NASA Icing Overview 2023

2023 SAE International Conference on Icing of Aircraft, Engines, and Structures
June 20 - 22, 2023 | Vienna, Austria

Presenter

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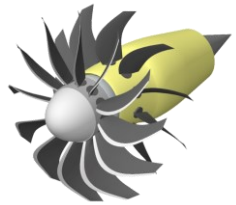
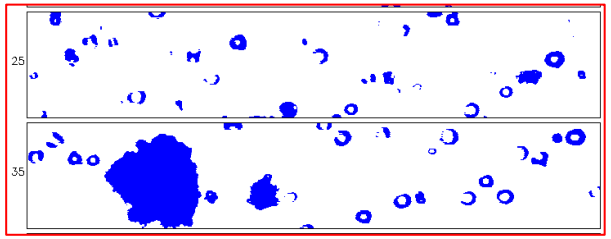
NASA Glenn Research Center
Cleveland, Ohio, USA

Outline

- NASA Aeronautics Overview
- NASA's Icing Mission and Capability Portfolio:
  - Test Facilities, Laboratories, and Computational Tools
  - 2020-21 Analysis of Alternatives Study in Icing
- Icing Research Update
- Collaboration opportunities with NASA – we can't do it alone!





NASA Aeronautics Strategic Thrusts

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations

Safe, Quiet, and Affordable Vertical Lift Air Vehicles

Innovation in Commercial Supersonic Aircraft

In-Time System-Wide Safety Assurance

Ultra-Efficient Subsonic Transports

Assured Autonomy for Aviation Transformation

NASA icing work contributes to these thrust areas

https://www.nasa.gov/aeroresearch/strategy

NASA Aeronautics Programs

Airspace Operations and Safety Program

Advanced Air Vehicles Program

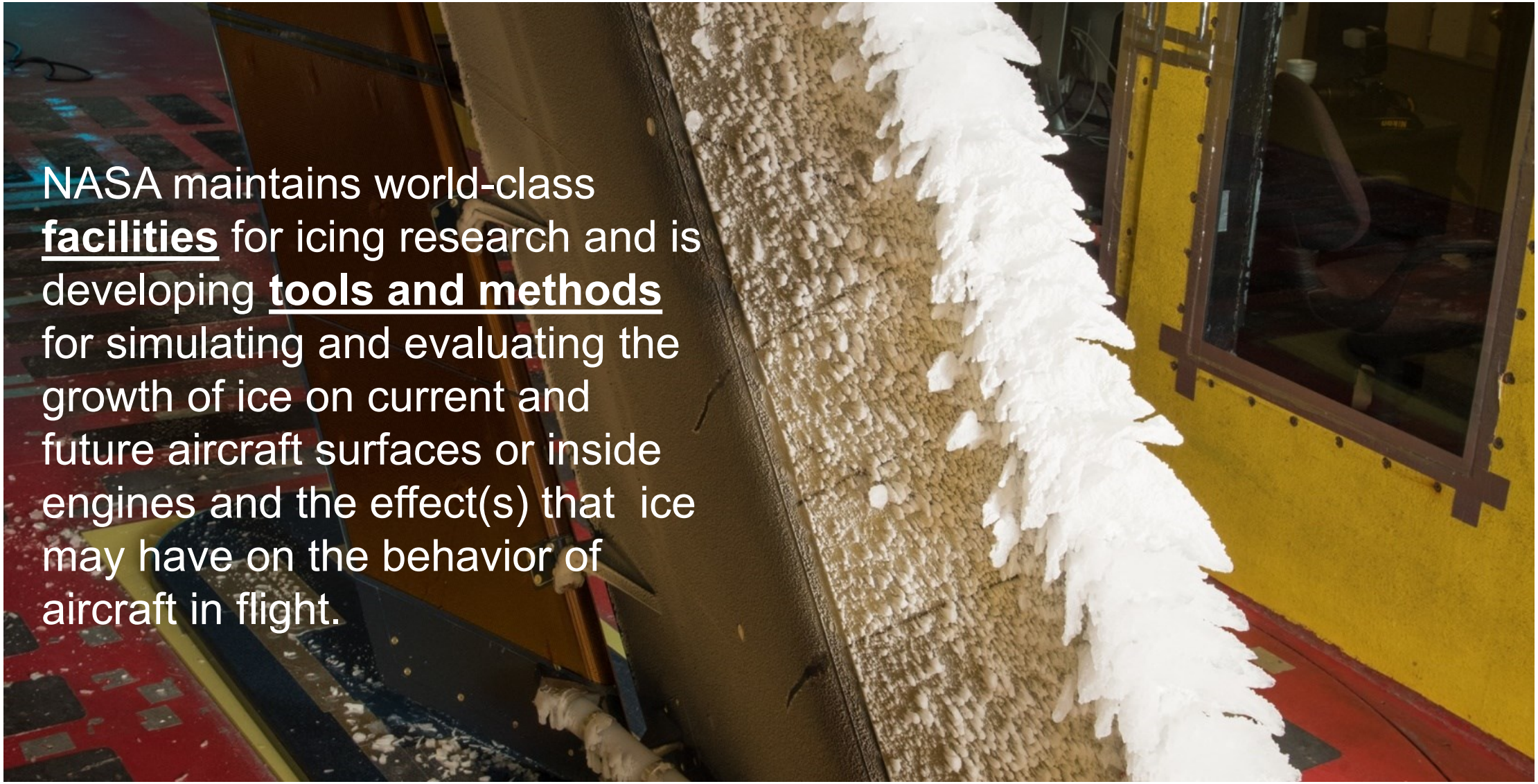
Integrated Aviation Systems Program

Transformative Aeronautics Concepts Program

Aerosciences Evaluation & Test Capabilities Portfolio

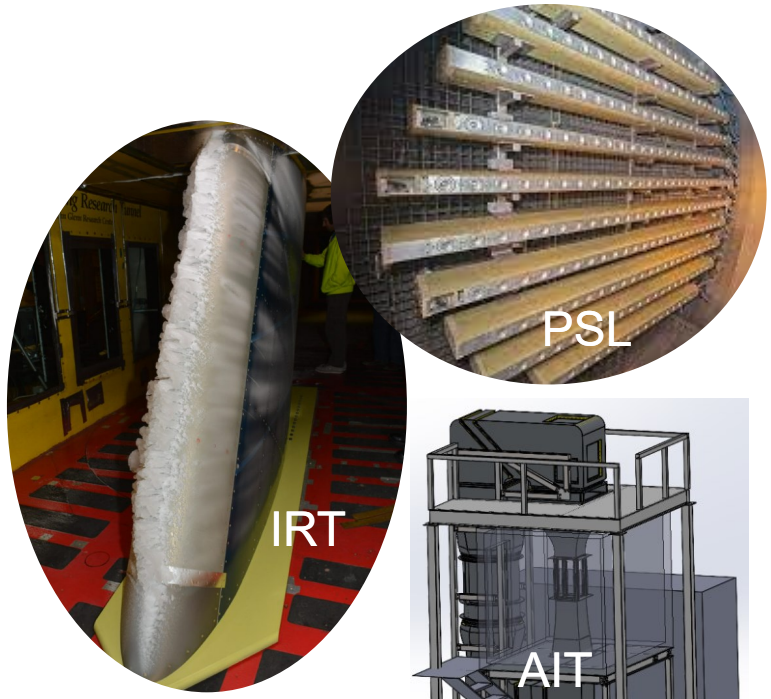
https://www.nasa.gov/aeroresearch/programs

NASA's Mission in Icing



Portfolio of NASA Capabilities in Icing

Facilities



Our Staff

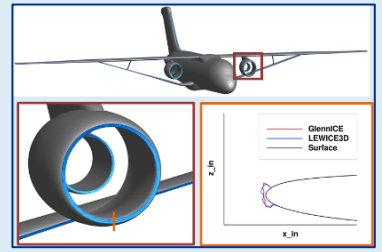
Simulation Tools

Ice accretion codes

LEWICE

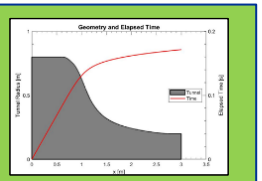
LEWICE 3D

GlennICE



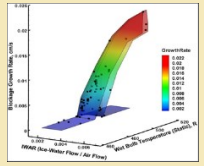
Facility Simulation

TADICE



Engine Icing Risk

COMDES-MELT



Laboratories

Icing Research Tunnel (IRT)

