44th AIAA Aerospace Sciences Meeting and Exhibit
9 - 12 January 2006, Reno, Nevada

AIAA 2006-82

A Study of U. S. Inflight Icing Accidents and Incidents, 1978 to 2002

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Abstract

334,190 event synopses and reports were screened to yield 9299 relevant reports. These reports were read and disposed into applicability categories. This led to a database of 645 accidents and incidents, and a separate database of 299 NASA Aviation Safety Reporting System reports. The data was analyzed extensively. The principal conclusion was that factors such as pilot training, pilot experience, icing equipage and icing certification are not as significant to icing events as is aircraft scale. Event sequences were modeled; the stall followed by loss of control is the most common occurrence, followed by hard landings. Ice protection systems on smaller aircraft may delay an event but not prevent it. Larger aircraft are more likely to encounter an icing event on final approach or during the landing. Freezing precipitation is present in 33% of the total events in the data. Snow is present in 32% of the events; these conditions are not mutually exclusive, as 7% of the events include both. Surface weather observations including temperatures of near freezing and ceiling of one thousand feet or less are generally associated with icing events.

I. Introduction

Since the 1994 accident at Roselawn, Indiana, considerable effort has been dedicated to developing interventions aimed at preventing inflight icing accidents. During that period a number of limited accident datasets have been studied, with a view toward identifying the characteristics of particular types of icing events. In order to understand the phenomena in a comprehensive manner, a detailed study was developed of all United States icing events recorded in the public databases of the National Transportation Safety Board and the Federal Aviation Administration. An extensive set of attributes was extracted from the factual and analytical information available in each report. These attributes were analyzed for patterns, trends and characteristics. The analyses were then used to consider questions of meteorology, certification, operating rules, pilot experience and aircraft scale. Event sequence models were developed, and possible interventions were considered.

II. Data Collection Methodology

Three public databases were used for this research. The primary database was the NTSB Accident Database and Synopses[1]. Additional databases were the FAA Accidents/Incidents Data System[2] (AIDS), and the NASA Aviation Safety Reporting System[3].

At the time of the study, the NTSB data was available in synopses text format or through the use of Microsoft Access files. Since Access software was not available, the author elected to access the synopses text formatted data. However, use of the website's search capability was time consuming and required subsequently identified synopses to be downloaded individually. The author then elected to download the complete database in synopses text format and then search the text locally. The resultant download captured 141,180 reports, with a date range from January 1, 1964 to December 31, 2002.

Using the file index and search capability of Apple OS 10.1, a search string was developed to capture the records of icing events. This string, in its first form, was:

"ice | icing | snow | snowing | freezing | rime | glaze | sleet | frost | de-ice | de-icing | de-iced | de-icer | deice | deicing | deiced | deicer | anti-ice | anti-icing | anti-icer".

This yielded 11,174 reports. Such a large number, considering the time available for the work, immediately led to a decision to shorten the data review period. Thus, events prior to January 1, 1978, were captured but not reviewed. This new start date corresponded to the start of FAA AIDS data, and also corresponded to the earliest NTSB full dockets that were available. The search from 1978 forward yielded 5604 reports.

A further review of the search string resulted in some refinements. The "snow" term tended to yield more "snowbanks" and "snow-covered runways" than anything else, so it was removed. The "ice" term alone resulted in numerous references to "service" and "officer". It was found that an actual icing event would nearly always contain the word "icing" as well as "ice", so the "ice" term was dropped. It was also determined that only one "icing" term was necessary, so other compounds of this word were dropped. The new string was thus:

"icing | freezing | rime | glaze | sleet | frost"

Following this refinement, reports containing the word "carburetor" were separated for later review. Most of these referred simply to carburetor icing; a few were later found to be aerodynamically significant and were added to the data. The end result of this process was 2212 reports to study.

The reports were then read and categorized. This yielded 693 events that were considered aerodynamically significant.

The FAA AIDS and NASA ASRS data were obtained through on-line key word searches from the National Aviation Safety Data Analysis Center (NASDAC). The AIDS data was searched with the string:

"ice OR icing OR freez% OR rime OR glaze OR sleet OR frost "

This yielded 1662 events. The "ice" term was retained since the number of events was sufficiently low to allow a reasonable disposition through reading the reports (this retention and disposition led to the conclusion to drop the "ice" term described above).

The ASRS data used the string:

"icing OR freez% OR rime OR glaze OR sleet OR frost"

This resulted in 2033 events. The disposition of ASRS data will be explained later in the paper.

III. Development of the Database

A master database was constructed and populated with data from the events which, following more careful study, were determined to be relevant. The principal criteria for inclusion were the presence of a purely aerodynamic event that took place at some point after the completion of the takeoff phase. Thus, no takeoff events were included. Events involving powerplant icing were also not included. The relatively minor datasets involving pitot icing and windshield icing were evaluated for accompanying aerodynamic events, but were generally not included if no aerodynamic event was found. An exception to this was in the case of hard landings. In many reports, a hard landing was reported following windshield icing. Often, the investigator concluded that the hard landing was a result of flaring too high (or low) due to restricted forward visibility. While this is certainly a possibility, it was interesting to note that in nearly all of these cases, no discussion was presented regarding the icing of aerodynamic surfaces. It seemed reasonable to at least presume that the ice on the windshield was also present on the airframe, and that aerodynamic icing may have played a role in many of these cases. Therefore, these cases were broken down into two sets. In one, the hard landing was either made off the side of the runway or was followed by a loss of directional control on the runway. These cases were discarded, as there was supporting evidence that windshield icing was truly the primary cause. In the second set, the hard landing was followed by adequate tracking on the runway and in some cases by taxiing clear of the runway. Because of their remarkable similarity to other hard landing cases that did not involve windshield icing, these latter cases were presumed to have been more likely a result aerodynamic icing. The latter set was included in the database, and the presence of windshield icing was recorded.

Those events, which were identified as candidates for inclusion based on the initial reading of the synopses, were then researched more thoroughly. This resulted in a further paring down of the retained events. The database, in its final form, contained 645 records characterized by 97 data fields. Of these records, 504 were from NTSB data, and 141 from AIDS data. ASRS data is often subjective and poorly defined with respect to the large number of data fields incorporated. Therefore, it was analyzed separately. In several cases, however, ASRS data led to the discovery of additional NTSB reports that had not been captured by the search strings. In all cases possible, an ASRS cross-reference was added to existing NTSB or AIDS data in the database.

The quality of this data ranges widely due to changes in reporting formats, diverse degrees of investigative detail, and varying scope of recoverable data from the actual accident artifacts. Quantitative analysis was possible in certain data fields; however, with respect to the nature and characteristics of the event sequences, it was necessary to add a carefully considered set of inferences to develop models of the accident morphology. This was rather like reconstructing a number of clay pots from the shards recovered at an archaeological dig. To obtain a sketch of the complete pot, certain gaps must be inferred. An example of such inferences is the addition of a "loss of control" element to a sequence that had concluded with an "uncontrolled descent". A more significant inference, which was used extensively, was the addition of a "stall" to the event sequence when a "loss of control" had been identified. The premise used in this case was that a loss of control, if in fact due to ice accretion, only occurs when some degree of flow separation takes place. A report, which suggested icing as a cause of an uncontrolled descent, would thus be described in the database as a stall, leading to a loss of control, and concluding with an uncontrolled descent. Analysis of this portion of the data was therefore more qualitative.

IV. Weather Analysis

Weather data was collected from the METAR or equivalent data provided by the reports, and was augmented by statements in the reports from qualified witnesses such as law enforcement officers or other pilots. The surface observations are only useful to describe those conditions close to the ground. However, in most cases, the actual altitude at which the critical ice accretion took place could not be determined. Rather than attempting to discard some of the data on this basis, it was all included, and the patterns extracted must be recognized as subject to this limitation.

Perhaps the most striking result of this analysis is the significant role played by freezing precipitation. Figure 1 illustrates the distribution of precipitation types across the data. Freezing rain was reported in 115 (21%) of 559 cases that reported precipitation data (including no precipitation); freezing drizzle was involved in 65 (12%) events; and snow was reported in 176 (32%) cases. These precipitations types are not mutually exclusive, since snow mixes with freezing rain or drizzle in 40 cases.

However, when the data is normalized with data from Bernstein* for the relative frequencies of the precipitation types in the continental United States, the enormous impact of freezing precipitation on aircraft icing events becomes clear. Snow is reported in 32% of the icing events which reported precipitation data in this study and accounts for 32% of all precipitation observed at the surface. Freezing precipitation is reported in 33% of the events in this study, but accounts for only 1.8% of all reported precipitation. Figure 2 shows the comparison.

Latitude and longitude data was added to the database so that a geographic distribution of the study events could be plotted. Figure 3 and 4 show the distribution of the events within the 48 conterminous states based on the range of surface precipitation types, with Fig. 4 showing only events that involved freezing precipitation. Within Alaska, 33 events took place which are not shown; of these, 23 involved either freezing rain or freezing drizzle. Caution must be used with these plots, since they have not been normalized for fleet concentrations. However, two observations are offered:

- The concentration of events around Chicago, the Pennsylvania/Ohio/West Virginia borders and the New Jersey-Connecticut axis are not intuitively consistent with fleet populations in those areas.
- There is a noticeable difference in the event distribution to the west of the Appalachian Mountains as compared to the east of those mountains.
- Freezing precipitation events more or less conform to the Great Plains, with some extension into the northeast. This pattern is consistent with previous studies of freezing precipitation reviewed by Cortinas, et.al.[4]

The absence of events involving freezing precipitation east of the Appalachians is peculiar. In 2002, nearly 13% of the general aviation and air taxi fleet is registered in this area[5]. Bernstein reported 43 hours of annual freezing precipitation in Greensboro, North Carolina, 27 hours in Pittsburgh and 30 hours in Green Bay, Wisconsin[6]. The area east of the Appalachians would seem to experience ample freezing precipitation, yet almost no events in this region report this type of precipitation.

An effort was made to develop a model of the typical surface observation parameters associated with icing events. Figures 5 through 8 illustrate the distributions of surface temperature, temperature/dew point spread,

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* Bernstein, Ben C., Private Communication, May 2004.

visibility and cloud ceiling, as they are associated with different types of precipitation[†]. A nominal model can be characterized using the interquartile mean (IQM) and interquartile range of the data. Table 1 describes this model.

Table 1. Interquartile Model of Typical Icing Surface Observation

Statistical Measure	Ceiling	Visibility	Surface Temperature	Temp-Dew Point Spread
IQM	1000 feet	3.9 statute miles	0˚C	1.75˚C
1st Quartile	500 feet	2 statute mile	-2˚C	1˚C
3rd Quartile	2200 feet	7 statute miles	2˚C	3.25˚C

This model is significant to all pilots, but particularly to the community of pilots operating aircraft not certificated for flight in icing. A typical Instrument Landing System (ILS) approach will have a visibility minimum of ½ mile. A conservative, instrument rated general aviation pilot might limit him/herself to a visibility of one mile. A reported visibility of 2 to 5 miles would not appear to be problematic, and in fact would be just the type of conditions for which the instrument rating was obtained. Further, the combination of marginal Visual Flight Rules (VFR) visibilities and cloud ceilings in the model also invites non-instrument-rated pilots to attempt operations when pressed. The same conditions are barely noticeable to an experienced instrument rated pilot operating an icing certificated aircraft.

Thus, a great number of pilots operating vulnerable aircraft are likely to see nothing intimidating in these conditions.

V. Aircraft Analysis

Data had been collected on a wide variety of aircraft characteristics, features and configurations. Reference was made to the Type Certificate Data Sheets and to the FAA's Aircraft Registry to develop data not provided by the accident or incident report. This enabled a robust basis from which to consider several characteristics. First, however, the actual event sequences were documented and examined.

A. Event Sequences

A set of sequence models was developed based on analysis of the individual event sequences. These sequences themselves were carefully built up from the reported occurrences first, augmented with inferred occurrences in the following manner:

- Loss of control. This occurrence was added only in cases that cited an uncontrolled descent as the final flight phase. In order to enter an uncontrolled descent, control must be lost; often this was cited in the report. If it was not, loss of control was added under these circumstances.

- Stall. This occurrence was added to events in which a loss of control was cited (or added as explained above) and no preceding aerodynamic event was found. It was reasoned that, if the loss of control resulted from ice accretion, then some type of flow separation must have occurred. There are no other mechanisms by which ice accretion, of itself, may lead to a loss of control. The stall occurrence added under these circumstances was identified separately in the database.

