A23 – Validation of Low-Altitude Detect and Avoid Standards Final Report

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This document serves as the final report for the validation of low altitude detect and avoid standards. This final report contains flight testing information and data analysis. It will aid in informing the public of the research conducted to ensure safe separation of aircraft in the National Airspace System.

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TABLE OF ACRONYMS

Acronym	Meaning
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance System Broadcast
AEM	Airspace Encounter Model
AGL	Above Ground Level
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society of Testing and Materials
CFR	Code of Federal Regulations
CPA	Closest Point of Approach
DAA	Detect and Avoid
DPS	Department of Public Safety
DSU	Delta State University
FAA	Federal Aviation Administration
FOV	Field of View
GA	General Aviation
GPS	Global Positioning System
IRB	Institutional Review Board
LoWC	Loss of Well Clear
LR	Loss of Well Clear Risk Ratio
MAC	Mid Air Collision
MIT LL	Massachusetts Institute of Technology Lincoln Laboratory
MSU	Mississippi State University
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NMAC	Near Mid Air Collision
PIC	Pilot in Command
PII	Personal Identifiable Information
RR	Risk Ratio
SAA	See-and-Avoid
sUAS	Small Unmanned Aircraft System
TCAS	Traffic Collision Avoidance System
TLX	Task Load Index
UAS	Unmanned Aircraft System(s)
UASSRF	Unmanned Aircraft Systems Safety Research Facility
WCV	Well Clear Volume

TABLE OF SYMBOLS

Symbol	Meaning
A	Visual cross section of the intruder
β	Pilot attentiveness factor
λ	Visual acquisition rate
π	Standard use of Pi
φ	Azimuth Angle
P	"Instantaneous" probability of visual acquisition of a target
Q	Opportunity integral
R	Visibility factor
r	Range between ownship and intruder
θ	Elevation angle

EXECUTIVE SUMMARY

This ASSURE research effort, A23 Verification & Validation of Low Altitude Detect and Avoid Standards, aimed to critically assess the performance of human pilots in detecting other air traffic, assess potential conflicts, and analyze potential maneuver options for avoidance of an intruder aircraft. Serving as a validation and extension of prior research conducted by Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) in the 1980s, the study underscores the importance of maintaining and enhancing safety in aviation, particularly within the realm of Unmanned Aircraft Systems (UAS) operating at low altitudes. The results of this effort will provide the Federal Aviation Administration (FAA) with vital data to determine if the risk ratio safety performance thresholds, as outlined in the American Society of Testing and Materials (ASTM) Detect and Avoid (DAA) standard, sufficiently capture the realities of pilot performance in low-altitude environments.

The effort involved a series of practical flight tests wherein 59 Subject Pilots flew against an intruder aircraft. Their task was to visually identify and announce the presence of the intruder aircraft, thereby providing real-world data on pilots' aircraft detection capabilities. Encounters were designed with varying geometries to produce a large dataset covering a range of angles and closing speeds. Delta State University's fleet of Cessna aircraft were the primary aircraft flown, primarily Cessna 172s and a Cessna 206. There were 298 encounters collected between fixed-wing aircraft with 143 of them resulting in detections and 155 resulting in a missed detection. A smaller subset of encounters between fixed wing and rotorcraft was also created.

A new model for visual acquisition of aircraft was created based on the detection data from the flight test encounters. This was done by following and updating prior work, primarily by finding a new pilot attentiveness factor, β. Researchers were able to determine a more exact FOV standard for the Cessna aircraft and apply it to the updated model and simulations. A baseline β value was found to be 7438±997. Encounter simulations were performed using the trajectories generated by the MIT Lincoln Laboratory Airspace Encounter Model. Two sets of avoidance simulations were recorded. In the first set, only the ownship vehicle was allowed to execute see-and-avoid behavior. In the second set, both the ownship and intruder could execute see-and-avoid maneuvers. In addition, six different delay times and four different turn rates were simulated. The full factorial combination of all these variables was performed for a total of 48 different possible parameter configurations. Each configuration was simulated 10 times for each of the 10,000 different encounter models, for a total of 4.8 million simulated encounters.

This Unmanned Aircraft Systems Safety Research Facility (UASSRF) led effort provides a pivotal step in understanding pilots' ability to visually detect other aircraft, particularly at low altitudes. The data and conclusions provided are applicable strictly to this encounter set given the specificity of the testing with the individual test subjects in this report. During the analysis, it was found that the ASTM risk ratios initially seem to be adequate when compared to the safety measured during the flight-testing campaign of this research effort. Future research by MSU through the A65 Detect and Avoid Risk Ratio Validation project seeks to build upon the dataset presented in this document and introduce a larger intruder aircraft pool, including large UAS and additional rotorcraft. By further exploring these findings and implementing the recommendations for improvement, researchers and regulators can collaborate to significantly enhance aviation safety, shape future regulatory standards, and provide a safer framework for the burgeoning UAS industry.

1 Introduction & Background

The Federal Aviation Administration (FAA) provides academic institutions with the necessary resources to conduct scientific evaluations of newly developing technology within the Unmanned Aircraft Systems (UAS) sector. Over two dozen institutions under the Alliance for System Safety of UAS through Research Excellence (ASSURE) are studying the critical research topics for safe and efficient integration of UAS into the National Airspace System (NAS). Within the ASSURE consortium are multiple FAA designated UAS test sites, thousands of square miles of environmentally diverse flight test airspace, and various affiliates that contribute to ASSURE's portfolio. Mississippi State University (MSU) has been designated as the UAS Safety Research Facility (UASSRF) by the FAA and is tasked with evaluating prior research that may need updated or expanded focus. The following report covers the research conducted under the A23 Validation of Low-Altitude Detect-and-Avoid standards effort started in October 2020 and continued until August 2023 by the UASSRF.

The tasking for this work expands on prior research on the performance of human pilots to detect other air traffic, assess the potential for conflict, and analyze potential maneuver options for avoidance against an intruder aircraft when a potential conflict exists. The results of data and analyses conducted during this effort will be used by the FAA to support a determination of whether the Risk Ratio (RR) safety performance thresholds defined in the American Society for Testing and Materials (ASTM) Detect-and-Avoid (DAA) standard are adequate. The report covers just over a year of flight test efforts from late 2021 until February 2023. The testing for this project took place at two locations. The first, Starkville, Mississippi, served as trial runs for the testing and data collection methods. Several procedures were improved over a handful of initial flight tests with MSU pilots. The remainder of the effort took place in Cleveland, Mississippi, with the Delta State University (DSU) Department of Commercial Aviation. DSU provided the Cessna aircraft used and the Subject Pilot participants under observation during flight testing for this research effort. DSU is an FAA-approved Part 141 flight training school with students from all levels of piloting experience. The Mississippi Department of Public Safety (DPS) provided an intruder rotorcraft, the Airbus H125, for generating encounters between subjects in fixed wing aircraft and a dedicated intruder rotorcraft. This pool of pilots helped provide data to better support a determination of the appropriateness of the ASTM DAA standards.

This report contains all procedures, flight paths, and equipment used to accomplish the numerous flight tests for this effort. Additionally, detailed analysis of the data used to generate a visual acquisition model and simulation is presented. This analysis determined the closest point of approach, simulated avoidance maneuvers, evaluation of detection distances, and other metrics related to the test data. Appendices with essential information related to the visual acquisition data, Subject Pilot metadata, and other test-related materials are provided.

1.1 Background

The UASSRF's work will be used by the FAA to determine adequate safety performance thresholds required by DAA systems that serve as an alternate means of compliance to existing manned aviation See-And-Avoid (SAA) regulations listed in 14 Code of Federal Regulations (CFR) §91.113 (General Operating & Flight Rules 14 C.F.R § 91, 2022). This work will provide the FAA with information necessary to develop and validate certification standards for DAA systems. The SAA performance metrics validated through this research are needed to measure the ability of manned aircraft pilots to see and to then avoid conflicts with other aircraft. Different SAA performance metrics exist depending on whether the pilot uses assistive technologies that aid in visual detection and whether the separation goal being evaluated is to remain well clear of other aircraft or to avoid a Near Midair Collision (NMAC) with other aircraft. The results of these assessments are expressed as RRs and are intended to inform the establishment of DAA performance ratios for UAS. The DAA RR will be compared to the performance of pilots flying by the see and be seen concept to determine whether the risk ratio meets or exceeds pilot performance.

As UASs continue to quickly integrate into the NAS, regulators seek input from industry stakeholders on technology readiness and effectiveness. ASTM International's F38.01 Airworthiness subcommittee engages in the development of industry consensus standards for UAS. This group has developed the *Standard Specification for Detect and Avoid System Performance Requirements* which covers DAA system design and provides requirements intended to unify industry's approach when developing DAA systems safe for integration into the NAS. Within the numerous requirements listed in that standard for DAA system development, there are four ratios related to maintaining well clear – a certain distance from intruder aircraft the subject aircraft, or ownship, must maintain throughout the length of an encounter. As there are no official requirements for the size of well clear, those provided by Figure 1 stem from research performed (Weinert, Campbell, Vela, Schuldt, & Kurucar, 2018) to determine the most appropriate volume for UAS within the scope of the ASTM standard. Figure 1 also provides the equations for RR and the Loss of Well Clear (LoWC) Risk Ratio (LR).

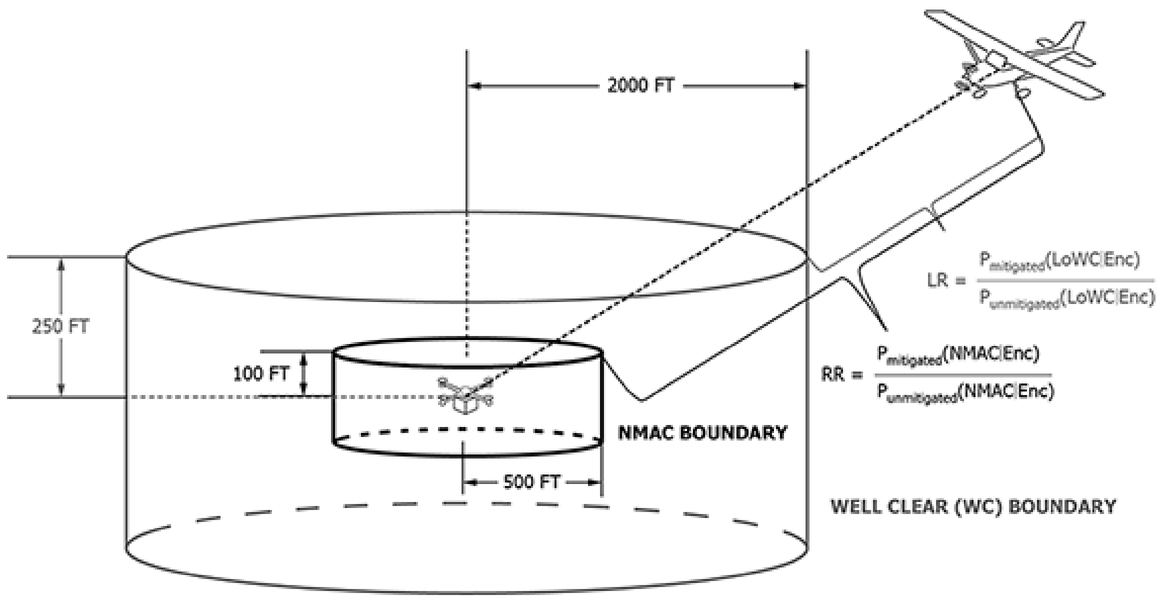

Figure 1. Visualization of the Well Clear volume for UAS within the scope of the ASTM standard (ASTM International, 2023).

These four values are the risk ratios against cooperative and uncooperative intruding aircraft. Cooperative aircraft are defined as aircraft equipped with a means to broadcast ownship location and/or intentions. Uncooperative aircraft are those without any means of communicating their location through interrogation of a transponder or receipt of an Automatic Dependent Surveillance System Broadcast (ADS-B) Out broadcast. Table 1 provides the current values of the ASTM standard's four risk ratio values selected by industry experts.

Table 1. Risk Ratio requirements from the ASTM DAA Performance Standard.

Intruder Equipage	**NMAC Risk Ratio (RR)**	**Loss of Well Clear Risk Ratio (LR)**
Cooperative (ADS-B Out)	≤ 0.18	≤ 0.40
Non-cooperative or transponder-only	≤ 0.30	≤ 0.50

The RR and LR values drive the performance-focused mindset of the standard, as the means of compliance do not specify a certain hardware or software approach. Although the values were selected by industry experts and based on collision risk assessments conducted by academia, these values had no influence from pilot acquisition performance data collected to yield a pilot-equivalent safety threshold for UAS to meet or exceed.

This research effort seeks to provide regulators and industry with the most concrete evaluation of pilot visual acquisition performance. As the FAA mandates, UAS must meet or exceed the same levels of safety as manned aviation performs currently while operating across the NAS. Therefore, the threshold for that level of safety needs to be established purposefully and scientifically. This effort, A23 Validation of Low Altitude Detect and Avoid Standards, aims to establish the threshold and determine the level of safety UAS will have to meet based on an extensive flight test program that collected pilot behavior data.

1.2 Development of a Well Clear Recommendation

The Well Clear Volume (WCV) referenced above comes from prior research performed (Weinert, Campbell, Vela, Schuldt, & Kurucar, 2018) and resulted in a horizontal separation of 2000 feet and a vertical separation of 250 feet, as illustrated in Figure 1. The main rationales for the hockey puck design of the WCV are due to the smaller wingspans for UAS contributing to a lower probability of a Mid-Air Collision (MAC) and how the puck design allows for small UAS to have enough time to detect an aircraft and execute an avoidance maneuver due to their typically lower airspeeds. For example, at a vertical speed of 300 feet per minute, it will take twenty seconds for a small UAS (sUAS) to gain 100 feet of vertical separation and for a faster speed of 800 feet per minute, it will take seven and a half seconds.

There have been multiple studies dedicated to determining the minimum separation requirements for large UAS. However, due to the difference in operating environments, these studies do not entirely apply to sUAS. Large UAS are typically able to utilize Traffic Alert and Collision Avoidance System (TCAS) and Air Traffic Control assistance, but these services only provide traffic advisories and do not provide maneuver-based advisories below 1,000 feet Above Ground Level (AGL). Through CFR Part 107, sUAS have the authority to regularly operate in very low-level altitudes below 400 feet AGL. Therefore, TCAS would not apply to sUAS, and various alternative means of alerting and guidance have been created.

Studies done with general aviation aircraft typically assume a probability of ten percent for experiencing a MAC if a NMAC occurs. The total summed wingspan of two general aviation aircraft will almost always be greater than that of a general aviation aircraft and sUAS which is typically less than fifty feet and highly unlikely to exceed 100 feet. As the sum of wingspans decreases the P(MAC|NMAC) decreases as well. Research from a 2023 MIT LL study (Underhill & al., 2023) show that an unmitigated encounter between a single engine fixed wing aircraft and a fixed wing UAS is in the range [0.001, 0.0006]. MIT researchers were able to determine these results leveraging the ASSURE effort A47 – sUAS Mid Air Collision Likelihood (De Abreu, et al., 2023).

1.3 Purpose

The primary objective of the flight test campaign under this ASSURE effort was to capture pilot visual acquisition performance during low altitude encounters at different geometries and closing rates. Researchers focused on key parameters that could affect pilot performance such as environmental conditions, pilot workload, and intruder aircraft characteristics. Other objectives included the continuous refinement of the test methods, analysis of perceived workload, and pilot interviews. The goal of this flight test campaign was to produce as many encounters between two aircraft while collecting data from audio recorders, video cameras, and Global Positioning System (GPS) logs for as many Subject Pilots as available.

2 Test Methods

Seventy-four flight tests were performed to collect data on the ability of pilots to visually acquire another aircraft during a typical flight. Three MSU staff made up the first three flight tests and served as a basis for refining methods prior to involving DSU. A variety of fixed-wing crewed aircraft, rotorcraft, UAS, pilots with varying experience, and flight routes were used to create a robust dataset. These flight tests consisted of controlled encounters between the aircraft during which a researcher would record the time the pilot announced they had visually acquired the other test aircraft along with other distractions, such as birds and ground clutter.

The following test methods section covers the necessary personnel for accomplishing the testing, outlines the procedures developed and followed, lists the equipment utilized for data acquisition, and details other necessary aspects of the flight test campaign. Safety considerations and procedures are also provided.

2.1 Personnel

The designated roles and role descriptions required to conduct the flight testing described in this report were as follows:

- **Test Director** - The Test Director was responsible for ensuring that the flight test was completed in accordance with the flight test plan. The Test Director ensured the test flight was conducted in a safe manner and in compliance with the flight test cards with accepted deviations, acted as backup to the Test Conductor, reviewed and approved flight test plans, had the responsibility of ensuring all members of the flight test team understood their roles and responsibilities, and ensured that all members of the flight test team were properly trained in their assigned roles and could carry out their responsibilities. The Test Director was the final authority on alterations to any test cards or the test plan.
- **Test Conductor** - The Test Conductor was responsible for coordinating personnel, aircraft, and equipment to meet the objectives of Test Cards during a test flight. The Test Conductor was the lead role for generating the flight test plans and flight test cards. The Test Conductor also participated in flight execution briefings as they oversaw the conduct of the test flight.
- **Safety Pilot** - The Safety Pilot ensured that the flight was safe and that all applicable procedures were followed. The Safety Pilot was responsible for associating flight paths and visually acquiring the other aircraft to ensure that safety thresholds were being met while in flight. The Safety Pilot was assisted by a traffic display that allowed them to confirm that the ownship and intruding aircraft were at the correct altitudes. The Safety Pilot was the Pilot-in-Command (PIC) and in the event of a possible unsafe encounter, the Safety Pilot had the authority to initiate a test card abort procedure and take control of the aircraft. In the instance of a dedicated intruder aircraft, two Safety Pilots occupied the aircraft. The pilot in the left seat maintained the responsibility of flying the aircraft and encountering the ownship aircraft and Subject Pilot while the other Safety Pilot would monitor traffic displays and supplement visual scanning.
- **Human Factors Researcher** - The Human Factors Researcher was responsible for monitoring the status of the aircraft and/or operating the system(s) during the flight test. The Human Factors Researcher was also tasked with data recording, system operation, and equipment emplacement. The Human Factors Researcher performed active data collection during the flights as well as provided all necessary post flight documentation to the Subject Pilot and conducted debriefs.
- **Subject Pilot** - The Subject Pilot was observed while flying under unassisted flight, without any traffic monitoring system or ADS-B alerts. The primary task of the Subject Pilot was to visually acquire the other aircraft that were in the air during the active test flight while safely operating the aircraft. The Subject Pilots had varying degrees of experience and qualification. The Subject Pilot was the sole manipulator of the controls throughout the flight – unless the Safety Pilot initiated a test card abort and took control of the aircraft. It should be noted that while the Subject Pilot was

part of the research, they were not aware of the focus of the testing until debriefing. Brief and debrief scripts are supplied in Appendix 1 of this report.

All fixed-wing aircraft were comprised of a flight crew of one Subject Pilot, one Safety Pilot, and one Human Factors Researcher. The Test Conductor and Director remained grounded during the flight tests and worked to ensure that the flight tests went smoothly by monitoring equipment and flight test progress. Flight test events that required a dedicated intruder (no Subject Pilot or Human Factors Researcher onboard) utilized two Safety Pilots in the aircraft, allowing one to fly and focus on generating the encounters while the other monitored the airspace and ensured that safety margins were met.

2.2 Equipment

All flight test supporting equipment was stored in individual flight bags, with each one containing all the necessary equipment for one aircraft. Table 2 lists all essential equipment for recording the Subject Pilot workload and encounters.

Table 2. Equipment list for each aircraft.

Equipment	Quantity
GoPro Hero 8 Black	3
microSD card	6
Apple iPad Mini 5th Gen	1
Samsung Galaxy S7 tablet	1
Suction cup mount	3
Audio splitter	1
Sony PX-470 digital audio recorder	1
Sentry ADS-B receiver	1

In addition to the equipment listed, the team had a surplus of extra camera batteries to allow for extended data collection. A singular battery was able to power a given GoPro for approximately one hour while recording at a resolution of 1080p. This required discharged batteries to be exchanged for charged batteries after each flight – charging the discharged batteries between flight events. Between flights, batteries were scrutinized for any damage outside of normal wear and tear. The microSD cards would also be replaced so the previous flight’s video files could be moved to an encrypted external solid-state drive to ensure adequate storage space for the large file sizes. Audio would typically be saved from the digital audio recorded at the end of the day once all flights had been completed and equipment was taken out of the aircraft. This aided the Test Conductor in keeping track of all the data and videos that were generated during a flight test event. The Sentry ADS-B receiver was mounted in the rear window of the aircraft to achieve the best GPS signal and allowing for more accurate location data to be recorded. The cameras were mounted on the windshield of the aircraft using suction cups as displayed in Figure 2.

Figure 2. Camera mounting locations in the cockpit of a Cessna 172.

The cameras on the left and right spanned a Field-Of-View (FOV) from the leading edge of the wing on each side to the center of the aircraft's nose. The middle camera is pointed towards the interior of the cockpit to capture video of the Subject Pilots during the flight tests. The audio splitter cable was plugged into the aircraft's headphone jack and the other end into the digital audio recorder and the Subject Pilot's headset. This allowed all audio that came through the pilot's headset to be recorded. Before the digital audio recorder was acquired, the splitter had an adapter that allowed it to be plugged directly into the middle GoPro to record the audio over the video. Figure 3 shows the test equipment.

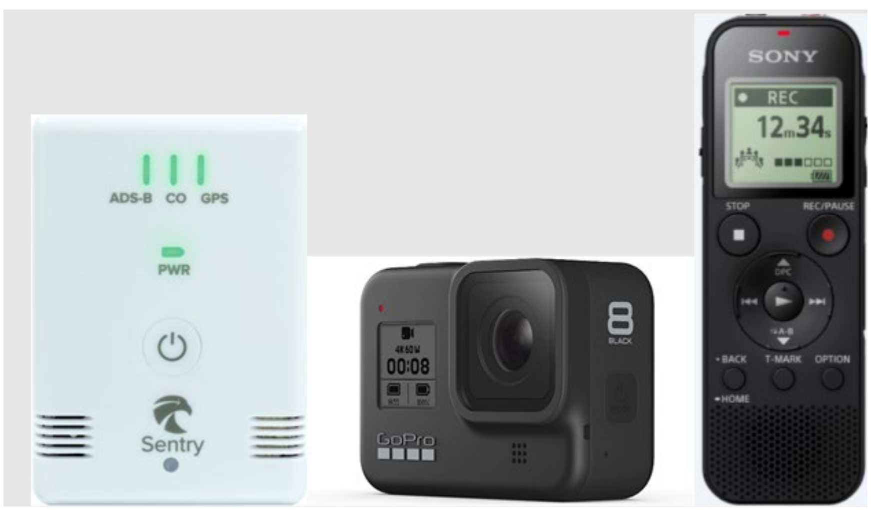

Figure 3. Sentry ADS-B receiver, GoPro Hero 8 Black camera, and Sony PX-470 digital audio recorder used throughout testing.

2.2.1 Data Management

Due to the participation of human subjects and the collection of Personal Identifiable Information (PII) throughout the flight tests, extreme care was taken to protect any data that could identify any of the participants. The Subject Pilots' names were not used in any data that was shared with the FAA or that was published. Each Subject Pilot was assigned an individual subject number and only that number was included in data collection forms. All audio recordings were transcribed, and the voice recording deleted. Once data collection had been completed and all data was confirmed and properly coded with a number, all information that could directly identify Subject Pilots was deleted. Test subjects were assured that only aggregate data would be shared back to the sponsoring agency and all questions were voluntary. Test subjects could have skipped or refused to answer any questions without fear of penalty. Research information, such as procedures, consent forms, and briefing documents, were shared with the MSU Institutional Review Board (IRB) and the Office for Human Research Protections and others who were responsible for compliance with laws and regulations related to research. Any PII collected or stored for any period of time throughout the research was encrypted and only the research personnel approved by the MSU IRB had access to the data. Additionally, the MSU policies and procedures for data privacy and protection were complied with.

2.3 Test Aircraft

Several aircraft were used throughout the research to achieve the desired number of flights under the conditions set by researchers. Three practice flight tests were performed over Starkville, Mississippi using Raspet Flight Research Laboratory's Boeing PT-17 Stearman and Grumman Tiger, as shown in Figure 4 and Figure 5, respectively.

Figure 4. MSU-owned Boeing PT-17 Stearman aircraft.

Figure 5. MSU-owned Grumman Tiger aircraft.

Many of the aircraft used in the flight tests were provided by the DSU flight school, particularly Cessna 172Ps, Cessna 172Rs, Cessna 152s, and a Cessna 206 as shown in Figures 6-8. These aircraft were chosen due to their availability and significant presence in the NAS. There were four different Cessna 172s flown throughout the flight tests with similar paint schemes and livery – providing consistent visual qualities.

Figure 6. DSU-owned Cessna 172 aircraft.

Figure 7. DSU-owned Cessna U206G Stationair aircraft.

Figure 8. DSU-Owned Cessna 152 aircraft.

In addition to these aircraft, an Airbus H125 helicopter owned by the Mississippi DPS, shown in Figure 9, participated in six flight tests under this effort.

Figure 9. Mississippi Highway Patrol's Airbus H125 helicopter used as a dedicated intruder during flight testing.

2.4 Flight Test Procedure

The flight test procedure began with a Subject Pilot volunteering to participate in the research. Prior to every event, a preflight briefing gave Subject Pilots a brief overview of the research as it relates to workload and visual acquisition – without divulging key details of the testing objective. Before and during the testing, researchers used checklists to ensure that all briefings were performed, and all equipment managed. Throughout the flight, researchers utilized a custom-built Android application to log GPS timestamped data whenever the subject announced an intruder aircraft. Special attention was made to ensure the time synchronization of every device used for data collection.

2.4.1 Preflight

Test subjects recruited by the UASSRF and DSU's Department of Commercial Aviation were required to provide documentation certifying they had obtained at least a Private Pilot Certificate or higher. The Subject Pilot was considered the sole manipulator of the controls and the Safety Pilot served as PIC. Test subjects were recruited based on the availability of pilots with varying levels of expertise. Test subjects and Safety Pilots conducted standard preflight procedures. The research team also placed the equipment in the aircraft. This would typically occur before the Subject Pilot made their way to the aircraft to limit interference with the subject. Researchers worked with the Subject and Safety Pilots to ensure equipment would not interfere with required space needed to manipulate the controls of the aircraft safely.

2.4.1.1 Preflight Brief

UASSRF researchers briefed the Subject Pilots on the high-level details of the test that they consented to participate in. Details surrounding the existence of a second aircraft or dedicated intruder aircraft were kept to a minimum. Key phrases such as "pilot workload measurement" were used in an effort to reduce the likelihood of the Subject Pilot altering their scanning rate or situational awareness. Although various misdirects were built into the procedure for interacting with the Subject Pilots, the existence of additional equipment in the cockpit, the interaction with UASSRF Researchers, and other variables related to human factors testing may have influenced the Subject Pilots to focus on textbook pilot skills, rather than natural cockpit behavior.

2.4.2 Inflight

During flight testing, three personnel occupied the aircraft. The Subject Pilot occupied the front left seat, the Safety Pilot in the front right seat, and the Human Factors Researcher in either rear seat. Upon takeoff, the Human Factors Researcher began recording the track log of the aircraft throughout the flight with ForeFlight. When the Subject Pilot would spot and announce visual acquisition of an intruding aircraft, the Human Factors Researcher logged the visual acquisition in the Human Factors Log application. The Human Factors Researcher would press the "Pilot Spotted Aircraft" button, creating a timestamp of when the Subject Pilot spotted the aircraft. The Human Factors Researcher would then check whether the aircraft that the Subject Pilot spotted was indeed a test aircraft or a non-test aircraft and make note of the intruding aircraft in the log. The researcher could do this either by visually confirming the aircraft themselves or by referencing the traffic monitor on ForeFlight. Typically, the GoPro cameras in the cockpit were turned on once the aircraft arrived at the testing location to conserve battery and ensure that the full flight test could be captured on the camera's limited battery life. Upon reaching the location, the researcher would have the pilots turn the cameras on and begin the recording.

2.4.3 Postflight

After testing, UASSRF researchers guided the pilots to an isolated area, a private and insulated room, to limit exposure to other Subject Pilots. The Subject Pilot would complete a demographic survey, the National Aeronautics and Space Administration (NASA) Task Load Index (TLX) perceived workload survey and be asked a series of questions about each of their encounters with the intruding aircraft. Additionally, the Human Factors Researcher would debrief the Subject Pilot, officially concluding their participation in the research.

2.4.3.1 Surveys

Following each flight, the Human Factors Researcher would provide the Subject Pilot with a survey, shown in Appendix 2, asking the Subject Pilot to detail their age, aircraft experience, estimated time flying aircraft with respect to category and class, certifications, and other general demographic information. Once those details were provided, UASSRF researchers guided the participant through questions directly related to workload and the encounters the Subject Pilot had with the other aircraft.

Participants were given opportunities to add additional information not limited to the format of the questionnaires. Researchers compiled the comments and made electronic copies of the handwritten answers to the questionnaires. Each questionnaire was then marked with a participant number, not linked to the individual. Individuals would later be linked to a set of participant numbers to determine if repeat participation had any effect on the validity of the data. Additionally, the Human Factors Researcher would provide a tablet with the NASA TLX on it to the Test Subject. The TLX weighted the factors that the test Subjects chose as having the most impact on their workload during the flight.

2.4.3.2 Debrief

The final step of a Subject Pilots' participation in the research was a debrief by the Human Factors Researcher. During the debrief, participants consented to the use of their performance data by signing an Informed Consent Form. This document contained the high-level details of the testing focus and was to be signed by the participant officially releasing them from the research. Researchers then read to the participant a script containing details related to the expected encounters. Participants were given the researcher contact information and then asked if the participant was open to participating in the test again at a later date under different circumstances.

2.4.4 Test Location

Flight testing and data collection occurred in the airspace surrounding Cleveland, Mississippi, shown in Figure 10. All aircraft took off and landed at DSU's home airport, Cleveland Municipal Airport (KRNV). KRNV, shown in Figure 11, is a non-towered General Aviation (GA) airport. The airport sees regular agricultural aircraft, occasional small jet, and consistent single and multi-engine pilot training traffic.

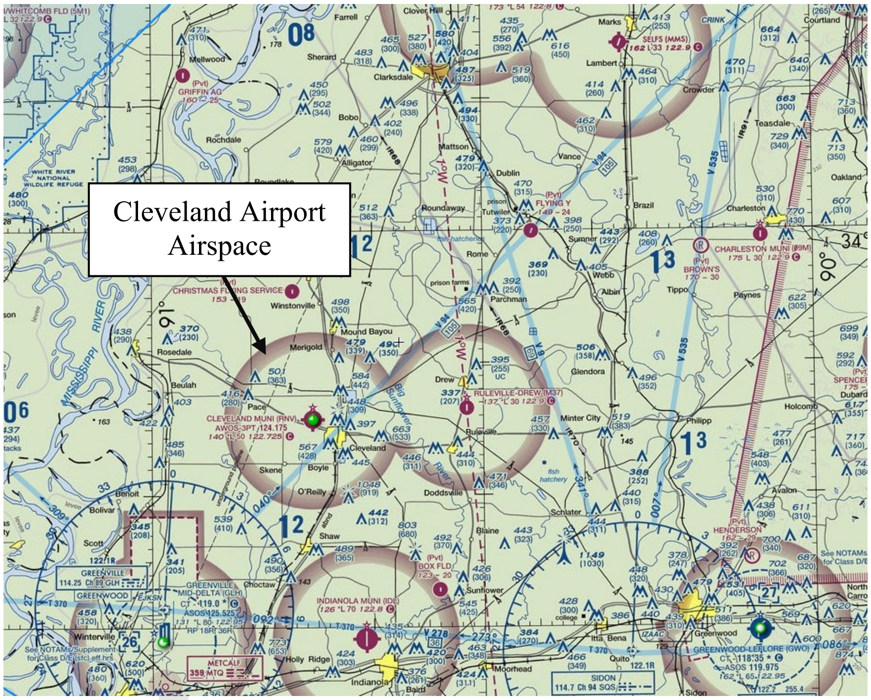

Figure 10. Sectional view of KRNV and its surrounding area.

Figure 11. Aerial view of KRNV.

DSU has 15 designated practice areas that deconflict the local airspace due to the high number of student flights occurring daily. Testing was kept within the boundaries of these practice areas, shown in Figure 12, although testing was not constrained to just one practice area. Areas 4, 5, 7, and 8 were used the most with occasional flights occurring in practice areas 1, 2, and 3.

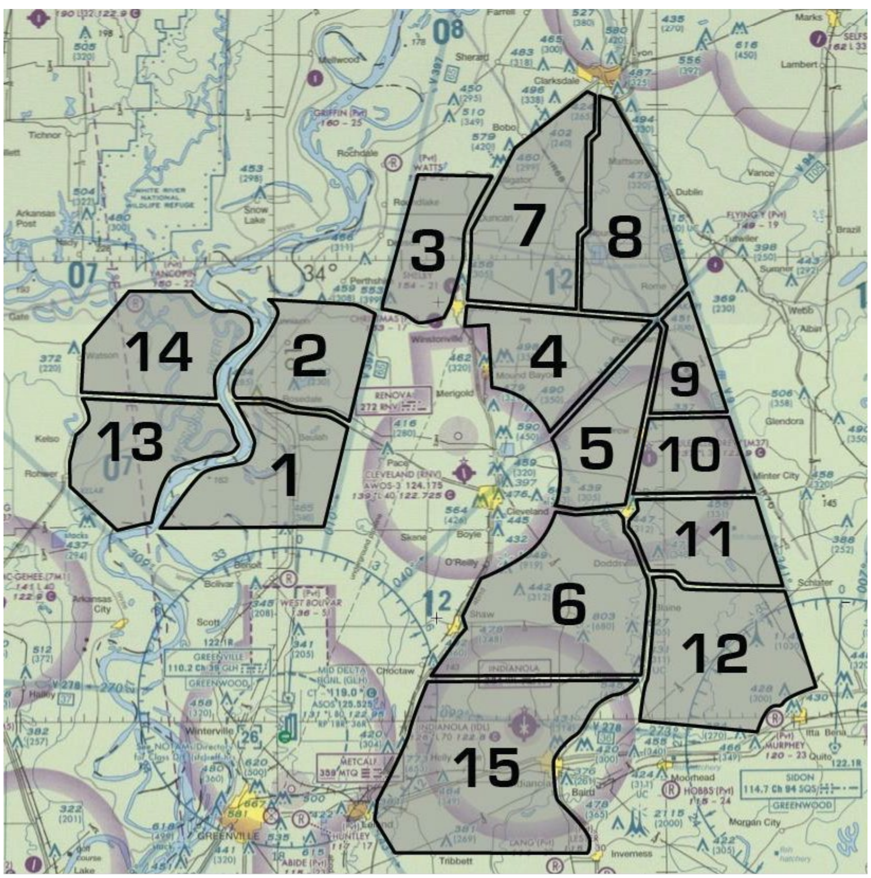

Figure 12. Delta State University's designated flight practice areas.

Prior to the first test event with DSU, three practice flight operations took place near Starkville, Mississippi, to the west of George M. Bryan Airport (KSTF). Figure 13 shows the sectional for the area around KSTF and Figure 14 shows an aerial image of the airport.

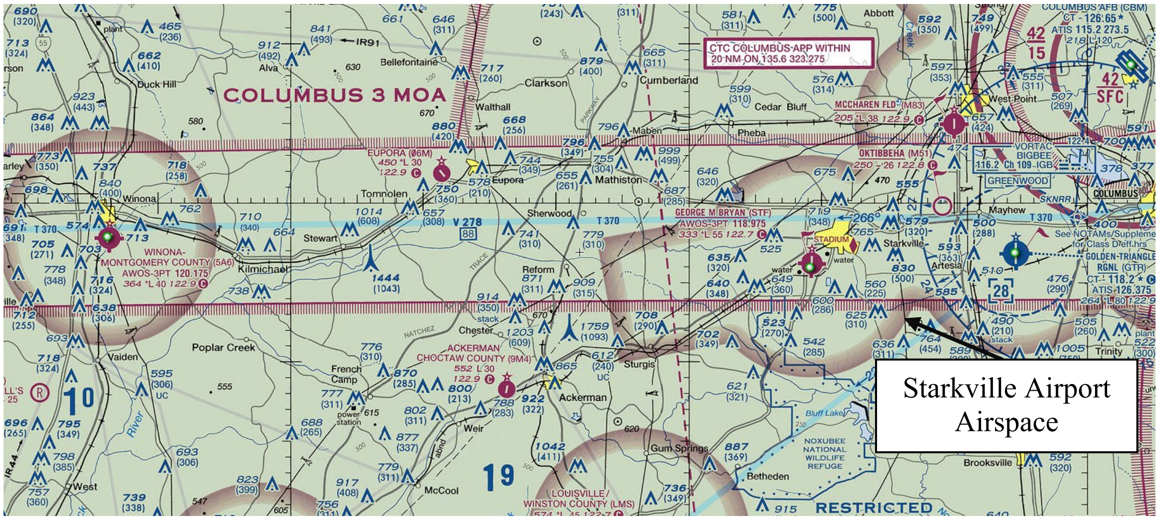

Figure 13. Sectional view of the airspace around KSTF.

Figure 14. Aerial view of KSTF.

2.4.5 Flight Paths

A variety of flight paths were used throughout the research to generate desired encounter types and a varied data set; not all flight path designs resulted in the same number of encounters as a result of differing geometry and testing conditions. The flight paths used in this research were designed to achieve desired geometries and testing conditions while also ensuring that participants would not be aware of the flight path ahead of their participation. The geometries were intended to only provide possible scenarios in which the intruder aircraft was within the reasonable FOV of the pilot. An experiment using a Cessna 182 was conducted to determine pilot FOV and Figure 15 shows the approximate FOV of a pilot sitting in high wing

GA aircraft. This FOV chart improves on previous research where it was assumed that pilots had a simplified symmetric field of view that did not account for cockpit obstructions or wings of the aircraft.

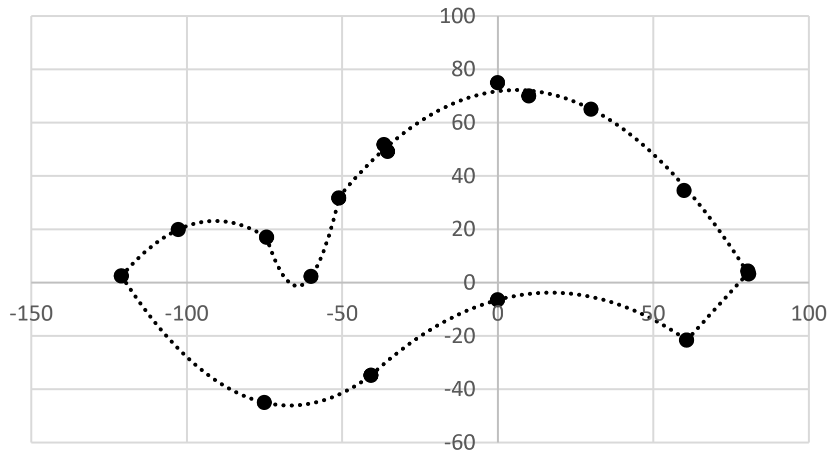

Figure 15. Cessna 182 Pilot FOV Study.

The practice flights at KSTF consisted of two different paths and methodologies. The first was a bowtie-like pattern, shown in Figure 16, with a dedicated ownship aircraft and a dedicated intruder aircraft. The ownship followed the path shown while the intruder did not have an explicit flight path and was instructed to generate a number of encounters in various locations as conditions permitted. The number of encounters that occurred during a given flight was dependent on the speed of both aircraft as well as the number of times the ownship flew the pattern. The team noted issues with the slower aircraft struggling to produce an encounter even with the large pattern given to the ownship.

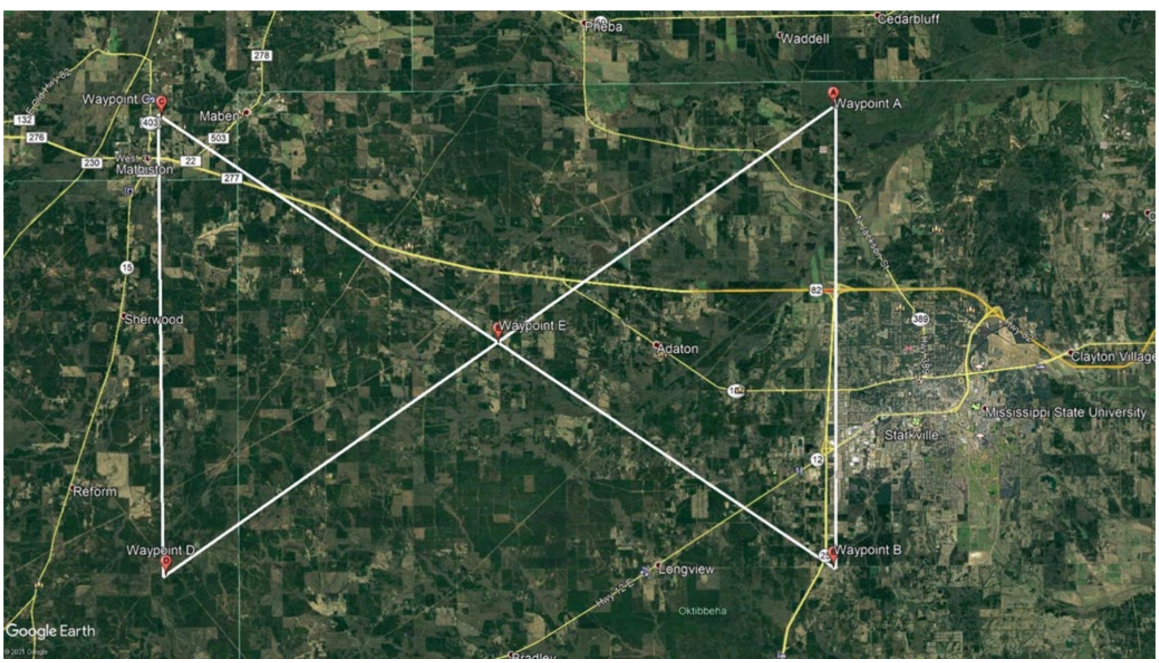

Figure 16. 'Bowtie' flight path at KSTF.

A second flight path, shown in Figure 17, was created as a result of flying practice routes with the original path, aptly named the asymmetrical bowtie flight path. This path was also only flown at KSTF. The west loop's size was decreased to reduce the time it takes to complete one circuit of the path, therefore increasing the encounter rate. The number of times the ownship was required to fly the path was increased from two to four for the asymmetrical bowtie flight path, allowing the intruder to have more opportunities to generate encounter scenarios.

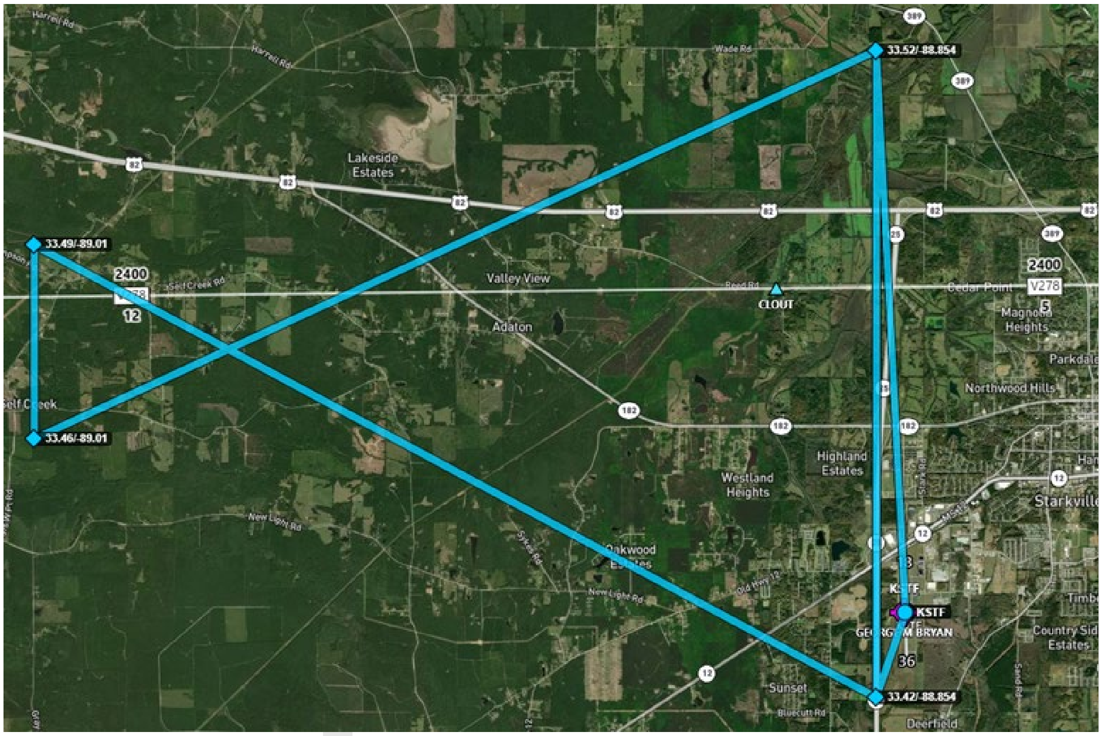

Figure 17. Asymmetrical bowtie flight path at KSTF.

To aid in pilot communication, a key was made that allowed the intruder pilots and Safety Pilots to communicate where the encounter would be without the Subject Pilot becoming aware – see Figure 18. The intruder pilot would provide a color and number to the ownship Safety Pilot that would correlate to the approximate location where the next encounter would occur.

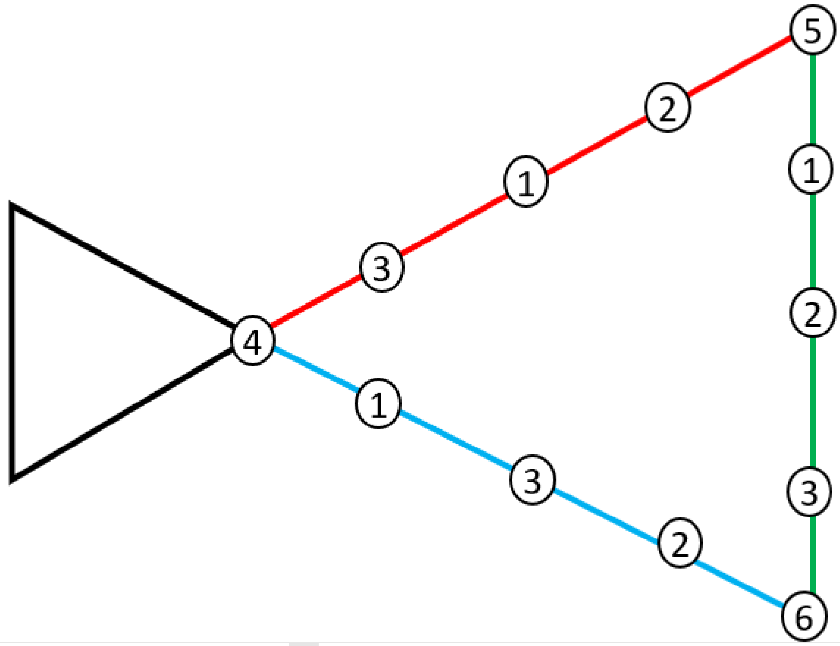

Figure 18. Encounter location key.

