Benchmark Supercritical Wing Results using NSU3D

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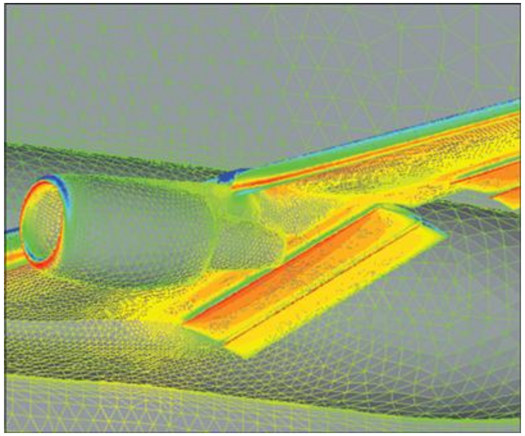
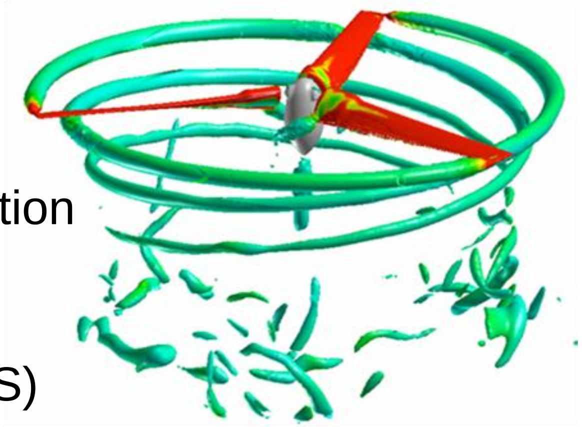
NSU3D Description





- 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

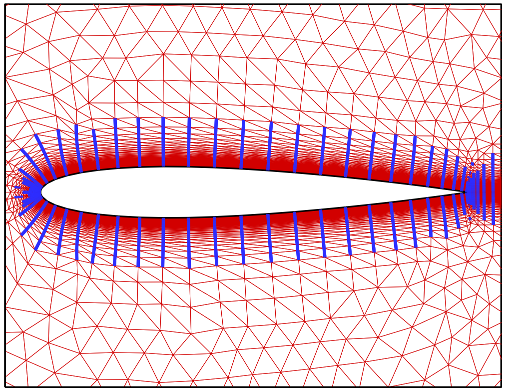
Solver Description (cont'd)

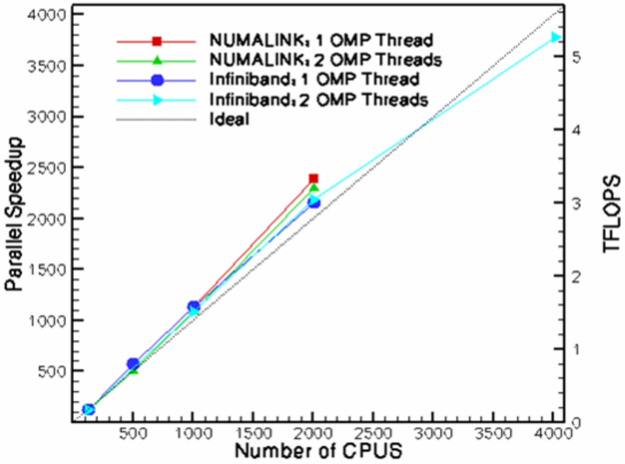
- Spalart-Allmaras turbulence model
  - (original published form)
  - Used exclusively in AePW calculations

- Options for
  - Wilcox k-omega model
  - Mentor SST Model
  - Not exercised in AePW

Solution Strategy

- Steady or BDF2 Implicit Time-stepping
  - Deforming meshes with GCL
- 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





