A Review of Pilot Ability to Assess Inflight Icing Hazards

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Introduction

On December 22, 1988, an ATR-42 experienced a roll upset event during an approach to the Central Wisconsin airport at Mosinee, Wisconsin. Control was recovered with an altitude loss of 600 feet; however, the event yielded a clear description of the human limitations which play a strong role in the question of inflight icing detection:

> "Halfway through the procedure turn with no stall warning, the aircraft started a buffet that got progressively worse, and then the bottom dropped out. The aircraft rolled sharply in one direction, then in the opposite direction about 90 degs. All the while the captain was asking if there was ice on the airframe and I was looking and just saw the airframe appear wet and responding that way."[1]

This is by no means an isolated incident. The author experienced a similar, albeit less dramatic, event in 1987 while operating a nighttime training flight with a Fairchild Sa-227 Metro III at Charlottesville, Virginia. During the cruise phase of this flight, while passing through intermittent cloud, repeated visual inspections of the wing revealed no ice accretion. Yet three successive practice landings yielded inappropriately firm touchdowns despite well-flown approaches by the student captain. While stopped on the ground to consider this problem, the second student captain informed the author that, after twenty minutes inspection with a flashlight, she had concluded that ice was present on the wing. The pneumatic deice boots were cycled while sitting on the ground, and massive quantities of ice burst from the wing, shattering on impact with the ramp. Subsequent landings were quite normal.

A more ominous report described ice accreted aft of the protected surface on an ATR-72.

> "Aircraft was being vectored for an approach into South Bend in flight conditions that included light rain and temps near freezing. Anti-icing and deicing equipment was in use at the time. No ice was visible on the windows, wipers, or ice evidence probe mounted just outside the captain's window. Also, no ice was seen on the leading edge of the wing.

> While being vectored to intercept the localizer, a buffet was noted at 170-180 kts. Power was advanced briskly, and within 2 to 3 seconds, the buffet stopped. Closer inspection of the wing showed that a ridge of ice about 1/2 inch thick had formed on top of the wing just aft of the boot."[2]

This particular incident took place approximately 50 miles west of Roselawn, Indiana, where, earlier the same afternoon, another ATR-72 had crashed in icing conditions, with the loss of 68 lives.

Operating Philosophy

The operating philosophy with respect to inflight icing is three fold. First, the pilot must develop an opinion of the potential effect of the expected icing conditions on the safety of flight prior to dispatch, and then update that opinion throughout the flight. Second, he needs to be able to see the actual ice accretion on the airplane during flight. Third, he must continuously evaluate that ice accretion throughout the flight in order to provide input to the aforementioned opinion regarding the effect on the safety of flight.

This philosophy is codified in two rules which reside in 14 CFR Part 121. The first and third parts of the philosophy are set forth in 14 CFR 121.629(a). It states:

> (a) No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher (domestic and flag operations only), icing conditions are expected or met that might adversely affect the safety of the flight.[3]

The second part of the philosophy is more subtle. 14 CFR 121.341(b) states:

> (b) No person may operate an airplane in icing conditions at night unless 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. Any illuminating that is used must be of a type that will not cause glare or reflection that would handicap crew members in the performance of their duties.[3]

The unstated implication is that the same surfaces are visible during the daytime without illumination.

Data Review

A substantial review of airborne icing event data has been conducted. This review has used approximately 1300 events provided by the United States National Transportation Safety Board, the Federal Aviation Administration, Transport Canada, the International Organization for Civil Aviation, the Flight Safety Foundation, and the EURICE consortium (Figure 1). This data has been reviewed for a variety of purposes. However, after the application of a number of filters, the data has presently yielded approximately 234 events, both accidents and incidents, which are solely aerodynamic events involving multi-engine aircraft (Figure 2).

Of these 234 events, 15 provided clear evidence that the flight crew was not aware of the ice accretion. In an additional 97 events, there is not adequate information to determine whether the flight crew was aware of the ice accretion or not. But in the final 122 events, information is available to determine that the pilot was indeed aware of the ice accretion (Figure 3).

