Airframe & Engine Icing

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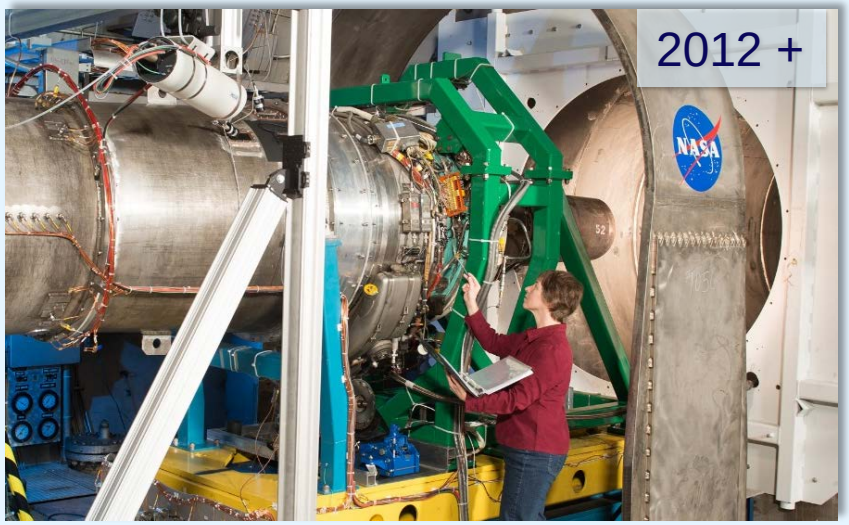
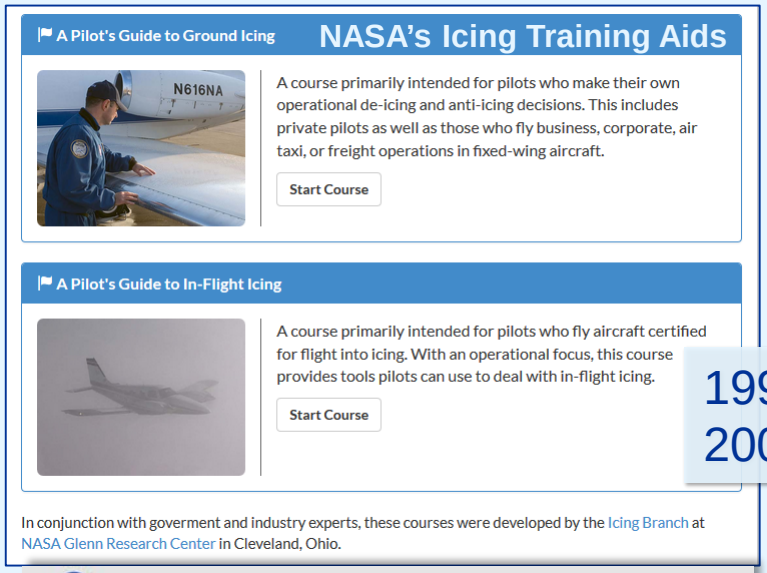
(Aero. Engineer)
NASA Glenn

Who am I?



Propulsion Systems Lab, PSL



Icing Research Tunnel, IRT

http://aircrafticing.grc.nasa.gov

Available Courses Icing Training

A Pilot's Guide to Ground Icing

A course primarily intended for pilots who make their own operational de-icing and anti-icing decisions. This includes private pilots as well as those who fly business, corporate, air taxi, or freight operations in fixed-wing aircraft.

Start Course

A Pilot's Guide to In-Flight Icing

A course primarily intended for pilots who fly aircraft certified for flight into icing. With an operational focus, this course provides tools pilots can use to deal with in-flight icing.

Start Course

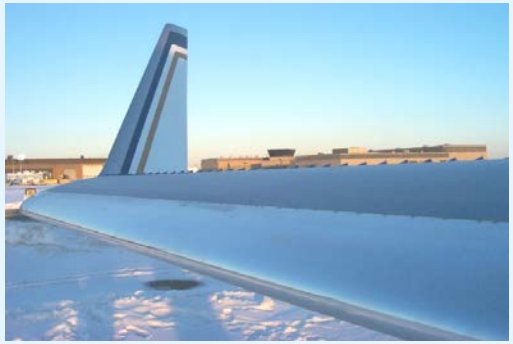
Search on "NASA Aircraft Icing"

In conjunction with goverment and industry experts, these courses were developed by the Icing Branch at NASA Glenn Research Center in Cleveland, Ohio.

Which do you (hope to) fly?

Piston
Single / Twin
IPS?

Turboprop,
typically
De-ice



Jet,
typically
Anti-ice

Outline

- **Ground Icing** (briefly)
- **In-Flight Airframe Icing *(IRT, IRA)***
  - Icing Basics
    - Where is the Ice?
    - Performance & Handling Issues
    - Supercooled Large Drops
  - Operational Considerations (supplement to AFM/POH)
    - Preflight: Anticipate & Develop Outs
    - In-Flight: Early Detection & Exit
    - Terminal Area: Wing vs Tail Stall
- **Turbine Engine Ice Crystal Icing *(PSL)***

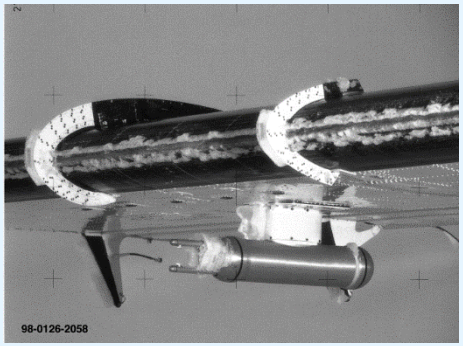
Target audience: Mostly for Pilots, but with a dash for Engineers

Definitions

Most images from NASA icing research aircraft flights

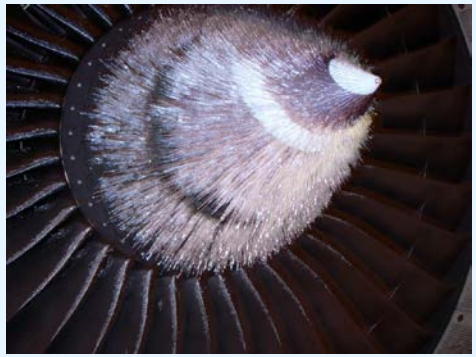
Airframe Icing:

supercooled *liquid* water impacts external airframe surfaces and phase changes to ice.



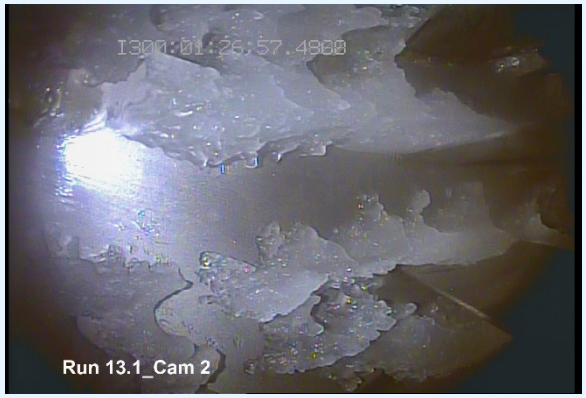
Engine Icing (traditional):

supercooled liquid water impacts spinner, prop, fan, nacelle.



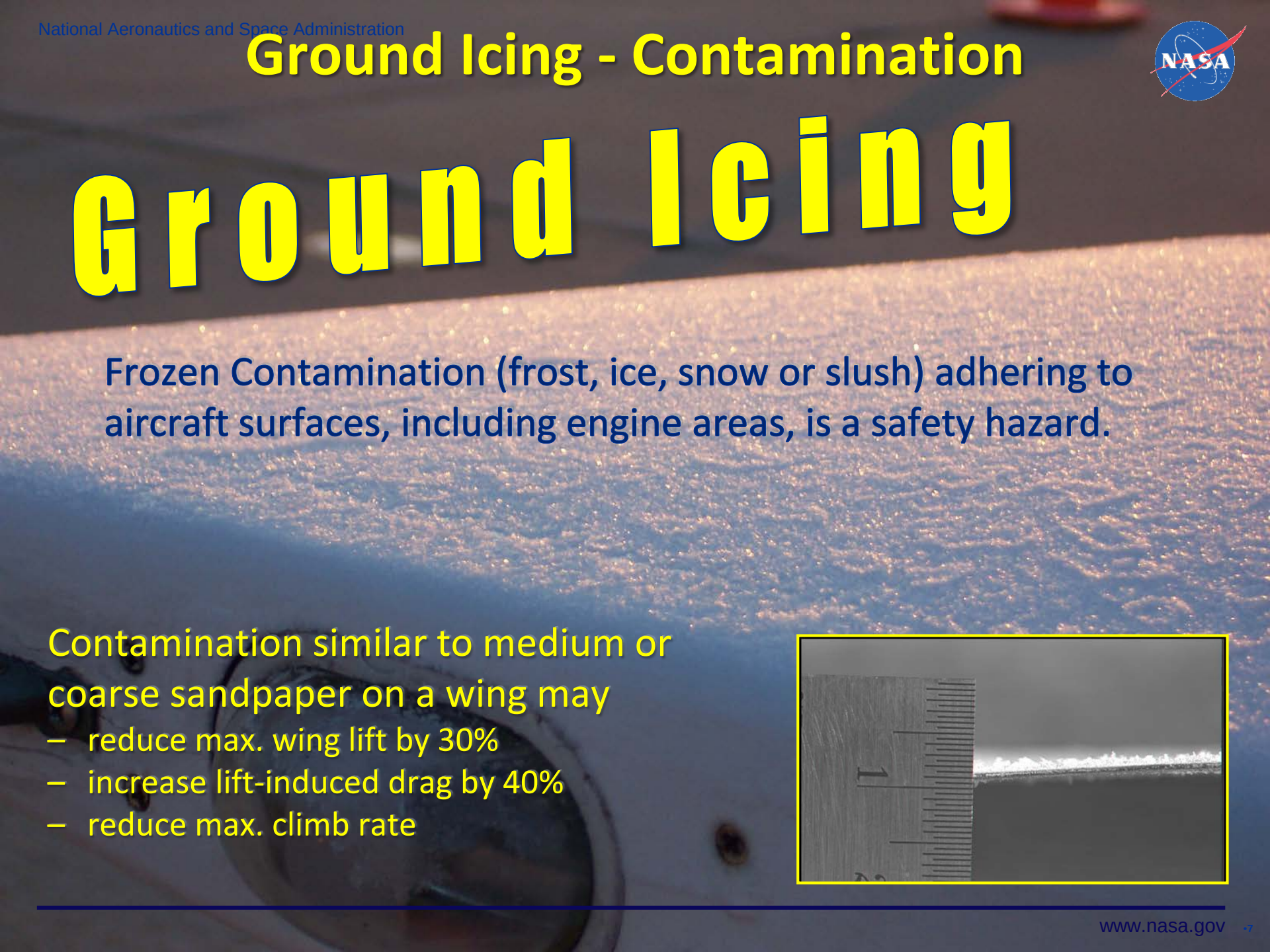
Engine *Ice Crystal* Icing:

ice crystals are ingested into the core flow path of turbine engines, cooling initially hot surfaces inside the compression system and causing power loss events.



