STAR-CCM+ Analysis Results

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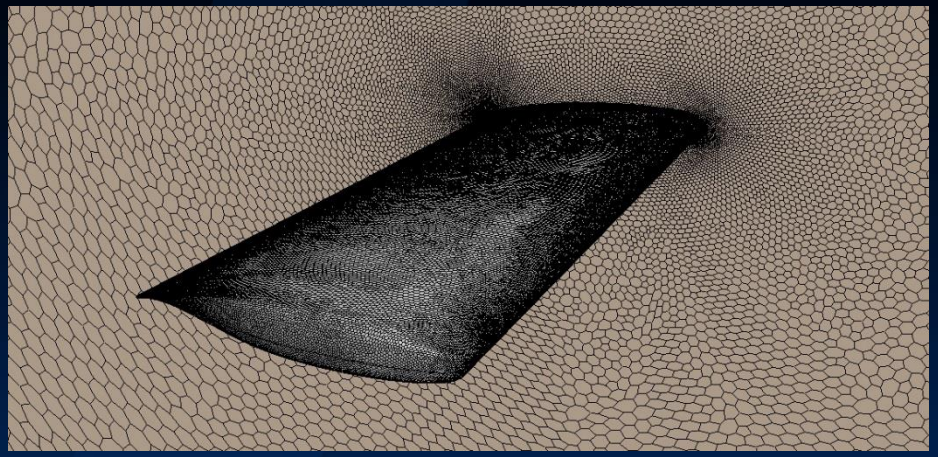
STAR-CCM+ Analysis v. 10.06

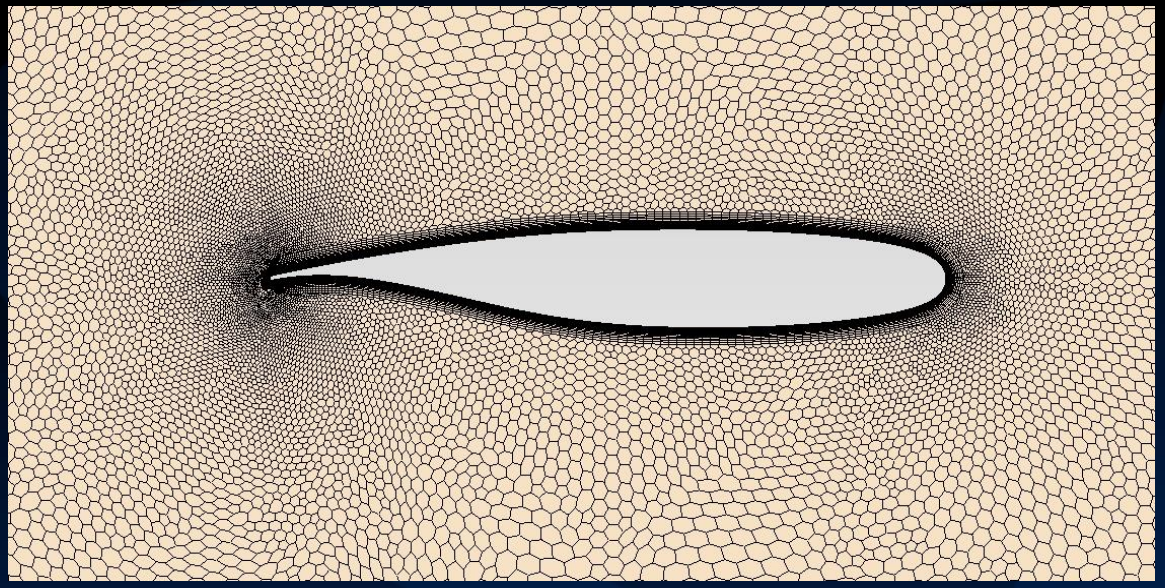
- General purpose Navier-Stokes code
  - Cell-centered finite volume
- Current analysis
  - Coupled solver for mass, momentum, energy
  - AUSM+ flux reconstruction
  - Venkatakrishnan slope limiter
  - k-ω SST turbulence model (RANS)
  - Pseudo-time-marching for steady flow
  - Implicit scheme for unsteady flow

Geometry and Grid

- Hemispherical domain
  - 3200 in. diameter
- STAR-CCM+ Mesher
- Arbitrary polyhedral cells
  - Coarse – 2.49 million cells
  - Medium – 9.10 million
  - Fine – 34.64 million
- Cell near-wall thickness
  - Coarse – $\Delta y = 0.000042''$
  - Medium – $\Delta y = 0.000038''$
  - Fine - $\Delta y = 0.000032''$
  - Cell y+ ≤ 1 in each case

