General Aviation Accident Modeling and Causal Determination of Pilot Loss of Aircraft Control

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Dedication

This Praxis is dedicated to all aviators and aerospace engineers (past, present and future). Safe flight

Acknowledgements

I offer gratitude to my Praxis director, Dr. Blackburn and advisor Dr. Malalla for their encouragement and tireless efforts, especially in the formative phase of my research. I thank you for not giving up on me in my most challenging time. I also offer my gratitude to Mr. Stephen Mulloy and Mr. Robert Conry for the technical guidance, mentorship and much needed friendship. To my dearest friend, Bridget Simpkiss, words do not you justice, nonetheless I offer you my gratitude. To my colleagues, former professors and friends thank you. To my aunty Ruth Buckley, thank you for being my advocate.

Abstract of Praxis

General Aviation Accident Modeling and Causal Determination: Pilot Loss of Aircraft Control

General Aviation (GA), a subset of the aviation industry, is currently facing a crisis of pilots losing control aircraft while inflight. The crisis is significant enough to warrant a formal petition from the National Transportation Safety Board ((NTSB), 2018) for the prevention of Pilot Loss of Aircraft Control (PLOC). In the formal petition, the NSTB argues that between 2008 to 2014, PLOC accounted for 48 percent of all GA accident fatalities. The NTSB petition also asserts that PLOC is attributed to loss of situational awareness (SA), weather and pilot distraction.

This Praxis proposes that PLOC is attributed to the pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload in addition to the noted NTSB contributing factors. The purpose of Praxis is therefore threefold:

- Develop a GA PLOC accident model to determine the contributing factors that results in PLOC accidents using binary logistic regression analysis of Aviation Safety Reports.
- Select 4 random GA PLOC accidents to determine if the model is useful to provide insights as to PLOC preventive measures.
- Propose a PLOC mitigation or prevention countermeasure in the form of a personal pilot checklist. This check will be independent from the aircraft checklist but use in conjunction as a pilot supplemental checklist.

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List of Acronyms

AC	Advisory Circular
AIC	Akaike Information Criterion
AIM	Aeronautical Information Manual
AOPA	Aircraft Owners and Pilots Association
ASRS	Aviation Safety Reporting System
BLR	Binary Logistic Regression
DoD	Department of Defense
FAA	Federal Aviation Administration
GA	General Aviation
H (1,2,3 & 4)	Hypothesis 1, 2, 3, &4.
ICAO	International Civil Aviation Organization
LOC-G	Loss of Control-Ground
LOC-I	Loss of Control-Inflight
NASA	National Aeronautics and Space Administration
n.d.	No Date
NTSB	National Transportation Safety Board
PLOC	Pilot Loss of Aircraft Control
SA	Situation Awareness
U.S.	United States
VIFs	Variance Inflation Factors
WX	Weather

Chapter 1—Introduction

1.1 Background

Aviation is a very complex system within the transportation industry which consists of railway, roadway, marine and naturally aviation. In early 2018, the National Transportation Safety Board (NTSB) issued a formal petition titled "NTSB 2017-2018 Most Wanted Lists of Transportation Safety Improvements," for the prevention of Pilot Loss of Control (PLOC) in general aviation (GA) (NTSB, 2018). This Praxis is a response to the NTSB's early 2018 formal petition and proposes that PLOC is attributed to the pilot deviation from established procedures, pilot experience within 90 days, communication breakdown, confusion, human-machine interface and workload.

While it is not the intention for this Praxis to be a treatise on aviation, a brief context to delineate aviation boundaries is essential since aviation interfaces and supports other industries. In fact, Wensveen (2016) posited that for every 100 jobs created in aviation, an additional 73 jobs are created in other industries. Aviation for the purpose of this Praxis is composed of flight operations, air traffic control and the federal agencies that provide regulatory and oversight functions. Aerospace engineering while an entity that directly contributes to the aviation industry, is intentionally not a focus area for this Praxis.

The Federal Aviation Administration (FAA) notes that aviation flight operations are composed of scheduled airline operations, scheduled commuter & on-demand operations, and GA (FAA, n.d.). Airline operations is what an average traveller is typically accustomed to. The current staple of airlines consists of air carriers such as American Airlines, Delta Airlines, and Southwest Airlines.

Commuter flight operations while similar to airline operations consists of feeder air carriers that provide connecting flights to, or from major airports. The major distinguishing criteria between the airlines and commuters is aircraft capacity. Commuter air carriers are limited by passenger capacity and payload specified by the federal government. Chartered flight operations can be selected from either the airlines for maximum passenger or payload capacity to commuter aircraft for medium passenger or payload capacity to GA aircraft that can offer minimum capacity.

The FAA Aeronautical Information Manual (FAR AIM, 2019) describes GA as civil aviation operations that does not include scheduled or unscheduled air carriers or commercial space operations, emphasis added on "air carriers." Similar to the FAA description, the International Civil Aviation Organization (ICAO), n.d.) describes GA as "All civil aviation operations other than scheduled air services and non-scheduled air transport operations remuneration or hire (ICAO, n.d.)." ICAO further delineated GA as non-commercial business flights, aerial work, instructional and recreational or other flight operations.

While the aforementioned descriptions for GA operations make a point to state that GA is not involved in scheduled or unscheduled air carrier flight operations, the Aircraft Owners and Pilots Association ((AOPA), n.d.)), a not for profit organization dedicate to GA and consultant to the FAA states that GA consists of 90 percent of all civil aircraft registered in the United States (U.S.). The AOPA (n.d.) argues that GA flight operations generate in excess of $150 billion annually. This annual revenue contribution to the U.S. gross domestic product is from services such as business and personal travel arrangements that are not constrained by air carrier schedules, overnight transportation of

cancelled checks throughout the Federal Reserve System, agriculture, law enforcement, and environmental protection surveillance.

The introduction for this Praxis commenced by asserting that aviation is a very complex system. As a complex system, aviation interfaces and interacts with people, aircraft and a dynamic environment. As such, it is highly regulated by federal agencies that provide policy direction and oversight. However, it is necessary to contextually define a complex system and whether aviation merits such a characterization before discussing how aviation is regulated.

Bar-yam (1997) defines a complex system as a system that is constructed from many components. Furthermore, such a system has emergent behavior that is not initially and conceptually expected. Bar-yam elaborated that the behavior of the system cannot be simply deduced from the behavior of the system's components. Cilliers (1998) also echoed Bar-yam's latter sentiment and added that because complexity is the result of the interactions between the system components, it is manifested the level of the system itself. Because aviation has multiple components and interactions in dynamic environments, the preceding definitions for complexity are deemed adequate to qualify aviation as a complex system.

The regulatory and oversight components to the complex aviation system consist of the FAA and the National Transportation Safety Board (NTSB), both are federal U.S. agencies. The Federal Aviation Act of 1958 (Government Publishing Office, 1958) established the FAA and commissioned it with the following responsibilities:

- The regulation of civil aviation to promote safety
- Encourage and develop civil aeronautics, including new aviation technology

- Development and operation of the national air traffic control and navigation system
- Research and development of the National Airspace System and civil aeronautics
- Development of programs to control aircraft noise and
- The regulation of U.S. commercial space transportation

The NTSB was established by the Air Commerce Act of 1926 (NTSB, n.d.), in which the U.S. Congress commissioned the U.S. Department of Commerce to investigate causes of aircraft accidents. According to its most updated charter (2018), the NTSB is required by Congress to conduct investigations into every civil aviation accident in the United States and significant accidents in other modes of transportation (railroad, highway, marine, and pipeline). The NTSB's investigative responsibilities per its current charter are delineated as follows:

- Determine the probable cause of the accidents
- Issue safety recommendations aimed at preventing future accidents
- Conduct special transportation safety studies and
- Coordinate the resources of the federal government and other organizations to assist victims and their family members who have been impacted by major transportation disasters.

1.2 Research Motivation

The motivation to embark on this research are threefold. First, there is scarcity of research on the management of risks associated with GA. Thus, decision-makers at legislative (Congressional) level enact policies that mitigate problem symptoms rather than the root factors as this research shall attempt to proof.

Second, although GA flight operations generates revenue in excess of $150 billion annually (AOAP, n.d.), it exists in the shadows of the scheduled airlines. This means that GA is overlooked in the allocation of dedicated federal resources to promote safety research despite of the increasing complexity in the operational environment and the technology inside and powering GA aircraft.

Third, and most importantly, an overwhelming need to contribute to the NTSB formal petition for the prevention of PLOC (NTSB, 2017-2018). The formal NTSB petition provided a list of potential causal factors to PLOC that this research will use as an initial baseline to be expanded upon.

1.3 Problem Statement

Problem Statement: Pilot Loss of Aircraft Control (PLOC) involving General Aviation (GA) aircraft account for 48% of all GA accidents (NTSB, 2018).

The NTSB attributes PLOC to (1) loss of situational awareness (SA), (2) weather, and (3) pilot distraction. A review and analysis of a sample of NTSB adjudicated accident cases suggests that there are other contributing factors to PLOC that include pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload in addition to the established three contributing factors to PLOC.

Notwithstanding the PLOC problem afflicting the GA community, the NTSB accident database indicates that aviation is a safer medium for transportation when compared to the highway, railway, pipeline and marine based transportation modality (Figure 1.). The NTSB attributes the current safety record to advances in technology in

comparison to early open cockpit flight decks of previous generations. Previous NTSB findings (2017) posit that GA safety as measured by total flight hours in a given year showed a flatlining in GA accidents per total flight hours (Figure 2.).

Transportation Accidents by Modality

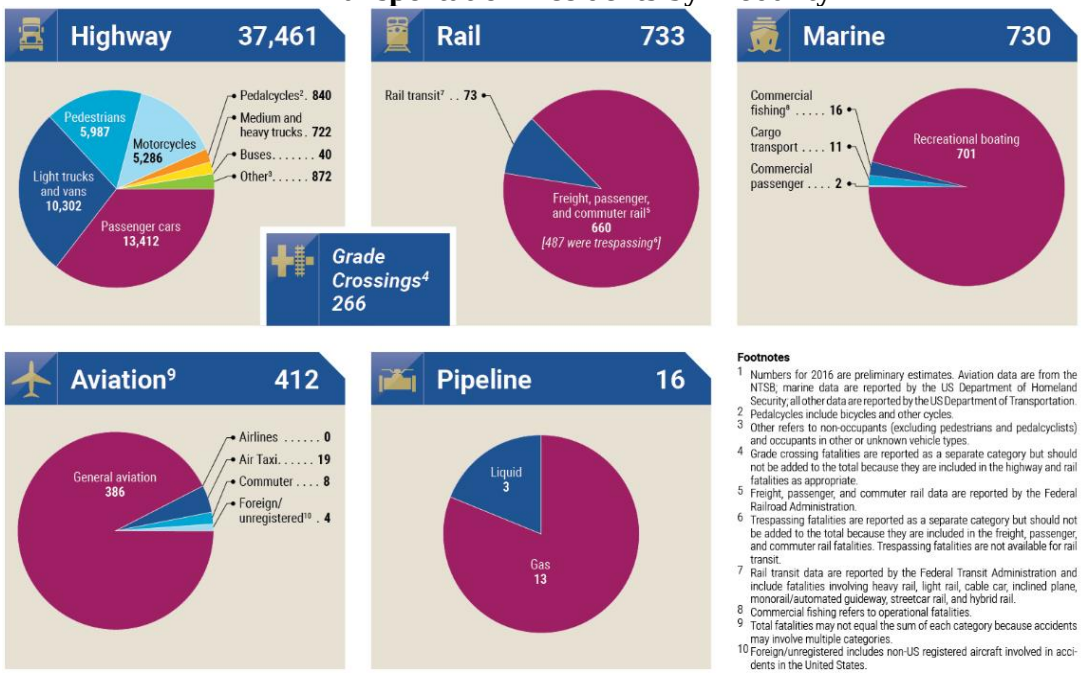


Figure 1. Comparison of Fatalities by Modality in 2016, from the NTSB (2017)

General Aviation Accidents per Flight Hours per Year

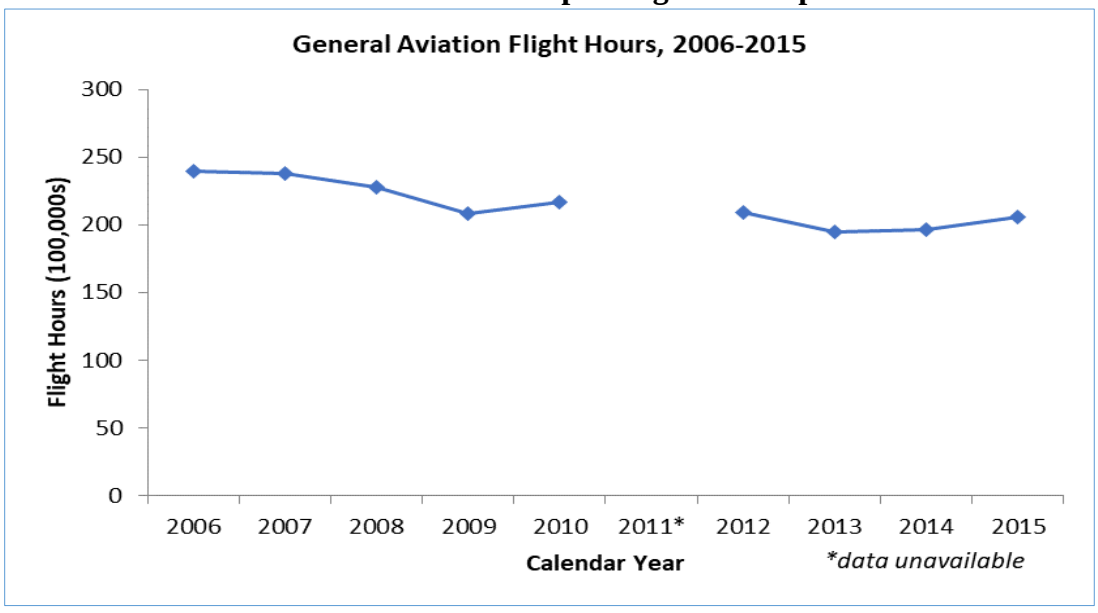


Figure 2. NTSB Analysis of GA Accidents in 2016, from the NTSB (2017)

1.4 Thesis Statement

A multi-factor accident prediction model that includes other contributing factors such as pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload in addition to the NTSB PLOC contributing factors will increase the scope and criteria for PLOC accident diagnosis.

1.5 Research Objectives

This Praxis is an attempt to respond to the NTSB 2017-2018 formal public petition for the prevention of PLOC. While the NTSB performed a preliminary analysis to determine the factors that contribute to PLOC, this Praxis will attempt to use NTSB PLOC contributing factors as baseline for the follow overarching objectives:

- Validate if the NTSB PLOC prediction that PLOC is attributed to loss of SA, weather and pilot distraction.
- Propose and develop a PLOC prediction model that includes the NTSB predictors and additional predictors to increases the scope of factors result in PLOC. Additionally, this Praxis intends to determine if the newly proposed PLOC prediction model is a better fit for potential use by the NTSB in accident and incident investigations.
- Given the new PLOC prediction model, the Praxis recommends the adaptation of a pilot checklist that when employed will contribute to the mitigation or reduction of PLOC in GA. The pilot checklist is a compliment to the traditional aircraft operations checklist.

1.6 Research Questions and Hypotheses

Figure 3. is an attempt to delineate PLOC induced accidents from no PLOC accidents. It is reiterated PLOC accounts for 48% of all accidents. Therefore, the research questions and hypotheses are aligned with events on the right side of Figure 3.

General Aviation Accident delineation (PLOC and Aircraft Component Failures

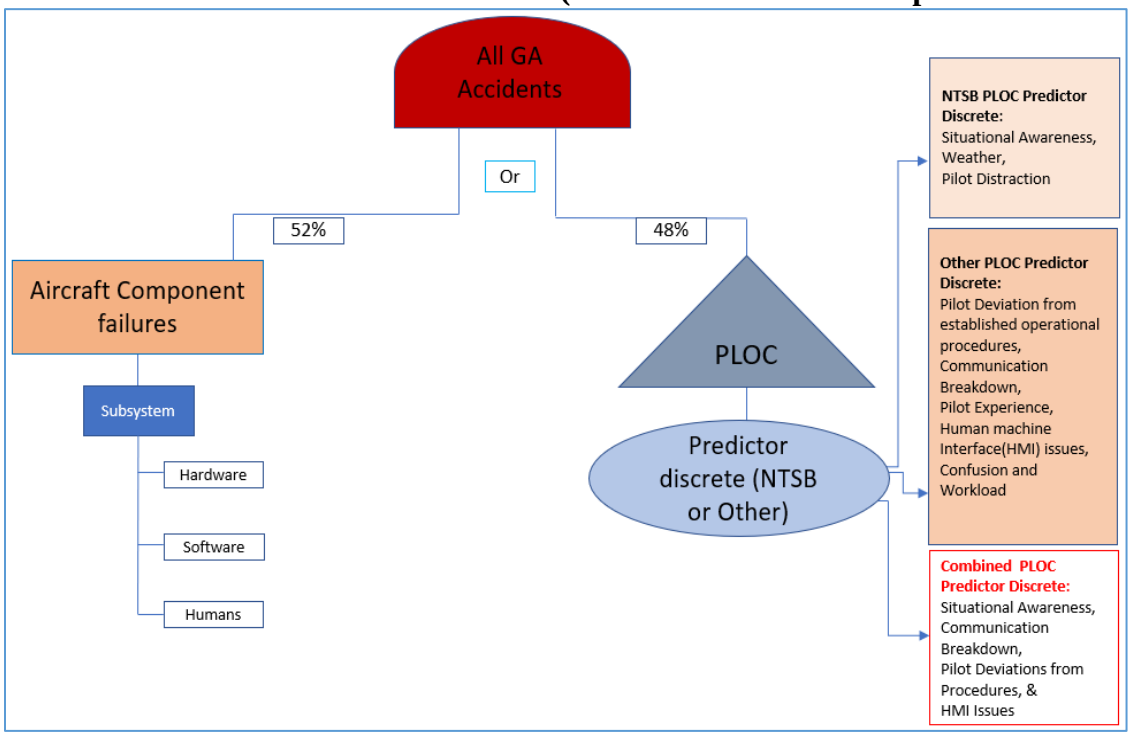


Figure 3. NTSB GA Accident Contributing Factors by Components and PLOC

The Praxis will attempt to answer the following questions in order to unambiguously determine the validity and accuracy of proposed PLOC accident prediction models and recommendation for PLOC mitigation such as the addition of pilot checklist as a compliment to the traditional aircraft operations checklist. The questions are noted as follows:

Research Question 1: Which of the contributing factors identified by the NTSB are predictors of PLOC accidents in GA?

Research Question 2: What other contributing factors also predict PLOC?

Research Question 3: What combination of contributing factors results in PLOC?

Research Question 4: How can PLOC be prevented or controlled?

The preceding research questions clearly attempt to accomplish the overarching research objectives. Naturally, the following hypotheses will attempt to similarly acquire insights to better structure the requisite framework to answer the research questions.

H1: The NTSB identified PLOC contributing factors (loss of SA, weather, and pilot distraction) are predictors of PLOC.

