11.2 A STATISTICAL REVIEW OF AVIATION AIRFRAME ICING ACCIDENTS IN THE U.S.

Kevin R. Petty* and Carol D. J. Floyd
National Transportation Safety Board, Washington, DC

1. INTRODUCTION

For years, airframe icing has been recognized as a significant aviation hazard. Icing encounters can lead to increased aerodynamic drag and weight, along with a reduction in lift and thrust. Together, these factors result in a higher stall speed and degradation in overall aircraft performance. To maintain altitude and counter the effects of drag during flight in icing conditions, the angle of attack is generally increased and power is applied to the engine(s). This can further expose unprotected regions of the aircraft to ice accretions. If exposure is prolonged, the aircraft will lose the ability to continue stable flight.

Of equal importance is ice that accumulates on aircraft surfaces prior to takeoff. One of the first jet air transport category accidents linked to airframe icing occurred on December 27, 1968. A Douglas DC-9, operated by Ozark Air Lines, Inc., crashed shortly after takeoff. In this case, the aircraft suffered substantial performance penalties when it was subjected to freezing drizzle before takeoff.

Considerable progress has been made in understanding the meteorological conditions associated with airframe icing (Sand et al. 1984; Cober et al. 1995; Bernstein and McDonough 2000; Politovich and Bernstein 2001). A substantial amount of interest and research into icing, with attention to supercooled large droplets (SLD), was generated when an ATR-72 was destroyed after it experienced an uncommanded departure from controlled flight and crashed near Roselawn, Indiana (1994). A ridge of ice that accreted behind the deice boots contributed to an unanticipated aileron hinge moment reversal and an abrupt loss of control. The accident raised awareness about the hazards of operating in SLD conditions, which are not accounted for in 14 Code of Federal Regulations (CFR) Part 25, Appendix C. Because supercooled large droplets can run back and freeze on surfaces behind an airplane's deicing boots, it is extremely hazardous.

In recent years, icing research has translated into applied technologies aimed at diagnosing and forecasting icing hazards for both ground and in-flight aviation operations (McDonough and Bernstein 1999; Rasmussen et al. 2001; McDonough et al. 2004). Continued development and improvement of such technologies, along with training initiatives, will aid in reducing the number of icing related accidents.

**Corresponding author address*: Kevin R. Petty, National Transportation Safety Board, Office of Aviation Safety (AS-30), 490 L'Enfant Plaza East, S.W., Washington, DC 20594-2000; email: pettyk@ntsb.gov

Past research has documented the hazards of aircraft icing by identifying icing related accidents in the late 1970s and 80s (Cole and Sand 1991). The study herein attempts to provide contemporary statistics on airframe icing accidents by examining events that took place from 1982 to 2000. Although airframe icing accidents only accounted for a small percentage of the total aviation accidents, they resulted in 583 accidents and more than 800 fatalities during the 19-year period.

2. DATA AND METHODOLOGY

The National Transportation Safety Board maintains a database of civil aviation accidents and incidents. An occurrence is defined as an accident when the operation of an aircraft, with the intent of flight, results in substantial damage to the aircraft or death or serious injury to any person. In contrast, an incident is an occurrence that influences the safety of an aircraft's operation, but does not meet the criteria for an accident (49 Code of Federal Regulations (CFR) 830.2). The NTSB database is composed mainly of accidents and contains over 650 fields for each accident record, including information regarding the aircraft, environment, crew, injuries, and phase of flight. The database was used to identify accidents in which airframe icing was either a cause or factor during the 19-year period from 1982-2000, with a factor defined as any condition or situation that played a role in the cause of the accident. This period was chosen to exclude the influence of September 11 and to ensure data continuity.

For portions of this study, accidents were stratified into their respective segments of operation, which include general aviation (GA) and 14 CFR Parts 135 and 121. The majority of general aviation flights are personal and recreational in nature; however, some flights are conducted with the intent of generating revenue. In general, GA constitutes civil aviation operations not covered under 14 CFR Parts 135 and 121. Part 135 generally refers to commuter airlines (i.e. scheduled) and air taxis (i.e. nonscheduled), and Part 121 normally references major airlines and cargo carriers[1]. Because of distinct operating characteristics within the Part 135 segment of operations, further segregation into schedule and nonscheduled operations was performed. The regulatory differences between

[1] Prior to March 1997, scheduled aircraft with 30 or more seats fell under Part 121, while those with less than 30 were considered Part 135. Because of regulatory changes, Part 121 now includes all aircraft with 10 or more seats; thus, some commuters once regarded as Part 135 are now considered Part 121.

scheduled and nonscheduled Part 135 operations is beyond the scope of this paper, but detailed definitions pertaining to these sectors of operation can be found in 14 CFR 119.3.