Recirculating Icing Wind Tunnel

6’ x 9’ test section

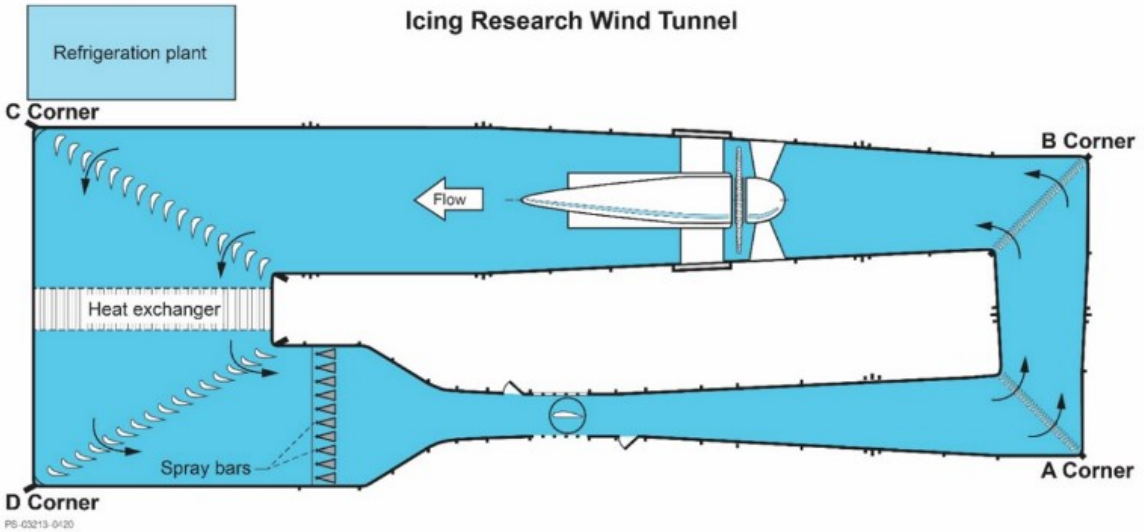
Constructed in 1943

Underwent numerous upgrades in its history

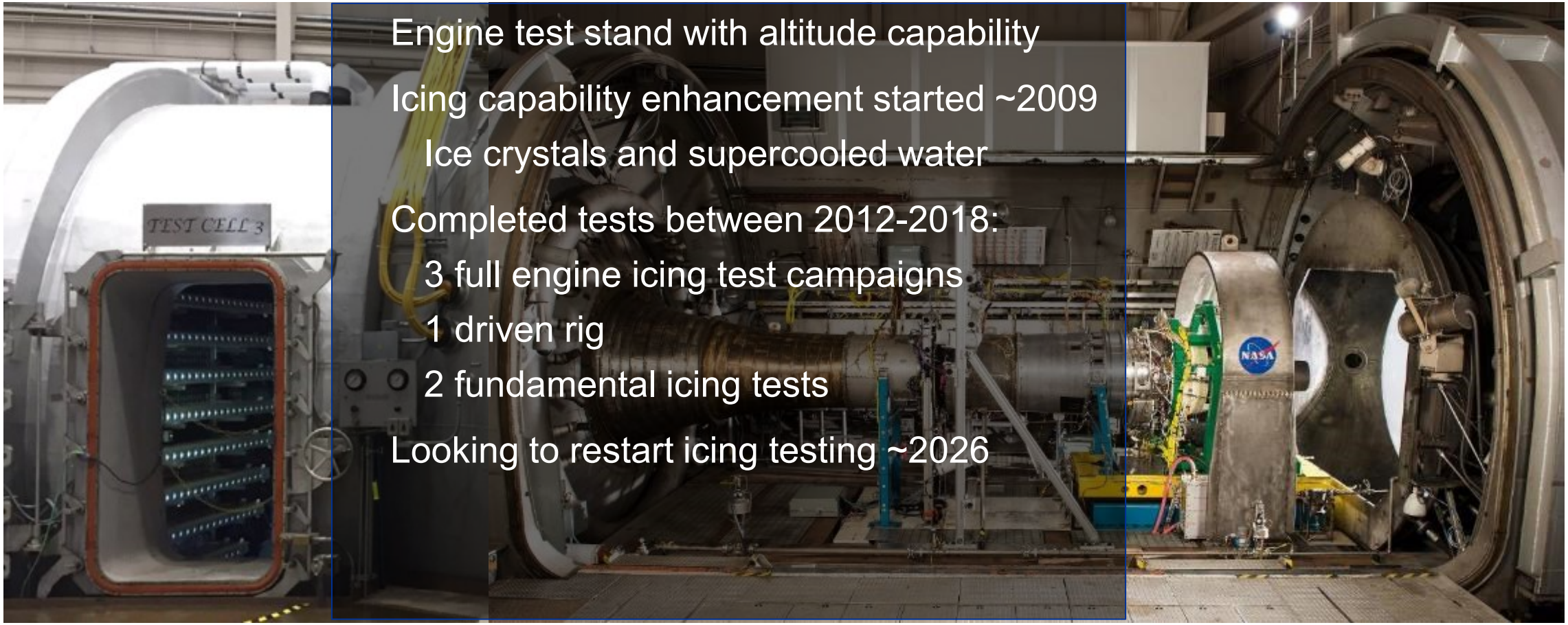
Heavily utilized by NASA, industry, DoD, …

Designed for super cooled water icing

Now some limited ice crystal capability



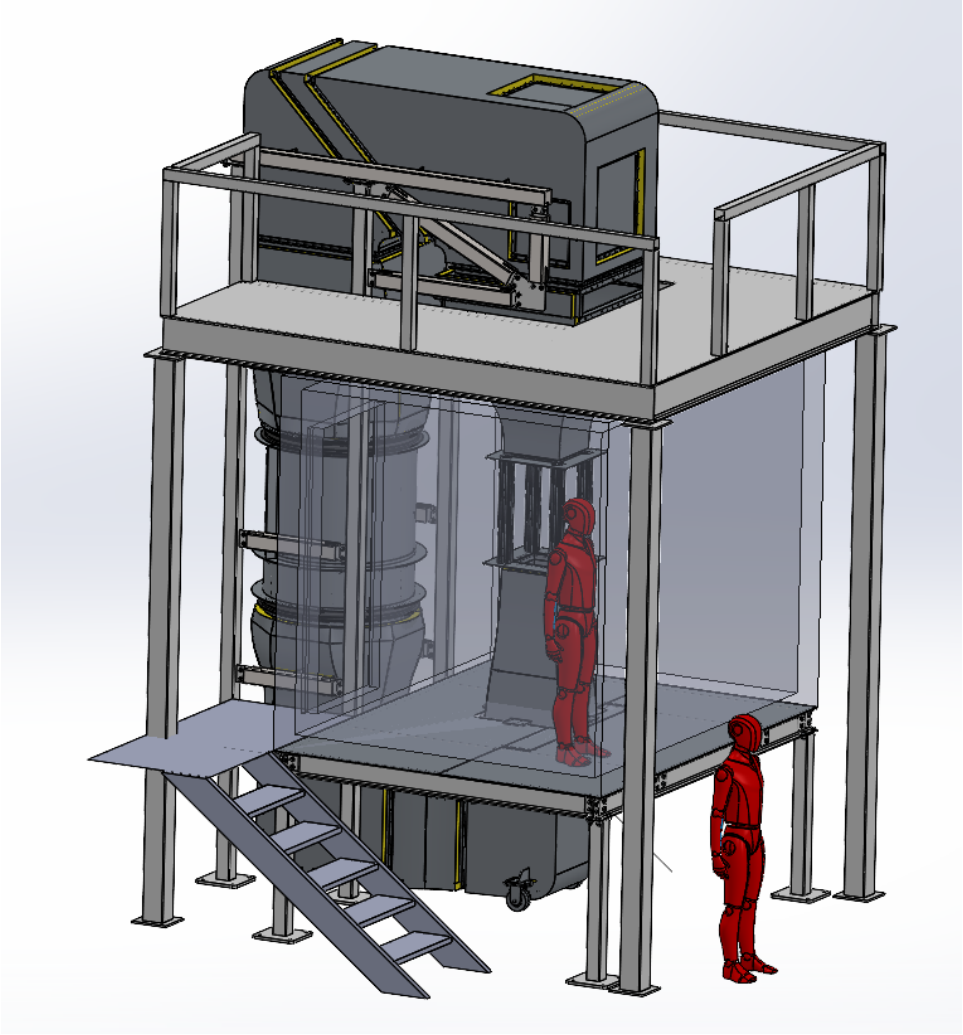
PSL: Propulsion Systems Lab



- Engine test stand with altitude capability
- Icing capability enhancement started ~2009
  - Ice crystals and supercooled water
- Completed tests between 2012-2018:
  - 3 full engine icing test campaigns
  - 1 driven rig
  - 2 fundamental icing tests
- Looking to restart icing testing ~2026

Adaptive Icing Tunnel (AIT)

