SUMAD Unsteady Analysis of the Benchmark SuperCritical Wing for the Aeroelastic Prediction Workshop 2

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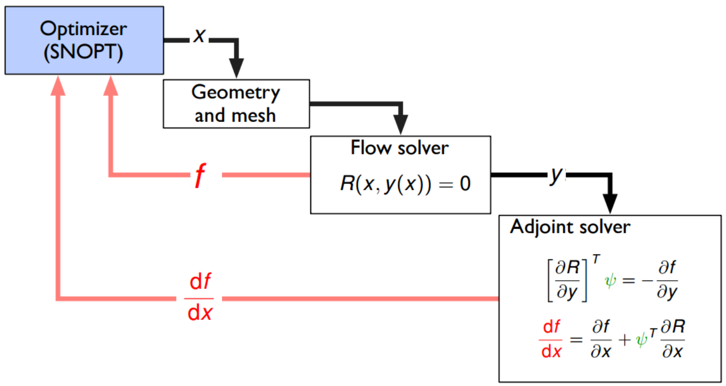
Aeroelastic Prediction Workshop 2
AIAA SciTech 2016

Aerospace Engineering
University of Michigan

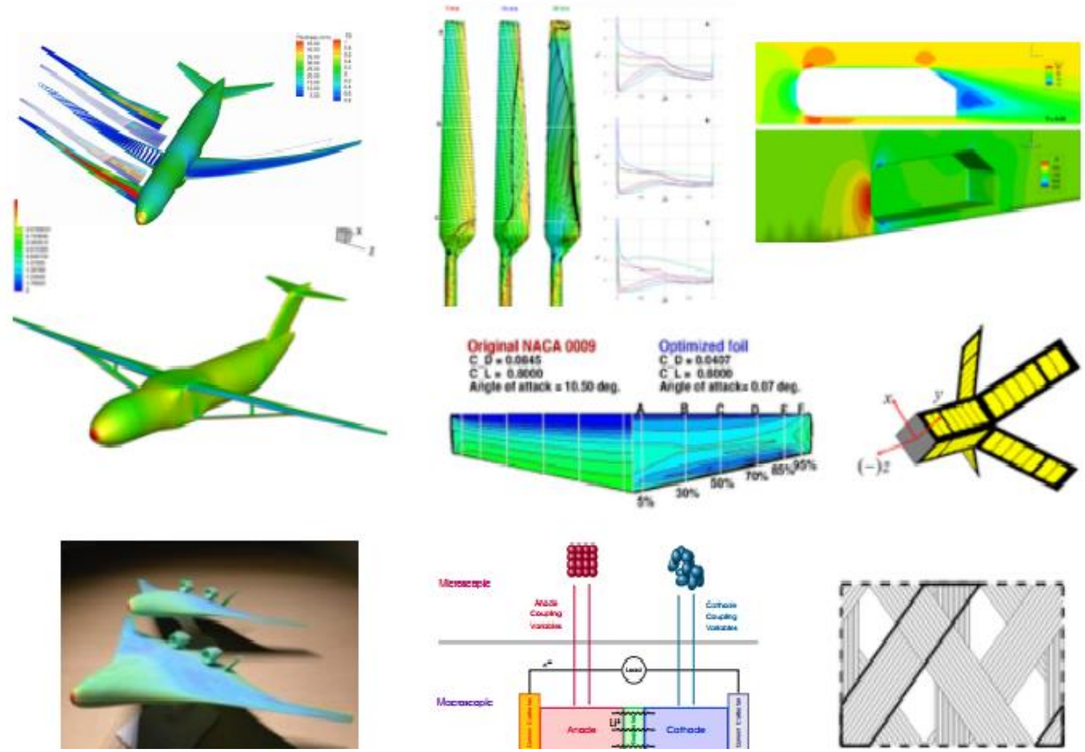
Research in Multidisciplinary Design Optimization Laboratory divided into two main thrust

Fundamental MDO algorithms



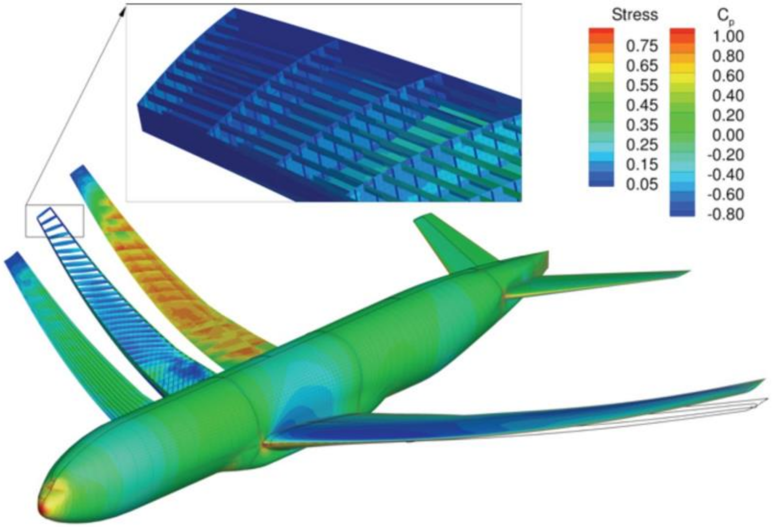
$$\frac{\partial R}{\partial u}\frac{du}{dr} = \mathcal{I} = \left[\frac{\partial R}{\partial u}\right]^T \left[\frac{du}{dr}\right]^T$$

Applications of MDO



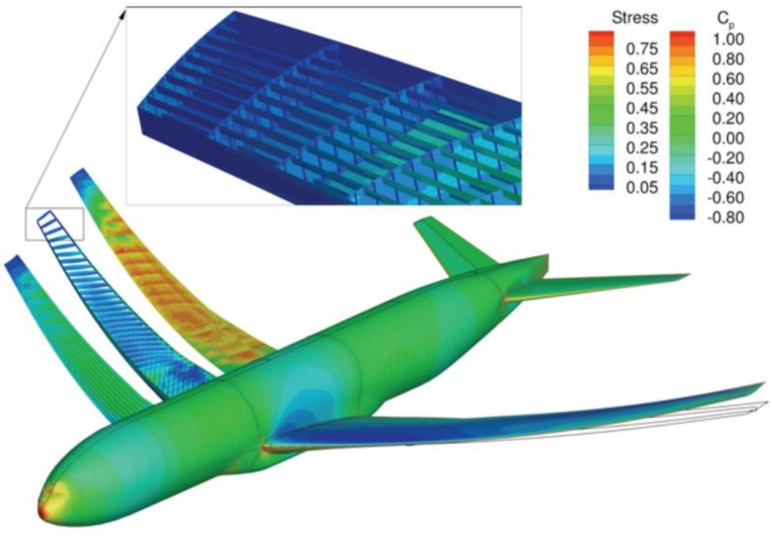
SUMAD Solver Overview

- General, parallel, finite-volume, cell-centered, structured multi-block solver
- Solves Euler/RANS equation in steady, unsteady, time-spectral modes
- Central Scalar (JST), Central Matrix, Upwind dissipation schemes
- Multgrid with Full Multigrid startup. Arbitrary cycling scheme
- Smoothers (RK, DDADI and NK)
- Turbulence models (SA, SAE, k-w modified, k-w Wilcox, k-tau, SST, v2f)
- Time integration scheme, Implicit BDF2
- Deforming grids, GCL compliant ALE scheme



