



# *Ground & In-Flight Icing*



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NASA Glenn




# Who am I?



**Propulsion Systems Lab**

**NASA's Icing Training Aids**

**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](#)

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**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](#)

1998 – 2005

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





## 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 government 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?**



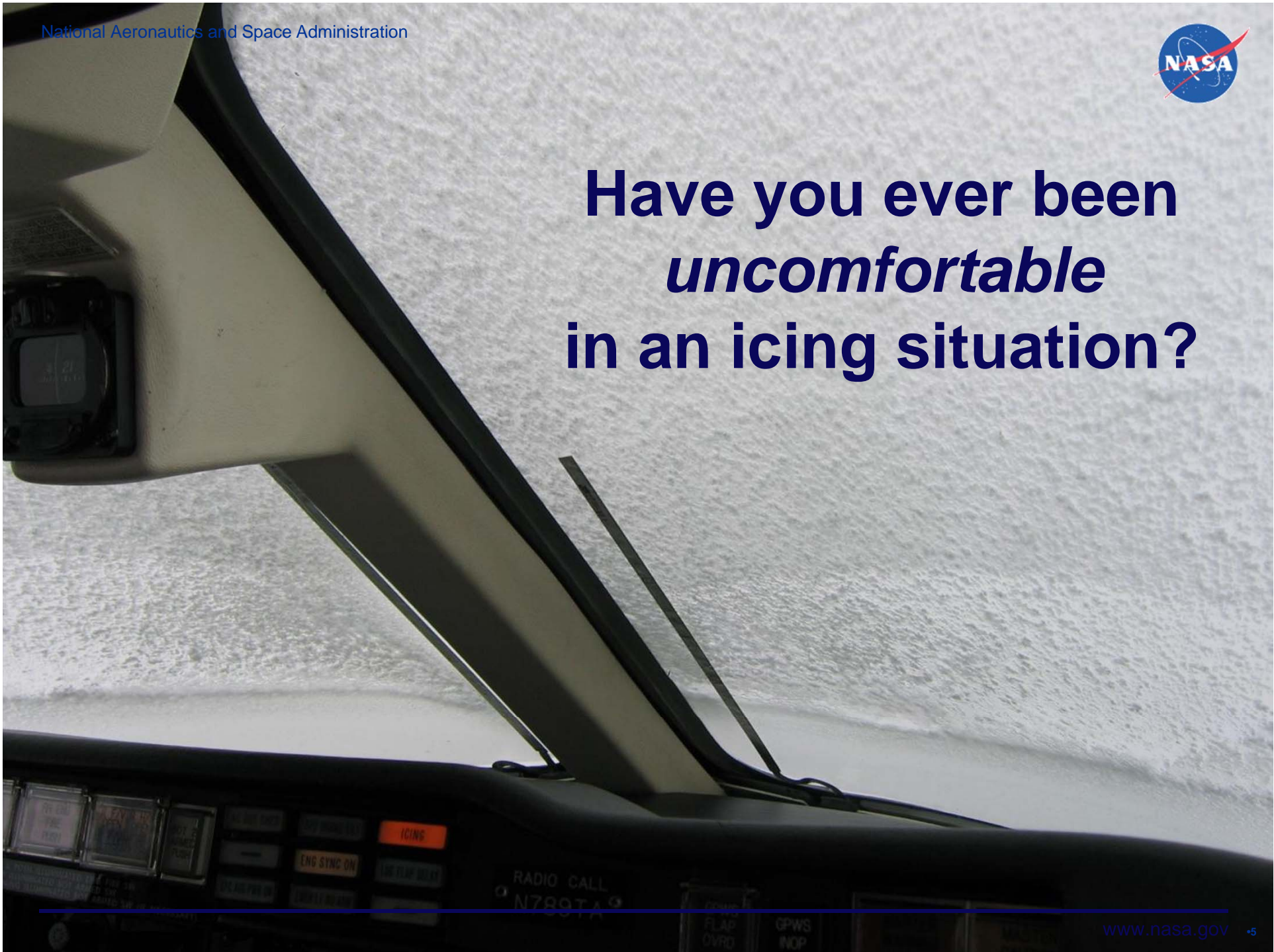
**Turboprop,  
typically  
De-ice**



**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

**FDR: 540.1** Birmingham

**PRELIMINARY**

**Vz**  
1.50  
1.25  
1.00  
0.75  
0.50

L AOA: 2.5  
R AOA: 2.7  
Avg AOA: 20  
15  
10  
5  
0

Rudder Position  
-20 -10 0 10 20

P: 0.2  
R: -0.8

060  
040  
020  
000

500  
400  
300  
200

30.33IN  
1027mb

0.0

34.4 34.5

WOW GEAR  
FLAPS 19

Flt Spirs: Stowed TR: Stowed  
GPWS: --- Grnd Spirs: Stowed

TSB - BST  
Canada



# Deice if contaminated

Remove all frost, ice & snow



**Broom/  
Squeegee**



**Spray Type I**

*Ensure (by touch) a  
clean aircraft.*



**Hot Air**



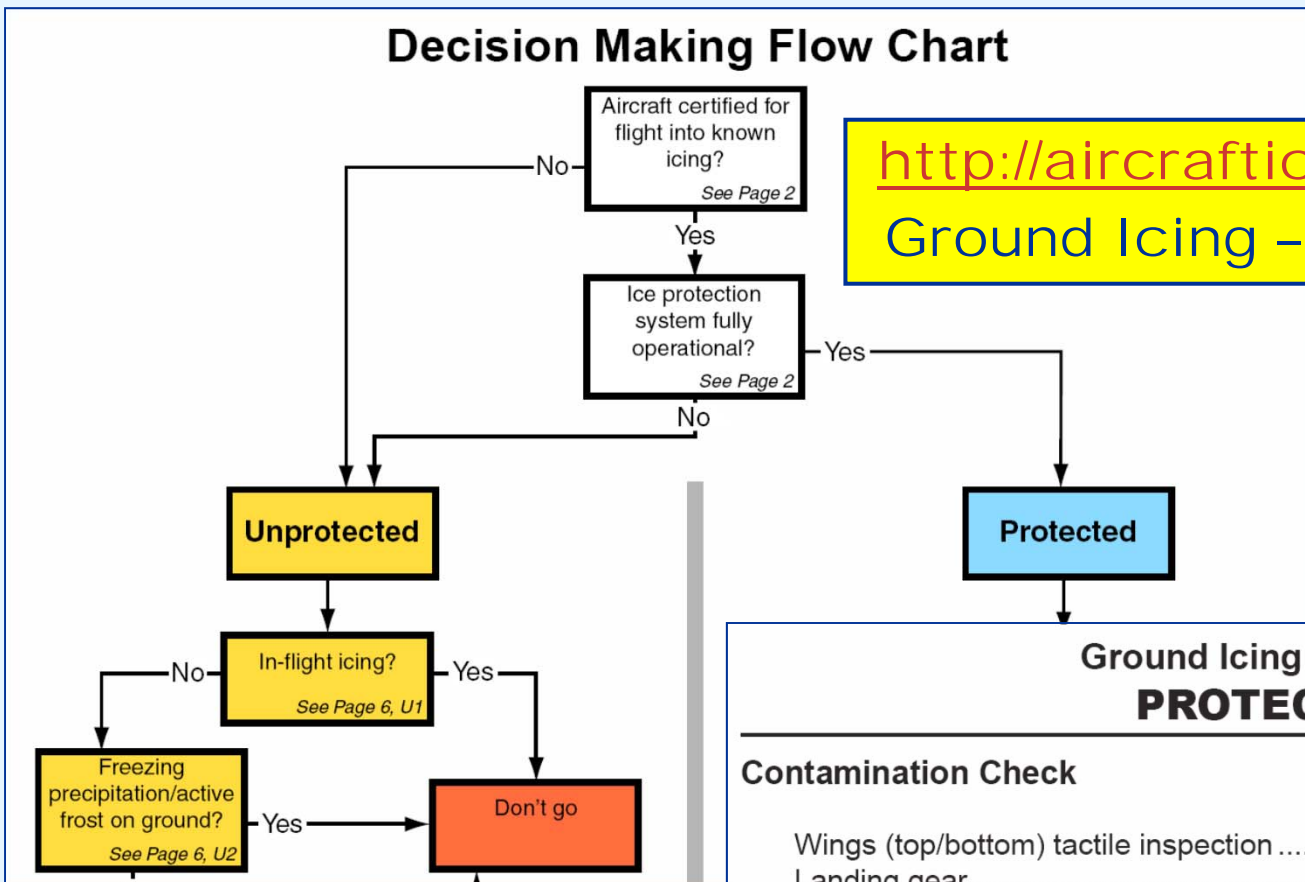
**Mop on Type I**



# A Pilot's Guide to Ground Icing: Review Material

## Decision Making Flow Chart

<http://aircrafticing.grc.nasa.gov>  
Ground Icing - Review Material



Ground Icing Checklist <b>PROTECTED</b>	
<b>Contamination Check</b>	
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

