The State of the Art Knowledge for Icing Accidents for General Aviation Aircraft

William L. Maynard
Wayne R. Sand

Follow this and additional works at: https://scholar.smu.edu/jalc

Recommended Citation
THE STATE OF THE ART KNOWLEDGE FOR ICING ACCIDENTS FOR GENERAL AVIATION AIRCRAFT

WILLIAM L. MAYNARD*
WAYNE R. SAND**

I. INTRODUCTION

AMONG THE investigation reports listed on the National Transportation Safety Board’s (“NTSB”) web site since January 1995 involving fatalities, 49 mention icing as a factor.

---

* William L. Maynard has specialized in handling aviation litigation for the past 20 years. During this time period, Mr. Maynard has successfully represented numerous product manufacturers, airlines, and repair stations in complex, multiparty, wrongful death litigation in state and federal courts across the country, with an emphasis on Texas litigation. Most recently, Mr. Maynard represented one of the defendants in the litigation arising out of the Mitsubishi MU-2 accident near Malad City, Idaho, discussed herein. He is a founding partner of one of the largest litigation specialty firms in Texas—Beirne, Maynard & Parsons, L.L.P.—Houston, Texas. He is board certified in civil trial law by the Texas Board of Legal Specialization. Mr. Maynard graduated summa cum laude from the Bates College of Law, University of Houston in 1973, where he was a member of the Houston Law Review.

** Wayne R. Sand is an aviation weather consultant with expertise in aircraft icing tests, analysis of icing accidents, and development of icing instrumentation. As former deputy director of the Research Applications Program at the National Center for Atmospheric Research, he developed aviation weather technology for the Federal Aviation Administration. Previously, Sand was a member of the Atmospheric Science Department at the University of Wyoming, where he managed its flight facility and piloted a King Air 200 weather research aircraft. He also conducted research on thunderstorms and convective icing at the South Dakota School of Mines and Technology and piloted carrier-based jets while serving in the U.S. Navy. Sand is co-holder of a patent on a technique for the remote detection of aircraft icing conditions. He holds a B.S. degree in mathematics and physical science from Montana State University, an M.S. in meteorology from the South Dakota School of Mines and Technology, and a Ph.D. in atmospheric science from the University of Wyoming.

The authors gratefully acknowledge the assistance of Donald W. Towe of Beirne, Maynard & Parsons, L.L.P. for his dedicated efforts and long hours in assimilating this paper.

---

Based on these accident reports, 105 people have died within the last five years in incidents related to aircraft icing.

Icing, the accumulation of super cooled liquid water on an aircraft, continues to be a persistent problem for aviation. An aircraft flying through a cloud containing super cooled droplets accumulates ice on the front portions of the airframe including, but not limited to, the wings, tail plane, and air intakes. Ice deposits on wing and tail plane surfaces can cause increased drag, decreased lift, and control problems. Ice accumulations in engine air intakes may result in power plant failure.

The purpose of this paper is to provide the reader with an overview of aircraft icing and the problems associated with this phenomenon, and to review current information on relevant topics such as meteorology, new products, icing accidents, safety recommendations, and airworthiness directives.

II. OVERVIEW OF AIRCRAFT ICING

Conditions conducive to aircraft icing may exist in two locations: (1) on the ground prior to departure and (2) in the air after departure. Each location presents a unique scenario which the pilot in command ("PIC") must recognize, evaluate and deal with responsibly. The PIC bears the ultimate responsibility of ensuring that the aircraft can be operated safely. Therefore, especially in weather conditions conducive to icing, safety begins with the PIC’s pre-flight actions.

Pre-flight weather briefings play an important role in route planning. In situations where icing conditions are possible, the weather briefing may determine whether or not the flight can be conducted under the applicable regulations. In addition, Pilot Reports ("PIREP") obtained from pilots who have recently flown along the anticipated travel route are a valuable source of weather data. For the purposes of reporting icing conditions to air traffic control ("ATC"), the Federal Aviation Administration has established the following severity categories:

Trace: Ice becomes perceptible. Rate of accumulation is slightly greater than rate of sublimination. It is not hazardous even though deicing/anti-icing equipment is not utilized, unless encountered for an extended period of time.

Light: The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occa-
sional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.

**Moderate:** The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.

**Severe:** The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.\(^3\)

On the ground, aircraft may be exposed to frozen precipitation, residual ice from a previous flight, and moisture in various forms from ramps, taxi ways and runways. Super cooled ground fog and frost may also cause frozen contamination accumulations on parked aircraft. A PIC is required to check the wings and control surfaces of his aircraft prior to takeoff from ground icing conditions.\(^4\) Propellers, leading edge slats, leading or trailing edge flaps, engine intakes, antenna, and pitot-static pressure probes, to mention only a few, should also be inspected with great care. As a general rule, the inspection should be completed within five minutes prior to departure. However, if departure delays are anticipated or if weather conditions are severe, an additional visual inspection should be conducted immediately prior to departure to ensure wing and control surfaces remain free of ice and snow. If any frozen contamination is detected on the aircraft, the PIC should initiate the appropriate steps to ensure the airworthiness of the aircraft. These steps may include deicing procedures, anti-icing procedures, or when appropriate, cancellation of the flight.\(^5\) If a PIC fails to perform a thorough, careful and timely inspection prior to departure, the result could be an accident.

After departure, aircraft may experience leading edge ice accumulations when flying through clouds at below-freezing temperatures. The types of icing encountered include:

\(^3\) See Aeronautical Information Manual, Para. 7-1-19(b) (1999).

\(^4\) See generally 14 C.F.R. § 91, § 121, § 125, § 135 (1999). Unless otherwise noted, the regulations cited herein governing aircraft operations are found in the January 1999 edition of Title 14 of the Code of Federal Regulations ("C.F.R."). Therefore, in the interest of clarity and brevity, subsequent citations will include only the part number and section number, i.e., 14 C.F.R. § 91.1 (1999), will be referred to as Part 91.1.

\(^5\) Further information on the subject of ground de-icing is available in the form of Federal Aviation Administration Advisory Circulars from the U.S. Department of Transportation, General Services Section, located in Washington, D.C.
Rime: Rough, milky, opaque ice formed by the instantaneous freezing of small super cooled water droplets.

Clear: A glossy, clear or translucent ice formed by relatively slow freezing of large super cooled water droplets.

Mixed: A mixture of rime and clear.6

Super cooled water droplets are liquid water at below freezing temperatures. “Because of their small size (between 10 and 40 microns), the water droplets in clouds can stay liquid at a temperature as low as −30°C.”7 NASA’s Lewis Research Center’s Icing Technology Branch has conducted research that indicates some clouds may contain individual droplets which are 10 times larger than those normally found in icing conditions.

In natural clouds, droplets are not all the same size, but are of various diameters. A statistical factor called median volume diameter is used to describe the relative droplet size distribution for a particular cloud. Typically, individual droplets range from two to fifty micrometers in diameter, and clouds usually have median volume diameters of less than 35 micrometers. Generally, it is thought that droplets tend to precipitate out as they reach 100 micrometers in diameter. However, under certain conditions, icing clouds with median volume diameters as high as 170 micrometers, with individual droplet diameters as large as 400 micrometers, may exist.8

Large-droplet testing has been conducted in the icing research tunnel with aircraft wing models—both with and without ice protection devices. On models with no ice-protection equipment, thin ice forms and breaks into pieces. These pieces then slide around slowly over a film of water on the airfoil. On the ice-protected models, small water rivulets flow aft from the leading edge to an ice ridge that forms aft of the ice protection. Here, some of the water freezes while some of it gets blown aft of the ridge, subsequently impinging on the model further aft, creating strange ice nodes that grow normal to the model surface.

---

It is imperative that the PIC recognize the adverse effect of ice, snow, and frost accumulations. The effects of ice on aircraft are cumulative—thrust is reduced, drag increases, lift lessens, and weight increase. The results are an increase in stall speed and a deterioration of aircraft performance. In extreme cases, 2 to 3 inches of ice can form on the leading edge of the airfoil in less than five minutes. It takes but one-half inch of ice to reduce the lifting power of some aircraft by fifty percent and increases functional drag by an equal percentage.\(^9\)

As noted, the effects of accumulations of ice on an aircraft can result in a marked deterioration of aircraft performance. Because large super cooled droplets may result in ice forming aft of ice protection devices, airmen who encounter icing conditions must constantly evaluate the type and extent of the ice build-up on their aircraft so they can take appropriate actions. The inexperienced airman or the airman who is not vigilant may find himself in a situation where ice accumulations are located beyond the reach of ice protection devices. In this scenario, the airman’s only alternative is to immediately remove the aircraft from the icing conditions. The failure to timely recognize and respond to this type of icing situation could place the airman in an unrecoverable situation because ice clogged instrument sensors, decreased lift and increased stall speeds combine over a relatively short period of time to render the aircraft unflyable.

Because ice can accumulate at rates which can significantly diminish aircraft performance in a very short period of time, a PIC has a very small window of time in which to recognize and respond to icing conditions. Timely recognition and appropriate responses are the product of pilot training and familiarization with icing conditions. A prudent PIC will be familiar with and abide by the applicable rules, regulations, and directives governing his flight and his aircraft. Regulations promulgated by the Federal Aviation Administration ("FAA") and codified in Title 14 of the CFRs govern aircraft operations in icing conditions. Air Worthiness Directives ("ADs"), also issued by the FAA, are designed to educate airmen on specific subjects related to various individual products or flight situations. ADs issued by the FAA serve multiple purposes, including but not limited to, educating and advising airmen regarding issues unique to particular aircraft models. It is beyond the scope of this paper to

\(^9\) See Aeronautical Information Manual, Para 701-19(a) (June 1999).
attempt an analysis of each and every AD issued by the FAA regarding icing.\textsuperscript{10}

Regarding airmen education, between 1994 and 1998, the FAA issued virtually the same AD regarding warnings related to icing conditions for at least a dozen aircraft. While the text of each AD was tailored to fit individual aircraft models, it is instructive to examine the broad principles addressed by the FAA. Language representative of the icing related AD is as follows:

\begin{verbatim}
WARNING
Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle, or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and may seriously degrade the performance and controllability of the airplane.

• During flight, severe icing conditions that exceed those for which the airplane is certificated shall be determined by the following visual cues. If one or more of these visual cues exists, it immediately requires priority handling from Air Traffic Control to facilitate a route or an altitude change to exit the icing conditions.
  — Unusually extensive ice accreted on the airframe in areas not normally observed to collect ice.
  — Accumulation of ice on the upper surface of the wing aft of the protected area.
  — Accumulation of ice on the propeller spinner farther aft than normally observed.
• All icing detection lights must be operative prior to flight into icing conditions at night. [NOTE: This supersedes any relief provided by the Master Minimum Equipment List (MMEL).]
\end{verbatim}

\textsuperscript{10} Those individuals desiring information regarding a particular type of aircraft may contact the FAA directly. For those individuals desiring to conduct historical research, an excellent searchable CD Rom disk is available from the National Technical Information Service which contains all FAA airworthiness directives (1940 through 1998), Type Certificate Data Sheets as of January 1999 and Supplemental Type Certificate Listings as of January 1998. The CD may be obtained by contacting the agency at:
U.S. Department of Commerce
Technology Administration
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 1-888-584-8332 or 1-703-605-6050.
THE FOLLOWING WEATHER CONDITIONS MAY BE CONDUCIVE TO SEVERE IN-FLIGHT ICING:

- Visible rain at temperatures below 0 degrees Celsius ambient air temperature.
- Droplets that splash or splatter on impact at temperatures below 0 degrees Celsius ambient air temperature.

