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Utilizing Flight Data Monitoring at a Part 141 Flight School to Determine Predictors for Unstabilized Approaches and Go-arounds

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MSF 700: Thesis

FINAL THESIS APPROVAL
UTILIZING FLIGHT DATA MONITORING AT A PART 141 FLIGHT SCHOOL TO DETERMINE PREDICTORS FOR UNSTABILIZED APPROACHES AND GO-AROUNDS

The graduate research project of *Hannah Rooney*, in contribution to the College of Aviation, Embry-Riddle Aeronautical University, under the title *Utilizing Flight Data Monitoring at a Part 141 Flight School to Determine Predictors for Unstabilized Approaches and Go-Arounds*, is approved as partial fulfillment of the Master of Science in Safety Science.

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Abstract

As general aviation accident rates are much higher than those of Part 121 air carriers, and the approach and landing phase of flight accounts for more accidents than any other phase of flight, the study of the approach and landing phase of flight is warranted in greater detail. Flight Data Monitoring provides an excellent source of data for the study of individual landing parameters. The intent of this study was to evaluate potential predictors of unstable approaches as well as go-arounds.

Flight data provided by a Part 141 flight school was examined to determine predictors for unstable approaches and go-arounds. The raw data was analyzed using General Electric's eFOQA® software, then exported to IBM's SPSS® for binomial logistic regression analysis. The independent variables evaluated as predictors for unstable approaches and go-arounds were Aircraft Type, Approach Type, Light Condition, Approach Location, Instrument Approach Procedure Type, and Runways.

Thirty-two percent of the 36,864 approaches evaluated were unstable. Aircraft Type, Approach Type, Approach Location, and Runways were found to be statistically significant predictors of approach stability. A Diamond DA-42 NG is 3.88 times less likely to experience an unstable approach. An approach conducted under VFR is 1.12 times less likely to experience an unstable approach. An approach conducted at an outlying airfield is 1.12 times more likely to experience an unstable approach. Four of the five runways evaluated were found to be statistically significant predictors of approach stability.

Of the 11,939 unstable approaches observed by the study, 75% of those approaches resulted in landings where they should have resulted in go-arounds. Aircraft Type, Light Condition, Approach Location, and Runways were found to be statistically significant predictors

of approach stability. A Diamond DA-42 NG is 2.98 times less likely to result in a landing after experiencing an unstable approach. An unstable approach at night is 4.67 times less likely to result in a landing. An unstable approach conducted at an outlying airfield is 1.2 times less likely to experience a landing**.** All of the evaluated runways were found to be statistically significant predictors of approach stability.

The study revealed significant predictors of both unstable approaches and go-arounds. Potential commonalities among the statistically significant predictors from both dependent variables (Approach Stability and Landing Outcome) include crew experience levels, crew familiarity with certain independent variables, and flight density at the airport. The disparity between IAPs and VFR approaches warrants a further examination of the differences between the two approach profiles. The disparities in go-around and stability likelihoods based on Runways could potentially be attributed to differences in runway width, slope, crew familiarity, and surrounding terrain, but further research is indicated to delve into these possibilities. Regardless of the reasons why, general aviation operators and the flight school specifically can use these results where indicated to tailor education to preventing unstable approaches and increasing the prevalence of go-arounds.

Table of Contents

Acknowledgement

This project has been a long time coming. I would like to express my gratitude to my Committee Chair, Brian Roggow, for his expertise, endless patience, and mentorship. I would also like to extend my gratitude to my other two committee chair members, Dr. Maxwell Fogleman and William Waldock for their contributions as well as several years of excellent instruction. This project would also not have been possible without the support of Dr. Timothy Holt and the College of Aviation, namely the Flight and Aviation Safety Departments.

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Chapter I: Introduction

Aviation safety has been the subject of scrutiny from both aviation experts and the public dating back to the Wright brothers' first flight in 1903. Technology, research, and regulation have greatly improved aviation safety in modern times; aviation is a very safe mode of transportation, with an accident rate of 0.139 accidents per 100,000 flight hours on Part 121 air carriers in 2021 (National Transportation Safety Board, 2023). However, general aviation flights accounted for 5.25 accidents per 100,000 flight hours in 2021, which is roughly 37 times the accident rate of Part 121 air carriers during the same year (National Transportation Safety Board, 2023). General aviation pilots generally lack the experience, training, and regulatory oversight that pilots operating for Part 121 air carriers possess (Northcutt, 2013).

Naturally, the discrepancy between general aviation and Part 121 air carrier accident rates has been the focus of several studies. Studies aim to explain the discrepancy between the two major sectors of aviation as well as explain specific risk factors for general aviation accidents. One study found that degraded visibility, geographical location, lack of flight experience, and pilot certifications have been found to be risk factors for general aviation accidents (Boyd, 2017). Annually, the Aircraft Owners and Pilots Association (AOPA) publishes the Joseph T. Nall Report which reorganizes National Transportation Safety Board (NTSB) data into specific categories that provide greater insight into general aviation accidents.

As all pilots must begin their journey as a student, flight training is of great interest to those studying aviation safety. Initial flight training begins under the umbrella of general aviation; advanced flight training can also fall within the definition of general aviation. While pilots may choose to become airline pilots working for Part 121 air carriers after their initial flight training is complete, many pilots choose to remain hobbyists. Therefore, flight training encompasses pilots of all experience and skill levels. Ratings and certificates are awarded on an increasing scale of difficulty, with standards outlined by the Federal Aviation Administration (FAA) within the United States.

The AOPA conducted a study in 2014 that examined training flight accident rates. This review found that the overall accident rate of instructional flights was not found to be significantly different from that of non-instructional flights, and that an accident occurring during an instructional flight was less likely to be fatal by less than half; however the review also found that "takeoffs, landings, and go-arounds made up half of all accidents in…instruction" (AOPA Air Safety Institute, 2014, p. 8). Additionally, the 2021 Joseph T. Nall Report states that 342 accidents of the 614 total pilot-related, non-commercial fixed wing accidents were attributed to the approach and landing phase of flight (AOPA Air Safety Institute).

The Federal Aviation Administration, as well as other prominent aviation-focused organizations such as the Flight Safety Foundation and the International Civil Aviation Organization, emphasize stable approaches as a protective measure against approach and landing accidents. The FAA defines a stabilized approach as an approach where "the pilot establishes and maintains a constant-angle glide path towards a predetermined point on the landing runway. It is based on the pilot's judgment of certain visual cues and depends on maintaining a constant final descent airspeed and configuration" (Federal Aviation Administration, 2021, p. 9-4). In the Airplane Flying Handbook (AFH), the FAA outlines specific criteria that define a stabilized approach, which includes specific numbers relating to airspeeds, glide path, and descent rates (2021). In a study conducted by the Flight Safety Foundation Approach-and-Landing Task Force, unstable approaches were found to be a causal factor in 66% of a sampling of accidents from 1984 to 1997 (Flight Safety Foundation, 2009). Jiao et al. (2018) found that 10.3% of approaches conducted in a Boeing 737 aircraft were found to be unstable (Jiao, Sun, Wang, & Han).

The FAA emphasizes the importance of conducting go-arounds in response to an unstable approach (Federal Aviation Administration, 2021). A go-around is a maneuver in which a pilot terminates the attempt at approach and landing and applies maximum power, sets an appropriate pitch to allow for the aircraft to climb, and reduces flaps. The pilot may then attempt the approach and landing again, ideally making changes to ensure that the approach is stable. The Flight Safety Foundation found that 54 percent of all accidents studied in a 16-year time frame could have been prevented by a go-around (Blajev & Curtis, 2017). Unfortunately, only three percent of unstable approaches result in go-arounds (Blajev & Curtis, 2017).

Flight data collection is instrumental in identifying unstable approaches. Flight data collection varies depending on the needs of the operator and the capabilities of the aircraft. For example, Part 121 air carriers generally operate transport category aircraft equipped with comprehensive Airborne Data Recording Systems. The data is then used to identify events such as hard landings, unstable approaches, and aircraft malfunctions. Despite having much to gain by data analysis, general aviation aircraft are not widely equipped to collect flight data. The cost and resources necessary to collect and analyze the data is often out of reach for general aviation operators. Larger general aviation flight schools, however, may be in a better position to allocate funds and resources to data collection and analysis.

As stated earlier, general aviation accidents occur at a higher rate than Part 121 air carriers. A large portion of general aviation accidents occur during approaches to landings, and many of these accidents are attributed to unstable approaches. However, very little research has been conducted utilizing flight data to learn more about approach stability in general aviation aircraft. Knowledge about unstable approaches and the conditions surrounding unstable approaches can help target training efforts. Flight training schools provide an opportunity to study approaches in-depth, largely due to the resources more often dedicated to data collection and analysis, as well as volume of flights providing large sample sizes.

Purpose Statement

The intent of this study is to utilize flight data provided by a Part 141 flight school to evaluate unstable approaches and go-arounds. Specifically, this study seeks to identify predictors of unstable approaches and predictors of go-arounds if an unstable approach is encountered using logistic regression.

Very little research has been conducted surrounding individual risk factors pertaining to general aviation unstable approaches. The findings of this study can be utilized by the source flight school to target education efforts, as well as potentially evaluating its stable approach criteria. The findings of this study can also contribute to the body of knowledge surrounding unstable approaches in both general aviation and the flight training environment.

Research Questions

The Part 141 flight school provided data spanning an academic semester which encompassed over 30,000 approaches. The flight school utilizes General Electric’s eFOQA software to analyze the data. Events were created with the eFOQA software in order to identify approaches, unstable approaches, go-arounds, and instrument approach procedures (IAPs). Other data, such as ambient light condition and location, were collected for each approach event. The events and their supporting data were examined using logistic regression to explore the following research questions:

1. Research Question 1: What variables are predictors of unstable approaches?

Hypothesis 1.1: A Cessna 172S Nav III is associated with an increased probability of an unstable approach.

Hypothesis 1.2: An Instrument Approach Procedure is associated with an increased probability of an unstable approach.

Hypothesis 1.3: An approach conducted at night is associated with an increased probability of an unstable approach.

Hypothesis 1.4: An approach conducted at an outlying airfield is associated with an increased probability of an unstable approach.

Hypothesis 1.5: Specific runways at the home base airport can be used to predict stability. Each hypothesis listed below is in comparison to Runway 30 in order to support the methodologies outlined in Chapter III of this paper.

> Hypothesis 1.5.1: Runway 21L is associated with a decreased probability of an unstable approach..
>
> Hypothesis 1.5.2: Runway 21R is associated with a decreased probability of an unstable approach.
>
> Hypothesis 1.5.3: Runway 3L is associated with a decreased probability of an unstable approach.
>
> Hypothesis 1.5.4: Runway 3R is associated with a decreased probability of an unstable approach.
>
> Hypothesis 1.5.5: Runway 12 is associated with a decreased probability of an unstable approach.

Hypothesis 1.6: If an IAP is conducted, a circling approach is associated with an increased probability for an unstable approach.

2. Research Question 2: If an unstable approach is encountered, what variables act as predictors that the approach will result in a go-around?

    Hypothesis 2.1: A Cessna 172S Nav III is associated with an increased probability of a go-around.

    Hypothesis 2.2: An Instrument Approach Procedure is associated with a decreased probability of a go-around.

    Hypothesis 2.3: An approach conducted at night is associated with a decreased probability of a go-around.

    Hypothesis 2.4: An approach conducted at an outlying airfield is associated with a decreased probability of a go-around.

    Hypothesis 2.5: Specific runways at the home base airport can be used to predict the likelihood of go-arounds. Each hypothesis listed below is in comparison to Runway 30 in order to support the methodologies outlined in Chapter III of this paper.

        Hypothesis 2.5.1: An unstable approach flown to Runway 21L is associated with a decreased probability of a go-around.

        Hypothesis 2.5.2: An unstable approach flown to Runway 21R is associated with a decreased probability of a go-around.

        Hypothesis 2.5.3: An unstable approach flown to Runway 3L is associated with a decreased probability of a go-around.

        Hypothesis 2.5.4: An unstable approach flown to Runway 3R is associated with a decreased probability of a go-around.

Hypothesis 2.5.5: An unstable approach flown to Runway 12 is associated with a decreased probability of a go-around.

Hypothesis 2.6: If an IAP is conducted, an unstable circling approach is associated with an increased probability for a go-around.

Delimitations

Flight data provides nearly limitless opportunities for study. This study focuses on the approach, landing, and go-around phases of flight due to the substantial portion of accidents related to approach and landing in general aviation. Unlike with Part 121 air carriers, very few studies have been conducted using flight data to further examine landings and go-arounds in small general aviation aircraft. The findings from this study can further the body of knowledge regarding best practices for training approaches, landings, and go-arounds.

Many factors, some not within the control of flight crews, contribute to landing outcomes. Air Traffic Control, weather, and aircraft condition are all external factors that could greatly impact approach stability, but are difficult to measure. Crew skill and experience levels can also have a strong effect on approach stability, but like the aforementioned factors, are difficult to measure objectively. The independent variables selected for this study were chosen due to their measurable, unambiguous nature as well as the knowledge that stands to be gained from the results of this study. Knowledge gained from the results of this study can be used to directly change teaching techniques of approaches and landings as well as SOPs. Continuing education can be directed to further examine statistically significant independent variables. For example, pilots can alter their techniques while landing at night in order to combat runway illusions attributed to darkness; instructors can place special emphasis on teaching these techniques to their students.

The time frame considered by this study was chosen to encompass an academic semester at the flight school, which also encompasses a strong seasonal change. The data included all flights conducted in a Diamond DA-42 NG or Cessna 172S Nav III between 1 January 2021 and 30 April 2021. This included training flights, currency flights, and rental flights. Because the same stable approach criteria and SOPs are used for all flights regardless of the intent of flight, no flights were eliminated from the study on the basis of intent.

Limitations and Assumptions

The analysis conducted in this study made several assumptions. The first is that flight crews adhered to the policies outlined in the flight school's Flight Operations Manual and procedures outlined in the flight school's SOPs. For example, however minimal, there exists the possibility that flight crews descended below 500 feet AGL while not in the vicinity of an airport. There also exists the possibility that flight crews were not intending to follow speed and altitude profiles prescribed by the flight school's SOPs, which could feasibly alter the data. However, the study assumed that pilots fully intended to comply with the flight school's SOPs, as evaluating intent was outside the scope of this study.

Not every go-around conducted by the flight school was included within this study. Go-arounds and Missed Approach Procedures (MAPs) can be conducted at any point on an approach for any reason deemed necessary by the flight crew; this study only examined go-arounds executed below 400 feet AGL, which coincides with the study's definition of an approach. Go-arounds may also be conducted out of a necessity to simply practice the maneuver, or at the direction of Air Traffic Control (ATC).

Additionally, not all of the stable approach criteria listed by the flight school was incorporated into this study. Some of the stable approach criteria were outside the capabilities of the software or the aircraft's ability to determine. The excluded stable approach criteria are further expanded upon in the Chapter 3 of this paper.

Summary

A significant portion of accidents are attributed to the approach and landing phases of flight. The FAA and other prominent organizations have emphasized a stable approach as a mitigating strategy for accidents related to approach and landing. General aviation also experiences accidents at a rate significantly higher than that of Part 121 air carriers. Flight data collection can offer incredible insight into a flight operation. While Part 121 air carriers collect flight data in large volumes, general aviation does not collect data on the same scale due to resource limitations. Therefore, very little research based in flight data collection exists which examines general aviation approaches and landings. Flight schools are a significant contributor to the general aviation population; large-scale flight schools may also equip their aircraft with the ability to collect flight data. Learning more about unstable approaches within the general aviation population can allow for better education regarding go-arounds and landing accident prevention.

This study seeks to examine predictors of both unstable approaches and go-arounds utilizing logistic regression. A Part 141 flight school provided data that represents an academic semester, representing over 30,000 approaches in two different types of aircraft. This data was analyzed using General Electric's eFOQA® software in order to find each occurrence of the desired independent and dependent variables. IBM's SPSS® was used to conduct binary logistic regression analyses of the data to test several hypotheses pertaining to unstable approaches and go-arounds.

The following chapters delve into the current literature surrounding approach stability and general aviation, explain methodology for the study to include data collection and analysis, and discuss the implications of the study results.

Chapter II: Literature Review

Aviation in The United States

The first governing body pertaining to aviation in the United States of America was established in 1926 as the Aeronautics Branch of the Department of Commerce, tasked with "fostering air commerce, issuing and enforcing air traffic rules, licensing pilots, certificating aircraft, establishing airways, and operating and maintaining aids to air navigation" (Federal Aviation Administration, 2016, p. 1-4). The Federal Aviation Agency, now known as the Federal Aviation Administration (FAA), was established after a series of accidents to assume the rule-making responsibilities of aviation, while the National Transportation Safety Board (NTSB) was established to assume investigative responsibilities of all transportation accidents, including non-aviation accidents (Federal Aviation Administration, 2016). FAA regulations are housed under Title 14 Code of Federal Regulations (CFR), which governs the entirety of civil aviation, from pilot licensure and operating rules to maintenance. According to the FAA (2016), "14 CFR part 91 provides guidance in the areas of general flight rules, visual flight rules (VFR), and instrument flight rules (IFR)" (p.1-8).

The National Transportation Safety Board (NTSB) divides types of aviation into air carrier operations, commuter and on-demand carriers, and general aviation. Air carrier operations are defined as operations regulated by Title 14 CFR Part 121 (National Transportation Safety Board, 2021). Commuter and on-demand carriers are defined as operations regulated by Title 14 CFR Part 135, and general aviation describes civil aviation that does not fall in either of the aforementioned categories (National Transportation Safety Board, 2021). General aviation operations are typically regulated by Title 14 CFR Part 91 (National Transportation Safety Board, 2021).

Flight Training and Pilot Licensure

The general public is most familiar with air carriers, whose airplanes are piloted by those holding Airline Transport Pilot (ATP) certificates. In order to earn an ATP certificate, pilots must first begin accumulating flight hours and lesser-tier licenses, including Private and Commercial certificates (Federal Aviation Administration, 2016). A Private Pilot Certificate allows a pilot to act as Pilot-In-Command (PIC) of an aircraft for which they are rated, but not for compensation or hire. A Commercial Certificate can enable a pilot to be compensated for flying. An Instrument Rating allows either a Private or Commercial Pilot to exercise their designated privileges under IFR (Federal Aviation Administration, 2016).

In order to obtain any level of certificate, from Private Pilot to Airline Transport Pilot, applicants must log a certain amount of flight hours and instruction received, and then pass both written and practical exams conducted by a designated examiner. Flight instruction is necessary to develop the skill sets required to meet standards outlined by the FAA. As detailed in the Pilot's Handbook of Aeronautical Knowledge, "FAA-approved training centers, FAA-approved pilot schools, noncertificated flying schools, and independent flight instructors conduct flight training in the United States" (Federal Aviation Administration, 2016, p. 1-16). 14 CFR Part 141, Part 142, and Part 61 regulate flight training. Flight schools certificated by the FAA under 14 CFR Part 141, otherwise known as Part 141 flight schools, conduct flight training after demonstrating an ability to meet "stringent requirements for personnel, equipment, maintenance, facilities, and….curriculum, which includes a training course outline (TCO) approved by the FAA" (Federal Aviation Administration, 2016, p. 1-19). Flight schools not meeting the above-mentioned criteria conduct training under 14 CFR Part 61 and are colloquially known as Part 61 flight schools. A Part 61 flight school does not follow a TCO, but rather meets minimum requirements for flight experience and knowledge-based training laid out by 14 CFR Part 61 (Federal Aviation Administration, 2016).

Practical examinations conducted at the completion of a course of flight training with the intent of licensure are known as “check rides.” The skill set required to be demonstrated for each practical exam depends on the certificate level for which the candidate is applying, with the required skill sets progressing in difficulty as the certificate levels advance. The FAA states that “the goal of the airman certification process is to ensure the applicant possesses the knowledge, ability to manage risks, and skill consistent with the privileges of the certificate or rating being exercised” (Federal Aviation Administration, 2018). The FAA houses its guidelines for pilot licensure in the Airman Certification Standards (ACS); the competencies that pilot applicants demonstrate on the Private Pilot, Instrument Rating, or Commercial Pilot practical exams must meet standards prescribed by the corresponding ACS (Federal Aviation Administration, 2016). Each ACS document outlines a ground and flight portion of the practical test; the skills required to be demonstrated on the practical test are appropriate for the rating or license being sought. Private and Commercial pilot exams primarily revolve around visual flight tasks and rules, while the Instrument Rating and Airline Transport Pilot exams primarily include instrument flight tasks and rules (Federal Aviation Administration, 2016).

