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General Aviation Loss of Control in Flight Accidents: Causal and Contributory Factors

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Loss of control in flight is the primary fatal accident category in general aviation. Forty six fixed-wing UK accidents from 2018 and 2019 were analyzed to identify precursors, human factors, and possible reasons for unsuccessful recovery. Most of the events were non-fatal (82.6%), and most occurred during low altitude flight phases, particularly landings and go-arounds. Pilots under 40 and over 75 were disproportionately more likely to experience loss of control in flight. It was mostly precipitated by ineffective recovery from an upset, inadequate energy management, abnormal/inadvertent control inputs or maneuvers, or improper procedures. Insufficient height above the ground was a factor in most unsuccessful recoveries, followed by limited pilot capability. Fatal accidents were much more likely to be unrecoverable due to a hazardous mental or physical state or incorrect recognition of the situation. Decision- and skill-based human errors contributed to most events; more than half of cases involved both errors. Fatal accidents were more complex in terms of pre-flight and latent human errors. These results informed a new definition of loss of control in flight for general aviation combined with a conceptual framework to inform future intervention strategies.

I. Introduction

Loss of control in flight (LOC-I) or the departure from controlled flight continues to threaten flight safety. It is the primary category of fatal accidents in both commercial aviation [1] and general aviation (GA) [2]. However, LOC-I is of particular concern in GA where there is a higher accident rate than in other aviation sectors [3]. In UK General Aviation from 2010 to 2015 inclusive, there were 72 fatal accidents of which 46% were due to LOC-I [4]. During this same period, there were only 25 fatal accidents for all western built commercial transport aircraft worldwide [5]. Nevertheless, there is a lack of understanding of the characteristics of LOC-I in GA, and there currently exists no definition of LOC-I specifically for GA.

Current qualitative definitions of LOC-I for commercial aviation were reviewed for four different organizations (Table 1, [6],[7],[8] [9]). Most notably, the International Air Transport Association (IATA) states that LOC-I involves

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unrecoverable deviations from the intended flight path, implying that LOC-I exclusively encompasses incidents where recovery was unsuccessful. This notion is directly challenged in research by Bromfield & Landry [10], who redefined LOC-I to expand the boundaries of the phenomena and emphasize the importance of including non-fatal and recoverable events. Further, the redefinition includes important information on common causal and contributory factors and recovery criteria to provide a conceptual framework (Figure 1). However, only commercial aviation was considered in developing the framework which limits its pertinence in characterizing LOC-I in GA, a sector with inherently dissimilar attributes and requirements [11].

The commercial aviation environment has higher levels of safety oversight and supervision, with aircraft operating from prepared runways. Pilots are professionals, typically operating in a two pilot environment, sharing the workload using Crew Resource Management (CRM) principles. They receive rigorous training and are required to fly to a higher degree of precision and demonstrate higher levels of proficiency. They are required to conduct biannual (not biennial) license proficiency checks and have access to certified flight simulators for supplementary training and development. Commercial aircraft are generally certified for Instrument Meteorological Conditions (IMC) and flight in icing conditions. They have higher wing loading, are more stable, less maneuverable and more gust resistant. They have higher demonstrated crosswind limits, fitted with stall warning and safety systems supported by high levels of automation.

Table 1. - Current definitions of LOC-I from 4 different organizations

Organization	LOC-I Definition
Federal Aviation Administration (FAA) [6]	"An unintended departure of an aircraft from controlled flight" that may occur "because the aircraft enters a flight regime that is outside its normal flight envelope and may quickly develop into a stall or spin. It can introduce an element of surprise for the pilot."
European Aviation Safety Agency (EASA) [7]	"Loss of control in flight is loss of aircraft control while, or deviation from intended flightpath, in flight. Loss of control in flight is an extreme manifestation of a deviation from intended flight path. LOC-I accidents often result from **failure to prevent or recover** from stall and upset."
Commercial Aviation Safety Team (CAST) and International Civil Aviation Organization (ICAO) Common Taxonomy Team (CICTT) [8]	"Loss of aircraft control while, or deviation from intended flightpath, in flight. Loss of control in flight is an extreme manifestation of a deviation from intended flightpath. The phrase "loss of control" may cover only some of the cases during which an unintended deviation occurred." "Loss of control can occur during either IMC or Visual Meteorological Conditions (VMC)" and "may occur as a result of a deliberate manoeuvre".
IATA [9]	"LOC-I refers to accidents in which the flight crew was unable to maintain control of the aircraft in flight, resulting in an **unrecoverable** deviation from the intended flight path."

Causal factors of LOC-I have been investigated in several previous studies using various methodologies [12],[13]. Table 2 and Table 3 present the statistical results from the accident analysis studies carried out by Jacobson and Belcastro et. al. respectively. Research by the IATA has cited latent conditions such as poor training systems and lack of regulatory oversight as contributory factors of LOC-I accidents [14]. Latent factors with respect to human influences have also been investigated using the Human Factors Analysis and Classification System (HFACS) framework developed by Wiegmann & Shappell to analyze commercial aviation accidents, although with limited focus on LOC-I [15]; [16]; their results are presented in (Table 4). However, the aforementioned studies focus mainly on commercial aviation and research specifically into GA is less widespread. Exclusive analysis of GA LOC-I accidents during approach & landing and departure & take-off has been undertaken by the General Aviation Joint Steering Committee (GAJSC) [17] using discrete "Standard Problem Statements" (SPS), a methodology which has also been applied in additional, closely related research [18]. Like the IATA, Branham and the GAJSC categorized the SPSs into pilot, environment or aircraft related with additional categories for latent problems such as Air Traffic Control (ATC), Builder, and Organization. Table 5 presents the 10 most frequently occurring SPSs. Pilot factors and inappropriate crew actions were significant across all the studies and in further research by Gratton & Bromfield [19], but the influence of system failures and environmental factors varies across the literature. The research of Branham and the GAJSC is also limited to certain phases of flight, and Jacobson, Branham and the GAJSC all use methodology that condenses event sequences into discrete problems or causal factors.

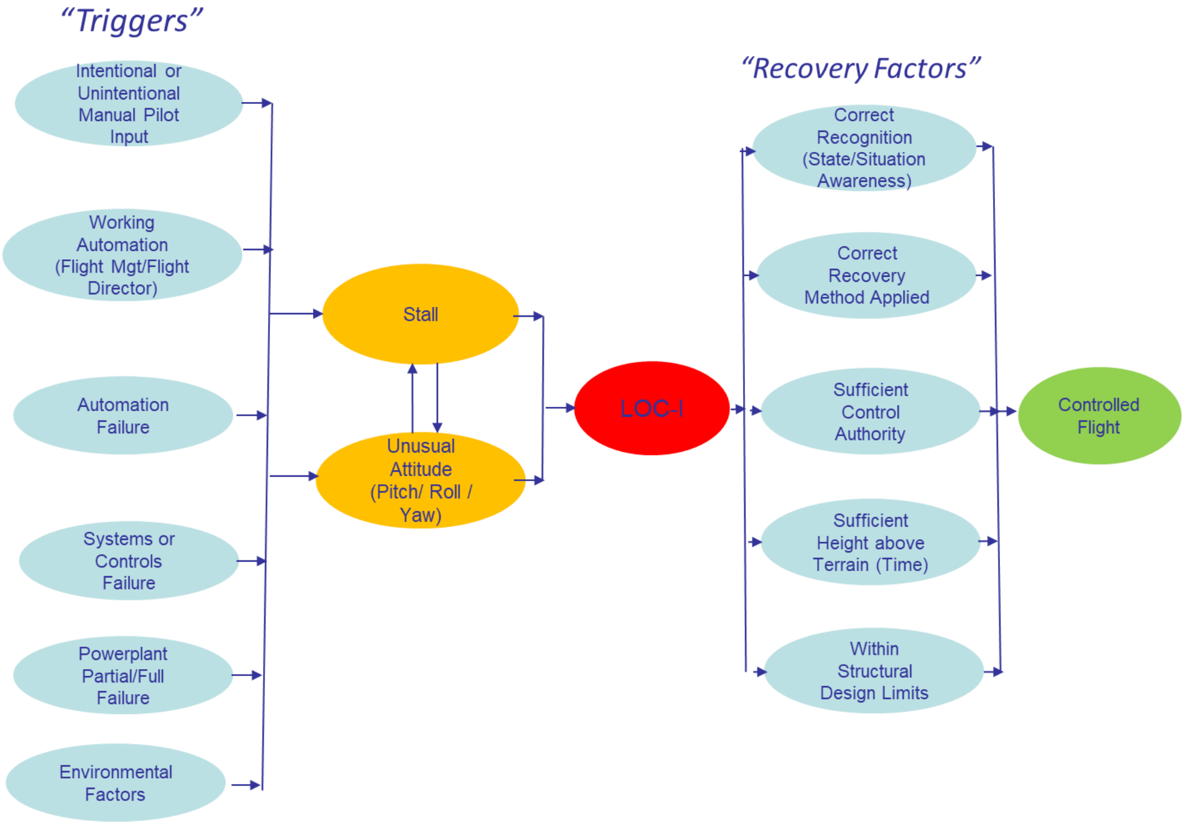


Figure 1. LOC-I Framework developed by Bromfield & Landry for Commercial Aviation LOC-I [10]

Conversely, Belcastro et. al.'s methodology included the temporal sequencing of the precursors in each accident, shown in Table 6, improving the understanding of accident sequences; such understanding has been crucial in other studies [20], but the methodology has yet to be applied to GA.

Table 2. Percentage of 275 commercial aviation accidents investigated by Belcastro et. al. which involved each causal factor category and sub-category

Precursor Category/Subcategory	Accidents/ Incidents	%
Adverse Onboard Conditions	**240**	**87.3**
Vehicle Impairment	86	31.6
System & Component Failures/Malfunctions	117	42.6
Inappropriate Crew Action/Inaction	160	58.2
External Hazards &Disturbances	**101**	**36.7**
Inclement Weather & Atmospheric/Disturbances	65	23.6
Poor Visibility	30	10.9
Obstacle	166	5.8
Abnormal Dynamics & Vehicle Upset Conditions	**220**	**80.0**
Abnormal Vehicle Dynamics	47	17.1
Vehicle Upset Conditions	188	68.4

Table 3. Percentage of 22 fatal commercial aviation LOC-I accidents investigated by Jacobson which involved each causal factor category and sub-category

Causal Factor	Accidents/ Incidents	%
Pilot/Human Induced		
Improper Procedure	10	45.45
Spatial Disorientation	6	27.27
Poor Energy Management	6	27.27
Distraction	5	22.73
Improper Training	5	22.73
Poor Design	2	9.09
Environmentally Induced		
Weather	3	13.64
Icing	2	9.09
Wake Vortex	1	4.55
Systems Induced		
Aircraft System Failures	5	22.73
Poor Design	2	9.09

Table 4. The percentage of 120 commercial aviation accidents investigated by Wiegmann & Shappell which were contributed to by each HFACS category

HFACS Category*	Accidents/ Incidents	%
Organizational Influences		
Resource Management	3	2.5
Organizational Climate	0	0.0
Organizational Process	10	8.4
Unsafe Supervision		
Inadequate Supervision	6	5.0
Planned Inappropriate Operations	1	0.8
Failed to Correct Problem	2	1.7
Supervisory Violations	2	1.7
Preconditions for Unsafe Acts		
Adverse Mental States	16	13.4
Adverse Physiological States	2	1.7
Physical/Mental Limitation	13	10.9
Crew Resource Management	35	29.4
Personal Readiness	0	0.0
Unsafe Acts		
Skill-based Error	72	60.5
Decision Error	34	28.6
Perceptual Error	17	14.3
Violations	32	26.9

* HFACS categories are describe in detail in reference [16]

Table 5. The top 10 standard problem statements identified by Branham in 193 GA LOC-I fatal accidents occurring on approach and landing