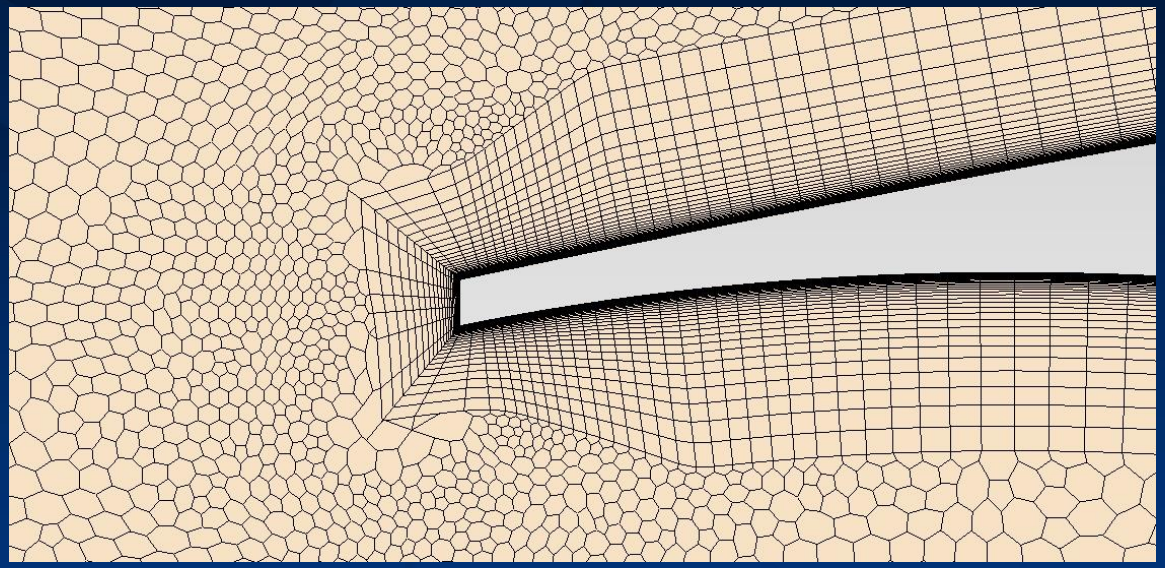


Mesh – Medium Resolution Example

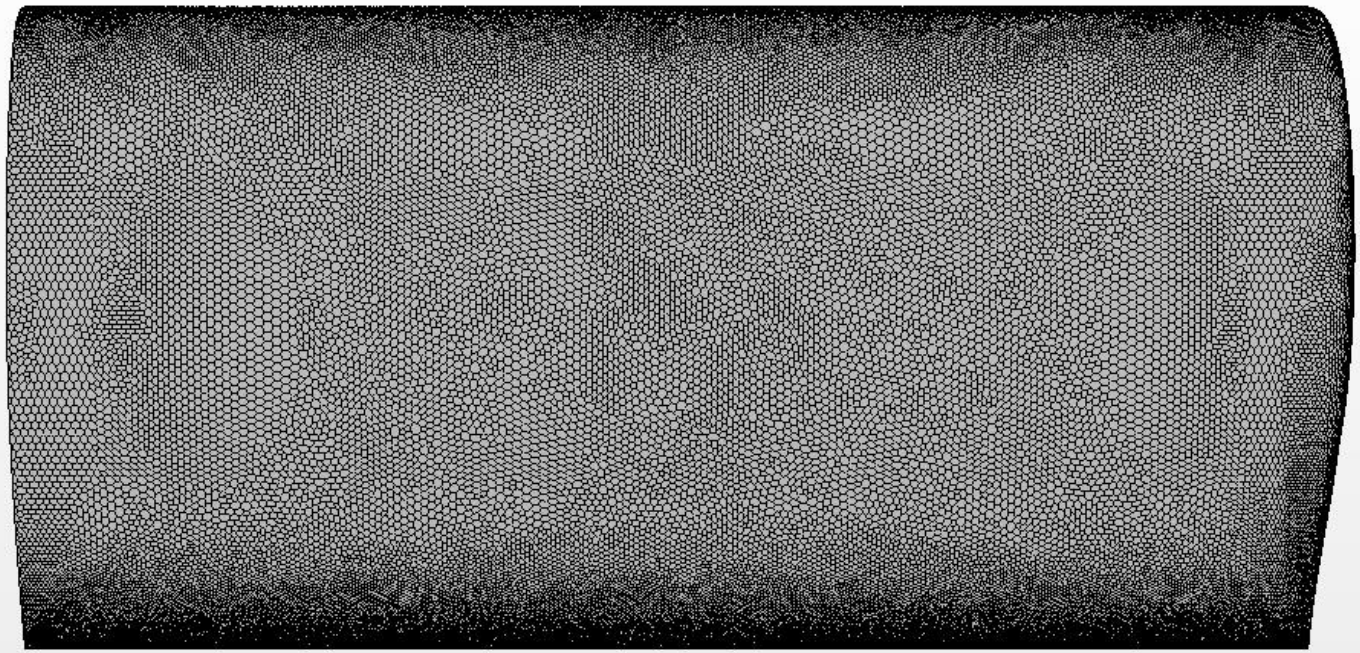


Mesh Near Wing

Mesh Near Trailing Edge



Mesh – Medium Resolution



Surface Mesh on Wing

- **Mid-chord stream-wise $\Delta x \approx 0.12''$**
- **Leading edge stream-wise $\Delta x \approx 0.05''$**
- **Trailing edge stream-wise $\Delta x \approx 0.02''$**

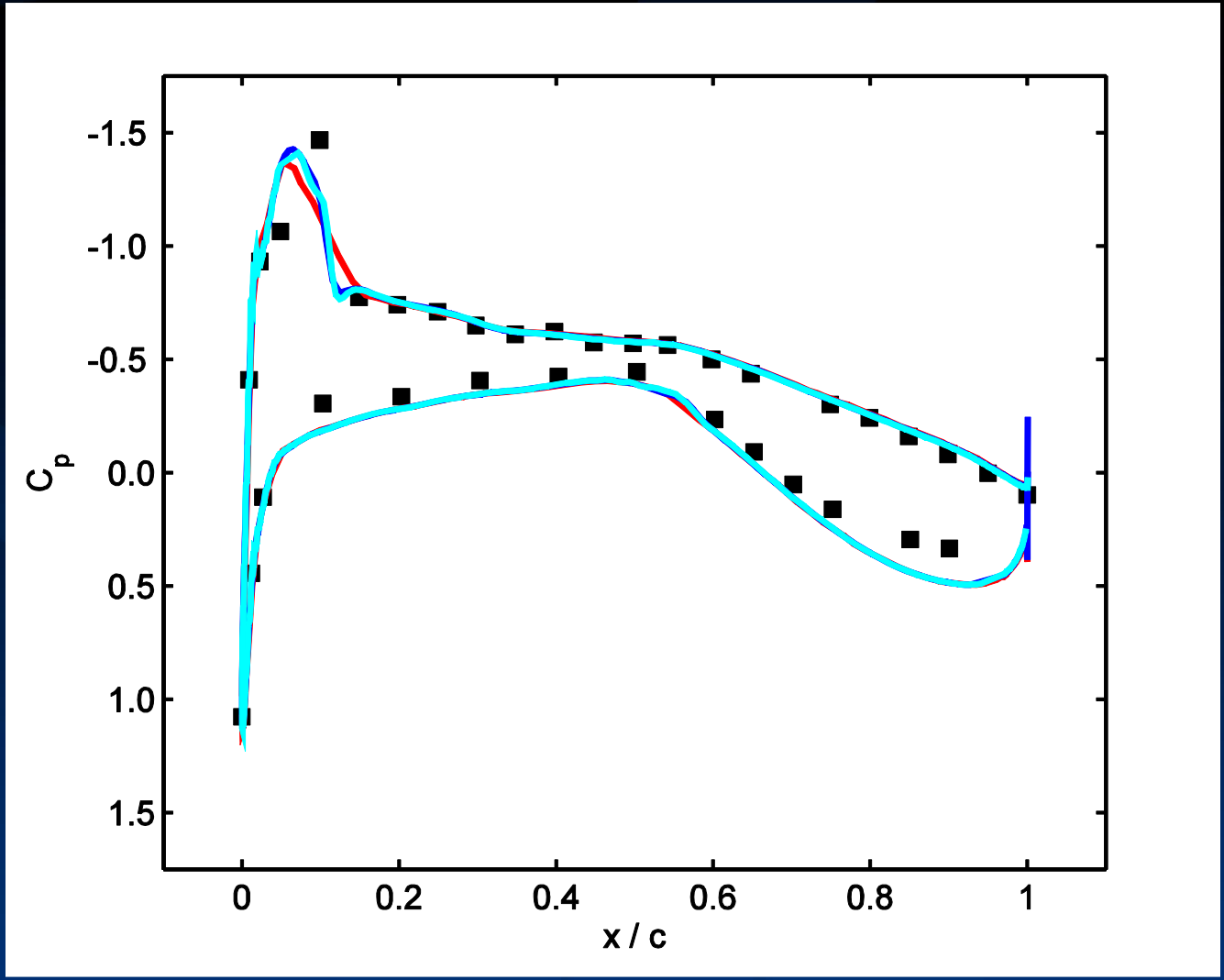
Solution Strategy – Case 1 Steady

- **Initialization:**
  - Inviscid flow solution (velocity, pressure, temperature)
  - Multigrid solution – 10 levels
  - 2 orders of magnitude (relative) drop in residuals
- **Full Solution:**
  - Additional 5 orders of magnitude (relative) drop in residuals
  - Algebraic Multigrid solution of matrix equations

