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Abstract

Aircraft accidents resulting from an in-flight loss of control have been the leading killer in aviation for more than a decade, but have only recently become a topic of serious concern in the aviation industry. There is a current trend of highly-trained and experienced pilots losing control of large, advanced multiengine turbine aircraft, resulting in catastrophic accidents, with many casualties. Utilizing an analysis of all National Transportation Safety Board accident reports involving multiengine turbine aircraft in the United States over the past ten years, this study examined the contributing factors among the fatal in-flight loss of control accidents involving such aircraft. The data were analyzed and the five most frequent causes of loss of control accidents were identified, along with a number of factors that shared strong interactions. The results provide important insight into the nature of these factors for future research and training techniques.

Keywords: in-flight loss of control, contributing factors, multiengine aircraft accidents

Introduction

Though it has accounted for the largest share of worldwide passenger deaths over the past decade, in-flight loss of control (LOC) accidents have only recently become a serious matter in the aviation industry. According to a 2011 Boeing Commercial Airplanes study of the worldwide commercial jet fleet (excluding aircraft manufactured in the Commonwealth of Independent States or former Union of Soviet Socialist Republics, due to a lack of operational data), there have been twenty fatal LOC accidents that resulted in nearly 1,850 deaths from 2001 to 2010 (Boeing Commercial Airplanes, 2011). This type of accident surpassed controlled flight into terrain (CFIT) as the leading cause of fatalities in commercial aviation in 2006, and continues to widen its margin each year since then (Chandler, 2011). There appears to be a disturbing trend that the highly-trained and qualified pilots at the controls of the aircraft involved in these seemingly preventable accidents, fail to maintain effective aircraft control.

The purpose of this study was to explore the factors contributing to fatal in-flight LOC accidents involving multiengine turbine aircraft over the past ten years. The findings of the study may help training programs and pilots address initiatives to mitigate their occurrence. It was hypothesized that due to the complex nature of operations and extensive training required to command a multiengine turbine-powered aircraft, in-flight LOC accidents occur more frequently as a result of events outside of a pilot's control, such as system failure.

Review of Literature

Defining Loss of Control

Because most LOC events involve a catastrophic impact, they often result in a significant number of fatalities. It has been estimated that 80 percent of all in-flight LOC accidents result in at least one fatality (National Aeronautics and Space Administration [NASA], 2010), and the number of deaths among LOC accidents involving airliners over the past decade is nearly twice that of the next highest accident type, controlled flight into terrain (Sorensen, 2011). The International Civil Aviation Organization (ICAO) estimates that in-flight LOC accounts for 9 percent of the total number of accidents, but 29 percent of fatal accidents and 28 percent of the total fatalities (International Civil Aviation Organization [ICAO], n.d.). This type of accident is responsible for an exceptional proportion of the fatalities in air carrier operations. To facilitate an understanding of the reasons for this, in-flight LOC must be clearly defined as the partial or complete loss of control of the airplane during an airborne phase of flight, or the period from when the wheels lift off the ground to when the wheels touch down. This loss of control can occur during either visual or instrument meteorological conditions, and weather, such as flight in icing conditions, can be a factor. Additionally, in-flight LOC can be the result of a deliberate maneuver by the pilot, including all intentional and unintentional stalls, as well as the configuring of the aircraft's lift control systems (flaps and slats). However, cockpit crew vision related events, such as collision with terrain due to somatogyral illusions, though the pilot's maintenance of control may be questionable, are classified as CFIT (ICAO, n.d.). It is the inability of the pilots to control the aircraft before it contacts the ground that is the fundamental difference between in-flight LOC and CFIT.

Types of Loss of Control

In the 2010 study *Causal Factors and Adverse Conditions of Aviation Accidents and Incidents Related to Integrated Resilient Aircraft Control*, NASA determined nine causes secondary to LOC:

1. LOC secondary to system/component failure/malfunction (SCFM): In each of these events, LOC occurred secondary to a failure/malfunction. In some of these

events, it may have been possible for the flight crew to maintain control, but in others the LOC was unavoidable.

