NASA Capabilities in Aircraft Icing

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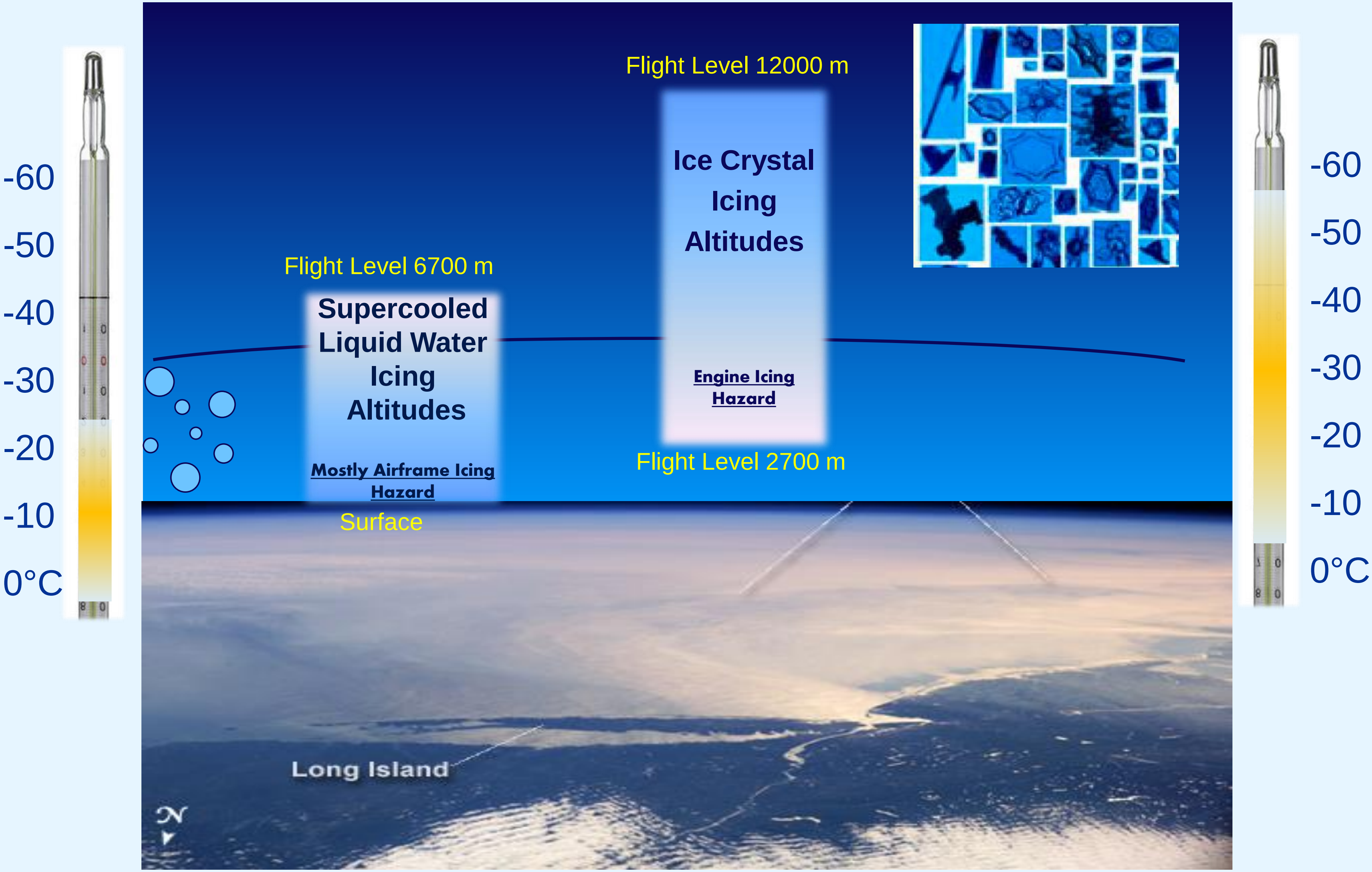
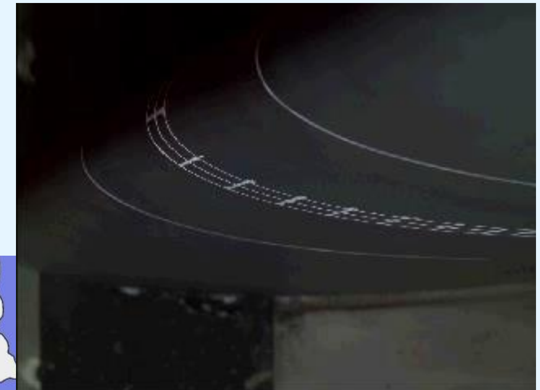
Icing Conditions Impacting Aviation Safety

