Computational Aerodynamic Analysis of Three-dimensional Ice Shapes on a NACA 23012 Airfoil

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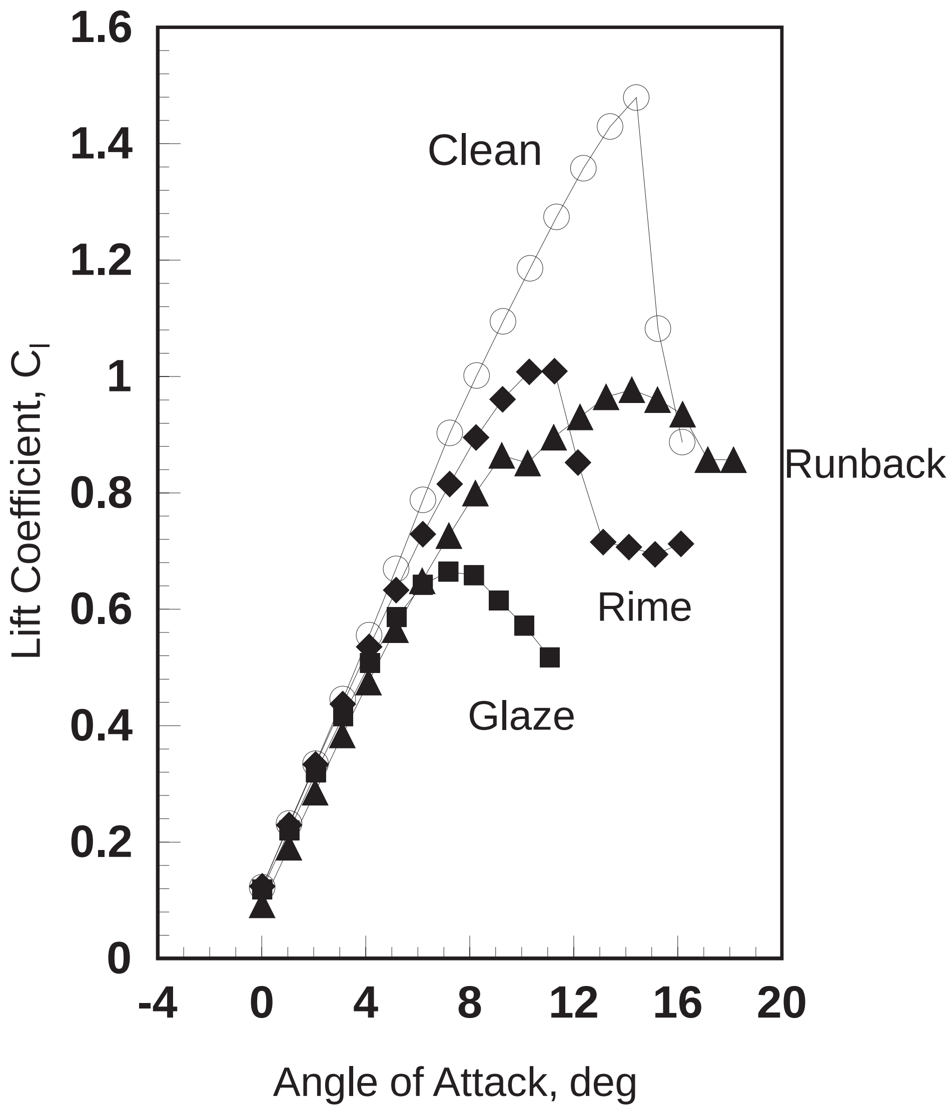
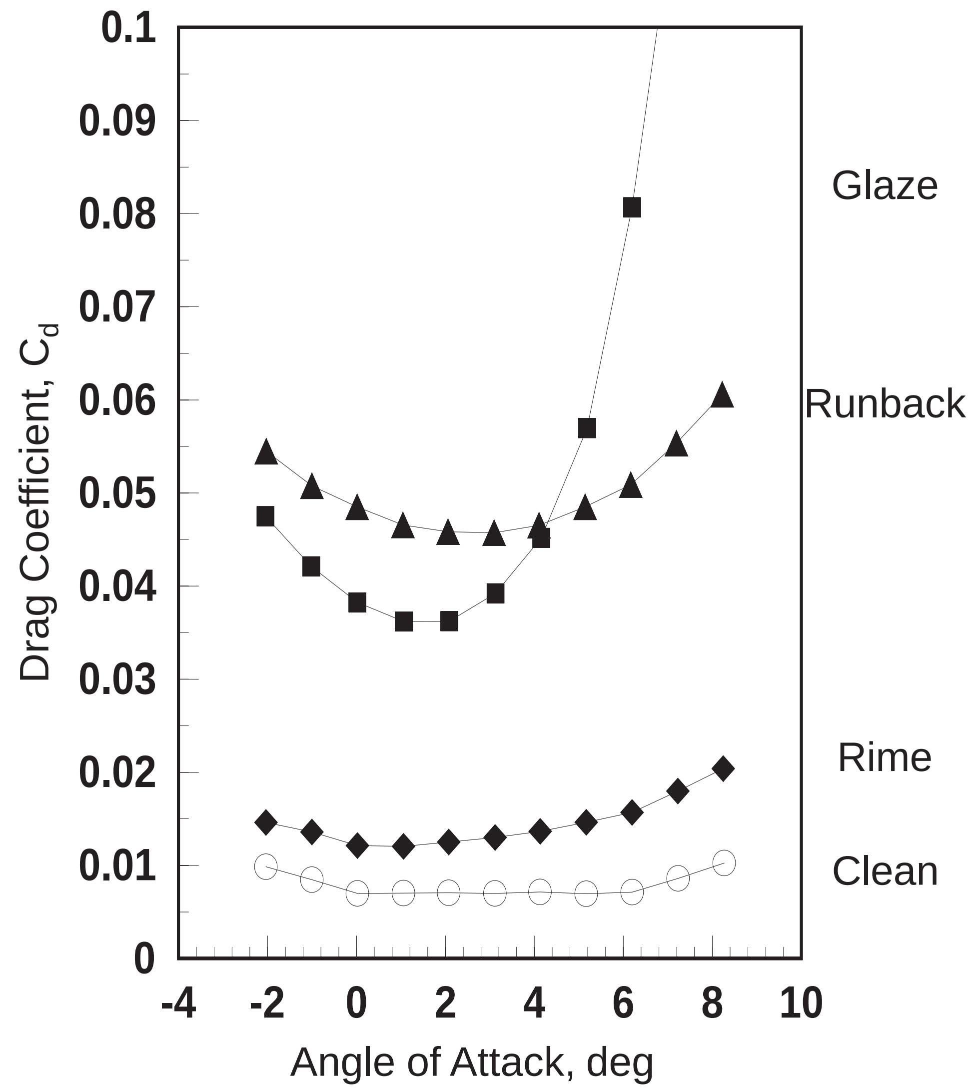
Overview

- Background
- Motivation
  - Ice Accretion Shapes
  - Workflow
- Approach
  - Grid Generation
  - CFD
- Results
- Future Work

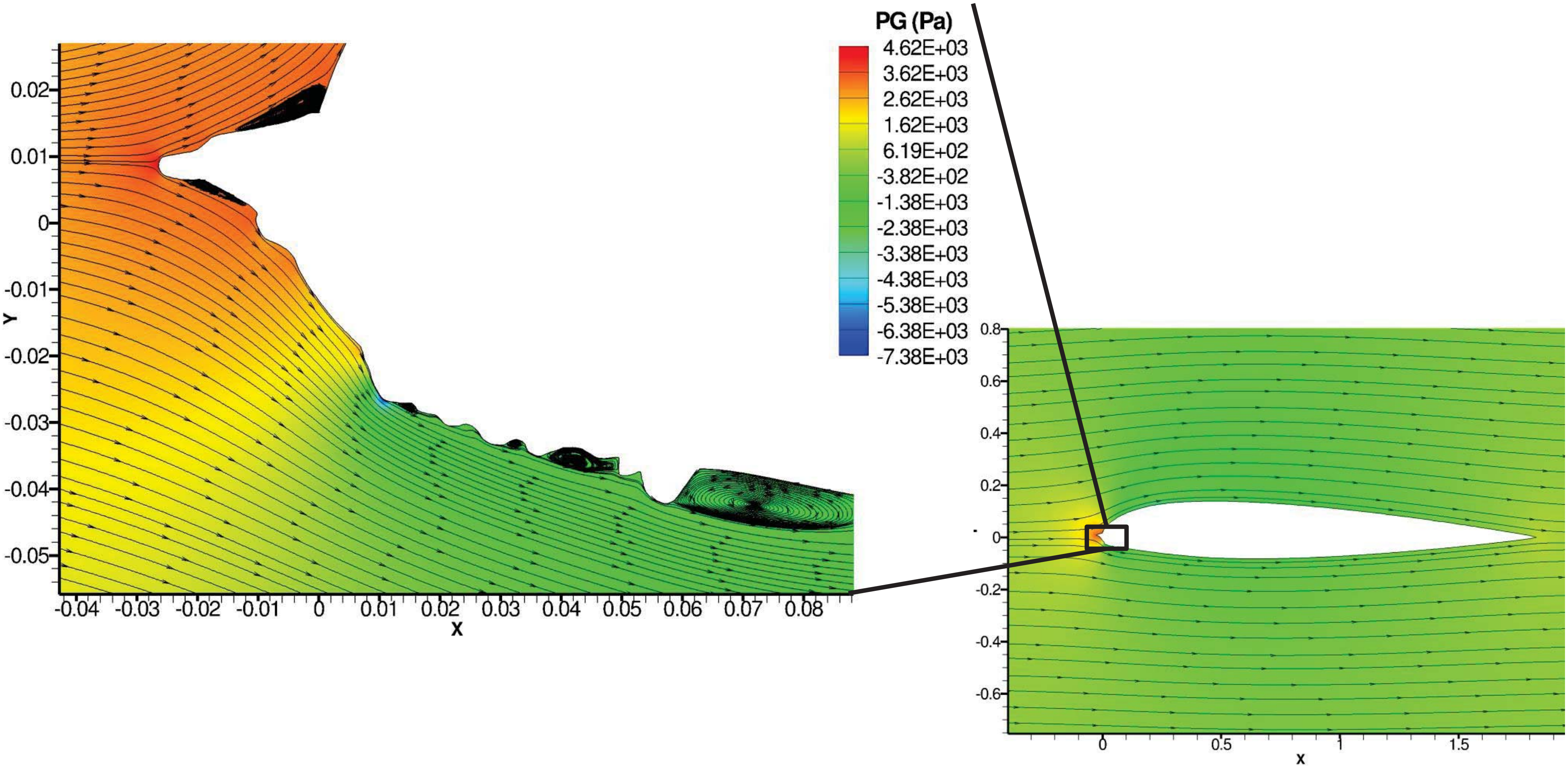
Background


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Lift Coefficient, C_l
-4
0
4
8
12
16
20
Angle of Attack, deg
Clean
Runback
Rime
Glaze


0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Drag Coefficient, C_d
-4
-2
0
2
4
6
8
10
Angle of Attack, deg
Glaze
Runback
Rime
Clean

Background

- To-date CFD analysis has been performed on, 2D cross-sections, 3D extrusions of 2D cross-sections, and 3D ice shapes generated by ice accretion codes