Flow

Ground Icing - Contamination

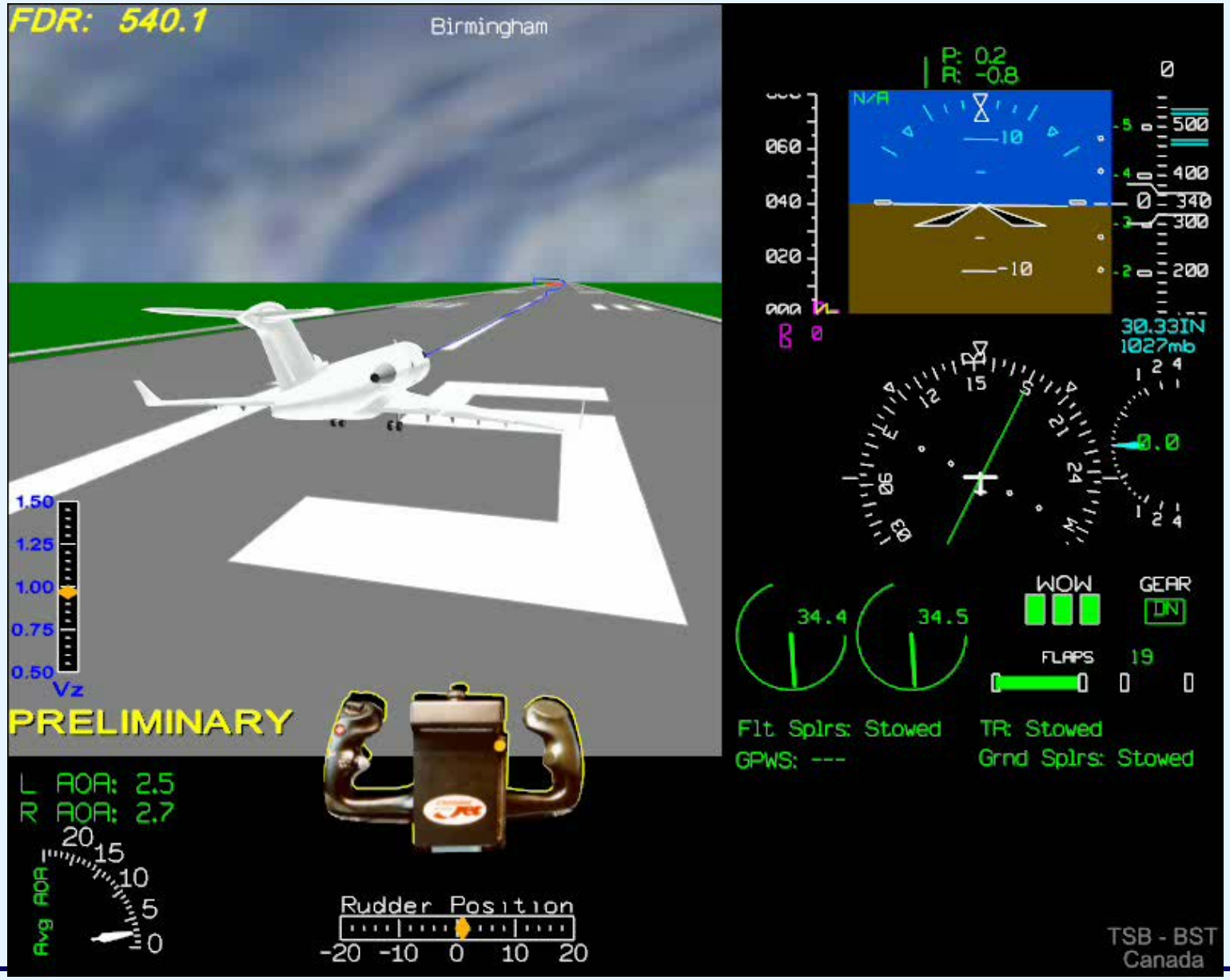


Frozen Contamination (frost, ice, snow or slush) adhering to aircraft surfaces, including engine areas, is a safety hazard.

Contamination similar to medium or coarse sandpaper on a wing may

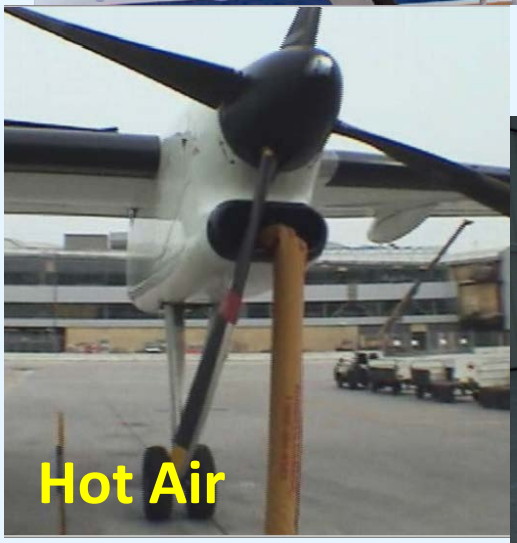
- reduce max. wing lift by 30%
- increase lift-induced drag by 40%
- reduce max. climb rate

Birmingham, UK – Jan 4, 2002



Deice if contaminated

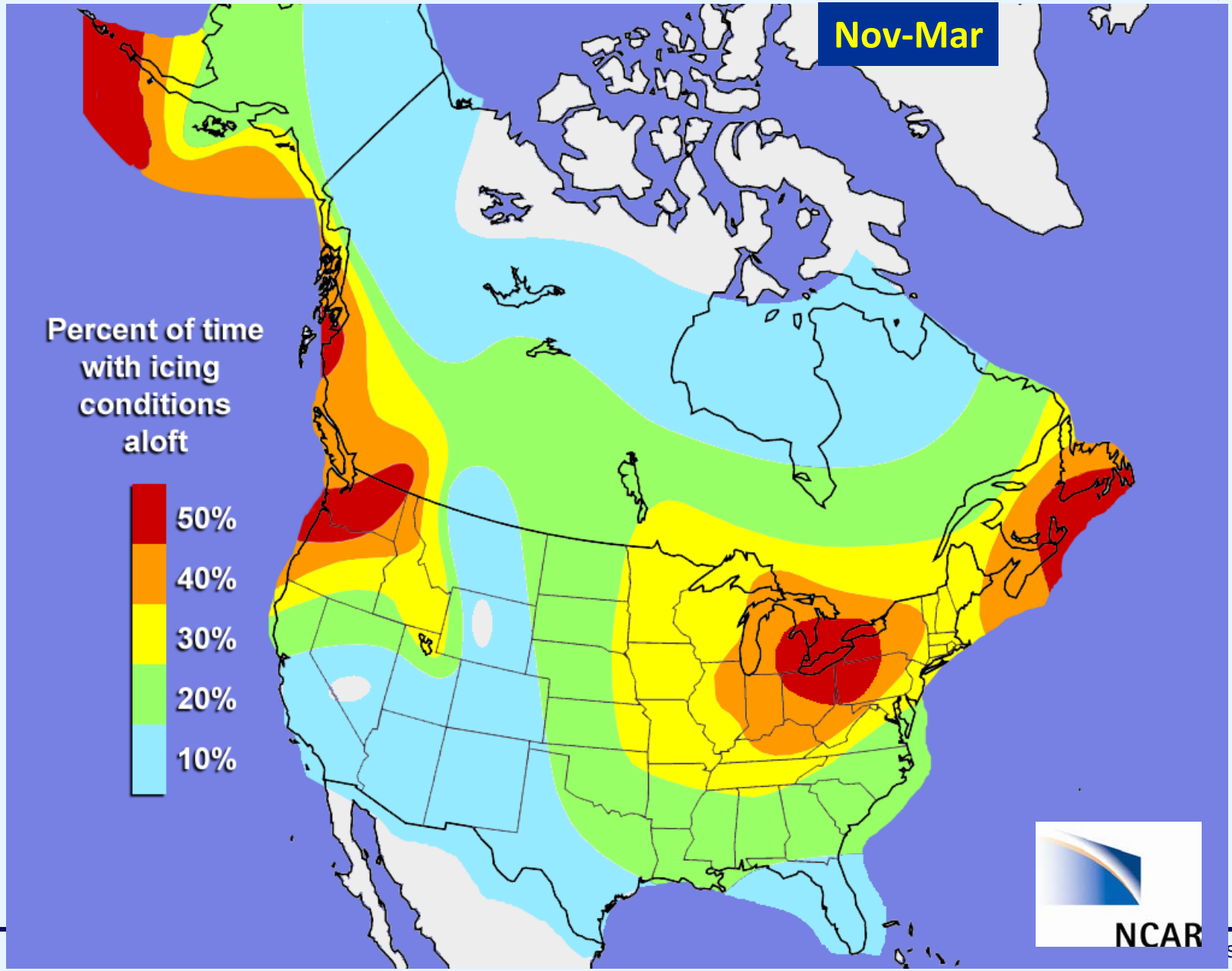
Remove all frost, ice & snow



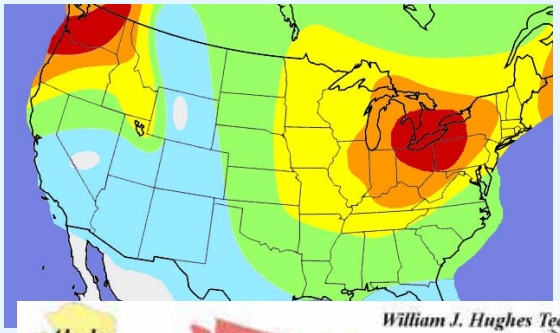
Ensure (by touch) a clean aircraft.

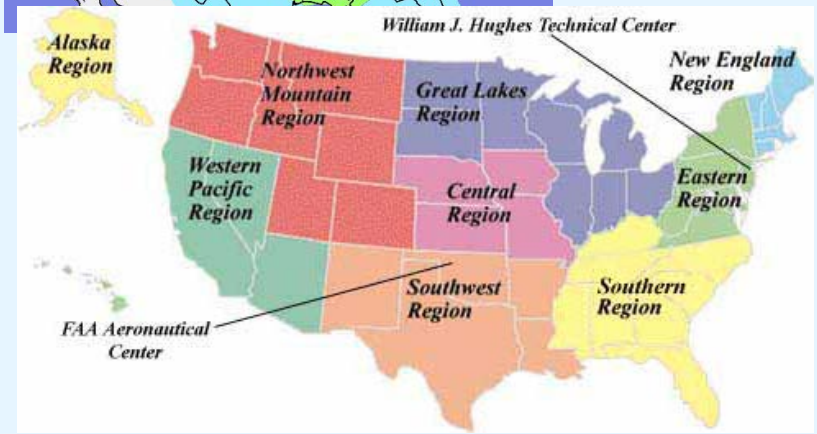
In-Flight Airframe Icing

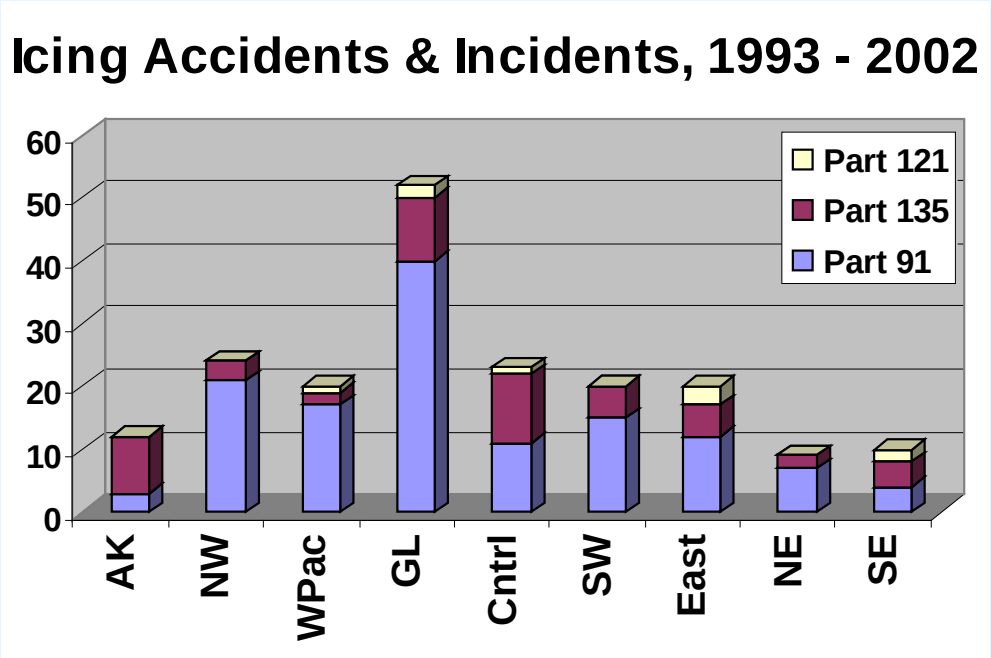
Where is the ice in Winter?