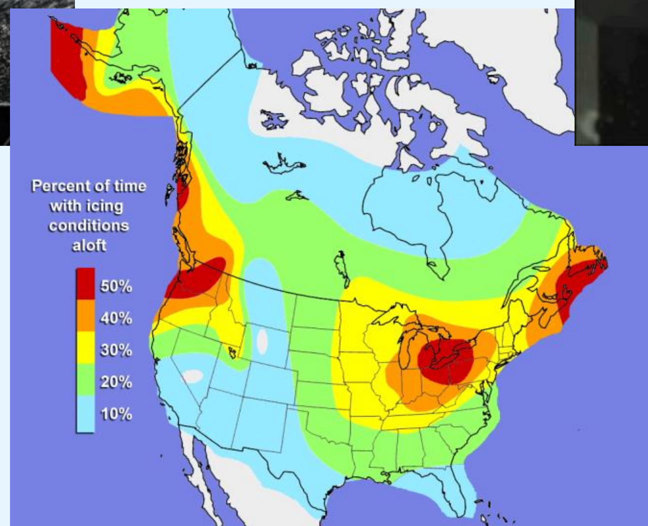


Airframe Icing- Supercooled Liquid Droplets

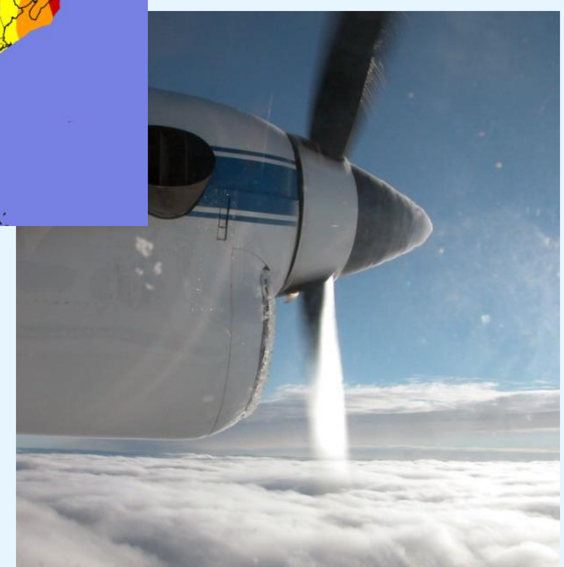
Airframe Icing on NASA DHC-6 “Twin Otter Aircraft”



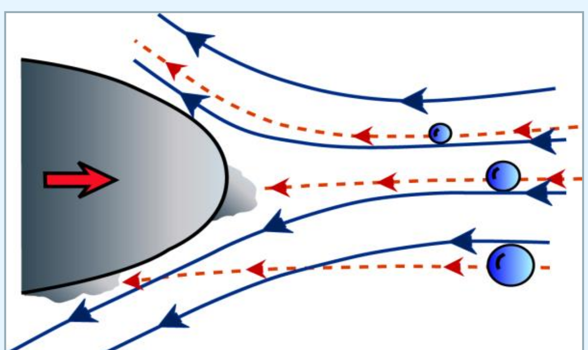
Ice Accretion Test in the NASA Icing Research Tunnel



Icing Potential during Winter Months, Nov – March (National Center for Atmospheric Research)



