Initial Low-Reynolds Number Iced Aerodynamic Performance for CRM Wing

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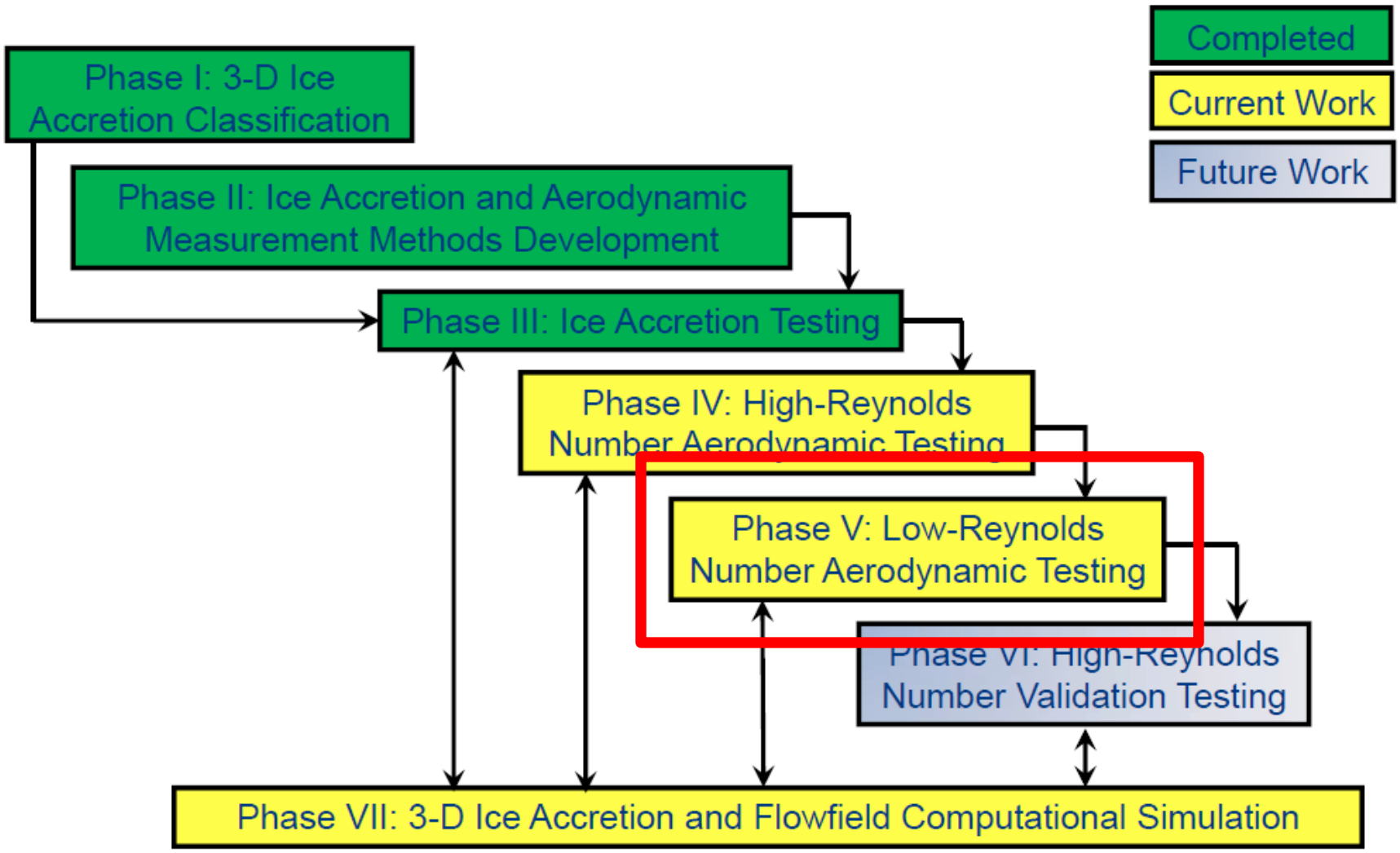
Low-Re Aerodynamic Testing

Low-Re Testing of Swept Wing with Ice



Goals

- **Overall Project Goal**
  - Improve the fidelity of experimental and computational simulation methods for swept-wing ice accretion formation and the resulting aerodynamic effect

- Goal of Low-Reynolds Number Aerodynamic Testing
  - Develop low-cost test capability for iced swept wings
  - Quantify the differences in aerodynamic performance and key flowfield features between the low- and high-Re testing

- Goal of Initial Low-Re Wind Tunnel Entry (this work)
  - Evaluate splitter plate effects
  - Evaluate roughness effects
  - Provide recommendations for high-Re testing

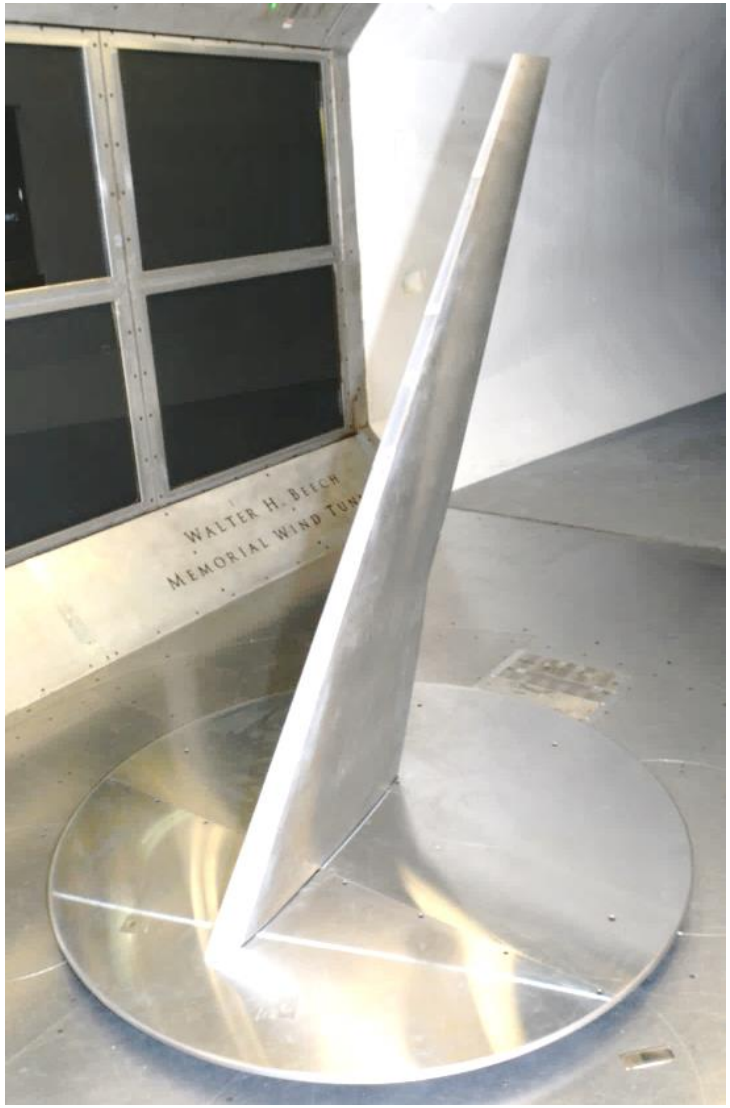
Wing Model

- Semispan Common Research Model (CRM)-based wing
  - 8.9% scale of the full-scale reference
  - Zero-g loading and zero dihedral

Leading Edge Sweep	Semispan	MAC	Aspect Ratio	Taper Ratio
37.2°	1.5 m	0.41 m	8.3	0.23

- Removable leading edge
- Leading-edge configurations
  - Clean aluminum
  - Rapid prototyped (RPM) clean
  - RPM horn ice
  - RPM roughness
  - Grit roughness
- Several splitter plate variations

