Ice-Accretion Test Results for Three-Large-Scale Swept-Wing Models in the NASA Icing Research Tunnel

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AIAA 8th ASE Conference Washington, D.C. June 13-17, 2016

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- Hybrid Model Design
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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.

Objective and Approach

Objective

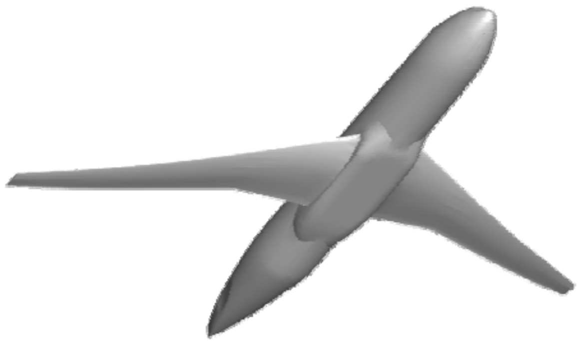
- Generate a database of ice-accretion geometry for large-scale, swept wings.

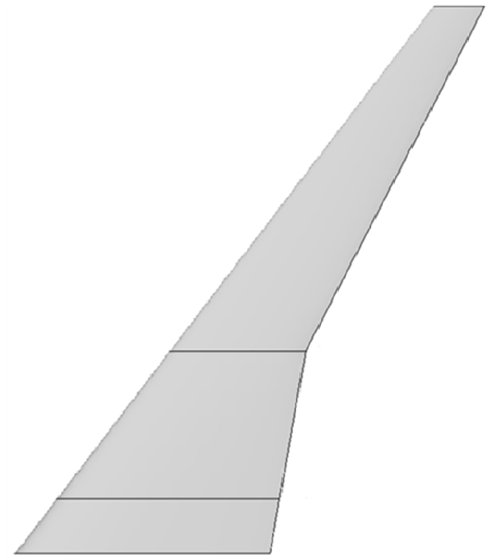
Approach

- Select baseline large-scale, swept-wing geometry.
- Identify three spanwise stations of interest—Inboard, Midspan and Outboard.
- Design hybrid or truncated wing-section models for IRT test section.
- Conduct ice-accretion testing in IRT.
- Measure ice geometry with 3D scanning technique.

Common Research Model (CRM)

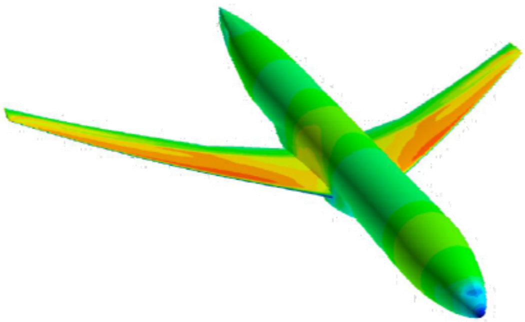
- Commercial transport class configuration.
- Contemporary transonic supercritical wing design.
- Publically available and otherwise unrestricted for world-wide distribution.
- A 65% scale CRM was selected as the full-scale, reference swept-wing geometry for this research.
- CRM65 size airplane is comparable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



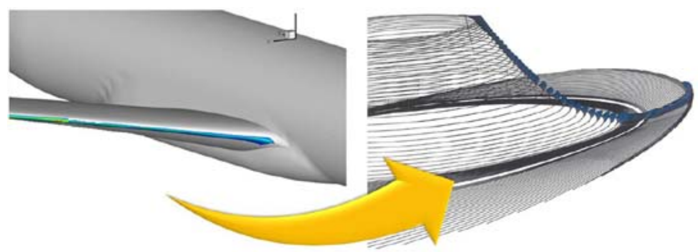


Hybrid Model Design

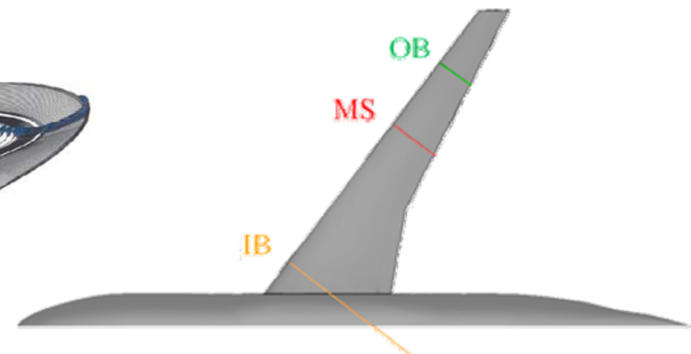
Clean Flight Baseline (CFB) OVERFLOW



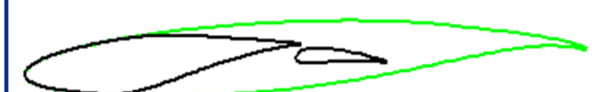
Iced Flight Baseline (IFB) LEWICE3D



Select wing stations for hybrid model design



- Design hybrid models to generate full-scale ice accretion.

