NASA Icing Update – Oct 2024

Presentation for the
SAE AC-9C Technical Committee Meeting
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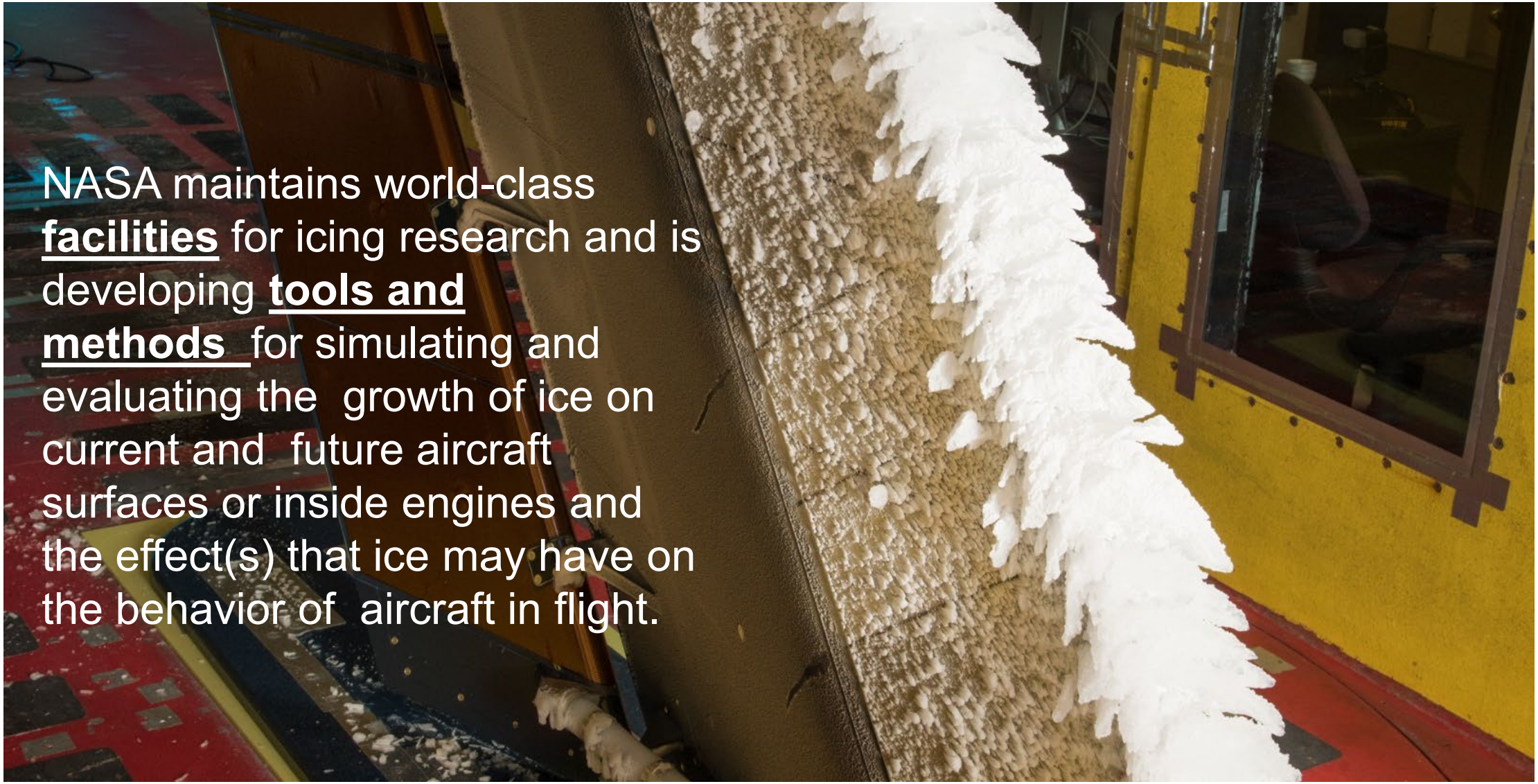
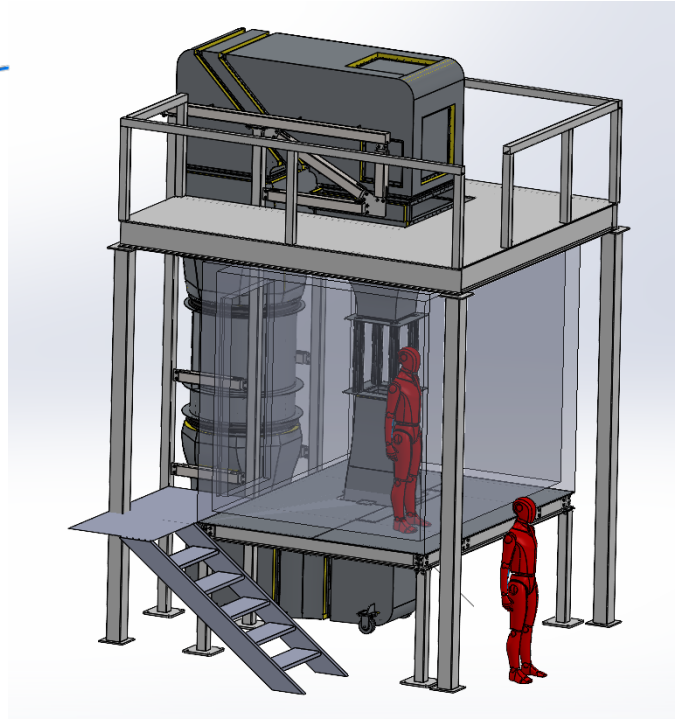
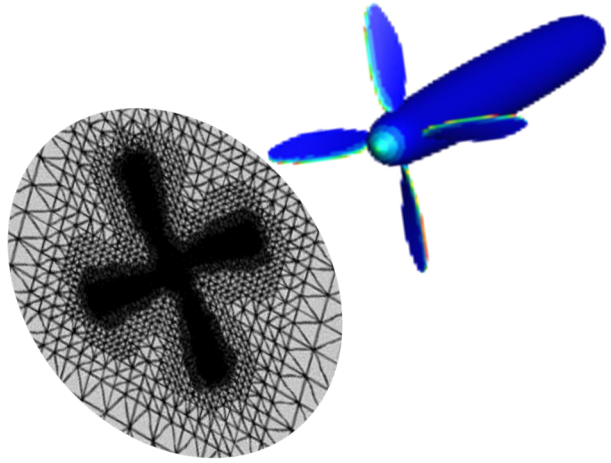
NASA's Mission in Icing



