ASSURE A46 - Validation of Visual Operation Standards for Small Uncrewed Aircraft Systems: Final Report

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16. Abstract

The Alliance for System Safety of UAS through Research Excellence (ASSURE) A46 research team investigated Visual Observer (VO) effectiveness in maintaining separation from crewed aircraft during a set of small uncrewed aircraft (sUA) flight operations. This research investigated two aspects of VO performance: (1) visual detection of a crewed aircraft and (2) the avoidance of a crewed aircraft. As a component of this research, the team (1) assessed the current state of the industry and identified key elements of previous VO experimental designs, (2) developed a flight test plan based on these findings, and (3) conducted flight test experiments that enabled the team to generate data on VO performance. This approach addressed questions regarding the abilities and limitations of VOs for Extended Visual Line of Sight (EVLOS) Operations and validation of previous data on the subject.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF ACRONYMS

AARC	Applied Aviation Research Center
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ANOVA	Analysis of Variance
ASSURE	Alliance for System Safety of UAS Through Research Excellence
BVLOS	Beyond Visual Line of Sight
COA	Certificate of Authorization
CPA	Closest Point of Approach
DAA	Detect and Avoid
EP	External Pilot
EVLOS	Extended Visual Line of Sight
FAA	Federal Aviation Administration
GPS	Global Positioning System
HMD	Horizontal Miss Distance
JER	Jornada Environmental Range
KSU	Kansas State University
MSU	Mississippi State University
NM	Nautical Miles
NMAC	Near Mid Air Collision
NMSU	New Mexico State University
NTSB	National Transportation Safety Board
RFP	Request for Proposal
RP	Remote Pilot
RPIC	Remote Pilot in Command
RTP	Research Task Plan
SDT	Signal Detection Theory
sUA	small Uncrewed Aircraft
sUAS	small Uncrewed Aircraft System
TCAS	Traffic Collision Avoidance System
UA	Uncrewed Aircraft
UAS	Uncrewed Aircraft System
VAD	Visual Acquisition Distance
VLOS	Visual Line of Sight
VMD	Vertical Miss Distance
VO	Visual Observer
WSU	Wichita State University

EXECUTIVE SUMMARY

The Alliance for System Safety of UAS through Research Excellence (ASSURE) A46 research team investigated Visual Observer (VO) effectiveness in maintaining safe separation from crewed aircraft during a set of uncrewed aircraft (sUA) flight operation trials. This research investigated two aspects of VO performance: (1) visual detection of a crewed aircraft and (2) the avoidance of a crewed aircraft. As a component of this research, the team (1) assessed the current state of the industry and identified key elements of previous VO experimental designs, (2) developed a flight test plan based on these findings, and (3) conducted flight test experiments that enabled the team to generate data on VO performance in terms of effectiveness in an Extended Visual Line of Sight (EVLOS) operational testing paradigm.

A thorough literature review demonstrated the variability in the current state of VO/Remote Pilot (RP) "see and avoid" research. Researchers have studied the principle of see and avoid, which relies on the visual detection capabilities of crewed aircraft pilots to avoid a potential collision with other traffic, for several decades. While most of the observations noted on the topic of the see and avoid principle are not directly related to VO performance, a few provided useful insight into visual detection and scanning strategies that could prove beneficial in VO tasks. The literature highlighted the importance of including team-based skills associated with situational awareness, problem-solving/decision-making, and communication in future VO training and training standards.