- Laboratory scale icing wind tunnel
- Closed loop, vertical
- Test section 1’ x 1’ (0.3 m 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
- Installation underway, followed by tunnel characterization

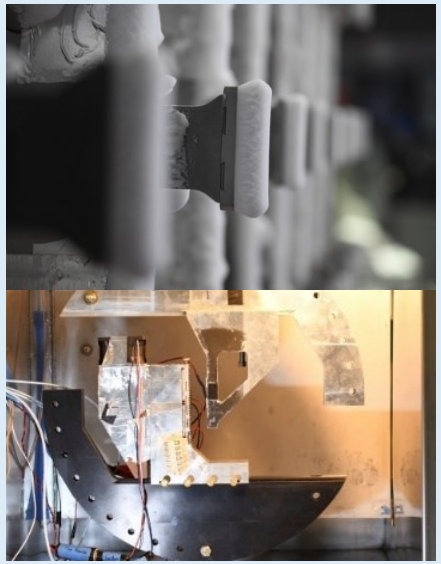


Material's Laboratories

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)

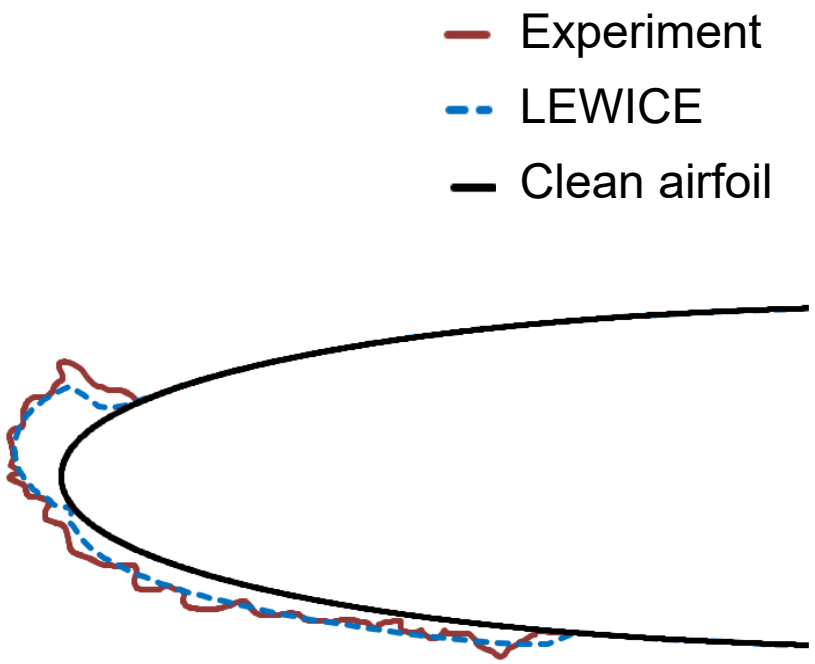
- Evaluate surface coatings
- Simulate contamination conditions
- Assess mitigation strategies

Adverse Environment Rotor Test Stand (AERTS) Jr.

NASA Icing Tools

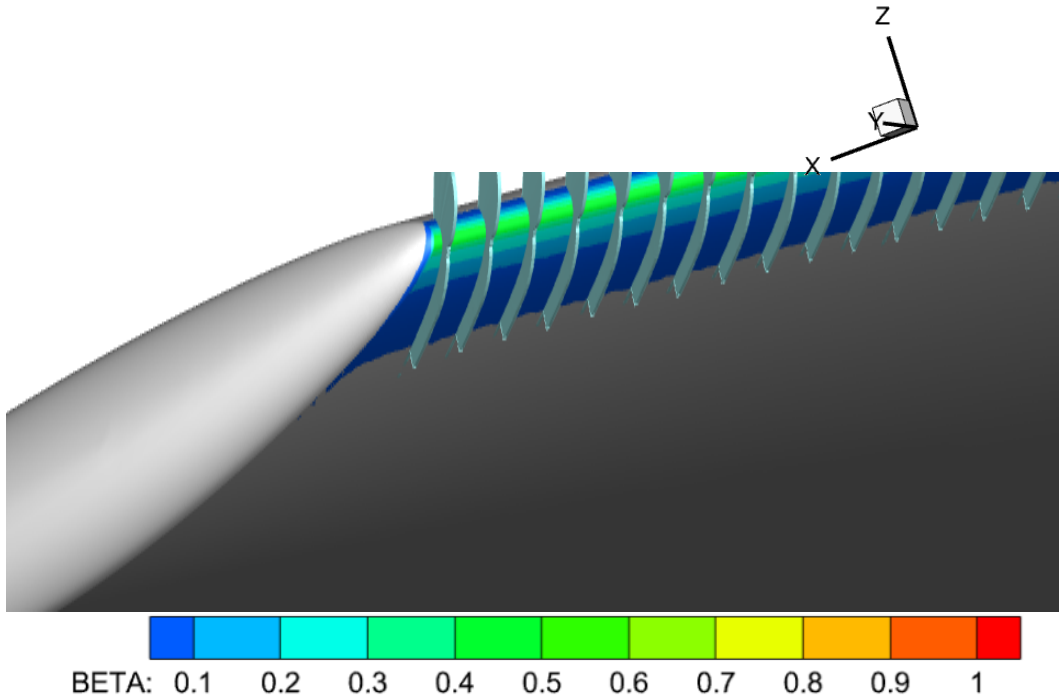
LEWICE (1980s – 2006)

Simulates 2D ice accretion using super-cooled droplets impinging on a body.



LEWICE3D (1993 – 2015)

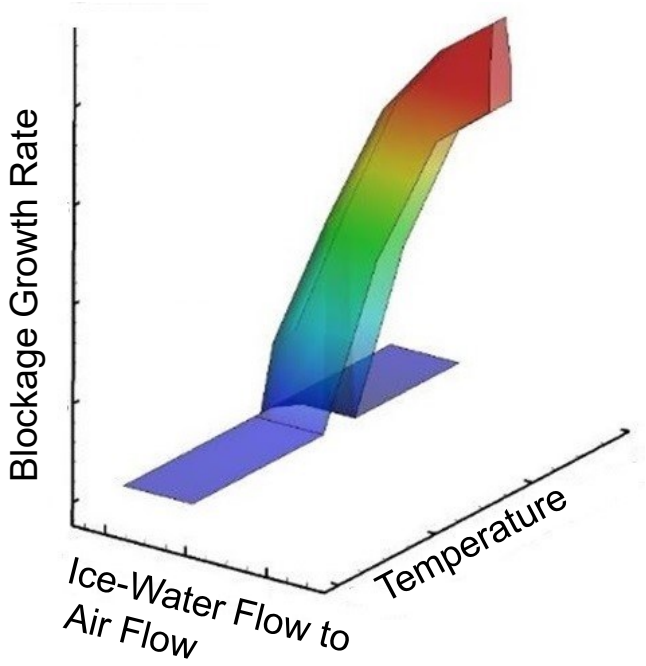
Simulates ice accretion in quasi-3D on user-specified cut planes using full 3D droplet trajectories.



NASA Icing Tools

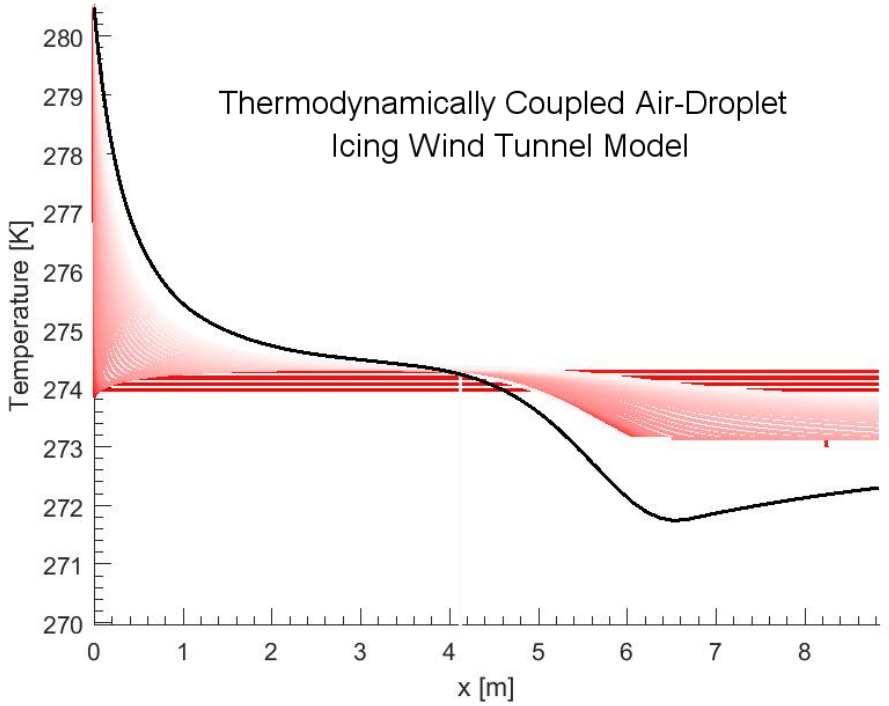
COMDES-MELT

Mean-line compressor analysis code coupled with an ice crystal thermodynamic state code, which is used as a turbofan engine icing risk analysis tool



