Sensitivity of Ice Shape Parameters to SLD Icing Cloud Conditions

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Outline

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- Objectives
- Approach
- Results
- Conclusions
- Recommendations

Background

"How good does it have to be?"

- **Question constantly asked of engineers and researchers**
- **With current effort to develop SLD Engineering Tools for certification (icing tunnels, tankers, codes)**
  - **This question has focused renewed attention on need for requirements**
- **Requirements were included in the SLD Technology Roadmap**
  - **Starting point for the development of SLD Tools**

Background

TASK 1.1 - Develop requirements for SLD simulation

Requirements (or metrics) need to be defined to provide a "target" for SLD simulation in quantified terms. These requirements serve a dual-purpose by providing guidance:

- **(1) about what essential features or characteristics need to be simulated**
- **(2) about how accurately these characteristics need to be simulated. It is anticipated that these requirements would be developed by means of sensitivity studies, either experimental or computational …**

Background

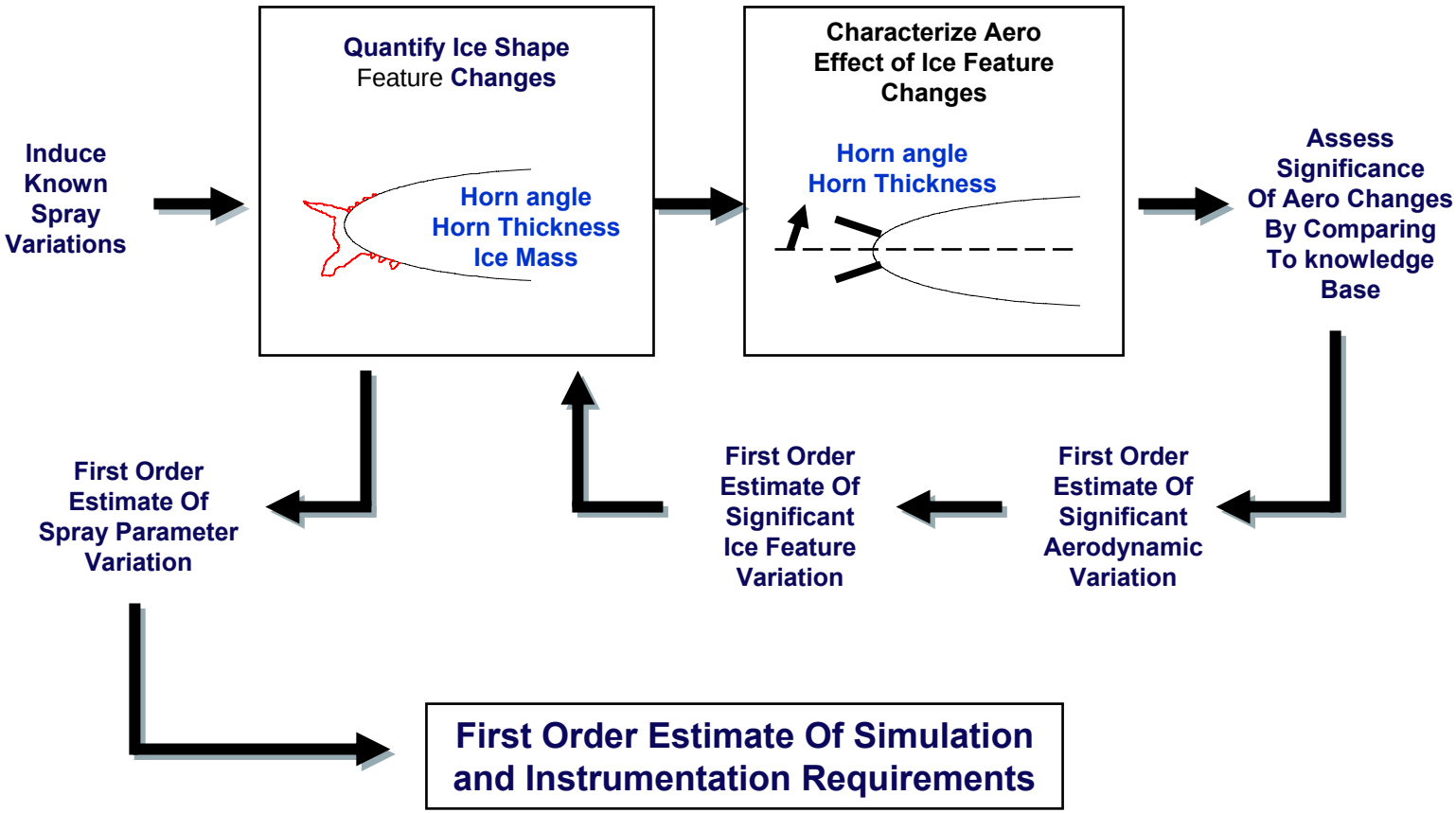
- **Previous efforts were conducted with App. C conditions**
  - **Proof of concept testing**
  - **Ability to simultaneously vary LWC and MVD**
- **Results documented in:**
  - **Miller, D., et al, "Preliminary Investigation of Ice Shape Sensitivity to Parameter Variations", AIAA-2005-0073**
  - **Miller, D., et al, "Additional Investigations of Ice Shape Sensitivity to Parameter Variations", AIAA-2006-0469**
  - **Campbell, S., et al, "Aircraft Performance Sensitivity to Icing Cloud Conditions", AIAA-2007-0086**

Objectives

- **Determine the minimum change in LWC or MVD which produces a discernible change in the ice shape**

- **Evaluate feasibility of using changes in ice shape features as a method to aid in developing requirements**
  - **For SLD ice prediction codes**
  - **For measurement of SLD icing conditions**

Approach


Induce Known Spray Variations
Quantify Ice Shape Feature Changes
Horn angle
Horn Thickness
Ice Mass
Characterize Aero Effect of Ice Feature Changes
Horn angle
Horn Thickness
Assess Significance Of Aero Changes By Comparing To knowledge Base
First Order Estimate Of Spray Parameter Variation
First Order Estimate Of Significant Ice Feature Variation
First Order Estimate Of Significant Aerodynamic Variation
First Order Estimate Of Simulation and Instrumentation Requirements

