Ground & In-Flight Icing

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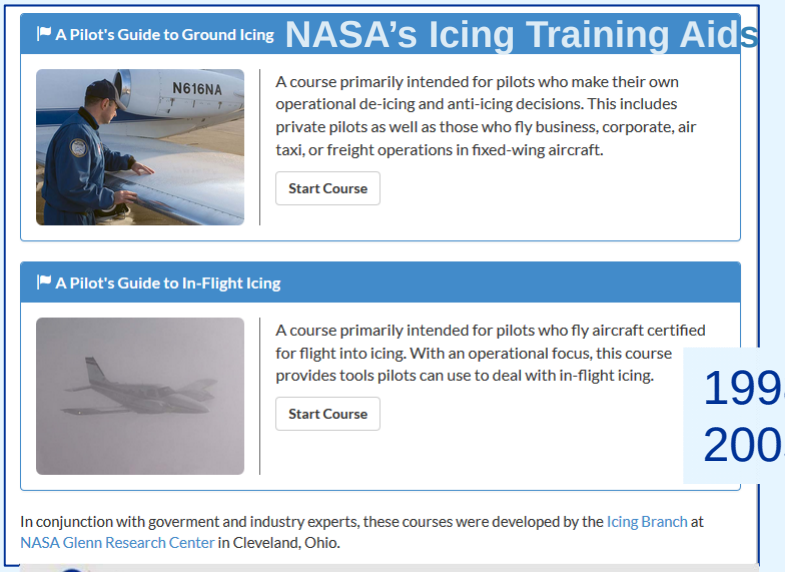
(Aero. Engineer)
NASA Glenn

Who am I?

Propulsion Systems Lab



1998 – 2005

Icing Research Tunnel

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"

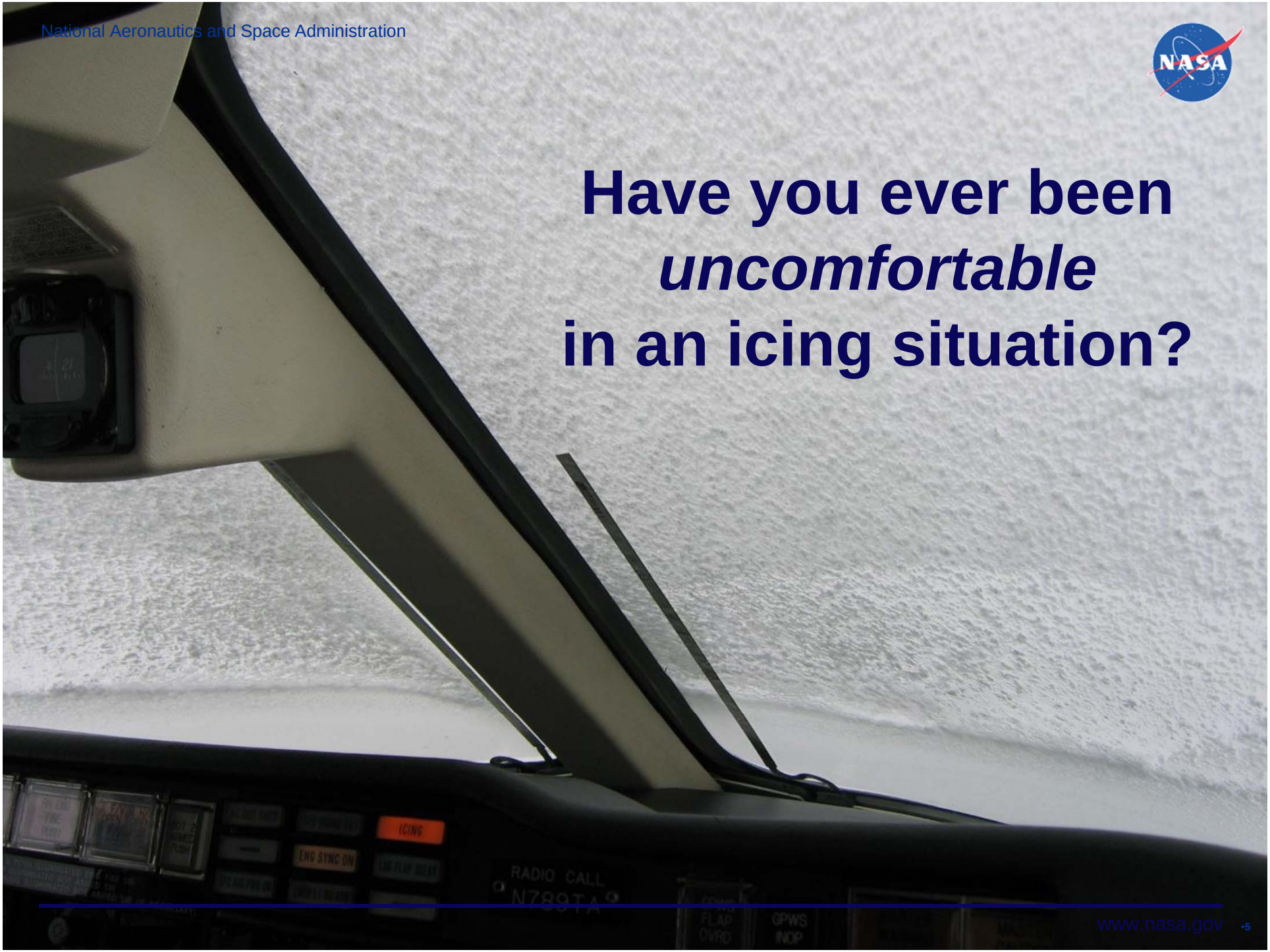
In conjunction with goverment and industry experts, these courses were developed by the Icing Branch at NASA Glenn Research Center in Cleveland, Ohio.

Which do you fly?

Piston
Single / Twin
IPS?

Turboprop,
typically
De-ice

Jet,
typically
Anti-ice



Have you ever been *uncomfortable* in an icing situation?

Outline

- **Ground Icing** (briefly)
- **In-Flight Airframe Icing**
  - 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

Ground Icing - Contamination

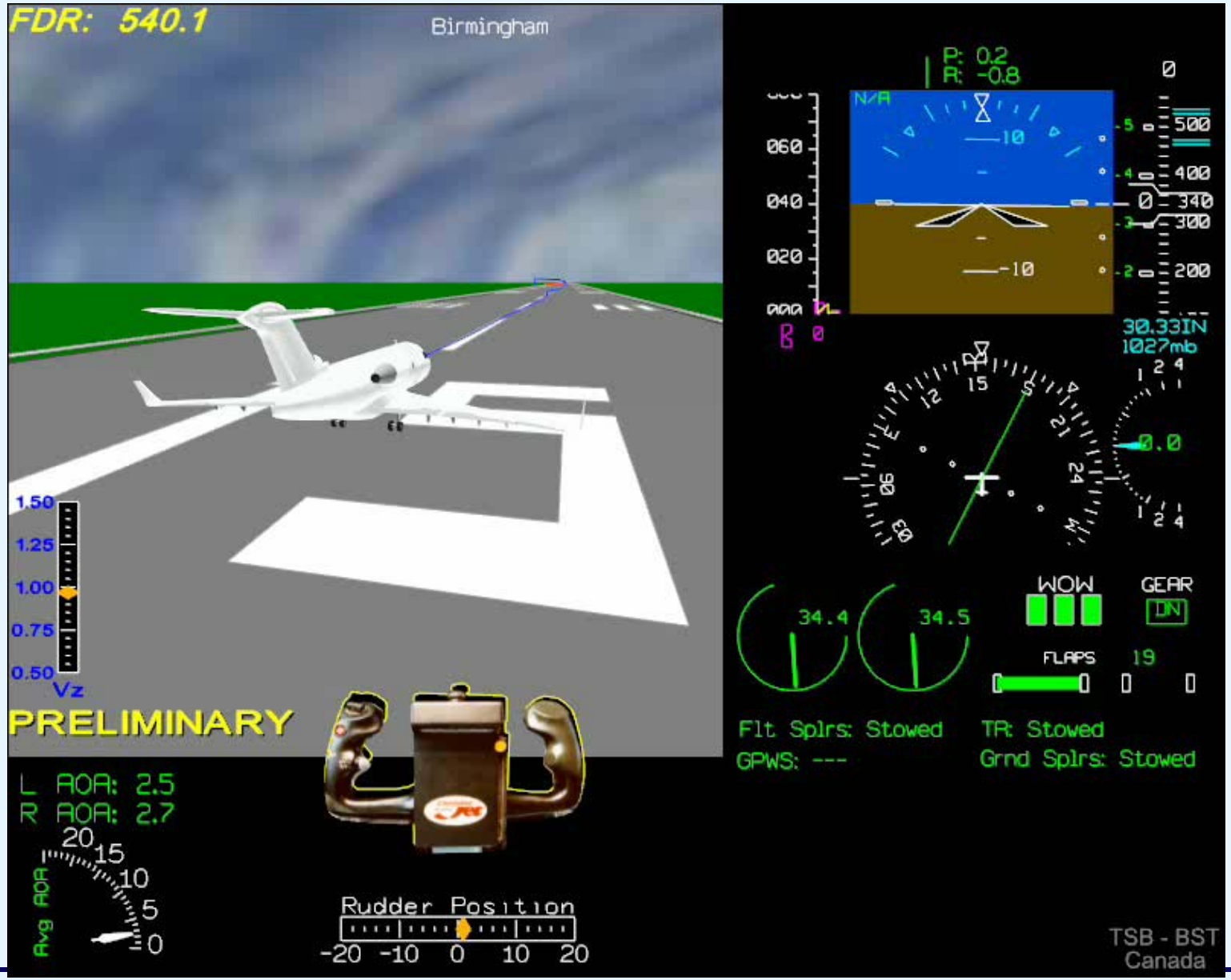
Ground Icing

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

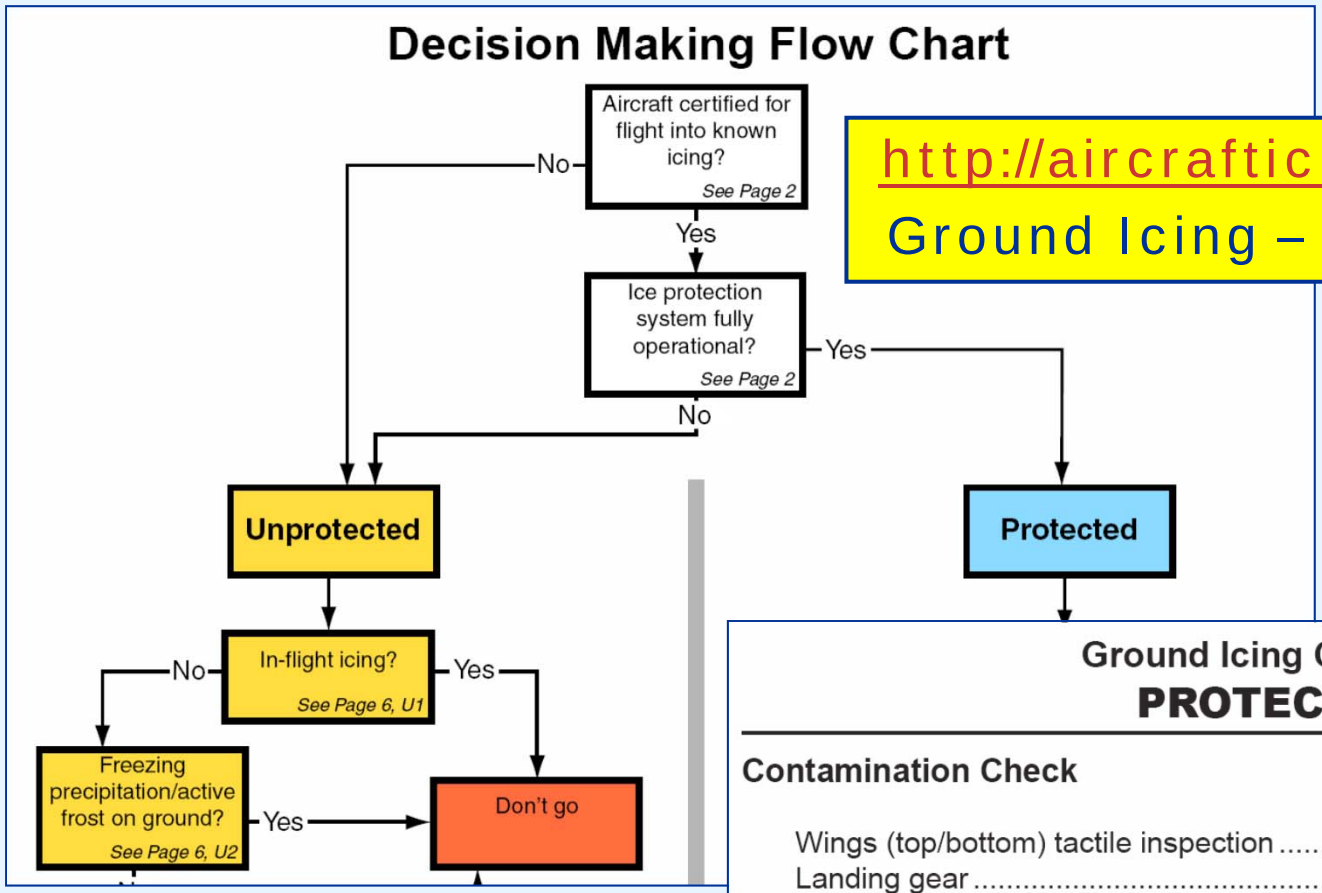


Deice if contaminated

Remove all frost, ice & snow

Ensure (by touch) a clean aircraft.