The ground portion of the Private and Commercial pilot exams include knowledge of regulations, weather, visual navigation, aircraft systems, and human factors (Federal Aviation Administration, 2018). The flight portion of the same exams require demonstration of aircraft preflight, visual takeoffs and landings, go-arounds, performance maneuvers, ground reference maneuvers, navigation, stalls, and emergency operations (Federal Aviation Administration, 2018). The Instrument Rating practical exam covers regulations, but also includes airplane systems related to IFR operations, compliance with air traffic control (ATC) clearances, holding procedures, instrument navigation, instrument approach procedures, and emergency operations related to IFR (Federal Aviation Administration, 2018).

Approaches, Landings, and Go-Arounds

Every practical exam conducted in pursuit of a certificate or rating contains sections of tasks dedicated to approaches and landings. Both the Private Pilot and Commercial Pilot ACS require pilot applicants to demonstrate tasks entitled Normal Approach and Landing, Short-Field Approach and Landing, and Soft-Field Approach and Landing (Federal Aviation Administration, 2018). The Commercial ACS contains a unique task known as a Power-Off 180° Accuracy Approach and Landing, a special type of precision landing (Federal Aviation Administration, 2018). The Instrument Rating ACS requires different types of Instrument Approach Procedures (IAPs) to be tested: Nonprecision Approaches, Precision Approaches, and Circling Approaches. Landing from an Instrument Approach is also a required task in the Instrument Rating ACS (Federal Aviation Administration, 2018).

Approaches conducted on practical examinations for the Private Pilot or Commercial Pilot certificates are markedly different from the approaches conducted for the Instrument Rating. The Pilot/Controller Glossary defines an Instrument Approach Procedure (IAP) as a "series of predetermined maneuvers for the orderly transfer of an aircraft under instrument flight conditions from the beginning of the initial approach to a landing or to a point from which a landing may be made visually" (Federal Aviation Administration, 2022). Approaches conducted to fulfill the landing tasks on the Private Pilot and Commercial Pilot practical exams are conducted primarily with visual references outside the aircraft, and follow no such strict predetermined path. Because IAPs vary so much in structure from the types of approaches found on the Private and Commercial Pilot exams, the standards for approaches found in the Instrument ACS differ from the approaches in the Private Pilot and Commercial Pilot ACS.

Go-arounds are another important task found in all pilot practical exams. Go-arounds, or rejected landings, are executed when a pilot or flight crew elects to discontinue an approach typically because “landing parameters deviate from expectations or when it is hazardous to continue” (Federal Aviation Administration, 2021, p. 9-10). Wind, pilot error, other aircraft, and, in some cases, ATC can prompt go-arounds. A missed approach is a “maneuver conducted by a pilot when an instrument approach cannot be completed to a landing” (Federal Aviation Administration, 2022, p. PCG M-4), i.e., a method for pilots to discontinue an instrument approach when necessary due to a variety of reasons. The large difference between a go-around and a missed approach is the type of guidance received once the decision to abandon the approach has been made; a missed approach procedure details a structured route of flight and altitudes to be flown, whereas a go-around does not (Federal Aviation Administration, 2022). Both go-arounds and missed approaches can be executed at any point during an approach.

Aviation Safety

NTSB Accident Investigations and Data

The National Transportation Safety Board has investigated over 152,000 aircraft accidents since its establishment. As the NTSB is an establishment independent of the Department of Transportation, the NTSB’s lack of authority over the transportation industry allows it to remain an independent investigative body (National Transportation Safety Board, 2022). Regulations pertaining to the NTSB are housed in Title 49 CFR – Transportation.

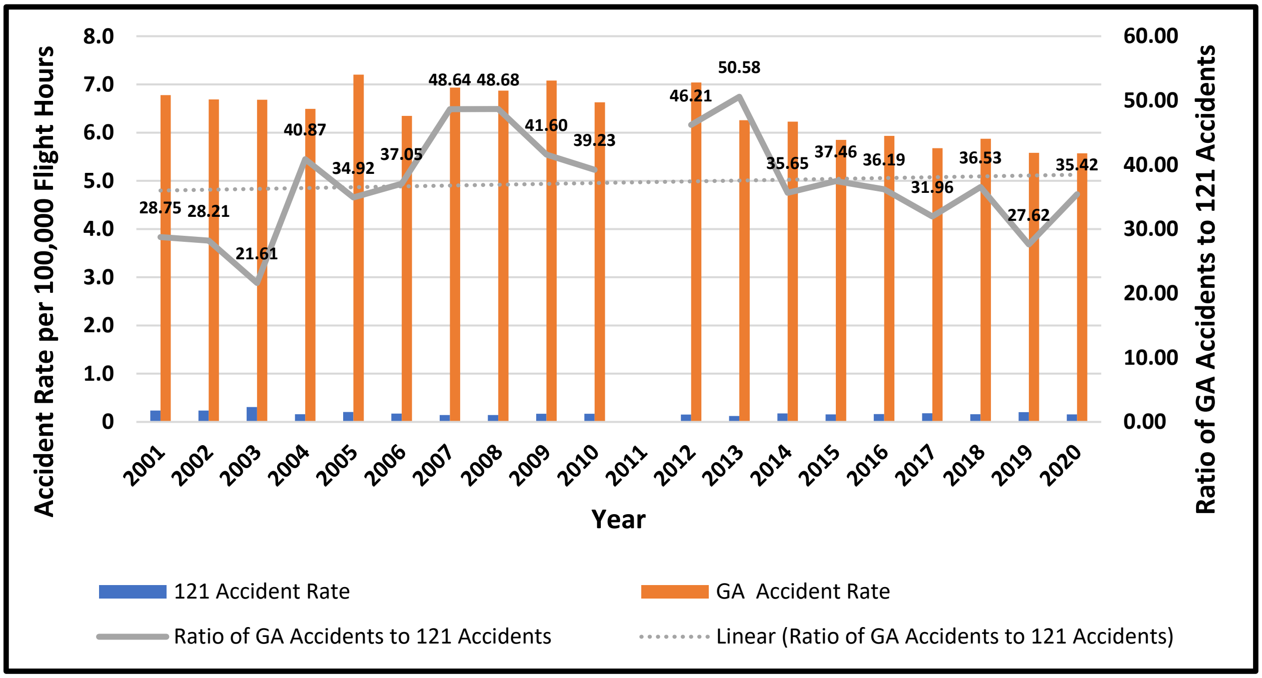
Title 49 C.F.R. § 830 defines an aircraft accident as:

> An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage (2022).

Figure 1 details general aviation and air carrier accident rates, and additionally displays the ratios of general aviation to air carrier accident rates.

Figure 1.

General Aviation and Air Carrier Accident Rates, Compared



Note. 121 and General Aviation Accident Rate data are sourced from the National Transportation Safety Board's "Aviation Accident Rates 2001-2020", US Civil Aviation Accident Rates, 2021. Copyright 2021 by the National Transportation Safety Board.

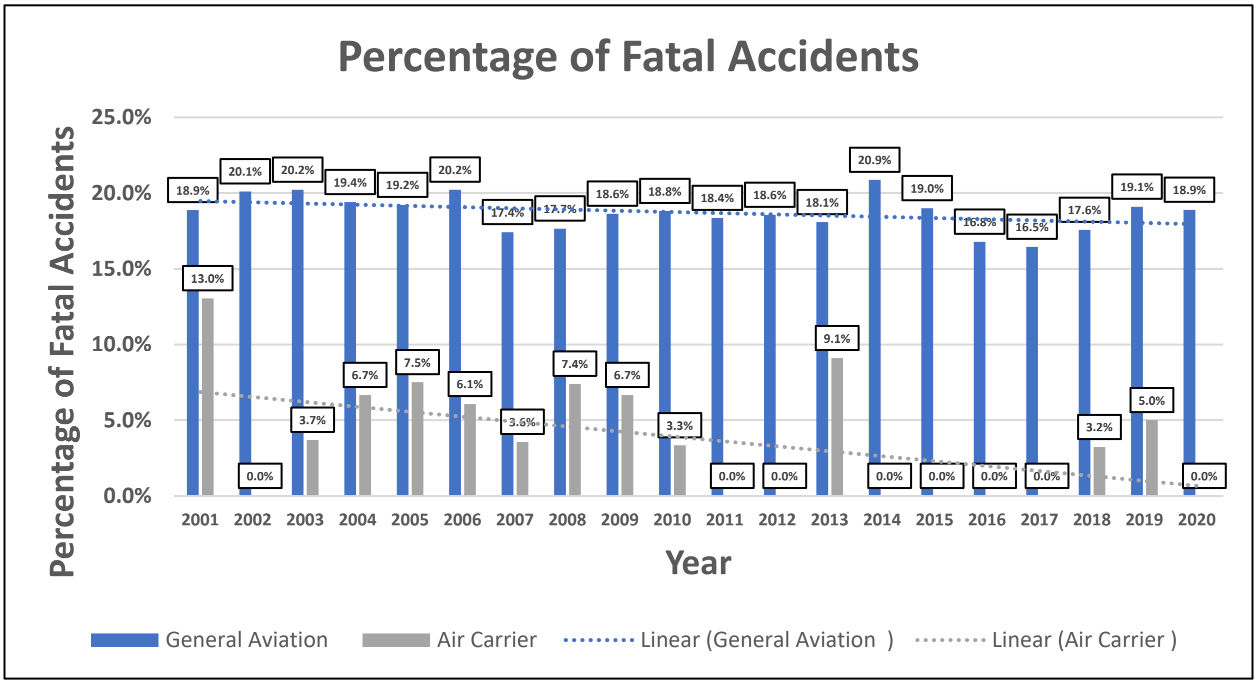
General aviation and air carriers have large discrepancies between their accident rates. In 2019, general aviation accidents occurred at a rate of 5.58 accidents per 100,000 flight hours, while air carriers experienced accidents at a rate of 0.202 accidents per 100,000 flight hours

(National Transportation Safety Board, 2021). That same year, the bulk of general aviation accidents occurred during approach and landing phases of flight, whereas the causes of 121 air carrier accidents were distributed equally between enroute and approach and landing phases of flight (National Transportation Safety Board, 2021). The raw comparison between the two major classifications of aviation travel indicates that accidents in 2019 were approximately twenty-seven times more likely to occur in general aviation than with air carriers. The aforementioned ratio peaked in 2013 and has decreased since, despite an overall increase since 2001 (National Transportation Safety Board, 2021).

Figure 2 details fatal accident percentages, differentiated between general aviation and air carriers between 2001 and 2020. Figure 2 also depicts general trends of fatal accident percentages over that same time frame.

Figure 2.

Fatal Accident Percentages for General Aviation and Air Carriers



Note. 121 and General Aviation Accident Rate data are sourced from the National Transportation Safety Board's "Aviation Accident Rates 2001-2020", US Civil Aviation Accident Rates, 2021. Copyright 2021 by the National Transportation Safety Board.

The NTSB's data clearly shows that while general aviation accounts for substantially higher accident rates, it also accounts for higher percentages of fatal accidents. In 2019, the percentage of fatal general aviation accidents was approximately 3.8 times higher than fatal air carrier accidents (National Transportation Safety Board, 2021).

Explaining Safety Discrepancies Between General Aviation and Air Carriers

While the air carrier accident rate has shown improvement since 2000, general aviation accident rates increased by twenty percent in the time frame from 2000 to 2013, with an increase in fatalities by twenty-five percent. General aviation crashes also tend to share "repeated causes of previous incidents" from year to year (Northcutt, 2013). Northcutt explores the discrepancies between air carriers and general aviation, specifically private pilots, by examining key areas where private pilot and airline pilots differ: training and experience, and current safety regulations.

A private pilot certificate, the most commonly held certificate held by general aviation pilots, requires only forty hours of flight time, whereas an Airline Transport Pilot certificate, which is required to work for an air carrier, requires a minimum of 1,500 flight hours. Northcutt states that "general aviation crashes were overwhelmingly (approximately 50%) more likely to occur for private pilots than all other pilots combined"(2013, p. 389), but counterintuitively, this data was not affected by the number of years of experience the pilots had. Accident likelihood not decreasing with number of flight hours after initial licensure indicates that the training for the license weighs more heavily than flight experience itself when it comes to predictors (Northcutt, 2013). An Instrument Rating, which requires further education and training, reduces a private pilot's risk for a weather-related accident by approximately five times, according to one NTSB study (National Transportation Safety Board, 2005).

Airlines are more strictly regulated by government agencies, due to public visibility and their inherent nature to serve the public for compensation. General aviation, which is generally less accessible to the travelling public, is not as strictly regulated. For example, in order to work as a pilot for an air carrier, one must hold an ATP, whereas general aviation encompasses several levels of pilot licenses. In order to exercise PIC privileges, private pilots only require a single recurrent training flight once every twenty-four calendar months, whereas ATPs exercising air transport privileges must go to a multi-day recurrent training every six or twelve months (Boyd, Scharf, & Cross, 2021). Additionally, air carriers are required to utilize FAA-certificated dispatchers to aid in flight planning and weather monitoring throughout the flight (Northcutt, 2013). Part 121 air carriers must also implement an FAA-approved Safety Management System (SMS), whereas most general aviation operators and pilots do not (Federal Aviation Administration, 2022). While it is impractical for a private pilot to utilize SMS as currently designed by the FAA, the lack of required participation in a safety system highlights the gaps in requirements for air carriers and general aviation.

General Aviation Accident Rates and Causes

Unfortunately, it is apparent that general aviation poses more safety risk to pilots and passengers than air carriers. Additionally, it is estimated that general aviation accidents cost, in total, $1.6-$4.6 billion when taking into account injury, death, investigative resources, loss of pay, and loss of property (Sobieralski, 2013). Several factors have been found to increase likelihood for accidents in general aviation flight, including degraded visibility, geographical location, lack of flight experience, and pilot certifications (Boyd, 2017).

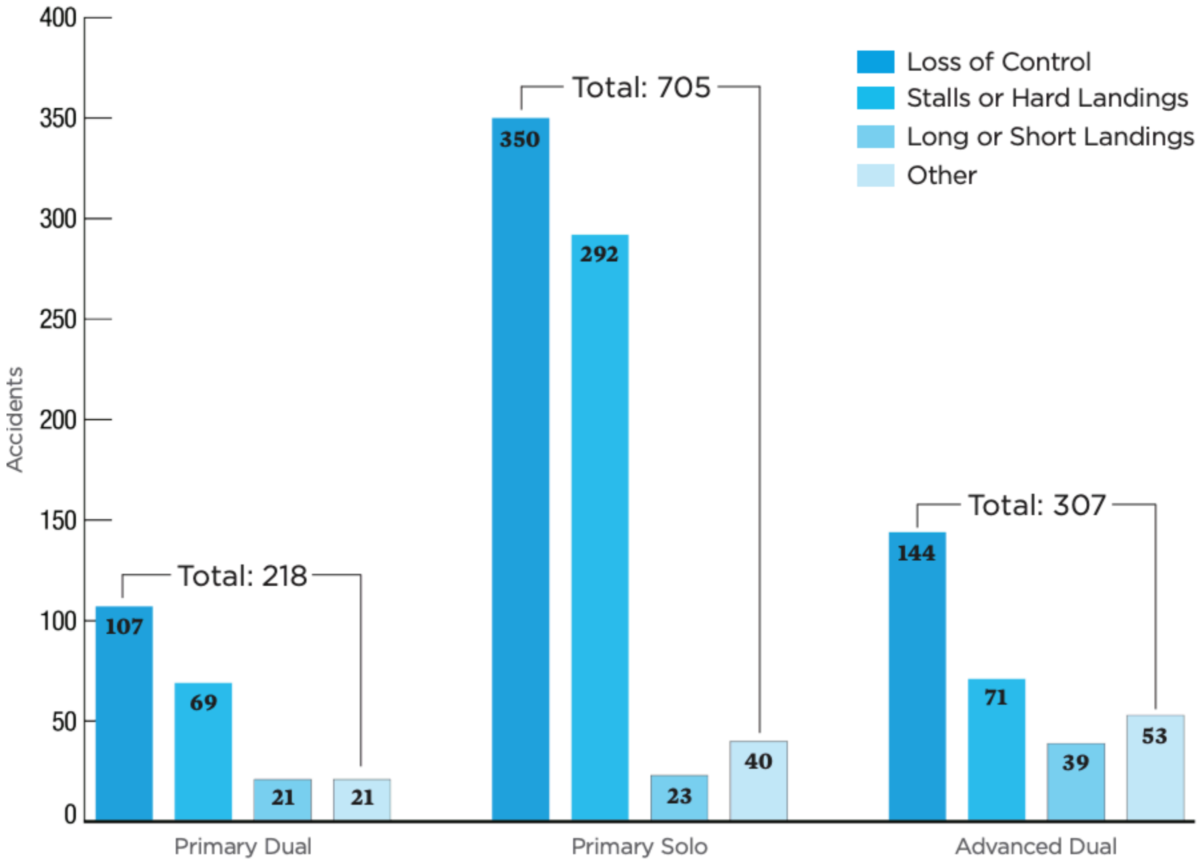
In 2019, fatal accidents made up roughly eighteen percent of all general aviation fixed-wing accidents (AOPA Air Safety Institute, 2021). The Aircraft Owners and Pilots Association (AOPA) 2019 Joseph T. Nall Report divides its data (sourced from NTSB reports) into commercial (which includes 14 CFR Part 135 and Part 137 operations, but not Part 121 operations) and non-commercial accidents. The Nall Report states that about eighty-two percent of non-commercial fixed wing general aviation accidents occurred in Day Visual Meteorological Conditions (VMC) (AOPA Air Safety Institute, 2021). Sixty-two percent of non-commercial general aviation fixed wing accidents were considered to be pilot-related accidents, as opposed to mechanical or unknown. Approach and landing accidents accounted for 342 of the 614 total pilot-related non-commercial fixed wing accidents; the other forty-four percent of accidents were attributed to take-offs, fuel management, maneuvering, weather, and other causes. Fortunately, only five percent of approach and landing accidents were fatal, accounting for sixteen percent of total fatal accidents (AOPA Air Safety Institute, 2021). A little more than half of the landing accidents could be attributed to loss of control; the next five highest contributing factors, in descending order based on number of occurrences, were: airspeed—stall, hard landings, runway conditions, gear operation, airspeed – long (AOPA Air Safety Institute, 2021).

Flight Training Accidents

A 2014 review conducted by the Aircraft Owners and Pilots Association (AOPA) sought to delve into accident rates associated with general aviation flight training. A major finding of this review stated that fatal accident rates during instructional flights were less than half of those during non-instructional flights. However, the overall accident rate of instructional flights was not found to be significantly different from that of non-instructional flights. The review also found that “takeoffs, landings, and go-arounds made up half of all accidents in…instruction” (AOPA Air Safety Institute, 2014, p. 8). Additionally, eighty percent of accidents on fixed-wing student solos occurred during takeoffs, landings, and go-arounds. Figure 3 shows the different causes for take-off, landing, and go-around accidents during fixed wing flight instruction, while also dividing accidents among the types of instruction. Advanced dual instruction refers to instruction where the student is already rated in the aircraft, while primary instruction refers to instruction where the student is not rated in the aircraft.

Figure 3.

Takeoff, Landing, and Go-around Accidents during Fixed-Wing Instruction



Note. From "Accidents During Flight Instruction: A Review", Aircraft Owners and Pilots Association (p. 10), 14. Copyright 2014 by the Aircraft Owners and Pilots Association.