Across the seventy-one Subject Pilots flown during the DSU flight tests, five unique flight paths were utilized. These routes were made with assistance from the Safety Pilots that would be present during the flights. This allowed for more varied geometry and flight conditions than previous testing conducted at KSTF. A higher variety of paths also allowed the team to use repeat pilots and ensure that no pilot was aware of the number of encounters, the specific geometries, and the flight path itself.

The initial routes used a similar bowtie flight path shape as utilized at KSTF; however, the path was rotated to have a north-south orientation to better fit within the surrounding airspace and DSU's designated practice areas. This route has been referred to as the hourglass pattern and can be seen in Figure 19, along with a variation that has an increased crossing angle from fifty degrees to near ninety-degrees in the center crossing location, as seen in Figure 20.

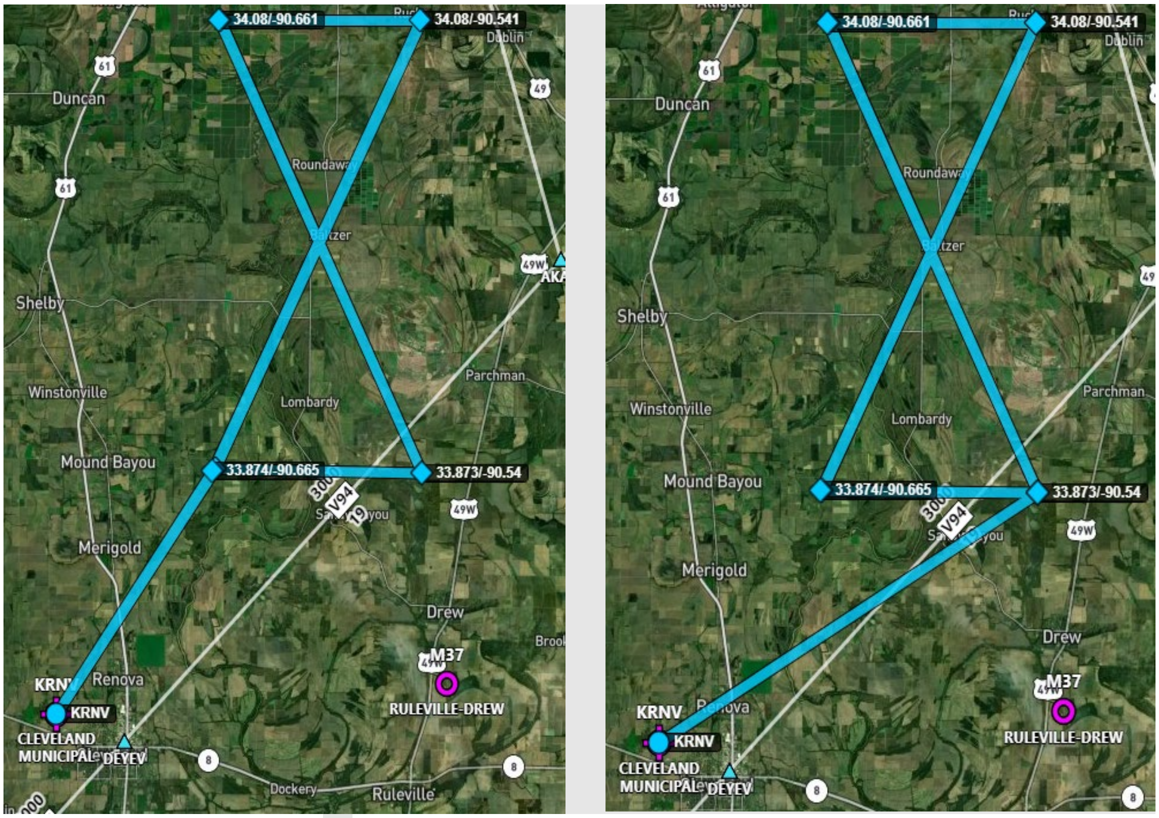

Figure 19. Hourglass flight path for ownship and intruder.

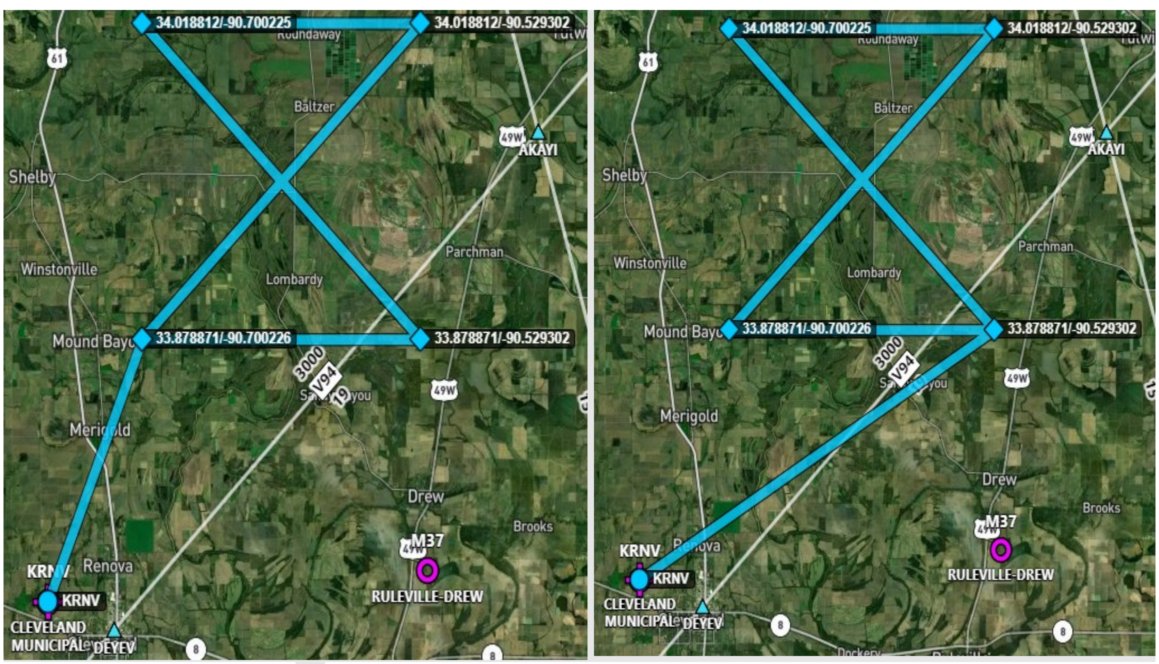

Figure 20. Hourglass flight path with near 90-degree variation.

To further expand encounter data sets, each aircraft that flew these routes simultaneously served as ownship and intruder (i.e., two aircraft in operation with a Subject Pilot, Safety Pilot, and Human Factors Research onboard – both aircraft acting as the ownship while also serving as intruder aircraft to one another). The

Subject Pilots flew to the designated starting locations in the southeast or southwest of the path and then flew opposite directions around the path twice. The target number of encounters during these paths was a total of eight, broken down further into four head-on encounters along the north and south segments and four crossing encounters at the central hourglass shape intersection, alternating the intruder's start position in the encounter from left to right.

The third route developed for flight testing at DSU was designed to reflect the flight paths that MIT LL used during its study on visual acquisition (Andrews J. , 1991). This triangular path, shown in Figure 21, was aimed to imitate a cross-country flight. The flight tests that occurred on this path used Cessna 206 acting as a dedicated intruder aircraft. The geometries and timing required a higher speed aircraft to maneuver around the testing area.

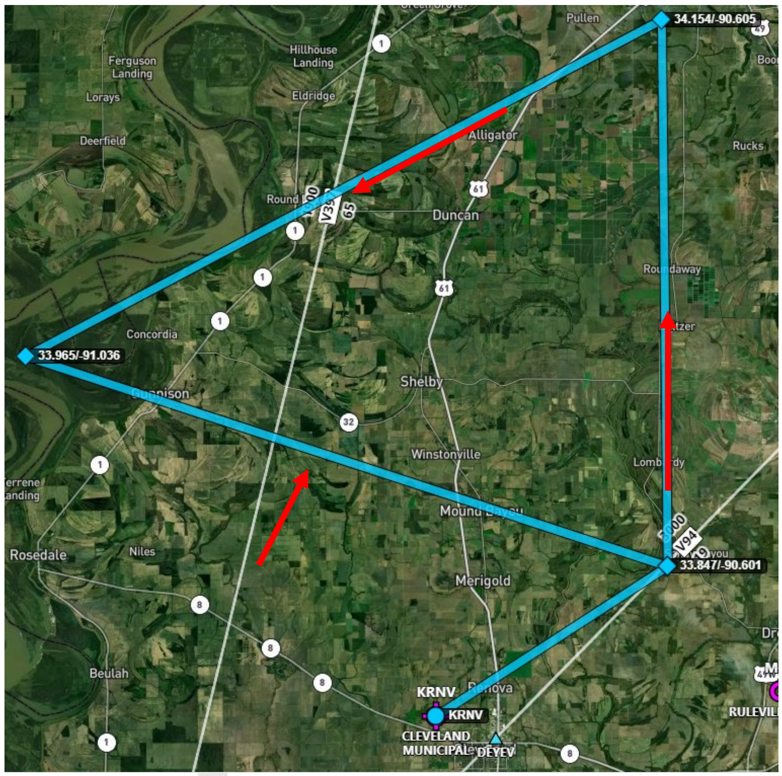

Figure 21. Triangular cross-country flight path.

Three planned encounters occurred on the straight portions of the route while the ownship followed the path. The intruding aircraft's approximate geometry is represented by the red arrows in Figure 21. The intruding aircraft Safety Pilots were instructed to generate one crossing encounter and two head-on encounters by the end of the flight. Due to the extended flight duration of forty minutes, the ownship aircraft was only required to complete the flight path once. This ensured that flight times would be comparable to other flight paths which pilots would follow as a circuit of two passes. Initially, there was not a designated path for the intruder aircraft and intruder Safety Pilots were instructed to generate the desired encounter geometries. Once the Safety Pilots became accustomed to the route, a dedicated intruder flight path was developed that would allow other Safety Pilots, that may have been unfamiliar with the research, to participate as the intruder aircraft for the triangular ownship flight path testing. This intruder flight path is depicted in Figure 22.

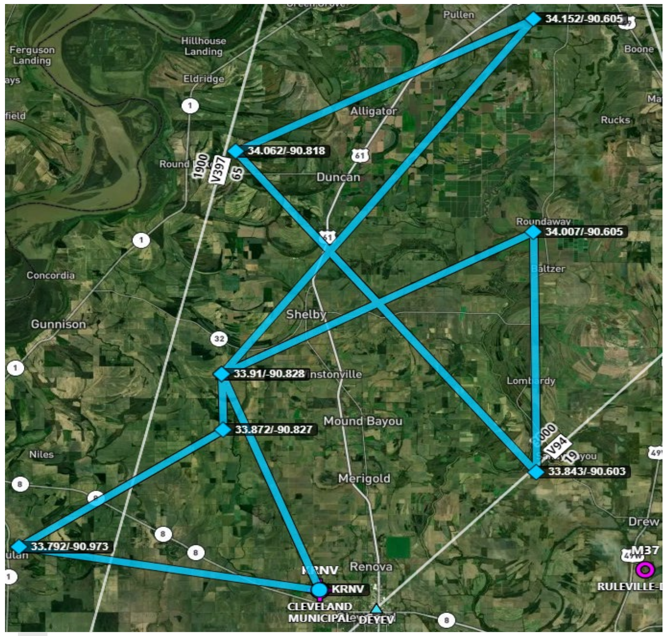

Figure 22. Intruder flight path for the triangular ownship flight path.

A hairpin-shaped path, shown in Figure 23, was developed to increase the workload of the Subject Pilot by requiring multiple heading changes while flying to the north end of the pattern before returning to KRNV. As was the case for the triangular flight path, the intent was to replicate a cross-country style flight, and the aircraft would only complete one circuit of the flight path. Both the ownship and intruder aircraft flew the same pattern but mirrored from one another, also depicted in Figure 23, to generate up to four crossing encounters with a final head-on encounter for a total of five encounters. During these flights, both aircraft functioned as an ownship and intruder aircraft with a Subject Pilot in either aircraft.

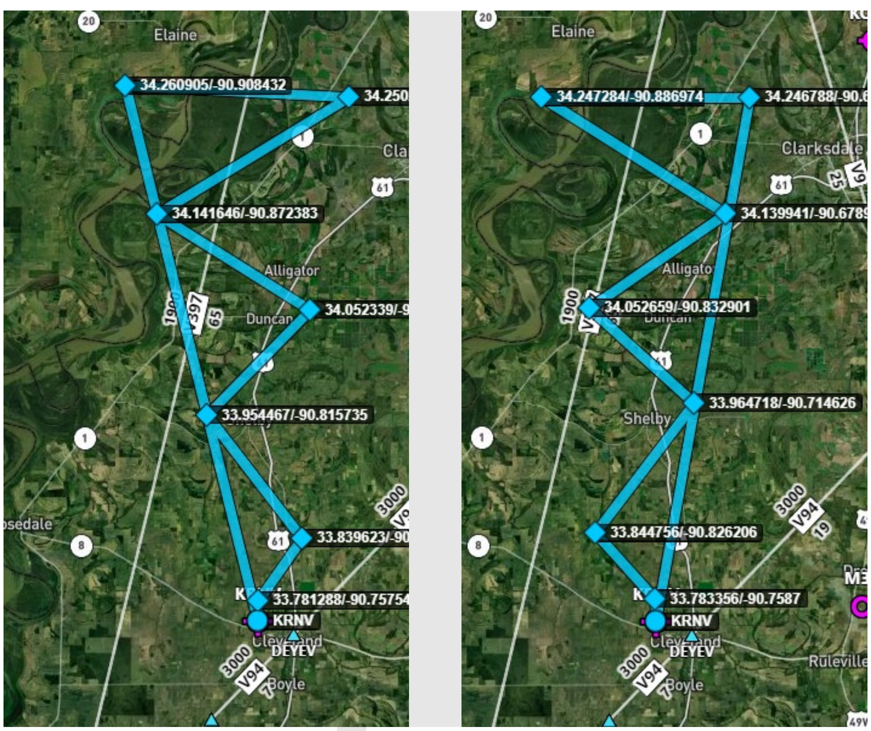

Figure 23. Hairpin flight paths.

Specialized flight paths were developed to generate overtake encounters. These paths, referred to as the "butterfly wing" due to their shape, was meant to be flown by an intruder aircraft at a lower speed while the ownship performed an overtake. The paths, depicted in Figure 24, differ in size from each other to allow time for the slower intruder aircraft to position itself such that the ownship was able to perform an additional overtake on the way back to KRNV.

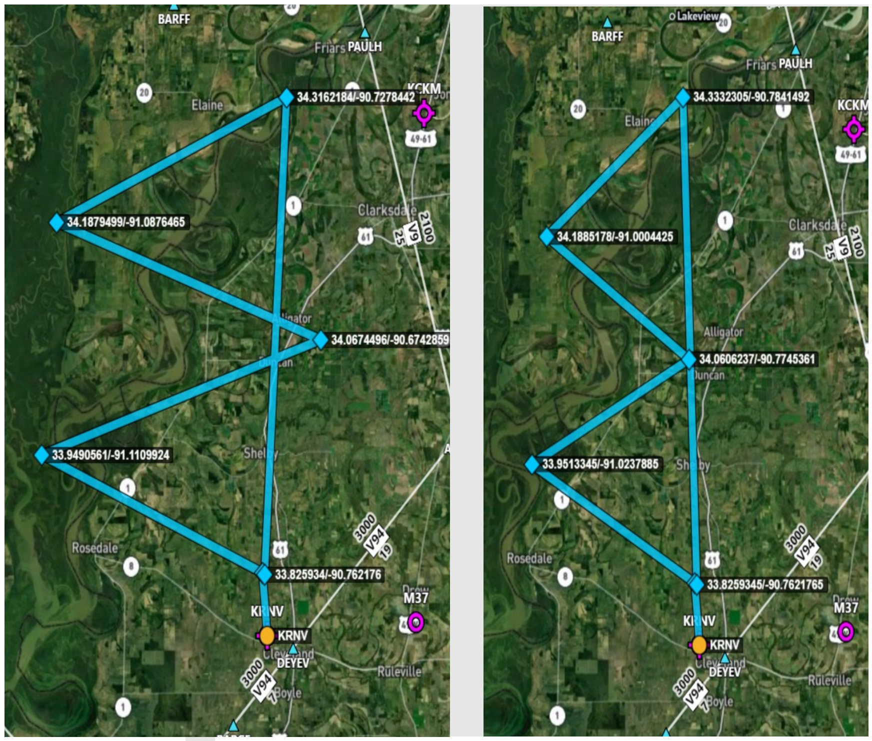

Figure 24. Butterfly wing flight paths used for overtakes.

After multiple pilots flew the butterfly wing routes, an updated intruder route was developed to allow for the intruder aircraft to more efficiently maneuver to its next encounter position once the ownship aircraft had overtaken it. This diamond-shaped intruder flight path is depicted in Figure 25.

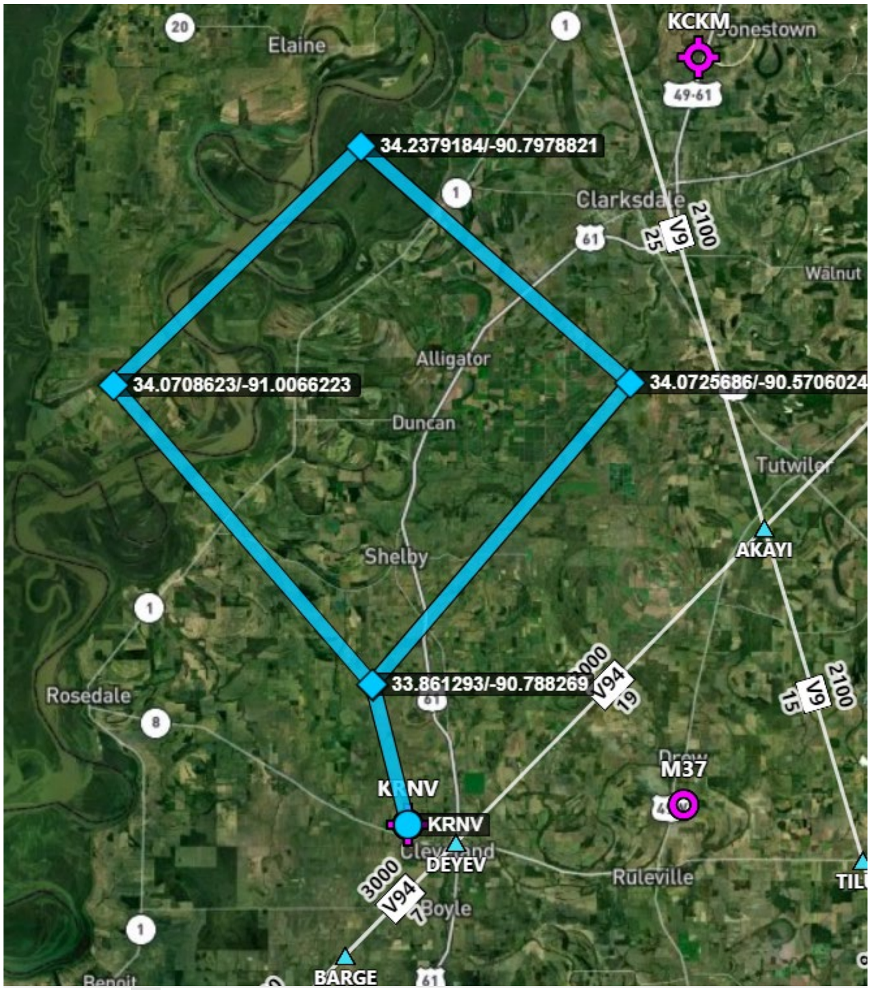

Figure 25. Intruder diamond flight path for overtaking encounters.

2.4.6 Safety Considerations

Due to the nature of the flight tests conducted, the development and application of appropriate safety measures were paramount. During the flights, the test aircraft were required to maintain a minimum of 500 feet vertical separation. Safety Pilots were made aware of this requirement and were instructed to monitor the altitude of their own aircraft, as well as the other test aircraft. Additionally, MSU researchers provided the Safety Pilot a tablet with ForeFlight installed for increased situational awareness. All Safety Pilots were confirmed to be acquainted with the software. This allowed the Safety Pilot to monitor the airspace and ensure that each Subject Pilot was following the flight path correctly and flying the correct altitude. Safety Pilots were also briefed at the start of each test day and week. The Safety Pilot was briefed to maintain awareness and separation from other aircraft and flying objects. In the event of a situation deemed unsafe by the Safety Pilot, the Safety Pilot served as the PIC and final authority over the operation of the aircraft. The Safety Pilot also had authority to terminate the test point or flight if deemed necessary. The Subject Pilot was the manipulator of the controls during testing unless the Safety Pilot was required to take control due to an unsafe situation.

Additionally, weather conditions were a safety consideration as a portion of the flight testing occurred during summer months. During the formal briefing conducted at the beginning of each test week, the Safety Pilots and research personnel were briefed by the Test Director on the weather forecast for the test week. This highlighted any elevated temperatures expected for the week and measures that would be taken due to the heat. Such measures included additional breaks and providing areas with air conditioning and hydration stations for use following flights. Flights in precipitation and/or instrument meteorological conditions were also prohibited for the purposes of the testing conducted. Flight testing was only conducted under visual flight rules conditions and the flight school's limitations on weather and crosswinds.

3 Flight Test Results

3.1 Participant Demographics

Throughout the seventy-four flights over the course of this project, forty-five individuals participated in the flight testing. A few pilots participated multiple times either as Subject Pilots, Safety Pilots, or both. Repeat pilots generally did not show an improvement or decline in their performance as flight paths were varied for each subsequent test. Subjects that participated more than once always flew a new flight path, and more experienced pilots likely flew in a higher performance aircraft by the end of the testing campaign. All the subject pilot demographic information can be found in Appendix 3

3.1.1 Experience

A wide variety of experience levels was exhibited by the pilots that participated in the research, as shown in Table 3.

Table 3. Summary of Subject Pilot's demographics and experience.

Parameter	Unit	Minimum	Maximum	Average	Mode	Median
Age	Years	18	37	23.0	21	22
Pilot experience	Years	1	11	3.81	4	4
Single-engine, non-complex experience	Hours	52.8	1600	324.7	250	250
Multi-engine experience	Hours	0	213	77.7	100	75
Complex experience	Hours	0	630	87.6	0	75
Cross-country experience in last 6 months	Hours	0	100	22.2	20	15.5

Additionally, over half of the Subject Pilots held a commercial rating and 85% were certified flight instructors, as shown in Table 4.

Table 4. Ratings held by Subject Pilots.

Rating	Percentage of Subject Pilots holding rating
Commercial	70.6 %
Multi-engine	51.5 %
Instrument	44.1 %
Certified flight instructor	85.3 %

3.1.2 Alertness and Scanning Rates

The effectiveness of pilot scanning rates was examined by searching for commonalities between the number of visual acquisitions made by test participants. Each participant scanned the surrounding airspace for potential hazards such as planes or birds. The time spent scanning by the pilot was considered as a percentage of the total time the study occurred and is referred to as the scanning rate. The scanning rate during the study was hypothesized to be a potential cause for variances in the number of total visual acquisitions between the participants.

UASSRF researchers determined that the most efficient way to find the scanning rate of a participant was to extract a 105 second clip from a random portion of the in-flight videos of the cockpit. The cockpit camera angle provided the researchers with a view of the eyes of the participants and the general direction of their observation. By performing a statistical sensitivity analysis on video clips ranging from 15 to 120 seconds, 105 seconds was confirmed to have the minimum deviation from the actual scanning rate and be the most time efficient. The researchers generated a binary data file which represented the participant in two states: 1) scanning outside of the cockpit (represented by a value of 1 in the data file) or 2) looking at something within the cockpit (represented by a value of 0 in the data file). A participant's scanning rate was determined by finding the ratio between these states. This process was performed for pilots that had a different amount of total visual acquisitions so that trends in the scanning rates among them could be analyzed.

A participant's scanning rate was concluded to be one of the contributing factors to a pilot's visual acquisition ability. A general trend between the number of visual acquisitions made and the rate of scanning was observed. Participants in the research that scanned at a rate equal to or higher than the FAA's 4:1 scanning ratio recommendation visually acquired the opposing aircraft in the study more often than the participants who scanned at lower rates. This general trend was not observed in pilots who had participated in the study more than once or if they were aware of the premise of the study beforehand. The methodology and results from this exercise can be found in Appendix 8.

3.2 Visual Acquisition Data

As Subject Pilots progressed through each prescribed set of flight paths, video cameras facing the Subject Pilot recorded distractions, scanning rate, and other cockpit behaviors. In post processing, researchers were able to determine the actual scanning rate of each Subject Pilot by reviewing each video. Considering the length of each test, and the amount of video data collected, researchers found that clips of 105 seconds in length were appropriately representative to determine if the Subject Pilot paid more attention to scanning their surroundings versus the instrument panel or other within cockpit distraction. During the human factors debrief after each flight test, Subject Pilots were asked to estimate what portion of the experiment they were scanning for traffic. In Table 5, researchers list the actual scanning rate derived from video data and the perceived scan rate that each Subject Pilot submitted in the debrief. Noticeably, very few Subject Pilots accurately assessed their own scanning rate performance. The four Subject Pilots included in Table 5 were selected to demonstrate the variance in this estimation. Summarizing these findings to date, researchers determined that Subject Pilots may not provide accurate assessments of their attention to scanning rate, and video data or other means should be used to determine this rate.

Table 5. Sample Subject Pilot visual acquisition data

	Pilot 13	**Pilot 15**	**Pilot 16**	**Pilot 19**
Number of Visual Acquisitions/Total Possible	2/8	5/8	8/8	8/8
Scan Rate (Percentage)	43%	72%	97%	85%
Perceived Scan Rate (Percentage)	80%	40%	80%	75%
NASA-TLX Overall Score	49.333	27.333	26	28.333
Total Hours Flying	1040	250	560	80
Instrument Rated	Yes	Yes	Yes	Yes

Age	34	21	23	22

3.3 Environment

Most of the flights performed in this research took place on clear or partially cloudy days with low wind speeds. Rain, wind, and low cloud ceilings were the main weather factors that prohibited testing. Table 6 contains relevant weather data for each scheduled day of testing throughout the year. The values shown are averages across the entire day. No flights occurred during rain and if it was noticed that conditions were becoming unfavorable during a test, i.e., rain or lower cloud ceiling, then the flight would be called off.

Table 6. Weather data for each scheduled test day (V.C. Corporation, 2023).

Date	Windspeed (mph)	Wind Dir (deg)	Cloud Cover (%)	Visibility (miles)	Conditions
2022-01-10	17.4	124.5	2.3	9.9	Clear
2022-01-11	4.7	66.5	8	9.7	Clear
2022-01-12	12.6	190.4	5.3	9.5	Clear
2022-02-08	9.6	162	3.8	8.4	Clear
2022-02-09	12.4	199.5	8.4	9.9	Clear
2022-02-10	9.5	213.2	8.2	9.4	Clear
2022-03-23	16.7	254.4	75.5	9.9	Partially cloudy
2022-03-24	14	211.7	10.4	9.9	Clear
2022-03-25	14	246.8	10.8	9.9	Clear
2022-04-26	17.9	97.1	8.8	9.9	Clear
2022-04-27	9.4	55.5	4.7	9.9	Clear
2022-04-28	9.8	106.5	7.6	9.8	Clear
2022-05-25	18.8	159.6	62.7	9.4	Rain, partially cloudy
2022-05-26	17.9	236	57.5	9.9	Rain, partially cloudy
2022-05-27	11.5	258	23.3	9.9	Partially cloudy
2022-06-14	11.9	194.4	7.4	9.1	Clear
2022-06-15	9	198.8	3	9.4	Clear
2022-06-16	5.3	99.7	10.9	9.4	Clear
2022-06-28	10.7	114.3	23.6	9.9	Partially cloudy
2022-06-29	9.8	41.6	21.8	9.9	Partially cloudy
2022-06-30	16.9	126.6	35	9.1	Rain, partially cloudy
2022-07-12	4.3	61.7	6.5	9.8	Clear
2022-07-13	10.2	95.6	26.3	9.8	Rain, partially cloudy
2022-07-14	5.7	67.1	17.3	9.2	Clear
2022-08-01	14.6	201.7	25.3	9.9	Partially cloudy
2022-08-02	11.2	178.7	24.7	9.9	Partially cloudy
2022-08-03	9.2	151.3	57.9	9.6	Partially cloudy
2022-08-04	7.2	147.1	32.7	9.7	Rain, partially cloudy
2022-08-05	10.3	154.5	20	9.7	Clear
2022-11-07	8.1	23.2	22.5	8.9	Clear
2022-11-08	8.7	35.7	19.6	7.7	Clear
2022-11-09	16.1	114.5	15.2	9.5	Clear
2023-02-21	17.6	196.2	58.7	9.5	Partially cloudy
2023-02-23	12.1	267.3	57.7	8.3	Partially cloudy
2023-02-24	18.6	22.6	93.5	9.7	Mostly cloudy

4 Visual Acquisition Performance

4.1 Interview Analysis

As the final portion of the questionnaire, the Human Factors Researcher would ask the following questions about each encounter they experienced during the flight test.

Think of the (first, second… nth) encounter (insert/describe type—fixed wing, rotary, UAS):

- *What were the characteristics of the aircraft that made it easy or difficult to spot?*
- *What were the environmental conditions that made it easy or difficult to spot?*
- *What were the flight conditions that made it easy or difficult to spot?*
- *Was there anything else that made detection easy or difficult to spot?*

During the interview, audio was recorded, and the researcher wrote down the Subject Pilot's answers. These recordings were later transcribed and used to formulate findings and conclusions on how Subject Pilots perceived the task of visually acquiring intruding aircraft and what parameters affected that task.

Each participant's questionnaire and NASA TLX data was linked to their interview using the qualitative data analysis software MAXQDA. This step was performed to be able to group transcripts by variable (i.e., dividing transcripts into groups based on age, years of experience, pilot certification, etc.). Next, all interview transcripts were examined thoroughly to become acquainted with their content, and initial summaries were written that would aid in categorizing interview segments. Additionally, a word cloud was generated to determine which words were said most often during the interviews, as seen in Figure 26. The size of each word serves as an indicator to the frequency of that word's usage throughout the interviews. The bigger a word's size correlated with the more frequently it was said. Words such as "uh," "like," "the," etc. were considered as filler words and were excluded from the word cloud. As seen below, the word 'pilot' was the most frequently used, followed closely by "difficult," "aircraft", "conditions", and "environmental" among other words. This in turn serves to guide the categorization process of the interview question answers.

Figure 26. Word cloud for most used words during interviews.

4.2 In-Depth Interview Analysis

A system was developed to categorize the different interview answers into the following categories: aircraft characteristics, environmental conditions, flight conditions, Subject Pilot characteristics, and other. Figure 27 and Figure 28 show the distribution of factors that affected aircraft detection per the full transcript and transcript segments, respectively. These segments are individual statements made by the Subject Pilots. Environmental conditions were mentioned in all transcripts, shown in Figure 27, followed closely by flight conditions at 96% and aircraft characteristics at 94%. Subject Pilot characteristics, such as aircraft familiarity or workload, were mentioned in 60% of transcripts, whereas other statements that do not fit in previous categories were mentioned in 43% of transcripts.

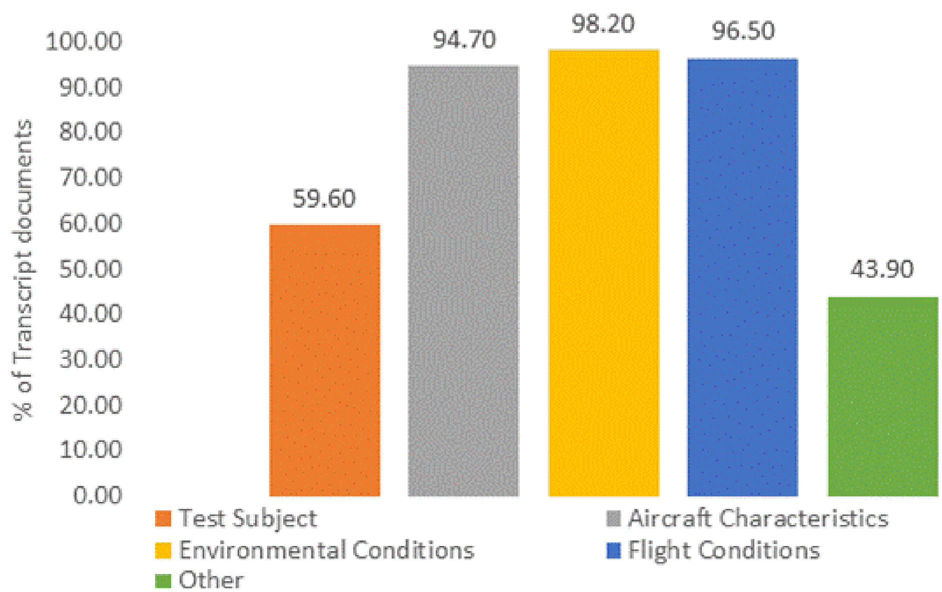

Figure 27. Factors that affected aircraft detection according to transcript.

Figure 28 shows that 40% of all statements made by pilots mentioned environmental conditions during the flight. The second most mentioned factor was the flight conditions at 29%.

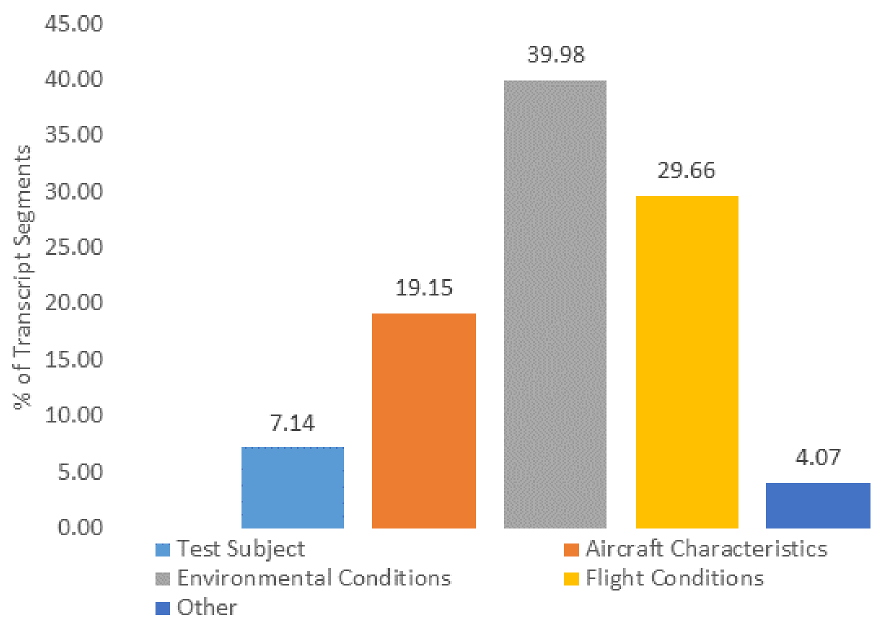

Figure 28. Factors that affected aircraft detection per coded interview segment.

The five previously mentioned categories were further organized into subcategories seen in Figure 29.

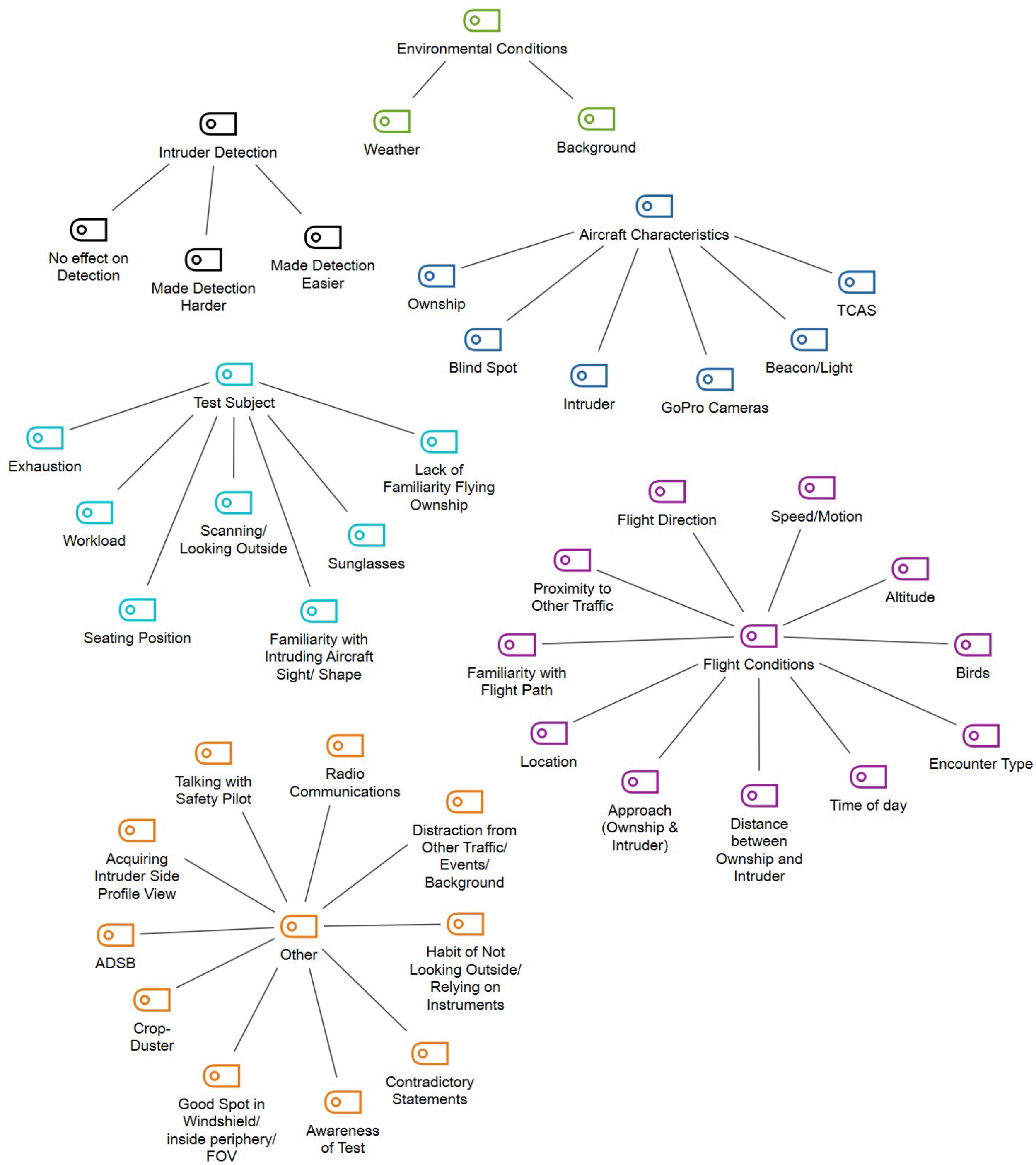

Figure 29. First round of fine coding segments into categories.

Figure 30 through Figure 35 show detailed breakdowns of each of these subcategories. The Subject Pilot characteristic that affected Subject Pilots the most was the workload in the aircraft as shown in Figure 30. Specifically, pilots indicated during their interview that a higher workload made aircraft detection more difficult since they had to spend more time inside the cockpit trying to maintain altitude and course instead of scanning the airspace. This increased workload was also closely related to turbulence, an environmental condition, as it would take more work to control the aircraft. Factors that Subject Pilots said made detection more difficult were lack of familiarity with the aircraft they flew, exhaustion, and not wearing sunglasses. Conversely, familiarity with the aircraft, the ability to scan more continuously, and wearing sunglasses were all factors Subject Pilots designated as making detection easier.

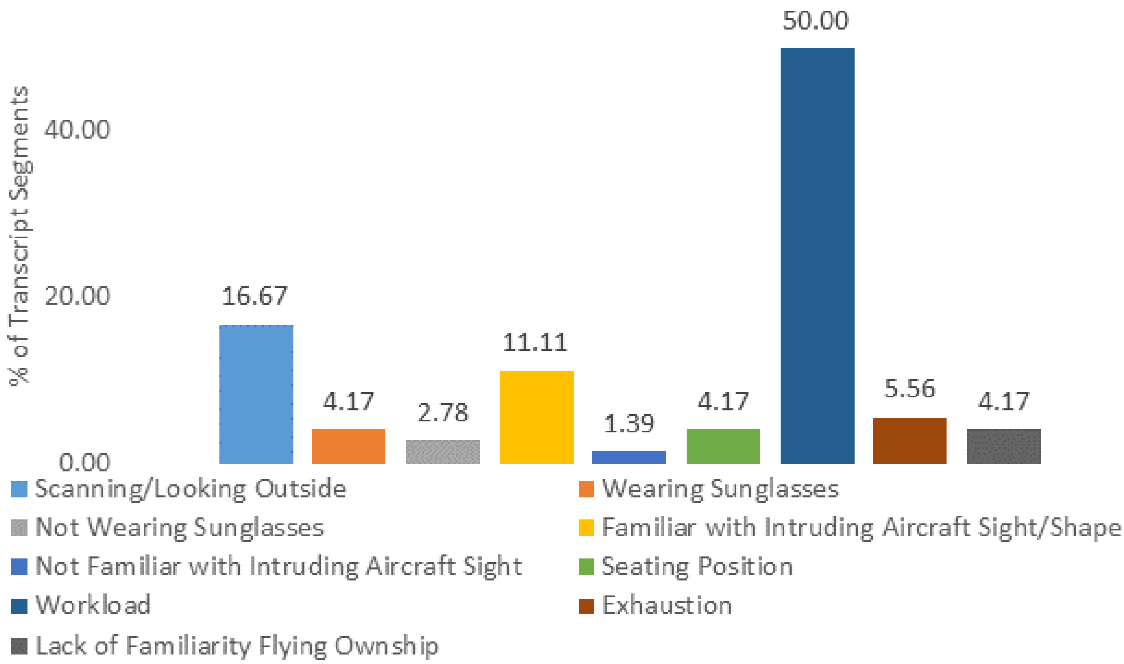

Figure 30. Pilot statements on important Subject Pilot characteristics.

Figure 31 shows that the white color of the intruding aircraft greatly impacted the pilots' ability to detect the intruder. Depending on the color of the background, the white color of the intruder aircraft could have made it easier or more difficult to spot. For instance, against a brown background, such as a field, the contrast was increased and easier to spot, but against the horizon or bodies of water it was harder to spot. Markings or bright colors on other aircraft also assisted the Subject Pilot in visually acquiring aircraft. Crop dusters in the nearby airspace, generally painted yellow, were easy to spot due to their brighter color creating sharp contrast with the sky. Other factors that made detection difficult were the intruder aircraft being in the Subject Pilot's blind spot, dirty windows, and the smaller cross-sectional area of the intruder.

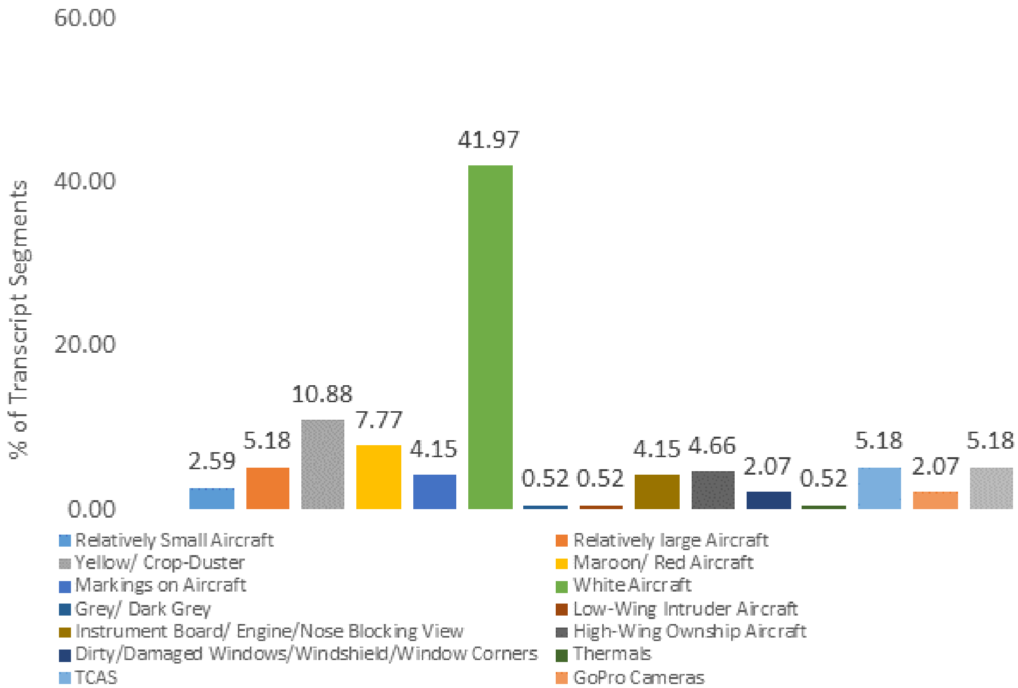

Figure 31. Pilot statements on important aircraft characteristics.

Figure 32 shows that the green background of trees and forests had the greatest impact in aircraft detection in the background category. The green background and white aircraft contrasted making it easier for the Subject Pilot to visually acquire the intruder. Busier backgrounds such as buildings, roads, and bodies of water made it more difficult for the pilot to visually acquire the aircraft due to a lack of contrast and more 'noise' when scanning the airspace.

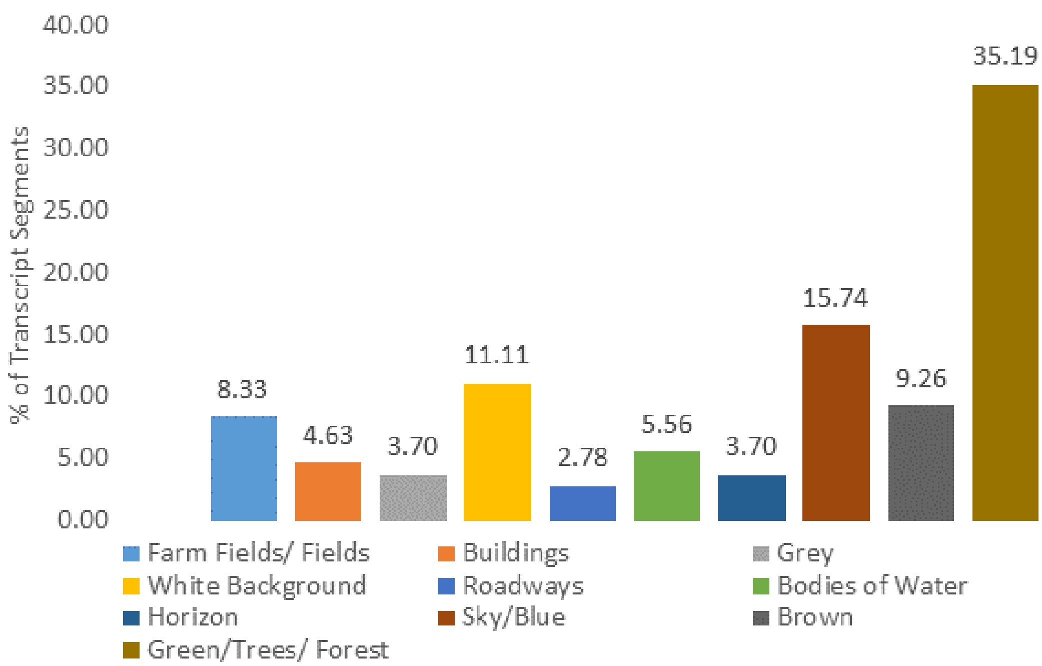

Figure 32. Pilot statements on important background characteristics.