Outline

1. Transonic Truss-Braced Wing Icing (Broeren)
2. High-Lift Common Research Model Icing (Broeren)
3. Adaptive Icing Tunnel (Chen)
4. Advanced Air Mobility Icing
5. GlennICE Update





Transonic Truss-Braced Wing Icing

Background

- NASA is collaborating with Boeing as a part of the Subsonic Ultra-Green Aircraft Research (SUGAR).

- A portion of this collaboration is dedicated to exploring the impacts of icing on the TTBW configuration.

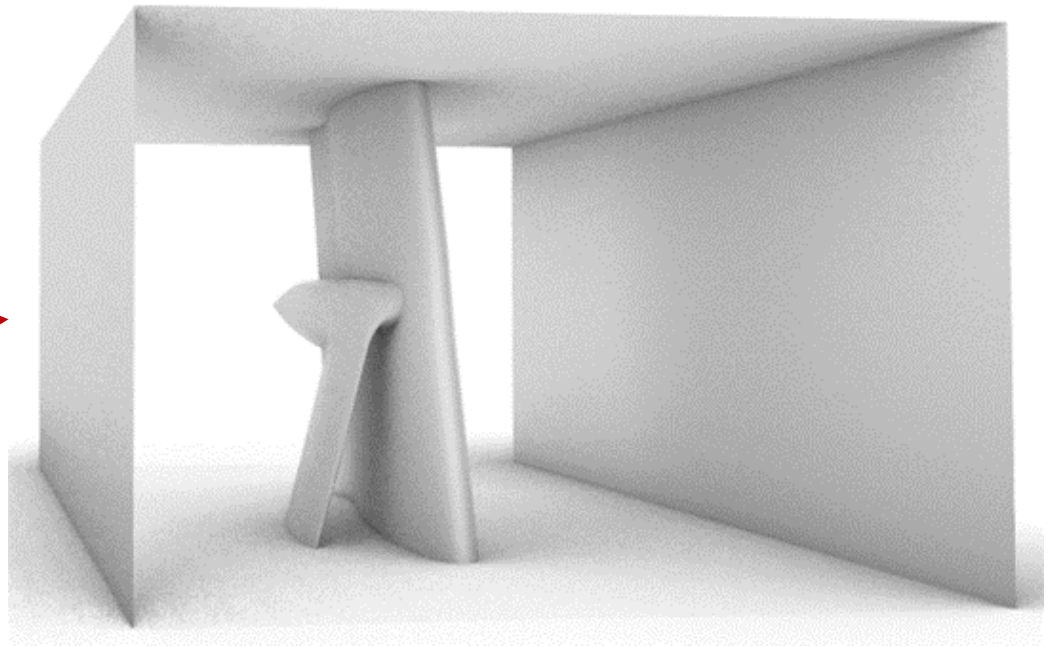
Icing Research Tasks

- IRT testing of TTBW components: (1) wing-truss junction region and (2) wing section with variable camber Krueger flap.
- Icing simulations with GlennICE and LEWICE3D: full aircraft in flight and wing sections in IRT.
- Iced aerodynamic testing with artificial ice shapes: semispan model at QinetiQ 5m wind tunnel.
- Iced aerodynamics CFD simulations: exploring wall-modeled LES methods
- Icephobic materials development: emphasis on durability in addition to low ice adhesion