SPS Rank	Description	% Accidents
1	Pilot failure to maintain airspeed	73.06
2	Pilot aerodynamic stall/spin	51.81
3	Pilot Aeronautical Decision Making/Poor Judgement	32.12
4	Significant Weather	29.02
5	Pilot failure to recognize stall and execute corrective	19.69
6	Pilot failure to fly stable approach	18.65
7	Pilot intentional non-compliance	15.03
8	Pilot improper flight planning	14.51
9	Pilot loss of situational awareness	12.95
10	Pilot insufficient aircraft system and limitation knowledge	10.88

Table 6. The temporal sequencing of the precursor categories and sub-categories identified by Belcastro et. al.'s research into 275 commercial aviation LOC-I accidents

	Position in Sequence						
Precursor Category/Subcategory	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
Adverse Onboard Conditions	167	153	88	39	10	3	0
Vehicle Impairment	41	32	11	4	3	0	0
System & Component Failures / Malfunctions	84	35	10	5	1	0	0
Inappropriate Crew Action/Inaction	42	86	67	30	6	3	0
External Hazards & Disturbances	86	16	4	2	0	1	0
Inclement Weather & Atmospheric Disturbances	58	6	1	1	0	0	0
Poor Visibility	19	6	2	0	0	0	0
Obstacle	9	4	1	1	0	1	0
Abnormal Dynamics & Vehicle Upset Conditions	0	89	78	55	33	11	3
Abnormal Vehicle Dynamics	0	23	14	8	4	1	0
Vehicle Upset Conditions	0	66	64	47	29	10	3
Unknown Precursor Events	22	N/A	N/A	N/A	N/A	N/A	N/A
Total	**275**	**258**	**170**	**119**	**43**	**15**	**3**

Experience and phase of flight have also been reported to affect the likelihood and fatality of LOC-I [21]. Taylor et. al.’s review of GA accidents between 2005 and 2011 found that fatal accidents generally involve pilots with greater total, but lower on-type, experience which is backed by the Civil Aviation Authority (CAA) [22]. In terms of flight phase, there are inconsistencies in the most significant flight phases associated with LOC-I observed within the literature, as shown in Table 7 [23],[24]; such contradiction motivates further study.

Table 7. Phase of Flight most associated with LOC-I according to various organizations and researchers

Source	Phase of Flight with most LOC-I Accidents	% of Accidents/ Incidents Investigated	Comments/Scope of Study
Jacobson [12]	Climb/Initial Climb	27	Worldwide Commercial Jet LOC-I 1999-2008
Belcastro et. al., [13]	Climb/Initial Climb	44	Worldwide Commercial Aviation LOC-I 1996-2010
IATA [14]	Climb/Initial Climb	29	Worldwide Commercial LOC-I 2010-2014
Aircraft Owners & Pilots Association (AOPA) [3]	Landing	Exact Value Not Stated	US GA Loss of Control Accidents 2007 - Scope of LOC-I not clearly defined
General Aviation Safety Council (GASCo) [24]	Maneuvering	35	Fatal UK GA LOC-I Accidents in VMC 2003-2012
CAA [25]	Cruise	34	UK GA LOC-I in VMC 1985-1994
National Transportation Safety Board (NTSB) [23]	Approach	23	US GA LOC-I accidents 2008-2014
Houston et. al., [20]	Landing	62	147 Instructional GA Loss of Control Accidents (including LOC-G)

There has yet to be a holistic study into the issue of LOC-I in GA considering all flight phases and with a focus on characterizing the causal and contributory factors to the extent of equivalent research into commercial aviation.

II. Methodology

Accident and incident reports were obtained from the Air Accidents Investigation Branch (AAIB) online database [26]. The GA fixed-wing and sports aviation and balloons categories were searched for reports on events occurring between January 2018 and December 2019 (24 months in total). This two-year time period was chosen since it can take up to 13 months elapsed time from the date of an accident to complete an investigation and this period also excludes possible effects on GA flying due to the Covid-19 pandemic. The manual effort to analyze individual reports is also considerable with 261 reports in total reviewed. Three-axis microlight and ultralight aircraft were considered within the sports aviation category, as well as GA fixed-wing aircraft. The ‘synopsis’ and ‘history of the flight’ subsections of each report identified by the initial search were examined, and the criteria in Table 8 were used to identify events involving LOC-I. Reports were reviewed by an individual researcher, educated, and trained in the use of analyses techniques. Any queries/exceptions were independently reviewed and verified by the research supervisor.

Table 8. Criteria used to identify accident and incident reports which involved LOC-I

Criteria	Description	Reasoning
ALL	The aircraft must be airborne at the instance of control being lost.	LOC-I only applies to events where control was lost whilst the aircraft was airborne. Loss of control on the ground, referred to as LOC-G, happens under very different circumstances and as such requires separate research and is not relevant to this study.
1	Significant and unintentional deviation of the aircraft from the pilot's intended flight path.	Most definitions of LOC-I involve deviation from the intended flight path. If an aircraft significantly deviates from the trajectory intended by the pilot, and pilot cannot immediately return to the desired trajectory, then it is likely that aircraft control has been lost.
2	Vehicle upsets, including stalls, spins, spiral dives, uncontrolled or abrupt descents, abnormal attitudes, airspeeds, angular rates, or flight trajectory.	Vehicle upset conditions are synonymous with LOC-I and unless part of aerobatics or upset training, are usually unintentional and indicate that the pilot is having difficulty controlling the aircraft or is unable to maintain steady flight.
3	Situations where the pilot had significantly reduced control authority	If, due control component failures or malfunctions or severe control restrictions, the pilot is unable to maintain the intended flight path and effectuate intended aircraft movements using the aircraft control surfaces, then control has been lost.
4	Situations where the motion of the aircraft was uncommanded and/or not under the control of the pilot	If the movement of the aircraft is unusual and not commanded or controlled by the pilot, then loss of control has also likely occurred, even if the intended flightpath is not significantly deviated from. For example, an uncommanded significant roll to the left or right possibly leading to an unusual attitude.

Any one or more of criteria 1 to 4 identified in a report indicated that loss of control was a key factor in the event and that the report should be retained for further analysis. Upsets are a common pre-cursor to LOC-I, and these can be identified by using the quantitative analysis of pitch angle exceedance, bank angle exceedance and/or airspeeds inappropriate for conditions [27]. In commercial aviation for larger aircraft, these data are available but in general aviation utilizing smaller aircraft, these data are not generally available hence a qualitative analysis method was used in this study based upon the description of the aircraft motions within the associated accident reports. The reports collected were then examined and the preliminary details in Table 9 were documented.

Table 9. Preliminary data types, and the reasoning for each, which were obtained from each report including personnel, environmental and flight details

Preliminary Data	Details	Comments
1	Accident, Serious Incident or Incident	Whether an event is classed as an incident, serious incident or accident gives an indication of event severity
2	Report Type	The type of report (field investigation, correspondence investigation) often determines the report level of detail
3	Aircraft Make and Model	It may be possible that some aircraft makes, and models are especially prone to LOC-I
4	Date of Occurrence	Indication of if significantly more events occurred in 2018 or 2019
5	Flight Type	To determine if the flight was private, training, etc.
6	Fatal or Non-Fatal	To determine how many events are fatal and identify differences between fatal and non-fatal data
7	Recovery or No Recovery	In some non-fatal cases, full recovery may have been made.
8	VMC or IMC	Meteorologic conditions are not always stated in reports, but if present may determine significance of IMC/VMC
9	Wind Speed	Exact wind speed and direction is not always stated in reports but if present may determine significance of wind effects
10	Day or Night	To identify how many accident flights occur at night
11	Phase of Flight	Indication of the most dangerous phases of flight with respect to LOC-I
12	Commander Experience	Commander hours (Total, On-Type, Last 90 Days and Last 28 Days) to investigate effects of experience
13	Commander Age	Indication of the potential effects of factors sometimes associated with pilot age on the likelihood of LOC – I

A simple statistical analysis was carried out on these data to determine significant trends, such as the flight phase during which most LOC-I events occur. This was followed by a more in-depth analysis of each report using the three analysis methods outlined in the remainder of this section.

A. Belcastro et. al. Precursor Sequence Analysis

The research of Belcastro et. al. into commercial air transport LOC-I accidents [13] identified an extensive list of precursors which could be used to analyze accident reports, and which could be organized into a sequence to represent the temporal progression of accidents and incidents from controlled flight to LOC-I events. Modifications were made to better reflect the context of General Aviation and supporting reasoning (Table 10).

For each accident report, the sequence of events was translated into an amended sequence of the precursors (Table 11). The resulting data were analyzed in terms of the number of occurrences of each precursor at each point in the accident sequences and which individual precursors occurred most across entire accident sequences. These data were also used to produce several flow charts which visualized the potential precursor sequences advancing from controlled flight to LOC-I.

Table 10. Changes made and reasoning for each, when adapting the original Belcastro et. al. precursor list for use in this study

Change	Details	Reasoning
1	System operational error (Design Flaw/Validation Error) and System Operational Error (Software/Verification Error) were removed	Precursors removed due to not being identified in any GA LOC-I reports and system & component failures being able to be successfully categorized into the remaining precursor categories.
2	Lack of Aircraft Type-Specific Knowledge/Experience was added	Precursor added to reflect a common case within GA of a pilot having low experience on a particular type of aircraft resulting in reduced proficiency in manual handling or aircraft procedure.
3	Low Currency was added	Precursor added to indicate cases where a lack of recent flying experience had a clear effect on the accident sequence and the pilot's capability to respond appropriately to loss of control situations
4	IMC added as a precursor	Precursor added to the poor visibility category to indicate the general case of flying in IMC contributing to loss of control
5	Stall/Departure (Falling Leaf/Spin) was simplified to stall/spin	Stall/Spin offers adequate detail whilst being simpler than the original precursor name
6	Wind (including crosswind) was added	Precursor added to indicate cases where the wind was not necessarily turbulent but still contributed to LOC-I, or there was a significant crosswind component responsible for a LOC-I during approach and landing
7	Uncontrolled Descent (spiral Dive) was expanded to Uncontrolled/Abrupt Descent (including Spiral Dive)	Precursor adjusted to include the common case of an unanticipated, sudden increase in rate of descent contributing to LOC-I

Table 11. Amended full list of precursors adapted from Belcastro et. al. for use in this study into GA*

Adverse Onboard Conditions	External Hazards & Disturbances	Abnormal Dynamics & Vehicle Upset Conditions
Vehicle Impairment	**Inclement Weather & Atmospheric Disturbances**	**Abnormal Vehicle Dynamics**
Inappropriate Vehicle Configuration	Thunderstorms / Rain	Uncommanded Motions
Contaminated Airfoil	Wind Shear	Oscillatory Vehicle Response (PIO)
Improper Loading: Weight, Balance, CG	Turbulence	Abnormal Control for Trim/Flight
Improper Loading: Cargo Problems and Loose Articles	Wake Vortex	Abnormal/Counter-intuitive Control Response
Airframe Structural Damage	Snow / Icing	**Vehicle Upset Conditions**
Engine Damage (FOD)	*Wind (Including Crosswind)*	Abnormal Attitude
System & Component Failures/Malfunction	**Poor Visibility**	Abnormal Airspeed
Control Component F/M	Fog / Haze	Abnormal Angular Rates
Engine F/M	Night	Undesired Abrupt Dynamic Response
Sensor/Sensor System F/M	*IMC*	Abnormal Flight Trajectory
Flight Deck Instrumentation F/M	**Obstacle**	*Uncontrolled/Abrupt Descent (Including Spiral Dive)*
System/Subsystem F/M (Non-control)	Fixed Obstacle	*Stall/Spin*
Inappropriate Crew Action/Inaction	Moving Obstacle	
Loss of Attitude State Awareness/ Spatial Disorientation		
Loss of Energy State Awareness/ Inadequate Energy Management		
Lack of Aircraft/System State Awareness/ Mode Confusion		
Aggressive Manoeuvre		
Abnormal/Inadvertent Control Input/Manoeuvre		
Improper/Ineffective recovery		
Inadequate/Loss of Crew Resource Monitoring/Management		
Improper Procedure		
Fatigue/Impairment (Inc. Hypoxia)		
Lack of Aircraft Type-Specific Knowledge/Experience		
Low Currency		

*Note: additional/amended conditions for GA shown in *italics*

B. Bromfield & Landry Recovery Criteria Analysis

The LOC-I framework developed by Bromfield & Landry [10] for commercial aviation included five ‘recovery factors’, representing 5 criteria considered essential for a successful recovery from LOC-I. Two additional recovery criteria, (non-hazardous mental/physical state and sufficient pilot capability/airmanship) determined by preliminary investigations into accident and incident reports and a review of the literature, were incorporated into the framework to give a total of seven criteria (Table 12) . For each event where there was no effective LOC-I recovery, the main recovery criteria which were not met were identified and documented. An accident or incident was only attributed to a failed recovery criterion if it was conspicuous from the report that failure to meet the criterion directly affected the likelihood or execution of a successful recovery procedure. It was possible for events to be attributed to multiple failed recovery criteria.