H2: Other factors not currently considered by the NTSB (pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload) are better at predicting PLOC than those identified by the NTSB in H1.

H3: Combination of contributing factors (factors from the NTSB and the other contributing factors) are stronger PLOC predictors than in H1 and H2.

H4: Pre-emptive application of mitigation controls against contributing factors will reduce the likelihood of PLOC.

1.7 Scope of Research

The research efforts for this Praxis are not and cannot be exhaustive enough to comprehensively determine all contributing factors to PLOC in GA for obvious reasons chiefly, the time limitation for research completion and anticipated emergent complexity. The NTSB petition for the prevention of PLOC in GA suggests a very applied research. To narrow the scope of the Praxis even farther, the contributing factors to PLOC as

determined by the NTSB are used as a baseline. Therefore, the scope of this research focuses on the combined contributing factors to PLOC in GA (both NTSB and other contributing factors as noted in Figure 3. (the right side of the figure)) and the proposal for a pilot checklist.

1.8 Research Limitations

This Praxis's lofty goal in responding to the formal NTSB petition (2017-2018) for the prevention of PLOC in GA is limited to quantitative incident data that is available from the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) database. While data quantity is not a factor for concern given that the ASRS data intake period dates to 1981 (Figure 4.), the accumulated ASRS datasets are collected with the ultimate goal to foster research for aviation safety.

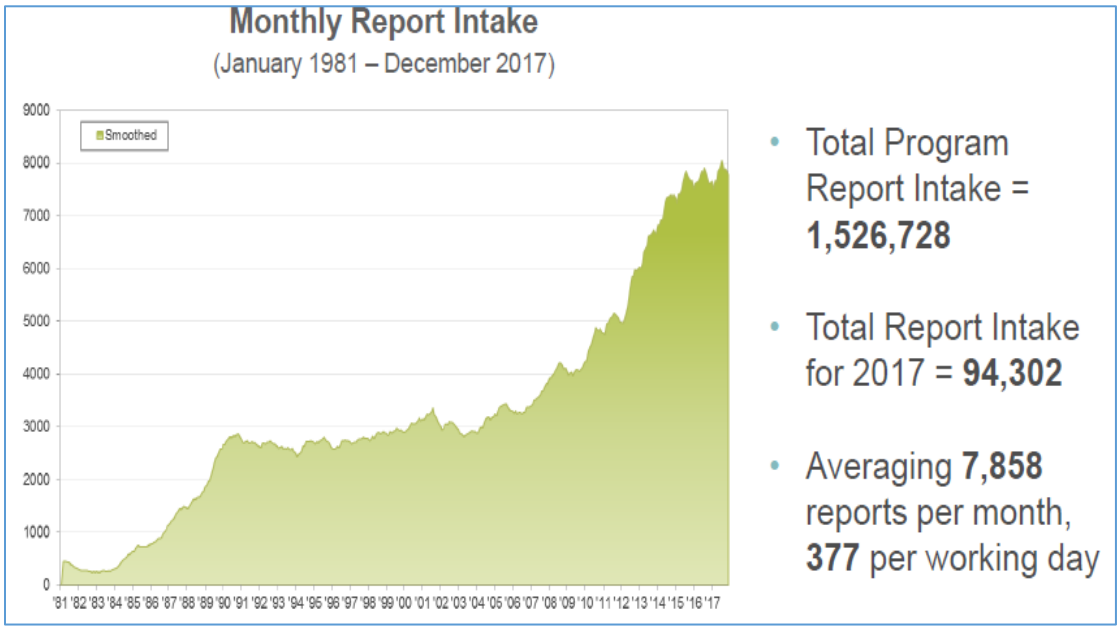


Figure 4. Data from NASA Report Intake Metrics for ASRS (1981 to 2017)

A second limitation is that engineering controls that contribute to the prevention of PLOC in GA are not candidates for this research. The de-emphasis on engineering controls is not to suggest that such controls are not viable; in fact, they are even more

viable and desirable as they are able to resolve PLOC actors from a system's design. The argument for PLOC prevention via engineering design is echoed by Endsley et al. (2012) for systems design centered on user situational awareness. The permanency of an engineering approach cannot be understated as the NTSB also argued for device that can alert a pilot when an aircraft critical angle of attack is exceeded in order to maintain situational awareness.

1.9 Organization of the Praxis

The first chapter of this Praxis provides a contextual introduction into aviation while delineating GA and its role as a contributor to the gross national product. The overarching research problem is also discussed here. The discussion on the research problem is decomposed into the driving problem statement that functioned as the impetus for the thesis statement research objectives. In a parent to childlike relationship, the problem statement birthed the thesis statement which then birthed the research objectives that are parent to the research questions and hypotheses. While this chapter does not cover the entirety of the Praxis, it is foundational to the research.

The second chapter of the Praxis is comprised of the literature review. Given the applied nature and timeline for completion of the research, the literature review is not entirely exhaustive; however, the recency of the problem, 2017 to 2018, means that the content of the literature is most up to date. Definitions and descriptions for the factors that contribute to PLOC such as loss of SA, weather, pilot distraction, deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload are discussed here.

The third chapter of the Praxis is comprised of research methods. The research methods commence by evaluating the collected raw data files from the NASA ASRS database. The raw data files are then formatted into binary data based on a taxonomy that is derived from the definitions and literature regarding the contributing factors to PLOC.

The fourth chapter of the Praxis is comprised of research results or findings. Binary logistic regression is used in the estimation of relationship between one or more predictors. A probabilistic Risk Assessment method is used to qualitatively determine effective PLOC control methods give three case studies of GA accidents that attributed to PLOC. The chapter on research methods concludes by providing a validation for the each of the proposed PLOC prediction models (NTSB, other and a combination of the two).

The fifth and final chapter of the Praxis is comprised of the discussion and conclusion. Main findings from the Praxis are summarized here as well as contributions to engineering management body of knowledge. The chapter concludes by introducing a pilot checklist can be used to prevent the probability of a PLOC occurrence and recommendations for future research.

Chapter 2—Literature Review

2.1 Introduction

This chapter reviews current literature in order to characterize the nuanced underpinnings for PLOC and its contributing factors to reach an affordable and implementable control processes or procedures in the form of a pilot checklist. It is noted that while the formal NTSB petition called for the prevention of PLOC in GA, this Praxis argues that such an endeavour requires the combination of basic and applied research effort that is more suitable as a follow-on to this Praxis. The rationale herein is that PLOC is a new challenge that requires additional comprehension to reach the desired NTSB *PLOC Prevention* end state. The chapter will proceed in the following sequence; first, attempt to define PLOC in order to frame the context for the literature. Second, define the contributing factors to PLOC (loss of SA, weather, pilot distraction, deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload). These definitions will play a pivotal role of established taxonomy in the methodology chapter of the Praxis. Third, briefly discuss how the relationship between the contributing factors and PLOC or how they potentially directly or indirectly contribute to PLOC. Finally, provide a conclusion summary.

2.2 Pilot Loss of Aircraft Control Defined

The United Nations' International Civil Aviation Organization (ICAO, n.d.) established two categories for Loss of Control (LOC); LOC-Ground (G) and LOC-in flight (I). ICAO (2017) notes that LOC-G occurs while the aircraft is on the ground. LOC-G can result from pilot failures (errors in judgement and task execution) and system failures in the form of contamination of runways and aircraft component malfunction

(powerplant failure). To distinguish LOC-G from LOC-I, ICAO (2017) posits that "LOC-I is an extreme manifestation of a deviation from intended flightpath." While LOC-I is limited to airborne phases of flight operations, its causal factors consists of pilot induced failures, component failures or a combination of both.

The NTSB adopted the ICAO definition for LOC-I with an interpretation that LOC-I for GA is the result of two incongruent interactions between aircraft and pilot.

- Aircraft does not comply with pilot inputs/instructions.
- Aircraft performs actions that are contrary to pilot inputs/instructions.

This Praxis added Pilot (P) added to LOC-I to focus on pilot induced failures to LOC-I. The ICAO and NTSB definition for LOC-I is use with focus on the pilot. For the purpose of this Praxis, PLOC is an extreme manifestation of pilot induced deviations from intended flightpath that can result in an incidents or accident.

2.3 Contributing Factors to Pilot Loss of Aircraft Control

In the 2017-2018 petition for the prevention of PLOC, the NTSB identified three factors it determined as contributing to PLOC. While this Praxis concurs with the three contributing factors, it argues that there are more than three factors that contribute to PLOC. Thus, focusing on only the three factors skews potential PLOC prevention strategies. This subsection of chapter two will attempt to define and characterize each of the contributing, both the NTSB and those proposed by the Praxis.

2.3.1 Loss of Situation Awareness

2.3.1.1 Definition of Situation Awareness

Before embarking on the underpinnings leading to loss of SA, it is necessary to briefly focus the discussion on a definition for SA, how it is acquired and most importantly how it is loss. Unlike the other contributing factors to PLOC, SA is most

dominant with extensive literature. Although SA is a ubiquitous connotation even in none technical settings, this Praxis argues that an understand of it, is less formal and more intuitive. The argument here is that while SA is commonly known, it is not commonly understood. While the origins of SA date to military operations during World War 1 (acquiring information regarding enemy activities), Woods (1998) asserts that SA transformed into a need for system operators (pilots) to understand system status as in the system's condition; system mode as in a configuration within the system.

Although there are several definitions for SA, Endsley (1988) offered the following formal and now accepted definition for SA. "SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Furthermore, Endsley decomposed SA into the following three level:

- Level 1, the perception of the elements in the environment. Endsley (Garland, Wise, & Hopkin, 1999, p.259) posits that an aircraft pilot needs to perceive all relevant elements in the pilot's operational environment such as the terrain, the state and modes of the aircraft the pilot is flying and other aircraft in the vicinity.
- Level 2, the comprehension of the current situation. Endsley notes that in progressing from "level 1" to "level 2," the pilot must now develop a deeper understanding of the significance of the perceived elements in the environment. This means that the pilot combines SA levels "1 & 2" to prepare for a corrective or evasive decision to land the aircraft.
- Level 3, the projection of future status. Endsley asserts that the pilot's flight experience influences the quality of (the pilot's) performance output in this level

of SA. In essence, the projection of future status is based on anticipation from which prior experiences are a perquisite.

In synergy with Endsley's now theory on SA, Klein et all (1989, 1991, & 1993) also assert that "SA is a prerequisite for good decision making, correlating positively with decision accuracy." This Praxis speculates that decision accuracy is a basic and prerequisite output for a Level 3 SA based on Endsley's widely accepted SA theory. Endsley provided a model on how SA influence decision-making within the context of tasks, system performance and human capabilities and limitations (Figure 5.).

Endsley's Situational Awareness Model

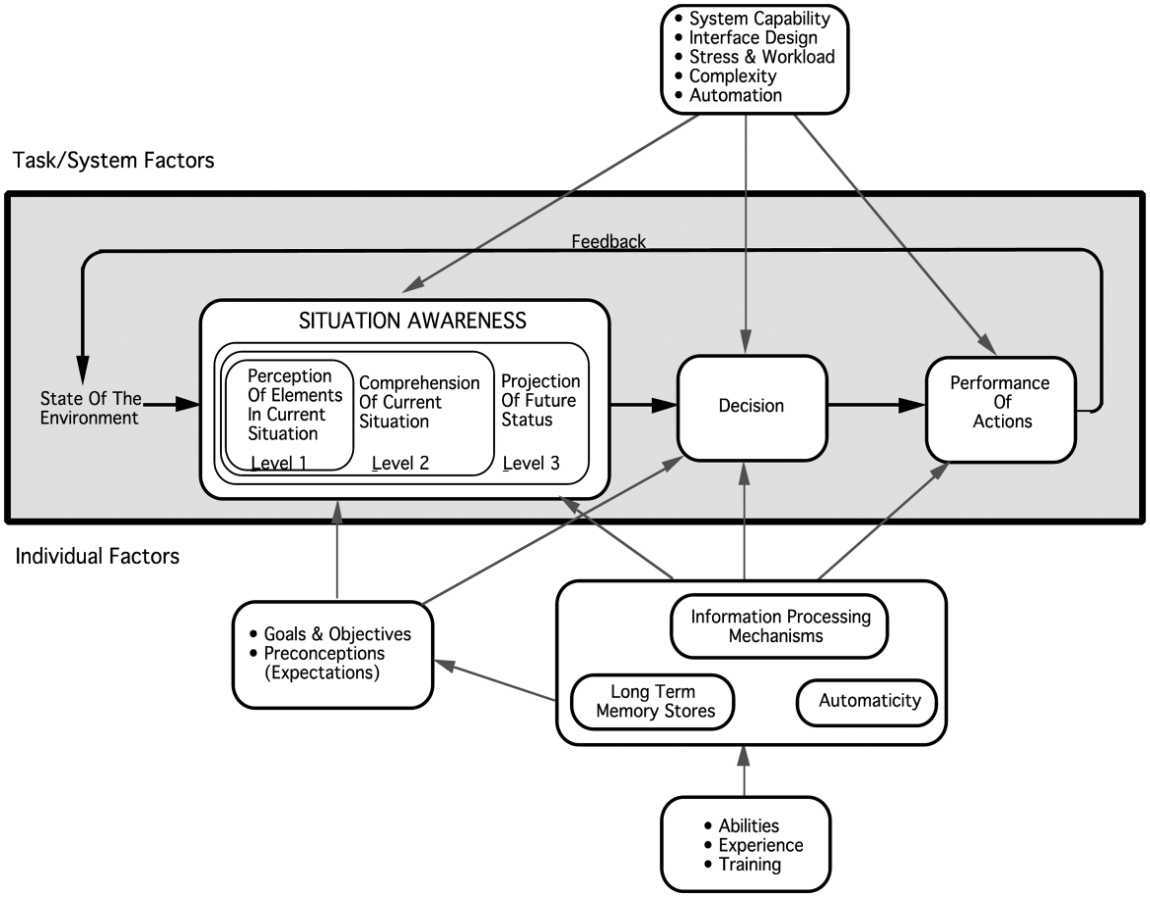


Figure 5. Model of SA in dynamic decision making, from Endsley (1995d, 1997.)

While there are other definitions for SA, the common thread is centered on the Endsley's three levels for SA. The FAA Risk Management Handbook (FAA-H-8083-2, 2016) defines SA as "The accurate perception and understanding of all the factors and conditions within the four fundamental risk elements (pilot, aircraft, environment, and type of operation) that affect safety before, during, and after the flight." While both Endsley's and the FAA definition echo a common sentiment, this Praxis will explicitly default to Endsley's definition for SA.

2.3.1.2 How Situation Awareness is Acquired

To better understand how SA is loss, it is requisite to understand how SA is acquired. Based on the preceding context to include Endsley's model, the underlying basis for SA is knowledge. O'Dell & Hubert (2011) defined knowledge as "information in action." The duo distinguished knowledge from data which they categorized as facts and information (analyzed data). Their argument is that knowledge is the embodiment of information with the addition of experience and perceptions. The addition of experience and perceptions echoes a sentiment from the recurring theme from the definitions and model for SA.

Hester & Adams (2017) echoed the O'Dell & Hubert's argument on the underpinnings of knowledge and propose a journey towards knowledge with origins in data and information as precursors. They define data as "a set if already interpreted in some way." This definition for data has strong congruence with Endsley's level 1 SA (the perception of elements in the environment); the argument here is that the elements being perceived are/is characteristically distinct. While Hester and Adams did not offer a definition for information, they described information as the application of contextualization, categorization, calculation, correction and condensation to data thereby

converting data into information. This description for information also strong congruence with Endsley's level 2 SA (comprehension of the current situation). Figure 6. provides Hester and Adams adoption of French's (2013) rendering on the transitioning of data to information and finally to knowledge. Table 1. provides a clarification of the meaning of the noted arrows and alphabet symbology.

A model rendering Hester & Adams's data transitioning to knowledge

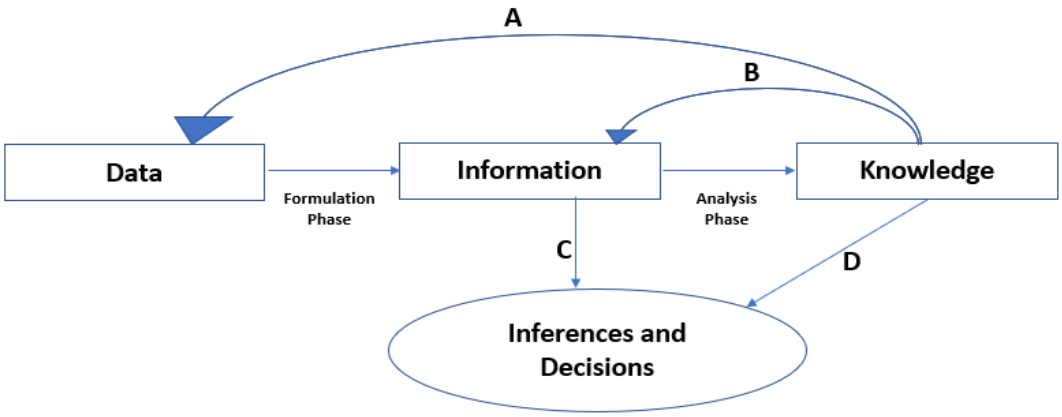


Figure 6 Data Information Knowledge and the making of inferences and decisions (French, 2013), from Hester & Adams (2017)

Table 1. Description of artefacts depicted in Figure 6 From Hester & Adams (2017)

Arrow	**Description of process**
A	Indicates uses of information in the formulation phases and detailed organization of the data in the analysis phase
B	Indicates that in order to recognize such patterns and form new knowledge, it requires insight and higher-level knowledge
C	Indicates that the decision makers are informed by the outputs of the formulation and analysis phases
D	Indicates that in order to understand the information and be able to use to improve their thinking, the users need to be conscious of their knowledge of the analytic methods used and how these have help them in the past.

To provide secondary definition akin to a second opinion, Davenport & Prusak (2000) defined knowledge as "a fluid mix of framed experience, values, contextual information, and expert insights that provides a framework for evaluating and

incorporating new experiences and information." Hester and Adams adopted this definition which reinforces the common thread regarding the variables that are conducive to knowledge.

While the basis for the acquisition of SA can be a doctoral Praxis unto itself, this discussion must provide a brief context on the acquisition of knowledge since knowledge is a precursor to SA. O'Dell & Hubert's established construct as used to provide the framework for the acquisition of SA point to an intertwined associate of knowledge acquisition, and learning. The dictionary provides the following definition for learning: "the acquisition of knowledge or skills through study, experience, or being taught." Similarly, Hilgard & Marquis (1940) defined learning as "Change in the strength of an act through training procedures (whether in the laboratory or the natural environment) as distinguished from changes in the strength of the act by factors not attributed to training." Echoing the sentiment from preceding definitions for learning, Chebykin, Bednyĭ, & Karwowski, (2008) make the argument that learning is the catalyst to attain mission goals during an activity. The definitions for learning emphasize a common theme, learning is an input for one to acquire knowledge and the acquired knowledge is an input for SA.