2. LOC secondary to aircraft damage – fire/explosion
3. LOC secondary to aircraft damage – mid-air collision with another aircraft, bird, or skydiver
4. LOC secondary to aircraft damage – weather-induced damage (from turbulence, hail or lightning)
5. LOC secondary to aircraft damage – pilot-induced (most often exceeding the designed stress limits of the aircraft)
6. Control upset – pilot-induced: Control was lost due to the actions or inaction of the pilot, without other preceding or concurrent events.
7. Control upset – low altitude operations: In these accidents, control was lost in conjunction with some type of low-level maneuvering (aerobatics, aerial application, banner towing, evasive maneuvers to avoid a collision, sight seeing, scud running, etc.)
8. Control upset – severe weather: In these events, the LOC was secondary to an encounter with severe weather – icing, turbulence, thunderstorm, or wind shear – or to inadequate ice/frost/snow removal prior to takeoff
9. Control upset – other events: The other events include loss of engine power, pilot incapacitation, or inadequate preflight inspections that resulted in open doors, gust locks that were not removed, or compromised pitot systems.

To better understand the factors involved in LOC accidents and why they happen, the circumstances surrounding each type of event must be analyzed. Because some of the nine causes determined by the NASA study share similar conditions, they can be classified into three overarching groups: SCFM, aircraft damage, and control upset. Twenty-four total systems and components have been cited as contributing to LOC secondary to SCFM, with the landing gear, brakes, aircraft flight control (linkages and cables), propulsion systems, and control surfaces being the most critical in regards to the frequency of incidents (NASA, 2010). An error in the operation of critical systems such as these can make the aircraft difficult or impossible for the flight crew to control. Loss of control secondary to aircraft damage occurs when the aircraft sustains damage from an external source, whether it is natural or artificial in nature. Lastly, control upset, which represents the largest, and often most preventable category of LOC accidents, is the failure of the flight crew to maintain control of the mechanically and structurally healthy aircraft (NASA, 2010). It is important to note that any cause secondary to LOC can overlap with another (Dornheim, 1998), as it is often multiple factors in conjunction with one another that lead to accidents.

Case Studies

Several specific accident reports can be examined to highlight the different characteristics and factors involved during each of the three groups of LOC accident.

Fatal crash of Marlin Air Cessna Citation into Lake Michigan. An example of a LOC accident secondary to SCFM is illustrated by the crash of a Cessna Citation as a result of the flight crew's incorrect handling of a flight control malfunction shortly after takeoff. The accident occurred during the early afternoon of June 4, 2007, as the Cessna Citation 550 impacted Lake Michigan on departure from General Mitchell International Airport in Milwaukee, Wisconsin. Almost immediately after takeoff and during the initial turn, the captain noticed the aircraft was forcing an uncommanded bank to the left, and stated he was "fighting the controls". While attempting to regain control of the aircraft and troubleshoot the control anomaly with the assistance of the first officer, the captain allowed the aircraft to accelerate beyond the manufacturer's maximum recommended speed for the given condition. Due to this excessive speed, the flight control forces were significantly increased and the aircraft became more difficult to control. Ultimately, the flight crew was unable to regain control of the aircraft and it struck the water in a steep nose-down, left-wing-low attitude. After completing its accident investigation and subsequent analysis, the NTSB concluded that two possible scenarios could explain the cause for this abnormal control situation: an inadvertent autopilot engagement or a runaway electric pitch trim. It was the failure of the aircraft's flight control system, coupled with the improper response by the crew that led to the loss of control of the aircraft (National Transportation Safety Board [NTSB], 2009).

