NASA Icing Update – May 2024

Presentation for the
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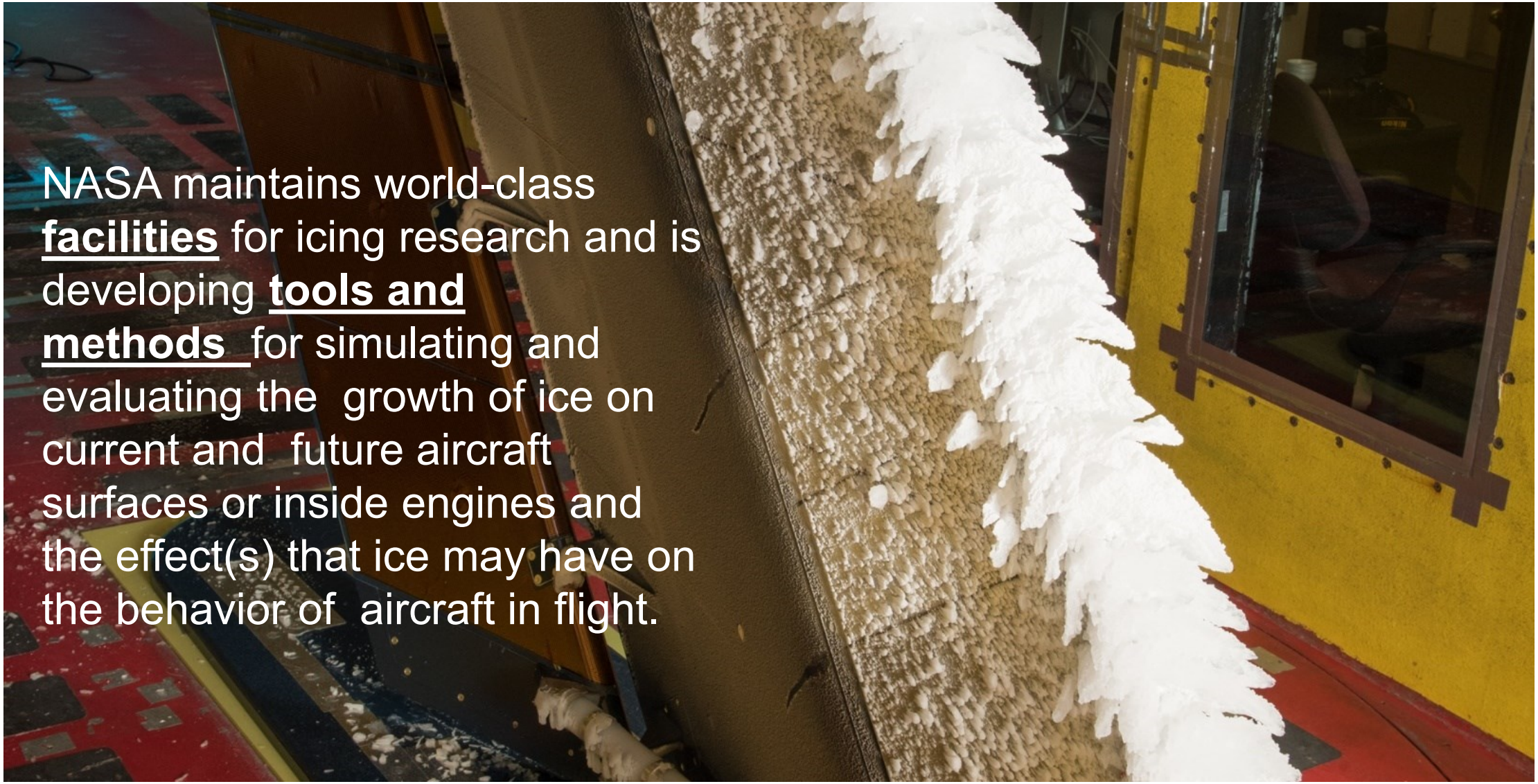
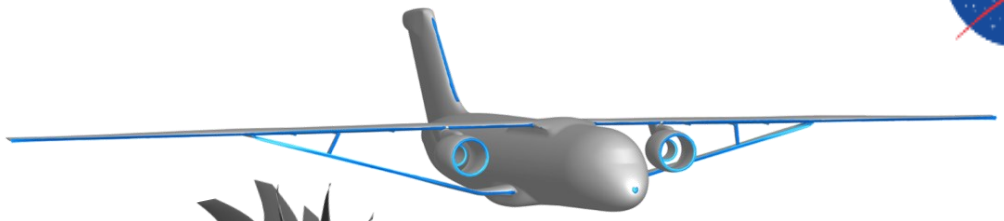
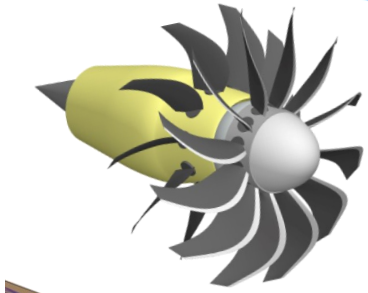
NASA's Mission in Icing

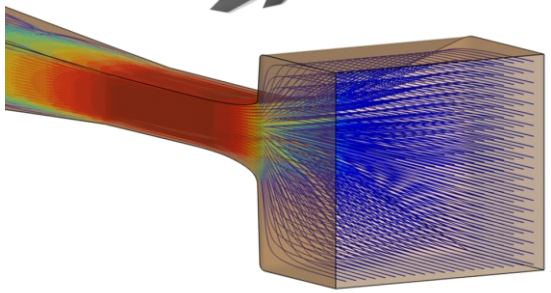


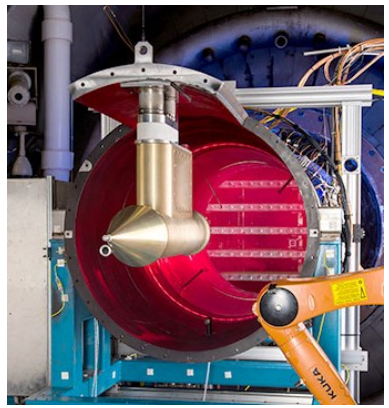
Outline

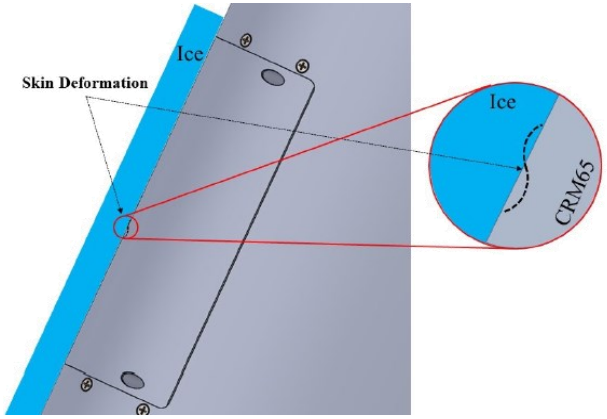
- Adaptive Icing Tunnel (AIT)
- Ice Adhesion / Deformed Skin Adhesion Test
- GlennICE
- Icing Research Tunnel (IRT) CFD Characterization
- Efficient Quiet Integrated Propulsor
- Propulsion Systems Lab (PSL)
- Supercooled Large Droplet (SLD) Research:
  - Instrument & Facility Intercomparisons
  - IRT Droplet Velocity Characterization