Jaber (2011) cautions that learning must consist of evidence and feedback to ensure its efficacy. He asserts that "one must have evidence of the effect and must feed that information back to those who make decisions and first implement the learning experience." A discussion on the underpinnings of learn is a treatise on the subject itself and deviates from the core issue of loss of SA in GA; however, since learning is the basic input to SA, a brief summary how learning is achieved is required. The rational here is to

establish a preliminary root causal traceability from a definition for SA to how SA is acquired and how it is lost.

Jaber notes that there three ways on how learning takes place: (1) rote learning which is based on memorization and repetition; (2) practiced variations, a follow-on to rote, however it is dependent on generated what-if scenarios (a standard practice in airline pilot training using simulators); and (3) innovation which in this context means to "introduce something new." A juxtapose of Jaber's three ways to learning and Endsley's three SA levels provides unique foundational insights for a potential and eventual approach to resolving loss of SA.

Endsley level 1 SA, the perception of the elements in the environment (an aircraft pilot perceiving all relevant elements in the pilot's operational environment such as the terrain, the state and modes of the aircraft the pilot is flying) is analogous to rote learning (memorization and repetition). Taking this comparative theme further, Endsley's level 2 SA, the comprehension of the current situation (the pilot developing a deeper understanding of the significance of the perceived elements in the environment) is analogous to Jaber's practiced variation, the second method to learning. Finally, Level 3 SA, the projection of future status (the pilot's flight experience influencing the quality of performance output) is equivalent to Jaber's innovation method to learning.

The final premise on this discourse on SA is learning curves (LC). The Merriam-Webster dictionary defines LC as "the course of progress made in learning something." The dictionary also defined financial LC as "the time it takes to master a concept. It is more of an idea than a chard or other visual representation of learning." In continuing with the theme for LC definition, Jaber (2011) defines LC as "a mathematical description

of worker's performance in repetitive tasks." He added that LC tools are efficient in monitoring a worker's performance in repetitive task. While repetitive tasks are most certainly predicable, a pilot's tasks are also repetitive with a caveat. A pilot uses a checklist, as such the repetitive nature of the tasks cannot be understated; however, a caveat is invoked to assert that the dynamic nature of the operational environment and aircraft performance most certain adds complexity to demand Endsley's level 3 SA or Jaber's innovation to resolve an emergent problem.

2.3.1.3 How Situation Awareness is Loss

If LC is to the how SA is acquired, is it possible that forgetting curve (FC) is to how SA is loss? The FAA (FAA-H-8083-2, 2016) describes loss of SA as "the result of a pilot not knowing where he or she is, an inability to recognize deteriorating circumstances, and the misjudgment of the rate of deterioration." This description identified the most salient underpinnings for SA: data, information, knowledge and Endsley's levels for SA.

Jaber (2011) posits that FC is human performance on memory tests over a plotted function of time. While a pilot's use of checklists challenges dependence on fallible human memory, much a pilot's work environment requires the ability to forecast future states of aircraft performance in a dynamic environment and simultaneously eliciting a response from the pilot's previous experiential knowledge memory banks, a level 3 SA.

Bainbridge (Garland, Wise, & Hopkin, 1999, p. 142) offers an equally compelling and notable somewhat contradicting opinion on how SA is loss. She notes that air traffic controllers anecdotally mention "losing the picture" as a whole potentially because the controllers' mental representation of the situation is structurally integrated. In summary Bainbridge makes the point that "people may then only notice information that is consistent with their expectations, and it may be difficult to change the structure of

inference if it turns out to be unsuccessful or inappropriate (this rigidity in thinking is called *perceptual set*." While Bainbridge's studies were done on closely related set of audience (air traffic controllers), the same argument can be made about pilots that they too are predisposed to noticing information that is consistent with their expectations.

As there are certainly other opinions on the loss of SA to warrant a Praxis unto itself, the primary takeaway in this case will center on Jaber's hypothesis on FC and Bainbridge's Perceptual set. Thus, the loss of SA is a combination of factors that include the decay (forgetting) information or knowledge over time and the propensity for pilots to forecast and only see their expected outcome. This argument provides the underpinnings to the FAA's description for the loss of SA for the GA pilot.

2.3.2 Weather

The FAA (2018) asserts that fatal GA accidents that are attributed to weather are caused by the pilot's inability to recognize deteriorating weather conditions. Lindholm (Garland, Wise, & Hopkin, 1999, p. 569) makes the argument that while the weather information that is available to a pilot is heavily regulated, weather forecast is "an inexact science" with questionable history at best. Although Lindholm's argument on the integrity and reliability of aviation weather is fairly dated, a recurring thread emerges, the pilot's in ability to recognize changing events. A clarification is hereby required before a linkage is established on the how weather contributes to PLOC.

Pilot flying privileges are grouped into those with the qualifications to only fly under visual meteorological conditions (VMC) and those who receive the specialized training and certification to fly under instrument meteorological conditions (IMC). Nolan (Garland, Wise, & Hopkin, 1999, p. 431) defines VMC as "weather conditions where

pilots are able to see and avoid other aircraft." Nolan points out that pilot who fly in VMC comply with visual flight rules (VFR). Additionally, Nolan defines IMC as "weather conditions where the visibility is below that required for VMC or the pilot cannot remain clear of clouds." Flight operations conducted under IMC require the pilot to comply with instrument flight rules (IFR).

The VFR and IFR governance aside, weather unto itself does not cause PLOC. As the FAA so asserted, the issue lies in a pilot's ability to use information (aviation weather information) to recognize changing events, a tenet of Endsley's level 3 SA. It is also acknowledged that the Jaber's FC plays a significant rule. In fact, Sternberg (2007) notes that human memory often gets distorted by interference and decay. Sternberg describes interference as an occurrence when previously information in memory competes for space given new information. He describes decay as "when the passage of time causes us to forget." Thus, weather directly does not cause PLOC, rather how a pilot uses weather information can contribute to PLOC.

2.3.3 Deviation from Established Procedures

FAA Order 8900.1 change 616 defines pilot deviations as "the actions of a pilot that result in an apparent deviation from title 14 of the Code of Federal Regulations or a North American Aerospace Defense (Command Air Defense Identification Zone) tolerance." While the definition for pilot deviation connotes extensive legal ramifications to include suspension or revocation of a pilot's license, research literature on the causal factors to pilot deviation is very limited to nonexistent. It is speculated that the lack of literature on pilot deviations, while a safety issue, is bounded by the secretive nature of national security directives. For clarity, the FAA definition for pilot deviations is interpreted as a

pilot straying from an assigned heading or altitude, instrument procedure, or if the pilot penetrates a controlled or restricted airspace without the required clearance from the responsible air traffic control authority. However, part 91.3 of the federal aviation regulations (FAR 91.3) gives the pilot in command of aircraft the final authority on the operation of the aircraft and allows the pilot to deviate from any rules to any extent to accommodate or meet an emergency.

Although not directly related to the issue of pilot deviation from operational procedures, Tsang & Vidulich (2003) make the point that role of the pilot is continuously changing. The duo not that as aircraft systems and components become more capable, some tasks that were traditionally performed by a pilot are outsourced to a subsystem or component such as an automation. Indeed, some or all of the offenses that the FAA associates with pilot deviations such as a pilot straying from an assigned heading or altitude are functions that are now performed by an autopilot. Landry (Salvendy, 2012, p. 1667) echoes Tsang's observation on the changing role of the pilot in asserting that autopilots allow a pilot greater reliability in maintaining desired headings, speeds and altitude. Furthermore, a navigation aid such as the global positioning system, now standard feature in GA aircraft, automates a pilot task to main geographic location of an aircraft (this is analogous to ensuring that a vehicle remain within the boundaries of a lane) from restricted airspaces.

2.3.4 Pilot Experience

Tsang (Tsang & Vidulich, 2003) observed that due to the complexity and multifaceted nature of piloting an aircraft, most of the methodologies used to assess a pilot's competency are primarily approximations. She makes the point that accident rates

pilot experiences are used as proxy to gauge the pilot performance. Indeed, the FAA and NTSB use a pilot's total flight and tests (practical and academic) to qualify a pilot candidate for the issuance of a license. In the case of a GA pilot who is licensed at the commercial pilot level (in accordance with Federal Aviation Regulation part 61.123), the minimum requirements include a total of 250 hours of flight time as a pilot, possession of aeronautical knowledge and experience, a third-class medical certificate (second if the pilot is flying commercial flight operations), and flight proficiency. Tsang notes the pilot experience as measured by total flight time is cumulative and also linked to a pilot's age. Thus, quantitatively greater flight time, a proxy used to determine experience and expertise is associated with advanced aged pilots.

Although Tsang alluded to a conundrum regarding pilot experience and advanced age, there is substantial discourse on an ageing mind and performance. However, it is beyond the scope of the Praxis to deliberate on the topic. Additionally, it is acknowledged that in previous studies on the relationship between ageing and pilot performance, Kay et al. (1994) determined that the number of recent flight hours, in contrast to total flight time was more significant in determining flight safety than the age of a pilot.

2.3.5 Communication Breakdown

Wickens (Tsang & Vidulich, 2003, p. 147) summarized and characterized the cycle of functions that are performed by a pilot into four meta tasks:

> "aviate (keeping the plane in the air); navigate (moving from point to point in 3-D space and avoiding hazardous regions of terrain, weather, traffic, or combat vulnerability); communicate (primarily with air traffic control and with others on board the aircraft; and manage systems."

The quantity of discourse on communication breakdown is substantive to justify being the focus of this Praxis; however, communication breakdown is only evaluated as a contributing factor to PLOC. Shannon & Weaver (Hester & Adams, 2017, p.66) define communication as "all of the procedures by which one mind may influence another." If this definition is applied to an operational GA environment, it is then speculated that the end goal of the influencing mind is to have a change in behavior or output from the influenced mind. A breakdown of communication is therefore the inability of the influencing mind to achieve the desired or intended effect over the influenced mind.

Hester & Adams (2017) posit that communications and control, as a pair, function as the catalyst for the transmission of operational properties related to a systems' performance. In their argument, the duo assert that without the ability to communicate essential operating properties such as elements of control could not be transmitted to a system. They adapted Shannon & Weaver's communication model (Figure 7.) to demonstrate their reasoning.

A model rendering Shannon & Weaver's Communication System Block Diagram

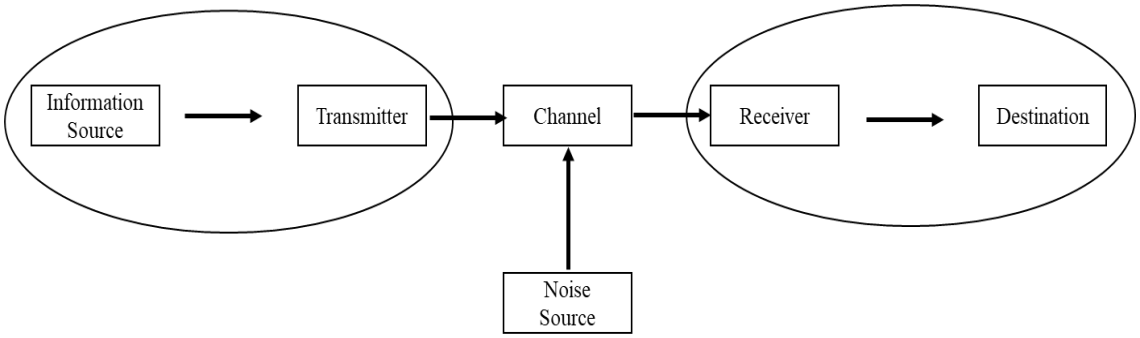


Figure 7. Communication System Block Diagram, from Hester & Adams (2017)

Table 2. provides a description of the elements noted in Figure 7.

Table 2. Description of elements depicted in Figure 7 From Hester & Adams (2017)

Arrow	**Description of process**
Information source	Produces and then selects the transmitted message from a number of possible messages.
Transmitter	Converts or encodes the message into a signal.
Channel	The medium over which the signal travels. This can be a sound pressure from airwave radio to an electric current on a wire.
Noise	The unfortunate characteristic that certain things are added to the signal which were not intended by the original information source.
Receiver	Changes or decodes the transmitted signal back to message.
Destination	Supplied to the destination by the receiver.

While Shannon & Weaver's communication model provides a reasonable context on the variables involved in basic communications, the level of communication complexity increases exponential in the GA environment. Factoring in Wickens' four meta tasks that a pilot must perform in a dynamic 3D environment, it is arguable that an intended message, the encoding of that message by the sender, the strength of the transmission and the channel itself, the decoding of the message by the receiver are lineal sequence of events such that each event has the potential to encounter distortions that result in breakdown (communication breakdown). It is also acknowledged that while the four meta tasks that a pilot must perform are individual complex by themselves,

2.3.6 Confusion

Literature on confusion as a topic unto itself seems nonexistent at this writing. Confusion appears to be the resulting byproduct of the state of existence from some event such as communication or miscommunication, perhaps even the loss of SA. The Oxford English dictionary gives a list of definitions for confusion that include: "uncertainty about what is happening, intended or required," "the state of being bewildered or unclear in

one's mind about something." Indeed, one can deduce that confusion is the end state to any of the discussed and yet to be discussed contributing factors to PLOC. However, in addition to having the direct potential to result in PLOC situation, confusion is also a state that causes or triggers the other contributing factors to PLOC.

The lack of literature on confusion does not preclude a brief summary to the underpinnings of the topic. To attempt to achieve this feat, one must revisit some salient points captured in the discussion on the loss of SA. Recall that the FAA (FAA-H-8083-2, 2016) describes loss of SA as "the result of a pilot not knowing where he or she is, an inability to recognize deteriorating circumstances, and the misjudgment of the rate of deterioration." McCloskey (1996) created a link between missing data and uncertainty by positing that missing data is a frequent source of uncertainty (or in this case confusion) particularly in high stakes or complex decision points. Thus, the pilot not knowing where he or she also stipulates "uncertainty" or "lack of clarity" about what is happening. Furthermore, Endsley's 3 levels for SA with emphasis on the first and second, (perception of the elements (level 1 SA) and comprehension of their meaning (level 2 SA)) reaffirms a reasoning that confusion can be: the consequence from the other contributing factors to PLOC, a trigger to initiate the other contributing factors and a contributor to PLOC itself.

2.3.7 Human Machine Interface

Human Machine Interface (HMI) is a subject with extensive research literature and research interests to be a PLOC doctoral Praxis unto itself. In complex systems that not only interact with humans, but also require human supervision (specifically judgment and decision making), the creation of machine interfaces (hardware or software) that are

naturally mapped to the target audience's natural capabilities and limitations can cause or deter undesired conditions that can result in a PLOC. Spath et el. (Salvendy, 2012, p. 1660/1) make the argument that "all components of a work system for functional interaction between the human and technical system are defined by the term human – machine interface." While the rendered definition is more a description, it provides two major points: 1) A machine is a work system. Naturally, an aircraft is a work system with functional interactions with the pilot, and the operational environment; and 2) the interface allows the human (pilot) to interact with the system to achieve some desired goal. Before continuing further with the discussion on HMI, brief contextual definitions for a system, an interface, and human capabilities and limitations as they pertain to HMI are deemed necessary.

Gibson et al. (2017, p. 4) define a system as "set of elements so interconnected as to aid driving towards a defined goal." While succinct, Gibson decomposes this definition to capture its attributes, focusing on "the set of elements," "interconnectedness," and "defined goal." Gibson and his colleagues postulated the following:

1) The set of elements is a group of objects with some common characteristics.
2) The objects must be capable of influencing one another (interconnected). This implies that the interface provides feedback to the pilot after receiving an input or instructions and the received feedback provides the pilot with new context (a continuous back and forth interaction).
3) The progression towards attainment of the goals must be unobstructed. In simpler terms, the information about what is happening must be clear to the pilot. Recall

McCloskey's (1996) argument that missing data is a frequent source of uncertainty.

Gibson's decomposed description for the essence of a system are directly in unison to an aircraft and pilot symbiotic coupling especially in light of Wickens' four meta tasks that a pilot must perform.

The Cambridge English dictionary defines an interface as "the place where two systems come together and have effect on each other, or a connection between two computers or a person and a computer." The dictionary also provided an expansion on the definition to include "to communicate with someone, especially in a work-related situation." This definition provides adequate basis on how an interface alone can be source of an undesired situation that can contribute directly or indirectly to PLOC. While there is substantial discourse on interface design and its effects on workload and system complexity, such a discussion exceeds the scope for this Praxis.

Although it is more metaphysical perhaps event theological to define a human, this is exceptional out of scope. However, from a biological and physiological perspective, Norman (2013) attests that humans have capabilities and limitations that must be considered in the design of work-related systems. Thus, the focus on the human component to HMI is centered on physical and cognitive human capabilities and limitations (the basis of human factors engineering). In synergy and support of Norman's attestation, Spath et al. (Salvendy, 2012, p. 1652/3) posit that "human capabilities fluctuate for each person and between individuals, increasing with training and declining with fatigue." While the consequences of a machine interface that not design to accommodate natural physical and cognitive capabilities can induce a PLOC, cognitive

interface mismatch is direr as it affects the pilot's knowledge about a work system's behavior and the subsequent decision-making process of that pilot.

This Praxis asserts that while it applicable, a comprehensive discussion on the distinction between physical and cognitive capabilities is better suited to a literature review on the design aspect of work systems. However, the following summary distinction between physical and cognitive capabilities is adequate for context. Physical human capabilities are biomechanical effectors that are part of the skeletal structure and central nervous system. Chaffin et al. (2006) define biomechanics as the "study of the physical interaction of workers with their tools, machines, and materials so as to enhance the worker's performance."

Cognitive human capabilities on the contrary are complex because they also depend on capabilities available in physical capabilities such as appendages. However, cognitive capabilities are primarily memory, attention, sensation, and perception orientated. Sternberg (2007) defines memory as "the means by which we retain and draw on our past experiences to information in the present." This definition leads to the discernment that memory is about knowledge; as established throughout the literature review, the corruption or degradation of knowledge can directly or indirectly lead to conditions conducive to PLOC.

Sternberg (2007) defines attention as "the active cognitive processing of limited amount of information from the vast amount of information available through the senses, in memory, and through cognitive processes; focus on a small subset of available stimuli." This definition casts light on one of the primary cruxes to PLOC causal factors. The pilot must switch attention between four meta tasks (recall from Wickens), while

discerning data to be converted to information or knowledge from an interface. Merriam-Webster's dictionary defines sensation as "a mental process (such as seeing, hearing, or smelling) resulting from the immediate external stimulation of a sense organ often as distinguished from a conscious awareness of the sensory process." Although this is not a clinical definition for sensation, it adequately illustrates the work-system interface must convey the correct message in the correct sequence to cause the desired influence.

Sternberg (2007) defines perception as "the set of processes by which we recognize, organize, and make sense of the sensations we receive from environmental stimuli." Sternberg's definition for perception implies that for pilot to attain Endsley's level 1 SA, the pilot depends on his or her sensory capabilities to interpret data or information on work-system interface. Doing so, the pilot must also attention switch between four meta tasks of "aviate," "navigate," "communicate," and "manage systems."

