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U.S Inflight Icing Accidents and Incidents, 2006 to 2010.

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To the Graduate Council:

I am submitting herewith a thesis written by Philip Appiah-Kubi entitled "U.S Inflight Icing Accidents and Incidents, 2006 to 2010.." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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U.S Inflight Icing Accidents and Incidents, 2006 to 2010.

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DEDICATIONS

This thesis is dedicated to my mother and father, Mary Badu and Charles Boachie Agyeman whose prayers and guidance kept me on path and also to Rhoda and my siblings who have always had faith in me, encouraging and supporting me to reach higher heights.

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Abstract

Through its recommendations, the National Transportation Safety Board (NTSB) has helped the Federal Aviation Administration (FAA) introduce regulations that have helped to curtail icing accidents[1] (an occurrence associated with the operation of an aircraft where as a result of the operation of an aircraft, any person receives fatal or serious injury or any aircraft receives substantial damage) and incidents[1] (an occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operations). However, "the only acceptable safety goal of zero accident," proposed by former Secretary of Transportation, Federico Fabian Pena, has not materialized. The aviation industry each year experiences more accidents and incidents. Steven D. Green of Flight Operations Research, Underhill, Vermont, researched US inflight icing accidents and incidents from 1978 to 2005.[3] Using the NTSB online database, he observed that 645 accidents and incidents occurred in the US from 1978 to 2005. He identified another 299 incidents in the NASA Aviation Safety Reporting System (ASRS) reports during the same period. The purpose of this thesis is to update and expand upon Mr. Green's research by studying US inflight icing accidents and incidents from 2006 to 2010. The NTSB and ASRS databases were respectively, the primary means of obtaining accident and incident reports. The databases revealed 228 icing related accidents and 30 inflight icing related incidents from 2006 to 2010. Forty of the accidents were related to inflight icing occurring on the wings, fuselage or control surfaces.

From all of the reports sampled it was determined that an aircraft in cruise is more likely to accrete ice than in any other phase of flight. Furthermore, aircraft in cruise are more prone to

inflight icing during instrument meteorological conditions (IMC) than in visual meteorological conditions (VMC). Throughout this report there did not appear to be a direct correlation between the number of flights and inflight icing accidents or incidents. Additionally, it was determined that icing events depended more upon the ice protection system (IPS) equipment, its use and effectiveness, as well as the management of ice accretion by the aircrew.

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Abbreviations and Symbols

AIAA	American Institute of Aeronautics and Astronautics
ASC	Aerodynamic Stability and Control
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Controller
FAA	Federal Aviation Administration
FZDZ	Freezing Drizzle
FZRN	Freezing Rain
GAATA	General Aviation Air Taxi Activity
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IPS	Ice Protection System
KBUF	Buffalo-Niagara International Airport
KDEN	Denver International Airport
KDTW	Detroit Metropolitan Wayne County Airport
KLGA	Flushing Airport
KORD	Chicago O'Hare Airport

MLS	Mean Sea Level
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
US	United States
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

CHAPTER 1

1.1 Introduction and General Information

Inflight icing accidents have been catastrophic to the aviation industry. The most recent commercial fatal icing accident in the US occurred at Clarence Center, New York, on February 12, 2009. Fifty souls were lost in this accident involving a Colgan Air Inc. Bombardier DHC-8-400 operating as Continental Flight 3407. Other deadly accidents have also occurred over the years. On January 9, 1997, the Embraer EMB-12RT collided with terrain at Monroe, Michigan, killing 27 people. Similarly, the Avions de Transport Regional ART – 72 collided with terrain at Roselawn, Indiana, killing 68 people. Twenty seven people perished in the Fokker 28-4000 (F-28) accident on March 22, 1992, in Flushing, New York. In 1987, an icing related accident at Denver, Colorado involving a McDonnell Douglas DC – 9 – 14 aircraft killed 28 people.

These accidents and others have generated considerable interest into researching inflight icing accidents. The NTSB is the primary repository of inflight icing accident reports. NASA's ASRS is also a repository of inflight icing related incidents. Although the ASRS reports are not investigated to check the veracity of the claims, the reports help to understand the aircrews' actions as they encounter icing conditions.

The results of icing related accident studies have had a great influence in the improvement of aviation safety. These results have led to the introduction of IPS and de-icing fluids, and to the development of regulation changes. Among the changes are rules specifying procedures for airspeed, and flaps selection in icing conditions.[9]

Meteorological forecasts over the years have not always been reliable. Pilots sometimes encounter unpredicted icing conditions en route which put them in dangerous situations. The introduction of the IPS has helped to drastically reduce the intensity of icing accidents, but the best way to avoid icing accidents has been avoidance of icing conditions. However, with the ever increasing demand for air transportation and scheduled flights, avoidance cannot always be relied upon. The IPS, although very useful, has not been able to completely overcome inflight icing accidents. Some aircraft equipped with IPS and certified to fly in moderate icing conditions encounter inflight icing that their IPS cannot shed, and, therefore, must request a climb or descent out of the icing conditions from air traffic controllers (ATC).

The most common experience that aircraft encounter in icing conditions are performance degradation, loss of control and stall. These events (defined in section 2.25) do not necessarily occur in chronological order. Depending on the icing severity, the aircraft can experience loss of control or stall that can lead to collision with terrain or a hard landing. Steven D. Green of Flight Operations Research, Underhill, Vermont, researched inflight icing accidents and incidents from 1978 to 2005.[3] He observed that aircraft's scale is more significant to icing events than pilot training, pilot experience, icing equipment and icing certification. This is because different categories of aircraft react differently to ice accretion. The effects of moderate icing (icing with rate of accumulation of 1 to 3 inches (2.5 to 7.5 cm) per hour[5]) on the flying characteristics of a twin turboprop engine with 50 + seats will be different than a single reciprocating engine with 1 to 4 seats. He also came to the conclusion that icing events are prevalent at near freezing temperatures and ceilings of one thousand feet or less. These conditions have moisture contents conducive to airframe icing.

This thesis was carried out to build upon Mr. Green's work and update the US inflight icing accidents and incidents from 2006 to 2010. The study takes into account geographic distribution of the accidents using the FAA's regional zoning [6], meteorological properties, pilot's experience, IPS usage, and event sequence by aircraft scale based on the General Aviation Air Taxi Activity (GAATA) scale index[10] shown in Table 1 (all tables shown in appendix I).

CHAPTER 2

2.1 Methodology and Data Collection

The NTSB Accidents and Synopses online database[1] is the primary source of information for this study. All of the accidents studied in this report were retrieved from the NTSB online database. This database can be accessed through the web address www.ntsb.gov. A series of search strings were used to query the NTSB database. Starting with the dates (January 1, 2006 to December 31, 2010), the database yielded 9361 accidents. To narrow the sample space to icing related accidents, the string "*icing*" was introduced in the narrative cell of the database. This search yielded 292 accidents. After reading the synopses of these accidents, it was discovered that some of the reports were related to pre-taxi de-icing. The remaining accidents were then filtered to eliminate all accidents that were not related to inflight icing. This reduced the sample space to 228 accidents. The accidents which were caused by carburetor icing or engine failure were also filtered out. Other strings such as "ice", "snow", "rime", "freezing", and "frost" were used; however, these strings yielded fewer accidents than the "icing" search revealed. These accidents were also filtered to include those that were not captured by the "icing" string. Forty inflight icing accidents (shown in the appendix) were found to have experienced performance or aerodynamic stability and control events such as stall, loss of control or performance, hard landing, etc., which were not a result of engine failure or carburetor icing. These accidents occurred when the aircraft flew in icing conditions and ice accreted on the wings, fuselage, windshield or control surfaces of the aircraft.

The NASA ASRS[2] was also searched with the strings "ice% OR icing% OR freeze% OR rime% OR glaze% OR sleet% OR frost%". This yielded 1221 incident reports. These report's synopses were reviewed and those that did not experience any performance or aerodynamic stability and control events mentioned above were omitted. For instance, the string “snow” mostly yielded reports about incidents that occurred when there was snow on the runway. Finally, the synopses and narratives yielded 30 incidents which involved inflight icing leading to performance or aerodynamic stability and control event. The incident reports from the ASRS are discussed separately from the NTSB, since the ASRS reports are not investigated to prove or disprove the claims. This makes the ASRS reports highly subjective. However, the ASRS reports help to understand the incidents from the pilot’s perspective, and offer a glimpse at how the inflight situations were managed during the ice accretion period.

