NASA Icing Update

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SAE AC-9C COMMITTEE MEETING

In-Person in San Diego, CA and Webex

April 4, 2022

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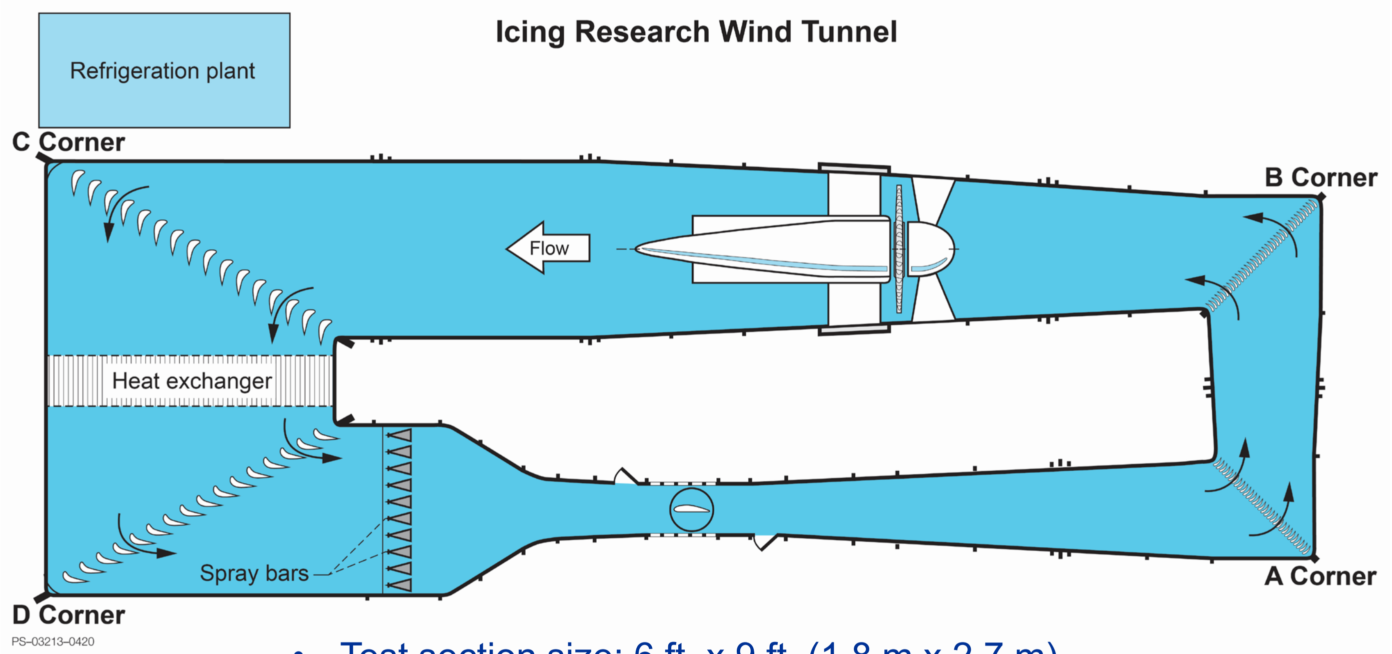
Icing Research Tunnel: Status Update



- Test section size: 6 ft. x 9 ft. (1.8 m x 2.7 m)
- Calibrated test section airspeed: 50 –300 kts
- Air temperature: -35ºC static to +15ºC total
- Two types of spray nozzles:
    - Standards = higher water flow rate
    - Mod1 = lower water flow rate
- Calibrated MVD range: 14 –270 µm
- Calibrated LWC range: 0.17 –4.0 g/m^3 (function of airspeed)

IRT Cloud Cals since 2019 Full Cal:

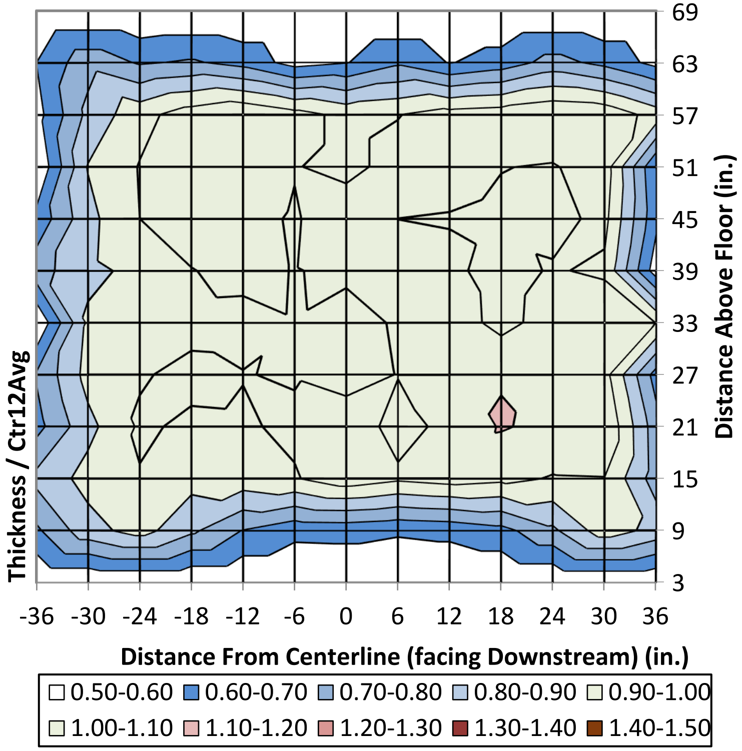
- 2019: Full Calibration
    - Cal Report now available on ntrs.nasa.gov: NASA TM-20205009045, by Timko, et. al
    - Uniformity (Grid)
    - LWC (Multi-wire)
        - Icing Blade confirmed low-impingement-rate conditions
    - Drop Size (CDP, OAP-230X, OAP-230Y)
- Jan & Mar 2020: 2 Check Cals
    - Uniformity & LWC
- ➢ *Mar 2020: IRT shut down for COVID*
- ➢ *Jan 2021: IRT restart efforts began, included a few large maintenance items*
- ➢ *Aug 2021: IRT fan restart*
- Sept 2021: IRT Restart Checks
    - Uniformity, LWC, and Drop Sizing
        - Icing Blade confirmed low-impingement-rate conditions
- Jan & Mar 2022: 2 Check Cals
    - Uniformity, LWC, and Drop Sizing

