Aircraft Icing

Introduction and Definitions

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Outline

- Introduction and definitions
- Aerodynamic effects of icing
- Factors effecting icing
- Cloud types
- Kinds of ice
- Icing related accidents
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- Icing software

Introduction

- Icing is one of the most serious hazards for aircraft. Icing comes from the freezing of cloud droplets, or **supercooled droplets** which remain in liquid state even at temperatures far below freezing, when they are struck by the aircraft during the flight.
- Cloud droplets may freeze instantaneously and form **rime ice** on unprotected surfaces or run downstream and freeze later forming **glaze ice** structure.
- Icing is most severe when the ambient temperature is near 0^oC but may be encountered at temperatures as low as -40^oC and as high as 10^oC.

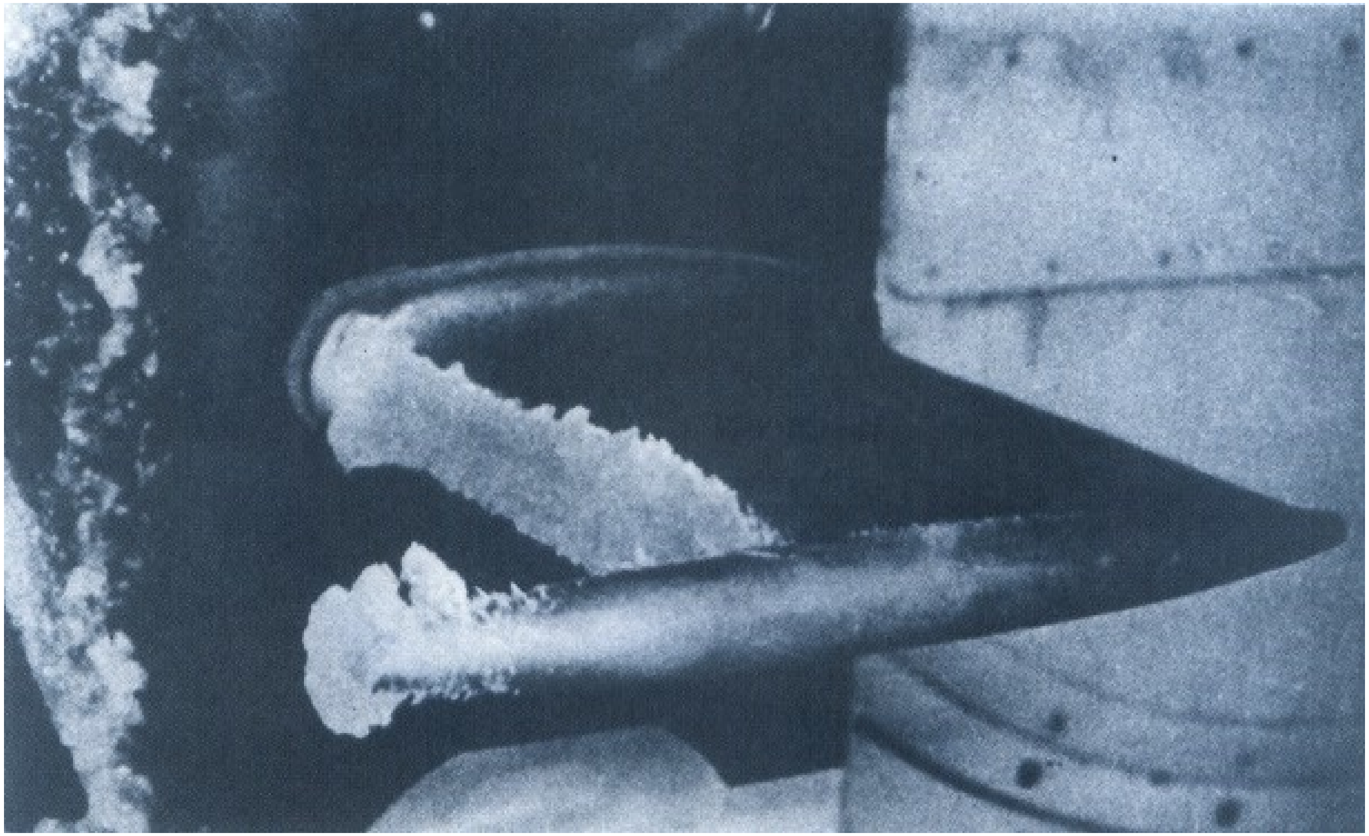
Introduction

- When and where will ice form?
  - Ice can form on **every exposed frontal surface** of the airplane at 0^oC or colder temperatures when liquid water is present, i.e. when flying through clouds.
  - Wings, tail surfaces, control surfaces, propeller, windshield, antennas, vents, intakes, cowlings, flight sensors, ...

