Low-Reynolds Number Aerodynamics of an 8.9% Scale Semispan Swept Wing for Assessment of Icing Effects

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- Experimental Methodology
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Introduction

- Development and use of 3D icing simulation tools.
- Lack of ice accretion and aerodynamic data for large-scale, swept wing geometries.
- Aerodynamic understanding important for evaluating efficacy of 3D icing simulation tools.
- Multi-faceted research effort called SUNSET II.

Introduction

Aerodynamic understanding important for evaluating efficacy of 3D icing simulation tools.

- Low-Reynolds number ($Re \leq 2.4\times10^6$) aerodynamic test campaigns.
- The artificial ice shapes were developed based upon a series of ice-accretion tests in the NASA Icing Research Tunnel.
  - High fidelity and low fidelity
- Higher-Reynolds number (up to $Re \approx 12\times10^6$) aerodynamic test campaigns.

Objectives and Approach

Objectives

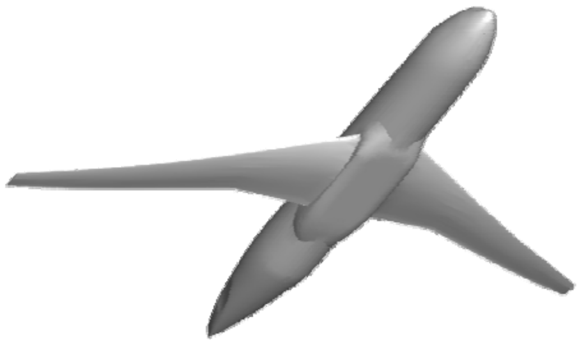
- Perform experimental and computational assessment of clean-wing aerodynamics, model installation and simulation of small ice roughness.

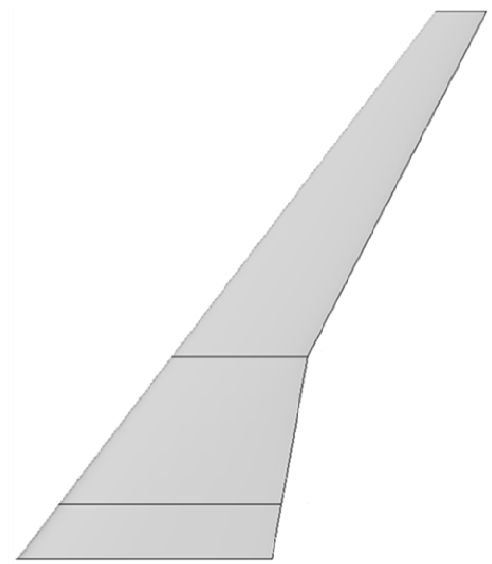
Approach

- Perform aerodynamic testing with 8.9% scale semispan swept wing model of CRM65 at low-Reynolds number.
- Perform 3D RANS simulations of clean wing fully turbulent and with free transition.
- Parametric study of model-mounting configurations.
- Investigate techniques for simulating small ice roughness.

Common Research Model (CRM)

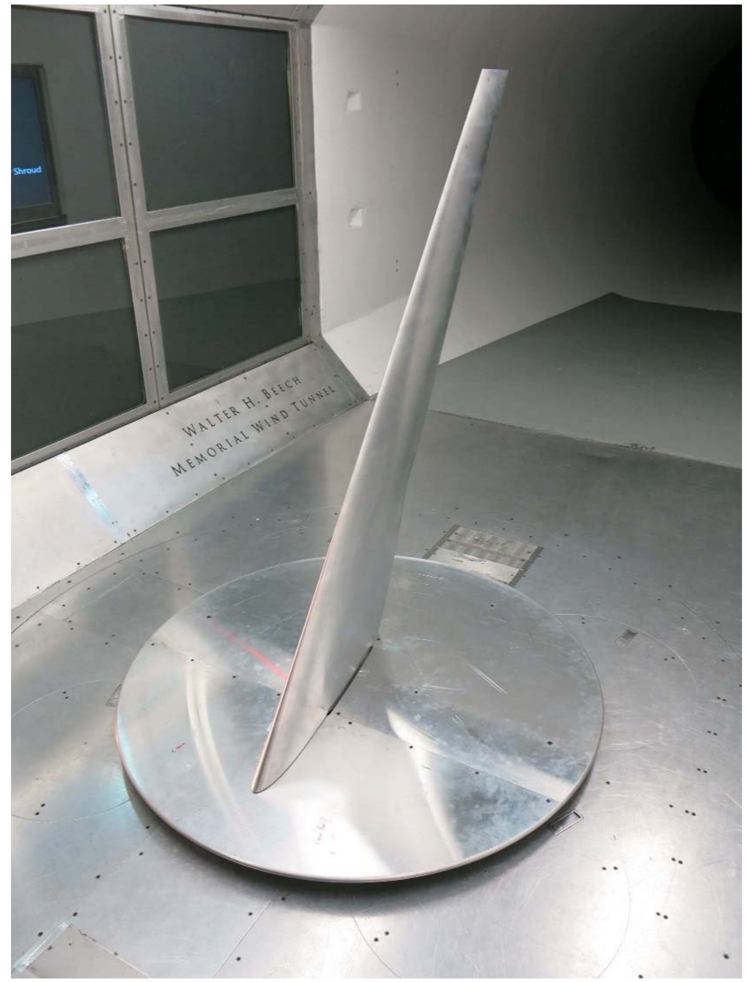
- Commercial transport class configuration.
- Contemporary transonic supercritical wing design.
- Publically available and otherwise unrestricted for world-wide distribution.
- A 65% scale CRM was selected as the full-scale, reference swept-wing geometry for this research.
- CRM65 size airplane is comparable to Boeing 757.