As an experimental construct, the research team leveraged a flight test campaign to (1) assess the accuracy of detection of a crewed aircraft by a VO, (2) explore the capacity for VOs to use visual references for avoidance, and (3) explore the capacity for the VO and RP to give way to crewed aircraft. This research used a mixed methods design utilizing a triangulated approach to capture both quantitative and qualitative data concurrently during the data collection phase of this study. These flight tests identified three common themes: (1) VOs with no prior aviation experience perform less effective than VOs with previous aviation experience, and (2) ambient conditions (e.g. contrast), ambient light, aircraft speed, and aircraft configuration (e.g., Cessna 172 versus Cirrus SR20) may have an impact on VO performance. Previous research ascertained VO ineffectiveness in estimating collision potential between an intruder crewed aircraft and the UA when the UA is within EVLOS. This research suggested that participants were 89.5% effective in identifying an intruder aircraft within 1 mile, with a significant degradation in performance effectiveness to 22.6% at 2 miles, and 3.3% at 3 miles. These findings ascertain that VOs may not be the most reliable as an effective source for collision avoidance. In fact, VOs did not perceive that an avoidance maneuver was necessary in 22 out of 54 (40.7%) encounters highlighted with Near Mid-Air Collision (NMAC) violations in the data set. Further research is deemed necessary to better understand the extent to which these independent variables impact VO/RP performance.

1 INTRODUCTION & BACKGROUND

The Alliance for System Safety of UAS through Research Excellence (ASSURE) A46 research team investigated the effectiveness of Visual Observer (VO) performance for Extended Visual Line of Sight (EVLOS) operations. More specifically, the A46 research team explored methods to quantify VO performance, identify potential human visual detection limitations, uncrewed aircraft (UA) avoidance decision-making limitations, and inform safety training for Visual Line of Sight (VLOS) and EVLOS operations.

The research tasks relevant to this report were as follows:

- Task 1 – Literature Review
- Task 2 – Updated Research Task Plan
- Task 3 – Initial Test and Analysis
- Task 4 – Flight Testing and Data Analysis
- Task 5 – Lessons Learned
- Task 6 – Final Report

As a whole, this approach enabled the research team to (1) identify the current state of research related to visual observer performance in terms of effectiveness, (2) develop initial flight test plans and analysis techniques to gather relevant VO performance data using both live and simulated aircraft in a real-world testing environment, (3) conduct revised flight testing based on lessons learned from initial flight test campaigns, and (4) generate a lessons learned document based on the findings from the flight tests conducted as a component of this work. This approach provided a means to address research questions regarding VO performance, how different physiological aspects may impact VO performance, and how training may impact VO performance. Overall, these tasks provided a means to gather data to depict the effectiveness of VOs at identifying crewed aircraft in the airspace and their accuracy towards maneuver suggestions based on specific flight test regimes.

2 RESEARCH QUESTIONS

The following questions guided this research methodology. The research questions provided an idea of the scope and scale of the project. Additionally, these questions informed the structure of research tasks and addressed the key requirements for this work.

Research Questions

- How well are VOs/RPs able to recognize potential collision hazards (other aircraft, terrain, obstacles, etc.) and avoid them through visual means during the day, during civil twilight, and at night?
- What are the primary variables, variable relationships, and failure modes that are important in regard to VO/RP functions to see and avoid collision hazards?
- What information on optical illusions and decision-making guidance to avoid collision hazards should VO/RP training standards include?
- What are recommended safe operational ranges from a small uncrewed aircraft to a visual observer that are acceptable for EVLOS operations? What safety justifications can be used to support these ranges? What additional training is needed for EVLOS operations?

Research tasks described in the following sections addressed the research questions listed above. As previously mentioned, this research emphasized VO effectiveness, focusing on the human ability to detect and avoid intruder aircraft during multiple trials of an Extend Visual Line of Sight (EVLOS) flight operation.

3 RESEARCH TASKS AND FINDINGS

The research team performed the following tasks for the A46 research effort. These tasks addressed research questions while generating deliverables that guided the research team. What follows is a description of each task, an overview of the findings, and a description of the conclusions and their relation to research goals. The research team omitted tasks that did not generate deliverables from this report. This report satisfies the requirements for A46 Task 6 – Final Report.