Wing icing

Propeller icing

Pitot tube icing



Introduction

- Why is ice bad?
  - Ice disturbs airflow, **increases drag, decreases lift**.
  - **Stall speed increases**, stall a.o.a. decreases considerably.
  - Tail stall is more severe than wing stall.
  - **Pitch and roll behavior unpredictable**, possibly **uncontrollable**. Recovery from stall or spin may be impossible.
  - May cause **engine stoppage** by icing the carburetor or blocking engine's air inlet (induction icing).
  - Windscreen icing may restrict or even **block forward vision**, especially during landing.
  - **Increases weight**.

Aerodynamic effects of icing

Run number	Duration, min	Temperature, °F	Velocity, ft/s	LWC, g/m^3	MVD, µm
17	10	26	159	0.92	14.4

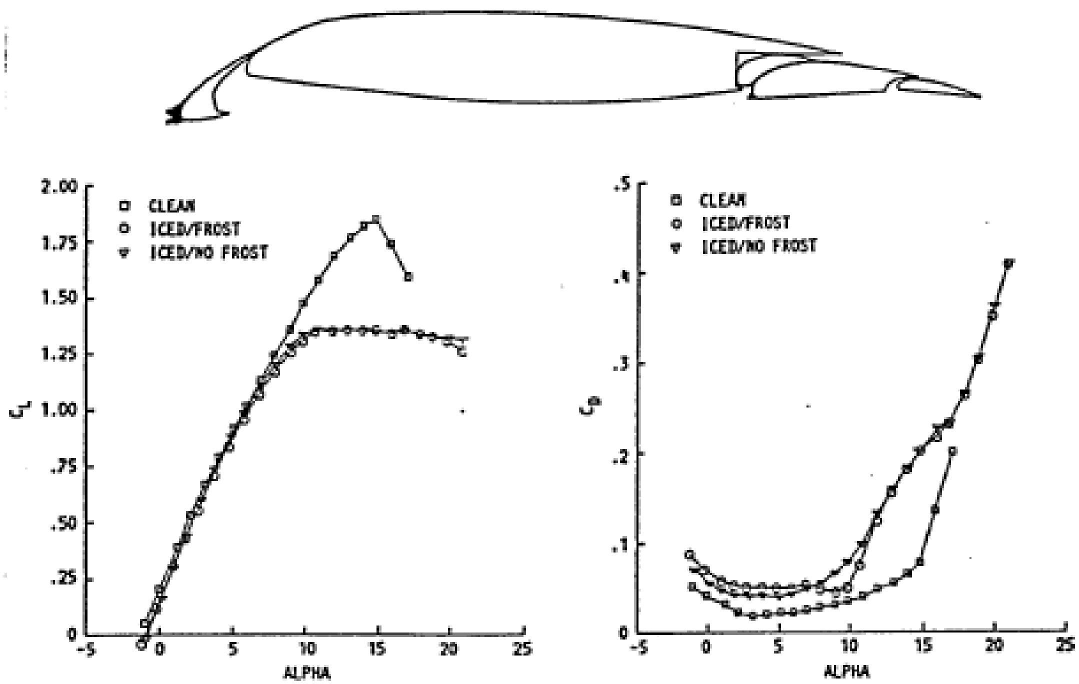


Fig. I.1 Effects of ice on lift and drag for the Boeing 737-200 wing model[10].

Tail stall

Normal forces — no ice

Tail stalls — loss of lift from horizontal tail

Aerodynamic effects of icing

- Drag may increase by 40% on unprotected wing surfaces,
- Lift may decrease by 30%,
- Propeller efficiency may reduce by 20%.