Case 1 Steady Results

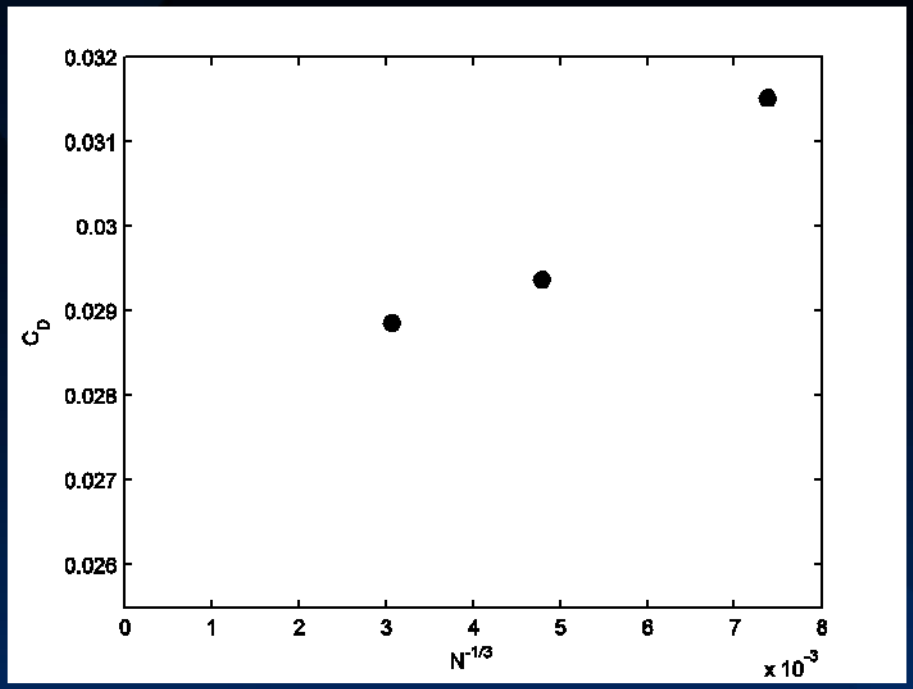
C_p @ 60% Span

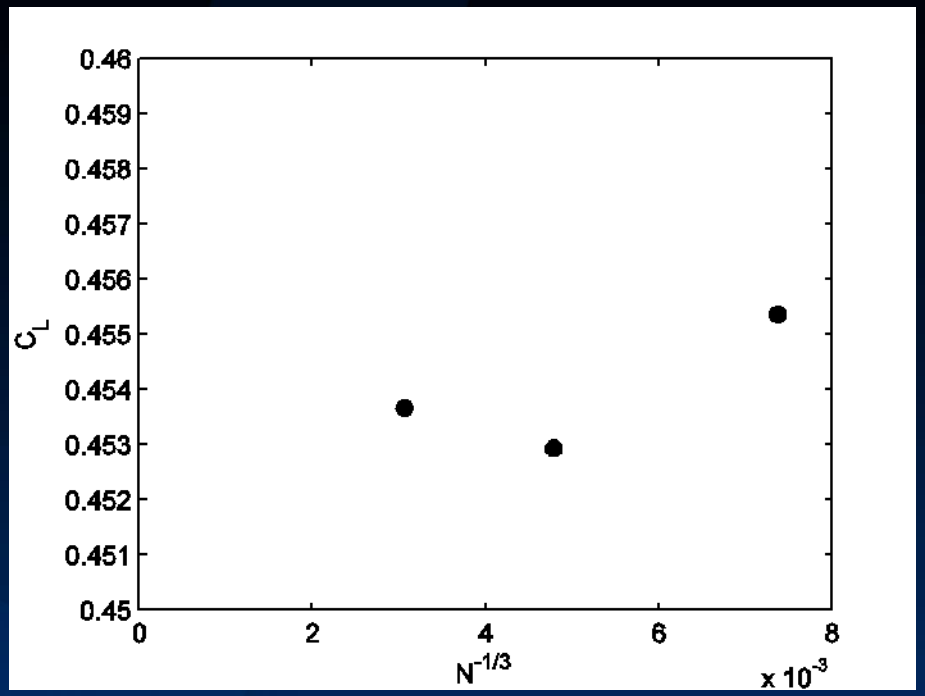
Red – Coarse
Blue – Medium
Cyan - Fine



Case 1 Steady – Mesh Convergence