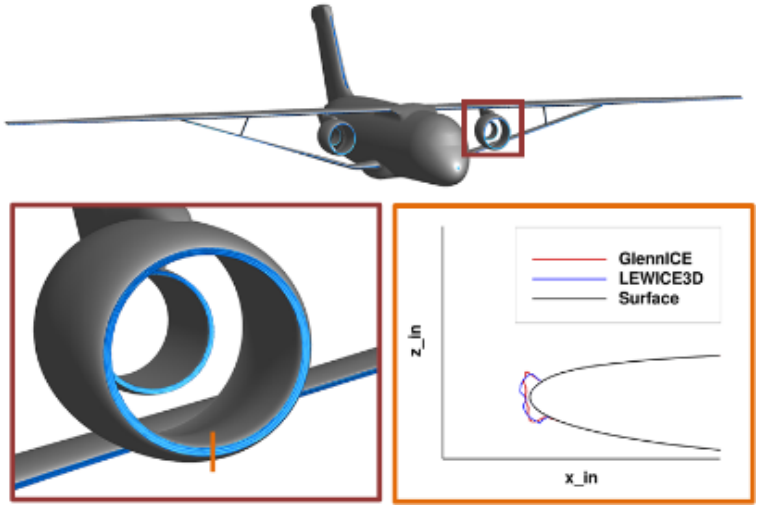
TADICE

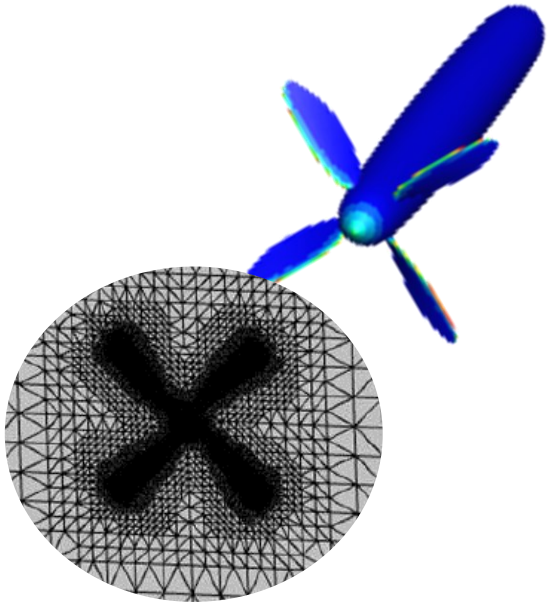
Icing wind tunnel simulation tool (1D) that models the thermodynamic interactions between the water/ice particles of an icing cloud as it flows down the tunnel.



NASA Icing Tools - GlennICE

- Fully 3D icing simulation tool
- CFD post processor
- Predicts water impingement & resulting ice growth on aircraft surfaces
- Lagrangian droplet tracking with adaptive refinement





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

GlennICE

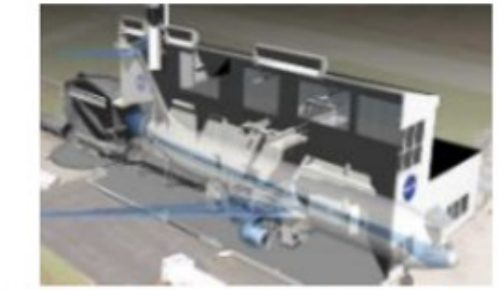
External Icing

Rotational Icing

Engine Icing

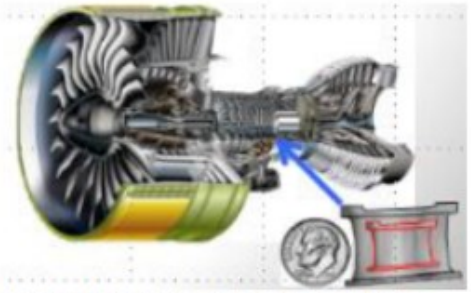
Analysis of Alternatives Study (AoA) for Icing

- In 2020-2021, study identified:
  - Priority needs for NASA Aeronautics
  - Enduring needs for aviation community



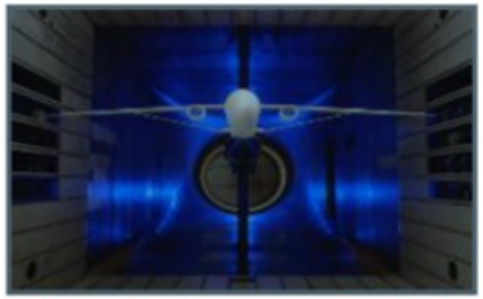
Electrified Aircraft Propulsion

synergistic



Small Core Gas Turbine

- Motivation:
  - NASA Aeronautics shifting focus
    - Advance key subsonic areas “Fab 4”
  - Recognition of potential enduring needs for the aviation community



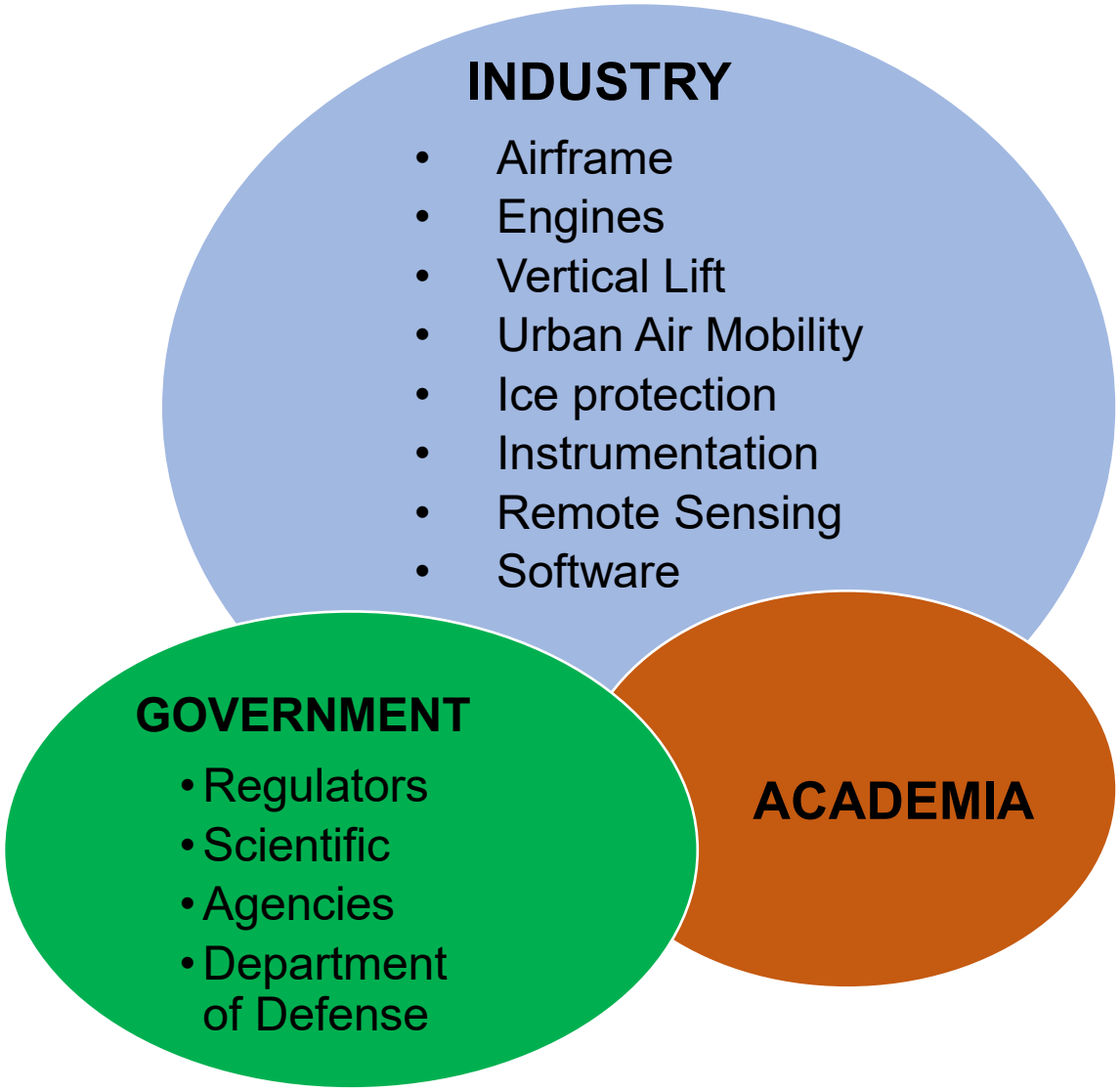
Transonic Truss-Braced Wing

synergistic

High Rate Composites

Analysis of Alternatives Study (AoA) for Icing

- Conducted 47 interviews from icing stakeholder community
- Re-baseline understanding of current community challenges & opportunities
- Maximize applicability and impact of future NASA research