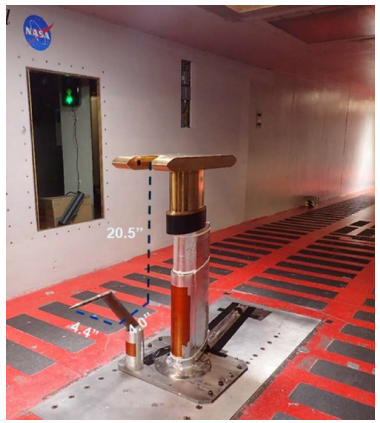


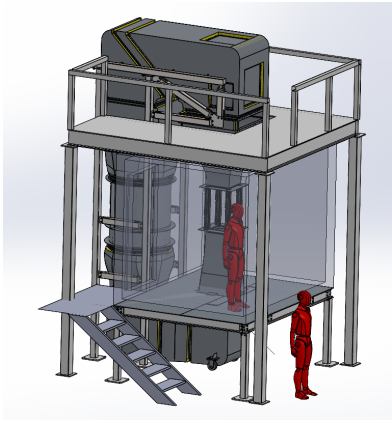


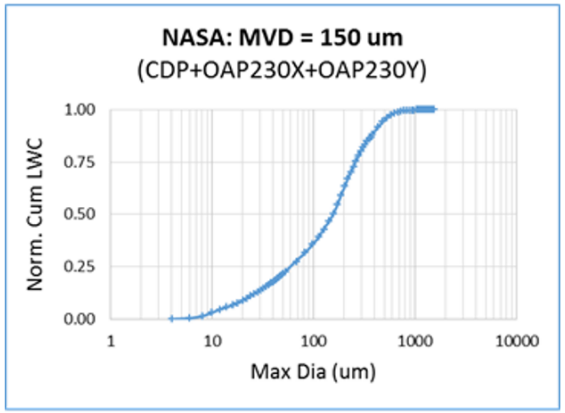






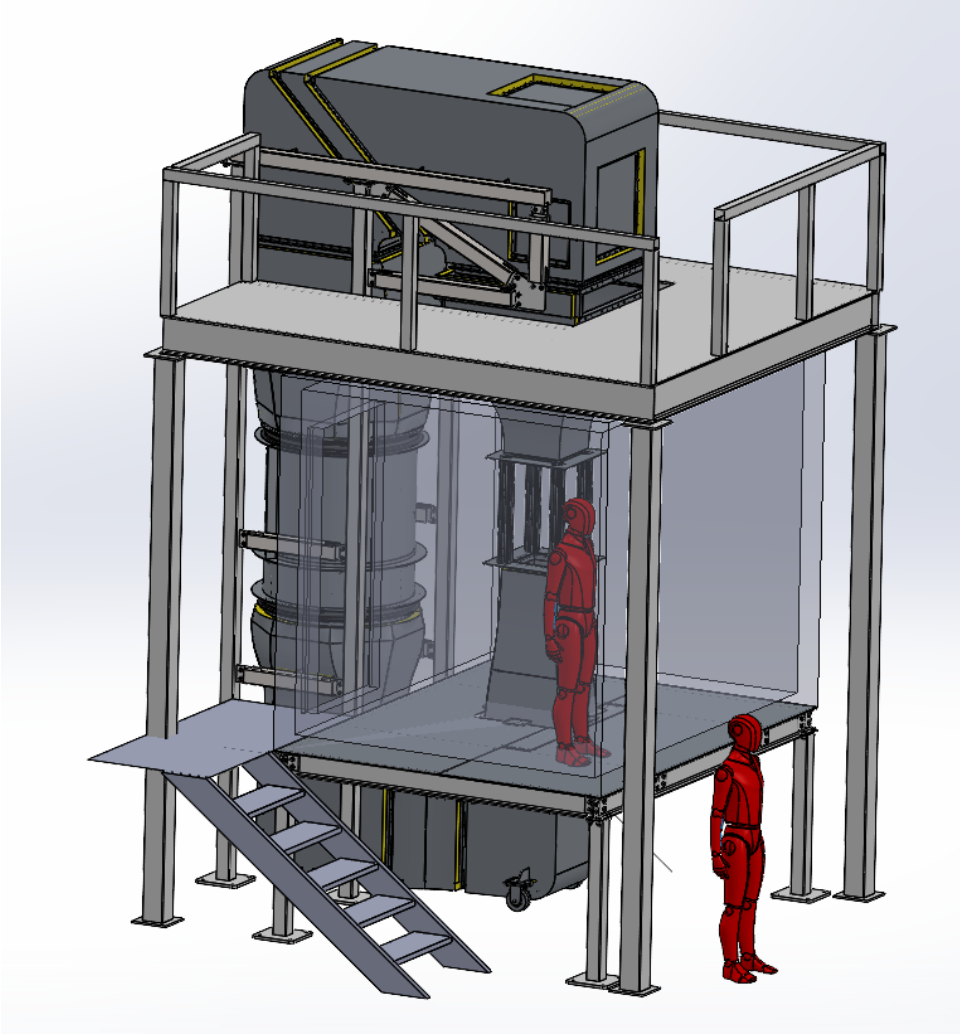






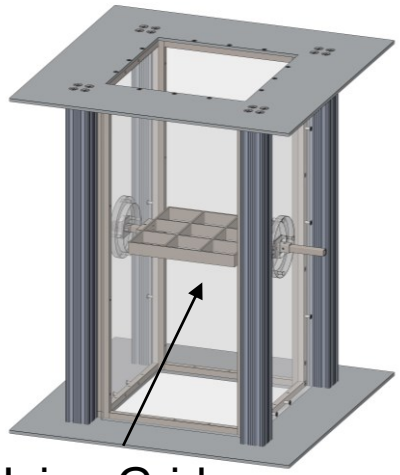
Adaptive Icing Tunnel (AIT) Description

- Laboratory scale icing wind tunnel
- Closed loop, vertical
- Test section 1 x 1 ft (0.3 x 0.3 m)
- Airspeeds up to ~210 knots (~110 m/s)
- Temperatures as cold as -20°C
- Walk-in freezer surrounding test section
- Plans for supercooled water & ice crystals