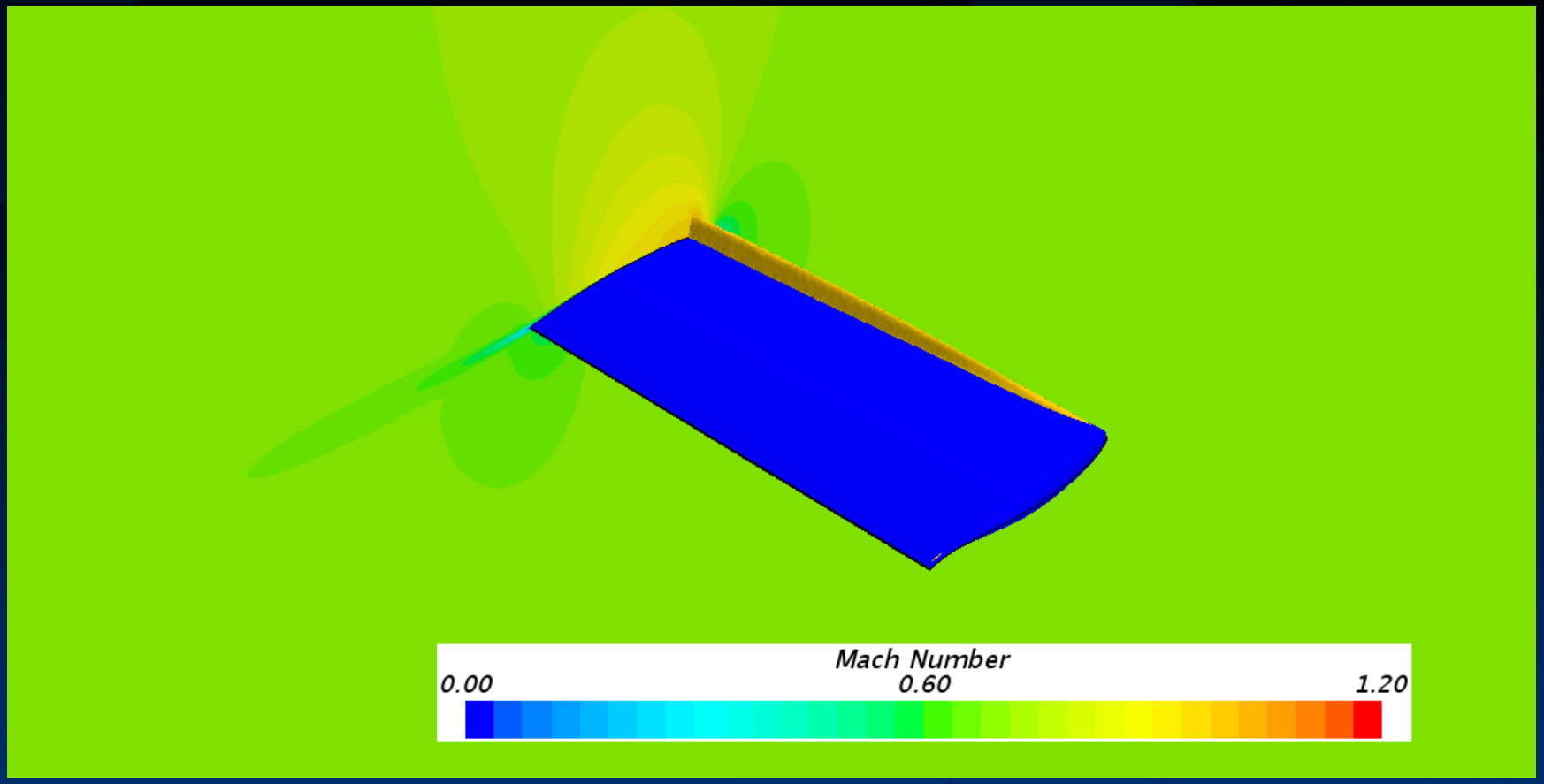
Total C_D and Total C_L vs. $N^{-1/3}$





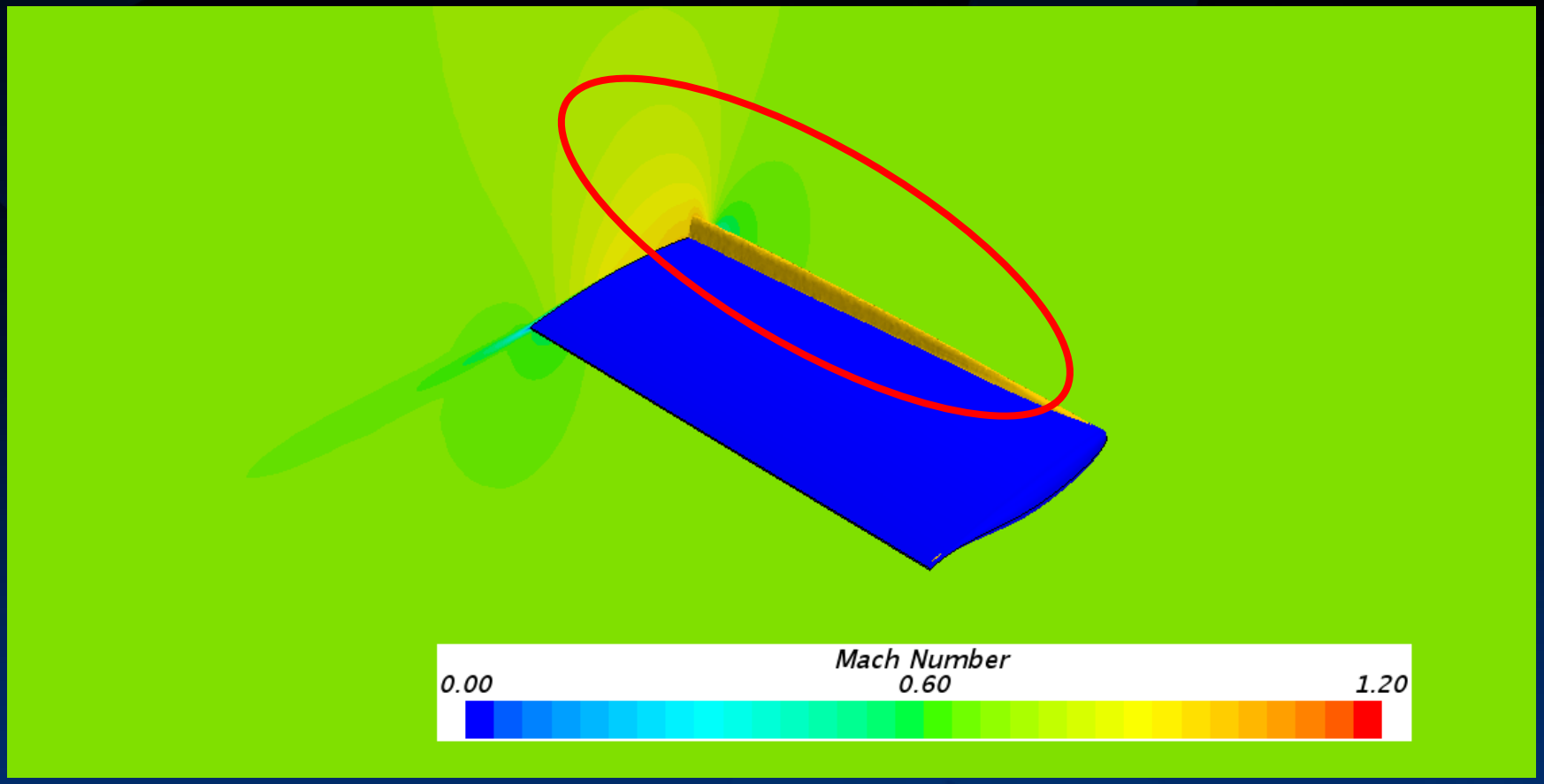
- From Medium to Fine Grid:
  - Less than 2% change CD
  - Less than 0.5% change CL