The 15 events indicate that there is a breakdown somewhere in the mechanism by which pilots become aware of ice accretion on their airplane. Because of the sizable number of cases for which adequate information on pilot awareness does not exist, it is not useful to consider this in a statistical manner. However, it is reasonable to assume that some percentage of the 97 unknown events would also fall into the category of flight crews not aware of ice accretion.

The 122 events indicate that in a very sizable number of cases, the flight crew is not correctly evaluating the potential effects of the ice accretion in a manner timely enough to prevent the event from taking place. One explanation is that the flight crew did not operate the ice protection system (IPS). In 16 cases of these 122, the IPS was not operated. In a further 58 cases, adequate information was not available to determine whether or not the IPS had been operated (Figure 4).

A typical reason that the flight crew might not operate the IPS has to do with the Airplane Flight Manual (AFM) procedure for that system.

On August 11, 1991, a British Aerospace ATP turboprop transport was climbing after departure from East Midlands Airport en route to Jersey. The aircraft experienced a roll upset event, due to ice accretion, in which aileron control was temporarily compromised and the airplane pitched down approximately 15 degrees and attained a maximum bank angle of 68 degrees.

The company operations manual in this case stated that

> "When approximately 1/2 inch of ice has accumulated the airframe deicing system is selected **ON** at the required level."[4]

The official accident report stated that

> "On this flight neither the commander nor the first officer saw more than 3/8 inch of ice buildup on the wipers or more than what appeared to be a small strip of rime ice on the leading edge of the wing..."[4]

The accident report further concluded that

> "The type of ice formation made it impossible for the crew to assess accurately the thickness of ice accretion on the wing and thus make a timely decision to operate the de-icing boots."[4]

Similar events have taken place in at least four Embraer EMB-120 roll upset events, and may have played a significant role in the initiation of the roll upset leading to the crash of Comair 3272 at Monroe, Michigan in January of 1997[5]. In November of 1998, the crew of a Saab 340 entering a holding pattern at the Eildon Weir VOR in Australia experienced a roll upset. At the time, they reported "that the only ice visible to them on the aircraft was a light accretion on the leading edge of the wings and a small build-up of ice on the windscreen-wiper arms.". Thus, they had not operated the ice protection system. During the holding pattern entry turn, the airspeed decayed rapidly. In this upset, the bank angle attained was 126 degrees, the pitch angle was 36 degrees nose down and 2,300 feet of altitude was lost before control was regained.[6]

Beyond these cases, the data reviewed indicated that in 48 of the 122 events cited above, the flight crew was aware of ice accretion and had operated the IPS. While some number of these may result from an inadequate operation of the IPS (there is almost never enough information to determine this), there are clearly a large number of cases in which procedural issues do not explain the flight crew's inadequate evaluation of the ice accretion effects. Although not all of the 122 events fall under 14 CFR 121, and thus the language of 121.629(a), many do. Further, the concept expressed in that rule is employed throughout aviation.

In the paper "The Question of Experience in Icing Conditions" presented at the 2000 Corporate Aviation Safety Seminar, the author detailed the abundance of misleading and incorrect definitions and information regarding inflight icing commonly found in pilot training literature.[7] Perhaps no issue better highlights this point than the question of ice bridging. Long held as fact, it has recently become clear that ice bridging is probably nearly non-existent, with certain limited exceptions. The paper also made the point that the average flight experience for the crews involved in recent major icing events was approximately 5500 hours. Yet the concept that experienced pilots can avoid icing mishaps is strongly held. Where does this concept originate?

It is worth considering the origins of the two operating rules and the language they employ. Neither are new rules.

Operating Philosophy History

Civil Aeronautics Regulation 61.7112, effective in November 1937, stated that:

> "No scheduled airline flight shall be dispatched, or permitted to continue in flight, when there is a known probability of its encountering any hazardous conditions in making or continuing the flight."[8]

By May of 1938, the rule had been amended to state:

> "No scheduled airline flight shall be dispatched when, in the opinion of the either the first pilot or the dispatcher, such flight cannot be completed with safety. No scheduled airline flight shall be continued toward any point cleared to when, in the opinion of either the first pilot or dispatcher, such continuation cannot be completed with safety unless, in the opinion of either, there is no safer method of procedure. In the latter event continuation shall constitute and emergency situation..."[9]

