NASA/FAA/ONERA Swept-Wing Icing and Aerodynamics

Summary of Research and Current Status

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Acknowledgements

Sponsor Organizations:

- NASA
- FAA
- ONERA

Supporting Organizations:

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

Outline

- Introduction
- Goals and Objectives
- Research Roadmap
- Description of Research Phases
- Summary
- Advertisement
- References

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-phase research effort.

Goal and Objectives

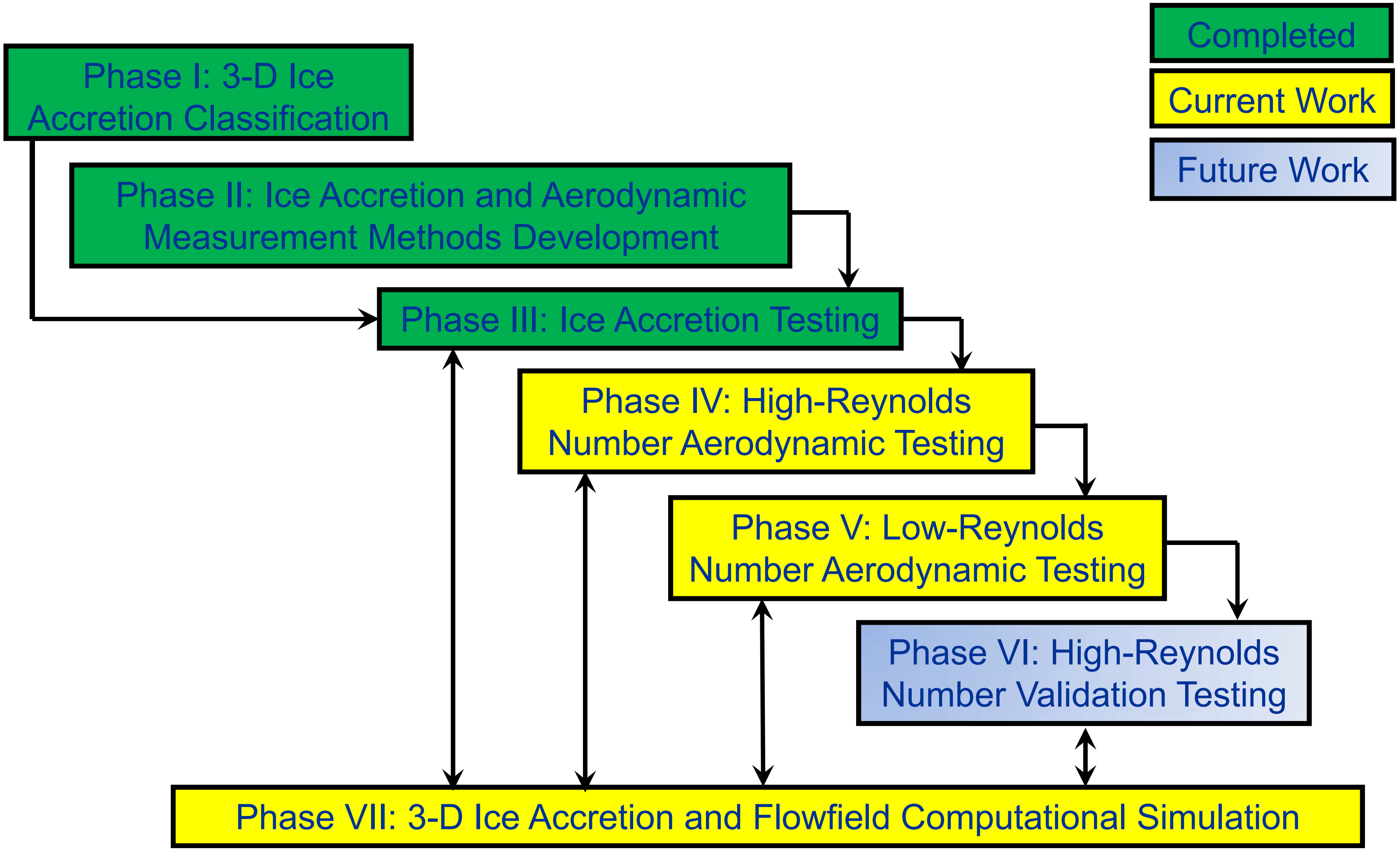
Overall Goal

- Improve experimental and computational simulation.