Uniformity Results—Overall

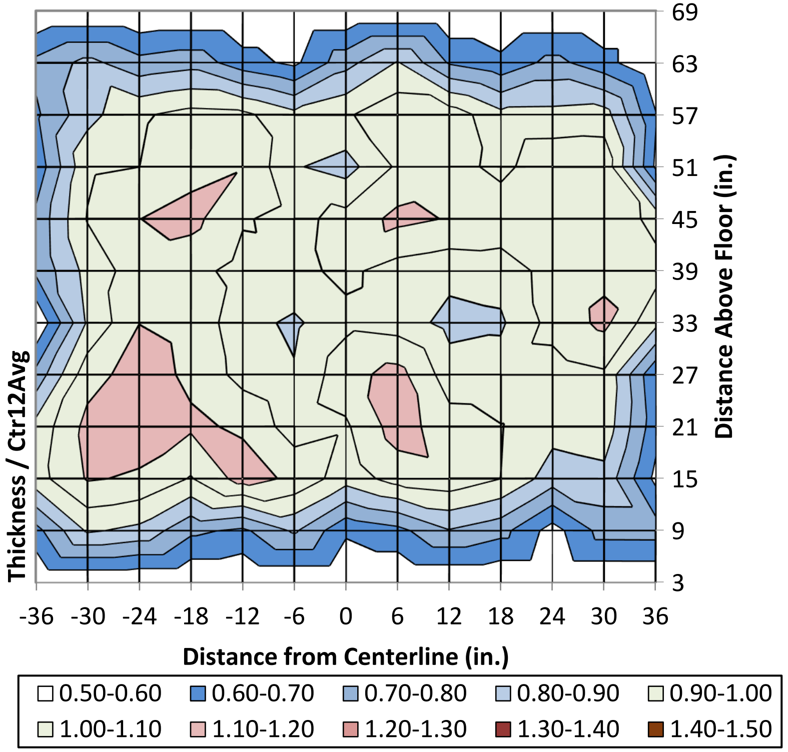
- Center Regions looked OK—central 2x2 ft was consistently within 10% of 2019
  - Some differences were seen in outer regions
- Example Cases shown here:
  - Standards Baseline: 150 kts, MVD=20.0 μm, LWC=1.37 g/m³
  - Mod1 Baseline: 150 kts, MVD=21.5 μm, LWC=0.85 g/m³

Mod1 Center 12 Average Thickness = 405 x10⁻³ in.
Off-white indicates 0-5% change,
light red/blue is 5-10%, darker red/blue is 10-15%

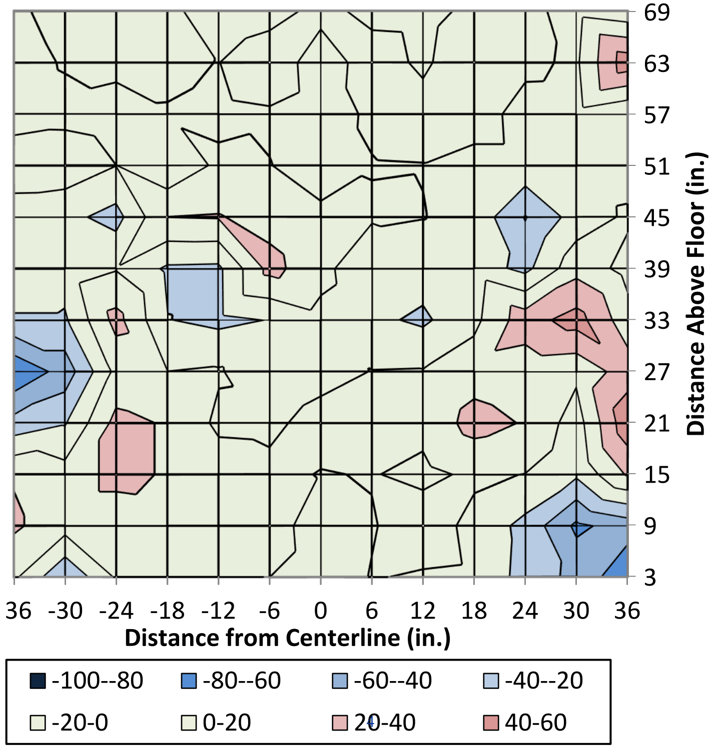
Normalized Unif: Standard Baseline, 9/10/21, Run #1