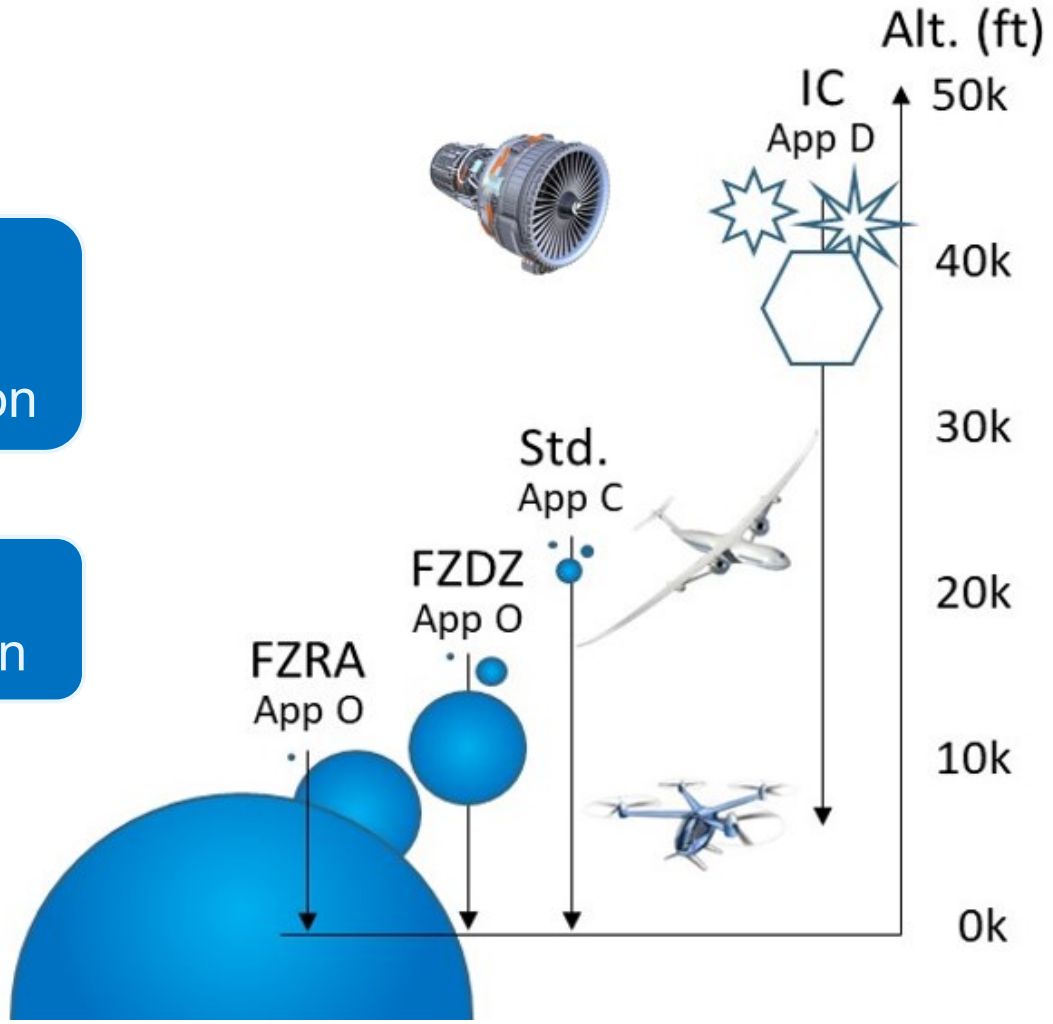


Common Themes Heard from Interviews

Primary Challenge

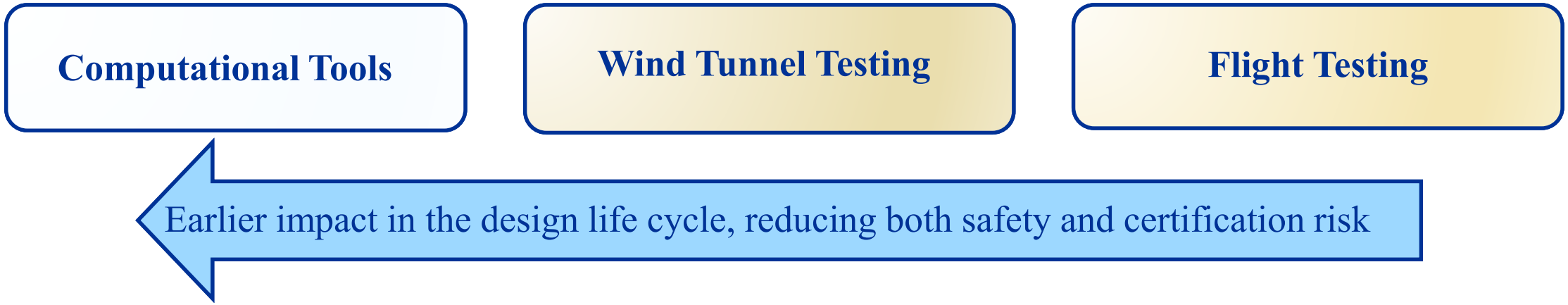
Newer icing regulations (App. C, D and O) will have large impacts on new airframes and propulsion systems design, cost, and certification

Cannot rely completely on similarity (e.g. comparative analysis) for design and certification



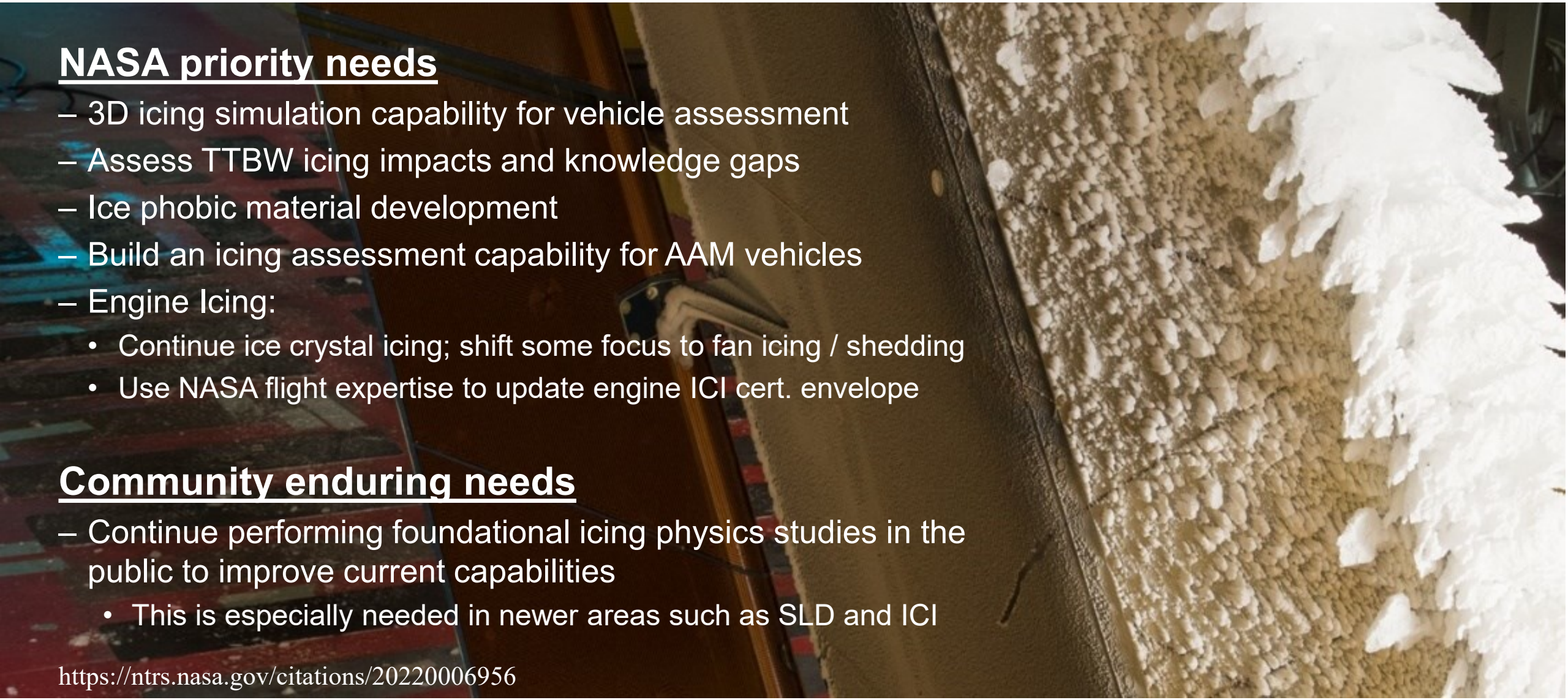
Community Needs

- Reduce amount of icing flight testing
- Include icing in Certification by Analysis