Low-Re Testing of Swept Wing with Ice

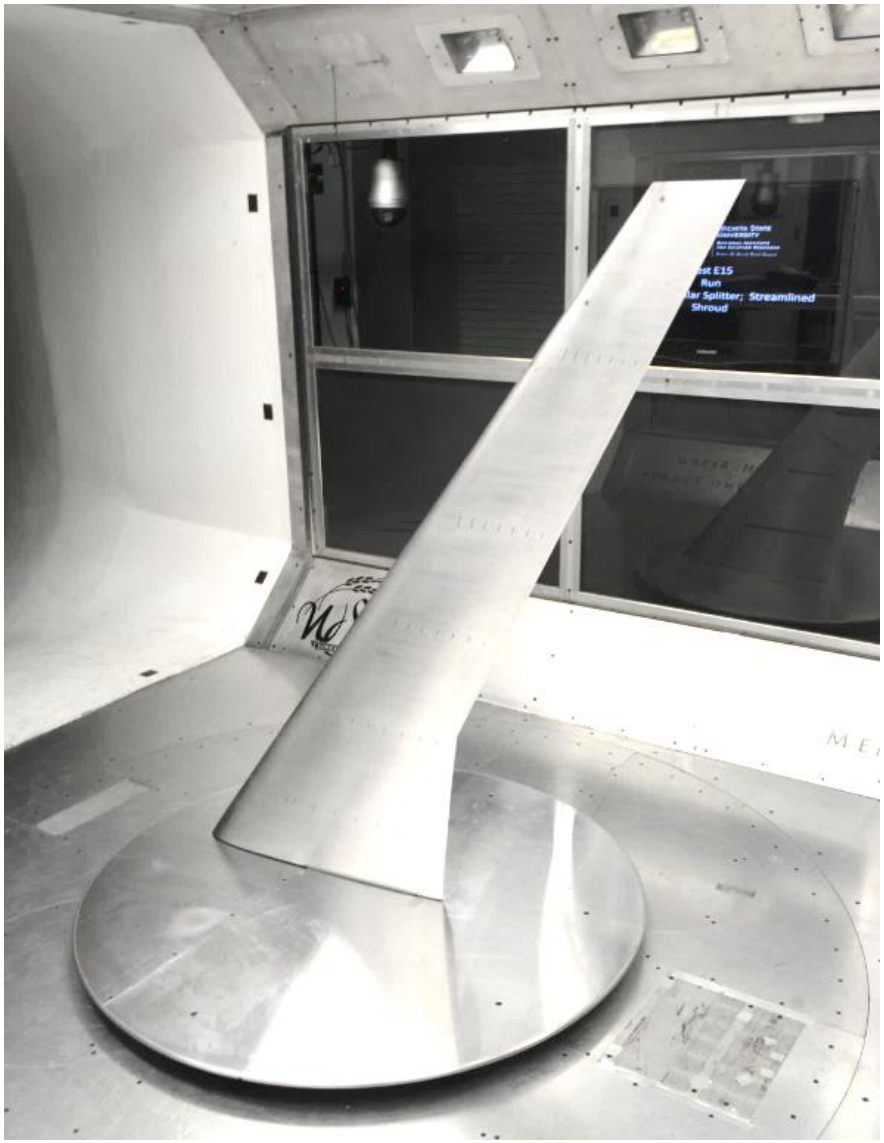


Model installed in wind tunnel with removable leading edge

Wind Tunnel Facility

Low-Re Testing of Swept Wing with Ice

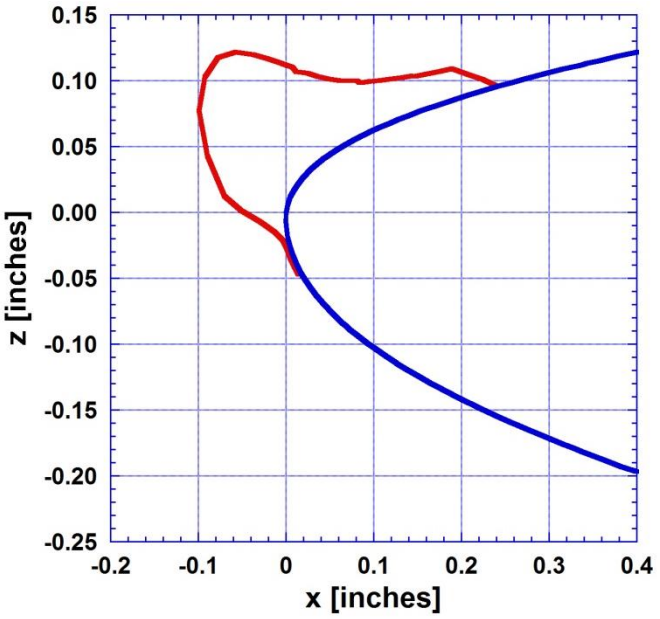
- Walter H. Beech 7x10 ft wind tunnel at Wichita St. University
- Atmospheric, closed-return type tunnel
- Test Conditions for these tests:
  - M = 0.09, Re = 0.8×10^6
  - M = 0.18, Re = 1.6×10^6
  - M = 0.27, Re = 2.4×10^6



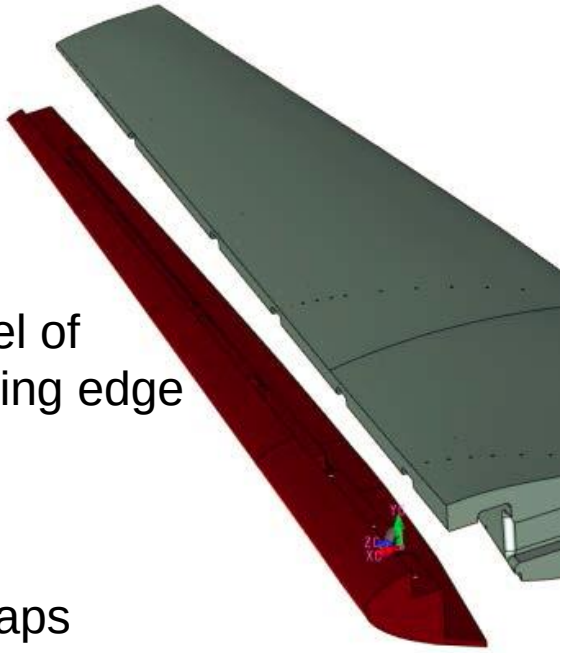
Model installed in wind tunnel with circular splitter plate and clean leading edge

Leading Edge Configurations

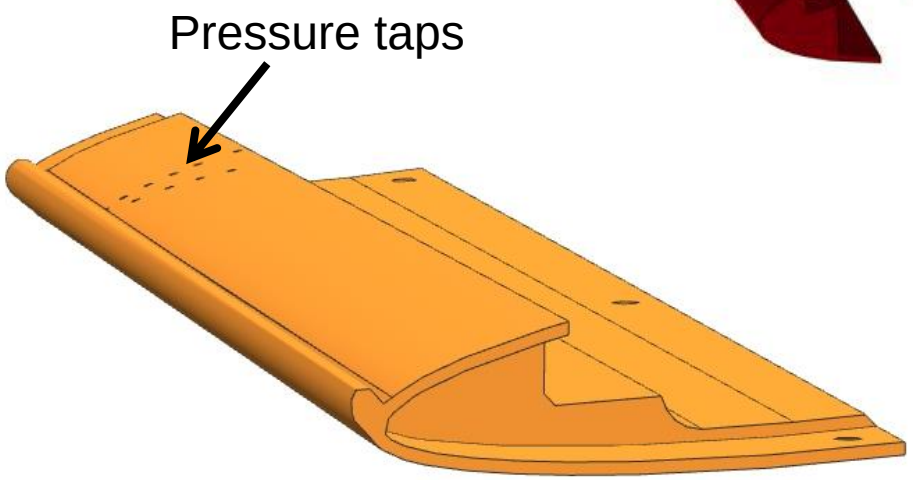
- Full span clean aluminum leading edge
- RPM leading edges mounted in 6 spanwise segments
- Horn ice shape simulation based on LEWICE3D predictions