Factors effecting icing

Parameter	Short-hand	Symbol
Ambient temperature		T_a [^oC or ^oF]
Freestream velocity		V_∞ [m/s or knots]
Altitude		h [ft]
Liquid water content	LWC	ρ_a [g/m^3]
Relative humidity	RH	RH
Droplet size (median volume diameter)	MVD	d_p [μm]
Total icing (exposure) time		t_{exp} [s]
Horizontal extent	HE	HE [nm]
Angle of attack		α
Shape and size		c

Cloud types

- The **stratiform clouds** (continuous icing conditions) with horizontal extents up to 200 miles, altitudes 5 000 ft, liquid water content ranging from 0.1 g/m^3 to 0.9 g/m^3 and droplet diameters varying from 5 to 50 microns,
- The **cumuliform clouds** (intermittent icing conditions) with vertical extents of 10 000 ft, horizontal extent of about 6 miles, liquid water content ranging from 0.1 g/m^3 to 1.7 g/m^3 and sometimes as high as 3.9 g/m^3 or more, and droplet diameters similar to the case of stratiform clouds.
- Icing can be serious when the cloud has a **high liquid water content**.

Stratiform cloud

- Gray, low cloud base,
- Sheet like,
- Usually associated with low pressure systems,
- Little or no turbulence,
- Can be associated with fog and rain.

Cumulus cloud

- Convective currents,
- Flat bases,
- Dome shaped tops,
- Rain not likely,
- Turbulence possible.

Towering Cumulus cloud

- Unstable air,
- Extensive vertical development,
- Cauliflower-shaped tops,
- Severe turbulence,
- Rain possible.

Icing risk

Icing Risk				
Cumulus Clouds		**Stratiform Clouds**		**Rain and Drizzle**
0° to -20°C 32° to -4°F	High	0° to -15°C 32° to 5°F	High	0°C and below 32°F and below
-20° to -40°C -4° to -40°F	Med.	-15° to -30°C 5° to -22°F	Med.	
< than -40°C <than -40°F	Low	< than -30°C <than -22°F	Low	

Icing risk

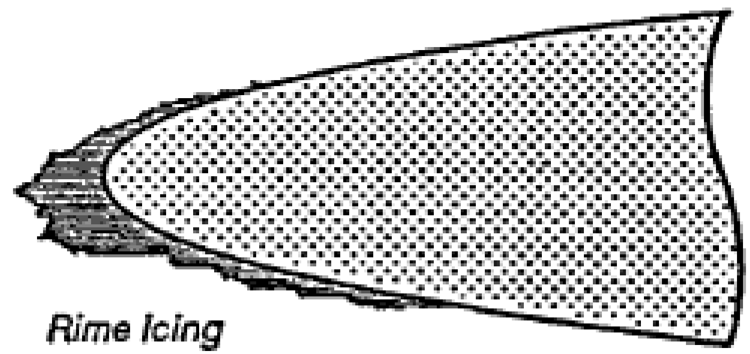
Kinds of ice

- Rime ice
  - **Low T_a and LWC**, **milky, opaque** appearance with shapes roughly following the contours of the surface. Can be **easily removed by de-icing** or **prevented by anti-icing systems**.
- Glaze ice
  - **Higher T_a and LWC**, **transparent appearance**, **irregular shapes** (horns, scallops, lobster tails, etc.). **Denser, harder, transparent and generally hard to break**.
- Mixed ice.

Rime and Glaze Ice

Rime ice conditions

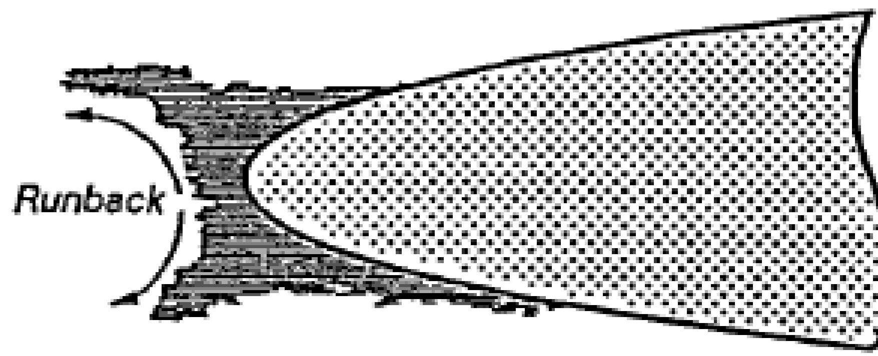
- Air temperature: Low
- Airspeed: Low
- Liquid Water Content: Low
- Water droplets: Freeze on impact



