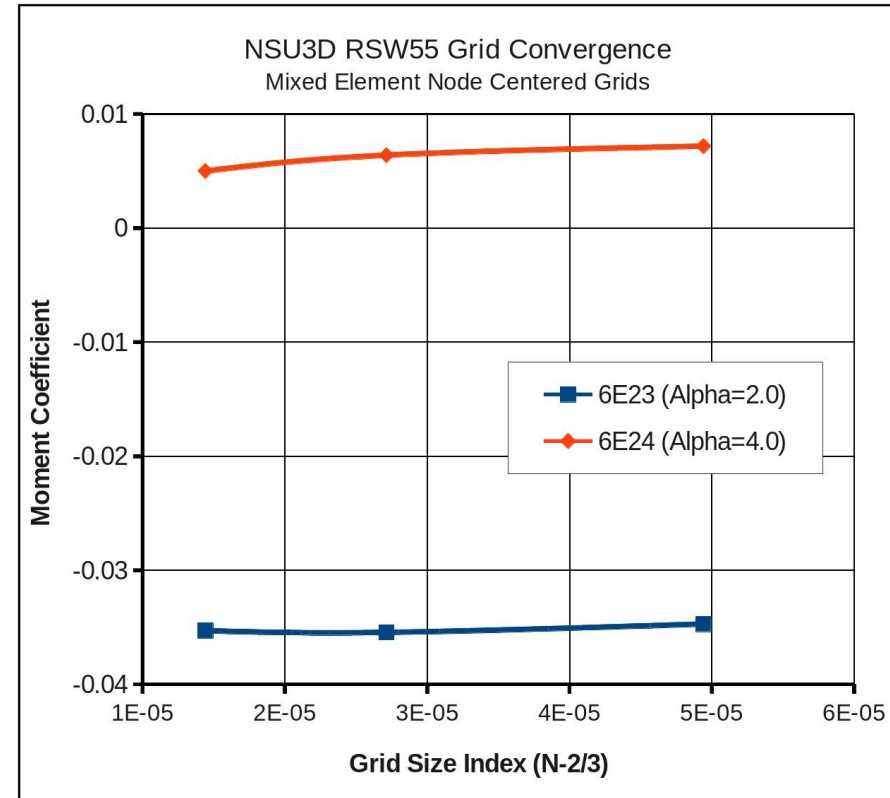
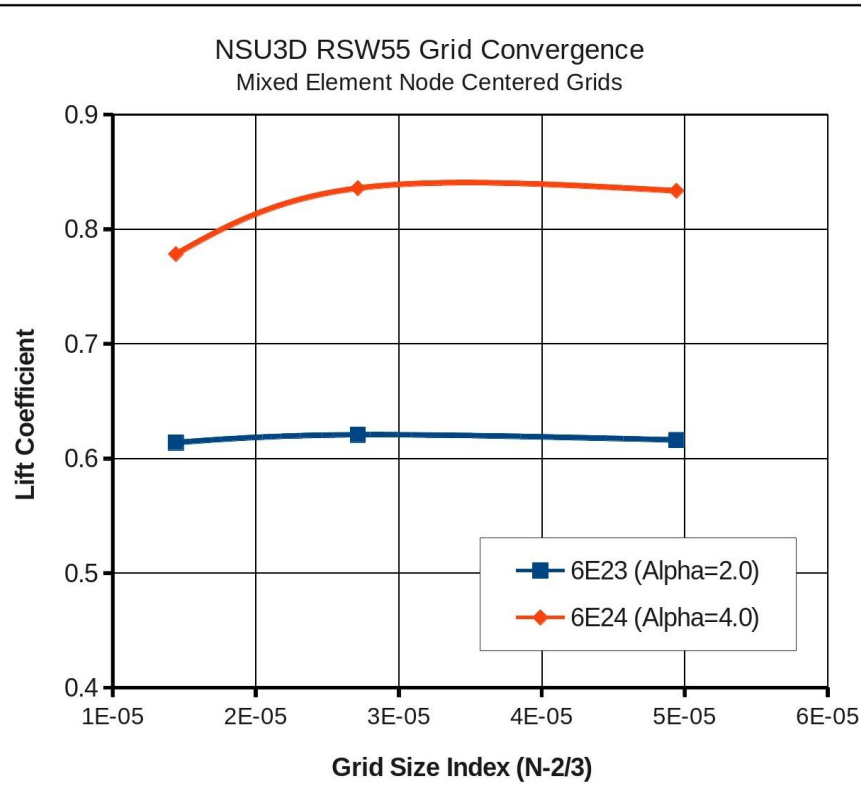
NSU3D RSW55 Grid Convergence
Mixed Element Node Centered Grids