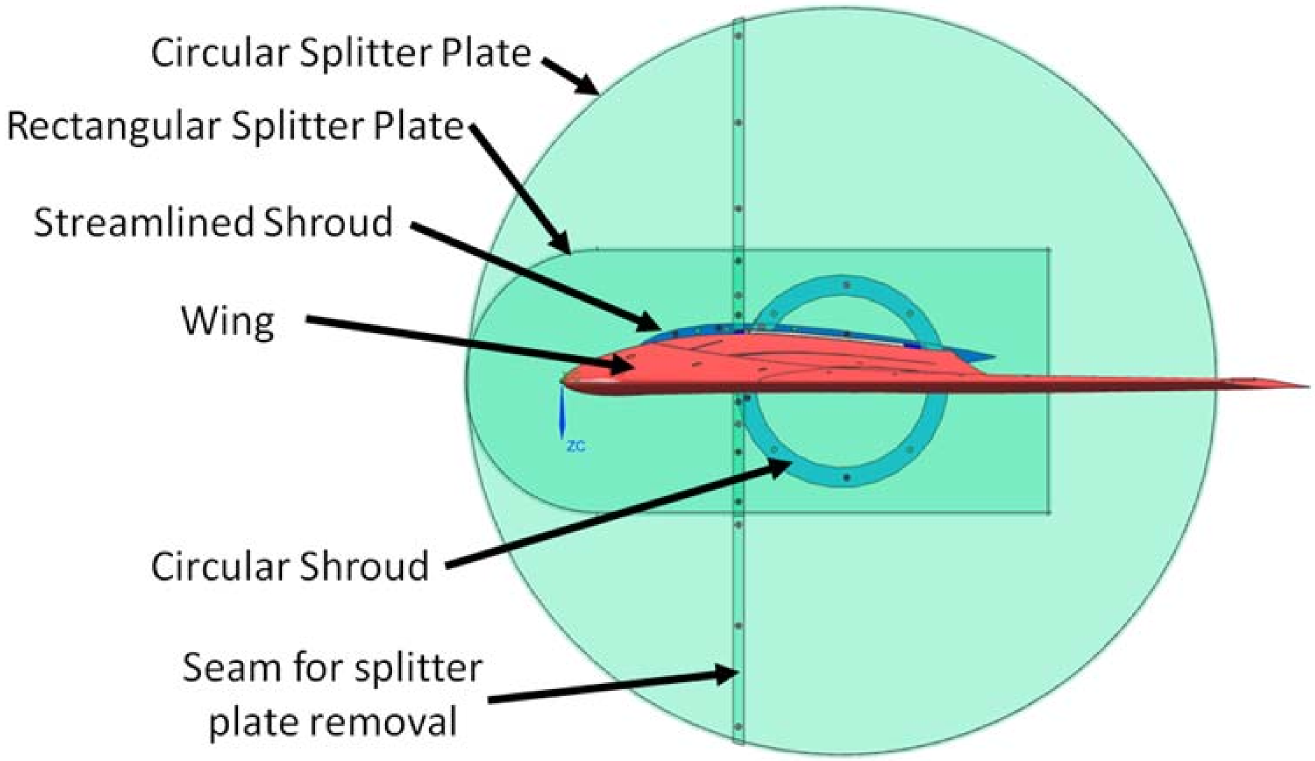


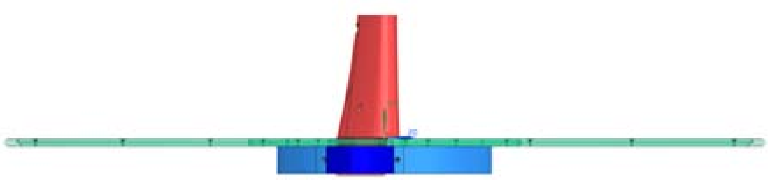
Experimental Methodology

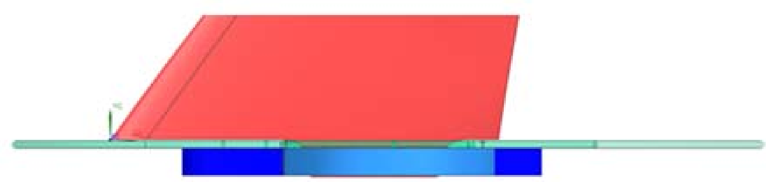
- Aerodynamic testing performed at Wichita State University Beech Wind Tunnel.
- Test section size 7-ft x 10-ft.
- 8.9%-scale semispan model of CRM65 geometry.
- Reynolds numbers = 0.8, 1.6 and 2.4×10^{6}
- Corresponding Mach numbers = 0.09, 0.18 and 0.27.
- Measure integrated aerodynamic performance with force balance
  - C_L, C_D, C_M.
- Measure surface pressure - C_P.
- Mini-tuft and surface-oil flow visualization.