Transonic Truss-Braced Wing Icing

IRT Testing of Wing-Truss Junction Model

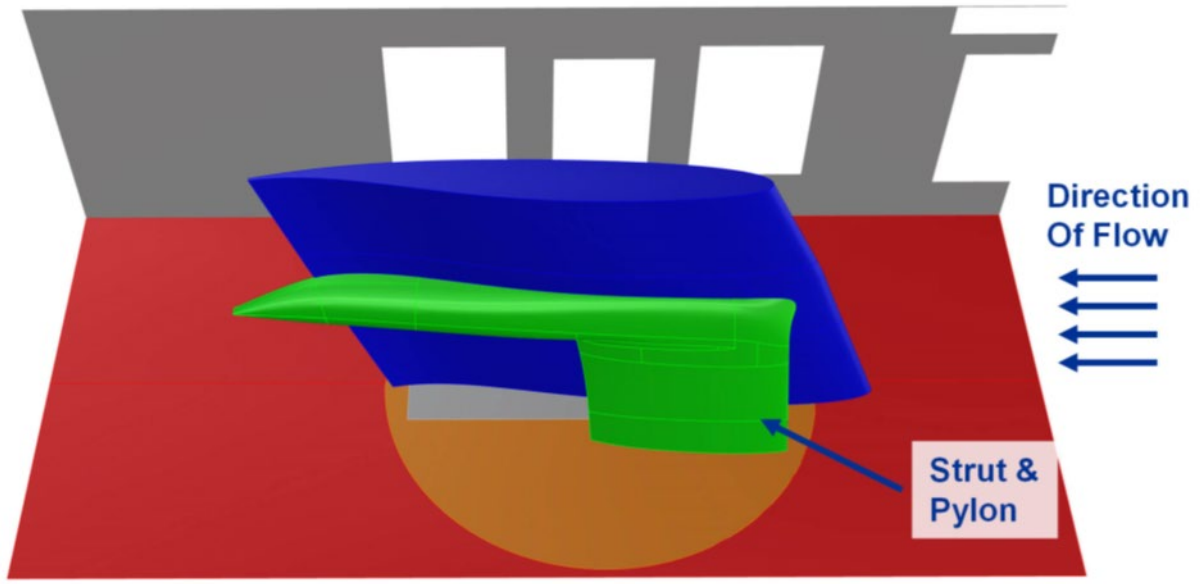
- A full-scale section of the wing with the strut and pylon was extracted from the airplane geometry.
- The resulting test article is large relative to the test section and maintains the full 3D features of the airplane.
  - No truncated design
  - No extruded wing section

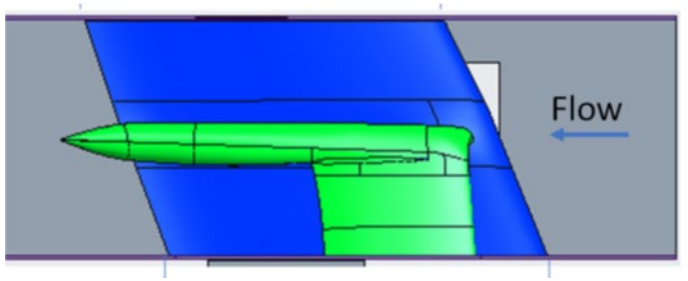


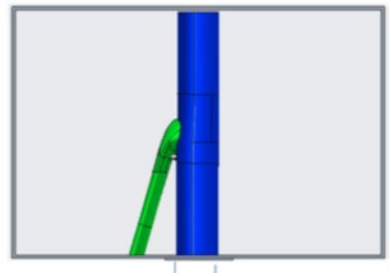
Transonic Truss-Braced Wing Icing

IRT Testing of Wing-Truss Junction Model

- Model designed such that it can be tested with and without the strut/pylon.
- No flap—will match attachment line location with angle of attack adjustments.
- IRT test campaign planned for Fall 2024.
- Test objectives:
  - Explore effect of ceiling gap on surface pressures and flow separation
  - Explore potential critical ice shape scenarios
  - Validation data for GlennICE and LEWICE3D

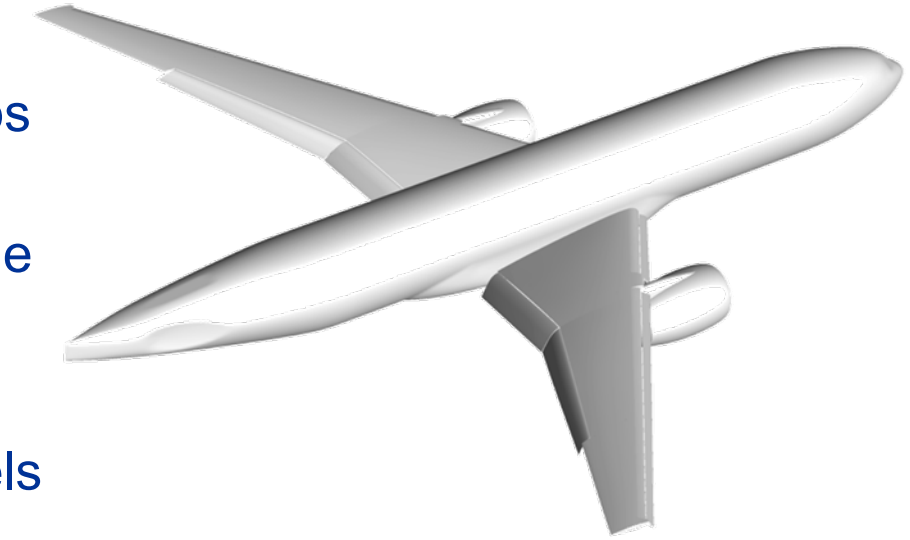






High-Lift Common Research Model Icing

Background



- The HL-CRM was developed for a series of AIAA workshops on CFD predictions (HLPW).
- The HL-CRM was first utilized in HLPW-3 conducted in June 2017.
- HLPW-5 was conducted in July 2024.
- Currently, there are at least nine different wind tunnel models based upon the HL-CRM geometry.
- Numerous wind-tunnel tests have been performed over a large range of Reynolds and Mach numbers.