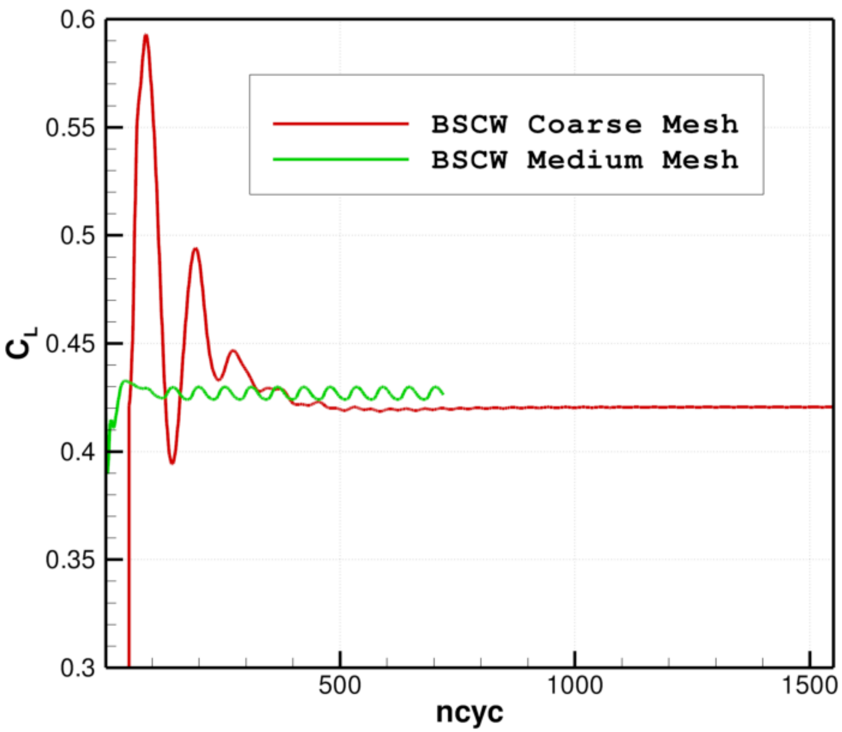
Cases Run

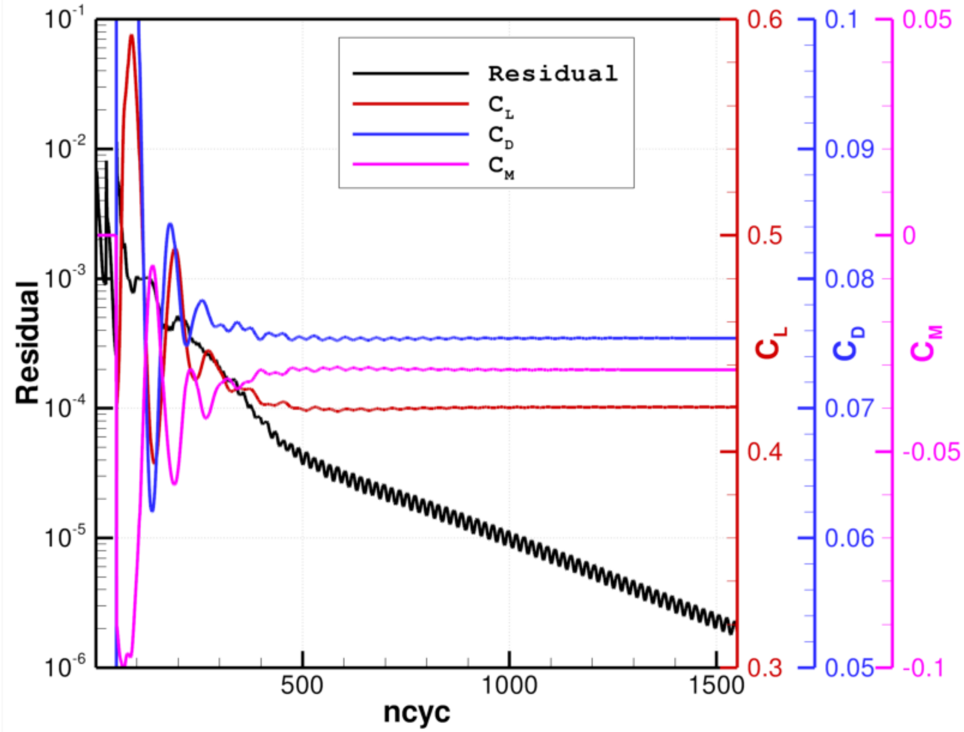
- Steady State
  - Coarse mesh
  - Medium mesh (steady and time-dependent)
- Time dependent runs
  - No mesh deformation (mesh rotated as solid body)
  - f=1hz and f=10hz
  - Coarse and medium meshes
  - Time step and convergence study
    - 180, 360, 720 time steps per period
    - 20 and 50 multigrid cycles per time step
    - 4 periods of simulation time

Sample Run Characteristics

- Use workshop meshes
  – Coarse, Medium (mixed NC unstructured)
- Steady-state runs
  – 500 to 1000 multigrid cycles
  – Coarse mesh converged
  – Medium mesh :incomplete convergence
    - Ran also in time dependent mode
- Run on in house 512 core cluster
  – Coarse grid: 128 cores: 1.08 secs/MG cycle
  – Medium grid: 256 cores, 1.85 secs/ MG cycle

BSCW Steady State Convergence





- Coarse mesh converged well
- Medium mesh did not produce steady solution
  - Run as time dependent case
  - Required resolving period of oscillation with small enough time step

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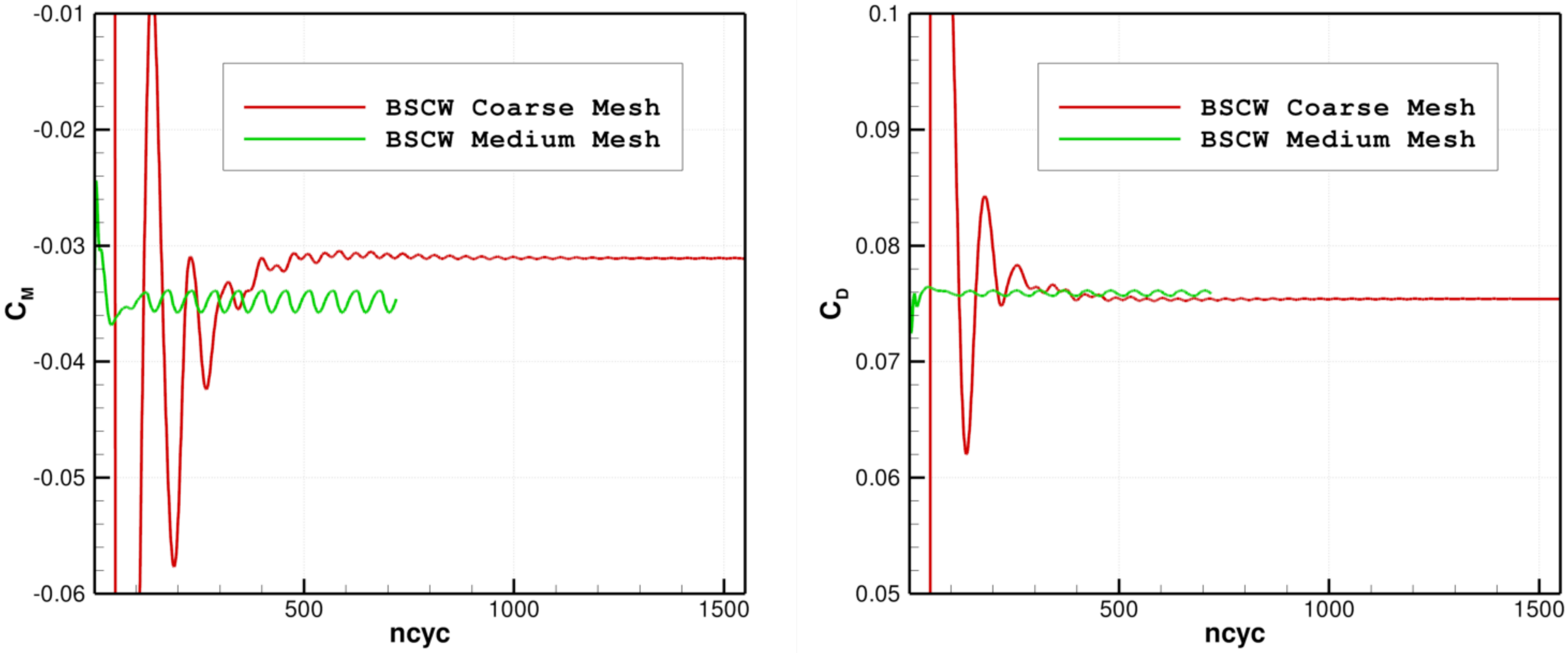