3. FINDINGS

3.1 *Annual Accidents, Fatal Accidents, and Fatalities*

Figure 1 displays all airframe icing accidents from 1982 to 2000. The accidents have been grouped into the three predominant segments of aviation operations: GA, Part 135, and Part 121. It is clearly evident that GA accidents dominate the total number of accidents during the period. GA accidents were responsible for 80.6% of all airframe icing accidents, while Part 135 and Part 121 accounted for 17.6% and 1.7%, respectively. However, the annual GA accident rate significantly declined during the same period. The number of general aviation accidents dropped from a high of 49 in 1982 to 17 in 2000.

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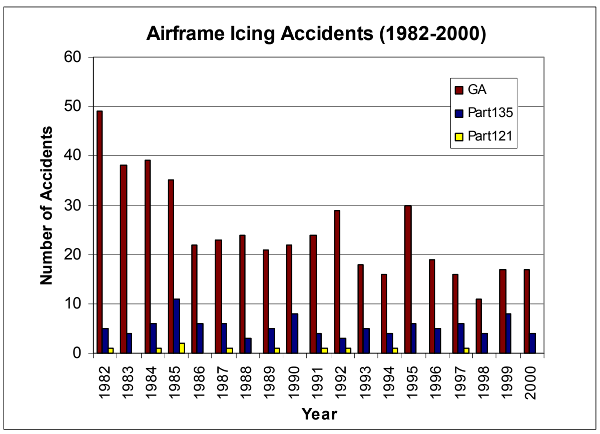

Figure 1. Aviation accidents associated with airframe icing for the period 1982-2000.

A graph depicting the number of fatal airframe icing accidents is provided in Figure 2. There were one or more fatalities in 47% of the GA accidents, while only 26% of Part 135 accidents were fatal. Six out of the ten Part 121 accidents during the period were fatal accidents.

Airframe icing accidents led to 819 deaths spanning the 19-year period reviewed in this study. As one might anticipate, GA accidents were responsible for the largest number of fatalities (522). The observed annual decrease in fatalities within the GA segment of operation is directly correlated with the decline in the overall number of GA accidents (Figure 3). Peaks in the number of fatalities linked to Part 135 and 121 operations are related to some very notable U.S. icing accidents, including Air Florida flight 90 (Washington, DC 1982), USAir flight 405 (Flushing, NY 1992), Comair flight 3272 (Monroe, MI 1997), and American Eagle flight 4184 (Roselawn, IN 1994).

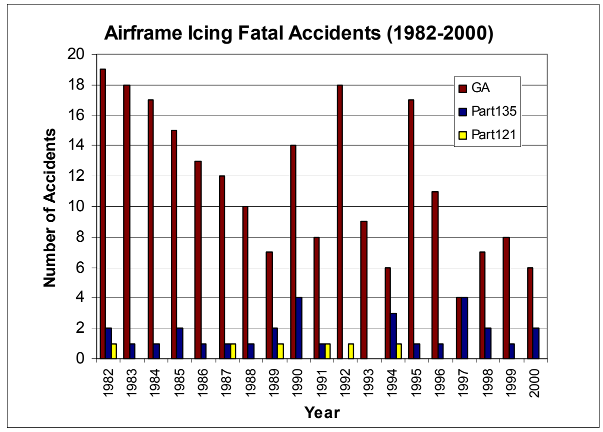

Figure 2. Fatal airframe icing accidents from 1982-2000.

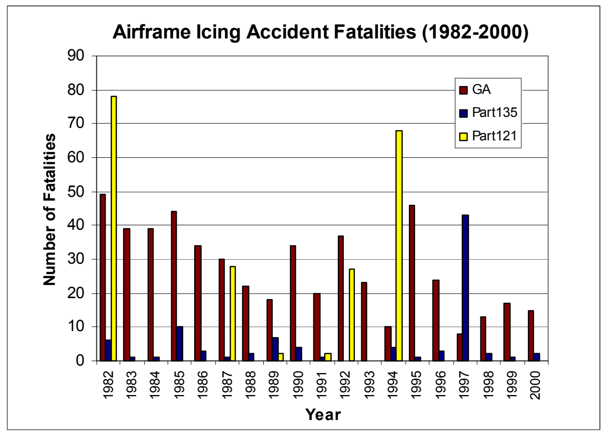

Figure 3. Fatalities resulting from airframe icing accidents for the period 1982-2000.