Nacelle and Spinner Icing on NASA DHC-6 “Twin Otter” Aircraft

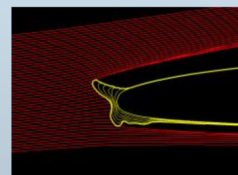


Drop Sizes Impact Ice Accretion Physics

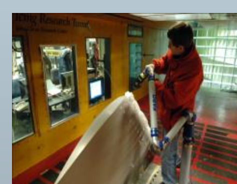
Airframe Icing Research Capabilities

Ice Accretion Physics

Computational Tools



Experimental Methods



Engineering Solutions

Airframe Icing Accretion and Aero Performance Tools

- *Advanced aircraft safety assessments*
- *Safe design for commercial aircraft*

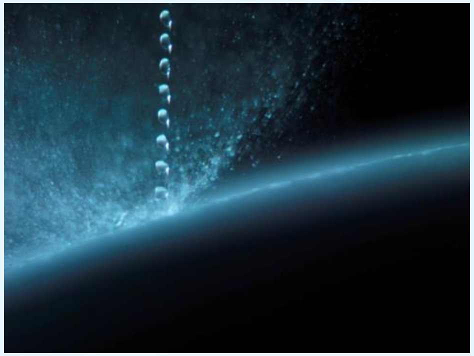
Airframe Icing Test Methodologies

- *Standard Icing Conditions*
- *Supercooled Large Droplet Conditions*

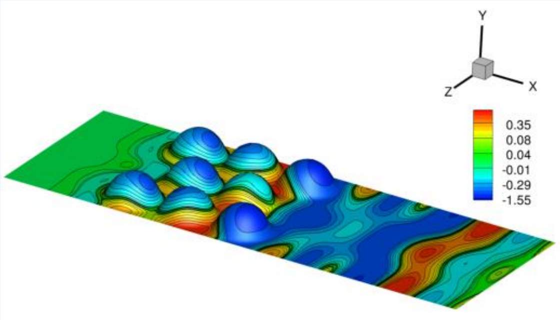
Airframe Ice Accretion Physics

- Foundational ice accretion physics research is performed in the following areas
  - Droplet Splashing
  - Droplet Rollback
  - Surface Roughness and Heat Transfer Effects
  - Scaling Effects
  - Altitude Effects

- Knowledge on ice accretion physics are mapped into improved computational and engineering tools



Droplet Breakup



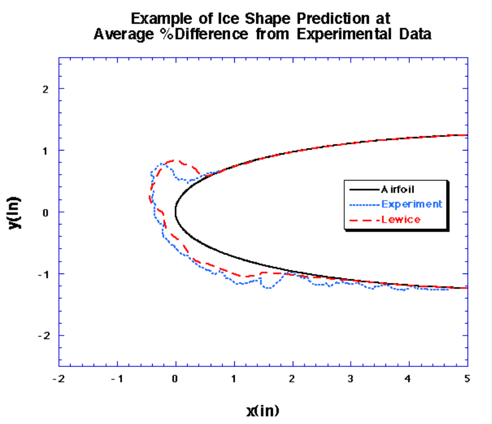
Droplet Rollback

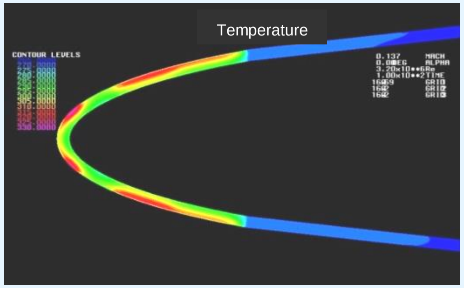
Altitude Effect on Thermal Ice Protection Systems

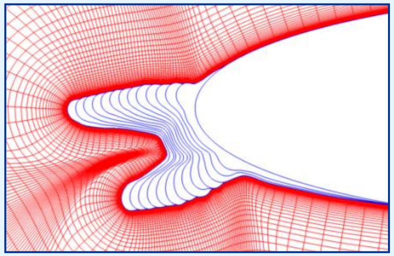
Surface Roughness

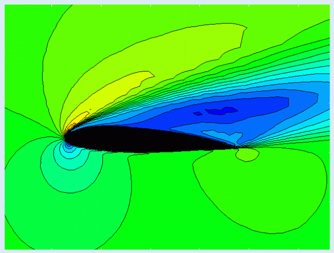
Airframe Icing Computational Tools

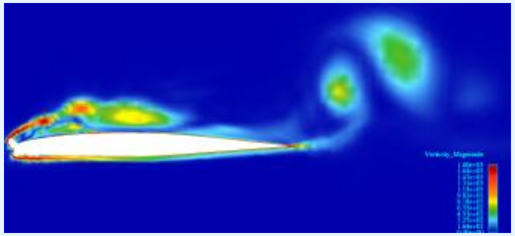
- NASA LEWis ICE (LEWICE) accretion program embodies an analytical ice accretion model that evaluates the thermodynamics of the freezing process that occurs when supercooled droplets impinge on a body.
- The code consists of four major modules and comes in 2-D and 3-D versions: 1) the flow field calculation, 2) the particle trajectory and impingement calculation, 3) the thermodynamic and ice growth calculation, and 4) the modification of the current geometry by addition of the ice growth.
- LEWICE applies a time-stepping procedure to "grow" the ice accretion.