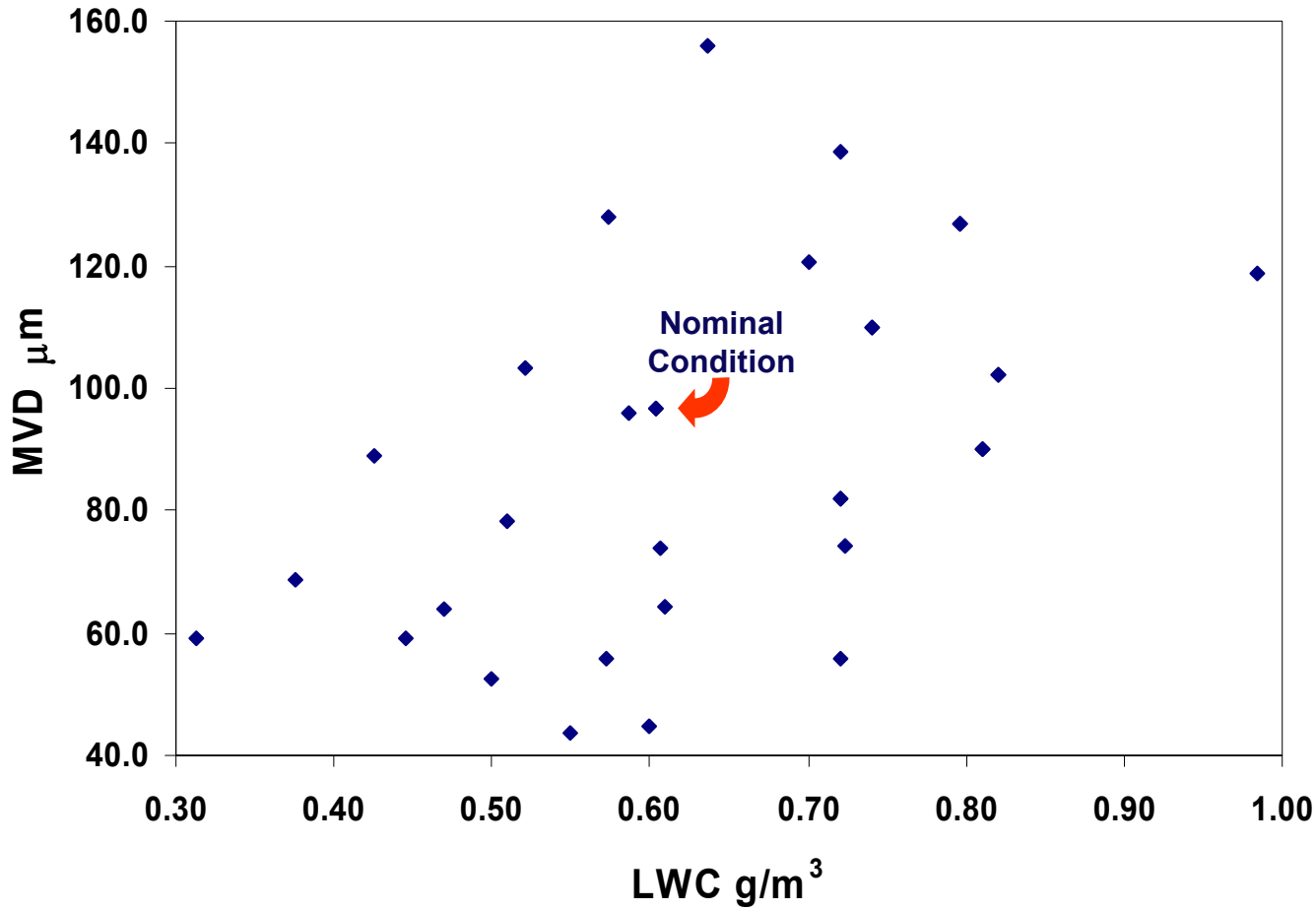
Approach

- First examination of sensitivity of SLD shapes to variations in LWC and MVD
- Ice shape changes evaluated for spray variations about nominal condition of:

  LWC=0.603 g/m^3, MVD=96.7 μm, T_s = 15°F (-9.4°C), V = 150 knot
- Varied LWC, MVD, and T using calibrated SLD conditions for the IRT

Approach

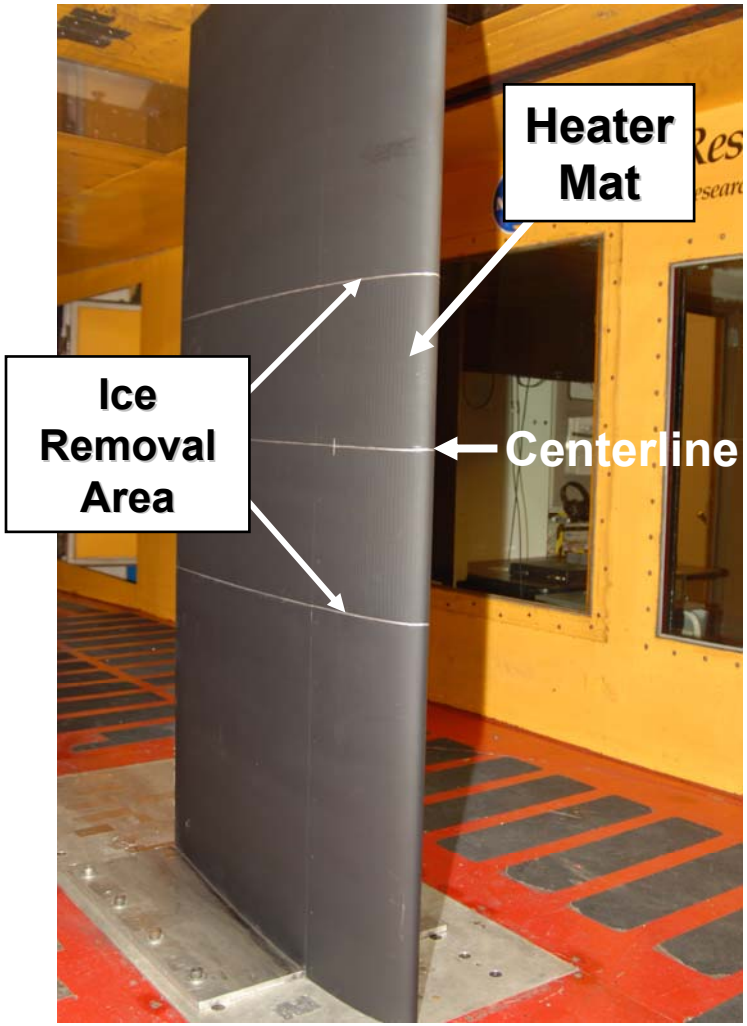
Grid of Spray Conditions in Test Matrix



Test Conditions

- LWC and MVD associated with grid of 31 spray conditions were the "variant" conditions
- Nominal condition: MVD=96.7μm, LWC=.603 g/m^3
- T_{tot} = 20.3°F (-6.5°C), T_s=15°F (-9.4°C)
- V = 150 knots
- AOA = 2.7°
- Spray = 15 minutes