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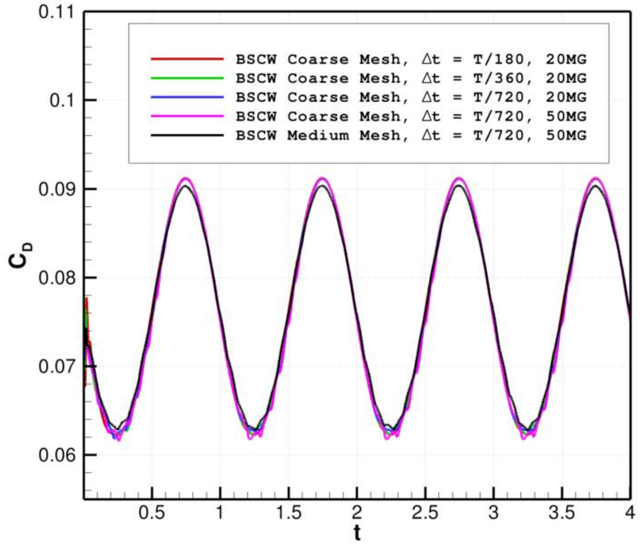
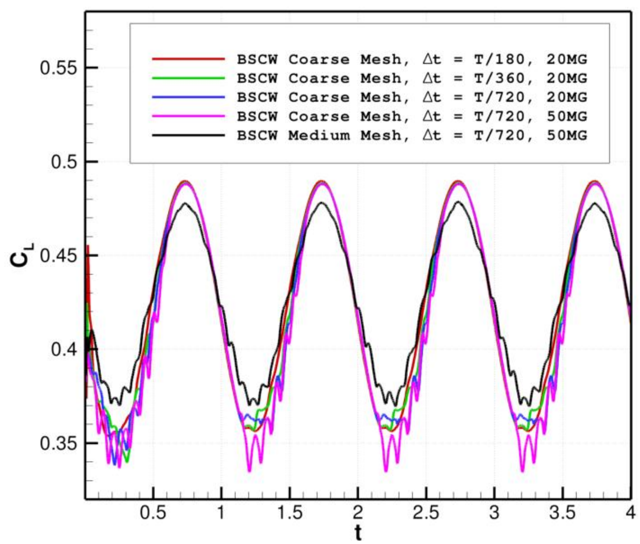
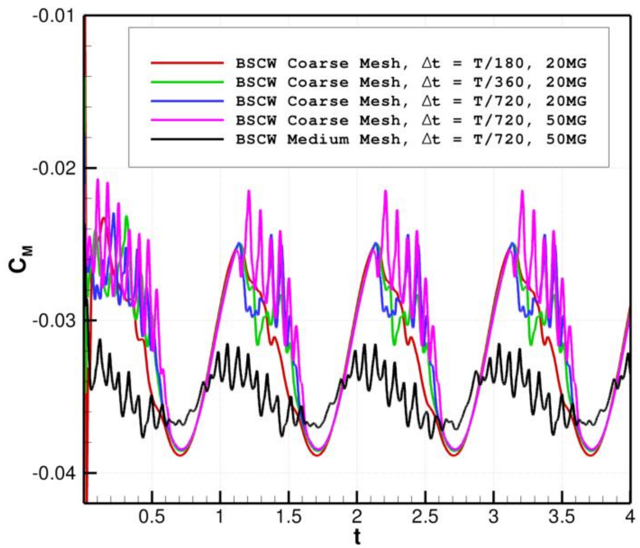
BSCW Time Dependent Results
(f=1Hz)



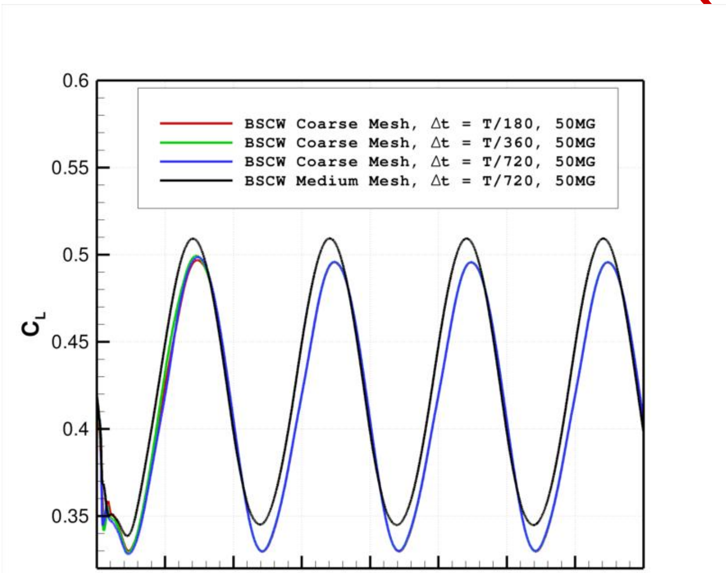


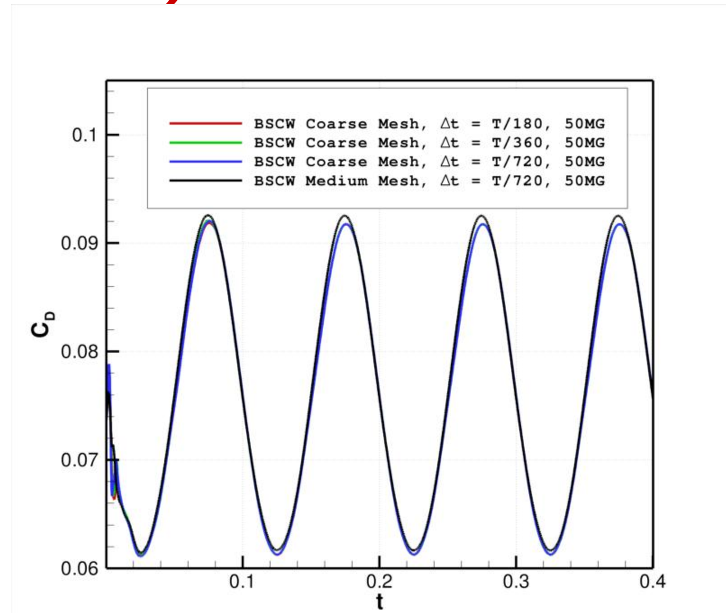


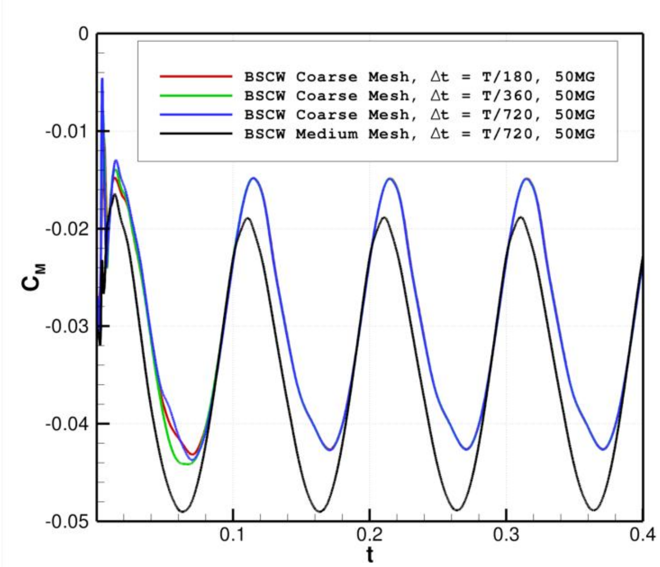
For f=1Hz, significant variation with C_L and C_M with:

- Time step size
- Number of subiterations
- Mesh size

BSCW Time Dependent Results
(f=10Hz)



