Introduction to Aircraft Icing

and NASA's Approach to Understanding It

Paul von Hardenberg
NASA Glenn Research Center

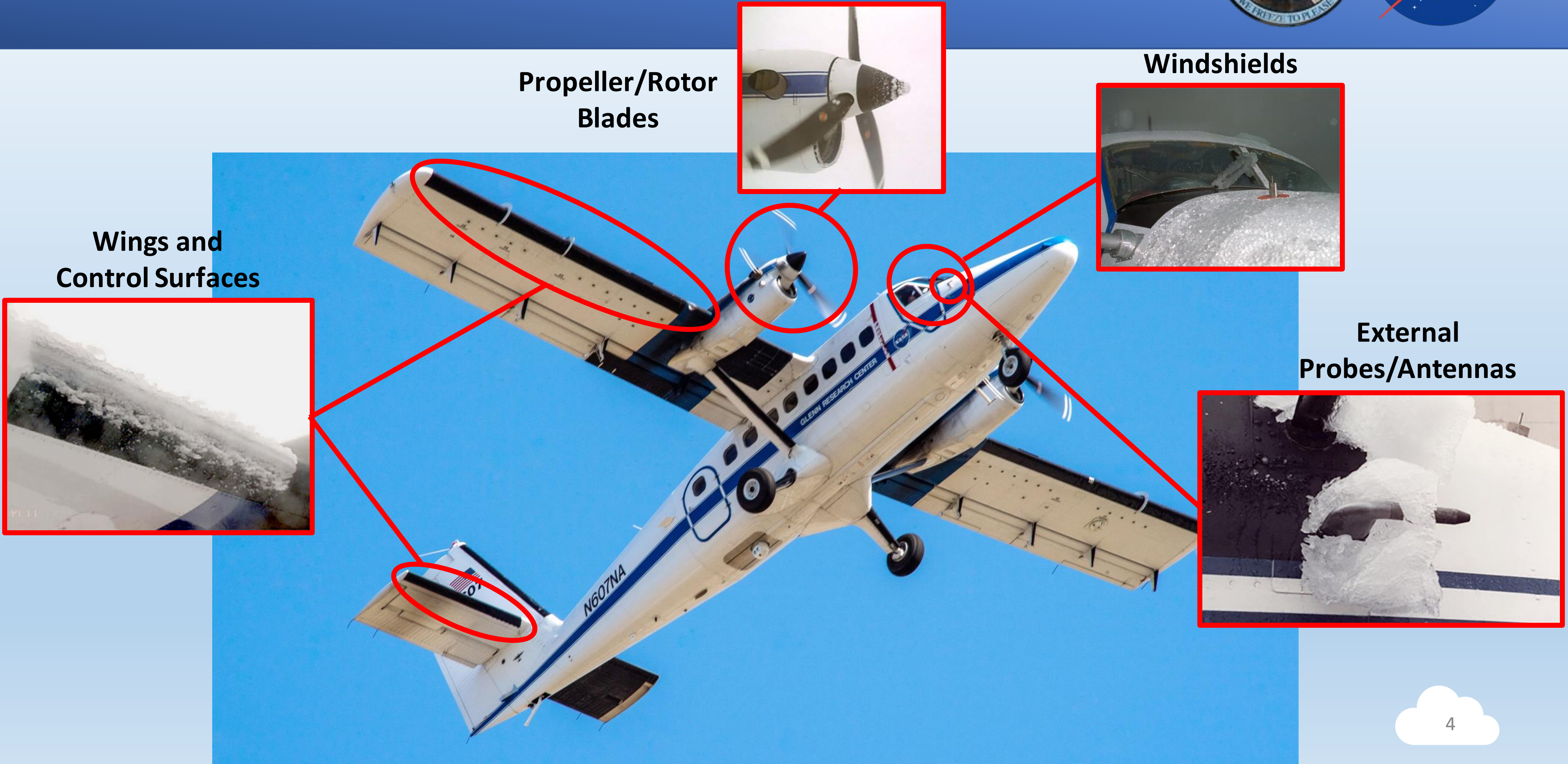
ASME Baltimore Section Lecture Series
April 6th, 2022

Overview

- What is Aircraft Icing?
  - Types of icing
  - Impact on aircraft performance
  - Parameters that influence icing
  - Engine and rotorcraft icing
- NASA's Approach to Understanding
  - Flight Tests
  - Wind tunnel Tests
  - Computational Tools
- The Future of Aviation

What is Icing?

What is Aircraft Icing?

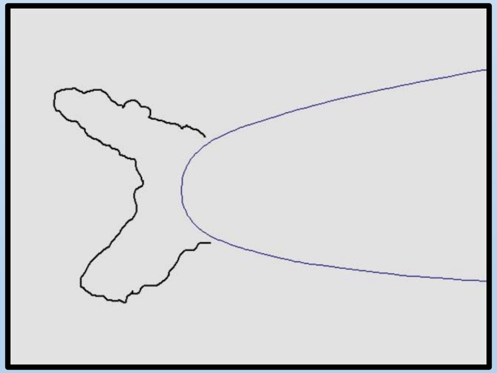


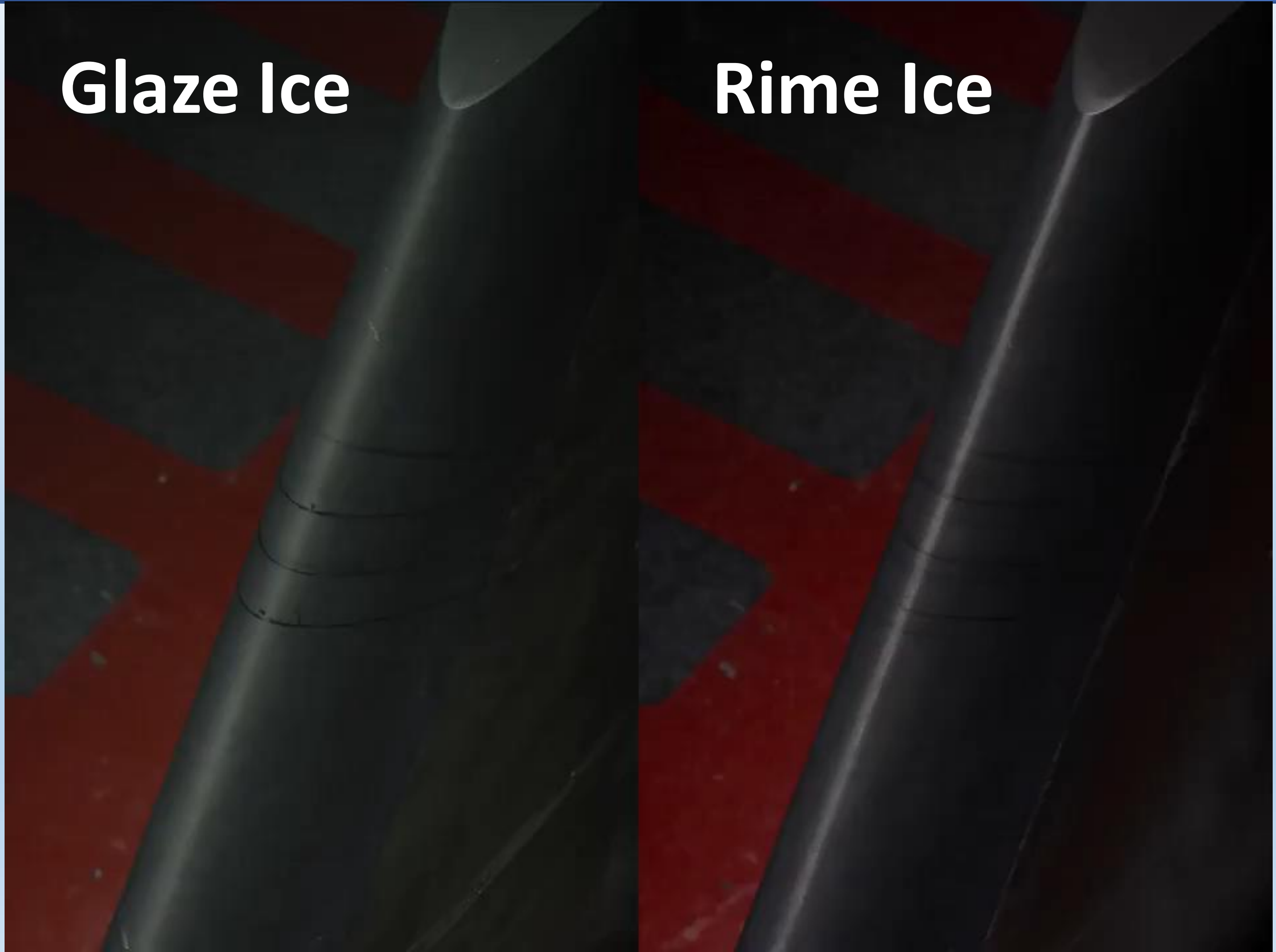
Glaze vs Rime Icing (Video)