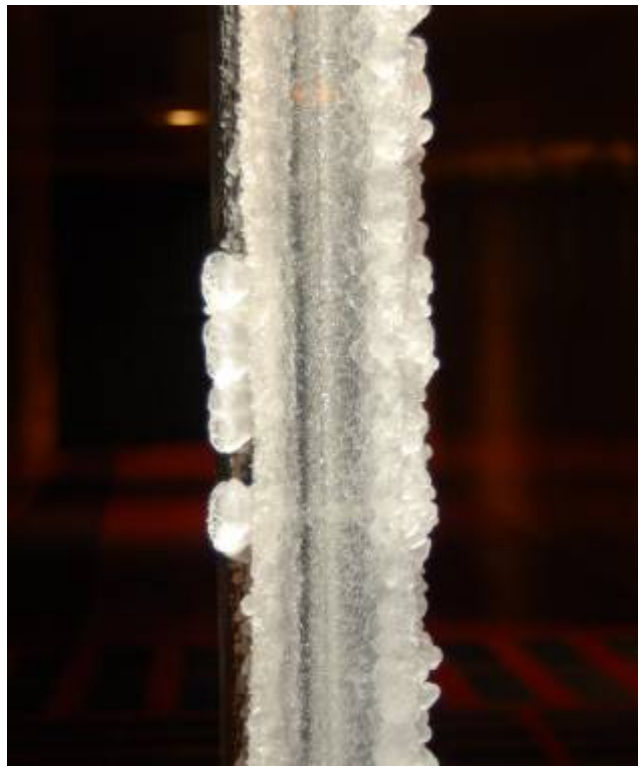
Test Article



NACA-0012 Airfoil

- 6 foot span (1.83 m)
- 3 foot chord (0.91 m)
- 2.7 deg AOA
- Heater Mat
  - 5 inches on upper surface (.127 m)
  - 10 inches on lower surface (.254 m)

Ice Build-up on Test Article

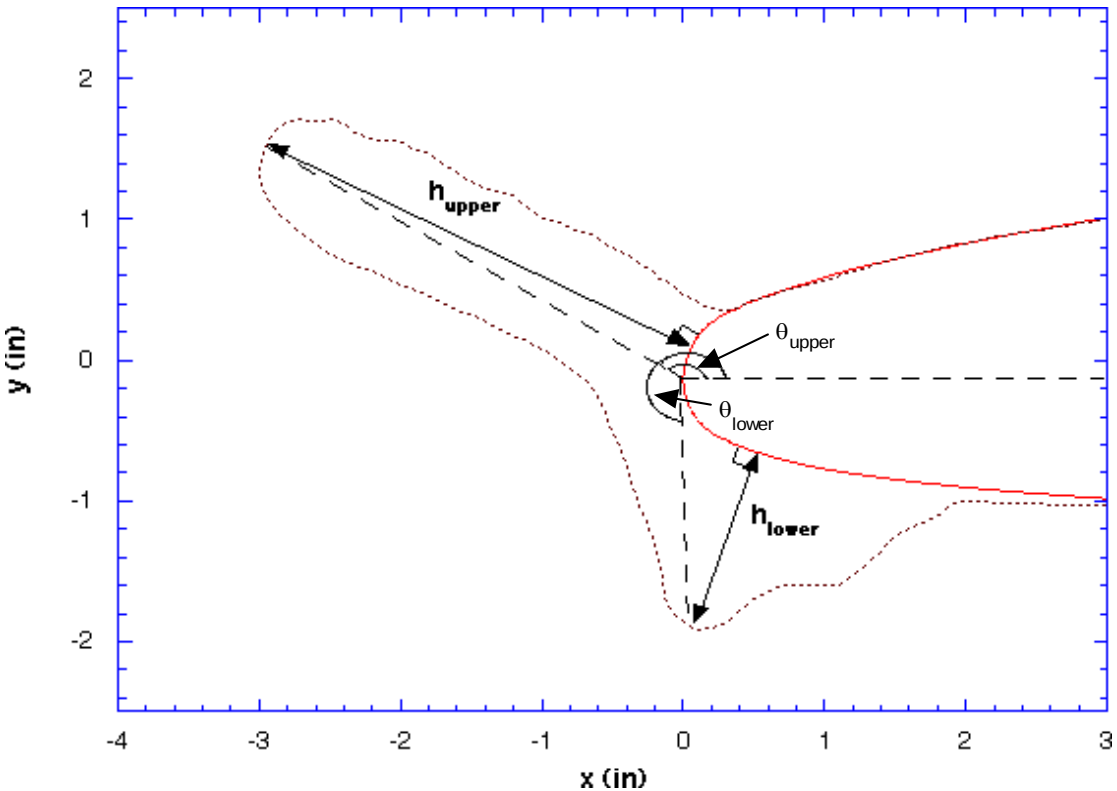


Test Procedure

- **Nominal and variation conditions were used to set tunnel operating values (i.e. tunnel velocity, air temperature, spray bar air and water pressures)**
- **Icing conditions were applied for the selected run time values**
- **After the spray was concluded and the tunnel velocity was set to idle:**
  - Photographs of the ice accretion were taken
  - An ice shape tracing was made at the mid-span location
  - The ice was cut at predetermined span-wise locations above and below mid-span
  - Heaters were turned on to de-bond the ice from the surface
  - Ice was removed and weighed

Quantitative Measurements

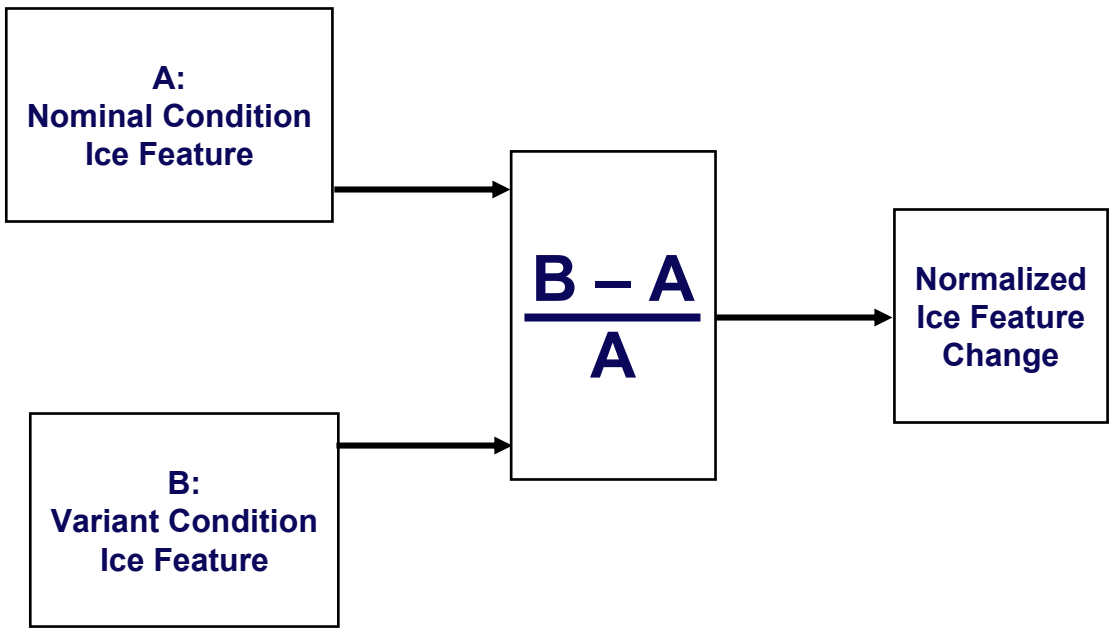
THICK program used to make quantitative measurements