3.2 *Seasonal Distribution*

Eighty-one percent of all airframe icing accidents took place between the beginning of October and the end of March. Figure 4 presents the percentage of icing accidents by month, and it shows that the largest percentage of accidents happened in January. The monthly distribution of accidents is well-correlated with the frequency of freezing precipitation and ice pellets in the U.S. Cortinas et al. (2004) found freezing precipitation and ice pellets occur most frequently in the U.S. and Canada during December, January, and February. However, they noted that Arctic coastal regions experience these precipitation types mostly between May and October. Utilizing pilot reports and measurements from research aircraft, Bernstein and McDonough (2000) found a significant relationship between lower atmospheric SLD conditions and surface observations of freezing precipitation and ice pellets. General aviation and Part 135 aircraft traditionally fly at lower altitudes and at slower speeds than air transport category aircraft; as a result, they are more likely to encounter icing conditions, including SLD environments.

Although it is evident that icing accidents are more likely to occur in the winter months, it should be noted that icing accidents do occur throughout the year. Contrary to what might be expected, none of the summer accidents were located in Alaska. A more detailed examination of June, July, and August cases showed that these accidents were confined to the northern portions of the contiguous U.S.

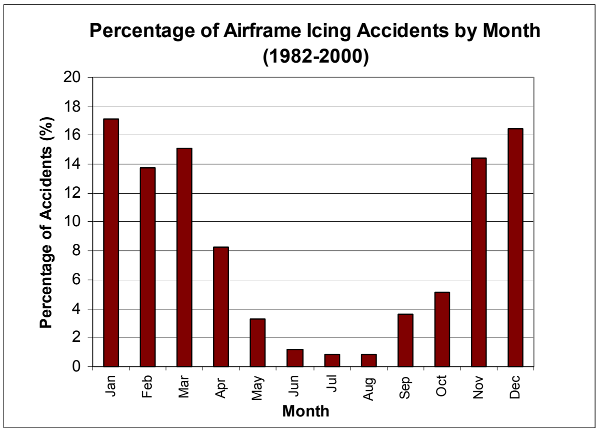

Figure 4. Percentage of airframe icing accidents by month for 1982-2000.

3.3 *Phase of Flight*

The NTSB accident database uses "occurrences" to document and define the sequence of events for each accident. For example, an accident aircraft may have experienced (1) an in-flight encounter with weather, (2) a forced landing, (3) a runway overrun, and (4) an on-ground collision with an object. Associated with each of these occurrences is a phase of flight (e.g. takeoff, landing, etc.). This study uses the phase associated with the first occurrence in the accident to compute statistics related to phase of flight (Figure 5).

In Figure 5, the values in black indicate the percentage of accidents for each phase of flight, and those in blue represent the percentage of fatal accidents. The data show that almost 40% of airframe icing accidents occurred when the airplane was in cruise, and 50% of fatal accidents were also found in this phase of flight. This is a period when pilot workload is relatively low; thus, the opportunity to monitor and respond to icing should be reasonably high.

Takeoff accidents are responsible for almost 19% of airframe icing accidents and 11.7% of fatal accidents. The number of takeoff accidents would have been cut considerably if proper preflight inspections and deicing procedures were followed. Seven out of the ten air transport category accidents reviewed in this study were takeoff accidents. Hence, attempting takeoff with frost/ice on an airframe is not only an issue in the general aviation community, but is a concern in all segments of aviation operations.

The percentage of total and fatal accidents that took place during the approach phase of flight is also noteworthy (15.8% and 14.9%, respectively). During the approach, adjustments are made to the configuration of the airplane (increase flap setting, reduce speed, etc.). When ice is present, configuration changes can cause an airplane to stall without warning.

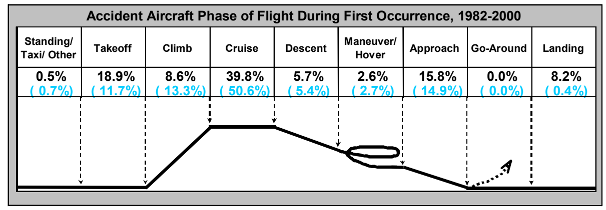

Figure 5. Percentage of accidents (black) and fatal accidents (blue) by phase of flight.