SUMAD models used for this work

- Solves RANS equation in steady, unsteady mode
- Central Scalar (JST) dissipation scheme
- DDADI and NK as smoothers
  - Switched to Newton-Krylov solver after partially converged solution to speed convergence
- Turbulence models
  - Spalart Allmaras (Standard) used exclusively for case 1
  - Menter SST used exclusively for case 3
- Time integration scheme, Implicit BDF2, GCL compliant ALE scheme

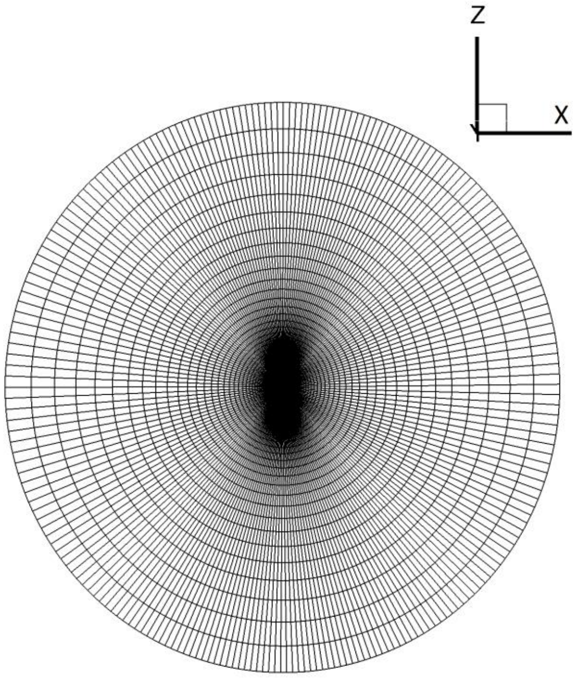


Grid information

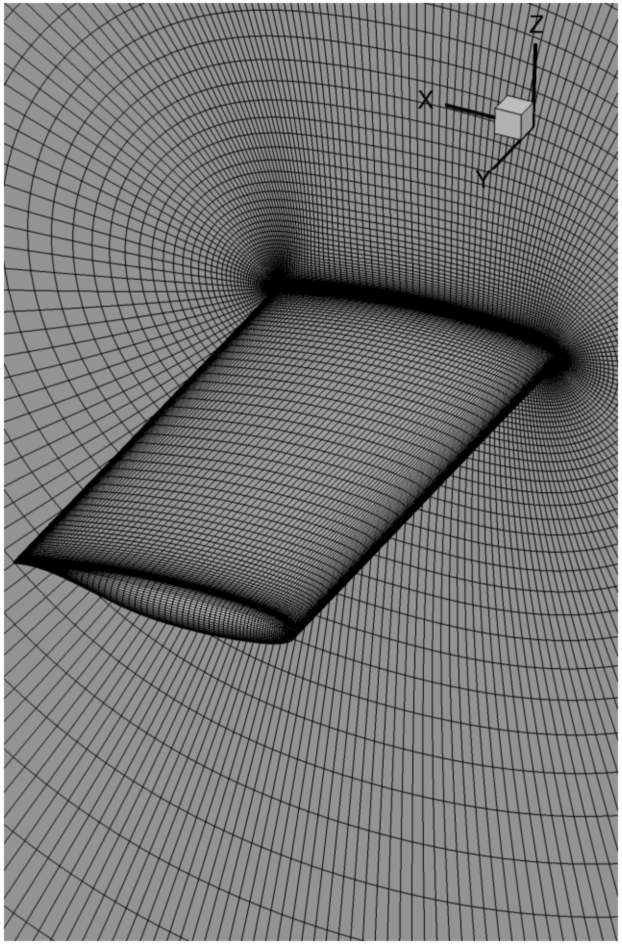
- Structured Multi-block, hexahedral elements, face matched block
- DPW gridding guidelines used
- Surface mesh created in ICEM
- Volume mesh generated using in-house hyperbolic extrusion code
- Coarse mesh obtained by removing every other node in each direction

	Fine	**Medium**	**Coarse**
# Nodes	23.4×10^{6}	7.0×10^{6}	2.9×10^{6}
# Elements	22.7×10^{6}	6.7×10^{6}	3.1×10^{6}
Max Y+	0.425	0.759	1.015
First layer height	1.067×10^{-6} m (42×10^{-6} in)	1.600×10^{-6} m (63×10^{-6} in)	2.388×10^{-6} m (94×10^{-6} in)
Outer boundary	100c	100c	100c
Multigrid	5 levels	5 levels	4 levels

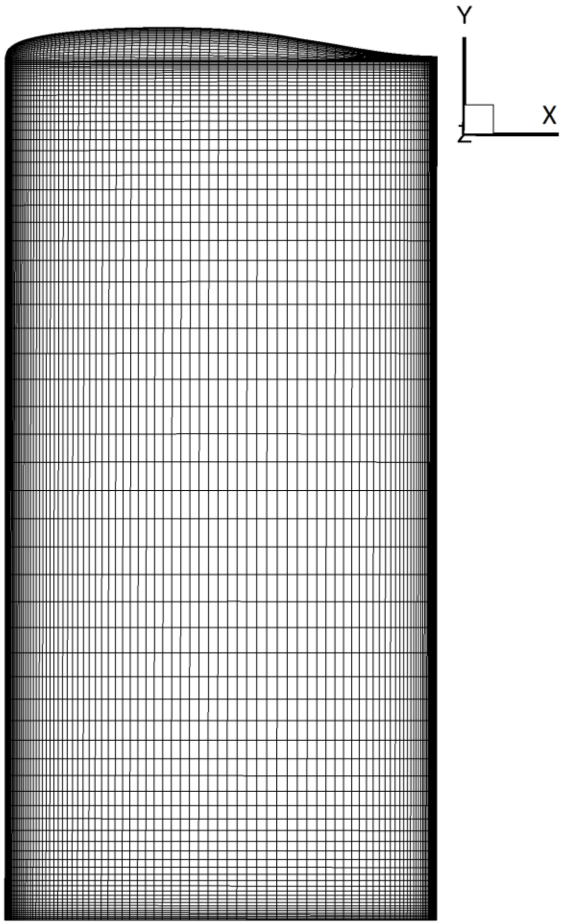
Computational domain is a semi-sphere. Grid wraps around the wing in a O-topology fashion.