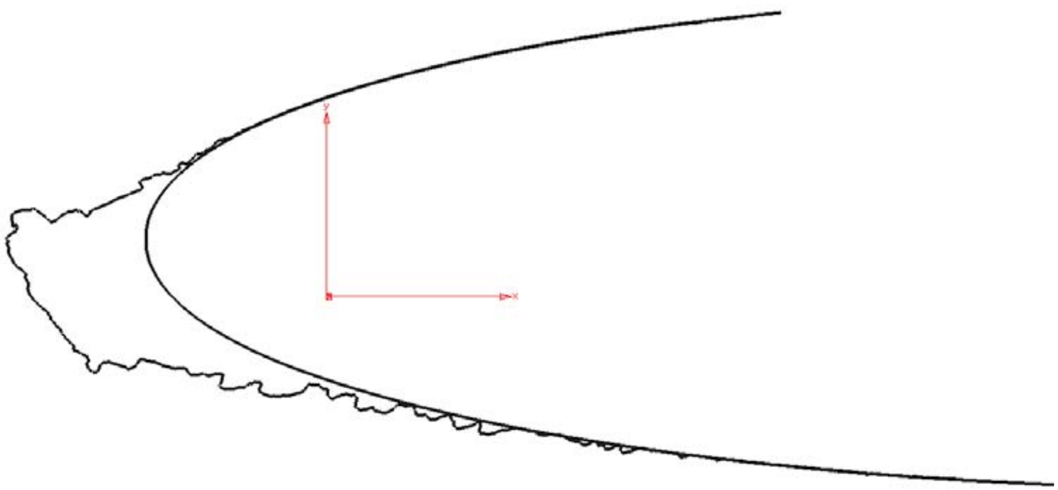


Motivation

- Complex 3D ice shape geometry data can now be collected
  - In-situ laser scans of ice accretion shapes
  - CAT scans have also been performed
  - Complete ice shape documentation, including surface roughness elements
- How good is good enough?
  - What level of ice shape detail must be simulated by ice accretion codes?
  - Detailed analysis of the aerodynamics and heat transfer mechanisms at the ice-liquid-air interface can shed light on the parameters of importance