Rime Icing

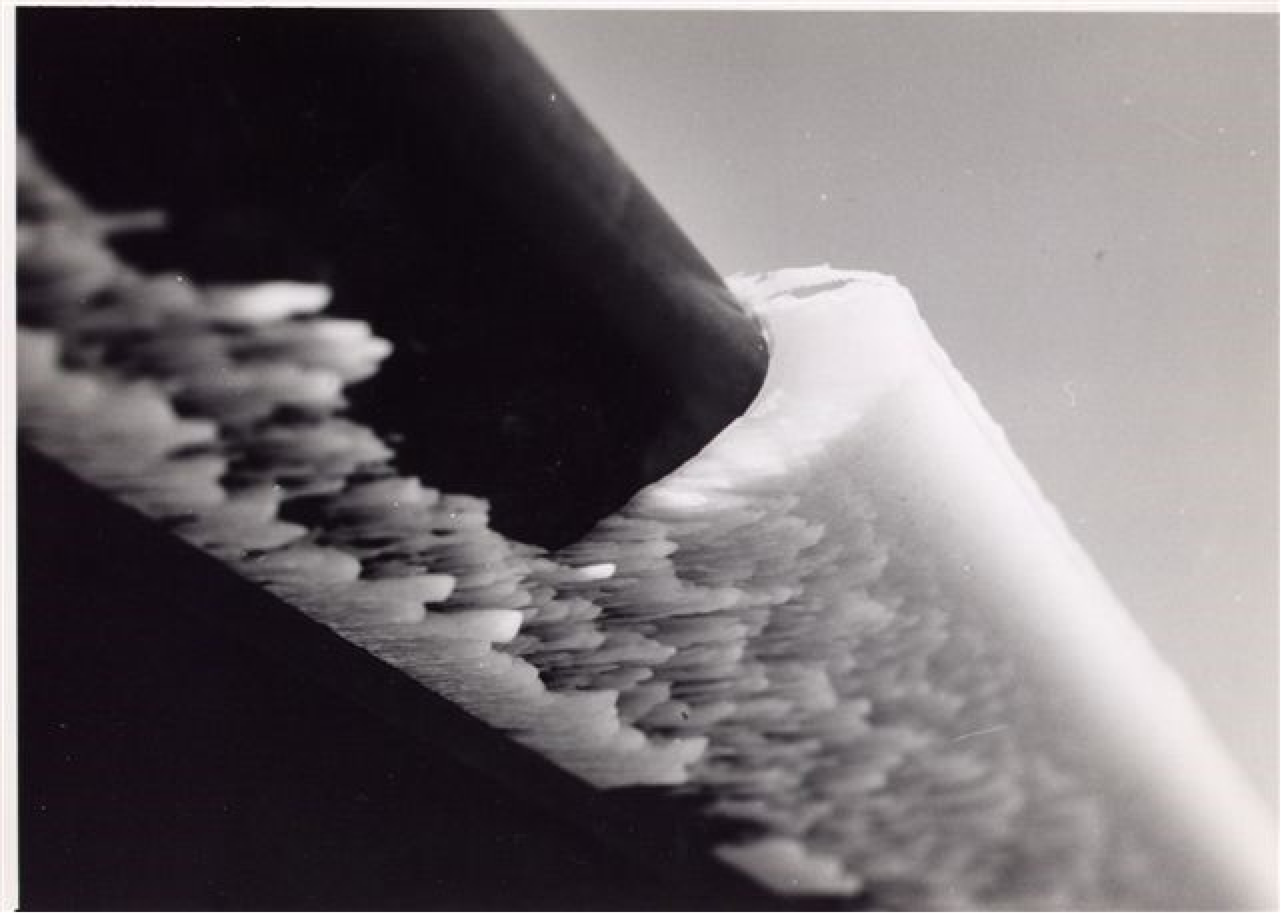
Glaze ice conditions

- Air temperature: High
- Airspeed: high
- Liquid Water Content: High
- Water droplets: Only a fraction freezes on impact, some flow on surface