A Pilot's Guide to Ground Icing: Review Material



http://aircrafticing.grc.nasa.gov

Ground Icing – Review Material

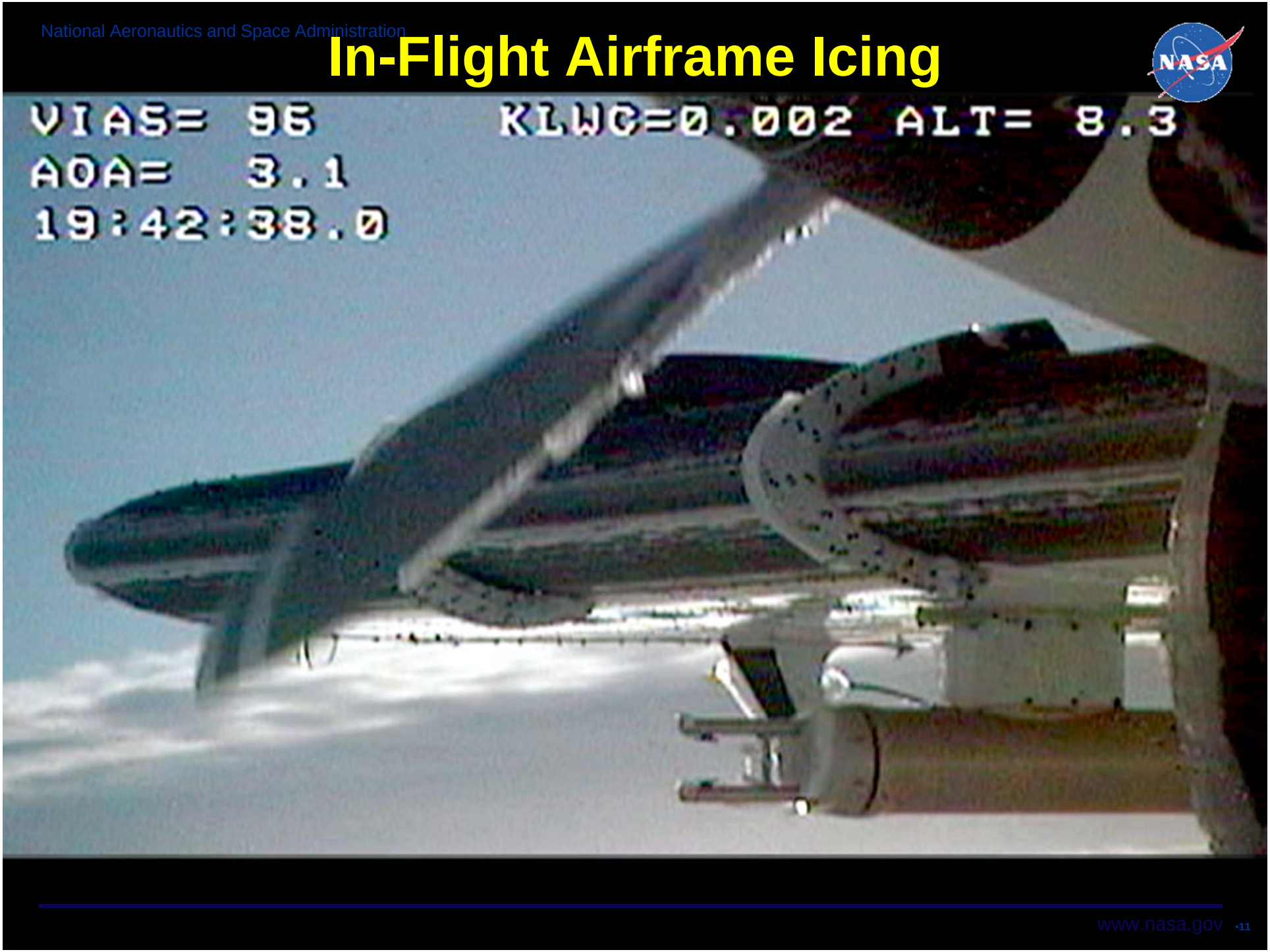
Ground Icing Checklist

PROTECTED

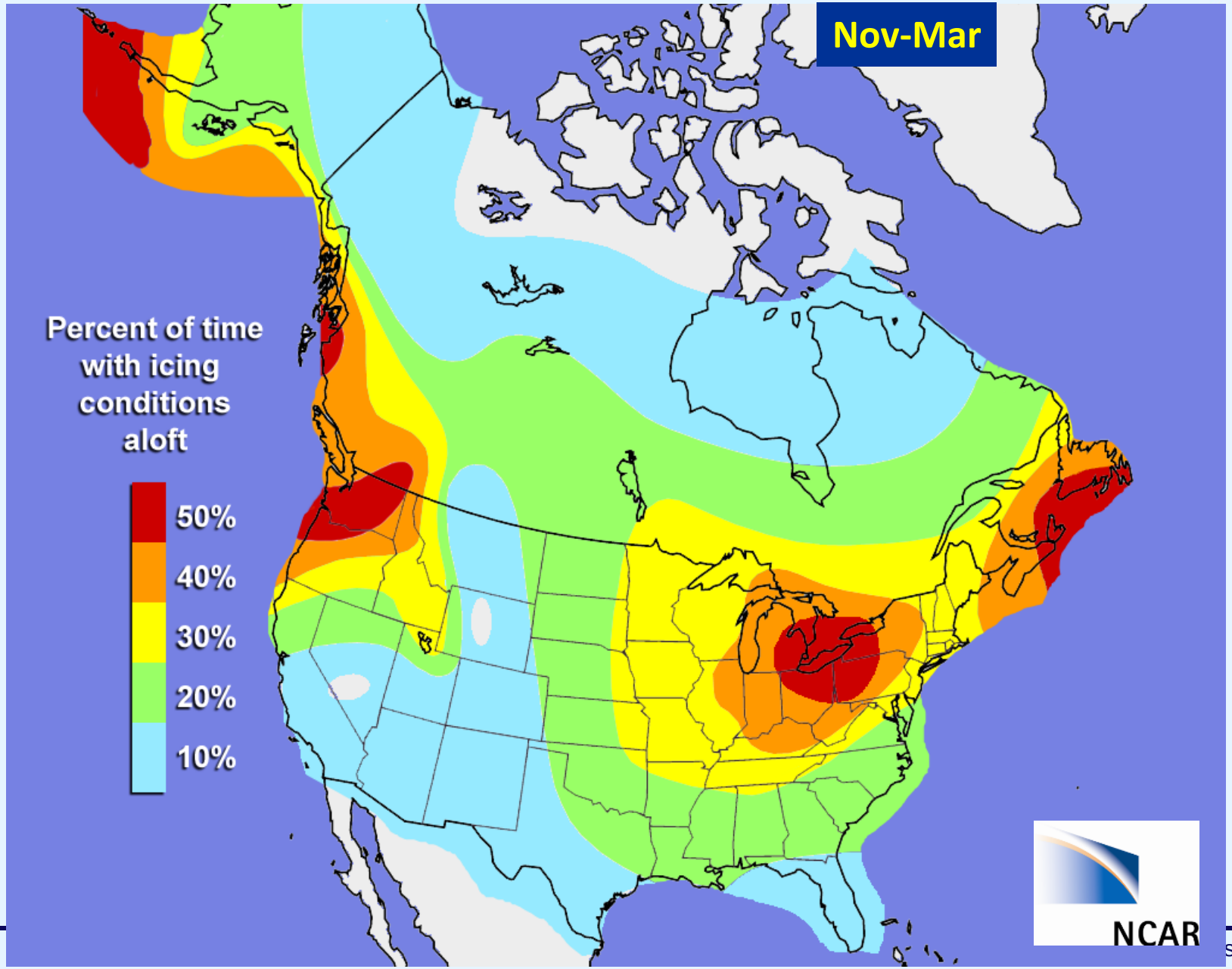
Contamination Check

Wings (top/bottom) tactile inspection	clear
Landing gear	clear
Horizontal stabilizer (top/bottom) tactile inspection	clear
Elevator/rudder control surfaces and gaps	clear
Aileron/flap/slats and gaps	clear
Engine/APU inlets	clear
Static ports/pitot tubes/sensors	clear
Fuselage	clear

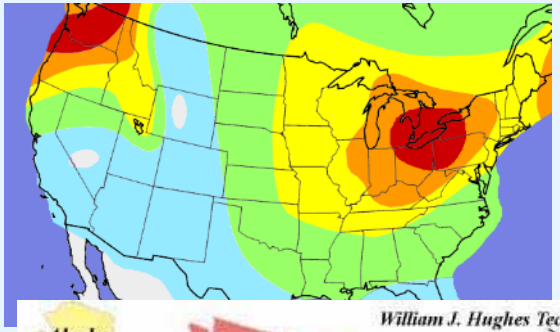
In-Flight Airframe Icing

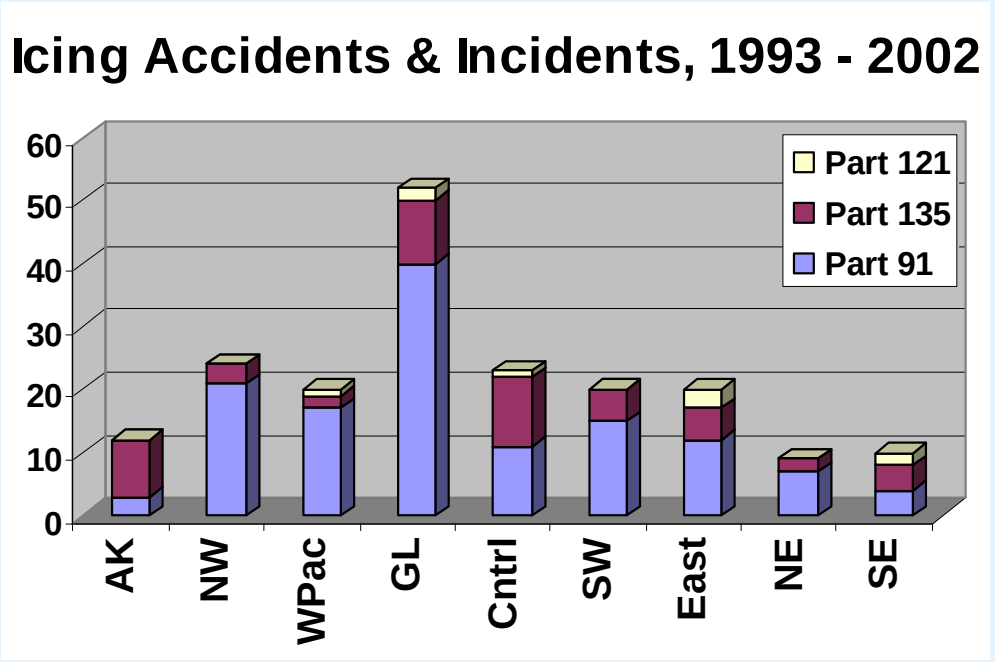


Where is the ice in Winter?



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

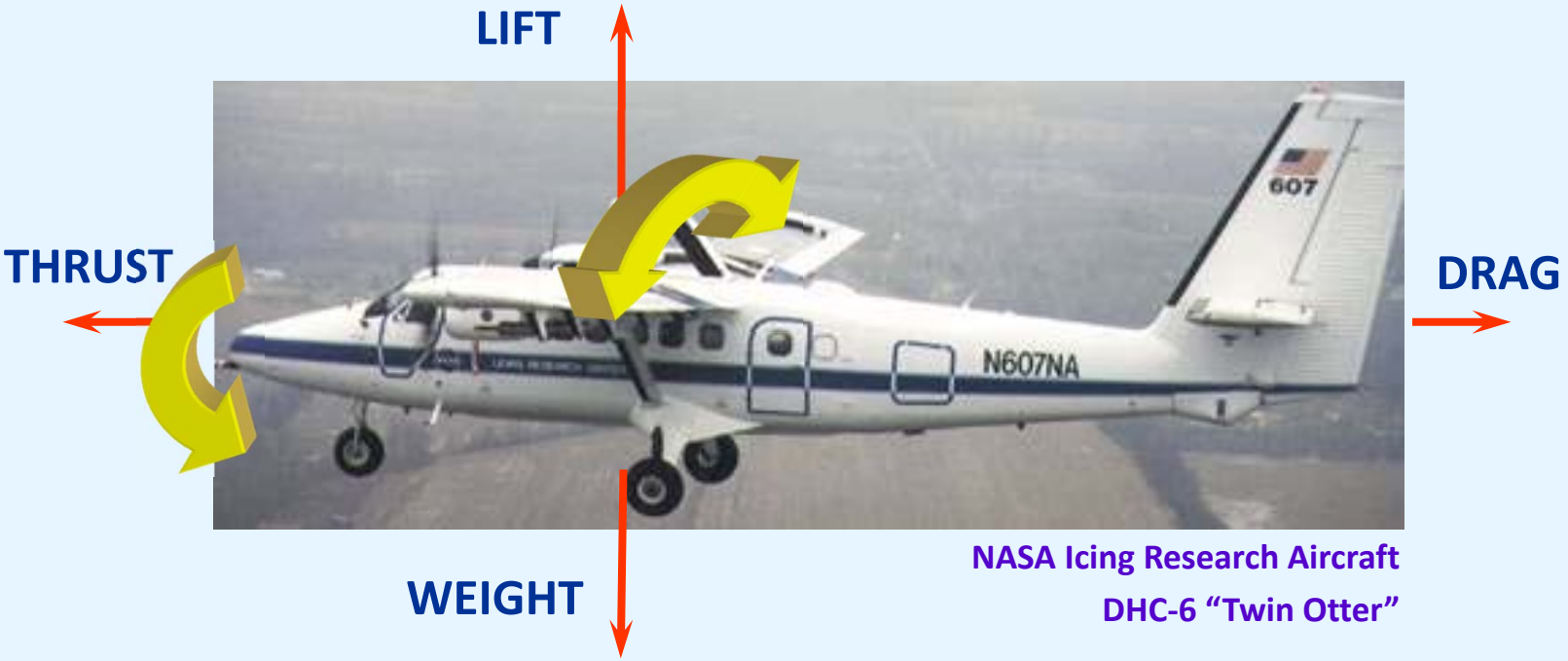
Part 91 ~ GA

Part 135 ~ Commuter & Air Taxi

Part 121 ~ Larger Revenue Service

Note: *Data not normalized by traffic*

Icing impacts Performance & Handling



NASA Icing Research Aircraft
DHC-6 "Twin Otter"