2D example of ice shape



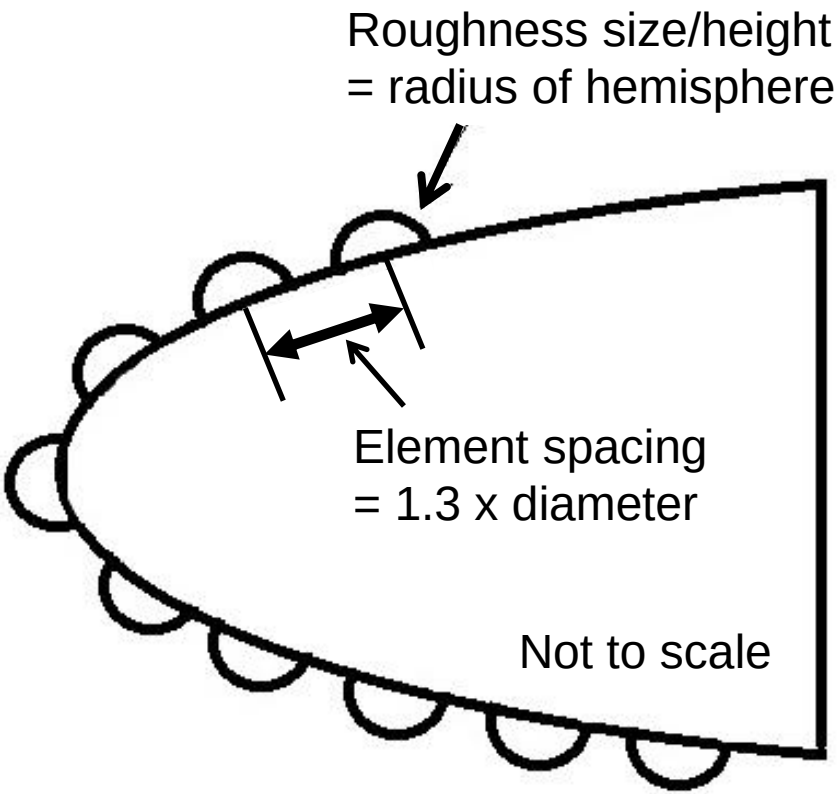
CAD model of clean leading edge

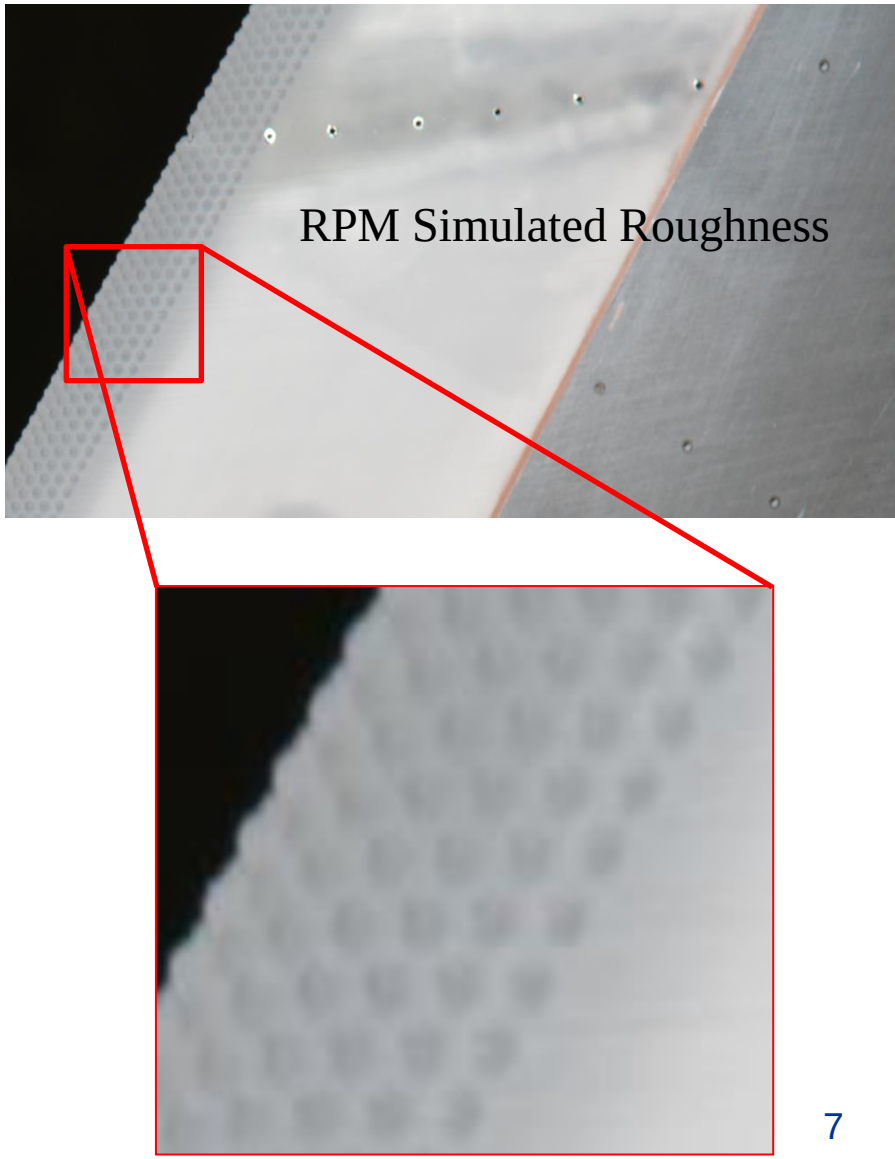


Horn ice example

RPM Roughness

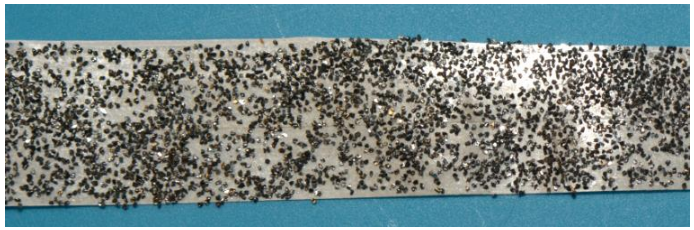
- Heights (k) of 0.01 and 0.02 inches
- Coverage extent along leading edge determined from LEWICE3D calculations
- Manufactured using Stereolithography (SLA) 3D printing



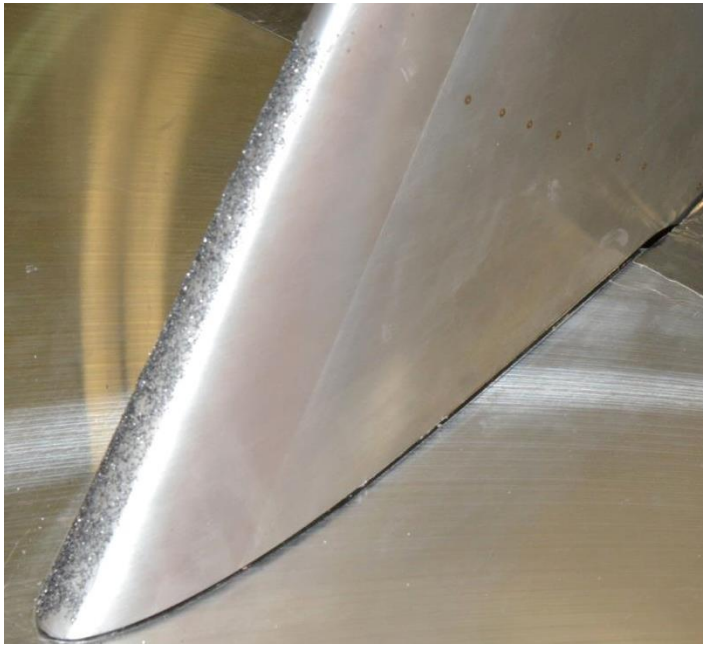


Grit Roughness

- Heights (k) of 0.005, 0.01, and 0.02 inches
- Coverage extent the same as RPM
- Silicon carbide
- Applied using double-sided tape



Grit Roughness



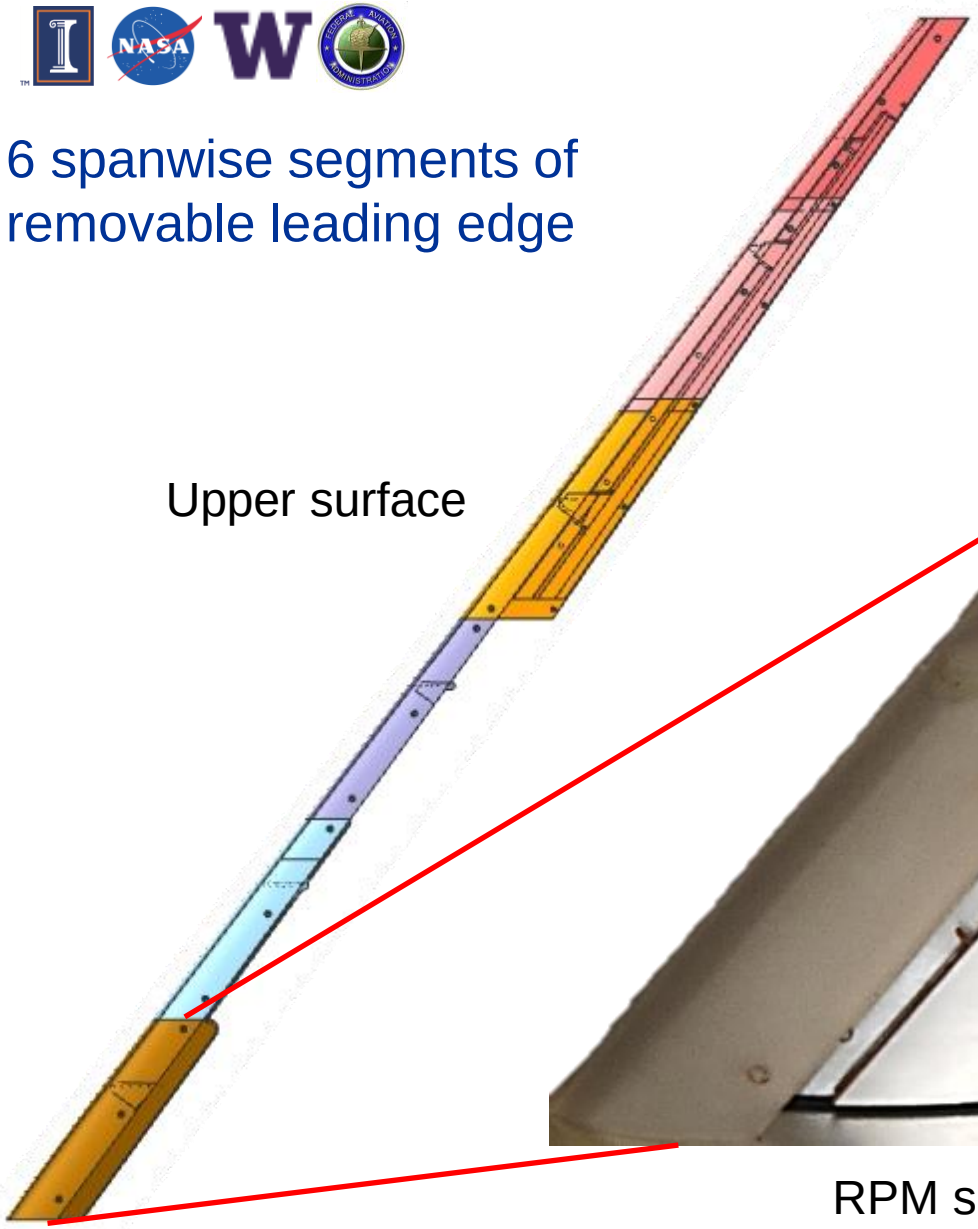
Grit roughness applied to model

Comparison to full scale:

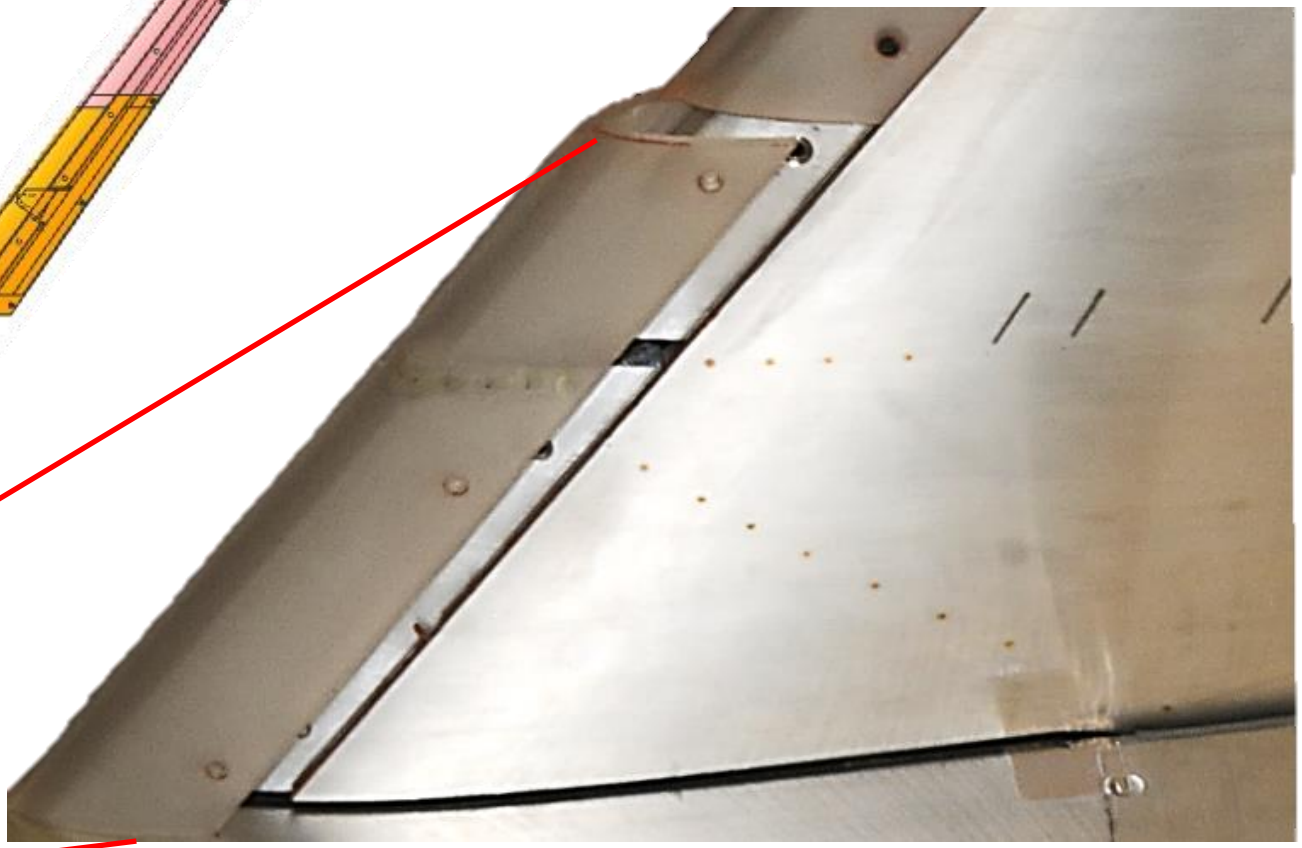
CRM65 Roughness Size (mm)	Low-Re Roughness Size (mm)	k/c_{mac}	Application Configuration
1.43	0.13	3.1×10^{-4}	Grit
2.85	0.25	6.3×10^{-4}	RPM/Grit
5.71	0.51	12.5×10^{-4}	RPM/Grit

Ice Shape Installation

6 spanwise segments of removable leading edge



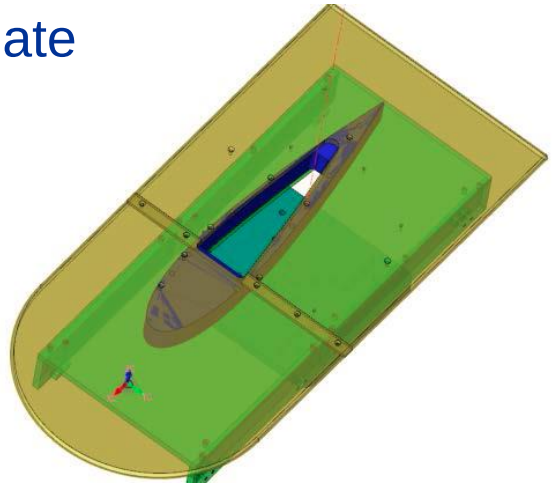
Upper surface



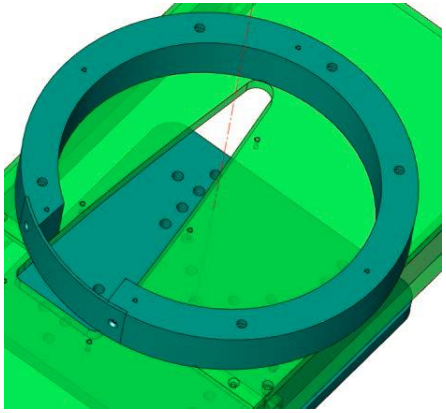
RPM segment installed on model

Splitter Plate

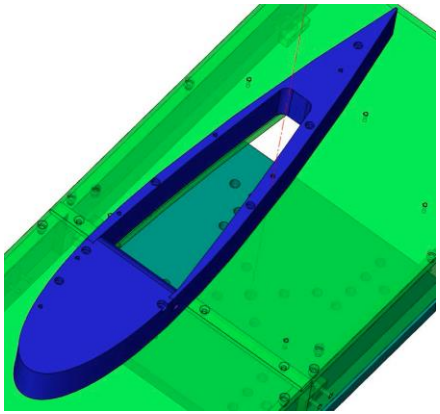
- Model designed for installation with a splitter plate
  - Allows model to be tested in different facilities
  - Reduces influence of different floor boundary layers
- Investigated several configurations:
  - Wing mounted directly to floor
  - Circular plate, Circular shroud
  - Circular plate, Streamlined shroud
  - Rectangular plate, Streamlined shroud