Stabilized Approaches

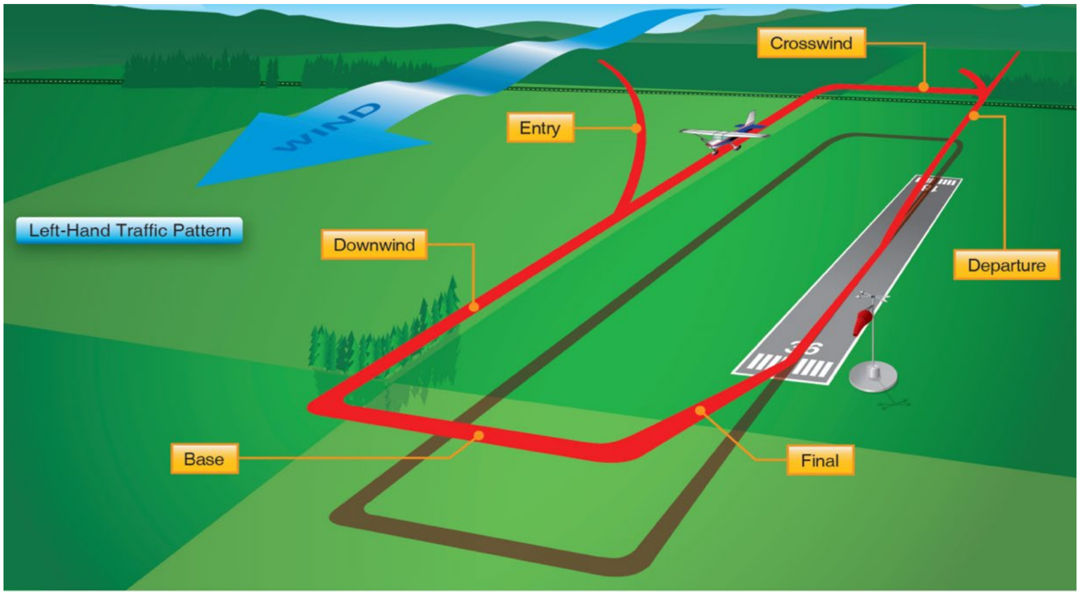
Accidents associated with the approach and landing phases of flight are concerning, as they account for a substantial portion of all accidents. The Airplane Flying Handbook (AFH) states that "the safe outcome of a landing should never be in doubt" (Federal Aviation Administration, 2021, p. 9-1). Despite differences in types of approaches flown, stable approach criteria should be met.

Approach Procedures Under VFR and IFR

Pilots are provided with structured guidance on how to maneuver to runways for approach and landing. Under VFR, pilots typically follow a traffic pattern to a runway. Figure 4 details a standard traffic pattern.

Figure 4.

Traffic Patterns



Note. From “Airplane Flying Handbook (FAA-H-8083-3C)”, United States Department of Transportation, Federal Aviation Administration, Flight Standards Service (p. 8-2), 2021. Copyright 2021 by the National Transportation Safety Board.

The AFH’s discussion on the Normal Approach and Landing begins on the base leg, and qualifies the positioning of base leg as a critical choice by the pilot to lay the foundation for a good landing. The final approach leg, defined as the leg for which the longitudinal axis of the airplane is aligned with the centerline of the intended landing surface, is the leg where the aircraft is expected to be fully configured. The pilot should use a combination of pitch and power adjustments to maintain the manufacturer’s recommended final approach speed as well as a desired rate of descent. The final approach path should be made to allow the aircraft to touch down in the first third of the runway (Federal Aviation Administration, 2021).

Under IFR, pilots may fly instrument approach procedures (IAP) to the runway. IAPs typically begin at an Initial Approach Fix (IAF) and provide means of instrument-based navigation from the IAF to a designated altitude and location in relation to the runway surface, from which the pilot is expected to be able to land the aircraft using visual outside references. The altitude and location the structured approach ends depends on the type of approach being flown.

Defining a Stabilized Approach

The FAA defines a stabilized approach as an approach where “the pilot establishes and maintains a constant-angle glide path towards a predetermined point on the landing runway. It is based on the pilot’s judgment of certain visual cues and depends on maintaining a constant final descent airspeed and configuration” (Federal Aviation Administration, 2021, p. 9-4). The act of establishing and maintaining stabilized approaches enables flight crews to be more situationally aware of the state of the aircraft and its trends, while providing more time for flight crews to monitor ATC clearances and to make go-around decisions, if necessary (Flight Safety Foundation, 2009).

While many factors come into play during a landing, generally speaking, stabilized approaches should be established before short final. Because hazardous landing events can be greatly reduced by stabilized approaches, it is important for pilots to recognize and correct deviations from a stable approach promptly. If prompt correction is not possible, a go-around should be executed immediately (Federal Aviation Administration, 2021). When aircraft are unable to establish a stable approach by 500 feet above ground level (AGL) in VMC, or 1000 feet AGL in IMC, it is typical for pilots to execute a go-around. When considering average general aviation aircraft, if an approach becomes unstabilized below 300 feet AGL, a go-around should be executed immediately (Federal Aviation Administration, 2021).

The following criteria are laid out as guidelines for a stable approach for a typical general aviation aircraft (Federal Aviation Administration, 2021, p. 9-6):

- Glide path should be a constant 3 degree path to the touchdown zone on the runway, obstacles permitting.
- Aircraft should track the centerline to the runway with minimal heading changes to account for wind; bank angle should be limited to fifteen degrees on final.
- Airspeed should be within +10/-5 knots of the manufacturer's recommended indicated airspeed.
- The appropriate aircraft configuration should be established with flaps, landing gear, and trim set appropriately.
- A descent rate should not generally exceed 500 to 1000 feet per minute.

- A power setting should be applied that is appropriate for the aircraft configuration and is recommended by the aircraft manufacturer.
- All necessary briefings and checklists should be completed prior to initiating the approach to ensure pilot focus on the approach.

As previously mentioned, if an approach to landing becomes destabilized at any point, a go-around should be executed by first applying maximum power, setting an appropriate pitch to allow for the aircraft to climb, and reducing flaps. Go-arounds are most critical when executed closer to the ground due to a tendency to incorrectly execute the go-around (i.e. increasing pitch to induce a climb when the aircraft is already close to stall speeds) and the lack of time available to execute the go-around. The FAA cautions pilots against falling prey to pride or expectancy when faced with the decision to go around (Federal Aviation Administration, 2021).

Dangers of Unstable Approaches

As previously discussed, a concerning percentage of accidents occur during the approach and landing phases of flight. The Flight Safety Foundation Approach-and-Landing (ALAR) Task force determined that unstabilized approaches, defined as approaches conducted outside predetermined glide path and speed parameters, were a causal factor in 66 percent of a sampling of accidents from 1984 to 1997 (Flight Safety Foundation, 2009). Additionally, the same task force determined that a flight crew's inability to ensure that an aircraft adhere to stable approach criteria was a causal factor in 45 percent of the same grouping of 76 accidents.

Data on Unstable Approaches and Landings

In their study of 76 serious jet accidents from 1984 to 1997, the Flight Safety Foundation ALAR Task force found that "rushing approaches, attempts to comply with demanding…ATC clearances, adverse wind conditions and improper use of automation" contributed to flight crews' inability to establish a stable approach (Flight Safety Foundation, 2009). The Flight Safety Foundation also outlines several contributing factors to unstable approaches (Flight Safety Foundation, 2009): (a) ATC instructions that result in flying outside glide path and airspeed parameters on approaches; (b) late runway changes given to crews by ATC; (c) inadequate awareness of wind conditions; (d) failure to recognize deviations from stable approach criteria; (e) excessive confidence by flight crews that the aircraft will become stabilized.

Upon examining unstable approaches, the Flight Safety Foundation also found the following types of deviations that led to the categorization of unstable approaches:

- entire approaches flown at idle power settings as an attempt to salvage an undesirably high approach or fast approach;
- approaches above or below the desired flight paths;
- low-airspeed;
- excessively high bank angles;
- activation of either the Ground Proximity Warning System (GPWS);
- late aircraft configuration;
- extended flare and touchdowns (Flight Safety Foundation, 2009).

Many of the above-listed deviations result from an attempt to correct another deviation from the list, leading to compounding errors which ultimately result in an unstable approach and landing.

If a stabilized approach is not achieved by the required altitude, or the aircraft exceeds a deviation from established parameters, a go-around must be executed immediately. However, when a go-around is not executed, the following behaviors have been found by the Flight Safety Foundation to be present (Flight Safety Foundation, 2009): (a) flight crews' excessive confidence in the ability to recover the approach; (b) the misconception that a low-gross-weight aircraft and a dry runway can make up for excessive airspeed; (c) lack of commitment to go-arounds as a course of action prior to beginning the approach; (d) fatigue or workload contributing to a lack of decision-making.

In a study conducted across 30,000 approach segments of Boeing 737 aircraft, 3100 approaches were found to be unstable, which equates to a ratio of approximately 10.3% (Jiao, Sun, Wang, & Han, 2018). The criteria used to build a “stable approach” for this study were: Indicated Airspeed, Indicated Vertical Velocity, Aircraft Configuration, Localizer (lateral approach path), Glide Slope (vertical approach path), Roll (bank angle), and N1 (thrust setting). Two of the main factors found to contribute to these unstable approaches were operating outside indicated airspeed parameters, which accounted for 77% of the deviations from a stable approach, and excessive lateral deviation from the pre-determined approach path, which accounted for 10% of the deviations (Jiao, Sun, Wang, & Han, 2018).

Because general aviation aircraft are not as widely equipped with technology that allows for specific tracking of approach parameters, very few studies exist that explore unstable approaches to the same depth that they do on transport category aircraft and at air carriers.

Unstable Approaches in Flight Training

Flight training presents a unique set of hazards in comparison to regular general aviation flight operations. A student learning to land, even with an instructor on board, inherently will present different complications than a seasoned pilot performing a landing. However, very little research exists in regards to unstable approaches in flight training, for the same reason that very little research has been conducted within general aviation as a whole.

One study, conducted in 2015, collected data between 1 July 2014 and 21 December 2014 to examine go-around prevalence when approaches do not meet stable condition requirements, the stability of approaches depending on time of day, and the stability of approaches at outlying airports compared to approaches conducted at the aircraft's home base (Bales & Roggow, 2015). The study found that approximately thirty percent of unstable approaches resulted in a go-around. The study also found that a stable approach was eight percent more frequent than an unstable approach during the day, while at night, the stable and unstable approach incidences are approximately equal. Stable approaches to outlying airports were found to be eight percent more frequent than unstable approaches, but the deviation between an approach to the home airport and an outlying airport was no more than two percent.

Explaining the Go-Around Gap

The Flight Safety Foundation states that 83 percent of runway excursions and 54 percent of all accidents studied in a 16-year time frame could have been prevented by a go-around (Blajev & Curtis, 2017). Unfortunately, only three percent of unstable approaches result in a go-around, even when company policy mandates a go-around (Blajev & Curtis, 2017).

When evaluating explanations for lack of go-arounds when deemed necessary, several findings arose. The first was general acceptance throughout the aviation industry of noncompliance with go-around policies, despite "empirical data that indicate this is the most common contributor to [approach and landing accidents]" (Blajev & Curtis, 2017, p. 4). Additionally, pilots do not find current go-around policies and criteria to be practical for their operational environments. Communication between crew members on the flight deck regarding go-arounds is ineffective. The perception is held by flight crews that a go-around can have hazardous outcomes. Lastly, because go-arounds are rare in the aviation industry, pilots are not as proficient in executing them (Blajev & Curtis, 2017).

Emotion and pilot decision-making have also been studied in an attempt to explain why go-around noncompliance is so prevalent among pilots. A 2013 study utilized functional magnetic resonance imaging (fMRI) and behavioral tests to study pilot decision-making, specifically to determine whether or not the study subjects would discontinue a course of action despite emerging evidence that safety was being compromised, otherwise known as plan continuation error (PCE) (Causse, Dehais, Peran, Sabatini, & Pastor, 2013). The study introduced a financial incentive to continue down an unsafe path, which led to an increase in risky decisions in periods of high uncertainty. In addition, the fMRI indicated high emotional states in the "emotion" areas of the brain, indicating impairment as emotion increased.

A different study was conducted in 2014 with the goal of explaining the origin of unstable approachess (Moriarty & Jarvis, 2014). The study recognizes that approaches are dynamic, ever-changing events, as opposed to a linear series of events, and uses grounded theory methodology to reach its conclusions. The study noted that pilots view approaches to landings as a culmination of multiple goals, including goals of outside agencies, and the ability or inability to "reconcile" those goals is the determining factor of approach success. Air traffic controllers' needs to fit several aircraft into a certain time frame frequently results in instructions issued to pilots to maintain speed or altitude profiles that make a stable approach difficult, if not impossible, to achieve. For example, a pilot may be presented with the need to configure an aircraft per the established approach profile, but the speed restriction given to them by ATC would exceed the aircraft's limitations on flaps. ATC restrictions, paired with goal fixation and an inappropriate expectation that the approach will become stabilized, can lead to continuing unstable approaches to landings. The study also discusses the importance of investigating regular habits of pilots on approaches, as opposed to limiting investigations to approaches that result in aircraft accidents (Moriarty & Jarvis, 2014).

Flight Data and its use for Aviation Safety

Flight data proves instrumental in providing quantitative data both for airline use and research. To make their determinations regarding parameters most commonly exceeded on unstable approaches, Jiao et al. (2018) required in-flight data. Another study found that utilizing flight data analysis programs are a "more accurate and effective way" to evaluate landing performance of flights (Wang, Zhang, Dong, Sun, & Ren, 2018).

Data collection in modern day transport category aircraft is commonplace. Flight Operational Quality Assurance (FOQA) is a voluntary safety program that many airlines choose to implement as a method for examining flight data and safety assurance. Pilot labor associations, companies, and the FAA enter into a FOQA program together to allow for maximum benefit from data collection. FOQA was created with the intent to "allow all three parties to identify and reduce or eliminate safety risks, as well as minimize deviations from the regulations" (Federal Aviation Administration, 2004, p. 1).

Airborne Data Recording Systems are systems that collect data in-flight via sensors, which is then sent to Ground Data Replay and Analysis Systems (GDRAS), which translates raw data into a usable form. GDRAS have the capability to compare data to predetermined norms and generate reports for use. The two major forms of analysis performed on flight data within a FOQA program are parameter exceedance analysis and statistical analysis. As confidentiality is the cornerstone of FOQA, the data is fully unable to be identified, except by a company-designated gatekeeper, who may be able to follow up with individual pilots depending on the company’s policy. Many entities who do not have formalized FOQA programs choose to use similar data collection procedures and implement similar policies regarding that data; data collection in this instance is called Flight Data Monitoring.

Data collection in transport-category aircraft typically used by United States airlines is easily sourced from flight data recorder systems, which are legally required by the FAA. Data in general aviation aircraft is not as easily sourced, as the aircraft are not always designed to collect data; if the aircraft does allow for data collection, the data is frequently limited to far fewer parameters in comparison to air carriers (Puranik & Mavris, 2017).

Initial cost to establish any form of data collection, regardless of FOQA participation or not, is a large deterrent (Swinney, 2013). Many general aviation companies and individual aircraft owners are not in a financial position to ensure their aircraft are equipped with the ability to collect the data, nor are they able to purchase and utilize software to analyze data. However, as technology advances, more aircraft are coming into the market with FDM capability already in place. This, paired with more commonplace GPS navigation, lays a strong foundation upon which general aviation can better utilize FDM for safety and maintenance purposes (Swinney, 2013).

Despite being a large, important sector of general aviation, many flight schools are not in a position to utilize Flight Data Monitoring (FDM). However, large scale Part 141 flight schools generally have more resources and the ability to invest in the necessary tools to develop a FDM program, namely university flight schools. University flight training presents its own unique challenges, such as pacing of training, advanced syllabi, and increased standards of performance. Universities such as Purdue University, the University of North Dakota, and Embry-Riddle

Aeronautical University were among the first to implement collegiate FDM programs (Swinney, 2013).

Chapter III: Methods

The collection of in-flight data, in the form of Flight Data Monitoring (FDM) or Flight Operational Quality Assurance (FOQA), is one of the most important information sources utilized to improve and maintain aviation safety. Part 121 air carriers use flight data on a regular basis in order to track safety performance goals, track unsafe events, and diagnose maintenance discrepancies. Flight data collection has not yet been universally adopted by general aviation. Arguably, however, the general aviation sector stands to gain the most from data collection due to its increased accident rates. University flight schools are at an advantage for implementing Flight Data Monitoring programs due to increased resource access, from both a fiscal and research perspective.

As unstable approaches contribute to a large percentage of accidents, general aviation safety can be greatly improved by a better understanding of the approach and landing phases of flight. Fortunately, Flight Data Monitoring provides a significant amount of information to be studied and understood. This research seeks to understand potential predictors of unstable approaches and the likelihood of go-arounds being conducted if an unstable approach is encountered.

Study Overview

A Part 141 flight school with an FDM program was the subject of this study. The flight school also describes specific stable approach criteria that flight crews are to abide by in order to continue an approach to a landing. These criteria were used to determine which approaches were unstable and compare unstable approach outcomes across several independent variables which may have an effect on approach stability. In addition, this study also evaluated which of the independent variables were likely to predict a go-around once an unstable approach was encountered.

Flight data was analyzed and evaluated using General Electric's eFOQA® program. Events were created within the program to provide information on approaches, landings, unstable approaches, and go-arounds. This data was then exported to a Microsoft Excel® workbook and further filtered to turn the data into categorical variables. Data representing over 30,000 approaches were then imported into IBM's SPSS® in order to conduct a binomial logistic regression analysis.

Flight School Overview

Flight Training Structure

The flight school is a Part 141 flight school with Training Course Outlines (TCOs) approved by the FAA. The flight school has a Single Engine Land Private Pilot training course, an Instrument Rating Airplane training course, a Single-Engine Land Commercial Pilot training course, and a Commercial Multi-Engine Land training course. The flight school also maintains TCOs for the Certificated Flight Instructor courses. The flight school will occasionally conduct Part 61 flight training where warranted. The majority of flight training at the flight school is conducted under Part 141. Regardless of the Part under which the training is performed, all operations comply with SOPs defining stable approach criteria.

Aircraft

The Part 141 flight school's aircraft fleet consists of seventy-five aircraft. Of those aircraft, sixty-two are Cessna 172S NAV IIIs and eight are Diamond DA-42 NGs. The DA-42 NGs are the flight school's multi-engine training aircraft, while the Cessna 172 Nav IIIs are the flight school's primary single-engine training aircraft. The Cessna 172S Nav IIIs and the

Diamond DA-42 NGs are the aircraft that are used for the vast majority of flight training at the flight school.

Flight Data Logging

The Diamond DA-42 NGs and the Cessna 172S Nav IIIs are equipped with FDM capabilities. On both the Diamond DA-42 NG and the Cessna 172S Nav III aircraft, FDM is collected by means of a Secure Digital (SD) card inserted into the Multi-Function Display (MFD) on the right-hand side of the flight deck. The SD card collects data whenever electrical power is supplied to the MFD. The card's data recording status can be verified by the user by viewing Auxiliary pages on the MFD (Garmin, 2018). Because electrical power is supplied to the MFD during every flight, the SD card collects data on every flight. Each time the power is supplied and then subsequently removed from the MFD, the SD card stores the parameters in a comma-separated values (CSV) file. Each file represents one time the electrical power was supplied to the MFD.

Parameters on both aircraft are collected at a rate of 1 hertz (Hz). Aircraft flap and landing gear configuration are not tracked by this FDM system. Additionally, there are no weight-on-wheels sensors on the flight school's aircraft. A detailed list of data parameters collected by the Flight Data Logging system can be found in Appendix A and Appendix B.

Flight School Data Analysis

Once per month, the flight school's Safety Department staff removes the SD cards from all of the FDM-equipped aircraft and uploads the data using a computer and SD card reader. The data is then housed both on flight school-owned solid-state hard drives and within a database managed by General Electric (GE). Files which logged ground action are filtered out before being entered into the database.

General Electric’s eFOQA® program is used by the flight school’s Safety Department to house and analyze flight data. The data is password-protected; only users with specifically-allocated accounts may access the data through a remote desktop application. GE’s eFOQA® can be programmed by the users to detect certain events or flight conditions within its Automated Parameter Measurement (APM) application. Because GE’s eFOQA® program lacks built-in events for the flight school’s aircraft, the flight school’s Safety Department has developed its own events specific to the flight school’s unique operation. For example, the flight school’s Safety Department has programmed the GE software to identify any over-bank condition whenever an aircraft exceeds a certain prescribed bank angle. The software can also be programmed to take certain useful measurements at the time of event occurrence. For example, when flagged, the over-bank condition event will also populate information on the maximum bank angle during the event and the duration for which the bank limitation was exceeded. Multiple events can be consolidated into a single “profile”, which can be programmed to run over a series of flights selected by the user in an “analysis”. For example, the flight school has created a profile that simultaneously tests selected flights for engine temperature exceedances, engine over-speeds, and engine shutdowns.

The Event Measurement System (EMS) application allows for profiles and events created in APM to be viewed and analyzed in greater detail. Users can select a certain range of flights to view under the lens of the desired profile. EMS allows users to view raw data in a tabular form, data exported to a map, and data exported to a flight deck view. Users can customize which parameters they would like to view at any given timeframe.

Data Range

A total of 36,864 approaches across 9,353 flights from January 1, 2021 until April 30, 2021 were included in the study. The date range captures a time frame of one academic semester at the flight school. The date range also captures a large seasonal change within the year, which brings with it varying winds and weather patterns.