Adaptive Icing Tunnel Status

- Chiller and most of tunnel loop installed
- Targeting assembly completion in May
- Goals:
  - Tunnel operation by July followed by initial characterization
  - Research by October
- Initial characterization planning:
  - Aero-thermal characterization
  - LWC – Icing Blade & ICD
  - Uniformity - Grid
  - PSD – Rotating Cylinders & CDP



Icing Grid

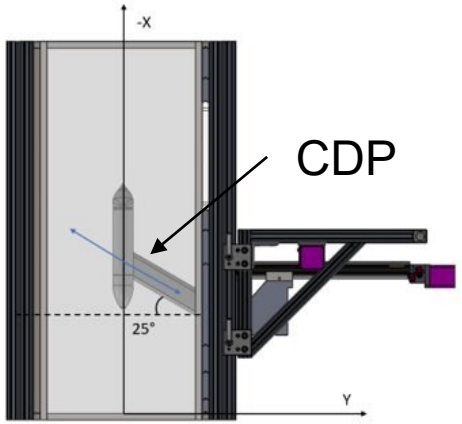


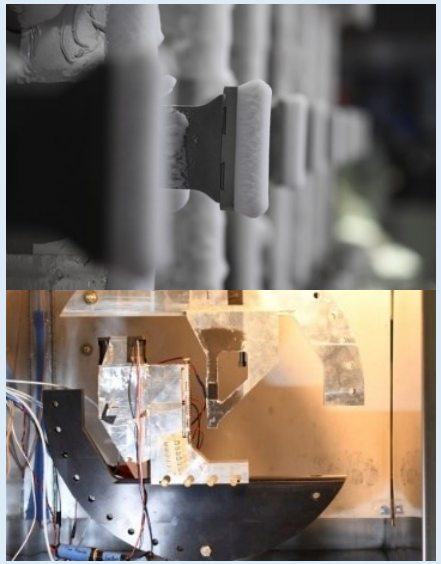
Photo of AIT build-up

Ice Adhesion Testing

Revolutionary Icing Materials Evaluation (RIME) Lab at NASA Glenn (Cleveland, Ohio)

- Ice adhesion testing
- Icing experiment
- Microstructural analysis

Shear adhesion testing



Centrifuge

Laboratory for Adhesion Mitigating Projects (LAMP) at NASA Langley (Hampton, VA)

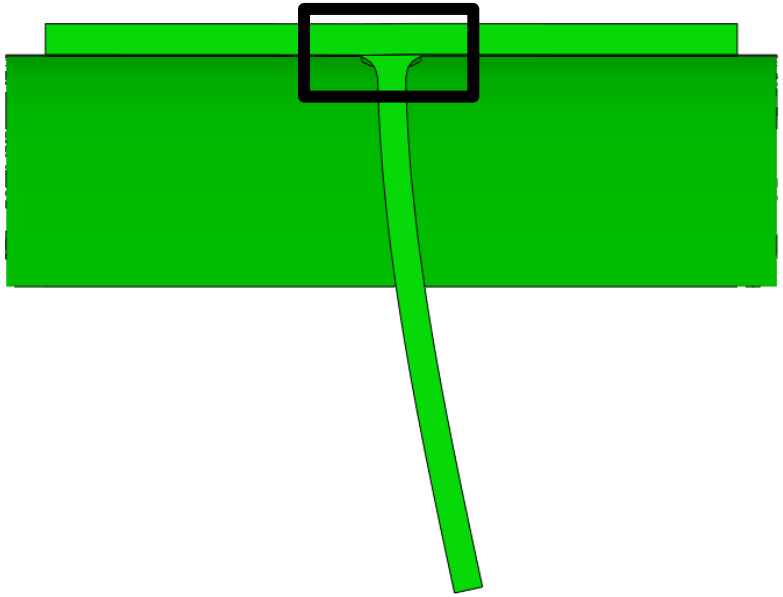
- Evaluate surface coatings
- Simulate contamination conditions
- Assess mitigation strategies

Adverse Environment Rotor Test Stand (AERTS) Jr.

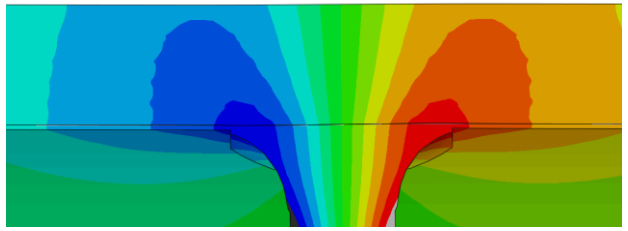
Deformed Skin Adhesion Test

- In-Situ ice adhesion testing method which allows for more repeatable measurements
- Uses controlled displacement rates to gradually increase stresses along the interface
- Experiments can be conducted while the tunnel is running
- Delamination events are observed when there is a global change in the behavior of the coupon, i.e. a decrease in the applied load or a change in coupon stiffness