Table 12. Criteria for successful recovery expanded from research by Bromfield & Landry [10]

No.	Recovery Criteria	Details	Example(s) of Criteria not being Met
1*	Non-hazardous Mental and Physical State	The pilot must not be in a hazardous physical mental state when recovering from LOC-I. This includes factors such as incapacitation, panic, high workload/stress, disorientation, confusion, or surprise which significantly affect the pilot's ability to make a recovery.	Pilot incapacitation during, or leading to, an upset. Pilot stress/workload sufficiently high to significantly affect their ability to select and apply a recovery method.
2	Correct Recognition (State/Situational Awareness)	To take corrective action, the pilot needs to correctly recognize the state and situation which the aircraft is in.	Failing to monitor the attitude, angular rates and airspeed of the aircraft and not realizing a stall or significantly abnormal attitude is imminent. Incorrectly identifying spin direction and consequently applying the incorrect recovery.
3	Correct Recovery Method Applied	The decision must be made to attempt the correct recovery technique given the situation the aircraft is in. (Only cited as a factor if a recovery attempt was made *and* the attempted technique was inappropriate)	Any attempt at a recovery which was not appropriate for the situation, for example, trying to recover from a stall without applying nose-down control inputs, or applying control inputs which increase the rate of spin during an attempted spin recovery.
4*	Sufficient Pilot Capability and Airmanship	Once the correct recovery method is attempted, the pilot must have the manual flying skills to execute it completely. If a correct recovery method was not attempted, there may also be clear indications that the pilot did not have the capability to deal with a situation, due to a lack of experience or proficiency in such a situation.	Correct stall recovery method attempted, but not effectuated quickly enough or with control inputs which are too gentle. Pilot attempting to land in a very high crosswind despite not having flown in a such a situation before (clear indication of lack of capability and experience)
5	Sufficient Control Authority	The control systems must be functional to an extent that allows the pilot to manoeuvre the aircraft as intended.	Malfunction of the elevator control surfaces leading to reduced control authority in pitch to the extent that LOC-I recovery is severely hindered or impossible
6	Sufficient Height Above Terrain (Time)	The aircraft must be a sufficient height above terrain to allow enough time for the pilot to take corrective action during a LOC-I situation before the aircraft contacts the ground.	Stalling within 50 ft of the ground so that the aircraft does not have enough altitude available for angle of attack to be safely reduced through nose-down control inputs without the aircraft contacting the ground.
7	Within Structural Design Limits	The necessary corrective action or recovery method must require control inputs and maneuvers which do not exert dangerously high forces on the aircraft to an extent which could inflict structural damage.	Stalling and entering a nosedive in which the airspeed increases to a level which cannot be recovered from without exerting damaging forces on the wings.

*Note: Criteria for GA added to original Bromfield & Landry Commercial Aviation LOC-I Framework [10]

C. HFACS Framework Analysis

Traditionally, the HFACS framework developed by Wiegmann & Shappell [16] facilitates the classification of human error at four different levels. Outside influences have been added to the framework including economic, and political influences from outside of the organizational level (Figure 2). Condition of aircraft (maintenance condition and/or flying qualities) has also been added to represent the influence of aircraft state on human performance. In this research, information contained in each accident or incident report was used to identify the HFACS categories at each level in the framework which played a contributory role in the event, extending the scope of human factors analysis beyond the day of an accident. The resulting data were analyzed for the percentage of GA LOC-I accidents in which each HFACS category was a contributory factor. HFACS is a traditional safety analysis technique, readers may also wish to refer to the work of Leveson [28] for an alternative approach to modelling systems based safety events.

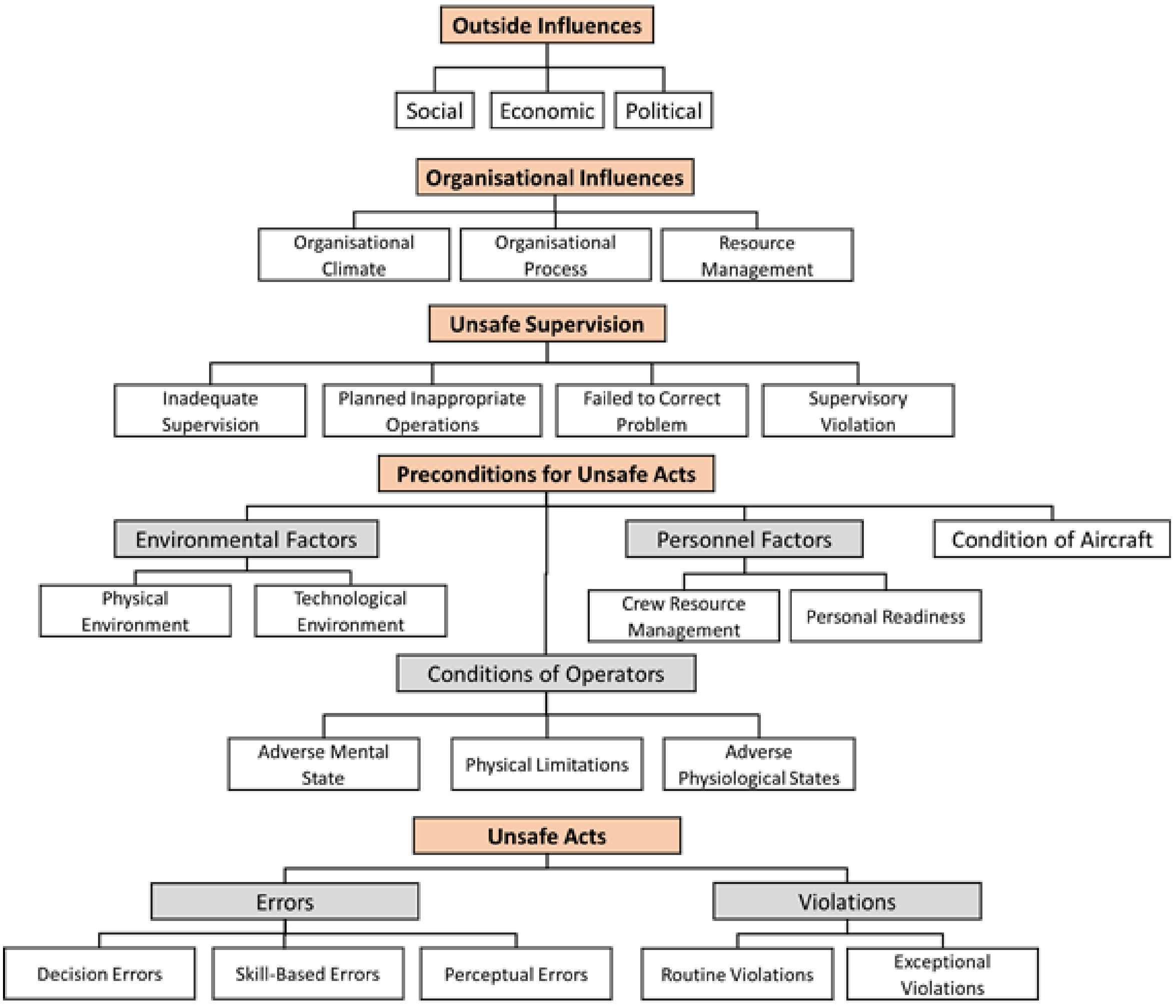


Figure 2. Extended HFACS framework adapted for use in this study into GA based on Wiegmann & Shappell [16]

D. Data Analysis and Framework Development

Key statistics and important trends identified from the analysis methods, including the initial analysis of basic report details, informed the development of a conceptual framework for LOC-I in GA. This was initially based on the framework developed for commercial aviation by Bromfield & Landry [10] shown in the introduction. Results from the Belcastro et. al. precursor analyses were combined with HFACS results to obtain a condensed list of GA LOC-I causal and contributory factors to replace the ‘triggers’ and results from the recovery criteria analysis were used to expand the ‘recovery factors’. The vehicle upset conditions of the Belcastro et. al. analyses were also used to expand the adverse aircraft state level of the framework. The insight into latent factors offered by the upper levels of the HFACS framework was also used to introduce a new set of pre-flight contributory factors preceding the ‘triggers’ in the original framework.

III. Results

In the initial search 261 accidents were identified, 46 of which were relevant to GA fixed-wing LOC-I; thus, of all non-rotorcraft and non-Uncrewed Aerial Systems (UAS) accidents and incidents within UK GA in 2018 and 2019, 17.6 % of events involved fixed-wing LOC-I. Key general statistics are outlined in Table 13.

Table 13. The key general statistics of the LOC-I events in 2018 and 2019

Statistic	Number of Events	% of Events
Year		
2018	27	58.7
2019	19	41.3
Event Category		
Accident	42	91.3
Serious Incident	4	8.7
Incident	0	0.0
Fatality		
Fatal	8	17.4
Non-Fatal	38	82.6
Meteorological Conditions		
VMC	26	56.5
IMC	3	6.5
Not Stated	17	37.0
Day or Night		
Day	44	95.7
Night	2	4.3
Type of Flight		
Private	40	87.0
Training	6	13.0
Recovery of Control		
Recovered	4	8.7
Not Recovered	42	91.3

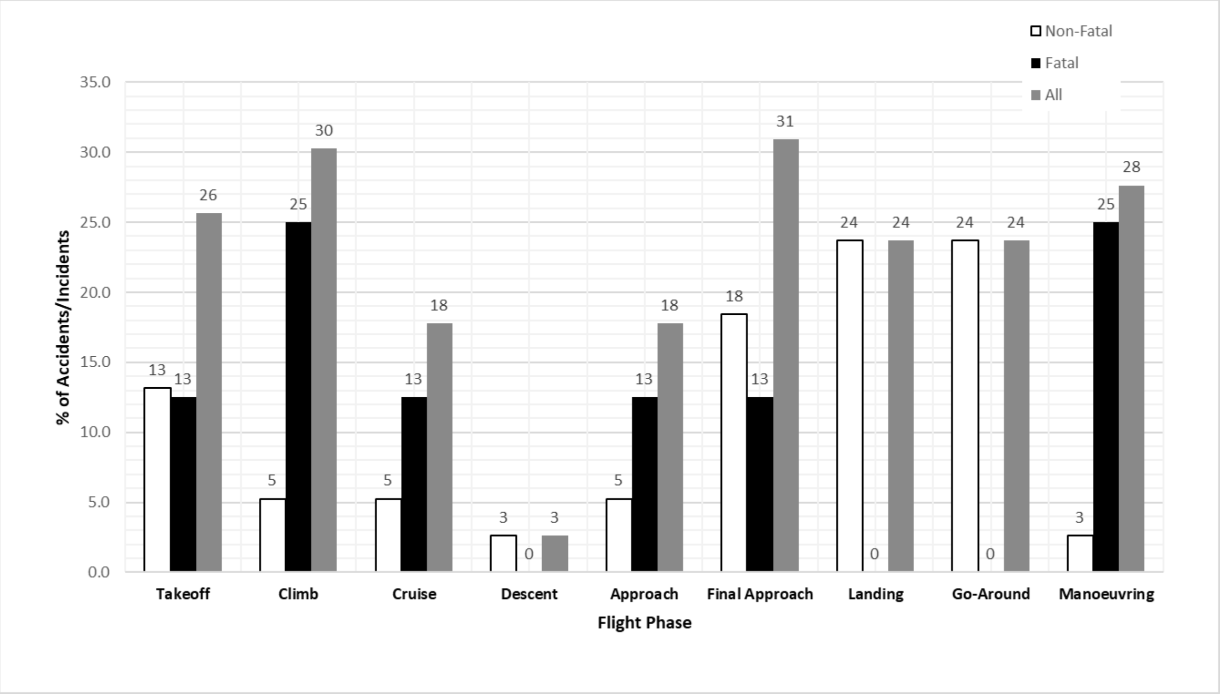


Figure 3. Percentage of LOC-I events in 2018 and 2019 which occurred during each flight phase