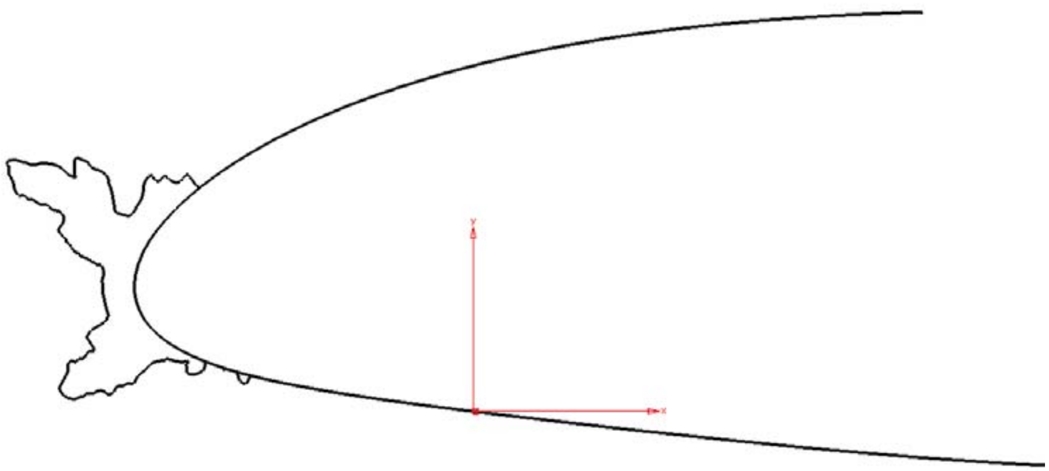
Ice Accretion Shapes

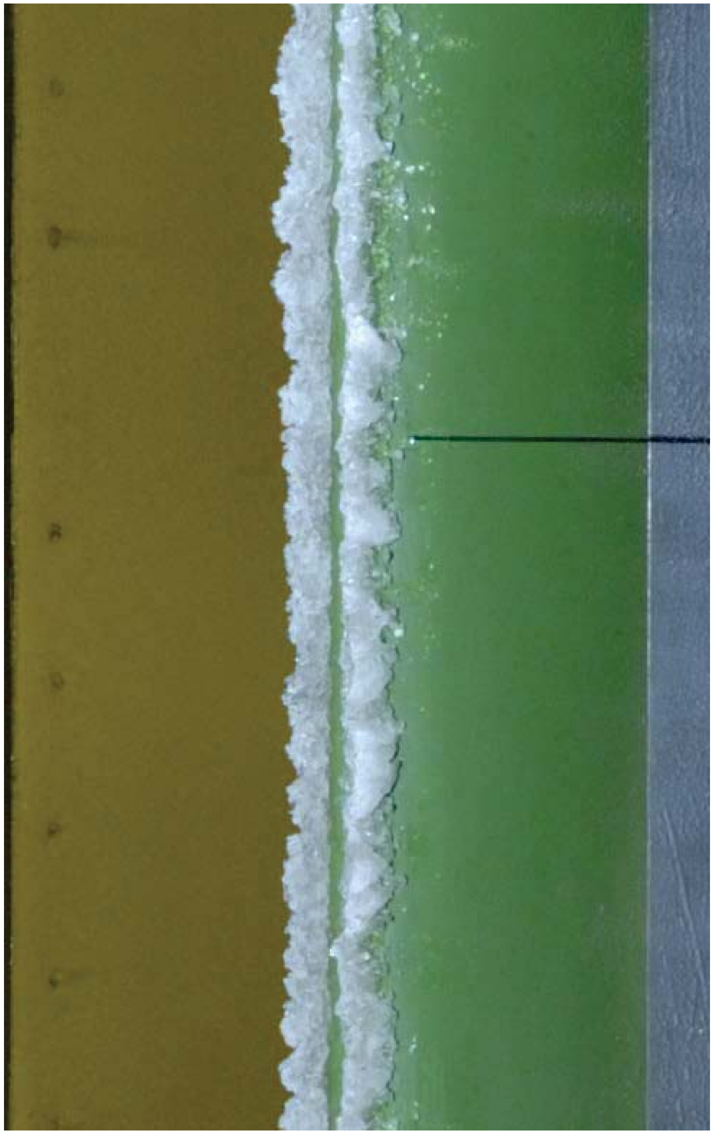
- Types of ice accretion
  - **Rime**



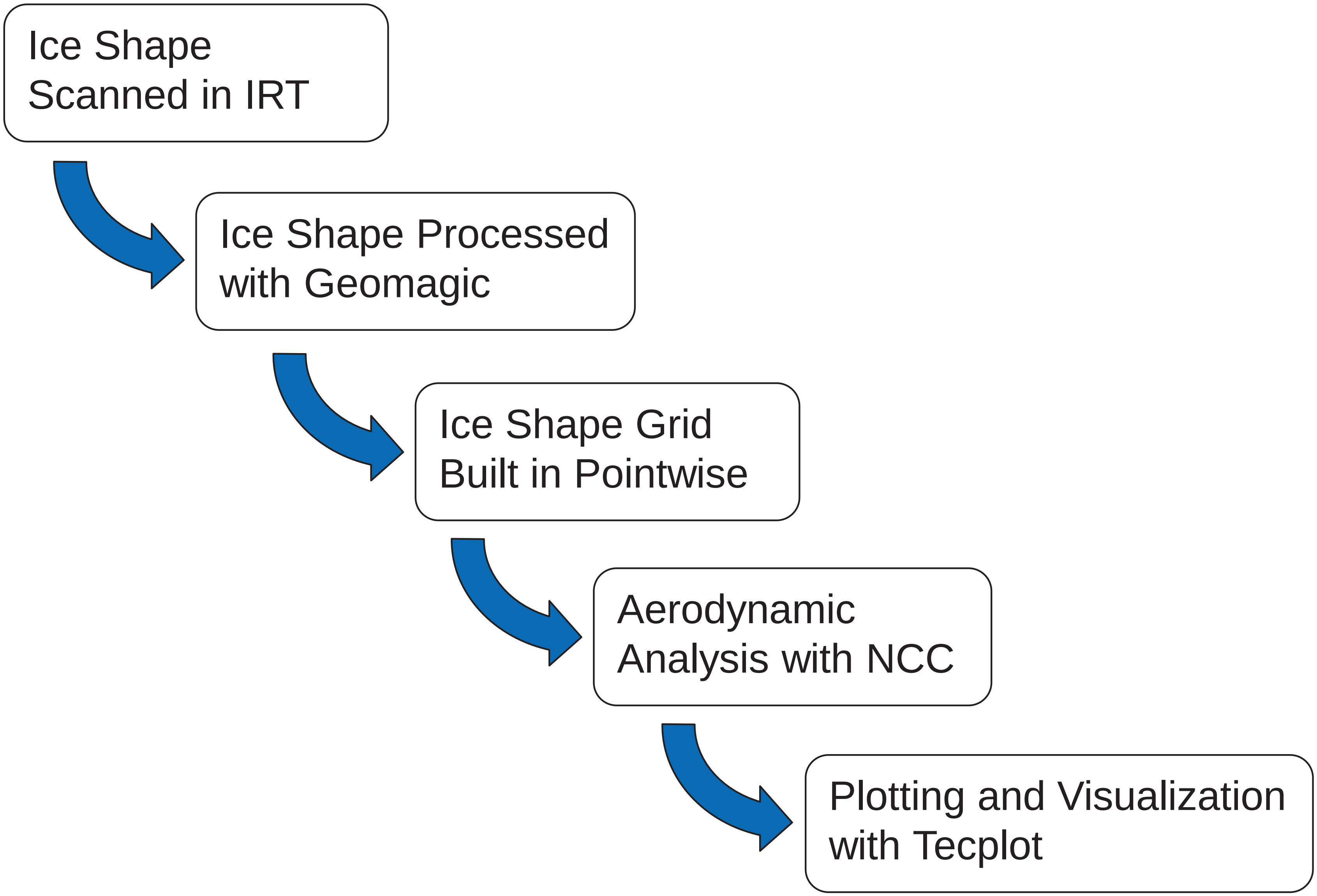
Ice Accretion Shapes

- Types of ice accretion
  - **Glaze**





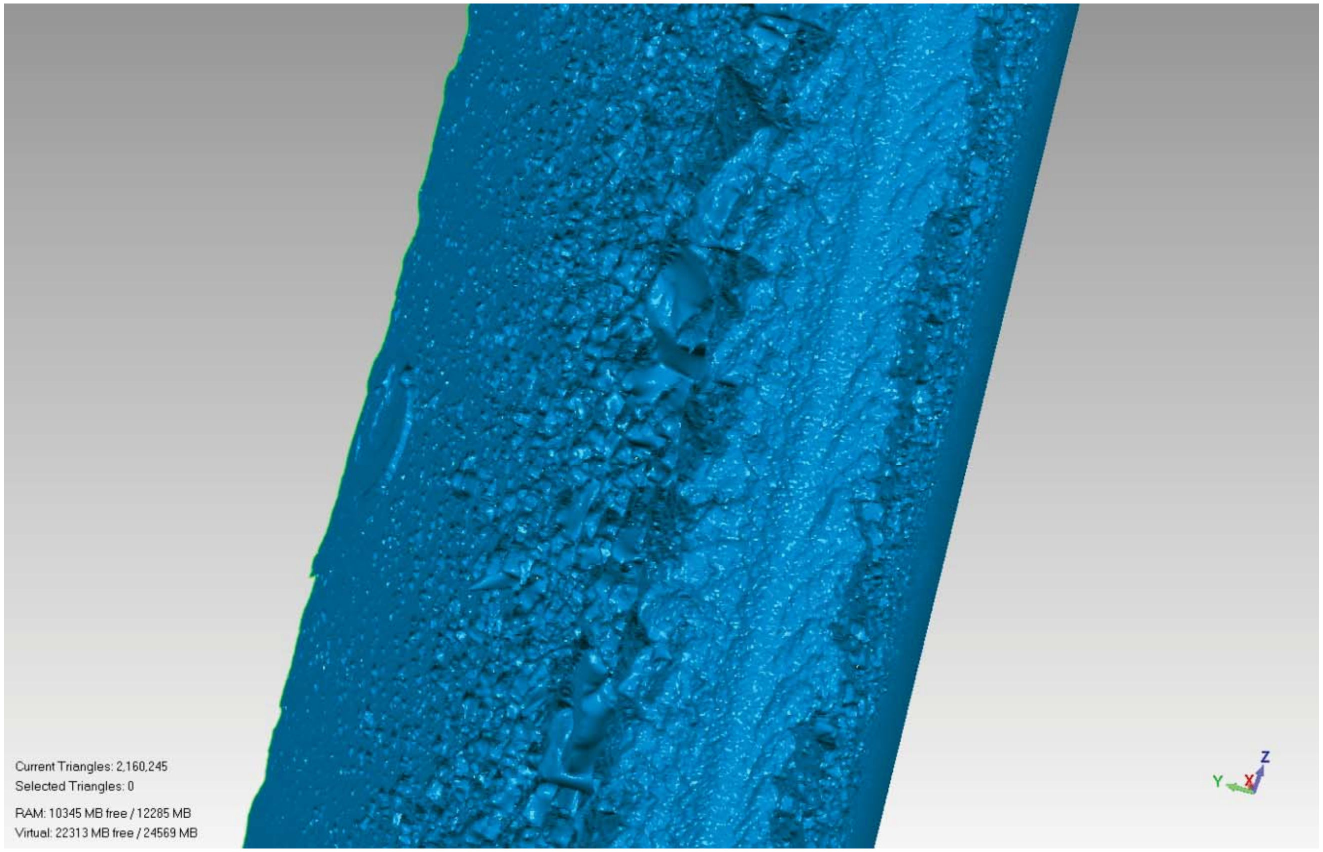
Workflow


Ice Shape Scanned in IRT
Ice Shape Processed with Geomagic
Ice Shape Grid Built in Pointwise
Aerodynamic Analysis with NCC
Plotting and Visualization with Tecplot

Approach (Grid Generation)

Geomagic

Commercial software used to create watertight surface from scanned point cloud data



Lee, S., Broeren, A. P., Addy, H. E., Jr., Sills, R., and Pifer, E. M., "Development of 3-D Ice Accretion Measurement Method," NASA/TM-2012-217702, AIAA Paper-2012-2938, 2012

Approach (Grid Generation)

Pointwise

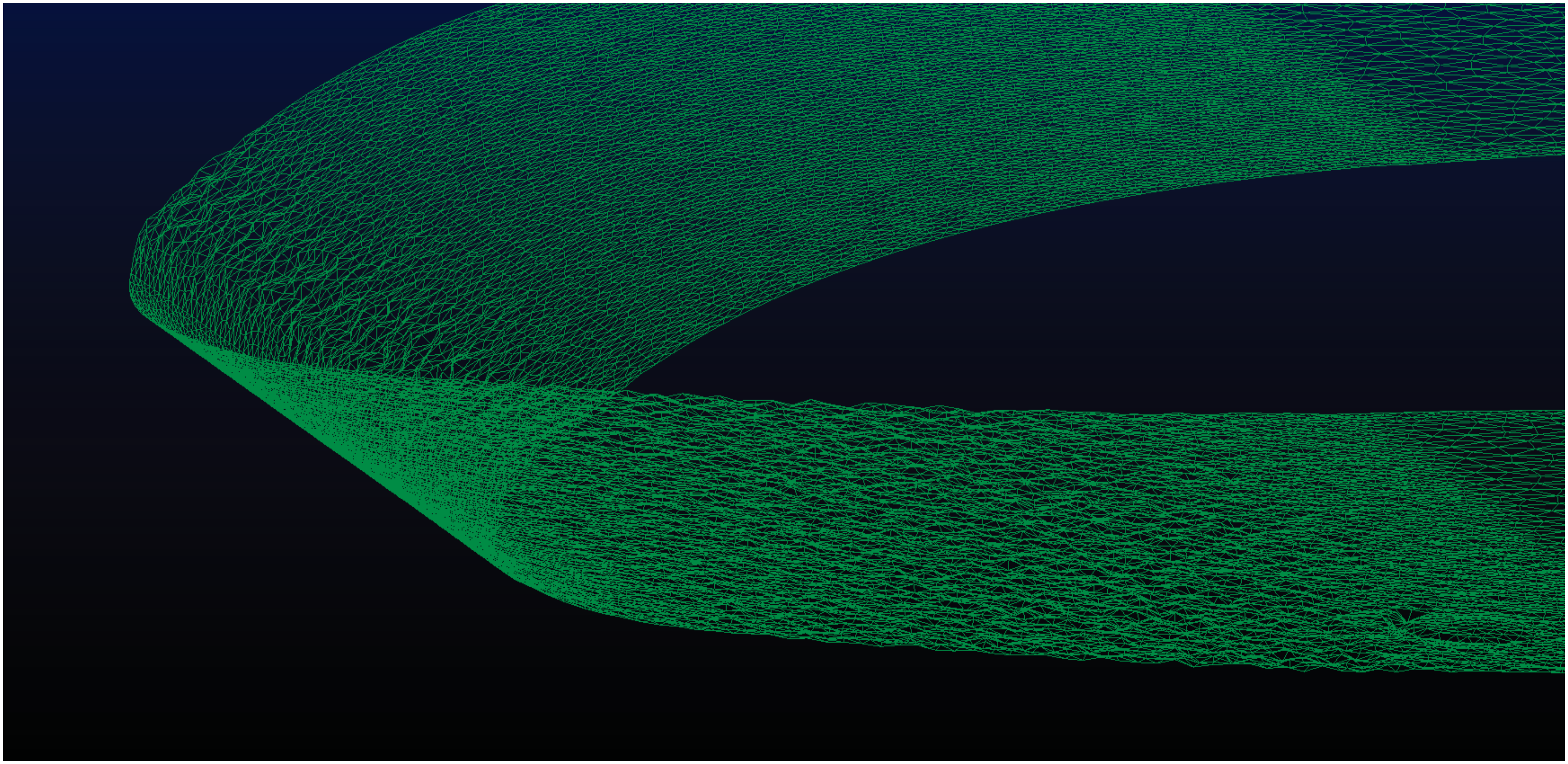
Commercial software used to import ice shape geometry data and create grid for CFD analysis

1. **Import Geometry**
    - **Database**
    - **Surface Grid**

Approach (Grid Generation)

Pointwise

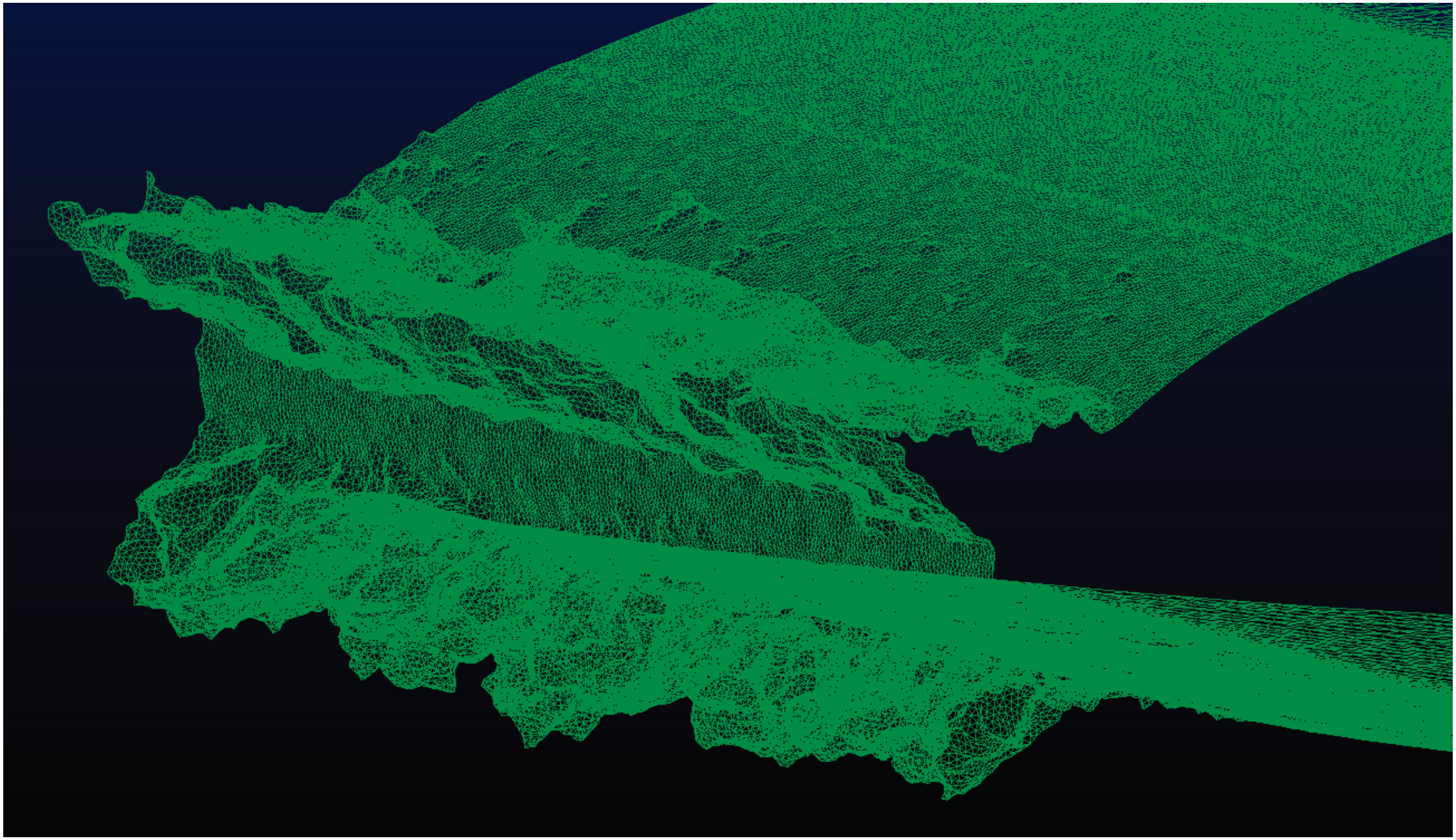
1. Import Geometry
2. **Create Surface Grid - Rime**



Approach (Grid Generation)