Weather played a significant role in Subject Pilots being able to spot the intruding aircraft. Figure 33 shows that during the post flight interviews, pilots expressed that a clear sky with high visibility and smooth air made detecting the intruder aircraft easier. Haze, winds, clouds, fog, and limited visibility made detection more difficult as pilots would have to pay more attention to flying the aircraft in these conditions while also putting more effort into visually scanning. Numerous Subject Pilots stated that glare played a role in them being able to spot an aircraft when the sun would hit the wing or windshield of the intruding aircraft. However, it did not always assist the pilots and was detrimental to their visual acquisition performance when it would reflect off bodies of water. This would make it not only harder for the pilot to see but also briefly distract them as they made the correct adjustments to be able to see without the sun reflecting into their eyes.

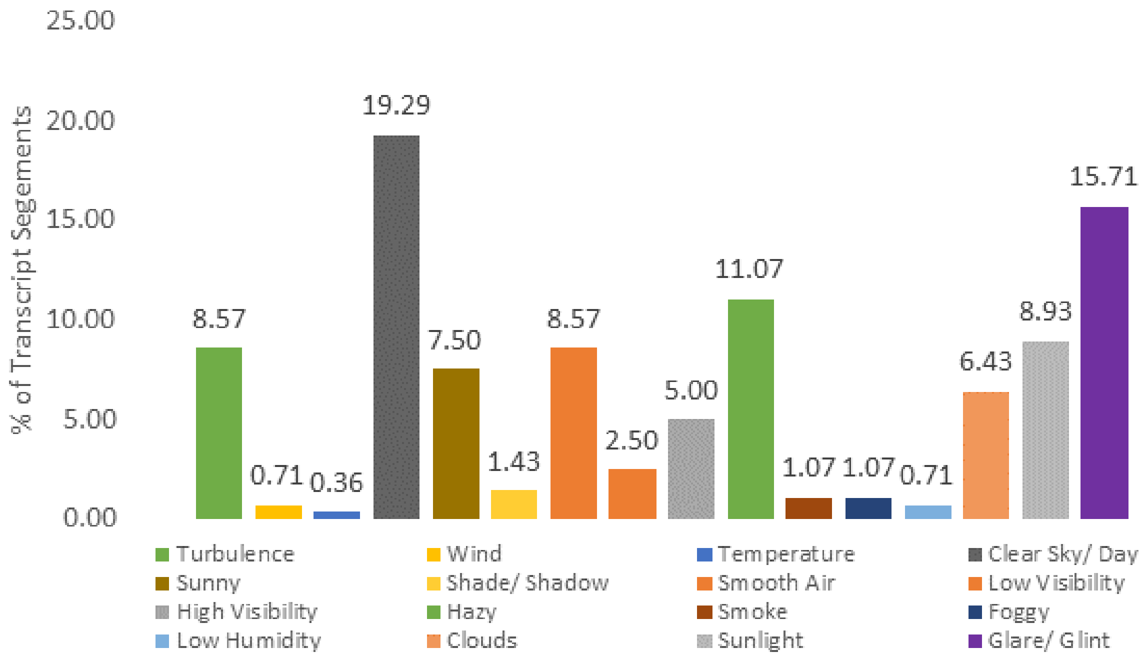

Figure 33. Pilot statements on important weather characteristics.

Figure 34 shows that many subjects indicated that the altitude of the ownship and the intruder was the primary flight condition factor affecting aircraft detection performance, closely followed by the encounter type (head-on, crossing, overtake, etc.), and approach direction. Many subjects indicated that once they were familiar with the flight path it was easier for them to spot the other aircraft. Noticing the flight path and test design would sometimes help the Subject Pilots predict where the intruder was going to be next so they would focus their scanning patterns in that general area. However, this did not often happen and even in instances where the Subject Pilot said they knew where the aircraft might be coming from, they still would not always visually acquire it. Flight tests were typically done in a test area away from other air traffic but sometimes there would be non-test aircraft within the area distracting the Subject Pilots from scanning. This was most likely to occur in areas closer to the airport where traffic was most likely to be. Different combinations of altitude, approach direction, speed, and the encounter type either helped or hindered detection. According to some, during head-on encounters, if the intruder aircraft was at a higher altitude, it was easier to spot. During crossing encounters, if the intruder aircraft was at a lower altitude, it was easier to detect because of the intruder's relative motion as it entered the Subject Pilot's FOV. Higher altitude of the intruding airplane when it was at a long distance from the Subject Pilot also made detection easier. On the other hand, head-on encounters when the intruder was flying at a lower altitude than the

Subject Pilot were difficult to visually acquire because the nose of the aircraft blocked the Subject Pilot's FOV in that direction. Crossing encounters from left or right, when the intruder was flying at a higher altitude than the Subject Pilot, were difficult to spot since the ownship aircraft's wings obscured the Subject Pilot's FOV in that direction. Other flight-testing conditions that affected Subject Pilots were altitude, approach direction, speed, and encounter geometry.

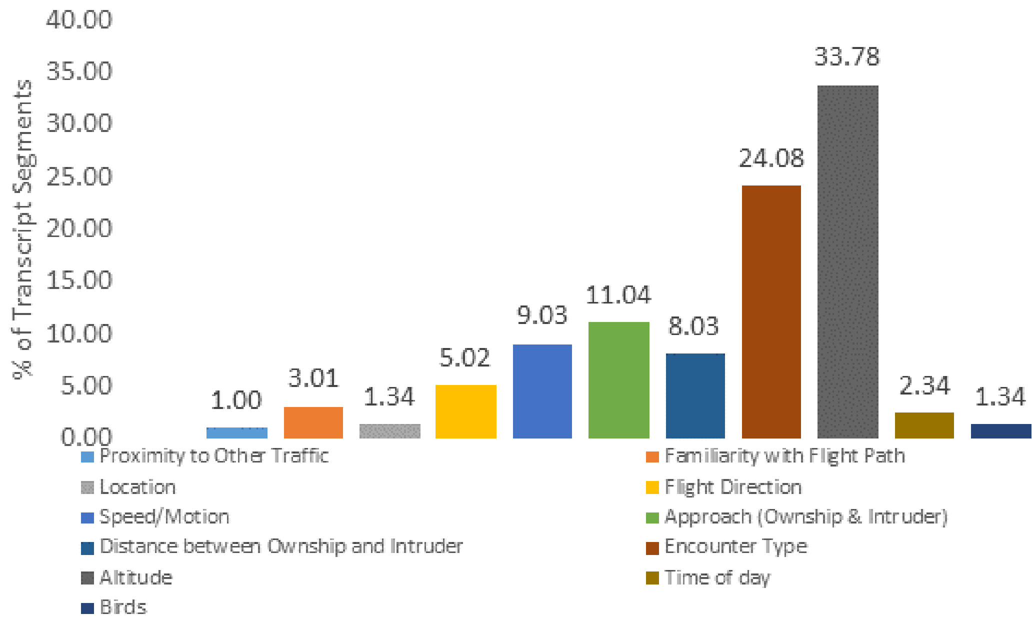

Figure 34. Pilot statements on important flight conditions.

Lastly, Figure 35 shows that Subject Pilots mentioned the side profile view of the intruding aircraft as a major factor in their ability to visually acquire the aircraft. The cross-sectional area of the side of the aircraft is higher than any other view and therefore made it easier for the Subject Pilot to detect the aircraft. Pilots also stated that detection was easier for them when the aircraft profile was conveniently within their FOV when looking straight ahead rather than having to move their eyes or head to find the aircraft. Although it was typically turned off, there were a few encounters where the TCAS would audibly alert the pilot to traffic. During instances where this happened, the Subject Pilots were able to very quickly visually acquire the other aircraft. Sustained radio communication or just general conversation with the Safety Pilot would sometimes lower the Subject Pilots' visual awareness as they were focused on tasks other than visually scanning the airspace.

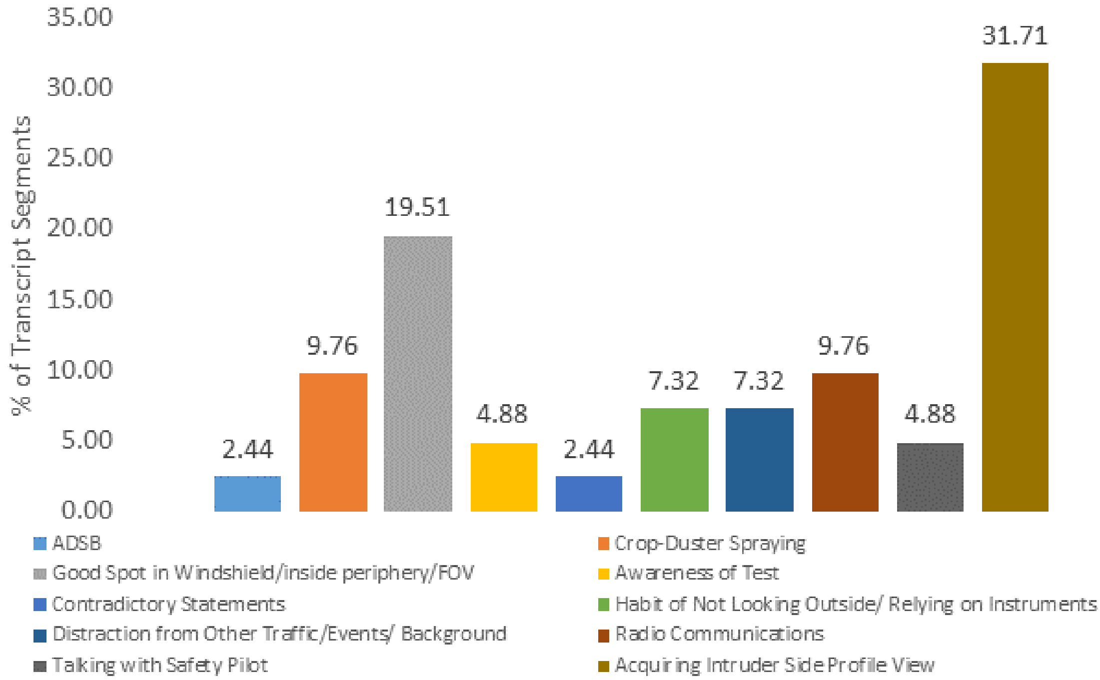

Figure 35. Miscellaneous factors mentioned by pilots.

Figure 30 through Figure 35 showed the frequency at which statements belonging to each sub-category were mentioned. Some of these factors impacted aircraft detection either positively or negatively, depending on which other subcategories the same statement belonged to. For example, a white aircraft could either make detection easier, by having great contrast against a green background, or it could have made it more difficult by blending in against the horizon or bodies of water. Therefore, three more categories were created encompassing the statements: "made detection easier," "had no effect on detection," and "made detection harder." Statements made by the Subject Pilots were grouped into these new categories to pinpoint the factors that affected aircraft detection the most. Figure 36 presents the most commonly occurring single and co-occurring factors that facilitated aircraft detection, whereas Figure 37 illustrates the most frequently occurring single and co-occurring factors that hindered aircraft detection. In both Figure 36 and Figure 37, only codes with a minimum frequency of four occurrences were included to prevent the plots from becoming too congested. The complete list of codes and their frequencies can be found in Appendix 6. The visualization of the most frequent factors in each category provides a clear overview of the primary influences on visual detection in this study, allowing for the identification of key patterns and trends in the data.

Figure 36 displays the single occurring and co-occurring codes that improved visual detection the most, with "Clear Sky/Day" being the most frequently occurring code with a frequency of 22 instances. The literature suggests that clear weather conditions are important for visual detection, as cloudy or hazy weather conditions can reduce visibility and increase the workload on pilots. The code "Familiarity with Flight Path" occurred 8 times, indicating that prior knowledge of the flight path can be beneficial for visual detection. The code "White Aircraft + Green Trees/Forest" occurred 7 times, and literature suggests that the contrast between a white aircraft and the green background can make it easier to detect. Additionally, the code "Smooth Air" also occurred 7 times, suggesting that the absence of turbulence can improve visual detection. The code "TCAS" occurred 9 times, and this is consistent with previous studies that have shown that the TCAS can be helpful in enhancing situational awareness and visual detection. The code "Intruder/ Traffic at Higher Altitude + head on encounters" also occurred 9 times, indicating that pilots had an easier time detecting the intruder when it was in the middle of their FOV. Overall, these results align with previous research in the field and highlight the importance of environmental factors and technological aids in improving visual detection during flight operations.

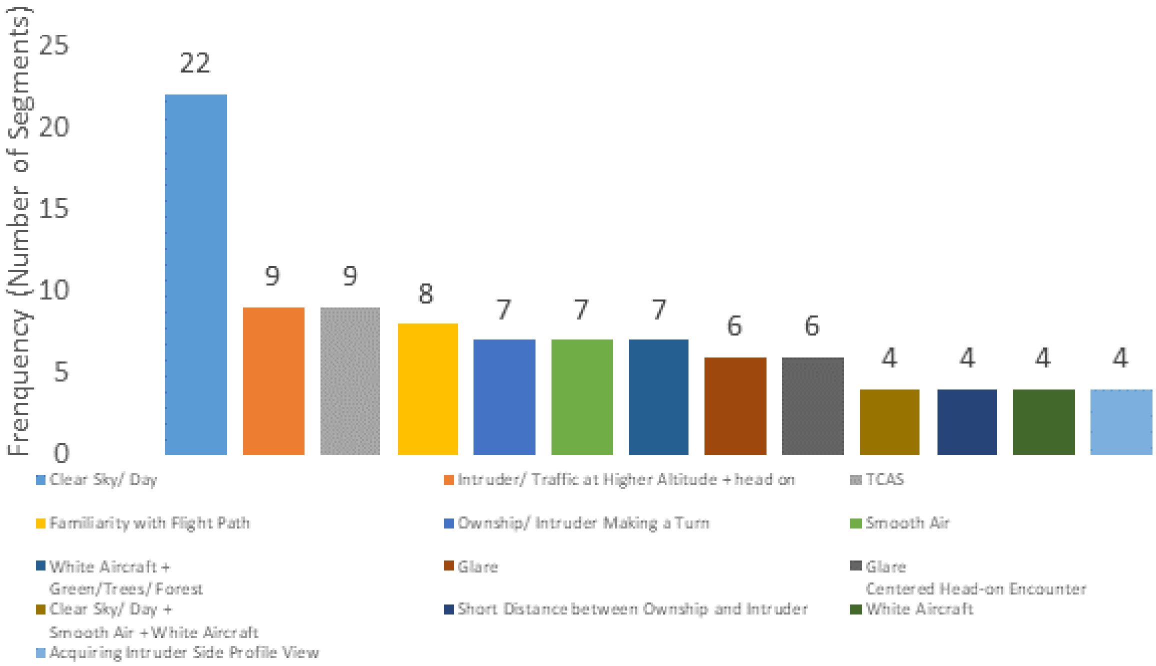

Figure 36. Most frequent factors improving aircraft detection.

Figure 37 presents the most frequent single occurring and co-occurring factors that hindered visual detection in aircraft. The most frequent factor was Hazy, which appeared in 15 instances. This finding is in line with previous research that has shown that environmental factors, such as weather, can significantly impact visual detection in aviation. The second most frequent factor was the combination of "Workload + Turbulence" (14 occurrences), indicating that maintaining ownship altitude and direction during turbulent conditions can increase workload and make visual detection more challenging. This finding is also supported by previous research that has identified workload and turbulence as factors that impact visual detection in aviation. Other factors that appeared frequently included Turbulence, often caused by fatigue after many consecutive flights on test day or from scanning outside too much (12 occurrences), Workload (9 occurrences), Flying Facing the Sun (9 occurrences), Blind Spot (7 occurrences), Clouds (7 occurrences), Dirty/Damaged Windows/Window Corners (5 occurrences), Exhaustion (4 occurrences), and Background + Intruder/Traffic at Lower Altitude (4 occurrences). These findings provide important insights into the factors that can impact visual detection and can inform the development of interventions to improve aviation safety.

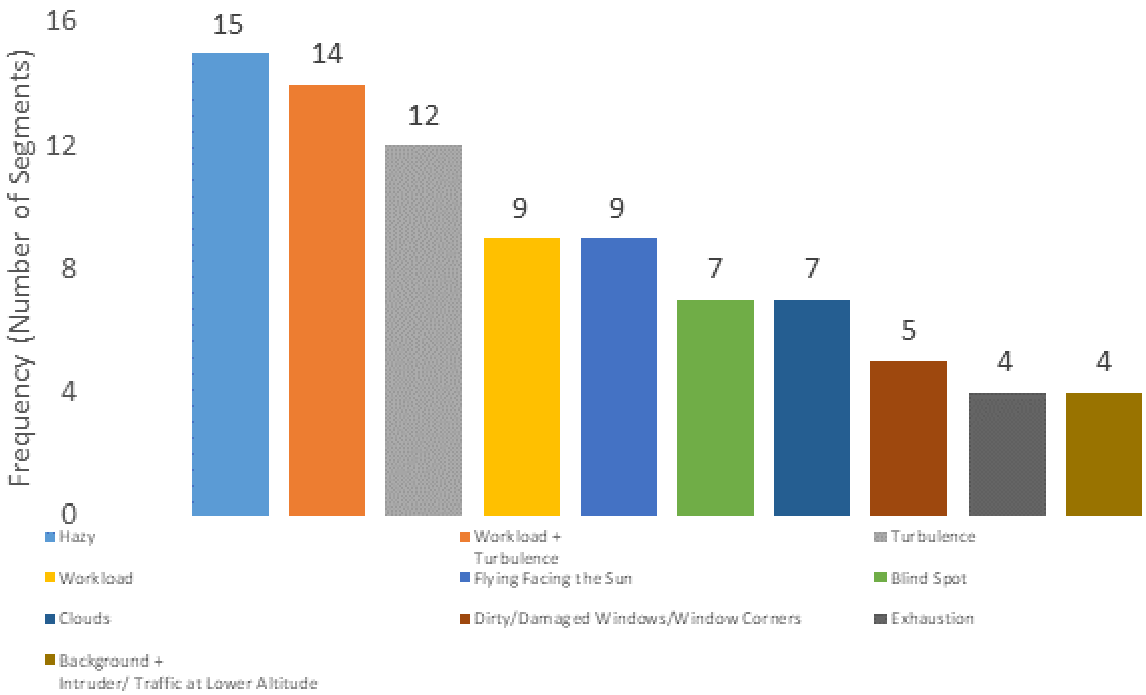

Figure 37. Most frequent factors hindering aircraft detection.

One way of looking into the relationship of these sub-categories was to add another level of sub-categories, as seen in Figure 38, and to look at their proximity to each other within the same statement. All factors that pilots mentioned affecting their ability to detect an aircraft can be found in Appendix 7.

Figure 38. Word cloud for subcategories.

Showing all the existing sub-category combinations in one figure is not feasible as it would lead to hundreds of links. Therefore, a simple example of this link mapping is shown in Figure 39. Here, 'white aircraft' has been linked in the statement to 'haze,' 'clouds,' 'white background,' and 'harder detection.' It has also been associated with 'workload' and 'easier detection.' 'Turbulence' and 'workload' combined are exclusively associated with a more difficult detection. Following the same procedure with other subcategories, it became possible to group sub-categories based on which combination made detection easier or harder. An example of this is seen in Figure 39.

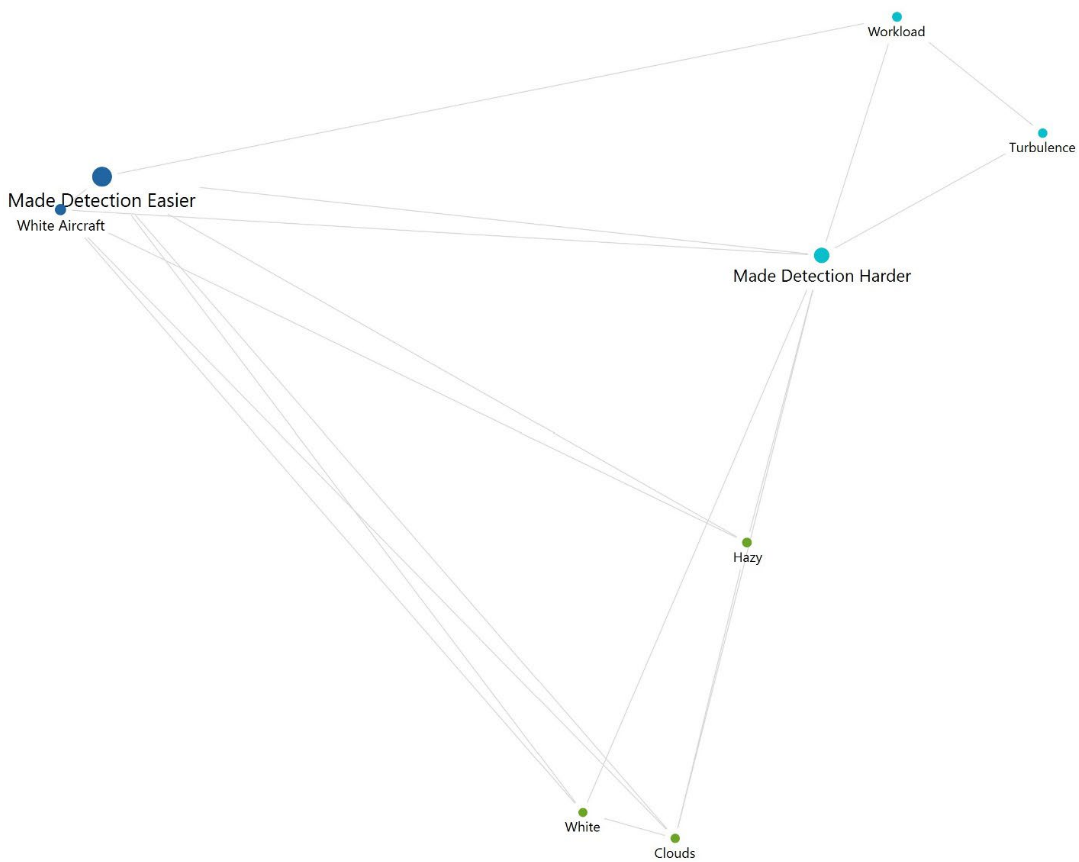

Figure 39. Link map of sub-categories.

Table 7 and Table 8 show the factors that pilots mentioned made detection easier or more difficult, respectively, during their flights.

Table 7. Factors that made visual acquisition easier for the Subject Pilot.

Made Visual Acquisition Easier
• The size of the intruding aircraft (larger aircraft were easier to acquire). • The contrast of the white color and markings of the intruding aircraft against a green or brown background, depending on which season the flight test was performed. • The bright white color of the intruding aircraft reflecting off sunlight, glare. • Clear weather day: sunny, high visibility, low humidity, no clouds, no fog, no haze, leading to a decreased workload trying to maintain the altitude and direction of the plane, so there was more focus on scanning for traffic. • Having visually acquired the intruding aircraft multiple times during the flight test; Subject Pilots become accustomed to seeing the other aircraft and know what it looked like during that time of the day. • The time of day when the flight test occurred, especially when the sun cast a dark shadow of the intruding aircraft on the ground.

• Being familiar with the airfield where the flight test occurred since it helped the Subject Pilot focus more on scanning and less on familiarization with the area, locating where they were, and listening to other traffic communications to avoid other aircraft. • Higher altitude traffic was easier to spot than lower altitude traffic. • Higher altitude of the intruding airplane when it is a long distance from the Subject Pilot; the intruding aircraft is more noticeable when it is in the middle of the test aircraft's windscreen. • The intruding aircraft making a turn, allowing for more of the intruder aircraft wing's surface to be seen by the Subject Pilot. • Visually acquiring the side view of the intruder aircraft. • Both the ownship and intruding aircraft flying at lower speeds. • Test subjects wearing sunglasses, especially when the encounter occurred with Subject Pilots facing the direction of the sun. • Test subjects being familiar with the visual characteristics of intruder aircraft. • Relative motion of the intruder aircraft against a still background. • Test subjects sitting on the left side of the plane so they could see aircraft to their left more readily. • During head-on encounters, if the intruder aircraft was at a higher altitude, it was easier to spot. • During crossing encounters, if the intruder aircraft was at a lower altitude, it was easier to spot because of the intruder's motion as it entered the Subject Pilot's FOV.

Table 8. Factors that made visual acquisition harder for the Subject Pilot.

Made Detection Harder
• Increased workload: trying to maintain the ownship's altitude and direction while still scanning for other aircraft or tracking another aircraft once visually acquired. • The dark shadows of a cloudy day typically make it more difficult to visually acquire the intruding aircraft against dark ground foliage. • Turbulence. When the air was more turbulent, Subject Pilots focused on maintaining altitude, which increased their workload. • Light haze obscuring the other aircraft. • Talking to the Safety Pilot, which could distract Subject Pilot from scanning for other aircraft. • Using radio communications, which could distract Subject Pilot from scanning for other aircraft. • Altitude of the intruding airplane and the angle at which it is approaching; head-on encounters when the intruder was flying at a lower altitude than Subject Pilot were difficult to visually acquire because the nose of the aircraft blocked the Subject Pilot's FOV in that direction. • Altitude of the intruding airplane and the angle at which it is approaching; crossing encounters from left or right when the intruder was flying at a higher altitude than Subject Pilot were difficult to spot since the ownship aircraft's wings obscured the Subject Pilot's FOV in that direction. • Test flights that occurred later during the day after Subject Pilot had been flying for an extended period of time and were becoming fatigued. • Intruder aircraft flying at a low altitude appeared to blend with the background to the Subject Pilot. • Sun reflecting on dirty or damaged (scratched) test aircraft windows/windshield, and obscured window corners. • Intruding aircraft in the direction of the sun, especially when Subject Pilots were not wearing sunglasses.

- Encountering birds since it distracted Subject Pilots from scanning for the intruder aircraft.
- Sun reflection from bodies of water.
- Intruder aircraft flying away from ownship at an angle.
- Intruder aircraft directly on the horizon.
- The relative motion of the ownship and intruder aircraft converging on the same point can make it appear as though the intruder aircraft is not moving causing it to blend with the background more.
- White intruder aircraft flying near roadways and blending in with white vehicles and buildings.
- The contrast of the white color and markings of the intruding aircraft against the sky or clouds when the intruder aircraft is above the ownship.
- The ownship having to fly slower than usual sometimes, which leads to a higher position of the aircraft's nose, which restricts the Subject Pilot's view of the front.

4.3 NASA TLX

Following each flight, the Subject Pilots completed a NASA-TLX form electronically. The NASA-TLX workload assessment consisted of two parts. The first part involved the Subject Pilot providing numerical ratings for each of the six scales, which reflected the magnitude of that factor in the task. The six scales were as follows:

- Mental demand: how much mental and perceptual activity (i.e., thinking, calculating, deciding, searching, looking, remembering) was required to perform the task. Was the latter easy or demanding, simple or complex, exacting or forgiving?
- Physical demand: the amount and intensity of physical activity required to complete the task (i.e., pushing, pulling, turning, activating, controlling). Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
- Temporal demand: the amount of time pressure involved in completing the task due to the rate or pace at which the task was performed. Was the pace slow and leisurely or rapid and frantic?
- Performance: the level of success in completing the task.
- Effort: how hard did the Subject Pilot have to work to accomplish and maintain their level of performance?
- Frustration level: how insecure, discouraged, irritated, stressed, and annoyed or secure, content, gratified, relaxed, and complacent did the Subject Pilot felt during the task.

Each scale was presented as a line divided into twenty equal intervals between bipolar descriptors of 'low' and 'high.' The performance scale is the only exception, ranging from 'good' to 'poor.' The overall workload score was calculated by multiplying each raw rating by the weight given to that factor by the Subject Pilot. The weighted score is determined by the number of times the Subject Pilot chose each measurement as contributing more to their workload. The sum of the weighted ratings was then divided by fifteen to give an absolute workload score, which would lie between zero and one hundred. In the second part of the NASA-TLX, Subject Pilots viewed a window in which they needed to slide along each of the six workload scales to the desired point on each scale to provide weightings to the scales by selecting which member of each pair contributed more to the workload. Overall, Subject Pilots described the flight test as highest in terms of performance, mental demand, and effort, indicating that the Subject Pilots were generally satisfied with how well they visually acquired the intruding aircraft, and that they believe they applied enough time and effort scanning for traffic. Box plots showing the rated and tallied NASA-TLX scores are provided in Appendix 4.

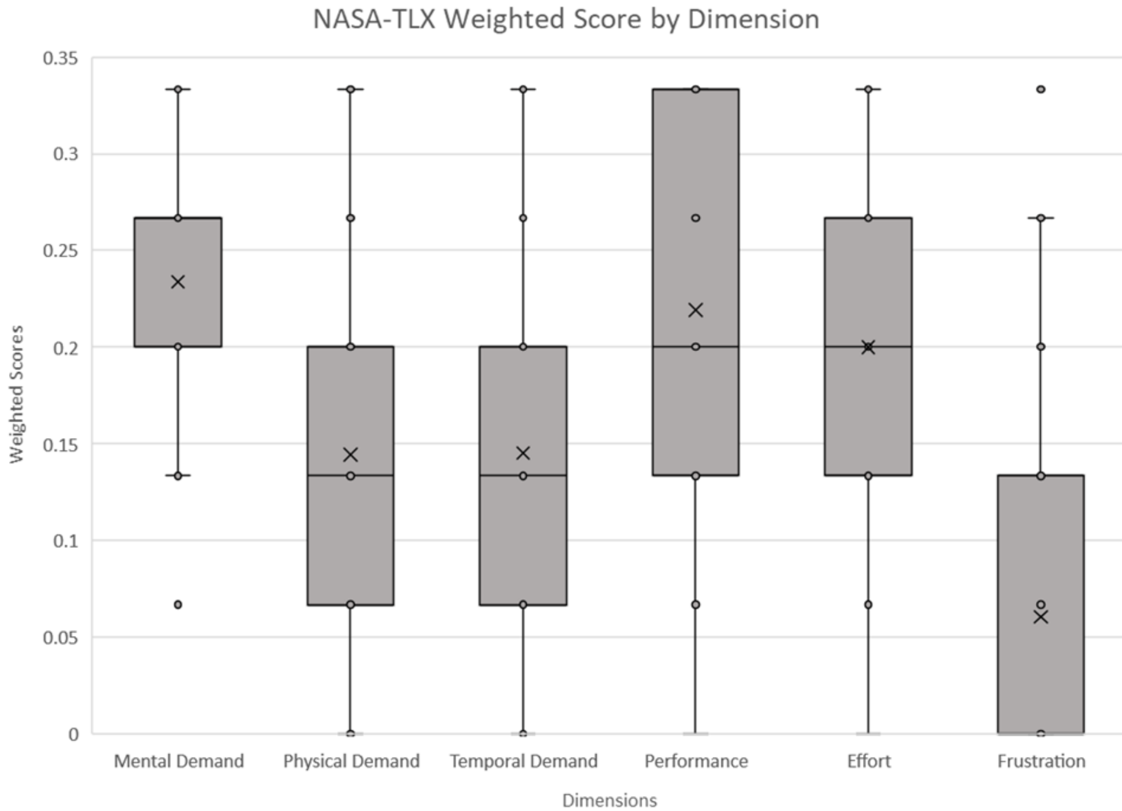

Figure 40. NASA-TLX weighted score by dimensions.

4.4 Encounter Set

The A23 flight testing effort produced 346 total encounters of varying geometries categorized as head on, crossing, and overtakes. The total number further breaks down to 298 encounters between fixed wing aircraft and forty-eight between a fixed wing aircraft and rotorcraft. The rotorcraft encounters have been separated into their own encounter set due to the differences in visual area, closing speed, and relative motion that they present when compared to fixed wing aircraft. There were an additional fifty encounters that were not included in the encounter set due to either track log errors or a failed encounter where the Subject Pilot never had a chance to detect the intruder due to one or both pilots slightly deviating course causing a timing or flight path geometry issue. Appendix 5 displays all visual acquisition parameters for each encounter. Table 9 shows the breakdown of encounters with the frequency of each type of encounters.

Table 9. Frequency of Encounters

Encounter Type	# of Encounters Generated
Head On	116
Overtake	12
Left Crossing	86
Right Crossing	84

4.4.1 Fixed Wing Encounters

Figure 41 shows the distribution of detection distances for every encounter. On average, Subject Pilots would acquire the intruding aircraft at 1.04 nmi (6,319 ft) with the furthest positive detection occurring at 2.64 nmi (16020 ft).

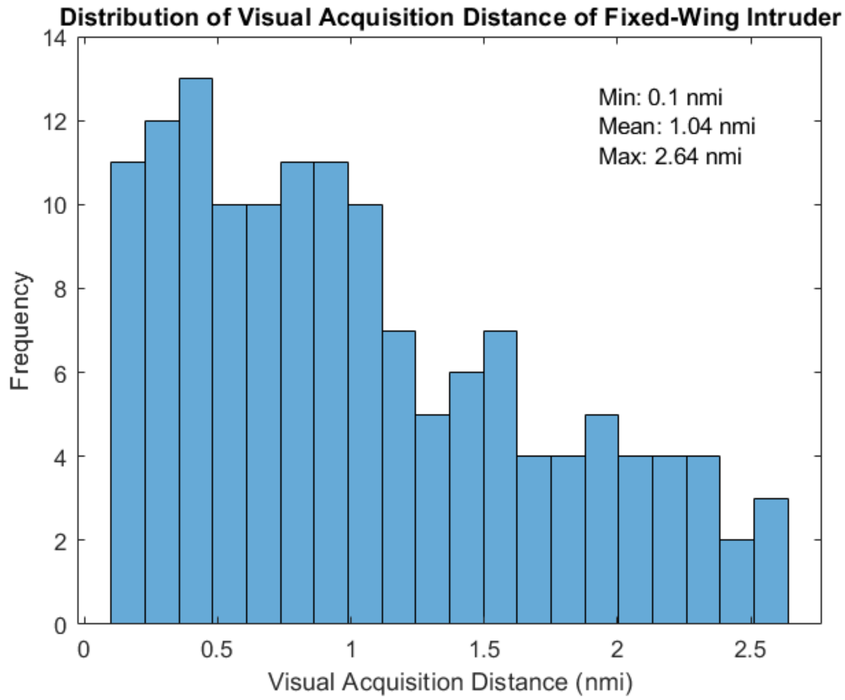

Figure 41. Visual acquisition distance of fixed wing aircraft by Subject Pilots.

The percentage of fixed wing aircraft not seen during the flight testing was plotted against the range between aircraft, shown below in Figure 42. The quadratic curve fit matches the data extremely well, producing an R^2 value of 0.9987. At a distance of 1 nmi, 80% of aircraft were not seen. Even within 0.25 nmi, over 50% of aircraft were not detected. This plot is only for the test geometries explored in this research and as such does not fully characterize the 360-degree area around the aircraft that is especially important for overtake encounters. For these encounters, it is expected that at lower ranges the percent of aircraft not seen would increase due to the FOV limitations of a pilot. The inverse of this plot, in Figure 43 shows the percentage of aircraft that were seen at each distance, decreasing as the range between the aircraft increases.

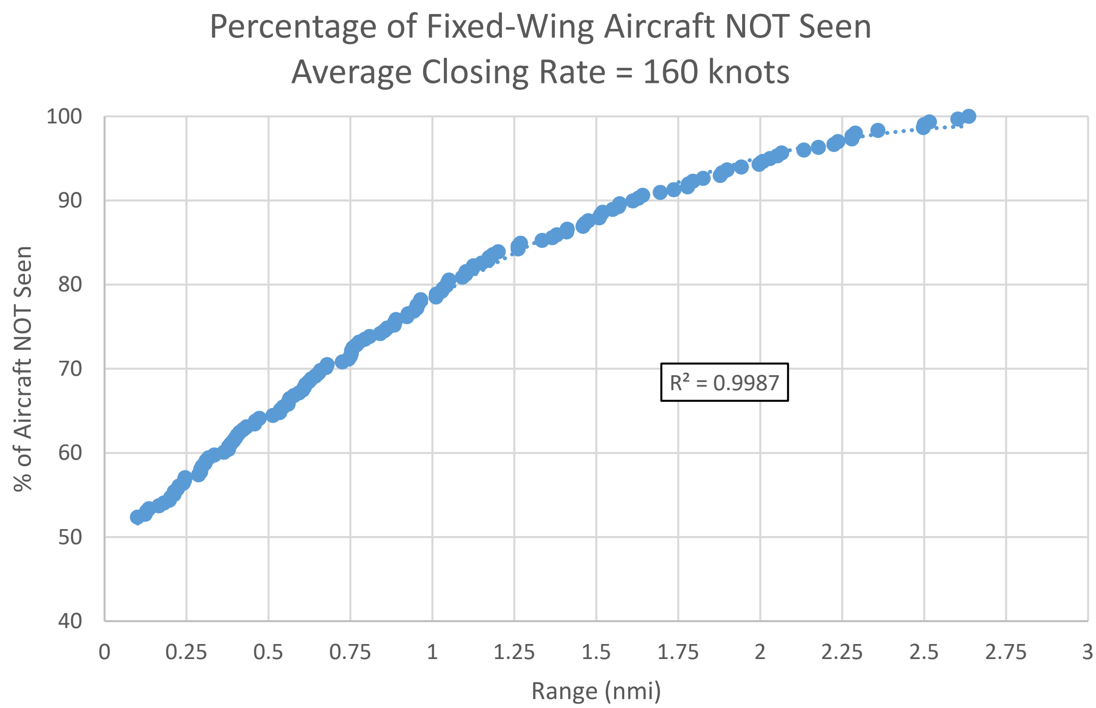

Figure 42. Percentage of aircraft not seen during flight testing.

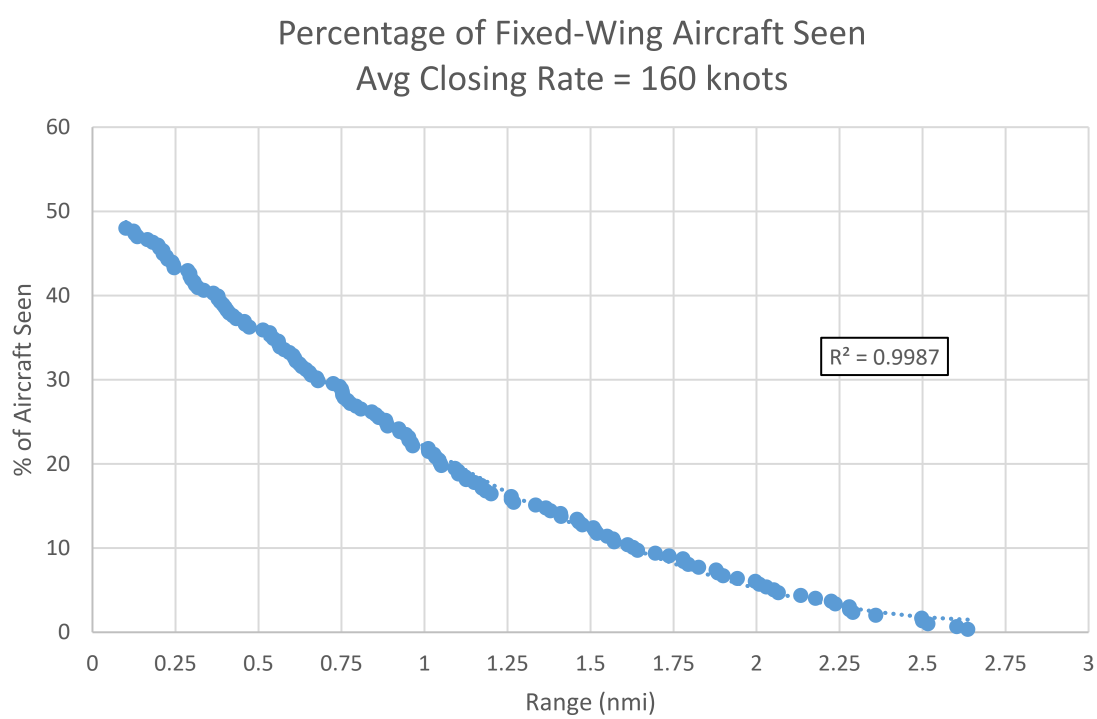

Figure 43. Percentage of fixed wing aircraft seen during flight testing.

A majority of the encounters occurred in head on scenarios, as can be seen in Figure 44, where the largest distribution is towards ±180°. Negative angles in the figure correlate to the intruder being to the left of the ownship aircraft and positive angles to the right. Other groupings can be seen around ±90°, highlighting the number of crossing encounters where pilots detected the intruder aircraft.

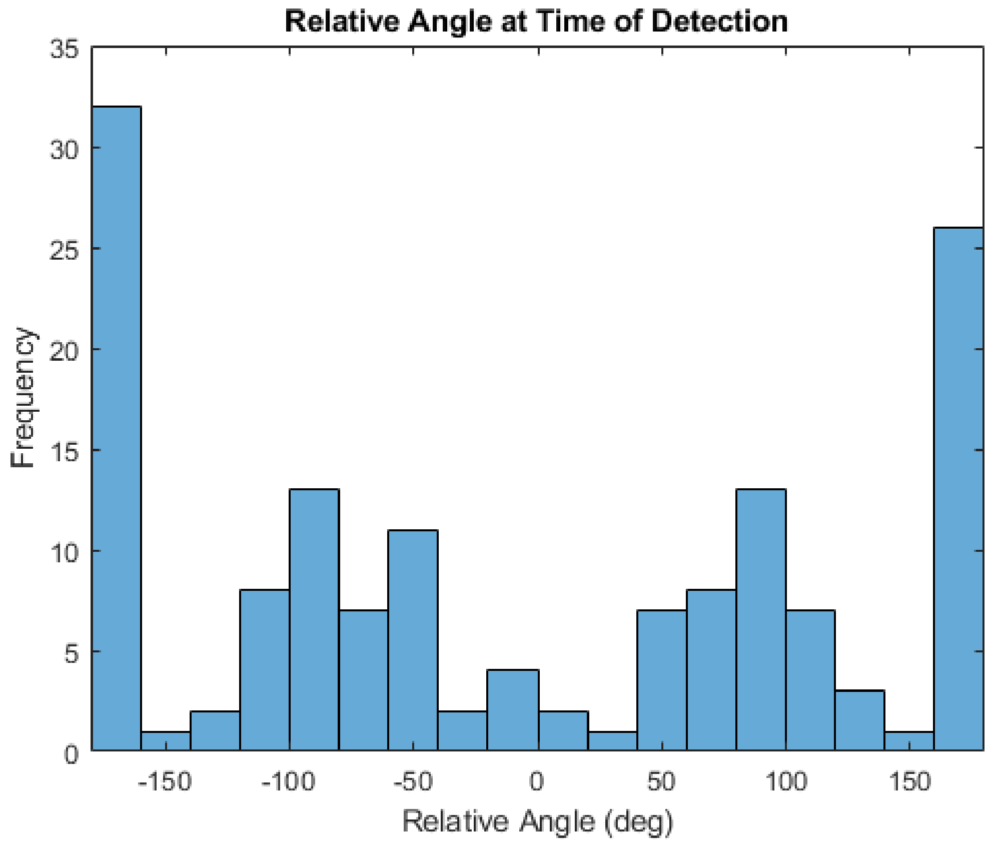

Figure 44. Relative angle between ownship and intruder aircraft at time of visual acquisition.

Likewise, the angle from ownship to intruder is shown below in Figure 45, where it can be seen that many of the visual acquisitions made by the Subject Pilots were directly in front of them.

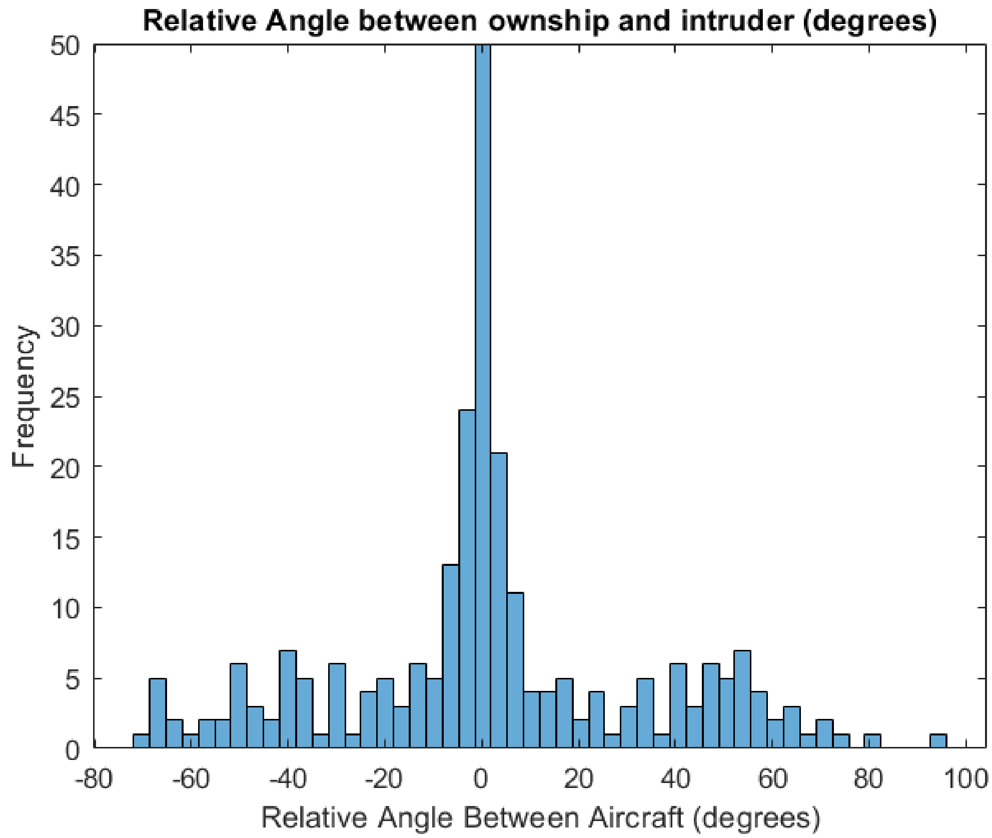

Figure 45. Angle between nose of ownship and intruder aircraft.

Due to flight testing safety considerations, Subject Pilots were required to maintain a 500 feet vertical separation from the other participating aircraft. The following two figures display the distribution of visual acquisitions when the intruder aircraft was lower or higher than the horizon of the Subject Pilot. Generally, Subject Pilots stated that it was easier to spot the intruder aircraft if it was higher due to less obstruction from the nose of the ownship. At further distances, the elevation difference did not affect pilots' ability to acquire the aircraft.