Glaze

Clear/translucent

Ice shapes protrude from the leading edge

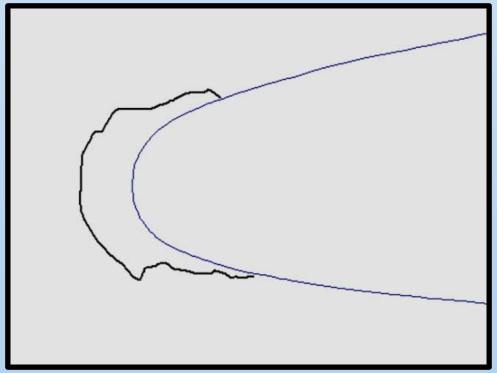




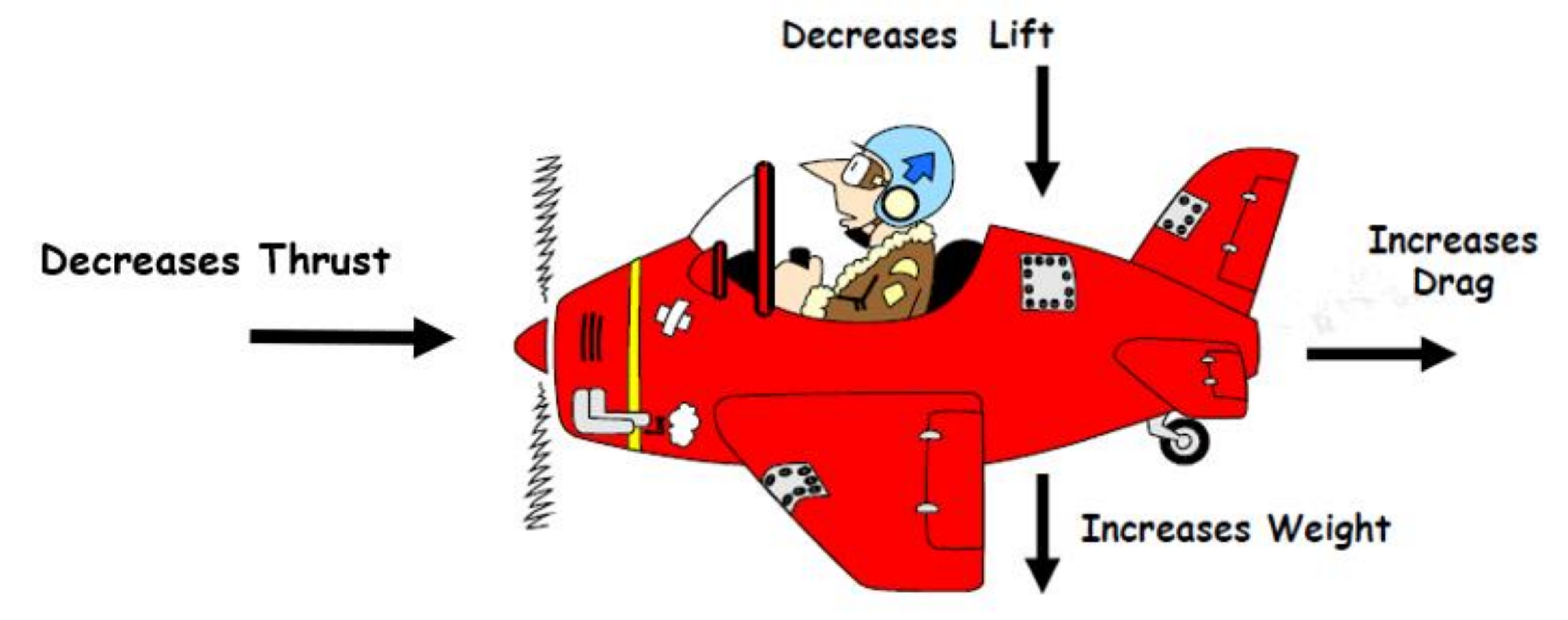
Rime

Opaque

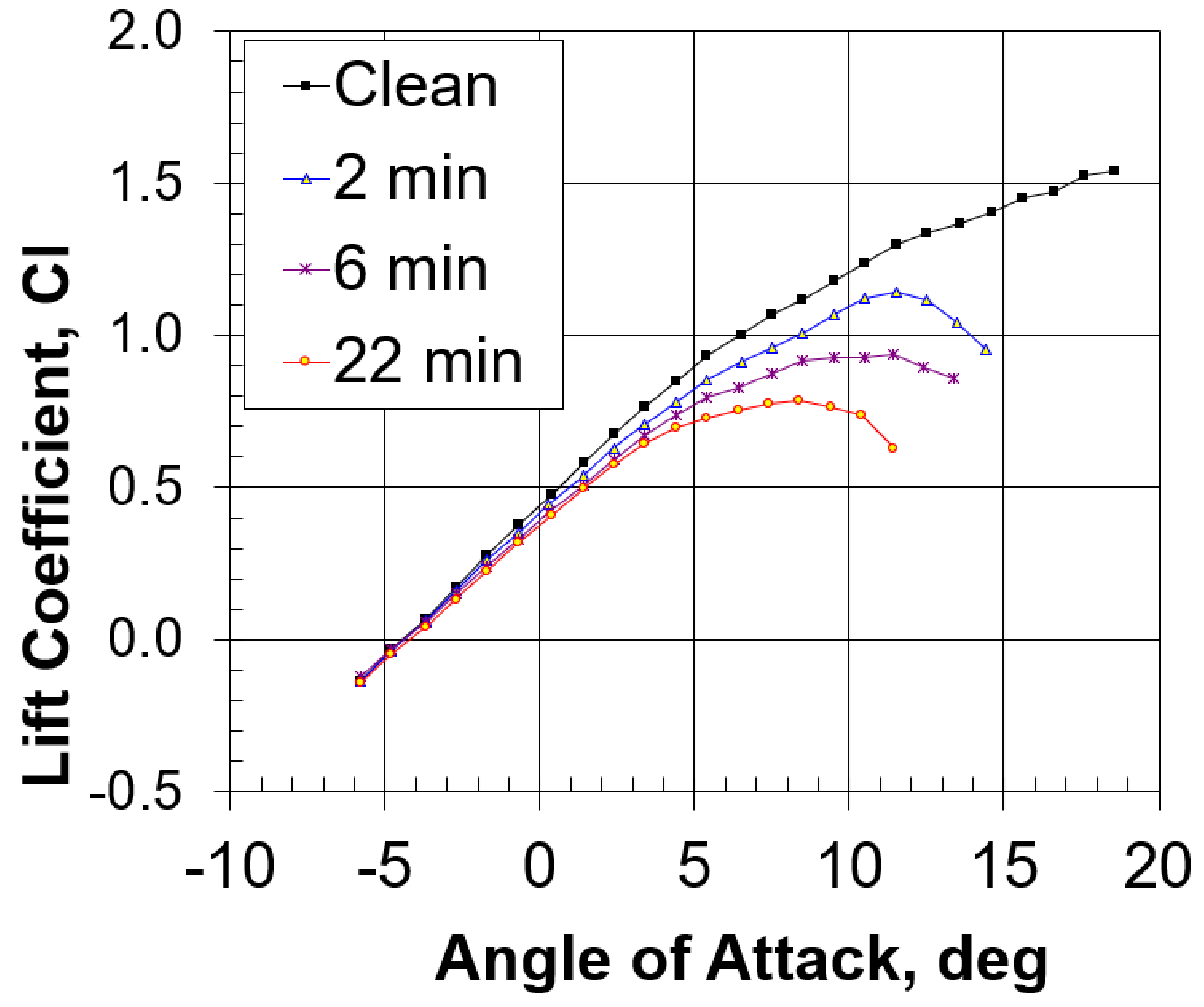
Streamlined ice shapes



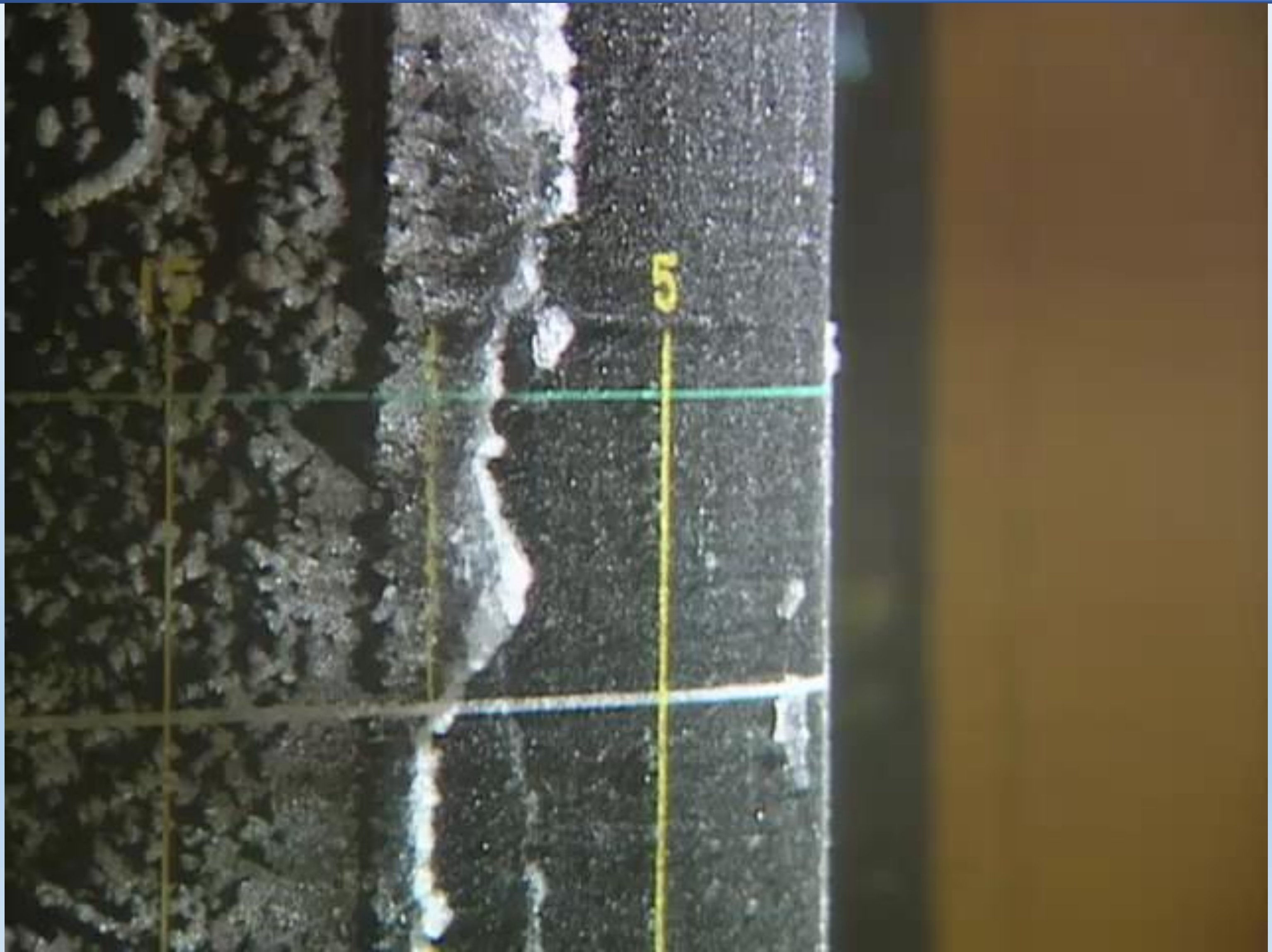
Impact on Aerodynamic Performance



Impact on Aerodynamic Performance



Deicing Boot (Video)



Meteorological Requirements for Icing

Aircraft icing requires two conditions to occur:

1. **Temperatures near or below freezing**
   - Icing is more frequent when the static air temperature (SAT) is between +2°C and -20°C.
2. **Existence of water droplets**
   - Liquid water must be present in the air for ice accretion to occur.
   - Water in the form of vapor, snow, or ice will generally not stick to an airplane's external surface and contributes little to the overall ice buildup.
   - If there is sufficient liquid water in the air to pose an icing threat, it will generally be visible in the form of a cloud or liquid precipitation.

Meteorological Conditions that Influence Icing Severity

The main meteorological conditions that influence icing severity include ***temperature***, ***liquid water content (LWC)***, and ***droplet size***.

Temperature

- Temperature effects both severity and type of icing.
- Most icing occurs between 0°C and -20°C. Icing is not severe below -40°C because this is the temperature droplets freeze without an icing nuclei.

Liquid Water Content (LWC)