Circular Farfield



Isometric view



Top view

Cases analysed

- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

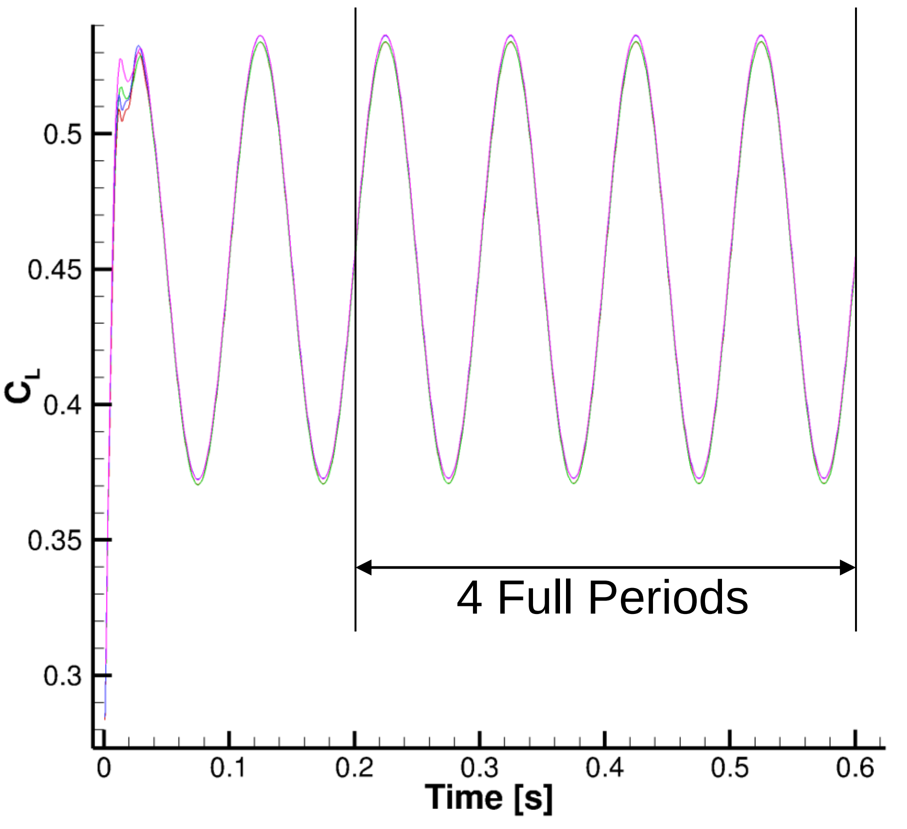
Run criterion for all cases

	Case 1 and 3
Multigrid cycles (Fine/Coarse)	4w/3w
Steady State convergence (rho)	8 orders of magnitude (1e8)
Unsteady convergence (each timestep)	30 inner iteration with MG (>1.5 - 2 orders of magnitude at each timestep)
Unsteady # of periods	6
Unsteady total physical time	0.6 s

- All steady state results converge well
- Time-accurate forces converged at each timestep

Unsteady post-processing for all cases

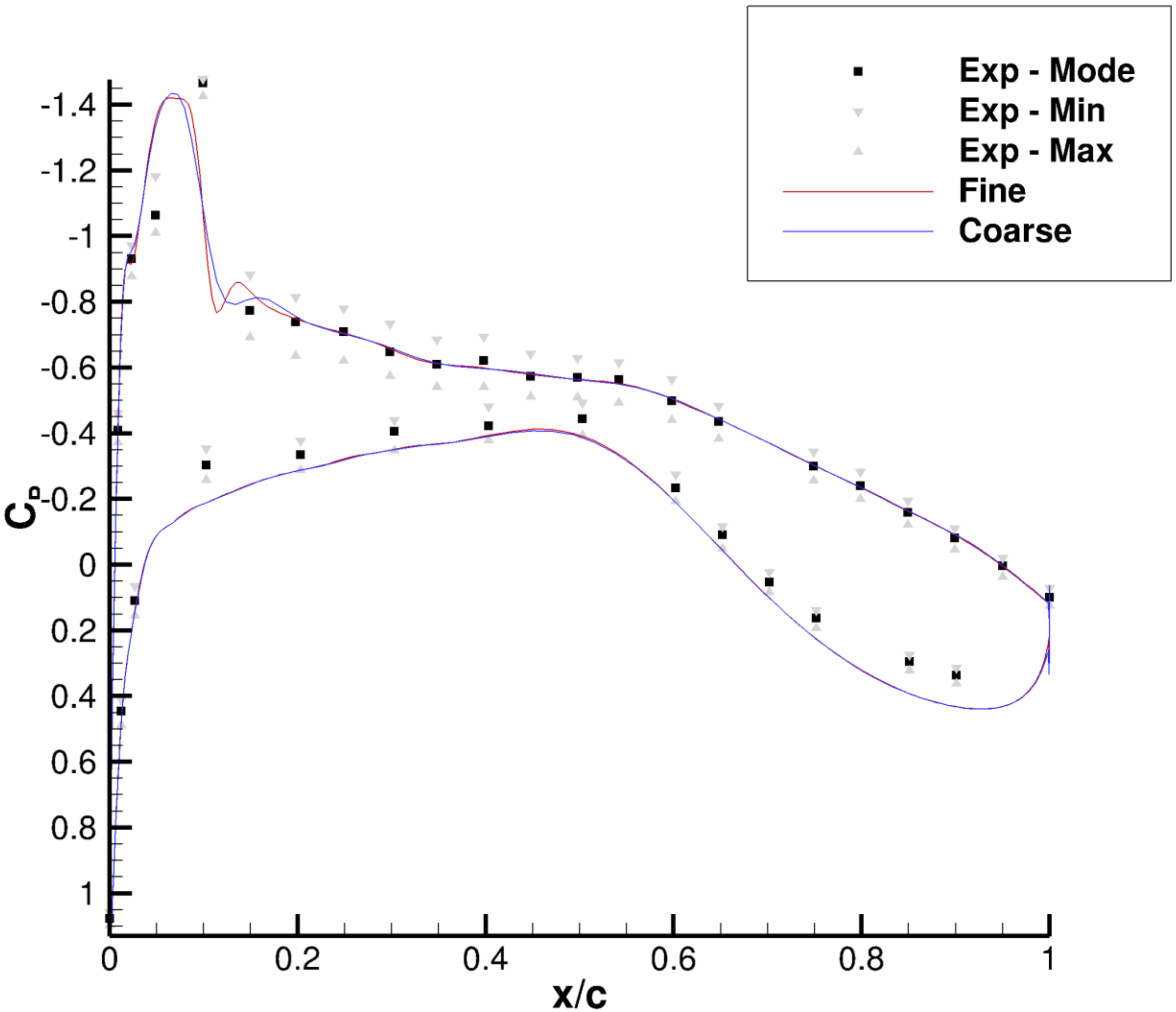
- Transients not present after 2 periods
- The last 4 periods are analyzed (0.4s)
- Only whole periods analyzed
- Rectangular window
- Block Overlap 80%
- 2 cycles per block



Cases analysed

- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

Case 1 – Steady state, C_p at $\eta = 0.6$



Cases analysed

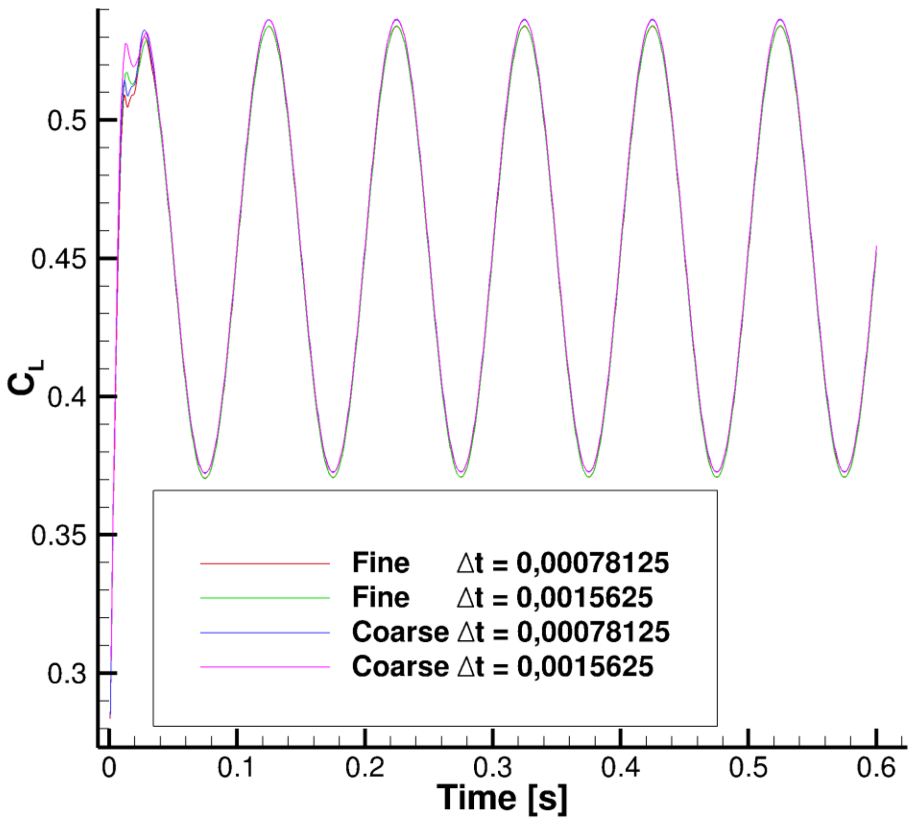
- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

