Aircraft Loss-of-Control Accident Analysis

Christine M. Belcastro* and John V. Foster†
NASA Langley Research Center, Hampton, Virginia, 23681

Loss of control remains one of the largest contributors to fatal aircraft accidents worldwide. Aircraft loss-of-control accidents are complex in that they can result from numerous causal and contributing factors acting alone or (more often) in combination. Hence, there is no single intervention strategy to prevent these accidents. To gain a better understanding into aircraft loss-of-control events and possible intervention strategies, this paper presents a detailed analysis of loss-of-control accident data (predominantly from Part 121), including worst case combinations of causal and contributing factors and their sequencing. Future potential risks are also considered.

Nomenclature

CAST	=	Commercial Aviation Safety Team
ICAO	=	International Civil Aviation Organization
LOC	=	Loss of Control (in-flight)
NASA	=	National Aeronautics and Space Administration
NextGen	=	Next Generation Airspace Operations Concept
NTSB	=	National Transportation Safety Board
PIO	=	Pilot Induced Oscillation

I. Introduction

Loss of control remains one of the largest contributors to fatal aircraft accidents. As shown in Figure 1, in-flight loss of control (LOC) is the largest fatal accident category for commercial jet airplane accidents worldwide occurring from 1999 through 2008, and resulted in 22 accidents and 1,991 total fatalities. [1] Aircraft loss of control is a significant contributor to accidents and fatalities across all vehicle classes, operational categories, and phases of flight. It is also a highly complex event, usually resulting from multiple causal and contributing factors that can occur individually or (more often) in combination. There is therefore no single intervention strategy that can be readily identified to prevent LOC accidents. In order to develop effective intervention strategies for preventing LOC accidents, it is necessary to analyze how these events unfold. In Reference [2], 74 LOC accidents were reviewed for the time period 1993 – 2007, which resulted in 42 hull loss accidents and 3241 fatalities. The analysis of this reference groups the accidents into the categories aerodynamic stall, flight control system, spatial disorientation of the crew, contaminated airfoil, and atmospheric disturbance. There is also a detailed discussion of accidents in each of these categories and a comparison with older accidents that occurred prior to 1993 in order to identify emerging trends. This reference also provides a definition of aircraft upset conditions, which is defined therein as "any uncommanded or inadvertent event with an abnormal aircraft attitude, rate of change of aircraft attitude, acceleration, airspeed, or flight trajectory". As also noted in Ref. [2], "abnormal" must be determined relative to phase of flight and aircraft type. Reference [3] contains an analysis of LOC accidents between 1988 and 2004 relative to operational categories, including Parts 121, 135, and 91. This report states that "in flight loss of control is a serious aviation problem", and that "well over half of the loss of control accidents included at least one fatality (80% in Part 121), and roughly half of all aviation fatalities in the studied time period occurred in conjunction with loss of control". The study of Ref. [3] also found that about 30% of Part 121 loss of control accidents involved system/component failure/malfunction, and that icing and adverse winds were also the primary cause of many

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* Senior Researcher, Dynamic Systems and Control Branch, MS 308, E-Mail: christine.m.belcastro@nasa.gov; AIAA Senior Member.
† Senior Researcher, Flight Dynamics Branch, MS 308, E-Mail: john.v.foster@nasa.gov; AIAA Senior Member.

accidents. In 2009, NASA commissioned an independent study of aircraft loss of control. [4] The final report from this study organized causal and contributing factors into human-induced, environmentally-induced, and systems-induced categories and concluded that "no single category is solely responsible for loss of control accidents" and that "accidents occur when combinations of breakdowns happen across human and engineering systems, and often in the presence of threats posed by the external environment". This report further states that "a sympathetic read of the loss of control accidents should leave one with little hope of reducing them if efforts toward improvement were aimed in a single direction or within a single category".

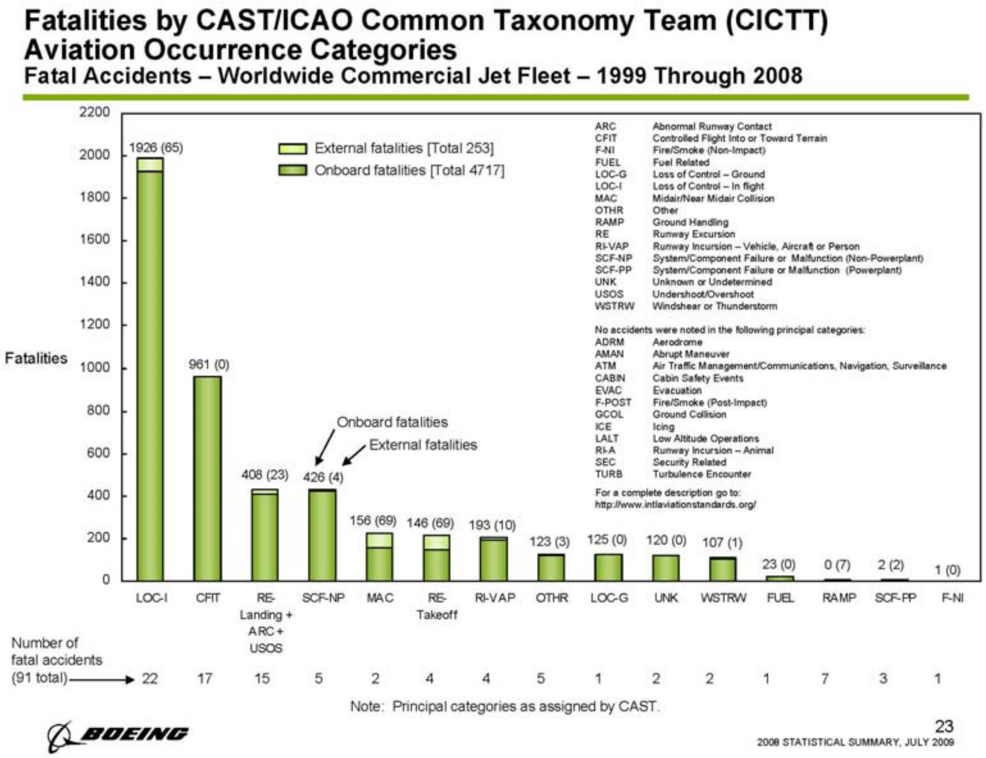

Figure 1. Aircraft Accident Statistics for Worldwide Commercial Jet Fleet, 1999 – 2008.

In this paper, the analysis seeks to identify worst case combinations and sequencing of precursors to aircraft LOC accidents that were predominantly from the Part 121 category operations (both large transports and smaller regional aircraft). These LOC accident precursors are called "causal and contributing factors" throughout this paper. The LOC accidents considered in this paper included accidents that involved vehicle upsets, as well as those involving failures, impairment, or damage to the flight control capability of the aircraft (including control surfaces, flight control system or components, and the engines) or to the vehicle airframe (when the damage was sufficient to alter vehicle dynamics and control characteristics) whether or not they led to an upset condition (or there was evidence of upset cited in the report). Causal and contributing factors were identified from reading the full reports available for each accident (not through key word search), and these factors were categorized into three groups so that worst case combinations and sequences could be identified. In understanding combinations of loss-of-control factors and how they occur sequentially, it may be possible to develop a holistic intervention strategy for breaking the sequences that result in loss of control accidents. This is the primary motivation for the LOC accident analysis presented in this paper. Section II contains the analysis results, and conclusions are given in Section III.

II. Aircraft Loss-of-Control Accident Analysis

A review of 126 LOC accidents (predominantly from Part 121, including large transports and smaller regional carriers) occurring between 1979 and 2009 (30 years) and resulting in 6087 fatalities was performed for the analysis, and a listing of these accidents is provided in the Appendix. This accident set does not represent an exhaustive search throughout this time period, and it does not include military, private, cargo, charter, and corporate accidents. Russian aircraft accidents were also excluded due to a general lack of detailed information in the associated reports. Of this total accident set, 91 accidents resulting in 4190 fatalities occurred between 1994 and 2009 (15 years). The review was based on accident reports available on the Aviation Safety Network [5] and National Transportation Safety Board (NTSB) [6] websites. The level of detail in analyzing each accident was therefore dependent on the level of detail provided in the accident reports. Information from each report was transcribed into a categorized set of causal and contributing factors, using the following scheme. The causal and contributing factors were grouped into three categories: adverse onboard conditions, vehicle upsets, and external hazards and disturbances.

Adverse onboard conditions included:

- vehicle impairment (including inappropriate vehicle configuration, contaminated airfoil, and improper vehicle loading);
- system faults, failures, and errors (resulting from design flaws, software errors, or improper maintenance actions);
- vehicle damage to airframe and engines (resulting from fatigue cracks, foreign objects, overstress during upsets or upset recovery, etc.); and
- inappropriate crew response (including pilot-induced oscillations, spatial disorientation, mode confusion, ineffective recoveries, crew impairment, and failures to take appropriate actions).

External hazards and disturbances included:

- poor visibility;
- wake vortices;
- wind shear, turbulence, and thunderstorms;
- snow and icing conditions; and
- abrupt maneuvers for obstacle avoidance or collisions.

Vehicle upsets included:

- abnormal attitude;
- abnormal airspeed, angular rates, or asymmetric forces;
- abnormal flight trajectory;
- uncontrolled descent (including spiral dive); and
- stall/departure (including falling leaf and spin).

A basic analysis of the contributions of each causal/contributing factor to the 126 accidents is given in Table 1. It should be noted in Table 1 that the factors are not mutually exclusive. For example, 119 LOC accidents involved one or more adverse onboard conditions, and the frequency of each individual factor within this category is listed. These numbers do not add up to 119, however, because there were many accidents involving more than one subfactor. Similarly, adding the number of accidents listed for the three categories exceeds the 126 total because many accidents involved multiple categories. The 23 accidents related to vehicle damage consisted of 20 airframe and system damage conditions, and 3 engine damage conditions. Table I is useful for determining the number of accidents and fatalities associated with individual causal and contributing factors, but it does not provide any information on combinations or sequencing of these factors. Nonetheless, this table identifies System Faults/Failures/Errors, Vehicle Impairment/Damage, Inappropriate Crew Response, Stall/Departure, Atmospheric Disturbances related to Wind Shear/Gusts, and Snow/Icing as the most significant contributors to the number of fatalities. The following subsections A and B address combinations and sequencing of LOC causal and contributing factors, respectively. Subsection C addresses future risks.

Table 1. Contributions to LOC Accidents and Fatalities by Individual Causal and Contributing Factors

Factor	Accidents	%	Fatalities	%
Adverse Onboard Conditions	**119**	**94.4**	**5683**	**93.4**
Vehicle Impairment	33	26.2	1134	18.6
System Faults / Failures / Errors	57	45.2	2807	46.1
Vehicle Damage	23	18.2	1780	29.2
Inappropriate Crew Response	54	42.8	2818	46.3
Vehicle Upsets	**98**	**77.8**	**4523**	**74.3**
Abnormal Attitude	18	14.3	219	3.60
Abnormal Airspeed / Angular Rates / Asymmetric Forces	14	11.1	701	11.5
Abnormal Flight Trajectory	4	3.2	272	4.47
Uncontrolled Descent	15	11.9	773	12.7
Stall / Departure	49	38.9	2622	43.1
External Hazards & Disturbances	**61**	**48.4**	**3246**	**53.3**
Poor Visibility	9	7.1	556	9.1
Wake Vortices	4	3.2	402	6.6
Wind Shear / Gusts / Thunderstorms	18	14.3	1126	18.5
Snow / Icing	28	22.2	595	9.8
Abrupt Maneuver / Collision	3	2.4	189	3.1

A. Analysis of Causal and Contributing Factor Combinations

In order to identify worst case combinations of LOC causal and contributing factors (as defined by number of accidents and resulting fatalities), 3-dimensional scatter plots were generated, and Figure 2 shows the first such plot. The three dimensions are aligned with the three categories identified in Table 1. Sphere size is directly proportional to the number of accidents, and sphere color depicts the number of fatalities as indicated by the legend. As indicated in Figure 2, worst case combinations include: system faults and failures occurring alone and in combination with upsets, icing conditions resulting in vehicle impairment, and inappropriate crew response combined with upset conditions. There are also a significant number of accidents and fatalities resulting from: vehicle damage occurring alone and combined with upsets, icing combined with inappropriate crew response and upsets, and wind shear and turbulence combined with inappropriate crew response and vehicle upsets. It should be noted that there is some overlap (i.e., some combinations that are not mutually exclusive) in the scatter plot of Figure 2, especially within the adverse onboard conditions dimension. This overlap is due to a significant number of accidents that involved multiple adverse onboard conditions. For example, some of the accidents shown for system faults and failures also involved inappropriate crew response. Alternatively, many of the accidents shown for inappropriate crew response also involved other adverse onboard conditions, such as vehicle impairment, failure, or damage. Some of this overlap (especially for the largest number of accidents and fatalities) is identified in Figure 3. While there is some overlap in the external hazards and disturbances and the vehicle upset dimensions, it is generally much smaller that the onboard dimension.

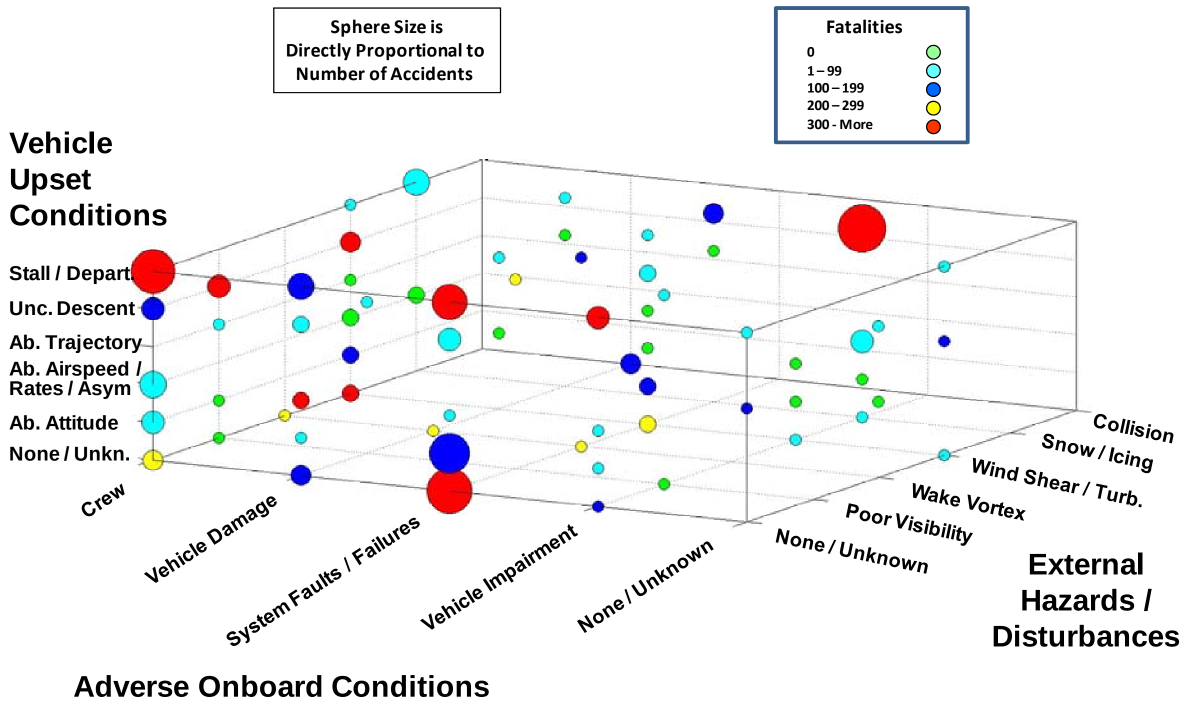

Figure 2. Combinations of LOC Causal and Contributing Factors, 1979 – 2009.