Objectives

- Generate a database of 3D ice-accretion geometry.
- Generate a database of iced-wing aerodynamic effects.
- Quantify ice-shape geometric fidelity requirements.

Research Roadmap



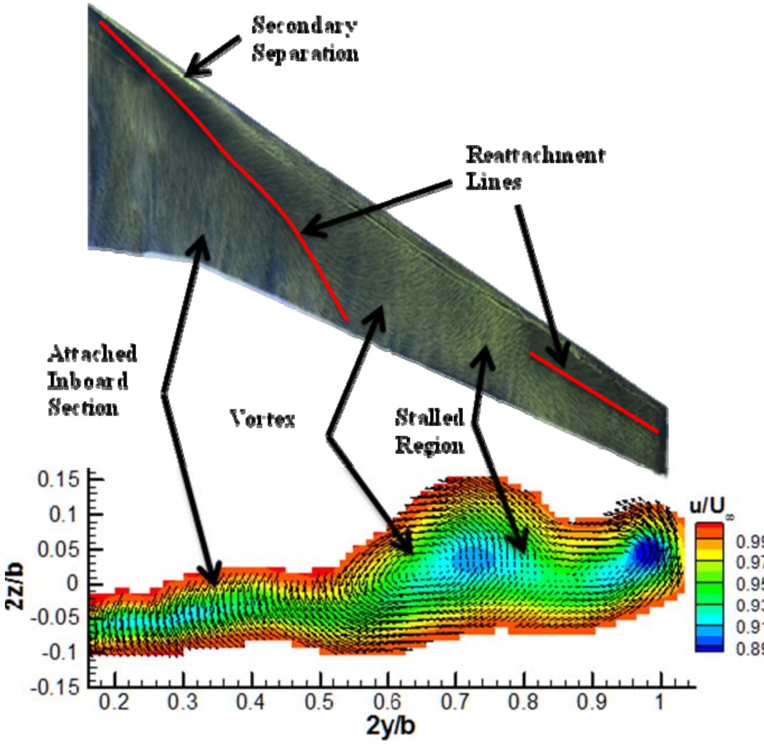
Phase I: Ice-Shape Classification

Define ice shapes based on their aerodynamic characteristics.

- Roughness
- Streamwise ice
- Horn ice
- Spanwise-ridge ice

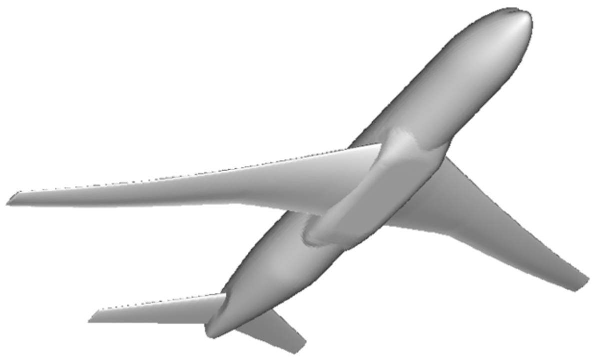
Phase II: Measurement Methods Development