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

Adverse Performance & Handling FX

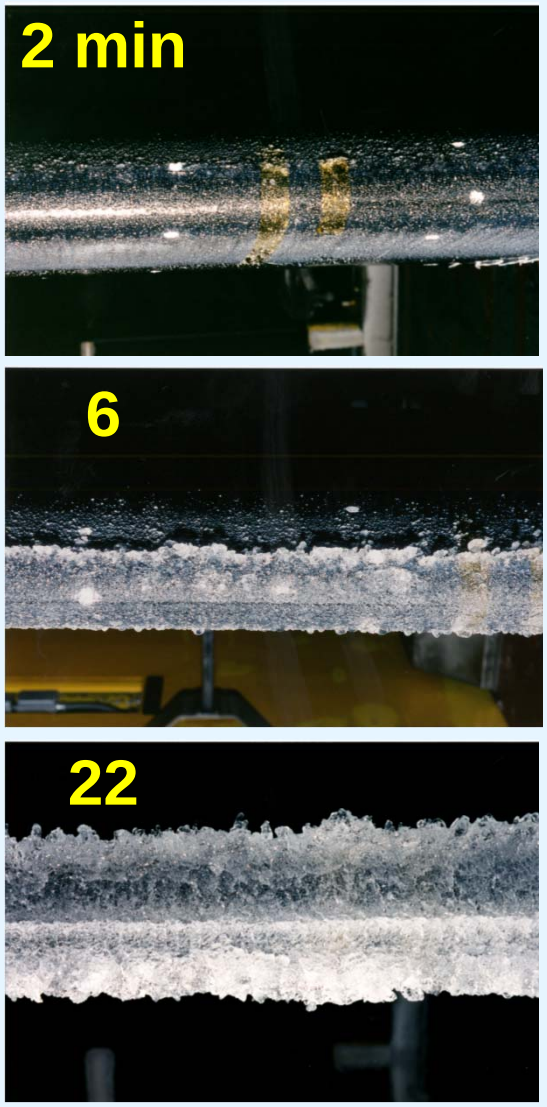
Performance Penalties

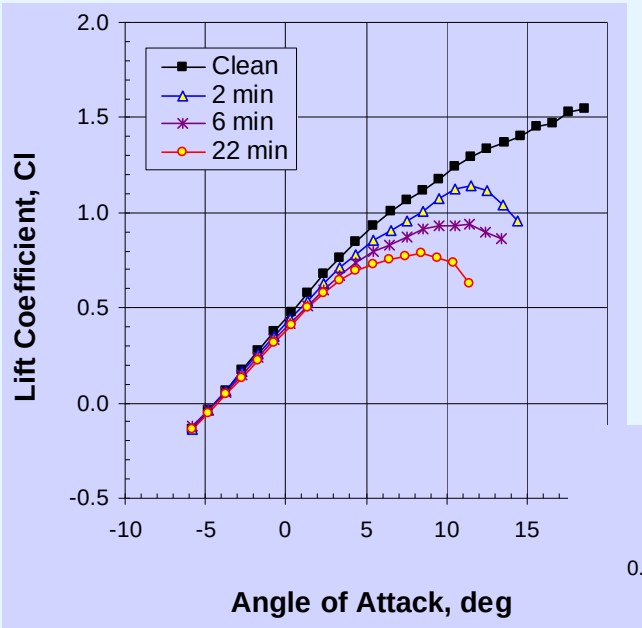
- Increase Drag
- Reduce Max Lift
- Decrease Thrust (possibly)

Handling Qualities

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

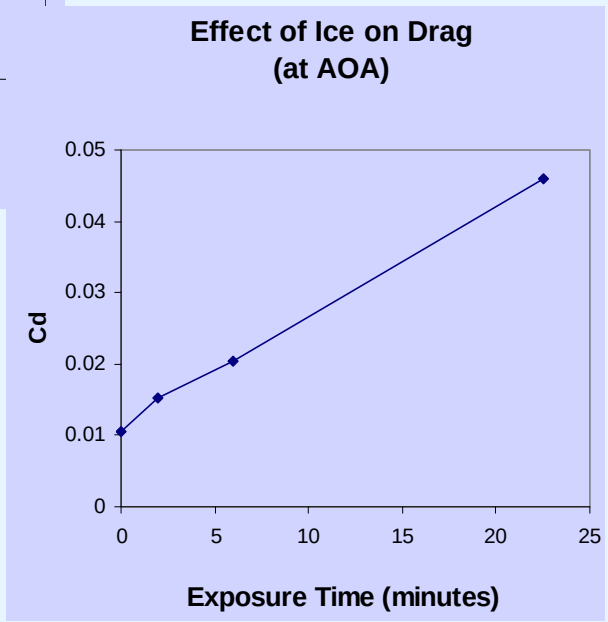
Ice Accretion – Performance Impact





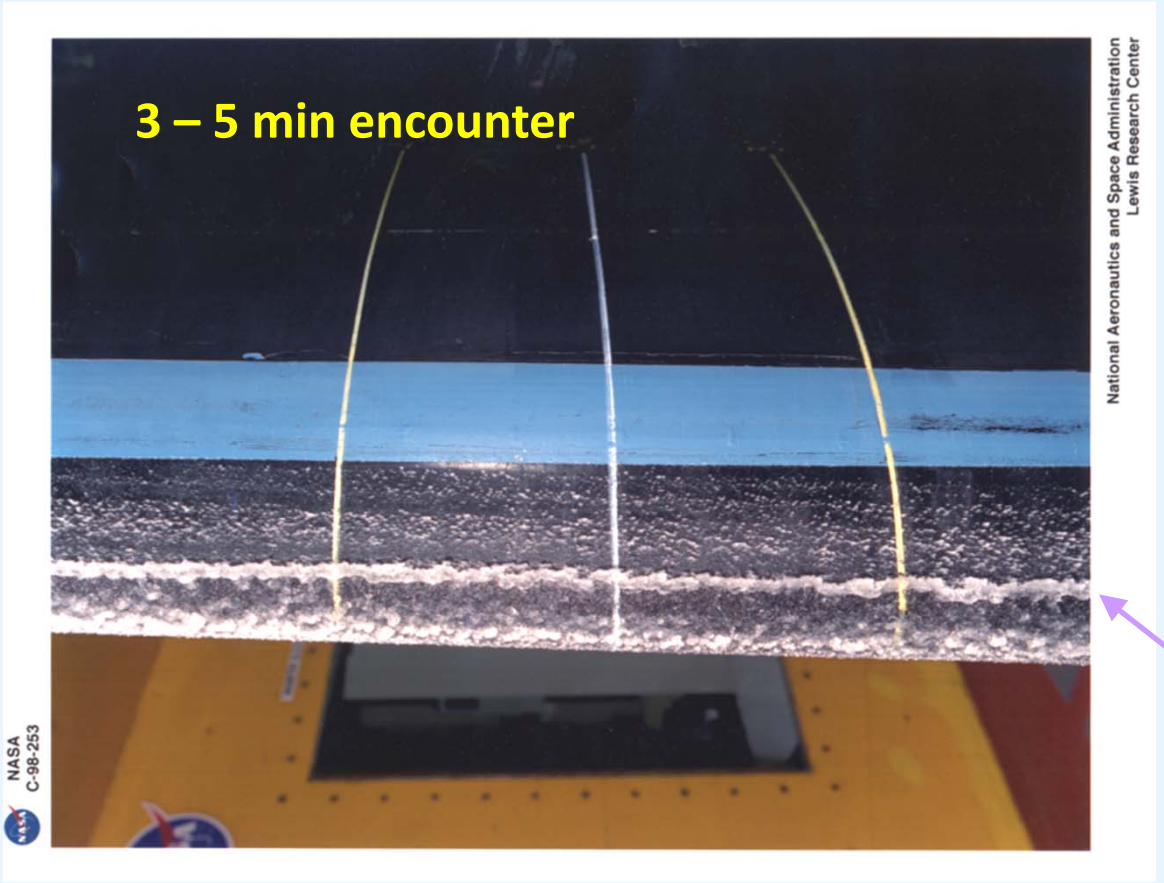
IRT Data – Stationary, Straight Wing

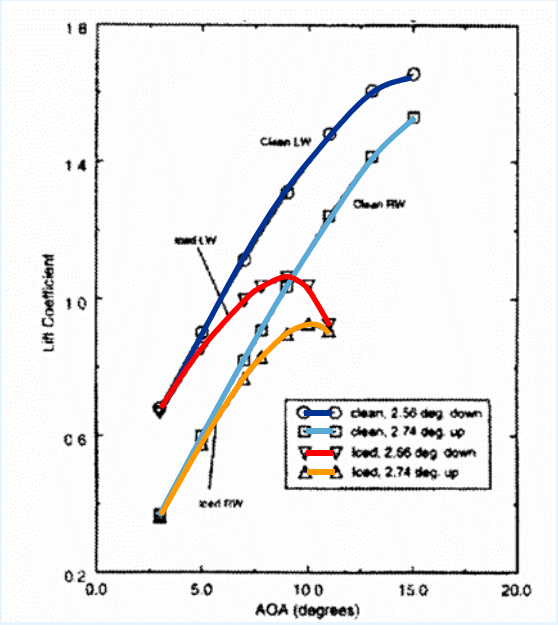
Noticeable performance degradations within 2 min.