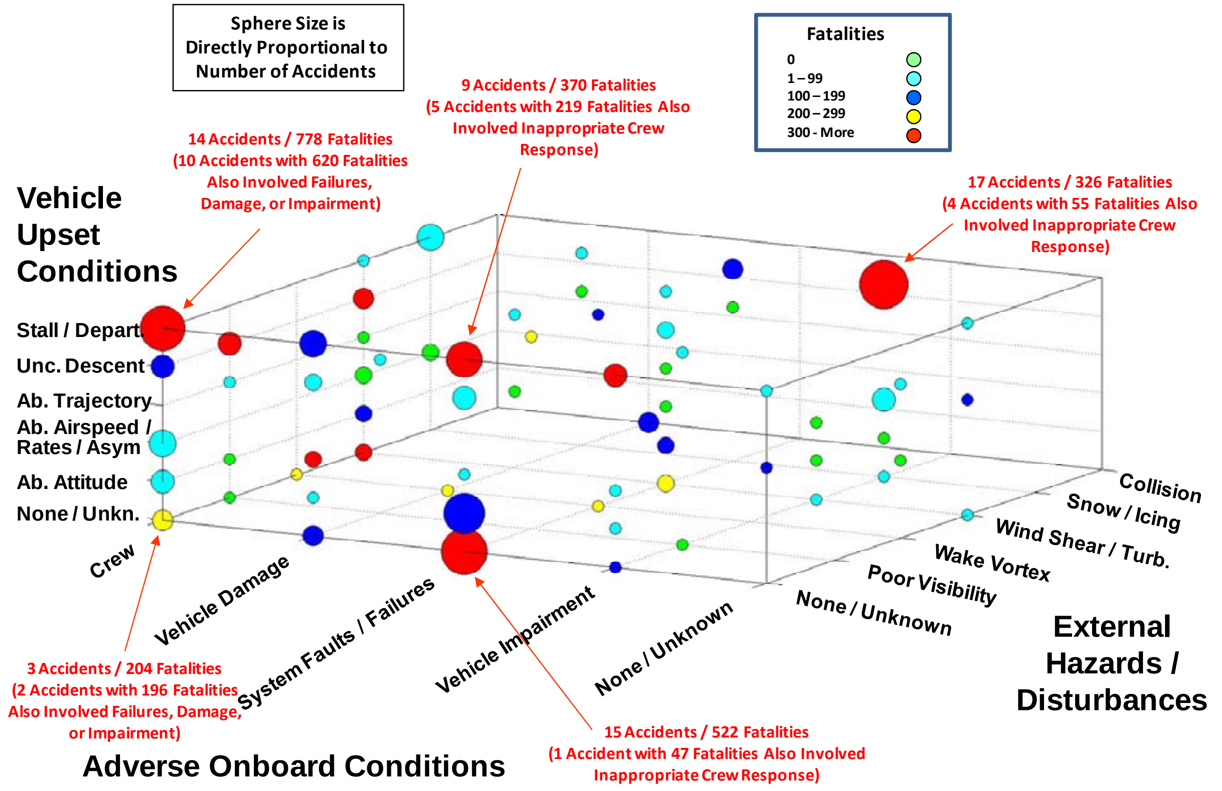

Figure 3. Identification of Overlap in LOC Causal and Contributing Factor Combinations, 1979 – 2009.

Figures 2 and 3 are based on the set of 126 accidents over the 30 year period analyzed in this study. It could be argued that some of the factors associated with accidents that occurred longer ago than 15 years could have already been resolved. While only 35 accidents in this data set occurred more than 15 years ago (i.e., between 1979 and 1994), this potential effect was considered by removing them in the scatter plot of Figure 4. As indicated in the figure, only minor differences are readily apparent. Some of these include: a lower number of fatalities for icing with vehicle impairment, and a lower number of accidents and fatalities associated with vehicle damage.

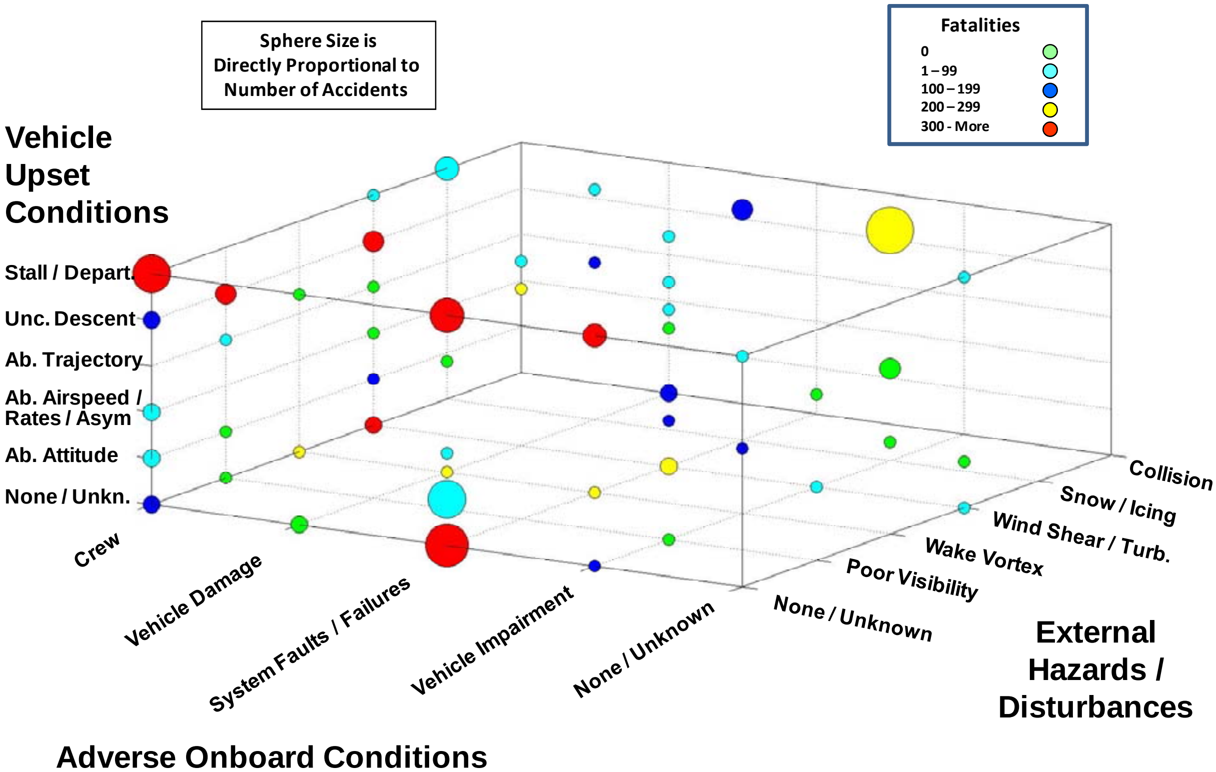

Figure 4. Combinations of LOC Causal and Contributing Factors, 1994 – 2009.

It is also of interest to consider LOC accidents that resulted in no fatalities. These accidents might be an indicator of conditions that were recoverable or of emerging trends leading to LOC fatal accident increases. Figures 5 and 6 show these plots for the 30 year and 15 year data, respectively.

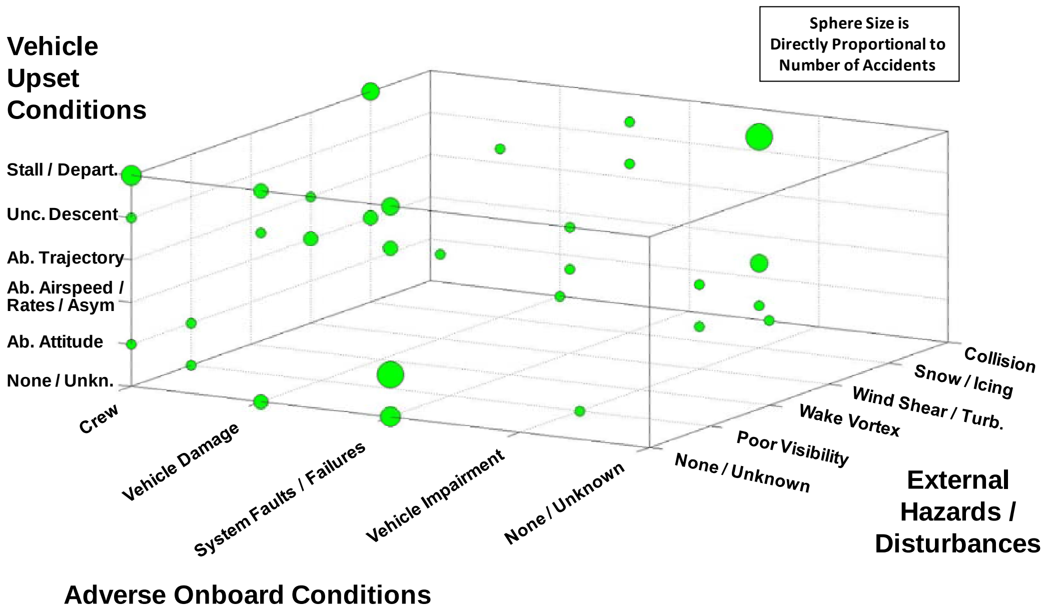

Figure 5. Combinations of LOC Causal and Contributing Factors for Nonfatal Accidents, 1979 – 2009.

The results of Figures 5 and 6 are very similar. This similarity indicates that many of the nonfatal accidents in the data set occurred during the more recent 15 year period (1994 – 2009). The largest numbers of nonfatal accidents were associated with failures (with and without upsets), vehicle damage (without upsets), icing and the associated vehicle impairment (with upsets), and inappropriate crew response combined with upsets (with and without wind shear / turbulence and icing conditions). It is not clear, however, whether these nonfatal accidents can be interpreted as emerging trends or simply as individual situations in which the crew was able to successfully recover. The latter might be assumed in this case, since there were also many accidents and fatalities associated with these conditions.

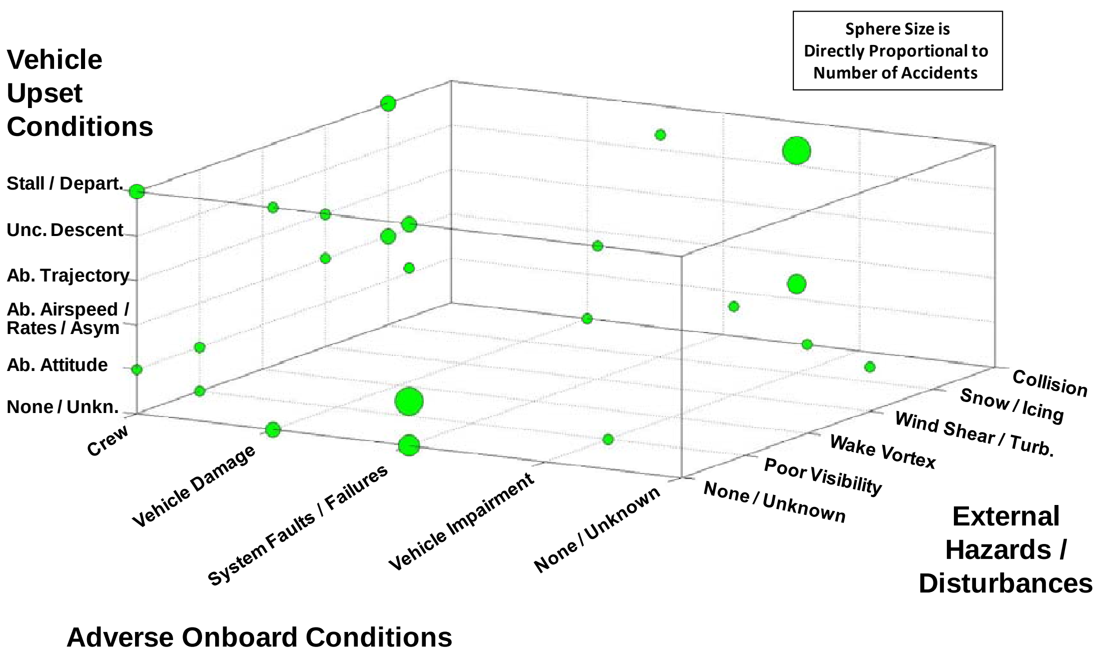

Figure 6. Combinations of LOC Causal and Contributing Factors for Nonfatal Accidents, 1994 – 2009.

B. Analysis of Causal and Contributing Factor Sequences

An analysis of the time sequencing of the LOC causal and contributing factors was performed for the 30-year data set. Table 2 provides a summary of this sequencing.

Table 2. Sequencing of LOC Accidents Causal and Contributing Factors

Factor	1st	2nd	3rd	4th	5th
Adverse Onboard Conditions	**69**	**69**	**24**	**6**	**0**
Vehicle Impairment	3	29	3	0	0
System Faults / Failures / Errors	42	11	4	0	0
Vehicle Damage	6	7	5	5	0
Inappropriate Crew Response	18	22	12	1	0
External Hazards & Disturbances	**54**	**6**	**0**	**0**	**0**
Poor Visibility	7	0	0	0	0
Wake Vortices	3	1	0	0	0
Wind Shear / Gusts / Thunderstorms	14	3	0	0	0
Snow / Icing	27	1	0	0	0
Abrupt Maneuver / Collision	3	1	0	0	0
Vehicle Upsets	**3**	**36**	**47**	**15**	**1**
Abnormal Attitude	0	12	3	3	0
Abnormal Airspeed / Angular Rates / Asymmetric Forces	0	3	7	4	0
Abnormal Flight Trajectory	1	1	3	1	0
Uncontrolled Descent	0	5	7	2	1
Stall / Departure	2	15	27	5	0

It should be noted that these sequences were identified without overlap. That is, there is no "double bookkeeping" of sequences in Table 2. Thus, the total number of initiating factors under column 1 sums to the total number of LOC accidents, since all LOC accidents result from at least 1 causal or contributing factor. Table 2 indicates that LOC events are usually first precipitated by an adverse onboard condition or an external hazard or disturbance. Moreover, external hazards and disturbances rarely occur further downstream in LOC sequences. Vehicle upsets are rarely the initial factor but rather an outcome of an external hazard or adverse onboard condition. Within adverse onboard conditions, system faults, failures, and errors are the leading initial factor, and inappropriate crew response is the second most likely initial event. Relative to external hazards and disturbances, the leading initial factor is icing, followed by wind shear, gusts, and thunderstorms. Adverse onboard conditions are also the most likely factor to occur second in the chain of events leading to aircraft LOC, with vehicle impairment being the most likely secondary factor to occur. This is due to vehicle impairment resulting from icing conditions (i.e., contaminated airfoil or reduced engine performance), faults or damage. Vehicle upsets most often occur as the second, third, or fourth factor in the LOC sequence. Only one 5-factor sequence was identified in this data set.

An analysis was also performed of each LOC sequence. This analysis is summarized in Table 3 and detailed in Figures 7 - 16. Table 3 provides the number of accidents and fatalities (and associated percentages) relative to each causal and contributing factor as the initial factor in the LOC sequence. Defining the LOC sequences in terms of the initiating factor allowed a comprehensive assessment without overlap.