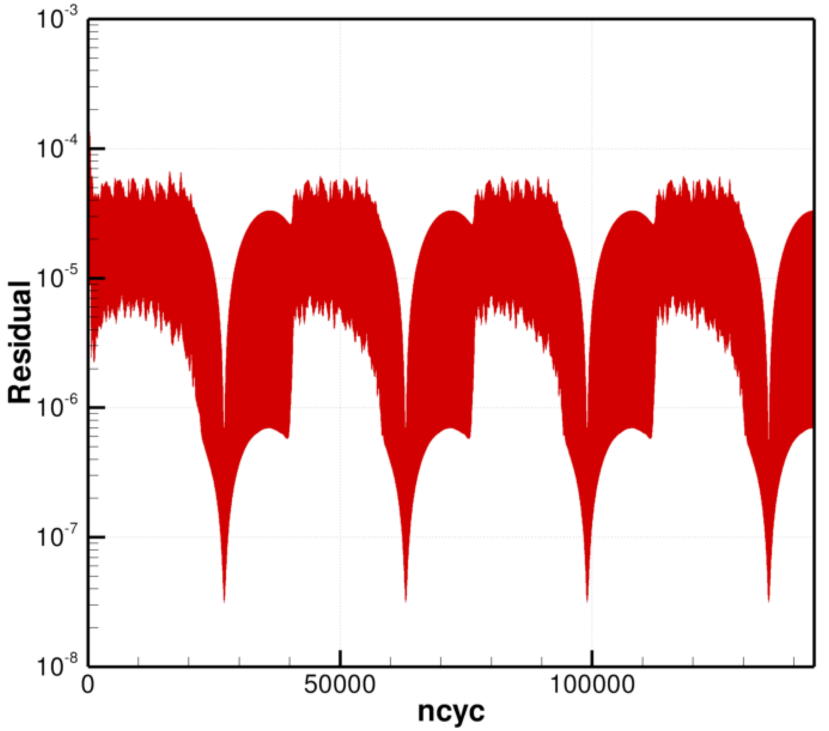


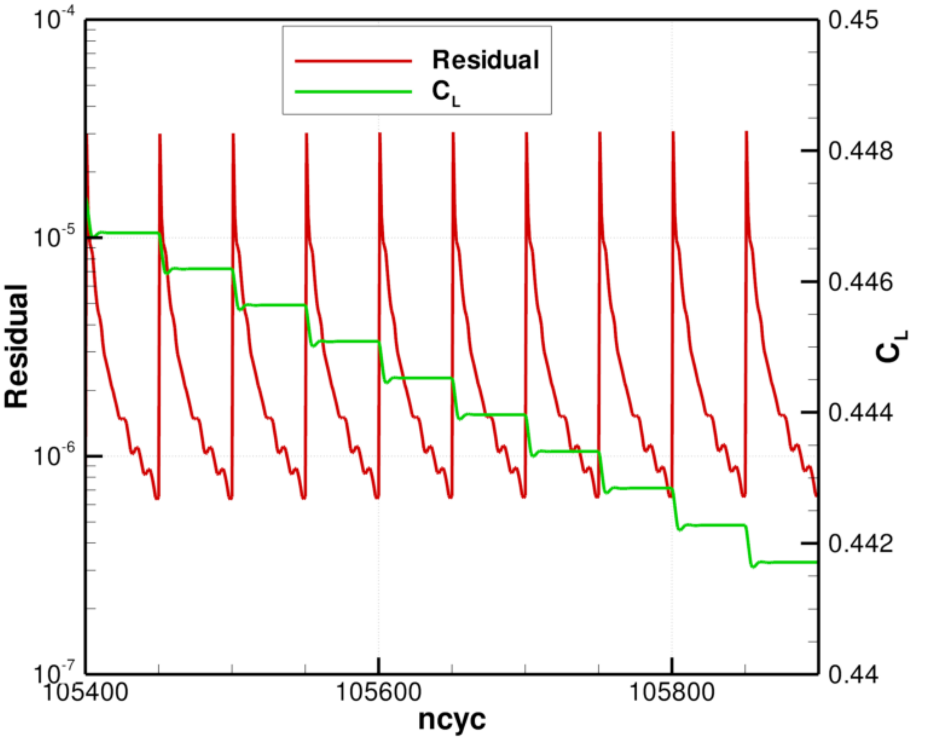


For f=10Hz:

- Time step size has little effect
- Effect due to mesh size
- Temporal convergence well behaved
  - Time steps small enough to resolve unsteady flow phenomena

BSCW Time Dependent Results (f=1Hz)

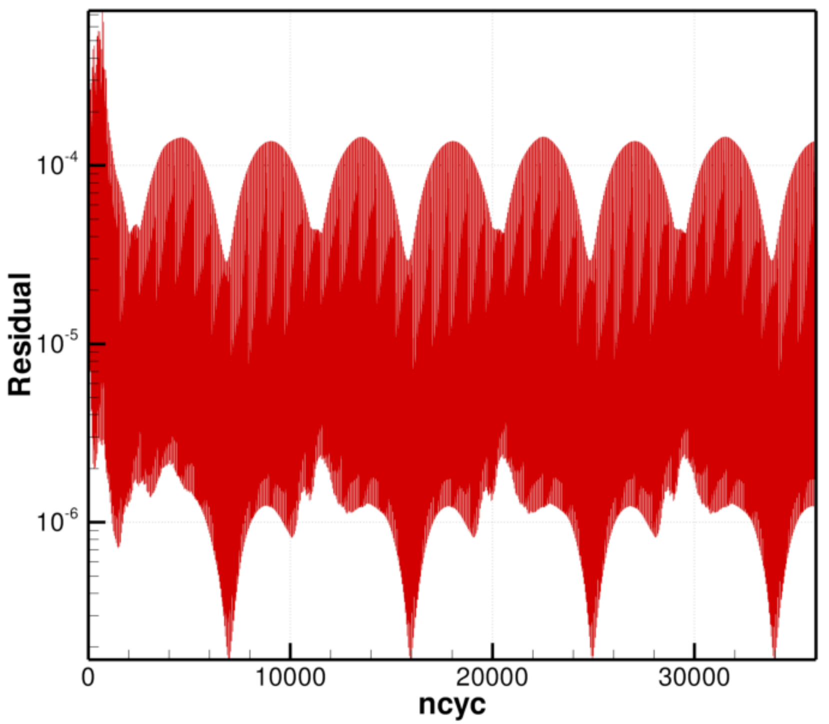


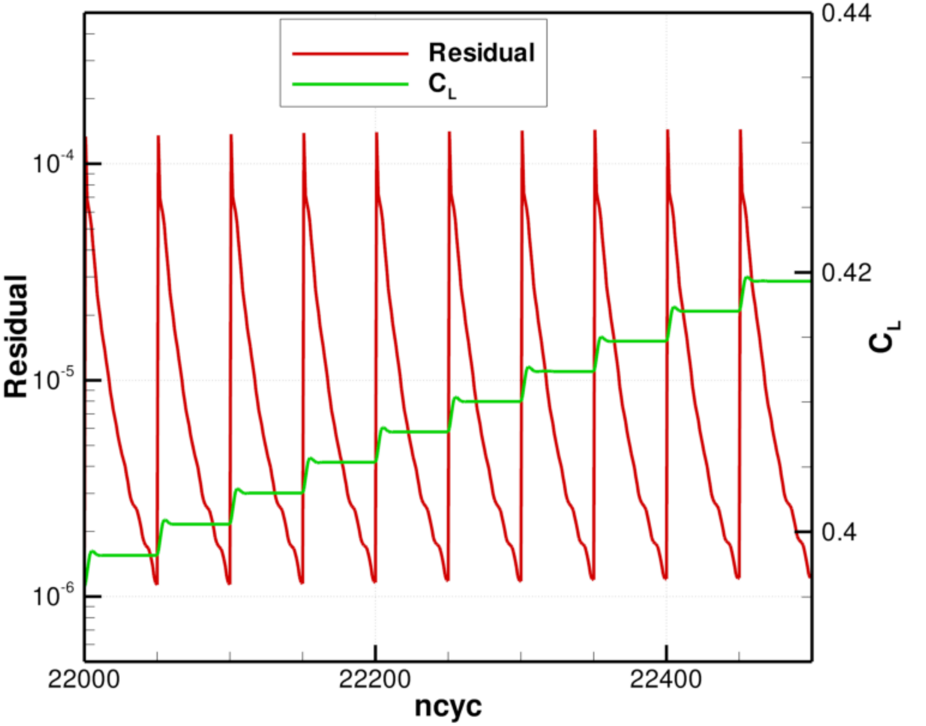


- Density correction converged 1.5 orders of magnitude at each time step (not residual)
- Forces well converged at each time step
- Convergence is variable for low frequency case