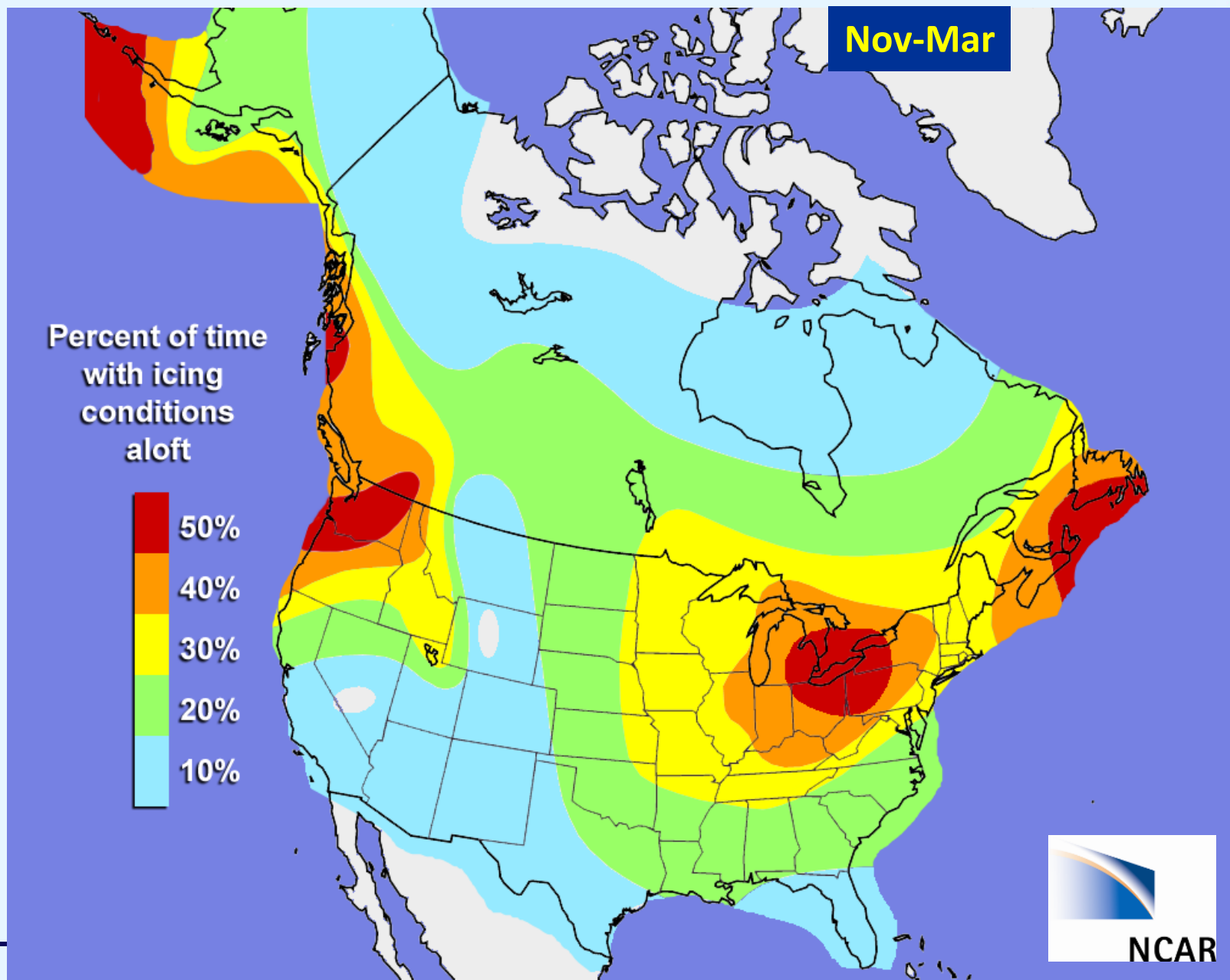


VIAS= 96                      KLWC=0.002    ALT= 8.3  
AOA= 3.1  
19:42:38.0



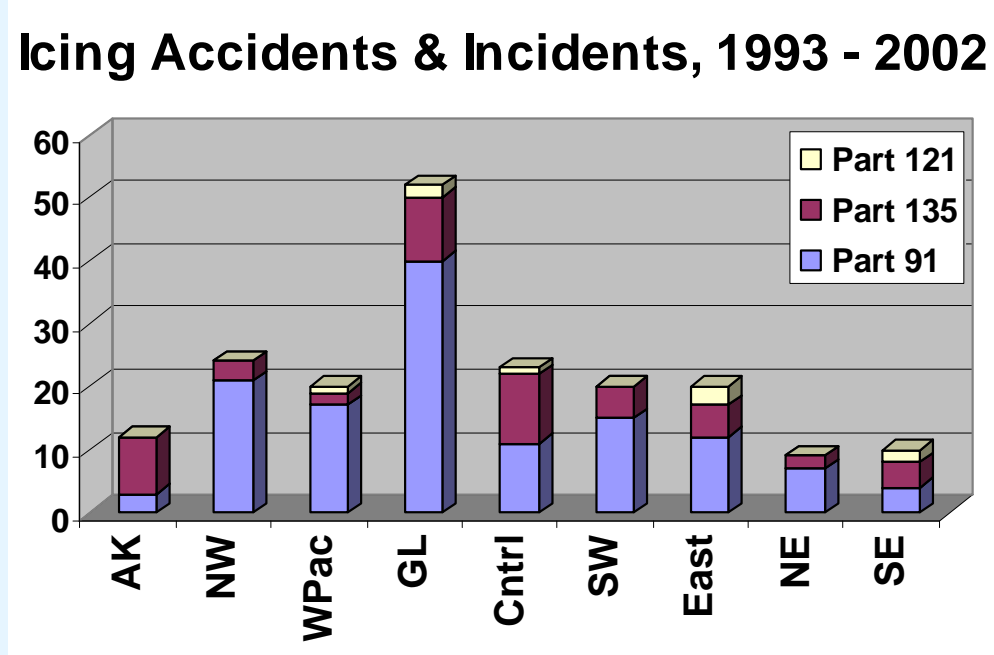
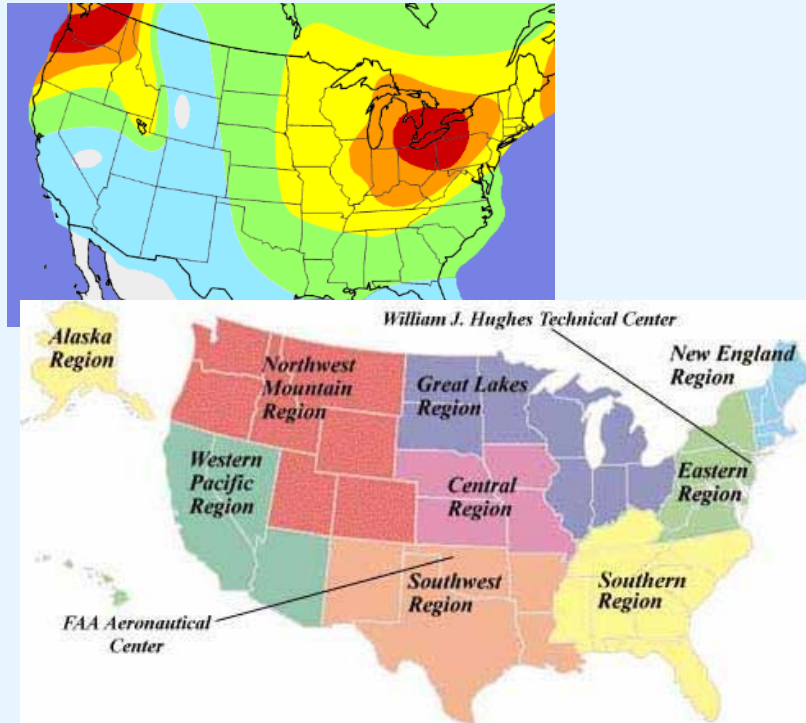


# Where is the ice in Winter?





# Icing Accidents by Region



## Average Pilot Experience

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

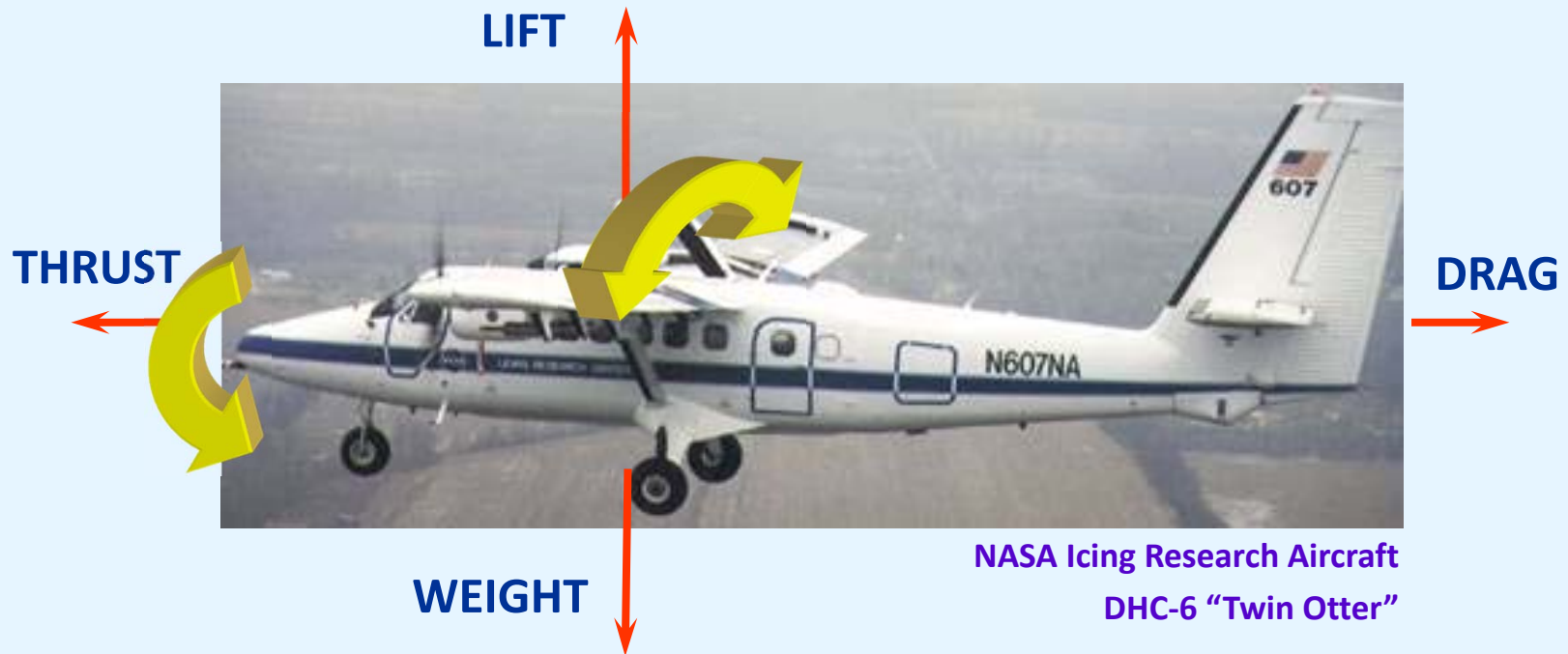
## NASA Commissioned Study: Green, 2004

- Part 91 ~ GA
- Part 135 ~ Commuter & Air Taxi
- Part 121 ~ Larger Revenue Service

