Ground & In-Flight Icing

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Who am I?

1997
Icing Research Aircraft

2012
Propulsion Systems Lab

1998 – 2005
Icing Research Tunnel

2006

NASA’s Icing Training Aids

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 Ground 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

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

National Aeronautics and Space Administration

www.nasa.gov
Available Courses Icing Training

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Start Course

Search on “NASA Aircraft Icing”

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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

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

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

Remove all frost, ice & snow

Broom/Squeegee

Hot Air

Spray Type I

Ensure (by touch) a clean aircraft.

Mop on Type I
A Pilot’s Guide to Ground Icing: Review Material

**Decision Making Flow Chart**

- **Aircraft certified for flight into known icing?**
  - **Yes**
    - Ice protection system fully operational?
      - **Yes**
        - See Page 2
      - **No**
        - See Page 2
  - **No**
    - See Page 2

- **In-flight icing?**
  - **Yes**
    - Freezing precipitation/active frost on ground?
      - **Yes**
        - See Page 6, U1
      - **No**
        - Don’t go
  - **No**
    - See Page 6, U2

**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?

Percent of time with icing conditions aloft:
- 50%
- 40%
- 30%
- 20%
- 10%
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
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)
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
Looking along LE of airfoil model in NASA’s Icing Research Tunnel.

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

Service Ceiling
FZLVL
MEA
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
Local – are you in icing conditions?
- Clouds & Precipitation
- Temperature (+2°C to -20°C)

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
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

Angle of attack at the tailplane increases due to flap deflection

Tail Stall!
Nose pitches down
Tail Stall Event

Footage of a Tail Stall Event

NASA Icing Research Aircraft

- 22 min “normal” icing accretion
- \( V = 1.5 \text{Vs} \) (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*
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.

Ice Induced Stall Pilot Training

Federal Aviation Administration
Published on Sep 29, 2016

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

SHOW MORE
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
   Increased Drag will
   increase stall speed
   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

![Graph showing Drag Change with Deice Cycling](image)

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Glenn Research Center
at Lewis Field

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9/6-7/09
Environmental Factors

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

Other Factors

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

Glenn Research Center

at Lewis Field
How does SLD Form?

Collision-Coalescence (96%)

Temperature Inversion
Warm/Stationary Front (4%)

FL120, SAT= -12 °C

T<0°C Snow
T>0°C Melts
T<0°C FZRA
Ice Accretion Video: $t = 0$ steps

Total Time 15 min
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, attitude 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.
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