NSU3D RSW55 Grid Convergence
Mixed Element Node Centered Grids

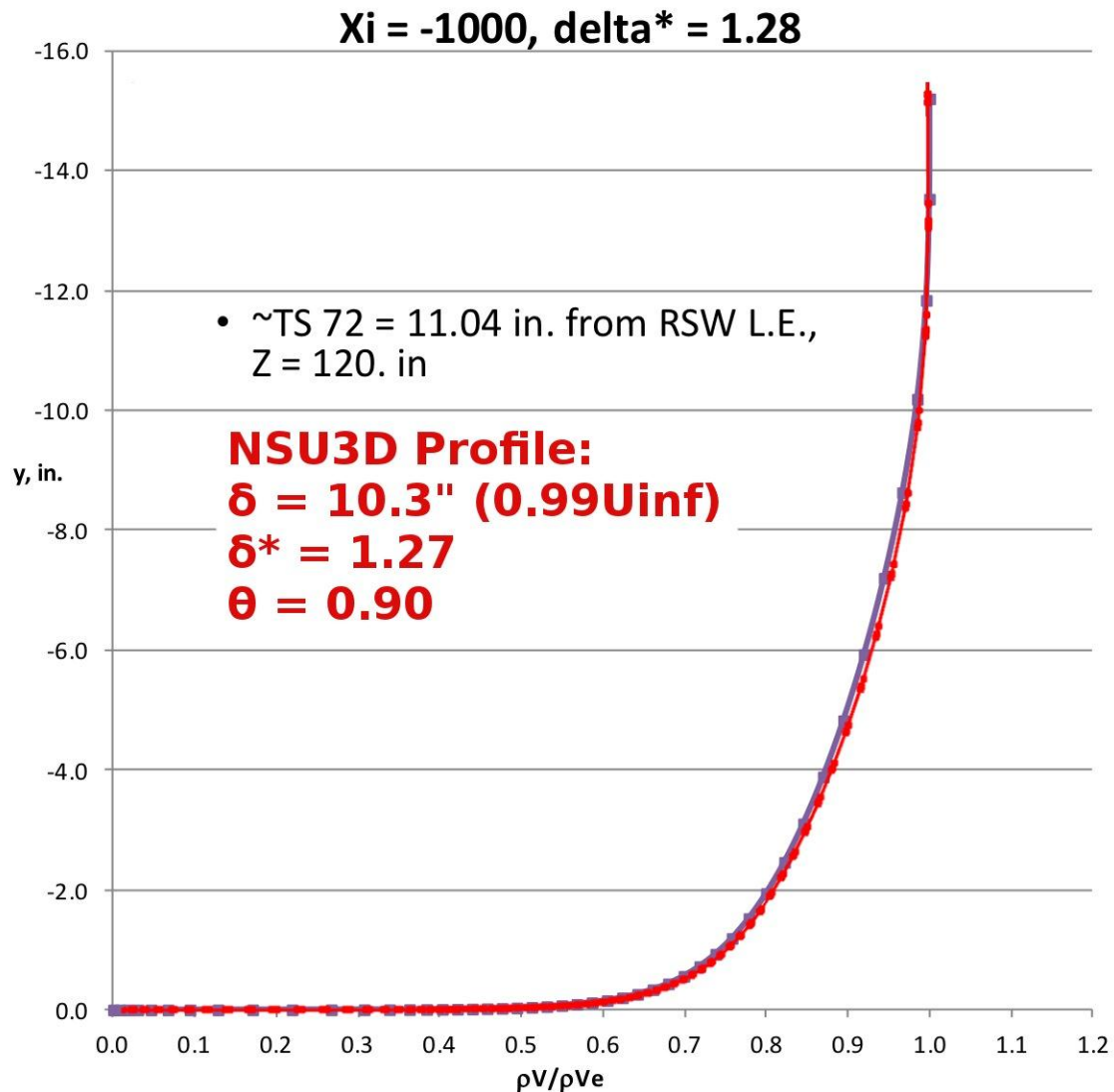


Grid Convergence



- Lift variation on fine grid at 4°
- Otherwise reasonable grid convergence

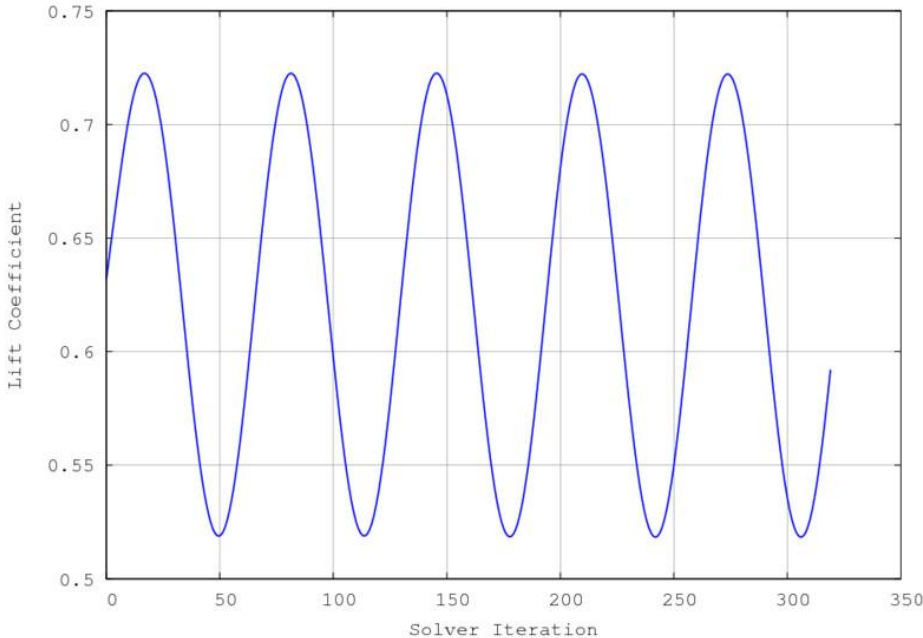
CFL3D Computed BL



Time Dependent Results

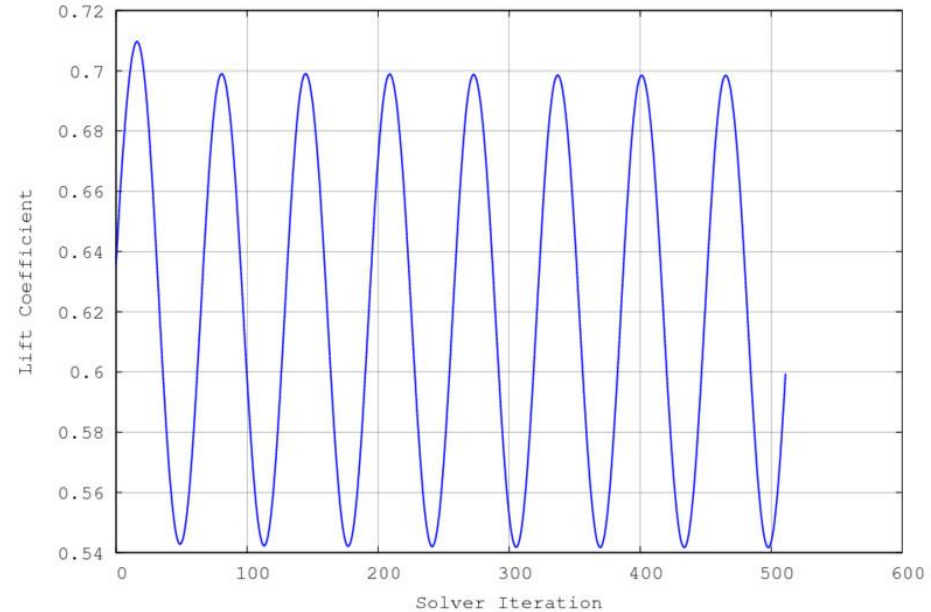
C_L Time histories

AePW-1 RSW55 Medium Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.



$f=10\text{Hz}$

AePW-1 RSW55 Medium Mixed NC 6E56 20.0Hz
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.
Wed Apr 11 08:05:16 2012

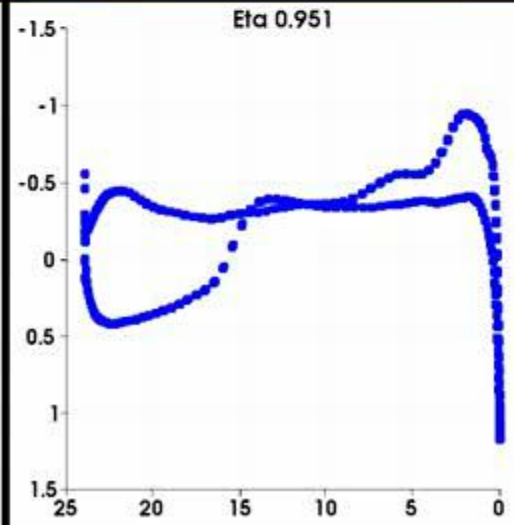
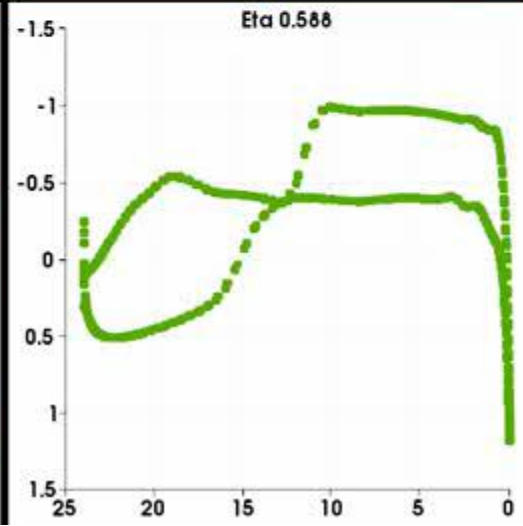
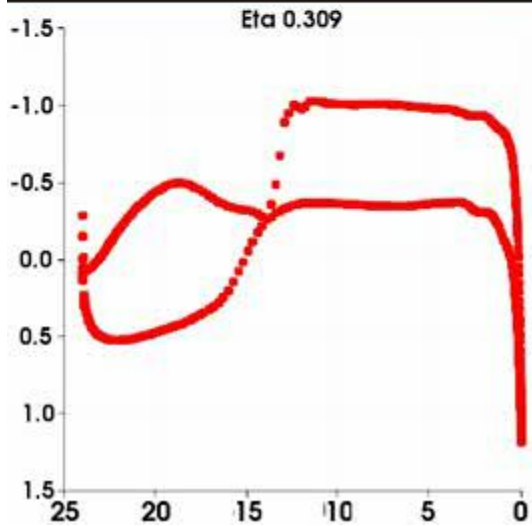
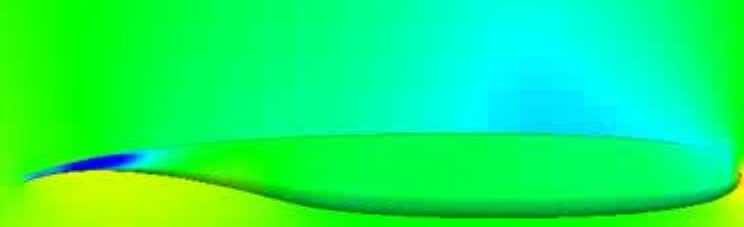
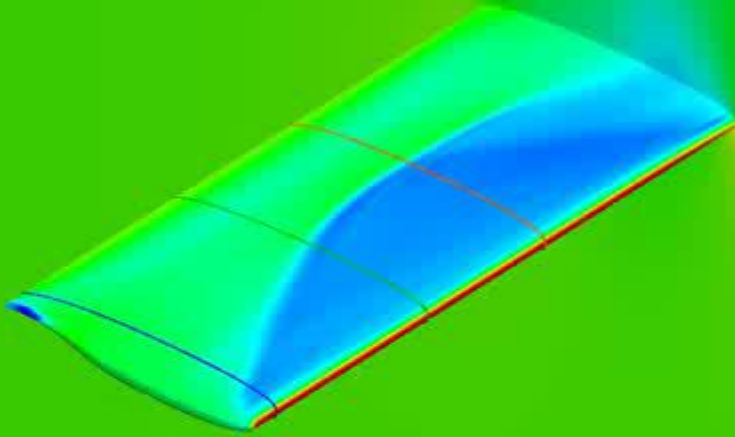


$f=20\text{Hz}$

- Relatively benign behavior (as expected)
 - 64 time steps per period

NSU3D AEPW-1 RSW55 6E54
Coarse Mixed NC Grid
Mach=0.825 Alpha=2+-1 Deg
Freq=10Hz k=0.15

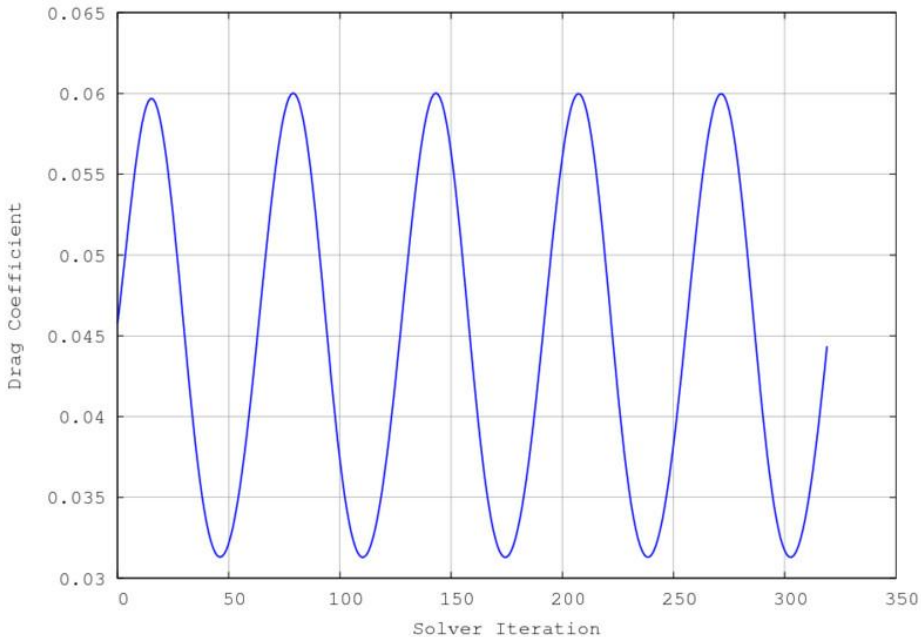
Time: 0.003



Time Dependent Results

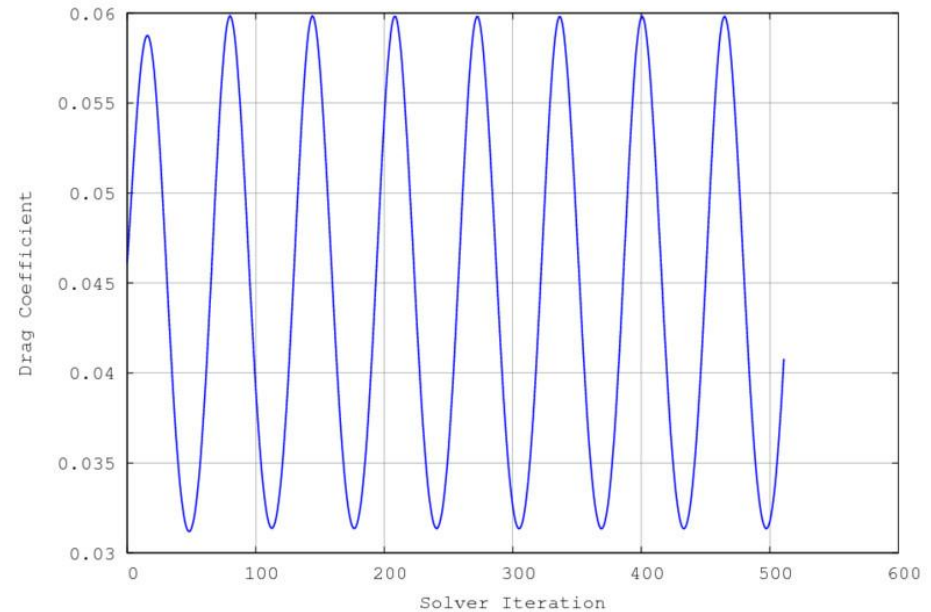
C_D Time histories

AePW-1 RSW55 Medium Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.