*Note: Data not normalized by traffic*



# Icing impacts Performance & Handling



*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)

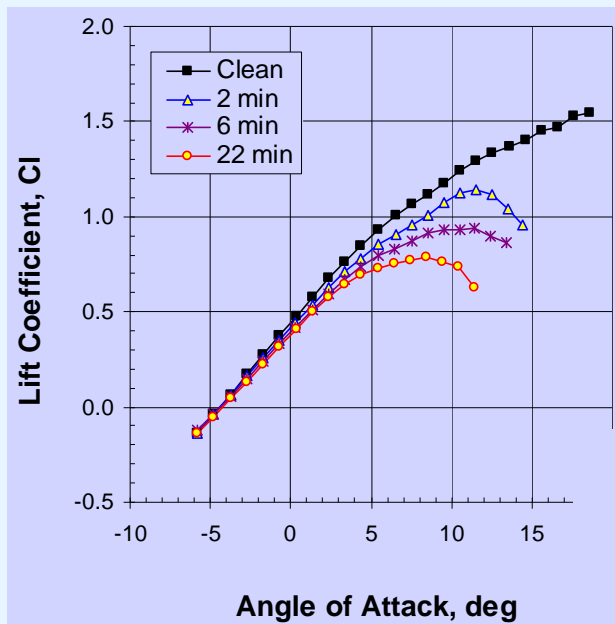
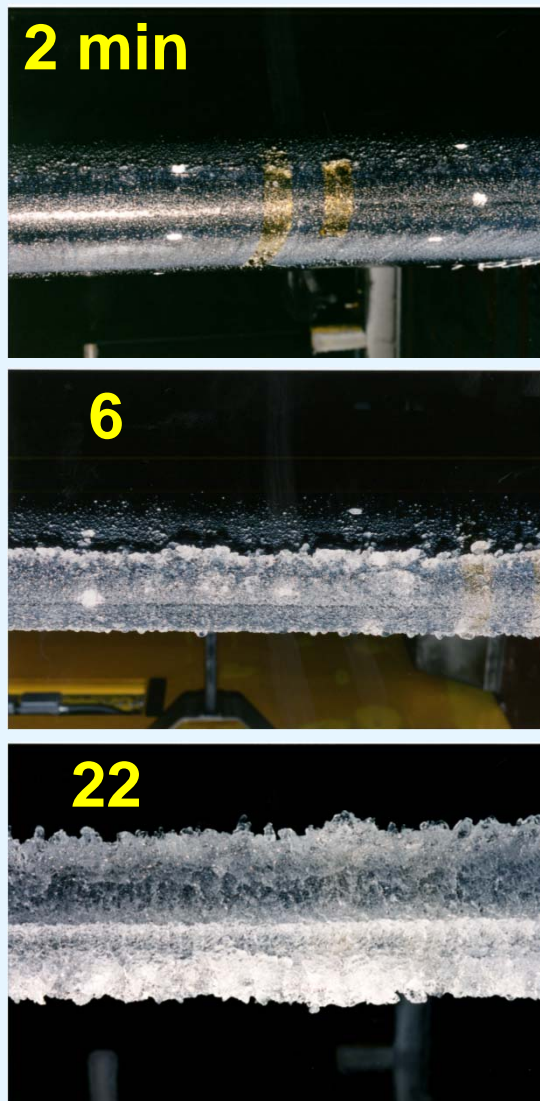
## Handling Qualities

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



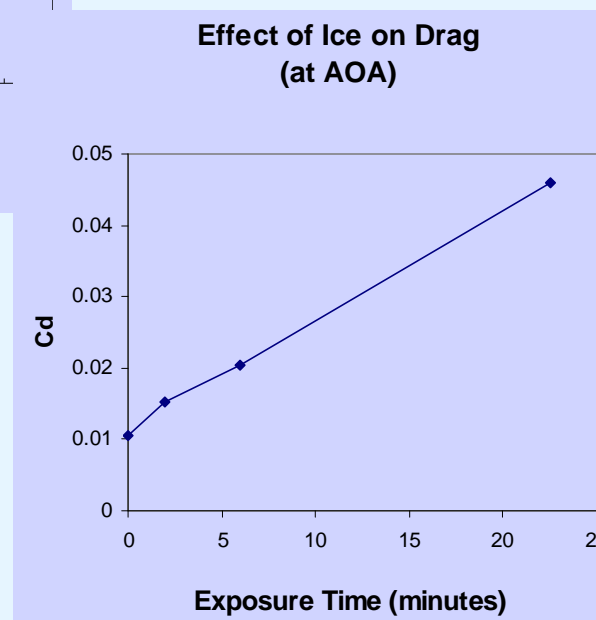


# Ice Accretion – Performance Impact



*IRT Data – Stationary, Straight Wing*

**Noticeable performance degradations within 2 min.**

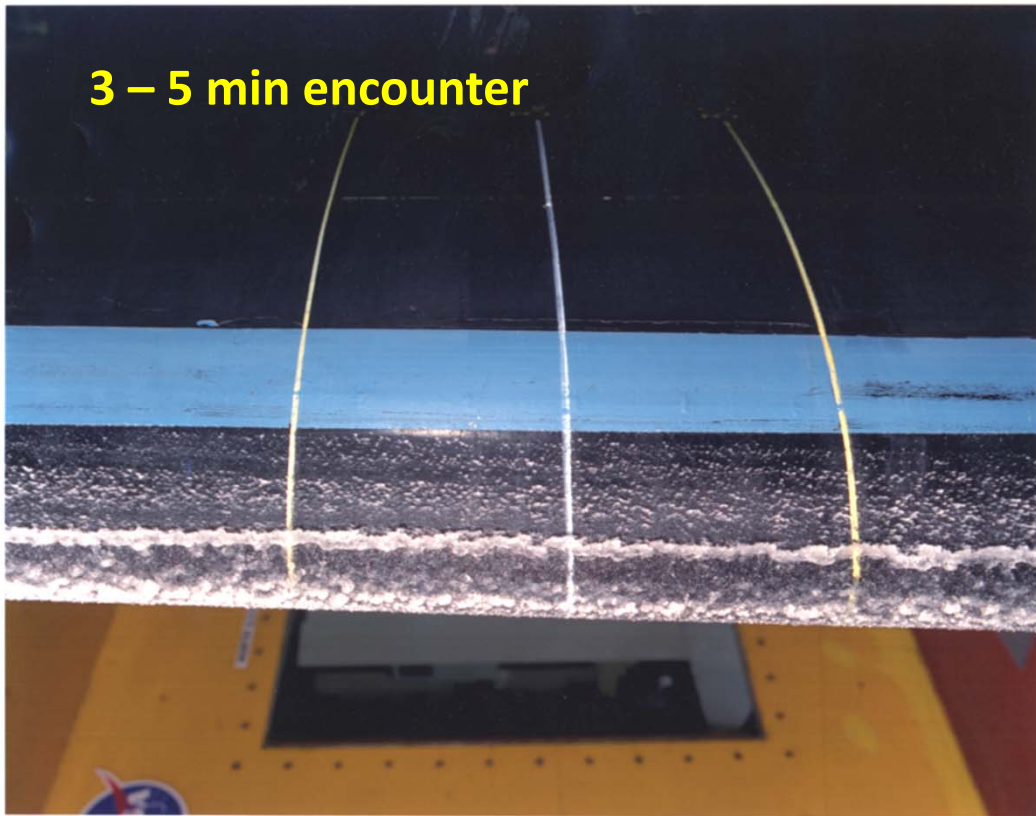




# The Insidious Nature of Icing

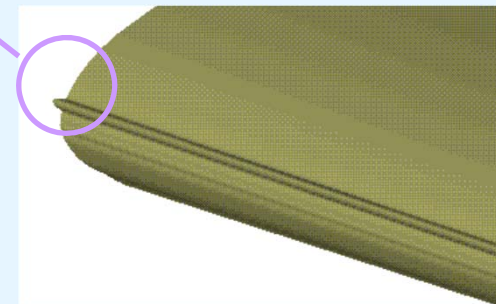
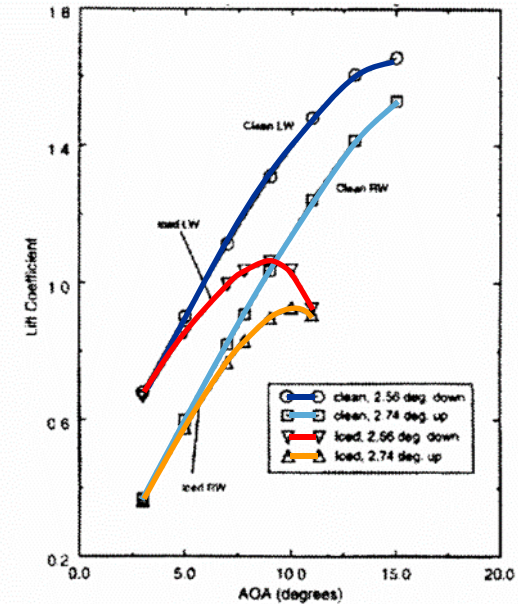
Accident: EMB-120; Monroe, MI; Jan 9, 1997