3.4 *Spatial Distribution*

Figure 6 displays the distribution of accidents by state. Alaska, with 59 accidents, had the highest number of recorded mishaps. Alaska was followed by California and Colorado, which had 38 and 36 icing accidents, respectively. Takeoff accidents accounted for 54% of the icing accidents in Alaska, but in California and Colorado, takeoff accidents comprised less than a quarter of the accidents in each state. A cluster of states near the Great Lakes (Michigan, Ohio, Indiana, and Pennsylvania) all had 20 accidents or more. Minnesota and Wisconsin were not far behind with 18.

The spatial distribution of accidents was consistent with that found by Cole and Sand (1991). They noted that a high percentage of icing accidents occurred near large bodies of water and in mountainous regions. Bernstein (2000) found that bodies of water and topographic features can play a role in the development of freezing precipitation. Orographic features act to enhance the icing environment through the lifting process, and large bodies of water provide additional moisture to an air mass, which can increase the supercooled liquid water content.

Though these data appear to show a relationship between accidents and topographic features, care should be taken when drawing this conclusion. Airframe icing accidents are also correlated with several other factors not associated with icing environments. For example, simply the number of aircraft that operate in a region will be tied to the number of accidents in the same area. The type of aviation operations will also be linked to the number of accidents. A good example of this is Alaska, where smaller, single engine aircraft, operate at lower altitudes, slower speeds, and in very remote areas. The speeds and altitudes at which these airplanes operate make them more vulnerable to icing conditions, while remote locations limit the available services a pilot may have at his or her disposal (e.g. deicing services).

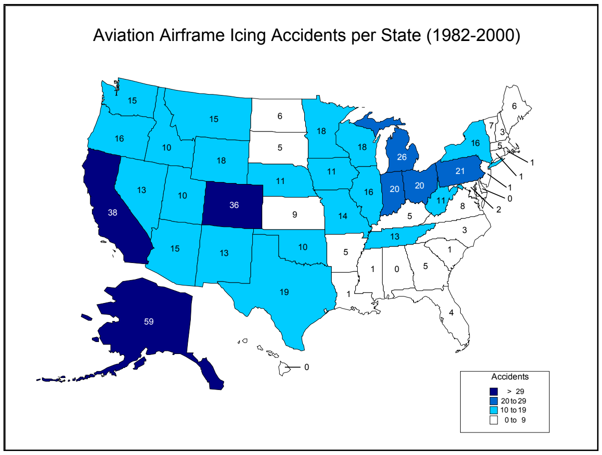

Figure 6. Distribution of airframe icing accidents per state for the period 1982-2000.

3.5 *Pilot In Command Experience*

Pilot experience is also an important factor in any aviation accident. Pilot in command (PIC) certification information for all accident pilots in this study is contained in Figure 7. Certification data indicate that there were almost an equal number of private and commercial rated accident pilots in the database. Nearly one-fifth of the pilots in command held an air transport pilot certificate. It should be noted that an instrument rating was held by 80% of accident pilots.

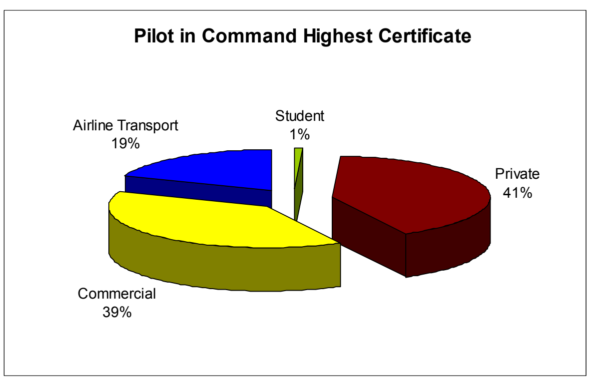

Figure 7. Highest certification for pilots in command.

Because general aviation and Part 135 accidents accounted for 98% of airframe icing accidents during the period of interest, further review of pilot experience in these categories was conducted. This was accomplished by reviewing the total number of flight hours pilots had at the time of the accident. In addition, the number of hours in the make and model of the accident airplane was also evaluated.