- Publicly available data to validate tools
- Continued need for IRT and PSL
- New technologies like icephobics, low power and weight IPS
- Ice shedding concern from nacelles, spinners, and fan blades

Icing Analysis of Alternatives Outcomes



NASA priority needs

- 3D icing simulation capability for vehicle assessment
- Assess TTBW icing impacts and knowledge gaps
- Ice phobic material development
- Build an icing assessment capability for AAM vehicles
- Engine Icing:
  - Continue ice crystal icing; shift some focus to fan icing / shedding
  - Use NASA flight expertise to update engine ICI cert. envelope

Community enduring needs

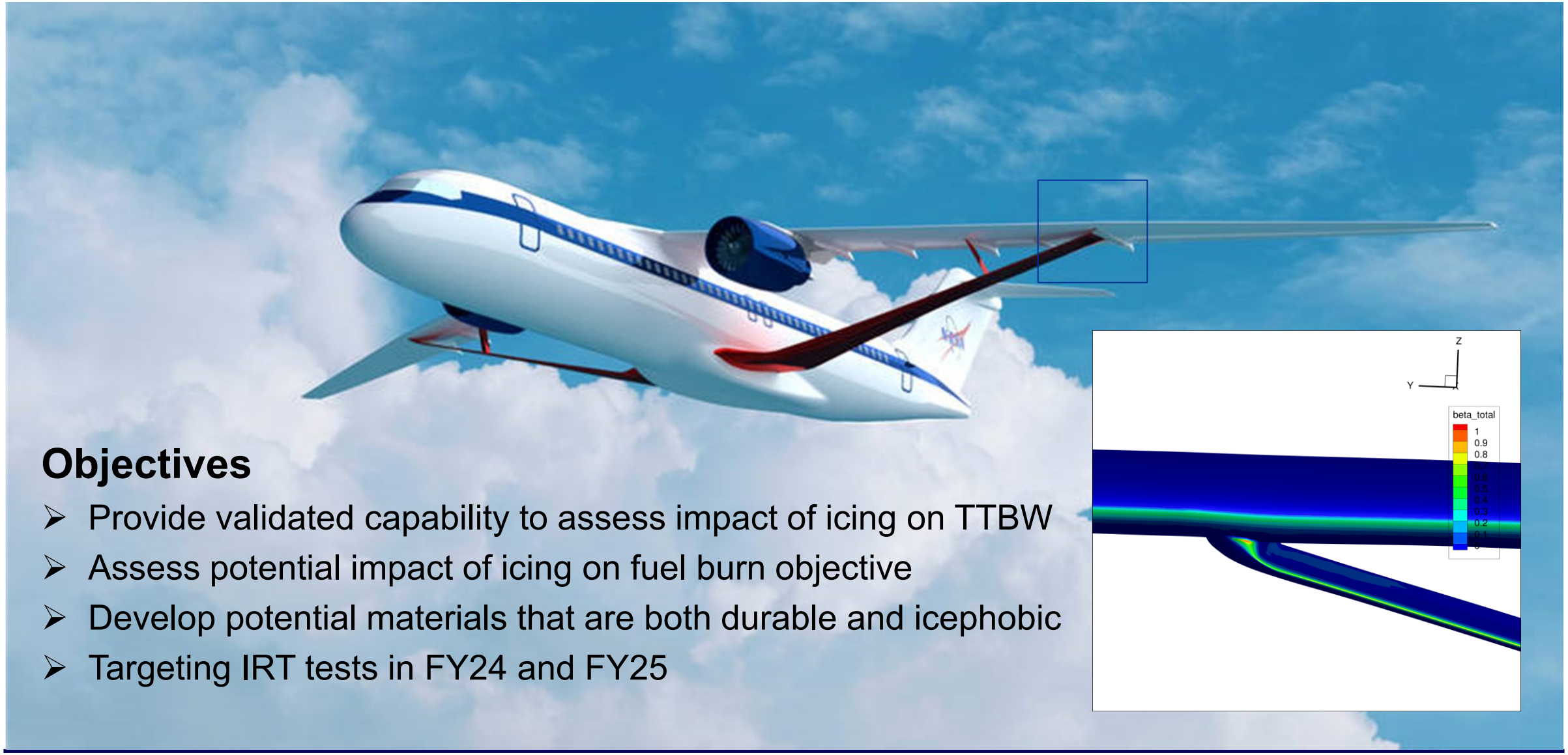
- Continue performing foundational icing physics studies in the public to improve current capabilities
  - This is especially needed in newer areas such as SLD and ICI

https://ntrs.nasa.gov/citations/20220006956

Research Update

1. Transonic Truss Brace Wing
2. High Lift Common Research Model
3. Advanced Air Mobility Icing
4. Characterization of Low Ice Adhesion Materials
5. High Ice Water Content (HIWC) Flight Research
6. Simulated Inter-compressor Duct Research Model (SIDRM)
7. Efficient Quiet Integrated Propulsor (EQUIP)

Transonic Truss Braced Wing Icing



Objectives

- Provide validated capability to assess impact of icing on TTBW
- Assess potential impact of icing on fuel burn objective
- Develop potential materials that are both durable and icephobic
- Targeting IRT tests in FY24 and FY25

High Lift Common Research Model - Icing

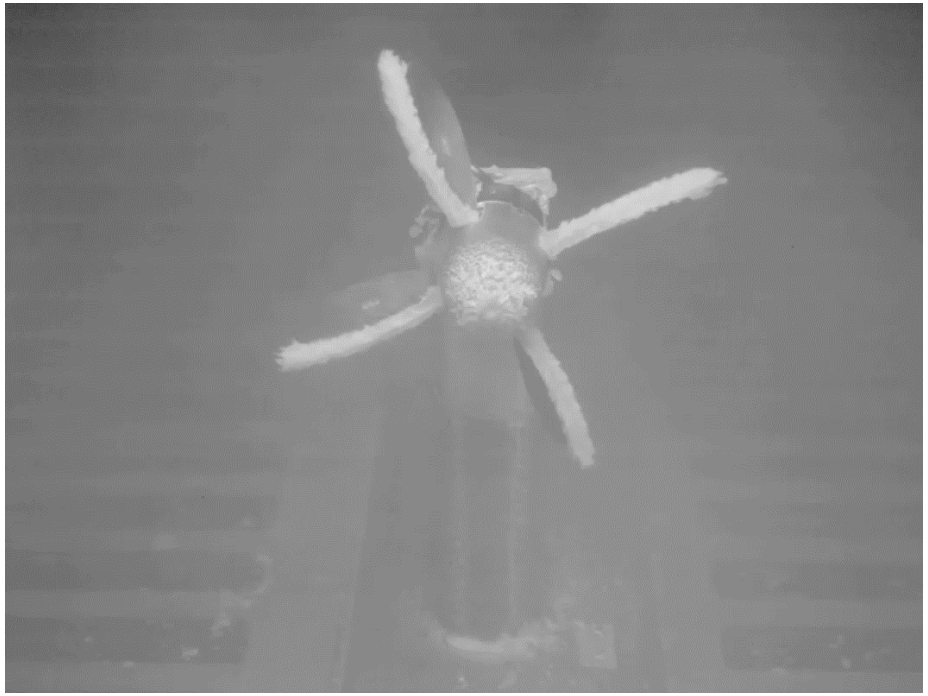
Objectives

- Benchmark computational tools to predict aerodynamic degradation due to icing
  - Generated ice shapes using LEWICE 3D
- Preparing for aerodynamic testing at the NASA National Transonic Facility in FY24