3.1 Task 1 – Literature Review and Market Analysis

Task 1 consisted of a literature review. This literature review was essential for providing the research team with a background on the industry's current state regarding Uncrewed Aircraft Systems (UAS) VO visual acquisition and avoidance of potential collision hazards. Additionally, Task 1 provided an opportunity for the research team to identify critical gaps associated with the effectiveness of VOs in UAS operations. The following sections outline the approach, methodology, and findings from the literature review. This task informed future tasks while bounding the project's scope.

3.1.1 Task 1-1: Literature Review – Conclusions

The team conducted a thorough literature review that explored multiple facets of VO/RP performance as stated in the research questions, visual acquisition, and avoidance of potential collision hazards, including avoidance of other aircraft, terrain, and obstacles. The primary purpose was to provide the FAA with a clear understanding of the following:

1. The current state of research on VO/RP visual acquisition and avoidance of other aircraft, terrain, and obstacles,
2. EVLOS operations, and
3. Operations in VLOS in which specific scenarios challenge visual conspicuity.

The following sub-sections offer vital insights and key takeaways from the A46 literature review. These sub-sections outline conclusions from the literature that framed the scope for future tasking and identified areas where more work may help quantify VO/RP performance. Appendix A of this report provides the complete literature review associated with Task 1 of this research.

3.1.1.1 *Human Factors Related to VO/RP Performance*

<u>Human Visual System Limits</u>

The human visual system is limited by the following factors: blind spot, acuity threshold, accommodation of the eye, empty field myopia, and focal traps (FAA, 2016a). The human visual system, specifically visual scanning, can be affected by attention and response to traffic movement, refocusing eyes with and without switching views, eye movement, threat spotting, retinal eccentricity, contrast threshold, small visual angle, visual obstructions, and visual search requirements.

Detecting and recognizing an intruder aircraft, assessing its collision potential, making an avoidance decision, and initiating and completing an avoidance maneuver takes a pilot a minimum of 12.5 seconds, according to the FAA Advisory Circular 90-48D. Significant caveats must be placed on this metric when considering human performance (FAA, 2016b). The reference Advisory Circular does not describe any encounter geometry used to generate the timing of this performance metric. The Advisory Circular provides a general idea of reaction time, which may not be typical or conservative. The Advisory Circular breaks down the elements into segments, with five seconds attributed to the pilot becoming aware of the collision geometry and four seconds for deciding an evasive response. This lends itself to the Advisory Circular's comment that the concept of “see and avoid” alone is insufficient for collision avoidance. One must consider these important caveats when using the 12.5-second reaction time as a human observer performance baseline for Detect and Avoid (DAA) compliance.

Human Visual Performance Models

Woo et al. (2020) developed a new mathematical model based on rendered images of sUA. The model from Woo et al. (2020) indicated that sUA is typically not visible to crewed aircraft pilots with enough time to avoid a collision. Woo et al. (2020) noted that at the minimum distance that allows pilots enough time to react and avoid a collision, many sUA had rendered image sizes were near or below one arc-minute. The study established this as the lower limit for human visual acuity. Therefore, according to the model shown by Woo et al. (2020), the see and avoid principle is unreliable for sUA detection. According to this model, the two most important factors that affect the sUA detection are the size of the sUA (positively correlated with detection) and the speed of the crewed aircraft (negatively correlated). Similarly, Wallace et al. (2019) noted that the visibility of the UA dropped to fewer than ten arc-minutes when operated at over 400 feet in altitude. They also stated that apart from the largest sUA, most sUA were difficult to see for operations that exceeded 4,000 ft.

sUA Visual Detection by VO/RPs

Based on this literature review, VOs are poor at estimating distance and altitude correctly (Crognale, 2009) and are 2.5 times more likely to overestimate distances rather than underestimate distances (Vance et al., 2017). Detection rates and detection distances vary significantly across the studies evaluated as a component of this literature review. Typically, detection distances are higher for larger sUA due to a larger visible cross-section. However, size alone cannot predict the visibility of sUA. Color and background contrast also have a significant impact on the visibility of the vehicle. Key factors that could hinder visual detection include the sUA size, sun position, and any visual obstructions encountered by VOs. In general, the visibility of an aircraft (crewed and uncrewed) during daytime is determined by the aircraft’s physical size and contrast against the sky and clouds. In contrast, lighting systems establish visibility during night operations. Experience of VOs, or lack thereof, and corrected vision (20/20) may have a negligible impact on a VO's ability to detect sUA visually.