$f=10\text{Hz}$

AePW-1 RSW55 Medium Mixed NC 6E56 20.0Hz
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.
Wed Apr 11 08:05:16 2012



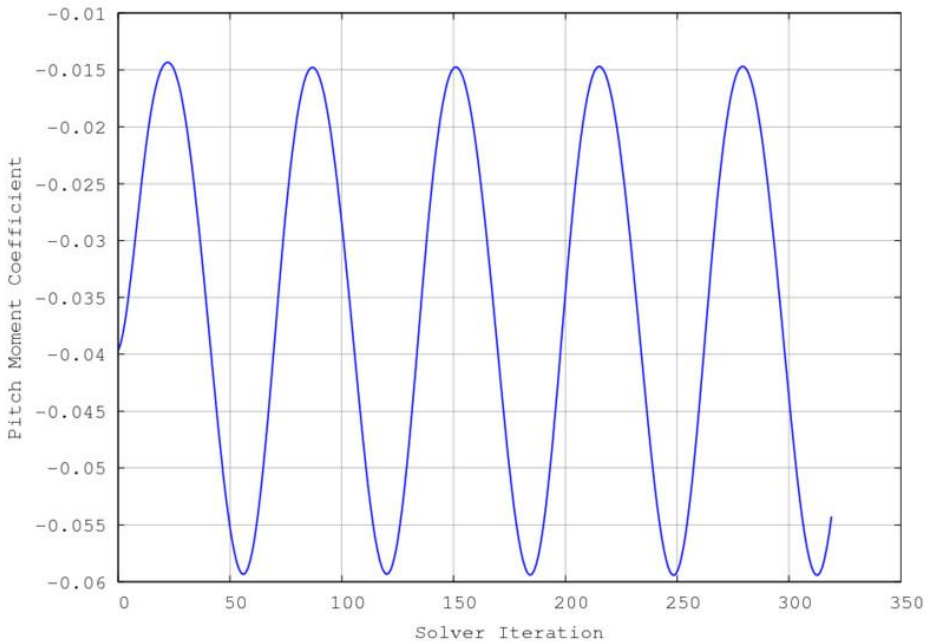
$f=20\text{Hz}$

- Relatively benign behavior (as expected)
 - 64 time steps per period

Time Dependent Results

C_M Time histories

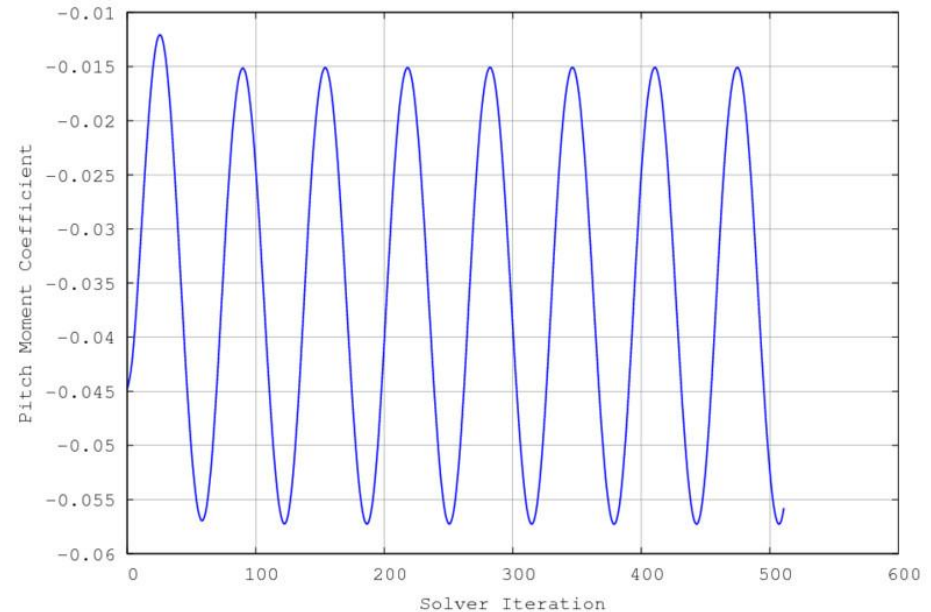
AePW-1 RSW55 Medium Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.



f=10Hz

- Relatively benign behavior (as expected)
 - 64 time steps per period

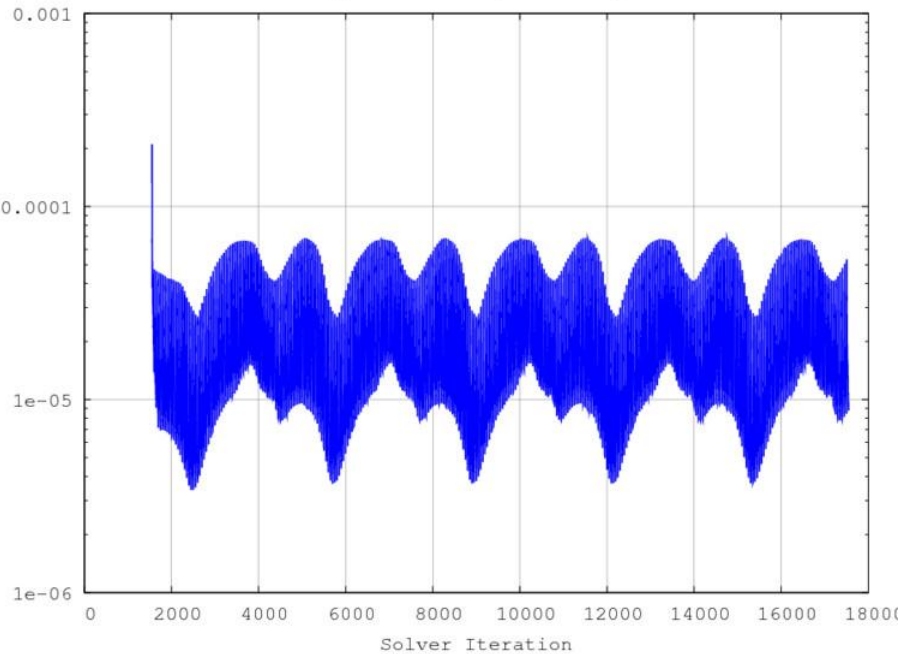
AePW-1 RSW55 Medium Mixed NC 6E56 20.0Hz
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.
Wed Apr 11 08:05:16 2012



f=20Hz

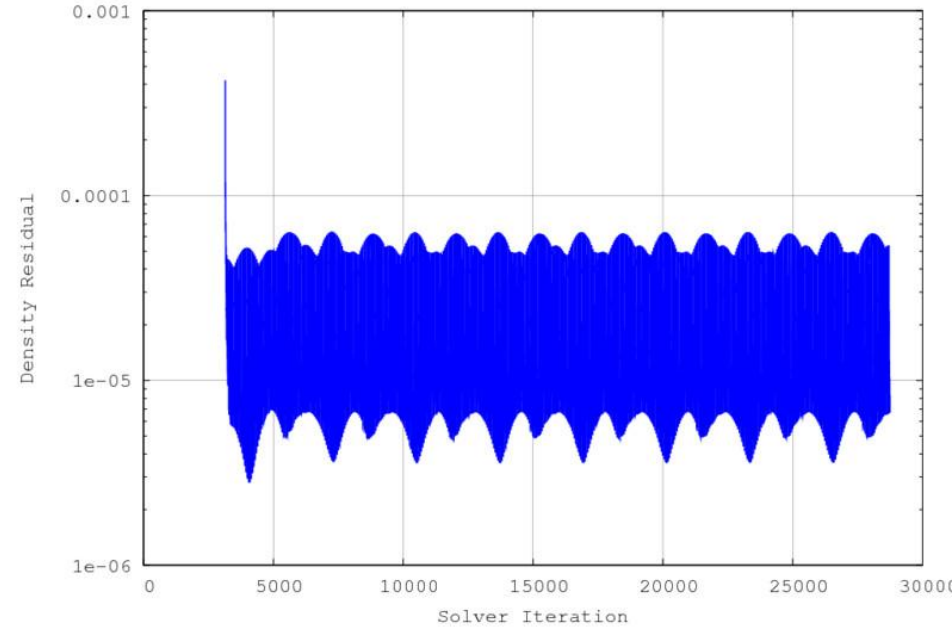
Time Dependent Residual Histories

AePW-1 RSW55 Medium Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.



f=10Hz

AePW-1 RSW55 Medium Mixed NC 6E56 20.0Hz
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.
Wed Apr 11 08:05:16 2012