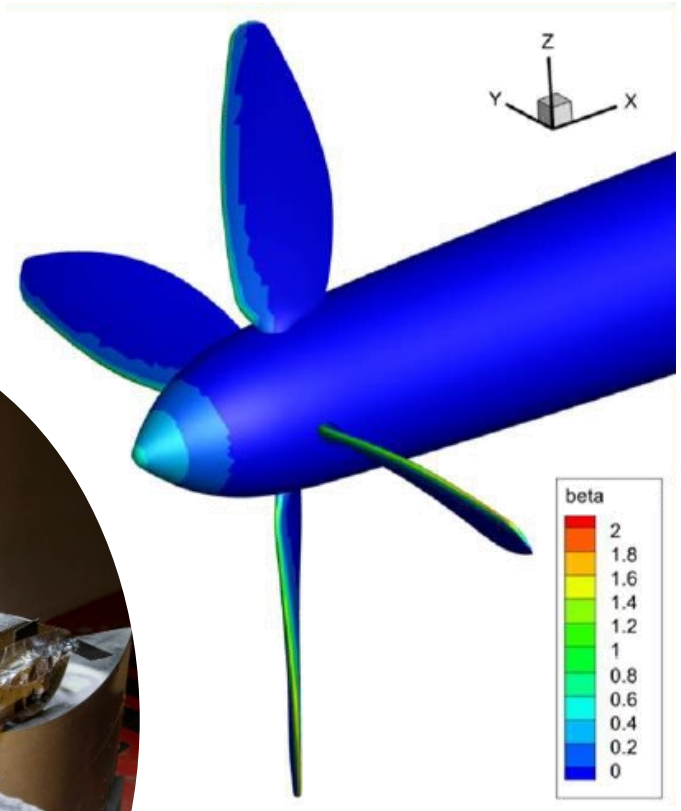
Advanced Air Mobility (AAM) Icing

Objectives

- Build an icing assessment capability for AAM vehicles
- Add rotational reference frame icing to GlennICE
- Initial IRT tests occurred March 2023
  - Next tests December 2023



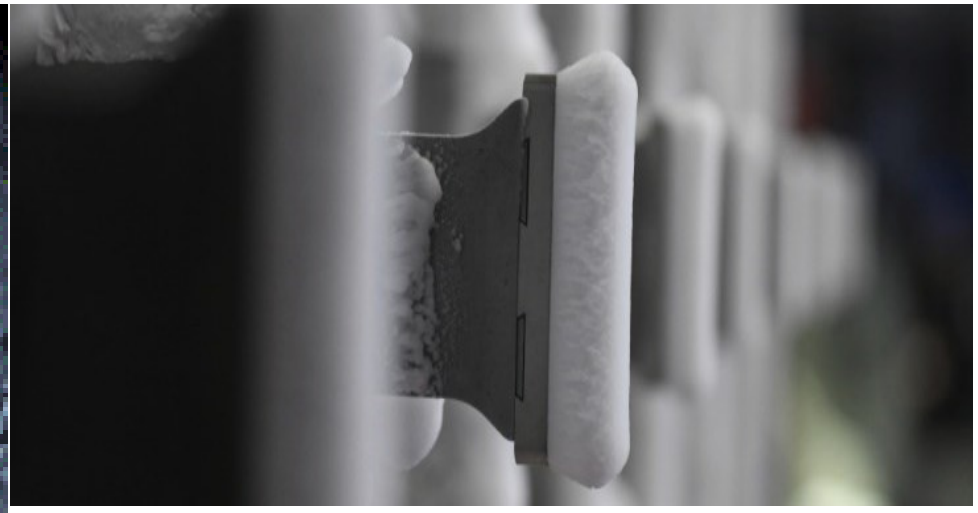
Video



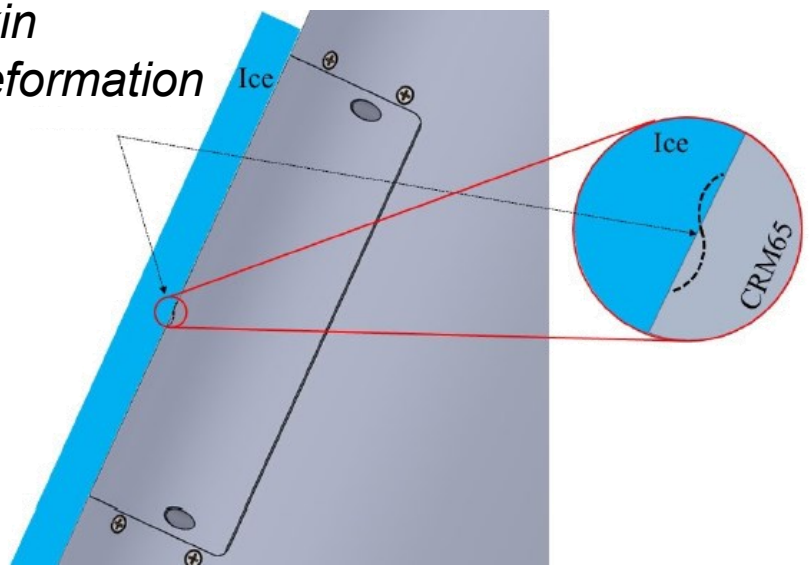
Characterization of Low Ice Adhesion Materials

Objectives

- Develop a better understanding of the adhesive properties of impact ice
  - Grain structure, residual stresses, …
- Examining various measurements of the adhesive strength of ice such as modified lap joint and centrifugal methods
  - Includes new Deformed Skin Adhesion Test (DSAT), with IRT test in Mar. 2023
- Evaluating icephobic coatings
- Overall, conducted 5 IRT tests since 2018 in this area



Skin Deformation



High Ice Water Content Flight Research

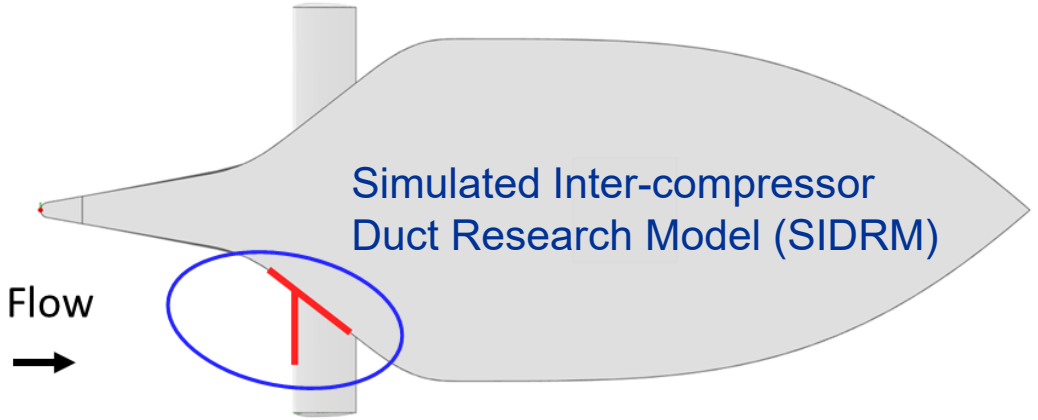
Objectives

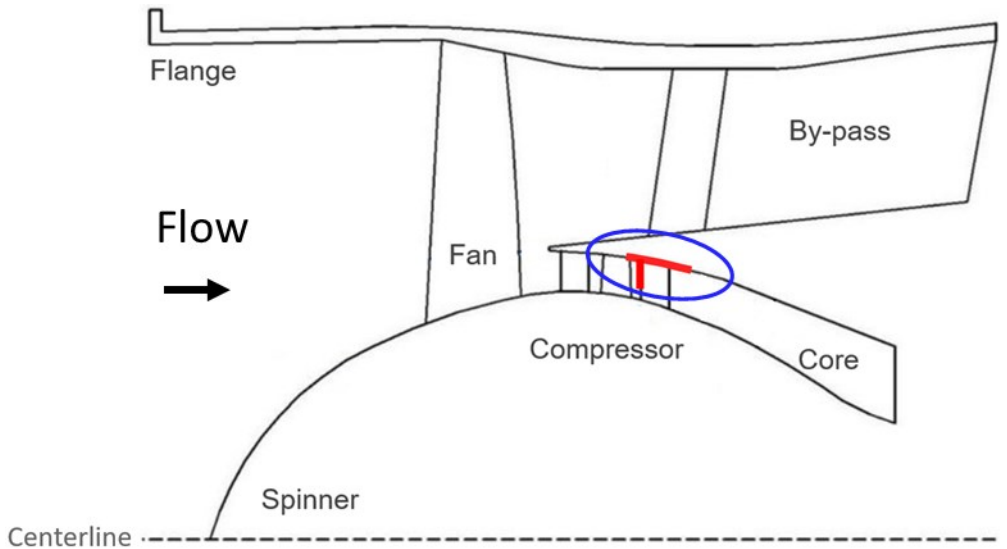
- Characterize ice crystal cloud properties
  - Participated in 5 campaigns; 3 with NASA DC-8
  - Most recently in 2022 in high-aerosols
- Determine globally representative and data-driven engine certification envelope limits