Inboard, 20% Semispan Scale Factor = 2.25	Midspan, 64% Semispan Scale Factor = 2	Outboard, 83% Semispan Scale Factor = 1.5
		

Experimental Methodology

- Ice-accretion testing was conducted at NASA Icing Research Tunnel (IRT) that simulates flight through an icing cloud at pressure-altitudes near sea level.
- IRT test section is 6 ft high by 9 ft wide by 20 ft long.
- Models were installed vertically from floor-to-ceiling with small gaps to provide clearance for angle of attack and flap angle changes.

Inboard Model

Midspan Model

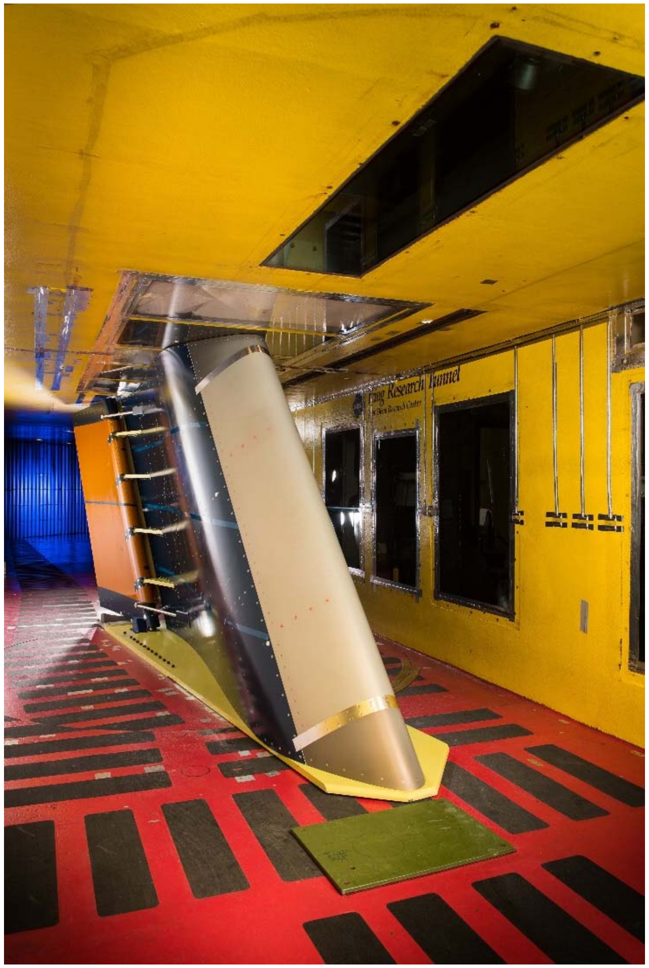
Outboard Model

Experimental Methodology

Models Description

- Streamwise pressure taps located at three spanwise stations
  - 18, 36 and 54 inches above the test-section floor.
- Single-element, slotted flap with anti-icing heater.
- Two removable leading edges
  - Pressure instrumentation
  - Icing

Model Section	Streamwise Chord Length (ft)	Model Scale Factor
Inboard	13.5	2.25
Midspan	6.3	2.0
Outboard	6.2	1.5