- Program developed by Bill Wright
- Used for LEWICE 2.0 validation
- Quantitative measurement of ice features
  - Horn angles
  - Horn thickness
  - Iced area
  - Icing Limits

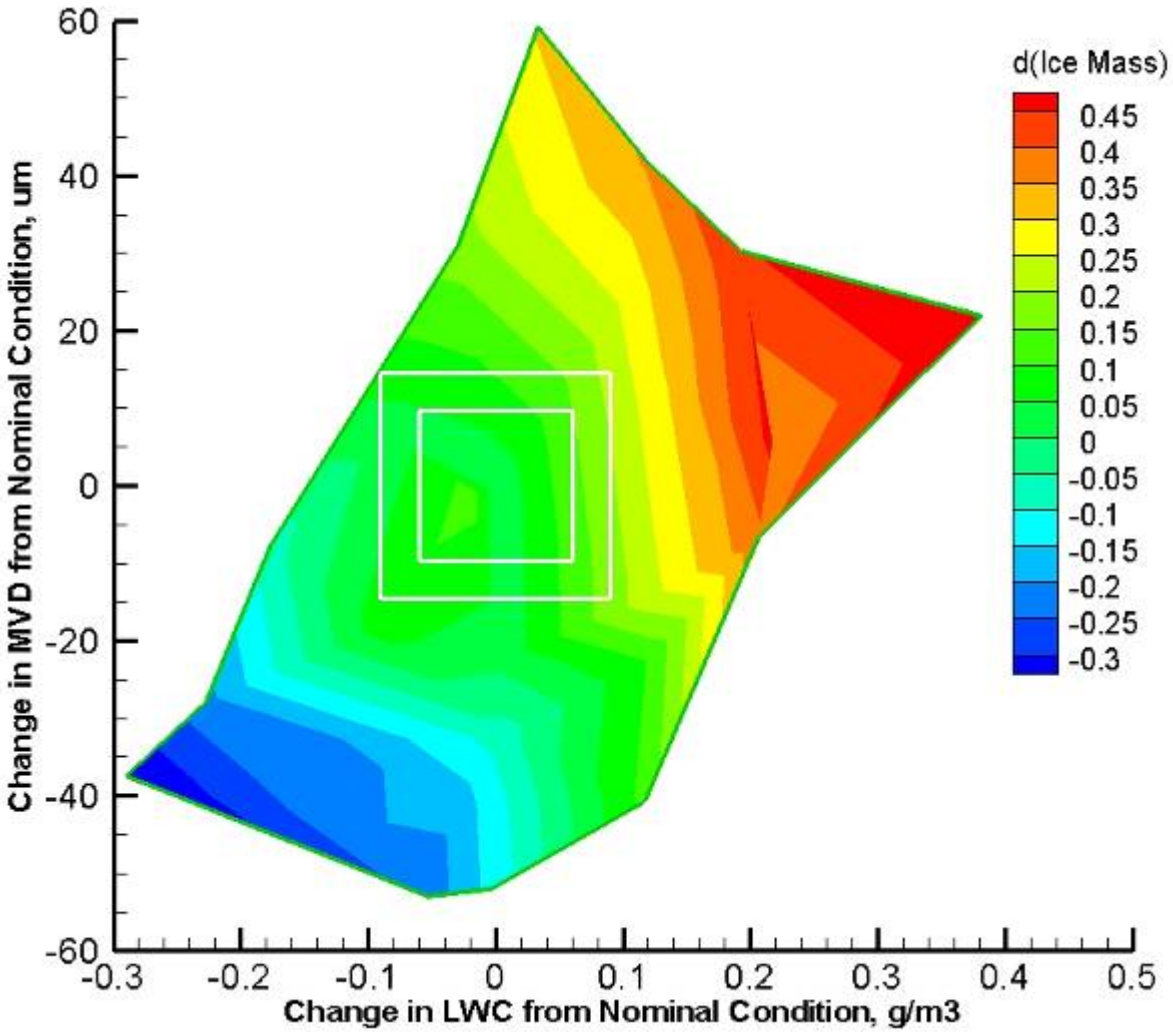
Data Analysis Method

Method used to process data for contour plots



Ice Features Legend:
- Mass
- Upper Horn Angle
- Lower Horn Angle
- Upper Horn Thickness
- Lower Horn Thickness

ΔMass wrt Nominal Condition



Test Conditions:

T_{tot} = 20.3°F (-6.5°C)

T_s = 15°F (-9.4°C)