Of the 9,353 flights, 801 flights were conducted in a Diamond DA-42 NG and the remaining 8,552 flights were conducted in a Cessna 172S Nav III. Cessna 172S Nav III approaches accounted for 34,249 approaches, while Diamond DA-42 NG approaches accounted for 2,615 approaches.

Flights were included in the sample regardless of the goal of the flight. The flight school regularly conducts flights to train for Private Pilot Certificates, Instrument Ratings, Commercial Certificates, and Commercial Multi-Engine Add-Ons. Additionally, employee currency flights and employee training flights occur on a regular basis at the flight school. Employees and students are also permitted to rent the aircraft for recreational use. Flight crews may consist of a solo student, an instructor and student, two instructors, or recreational users.

Ethics Review

Confidentiality is a cornerstone of flight data collection in any form, FDM or FOQA. The flight school maintains a strict confidentiality policy surrounding FDM data, mirroring FOQA programs utilized by Part 121 air carriers. Permission to use FDM data for the study was obtained from the flight school's Aviation Safety and Flight Departments, as well as the Dean of the College under which the data is collected.

The study also required Institutional Review Board approval for Exempt Status due to the human subjects in the archival flight data. Because the archival data is de-identified prior to entering the General Electric database and there was no available method to attach any identifying information to the flights within the database, Exempt status was granted.

Event Programming

The study required the GE eFOQA® program to indicate (a) whenever aircraft were on approach, (b) whether or not the approach was stable per the flight school's pre-established criteria, (c) whether or not a go-around was conducted, and (d) whether or not the aircraft was flying on an instrument approach procedure (IAP). Because neither of the subject aircraft are equipped with weight-on-wheel sensors that can overtly translate to the aircraft being airborne, events were developed specifically for the study to identify the aforementioned flight conditions as opposed to utilizing using GE's pre-written events, which rely on weight-on-wheels sensors.

Cessna 172S Nav III Event Programming

A profile was created within APM called "Unstable Approaches C172 at 100' AGL". Four events were created within this profile: (a) "Approach C172", (b) "Go-around C172", (c) "Unstable Approach C172", and (d) "IAP C172".

Cessna 172S Nav III Approach Events. An approach to landing in a Cessna 172S Nav III is generally characterized by a regular descent and a slowly decreasing airspeed not to decrease below aircraft stall speed.

The Approach C172 event was designed to trigger when the all following conditions were met:

- altitude between 0 and 400 feet above ground level (AGL);
- propeller speed less than 2200 revolutions per minute (RPM);
- Indicated Air Speed (IAS) between 55 and 80 knots.

The altitude range of 0 to 400 feet AGL was selected to eliminate the possibility of low-level flight maneuvers commonly practiced by the flight school, such as Turns Around a Point or Simulated Emergency Approach and Landings, erroneously showing up as true approaches to landings. The flight school's policies prohibit descending below 500 feet AGL unless necessary for a landing or takeoff. Additionally, an altitude of 400 feet AGL was chosen to compensate for potential barometric pressure differences from day to day. While the possibility exists that not all flights adhere to this policy, either intentionally or mistakenly, it was determined that the likelihood was sufficiently negligible for use of the aforementioned altitude range.

The propeller speed parameter maximum of 2200 RPM was selected to increase the probability that the aircraft is descending on approach; generally, a Cessna 172S Nav III conducts its approaches with a power setting less than 2200 RPM. Occasionally, in the event of a large headwind or significant downdraft, the RPM will need to temporarily be set above 2200 RPM. However, the RPM will need to decrease again to resume a normal descent, and will do so somewhere between 0 feet and 400 feet AGL. The selected power setting parameter also eliminates erroneous climbs from presenting as approaches, as the flight school generally conducts any climbs below 400' AGL at power settings above 2200 rpm.

The IAS range of 55 knots to 80 knots was selected to ensure that the aircraft is airborne, as opposed to taxiing on the ground. The highest published rotation speed of a Cessna 172S Nav III is 55 knots (Cessna Aircraft Company, 2010, p. 4-18). Within the altitude range of 0 feet and 400 feet AGL, approach speeds are much closer to 70 knots; the higher end of the selected airspeed range, 80 knots, was selected to capture approach speeds that could exceed 70 knots but still feasibly be considered an approach within the selected altitude range.

Additional measurements collected for each approach event included:

- latitude at Start of Event
- longitude at Start of Event
- ambient light condition at the start of the event
- communication frequencies at the start of the event
- magnetic heading 30 seconds after the start of the event
- GPS altitude in Mean Sea Level (MSL) at the start of the event

Cessna 172S Nav III Go-around Events. Go-arounds in a Cessna 172S Nav III are generally characterized by a change in engine RPM from a previous descent-inducing power setting to a full power setting until reaching at least traffic pattern altitude (TPA) while maintaining runway heading until reaching 300 feet below TPA (Federal Aviation Administration, 2021).

The Go-around C172 event was designed to trigger when the all following conditions were met:

- altitude between 0 and 400 feet above ground level (AGL);
- a change in RPM greater than 100 RPM;
- IAS greater than 45 knots;
- yaw rate was less than 3 degrees per second for 15 seconds after the event occurred;
- power setting greater than 1500 RPM for 120 seconds after the event occurred.

The altitude range of 0 and 400 feet AGL was selected to mirror the altitude range defined by the Cessna 172S Nav III Approach event to ensure the go-arounds were associated with approaches within the vicinity of an airport. Climbs that resemble go-arounds can occur while practicing maneuvers and go-arounds can occur at any point on an approach. The study was designed to evaluate go-arounds associated with approaches that occurred below 400 feet AGL.

The RPM change of 100 RPM was selected to ensure that the event captured an RPM increase.

The IAS minimum of 45 knots was established in order to ensure that touch-and-gos were not erroneously mistaken for go-arounds; generally, a Cessna 172S Nav III is airborne above 45 knots during the landing phase of flight, as the aircraft's published stall speed in a landing configuration is 40 KIAS (Cessna Aircraft Company, 2010). A higher speed was not selected because researchers also wanted to ensure that low-level go-arounds were also captured in this study.

The yaw rate maximum of 3 degrees per second was selected to mirror the definition of a standard rate turn (Federal Aviation Administration, 2012). While it is possible that the aircraft may turn at a rate less than 3 degrees per second following a go-around, it is very unlikely, as generally, aircraft maintain runway heading until reaching a safe altitude. Fifteen seconds was selected to ensure that a straight heading was maintained long enough to categorize the event as a go-around, but not so long that the aircraft would reach 300 feet (the point where an aircraft usually makes a ninety-degree traffic pattern turn) below TPA prior to the event flagging.

The propeller speed minimum of 1500 RPM for 120 seconds was selected to ensure that the power setting indicated a go-around, not a temporary power setting used to arrest excessive descent rates. Once go-arounds begin, they are very rarely discontinued. Therefore, the 120 second minimum duration ensures that the aircraft is truly conducting a go-around.

No additional measurements were taken for go-around events.

Cessna 172S Nav III Unstable Approach Events. The flight school requires flight crews to execute immediate go-arounds if any of the following conditions are not met by 100 feet AGL on approach:

- constant final approach pitch attitude;
- airplane trimmed to maintain final approach pitch attitude;
- airspeed within 5 knots of appropriate approach speed (including gust factor);
- landing configuration established;
- airplane on proper approach-path to desired aiming point;
- airplane properly aligned with runway centerline; and
- “STABLE” callout complete

Trim settings, appropriate landing configuration, and callouts are outside the capability of the aircraft to record. Additionally, due to the inability of the software to recognize more than one landing runway per flight, runway alignment was not programmed as a triggering parameter. A desired landing point on the runway can change depending on the desire of the flight crew and the goal of the landing, making proper approach-path to desired aiming point infeasible to measure.

The Unstable Approach C172 event was designed to trigger when the following conditions were met:

- altitude between 80 and 120 feet AGL;
- propeller speeds between 1200 RPM and 2200 RPM;
- IAS above 35 knots

The altitude range of 80 and 120 feet AGL was chosen to capture the aircraft passing through 100 feet AGL as precisely as possible. Because the FDM system only captures data at a rate of 1 Hz, and GE’s EMS® does not interpolate between data points, the system may not always be able to capture the exact moment when the aircraft passes through 100 feet AGL. Due to the dynamic nature of approaches and landings, flight crews are likely not paying attention to the altimeter in this close of detail; they are estimating 100 feet AGL as closely as possible while managing several other tasks. The selected altitude range, therefore, captures 100 feet AGL as precisely as possible within the restrictions of the analysis program.

The propeller speed range of 1200 RPM to 2200 RPM was selected in order to ensure that the aircraft was airborne while also being on a descent to landing. The upper limit of the RPM range was selected to mirror the “Approach C172” Event. The lower limit of the RPM range was selected to reflect the approximate aircraft idle setting while airborne; an aircraft idles at a higher RPM while airborne.

The airspeed of 35 knots was selected to ensure that the aircraft was not taxiing while also ensuring that speeds drastically outside the stable approach criteria were allowed to trigger the event. Taxiing usually occurs at speeds much lower than 35 KIAS; taxi speeds are usually not sufficient enough to register an indicated airspeed.

Additionally, the Unstable Approach C172 event was programmed to trigger if any of the following conditions were met while also meeting the aforementioned Unstable Approach C172 criteria:

- IAS greater than 70 knots while the Landing Wind Speed was less than 15 knots;
- IAS less than 56 knots;
- pitch attitude greater than 2 degrees;
- pitch attitude less than -3 degrees; or
- pitch rate exceeded 2 degrees per second

A Cessna 172S Nav III’s final approach indicated airspeeds, as stated by the manufacturer, range from 61 knots to 65 knots. Occasionally, flights are flown at 70 knots for no-flap landings, but the no-flap landings account for a very small portion of total landings. Per flight school SOPs, flight crews increase their landing approach speeds by half the gust factor. For example, if the winds are reported to be sustaining 10 knots, but gusting up to 20 knots, the flight crew should add 5 knots to the final approach speed of the aircraft.

The upper limit of 70 knots, given that the wind is less than 15 knots, was established in order to capture the vast majority of approaches. Because higher speed, no-flap approaches are a small portion of all approaches flown at the flight school, selecting a higher speed would likely have flagged fewer unstable approaches than actually occurred. Most approaches flown at the flight school are flown between 61 to 65 knots, putting an airspeed of 70 at the higher range of stable as defined by the flight school. If a speed of 75 knots had been selected, all of the approaches between 70 and 75 knots would not have flagged as unstable, even though they likely were unstable. Limitations within the GE eFOQA® software prevented researchers from determining an appropriate gust factor for each approach. Therefore, a wind speed of 15 knots was selected as an exception to the 70-knot upper speed limit.

The lower indicated airspeed limit of 56 knots was selected due to it being 5 knots less than 61 knots, in keeping with the flight school’s stable approach criteria.

All three pitch attitude criteria were selected to reflect pitch stability. Generally, while in landing configuration, pitch attitudes lower than -3 yield speeds too fast to be considered stable, while pitch attitudes higher than +2 yield speeds too slow to be considered stable. The flight school’s Standardization Manual states that a target pitch attitude for Final Approach in a Cessna

172S Nav III is -2 degrees. A pitch rate greater than 2 degrees per second exceeds stable approach criteria.

No additional measurements were taken for unstable approach events.

Cessna 172S Nav III Instrument Approach Events. Instrument approaches are more difficult to categorize and differentiate from other types of flight maneuvers. While GE's eFOQA® software can identify when instrument approaches are being followed, it cannot do so reliably when there are multiple instrument approaches flown on one flight. A flight school environment often demands that multiple instrument approaches are flown on the same flight. Additionally, the speed ranges and power settings associated with flying an instrument approach procedure have very broad ranges that also overlap with many other flight maneuvers practiced by the flight school. An event was created that identified most of the distinguishing features of an instrument approach. Instrument approaches can be characterized by a consistent heading and/or approach path in their final segments while descending.

The IAP C172 event was programmed to trigger when all of the following conditions were met:

- altitude less than 1,550 feet AGL for 120 seconds;
- altitude greater than 1,500 feet for at least 20 seconds prior to the start of the event; and
- heading changed no more than 16.6% for 120 seconds.

The aircraft altitude maximum of 1,550 feet AGL was established because instrument approach procedures involve steady descents to an airport environment from a higher altitude than TPA, typically from the arrival environment. The time frame of 120 seconds was established to ensure that the event did not trigger if an aircraft climbed back above 1,500 feet

AGL. The aircraft altitude minimum of 1,500 feet AGL for 20 seconds prior to the start of the event ensures that the aircraft descended through the altitude of 1,500 feet AGL prior to triggering the event; otherwise, repeated traffic pattern operations could trigger the event.

The heading change limitation was established because the Final Approach Segments of instrument approach procedures flown by the flight school consist of a straight-line flight path. The numeric value of 16.6% of change in heading was established to allow a heading deviation of 30 degrees on either side of the approach path. While the Instrument Airman Certification Standards (ACS) require flight crews to remain within 10 degrees of the selected heading, not all approaches are flown in accordance with the ACS in the flight training environment; a larger heading tolerance was required in order to capture the imperfect instrument approaches.

The aforementioned criteria were not sufficient enough to separate out IAPs from a long, steady, visual approach to the airport. Therefore, each flagged IAP was verified by comparing flight paths of IAP C172 Events to known published IAPs as well as verifying that the active GPS waypoints recorded by the avionics system matched waypoints on the published IAPs. Verifying the flight path of each IAP also allowed for the classification of the IAP into one of two types: circling approaches or straight-in approaches.

No additional measurements were taken for instrument approach events.

Diamond DA-42 NG Event Programming

A profile was created using GE’s APM® called “Unstable Approaches DA42 at 100’ AGL”. Four events were created within this profile: (a) “Approach DA42”, (b) “Go-around DA42”, (c) “Unstable Approach DA42”, and (d) “IAP DA42”.

Diamond DA-42 NG Approach Events. An approach to landing in a Diamond DA-42 NG is generally characterized by a regular descent and a slowly decreasing airspeed not to decrease below aircraft stall speed.

The Approach DA42 event was programmed to trigger when all of the following conditions were met:

- altitude between 0 and 400 feet above ground level (AGL);
- power setting on either engine was less than 40%; and
- IAS between 79 and 90 knots.

The altitude range of 0 to 400 feet AGL was selected to eliminate the possibility of low-level flight maneuvers commonly practiced by the flight school, such as Simulated Emergency Approaches and Landings, erroneously showing up as true approaches to landings. The flight school's policies prohibit descending below 500 feet AGL unless necessary for a landing or takeoff. While the possibility exists that not all flights adhere to this policy, either intentionally or mistakenly, it was determined that the likelihood of an aircraft descending below 400 feet AGL while not on approach to landing was sufficiently negligible for use of the aforementioned altitude range. Additionally, an altitude of 400' AGL was chosen to compensate for potential barometric pressure differences from day to day.

The propeller speed parameter of 40 percent was selected to ensure that the aircraft was descending on approach; generally, a Diamond DA-42 NG conducts its approaches with power settings less than 40%. Occasionally, in the event of a large headwind or significant downdraft, the RPM will need to temporarily be set above 40%. However, the power setting will need to decrease again to resume a normal descent, and will do so somewhere between 0 feet and 400 feet AGL. The selected power setting parameter also eliminates erroneous climbs from presenting as approaches, as the flight school conducts any climbs below 500’ AGL at a full power setting. Because the flight school consistently practices single-engine approaches to landings, only one of the engines needs to be at a power setting below 40% in order to trigger the event.

The IAS range of 79 knots to 90 knots was selected to ensure that the aircraft is airborne, as opposed to taxiing on the ground. The highest published rotation speed of a Diamond DA-42 NG is 76 knots (Diamond Aircraft, 2012, p. 4A-4). Within the altitude range of 0 feet and 400 feet AGL, approach speeds are much closer to 85 knots; the higher end of the selected airspeed range, 90 knots, was selected to capture approach speeds that could exceed 85 knots but still be feasibly considered an approach within the selected altitude range.

Additional measurements collected for each approach event included:

- latitude at the start of the event;
- longitude at the start of the event;
- ambient light condition at the start of the event;
- communication frequencies at the start of the event;
- magnetic heading 30 seconds after the start of the event;
- GPS altitude in Mean Sea Level (MSL) at the start of the event

Diamond DA-42 NG Go-around Events. Go-arounds in a Diamond DA-42 NG are generally characterized by a change in power setting on both engines from a previous descent-inducing power setting to a full power setting until reaching at least 500 feet and while maintaining runway heading until reaching 300 feet below TPA (Federal Aviation Administration, 2021). Single-engine go-arounds are prohibited by the flight school.

The Go-around DA42 event was defined as an event that met all of the following criteria:

- altitude between 0 and 400 feet above ground level (AGL);
- IAS was greater than 68 knots;
- yaw rate was less than 3 degrees per second for 15 seconds after the event occurred;
- power setting for both engines was greater than 50% for 15 seconds after the event occurred.

The altitude range of 0 and 400 feet AGL was selected to mirror the altitude range defined by the Approach DA42 event to ensure the go-arounds were associated with approaches within the vicinity of an airport. Climbs that resemble go-arounds can occur while practicing maneuvers and go-arounds can occur at any point on an approach. The study was designed to evaluate go-arounds associated with approaches that occurred below 400 feet AGL.

The IAS minimum of 68 knots was established in order to ensure that neither touch-and-gos nor takeoffs were erroneously mistaken for go-arounds; generally, a Diamond DA-42 NG is operated above 68 knots due to Minimum Controllable Airspeed (Vmc) considerations (Diamond Aircraft, 2012, p. 2-4). A higher speed was not selected because researchers also wanted to ensure that low-level go-arounds were captured in this study.

The yaw rate maximum of 3 degrees per second was selected to mirror the definition of a standard rate turn (Federal Aviation Administration, 2012). While it is possible that the aircraft may turn at a rate less than 3 degrees per second following a go-around, it is very unlikely, as generally, aircraft maintain runway heading until reaching a safe altitude. Fifteen seconds was selected to ensure that a straight heading was maintained long enough to categorize the event as a go-around, but not so long that the aircraft would reach 300 AGL (the point where an aircraft usually makes a ninety-degree traffic pattern turn) below TPA prior to the event flagging.

The power setting of both engines at a minimum of 50% was selected to ensure that the power setting indicated a go-around, not a temporary power setting used to arrest excessive descent rates. Once go-arounds begin, they are very rarely discontinued. Therefore, the 15 second minimum duration ensures that the aircraft is truly conducting a go-around. The minimum duration required is significantly shorter than a Cessna 172S Nav III's due to the Diamond DA-42 NG's relatively greater performance capabilities.

No additional measurements were taken for go-around events.

Diamond DA-42 NG Unstable Approach Events. Approaches flown in the Diamond DA-42 NG must adhere to the same stable criteria as outlined in 'Cessna 172S Nav III Unstable Approach Events'.

As in the Cessna C172S Nav III aircraft, trim settings, landing gear and flap configuration, and callouts are outside the capability of the aircraft to record. Additionally, runway alignment was outside the ability of researchers to program, due to the inability of the GE software to recognize more than one landing runway per flight.

The Unstable Approach DA42 event was defined as an event that met all of the following criteria:

- altitude between 80 and 120 feet AGL;
- power setting for either engine was less than 40%; and
- IAS above 45 knots

The altitude range of 80 and 120 feet AGL was chosen to capture the details of aircraft stability while the aircraft was as close as possible to 100 feet AGL. The justification is the same as the justification for the same altitude range associated with the Unstable Approach C172 event.

The power setting maximum of 40% on either engine was selected to mirror the power setting maximum for the Approach DA42 event to ensure the aircraft was on approach.

The airspeed of 45 knots was selected to ensure that the aircraft was not taxiing while also ensuring that speeds drastically outside the stable approach criteria were allowed to trigger the event. Taxiing usually occurs at speeds much lower than 45 KIAS; taxi speeds are usually not sufficient enough to register an indicated airspeed.

Additionally, the unstable approach event was programmed to trigger if any of the following conditions were met while also meeting the aforementioned “Unstable Landing DA42” criteria:

- IAS greater than 90 knots while the Landing Wind Speed was less than 15 knots;
- IAS less than 79 knots;
- pitch attitude greater than 2 degrees;
- pitch attitude less than -3 degrees; or
- pitch rate exceeded 2 degrees per second

The Diamond DA-42 NG’s final approach indicated airspeed, as stated by the manufacturer, ranges from 84 knots to 86 knots. No flap landings in the Diamond DA-42 NG are flown at 86 knots. As in the Cessna 172S Nav III, flight crews increase their landing approach speeds by half the gust factor per the flight school SOPs.