Fatal crash of American Airlines Flight 587 in Belle Harbor, New York. A commonly-cited example of loss of control due to aircraft damage is the crash of American Airlines flight 587 in Belle Harbor, New York after departing from John F. Kennedy International Airport on November 12, 2001. Shortly after takeoff and while in trail of a recently departed Japan Air Lines 747-400, the Airbus A300 was directed by air traffic control to fly a visual departure procedure and continue its climb. Less than a minute later, the first officer, who was the flying pilot, commenced a turn to the southeast. During this turn and while climbing through two thousand feet, the aircraft encountered wake turbulence generated by the 747-400 that had departed less than two minutes before. The NTSB determined that, to counter the abrupt change in aircraft attitude, the first officer applied unnecessary and excessive rudder pedal inputs causing the vertical stabilizer and rudder to separate from the aircraft. Upon the separation of this critical airframe component, control was lost and the aircraft crashed (NTSB, 2005).

Fatal crash of Learjet 35 on approach to the Truckee-Tahoe Airport. Unfortunately, there are many examples of loss of control accidents due to control upsets, many of which involve high performance and technologically advanced aircraft. In particular, the December 28, 2005 crash of a Learjet 35 attempting to land from a circling approach at the Truckee-Tahoe Airport in Truckee, California illustrates how a flight crew consisting of two qualified pilots can make critical mistakes leading to the loss of control of the aircraft without any preceding event. As the aircraft entered the traffic pattern from the circling approach, the captain failed to properly correct for a gusty surface wind, and as a result, experienced an inadvertent stall while attempting to align with the runway. It was the simple inadequate management of airspeed while maneuvering the aircraft that led directly to the loss of control and subsequent crash. There were no abnormal conditions or occurrences that contributed to the accident, and as a result, the NTSB concluded the cause of the accident to be pilot error (NTSB, 2007).

Concerns Regarding Loss of Control Accidents

With such a large number of LOC accidents attributable to pilot error, questions arise regarding the presumably well-trained and experienced pilots at the controls. Aircraft with modern avionics have made commercial aviation statistically safer by providing pilots with more comprehensive and relevant information, thus reducing the workload during critical phases of flight. Occasionally, however, minor problems can quickly snowball out of control, resulting in devastating results when pilots do not understand, misinterpret, or act incorrectly upon the increasingly complex systems in the cockpit. A commonly-cited area of deficiency is aircraft automation. There is growing concern that pilots exhibit increasing reliance upon automated flight control systems, possibly dulling their flying skills and leaving them less than proficient to take the controls in times when their skills and experience are needed most (Sorensen, 2011).

Methodology

The data for this study were acquired from the National Transportation Safety Board (NTSB) Accident Database and Synopses, which contains information about civil aviation accidents and selected incidents in the United States, its possessions and territories, and international waters. Using the query function, data were collected utilizing the following criteria:

Event Start Date: 11/01/2001

Event End Date: 11/01/2011

Injury Severity: Fatal

Category: Airplane

Amateur Built: No

Number of Engines: 2/3/4

Engine Type: Turbo Fan/Turbo Jet/Turbo Prop/Turbo Shaft

Report Status: Probable Cause

The reports returned from these search criteria accounted for all accidents involving these types of aircraft over the specified time period. In order to narrow the selection to just LOC accidents, each NTSB published Brief of Accident was read to determine whether the accident was an in-flight LOC per the ICAO definition. Additionally, accidents outside the contiguous United States were disregarded to reduce the chance of confounding factors unique to areas such as Alaska and Hawaii. Of the 131 total accidents from 11/1/2001 to 11/1/2011, 52 were determined to be LOC. Accidents other than in-flight LOC, and LOC accidents occurring for undetermined reasons, were not considered.