Table 3. Summary of LOC Accident Sequences

Initial Factor in LOC Sequence	Accidents	%	Fatalities	%	Figures
Adverse Onboard Conditions	**69**	**54.8**	**3733**	**61.3**	**7 - 10**
Vehicle Impairment	3	2.4	186	3.1	7
System Faults / Failures / Errors	42	33.3	1544	29.0	8
Vehicle Damage	6	4.8	908	14.9	9
Inappropriate Crew Response	18	14.3	1095	14.3	10
External Hazards & Disturbances	**54**	**42.8**	**2228**	**36.6**	**11-15**
Poor Visibility	7	5.5	438	7.2	11
Wake Vortices	3	2.4	137	2.2	12
Wind Shear / Gusts / Thunderstorms	14	11.1	874	14.4	13
Snow / Icing	27	21.4	590	9.7	14
Abrupt Maneuver / Collision	3	2.4	189	3.1	15
Vehicle Upsets	**3**	**2.4**	**126**	**2.1**	**16**
Abnormal Attitude	0	0	0	0	-
Abnormal Airspeed / Angular Rates / Asymmetric Forces	0	0	0	0	-
Abnormal Flight Trajectory	1	0.8	117	1.9	16
Uncontrolled Descent	0	0	0	0	16
Stall / Departure	2	1.6	9	0.2	16
Totals	**126**	**100**	**6087**	**100**	**7 - 16**

As indicated in Table 3, LOC events initiated by adverse onboard conditions comprised 54.8% of the accidents and 61.3% of the fatalities within the data set considered in this analysis. Of these, system failures, faults, and errors initiated 33.3% of accidents and 29% of fatalities, followed by inappropriate crew response, vehicle damage, and vehicle impairment. External hazards and disturbances initiated 42.8% of the accidents and 36.6% of the fatalities in the LOC accidents considered. Within this category, icing represented 21.4% of accidents and 9.7% of fatalities, whereas wind shear, turbulence, and thunderstorms initiated 11.1% of accidents and 14.4% of fatalities. These factors were followed in frequency of occurrence by poor visibility, wake vortices, and abrupt maneuver or collision (with the last two having the same frequency of occurrence). It is interesting to note that icing initiated more accidents, but wind-related disturbances resulted in more fatalities. This is because the predominance of icing-induced accidents in the data set of this study involved smaller aircraft, whereas the preponderance of wind-induced accidents in this data set involved large transports. As indicated previously, vehicle upsets are rarely the precipitating factor in the LOC sequence, with these comprising 2.4% of the accidents and 2.1% of the fatalities considered in this study. Within this category, stall/departure initiated 1.6% of the accidents and 0.2% of fatalities, and abnormal flight trajectory initiated 0.8% of accidents and 1.9% of fatalities in the data set. While upsets are not usually the precipitating factor, many LOC sequences include vehicle upset somewhere in the chain of events (as indicated in Table 2). The last column of Table 3 references the figures that present the detailed LOC sequences associated with each initial factor. Sequences initiated by adverse onboard conditions are provided in Figures 7 - 10, those initiated by external hazards and disturbances are shown in Figures 11 – 15, and Figure 16 provides the sequences initiated by vehicle upsets. Each figure lists the LOC sequence number on the left, and the accident identification number from the Appendix is identified on the right in parentheses. The number of accidents and fatalities associated with each sequence is also provided.

Figure 7 shows the 5 LOC sequences initiated by vehicle impairment, with the associated number of accidents and fatalities provided for each sequence. The initiating events for these accidents included: aircraft overweight (1 accident that was overloaded with passengers), inappropriate vehicle configuration (1 accident), and an emulated engine failure during a training flight (1 accident). As indicated in Figure 7, 33% of these LOC sequences culminated in a vehicle upset, and 33% involved an inappropriate crew action or response.

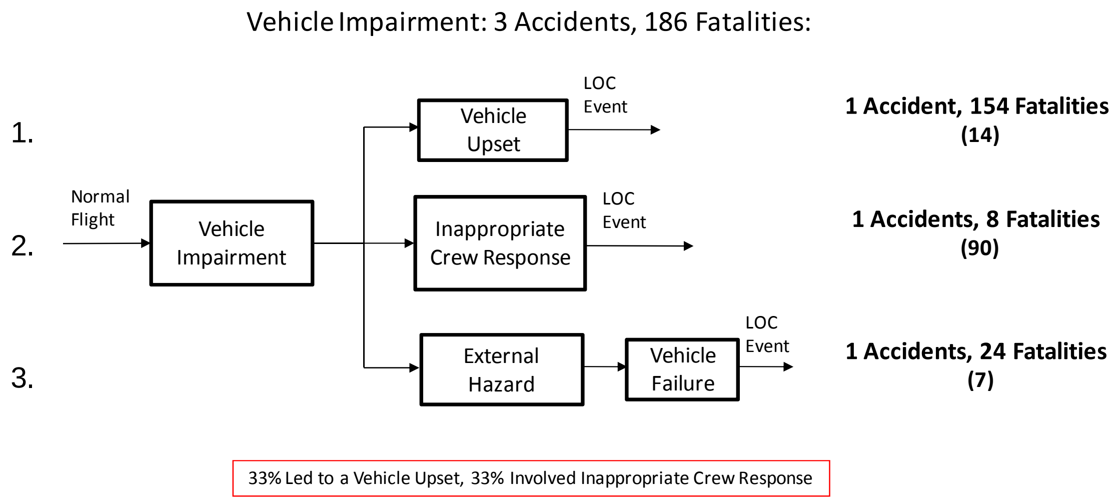

Figure 7. LOC Accident Sequences Initiated by Vehicle Impairment.

Figure 8 shows the 42 LOC sequences initiated by system failures. The initiating events for these accidents included: engine and engine control failures (17 accidents), flight control sensors and instrumentation failures and malfunctions (9 accidents), flight control system and component design errors and failures (15 accidents), and flight deck warning system failures (1 accident). External hazards and disturbances associated with these sequences included turbulence (2 accidents), wake vortices (1 accident), and an external obstruction (1 accident). As indicated in Figure 8, 26% of these sequences involved only the failure condition, 57% of these sequences led to vehicle upset, and 26% involved inappropriate crew response. All types of vehicle upsets (i.e., abnormal attitude; abnormal airspeed, angular rates, or asymmetric forces; abnormal flight trajectory; uncontrolled descent; and stall/departure) occurred in these LOC sequences.

Figure 9 shows the 11 LOC sequences initiated by vehicle damage. The precipitating damage events in these sequences included airframe structural damage (5 accidents) and engine damage (1 accident involving fatigue cracks in the engine). As indicated in Figure 9, 83% of these sequences culminated in vehicle upset, and only 1 sequence involved inappropriate crew response.

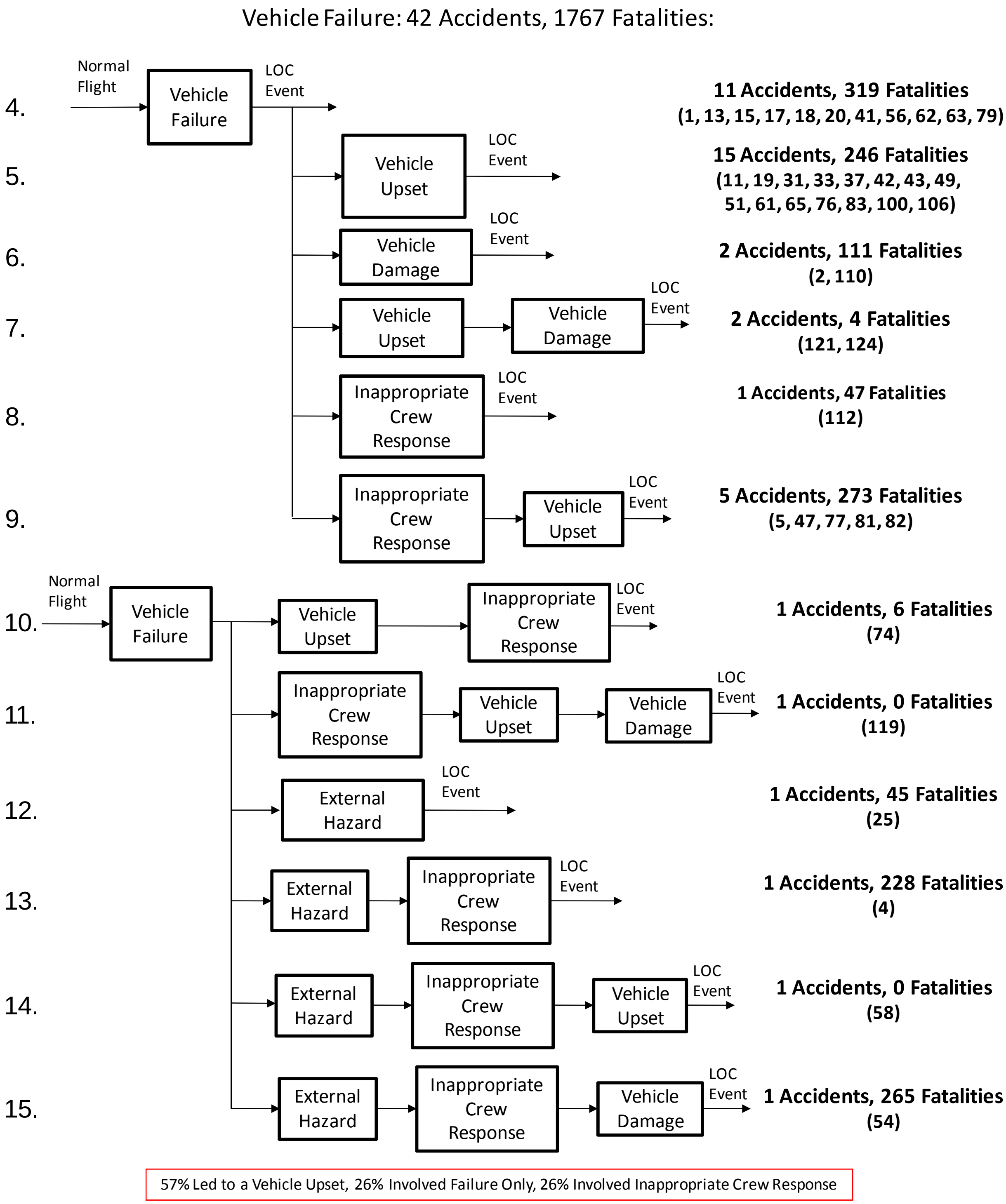

Figure 8. LOC Accident Sequences Initiated by Failures.

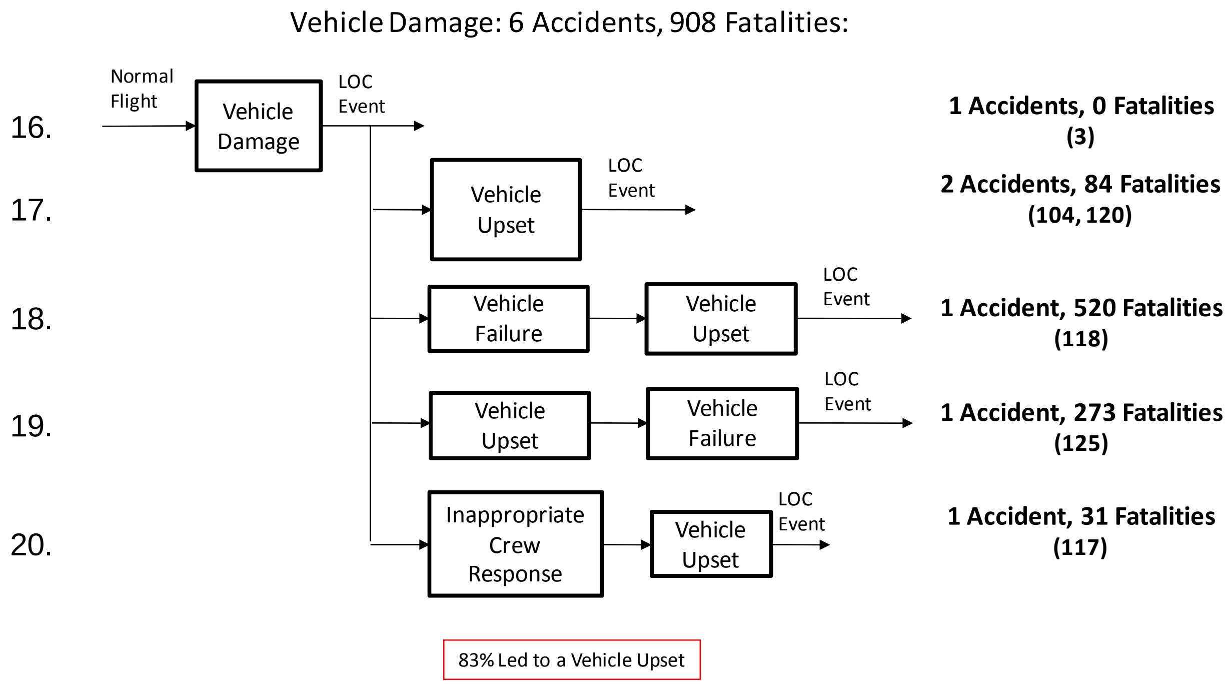

Figure 9. LOC Accident Sequences Initiated by Damage.

Figure 10 shows the 18 LOC sequences initiated by inappropriate crew actions. These actions included: improper and inadvertent control inputs (9 accidents), crew impairment and distraction (3 accidents), spatial disorientation (2 accidents), failure to configure the vehicle properly (3 accidents), and improper pre-flight planning or preparation (1 accident). As indicated in Figure 10, 100% of these sequences led to an upset condition, and 50% resulted in vehicle impairment or damage.

Figures 11-15 show the LOC sequences that were initiated by external hazards and disturbances. Figure 11 shows the 7 sequences precipitated by poor visibility. As indicated in the figure, 86% of these sequences culminated in a vehicle upset condition, and 86% involved inappropriate crew response. Of the 6 sequences involving inappropriate crew response, 5 resulted from spatial disorientation. Figure 12 shows the 3 LOC sequences initiated by a wake vortex encounter. All of these sequences culminated in a vehicle upset. Figure 13 shows the 14 LOC sequences initiated by wind shear, turbulence, and thunderstorms. As indicated in the figure, 86% of these sequences led to a vehicle upset condition, and 64% involved inappropriate crew response.