3 – 5 min encounter



NASA  
C-98-253

National Aeronautics and Space Administration  
Lewis Research Center





# New Rule for SLD and Ice Crystals



## FEDERAL REGISTER

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Vol. 79            Tuesday,  
No. 213            November 4, 2014

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Part III

Department of Transportation

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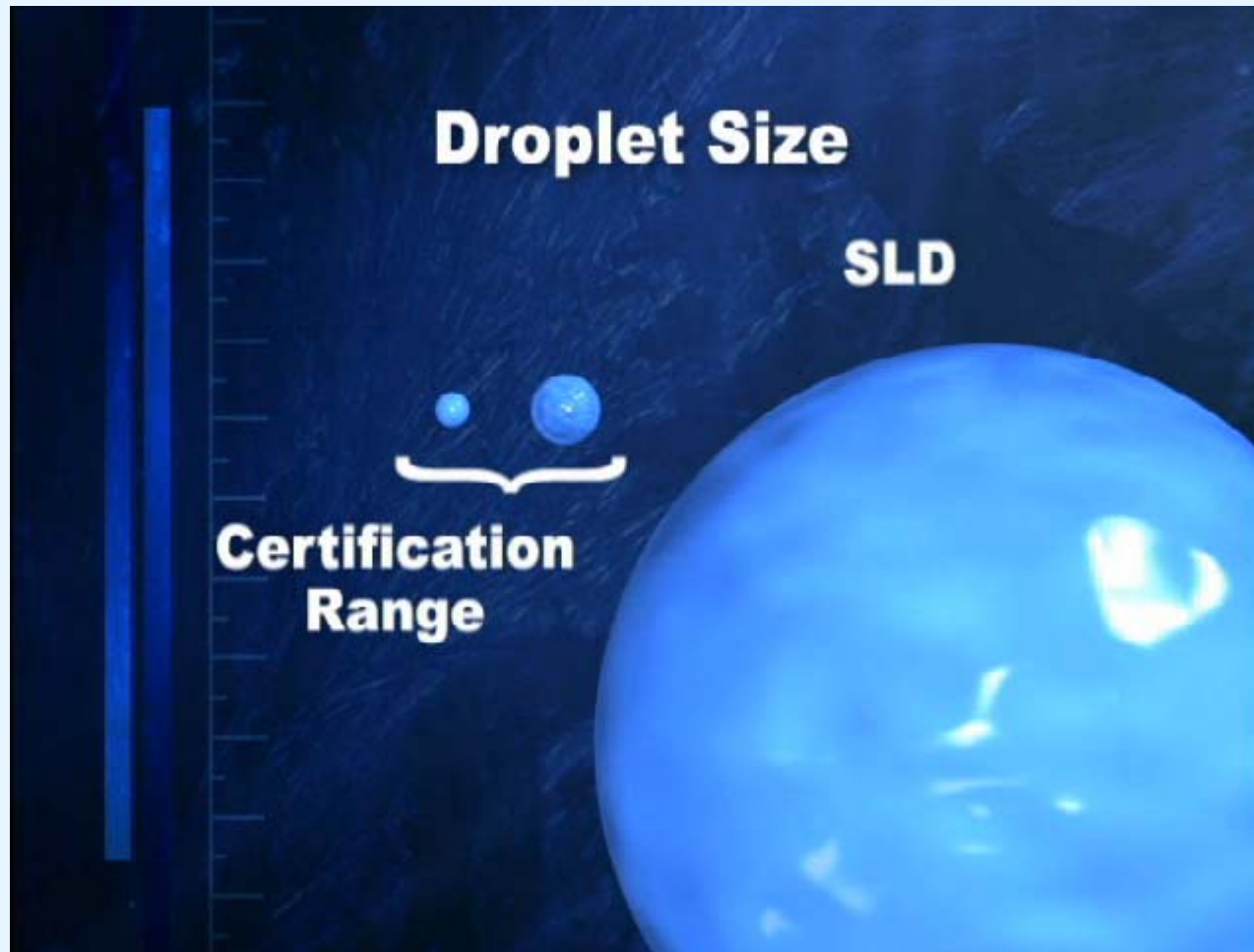
Federal Aviation Administration  
14 CFR Parts 25 and 33  
Airplane and Engine Certification Requirements in Supercooled Large Drop,  
Mixed Phase, and Ice Crystal Icing Conditions; Final Rule

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

NASA  
C-98-1420



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

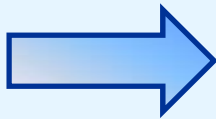


Ice on entire upper wing surface aft of boot



# SLD Ice Accretion Video

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



Time lapse video  
accretion in MVD  
= 140  $\mu\text{m}$  (FZDZ)



stills



# Operational Considerations



# Preflight Planning





# Preflight: Anticipate

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

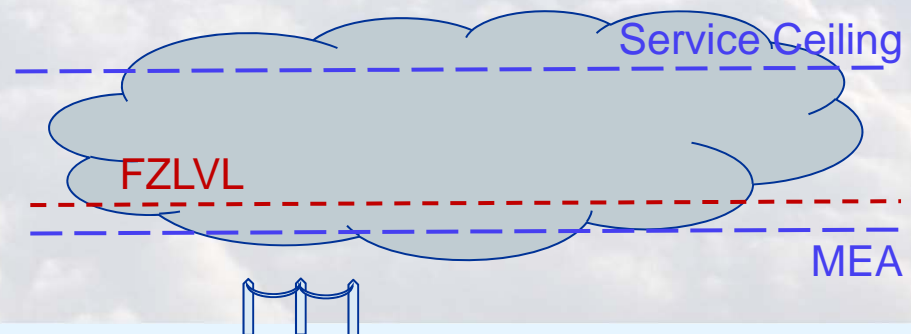
**Visible Moisture** & **Freezing Temps**  
(Clouds & Precipitation) (AFM / +2 C to -20 C)

**Be sure you know:**

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

**Compare to:**

- MEA / MVA
- Practical Ceiling

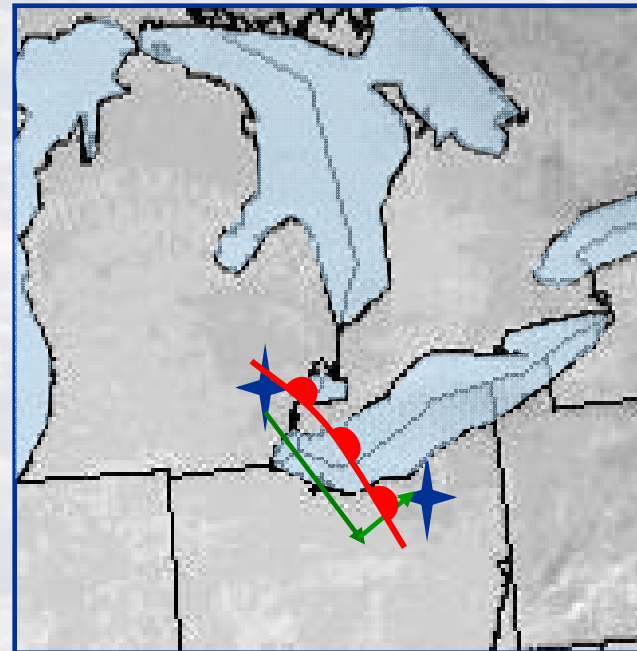




# Preflight Decisions

## 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

The screenshot shows the NOAA's National Weather Service Aviation Weather Center website. The header includes the NOAA logo, the text "NOAA's National Weather Service Aviation Weather Center Aviation Digital Data Service (ADDS)", and the URL "weather.gov". Below the header is a navigation menu with "Home", "News", "Organization", and "Search". A secondary menu lists categories: "Turbulence", "Icing", "Convection", "Winds/Temps", "Prog Charts", and "Java Tools". A third menu lists specific data types: "METARs", "TAFs", "PIREPs", "AIR/SIGMETs", "Satellite", and "Radar". The main content area features four sections: "Current Icing advisories:" with a map of the contiguous U.S. showing icing advisories; "Pilot reports of Icing:" with a map of the contiguous U.S. divided into regions (NorthWest, NorthCentral, NorthEast, Southwest, SouthCentral, SouthEast, Alaska); "Supplementary Icing Information (CIP / FIP)" with a map showing icing information; and "Freezing Level Graphics:" with a map showing freezing levels. A footer note says "See more detailed CIP/FIP plots in the New Flight Path Tool". A left sidebar contains links for "Local forecast by City, St or Zip Code", "Advisories", "Forecasts", "Observations", "Java Tools", and "Related Information".