Case 1 Steady - Visualization



Mach No. @ Medium Resolution Mesh

Case 1 Steady - Visualization

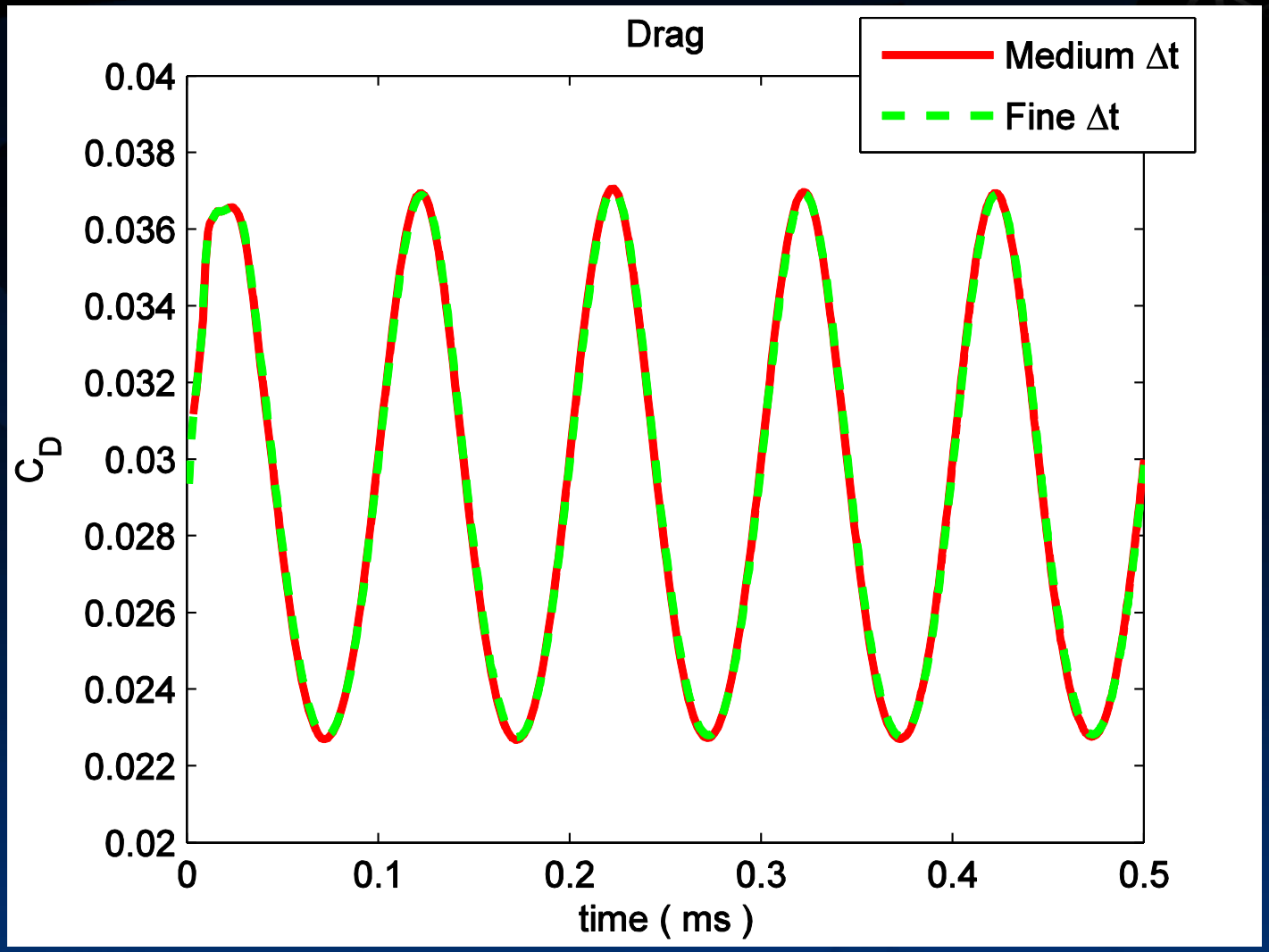


Mach No. @ Medium Resolution Mesh

Solution Strategy – Case 1 Unsteady

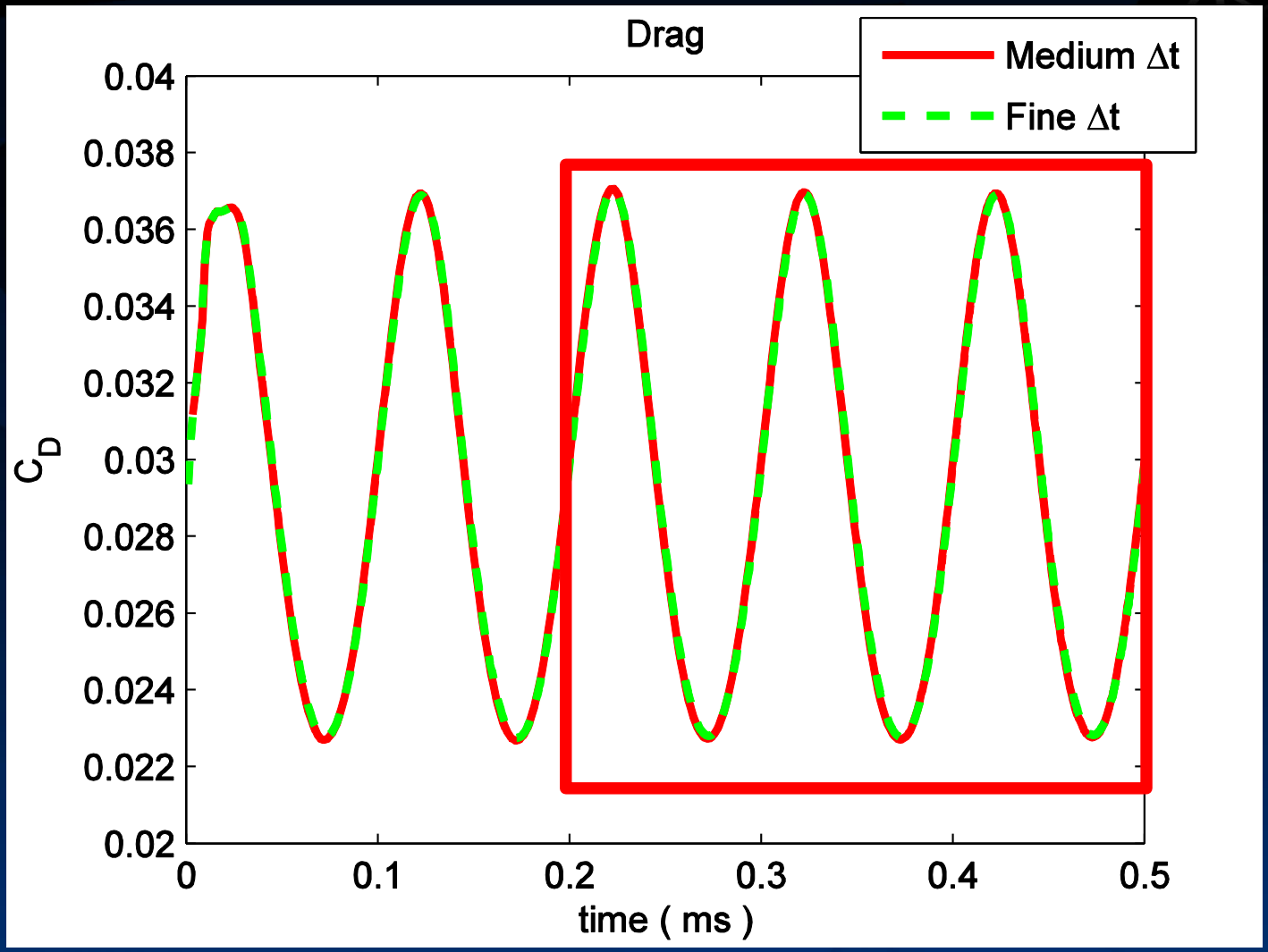
- Medium Mesh Spatial Resolution
- Refinement in Δt
  - 1.0 ms (100 steps per period)
  - 0.5 ms (200 steps per period)
  - 0.25 ms (400 steps per period)
- 15 Sub-iterations per global time step
  - About 6 orders of magnitude drop in residuals per step
- 2nd Order BDF time integration
- Specified Rigid Body Rotation for wing
  - No Mesh Deformation