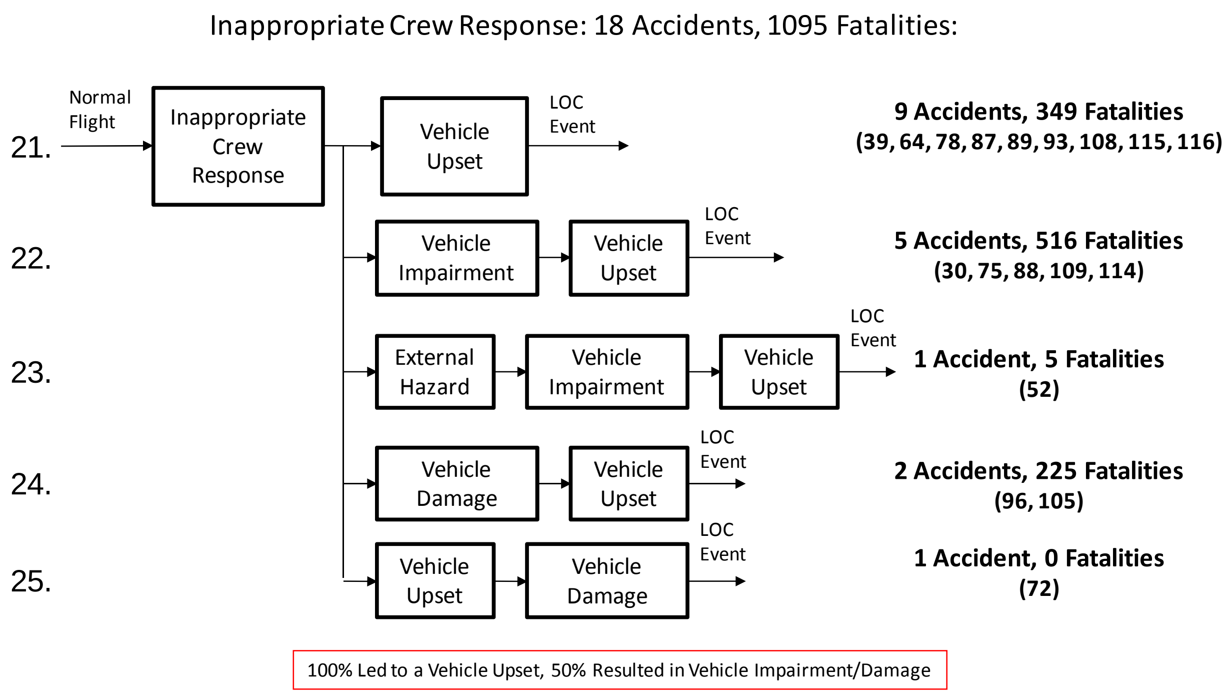

Figure 10. LOC Accident Sequences Initiated by Inappropriate Crew Input.

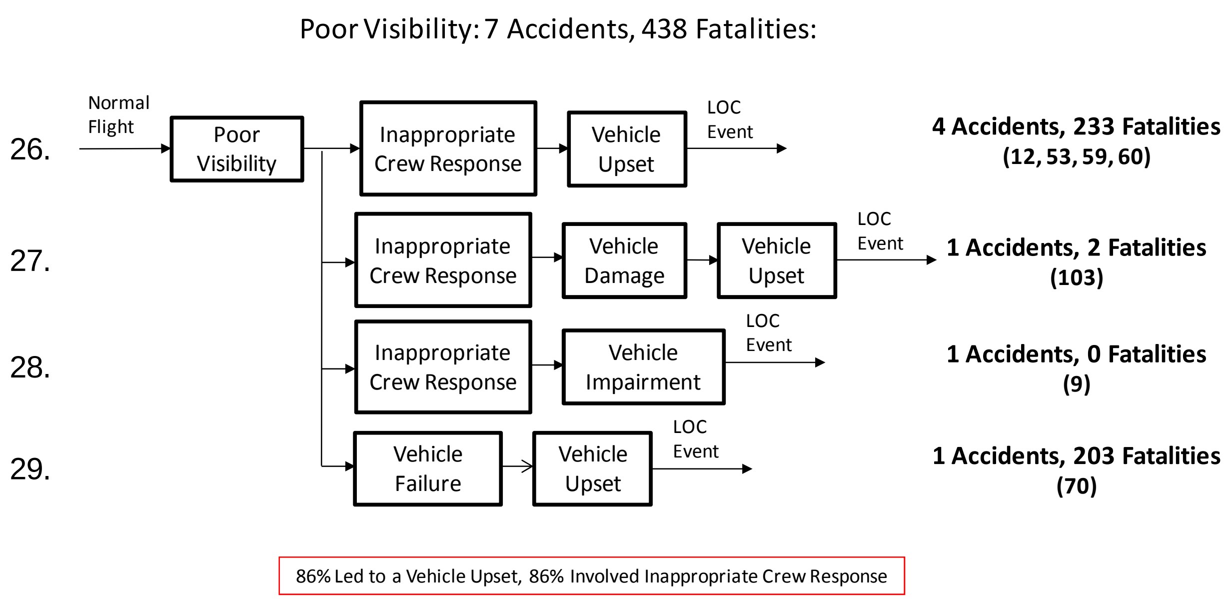

Figure 11. LOC Accident Sequences Initiated by Poor Visibility.

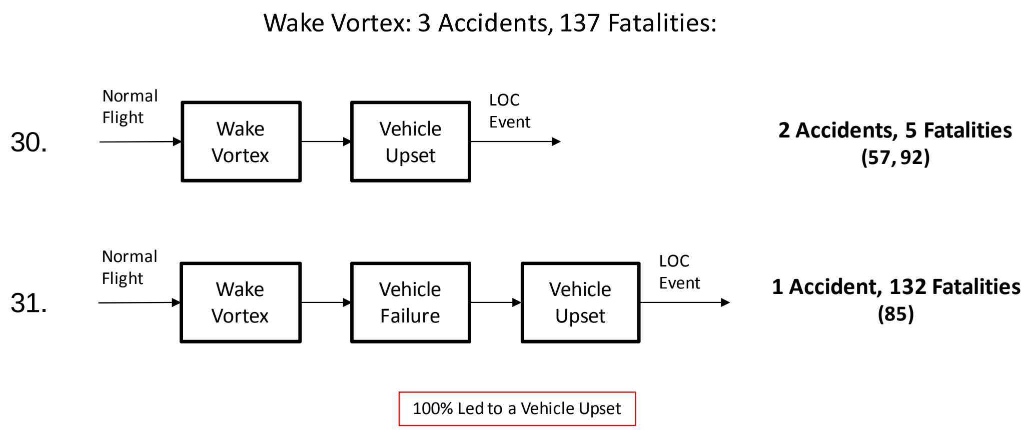

Figure 12. LOC Accident Sequences Initiated by Wake Vortex Encounter.

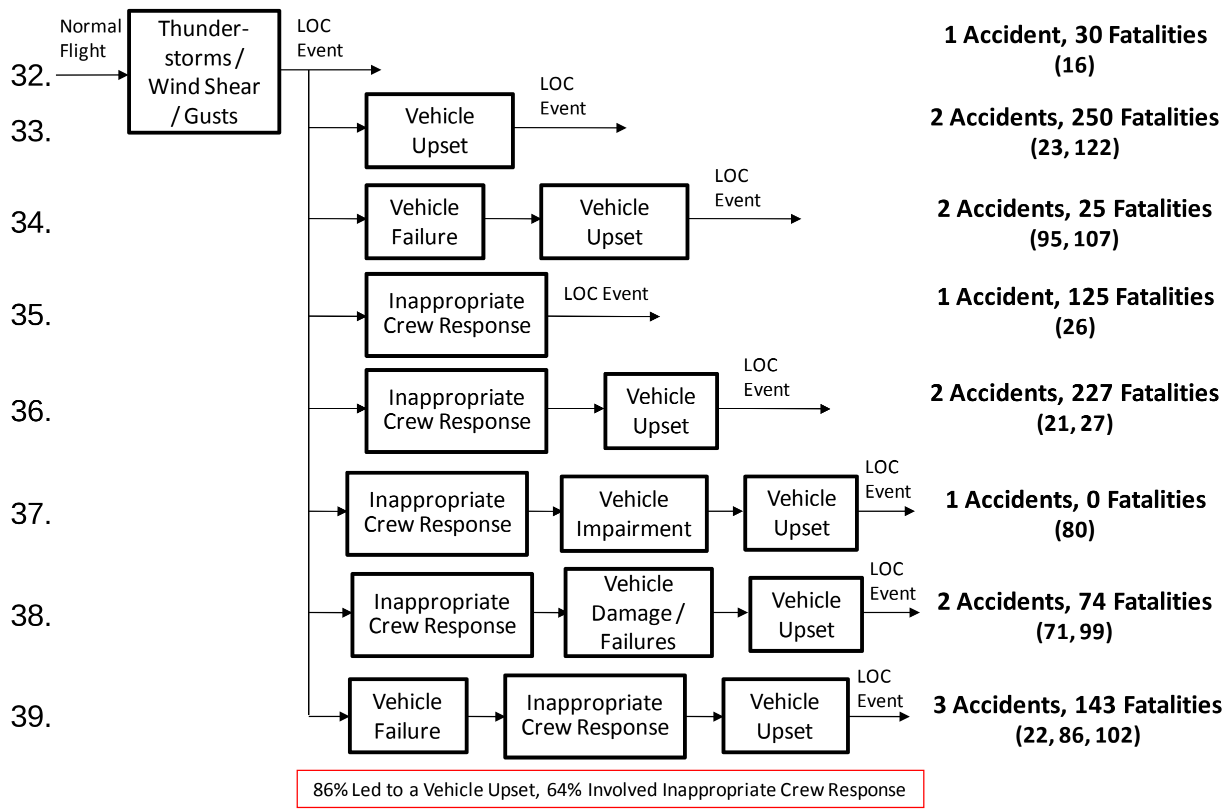

Figure 13. LOC Accident Sequences Initiated by Wind Shear, Gusts, & Thunderstorms.

Figure 14 shows the 27 LOC sequences that were initiated by snow and icing conditions. As indicated in the figure, 10% of these sequences led to a vehicle upset, and 22% involved inappropriate crew response.

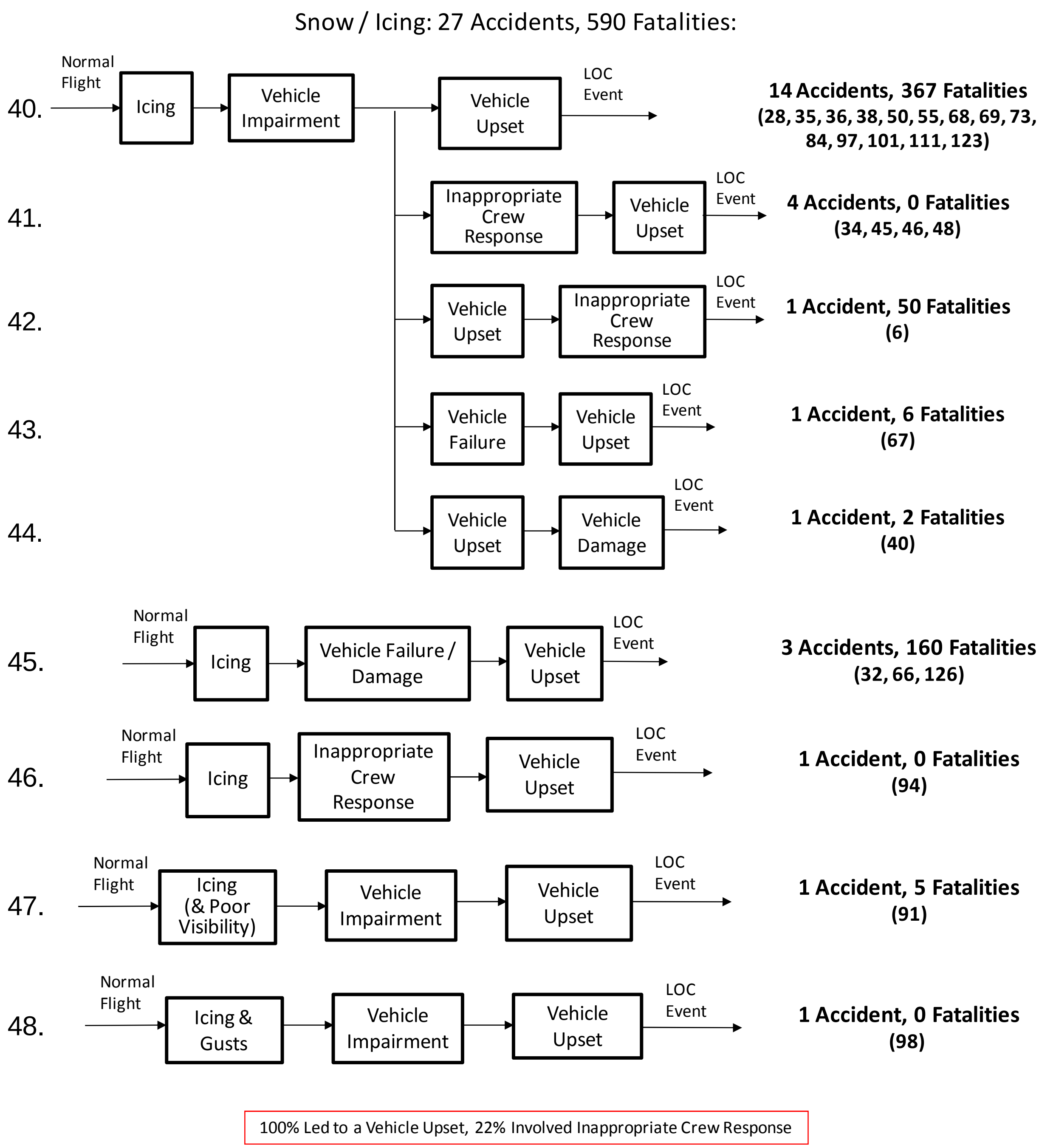

Figure 14. LOC Accident Sequences Initiated by Snow / Icing.

Figure 15 shows the 3 LOC sequences that were initiated by abrupt maneuvers and collisions. All of these sequences were initiated by a mid-air collision (1 with another aircraft, and 2 with a flock of birds).

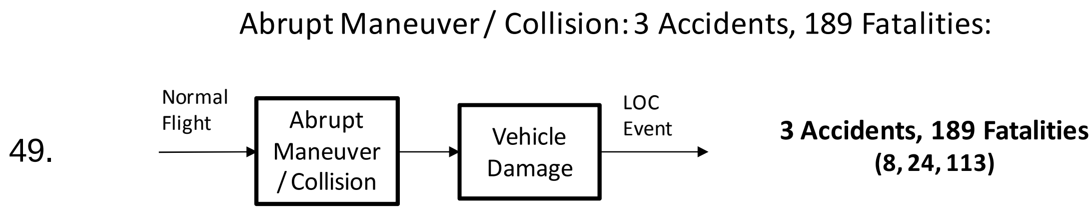

Figure 15. LOC Accident Sequences Initiated by Abrupt Maneuver / Collision.

Figure 16 shows the 7 LOC sequences initiated by vehicle upsets. The precipitating event for these upsets was undetermined. The last accident associated with Sequence 52 occurred during a low-speed check to activate the alpha floor protection system following maintenance. In this accident, the aircraft stalled on approach and recovery was impaired by the vehicle being configured inappropriately for go-around. It is unclear at this time whether the initial stall condition resulted from incorrect or inappropriate flight procedures or an error in the flight control system.