Model Mounting Configurations

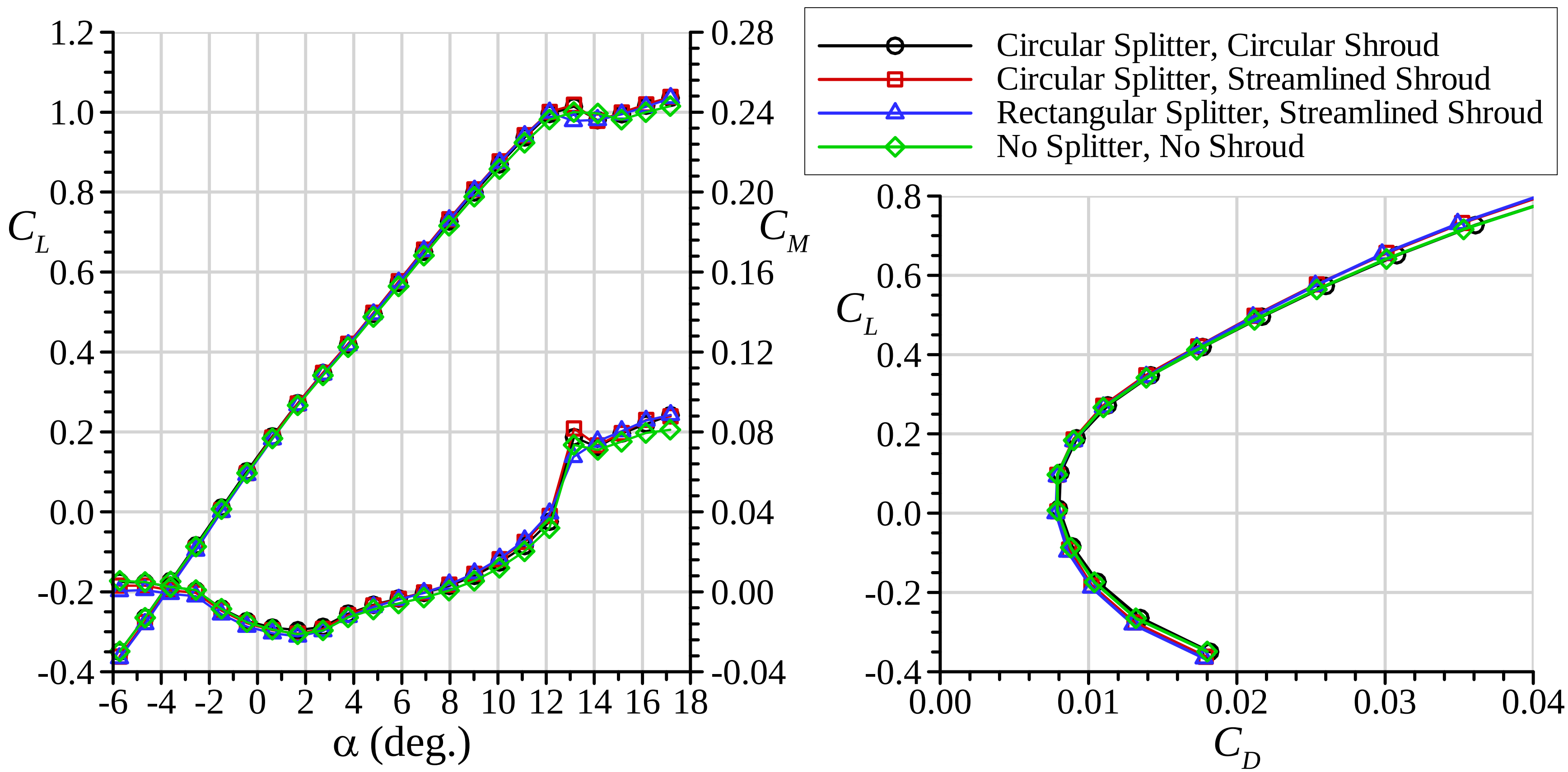






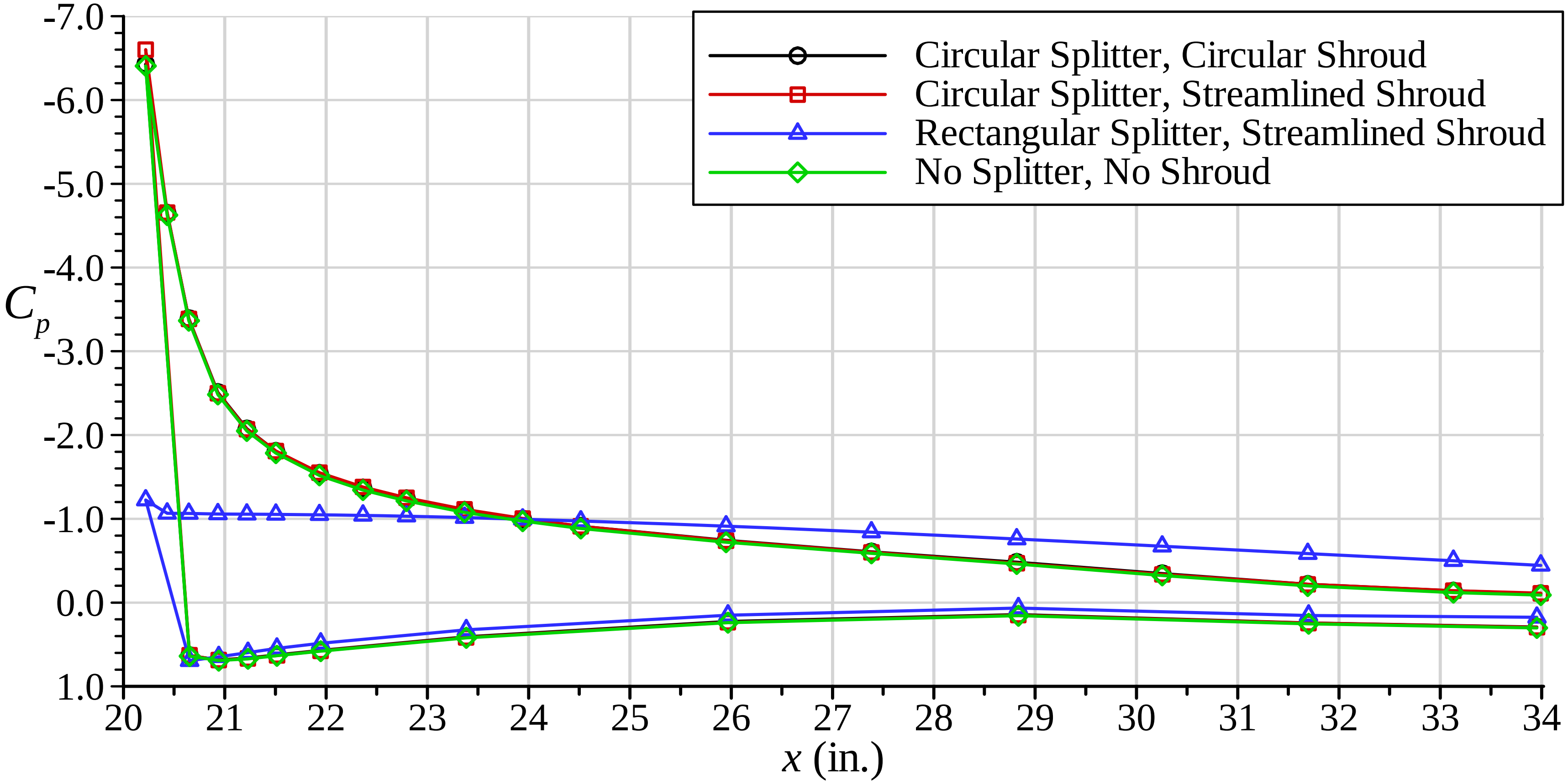
Model Mounting Configurations

- Effect of model mounting on aerodynamic performance at $Re = 2.4\times10^6$, $M = 0.27$.



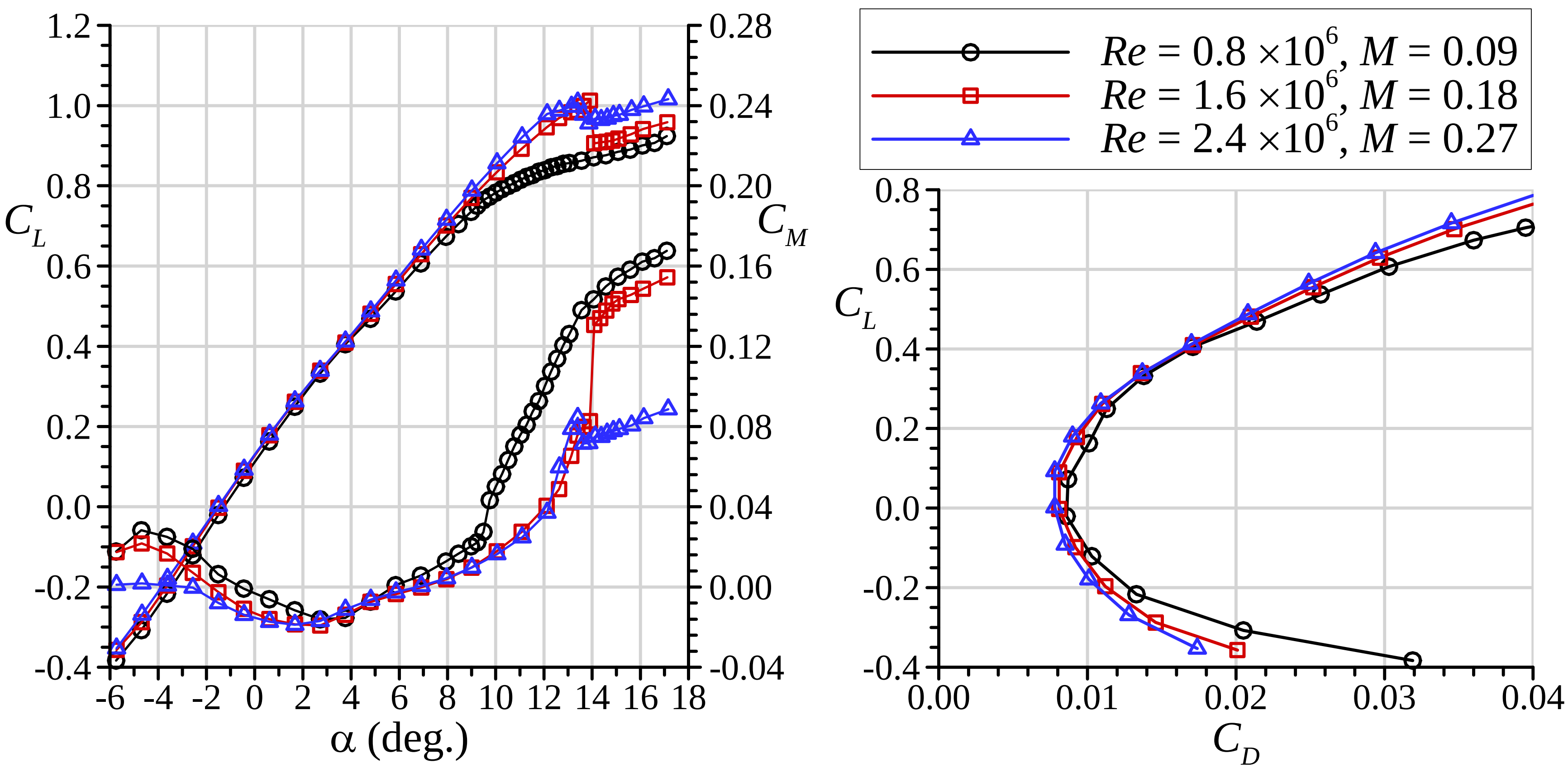
Model Mounting Configurations

- Surface pressure distribution at *y/b* = 0.44, α = 13.2 deg., *Re* = 2.4×10^6, *M* = 0.27.