The 1938 version of CAR 61 also saw the introduction of specific guidance regarding operation in icing conditions. CAR 61.7701 that year stated:

> "When an aircraft, equipped with wing and propeller deicing equipment, is engaged in scheduled airline operation and encounters an icing condition, the pilot shall so alter the course or altitude of the flight as to withdraw from such condition, if, in his opinion, it appears that the icing condition may be of such duration or severity as to otherwise endanger the safety of the flight. The pilot shall, if possible, immediately notify his company radio ground station."[9]

The question must be asked, how did these rules intend for the pilot in command to determine whether the ice accretion might endanger the safety of the flight? The general notion at the time was that there could be no substitute for experience and good judgment. But there was little substance behind these words. In the report on the investigation of an accident involving United 21 at Chicago on December 4, 1940, the Civil Aeronautics Board stated that "[while]pilots are not in agreement as to the degree of effect of ice upon the performance of the aircraft, they all agree that ice does raise the stalling speed."[10] The Board conducted extensive interviews with line pilots and also took note of several research flights conducted by United following the accident. They concluded that:

> "Although pilots do not agree as the effect of ice on the DC-3, it may be concluded that ice does raise the stalling speed to some unpredictable extent and that the effect cannot be stated in terms of the amount of ice alone, but is dependent upon both the amount of accumulation and its location on the wing."[10]

The crash from a very low altitude during an approach was described as "an exaggerated stall" and took place in what were obviously freezing drizzle conditions with significant ice accumulations being reported. Interestingly, the Board specifically concluded that neither the pilot nor the dispatcher could be faulted for continuing the flight into these conditions.[10]

The 1941 version of CAR 61 deleted 61.7701. Thereafter, until 1953, the language of 61.7112, covering flight hazards, remained in force and would have been interpreted as covering icing conditions.[11]

The report of the investigation of the October 30, 1941 accident at Moorhead, North Dakota involving Northwest flight 5, another DC-3, yields perhaps the most compelling description of the paradox facing pilots at the time. During the descent for approach into Fargo, North Dakota, the pilot reported that shortly before leveling at 1500 feet MSL, "'we did start to pick up quite a lot more ice'"[12] The accident report then stated that, "However, having on previous flights experienced what he considered heavier ice accumulation, he still was not unduly concerned."[12]

Immediately following this observation, when leveling the airplane at 1500 feet, the captain reported that

> "'the airplane started to act peculiarly and I knew something was the matter I yelled, 'Gear up', to the cc-pilot, the idea being to keep all the speed I could possibly get, and I increased to full horsepower to fly straight ahead at 1500 feet until I could find out what was the matter ...the airplane started to flutter or shake, and the controls worked hard I had difficulty turning the wheel and the Yoke worked hard fore and aft..."[12]

Despite one-half to two and one-half inches of ice found on the outboard right wing after the accident (although the boots were operated), the Board did not recognize ice accretion as a principal cause. Instead they focused on a power-on stall characteristic of the DC-3 not previously recognized. Perhaps this was appropriate; however the Board's ambivalent dismissal of ice accretion paints in interesting picture of the contemporary understanding behind the rules.

> "A careful consideration of the evidence has satisfied us that the partial loss of control was not caused solely by the ice which had been accumulated on the airplane. A collection of ice upon airplane surfaces is not an uncommon experience and, while it is to be avoided to the fullest extent possible by the exercise of great caution, in the nature of things it cannot be eliminated entirely. Although the amount of ice which had been accumulated on the airplane was substantial, experience has demonstrated that aircraft may safely be flown with a far greater-accumulation of ice than that which obtained in this case. The testimony in the record of this accident, as well as general knowledge previously acquired, convincingly shows that the accident was not caused solely by ice. It is equally clear, however, that the amount of ice which had been gathered by the airplane was sufficient to affect materially the flight characteristics of the plane. The effect of such ice is to reduce air speed and increase the stalling speed."[12]

It is worth noting that the Board's report does not appear to have considered the captain's report of difficulty turning the wheel and the yoke "working hard" fore and aft. They also did not appear to consider that the buffeting prior to the accident began before full power was applied, whereas it appeared to have initiated during the flight tests after full power was applied.