Figure 8 shows a histogram of total hours[2] GA PICs had at the time of the accident. As expected, the majority of total flight time counts for accident pilots are clustered towards the left side of the figure. Approximately 40% of the GA accident pilots had 1,000 or less total flight hours, and 22% of the pilots had 500 or less hours of flight time. Surprisingly, 26% of the pilots had over 3000 hours of flight time, with 31 of these pilots logging over 10,000 flight hours. This suggests that both experienced and inexperience pilots are susceptible to airframe icing hazards.

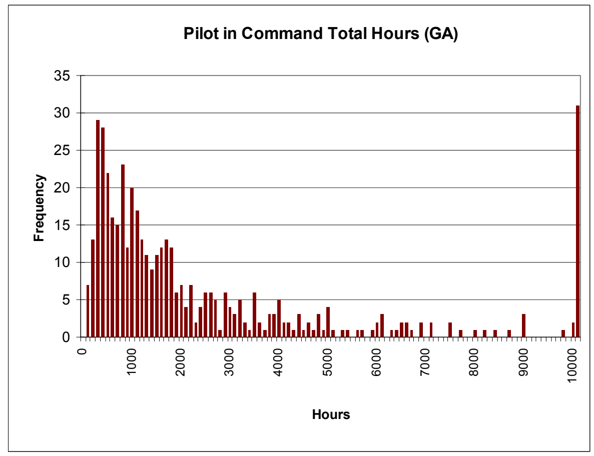

Figure 8. Histogram displaying frequency of PIC total hours at the time of accident. Each bin is 100 hours from 0 to 10,000. Last bin contains all cases with PIC flight time greater than 10,000 hours.

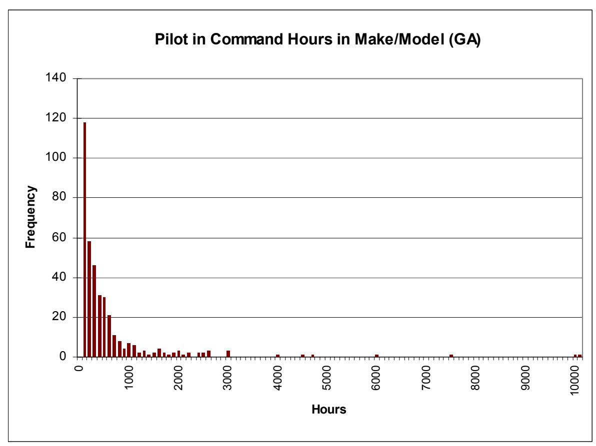

Figure 9. As in Figure 8, except for hours in make and model.

Data regarding GA PIC flight time in make and model were strongly skewed towards the left side of the diagram (Figure 9), indicating a large number of pilots did not have much flight time in the type of aircraft in which the accident occurred. Unlike total flight hours, only 7 pilots had more than 3,000 hours. There were 87.6% with 1,000 hours or less. Further, 74.3% had 500 or less flight hours in make and model.

[2] There were 459 GA cases with total flight hour data and 381 cases with pilot in command hours in make and model.

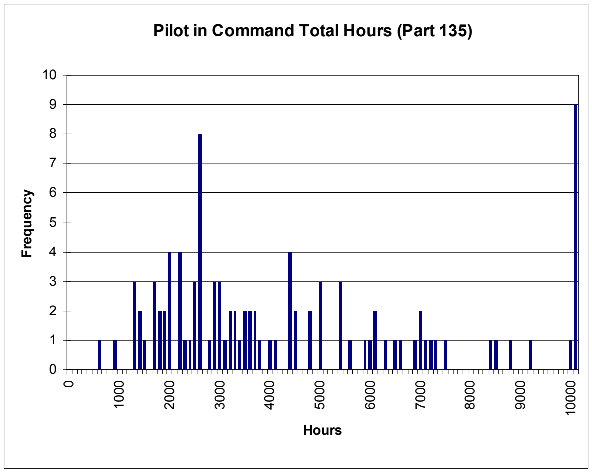

Figure 10. As in Figure 8, except for Part 135.