The Ability of VO/RPs to Avoid a Potential Collision

According to the literature review, VOs are poor at estimating the collision likelihood of UA with surrounding traffic (Crognale, 2009). When evaluating the ability of VOs to assess the potential for a collision between a Boeing-Insitu Scan Eagle and an intruding aircraft, Crognale (2009) found that VOs cannot evaluate the likelihood of a collision unless they can see the crewed intruder aircraft and the UA at the same time. Crognale (2009) also found that without audible signals, Traffic Collision Avoidance System (TCAS), or radio announcements, visual detection by VOs is unlikely to contribute to collision avoidance in a significant way. VOs may significantly contribute to collision avoidance by utilizing trajectory estimation strategies, like tracking an object projected on a flat plane rather than maintaining a linear optical trajectory. Vance et al. (2017) found that based on the error intercept time with respect to the average intercept time, there is a significant risk of RPs not having enough time to avoid a collision. RPs could take longer than the 12.5-second estimate to follow the required procedures for collision avoidance. Last, Vance et al. (2017) also found that VOs perceive a worse collision potential than reality and overestimate the closure rate rather than underestimate it.

3.1.1.2 *Factors Related to Aircraft Visual Conspicuity*

Lighting Systems

Lighting systems make the aircraft more visible to other aircraft and to ground traffic. The increased visibility reduces the chances of collision. The two external lighting systems currently used on crewed aircraft are position and anticollision lights.

Dolgov (2016) found that factors such as background illumination, presence of other lights in the background, low level of contrast between the UA equipped with lights and the background, and time required for the human eye to adapt to the dark adversely affect the ability of a VO/RP to detect anticollision lights. Dolgov (2016) also noted that lighting systems on aircraft (crewed and uncrewed) offer a contrast against overcast or dark skies, enabling VOs to track a sUA more efficiently during dusk and night conditions.

Paint Schemes

Hobbs (1991) suggests that a paint scheme that maximizes the contrast of the aircraft color with its background is more useful in increasing the visibility of the aircraft. However, the contrast of the aircraft against the background also depends on the background luminance. A light-colored aircraft is less visible against a light background on a dark day. However, increasing the background luminance will reduce the contrast of the aircraft with the background. The reduction, in contrast, will reduce the visibility of the aircraft. Considering these factors, Nelson et al. (2020) stated that paint on the top surface of the UA rather than the bottom surface provides a better contrast against the ground. Nelson et al. (2020) also found that fluorescent paint is more effective than no fluorescent paint in increasing the conspicuity of an aircraft and that adding reflective strips on larger UA may be beneficial in increasing UA detectability.

3.1.1.3 *The Current VO/RP Training Paradigm*

There are no standardized training requirements for VO; however, many universities and institutions have their own training guidelines.

While the number of categories covered and the depth of training by subject did vary, the Test Sites and university materials reviewed had central core topics such as airspace knowledge, Certificate of Authorization (COA) requirements, waivers, FAA requirements, and communication procedures.

Many training programs reviewed by the research team detail topics not specific to VO tasks, such as site-specific information, including state and local regulations, wildlife interactions, and weather safety.