2.3.8 Workload

The literature on workload is substantial, particularly its effects human reliability in an era of multitasking and attention switching between tasks. While workload is identified as a contributing factor to PLOC, it's contributions can be surreptitious in the highly technical system environment where most of the actual work involve knowledge, judgement, and supervision of the system (aircraft). Bainbridge (Garland, Wise, & Hopkin, 1999, p. 157) makes the argument that the relationship between task performance and workload are not the same for physical and mental work. Bainbridge notes that in physical work, "conservation of energy ensures there is a monotonic relation between physical work and task performance." In mental work, "if there are alternative working methods for meeting given task demands, there is not necessarily a linear

relation between the task performance achieved and the amount of mental work needed to achieve it." In theory, while a pilot may be limited in the ways to interact with an aircraft interface, that same pilot will choose a less demanding methodology to respond to a task. Off course in being efficient (conserving mental resources), the pilot is employing previous knowledge to forecast a future state, Endsley's level 3 SA.

Spurgin (2010) defines workload as "a series of actions to be taken by a person or a team in responding to an event in a given time." Spurgin points out that there is substantial perception that workload leads to increased stress, however stress is often induced by an operator's (in this case a pilot) perception that they are not in control. Spurgin concludes that workload is typically associated with quantity and simultaneousness of the tasks to be performed. Considering the microtasks/subtasks that a pilot must perform in order to accomplish the four primary meta tasks (aviate, navigate, communicate and manage systems), a pilot's performance degradation is naturally expected. In echoing this sentiment, Bainbridge (Garland, Wise, & Hopkin, 1999, p. 153) makes the argument that:

> "the amount of mental work a person can do in a given time is not a simple quantity to specify. If it is assumed that a person can do only one thing at a time, then every factor that increases the time taken to do a unit task will decrease the number of those tasks that can be done in given time interval, and so decrease performance capacity."

In responding to the lack thereof or the subjective nature of workload, Bainbridge proposed the following equation: "Total workload = workload in one task × number tasks." This means that for the pilot in question, the total amount of workload to maintain

an aircraft airborne is: the subtasks to aviate × 4 (four meta tasks that a pilot must perform).

2.4 Summary and Conclusion

This literature review focused on the underpinnings of the factors identified as contributing to PLOC. To accomplish this feat, the literature review provided authoritative definitions for each potential contributing factor as well as how each factor actually or potentially contributes to the undesired PLOC occurrence. It is noted that while the NTSB identified pilot distraction, loss of SA, and weather as the contributing factors to PLOC, this Praxis proposed the addition of other factors to expand the scope of forensic analysis for future application in accident and incident investigation.

Although the depth of literature is not as comprehensive, it is deemed adequate and satisfactory as it did not only provide definitions for the contributing factors and relationship to PLOC, but also closely examined some of the contributing factors in greater detail due to abundance of literature. Loss of SA clearly received greater scrutiny with emphasis on definitions, how it is acquired, and how it is lost.

The salient fact about the contributing factors is that they potentially influence one another, functioning as enablers or the requisite catalyst for others. For example, HMI can increase the amount of workload while simultaneously causing loss of SA because the pilot did accurately perceive the elements in the environment, a precursor to knowledge and decision-making. The bottom line is that PLOC is a difficult problem. To put it in more succinct way, Savransky (2000) posits that "difficulty is defined in terms of the number of variables involved in the problem."

Chapter 3—Methodology

3.1 Introduction

This chapter presents the research methods employed to produce the data used to quantitatively and qualitatively make the case for the factors that are alleged as contributing to PLOC occurrence. Thus, the methodology discussion is structured to proceed in the following sequence: First, reorient the discussion by reintroducing the problem statement, research questions, and research and hypothesis. Second, discuss the data source and describe the data. Finally, close the discussion by addressing methodology and provide a sample data.

3.2 The Problem

In early 2018, the NTSB formally petitioned industry, academia and other government agencies for the prevention of PLOC in GA. The formal petition was issued via a documentation known as the "NTSB 2017-2018 Most Wanted List of Transportation Safety Improvements." According to the NTSB, PLOC involving GA aircraft account for 48% of all GA accidents. Furthermore, the NTSB attributes PLOC to: (1) Loss of SA, (2) Weather, and (3) Pilot distraction. A preliminary analysis of sample NTSB adjudicated accident cases suggests that there are potentially other contributing factors to PLOC. This Praxis alleges that in addition to three state factors that the NTSB identified as contributing to PLOC, the following are also contributing factors:

- Pilot deviation from established procedures
- Pilot experience
- Communication breakdown
- Confusion

- Human-machine interface
- Workload

3.2.1 The Research Questions

Hester & Adams (2017, p. 20) posit that "a system age problem is ill-structured when circumstances and conditions surrounding the problem are potentially in dispute, not readily accessible, or lack sufficient consensus for an initial problem formulation and bounding." Although the NTSB is succinct in its assertation regarding the contributing factors to PLOC, Hester & Adams preceding argument was inadvertently invoked by this Praxis' addition of the other alleged contributing factors to PLOC. The goal herein is to attempt to determine the accuracy of the NTSB identified contributing factors to PLOC thereby establishing an NTSB PLOC prediction model, a new PLOC prediction model based on the other alleged contributing factors and finally a PLOC model that prediction model that combines both models. A prediction model that determined to be more accurate will be proposed to the NTSB to use as criterial for accident investigation. The following questions are posed in attempt to accomplish this feat:

Research Question 1: Which of the contributing factors identified by the NTSB are predictors of PLOC accidents in GA?

The NTSB already identified three contributing factors to PLOC (loss of SA, weather, and pilot distraction). The goal herein then is to use these factors as a model to predictor a PLOC occurrence in incident dataset whereby PLOC is reported as an event.

Research Question 2: What other contributing factors also predict PLOC?

This Praxis also identified other contributing factors to PLOC (pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface, and workload). Similar to the first research question, the goal herein is to use these factors as a model to predict a PLOC occurrence using the same dataset as used for first research question.

Research Question 3: What combination of contributing factors results in PLOC?

The goal of this question is to combine both the NTSB and the alleged contributing factors to PLOC (loss of SA, weather, pilot distraction, pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface, and workload). This PLOC prediction model will also use the same dataset as used for questions one and two.

Research Question 4: How can PLOC be prevented or controlled?

Once an accurate PLOC prediction model is established based on result from the research questions above, then a pilot personal checklist that a GA pilot can use as a PLOC preventative measure will be create. This pilot checklist is distinct from an aircraft checklist as it focuses on the pilot as aircraft component. This checklist will underscore the PLOC contributing underpinnings discussed in the literature review section of the Praxis.

3.2.2 The Research Hypothesis

In order to accurately answer the research questions above using statistical analysis, the following hypotheses are proposed.

H1: The NTSB identified PLOC contributing factors (loss of SA, weather, and pilot distraction) are predictors of PLOC.

H2: Other factors not currently considered by the NTSB (pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload) are better at predicting PLOC than those identified by the NTSB in H1.

H3: Combination of contributing factors (factors from the NTSB and the other contributing factors) are stronger PLOC predictors than in H1 and H2.

H4: Pre-emptive application of mitigation controls against contributing factors will reduce the likelihood of PLOC.

3.3 The Data Source – National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) collects and maintains incident data in a voluntary Aviation Safety Reporting System (ASRS) database. NASA (n.d.) stipulates that the:

> "ASRS receives, processes and analyzes voluntarily submitted incident reports from pilots, air traffic controllers, dispatchers, cabin crew, maintenance technicians, and others. Reports submitted to ASRS may describe both unsafe occurrences and hazardous situations. Information is gathered from these reports and disseminated to stakeholders. ASRS's particular concern is the quality of human performance in the National Airspace System."

NASA asserts that it's ASRS staff are composed of highly experience aviators, air traffic controllers, mechanics, and aviation human factors engineers. Furthermore, this interdisciplinary staff have a cumulative 600 years of aviation expertise covering the entirety of the PLOC contributing factors identified in this Praxis.

NASA (n.d.) credits the establishment of the ASRS to the 1958 FAA enactment hearings (U.S. Public Law 85-726-August 23, 1958) on the need for a U.S. Incident Data System. Furthermore, FAA Advisory Circular 00-46E (2011) identifies NASA as a third part to receive and process Aviation Safety Reports for research and to promote safety. As already discussed, the FAA is a regulatory agency with prosecutorial obligations that can deter the free flow of information from a would-be self-reporting volunteer who fears inadvertent self-incrimination. NASA's qualified interdisciplinary ASRS staff collect incident reports and makes the raw data available to the public for research to promote aviation safety. NASA also notes that its month data has been gradually increasing since 1981 to late 2017, Figure 8.

Figure 8. NASA's Month and Voluntary Incident Reports, from NASA (2017)

NASA notes that while the data it collects is voluntary and susceptible to an inaccurate reporting by the volunteer (pilot), its data capture and documentation methods are

rigorous. Thus, a staff member with subject matter knowledge captures the data for documentation to ensure accuracy and reliability, Figure 9. This means that if the volunteer pilot reports a PLOC incident that is attributed to loss of SA, then a staff member with qualification as a pilot who is also equipped with the requisite body of knowledge on SA is authorized to perform the function.

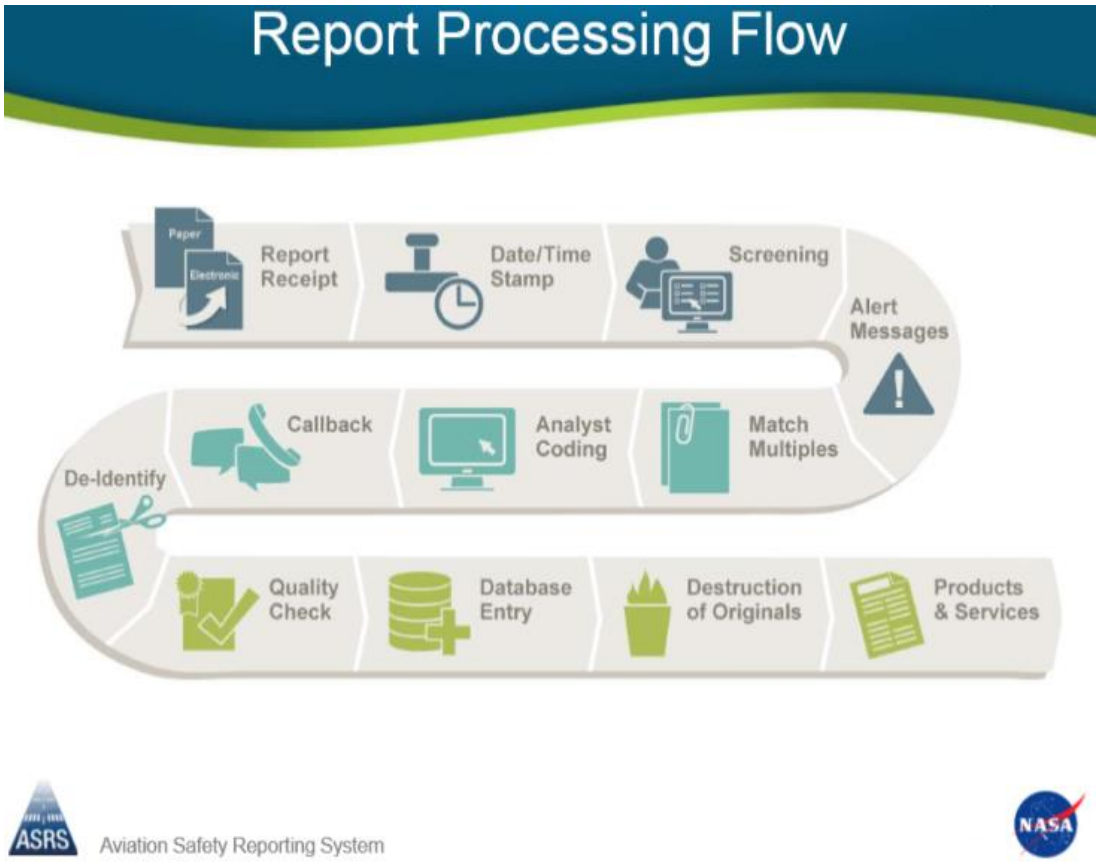
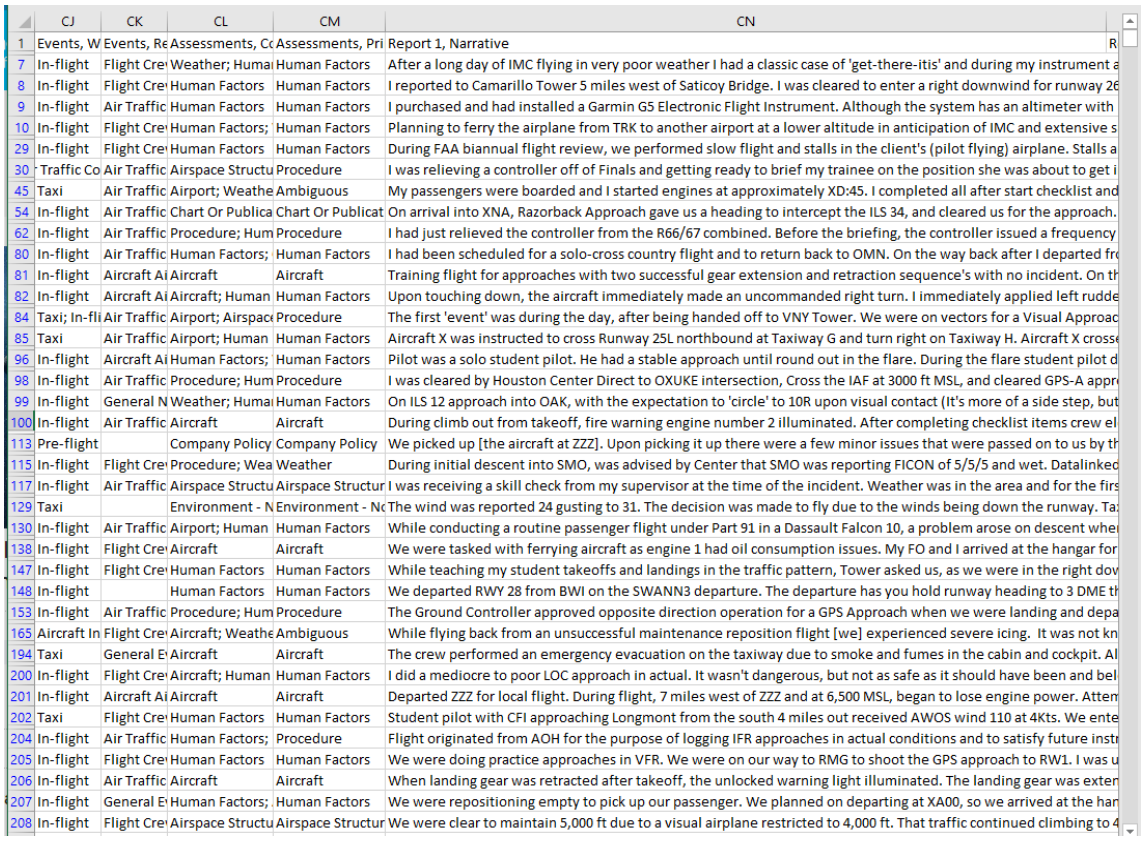


Figure 9. NASA (2017) Sequential Methodology to Document Incident Data

3.3.1 The Description of the Data

Although NASA employees a rigorous methodology to capture the ASRS data, the data itself is captured qualitatively in short narrative paragraph form downloadable as Excel comma-separated values, Figure 10. In addition to the paragraph describing the condition and configurations preceding and during the even that result in a PLOC, the

ASRS database also identified contributing factors in separate columns for each row that captures each reported incident. It is noted that ASRS database capture all aviation data and not just GA.



	CJ	CK	CL	CM	CN
1	Events, W	Events, Re	Assessments, Cc	Assessments, Pri	Report 1, Narrative
7	In-flight	Flight Cre	Weather; Humai	Human Factors	After a long day of IMC flying in very poor weather I had a classic case of 'get-there-itis' and during my instrument a
8	In-flight	Flight Cre	Human Factors	Human Factors	I reported to Camarillo Tower 5 miles west of Saticoy Bridge. I was cleared to enter a right downwind for runway 26
9	In-flight	Air Traffic	Human Factors	Human Factors	I purchased and had installed a Garmin G5 Electronic Flight Instrument. Although the system has an altimeter with
10	In-flight	Flight Cre	Human Factors;	Human Factors	Planning to ferry the airplane from TRK to another airport at a lower altitude in anticipation of IMC and extensive s
29	In-flight	Flight Cre	Human Factors	Human Factors	During FAA biannual flight review, we performed slow flight and stalls in the client's (pilot flying) airplane. Stalls a
30	Traffic Co	Air Traffic	Airspace Structu	Procedure	I was relieving a controller off of Finals and getting ready to brief my trainee on the position she was about to get i
45	Taxi	Air Traffic	Airport; Weathe	Ambiguous	My passengers were boarded and I started engines at approximately XD:45. I completed all after start checklist and
54	In-flight	Air Traffic	Chart Or Publica	Chart Or Publicat	On arrival into XNA, Razorback Approach gave us a heading to intercept the ILS 34, and cleared us for the approach.
62	In-flight	Air Traffic	Procedure; Hum	Procedure	I had just relieved the controller from the R66/67 combined. Before the briefing, the controller issued a frequency
80	In-flight	Air Traffic	Human Factors;	Human Factors	I had been scheduled for a solo-cross country flight and to return back to OMN. On the way back after I departed fr
81	In-flight	Aircraft Ai	Aircraft	Aircraft	Training flight for approaches with two successful gear extension and retraction sequence's with no incident. On th
82	In-flight	Aircraft Ai	Aircraft; Human	Human Factors	Upon touching down, the aircraft immediately made an uncommanded right turn. I immediately applied left rudde
84	Taxi; In-fli	Air Traffic	Airport; Airspac	Procedure	The first 'event' was during the day, after being handed off to VNY Tower. We were on vectors for a Visual Approac
85	Taxi	Air Traffic	Airport; Human	Human Factors	Aircraft X was instructed to cross Runway 25L northbound at Taxiway G and turn right on Taxiway H. Aircraft X cross
96	In-flight	Aircraft Ai	Human Factors;	Human Factors	Pilot was a solo student pilot. He had a stable approach until round out in the flare. During the flare student pilot d
98	In-flight	Air Traffic	Procedure; Hum	Procedure	I was cleared by Houston Center Direct to OXUKE intersection, Cross the IAF at 3000 ft MSL, and cleared GPS-A appr
99	In-flight	General N	Weather; Humai	Human Factors	On ILS 12 approach into OAK, with the expectation to 'circle' to 10R upon visual contact (It's more of a side step, but
100	In-flight	Air Traffic	Aircraft	Aircraft	During climb out from takeoff, fire warning engine number 2 illuminated. After completing checklist items crew el
113	Pre-flight		Company Policy	Company Policy	We picked up [the aircraft at ZZZ]. Upon picking it up there were a few minor issues that were passed on to us by th
115	In-flight	Flight Cre	Procedure; Wea	Weather	During initial descent into SMO, was advised by Center that SMO was reporting FICON of 5/5/5 and wet. Datalinked
117	In-flight	Air Traffic	Airspace Structu	Airspace Structur	I was receiving a skill check from my supervisor at the time of the incident. Weather was in the area and for the firs
129	Taxi		Environment - N	Environment - Nc	The wind was reported 24 gusting to 31. The decision was made to fly due to the winds being down the runway. Ta
130	In-flight	Air Traffic	Airport; Human	Human Factors	While conducting a routine passenger flight under Part 91 in a Dassault Falcon 10, a problem arose on descent whe
138	In-flight	Flight Cre	Aircraft	Aircraft	We were tasked with ferrying aircraft as engine 1 had oil consumption issues. My FO and I arrived at the hangar for
147	In-flight	Flight Cre	Human Factors	Human Factors	While teaching my student takeoffs and landings in the traffic pattern, Tower asked us, as we were in the right dov
148	In-flight		Human Factors	Human Factors	We departed RWY 28 from BWI on the SWANN3 departure. The departure has you hold runway heading to 3 DME th
153	In-flight	Air Traffic	Procedure; Hum	Procedure	The Ground Controller approved opposite direction operation for a GPS Approach when we were landing and depa
165	Aircraft In	Flight Cre	Aircraft; Weathe	Ambiguous	While flying back from an unsuccessful maintenance reposition flight [we] experienced severe icing. It was not kn
194	Taxi	General E	Aircraft	Aircraft	The crew performed an emergency evacuation on the taxiway due to smoke and fumes in the cabin and cockpit. Al
200	In-flight	Flight Cre	Aircraft; Human	Human Factors	I did a mediocre to poor LOC approach in actual. It wasn't dangerous, but not as safe as it should have been and bel
201	In-flight	Aircraft Ai	Aircraft	Aircraft	Departed ZZZ for local flight. During flight, 7 miles west of ZZZ and at 6,500 MSL, began to lose engine power. Atten
202	Taxi	Flight Cre	Human Factors	Human Factors	Student pilot with CFI approaching Longmont from the south 4 miles out received AWOS wind 110 at 4Kts. We ente
204	In-flight	Air Traffic	Human Factors;	Procedure	Flight originated from AOH for the purpose of logging IFR approaches in actual conditions and to satisfy future instr
205	In-flight	Flight Cre	Human Factors	Human Factors	We were doing practice approaches in VFR. We were on our way to RMG to shoot the GPS approach to RW1. I was u
206	In-flight	Air Traffic	Aircraft	Aircraft	When landing gear was retracted after takeoff, the unlocked warning light illuminated. The landing gear was exten
207	In-flight	General E	Human Factors;	Human Factors	We were repositioning empty to pick up our passenger. We planned on departing at XA00, so we arrived at the han
208	In-flight	Flight Cre	Airspace Structu	Airspace Structur	We were clear to maintain 5,000 ft due to a visual airplane restricted to 4,000 ft. That traffic continued climbing to 4