- Defined as the density of liquid water in a cloud expressed in grams of water per cubic meter (g/m^3)
- In general, the higher the LWC, the greater the icing severity.

Continued…

Meteorological Conditions that Influence Icing Severity

Droplet Size

- Droplet diameter is usually expressed in microns (µm) and represented by an average value called **Median Volumetric Diameter (MVD)**.
- Droplet size affects the collection of water drops on the surface of the aircraft; **smaller drops tend to impact near the leading edge of a wing whereas larger droplets can impact farther aft.**

Non-meteorological Factors that Influence Icing Severity

Airspeed and **collecting surface geometry** are important non-meteorological factors that influence icing type and severity.

Airspeed

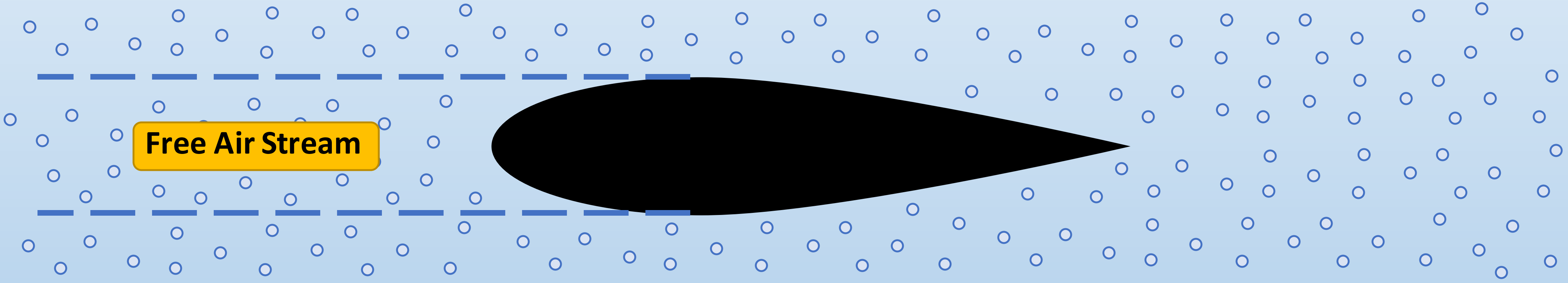
- The higher the airspeed, the higher the rate of ice accumulation.
- Airspeed also determines where ice collects on a surface; higher airspeeds allows for more droplets to impinge farther aft on an airfoil.

Collecting Surface Geometry

- Often described by the radius of curvature of the leading edge.
- Surfaces with smaller radiuses of curvature have greater collection efficiency's and thus collect more droplets.

Collection Efficiency (β)

Not all water droplets in the free air stream will strike the airframe. Droplets with small inertial forces will closely follow the streamlines and avoid striking the airframe.