Normalized Unif: Mod1 Baseline, 9/10/21, Run #2

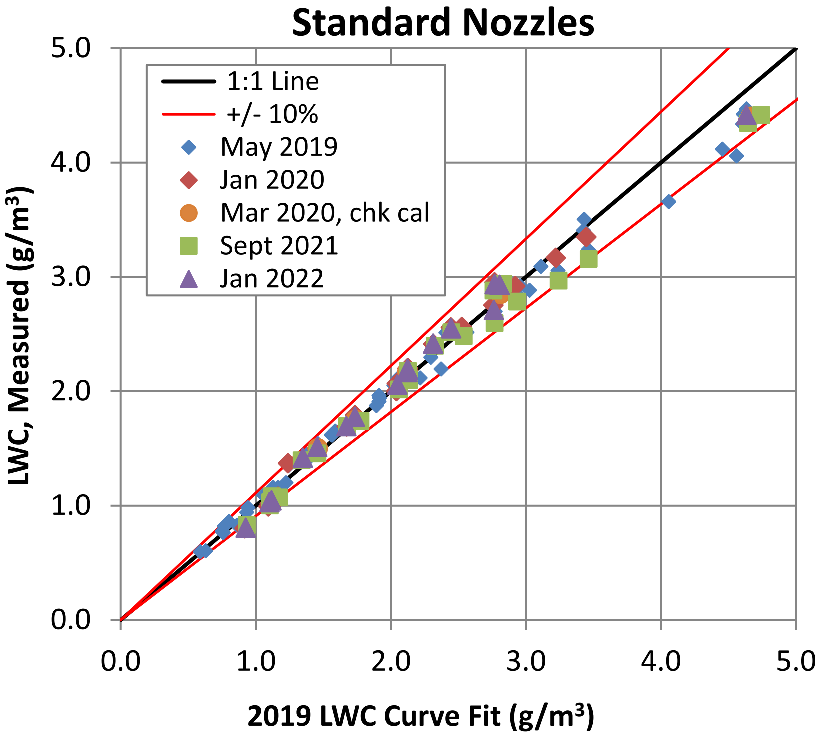


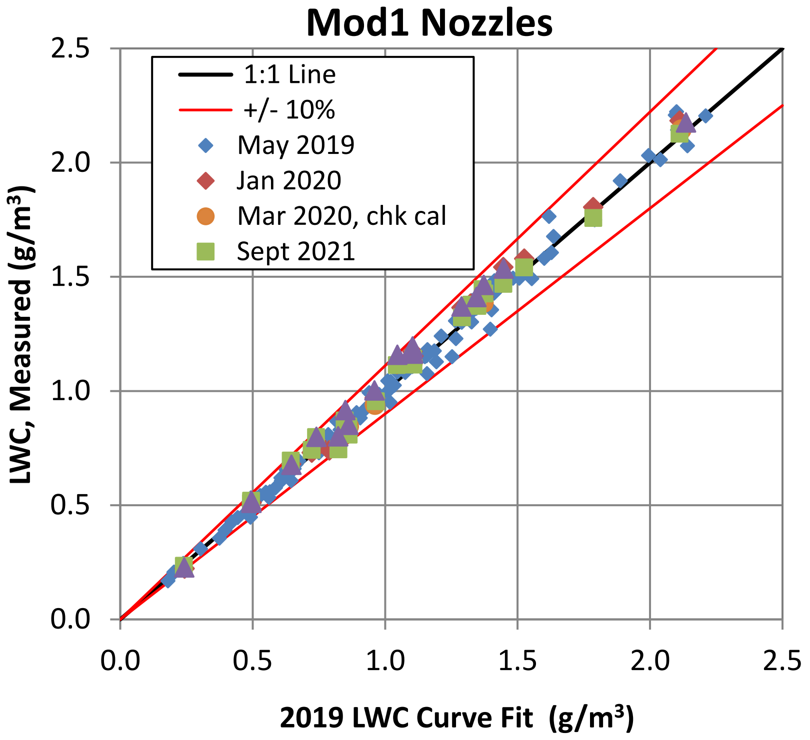
Difference Map, 9/10/21 Run #2 vs. Mod1 baseline on 5/23/19, Run #2