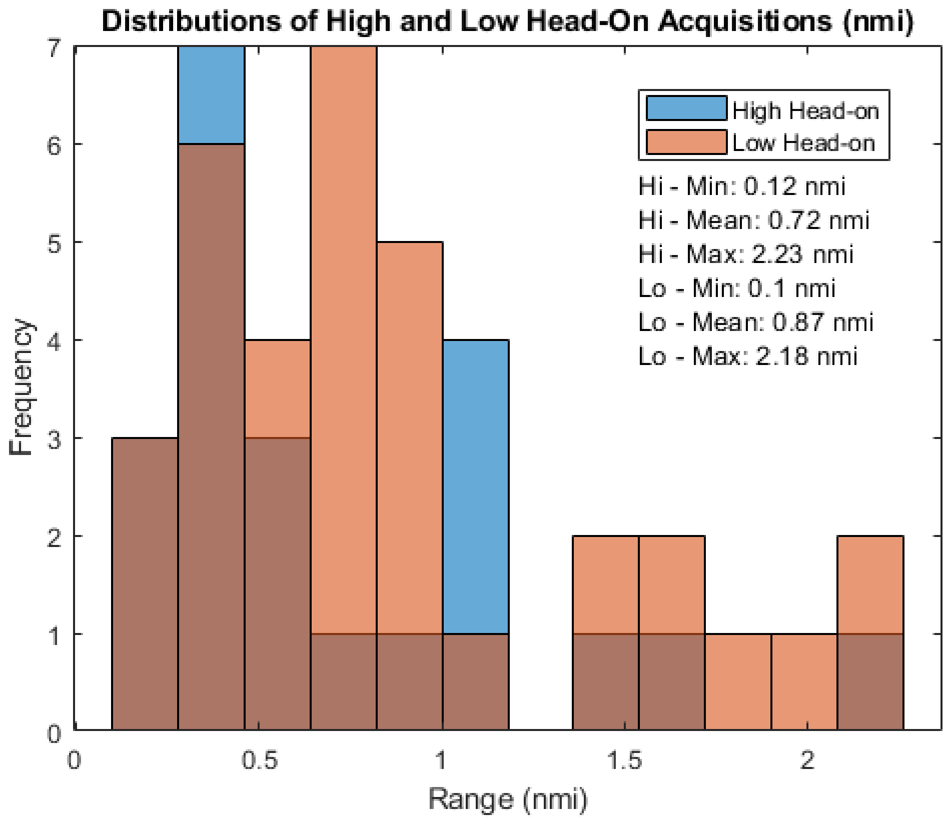

Figure 46. Visual acquisition distribution for intruder position relative to the ownship aircraft at time of detection.

These high and low encounters were then used to determine the percentage of aircraft not seen at each distance. It can be seen in Figure 47 that when the intruder was lower, there is a lower percentage of the aircraft not being seen when compared to when the intruder was higher.

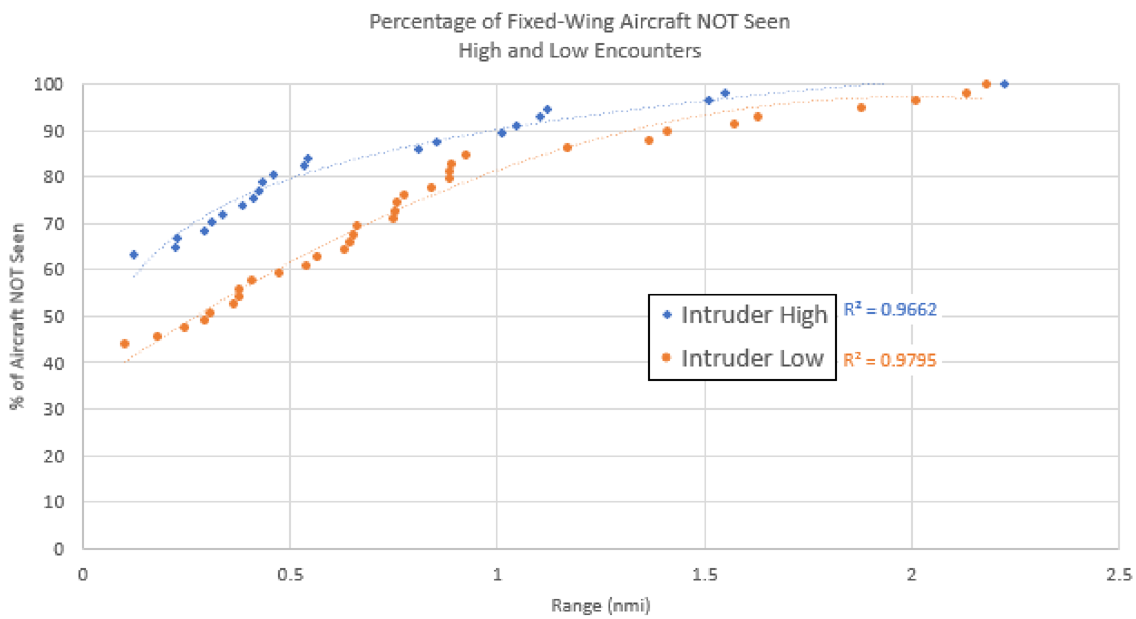

Figure 47. Percentage of fixed wing aircraft detected during high and low flight-testing encounters.

Crossing encounters occurred at a multitude of angles due to design and flight conditions. Subject Pilots detected the aircraft at a lower average distance of 1.14 nmi (6,927 ft) in right hand crossings compared to 1.22 nmi (7,413 ft) average distance when the intruder enclosed from the left. While the average detection difference is slightly lower on left hand crossing, the data is more consistent in the 0.5 nautical mile range to 2 nautical mile range. Typically, the pilot has a higher FOV on the left side of the aircraft due to their seat position. When a pilot looks to the right their FOV is severely limited as illustrated in the FOV chart shown in Figure 15.

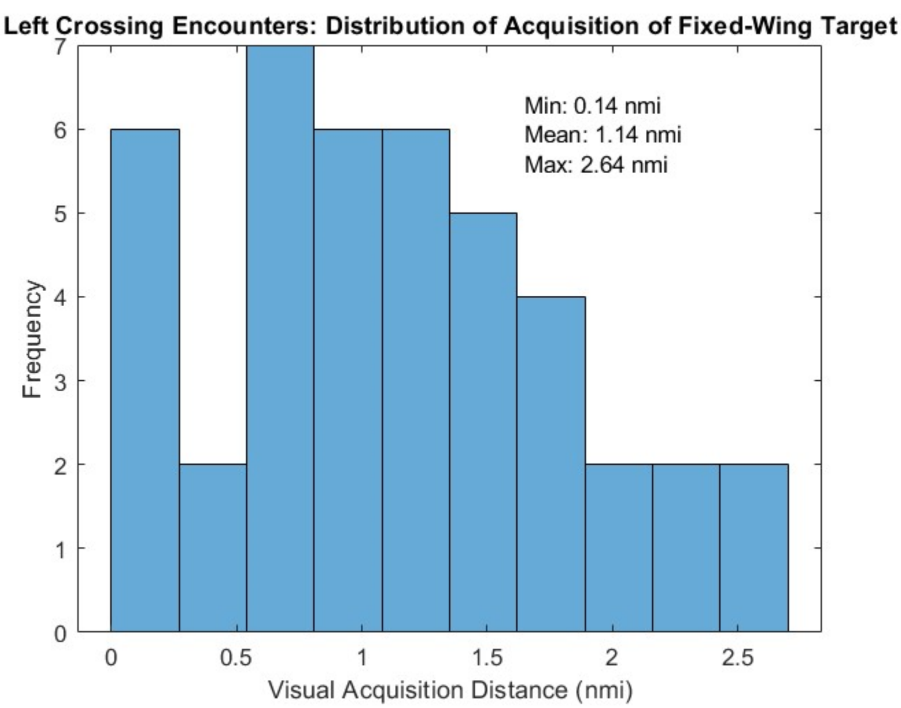

Figure 48. Visual Acquisition Distribution of Left Crossing Encounters of Fixed-Wing Aircraft.

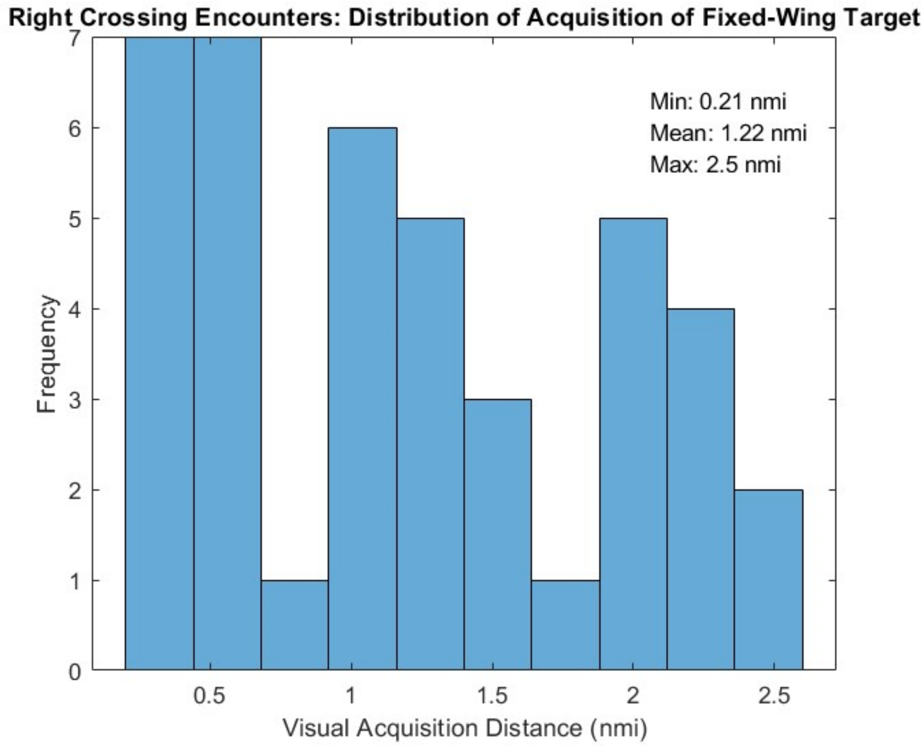

Figure 49. Visual Acquisition Distribution of Right Crossing Encounters of Fixed-Wing Aircraft.

The percentage of fixed-wing aircraft not seen during the right and left crossing encounters was also plotted in Figure 50. These results are comparable to the head on encounters and continue to show agreement with the quadratic curve fit.

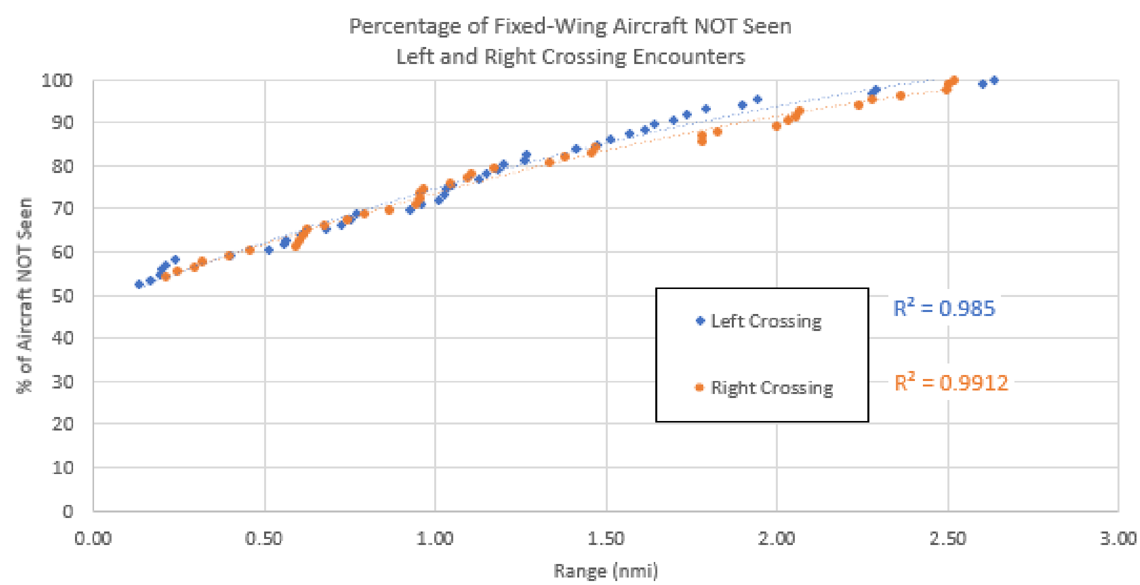

Figure 50. Percentage of fixed wing aircraft not acquired in the left and right crossing encounters at various angles.

The average visual acquisition distance for head on and overtake encounters was 0.84 nmi (5104 ft) as shown in Figure 51. Head-on encounter geometry was used more often that overtakes; as such, overtakes will be further explored in future research.

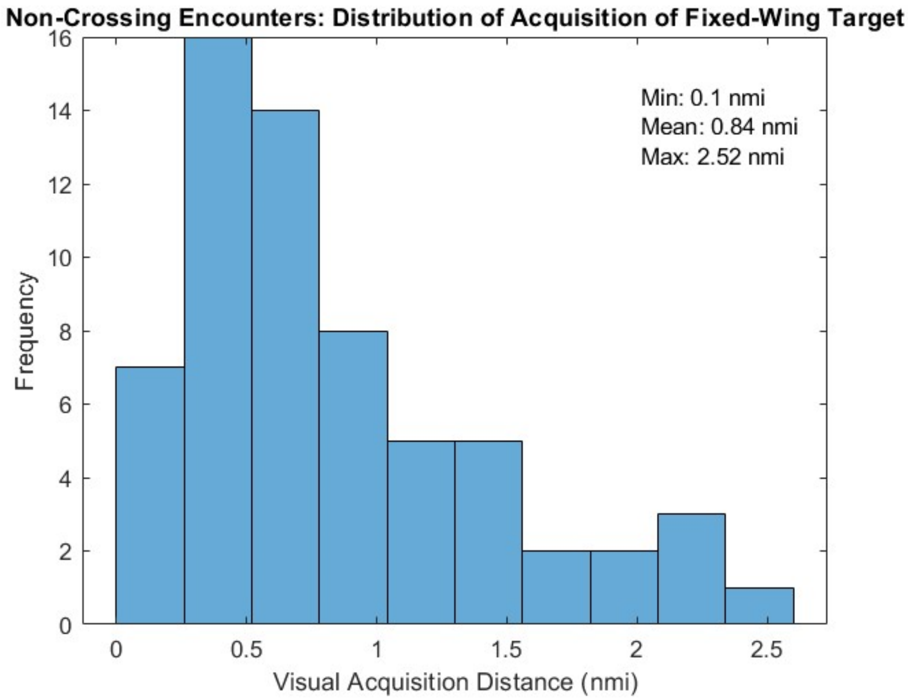

Figure 51. Fixed-Wing Head-on and Overtake Encounters Distribution of Acquisition Distance

The Closest Point of Approach (CPA) for each encounter, regardless of detection, is shown in the following figures. These values were obtained by having unmitigated pilot response from both the ownship and intruder, meaning neither aircraft changed course during testing unless the safety margins of the test were impeded, and the Safety Pilots needed to take control; however, actions to maintain the safety of the test were never needed during the flight-testing campaign. The minimum lateral CPA was 0.08 nmi (458 ft), and the maximum was 1.97 nmi (11,993 ft). Longer CPA distances were generally associated with failed test points unless the intruder aircraft was reasonably within the FOV of each Subject Pilot.

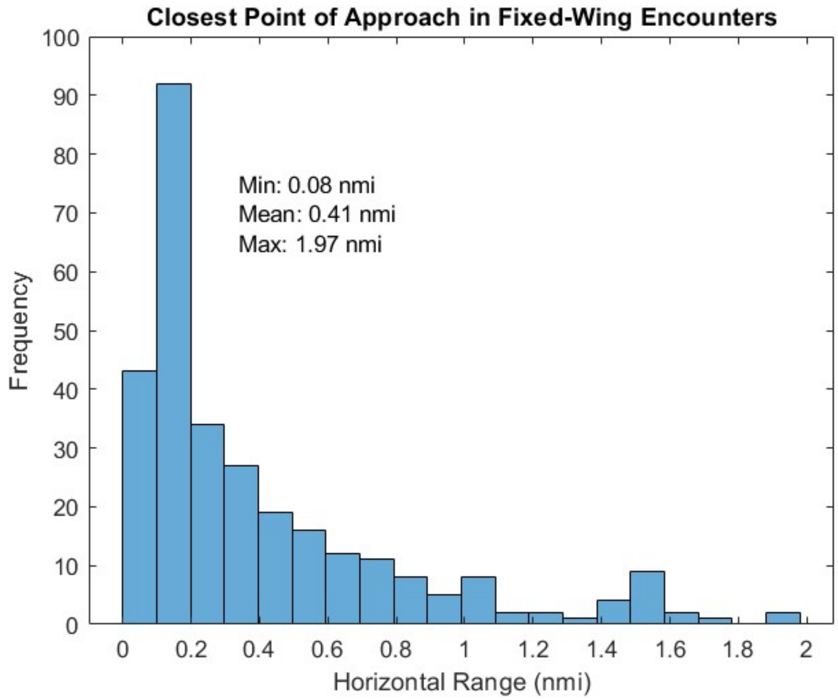

Figure 52. Closest Point of Approach Distance for Fixed Wing Aircraft.

Figure 53 compares the CPA distances for detections and missed detections. CPA's track closely together with the average Detection CPA being slightly shorter than the average No Detection CPA at 0.37 nmi (2,248 ft).

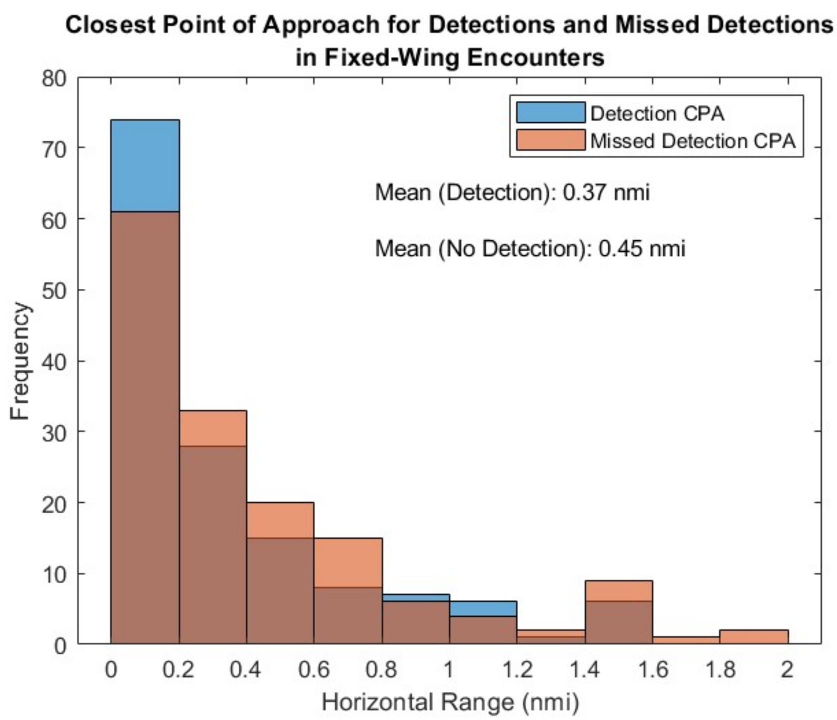

Figure 53. Closest Point of Approach for Detection vs No Detection

By only focusing on CPA values that would have resulted in a WCV violation (less than 2,000 feet or 0.33 nmi) in Figure 54, it can be seen that there were 175 encounters that resulted in a horizontal WCV violation and in a majority of the encounters, the aircraft flew within 0.16 nmi (1,000 ft) of each other.

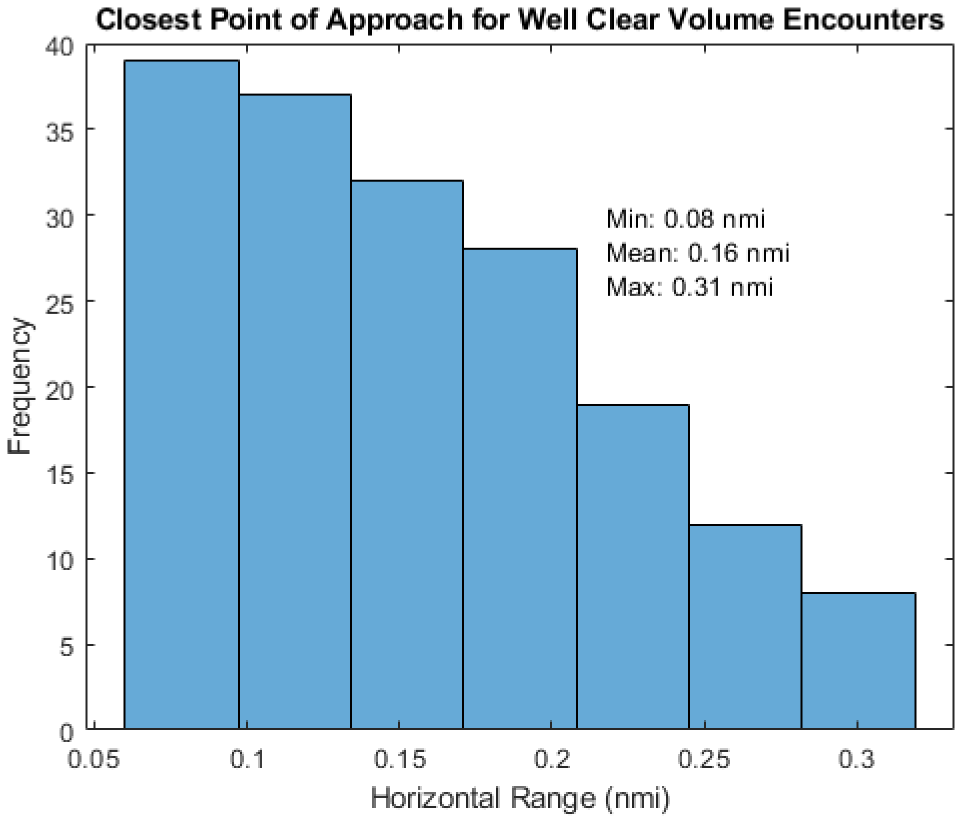

Figure 54. CPA Distribution for CPA's less than 0.3 nmi (2000 ft).

The average closing speed for all fixed wing encounters is shown in Figure 55. Using the time passed for aircraft to begin a maneuver indicated by the Advisory Circular (AC) in Table 12. Timeline from an assumed detection of an intruder on collision course to maneuver initialization (Transportation Safety Board of Canada, 2018)., the aircraft will have moved almost half a mile at the mean closing rate.

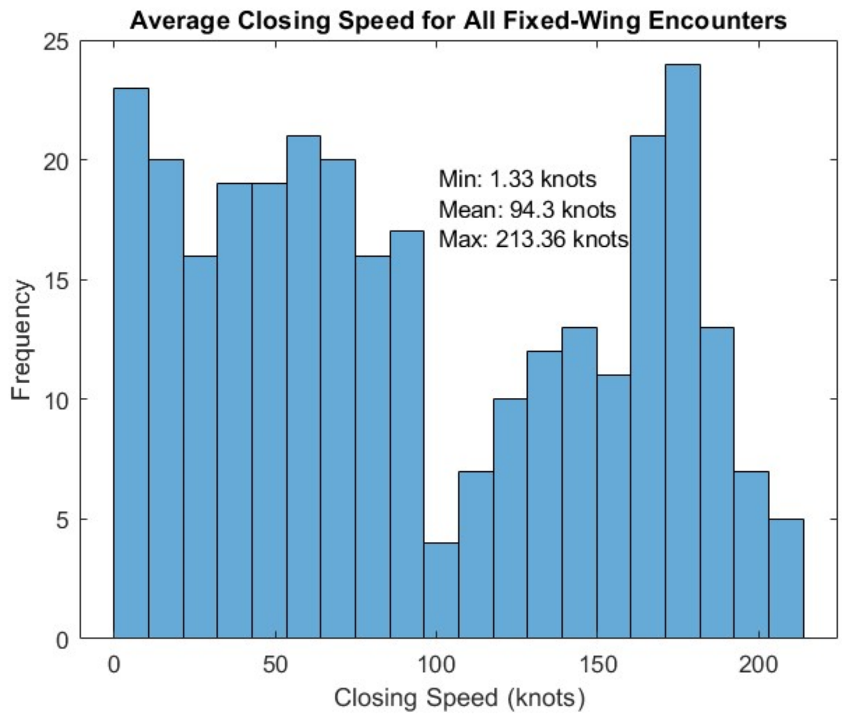

Figure 55. Average Closing Speed for Fixed-Wing Encounters.

The figure above can be further organized into the head on and crossing encounters to highlight the difference in closing speeds between the two encounter types. The closing speeds for head on encounters is understandably higher than those in the crossing encounters due to the aircraft flying directly at each other. Head on encounters had an average closing speed around 95 knots faster than the average crossing encounter.

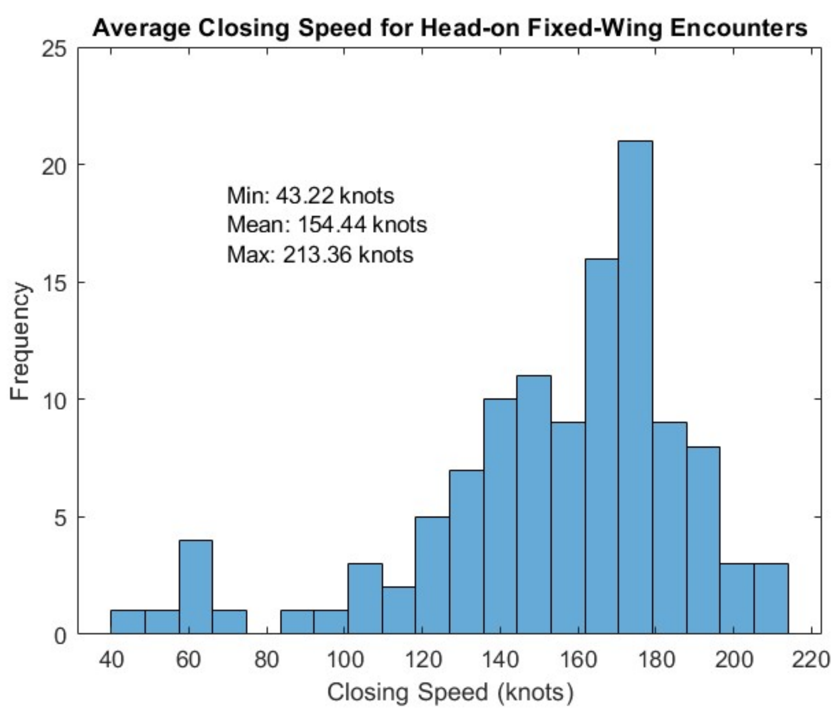

Figure 56. Average Closing Speed for Head-on Fixed-Wing Encounters.

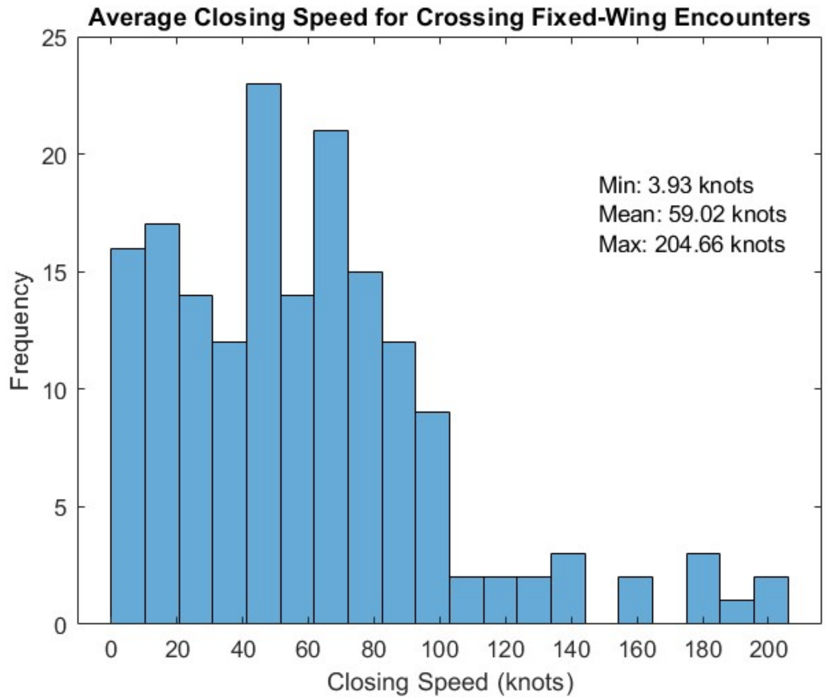

Figure 57. Average Closing Speed for Crossing Fixed-Wing Encounters.

4.4.2 Rotorcraft Encounters

The UASSRF performed two days of flight testing with five Subject Pilots in October of 2022 between a Cessna 206 and an Airbus H125. The flight paths chosen for the event consisted of the bowtie pattern to generate four crossing and four head-on encounters per flight window and the hairpin to generate four crossing and one head-on encounters during the flight window. During the event, there were 48 total encounters with the rotorcraft from a fixed-wing aircraft resulting in 25 visual acquisitions. The distribution of visual acquisitions can be found in Figure 58 where, on average, the rotorcraft was detected laterally at 1.04 nmi (6,319 ft) away from the subject aircraft with a maximum lateral detection distance at 2.64 nmi (16,041 ft). The test pool for rotorcraft encounters was much lower than that of fixed-wing vs fixed-wing encounters so it is difficult to make meaningful conclusions on why the visual detection range is so large for the rotorcraft at this time. The follow-on research will dive deeper into this type of encounter and build on the dataset presented in this document and allow for a more thorough analysis to be performed using this flight-testing data. Testing on this specific type of intruder will be expanded in future ASSURE efforts.

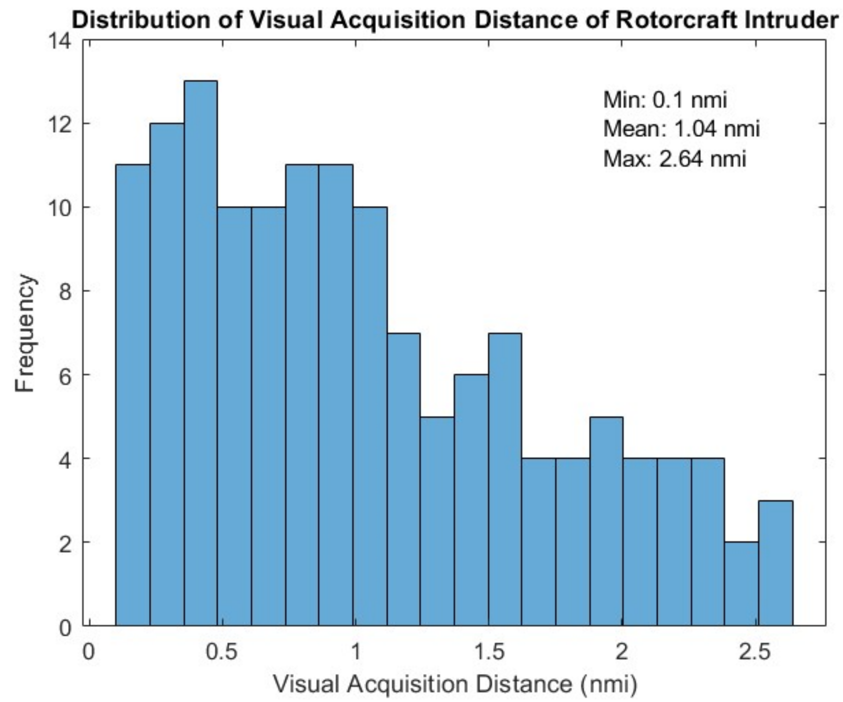

Figure 58. Distances that Subject Pilots visually acquired the rotorcraft.

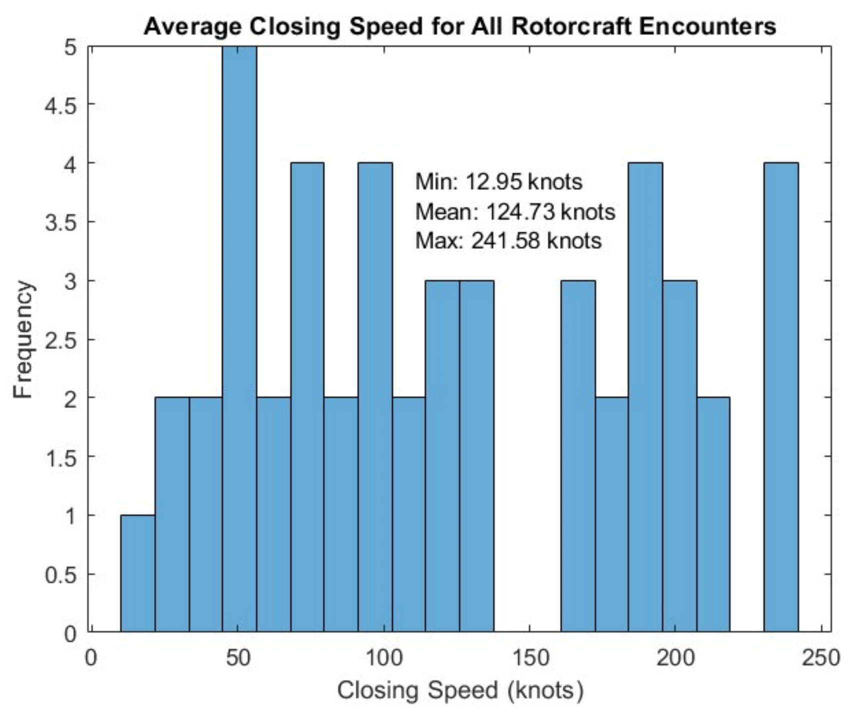

Figure 59. Average Closure Speed for Rotorcraft Encounters.

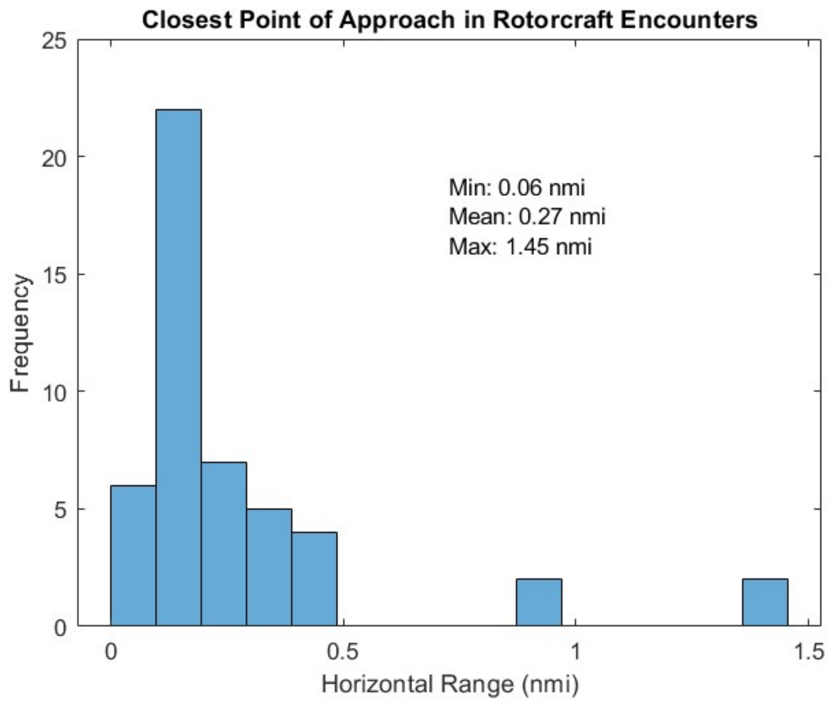

Figure 60. CPA for all Rotorcraft Encounters

5 Modeling and Simulation

The final A23 encounter (fixed wing vs fixed wing) dataset contained 298 encounters, 143 of which had a detection of the intruder by the ownship pilot. The position, speed, and orientation of both the ownship and intruder vehicle were logged at 1 second intervals, along with a Boolean variable signifying the detection of the intruder. Our goal was to develop a model for visual acquisition based on this encounter dataset. Prior work (Andrews J. , 1991) has shown that a good model of the "instantaneous" probability of visual acquisition of a target is given by:

$$P = e^{-\lambda} \tag{1}$$

Where λ is the visual acquisition rate, which can be modeled as

$$\lambda = \frac{\beta A}{r^2} e^{-2.996r/R} \tag{2}$$

In this equation, r [nmi] is the range between the ownship and intruder, β [nmi^2/sr] is the pilot attentiveness factor, A is the visual cross section of the intruder [nmi^2], and R [nmi] is the visibility. In our encounter measurements, the values for A, r, and R are all known from our measurements, and A and r may vary with time. The view-angle dependent value of A has been found for the Cessna aircraft used in our study (Underhill & al., 2023) and visibility was clear (R=10 nmi) for all our experiments. In this case, the time-logged data can be used to estimate β with a fitting procedure.

Previous work (Andrews J. , 1991) has suggested integrating the time varying parts of Equation (2) into a single value, the "opportunity integral", Q:

$$Q = \int_0^t \frac{A}{r^2} e^{-2.996r/R} dt \tag{3}$$

The integration begins when the intruder enters the FOV of the ownship and ends when the intruder either leaves the FOV or is detected by the ownship pilot. This approach results in 298 datapoints, one for each encounter, with each point having a Q value and a Boolean value indicating whether there was a detection or not. In order estimate a probability of detection versus Q, the 298 points are binned into a histogram with bins in Q and the probability being the number of points with a detection in a particular bin divided by the total number of points in that bin. With this process complete, it is only necessary to fit the equation.

$$P(Q) = e^{-\beta Q} \tag{4}$$

The value of β is the free parameter in the fit. As mentioned above, the start and end times of the integral in Equation (3) are when the intruder vehicle enters and exits the pilots' FOV. Consequently, the final measured value for β is very sensitive to the assumed limits taken for the FOV of the pilot. The canonical measurements by (Andrews J. W., 1984), which found β=17000, used a relatively narrow field of view that allowed for ±10° of elevation and ±60° horizontal. More recent work (Underhill & al., 2023) used a broader field of view with the elevation angle ranging from [-17,15] degrees and the horizontal angle ranging from [-120,80] degrees, better approximating the actual FOV from a Cessna cockpit. Finally, recent measurements by the UASSRF have determined a more exact representation of Cessna FOV using a polygon. Figure 61 shows the overlap and relative size between the different standards for FOV.

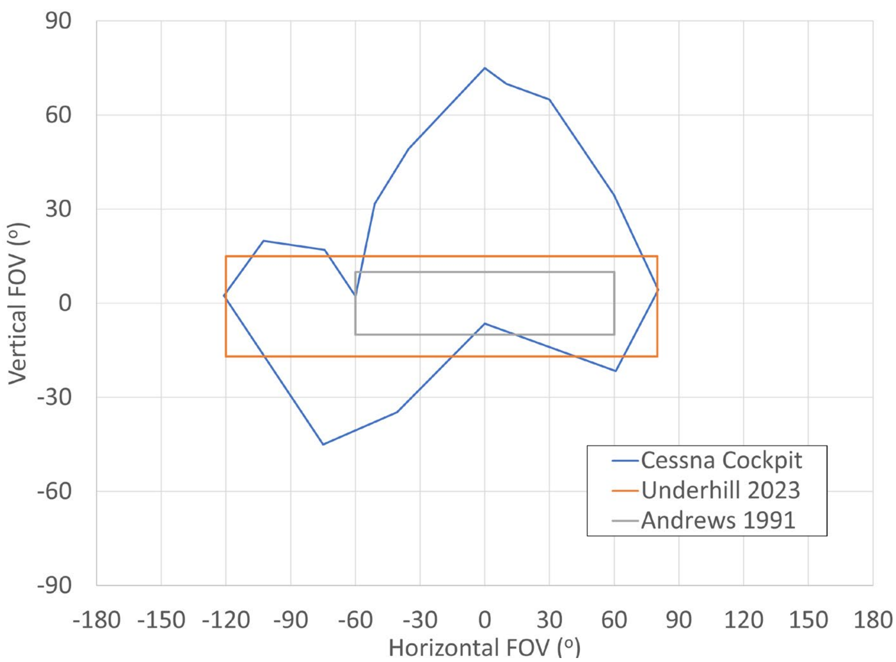

Figure 61. Field-of-view standards

The β fitting procedure described above was performed for all three of the FOV models shown in Figure 61. In addition, a fourth FOV model which included all angles was included. The resulting values for the measured values of β are shown in Table 10.

Table 10. Beta Values Calculated through Various Methods

FOV	β	R^2	# Detections
Andrews 1984	17988 ± 1151	0.967	86/298
Underhill 2023	8563 ± 1308	0.846	118/298
Cessna Cockpit	9401 ± 924	0.926	105/298
All angles	5819 ± 1106	0.856	127/298

Detections which occur outside the specified FOV are listed as "no detections" in this analysis of the encounters. In addition, in keeping with (Andrews J. W., 1984), the fitting process excludes detections which occur at <0.3 nmi, since the negative exponential model for visual acquisition is known to be invalid at these close ranges. With these restrictions, the number of detections in each analysis will be different, despite the data coming from the same encounter set.

Due to the discrepancies in the result based on which FOV was chosen, an alternative model was proposed in which the search effectiveness model parameter, β, was taken to be a function of view angle. This is like the approach of (Underhill & al., 2023), who adjusted the pilot search "dwell" time based on angle. Propose the following model for an angular-dependent β:

$$\beta(\theta, \varphi) = \beta_0 \frac{(cos\, \varphi + 1)(cos\, 2\theta + 1)}{4} \tag{5}$$

where θ is the elevation angle and φ is the horizontal angle. This model has the property that it is normalized to one when the intruder is straight ahead (θ, φ=0) and goes to zero when the intruder is directly above (θ=π/2), below (θ=-π/2), or behind (φ=± π). In addition, the relative strength of the variation with angle matches that of the linear model proposed in (Underhill & al., 2023). The model is shown in Figure 62. In edge cases, the simulation overestimated pilot performance due to differences in closure speeds and testing geometries compared to flight testing. For the initial simulation this is still useful as it generates safer risk ratios that could be refined in future work as the simulation test pool improve.

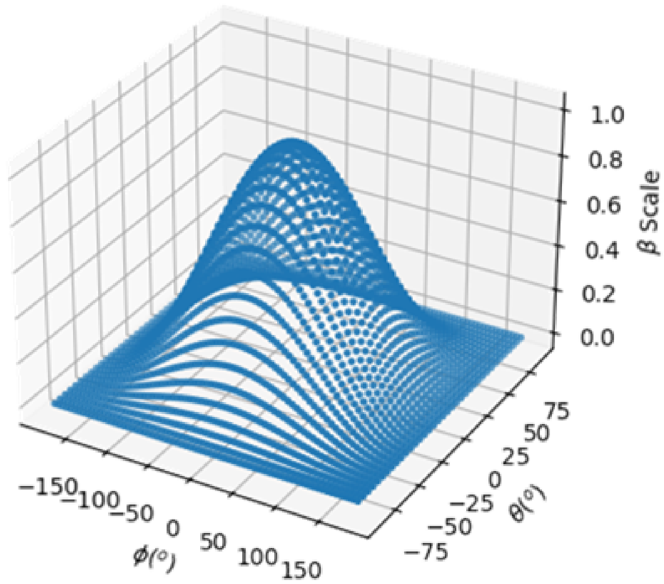

Figure 62. Angular scaling of the view-dependent model for search effectiveness

With the angular scaling model for β shown in Figure 62, it was possible to fit the encounter data without excluding datapoints based on angle. Instead, the integral for Q in Equation (3) was updated to include the angular dependence of beta, such that Equation (3) becomes:

$$Q(\theta,\phi) = \int_0^t (\cos\varphi + 1)(\cos 2\theta + 1)\frac{A}{4r^2}e^{-2.996r/R}dt \tag{6}$$

And Equation (4) becomes:

$$P(Q) = e^{-\beta_0 Q} \tag{7}$$

Using this process, it was found that β_0=7438±997 with an R^2=0.898.

5.1 Encounter Simulations

Encounter simulations were performed using trajectories generated from the Airspace Encounter Model (AEM) developed by MIT-Lincoln Laboratory (Weinert & al, 2013). Ten-thousand encounters were generated using inputs provided by MIT-LL. For each simulated encounter, the ownship and intruder traveled along the generated trajectories and the visual acquisition model was queried at each time step. The instantaneous probability of detection was compared to a random test variable, τ, which varied from 0-1 and was regenerated at each time step. If the probability of visual acquisition exceeded the value of τ, a detection was logged. If a detection occurred, then after a certain delay time an avoidance maneuver was initiated using some multiple of a standard rate turn. Both the delay time and turn rate were varied in our analysis, with the results shown below. The dynamics of the aircraft during the turn were simulated using a point-mass model like that implemented by (McLain, Beard, & Owen, 2014). The simulation flowchart is shown in Figure 63.

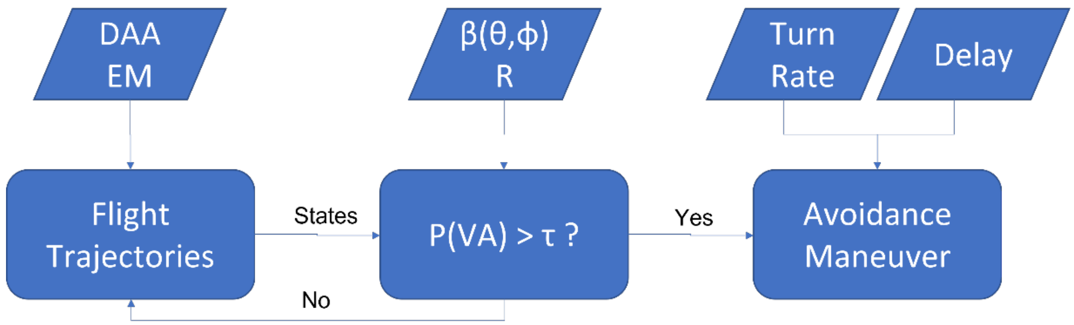

Figure 63. Simulation block diagram

The closest horizontal and vertical offsets were logged for each encounter, and the encounters that violated the well-clear (WC) and NMAC guidelines were logged. Each simulation was repeated with the visual-acquisition and avoidance turned off. The ratios were the number of WC/NMAC encounters with the avoidance system divided by the number that occurred without the avoidance system.

Two sets of avoidance simulations were recorded. In the first set, only the ownship vehicle was allowed to execute see-and-avoid behavior. In the second set, both the ownship and intruder could execute see-and-avoid. For either of these sets the aircraft would always maneuver once a detection was made. However, in the real world this is not always the case resulting in this simulation slightly overestimating pilot performance. In addition, six different delay times were simulated [0,3,6,9,12,15] seconds, and four different turn rate multipliers, [1,1.5,2,3] times the standard rate of 3 deg/s. The full factorial combination of all these variables was performed for a total of 2 avoidance modes times 6 delays times 4 turn rates equals 48 different possible parameter configurations. Each configuration was simulated 10 times for each of the 10,000 different encounter models, for a total of 4.8 million simulated encounters. The average results for each of the 48 parameter combinations are tabulated in the Simulation Parameter Combinations and Risk Ratios table located in Table 11. Instances where only one aircraft could maneuver are represented by the "Own Only" columns and instances where both could maneuver are in the "Both" columns.