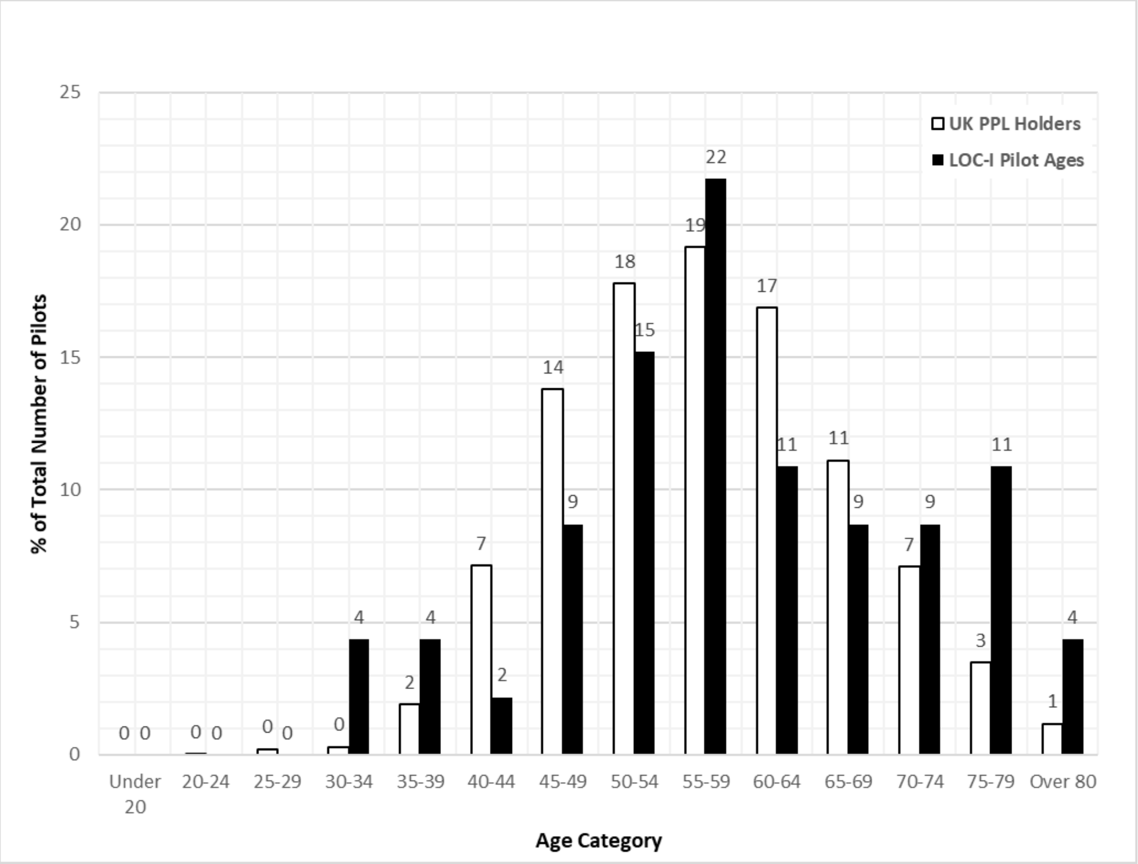


Figure 4. Age distribution of UK PPL Holders in 2018 compared to age distribution of pilots involved in LOC-I events in 2018 and 2019

LOC-I events occur in all phases of flight but predominantly in the takeoff and climb, final approach and landing and maneuvering flight. Climb and maneuvering flight are more likely to be fatal (Figure 3). In this study UK PPL holders below the age of 40 and above the age of 75 were more likely to be involved in a LOC-I event (Figure 4). Figure 5 to Figure 8 show the distribution of all, fatal and non-fatal accident pilots across different ranges of total, on-type, last 90 days and last 28 days experience, respectively indicating recency.

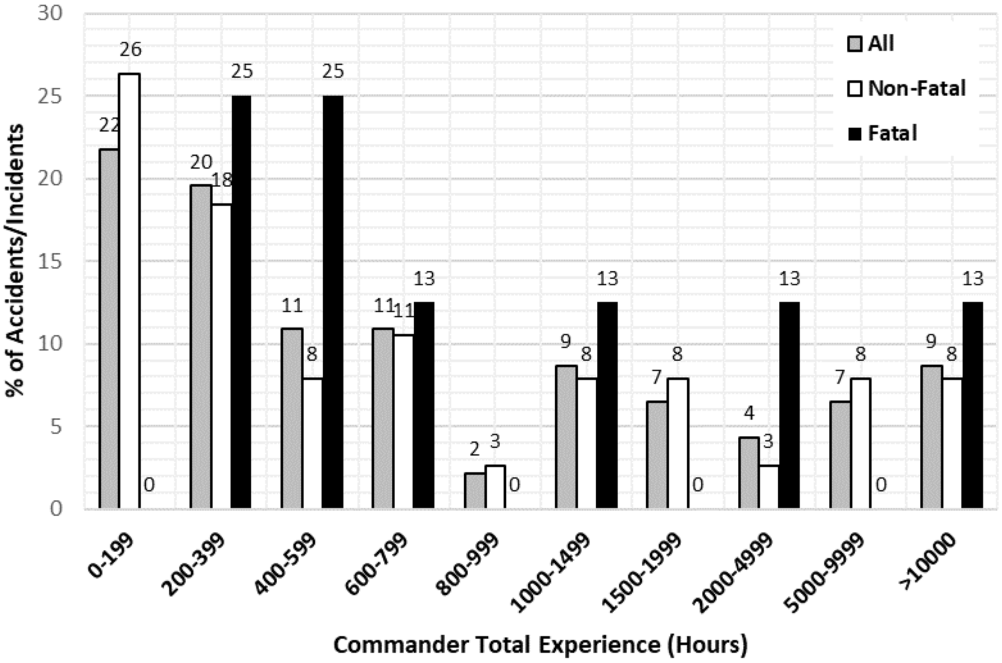


Figure 5. Distribution of total experience of pilots involved in LOC-I events in 2018 and 2019 across all events

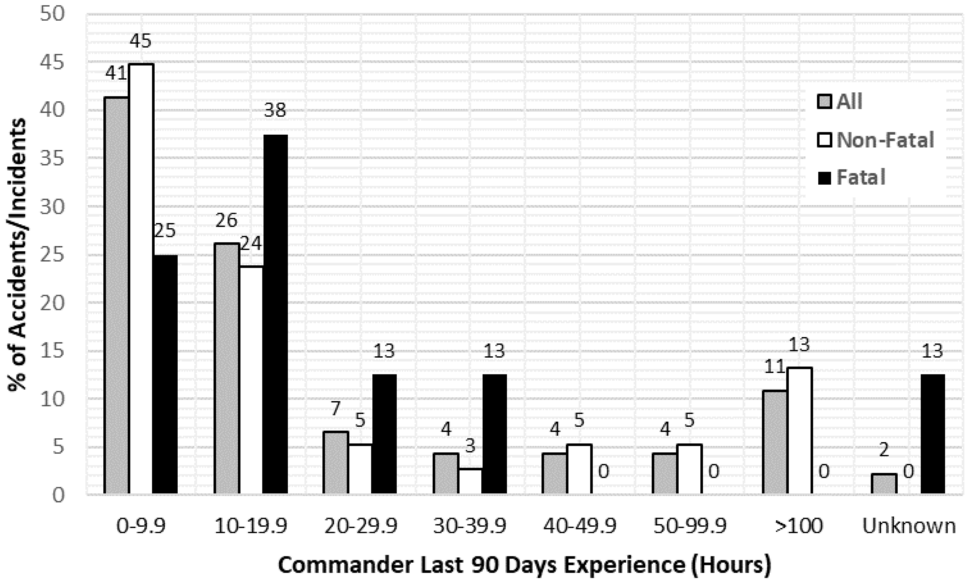


Figure 6. Distribution of pilot flying hours within 90 days of a LOC-I event in 2018 and 2019 across all events

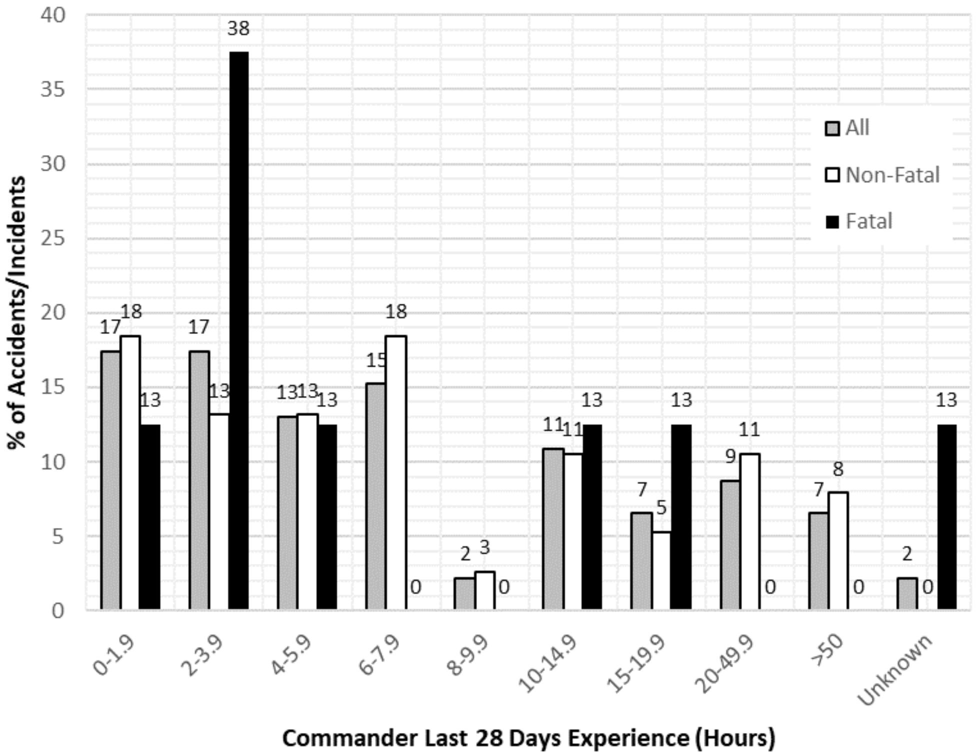


Figure 7. Distribution of pilot flying hours within 28 days of a LOC-I event in 2018 and 2019 across all events

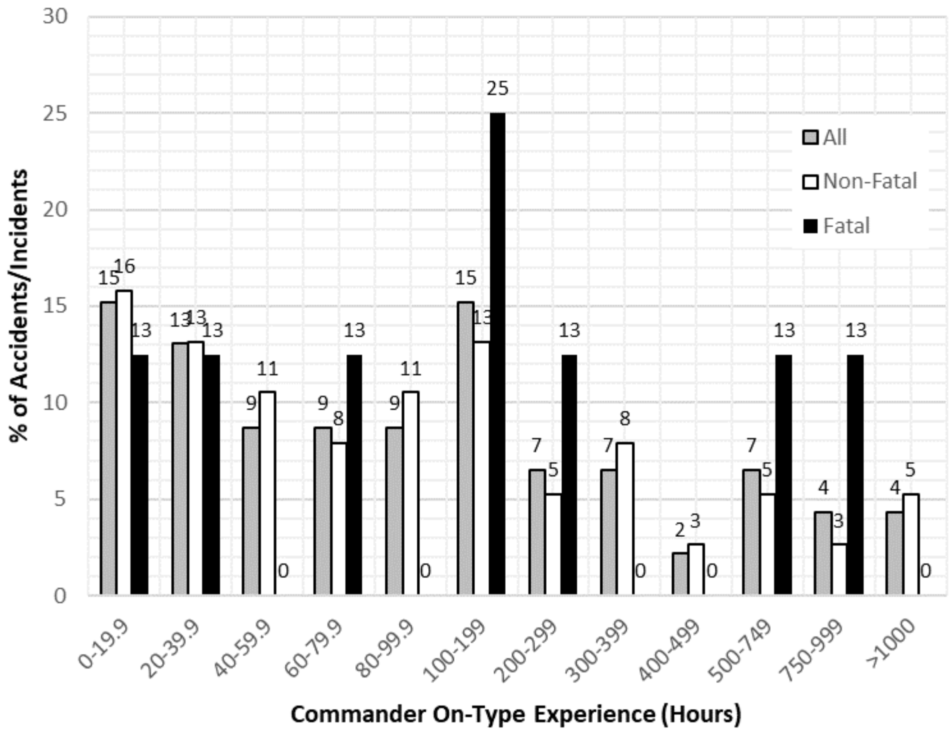


Figure 8. Distribution of pilot on-type experience involved in LOC-I events in 2018 and 2019 across all events

A. Belcastro et. al. Precursor Analysis Results

The results of the Belcastro et. al. precursor analysis in terms of the number of occurrences of each category and sub-category at each point in the accident sequences were analyzed and broken down into the individual precursors (Table 14, Table 15 & Table 16).