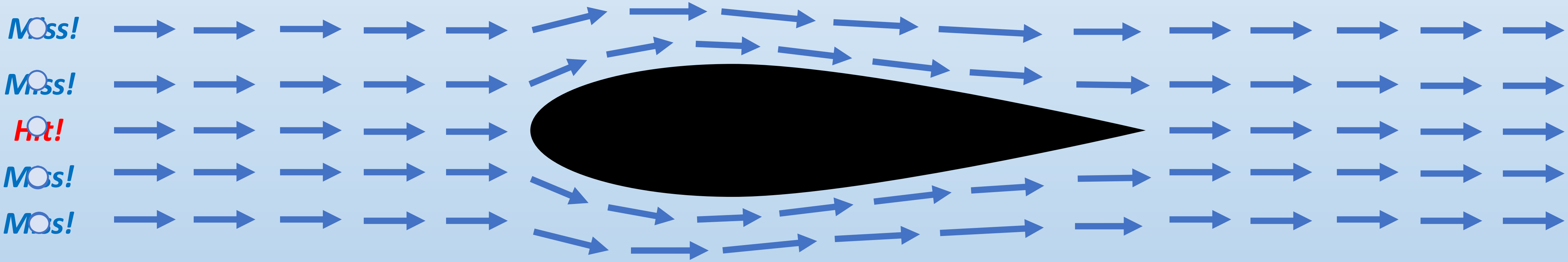


The ratio of the water mass striking the airframe to the water mass in the free airstream is known as the **Collection Efficiency (β)**.

- *As collection efficiency increases, so will the rate of ice accretion.*

Collection Efficiency (β)

Not all water droplets in the free air stream will strike the airframe. Droplets with small inertial forces will closely follow the streamlines and avoid striking the airframe.



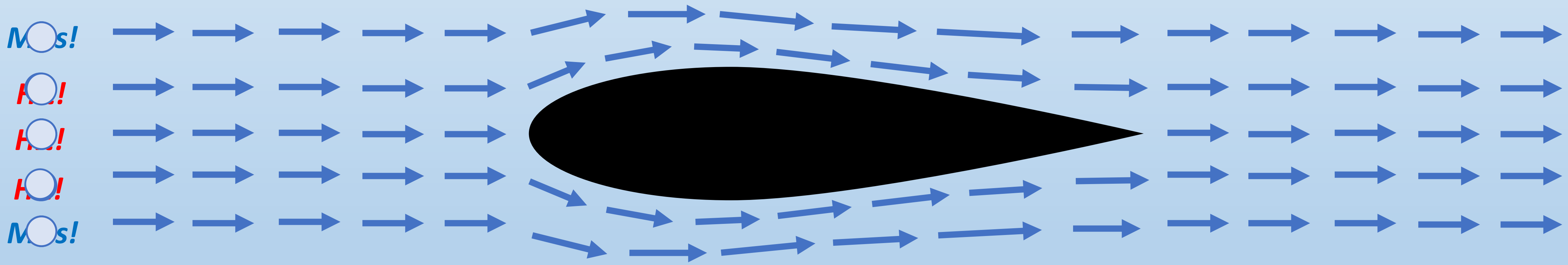
The ratio of the water mass striking the airframe to the water mass in the free airstream is known as the **Collection Efficiency (β)**.

- *As collection efficiency increases, so will the rate of ice accretion.*

Collection Efficiency (β)

Collection Efficiency (β) is influenced by:

- **Airspeed** (increase in airspeed = increase in β)
- **Droplet Size** (increase in droplet size = increase in β)
- **Collecting Surface Geometry** (smaller radius of curvature = increase in β)

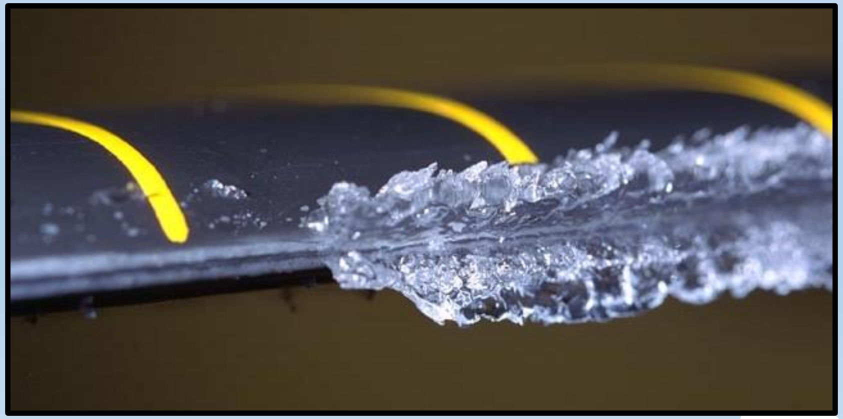


Due to having greater inertia, droplets with higher mass and/or velocity are less likely to follow streamlines and more likely to strike the object.

Engine Icing (Video)

Rotorcraft Icing

- **Rotorcraft are often required by mission objectives to operate in icing conditions for prolonged periods of time.**
  - Military Operations
  - Search and Rescue
  - Urgent Transportation
  - Operate at lower altitudes
- **Current certification process is time consuming and expensive.**
  - Flight campaigns in natural icing conditions
  - Simulated icing conditions using a tanker
- **Conventional electrothermal deicing systems can be unreliable and consume a lot of power.**
- **Severe vibration or damage due to ice shedding from rotor blades.**



Helicopter Icing Spray System (HISS)