PROCEDURES FOR EXITING THE SEVERE ICING ENVIRONMENT:

These procedures are applicable to all flight phases from takeoff to landing. Monitor the ambient air temperature. While severe icing may form at temperatures as cold as -18 degrees Celsius, increased vigilance is warranted at temperatures around freezing with visible moisture present. If the visual cues specified in the Limitations Section of the AFM for identifying severe icing conditions are observed, accomplish the following:

- Avoid abrupt and excessive maneuvering that may exacerbate control difficulties.
- Do not engage the autopilot.
- If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.
- If an unusual roll response or uncommanded roll control movement is observed, reduce the angle-of-attack.
- Do not extend flaps during extended operation in icing conditions. Operation with flaps extended can result in a reduced wing angle-of-attack, with the possibility of ice forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.
- If the flaps are extended, do not retract them until the airframe is clear of ice.
- Report these weather conditions to Air Traffic Control.

The first paragraph of this exemplar AD addresses the problems created by supercooled large droplets (SLD's discussed herein in the section on meteorology) which result in the formation of ice aft of protected surfaces or formations exceeding the capability of the ice protection system. This AD sets forth three specific visual cues which may serve to alert an airman to the existence of severe icing. If the pilot observes any one of these visual cues, the AD instructs the pilot to immediately initiate action to exit the icing conditions.

The AD language notes the autopilot feature may mask clues that indicate adverse changes in handling characteristics. Given the fact that as little as one-half inch of ice can drastically reduce the performance of an aircraft and that under certain circumstances, one-half inch of ice can accumulate in less than three
minutes, it is not difficult to image a scenario in which a crash results because a pilot, cruising on autopilot, fails to timely recognize icing conditions in time to initiate an appropriate response. In *Moorhead v. Mitsubishi Aircraft International, Inc.*, the court found that the PITOT System, which provides airspeed information to the pilot and autopilot system, froze over, so that neither the pilot nor the autopilot could recognize the problem by reference to flight instruments.

The warning instructs the pilot, first and foremost, to exit the icing conditions. Beyond that, the AD warns the pilot to, among other things, avoid abrupt maneuvers, not to use the autopilot, to reduce the angle of attack if unusual roll responses are experienced and to avoid movement of the flaps.

### III. CURRENT METEOROLOGY

#### A. INTRODUCTION

The crash of Flight 4184 at Roselawn, IN on 31 October 1994 resulted in 68 fatalities. The accident prompted a flurry of activity by the FAA, foreign certification authorities and meteorologists when it was realized that the aircraft likely crashed as a result of flight into icing conditions outside the aircraft icing certification envelope. Clearly, the NACA data on which the FAR Part 25, Appendix C icing certification criteria are based included recognition that there could be icing conditions outside the drop size and temperature envelopes presented in Appendix C. Since the 1940's these conditions "outside the certification envelope" were termed freezing drizzle and freezing rain and were considered to be low probability, short duration events. Therefore, the FAA and other certification authorities did not require the manufacturers to test their airplanes in such conditions. When manufacturers addressed the issue, they normally advised pilots to avoid encounters with freezing drizzle and freezing rain and to exit those conditions when encountered. No airplanes have been designed to cope with these severe icing encounters since there was no requirement to do so.

Prior to the Roselawn accident, the term supercooled large droplets (SLD) had not been used and few people had any real

---

understanding of SLD icing conditions. In 1984, two papers addressed the meteorological conditions encountered during flight in icing conditions and the effect on the performance of a twin-engine turbo-prop airplane. This work was based on flights made with a “weather research” aircraft equipped to measure atmospheric parameters relevant to icing (supercooled liquid water content, icing rate, temperature, droplet size spectra). The aircraft data system could also measure the effects of the ice on the performance of the aircraft. The reports were based on approximately 1100 hours of flight in potential icing conditions. A third paper in 1985 focused on two specific icing encounters from these 1100 flight hours. These two encounters were termed “unusual icing” and were related to encounters with supercooled droplets in the 40 to 300 micron size ranges. It was hypothesized that these “unusual” icing conditions were related to the existence of embedded convection. The terminology related to such large drop icing conditions is still evolving, from what was initially called “freezing drizzle and freezing rain” to “unusual icing” to “supercooled drizzle drops” and to the currently used “supercooled large drops” (“SLD”) nomenclature. The terminology confusion results, in part, from the weak meteorological definitions which do not consider the size range from 100 to 200 microns. The FAA and others are currently attempting to clarify the terminology.

The present study has benefited from increased quantities of accurate, high-resolution data from a number of new, state-of-the-art meteorological sensors. With the widespread deployment (by NWS, FAA and DOD) of the new Next Generation Radar (NEXRAD, WSR-88D), the capability now exists for detailed radar examination of icing conditions in virtually any part of the United States. This was made possible not only by the nearly complete radar coverage of the continental United States, but also by the fact that the radar is far more sensitive and is programmed to scan at a number of elevation angles. The National Weather Service (NWS) has also been active in deployment of Geostationary Operational Environmental Satellites (GOES) that are also far more capable than previous satel-

---


lites. It is now possible to determine more detailed cloud top temperatures provided there are no intervening upper level clouds. Further, the NWS is testing a number of wind profiling radars in the central part of the United States which have the ability to nearly continuously monitor the wind profile immediately over those locations.

All of the above sensors, along with others, were available at the time of the Roselawn accident and were analyzed along with the detailed flight data recorder information from the accident aircraft. This complete data set enabled a great deal of confidence to be placed in the analysis and the conclusions that follow.

B. SLD CLOUD PHYSICS

The processes that produce freezing drizzle and freezing rain have traditionally been related to snow or graupel particles melting as they fall through a warm layer followed by the resulting rain or drizzle falling into a sub-freezing layer where it becomes freezing rain or freezing drizzle. This "classic" process has been well understood for years. What is different in some of the more recently documented SLD situations is that there was no warm layer above; the droplets appeared to grow entirely in the sub-freezing environment while remaining liquid.

Supercooled liquid water exists because there is a lifting and/or cooling process taking place in the atmosphere that condenses vapor onto available cloud condensation nuclei. These lifting/cooling processes are associated with fronts, convergence around low-pressure centers, convection and orographic lifting. The water becomes supercooled when the droplets are formed in sub-freezing temperatures or are carried upward into a sub-freezing environment. As additional condensate is made available, the droplets will continue to grow directly from the vapor (condensation), but this process is so slow that it alone will not likely grow droplets to SLD sizes. On the other hand, droplets can continue to grow by colliding with each other (coalescence), a process that will allow droplets to grow fast enough and large enough to become SLD. If the processes of condensation and coalescence growth continue, the droplets will grow large enough to fall relative to any co-existing vertical velocities (drizzle to rain). The introduction of ice crystals (snow) depletes the suspended supercooled liquid water content and diminishes the icing threat. Therefore, in a situation where processes are working to produce additional supercooled liquid
water (lifting and/or cooling) and no processes exist to deplete this liquid (snow or rain) the droplets will continue to grow. As a significant fraction of the supercooled liquid droplets grow to sizes in excess of fifty microns diameter, the resulting conditions will be outside the icing certification envelope for any aircraft. Statistically, clouds do not contain droplets in this size range for a long period of time and these conditions do not occur very often. However, when they do exist, severe icing SLD encounters are possible if aircraft spend significant time (eleven to twelve minutes in this case) in the area.

C. SYNOPTIC AND LOCAL WEATHER

Synoptically, a strong and very widespread low-pressure system was centered just southwest of the accident location causing widespread lifting, cooling, cloudiness, and icing conditions. A warm front extended from the center of the low to the east, just south of the accident location. A cold front extended from the low to the south-southwest to the Gulf coast of Texas. There was widespread cloud cover and numerous reports of icing conditions associated with this system, both before and after the accident. AIRMET's for light to occasionally moderate rime icing in clouds, and in precipitation from the freezing level to 19,000 feet had been issued for the area. The holding pattern for the accident aircraft was located at 10,000 feet in the area ahead of the warm front, an area recognized for its widespread icing potential (see figure 1, the cloud pattern at 21:32Z). The accident occurred at about 21:59Z.

Locally, weak embedded convection existed in the area of the holding pattern. This was evidenced by the surface reports of showery precipitation, an atmospheric temperature profile showing instability above about 14,000 ft and patchy radar returns.

D. SATELLITE DATA

The GOES-8 weather satellite provided a comprehensive overview of the extent of the visible cloudiness (figure 1). The key information available from the satellite data, however, was the cloud top temperature analysis. This was combined with an at-

---

Atmospheric temperature sounding derived for the accident area to determine cloud top altitudes. Indicated cloud top locations were corrected for parallax errors in order to accurately position the cloud tops over the area where the aircraft was holding. The result was the ability to generate a 4-dimensional cloud top temperature and height analysis.

A lower, warmer area of cloud tops (about \(-16^\circ C\)) was detected moving over the accident area during the final eleven to twelve minutes prior to the accident. This area of reduced cloudiness is commonly referred to as a "dry tongue" and is clearly visible on the satellite data (figures 1 and 2). Relatively warm (normally considered to be warmer than about \(-15^\circ C\)) cloud top temperatures have also been associated with more severe icing conditions based on unpublished work and flight experience by author Sand.

E. Radar Data

The WSR-88D Doppler radar located at Lockport, IL (about 45 nm from the accident site) was used as the principle source of radar data. Since digitally recorded magnetic tape data was not available, the radar photographic images were digitized and interpolated in time and space to derive plan-views at the aircraft altitude in the area of the holding pattern and vertical cross sections along the aircraft track. The objective was to determine the radar reflectivity in 4-dimensional space around the aircraft. Engineering Animation Incorporated (EAI) developed the analysis results into a video presentation of the plan view of the reflectivity around the aircraft (see figure 3). EAI also developed a video presentation of the vertical profile along the track of the aircraft showing the reflectivity above, below, behind and ahead of the aircraft (see figures 4 and 5). The analysis revealed that there were weak embedded convective cells along the path of the aircraft while it was holding (see figures 3, 4 and 5, note the cellular nature of the reflectivity patterns).

These radar data were combined with the satellite-derived cloud top data discussed above and cloud base data determined from surface observations. When the satellite, radar and surface observations are combined and interpolated in time and space, the 4-dimensional cloud extent and radar reflectivity patterns were determined.
F. Radar/Satellite Data Analysis

The warm cloud top temperatures combined with the location of the cloud tops near the top of the five dBZ radar reflectivity contour indicates that SLD were being generated near the cloud top (see figure 5). We are thus led to conclude that the cause of the higher reflectivity near the cloud tops is large liquid drops, SLD.

Figure 4 shows a time period when the cloud tops were well above the reflectivity tops. There is minimal icing at the level of the aircraft at this time because of the cold cloud top temperatures and the large depth of cloud above the detectable radar signatures. Aircraft performance data from the flight data recorder (FDR) and crew comments corroborate this conclusion. With cold cloud tops, there was likely ice present, which would deplete the supercooled liquid water content. In contrast, figure 5 shows a period of time when the radar reflectivity was greater than five dBZ near the satellite determined (warmer) cloud top indicating SLD conditions. At this time there was likely little or no ice present to deplete the supercooled liquid water and the drops were continuing to grow by coalescence (as described above). During the final eleven to twelve minutes of the flight, SLD conditions were present and the aircraft accumulated significant ice in areas not protected by the de-icing system.