BSCW Time Dependent Results

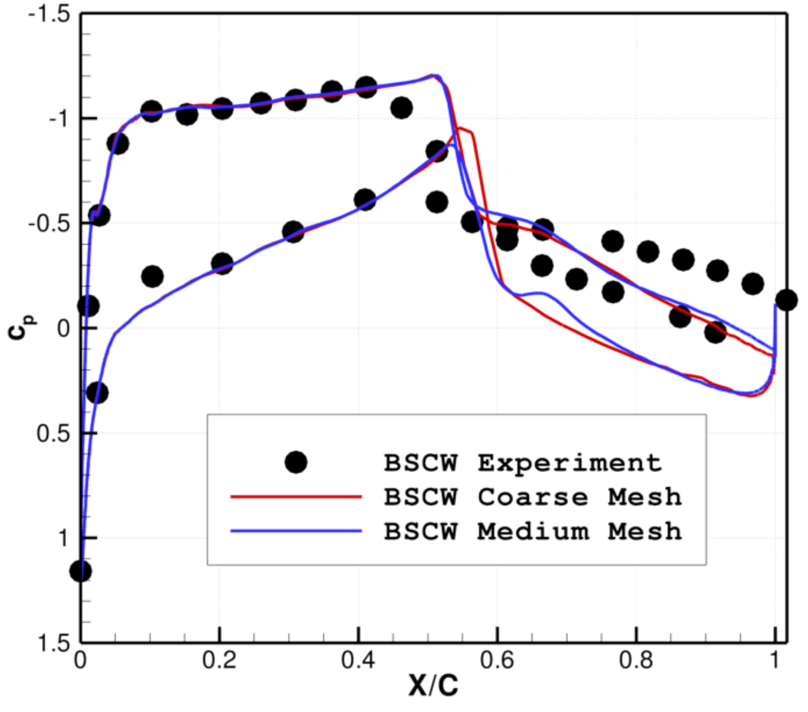
(f=10Hz)

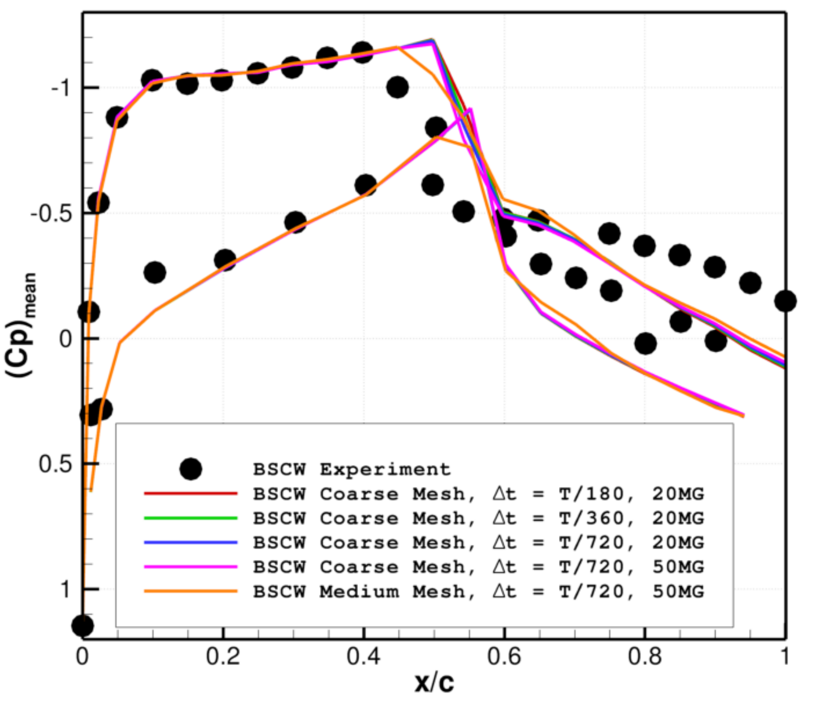




- Density correction converged 2 to 3 orders of magnitude at each time step (not residual)
- Forces well converged at each time step
- Convergence more unifiorm for hogh frequency case
  - Smaller physical time step (compared to shock instability)