V = 150 knots

AOA = 2.7°

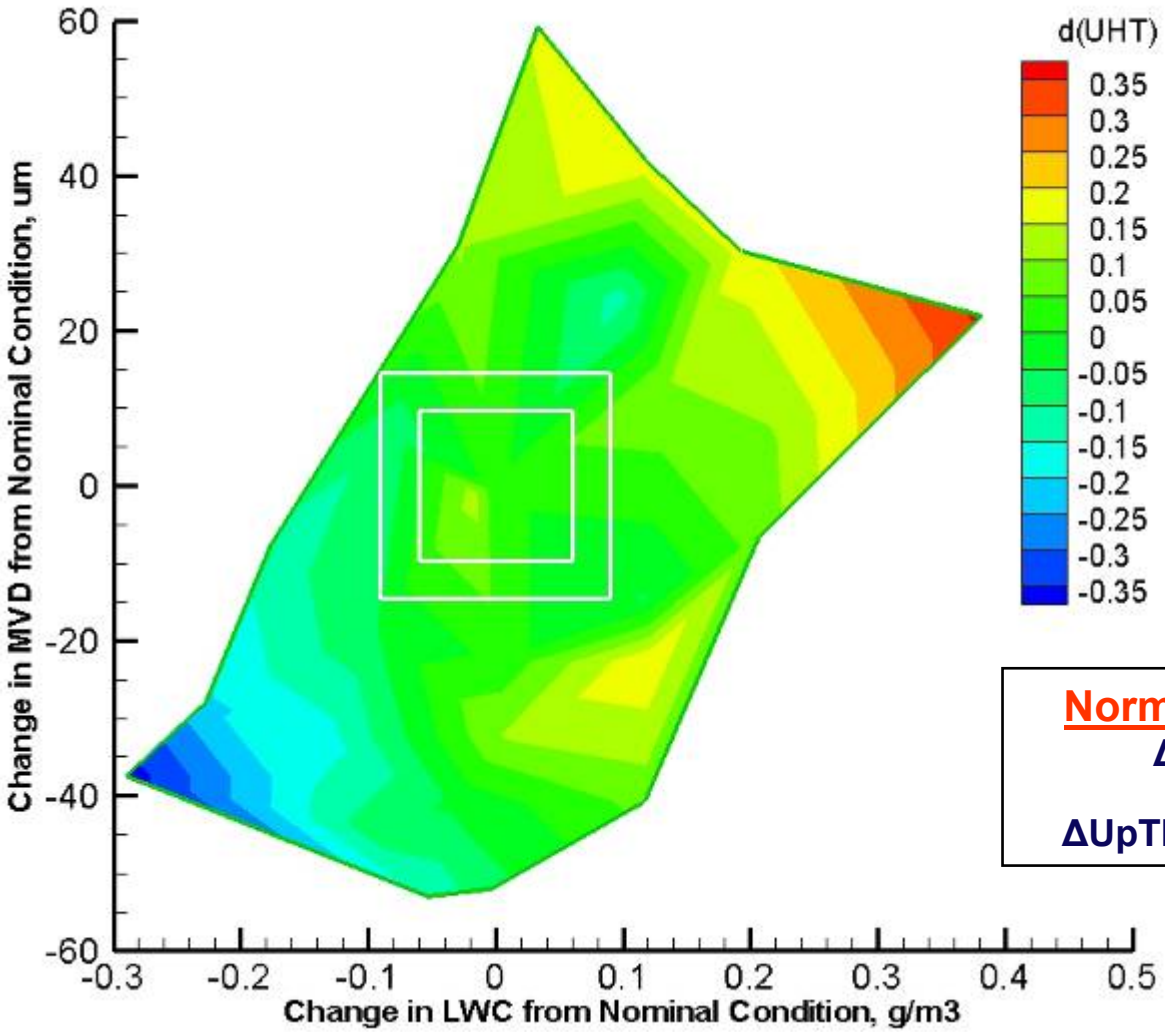
Spray = 15 min

Normalized Mass

$\Delta Mass / Mass_{nom}$

$\Delta Mass = Mass - Mass_{nom}$

ΔUpper Horn Thickness wrt Nominal Condition



Test Conditions:

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T_s = 15°F (-9.4°C)