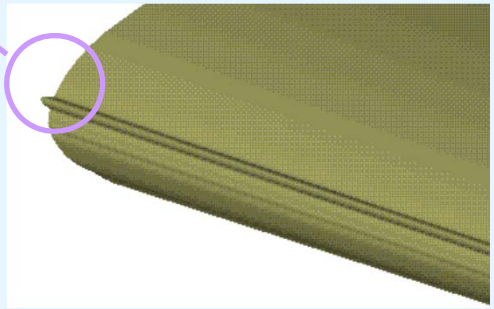


The Insidious Nature of Icing

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







New Rule for SLD and Ice Crystals

FEDERAL REGISTER

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Part III

Department of Transportation

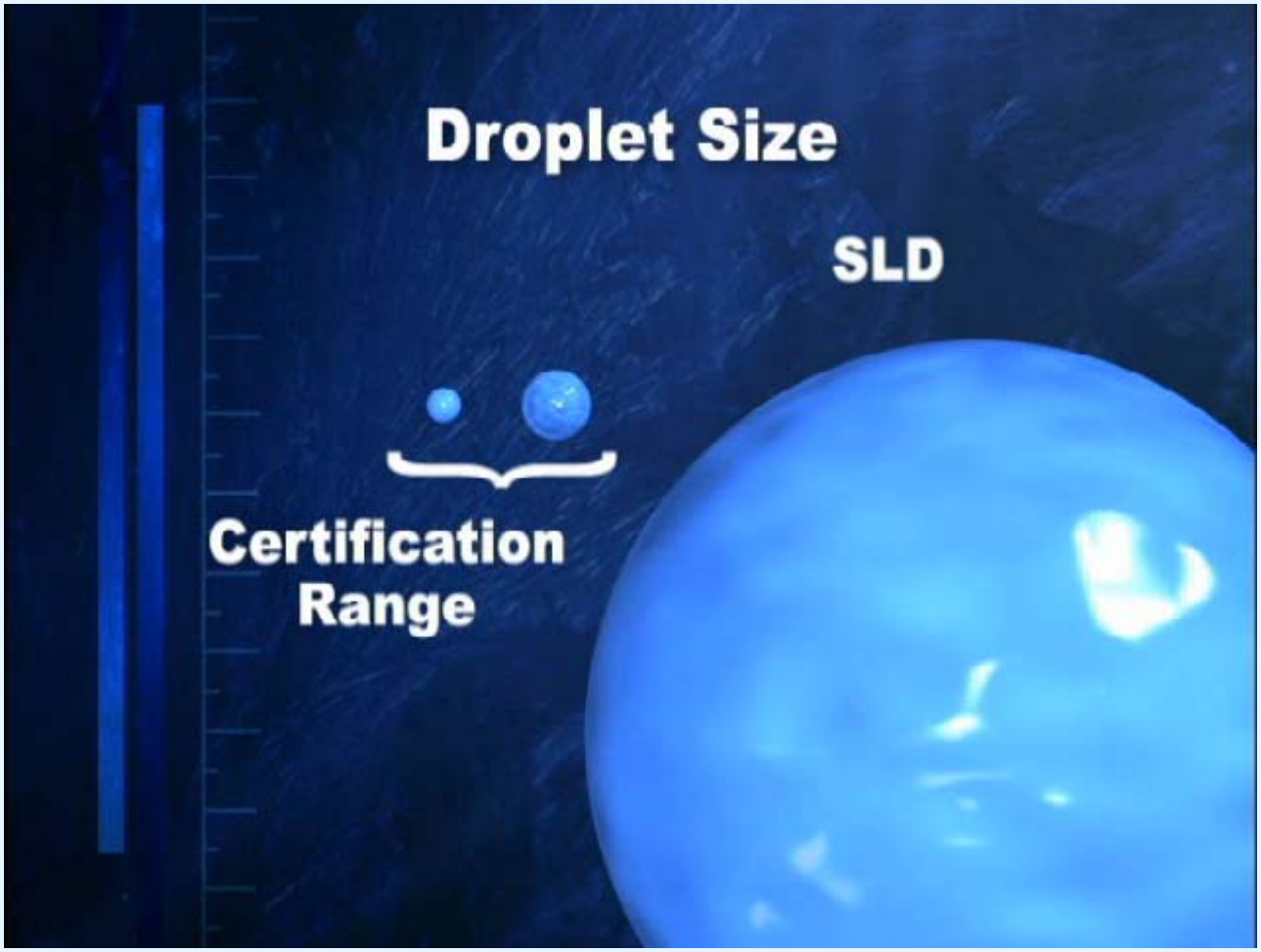
Federal Aviation Administration

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

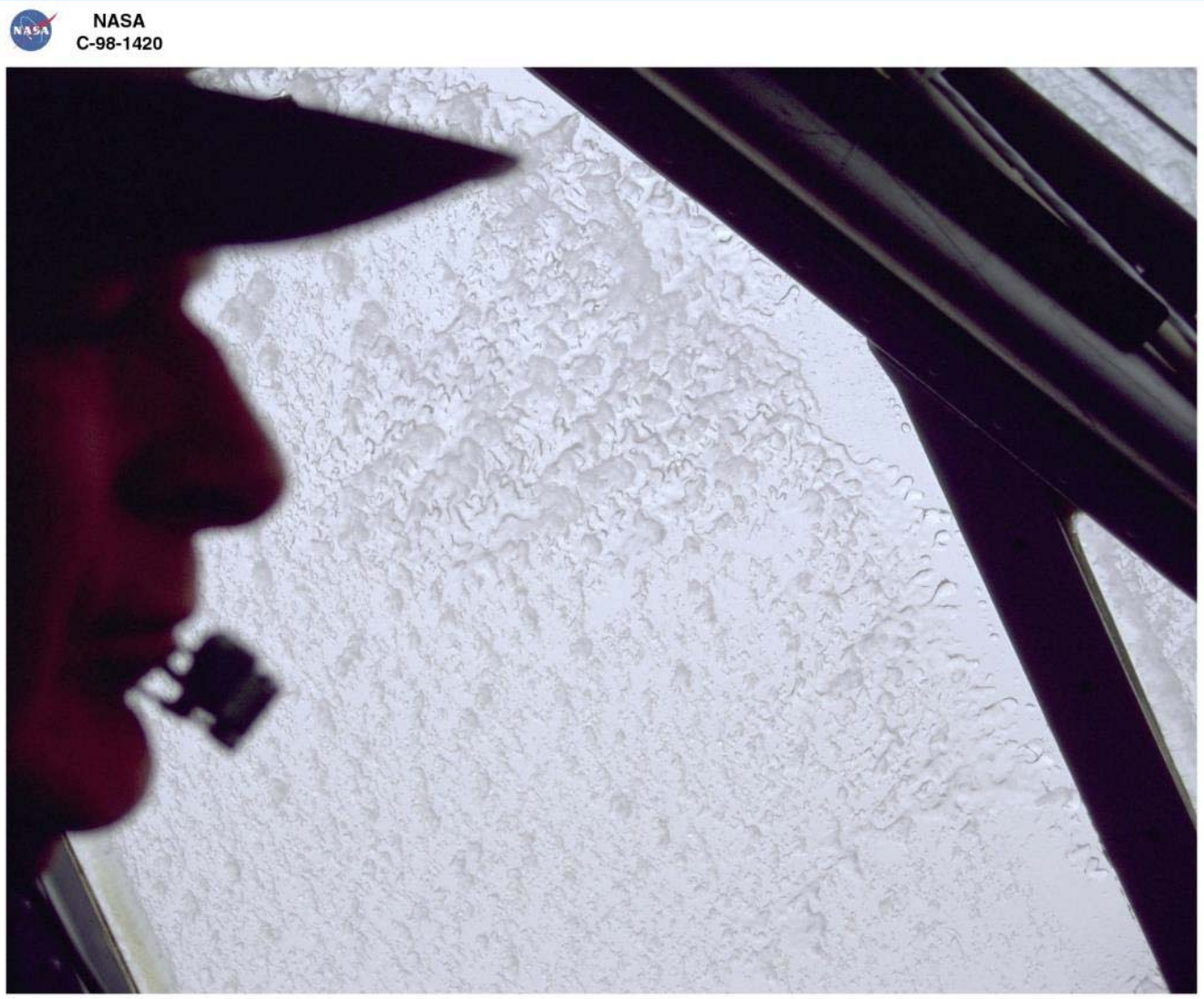
Supercooled Large Drop (SLD) Icing

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



SLD Icing on Side Window

Image of SLD on NASA Icing Research Aircraft



Ice on side window

SLD Icing on Spinner

Image of SLD on NASA Icing Research Aircraft

SLD Icing on Wing

Image of SLD on NASA Icing Research Aircraft

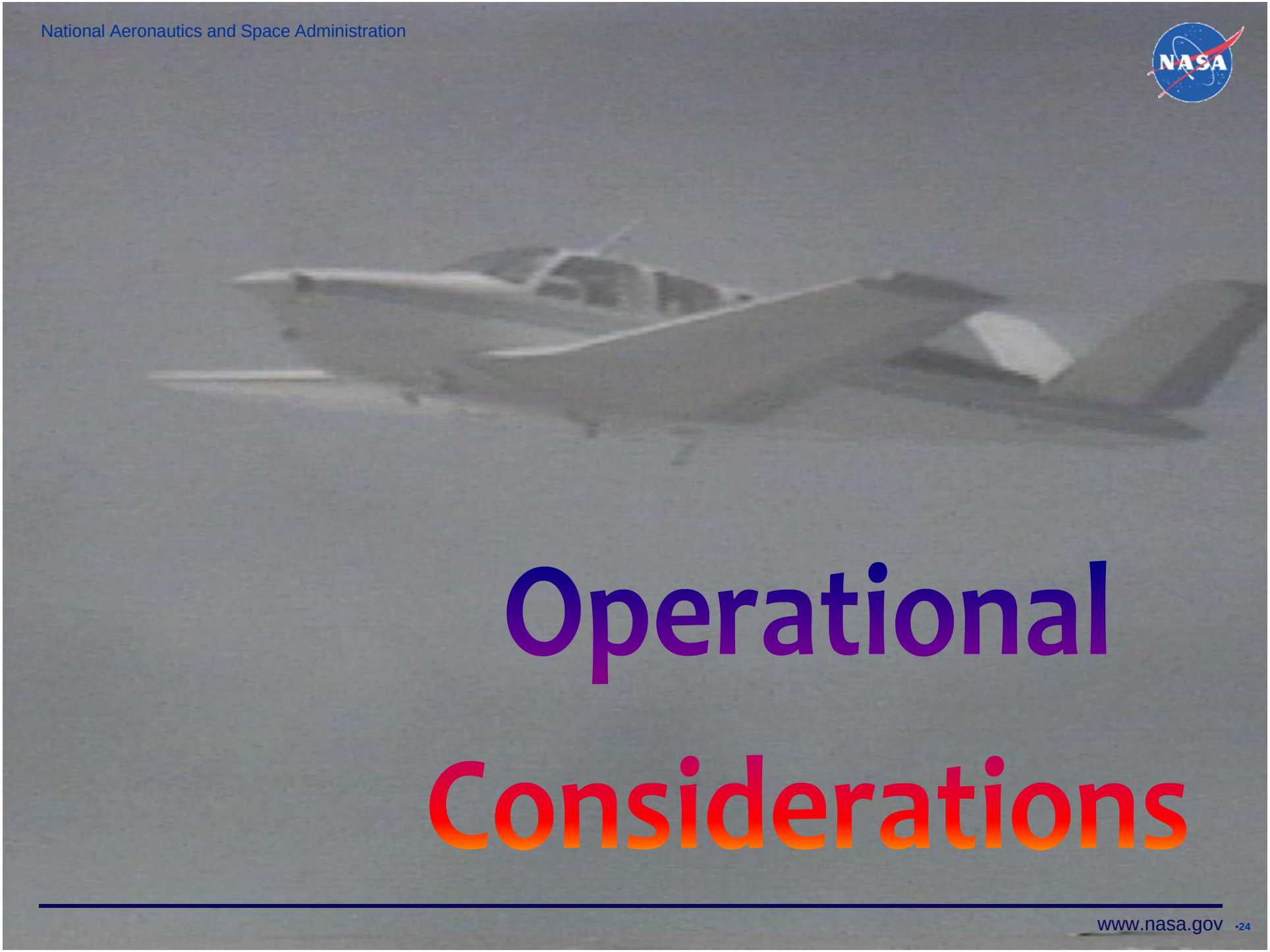
Ice on entire upper wing surface aft of boot

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

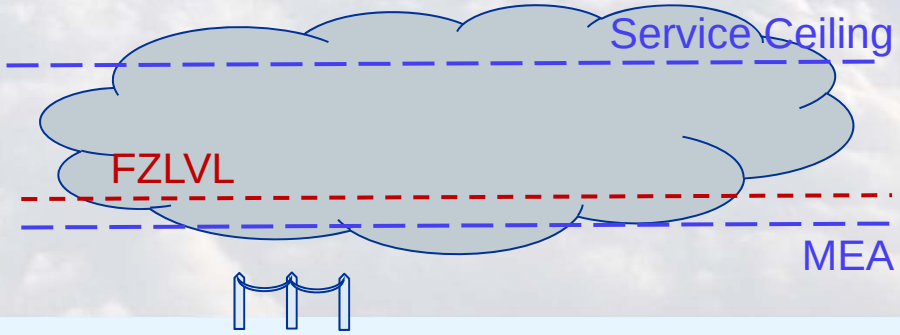
Preflight: Anticipate

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

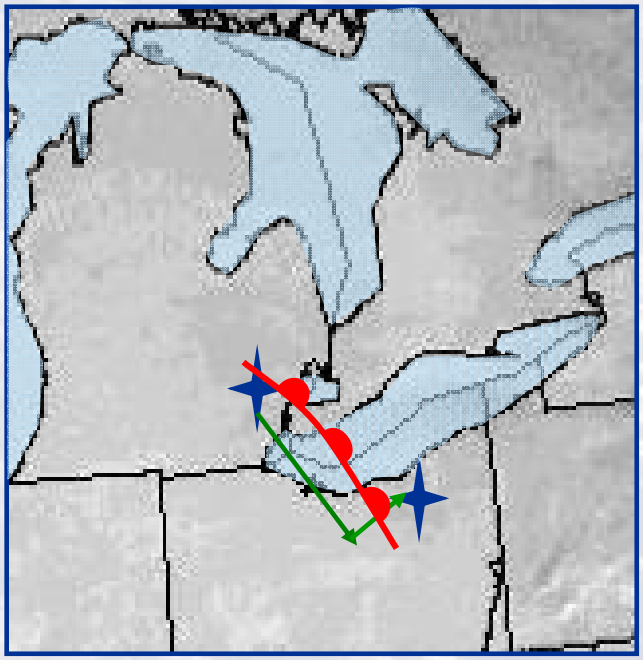
Compare to:
- MEA / MVA
- Practical Ceiling