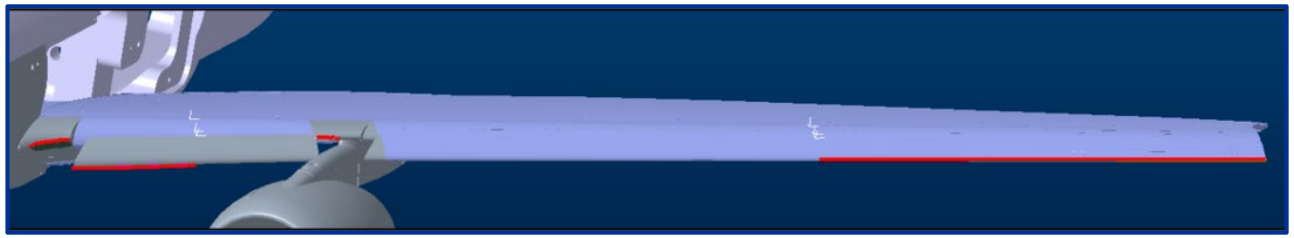
Icing Effects

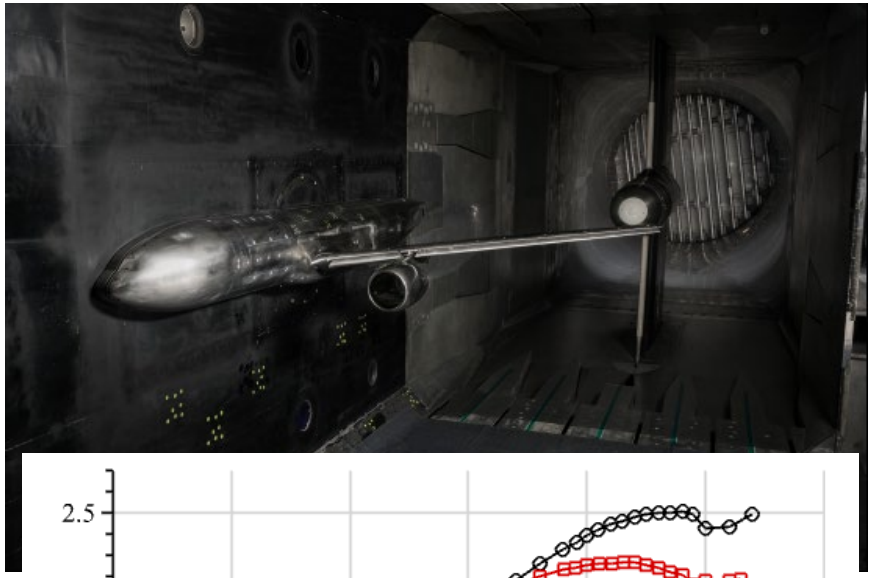
- The effects of ice on aerodynamic performance were introduced into the HL-CRM ecosystem in 2019.
- Goal is to benchmark CFD capability for iced high-lift configuration aerodynamics.

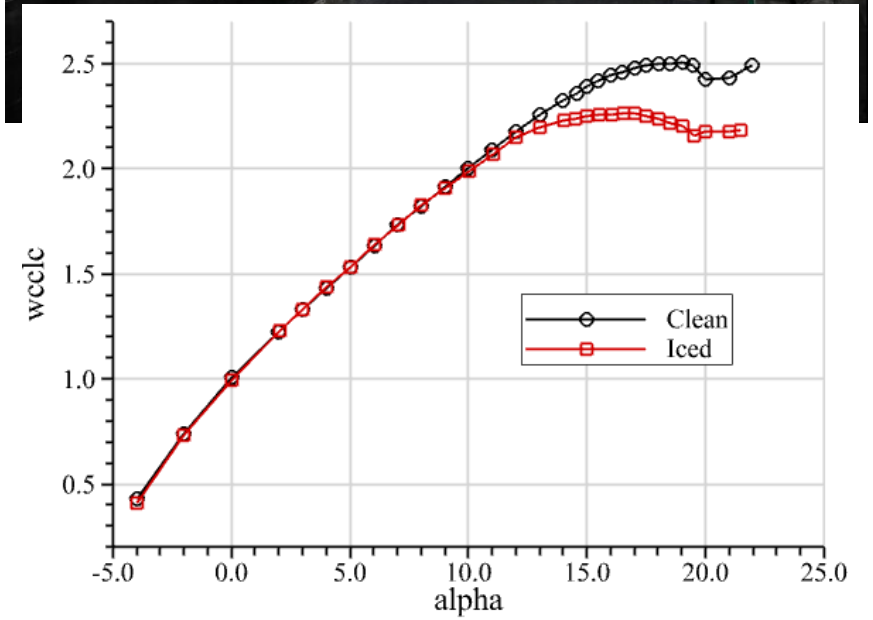
High-Lift Common Research Model Icing

NASA-Boeing Collaboration

- Developed artificial ice shapes using LEWICE3D for HL-CRM icing scenario.
- In Spring 2022, performed risk-reduction testing for adhering artificial ice shapes to a wind-tunnel model in a cryogenic environment
- In Spring 2024, performed artificial ice shape aerodynamic test on 5.2% semispan model of HL-CRM in NASA National Transonic Facility (NTF).
- Planned NTF test campaigns with 2.7% scale full-span and semispan models up to Re up to 16×10^6 at M = 0.26