Pointwise

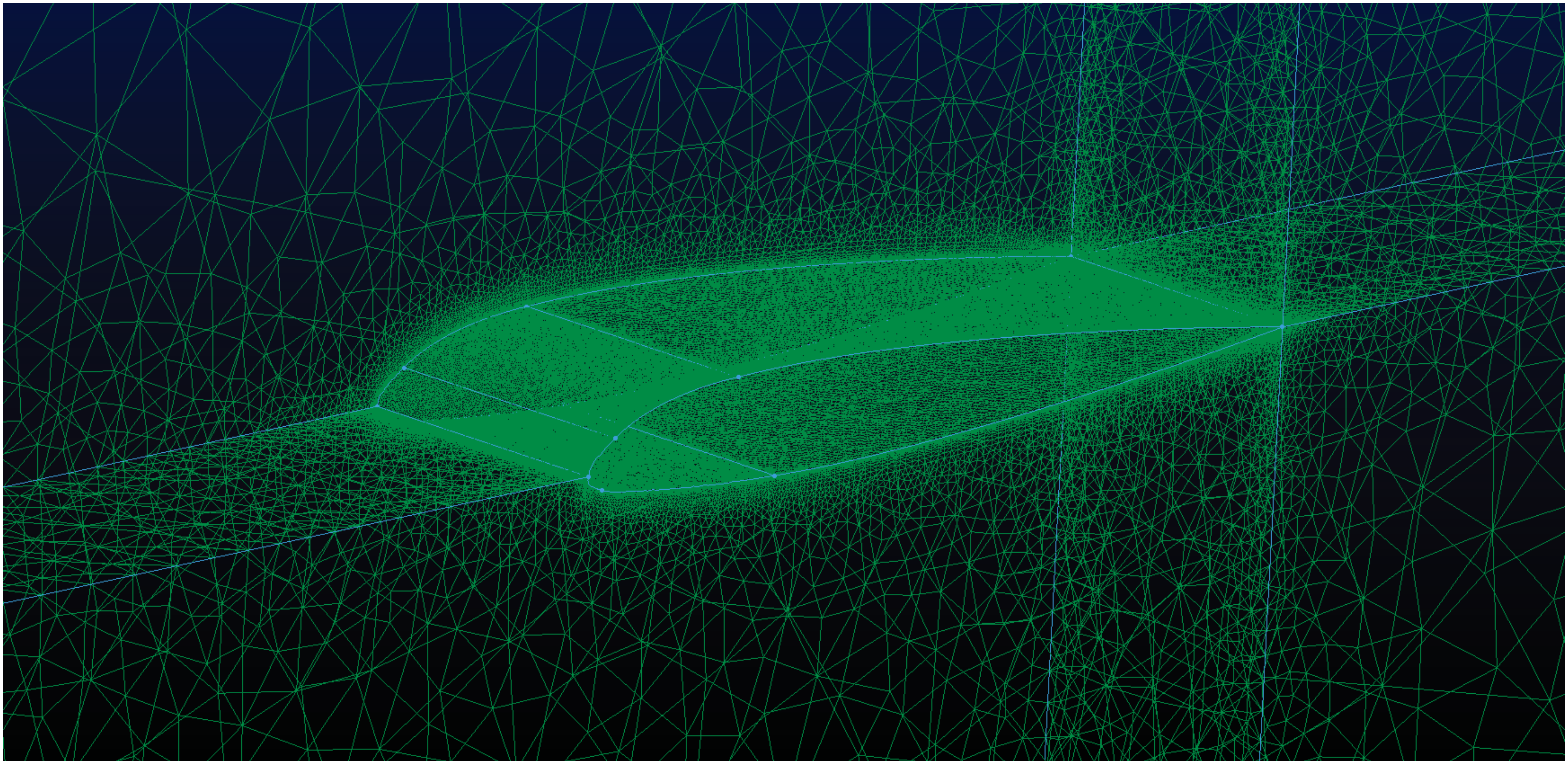
1. Import Geometry
2. **Create Surface Grid - Horn**



Approach (Grid Generation)

Pointwise

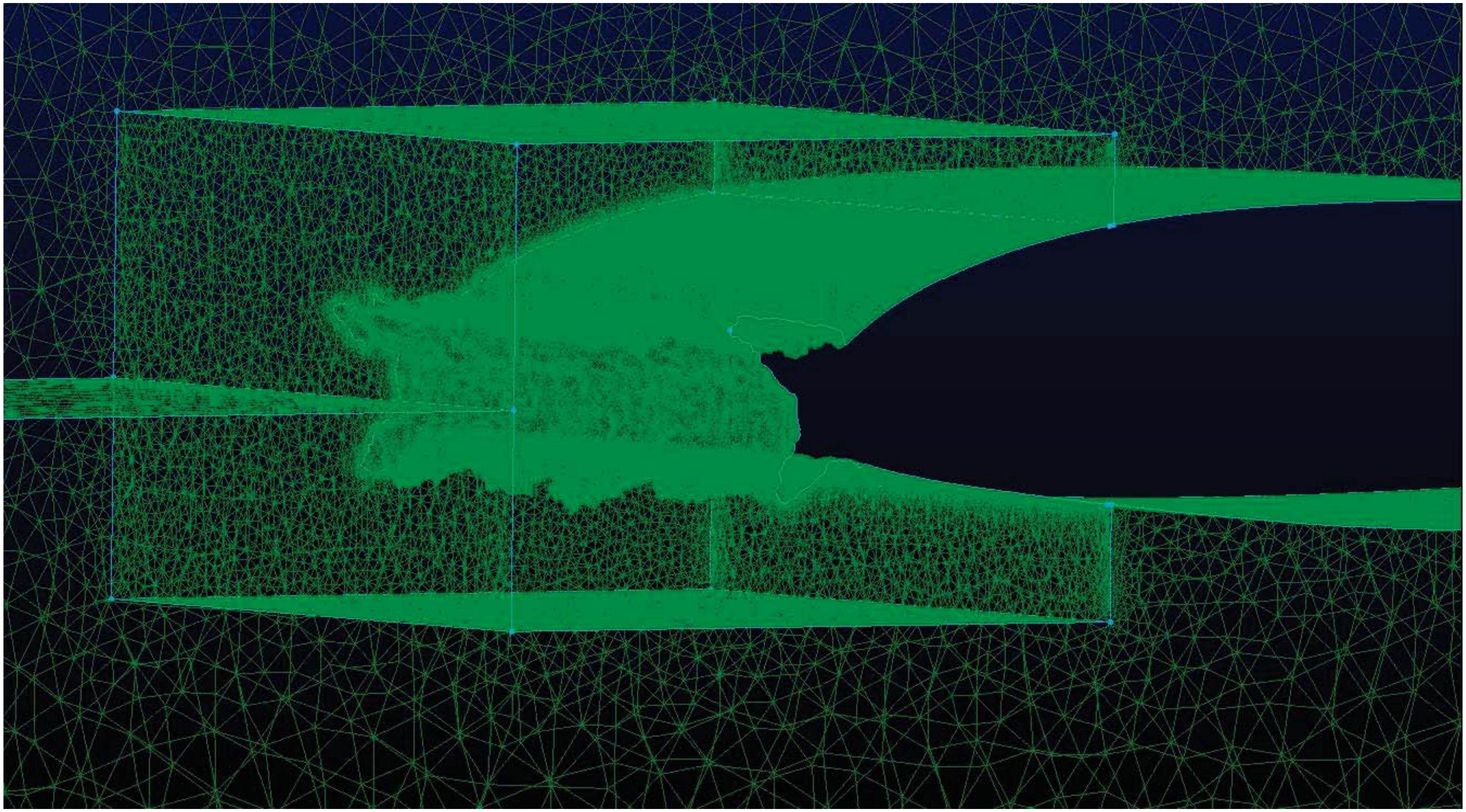
1. Import Geometry
2. Create Surface Grid
3. **Create Volume Grid - Rime**



Approach (Grid Generation)

Pointwise

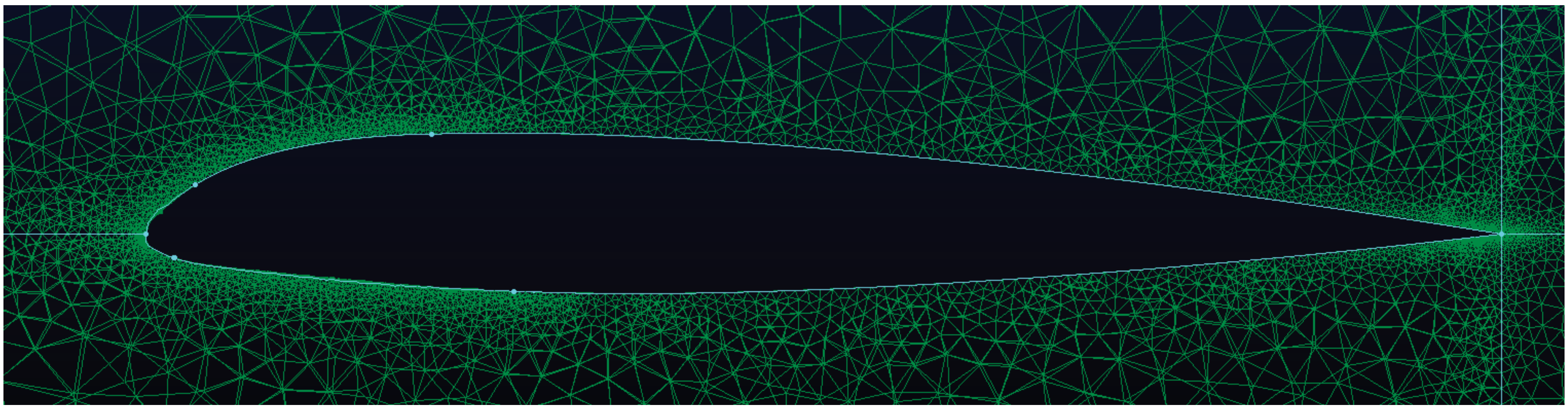
1. Import Geometry
2. Create Surface Grid
3. **Create Volume Grid - Horn**

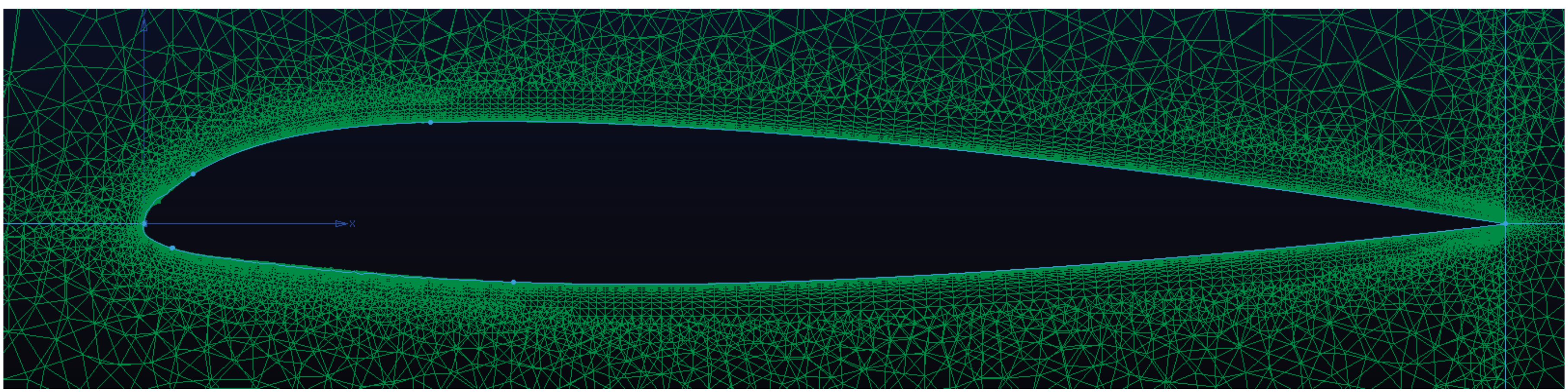


Approach (Grid Generation)