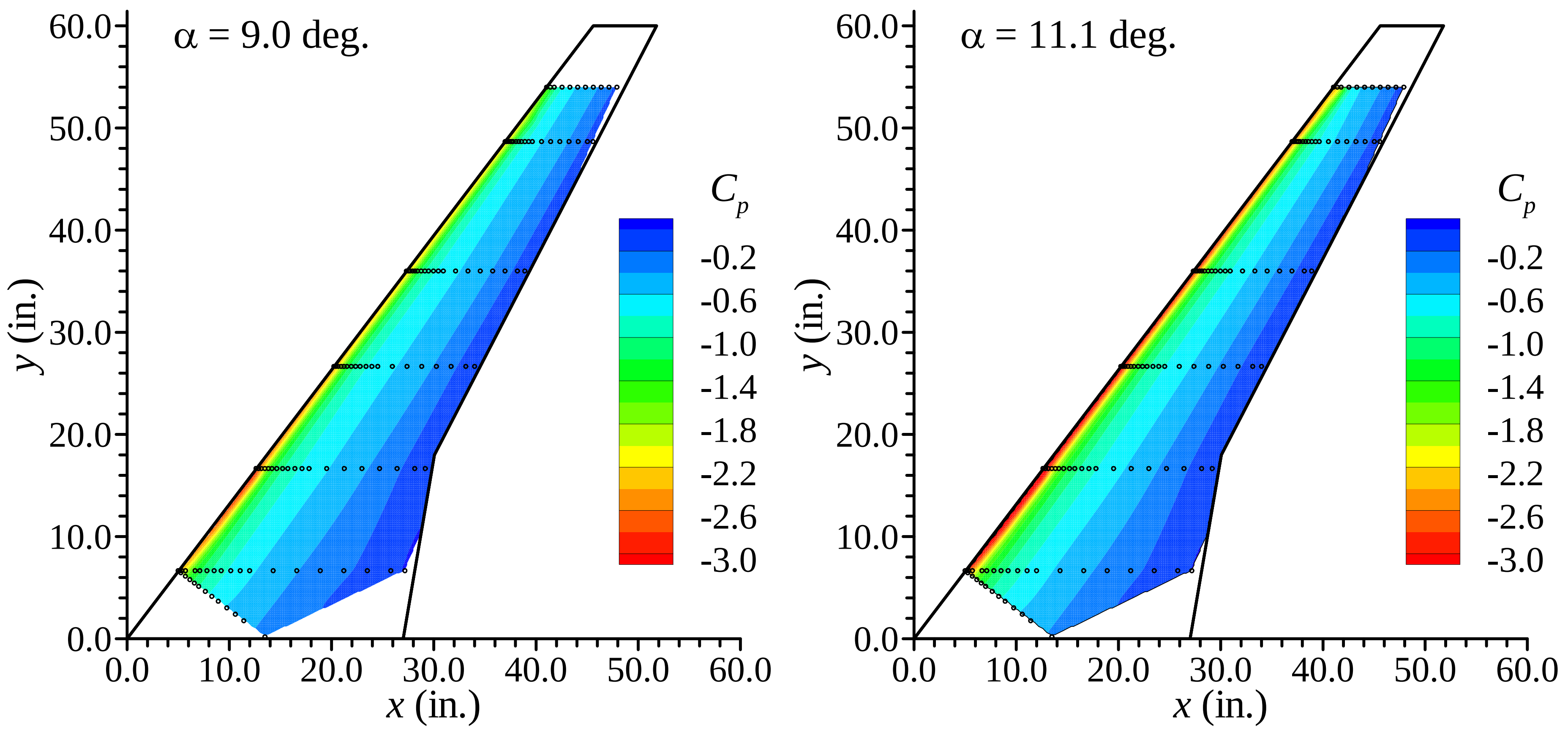
Clean Model Aerodynamics

- Effect of Reynolds and Mach number on clean wing configuration.



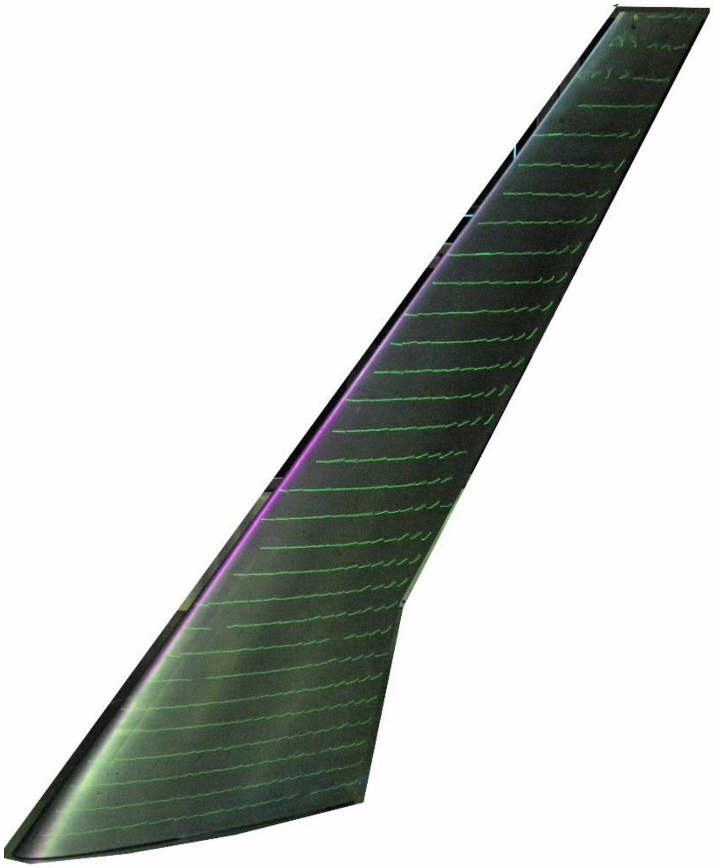
Clean Model Aerodynamics

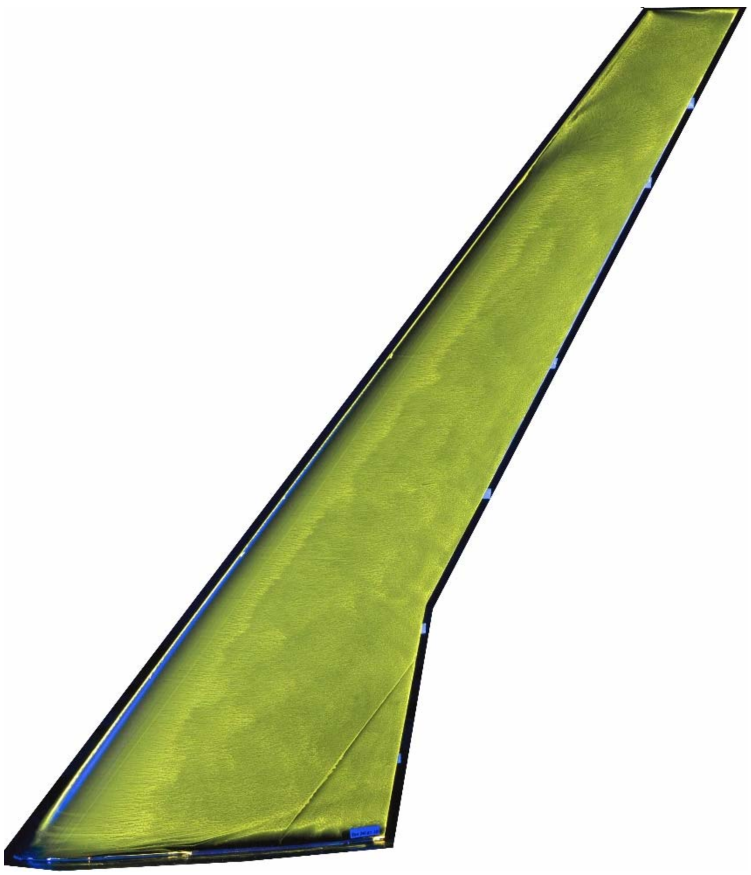
- Surface pressure distribution at $Re = 1.6\times10^{6}$, $M = 0.18$.



Clean Model Aerodynamics

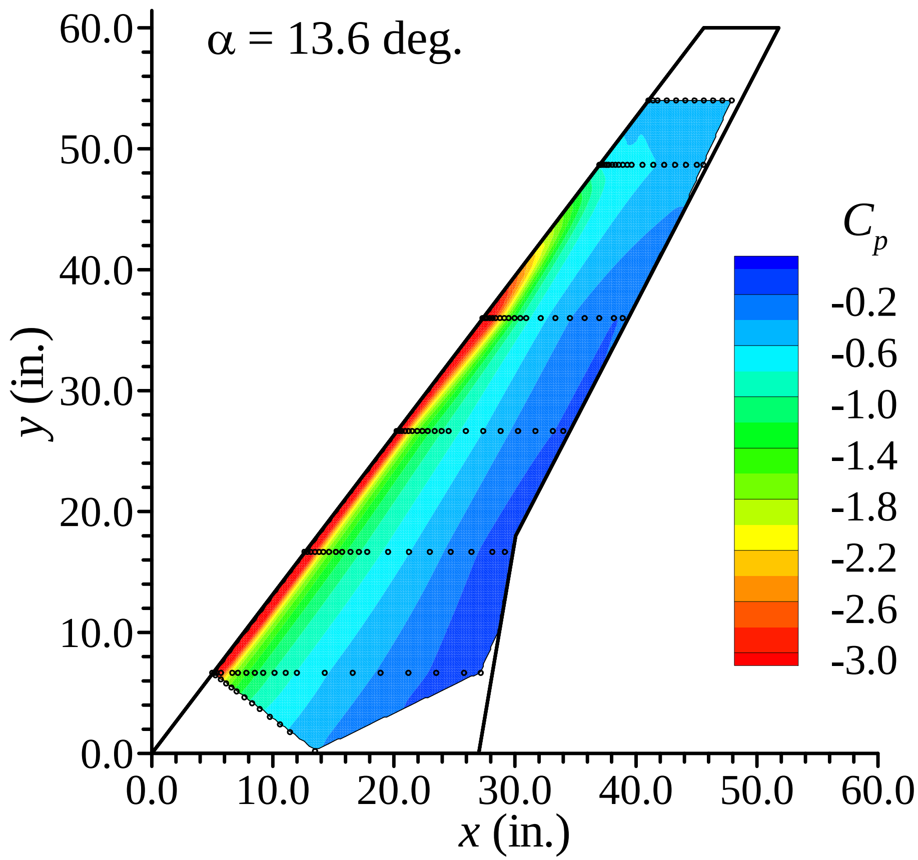
- Mini-tuft and surface-oil flow visualization at α = 11.1 deg., and *Re* = 1.6×10^6, *M* = 0.18.