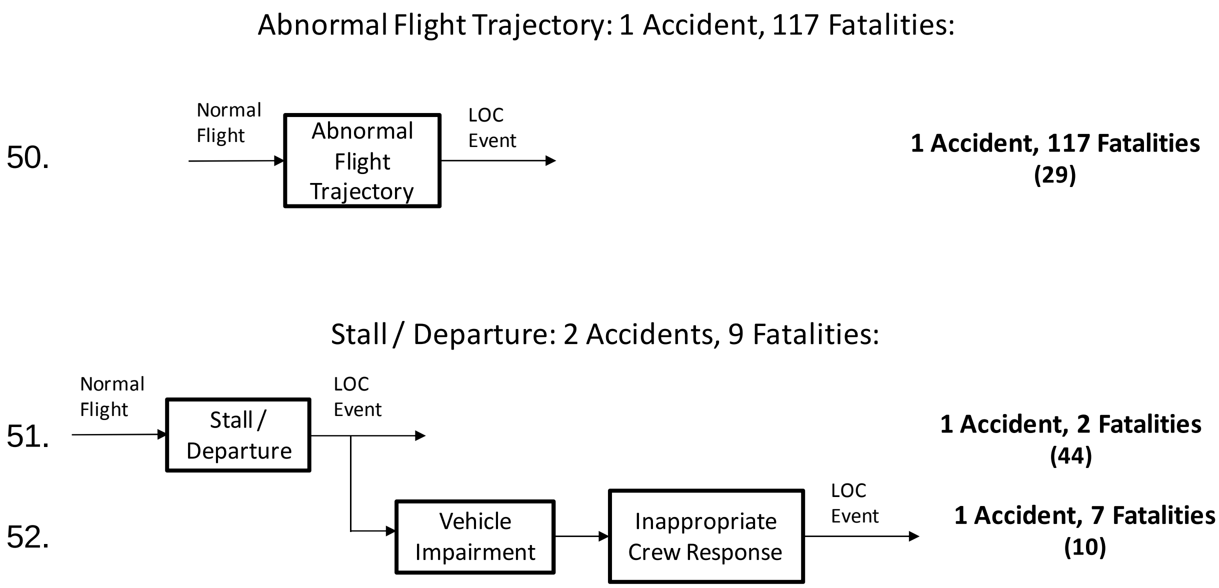

Figure 16. LOC Accident Sequences Initiated by Vehicle Upsets.

In order to condense the LOC sequences of Figures 7-16 into smaller, more actionable groupings, these sequences can be combined and generalized. In an effort to represent a large majority of the sequences identified in this study. Figure 17 shows the top 10 LOC combined sequences relative to number of accidents and fatalities. Dashed boxes represent factors that occurred in some subset within the sequence. As indicated in Figure 17, this top 10 set of combined LOC sequences represents 86.5% of the accidents and 89.1% of the fatalities considered in this study. This set can be further reduced by generalizing the sequences. Some generalized sequences are shown in Figure 18 along with the associated number of accidents and fatalities. These 7 generalized sequences represent 112 accidents (88.9%) and 5529 fatalities (90.8%).

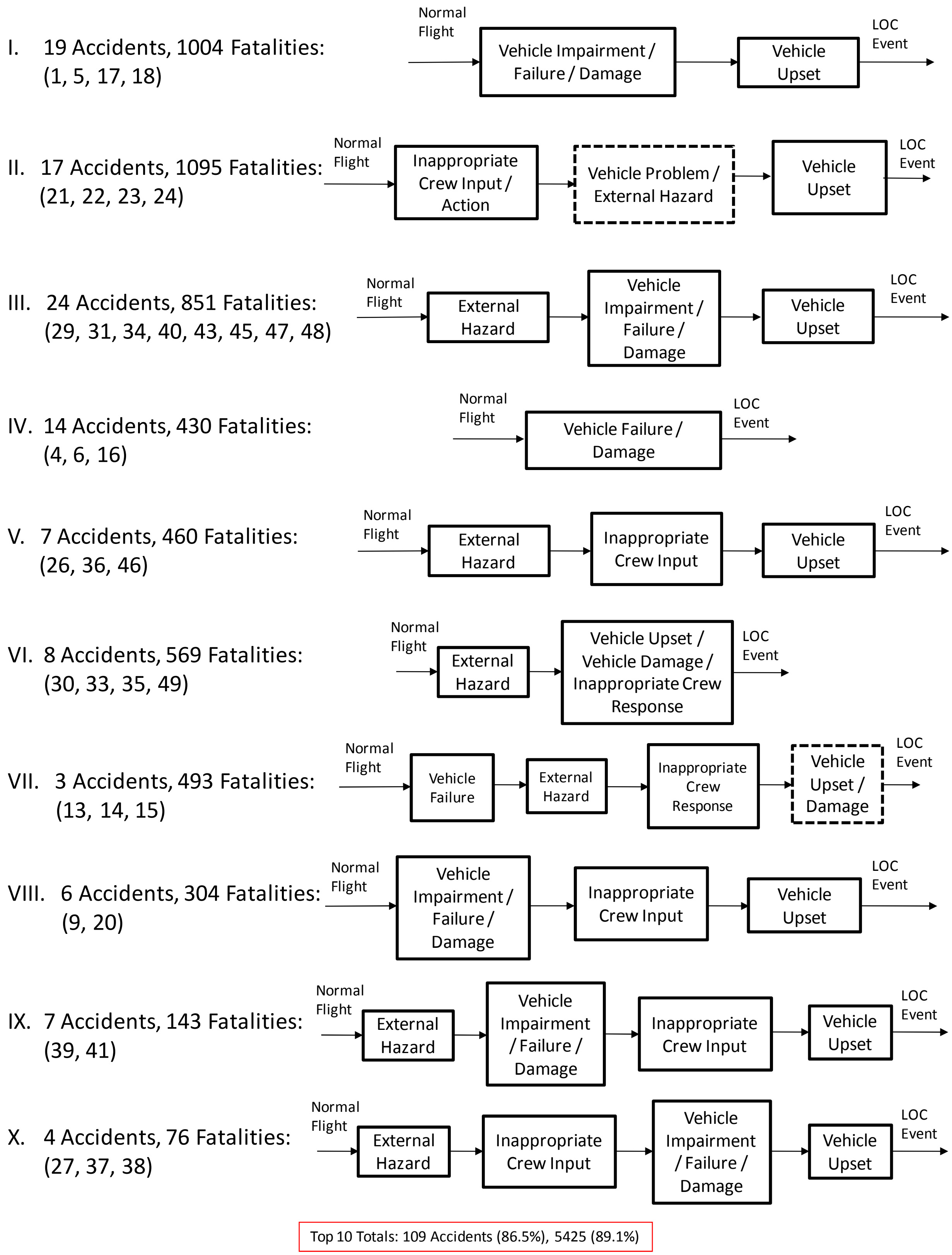

Figure 17. Top 10 LOC Accident Sequences.

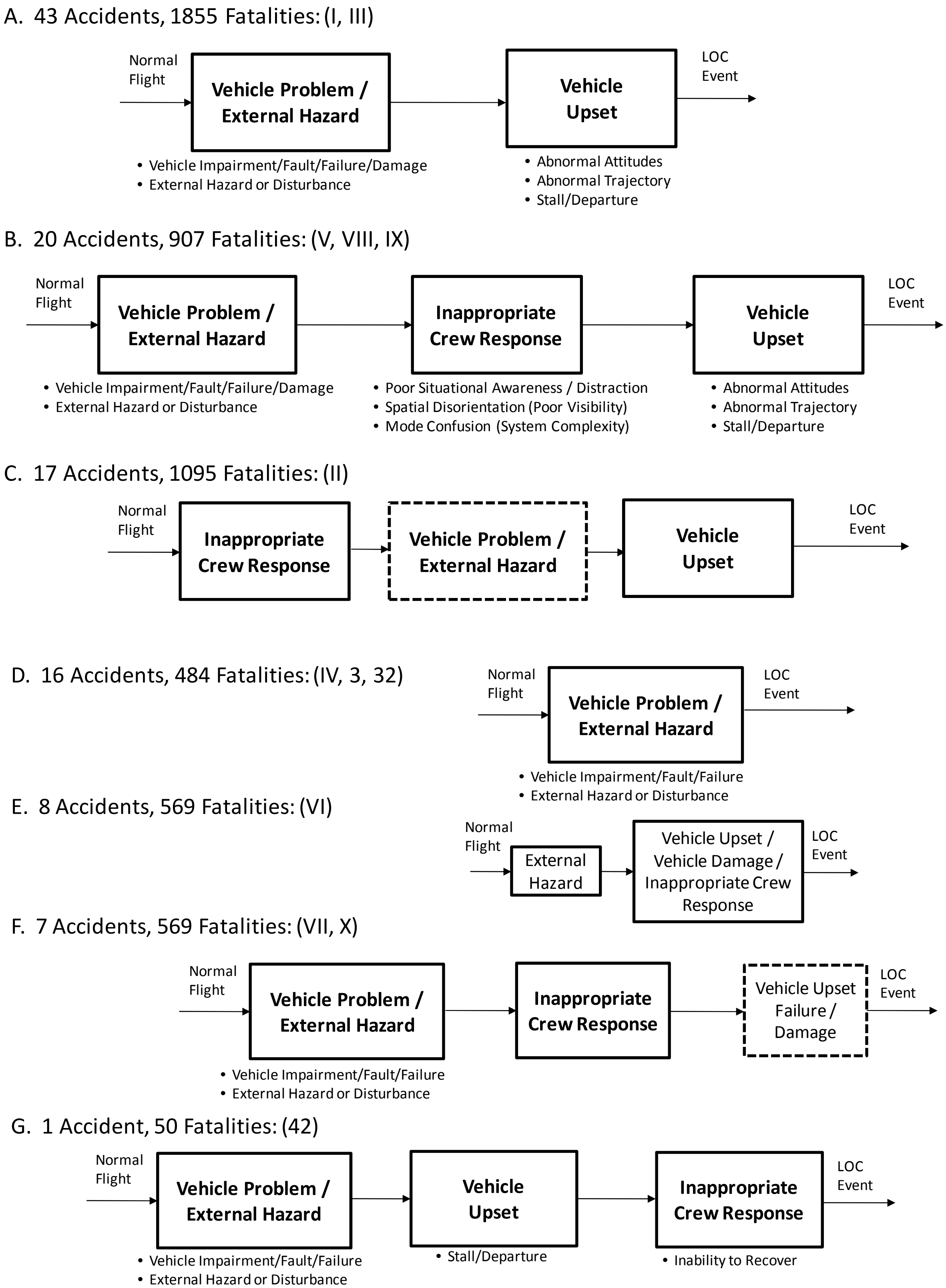

Figure 18. Generalized LOC Accident Sequences.

C. Future Considerations

In addition to looking at historical accident data, potential future LOC accident risks should be identified relative to known (as well as new) precursors. This is more difficult, because (without data) it becomes more speculative. However, the identification of potential future risks might enable the development of a comprehensive intervention strategy that anticipates and mitigates these future potential risks. One area of consideration is airspace operation under the Next Generation (NextGen) Air Transportation System. [7] The NextGen concept of operations provides an integrated view of airspace operations in the 2025 timeframe and includes high-density, all-weather, and self-separation operational concepts. There is also expected to be mixed-capability aircraft operating within the same airspace, including piloted aircraft and unmanned aircraft systems. High-precision 4-D trajectories are envisioned that will enable safely flying with closer spacing to inclement weather, terrain, and other aircraft, and these trajectories can be altered if necessary during the flight. Other areas of consideration include increasing airspace and vehicle system complexity without developing comprehensive methods for their validation and verification (V&V), and increased automation without improved crew interfaces.

In an effort to identify areas of potential future LOC risk in terms of known precursors, Figure 19 illustrates several areas of possible increase in causal and contributing factors with the potential for increased LOC accidents or incidents. If all-weather operations and highly precise trajectories that enable closer spacing to inclement weather increase the probability of an aircraft actually encountering inclement weather during flight, this could result in a larger number of weather-related LOC accidents (particularly in the terminal area). If airspace and vehicle system complexity is increased without comprehensive methods for their V&V, this could lead to a larger number of LOC events initiated by system faults, failures, and errors. If high-density mixed-vehicle operations and high-precision tracking that enables closer spacing between aircraft increase the probability of aircraft encountering other aircraft during flight, this could result in a larger incidence of wake-induced LOC events or ultimately those initiated by vehicle damage resulting from mid-air collisions. Increased automation without improved crew interfaces could result in a higher incidence of LOC events precipitated by inappropriate crew actions.

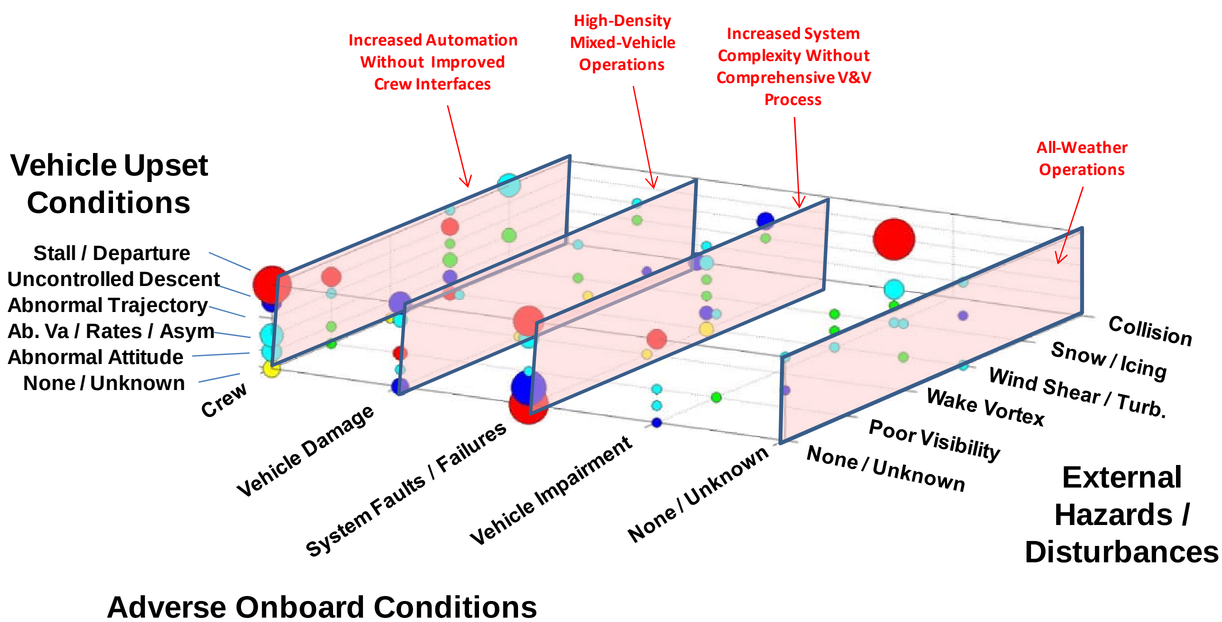

Figure 19. Potential Areas of Future Increased LOC Risk.

In order to consider LOC sequences that could become more prevalent under NextGen, Figure 20 shows summarized sequences grouped by relevance to NextGen operations. High-density operations are represented by LOC sequences that were initiated by wake vortex encounters or mid-air collisions. All-weather operations are represented by a summary of LOC sequences initiated by weather-related events. Crew-automation vulnerability is represented by LOC sequences that were initiated by system faults and crew errors. Future intervention strategies for preventing LOC events will need to be able to provide interventions for these sequences with an emphasis on takeoffs and landings under wake and wind shear conditions, terminal area maneuvering and landing under vehicle impairment conditions while penetrating external disturbances, and self-separation and abrupt maneuvering for collision avoidance under all-weather and vehicle impairment conditions.