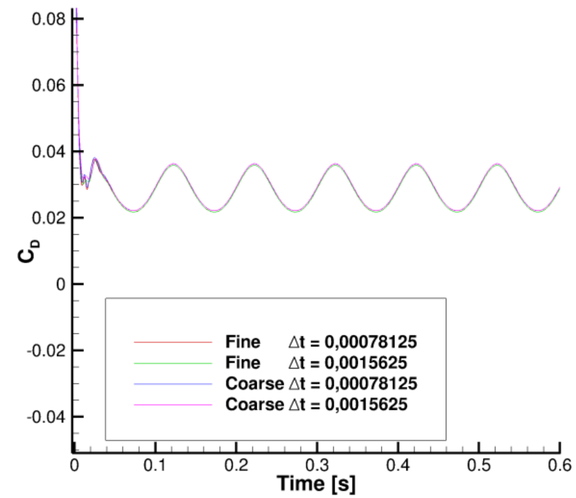
Case 1 Unsteady forced timestep size

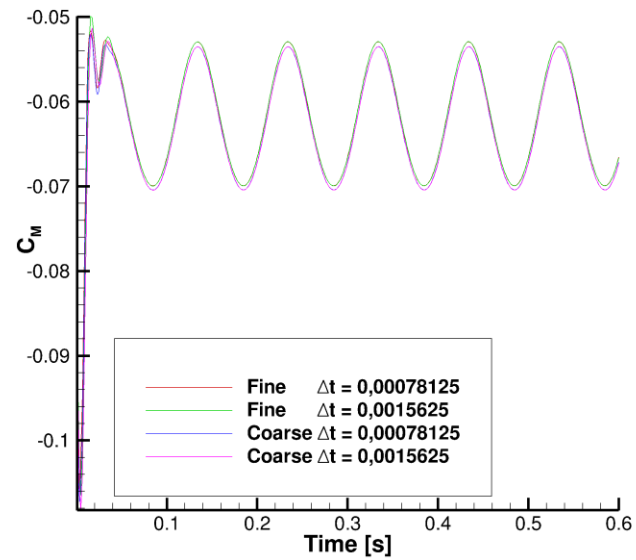
- Forcing frequency f = 10 Hz
- Solution stated from freestream velocity

Timestep dt [s]	**# steps per period**	**# cycles**	**Total # of steps**	**Total physical time [s]**
0,0015625	64	6	384	0.6
0,00078125	128	6	768	0.6

Case 1 Smaller timestep has little effect on lift, drag and moment coefficients.

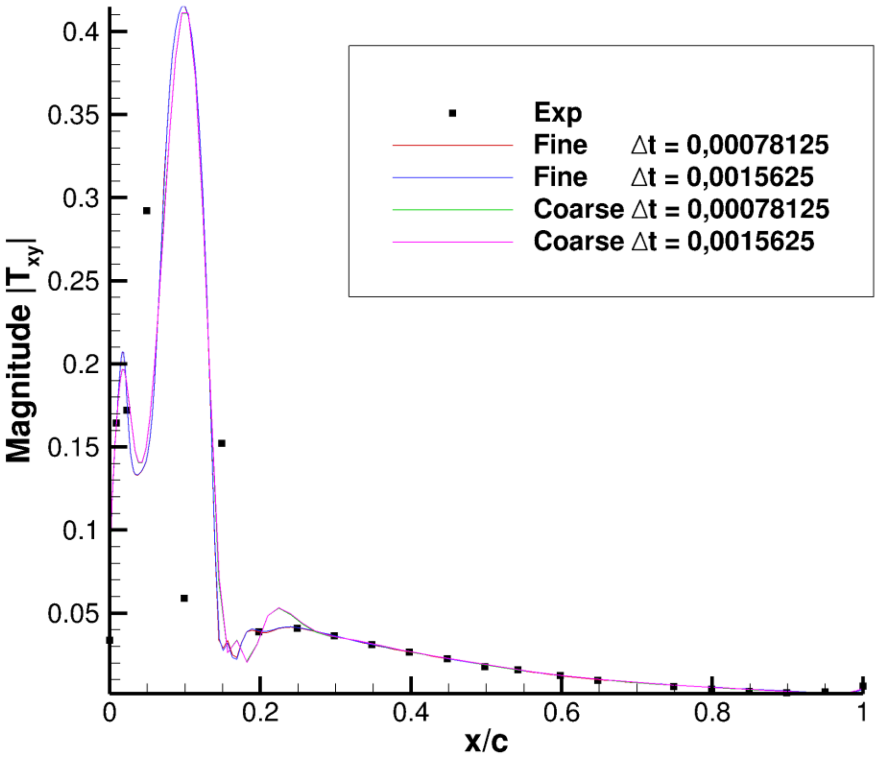




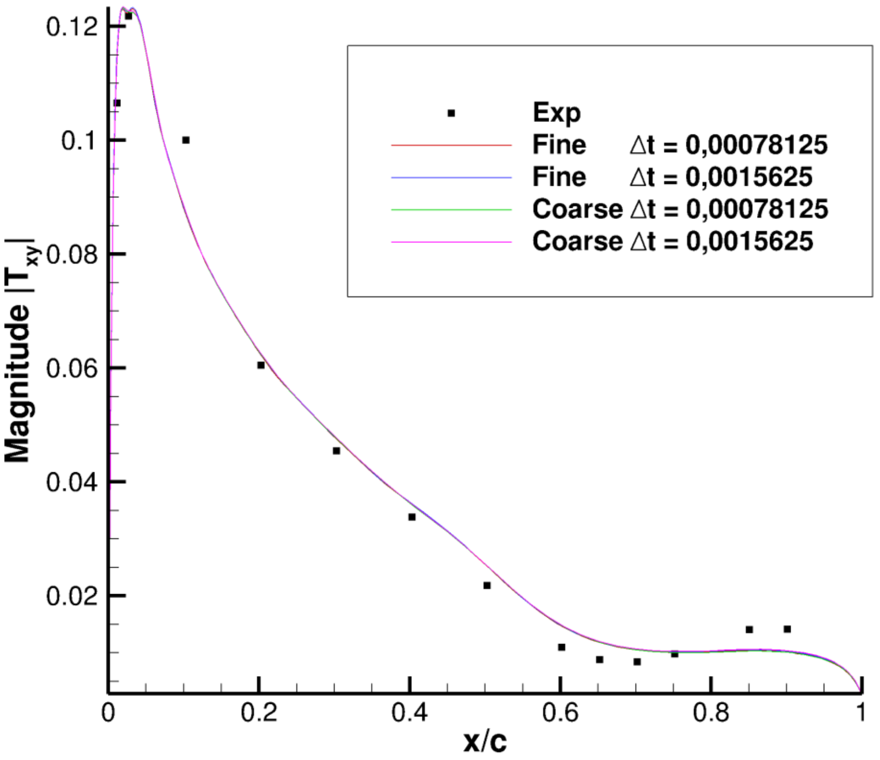


	Min	Max	Mean
Fine (128)	0,370921	0,533943	0,452059
Fine (64)	0,370736	0,534137	0,452051
Coarse (128)	0,372832	0,536309	0,454168
Coarse (64)	0,372610	0,536608	0,454167