- Decision to Land. In cases where a precautionary landing was either made or planned, as a direct result of ice accretion (and not, for example, because of engine failure), then an occurrence "decision to land" was placed in the sequence. This represents a threshold point in the event sequence for the pilot; it indicates some type of assessment on the pilot's part of the icing conditions and the effect they are having on the airplane.

- Loss of Performance. This is added to indicate that insufficient performance was retained to avoid to an inflight collision with either terrain/water or obstacles, but no indication was present of either a stall of loss of control.

[†] The temperature is plotted in degrees Fahrenheit due to the difficulty with getting Microsoft Excel to produce a box-and-whiskers plot involving negative numbers.

- High Sink Rate. This occurrence was added to cases that terminated with a hard landing within the intended touchdown zone, if no other aerodynamic event was found. Absent a clearly defined stall, for example, the hard landing had to be preceded by a high sink rate.

Once these sequences had been filled in, the data was reconsidered in a manner designed to remove uniformity in time. It is not possible to construct realistic timelines for the sequences; however, it is also unrealistic to consider them as simple sequences of "1,2,3,4,5..." To avoid this problem, the sequences were considered to have an initial boundary, usually the first encounter with icing, and a terminating boundary, nearly always the collision with the ground. The predominant flight phase for the initial encounter with icing conditions is cruise. The principal outcome of these events, in 51% of the cases, is inflight collision with the ground/water. The next most likely outcome is a hard landing, which terminates 23% of the events. Interestingly, 10% of the events are terminated with a precautionary landing. This last must be viewed with caution. In order to be included in the data, the event must have risen to at least the level of a reportable incident; it is not possible to know how many other events terminated with a precautionary landing but were never reported. This data is illustrated in Fig. 9.

The middle occurrences were divided into "pilot action" occurrences and "aerodynamics, stability and/or control" (ASC) occurrences. Pilot actions are essentially two: operation of the ice protection system (IPS) and/or making the decision to land. The study defined six types of ASC events, described as follows:

- Degradation of performance. This term is used in all cases that report in inability to maintain airspeed and/or altitude. Often, this occurrence alone is enough to lead to a decision to land and a subsequent successful precautionary landing. In other cases, this is the beginning of an accident.

- Loss of Performance. This occurrence applies in cases in which, although the aircraft has not stalled, there is insufficient performance remaining to avoid premature ground contact. In addition to the cases in which it was added as an occurrence, this also covered cases that reported an inability to maintain a glide path to the intended area of landing touchdown.

- Stall/Loss of Control. These occurrences were frequently preceded by a degradation in performance. A stall is clearly identified in the report or inferred by the study (see above). Subsequent loss of control is reported or inferred based on the final phase of uncontrolled descent.

- Stall/Other. There may be other outcomes following a stall, such as a hard landing or landing short without a complete loss of control. These fall into this category.

- High Sink Rate. As defined above.

- Flight Control Degradation. This refers to events in which one or more flight controls exhibit degraded or failed performance. This includes pitch control difficulties, which can generally be attributed to ice contaminated tailplane stall (ICTS).

The primary ASC occurrence was defined as the occurrence that determined the severity of the accident or incident. Some incidents were precipitated only by a performance degradation, and thus the degradation would be the primary ASC occurrence. In other cases, a performance degradation may have occurred, followed later by a stall and loss of control. This latter occurrence would be considered the primary ASC occurrence in this case. Figure 10 shows the distribution of the primary ASC occurrences.

Little can be said regarding operation of the IPS, except that in 41 cases, it was definitely operated and in 14 cases, it was not. In those cases in which the IPS was operated, there is no way to determine how completely or correctly it was operated.

Some insight may be gained into the decision to not operate the IPS from the small set of data that reported an estimated ice thickness. In 5 of the 6 cases that reported both IPS operation and ice thickness, the estimated ice thickness measurements were all equal to or greater than ½ inch. In all of the 9 cases that reported the IPS was not operated and an estimated ice thickness, the measurements were equal to or less than ½ inch (the median was ¼ inch). These numbers are consistent with the standard practice used with pneumatic boots of allowing approximately ½ inch of ice to develop prior to boot operation.

The study made no attempt to distinguish between elective precautionary landings and forced landings. Thus, the decision to land action covers all occurrences from a precautionary diversion to an intentional forced landing short of the runway while still under control. Nonetheless, in 84 events, the pilot elected to land after encountering inflight icing but prior to any ASC occurrence taking place. These “early” decisions to land yielded only 19 precautionary landings as the terminating occurrence. In a further 58 events, the pilot elected to land after experiencing the first ASC occurrence, typically a performance degradation. In only 14 of these cases was a precautionary landing recorded as the terminating occurrence. In both sets, all other terminating occurrences were somewhat more severe. This is sufficient to support a conclusion that the decision to land, in itself, is not an adequate intervention.

Four generalized sequence models were derived from this data. these are shown below.

- While in either climb or cruise, the pilot detects an inability to maintain altitude/airspeed. The pilot elects to make a precautionary landing and initiates a descent. In most cases, he will attempt to land at an airport, but in a significant minority of cases, he may elect to land off the airport. In a subset of these cases, a stall or other loss of control will occur during the descent. In another subset, the pilot will have difficulty maintaining the glide path to his precautionary landing site. This may result in a landing short of the runway (undershoot). During the angle of attack increase to a landing attitude, a high sink rate may develop leading to a hard landing. If sufficient performance is lost during the final approach, an inflight collision with the terrain or water may result.

- The pilot detects an inability to maintain airspeed/altitude. He attempts to maintain altitude, resulting in a stall and subsequent loss of control. The airplane may enter a spiral or a spin. This almost invariably results in an inflight collision with terrain/water, but in a small number of cases a recovery is effected. This is a typical scenario in western mountainous regions, were the Minimum EnRoute Altitudes are quite high, leaving the pilot little room to maneuver and strongly influencing him to lose as little altitude as possible.

- With no prior occurrences, the pilot finds that he/she is unable to maintain the glide path. In those cases that become accidents, this usually indicates an almost complete loss of performance. If the aircraft does not stall this will still result in an in-flight collision with terrain/water, although under some degree of control.

- After accreting ice in almost any phase, the pilot is able to maintain adequate performance until he/she finds that a high sink rate develops during the pitch rotation to the landing attitude. This is followed by a hard landing. In a small subset of these cases, the high sink rate develops with flap or gear extension.

B. Aircraft Certification

Airplanes certificated for flight in icing under CAR 3 rules had no requirement other than to demonstrate a positive means for deflating pneumatic boots. Indeed, regardless of certification, the Bureau of Flight Standards Release No. 434[7] of November 1959 allowed that any aircraft, if equipped with ice protection for wings, tail, propellers, radio masts, pitot tubes and windshield was approved for operation in light icing.

Appendix C was introduced into CAR 4b in July 1955. When CAR 4b became FAR 25 ten years later, Appendix C was well established. However, it did not migrate into FAR 23, the successor of CAR 3, until 1973.

The study looked carefully at both certification and equipage, and this is illustrated in Fig. 11. Not surprisingly, the majority of airplanes were neither certificated nor equipped for flight in icing. Of those that were equipped, some were type certificated under one of two versions of CAR 3 and thus had no real icing certification beyond the allowance of Release 434. Others were indeed certificated under FAR 23.1419; in some cases this was an added certification after the original type certificate had been issued under CAR 3. In many cases, the icing certification was predicated on the equipage, which was optional.

This illustration serves as the starting point for the consideration of the benefits gained from equipage and certification. If nothing else, it is clear that both, in themselves, do not preclude significant numbers of events. The actual effect of ice protection equipage will be considered after some aspects of exposure and scale are discussed.

C. The Influence of Scale

The next aspect of investigation considered aircraft scale. To do this, it was necessary to select a scale index that could be uniformly applied. The definition of scale has always been problematic with respect to icing. Maximum certificated gross weight is perhaps the most natural choice, but the actual effects of icing may have more to do with wing chord, as suggested by the role that wing chord plays in the determination of the modified inertial parameter (K_o). The choice of a scale index that would be compatible with additional, external data for the purpose of estimating exposure was considered to be the most important aspect. Thus, the scale index used by the FAA General Aviation and Air Taxi Activity (GAATA) was selected. This scale is based primarily on seating capacity and powerplant installation for civilian aircraft. The largest civilian scale used by the GAATA survey is the twin turboprop configuration of thirteen or more seats. Since the study also included larger scale aircraft used in air carrier operations, the index was modified to accommodate scales typical for air carrier aircraft. The scale terminology of the modified GAATA index is shown in Table 2.

Table 2 – Modified GAATA Survey Aircraft Scale Index

Scale Code	Scale Definition
1 RP: 1-3 seats	Single Reciprocating Engine, 1 to 3 seats
1 RP: 4+ seats	Single Reciprocating Engine, 4 or more seats
2 RP: 1-6 Seats	Twin Reciprocating Engine, 1 to 6 seats
2 RP: 7+ seats	Twin Reciprocating Engine, 7 or more seats
2 TP: 1-12 seats	Twin Turboprop Engine, 1 to 12 seats
2 TP: 13+ seats	Twin Turboprop Engine, 13 or more seats (non-air carrier use)
2 TP: 13-19 seats	Twin Turboprop Engine, 13 to 19 seats (air carrier use)
2 TP: 20-50 seats	Twin Turboprop Engine, 20 to 50 seats (air carrier use)
2 TP: 50+ seats	Twin Turboprop Engine, 50 or more seats (air carrier use)

Figure 12 illustrates the ranges of gross weights for aircraft in the database with respect to these scale definitions. Figure 13 shows the distribution of primary ASC occurrences across the modified GAATA index. Not surprisingly, smaller, single engine aircraft account for a majority of the events. These aircraft are typically not ice protected. It is at least encouraging to note that few aircraft of the 1 to 3-seat scale appear in the data. These aircraft are typically not ice protected, and are also not usually certificated for flight under Instrument Flight Rules (IFR). One would hope not to see them in the database, and indeed, they appear infrequently.

It should be noted that the single turboprop category has been omitted. There is essentially only one aircraft in current use in this category, the Cessna 208. It has a fairly high rate of icing events associated with it, but given its dominance of the category, little comparative information could be obtained.

Furthermore, a few other types tend to play strong roles within a scale category. In the case of the twin turboprop 1 to 12 seats, the MU-2 accounts for 11 of the 21 events in the data. With regard to the larger scale fleets, the ATR-42, ATR-72 and EMB-120 fleets dominate the stall followed by loss of control category during the period of this dataset (1991 through 2002). Considered together, the ATR-42 and the EMB-120 aircraft account for 33% of the total operating hours of the 20-50 seat twin turboprop fleet during this period, as well as all six of the stall/loss of control events. The ATR-72 likewise accounts for 52% of the 50+ seat twin turboprop operating hours and the single stall/loss of control event. However, within the broader dataset, covering the period 1978 through 2002, there are events involving the Saab 340 and the Shorts SD-330 and 360 aircraft, as well as the Nihon YS-11. Although the ATR and Embraer 120 aircraft have experienced significant accidents due to icing, the visibility of these accidents has probably led to elevated reporting of incidents involving those aircraft. One could argue, for example, that had the YS-11 accident at West Lafayette, Indiana in March of 1989 been carrying passengers, instead of operating as an empty freighter, the visibility given to the accident may have caused additional events involving YS-11 aircraft, beyond the incident of one year later, to have been reported. Likewise, this may be influenced by the fleet size. The ATR and Embraer fleets are large and continue in extensive operation, while the YS-11 was at its sunset near the time of the accident.

One of the most interesting observations to emerge from the data pertains to the reciprocating twin engine 7+-seat class. Within this class are a number of aircraft; two very predominant types are the Cessna 400 series and the Piper PA-31. The Cessna 400 series aircraft seat six to eight passengers and are certificated for takeoff at approximately 6500 pounds. The PA-31 is also certificated for takeoff at 6500 pounds, and also seats six to eight passengers. At the end of 2005, there were 3114 examples of the Cessna 400 series aircraft identified in the FAA Aircraft Registry database, and 2149 examples of the PA-31. Presumably both are flown by very similar pilots and within nearly identical mission profiles. However, while there are 40 events in the database involving Cessna 400 series aircraft, there is only one involving the PA-31.

Overall, a scale influence can be seen, particularly in the volume of events classified as stall followed by loss of control. In order to investigate this further, it was necessary to develop some exposure data.