V = 150 knots

AOA = 2.7°

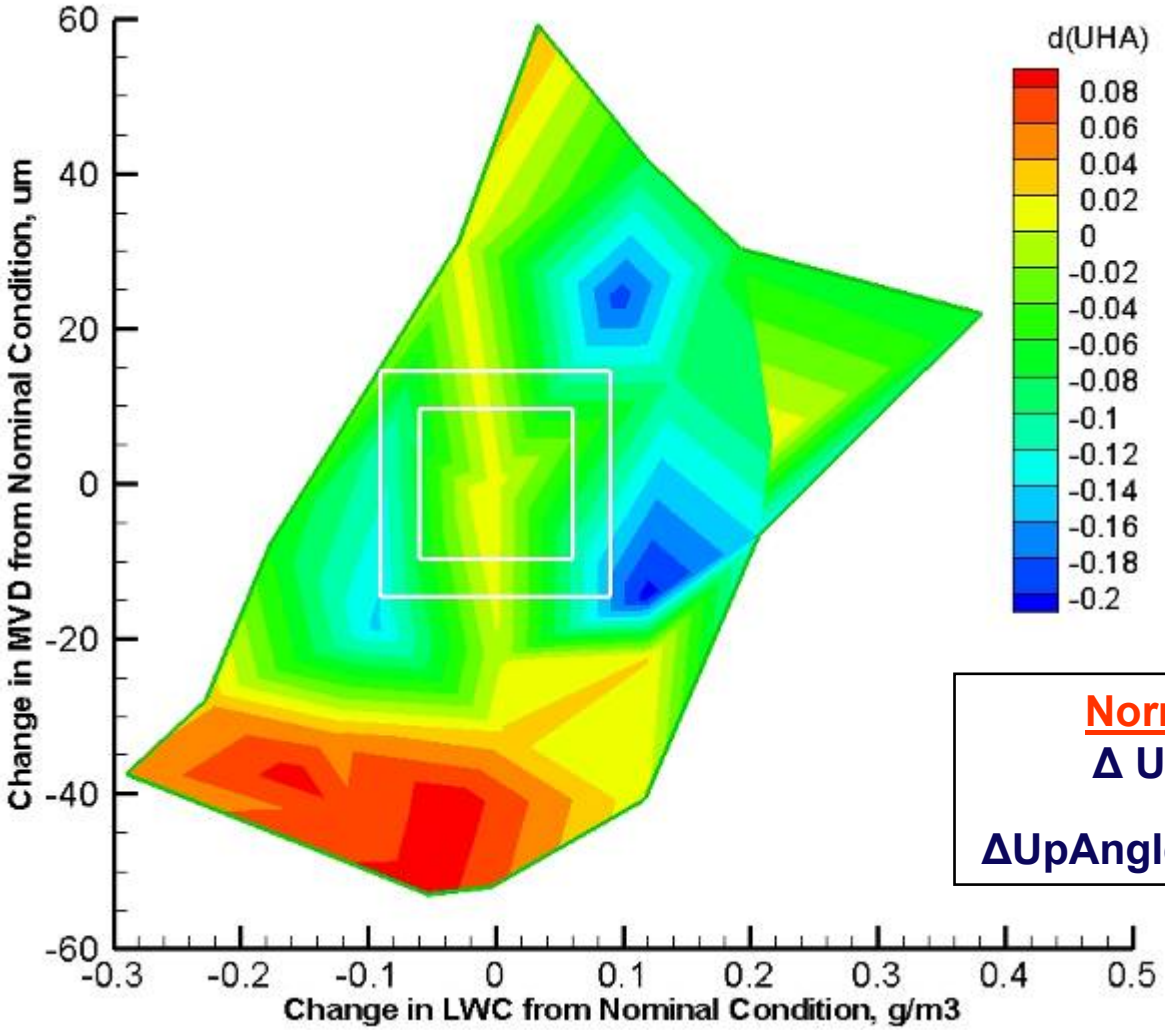
Spray = 15 min

Normalized Upper Thickness

Δ UpThick / $UpThick_{nom}$

$\Delta UpThick = UpThick - UpThick_{nom}$

ΔUpper Horn Angle wrt Nominal Condition



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V = 150 knots

AOA = 2.7°

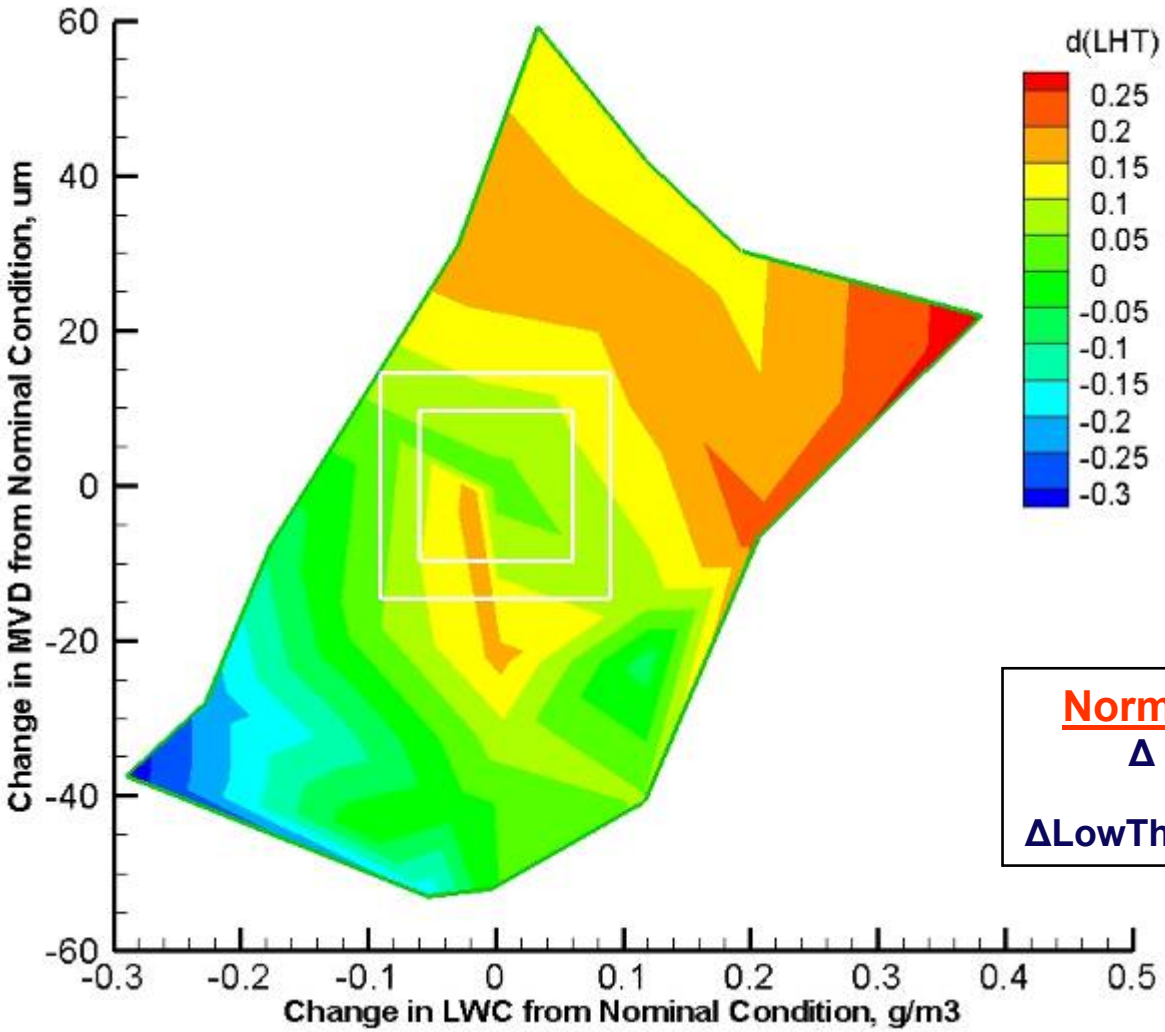
Spray = 15 min

Normalized Upper Angle

$\Delta\ UpAngle / UpAngle_{nom}$

$\Delta UpAngle = UpAngle - UpAngle_{nom}$

ΔLower Horn Thickness wrt Nominal Condition



Test Conditions:

T_{tot} = 20.3°F (-6.5°C)

T_s = 15°F (-9.4°C)

V = 150 knots

AOA = 2.7°

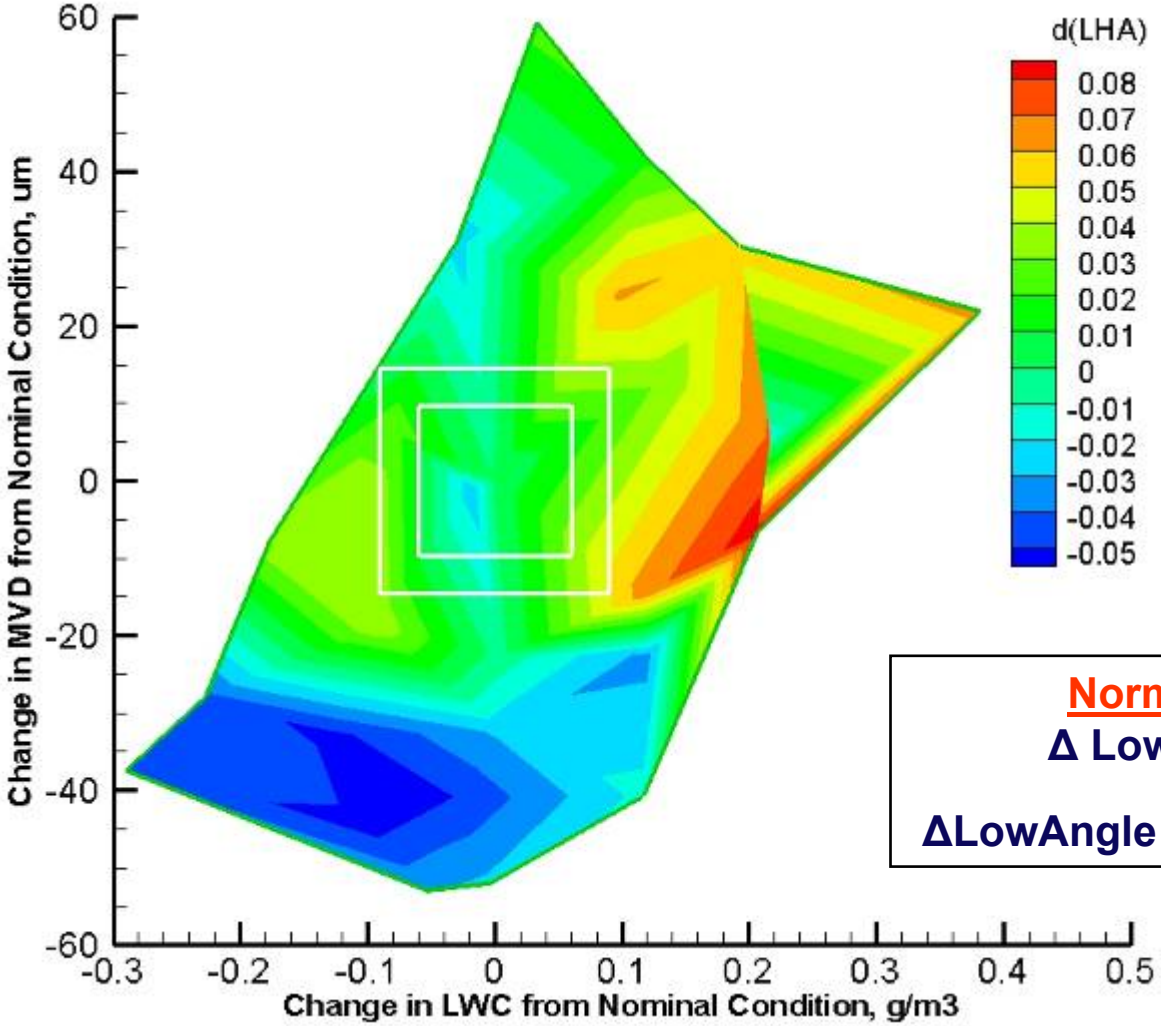
Spray = 15 min

Normalized Lower Thickness

Δ LowThick / $LowThick_{nom}$

$\Delta LowThick = LowThick - LowThick_{nom}$

ΔLower Horn Angle wrt Nominal Condition



Test Conditions:

T_{tot} = 20.3°F (-6.5°C)

T_s = 15°F (-9.4°C)

V = 150 knots

AOA = 2.7°

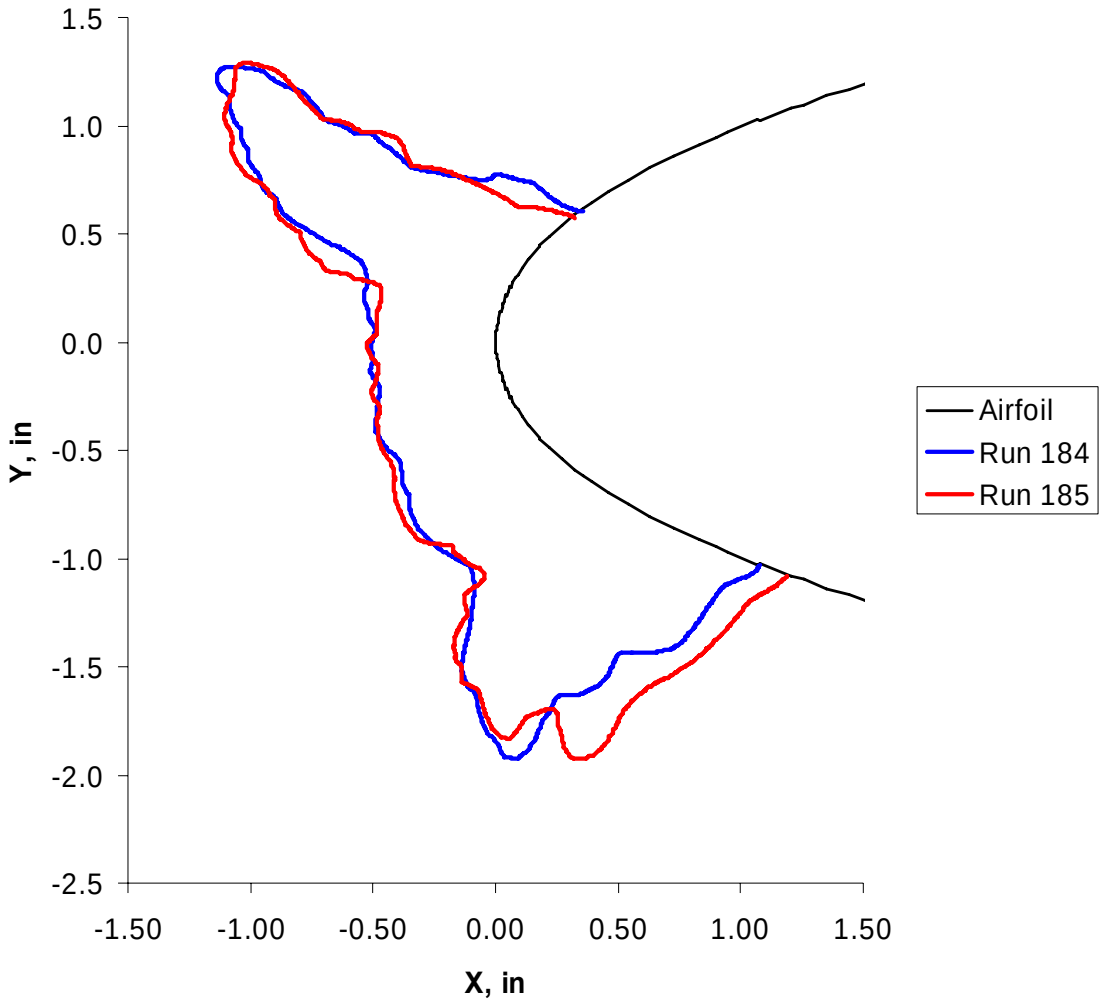
Spray = 15 min

Normalized Lower Angle

$\Delta\ LowAngle / LowAngle_{nom}$

$\Delta LowAngle = LowAngle - LowAngle_{nom}$

Ice Shape Repeatability



Nominal Condition

MVD=96.7µm

LWC=.603 g/m^3

T_{tot} = 20.3°F (-6.5°C)

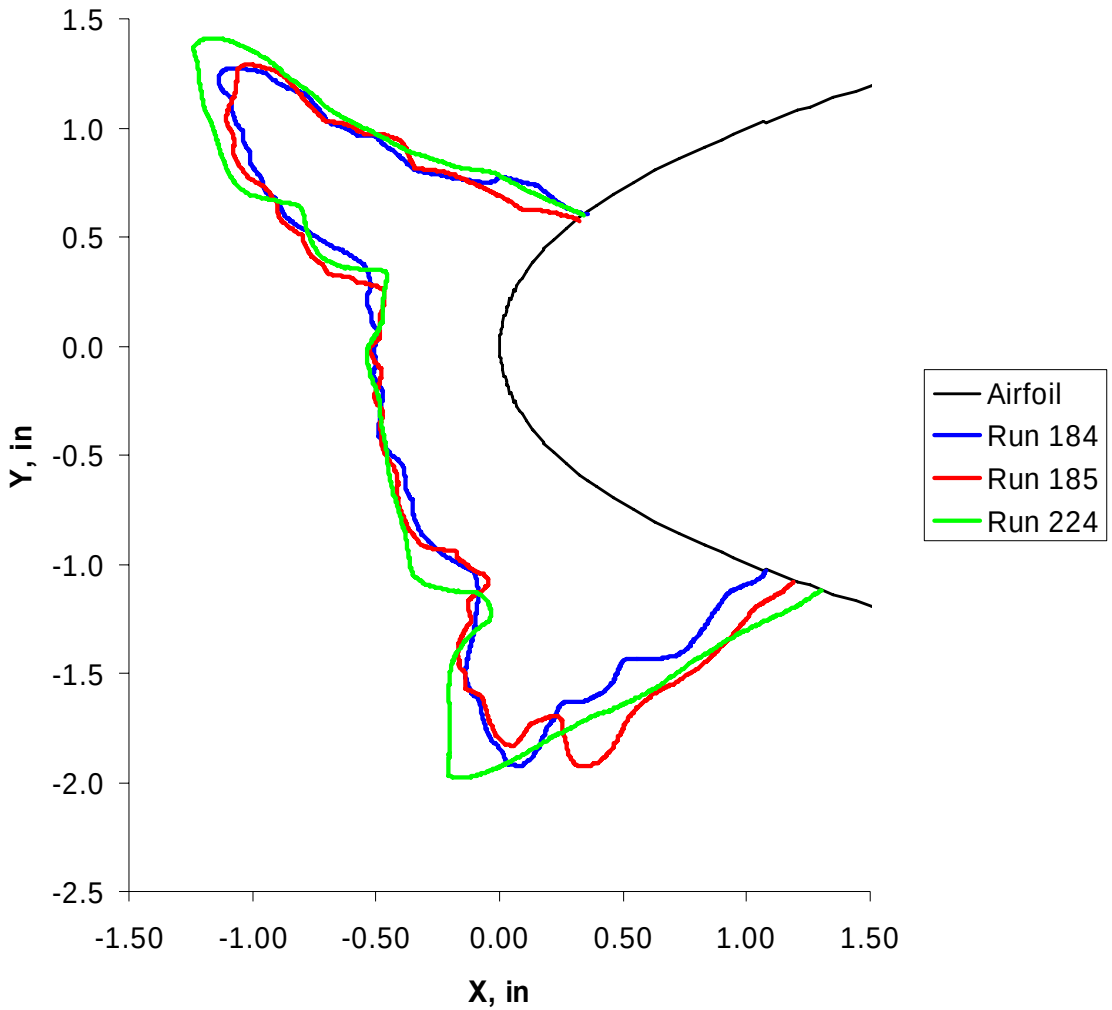
T_s = 15°F (-9.4°C)