High-Lift Common Research Model Icing

NASA-ONERA-NRC Collaboration "SUNSET 3"

- NASA, ONERA and NRC are collaborating on high-lift system icing.
- ONERA will perform aerodynamic testing at F1 pressurized wind-tunnel using their 1/19.5 scale full span HL-CRM.
  - All groups will generate ice shapes with in-house codes (e.g., GlennICE, IGLOO3D, NRC Morphogenic, LEWICE3D).
  - NASA will fabricate artificial ice shapes for F1 test campaign.
- NRC will perform icing tests on small-scale, high-lift airfoil model in the Altitude Icing Wind Tunnel (AIWT).
  - Initial icing test campaign planned for Fall 2024.
- All groups plan to perform additional CFD simulations for comparison to iced HL-CRM aerodynamic data and icing simulations for comparison to ice accretion test data.

High-Lift Common Research Model Icing

High-Lift Prediction Workshop with Ice Effects

- Iced HL-CRM aerodynamic data collected in this effort is being directed toward a CFD prediction workshop that includes effect of ice on airplane performance including $C_{L,max}$.
- The intent is to engage the current CFD community working in the HLPW series in the unique aspects and challenges of iced aerodynamics.
- The timing and location of HLPW with ice effects is still being planned. Communication and coordination with the icing community (e.g. IPW committee) is being maintained to avoid obvious conflicts with major events in the icing community.

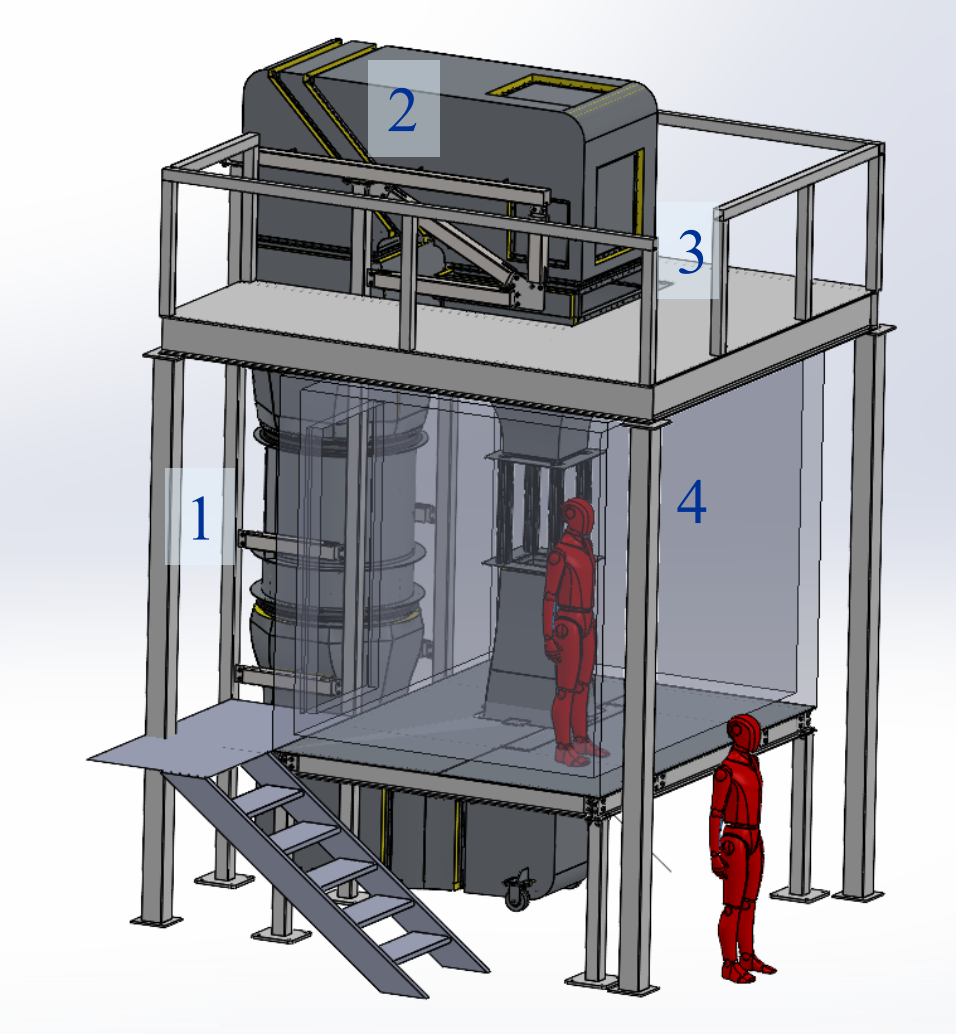
Adaptive Icing Tunnel (AIT)