Icing Accidents by Region







Average Pilot Experience

- **Part 91: ~ 2500 hrs**
  60% had over 1000 hrs
- **Part 135: ~ 5000 hrs**
- **Part 121: ~ 9500 hrs**

NASA Commissioned Study: Green, 2004

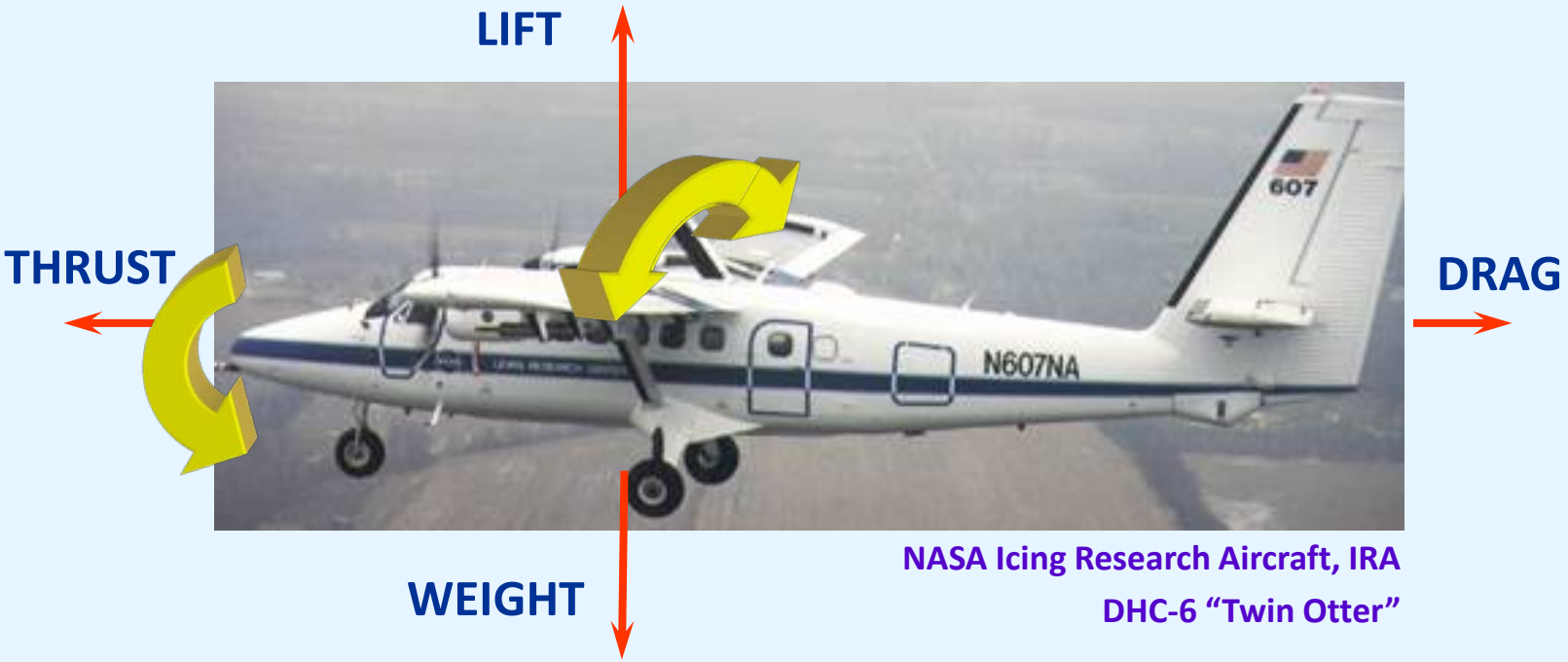
Part 91 ~ GA

Part 135 ~ Commuter & Air Taxi

Part 121 ~ Larger Revenue Service

Note: *Data not normalized by traffic*

Icing impacts Performance & Handling



NASA Icing Research Aircraft, IRA
DHC-6 "Twin Otter"

Icing negatively impacts each of these forces and/or may cause Roll or Pitch Upsets

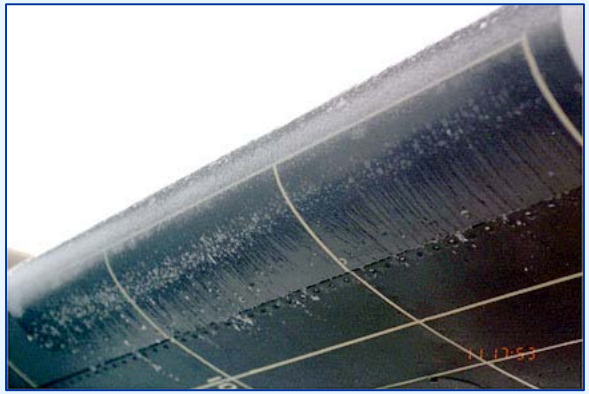
Adverse Performance & Handling FX

Performance Penalties

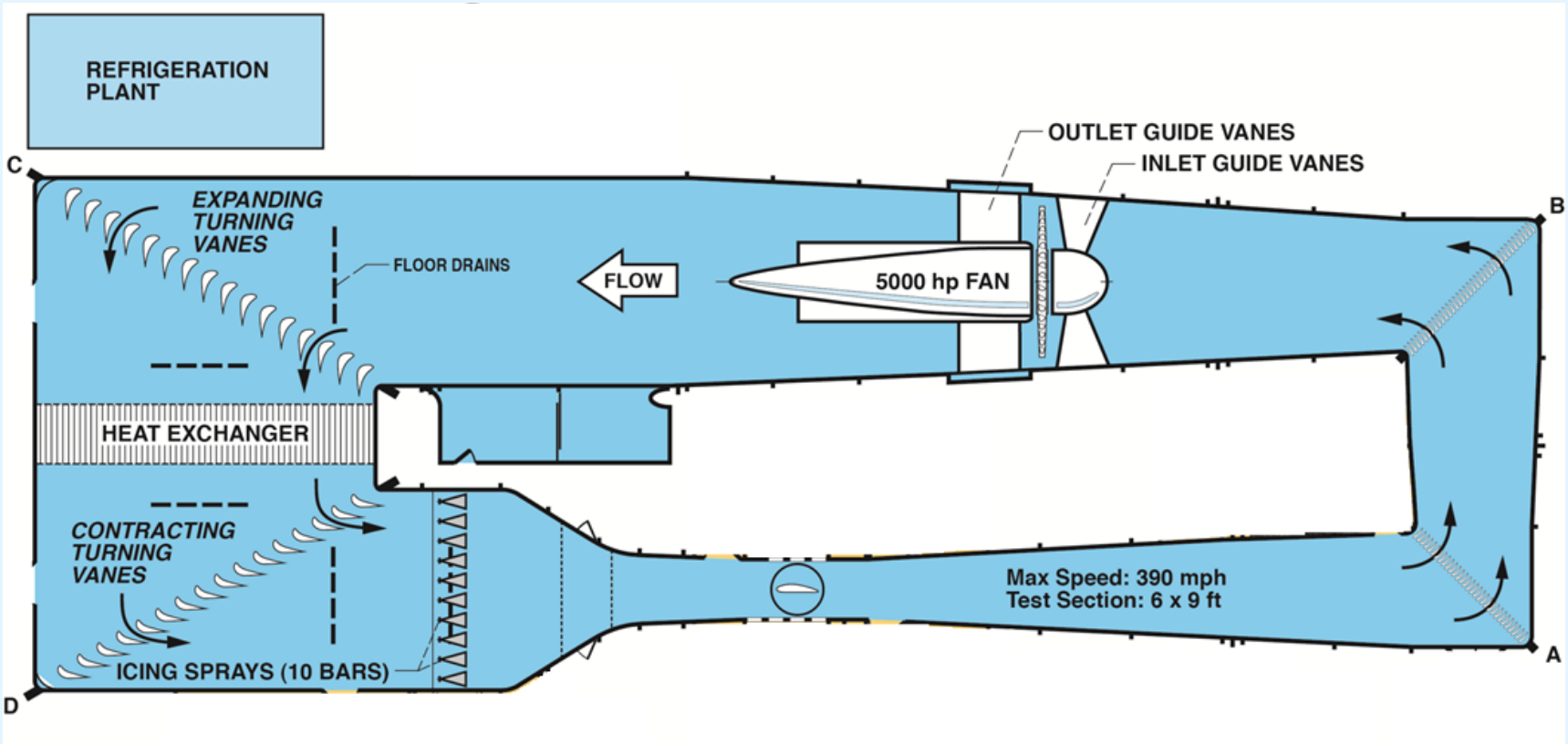
- Increase Drag
- Reduce Max Lift
- Decrease Thrust (possibly)

Handling Qualities

- Wing Stall (Roll or Pitch Upset)
- Tail Stall (Pitch Upset)



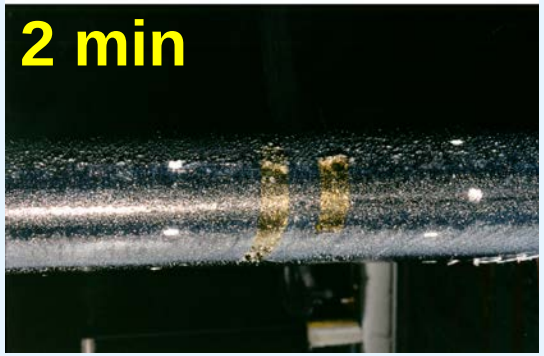
Icing Research Tunnel Schematic

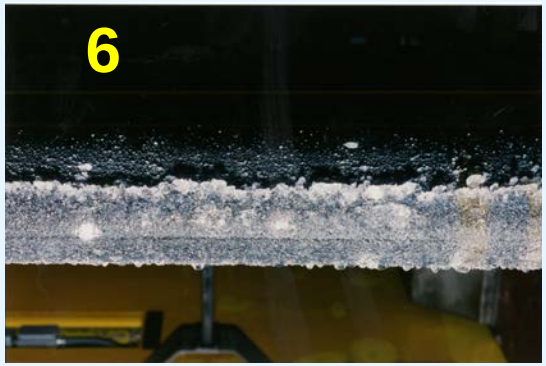


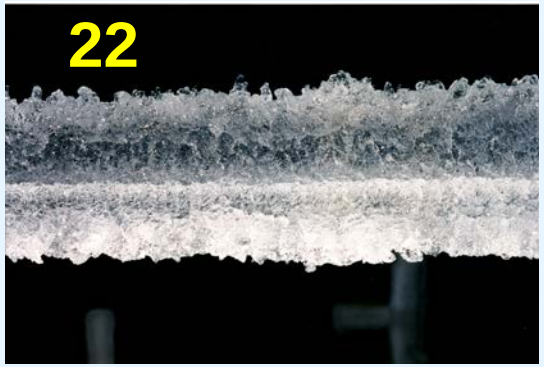
Simulates flight through an icing cloud:

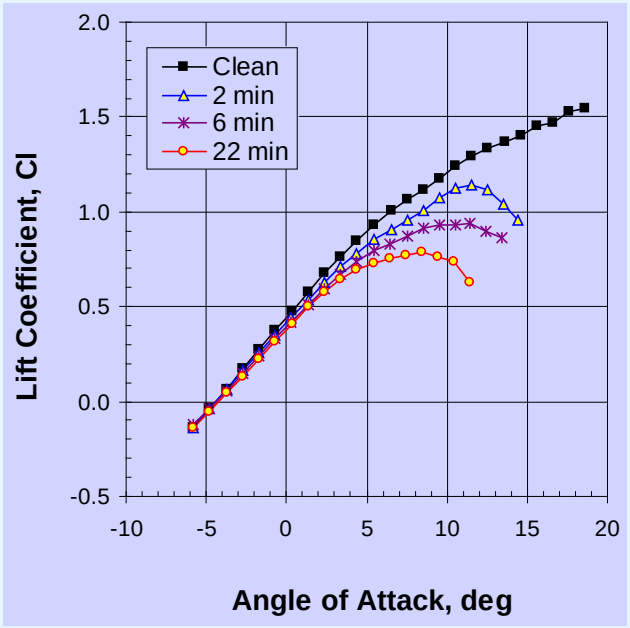
Airspeeds upto 300 kts, temperatures down to -35C, in cloud.