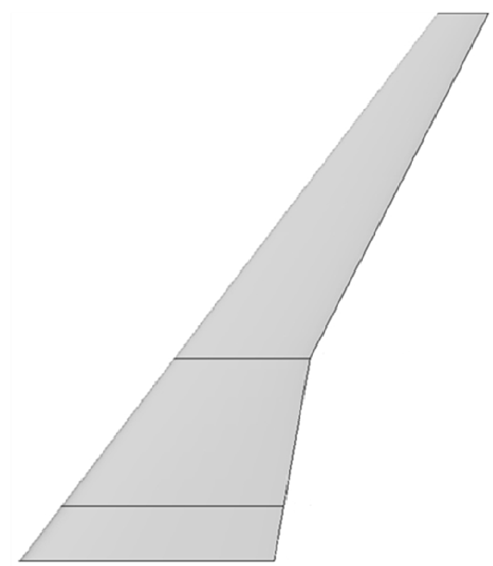
- Common Research Model selected as the baseline, full-scale, reference geometry for the swept-wing configuration.
- Applied and validated existing 3D laser scanning methods to measure highly 3D ice accretion.
- Applied existing 3D wake survey methods to iced swept wings.



Common Research Model (CRM)

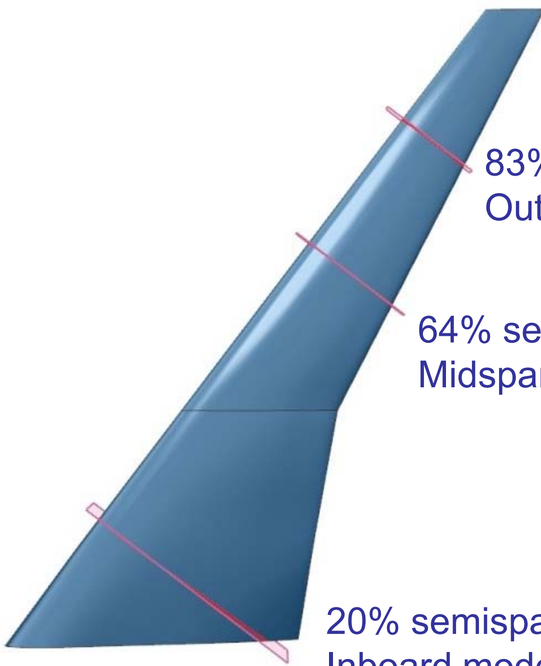
- Commercial transport class configuration.
- Contemporary transonic supercritical wing design.
- Publically available and otherwise unrestricted for world-wide distribution.
- A 65% scale CRM was selected as the full-scale, reference swept-wing geometry for this research.
- CRM65 size airplane is comparable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





Phase III: Ice Accretion Testing

- Three spanwise stations selected for IRT testing.
- Required hybrid model design—see oral presentation by Gustavo Fujiwara.
- Related presentations:
  - oral presentation by Emmanuel Radenac
  - SAE paper 2015-01-2122 by Eric Loth
- A two-week IRT test campaign was completed for each model.