2.2 Development of Data

The final database consists of accidents and incidents that were found to have experienced performance or aerodynamic stability and control events. The synopses and narratives of the accidents and incidents were carefully studied to identify the trend of the aerodynamic events occurred. Among these trends are uncontrolled descent, high sink rate, loss of control, performance degradation, and stall. The final database includes all accidents and incidents for which these performance and aerodynamic stability and control events occurred as a result of inflight icing on wings, fuselage, windshield or control surfaces. It involves accidents and incidents that accreted ice from initial climb to the landing phase of the flight. Since the focus of this thesis is inflight icing, accidents and incidents which resulted from taxi and take off icing were not considered in this study. During incidents in general, the pilots were able to regain control and either continued the flight to the destination or diverted to a nearby airport for an emergency landing. However, the accidents typically resulted in stall and inflight collision with terrain or water.

2.21 Meteorology

Meteorological information about temperature, dew point, visibility, wind speed, wind direction, and surface precipitation type were extracted from the reports. The phase of the flight that the pilot or air crew recognized ice accretion was also extracted; however, the exact point during the flight that ice accretion started could not be determined by the investigators. In some reports the pilots were able to estimate the thickness of the ice, while some were determined after the accident. The latter measurements are rough estimates as it takes time for investigators to reach the accident site and determine the thickness of ice accretion. Contamination of these measurements can occur by either sublimation due to temperature difference resulting in less ice accretion than experienced inflight or additional ice formation resulting in more ice accretion than experienced inflight. Some accidents involved post accident fires therefore, the thickness of ice that was accreted inflight could not be determined.

2.22 Pilot Experience

Pilot experience was also extracted to determine the pilot's total flight hours and flight hours in the aircraft model/type with which the accident or incident occurred. This was analyzed by aircraft's scale index (GAATA scale index)[10] and certification (FAR Parts 91, 121 and 135).

2.23 Aircraft Analysis by Scale

Data was collected about the type of aircraft involved in the accidents. These aircraft were classified based of the number of engines and seating capacity. The FAR Part under which the aircraft were operating was also extracted from the reports. The General Aviation Air Taxi Activity scale index[10] used by the FAA in the 2002 survey was used to classify the aircraft as shown in Table 1. The GAATA scale index covers up to civilian aircraft with 13 + seats, so the modified scale index [3] was used to cover larger civilian aircraft.

2.24 Aircraft Analysis by IPS Certification

The FAA permits aircraft equipped with ice protection systems to operate in light icing conditions (icing with 1/4 inch to one inch (0.6 to 2.5 cm) rate of accumulation per hour). Data was therefore collected about the aircraft's IPS status. Those equipped with IPS were also considered whether the systems were operated during the ice accretion period or not. There is a dearth of information about the IPS status of some of the aircraft because some reports never state whether they were equipped or activated. Mr. Green[3] observed that in the cases that the IPSs were operated, there was no information to determine whether it was operated correctly.

2.25 Aerodynamic Stability and Control (ASC) Events

Performance and ASC events contributed to the inclusion or exclusion of an accident or incident for the discussion. Performance degradation, loss of control, stall, high sink rate, and hard landing were the primary events that were used for the discussion. The accidents were classified based on the following occurrences:[3]

- Loss of control: The occurrence in which an uncontrolled descent was cited as the final flight phase. “In order to enter an uncontrolled descent, control must be lost”.[3]
- Stall: The occurrence in which loss of control was cited or added and no preceding aerodynamic event was found; “if the loss of control resulted from ice accretion, then some type of flow separation must have occurred."[3]
- Loss of Performance: The occurrence in which insufficient performance was retained to avoid an inflight collision with terrain, water or obstacles, but no indication was present of either a stall or loss of control.
- High Sink Rate: Events that terminated with a hard landing within the intended touchdown zone assuming no other aerodynamic event was found.

2.26 Regional Distribution of Events

The FAA has zoned the United States into nine regions: Alaska, Central, Eastern, Great Lakes, New England, Northwest Mountain, Southern, Southwest, and West-Pacific regions. The accidents were classified under these regions to develop a regional distribution of accidents in the US. The flight concentration in these regions were based on the total flight hours and compared with the number of accident(s) per state in the region. The location of the incidents from ASRS could not be determined because the reports do not state where they occurred.

CHAPTER 3

3.1 Five Most Fatal Contemporary Icing Accidents

The aviation industry over the years has suffered many catastrophic accidents as a result of icing. Notable among them is the Colgan Air flight at Clarence Center, New York; Comair flight at Monroe, Michigan; American Eagle flight at Roselawn, Indiana; USAIR flight at Flushing, New York; and Continental flight at Denver, Colorado. To bring into bare an extent of damages icing accidents had caused, this chapter presents the five most catastrophic icing accidents involving commercial US flights.

3.11 Colgan Air Inc. Accident at Clarence Center, New York

On Feb 12, 2009, the Bombardier Inc DHC – 8 – 402 twin engine aircraft impacted the ground at 22:17 EST. Four crew members and 45 passengers aboard the aircraft were killed in addition to one person on the ground. The aircraft was on an instrument approach to Buffalo-Niagara International Airport (KBUF) in Buffalo, New York, but crashed into a residence in Clarence Center, New York, about 5 nautical miles northeast of the airport.

The NTSB report[1] stated that “Colgan Air’s inadequate procedure for airspeed selection and management during approaches in icing conditions” were among the probable causes of the accident. The aircraft was equipped with ice detection system on the fuselage, wings, tails, propellers, windshield and the pilot and copilot’s window. The ice detection parameter in the cockpit was programmed to show “detected” when there was ice accumulation and “not detected” after the ice was completely shed. From 22:07:53 to 22:08:58, 22:09:21 to 22:11:05 and 22:11:17 to 22:12:17 the ice parameter indicator changed from “not detected” to “detected” then back to “not detected”. It also changed from “not detected” to “detected” from 2216:25 until the end of the recording. Although these indications are very useful for airspeed selection in icing conditions, they do not adequately inform pilots as to when to activate the IPS. The Flight crew's workload management also contributed to this accident. NTSB[1] stated that the captain inappropriately responded to the activation of the stick shaker and also failed to monitor the airspeed which resulted in stall. Furthermore, the flight crew also failed to observe the sterile cockpit procedures.

3.12 Embraer EMB – 120RT Accident at Monroe, Michigan

On January 9, 1997, the Embraer EMB – 120RT twin engine aircraft operated by COMAIR, INC impacted the ground on approach to runway 3R at Detroit Metropolitan Wayne County Airport (KDTW). The accident occurred approximately 19 nautical miles southwest of the airport killing 3 flight crew and 26 passengers aboard the aircraft. This accident also resulted in a post crash fire. The NTSB[1] investigation revealed that it was likely that the aircraft had gradually accumulated a thin rough glaze/mixed ice coverage on the leading edge deicing boot surfaces as it descended from 7000ft MSL to 4000ft MSL through icing conditions. The investigation also stated that the pilot might not have been aware of the icing conditions and that the "FAA's failure to require the establishment of adequate minimum airspeed for icing conditions"[1] was a probable cause of the accident.

3.13 America Eagle Airline Accident at Roselawn, Indiana

An inflight icing accident involving the twin engine ATR – 72 -212 occurred on October 31, 1994, at Roselawn, Indiana. The aircraft en route to Chicago, Illinois, was in a holding pattern for sequencing into Chicago's O'Hare Airport (KORD). Upon clearance to descend from 10000ft to a newly assigned altitude of 8000ft, it rolled approximately 70 degrees right wing down followed by a rapid descent and crashed into the ground. Attempt by the aircrew to recover the airplane from the initial roll proved futile. Among the probable causes cited by the NTSB[1] was ice accretion beyond the de-ice boots while the airplane was in a holding pattern, which resulted in loss of control. Four crew members and 64 passengers aboard the aircraft were killed.