BSCW Steady/Mean Cp Distribution

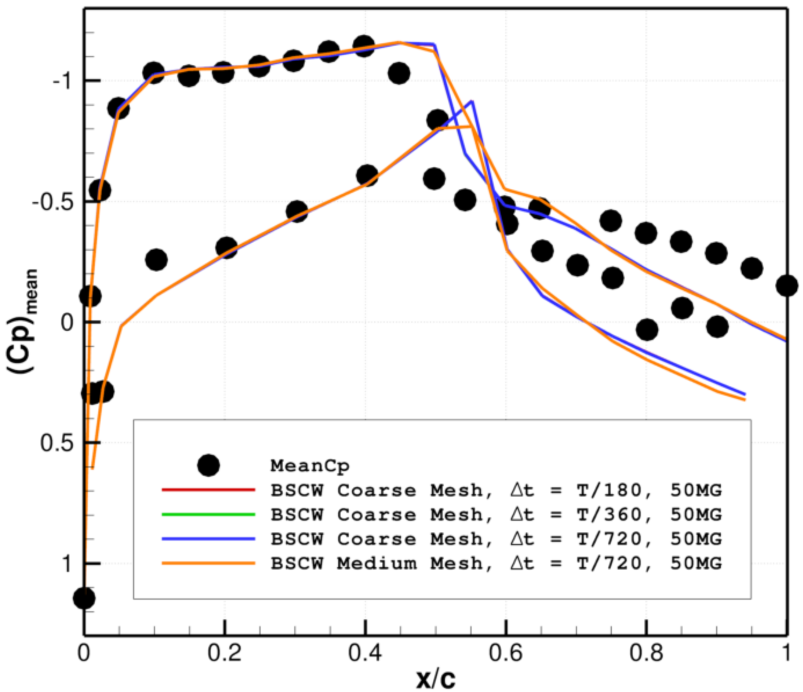


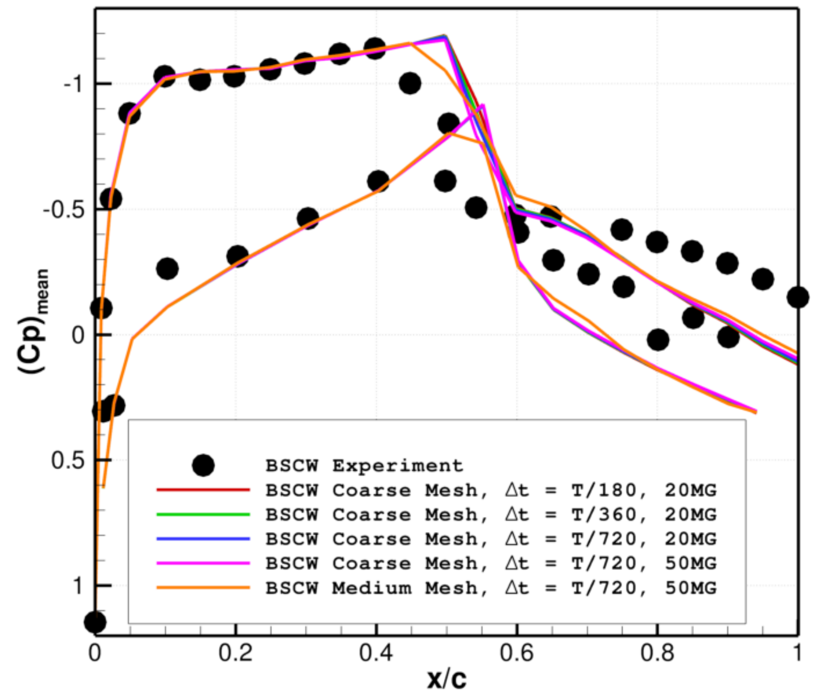


Steady Mean at f=1Hz

- Reasonable agreement with experimental data

BSCW Steady/Mean Cp Distribution



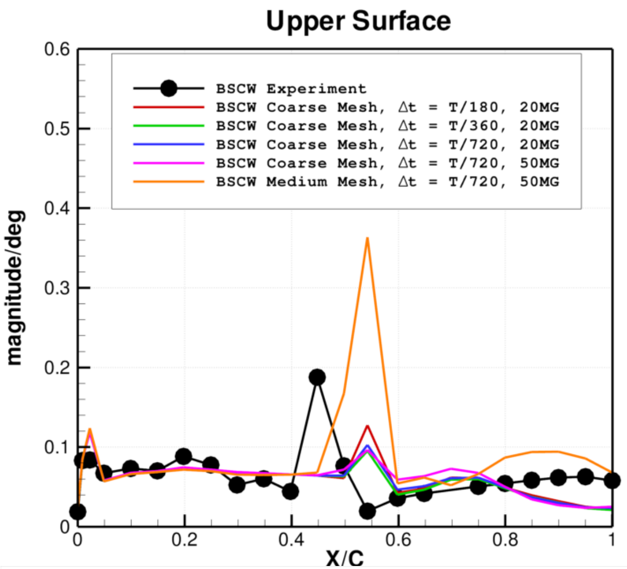


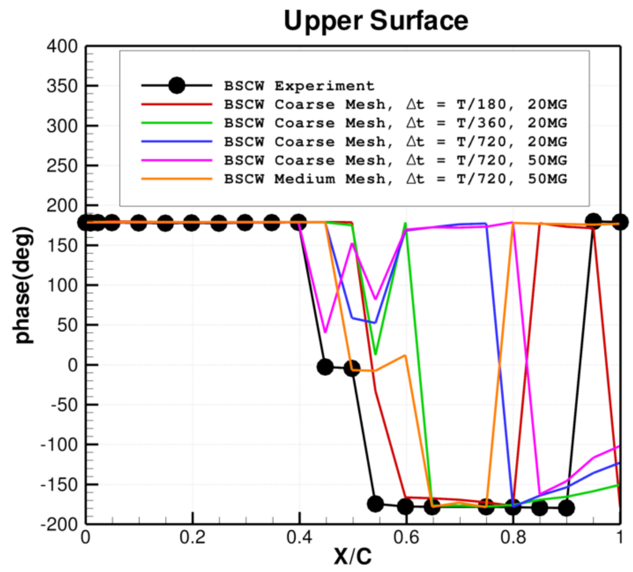
Mean at f=10Hz

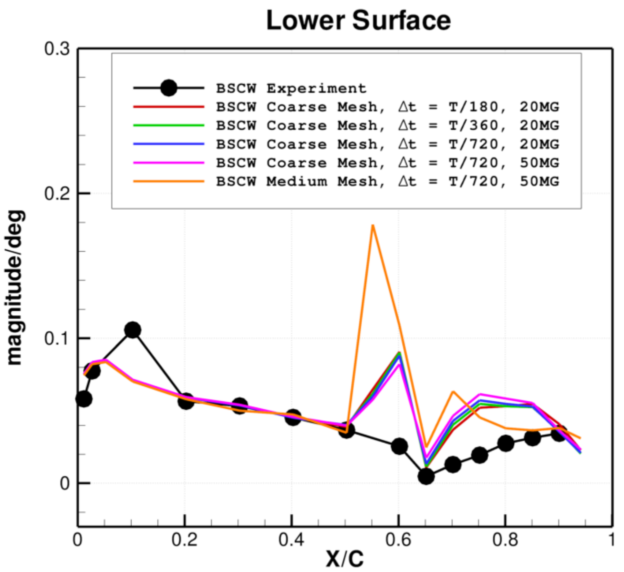
Mean at f=1Hz

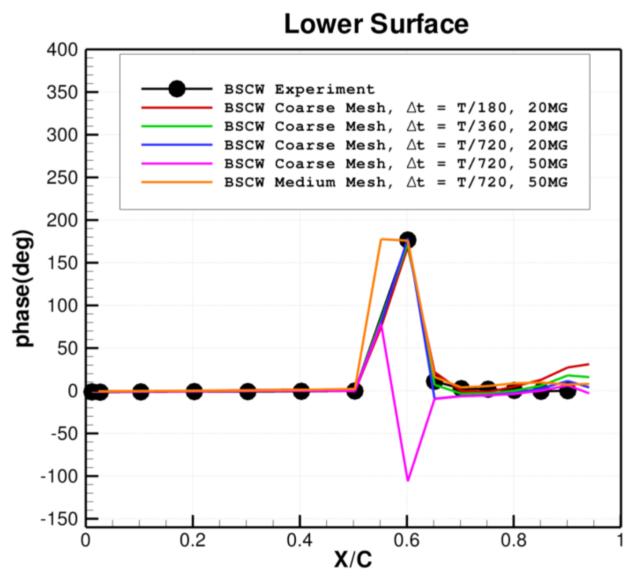
- Reasonable agreement with experimental data

BSCW Unsteady Pressures (f=1hz)