Pointwise

1. Import Geometry
2. Create Surface Grid
3. Create Volume Grid
4. **Refinement**

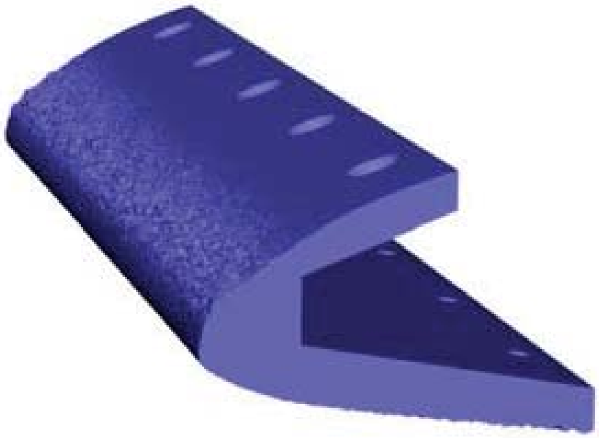




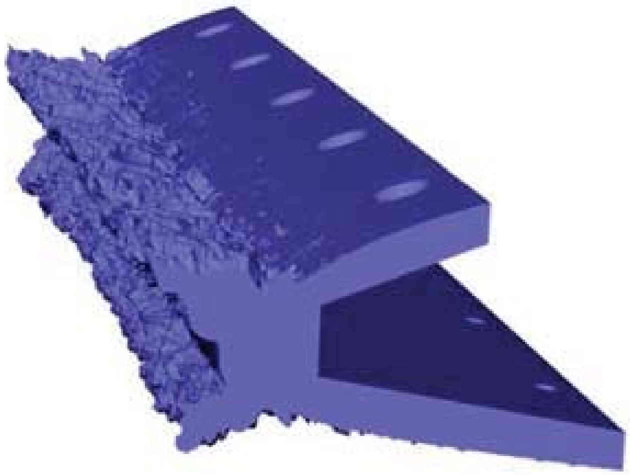
Statistics of Initial Grids

	Ice Shape Geometry	Chord length (in)	Span length (in)	Grid Type	Volume grid cell count
Clean	-	18	12	Structured	0.5 million
Rime	ED1966	18	6	Unstructured	1.6 million
Glaze	ED1978	18	6	Unstructured	3.7 million

Broeren, A.P., Addy, H.E., Lee, S., and Monastero, M.C., "Validation of 3-D Ice Accretion Measurement Methodology for Experimental Aerodynamic Simulation," AIAA 6th Atmospheric and Space Environments Conference, Atlanta, GA, June 16-20, 2014



ED1966



ED1978

National Combustion Code (NCC)

- Solver
  - Finite-volume
  - Explicit, four-stage Runge-Kutta integration algorithm
  - RANS, URANS
- Turbulence
  - $k - \epsilon$ model
  - higher order, non-linear method
  - Partially Resolved Numerical Simulation (PRNS)
- Parallel Computing
  - Parallel Virtual Machine (PVM)
  - Message Passing Interface (MPI)

Liu, N.-S. and Shih, T.-H., "Turbulent Modeling for Very Large-Eddy Simulation," AIAA Journal, Vol. 44, No. 4, April 2006

Domain Conditions

- Boundary Conditions
  - Velocity Inlet
  - Pressure Outlet
  - No-slip Airfoil Wall
  - Periodic Side Walls

- Freestream Conditions

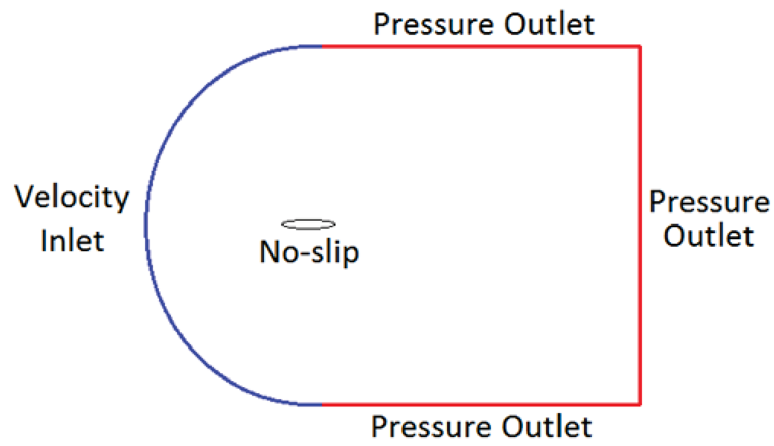
  $M = 0.10, 0.18$

  $Re = 1.0\text{x}10^6, 1.8\text{x}10^6$

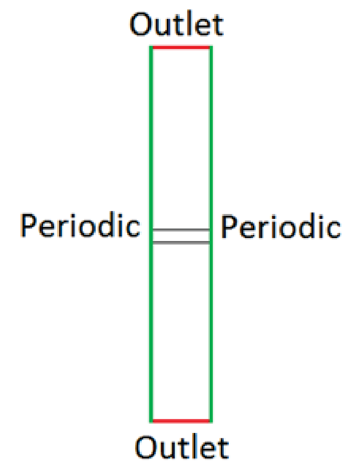
  $P_\infty = 98{,}595$ [Pa]

  $T_\infty = 294.3$ [K]

  $\alpha = 0° \text{ to } 10°$

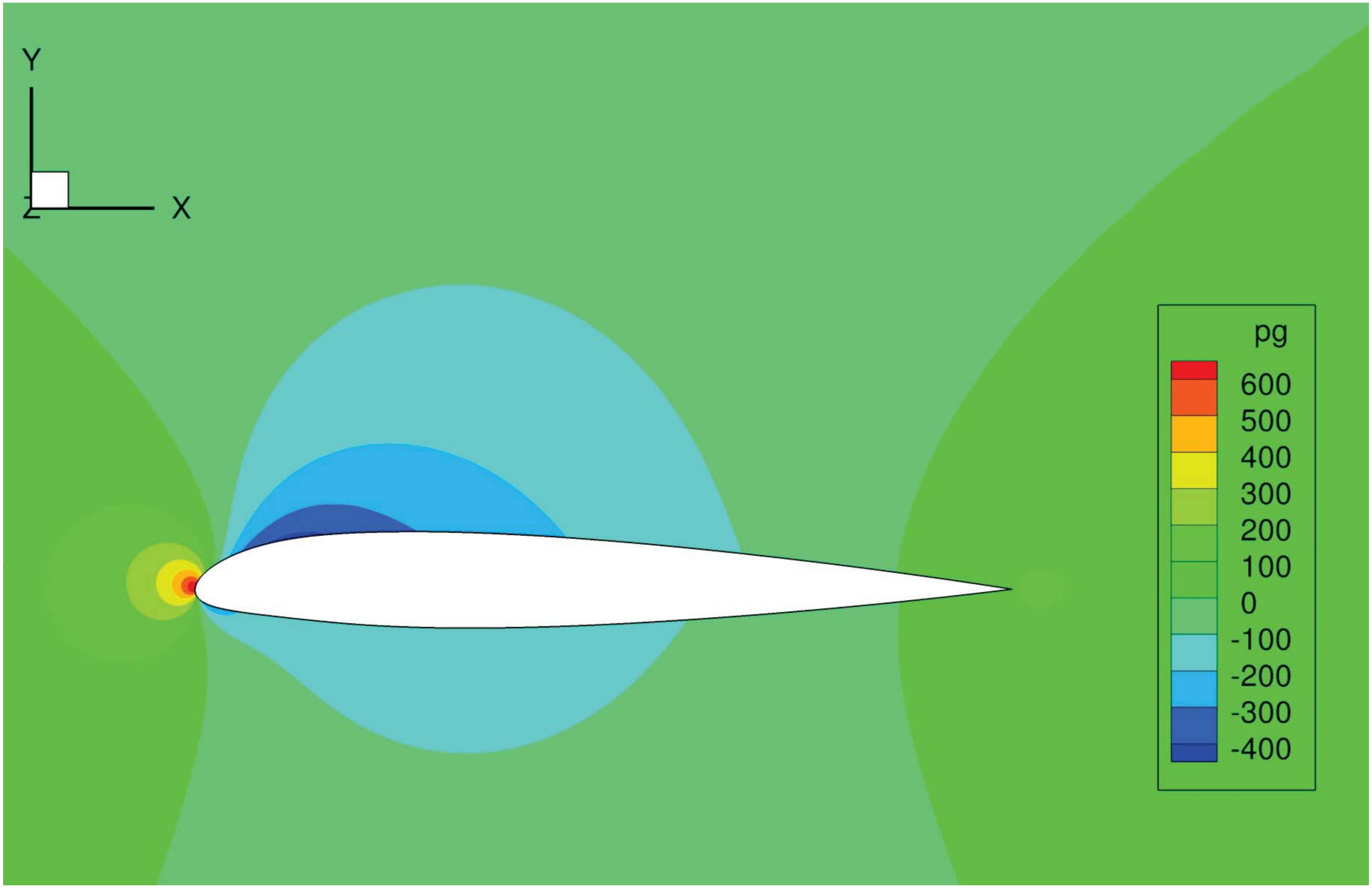


Side View

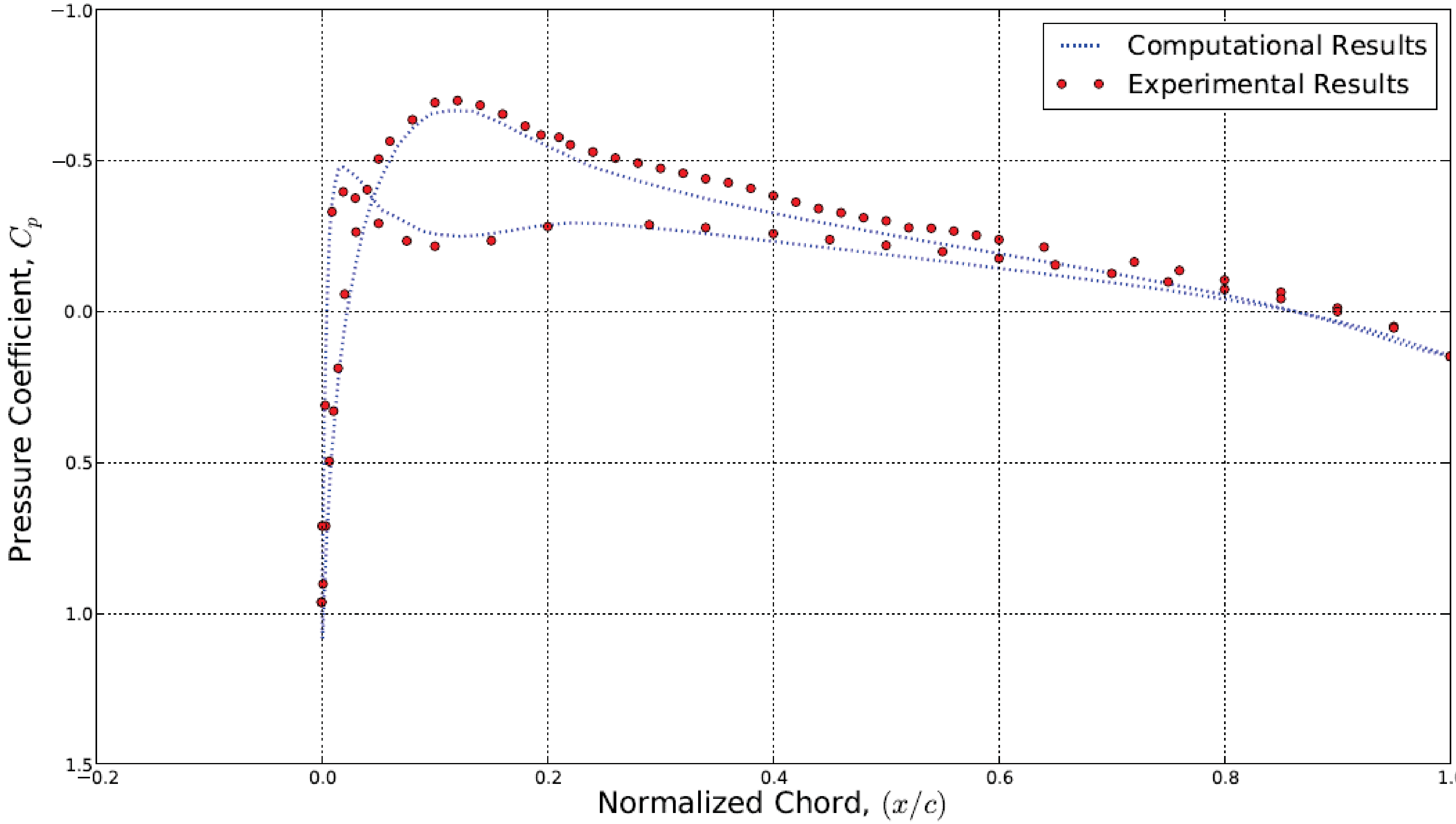


Front View

Clean Wing (M=0.10 @ 0°)