Preflight Decisions

Develop Plan & Outs

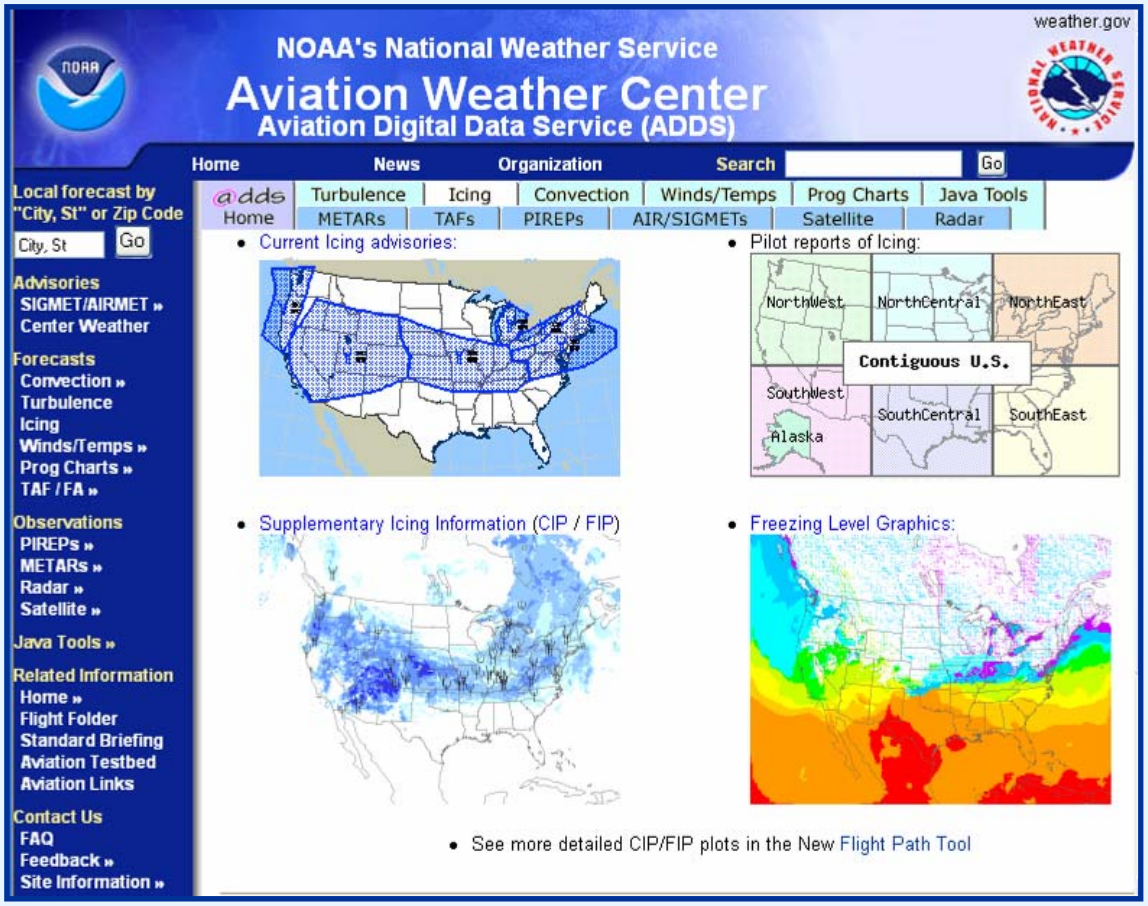
- **Safe Altitudes**
- **Re-Routes**
  - **If crossing a front, consider penetrating front perpendicularly**
- **Alternates**
  - **Precision Approach (ILS)**



Make & Pay attention to your personal minimums

If no outs, should you go?

Preflight Tools: Self Dispatch



Where to look:

- Official Briefing
- http://adds.aviationweather.gov
- http://www.weather.gov (dew point)

Skew-T: Careful when Temp & Dew Point are close

Prior to Takeoff

Make sure (*by touch*) you have a clean wing (*NTSB Advisory, 12/29/04*)

Make sure IPS & Pitot Heat are working

Monitor the Environment

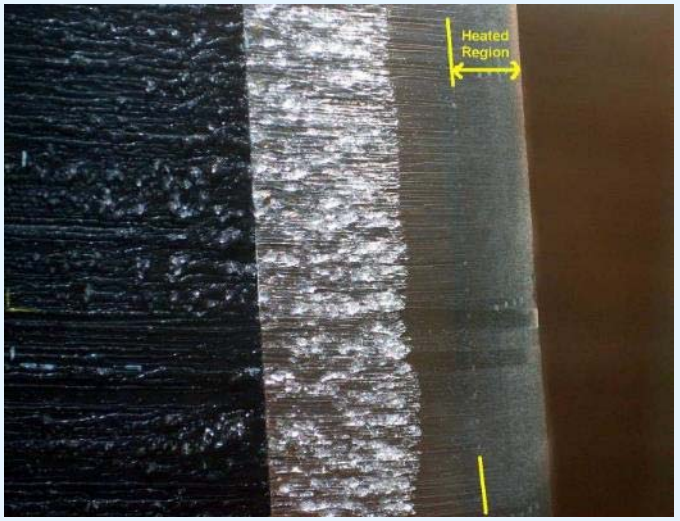
Local – are you in icing conditions?

- **Clouds & Precipitation**
- **Temperature (+2C to -20C)**

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

Activate IPS (per AFM/POH)

- Pitot – always on
  - Iced pitot: erroneous speed and/or altimeter readings
- De-icing (boots)
  - First sign of ice accretion
- Anti-icing (thermal, TKS)
  - Prior to cloud penetration
  - Beware Ice Ridge!
- Jets: Engine Anti-ice On
  - AFM (Vis. Moisture & +10C)



IB

Detect Icing Conditions

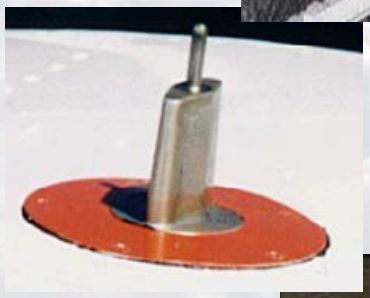
Visual Cues

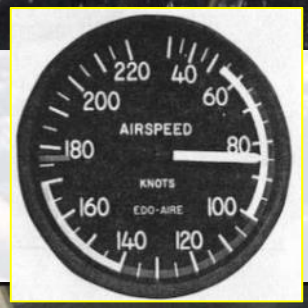
Ice accretes first on objects with a small LE radius (sharp):

- 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?



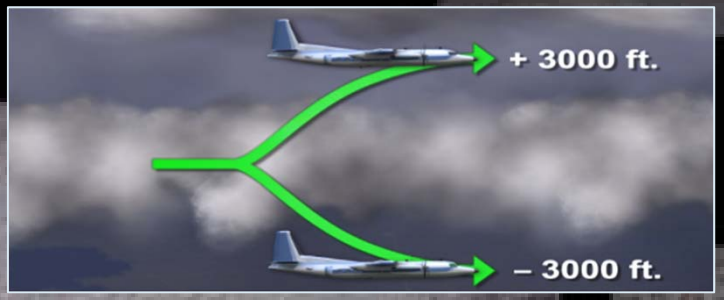


HAND-FLY in Icing
(*at least periodically*)

Work to Exit Icing Conditions

If in Mod – Severe Icing

- Climb
- Descend
- Divert
- Return
- Continue



Limit autopilot use while maneuvering.

Make a PIREP (when able)

*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

PIREPS

Source of what's happening NOW

Give & Get PIREPs

- **Location, Time, Altitude *of icing encounter***
- **Type of Aircraft**
- **Phase of Flight**
- **Temperature**
- **Ice Severity**
- **Remarks**

UA/OV OSU/TM 1700/FL060/

TP C-208/TA M02/

IC MDT CLR 030-050/RM

Lost 10 knts airspeed

AOPA SkySpotter - PIREPs

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

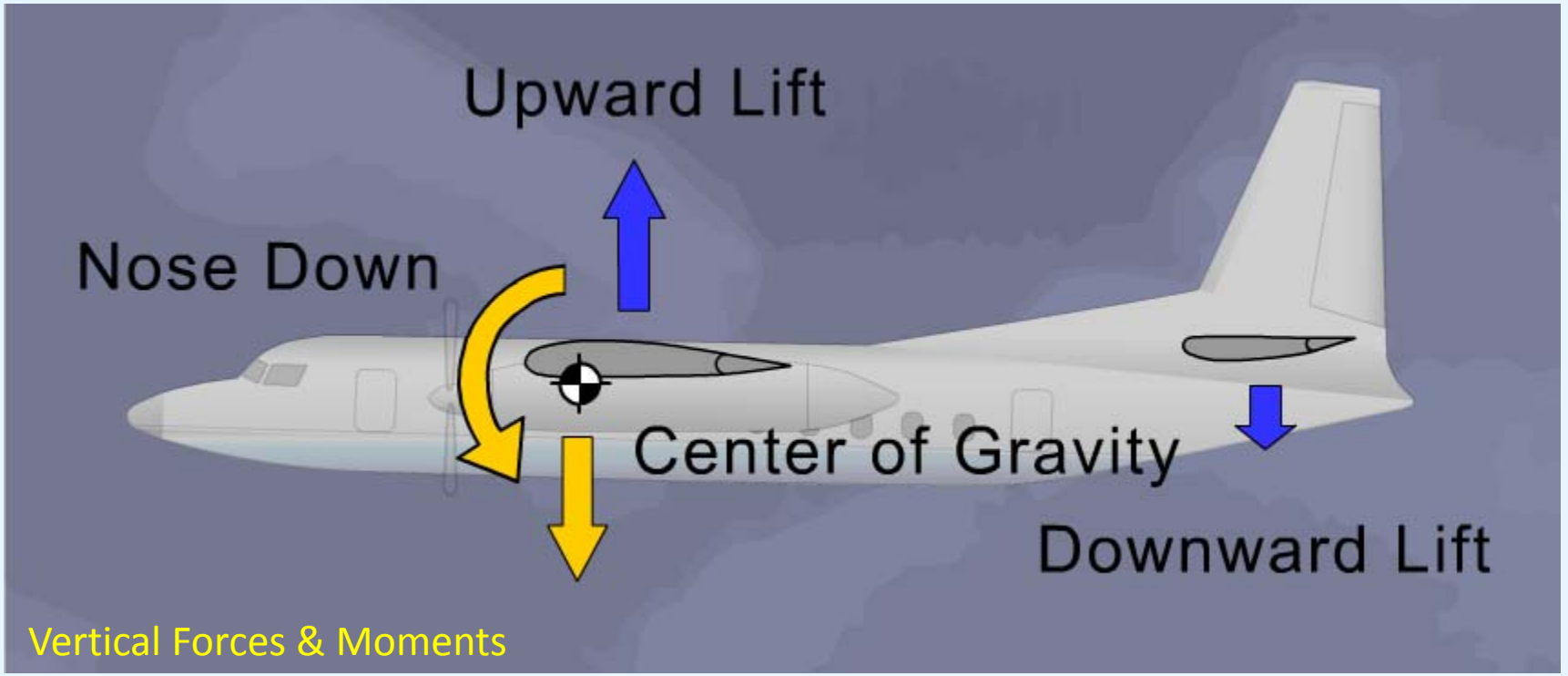
What:

- Roll Upset
- Pitch Upset

Recovery: Lower AOA

- Stick Forward
- Add Power

Role of the Tailplane



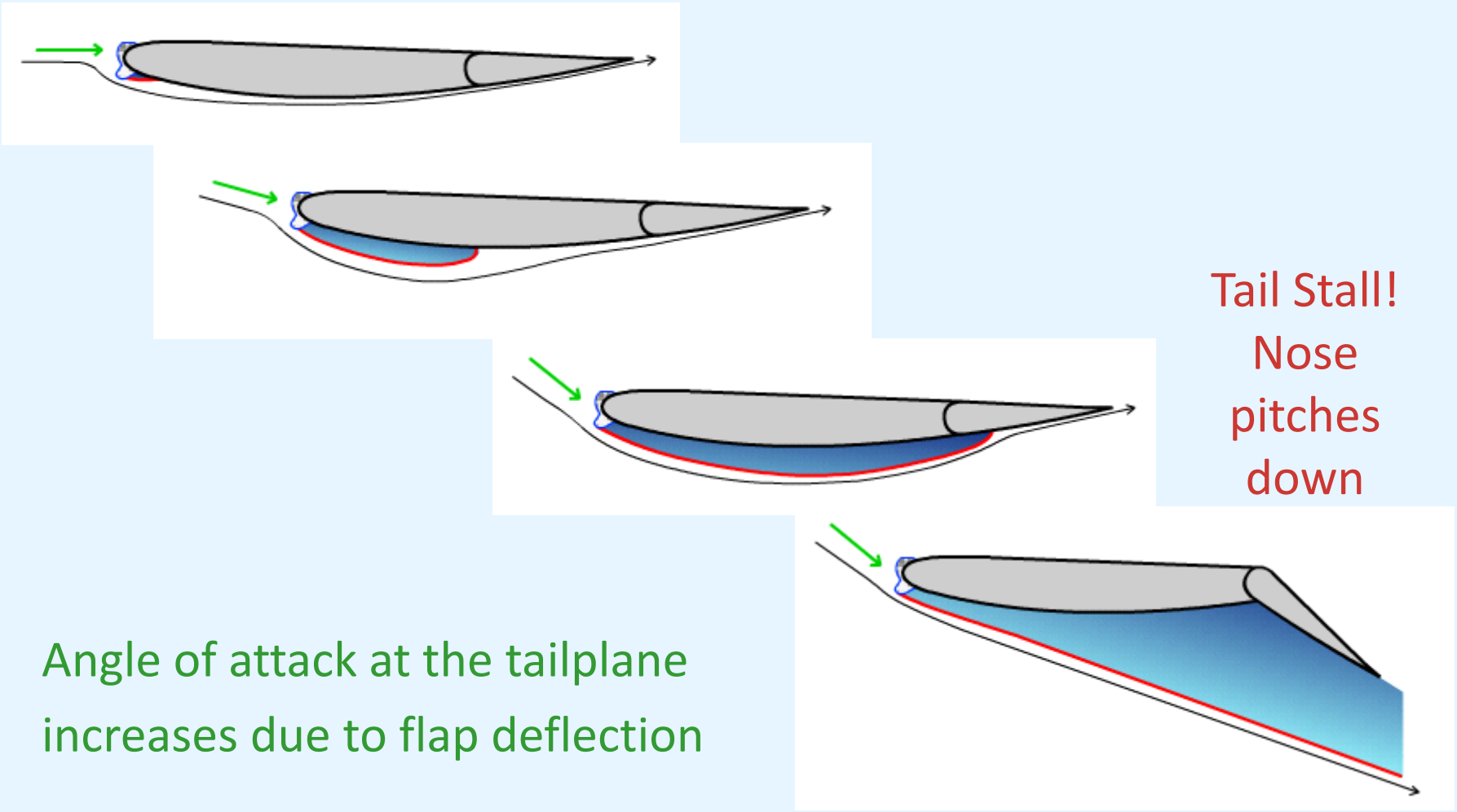
Tail Provides Downward Lift (upside down wing)