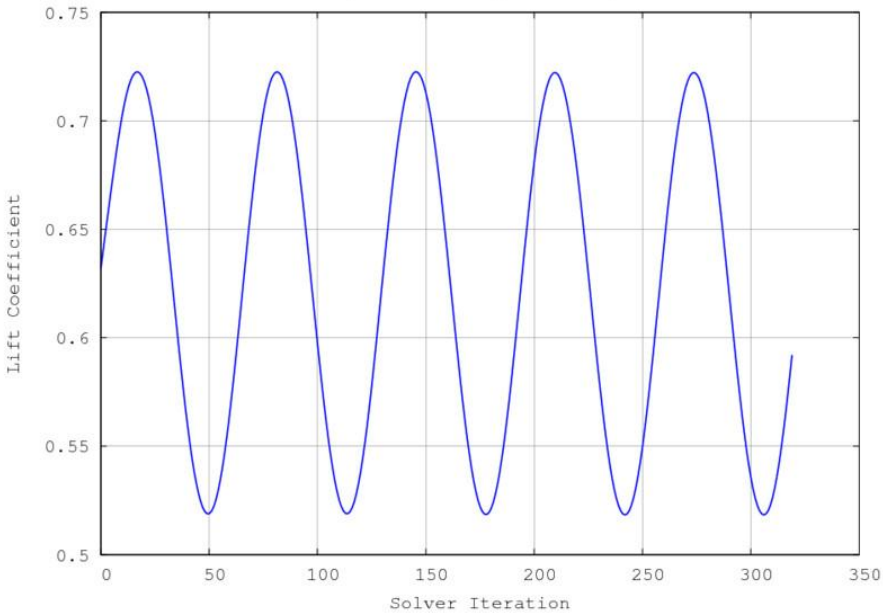
f=20Hz

- Approximately 1 order magnitude convergence per time step
 - 64 time steps per period, 50 multigrid cycles per time step
- RMS density correction (not residual)
- Forces adequately converged at each time step
- 20Hz case delivers more consistent convergence (expected)
- Influence of time step size studied on coarser mesh
 - Little effect: smooth force/moment histories

Time Dependent Results

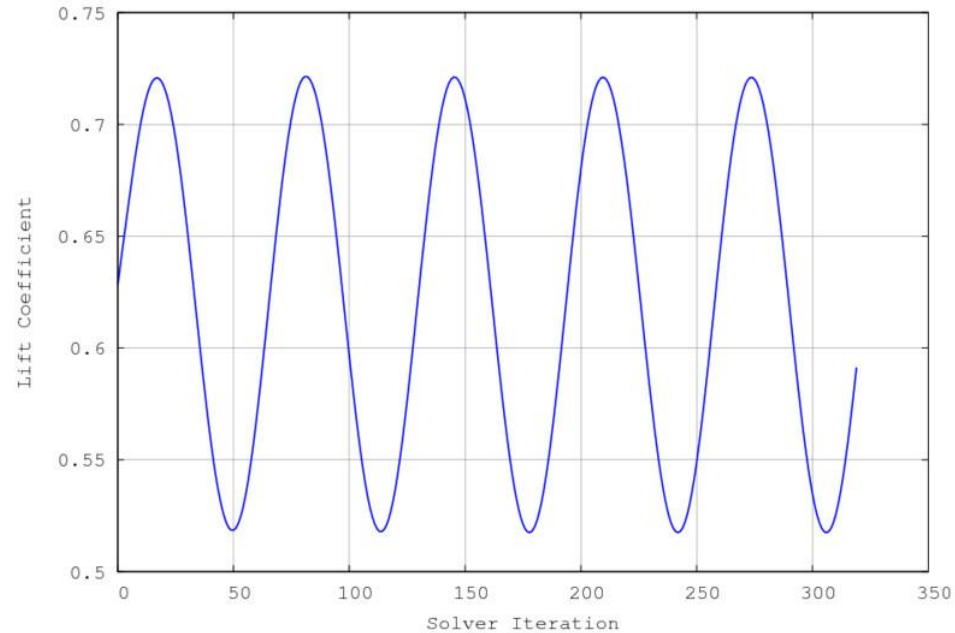
C_L Time histories

AePW-1 RSW55 Medium Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.



Medium Grid

AePW-1 RSW55 Coarse Mixed NC 6E54 10.0Hz k=0.15
Mach=0.825, Re=4010000., ITURB=4., VIS2=10.
Mon Apr 2 13:24:57 2012



Coarse Grid

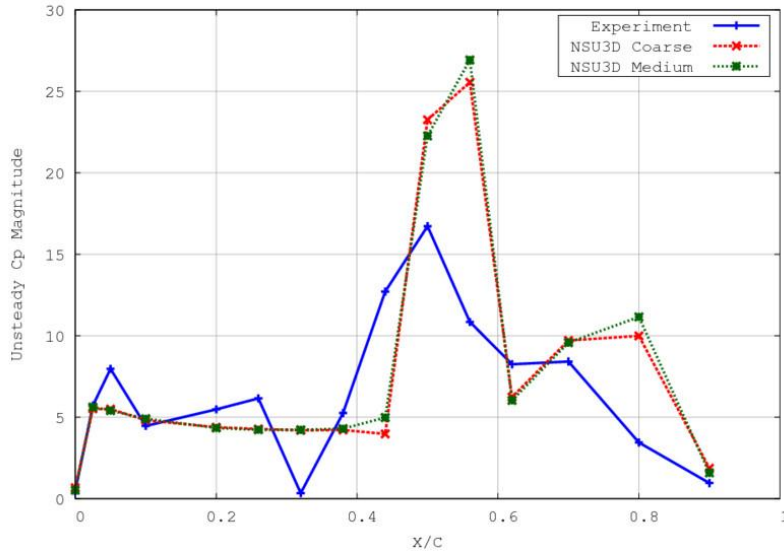
- Little influence of grid size (also seen in C_p s)
- Fine grid not run time dependent

Unsteady Pressures

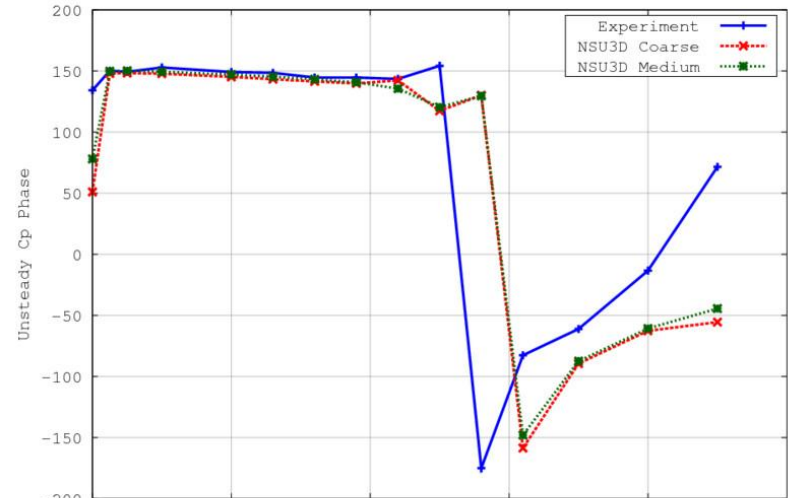
$f=10\text{Hz}$

$\eta=0.309$

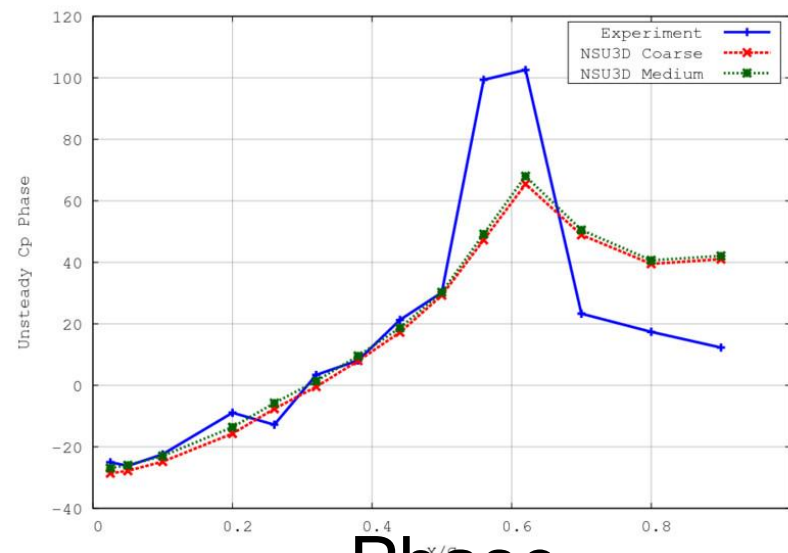
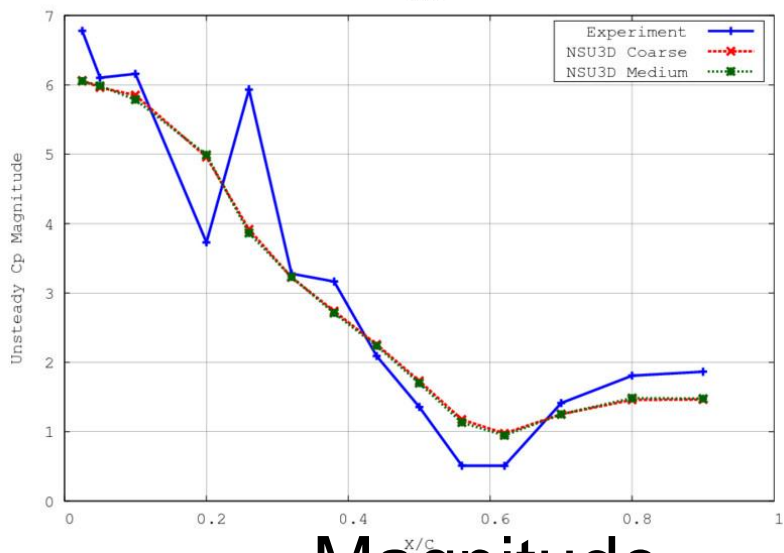
RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.309 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.309 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.309 Lower Surface