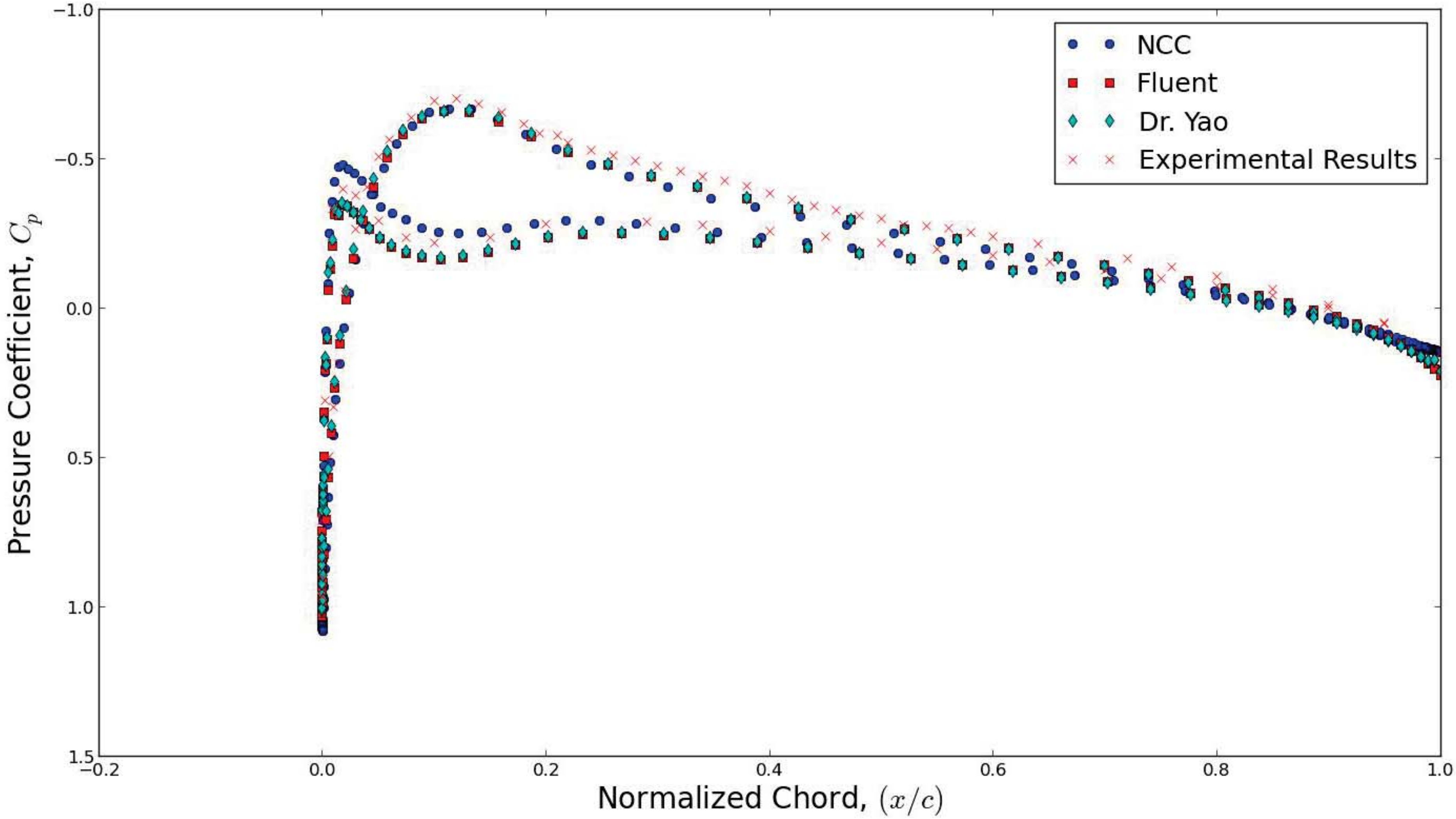


Clean Wing (M=0.10 @ 0°)



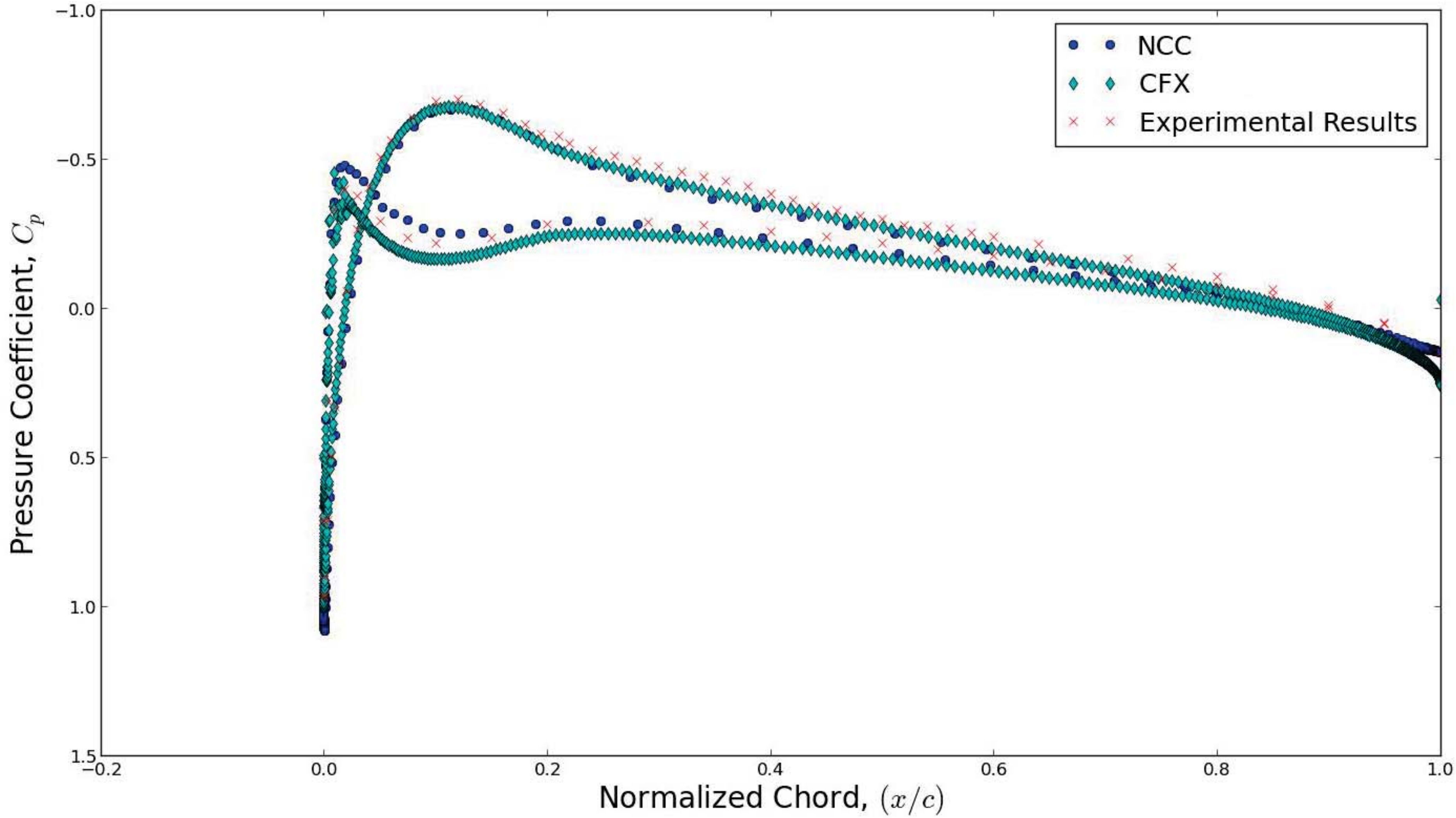
Clean Wing (M=0.10 @ 0°)

Other CFD Solvers

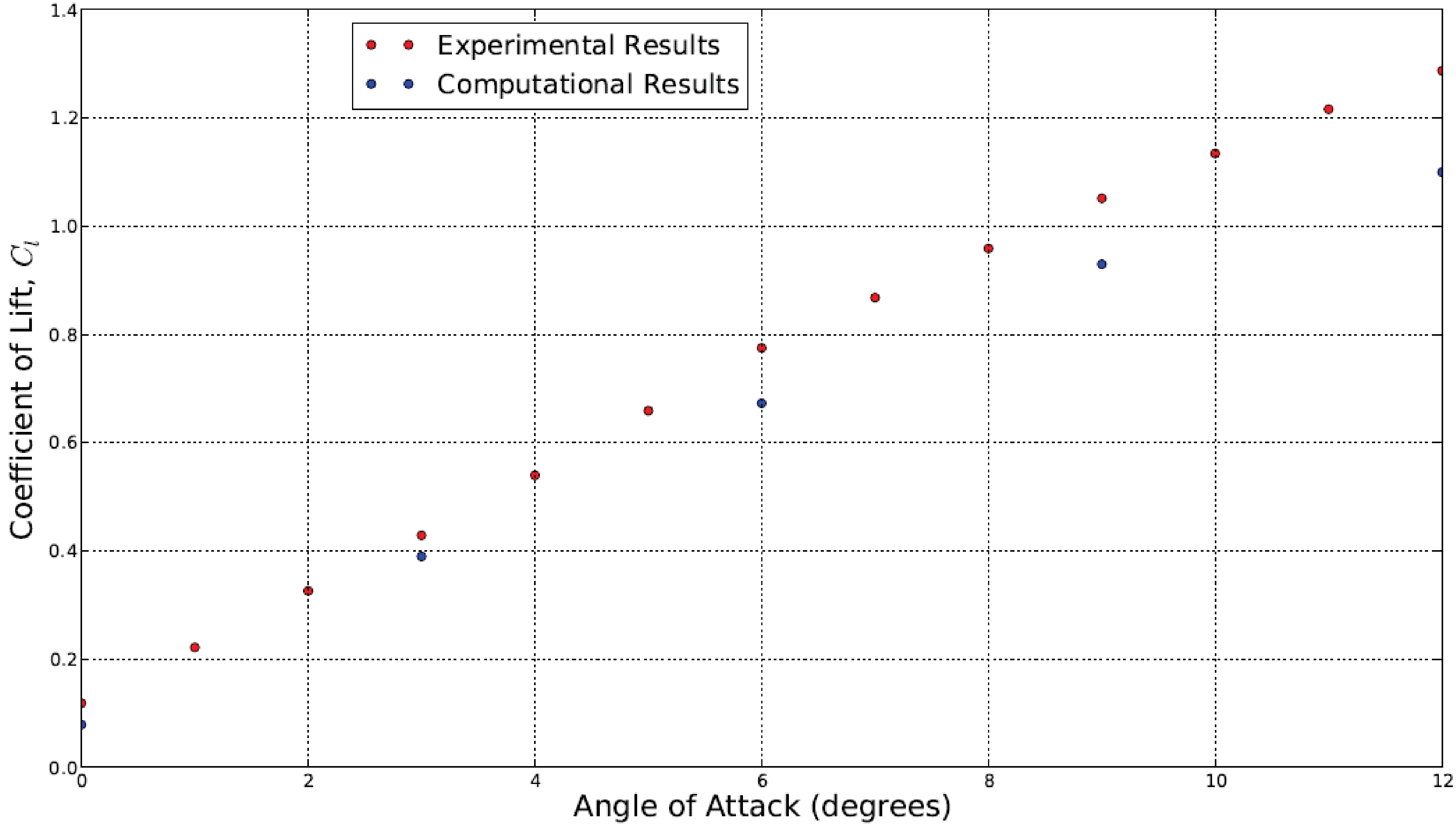


Clean Wing (M=0.10 @ 0°)