Ice Accretion – Performance Impact



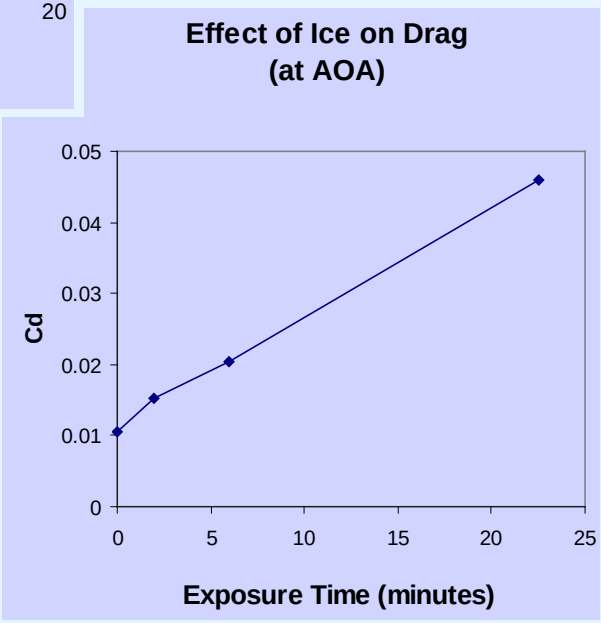






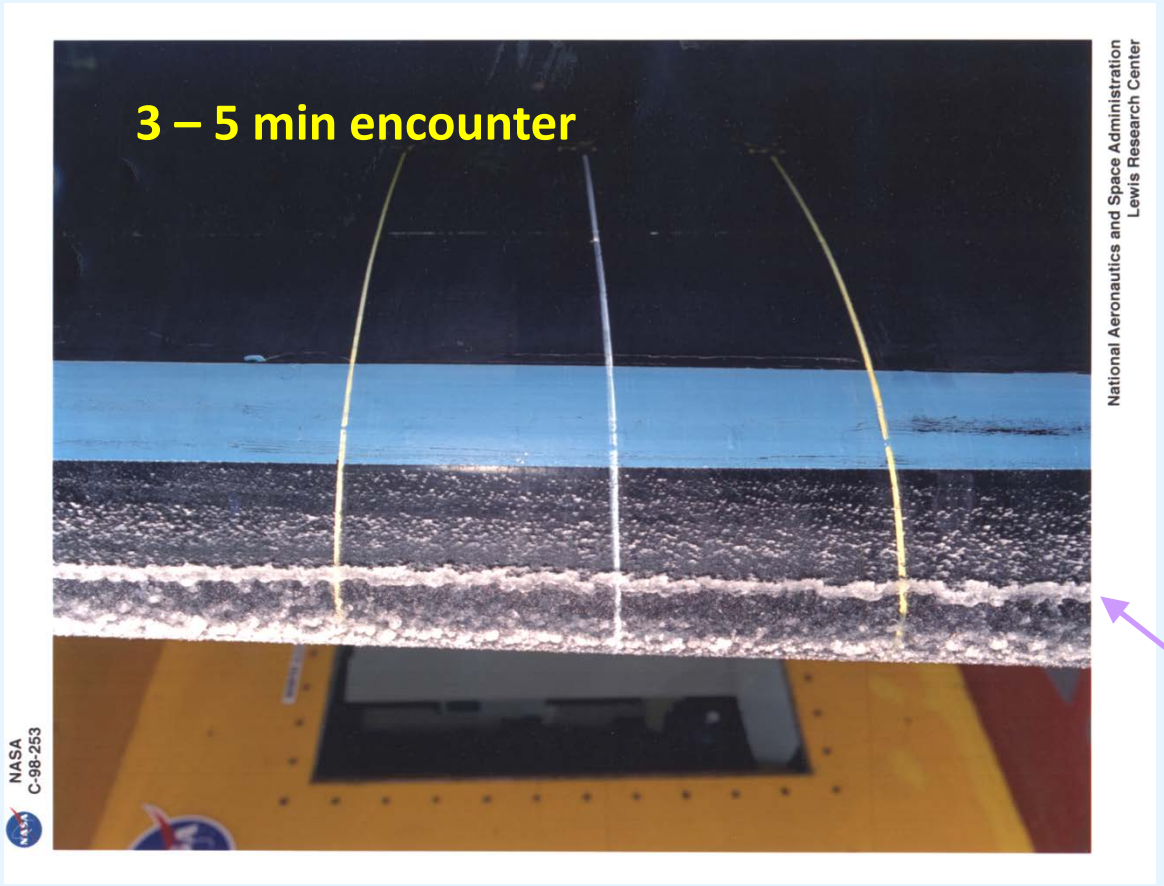
IRT Data – Stationary, Straight Wing

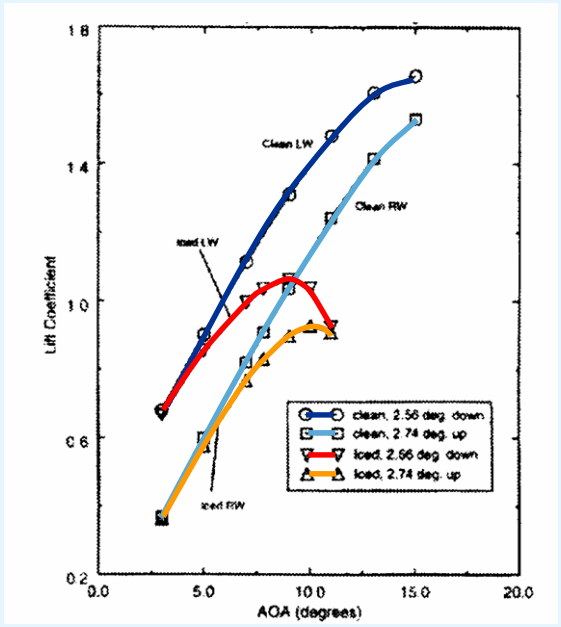
Noticeable performance degradations within 2 min.

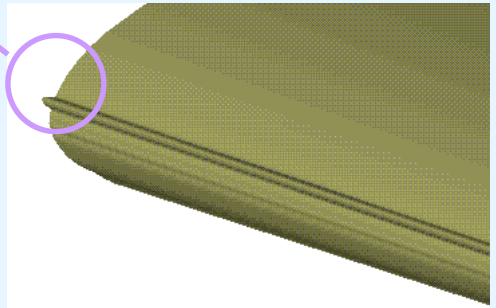


The Insidious Nature of Icing

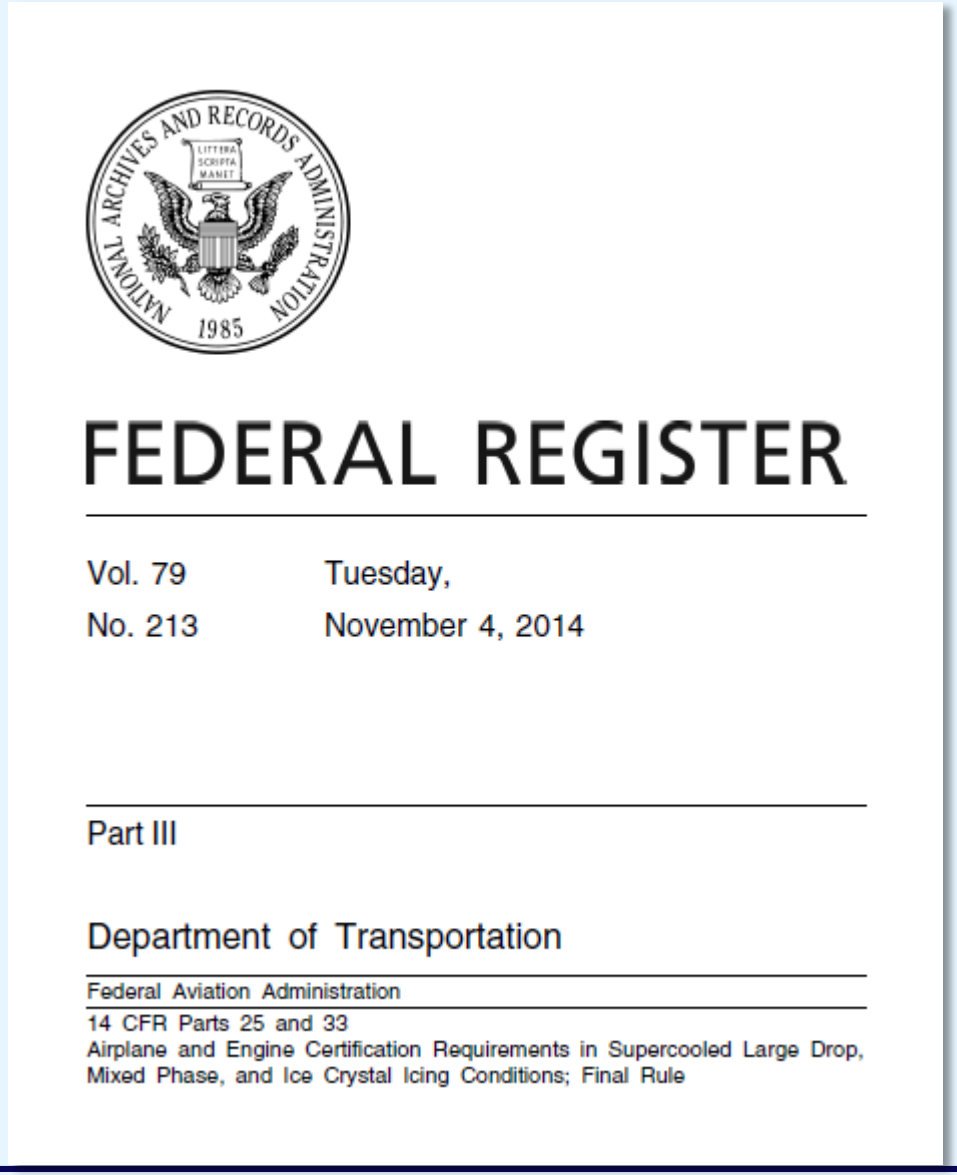
Accident: EMB-120; Monroe, MI; Jan 9, 1997