Magnitude

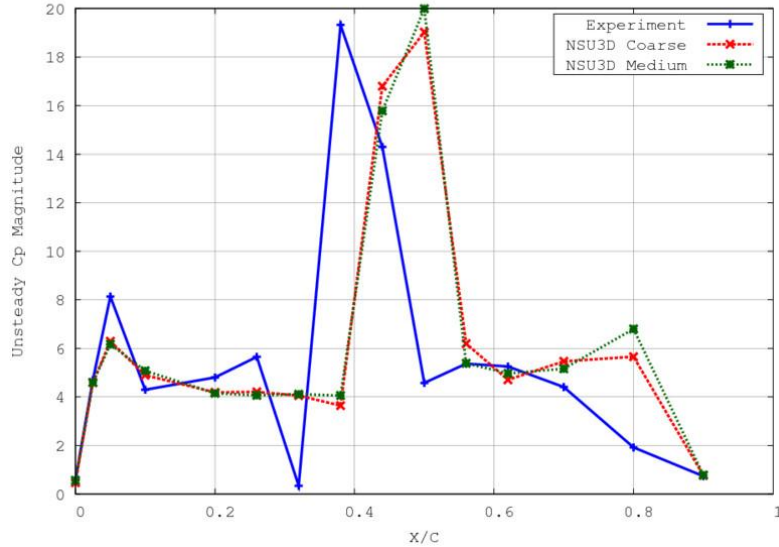
Phase

Unsteady Pressures

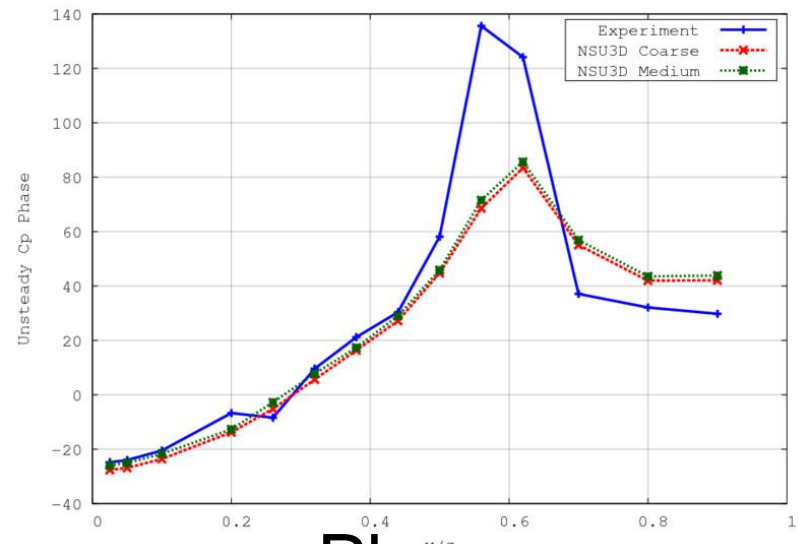
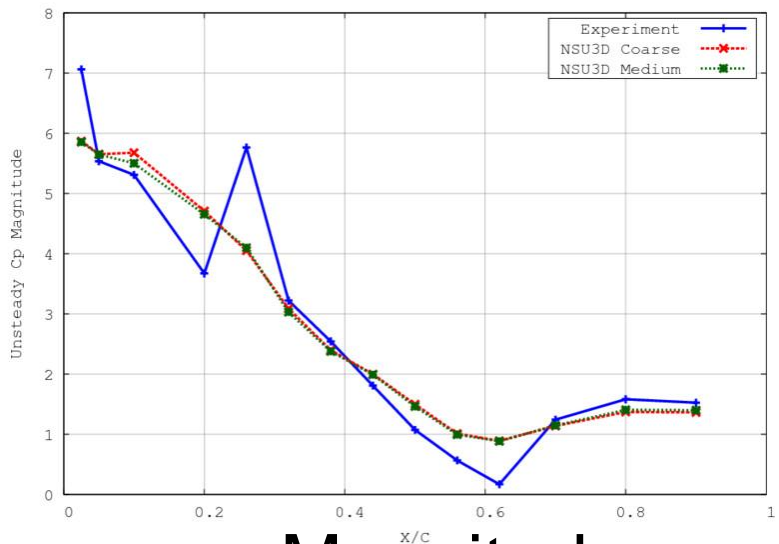
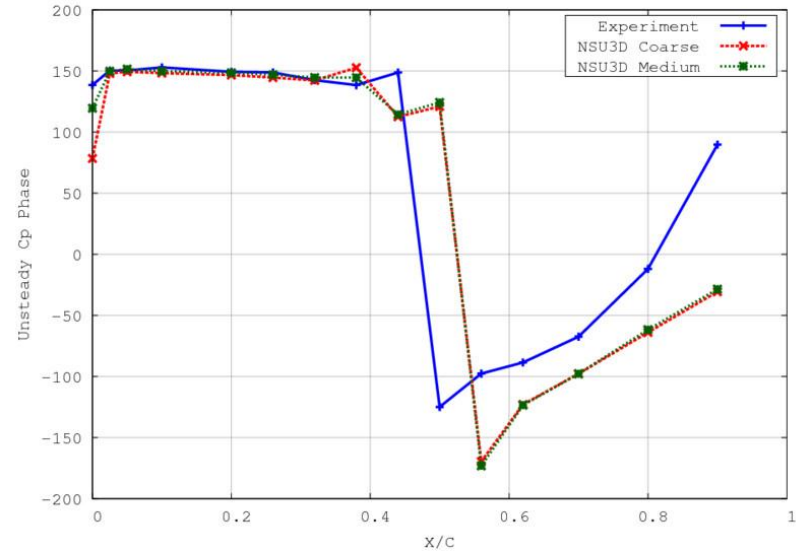
$f=10\text{Hz}$

$\eta=0.588$

RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.588 Upper Surface



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Eta=0.588 Upper Surface



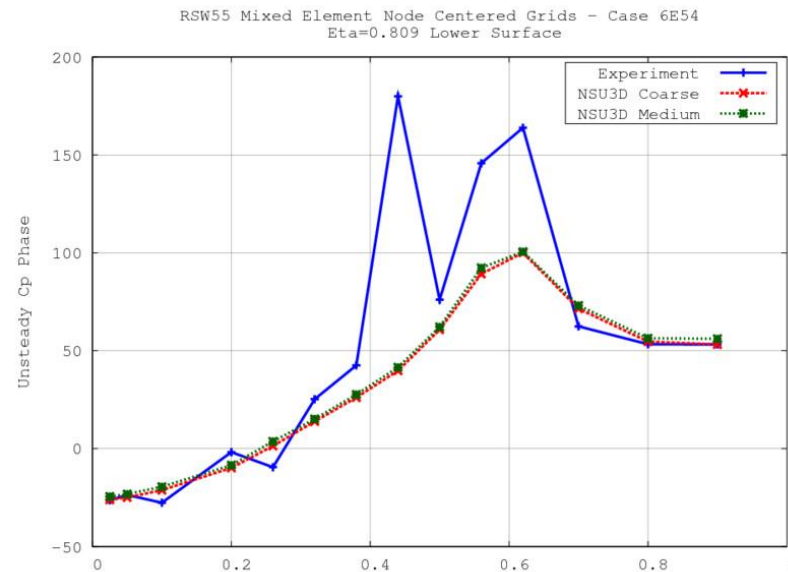
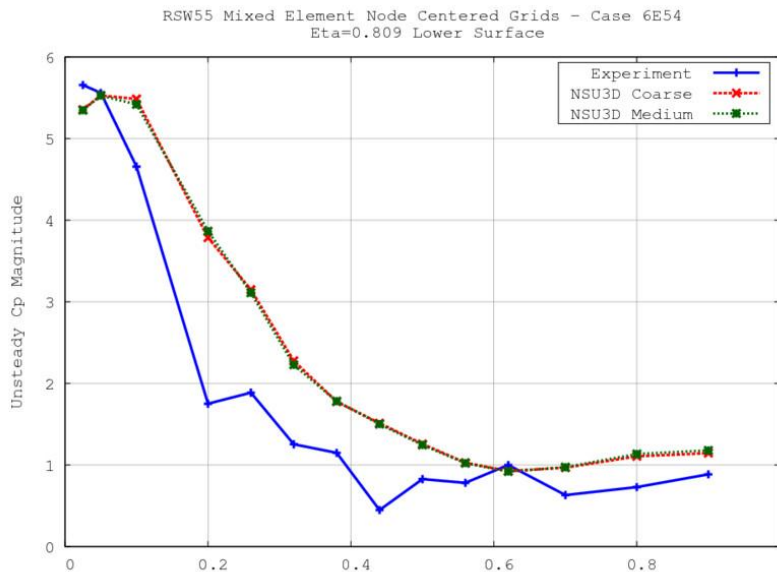
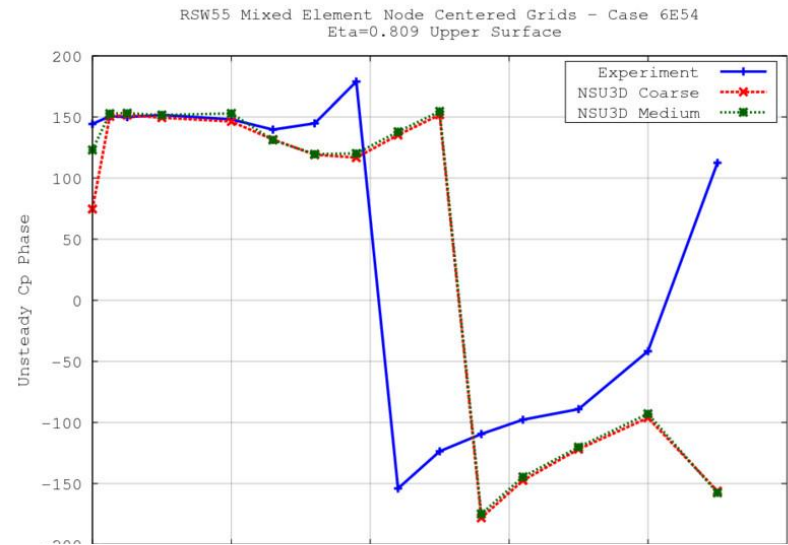
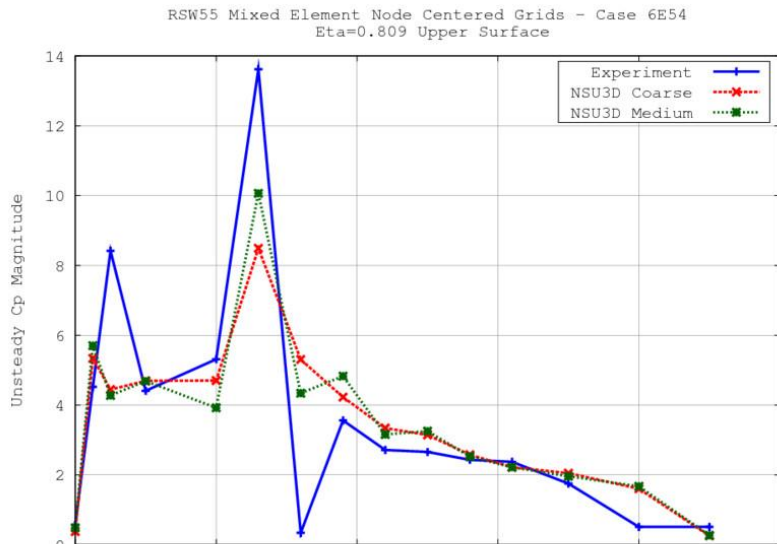
Magnitude