A database was compiled from the 52 NTSB probable causes. The narratives were analyzed against the nine secondary causes to LOC accidents as discussed in the 2010 NASA study. These were coded into nine categories: 1.) System/Component Failure/Malfunction, 2.) Aircraft Damage – Fire/Explosion, 3.) Aircraft Damage – Mid-air Collision, 4.) Aircraft Damage – Weather-Induced, 5.) Aircraft Damage – Pilot-Induced, 6.) Control Upset – Pilot-Induced, 7.) Control Upset – Low Altitude Operations, 8.) Control Upset – Severe Weather, and 9.) Control Upset – Other Events. Nine columns were added to the database for each category. As the accidents were assigned to the applicable secondary causes, a mark was placed in the corresponding column. Each probable cause was assigned to one or more secondary causes based on the definition from NASA's work, as interpreted by the researcher. Two unbiased third party experts, each possessing extensive practical and academic experience in aviation, repeated this process, to help ensure the accuracy of the selections.

Each of the nine columns was tallied to determine the most frequent cause secondary to in-flight LOC accidents, and the results recorded in a table. The number of times each category was the only secondary cause to the LOC accident was also noted. Additionally, because of the high frequency of interactions among multiple categories, an incidence matrix was constructed. An incidence matrix is "a way of representing the relation *R* that's particularly useful for calculating various measures of connection between the elements of the two sets under consideration" (Casti, 1994, p. 174). This incidence matrix provides a means of analyzing the relationships between the different causes secondary to LOC, specifically the frequency of interactions between them. The table and incidence matrix facilitate a means of analyzing the data in order to determine the most frequent cause secondary to LOC and the frequencies in which each cause interacts with the others. From this analysis, a series of specific areas of focus were determined for future research and training consideration.

Results

The categorized data from the database were organized into a table. Table 1 shows the frequency of each category of causes secondary to LOC in the fatal accidents of multiengine turbine aircraft in the United States over the past ten years.

Table 1

Frequency of categories cited as the cause to a LOC accident in descending order

	Category	Total	Only Cause
7	Control Upset - Low Altitude Ops	21	0
6	Control Upset - Pilot-Induced	18	2
1	SCFM	14	7
8	Control Upset - Severe Weather	13	7
9	Control Upset - Other Events	12	3
3	Aircraft Damage - Mid-air Collision	3	3
4	Aircraft Damage - Weather-Induced	3	1
5	Aircraft Damage - Pilot Induced	2	0
2	Aircraft Damage - Fire/Explosion	0	0

The most common factor secondary to LOC accidents was a control upset during low altitude operations. This could include any loss of control in conjunction with some type of low-level maneuvering, such as evasive maneuvers to avoid a collision, sightseeing, scud running, traffic pattern operations, initial climbout, approach to landing, or a missed approach/go-around. Second was pilot-induced control upset, in which control was lost due to the actions or inactions of the pilot, but without any other preceding events. The third most common was a loss of control due to a system/component failure/malfunction. The fourth most frequent cause was a control upset as a result of an encounter with severe weather, such as thunderstorms, turbulence, and icing. The fifth most frequent cause was simply a control upset due to other events, including loss of engine power and pilot incapacitation or impairment. The remaining categories, aircraft damage sustained from a mid-air collision, weather-induced aircraft damage, pilot-induced aircraft damage, and damage as a result of a fire or explosion, respectively, were cited as causes significantly less frequently. Loss of control due to SCFM and encounters with adverse weather, as compared to the other categories, were most frequently the only factors leading to a LOC accident.

Twenty-nine of the 52 total accidents were attributed to two or more causes. The incidence matrix in Figure 1 illustrates the interactivity between the different factors secondary to the LOC accidents. Of the 18 and 21 total accidents attributed to categories 6 and 7, respectively, 14 accidents involved an interaction between the two. The interaction between categories 7 and 9 was the second most frequent, with 6 occurrences. Following that are the relationships between categories 1 and 9, 6 and 8, and 7 and 8. Of the 45 different relationships possible, there existed 10 actual relationship occurrences.