Other CFD Solvers

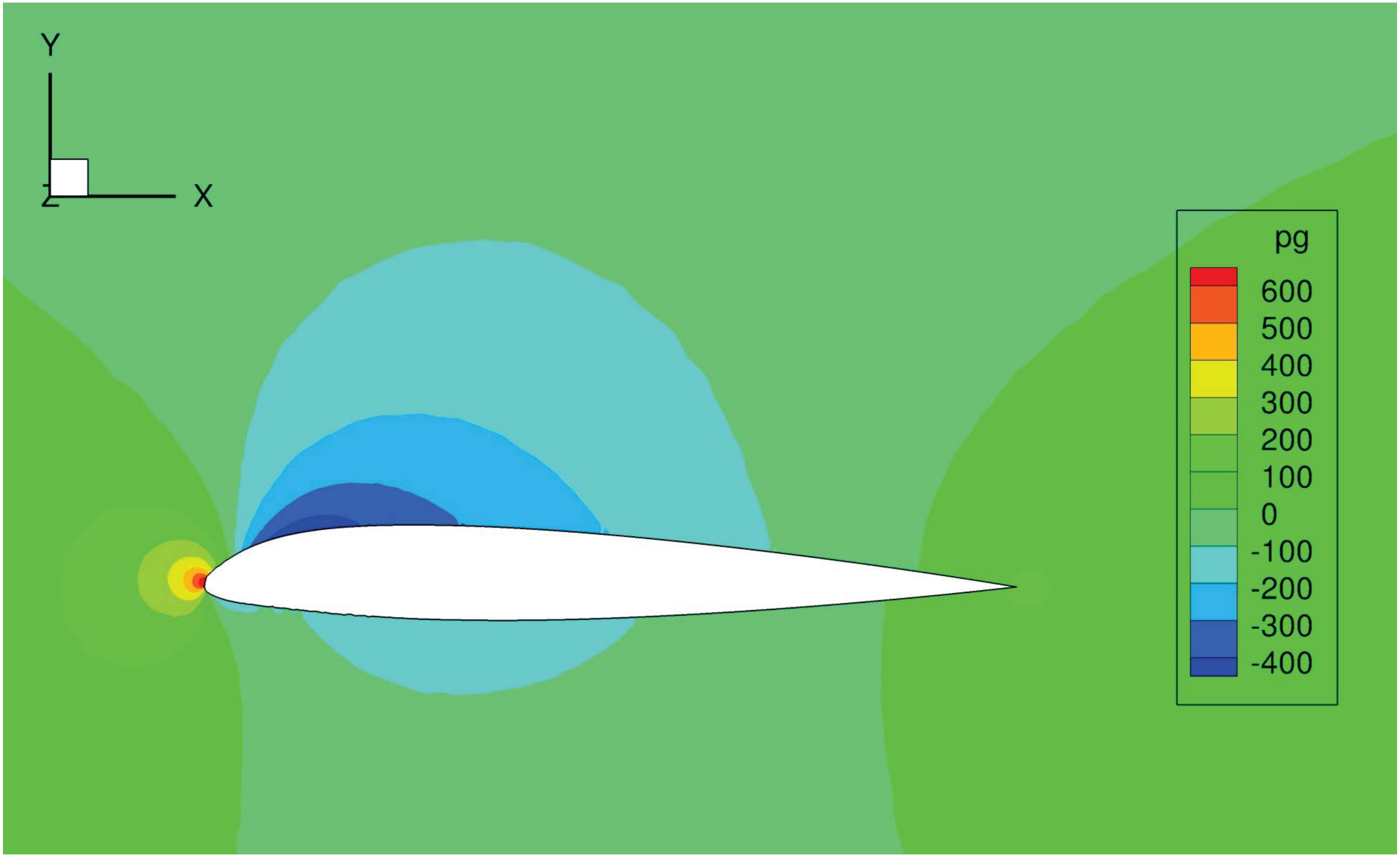


Clean Wing C_L Curve (M=0.10)



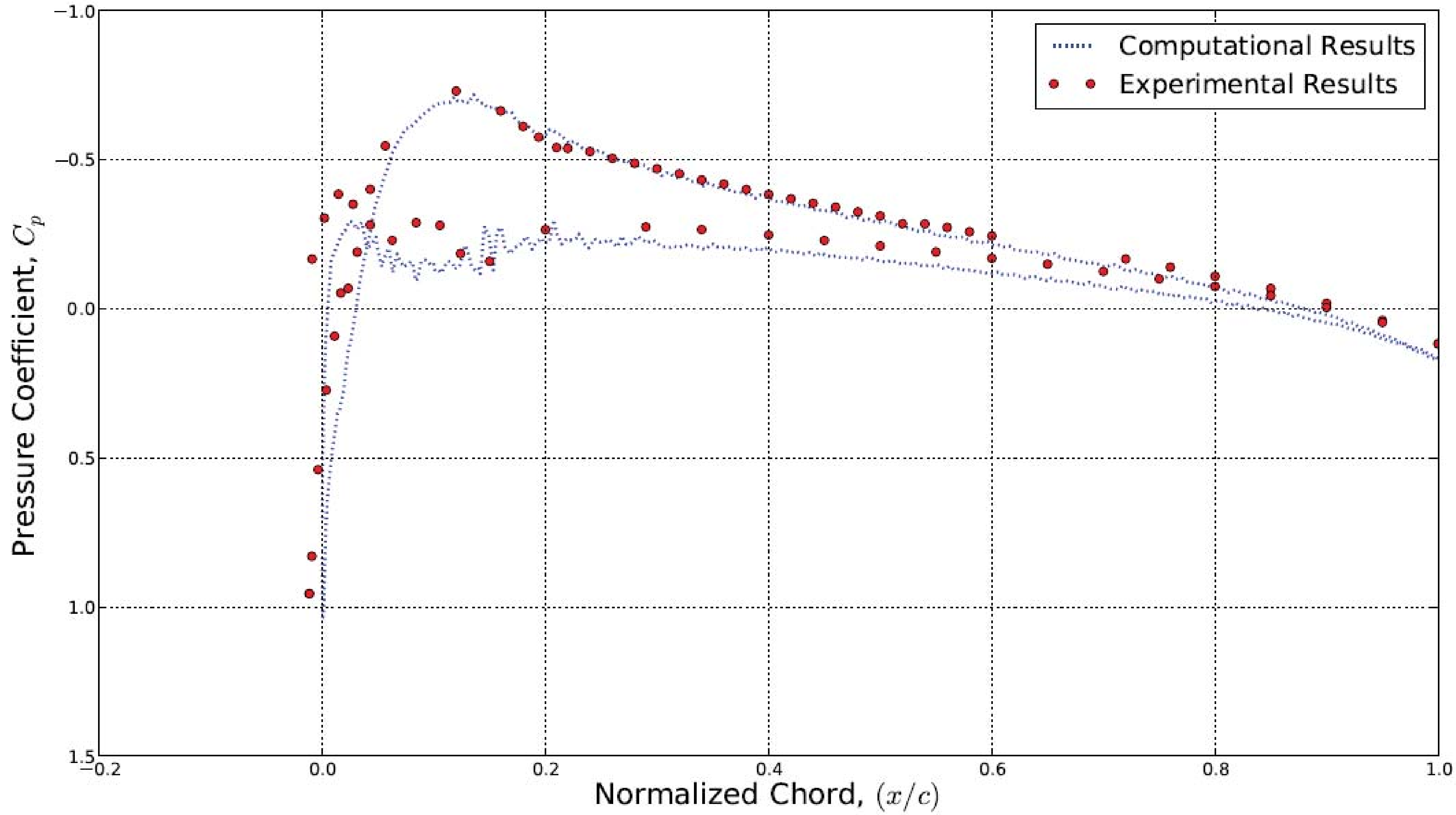
ED1966 Wing (M=0.10 @ 0°)

Rime Shape



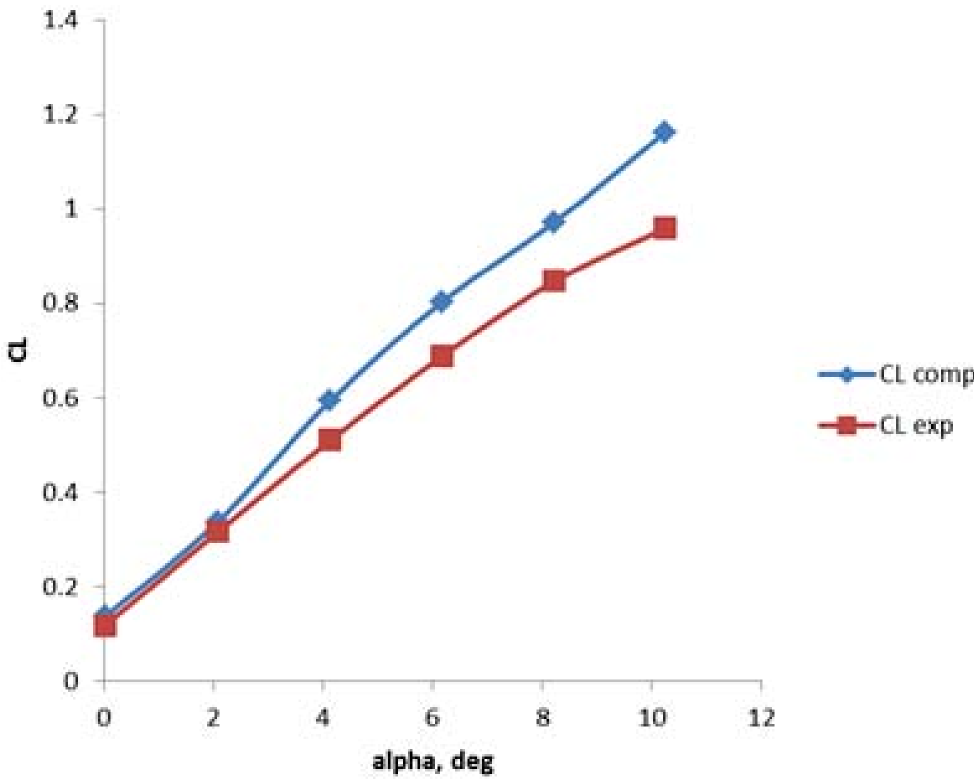
ED1966 Wing (M=0.10 @ 0°)