Phase

Unsteady Pressures

$f=10\text{Hz}$

$\eta=0.809$



Magnitude

Phase

Unsteady Pressures

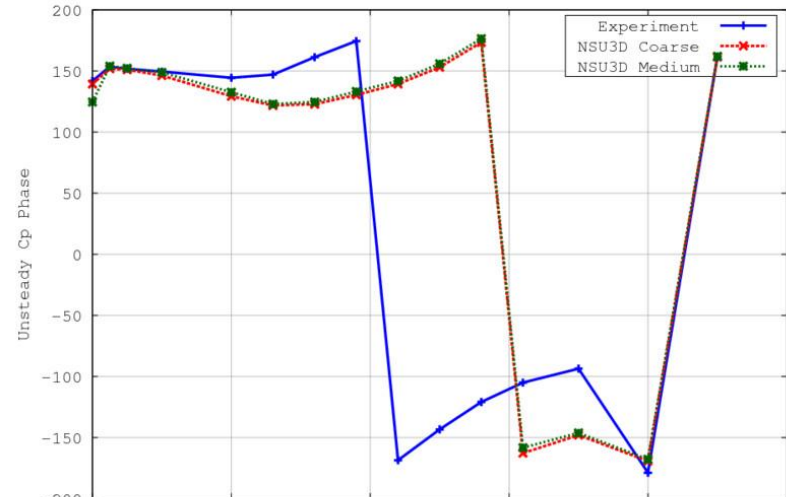
$f=10\text{Hz}$

$\eta=0.951$

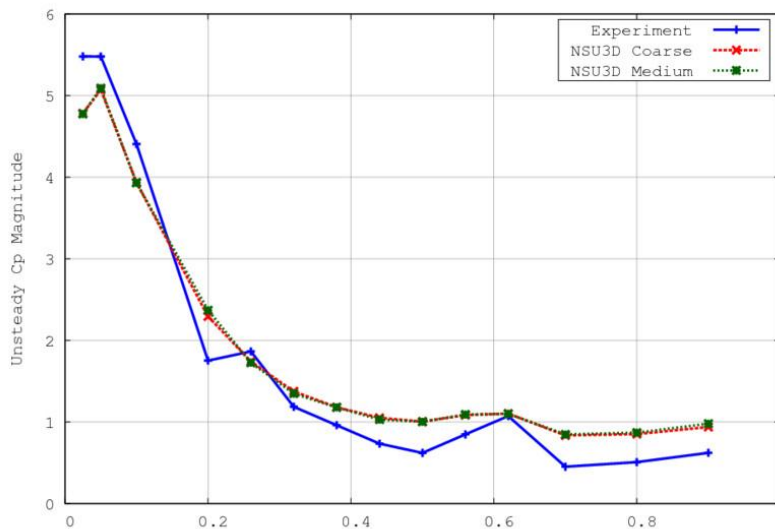
RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.951 Upper Surface



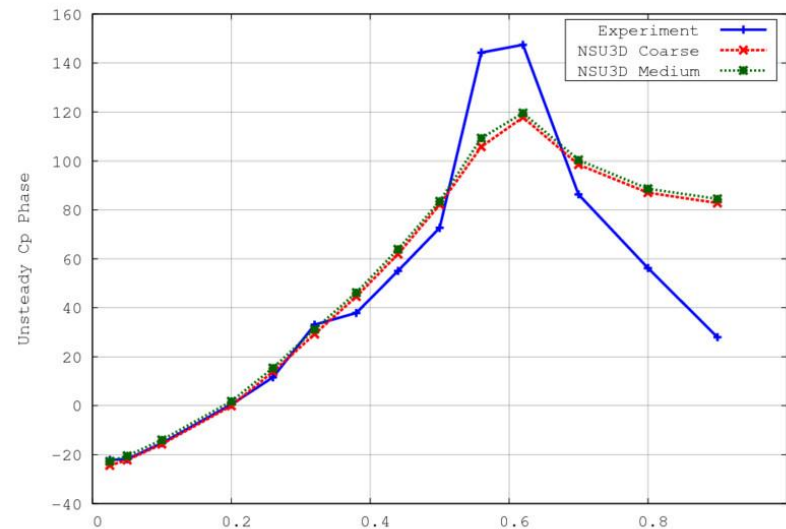
RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.951 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.951 Lower Surface



RSW55 Mixed Element Node Centered Grids - Case 6E54
Eta=0.951 Lower Surface



Magnitude

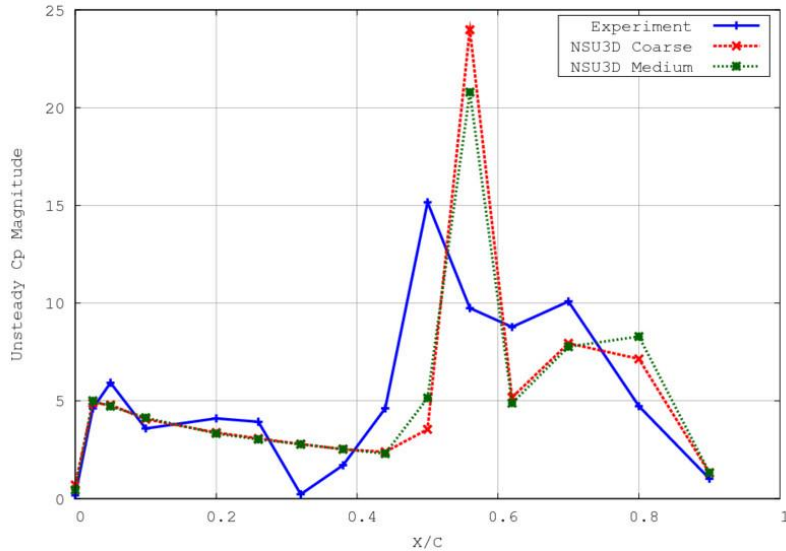
Phase

Unsteady Pressures

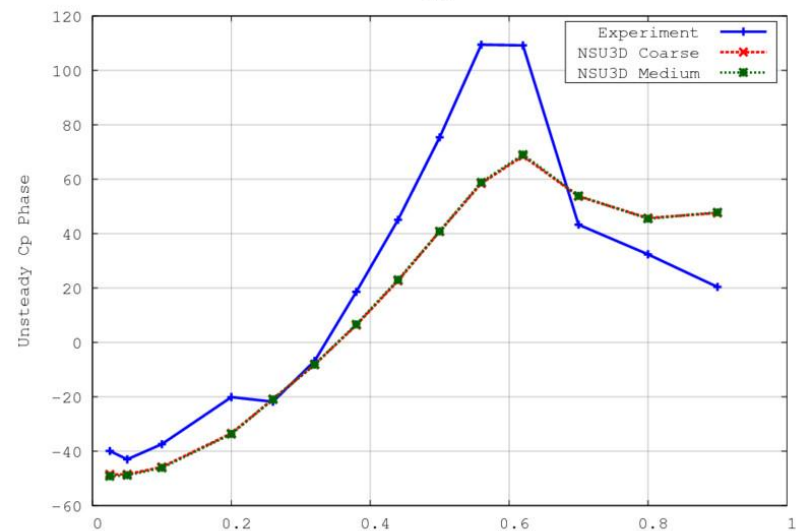
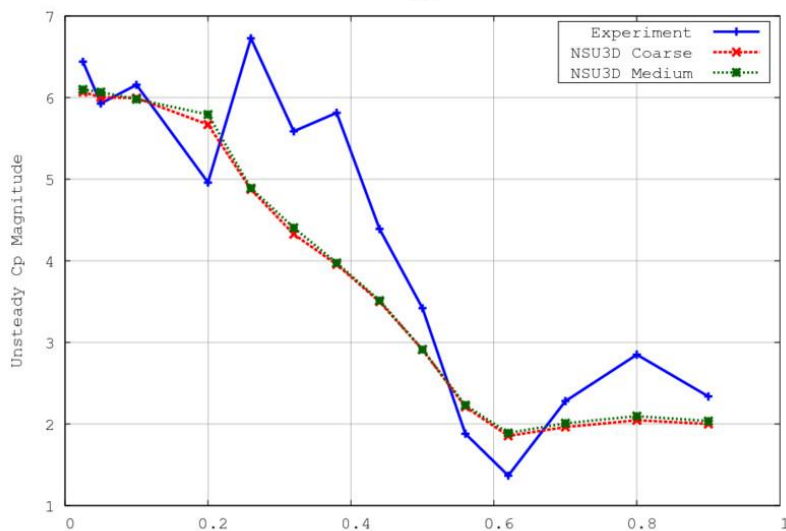
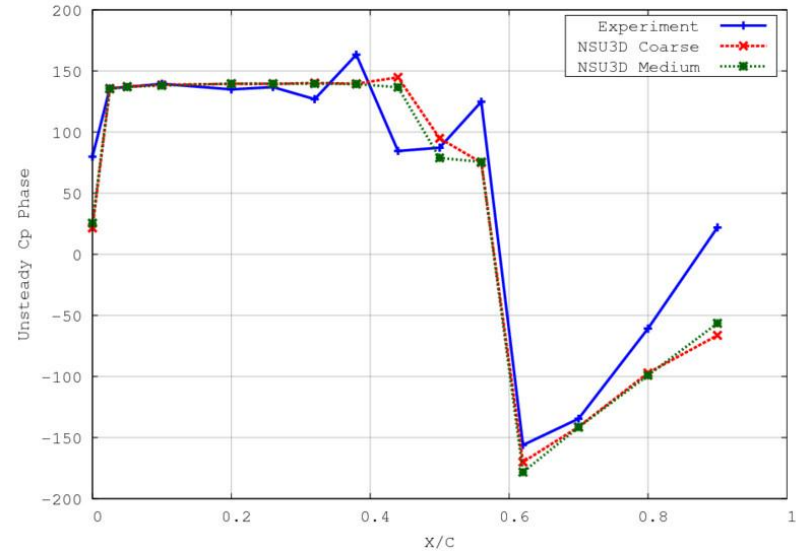
$f=20\text{Hz}$