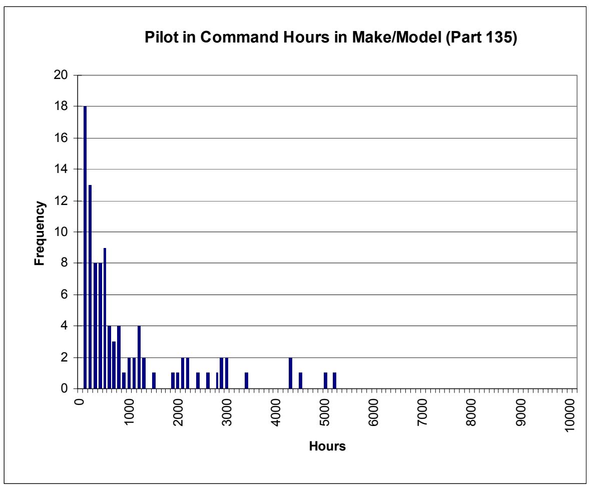

Figure 11. As in Figure 9, except for Part 135.

Histograms containing data related to the flight hours of Part 135 pilots are presented in Figures 10 and 11. Though these data showed that the total flight time of Part 135 accident pilots was generally higher than that of GA pilots, the flight time in make and model showed a very similar trend to GA operations. Over 55% of the Part 135 PICs had a total of 500 or less hours in make and model.

A lack of flight time and experience in an airplane may make a pilot more susceptible to the dangers of icing hazards. Examination of flight hours indicates that a significant number of the pilots involved in airframe icing accidents were experienced aviators in terms of total flight hours, but inexperienced in regard to the total hours they had in the make and model of the accident airplane. This may have resulted in an inadequate level of proficiency in the airplane when faced with icing conditions. It is likely that this factor was responsible for a number of icing accidents.

3.6 *Weather Briefings*

Pilots are required to obtain weather reports and forecasts if their planned flight is IFR or not in the vicinity of the departure airport. A thorough preflight briefing will provide the pilot with a complete picture of the expected weather along his or her route of travel. In the case of icing, a brief can aid in defining the freezing level, icing locations, type and severity, allowing the pilot to plan appropriately. This study found that 81% of the accident pilots received some type of weather briefing, and 82% of the weather briefings were from flight service stations.

The percentage of weather briefings received by pilots is somewhat unanticipated considering the number of icing accidents. It also raises some interesting questions. Are pilots receiving accurate and timely information? Is this information understood and used appropriately? These questions could not be answered using the NTSB database.

4. CONCLUSIONS

Airframe icing accident data for the period 1982-2000 suggests that that the number of icing related accidents is declining. The decline is mainly associated with the general aviation segment of aviation operations, which was responsible for the highest number of accidents during the period. It is conceivable that better icing analysis and forecasting techniques in recent years has played a role in reducing accidents. In addition, it is likely that pilots have become more aware of the hazards associated with airframe icing.

Icing accidents occurred throughout the year, with a peak frequency in January. A large part of accidents were located in mountainous regions and near large bodies of water. Operators should recognize that these areas may be more favorable for airframe icing.

Most accidents took place when the aircraft was in the cruise portion of flight. Takeoff accidents also accounted for a large fraction of icing related accidents. These findings suggest that flight crews need to be more vigilant about ensuring airplanes are free of ice prior to departure. Even small amounts of frost on a wing can reduce its ability to generate lift. Every effort should also be made to monitor the aircraft for signs of icing while in flight. Pilots should have an understanding of how ice accretions will impact their aircraft's performance, keeping in mind that different aircraft will perform differently in identical icing conditions. Accident statistics showed that pilots exhibited limited flight hours in the make and model of the aircraft they were operating at the time of upset. The findings also suggest that even the most experienced pilots can have difficulty operating safely in icing environments.

The fact that over three-quarters of the accident pilots received a weather brief suggests there may be some type of deficiency in terms of weather information or how the information is utilized. Without supplemental data, it is difficult to quantify whether these deficiencies actually exist and to what extent. In recent years advancements in icing research and technology has put very viable tools in the hands of both the briefer and pilots (e.g. Current Icing Potential (CIP), Forecast Icing Potential (FIP), etc.). Pilots' decision-making process regarding icing should be enhanced by the utilization of such tools; in turn, a continued drop in icing accidents should follow.

Airframe icing continues to be a serious aviation hazard, but following certain precautions and procedures can considerably reduce the probability of having an icing related mishap. Pilots should develop a comprehensive understanding of icing (type, environments, signs, etc.) and the impacts it can have on the performance of their aircraft. They should obtain current information regarding icing location, type, and severity along their route of flight just before departure, always make certain that frost/ice is removed prior to takeoff, and have an exit strategy in place in the event an unexpected icing encounter does occur.

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