- The top-level "Training Topics" included the following:
    - COA Requirements and Waivers
    - Federal Aviation Requirements (General Knowledge)
    - Federal Aviation Requirements (VO Specific)
    - Airspace Knowledge
    - Part 107 - Operating Limits
    - Part 101 – Moored Balloons, Kites, Amateur Rockets, Uncrewed Free Balloons, and Certain Model Aircraft.
    - Team Composition and Reporting
    - Responsibilities for Primary (Inside) Observer
    - Responsibilities for Secondary (Outside) Observer
    - Responsibilities for RPIC
    - VO Placement
    - Communications
    - Situational Awareness
    - UAS Observer Issues
    - Spatial Disorientation
    - Techniques
    - Emergency Procedures
    - Practical training/application – demonstrated knowledge and field demonstrations for training.
    - Site-specific knowledge and Safety Training
    - Other

Implementing a demonstration of knowledge or practical skills, such as a successful test operation where the VO demonstrates their ability to ensure the separation of the UA from other aircraft, would be beneficial for determining whether a trainee can perform VO tasks successfully.

3.1.1.4 *The Role of VO/RP in Testing of DAA*

Researchers investigated the VO and RP's roles in testing DAA systems. These two roles are commonly part of all operations. The desire was to assess if there were any differences or changes in their roles during DAA system testing. DAA system testing involves planned encounters with an intruder aircraft, which is more complex than just flight operations that look for and assess random air traffic that may or may not impact the UA flight. Planned encounters require another level of planning and safety to maintain safe separations and in-flight situational awareness.

DAA testing involves planned encounters with piloted aircraft. During the mission-specific briefs, there is a discussion about the specific flight profiles. RPs and VOs are fully aware of the encounter set and the safe separation criteria designed into the test plan, individual test cards, and predetermined vertical and lateral offsets for safe separation to aid the VOs in their assigned duties. Mission planning highlights the communication and roles of the RP and VO as they are integral to safe operation. However, the roles of VO/RP are formally undefined beyond what is best practice for all flight testing.

3.2 Task 2 – Updated Research Task Plan

The Research Task Plan (RTP) was a living document throughout this project. The RTP received updates as needed in coordination with the sponsor. The RTP informed modifications to the methodology as researchers developed and exercised initial test plans. The sponsor received the final draft of the RTP on February 1, 2023, capturing the methods used for the flight testing within associated tasks/subtasks. Appendix B of this report contains the RTP.

3.3 Task 3 – Initial Test and Analysis

Task 3 consisted of six sub-tasks. The six sub-tasks included (1) the development of an experimental plan, (2) the development of a draft flight test plan, (3) the development of a draft data analysis plan, (4) flight test and data analysis peer review coordination meetings, (5) VO training development, and (6) an updated flight test plan. The findings from the subsequent literature review in Task 1 guided the initial flight test planning.

3.3.1 Task 3-1: Develop an Experimental Plan

With clear definitions, an evaluation plan, identified variables, and data collection and processing procedures, the research team developed an experimental methodology to inform the initial flight testing and data analysis as a component of sub-tasks 3-3 and 3-5. The following sections summarize the key elements associated with the experimental plan. Below are a series of questions developed by the performing team to guide the flight test plan methodology and flight test campaign established from four of the research questions outlined in this report and captured in the RFP. Appendix C provides the finalized Experiment Plan.

1. What is the visual detection time for a ground-based visual observer?
2. At what point does the visual observer (a) see the intruder aircraft, (b) alert the RPIC, and (c) suggest an avoidance maneuver?
3. How many suggested avoidance maneuvers were accepted or rejected by the RPIC?
4. How long does it take for the RPIC to decide regarding the suggested avoidance maneuver?
5. How long does it take to complete the avoidance maneuver?
6. How does distance/angular distance and/or the associated portion of the field of view between the VO and the intruder aircraft affect the probability of detection?
7. Do ambient light levels affect detection performance?

- What may improve VO performance? This will be answered anecdotally based on input from subject matter experts.
- What was the closest point of approach (CPA) for each trial (see Section 3.7 for the Data Analysis)?