The upper limit of 90 knots given that the wind is less than 15 knots was determined in accordance with the 5-knot exceedance limitation described by the flight school’s Stable Approach Criteria. Because higher speed, no-flap approaches are a small portion of all approaches flown at the flight school, selecting a higher speed would likely have flagged fewer unstable approaches than actually occurred. Most approaches are flown at 84 to 85 knots, putting an airspeed of 91 at the higher range of stable as defined by the flight school. If a speed of 91 knots had been selected, all of the approaches between 90 and 91 would not have flagged as unstable, even though they likely were unstable. Limitations within the GE eFOQA® software prevented the establishment of an appropriate gust factor for each approach. Therefore, a wind speed of 15 knots was selected as an exception to the 90-knot upper speed limit.

The lower indicated airspeed limit of 79 knots was selected due to it being 5 knots less than 84 knots, aligning with the flight school's stable approach criteria.

All three pitch attitude criteria were selected to reflect pitch stability. Generally, while in landing configuration, pitch attitudes lower than -3 yield speeds too fast to be considered stable, while pitch attitudes higher than 2 yield speeds too slow to be considered stable. The flight school's Standardization Manual states that a target pitch attitude for Final Approach in a Diamond DA-42 NG is -2 degrees. A pitch rate greater than 2 degrees per second exceeds stable approach criteria.

No additional measurements were taken for unstable approach events.

Diamond DA-42 NG Instrument Approach Events. The IAP DA42 event was programmed to trigger when all of the following criteria were met:

- altitude less than 1,550 feet AGL for 90 seconds;
- altitude was greater than 1,500 feet AGL for at least 20 seconds prior to the start of the event; and
- heading changed no more than 16.6% for 90 seconds.

The event criteria and reasoning are identical to the criteria used to trigger the IAP C172 event with the exception of the durations. The specific duration of 90 seconds for the altitude and heading change maximums were chosen after assessing a common Home Base approach and determining the average time it takes to get from the Final Approach Fix to altitude minimums using average ground speed of the Diamond DA-42 NG during that segment of the approach. The ground speeds may vary depending on winds and speed restrictions placed on the aircraft's crew by air traffic control. However, each instrument approach procedure was individually verified as described previously by the researchers due to the same limitations of the IAP C172 event.

No additional measurements were taken for instrument approach events.

External Approach Factors

In order to collect data on the proposed independent variables that could have an effect on approach stability, information in addition to the previously-listed events was required. The aforementioned additional measurements associated with the Approach C172 or the Approach DA42 events were used to determine the ambient light conditions at the time of approach, the location of the approach, and the specific home base runway associated with the approach.

Ambient light condition measurements returned values of 'Day', 'Twilight', and 'Night'. For the purpose of this study, 'Twilight' was considered to be a value of day, as the question of approach stability at nighttime is related to the level of darkness seen by the crew.

Whether or not the aircraft was conducting an approach at its home base or at an outlying airfield was determined by a combination radio frequencies and GPS altitudes at the time of the approach. The aircraft's home airport field elevation was a known figure: 5045 feet. Measurements of GPS altitude taken at the time of the event were compared to the home airport field elevation. If the GPS altitude at the time the Approach event was triggered was either 1000 feet higher or 500 feet lower than the field elevation of the home airport, it was deduced that the approach occurred at an outlying airfield. If either communications frequency at the time of the approach event did not match communications frequencies of the home base airport, it was deduced that the approach occurred at an outlying airfield.

Once aircraft location (home base or outlying) was determined, the home base approach runway was determined by a combination of magnetic heading, communications frequencies, and latitude and longitude. The heading was measured 30 seconds after the approach event triggered, ensuring that the aircraft would be as closely aligned to its final approach path as possible. Table 1 below details the heading ranges used to assign runways to approaches:

Table 1

Heading Ranges Used to Assign Runways

Runway Designator	Heading Range (Degrees Azimuth)
Runway 21L	165-255
Runway 21R	165-255
Runway 3L	344.99-074.99
Runway 3R	344.99-074.99
Runway 12	254.99-345
Runway 30	075-164.99

Parallel runways were distinguished from one another by utilizing a combination of communications frequencies and latitude and longitude. The home base airport most commonly splits communication frequencies on parallel runways to streamline communications with aircraft crew and ATC; one frequency is assigned to one runway while a different frequency is assigned to another runway. The programmed frequencies at the time of the event determined which of the parallel runways was assigned to the event. If both the runway frequencies were programmed at the time of the event, latitude and longitude were used to determine which runway was in use.

Data Analysis

Exporting Data

Upon the completion of programming each event, an analysis was run in GE's EMS® to apply the event filters to the selected flights within the GE database. The events and their additional measurements were exported to a delimited text file, which was then exported to a Microsoft Excel® workbook. Each event had a timestamp and Flight Record number associated with it. A Flight Record number is assigned by GE to each individual flight, and the timestamps were measured in seconds from the beginning of the flight. One Microsoft Excel® workbook was created per event type per month in the selected time range for the Cessna 172S Nav III flights. One Microsoft Excel® workbook was created per event across the entire selected time frame for the Diamond DA-42 NG flights. The events and their additional measurements were consolidated into a single workbook. Each event and its additional measurements were turned into dichotomous variables. Additionally, IAPs and IAP types were verified during this process. Runways at the home base airport were also processed during these steps.

Statistical Analysis

Statistical Analysis was conducted using IBM SPSS® Version 29.

Research Method

Logistic regression was conducted to evaluate two Research Questions. The first Research Question, 'What variables are predictors of unstable approaches?', was evaluated across 6 independent variables. One hypothesis was tested per independent variable category. The second Research Question, 'If an unstable approach is encountered, what variables act as predictors that the approach will result in a go-around?' was evaluated also across 6 independent variables. One hypothesis was tested per independent variable category. While the First Research question was evaluated across all approaches in the allotted time frame, the second Research Question was only evaluated using data that represented unstable approaches in the allotted time frame. A separate logistic regression analysis was run for both Research Questions' 'IAP Type' independent variable in order to avoid multicollinearity, as only approaches that were identified as containing an IAP could include an 'IAP Type'.

Binomial Logistic Regression. Binomial Logistic Regression, hereafter referred to as 'logistic regression', was selected as the statistical method for analyzing predictors of unstable approaches and go-arounds once the approach was determined to be unstable. Logistic Regression was chosen because the dependent variables are of a dichotomous nature and because the independent variables are categorical in nature. Logistic regression is utilized to determine which independent variables have a statistically significant effect on the dependent variable and determine how well the overall model predicts the dependent variable. Additionally, odds ratios resulting from binomial logistic regression can be used to determine the weight of each independent variable on the dependent variable.

Assumptions. Logistic regression is appropriate because the data meets the necessary requirements.

The first requirement mandates that the dependent variable is a dichotomous variable (Laerd Statistics, 2013). The first dependent variable, Stability, has two outcomes: "Stable" or "Unstable". The second dependent variable of Landing Outcome has two outcomes: "Landing" or "Go-around".

The second requirement mandates that the independent variables be either continuous or categorical (Laerd Statistics, 2013); the independent variables in this study were all categorical. The Table 2 indicates the categories of the independent variables associated with Research Question 1 and Research Question 2:

Table 2

Independent Variables – Research Questions 1 and 2

Variable Name	Variable Categories	Variable Abbreviations
Aircraft Type	Cessna 172S Nav III, Diamond DA-42 NG	C172, DA42
Approach Type	VFR Approach, IFR Approach	VFR, IFR
Light Condition	Day, Night	Day, Night
Approach Location	Home Base Airport, Outlying Airport	Home Base, Outlying
Runways	Runway 21L, Runway 21R, Runway 3L, Runway 3R, Runway 12, Runway 30	21L, 21R, 3L, 3R, R12, R30
IAP Type	Straight-In, Circling	Straight-In, Circling

The third requirement states that there must be an “independence of observations” (Laerd Statistics, 2013) and that the dependent variable has “mutually exclusive and exhaustive categories” (Laerd Statistics, 2013). One approach does not affect the next and the dependent variable categories are both comprehensive and exclusive.

The fourth requirement states that a minimum of “15 cases per independent variable” (Laerd Statistics, 2013) be available. The data set well exceeds this requirement.

The fifth requirement mandates a linear relationship between the continuous independent variables and the logit transformation of the dependent variable (Laerd Statistics, 2013). Because the dependent variables are categorical and not continuous in nature, a linear relationship test is not required (Laerd Statistics, 2013).

The sixth requirement mandates that the data does not show multicollinearity. The potential for multicollinearity exists for the flights that occur at night due to the structure of the flight school's flight courses. The flights used to train IFR procedures occur are frequently scheduled at night due to resource management. Therefore, the Flight Rules and Type of IAP independent variables could be related to Light Condition. However, flights conducted in the Diamond DA-42 NG do not heavily favor nighttime but still require IAP training.

The seventh requirement mandates that there should be "no significant outliers, high leverage points, or highly influential points" (Laerd Statistics, 2013). Because there are no continuous variables, the changes of a significant outlier are very small.

Hypothesis Testing. Hypothesis testing was conducted using IBM's SPSS®. SPSS'® output was interpreted to determine the results. First, the dependent variable coding was verified to ensure that the interpretation of the results was accurate. Second, the model was tested for significance using the Sig. column in the Model row of the *Omnibus Tests of Model Coefficients* table. A Sig. of $p < .05$ indicates that the model is significant. The significance was verified using the Sig. value of the *Hosmer and Lemeshow Test* table. A Sig. value of $p < .05$ in this table would indicate that the model is not a good fit.

After the model's significance is verified, the *Model Summary* table was used to evaluate how much variance in the dependent variable can be attributed to the model. The Cox and Snell R Square and the Nagelkerke R Square values were converted to percentages to determine what percentage of the variance in the dependent variable can be attributed to the model. The Nagelkerke R Square values are preferred because the Cox and Snell R Square will never reach a value of one (Laerd Statistics, 2013). The *Classification Tables* indicate how much improvement is gained by adding the independent variables to the model by comparing the *Step 0 Classification Table* to the *Step 1 Classification Table*. Sensitivity, or the "percentage of cases that had the observed characteristic which were correctly predicted by the model" (Laerd Statistics, 2013) was obtained from the Percentage Correct column and the "Yes" row of the *Step 1 Classification Table*. Specificity, or the "percentage of cases that did not have the observed characteristic" (Laerd Statistics, 2013) that were correctly predicted by the model as not having the observed characteristic was obtained by examining the "Percentage Correct" column and the "No" column of the *Step 1 Classification Table*. The positive predictive values, or the percentages of correctly predicted events with the desired characteristic compared to the total number of cases of the event, were calculated using Equation (1) (Hennekens & Buring, 1987, p. 336):

$$PV^{+} = \frac{a}{a+b}$$

where:

$PV^{+} = Positive\ Predictive\ Value$

$a = Number\ of\ True\ Positives$

$b = Number\ of\ False\ Positives$

The negative predictive values, or the percentages of correctly predicted events without the desired characteristic compared to the total number of cases of the event, were calculated using Equation (2) (Hennekens & Buring, 1987, p. 337):

$$PV^{-} = \frac{d}{c+d}$$

where:

$PV^{-} = Negative\ Predictive\ Value$

$d = Number\ of\ True\ Negatives$

$c = Number\ of\ False\ Negatives$

The *Variables in the Equation* table was used to determine the effect of the individual Independent Variables on the model. The Wald test was used to evaluate each variable's significance and the resulting Sig. column in the *Variables in the Equation* table reports the statistical significance. A value of $p < .05$ in the Sig. column indicates statistical significance. The *Exp(B)* column indicates a "change in the odds for each increase in one unit" of the independent variable by reporting the odds ratio (Laerd Statistics, 2013). The Confidence Intervals (CI) were also reported at a 95% level for each independent variable. A value of *Exp(B)* greater than 1 with a CI entirely above 1 indicates an increase in the odds attributed to the independent variable. A value of *Exp(B)* less than 1 with a CI entirely below 1 indicates a decrease of odds attributed to the independent variable. Values less than one in the *Exp(B)* column were reported as inverted variables, meaning that those values were divided into 1 in order to achieve a value on the same scale as the values greater than 1. A value in the Sig. column where $p > .05$ and a CI that passes through 1 indicates a lack of significance.

Summary

In-flight data is an invaluable information source that can contribute to aviation safety. A large percentage of general aviation accidents can be attributed to unstable approaches. Despite the fact that the general aviation sector stands to gain the most from data collection, flight data analysis has not been broadly adopted across general aviation operators. Large scale flight schools are examples of general aviation operators which may possess the resources to collect and analyze flight data.

This research seeks to understand potential predictors of unstable approaches and the likelihood of go-arounds being conducted if an unstable approach is encountered. A Part 141 flight school with an FDM program was the subject of this study. The flight school provided flight data spanning an academic semester. This data was analyzed using GE's eFOQA® software and logistic regression was performed using IBM's SPSS in order to determine predictors of both unstable approaches and go-arounds.

Chapter IV: Results

This chapter contains the results of the analysis process described by Chapter III: Methods. Both Research Questions were comprised of many hypotheses, with each hypothesis representing an independent variable category. Each hypothesis was tested by creating a model using binary logistic regression. Each model's significance and validity were tested and each independent variable was evaluated for significance and any relevant descriptive statistics. The analysis is explained below.

Data Results

Table 3 details data totals and subtotals for all approaches. A total of 36,865 approaches were evaluated. Of those approaches, the vast majority of approaches were VFR approaches conducted in a Cessna C172S Nav III aircraft. Additionally, the majority of approaches were stable and resulted in landings. Most approaches were conducted during the day, and an overwhelming amount of approaches were conducted at the home base airport.

Table 3

Data Totals – All Approaches

Variables	Categories	Cases	Percentage of Total
Aircraft Type	C172	34,249	92.90%
	DA42	2,615	7.09%
Approach Type	IFR	2,100	5.70%
	VFR	34,759	94.29%
Approach Stability	Stable	24,925	67.61%
	Unstable	11,939	32.39%
Landing Outcome	Landing	27,627	74.94%
	Go-around	9,237	25.06%
IAP Type	Straight-In	1,118	3.03%
	Circling	987	2.68%
Time of Day	Day	33,760	91.58%
	Night	3,057	8.29%
Approach Location	Home Base	30,789	83.52%
	Outlying	6,074	16.48%

Table 4 details data totals for runways used at the home base airport. Most approaches were conducted to Runway 21L, while the least approaches were conducted to Runway 30.

Table 4

Runway Totals – All Approaches

Runways	Cases	Percentage of Total
Runway 21L	11,850	39.16%
Runway 21R	7,154	23.64%
Runway 3L	2,264	7.48%
Runway 3R	3,726	12.31%
Runway 12	3,409	11.26%
Runway 30	1,861	6.15%

Table 5 details data totals and subtotals for unstable approaches. A total of 11,939 unstable approaches were detected. In the data set, most of the unstable approaches resulted in landings and occurred during the day at the Home Base airport.

Table 5

Data Totals – Unstable Approaches

Independent Variables	Categories	Cases	Percentage of Total
Aircraft Type	C172	10,735	89.92%
	DA42	1,564	13.10%
Approach Type	IFR	704	5.90%
	VFR	11,232	94.08%
Landing Outcome	Landing	8,927	74.77%
	Go-around	3,012	25.23%
IAP Type	Straight-In	344	2.88%
	Circling	362	3.03%
Time of Day	Day	11034	92.42%
	Night	890	7.45%
Approach Location	Home Base	9,788	81.98%
	Outlying	2,151	18.02%

Table 6 details unstable approach totals for runways used at the home base airport. Most unstable approaches were conducted to Runway 21L, while the fewest unstable approaches were conducted to Runway 12.

Table 6

Runway Totals – Unstable Approaches

Runways	Cases	Percentage of Total
Runway 21L	3,655	37.8%
Runway 21R	1,896	19.6%
Runway 3L	977	10.1%
Runway 3R	1,634	16.9%
Runway 12	752	7.8%
Runway 30	762	7.9%

Dependent Variables

The dependent variables analyzed in this study were Approach Stability and Landing Outcome.

The Approach Stability variable had the potential for two outcomes: Stable or Unstable. The criteria to determine stability was determined using the Part 141 flight school's policy surrounding stable approaches. If any of the programmed stable criteria were detected, the approach was considered to be unstable.

The Landing Outcome variable had the potential for two outcomes: landing or go-around. If a go-around was not conducted, a landing was assumed to have occurred.

Both dependent variables tested had two mutually exclusive and comprehensive outcomes.

Independent Variables

The same independent variables were tested for each Research Question. The independent variables were all categorical in nature. The independent variables are described in Table 7:

Table 7

Independent Variables – Research Questions 1 and 2

Variable Name	Variable Categories	Variable Abbreviations
Aircraft Type	Cessna 172S Nav III, Diamond DA-42 NG	C172, DA42
Approach Type	VFR Approach, IFR Approach	VFR, IFR
Light Condition	Day, Night	Day, Night
Approach Location	Home Base Airport, Outlying Airport	Home Base, Outlying
Runways	Runway 21L, Runway 21R, Runway 3L, Runway 3R, Runway 12, Runway 30	21L, 21R, 3L, 3R, R12, R30
IAP Type	Straight-In, Circling	Straight-In, Circling

Aircraft Type is a categorical, binary variable. The approach could have been conducted in either a Cessna 172S Nav III aircraft or a Diamond DA-42 NG aircraft.

Approach Type is a categorical, binary variable. The approach could have been conducted following guidelines for a landing under Visual Flight Rules or using an Instrument Approach Procedure (IAP).

Light Condition is a categorical, binary variable. An approach was either conducted during the day or at night. Night is defined as the time period which begins an hour after sunset and ends an hour before sunrise, mirroring the definition outlined by 14 CFR § 61.57 Recent Flight Experience: Pilot in Command (2023).

Approach Location is a categorical, binary variable. An approach was either conducted at the Home Base airport or an Outlying airport.

Runway is a categorical variable. The runways evaluated were at the Home Base airport. The runways included Runway 21L, Runway 21R, Runway 12, Runway 30, Runway 3R, and Runway 3L. Runway 21L and 21R are parallel runways, as are Runways 3R and 3L.

Instrument Approach Procedure Type is a categorical, binary variable. This variable was only observed in approaches which contained an IAP. If an IAP Type was observed, it was either associated with a Circling or Straight-In Approach.

Research Question 1: What variables are predictors of unstable approaches?

The model evaluated using binomial logistic regression comprised of six independent variables to evaluate the dependent variable, Approach Stability.

The data included 36,863 cases, or approaches, and all cases were included in the analysis.

Table 8 displays the Omnibus Tests of Model Coefficients. The value in the Sig. column on the Model row of $p < .001$ indicates that the model is statistically significant, as $p < .05$.

Table 8

Omnibus Tests of Model Coefficients - Research Question 1

	Chi-Square	df	Sig.
Step	1614.915	9	<.001
Block	1614.915	9	<.001
Model	1614.915	9	<.001

Table 9 displays the Hosmer and Lemeshow Test, which also indicates that the model is a good fit, as the value in the Sig. column is $p = .089$, which is greater than .05. A value of $p < .05$ would indicate that the model is not a good fit.

Table 9

Hosmer and Lemeshow Test – Research Question 1

Step	Chi-Square	df	Sig.
1	10.981	6	.089

Table 10 displays the variance in the dependent variable, Approach Stability, that can be explained by the model. The model can explain anywhere from 4.3% to 6% of the variance in the dependent variable. The Nagelkerke R Square value of 0.06 is the preferred value because the Nagelkerke R square has the ability to reach a value of 1.

Table 10

Model Summary – Research Question 1

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	10.981	.043	.060

Table 11 demonstrates that the model, without any independent variables, assuming that an approach is stable will yield a correct outcome 67.6% of the time. The cut value is .500, meaning that if the probability of a case being classified into the ‘Yes’ category is .500 or greater, then it is classified as a ‘Yes’.

Table 11

Classification Table A – No Independent Variables

			Predicted		
			Unstable		
Observed			No	Yes	Percentage Correct
Step 0	Unstable	No	24924	0	100.00
		Yes	11939	0	0
	Overall Percentage				67.6

Note. The cut value is .500

Table 12 demonstrates the classifications of the dependent variable as predicted by the model with the independent variables added. A correct outcome will be classified 69% of the time. As in *Classification Table B – No Independent Variables,* the cut value is .500, indicating that if the probability of a case being classified into the 'Yes' category is .500 or greater, then it is classified as a 'Yes'.

Table 12

Classification Table B – Independent Variables

			Predicted		
			Unstable		
Observed			No	Yes	Percentage Correct
Step 0	Unstable	No	23951	973	96.1
		Yes	10440	1499	12.6
	Overall Percentage				69.0

Note. The cut value is .500.