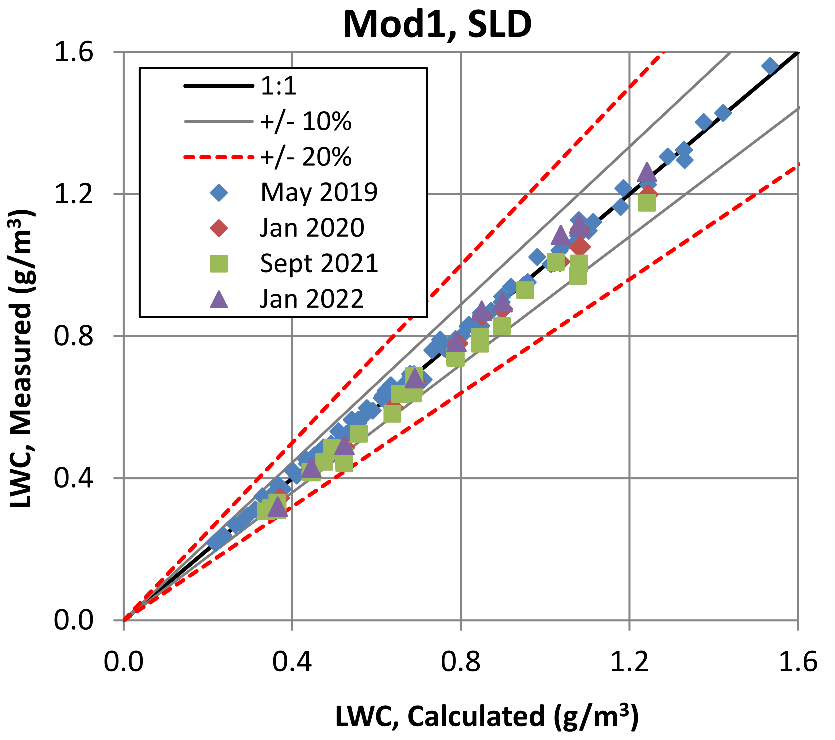


IRT Liquid Water Content Results

- In 2021 & 2022, the LWC for most conditions in our operating envelope fit the IRT's stated repeatability values
  - ±10% for normal (App C) operating conditions and ±20% for SLD conditions
- We do have some small regions of the operating envelopes that we're keeping an eye on—we have been and will continue to have conversations with customers about any test points they may have in these regions as the need arises

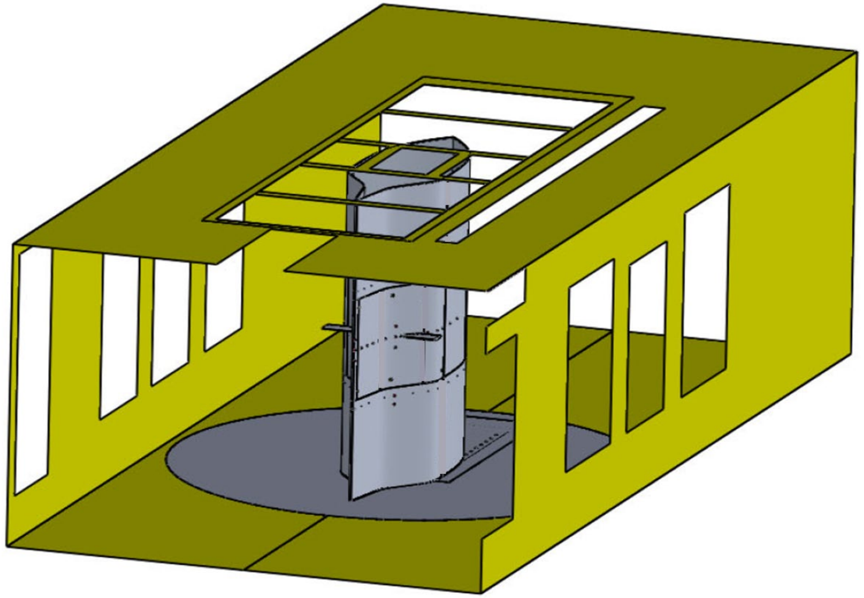


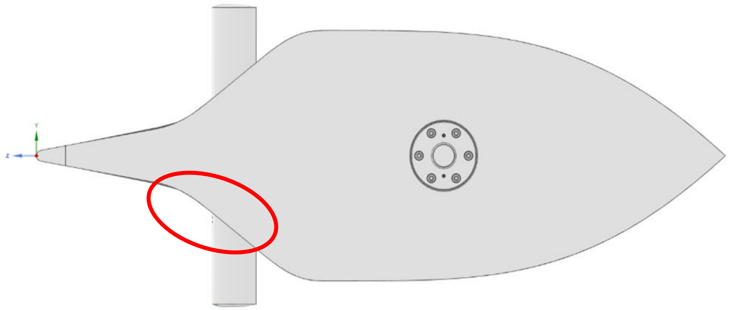


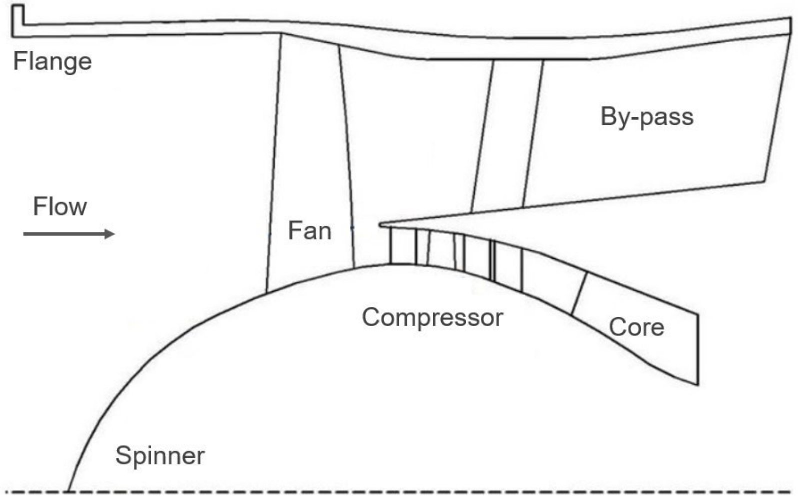


Ice Crystal Icing Experimental Research

- Generate a set of ice accretion data on a 3D test article to validate GlennICE ice accretion models
- Conduct ice crystal icing and supercooled water icing tests in the NASA Icing Research Tunnel (IRT)
- Utilize Simulated Inter-compressor Duct Research Model (SIDRM)
  - Representative of an inter-compressor duct and strut region of a turbofan engine (heated curved surface with a strut)
- 17 days of icing tests with SIDRM test article (Feb 16 - 25 and April 11 – 22)
- 13 day of Ice Crystal Cloud Characterization (Jan 31 – Feb 13 and March 14 – 16)