3.3.1.1 *Methodology and Experiment Design*

The research team utilized a sUAS flight test campaign in Kansas to collect data associated with this experimental design. This experimental design emphasized the human factors complexities of VO tasking during a sUAS EVLOS operation. Flight tests conducted afforded the research team the ability to measure specific dependent variables related to VO and RPIC performance, such as:

1. The time it takes for a participant to detect an intruder aircraft visually.
2. The distance at which a participant visually detects an intruder aircraft.
3. The time for the participant to decide whether an avoidance maneuver is required to ensure safe separation between aircraft.
4. The time it takes for the RPIC to initiate the maneuver.
5. The time it takes to complete the maneuver.

The experimental design offered the benefit of directly addressing the research questions by:

1. Enabling the research team to evaluate the ability of VOs and RPs to detect conventional aircraft accurately.
2. Exploring the capacity for VOs and RPIC to use visual references for avoidance.
3. Identifying challenges associated with VO/RPIC communications.
4. Exploring the capacity of the RPIC to give way to the conventional aircraft.

The experimental design allowed the research team to collect general information that may have impacted VO detection performance, such as ambient noise, light levels, and individual physiological differences related to visual acuity, color deficiency, and hearing capabilities. This information served as a baseline for considering future training criteria for VOs and RPICs. NMSU conducted a series of preliminary test runs of the experiment design in New Mexico before the final data collection flights in Kansas. This initial testing assessed personnel layout, data collection methods, flight path geometries, data gathering approaches, and other testing elements to ensure successful testing with participants in Kansas. The initial tests validated the test design and maximized data collection potential before conducting flight tests in Kansas. Additionally, lessons learned from the New Mexico flights were applied to the data collection flight test methods.

A mixed methods design utilizing a triangulated approach was used for this research to capture both quantitative and qualitative data. Qualitative and Quantitative data were equally weighted during the data collection phase of this study. The primary advantage of implementing a mixed methods experimental design was to counterbalance the weaknesses presented by each method. For instance, this method leveraged the strengths of the qualitative data collection methods (e.g., data about the context) to offset the weakness of the quantitative data collection methods (e.g., ecological validity). Likewise, the strengths of the quantitative data collection methods (e.g., generalizability) offset the weaknesses associated with the qualitative data collection methods (e.g., context dependence; Mills & Gay, 2012). As such, the research team validated this design as well suited to investigate the parameters associated with VO effectiveness.

The rationale for choosing a mixed methods design stemmed from the notion that quantitative data gathered via the Cessna-172 and SR20 flight logs, ground control station (GCS), and in-situ environmental observations could be collected concurrently with the qualitative data from the VO participants. While the quantitative and qualitative data were gathered concurrently, the analyses were performed separately; after both analyses were complete, the team compared results to draw overall conclusions.

3.3.1.2 *Validity and Reliability*

Maximizing internal validity and reliability was a crucial element during the experimental design phase of this research. Mills and Gay (2012) described internal validity as the degree to which observed differences in the dependent variable result solely from manipulating the independent variables and not from any uncontrolled extraneous variables. Of foremost importance was to collect data in a manner that was credible and reliable to minimize any threat to the internal validity of this experiment (Mills & Gay, 2012). Thus, instituting standardized procedures, establishing a fixed location, and ensuring consistent data collection methods enhanced the internal validity of this methodology.

This experimental design used a double-blind procedure to enhance internal validity. The VO participants, RPIC staff, and researchers did not know the chosen flight path for each experimental run. Only the C-172 pilot and an "Air Boss" on the ground were aware of the selected flight paths. Double-blind procedures helped to minimize the possible effects of participant and research bias (Frey, 2018). In turn, enhancing the study's internal validity also enhanced the external validity of the results, allowing the results to serve as a baseline representation of the types of data required when evaluating VO and RPIC performance.