Comparing Table 11 and Table 12 demonstrates that adding the independent variables to the model improves the model by 1.4%. A sensitivity of 12.6% is noted, indicating that 12.6% of unstable approaches were correctly predicted by the model to be unstable approaches. A specificity of 96.1% indicates that 96.1% of stable approaches were correctly predicted by the model to be stable approaches. The positive predictive value is .606, which indicates that 60.6% of all the cases predicted to be unstable were correctly predicted. The negative predictive value is .696, which indicates that 69.6% of all the cases predicted to be stable were correctly predicted.

Table 13 directly summarizes the impact of each independent variable on the model and how well each independent variable act as a predictor of the dependent variable.

Table 13

Variables in the Equation – Research Question 1

							95% CI for *Exp(B)*	
Predictors	B	S.E	Wald	df	Sig.	Exp(B)	Lower	Upper
Airplane Type	-1.270	.044	848.266	1	<.001	.281	.258	.306
Approach Type	-.109	.051	4.577	1	.032	.896	.811	.991
Light Condition	.047	.044	1.148	1	.284	1.048	.962	1.143
Approach Location	.157	.052	8.966	1	.003	1.170	1.056	1.297
Runways			651.815	5	<.001			
Runways (21L)	-.491	.050	97.683	1	<.001	.612	.555	.675
Runways (21R)	-.537	.052	105.287	1	<.001	.584	.527	.647
Runways (3L)	.206	.062	11.060	1	<.001	1.229	1.088	1.387
Runways (3R)	.100	.056	3.161	1	.075	1.105	.990	1.234
Runways (12)	-.842	.060	194.557	1	<.001	.431	.383	.485
Constant	.573	.068	70.007	1	<.001	1.773		

Hypothesis 1.1. A Cessna 172S Nav III is associated with an increased probability of an unstable approach.

With the Sig. value less than .001, airplane type was found to be statistically significant. An Exp(B) value of 0.281 and the 95% Confidence Interval (CI) [0.258, 0.306] indicates that a Diamond DA-42 NG is 3.88 times less likely to experience an unstable approach. Therefore, the hypothesis is supported.

Hypothesis 1.2. An Instrument Approach Procedure is associated with an increased probability of an unstable approach.

With the Sig. value of .032, Approach Type was found to be statistically significant. An *Exp(B)* value of 0.896 and the 95% CI [0.811, 0.991] indicates that an approach conducted under VFR is 1.12 times less likely to experience an unstable approach. Therefore, the hypothesis is supported.

Hypothesis 1.3. An approach conducted at night is associated with an increased probability of an unstable approach.

Light Condition was not found to be significant, with a Sig. value of .284. The 95% CI [0.962, 1.143] also spans 1, which supports the claim that Light Condition is not significant. Therefore, the hypothesis is not supported.

Hypothesis 1.4. An approach conducted at an outlying airfield is associated with an increased probability of an unstable approach.

With the Sig. value of .003, Approach Location was found to be statistically significant. An *Exp(B)* value of 1.17 and the 95% CI [1.056, 1.297] indicates that an approach conducted at an outlying airfield is 1.12 times more likely to experience an unstable approach. Therefore, the hypothesis is supported.

Hypothesis 1.5. Specific runways at the home base airport can be used to predict stability.

Hypothesis 1.5.1. Runway 21L is associated with a decreased probability of an unstable approach in comparison to Runway 30. The Sig. value less than .001 indicates Runway 21L is a statistically significant variable within the model. The *Exp(B)* value of 0.612, in conjunction with the 95% CI [0.555, 0.675], indicates that approaches flown to 21L are 1.63

times less likely to be unstable in comparison to approaches flown to Runway 30. The hypothesis is supported.

Hypothesis 1.5.2. Runway 21R is associated with a decreased probability of an unstable approach in comparison to Runway 30. The Sig. value less than .001 indicates Runway 21R is a statistically significant variable within the model. The *Exp(B)* value of 0.584, in conjunction with the 95% CI [0.527, 0.647], indicates that approaches flown to 21R are 1.71 times less likely to be unstable in comparison to approaches flown to Runway 30. The hypothesis is supported.

Hypothesis 1.5.3. Runway 3L is associated with a decreased probability of an unstable approach in comparison to Runway 30. The Sig. value less than .001 indicates Runway 3L is a statistically significant variable within the model. The *Exp(B)* value of 1.229, in conjunction with the 95% CI [1.088, 1.387], indicates that approaches flown to 3L are 1.229 times more likely to be unstable in comparison to approaches flown to Runway 30. The hypothesis is not supported.

Hypothesis 1.5.4. Runway 3R is associated with a decreased probability of an unstable approach in comparison to Runway 30. The Sig. value of .075 indicates that Runway 3R is not a statistically significant indicator. The 95% CI [0.99, 1.234] also spans 1, which further indicates that the variable is not statistically significant. Therefore, the hypothesis is not supported.

Hypothesis 1.5.5. Runway 12 is associated with a decreased probability of an unstable approach in comparison to Runway 30. The Sig. value less than .001 indicates Runway 12 is a statistically significant variable within the model. The *Exp(B)* value of 0.431, in conjunction with the 95% CI [0.383, 0.485], indicates that approaches flown to Runway 12 are

2.32 times less likely to be unstable in comparison to approaches flown to Runway 30. Therefore, the hypothesis is supported.

Hypothesis 1.6. If an IAP is conducted, a circling approach is associated with an increased probability for an unstable approach.

Hypothesis 1.6 required its own logistic regression process with all variables due to the extreme dependency the associated variable has on the 'Approach Type'; this independent variable only exists if the 'Approach Type' is 'IFR'. Only approaches categorized as following an IAP were included in this logistic regression analysis, for a total of 2,100 approaches.

Table 14 displays the Omnibus Tests of Model Coefficients, which indicates whether or not the model is significant. The Sig. value in the Model row that that indicates $p < .001$ indicates that the model is significant.

Table 14

Omnibus Tests of Model Coefficients - Hypothesis 1.6

	Chi-Square	df	Sig.
Step	156.39	9	<.001
Block	156.39	9	<.001
Model	156.39	9	<.001

Table 15 displays the Hosmer and Lemeshow Test, which also indicates that the model is a good fit, as the value in the Sig. column is $p = .293$, which is greater than .05. A value of $p < .05$ would indicate that the model is not a good fit.

Table 15

Hosmer and Lemeshow Test – Hypothesis 1.6

Step	Chi-Square	df	Sig.
1	9.612	8	.293

Table 16 displays the variance in the dependent variable, Approach Stability, that can be explained by the model. The model can explain anywhere from 7.2% to 10% of the variance in the dependent variable. The Nagelkerke R Square value of 0.10 is the preferred value because the Nagelkerke R Square has the ability to reach a value of 1.

Table 16

Model Summary – Hypothesis 1.6

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	2503.746	.072	.100

Table 17 demonstrates that the model, without any independent variables, assuming that an approach is stable will yield a correct outcome 64.4% of the time. The cut value is .500, meaning that if the probability of a case being classified into the ‘Yes’ category is .500 or greater, then it is classified as a ‘Yes’.

Table 17

Classification Table C – No Independent Variables

			Predicted		
			Unstable		
Observed			No	Yes	Percentage Correct
Step 0	Unstable	No	1395	0	100.00
		Yes	705	0	0
	Overall Percentage				66.4

Note. The cut value is .500

Table 18 demonstrates the classifications of the dependent variable as predicted by the model with the independent variables added. A correct outcome will be classified 68.5% of the time. As in *Classification Table C – No Independent Variables,* the cut value is .500, indicating that if the probability of a case being classified into the 'Yes' category is .500 or greater, then it is classified as a 'Yes'.

Table 18

Classification Table D – Independent Variables

			Predicted		
			Unstable		
Observed			No	Yes	Percentage Correct
Step 0	Unstable	No	1282	113	91.9
		Yes	549	156	22.1
	Overall Percentage				68.5

Note. The cut value is .500.

Comparing Table 17 and Table 18 demonstrates that adding the independent variables to the model improves the model by 2.1%. A sensitivity of 22.1% is noted, indicating that 22.1% of unstable approaches were correctly predicted by the model to be unstable approaches. A specificity of 91.9% indicates that 91.9% of stable approaches were correctly predicted by the model to be stable approaches. The positive predictive value is .58, which indicates that 58% of all the cases predicted to be unstable were correctly predicted. The negative predictive value is .701, which indicates that 70% of all the cases predicted to be stable were correctly predicted.

Table 19 directly summarizes the impact of each independent variable on the model and how well each independent variable acts as a predictor of the dependent variable.

Table 19

Variables in the Equation – Hypothesis 1.6

							95% CI for *Exp(B)*	
Predictors	B	S.E	Wald	df	Sig.	Exp(B)	Lower	Upper
Airplane Type	-1.180	.117	101.762	1	<.001	.307	.244	.386
IAP Type	.202	.106	3.636	1	.057	1.224	.994	1.507
Light Condition	.012	.120	.010	1	.919	1.012	.800	1.281
Approach Location	-.192	.272	.497	1	.481	.825	.484	1.407
Runways			31.406	5	<.001			
Runways (21L)	-.206	.230	.804	1	.370	.813	.518	1.277
Runways (21R)	.028	.279	.010	1	.920	1.028	.595	1.778
Runways (3L)	.504	.316	2.545	1	.111	1.656	.891	3.077
Runways (3R)	.503	.247	4.137	1	.042	1.653	1.018	2.683
Runways (12)	-.275	.255	1.163	1	.281	.760	.461	1.252
Constant	.328	.222	2.173	1	.140	1.388		

Table 19 demonstrates that IAP Type is not significant, with a Sig. value of $p = .057$, which is greater than .05. The 95% CI [0.994, 1.507] that spans 1 also confirms that IAP Type is not significant. Therefore, the hypothesis is not supported.

Research Question 2: If an unstable approach is encountered, what variables act as predictors that the approach will result in a go-around?

The model was evaluated using binomial logistic regression comprised of six independent variables to evaluate the dependent variable, Landing Outcome.

The data included 11,939 cases, or approaches, and all cases were included in the analysis. The logistic regression analysis identified 262 outliers. However, the outliers were left within the data pool due to the fact that all of the variables are categorical.

Table 20 displays the Omnibus Tests of Model Coefficients. The value in the Sig. column on the Model row of $p < .001$ indicates that the model is statistically significant, as $p < .05$.

Table 20

Omnibus Tests of Model Coefficients - Research Question 2

	Chi-Square	df	Sig.
Step	697.913	9	<.001
Block	697.913	9	<.001
Model	697.913	9	<.001

Table 21 displays the Hosmer and Lemeshow Test, which also indicates that the model is a good fit, as the value in the Sig. column is $p = .248$, which is greater than .05. A value of $p < .05$ would indicate that the model is not a good fit.

Table 21

Hosmer and Lemeshow Test – Research Question 2

Step	Chi-Square	df	Sig.
1	9.063	7	.248

Table 22 displays the variance in the dependent variable, Landing Outcome, that can be explained by the model. The model can explain anywhere from 5.7% to 8.4% of the variance in the dependent variable. The Nagelkerke R Square value of 0.064 is the preferred value because the Nagelkerke R square has the ability to reach a value of 1.

Table 22

Model Summary – Research Question 2

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	12789.069	.057	.084

Table 23 demonstrates that the model, without any independent variables, assumes that an unstable approach will result in a landing will yield a correct outcome 74.8% of the time. The cut value is .500, meaning that if the probability of a case being classified into the 'Landing' category is .500 or greater, then it is classified as a 'Landing'.

Table 23

Classification Table E – No Independent Variables

			Predicted		
			Landing Outcome		
Observed			Go-around	Landing	Percentage Correct
Step 0	Landing Outcome	Go-around	0	3012	0
		Landing	0	8927	100.00
	Overall Percentage				74.8

Note. The cut value is .500

Table 24 demonstrates the classifications of the dependent variable as predicted by the model with the independent variables added. A correct outcome will be classified 74.8% of the time. As in *Classification Table E – No Independent Variables,* the cut value is .500, indicating that if the probability of a case being classified into the ‘Landing’ category is .500 or greater, then it is classified as a ‘Landing’.

Table 24

Classification Table F – Independent Variables

			Predicted		
			Landing Outcome		
Observed			Go-around	Landing	Percentage Correct
Step 0	Landing Outcome	Go-around	0	3012	0
		Landing	0	8927	100.00
	Overall Percentage				74.8

Note. The cut value is .500.

Comparing Table 23 and Table 24 demonstrates that adding the independent variables to the model does not change the model. A sensitivity of 100% is noted, indicating that 100% of landings from unstable approaches were correctly predicted by the model to be landings.
Table 25 below directly summarizes the impact of each independent variable on the model and how well each independent variable act as a predictor of the dependent variable.

Table 25

Variables in the Equation – Research Question 2

Predictors	B	S.E	Wald	df	Sig.	Exp(B)	95% CI for *Exp(B)* Lower	95% CI for *Exp(B)* Upper
Airplane Type	-1.095	.090	148.916	1	<.001	.335	.281	.399
Approach Type	.076	.110	.476	1	.490	1.079	.869	1.340
Light Condition	-1.543	.143	117.128	1	<.001	.214	.162	.283
Approach Location	-.179	.087	4.217	1	.040	.836	.705	.992
Runways			146.856	5	<.001			
Runways (21L)	.628	.086	53.802	1	<.001	1.873	1.584	2.216
Runways (21R)	.437	.089	23.843	1	<.001	1.548	1.299	1.844
Runways (3L)	.338	.101	11.217	1	<.001	1.403	1.151	1.710
Runways (3R)	.721	.097	55.297	1	<.001	2.056	1.700	2.486
Runways (12)	1.487	.136	120.199	1	<.001	4.423	3.391	5.770
Constant	3.235	.175	342.794	1	<.001	25.416		

Hypothesis 2.1. An unstable approach in a Cessna 172S Nav III is associated with an increased probability of a go-around.

With the Sig. value less than .001, airplane type was found to be statistically significant. An *Exp(B)* value of 0.335 and the 95% CI [0.281, 0.399] indicates that a Diamond DA-42 NG is 2.98 times more likely to go-around after experiencing an unstable approach. Therefore, the hypothesis is not supported.

Hypothesis 2.2. An unstable approach following an Instrument Approach Procedure is associated with a decreased probability of a go-around.

With the Sig. value of .490, Approach Type was not found to be statistically significant. The *Exp(B)* value of 1.079 and the 95% CI [0.869, 1.340] further highlight the statistical insignificance. Therefore, the hypothesis is not supported.

Hypothesis 2.3. An approach conducted at night is associated with a decreased probability of a go-around.

Light Condition was found to be significant, with a Sig. value of $p < .001$. The Exp(B) value of 0.214 and the 95% CI [0.162, 0.283] indicate that an unstable approach at night is 4.67 times more likely to go-around. Therefore, the hypothesis is not supported.

Hypothesis 2.4. An unstable approach conducted at an outlying airfield is associated with a decreased probability of a go-around.

With the Sig. value of .040, Approach Location was found to be statistically significant. An *Exp(B)* value of 0.836 and the 95% CI [0.705, 0.992] indicates that an unstable approach conducted at an outlying airfield is 1.2 times more likely to go-around. Therefore, the hypothesis is not supported.

Hypothesis 2.5. Specific runways at the home base airport can be used to predict the likelihood of go-arounds.

Hypothesis 2.5.1. Unstable approaches flown to Runway 21L are associated with a decreased probability of a go-around in comparison to Runway 30. The Sig. value less than .001 indicates Runway 21L is a statistically significant variable within the model. The *Exp(B)* value of 1.873, in conjunction with the 95% CI [1.584, 2.216], indicates that unstable approaches flown to Runway 21L are 1.87 times less likely to go-around in comparison to unstable approaches flown to Runway 30. The hypothesis is supported.

Hypothesis 2.5.2. An unstable approach flown to Runway 21R is associated with a decreased probability of a go-around in comparison to Runway 30. The Sig. value less than .001 indicates Runway 21R is a statistically significant variable within the model. The *Exp(B)* value of 1.548, in conjunction with the 95% CI [1.299, 1.844], indicates that unstable approaches flown to 21R are 1.548 times less likely to go-around in comparison to approaches flown to Runway 30. The hypothesis is supported.

Hypothesis 2.5.3. An unstable approach flown to Runway 3L is associated with a decreased probability of a go-around in comparison to Runway 30. The Sig. value less than .001 indicates Runway 3L is a statistically significant variable within the model. The *Exp(B)* value of 1.403, in conjunction with the 95% CI [1.151, 1.710], indicates that unstable approaches flown to Runway 3L are 1.403 times less likely to go-around in comparison to approaches flown to Runway 30. The hypothesis is supported.

Hypothesis 2.5.4. An unstable approach flown to Runway 3R is associated with a decreased probability of a go-around in comparison to Runway 30. The Sig. value less than .001 indicates Runway 3R is a statistically significant variable within the model. The *Exp(B)* value of 2.056, in conjunction with the 95% CI [1.7, 2.486], indicates that unstable approaches flown to 3R are 2.056 times less likely to go-around in comparison to approaches flown to Runway 30. Therefore, the hypothesis is supported.

Hypothesis 2.5.5. An unstable approach flown to Runway 12 is associated with a decreased probability of a go-around in comparison to Runway 30. The Sig. value less than .001 indicates Runway 12 is a statistically significant variable within the model. The *Exp(B)* value of 4.423, in conjunction with the 95% CI [3.391, 5.770], indicates that approaches flown to Runway 12 are 4.423 times less likely to go-around in comparison to approaches flown to Runway 30. Therefore, the hypothesis is supported.

Hypothesis 2.6. If an IAP is conducted, an unstable circling approach is associated with an increased probability for a go-around.

Hypothesis 2.6 required its own logistic regression process with all variables due to the extreme dependency the associated variable has on the 'Approach Type'; this independent variable only exists if the 'Approach Type' is 'IFR'. Only unstable approaches categorized as following an IAP were included in this logistic regression analysis, for a total of 705 approaches.

Table 26 displays the Omnibus Tests of Model Coefficients, which indicates whether or not the model is significant. The Sig. value of .238 in the Model row indicates that the model is not significant.

Table 26

Omnibus Tests of Model Coefficients - Hypothesis 2.6

	Chi-Square	df	Sig.
Step	11.58	9	.238
Block	11.58	9	.238
Model	11.58	9	.238

Table 27 below displays the Hosmer and Lemeshow Test, which also indicates that the model is a good fit, as the value in the Sig. column is $p = .293$, which is greater than .05. A value of $p < .05$ would indicate that the model is not a good fit.

Table 27

Hosmer and Lemeshow Test – Hypothesis 2.6

Step	Chi-Square	df	Sig.
1	7.815	8	.452

Table 28 displays the variance in the dependent variable, Landing Outcome, that can be explained by the model. The model can explain anywhere from 1.6% to 2.8% of the variance in the dependent variable. The Nagelkerke R Square value of 0.028 is the preferred value because the Nagelkerke R Square has the ability to reach a value of 1.

Table 28

Model Summary – Hypothesis 2.6

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	612.319	.016	.028

Table 29 demonstrates that the model, without any independent variables, assuming that an approach is stable will yield a correct outcome 83.8% of the time. The cut value is .500, meaning that if the probability of a case being classified into the ‘Landing’ category is .500 or greater, then it is classified as a ‘Landing’.

Table 29

Classification Table G – No Independent Variables

			Predicted		
			Landing Outcome		
Observed			Go-around	Landing	Percentage Correct
Step 0	Landing Outcome	Go-around	0	114	0
		Landing	0	591	100.00
	Overall Percentage				83.8

Note. The cut value is .500

Table 30 demonstrates the classifications of the dependent variable as predicted by the model with the independent variables added. A correct outcome will be classified 83.8% of the time. As in *Classification Table G – No Independent Variables,* the cut value is .500, indicating that if the probability of a case being classified into the 'Yes' category is .500 or greater, then it is classified as a 'Yes'.

Table 30

Classification Table H – Independent Variables

			Predicted		
			Landing Outcome		
Observed			Go-around	Landing	Percentage Correct
Step 0	Landing Outcome	Go-around	0	114	0
		Landing	0	591	100.00
	Overall Percentage				83.8

Note. The cut value is .500.

Comparing Table 29 and Table 30 demonstrates that adding the independent variables to the model does not change the model. A sensitivity of 100% is noted, indicating that 100% of landings from unstable approaches were correctly predicted by the model to be landings.

Table 31 directly summarizes the impact of each independent variable on the model and how well each independent variable acts as a predictor of the dependent variable.