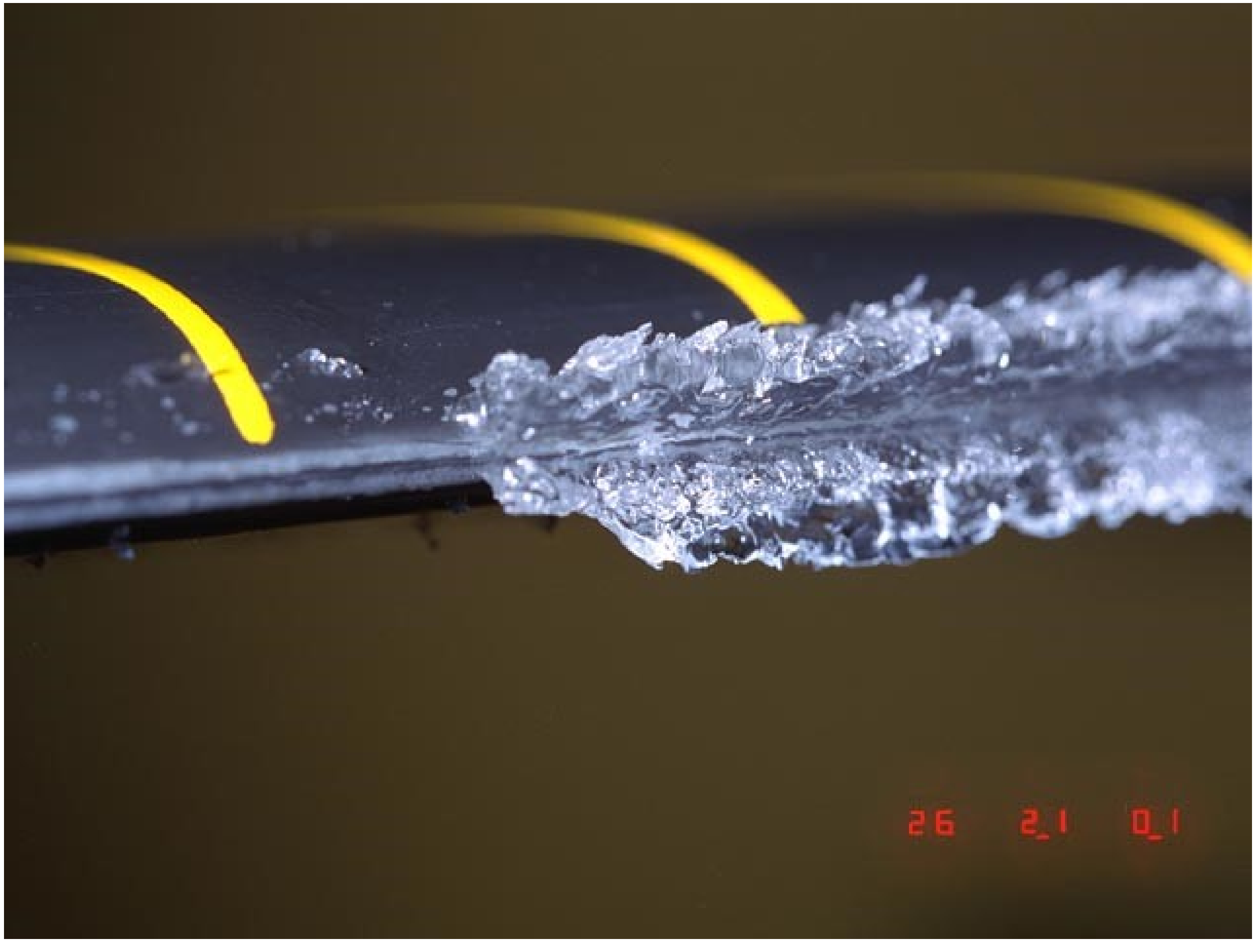


Glaze icing

Rime Ice



Glaze Ice



Mixed Ice

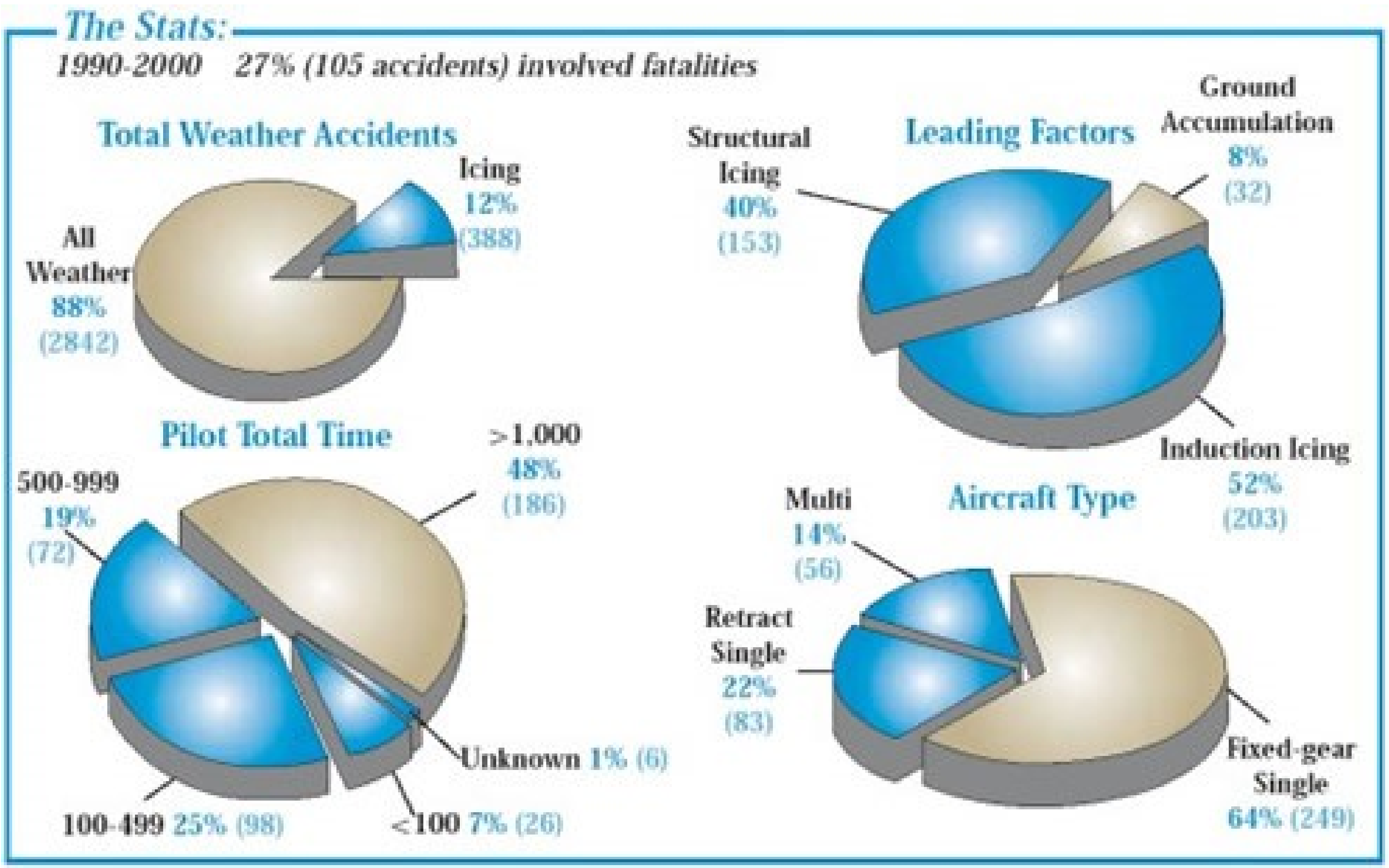
Mixed ice formation on wing leading edge

Icing related accidents

Table I.1 List of icing related accidents.