Reliability refers to the degree to which a test (or qualitative research data) consistently measures whatever it measures and includes both the instruments and tests and the techniques being used to collect data (Mills & Gay, 2012). To enhance the reliability of this study, experienced RPICs with FAA Remote Pilot Certificates and previous flight experience were utilized to evaluate VO participant performance. The construction, planning, and testing of all instruments were also documented and described, and the researcher's relationship with the groups and setting was detailed and captured.

3.3.1.3 *Limitations and Assumptions*

The research team considered seven limitations and seven assumptions when developing the methodology for the flight test campaign. These limitations and assumptions resulted from (1) individual human performance limitations, (2) a limited participant pool, and (3) challenges associated with generalizing results across a wide variety of unique or novel sUAS use cases.

Limitation 1: Human performance could vary significantly between individuals/participants.

Limitation 2: Since participants had little to no VO experience, conclusions about VO performance may not translate to VOs with more experience.

Limitation 3: Kansas State University Salina has a smaller campus population, limiting the number of participants.

Limitation 4: The brief time available for this task was limited to the ability to recruit and schedule participants.

Limitation 5: Flight tests simulated a fixed-wing hybrid VTOL sUA; thus, the time it took for this system to initiate and complete an avoidance maneuver varied compared to other sUA platforms. Therefore, the results may not translate to operations using other sUA platforms.

Limitation 6: BVLOS flight operations used for this experiment were limited to daytime operations under Visual Meteorological conditions (VMC). The results from this study may not apply to operations conducted under different conditions, such as nighttime operations.

Limitation 7: The data collected for the time it took a participant to see an intruder aircraft may be skewed because as the variability in time increases across participants, the data will become positively skewed.

The following assumptions drove the experimental design and flight test campaign.

Assumption 1: Experienced VOs would perform differently. What constituted an experienced VO was undefined by previous literature. For the sake of this research, a VO was grouped into the experienced category if they had an FAA Remote Pilot Certification and/or any Private, Commercial or Airline Transport certification. If a VO had no prior aviation experience they were categorized as having no experience.

Assumption 2: Trained and experienced RPICs would be better at confirming if the suggested VO avoidance maneuver was the best option.

Assumption 3: The VO training provided to the participants was an adequate amount of information to help them understand the roles and responsibilities of a VO during a sUAS operation.

Assumption 4: Participants would follow the processes given during the VO training, including using correct callouts and the specified scanning techniques.

Assumption 5: The participants would not look to their fellow participants for clues about where the intruder aircraft is located.

Assumption 6: Participants would follow instructions and not yell their callouts and/or not use hand gestures to identify where the intruder aircraft is in the airspace.

Assumption 7: The RPICs and the research administrators would not scan the airspace and give inadvertent clues to the participants as to where the intruder aircraft is located.

3.3.2 Task 3-2: Initial Flight Test Plan

The New Mexico State University Unmanned Aircraft Systems Test Site (NMSU UASTS) developed and documented an initial flight test plan before initial flight testing. This document was titled "A46 Visual Observer Assessment Test Plan" and dated May 9, 2022. The research team previously provided a copy of this initial flight test plan to the FAA, attached in Appendix D. Items discussed in the Initial flight test plan and the general methodology are shown below:

1. Introduction
    1.1 Project Overview
    1.2 Scope of Testing
2. Test Architecture
    2.1 Delayed Assets
3. Aircraft and Support Equipment
4. Flight Locations
5. Encounter Geometrics
6. Success Criteria
7. Participants and Roles
8. Schedule
    8.1 General Flight Day
9. Data Management Plan
    9.1Metadata Spreadsheet
    9.2 Test Card Data
    9.3 Flight Data
    9.4 VO Data and Other Test Data
10. Flight Day Communications Plan

A few items in this initial test plan were worth highlighting to provide basis, background, and clarity. This includes information on the intruder aircraft, test location, and various encounter geometries.