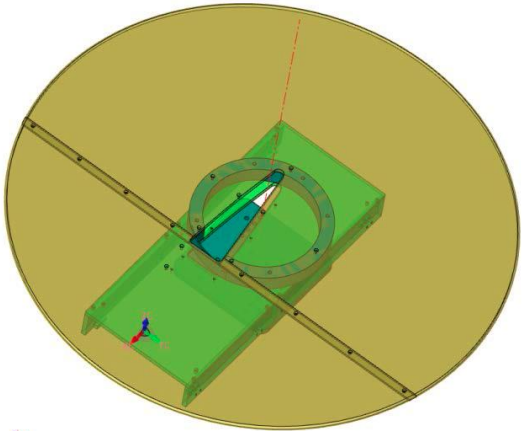
Rectangular plate, Streamlined shroud



Circular shroud

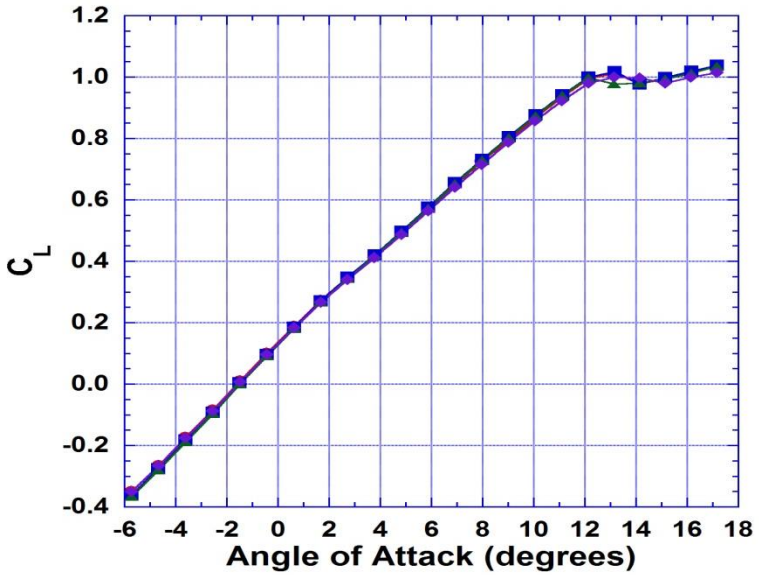


Streamlined shroud



Circular plate, Circular shroud

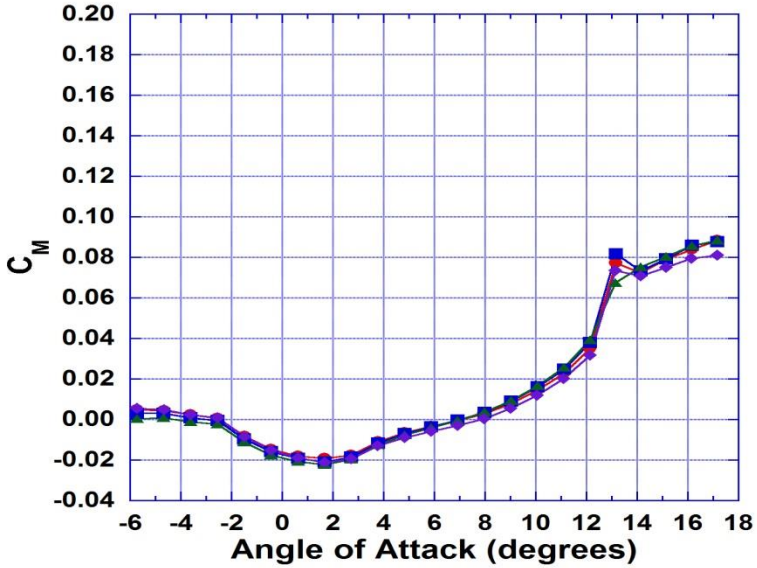
Effect of Splitter Plate

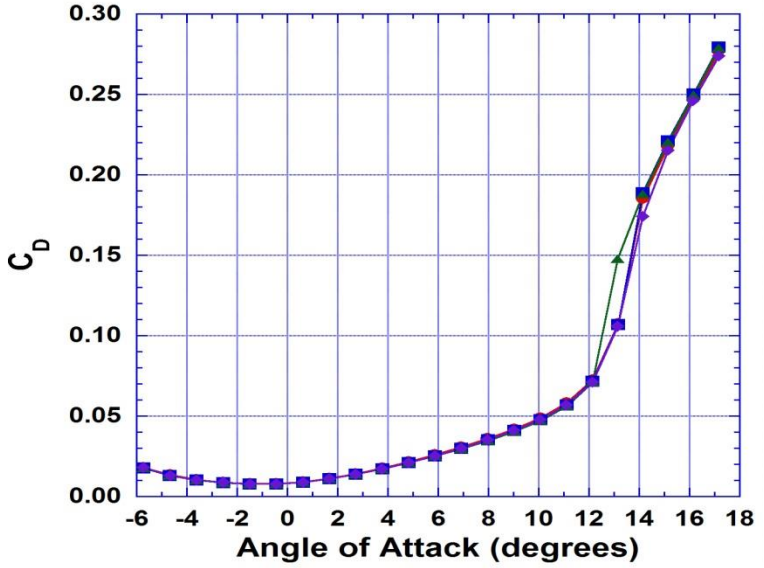


Clean LE, Re = 2.4 x 10^6, M = 0.27

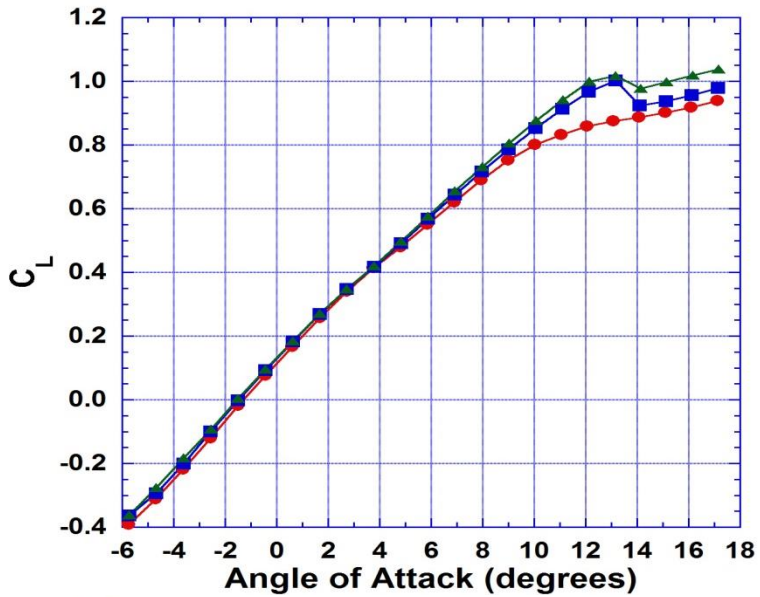
- Circular Splittler Plate, Circular Shroud
- Circular Splitter Plate, Streamlined Shroud
- Rectangular Splittler Plate, Streamlined Shroud
- No Splitter Plate, No Shrould

Circular plate and streamlined shroud selected for baseline case.

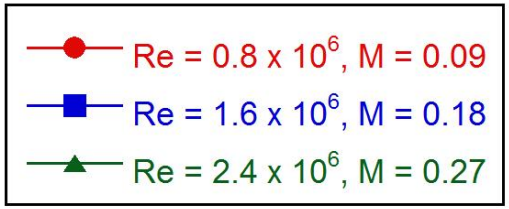


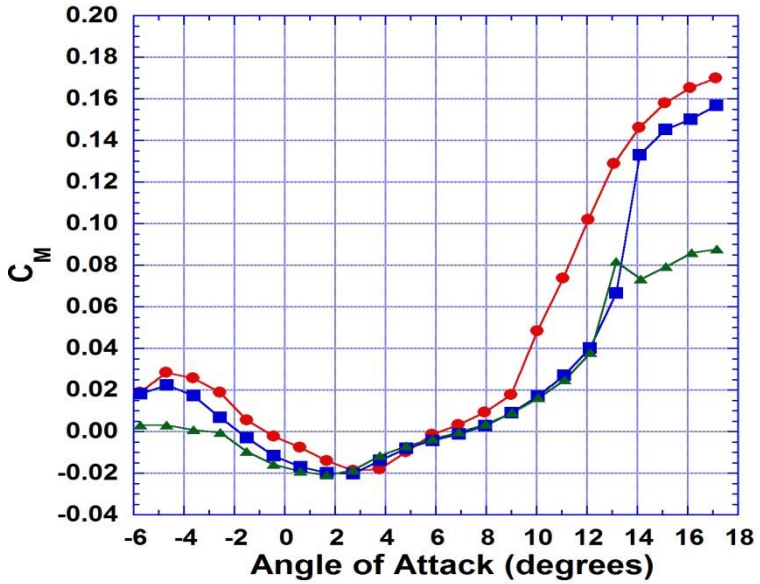


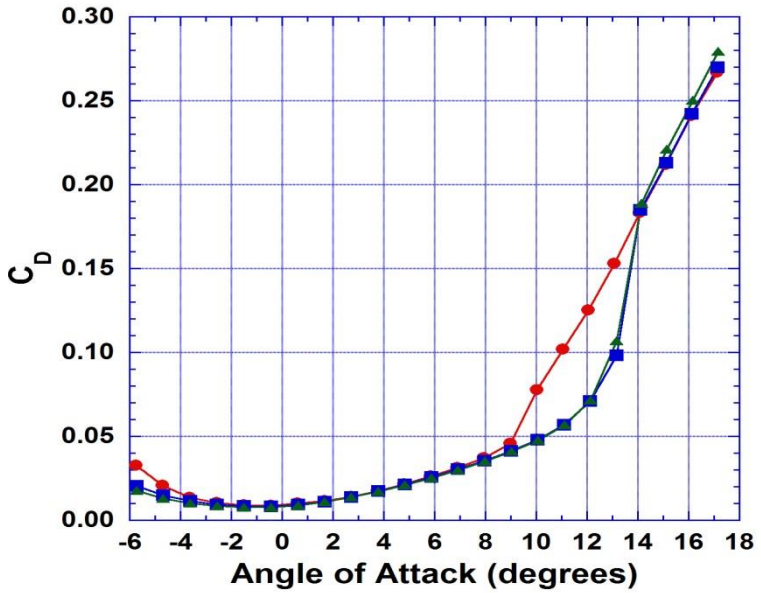
Baseline Clean



Clean LE, Circular Splitter Plate, Streamlined Shroud

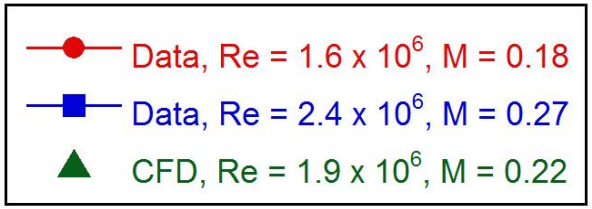


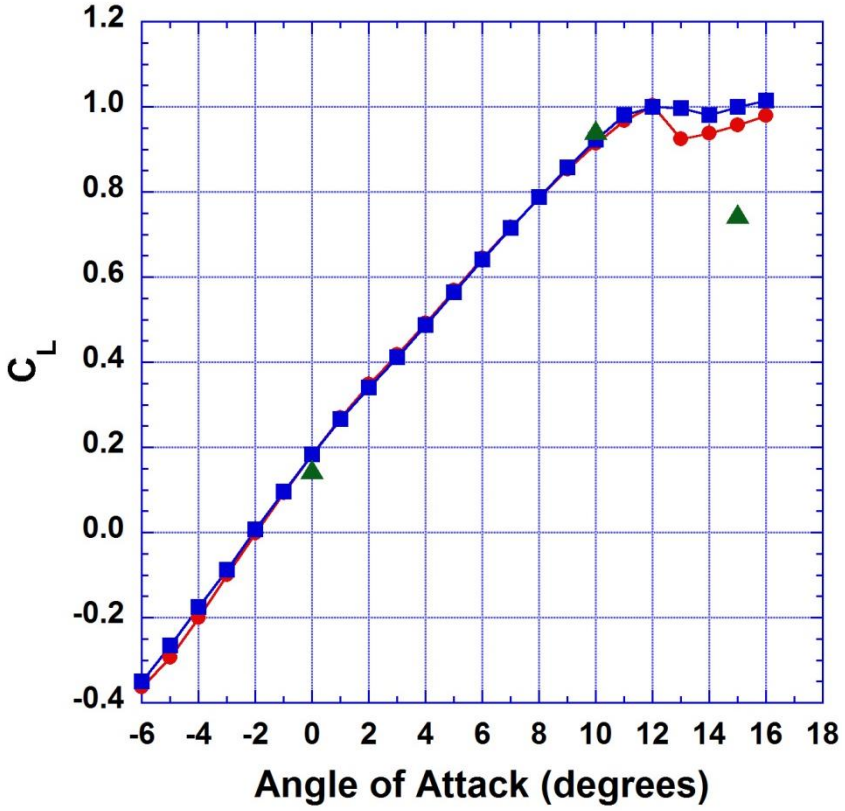


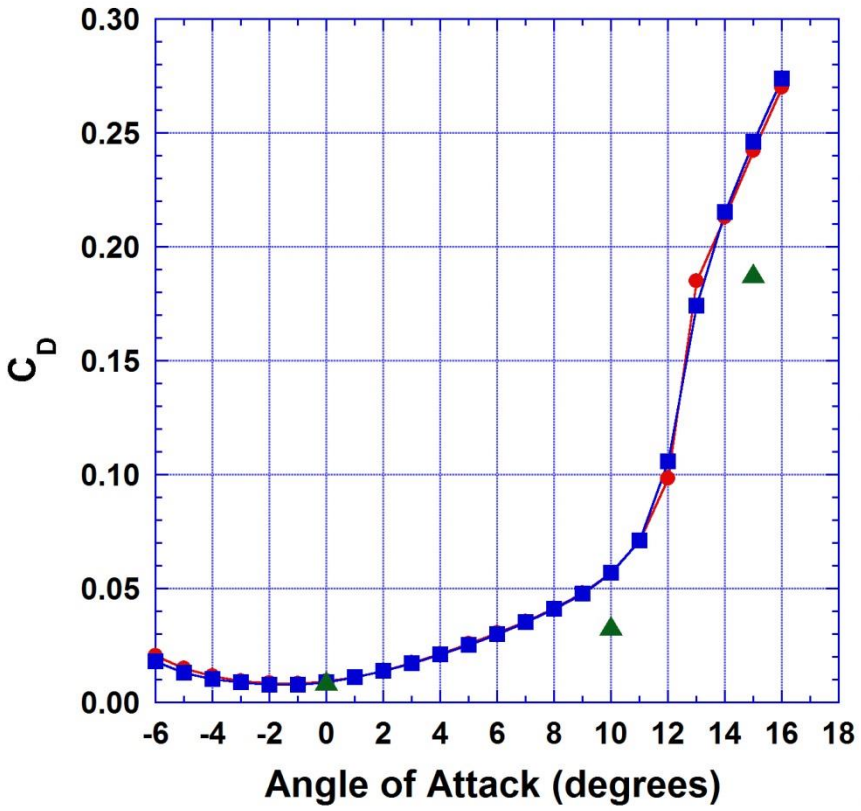


CFD Comparison

- ANSYS Fluent viscous simulation of baseline clean model case
- No splitter plate, no shroud