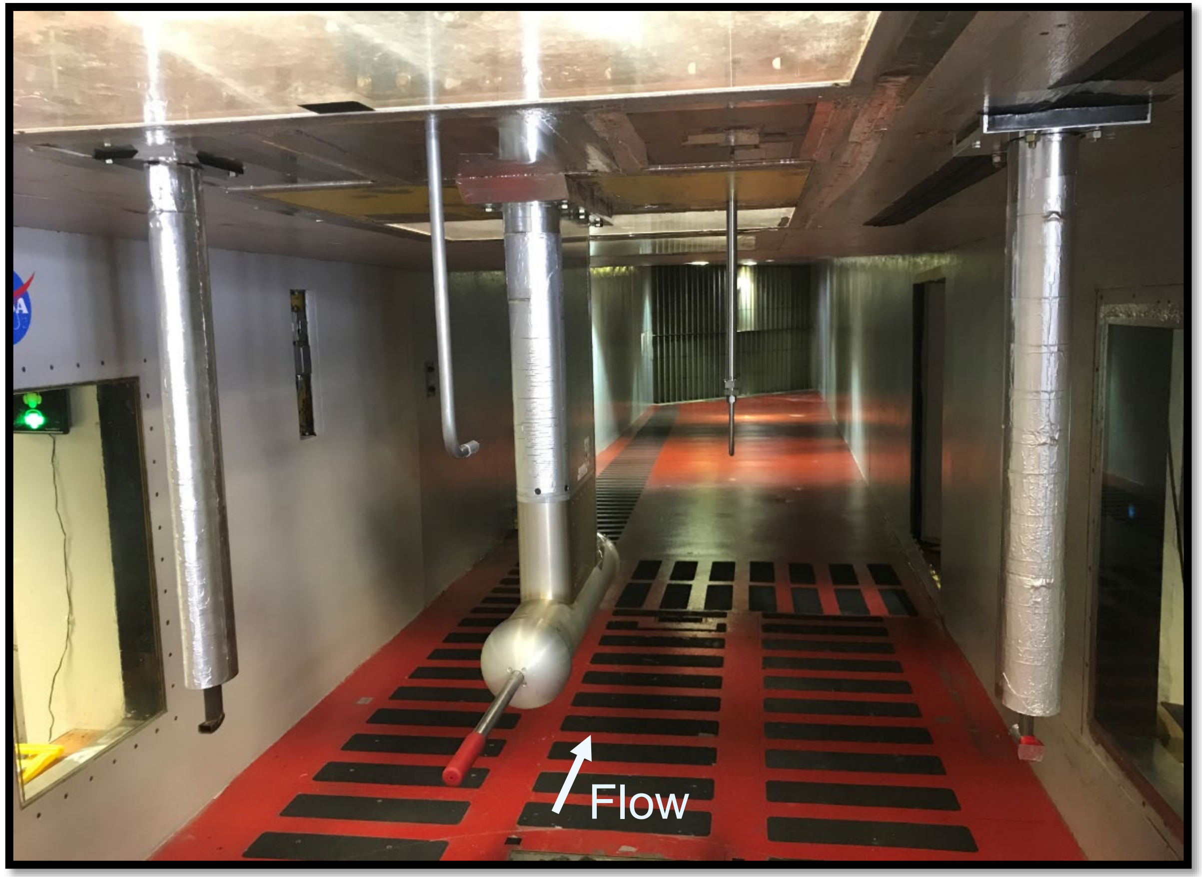




Ice Crystal Cloud Characterization at IRT

- Ice crystal generation is not well characterized at IRT
- Ice crystal cloud envelope limited to colder, slower, and smaller diameter.
- Well characterized cloud needed to properly model resulting icing data
- Objective: Characterize IC cloud using following instrument suite

Instrument	Measurement
Multiwire	Melt ratio & recirculation
Isokinetic Probe	Total water content & recirculation
Rearward Facing Probe	Air temperature and humidity
Ice Crystal Particle Imager (Artium)	Particle size distribution
TAT probe (Rosemount)	Air temperature
Ice Detector (UTC Aerospace)	Glaciation (liquid presence)
Test Section Background Hum	Test section humidity
Spray Bar Background Hum	Upstream humidity
Light Extinction Probe	Recirculation



Various probes installed in the NASA IRT test section during IC cloud characterization tests in Feb 2022

SIDRM Tests and Objectives

<u>Test type and Objectives:</u>

1. Perform aero-thermal characterization of SIDRM test article
2. Generate supercooled water ice accretion data for various conditions
3. Generate ice-crystal icing data for various conditions utilizing a conducting (heated) surface
4. Investigate transient heat conduction during ice crystal icing