Description

- Laboratory scale icing wind tunnel
- Closed loop, vertical
- Test section 1 x 1 ft (0.3 x 0.3 m)

Features

1. Fan
2. Heat Exchanger
3. Spray Bars
4. Test Section
5. Walk-in Freezer



Adaptive Icing Tunnel

Capabilities

- Airspeeds up to ~210 knots (~110 m/s)
- Temperatures as cold as -20°C
- Walk-in freezer around test section
- Supercooled Liquid and Ice Crystal

Expect to start testing Jan 2025

- Calibration
- Ice Adhesion Testing
- Probe development

1. Fan
2. Heat Exch.
3. Spraybars
4. Test Section

Walk-in Freezer installed
Aug 2024

Advanced Air Mobility (AAM) Icing

PROBLEM While icing engineering tools and methods for means of compliance are fairly mature for existing legacy aircraft, there are no accepted icing engineering tools specifically developed and rigorously tested for AAM class vehicles.

OBJECTIVE Develop experimental and computational icing simulation capabilities for eVTOL vehicles.

APPROACH

- Acquire **experimental ice shapes** on non-proprietary propeller/rotor geometries for code validation and development.
- Establish **best practices** and **scaling methodologies** for conducting icing tests on rotating geometries.
- Acquire **experimental shedding data** to support development of ice shedding prediction capabilities.

ACCOMPLISHMENTS

- Successfully completed two test entries of a generic eVTOL propeller in the Icing Research Tunnel in 2023 and 2024.
- Acquired ice shapes, propeller performance degradation, and high-speed images of shedding events.

NASA Tiltwing Concept Vehicle
(cruise configuration)

AAM Propeller Test Stand Installed in
Icing Research Tunnel (IRT)

NASA Icing Tools - GlennICE

- Acts as a CFD post processor
- Lagrangian droplet tracking with adaptive refinement
- Fully 3D icing simulation and particle tracking tool
- Predicts water impingement & resulting ice growth on arbitrary aircraft surfaces
- Fully parallelized trajectory scheme built for HPCs

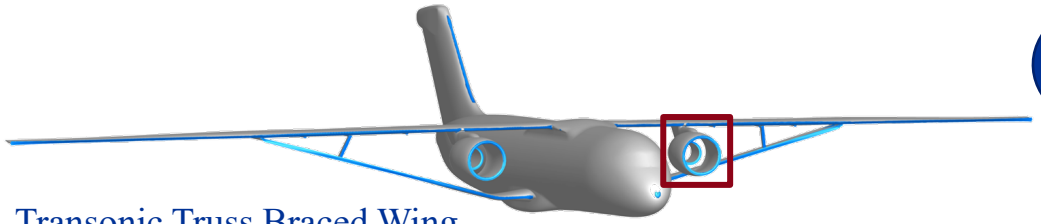
GlennICE [1]

External Icing

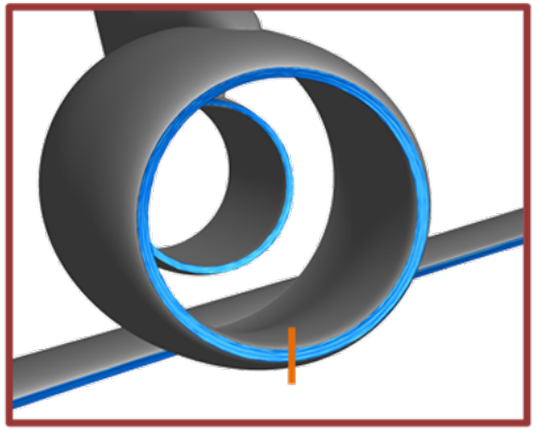
Rotational Icing

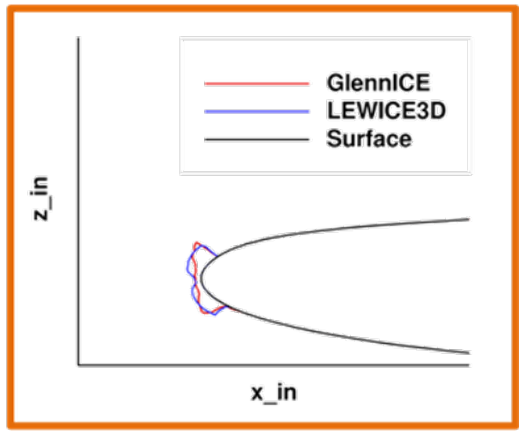
Ice Crystal Icing

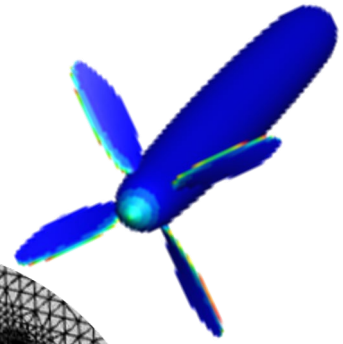
As of 2018,GlennICE is the foundational code through which NASA will develop and evaluate physical models associated with ice accretion