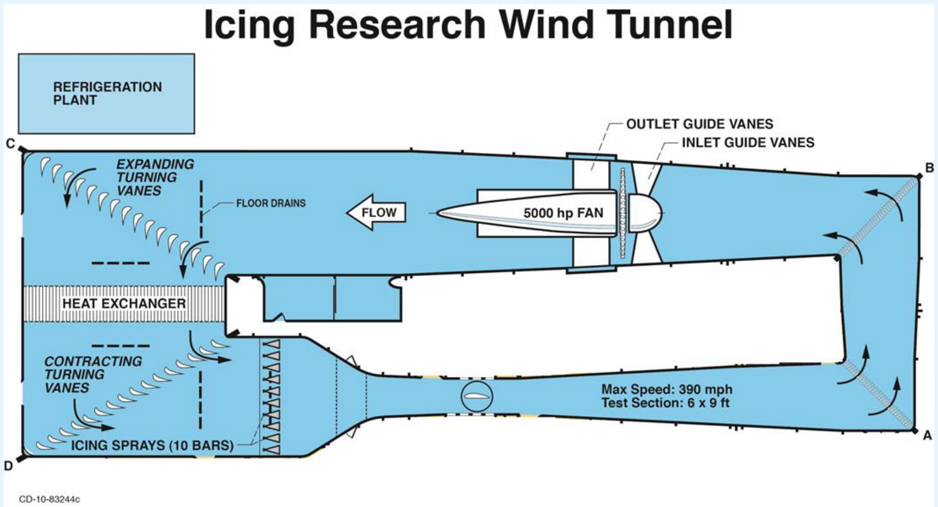


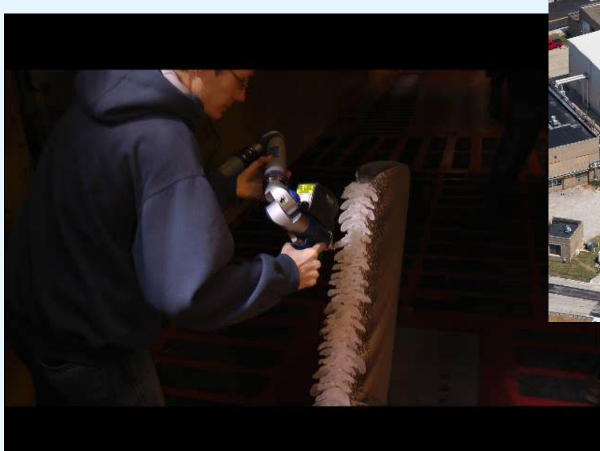




Icing Data Method	Data Points Obtained	Time Requirements	Cost
Flight Testing	10 - 50	2-3 months	Over $1 million
Icing Tunnel Testing	100 - 150	2-3 weeks	Approx. $500 thousand
LEWICE	Over 1000	1 day	One days salary

Airframe Icing Experimental Methods- Ground





- **Description**
- Type: Closed-return, atmospheric-type wind tunnel
- Refrigerated for all-year operation

- **Test Chamber Dimensions**
- Height: 1.8 m (6 ft.)
- Width: 2.7 m (9 ft.)
- Length: 6.1 m (20 ft.)