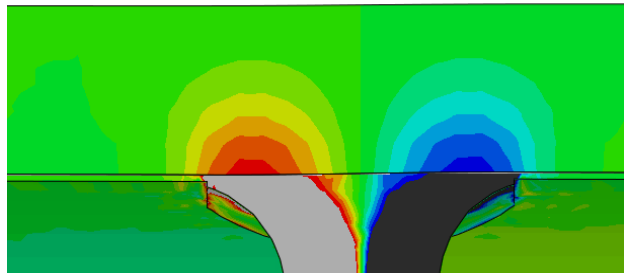
Deformed Coupon Shape

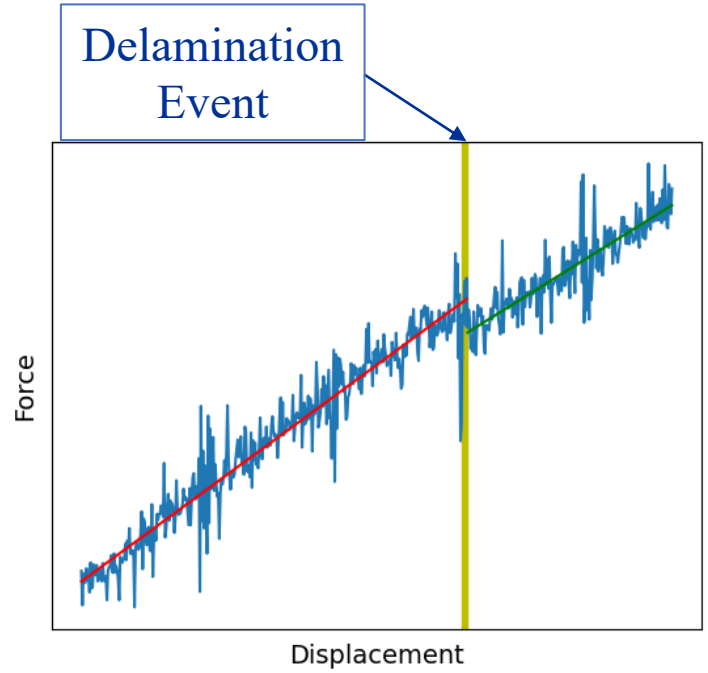


Opening Displacements



Opening Stresses





NASA Icing Tools - GlennICE

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

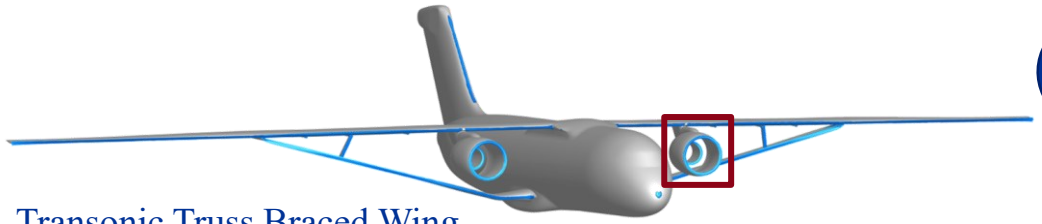
GlennICE [1]

External Icing

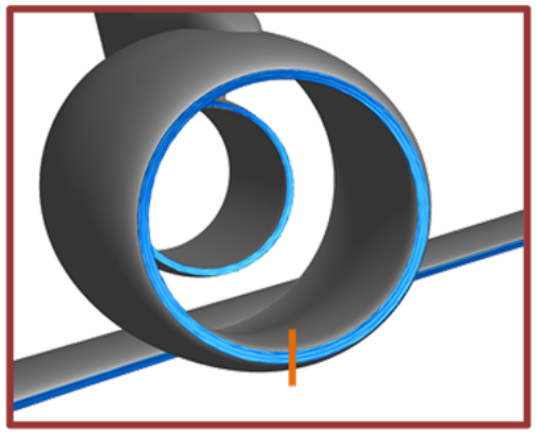
Rotational Icing

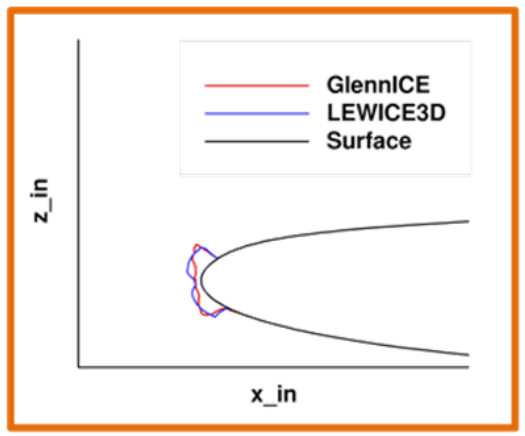
Ice Crystal Icing

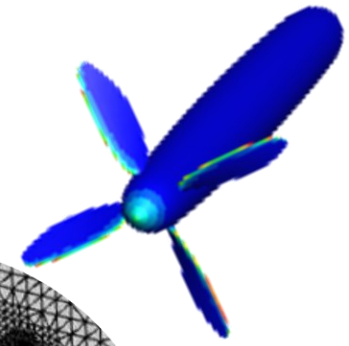
As of 2018,GlennICE is the foundational code through which NASA will develop and evaluate physical models associated with ice accretion

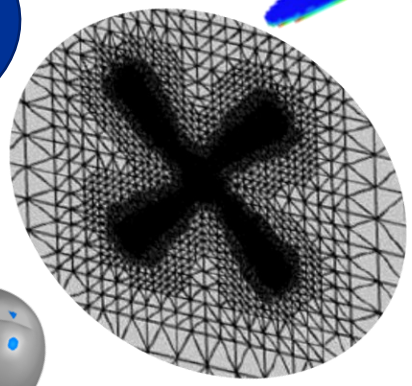


Transonic Truss Braced Wing









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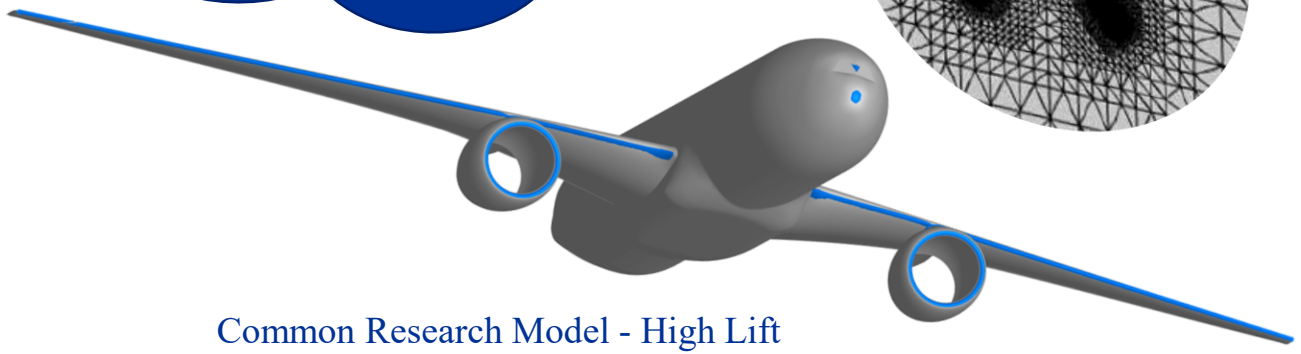
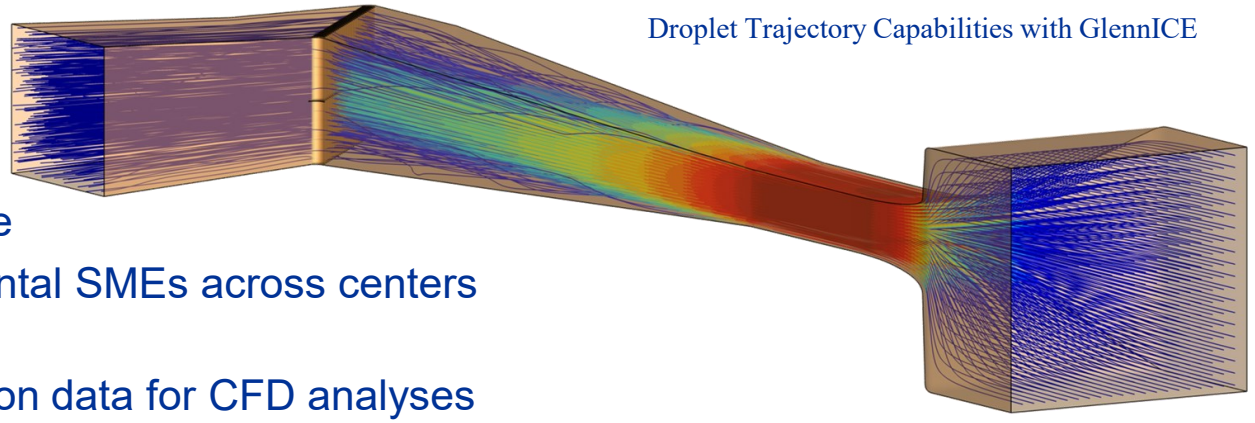