Temporal Convergence Results



Total C_D vs. time

Temporal Convergence Results

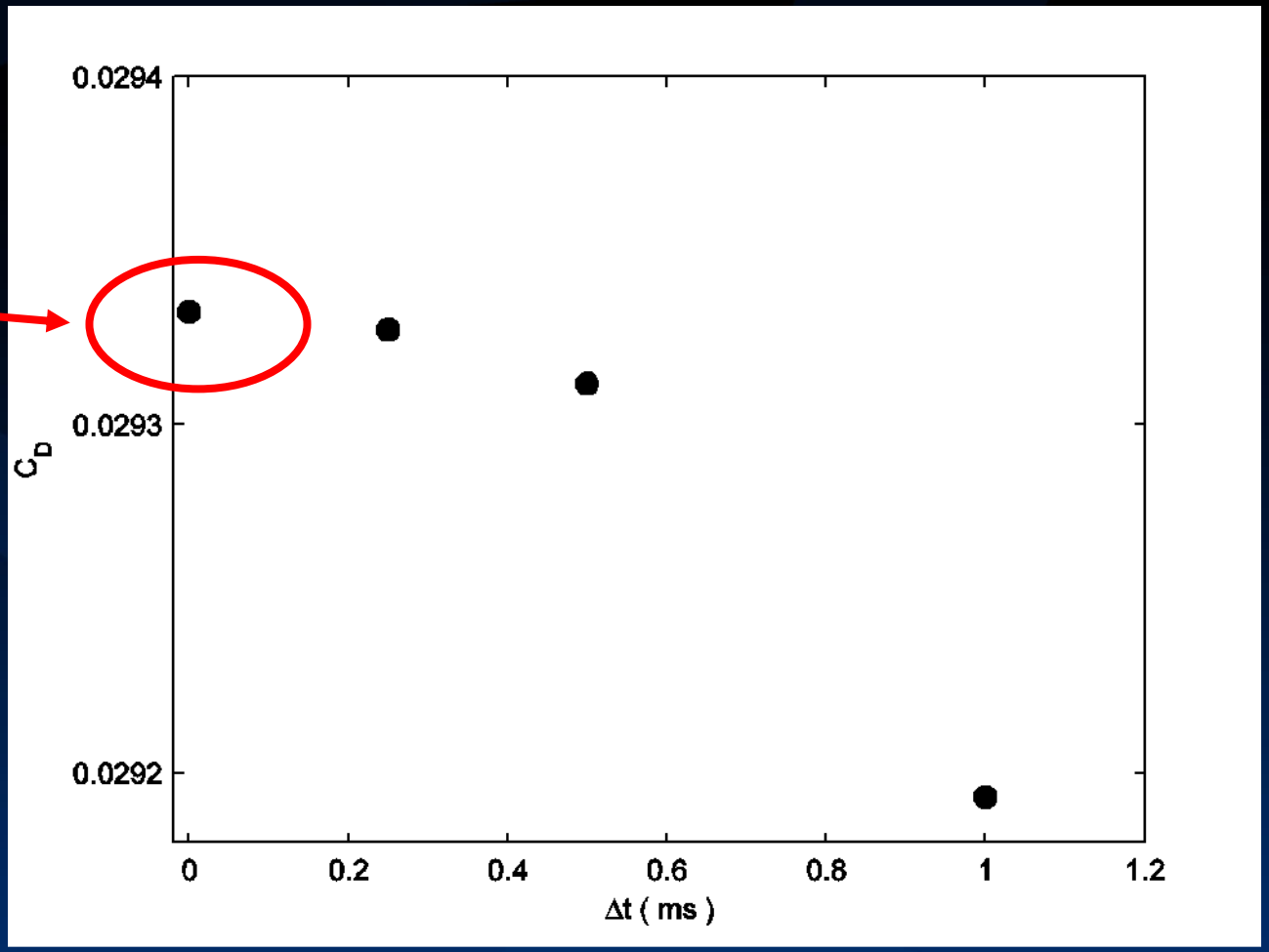


Total C_D vs. time

Temporal Convergence Results

CD-adapco

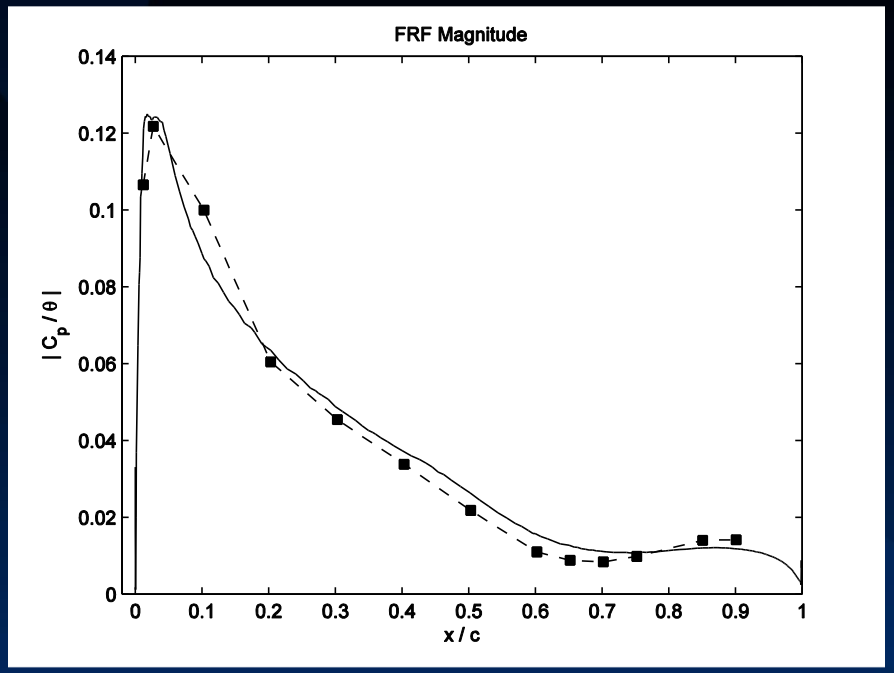
Richardson Extrapolation