Where to look:

- Official Briefing

- <http://adds.aviationweather.gov>

- <http://www.weather.gov> (dew point)

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



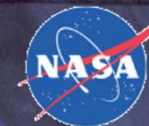
# Prior to Takeoff

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?**

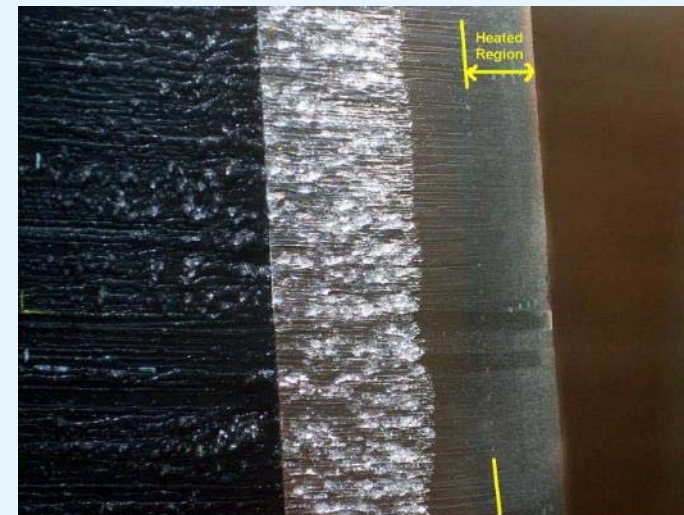
- Clouds & Precipitation
- Temperature (+2C to -20C)

**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)





# Detect Icing Conditions

## Visual Cues

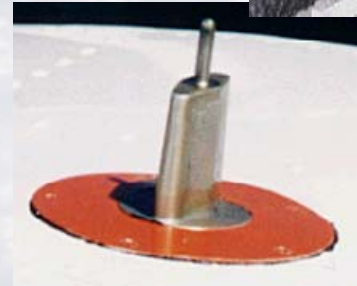
Ice accretes first on objects with a small LE radius (sharp):

- 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)*



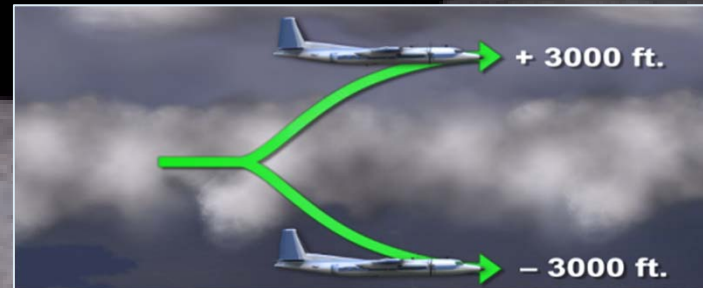


# Work to Exit Icing Conditions

## 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**

# 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

15:40:18.8

VIAS=109 TT= 0.50 TS=-1.30

97-12-11 KLWC=-0.0P.ALT= 1.25



# 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:**

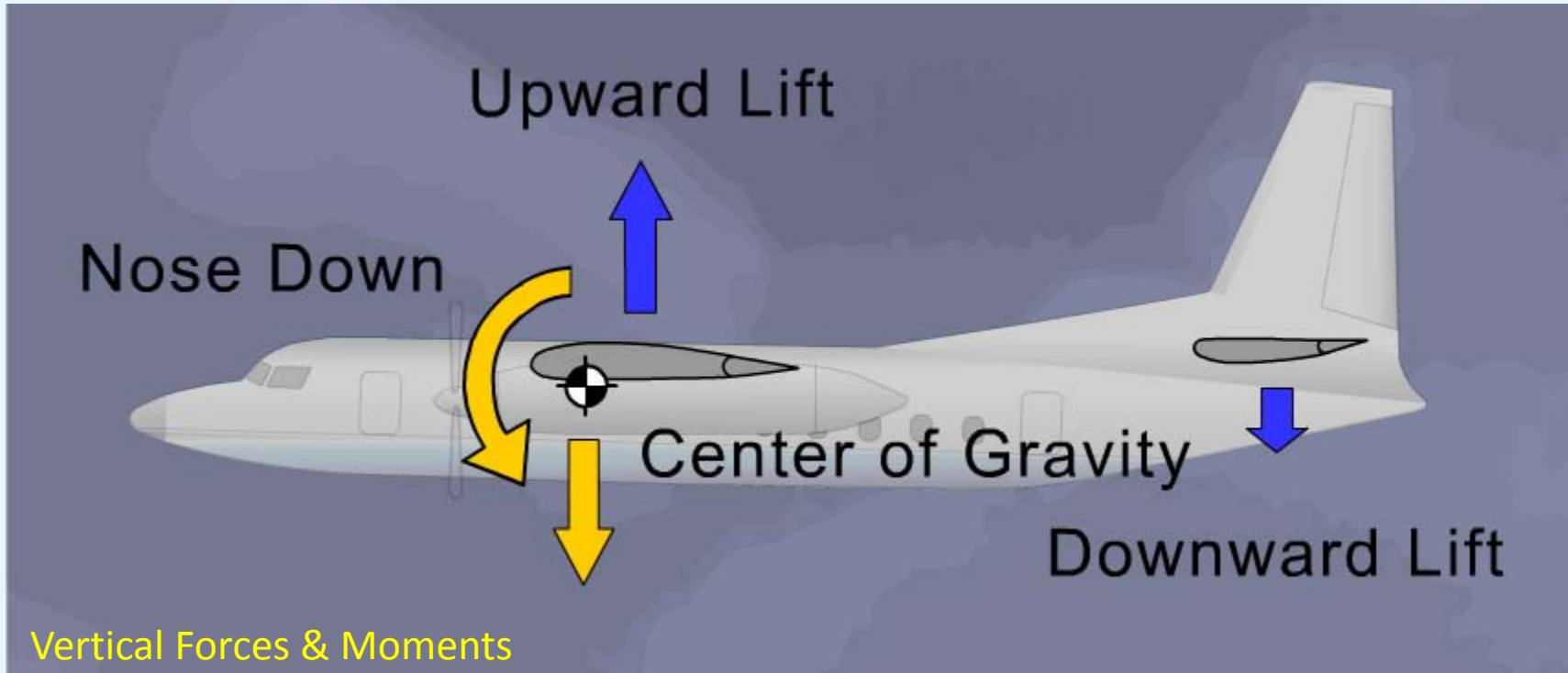
- Roll Upset
- Pitch Upset

**Recovery:** Lower AOA

- Stick Forward
- Add Power



# Role of the Tailplane



Tail Provides Downward Lift (upside down wing)

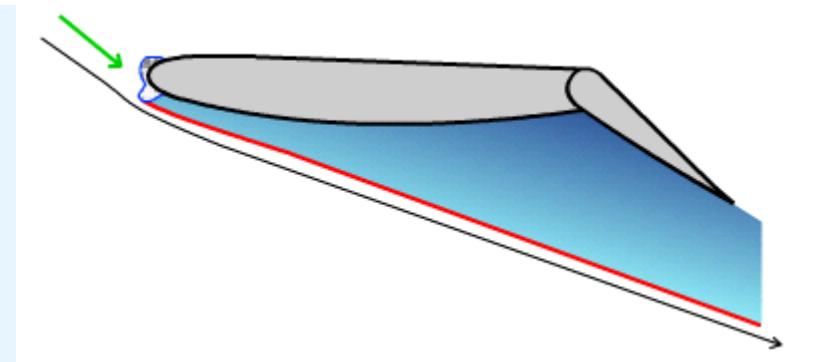
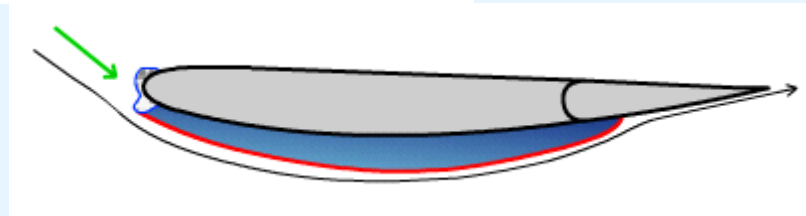
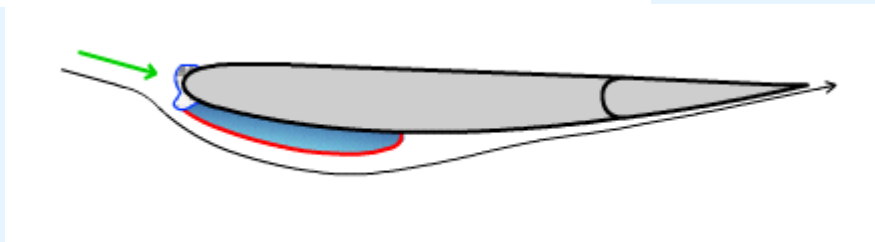
*Tail is Opposite of Wing*

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
- $V = 1.5 V_s$  (High Speed)
- Flaps =  $40^\circ$
- *Increasing Thrust*





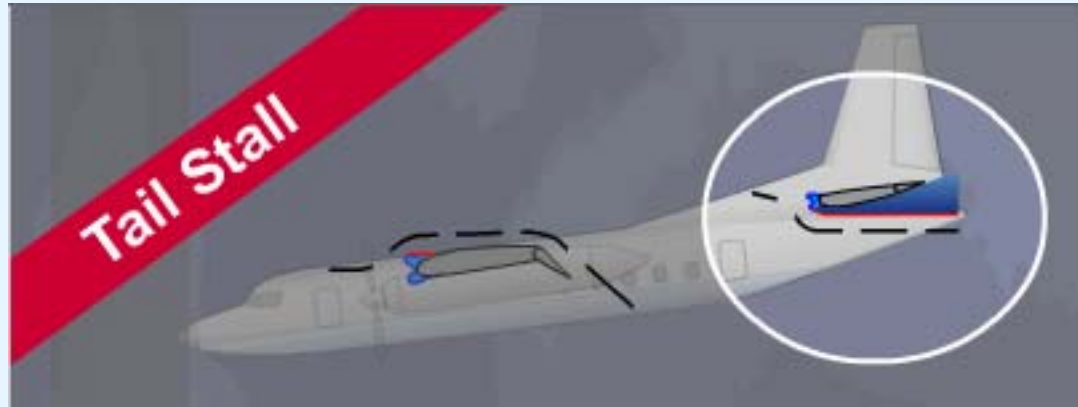
# Tail Stall Event

## 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



Ice Induced Stall Pilot Training

45,045 views



**Federal Aviation Administration**  
Published on Sep 29, 2016

This training aid is intended to help pilots understand the phenomenon of tailplane stall while flying in icing conditions. The training also explains icing certification rules and recommends cockpit procedures to mitigate ice induced stall in order to maintain control of the aircraft.