Table 11. Simulation Parameter Combinations and Risk Ratios

Turn Rate (x Standard)	Delay (s)	Risk Ratio, NMAC (Own Only)	Risk Ratio, Well-clear (Own Only)	Risk Ratio, NMAC (Both)	Risk Ratio, Well-clear (Both)
1	0	0.527	0.721	0.508	0.704
1	3	0.603	0.753	0.572	0.735
1	6	0.657	0.784	0.624	0.764
1	9	0.699	0.805	0.663	0.785
1	12	0.727	0.822	0.691	0.800
1	15	0.752	0.837	0.717	0.818
1.5	0	0.459	0.667	0.434	0.650
1.5	3	0.555	0.716	0.533	0.700
1.5	6	0.620	0.750	0.584	0.733
1.5	9	0.664	0.776	0.637	0.764
1.5	12	0.703	0.799	0.676	0.786
1.5	15	0.733	0.816	0.695	0.802

2	0	0.405	0.630	0.388	0.614
2	3	0.510	0.683	0.488	0.667
2	6	0.590	0.728	0.567	0.711
2	9	0.648	0.762	0.617	0.742
2	12	0.688	0.785	0.654	0.767
2	15	0.718	0.806	0.685	0.789
3	0	0.321	0.563	0.308	0.551
3	3	0.458	0.637	0.439	0.626
3	6	0.555	0.693	0.524	0.676
3	9	0.615	0.732	0.591	0.718
3	12	0.667	0.768	0.633	0.749
3	15	0.698	0.791	0.668	0.773

Although a pilot response delay of 12 seconds is currently accepted as the standard amount of time for a pilot to recognize, react, and begin a maneuver (see Table 13), it is believed that this is a conservative value and it is believed that future pilot response studies will support reducing this estimate. In the above table, the pilot responses of 6 and 9 seconds are believed to be a more accurate representation of true pilot behavior, however, future efforts will evaluate this response time further.

The variation of the risk ratios with delay and turn rate is shown in Figure 64, which shows the risk ratios for both the NMAC and well clear conditions as a function of delay. The figure shows results for turn rates of 1x and 3x the standard turn rate for instances where just the ownship would maneuver (See and Avoid) and then where both aircraft would maneuver (See and Be Seen).

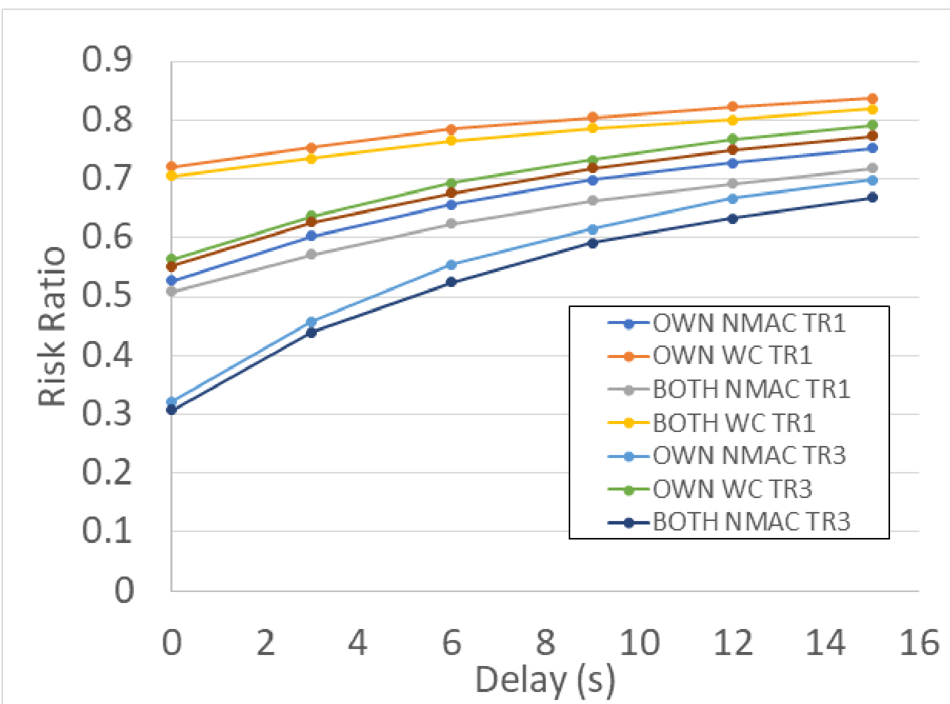

Figure 64. Risk ratios versus delay for different turn rates

Figure 64 shows the trend that all risk ratios increase as a function of delay. Although there is some variation, in general the risk ratios increase by an average of 22% as the delay increases from 0 to 15 seconds. This demonstrates ≈1.2% increase to the risk ratio for each second of delay. Figure 64 also shows the difference in risk ratio between a standard turn and 3x standard turn. For most cases, there is about a 5% decrease in risk ratio when the turn rate increases from 1x to 3x the standard rate. This shows ≈1.7% decrease in risk ratio for each multiple of the standard turn rate. In contrast, the change in risk ratio versus the search effectiveness is shown in Figure 65. In these simulations, the turn rate was the standard rate, and the delay was 12 seconds. Ten simulations for each of the 10,000 encounters were simulated, and the search effectiveness parameter, β_0, was varied.

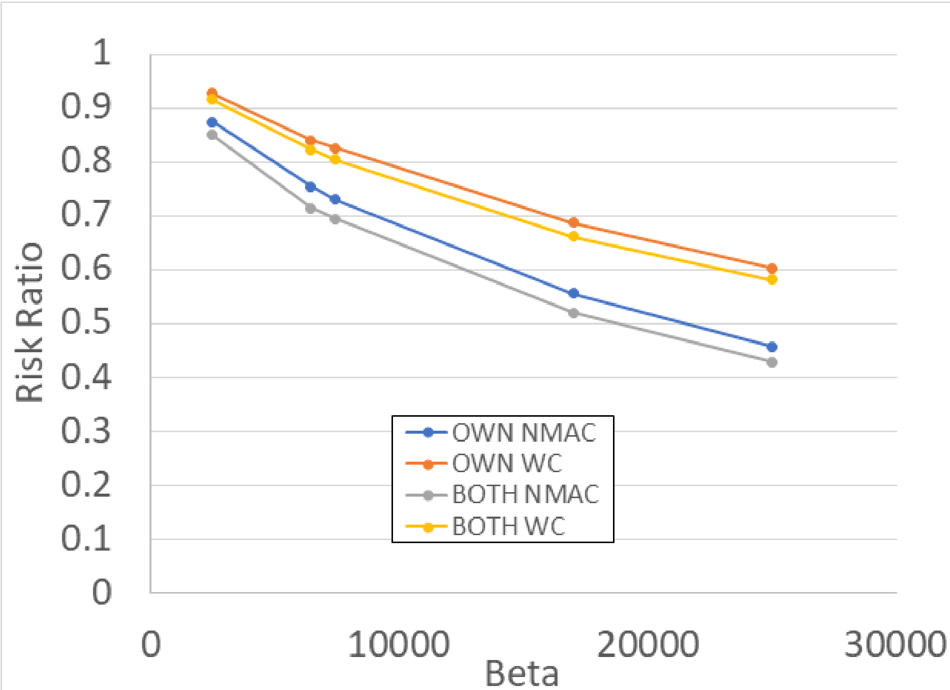

Figure 65. Risk ratio versus search effectiveness

The lines in Figure 65 show a decline of the risk ratios as search effectiveness increases, with declines upwards of 30% or more between the lowest and highest search effectiveness values.

5.2 Modeling and Simulation Summary

Using this new model, it was determined β_0=7438±997 with an R^2=0.898. This visual acquisition model was integrated into a simulation environment that used encounters generated by the AEM and studied the effect of pilot delay and turn rate. It was found that the risk ratios depend strongly on the search effectiveness parameter with an exponential reduction in risk ratio as search effectiveness increases. It was found that delay and turn rate have a weak linear relationship to risk ratio, with the ratio decreasing as turn rate increases and increasing as delay increases.

6 Traceability to Detect-and-Avoid Standards

As this research effort is focused on low-altitude DAA standards validation there is a need to show how the results from encounters between manned aircraft can be leveraged to support DAA standards. This traceability can help guide research which in turn helps Civil Aviation Authorities and other stakeholders make decisions on the target level of safety that UAS integrating into the NAS should meet. Tracing the research to industry consensus standards also gives some applicability to the outputs of the research. This relationship-building also helps to build industry trust in regulatory decisions by the various Civil Aviation Authorities responsible for safe integration of modern technologies into existing frameworks. The UASSRF collaborated with MIT LL to develop the simulation presented in this report. The simulation leverages the encounter set established in MIT LL's recent research effort (Underhill & al., 2023). This encounter set allowed for the calculation and comparison of the RR values presented in this document.

6.1 Relevant Standards

This ASSURE A23 research effort specifically addresses the two non-cooperative RR requirements in ASTM International's F38.01 DAA Performance Standard. These requirements are safety targets for the performance of DAA systems attempting to comply with SAA rules. Embedded in these requirements is a generalized safety assessment of the DAA system's ability to Detect, Alert, and Avoid when presented with an intruding aircraft in nearby airspace. The scope of this standard is currently limited to drones with a span of less than twenty-five feet and airspeed no greater than 100 knots. This standard also does not specify the means by which the system detects the incoming aircraft. The decision is left to the applicant on which technologies to leverage to comply with the RR requirements. Acoustic, electro-optical, radar, and other means of sensing an intruder are all within the scope of the DAA Performance Standard. Given this agnosticism to sensor type, it is imperative to draw parallels between the basic DAA functions and human response if visual acquisition performance is to define the safety threshold for UAS integration. The key difference between the two lies in the GA pilot's ability to be seen, whereas sUAS generally are too small to rely on an intruder to avoid them.

6.2 Linking SAA to DAA

The intent of this research is to evaluate pilot visual acquisition performance in encounters between two manned aircraft and quantify it. The same will be done for future work for encounters between a manned aircraft and UAS. This risk can then be compared between the two to determine if the risk when a UAS is present is greater than when encountering traditional aircraft or at a minimum the same. Although a direct mapping is not intended, there are shared functions for DAA systems and pilots using SAA techniques allowing for a linkage to be made between the two. F38.01's DAA Performance Standard requires users of the standard to perform a timing analysis of their DAA system. This timeline covers from time of detection to the conclusion of an avoidance maneuver. Likewise, SAA follows a similar breakdown of events. The European Aviation Safety Agency states in a 2012 report that at an operational level, the see-and-avoid concept can be divided into four steps (Speijker, Verstraeten, Kranenburg, & van der Geest, 2012). Steps are further broken down below to discover parallels between the DAA and SAA timelines. It should be noted that the timelines for the two concepts are not the same and that in many cases a DAA system could easily outperform a human's ability to see and avoid, potentially resulting in lower risk.

1. Detection of objects in the sky

This step includes scanning, detection, and tracking of object movement. A pilot controls their eye movement to search across the forward FOV when in straight and level flight and may clear certain portions of the FOV prior to turns. If the pilot is searching and a contrasting or recognizable object falls within the small FOV of the current scan, the pilot may detect an aircraft. Finally, assuming a detection has occurred, the pilot's eyes will then home in on the features of the object and begin tracking its movement.

2. Identification of an object as an aircraft and assessing if there is a conflict

This step includes classification of object, determination of orientation, determination of relative movements, conflict determination, and resolution decision which are specific steps towards the identification and assessment of an intruder. At this point in the timeline, the pilot's eyes have adjusted and the range between the object and pilot is close enough to determine the classification of the object as an aircraft. Once the pilot classifies the target, further information gathering will help the pilot assess the orientation of the aircraft and relative movement in parallel. Closely tied to the alerting processes in DAA, a pilot may then use their experience and instinct to evaluate the risk of a closer encounter and calculate the need for a resolution.

3. Determination of evasive maneuver to execute if there is a conflict
Parallel to DAA alerting algorithms, pilots will then calculate maneuver options and finally determine which option or maneuver they will proceed with.

4. Execution of the evasive maneuver
Initialization of the selected maneuver, aircraft response and lag time are to follow. Once the pilot reaches this point in the timeline, reassessment of the potential conflict will cause the pilot to reiterate through the previous alerting and avoidance steps. The DAA timeline is broken down similarly in Figure 66. Three distinct actions are performed by an end-to-end DAA system: Detect, Alert, and Avoid. Several smaller actions occur at a rapid pace in highly automated systems. Definitions for each individual step may be found in the ASTM DAA Performance Standard Appendices.

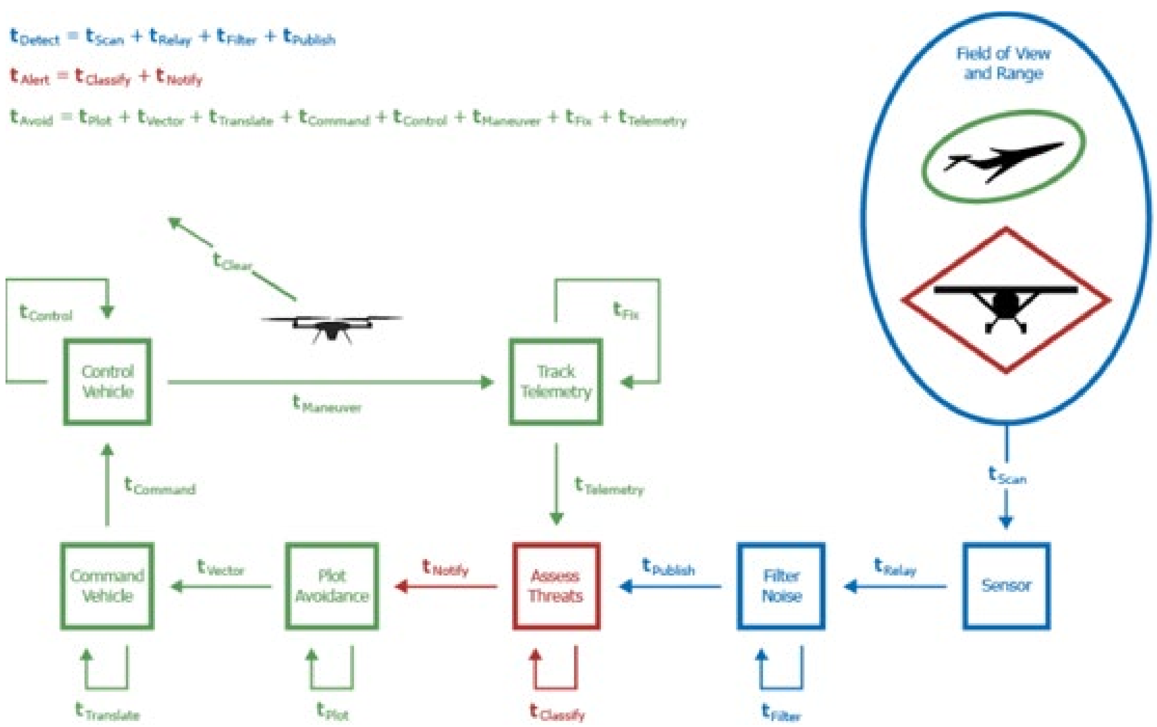

Figure 66. Timeline of Detect-and-Avoid systems (ASTM International, 2023)

Within , the three primary DAA functions are further broken down into their basic components. As a DAA system attempts to detect an intruder, the system scans its FOV, relays data between the sensor and processor(s), filters for valuable information, and then publishes results to the next DAA function. As information is passed along to the Alert function, most DAA systems try to classify the detection data. There are two types of classification: track classification where the DAA system determines whether there is an intruder or not and intruder threat classification where the system determines if there is a collision threat with said intruder. Once a threat is identified, the Avoid function is called upon to then plan a course of action. The subcomponents of the Avoid function are shown in Figure 66 in green. This timeline is an iterative process and a skeleton example of how DAA systems should operate in accordance with the DAA Performance standard. Table 11 summarizes the functions of both SAA and DAA and how they can compare to each other.

Table 12. See-and-Avoid and Detect-and-Avoid function comparison.

<table>
<tr><th></th><th>SAA</th><th>DAA</th><th></th></tr>
<tr><td rowspan="3">See</td><td>Scanning for Objects</td><td>Scan</td><td rowspan="3">Detect</td></tr>
<tr><td>Detection of Object</td><td rowspan="2">Filter Noise</td></tr>
<tr><td>Tracking of Movement</td></tr>
<tr><td rowspan="3">Alert</td><td>Classification</td><td>Classify</td><td rowspan="2">Alert</td></tr>
<tr><td>Conflict Determination</td><td>Notify</td></tr>
<tr><td>Resolution Decision</td><td>Plot Avoidance Action</td><td rowspan="4">Avoid</td></tr>
<tr><td rowspan="3">Avoid</td><td>Initialization</td><td>Command</td></tr>
<tr><td>Aircraft Response</td><td>Control</td></tr>
<tr><td>Reassessment</td><td>Track Telemetry</td></tr>
</table>

The FAA's AC 90-48E (Federal Aviation Administration, 2022) provides references to work done by the military to estimate the SAA timeline, assuming a detection has already occurred. Table 12 provides an estimate of the time needed for the pilot to react and begin collision avoidance.

Table 13. Timeline from an assumed detection of an intruder on collision course to maneuver initialization (Transportation Safety Board of Canada, 2018).

Process/Task	Response (seconds)	Cumulative (seconds)
See an object ahead	0.1	0.1
Recognize that object is an aircraft	1.0	1.1
Become aware that a collision course exists	5.0	6.1
Make a decision to turn left or right	4.0	10.1
Muscular reaction	0.4	10.5
Aircraft lag in response to flight control input	2.0	12.5
Total time before aircraft begins to move	12.5	

Video collected from the tests where pilots initially detect and increase focus on the detected object seems to substantiate the 1.1 seconds assumption for steps one and two identified in the AC. Several instances point to pilots "doubling back" on areas that were just recently searched, indicating that response time between a scanning and detection are part of two separate processes in practice. The near instantaneous revisiting of the previously scanned area suggests detection and tracking can be reasonably assumed to be within the 1.1 seconds proposed by the AC and referenced research. A pilot becoming aware of a collision course and making a maneuver decision is estimated to take nine seconds. This is a conservative assumption as pilot experience, instinct, ownship aircraft type, current airspace, and the distance at which the aircraft is detected contribute to the duration of these two steps. With a reaction time of 12.5 seconds, an aircraft cruising at 100 kts would travel 2,110 ft before the aircraft would even begin its avoidance maneuver. This time and distance could result in a violation of the WCV or potentially an NMAC or MAC in constant bearing scenarios. In observed encounters, closure rates were as high as 213 kts in head-on scenarios, and as low as 4 kts in crossing encounters. These human response delays could add up to a combined 4,500 ft loss of separation in head-on encounters where intruders were generally detected the farthest. For the much slower crossing encounters, upwards of 1,400 ft of separation could be lost after detecting the intruder aircraft. A means of measuring the capability of pilots to determine and execute safe maneuvers must be assessed to validate this timeline made by AC 90-48E (Federal Aviation Administration, 2022).

7 Conclusion and Next Steps

Pilot visual acquisition performance was measured over the course of this research effort. Factors that contributed to successful acquisition of the target aircraft were primarily the aircraft's paint contrasting with the environment, consistent scanning rate and techniques by the pilots, and encounters when the intruder was above and to the right side of the Subject Pilot's aircraft. Over the course of the flight-testing campaign there was a multitude of head on, crossing, and overtake encounters to constitute a full dataset of 298 encounters. A model was developed from the A23 dataset that added angular dependence to the search effectiveness parameter, β, drastically lowering its value from the standard 17000 to $\beta = 7438 \pm 997$. This is the result of the FOV being changed to align more realistically with what a pilot would experience in a Cessna cockpit. The A23 model was then combined with the MIT AEM to produce a broad simulation that covered a multitude of pilot response times, turn rates, and both the see and be seen as well as see and avoid maneuvers. These simulations resulted in 48 NMAC risk ratios that are tied to the specific parameters for each configuration and likewise for the loss of well clear ratios. Additional analyses, including an investigation in the adequacy of the ASTM RR values could be performed in future research to refine and add additional robustness the RR values presented in this document. The UAS industry expects to outnumber manned aircraft in the NAS by 1000:1, this estimation will need to be considered when comparing RR's to manned aviation to create a more representative assessment of the impacts that UAS will introduce when integrated in the NAS Another aspect to consider in terms of any comparisons of this research to other efforts is that this research effort used a R value of 10 nmi in modelling, and previous research used various values, industry should consider the effect that visibility has on the overall risk ratio. Industry and future research efforts should also look at the Well Clear Volume criteria. Given the risk of a drone colliding with a manned aircraft to be significantly less with DAA integrated, future efforts should consider the criteria assumed for separation distances and determine their appropriateness with regards to both regulatory and safety definitions of Right-of-Way.

7.1 Lessons Learned

As the team progressed through the flight-testing campaign, alterations were made to the flight test plan and procedures. These changes were implemented due to researcher observations or because of direct feedback from the Safety Pilots and Subject Pilots. This led to the research team relocating the initial flight paths from the south of KRNV, where the flight paths would have been located within the glide slope of the airport. Another prominent change early in the process was the introduction of a Safety Pilot briefing. Initially, the research team conducted a preflight brief with the Safety Pilot and provided the information for the intended flight path at that time. This was changed to a formal briefing to allow additional time for the Safety Pilots to provide feedback to researchers while also increasing the safety of the flights as the Safety Pilots had heightened awareness of the purpose of the research and the specific route they would be flying. This was especially beneficial for the flight paths that had a dedicated intruder and required increased responsibility of Safety Pilots. The formal safety briefing was held at the beginning of each test week at KRNV and was attended by the Safety Pilots that would be assisting with the research that week. The formal briefing included the planned flight paths to be used during the test week, general weather overview, equipment to be used, responsibilities of the researcher, research confidentiality, a general safety briefing, and any pertinent information specific to that test week. The formal briefing also provided a forum for the Safety Pilots to provide feedback to the research team on flight paths to improve encounter probability and further reduce risk. In addition to the formal briefing, there were other minor alterations throughout the research that helped improve the efficiency of the team. One of these changes was the removal of the GoPro remote used for the GoPro cameras mounted in the cockpit. The remote did not work as effectively as the team had expected, causing data collection issues, and thus it was determined that manual input for operation would be utilized going forward. Another addition that improved efficiency in the preflight process was the creation of a checklist for the presence and operationality of equipment in the cockpit of the aircraft. These alterations helped improve the overall data collection efficiency.

Encounters between a manned aircraft and a large UAS were set to be accomplished for this research, however, limiting factors meant that only three pilots were able to be tested and the test data deemed unsuitable. A Navmar Applied Science Corporation Tigershark was the intruder aircraft in these encounters, however, limitations on visual-line-of-sight flight meant the Tigershark flight plan was restricted to 2 nm of the airport during testing. This presented a significant barrier as the Subject Pilots would be made aware of the Tigershark before their flight and assume that they are looking for it. Additionally, these flights were performed at KSTF and due to the populated area to the north and east of the airfield, the operational area for the UAS was even smaller than the 2 nm radius. This meant that the encounters would all happen in the same area and would easily tip off the Subject Pilots to become more aware than they would in normal flight while also operating in terminal airspace. Slower closing speeds also meant that there was more “downtime” between encounters where the Subject Pilot would have to fly away from the airport to lose sight of it only to return to it for the next encounter setup with the UAS. Ultimately, the team noted that UAS flights would have to occur in areas where the UAS and Subject Pilots were more separated before the flight test and where the UAS could freely maneuver to set up different encounter geometries and locations with the test aircraft. In the future ASSURE project A65 Detect and Avoid Risk Ratio Validation, more emphasis is placed on testing with UAS, and flight test planning efforts will reflect this by leveraging the lessons learned in this project.

7.2 Future Work

In future work, MSU Researchers will reconcile the view-angle based detection model developed in this effort to the current range and visibility-based model, integrating the two approaches into a single unified model. In addition, researchers will integrate improved flight and maneuver models into future simulations to improve the overall simulation results. Measured delay in pilot response to detections will also be added to the simulation framework based on guidance from previous research. Future ASSURE research efforts will have more focus on encounters to include large UAS and rotorcraft. Additionally, the use of eye tracking glasses will allow researchers to quantify time spent scanning as well as scanning locations with higher precision. This addition will allow for more accurate data to be collected and used in simulations and provide regulators and researchers with a much higher quality data set for evaluating pilot visual acquisition. Additionally, the number of UAS in the airspace is expected to increase rapidly and will quickly outnumber traditional aircraft by the thousands. This vast increase will present substantial challenges to regulation efforts as the NAS would become saturated with drone traffic presenting new and more common confliction points between aircraft of all types.

8 Appendix

8.1 Subject Pilot Brief and Debrief Scripts

Prior to each flight the Human Factors Researcher would read the following briefing script to the Subject Pilot.

"Hello, my name is [state name]. I'm here to tell you about a research study that is being funded by the FAA and conducted by researchers at Mississippi State University. Ultimately, this research will be used by the FAA to create rules and policies that continue to ensure safe operations in the National Airspace System (NAS) as the presence of unmanned aircraft systems (UAS) increases. The focus is the pilot workload in the cockpit under normal flight conditions.

There will be little to no risk associated with this study, other than the normal risks associated with any flight. There will be no incentive to participate in this study, other than potentially helping you improve your overall performance as a pilot. If you choose to participate, we will not share your information with others, and there will be no penalty or loss of benefits to you should you choose not to participate or discontinue your participation.

You will be asked to fill out a short demographic questionnaire after the flight(s). During the flight, a researcher will accompany you and collect data based on observations they make regarding cockpit activity. The researcher does not intend to be any more of a distraction than any other passenger and will limit their interactions to comply with pre-flight guidance from the pilot in command (PIC). After the flight, you will be asked to fill out a perceived workload survey and a very brief survey about certain aspects of the flight and complete an informed consent document. If you are interested in participating or would like additional information, please contact Dr. Kari Babski-Reeves at [POC email address]

Upon completion of each flight and all data collection the Human Factors Researcher would have the Subject Pilot sign the informed consent form and then debrief them with the following script.

"Thank you for participating in this research. As you experienced during the flight, we planned for you to have a number of encounters, or opportunities for you to detect another aircraft and different types of aircraft. Because we didn't want to influence your scanning patterns, we did not tell you about the planned encounters. Please do not discuss your experience with the others that may participate in this study.

We may need for you and other participants to complete additional flights. Would you be willing to complete these same flight tasks on a different day? The number of encounters, the types of encounters, flight parameters such as speed, altitude, approach direction, the time of day, and weather conditions may be different."

8.2 Demographic Survey

Situation Awareness (SA) Questionnaire / Semi-Structured Interview

Participant Number: _____
Age: _____
Years of experience as a pilot: _____
Ratings held: ____
____

Military flight training? _____ Yes _____ No

Aircraft Experience:

Single-engine: _____ hours Complex: _____ hours
Multi-engine: _____ hours

How much cross-country time in the last 6 months? _____ hours
What aircraft have you had the most time in over the last 6 months (make/model?)
____

Have you flown a __________in the last 6 months? _____ Yes _____ No
Are you familiar with Foreflight? _____ Yes _____ No
Do you use it regularly to navigate while flying? _____ Yes _____ No
Do you have a current FAA medical certification? _____ Yes _____ No

Situation Awareness Questions

How familiar were you with the airplane during flight?
Not at all / slightly / moderately / heavily
How heavily did you rely upon visual landmarks to navigate?
Not at all / slightly / moderately / heavily
How much time did you spend in visual search? _____ %
Did you search in directions other than 12 o'clock?
Never / rarely / occasionally / regularly
Did you wear sunglasses? Yes/No
Was your overall flight technique normal given your experience and background level?
No / fairly / Yes
If no, please explain.

Prior to coming to the airfield, did you discuss this flight test with any previous Subject Pilot?
Yes/no
How much did unfamiliarity with the aircraft increase your workload while flying?
Not at all / slightly / significantly
During the flight, did you give more or less attention than you normally would to any of the following aspects of flight? Please give thoughtful and honest consideration to artificial factors such as your knowledge that you were in a test, presence of the Safety Pilot, it may not have been your normal aircraft, etc.:

	Somewhat less	About the same	Somewhat more
fuel management	_____	_____	_____
navigation	_____	_____	_____

visual search for traffic	_____	_____	_____
holding altitude	_____	_____	_____
holding course	_____	_____	_____
weather	_____	_____	_____

Other comments:

Think of the (first, second… nth) encounter (insert/describe type—fixed wing, rotary, UAS):

- What were the characteristics of the aircraft that made it easy/difficult?
- What were the environmental conditions that made it easy/difficult?
- What were the flight conditions that made it easy/difficult?
- Was there anything else that made detection easy/difficult?

Repeat for each encounter.

8.3 Subject Pilot Database

Selected background information on the fifty-six unique Subject Pilots was compiled in a computer database. A list of the variables and the coding/description used is provided in Table A1. The database itself is provided in Table A2 through Table A10. In addition to data collected from the pilot background questionnaire, the table contains some descriptive data collected from the situational awareness questionnaire and the NASA-TLX.

Table A 1. Variables used to describe Subject Pilots.

Variable	Description
Age	Pilot's age
Pilot (yrs.)	Years of experience as a pilot (Years)
Priv Pilot	Private Pilot Yes= 1, No=0
Comm Pilot	Commercial Pilot. Yes= 1, No=0
ATP	Airline Transport Pilot. Yes= 1, No=0
CFI	Commercial Flight Instructor I. Yes= 1, No=0
CFII	Commercial Flight Instructor II. Yes= 1, No=0
MEI	Multi-Engine Flight Instructor I. Yes= 1, No=0
Inst	Instrument rating. Yes= 1, No=0
SEL	Single-engine landing. Yes= 1, No=0
MEL	Multi-engine landing. Yes= 1, No=0
Helicopter	Helicopter. Yes= 1, No=0
Mil training	Military flight training Yes= 1, No=0
SE (hrs.)	Single-engine aircraft experience (Hours)
ME (hrs.)	Multi-engine aircraft experience (Hours)
Complex (hrs.)	Complex aircraft experience (Hours)
CX time	Cross-country time in the last six months (Hours)
6 months A.	Aircraft with most time in during last six months
Test A.	Aircraft used during study
Flown test A. 6	Flown aircraft during last six months. Yes= 1, No=0
FF fam	Familiarity with Foreflight Yes= 1, No=0
FF nav	Use of Foreflight regularly to navigate while flying Yes= 1, No=0
FAA med	Current FAA medical certification Yes= 1, No=0
Familiarity	Familiarity with airplane during flight Heavily=3, Moderately=2, Slightly=1, Not at all=0
Vis nav	Use of visual landmarks to navigate Heavily=3, Moderately=2, Slightly=1, Not at all=0
Vis search (%)	Time spent in visual search (%) Percentage of time spent in visual search

Variable	Description
Age	Pilot's age
Search X 12	Search in directions other than 12 o'clock Regularly=3, occasionally=2, Rarely=1, Never=0
Sunglasses	Wearing sunglasses Yes= 1, No=0
Norm tech	Normal overall flight technique Yes= 1, No=0
Disc test	Discussing flight test with other Subject Pilots before coming to airfield Yes= 1, No=0
Unfam vs wl	Unfamiliarity with aircraft increased workload while flying Significantly=2, Slightly=1, Not at All=0
Fuel management	Level of attention to fuel management during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
Nav	Level of attention to navigation during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
Vis. search	Level of attention to visual search for traffic during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
Hold alt	Level of attention to holding altitude during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
Hold course	Level of attention to holding course during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
Weather	Level of attention to weather during test flight vs normal flights Somewhat more=2, About the same=1, Somewhat less=0
# Encounters	Total number of encounters
# sub detect	Total subject Detections
# inst detect	Total instructor Detections
# False detect	Number of false spots
Birds	Number of birds spotted
Clutter	Clutter of birds
NTA	Non-test aircraft
Other	Other types of encounters/ detections
Mental	NASA-TLX mental demand weight
Physical	NASA-TLX physical demand weight
Temporal	NASA-TLX temporal demand weight
Performance	NASA-TLX performance weight
Effort	NASA-TLX effort weight
Frustration	NASA-TLX frustration weight
Overall	NASA-TLX overall score

Table A 2. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results.

Variable	**Subject Pilot Number**					
	1	**2**	**3**	**4**	**5**	**6**
Age	24	30	21	27	20	23
Pilot (yrs.)	1	11	6	4	2	4
Priv Pilot	1	1	1	1	1	1
Comm Pilot	0	0	1	1	0	1
ATP	0	0	0	0	0	0
CFI	0	0	1	1	0	1
CFII	0	0	1	1	0	1
MEI	0	0	0	1	0	1
Inst	0	1	1	1	1	1
SEL	1	1	1	1	1	1
MEL	0	1	1	1	0	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs.)	80	730	1600	264.3	160	660
ME (hrs.)	0	100	45	78.5	0	189
Complex (hrs.)	0	630	200	78.5	0	200
CX time	15	20	50	20	10	15
6 months A.	Grumman AA5B Tiger	Skylane 182 P	Cessna 172	Cessna 172 P	Cessna 172 R	Cessna 172 R
Test A.	Grumman Tiger	Grumman Tiger	Grumman Tiger	Cessna 172	Cessna 172	Cessna 172 P
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	0	1
FAA med	1	1	1	1	1	1
A.fam	3	3	2	3	2	3
Vis nav	1	0	1	1	1	1
Vis search (%)	50	50	90	80	60	90
Search X 12	3	3	3	3	3	3
Sunglasses	1	0	0	1	0	1
Norm tech	2	0	2	2	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	0	0	1	0	0	0
Fuel mngmt	0	1	1	1	1	1
Nav	1	1	1	1	2	2
Vis. search	2	1	2	1	1	2

Variable	Subject Pilot Number					
	1	2	3	4	5	6
Hold alt	2	1	2	2	1	1
Hold course	1	1	1	1	2	1
Weather	0	1	1	1	1	1
# Encounters	9	6	3	8	8	8
# sub detect	10	7	13	5	4	5
# inst detect	2	2	1	1	0	1
# False detect	0	0	0	0	0	0
Birds	0	0	2	0	3	1
Clutter	0	0	0	0	0	0
NTA	2	2	6	1	1	0
Other	0	0	0	0	0	0
Mental	0.33	0.27	0.20	0.27	0.33	0.20
Physical	0.20	0.13	0.20	0.00	0.00	0.07
Temporal	0.07	0.33	0.07	0.33	0.20	0.20
Performance	0.20	0.13	0.33	0.13	0.07	0.27
Effort	0.20	0.00	0.20	0.13	0.27	0.27
Frustration	0.00	0.13	0.00	0.13	0.13	0.00
Overall	48.33	24.67	23.33	19.00	9.33	45.00

Table A 3. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	7	9	10	11	12	13
Age	25	23	23	24	20	34
Pilot (yrs)	1	1	4	6	2	4
Priv Pilot	1	1	1	1	1	1
Comm Pilot	0	0	1	1	1	1
ATP	0	0	0	0	0	0
CFI	0	0	1	1	1	1
CFII	0	0	1	1	1	1
MEI	0	0	1	1	0	1
Inst	1	0	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	0	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	210	103	470	350	250	600
ME (hrs)	21	0	30	100	75	200
Complex (hrs)	25	0	30	100	75	200

Variable	Subject Pilot Number					
	7	**9**	**10**	**11**	**12**	**13**
CX time	30	8	25	30	19	40
6 months A.	Cessna 152	Cessna 172 R	Cessna 172	Cessna 172 R	Cessna 172 R	Diamond DA-42
Test A.	Cessna 172 P	Cessna 172 R	Cessna 172	Cessna 172	Cessna 172	Cessna 172
Flown test A. 6	0	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	0	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	2	3	3	3	3	3
Vis nav	0	2	2	1	1	2
Vis search (%)	45	50	75	75	45	80
Search X 12	2	2	3	3	3	2
Sunglasses	0	1	1	1	1	0
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	0	1	0	1	1	2
Nav	1	1	1	1	1	0
Vis. search	2	1	2	2	2	1
Hold alt	1	2	2	2	1	1
Hold course	1	2	1	2	1	1
Weather	0	1	0	1	0	2
# Encounters	8	8	8	8	8	8
# sub detec	4	2	7	0	12	3
# inst detec	0	3	0	4	1	3
# False detec	0	0	0	0	0	0
Birds	0	1	1	0	3	0
Clutter	0	0	0	0	0	0
NTA	4	0	0	1	2	1
Other	0	0	0	0	0	0
Mental	0.27	0.20	0.20	0.27	0.27	0.33
Physical	0.13	0.13	0.00	0.00	0.07	0.13
Temporal	0.13	0.20	0.27	0.20	0.20	0.07
Performance	0.33	0.27	0.07	0.33	0.33	0.27
Effort	0.13	0.20	0.13	0.13	0.13	0.20
Frustration	0.00	0.00	0.33	0.07	0.00	0.00
Overall	7.33	53.67	22.00	8.33	17.33	49.33

Table A 4. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	14	15	16	17	18	19
Age	29	21	23	21	20	22
Pilot (yrs)	3.5	3	4	3	2	1
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	1	1	0	1	0
ATP	0	0	0	0	0	0
CFI	1	0	1	0	1	0
CFII	1	0	1	0	1	0
MEI	1	0	1	0	1	0
Inst	1	1	1	1	1	0
SEL	1	1	1	1	1	1
MEL	1	1	1	0	1	0
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	760	100	470	120	260	70
ME (hrs)	120	100	30	0	74	0
Complex (hrs)	120	50	30	0	74	0
CX time	30	0	30	20	5	10
6 months A.	Cessna 172 R	Diamond DA-42	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172 R
Test A.	Cessna 206	Cessna 172 P	Cessna 206	Cessna 172 P	Cessna 206	Cessna 172 R
Flown test A. 6	1	0	1	0	0	1
FF fam	1	1	1	1	1	1
FF nav	1	0	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	2	3	2	3	2	3
Vis nav	1	1	2	1	2	2
Vis search (%)	75	40	80	85	60	75
Search X 12	3	2	3	3	3	3
Sunglasses	1	0	1	1	1	1
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	0	0	1
Unfam vs wl	0	0	1	1	1	0
Fuel mngmt	0	1	2	1	1	1
Nav	1	1	1	1	1	1
Vis. search	2	1	2	2	2	2
Hold alt	2	2	1	1	2	1
Hold course	2	2	1	1	1	1

Variable	Subject Pilot Number					
	14	15	16	17	18	19
Weather	1	1	0	1	0	1
# Encounters	8	8	8	8	8	8
# sub detec	5	9	8	7	6	8
# inst detec	3	2	1	1	1	0
# False detec	0	0	0	0	0	0
Birds	0	0	1	0	0	0
Clutter	0	0	0	0	0	0
NTA	1	4	3	0	1	0
Other	0	0	0	0	0	0
Mental	0.27	0.20	0.27	0.27	0.13	0.33
Physical	0.07	0.27	0.00	0.07	0.20	0.13
Temporal	0.20	0.07	0.20	0.13	0.07	0.13
Performance	0.27	0.33	0.13	0.20	0.33	0.20
Effort	0.20	0.13	0.13	0.27	0.27	0.20
Frustration	0.00	0.00	0.27	0.07	0.00	0.00
Overall	59.33	27.33	26.00	53.67	33.00	28.33

Table A 5. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	20	21	22	23	24	25
Age	21	21	22	21	25	21
Pilot (yrs)	3	5	4	3	6	3
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	1	0	1	1	1
ATP	0	0	0	0	0	0
CFI	0	0	0	0	1	0
CFII	0	0	0	0	1	0
MEI	0	0	0	1	1	0
Inst	1	1	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	1	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	166.3	147.7	125	100	400	144
ME (hrs)	66.6	43	45	100	100	63
Complex (hrs)	66.6	43	45	100	100	63
CX time	13.2	9.9	3.5	0	20	0
6 months A.	Cessna 172s, Ps and Rs	Diamond DA-42	Cessna 172 R, Diamond DA-42	Diamond DA-42	Cessna 172 R	Cessna 172 P

Variable	Subject Pilot Number					
	20	21	22	23	24	25
Test A.	Cessna 206	Cessna 172	Cessna 206	Cessna 172	Cessna 172 P	Cessna 172 P
Flown test A. 6	0	1	0	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	2	3	0	3	2	3
Vis nav	0	0	2	2	1	2
Vis search (%)	10	30	70	40	80	70
Search X 12	2	2	2	2	3	2
Sunglasses	0	1	0	0	1	0
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	1	0	1	0	0	0
Fuel mngmt	1	1	1	1	1	1
Nav	1	2	1	2	1	0
Vis. search	0	1	2	1	1	2
Hold alt	1	2	1	1	2	1
Hold course	1	2	1	1	1	2
Weather	0	1	1	0	0	1
# Encounters	8	8	8	3	3	8
# sub detec	1	0	4	4	4	5
# inst detec	3	5	4	0	0	2
# False detec	0	0	0	0	0	0
Birds	0	0	0	0	1	0
Clutter	0	0	0	0	0	0
NTA	0	0	1	1	1	0
Other	0	0	0	0	0	0
Mental	0.13	0.20	0.20	0.20	0.20	0.20
Physical	0.27	0.20	0.20	0.20	0.20	0.27
Temporal	0.07	0.07	0.00	0.13	0.27	0.07
Performance	0.33	0.27	0.33	0.13	0.20	0.13
Effort	0.20	0.27	0.13	0.33	0.13	0.33
Frustration	0.00	0.00	0.13	0.00	0.00	0.00
Overall	37.00	31.33	45.33	52.33	25.00	43.33

Table A 6. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	26	27	28	29	30	31
Age	21	37	23	23		21
Pilot (yrs)	4	2	6	6		3
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	0	1	1	1	1
ATP	0	0	0	0	0	0
CFI	1	0	1	1	1	1
CFII	1	0	1	1	1	1
MEI	1	0	1	1	1	1
Inst	1	0	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	0	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	235	153.2	256.2	256.2	300	320
ME (hrs)	73.7		76.3	78.3	200	75
Complex (hrs)	73.7	1.9	82.6	82.6	200	75
CX time	11	0	2.6	2.6	30	16
6 months A.	Cessna 172 P	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172 P, Cessna 172 R, Diamond DA-42	Cessna 172 R
Test A.	Cessna 172 P	Cessna 172 P	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172 P
Flown test A. 6	1	0	1	1	1	0
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	3	2	3	3	3	3
Vis nav	2	0	2	2	0	1
Vis search (%)	60	60	85	90	80	70
Search X 12	2	2	3	3	3	3
Sunglasses	0	0	1	1	1	1
Norm tech	2	1	2	2	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	1	1	1	1	0	1
Nav	0	2	2	2	1	2
Vis. search	2	2	1	1	1	1
Hold alt	2	2	1	1	1	1
Hold course	2	2	1	1	1	1
Weather	1	1	1	1	1	1
# Encounters	3	3	4	3	3	2

Variable	Subject Pilot Number					
	26	27	28	29	30	31
# sub detec	4	1	2	2	2	2
# inst detec	1	1	3	1	1	0
# False detec	0	0	0	0	0	0
Birds	0	0	1	0	1	0
Clutter	0	0	0	0	0	0
NTA	2	0	0	0	0	0
Other	0	0	0	0	0	0
Mental	0.27	0.27	0.33	0.27	0.13	0.27
Physical	0.27	0.27	0.27	0.20	0.27	0.13
Temporal	0.13	0.13	0.13	0.07	0.07	0.07
Performance	0.13	0.20	0.13	0.27	0.27	0.33
Effort	0.20	0.13	0.13	0.20	0.27	0.20
Frustration	0.00	0.00	0.00	0.00	0.00	0.00
Overall	43.67	68.33	73.33	71.67	18.33	27.67

Table A 7. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	32	33	34	35	36	37
Age	24	21	26	23	24	21
Pilot (yrs)	3.5	2	7	5	4	3
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	0	1	1	1	1
ATP	0	0	0	0	0	0
CFI	0	0	1	0	1	1
CFII	0	0	0	0	1	0
MEI	0	0	0	0	1	0
Inst	1	1	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	1	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	146	180	250	178.2	230	173
ME (hrs)	52	40	150	62.4	72	74
Complex (hrs)	56	40	150	62.4	72	5.6
CX time	20	10	6	2	8	0
6 months A.	Diamond DA-42	Cessna 172 R	Cessna 172 R	Cessna 172	Cessna 172	Cessna 172 P
Test A.	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172	Cessna 172 R	Cessna 172 R
Flown test A. 6	1	1	1	1	1	0
FF fam	1	1	1	1	1	1

Variable	Subject Pilot Number					
	32	33	34	35	36	37
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	3	3	3	3	3	3
Vis nav	2	1	1	2	2	1
Vis search (%)	80		30	70	70	70
Search X 12	2	2	3	3	3	2
Sunglasses	1	0	1	0	1	0
Norm tech	2	2	2	2	2	1
Disc test	0	0	0	0	0	0
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	1	1	1	1	1	0
Nav	2	2	2	1	2	0
Vis. search	2	2	1	1	2	2
Hold alt	1	2	1	1	1	1
Hold course	2	2	1	1	1	1
Weather	2	1	1	2	1	0
# Encounters	4	5	5	4	5	2
# sub detec	3	5	3	4	5	1
# inst detec	1	0	2	1	0	1
# False detec	0	0	0	0	0	0
Birds	1	0	0	1	0	2
Clutter	0	0	0	0	0	0
NTA	0	0	0	1	0	0
Other	0	0	0	0	0	0
Mental	0.13	0.27	0.07	0.27	0.13	0.27
Physical	0.07	0.00	0.33	0.20	0.33	0.07
Temporal	0.20	0.27	0.13	0.20	0.07	0.00
Performance	0.33	0.07	0.27	0.27	0.27	0.20
Effort	0.27	0.20	0.20	0.13	0.13	0.33
Frustration	0.00	0.20	0.00	0.00	0.07	0.13
Overall	37.33	15.67	31.00	36.00	70.00	41.00

Table A 8. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	38	39	40	41	42	43
Age	23	23	23	22	20	27
Pilot (yrs)	5	5	5	5	<1	4
Priv Pilot	1	1	1	1	0	1
Comm Pilot	1	1	1	1	0	1
ATP	0	0	0	0	0	0
CFI	0	1	1	1	0	1

Variable	Subject Pilot Number					
	38	**39**	**40**	**41**	**42**	**43**
CFII	0	1	1	1	0	1
MEI	0	0	1	1	0	1
Inst	1	1	1	1	0	1
SEL	1	1	1	1	0	1
MEL	1	1	1	1	0	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	170	625	404.1	650		380
ME (hrs)	65	100	87.7	110		80
Complex (hrs)	65	100	87.7	110		80
CX time	2	75	19.3	30	12	40
6 months A.	Cessna 172	Cessna 172	Cessna 152	Diamond DA-42 L360	Cessna 172 P	Cessna 172 P
Test A.	Cessna 172	Cessna 206	Cessna 172	Cessna 206	Cessna 172 P	Cessna 206
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	3	3	3	3	3	2
Vis nav	2	2	2	2	1	1
Vis search (%)	65	75	75	65	<50	75
Search X 12	3	3	3	3	3	3
Sunglasses	0	1	1	0	0	1
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	1	0	0
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	1	0	1	1	0	1
Nav	1	0	2	0	1	0
Vis. search	1	2	2	2	1	1
Hold alt	1	1	2	1	1	1
Hold course	1	1	2	1	1	1
Weather	1	1	0	1	1	1
# Encounters	1	4	3	9	2	5
# sub detec	1	4	3	4	2	5
# inst detec	0	0	0	5	0	1
# False detec	0	0	0	0	0	0
Birds	0	0	0	0	0	0
Clutter	0	0	0	0	0	0
NTA	0	0	0	0	0	1
Other	0	0	0	0	0	0