Table 14. Number of occurrences of each individual precursor within adverse onboard conditions category at each point the LOC-I event sequences

	Position of Precursor in Sequence									
Precursor/Event Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**TOTAL**
Adverse Onboard Conditions	**22**	**17**	**19**	**15**	**10**	**9**	**2**	**1**	**1**	96
Vehicle Impairment	**4**	**3**	**0**	**0**	**2**	**0**	**1**	**1**	**0**	11
Inappropriate Vehicle Configuration	2	2	0	0	2	0	1	0	0	7
Contaminated Airfoil	0	0	0	0	0	0	0	0	0	0
Improper Loading: Weight, Balance, CG	1	1	0	0	0	0	0	0	0	2
Improper Loading: Cargo Problems and Loose Articles	1	0	0	0	0	0	0	0	0	1
Airframe Structural Damage	0	0	0	0	0	0	0	1	0	1
Engine Damage (FOD)	0	0	0	0	0	0	0	0	0	0
System & Component Failures/Malfunction	**7**	**2**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	10
System Operational Error (Design Flaw/Validation Error)	0	0	0	0	0	0	0	0	0	0
System Operational Error (Software/Verification Error)	0	0	0	0	0	0	0	0	0	0
Control Component F/M	3	1	0	0	0	0	0	0	0	4
Engine F/M	3	0	0	1	0	0	0	0	0	4
Sensor/Sensor System F/M	0	1	0	0	0	0	0	0	0	1
Flight Deck Instrumentation F/M	1	0	0	0	0	0	0	0	0	1
System/Subsystem F/M (Non control)	0	0	0	0	0	0	0	0	0	0
Inappropriate Crew Action/Inaction	**11**	**12**	**19**	**14**	**8**	**9**	**1**	**0**	**1**	75
Loss of Attitude State Awareness/ Spatial Disorientation	0	1	1	1	1	0	0	0	0	4
Loss of Energy State Awareness/ Inadequate Energy Management	0	2	5	2	2	1	0	0	0	12
Lack of Aircraft/System State Awareness/ Mode Confusion	0	1	0	0	0	0	0	0	0	1
Aggressive Maneuver	1	0	1	1	0	0	1	0	0	4
Abnormal/Inadvertent Control Input/Manoeuvre	1	4	1	4	1	0	0	0	0	11
Improper/Ineffective recovery	0	0	5	3	3	5	0	0	1	17
Inadequate/Loss of Crew Resource Monitoring/Management	1	0	1	3	0	1	0	0	0	6
Improper Procedure	4	1	2	0	0	2	0	0	0	9
Fatigue/Impairment (Inc. Hypoxia)	1	0	3	0	0	0	0	0	0	4
Lack of Aircraft Type-Specific Knowledge/Experience	1	3	0	0	1	0	0	0	0	5
Low Currency	2	0	0	0	0	0	0	0	0	2

Table 15. Number of occurrences of each individual precursor within the external hazards & disturbances category at each point the LOC-I event sequences

	Position of Precursor in Sequence									
Precursor/Event Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**TOTAL**
External Hazards & Disturbances	**22**	**3**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	29
Inclement Weather & Atmospheric Disturbances	**16**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	19
Thunderstorms / Rain	0	1	0	0	0	0	0	0	0	1
Wind Shear	3	1	0	0	0	0	0	0	0	4
Turbulence	5	1	0	0	0	0	0	0	0	6
Wake Vortex	0	0	0	0	0	0	0	0	0	0
Snow / Icing	1	0	0	0	0	0	0	0	0	1
Wind (Including Crosswind)	7	0	0	0	0	0	0	0	0	7
Poor Visibility	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	3
Fog / Haze	0	0	0	0	0	0	0	0	0	0
Night	2	0	0	0	0	0	0	0	0	2
IMC	1	0	0	0	0	0	0	0	0	1
Obstacle	**3**	**0**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	7
Fixed Obstacle	1	0	1	3	0	0	0	0	0	5
Moving Obstacle	2	0	0	0	0	0	0	0	0	2

Table 16. Number of occurrences of each individual precursor within the abnormal dynamics & vehicle upset conditions category at each point the LOC-I event sequences

	Position of Precursor in Sequence									
Precursor/Event Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**TOTAL**
Abnormal Dynamics & Vehicle Upset Conditions	**2**	**26**	**24**	**21**	**18**	**10**	**8**	**2**	**0**	111
Abnormal Vehicle Dynamics	**0**	**4**	**8**	**3**	**1**	**0**	**0**	**0**	**0**	16
Uncommanded Motions	0	2	2	0	0	0	0	0	0	4
Oscillatory Vehicle Response (PIO)	0	0	1	0	0	0	0	0	0	1
Abnormal Control for Trim/Flight	0	1	0	0	0	0	0	0	0	1
Abnormal/Counterintuitive Control Response	0	1	5	3	1	0	0	0	0	10
Vehicle Upset Conditions	**2**	**22**	**16**	**18**	**17**	**10**	**8**	**2**	**0**	95
Abnormal Attitude	0	4	5	5	5	1	1	0	0	21
Abnormal Airspeed	1	2	1	3	2	2	0	0	0	11
Abnormal Angular Rates	0	1	3	0	0	0	1	0	0	5
Undesired Abrupt Dynamic Response	0	0	0	0	0	0	0	0	0	0
Abnormal Flight Trajectory	1	6	4	7	2	1	1	0	0	22
Uncontrolled/Abrupt Descent (Including Spiral Dive)	0	6	1	0	2	1	0	1	0	11
Stall/Spin	0	3	2	3	6	5	5	1	0	25

A review of each individual LOC-I event identified the top four specific scenarios of interest. In combination these scenarios account for more than half the total number of events, 54.3% (Table 17).

Table 17. Top four particular scenarios of interest identified from analyzing the full list of individual accident and incident sequences

Scenario	Number of Events (/46)	% of Total Number of Events	Description
1	15	32.6 %	Encounter with wind, turbulence or wind shear leading to a vehicle upset followed by inappropriate and inadequate crew response, including aggressive or abnormal maneuvers and control inputs, ineffective recoveries (9/15 of cases), crew resource management problems and loss of energy state awareness/management. This in turn leads to further upsets, with stalls or spins in 6/15 of these scenarios.
2	4	8.7 %	Improper procedure, followed by a series of vehicle problems/upsets, further human errors, and environmental problems before the aircraft enters a stall or spin.
3	3	6.5 %	Engine failure or malfunction followed by improper procedure and/or loss of energy state awareness/inadequate energy management, followed by a stall or spin.
4	3	6.5 %	Control component failure or malfunction followed by abnormal vehicle dynamics and ultimately a vehicle upset
TOTAL	**25**	**54.3%**	

A consolidated schematic representation of the possible sequence of precursors in LOC-I events initiated by each of the top 4 scenarios was developed to further understand and illustrate contributory and causal factors. One example, the schematic for inclement weather & atmospheric disturbances for which there were 16 events, is shown in Figure 9. Numbers in the rectangular boxes indicate the number of events which follow that event path, whilst the numbers in brackets adjacent to individual precursors indicate the number of occurrences of that precursor at that point in the sequence.

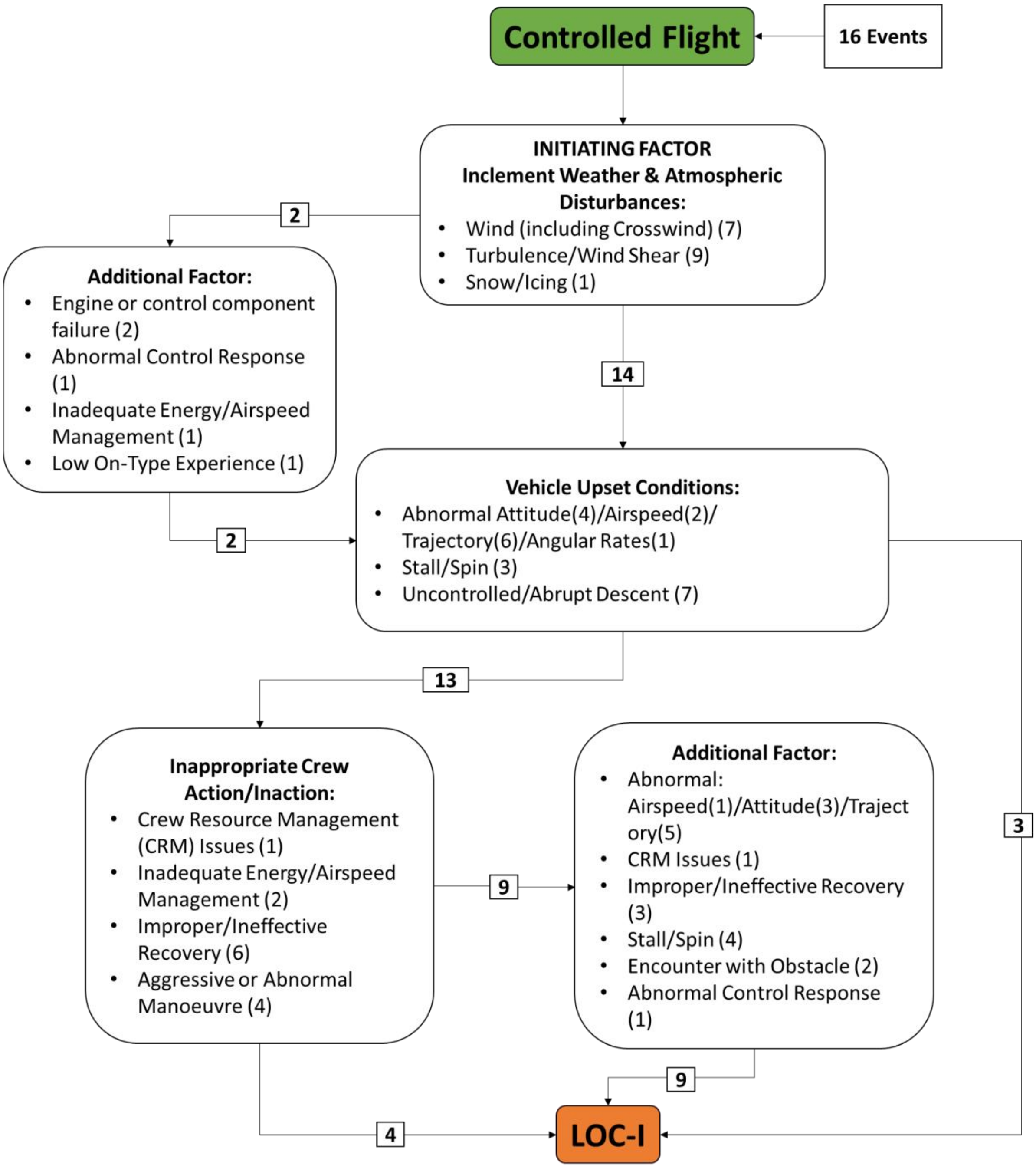


Figure 9. Schematic representation of possible sequence of precursors in LOC-I events initiated by inclement weather & atmospheric disturbances

This schematic (Figure 9) demonstrates the highly variable nature of LOC-I events even when they are all initiated by weather-related disturbances in this case. The factors/numbers contained in brackets () in each box may not add up to the total number of individual events being input to the box as several closely related factors may occur in quick succession in some events, in which case these have been grouped together for succinctness. The exception to this is the initial Inappropriate Crew Action/Inaction box following Vehicle Upset Conditions; in this instance, the initial inappropriate crew response immediately following a vehicle upset was considered of great importance to understanding the sequence of LOC-I precursors in the 13 events which followed this path, and as such only the first precursor of this nature following a vehicle upset is included in this box. The numbers in brackets therefore add up to the total of 13 events.