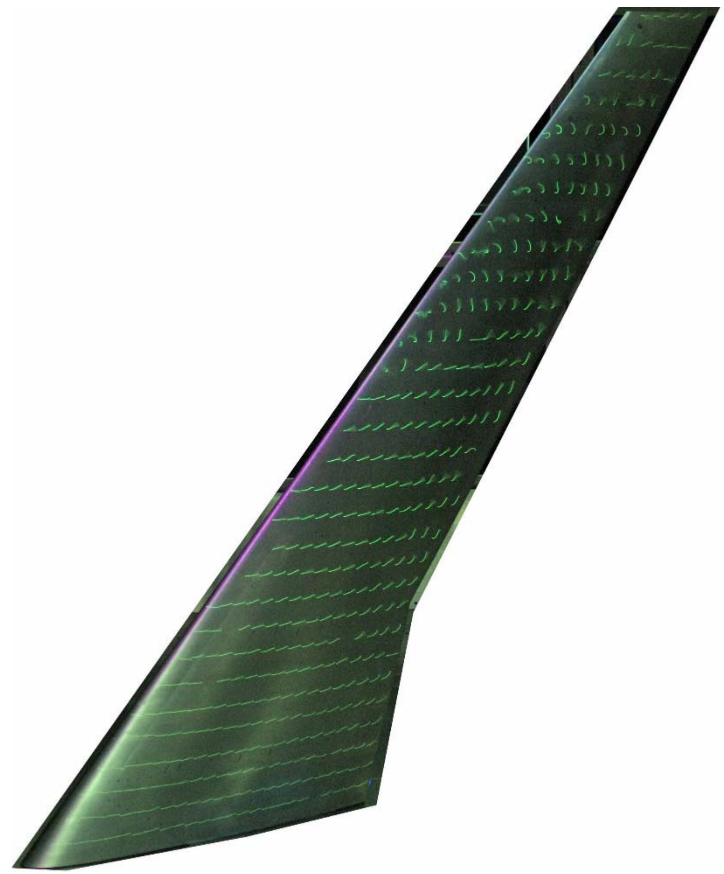




Clean Model Aerodynamics

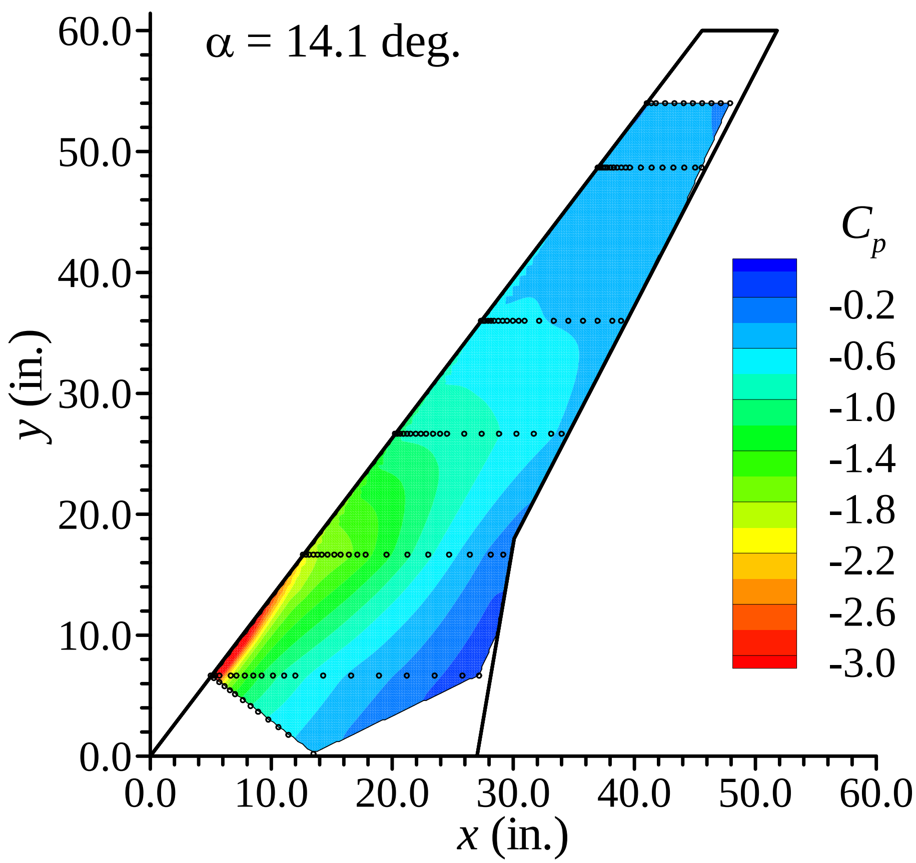
- Surface-pressure distribution and mini-tuft flow visualization at α = 13.6 deg., and Re = 1.6×10^6, M = 0.18.