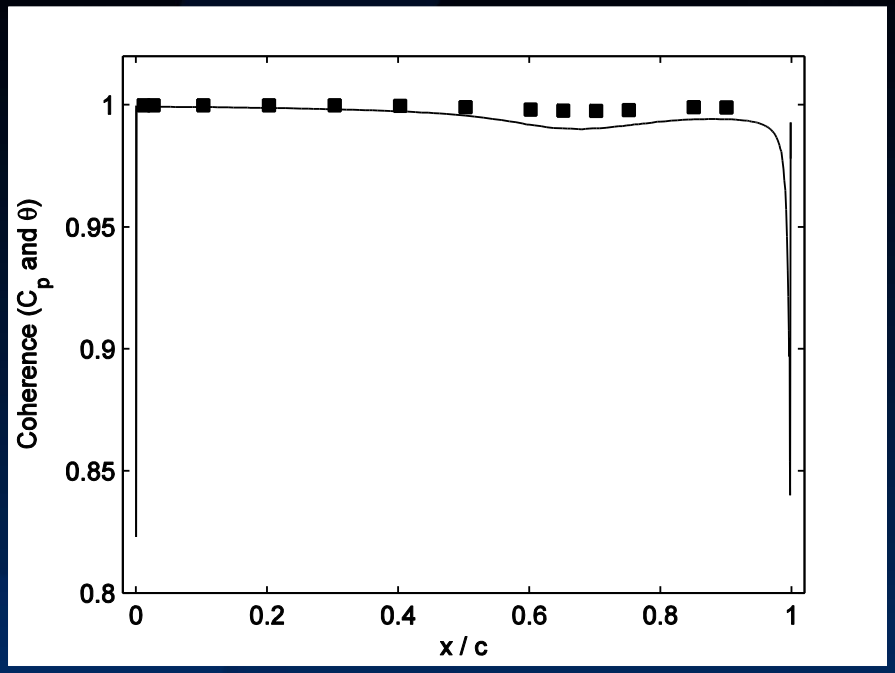


Time-Averaged Total C_D vs. time step size

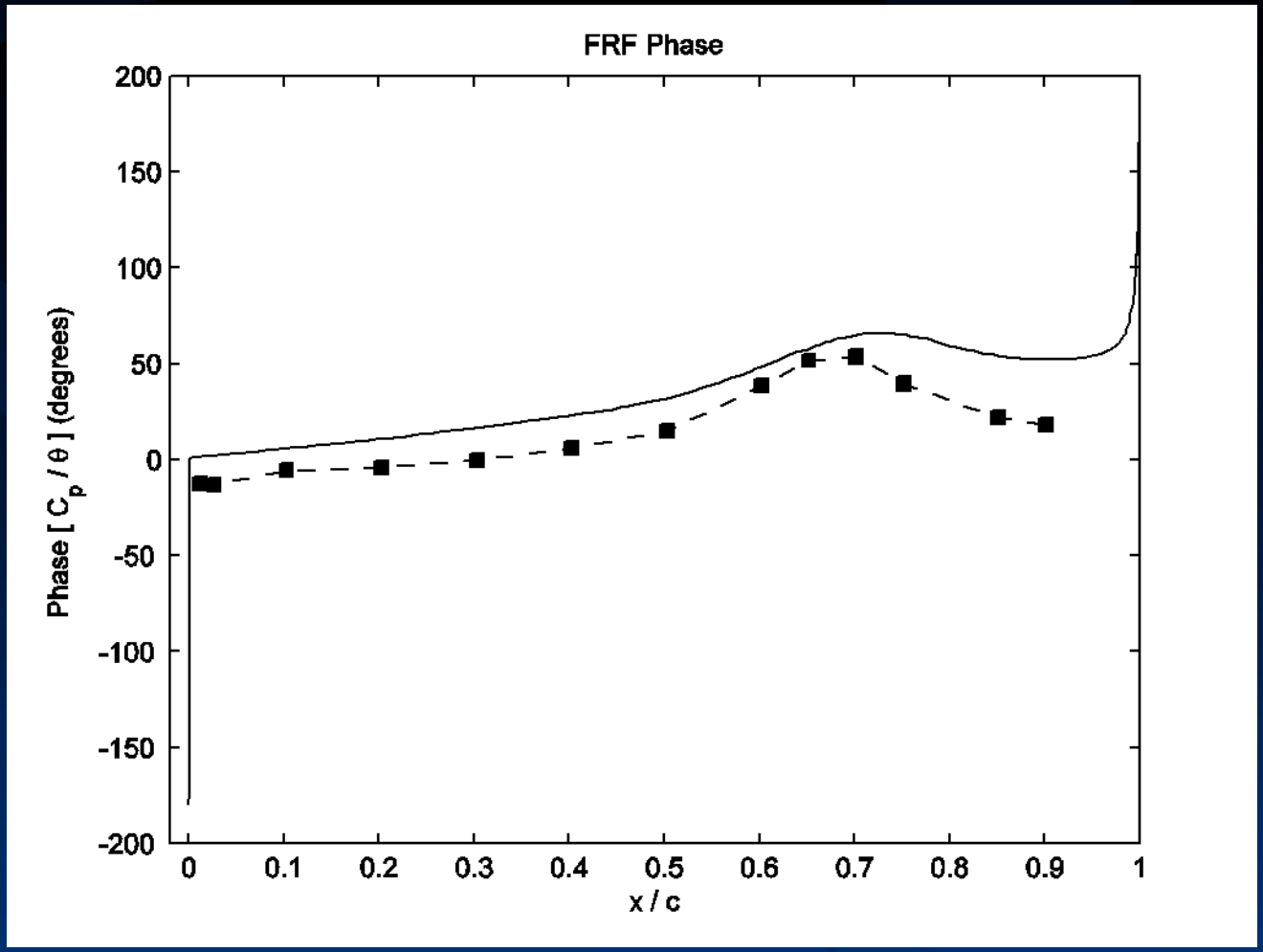
C_D within 0.02% of asymptotic value

FRF Results – Lower Surface @ 60%Span

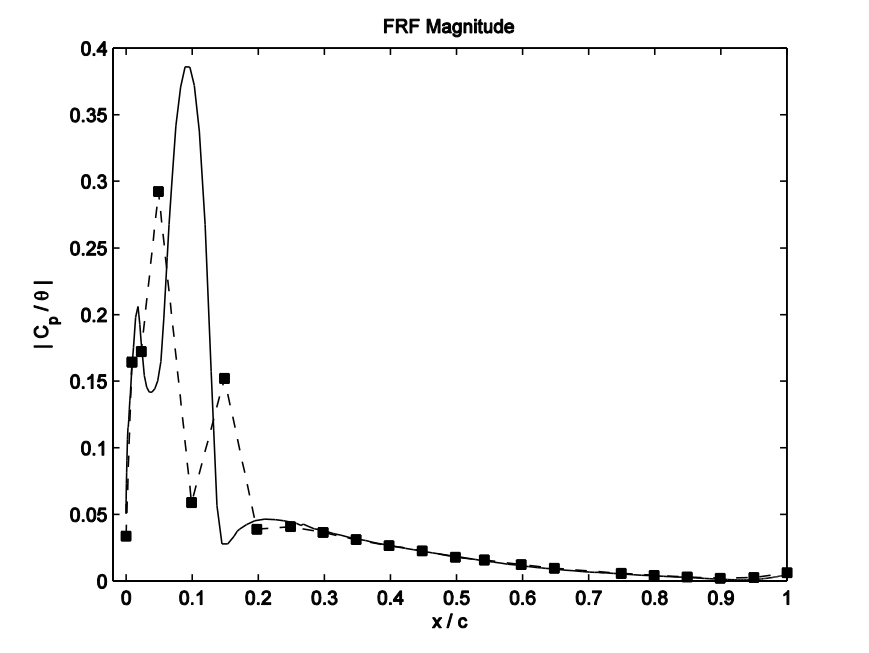


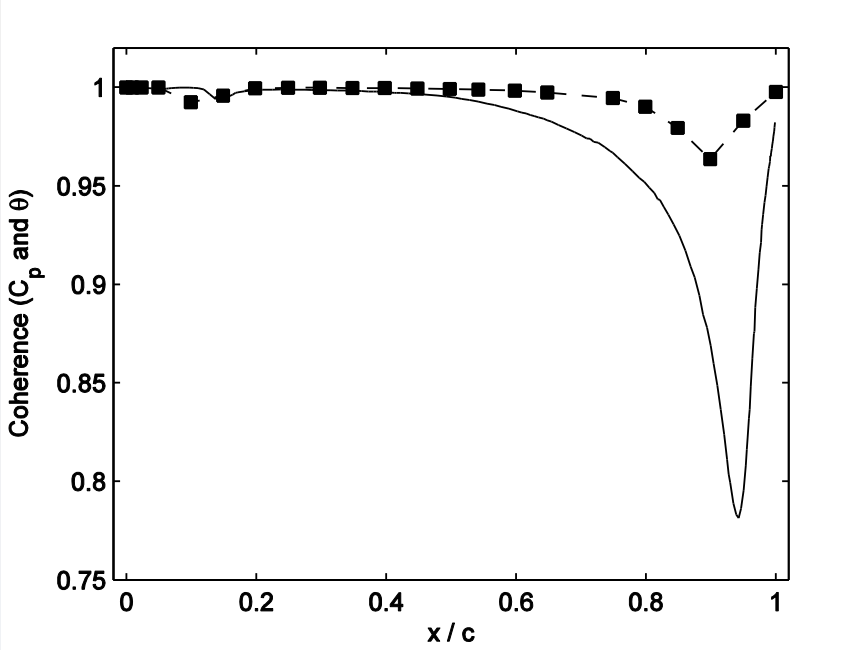