SHOW MORE

Recent airplane certification experience, analysis of icing events, and research, has led to this updated Ice Induced Stall pilot training

The information in this training video supersedes, supplants and replaces the instruction in all previous NASA tail stall icing training videos

NASA-GRC-508 • October 1, 2016

Ice Induced Stall Pilot Training



# 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





# 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?

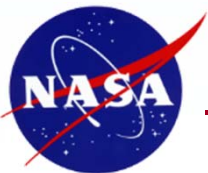
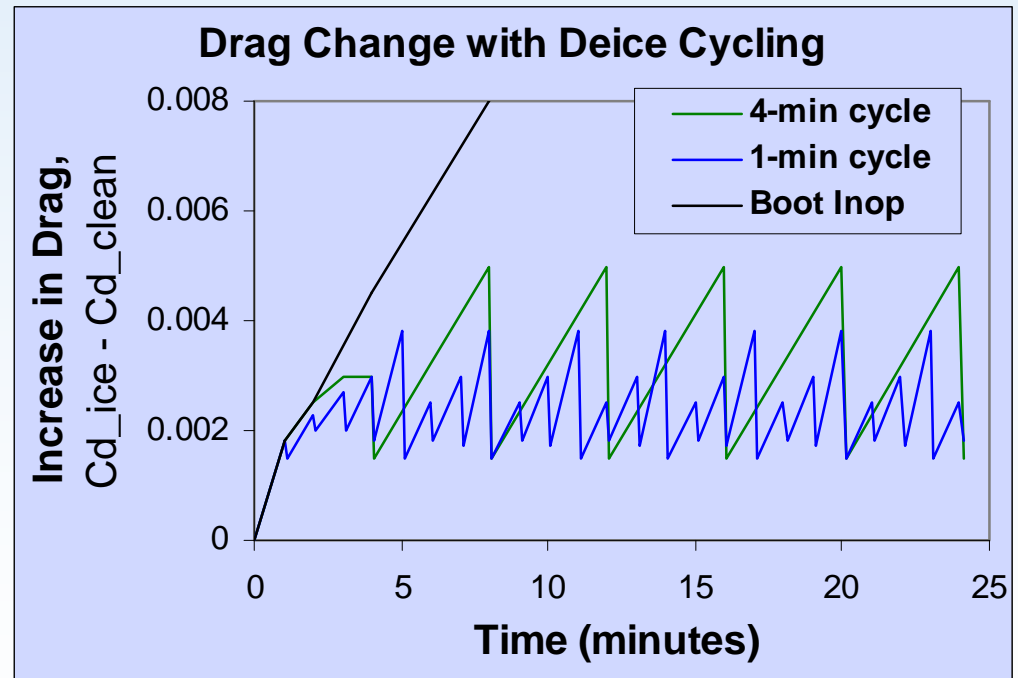
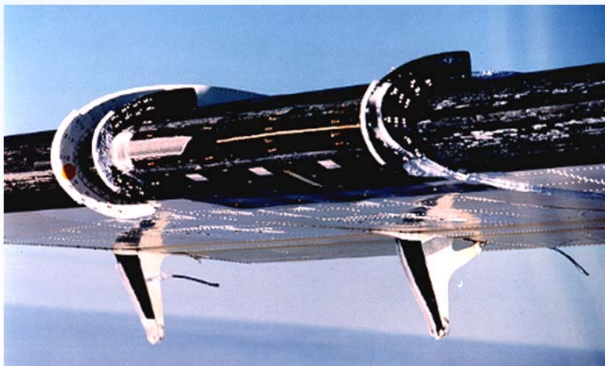


# Myth of Ice Bridging

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




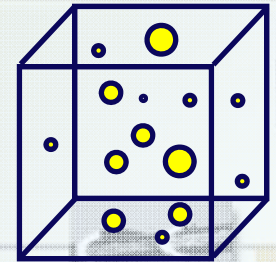









Glenn Research Center

[return](#)

# Basic Icing Physics

## Ice Type and Severity

	Light	Moderate	Severe
<b>Clear</b>			 
<b>Mixed</b>			 
<b>Rime</b>			

### Environmental Factors

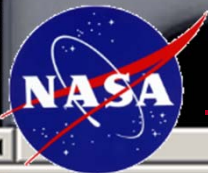
- Temperature
- Liquid Water Content ( $g_{\text{water}}/m^3$ )
- Droplet Size (mm)

Meaningful images of Severe Mixed are not available.

### Other Factors

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

Most ice accumulations in 10-15 minutes.



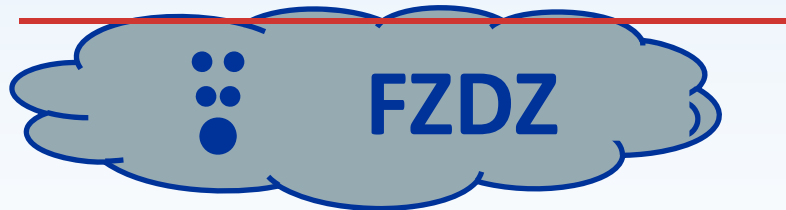
Glenn Research Center

# How does SLD Form?

## Collision-Coalescence

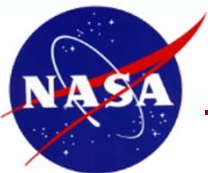
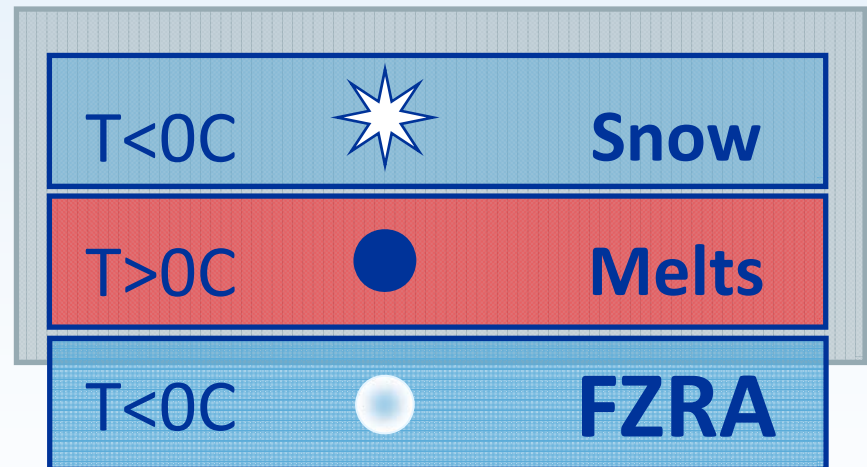
(96%)

FL120, SAT= -12 C



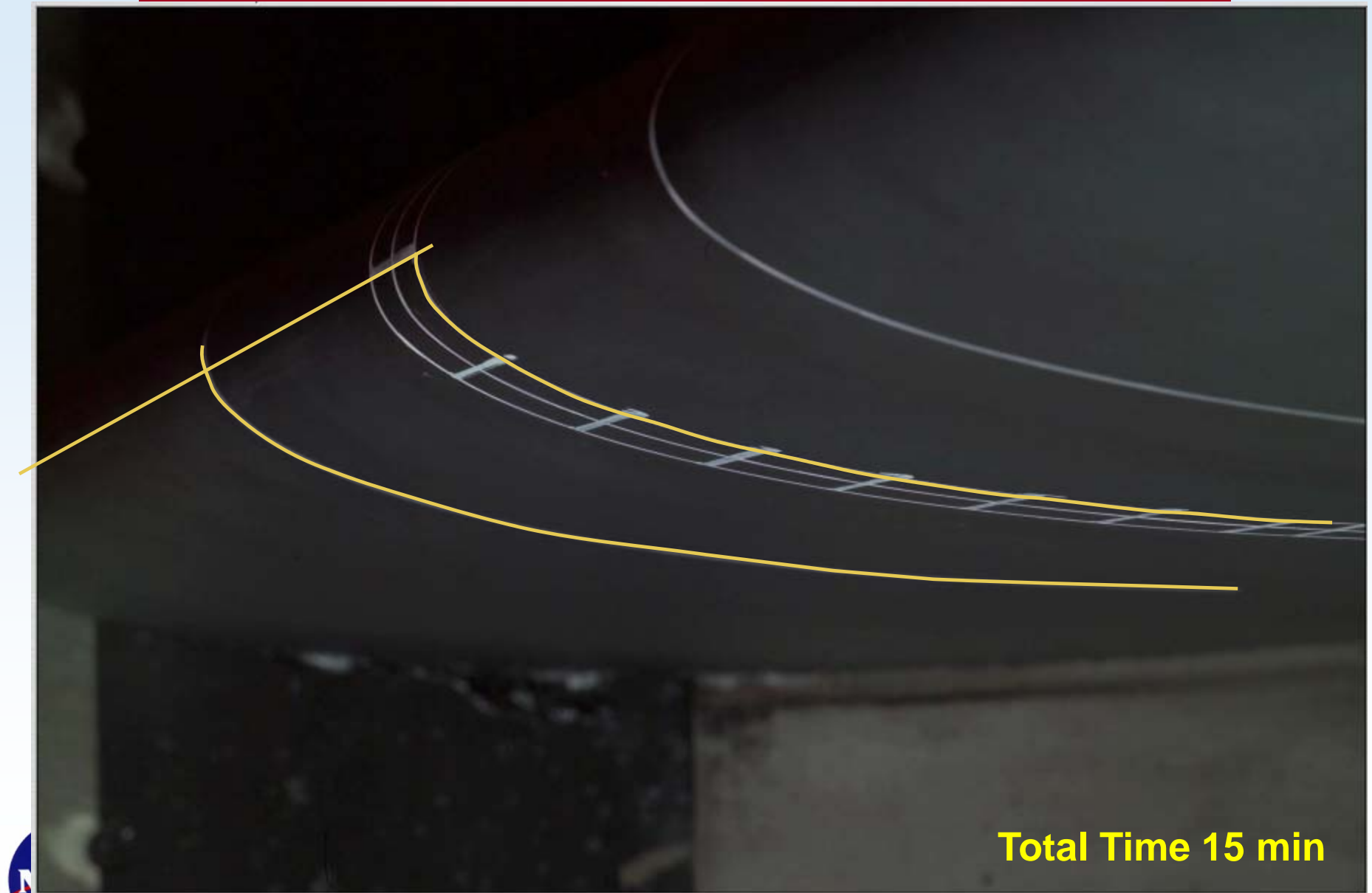
## Temperature Inversion

Warm/Stationary Front (4%)