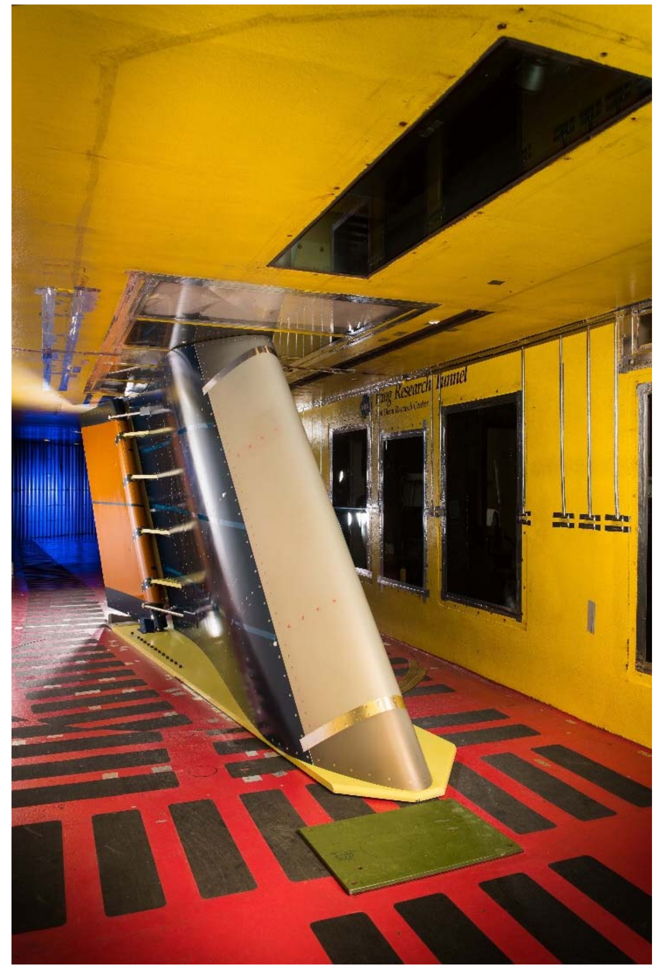


Phase III: Ice Accretion Testing

Models Description

- Full-scale leading edge, truncated afterbody.
- Streamwise pressure taps located at three spanwise stations.
- 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



Phase III: Ice Accretion Testing

Icing Test Matrix Development

- Generate range of ice accretion (Phase I).
- 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).
  - See oral presentation by Paul Tsao.

Baseline Flight Reference Conditions

Case	AoA deg.	TAS Knots	Total Temp deg. C	Static Temp deg. C	MVD µm	LWC g/m^3	Exp. Time min.
33	3.3	230	-18.4 to 1.1	-25.0 to -6.0	20	0.17 to 0.55	45
41	4.4	220	-6.0 to 1.1	-10.0 to -3.0	20	0.51	45
52	2.1	260	-4.1	-13.0	20	0.36	4

Phase III: Ice Accretion Testing

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.
TG2410	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

Phase III: Ice Accretion Testing

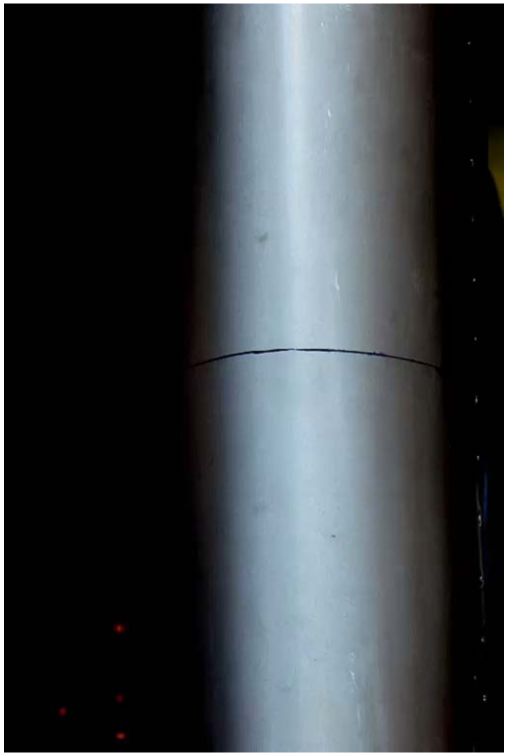
Identical Condition Run on Each Model

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
TH2450	3.7	130	-6.3	-8.5	25	1.0	29
TI2461	3.7	130	-6.3	-8.5	25	1.0	29

Phase III: Ice Accretion Testing

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



Phase IV: High-Re Aerodynamic Testing

- Build and test 13.3% scale model of the CRM65 in ONERA F1 pressurized wind tunnel.
- Range of Reynolds and Mach numbers up to $Re = 12 \times 10^6$ and $M = 0.3$.
- Design and build full-span artificial ice shapes from the IRT tests of the 20%, 64% and 83% semispan stations of the CRM65 wing—see oral presentation by Sam Lee.
- Vary the geometric fidelity and quantify aerodynamics.