G. Icing Environment

Widespread icing was forecast and occurring. SLD icing was very localized since no other pilots were reporting severe icing or any problems with icing.

Assuming liquid drops, the radar equations can be used to compute the relationships between the droplet sizes, droplet concentrations, radar reflectivity and liquid water content (figure 6). These relationships can be used to calculate the possible combinations of droplet concentration, droplet size and supercooled liquid water content based on the measured radar reflectivity values. To further simplify, assume that the supercooled liquid water content is a constant 0.5 gms/m (a reasonable value in this case) and that the droplet concentration remains constant within a reasonable range (near 100 per liter). This then allows a calculation of mono-disperse droplet size. Through most of the SLD encounter droplet sizes of 130 to 260 microns diameter are calculated (based on these assumptions).
are reasonable values for liquid water content and larger (more dangerous) droplet sizes in an SLD environment. During the final minute and 15 seconds, the aircraft was exposed to calculated droplet sizes ranging from 260 to 570 microns in diameter. These larger sizes were the result of the flying aircraft in a more pronounced, developing convective cell just prior to the loss of control. It is possible that the larger measured radar reflectivity and calculated larger drop sizes near the end of the flight could have been influenced by snow or graupel particles coexisting with the liquid droplets in this stronger convective cell.

The ambient air temperature at the holding altitude was −3 to −4°C as recorded by the FDR. Based on the holding speed of about 175 knots, the total air temperature was +2 to +3°C. The combination of SLD and significant temperature rise near the wing leading edge resulted in considerable flow-back icing. Thus, the combination of SLD, warm temperatures and relatively high speed in the holding pattern produce an ideal situation for ice to form atop the wing in a ridge, aft of the boots. These atmospheric conditions were duplicated during icing tanker tests and produced ice ridges as depicted in figure 7.

H. Generation of SLD

It is generally accepted that this aircraft encountered SLD conditions and that the resulting ice was a major factor in the ensuing accident. A number of mechanisms might produce SLD conditions. One study concludes that windshear near cloud top is a “necessary” condition for the production of SLD.\footnote{See Brenda M. Pobanz & John D. Marwitz, \textit{Conditions Associated with Large-Drop Regions}, 33 J. Applied Meteorology, 1366, 1372 (1994).} A previous study of the weather surrounding this accident\footnote{J. Marwitz, et al. \textit{Meteorological Conditions Associated with the ATR72 Aircraft Accident near Roselawn, Indiana, on 31 October 1994}, 678 Bull. Am. Meteorologist Soc’y, 41, 52 (1997).} mainly uses wind profiler data taken at Winchester, IL (about 135 nm southwest of the accident site) to examine windshear. They determined that strong windshear was associated with the warm frontal surface in the vicinity of the flight altitude of the aircraft and that the windshear caused the SLD conditions. A more logical conclusion is that weak, embedded, high-altitude convection was the key feature that drove the production of SLD in this case.
IV. ACCIDENTS

MITSUBISHI MU-2, PUTNAM, TEXAS

On February 14, 1990, at approximately 7:53 CST, a Mitsubishi MU-2B-60, N300CW, being operated by Williams Aviation Company, impacted the terrain near Putnam, Texas during a 14 CFR, part 91, business flight. The pilot in command, Kenneth B. Mardis, was an ATP rated pilot with 11,720 hours total time. He had type ratings for the lear jet and the NA-265 and had recently completed the MU-2-60 Flight Safety International course.

N300CW was a 1980 model Mitsubishi MU-2B-60 twin engine turbo prop, high wing airplane. The airplane was equipped with ice protection systems and was certified for flight into known icing conditions. All pre-flight checks, before flight checks and in-flight operational use information were covered in the airplane flight manual.

THE RADAR TRACKING DATA: The flight started at 7:10 CST and lasted approximately forty-three minutes. The aircraft climbed to an altitude of 15,000 feet. The last communication from the pilot occurred at 7:50:36, when the pilot requested permission to go down to 13,000 feet.

The radar tracking data revealed an interesting flight profile. Between 7:39 CST and 7:46 CST, the ground speed gradually decreased about four knots per minute from 297 knots to 270 knots. Between 7:46 CST and 7:50 CST, the ground speed indicated a more rapid decrease to approximately 150 knots. Between 7:50:57 CST and 7:51:09 CST, the ground speed decreased to approximately 100 knots. At 7:51:09 CST, the aircraft was at an altitude of 14,800 feet and made a turn to the right and a return to the true track at 7:51:33 CST. At 7:51:33 CST, the aircraft altitude was 9,700 feet. Two witnesses observed the airplane appear suddenly out of low clouds at a very steep angle of descent, estimated at 45 degrees, then go out of sight before impact. The National Transportation Safety Board concluded the probable causes of the accident included improper planning/decisions by the pilot, which resulted in excessive accumulation of structural icing and his failure to maintain adequate air speed and aircraft control, coupled with the pilot’s inadequate weather evaluation due to lack of available informa-

18 See NTSB Report FTW 90-A072.
tion and the pilot's inexperience in this make and model of aircraft in icing conditions at cruise altitude.

**Mitsubishi MU-2, McCleod, Texas**

On September 2, 1981, a Mitsubishi MU-2B crashed near McCleod, Texas killing the five occupants of the plane. After a routine take-off and climb to an altitude of approximately 21,000 feet, the aircraft gradually increased its speed to a maximum velocity of near 200 knots. During a short period of time (less than five minutes), the speed dropped to 125 knots and the plane began to quickly descend, losing 3,000 feet in the last minute before the aircraft lost radar contact at 4:52 p.m. Witnesses observed the aircraft approximately 3,000 feet above the ground in a steep nosedown attitude, spinning rapidly to the right as it fell out of the clouds and into their view.

In the litigation that followed (discussed infra), the court concluded that the PITOT system had frozen over depriving the pilot and autopilot system of accurate airspeed information. The court concluded that when the PITOT froze over, it acted like an altimeter.

**Mitsubishi MU-2, Malad City, Idaho**

On January 15, 1996, a Mitsubishi MU-2B crashed near Malad City, Idaho resulting in the deaths of all eight occupants on board the aircraft. Radar transponder data shows a flight path deviation of about twenty degrees to the right at approximately 6:14 M.S.T. (approximately three minutes before the accident), with a subsequent correction to the previous heading. This time also marked the beginning of oscillations in altitude between 16,000 and 15,800 feet. Between 16:16:30 and 16:17:30 M.S.T., the airspeed decreased approximately 40 knots with increases in pitch attitude and angle of attack. Over the next 40 seconds the airspeed reduced to approximately 120 knots. At 6:17:40, airspeed decreased to about 100 knots. At 16:17:51, the aircraft crew notified ATC that, "... we got an emergency." There were no further communications.

Remaining primary radar returns indicate a rolling right turn as the aircraft further decelerated, followed by a rapid increase in airspeed as the aircraft abruptly shifted to a steep nose-down attitude. Final radar returns are indicative of the airplane experiencing an uncontrolled high-speed descent in a steep nose-
down attitude. The aircraft impacted the ground in an attitude of approximately 105 degrees nose down.

As a result of a joint effort between the Federal Aviation Administration and the Japanese Civil Aviation Bureau, a blue ribbon team was assembled to conduct a special certification review of the MU-2B series airplane. A formal report of this Fact-Finding Focused Special Certification Review (FFFSCR) of the Mitsubishi Heavy Industry MU-2B series airplane was published on June 27, 1997.

The blue ribbon team initially reviewed the MU-2B service and accident history, revealing at least thirteen fatal accidents occurring in the presence of icing conditions. Prior to the completion of the review, the FAA issued an AD 96-2502 which included icing-related limitations and procedures for SLD recognition and exit criteria. The team recommended a comprehensive list of required modifications to the automatic flight guidance system, the flight control system, the ice protection system, the propulsion system, the AFM guidance and maintenance procedures. In addition, additional airworthiness directives were recommended. The airworthiness directive recommendations included:

1. Additional initial training with bi-annual review requirements for icing awareness, anti-ice and de-icing system operation, icing severity questions and icing environment exit criteria;
2. A longitudinal trim in motion oral notification system;
3. Ice detector systems;
4. Autopilot disconnect system; and
5. An indicator system to alert the pilot that the tail de-ice system is operating.

The blue ribbon panel study included a study of the effect of SLD icing on the aerodynamic characteristics of the MU-2B. The MU-2B aircraft was certified to meet the standards of Appendix C of 14 CFR § 25 which defines the Liquid Water Content (LWC) and droplet sizes. Design criteria requires the de-ice system to protect against all twenty micron drops and as many forty micron drops as practicable over the operating range of the angle-of-attack (AOA) for the aircraft.

The study reflects that flight into conditions involving SLD ice can result in:
1. development of icing beyond the areas protected by the de-ice systems;
2. asymmetric shapes of icing which may induce asymmetric effects on the aerodynamic characteristics of the airplane;
3. icing aft of the de-ice system on the upper and lower surface of the airplane's airfoils;

The adverse effects of the ice are disproportionate to the size. Small ice shapes with certain texture characteristics can be worse than larger shapes. Ice that appears less severe may cause dramatic increases in drag, substantial decrements in performance, and adverse changes to the aerodynamic characteristics such as stall angle or hinge movement. SLD ice causes an increase in drag, an increase in stall speed, and possible loss of artificial stall warning.

The blue ribbon team commented on tail plane icing for the MU-2B, pointing out that icing could form on unprotected parts of the tail and on the right hand stabilizer leading edge. There are no de-ice boots on the horizontal stabilizer leading edge aft of the engine due to the effects of exhaust gases. The heat from exhaust gases can provide some protection from icing. The team pointed out, however, that this protection is limited. There is an asymmetric flow field from the engines and SLD icing may be a problem. Earlier reports indicated a temperature asymmetry of as much as 52 degrees between the left horizontal stabilizer and the right horizontal stabilizer tip. The team recommended conducting additional tailplane temperature testing.

The blue ribbon team's study of the MU-2B accident history since 1983 revealed a number of common attributes, as follows:

1. Icing conditions were reported or forecast;
2. The autopilot was engaged;
3. There was an uncommanded and unobserved airspeed decrease (frequently below the 180 knots minimum airspeed specified in the AFM);
4. The pilot did not take steps to exit the hazardous icing condition;
5. Airspeed reduction due to ice accretion was rapid using the altitude hold mode of the autopilot system.
6. The stall speed increased;
7. The airplane departed control flight with incorrect or no pilot flight control inputs.
**Embraer EMB-120RT, Monroe, Michigan**

On January 9, 1997 an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by Comair Airlines, Inc., as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. The accident resulted in the death of two flight crew members, one flight attendant, and twenty-six passengers onboard. As a result, the NTSB issued SAFETY Recommendation A-98-95, requiring the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions.

The FAA agreed with the intent of the safety recommendation and on May 28, 1999, issued several Joint Flight Standards Handbook Bulletins, including a Handbook Bulletin for Air Transportation (HBAT), Airworthiness (HBAW), and General Aviation (HBGA) and a flight standards policy for company operating manuals and company training program revisions.