Following inappropriate crew action/inaction, 4 events proceeded directly to LOC-I, whereas 9 events had additional "complicating" factors. These additional factors, presented in the correspondingly titled box in Figure 9, consisted of precursors which may have already occurred in an event sequence or may have appeared earlier in other event sequences. As a result, it may appear that this "additional factors" box is repeating information already presented, but it provides insight into the further complications which can occur following inappropriate crew responses. These complications may be similar to preceding precursors, but they are unique in their effects manifesting *after* an already inappropriate crew response to a vehicle upset, which warrants their inclusion as the "additional factors"; this is an example of the importance of considering the temporal sequencing of events in providing a more detailed understanding of LOC-I events, rather than considering simple lists of contributing factors in which such information is lost. With 16 events, the repetition of some precursors is highly likely, but their occurrence at different times within a sequence distinguishes many LOC-I events.

To aid further understanding, the process of an example accident event sequence (LOC-I event number 25) being processed using the framework (Figure 9) is presented in Figure 10. It is apparent from this diagram that some information concerning the sequence of events in the "additional factors" section of this particular event is unfortunately lost, but this is a necessary consequence of consolidating/condensing 16 individual and unique LOC-I events into a single diagram which represents the main characteristics of LOC-I whilst maintaining succinctness; further separation of these factors into discrete categories would have led to an unnecessarily complex diagram.

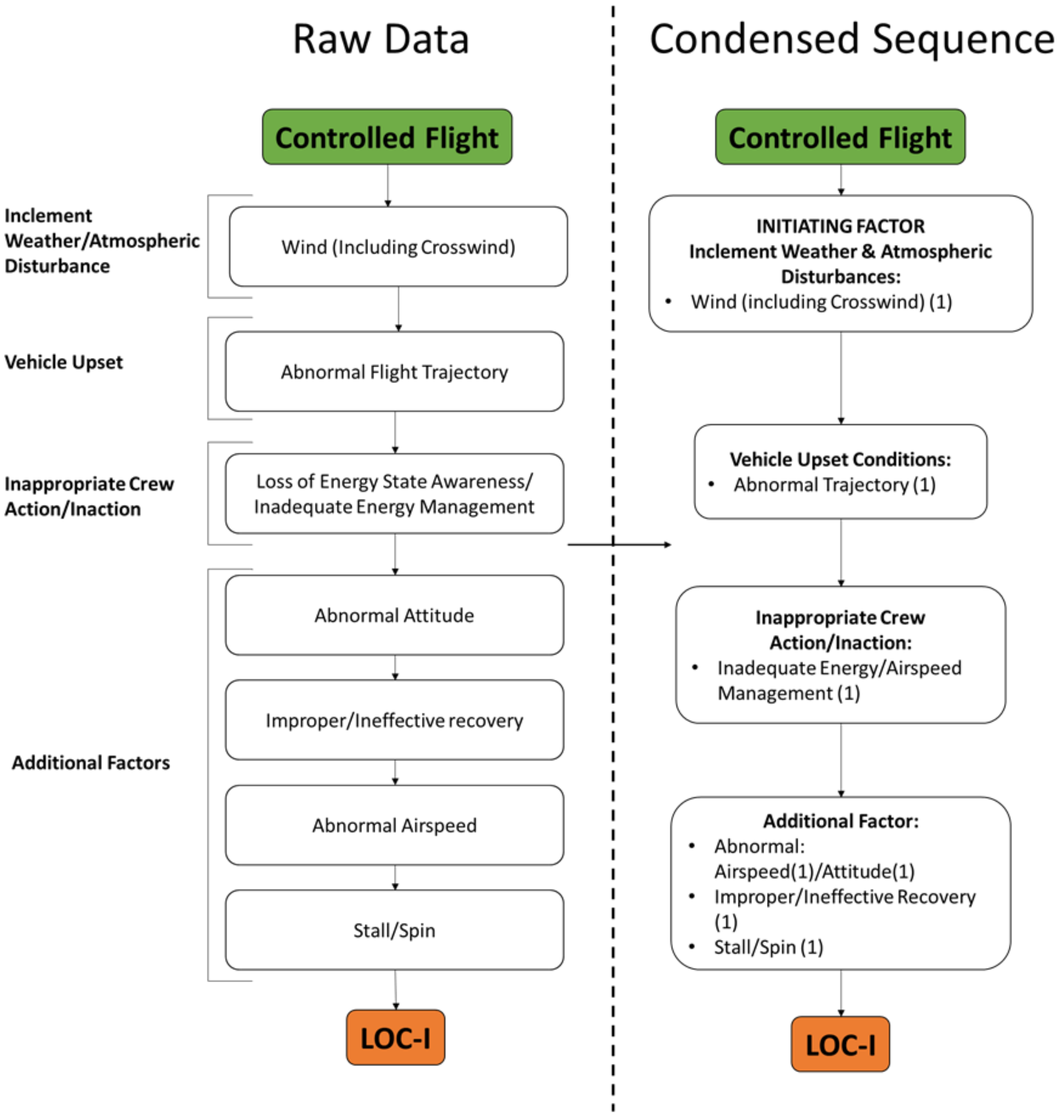


Figure 10. Example accident sequence processed using the framework

E. Bromfield & Landry Recovery Factor Analysis Results

The results of the recovery factor analysis across the LOC-I events were analyzed (Figure 11) and recovery criteria separated into fatal and non-fatal event categories. In both cases, sufficient height above terrain for recovery (limited available time for recovery) is dominant.

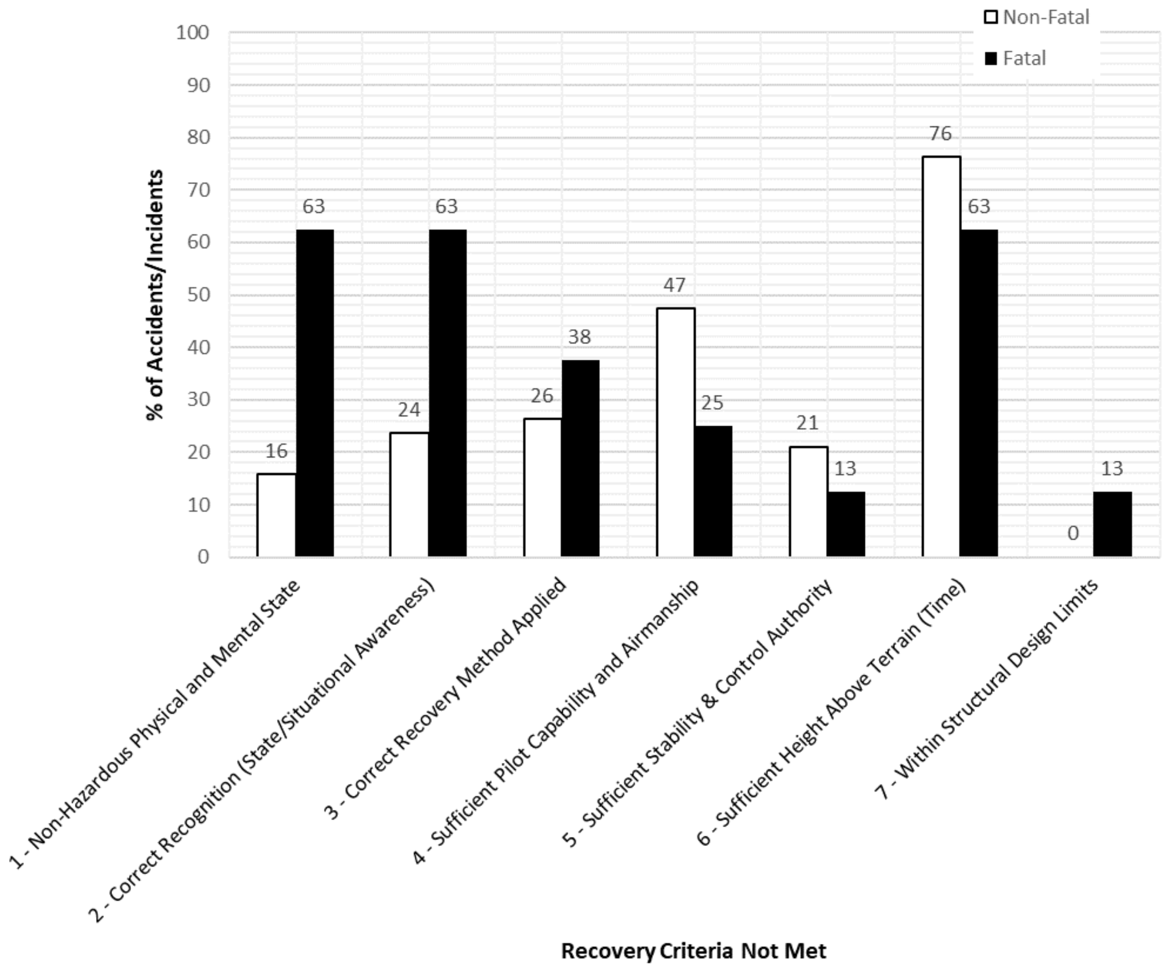


Figure 11. Percentage of fatal and non-fatal LOC-I events during which each recovery criteria was not met

F. HFACS Analysis Results

The results of the HFACS analysis for all of the LOC-I events in 2018 and 2019, organized in order of each HFACS level were analyzed and split into fatal and non-fatal events in order of the significance of each HFACS category in the fatal accidents (Figure 12). As for the recovery factors, the percentages for the fatal and non-fatal events were calculated separately with respect to the total number of events in each category (either fatal or non-fatal).