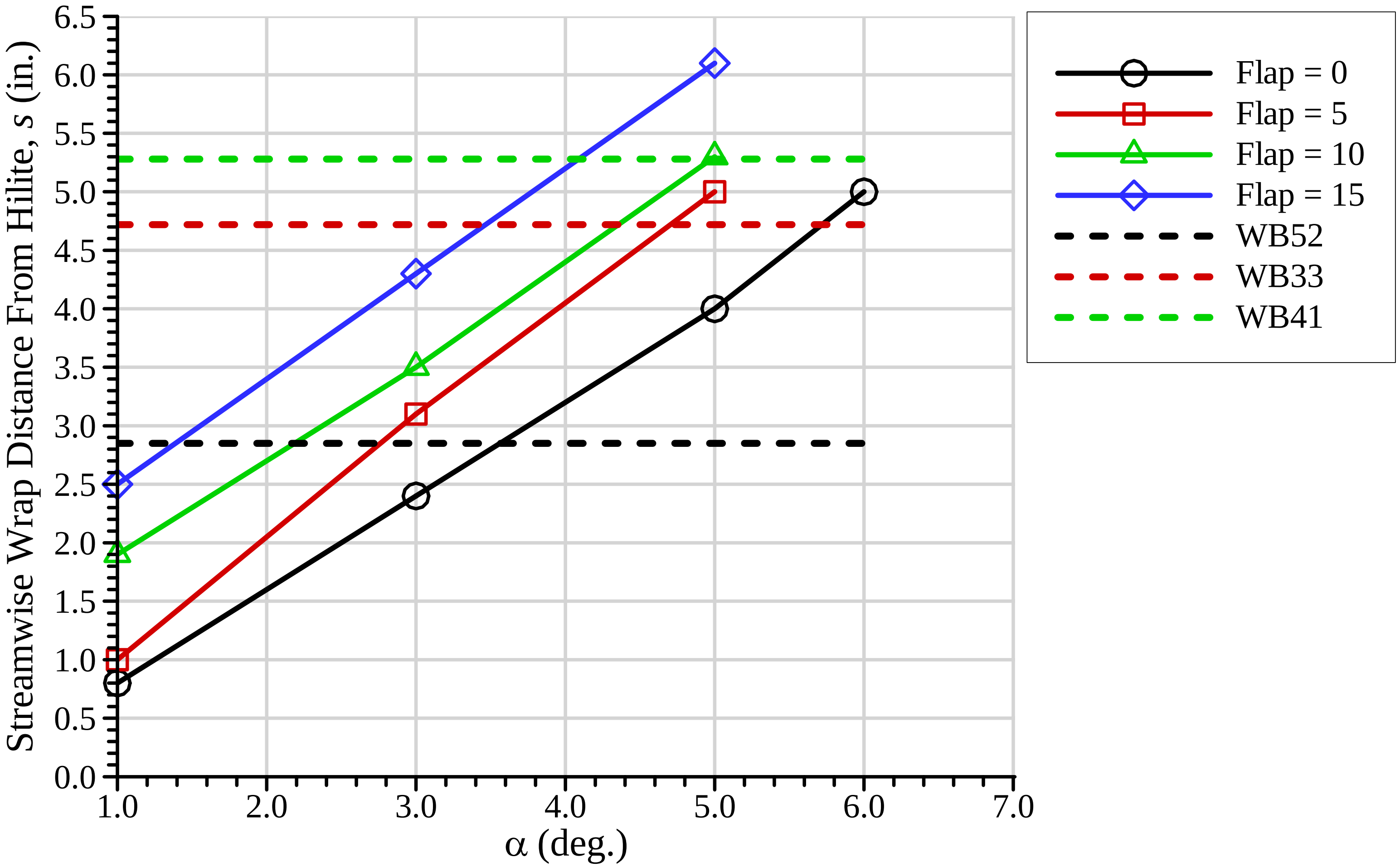
Aerodynamic Calibration Results

- An aerodynamic calibration of the hybrid models was performed in order to match the attachment point location on the IRT models to the corresponding location on the CRM65, full-scale reference airplane.
- The model incidence and flap angles were systematically varied to track the attachment line location at the 36-inch model centerline station.
- The attachment line location was defined as the location of the maximum pressure coefficient.

Flight Case	AoA deg.	Streamwise Wrap Distance—Inches From Hilite		
		Inboard Model	Midspan Model	Outboard Model
WB33	3.7	4.72	1.66	1.06
WB41	4.4	5.28	1.91	1.42
WB52	2.1	2.85	0.57	0.36