Phase V: Low-Re Aerodynamic Testing

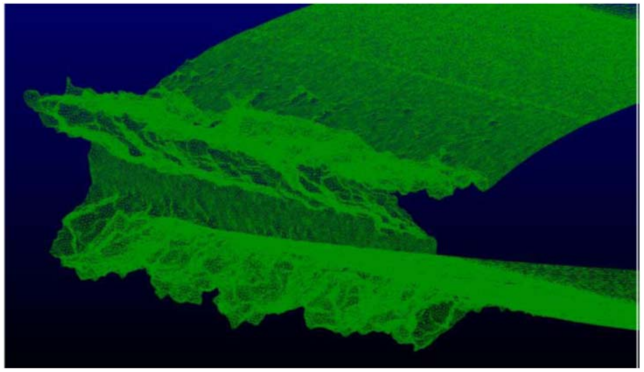
- Initial test campaign completed in August 2014—see oral presentation by Brian Woodard.
- 8.9% scale CRM65 was built for the Wichita State University 7 ft. x 10 ft. size wind tunnel.
- Aerodynamic performance and 3D wake surveys up to *Re* = 2.4×10^{6} and *M* = 0.27.
- Scale models of the artificial ice shapes used in the ONERA F1 tests.
- Quantify the differences between low and high-Re results.
- Investigate sensitivity to ice features.

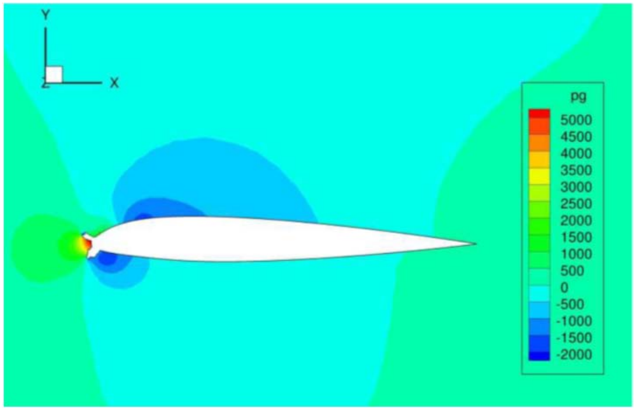
Phase VI: High-Re Validation Testing

- Identify critical ice shape configurations from Phase V.
- Build and test these configurations in ONERA F1 pressurized wind tunnel.
- Range of Reynolds and Mach numbers up to *Re* = 12×10^6 and *M* = 0.3.
- Quantify the differences in aerodynamic performance and key flowfield features between the low and high-Reynolds number tests.

Phase VII: Computational Simulation

- Identify critical elements for accurate ice-shape predictions and iced swept wing aerodynamics.
- NASA will investigate methods for smoothing and gridding of ice-accretion geometry from the 3D scan data of the IRT ice accretion leading to computational flow simulations.
- ONERA will investigate the use of the "Immersed Boundary Conditions" (IBC) method in order to take the exact ice shape into account without having to mesh it explicitly.
- Conducted in parallel with the other tasks throughout the project.





Summary

NASA, FAA and ONERA are sponsoring a research effort dedicated to improving computational and experimental simulation methods for swept-wing icing. The anticipated research products are:

- Database of swept-wing ice accretion geometry
- Database of high-Reynolds number aerodynamic data for swept-wing ice accretion.
- An understanding of the geometric fidelity required for accurate aerodynamic simulation of swept-wing ice accretion.
- Hybrid-model design methods for conducting icing-tunnel tests of large-scale swept wings.
- A validated low-cost, low-Reynolds number test capability for evaluation of performance characteristics and aerodynamics of iced-swept-wing geometries.
- Improved methods for quantifying ice accretion geometry and developing high-fidelity artificial ice shapes.