<u>Key Measurements:</u>

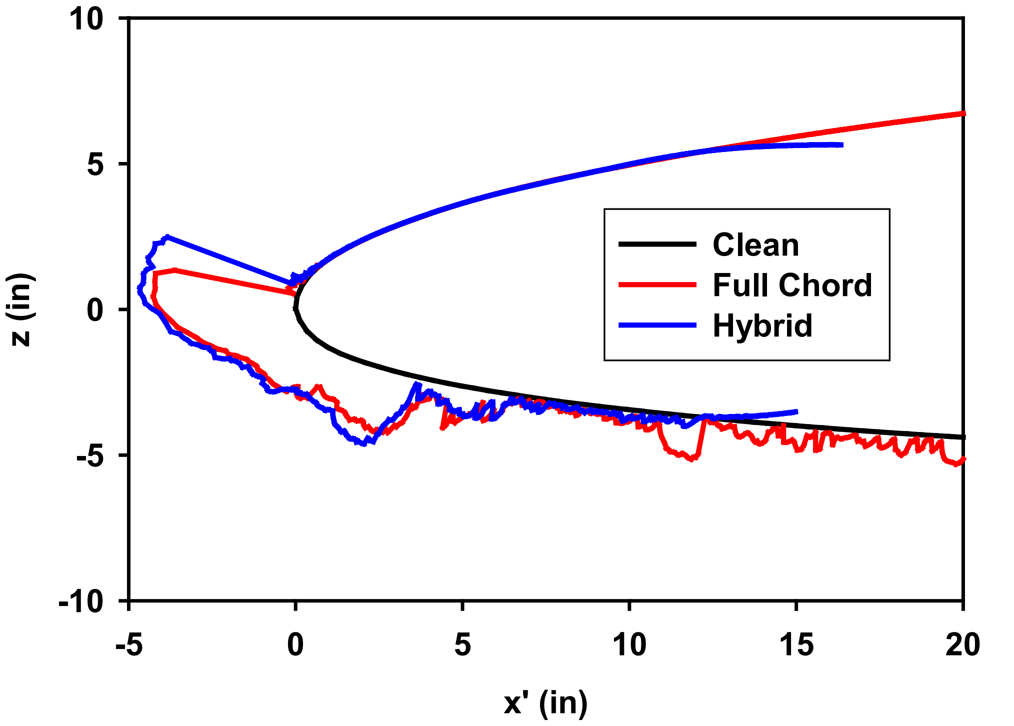
- Laser scanned 3D geometry of ice accretion
- 1D and 2D accretion profiles extracted from video
- Ice mass (and density)
- Surface temperature
- Surface heat flux

Flow

Ice accretion on the SIDRM test article due to supercooled water icing (left) and ice crystal icing (right) during tests in Feb 2022

Hybrid and Full Chord CRM65 IRT Testing

- In January 2022, three week of IRT testing were completed with the hybrid and full-chord versions of the CRM65 wing sections.
- This completed the work begun in 2020 to confirm the hybrid model design approach and extend the ice accretion database for large-drop conditions. See AIAA Papers 2021-2678 and 2021-2679.



Bimodal Ice Accretion on CRM65 Midspan Models

Hybrid and Full-Chord

OBJECTIVE:

- Develop database of ice shapes for bimodal icing conditions on the CRM65 hybrid and full-chord midspan wing section models.
- Establish a correlation between hybrid and full chord model ice shapes.

CHALLENGES:

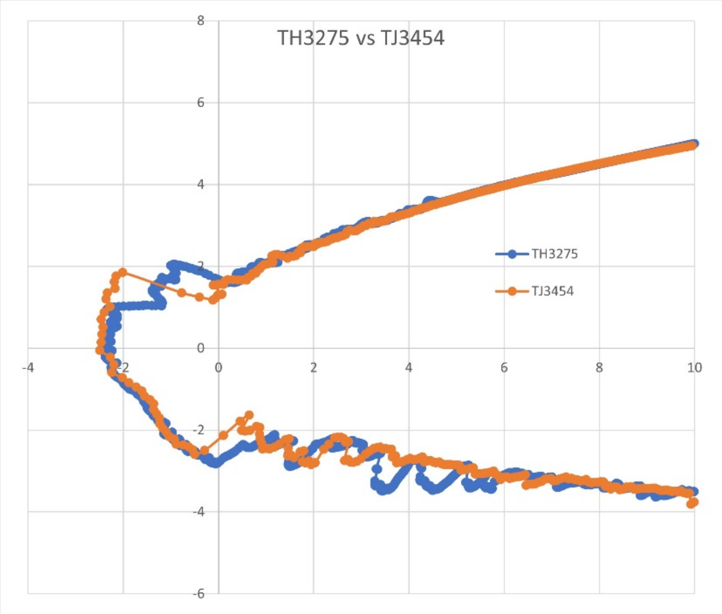
- Obtain large ice scallop at high velocity conditions without shedding.
- Models were able to run at 230 and 180 knots at high lift to compare with several bimodal cloud conditions.

RESULTS:

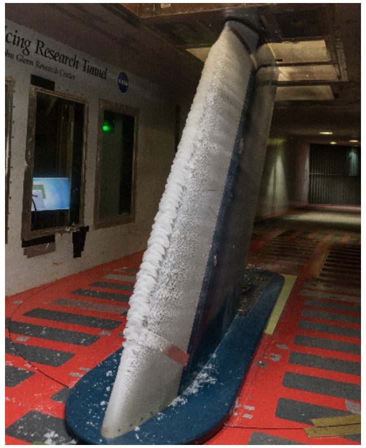
- Collected photographs, digital ice shape scans, and ice mass measurements for each spray.
- Preliminary full-chord results show good correlation with hybrid model results from December 2021 test entry.

CURRENT STATUS:

- A paper to be presented in AIAA 2022 Aviation Forum to show ice shape comparisons on hybrid and full-chord models with bimodal cloud at different icing conditions



MCCS ice profile and ice mass comparison for TH3275 (603g) vs TJ3454 (629g)



Large ice scallop on hybrid mid-span model in IRT, TH3275

Large ice scallop on full-chord mid-span model in IRT, TJ3454

GlennICE Development

Version Timeline

Version	0.1	0.2	1.0	1.1	1.2	2.0	2.1	2.2	3.0	3.1	3.2	4.0	4.1	4.2	5.0	5.1	5.2	6.0	6.1	6.2
Date	2/20	6/20	10/20	2/21	6/21	10/21	2/22	6/22	10/22	2/23	6/23	10/23	2/24	6/24	10/24	2/25	6/25	10/25	2/26	6/26

External Icing

- Quasi-3D (LEWICE3D) → Full 3D (GlennICE)
- Utilize modern programming practices and capabilities.