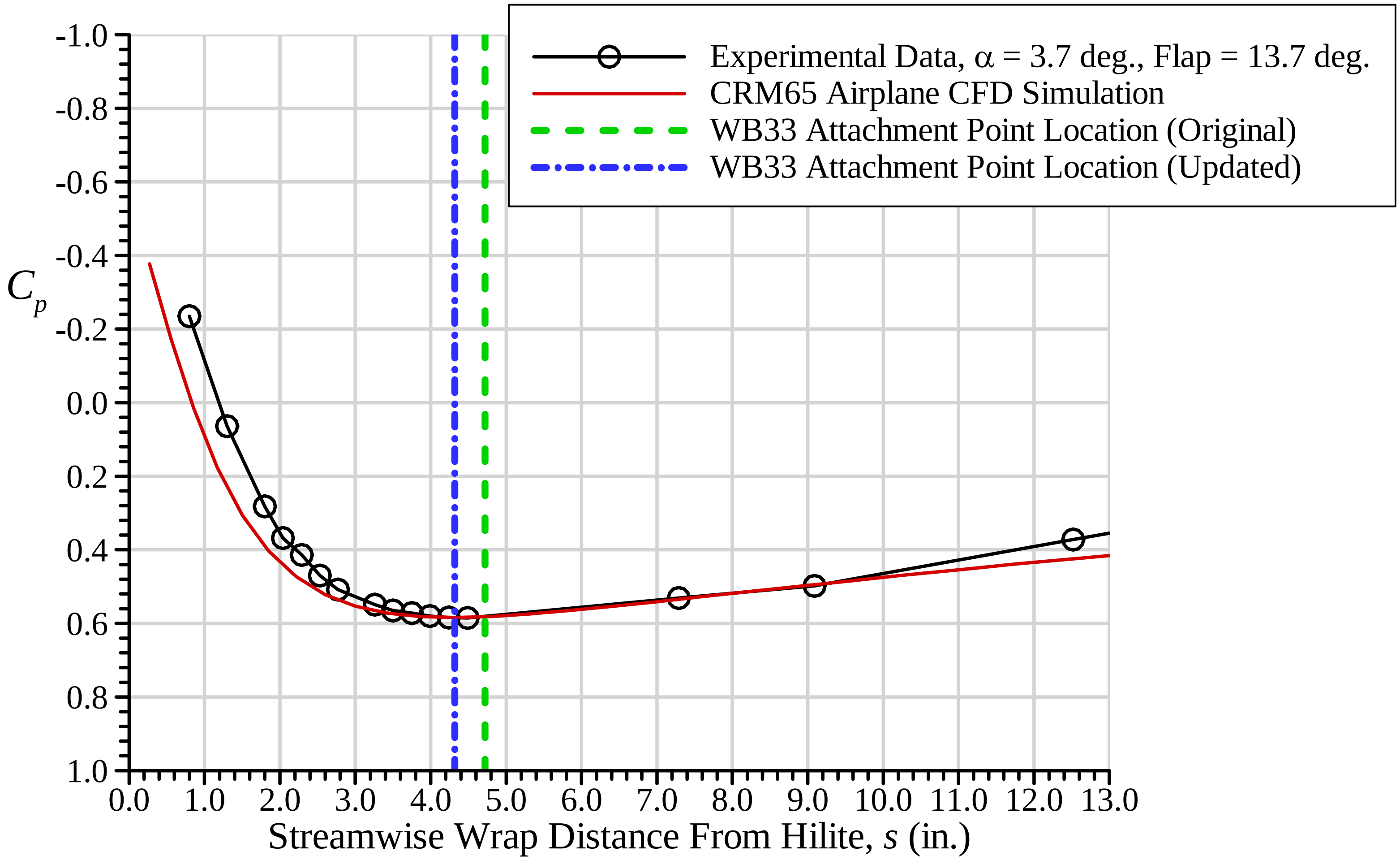
Aerodynamic Calibration Results

- Aerodynamic calibration for Inboard Model.



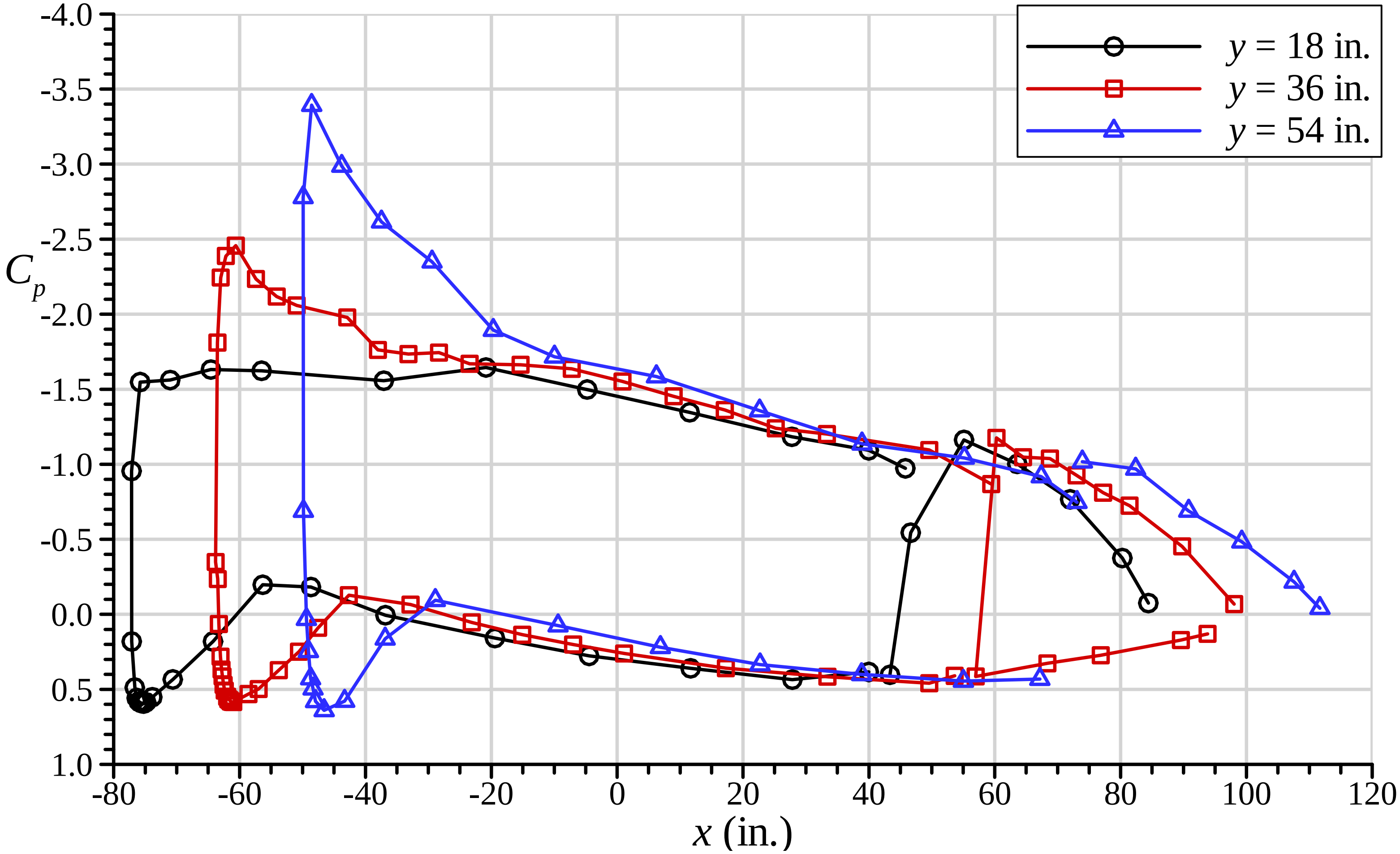
Aerodynamic Calibration Results

- Surface pressure data near attachment point for Inboard Model.



Aerodynamic Calibration Results

- Surface pressure data for Inboard Model.