**ATR72, Roselawn, Indiana**

On October 31, 1994, an Avions de Transport Regional, Model 72-212 (ATR72) registration No. N401AN airplane operated by Simmons Airlines, Inc., and doing business as American Eagle Flight 4184, crashed near Roselawn, Indiana during a rapid descent after an uncommanded roll excursion. The captain, first officer, two flight attendants and 64 passengers received fatal injuries. As a result of this accident, a Special Certification Review followed, and ATR contracted with the United States Air Force to conduct a series of flight tests to study ice accretion characteristics. The tests confirmed that the ATR72 was in compliance with the icing envelope specified in 14 CFR Part 25 for certification. Additional tests conducted with large water droplets (outside Part 25 Icing Standards) revealed that ice accretes aft of the de-ice boots and disrupts the airflow over the aileron when the flaps were raised to zero degrees, causing uncommanded aileron deflection and unusual control wheel forces. The tests also revealed that ice formed on the unheated portion of the pilot's side window when the plane was
operated in large water droplet conditions. As a result, the NTSB issued several safety recommendations, as follows:

SAFETY RECOMMENDATION A-96-65

Evaluate the need to require a sterile cockpit environment for airplanes holding in such weather conditions as icing and convective activity, regardless of altitude.

SAFETY RECOMMENDATION A-96-61

Require all principal operations inspectors (POIs) of 14 CFR Parts 121 and 135 operators to ensure that training programs include information about all icing conditions, including flight into freezing drizzle/freezing rain conditions.

SAFETY RECOMMENDATION A-94-184

Provide guidance and direction to pilots of ATR-42 and ATR-72 airplanes in the event of inadvertent encounter with icing conditions by the following action:

(1) define optimum airplane configuration and speed information;
(2) prohibit the use of the autopilot;
(3) require the monitoring of lateral control forces;
(4) define a positive procedure for reducing angle of attack.

SAFETY RECOMMENDATION A-94-183

Issue a general notice to ATC personnel to provide expedited service to ATR-42 and ATR-72 pilots who request route, altitude, or airspeed deviations to avoid icing conditions. Waive the 175 knot holding airspeed restriction for ATR-42 and ATR-72 airplanes pending acceptable outcome of the special certification effort.

SAFETY RECOMMENDATION A-94-185

Caution pilots of ATR-42 and ATR-72 airplanes that rapid descents at low altitude or during landing approaches or other deviations from prescribed operating procedures are not an acceptable means of minimizing exposure to icing conditions.

In response to the safety recommendations, the FAA took the following actions:

(1) On February 25, 1997, the FAA issued changes to AC-120-51B “crew resource management” which recommends
CRM training for crew members, and identifies conditions in which additional vigilance is required (e.g., holding in icing or near convective activity).

(2) The FAA issued a Flight Standard Information Bulletin (FSAT97-03) to require all principal operations inspectors (POIs) to ensure that training programs include information about all icing conditions for flight into freezing drizzle/freezing rain conditions.

(3) On November 16, 1994, the FAA issued telegraphic ADT94-24-51 which prohibits the use of autopilot in icing conditions or in moderate or greater turbulence.


(5) On March 20, 1995, the FAA approved new enlarged de-ice boots for the ATR fleet.

(6) On April 24, 1995, the FAA issued AD96-09-28 which superseded an existing AD. This AD specified that unless modifications were accomplished or alternative procedures and training adopted, operation of the airplane would be prohibited in certain icing conditions. It also required restrictions on the use of the autopilot in certain conditions.

(7) On November 11, 1994, the FAA issued General Notice (GNOTRWA4-85) which required air traffic controllers to provide priority handling to ATR-42 and ATR-72 pilots when they request route, altitude or airspeed deviations to avoid icing conditions.

(8) The FAA issued information bulletin FSIB94-16 which cautions pilots that rapid descents at low altitudes or during landing approaches or any deviations from these approved procedures as a means of minimizing exposure to icing conditions should be avoided.

Piper Malibu Accidents

The NTSB conducted a special investigation and analysis of a series of Piper Aircraft Corporation Model PA-46 airplane accidents, including five fatal accidents over a two-year period between May 31, 1989 and March 17, 1991. As a result, the NTSB issued several safety recommendations.
SAFETY RECOMMENDATION A-92-84

This required modifications to the Piper Aircraft Corporation's Airplane Flight Manual and Pilot's Operating Handbook for the PA-46 series airplane to add warnings in the normal procedures' checklist for crews, that pertinent ice protection equipment should be turned on if instrument meteorological conditions are encountered near and above the freezing ice level. The FAA agreed with this recommendation and pointed out that Piper Aircraft Corporation added a warning note to the "before take-off" section of the abbreviated and expanded airplane flight manual checklist, which required activation of the aircraft ice protection system, including the PITOT heat, before flight into icing conditions.

SAFETY RECOMMENDATION A-92-85

This required modification of the PA-46 series airplanes to provide for a PITOT heat operating light similar to the light required by 14 CFR § 25.1326 for transport category airplanes. In response, the FAA formed a special certification review team for the PA-46. This team recommended that the pilot's operating handbook be modified to inform the pilot that PITOT heat should be on during all operations in visible moisture when outside air temperature is less than five degrees Celsius and recommended a regulatory change for small airplanes that are approved for flight into known icing that would require a PITOT heat operating light similar to 14 CFR § 25.1326.

SAFETY RECOMMENDATION A-92-86

Consider application of safety recommendations A-92-84 and A-92-85 to all models of small airplanes certified to operate in icing conditions and at altitudes of 18,000 feet mean sea level and above. In response, the FAA issued advisory circular AC23.1419-2 (Certification of Small Airplanes) for Flight in Icing Conditions so that the Airplane Flight Manuals (AFMs) will include a warning to advise the pilot to activate the ice protection equipment if instrument meteorological conditions are encountered near or above the freezing level.

On January 21, 1996, the FAA revised 14 CFR § 23.1326 to require installation of a PITOT heat operating light to warn the flight crew if the PITOT heat is switched off or if a heater element has failed.
On December 26, 1989, United Express Flight 2415, operating a British Aerospace BA-3101 Jet Stream, N410UE, crashed 400 feet short of runway 21R at Tri-Cities Airport, Pasco, Washington. The two pilots and all four passengers received fatal injuries. As a result of this accident, the NTSB issued Safety Recommendation A-91-90, revising Advisory Circular (AC) 20-73, “Aircraft Ice Protection” and AC-23.1419-1, “Certification of Small Airplanes for Flight in Icing Conditions” allowing guidance for the fulfillment of 14 CFR Parts 23.1416(c) and 25.1416(c) by ensuring that the pneumatic pressure threshold at which each de-ice boot indication light is designed to illuminate is sufficient pressure for effective pneumatic de-ice boot operation. In response, on August 18, 1998, the FAA published AC 23.1419-2a, Certification of Small Airplanes for Flight in Icing Conditions. The AC includes guidance to ensure that the pneumatic pressure threshold at which each de-ice boot indication light is designed to illuminate is sufficient pressure for effective pneumatic de-ice boot operation.

On January 30, 1991, a British Aerospace Jetstream BA-3101 airplane, operated under 14 CFR Part 135 by CCAir, Inc., as U.S. Air Express Flight 4743 crashed on final approach to runway 19 at Beckley Airport, West Virginia. The two crew members and 17 passengers survived, but some sustained serious injuries. As a result of this accident, the NTSB issued several safety recommendations, as follows:

**SAFETY RECOMMENDATION A-92-59**

This amends FAA order 8400.10, volume 3, chapter 7, section 2, parts 121/135, “Weather Information Systems,” para. 1425, to specify that Principal Operations Inspectors ensure that operators under 14 CFR Part 135, who elect to use a weather information system, make available to flight crews, as well as to dispatch and/or flight control personnel, weather products listed under Section 2 that are appropriate to flight operations. Principal Operations Inspectors should ensure that initial and recurrent flight crew training includes the use of computerized weather systems, if such systems are a source of flight crew weather information.
On October 19, 1993, the FAA issued Air Carrier Operations Bulletin ACOB8-93-4, Flight In Potential Icing Conditions and the Avoidance, Recognition, and Response to Tailplane Ice. The bulletin requires that appropriate weather products listed in FAA order 8400.10, Air Transportation Inspector's Handbook, volume 3, chapter 7, section 2 be used, and that appropriate training and recurrent training for computerized systems be mandated.

**SAFETY RECOMMENDATION A-92-61**

Issue an Air Carrier Operations Bulletin directing all Principal Operations Inspectors to examine the meteorological training curricular of 14 CFR Part 135 operators and ensure that they provide adequate information regarding icing conditions and cold weather operating limitations applicable to their particular aircraft, as well as pre-flight and in-flight de-icing procedures. In response, the FAA issued ACOB8-93-4 to direct POI's to examine the meteorological training curriculum assigned to 14 CFR Part 135 operators to ensure the inclusion of adequate information regarding icing conditions and cold weather operating limitations applicable to their particular aircraft, as well as pre-flight and in-flight de-icing procedures.

**SAFETY RECOMMENDATION A-92-62**

This requires British Aerospace Inc. to show, by flight tests, that the limitations of flaps to thirty-five degrees, currently incorporated into BA-3200 airplanes and available in kit form for installation on BA-3100 airplanes, provides an adequate safety margin against tailplane stall in icing conditions; and if the margin is adequate, require operators of BA-3100 airplanes to install the flap extension limitation modifications on the airplane. The FAA reviewed a British Aerospace Inc. (BAe) flight test report on the effect of tailplane ice on the Jetstream 3100 airplanes and preliminary findings from a research project investigating the contaminated tailplane stall (CTS). In June, 1992, the FAA technical center issued a research project to analyze the susceptibility of turboprop airplanes used in 14 CFR Parts 121 and 135 service to CTS.

On April 2, 1991, the FAA issued airworthiness directive AD91-08-01 applicable to Jetstream 3101 airplane which states, "Do not extend the flaps beyond the 20 degree position if any ice is visible on the airplane."
On January 22, 1993, the FAA issued AD93-01-02 which addresses action taken by BAE and the FAA to correct a potentially unsafe condition of the tailplane deicing system designs.

On January 18, 1995, the FAA issued AD95-01-06 to require the 35 degree flap modification on all Jetstream model 3100 airplanes.

SAFETY RECOMMENDATION A-92-64

Issue an airworthiness directive, applicable to airplanes using pneumatic airframe deicing systems, requiring that the control switches for these systems be modified so that a single manual activation of the switch will allow a complete cycle of the wing and tail leading edge de-ice system.

On May 10, 1996, the FAA issued AD96-11-01 applicable to Jetstream 3101 and 3201 airplanes requiring modification of the automatic airframe de-ice system in accordance with Jetstream Service Bulletin No. 30-JK12033, which allows the wing and tail de-ice boots to automatically operate through one cycle.

ROCKWELL 690A, GUTHRIE, OKLAHOMA, NTSB REPORT FTW95FA114

On February 12, 1995, at 17:21 C.S.T., a Rockwell International 690A, N69TM, was destroyed after impacting terrain during an approach to Wiley Post Municipal Airport, near Guthrie, Oklahoma. The commercial pilot and passenger were fatally injured. The aircraft was being operated under 14 CFR § 91 when the accident occurred. The flight originated in Wichita, Kansas, and was en route to Guthrie.