3.14 USAIR INC. Accident at Flushing, New York

Another fatal icing related accident occurred on March 22, 1992, which caused the death of 2 crew members and 25 passengers. However, twenty three people including one crew member survived the accident with serious and minor injuries. The accident involved a twin engine Fokker - 28 – 4000 aircraft. The aircraft was de-iced twice before leaving the gate, but there was a 35 minute holding period between the second de-icing and take off. The NTSB[1] report states that the 35 minutes exceeded the 11 minutes safe holding period for the type 1 de-icing fluid used. The aircraft accumulated ice under the wing during this time interval, which was unnoticed by the pilot. The aircraft collided with the terrain right after takeoff from Flushing Airport (KLGA), New York.

3.15 Continental Airlines Inc. Accident at Denver, Colorado

On November 15, 1987, an inflight icing related accident occurred at Denver, Colorado, Stapleton International Airport now Denver International Airport (KDEN), involving a McDonnell Douglas DC – 9 – 14 aircraft. Among the probable causes of the accident reported by the NTSB[1] was the accumulation of ice on the lifting surfaces. The aircraft was de-iced but there was a 27 minute delay between final de-icing and takeoff. The aircraft is believed to have accumulated ice on the lifting surfaces during the 27 minutes between de-icing and take off. This accident resulted in 28 fatalities and 54 serious and minor injuries.

CHAPTER 4

4.1 Results and Discussion

Steven Green[3] observed that aircraft are more prone to icing events under IMC than VMC from 1978 to 2005. Out of the 40 accidents from 2006 to 2010, 21 occurred under IMC, while 19 occurred under VMC. One would have expected the IMC accidents to have greatly exceeded that of the VMC, but the IMC accidents exceed the VMC accidents to 2. Intuitively, pilots and air crew are more vigilant for icing when flying under IMC. The FAA GAATA survey[10] is a repository of aircraft exposure to IMC, VMC and total hours of flight for general aviation and part 135 aircraft. The 2009 GAATA survey is the most current data available. Out of approximately 98.6 million total flight hours from 2006 to 2009, 86% were under VMC with the remaining 14% under IMC. This might be the reason why the VMC accidents amount almost to the same number as the IMC accidents. Although flights under IMC comparatively contributed to a smaller percentage of the total flight hours, it also contributed to the greater percentage of the number of accidents. This means that aircraft are more prone to inflight icing under IMC than VMC. This is not to trivialize the need for aircrew to be on the lookout for icing under VMC, since a lot of inflight icing accidents have occurred under VMC.

The 1 to 3 seats and 1 to 4+ seats categories based on the GAATA scale index, contributed to the greatest number of hours under VMC. These aircraft are typically not equipped with IPS and ostensibly do avoid flying under IMC. However, due to occasional uncertainty in weather forecasts, some of these aircraft end up in IMC even after filing VMC flight plans. Mr. Green[3] observed that from 1978 to 2005, the 1 to 3 seats scale accounted for the least amount of total flight time under IMC exposure. This scale of aircraft, he explained, are single engine aircraft such as Cessna 150 which typically do not have the equipment to fly in IMC. He also observed that IMC exposure increased with increase in aircraft size. This was also the trend from 2006 to 2010. Larger aircraft, such as the 7+seats and above, are typically equipped with an IPS and pilots who have extensive training and flight experience under IMC.

As much as 50% of the accidents occurred when there was no surface precipitation at the accident site. Snow and rain contributed 10% each. Freezing rain, freezing drizzle, ice pellets and ice crystal contributed 2.5% each, while the remaining 20% occurred under unknown surface precipitation. From 1978 to 2005, Mr. Green[3] observed that freezing precipitation and snow accounted for 33% and 32% respectively of inflight icing accidents. These values would be more useful if there were ways to determine the type of precipitation that the accident aircraft went through from the period prior to ice accretion, and the occurrence of the first performance or aerodynamic stability and control event prior to the accident. Unfortunately, the current state of the art is not capable of providing this data. ICEPRO[7] software although yet to be integrated into transport aircraft, is purported to have the capability to inform aircrew of particular inflight icing conditions, icing severity, and how these icing conditions may alter the aircraft's baseline performance, and stability and control. The surface precipitation data does little to explain exactly what the aircraft went through inflight before the accident. It is possible for an aircraft to accumulate inflight icing in an area with little or no precipitation, but end up stalling and crashing at a place with entirely different surface precipitation. Figure 1 (all figures shown in appendix II) shows the statistical display of the surface precipitation data.

Statistical display of the meteorological parameters is shown in Table 2. In order to calculate the percentiles the temperatures were converted from degree Celsius to degree

Fahrenheit to avoid distortions by negative numbers. Fifty percent of the accidents occurred under a ceiling of 1600ft. From 1978 to 2005 Mr. Green[3] observed that aircraft are more prone to icing under a 1000ft ceiling. This is because near surface ceilings typically have moisture contents that support inflight icing.

Approximately 62% of the accidents occurred at surface temperature greater than 0^{o}C, while 38% occurred at surface temperature less than or equal to 0 ^{o}C. All of the accidents occurred between +21^{o}C and -21^{o}C (surface temperature). Although the scope of the study is only 5 years, it can be inferred from this data that inflight icing is less likely to occur at surface temperatures greater than 21^{o}C since inflight icing occurs only at freezing temperature. From 1978 to 2005, Mr. Green developed a typical icing surface interquartile model (Table 3) for the above meteorological parameters. The 1st quartile or 25th percentile, interquartile means (IQM), and 3rd quartile respectively represent 25%, 50% and 75% of the events. This is more useful since it covers many years and therefore, aircrews can expect icing when flying under these conditions.

Steven Green stated in his publication, "A study of U.S. Inflight Icing Accidents, 1978 to 2002. AIAA 2006 – 82," that "a reported visibility of 2 to 5 miles would not appear to be problematic"; however, 84% of the accidents from 2006 to 2010 occurred with reported visibility of 3 to 10 miles with 84% of those occurring under reported visibility from 5 to 10 miles. This is to say that although flying under VFR might not seem problematic as Steven[3] explains, aircraft are equally prone to inflight icing accidents under VFR as IFR depending on inflight temperature and moisture content.

Out of approximately 81 million total flight hours from 2006 to 2009, 53% was under IFR. The single reciprocating engine with 4 or more seats based on GAATA scale index contributed to 42.5% of the accidents. These aircraft are typically not certified to fly under icing conditions. As discussed in the incidents reports obtained from the ASRS, some pilots file for VFR but inadvertently end up in IFR which in most cases depending on pilot experience and IPS equipment, lead to a decision to land at a nearby airport. Sixteen out of the 17 single reciprocating engine aircraft with 4 or more seats operated under FAA Part 91 at the time of the accident as general aviation aircraft. This was expected because these aircraft were either not equipped with IPS or there was no information about their IPS status. These aircraft are generally not certified to fly under icing conditions. For research purposes the NTSB report will be more informative if the IPS status of every accident/incident aircraft is explicitly stated.

The 20 to 50 and 50+ twin turboprop engine aircraft and the single reciprocal engine aircraft (1 to 3 seats) contributed to the least number of accidents as shown in Table 4. This is not surprising since the single reciprocal engine aircraft are not certified to fly under icing conditions. The 20 to 50 and 50+ twin turboprop engine aircraft operate under FAA Part 121: air carrier, and are required to have IPS. Since its introduction, IPS has helped commercial flight operators mitigate icing related hazards since the avoidance of icing conditions cannot be relied upon. However, there have been instances where the IPS has failed to operate or operated without shedding all accreted ice. Steven Green[3] noted that when IPS' were operated there was no information to determine whether they were operated correctly or at the right time and/or duration. Aircraft with manual IPS are operated solely by the judgment of the aircrew. The NTSB reports on aircraft equipped with IPS do not provide information about how the IPS was operated. Some reports also do not state whether the accident aircraft was equipped with IPS. From Figure 3 the status of the IPS equipment was unknown for 22 of the accidents.