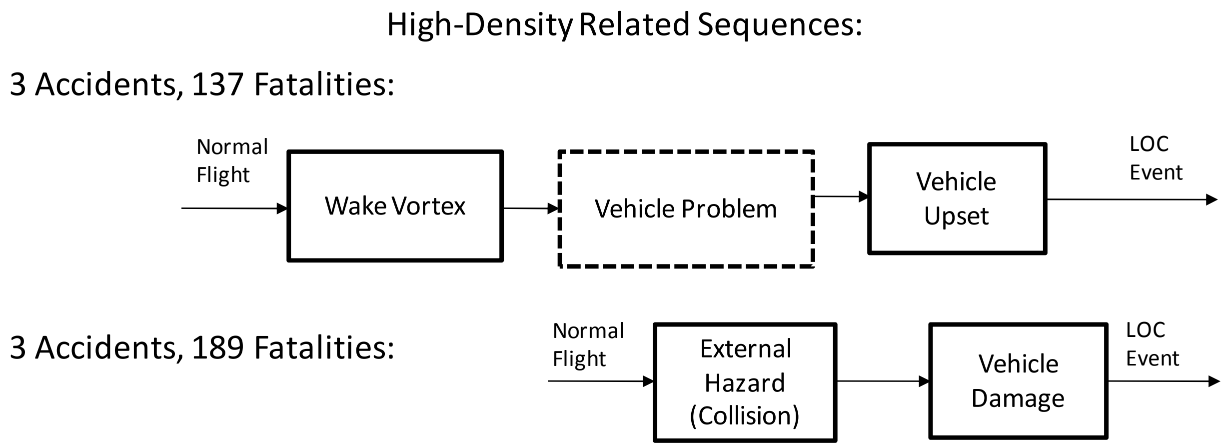

Figure 20a. Potential LOC Sequences Related to Future Risk (High-Density Related Sequences).

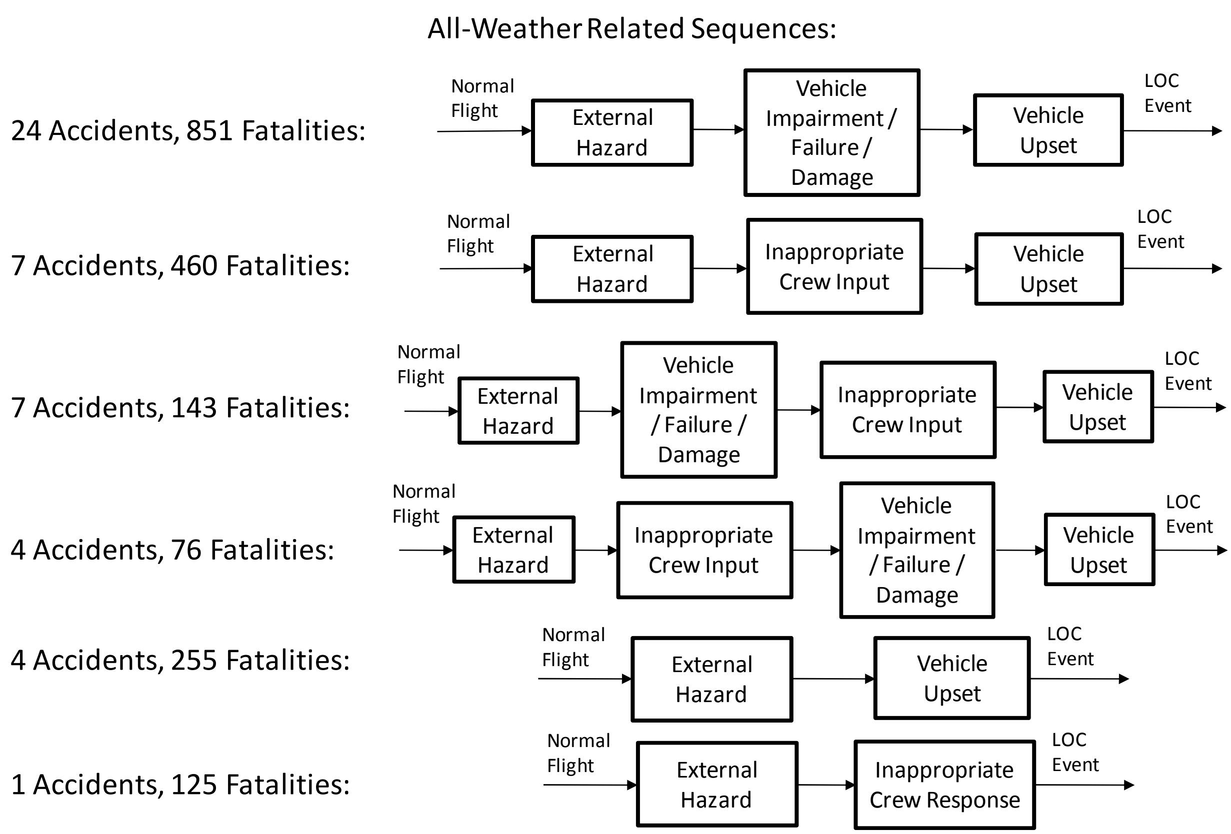

Figure 20b. Potential LOC Sequences Related to Future Risk (Weather Related Sequences).

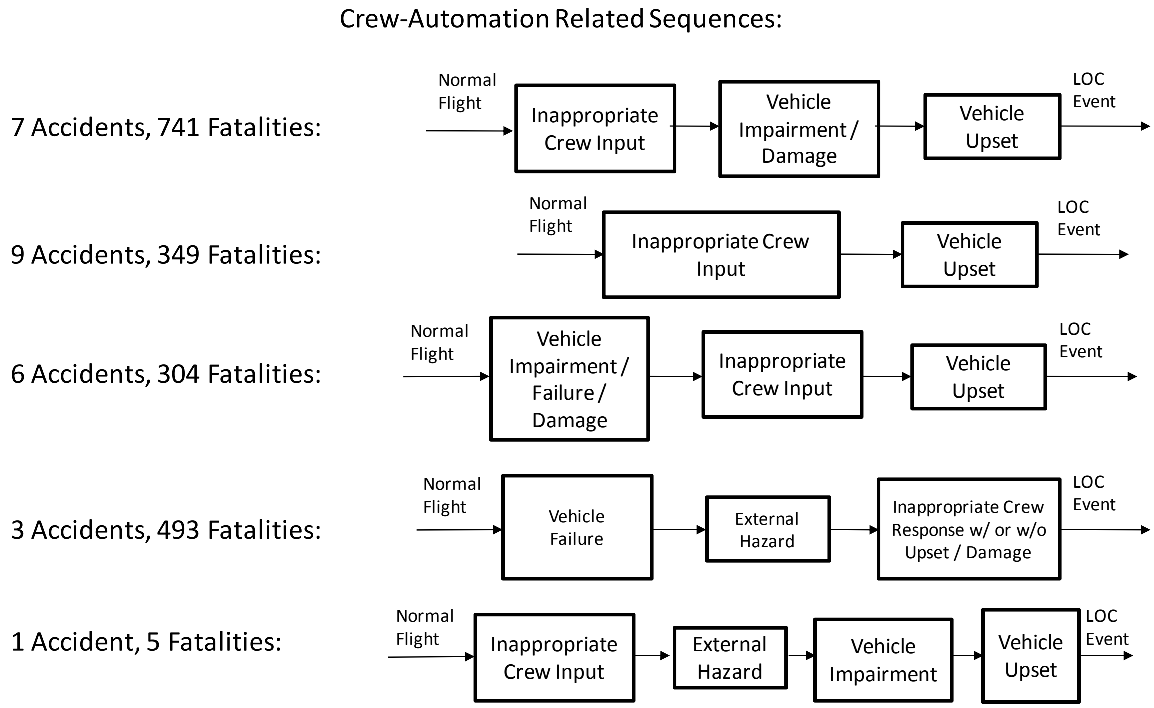

Figure 20c. Potential LOC Sequences Related to Future Risk (Crew-Automation Related Sequences).

New LOC precursors associated with failure modes of future vehicle and airspace systems must also be identified and considered (particularly during V&V of these systems), and their potential ramifications considered (particularly under off-nominal operating conditions). New types of crew-induced LOC precursors must also be considered.

III. Conclusion

Aircraft LOC accidents cause a significant percentage of aviation fatalities across all aircraft classes and operations, and result from a large number of causal and contributing factors that occur individually or (more often) in combination. A detailed analysis of causal and contributing factors associated with aircraft LOC accidents (predominantly for Part 121 operations) has been performed and documented in this paper. The LOC accidents considered in this paper included accidents that involved vehicle upsets, as well as those involving failures, impairment, or damage to the flight control capability of the aircraft (including control surfaces, flight control system or components, and the engines) or to the vehicle airframe (when the damage was sufficient to alter vehicle dynamics and control characteristics) whether or not they led to an upset condition (or there was evidence of upset cited in the report). The data set used in the analysis consisted of 126 LOC accidents that resulted in 6087 fatalities during the 30-year period 1979 – 2009. The analysis included the identification of worst case combinations of causal and contributing factors using scatter plots generated from the accident data, and a detailed compilation of LOC sequences based on temporal ordering of causal and contributing factors. A list of the top 10 LOC summarized sequences was developed, which represents 86.5% of the accidents and 89.1% of the fatalities considered in this paper. A set of 7 generalized LOC sequences was also defined, which are representative of 88.9% of the accidents and 90.8% of the fatalities considered in this study. The data set was analyzed for trends potentially attributable to the introduction of new technologies in the last 15 years. This analysis showed little effect. The data was also analyzed for differences between nonfatal and fatal accidents. This analysis also did not yield significant results. Finally, future risks with the potential to increase LOC accidents were considered. Research in the development of holistic intervention strategies that can prevent LOC accidents under current and future airspace operations is recommended.

Appendix

Date	Aircraft / Airline	Location	Fatalities (Total Onboard)	Phase of Flight	Accident Summary	Probable Primary Cause	Accident No.
9/24/2009	British Aerospace 4121 Jetstream 41, ZS-NRM / SA Airlink	Merebank, Near Durban International Airport South Africa	0	Takeoff	System / Component Failure - Engine	Engine Failure	1
8/3/2009	B707, EP-SHK / Saha Air (Flt. 124)	Ahwaz Airport, Iran	0	Cruise	Uncontained Engine Failure Resulting in Unknown Level of Vehicle Damage	System / Component Failure - Engine	2
7/13/2009	B737, N387SW / Southwest Airlines (Flt. 2294)	Near Charleston, WV, USA	0	Cruise	Vehicle suffered rapid decompression resulting from a hole in the fuselage measuring 17"x8"	Damage to fuselage from unknown source	3
6/1/2009	A330, F-GZCP / Air France	~160 km NNW off Sao Pedro and Sao Paulo Archipelago in the Atlantic Ocean	228 (228)	Cruise	Instrument failure of the Air Data Inertial Reference Unit (ADIRU), possibly coupled with severe turbulence	System/Component Failure - Airspeed Instrumentation	4
2/25/2009	B737, TC-JGE / Turk Hava Yollari (Flt. 1951)	1.5 km N of Amsterdam-Schiphol International Airport Netherlands	9 (135)	Approach/Landing	Possible fault with radio altimeter, Possible fault in autothrottle system, Possible mode confusion by crew, Aircraft Stall	System/Component Error - Flight Control System (Flight systems drove aircraft into a stall)	5
2/12/2009	de Havilland Canada DHC-8, N200WQ / Colgan Air (Flt. 3407)	10 km NE of Buffalo Niagara International Airport, NY	49 (49) +1 on Ground	Approach	Vehicle stall possibly due to vehicle impairment from icing combined with inappropriate crew input for recovery	Inappropriate Crew Response During Stall Recovery	6
2/7/2009	Embraer 110, PT-SEA / Manaus Aerotaxi	Off Santo Antonio, AM Brazil	24 (28)	Cruise	Loss of control due to weather, engine failure, and possible overloaded condition	System and Component Failure - Engine	7
1/15/2009	A320, N106US / US Airways (Flt. 1549)	Off Weehawkin, NJ [Hudson River, NY] USA	0	Takeoff - Initial Climb	Damage to both engines due to impact with flock of geese	Vehicle Damage - Engines	8

1/4/2009	Cessna 550, N815MA / Caribair, S.A.	Wilmington-New Hanover County International Airport, NC, USA	0	Approach/Landing	Poor Visibility forced 3 Missed Approaches, Loss of both engines due to low fuel on fourth approach	Inappropriate Crew Action Resulting in Vehicle Impairment - Engines	9
11/27/2008	A320, D-AXLA / XL Airways Germany (Leased from Air New Zealand)	5 km E off Canet-Plage, France	7 (7)	Approach / Go-Around (following maintenance during a low-speed check to activate the alpha floor protection system)	Aircraft was flown into stall on approach by crew and/or flight control system during checkout flight – recovery was impaired by the vehicle being configured inappropriately for go-around	Stall	10
10/7/2008	A330, VH-QPA / Qantas (Flt. QF72)	154 km W of Learmonth, WA, Australia	0	Cruise	Failure of the air data IRU resulting in uncommanded pitch downs during cruise	System and Component Failure - ADIRU	11
9/14/2008	B737, VP-BKO / Aeroflot-Nord (Flt. 821)	11.5 km NE of Perm Airport, Russia	88 (88)	Approach	Uncontrolled descent resulting from spatial disorientation of the crew and possible atmospheric disturbances	Crew Spatial Disorientation	12
9/1/2008	Convair 580, N587X / Air Tahoma	1.6 km SW of Columbus-Rickenbacker International Airport, OH, USA	3 (3)	Emergency Landing	Loss-of-Control resulting from reverse rigging of elevator trim cables	Elevator System Failure	13
8/20/2008	MD-82, EC-HFP / Spanair (Flt. 5022)	Madrid-Barajas Airport, Spain	154 (172)	Takeoff	Stall During Takeoff Resulting from Inappropriate Vehicle Configuration	Stall - Inappropriate Vehicle Configuration	14
7/7/2008	B747, N714CK / Centurion Air Cargo	8 km N of Bogota-Eldorado Airport, Colombia	0 +3 on ground	Takeoff - Initial Climb	Engine Fire during Initial Climb	Engine Failure	15
6/10/2008	A310, ST-ATN / Sudan Airways (Flt. 109)	Khartoum-Civil Airport, Sudan	30 (214)	Landing	Aircraft crashed on landing, possibly due to wind shear	Atmospheric Disturbance	16

5/2/2008	Beechcraft 1900, 5Y-FLX / Southern Sudan Air Connection	45km NW of Rumbek, Sudan	21 (21)	Cruise	Failure of both engines during cruise	Engine Failure	17
2/7/2008	Britten-Norman BN-2A, HI-653CA / Caribair, S.A.	El Seibo, Dominican Republic	0	Enroute	Crash-landed after Engine Failure	Engine Failure	18
1/17/2008	B777, G-YMMM / British Airways	London-Heathrow Airport, United Kingdom	0	Landing	Engines failed to respond to increased thrust command from autothrottle and from flight crew advancing the throttle levers, Aircraft entered an uncontrolled descent	System and Component Failure - Engines	19
1/4/2008	Let 410, YV2081 / Transaven	20 km S of Los Roques Airport, Venezuela	14 (14)	Descent	Failure of both engines	System and Component Failure - Engines	20
5/5/2007	B737-800, 5Y-KYA / Kenya Airways	5.5 km SE of Douala Airport Cameroon	114 (114)	Takeoff - Initial Climb	Vehicle Upset resulting from possible wind shear and/or inappropriate crew response	Atmospheric Disturbances, Inappropriate Crew Response	21
1/1/2007	B737-4Q8 PK-KKW / AdamAir	85 km (53.1 mls) W off Pambauang, Indonesia	102 (102)	Cruise	Crew distracted with trouble-shooting the IRS, loss of situational awareness & spatial disorientation during upset	Loss of Situational Awareness During Failure, Leading to Upset	22
10/29/2006	B737-2B7 5N-BFK / ADC Airlines	Near Abuja Int. Airport (ABV) Nigeria	96 (105) +1 on Ground	Takeoff	Stall, possibly resulting from wind shear and gusts	Stall	23
9/29/2006	B737-8EH PR-GTD / GOL Transportes Aereos	30 km from Peixoto Azevedo, MT Brazil	154 (154)	Cruise	Mid-Air Collision Resulting in Vehicle Damage	Mid-Air Collision	24
7/10/2006	Fokker F-27 Friendship 200 AP-BAL / Pakistan International Airlines	Near Multan Airport (MUX) Pakistan	45 (45)	Takeoff – Struck Electrical Power Lines	Engine failure on takeoff leading to collision with external hazard (power lines)	Engine Failure	25