Ice Accretion Results

Icing Test Matrix Development

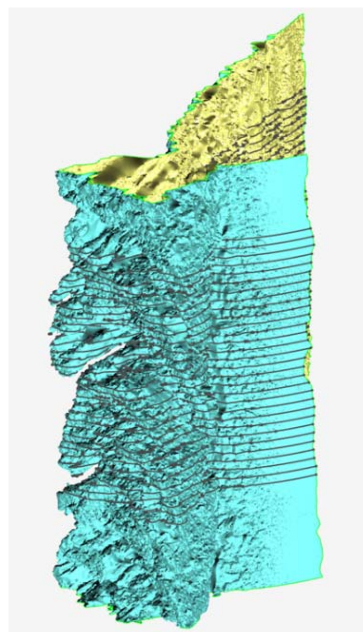
- Generate range of ice accretion.
- Hold and descent for CRM65 airplane in App. C.
- Large range of temperatures, limited variations in MVD and LWC.
- Large model size limited maximum speed in IRT.
  - Conditions were scaled to IRT test speed (130 knots for most cases).
  - Effects of velocity scaling were investigated for Midspan and Outboard models.

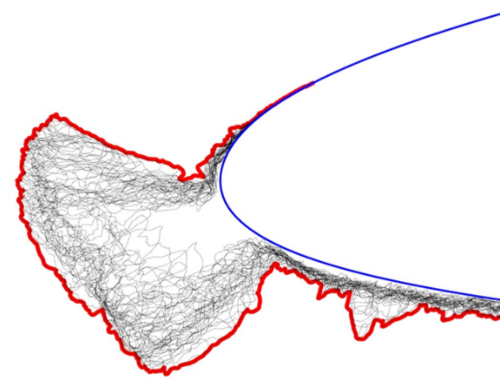
Baseline Flight Reference Conditions

Case	AoA deg.	Altitude (ft)	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD μm	LWC g/m^3	Exp. Time min.
WB33	3.7	10,000	230	-18.4 to 1.1	-25.0 to -6.0	20	0.17 to 0.55	45
WB41	4.4	5,000	220	-6.0 to 1.1	-10.0 to -3.0	20	0.51	45
WB52	2.1	5,000	260	-4.1	-13.0	20	0.36	4

Ice Accretion Results

- Ice accretion was documented with photographs and 3D scans.
- 3D scan data were post-processed to provide the Maximum Combined Cross Section (MCCS).

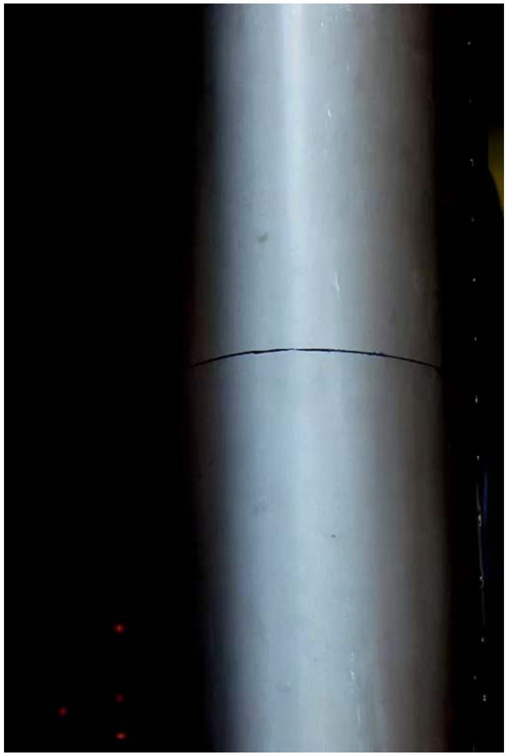




Ice Accretion Results

Time lapse video—Midspan Model

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
TG2450	3.7	130	-6.3	-8.5	25	1.0	29