D. The Development of Exposure Data

The GAATA Survey has been available for many years[8]. It is a sampled survey conducted by the FAA annually, and is subject to a number of fluctuations and shortcomings of data collection and interpretation. Depending on the fleet, standard errors are cited in the data anywhere from 4% to 20%. However, it is the only such data available for general aviation, and its inconsistencies are less significant when considered over a long period of time. It is also the only dataset available that provides estimates for exposure to Instrument Meteorological Conditions (IMC). Consequently consideration was given to whether exposure to IMC is representative of exposure to icing.

If the geographic area to be considered is applied to all fleets, then the meteorological aspects of the relationship between IMC and icing conditions are uniform to those fleets. The exposure is also a function of aircraft mission profile. The mission profile itself may be defined by the type of flying the aircraft is used for, the vertical and horizontal dimensions of a typical flight segment, and by the true airspeed, climb and descent rates at which the segment is flown. For the assumption of a normal distribution of icing conditions within IMC to be useful, factors that are known to skew this relationship in one direction or another must be removed. Two variables that may have this effect are high airspeeds, resulting in significant differences between static and total air temperature, and extensive operation at high altitudes.

Constraining the mission profile to minimize the impact of these variables required that jet aircraft not be included in the analysis, since it was not possible to estimate the portion of time exposed to IMC that is flown at high total air temperatures or at altitudes at which IMC is almost always comprised of glaciated clouds. Conversely, the operational envelope for most reciprocating and turboprop aircraft is below 20,000 feet pressure altitude and 250 knots indicated airspeed. This keeps the total air temperature during any portion of the mission profile to less than 10 degrees of the static air temperature and limits the atmospheric environment to one more comparable between fleets. This gives reasonable confidence that the relationship between IMC exposure and icing is consistent.

F. Normalization Based on IMC Exposure

Data regarding total fleet operating hours and IMC exposure was obtained in the following manner. First, GAATA data for total operating hours and IMC exposure was collected for the years 1983, 1984, 1986, 1987, and 1990 through 2002. After examination, the IMC data for 1999 was discarded due to inconsistent and substantial divergences from the other years. The remaining data was then processed to develop a set of ratios between IMC hours and total hours for each fleet in each year. A median was taken of the ratios for each fleet, giving a coefficient for that fleet by which a modified estimation of total operating hours may be multiplied to obtain an estimate of IMC exposure. These coefficients are shown in Table 3.

Table 3 – IMC Exposure Coefficients

Scale Code	IMC Exposure Coefficient
1 RP: 1-3 seats	*0.0085*
1 RP: 4+ seats	*0.0885*
2 RP: 1-6 Seats	*0.2024*
2 RP: 7+ seats	*0.2200*
2 TP: 1-12 seats	*0.2773*
2 TP: 13+ seats	*0.2676*
2 TP: 13-19 seats	0.2724
2 TP: 20-50 seats	0.2724
2 TP: 50+ seats	0.2724

The GAATA does not provide any information for Part 121 air carriers. It did include commuter carrier activity until 1993, after which commuter activity was not included. However, the Bureau of Transportation Statistics (BTS) provides annual summaries for all air carriers that are required to file Form 41 data to the BTS. This data was extracted from the T100 database at the BTS for all aircraft types which conformed to the above cited mission profile constraints. This data was available from 1991 through 2002, so this period set the time constraint for the analysis.

The T100 data was compiled into categories that aligned with the scale categories shown in Table 2. It was then added to the GAATA data for the same year for each respective scale category. The GAATA survey estimates for commuter carrier in activity were removed from the total for the years 1991 and 1992. The process thus yielded a fair estimate of total operations for each year.

Since IMC exposure data was not available for the T100 information, the combined annual totals were multiplied by the previously developed IMC coefficients to arrive at estimates for each fleet's total exposure to IMC conditions. Since the mission profiles for the turboprop fleets are very similar, a median was taken between the calculated coefficients for the 1 to 12 seat and the 13 or more seat turboprops, and this was then applied to the additional air carrier categories.

This allowed the normalization of the primary ASC occurrences for the period 1991 through 2002. The distribution of these occurrences is shown in Fig. 14, and the normalization in Fig. 15. Figure 15 includes bars for total operating hours and estimated IMC exposure hours. Some observations can be made.

- Although the 1-3 seat scale accounts for a considerable portion of the annual total flight time, very little IMC exposure is incurred with very few icing events. This scale consists of smaller, single engine aircraft such as the Piper Cub and Cessna 150. Very few aircraft of this class are equipped for flight in IMC, and the data suggests that indeed, few pilots are attempting to fly them in IMC.

- The relationship between total annual flight hours and annual IMC hours for the 4+-seat scale indicates that these airplanes fly a significant amount of IMC. They are generally equipped for IMC and flown by pilots who are, generally, qualified. Icing events for this scale appear commensurate with the IMC exposure; the exception being events that exhibit only a performance degradation.

- The reciprocating twin engine fleets are significantly present in the high sink rate event, leading to hard landings.

- The percentage of stall/loss of control, stall/(other), and loss of performance for reciprocating twin engine fleets are on average slightly greater than their respective percentages of total IMC exposure.

- The larger scales are noticeably absent from the performance degradation event.

- The number of events, as a function of IMC exposure, generally diminishes with scales above the 7+-seat twin reciprocating scale. However, this trend is offset by the influence of the EMB-120 events and ATR events, as discussed above.

G. The Influence of Ice Protection Equipment

The question then arises: what effect does the installation and usage of ice protection equipment have? For the most part, it is impractical to isolate this parameter. The installation of ice protection equipment tends to be a function of scale. Larger aircraft are nearly always equipped, and smaller aircraft are nearly always not equipped. Further, the quality of data in this regard is often poor; there are 645 events in the database; in 156 cases, the ice protection equipage could not be determined. Further, any consideration of this question must take into account the dearth of information regarding whether the ice protection system was operated, when, and if it was operated correctly.

For the 1978 – 2002 dataset, Fig. 16 details the distribution of events within each type of primary ASC occurrence based on ice protection equipage. Some observations can be made. First, the relationship between ice protected, not ice protected, and ice protection unknown cases is essentially the same across the first three types of occurrences. The same number of ice protected airplanes are also involved in the fourth occurrence, loss of performance, however the relationship changes due to a somewhat greater number of non-ice protected airplanes being in this dataset. In the fifth occurrence, performance degradation, the ice-protected airplanes are present to a much smaller degree. The implication here is that, for these scales, ice protection equipment is effective at managing the performance degradations or losses. However, if consideration is given to occurrences that are more sensitive to angle of attack changes, such as the stalls and high sink rate occurrences, then ice protection equipment may be somewhat less effective at preventing events, at least in the context of the predominant usage.

This last point should be emphasized. During the data period, the predominant method of operation for pneumatic ice protection systems had been to wait until a thickness of one quarter to one half inch of ice had accumulated before operating the system. Since the dataset is limited to non-turbojet aircraft, the pneumatic ice protection system is the only system in the data. Further, it is impossible to determine whether even this method was used correctly, even in those cases that reported IPS operation. In those cases in which a detailed narrative was provided, it was noted that operation of the pneumatic IPS tended to be on a workload allowable basis; when the pilot's workload increased, the boot operation may have been less rigorous.

Further insight can be obtained by looking at the phase of flight in which the primary ASC occurrence took place. In Fig. 17, it can be seen that the non-ice protected aircraft experience a fairly even distribution of events across the cruise, approach and landing phases of flight. However, the ice protected aircraft exhibit a pronounced shift in events toward the approach and landing phases. Closer investigation of this is shown in Fig. 18. This plot details the cruise, approach and landing flight phases, with events distributed by scale. While the 4 plus seat reciprocating single fleet dominates, the ice protected 1-6 seat and 7+ seat reciprocating twins exhibit more events in the approach phase than in the cruise, and yet again more in the landing phase. At scales larger than this, events in general diminish and nearly all aircraft are equipped with ice protection systems, which can be seen in the data for the 1 to 12 seat turboprops. Thus, for the smaller scales, ice protection may delay an event but not entirely prevent it.

VI. Influence of Flight Experience and Operating Rule

Data was collected for pilot experience (both total flight hours and flight hours in type) and also for the type and category of operation. The latter includes the particular operating rule, or Federal Aviation Regulation, under which the flight was conducted. Essentially, the relevant FARs are CFR 14 Parts 91, 135 and 121. Part 91 covers all operations except those under which the more specific rules of Part 135 or Part 121 apply. Part 135 addresses commercial activities, primarily those using aircraft up to 9 seats or 7,500 pounds payload capacity. Part 121 addresses scheduled air carrier operations using turbojet aircraft, aircraft of 10 seats or more, or with a payload capacity greater than 7500 pounds.

Opportunities to investigate the influence of the operating rule are limited; since several parameters generally associated with scale naturally follow the criteria which determines the applicable operating rule. Part 121 offers no such opportunities, both due to the singularity of its fleet and due to the few events available for study.

Within Part 135, operations can be separated into two general categories: air taxi and scheduled air carrier operations. Air taxi activities comprise charter and other irregular operations, extending into larger aircraft in the freight market due to the 7,500-pound payload criteria. While the current scope of Part 135 passenger scheduled air carrier activities is quite limited, that change did not take place until 1998. Prior to that, Part 135 air carrier operations included aircraft with up to 30 seats. For this reason, and because there would be no comparable fleet and category of operation available within Part 121, scheduled air carrier activities under Part 135 were also not investigated at length.

Part 91 operations can also be broken down into several components. The most common, and the most visible in icing events, are personal flying and business/corporate flying. The latter in particular covers a very broad range of aircraft, from reciprocating single engine aircraft of four seats through corporate jets.

Within these sets, the similarities between the Part 91 business fleet and the Part 135 air taxi fleet offer the best opportunity to examine the influence of operating rule on icing events. Part 91 and Part 135 have similar language regarding operations in icing conditions. For all practical purposes, both rules do not limit the operation of aircraft that are certificated under Part 25 or equivalent rules. However, for aircraft not meeting these requirements, there is a notable distinction. Part 91 precludes operation in moderate icing, while Part 135 precludes operation in light and/or moderate icing. Jeck[9] has investigated the ambiguous language used in these rules in detail. Also, Subpart H of Part 135 requires considerable training for crewmembers, including training that addresses icing. Part 91 has no such specific requirement, relying solely on the licensing requirements that are applicable to all fleets.

Two parameters were examined first, in order to identify any trends that might influence the event history. First, as shown in Fig. 19, the annual number of events was plotted, by category of operation, against the annual operating hours for that category. The data for annual operating hours was obtained from the GAATA Survey data[8]. A number of gaps appear in the GAATA data due to availability of the data and to reporting format changes; however this plot provided some confidence that the relationship between annual hours and number of events was fairly consistent. Part 91 personal operations were included in this plot for reference and context.

Second, pilot experience was plotted to evaluate differences between the fleets. Figure 20 is a box and whisker plot of the total flight experience of the pilot in command, and Fig. 21 shows the flight experience in type. While Federal Aviation Regulations set some minimum experience requirements for Part 135, they are quite low, and there are no such requirements beyond those of the license for Part 91. Flight experience criteria is generally driven by the hiring and insurance practices of commercial operators, and the insurance requirements of private ownership. Within the reciprocating single engine 4+-seat category, some upward trend can be seen with the Part 135 air taxi experience levels; these are still quite low compared to similar category operations using larger scale aircraft. Beyond that, the median total flight times for the Part 91 business and Part 135 air taxi categories of operation are very similar across the larger scale aircraft. However, without normalization data for the entire population of pilots, little more can be said here except that a significant number of pilots with 3000 hours or more of total flight time get themselves into trouble with ice.

An interesting observation can be made with respect to the flight time in type: nearly all categories exhibit a median of around 200 to 400 hours in type. Again, without normalization data, this doesn't necessarily say much, but it is a curious pattern, disrupted only by the 1951 hour median experience in type for the turboprop twin engine air carrier pilots.

The differences in operating rule apply to operation in types of icing, rather than in different classes of aircraft. The training required by Part 135 specifically addresses the meteorological aspects of icing. Therefore, in order to assess the influence of the operating rule, the investigation focused on the weather parameters. The least ambiguous of these parameters is the reported surface precipitation.

Figure 22 plots the number of events in the seven categories of surface precipitation discussed earlier. The data is normalized by median total annual hours of flight time for each category of operation. These medians are obtained from the annual operating hour data plotted in Fig. 19. While the number of events in cases of no precipitation and drizzle/rain is fairly consistent with the distribution of median annual operating hours, this relationship changes in the cases of freezing precipitation and snow. What is most interesting is the relationship of Part 91 business flying to Part 135 air taxi flying in the cases of freezing precipitation.