Engine Ice Accretion Testing – SIDRM

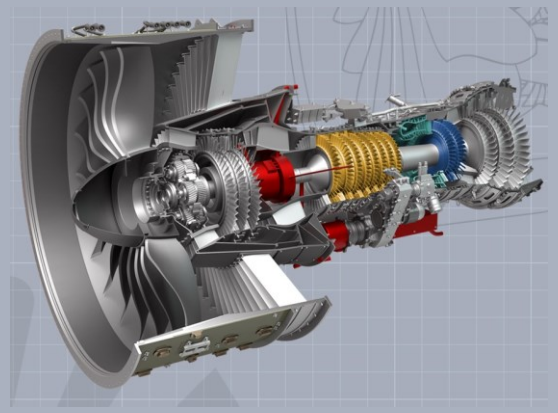
Objectives

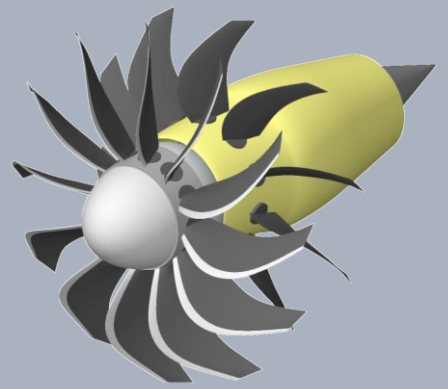
- Gather data to develop & validate computational icing tools for ice crystal (IC) icing
- Developed SIDRM Model
  - Simulates inner compressor duct & strut region
  - IC accretion using a heated surface
- Characterized IC cloud at IRT
- Conducted IRT tests in 2022 and 2023
- Also conducted supercooled water tests





Efficient Quiet integrated Propulsor (EQuiP)





New Tech Challenge (FY24-FY28)

Overall EQuiP Goals

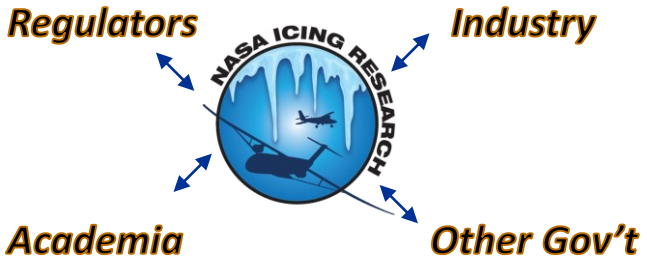
Predict, model, and assess…next-gen propulsors
…while reducing risk* for use on…aircraft in 2030s

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

Icing Work Areas:

- Fan Icing
  - 3D rotational icing simulation
  - Ice shedding simulation
  - Requirements for engine fan icing test rig
- Ice Crystal Icing (ICI)
  - Simulation tools / SIDRM analysis
  - IC capability development for IRT / AIT
- Model Based System Analysis & Engineering Tools

NASA Collaborations in Icing



NASA Partnerships

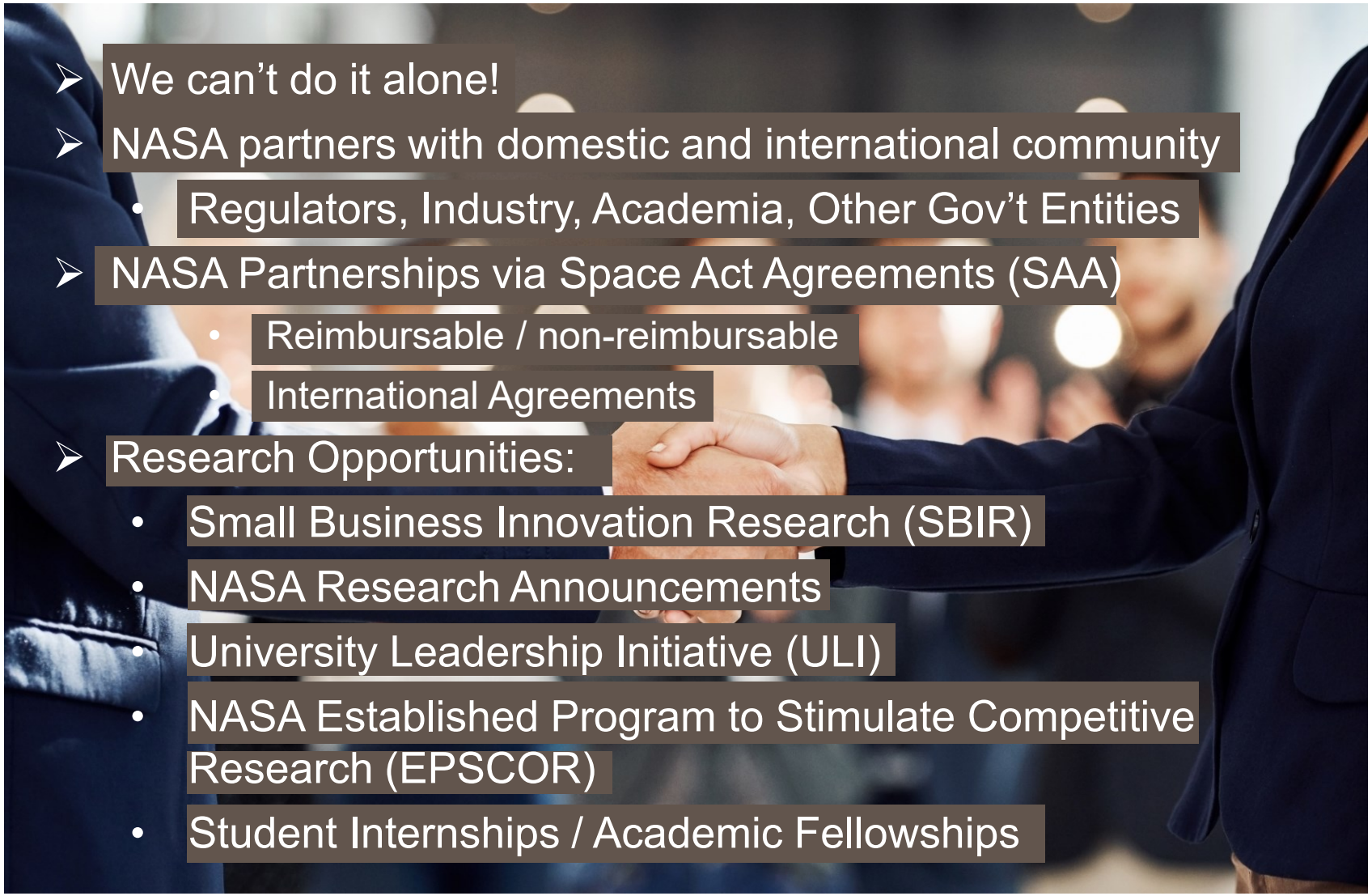
SBIR · STTR

NASA | NSPIRES

NASA EPSCoR

ULI UNIVERSITY LEADERSHIP INITIATIVE

NPP NASA Postdoctoral Program



- We can't do it alone!
- NASA partners with domestic and international community
  - Regulators, Industry, Academia, Other Gov't Entities
- NASA Partnerships via Space Act Agreements (SAA)
  - Reimbursable / non-reimbursable
  - International Agreements
- Research Opportunities:
  - Small Business Innovation Research (SBIR)
  - NASA Research Announcements
  - University Leadership Initiative (ULI)
  - NASA Established Program to Stimulate Competitive Research (EPSCOR)
  - Student Internships / Academic Fellowships

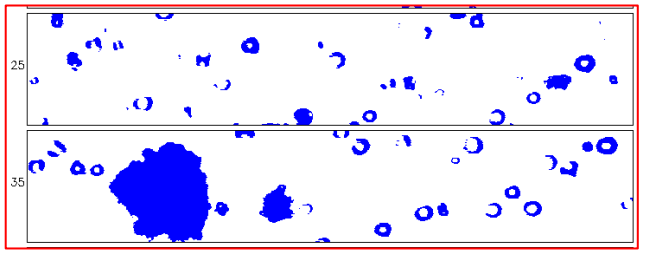
Summary

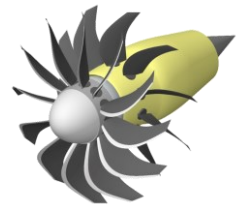
NASA:

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

Conducting research activities guided by recent study

Continually seeking collaboration opportunities





Icing Research Topics

1. Transonic Truss Brace Wing
2. High Lift Common Research Model
3. Advanced Air Mobility
4. Low Ice Adhesion Methods & Materials
5. HIWC Flight Research
6. Ice Crystal Icing - SIDRM
7. Efficient Quiet Integrated Propulsor

Thank You!