The operating philosophies in use at this time must also be considered with respect to the official view of what defined a competent pilot. The 1939 edition of Civil Aeronautics Bulletin No. 5, "Flight Instructor's Manual", contains some interesting insight. The Manual defines judgment as

> "the ability to size up a situation quickly and accurately and deduce the correct procedure to be followed under the circumstances...to analyze accurately the probable result of a given set of circumstances or a proposed procedure; the exercise of due care and regard for safety; the ability to accurately gauge the performance of an aircraft; the ability to recognize personal limitations and limitations of the aircraft and avoid approaching the critical points of each...judgment should be perfected by experience."[13]

This is the view during the same period when pilots cannot agree as to the effect of icing on a DC-3. As if to officially punctuate the overall requirements on pilots, the Flight Instructor's Manual in Chapter X states, among other axioms for the pilot, that "the capable and competent pilot will never allow an airplane to crack up". [13]

These observations describe the context within which the present day operating rule language was crafted. In 1953, the CAA decided to merge CAR Parts 40 and 61. Whereas Part 40 had covered only the certification of scheduled airlines, the new Part 40 would cover both the certification of scheduled airlines and the operation of aircraft in scheduled airline service. In October 1953, the new Part 40 was issued. As had been the case in 1938, the new rules presented the icing case as a stand alone rule, separate from other flight hazards. CAR 40.391 addressed flight hazards:

> "(a) No aircraft shall be continued in flight toward any airport to which it has been dispatched when, in the opinion of the pilot in command or the aircraft dispatcher, the flight cannot be completed with safety, unless there is no safer procedure. In the latter event, continuation shall constitute an emergency situation as set forth in 40.360."[14]

CAR 40.392 addressed icing:

> "(a) An airplane shall not be dispatched, en route operations continued, or landing made when, in the opinion of the pilot in command or aircraft dispatcher, icing conditions are expected or encountered which might adversely affect the safety of flight."[14]

For all practical purposes, both of these rules passed without significant alteration into FAR Part 121 when it was introduced to replace CAR Part 40 in 1964. Today they reside in Part 121 as 121.627 and 121.629.

The 1953 change to CAR Part 40 also introduced the requirement for an ice light. CAR 40.207 was worded nearly exactly as FAR 121.341 is today. The discussion of this rule presented at the time indicated that it would not present much burden to industry since most affected airplanes already were so equipped.

Interestingly, CAR Part 4b, the rules covering the certification of transport airplanes at that time, did not contain a requirement comparable to CAR 40.207(b). When CAR Part 4b became FAR Part 25 in 1964, no such requirement was added. It was not until 1977 that FAR 25.1403 was added, requiring exactly the same means as that required under 121.341(b).

As late as the 1991 AAIB report on the incident at Cowly, concern was raised regarding the focus of the wing ice inspection light. It was determined that wing flexing during flight may cause the light beam to miss the wing. Nonetheless, this report finally raises the question of what the pilot can actually see on a wing over 30 feet from the cockpit.[4]

The rule calls for a means for "illuminating...the formation of ice on the parts of the wings that are critical from the standpoint of ice accumulation.". Yet in the FAA's Inflight Aircraft Icing Plan, the plan details of Task 12A state that "Criticality of possible ice accretions is not well understood..."[15] The Plan goes on to state that "the Working Group will evaluate numerous ice shapes to help define areas of concern about the effect of ice accretion on airfoil performance and aircraft stability, control and handling characteristics."[15] The plan details of Task 12C call for "using simulated ice accretions to determine the sensitivity of ice shape and location on airfoil performance and control surface hinge moment as a function of angle of attack..."[15] One wonders, in the apparent absence of this information, where the required ice light was supposed to be pointed.

One also wonders, based on the statement that the criticality of possible ice accretions is not well understood, on what basis the captain of Northwest flight 5 was "not unduly concerned". It was only a few months earlier that the CAB had released their report on the

United 21 accident, concluding that ice would raise the stalling speed of the DC-3 by some "unpredictable" amount. What type of analysis was the captain of Northwest 5 using to determine, in the regulatory language of the day, whether "the icing condition may be of such duration or severity as to otherwise endanger the safety of the flight. "?