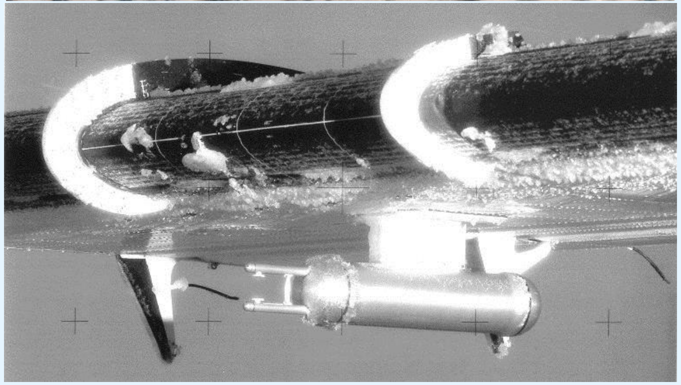
- **Performance and Capability**
- Continuous air speeds from 50 to 395 mph (50 to 350 knots); 22-156 m/s
- Mach number variation ±0.005 Mach
- Year-round temperature as low as -25°F, controllable to 1°F (-30°C, 0.2C)
- Supercooled water droplets between 14 and 50 microns (Mean Volumetric Diameter from 14 to 270 microns; largest drop size measured, D_{max} = 1200 microns)
- Water content controllable between 0.5 and 2.5 g/m^3 can be produced to form an icing cloud 6 ft (1.8 m) by 5 ft (1.5 m) (upper limit: 4 g/m3)
- 8.67 ft. (2.64 m) diameter turntable can be rotated ±20 degrees

Airframe Icing Experimental Methods- Flight

- NASA 607, a DHC-6 Twin Otter serves as NASA's Icing Research Aircraft (IRA)

- The IRA has been modified to be a flying icing physics laboratory and research aircraft for:
  - Icing cloud characterization
  - Natural icing physics studies
  - Source of validation data for IRT and CFD tools
  - Full scale iced aircraft aerodynamics
  - Support ice protection/detection development

- Twin Otter Instrumentation
  - Meteorological
    - Droplet Sizing
    - Liquid Water Content
    - Temperature
    - Ice Detector
  - Imaging
  - Aircraft Aerodynamics



The Phenomenon of
Jet Engine Icing

Researchers are exploring the theory that flight into certain kinds of storm clouds might cause ice to build up inside the core of an airplane's jet engine. Since 1988 there have been 153 engine power loss events* on a variety of airplane and engine types attributed to engine icing. A power loss event is a surge, stall, rollback or flameout of one or more engines. Events have occurred up to 41,000 feet and in different regions of the world. The majority occurred in descent and cruise. A multi-national research effort is now underway to identify exactly what causes this phenomenon and how to prevent it.

* Events reported through January 2010, FAA.

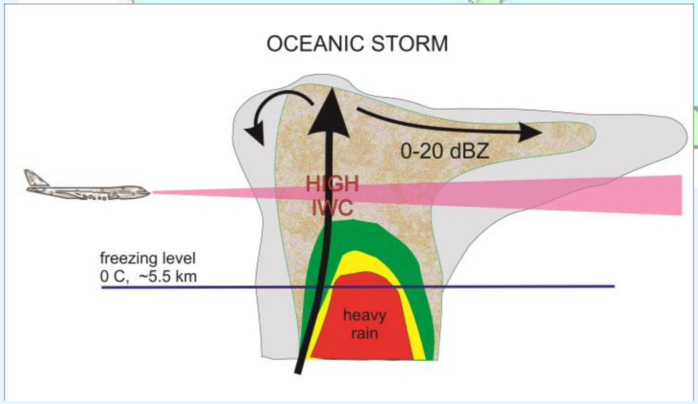
1 The belief is that jet engine icing can occur during flights into cold, high-altitude storm clouds holding massive quantities of small ice crystals. These conditions are not currently detectable on pilot radar. Ice crystals are drawn into the engine inlet where some are ingested with air that flows through the compressor and engine core; the rest are ejected with the air that bypasses the core.

2 As core flow is compressed, the air temperature rises and internal engine components warm above the ambient temperatures. Some ice crystals impact those components, forming a thin film of liquid water that captures additional ice crystals. This accumulation reduces the engine component temperatures so that ice can form.

3 At some point, ice breaks off from the components, which causes the engine to surge, stall, flame out or experience other malfunctions.