The mission profiles of these two categories are virtually the same. In Part 91 business flying, the airplane is owned by the business entity, whether that is a sole proprietor of a business or a large corporation. In Part 135 air taxi flying, the airplane is owned by a third party, often a party in business solely to do Part 135 flying. In both cases, the flight segments, degree of schedule fidelity, and flight experience of the crews are nearly identical. Further, as was discussed earlier, the fleets are also identical for the most part.

However, Part 135 air taxi operations experience considerably more events in freezing rain and freezing drizzle than the median operating hours would suggest when compared to the similar activities of Part 91 business operations.

Figure 23 checks the distribution of events based on scale between the two fleets. Indeed, the distribution is fairly consistent across the types of aircraft, with everything from 4+ seat reciprocating singles to 13+ seat turboprop twins getting involved. No discernable bias toward one scale or another is evident.

The conclusion that can be drawn is that the more restrictive language and the more specific training requirements of Part 135 do not appear to have the desired effect. There are many possible reasons for this, ranging from schedule pressure to overconfidence based on frequency of operations. But the intended objective of the more rigorous operating structure of Part 135, and, one could speculate, Part 121, may not be achieving the goal of public safety with respect to inflight icing.

VII. Review of NASA ASRS Data

The 2,003 events captured from a search of the NASA ASRS data were considered separately from the other events. ASRS data is unique for several reasons. First, it is developed from a voluntary reporting program, and therefore no defined reporting threshold exists. Second, it is based on reports written by surviving crewmembers; thus, it is limited to events that allow survival. Third, because it is developed from personal narrative, it is very subjective.

The ASRS reports data was analyzed with respect to six principal categories: the presence of freezing precipitation, conflicts with air traffic control, non-compliance with an ATC clearance, an aerodynamic occurrence such as a stall, any type of performance degradation, and the decision to make a precautionary landing. 299 reports were included in this analysis.

Five observations are useful from this data. First, a number of reports address the inability to remain above the Minimum Enroute Altitude (MEA) in the western states. The MEA is designed to insure both radio navigation signal reception and obstacle clearance. MEAs over the mountainous regions in the west can be very high, and many smaller aircraft barely have adequate performance at these altitudes. The outcome of the events in the ASRS reports is always favorable, since the reporter survives. However, the personal narrative provided paints a very grim picture of the effects of ice accretion that undoubtedly led to many of the accidents in the database involving such aircraft in which there were no survivors.

Secondly, many pilots were surprised by the speed of ice accretion. In many cases, they believed that a short encounter would not be a problem, only to find that it was. Often this involved a descent through a layer of cloud; even when attempting to expedite the descent, significant ice was accumulated.

Secondly, conflicts with ATC are very prevalent. In 59 of 299 events, a conflict arose between ATC and the pilot. Very often this was because the pilot deviated from an IFR clearance and failed to declare an emergency, or otherwise clarify the situation with the controller. In a subset of these cases, the controller actually offers to declare an emergency for the pilot, but the pilot declines. In another subset, the frequency is too busy for communications, often because the controller is overwhelmed with traffic. A number of pilots were alarmed by the absence of an immediate response from ATC when they reported difficulties after encountering ice. In general, they seemed to expect ATC to provide them with a blanket clearance to escape icing without first declaring a state of emergency.

Third, it was common for a heated pitot tube to become overwhelmed or for the static source to be blocked. Airspeeds were often reported as zero. A common consequence of this applies to the Piper PA-28R aircraft. This aircraft has a retractable landing gear equipped with an automatic extension system. This system is cued by airspeed; below a certain airspeed the gear automatically extends. Unfortunately, this is a pitot system function. Often, in icing, the gear falls out and cannot be retracted.

Fourth, pilots were often surprised by the speed of ice accretion, complaining that they thought only a couple of minutes passing through the icing would not be a problem, only to find themselves with considerable ice after a very short encounter. One strategy that appears in the reports from time to time is that of the rapid descent through the weather to either VMC or to the final approach course. Often this plan is foiled by ATC requirements; one has to wonder how many accidents resulting from unstabilized approaches has been avoided by ATC inhibitions of the rapid descent strategy. Nonetheless, it is an indicator of the pilot's expectation that he can avoid hazard by passing quickly through the conditions.

Finally, there is a great deal of discussion about weather briefings; most reporters describe a typical weather briefing prior to the flight. It is impossible to know what weather information was available for the briefing that was not used by the reporter, or, indeed, what was said by the briefer but not heard by the pilot. In some cases, pilot-reporters have described a plan for operating on the warm side of the freezing level only to find that the freezing level was not where they thought it would be. At least one reporter was surprised by how much the SAT dropped upon entering a cloud.

It is worth noting that the frequency of ASRS reports diminishes rapidly with scale; there are virtually no reports filed by crews of large jet transports. This may be due to the effects of scale, but may also be due to variations in the motivation of crews to file such reports based on the type of operation they are employed in.

VIII. Conclusions

An extensive database of icing events was constructed and evaluated. The following conclusions are offered:

1. Freezing precipitation is involved in 33% of the events for which precipitation data was available, but only accounts for 1.8% of the reported surface precipitation in the United States. Snow, on the other hand, was associated with 32% of the events and also with 32% of the surface observations of precipitation.

2. The surface weather observation at the time of an icing event will typically exhibit temperatures which average between -2.5˚C and 1.75˚C, cloud ceilings which average between 450 and 1900 feet, and surface visibilities which range between 1.5 and 5.5 statute miles in precipitation, and 3 to 10 miles with no precipitation. The dew point spread will rarely be greater than 3 degrees Celsius.

3. Events involving freezing precipitation are predominantly experienced in the Great Plains area, along with a portion of the northeast.

4. While the predominant sequence of events involves a stall followed by loss of control, a significant number of events occur during the landing phase, resulting in a hard landing. This type of event may be coupled with a smaller subset in which sufficient performance is lost during the approach so as to force descent below the glide path. In both cases, the pilot may be unfamiliar with or unable to cope with the effects of icing previously accreted when the angle of attack is increased.

5. Smaller scale reciprocating engine aircraft, which are not equipped with ice protection systems, experience the significant majority of the events that involve only performance degradation. For this fleet, events that are more severe are distributed somewhat evenly across the phases of flight, with larger portions taking place in cruise and descent than during approach and landing.

6. Smaller scale reciprocating engine aircraft, which are equipped with ice protection, do not experience many events that involve only performance degradation. However, the more severe events experienced by this fleet tend to occur during the approach and landing phases, with few taking place during cruise and descent. This may indicate that, for smaller scales, ice protection equipment as currently utilized is effective at reducing en route performance degradations but is not as effective at minimizing the effects experienced when the angle of attack is increased.

7. There is generally a trend in which icing events, as a function of IMC exposure, diminish with larger scale. This may be due to the greater percentage of aircraft equipped with ice protection systems, or due to a greater power margin, or due to the effects of airfoil scale, or some combination thereof.

8. The decision to land, in which a pilot elects to divert and make an unscheduled landing due to ice accretion, is effective in less than 25% of the cases that reached the required threshold of an accident or reported incident.

9. Despite more rigorous operating criteria and training requirements, the Part 135 air taxi fleet experiences a number of events in freezing precipitation that is disproportionate to the median annual operating hours of this fleet. This relationship is not consistent with the number of events experienced by the Part 91 business fleet with respect to its median annual operating hours, and thus suggests that Part 135 operating rules and training are not effective at preventing these types of events.

Acknowledgements

This work was conducted under a contract with the QSS Corporation, Brookfield, Ohio. The project was funded by the National Aeronautics and Space Administration. The author would like to thank Mr. Tom Bond of NASA and Mr. Paul Giel of QSS for their support and assistance. Also, the author is indebted to Messrs. Darryl Bertolucci, Paul Pellicano and Joe Mooney of the FAA for their assistance in obtaining records and data.

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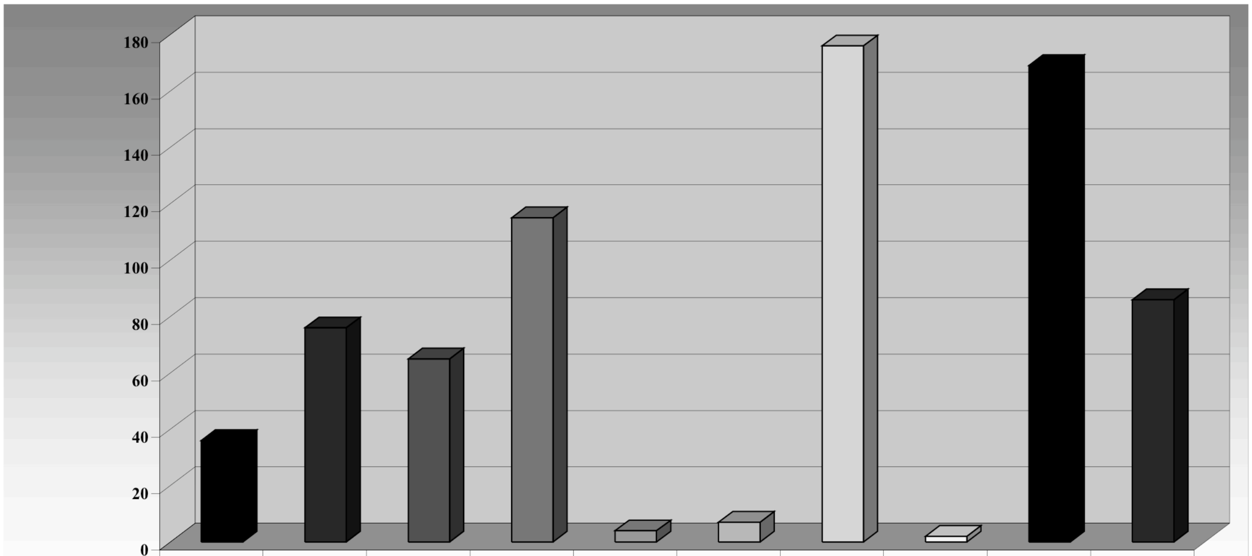
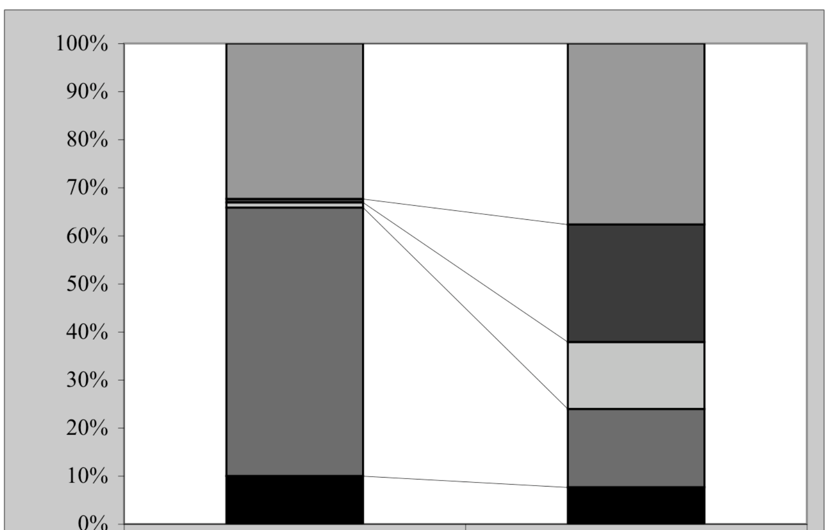


	Drizzle	Rain	FZDZ	FZRA	Ice Pellets	Sleet	Snow	Snow Pellets	None	Unknown
Number of Events	36	76	65	115	4	7	176	2	169	86

Figure 1. Distribution of Events Based on Reported Surface Precipitation



	Precipitation Reports	Icing Events
Snow	1,587,054	176
FZRA	36,417	115
FZDZ	50,332	65
Rain	2,742,978	76
Drizzle	490,046	36