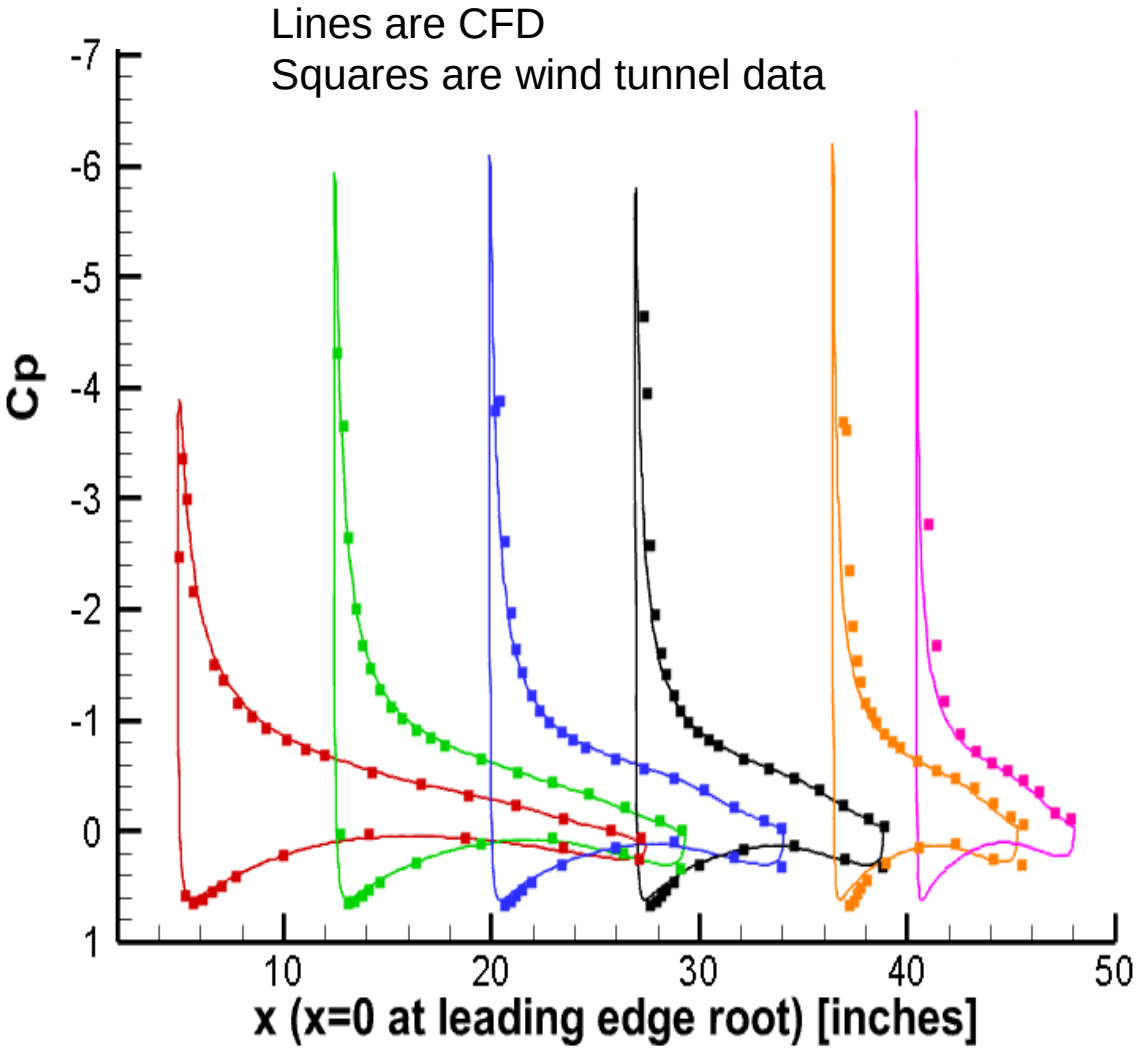




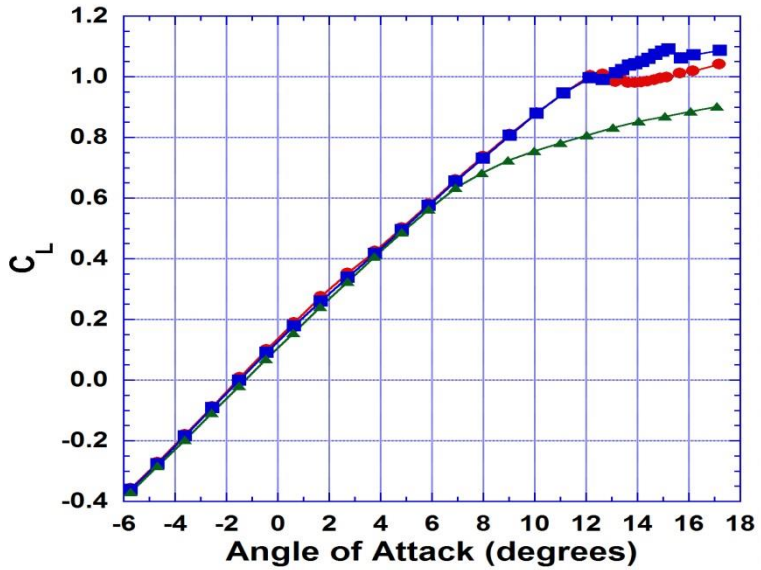


Surface Pressure Comparison

- Angle of attack of 10°
- Overall agreement between CFD and pressure tap data is good
  - Attachment line location matches well
  - Pressure tap resolution may not be high enough to accurately capture suction peak