Case 1 FRF magnitude at $\eta = 0.6$

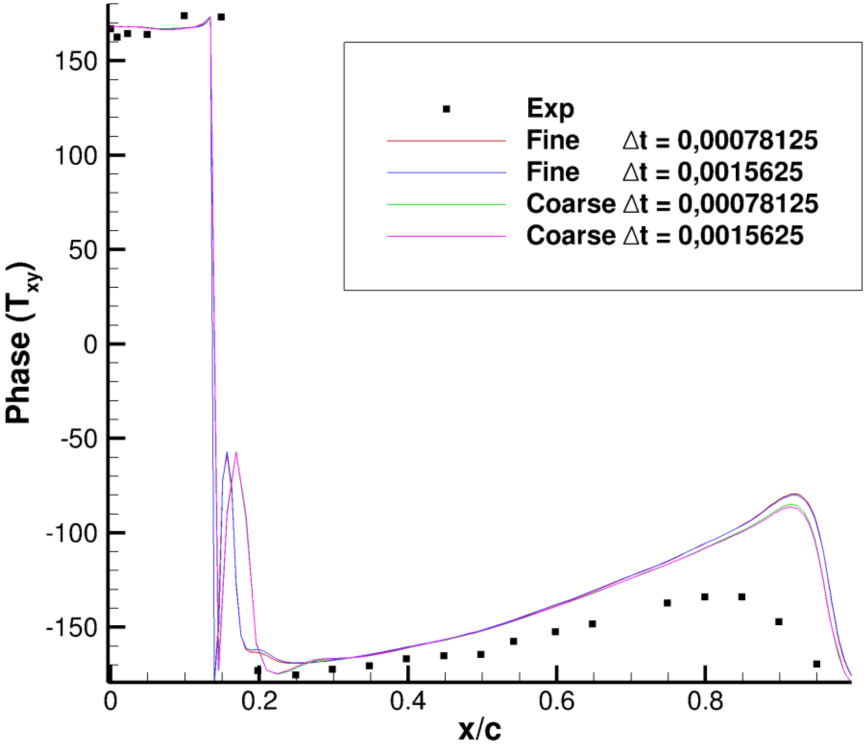


Upper Surface

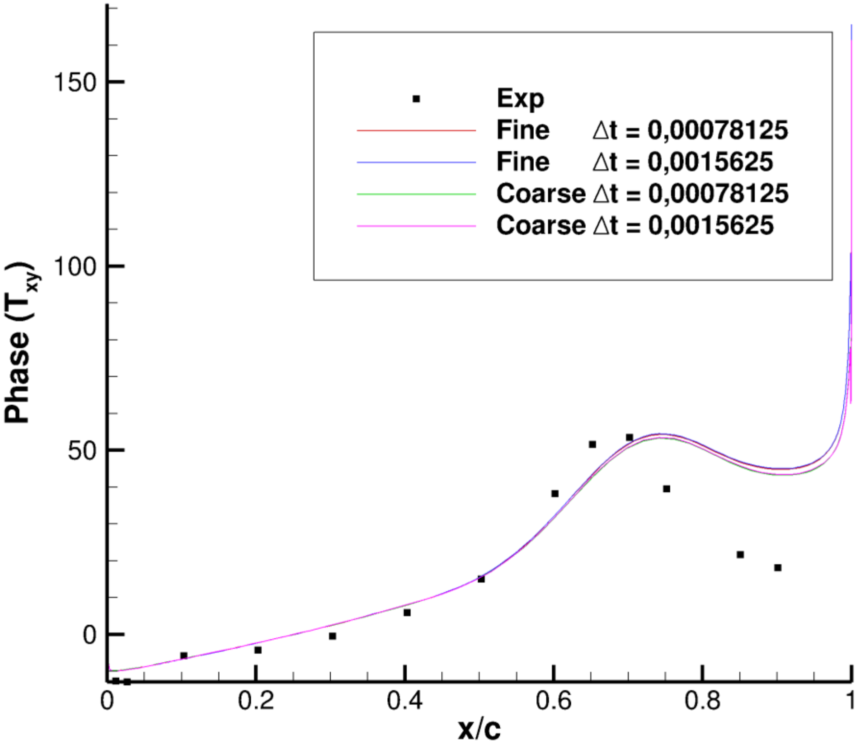


Lower Surface

Case 1 FRF phase at $\eta = 0.6$



Upper Surface

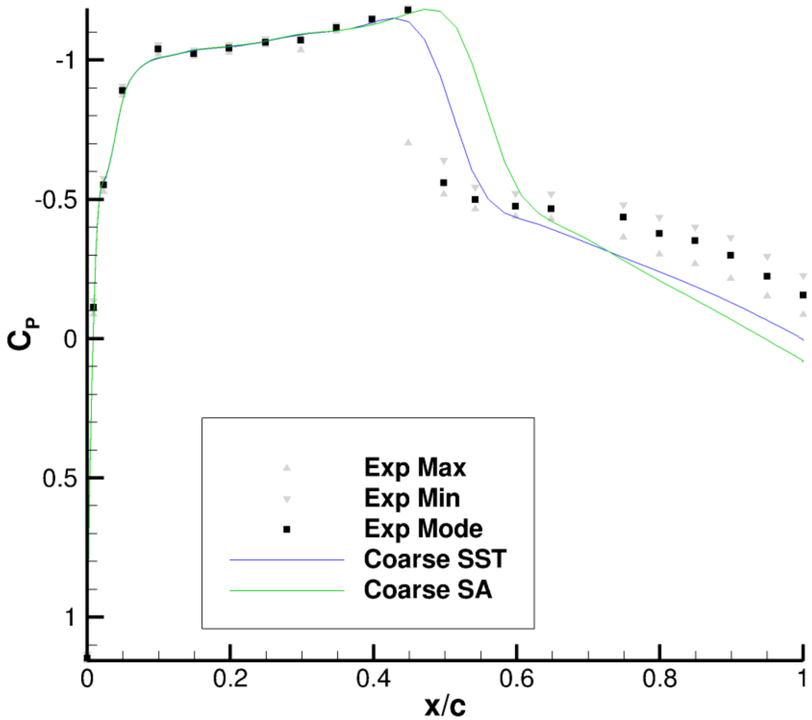


Lower Surface

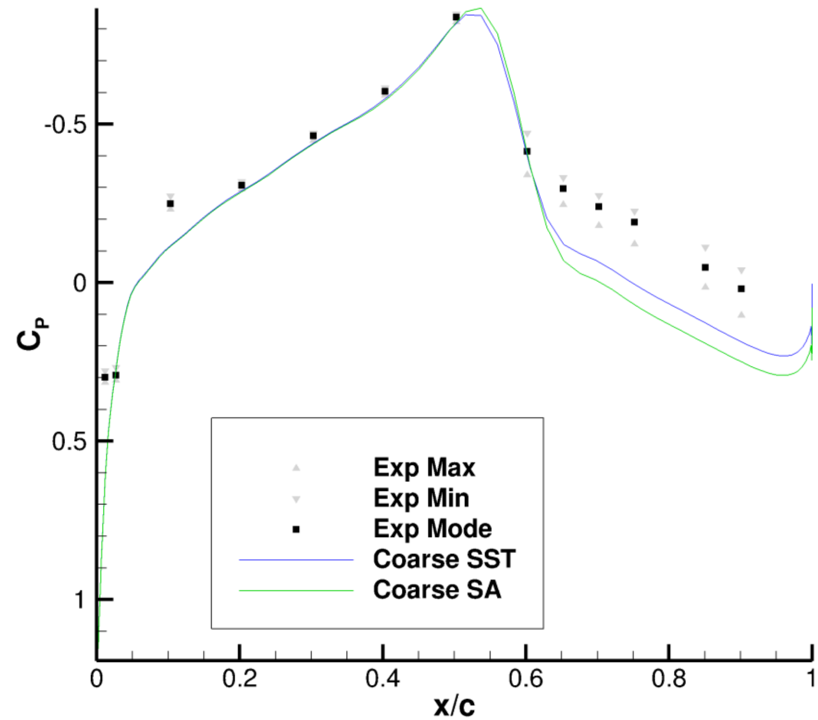
Cases analysed

- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

Case 3 – Steady state, C_p at η = 0.6. Turbulence model SA predicts shock further aft than SST