Variable	Subject Pilot Number					
	38	39	40	41	42	43
Mental	0.33	0.27	0.33	0.27	0.27	0.27
Physical	0.13	0.00	0.13	0.07	0.07	0.07
Temporal	0.00	0.27	0.00	0.00	0.20	0.27
Performance	0.20	0.07	0.27	0.20	0.33	0.27
Effort	0.27	0.27	0.20	0.13	0.13	0.13
Frustration	0.07	0.13	0.07	0.33	0.00	0.00
Overall	38.33	39.00	69.67	45.33	30.00	34.67

Table A 9. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	44	45	46	47	48	49
Age	23	27	21	23	24	22
Pilot (yrs)	1	4	4	5	3	5
Priv Pilot	1	1	1	1	1	1
Comm Pilot	0	1	0	1	0	1
ATP	0	0	0	0	0	0
CFI	0	1	0	1	0	1
CFII	0	1	0	1	0	1
MEI	0	1	0	1	0	1
Inst	1	1	1	1	1	1
SEL	1	1	1	1	1	1
MEL	0	1	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	100	380	203.7	610	185.5	600
ME (hrs)	30	80	27.4	100	45.7	180
Complex (hrs)	30	80	27.4	100	45.7	180
CX time	30	60	11.7	75	16.3	76
6 months A.	Diamond DA-42	Cessna 172 P	Cessna 172 R	Cessna 172	Diamond DA-42	Cessna 172
Test A.	Cessna 172	Cessna 206	Cessna 172 R	Cessna 206	Cessna 172	Cessna 206
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	2	2	2	2	2	3
Vis nav	1	1	2	2	1	0
Vis search (%)	70	80	70	70	60	90
Search X 12	3	3	3	3	3	2
Sunglasses	1	1	0	1	0	0

Variable	Subject Pilot Number					
	44	45	46	47	48	49
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	0	0	1
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	1	1	1	1	0	1
Nav	1	1	1	0	2	0
Vis. search	1	1	2	2	2	2
Hold alt	1	1	2	0	1	2
Hold course	1	1	1	2	1	1
Weather	1	0	1	0	0	1
# Encounters	1	5	0	1	0	8
# sub detec	1	6	6	2	9	14
# inst detec	0	1	0	0	0	0
# False detec	0	0	0	0	0	0
Birds	0	0	1	0	3	1
Clutter	0	0	2	0	0	0
NTA	0	2	3	1	1	5
Other	0	0	0	0	5	0
Mental	0.33	0.33	0.13		0.20	0.27
Physical	0.07	0.07	0.27		0.13	0.13
Temporal	0.27	0.27	0.13		0.13	0.07
Performance	0.13	0.20	0.33		0.33	0.27
Effort	0.20	0.13	0.13		0.13	0.27
Frustration	0.00	0.00	0.00		0.07	0.00
Overall	33.33	41.67	25.33		17.67	59.33

Table A 10. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	50	51	52	53	54	56
Age	25	22	23	20	20	22
Pilot (yrs)	7	5	5	<1	2	1.5
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	1	1	0	0	0
ATP	0	0	0	0	0	0
CFI	1	1	1	0	0	0
CFII	1	1	1	0	0	0
MEI	1	1	1	0	0	0
Inst	1	1	1	0	0	0
SEL	1	1	1	1	1	1
MEL	1	1	1	0	0	0
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0

Variable	Subject Pilot Number					
	50	**51**	**52**	**53**	**54**	**56**
SE (hrs)	500	420	600	52.8	63	130
ME (hrs)	150	80	150			
Complex (hrs)	150	100	150			
CX time	100	20	75	9.3	15	7
6 months A.	Cessna 172 R	Cessna 172	Cessna 172	Cessna 172 R	Cessna 172 P	Cessna 172 R
Test A.	Cessna 206	Cessna 206	Cessna 206	Cessna 172	Cessna 172 P	Cessna 172 R
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	0	1	1
FAA med	1	1	1	1	1	1
A.fam	2	1	3	1	3	3
Vis nav	2	2	2	0	2	2
Vis search (%)	80	80	75	75	40	80
Search X 12	3	3	3	2	3	3
Sunglasses	1	1	1	1	0	0
Norm tech	2	2	2	2	2	2
Disc test	1	0	0	0	0	0
Unfam vs wl	1	0	0	0	0	0
Fuel mngmt	1	1	0	1	0	1
Nav	0	0	2	1	2	2
Vis. search	1	1	2	1	1	2
Hold alt	2	2	1	1	1	2
Hold course	1	1	1	1	1	2
Weather	0	0	0	1	1	1
# Encounters	5		4	1		5
# sub detec	5		4	0		5
# inst detec	0		0	0		0
# False detec	0		0	0		0
Birds	0		0	0		0
Clutter	0		0	0		0
NTA	0		0	0		0
Other	0		0			0
Mental	0.20	0.33	0.20	0.07	0.27	0.20
Physical	0.33	0.00	0.07	0.20	0.07	0.07
Temporal	0.07	0.13	0.33	0.33	0.20	0.07
Performance	0.13	0.07	0.13	0.27	0.33	0.33
Effort	0.27	0.20	0.20	0.13	0.13	0.27
Frustration	0.00	0.27	0.07	0.00	0.00	0.07
Overall	50.00	43.33	44.00	19.00	24.00	34.67

Table A 11. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	**Subject Pilot Number**					
	57	**58**	**59**	**60**	**61**	**62**
Age	24	21	23	23	24	23
Pilot (yrs)	5	5	5	5	5	5
Priv Pilot	1	1	1	1	1	1
Comm Pilot	1	1	1	1	1	1
ATP	0	0	0	0	0	0
CFI	1	1	1	1	1	1
CFII	1	1	1	1	1	1
MEI	1	1	1	1	1	1
Inst	1	1	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	1	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	725	480	498.5	738	727	499
ME (hrs)	175	70	114.1	213	175	91.4
Complex (hrs)	175	70	91.4	213	175	114
CX time	67	16	34.1	85	67	21
6 months A.	Cessna 172 R	Cessna 172	Cessna 152/172	Cessna 172 R	Cessna 172	Cessna 152/172
Test A.	Cessna 206	Cessna 206		Cessna 206	Cessna 206	Cessna 206
Flown test A. 6	1	1		1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	3	2	2	3	3	2
Vis nav	2	1	0	0	2	0
Vis search (%)	80	65	40	60	75	50
Search X 12	3	2	3	2	2	3
Sunglasses	1	0	1	0	1	1
Norm tech	2	2	2	1	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	0	1	0	0	0	0
Fuel mngmt	0	0	1	0	0	0
Nav	1	1	2	1	1	2
Vis. search	2	1	1	2	2	1
Hold alt	1	1	2	1	2	2
Hold course	1	2	2	2	1	2
Weather	0	0	0	0	0	0

Variable	Subject Pilot Number					
	57	58	59	60	61	62
# Encounters	8	8	8	8	8	
# sub detec	4	4	5	4	8	
# inst detec	0	0	0	0	0	
# False detec	0	0	0	0	0	
Birds	0	2	0	1	0	
Clutter	0	0	0	0	0	
NTA	0	0	1	0	0	
Other	0	0	0	0	0	
Mental	0.07	0.07	0.07	0.20	0.33	0.27
Physical	0.07	0.33	0.13	0.33	0.00	0.27
Temporal	0.33	0.20	0.20	0.07	0.27	0.07
Performance	0.07	0.13	0.33	0.13	0.13	0.13
Effort	0.20	0.27	0.27	0.27	0.07	0.27
Frustration	0.27	0.00	0.00	0.00	0.20	0.00
Overall	29.00	66.67	64.33	74.67	44.33	65.00

Table A 12. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	63	64	65	66	67	68
Age	18	20	22	21	22	21
Pilot (yrs)	1.5	1	3	3	2	4
Priv Pilot	1	1	1	1	1	1
Comm Pilot	0	0	0	1	1	1
ATP	0	0	0	0	0	0
CFI	0	0	0	0	0	1
CFII	0	0	0	0	0	0
MEI	0	0	0	0	0	1
Inst	0	0	1	1	1	1
SEL	1	1	1	1	1	1
MEL	0	0	0	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	90	90	143	230	349	120
ME (hrs)			21	30	80	75
Complex (hrs)				30	93	75
CX time	0	11.5	1.6	20	91.6	0
6 months A.	Cessna 172 R	Cessna 172 R	Cessna 172	Cessna 172 R	Cessna 152	Diamond DA-42-L360
Test A.		Cessna 172	Cessa 172	Cessna 172 R	Cessna 172	Cessna 172

Variable	Subject Pilot Number					
	63	64	65	66	67	68
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	0	1
FAA med	1	1	1	1	1	1
A.fam	3	3	3	3	3	3
Vis nav	1	1	2	2	1	1
Vis search (%)	30	60	70	50	60	80
Search X 12	0	2	3	3	3	3
Sunglasses	1	0	0	1	1	1
Norm tech	2	2	2	2	2	2
Disc test	0	0	0	0	0	0
Unfam vs wl	0	0	0	0	0	0
Fuel mngmt	1	0	1	1	0	0
Nav	1	1	2	0	1	2
Vis. search	2	1	2	2	1	2
Hold alt	2	2	1	1	1	1
Hold course	2	2	1	1	0	1
Weather	1	0	1	0	0	0
# Encounters	1	2	9		8	7
# sub detec	0	1	6		7	5
# inst detec	0	0	1		0	0
# False detec	0	0	0		0	0
Birds	0	0	0		3	0
Clutter	0	0	0		0	0
NTA	0	0	0		0	0
Other	0	0	0		0	0
Mental	0.13	0.20	0.20	0.33	0.13	0.33
Physical	0.33	0.00	0.20	0.20	0.07	0.27
Temporal	0.07	0.07	0.07	0.20	0.13	0.13
Performance	0.20	0.27	0.27	0.00	0.33	0.13
Effort	0.27	0.33	0.27	0.20	0.20	0.13
Frustration	0.00	0.13	0.00	0.20	0.13	0.00
Overall	23.00	51.67	44.00	37.00	35.00	45.33

Table A 13. Subject Pilot characteristics, SA questionnaire, and NASA-TLX results, continued.

Variable	Subject Pilot Number					
	69	70	71	72	73	74
Age	22	20	22	22	21	22
Pilot (yrs)	3	1	3	4	4	4
Priv Pilot	1	1	1	1	1	1
Comm Pilot	0	0	1	1	1	1

Variable	Subject Pilot Number					
	69	**70**	**71**	**72**	**73**	**74**
ATP	0	0	0	0	0	0
CFI	0	0	0	1	0	0
CFII	0	0	0	1	0	0
MEI	0	0	0	0	0	0
Inst	1	0	1	1	1	1
SEL	1	1	1	1	1	1
MEL	1	0	1	1	1	1
Helicopter	0	0	0	0	0	0
Mil training	0	0	0	0	0	0
SE (hrs)	147	90	260	402.9	250	240
ME (hrs)	21		50	75.6	30	40
Complex (hrs)	6		50	75.6	40	40
CX time	8	11	10	40.1	10	3.5
6 months A.	Cessna 172	Cessna 172	Cessna 172 P	Cessna 172 P	Cessna 172 R	Cessna 172 R
Test A.	Cessna 172	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172 R	Cessna 172 R
Flown test A. 6	1	1	1	1	1	1
FF fam	1	1	1	1	1	1
FF nav	1	1	1	1	1	1
FAA med	1	1	1	1	1	1
A.fam	3	3	3	2	3	1
Vis nav	2	1	2	1	2	2
Vis search (%)	80	60	55	70	80	80
Search X 12	3	2	3	3	2	3
Sunglasses	1	0	0	0	0	0
Norm tech	2	2	2	1	2	2
Disc test	0	1	0	0	0	0
Unfam vs wl	0	1	0	0	0	1
Fuel mngmt	1	0	1	1	1	0
Nav	2	1	2	1	1	1
Vis. search	2	2	2	2	2	2
Hold alt	1	2	1	1	2	1
Hold course	1	2	1	1	2	1
Weather	1	1	0	1	0	1
# Encounters	9	7				
# sub detec	6	3				
# inst detec	2	0				
# False detec	0	0				
Birds	0	0				
Clutter	0	0				

Variable	Subject Pilot Number					
	69	70	71	72	73	74
NTA	0	0				
Other	0	0				
Mental	0.20	0.27	0.33	0.33	0.20	0.33
Physical	0.00	0.07	0.00	0.20	0.27	0.07
Temporal	0.07	0.07	0.20	0.07	0.00	0.13
Performance	0.33	0.20	0.13	0.13	0.13	0.20
Effort	0.20	0.27	0.07	0.27	0.33	0.27
Frustration	0.20	0.13	0.27	0.00	0.07	0.00
Overall	28.00	69.33	47.33	25.33	57.67	26.33

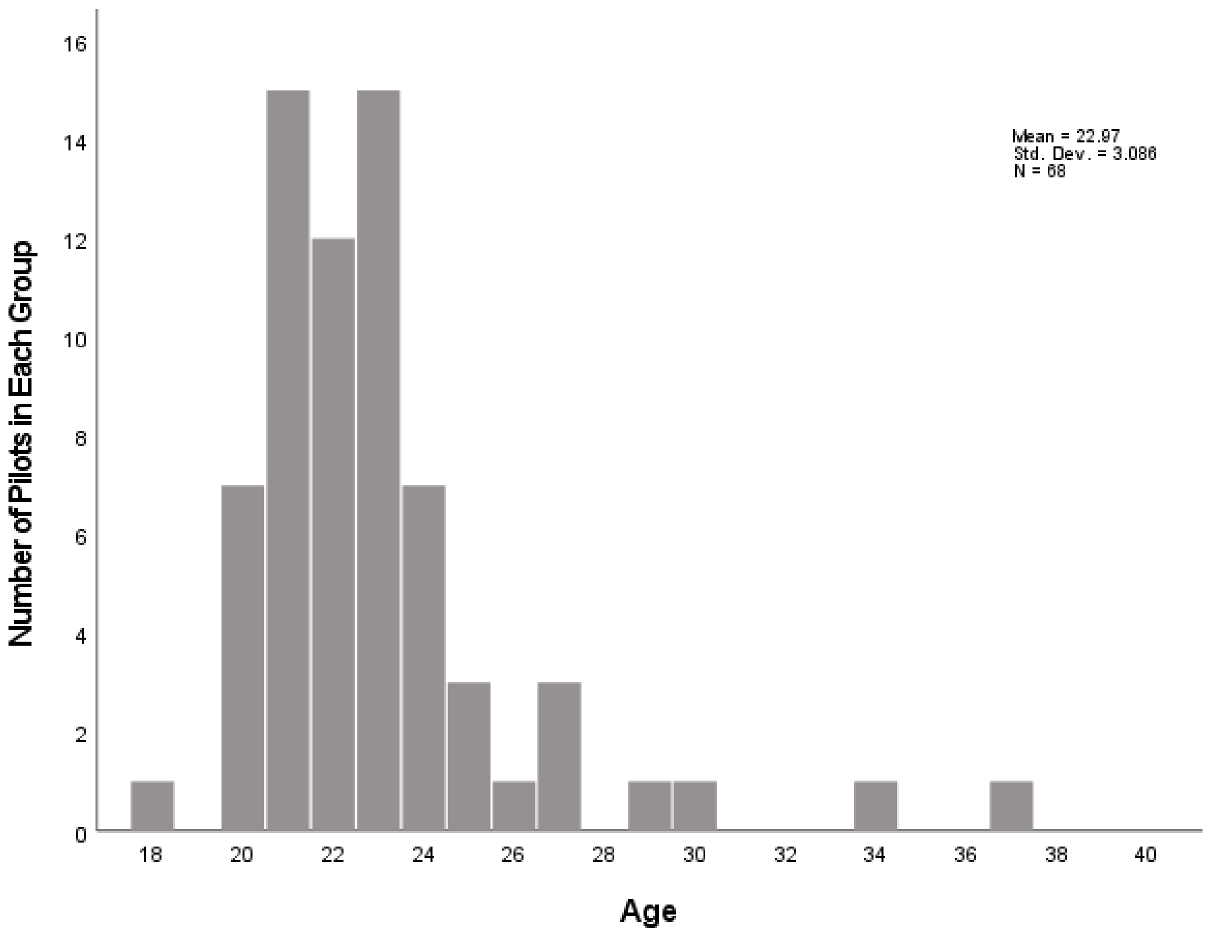

Figure A 1. Age demographics of Subject Pilots.

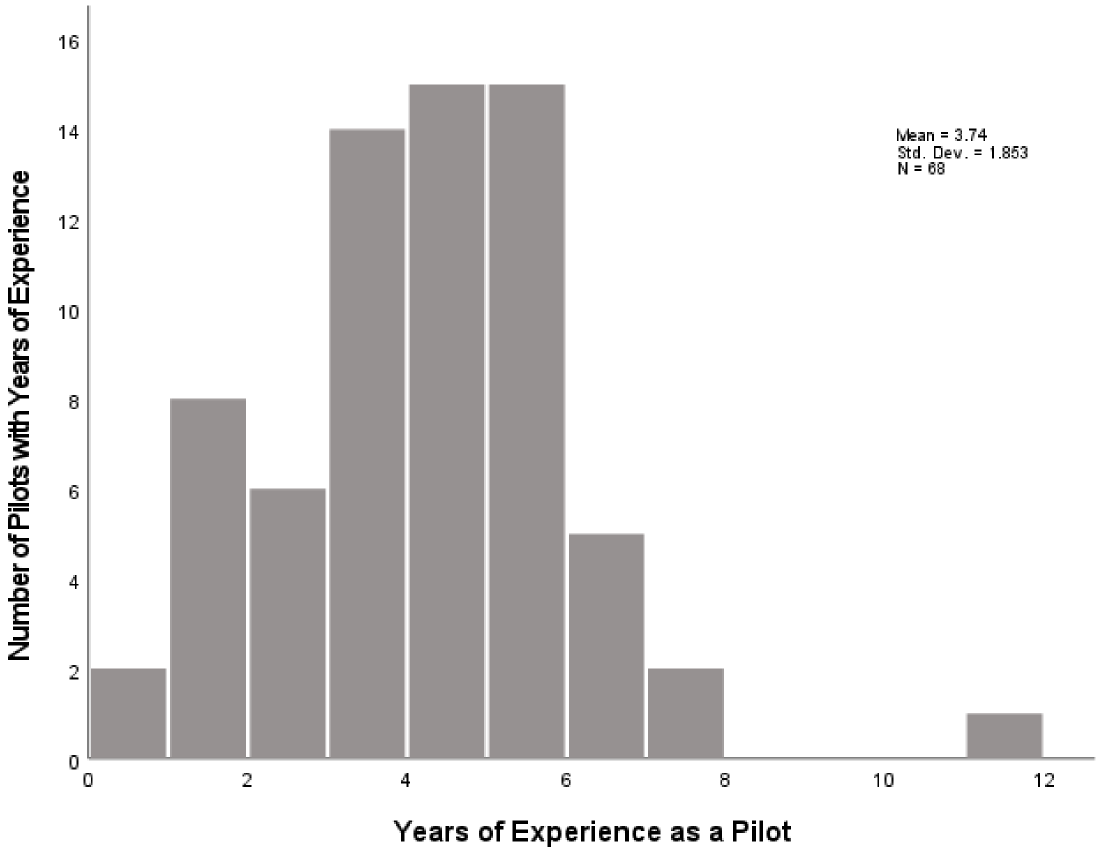

Figure A 2. Years of experience of Subject Pilots.

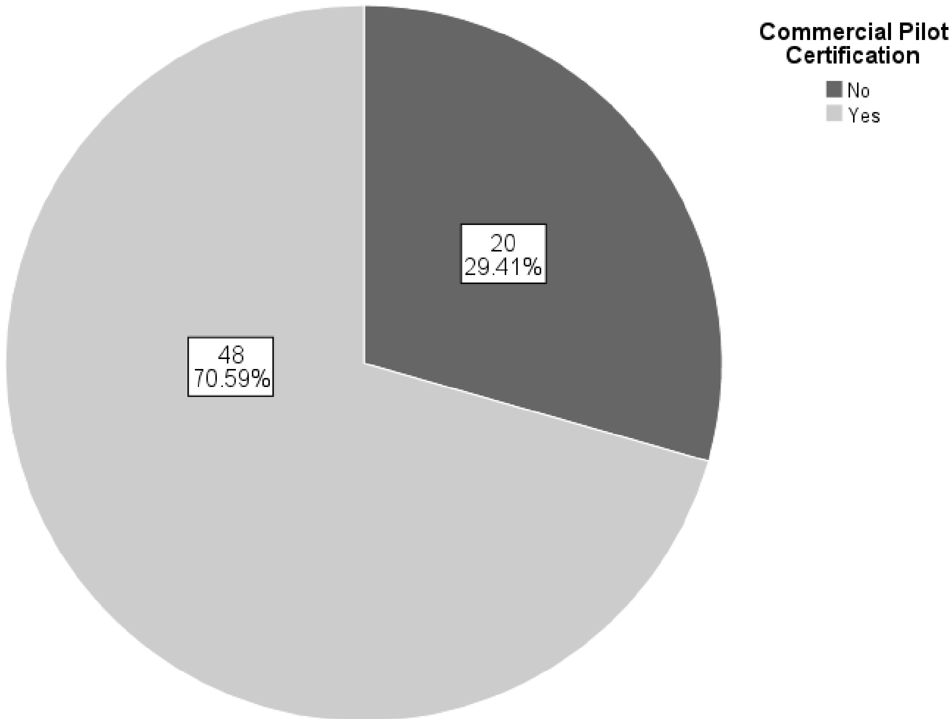

Figure A 3. Percentage of Subject Pilots with commercial pilot certification.

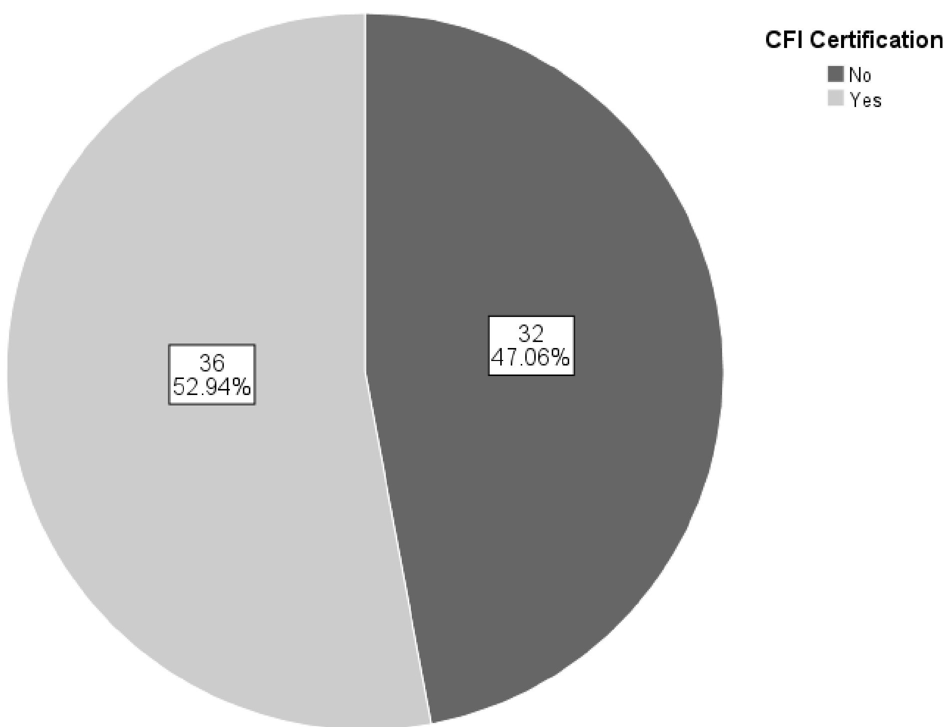

Figure A 4. Percentage of Subject Pilots with CFI certification.

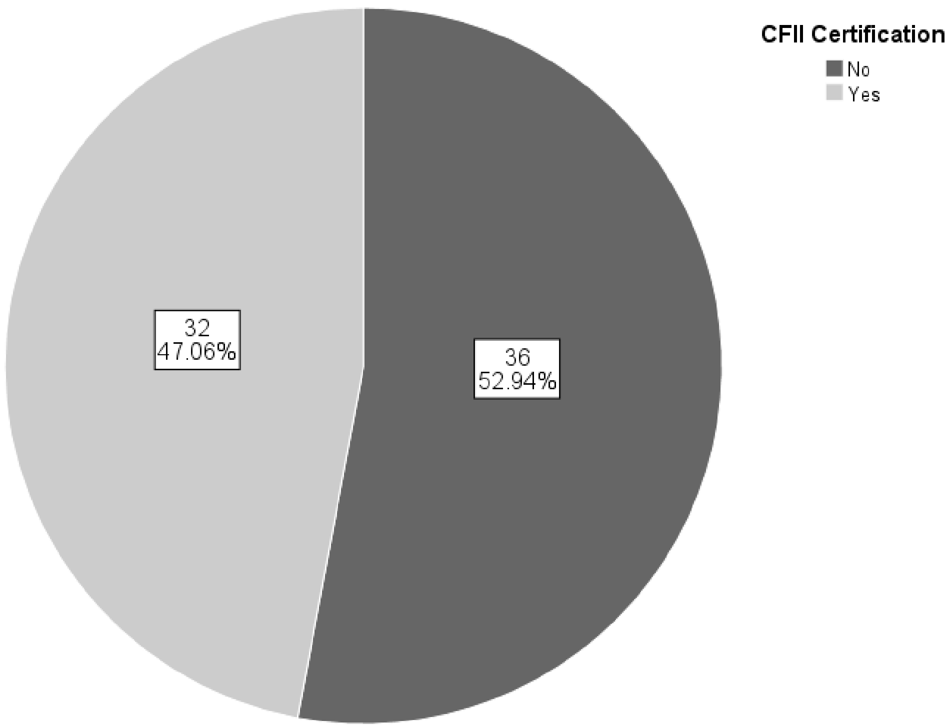

Figure A 5. Percentage of Subject Pilots with CFII certification.

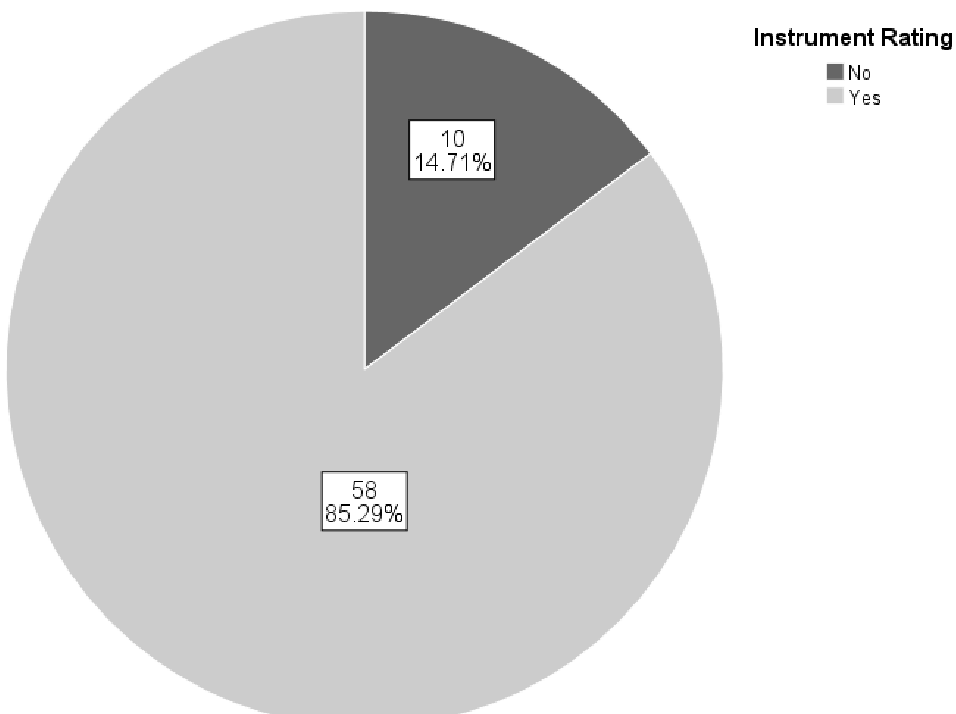

Figure A 6. Percentage of Subject Pilots with instrument rating.

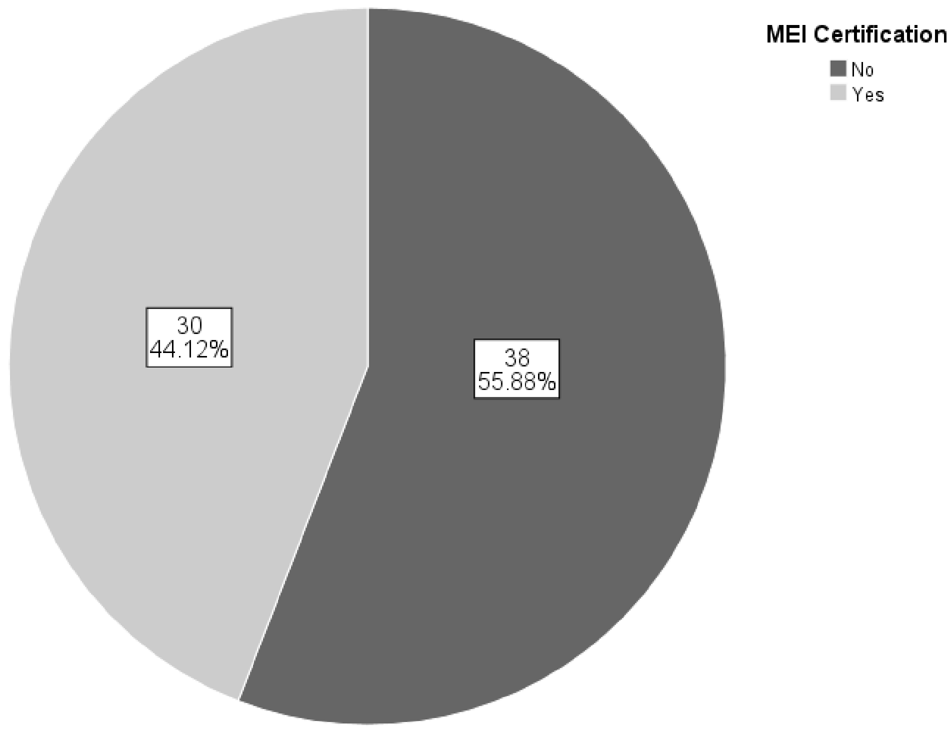

Figure A 7. Percentage of Subject Pilots with MEI certification.

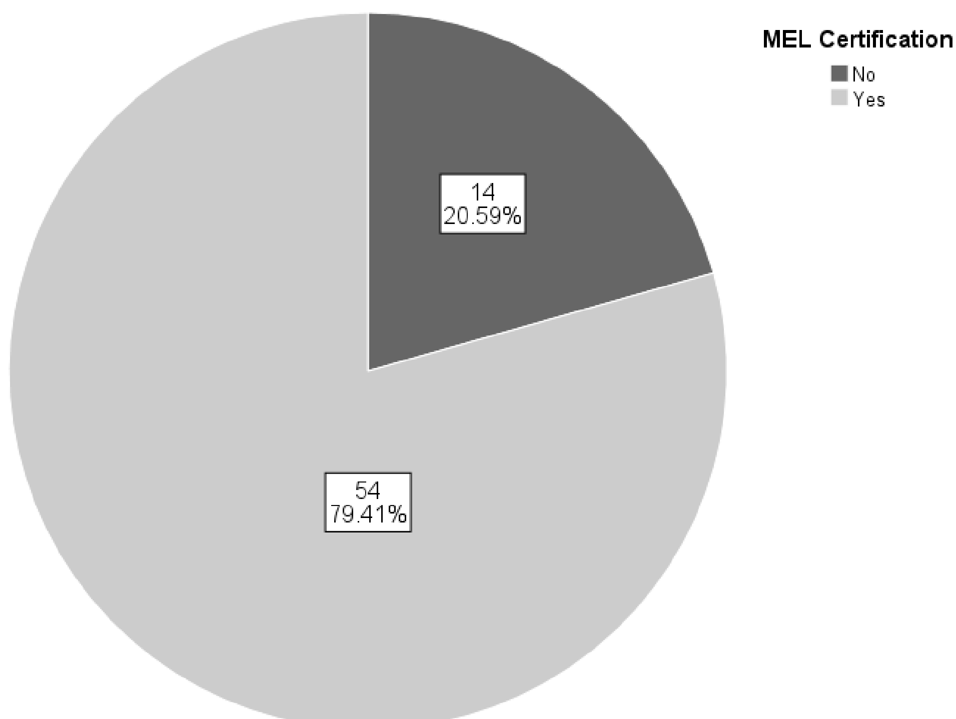

Figure A 8. Percentage of Subject Pilots with MEL rating.

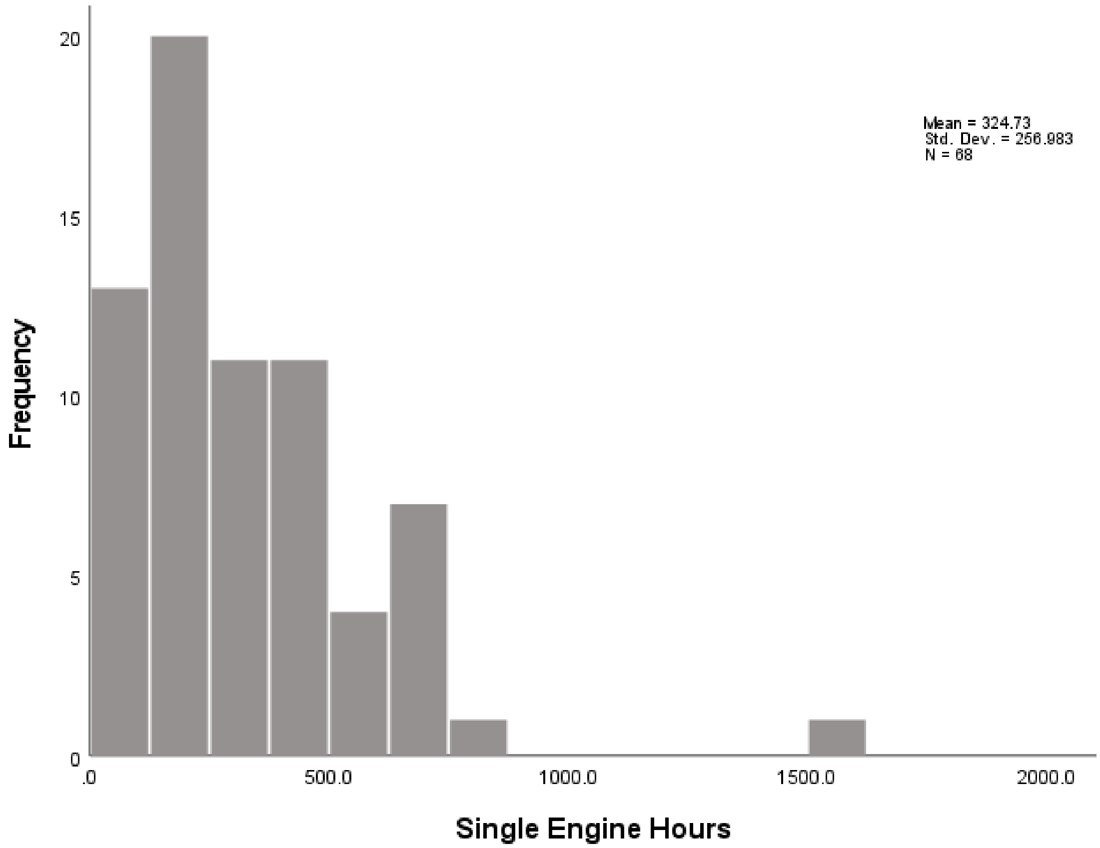

Figure A 9. Subject Pilot's single engine experience.

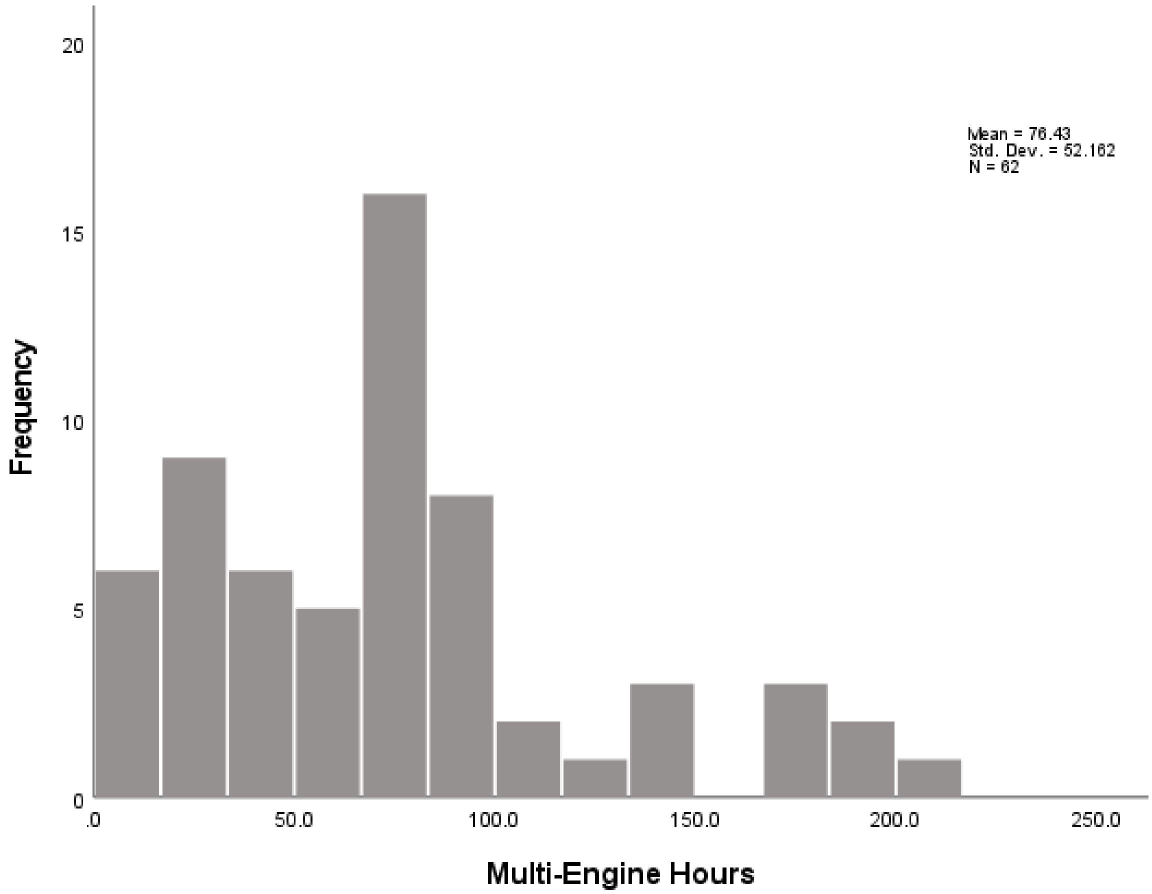

Figure A 10. Subject Pilot's multi engine experience.

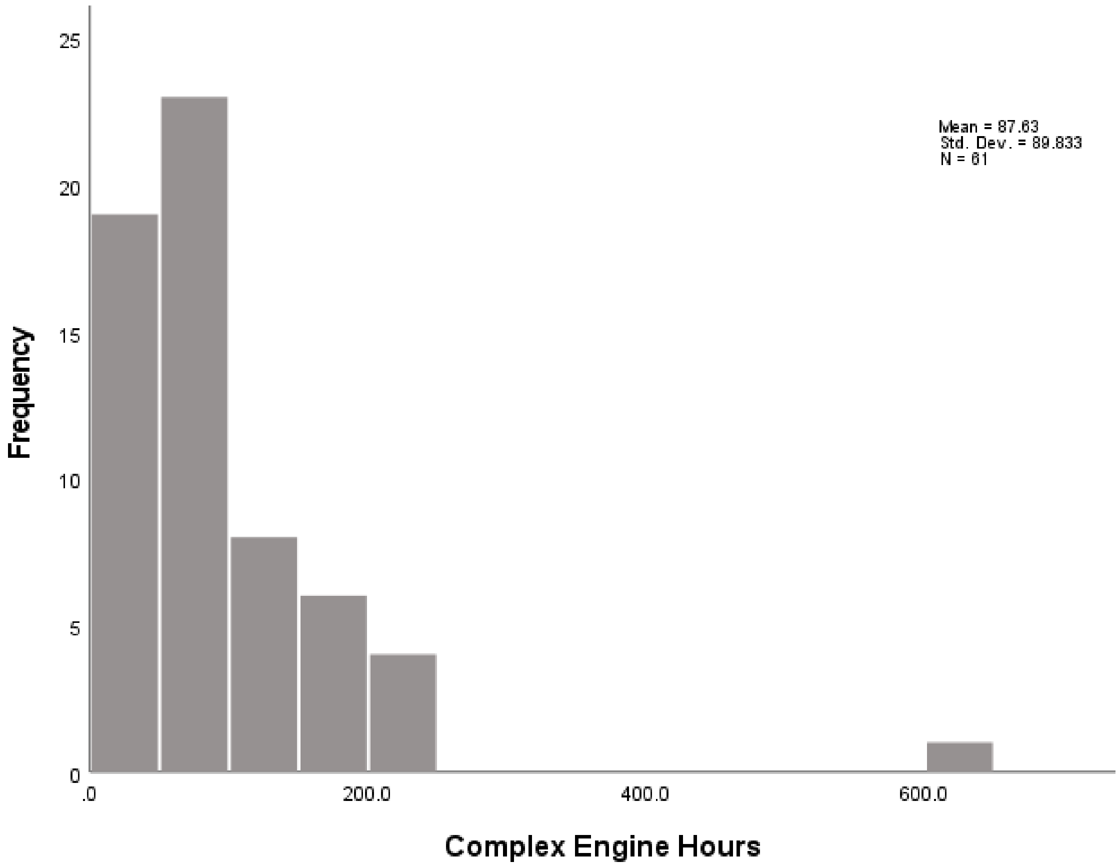

Figure A 11. Subject Pilot's complex engine experience.

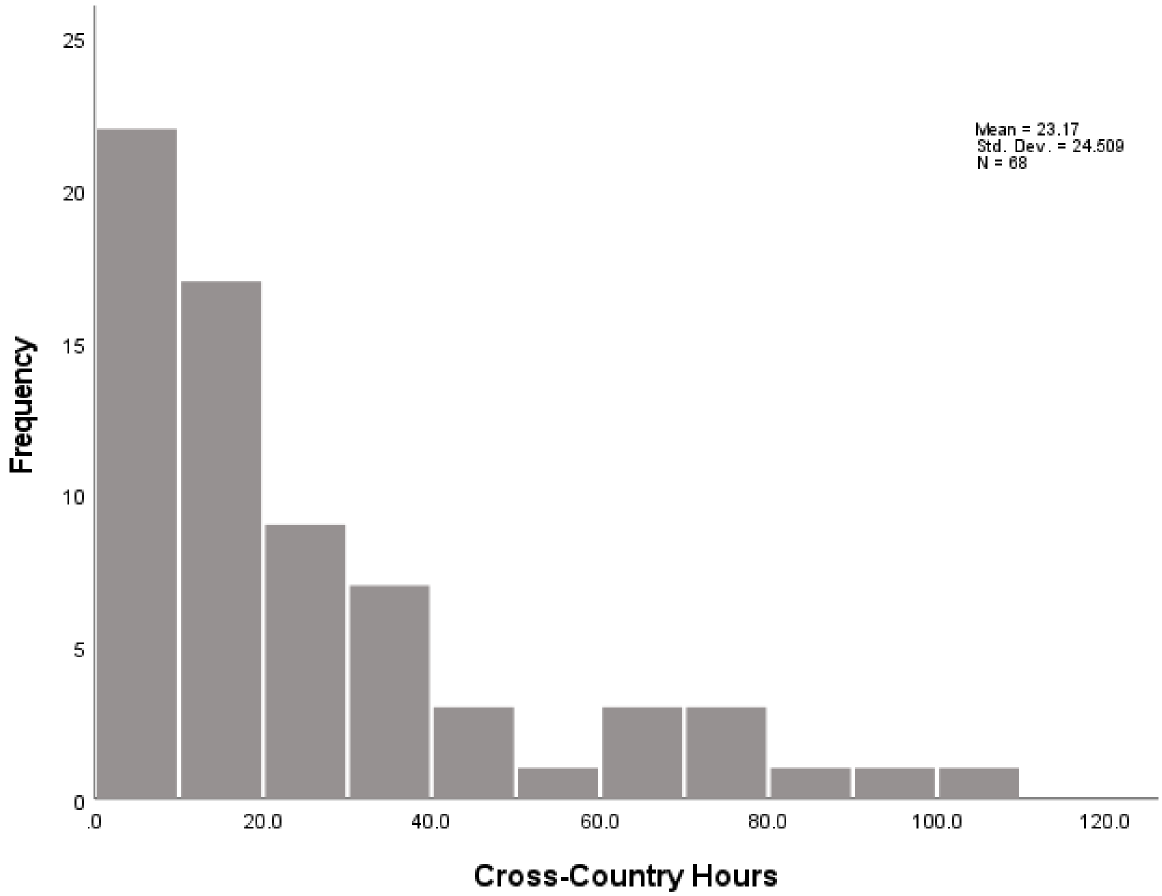

Figure A 12. Subject Pilot's cross-country hours in the prior six months.

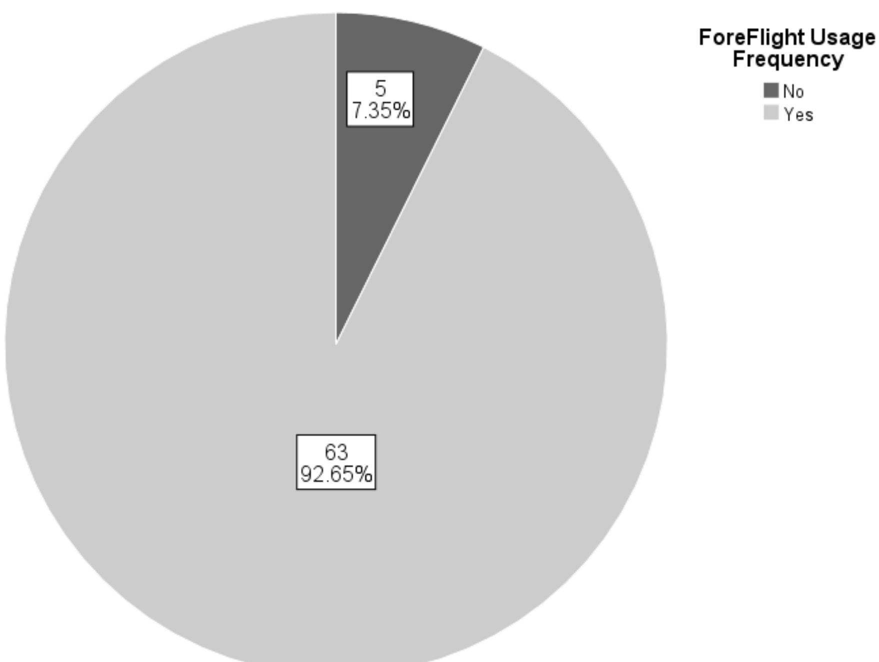

Figure A 13. Frequency of ForeFlight usage by Subject Pilots.