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 Event

Footage of a Tail Stall Event

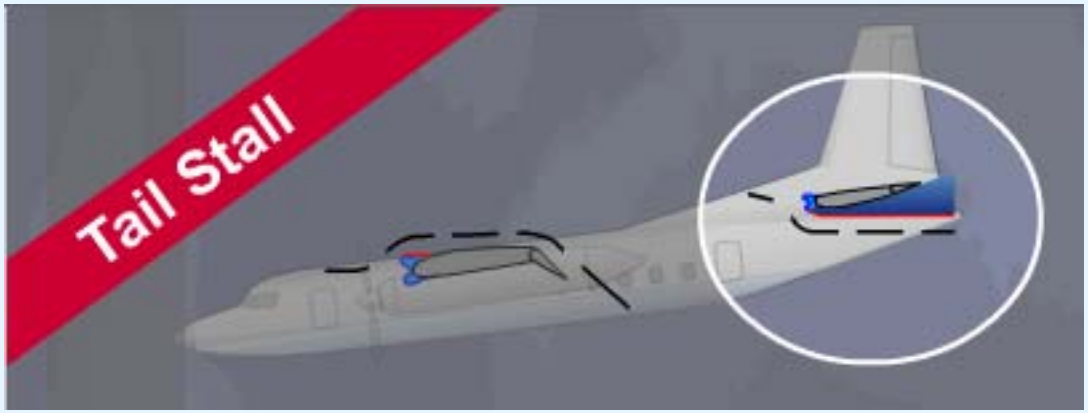
NASA Icing Research Aircraft

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

Tail Stall Event

NASA Icing Research Flight

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:

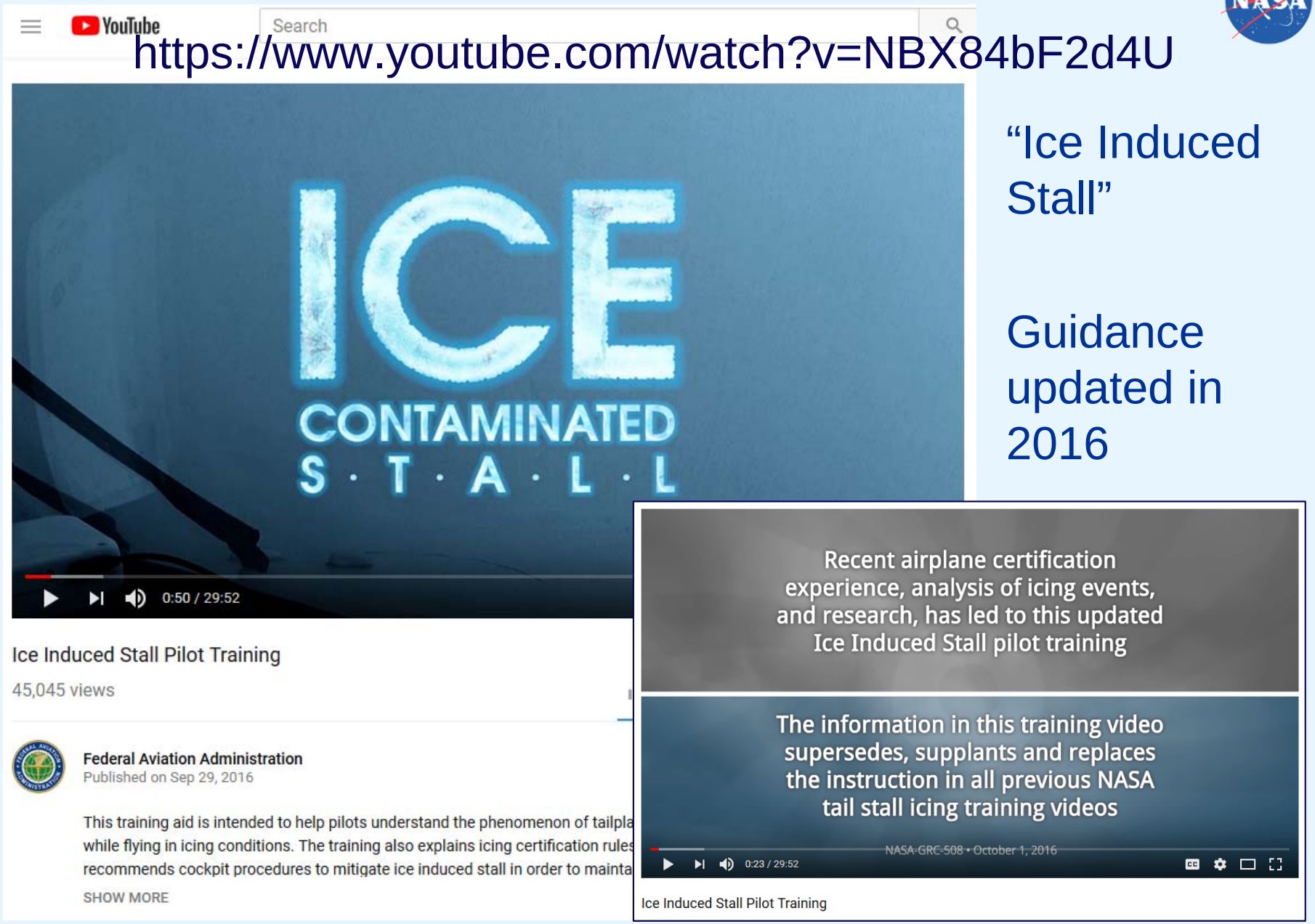
- Pitch Upset

Recovery: Lower Tail AOA

- Flaps Up
- Stick Back
- Maintain/Reduce Power

Undo What You Just Did

https://www.youtube.com/watch?v=NBX84bF2d4U



"Ice Induced Stall"

Guidance updated in 2016

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**"


Questions?

Myth of Ice Bridging

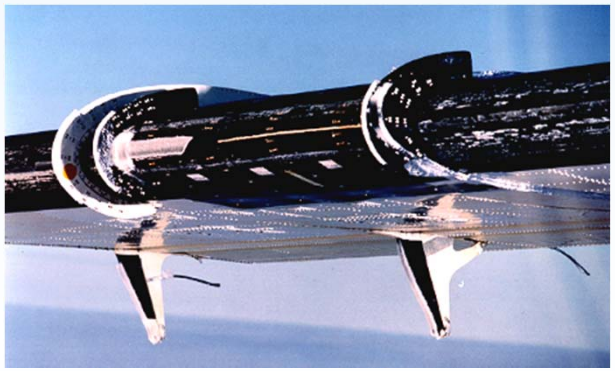
ICE BRIDGING does NOT exist.

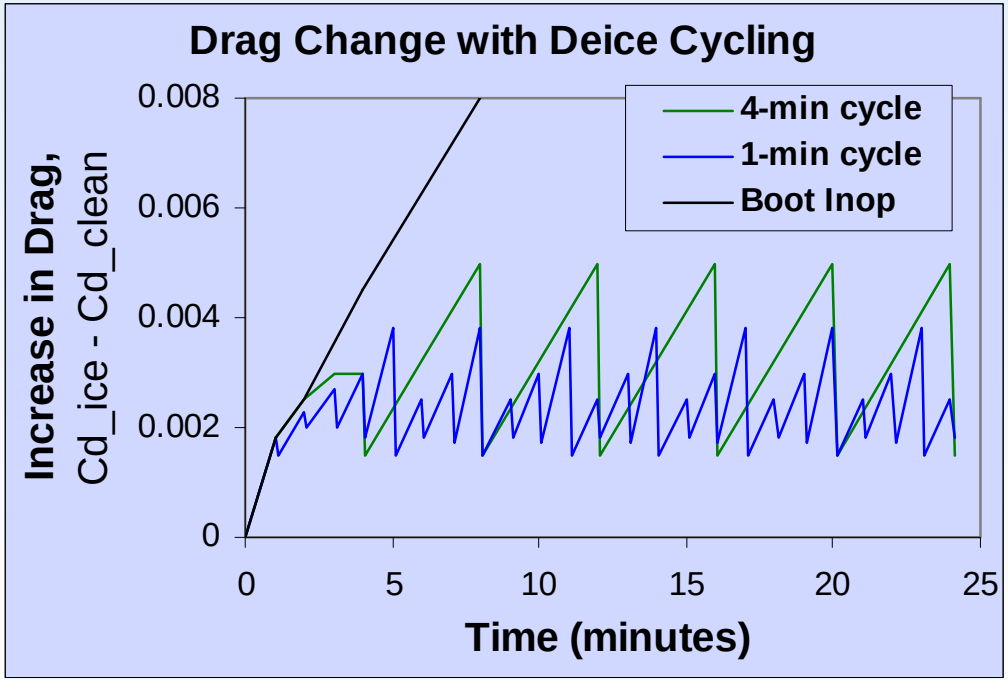
What does exist is RESIDUAL ICE

which will clear with subsequent Boot cycles.

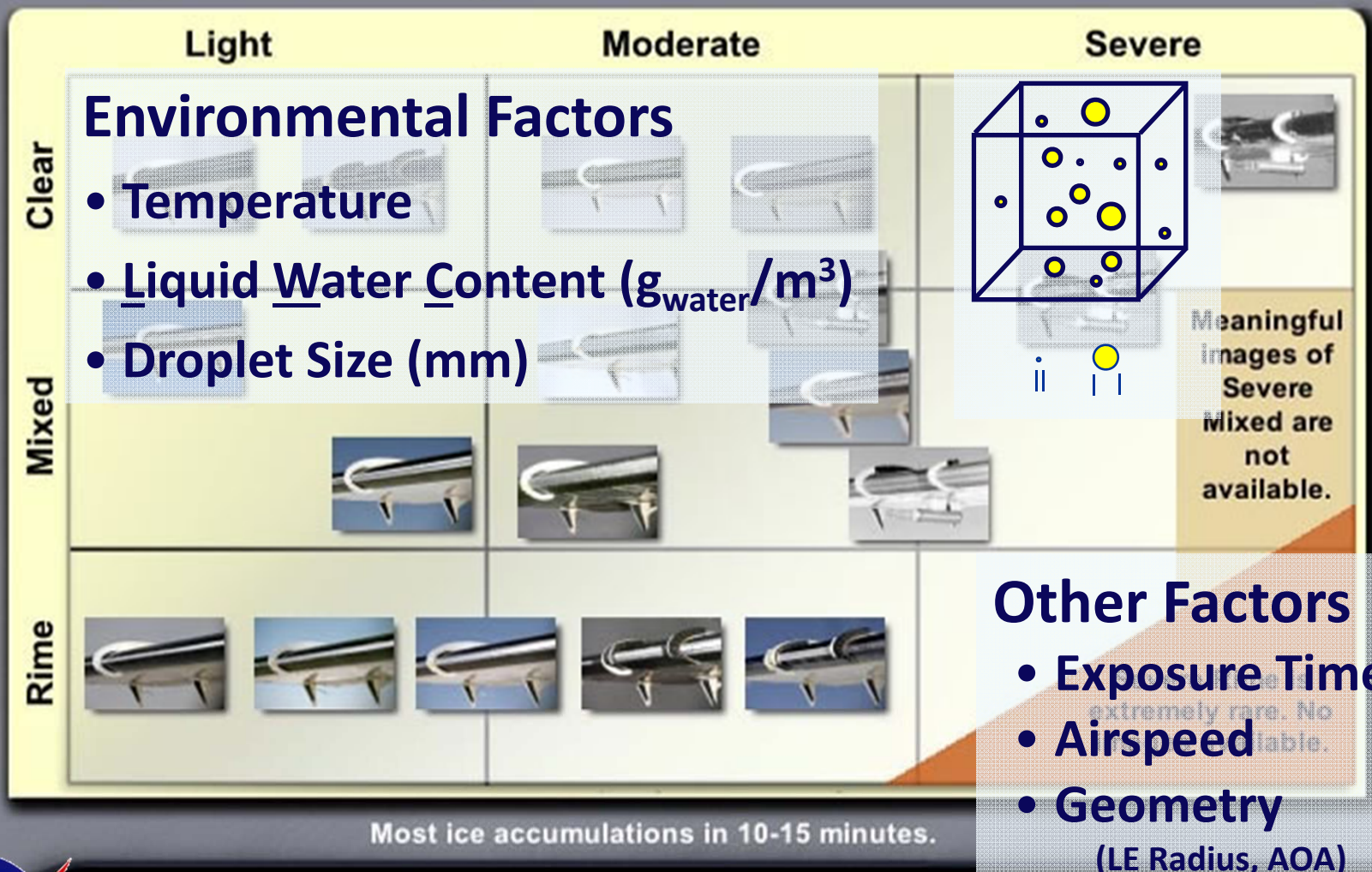
Modern boots characteristically don't have ice bridging problems

- No incidents/accidents
- No evidence during flight tests
- No reports from Pilot Surveys





Basic Icing Physics



Other Factors

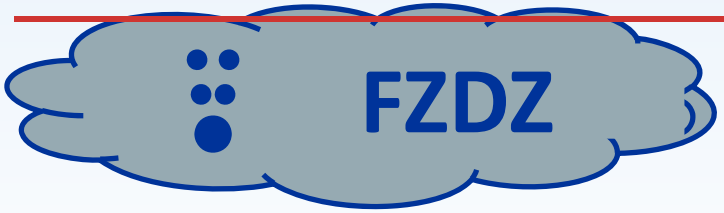
- Exposure Time
- Airspeed
- Geometry
  (LE Radius, AOA)

How does SLD Form?