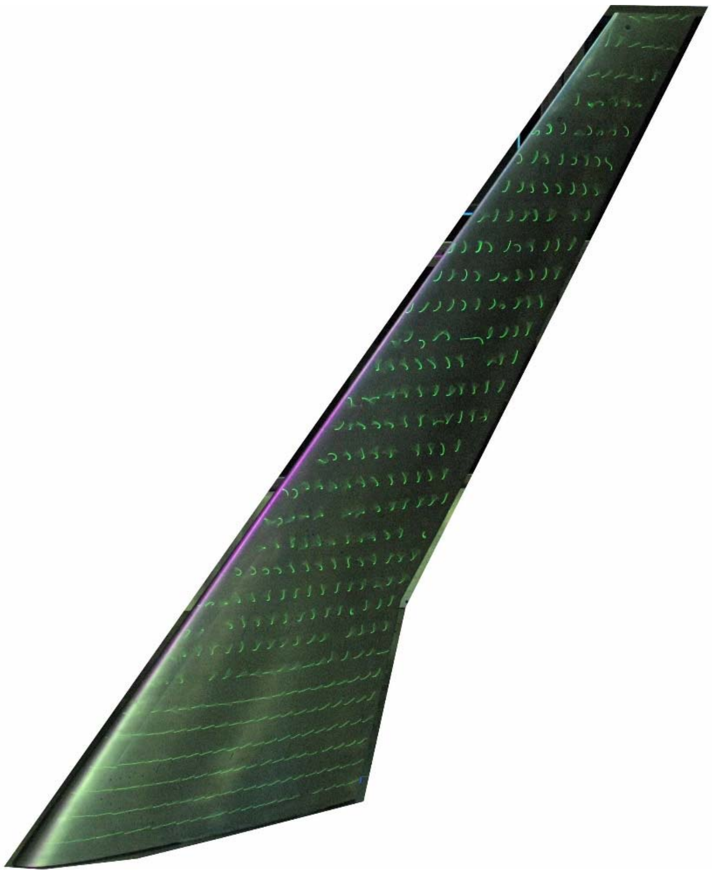




Clean Model Aerodynamics

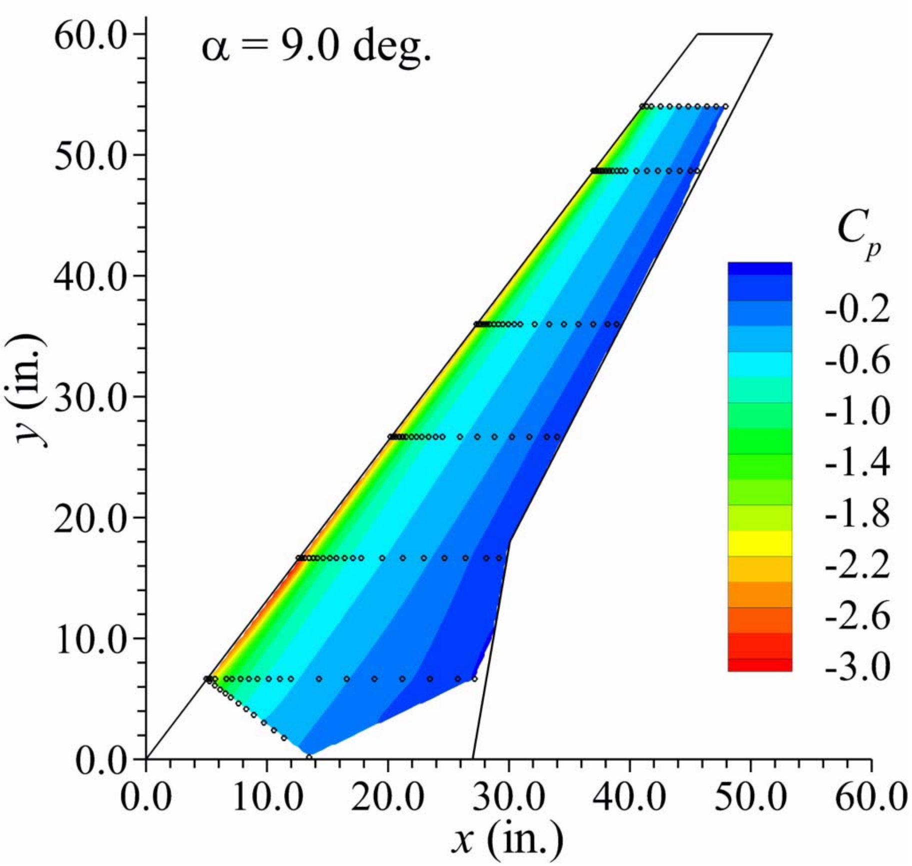
- Surface-pressure distribution and mini-tuft flow visualization at α = 14.1 deg., and *Re* = 1.6×10^6, *M* = 0.18.





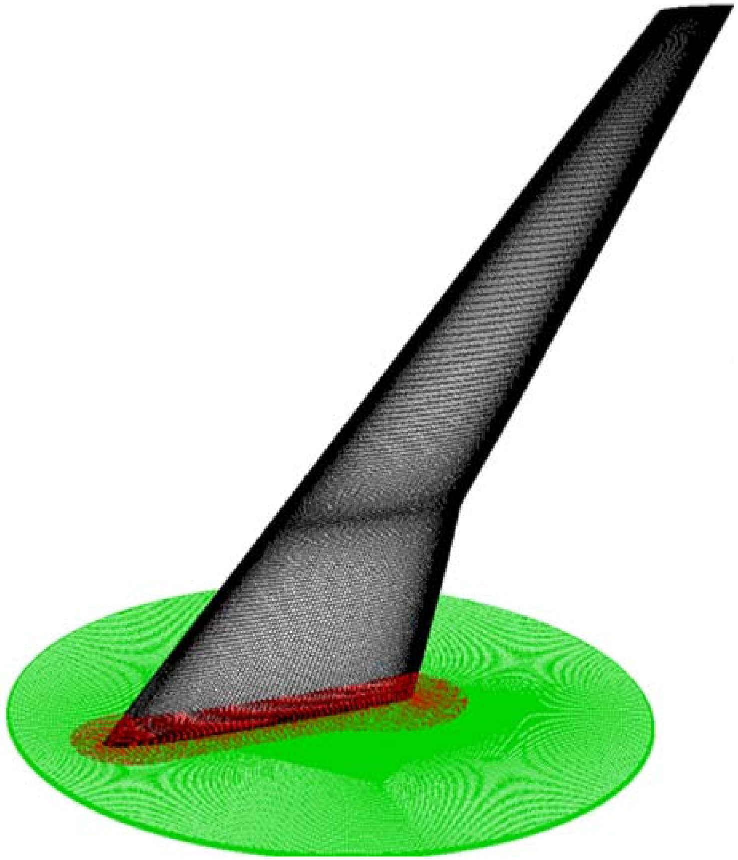
Clean Model Aerodynamics

- Surface-pressure distribution animation at $Re = 1.6\times10^6$, $M = 0.18$.



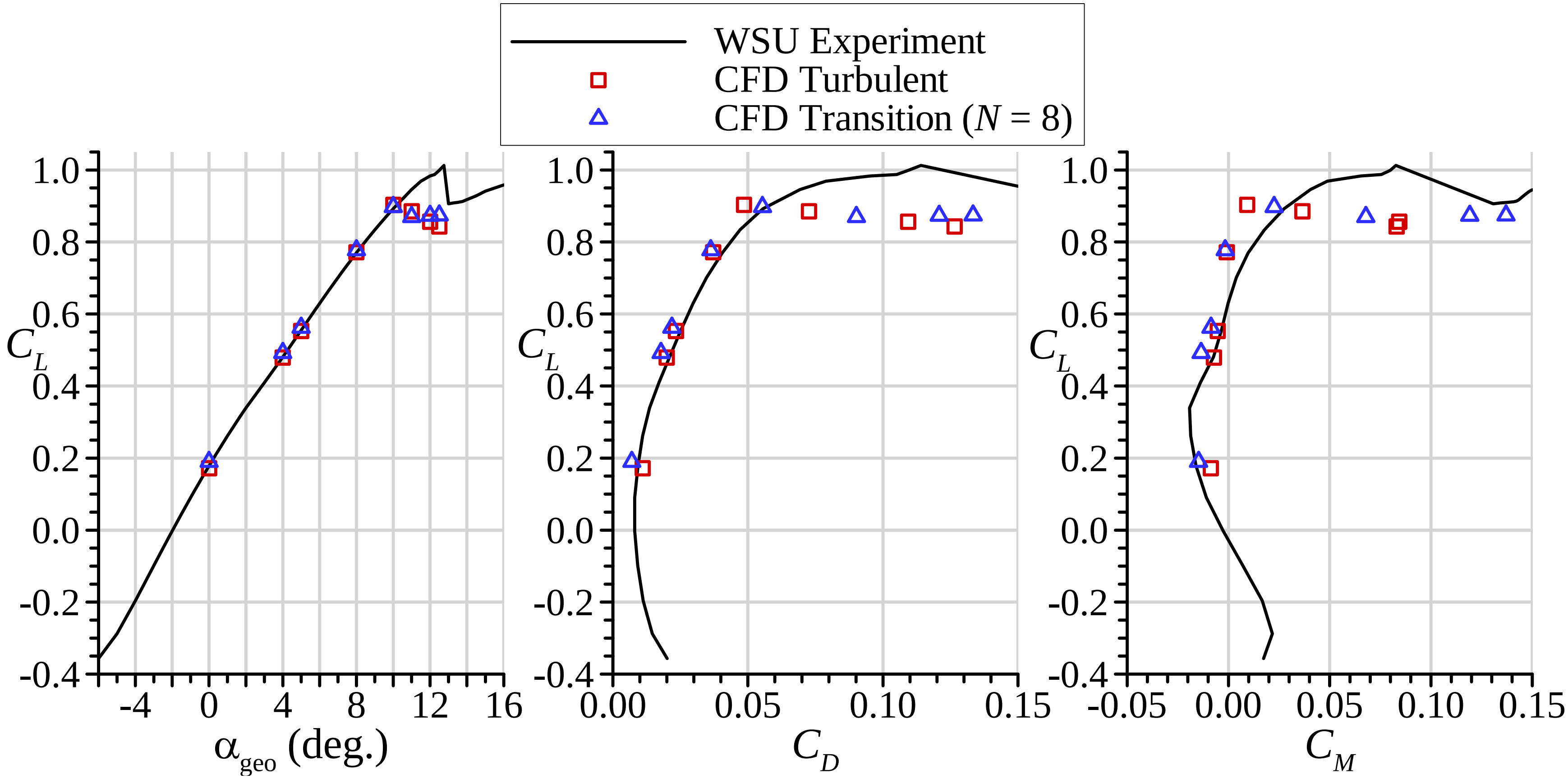
CFD Simulation Methodology

- CFD simulation included the wing and splitter plate, no shroud.
  - Test-section floor included as symmetry plane.
- Chimera overset grid based upon ONERA methodology.
  - Wing: ~9.4×10^6 cells
  - Splitter: ~6.5×10^6 cells
  - Collar grid: ~0.65×10^6 cells
- ONERA elsA solver for 3D compressible RANS equations.
- One equation Spalart-Allmaras turbulence model.
- Free-transition model criteria based upon free-stream turbulence intensity of 0.11% (N_T = 8) corresponding to WSU wind tunnel.