Figure 2. Number of Events Normalized to 30 Year Surface Observation Summary

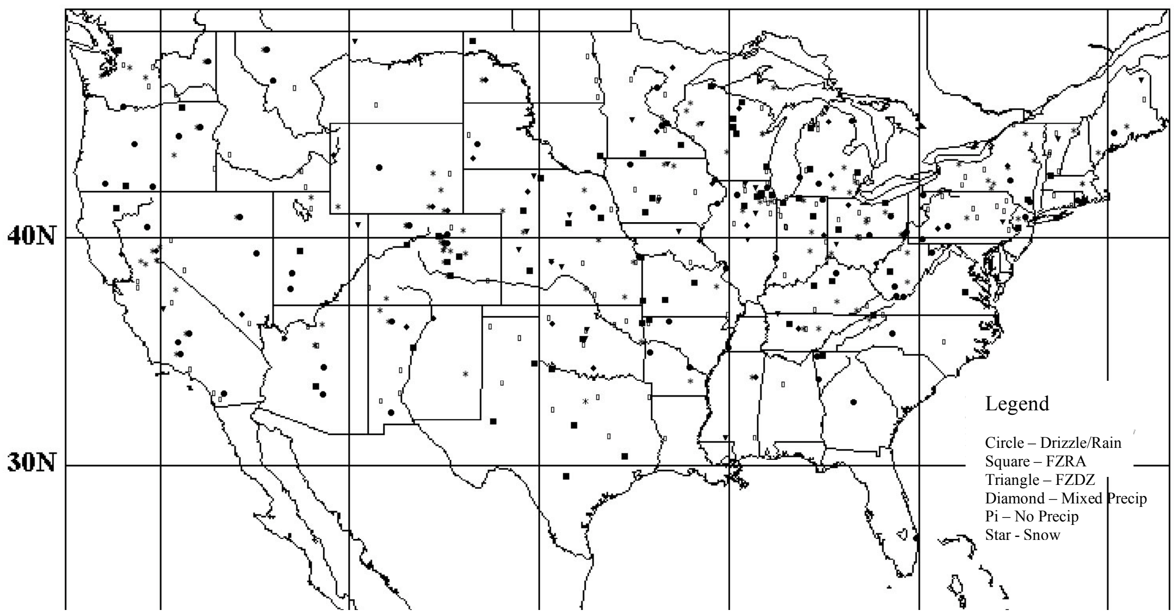


Figure 3. Geographic Distribution of Complete Database

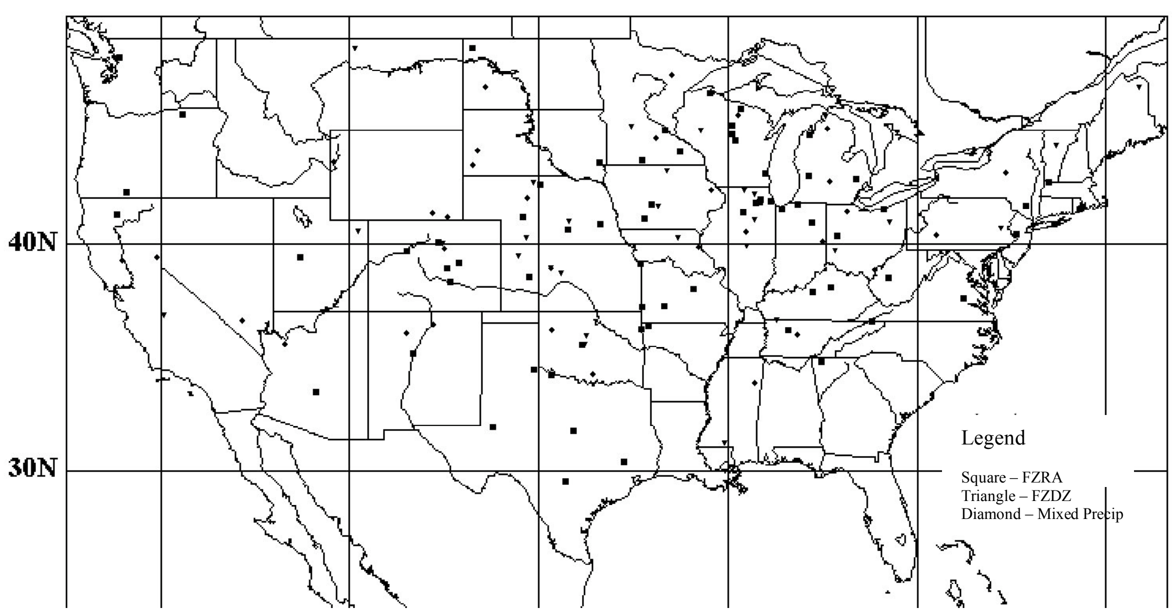


Figure 4. Geographic Distribution of Freezing Precipitation Events

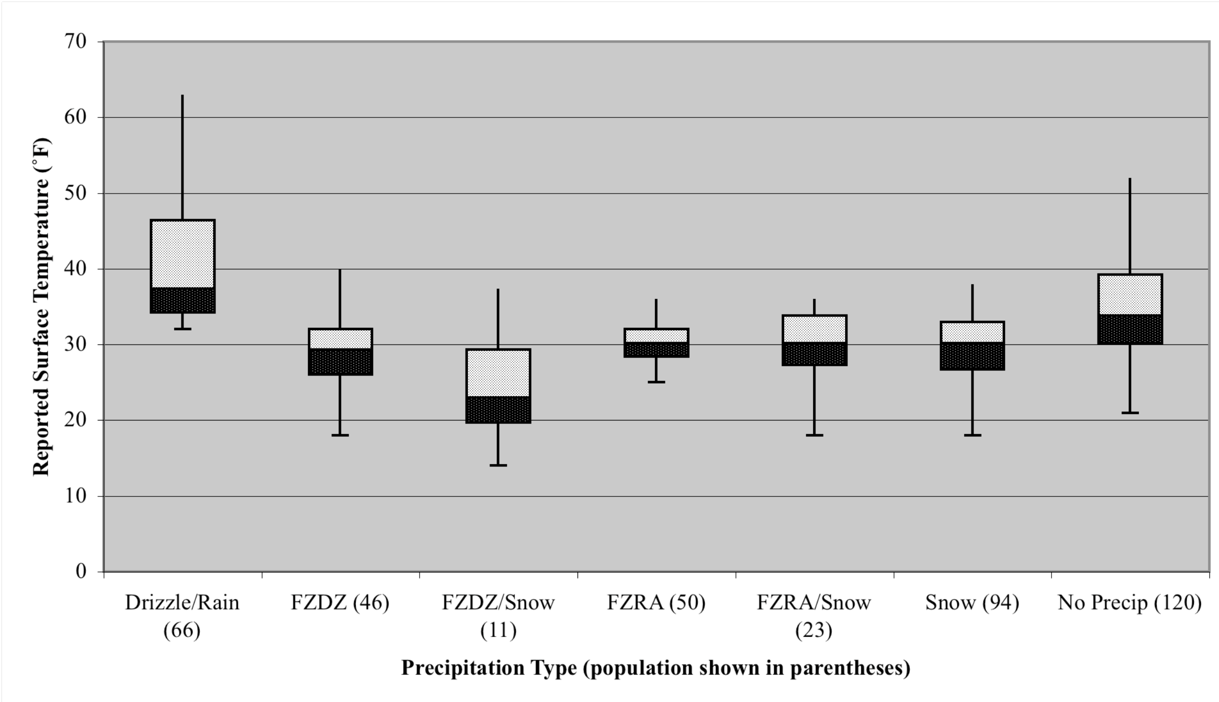


Figure 5. Distribution of Reported Surface Temperature

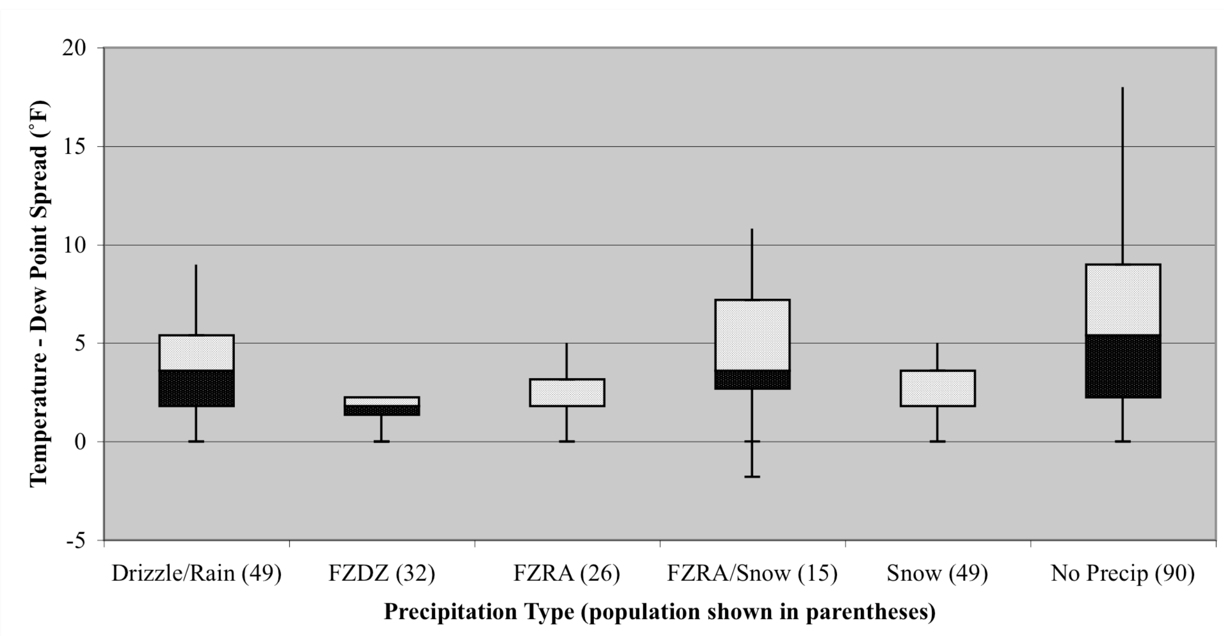


Figure 6. Distribution of Temperature – Dew Point Spread

Note: Outliers are not plotted. Ranges are limited to 3/2 Interquartile Range.