Figure 10 ASRS Raw Excel comma-separated values file

Each reported narrative incident was reviewed to determine whether it was a PLOC or not PLOC related. None PLOC incidents were categorize as system failures with no inputs for failings from the pilot. Reported incidents where PLOC was factor were reviewed (the captured narrative was reviewed) to determine the reported PLOC attribute. This review was performed in addition to the fact that the NASA ASRS staff also identified categories against each incident, Figure 11. The categories consisted of all the factors identified earlier in problem statement and later literature review as PLOC contributing factors.

	H	I	J	K	L	M	N
1	**Pilot Qualification**	**Pilot Experience**	**Human Factors**	**Events, Anomaly**	**Assessments, Contributing Factors**	**Assessments, Primary Problem**	**Report 1, Narrative**
11	Flight Crew Student	Flight Crew Total 70	Confusion; Distraction; Training / Qualificati on; Situational Awareness	Airspace Violation All Types; Deviation - Procedural Published Material / Policy; Deviation - Track / Heading All Types	Human Factors; Chart Or Publication	Human Factors	I had been scheduled for a solo-cross country flight and to return back to OMN. (way back after I departed from my destination I got lost on the way back to OMN didn't figure it out until I reached a city where I couldn't figure out where I was s called the Jacksonville Approach and requested to confirm my location because lost. All I heard was squawk a number and I did as requested flew near the ocea try to figure out where I was on a low altitude 1000 feet. Then I decided to call th emergency frequency but ended up calling the wrong frequency. I dialed in 120. requested help because I didn't recognize where I was and they kindly helped t me up back on my route and they gave me a number to let my instructor call the when I reach OMN and land safely. On my way back I figured that I had low fuel informed the Approach and he asked me to either land on FIN or continue to OM choose to continue. I could see Tamoka Basin from my location.Mistakes I made during the flight are the following, I flew on a wrong heading which ended me u the wrong place. I didn't figure out that I was lost earlier. I didn't have flight foll on my way back. I did not follow the lost procedure correctly. I made a very poo decision to continue flying while I am low on fuel. I ended up entering some restricted or military areas without even recognizing it.
12	Flight Crew Air Transport Pilot (ATP); Flight Crew Flight Engineer; Flight Crew Flight Instructor	Flight Crew Last 90 Days 40; Flight Crew Total 10200; Flight Crew Type 800		Aircraft Equipment Problem Critical; Ground Event / Encounter Other / Unknown	Aircraft	Aircraft	Training flight for approaches with two successful gear extension and retraction sequence's with no incident. On the third visual pattern the right gear down and locked light was not illuminated. We retracted the gear with no problems, atten to lower the gear again the same right gear light would not illuminate with gear selected down. Retracted the gear and ran the abnormal gear extension checkli returned to ZZZ. After clearance for the approach, the gear was lowered with th gear light not illuminated. Landing gear circuit breaker checked and gear down l push to test checked, again all normal. Asked the tower to confirm what we saw the cockpit the gear down in the normal position and tower confirmed that both appeared to be down. Briefed on a soft touchdown and to exit the runway and shutdown and wait for tow. Also, briefed if the gear collapsed the plan was perf the emergency engine shut down on the ground and egress out of the main cab door. The gear collapsed after the rollout and the start of taxi off the runway. Performed as briefed the emergency engine shut down and evacuation.
	Flight Crew Sea; Flight	Flight Crew Last 90 Days	Situational Awareness	Aircraft Equipment	Aircraft; Human	Human Factors	Upon touching down, the aircraft immediately made an uncommanded right tur immediately applied left rudder and brake. This halted the rotation, but my plan

Figure 11 ASRS Data with categories for each contributing factor

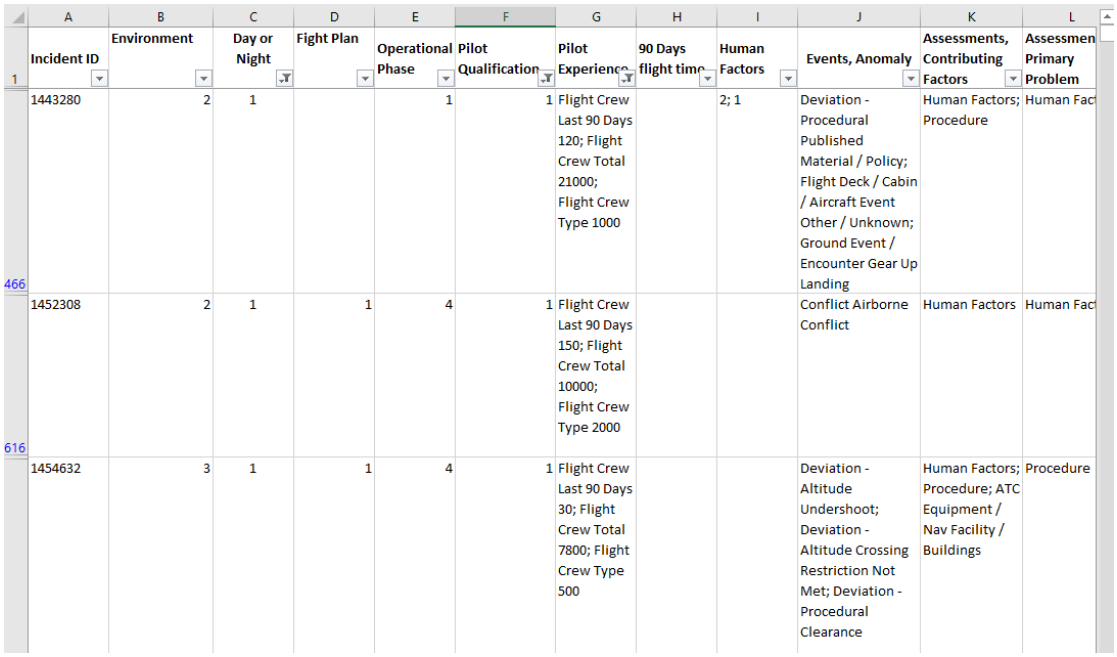
3.4 The Methodology

The research approach into this inquiry commenced with the raw incident data files downloaded from NASA's ASRS database. The data files contained qualitative description of self-reported (pilot) incidents that also contained all categories of aviation operations (airlines to GA and experimental aircraft).

After extensive analysis to qualify an incident as PLOC related or not, the narrative of those incidents where PLOC was identified as a factor also received supplemental analysis to determine how PLOC was contributing factor. The literature review, given its rendered definitions on the factors alleged to contribute to PLOC, functioned as the basis to definitively assign a PLOC incident as either SA, weather, pilot distraction, pilot

deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface, and workload or a combination thereof.

An attempt was made to determine if other factors such as pilot experience as measured within the preceding 90 days also determine the likelihood of a PLOC in contrast total flight time which the standard metric use document a pilot's qualification in addition any specialized ratings, Figure 12.



	A	B	C	D	E	F	G	H	I	J	K	L
1	Incident ID	Environment	Day or Night	Fight Plan	Operational Phase	Pilot Qualification	Pilot Experience	90 Days flight time	Human Factors	Events, Anomaly	Assessments, Contributing Factors	Assessmen Primary Problem
466	1443280	2	1		1	1	Flight Crew Last 90 Days 120; Flight Crew Total 21000; Flight Crew Type 1000		2; 1	Deviation - Procedural Published Material / Policy; Flight Deck / Cabin / Aircraft Event Other / Unknown; Ground Event / Encounter Gear Up Landing	Human Factors; Procedure	Human Fac
616	1452308	2	1	1	4	1	Flight Crew Last 90 Days 150; Flight Crew Total 10000; Flight Crew Type 2000			Conflict Airborne Conflict	Human Factors	Human Fac
	1454632	3	1	1	4	1	Flight Crew Last 90 Days 30; Flight Crew Total 7800; Flight Crew Type 500			Deviation - Altitude Undershoot; Deviation - Altitude Crossing Restriction Not Met; Deviation - Procedural Clearance	Human Factors; Procedure; ATC Equipment / Nav Facility / Buildings	Procedure

Figure 12. Pilot flight experience within the preceding 90 days

3.4.1 The Methods

Because of the structure of the sample dataset for this inquiry, Binary Logistic Regression (BLR) to estimate the probability of a binary response based on one or more predictor variable and Probabilistic Risk Assessment (PRA) to evaluate the effectiveness of PLOC mitigation controls were determined to be the most suitable methods. Before the sample dataset is presented herein, contextual descriptions for the aforementioned methods are requisite.

3.4.1.1 Binary Logistic Regression

Boslaugh (2013) asserts that logistic regression is statistical methodology that is used to predict the relationship between the predictors (in this case the NTSB and Other contributing factors) and the predicted event (PLOC). Binary is added to this logistic regression methodology to signify the binary nature of the dichotomous variable outcome of either a "Yes = 1" and a "No =0." The statistical software, Minitab ® 18 was used to perform the BLR for the estimation binary response on one or more predictor variables based the following equation: P (1) =exp(Y')/(1 + exp(Y')). In case of (NTSB predictors),

Y' = -1.402 + 1.511 Weather; Y=1, N=0 + 2.178 Situational Awareness; Y=1, N=0
+ 1.466 Pilot Distraction; Y=1, N=0

It is noted that while this equation will be repeatedly used for H1, H2 and H3, the Y' values will be specific to each to hypothesis.

Results from a BLR analysis while using the Minitab ® 18 statistical software, produce a model summary as noted in Figure 6., of the subsequent chapter. This model summary features the Akaike Information Criterion (AIC), R-Squared, and the Adjusted R-Squared. Osborne (2015) notes that AIC is calculated "as AIC = -2 Log Likelihood +2((k – 1) + s) where k is the number of levels of the dependent variables and s is the number of the predictors in the model. Osborne asserts that a model with the smallest AIC numerical value is considered best fit in prediction. Thus, the PLOC prediction model with the smallest AIC is a stronger predictor and by default recommended for PLOC forensic accident and incident investigations and analyses.

R-Squared also known as the coefficient of determination (Boslaugh), is the statistical measurement of predictors variables relative to a fitted regression line. R-Squared is essentially the strength and direction of a linear relationship between variables. While

adjusted R-Squared performs the same function as the normal R-Squared, the adjusted R-Squared accounts for the response variables in the prediction model. Thus, adjusted R-Squared assesses if the number of predictors in a regression model have better prediction power. The equation for adjusted R-Squared is noted as follows:

Adj. R-Sq = 1- (1-R^2) (N-1)/N-p-1;

A deviance table such as the one referenced in Figure 3., indicates if a PLOC predictor has a statistically significant relation with the response variable. This means that the noted P-Value associated with loss of SA as noted in the referenced Figure 3., is statistically significant, given its P-Value of .0. A predictor with a P-Value of greater than alpha = .0.5 is not as strong as a predictor with alpha is ≤ 0.05.

3.4.1.1 Probabilistic Risk Assessment

Modarres et al (2017) described PRA as the systematic methodology to investigate the ways in which complex systems are built and operated. The trio assert that PRA invokes the estimation of the probability of loss. They narrowed the application of PRA to following three takeaways: 1- the scenario regarding what can go wrong, 2- the likelihood of the occurrence and 3- the consequence of the occurrence. Three adjudicated accidents are selected as case studies and evaluated using referenced PRA.

3.4.2 Data Sample

Following extensive analysis, the ASRS incident data was significant restructured into usable quantitative form. New spreadsheet cells were created to indicate a binary status of an incident "1" for PLOC and "0" for no PLOC. Subsequent cells also depicted a "1" if an identified and allege PLOC factor was a contributor or "0" no contribution to

LOC. Figure 13. depicts the final format and structure of the data to be use for analysis in this Praxis.

	A	B	C	D	E	F	G	H	I	J	K	L
1		NTSB PLOC Predictors				Praxis Based Other PLOC Predictors						
2	Incident ID	Weather; Y=1, N=0	Situational Awareness; Y=1, N=0	Pilot Distraction; Y=1, N=0	PLOC = 1, no PLOC = 0	Pilot Deviation from established procedures; Y=1, N=0	Communication Breakdown; Y=1, N=0	Pilot Experience Total Flight Time	Pilot Experience within 90 Days	Human Machine Interface Issues; Y=1, N=0	Confusion; Y=1, N=0	Workload; Y=1, N=0
3	1140002	1	0	0	1	1	1	6500	150	1	0	0
4	1140015	0	0	0	0	0	0	270	20.6	0	0	0
5	1140020	0	0	0	0	0	0	860	7	0	0	0
6	1140870	0	0	1	0	0	0	730	200	0	1	0
7	1141959	1	1	1	1	1	1	375	30	0	0	0
8	1142542	0	1	0	1	1	0	450	80	0	1	1
9	1142545	1	0	0	0	0	0	2500	30	0	0	0
10	1143900	0	0	0	1	0	0	12500	75	1	0	1
11	1143924	1	1	0	1	1	0	1559	90.2	1	0	0
12	1143927	0	1	0	1	1	0	7130	15	0	0	0
13	1143941	0	0	0	0	0	0	4956	100	0	0	0
14	1143958	0	0	0	1	0	0	31838	41	1	0	0
15	1143989	0	1	0	0	0	0	557	30	0	0	0
16	1143993	1	1	0	1	1	0	630	30	0	0	0
17	1144545	1	0	0	1	1	0	13000	120	1	1	0
18	1144763	1	1	0	1	1	1	5500	35	1	1	0
19	1144785	0	1	0	1	0	0	107.7	0.9	1	1	0
20	1145322	0	1	1	1	0	1	20000	50	0	1	1
21	1145329	0	0	0	1	1	1	1060	140	0	0	0
22	1145333	0	0	0	0	0	0	2900	25	0	0	0
23	1145340	1	1	1	1	1	1	602	65	0	1	1
24	1145401	0	1	0	1	1	0	233.3	30.1	0	0	0
25	1145792	0	0	0	0	0	0	10000	20	0	0	0
26	1145807	0	1	0	0	0	0	15200	20	0	0	1
27	1145821	1	1	0	1	1	0	7500	75	0	1	0
28	1146047	0	0	0	0	0	0	3250	45	0	0	0
29	1146055	0	1	0	0	0	0	2000	30	0	0	0
30	1146341	0	0	0	0	0	0	8300	80	0	0	0
31	1146345	0	0	0	0	0	0	1000	10	0	0	0
32	1146357	1	0	1	1	1	0	1018	57	1	1	1
33	1146369	0	1	0	0	0	0	161.2	13.8	0	0	0
34	1147193	1	0	1	1	1	0	8000	60	1	0	0
35	1147226	0	1	0	1	1	0	4700	20	0	0	0
36	1147534	1	0	0	0	1	0	8400	200	0	0	0
37	1147544	0	0	1	1	1	1	5700	20	1	0	0
38	1147550	0	0	0	0	0	0	3000	10	0	0	0
39	1148167	0	0	0	0	1	0	1300	20	0	0	0
40	1148186	0	1	0	0	0	0	3400	100	0	0	0
41	1148188	1	0	0	0	1	0	9500	50	0	0	0
42	1148730	1	1	0	1	1	0	1300	150	0	0	0
43	1148747	1	1	0	1	1	1	440	40	0	1	0
44	1149038	1	1	0	1	1	0	4100	77	0	0	0
45	1149043	0	0	0	0	0	0	9000	40	0	0	0
46	1149376	0	0	0	1	0	1	5000	250	0	1	0
47	1149625	1	0	0	0	0	0	6200	75	0	1	0
48	1149636	0	1	0	1	0	1	560	45	0	1	1
49	1149850	0	1	0	0	0	0	843	60.1	0	0	0
50	1149863	0	0	0	0	0	0	4800	100	0	1	1
51	1149869	0	1	0	1	1	0	7500	30	0	0	1
52	1149873	0	1	0	0	0	0	8175	85	1	0	0
53	1150669	0	0	0	0	0	0	1600	250	0	1	1
54	1150688	0	0	1	0	0	1	5800	100	1	1	1
55	1150726	0	1	1	1	1	1	1335	28	0	1	0
56	1150777	0	1	0	1	1	1	389.3	7.6	0	1	0
57	1150811	1	1	0	1	1	0	14000	30	1	1	1
58	1151031	0	1	0	1	1	1	11000	100	0	1	1
59	1151238	1	0	0	1	1	1	142.7	38.4	0	0	0
60	1151239	1	1	0	1	1	0	2500	85	0	0	0
61	1151240	0	0	0	1	0	0	87	14.2	1	0	0
62	1151243	0	0	1	1	1	1	1250	50	0	1	1
63	1151260	1	0	0	0	0	1	3000	60	0	0	0
64	1151266	0	1	0	1	1	0	4608.7	46.8	0	0	0
65	1151283	0	1	0	1	1	0	802	15	0	0	0
66	1151568	0	1	0	0	0	0	1080	10	0	1	0
67	1151591	0	0	1	0	1	1	9900	180	0	1	0
68	1151604	0	0	0	0	0	0	1135	14.6	1	0	1
69	1152224	0	1	0	1	1	0	1600	60	0	0	0
70	1152259	0	0	0	0	1	0	1605	255	1	0	0
71	1152262	0	0	0	1	0	1	282	57	0	1	0
72	1152265	0	1	0	1	1	0	12000	175	0	1	0
73	1152315	0	0	0	0	0	0	4000	15	1	0	0
74	1152834	0	0	0	0	0	0	15753	93	1	0	0
75	1485667	0	1	0	1	1	0	180	10	0	0	0

Figure 13. Structured ASRS data as used to develop the case for PLOC

Chapter 4—Results

4.1 Introduction

The goal of this Praxis was and remains a response to the formal NTSB petition for the prevention of PLOC in GA. According to the NTSB, PLOC accounts for 48% of all GA accidents. While the NTSB attributes PLOC to loss of SA, weather, and pilot distraction, this Praxis alleges that there are other attributes in addition to those identified by the NTSB that also contributed to PLOC. The alleged contributing factors to PLOC as suggested by this Praxis include: pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface and workload.