Rotating Icing (Super Cooled)

- Introduce rotating reference frames (Engine Fan and Propellors).
- Handle periodic boundary conditions/mixing planes.

Internal Icing (Ice Crystal)

- Introduce ice crystals and related physics
- Address multiphase runback and icing.

Version 2.1 Improvements

- Multiple node, distributed memory parallelization.
- Significantly improved release point initialization efficiency.

Version 2.2 Planned Additions

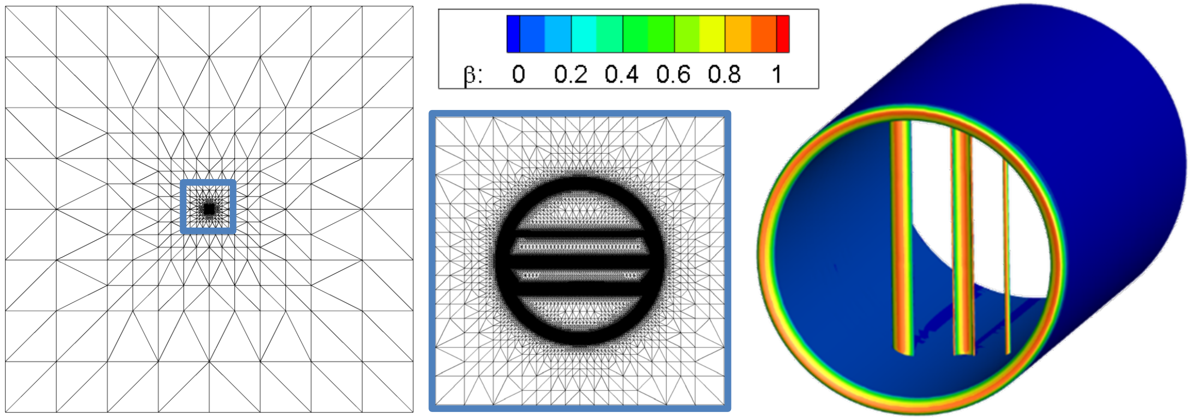
- Introduce rotating reference frames.
- Improved robustness of feature finding.
- Single node, shared memory parallelization.
- Removed requirement to be provided volume/surface nodal connectivity.

GlennICE is currently not available on NASA's Software Store.

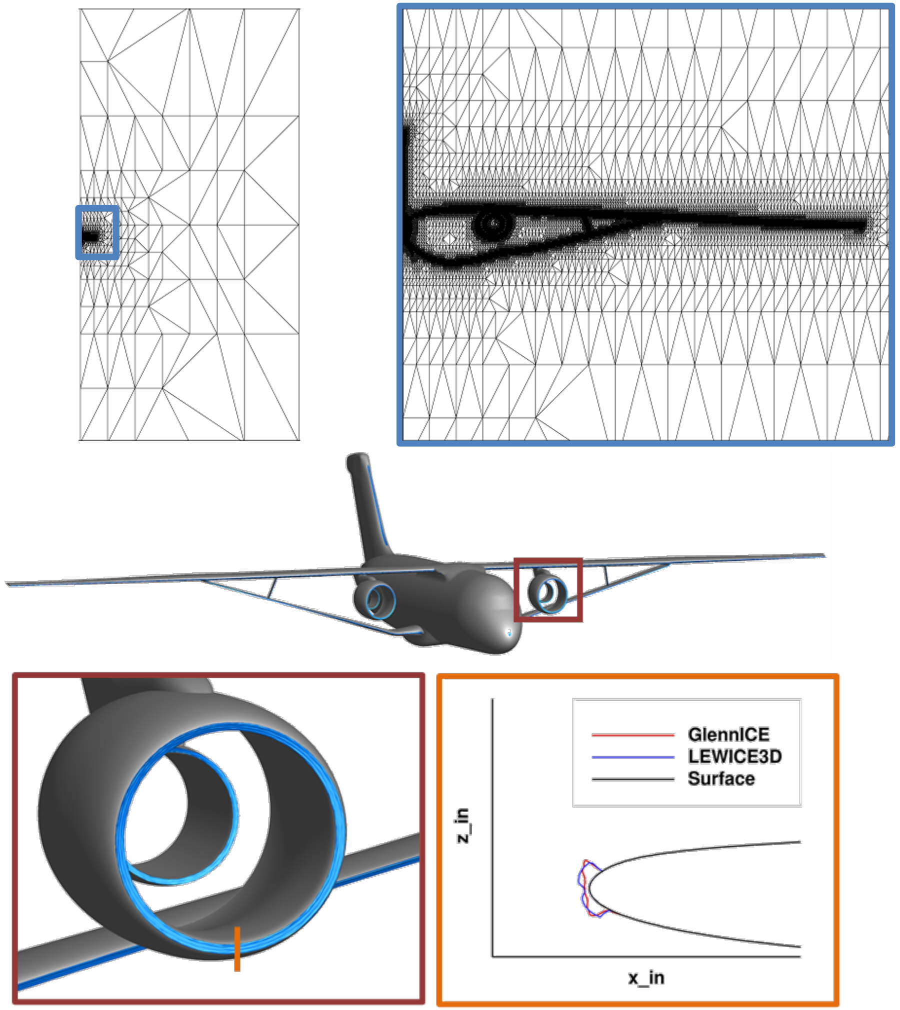
External Icing Simulations with GlennICE

- Implemented a two-part adaptive trajectory refinement scheme:
  - Feature finding (limit misses)
  - Collection based adaptive refinement (reduce hits that don’t improve the prediction of collection efficiency)

- Implemented a fully three-dimensional ice growth formulation:
  - Runback is an algebraic model based on shear
  - Heat transfer is augmented as a function of local roughness computed using McClain’s[1] method.
  - Ice growth is a prismatoid extrusion method with node based smoothing[2].