Collision-Coalescence

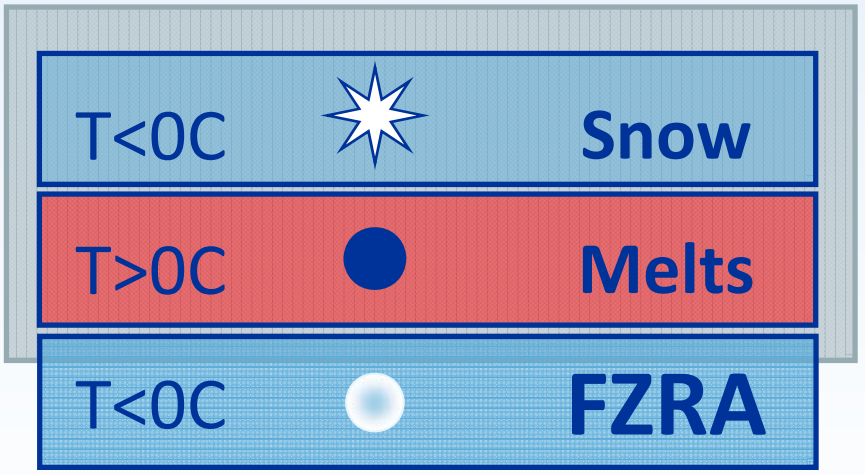
(96%)

FL120, SAT= -12 C

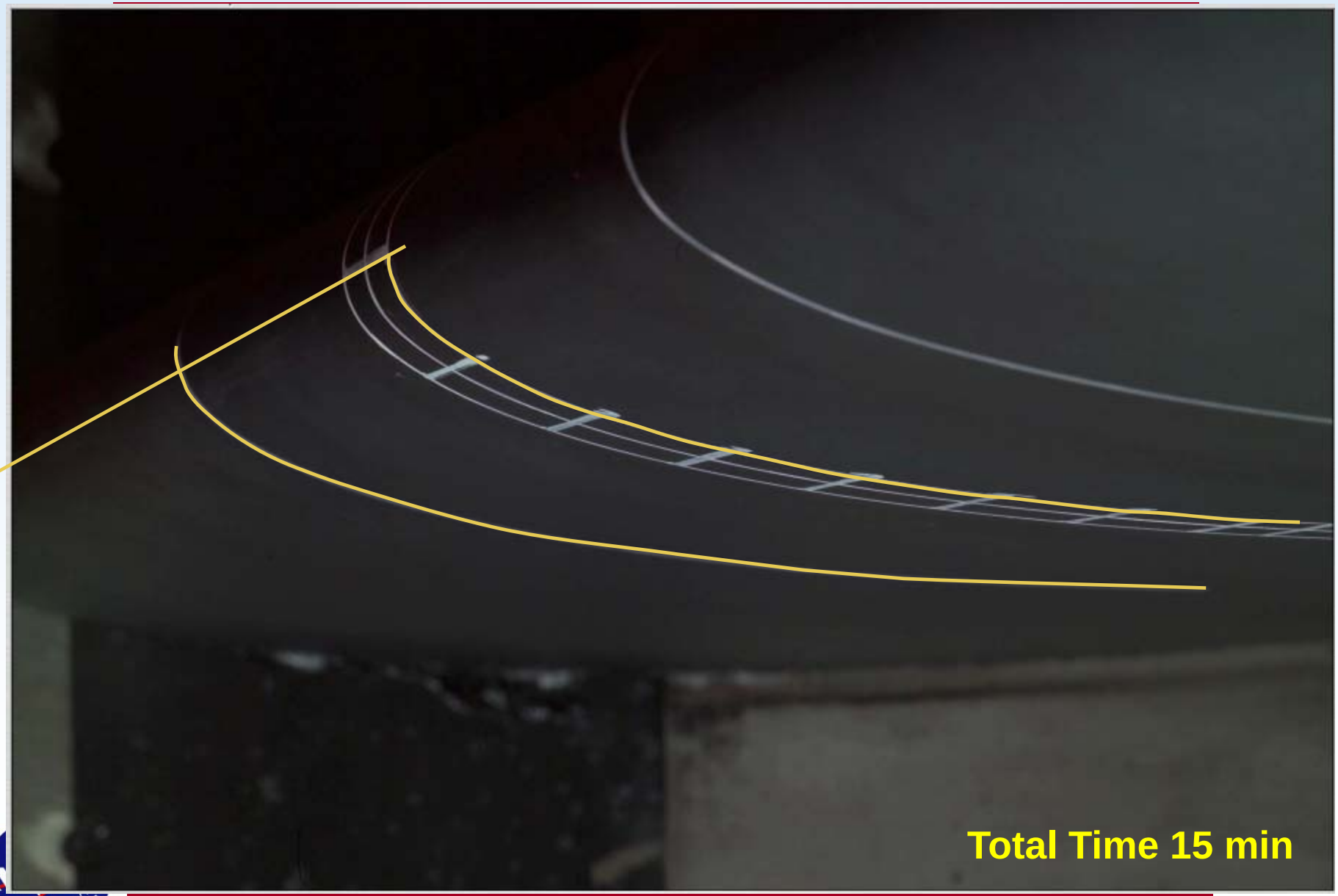


Temperature Inversion

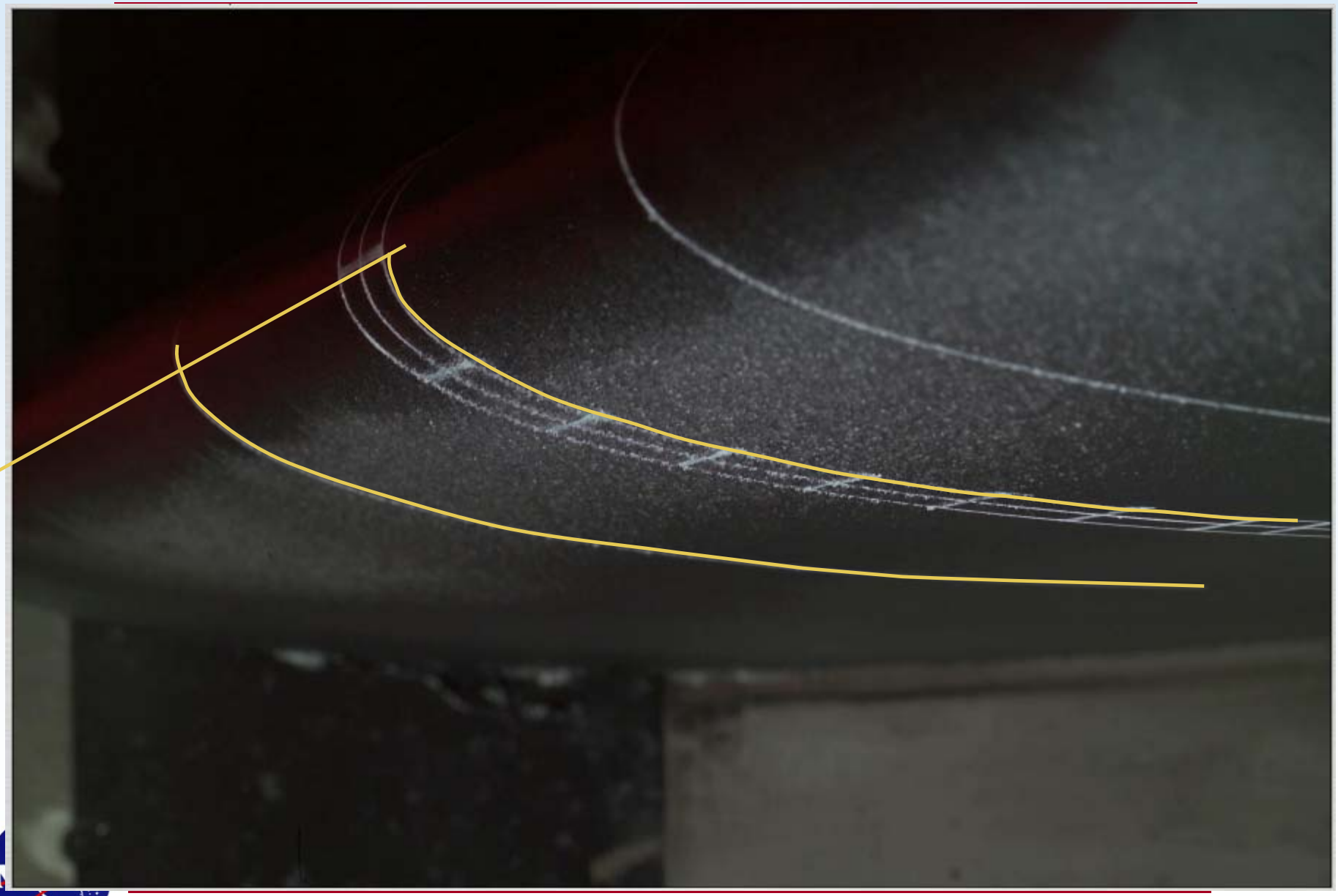
Warm/Stationary Front (4%)