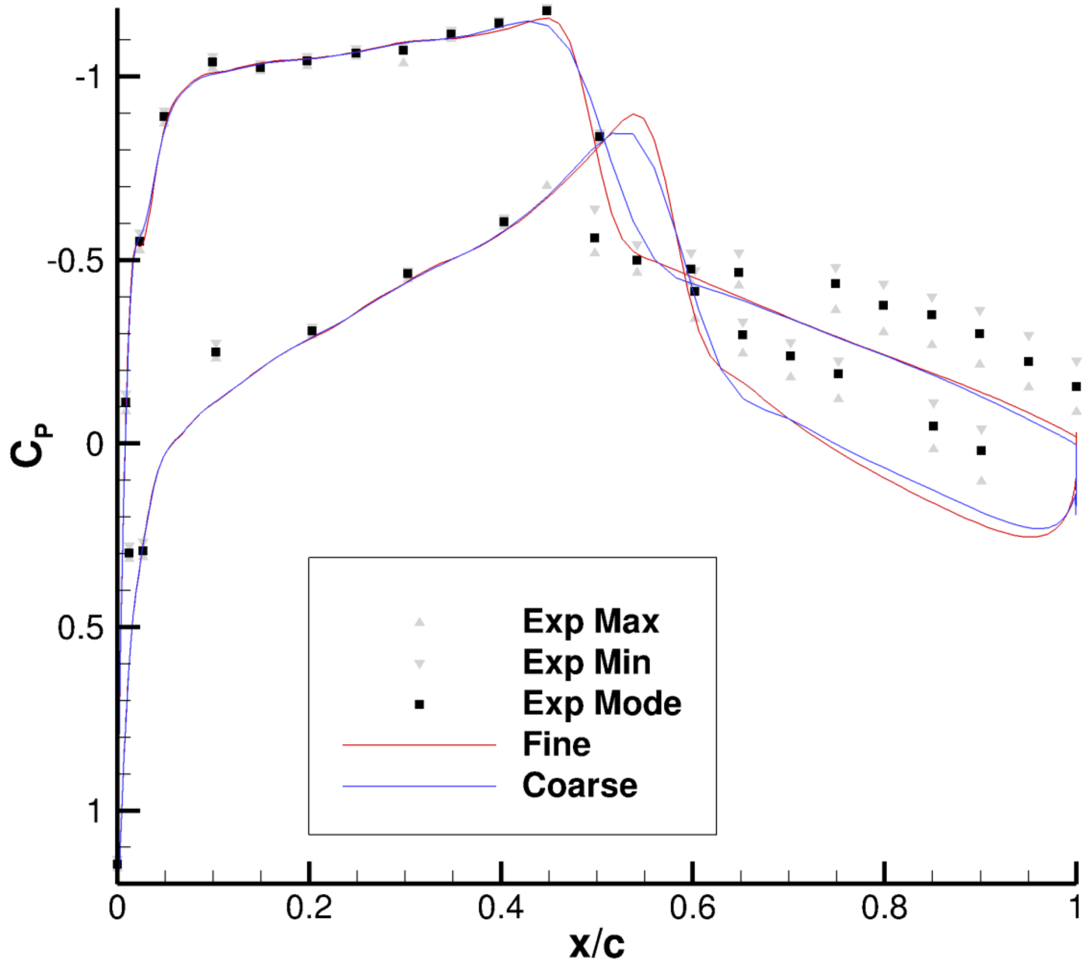


Upper Surface



Lower Surface

Case 3 – Steady state, C_p at η = 0.6



Cases analysed

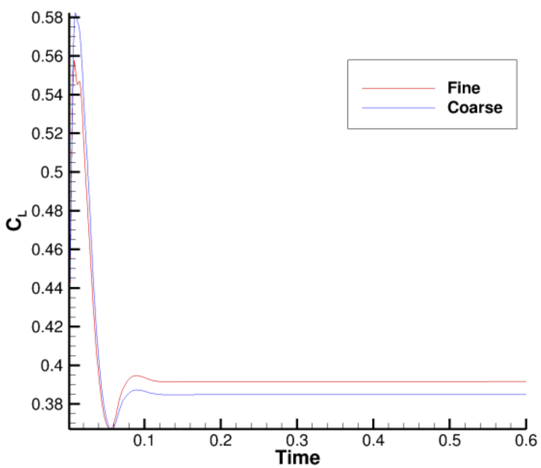
- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

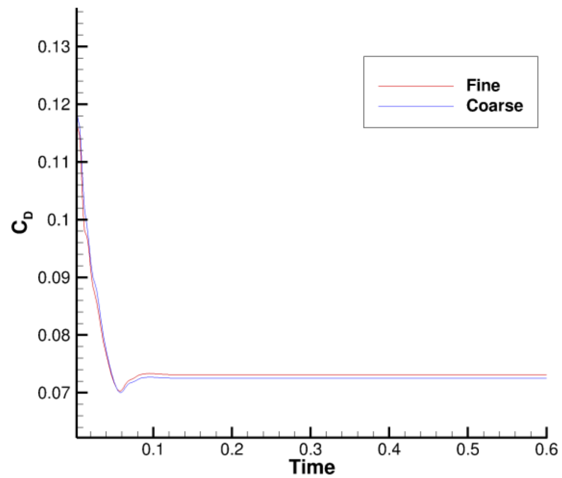
Case 3 Unsteady unforced timestep

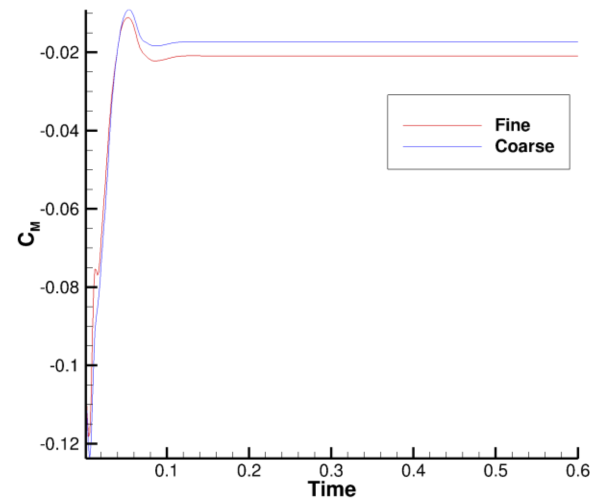
- Unforced (frequency f = 0 Hz)
- Solution stated from freestream velocity

Timestep dt [s]	# steps per period	# cycles	Total # of steps	Total physical time [s]
0,0015625	64	6	384	0.6