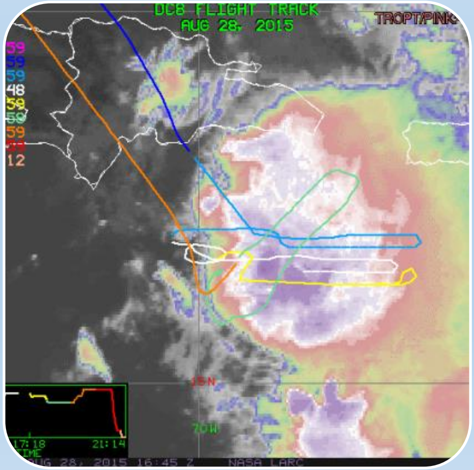
NASA's Approach to Understanding Icing

Wind Tunnel Tests

Simulate the Environment

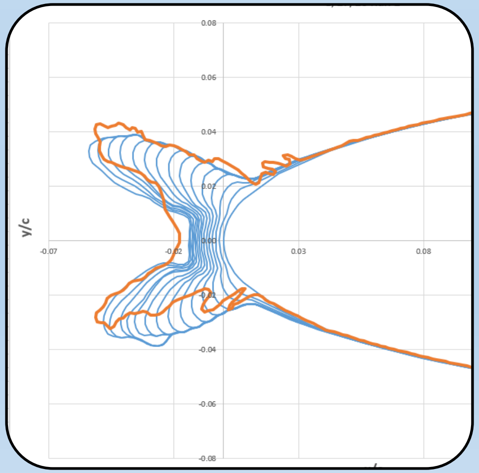
Flight Tests

Understand the Environment

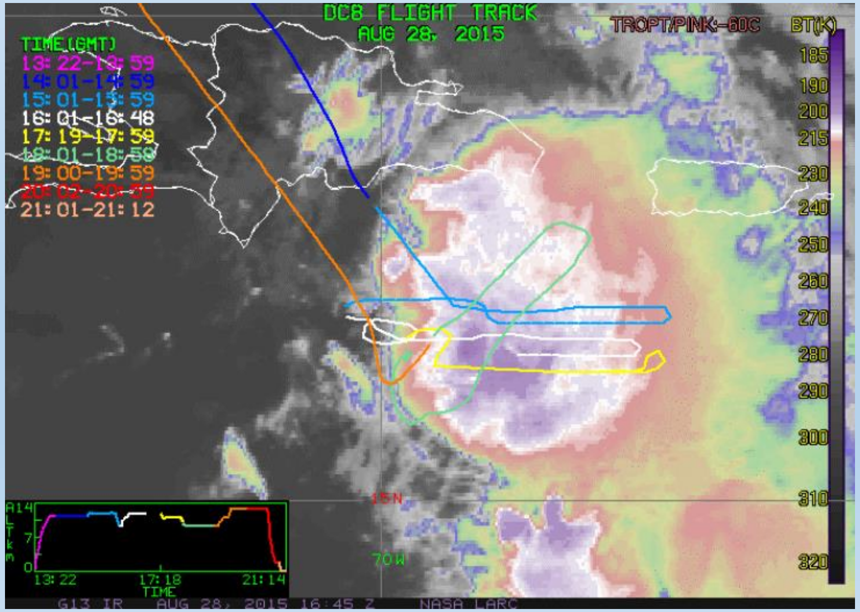


Computational Tools

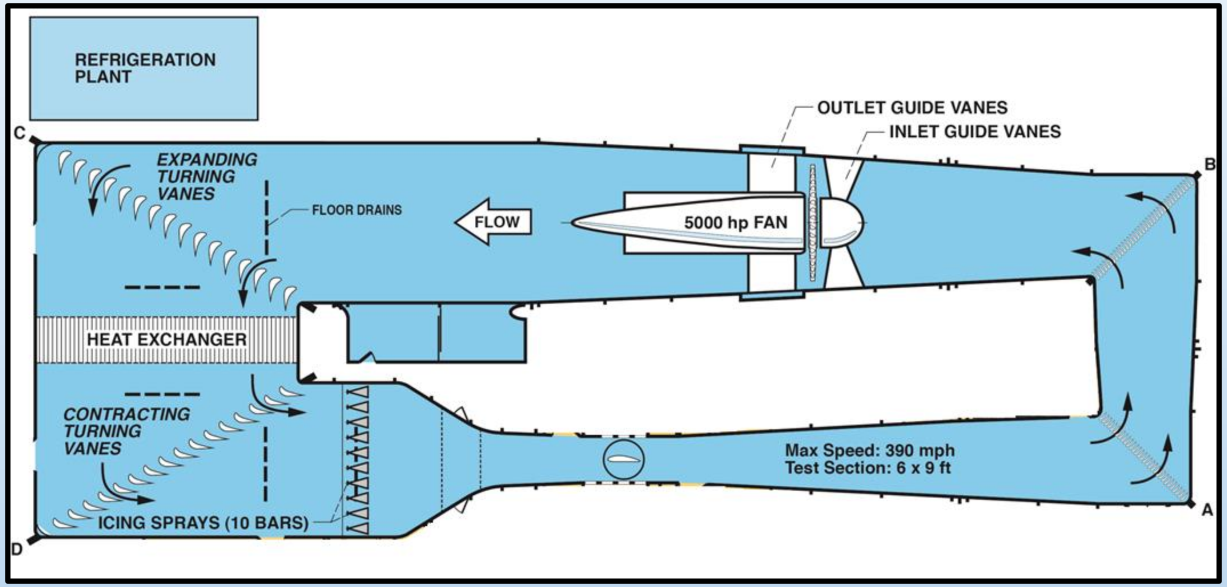
Model the Environment



Flight Tests



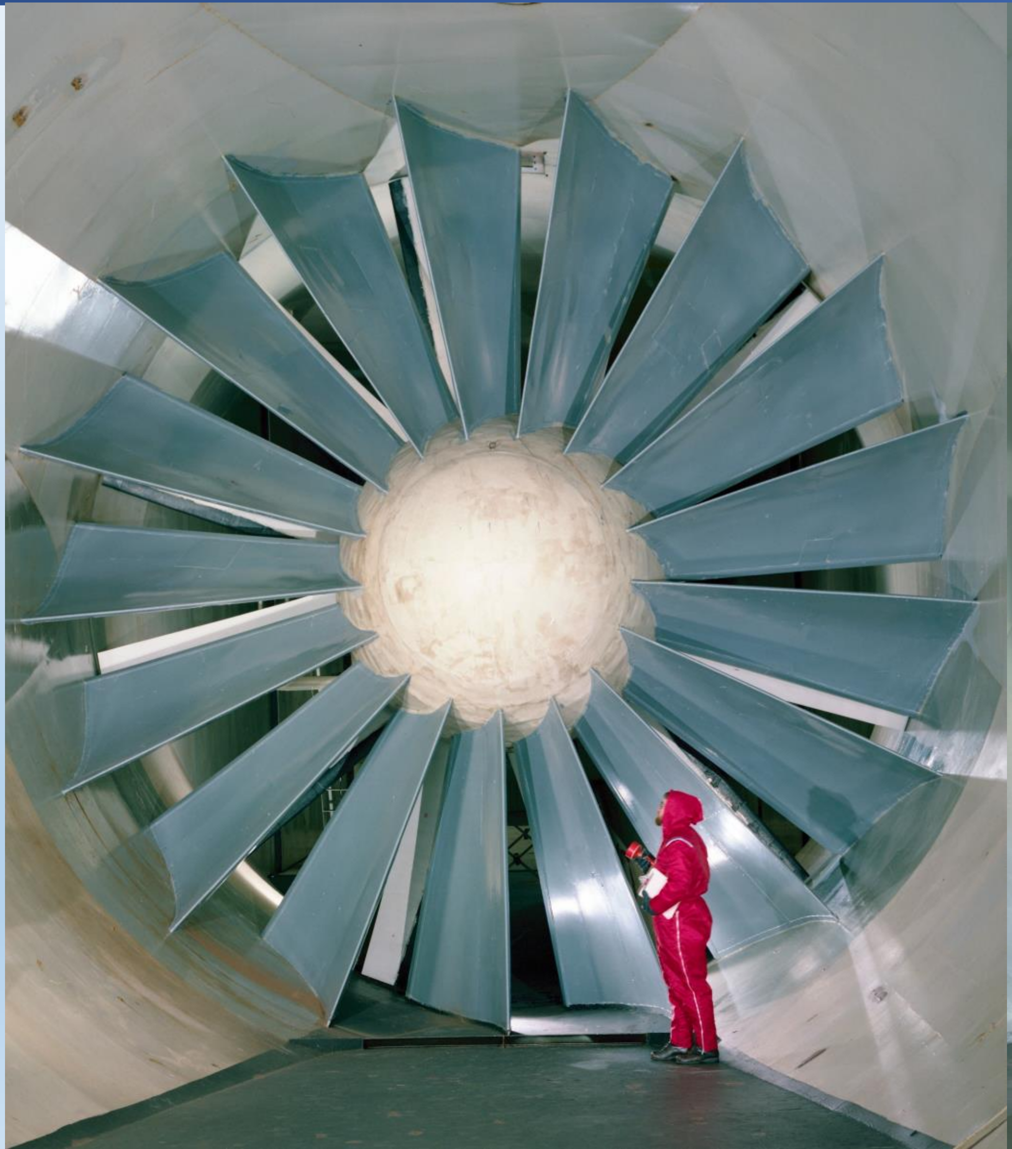
Wind Tunnel Tests



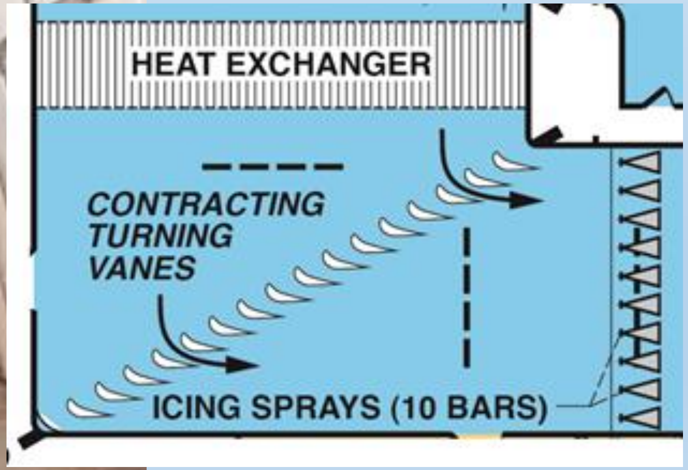
Icing Research Tunnel Quick Facts	
Test Section	6 ft tall by 9 ft wide by 20 ft long
Airspeeds	50 to 325 knots
Temperatures	As low as -35°C (controllable to +/- 0.5°C)
Droplet Size	15 to 275 microns
Water Content	0.15 to 4.0 g/m^3

IRT Test Section

Icing Research Tunnel (IRT)