R	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1					2	1	2		4
2									
3									
4								2	
5									
6							14	4	2
7								4	6
8									
9									

Figure 1. Incidence matrix showing the relationships between the different categories of factors secondary to LOC accidents.

Discussion

From this analysis, it was determined that the five most frequent contributing factors secondary to fatal LOC accidents of multiengine turbine aircraft over the past ten years were control upset in conjunction with low altitude operations, pilot-induced control upset, system/component failure/malfunction, control upset as a result of an encounter with severe weather, and control upset due to other events. Because of the subjective nature of assigning one or more causes to an accident, the validity of this selection was confirmed through the comparison of the selections submitted by the third party experts. Though the submissions did not match exactly the researcher's selections, the top five most frequent causes to loss of control were confirmed. This provides a degree of confidence that those causes were attributable as the most frequently occurring in the scope of the study.

An analysis of the frequency of the top five contributing factors casts an incomplete picture of in-flight LOC accidents. Because more than half of the accidents in the dataset were attributed to multiple causes, those frequencies insufficiently describe the data. An additional careful consideration of the relationships between the causes must also be made. There are a total of 41 relationships among the different causes. Most of these relationships were infrequent and not appreciably greater or less than the others. However, control upset during low altitude operations and pilot-induced control upset had the highest rates of interaction by a large margin, with 14 accidents citing both causes. This was more than double the relationship of causes 7 and 9, which had the next highest frequency of interaction. Since these two factors also have the highest rate of occurrence, an important correlation can be postulated. Accidents involving a loss of control due to pilot error without preceding events frequently happened in conjunction with low altitude maneuvering. This contradicts the hypothesis that most LOC accidents involving multiengine turbine aircraft occurred for reasons at least partially outside of the pilots' control. In both of these factors determined to be the most important for LOC accidents, it was essentially pilot error that lead to the accident. This indicates the need for training programs to raise awareness, identify the dangers, and adjust the focus to issues regarding interaction of pilot error as a contributing factor in LOC accidents, in low altitude maneuvering scenarios. An emphasis on this is important, although addressing the three other primary causes secondary to LOC (system/component failure/malfunction, weather-induced control upset, and control upset occurring due to other events) must not be overlooked.

The scope of this study was limited to accidents involving multiengine turbine aircraft in the contiguous United States over the past ten years. Loss of control accidents occur in all types of aircraft, all over the world. Further research should be conducted to explore the frequency and interactions of the causes of these accidents. Also, further study is recommended of the relationships among the different causes of loss of control, to better understand how they interact, specifically between pilot-induced control upset and control upset in conjunction with low altitude maneuvering.

Conclusions

In-flight loss of control accidents are responsible for the highest number of fatalities in the aviation industry in both the United States and the world. Having surpassed CFIT within the recent decade as being responsible for the most fatalities, significant attention has been aimed towards mitigating this type of accident. Even in advanced, high performance aircraft, operated in large part by highly-trained and experienced pilots, it is pilot error that most often leads to a loss of control of the aircraft and the subsequent crash. Specifically, the findings of this study determined pilot-induced control upsets without preceding events and control upsets in conjunction with low altitude maneuvering to be the two most frequent causes of LOC accidents. Importantly, a frequent interaction between the two causes was found to exist, implying that the two types of causes are interactive with each other and therefore must be studied together. Single causes cannot be attributed to most LOC accidents, as it is the complex interaction among different factors that, together, result in disaster.

Some preliminary recommendations can be generated from the findings of this study with the ultimate goal to begin decreasing the number of in-flight LOC accidents involving multiengine turbine aircraft:

1. Conduct further research on the interactions between the different causes secondary to LOC accidents, with a primary focus on the relationship between pilot-induced control upset and control upset in conjunction with low altitude maneuvering.
2. Place a stronger emphasis on low altitude, low speed operations in training.
3. Stress the always-present vulnerability to pilot error, even for pilots with considerable experience and training.

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