Case 3 Unsteady unforced converge to steady state values for respective grid







	Coefficient	Steady	Unforced	|Δ|
Fine Grid	C_L	0,39159	0,39159	0
	C_D	0,07312	0,07312	0
	$-C_M$	0,02095	0,02094	1E-05
Coarse Grid	C_L	0,38493	0,38485	8E-05
	C_D	0,07251	0,07250	1E-05
	$-C_M$	0,01737	0,01734	3E-05

Cases analysed

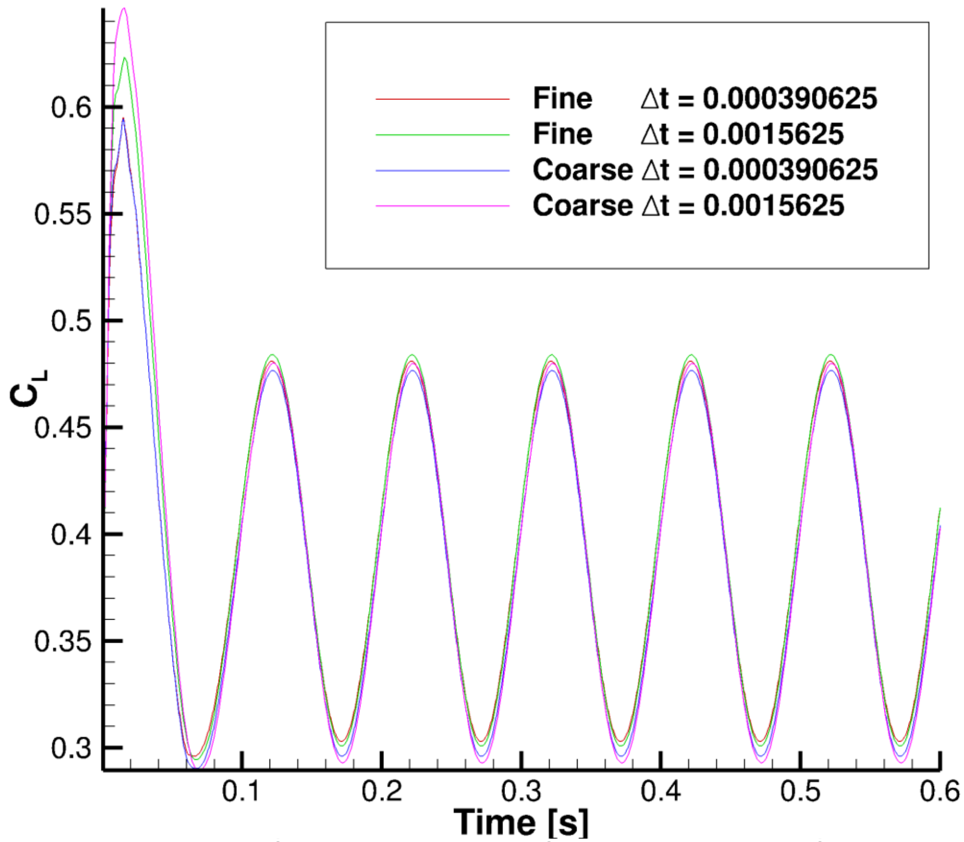
- Case 1
  - Steady State
  - Unsteady forced
- Case 3
  - Steady Sate
  - Unsteady Unforced
  - Unsteady Forced

Case 3b timestep size

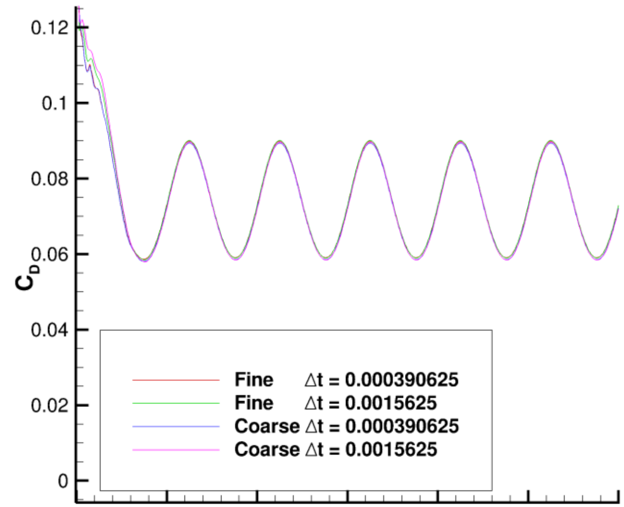
- Forcing frequency f = 10 Hz
- Solution stated from freestream velocity

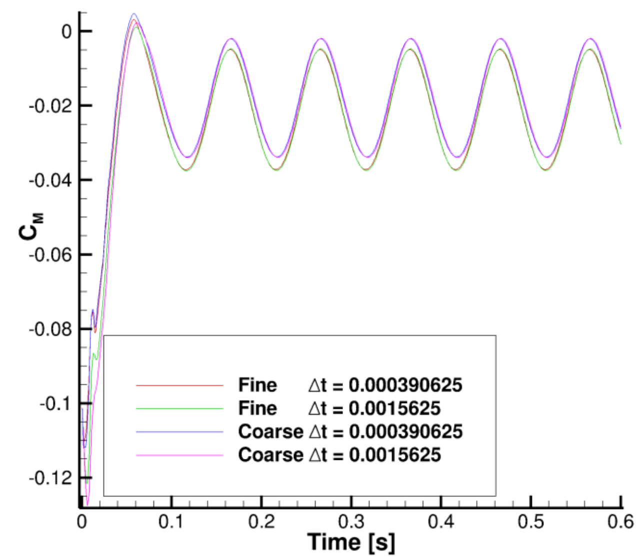
Timestep dt [s]	# steps per period	# cycles	Total # of steps	Total physical time [s]
0,0015625	64	6	384	0.6
0,00039	256	6	1536	0.6

Case 3b Smaller timestep has little effect on lift, drag and moment coefficients

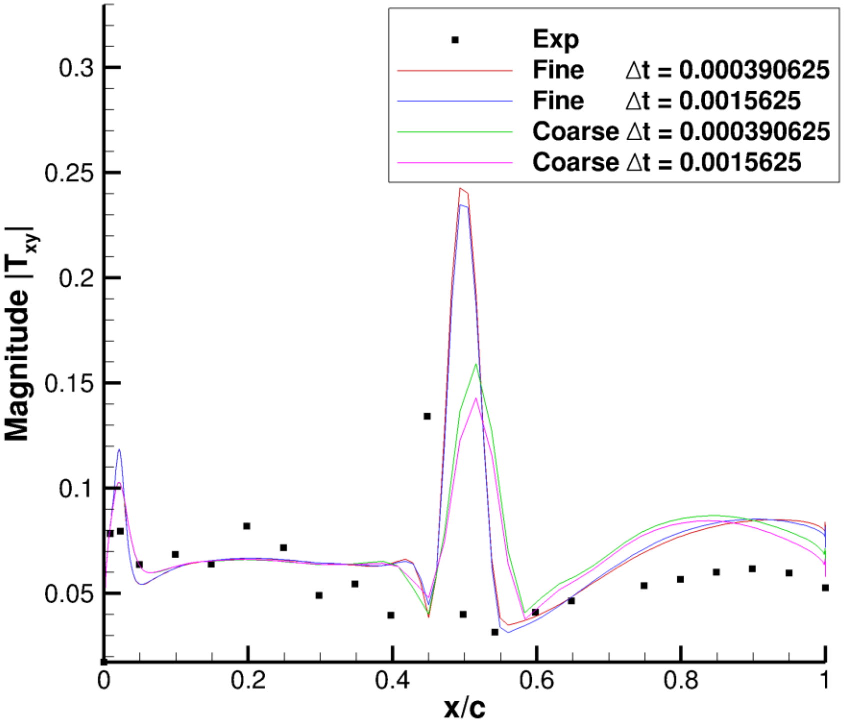


	Min	Max	Mean
Fine (256)	0,302953	0,481044	0,392352
Fine (64)	0,300794	0,484105	0,392751
Coarse (256)	0,295979	0,476621	0,386582
Coarse (64)	0,292924	0,479955	0,386835