FRF Results – Lower Surface @ 60%Span

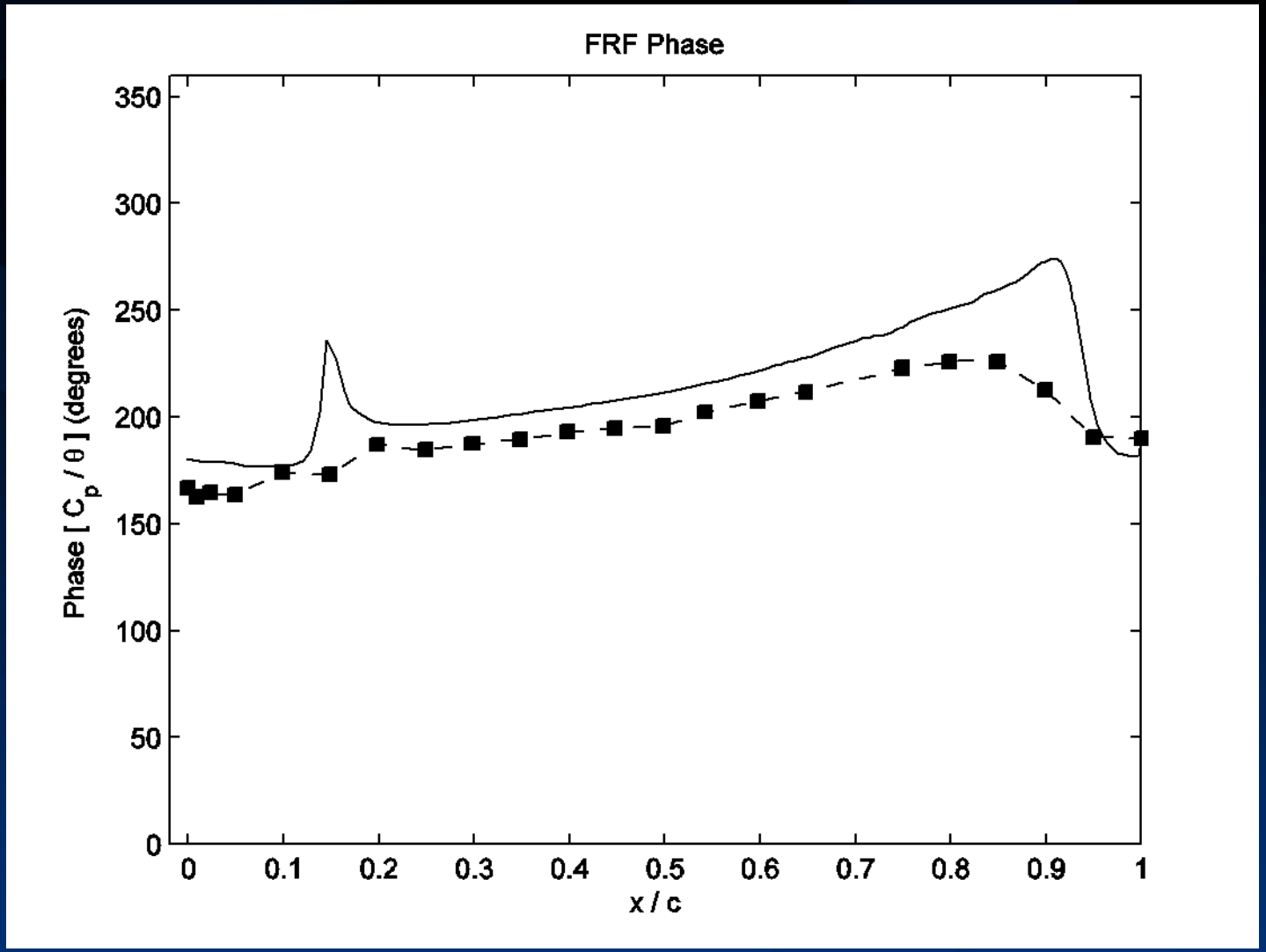


FRF Results – Upper Surface @ 60%Span

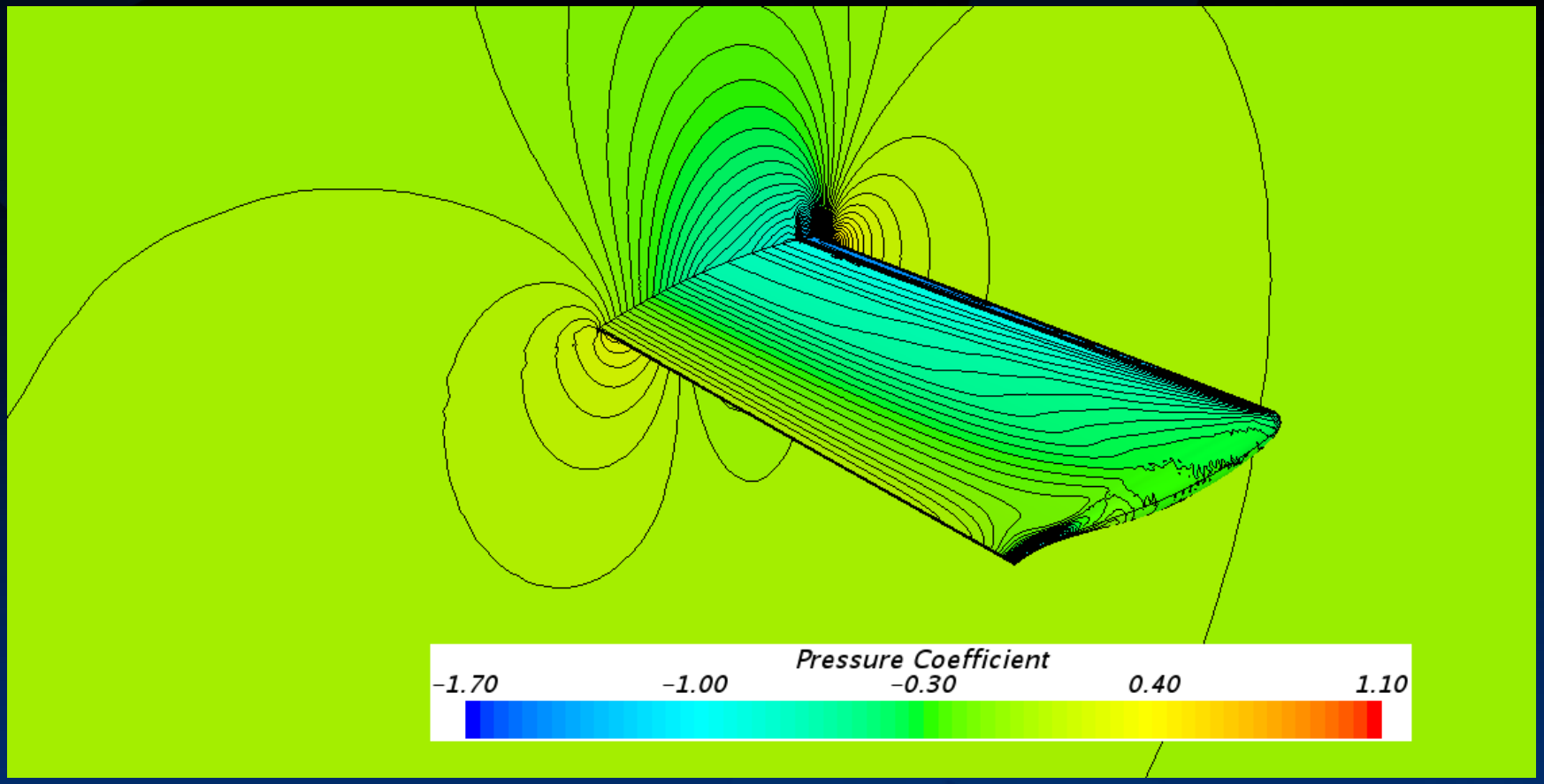




FRF Results – Upper Surface @ 60%Span



Case 1 Steady - Visualization



Pressure Coef. @ Medium Resolution Mesh