Advertisement

Stay tuned in the next two sessions:

NASA/FAA/ONERA Swept-wing Icing & Aerodynamics—Part 1 of 2		
Oral Only	NASA/FAA/ONERA Swept-Wing Icing and Aerodynamics: Summary of Research and Current Status	Andy Broeren
Oral Only	Design of Wind Tunnel Models for Full-Scale Swept-Wing Ice Accretion	Gustavo Fujiwara
SAE Paper 2015-01-2122	Detached Eddy Simulation on a Swept Hybrid Model in the IRT	Eric Loth
NASA/FAA/ONERA Swept-wing Icing & Aerodynamics—Part 2 of 2		
Oral Only	Method to Generate Full-Span Ice Shape on Swept Wing Using Icing Tunnel Data	Sam Lee
Oral Only	Initial Low-Reynolds Number Iced Aerodynamic Performance for CRM Wing	Brian Woodard
Oral Only	3D Modeling of Ice Accretion with Application to Swept Wing Test-Cases	Emmanuel Radenac
Oral Only	Velocity Effect on Swept-Wing Ice Accretion for Scaling Consideration	Paul Tsao

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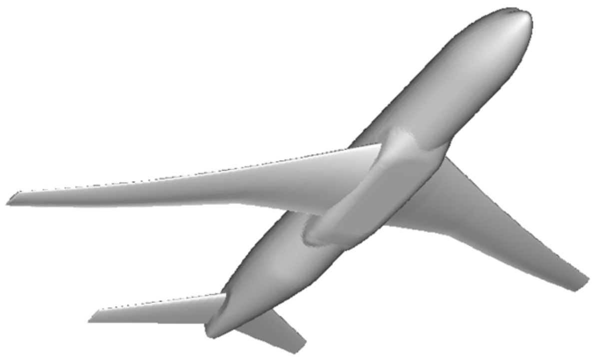
Baseline Swept-Wing Model Selection

- Common Research Model (CRM).
- Commercial transport class configuration.
- Contemporary transonic supercritical wing design.
- Publically available and otherwise unrestricted for world-wide distribution.

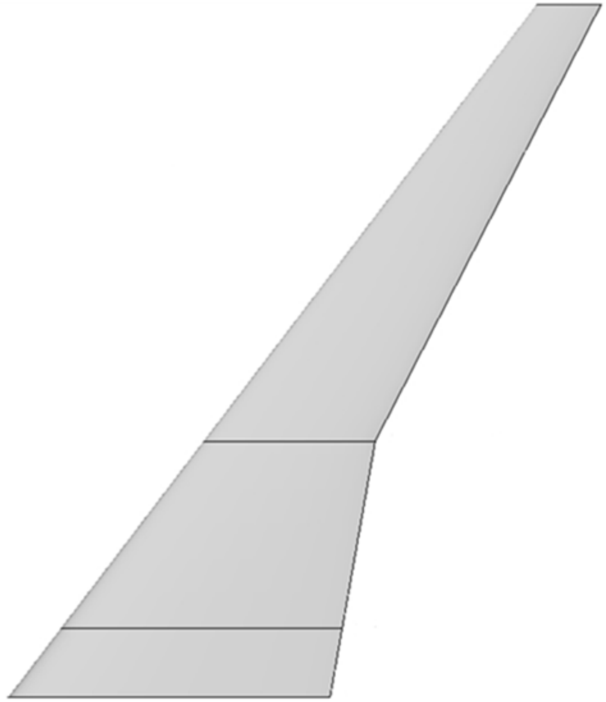


Airplane	Span (ft)	MAC (ft)	Area (ft^2)	Aspect Ratio	Taper Ratio	Sweep, c/4 (deg.)
CRM	192.8	23.0	4,130	9.0	0.28	35
Airbus A330-200/300	198.0	23.9	3,892	9.5	0.22	30
Boeing 777-200	199.9	26.5	4,389	8.7	0.27	31
Boeing 787-9	197.0	20.6	3,880	9.6	0.18	32
Boeing 747-400	211.4	29.8	5,417	7.7	0.28	37

Reference: Vassberg, J.C., DeHann, M.A., Rivers, S.M., and Wahls, R.A., “Development of a Common Research Model for Applied CFD Validation Studies,” AIAA Paper 2008-6919, Aug. 2008.