Graphic: NASA

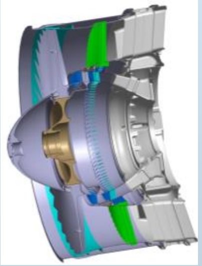
Engine Ice Crystal Icing Power Loss Events



Engine Icing Research Capabilities

Ice Accretion Physics

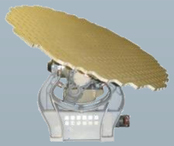
Computational Tools



Experimental Methods

Atmospheric Characterization

Detection



Engineering Solutions

Engine Icing Accretion and Performance Tools

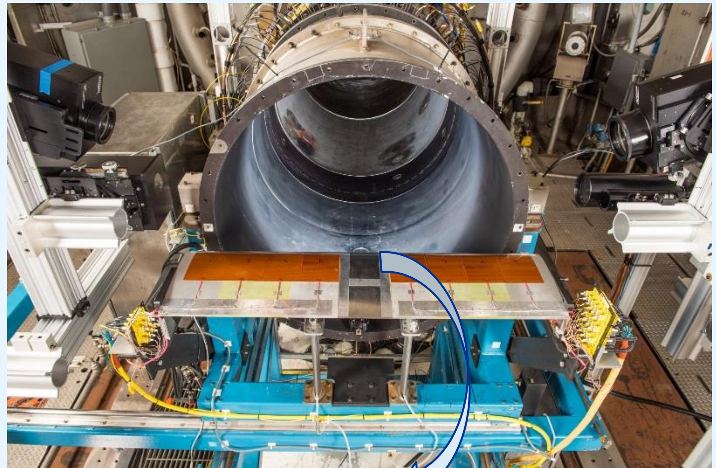
Engine Icing Test Methodologies

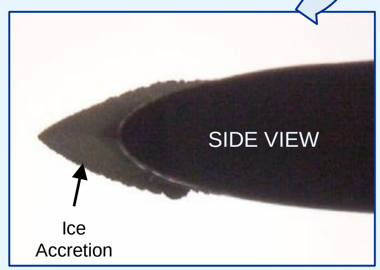
Sensor Technologies to Provide Hazard Detection and Measurement

Engine Ice Accretion Physics

- Foundational ice accretion physics research is performed in the following areas
  - Ice particle Breakup
  - Ice particle Melting and Freezing
  - Liquid/Ice Crystal Accretion
  - Scaling/Altitude Effects

- Knowledge on ice accretion physics are mapped into improved computational and engineering tools





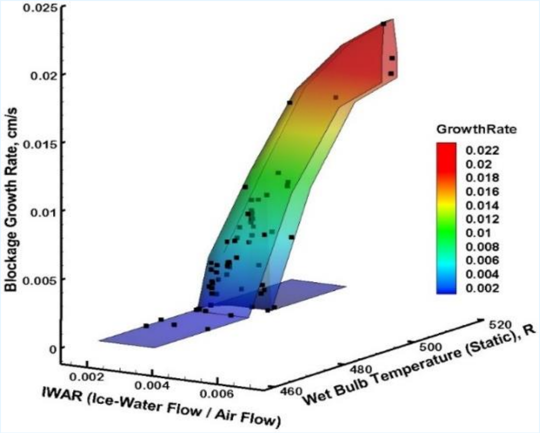
Research Airfoil Along With Temperature and Humidity Measurement Probes at Propulsion Systems Laboratory

National Research Council of Canada-NASA Testing of Wedge Shape

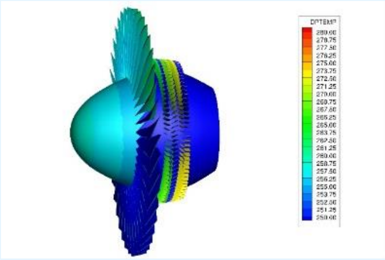
Ice Particle Impact Studies

Engine Icing Computational Tools

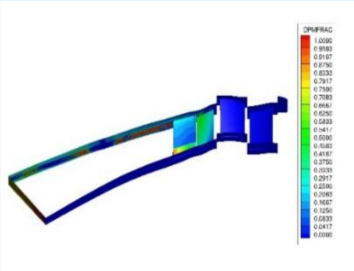
- Developing a system of codes that can model the performance of an engine and estimate the risk of accretion due to ice crystal ingestion at high altitude and ultimately actual ice accretion.
- Identifying codes, modify as necessary, and couple an engine system code, a compressor mean line code and an ice particle tracking and melt code to assess the risk of ice accretion and ultimately actual ice accretion.