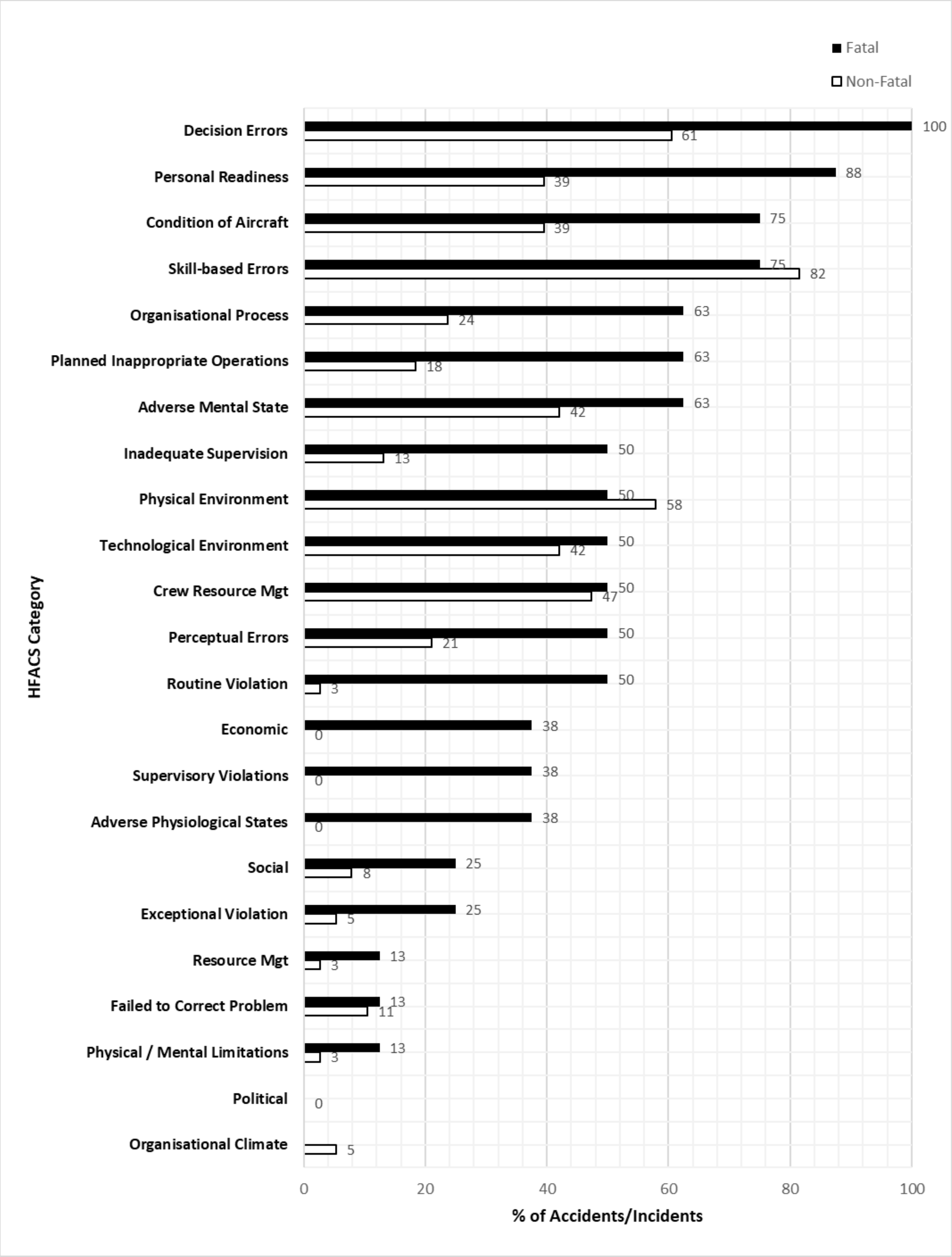


Figure 12. Percentage of fatal and non-fatal LOC-I events in which each HFACS category played a contributory role

LOC-I Framework

The key results have been condensed and superimposed to give the framework presented in Figure 13.

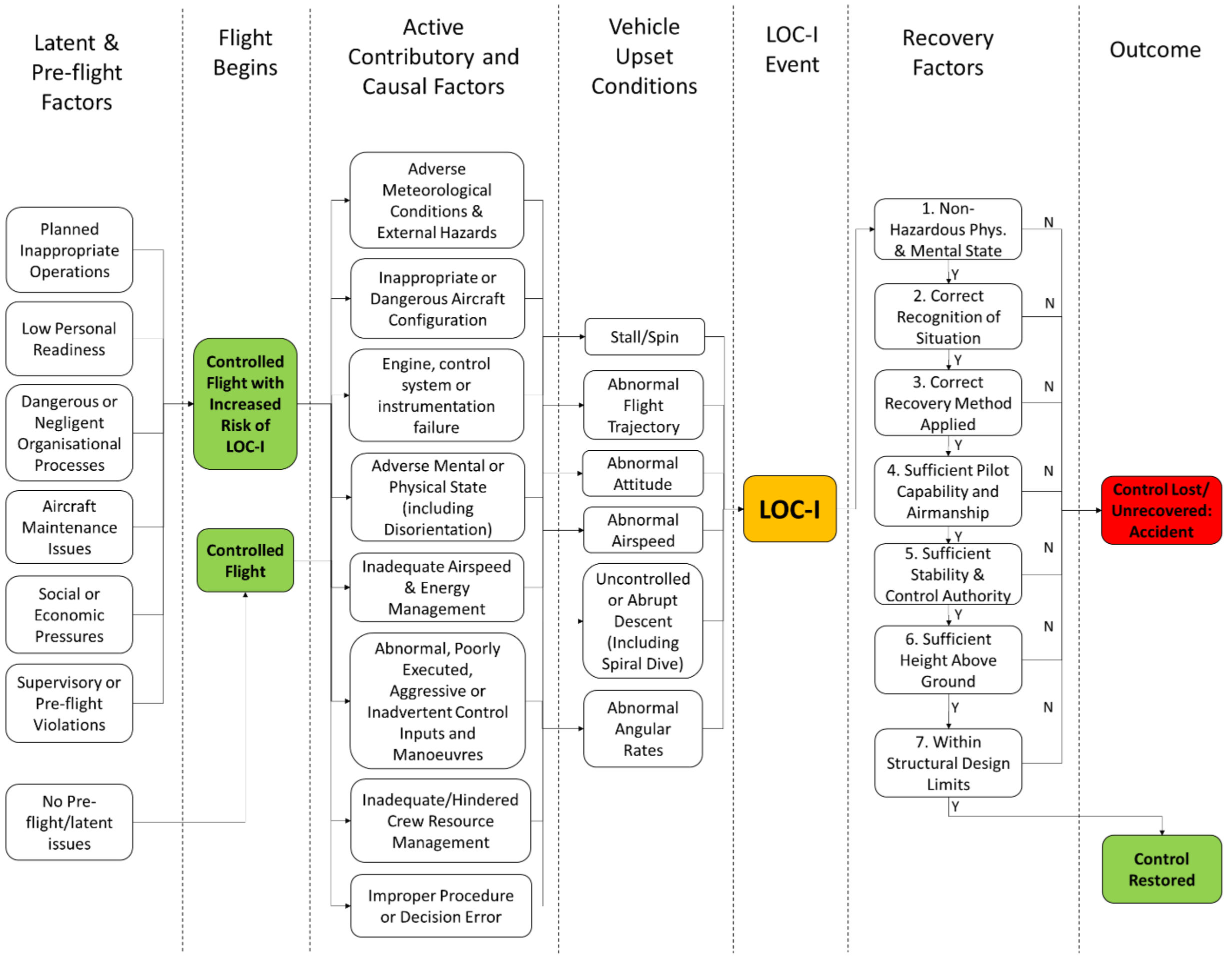


Figure 13. GA LOC-I conceptual framework - culmination of all the analyses methods used in this study and superposition of key findings from each method

IV. Discussion of Results

Most of the GA fixed-wing LOC-I events in the period analyzed (January 2018 to December 2019 inclusive) were non-fatal, and there was complete recovery in 4 out of 46 of the events. It is therefore possible for LOC-I to be non-fatal and recoverable, echoing the propositions of Bromfield & Landry [10] and underpinning the necessity of redefining GA LOC-I to expand its scope. Houston et. al.'s research into instructional LOC-I accidents was based on half of GA accidents in the US occurring during flight training, but in terms of LOC-I, this trend is not reflected in the UK, with most LOC-I accidents occurring during private flights with mostly fully qualified pilots. The distribution of accident pilot ages from this study roughly agrees with the normal distribution of the wider population of UK PPL holders except for the ages of under 40 and over 75, where LOC-I accident pilots become disproportionately more prominent; pilots much younger or much older than the mean UK PPL holder age were more likely to experience LOC-I for the period analyzed.

Final approach (17.4%), landings (19.6%) and go-arounds (19.6%) were the three most common phases of flight for loss of control in-flight, accounting for 56.6 % of all LOC-I events during the period analyzed. This is largely within agreement with research by Houston et. al [20]., Taylor et. al. [21] and the NTSB [23]. However, Jacobson [12] , Belcastro [13] and the IATA [14] all arrived at a different conclusion, having focused their research on commercial aviation and not general aviation. In this study the percentage of LOC-I events occurring during each phase decreases from take-off to a minimum during the descent phase, before increasing rapidly through the approach, landing and go-around phases. As this largely corresponds with the altitude, and thus the energy and time, available to an aircraft during each phase of flight; it may be concluded that LOC-I becomes much more likely as altitude decreases. However, fatal accidents were much more likely to occur during the climb, cruise, approach, and maneuvering phases of flight, whilst no fatal accidents occurred during landings or go-arounds.

Interestingly, there were no fatal accidents involving pilots with less than 200 hours of total experience, despite over 20 % of LOC-I events involving this pilot category. This suggests that fatal LOC-I events may become more likely with increased pilot experience, perhaps due to complacency, over-confidence, or increased time since flight training. This agrees with findings by Taylor et. al. [21] and the CAA [22]. Fatal LOC-I events are slightly more prominent than expected, with respect to the total number of events, for pilots with less than 4 hours flying time in the last 28 days. This trend is notable, but not sufficient to conclude that currency in the last 4 weeks is a strong indicator of the likelihood of LOC-I being fatal given the number of fatal accidents in this research is relatively small compared to the total number of events. Research with a larger sample size would be beneficial in this respect.

The original study by Belcastro et. al. [13] and the present study both identified external hazards & disturbances and adverse onboard conditions as the factors which initiate LOC-I sequences, with vehicle upsets and abnormal dynamics becoming more prominent in the subsequent events. However, Belcastro et. al found that adverse onboard conditions were twice as prominent as external disturbances as initiating factors, compared to an equal split as is the case in the present study into GA; external disturbances appear more significant in GA than commercial aviation as accident initiators. Both studies show external disturbances dropping rapidly after the 1st precursor in a LOC-I sequence, indicating they are significant as initiating factors only. System and component failures were found to be much more prominent than inappropriate crew actions by Belcastro et. al., but the opposite was found to be true in GA; this indicates that in GA, the crew is much more commonly responsible for initiating LOC-I sequences than in commercial aviation. Both studies indicate that inappropriate crew actions and vehicle upsets persist well into accident sequences.

Across entire accident sequences, improper/ineffective recovery and abnormal/inadvertent control inputs or maneuvers are much more prominent in GA, whilst lack of energy awareness/inadequate energy management and improper procedure were prominent in both studies. The manual handling response to upsets and the execution and decision-making of maneuvers therefore appear much more of a problem in GA. Stalls and spins were the top vehicle upset condition in both studies. Problems with energy management are echoed in the studies by Branham [18] and Jacobson [12] , the former also agreeing particularly favorably with the present study on the percentage of GA LOC-I accidents involving stalls and spins; Branham cited the value as 51.81 % whilst the present study found it to be 54.3 %. However, the present research found weather to be a much more significant precursor than Jacobson, likely due to Jacobson's study including commercial aviation.

Almost one third of the accidents in 2018 and 2019 were initiated by an encounter with wind or turbulence and followed by a vehicle upset and subsequent inadequate response from the crew. Future LOC-I prevention will require great focus on preparing pilots for dealing with wind and turbulence related situations and improving their response to upsets in such situations, particularly during approach and landing where less height is available for recovery. Engine failure, followed by inappropriate crew response and ultimately a stall or spin, remained a prominent LOC-I scenario in 2018 and 2019. Additionally, all accident scenarios initiated with improper procedure eventually resulted in a stall or spin, with various human errors and vehicle issues occurring in-between. Improved flight training to emphasize the importance of following regulatory guidelines and following good practice and decision making throughout flights could prevent improper procedure, preventing such accident sequences from being initiated.