7/9/2006	Airbus A.310-324 F-OGYP / S7 Airlines	Irkutsk Airport (IKT) Russia	125 (203)	Landing – Over-ran Runway	Rain/Thunderstorms, During landing pilot inadvertently touched #1 power lever increasing thrust - No. 1 engine thrust reverser de-activated & set to idle, No.2 thrust reverser deployed	Inappropriate crew inputs	26
5/3/2006	Airbus A.320-211 EK-32009 / Armavia (Flt. 967)	6 km SW Off Adler/Sochi Airport (AER) Russia	113 (113)	Approach (Aborted – Climbing Turn Maneuver)	Inappropriate crew inputs (excessive nose down pitch commands) resulting from possible wind shear leading to uncontrolled descent	Inappropriate crew inputs	27
1/2/2006	Saab-340 N-380AE / American Eagle	Over Santa Maria, CA USA	0	Climb	Vehicle upset resulting from icing conditions	Icing	28
10/22/2005	B737, 5N-BFN / Bellview Airlines	Near Lisa Nigeria	117 (117)	Takeoff	Abnormal flight trajectory on takeoff	Undetermined	29
9/5/2005	B737-230, PK-RIM / Mandala Airlines	Medan-Polonia Airport Indonesia	100 (117) +49 on Ground	Takeoff - Initial Climb	Airplane failed to become airborne due to inappropriate vehicle configuration - flaps and slats were not deployed	Inappropriate vehicle configuration resulting from crew error	30
9/5/2005	B737, PR-BRY /		0	Cruise	Vehicle driven into an upset condition by the autopilot	Autopilot Failure	31
8/16/2005	MD-80, HK-4374X / West Caribbean Airways (Flt 708)	Near Machiques Venezuela	160 (160)	Cruise	Stall resulting from possible engine icing condition or failure	Stall, Engine Failure/Impairment	32
8/1/2005	B777, 9M-MRG / Malaysia Airlines (Flt 124)	240 km NW of Perth, WA Australia	0	Climb	Fault in flight control instrumentation system and software leading to vehicle upset (Software error allowed faulty sensor to be used by primary flight control system)	Flight control system fault	33

5/27/2005	DHC-8, C-GZKH / Provincial Airlines Limited	Near Newfoundland	0	Takeoff - Initial Climb	Vehicle Stall during initial climb Induced by Icing and coupled with inappropriate crew response (Crew Interpreted Upset as Severe Turbulence, which Delayed Effective Stall Recovery)	Stall, Icing	34
11/28/2004	Canadair CL-600, N873G / Global Aviation (Flt 73)	Montrose County Airport, CO USA	3 (6)	Takeoff	Stall Induced by Icing during takeoff	Stall, Icing	35
11/21/2004	Canadair CL-600, B-3072 / China Yunnan Airlines (Flt 5210)	Near Baotou Airport China	53 (53) +2 on Ground	Takeoff - Initial Climb	Stall induced by Icing during initial climb	Stall, Icing	36
10/14/2004	Canadair CL-600, N8396A / Pinnacle Airlines / Northwest Airlink (Flt 3701)	Jefferson City, MO USA	2 (2)	Approach	Stall Induced by Engine Failure (Double Engine Flame-Out)	Stall, Engine Failure	37
6/18/2004	Saab-SF340 VH-KEQ /	83 km SW Albury Australia	0	Descent	Contaminated Airfoil due to Icing	Stall due to Icing	38
1/3/2004	B737-300 SU-ZCF / Flash Airlines (Flt 604)	Red Sea, Near Sharm El-Sheikh, Eqypt	148 (148)	Takeoff	Loss of Control resulting from inappropriate control actions by the crew due to spatial disorientation	Spatial Disorientation, Spiral Dive	39
10/3/2003	Convair CV-580, ZK-KFU / Air Freight NZ (Flt 642)	10 km N off Paraparaumu, New Zealand	2 (2)	Initial Descent	Icing-induced stall and departure resulting in severe vehicle damage	Stall, Icing and Damage	40
7/8/2003	B737, ST-AFK / Sudan Airways (Flt 139)	5 km E of Port Sudan Sudan	116 (117)	Missed Approach	Loss of control due to engine failure	Engine Failure	41

4/23/2003	Beechcraft 99, C-FDYF / Transwest Air (Flt 602)	11 km from Prince Albert, SK Canada	0	Approach	Vehicle upset resulting from Flight control system failure (Horizontal stabilizer failure / detachment resulting from improper maintenance)	Flight control system failure	42
1/8/2003	Beechcraft 1900, N233YV / US Airways Express (Flt 5481)	Charlotte-Douglas International Airport, NC USA	21 (21)	Takeoff - Initial Climb	Loss of pitch control due to flight control system fault (Fault of the elevator system due to an improper maintenance action)	Flight control system fault	43
12/21/2002	Aerospatiale ATR-72, B-22708 / Transasia Airways (Flt 791)	11.3 km NW off Pachao Tao, Penghu Islands (Taiwan)	2 (2)	Cruise - During Descent	Stall during descent (undetermined cause)	Stall	44
12/7/2002	A-320, C-GJVX / Air Canada (Flt 457)	Lester B. Pearson International Airport, Toronto, Ontario, Canada	0	Landing	Vehicle Upset (roll oscillation on landing) due to possible contaminated airfoil from icing or PIO	Upset/PIO due to Contaminated Airfoil	45
12/7/2002	A-320, C-GIUF / Air Canada (Flt 1130)	Lester B. Pearson International Airport, Toronto, Ontario, Canada	0	Landing - During Go Around	Vehicle Upset (roll oscillation on landing) due to possible contaminated airfoil from icing or PIO	Upset/PIO due to Contaminated Airfoil	46
10/20/2002	B757-200, TF-FII / Icelandair (Flt 662)	Near Baltimore-Washington International Airport, MD USA	0	Cruise - During Vehicle Climb	Stall induced by system anomalies (Instrument problem with flight director and airspeed indicator displays and/or Air Data Computer) and possible loss of crew situational awareness	Stall, Instrumentation Error	47
6/28/2002	Saab SF-340, VH-OLM / Hazelton Airlines (Flt 185)	7 km ESE of Bathurst, NSW Australia	0	Approach	Vehicle upset/stall induced by icing and Failure by crew to activate de-icing system	Icing coupled with crew inaction	48
6/14/2002	A-340, C-GHLM / Air Canada (Flt. 875)	Frankfurt Germany ILS Facility	0	Approach	Possible Autopilot Fault - Pitch to 27 deg during glideslope capture	System Fault	49

6/4/2002	MD-80, N823NK / Spirit Airlines (Flt 970)	37 km W of Wichita, KS USA	0	Cruise	Autopilot-induced stall resulting from icing (Engine power loss resulting from false engine pressure ratio indication caused by icing of engine inlet probes while in Autopilot Mode)	Stall	50
5/4/2002	British Aircraft Corp. 111, 5N-ESF / Executive Airline Services (Flt. 4226)	Kano, Nigeria	71 (77) + 78 on Ground	Shortly afer Takeoff	Stall, Possibly Resulting from Engine Failure	Stall	51
1/4/2002	Canadair CL-600, N90AG / Epps Air Service (Executive Flight)	Birmingham International Airport, United Kingdom	5 (5)	Takeoff - Initial Climb	Stall due to contaminated airfoil coupled with Possible impairment of crew due to combined effects of non-prescription drug, jet-lag, and fatigue	Stall	52
12/20/2001	Cessna 560 Citation V, HB-VLV / Eagle Air (Flt. 220)	Zurich-Kloten Airport, Switzerland	2 (2)	Takeoff - Initial Climb	Spatial disorientation resulting from poor visibility	Crew Spatial Disorientation	53
11/12/2001	A300-605R N14053 / American Airlines (Flt 587)	Belle Harbor, NY USA	260 (260) + 5 on ground	Takeoff	Pilot-Induced Vehicle Damage brought on by excessive and unnecessary reaction to wake vortex encounter	Atmospheric Disturbance and Inappropriate Crew Response	54
3/19/2001	Embraer 120, N266CA / Comair/Delta Connection (Flt. 5054)	Near West Palm Beach, FL USA	0	Descent	Stall Resulting from Icing Conditions	Stall, Icing	55
12/27/2000	Embraer 120, N721HS / American Eagle (Flt. 230)	O'Hare International Airport, Chicago, IL USA	0	Takeoff - Initial Climb	Pitch Control System Design Flaw Resulting in Excessive Nose-Up Trim, Jammed Stabilizer	Flight Control System Failure	56
10/26/2000	Bombardier CL-600, N958CA / Comair	Falmouth, KY USA	0	Cruise	Vehicle Upset Induced by Wake Vortex Encounter	Atmospheric Disturbance, Wake	57

10/2/2000	A340, TC-JDN / Turkish Airlines	North Atlantic	0	Cruise	Flight Control Mode Change Triggered by Severe Turbulence Encounter, Coupled with Crew Mode Confusion	Atmospheric Disturbance, Turbulence	58
8/23/2000	A320, A40-EK / Gulf Air (Flt. 072)	2 km N off Nahrain International Airport, Bahrain	143 (143)	Approach (During a Go-Around)	Inappropriate control input by crew resulting from spatial disorientation (which caused pilot to falsely perceive aircraft was pitching up and to input a nose down command)	Human Factors - Inappropriate crew response	59
3/30/2000	B767, N182DN / Delta Airlines (Flt. 106)	New York City, NY, USA	0 (225 Injuries)	Takeoff - Initial Climb	Upset caused by Crew Spatial Disorientation under Poor Visibility	Upset, Inappropriate Crew Input	60
2/27/2000	B747, G-BDXL / British Airways (Flt. 179)	Near Providence, RI, USA	0 (12 Serious Injuries)	Approach - Initial Descent	Possible Autopilot Anomaly Resulting from an Inappropriate maintenance action	Autopilot Induced Upset	61
2/16/2000	DC-8, N8079U / Emery Worldwide (Flt. 17)	Sacramento, CA USA	3 (3)	Takeoff - Initial Climb	Elevator failure at lift-off caused by an improper maintenance action (Loss of pitch control resulting from the disconnection of the right elevator control tab)	Flight Control System Failure	62
1/31/2000	MD-83 N963AS / Alaska Airlines (Flt 261)	~2.7 Miles N of Anacapa Island, CA USA	88 (88)	Cruise	Failure of Horizontal Stabilizer Trim System Jackscrew Assembly (Improper Maintenance)	Flight Control System Failure	63
1/10/2000	Saab 340B, HB-AKK / Crossair (Flt 498)	Near Nassenwil, Switzerland	10 (10)	Takeoff - Climb	Vehicle upset (spiral dive) due to spatial disorientation of crew	Human Factors - Inappropriate crew response due to Spatial Disorientation	64
12/22/1999	B747, HL7451 / Korean Air (Flt. 8509)	Near Great Hallingbury, United Kingdom	4 (4)	Takeoff - Initial Climb	Vehicle Upset During Initial Climb Resulting from Instrument Failure	System & Component Failure	65
10/18/1999	Saab SF-340, SE-LES / GAO (Flt 750)		0		Autopilot-Induced Stall under Icing Conditions	Stall, Icing	66

4/7/1999	B737, TC-JEP / Turk Hava Yollari	Near Ceyhan, Turkey	6 (6)	Takeoff - Climb	Stall due to Icing, Erratic Airspeed Indication - Possibly due to icing of pitot static tube	Stall, Icing	67
11/11/1998	Saab 340B, VH-LPI / Kendell Airlines	Eildon Weir, VIC Australia	0	Holding Pattern	Stall due to Icing	Stall, Icing	68
6/16/1998	Saab 340, SE-LEP / GAO (Flt. 758)		0		Autopilot-Induced Stall under Icing Conditions	Stall, Icing	69
2/16/1998	A300, B-1814 / China Airlines (Flt. 676)	Taipei, Taiwan	196 (196) +7 on ground	Approach - During Go-Around	Autopilot-Induced Stall	Autopilot	70
10/10/1997	DC-9-32, LV-WEG / Austral Lineas Aereas (Flt. 2553)	Near Nuevo Berlin, Uruguay	74 (74)	Cruise / Initial Descent	Vehicle Upset (uncontrolled descent) due to High-Speed Slat/Flap Extension by Crew Causing Vehicle Asymmetry, Possibly Exacerbated by Weather (Wind Shear) Conditions	Flight Control System Configuration Asymmetry	71
5/12/1997	A300, N90070/ American Airlines (Flt. 903)	West Palm Beach, FL USA	0	Approach - Initial Descent	Improper Use of Autothrottle by Crew which resulted in loss of airspeed and stall, Forces during the upset exceeded the design limit for the vertical tail	Stall	72
1/9/1997	Embraer-120 / Comair/Delta Connection (Flt 3272)	Near Monroe, MI USA	29 (29)	Approach	Uncontrolled descent following icing encounter	Icing, stall	73
12/22/1996	DC-8 / Airborne Express (Flt. 827)	6.5 km W of Narrows, VA USA	6 (6)	Cruise	Stall Followed by Falling Leaf Upset, Inappropriate Control Inputs for Stall Recovery, Inoperative Stall Warning System	Inappropriate crew training for stall recovery (inadequate training simulator fidelity in reproducing airplane's stall characteristics)	74

10/31/1996	Fokker 100, PT-MRK / TAM Brasil (Flt. 402)	Congonhas Airport, Sao Paulo, Brazil	95 (95) +4 on Ground	Takeoff – Aircraft Failed to Gain Altitude & Collided with Tall Building	Stall Resulting from Inadvertent Deployment of Thrust Reverser on No. 2 Engine resulting in Asymmetric Forces on Aircraft	Stall - Engine Impairment Resulting from Inadvertent Deployment of Thrust Reverser	75
6/9/1996	B737-200, N221US / Eastwind Airlines (Flt. 517)	Near Richmond, VA USA	0 (Incident)	Approach	Rudder System Malfunction (Rudder Reversal)	Flight Control System Failure	76
2/6/1996	B757-200, TC-GEN / Birgenair (Flt. 301)	26 km NE off Puerto Plata, Dominican Republic	189 (189)	Takeoff	Aircraft Stall Resulting from Faulty Instrumentation (Blocked Pitot Tube Resulting in Erroneous Airspeed Readings to Autopilot and Pilot), Poor Situational Awareness and Reaction by Crew to Faulty Airspeed Indicator	Flight Control System Failure	77
2/4/1996	DC-8, HK-3979X / LAC Colombia (Cargo)	2 km N of Asuncion-Silvo Pettirossi International Airport, Paraguay	4 (4) + 20 on Ground	Takeoff - Initial Climb	2 Engines Throttled Back on Same Wing During Unauthorized Single Engine-Out Training (Gear Down and Flaps at 15 deg)	Vehicle upset (asymmetric forces and reduced airspeed) Due to Unauthorized Engine Throttle Back	78
12/3/1995	B737-200, TJ-CB / Cameroon Airlines	Douala, Cameroon	71 (76)	Approach / Go-Around	Engine Failure on Go-Around	Flight Control System Failure - Engines	79
4/27/1995	A320, N331NW / Northwest Airlines (Flt. 352)	Washington D.C., USA	0	Visual Approach	Inappropriate control input by crew (PIO) in response to wind gusts	PIO	80
3/31/1995	A310, YR-LCC / Tarom (Flt. 371)	Near Balotesti, Romania	60 (60)	Takeoff / Climb	Engine Failed to Advance Resulting in Thrust Asymmetry, Possible Pilot Incapacitation	Engine Failure	81
12/13/1994	Jetstream 32, N918AE / American Eagle (Flt. 3379)	7.4 km SW of Raleigh/Gurham Airport, NC USA	15 (20)	Approach	Inappropriate Crew Response to Possible Engine Failure on Approach and Ineffective Stall Recovery	Vehicle Stall Resulting from Inappropriate Crew Control Inputs	82