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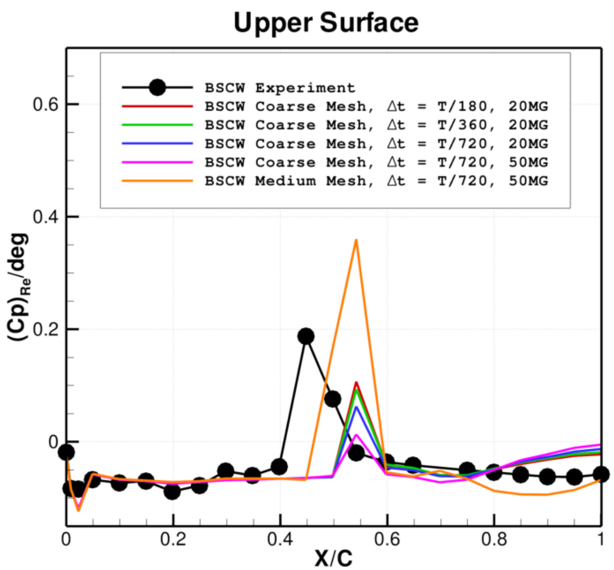
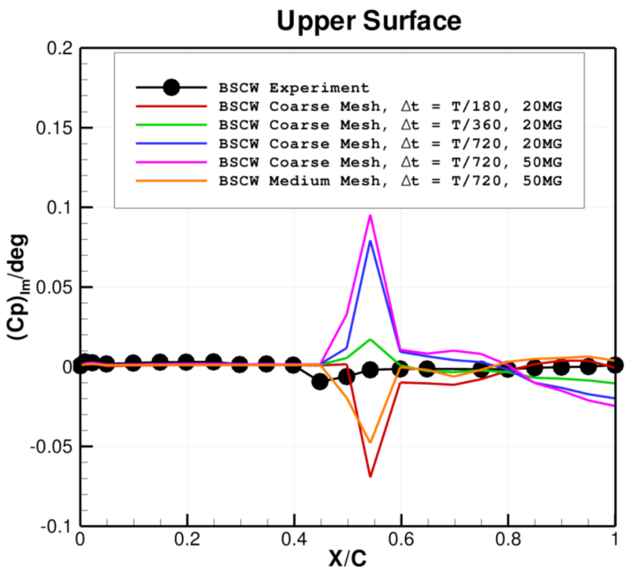
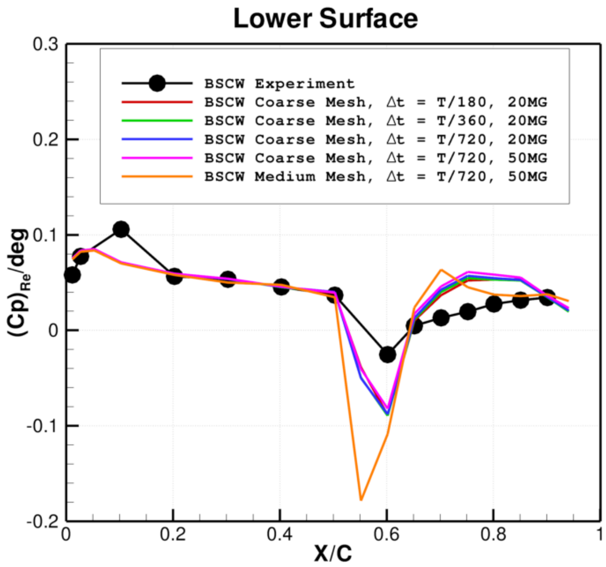
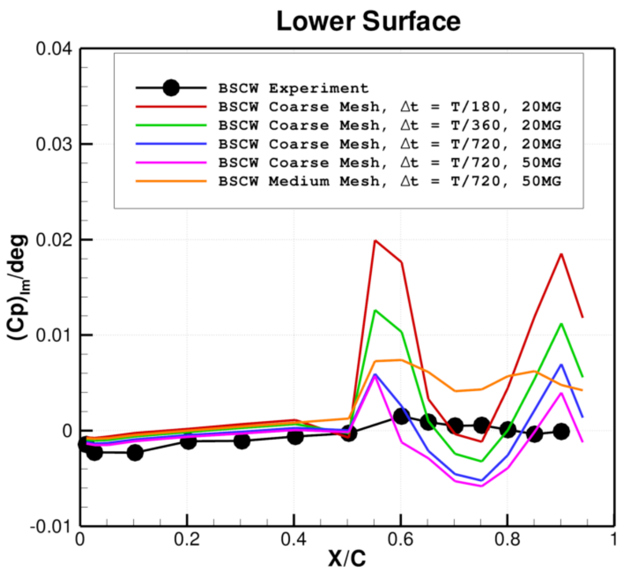