Common Research Model - High Lift

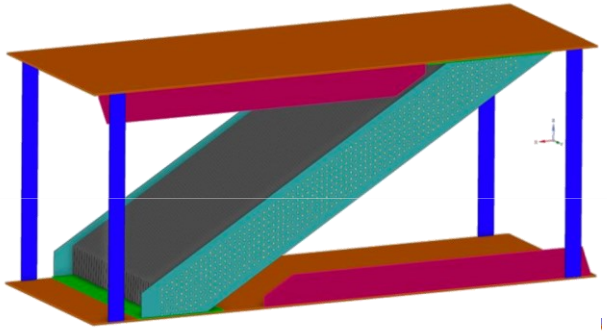
[1] "GlennICE Manual 4.1.0." *NASA Glenn Research Center*, NASA-TM-20240002191, https://ntrs.nasa.gov/citations/20240002191

IRT CFD and Wind-Tunnel Characterization

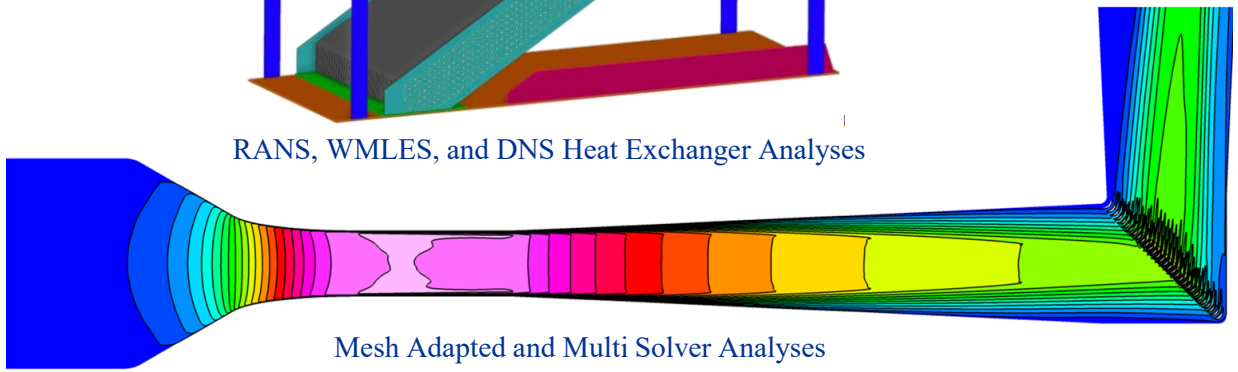
- Establish a tighter coupling between flow characterization work and CFD
- Assisting in test development
  - Model sizing
  - Load verification
  - Interpretation of measured data
- Develop CFD ready geometry based on technical knowledge
- Improve collaboration between computational and experimental SMEs across centers and disciplines
- Experimental testing has been conducted to provide validation data for CFD analyses



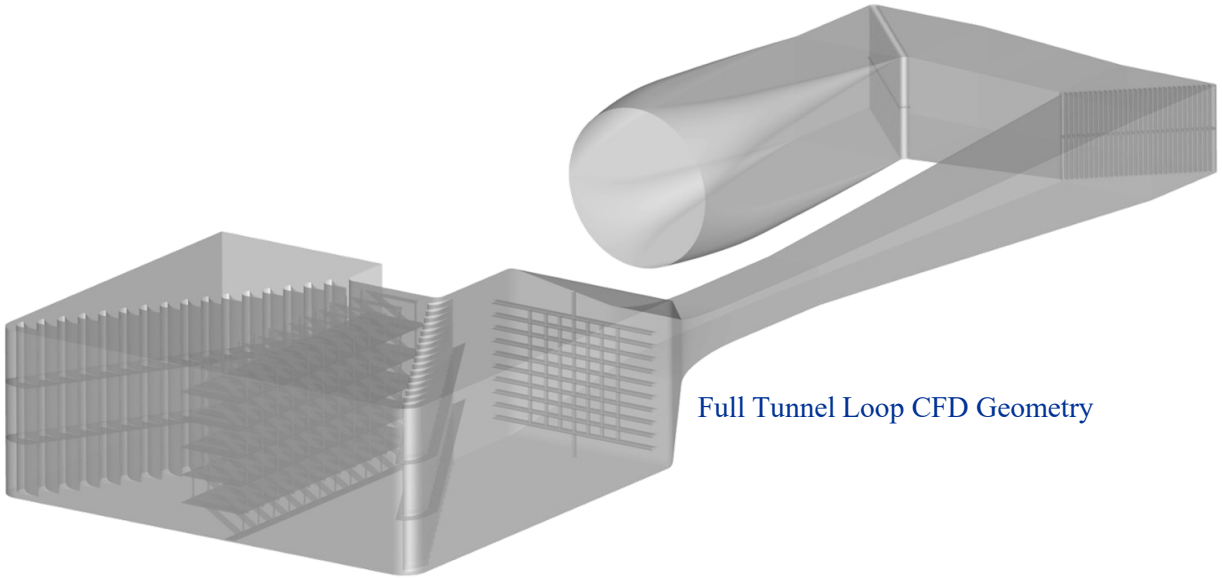
Droplet Trajectory Capabilities with GlennICE



RANS, WMLES, and DNS Heat Exchanger Analyses

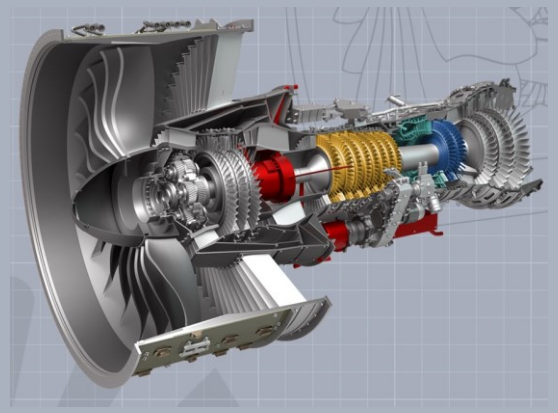


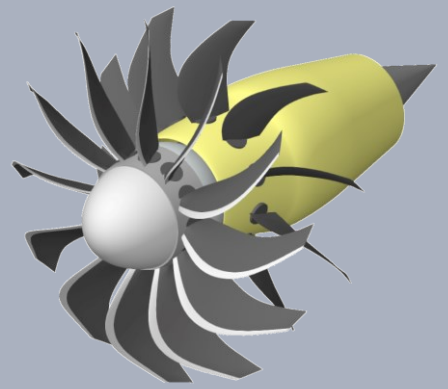
Mesh Adapted and Multi Solver Analyses



Full Tunnel Loop CFD Geometry

Efficient Quiet integrated Propulsor (EQuiP)