Seed plane of released trajectories and the resulting computational prediction of collection efficiency (beta) utilizing GlennICE on the SEA Multi-Element Probe, an experimental device that measures total water content.



A full 3D GlennICE simulation of an ice accretion due to a 15 μm cloud on the TTBW. Insets depict the accretion on the engine inlet, with the line plot including a comparison to the legacy quasi-3D icing software, LEWICE3D.

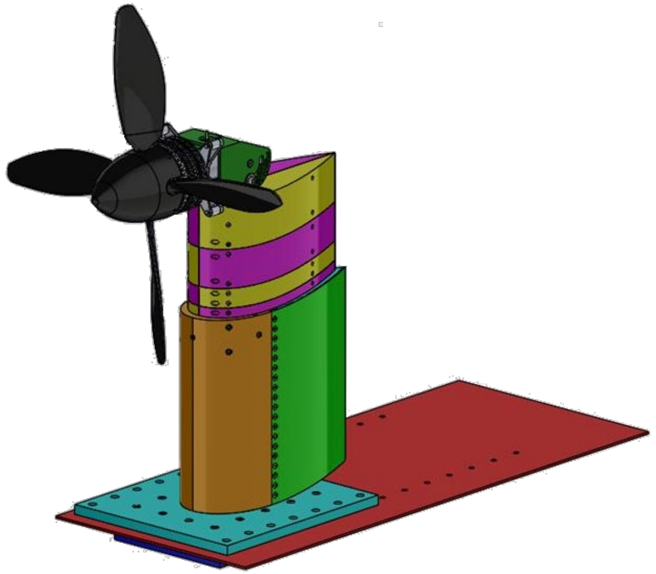
[1] McClain, Stephen T., et al. "A Model for Ice Accretion Roughness Evolution and Spatial Variations." AIAA AVIATION 2021 FORUM. 2021.
[2] Porter, Christopher E., and David L. Rigby. "Three Dimensional Surface Redefinition Method for Computational Ice Accretion Solvers." AIAA AVIATION 2020 FORUM. 2020.

Rotating Reference Frame in GlennICE

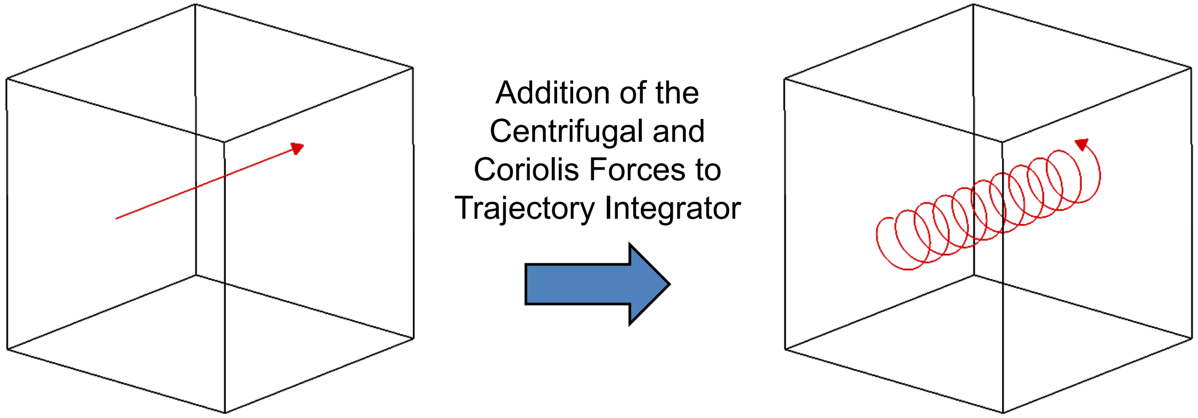
The next major feature enhancement to GlennICE is the ability to handle rotating reference frames.

This addition will enable GlennICE to perform supercooled liquid icing analysis on rotating geometries such as propellers and fans.

A propeller test geometry that aligns with the AAM effort sponsored by RVLT will be utilized to benchmark the addition of rotating reference frames.

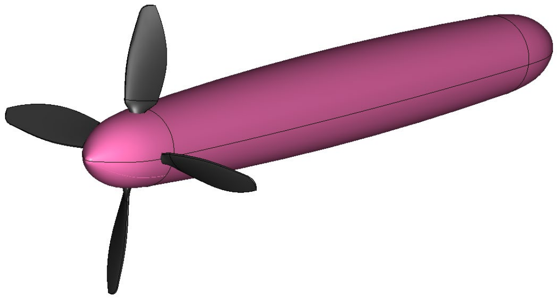


Schematic of the Advanced Air Mobility Rotor Test Stand.



Non-Rotating Frame of Reference

Rotating Frame of Reference



A proposed defeatured computational geometry to demonstrate the capability of GlennICE to handle rotating reference frames.