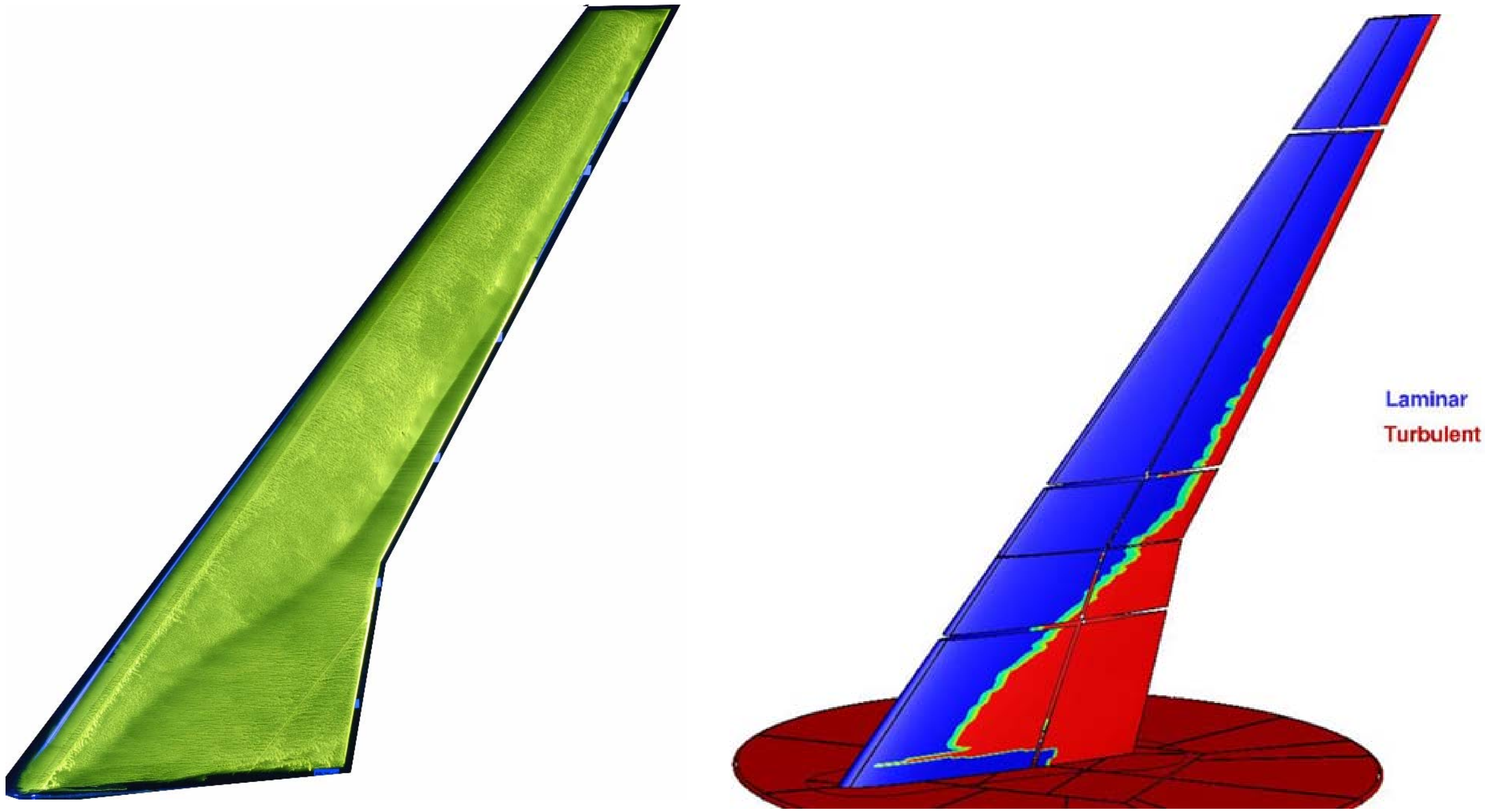
CFD Simulation Comparison

- Clean wing performance at $Re = 1.6 \times 10^6$, $M = 0.18$.



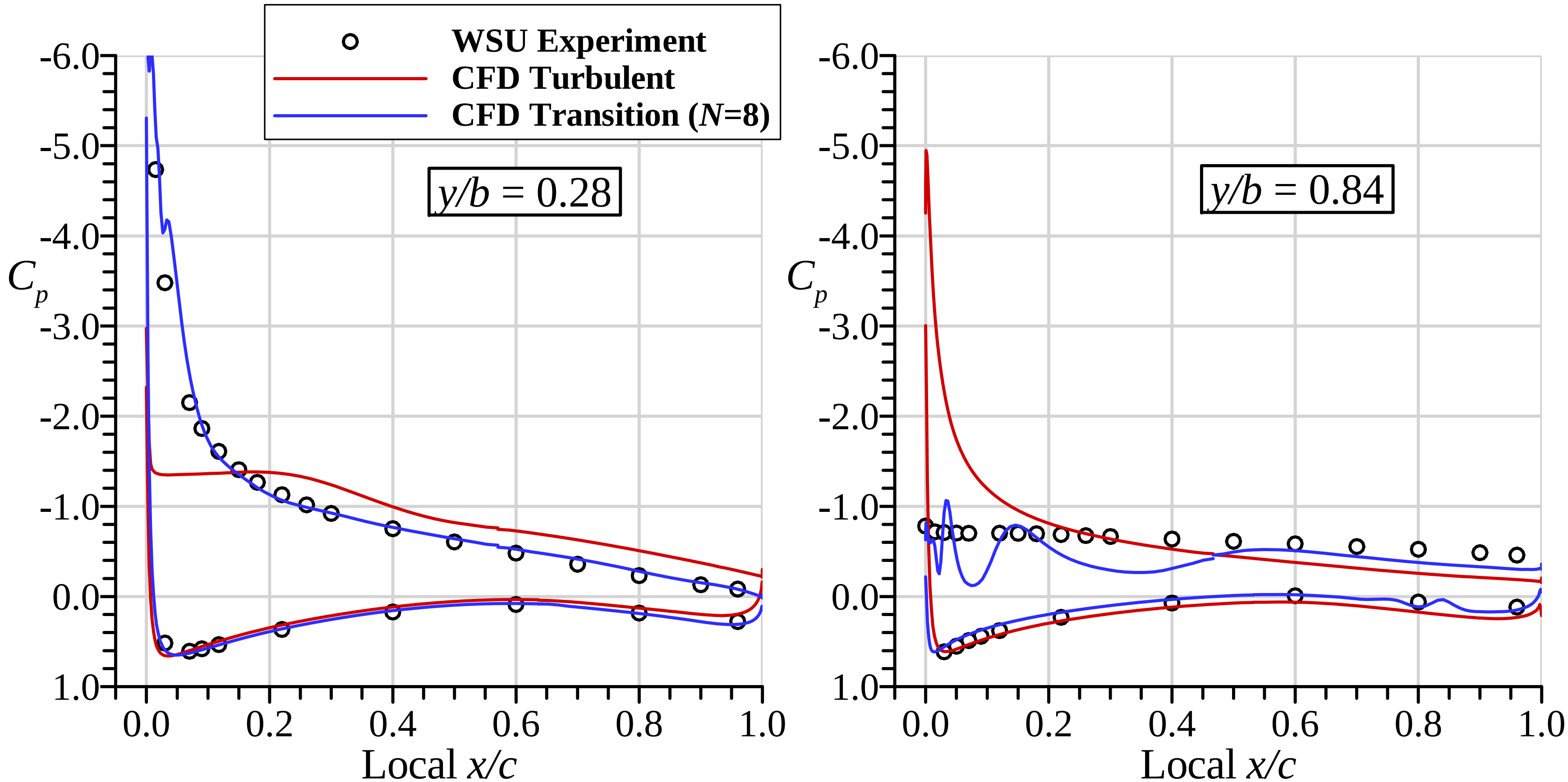
CFD Simulation Comparison

- Surface oil flow visualization and transition location at $\alpha = 0$ deg. and $Re = 1.6\times10^6$, $M = 0.18$.