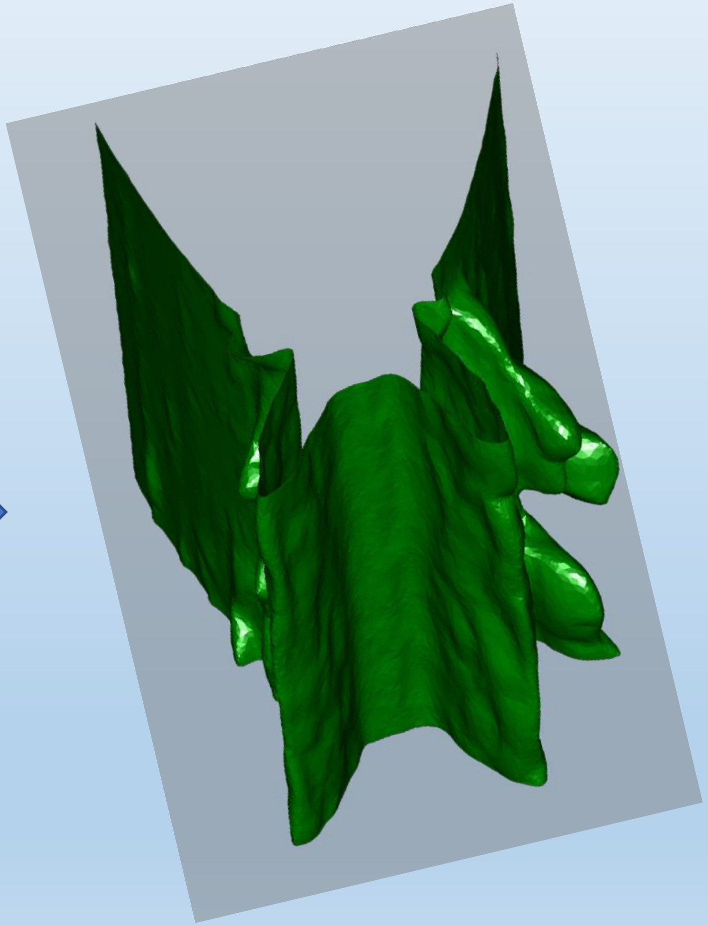
Icing Research Tunnel (IRT)



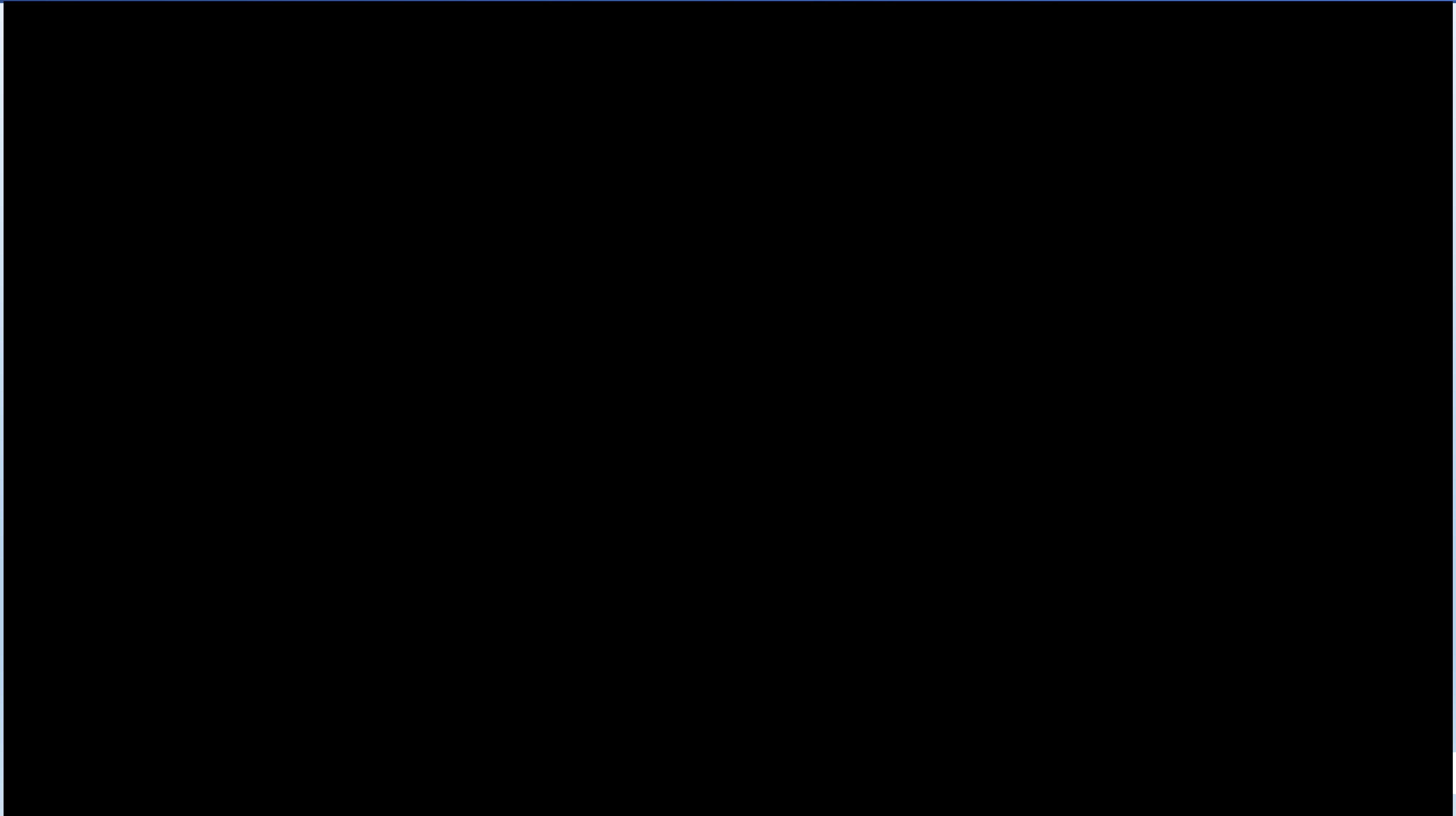
Icing Research Tunnel (IRT)

Spray Bars
(Video)