Table 31

Variables in the Equation – Hypothesis 2.6

							95% CI for *Exp(B)*	
Predictors	B	S.E	Wald	df	Sig.	Exp(B)	Lower	Upper
Airplane Type	-.595	.245	5.921	1	.015	.551	.341	.891
IAP Type	.206	.237	.753	1	.386	1.228	.772	1.956
Light Condition	.028	.268	.011	1	.916	1.029	.608	1.740
Approach Location	-.600	.534	1.264	1	.261	.549	.193	1.562
Runways			4.751	5	.447			
Runways (21L)	.631	.439	2.069	1	.150	1.879	.796	4.438
Runways (21R)	.152	.518	.086	1	.769	1.164	.422	3.214
Runways (3L)	.348	.575	.368	1	.544	1.417	.459	4.370
Runways (3R)	.646	.461	1.959	1	.162	1.908	.772	4.713
Runways (12)	1.002	.536	3.494	1	.062	2.723	.952	7.783
Constant	1.961	.473	17.226	1	<.001	7.110		

Table 31 demonstrates that IAP Type is not significant, with a Sig. value of $p = .386$, which is greater than .05. The 95% CI [0.772, 1.956] which spans 1 also confirms that IAP Type is not significant. Therefore, the hypothesis is not supported.

Summary

Binary logistic regression was conducted to analyze two research questions:

- Research Question 1: What variables are predictors of unstable approaches?

- Research Question 2: If an unstable approach is encountered, what variables act as predictors that the approach will result in a go-around?

Research Question 1 was evaluated across eleven hypotheses and 36,863 approaches. The data was coded appropriately for interpretation. The significance and validity of the model was tested. Each independent variable was evaluated for its contributions to the model. Hypothesis 1.6 required its own binary logistic regression analysis across 2,100 approaches.

Hypothesis 1.1, concerning aircraft type, and Hypothesis 1.2, concerning approach type, were supported. The testing of Hypothesis 1.3 revealed that Light Condition was not a statistically significant independent variable. Hypothesis 1.4, pertaining to approach location, was supported.

Hypothesis 1.5 was sometimes supported, meaning that some runways were found to be significant. The runways tested by Hypothesis 1.5.1 and Hypothesis 1.5.2 were found to be significant and both the hypotheses were supported. The runway tested by Hypothesis 1.5.3 was found to be significant, but the Hypothesis was not supported. The runway tested by Hypothesis 1.5.4 was not a significant independent variable. The runway tested by Hypothesis 1.5.5 was found to be significant and the hypothesis was supported.

The independent variable Approach Type, pertaining to Hypothesis 1.6, was not found to be significant.

Research Question 2 was evaluated across eleven hypotheses and 11,939 approaches. The significance and validity of the model was tested. Each independent variable was evaluated for its contributions to the model. Hypothesis 2.6 required its own binary logistic regression analysis across 705 approaches.

Hypothesis 2.1, pertaining to the Independent Variable Aircraft Type, was supported. Hypothesis 2.2 was not supported due to the fact that the independent variable, Approach Type, was not found to be significant. Hypothesis 2.3, pertaining to the significant independent variable Light Condition, was not supported. Hypothesis 2.4, pertaining to the significant independent variable Approach Location, was not supported.

Hypothesis 2.5 was sometimes supported, meaning that some runways were found to be significant. All of the runways tested to explore this hypothesis were found to be significant independent variables, and Hypotheses 2.5.1 through 2.5.5 were supported.

Hypothesis 2.6 was not supported due to IAP Type not being found to be a significant independent variable.

Chapter V: Discussion and Conclusions

This chapter contains the interpretation of the results contained within Chapter IV: Results. Additionally, recommendations to both the flight school and general aviation operators are discussed. Finally, recommendations for further research are also included.

Using logistic regression, two research questions pertaining to unstable approaches and go-arounds were explored by testing 22 hypotheses. The study aims to identify predictors of unstable approaches, and if the approaches are unstable, predictors that those approaches will result in go-arounds. The archival data was provided by a Part 141 flight school and analyzed using General Electric's eFOQA® software to identify stable and unstable approach events as well as approach outcomes.

Discussion

The study evaluated independent variables that could be significant contributors to approach stability and go-around decisions. The results for each Research Question's associated hypotheses are discussed. Potential explanations for the results of the hypothesis testing, as well as potential direction for further research, are explored where appropriate.

General Discussion

Ninety-two percent of the approaches conducted in the selected time frame were conducted in a Cessna 172S Nav III. The Cessna 172S Nav III was also associated with a higher percentage of the unstable approaches flown in the same time frame. The vast majority of approaches conducted were VFR approaches (94.29%) conducted during the day (91.58%). If the approach was an IAP, the IAP type occurrences were nearly equal, with 1,118 of IAPs being Straight-In approaches and 987 approaches being Circling approaches. Sixty-seven percent of approaches were considered to be stable, while nearly 75% of approaches resulted in a landing.

Of arguably larger interest are the statistics surrounding unstable approaches. Of the 11,939 unstable approaches surveyed, 74.7% of those approaches resulted in landings where they should have resulted in go-arounds. As both the flight school and the FAA expect go-arounds upon encountering an unstable approach, this statistic is potentially the most concerning. VFR approaches, daytime approaches, and approaches flown at the home base airport make up 94.08%, 92.42%, and 81.98% of the unstable approaches in the data set, respectively. Further details are explored with the hypothesis testing outlined later in this Chapter.

Research Question 1: What variables are predictors of unstable approaches?

Research Question 1 was explored out of a desire to provide flight crews with advance knowledge of which approaches are more likely to be unstable. This knowledge could potentially aid flight crews in decision making, as well as allow flight crews to tailor approach techniques to the conditions of the approach.

Hypothesis 1.1. Aircraft Type was evaluated as a potential predictor for unstable approaches. The independent variable, Aircraft Type, represented two different aircraft, the Cessna 172S Nav III and the Diamond DA-42 NG. The hypothesis stated that a Cessna 172S Nav III is associated with an increased probability of an unstable approach. Aircraft Type was chosen as an independent variable due to the categories' associations with different types of students and instructors at the flight school.

Aircraft Type ($p < .001$, $Exp(B) = 0.281$, 95% CI [0.258, 0.306]) was found to be statistically significant. A Diamond DA-42 NG aircraft was 3.88 times less likely to experience an unstable approach. The hypothesis was supported.

A potential explanation for the results of this hypothesis test lies in the differences in crews operating the different aircraft. The flight school's flight course sequence is structured such that more experienced students are flying the multi-engine aircraft. Similarly, more experienced employees are acting as instructors in the DA-42 NG aircraft. More research is indicated in order to evaluate the effect of experience and crew composition on approach stability.

Hypothesis 1.2. Approach Type was evaluated as a potential predictor for unstable approaches. VFR approaches and IFR approaches were the two potential categories under which this independent variable could fall. This independent variable was chosen for testing due to the different structures of the approach types; the flight school's altitude, speed, and configuration profiles for VFR and IFR approaches are vastly different. Hypothetically, the differences in the profiles could contribute to instability. Because flight crews conduct more VFR approaches in training due to structure of the flight courses, it stands to reason that the flight crews are more familiar with VFR approaches, and therefore, VFR approaches are less likely to be unstable.

The Approach Type independent variable was found to be significant (p = .032, *Exp(B)* = 0.896, 95% CI [0.811, 0.991]) and VFR approaches were found to be 1.12 times less likely to experience an unstable approach. Therefore, the hypothesis was supported. The disproportionate number of VFR approaches in comparison to IFR approaches potentially supports the suggested reasoning associated with flight crew familiarity. Additionally, the transition from using only instrument references to switching to visual references can take some adjustment from the pilot flying.

Hypothesis 1.3. Light Condition was evaluated as a potential indicator for approach instability. The two categories this independent variable could fall under were Day and Night. Approaches and landings at night are subject to night illusions, which can cause an unprepared pilot to subconsciously destabilize an approach (Federal Aviation Administration, 2016, p. 17-

10). A nighttime approach was hypothesized to be more likely to be unstable. However, Light Condition (*p* = .284, CI [0.962, 1.143]), was not found to be a statistically significant.

Nighttime illusions are widely studied in flight training. The Private Pilot Airman Certification Standards (ACS) has a testing section devoted to Night Operations (Federal Aviation Administration, 2018, p. 62). Both the Private Pilot ACS and the Commercial Pilot ACS have testing sections devoted to Human Factors, which directly addresses optical illusions (Federal Aviation Administration, 2018); (Federal Aviation Administration, 2018) A possible explanation for this finding is that the flight school's education surrounding nighttime approaches and landings currently equalizes the probability of stability between day and night approaches.

Hypothesis 1.4. Approach Location was evaluated as a dichotomous independent variable which had the potential for two categories: Home Base Airport and Outlying Airports. The Home Base airport was associated with 30,789 approaches, whereas Outlying airports accounted for 6,074 approaches. The disproportionate number of approaches favoring the Home Base airport led to the hypothesis that Outlying airfields were more likely to see unstable approaches, on the foundation that airport familiarity leads to more stable approaches. Approach Location was found to be a significant independent variable (*p* = .003, *Exp(B)* = 1.170, 95% [0.962, 1.143]), indicating that an approach conducted at an outlying airfield is 1.12 times more likely to experience an unstable approach. The hypothesis was supported.

Familiarity with the Home Base airport could be an explanation for the disparity between the two categories. In addition, Outlying airports exist in different environments; different density altitudes can affect aircraft performance, which affects the pitch and power settings necessary to maintain stable approaches (Federal Aviation Administration, 2016, p. 11-4). Lack of familiarity with environmental changes could have an influence on a flight crew's ability to adjust to those environmental changes. Lastly, student solo flights often occur at Outlying airports; it stands to reason that a solo student would be more likely to experience an unstable approach as opposed to a flight crewed by a student and instructor.

Hypothesis 1.5. The available runways at the home base airport were selected as independent variables to test for approach stability predictors. Of the six available runways at the home base airport, four were found to be statistically significant predictors in comparison to one Runway. Runway 30 was selected as the comparison runway because it was the runway least used in the data range, for a total of 1,861 approaches. In comparison to Runway 30, Runway 12 was found to be the least likely to result in an unstable approach, while Runway 3L was found to be the most likely to result in an unstable approach.

Hypothesis 1.5.1. Runway 21L was compared to Runway 30. Accounting for 11,850 total approaches, Runway 21L accounted for the most approaches in the data set; it was hypothesized that Runway 21L would be associated with a decreased probability for an unstable approach due to the elevated event frequency. Elevated event frequency would hypothetically be associated with more familiarity with the runway, leading to crews using it as a "baseline" runway. The runway would therefore be associated with fewer runway width illusions. Runway 21L was found to be statistically significant ($p < .001$, *Exp(B)* = 0.612, 95% CI [0.555, 0.675]) and was associated with reduction in probability for an unstable approach by 1.63 times. Therefore, the hypothesis was supported.

Hypothesis 1.5.2. Runway 21R was compared to Runway 30. Runway 21R accounted for 7,154 approaches in the dataset, which is the next-highest approach count per runway behind Runway 21L. Runway 21R was hypothesized to be associated with a decreased probability for an unstable approach due to the same familiarity reasoning as used for Hypothesis 1.5.1. Runway 21R was found to be statistically significant ($p < .001$, *Exp(B)* = 0.584, 95% CI [0.527, 0.647]), with a reduction in probability by 1.71 times for an unstable approach. This hypothesis was supported.

Hypothesis 1.5.3. Runway 3L was compared to Runway 30. Runway 3L accounted for 2,264 approaches, compared to Runway 30's 1,861 approaches. Runway 3L was hypothesized to be associated with a decreased probability for an unstable approach due to the same familiarity reasoning as used for Hypothesis 1.5.1. Runway 3L was found to be statistically significant ($p < .001$, *Exp(B)* = 1.229, 95% CI [1.088, 1.387]), but the hypothesis was not supported because approaches flown to Runway 3L was 1.229 times more likely to experience unstable approaches. Despite being a runway utilized slightly more by the flight school, Runway 3L was less likely to experience stable approaches. A potential explanation for this outcome could lie in runway width; Runway 30 is 75 feet wide, while Runway 3L is 60 feet wide, which could potentially contribute to optical illusions (Federal Aviation Administration, 2016, p. 17-10). Additionally, the approach path to Runway 3L lies directly over several buildings and other unnatural obstacles, which are likely to influence crews' approaches, even if subconsciously. Additionally, Runway 3L has a significant displaced threshold of 811 feet, which can also present illusions to flight crews. Runway 30 has no displaced threshold, nor do Runways 21R or 21L.

Hypothesis 1.5.4. Runway 3R was also compared to Runway 30 as a potential predictor for unstable approaches. Runway 3R was predicted to be less likely than Runway 30 to be associated with unstable approaches due to the same familiarity reasoning as Hypothesis 1.5.1. However, Runway 3R was not found to be significant (p=.075). The hypothesis is not supported.

Hypothesis 1.5.5. Runway 12 was predicted as being a significant predictor of unstable approaches and was hypothesized to be associated with a decreased probability of an unstable approach in comparison to Runway 30. This hypothesis was supported, as Runway 12 was found to be statistically significant ($p < .001$, $Exp(B) = 0.431$, 95% CI [0.383, 0.485]) and 2.32 times less likely to be unstable in comparison to approaches flown to Runway 30. The familiarity argument could also support this result. Additionally, however, Runway 30 has terrain on the approach end of the runway that Runway 12 does not, which could potentially contribute to turbulent weather patterns associated with the runway (Federal Aviation Administration, 2022, p. 19-4).

Hypothesis 1.6. If an IAP was conducted, the IAP Type was evaluated as a predictor for unstable approaches. An IAP could either be a Straight-In or Circling approach. A circling approach was hypothesized to be more likely to be associated with an unstable approach, as circling approaches are associated with more complexity (Federal Aviation Administration, 2017). However, IAP Type was not found to be statistically significant (p=.057). The hypothesis was not supported, as IAP Type is not a good predictor for approach stability. Hypothesis 1.2's testing revealed that IAPs were more likely to result in unstable approaches, but there is no significant difference between the types of IAPs. This could imply that it is equally difficult to maintain a stable approach regardless of the IAP Type.

Research Question 2: If an unstable approach is encountered, what variables act as predictors that the approach will result in a go-around?

Research Question 2 was explored out of a desire to begin to explain reasoning behind go-around decision-making. First, it's important to understand whether or not go-arounds are occurring when they should. Second, it's important to know exactly how to target go-around education to promote go-arounds when approaches are unstable.

Hypothesis 2.1. Aircraft Type was evaluated as a potential predictor for go-arounds if an unstable approach is encountered. It was hypothesized that a Cessna 172S Nav III would be more likely to conduct a go-around due to the instructional emphasis placed on go-arounds during early flight training. A 'Landing Safety Briefing' is required to be administered early on in the flight school's courses and under a few other circumstances; the requirement does not apply to students operating the Diamond DA-42 NG aircraft in a flight course. The independent variable was found to be significant ($p < .001$, *Exp(B)* = 0.335, 95% CI [0.281, 0.399]), and the Diamond DA-42 NG was found to be 2.98 times less likely to continue a landing than a Cessna 172S Nav III, if an unstable approach is encountered. The hypothesis was not supported. A potential explanation for these results is that more experienced pilots have the ability to discern when a go-around is necessary.

Hypothesis 2.2. Approach Type was evaluated as a predictor for go-arounds if an unstable approach is encountered. It was hypothesized that approaches following an IAP were less likely to result in a go-around due to the lack of go-around emphasis in the Instrument ACS as compared to the Private Pilot ACS and Commercial Pilot ACS. However, Approach Type was not found to be statistically significant ($p < .490$).

Hypothesis 2.3. Light Condition was evaluated as a predictor for go-arounds if an unstable approach is encountered. It was hypothesized that unstable approaches conducted at night were less likely to result in a go-around. Night approaches tend to be conducted with the goal of logging a landing for the sake of currency or to meet requirements outlined by a flight course. Therefore, it stands to reason that the pressure of logging a night landing might outweigh the need to go-around when indicated. Light Condition was found to be significant ($p < .001$, *Exp(B)* = 0.214, 95% CI [0.162, 0.283]). However, an unstable approach at night was 4.67 times less likely to result in a landing, which indicates that the hypothesis was not supported. A potential explanation for this lies in the fact that pilots may be more vigilant at night due to the existing education on nighttime approach and landing hazards.

Hypothesis 2.4. Approach Location was evaluated as a predictor for go-arounds if an unstable approach is encountered. It was hypothesized that approaches at outlying airfields were less likely to result in a go-around if the approach was already unstable. Similar to the reasoning for Hypothesis 2.3, approaches to outlying airfields frequently are conducted in order to achieve the goals outlined by flight courses; the pressure to log a landing at an outlying airfield may outweigh the necessity to go-around when indicated. Approach Location was found to be statistically significant ($p = .040$, *Exp(B)* = 0.836, 95% CI [0.705, 0.992]). Outlying airfields were 1.2 times less likely to experience a landing if an unstable approach was encountered. Therefore, the hypothesis was not supported. A potential explanation for this result is similar to the explanation provided for Hypothesis 2.3. Feasibly, pilots could be more uncomfortable at outlying airfields than at their home base airport and more willing to recognize personal limitations.

Hypothesis 2.5. The available runways at the home base airport were selected as independent variables to test as go-around predictors among unstable approaches. All of the tested runways were found to be significant in comparison to Runway 30. Runway 30 was selected as the comparison runway to mirror the indicator variables in Research Question 1. Potentially, crews acknowledge a lack of familiarity with Runway 30; flight crews may have been more prepared to execute a go-around. In comparison to Runway 30, unstable approaches to Runway 3L were the least likely to result in a landing, while unstable approaches to Runway 12 were the most likely to result in a landing.

Hypothesis 2.5.1. Runway 21L was compared to Runway 30 in an attempt to determine which unstable approaches were more likely to result in go-arounds. It was hypothesized that an unstable approach flown to Runway 21L would be associated with a decreased probability of a go-around. Hypothetically, flight crews were more familiar with Runway 21L than Runway 30, and therefore were more likely to attempt to "salvage" a landing after it became unstable. Runway 21L accounted for 3,655 of the unstable approaches in the data set, whereas Runway 30 accounted for 762 unstable approaches. Runway 21L was found to be significant ($p < .001$, *Exp(B)* = 1.873, 95% CI [1.584, 2.216]). If an unstable approach was encountered, an approach flown to Runway 21L was 1.873 times more likely to result in a landing. The hypothesis is supported.

Hypothesis 2.5.2. Runway 21R was compared to Runway 30 in an attempt to explore which unstable approaches were more likely to result in go-arounds. Similar reasoning to Hypothesis 2.5.1 related to runway familiarity was used to establish the theory that an unstable approach flown to Runway 21R was less likely to result in a go-around. Runway 21R accounted for 1,896 unstable approaches in the data set. The hypothesis was supported, as Runway 21R was found to be significant ($p < .001$, *Exp(B)* = 1.548, 95% CI [1.299, 1.844]) and Runway 21R was 1.548 times more likely to result in a landing after experiencing an unstable approach.

Hypothesis 2.5.3. Unstable approaches to Runway 3L were compared to Runway 30 in an attempt to determine if the runway could act as a predictor for go-arounds. Similar reasoning to Hypothesis 2.5.1 related to runway familiarity was used to establish the theory that an unstable approach flown to Runway 3L was less likely to result in a go-around; Runway 3L accounted for

977 unstable approaches. Runway 3L was found to be statistically significant and unstable approaches flown to Runway 3L were 1.403 times more likely to experience a landing in comparison to Runway 30 ($p < .001$, *Exp(B)* = 1.403, 95% CI [1.151, 1.710]). The hypothesis was supported.

Hypothesis 2.5.4. Unstable approaches to Runway 3R were compared to unstable approaches to Runway 30 to determine a potential predictor for go-arounds. Similar reasoning to Hypothesis 2.5.1 related to runway familiarity was used to establish the theory that an unstable approach flown to Runway 3R was less likely to result in a go-around; Runway 3R accounted for 1634 unstable approaches. Runway 3R was statistically significant ($p < .001$, *Exp(B)* = 2.056, 95% CI [1.7, 2.486]) and unstable approaches flown to Runway 3R were found to be 2.056 times more likely to result in a landing compared to unstable approaches flown to Runway 30. The hypothesis was supported.