At 16:26, the pilot telephoned the Wichita Automated Flight Service Center and filed an IFR flight plan from Wichita to Guthrie and did not request a weather briefing. At 17:15 C.S.T., the pilot contacted Oklahoma City Approach Control and, according to radar data, was descending through 12,800 feet. Approach Control advised the pilot to "descend at pilot's discretion" to 3,000 feet. After the pilot informed Approach that he "broke out" of the clouds at 5,400 feet, the airplane continued to descend to join localizer approach to Wiley Post. At approximately 17:20 C.S.T., the pilot informed Approach he accumulated "some clear and rime" ice during the descent. Thir-

---

19 See NTSB Report FTW 95FA114.
teen seconds later, the pilot made a distress call and stated, "we're in trouble, we're going down."

Radar Tracking Data. According to Oklahoma radar track data, during the time period from 17:12:19 to 17:20:10, the airplane descended from 16,700 feet to 3,700 feet. During the descent, the airplane decelerated from 268 knots to 92 knots ground speed. The last radar information at 17:20:10 showed the aircraft descending through 3,700 feet, at a ground speed of 92 knots. An eyewitness reported that he observed the airplane before it impacted the ground. He stated, "The plane was going up [and] then headed straight down in a spin [and] it appeared that it was trying to pull out when it slammed into the ground."

The NTSB listed the probable cause of the accident as the pilot's failure to maintain adequate airspeed due to airframe ice. Contributing factors were the pilot's continued flight into adverse weather, his failure to obtain weather information either before or during the flight, and icing conditions.

**Piper Comanche PA-24, Boise, Idaho**

On March 7, 1997, at approximately 16:30 M.S.T., a Piper PA-24-250, N7583P, impacted terrain about 40 miles north of Boise, Idaho.\(^2\) The instrument-rated private pilot and his two passengers received fatal injuries. The flight was being conducted as a FAR Part 91 personal pleasure flight.

On the day of the accident, the pilot contacted the Boise Automated Flight Service Station and received a full standard weather briefing. The brief included a prediction of light occasional moderate rime or mixed icing in clouds or in precipitation from the freezing level up to 16,000 feet. The flight departed Jerome at 15:29 M.S.T. At 16:18 M.S.T., the pilot reported, "... we are picking up some ice, would like to try one four thousand." the pilot reported he was, "... approaching one three thousand five hundred, coming out of the clouds." At 15:28,\(^2\) the pilot transmitted, "... we're about as high as we want to go and we're still in some ice, I think we're going to make a one-eighty." At 15:35:52, the pilot transmitted, "Coman-

---

\(^2\) See NTSB Report SEA 97FA070.

\(^2\) The time is reported in the NTSB Report, which contains no explanation for the discrepancy. It is suspected the aircraft crossed into the Pacific Standard Time Zone and these notations are now Pacific Standard Time rather than Mountain Standard Time.
The NTSB noted the probable cause of the accident as the accumulation of airframe ice on the aircraft and the pilot's delayed remedial action after intentionally flying into forecast adverse weather conditions.

**NIHON YS-11, PURDUE UNIVERSITY, INDIANA**

On March 15, 1989, Mid-Pacific Airlines Flight 101 crashed on approach to Purdue University Airport, West Lafayette, Indiana. Eyewitnesses noted that the airplane's nose suddenly pitched downward while on short final approach. A substantial quantity of ice was found on the leading edges of the horizontal stabilizer shortly after the crash. The National Transportation Safety Board issued several safety recommendations, as follows:

**SAFETY RECOMMENDATION A-90-121**

A directed safety review was conducted on the Nihon YS-11 icing certification to include the effect of flap extension and forward CG loading on pitch control with tail plane ice accumulation. As a result, the FAA conducted a safety review of the Mitsubishi Heavy Industries (MHI) (formerly Nihon Airplane Manufacturing Co.) YS-11 airplane icing certification. The FAA determined that since the horizontal stabilizer could accrete ice more readily than the wing, the absence of wing ice would not be indicative of the absence of ice accretion on the tail. The MHI and Japanese Civil Aviation Bureau (JCAB) report stated that during the flight test the tail was not observed, therefore there is no available data regarding ice accretion on the tail of the YS-11. The Safety Board concluded that there is no alternative solution to a possible tail plane icing problem on the airplane except to avoid aircraft configurations common to the accident scenarios; that is, wing flaps greater than twenty with landing gear down in icing conditions, and closed the safety recommendation.

**SAFETY RECOMMENDATION A-90-122**

Issue an emergency airworthiness directive applicable to YS-11 airplanes that limits the use of flaps to twenty or less for landing in the presence of known icing conditions.

The FAA issued an AD (Docket No. 91-NM-06-AD, Amendment 39-6922) applicable to all MHI model YS-11/11A series air-
planes. This AD requires changing the AFM to limit flap positions to no more than twenty in known or potential icing conditions on final approach to landing.

SAFETY RECOMMENDATION A-90-123

Issue an Air Carrier Operations Bulletin to Principal Operations Inspectors to advise YS-11 operators of the potential for loss of pitch control of the airplane when using flaps greater than twenty for landing with ice on the tail plane.

The FAA issued an AD (Docket No. 91-NM-06-AD, Amendment 39-6922) applicable to all MHI model YS-11/11A series airplanes, requiring changes to the AFM to limit flap positions to no more than twenty in known or potential icing conditions on final approach to landing.

SAFETY RECOMMENDATION A-91-122

Issue an Operations Bulletin to Principal Operations Inspectors 14 CFR §§ 121 and 135 air carriers to verify that air carriers have established procedures for flight crews to take appropriate actions when they have encountered icing conditions during a flight to check for the presence of and rid airplanes of accumulated airframe ice prior to initiating final approach.


BEECH DUKE A60, SNOQUALMIE, WASHINGTON

November 21, 1992, a Beechcraft Duke Model A60, N100EK, crashed about two miles west of Snoqualmie Pass, Washington. The radar tracking data indicated that the aircraft flew into mixed icing conditions after experiencing two abrupt altitude excursions and then entered a steep descending left turn. The pilot and five passengers on board died in the accident. As a result, the National Transportation Safety Board issued several safety recommendations, as follows:

SAFETY RECOMMENDATION A-94-138

Issue an Advisory Circular (AC) concerning the flight of small general aviation airplanes in icing conditions. The AC should contain current technological/operational information aimed at helping pilots minimize the potential hazard of an icing encounter and include specific explanatory material related to the
importance of maintaining an appropriate minimum airspeed during sustained flight in icing conditions; the hazards of an ice-induced tail plane stall; the effects of flap extension and air speed on an ice-contaminated airplane; aircraft performance degradation due to icing because of increased drag in stalling speeds; the relative high ice collection efficiency of tail plane surfaces; ways and means of reliably determining the existence and extent of tail plane icing; and the limitations of aircraft certified for flight in icing conditions to provide protection against freezing rain, freezing drizzle, and mixed icing conditions. On July 17, 1996, the Federal Aviation Administration (FAA) issued Advisory Circular (AC) 91-51a, effects of icing on aircraft control and airplane de-ice and anti-ice systems. This AC provides information for pilots regarding the hazards of aircraft icing and the use of airplane de-ice and anti-ice systems. Additionally, the FAA published a three part series of articles in the FAA Aviation News entitled “The Clean Aircraft Concept”. These articles provide information relating to aircraft icing conditions.

SAFETY RECOMMENDATION A-94-137

Require that all pilot operating handbooks and airplane flight manuals applicable to aircraft for flight in icing conditions contain precautionary operational information to help ensure that ice will not accumulate on the under surface of the wing aft of the area protected by the de-ice boot or on other unprotected areas of the airplane. The information should include specification of a minimum indicated air speed that should be maintained during sustained operations in icing.

On October 12, 1995, the FAA issued Airworthiness Directive (AD) 95-22-03 applicable to Beech 60 and A60 series airplanes. The AD requires that the minimum air speed be included in the limitation sections of the pilots operating handbook.

V. ADDITIONAL NTSB SAFETY RECOMMENDATIONS RELATIVE TO ICING

A-96-54: Revise the icing criteria published in 14 C.F.R. Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent development in both the design and use of aircraft. Also expand the Part 25 Appendix C icing certification envelope to include freezing drizzle/
freezing rain and mixed water/ice crystal conditions, as necessary.

A-98-88: Amend the definition of trace ice contained in FAA Order 7110.10L, "Flight Services," and in other FAA documents as applicable so that it does not indicate that trace icing is not hazardous.

A-98-91: Require manufacturers and operators of certain modern turbopropeller-driven airplanes to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge de-icing boots should be activated as soon as the airplane enters icing conditions.

A-98-93: Actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then require their installation on newly manufactured and in-service airplanes certified for flight in icing conditions.

A-98-94: Require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and non-icing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in supercooled large droplet icing conditions, and tailplane icing.

A-98-96: Require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

A-98-97: Require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems.

A-98-100: When the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing
and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards.

VI. REPORTED CASES

Within the past five years, the number of reported cases involving aircraft accidents resulting from icing conditions has declined. The cases referenced below provide an illuminating and representative sample of the legal and factual issues which are typically involved in reported icing litigation.

A. IN RE AIR CRASH DISASTER NEAR ROSELAWN, INDIANA

This case arises out of the crash of the ATR-72 aircraft near Roselawn, Indiana on October 31, 1994. The accident resulted after the aircraft suddenly experienced a catastrophic loss of control, and entered into an uncorrectable roll that caused the plane to crash. The NTSB's conclusions of probable cause included the finding that the loss of control was attributed to a sudden and unexpected aileron hinge movement reversal that occurred after a ridge of ice accreted beyond the de-ice boots. The reported decision involved a discovery dispute over whether plaintiffs were entitled to, among other things, conduct discovery into the history of the ATR-42, a predecessor of the ATR-72. Plaintiffs' discovery request covered the following areas:

1) Incidents of the ATR-42 involving icing;
2) Icing tests and results conducted on the ATR-42;
3) Wing profile information on the ATR-42;
4) Placement of the vortex generators on the ATR-42;
5) Information relating to the crash of an ATR-42 in northern Italy;
6) Information on the reliability of wing boots of the ATR-42; and
7) Information relating to meetings between ATR and United States officials regarding icing incidents on the ATR-462.

The ice protection system utilized on the ATR-72 included:

1) A pneumatic system (leading edge inflatable boots);
2) A pneumatic system for deicing the engine air intakes;
3) Electrical heating for anti-icing of the propeller blades, the windshield and forward portion of the side windows, the

---

pitot tubes, static tube caps TAT (total air temperature) probe and AOA veins;
4) Electrical heating for anti-icing of the aileron, elevator and rudder balance horn;
5) Windshield wiping system for the forward windows;
6) Anti-icing advisory system (AAS) which provided a visual and aural alert when ice begins to accrete.

The Court commented on aileron hinge reversal, quoting the NTSB report as follows:

Aileron hinge movement reversal is described to occur when ice accumulates aft of the deicing boots on the top of the wings causing the wing to cease to be an effective airfoil and it stalls out. This phenomenon can be aggravated by the vacuum-like condition (low pressure area) which exists when the wind travels across the wing surfaces, and loses its continuity with the wing. At this point, the autopilot shuts off. The residual “vacuum” snatches or deflects the aileron upward (hinge movement reversal). At this point, the wing plunges downward and the airplane goes into a violent and dramatic roll.\(^3\)

Based on the evidence presented, the district court concluded that plaintiffs were entitled to conduct discovery regarding the history of the ATR-42 design.