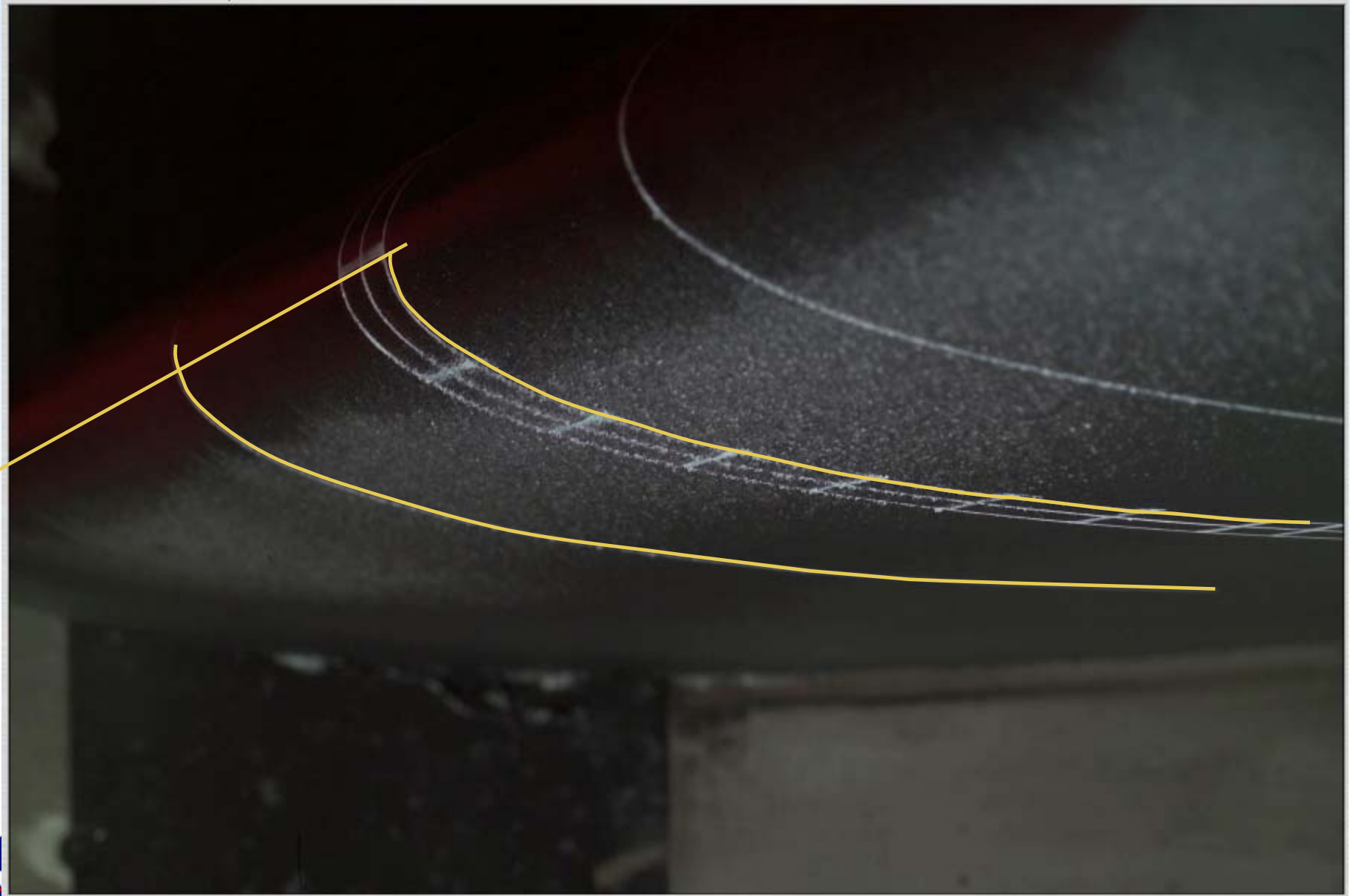


Glenn Research Center

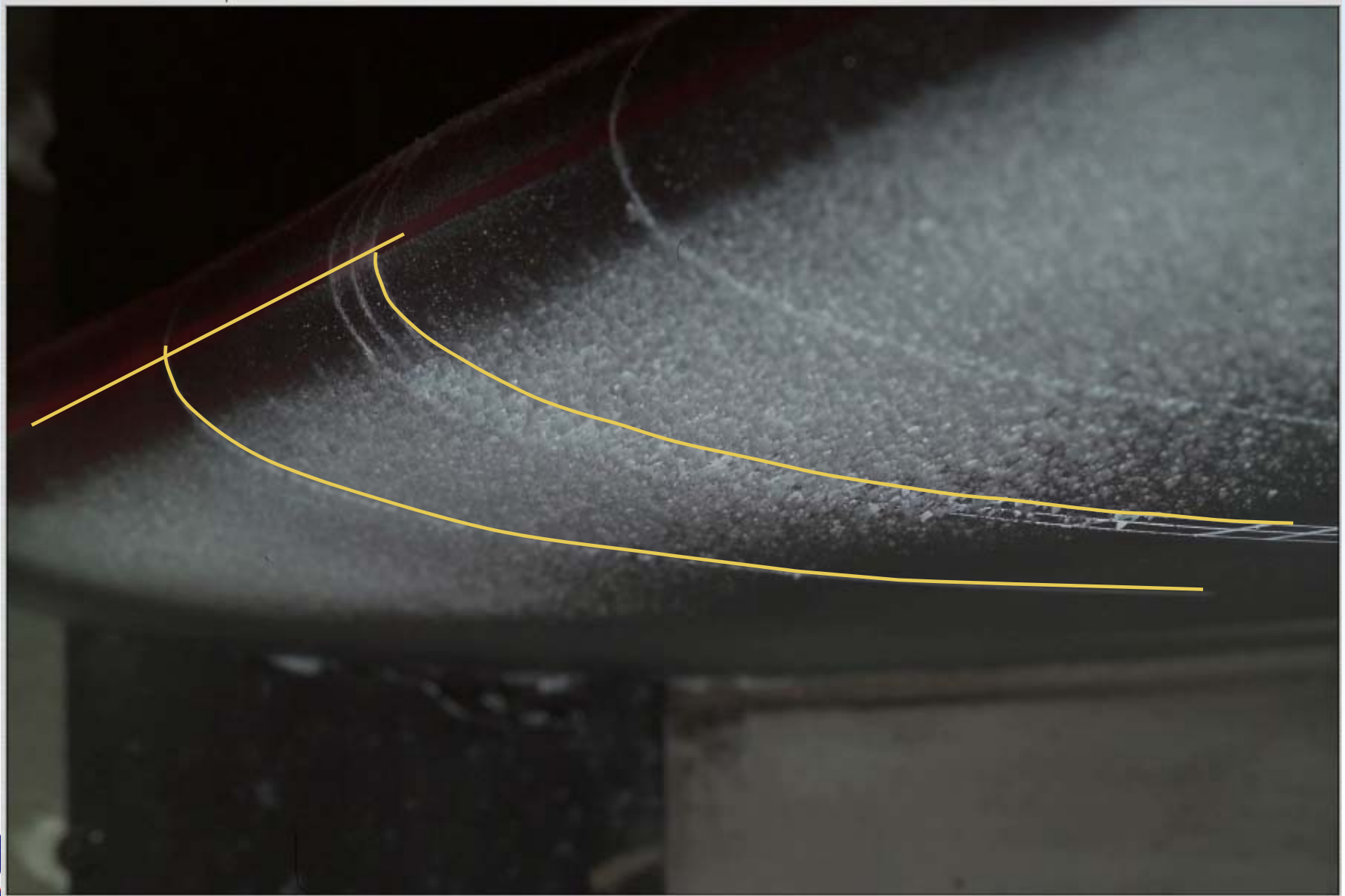
# Ice Accretion Video: t= 0 steps



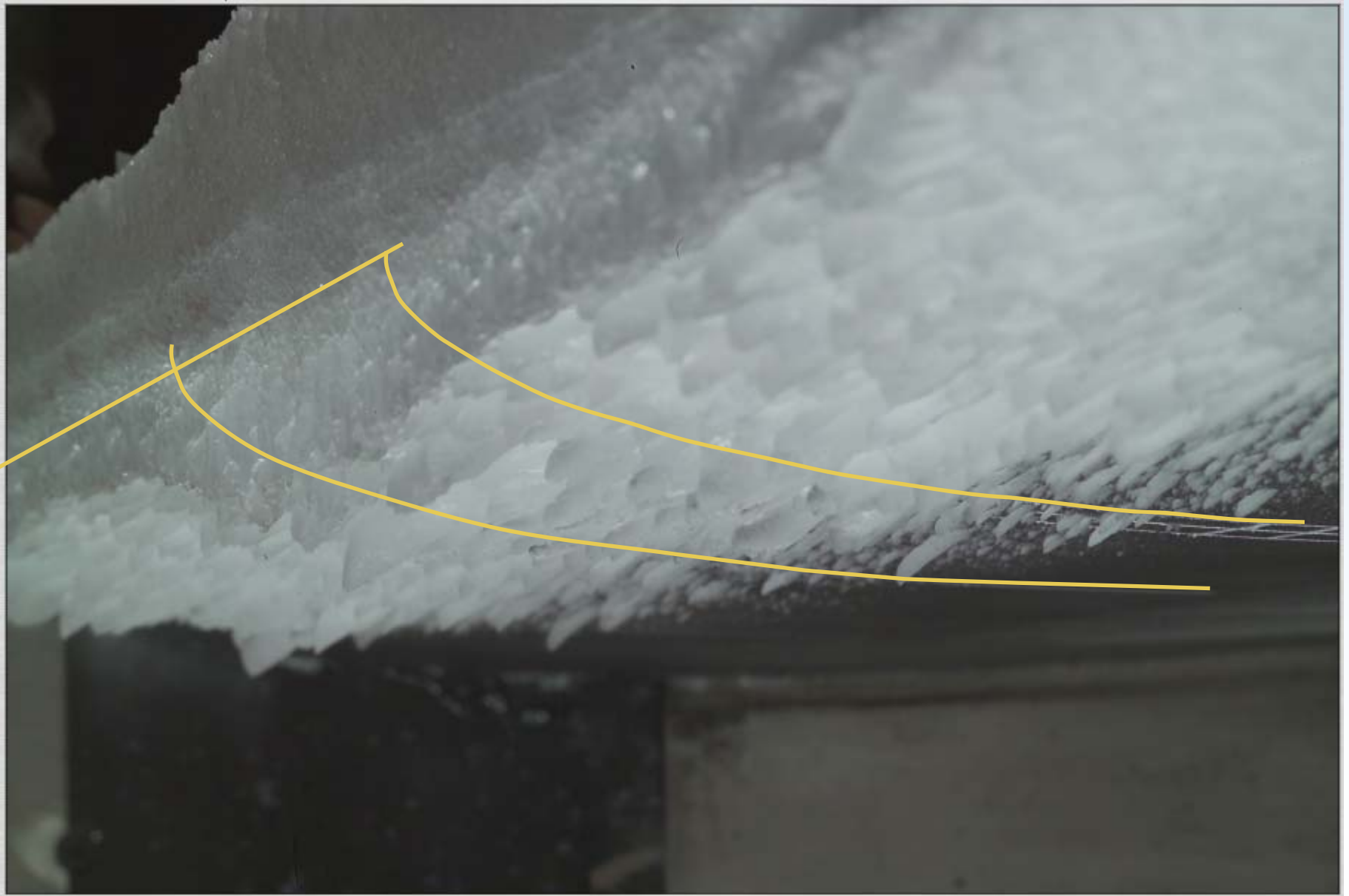
# Ice Accretion Video: t= 2 steps



# Ice Accretion Video: t= 4 steps



# Ice Accretion Video: $t = 25$ steps





# Case Study: In-Flight Icing

## NTSB Animation: Colgan Air, 2/12/09

This three-dimensional (3-D) animated reconstruction shows the last 2 minutes of the February 12, 2009, accident involving a Bombardier DHC-8-400, N200WQ, operated by Colgan Air, Inc., which crashed about 5 nautical miles northeast of Buffalo-Niagara International Airport, Buffalo, New York, while on an instrument landing system approach to runway 23. During the approach, a pitchup motion occurred, followed by a left roll and then a right roll. During these maneuvers, both the stick shaker and stick pusher were activated, and the speed decreased. After further pitch and roll excursions, the airplane entered a steep descent from which it did not recover.

The animation shows excerpts from the flight data recorder (FDR), the cockpit voice recorder (CVR) transcript, recorded radar data, and aircraft performance data. It does not depict the weather or visibility conditions at the time of the accident. The animation does not include audio.