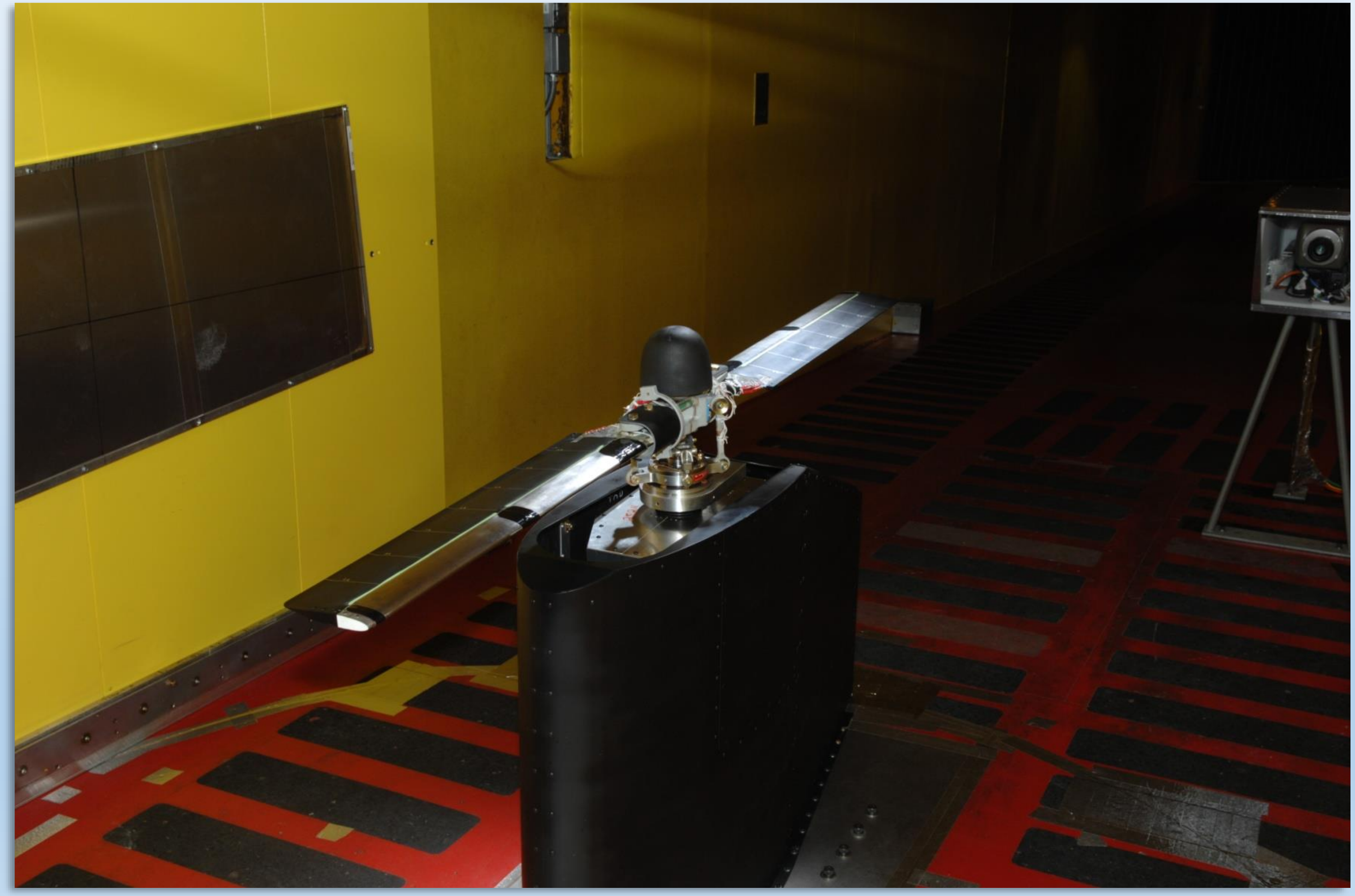
Laser Scanner Technology

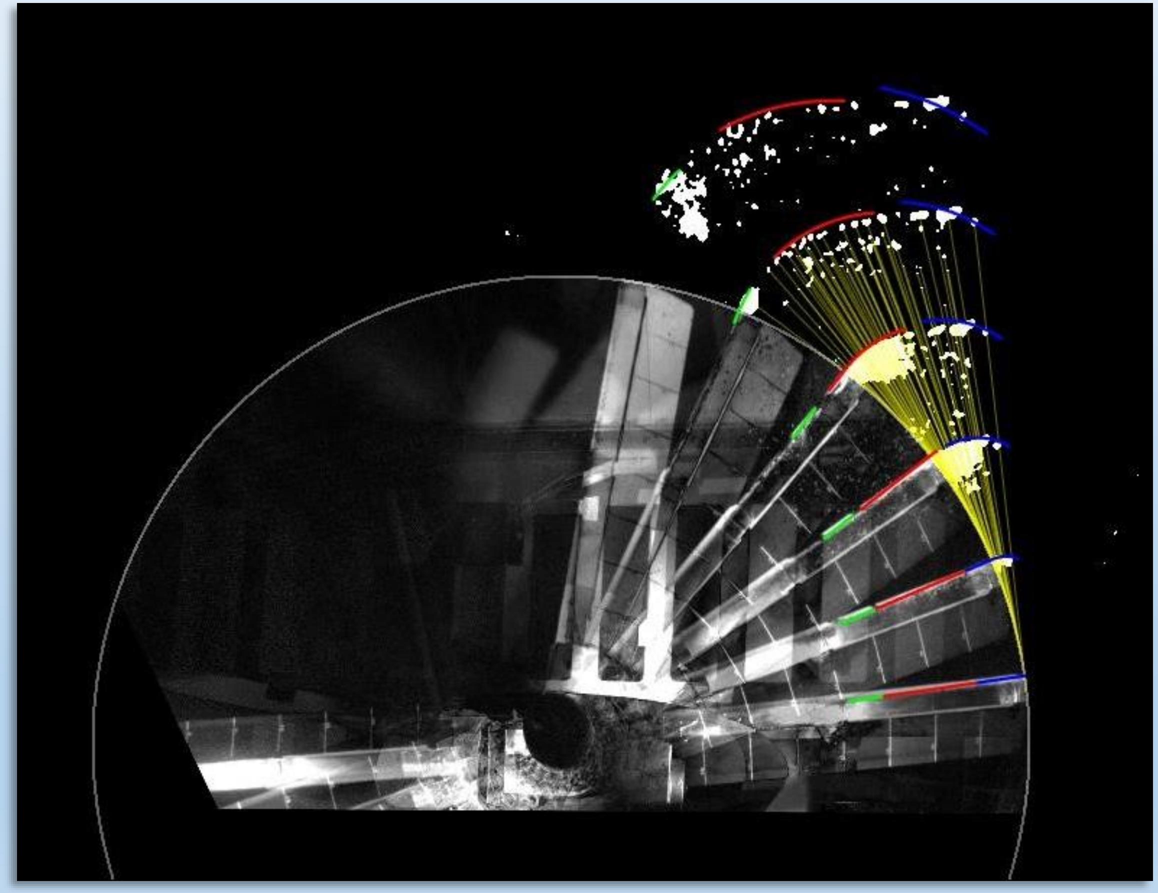


Laser Scanner Technology (Video)

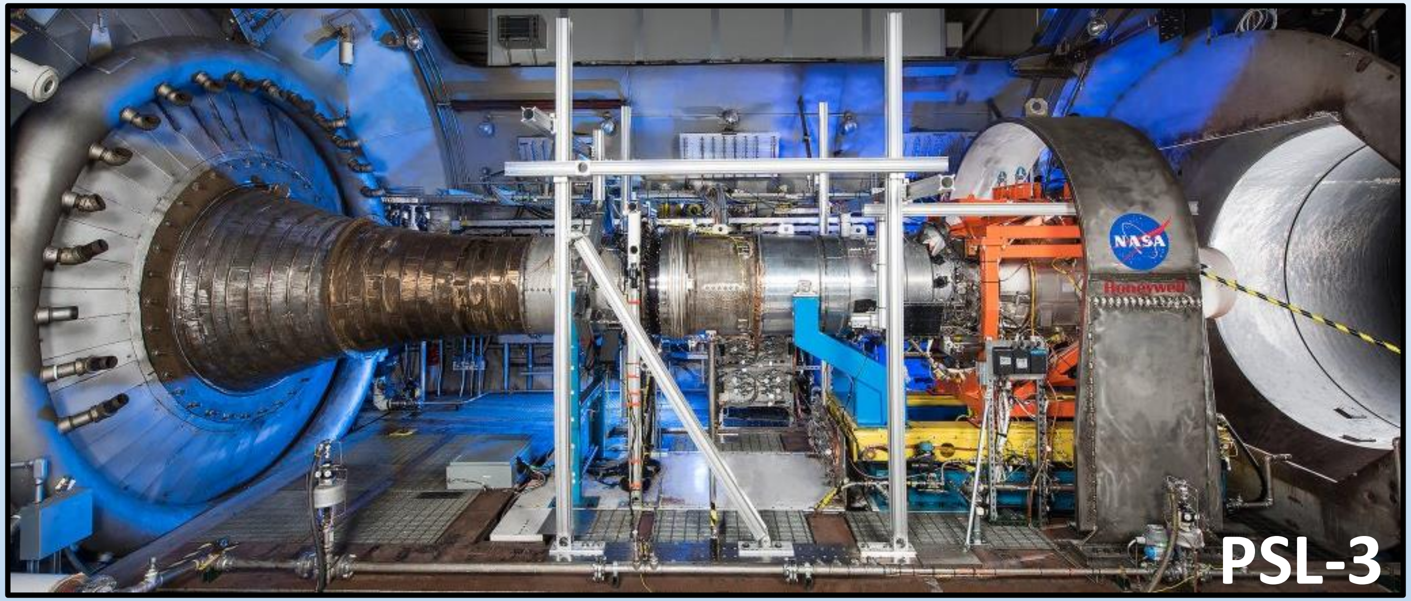


IRT Rotorcraft Icing Studies

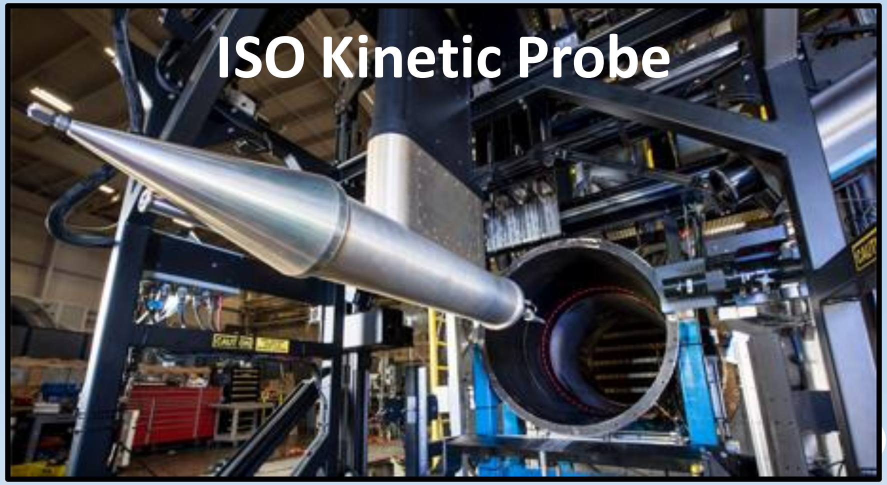




Propulsion Systems Laboratory (PSL)