B. JACKSON v. UNITED STATES\(^{24}\)

The accident giving rise to this litigation occurred on March 27, 1992 when the pilot and owner, Dr. Jackson, operated his Mooney Model M20M aircraft into icing conditions and crashed near Charleston, West Virginia. The Mooney M20M was not approved for flight into known icing conditions and contained a warning in the pilot’s operating manual and a plaque inside the cockpit warning that it was not safe to fly the plane into icing conditions. The weather forecast included occasional light to moderate rime ice in the area and numerous pilots had reported encountering icing en route. The radar showed that the aircraft descended below and flew off the prescribed approach course at almost a ninety degree angle. The flight ended when the aircraft lost additional altitude, rocked from side to side, and crashed into a hillside. After the crash, long, thin pieces of ice were found near the wreckage. The pilot’s widow brought an action against the United States of America claiming the Fed-

\(^3\) See NTSB report, pp. 93-94.
eral Aviation Administration was negligent in failing to warn the
pilot of the icing conditions. The court concluded that the
Charleston radar controller was negligent in failing to convey
Pirep information to the pilot.25 This negligence, however, was
outweighed by the negligence of the pilot who had the sole re-
sponsibility of determining whether it was safe to undertake the
flight.26 The court pointed out that since the pilot had been
given warning that icing conditions were "likely to exist," he had
the affirmative duty to seek out and obtain further information
en route.27 It was the pilot's duty to inquire about whether icing
was a factor.28 In addition, the pilot should have known, based
upon his own observations and outside air temperature, that ic-
ing was likely to occur and should have seen the ice developing
on his aircraft.29 The court pointed out that the pilot violated
two federal air regulations: (1) operating the plane contrary to
specified operating limitations in violation of 14 C.F.R. § 91.9,
and (2) operating the aircraft carelessly and recklessly in viola-
tion of 14 C.F.R. § 91.13.30

With regard to the controller's duty, the court states, "The
duty to provide data sufficient to inform the pilot of the condi-
tions he might reasonably encounter does not include the duty
to fine-tune the weather detail to the degree the plaintiff seems
to contend."31

C. MOOREHEAD V. MITSUBISHI AIRCRAFT INTERNATIONAL, INC.32

The Moorehead case arises out of the Mitsubishi MU-2 accident
at McCleod, Texas, discussed above.

In Moorehead, the court concluded that the pilot's negligence
was 60% responsible for the crash and a defective PITOT system
was 40% responsible.33 The Moorehead case was an action
brought for wrongful death by survivors of the passengers killed
in the crash. The plaintiffs alleged the accident was caused by
the negligence of the government in failing to provide a proper
weather briefing. In a trial to the court, the court pointed out

25 See id. at 281-82.
26 See id. at 282.
27 See id.
28 See id.
29 See id. at 282-83.
30 See id. at 283.
31 Id. at 281.
33 See id. at 405.
that the pilot was directly responsible for, and was the final authority as to, the operation of the airplane, finding that the pilot Baker was negligent in three respects:

1. Baker should not have entered the cloud responsible for his icing encounter;
2. Once in it, he waited too long before trying to get out of it; and
3. He mismanaged the flight controls after the plane stalled, and this mismanagement caused a spin from which the plane never recovered.\(^{34}\)

The Moorehead court also concluded, as a matter of law, that even if the government was negligent in its weather forecasting, such negligence could not be a proximate cause of the accident, due to the lack of foreseeability. The court pointed out that government employees have no duty to anticipate pilot negligence.

As a general rule of law, applied specifically in cases of this nature, government employees have no duty to anticipate pilot negligence. *Brooks v. United States*, 695 F.2d 984, 987 (5th Cir. 1983) (stating that a person is not bound to anticipate the negligence conduct of another under Texas law); *Colorado Flying Academy, Inc. v. United States*, 506 F. Supp. 1221, 1228 (D. Colo. 1981), aff'd 724 F.2d 871 (10th Cir. 1984) (FAA employees are entitled to assume pilots will abide by regulations and are not required to foresee their negligence).\(^{35}\)

The Moorehead court also found that the PITOT system was defective. The court found that the PITOT system froze just prior to the accident, causing the plane's airspeed indicator to function like an altimeter. As the plane increased altitude, the airspeed reading increased. As the plane decreased altitude, the airspeed reading decreased. During level flight, the airspeed indicator remained constant regardless of the plane's actual airspeed. Under these circumstances, the pilot had no warning that his airspeed had dropped dramatically. In fact, a climb to a higher altitude had been requested during the last few minutes of the flight, which caused the pilot to believe his airspeed was actually increasing.

\(^{34}\) See id. at 398.

\(^{35}\) Id. at 397.
VII. NEW PRODUCTS

A. NNICE

Information available to help pilots predict icing conditions is now available on an experimental section of the American Weather Center’s Internet site entitled “Neural Network Ice” (NNICE).\textsuperscript{36}

NNICE is an artificial intelligence tool (Neural Network) that recognizes a pattern of the conditions for significant icing (temperature, relative humidity, and slight convective potential). The Internet site uses a simple version of a mammalian brain which is taught to recognize input data patterns through a relatively simple pure rote learning technique. The information is presented in a layered model which presents information from a rapid update cycle model (RUC2) in layers of approximately 1,000 feet thick. The output values range from zero to six, with zero representing no icing and six representing severe icing.

Please note that the modeling is still in the experimental stage and the Aviation Weather Center is evaluating the output to see if there are any flaws.

B. VVICE

Another experimental tool currently available on the Internet is “Vertical Velocity Icing” (VVICE)\textsuperscript{37}, a physically-based aircraft icing diagnostic/forecast tool.

VVICE bases aircraft icing forecasts on ice accumulation potential and the subsequent degradation of aircraft performance. VVICE shows forecast icing contours as a PERCENT POWER INCREASE (PPI) required to overcome the additional drag so that the aircraft can continue at a steady speed and altitude. VVICE computes PPI for a set of standard aerodynamic conditions:

- 1-meter cord NACA 23012 aluminum air foil
- 80-meter-per-second (155 knot speed)
- 2° angle of attack
- 15-minute exposure
- No ice removal

\textsuperscript{36} The information herein is taken from Internet press releases and other sources of information from third parties. See Aviation Weather Center NNICE: An Icing Intensity Predictive Forecast Tool <http://www.kc.noaa.gov/awc/nnice.html> (visited June 11, 2000).

The information is presented for PPIs as follows:

- Trace – 1%-10%
- Light – 11%-30%
- Moderate – 31%-90%
- Severe – 90% or greater

Ice accumulation on aircraft depends on several aerodynamic factors: design, speed, and flight profile; and on several meteorological factors: cloud liquid water amount, cloud droplet size, and air temperature. VVICE takes the meteorological information available and makes an initial interpretation of the possible aerodynamic consequences of these forecasts.

The VVICE program computes the maximum upward vertical velocity and uses simple cloud physics equations to estimate highest possible cloud liquid water content and the largest possible cloud droplet size and combines this information with the forecast air temperature. The aerodynamic criteria are significant because icing is not as hazardous in environments with small droplets and cold temperatures (the drops that do make contact freeze quickly on the leading edge) or very large droplets in temperatures near 0°C (drops roll back and freeze on the trailing edges). Drag increase is greatest when ice accumulates just after the leading edge. This usually occurs at temperatures around -4°C to -12°C and with droplets that are drizzle-sized (50-400 micron diameter), but can also occur with small droplets at temperatures near 0°C and with large droplets at cold temperatures (less than -12°C).

VVICE is an experiment attempting to improve icing forecasts, improve communications of the icing threat to pilots, and improve pilot reporting of the icing threat to forecasters.

C. NGM-BASED MOS6-H AIRCRAFT ICING INDEX FORECAST

Techniques Development Laboratory's new NGM-based MOS6-H Aircraft Icing Index Forecast for the contiguous U.S. are produced daily from the National Centers of Environmental Prediction's (NCEP) Aviation Weather Center (AWC) and Hydrometeorological Prediction Center (HPC).38

---

D. Ice Zapper

The Ice Zapper, officially known as the "Electro-Expulsive Separation System," was licensed by NASA to Ice Management Systems, Inc., in Temecula, California. Testing is planned on the LANCAIR IV aircraft. The Ice Zapper uses a powerful electronic photo flash-like power supply combined with a thin copper ribbon embodied in rubbery plastic. The system sends bursts of high-current electricity through two parallel layers of copper ribbon, creating repelling magnetic fields. The high-acceleration movement of the ribbon breaks the ice bond and shatters the ice into table-salt-sized particles. The system can run continually during flight.

E. Smart Boot

BF Goodrich Aerospace is marketing a new product called the SMART Boot De-Ice and Protection System.40

F. TKS Ice Protection System

The TKS Ice Protection System uses a liquid antifreeze solution, which is pumped from panels mounted on the leading edges of the wings, and the horizontal and vertical stabilizers. The liquid solution provides a protective film of glycol, preventing the formation of ice.

G. Eddy Current Repulsion De-Icing Strip42

The concept consists of a spiral coil encapsulated in an elastomer and bonded with composites to the leading edges of airfoils. The eddy currents are discharged through the coils, creating an impulse de-icing force.

H. Detection Filter Theory System43

A study is being conducted regarding the possibility for using a novel concept of "detection filter theory" as a means for detecting aircraft ice secretions. The detection filter theory

43 See <http://sbir.gsfc.nasa.gov/95abstracts/03.01/951743.html>.
utilizes a sensitive ice detection scheme that can generate both the location and the severity of the icing.

I.IDI Detector\textsuperscript{44}

The IDI Detector consists of a thin capacitance sensory array that uses two electrodes designed to measure the dielectric constant between the electrodes. The dielectric constant of ice is different from water and air. A signal processing technique determines ice thickness as well as the type of ice, and then relays the information back to the pilot. This system has been licensed to BF Goodrich Aerospace to incorporate into their pneumatic de-ice boots.

J. Ultra Sonic Detection\textsuperscript{45}

The Ultra Sonic Detection method is based on reflectivity changes at a metal-ice interface, using echo-ranging techniques that utilize pulses of longitudinal and sheer waves. An Army SBIR Grant to J-Tech Associates, Inc. supports the analysis of this system.

K. Infratek System\textsuperscript{46}

The Infratek System uses infrared technology as an alternative to a chemical ice removal system for structural ice removal.