The literature review attempted to provide formal definitions for the factors attributed to PLOC, both NTSB and alleged. In addition to definitions, the literature review also tried to underscore how both factors (NTSB and alleged) could contribute to PLOC. Incident data was retrieved from the NASA controlled and maintained ASRS database in attempt to establish a comprehensive list of factors that contribute to PLOC in order to build a stronger case in support of the NTSB petition. Although ASRS database is vast and comprehensive, the data contain therein is qualitative and impractical for use. An attempt was made to structure the data into quantitative form for the requisite statistical analysis. In essence, and based on the narrative within each self-reported incident, a decision criterion under the auspices of the descriptions in the literature review to assign a PLOC attribute. It is noted that the assigning of PLOC attributes to each self-reported incident was in supplement of NASA's attribute allocation for each incident. The final structured data is in binary form such that each reported incident is assigned a "1" for

PLOC and a “0” for no PLOC. Similarly, a “1” is assigned if a particular attribute is associated with the incident and a “0” for no attribute association.

This chapter presents the results of the analysis performed on the newly structured ASRS data (PLOC and no PLOC). Given the binary structure of the data, Binary Logistic Regression to estimate the probability of a binary response based on one or more predictor variables was determined as most suitable for three of the hypotheses. It is noted that a total of three hypotheses were formulated to evaluate the accuracy and comprehensiveness of the factors attributed to PLOC and a fourth hypothesis to determine if a pre-emptive application of PLOC prevention controls against contributing factors will reduce the likelihood of a PLOC. The four hypotheses are:

H1: The NTSB identified PLOC contributing factors (loss of SA, weather, and pilot distraction) are predictors of PLOC.

H2: Other factors not currently considered by the NTSB (pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface, and workload) are better predictors of PLOC than those identified by the NTSB.

H3: Combination of contributing factors (factors from the NTSB and the other contributing factors) are stronger PLOC predictors than in H1 and H2.

H4: Pre-emptive application of PLOC prevention controls against contributing factors will reduce the likelihood of a PLOC occurrence.

Given the preceding context, this chapter is structured to proceed in the following sequence: First, present the statistical analysis results associate with hypotheses one through 3, and include any respective PLOC predictor model and the model’s accuracy.

Second, discuss how PLOC can be prevented in response to the fourth hypothesis and provide evidence on how the application of pre-emptive application of mitigation controls will reduce the likelihood of a PLOC incident or accident. Finally, close the discussion by introducing a pilot checklist that can be used by a GA pilot control the occurrence of a PLOC incident or accident.

4.2 Hypothesis one

The goal of this hypothesis is to the determine if the NTSB identified PLOC contributing factors (loss of SA, weather, and pilot distraction) can predict PLOC in GA.

H1: Loss of SA, weather, and pilot distraction are predictors of PLOC.

A sample size of 73 randomly selected incidents from the NASA controlled ASRS is being used to determine the predictive capabilities of: loss of SA, weather, and pilot distraction. It is noted that while the ASRS database dates to 1981, the sample incidents selected for the Praxis are from 2018. The rationale to use present day data rather than significantly older incident data is to ensure that any potential PLOC prevention strategies will actually be applicable to present day PLOC problems.

Given the binary nature of the structured dataset form the ASRS database, BLR to estimate the probability of a binary response based on one or more predictor variables (in this case, three predictors) is suited for this statistical analysis. The statistical software Minitab ®18 is used for this analysis with the methodology “Link Function Logic” and the results are captured in Figure 14. These results are based on the following Regression Equation:

$$P(1) = \exp(Y')/(1 + \exp(Y'))$$

Y' = -1.402 + 1.511 Weather; Y=1, N=0 + 2.178 Situational Awareness; Y=1, N=0

+ 1.466 Pilot Distraction; Y=1, N=0

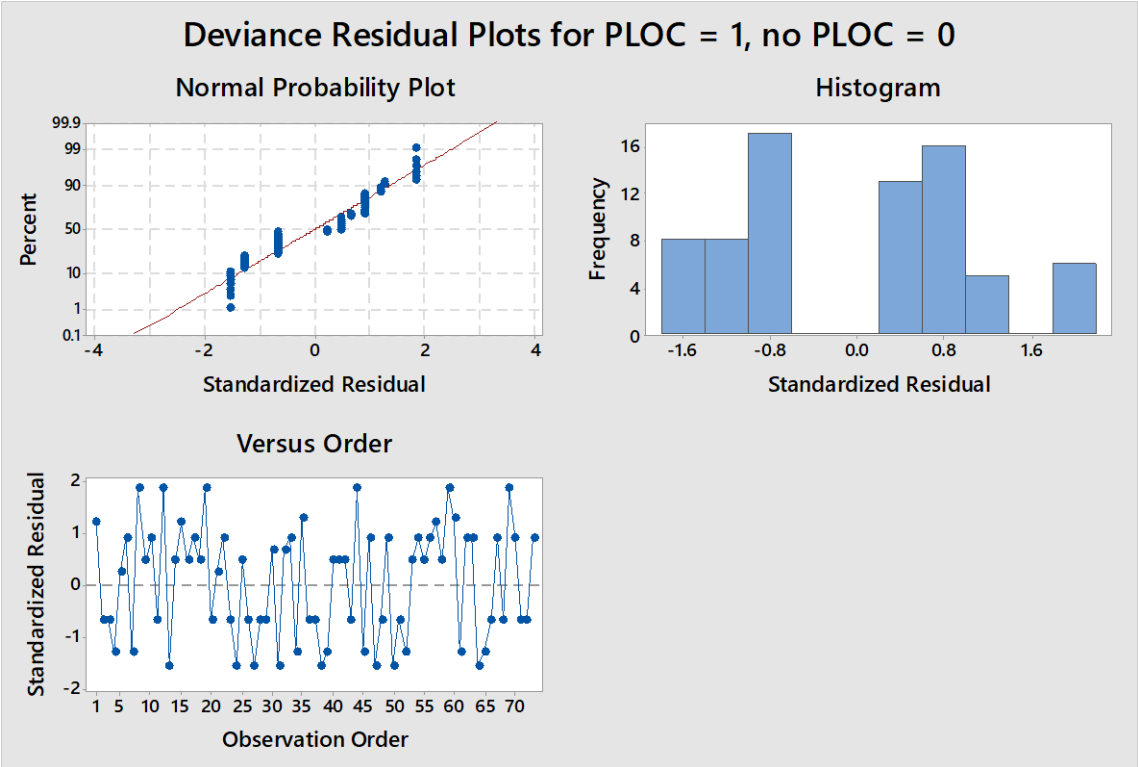


Figure 14. NTSB Deviance Residual Plots for PLOC =1, No PLOC = 0

The variables for the response information in this regression analysis is distributed as 40 incidents identified as PLOC and 33 incidents identified a s none PLOC for the total count of 73 incidents. While these variables differ in ratio when compared to the NTSB assertion that PLOC accounted for 48% of all accidents, it speculated that the apparent skewing of the results in favor of PLOC accidents is due to chance in the randomness of selection of data from the ASRS. Table 3 denotes the Deviance for the NTSB PLOC predictors.

Table 3 Deviance Table for NTSB Predictors

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	3	23.185	7.728	23.18	0.000
Weather; Y=1, N=0	1	5.679	5.679	5.68	0.017
Situational Awareness; Y=1, N=0	1	16.028	16.028	16.03	0.000
Pilot Distraction; Y=1, N=0	1	3.289	3.289	3.29	0.070
Error	69	77.343	1.121		
Total	72	100.527			

Table 4. depicts the results of attempts to detect the possibility of multicollinearity or Variance Inflation Factors (VIFs) in the logistic regression analysis for the NTSB PLOC prediction model.

Table 4 Coefficients for and VIFs for NTSB Attributes to PLOC

Term	Coef	SE Coef	VIF
Constant	-1.402	0.475	
Weather; Y=1, N=0	1.511	0.672	1.06
Situational Awareness; Y=1, N=0	2.178	0.595	1.13
Pilot Distraction; Y=1, N=0	1.466	0.845	1.08

Table 5. depicts the results of an attempt to discern the discrepancy between the observed values and the expected values also known as the “Goodness-of-Fit Test.

Table 5 Goodness-of-Fit Test

Test	DF	Chi-Square	P-Value
Deviance	69	77.34	0.230
Pearson	69	67.31	0.535
Hosmer-Lemeshow	3	3.39	0.335

Table 6 (Model Summary) depicts the results for the AIC. It is reiterated that AIC is calculated “as AIC = -2 Log Likelihood +2((k – 1) + s) where k is the number of levels of the dependent variables and s is the number of the predictors in the model.”

Table 6 Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
23.06%	20.08%	85.34

R-Sq is the percentage of variation in the response that is explained by the variation of the predictors. It is calculated as 1 – (the ratio of the error sum of squares) which is the variation that is not explained by model)) to the total sum of squares (which is the total variation in the model). R-Sq(adj) is the percentage of the variation in the response that is explained by the model, adjusted for the number of predictors in the model relative to the number of observations. R-Sq(adj) is calculated as 1 – (the ratio of the mean square error (MSE) to the mean square total (MS Total)).

An attempt to determine the accuracy of the NTSB PLOC attributes (loss of SA, weather, and pilot distraction) as a PLOC event predictor, Table 7. It is noted that using 73 ASRS incidents, the NTSB PLOC predictions as a model has an accuracy rating of 63%.

Table 7 NTSB PLOC Predictor Model

NTSB PLOC Prediction Model Accuracy	
Threshold Probality	0.85
Total Sample	73
Error	27
Accuracy of Model	63%

H1: Loss of SA, weather, and pilot distraction are predictors of PLOC. As a PLOC prediction model with an accuracy of 63%, it's use as a PLOC predictor should only be a last resort if other stronger predictors are not available.

4.3 Hypothesis two

The goal of this hypothesis is to the determine if the "Other" proposed PLOC contributing factors (pilot deviation from established procedures, pilot experience, communication breakdown, confusion, human-machine interface, and workload) are better fit in predicting PLOC in GA.

> **H2**: Pilot deviation from established procedures, pilot experience within the 90 days, communication breakdown, confusion, human-machine interface, and workload are better predictors of PLOC than the NTSB.

The same 73 incident data sample used for H1 is also used to determine the predictive capabilities of pilot deviation from established procedures, pilot experience within 90 days, communication breakdown, confusion, human-machine interface, and workload. The reason to use the same data is to enable the comparison of both PLOC prediction models (NTSB and Other) and determine their accuracies against one another. It is noted that the same 73 incident data sample will also be used for H3.

Given the binary nature of the structured dataset form the ASRS database, BLR to estimate the probability of a binary response based on one or more predictor variables (in this case, four predictors) is suited for this statistical analysis. The statistical software Minitab ®18 is also used for this analysis with the methodology "Link Function Logic" and the results are captured in Figure 15. This analysis reduced the PLOC contributing factors for H2 from six to four significant contributing factors with P-Values of less than 0.05. The excluded factors, confusion and workload removes least significant factors and resolves potential collinearity issues as evidenced by VIFs that are lower than 5. The updated PLOC contributing factors for H2 consists of the: Pilot deviation from

established procedures, pilot experience within the 90 days, communication breakdown, and human-machine interface. Given the updates on H2, the updated H2 is captured as follows:

> **New H2**: Pilot deviation from established procedures, pilot experience within 90 days, communication breakdown, and human-machine interface are better at predicting PLOC than the NTSB predictors.

These results are based on the following Regression Equation:

P(1) = exp(Y')/(1 + exp(Y'))

Y' = -1.766 + 3.968 Pilot Deviation from establishe - 0.01333 Pilot Experience within 90 Days + 1.706 Human Machine Interface Issues; + 2.80 Communication Breakdown; Y=1, N

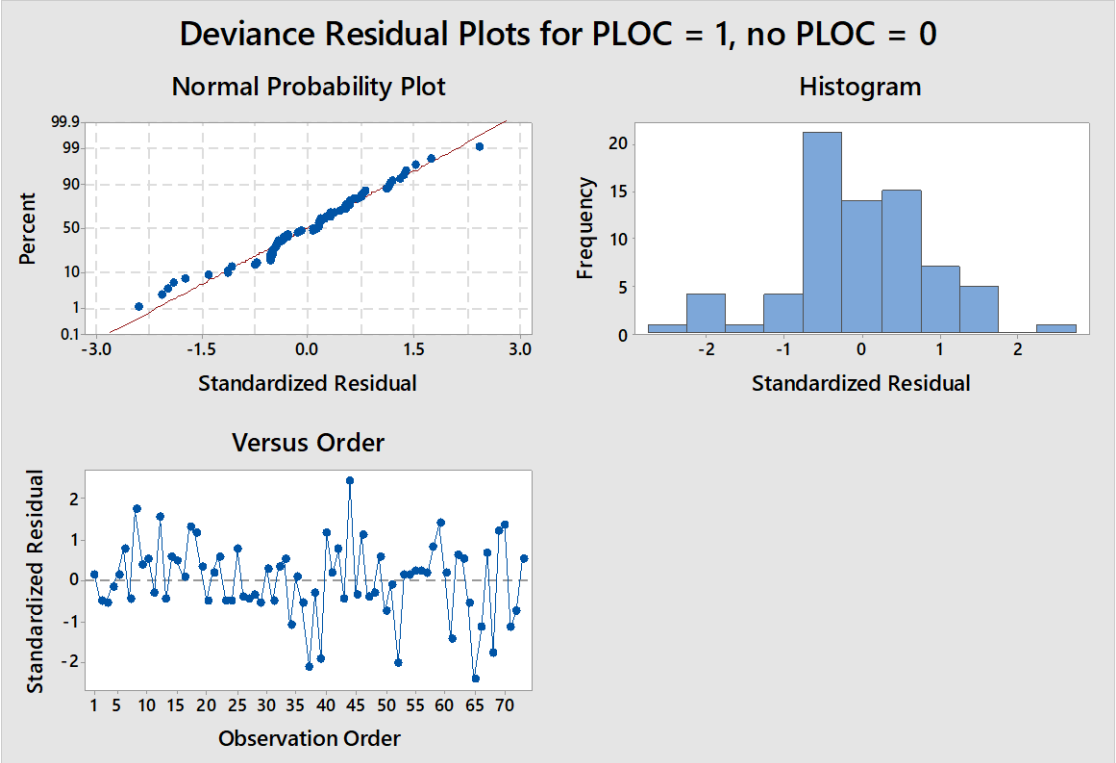


Figure 15. Other Deviance Residual Plots for PLOC =1, No PLOC = 0

It is reiterated that the variables for the response information in this regression analysis is distributed as 40 incidents identified as PLOC and 33 incidents identified a s none PLOC for the total count of 73 incidents. Table 8 denotes the Deviance for the Other PLOC predictors.

Table 8 Deviance Table for Other PLOC Predictors

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	4	47.968	11.9920	47.97	0.000
Pilot Deviation from establishe	1	35.116	35.1158	35.12	0.000
Pilot Experience within 90 Days	1	4.795	4.7952	4.80	0.029
Human Machine Interface Issues;	1	4.468	4.4682	4.47	0.035
Communication Breakdown; Y=1, N	1	9.674	9.6736	9.67	0.002
Error	68	52.559	0.7729		
Total	72	100.527			

Table 9. depicts the results of attempts to detect the possibility of multicollinearity / VIFs in the logistic regression analysis for the “Other” PLOC prediction model.

Table 9. Coefficients for and VIFs using Other PLOC Attributes

Term	Coef	SE Coef	VIF
Constant	-1.766	0.680	
Pilot Deviation from establishe	3.968	0.891	1.59
Pilot Experience within 90 Days	-0.01333	0.00651	1.31
Human Machine Interface Issues;	1.706	0.853	1.24
Communication Breakdown; Y=1, N	2.80	1.03	1.25

Table 10. depicts the results of attempts to discern the discrepancy between observed values and the expected values (Goodness-of-Fit Test).

Table 10. Goodness-of-Fit Test

Test	DF	Chi-Square	P-Value
Deviance	68	52.56	0.916
Pearson	68	61.31	0.704
Hosmer-Lemeshow	8	6.33	0.610

Table 11 (Model Summary) depicts the results for AIC. It is reiterated that AIC is calculated "as AIC = -2 Log Likelihood +2((k – 1) + s) where k is the number of levels of the dependent variables and s is the number of the predictors in the model."

Table 11. Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
47.72%	43.74%	62.56

It is noted that the R-Sq(adj) increased from 20.08% in H1, to 43.74% and the AIC decreased from 85.34, for H1, to 62.56, for H2 indicates that H2 is a better model. An attempt to determine the accuracy of the "Other" PLOC attributes (pilot deviation from established procedures, pilot experience, communication breakdown, and human-machine interface) as a PLOC event predictor. It is noted that using 73 ASRS incidents, the "Other" PLOC predictions as a model has an accuracy rating of 75%.

Table 12. Other Factors PLOC Predictor Model

Other PLOC Prediction Model Accuracy	
Threshold Probality	0.85
Total Sample	73
Error	18
Accuracy of Model	75%

The new H2: Pilot deviation from established procedures, pilot experience within 90 days, communication breakdown, and human-machine interface are predictors of PLOC. As a PLOC prediction model with an accuracy of 75% it is superior to H1 as a PLOC predictor as it has more prediction strength (higher accuracy, higher RSq Adj, and lower AIC).

4.3 Hypothesis three

The goal of this hypothesis is to the determine if the combined NTSB and the "Other" proposed PLOC contributing factors are stronger predictors of PLOC occurrences in GA.

> **H3**: Loss of SA, weather, pilot distraction, pilot deviation from established procedures, pilot experience within the 90 days, communication breakdown, confusion, human-machine interface, and workload are stronger predictors of PLOC occurrences in GA.

The same 73 incident data sample used for H1 and H2 is also used to determine the predictive capabilities of the combined PLOC prediction model. The analysis excluded PLOC predictors removes least significant factors and resolves potential collinearity in the updated (combined, NTSB and "Other") PLOC prediction model. The updated contributing factors for a new H3 consists of: Loss of SA, pilot deviation from established procedures, communication breakdown, and human machine interface. Given the updates on H3, the updated H3 is captured as follows:

> **New H3**: Loss of SA, pilot deviation from established procedures, communication breakdown, and human-machine interface are stronger predictors of PLOC occurrences in GA.