FAA introduced new regulations on August 3, 2009 that changed the certification standards for transport category airplanes. However, the new rules apply only to new transport aircraft designs. It fails to address transport aircraft in existence prior to August 3, 2009. According to the FAA[5], the new regulations state that new transport aircraft must incorporate one of the following measures to detect icing and activate the IPS when flying under icing conditions:

a. An ice detection system that automatically activates or alerts pilots to turn on the ice protection system.
b. A definition of visual signs of ice buildup on a specified surface (e.g., wings) combined with an advisory system that alerts the pilots to activate the ice protection system; or
c. Identification of temperature and moisture conditions conducive to airframe icing that would tip off pilots to activate the ice protection system.

The standards further require that after initial activation, the ice protection system must operate continuously, automatically turn on and off, or alert the pilots when the system should be cycled.

Although these new regulations are very important, they fail to address the old transport aircraft that are still in operation. Some already have an ice detection system that alerts pilots when there is ice accretion, but do not specify where on the aircraft that ice has accreted. There is also no information about the thickness or type of ice accreted. The Feb 12, 2009, accident at Clarence Center, New York, involved the Bombardier Inc DHC – 8 – 402 twin engine aircraft that was equipped with an ice detection system on the fuselage, wings, tails, propellers, windshield and pilot and copilot's window. The NTSB investigation revealed that the ice detection parameter in the cockpit was programmed to show "detected" when there was ice accumulation and "not detected" after the ice had been cleared. Between 2207:53 to 2208:58, 2209:21 to 2211:05 and 2211:17 to 2212:17, the ice parameter indicator changed from "not detected" to "detected" then back to "not detected". It also changed from "not detected" to "detected" from 2216:25 to the end of the recording. However, the ice parameter indicator did not tell the pilot the intensity of the accreted ice. Neither did it tell the pilot when to operate the IPS. Without giving the pilot information on operating the IPS, the ice detected message only becomes useful for airspeed selection. In this accident the pilot failed to monitor and eventually stalled.

An aircraft in the cruise phase is more likely to accrete ice than any other phase. Ice accretion in 40% of the accidents from 2006 to 2010 was detected during the cruise phase of the flight. This is consistent with Steven Green's[3] observations on inflight icing accidents from 1978 to 2005. The majority of the accident aircraft accreted ice during the cruise phase of the flight. This should be expected since cruise forms the greater duration of most air transportation. Figure 2 shows the distribution of the number of events by the phase of flight.

Out of the 40 accidents, only 2 recovered from stall. Five resulted in hard landing, 18 resulted in inflight collision with terrain and 15 resulted in a ground collision with ground or water. This is consistent with what Mr. Green observed from 1978 to 2005. Mr. Green observed that 53% of the accidents resulted in inflight collision with terrain, while 3.08% and 23.82% terminated in stall recovery and hard landing, respectively. Figure 4 shows the distribution of the terminating events from 2006 to 2010.

The research also considered the pilots total flight hours and the hours in the accident aircraft model/type. This was done only for the pilot in command as there were no details about the copilot's flight experience. In 14 of the accidents, the pilot in command's flight experience in the type/model of aircraft was unknown. For research purposes, the total flight hours of the captain and the first officer in type/model of the accident aircraft would be very useful. The box and whiskers plot in Figure 5 shows the total flight hours for the scales of aircraft that contributed to the greater number of the accidents. All the scales of aircraft in Figure 5 show extreme values to the right. The lower part of the boxes, the middle line and the upper part respectively represent the lower quartile (median of the lower half of the data), the median and the upper quartile (median of the upper half of the data).

The FAA Part under which the aircraft were operating was also considered. Figure 6 shows that 80% of the accidents operated under FAA Part 91. 15% operated under Part 135, while 5% operated under Part 121. The Part 91 aircraft by regulation[9] are mostly prevented from operating in moderate icing. These aircraft, personal and business/corporate flying jets ranging from single engine with four seats through corporate jets, are most common in icing events, Steven Green[3] explained. He further explained that unlike Part 135 which demands considerable amount of training of crew members, Part 91 does not but solely relies on the licensing requirement applicable to all flights. Part 121 aircraft are mostly scheduled air carriers. These aircraft are equipped with IPS hence their contribution to a smaller percentage of the accidents.

The Part 91 aircraft which contributed to 32 out of the 40 accidents also accounted for a greater percentage of the total flight hours as show in Figure 7. The single reciprocal engine 1 to

4 seats aircraft which operated under Part 91 contributed to approximately 39.5% of the total flight hours. It's therefore not surprising it contributed to 32 of the accidents.

The most common ASC events in the accidents were stall and loss of control. In most reports, these events were explicitly stated. Stall was inferred from reports that cited loss of control as the primary aerodynamic event without any other occurrence. From 1987 to 2005, most accidents[3] involved stall, which was followed by loss of control. This trend was expected as inflight icing increases the stall speed; the Federal Aviation Regulations Aeronautical Information Manual[8] explains that inflight icing has a cumulative effect on the performance of aircraft. It explains that inflight icing comes with reduced thrust, increased weight, loss of lift, and increased drag. This results in increased stall speed and performance degradation. It further explains that ½ inch of ice can reduce the lifting power of an aircraft by 50% and increase frictional drag by the same amount. Figure 8 shows the distribution of primary performance and ASC event. Twenty one (approximately 53%) of the accidents from 2006 to 2010 experienced stall and loss of control.

The accidents were also classified using the FAA nine regional zones. Figure 9 shows the regional distribution of the accidents according to the FAA regional zones. The Northwest Mountain region contributed to 22.5% of the accidents. Next, the Central region, Great Lakes region, and Southern region contributed to 17.5% of the accidents each. Alaska and Eastern regions contributed to 7.5% of the accidents each, while New England and Western Pacific regions contributed to 5% of the accidents each.

Comparing the FAA GAATA survey[10] from 2006 to 2009 to the accidents indicates that there is no direct correlation between the number of accidents and fleet concentration in a region. From 2006 to 2009, Southern region had the most day and night flight hours at 19.7%, while the Southwest region was second with 17.1%. Southwest region recorded no icing accident from 2006 to 2010. The Northwest Mountain region, which recorded the highest number of accidents, had 11.4% of the total day and night flight hours. This means that number of flight hours in a region and number of accidents are not in direct proportion. IPS equipment, operation and effectiveness, exposure to icing conditions, pilot's management of events and decision making in icing conditions are more important factors affecting the occurrence of inflight icing accidents.

4.2 NASA ASRS Data

Thirty inflight icing incidents were identified in the ASRS database. Ten of the incidents involved aircraft with IPS systems that were operated during the icing event. The pilots operated their IPS with an estimated ½ inch of ice build-up. This is the specification on most IPS equipped aircraft; however, technology at this time cannot estimate the thickness of ice build-up. When the IPS is ineffective pilots will report to ATC and ATC will advise them to either climb or descend to an altitude that is free of icing conditions. The FAA[8] explains that warmer altitudes are not always below the flight's altitude.

The most common event observed in the incident reports is performance degradation. Twenty-three out of the 30 incidents were either unable to climb, maintain airspeed and altitude. There was a single case in which a pilot descended to an unassigned altitude before communicating with ATC. From the reports it appears that ATC has been very supportive in guiding pilots out of icing conditions. Under serious conditions, ATC does not hesitate to declare an emergency even if the pilot fails to declare an emergency. The end result has been predominantly safe landings at the nearest airport.

Nineteen of the incidents also reported accumulation of ice during the cruise phase of the flight. This is analogous to the trend identified in the accident database. IMC accounted for 24 of the incidents. Some pilots were amazed at the rate of ice accumulation even though they had been in icing condition for only a few minutes. In some cases, as little as 2 - 5 minutes were enough for pilots to describe the rate of ice accumulation as “very alarming”. Some pilots reported that there were no reports of icing en route during their weather briefing, and therefore, became overwhelmed when they found themselves accreting ice or in icing conditions.

4.3 Conclusions

1. 50% of the accidents occurred under zero surface precipitation at the accident site. Snow and rain contributed to 10% each. Freezing rain, freezing drizzle, ice pellets and ice crystals also contributed to 2.5% each, while 20% occurred under unknown surface precipitation type. From 1978 to 2005[3] freezing precipitation and snow contributed to 33% and 32% respectively. This means that surface precipitation data alone is not enough for inflight icing prediction. However, inflight precipitation condition is the determining factor.