$\eta=0.309$

RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.309 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.309 Upper Surface



Magnitude

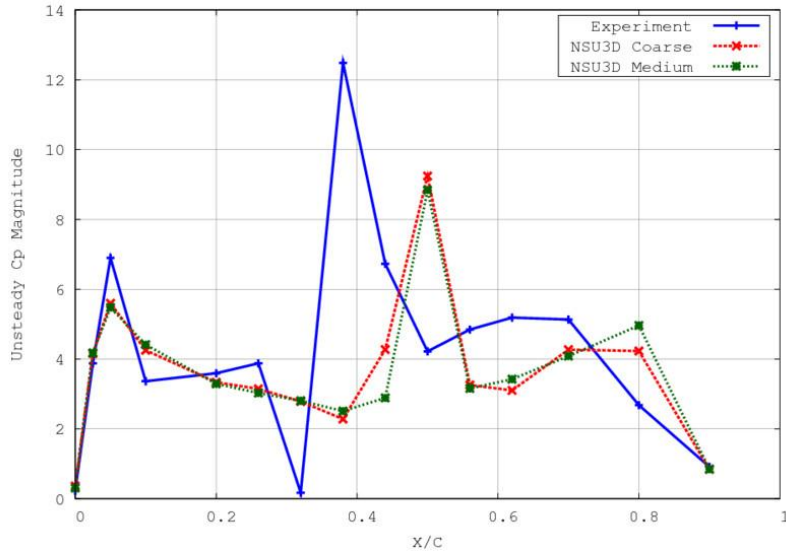
Phase

Unsteady Pressures

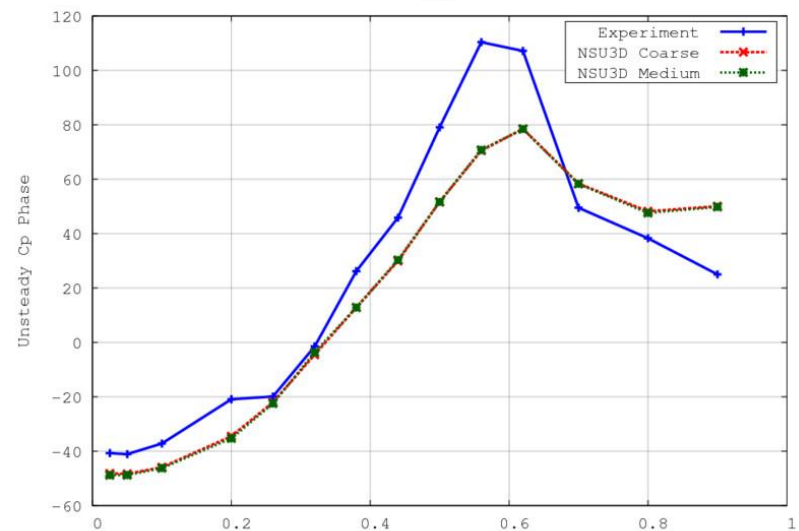
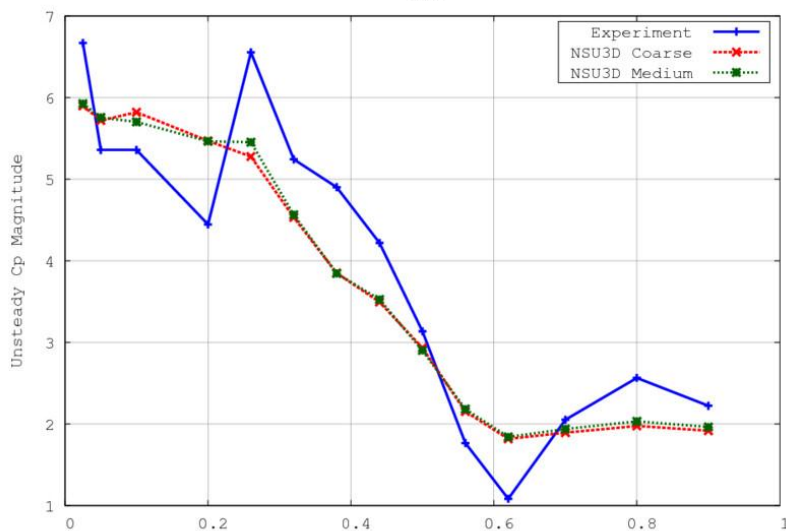
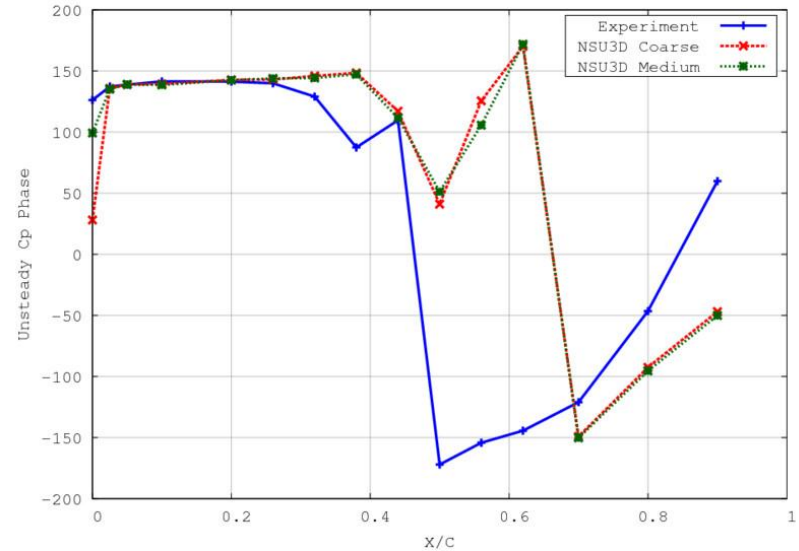
$f=20\text{Hz}$

$\eta=0.588$

RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.588 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.588 Upper Surface