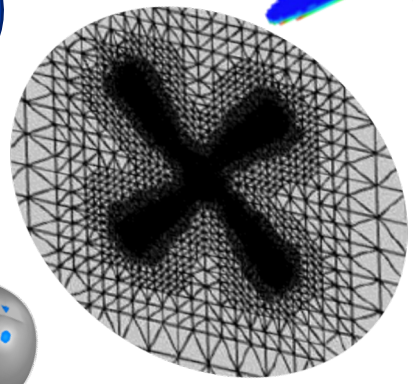


Transonic Truss Braced Wing









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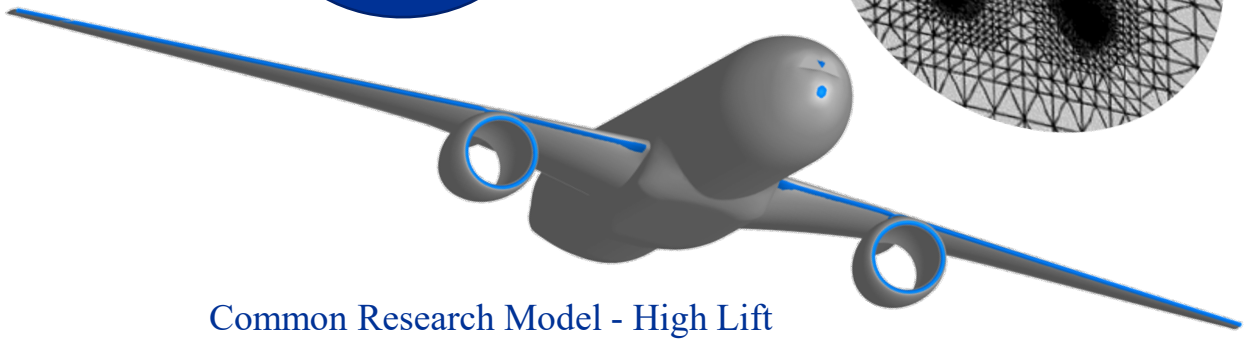


Common Research Model - High Lift

[1] "GlennICE Manual 4.1.0." *NASA Glenn Research Center*, NASA-TM-20240002191, https://ntrs.nasa.gov/citations/20240002191

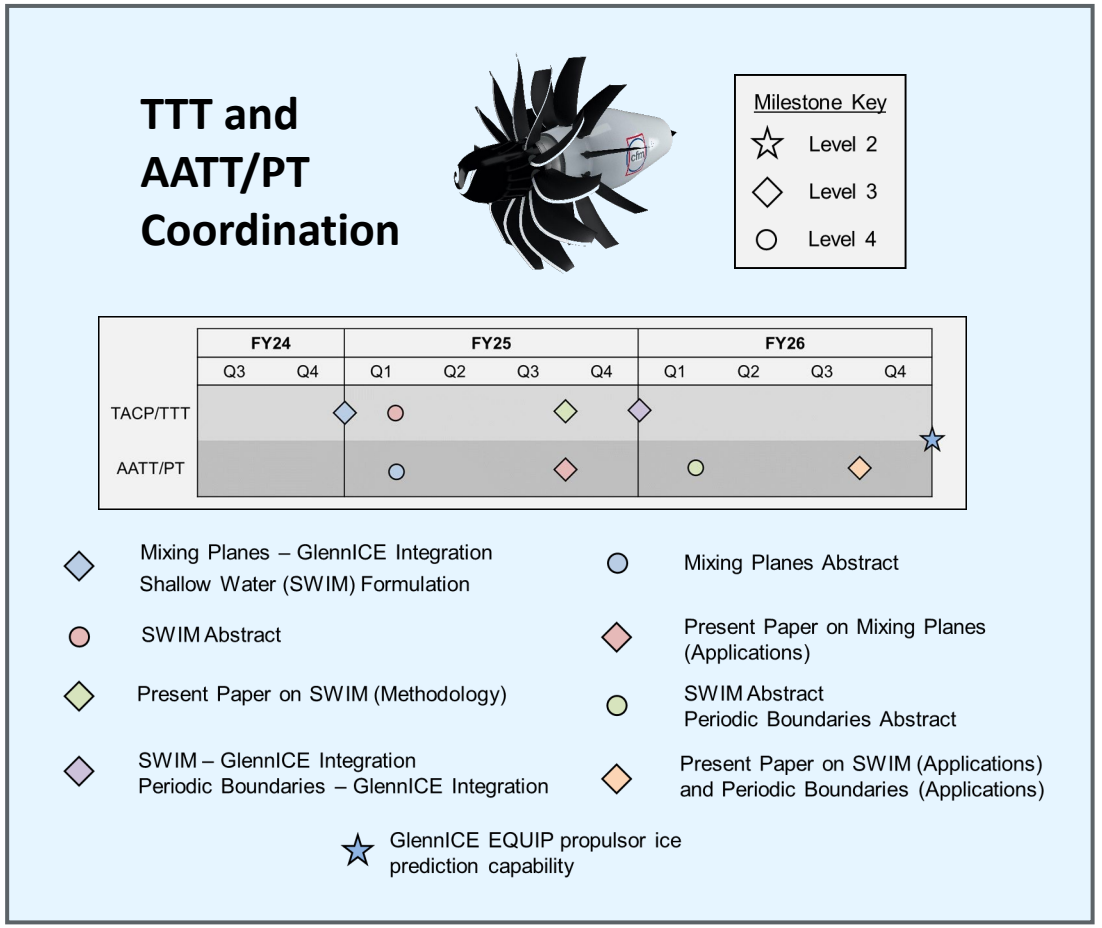
GlennICE Fan Icing

FY24-FY26

Engine Fan Icing Work Areas:

- 3D rotational icing simulation
- Rotating Reference Frame, Mixing Planes, Water Runback, and Periodic Boundary Conditions
- Ice shedding simulation
- Model onset time and mass of shed ice
- Defining requirements for engine fan icing test rig
- Actively meeting with industry stakeholders

- The GlennICE Software is utilized by various organizations:
  - AATT/AT – Transonic Truss Braced Wing
  - AATT/PT – Efficient Quiet Integrated Propulsor
  - AETC – Icing Research Tunnel CFD Characterization External Customers



GlennICE development coordination to support AATT/PT EQUIP Technical Challenge.

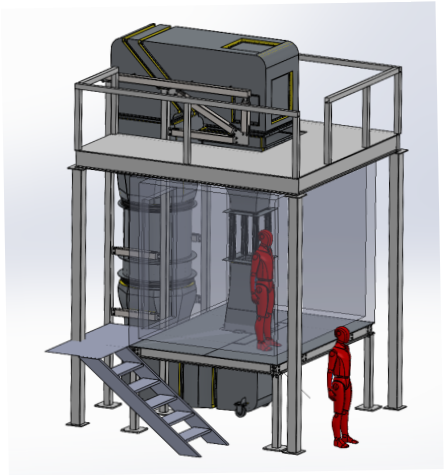
Papers with NASA Authors & Co-Authors at 2024 AIAA Aviation

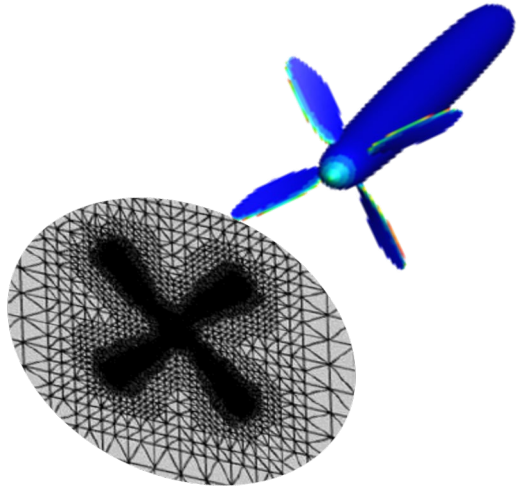
Lead Author	Co-Authors	AIAA-2024-Paper #	Paper Title
Struk		N/A	NASA Icing Research Update 2024
Ozoroski	Broeren, Porter, Lee	-3683	Analysis of Ice Mass Growth Over Time on the CRM65 Midspan Hybrid Model
Porter	Rigby	-3685	Utilization of Streamtubes to Analyze the Physical Interation of a Dispersed Cloud with the CRM65 Hybrid Midspan Model
Bartkus	Lee	-3845	Icing Physics Studies Using the 3D SIDRM Test Article: Ice Crystal Icing Analysis
Chen	Ratvasky, *Strapp, Lilie*	-3929	Analysis of Hot-Wire Probe Ice Water Content Measurements in High IceWater Content Conditions
Ratvasky	*Strapp, Lilie, Bansemer*, Chen	-3930	Air Data Probe Anomalies in Flight through Measured High Ice Water Content Conditions
Strapp	Ratvasky, *Bansemer, Lilie*, Harrah, *Diskin, DiGangi*	-3931	Summary of Additional In-situ Cloud Data in High Ice Water Content Conditions from Three Recent Flight Campaigns
Giuffre		-4070	In-Situ Ice Adhesion Testing using the Deformed Skin Adhesion Test
Wright		-4164	Improvements to GlennICE Collection Efficiency Algorithm
Sabri	Porter	-4165	A Study of Parallel Scalability and DynamicWorkload Balancing in GlennICE
Tsao	Vargas, Sabri, Insana, Stewart, Timko, *Payne*	-4245	Characterization of Large Drop Velocity in the NASA Icing Research Tunnel
Esposito	*Lilie*, Timko, L. Acosta, *Strapp, Bansemer*	-4246	Wind Tunnel PSL and MVD Characterization using New 1D2D Optical Array Probes
von Hardenberg	Flack, Rigby	-4448	Ice Shape Analysis of an eVTOL Propeller in Forward Flight at the NASA Glenn Icing Research Tunnel
Rigby	von Hardenberg	-4449	GlennICE Simulation of 24”, 28” and 36” eVTOL Propellers in Forward Flight

Summary

Icing research in this briefing:

- TTBW
- High-Lift CRM
- AIT
- AAM Icing
- GlennICE Update
- 2024 AIAA Aviation Papers





Thank You!