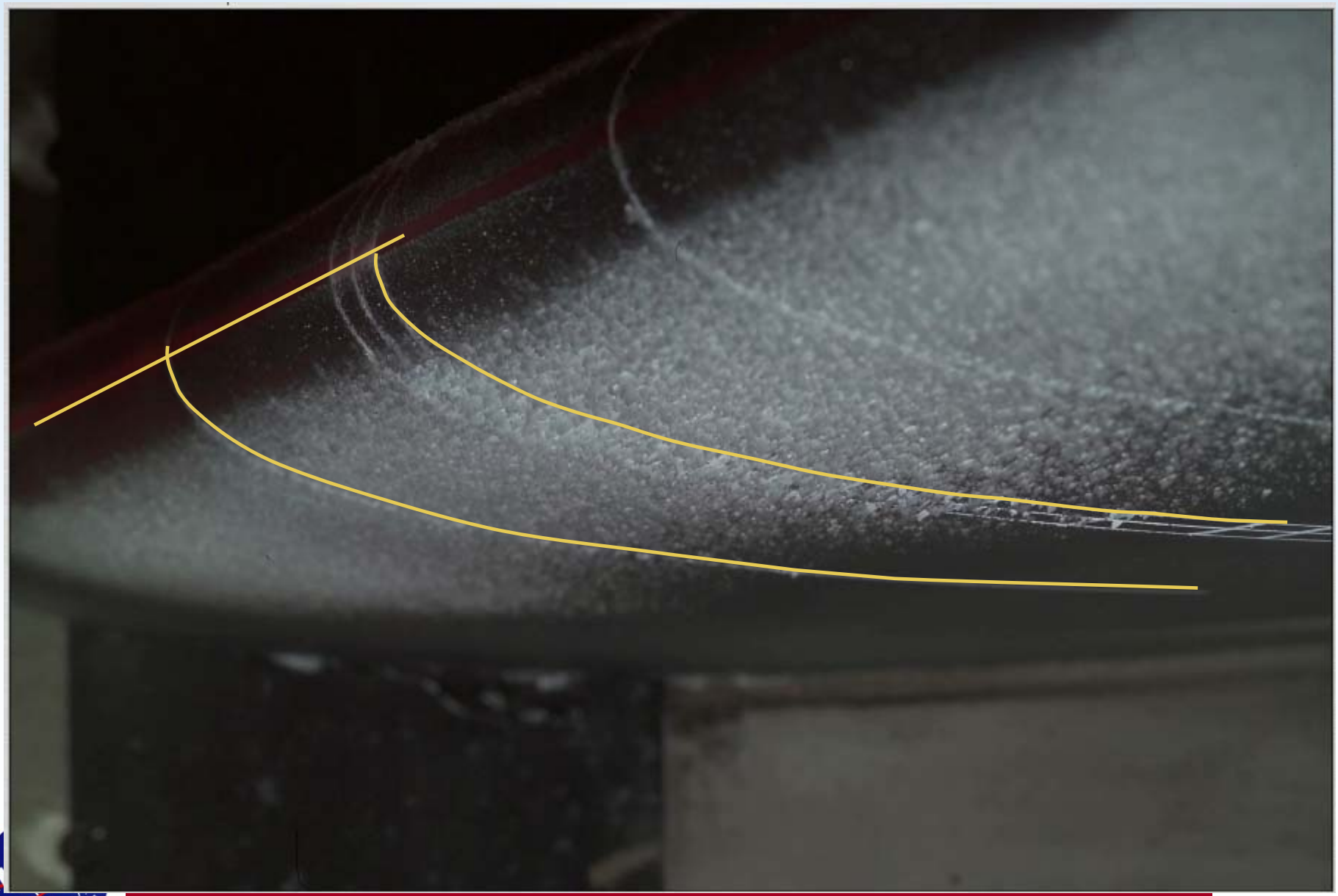
Ice Accretion Video: t= 0 steps



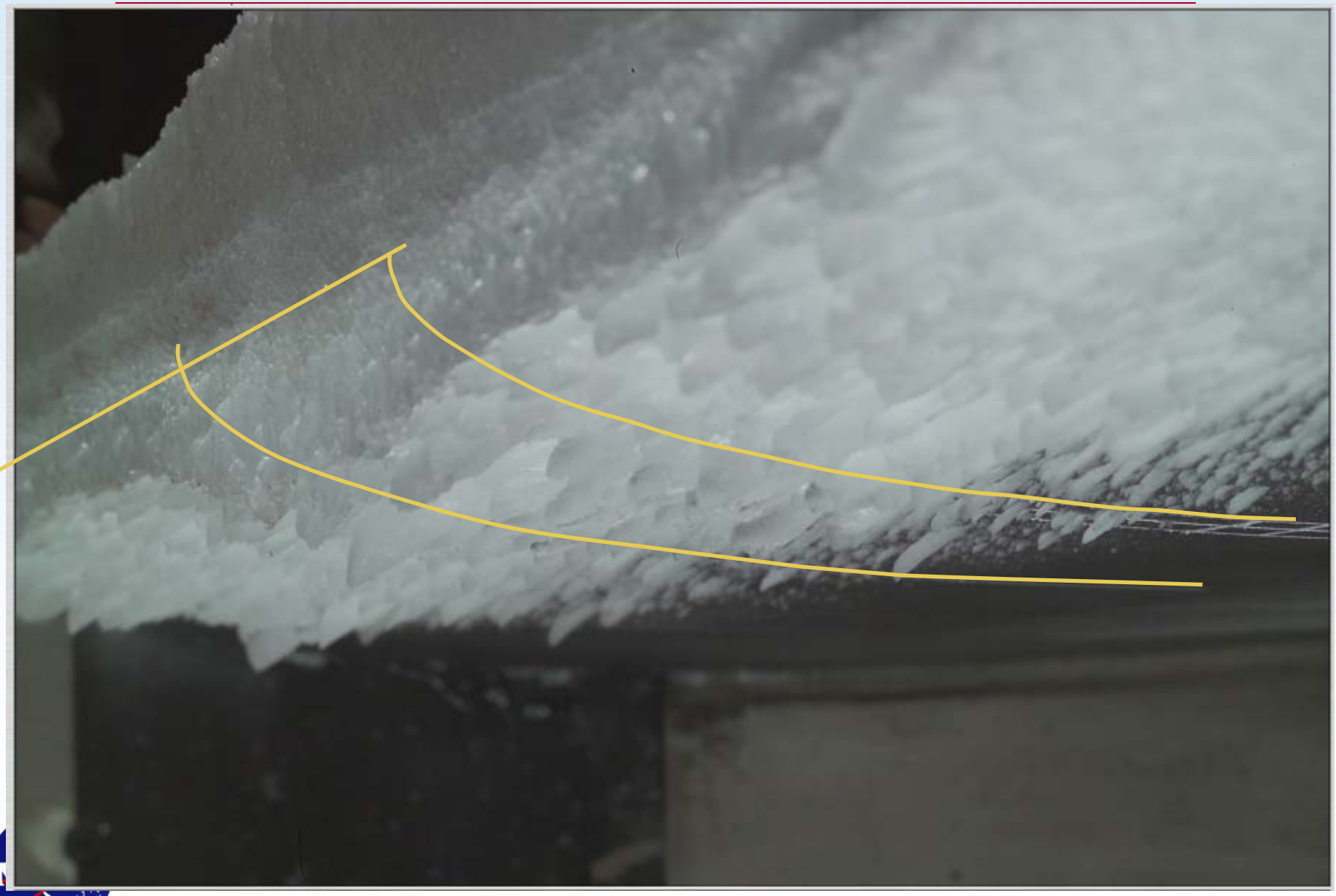
Ice Accretion Video: t= 2 steps



Ice Accretion Video: t= 4 steps



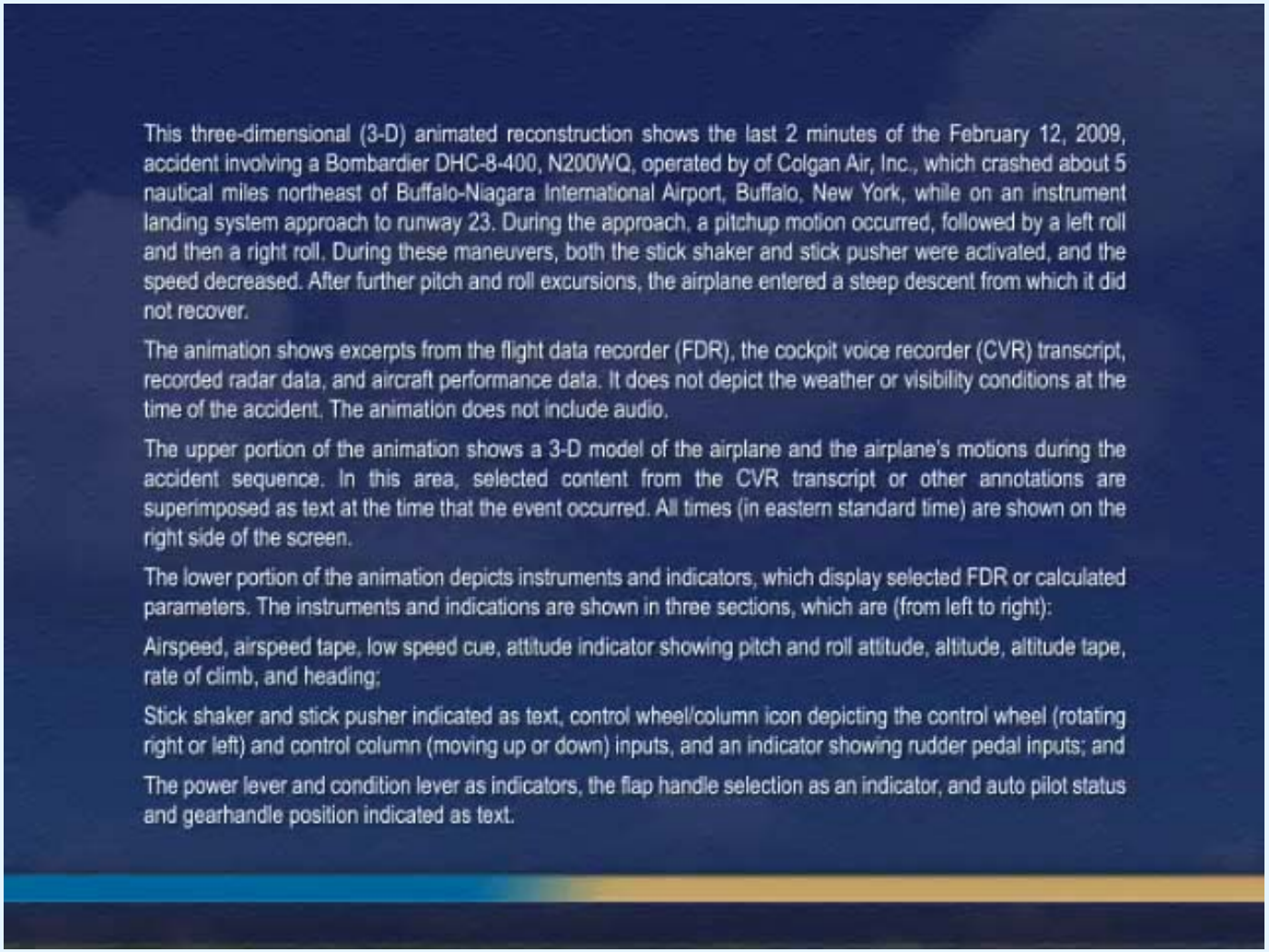
Ice Accretion Video: t= 25 steps



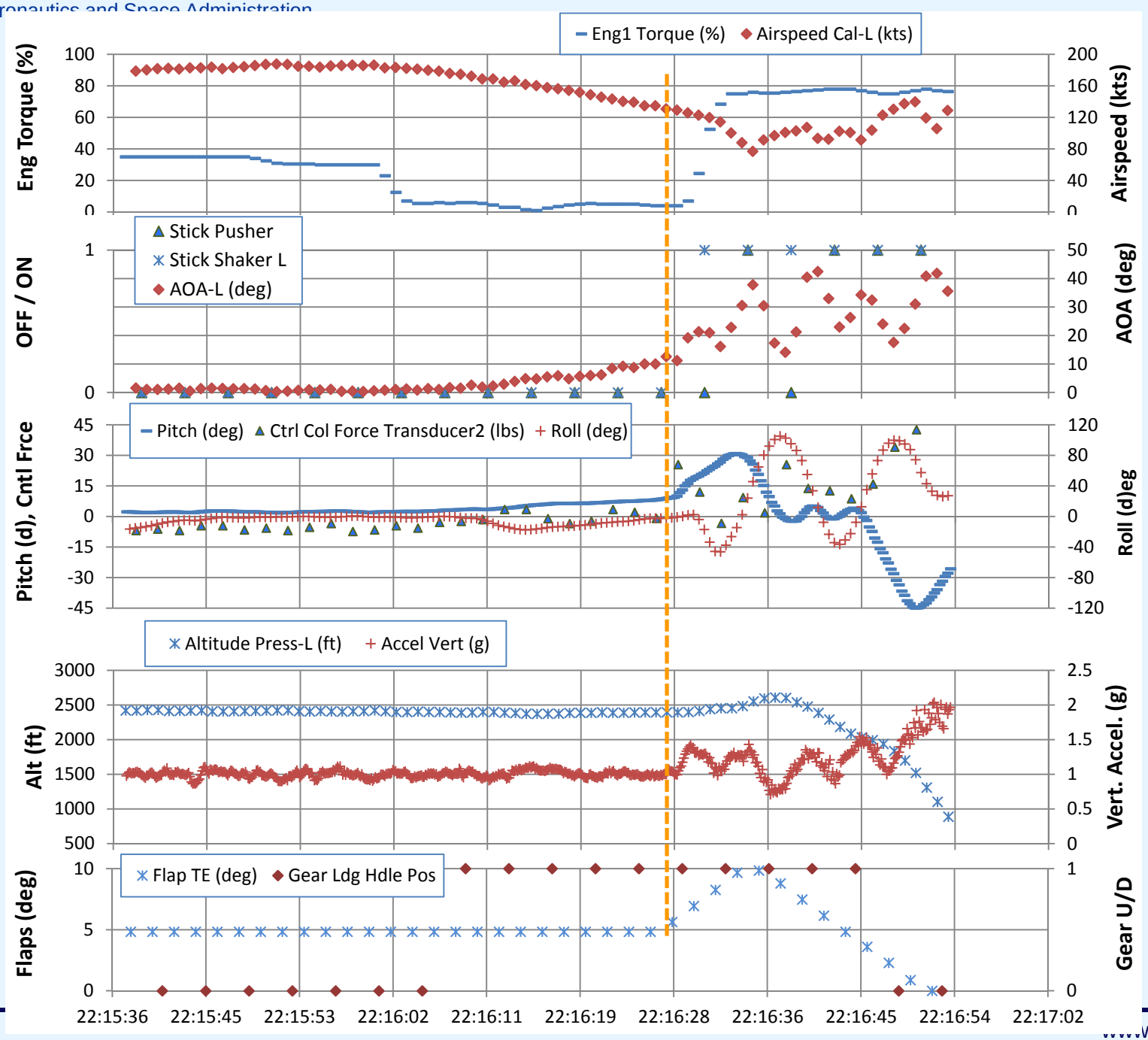
return at Lewis Field

Case Study: In-Flight Icing

NTSB Animation: Colgan Air, 2/12/09

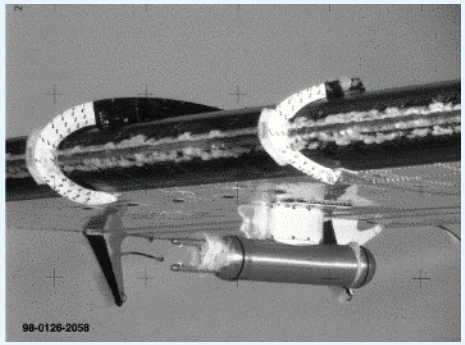


NTSB - FDR (#417237)

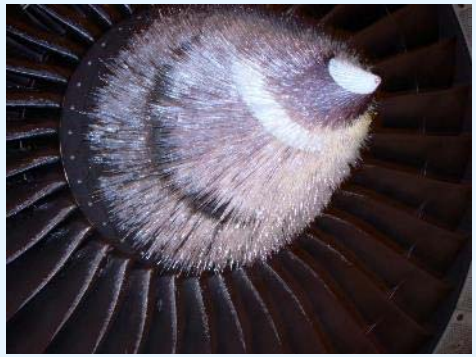


Definitions

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.



Most images from NASA icing research aircraft flights

Carburetor Icing:
outside the scope of this talk.
Occurs in high humidity