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
- Requirements for engine fan icing test rig
  - Actively meeting with industry stakeholders

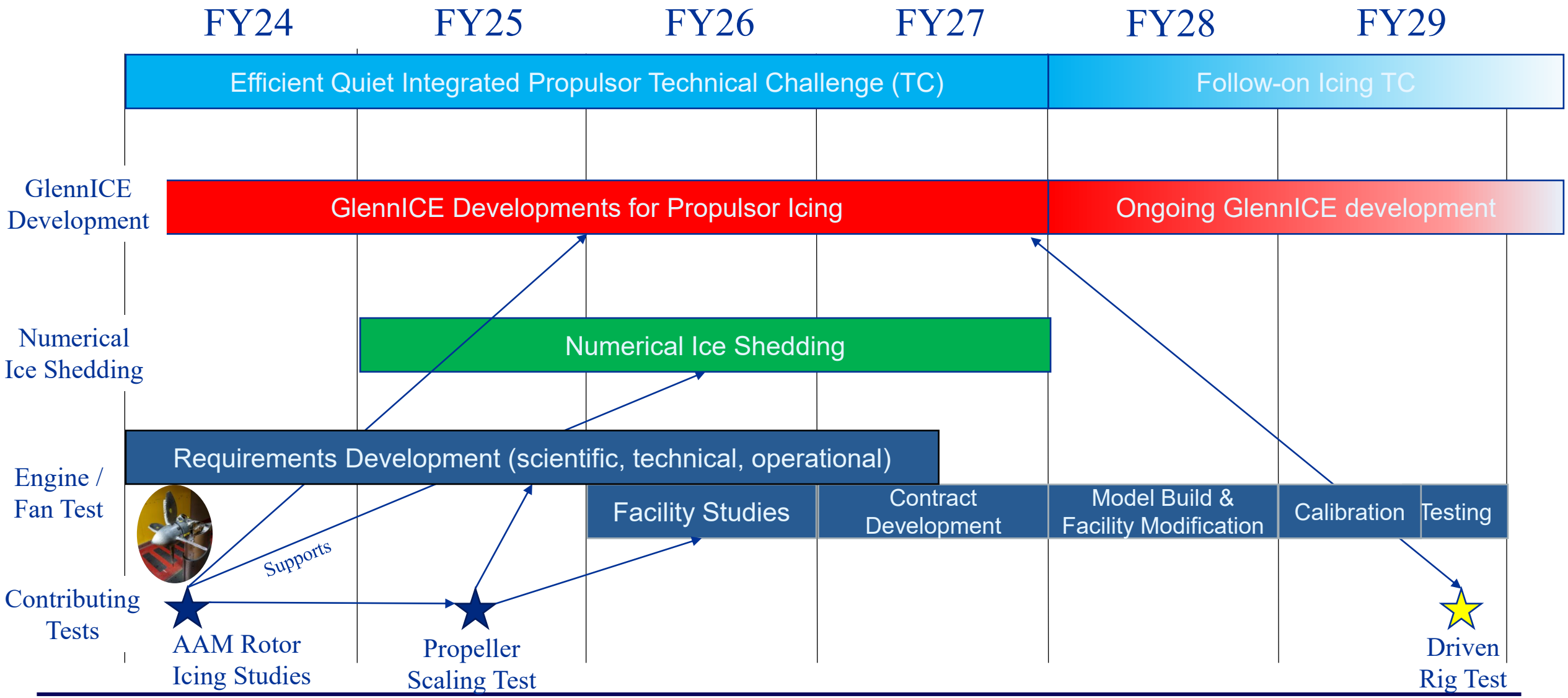
New Tech Challenge (FY24-FY28)

Overall EQuiP Goals

Predict, model, and assess…next-gen propulsors
…while reducing risk* for use on…aircraft in 2030s

* Icing work in EQuiP seeks to reduce risk by raising TRL of engine icing simulation tools

EQUIP Icing Notional Timeline



Propulsor Icing Testing Timeline

EQuIP | Propulsor Icing Tech Challenge (Proposed)

FY24 FY25 FY26 FY27 FY28 FY29 FY30 FY31

ARIES 2

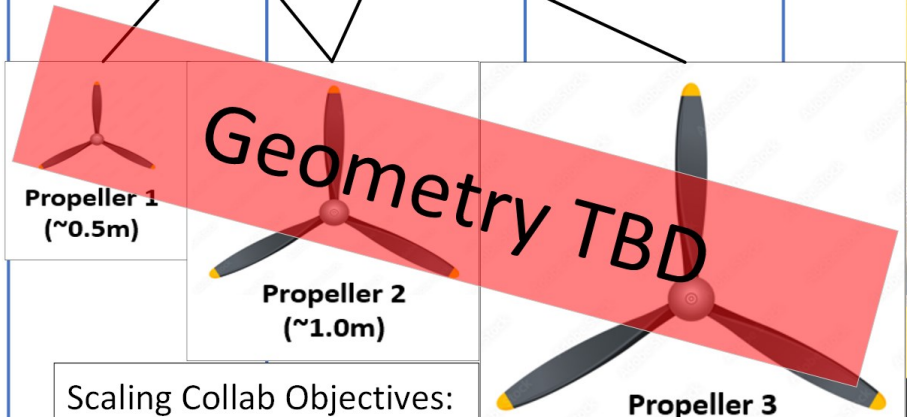
Completed

AAM Rotor Icing Studies
Objectives:
-Conditional scaling
-Glaze ice conditions
-Parametric ice shed sweeps

Rail Tec Arsenal Scaling Collaboration
(Pending Approvals)