Given the binary nature of the structured dataset form the ASRS database, BLR to estimate the probability of a binary response based on one or more predictor variables (in this case, four predictors) is suited for this statistical analysis. The statistical software Minitab ®18 is also used for this analysis with the methodology "Link Function Logic" and the results are captured in Figure 16. These results are based on the following Regression Equation:

$$P(1) = \exp(Y')/(1 + \exp(Y'))$$

Y' = -4.09 + 2.843 Situational Awareness; Y=1, N=0 + 3.208 Pilot Deviation from establishe

+ 3.15 Communication Breakdown; Y=1, N + 2.66 Human Machine Interface Issues;

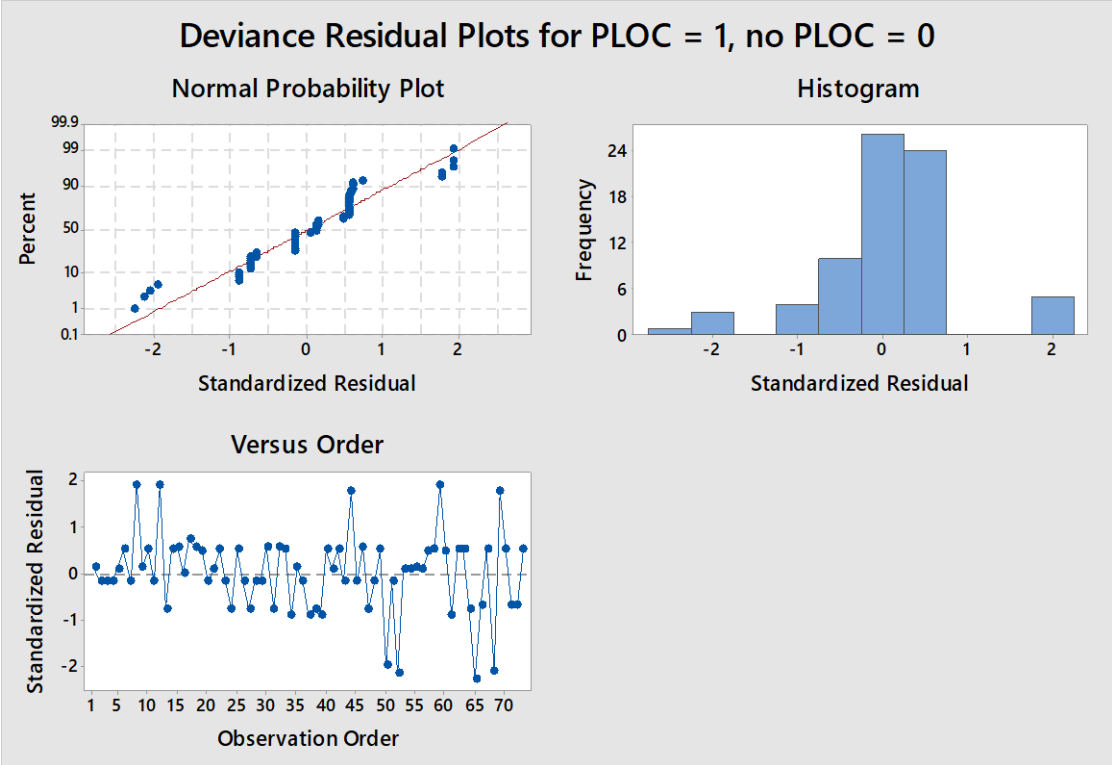


Figure 16 Deviance Residual Plots for PLOC =1, No PLOC = 0

Table 13. denotes the Deviance for the combined NTSB and "Other" PLOC predictors

Table 13. Deviance Table for Other PLOC Predictors

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	4	55.279	13.8197	55.28	0.000
Situational Awareness; Y=1, N=0	1	12.106	12.1060	12.11	0.001
Pilot Deviation from establishe	1	20.844	20.8443	20.84	0.000
Communication Breakdown; Y=1, N	1	11.218	11.2178	11.22	0.001
Human Machine Interface Issues;	1	8.318	8.3183	8.32	0.004
Error	68	45.249	0.6654		
Total	72	100.527			

Table 14. depicts the results of attempts to detect the possibility of multicollinearity / VIFs in the logistic regression analysis for the combined NTSB and "Other" PLOC predictors.

Table 14. Coefficients for and VIFs using Other PLOC Attributes

Term	Coef	SE Coef	VIF
Constant	-4.09	1.06	
Situational Awareness; Y=1, N=0	2.843	0.944	1.52
Pilot Deviation from establishe	3.208	0.822	1.14
Communication Breakdown; Y=1, N	3.15	1.13	1.38
Human Machine Interface Issues;	2.66	1.06	1.54

Table 15. depicts the results of attempts to discern the discrepancy between observed values and the expected values (Goodness-of-Fit Test).

Table 15. Goodness-of-Fit Test

Test	DF	Chi-Square	P-Value
Deviance	68	45.25	0.985
Pearson	68	51.05	0.938
Hosmer-Lemeshow	5	4.58	0.469

Table 16. (Model Summary) depicts the results for AIC in reference to the new H3.

Table 16. Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
54.99%	51.01%	55.25

Figure 17. depicts the normal probability plot for the combined NTSB and "Other" PLOC prediction model given a confidence interval of 95%. While there is a minor departure from normality, a test for accuracy of the model will be performed to ensure its viability (Table 17.).

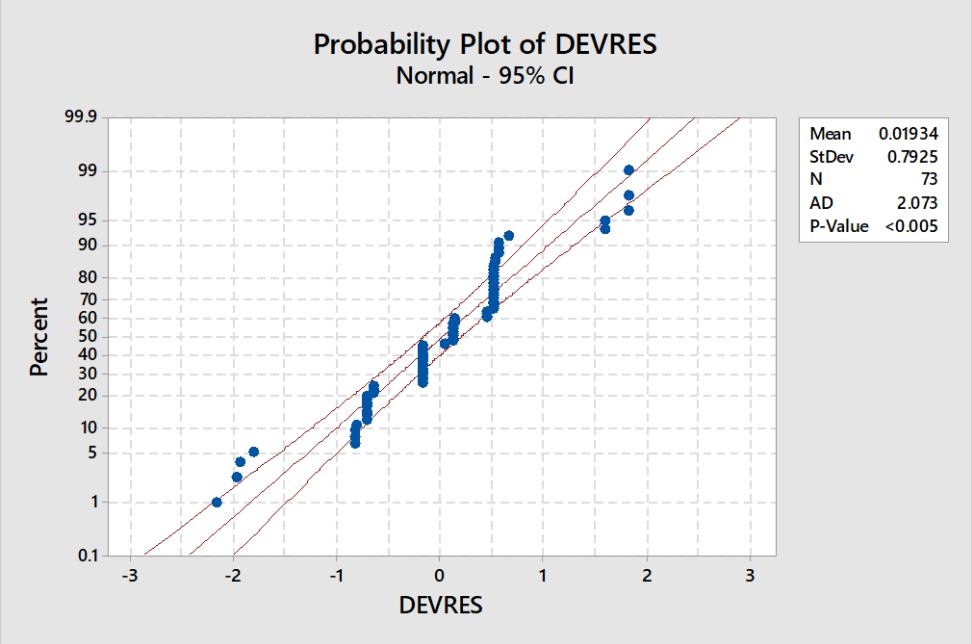


Figure 17. Normal Distribution of Residuals for combined NTSB and Other Predictor of PLOC using P-Value <0.005

An attempt to determine the accuracy of the combined NTSB and the "Other" PLOC attributes as a PLOC event predictor is captured in Table 17.

Table 17 Combined NTSB and Other Factors PLOC Predictor Model

Combined PLOC Prediction Model	
Threshold Probability	0.85
Total Sample	73
Error	8
Accuracy of Model	89%

The new H3: Loss of SA, pilot deviation from established procedures, communication breakdown, and human-machine interface are predictors of PLOC. As a PLOC prediction model with an accuracy of 89%, higher R-Sq(adj), and lower AIC, it is a stronger alternative to both H1 and new H2 as a PLOC predictor model.

4.4 Hypothesis four

The goal of this hypothesis is to determine if a pre-emptive application of PLOC prevention controls against contributing factors will reduce the likelihood of a PLOC occurrence (event). Based on the results of the new H3 and its PLOC prediction accuracy of 89%, it posited that loss of SA can be mitigated by the retention of situation awareness once it is acquired as discussed in the literature review (Chapter 2). Naturally, deviation from established procedures can be mitigated by adherence to established procedures, Human Machine Interface issues can be mitigated with management of the functions that are allocated to each interface for each flight operation, communication breakdown can be prevented by communication conformance forcing functions. Figure 18. depicts the undesired PLOC event and application of mitigation controls for each of contributing factors.

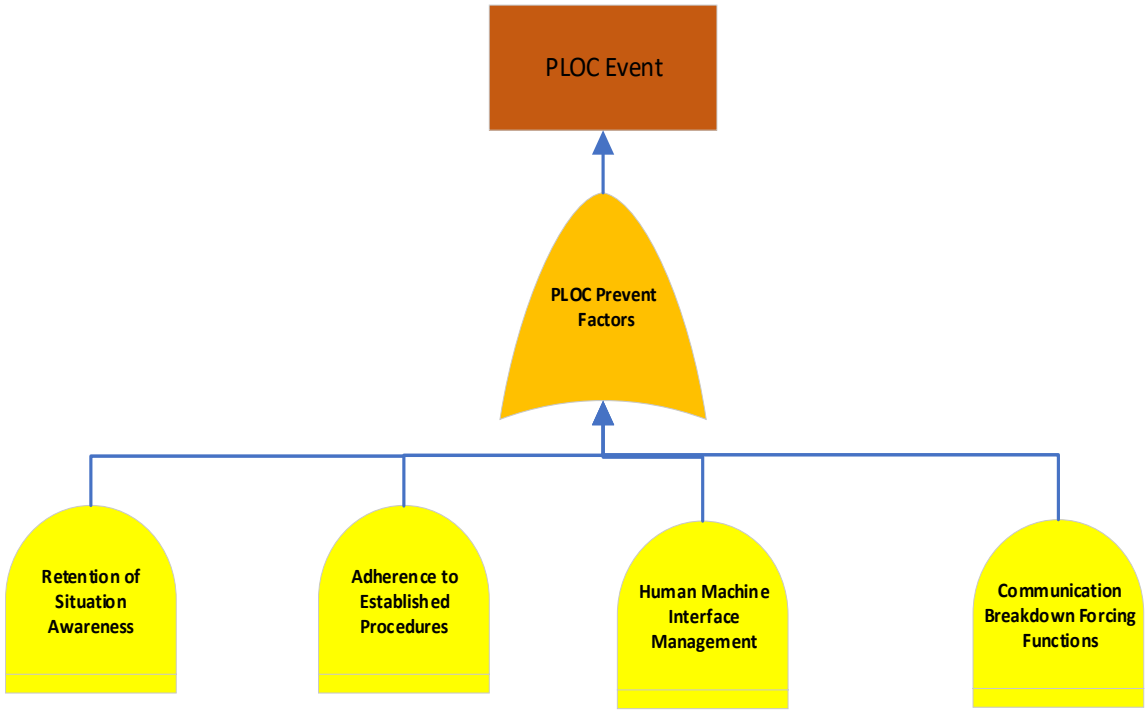


Figure 18 PLOC prevention Factors

It is noted that the target pilot population (GA) will incur minimal financial costs in the implementation of the PLOC prevention controls depicted in Figure 18. Since the literature review provided more comprehensive insights regarding the intricacies associated with each PLOC, the PLOC prevention factors are only briefly discussed.

4.4.1 Retention of Situation Awareness

Given that the PLOC prediction model from the new H3 identified loss of SA as contributing factor to a PLOC event, H4 asserts that retention of situation awareness corrects the problem. As discussed in the literature review, the FAA describe loss of SA as "the result of a pilot not knowing where he or she is, an inability to recognize deteriorating circumstances, and the misjudgement of the rate of deterioration." Thus, loss of SA is a function of forgetting curve ((FC) Chapter 2). FC is increases with time without reinforcement. This means that recurring learning is required at a frequent interval. Figure 19. depicts the factors necessary for the retention of SA.

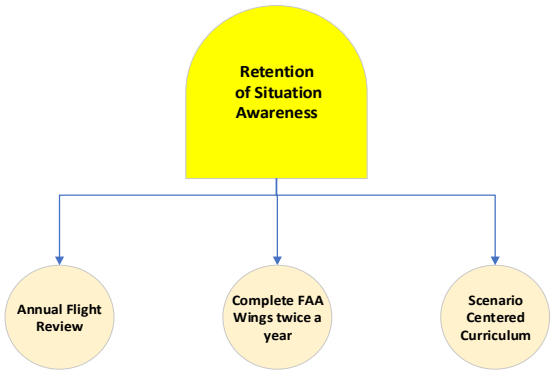


Figure 19. Mitigation of Loss of Situational Awareness through Retention

4.4.1.1 Annual Flight Review

Pilots and flight instructors are required by the FAA (CFR section 61.56) to complete a biennial flight review. The current FAA policy regarding the certification of pilots and instructors stipulates that a "flight review consists of a minimum of 1 hour of flight

training and 1 hour of ground training." Since the focus of the flight review is to reinforce knowledge for a pilot remain competent to exercise the privilege of a pilot certificate or licensure, an annual as opposed to biennial flight review mitigates FC (FC is a function of time) which contributes to deterioration of knowledge. This argument is congruent with FAA studies on aeronautical knowledge retention. In the study (FAA-H-8083A, 2008), the FAA concluded that the granularity of a pilot's recollection of learned information since a flight review is related to the number of months since a pilot's last flight review. Thus, 24 months to a pilot's next flight review exposes the pilot knowledge to decay and ultimately loss competence.

4.4.1.2 Complete two FAA WINGS Programs

According to FAA advisory circular AC 61-91J (2011), the objective of the WINGS program is to reduce the number of accidents in GA by providing pilots educational opportunities. The WINGS program encourages an on-going training program that provides a pilot an opportunity to fly on a regular basis with an authorized flight instructor. The FAA argues that the program is most effective if the training is accomplished regularly throughout the year, thus affording a pilot the opportunity to fly in different seasons and in different flight conditions.

Echoing the efforts of the WINGS program, the rule of exercise (FAA-H-8083, 2008), asserts that learning is strengthened with practice and diminished when discontinued. The literature review established that knowledge decays proportional to the passage of time. Thus, to enhance the retention of knowledge for SA, supplementary learning is required. This argument is supported by the rule of recency (FAA-H-8083, 2008, p. 2-11) which stipulates the following:

"things most recently learned are best remembered. Conversely, the further a learner is removed in time from a new fact or understanding, the more difficult it is to remember. For example, it is easy for a learner to recall a torque value used a few minutes earlier, but it is more difficult or even impossible to remember an unfamiliar one used a week earlier."

4.4.1.3 Scenario Centered Curriculum

In light of the four tasks that a pilot must perform, discussed in the literature review (aviate; navigate; and manage systems), the curriculum for an annual flight review (not biennial) the should reinforce level 3 SA. This is because the minimum 1-hour period of instruction for ground instruction and 1 hour for flight lesson are insufficient to impart additional knowledge and subsequently measure the pilot's comprehension of the knowledge.

4.4.2 Adherence to Established Procedures

The new H3 identified deviation from established procedures as a contributing factor to PLOC. Figure 20. depicts the factors necessary for adherence to established procedures as the need for both a risk management culture and continual knowledge remediation.

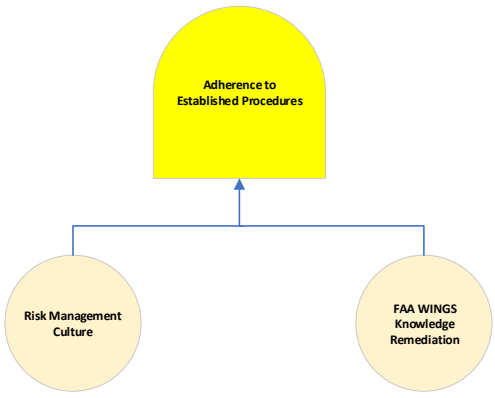


Figure 20. Adherence to Established Procedures to Prevent PLOC

4.4.2.1 Risk Management Culture

Deviation from established procedures can be categorized as either intentional actions to avoid compromising safety of flight, intentional due to a pilot's negligence for established procedures, or unintentional due to absence of knowledge. The focus herein is on the latter two. Whether intentional or unintentional, the underpinnings regarding deviations are traced to the pilot's decision to choose an action. O'hare (Tsang & Vidulich, 2003, p.210) makes the point that good decision-making involves "careful weighing of risks and benefits, searching for new information and reevaluating options." The main argument here is that pilot must embrace a culture of risk management. Modarres et al. (2017, p. 427) define risk management as "the process through which the potential (likelihood or frequency) magnitude and contributors to risk (loss) are evaluated, minimized, and controlled." A risk management culture should be part of a pilot's annual flight review body of knowledge. Risk management provides a pilot with requisite skillsets to make good decisions.

4.4.2.2 FAA WINGS Knowledge Remediation

Tsang &Vidulich (2003) made the argument that the role of the pilot is on a continual change; however, it is equally true that the pilot's operational environment is also on a continual change with updates, revisions, cancellation of FAA procedures and processes. This means that the requisite body of knowledge for a pilot to operate an aircraft is on a continual modification. To counter knowledge deficits that results in a pilot's negligent or unintentional deviation from established procedures, the pilot needs to acquire the new knowledge. Such knowledge is available to the pilot via the FAA WINGS program; and

will enable the pilot to achieve at a minimum a level 2 SA (the comprehension of the current situation).

4.4.3 Human Machine Interface Management

The new H3 identified Human machine interface issues as the third significant contributing factor to PLOC. Figure 21. depicts the factors necessary to the management of human machine interface issues (system knowledge and pre-flight task loading).

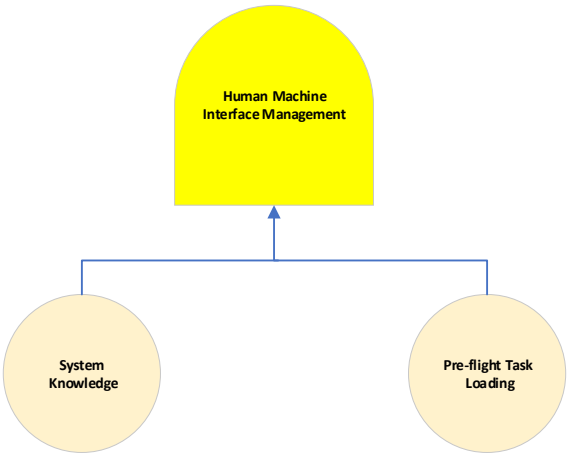


Figure 21. Human Machine Interface Management

4.4.3.1 System Knowledge

System knowledge with regards to human machine interface refers to the pilot's knowledge of the system. Optimal system performance is achieved when the pilot can develop and sustain level 3 SA (the pilot is able to anticipate an aircraft's behavior given a set of inputs). To accomplish this feat, the pilot requires comprehensive knowledge about the information or displayed or conveyed by the interfaces. Such knowledge validation during the annual flight review.