New Rule for SLD and Ice Crystals



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Part III

Department of Transportation

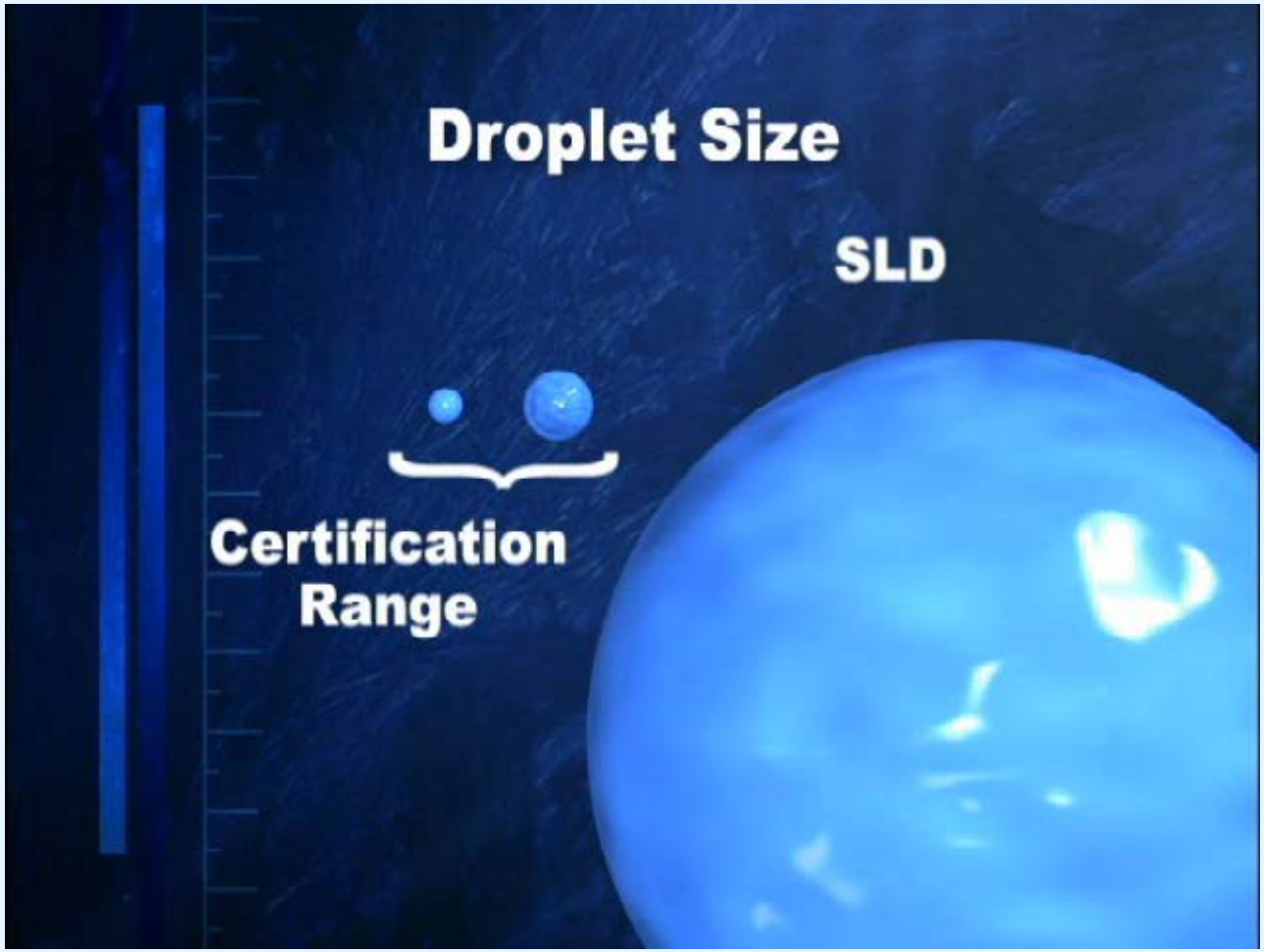
Federal Aviation Administration

14 CFR Parts 25 and 33
Airplane and Engine Certification Requirements in Supercooled Large Drop, Mixed Phase, and Ice Crystal Icing Conditions; Final Rule

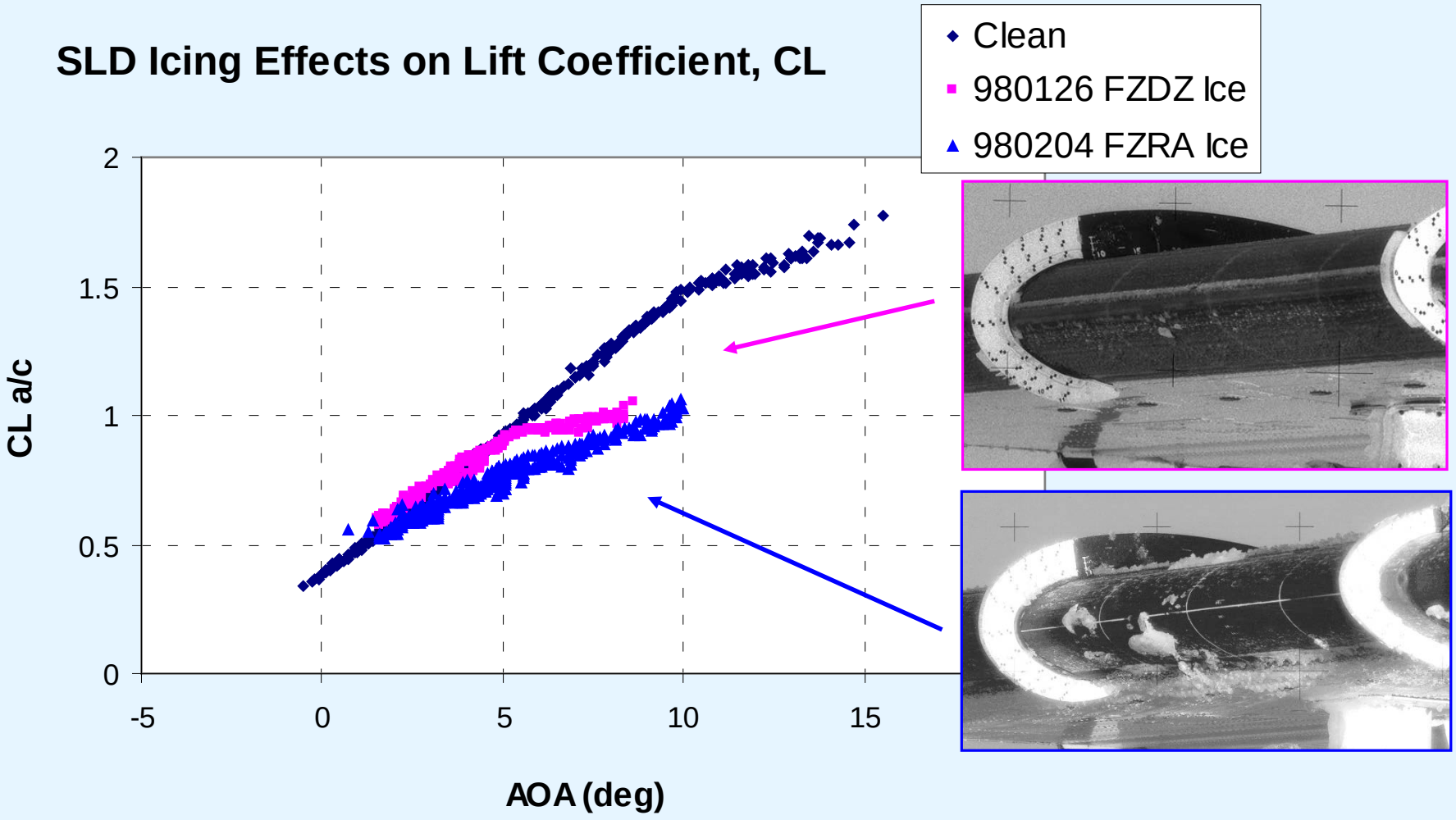
14 CFR **Parts 25 and 33**
Airplane and Engine
Certification Requirements in
Supercooled Large Drop,
Mixed Phase and
Ice Crystal Icing Conditions;
Final Rule

Supercooled Large Drop (SLD) Icing

Reported as FZDZ, FZRA @ surface; but may exist only at altitude (PL)



IRA: Flight Campaign in SLD



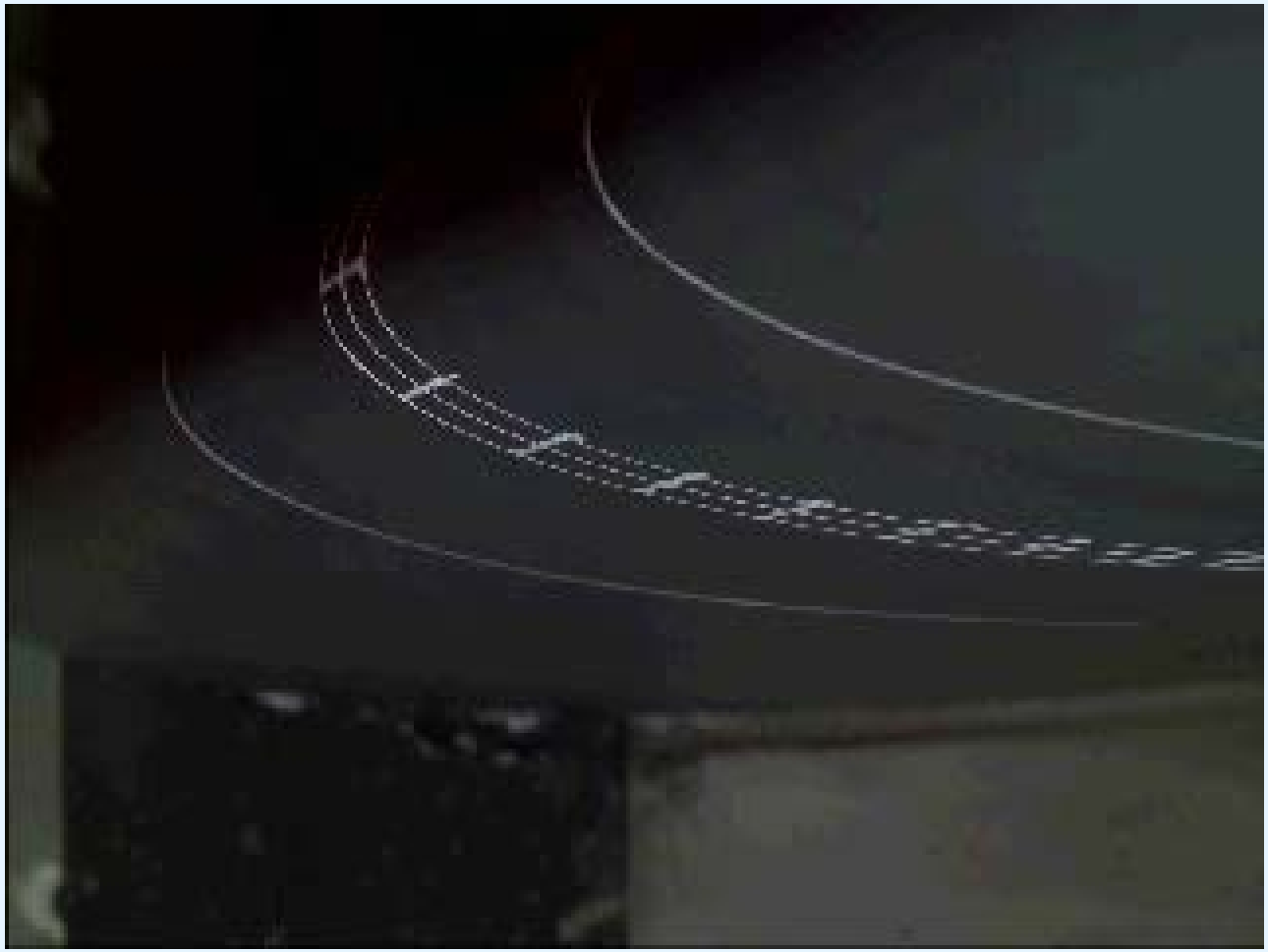
SLD Icing on Side Window

Image of SLD on NASA Icing Research Aircraft

Ice on side window

SLD Ice Accretion Video

Looking along LE of airfoil model in NASA's Icing Research Tunnel.