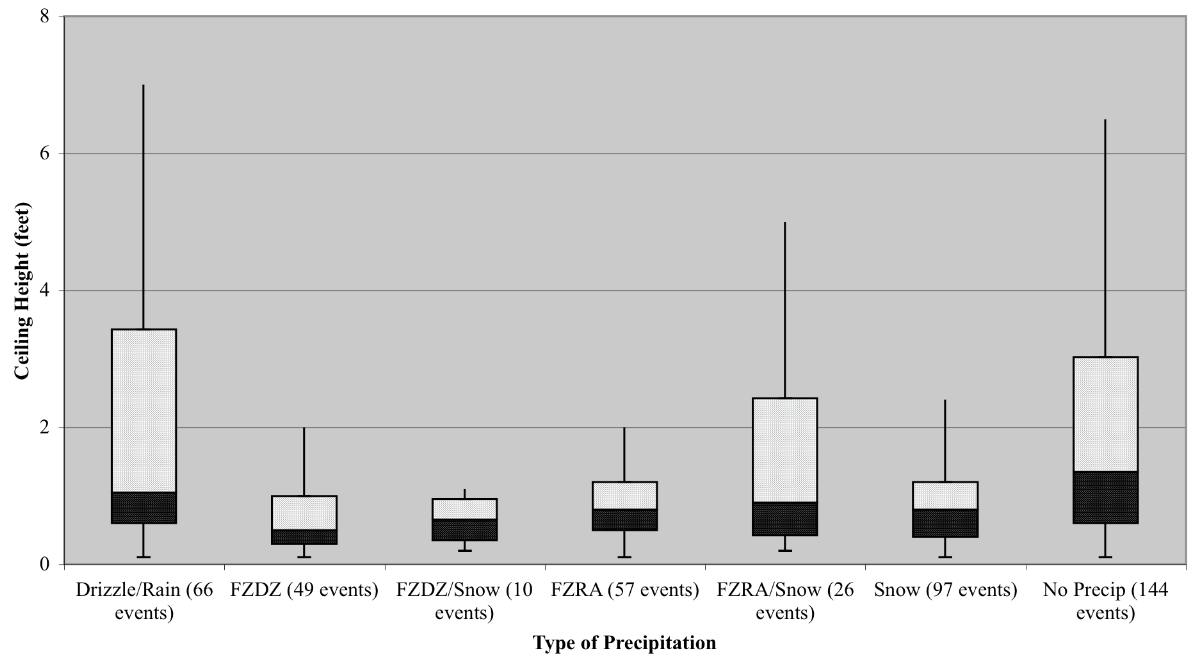


Figure 7. Distribution of Cloud Ceilings

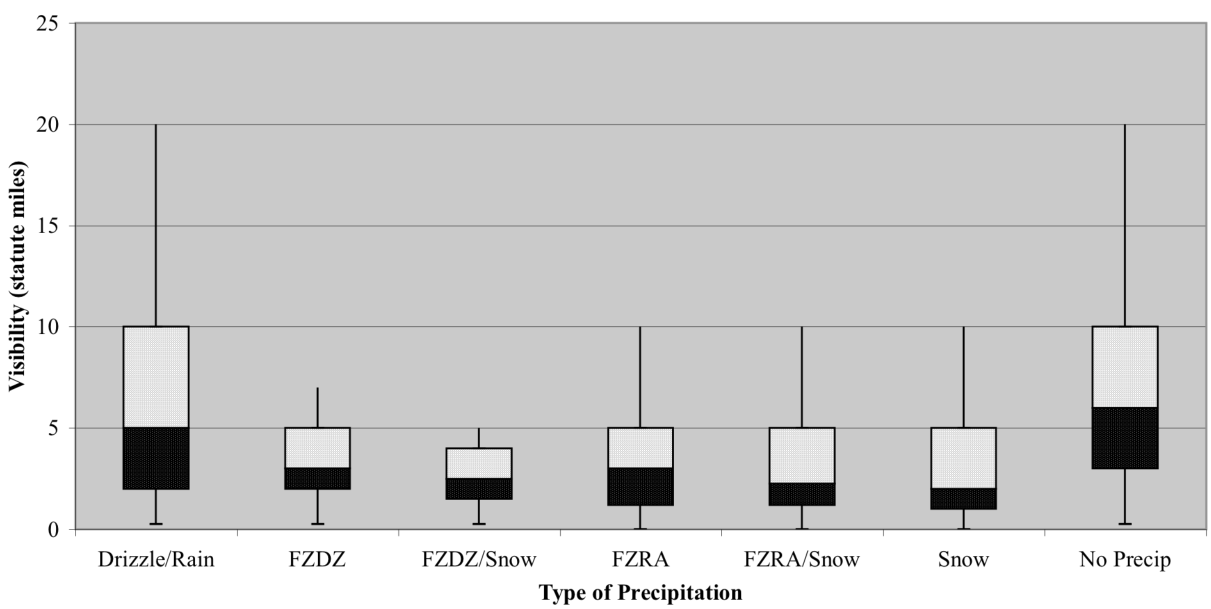


Figure 8. Distribution of Reported Surface Visibility

Note: Outliers are not plotted. Ranges are limited to 3/2 Interquartile Range

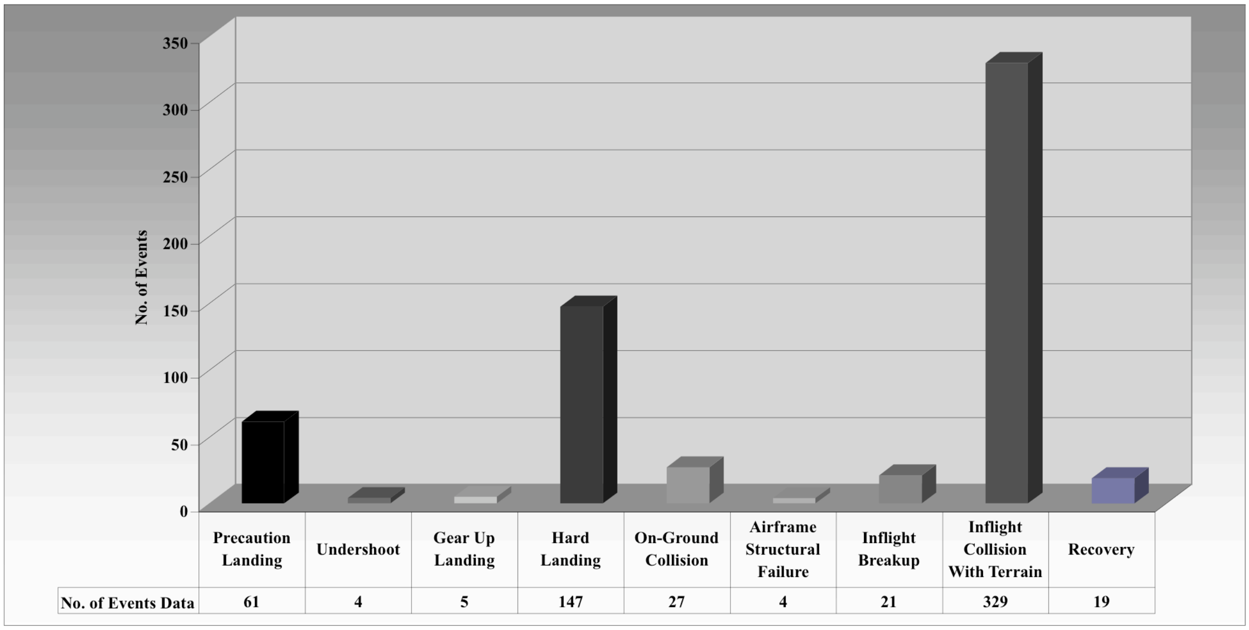


Figure 9. 1978-2002 Distribution of Terminating Occurrences

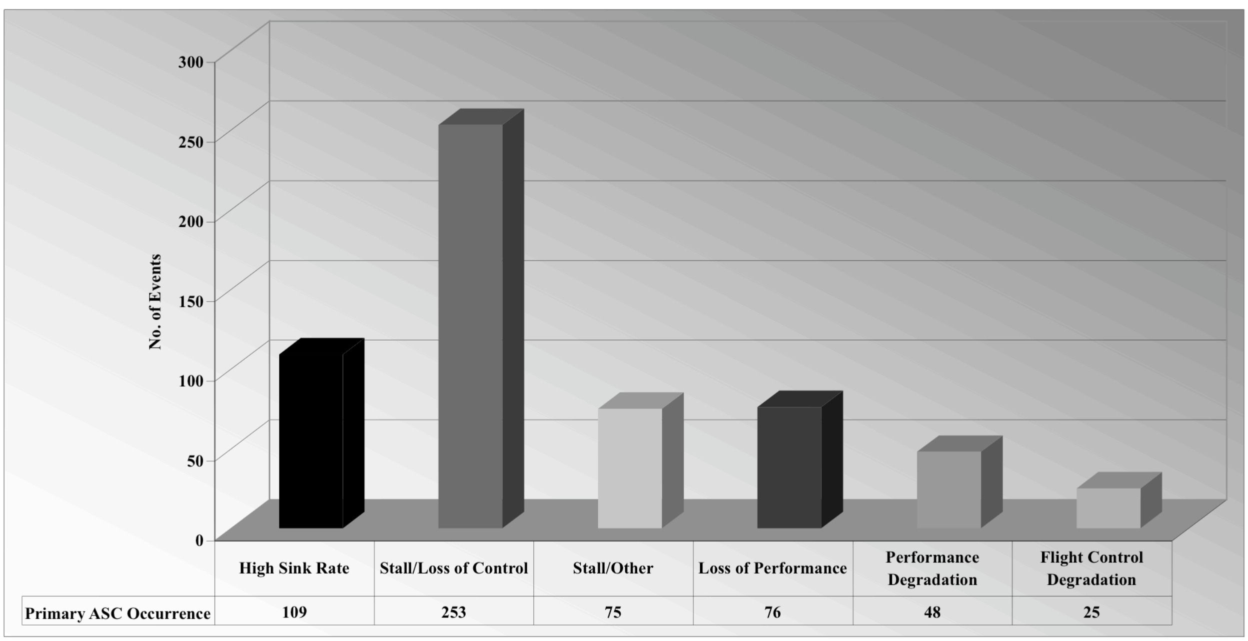
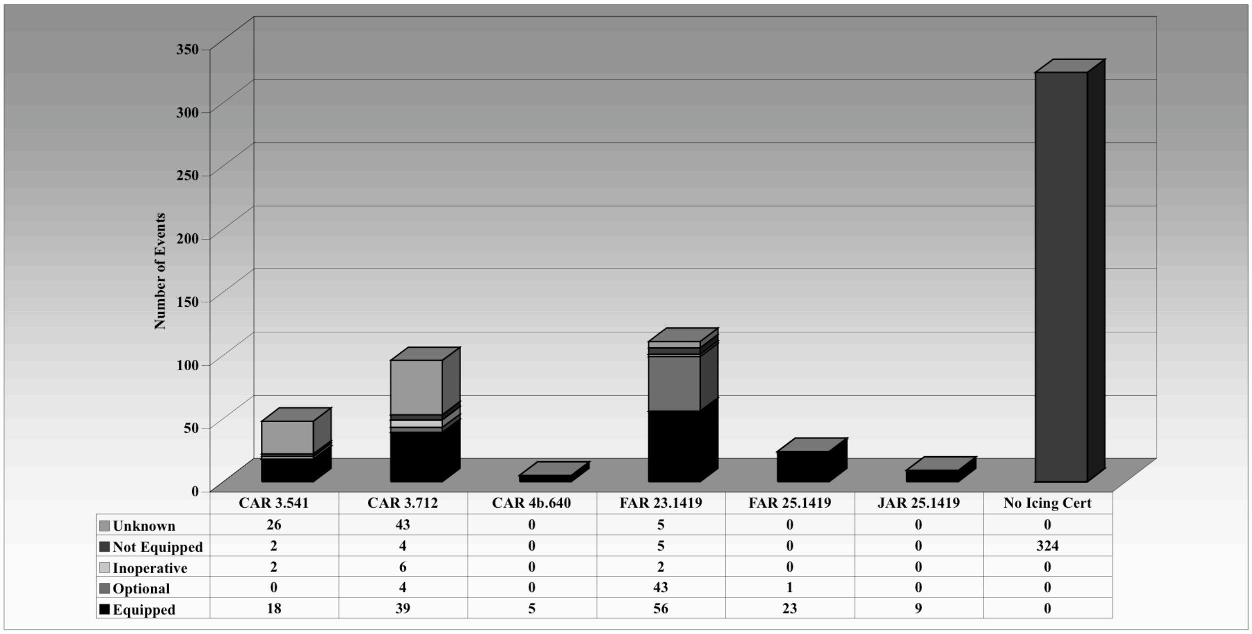


Figure 10. 1978-2002 Distribution of Primary ASC Occurrences



	CAR 3.541	CAR 3.712	CAR 4b.640	FAR 23.1419	FAR 25.1419	JAR 25.1419	No Icing Cert
Unknown	26	43	0	5	0	0	0
Not Equipped	2	4	0	5	0	0	324
Inoperative	2	6	0	2	0	0	0
Optional	0	4	0	43	1	0	0
Equipped	18	39	5	56	23	9	0

Figure 11. 1978-2002 Certification Rule and Icing Equipage

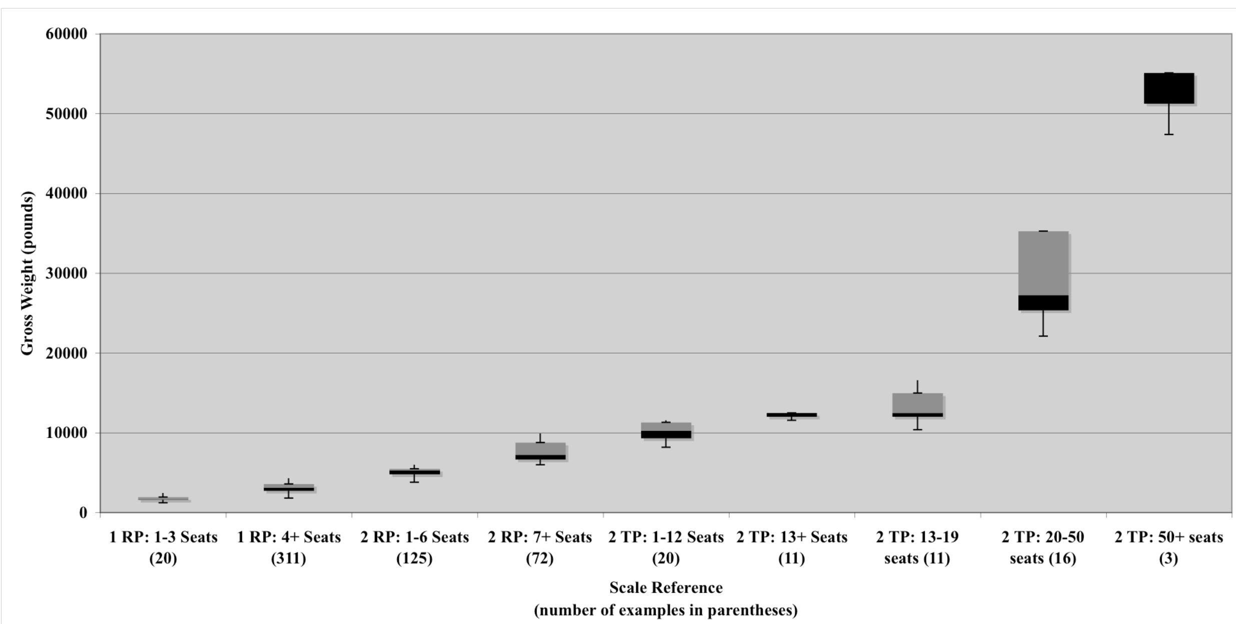
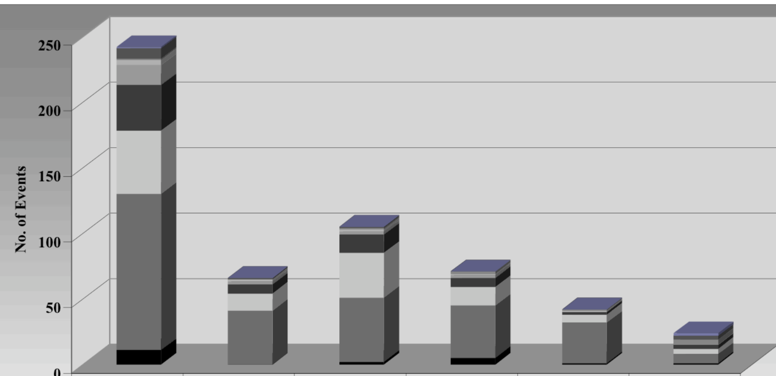