Ice Accretion Results

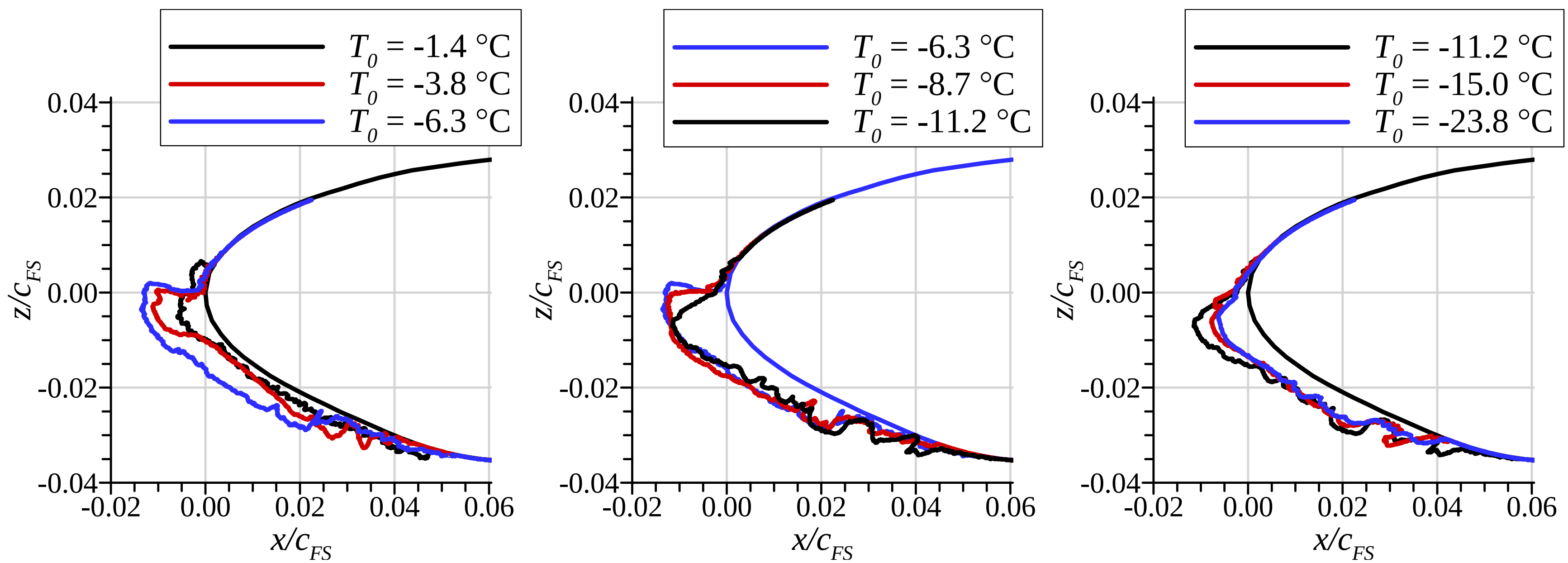
Inboard Model—Effect of Temperature

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
TG2421	3.7	130	-3.8	-6.0	25	1.0	29
TG2402	3.7	130	-8.7	-11.0	25	1.0	29
TG2415	3.7	130	-23.8	-25.0	25	1.0	29

Ice Accretion Results

Inboard Model—Effect of Temperature

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m³	Exp. Time min.
-	3.7	130	-1.4 to -23.8	-3.6 to -25.0	25	1.0	29



Ice Accretion Results

Identical Condition Run on Each Model—Total Temperature = -3.8˚C

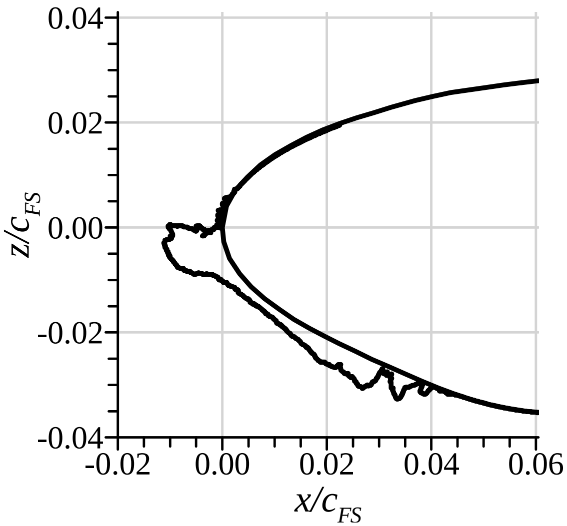
Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
TG2421	3.7	130	-3.8	-6.0	25	1.0	29
TH2438	3.7	130	-3.8	-6.0	25	1.0	29
TI2462	3.7	130	-3.8	-6.0	25	1.0	29

Ice Accretion Results

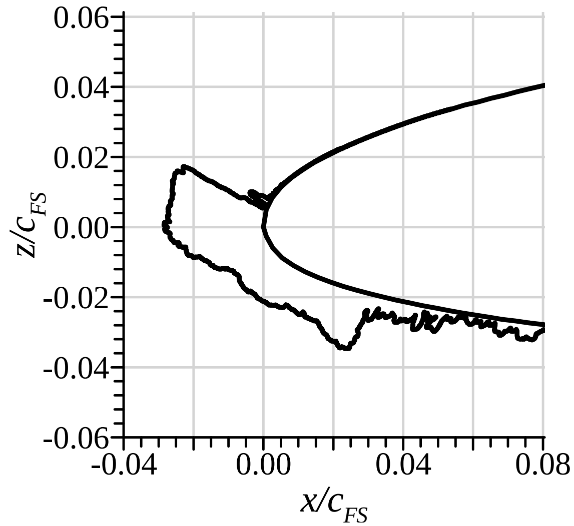
Identical Condition Run on Each Model—Total Temperature = -3.8˚C

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m³	Exp. Time min.
TG2421	3.7	130	-3.8	-8.5	25	1.0	29
TH2438	3.7	130	-3.8	-8.5	25	1.0	29
TI2462	3.7	130	-3.8	-8.5	25	1.0	29