12/11/1994	B737, N681MA / Markair (Flt. 308)	Anchorage, Alaska USA	0	Climb	Vehicle Upset Resulting from Autopilot Elevator Actuator Failure	Flight Control System Failure	83
10/31/1994	ATR-72, N401AM / American Eagle (Flt 4184)	Near Roselawn, IN USA	68 (68)	Approach - Holding	Vehicle Impairment under Icing Conditions Resulting in Aircraft Stall (Sudden and Unexpected Aileron Hinge Moment Reversal Resulting from Contaminated Airfoil)	Icing, stall	84
9/8/1994	B737-300 N513AU / USAir (Flt 427)	Near Pittsburg, PA (Aliquippa) USA	132 (132)	Approach	Vehicle stall resulting from Rudder System Failure (rudder reversal) subsequent to a wake encounter	Flight Control System Failure, Stall	85
7/2/1994	DC-9, N954VJ / USAir (Flt. 1016)	Charlotte-Douglas International Airport, NC, USA	37 (57)	Approach - During Go-Around	Vehicle stall resulting from wind shear encounter, Failure of Wind Shear Warning System to Activate (Due to inadequate software logic), Thrust Setting was below standard go-around EPR limit of 1.93	Atmospheric Disturbance, Wind Shear, Resulting in Stall	86
6/29/1994	MD-11, N1752K / American Airlines (Flt. 901)	Over the Caribbean Sea, South of Cuba	0 (1 Serious Injury)	Cruise	Vehicle Upset Resulting from Inappropriate Control Input by Crew (Unintended Control Column Input resulting from inadvertent movement of the first officer's seat)	Inappropriate/Inadvertent Control Input by Crew	87
4/26/1994	A300, B-1816 / China Airlines (Flt. 140)	Nagoya-Komaki, Japan	264 (271)	Approach	Vehicle Stalled as a result of inadvertent control setting on approach (Inadvertent Engagement of Take Off Go Around (TOGA) Mode) and Abnormal Out-of-Trim Condition	Stall, Inappropriate control input by crew	88

3/23/1994	A310, F-OGQS / Aeroflot Russian International Airlines (Flt. 593)	Near Mezhduretshensk, Russia	75 (75)	Cruise	Aircraft stalled as a result of inadvertent partial disengagement of autopilot (unauthorized person in cockpit inadvertently disabled autopilot's control of the ailerons)	Stall, Mode Confusion	89
3/8/1994	B737, VT-SIA / Sahara India Airlines	Delhi-Indira Ghandi International Airport, India	4 (4) + 4 on ground	Takeoff (Training Flight)	Inappropriate Control Input by Crew (Trainee Pilot Applied Incorrect Rudder Input During Engine Failure Exercise)	Loss of control resulting from inappropriate control input	90
1/7/1994	Jetstream 41, N304UE / United Express (Flt. 6291)	1.9 km E of Columbus International Airport, Ohio, USA	5 (9)	Approach	Aircraft stall on final approach, possibly under icing conditions	Stall	91
12/15/1993	IAI-1124, N309CK / Martin Aviation	6.5 km N of Santa Ana, CA USA	5 (5)	Approach	Loss of control resulting from atmospheric disturbance	Atmospheric Disturbance, Wake	92
8/18/1993	DC-8, N814CK / Kalitta International (Flt. 808)	Guantanamo, Cuba	0	Approach	Vehicle stalled on final approach coupled with flight crew fatigue	Stall	93
4/29/1993	Embraer 120, N24706 / Continental Express (Flt. 2733)	Pine Bluff, AR USA	0	Climb	Autopilot-induced stall, Crew Fatigue, Possible PIO	Stall	94
4/7/1993	B757, C-FOOA / Canada 3000 Airline Charter (Elite Flt. 833)	30 miles S of Houston, TX USA	0	Cruise	In-flight upset as a result of extreme turbulence and system failure (Aircraft generators came off-line with loss of power to all flight, navigation, and engine instruments)	Atmospheric Disturbance, Turbulence	95
4/6/1993	MD-11, B-2171 / China Eastern Airlines (Flt. 583)	1760 km S of Shemya, AK USA	2 (255)	Cruise	In-flight upset as a result of inadvertent slat deployment during cruise, Large Load Factor Excursions Resulting in Structural Damage	Vehicle Upset, Inappropriate / Inadvertent Control Input	96

3/5/1993	Fokker 100, PH-KXL / Palair Macedonian (Flt. 301)	Skopje Airport, Macedonia	83 (97)	Takeoff - Initial Climb	Loss of roll controllability due to contaminated wing resulting from icing	Icing - Contaminated Airfoil	97
3/4/1993	Aerospatiale ATR-42, N99838 / Britt Airways (Flt 3444)	Near Newark International Airport, NJ USA	0	Approach	Loss of roll control due to contaminated wing resulting from icing	Icing - Contaminated Airfoil	98
12/7/1992	MD-11, B-150 / China Airlines (Flt. 012)	Near Kushimoto, Japan	0	Cruise	Vehicle upset resulting from turbulence, Excessive control inputs by pilot, Damage sustained to left and right outboard elevator resulting in loss of portions of these surfaces	Atmospheric Disturbance - Turbulence	99
6/6/1992	B737-204 HP-120 / COPA Airlines	Tucuti, Panama	47 (47)		Uncontrolled Descent resulting from instrumentation fault/failure (Incorrect Bank Indication)	Uncontrolled Descent, Flight control component failure	100
3/22/1992	Fokker F-28, N485US / USAir (Flt. 405)	New York La Guardia Airport, NY, USA	27 (51)	Takeoff - Initial Climb	Vehicle stalled as a result of icing conditions	Stall / Icing	101
2/15/1992	DC-8, N794AL / Air Transport Internation (ATI) (Flt. 805)	5 km NW of Toledo-Express Airport, OH USA	4 (4)	Approach	Vehicle upset resulting from possible crew disorientation or instrumentation failure (attitude director)	Vehicle Upset - Unusual Attitudes	102
9/18/1991	Convair CV-580, C-FICA / Canair Cargo	Belvedere Center, VT, USA	2 (2)	Cruise	Vehicle upset resulting from spatial disorientation, In-flight break-up resulting from exceedance of design stress limits of the aircraft	Vehicle upset - spatial disorientation	103
9/11/1991	Embraer 120, N33701 / Jet Link - Continental Express (Flt. 2574)	Eagle Lake, TX USA	14 (14)	Cruise	Vehicle upset resulting from airframe damage (In-flight separation of the left horizontal stabilizer leading edge resulting from improper maintenance to replace the de-ice boots)	Vehicle upset - airframe damage	104

5/26/1991	B767, OE-LAV / Lauda Air (Flt. 004)	5.6 km NNE of Phu Toey, Thailand	223 (223)	Initial Climb	Vehicle stall and damage to and partial separation of the rudder and left elevator resulting from in-flight deployment of thrust reverser; This was followed by the down-and-aft separation of most of the right horizontal stabilizer; a torsional overload then caused the separation of the vertical and left horizontal stabilizers, followed by complete break-up of the wing and fuselage. The complete breakup of the tail, wing, and fuselage occurred in a matter of seconds.	Stall - Flight control system fault/failure or inadvertent / erroneous crew action	105
4/5/1991	Embraer 120, N270AS / Atlantic Southeast Airlines - Delta Connection (Flt. 2311)	Brunswick, GA USA	23 (23)	Approach	Vehicle upset resulting from propeller system failure (Malfunction of the left engine propeller control unit, which resulted in an uncommanded and uncorrectable movement of the blades of the left propeller below the flight idle position)	Flight Control System/Component Failure	106
3/3/1991	B737-291 N999UA / United Airlines (UA 585)	Colorado Springs, CO USA	25 (25)	Approach	Vehicle upset resulting from rudder system failure (rudder reversal)	Flight Control System / Component Failure	107
2/11/1991	A310, D-AOAC / Interflug	Near Moskva Russia	0	Approach	Vehicle stall during go-around resulting from inappropriate crew inputs (Crew overrode autopilot during go-around)	Stall - Inappropriate Crew Control Inputs	108
9/20/1990	B707-321B NN320MJ /	Maranza, AZ USA	1 (3)	Takeoff (with Limited Instruments)	Vehicle upset during takeoff due to inappropriate rudder trim (Rudder Trimmed Nose Right), Improper Pre-Flight Planning & Preparation by Pilot	Vehicle upset - inappropriate rudder trim	109

7/19/1989	DC-10-10 N1819U / United Airlines (Flt 232)	Sioux City, Iowa USA	111 (296)	Cruise	Uncontained engine failure resulting in vehicle damage and loss of hydraulics to control surfaces, Pilot Used Differential Engines to Crash Land Near Sioux City Gateway Airport	Flight control system/component failure	110
3/10/1989	Fokker F-18, C-FONF / Air Ontario (Flt. 1363)	Dryden Municipal Airport, ON Canada	24 (69)	Takeoff - Initial Climb	Aircraft was unable to gain altitude due to contaminated airfoil from icing	Icing - Contaminated Airfoil	111
1/8/1989	B737, G-OBME / British Midland Airways (Flt. 092)	Kegworth, United Kingdom Near East Midlands	47 (126)	Approach	Engine Failure Combined with Inappropriate Crew Response (Crew Shut Down Wrong Engine)	Engine Failure	112
9/15/1988	B737, ET-AJA / Ethiopian Airlines (Flt. 604)	10 km SW of Bahar Dar Airport, Ethiopia	35 (104)	Takeoff	Loss of both engines due to ingestion of foreign objects (birds)	Engine Damage	113
2/9/1988	Jetstream 31, N823JS / Jetstream International - Piedmont Commuter	Springfield Airport, OH, USA	3 (3)	Approach - During Go-Around	Loss of control resulting from inappropriate vehicle configuration during go-around; Insufficient supervision during training flight	Vehicle Impairment - Inappropriate Vehicle Configuration	114
8/31/1987	B737, HS-TBC / Thai Airways (Flt. 365)	15 km off Phuket, Thailand	83 (83)	Approach	Vehicle stalled on final approach, Pilot distracted by traffic pattern on approach and did not execute a recovery in time to save the vehicle	Stall	115
3/4/1987	CASA C-212, N160FB / Northwest Airlink (Flt. 2268)	Detroit Metropolitan Wayne County Airport, MI USA	9 (19)	Final Approach	Vehicle upset resulting from inappropriate control inputs by Crew (Asymmetric power condition at low speed following pilot's intentional use of beta mode of propeller operation to descend and slow the airplane rapidly on final approach)	Inappropriate Control Input by Crew	116

9/6/1985	DC-9-14 N100ME / Midwest Express (Flt 105)	Milwaukee, WI USA	31 (31)	Takeoff	Vehicle stall resulting from engine failure and inappropriate crew response (Pilot Input Incorrect Rudder Command)	Engine, stall	117
8/12/1985	B747, JA8119 / Japan Air Lines (Flt. 123)	Near Ueno Japan	520 (524)	Cruise	Airframe damage that resulted in loss of control surfaces (Rupture of aft bulkhead initiated by fatigue cracks, resulting in separation of a portion of the vertical fin and the section of the tailcone that contains the auxiliary power unit; this damage caused a drop in hydraulic pressure, which resulted in the inoperability of the control surfaces)	Airframe Failure	118
2/19/1985	B747, N4522V / China Airlines (Flt. 006)	550 km NW off San Francisco, CA USA	0 (2 Serious Injuries)	Cruise	In-flight upset following engine failure resulting from insufficiency of the autopilot for operation under abnormal conditions; Crew was distracted with the engine failure, relied too heavily on the autopilot, and failed to monitor airplane's flight instruments; Successful recovery and safe landing were made by the crew; Airplane suffered major structural damage during the upset, descent, and subsequent recovery	Flight Control System Failure - Engines, Autopilot Insufficiency for Off-Nominal Operation	119

1/21/1985	Lockheed L-188 Electra, N5532 / Galaxy Airlines (Flt. 203)	3 km SE of Reno / Tahoe International Airport, NV USA	70 (71)	Takeoff - Initial Climb	Aircraft stalled as a result of in-flight vehicle anomaly / damage (Failure of ground crew to secure the air start access door, which caused unexpected "thunking" noise and vibration during takeoff - and possible airframe damage)	Stall	120
5/30/1984	Lockheed L-188 Electra, N5523 / Zantop International Airlines (Flt. 931)	Chalkhill, PA USA	4 (4)	Cruise	Vehicle upset resulting from instrumentation failure (No. 2 Gyro Malfunction; Possible conflicting pitch and roll information to flight crew), In-flight damage and breakup resulting from overstress during upset and attempted recovery	System & Component Failure - Instrumentation	121
7/9/1982	B727, N4737 / Pan American World Airways (Flt. 759)	New Orleans, LA USA	145 (145) + 8 on ground	Takeoff - Initial Climb	Microburst wind shear encounter on takeoff	Atmospheric Disturbance - Wind Shear	122
1/13/1982	B737, N62AF / Air Florida (Flt. 90)	1.4 km N of Washington-National Airport, DC, USA	74 (79) + 4 on ground	Takeoff - Initial Climb	Vehicle stalled as a result of icing conditions that contaminated the airfoil	Stall / Icing	123
11/11/1979	DC-10, XA-DUH / AeroNaves (Flt. 945)	Near Luxemburg, Germany	0	Takeoff - Climb to Cruise	Autopilot-Induced stall in vertical speed mode; Overload failure to elevator assembly attachments (in-flight separation)	Stall	124

5/25/1979	DC-10-10, N110AA / American Airlines (Flt. 191)	O'Hare International Airport Chicago, IL USA	271 (271) +2	Takeoff (Just After Rotation)	Vehicle stalled as a result of vehicle damage (separation of Left Engine & Pylon Assembly & ~3 ft. of Leading Edge from Left Wing with Uncommanded Retraction of Left Wing Outboard LE Slats (Resulted from Poor Maintenance)); Failure of Stall Warning System	Airframe Damage / Stall	125
4/4/1979	B727, N840TW / Trans World Airlines (Flt. 841)	Near Saginaw, MI USA	0	Cruise	Vehicle Upset resulting from control surface failure - Slat Asymmetry: Aircraft's No. 7 leading edge slat (on its right wing) was stuck in the extended or partially extended position and could not be retracted (due to a pre-existing misalignment and the resulting air loads); No. 7 slat was torn from the aircraft	System / Component Failure - Flight Control System	126

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