2. Out of 40 accidents, 21 occurred under IMC, while 19 occurred under VMC. Out of approximately 98.6 million total flight hours from 2006 to 2009, 86% were under VMC, with the remaining 14% under IMC. This means that inflight icing is more prevalent under IMC exposure than VMC. This was also the trend from 1978 to 2005.[3]

3. Approximately 62% of the accidents occurred at surface temperatures greater than $0^{o}C$, while 38% occurred at surface temperature less than or equal to $0^{o}C$. All of the accidents occurred between $+21^{o}C$ and $-21^{o}C$. This means that an aircraft is more likely to experience inflight icing conducive temperature when there is a surface temperature less than $+21^{o}C$ depending on the altitude it flies since temperature linearly decreases in the troposphere.

4. The Single Reciprocating Engine with 4 or more seats contributed to the greatest percentage of the accidents. Sixteen of these accidents operated under FAA Part 91 as general aviation aircraft. These aircraft were either not equipped with IPS or their IPS status was unknown. IPS has been very useful in preventing inflight icing accidents.

5. The 20 to 50 and 50+ twin turboprop engine aircraft and the single reciprocal engine aircraft (1 to 3 seats) contributed to the least number of accidents. Most single reciprocating engine aircraft are not equipped with IPS and completely avoid flying into forecasted icing conditions. The 20 to 50 and 50+ category aircraft are mostly equipped with IPS, which allow them to fly in moderate icing conditions. The rigorous training requirements of pilots for these types of aircraft might have also contributed to the fewer numbers of accidents.

6. Aircraft in the cruise phase is more likely to accrete ice than any other phase. Ice accretion in 40% of the accidents was detected during the cruise phase of the flights. This is consistent with the trend from 1978 to 2005[3]. This is because the cruise phase forms the greatest duration of most air transportation.

7. Although experience is very important in controlling aircraft under icing conditions, there is no clear cut answer as to the amount of experience a pilot needs in icing conditions. Much depends on the intensity and type of ice accreted, the effectiveness of the IPS and the pilot's physical and emotional management of the situation.

8. Aircraft are more likely to experience stall/loss of control than any other aerodynamic performance or stability and control event since icing increases the stall speed. From 1978 to 2005 Mr. Green[3] observed stall/loss of control in most of the accidents than any other ASC events. Since the Roselawn accident, manufacturers were instructed to specify the procedure for the selection of airspeed during icing conditions.

9. Flight concentration or intensity in a region does not have a linear relationship to inflight icing accidents. Although the Northwest Mountain recorded the highest number of accidents, it only accounted for 11.4% of the total flight hours from 2006 to 2009. The Alaskan region with only 2.8% of total flight hours recorded three accidents, while the Southwest region with 17.1% of the total flight hours recorded no accident. IPS equipment, operation and effectiveness, exposure to icing conditions, pilot's management of events and decision making in icing conditions are more important factors affecting the occurrence of inflight icing accidents.

4.4 Recommendation

There is no clear cut answer as to how the various types of icing affect the flying capabilities of an aircraft. Although a considerable amount of work has been done on the effect of icing on aircraft's aerodynamics, there is little information about how fast the various types of icing affect the handling capabilities of an aircraft. Also, technology at this time cannot predict the thickness, type and location of ice on an aircraft inflight.

Future research in these areas will help to understand the problem further and manage inflight icing more effectively.

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APPENDICES

Appendix I

Modified GAATA Survey Scale Index

Table 1: Modified GAATA Survey Aircraft Scale Index, by Steven Green[3]	
Scale Code	Scale Definition
1 RP: 1 – 3 seats	Single Reciprocating Engine, 1 to 3 seats
1 RP: 1 – 4+ seats	Single Reciprocating Engine, 4 or more seats
2 RP: 1 – 6 seats	Twin Reciprocating Engine, 1 to 6 seats
2 RP: 1 – 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)

Tables 2 and 3 illustrate the statistical measure of the meteorological parameters from 2006 to 2010, and 1978 to 2005 respectively.

Table 2: Statistical Measure of Surface Meteorological Parameters						
Statistical Measure	Surface Temperature (^oF)	Temperature Dew-Point (^oF)	Wind Speed (Kts)	Wind Direction (Deg)	Visibility (sm)	Ceiling (ft)
25 %tile	21.2	6.5	7	180	3	581.5
50 %tile	33.8	8	8	265	9	1600
75 %tile	47.3	14	14	310	10	2800

Table 3: Interquartile Model of Typical Icing Surface Observation, by Steven Green[3]				
Statistical Measure	Ceiling	Visibility	Surface Temperature	Temp – Dew Point spread
IQM	1000 feet	3.9 statute miles	0^oC	1.75^oC
1st Quartile	500 feet	2 statute miles	-2^oC	1^oC
3rd Quartile	2200 feet	7 statute miles	2^oC	3.25^oC

Tables 4 and 5 respectively show the classification of the accident aircraft using the GAATA scale index, and the 40 accidents from the NTSB online database.

Table 4: Classification of Aircrafts using Steven Green's[3] GAATA Modified Scale Index		
Scale Code	Scale Definition	No of Aircrafts
1 RP: 1 – 3 seats	Single Reciprocating Engine, 1 to 3 seats	1
1 RP: 1 – 4+ seats	Single Reciprocating Engine, 4 or more seats	17
2 RP: 1 – 6 seats	Twin Reciprocating Engine, 1 to 6 seats	5
2 RP: 1 – 7+ seats	Twin Reciprocating Engine, 7 or more seats	5
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)	1
2 TP: 50+ seats	Twin Turboprop Engine, 50 or more seats (air carrier use)	1

Table 5: Details of Inflight Icing Accidents (2006 to 2010)

No	NTSB REPORT ID	AIRCRAFT REG No	DATE	PLACE
1	CEN11CA135	N385AS	12/25/2010	Troy, MI
2	ERA11LA048	N7SY	11/5/2010	Winchester, TN
3	WPR11FA032	N201HF	10/25/2010	Lander, WY
4	ERA10LA105	N5118J	10/21/2010	Greenbush, ME
5	ERA10FA148	N7778W	2/23/2010	Springfield, KY
6	CEN10LA090	N206AV	1/6/2010	Kearney, NE
7	CEN10LA068	N108L	12/6/2009	Dodge City, KS
8	WPR10LA059	N2650R	11/20/2009	Susanville, CA
9	ANCO9LA038	N629SP	5/6/2009	Bethel, AK
10	CEN09LA206	N402BP	3/10/2009	Aberdeen, SD
11	DCA09MA027	N200WQ	2/12/2009	Clarence Center, NY
12	CEN09CA136	N6509T	1/17/2009	Lafayette, IN
13	CEN09FA135	N840NK	1/15/2009	Wray, CO
14	CEN09LA122	N92WT	1/6/2009	Three Rivers, MI
15	CEN09FA099	N9299N	12/19/2008	North Canton, OH
16	WPR09CA051	N6693A	11/29/2008	Rock River, WY
17	ANC09LAO12	N36CF	11/14/2008	Napaskiak, AK
18	NYCO8LA176	N101BX	5/8/2008	Snow Hill, NC
19	NYCO8FA139	C-FRSK	3/16/2008	Atkins, VA
20	SEA08LA072	N329BW	2/8/2008	Albany, OR