IRT Test

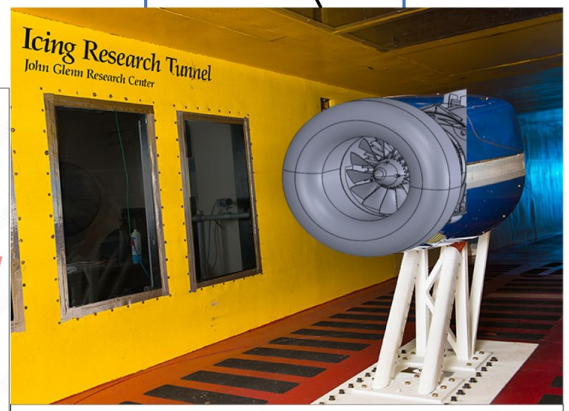
RTA Test



Geometry TBD

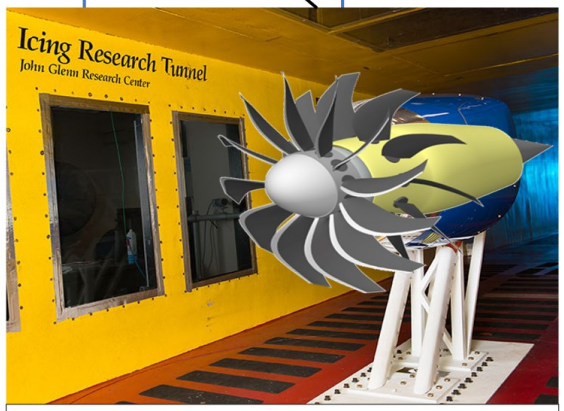
Scaling Collab Objectives:
-Geometric scaling
-Facility comparison

Fan Test



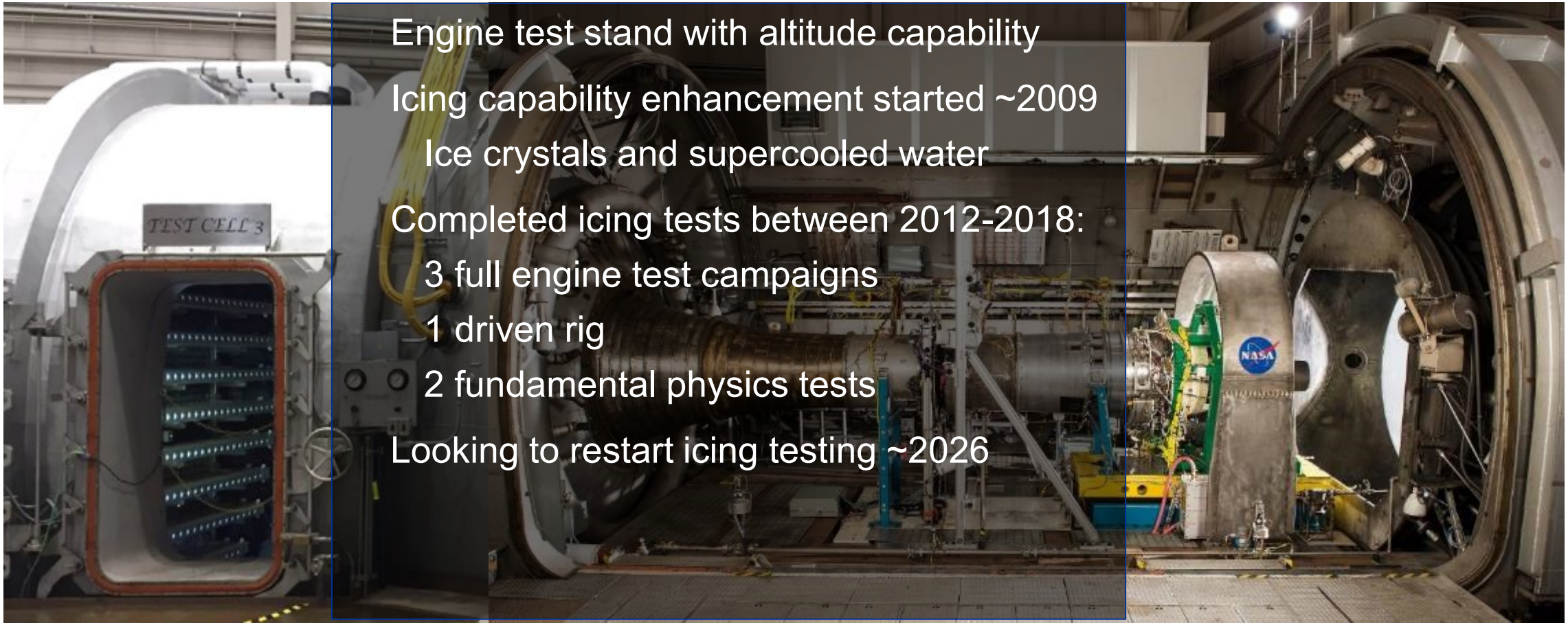
Test Objectives:
-Validation of ice accretion codes on a traditional fan.

Novel Propulsor Test



Test Objectives:
-Validation of propeller scaling techniques
-Validation of icing simulations
-Assessment of icing risks

PSL: Propulsion Systems Lab



Engine test stand with altitude capability

Icing capability enhancement started ~2009

- Ice crystals and supercooled water

Completed icing tests between 2012-2018:

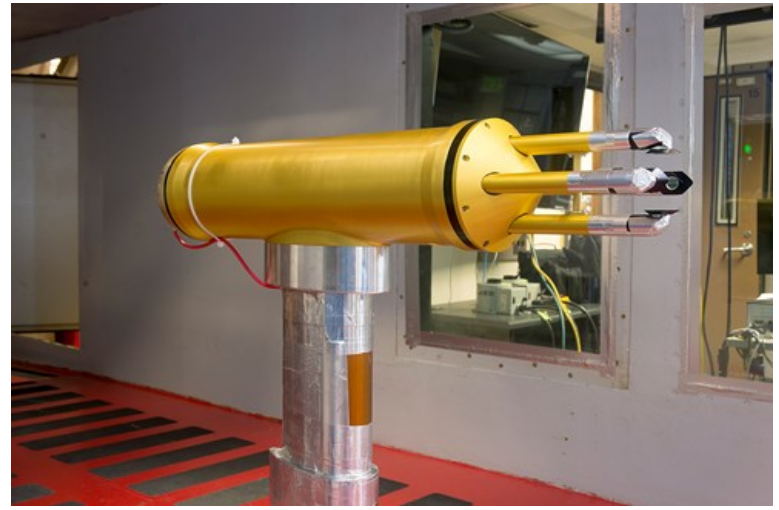
- 3 full engine test campaigns
- 1 driven rig
- 2 fundamental physics tests

Looking to restart icing testing ~2026

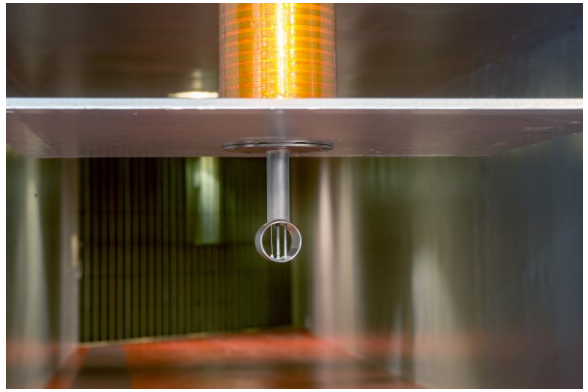
https://www.nasa.gov/directorates/armd/aetc/propulsion-systems-laboratory-psl-facility/

Instrument & Facility Intercomparison in SLD

- Partners:
  - NASA, CIRA, FAA, NRCC, ECCC
  - Began ~2016
- Motivation, better understand SLD:
  - Probes and data processing
    - PSD, Particle Size Distribution
    - LWC, Liquid Water Content
  - Simulation in several facilities:
    - NRCC's Altitude Icing Wind Tunnel
    - NASA's Icing Research Tunnel
    - CIRA's Icing Wind Tunnel
  - Evaluate potential for inter-facility bias from calibration instruments
- Results to date:
  - NRCC & NASA completed testing; CIRA to test in FY25.
  - Improvements to IRT SLD Cal instrumentation being investigated.