Time lapse video accretion in MVD = 140 μm (FZDZ)

stills

Operational Considerations

Preflight Planning

Preflight: Anticipate

Airframe structural icing *may* occur when supercooled *liquid* water strikes the aircraft

Visible Moisture & **Freezing Temps**

(Clouds & Precipitation) **(AFM / +2 C to –20 C)**

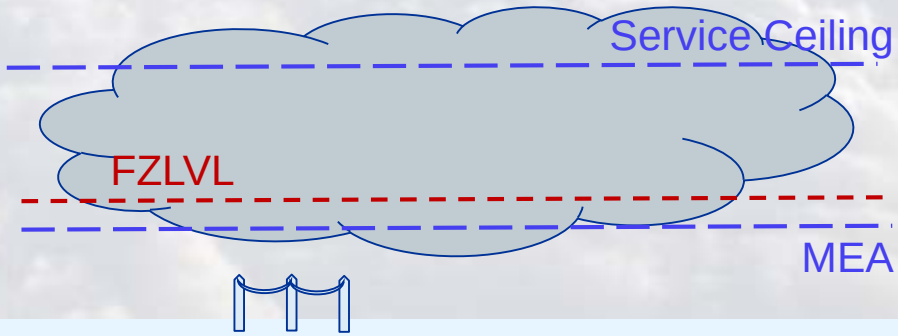
Be sure you know:

- Ceilings
- Cloud Tops
- Freezing Level
- PIREPS
- Frontal Activity

ADDS is a good source

Compare to:

- MEA / MVA
- Practical Ceiling



Monitor the Environment

Local – are you in icing conditions?

- Clouds & Precipitation
- Temperature (+5C to -20C)

Request Weather Updates / PIREPs
Enroute/ Destination/ Alternates
Update Alternates as req'd

Detect Icing Conditions

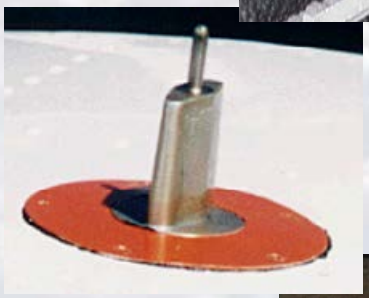
Visual Cues

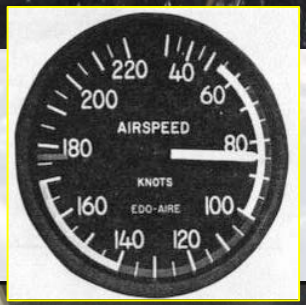
Ice accretes first on objects with a small LE radius (sharp):

- Wipers, OAT probe, struts, spinner

Tactile & Instrument Cues

- Ice Detector
- Airspeed bleed
- Trim in Motion (autopilot)
- Stall Warning – Do Stick Shaker/ Pusher adjust if IPS turned on?





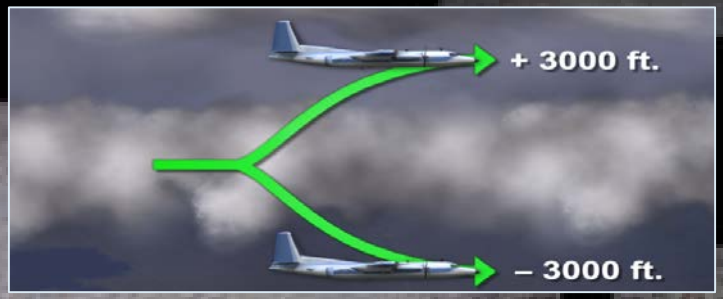
HAND-FLY in Icing
(*at least periodically*)

Work to Exit Icing Conditions

If in Mod – Severe Icing

- Climb
- Descend
- Divert
- Return
- Continue

Make a PIREP (when able)



Limit autopilot use while maneuvering.

*Convey the **why, what** & **when** to ATC*

e.g. "I'm in moderate icing, I need to ____ immediately"

If all else fails…

Declare an Emergency

Terminal Area – Approach & Landing

- Low
- Slow
- Configuring

Handling – Wing Stall

When: Iced wing will stall at lower AOA than clean wing

- Slow Airspeed
- High “g” flight (e.g., bank)

Feels like:

- Buffet in Airframe
- Abnormal Roll Control

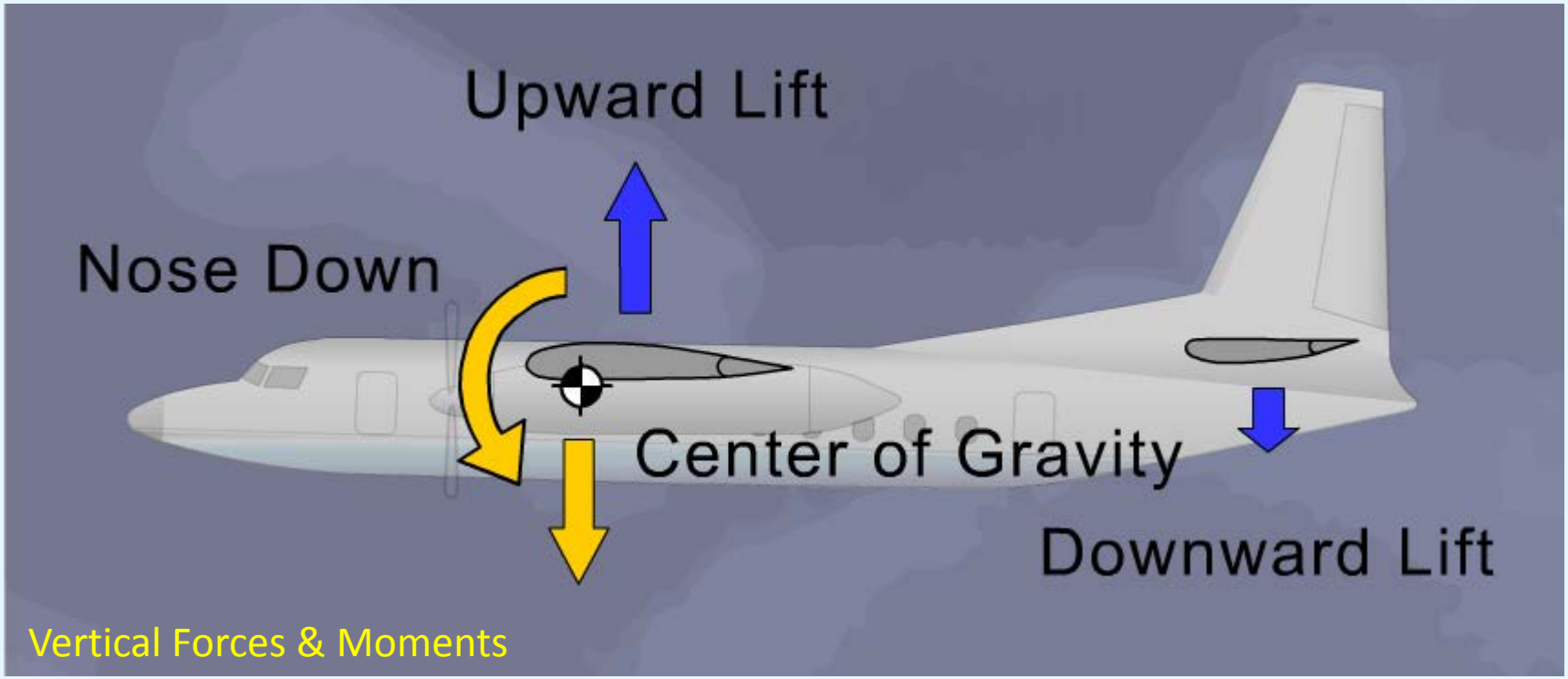
What:

- Roll Upset
- Pitch Upset

Recovery: Lower AOA

- Stick Forward
- Add Power

Role of the Tailplane



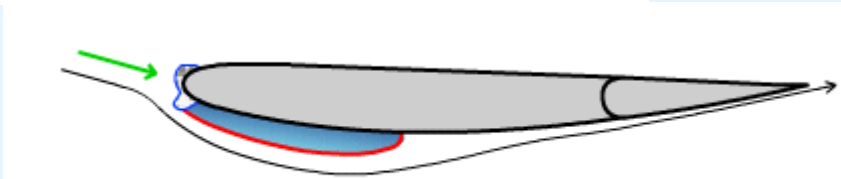
Tail Provides Downward Lift (upside down wing)

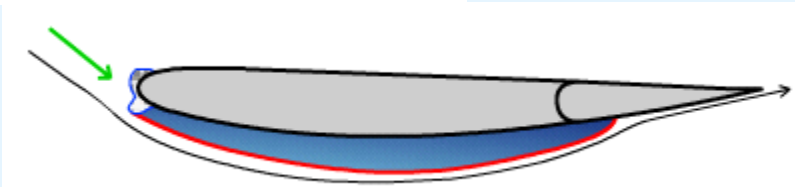
Tail is Opposite of Wing

Which aircraft have experienced tail stall?

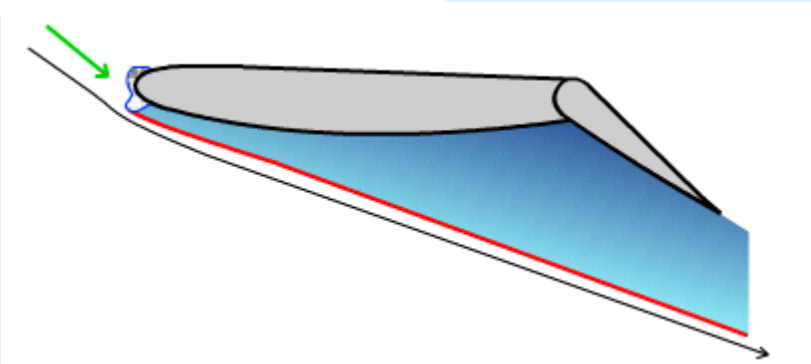
Historically, turboprops w/ large flap deflections and unpowered controls that use aerodynamic balance to trim.