Table 5 continued

No	NTSB REPORT ID	AIRCRAFT REG No	DATE	PLACE
21	SEA08FA042	N925TT	12/10/2007	Salmon, ID
22	ANCO8CA020	N170BP	11/18/2007	Nikolai, AK
23	LAX08MA007	N430A	10/7/2007	Naches, WA
24	SEA08FA006	N85WT	10/7/2007	Ekalaka, MT
25	CH107FA183	N477MD	6/28/2007	Wellsville, MO
26	CH107FA102	N8969J	4/14/2007	Vibumum, MO
27	NYCO7LA081	N511AT	3/17/2007	Beverly, MA
28	ATLO7FA040	N506BC	2/9/2007	Hinesville, GA
29	DEN07FA059	N45GM	2/9/2007	Great Bend, KS
30	CH107LA059	N425TN	1/12/2007	Harbor Springs, MI
31	NYCO7FA051	N400CS	12/26/2006	Johnstown, PA
32	CH107FA046	N55MB	12/26/2006	Jasper, TN
33	CH107FA041	N9073P	12/17/2006	Bucyrus, OH
34	LAX07FA021	N121LD	10/25/2006	Meadview, AZ
35	DEN06FA131	N787SL	9/15/2006	Maybell, CO
36	CHI06IA127	N71MT	5/4/2006	Lincoln, NE
37	DEN06LA050	N33AFC	3/20/2006	Emporia, KS
38	SEA06FA147	N69KM	1/25/2006	Carson, WA
39	ATLO6LA035	N87HK	1/13/2006	Childersburg, AL
40	LAX061A076	N390AE	1/2/2006	Santa Maria, CA

Appendix II

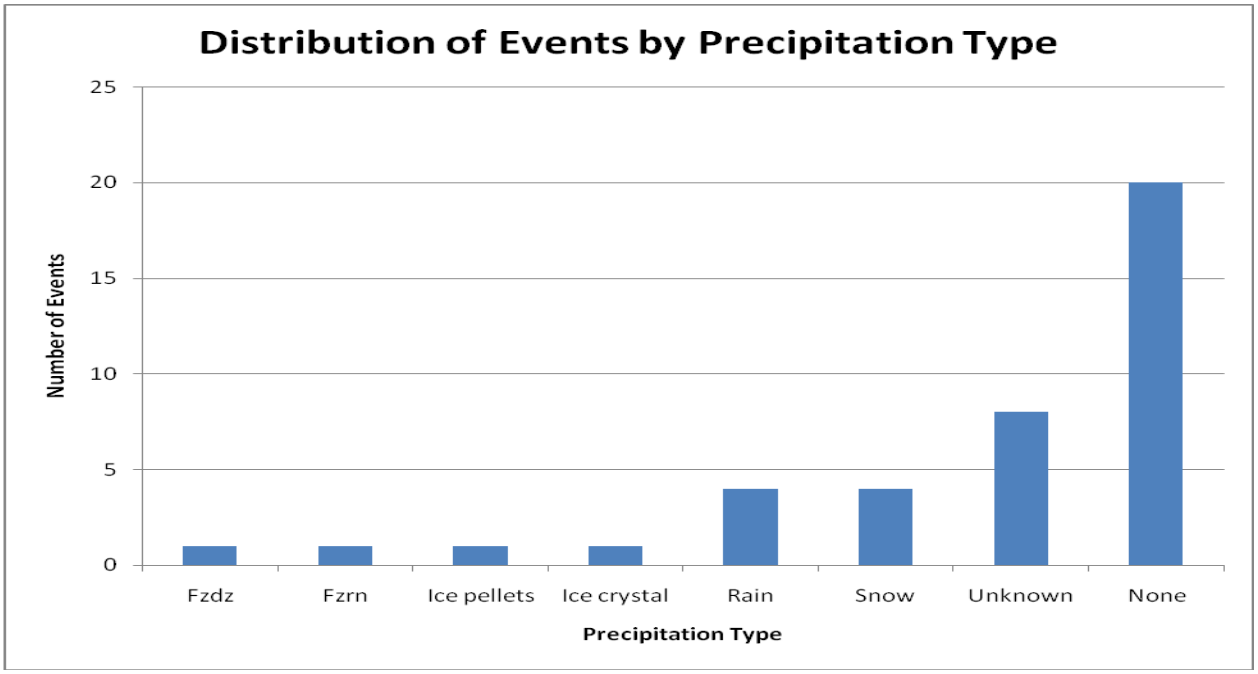


Figure 1: Distribution of Events by Surface Precipitation Type

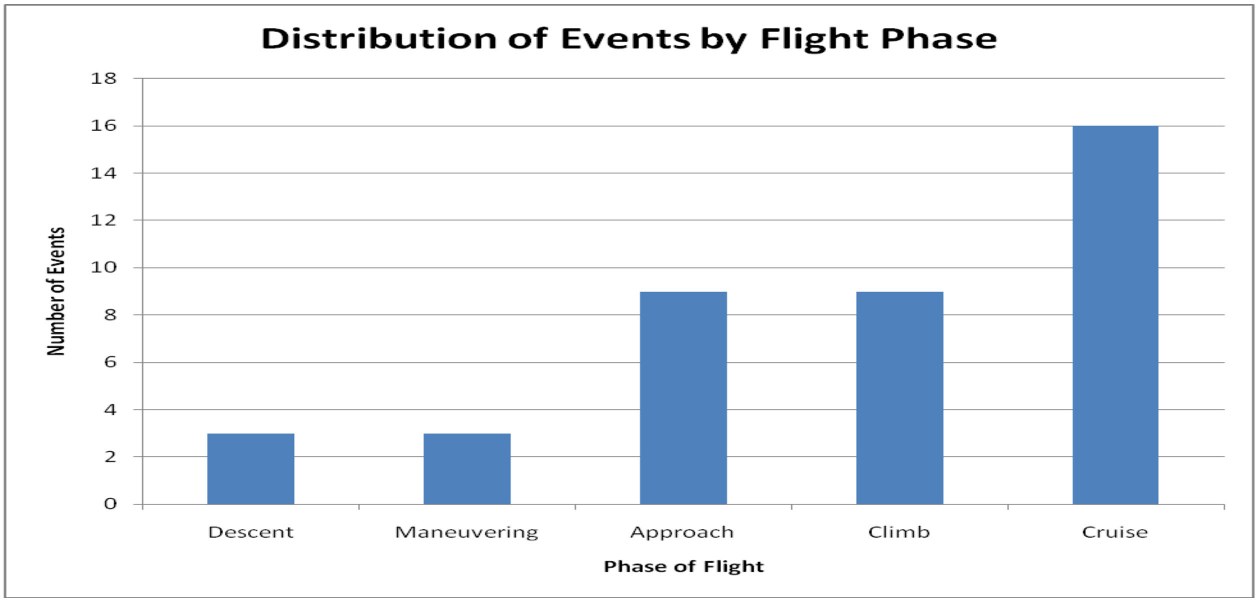


Figure 2: Distribution of Events by Phase of Flight.