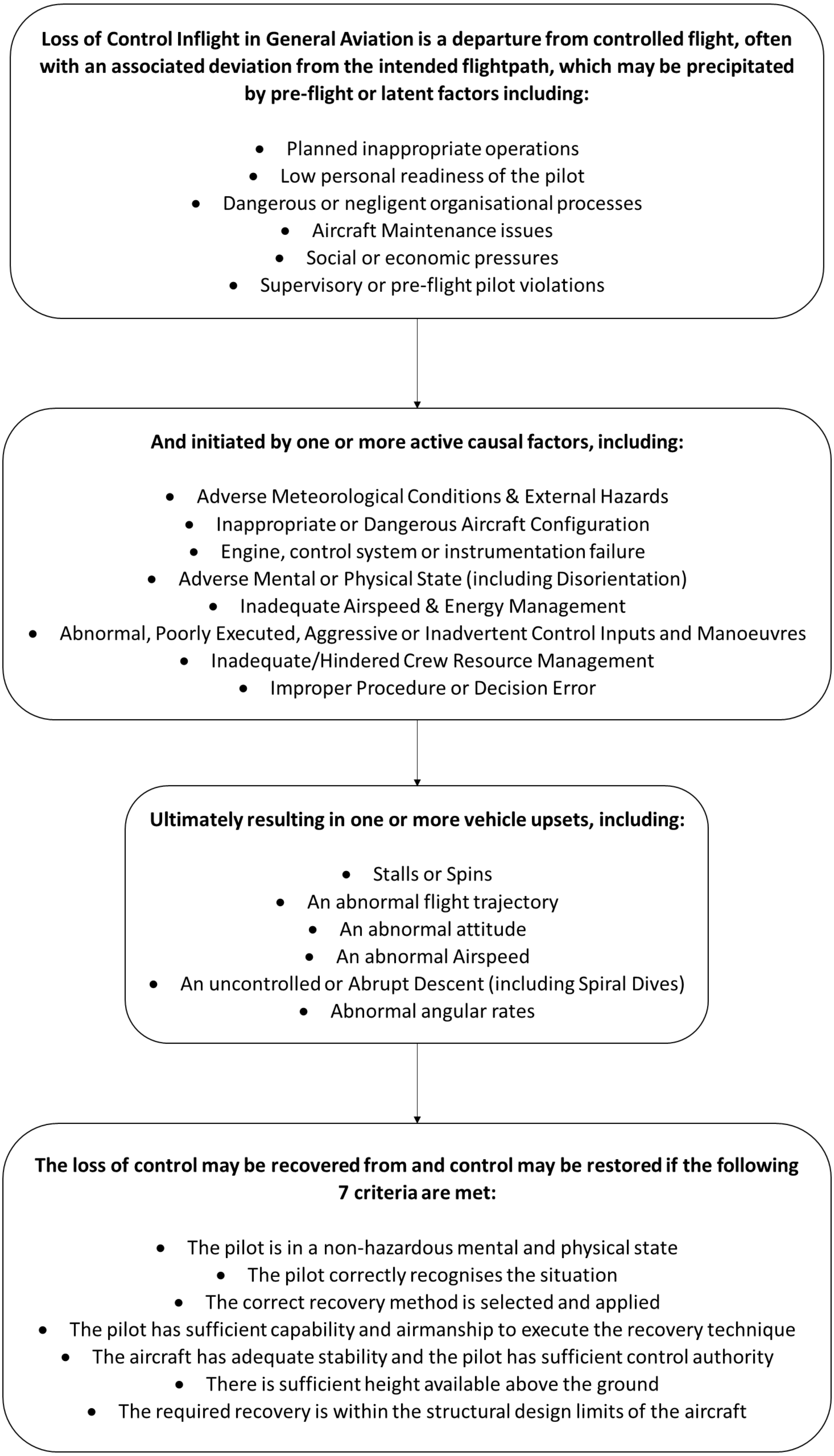
Most LOC-I events were non-recoverable due to insufficient height above the ground. However, in most cases where sufficient height *was* available, there were other factors which need to be addressed, particularly insufficient pilot capability and airmanship. Applying the incorrect recovery method and incorrect recognition of the situation were also significant factors in unsuccessful recoveries, at 28.3 and 30.4 % of accidents respectively, reflected by the SPS "of Pilot failure to recognize stall and execute corrective action" used by Branham to describe 19.69 % of GA approach & landing LOC-I accidents. Both problems could be directly addressed by Upset Prevention and Recovery Training (UPRT) to improve upset recognition and selection of the appropriate recovery technique, particularly for fatal accidents, where failure to recognize the situation increases to 62.5 % of accidents. Hazardous physical and mental states were also more significant in non-fatal accidents; preventing hazardous mental states may also be achievable through UPRT through familiarizing pilots with dangerous situations and reducing stress and panic. Preventing hazardous physical states such as incapacitation is a much more complex task. However, it can be concluded that correct recognition of the situation and a non-hazardous physical and mental state are essential to recover from, or prevent, fatal situations.

LOC-I recovery was highly dependent on crew response to upsets; the only 2 events with no unsafe acts within the HFACS framework were instances where a full recovery was made. In the remaining 44 LOC-I events investigated, however, human involvement at the unsafe acts level was widespread. Skill-based errors and decision errors contributed to 80.4 and 67.4 %, respectively, of LOC-I events in 2018 and 2019. Similarly, Wiegmann & Shappell [16] found that skill-based errors and decision errors contributed to 60.5 % and 28.6 %, respectively, of commercial aviation accidents. However, it should be noted that the values for the present study into GA are much higher in absolute terms for both error types, likely due to Wiegmann & Shappell investigating commercial aviation only, and not exclusively considering LOC-I accidents. 24 events (52.2 % of total) in this research involved both decision and skill-based errors; in other words, in more than half of cases, the pilot decided to follow an unsafe course of action and executed it poorly. Many of these cases involved an incorrect decision not to go-around when faced with an unstable approach, followed by a poorly executed landing procedure.

The preconditions for unsafe acts category were also significant in this study. Physical environment contributed to more than half of events, concurring with the significance of external disturbances in the Belcastro et. al. precursor analysis. The significance of personal readiness as a contributory factor indicates that many LOC-I events occur when the pilot is unprepared for a particular situation, due to low experience or currency or flying in unfamiliar circumstances. Crew resource management and adverse mental states were problems in the study by Wiegmann & Shappell and the present study, but much more prominent in GA.

Fatal accidents were almost invariably more complex than non-fatal accidents in terms of the pre-flight and latent human factors. The planning of inappropriate operations, inadequate supervision, economic pressures, and supervisory violations were all much more significant in fatal accidents, the latter exclusively precipitating fatal events; many fatal LOC-I accident sequences in GA were set into motion, or at least made more likely, even before the accident flight commenced. Adverse physiological states also only precipitated fatal accidents, reflecting the increased significance of hazardous mental and physical states in fatal accidents in the recovery criteria analysis.

The LOC-I framework combined pre-flight contributory factors from the Belcastro et. al. precursor analysis and the HFACS framework to produce the ‘pre-flight and latent factors’ level of the framework. The top active causal factors from both analysis methods were condensed into 8 factors, of which 1 or more may be present in an accident sequence. This ‘active causal factors’ category, without any mitigative action, gives way to one or more vehicle upsets from the Belcastro et. al. research. Without immediate recovery, control is considered to be lost, and the subsequent events may take one of two paths; either the 7 criteria for successful recovery, adapted from Bromfield & Landry [10], are met and control is restored, or the criteria are only partially met, and the recovery attempt is ineffective leading to an accident. Interpreting the framework from left to right gives the definition of LOC-I for GA (Figure 13) . This definition expands the scope of the term LOC-I for GA and provides a comprehensive basis for identifying and characterizing LOC-I events.



Loss of Control Inflight in General Aviation is a departure from controlled flight, often with an associated deviation from the intended flightpath, which may be precipitated by pre-flight or latent factors including:

- Planned inappropriate operations
- Low personal readiness of the pilot
- Dangerous or negligent organisational processes
- Aircraft Maintenance issues
- Social or economic pressures
- Supervisory or pre-flight pilot violations

And initiated by one or more active causal factors, including:

- Adverse Meteorological Conditions & External Hazards
- Inappropriate or Dangerous Aircraft Configuration
- Engine, control system or instrumentation failure
- Adverse Mental or Physical State (including Disorientation)
- Inadequate Airspeed & Energy Management
- Abnormal, Poorly Executed, Aggressive or Inadvertent Control Inputs and Manoeuvres
- Inadequate/Hindered Crew Resource Management
- Improper Procedure or Decision Error

Ultimately resulting in one or more vehicle upsets, including:

- Stalls or Spins
- An abnormal flight trajectory
- An abnormal attitude
- An abnormal Airspeed
- An uncontrolled or Abrupt Descent (including Spiral Dives)
- Abnormal angular rates

The loss of control may be recovered from and control may be restored if the following 7 criteria are met:

- The pilot is in a non-hazardous mental and physical state
- The pilot correctly recognises the situation
- The correct recovery method is selected and applied
- The pilot has sufficient capability and airmanship to execute the recovery technique
- The aircraft has adequate stability and the pilot has sufficient control authority
- There is sufficient height available above the ground
- The required recovery is within the structural design limits of the aircraft

Figure 14. Definition of LOC-I as applied to General Aviation

V. Conclusions

Forty six LOC-I accident and incident reports from UK fixed-wing GA and sports aviation between January 2018 and December 2019 were analyzed to characterize LOC-I. Only 17.4 % of the LOC-I events were fatal. LOC-I was most likely to occur during approach (17.4%), landing (19.6%) or go-around (19.6%). Generally, LOC-I was more likely to occur during low altitude flight phases. Fatal accidents were disproportionately more than twice as likely to occur during the climb and maneuvering phases of flight. LOC-I accident pilots were more likely to be over 75 or under 40 compared to the wider pilot population. Fatal accidents did not involve any pilots with less than 200 hours but were slightly more likely for accident involving pilots with less than 4 hours flying time in the last 28 days compared to pilots with more than 4 hours. However, to establish if these relationships are significant, further analysis over an extended period with an increased number of events is proposed in addition to more in depth statistical analysis of the effects of age and recency combined. In relation to the newly developed GA LOC-I conceptual framework (Figure 13) key conclusions are presented.

A. Recovery Factors

Most LOC-I events could not be recovered from due to insufficient height above the ground in 73.9 % of cases, followed by insufficient pilot capability in 43.5 % of cases. Fatal accidents were much more likely to be unrecoverable due to a hazardous mental or physical state or incorrect recognition of the situation.

B. A. Vehicle Upset Conditions

The most common vehicle upsets were stalls and spins followed by abnormal flight trajectories and abnormal attitudes. Most accidents were initiated by external hazards & disturbances, inappropriate crew actions, or system & component failures.

C. Active Contributory & Causal Factors

The top precursors to LOC-I across the full set of accident sequences were: ineffective recoveries, inadequate energy management, abnormal/inadvertent control inputs or maneuvers, and improper procedure. Decision and skill-based errors contributed to 67.4 and 80.4 % of the LOC-I events, respectively, and more than half of cases involved both errors. 100 % of the fatal accidents involved decision errors and were much more likely to involve personal readiness of the pilot. In half of the cases, decisions errors were combined with skill-based errors where the pilot decided on an unsafe course of action and then executed it poorly (e.g., go-arounds and continue to land rather than go-around). Inappropriate crew actions and vehicle upsets subsequently persisted into most accident sequences whilst external hazards and system failures became largely insignificant. 32.6 % of the LOC-I events constituted an encounter with wind, turbulence or wind shear leading to a vehicle upset followed by inadequate crew response and a further upset, with stalls or spins in 6 out of 15 of these scenarios.

D. Latent & Pre-flight Factors

The LOC-I framework combined pre-flight contributory factors from the Belcastro et. al. precursor analysis and the HFACS framework to produce the 'pre-flight and latent factors' level of the framework. Fatal accidents were much more complex in terms of pre-flight and latent contributions. 100 % of accidents with no recovery involved an unsafe act. The planning of inappropriate operations, inadequate supervision, economic pressures, and supervisory violations were more significant in fatal accidents, the latter exclusively precipitating fatal events; many fatal LOC-I accident sequences in GA were set into motion, or at least made more likely, even before the accident flight commenced.

LOC-I has been redefined for GA, with an associated conceptual framework, to include pre-flight and latent factors, active causal factors, common vehicle upsets, and criteria for a successful recovery. This will facilitate the easier identification and characterization of LOC-I events, and the development of intervention strategies which can break the sequence of events before an event becomes LOC-I. Future intervention strategies related to education and training could be enhanced by an improved understanding of LOC-I in the context of GA using the framework and dominant causal and contributory factors could be incorporated within scenario-based training. Ultimately, such actions have the potential to lower accident rates and save lives.

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