Flow Separation – Ice on the Tailplane



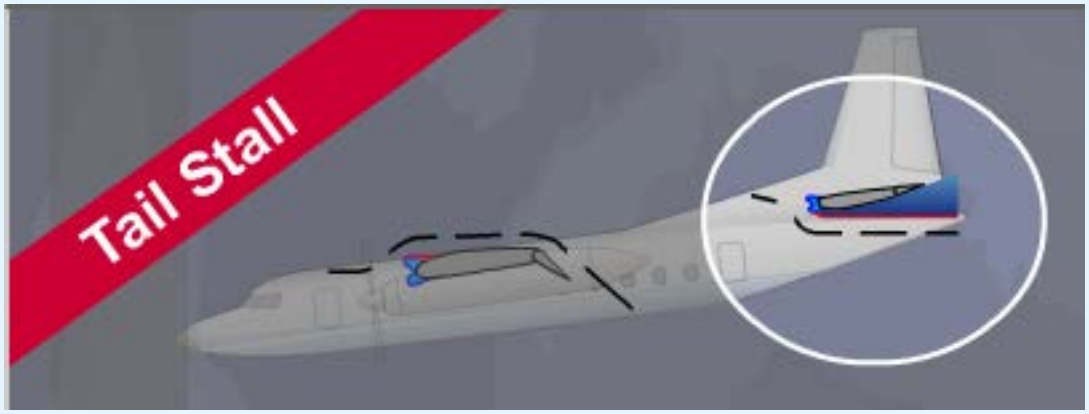


Tail Stall!
Nose pitches down



Angle of attack at the tailplane increases due to flap deflection

Tail Stall – Summary



When: Iced tailplane can stall

- Flaps Down
- High Airspeed
- High Thrust (hi thrust line A/C)

Feels like:

- Lightening / Buffet in Stick
- Can't Trim Pitch
- Pitch Excursions (PIO)

What:

- Pitch Upset

Recovery: Lower Tail AOA

- Flaps Up
- Stick Back
- Maintain/Reduce Power

Undo What You Just Did

Tail Stall Event

Footage of a Tail Stall Event

NASA Icing Research Aircraft

- 22 min “normal” icing accretion
- V = 1.5 Vs (High Speed)
- Flaps = 40°
- *Increasing Thrust*

Tail Stall Event

NASA Icing Research Flight

Maintain Control

If your airframe becomes iced:

1. Maintain control of your aircraft
   (You may have to exchange altitude for airspeed)

2. Realize your speed range may have shrunk
   Reduced max Lift will increase stall speed
   Increased Drag will reduce max speed & ROC

Vs → **← Vmax**

Airframe Icing Summary

- Ground Icing
  - Get It Off! Keep It Off!
- In-Flight Airframe Icing – *Smart Decision Making*
  - Pre-flight to avoid the ice; Know your Outs.
  - Update information enroute
  - Monitor for ice accretion…work to exit
    - Hand-Fly (periodically)
  - Terminal Area: Wing vs Tail Stall

For more information

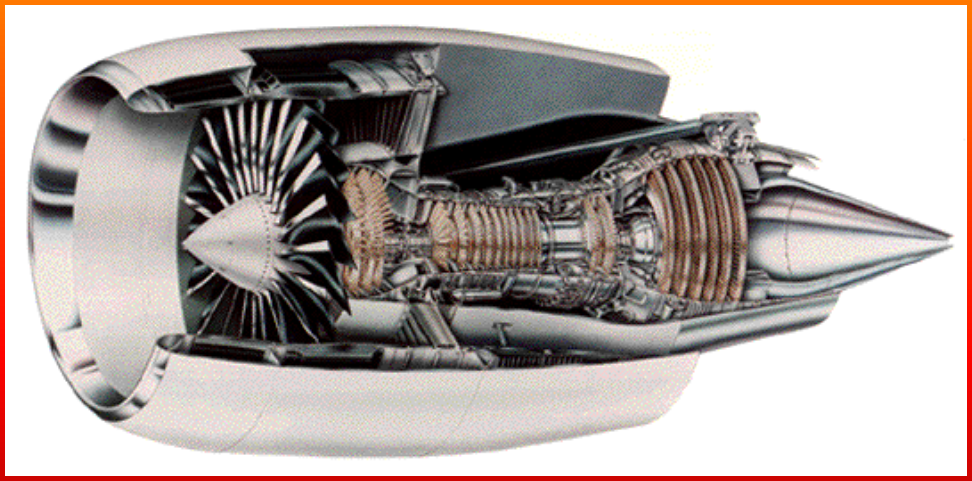
http://aircrafticing.grc.nasa.gov

Or search on "**NASA aircraft icing**"

Turbine Engine Ice Crystal Icing

Engine Ice Crystal Icing: ice crystals, in ultra high quantities (g_ice/m^3), are ingested into a turbine engine.

Sometimes the engine experiences power loss events such as rollback, stall, surge, flameout or FOD.

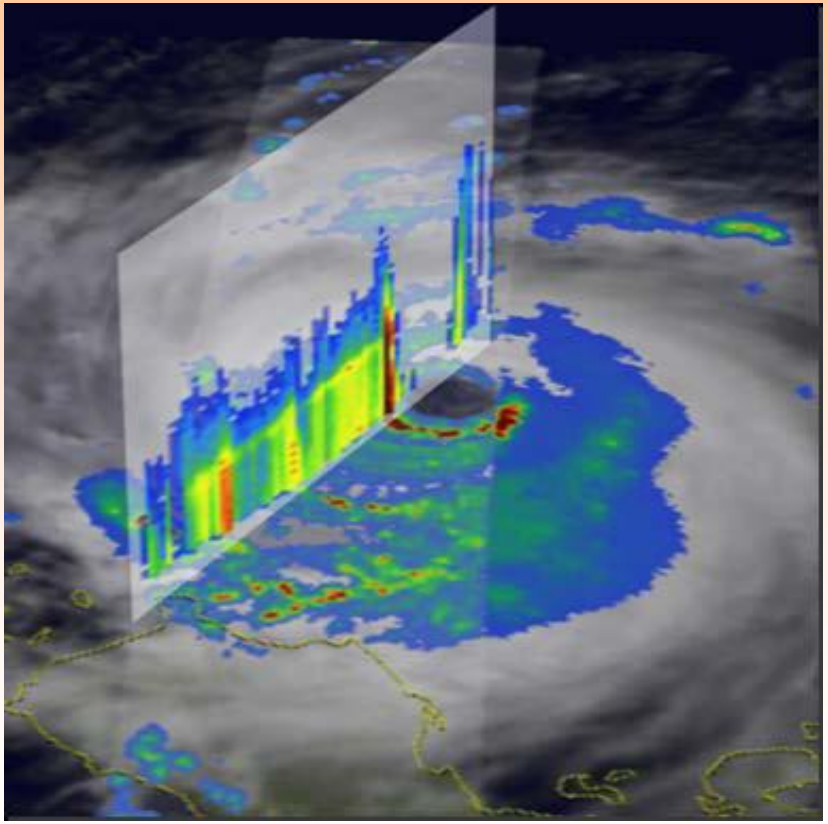


Ice Crystal Environment

- Over deep convective activity*: CB, TS…Typhoon
- Typically above FL220, where supercooled liquid not likely present.
- TAT reading *warmer* than normal (Tropical Day)

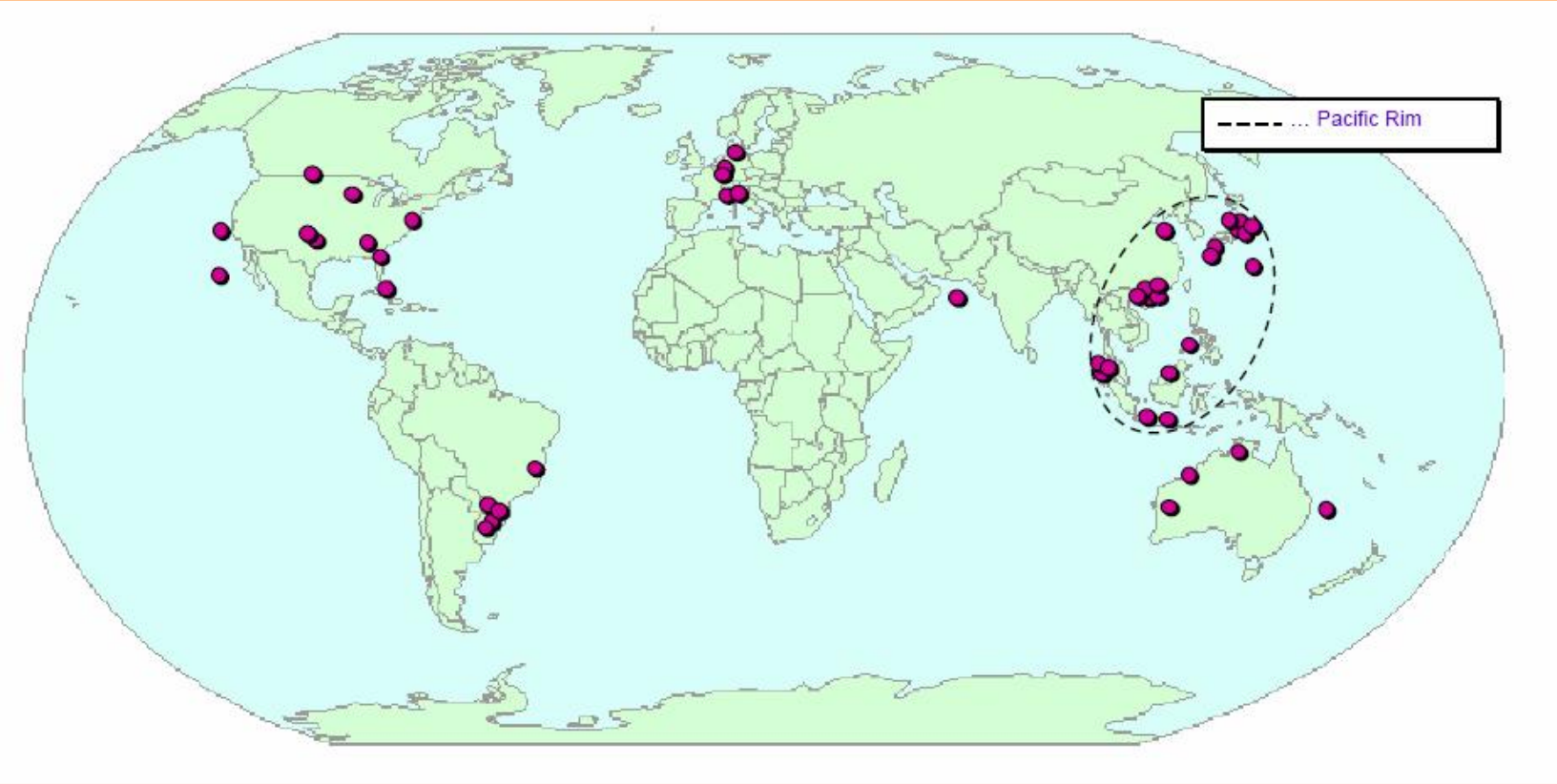
Possible Cues

- Light – Mod Turbulence
- No airframe icing
- In visible moisture, green or black on pilot radar at flight level



* Moisture, lifted up, becomes ice crystals in very large quantities (upto 9 g/m^3), but with sizes too small to trigger typical radar thresholds.