The upper portion of the animation shows a 3-D model of the airplane and the airplane's motions during the accident sequence. In this area, selected content from the CVR transcript or other annotations are superimposed as text at the time that the event occurred. All times (in eastern standard time) are shown on the right side of the screen.

The lower portion of the animation depicts instruments and indicators, which display selected FDR or calculated parameters. The instruments and indications are shown in three sections, which are (from left to right):

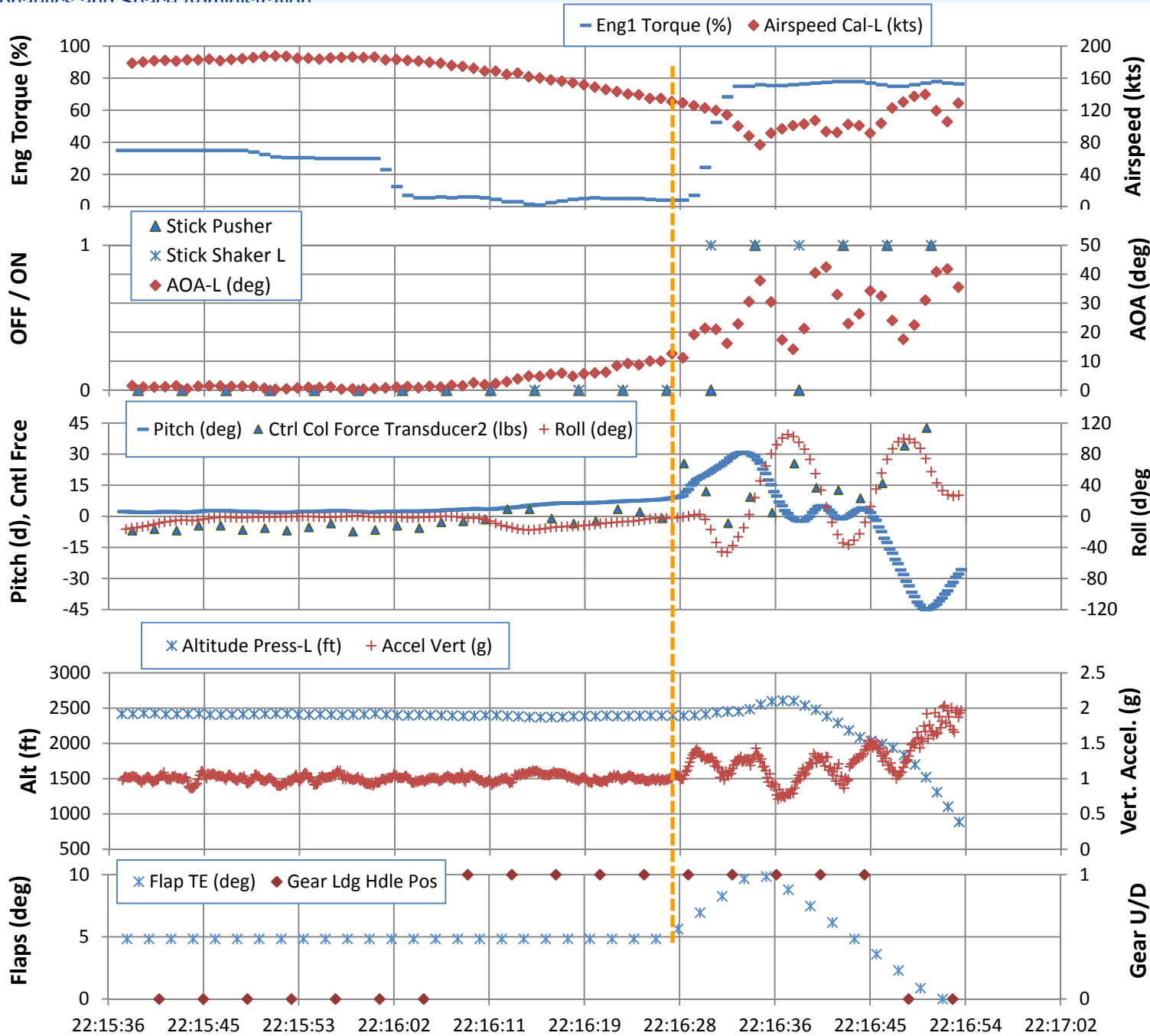
Airspeed, airspeed tape, low speed cue, altitude indicator showing pitch and roll attitude, altitude, altitude tape, rate of climb, and heading;

Stick shaker and stick pusher indicated as text, control wheel/column icon depicting the control wheel (rotating right or left) and control column (moving up or down) inputs, and an indicator showing rudder pedal inputs; and

The power lever and condition lever as indicators, the flap handle selection as an indicator, and auto pilot status and gearhandle position indicated as text.



# NTSB - FDR (#417237)

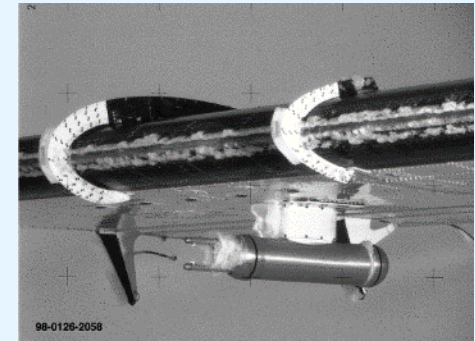




# Definitions

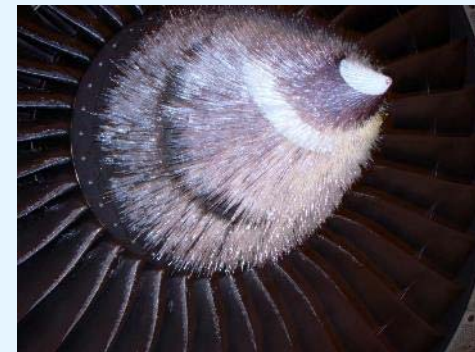
## Airframe Icing:

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



## Engine Icing (traditional):

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



## Carburetor Icing:

outside the scope of this talk.  
Occurs in high humidity

*Most images from NASA  
icing research aircraft flights*