VIII. FEDERAL AVIATION REGULATIONS REGARDING ICING

Part 91.1 et. seq. of Title 14 of the Code of Federal Regulations establishes the general operating and flight rules that are applicable to "the operation of aircraft . . . within the United States, including the waters within 3 nautical miles of the U.S. Coast."\textsuperscript{47}

Part 91.527(a) governs operations in icing conditions. Part 91.527(a) prohibits a pilot from taking off in an airplane that has:

(1) Frost, snow, or ice adhering to any propeller, windshield, or powerplant installation or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;

\textsuperscript{44} See <http://nctn.hq.nasa.gov/Innovation/34/Icing.html>.
\textsuperscript{45} See <http://sound.media.mit.edu/AUDITORY/asamtgs/asa93dnv/3aEA/3aEA5.html>.
\textsuperscript{46} See <http://www.clamshell.com/rp46.htm>.
\textsuperscript{47} 14 C.F.R. § 91.1 (1999).
(2) Snow or ice adhering to the wing or stabilizing or control surfaces; or

(3) Any frost adhering to the wings or stabilizing or control surfaces, unless that frost has been polished to make it smooth.\textsuperscript{48}

Except for aircraft which meet the requirements of Section 34 of Special Federal Aviation Regulation 23\textsuperscript{49} or for transport category airplane type certification, Part 91.527 prohibits pilots from flying: (1) Under IFR [instrument flight rules] into known or forecast moderate icing conditions; or (2) Under VFR [visual flight rules] into light or moderate icing conditions unless the aircraft has functioning de-icing or anti-icing equipment protecting [specified aircraft areas and instruments].\textsuperscript{50}

Part 91.527(a) and (b) serve to emphasize the importance of having an aircraft which is free of frozen contamination prior to departure. Obviously, beginning a flight with a “clean” airplane is the first step to a successful operation in icing conditions. Part 91.527 also emphasizes that a PIC must make decisions as to his anticipated route of travel. If icing conditions can be avoided, the problem is eliminated. On the other hand, the PIC must recognize their own limitations and if they know or become aware of icing conditions existing along the anticipated route of travel, they must make the decision to re-route or terminate the flight.

Part 91.527(c) prohibits a pilot from flying an airplane into known or forecast severe icing conditions unless the airplane “has ice protection provisions that meet the requirements in sec-

\textsuperscript{48} 14 C.F.R. § 91.527(a) (1999).

\textsuperscript{49} Section 34 of Special Federal Aviation Regulations 23 provides:

Ice Protection. If certification with ice protection provisions is desired, compliance with the following requirements must be shown:

(a) The recommended procedures for the use of the ice protection equipment must be set forth in the Airplane Flight Manual.

(b) An analysis must be performed to establish, on the basis of the airplane’s operational needs, the adequacy of the ice protection system for the various components of the airplane. In addition, tests of the ice protection system must be conducted to demonstrate that the airplane is capable of operating safely in continuous maximum and intermittent maximum icing conditions as described in FAR 25. Appendix C.

(c) Compliance with all or portions of this section may be accomplished by reference, where applicable, because of the similarity of the designs, to analysis and tests performed by the applicant for a type certificated model.


\textsuperscript{50} 14 C.F.R. § 91.527(b) (1999).
tion 34 of Special Federal Aviation Regulation 23, or those for transport category airplane type certification. . ."51

The purpose of this regulation is obvious. A PIC is required to avoid icing conditions if his aircraft is not properly equipped.

Part 91.527.(d) provides a basis for many arguments raised by plaintiffs in icing-related aircraft accidents. Part 91.527(d) states:

If current weather reports and briefing information relied upon by the pilot in command indicate that the forecast icing conditions that would otherwise prohibit the flight will not be encountered during the flight because of changed weather conditions since the forecast, the restrictions in paragraphs (b) and (c) of this section based on forecast conditions do not apply.52

A common issue raised in suits arising from icing related aircraft crashes is whether the United States of America acting through the FAA's Automated Flight Service Stations failed to properly advise the pilot of the appropriate weather conditions and whether this failure was the proximate cause of the accident. However, this argument often overlooks the fact that the PIC bears the ultimate responsibility for the safety of his flight and retains the final decision making authority as to whether to enter or continue flying in icing conditions. Further, if a PIC is alerted to the potential for icing conditions along his announced flight path, the PIC has an ongoing duty to inquire as to any changed weather conditions while he is en route.53

Within Part 121, paragraphs 341, 342, and 629 relate to aircraft icing. Part 121.341 sets forth the instrument and equipment requirements for operating in icing conditions.54 Part 121.342 specifically addresses pitot heat indication systems.55 Part 121.629 covers dispatching and flight release rules in icing conditions.56

51 14 C.F.R. § 91.527(c) (1999).
52 14 C.F.R. § 91.527(d) (1999).
53 See supra text accompanying notes 24-31.
56 See 14 C.F.R. § 121.629 (1999). On December 20, 1995, the Federal Aviation Administration published rule changes requiring commuter operators conducting scheduled passenger-carrying operations in aircraft having passenger seating configurations of ten to thirty seats and those conducting passenger-carrying operations in turbo jet airplanes regardless of configuration under 14 C.F.R. § 135 to conduct those operations under 14 C.F.R. § 121.
Part 121.341 prohibits the operation of an aircraft in icing conditions "unless it is equipped with means for the prevention or removal of ice on windshields, wings, empennage, propellers, and other parts of the airplane where ice formation will adversely affect the safety of the airplane."\(^5\)

Part 121.341(a) does provide two exceptions to this prohibition against aircraft operations in icing conditions.\(^5\) Part 121.341(a) also states:

Except as permitted in paragraph (c)(2) of this section, unless an airplane is type certificated under the transport category airworthiness requirements related to ice protection, or unless an airplane certificated after December 31, 1964, that has the ice protection provisions that meet section 34 of appendix A of part 135 of this chapter,\(^5\) no person may operate an airplane in icing conditions...\(^6\)

For those operations subject to Part 121, Part 121.341(a) provides the airman with guidance as to the minimum equipment required for operations in icing conditions. From a general perspective, it appears Part 121.341(a) is designed to ensure the airman has the means at his disposal to combat icing conditions if or when they are encountered.

Part 121.341(b) addresses a problem which might not occur to a non-pilot, i.e., how do you detect icing conditions when flying at night? Part 121.341(b) provides in relevant part, "[n]o person may operate an airplane in icing conditions at night un-

---


\(^6\) See id. Section 34 of Appendix A to Part 135 provides:

\begin{quote}
Ice Protection. If certification with ice protection provisions is desired, compliance with the following must be shown:

(a) The recommended procedures for the use of ice protection equipment must be set forth in the Airplane Flight Manual.

(b) An analysis must be performed to establish, on the basis of the airplane's operational needs, the adequacy of the ice protection system for the various components of the airplane. In addition, tests of the ice protection system must be conducted to demonstrate that the airplane is capable of operating safely in continuous maximum and intermittent maximum icing conditions as described in Appendix C of Part 25 of this chapter.

(c) Compliance with all or portions of this section may be accomplished by reference, where applicable because of similarity of the designs, to analysis and tests performed by the applicant for a type certificated model.
\end{quote}

less means are provided for illuminating or otherwise determining the formation of ice on the parts of the wings that are critical from the standpoint of ice accumulation.\textsuperscript{61}

From an icing problem analysis, Part 121.341(b) is designed to assist the PIC in detection of icing conditions by enabling him to make a visual inspection while in flight at night.

Part 121.341(c) is very similar, although not identical, to Part 91.527(b). Part 121.341(c) provides:

Non-transport category airplanes type certificated after December 31, 1964. Except for an airplane that has ice protection provisions that meet section 34 of appendix A of Part 135 of this chapter, or those for transport category airplane type certification, no person may operate—

(1) Under IFR into known or forecast light or moderate icing conditions;
(2) Under VFR into known light or moderate icing conditions; unless the airplane has functioning deicing anti-icing equipment protecting each propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system; or
(3) Into known or forecast severe icing conditions.\textsuperscript{62}

As previously discussed in relation to Part 91.527(b), this regulation mandates that a PIC recognize his own training and skill limitations in order to prevent icing-related aircraft accidents.

Part 121.341(d) contains the same language as Part 91.527(d) with the exception that the weather forecast related restrictions are found in paragraph (c) of Part 121.341 and are so noted in Part 121.341(d).\textsuperscript{63}

Part 121.342 requires an operable pitot heat indication system be installed on certain aircraft. Part 121.342 provides:

No person may operate a transport category airplane or, after December 20, 1999, a nontransport category airplane type certificated after December 31, 1964, that is equipped with a flight instrument pitot heating system unless the airplane is also equipped with an operable pitot heat indication system that complies with § 25.1326 of this chapter in effect on April 12, 1978.\textsuperscript{64}

\textsuperscript{61} 14 C.F.R. § 121.341(b) (1999).
\textsuperscript{62} 14 C.F.R. § 121.341(c) (1999).
\textsuperscript{63} See discussion of Part 91.527(d) supra at page 758.
\textsuperscript{64} 14 C.F.R. 121.342 (1999). Part 121.342 was last amended in 1995 by the same rule which amended § 121.341. See supra note 56.
As previously noted, one of the adverse effects of ice accumulation on an aircraft is an increased stall speed. The pitot tube is the vital sensor for obtaining an accurate airspeed indication. If the pitot tube becomes clogged with ice, the indicated airspeed will not be accurate. In icing conditions, a PIC may believe he is maintaining speed when in fact his aircraft is gradually slowing down. The decrease in airspeed may be so gradual that the PIC does not sense any decrease until the aircraft actually stalls. At that point, the stall may or may not be recoverable.

Part 121.629 governs the dispatching and flight release rules for domestic, flag, and supplemental operations in icing conditions. Paragraph (a) of Part 121.629 prohibits the dispatch, release, or continued operation of an aircraft when, in the opinion of the PIC, icing conditions are expected or might be met that might adversely affect the safety of the flight.\(^65\) Part 121.629(b) prohibits takeoffs when frozen contamination of critical surfaces may reasonably be expected.\(^66\) Part 121.629(c) provides an exception by prohibiting the dispatch, release and take off of an aircraft, “unless the certificate holder has an approved ground deicing/anti-icing program in its operation specifications and [if] the dispatch, release, and take off comply with this program.”\(^67\) Paragraph (d) of Part 121.629 allows a certificate holder to operate under Part 121.629 without a program such as that described in paragraph (c) if the certificate holder includes in its operations specifications the requirement that an inspection, be made from outside the aircraft, within five minutes of takeoff when conditions are such that frost, ice or snow are reasonably likely to adhere to the aircraft.\(^68\)

The language of Part 121.629 clearly addresses the importance of having an appropriately equipped aircraft when conducting operations in icing conditions. It is noteworthy that Part 121.629 clearly delegates to the PIC the responsibility to terminate a flight if, in his opinion, he might encounter icing conditions that would compromise the safety of the flight. As a final note, this part further emphasizes the necessity of insuring the aircraft is “clean”, without any frozen contamination prior to departure.

---

\(^{65}\) See 14 C.F.R. § 121.629(a) (1999).

\(^{66}\) See 14 C.F.R. § 121.629(b) (1999).

\(^{67}\) 14 C.F.R. § 121.629(c) (1999).

\(^{68}\) 14 C.F.R. 121.629 (1999).
Part 125 applies to aircraft with a seating capacity of twenty or more passengers or a minimum payload capacity of 6,000 pounds or more.\textsuperscript{69} The sections of Part 125 which are relevant to the issue of icing are 123, 181, 206, and 221. Part 125.123 mandates that if combustible fluid is used for propeller deicing, the certificate holder must comply with Part 125.153 regarding the location and installation of the reservoir to contain the fluid.\textsuperscript{70}

Part 125.181 requires that a means for preventing the malfunctioning of each engine due to ice accumulations in the engine air induction system must be provided for each airplane.\textsuperscript{71} It is interesting to note the appearance in the CFR's of a regulation specifically addressing the issue of air induction for aircraft engines. As previously noted, engine failures may occur when ice chokes off the air supply to the engine. This phenomenon occurs when ice accumulates around carburetor throats or, depending on engine type, actually closes off the air induction conduits for the engine. In either case, the result is the same, a gradual loss of engine power with the engine ultimately failing.