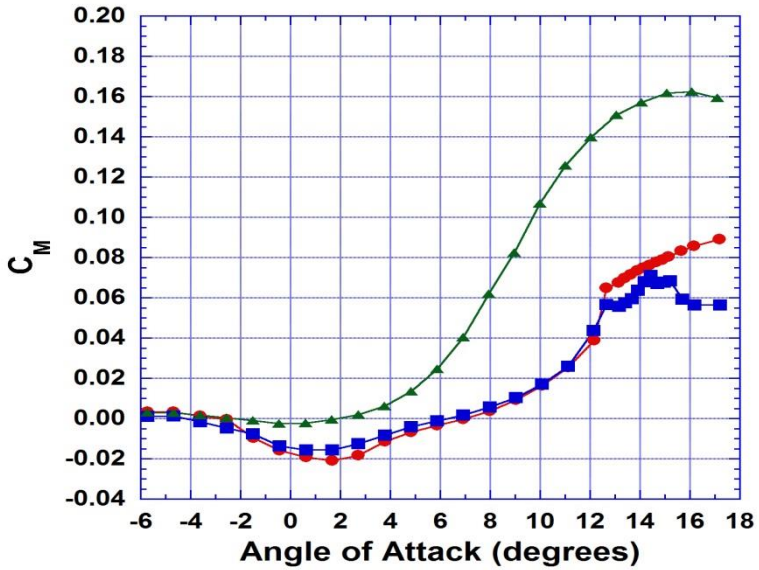


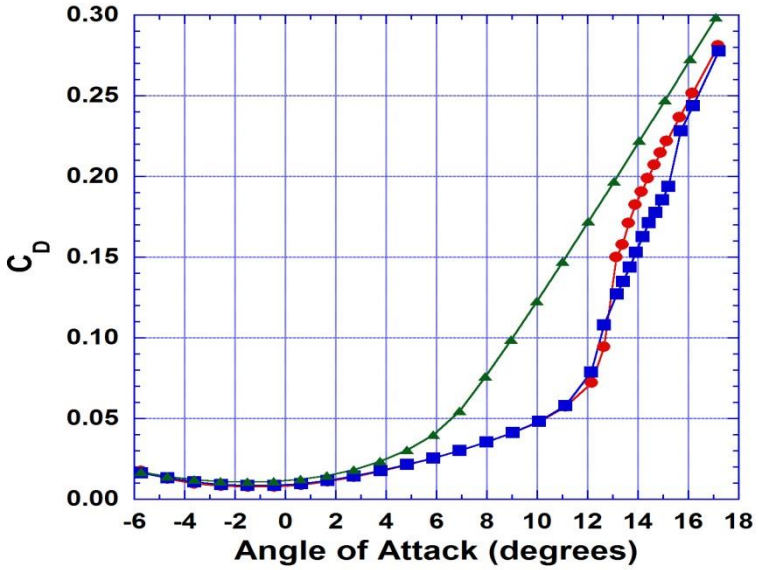
RPM Clean and Ice



Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27

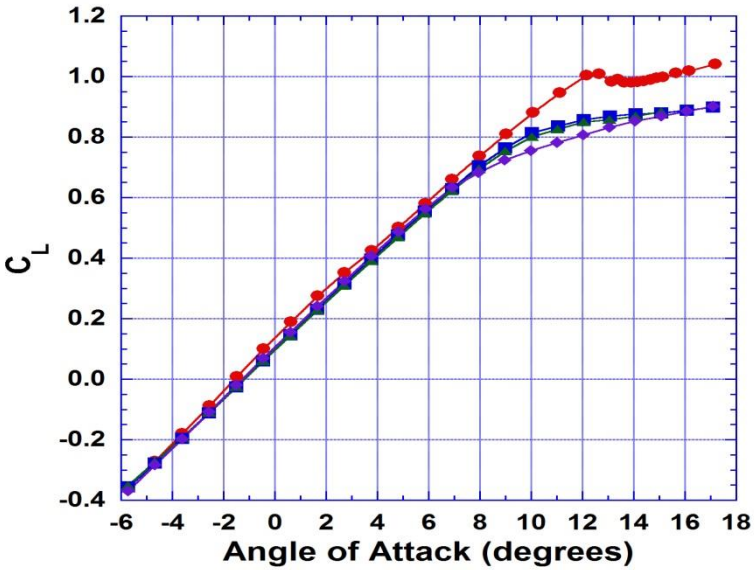
RPM “Clean” LE consists of 6 spanwise segments with no ice shape or roughness