Magnitude

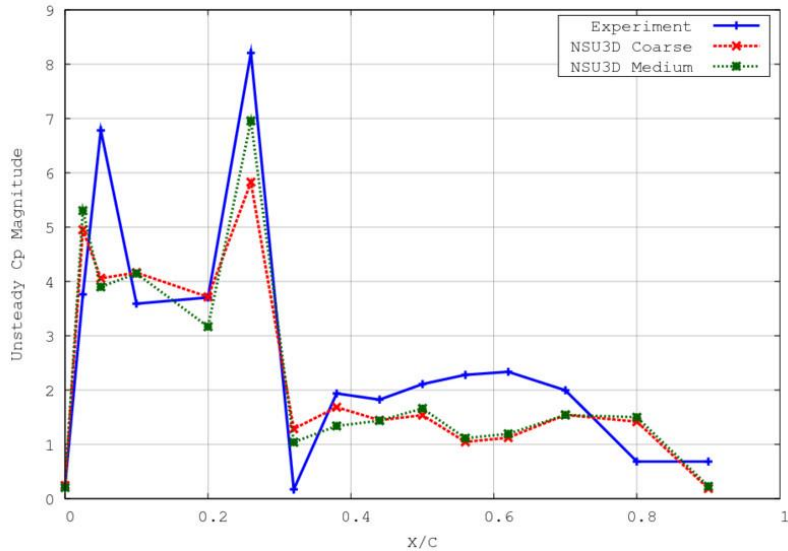
Phase

Unsteady Pressures

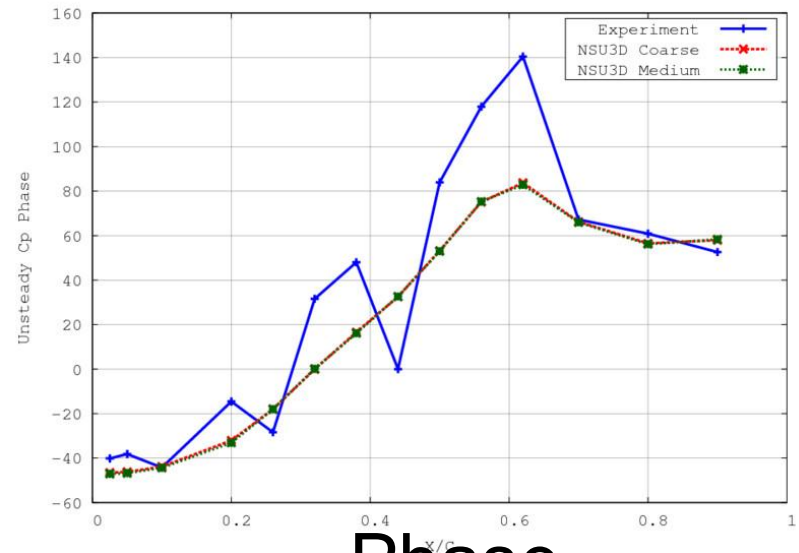
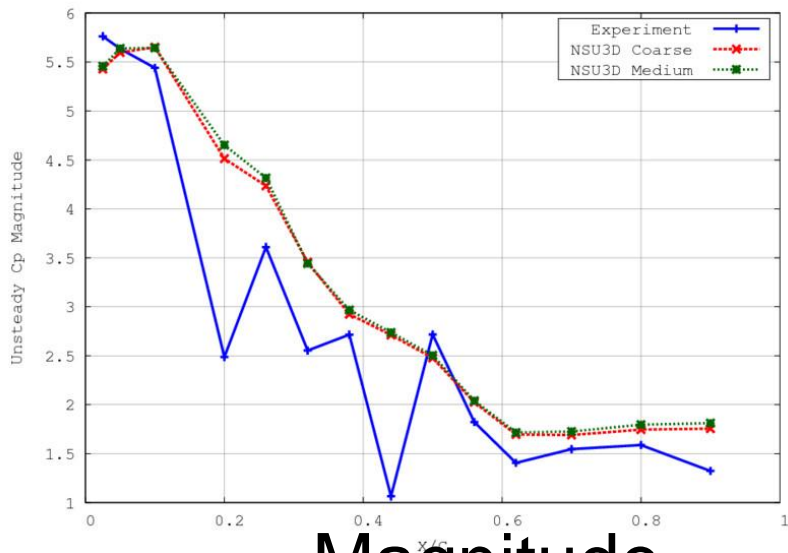
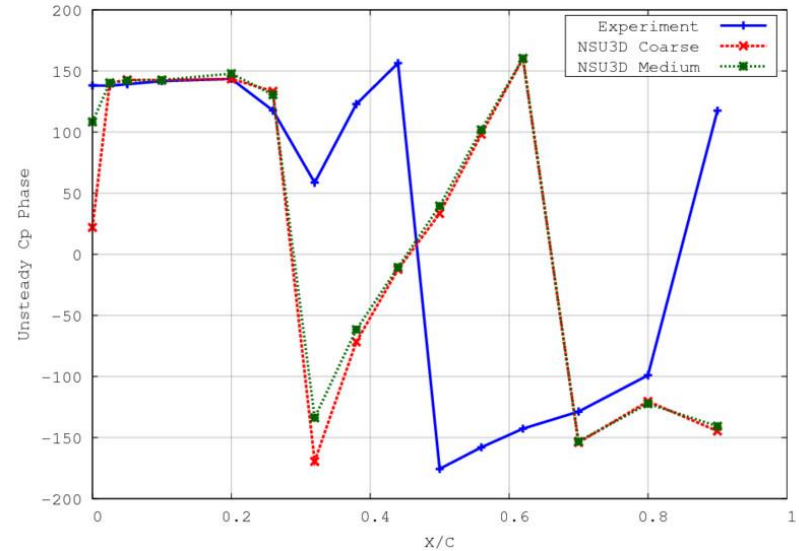
$f=20\text{Hz}$

$\eta=0.809$

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Eta=0.809 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.809 Upper Surface



Magnitude

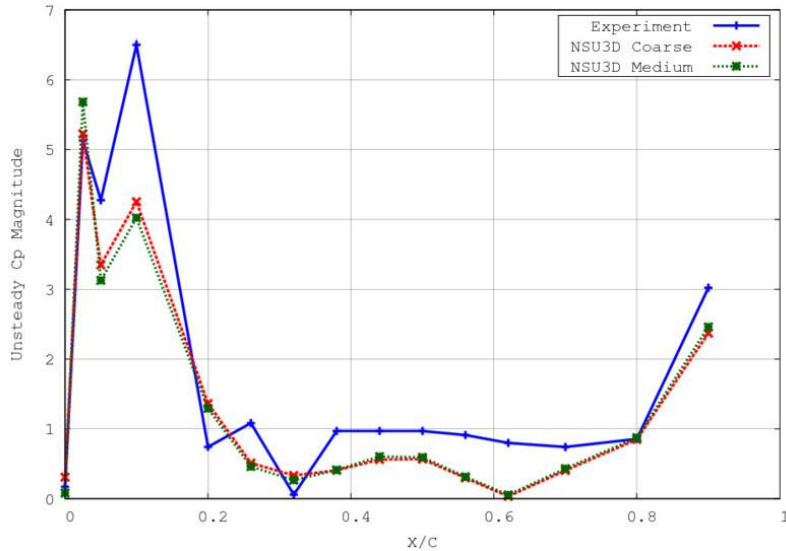
Phase

Unsteady Pressures

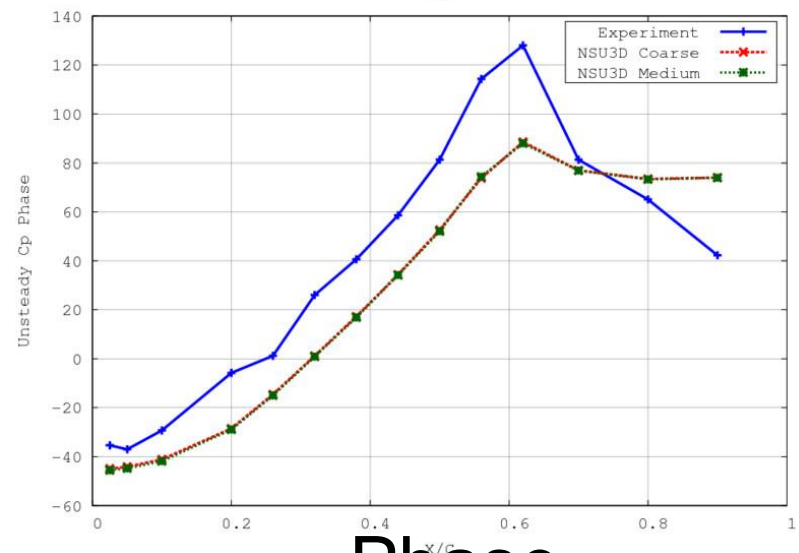
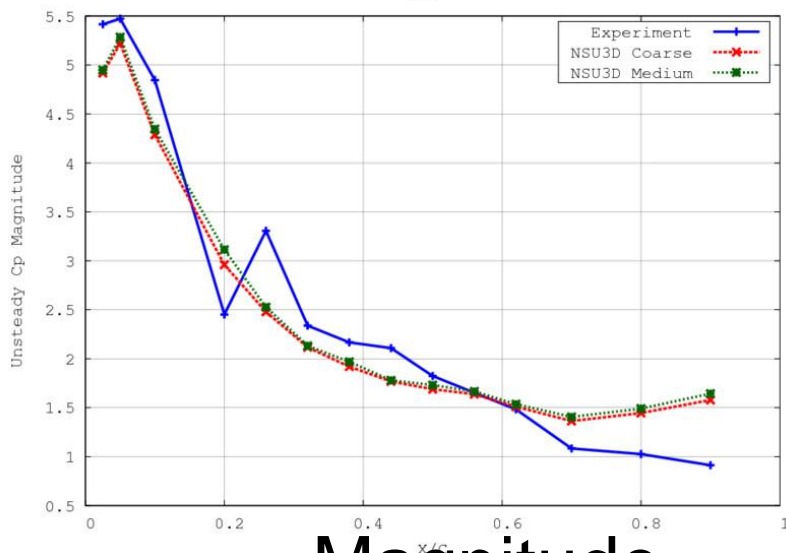
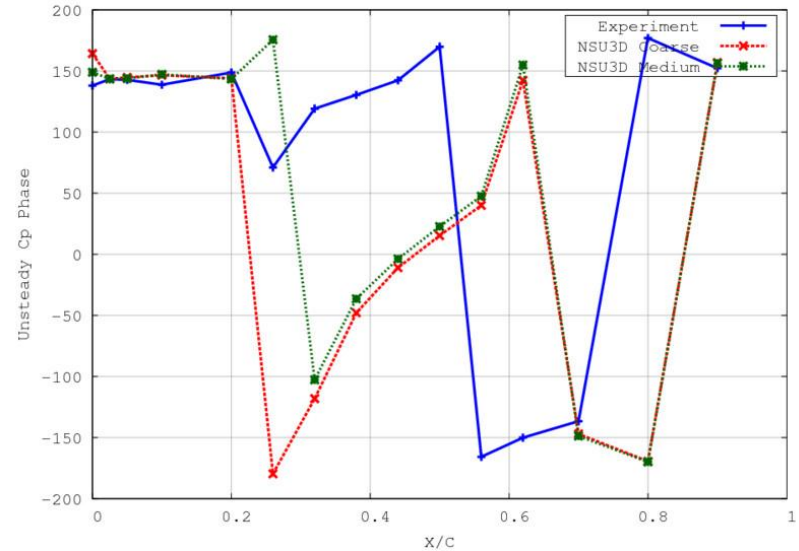
$f=20\text{Hz}$

$\eta=0.951$

RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.951 Upper Surface



RSW55 Mixed Element Node Centered Grids - Case 6E56
Eta=0.951 Upper Surface



Magnitude

Phase

Conclusions and Future Work

- Little sensitivity of mag/phase C_p to mesh size
 - (coarse, medium)
- Little expected sensitivity to time step size
- Investigate wall boundary layer effects
- More extensive steady state convergence
- Run fine grid time dependently
- Time step and convergence study on finer meshes
 - Not expected to change results