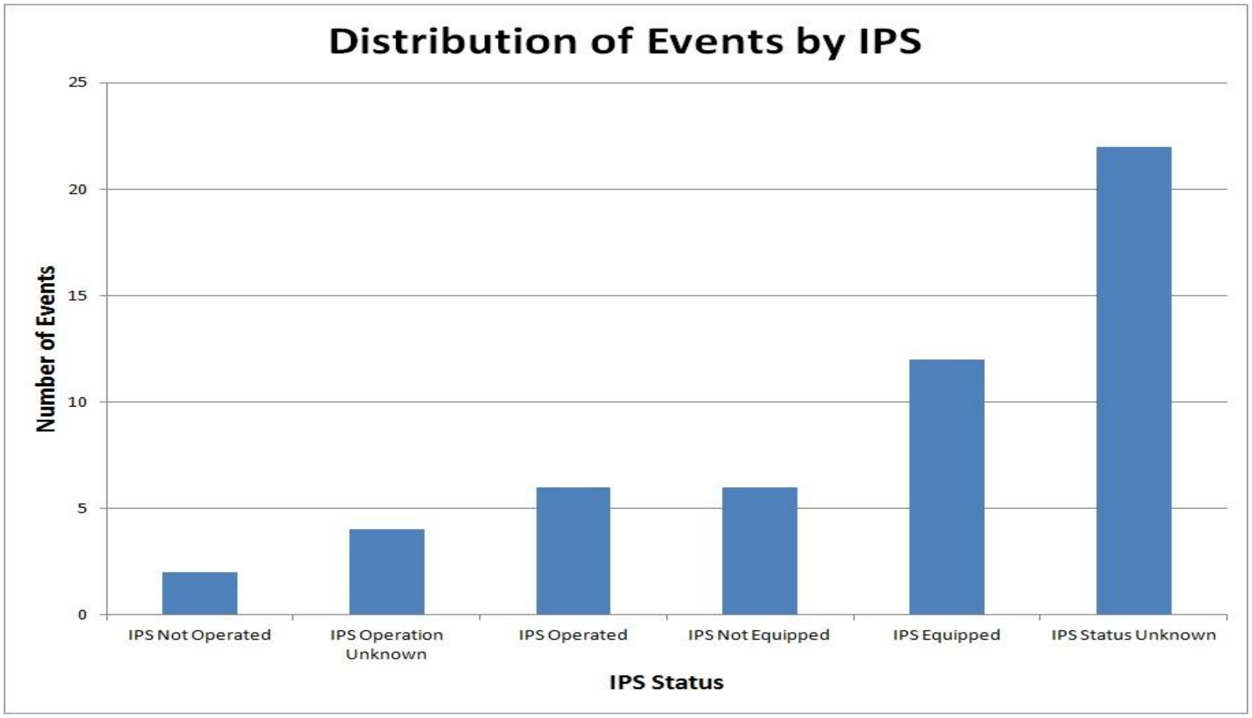


Figure 3: IPS Status and Operation

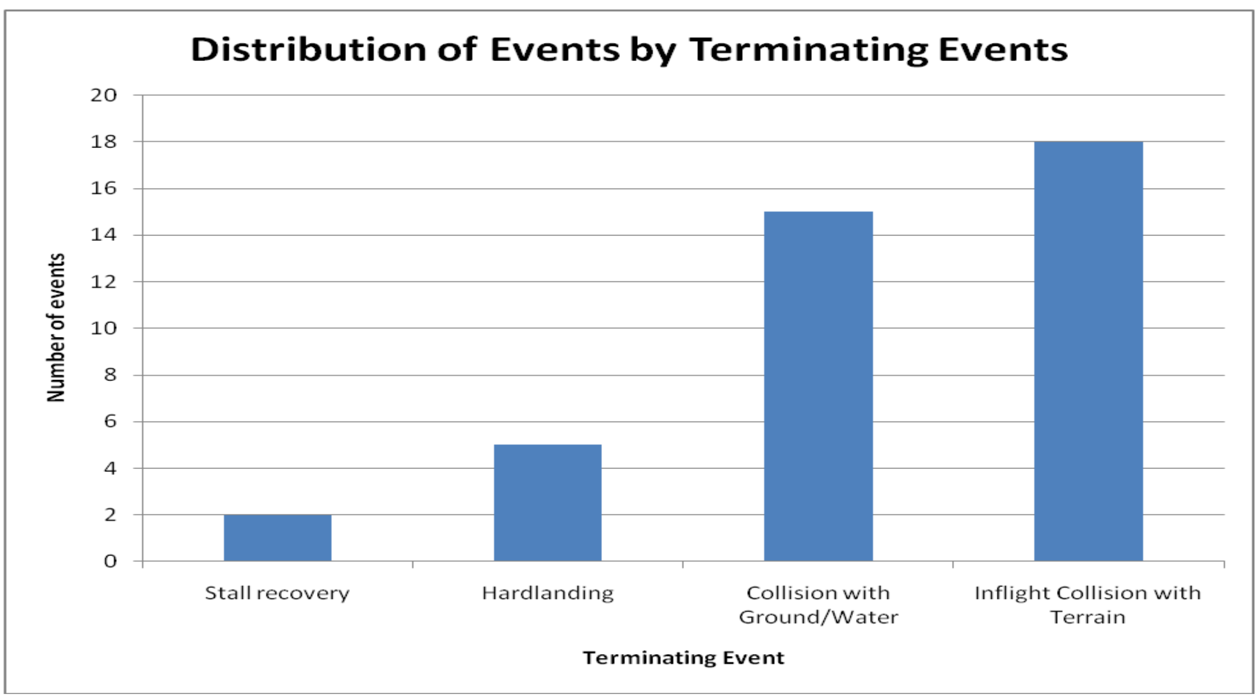


Figure 4: Distribution of Terminating Events

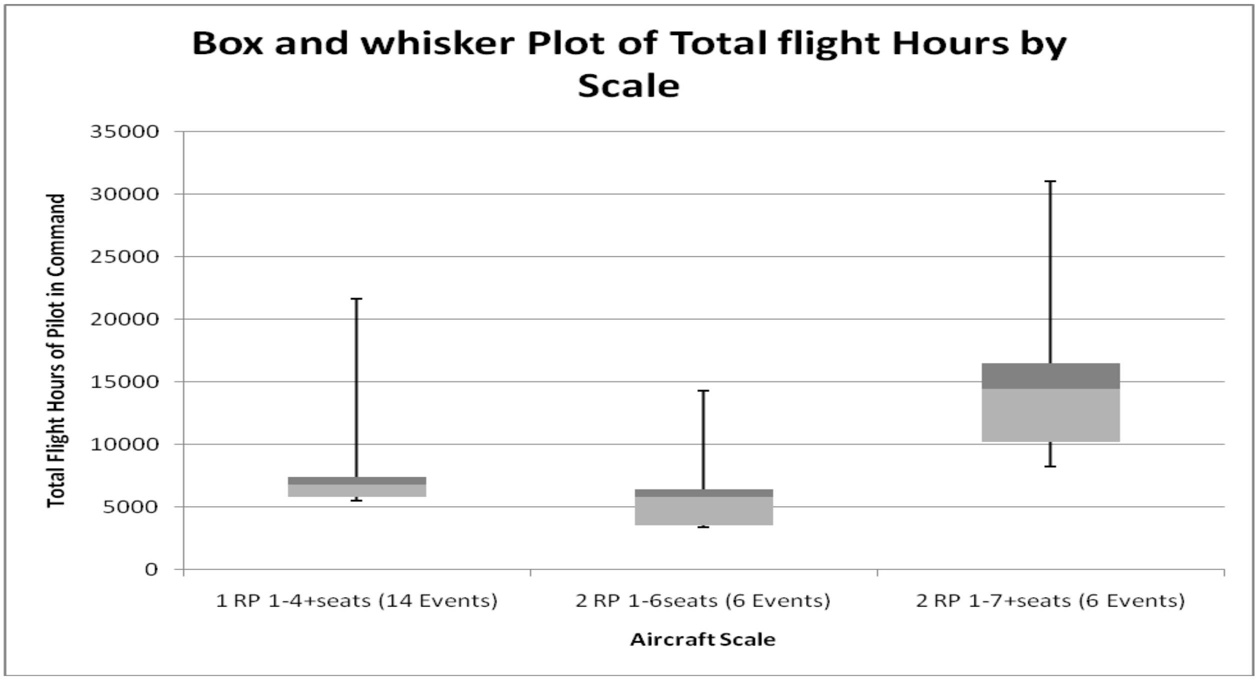


Figure 5: Distribution of Total Flight Hours by Scale

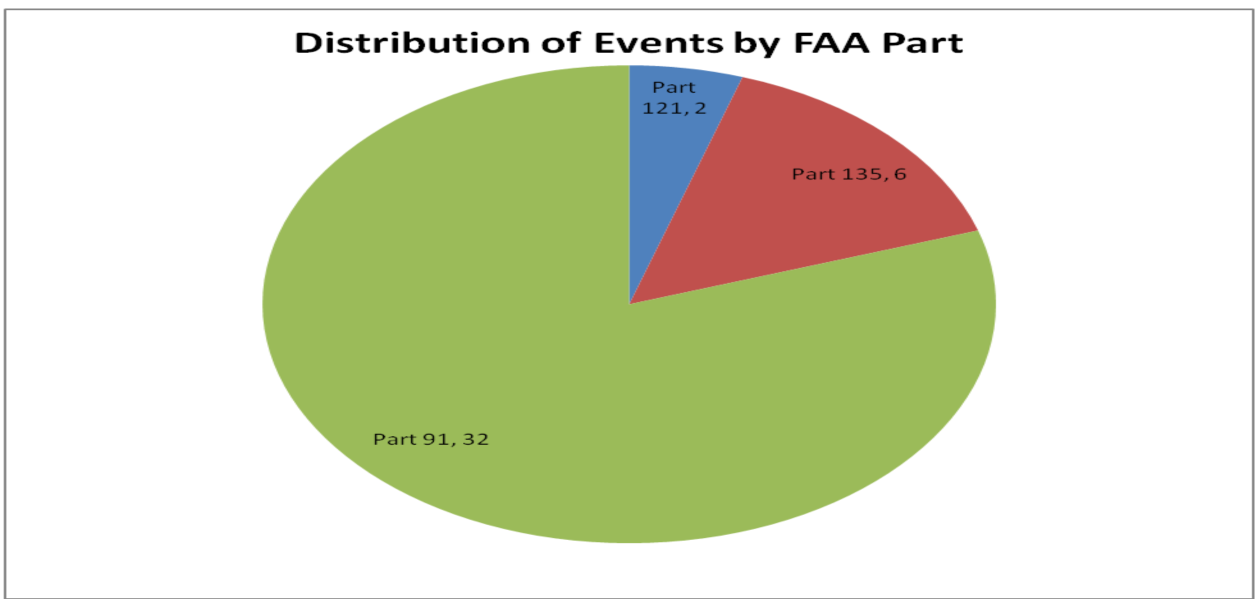
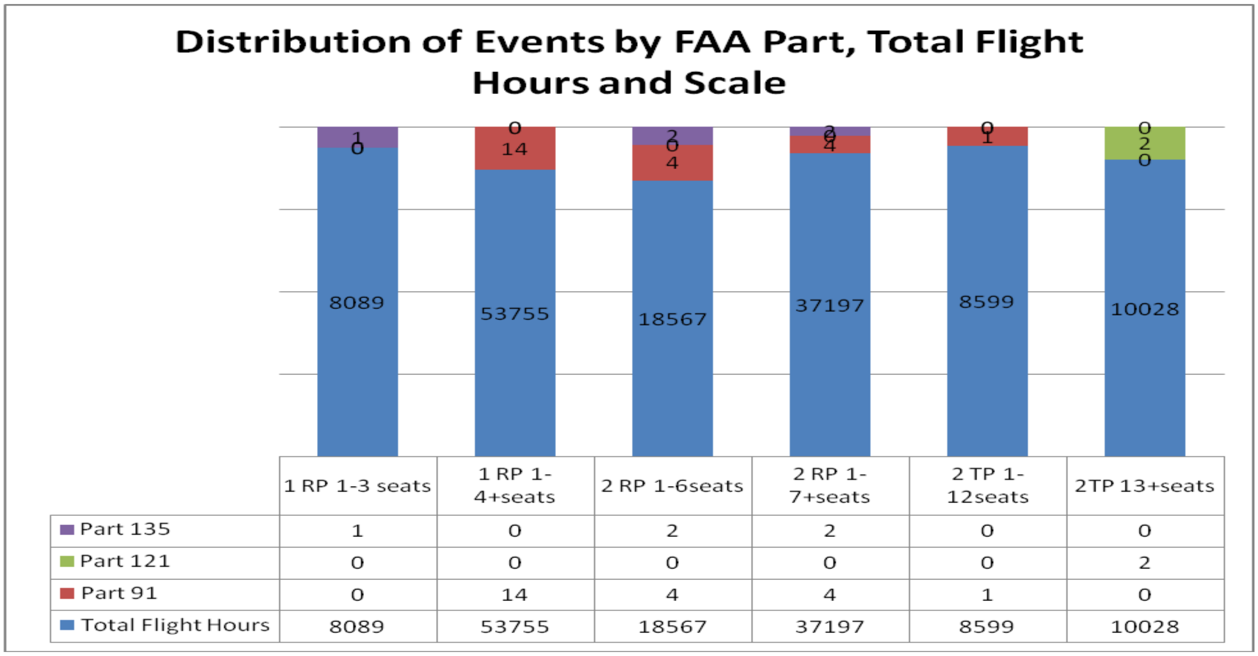


Figure 6: Distribution of Events by FAA Part



	1 RP 1-3 seats	1 RP 1-4+seats	2 RP 1-6seats	2 RP 1-7+seats	2 TP 1-12seats	2TP 13+seats
Part 135	1	0	2	2	0	0
Part 121	0	0	0	0	0	2
Part 91	0	14	4	4	1	0
Total Flight Hours	8089	53755	18567	37197	8599	10028

Figure 7: Distribution of Events by FAA Part and Total Flight Hours