Date	Location, Airline and Aircraft Type	Precipitation/Observations
26 Jan. 74	Cumaovas THY F28	Frost accretion on the wings
03 Jan. 77	Anchorage JAL DC-8-62	Fog
04 Jan. 77	Frankfurt ? B737	Light snow, rime ice
27 Nov. 78	Newark TWA DC-9-10	Blowing rain and snow
20 Dec. 78	Mineapolis N4OSN Learjet	Probable cause: snow and ice on wing
19 Jan. 79	Detroit N73161 Learjet	Premature stall, ice on wing
12 Feb. 79	Clarksburgh ALLEGHENY Nord 262	Light snow, frozen snow on empennage
18 Feb. 80	Boston REDCOTE Bristol 253	Light snow
13 Jan. 82	Wash. D.C. AIR FLORIDA B737	Moderate to heavy snowfall
05 Feb. 85	Philadelphia AIRBORNE DC-9-10	Light freezing rain, ice & snow pellets fog
12 Dec. 85	Gander ARROW AIR DC-8-63	Light freezing drizzle, snow grains
15 Nov. 87	Denver CONTINENTAL DC-9-10	Moderate snow, fog
18 Jan. 88	New Mexico N2614U Cessna 402	Prob. cause: Ice/Frost removal inadequate
06 Feb. 88	California N2832J Cessna	Ice/Frost removal inadequate
23 Dec. 88	Montana N5570H Piper	Probable cause: Wing ice
10 Mar. 89	Dryden AIR ONTARIO F28	Heavy snow
25 Nov. 89	Kimpo KOREAN AIR F28	Dense fog, ice on the wing
16 Feb. 91	Cleveland RYAN DC-9-10	light snow
Dec. 91	Stockholm SAS MD-80	Freezing precipitation, ice on wing
22 Mar. 92	LaGuardia, NY USAIR F28	Heavy snow
31 Oct. 94	Roselawn, IN American Eagle ATR72	Probable cause, ice due to freezing rain

Accident Statistics



Certification
FAR § 25.1419 and Appendix C, O and D

- If certification with ice protection provisions is desired, the airplane must be able to safely operate in the continuous maximum and intermittent maximum icing conditions of Appendix C. To establish that the airplane can operate within the continuous maximum and intermittent maximum conditions of Appendix C:

  (a) An analysis must be performed to establish that the ice protection for the various components of the airplane is adequate, taking into account the various airplane operational configurations; and

  (b) To verify the ice protection analysis, to check for icing anomalies, and to demonstrate that the ice protection system and its components are effective, the airplane or its components must be flight tested in the various operational configurations, in measured natural atmospheric icing conditions and, as found necessary, by one or more of the following means:

Certification
FAR § 25.1419 and Appendix C, O and P

1. Laboratory dry air or simulated icing tests, or a combination of both, of the components or models of the components.
2. Flight dry air tests of the ice protection system as a whole, or of its individual components.
3. Flight tests of the airplane or its components in measured simulated icing conditions.

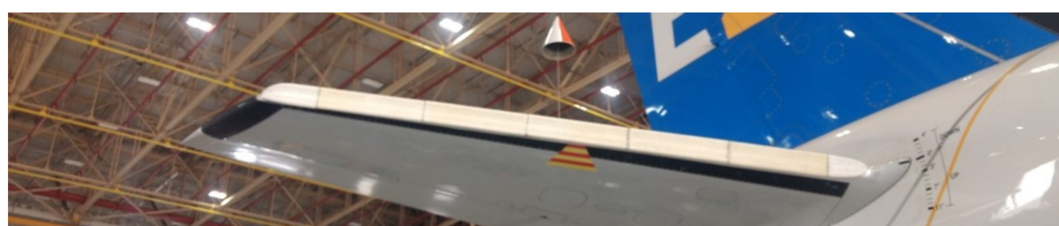
Icing test methods

Flight tests in natural icing conditions

Flight testing in a simulated cloud produced by an icing tanker

Ground testing in icing wind tunnels

Flight testing with simulated ice shapes



Icing Software

1. LEWICE – NASA Lewis Research Center/USA,
2. CANICE – Bombardier Aerospace and Ecole Polytechnique de Montreal/Canada,
3. FENSAP-ICE – Newmerical Technologies/USA
4. CIRA/Italy, ONERA/France and TAI/Turkey also have in-house icing codes.