Map of Ice Crystal Engine Icing Events

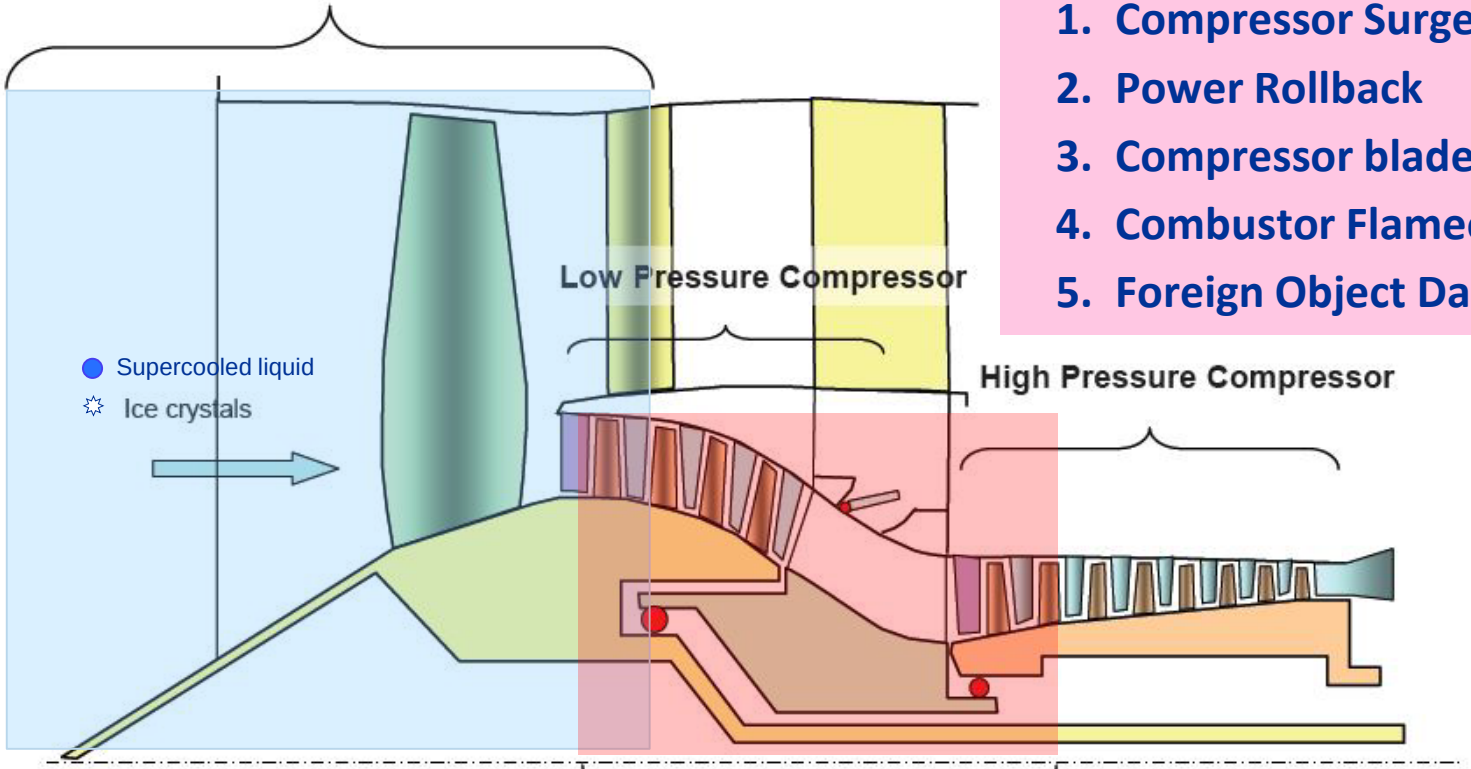


Icing Threat Regions w/in Turbine Engines

Supercooled Liquid Water Region of Concern

Ice accretion in Core flow path may cause

1. **Compressor Surge, Stall**
2. **Power Rollback**
3. **Compressor blade damage**
4. **Combustor Flameout**
5. **Foreign Object Damage**



Turbine Engine Cross-Section

Ice Crystal Region of Concern

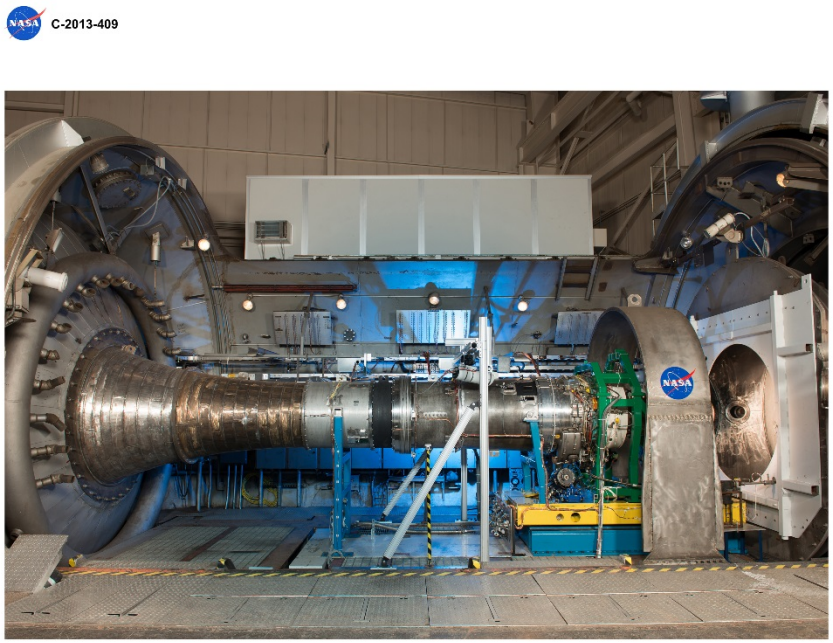
Propulsion Systems Laboratory

PSL Icing Enhancement Hardware

18-ft Plenum and
Spraybars

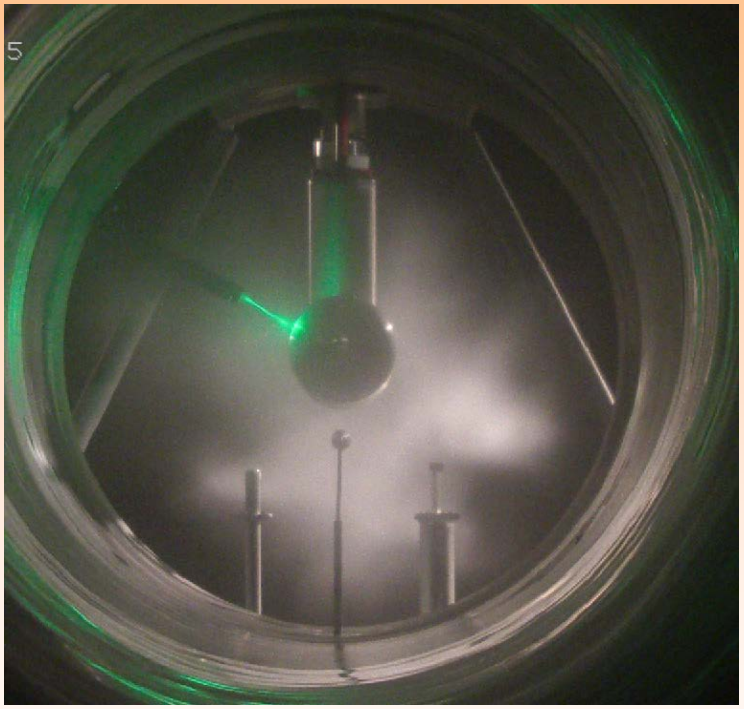
There is exactly 1 altitude
engine test stand with
ice crystal capability.

Engine Installed



National Aeronautics and Space Administration
Glenn Research Center at Lewis Field

Cloud & Instrumentation in PSL

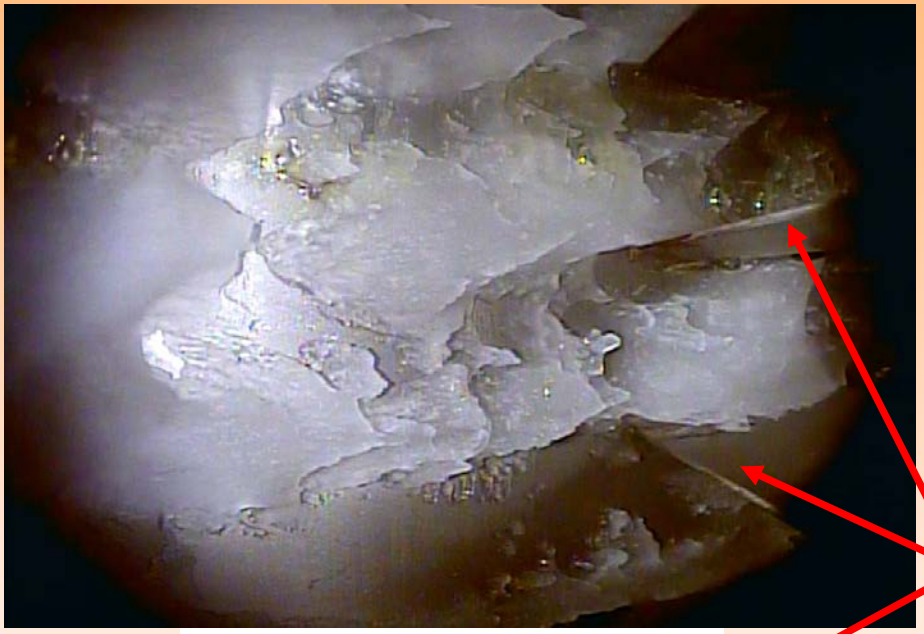


View from the Plenum

Instrumentation to measure:

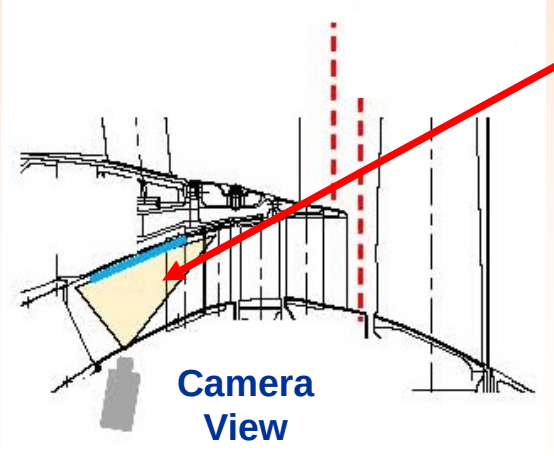
- Total Water Content, g_{H2O} / m^3_{air}
- Temperature of air
- Temperature of particles (ice and/or water)
- Specific Humidity, $g_{water\ vapor}$/ $kg_{dry\ air}$

Ice Accretion in the LPC



Flow

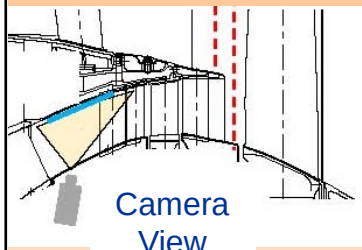
Exit Guide Vanes



Flow

PSL: Engine Ice Crystal Icing

Time lapse, looking at outer wall aft of Exit Guide Vanes



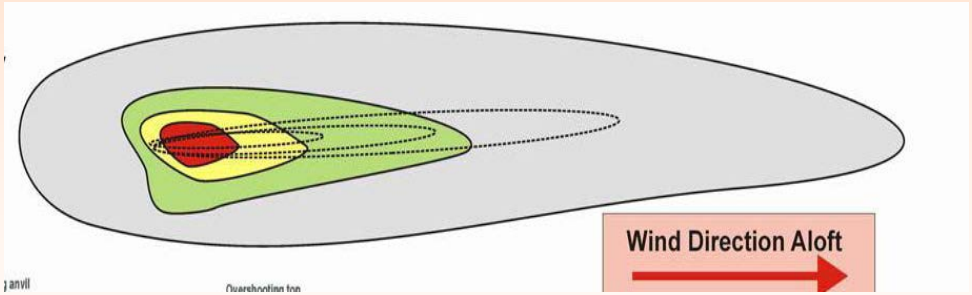
Flow

This engine is obsolete

Engine Ice Crystal Summary

- **Power Loss Events can happen in high IWC on a wide class of turbine engines**

- **Avoid (when possible) ice crystal environments**
  - **Over & Downwind (the anvil) of deep convective activity**



Questions?

Pilot Training Aids:

http://aircrafticing.nasa.gov/

[*A Pilot's Guide to In-Flight / Ground Icing*]