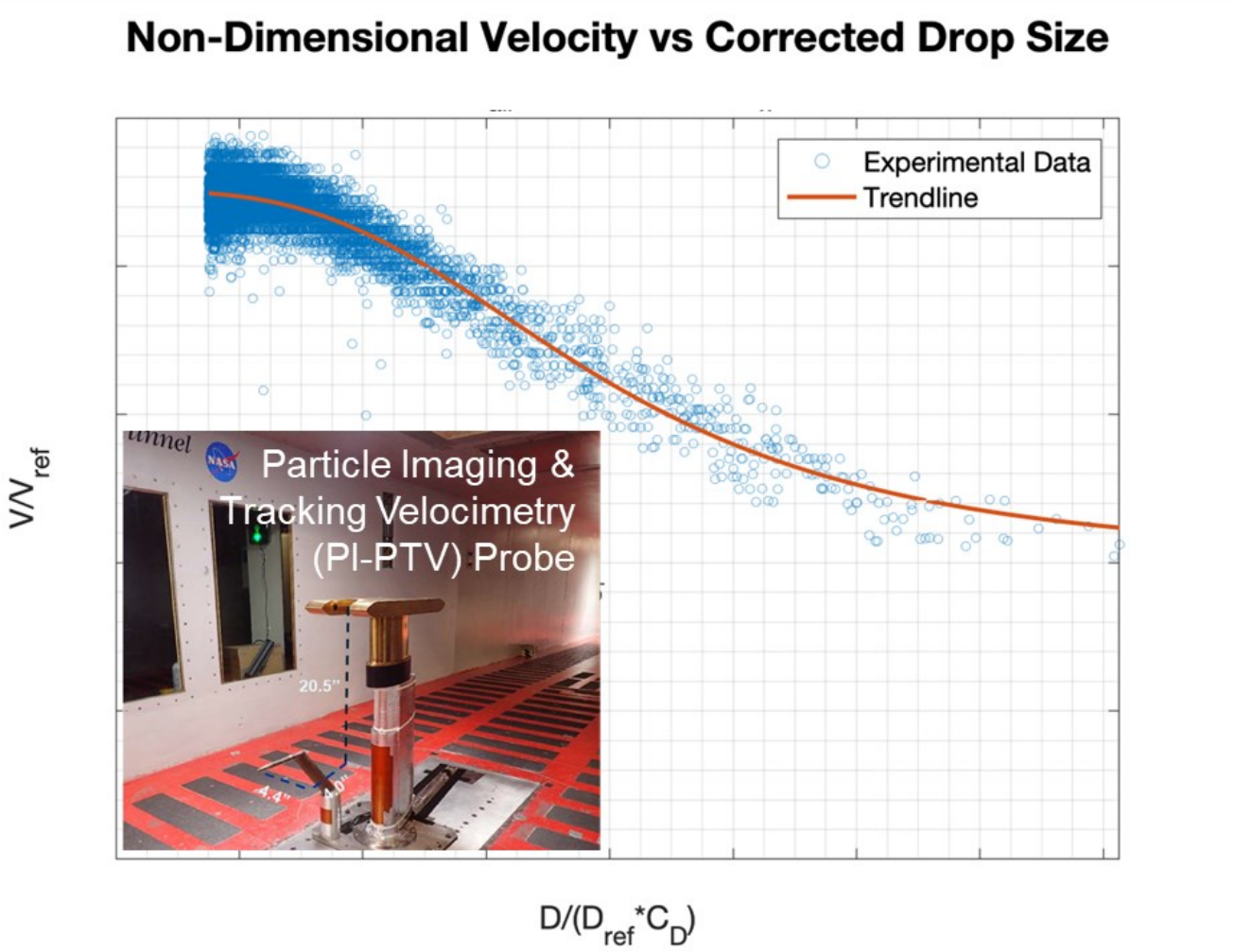


Common Reference Probes tested at each facility: CDP-2, 2D-S and Multi-wire



SLD – IRT Droplet Velocity Characterization

- Experimental measurements of large droplet velocities completed in IRT
- Used Artium PI-PTV Probe
  - Studied probe via CFD to better understand local airflow & particle behavior near probe
- Results
  - Non-dimensional data collapses to a single correlation of velocity (V) vs. diameter (D)
  - Independent of spray bar pressures & tunnel velocity
  - Full paper to appear in 2024 AIAA Aviation Forum



Summary

NASA:

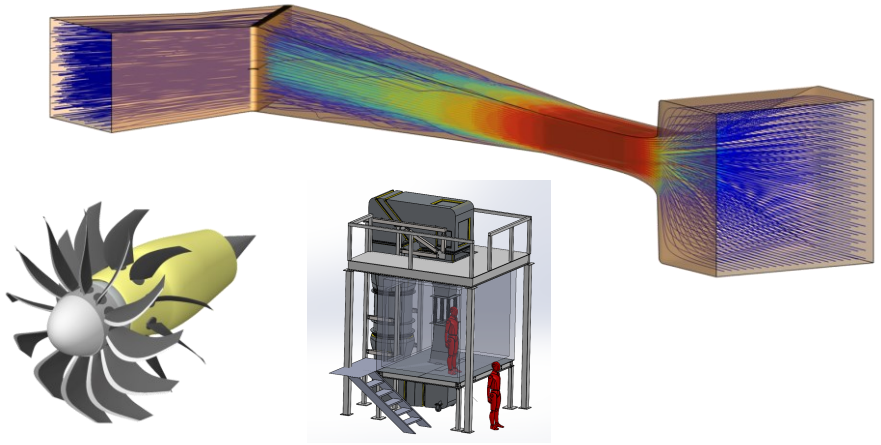
- Maintains world-class icing facilities
- Develops tools and methods for icing simulation

Provided update on some ongoing research

Continually seeking collaboration opportunities

Icing research in this briefing:

- Adaptive Icing Tunnel
- Ice Adhesion / Deformed Skin Adhesion Test
- GlennICE
- IRT CFD Characterization
- Efficient Quiet Integrated Propulsor
- Propulsion Systems Lab
- SLD Research



Thank You!