Rime Shape

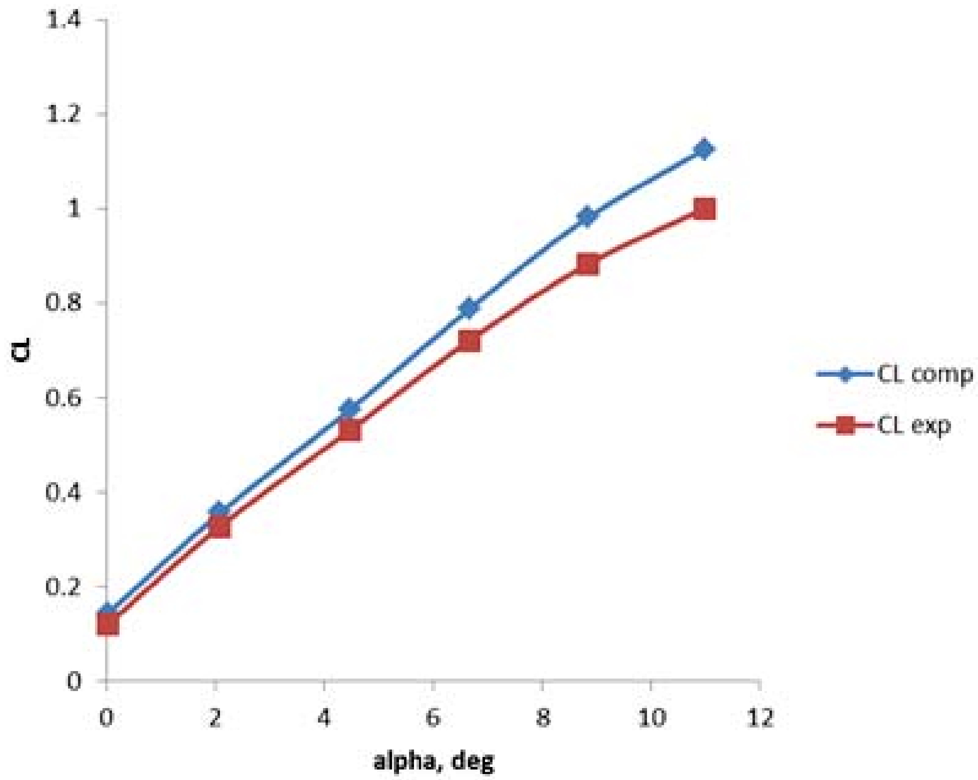


ED1966 Wing Lift Coefficient Results

Rime Shape



Re = 1.0x10^6, M = 0.1

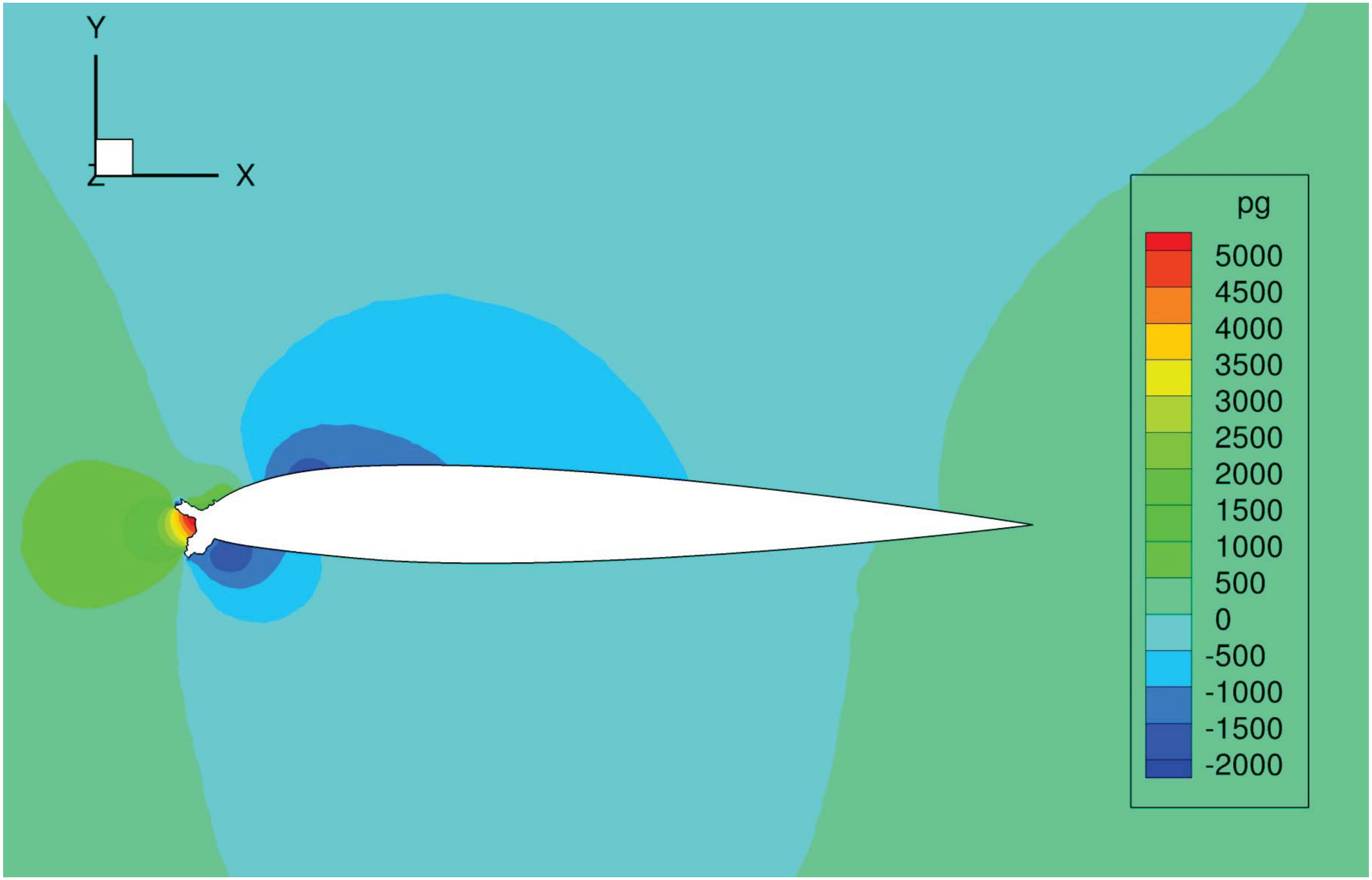


Re = 1.8x10^6, M = 0.18

- Results suggest that viscous effects play a role for the rime ice case, consistent with expectations
- Results from a single instantaneous pressure profile, used in the computation, need to be replaced with time averaged and spatially integrated results

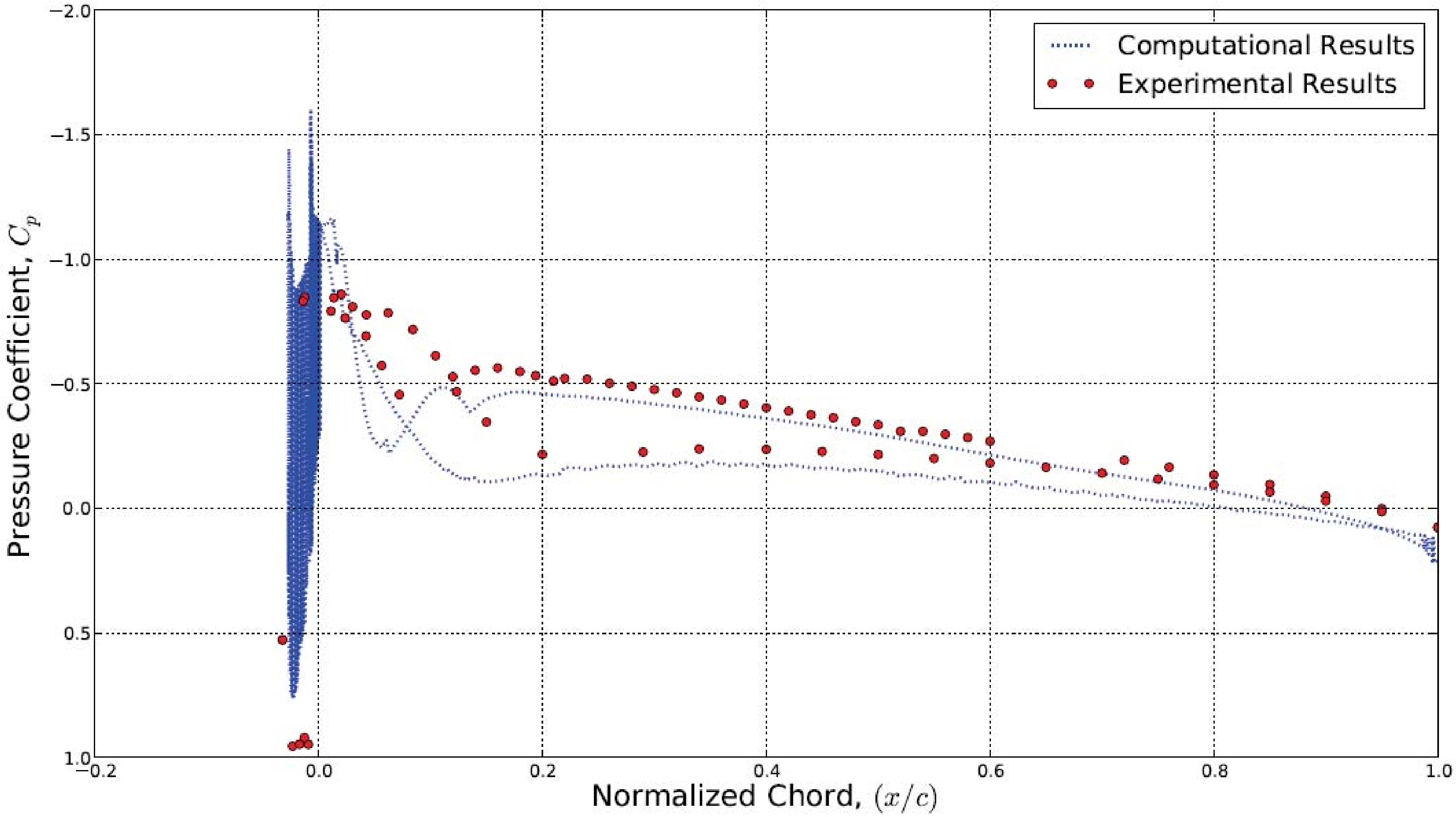
ED1978 Wing (M=0.18 @ 0°)

Glaze shape



ED1978 Wing (M=0.18 @ 0°)

Glaze Shape



Future Work

- Detailed examination of solutions
  - Both ice shapes (ED1966 and ED1978)
    - Variations in flow field results across the span
    - Time averaging of unsteady results
    - Spatial integration across the span
    - Grid resolution studies
    - Turbulence models
  - Glaze ice shape (ED1978)
    - Investigate cause of pressure fluctuations near leading edge
- Parametric study of mesh quality
  - Establish minimum amount of grid points along airfoil surface
- Perform detailed analysis of ice surface roughness region
- Develop post-processing modules for NCC to calculate standard external aerodynamic parameters

Thank You!

Questions?