Baseline Swept-Wing Model Selection

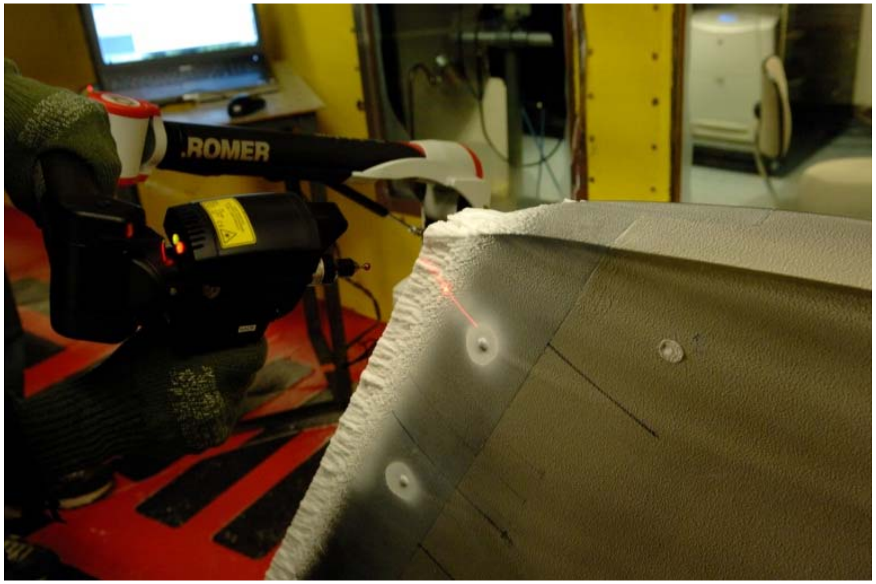
- A 65% scale CRM was selected as the full-scale, reference swept-wing geometry for this research.

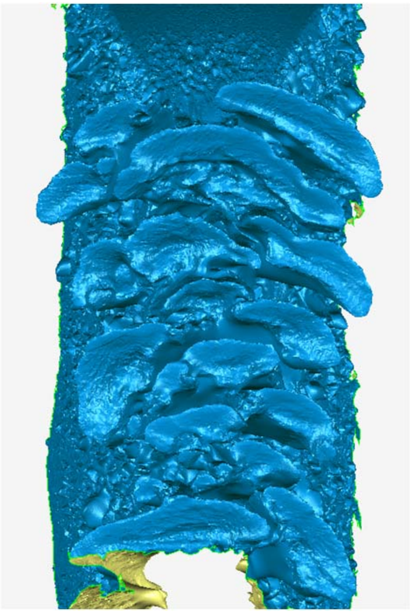


Airplane	Span (ft)	MAC (ft)	Area (ft^2)	Aspect Ratio	Taper Ratio	Sweep, c/4 (deg.)
CRM65	125.3	15.0	1,745	9.0	0.28	35
Airbus A320	112.0	14.1	1,320	9.5	0.21	25
Boeing 737-800	112.6	13.0	1,341	9.5	0.16	25
Boeing 757-200	124.8	16.7	1,847	7.8	0.21	25

3D Ice Accretion Measurement

- Requirement for ice accretion database and for artificial ice shapes used in aerodynamic testing.
- Commercial, laser-based scanning system adapted for ice accretion measurement.
- Research and validation efforts have been completed.





3D Aerodynamic Measurement Methods

- 3D wake survey method applied to ice swept wing.
- Understand origin of ice-wing performance degradation.
- Development and validation of computational simulation tools.