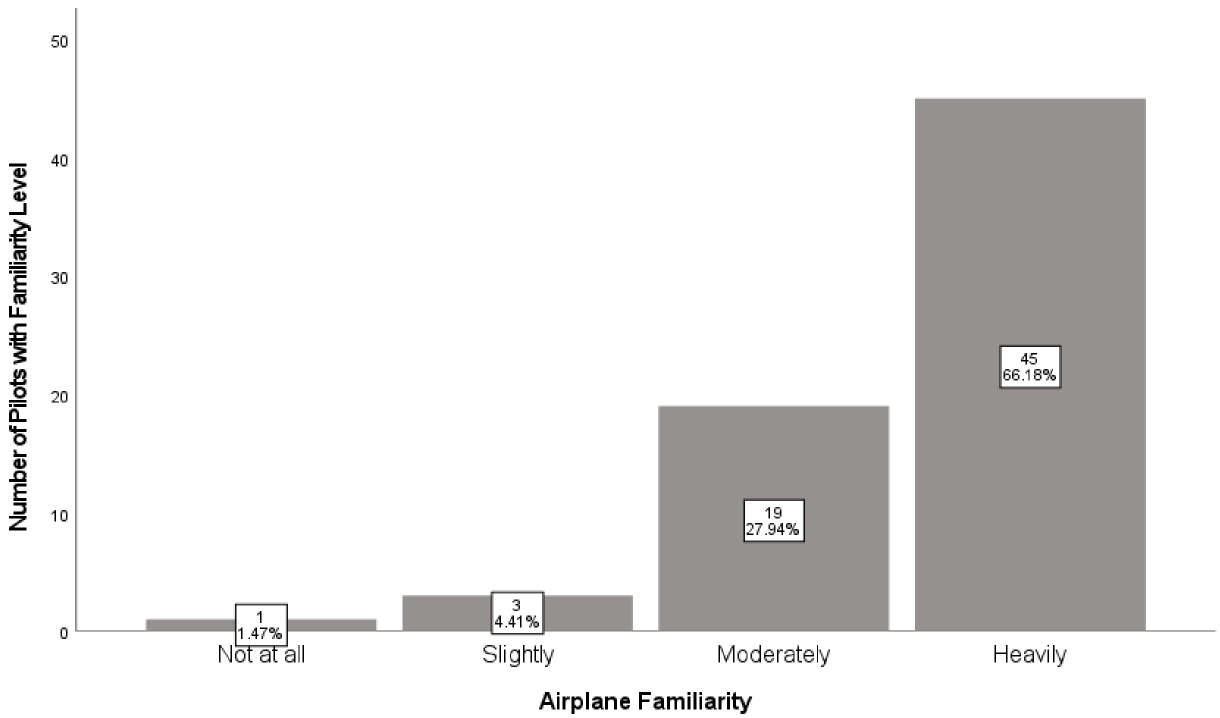

Figure A 14. Subject Pilot's level of familiarity with test aircraft.

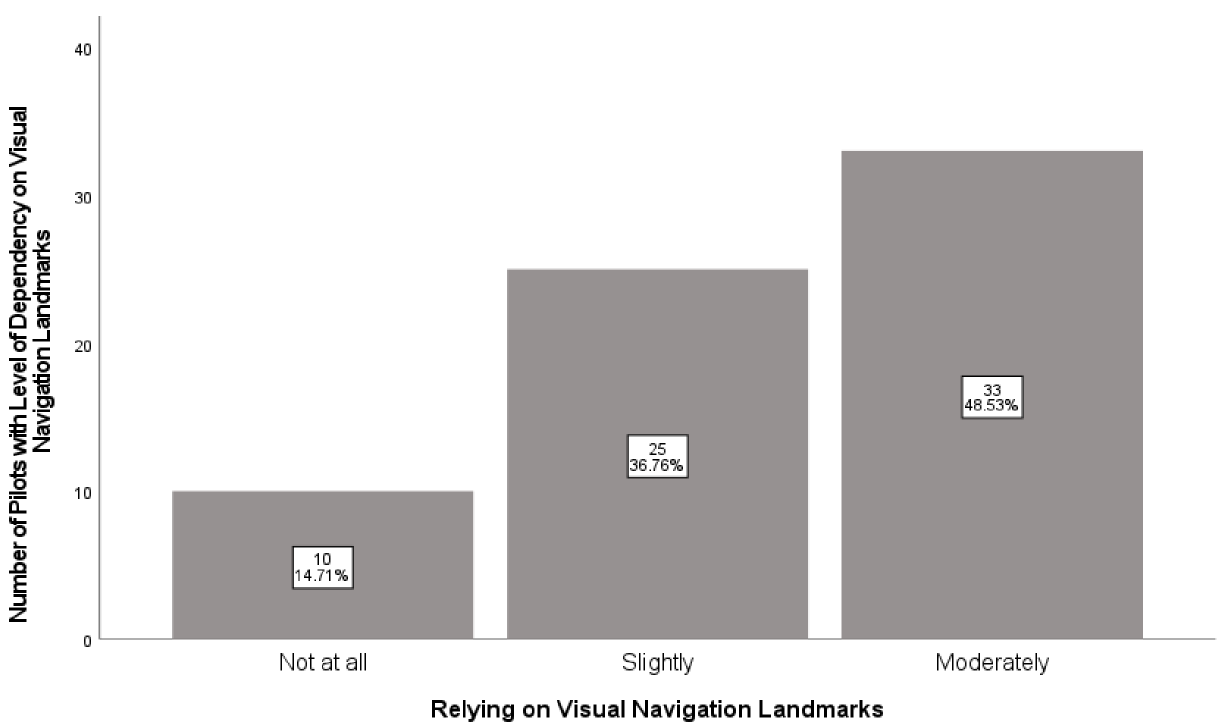

Figure A 15. Subject Pilot's level of reliability on visual landmarks for navigation.

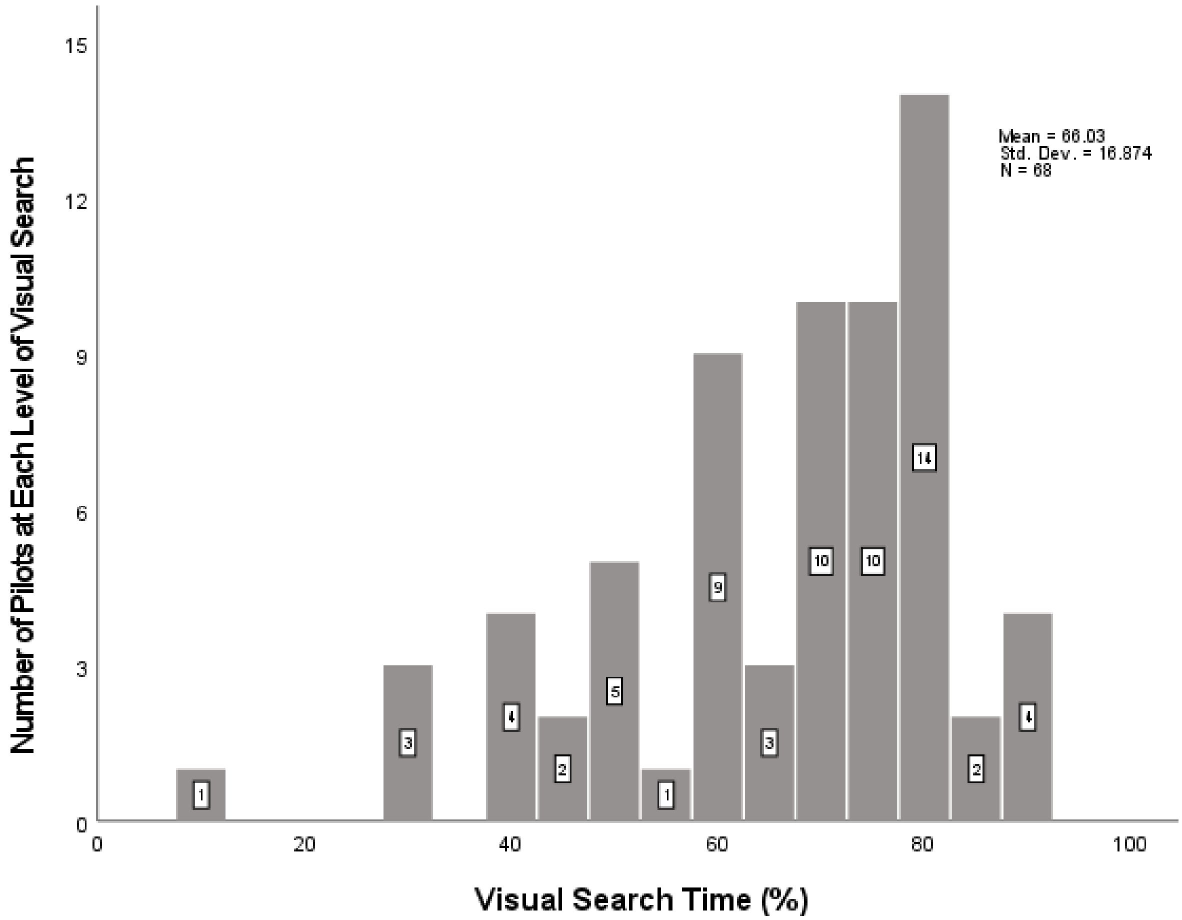

Figure A 16. Amount of time Subject Pilots estimated they spent in visual search.

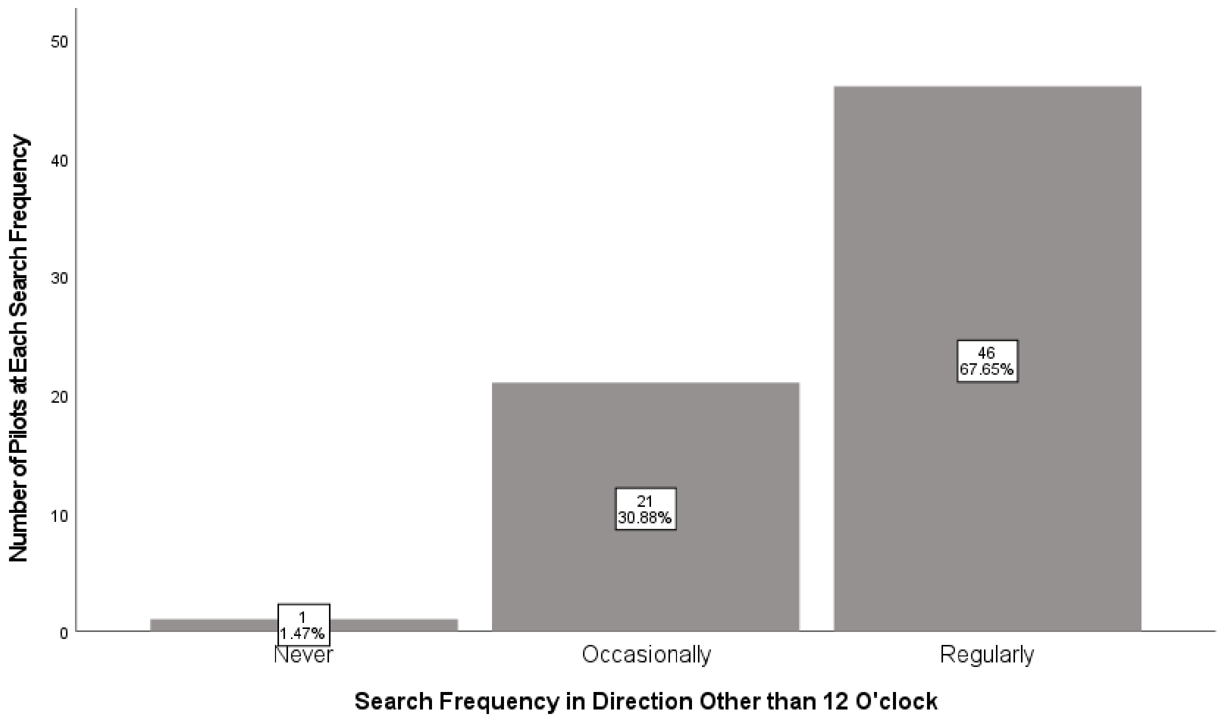

Figure A 17. Subject Pilot's frequency of traffic scanning in a direction other than 12 o'clock.

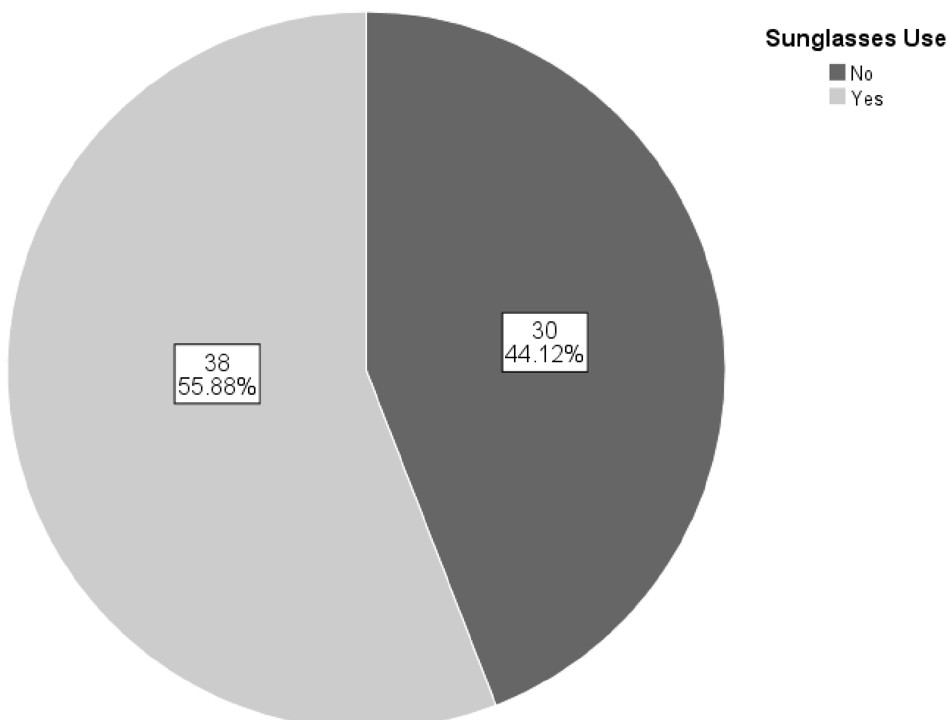

Figure A 18. Number of Subject Pilots that used sunglasses during flight.

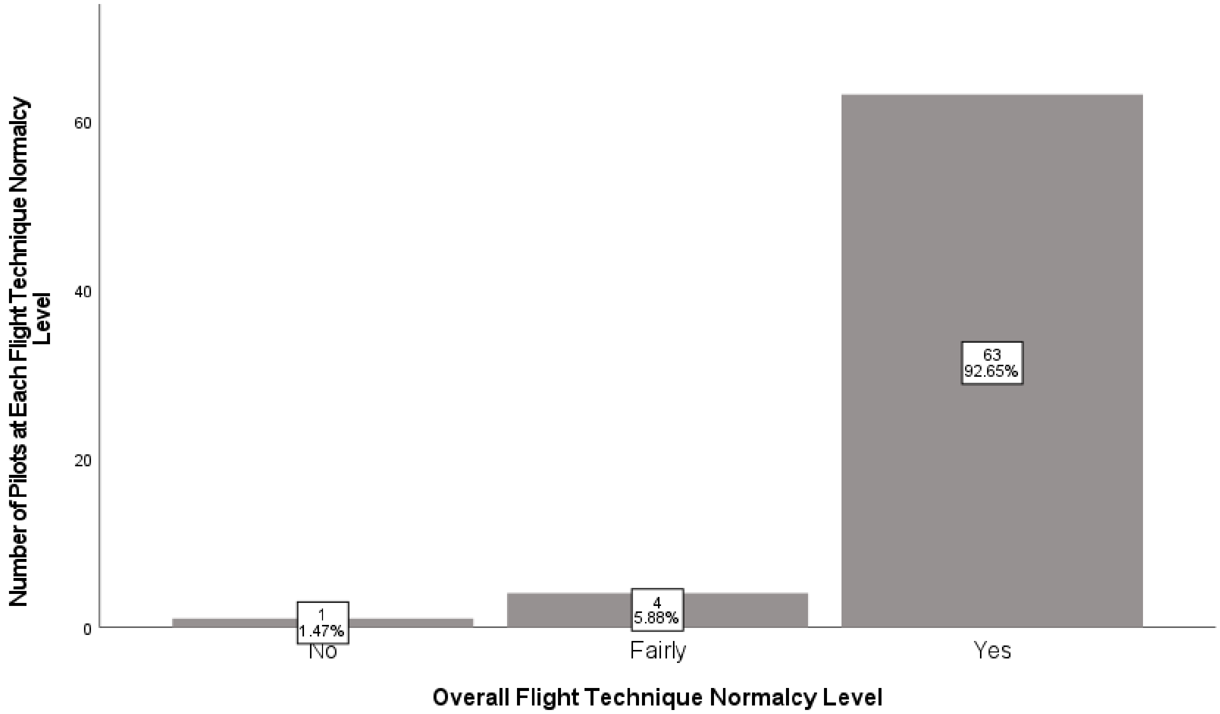

Figure A 19. Subject Pilot's normalcy level of overall flight technique.

Figure A 20. Subject Pilot's unfamiliarity level with aircraft vs workload during flight.

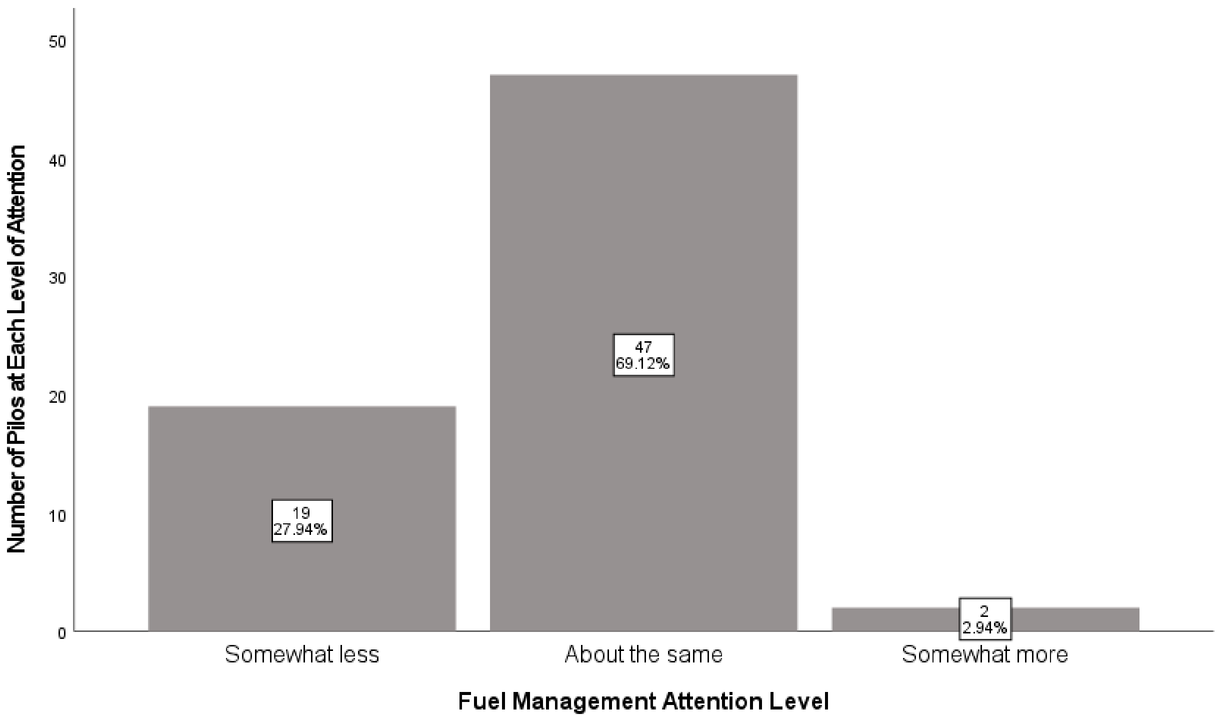

Figure A 21. Subject Pilot's fuel management attention level compared to a normal flight.

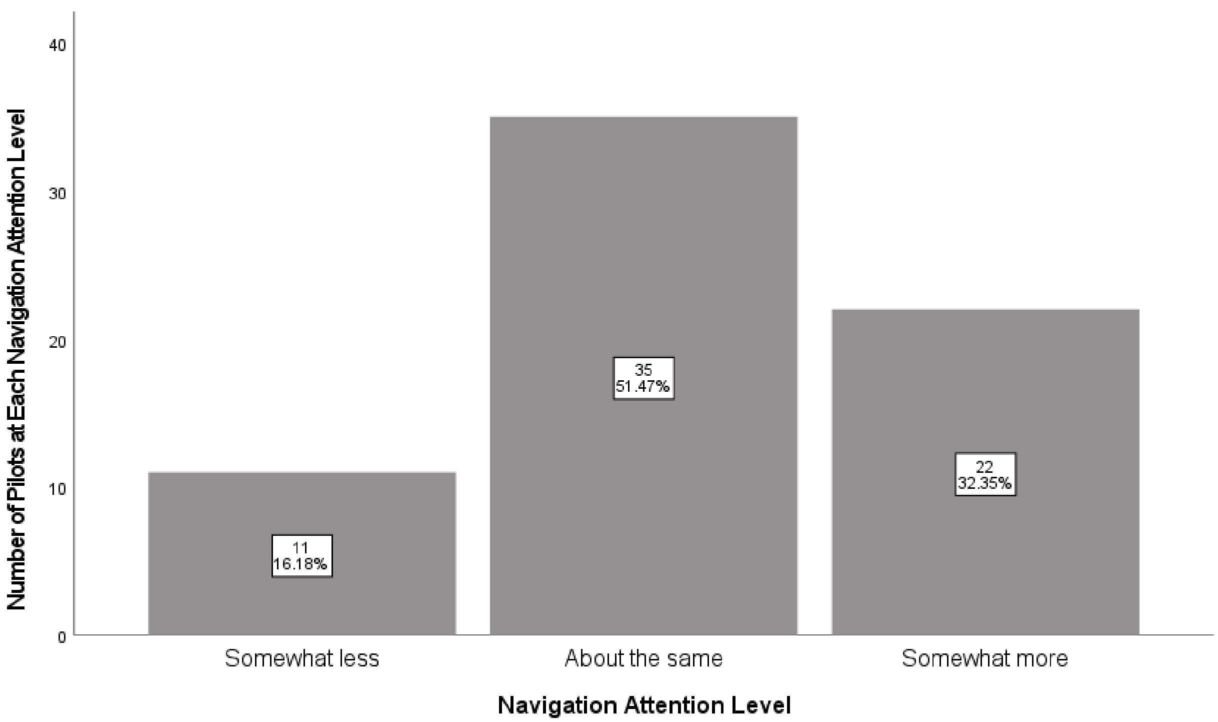

Figure A 22. Subject Pilot's navigation attention level compared to a normal flight.

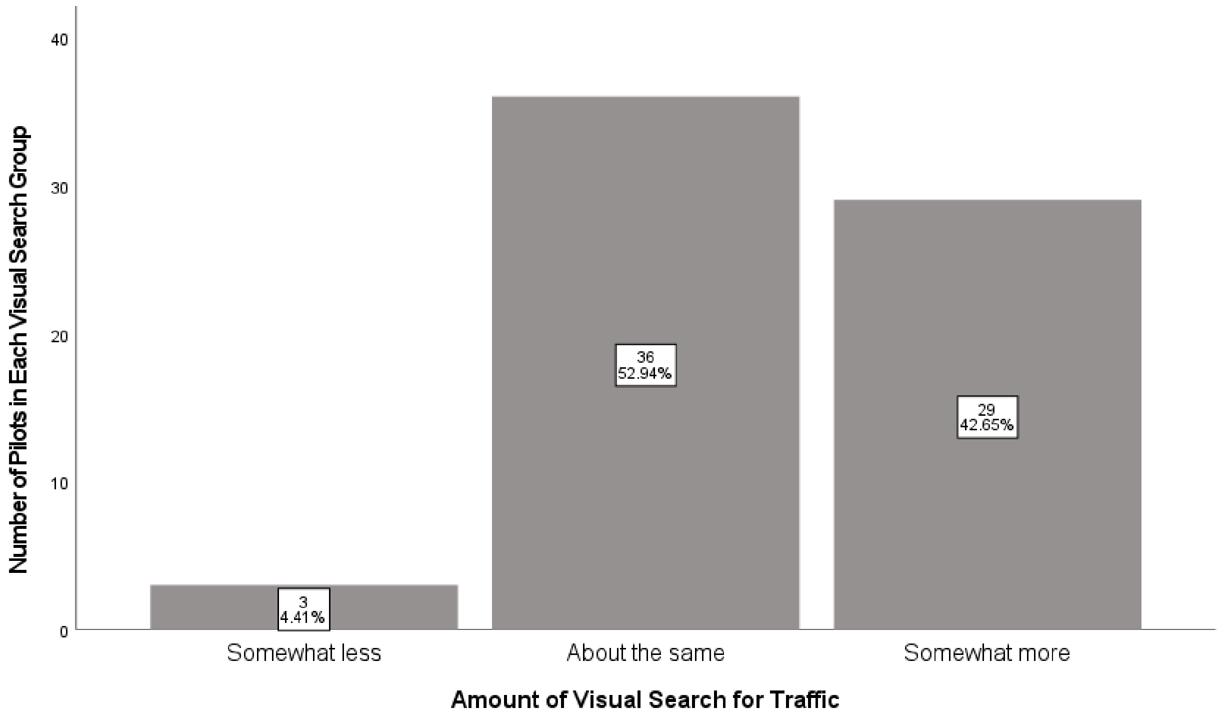

Figure A 23. Subject Pilot's visual search for traffic compared to a normal flight.

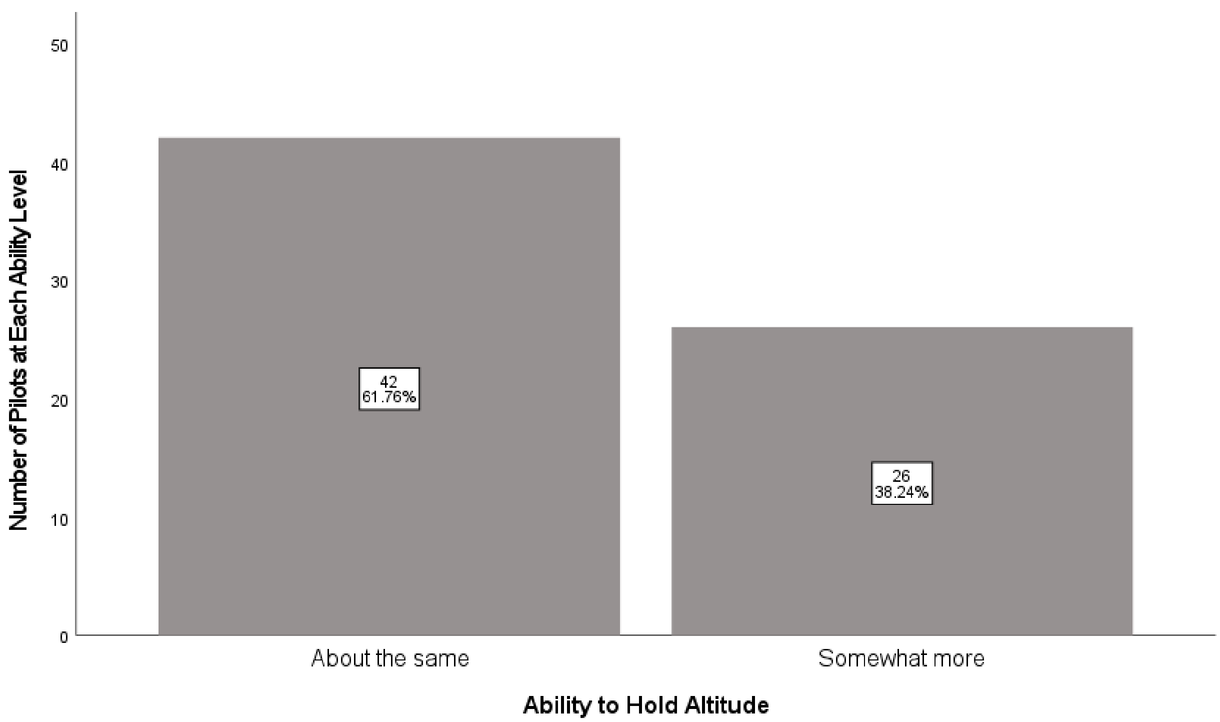

Figure A 24. Subject Pilot's ability to maintain altitude compared to a normal flight.

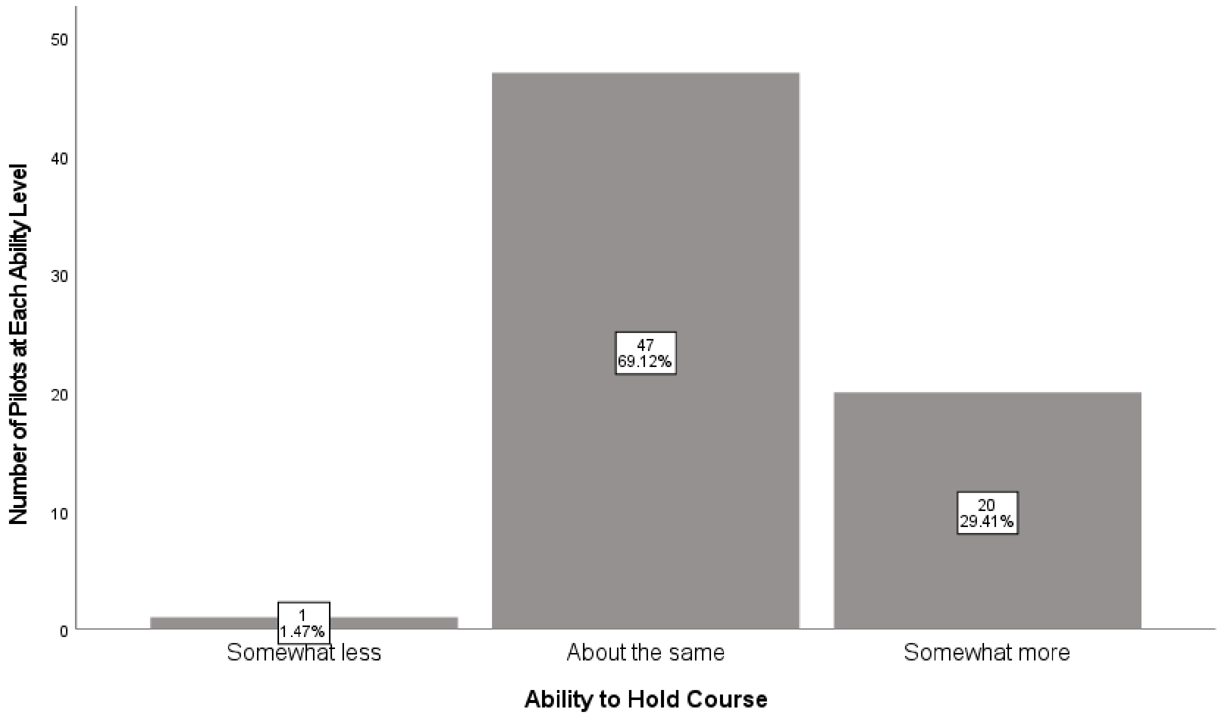

Figure A 25. Subject Pilot's ability to maintain course compared to a normal flight.

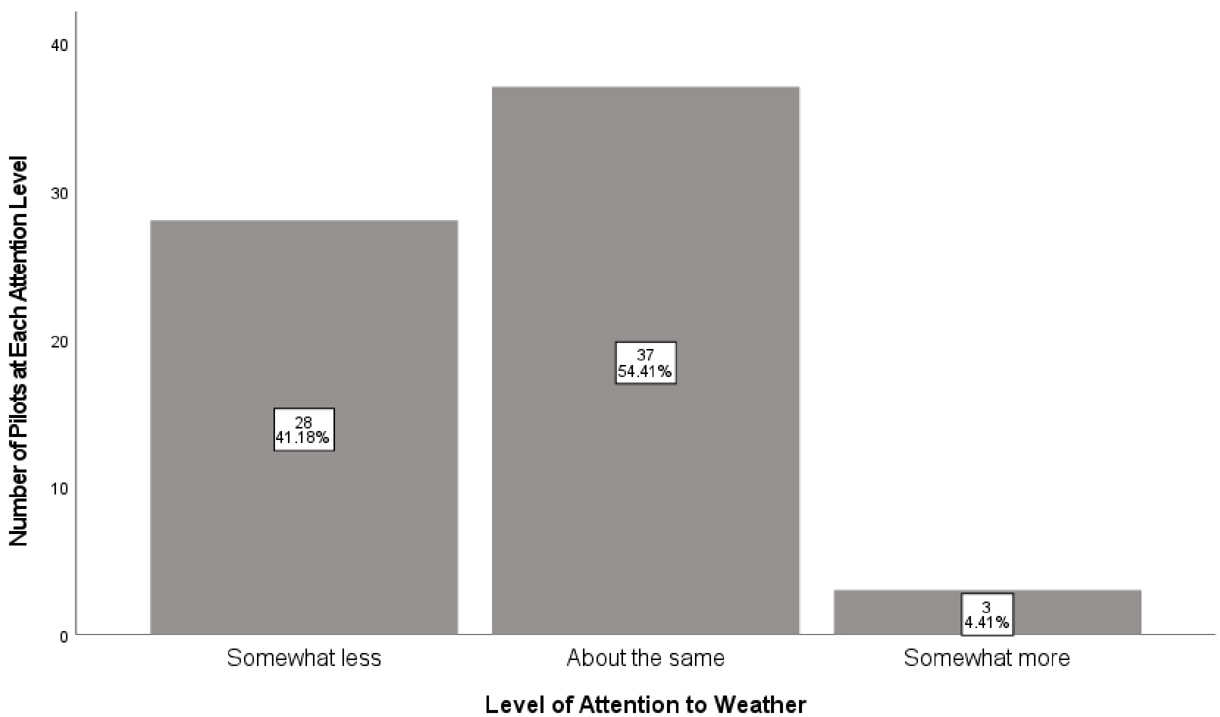

Figure A 26. Subject Pilot's attention level to weather compared to a normal flight.

8.4 TLX Responses

Table A 14. NASA-TLX Subject Pilot responses.

Participant number	Mental demand rating	Mental demand tally	Mental demand weight	Physical demand rating	Physical demand tally	Physical demand weight	Temporal demand rating	Temporal demand tally	Temporal demand weight	Performance rating	Performance tally	Performance weight	Effort rating	Effort tally	Effort weight	Frustration rating	Frustration tally	Frustration weight	Overall
1	45	5	0.333	20	3	0.2	20	1	0.067	70	3	0.200	70	3	0.200	25	0	0.000	48.333
2	35	4	0.267	30	2	0.133	30	5	0.333	5	2	0.133	30	0	0.000	5	2	0.133	24.667
3	65	3	0.200	15	3	0.2	10	1	0.067	5	5	0.333	25	3	0.200	5	0	0.000	23.333
4	35	4	0.267	55	0	0	15	5	0.333	10	2	0.133	20	2	0.133	5	2	0.133	19.000
5	10	5	0.333	5	0	0	10	3	0.200	10	1	0.067	10	4	0.267	5	2	0.133	9.333
6	25	3	0.200	20	1	0.067	20	3	0.200	75	4	0.267	55	4	0.267	10	0	0.000	45.000
7	5	4	0.267	5	2	0.133	5	2	0.133	10	5	0.333	10	2	0.133	5	0	0.000	7.333
8	35	2	0.133	25	3	0.2	20	3	0.200	15	3	0.200	15	3	0.200	5	1	0.067	20.000
9	80	3	0.200	40	2	0.133	50	3	0.200	35	4	0.267	65	3	0.200	35	0	0.000	53.667
10	30	3	0.200	35	0	0	20	4	0.267	20	1	0.067	20	2	0.133	20	5	0.333	22.000
11	5	4	0.267	5	0	0	5	3	0.200	15	5	0.333	5	2	0.133	5	1	0.067	8.333
12	25	4	0.267	5	1	0.067	5	3	0.200	20	5	0.333	20	2	0.133	10	0	0.000	17.333
13	75	5	0.333	70	2	0.133	15	1	0.067	15	4	0.267	50	3	0.200	5	0	0.000	49.333
14	75	4	0.267	60	1	0.067	45	3	0.200	50	4	0.267	65	3	0.200	55	0	0.000	59.333
15	25	3	0.200	20	4	0.267	20	1	0.067	35	5	0.333	30	2	0.133	30	0	0.000	27.333
16	25	4	0.267	35	0	0	30	3	0.200	35	2	0.133	35	2	0.133	15	4	0.267	26.000
17	30	4	0.267	25	1	0.067	15	2	0.133	80	3	0.200	95	4	0.267	10	1	0.067	53.667
18	35	2	0.133	25	3	0.200	5	1	0.067	45	5	0.333	30	4	0.267	5	0	0.000	33.000
19	20	5	0.333	15	2	0.133	20	2	0.133	60	3	0.200	25	3	0.200	10	0	0.000	28.333
20	45	2	0.133	30	4	0.267	30	1	0.067	30	5	0.333	55	3	0.200	30	0	0.000	37.000
21	25	3	0.200	20	3	0.200	15	1	0.067	10	4	0.267	70	4	0.267	5	0	0.000	31.333
22	35	3	0.200	35	3	0.200	5	0	0.000	70	5	0.333	55	2	0.133	5	2	0.133	45.333
23	40	3	0.200	55	3	0.200	30	2	0.133	70	2	0.133	60	5	0.333	15	0	0.000	52.333
24	25	3	0.200	30	3	0.200	5	4	0.267	30	3	0.200	50	2	0.133	5	0	0.000	25.000
25	45	3	0.200	45	4	0.267	25	1	0.067	55	2	0.133	40	5	0.333	15	0	0.000	43.333
26	55	4	0.267	35	4	0.267	15	2	0.133	80	2	0.133	35	3	0.200	30	0	0.000	43.667
27	75	4	0.267	85	4	0.267	45	2	0.133	65	3	0.200	50	2	0.133	15	0	0.000	68.333
28	100	5	0.333	75	4	0.267	45	2	0.133	15	2	0.133	90	2	0.133	45	0	0.000	73.333
29	75	4	0.267	75	3	0.200	55	1	0.067	75	4	0.267	65	3	0.200	30	0	0.000	71.667
30	35	2	0.133	5	4	0.267	5	1	0.067	20	4	0.267	25	4	0.267	5	0	0.000	18.333
31	25	4	0.267	5	2	0.133	5	1	0.067	45	5	0.333	25	3	0.200	5	0	0.000	27.667
32	40	2	0.133	35	1	0.067	40	3	0.200	25	5	0.333	50	4	0.267	20	0	0.000	37.333
33	15	4	0.267	10	0	0	10	4	0.267	45	1	0.067	10	3	0.200	20	3	0.200	15.667
34	45	1	0.067	35	5	0.333	20	2	0.133	25	4	0.267	35	3	0.200	20	0	0.000	31.000
35	50	4	0.267	40	3	0.200	30	2	0.200	25	4	0.267	30	2	0.133	20	0	0.000	36.000
36	70	2	0.133	90	5	0.333	25	1	0.067	80	4	0.267	55	2	0.133	5	1	0.067	70.000
37	30	4	0.267	20	1	0.067	20	0	0.000	60	3	0.200	45	5	0.333	35	2	0.133	41.000
38	50	5	0.333	45	2	0.133	25	0	0.000	15	3	0.200	45	4	0.267	10	1	0.067	38.333
39	55	4	0.267	10	0	0.000	25	4	0.267	25	1	0.067	45	4	0.267	30	2	0.133	39.000

Participant number	Mental demand rating	Mental demand tally	Mental demand weight	Physical demand rating	Physical demand tally	Physical demand weight	Temporal demand rating	Temporal demand tally	Temporal demand weight	Performance rating	Performance tally	Performance weight	Effort rating	Effort tally	Effort weight	Frustration rating	Frustration tally	Frustration weight	Overall
40	90	5	0.333	60	2	0.133	30	0	0.000	65	4	0.267	70	3	0.200	5	1	0.067	69.667
41	70	4	0.267	30	1	0.067	35	0	0.000	50	3	0.200	60	2	0.133	20	5	0.333	45.333
42	40	4	0.267	30	1	0.067	20	3	0.200	20	5	0.333	50	2	0.133	5	0	0.000	30.000
43	35	4	0.267	60	1	0.067	5	4	0.267	50	4	0.267	50	2	0.133	15	0	0.000	34.667
44	65	5	0.333	20	1	0.067	15	4	0.267	10	2	0.133	25	3	0.200	5	0	0.000	33.333
45	50	5	0.333	20	1	0.067	45	4	0.267	25	3	0.200	50	2	0.133	15	0	0.000	41.667
46	30	2	0.133	40	4	0.267	15	2	0.133	20	5	0.333	15	2	0.133	15	0	0.000	25.333
47	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
48	25	3	0.200	15	2	0.133	15	2	0.133	15	5	0.333	25	2	0.133	5	1	0.067	17.667
49	65	4	0.267	30	2	0.133	30	1	0.067	80	4	0.267	55	4	0.267	30	0	0.000	59.333
50	5	3	0.200	80	5	0.333	5	1	0.067	55	2	0.133	55	4	0.267	5	0	0.000	50.000
51	55	5	0.333	25	0	0.000	55	2	0.133	20	1	0.067	55	3	0.200	20	4	0.267	43.333
52	55	3	0.200	40	1	0.067	30	5	0.333	40	2	0.133	65	3	0.200	30	1	0.067	44.000
53	25	1	0.067	25	3	0.200	15	5	0.333	10	4	0.267	35	2	0.133	30	0	0.000	19.000
54	20	4	0.267	5	1	0.067	20	3	0.200	15	5	0.333	70	2	0.133	15	0	0.000	24.000
55	60	4	0.267	20	2	0.133	15	3	0.200	10	5	0.333	40	1	0.067	10	0	0.000	27.667
56	55	3	0.200	25	1	0.067	30	1	0.067	35	5	0.333	30	4	0.267	5	1	0.067	34.667
57	30	1	0.067	45	1	0.067	30	5	0.333	25	1	0.067	35	3	0.200	20	4	0.267	29.000
58	45	1	0.067	80	5	0.333	45	3	0.200	80	2	0.133	65	4	0.267	25	0	0.000	66.667
59	75	1	0.067	90	2	0.133	35	3	0.200	65	5	0.333	70	4	0.267	25	0	0.000	64.333
60	75	3	0.200	80	5	0.333	55	1	0.067	80	2	0.133	70	4	0.267	25	0	0.000	74.667
61	65	5	0.333	75	0	0.000	35	4	0.267	20	2	0.133	70	1	0.067	30	3	0.200	44.333
62	80	4	0.267	80	4	0.267	25	1	0.067	25	2	0.133	65	4	0.267	50	0	0.000	65.000
63	25	2	0.133	25	5	0.333	10	1	0.067	20	3	0.200	25	4	0.267	10	0	0.000	23.000
64	24	3	0.200	35	0	0.000	20	1	0.067	15	4	0.267	90	5	0.333	55	2	0.133	51.667
65	65	3	0.200	50	3	0.200	35	1	0.067	15	4	0.267	55	4	0.267	60	0	0.000	44.000
66	55	5	0.333	25	3	0.200	25	3	0.200	25	0	0.000	35	3	0.200	15	3	0.200	37.000
67	40	2	0.133	40	1	0.067	10	2	0.133	45	5	0.333	40	3	0.200	20	2	0.133	35.000
68	60	5	0.333	45	4	0.267	45	2	0.133	20	2	0.133	35	2	0.133	25	0	0.000	45.333
69	50	3	0.200	20	0	0.000	20	1	0.067	20	5	0.333	25	3	0.200	25	3	0.200	28.000
70	85	4	0.267	45	1	0.067	85	1	0.067	50	3	0.200	70	4	0.267	70	2	0.133	69.333
71	65	5	0.333	20	0	0.000	15	3	0.200	70	2	0.133	20	1	0.067	45	4	0.267	47.333
72	25	5	0.333	10	3	0.200	25	1	0.067	30	2	0.133	35	4	0.267	30	0	0.000	25.333
73	55	3	0.200	65	4	0.267	25	0	0.000	50	2	0.133	65	5	0.333	15	1	0.067	57.667
74	25	5	0.333	30	1	0.067	30	2	0.133	20	3	0.200	30	4	0.267	30	0	0.000	26.333

8.5 Visual Acquisition Data

All the data presented in this section is from the experimental flight-testing efforts in which participants were required to maintain course during encounters to achieve an unmitigated encounter set. There were 298 viable encounters between fixed wing aircraft with 155 missed detections and 143 detections within that subset. Table A 15 describes the encounter data. The Encounter Number, which is the relative number of each encounter with respect to the dataset in its entirety, and Pilot Number are presented first. The CPA distances are presented in nautical miles. The Encounter Type depended on the relative angle between aircraft at the start and midpoints of every encounter. 'Left crossing' was used to denote an encounter where the intruder would cross from left to right with respect to the ownship Subject Pilot, and 'right crossing' for those from right to left. The Intruder Relative Altitude can be either High or Low. High denotes encounters where the intruder flew above the ownship aircraft. Finally, the detection distance is presented in nautical miles. For those encounters where the intruder was not spotted, the detection distance is listed as 0.00 nautical miles.

Table A 15. Encounter data for each visual acquisition made by a pilot.