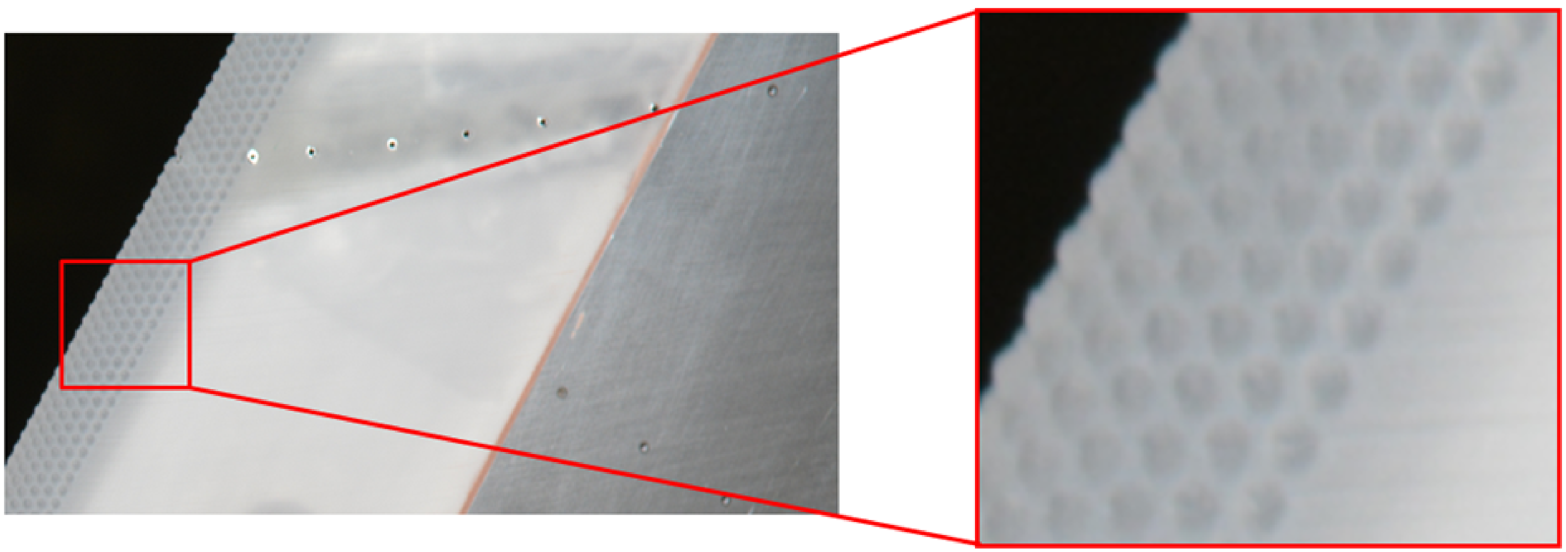
CFD Simulation Comparison

- Surface pressure distribution at α = 13.1 deg. and *Re* = 1.6×10^6, *M* = 0.18.



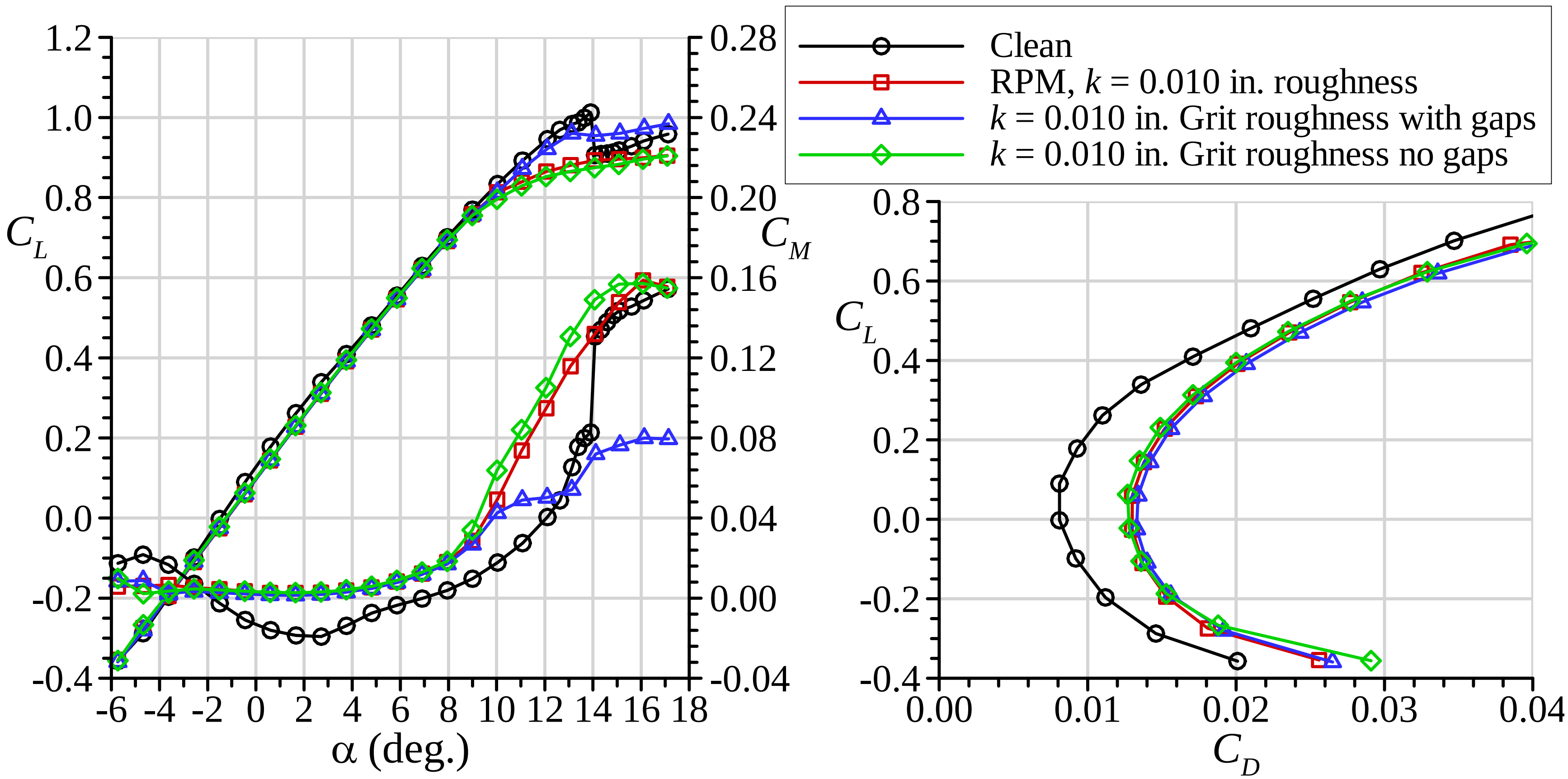
Roughness Simulation Methodology

- Full-span artificial ice shapes were bolted to the wing leading edge.
- Artificial ice shapes were made using rapid-prototype manufacturing (RPM).
- Small ice roughness was simulated with regular pattern of hemispheres in the RPM shape.
- Aerodynamic results were compared to carborundum grit of equivalent size applied to the clean leading edge.



Roughness Simulation Comparison

- Aerodynamic performance at *Re* = 1.6×10^6, *M* = 0.18.



Summary

- Experimental and computational study of 8.9% scale CRM65 semispan wing at *Re* = 0.8, 1.6 and 2.4×10^6 and *M* = 0.09, 0.18 and 0.27.
- Four different model mounting configurations were investigated.
  - Circular splitter plate and streamlined shroud selected for further work.
- A detailed study of clean wing aerodynamics was performed:
  - For all *Re* and *M* conditions, the flow over the outboard sections of the wing separated as the wing stalled with the inboard sections near the root maintaining attached flow.
  - This behavior was captured for 3D RANS CFD simulations with free transition model, with opposite results for fully turbulent simulations.
- Artificial ice roughness simulated with hemispherical patterns in RPM shapes generated aerodynamic effects equivalent to similar size carborundum grit roughness.
  - Size of RPM-based hemispherical roughness limited to height = 0.010 inches due to manufacturing limitations.

Acknowledgements

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