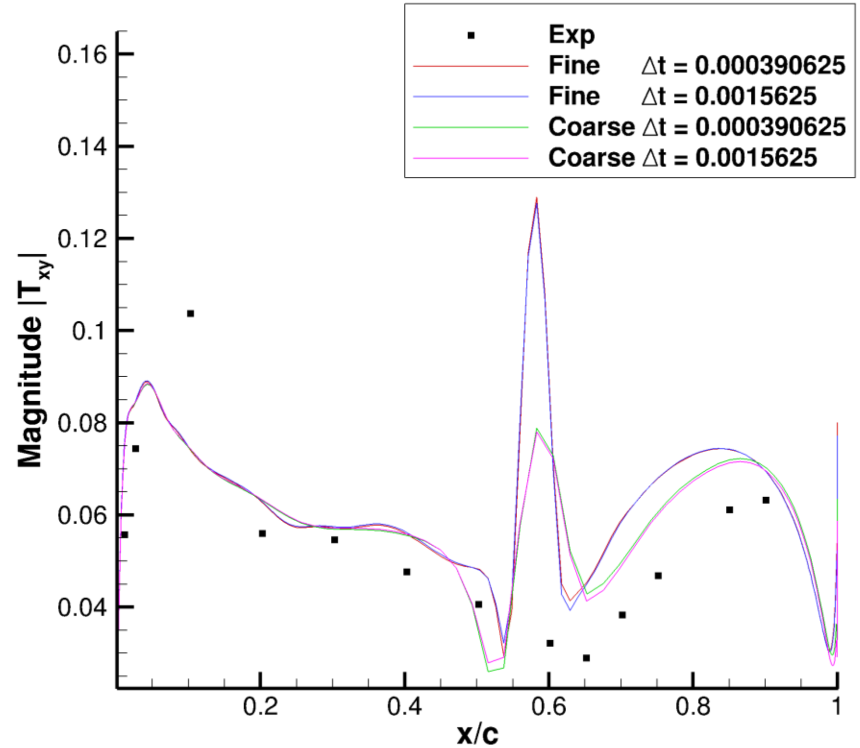




Case 3b FRF magnitude at $\eta = 0.6$

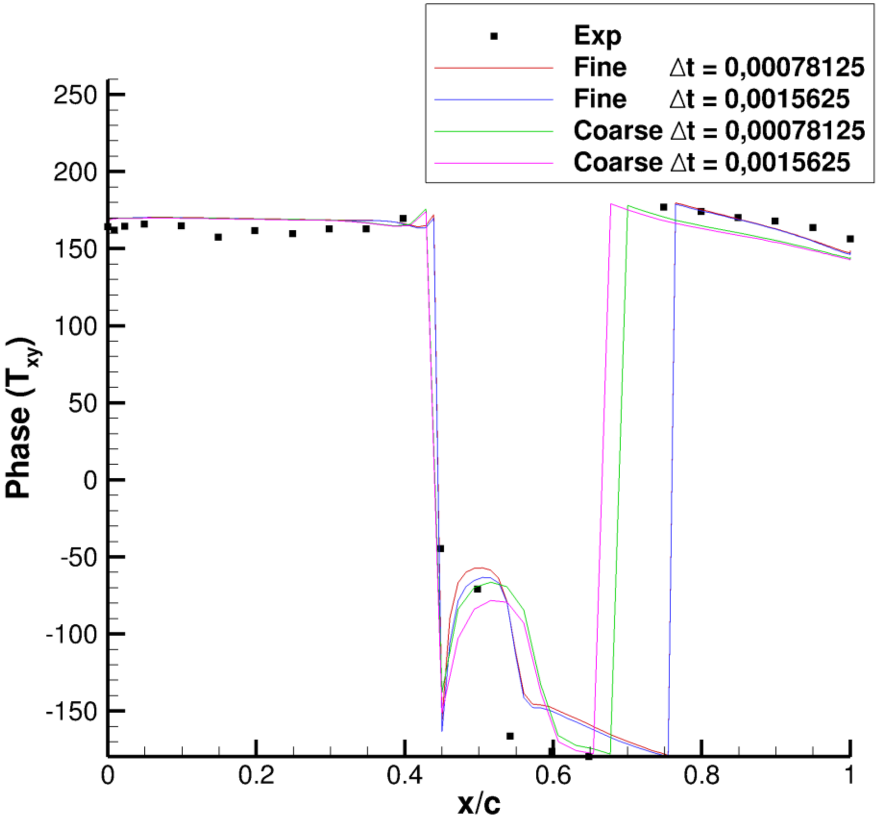


Upper Surface

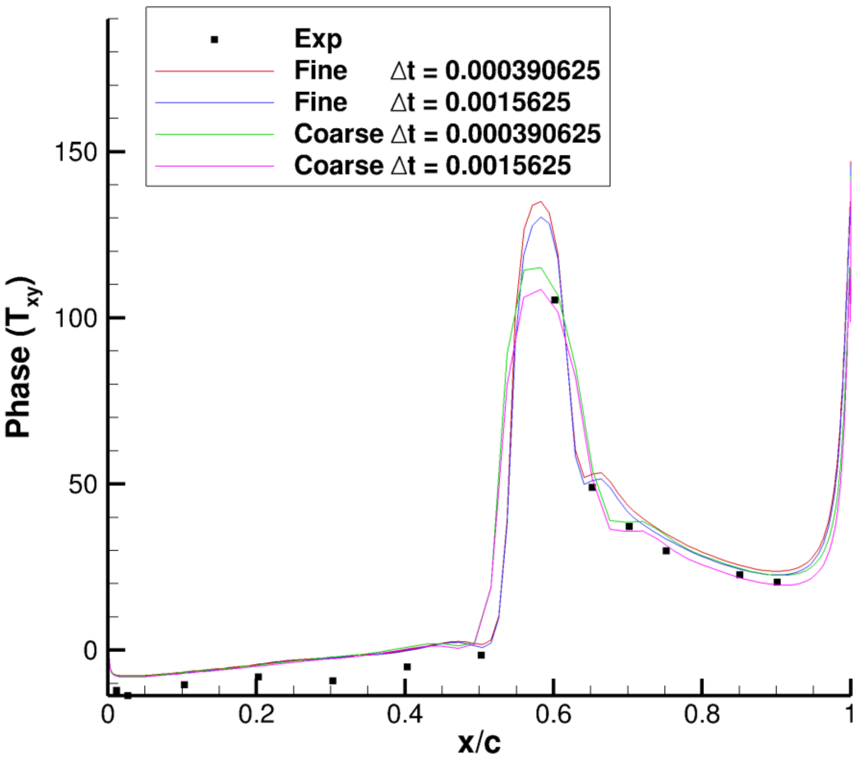


Lower Surface

Case 3b FRF phase at $\eta = 0.6$



Upper Surface



Lower Surface

Questions?

More information available at:

http://mdolab.engin.umich.edu

This work was mostly completed on the Stampede cluster, using the Extreme Science and Engineering Discovery Environment (XSEDE).

XSEDE

Extreme Science and Engineering
Discovery Environment