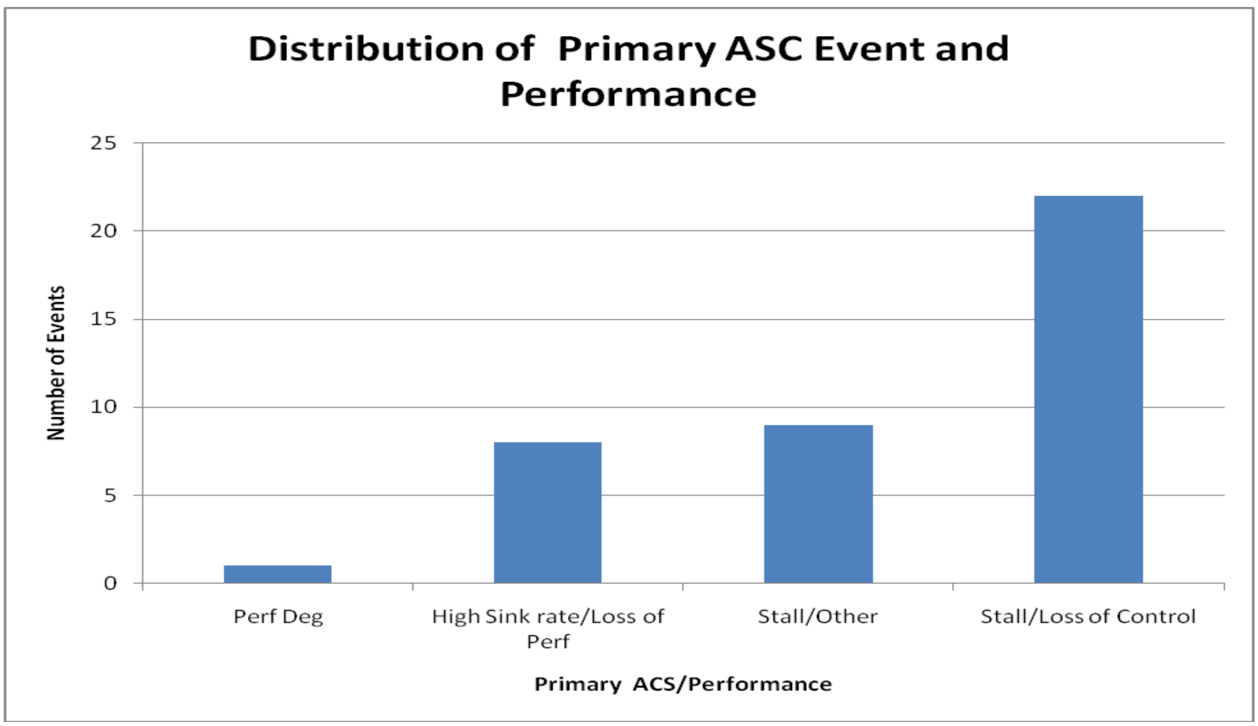


Figure 8: Distribution of ASC Events by Scale

FAA Region										
Alaska	AK									
	3									
Central	IA	KS	MO	NE						
		3	2	2						
Eastern	DC	DE	MD	NJ	NY	PA	VA	WV		
					1	1	1			
Great Lakes	IL	IN	MI	MN	ND	OH	SD	WI		
		1	3			2	1			
New England	CT	ME	MA	NH	RI	VT				
		1	1							
Northwest Mountain	CO	ID	MT	OR	UT	WA	WY			
	2	1	1	1		2	2			
Southern	AL	FL	GA	KY	MS	NC	PR	SC	TN	VI
	1		1	1		1			3	
Southwest	AR	LA	NM	OK	TX					
Western Pacific	AZ	CA	HI	NV						
	1	1								

Figure 9: Distribution of Events by FAA Regional Zoning

Vita

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