Hypothesis 2.5.5. Unstable approaches to Runway 12 were compared to unstable approaches flown to Runway 30. It was hypothesized that Runway 12's unstable approaches were more likely to result in go-arounds. Even though Runway 12 accounted for 10 fewer unstable approaches, Runway 12 is still the more commonly used runway. Runway 12 was found to be statistically significant ($p < .001$, *Exp(B)* = 4.423, 95% CI [3.391, 5.770]) and its unstable approaches were found to be 4.423 times more likely to result in landings than unstable approaches flown to Runway 30. The hypothesis was supported. The substantially increased results compared to the other runways tested could potentially be explained due to lack of opportunity to land on Runway 12. If Runway 12 is in use, there is no parallel runway to allow for practice flights; Runway 12 becomes very crowded. Training flights to Runway 12 can potentially mean a substantially lower number of practice approaches conducted to the runway.

The pressure to land to meet practicing goals could feasibly outweigh the motivation to go-around.

Hypothesis 2.6. If an IAP was conducted, IAP Type was evaluated to determine whether or not it was a predictor of go-arounds if an unstable approach was encountered. IAP Type was not found to be significant (*p* = .386). Neither independent variable associated with IFR approaches was found to be significant.

Implications

Research Question 1 - Implications and Further Research

Hypothesis 1.1. The Cessna 172S Nav III was more likely to experience an unstable approach. The AOPA's 2019 Joseph T. Nall Report indicates that multi-engine aircraft were responsible for 8.5% of non-commercial fixed-wing accidents, while single-engine aircraft account for 89.5% of non-commercial fixed-wing aircraft (Aircraft Owners and Pilots Association, 2019). If unstable approaches are strong contributors to accidents, and single-engine aircraft account for the majority of accidents, it stands to reason that the data resulting from this study would state that single-engine aircraft are more likely to encounter unstable approaches.

The strongest potential explanation for the disparity between Cessna 172S Nav IIIs and Diamond DA-42 NGs lies in pilot experience. The flight school's flight courses are structured such that a student only begins to fly in the multi-engine aircraft after obtaining a Commercial Pilot Certificate with an Instrument Rating prior. Flight instructors who instruct in the Diamond DA-42 NG must earn a multi-engine class on flight instructor certificate for which they must take a check ride in order to obtain. Overall, the combined experience level of a typical flight crew on board the Diamond DA-42 NG aircraft is higher than on a Cessna 172S Nav III. An experienced flight crew may be more likely to recognize conditions that warrant a go-around, as well as understand the importance of executing the go-around when indicated.

Research that delves into instructor and student experience could further explain the discrepancy between the two aircraft types. This research could also be expanded to include pilot experience across the entire general aviation pilot population.

Hypothesis 1.2. Instrument Approach Procedures were associated with an increased probability of an unstable approach. The potential implications are two-fold. First, IAPs are not as commonly flown as VFR approaches within the flight school's environment. The principle of exercise would indicate that the more frequently a task is accomplished, the more proficient one is at the task (Federal Aviation Administration, 2020, p. 3-13). The second implication lies in the fact that the flight school's speed, altitude, and configuration profiles are different when comparing VFR approaches and IAPs. In a Cessna 172S Nav III, the final segment of an IAP is conducted at 80 KIAS and 10 degrees of flaps. The approach is only slowed to final approach speed and the aircraft further configured to final flap configuration upon the decision to descend below minimums, which could be as low as 200 feet AGL. The final segment of a VFR approach in the same aircraft is conducted at 65 KIAS and 30 degrees of flaps, and occurs on the turn from base-to-final, around 400 feet AGL. As currently established by the flight school's SOPs, an IAP does not allow a flight crew the same amount of time to establish final landing configuration as a VFR approach. This, in combination with the lack of frequency of IAPs, could potentially explain the discrepancy.

Further research which compares each stable approach parameter of both IAPs and VFR approaches could further explain the discrepancy between the two types of approaches. Additionally, comparing IAP data from this Part 141 flight school to IAP data from a different flight school with different IAP profiles could provide insight into the stability discrepancies across Approach Types.

Hypothesis 1.3. Light Condition was not found to be a significant predictor of approach stability. This can imply that the flight school's current education on day and night flight is adequate to prevent large discrepancies between the two. However, this finding only applies to this flight school. This Part 141 flight school provides a comprehensive education surrounding the hazards of night flight. A Part 141 flight school is not necessarily representative of the general aviation population. Further research is indicated in order to determine whether or not this lack of significance can be found across other general aviation operators. Additional research could also be conducted to compare flight crew composition for night flights and explore night flights within different flight courses.

Hypothesis 1.4: Outlying airfields were found to be associated with an increased probability of an unstable approach. Because more approaches are conducted at the Home Base airport than at Outlying airports, flight crews are more familiar with the Home Base airport. Outlying airports are also more likely to occur at different density altitudes. An approach at a lower density altitude will require different power settings due to increased engine performance, as well as increased pitch to maintain the same approach speed. Flight crews who have consistently flown approaches at one airport will have a harder time adjusting to the environment of a new airport to maintain stability. Additionally, crew composition is more likely to vary at outlying airports; student solos make up a larger percentage of activity at outlying airfields than they do at the home base airport. Finally, the Home Base airport is equipped with an Air Traffic Control tower, whereas many Outlying airports are not; pilots are left to fly approaches without direction from ATC. Further research may be conducted to evaluate the influence of ATC on approach stability.

Further research is indicated to evaluate the causes of the discrepancy in probability of unstable approaches at outlying airfields. Density altitude and different approach parameters such as airspeed, pitch, and power settings can be evaluated to potentially explain the differences between the home base and outlying airfields. Additionally, flight crew composition can be evaluated to potentially explain the approach stability differences between outlying and home base airports.

Hypothesis 1.5. Hypothesis 1.5 examined the significance of runways as predictors of approach stability. In comparison to Runway 30, all runways at the home base airport, with the exception of Runway 3R, were found to be significant predictors. In comparison to Runway 30, Runway 12 was found to be the least likely to result in an unstable approach, while Runway 3L was found to be the most likely to result in an unstable approach. However, the exact reasons why different runways are more likely to result in unstable approaches are unclear. Runway familiarity does not seem to be associated with these results, as Runway 12 is the second least used runway in the data set.

Further research is indicated to explore this finding. Runways have multiple characteristics which could be examined. For example, runway width and lighting can contribute to optical illusions which may cause pilots to fly an approach at a steeper or shallower angle than appropriate (Federal Aviation Administration, 2016). Terrain and obstacles surrounding a runway can influence approach angle as well as contribute to localized wind pattern (Federal Aviation Administration, 2022, p. 19-4).

Hypothesis 1.6. Hypothesis 1.6 evaluates IAP Type as a predictor for unstable approaches, if an IAP was conducted. IAP type was not found to be significant. In combination with Hypothesis 1.2, this finding indicates that all IAPs flown are more likely to be associated with an unstable approach, regardless of IAP type. Further research should be directed toward the efforts described in Hypothesis 1.2.

Research Question 2 - Implications and Further Research

Hypothesis 2.1. If an unstable approach was encountered, Aircraft Type was evaluated as a predictor for go-arounds. Cessna 172S Nav IIIs were found to be associated with a decreased probability of go-arounds in comparison to Diamond DA-42 NGs. The implication is that flight crews are not conducting go-arounds where a go-around is indicated. In the data set, 8,927 unstable approaches resulted in landings, whereas 3,012 unstable approaches resulted in a go-around. Further research is suggested to delve into flight crew experience as it relates to go-around decision making. As suggested in Hypothesis 1.1, the flight crew experience gap between the two subject aircraft is the most obvious difference as it relates to go-around decisions. A more experienced crew may be more likely to first, perceive the unstable condition of the aircraft, and second, decide to execute the go-around.

Hypothesis 2.2. Approach Type was evaluated as a predictor for go-arounds after unstable approaches were encountered. Approach Type was not found to be statistically significant, indicating that no distinct difference exists in terms of go-around decisions between VFR approaches and IAPs. Both types of approaches would require equal attention to improve go-around rates.

Hypothesis 2.3. Light Condition was evaluated as a potential predictor for go-arounds if an unstable approach is encountered. The results of the study revealed that Light Condition was a significant variable, and that unstable approaches at night are far more likely to result in go-arounds. The hypothesis predicted that unstable approaches would be less likely to result in go-arounds at night. Further research is indicated to determine why daytime approaches are less likely to result in go-arounds when an unstable approach is encountered. The potential that flight crews recognize their limitations during nighttime flight exists. Daytime flights are more common, and therefore, flight crews would be more comfortable operating during the day, leading to more "salvaged landings."

Additionally, flights during nighttime are not competing with other flights as aggressively for a chance at landing on a runway; night approaches accounted for 3,057 approaches in the data set, whereas day approaches accounted for 33,760 approaches. Only a certain amount of flights can operate using the same runway at any given time. If flight crews are concerned about opportunities to practice landings, they may be more inclined to forego go-arounds for the sake of gaining experience, even though that experience might result in a negative transfer of learning. Further research could determine whether or not flight training density contributes to poor go-around decision-making.

Hypothesis 2.4. Approach Location was evaluated as a potential predictor for go-arounds if an unstable approach was encountered. Approach Location was found to be significant, but the hypothesis that Outlying airfields experience more landings from unstable approaches was not supported. The Home Base airport was more likely to experience landings from unstable approaches. The theories explored in Hypothesis 2.3, relating to flight crew comfort level at the Home Base airport and flight training density at the Home Base airport are relevant. Home Base approaches accounted for 30,780 approaches in the data set, whereas Outlying Airport approaches accounted for 6,074 approaches. Flight crews could be better at recognizing limitations when they are less familiar with the environment. Additionally, the reduced flight density at outlying airports could give pilots the benefit of less perceived pressure to accomplish a landing on the first try. Further research is indicated to evaluate the effects of flight density and environment familiarity on go-around decision-making.

Hypothesis 2.5. Runways were evaluated as potential predictors for go-arounds once unstable approaches were encountered. All of the Runways at the Home Base airport were found to be significant predictors in comparison to Runway 30; all of the evaluated runways were associated with an increased likelihood of landing from an unstable approach in comparison to Runway 30, with Runway 12 being the most likely to result in a landing from an unstable approach, and Runway 3L being the least likely to result in a landing from an unstable approach. The ideas explored in Hypothesis 2.3 regarding opportunities to land can be further explored to explain these findings as well.

Hypothesis 2.6. IAP Type was explored as a predictor for go-arounds, if an IAP was conducted. IAP Type was not found to be a significant independent variable. This finding, in combination with the findings resulting from Hypothesis 2.2, indicates that IAPs are not distinguishing factors in go-around decision making.

Recommendations

While this research did not evaluate independent variables in enough detail to warrant many recommendations, a few recommendations are appropriate.

First, the flight school could address the probability disparities between Diamond DA-42 NG and Cessna 172S Nav III aircraft by targeting Cessna 172S Nav III flight crews for technique and go-around education.

Second, Instrument Approach Procedures and VFR approaches are not equal in their likelihoods of being associated with unstable approaches; VFR approaches were less likely to result in unstable approaches. The flight school could focus attention on developing education specifically directed at the 'Landing from an Instrument Approach' task in the Instrument ACS. The flight school could also evaluate their IAP profiles to identify their contribution to approach stability.

Third, the flight school placing further emphasis on the differences between how approaches change at different airports from the Home Base airport potentially improving the unstable approach rates at Outlying airports.

Fourth, the flight school can also continue delivering education about the necessity to go-around if an unstable approach is encountered.

Recommendations for Further Research

Targeted research pertinent to the specific results of the study have been suggested above. However, broader research can certainly contribute to the body of knowledge surrounding the topics explored by this study.

First, similar studies can be conducted with larger data sets. Data sets over a longer time frame can capture a full academic year of approach information. A full year of seasonal changes and student growth could reveal further information about approaches and go-arounds. Data sets containing multiple years' worth of information can reveal how larger aviation industry changes have affected approach and landings.

Second, flight density can be evaluated as a contributing factor to approach stability and go-around rates, specifically for parallel and single runway configurations.

Third, a Part 141 flight school is not necessarily representative of the general aviation population at large. One Part 141 flight school's techniques may vary from another Part 141 flight school's techniques. Expanding the data set to include other operators or the broader general aviation population could yield potentially different results.

Lastly, the flight school's threshold for approach stability is 100 feet AGL, whereas the FAA recommends a 500-foot threshold (Federal Aviation Administration, 2021) in VMC. Hypothetically, a 500-foot threshold would leave a flight crew with more time to perceive and respond to an unstable approach. Of course, a flight crew is never committed to a landing. However, evaluating the same data set at different altitudes could potentially reveal whether or not the data is markedly different if flight crews have more time to make their decisions. It could also reveal at which point an approach truly deviates from a stable profile.

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Appendix A

List of FDM Data Parameters – Cessna 172S Nav III

Parameter	Units	Parameter	Units	Parameter	Units
Date	-	*Longitude*	(Degrees; Geodetic)	***AFCS Roll/Pitch Commands***	-
Time	-	*Magnetic Heading*	Degrees	*GPS Fix*	-
GPS Altitude MSL	Feet MSL	*HSI Source*	-	*GPS Horizontal Alert Limit*	-
GPS Altitude	WGS84 Datum	*Selected Cource*	Degrees	*GPS Vertical Alert Limit*	-
Baro-Corrected Altitude	Feet	*Com1/Com2 Frequency*	mHz	*SBAS GPS Horizontal Protection Level*	-
Indicated Airspeed	Knots	*Nav1/Nav2 Frequency*	mHz	*SBAS GPS Horizontal Protection Level*	-
Vertical Speed	Feet per Minute	*CDI Deflection*	Degrees	*Fuel Quantity (Right and Left)*	Gallons
GPS Vertical Speed	Feet per Minute	*VDI/GP/GS Deflection*	-	*Fuel Flow*	Gallons per Hour
Outside Air Temperature	Degrees Celsius	*Wind Direction*	Degrees	*Oil Pressure*	Pounds per Square Inch
True Airspeed	Knots	*Wind Speed*	Knots	*Oil Temperature*	Degrees F
Pitch Attitude Angle	Degrees	*Active Waypoint Identifier*	-	*Engine Speed*	RPM
Roll Attitude Angle	Degrees	*Distance to Next Waypoint*	Nautical Miles		
Lateral and Vertical G Force	Gs	*Bearing to Next Waypoint*	Degrees		
Ground Speed	Knots	*Magnetic Variation*	Degrees		
Ground Track	Degrees Magnetic	***Autopilot On/Off***	-		
Latitude	Degrees; Geodetic	***AFCS Roll/Pitch Modes***	-		

Note: The items in bold are only available on aircraft equipped with an autopilot system.

Note: This table was created using the Garmin NXi Pilot’s Guide. From *Garmin G1000 NXi Pilot's Guide* (A ed., p. 453). (2018). Garmin International.

Appendix B

List of FDM Data Parameters – Diamond DA-42 NG

Parameter	Units	Parameter	Units	Parameter	Units
Date	-	*Longitude*	(Degrees; Geodetic)	*AFCS Roll/Pitch Commands*	-
Time	-	*Magnetic Heading*	Degrees	*GPS Fix*	-
GPS Altitude MSL	Feet MSL	*HSI Source*	-	*GPS Horizontal Alert Limit*	-
GPS Altitude	WGS84 Datum	*Selected Cource*	Degrees	*GPS Vertical Alert Limit*	-
Baro-Corrected Altitude	Feet	*Com1/Com2 Frequency*	mHz	*SBAS GPS Horizontal Protection Level*	-
Indicated Airspeed	Knots	*Nav1/Nav2 Frequency*	mHz	*SBAS GPS Horizontal Protection Level*	-
Vertical Speed	Feet per Minute	*CDI Deflection*	Degrees	*Fuel Quantity (Right and Left)*	Gallons
GPS Vertical Speed	Feet per Minute	*VDI/GP/GS Deflection*	-	*Fuel Flow*	Gallons per Hour
Outside Air Temperature	Degrees Celsius	*Wind Direction*	Degrees	*Oil Pressure*	Pounds per Square Inch
True Airspeed	Knots	*Wind Speed*	Knots	*Oil Temperature*	Degrees F
Pitch Attitude Angle	Degrees	*Active Waypoint Identifier*	-	*UTC Offset*	-
Roll Attitude Angle	Degrees	*Distance to Next Waypoint*	Nautical Miles	*Voltage (Each Engine)*	Volts
Lateral and Vertical G Force	Gs	*Bearing to Next Waypoint*	Degrees	*Amperage (Each Engine)*	Amps
Ground Speed	Knots	*Magnetic Variation*	Degrees	*Engine Speed (Each Engine)*	RPM
Ground Track	Degrees Magnetic	*Autopilot On/Off*	-	*Engine Power (Each Engine)*	Percent
Latitude	Degrees; Geodetic	*AFCS Roll/Pitch Modes*	-		

Note: This table was created using the Garmin NXi Pilot’s Guide. From *Garmin G1000 NXi Pilot's Guide* (A ed., p. 473). (2018). Garmin International.

Appendix C

Variable Coding

Research Question 1 Variable Coding

Table C1

Dependent Variable Encoding – Research Question 1

	Original Value	Internal Value
Unstable	No	0
	Yes	1

Table C2

Categorical Variable Coding – Research Question 1

		Parameter Coding					
Variable		(1)	(2)	(3)	(4)	(5)	(6)
Runways	21L	1.000	.000	.000	.000	.000	.000
	21R	.000	1.000	.000	.000	.000	.000
	3L	.000	.000	1.000	.000	.000	.000
	3R	.000	.000	.000	1.000	.000	.000
	Outlying	.000	.000	.000	.000	1.000	.000
	R12	.000	.000	.000	.000	.000	1.000
	R30	.000	.000	.000	.000	.000	.000
Approach Type	IFR	1.000					
	VFR	.000					
Time of Day	Day	1.000					
	Night	.000					
Location	Home Base	1.000					
	Outlying	.000					
Airplane Type	C172	1.000					
	DA42	.000					

Table C3

Dependent Variable Encoding – Hypothesis 1.6

	Original Value	Internal Value
Unstable	No	0
	Yes	1

Table C4

Categorical Variable Coding – Hypothesis 1.6

Variable		Parameter Coding					
		(1)	(2)	(3)	(4)	(5)	(6)
Runways	21L	1.000	.000	.000	.000	.000	.000
	21R	.000	1.000	.000	.000	.000	.000
	3L	.000	.000	1.000	.000	.000	.000
	3R	.000	.000	.000	1.000	.000	.000
	Out	.000	.000	.000	.000	1.000	.000
	R12	.000	.000	.000	.000	.000	1.000
	R30	.000	.000	.000	.000	.000	.000
IAP Type	Circling	1.000					
	Straight-In	.000					
Time of Day	Day	1.000					
	Night	.000					
Location	Home Base	1.000					
	Outlying	.000					
Aircraft Type	C172	1.000					
	DA42	.000					

Research Question 2 Variable Coding

Table C5

Dependent Variable Encoding – Research Question 2

	Original Value	Internal Value
Landing Outcome	Go-Around	0
	Landing	1

Table C6

Categorical Variable Coding – Research Question 2

		Parameter Coding					
Variable		(1)	(2)	(3)	(4)	(5)	(6)
Runways	21L	1.000	.000	.000	.000	.000	.000
	21R	.000	1.000	.000	.000	.000	.000
	3L	.000	.000	1.000	.000	.000	.000
	3R	.000	.000	.000	1.000	.000	.000
	Outlying	.000	.000	.000	.000	1.000	.000
	R12	.000	.000	.000	.000	.000	1.000
	R30	.000	.000	.000	.000	.000	.000
Approach Type	IFR	1.000					
	VFR	.000					
Time of Day	Day	1.000					
	Night	.000					
Location	Home Base	1.000					
	Outlying	.000					
Airplane Type	C172	1.000					
	DA42	.000					

Table C7

Dependent Variable Encoding – Hypothesis 2.6

	Original Value	Internal Value
Landing Outcome	Go-Around	0
	Landing	1

Table C8

Categorical Variable Coding – Hypothesis 2.6

Variable		Parameter Coding					
		(1)	(2)	(3)	(4)	(5)	(6)
Runways	21L	1.000	.000	.000	.000	.000	.000
	21R	.000	1.000	.000	.000	.000	.000
	3L	.000	.000	1.000	.000	.000	.000
	3R	.000	.000	.000	1.000	.000	.000
	Out	.000	.000	.000	.000	1.000	.000
	R12	.000	.000	.000	.000	.000	1.000
	R30	.000	.000	.000	.000	.000	.000
IAP Type	Circling	1.000					
	Straight-In	.000					
Time of Day	Day	1.000					
	Night	.000					
Location	Home Base	1.000					
	Outlying	.000					
Aircraft Type	C172	1.000					
	DA42	.000					

List of Tables