The pitot heat indication system is the subject of Part 125.206.\textsuperscript{72} While this section addresses the same issues as Part 121.342, Part 125.206 contains different timing requirements for compliance and provides a means for obtaining an extension of the compliance deadline. Paragraph (a) indicates, "...after April 12, 1981, [subject to an exception set forth in paragraph (b)], no person may operate a transport category airplane equipped with a flight instrument pitot heating system unless the airplane is equipped with an operable pitot heat indication system that complies with § 25.1326 of this chapter that was in effect on April 12, 1978."\textsuperscript{73} Paragraph (b) allows a

\textsuperscript{69} See 14 C.F.R. § 125.1 (1999).
\textsuperscript{70} See 14 C.F.R. § 125.123 (1999).
\textsuperscript{71} See id. § 125.181.
\textsuperscript{72} See 14 C.F.R. § 125.206 (1999).
\textsuperscript{73} 14 C.F.R. § 125.206(a) (1999). Section 25.1326 provides:

\textbf{Pitot heat indication systems.}

If a flight instrument pitot heating system is installed, an indication system must be provided to indicate to the flight crew when that pitot heating system is not operating. The indication system must comply with the following requirements:

(a) The indication provided must incorporate an amber light that is in clear view of a flight crewmember.

(b) The indication provided must be designed to alert the flight crew if either of the following conditions exist:
Part 125.221 sets forth operating limitations in icing conditions and tracks very closely the language of Part 91.527. Part 125.221(a) prohibits a pilot from taking off in an airplane that has "frost, ice or snow adhering to any propeller, windshield, wing, stabilizing or control surface, to a powerplant installation, or to an airspeed, altimeter, rate of climb or flight attitude instrument system [except under certain specified conditions]."75

Section 125.221(a)(1) allows take offs to be made "with frost adhering to the wings, or stabilizing or control surfaces, if the frost has been polished to make it smooth."76 Takeoffs with frost under the wings in the area of the fuel tanks may be made if permitted by the Administrator.77

Part 125.221(b) prohibits takeoffs at "any time conditions are such that frost, ice, or snow may reasonably be expected to adhere to the airplane . . ."78 unless the pilot complies with the additional testing/training requirements of Part 125.287(a)(9) and completes one of three enumerated options.79 One of the options available to the PIC is to complete a pre-takeoff contamination check within five minutes prior to beginning takeoff.80 Part 125.221(b)(1) defines a pre-takeoff contamination check as "a check to make sure the wings and control surfaces are free of frost, ice and snow."81

---

(1) The pitot heating system is switched "off."
(2) The pitot heating system is switched "on" and any pitot tube heating element is inoperative.

Id. 74 See 14 C.F.R. § 125.206(b) (1999).
75 14 C.F.R. § 125.221(a) (1999).
76 Id. § 221(a)(1).
77 See id. 221(a)(1).
78 Id. § 221(b).
79 14 C.F.R. § 125.287(9) requires testing on the knowledge and procedures for operating during ground icing conditions.
80 In addition to a pre-takeoff contamination check noted in 125.221 (b)(1), § 125.221(b) provides the following additional options: "(2) The certificate holder has an approved alternative procedure and under that procedure the airplane is determined to be free of frost, ice, or snow; (3) The certificate holder has an approved deicing/anti-icing program that complies with § 121.629(c) of this chapter and the takeoff complies with that program." 14 C.F.R. § 125.221(b) (1999).
Part 125.221(c) tracks very closely the language of Part 91.527(a) and Part 121.341(c). Although these sections are similar, they are not identical. Part 125.221(c) states:

Except for an airplane that has ice protection provisions that meet Appendix C of this part or those for transport category airplane type certification, no pilot may fly—

(1) Under IFR into known or forecast light or moderate icing conditions; or
(2) Under VFR into known light or moderate icing conditions, unless the airplane has functioning deicing or anti-icing equipment protecting each propeller, windshield, wing, stabilizing or control surface, and each airspeed, altimeter, rate of climb, or flight attitude instrument system.82

Again, the FAA regulations place the burden on the PIC to recognize his own training and skill limitations when operating in icing conditions. The regulations also require the PIC to be familiar with the ice protection capabilities of his particular aircraft.

Part 125.221(d) is analogous to Part 91.527(c) in that it prohibits a pilot from flying into known or forecast severe icing conditions unless the aircraft has the ice protection provisions that meet appendix C of Part 125 or has a transport category type airplane certification.83 Part 125.221(e), containing weather related restrictions, is identical to Part 91.527(d).84

Part 135.1 et seq. establishes the operating requirements for commuter and on demand operations.85

The portions of Part 135 that are relevant to icing include 149, 158, and 227. Part 135.149 addresses general equipment requirements.86 Paragraph (b) of this section requires aircraft subject to this regulation to be equipped with heating or deicing equipment for each carburetor or, for a pressure carburetor, an alternate air source.87

Part 135.158 sets forth the regulations governing pitot heat indication systems.88 The language of Part 135.158 is identical

82 14 C.F.R. § 125.221(c) (1999).
83 See 14 C.F.R. § 125.221(d) (1999).
84 See 14 C.F.R. § 125.221(e) (1999).
ICING ACCIDENTS

Part 135.227 governs operating limitations in icing conditions.\(^8\)\(^9\) Part 135.227 is substantially similar to Part 125.221 although Part 135.227 includes helicopters while Part 125.221 does not. Part 135.227(a)(1) and (2) contain the same prohibitions regarding takeoffs in aircraft with frost, ice, and snow adhering to portions of the aircraft as those contained in Part 125.221(a)(1) and (2). Because Part 135.227(a) governs helicopters, however, the list of specific components to be checked has been expanded to include rotors.

Paragraph (b) of Part 135.227 imposes different training requirements from those contained in Part 125.221(b) in order to meet an exception allowing operations in conditions where frost, ice or snow may be reasonably expected to adhere to the aircraft. Part 135.227(b) requires that the pilot complete all applicable training as required by 14 CFR 135.341.\(^9\)\(^0\) Section 125.221(b) is more stringent in that it requires the pilot to complete the testing required under section 125.287(a)(9).\(^9\)\(^1\)

In addition to the training requirements specified in Part 135.227(b), a pilot \textit{must} complete one of three specified requirements enumerated in paragraphs (1), (2), and (3) of 227(b). These requirements are identical to those enumerated in paragraphs (1), (2), and (3) of Part 125.221(b).

Part 135.227(c) is very similar to Part 125.221(c) discussed above.\(^9\)\(^2\) Both Part 135.227(c) and Part 125.221(c) require aircraft to meet certain specified ice protection levels in order to qualify for the exceptions set forth in the respective sections to the prohibition against flights in icing conditions. At first blush, it would appear the ice protection levels might be different because the references contained within the respective sections are

---


\(^{9}\) See 14 C.F.R. § 135.227(b) (1999). Part 135.341 addresses pilots and flight attendants in more general terms but does include a mandate that crews be adequately trained to meet the requirements of 14 C.F.R. § 135.293 - .301. Part 135.293(a)(7)(iii), in turn, references operations in or near thunderstorms including icing and other potentially hazardous meteorological conditions.

\(^{9}\) Section 125.287(a)(9) requires the pilot pass a written or oral test on his knowledge of procedures for operating during ground icing conditions. See 14 C.F.R. § 125.287(a)(9) (1999).

\(^{9}\) See 14 C.F.R. § 135.227(c) (1999).
enumerated differently. However, on closer examination, both sections refer to identical language.

The exceptions to the prohibitions against takeoffs in icing conditions contained in Part 135.227(c)(1) and (c)(2) are identical to the exceptions contained in Part 125.221(c)(1) and (c)(2).

Paragraph (d) of Part 135.227 prohibits a pilot from flying a helicopter, "under IFR into known or forecast icing conditions or under VFR into known icing conditions unless it has been type certificated and appropriately equipped for operations in icing conditions." Paragraph (d) has no counterpart in Part 125.221.

Paragraph (e) of Part 135.227 is identical to paragraph (d) of Part 125.221. Paragraph (f) of Part 135.227 is virtually identical to Part 125.221(e) except that Part 125.227(f) includes a reference to the restrictions placed on helicopters in addition to those placed on aircraft by the preceding provisions of Part 135.227.

IX. CONCLUSION

NTSB statistics indicate that aircraft icing continues to threaten the safety of airmen. However, this threat can be minimized by an airman conscientiously familiarizing himself with the applicable federal regulations and airworthiness directives for the aircraft he operates. Just as there will always be someone who fails to drive the posted speed limit in their automobile, there will be airmen who fail to follow safe practices in icing conditions. This course of action often leads to accidents, which in turn, lead to litigation.

It is undisputed that a pilot in command of his aircraft has the final authority over the operations of that aircraft. However, in the event of an accident, subsequent lawsuits generally fall into either the products liability or negligence arena. Within these classifications, the plaintiff’s bar often focuses on some aspect of the aircraft’s design, testing, certification, equipment or maintenance as the basis for a lawsuit. Another aspect of aircraft operations which is frequently the subject of litigation is the federal

---

93 Section 135.227(c) refers to “Section 34 of appendix A” while § 125.221(c) refers to “Appendix A of this part.”
government's role in supplying weather information to the pilot in command.

On final analysis, it appears many icing related aircraft accidents are preventable if the pilot in command follows the rules and uses good judgment. However, if an accident occurs and litigation ensues, the inescapable fact remains that the pilot in command always bears the ultimate responsibility for the safety of the flight.
Figure 1. 21:32Z IR satellite photo shows the cloud features associated with the low pressure area to the southwest of the accident site, a cold front trailing off to the southwest and a warm front off to the east. Center red cross is the location of the accident site, lower right cross is departure point, Indianapolis, and upper right cross is planned destination, Chicago.
Figure 2. 21:45Z contoured IR (in degrees Kelvin) satellite photo showing low (warmer) cloud top area moving from the southwest over the accident site area. Accident site is lower red cross in the center of the photo with the upper cross representing the holding fix. The vertical green line in the center of the photo represents border between Illinois and Indiana with the southern end of Lake Michigan to the north.
Figure 3. 21:47:10Z plan view of the weather radar data near the accident site at the holding altitude. Airplane holding track is shown by line with aircraft location just prior to the accident shown as the black circle. Color code for reflectivity is: white less than 0 dBZ, dark blue for 0 to 5 dBZ, then 5 dBZ steps to 30 dBZ (the red spots in the left side of the figure). Note uneven pattern denoting cellular structure.
Figure 4. 21:41:10Z vertical cross section along the flight path. Note high cloud tops and reflectivity well below the cloud top. Airplane holding track and location in the small inset. Dark blue color represents reflectivity in the 0 to 5 dBZ range. Cloud top altitude is represented by the top of the white area.
Figure 5. 21:55:10Z vertical cross section along the flight path. Note cloud tops very close to the top of the detectable radar reflectivity. Airplane holding track and location in the small inset. Dark blue color represents reflectivity in the 0 to 5 dBZ range. Cloud top altitude is represented by the top of the white area.
Figure 6. Graphical representation of the radar equations showing the relationship between equivalent reflectivity \( Z_e \) (in dBZ), liquid water content (g m\(^{-3}\)), droplet concentration (#/liter) and droplet size (p.m, microns).
Figure 7. Ice ridge on top of wing during icing tanker tests due to SLD (200 micron) conditions. Aircraft was being flown with flaps 15 degrees down. A dye has been added to the water dispersed by the USAF icing tanker so that the ice has an easily detectable yellow color.