Encounter Number	Pilot Number	CPA (nmi)	Encounter Type	Intruder Relative Altitude	Detection Distance (nmi)	Avg. Closing Speed (kts)
1	4	1.59	'right crossing'	'High'	1.88	12.4
2	4	0.34	'head on'	'High'	0.31	153.9
3	4	0.82	'left crossing'	'Low'	1.05	30.5
4	4	0.19	'head on'	'High'	0.00	229.3
5	4	0.76	'right crossing'	'High'	0.00	25.8
6	4	0.16	'head on'	'Low'	0.00	233.4
7	4	0.14	'right crossing'	'Low'	0.61	235.4
8	5	1.59	'left crossing'	'Low'	0.00	11.7
9	5	0.34	'head on'	'Low'	0.00	156.5
10	5	0.82	'right crossing'	'High'	0.00	32.9
11	5	0.19	'head on'	'Low'	0.00	215.6
12	5	0.76	'left crossing'	'Low'	0.00	25.9
13	5	0.16	'head on'	'High'	0.00	238.6
14	5	0.14	'left crossing'	'High'	0.00	229.5
15	6	1.50	'left crossing'	'High'	0.00	12.7
16	6	0.12	'head on'	'High'	0.29	249.7
17	6	1.97	'right crossing'	'Low'	0.00	6.6
18	6	0.23	'head on'	'High'	0.53	213.1
19	6	1.54	'left crossing'	'High'	0.00	13.1
20	6	0.10	'head on'	'Low'	0.89	292.6
21	6	0.28	'right crossing'	'Low'	0.00	74.0
22	6	0.19	'head on'	'Low'	0.54	227.8
23	7	1.50	'right crossing'	'Low'	0.00	13.4
24	7	0.12	'head on'	'Low'	0.00	250.9
25	7	1.97	'left crossing'	'High'	0.00	7.8
26	7	0.23	'head on'	'Low'	0.00	200.2
27	7	1.54	'right crossing'	'Low'	0.00	13.5
28	7	0.10	'head on'	'High'	0.00	297.6
29	7	0.28	'left crossing'	'High'	0.00	73.8

30	7	0.19	'head on'	'High'	0.00	233.6
31	8	1.23	'left crossing'	'Low'	0.00	14.2
32	8	0.23	'head on'	'High'	0.00	251.1
33	8	0.19	'right crossing'	'High'	0.00	82.0
34	8	0.14	'right crossing'	'High'	0.00	308.4
35	8	0.48	'left crossing'	'High'	0.00	55.5
36	8	0.12	'head on'	'High'	0.00	308.1
37	8	0.45	'right crossing'	'Low'	0.00	30.2
38	8	0.12	'head on'	'High'	0.00	306.4
39	9	1.23	'right crossing'	'High'	0.00	15.2
40	9	0.23	'head on'	'Low'	0.00	281.8
41	9	0.19	'left crossing'	'Low'	0.00	72.3
42	9	0.14	'left crossing'	'Low'	0.00	301.2
43	9	0.48	'right crossing'	'Low'	0.86	64.0
44	9	0.12	'head on'	'Low'	0.00	303.5
45	9	0.45	'left crossing'	'High'	0.00	30.8
46	9	0.12	'head on'	'Low'	0.00	290.6
47	10	0.09	'left crossing'	'High'	2.60	126.8
48	10	0.14	'head on'	'High'	0.00	240.2
49	10	0.77	'right crossing'	'High'	2.05	16.3
50	10	0.08	'head on'	'Low'	1.88	287.5
51	10	0.26	'left crossing'	'Low'	2.64	72.5
52	10	0.17	'head on'	'Low'	0.36	247.9
53	10	0.79	'right crossing'	'Low'	0.00	16.9
54	10	0.12	'head on'	'Low'	0.78	255.4
55	11	0.09	'right crossing'	'Low'	0.00	125.4
56	11	0.14	'head on'	'Low'	0.00	250.9
57	11	0.77	'left crossing'	'Low'	0.00	14.7
58	11	0.08	'head on'	'High'	0.00	281.3
59	11	0.26	'right crossing'	'High'	0.00	65.9
60	11	0.17	'head on'	'High'	0.00	247.6
61	11	0.79	'left crossing'	'High'	0.00	18.2
62	11	0.12	'head on'	'High'	0.00	263.5
63	12	0.25	'left crossing'	'High'	0.20	70.7
64	12	0.09	'head on'	'Low'	0.10	277.4
65	12	0.16	'right crossing'	'Low'	1.78	53.5
66	12	0.10	'head on'	'Low'	0.66	287.7
67	12	0.31	'left crossing'	'High'	0.73	44.0
68	12	0.09	'head on'	'Low'	1.17	295.7
69	12	0.39	'right crossing'	'Low'	2.07	24.6
70	12	0.09	'head on'	'High'	1.55	301.0
71	13	0.25	'right crossing'	'Low'	0.00	71.8
72	13	0.09	'head on'	'High'	0.00	282.0

73	13	0.16	'left crossing'	'High'	0.14	54.7
74	13	0.10	'head on'	'High'	0.00	309.3
75	13	0.31	'right crossing'	'Low'	0.00	47.2
76	13	0.09	'head on'	'High'	0.00	295.9
77	13	0.39	'left crossing'	'High'	1.70	28.9
78	13	0.09	'head on'	'Low'	0.00	281.9
79	14	0.45	'left crossing'	'Low'	0.00	103.3
80	14	0.08	'head on'	'Low'	0.76	344.8
81	14	0.17	'right crossing'	'High'	0.24	140.2
82	14	0.22	'head on'	'High'	0.00	238.5
83	14	0.36	'left crossing'	'Low'	0.00	118.0
84	14	0.18	'head on'	'High'	0.42	253.9
85	14	0.09	'right crossing'	'High'	0.59	210.6
86	14	0.34	'head on'	'High'	1.10	208.8
87	15	0.14	'head on'	'Low'	0.47	281.0
88	15	0.62	'left crossing'	'High'	0.00	68.4
89	15	0.08	'head on'	'High'	0.12	317.8
90	15	1.77	'right crossing'	'Low'	0.00	24.1
91	15	0.20	'head on'	'Low'	0.31	232.1
92	15	0.36	'left crossing'	'Low'	0.61	101.9
93	15	0.08	'head on'	'Low'	2.18	271.3
94	16	0.13	'head on'	'High'	2.23	269.0
95	16	0.62	'right crossing'	'Low'	1.04	72.0
96	16	0.08	'head on'	'Low'	0.00	300.9
97	16	0.20	'head on'	'High'	0.00	227.6
98	16	0.36	'right crossing'	'High'	0.00	107.5
99	16	0.08	'head on'	'High'	1.51	263.5
100	17	0.17	'right crossing'	'High'	0.32	148.0
101	17	0.09	'head on'	'Low'	1.57	264.6
102	17	0.17	'left crossing'	'Low'	1.51	129.2
103	17	0.18	'head on'	'Low'	0.75	216.4
104	17	0.46	'right crossing'	'Low'	0.00	69.7
105	17	0.08	'head on'	'High'	0.85	299.8
106	17	0.35	'left crossing'	'Low'	0.56	109.0
107	17	0.10	'head on'	'High'	0.22	283.5
108	18	0.17	'left crossing'	'Low'	1.94	156.8
109	18	0.09	'head on'	'High'	0.00	278.1
110	18	0.17	'right crossing'	'High'	0.39	143.4
111	18	0.18	'head on'	'Low'	0.00	219.9
112	18	0.46	'left crossing'	'High'	1.26	90.7
113	18	0.08	'head on'	'Low'	2.13	321.8
114	18	0.35	'right crossing'	'High'	1.10	111.6
115	18	0.10	'head on'	'Low'	2.01	275.3

116	19	0.13	'right crossing'	'High'	1.38	179.2
117	19	0.09	'head on'	'High'	0.41	337.6
118	19	0.17	'left crossing'	'High'	0.75	151.9
119	19	0.19	'head on'	'Low'	0.75	254.3
120	19	0.47	'right crossing'	'High'	1.17	90.4
121	19	0.12	'head on'	'Low'	0.38	271.6
122	19	0.23	'left crossing'	'High'	1.64	134.6
123	19	0.19	'head on'	'High'	0.39	240.0
124	20	0.13	'left crossing'	'Low'	0.00	185.1
125	20	0.09	'head on'	'Low'	0.00	317.7
126	20	0.17	'right crossing'	'Low'	0.00	155.4
127	20	0.19	'head on'	'High'	0.00	259.1
128	20	0.47	'left crossing'	'Low'	0.00	117.1
129	20	0.12	'head on'	'Low'	0.00	298.7
130	20	0.23	'right crossing'	'Low'	0.00	138.6
131	20	0.19	'head on'	'Low'	0.18	227.0
132	21	0.09	'right crossing'	'High'	0.00	341.9
133	21	0.94	'left crossing'	'High'	0.00	45.6
134	21	0.22	'left crossing'	'Low'	0.00	269.9
135	21	0.82	'right crossing'	'Low'	0.00	55.6
136	21	0.08	'head on'	'Low'	0.00	323.5
137	21	0.66	'left crossing'	'High'	0.00	87.7
138	21	0.30	'head on'	'Low'	0.00	184.1
139	22	1.51	'left crossing'	'Low'	1.90	30.1
140	22	0.10	'left crossing'	'High'	0.00	345.5
141	22	0.94	'right crossing'	'Low'	1.78	42.3
142	22	0.22	'right crossing'	'High'	0.00	273.3
143	22	0.82	'left crossing'	'High'	1.13	53.2
144	22	0.08	'head on'	'High'	0.00	312.6
145	22	0.66	'right crossing'	'Low'	0.00	101.1
146	22	0.30	'head on'	'High'	0.00	194.5
147	23	0.15	'left crossing'	'Low'	0.56	153.3
148	23	0.15	'head on'	'Low'	0.64	249.0
149	23	0.11	'head on'	'High'	0.00	301.7
150	24	0.14	'left crossing'	'Low'	0.24	114.5
151	24	0.11	'head on'	'Low'	0.00	316.7
152	24	0.09	'head on'	'High'	0.43	316.7
153	25	0.35	'right crossing'	'High'	0.00	111.9
154	25	0.11	'head on'	'Low'	1.37	300.8
155	25	0.15	'left crossing'	'High'	1.41	140.1
156	25	0.10	'head on'	'Low'	0.00	284.4
157	25	0.25	'right crossing'	'High'	0.00	159.6
158	25	0.08	'head on'	'High'	1.05	290.2

159	25	0.50	'left crossing'	'High'	0.00	72.7
160	25	0.21	'head on'	'High'	0.23	206.4
161	26	0.31	'left crossing'	'Low'	0.21	48.6
162	26	0.10	'head on'	'High'	0.34	290.9
163	26	0.09	'head on'	'Low'	0.00	317.2
164	27	0.17	'left crossing'	'Low'	0.00	98.5
165	27	0.15	'head on'	'Low'	0.25	270.5
166	27	0.10	'head on'	'High'	0.00	325.7
167	28	0.10	'left crossing'	'Low'	0.51	162.0
168	28	0.11	'head on'	'High'	0.00	290.6
169	28	0.10	'head on'	'High'	0.00	336.6
170	28	0.67	'right crossing'	'Low'	0.00	96.2
171	29	0.59	'left crossing'	'High'	0.00	55.5
172	29	1.04	'head on'	'Low'	1.41	73.0
173	29	0.24	'head on'	'High'	1.01	183.5
174	29	0.36	'right crossing'	'Low'	0.00	136.7
175	30	0.23	'left crossing'	'High'	0.00	110.9
176	30	0.10	'head on'	'High'	0.46	315.6
177	30	0.12	'head on'	'Low'	0.88	286.1
178	31	1.15	'left crossing'	'Low'	1.48	75.5
179	31	0.25	'head on'	'High'	0.00	274.2
180	31	0.12	'head on'	'Low'	0.29	298.0
181	34	1.56	'left crossing'	'High'	1.61	9.9
182	34	0.40	'right crossing'	'Low'	0.60	113.0
183	34	1.07	'left crossing'	'High'	0.00	82.7
184	34	0.82	'right crossing'	'Low'	0.00	71.0
185	34	0.14	'head on'	'High'	1.12	287.9
186	35	1.56	'right crossing'	'Low'	0.00	10.3
187	35	0.40	'left crossing'	'High'	0.40	122.6
188	35	1.07	'right crossing'	'Low'	1.09	71.6
189	35	0.82	'left crossing'	'High'	1.18	76.3
190	35	0.14	'head on'	'Low'	0.38	301.4
191	36	1.56	'left crossing'	'Low'	2.28	37.4
192	36	0.36	'right crossing'	'High'	1.47	107.0
193	36	0.15	'left crossing'	'Low'	0.17	234.5
194	36	0.54	'right crossing'	'Low'	2.00	114.0
195	36	0.88	'head on'	'Low'	0.89	92.0
196	37	1.56	'right crossing'	'High'	0.00	27.8
197	37	0.36	'left crossing'	'Low'	0.00	94.5
198	37	0.15	'right crossing'	'High'	0.00	219.5
199	37	0.54	'left crossing'	'High'	1.15	113.6
200	37	0.88	'head on'	'High'	0.00	102.7
201	38	0.11	'head on'	'Low'	0.00	326.2

202	38	0.75	'head on'	'High'	0.81	121.2
203	39	1.03	'right crossing'	'Low'	2.50	22.1
204	39	0.69	'left crossing'	'Low'	1.27	74.2
205	39	0.49	'right crossing'	'Low'	2.50	145.6
206	39	0.52	'left crossing'	'Low'	1.01	138.4
207	39	0.10	'head on'	'High'	0.00	350.9
208	40	1.03	'left crossing'	'High'	0.00	24.0
209	40	0.69	'right crossing'	'High'	0.00	78.4
210	40	0.49	'left crossing'	'High'	0.00	147.8
211	40	0.52	'right crossing'	'High'	0.68	131.5
212	40	0.10	'head on'	'Low'	0.84	350.7
213	41	0.17	'right crossing'	'Low'	0.30	165.0
214	41	0.74	'left crossing'	'Low'	1.20	59.8
215	41	0.18	'right crossing'	'High'	0.21	157.8
216	41	0.60	'left crossing'	'Low'	1.03	111.3
217	42	0.17	'left crossing'	'High'	0.00	172.6
218	42	0.74	'right crossing'	'High'	0.96	76.0
219	42	0.18	'left crossing'	'Low'	0.00	157.8
220	42	0.60	'right crossing'	'High'	1.83	111.4
221	43	0.90	'right crossing'	'Low'	1.46	44.2
222	43	0.64	'left crossing'	'High'	0.00	62.1
223	43	0.55	'right crossing'	'Low'	0.95	130.0
224	43	0.56	'left crossing'	'Low'	1.74	79.9
225	43	0.44	'head on'	'Low'	0.57	183.1
226	44	0.90	'left crossing'	'High'	0.00	59.8
227	44	0.64	'right crossing'	'Low'	0.00	76.2
228	44	0.55	'left crossing'	'High'	0.77	133.6
229	44	0.56	'right crossing'	'High'	0.00	78.2
230	44	0.44	'head on'	'High'	0.00	187.0
231	45	1.46	'right crossing'	'Low'	2.03	15.7
232	45	0.40	'left crossing'	'High'	1.79	173.0
233	45	0.41	'right crossing'	'Low'	0.94	146.7
234	45	0.53	'left crossing'	'Low'	1.03	94.3
235	45	0.69	'head on'	'High'	0.00	105.0
236	46	1.46	'left crossing'	'High'	0.00	19.8
237	46	0.40	'right crossing'	'Low'	0.00	145.9
238	46	0.41	'left crossing'	'High'	0.00	139.1
239	46	0.53	'right crossing'	'High'	0.00	106.8
240	46	0.69	'head on'	'Low'	0.00	110.1
241	47	0.23	'right crossing'	'High'	2.28	117.4
242	47	1.07	'left crossing'	'High'	0.00	43.8
243	47	0.55	'right crossing'	'Low'	0.00	75.8
244	47	0.54	'left crossing'	'Low'	0.00	127.6

245	47	0.13	'head on'	'Low'	0.00	257.0
246	48	0.23	'left crossing'	'Low'	0.00	137.7
247	48	1.07	'right crossing'	'Low'	0.00	37.3
248	48	0.55	'left crossing'	'Low'	0.00	97.7
249	48	0.54	'right crossing'	'High'	0.00	118.2
250	48	0.13	'head on'	'High'	0.00	271.5
251	52	1.18	'overtake'	'Low'	1.26	2.2
252	52	1.46	'head on'	'Low'	0.00	109.8
253	52	0.37	'overtake'	'High'	0.00	15.4
254	53	0.23	'right crossing'	'High'	0.00	36.2
255	53	0.27	'overtake'	'Low'	0.00	46.1
256	53	0.26	'right crossing'	'Low'	0.74	12.5
257	53	0.34	'right crossing'	'Low'	0.00	45.9
258	53	0.44	'overtake'	'Low'	0.00	10.6
259	54	0.29	'overtake'	'Low'	0.29	19.6
260	54	0.36	'overtake'	'Low'	0.58	44.1
261	54	0.18	'overtake'	'High'	0.00	63.6
262	54	0.11	'overtake'	'Low'	1.52	56.9
263	55	0.13	'overtake'	'Low'	0.13	13.3
264	55	0.21	'overtake'	'Low'	0.00	27.6
265	55	0.16	'right crossing'	'High'	2.52	14.1
266	68	1.43	'right crossing'	'High'	0.00	27.3
267	68	0.09	'head on'	'Low'	0.00	360.2
268	68	0.21	'left crossing'	'High'	0.20	102.2
269	68	0.16	'head on'	'High'	0.00	289.7
270	68	0.09	'right crossing'	'High'	0.79	194.9
271	68	0.08	'right crossing'	'High'	0.46	295.9
272	68	0.17	'left crossing'	'High'	0.68	128.3
273	68	0.29	'head on'	'Low'	0.41	230.4
274	69	1.07	'right crossing'	'High'	2.36	20.7
275	69	0.11	'right crossing'	'High'	1.33	329.1
276	69	0.42	'left crossing'	'Low'	0.00	92.3
277	69	0.14	'head on'	'High'	0.00	294.0
278	69	0.15	'right crossing'	'Low'	2.24	162.3
279	69	0.17	'head on'	'Low'	1.63	281.3
280	69	0.23	'left crossing'	'Low'	0.93	114.3
281	69	0.23	'head on'	'High'	0.55	238.8
282	70	0.25	'right crossing'	'Low'	0.95	90.7
283	70	0.12	'head on'	'Low'	0.00	296.1
284	70	0.16	'left crossing'	'Low'	0.96	85.1
285	70	0.62	'right crossing'	'Low'	0.00	199.0
286	70	0.13	'right crossing'	'Low'	0.62	151.8
287	70	0.36	'head on'	'High'	0.00	215.0

288	70	0.22	'left crossing'	'Low'	0.00	106.8
289	70	0.26	'head on'	'Low'	0.92	290.9
290	72	0.08	'overtake'	'Low'	0.00	60.8
291	72	0.08	'left crossing'	'High'	1.57	48.8
292	72	0.98	'overtake'	'High'	0.00	9.7
293	73	0.31	'left crossing'	'High'	0.00	105.6
294	73	0.36	'head on'	'High'	0.00	208.2
295	73	0.11	'head on'	'High'	0.00	330.2
296	74	1.29	'left crossing'	'High'	2.29	35.0
297	74	0.15	'head on'	'Low'	0.63	313.5
298	74	0.09	'head on'	'Low'	0.65	279.9

The same data collected during encounters against a helicopter are shown below. Future research will expand upon these.

Table A 16. Encounter data for each helicopter encounter that occured.

Encounter Number	Pilot Number	CPA (nmi)	Encounter Type	Intruder Relative Altitude	Detection Distance (nmi)	Avg. Closing Rate (kts)
1	57	0.920	'right crossing'	'Low'	0.000	81.0
2	57	0.260	'head on'	'Low'	0.063	241.6
3	57	0.133	'left crossing'	'Low'	0.000	28.5
4	57	0.126	'left crossing'	'Low'	0.000	111.8
5	57	0.402	'right crossing'	'High'	1.024	130.0
6	57	0.211	'head on'	'High'	2.108	179.8
7	57	0.141	'left crossing'	'High'	0.348	76.0
8	57	0.251	'head on'	'High'	0.000	61.9
9	58	0.127	'right crossing'	'High'	0.000	55.2
10	58	0.227	'right crossing'	'Low'	0.000	195.5
11	58	0.144	'left crossing'	'Low'	0.000	126.2
12	58	0.299	'head on'	'High'	0.000	130.8
13	58	0.269	'right crossing'	'High'	1.440	52.3
14	58	0.483	'right crossing'	'Low'	1.088	188.1
15	58	0.151	'left crossing'	'Low'	0.243	71.5
16	58	0.230	'left crossing'	'High'	0.093	189.2
17	59	0.364	'right crossing'	'Low'	0.405	36.8
18	59	0.398	'right crossing'	'High'	0.148	167.8
19	59	0.130	'left crossing'	'Low'	0.000	49.7
20	59	0.055	'left crossing'	'Low'	0.555	125.8
21	59	0.093	'right crossing'	'High'	0.482	40.4
22	59	0.172	'head on'	'Low'	0.000	167.4
23	59	0.139	'left crossing'	'Low'	1.090	66.4
24	59	0.088	'left crossing'	'Low'	0.433	120.5
25	60	0.085	'left crossing'	'Low'	0.000	52.0
26	60	0.129	'head on'	'Low'	0.000	195.8
27	60	0.102	'right crossing'	'High'	0.000	99.8
28	60	0.134	'head on'	'High'	0.000	203.4

29	60	0.194	'left crossing'	'High'	0.000	52.8
30	60	1.365	'head on'	'High'	0.000	168.8
31	60	0.110	'right crossing'	'High'	0.000	114.2
32	60	1.455	'head on'	'High'	0.801	192.2
33	61	0.378	'left crossing'	'Low'	2.254	70.3
34	61	0.128	'right crossing'	'High'	0.000	211.2
35	61	0.104	'right crossing'	'Low'	0.000	89.4
36	61	0.099	'left crossing'	'High'	0.633	184.0
37	61	0.077	'left crossing'	'Low'	2.142	12.9
38	61	0.106	'right crossing'	'High'	0.293	199.0
39	61	0.084	'right crossing'	'Low'	0.000	28.0
40	61	0.194	'head on'	'High'	0.000	122.9
41	62	0.113	'left crossing'	'High'	1.001	73.6
42	62	0.920	'head on'	'High'	0.000	235.3
43	62	0.260	'right crossing'	'High'	0.000	100.5
44	62	0.133	'head on'	'Low'	1.561	231.0
45	62	0.126	'left crossing'	'High'	2.684	100.0
46	62	0.402	'head on'	'High'	2.144	218.5
47	62	0.211	'right crossing'	'High'	2.302	97.5
48	62	0.141	'head on'	'Low'	1.939	239.5

8.6 Subject Pilot Quotations

Pilots were invited to add comments further clarifying their responses. Verbatim quotations are shown below:

- “Um, I would say, well, its size made it easy to spot compared to a large biplane. Uh, color, the bright white, uh, on the plane it reflects off the sunlight easily, um, or greatly, I'd say. … Um, I mean, obviously workload plays into it. You're trying to maintain altitude, um, maintain the aircraft while still looking at the other aircraft. Um, yeah, I would say that's about it.”
- “Probably the color mostly for the first one, because I just had to recognize seeing it. Um, cuz I mean it looks different every type of every time the suns in a different spot now. Right. Um, so definitely the color, uh, but the size always makes it easier. Um, but recognizing the color of it for the first encounter. Um, yeah, I would say that was the main thing.”
- “Um, it's typically difficult … to, uh, spot aircraft on a cloudy day. So, the sunlight definitely made it easier. Cause the sunlight, like I said reflects off that white paint on the bird. Um, so the dark shadows of a cloudy day typically make it hard to spot up against the dark trees. Um, so that sunlight shining off the aircraft definitely made today, um, easier circumstances for, for flying the aircraft.”
- “… I was gonna say turbulent or something like that. Yeah. So, I would say like this afternoon the air was a little more rough and so I was having to pay more attention to altitude, um, and maintaining that cause I was taking a lot more trim trying to set my trim, um, and then maintaining yield pressure. Uh, so I'll say the air was bumpier this afternoon, which made it more difficult to spot the aircraft, but uh, yeah, I would say that”
- “Oh yeah, yeah. Okay. You're saying on radio communications, radio communications. Yeah. So that, that definitely, I didn't even think about that. And I wouldn't anywhere in here, radio communications definitely play a big role because at the same time you're looking for other aircraft, you're also saying your intentions where you're at, where you're maneuvering, what altitude, and you're also listening for other aircraft to see if they're gonna be in convergence with you. Um, so that's, that's a big thing too, it's like when I'm hearing somebody on the radio, I kind of stop my scan from looking at people to hear listening to the radio. Then I go back to my scan. Um, so yeah, good point though. Okay. Definitely definitely plays a role in, um, I didn't see that as an option anywhere on here, but I, we could talk about that on here. I guess that's another thing that I didn't think about that does make it more difficult was radio communications and distractions such as that.”
- “I think it makes, it makes it easier to see planes when they're, in higher altitude than you were… because the whole fight he was higher than we were. Yeah. It, it stands out a lot better when it's in the middle of the windscreen”
- “The fact that we were at a lower altitude was not helpful. Uh, traffic farther away from me is always gonna be looking like it's into the ground.”
- “Um, first time I saw it, he was turning downwind, so he was in a turn, that's probably the most important thing or most relevant thing that I saw…. Uh, it was three airplanes. There was two on the downwind and he was turning or two on the final and he was turning downwind. So, it was a lot of stuff going on, but he was below me, which the wings were white and everything else was green or brown, so it stood out a lot.”
- “Weather. It was great. Uh, high visibility. I think it was low, uh, humidity today. So, it was really clear. No clouds, very sunny. I think the conditions were favorable for this. Yeah.”
- “I mean, yeah. It [birds], um, definitely takes your eyes from looking, you know, it, it adds another task, I guess you could say. So, kind of, kind of like makes you focus on the birds and not the actual flying happens a lot at 1500 feet.”
- “The difficult part was it being so low and close and the background. Um, it kind of blended in with the background until it got fairly close within a mile…Uh, the easy part of spotting it would've been its color. Um, you know, being white once it got close and there were no buildings

in the background once it was kind of, I was looking down on it, the light against the brown background of the earth, uh, made it fairly easy to see at that point. And that's gonna be true for just about, for every single encounter."

- "And I didn't see it at all when it was dead center. Yeah. Cause the, you know, the instrument board is really high, so I, whenever you said I see it, I didn't see it at all."
- "Um, that was a same track for each aircraft uh, inverse. So, it was easy to predict where they would be at."
- "Uh, if talking about when it was directly in front of us, it kind of makes it more difficult for the higher aircraft to see the lower one. Cause the engine was in the way."
- "Uh, the first encounter, um, was when they came from the back left, we're high-wing and they're low-wings, it made it easier for them to spot, but they did come from behind. Um, so it's, it was easier because it was a high-wing aircraft. I could see below me, but it was a little bit more difficult because uh, they came in from behind."
- "They were directly on the horizon in between ground and air. So, it made it extremely difficult to spot cause they kind of blended in with that horizon? Uh, they were at the same altitude, so it was just kind of slightly below the wing. Um, and because we were converging on the same point, it made it look like it wasn't moving at all."
- "Um, no, just made it difficult was if I was, um, like the times when I saw them, they were crossing over me and I was at a lower altitude, like in the Cessna you have the high wing. So that made it kind of hard for me to tell, you know, where, where they were until they were, you know, almost right there, um, a couple times."
- "Yeah, sometimes like the, like the windscreen on like the windshield at like some of those corners, like where it rounds off on the edge...It kind of like, defracted it a little bit, like, if that makes sense, you know what I mean? Just kind of obscure the view slightly, but besides that, um,"
- "Uh, with it being below us, it was easier to spot when I could see the entire, like top of the wing, whenever I had like the greatest surface area towards me. Uh, also when the sun was reflecting off it, that really helped."
- "The ones above us definitely having the high wing limited quite a bit of my visibility, uh, being able to see them, uh, it definitely makes it a lot harder to see up and right. We do kind of get a little bit of a view from the canopy kind of coming around, but still that wing blocks the surface area."
- "When we were above them, it was easier to see them coming from the side. Um, when we were below them, it was easier to see 'em coming head on. Um, cuz when they were below us, I had to deal with looking around my nose versus when we were"
- "Oh, okay. So yeah, so like that made easy, cause it was on like the side I could see on the left side of the plane. So, it's easier seeing on the left side of the plane, than it would be on the right."
- "Uh, well, I mean, it was kind of easier cause it was off to the left slightly. If it was straight in front of me a little bit, it was... that's why it took me so long to see it is, cause I got a little bit off course. I was actually able to see it then. So, it being a little bit off center, made it a little easier to see to the left, but yeah, if it was straight in front of me, because of the engine itself it would be hard to see"
- "The aircraft was white. I mean, it's a bright color and the TCAS system in the airplane, it helped, like it called it out. And it told you which direction the airplane was in. So that's the direction I started looking at. And it said it was below at 10 o'clock and below, so, and found the airplane."
- "Yeah. Uh, it was a high wing, so the wings obscured it. Um, other than that, it wasn't too bad to see them. It's just, if it had been a low-wing I would've seen 'em easier. And also, if we had our traffic page and able to use that, that'd been way easier too."
- "Us being a high wing was easier for us to see them than obviously for them to see us to see us because we don't have wings down low, our wings are up."

- "It probably got in the way a little bit, cause the sky was a little bit clear so you could see further distances. So, I may have been looking further than I needed to be looking in order to see the aircraft. Um, cause I wanna say, I think I was looking over to my left and then I looked back and I was like, oh aircraft."
- "Uh, I'm gonna say our speed made it a little easier, a little easier to spot, uh, slower aircraft are easier to spot cause you have more time to do so. Um, I don't really think there were any flight conditions, that, well, yeah, us being so slow, we had to be nose up more than normal, which made it easier, or harder to see out in front of us."
- "So, like the heading we were on, I think it was kind of while we were turning out towards it and then I saw a bird and kind of focused more on that."

8.7 Factors Affecting Visual Acquisition

Codes (Factors that improved aircraft detection)	**Times mentioned**
Clear Sky/ Day	22
Intruder/ Traffic at Higher Altitude + head on	9
TCAS	9
Familiarity with Flight Path	8
Ownship/ Intruder Making a Turn	7
Smooth Air	7
White Aircraft + Green/Trees/ Forest	7
Glare	6
Glare Centered Head-on Encounter	6
Clear Sky/ Day + Smooth Air + White Aircraft	4
Short Distance between Ownship and Intruder	4
White Aircraft	4
Acquiring Intruder Side Profile View	4
Background	3
Clear Sky/ Day Sunny	3
Crop-Duster Spraying	3
Crossing Encounter	3
Crossing in Front of Ownship	3
Good Spot in Windshield/inside periphery/FOV	3
High Visibility	3
Maroon/ Red Aircraft	3
Off-Center Head-On Encounter	3
Ownship/ Intruder Making a Turn Acquiring Intruder Side Profile View	3
Proximity to Other Traffic	3
Relative to Still Background	3
Scanning/Looking Outside	3
Sunny	3
White Aircraft Sky/Blue	3
Beacon/Light	2
Centered Head-on Encounter Intruder/ Traffic at Higher Altitude (+)	2
Clouds White	2
Familiar with Intruding Aircraft Sight/Shape	2
Familiarity with Test Location	2
Glare Centered Head-on Encounter	2

Green/Trees/ Forest Intruder/ Traffic at Lower Altitude (+)	2
High-Wing Ownship Aircraft	2
Intruder/ Traffic at Lower Altitude (+)	2
Off-Center Head-On Encounter Intruder/ Traffic at Higher Altitude (+)	2
Ownship Cruising	2
Short Distance between Ownship and Intruder Centered Head-on Encounter Intruder/ Traffic at Higher Altitude (+)	2
Sunlight Glare Ownship/ Intruder Making a Turn	2
Wearing Sunglasses	2
White Aircraft Brown Green/Trees/ Forest	2
White Aircraft Clear Sky/ Day	2
White Aircraft Glare	2
White Aircraft Green/Trees/ Forest Intruder/ Traffic at Lower Altitude (+)	2
White Aircraft Intruder/ Traffic at Lower Altitude (+)	2
White Aircraft Markings on Aircraft	2
White Aircraft Sunlight	2
Workload Smooth Air	2
Yellow/ Crop-Duster Brown	2
Awareness of Test	1
Background Long Distance between Ownship and Intruder Intruder/ Traffic at Lower Altitude (+)	1
Beacon/Light Nighttime	1
Centered Head-on Encounter	1
Centered Head-on Encounter Intruder/ Traffic at Lower Altitude (+)	1
Clear Sky/ Day Flying Away from the Sun	1
Clear Sky/ Day High Visibility	1
Clear Sky/ Day Intruder/ Traffic at Higher Altitude (+)	1

Clear Sky/ Day Intruder/ Traffic at Lower Altitude (+)	1
Clear Sky/ Day No Haze	1
Clear Sky/ Day Smooth Air High Visibility	1
Clear Sky/ Day Sunny Hazy	1
Clear Sky/ Day Sunny Shade/ Shadow Intruder/ Traffic at Higher Altitude (+)	1
Clouds Background	1
Clouds Green/Trees/ Forest	1
Crossing Encounter Good Spot in Windshield/inside periphery/FOV	1
Crossing Encounter Intruder/ Traffic at Lower Altitude (+)	1
Crossing From the Left Intruder/ Traffic at Lower Altitude (+)	1
Crossing From the Right Intruder/ Traffic at Higher Altitude (+)	1
Crossing in Front of Ownship Acquiring Intruder Side Profile View	1
Crossing in Front of Ownship Good Spot in Windshield/inside periphery/FOV	1
Crossing in Front of Ownship Intruder/ Traffic at Lower Altitude (+)	1
Familiar with Intruding Aircraft Sight/Shape Acquiring Intruder Side Profile View	1
Familiar with Intruding Aircraft Sight/Shape Centered Head-on Encounter Intruder/ Traffic at Higher Altitude (+)	1
Familiar with Intruding Aircraft Sight/Shape Markings on Aircraft	1
Familiar with Intruding Aircraft Sight/Shape Maroon/ Red Aircraft	1
Familiar with Intruding Aircraft Sight/Shape White Aircraft	1
Farm Fields/ Fields	1
Farm Fields/ Fields Intruder/ Traffic at Lower Altitude (+)	1
Farm Fields/ Fields Relative to Still Background	1
Flying Away from the Sun	1

Glare Ownship/ Intruder Making a Turn	1
Glare Ownship/ Intruder Making a Turn Acquiring Intruder Side Profile View	1
Glare Relative to Still Background	1
Green/Trees/ Forest Intruder Climb-Ups	1
Grey Sky/Blue Intruder/ Traffic at Higher Altitude (+)	1
Hazy	1
High Visibility Foggy	1
High Visibility Hazy Foggy Clouds	1
High Visibility Long Distance between Ownship and Intruder	1
High Visibility No Fog	1
High-Wing Ownship Aircraft Crossing From the Left Intruder/ Traffic at Lower Altitude (+)	1
Horizon Relative to Still Background	1
Instrument Board/ Engine/Nose Blocking View Crossing Encounter Intruder/ Traffic at Lower Altitude (+)	1
Intruder/ Traffic at Higher Altitude (+) Ownship and Intruder/ Traffic on the Same Level	1
Long Distance between Ownship and Intruder	1
Long Distance between Ownship and Intruder Off-Center Head-On Encounter	1
Low-Wing Intruder Aircraft High-Wing Ownship Aircraft Intruder/ Traffic at Lower Altitude (+)	1
Markings on Aircraft	1
Markings on Aircraft Intruder/ Traffic at Higher Altitude (+)	1
Maroon/ Red Aircraft Clouds White	1
Maroon/ Red Aircraft Glare	1
Maroon/ Red Aircraft Sunlight	1

Maroon/ Red Aircraft Sunlight Glare	1
Ownship Speed/Motion	1
Ownship/ Intruder Making a Turn Centered Head-on Encounter	1
Ownship/ Intruder Making a Turn Crossing From the Right Acquiring Intruder Side Profile View	1
Radio Communications	1
Relative to Still Background Good Spot in Windshield/inside periphery/FOV	1
Relative to Still Background Relative to Ownship	1
Relatively large Aircraft	1
Relatively large Aircraft Short Distance between Ownship and Intruder	1
Relatively large Aircraft White Aircraft	1
Relatively large Aircraft White Aircraft Afternoon	1
Relatively large Aircraft White Aircraft Short Distance between Ownship and Intruder	1
Relatively large Aircraft Yellow/ Crop-Duster	1
Relatively large Aircraft Yellow/ Crop-Duster Clear Sky/ Day Background Intruder/ Traffic at Lower Altitude (+)	1
Relatively large Aircraft Yellow/ Crop-Duster Ownship/ Intruder Making a Turn	1
Scanning/Looking Outside High-Wing Ownship Aircraft	1
Scanning/Looking Outside Ownship Cruising	1
Scanning/Looking Outside Smooth Air	1
Seating Position White Aircraft Intruder/ Traffic at Higher Altitude (+)	1
Shade/ Shadow	1
Shade/ Shadow Crossing From the Left	1
Short Distance between Ownship and Intruder Intruder/ Traffic at Higher Altitude (+)	1

Sky/Blue	1
Sky/Blue Intruder/ Traffic at Higher Altitude (+)	1
Sky/Blue Relative to Still Background Intruder/ Traffic at Higher Altitude (+)	1
Smoke Grey	1
Smooth Air High Visibility	1
Smooth Air High Visibility Low Humidity	1
Sunlight Afternoon	1
Sunlight Glare Directly Below	1
Sunlight Glare Flying Facing the Sun	1
Sunny Glare	1
Sunny High Visibility Low Humidity	1
Sunny Sky/Blue	1
Sunny Smooth Air High Visibility	1
Talking with Safety Pilot	1
Temperature	1
Wearing Sunglasses Glare	1
White Aircraft Background	1
White Aircraft Background Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Brown	1
White Aircraft Brown Green/Trees/ Forest Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Brown Intruder/ Traffic at Lower Altitude (+)	1

White Aircraft Clear Sky/ Day Short Distance between Ownship and Intruder	1
White Aircraft Clear Sky/ Day Sky/Blue	1
White Aircraft Clouds Relative to Still Background	1
White Aircraft Crossing From the Right Crossing in Front of Ownship Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Crossing in Front of Ownship Intruder/ Traffic at Higher Altitude (+)	1
White Aircraft Farm Fields/ Fields	1
White Aircraft Farm Fields/ Fields Green/Trees/ Forest	1
White Aircraft Glare Sky/Blue Intruder/ Traffic at Higher Altitude (+)	1
White Aircraft Green/Trees/ Forest Crossing in Front of Ownship Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Green/Trees/ Forest Long Distance between Ownship and Intruder	1
White Aircraft Grey Crossing Encounter Acquiring Intruder Side Profile View	1
White Aircraft Grey White Relative to Still Background	1
White Aircraft Horizon Green/Trees/ Forest	1
White Aircraft Markings on Aircraft Background	1
White Aircraft Markings on Aircraft Relative to Still Background	1

White Aircraft Sunlight Glare Green/Trees/ Forest	1
White Aircraft Sunny	1
White Aircraft Sunny Good Spot in Windshield/inside periphery/FOV	1
White Aircraft Sunny Sunlight Glare Brown Green/Trees/ Forest	1
Wind Hazy	1
Wind Hazy Foggy	1
Workload	1
Workload Scanning/Looking Outside	1
Workload Scanning/Looking Outside Clear Sky/ Day Smooth Air	1
Workload Scanning/Looking Outside Ownship Cruising	1
Workload Scanning/Looking Outside Smooth Air	1
Workload Smooth Air Ownship Cruising	1
Yellow/ Crop-Duster Clear Sky/ Day Smooth Air	1
Yellow/ Crop-Duster Clear Sky/ Day Sunny	1
Yellow/ Crop-Duster Farm Fields/ Fields	1
Yellow/ Crop-Duster Farm Fields/ Fields Intruder/ Traffic at Lower Altitude (+) Crop-Duster Spraying	1
Yellow/ Crop-Duster Hazy	1

Yellow/ Crop-Duster Intruder Landing/ Descending	1
Yellow/ Crop-Duster Long Distance between Ownship and Intruder	1
Yellow/ Crop-Duster Sky/Blue Green/Trees/ Forest	1

Codes (Factors that hindered aircraft detection)	**# Times mentioned**
Hazy	15
Workload + Turbulence	14
Turbulence	12
Workload	9
Flying Facing the Sun	9
Blind Spot	7
Clouds	7
Dirty/Damaged Windows/Window Corners	5
Exhaustion	4
Background + Intruder/ Traffic at Lower Altitude	4
Habit of Not Looking Outside/ Relying on Instruments	3
Lack of Familiarity Flying Ownship	3
Low Visibility	3
Low Visibility Hazy	3
Radio Communications	3
White Aircraft	3
White Aircraft White	3
Birds	2
Blind Spot Intruder/ Traffic at Lower Altitude (+)	2
Centered Head-on Encounter Intruder/ Traffic at Higher Altitude (+)	2
Coming from Behind	2
Distraction from Other Traffic/Events/ Background	2
Glare Bodies of Water	2
Glare Flying Facing the Sun	2
Green/Trees/ Forest	2
Horizon	2
Instrument Board/ Engine/Nose Blocking View	2
Instrument Board/ Engine/Nose Blocking View Intruder/ Traffic at Lower Altitude (+)	2

Intruder/ Traffic at Lower Altitude (+)	2
Lack of Familiarity with Test Location	2
Maroon/ Red Aircraft Green/Trees/ Forest	2
Ownship Speed/Motion	2
Relatively Small Aircraft	2
White Aircraft Hazy	2
ADSB	1
Background Intruder/ Traffic at Higher Altitude (+)	1
Background Relative to Still Background Intruder/ Traffic at Lower Altitude (+)	1
Brown Green/Trees/ Forest Intruder/ Traffic at Lower Altitude (+)	1
Centered Head-on Encounter Intruder/ Traffic at Higher Altitude (+) Ownship and Intruder/ Traffic on the Same Level	1
Centered Head-on Encounter Intruder/ Traffic at Lower Altitude (+)	1
Clear Sky/ Day	1
Clear Sky/ Day Hazy	1
Clouds Green/Trees/ Forest	1
Crossing From the Right Contradictory Statements	1
Directly Below	1
Familiar with Intruding Aircraft Sight/Shape Shade/ Shadow Afternoon	1
Flight Direction	1
Flying Facing the Sun Centered Head-on Encounter	1
GoPro Cameras	1
Green/Trees/ Forest Intruder/ Traffic at Higher Altitude (+)	1
Hazy Clouds	1
Hazy Long Distance between Ownship and Intruder	1
Hazy Smoke	1
High-Wing Ownship Aircraft	1

High-Wing Ownship Aircraft Crossing Encounter Intruder/ Traffic at Higher Altitude (+)	1
High-Wing Ownship Aircraft Crossing From the Right Intruder/ Traffic at Higher Altitude (+)	1
High-Wing Ownship Aircraft Intruder/ Traffic at Higher Altitude (+)	1
Instrument Board/ Engine/Nose Blocking View Centered Head-on Encounter Intruder/ Traffic at Lower Altitude (+)	1
Instrument Board/ Engine/Nose Blocking View Centered Head-on Encounter Intruder/ Traffic at Lower Altitude (+) Contradictory Statements	1
Intruder Flying Away from Ownship	1
Intruder/ Traffic at Higher Altitude (+)	1
Low Visibility Clouds Bodies of Water	1
Maroon/ Red Aircraft Clouds	1
Maroon/ Red Aircraft Green/Trees/ Forest Intruder/ Traffic at Higher Altitude (+)	1
Not Familiar with Intruding Aircraft Sight	1
Not Wearing Sunglasses Flying Facing the Sun	1
Ownship/ Intruder Making a Turn Birds Distraction from Other Traffic/Events/ Background	1
Ownship/ Intruder Making a Turn Intruder Flying Away from Ownship	1
Relative to Ownship	1
Relative to Ownship Ownship and Intruder Converging Ownship and Intruder/ Traffic on the Same Level	1
Relatively Small Aircraft Long Distance between Ownship and Intruder	1
Relatively Small Aircraft Relative to Ownship	1
Roadways Green/Trees/ Forest	1
Seating Position	1
Sky/Blue Intruder/ Traffic at Higher Altitude (+)	1
Sunlight Glare	1

Sunlight Glare Afternoon	1
Sunny	1
Sunny Intruder/ Traffic at Lower Altitude (+)	1
Sunny Sunlight	1
Talking with Safety Pilot	1
Turbulence Afternoon	1
Turbulence Intruder/ Traffic at Higher Altitude (+)	1
White Aircraft Buildings White	1
White Aircraft Buildings White Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Buildings White Roadways Intruder/ Traffic at Lower Altitude (+)	1
White Aircraft Clouds	1
White Aircraft Markings on Aircraft Green/Trees/ Forest	1
White Aircraft Roadways	1
White Aircraft Sky/Blue	1
White Aircraft Sky/Blue Intruder/ Traffic at Higher Altitude (+)	1
White Aircraft White Sky/Blue	1
White Aircraft Yellow/ Crop-Duster Sky/Blue	1
Workload Birds	1
Workload GoPro Cameras	1

Workload Scanning/Looking Outside Turbulence	1
Workload Thermals	1
Workload Turbulence Afternoon	1

8.8 Pilot Scanning Rate Estimation Method

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Statistical Sensitivity Analysis of Pilot Scanning Rate Estimation Methods for Detect-and-Avoid and Unmanned Aircraft Systems Standardization

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08/2/2022

Problem Statement:

Determine the most representative length of a randomized video clip sample from a full 35-minute video to accurately estimate the true scanning rate of pilots in flight. Understanding the effective scan rate for pilots will improve the See-And-Avoid (SAA) standards for manned flights set by the Federal Aviation Administration (FAA) as the integration of unmanned aerial systems into local airspace increases.

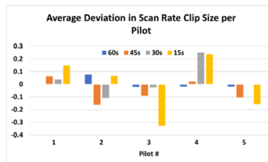
Objectives:

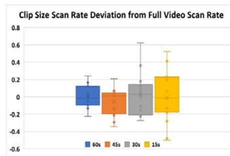
- Establish the most representative clip size for determining pilot scan rate.
- Utilize a MATALB script with clip sizes up to 120 seconds to further analyze with bootstrapping methods the binary data received from the Arduino program.
- Implement an Arduino program to more effectively determine the time spent scanning.
- Calculate and analyze the scanning rates differences of the pilots in the sample clips versus the full videos.
- Determine the scanning rate of the pilots in the set of clips and full-length videos.
- Record the faces of various pilots following specific flight paths and create sets of three clips from the full-length videos that are in increments of 15s, 30s, 45s, and 60s.

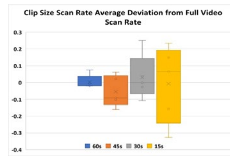
Background:

- The FAA recommends pilots to scan surroundings 3-4 times more than the instrument panel for the full duration of the flight.
- SAA standards are procedures used by pilots to avoid traffic collisions.
- Bootstrapping is a statistical method that employs sampling of a dataset to estimate the confidence of a single random sample to the entire population.

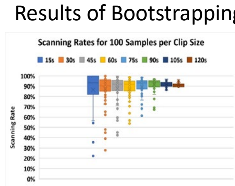
Scanning Rate Data for All Pilots:

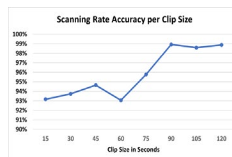


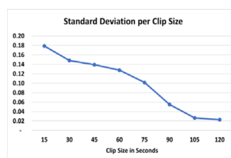




Results of Bootstrapping with MATLAB:







Conclusions:

After originally conducting a sensitivity analysis without the assistance of MATLAB for up to a 60 second clip size, the data was considered too volatile and inaccurate. Therefore, the decision was made to investigate longer clip sizes for up to 120 seconds.

For the purposes of this research, the investigator determined that the 105 second samples were the most optimal and time efficient clip size. In this case, the scanning rate's standard deviation was on average 0.03. Although the 90 second clip size's standard deviation is on average 0.05 and more time efficient, there are more outliers that could skew from the true scanning rate of pilots in flight. The accuracy of the 105 second clip size to the full video's scan rate is 98.59%.

Future Work:

- Using the results of this research to improve visual acquisition models to evaluate pilot performance.
- Further development of standards for unmanned systems.
- Establish the relationship between scanning rate and pilot visual acquisition.

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