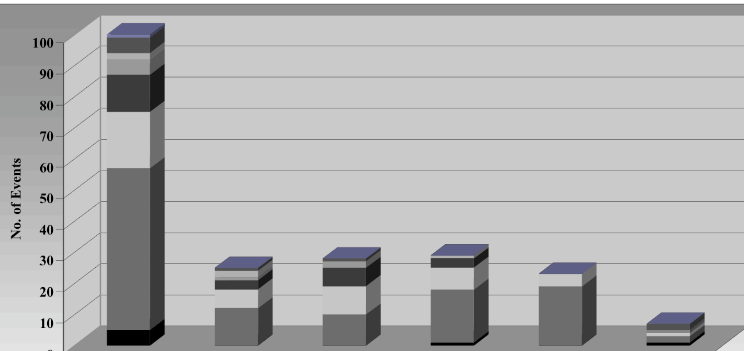
Figure 12. 1978-2002 Distribution of Gross Weight Based on Modified GAATA Scale Index

Note: Outliers are not plotted. Ranges are limited to 3/2 Interquartile Range



	Stall/LoC	Stall/Other	High Sink Rate	Loss of Performance	Performance Degradation	Flight Control Degradation
2 TP: 50+ seats	1	0	0	0	0	2
2 TP:20-50 seats	8	1	1	0	0	3
2 TP:13-19 seats	1	0	1	2	1	4
2 TP: 13+ seats	4	2	2	1	1	0
2 TP: 1-12 seats	15	2	2	2	0	0
2 RP: 7+ seats	35	7	14	7	2	3
2 RP: 1-6 Seats	48	13	34	14	6	4
1 RP: 4+ seats	119	41	49	40	31	7
1 RP: 1-3 seats	11	0	2	5	1	1

Figure 13. 1978-2002 Distribution of Primary ASC Occurrence by Scale



	Stall/LoC	Stall/Other	High Sink Rate	LoP	PeD only	FCD
2 TP: 50+ seats	1	0	0	0	0	0
2 TP:20-50 seats	5	1	1	0	0	2
2 TP:13-19 seats	0	0	0	0	0	1
2 TP: 13+ seats	2	2	0	1	0	0
2 TP: 1-12 seats	5	1	2	0	0	0
2 RP: 7+ seats	12	3	6	3	0	0
2 RP: 1-6 Seats	18	6	9	7	4	1
1 RP: 4+ seats	52	12	10	17	19	2
1 RP: 1-3 seats	5	0	0	1	0	1

Figure 14. 1991-2002 Distribution of Primary ASC Occurrences by Scale

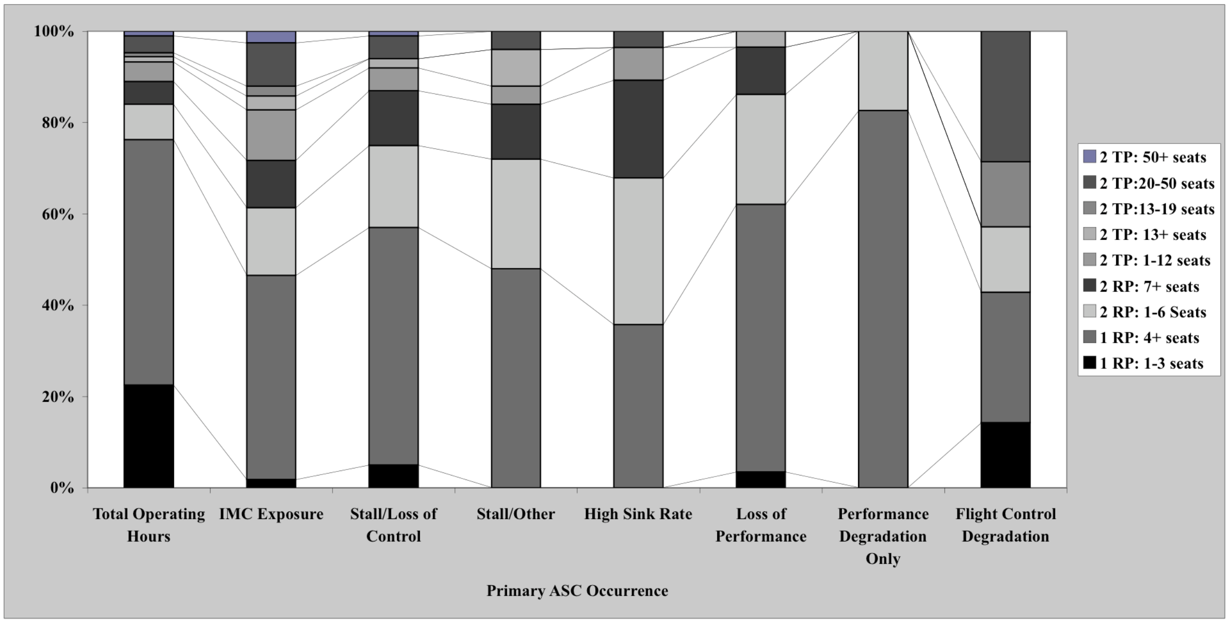
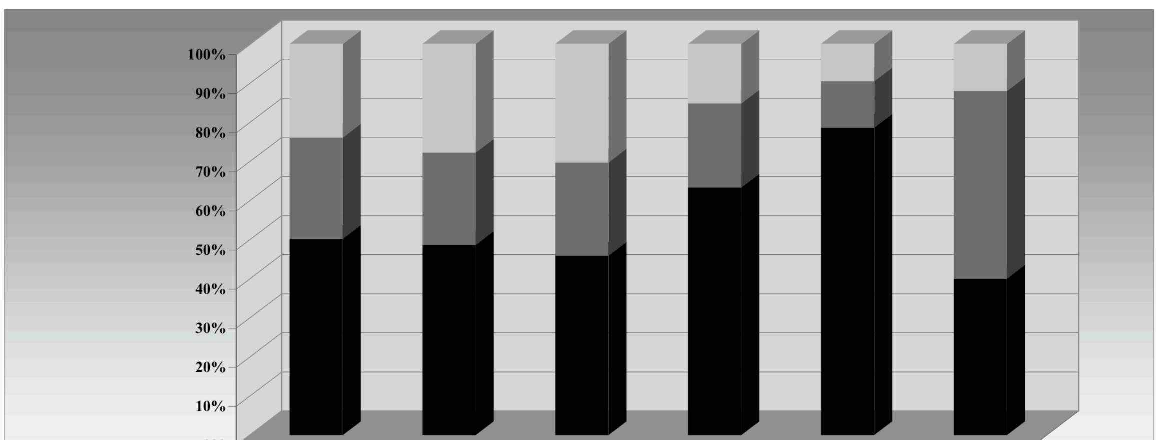
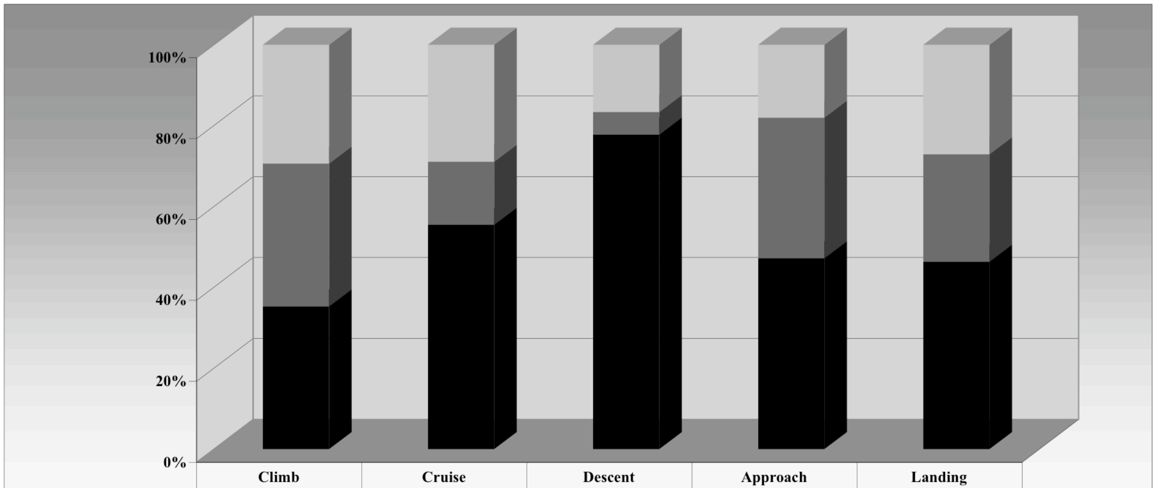


Figure 15. 1991-2002 Events Normalized to IMC Exposure



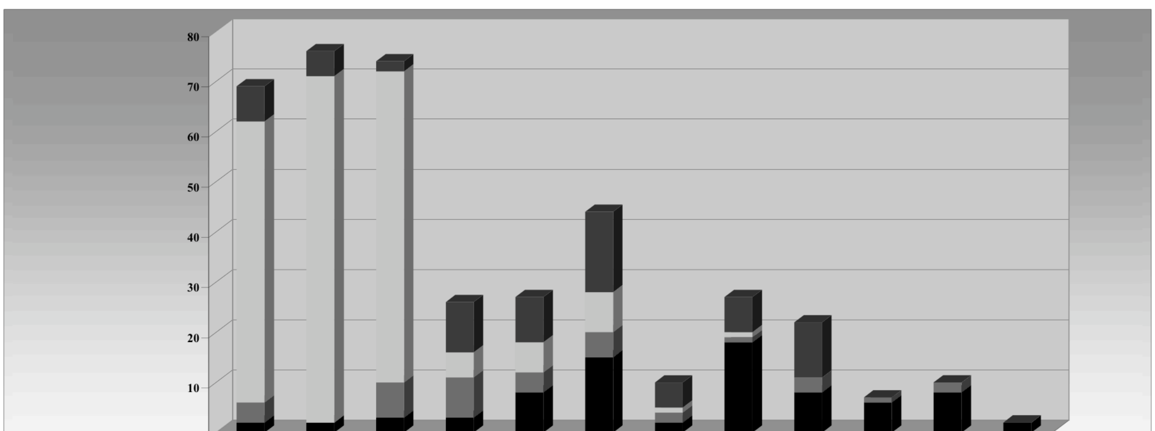
	Stall/Loss of Control	Stall/Other	High Sink Rate	Loss of Performance	Performance Degradation	Flight Control Degradation
Unknown	61	20	33	12	4	3
Icing Equipped	66	17	26	17	5	12
Not Icing Equipped	128	35	50	50	33	10

Figure 16. 1978-2002 Distribution of Primary ASC Occurrences Based on Ice Protection Equipage



	Climb	Cruise	Descent	Approach	Landing
Unknown	10	37	3	29	45
Equipped	12	20	1	56	44
Not Equipped	12	71	14	76	77