4.4.3.2 Pre-flight Task Loading

The concept of pre-flight task loading is to reduce the number of tasks that a pilot performs while flying an aircraft (aviate, navigate, communicate, and manage systems).

This means that in addition to acquiring system knowledge, the pilot identifies the required tasks for each phase of the flight and then pre-load those tasks to the interface.

4.4.4 Communication Breakdown Prevention

The new H3 identified communication breakdown as the final significant contributing factor to PLOC. Figure 22. depicts the factors necessary to mitigate communication breakdown.

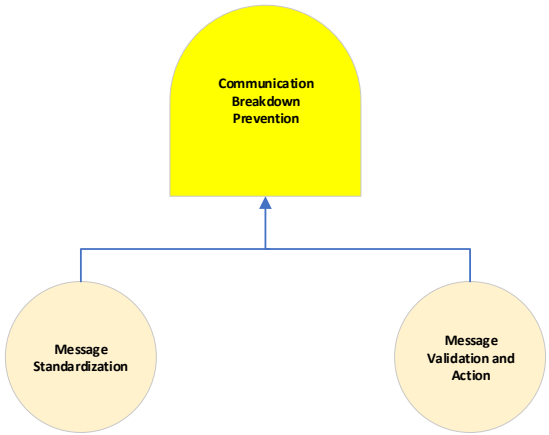


Figure 22. Communication breakdown prevention

4.4.4.1 Message Standardization

The literature review noted that Shannon & Weaver's (2017) communication system model adequately describes the GA environment. It is reiterated that this model consists of the following elements: information source (can a pilot or an air traffic controller), transmitter (encodes message into a signal), channel (medium, usually a radio), noise (environmental interferences), the receiver (can be a pilot or an air traffic controller) and destination (can a pilot or an air traffic controller). As this model can indicate, a communique is susceptible to degradation. This means that communiques should be

precise and convey the desired intentions without ambiguity. This can effectively be achieved by standardization of aeronautical language.

4.4.4.2 Message Validation and Action

While the standardization of aeronautical language between pilots and controllers can resolve ambiguity and confusion, the addition of formal message confirmation to validate the communicate is also essential. Although the validation of message receipt is expected in flight operations, formalization of communication process and procedures

4.5 The Checklist

This Praxis is a response to the NTSB petition for the prevention of PLOC. Given the complexity of the four significant contributing factors to PLOC (loss of SA, pilot deviation from established procedures, human machine interface issues, and communication breakdown), there is reasonable doubt that the application of mitigation controls against the contributing factors can prevent PLOC, at most reduce the probability of a PLOC occurrence. A PLOC control or management checklist is therefore proposed as a cost-effective tool for a pilot. The content of the checklist is derived from controls to four contributing factors to PLOC (retention of SA, adherence to established procedures, human machine interface management, and communication breakdown prevention).

It is noted that the checklist is to be used in preparation for flight and not during flight. The rationale to restrict a pilot PLOC management checklist to before flight operations is because the goal of the checklist is to sets the conditions for a PLOC free flight and not to additional tasks to the four tasks that the pilot must perform. The checklist is depicted on Table 18.

Table 18. PLOC Management Checklist

	Controls	Yes	Actions for yes	No	Actions for no	Traceability
1	Flight Review?	**if yes**	go to 2	**if no**	complete 1 & 3	Retention of SA criteria
2	Did the flight review include scenarios?	**if yes**	go to 3	**if no**		
3	2 FAA WINGS programs within the preceding 6 months?	**if yes**	go to 4	**if no**		
4	Did the flight review include risk management?	**if yes**	go to 6, 5 is optional	**if no**	complete 4 & 5	Adherence to Established Procedures
5	FAA WINGS knowledge remediation	**Optional**	Optional			
6	Knowledge currency and recency about aircraft, air traffic alerts/warnings, new procedures?	**if yes**	go to 7	**if no**	flight not recommended, complete 1, 2, 4, &6	Human Machine Interface Management
7	Pre-flight task loading based on input from 6?	**if yes**	go to 8			
8	1 FAA WINGS program on communication and lost procedures?	**if yes**	recommend going to 9	**if no**	complete 8 & 9	Communication Breakdown Prevention
9	1 FAA WINGS program on communications procedures in a controlled airspace?	**Optional**	Optional			

4.6 The Case Studies

Given the PLOC management checklist (Table 18), the final phase of H4 is to determine if a pre-emptive application of the checklist could have reduced the probability of PLOC induced accident. Three adjudicated and randomly selected accidents were

retrieved from an NTSB database as case studies. It is noted that an adjudicated accident from the NTSB accident database is an accident that has completed the investigation process. Additionally, adjudicated accidents investigations specify the both the causal and contributing factors to the accident. The three randomly selected accidents identify PLOC as the primary cause. Tables 19-21 depict the three PLOC induced accidents as well as the contributing factors to each PLOC accident.

Table 19. Case Study one

	Case Number	NTSB Accident Narrative	Traceability to the PLOC Management Checklist	PLOC management control actions (using the yes column)
Case Study 1	ERA16FA064	The pilot failed to maintain control of the airplane after a cabin door came open in flight, which resulted in the airplane exceeding its critical angle of attack and experiencing aerodynamic stall. Contributing to the accident was the pilot's misuse of amphetamine.	The pilot deviated from established procedures by consuming illicit drugs.	control 1 & 3
			The pilot also did not maintain SA as evidence by the door opening in-flight.	control 2 & 6
			The pilot failed to manage system interfaces by not securing do pre-flight.	control 4, 5 & 6
			The pilot failed to manage risks not adhering to the pilot operating handbook guidance that the cabin door could become open while in-flight if not latched.	control 4 & 6

This description for the content of Table 19. is also used to capture the contents to Tables 20 & 21 and depicts a PLOC accident summarized in the NTSB narrative column. The column titled “Traceability to the PLOC Management checklist” describes the specific PLOC predictor. The column titled PLOC management control actions specifies

the action necessary to reduce the probability of occurrence for each item from the PLOC management checklist column.

Table 20. Case Study two

	Case Number	NTSB Accident Narrative	PLOC Management Checklist	PLOC management control actions (using the yes column)
Case Study 2	CEN17FA005	The flight instructor's loss of control during an aerodynamic stall demonstration, which resulted in an inadvertent spin from which he was unable to recover. Contributing to the accident was the flight instructor's lack of familiarity with the airplane's stall characteristics.	The instructor pilot did not have the knowledge and currency to operate the aircraft.	control 2, 4 & 6
			The pilot also did not establish level 1 SA (to perceive the what the system is doing).	control 2 & 3
			The pilot did not attend any FAA WINGS program that had details about uniquely behavioral characteristics regarding the accident aircraft.	control 5 & 6
			The pilot did not attend any FAA WINGS program that detail risk management or scenarios.	control 1 & 5

Table 21. Case Study three

	Case Number	NTSB Accident Narrative	PLOC Management Checklist	PLOC management control actions (using the yes column)
Case Study 3	CEN16FA211	The pilot's improper go-around procedure that did not ensure that the airplane was at a safe airspeed before raising the flaps. The local controller's issuance of an unnecessarily complex clearance during a critical phase of flight. A review of the pilot's logbook indicated the pilot did not receive the required biennial flight review in the preceding 24 months.	The pilot deviated from established by not conducting the flight using the authorized procedures.	control 1 thru 5
			The pilot did not complete the mandatory biennial flight review.	control 1
			There was communication breakdown the pilot the controller that exacerbated the conditions conducive to PLOC.	control 8 & 9
			The pilot did not have the requisite knowledge to conduct a go-around procedure due to knowledge decay as evidenced by absence of a biennial flight review.	control 1 thru 9

4.7 Conclusion

The objective of this chapter was to determine if PLOC is attributed to the three NTSB factors for H1 (loss of SA, pilot distraction, and weather), the "Other" factors proposed by this Praxis for the new H2 (pilot deviation from established procedures, pilot experience within 90 days, communication breakdown, and human-machine interface), or a combination of both, the new H3 (loss of SA, pilot deviation from established procedures, human machine interface, and communication breakdown). The analyses

herein this chapter determined that a combination of both NTSB and the “Other” PLOC model are better predictors of a PLOC event with an accuracy of 89%.

Given a PLOC prediction model with an 89% accuracy, H4 attempted to establish controls for each factor the contributed to PLOC. The conclusion of this effort was the creation of pilot checklist for use before flight. The checklist was evaluated to determine it was capable of reducing the probability of a PLOC event given three PLOC case studies.

Chapter 5—Discussion and Conclusions

5.1 Discussion

While the goal for this study was to respond to the 2017/2018 NTSB petition for the prevention of PLOC, the research effort approached the noted NTSB PLOC contributing factors with skepticism. The study commenced by acknowledging that although the factors that the NTSB identified as PLOC contributing factors were indeed contributors. However, those factors were not wholly representative of the all the factors that contributed to PLOC and can therefore skew a problem formulation and any subsequent solution to the problem will also be skewed.

Thus, the study proposed four new contributing factors to PLOC that were used as PLOC predictors. PLOC and no PLOC dataset from NASA was use to test both accuracy of the NTSB PLOC prediction model and a new PLOC prediction model using the new proposed contributing factors. Analysis of the NASA dataset indicated that the NTSB PLOC prediction model had an AIC of 85.34, an R-Sq. of 23.06%, an R-Sq. (adjusted) of 20.08%, and a prediction accuracy of 63%. While the study did not reject the NTSB PLOC prediction model, it recommended the model as an alternative.

The results of the PLOC prediction model proposed by the studied produced the following results: An AIC of 62.56, an R-Sq. of 47.72%, an R-Sq. (adjusted) of 43.74%, and a prediction accuracy of 75%. It was discernable that the proposed PLOC prediction model was a better predictor.

When both predictors were combined while retaining significant predictors, the following factors emerged as predictors: loss of SA, pilot deviation from established procedures, human machine interface and communication breakdown. The results of the

analyses are noted as follows: an AIC of 55.25, an R-Sq. of 54.99%, an R-Sq. (adjusted) of 51.01%, and a prediction accuracy of 89%.

Informed by the literature review, the study then attempted to establish controls to mitigate the probability of occurrence for each of the latter predictors. It is noted that the retention of SA, adherence to established procedures, human machine interface management, and communication breakdown prevention were identified as candidate controls to reduce the probability of a PLOC event.

A PLOC management checklist (Table 18.) was developed as tool to aid pilots in preparation for a flight. The checklist is intended to be flight supplement to ensure adequacy of the pilot's preparation to complete flight operation with reduced probability of a PLOC occurrence.

In summary, this Praxis attempted to contribute to the resolution of a problem associated with a complex system posited thusly, "PLOC involving GA aircraft account for 48% of all GA accidents. In this effort, four hypotheses were posited; to which three of the hypotheses were to developed for an eventual better predictor of PLOC occurrences and one hypothesis associated with the control significant PLOC contributors.

- The first hypothesis was to determine if the factors that the NTSB identified were predictors of a PLOC occurrence. It is noted that NTSB predictors had an AIC of 85.34.
- The second hypothesis was to determine if other factors that were not considered by the NTSB predicted of PLOC. The second hypothesis had an AIC of 62.56.

- The third hypothesis was to determine if a combination of contributing factors (NTSB and other) were better at predicting PLOC. It is noted that third hypothesis had an AIC of 47.72.

Recall Osborne's assertion in the methodology discussion that small AICs were considered best fit at prediction. This suggests that the third hypothesis produced a stronger model for predicting PLOC.

5.2 Conclusions

Despite its applied nature, a study on the prevention of PLOC in GA is also a well-suited topic for a traditional dissertation that affords a researcher the requisite time to deliberate over the factors that contribute to PLOC. However, a caveat is posited that a researcher embarking to understand PLOC in order to produce foundational knowledge should have both academic and experiential competencies to do so. The rationale for the caveat is that any deficiency in academic and experiential knowledge can result in an ill-defined problem and an ill-suited solution. As noted, the study commenced by challenging the comprehensiveness of the NTSB PLOC predictors and subsequently discovered that some of the PLOC predictors that the NTSB identified (pilot distraction and weather) were not significant contributors to PLOC events.

Thus, to allocate finite resources to mitigate factors that may not be significant contributors to PLOC is not only wasteful but also mutates a problem. It is very likely that pilot distraction contributes to PLOC, however, pilot distraction can also be attributed to loss of SA, or contribute to loss SA, perhaps even the by-product of human machine interface.

5.3 Contributions to Body of Knowledge

1. This study contributed a PLOC prediction model for accidents that are PLOC induced. It is noted that the PLOC prediction model has an accuracy of 89%. The new model can be used to increase the scope of forensic investigations for accidents involving GA pilot
2. This study also developed a pilot checklist (shown in Table 18.) that can be used by any pilot but primarily GA pilots to equip them with the requisite knowledge to avoid PLOC induced accidents and incidents.
3. While this study did not create foundational knowledge, it extrapolated existing literature to arrive at new insights that can be used create foundational research on retention of SA, and the interaction between PLOC contributing factors.

5.4 Recommendations for Future Research

While GA operations makes significant contributions to the national gross domestic product, it remains obscured by the scheduled airlines. As previously noted, GA fulfills a crucial role, it is also functions as a career gateway to the airlines for younger pilots. That said, the role of the pilot continues to evolve and changes with developments technology. Traditionally a pilot trained to manually operate an aircraft, however, the way in which an aircraft is operated and the environment in which the aircraft is operated is changing. This poses a challenge as the four primary tasks that a pilot must perform (aviate, navigate, communicate, and manage systems) remain the same on the theoretical level yet they are morphing at the system behavior and interface level. This means that special attention is required to ensure that work systems such as aircraft have interfaces that convey information to a pilot for the much-desired sustainment of SA.

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Appendix A

Table A-1. Spreadsheet attachment for Praxis PLOC dataset

	NTSB PLOC Predictors			PLOC = 1, no PLOC = 0	Praxis Based Other PLOC Predictors						
Incident ID	Weather; Y=1, N=0	SA; Y=1, N=0	Pilot Distraction ; Y=1, N=0		Pilot Deviation from established procedures ; Y=1, N=0	Comm Breakdown ; Y=1, N=0	Pilot Experience Total Flight Time	Pilot Experience within 90 Days	HMI; Y=1, N=0	Confusion; Y=1, N=0	Workload; Y=1, N=0
1140002	1	0	0	1	1	1	6500	150	1	0	0
1140015	0	0	0	0	0	0	270	20.6	0	0	0
1140020	0	0	0	0	0	0	860	7	0	0	0
1140870	0	0	1	0	0	0	730	200	0	1	0
1141959	1	1	1	1	1	1	375	30	0	0	0
1142542	0	1	0	1	1	0	450	80	0	1	1
1142545	1	0	0	0	0	0	2500	30	0	0	0
1143900	0	0	0	1	0	0	12500	75	1	0	1
1143924	1	1	0	1	1	0	1559	90.2	1	0	0
1143927	0	1	0	1	1	0	7130	15	0	0	0
1143941	0	0	0	0	0	0	4956	100	0	0	0
1143958	0	0	0	1	0	0	31838	41	1	0	0
1143989	0	1	0	0	0	0	557	30	0	0	0
1143993	1	1	0	1	1	0	630	30	0	0	0
1144545	1	0	0	1	1	0	13000	120	1	1	0
1144763	1	1	0	1	1	1	5500	35	1	1	0
1144785	0	1	0	1	0	0	107.7	0.9	1	1	0
1145322	0	1	1	1	0	1	20000	50	0	1	1
1145329	0	0	0	1	1	1	1060	140	0	0	0
1145333	0	0	0	0	0	0	2900	25	0	0	0
1145340	1	1	1	1	1	1	602	65	0	1	1
1145401	0	1	0	1	1	0	233.3	30.1	0	0	0
1145792	0	0	0	0	0	0	10000	20	0	0	0
1145807	0	1	0	0	0	0	15200	20	0	0	1
1145821	1	1	0	1	1	0	7500	75	0	1	0
1146047	0	0	0	0	0	0	3250	45	0	0	0
1146055	0	1	0	0	0	0	2000	30	0	0	0
1146341	0	0	0	0	0	0	8300	80	0	0	0
1146345	0	0	0	0	0	0	1000	10	0	0	0
1146357	1	0	1	1	1	0	1018	57	1	1	1
1146369	0	1	0	0	0	0	161.2	13.8	0	0	0
1147193	1	0	1	1	1	0	8000	60	1	0	0
1147226	0	1	0	1	1	0	4700	20	0	0	0

1147534	1	0	0	0	1	0	8400	200	0	0	0
1147544	0	0	1	1	1	1	5700	20	1	0	0
1147550	0	0	0	0	0	0	3000	10	0	0	0
1148167	0	0	0	0	1	0	1300	20	0	0	0
1148186	0	1	0	0	0	0	3400	100	0	0	0
1148188	1	0	0	0	1	0	9500	50	0	0	0
1148730	1	1	0	1	1	0	1300	150	0	0	0
1148747	1	1	0	1	1	1	440	40	0	1	0
1149038	1	1	0	1	1	0	4100	77	0	0	0
1149043	0	0	0	0	0	0	9000	40	0	0	0
1149376	0	0	0	1	0	1	5000	250	0	1	0
1149625	1	0	0	0	0	0	6200	75	0	1	0
1149636	0	1	0	1	0	1	560	45	0	1	1
1149850	0	1	0	0	0	0	843	60.1	0	0	0
1149863	0	0	0	0	0	0	4800	100	0	1	1
1149869	0	1	0	1	1	0	7500	30	0	0	1
1149873	0	1	0	0	0	0	8175	85	1	0	0
1150669	0	0	0	0	0	0	1600	250	0	1	1
1150688	0	0	1	0	0	1	5800	100	1	1	1
1150726	0	1	1	1	1	1	1335	28	0	1	0
1150777	0	1	0	1	1	1	389.3	7.6	0	1	0
1150811	1	1	0	1	1	0	14000	30	1	1	1
1151031	0	1	0	1	1	1	11000	100	0	1	1
1151238	1	0	0	1	1	1	142.7	38.4	0	0	0
1151239	1	1	0	1	1	0	2500	85	0	0	0
1151240	0	0	0	1	0	0	87	14.2	1	0	0
1151243	0	0	1	1	1	1	1250	50	0	1	1
1151260	1	0	0	0	0	1	3000	60	0	0	0
1151266	0	1	0	1	1	0	4608.7	46.8	0	0	0
1151283	0	1	0	1	1	0	802	15	0	0	0
1151568	0	1	0	0	0	0	1080	10	0	1	0
1151591	0	0	1	0	1	1	9900	180	0	1	0
1151604	0	0	0	0	0	0	1135	14.6	1	0	1
1152224	0	1	0	1	1	0	1600	60	0	0	0
1152259	0	0	0	0	1	0	1605	255	1	0	0
1152262	0	0	0	1	0	1	282	57	0	1	0
1152265	0	1	0	1	1	0	12000	175	0	1	0
1152315	0	0	0	0	0	0	4000	15	1	0	0
1152834	0	0	0	0	0	0	15753	93	1	0	0
1485667	0	1	0	1	1	0	180	10	0	0	0