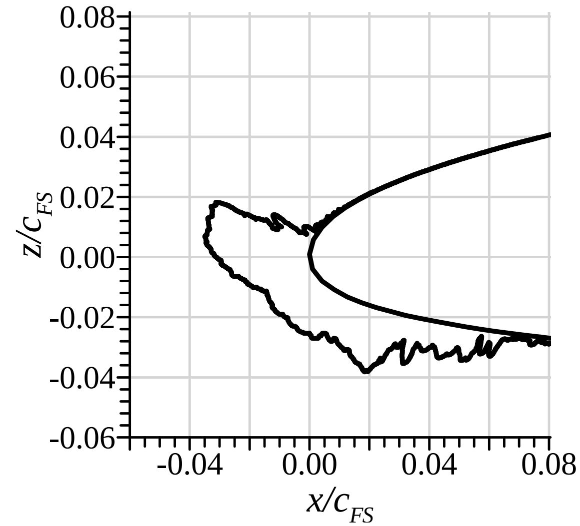
Inboard



Midspan



Outboard



Ice Accretion Results

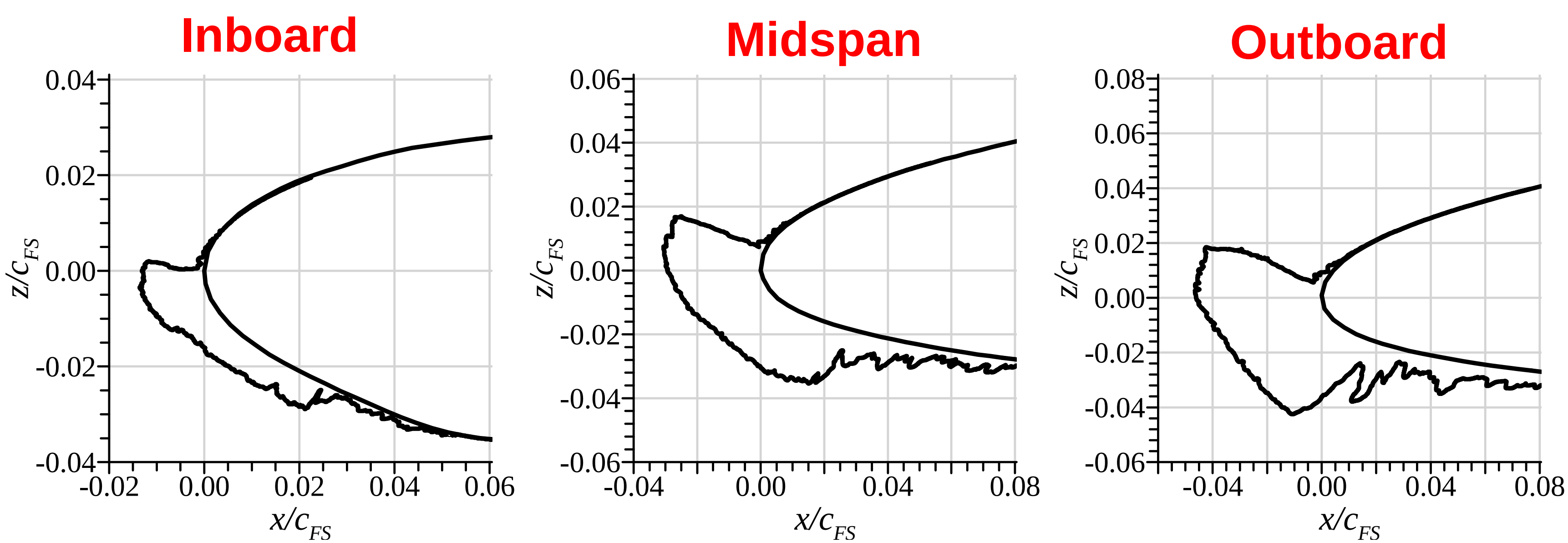
Identical Condition Run on Each Model—Total Temperature = -6.3˚C

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD μm	LWC g/m^3	Exp. Time min.
TG2411	3.7	130	-6.3	-8.5	25	1.0	29
TH2452	3.7	130	-6.3	-8.5	25	1.0	29
TI2479	3.7	130	-6.3	-8.5	25	1.0	29

Ice Accretion Results

Identical Condition Run on Each Model—Total Temperature = -6.3°C

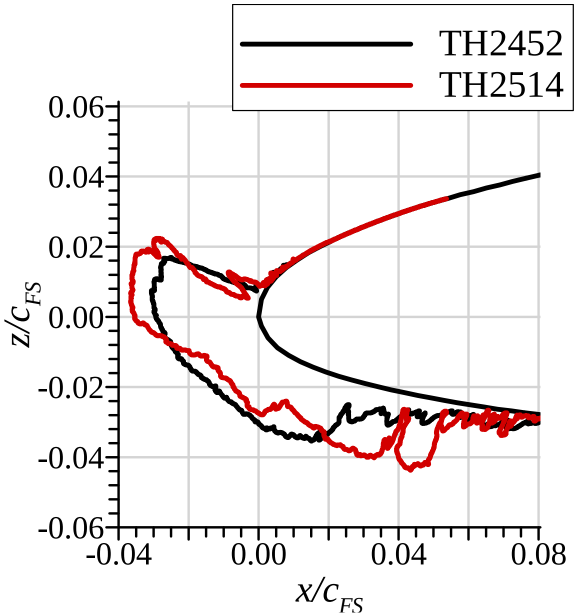
Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
TG2411	3.7	130	-6.3	-8.5	25	1.0	29
TH2452	3.7	130	-6.3	-8.5	25	1.0	29
TI2479	3.7	130	-6.3	-8.5	25	1.0	29