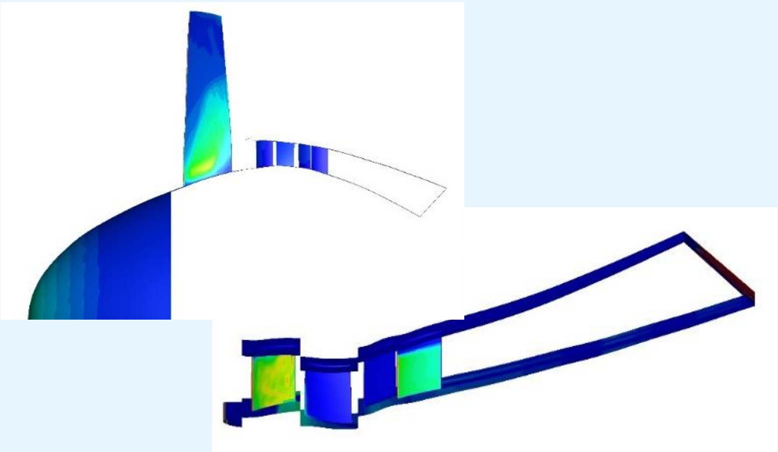


Risk of Ice Accretion Criteria

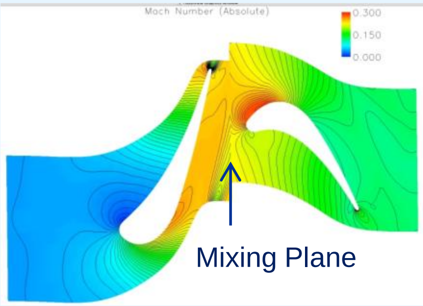


Particle Temperature





Collection Efficiency on Surfaces



Mixing Plane

Engine Icing Experimental Methods- Ground

Propulsion Systems Laboratory

C-2013-446

Video

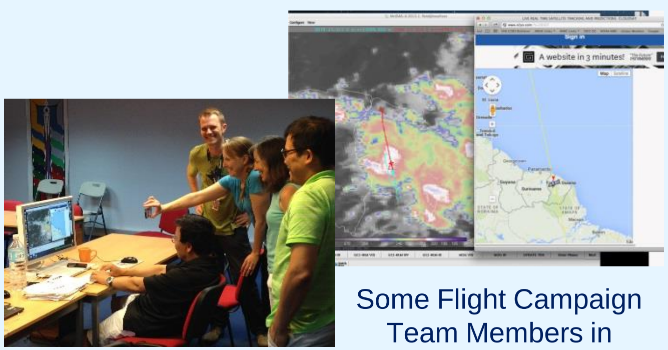
National Aeronautics and Space Administration
Glenn Research Center at Lewis Field

Engine Icing Atmospheric Characterization

NASA-provided Iso-Kinetic Probe on the Falcon-20

Cayenne Team End of Campaign Photo May 29th 2015

View Out of SAFIRE (Service des Avions Francais Instruments pour la Rechcerche en Environment-French government) atmospheric Falcon-20 aircraft



Some Flight Campaign Team Members in South America Observing Weather

Objective:

– Characterize the ice crystal cloud environment obtained during flight campaigns to determine 99th percentile ice water content levels and ice particle size spectra to support engine and air data probe design standards, modeling and simulation, and simulated engine ground testing.

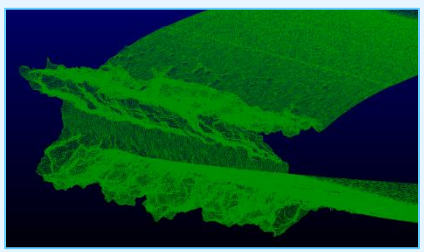
Approach:

– Partnered with the European High Altitude Ice Crystal (HAIC) Consortium in a January-March 2014 field campaign in Darwin, Australia and a May 2015 field campaign in Cayenne, French Guiana (South America); NASA provided the critical iso-kinetic probe (IKP), spare meteorological probes, and ground support personnel.

Engine Ice Detection
DC-8 Aircraft

Video

Summary



- NASA has a rich and successful history, since the 1940’s, of successfully addressing the aviation hazards of airframe and engine icing

- NASA has icing capabilities to improve aviation safety for existing and next generation aircraft
  - Fundamental icing physics
  - Computational tools
  - Experimental methods- ground and flight
  - Atmospheric characterization
  - Hazard detection

- NASA’s open to information and best practice sharing to further improve understanding of icing and its mitigation