Perhaps he used a similar basis as the other 48 crews in the data who experienced either an accident or an incident although they were aware of the ice accretion and had operated the IPS. Perhaps the answer lies with the incorrect interpretation of past experience, and the consequent reinforcement of a mistaken belief in an ability to evaluate an ice accretion and predict its effect on the safety of flight. The single most confounding aspect of inflight icing is its ability to mask a vicious nonlinearity just above a fairly benign linearity. This while the specific characteristics of the nonlinearity are defined by parameters which are essentially impossible to evaluate from the cockpit with only visual information.

In the 1944 edition of the U.S. Army Pilot Information File, the following pilot report appears:

> "On a trip from Newark to Chicago last winter we encountered a light icing condition near Chicago. We examined the leading edges with a flashlight and the amount of ice appeared negligible. Upon landing at Chicago, however, the plane stalled at about 90 mph. Fortunately, we came over the edge of the field with plenty of speed. Upon examination on the ground we found very little ice on the wing, but quite a bit on the stabilizer extending back on top..."[16]

In February 2001, the following pilot report was received:

> "There was a SIGMET for severe icing in the MSP area that morning... As a precaution, we briefed for an ice encumbered approach, bumped the speeds, and hand flew. Approach allowed us to stay at 9000 feet at our discretion and cleared us for the approach. We stayed above the clouds until it was necessary to descend outside the marker. I was in the icing conditions for about 5 minutes. During the approach, we ran the deicing equipment, and it appeared to be handling it normally. The accumulation was clear ice, and appeared to be nothing more than moderate, based on the usual visual cues visible to the crew. Due to the clearness of the ice, I could not ascertain whether the ice had accumulated past the black ring on the spinner, which is a good indicator of the intensity of the ice. Based upon what I observed, I also felt the ice was nothing more than light to moderate. Upon landing, I conducted a post flight inspection. I was shocked to find Ice all the way back on the spinner. There was also bumpy clear ice on the entire

upper surface of the wing, and half way back on the underside of the wing. The elevator had the same level of contamination. ... I examined the rest of the aircraft. There was bumpy clear ice on the skin of the aircraft, from the nose extending uniformly back to a point under the side windows of the cockpit. I them looked at several other aircraft on the ramp that had just landed. They all exhibited the same contamination, if not worse. The visual cues available from the cockpit gave me no reason to believe that the flight was in severe ice, and that it could become a dangerous situation if it continued. I only was able to determine severe icing had occurred after shutdown. "[17]

Conclusion

In many respects, pilots today are no better off than they were in 1940. The regulatory requirements have not evolved. In 1940 the regulatory requirement was to evaluate the icing condition to determine if it "may be of such duration or severity as to otherwise endanger the safety of the flight", while the official state of knowledge at the time was "that ice does raise the stalling speed to some unpredictable extent and that the effect cannot be stated in terms of the amount of ice alone, but is dependent upon both the amount of accumulation and its location on the wing."

Today, the regulatory requirement is to evaluate the icing conditions to determine if they "might adversely affect the safety of flight" The state of knowledge today was identified in the NTSB accident report on Comair 3272 in January, 1997. This report stated that "pilots may observe what they perceive to be an insignificant amount of ice on the airplane's surface and be unaware that they may still be at risk because of reduced stall margins resulting from icing-related degraded airplane performance."[5] The report also noted that "wind tunnel test results indicated that considerable...aerodynamic degradation could occur before a pilot perceived ice accumulation on the airplane."[5]

It is apparent that for over 60 years, there has been an expectation of pilot judgment that was never actually attainable. Yet the success of operations in icing has led to a belief that the requisite pilot judgment was routinely developed with experience, and that occasional failures in this judgment were explainable by incompetence or negligence. The problem cannot be addressed until design, certification, operations and maintenence segments develop complete understandings of each other's capabilities and limitations, and no longer rely solely on "capable and competent" pilots who never allow airplanes to "crack up".