Ice Accretion Results

Maximum Scallop vs. App. C Scaled Conditions on Midspan Model

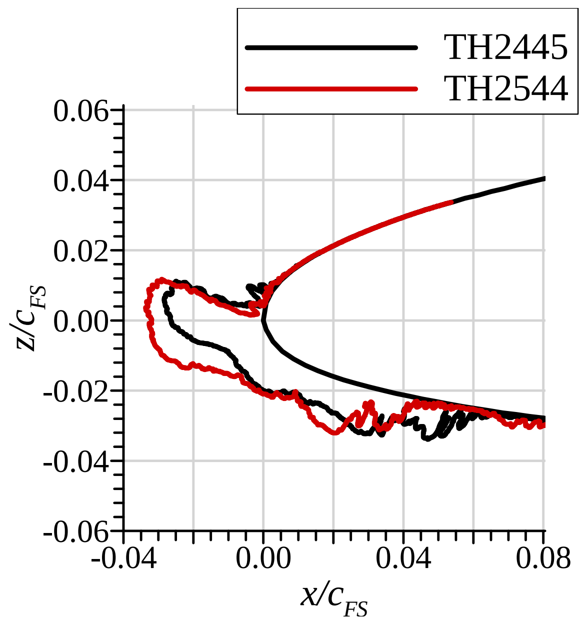
Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m³	Exp. Time min.
TH2452	3.7	130	-6.3	-8.5	25	1.0	29
TH2514	3.7	130	-3.1	-5.3	27	0.91	45



Ice Accretion Results

Effect of Velocity on Ice Accretion on Midspan Model

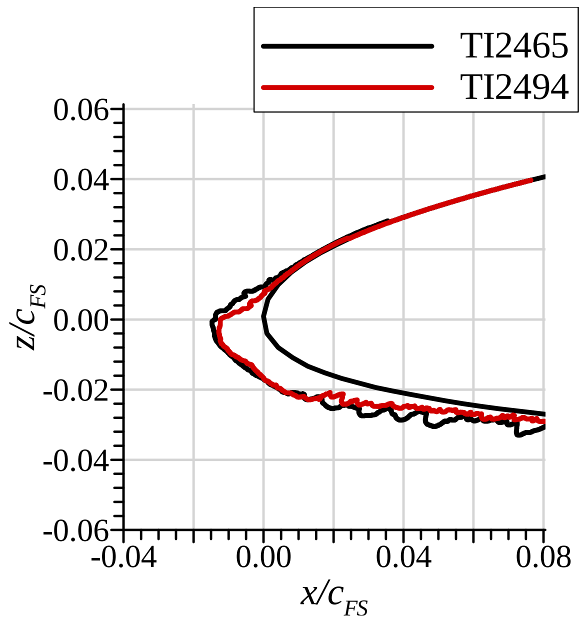
Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m³	Exp. Time min.
TH2445	3.7	130	-3.1	-5.3	27	0.91	32
TH2444	3.7	180	-2.0	-6.0	24	0.65	32

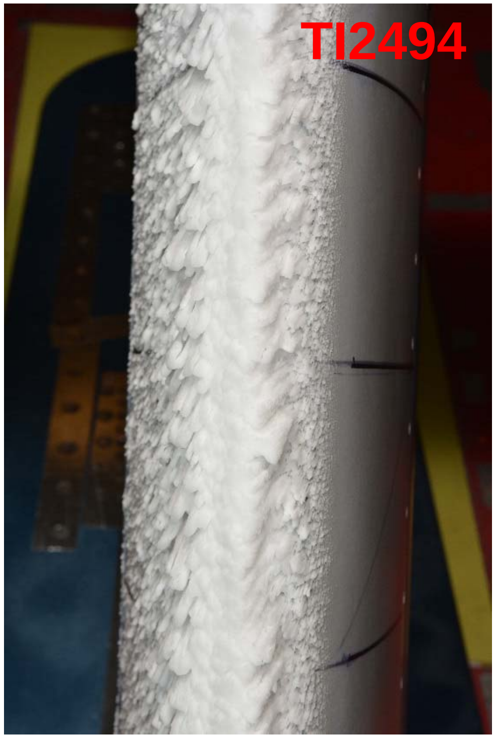


Ice Accretion Results

Effect of Velocity on Ice Accretion on Outboard Model

Run	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
TI2465	3.7	130	-17.9	-20.1	25	0.60	23
TI2494	3.7	232	-11.2	-18.3	20	0.30	25.3





Summary

- A large database of ice accretion geometry was generated for three sections of the CRM65 large-scale, swept wing.
- Hybrid models with full-scale leading-edges were used to obtain full-scale ice accretion at the Inboard (20%), Midspan (64%) and Outboard (83%) stations.
- The ice accretion database consists of the 3D ice accretion geometry along with surface pressure measurements on the clean hybrid models at corresponding aerodynamic conditions.
- For most cases, each model was subjected to identical icing conditions which limited the speed to 130 knots because of the large size of the Inboard model.
- The Appendix C-based icing conditions were scaled from flight reference values to account for the difference in velocity.
- A limited number of higher-velocity cases were run on the Midspan and Outboard models—results were limited by ice shedding.

Acknowledgements

Sponsor Organizations:

- NASA—Advanced Air Transport Technology Project
- FAA
- ONERA

Supporting Organizations:

- Boeing
- University of Illinois
- University of Virginia
- University of Washington