Figure 17. 1978-2002 Distribution of Primary ASC Flight Phase Based on Ice Protection Equipage



	1 RP: 4+ seats (cruise)	1 RP: 4+ seats (approach)	1 RP: 4+ seats (landing)	2 RP: 1-6 Seats (cruise)	2 RP: 1-6 Seats (approach)	2 RP: 1-6 Seats (landing)	2 RP: 7+ seats (cruise)	2 RP: 7+ seats (approach)	2 RP: 7+ seats (landing)	2 TP: 1-12 seats (cruise)	2 TP: 1-12 seats (approach)	2 TP: 1-12 seats (landing)
Unknown	7	5	2	10	9	16	5	7	11	0	0	0
Not Icing Equipped	56	69	62	5	6	8	1	1	0	0	0	0
Optional	4	0	7	8	4	5	2	1	3	1	2	0
Icing Equipped	2	2	3	3	8	15	2	18	8	6	8	2

Figure 18. 1978-2002 Comparison of Scale and Flight Phase Based on Ice Protection Equipage

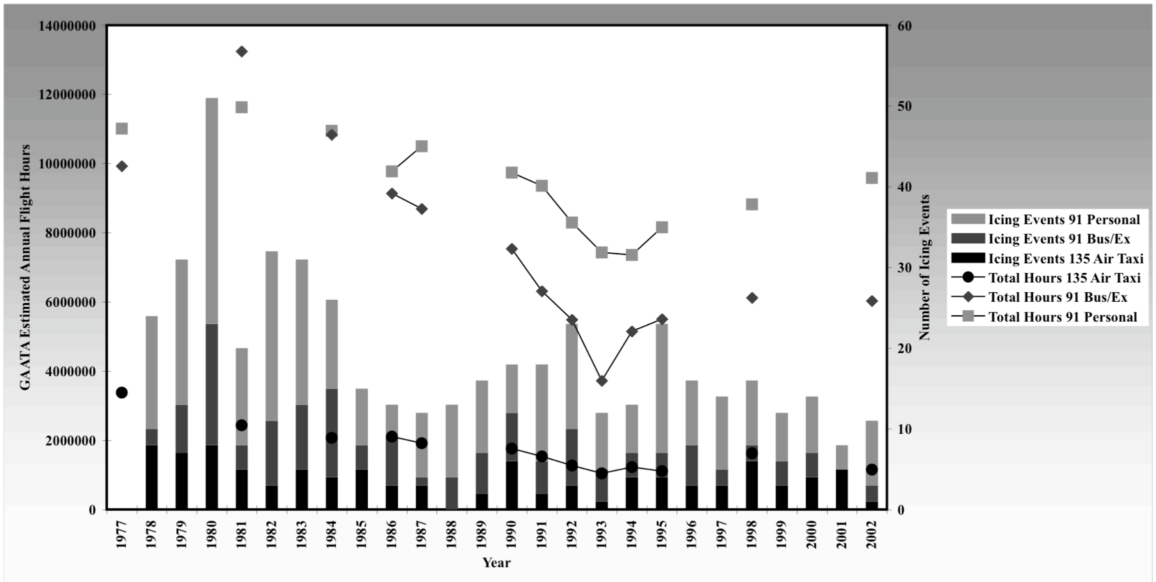


Figure 19. 1978-2002 Events and Operating Hours by Category of Operation

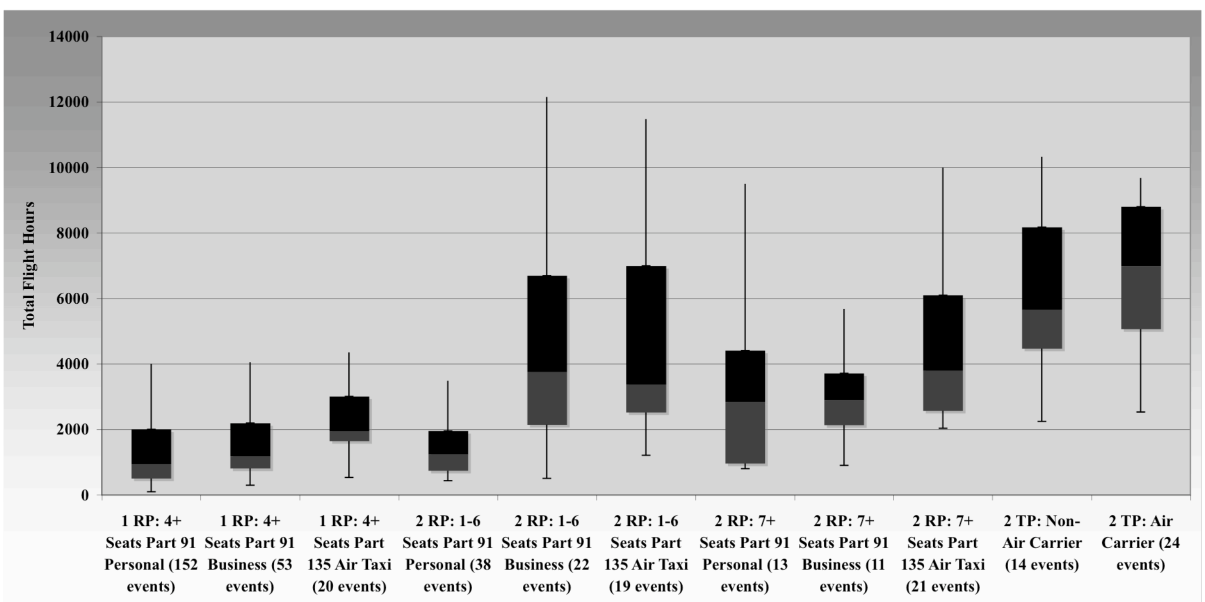


Figure 20. Total Flight Time for Pilot-in-Command by Scale and Category of Operation

Note: Outliers are not plotted. Ranges are limited to 3/2 Interquartile Range

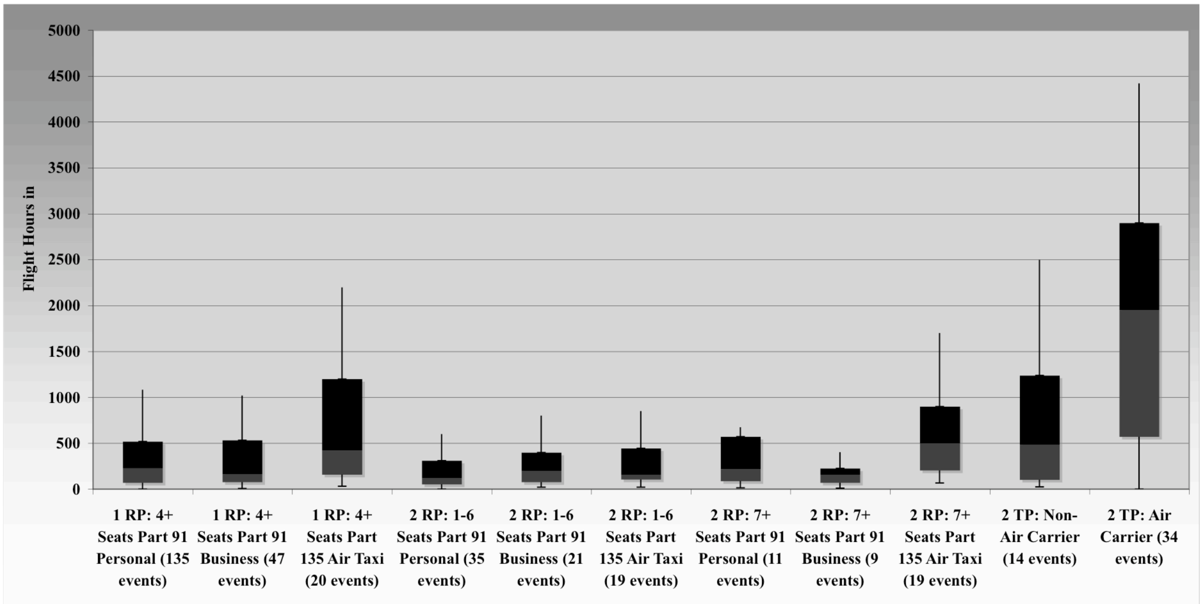
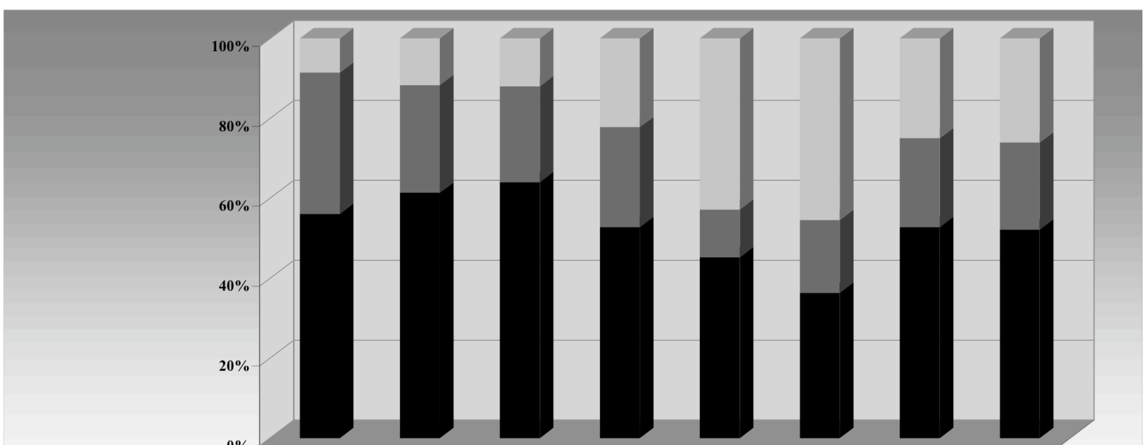


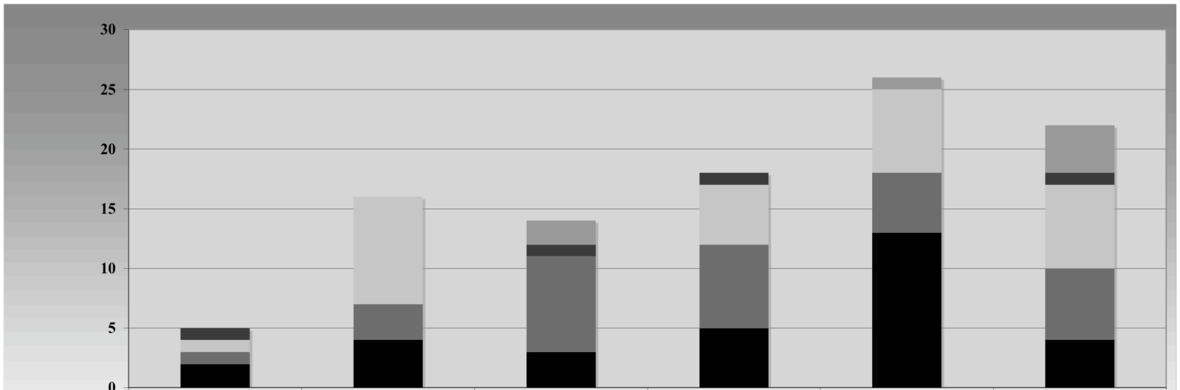
Figure 21. Time in Type for Pilot-in-Command by Scale and Category of Operation



	Median Annual Hours	No Precip	Drizzle/Rain	Snow	FZDZ	FZDZ/Snow	FZRA	FZRA/Snow
Part 135 Air Taxi	1492395	17	9	24	18	5	18	6
Part 91 Business/Corporate	6123399	39	18	27	5	2	16	5
Part 91 Personal	9734914	89	48	57	19	4	38	12

Figure 22. 1978-2002 Distribution of Events By Surface Precipitation and Category of Operation

Note: Outliers are not plotted. Ranges are limited to 3/2 Interquartile Range



	FZDZ		FZRA		Snow	
	Part 91 Business	Part 135 Air Taxi	Part 91 Business	Part 135 Air Taxi	Part 91 Business	Part 135 Air Taxi
2T:13+ seats	0	0	2	0	1	4
2T:1-12 seats	1	0	1	1	0	1
2R:7+ seats	1	9	0	5	7	7
2R:1-6 seats	1	3	8	7	5	6
1R:4+ seats	2	4	3	5	13	4

Figure 23. Comparison of Operating Rule in Freezing Precipitation by Scale