Data Origin	Number of Events	Data Start Date	Data End Date
Transport Canada	25	May-79	Dec-97
NTSB	60	Jan-83	Dec-96
Eurice	95	Feb-70	Mar-97
ICAO	19	Feb-75	Jan-97
Flight Safety Foundation	35	Nov-47	Feb-87

Figure 1 - Accident/Incident Data Origins

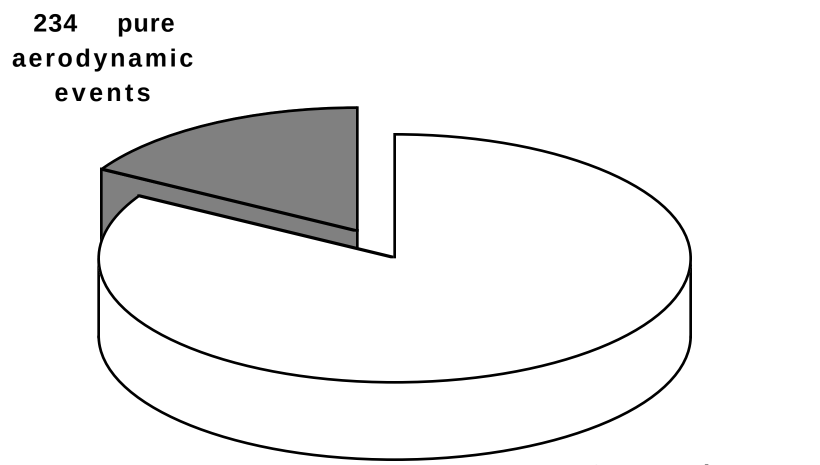

Figure 2 - Data Breakout by Cause

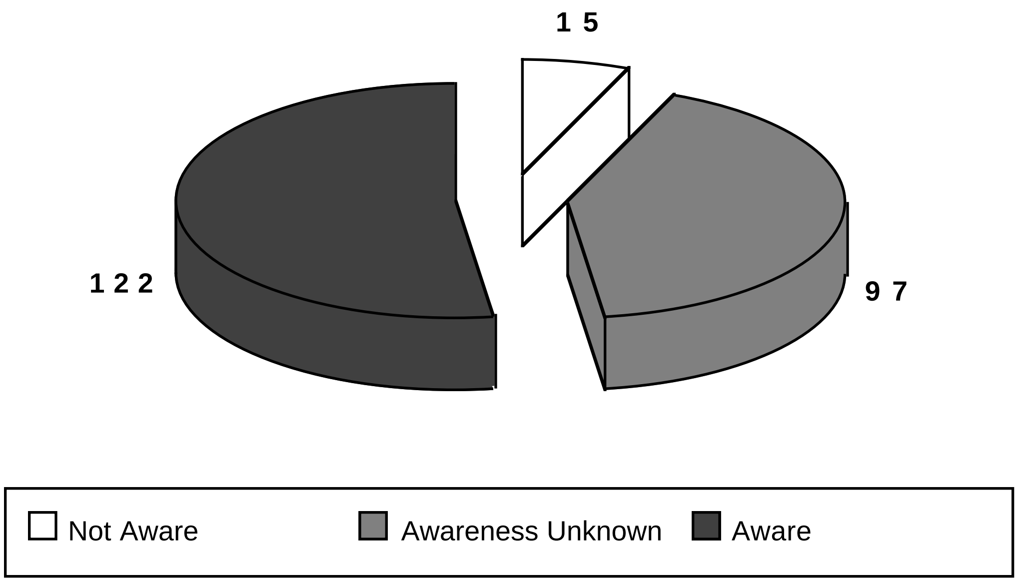

Figure 3 - Data Breakdown by Crew Awareness of Ice Accretion (234 events)