V = 150 knots

AOA = 2.7°

Spray = 15 min

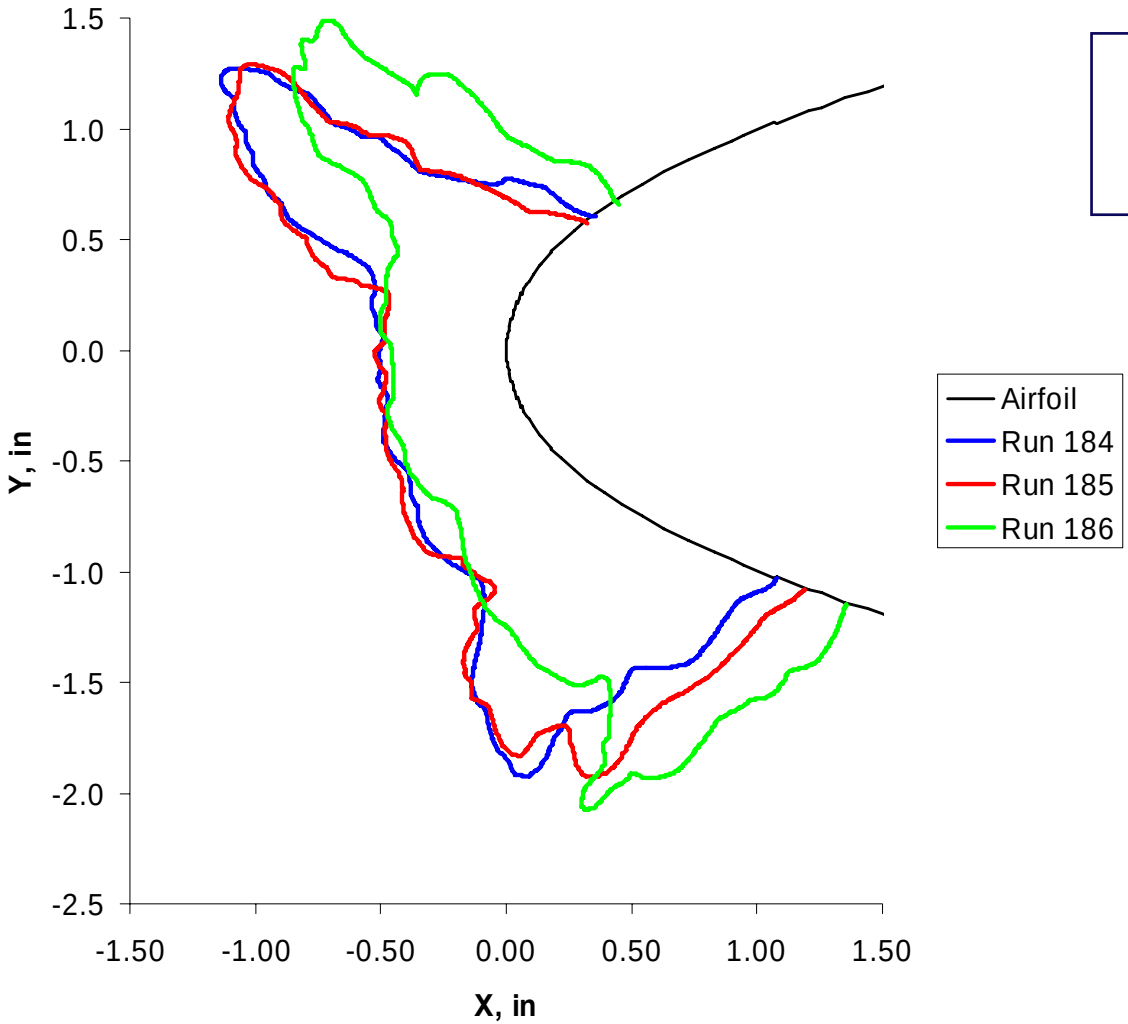
Ice Shape Comparisons



1% variation in MVD

3% variation in LWC

Ice Shape Comparisons



14% variation in MVD

7% variation in LWC

Parameter Variations

Percent Variation

Parameter	Run 224	Run 186
Mass	12	2.4
Upper Horn Thickness	12	8.6
Upper Horn Angle	0.8	11
Lower Horn Thickness	17	3.4
Lower Horn Angle	2.5	2.7

Parameter Variations

Percent Variation

Parameter	Run 224	Run 186
Mass	12	2.4
Upper Horn Thickness	12	8.6
Upper Horn Angle	0.8	11
Lower Horn Thickness	17	3.4
Lower Horn Angle	2.5	2.7

Conclusions

- An ice shape sensitivity test was conducted in SLD conditions to evaluate the effect of LWC and MVD variations on ice features
- Variations in ice mass appear to be most closely correlated to changes in in MVD and LWC
- Variations in horn thickness also appeared to be well behaved
- Variations in horn angle showed the least correlation to changes in MVD and LWC
- More data is needed to develop more quantitative statistical information

Recommendations

1. Conduct follow on sensitivity tests to develop statistical information on repeatability and variability
   - More repeat data
   - Fill in the matrix
2. Work with IRT cloud specialists to identify more SLD conditions in order to “fill in the matrix”
3. Perform aerodynamic testing to relate ice shape sensitivity to aerodynamic characteristics

Acknowledgements

- Dean Miller
- Judy Van Zante
- Tammy Langhals
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