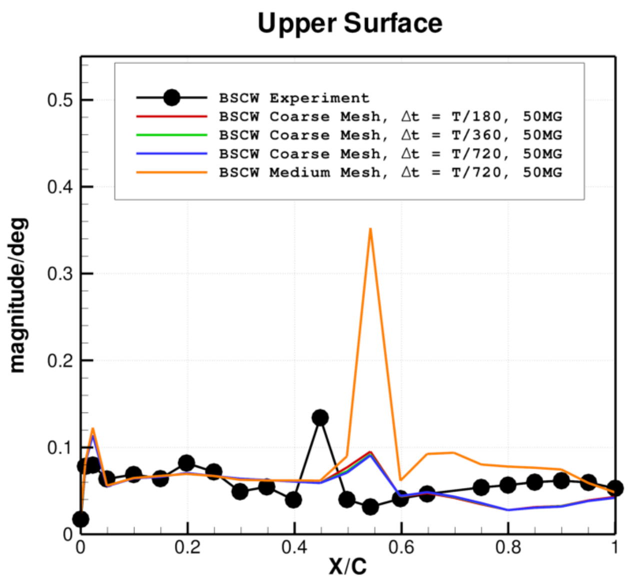


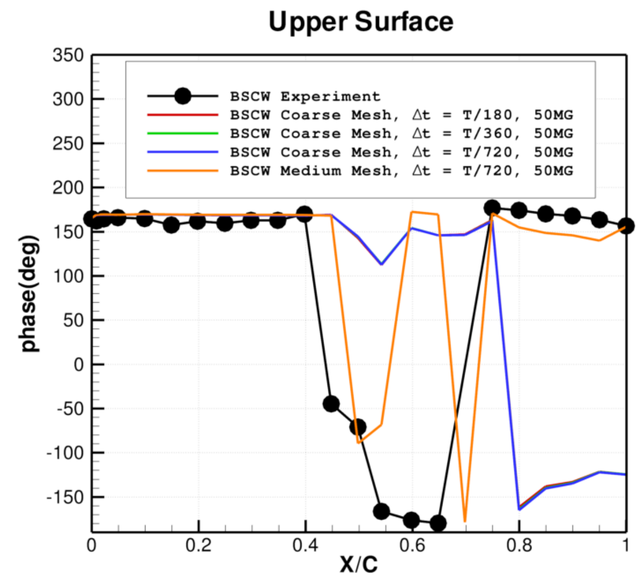


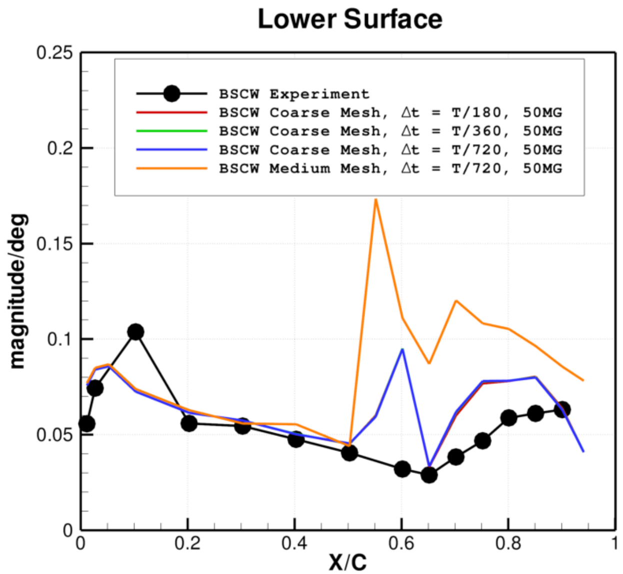


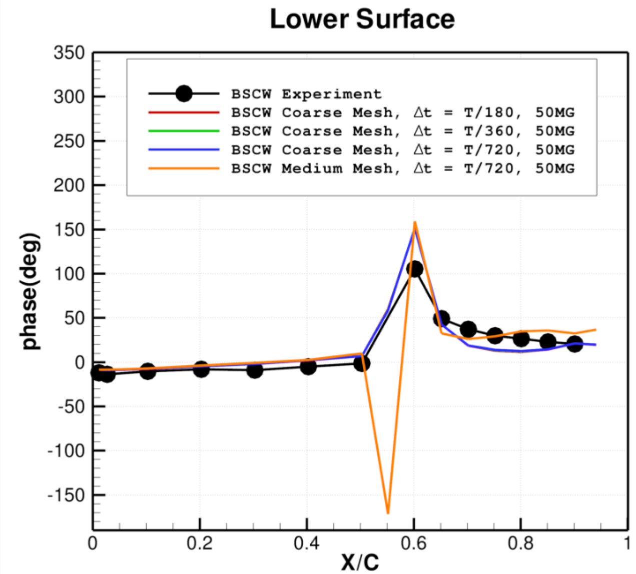
BSCW Unsteady Pressures

(f=10hz)



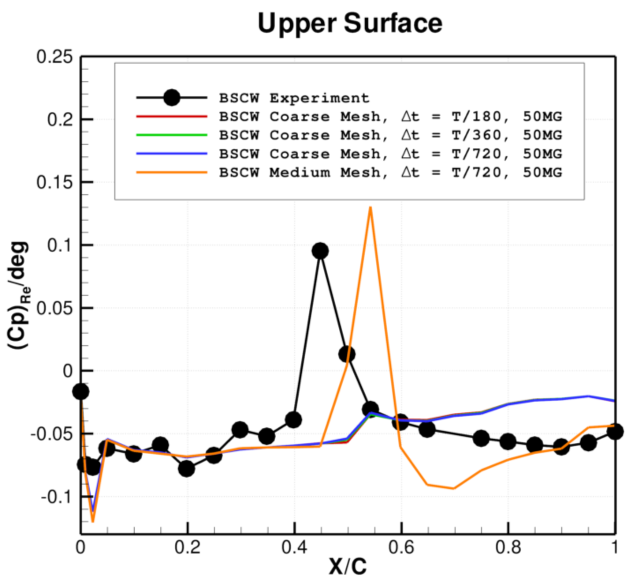


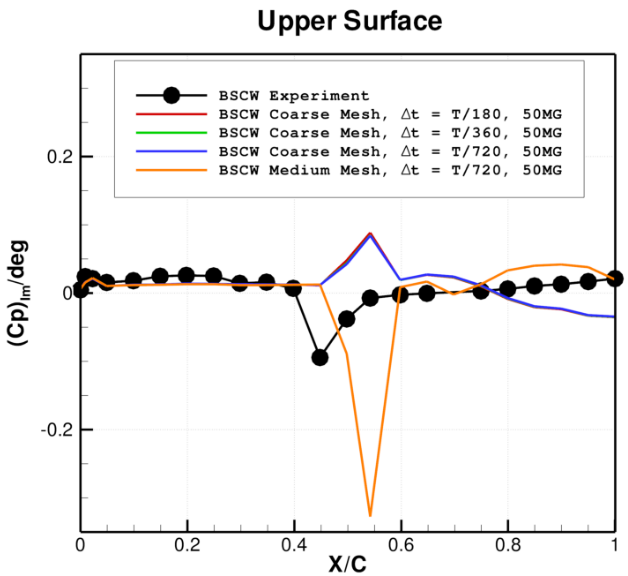


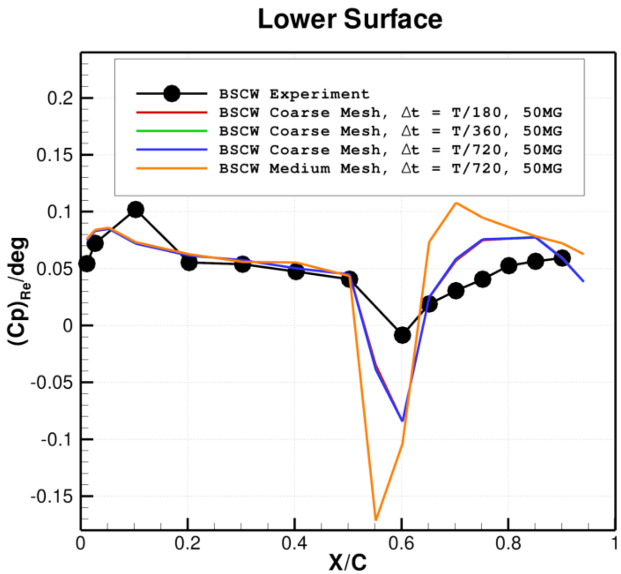


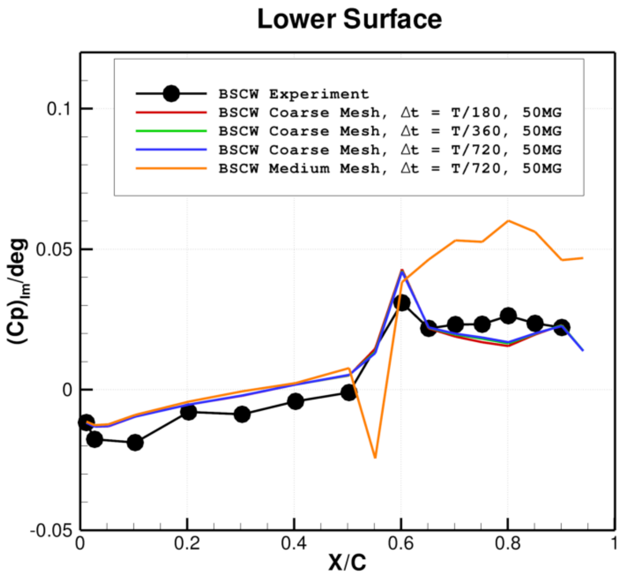
BSCW Unsteady Pressures

(f=10hz)









Conclusions and Future Work

- f=1hz results sensitive in some locations to:
  - Time step size
  - Level of implicit time step convergence
- f=10hz insensitive to time step size
- Both f=1Hz,10Hz sensitive to grid size
- SA turb model well known deficiencies for shock-boundary-layer separation
- Future work to investigate finer meshes, time steps using tight convergence tolerances, SST model