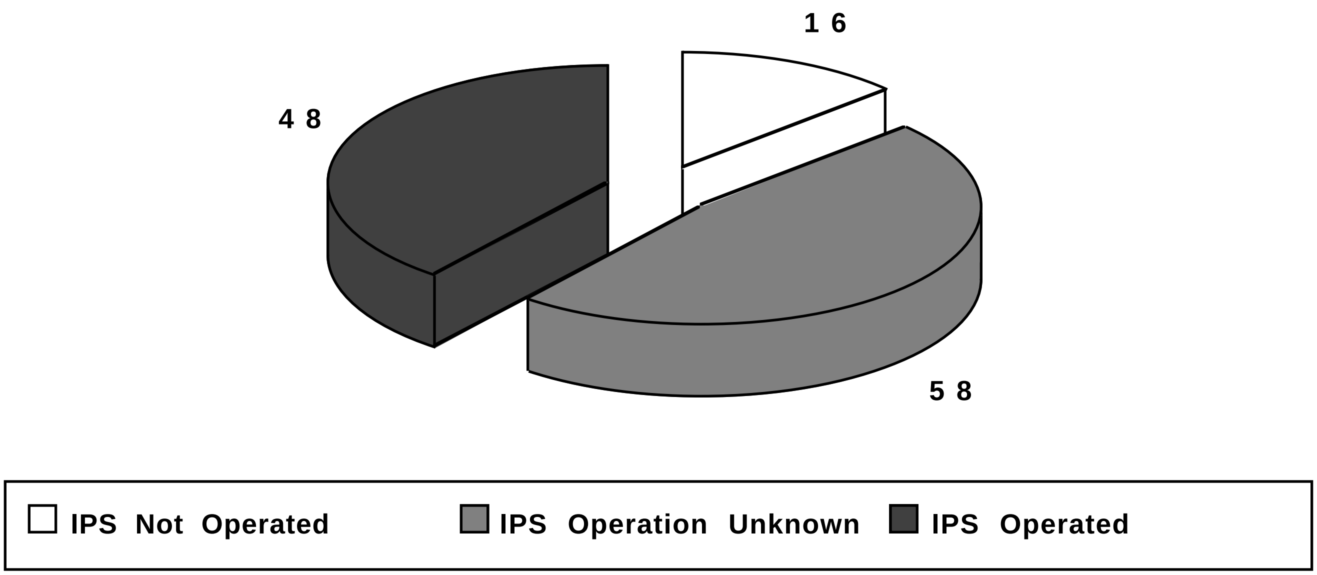

Figure 4 - Data Breakdown by Operation of Ice Protection System (122 Events)

References

1. National Aeronautics and Space Administration, *Aviation Safety Reporting System, Accession Number 100792.*

2. National Aeronautics and Space Administration, *Aviation Safety Reporting System, Accession Number 287615.*

3. United States Code of Federal Regulations, Title 14, Part 121.

4. U.K. Air Accidents Investigation Branch, *Report on the Incident to British Aerospace, ATP, G-BMYK, 10 miles north of Cowly, near Oxford, on 11 August 1991*, Aircraft Accident Report 4/92, 1992.

5. National Transportation Safety Board, *In-flight Icing Encounter and Loss of Control, Comair flight 3272, EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997*, NTSB AAR-98-04, November 1998.

6. Australian Bureau of Air Safety Investigation, *Incident at Eildon Weir, Victoria, 11 November 1998,* Interim Factual Report 199805068.

7. Green, S.D., *The Question of Experience in Icing Operations,* Proceedings, 45th Corporate Aviation Safety Seminar, San Antonio, Texas, April 25-27, 2000.

8. Bureau of Air Commerce, *Civil Aeronautics Regulations, Part 61*, November 1937.

9. Bureau of Air Commerce, *Civil Aeronautics Regulations, Part 61*, May 1938.

10. Civil Aeronautics Board, Docket No. (unknown), *Report of the investigation of an accident involving civil aircraft of the United States NC 25678 which occurred near Chicago, Illinois, on December 4, 1940*.

11. Civil Aeronautics Board, *Civil Aeronautics Regulations, Part 61,* January 1941.

12. Civil Aeronautics Board, Docket No. SA-53, *Report of the investigation of an accident involving civil aircraft of the United States NC 21712 which occurred near Moorhead, Minnesota, on October 30, 1941*, Adopted 1/30/42.

13. Civil Aeronautics Authority, *Civil Aeronautics Bulletin No. 5, Flight Instructor's Manual,* June 1939.

14. Civil Aeronautics Board, *Civil Aeronautics Regulations, Part 40,* October, 1953.

15. Federal Aviation Administration, *Inflight Aircraft Icing Plan*, April 1997.

16. United States Army Air Corps, *Pilot's Information File,* February, 1944.

17. Private Correspondence, February, 2001.