Test Cell:	PSL-3	PSL-4
Test Section	38-ft long and 24-ft wide in diameter	
Altitude	90,000 ft	
Mach Number	0 to 3.0	0 to 6.0
Temperatures	-40°F to 500°F	-90°F to 1,050°F
Icing Capability	YES	NO

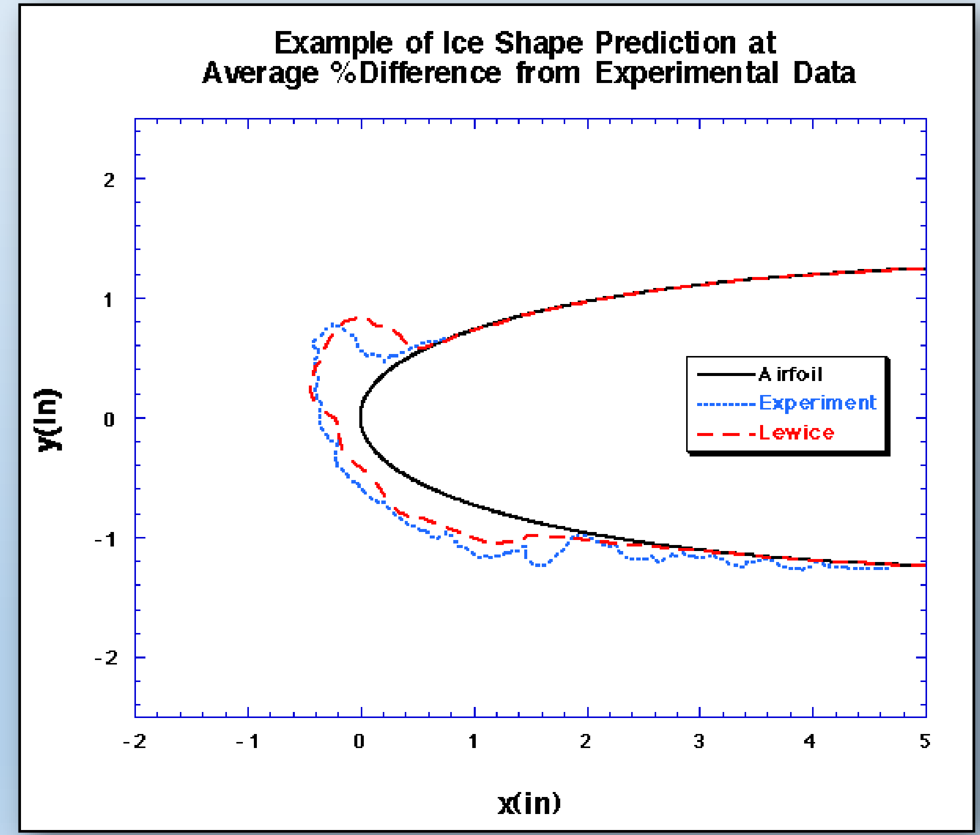


Propulsion Systems Laboratory (Video)

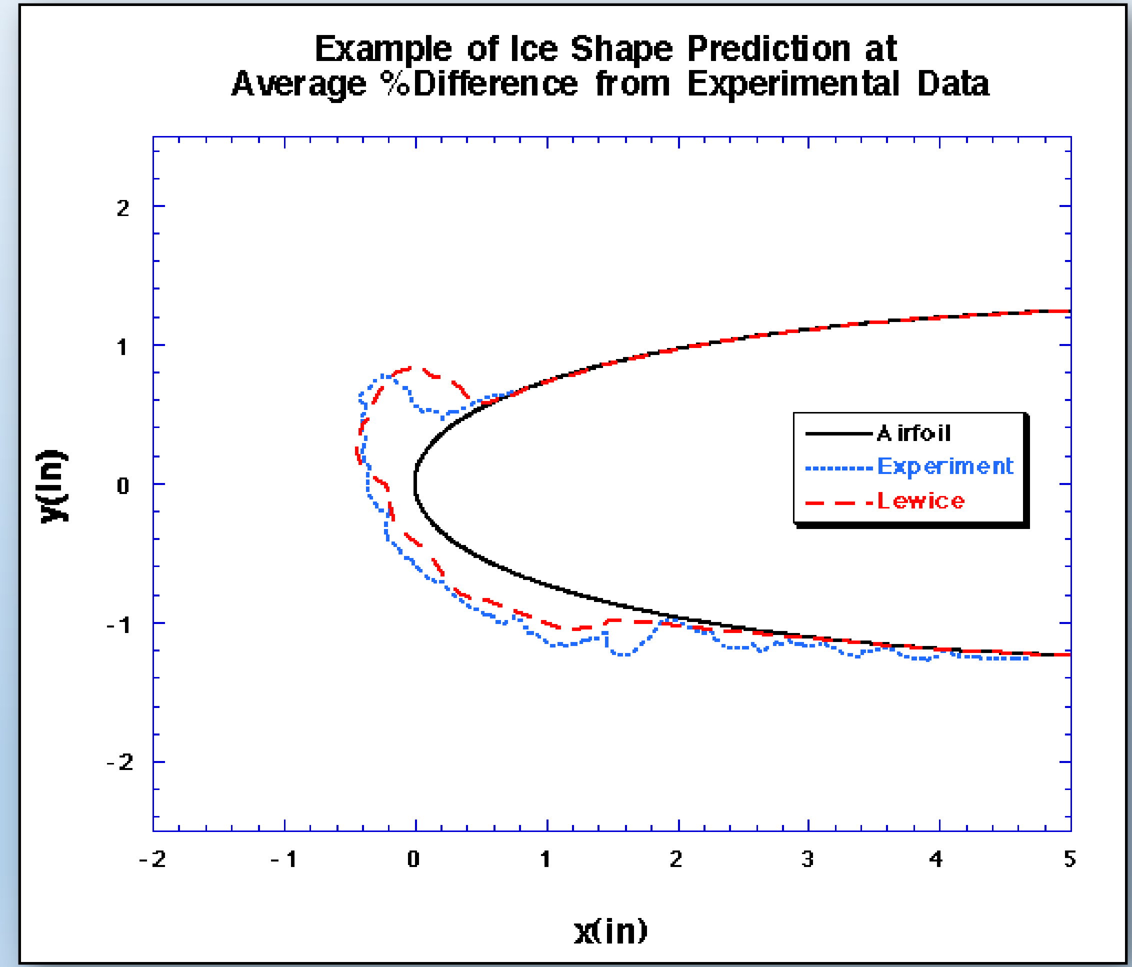
Icing Computational Tools

Some of NASA's current computational capabilities:

- **LEWICE 2D**
  - 2D ice accretion simulation; multi time step
  - Quick and easy!
- **LEWICE 3D**
  - 3D ice accretion simulation; single time step
  - Used in conjunction with many 3D CFD tools
- **GlennICE**
  - Currently under development
  - 3D ice accretion simulation; multi time step



Icing Computational Tools: LEWICE



Example LEWICE Simulation

Output

- Ice shape geometry
- Collection efficiencies
- Freezing fractions
- Heat transfer values
- Temperatures along surface

The Future of Aviation

Image credits: Lockheed Martin


Image credits: Boeing

Advanced Air Mobility (AAM)

NASA's Vision for Advanced Air Mobility (AAM)

Advanced Air Mobility (AAM): An air transportation system that moves people and cargo between places previously not served or underserved by aviation.

Why AAM?

- Decreased surface traffic congestion
- Decreased pollution (emissions and noise)
- Fast and reliable transportation

Advanced Air Mobility (AAM)

What makes AAM unique from traditional rotorcraft?

vs

Advanced Air Mobility (AAM)

What makes AAM unique from traditional rotorcraft?

Autonomous

Smaller blades

Multirotor
Tilt-rotors
Ducted-rotors
Coaxial rotors

Slower tip speeds

Fixed pitch blades

Hybrid/fully electric

Sharper leading edges

36

Questions?