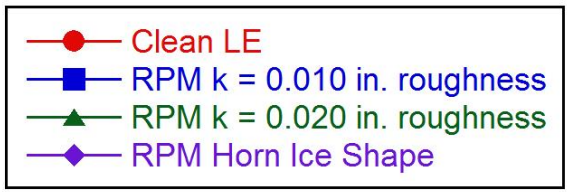


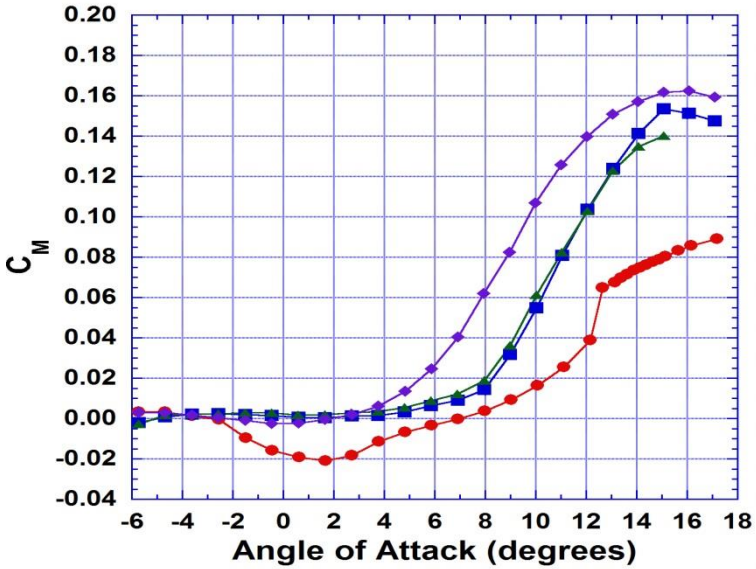


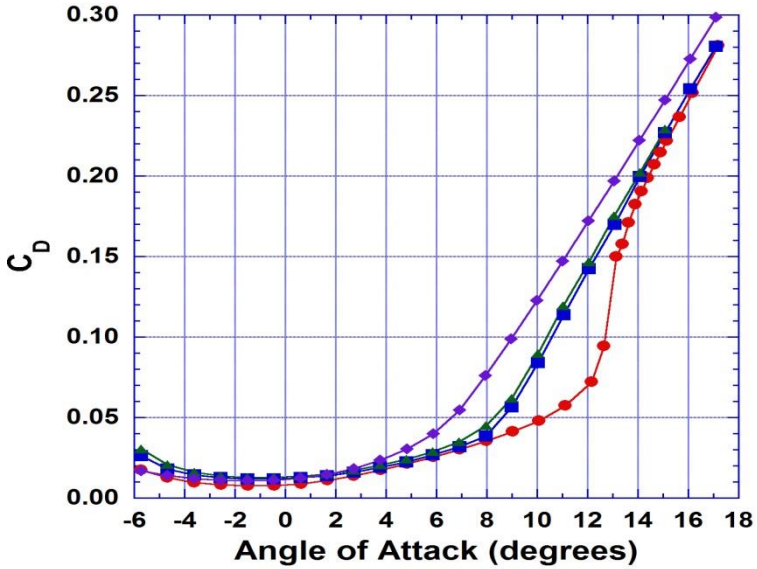
RPM Roughness

Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27



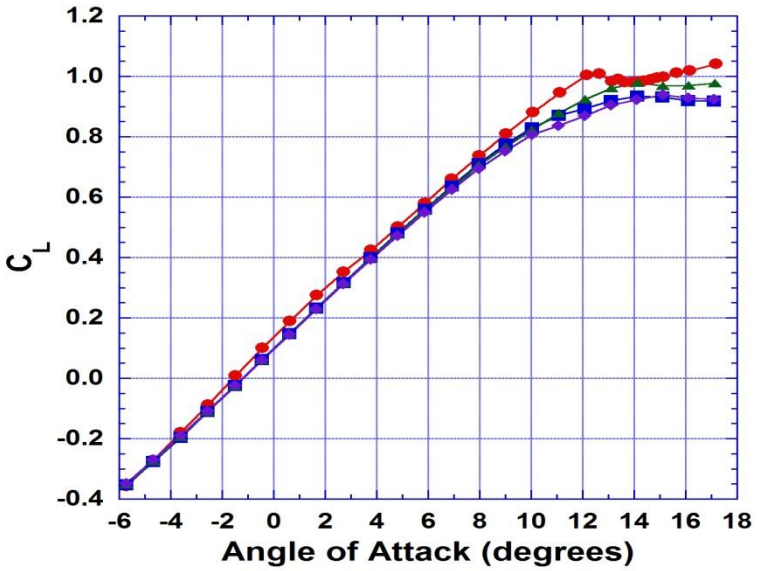


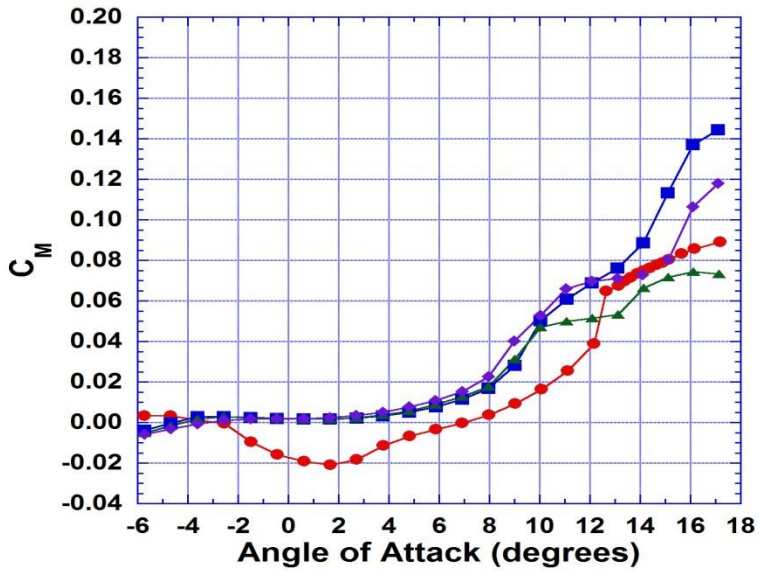


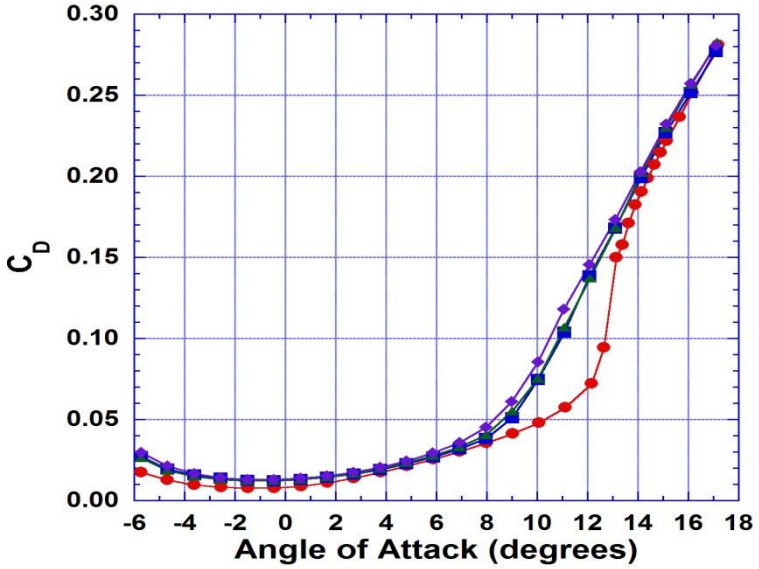


Grit Roughness

Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27

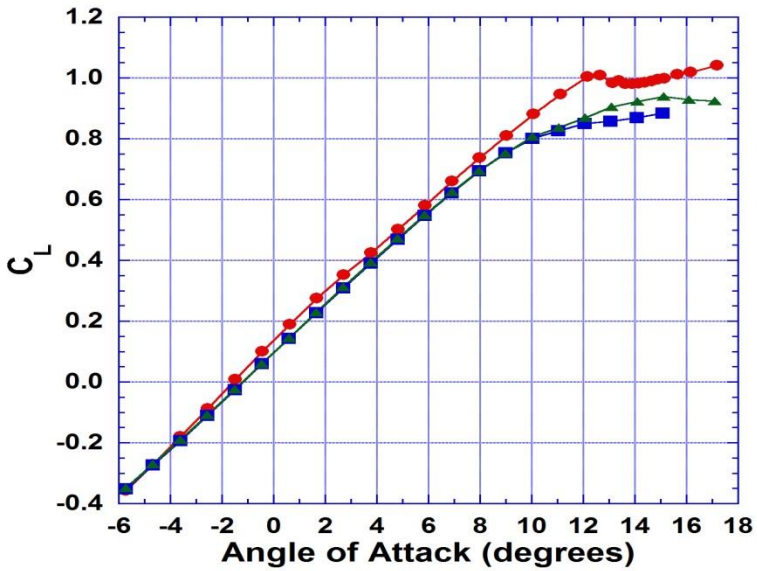


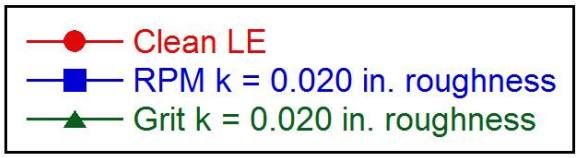


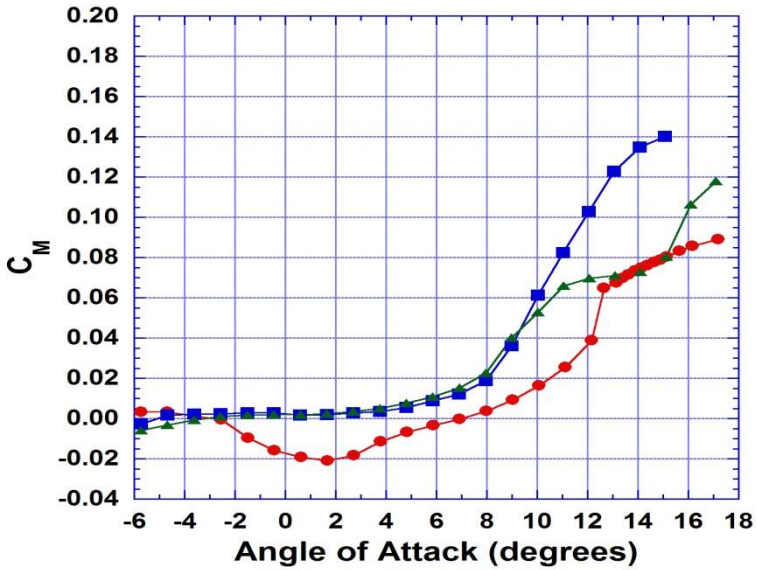


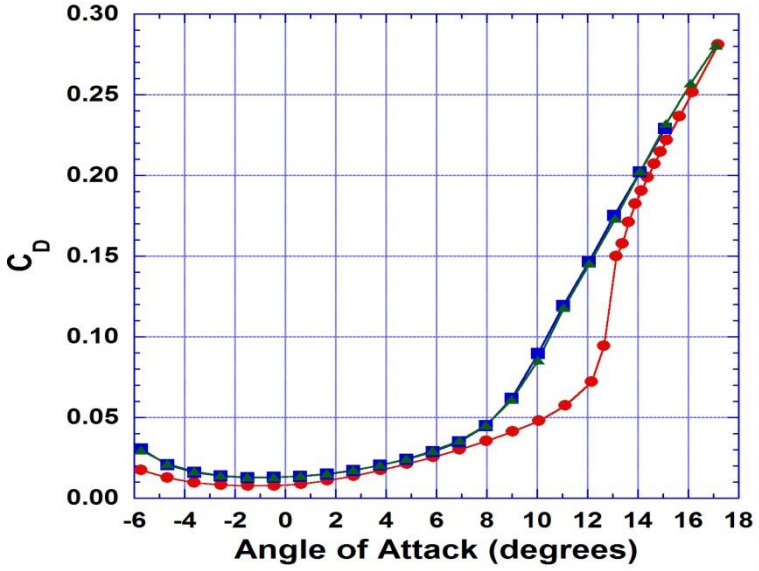
Grit and RPM Roughness Compared

Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27









Surface Oil Flow: Clean Wing

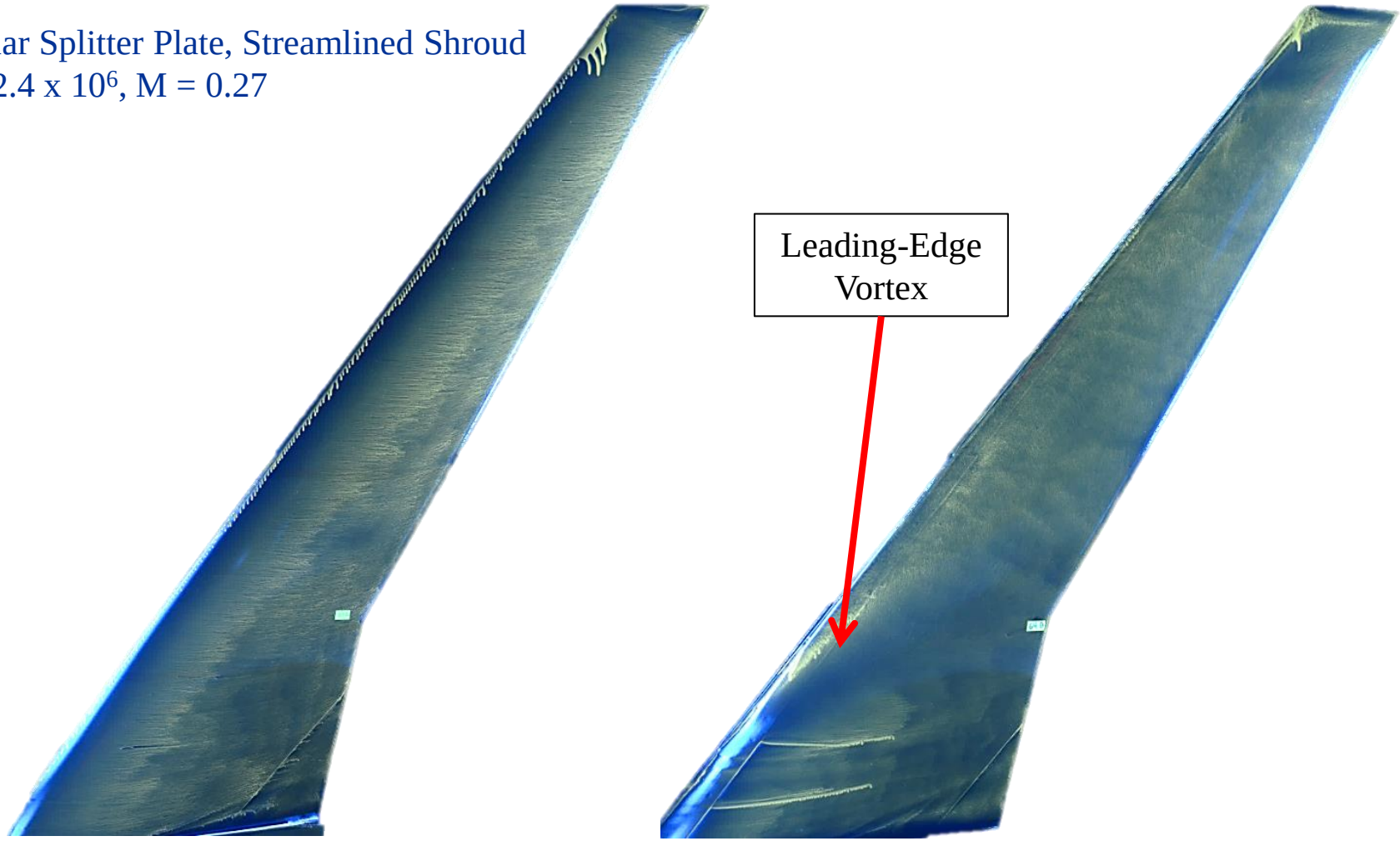
Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27

Clean wing, α = 0°

Clean wing, α = 12°

Oil Flow: Comparison of Clean and Ice

Circular Splitter Plate, Streamlined Shroud
Re = 2.4 x 10^6, M = 0.27



Clean wing, α = 8°

Ice wing, α = 8°

Conclusions

- Aerodynamic
  - Splitter plates
    - Aerodynamic differences between configurations were minimal
    - Circular splitter plate with streamlined shroud selected
  - Roughness
    - For the tested conditions, all roughness configurations had the same impact on the performance of the wing
      - 15% reduction in C_L at 12° angle of attack
      - 100% increase in C_D at 12° angle of attack
    - Rapid prototyped manufacturing techniques are capable of capturing ice roughness details (down to a height of 0.010 inches)
- Practical
  - Working with multiple spanwise removable segments is challenging especially with pressure taps
  - Future iterations will have fewer spanwise segments

Future Work with this Model

- Full-scale ice shapes acquired for spanwise segments of this model geometry in the NASA Icing Research Tunnel during spring 2015
- Those ice shapes will be extrapolated to create full-span ice shapes for this model
- Low-Re testing will resume with those high fidelity ice shapes in the spring of 2016
- The same experimental techniques presented here will be employed with the addition of a wake survey

Questions?

- Acknowledgments
  - FAA Grant 10-G-004
  - Technical monitor: Dr. James Riley
  - Gustavo Fujiwara and Brock Wiberg for their assistance with the CFD simulations