The NMSU UASTS utilized a Flight Design CTLS, owned and operated by NMSU, as the intruder aircraft. Table 1 provides the CLTS aircraft information card.

Table 1. Flight Design CTLS.

	The Flight Design CTLS is a two-seater Light Sport Aircraft designed around the FAA LSA regulation. It is all composite construction and uses a Rotax 90HP engine. The CTLS served as the intruder aircraft during the flights at NMSU.		
Wingspan	28ft 8 in	**Cruise Speed**	80-90 knots
Maximum Takeoff Weight	1,600 pounds	**UAS Operator**	NMSU
Fuel Capacity	34 gallons		

Crewed aircraft took off from Las Cruces International Airport (KLRU). The test area was ~18 NM Northeast of Las Cruces International Airport (Figure 1). Flight maneuvers took place away from the airport to minimize the impact on general aviation operations. The area is sparsely populated, and all maneuvering of the crewed aircraft was performed at or above 500 ft Above Ground Level (AGL). The simulated sUA in this testing maneuvered at or below 400 ft AGL. To maintain safety, the crewed aircraft involved in the operation had ADS-B in/out installed so that all pilots had high situational awareness. The VO test subjects were located at the Jonada Range.

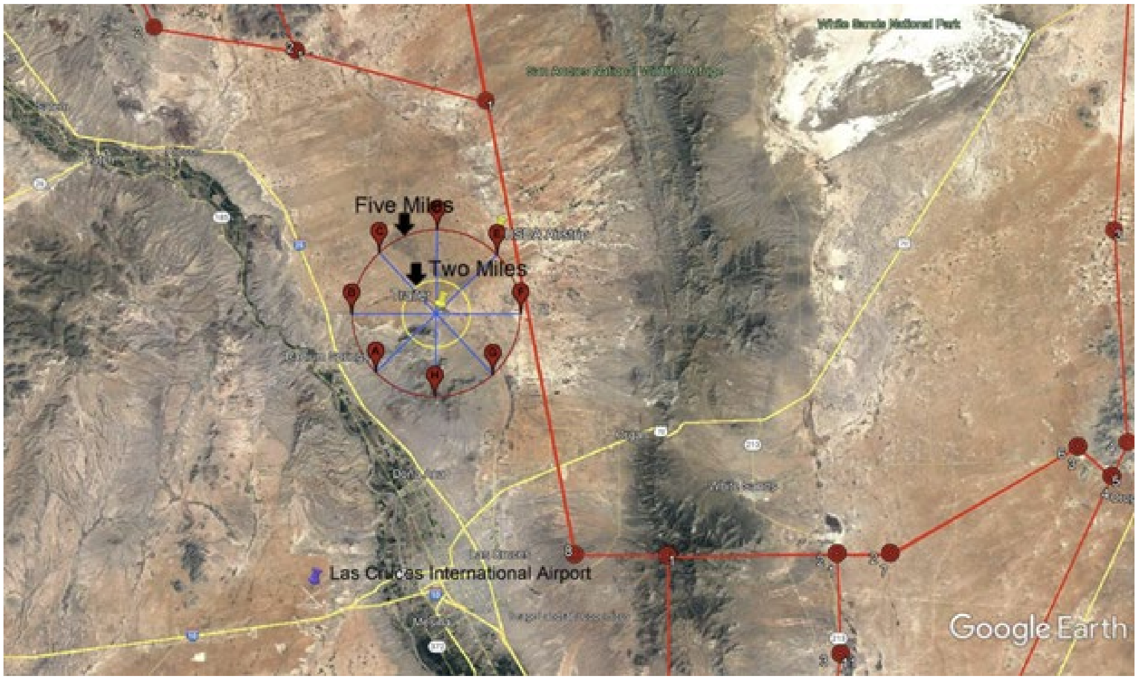


Figure 1. Wide View of the NMSU Testing Area.

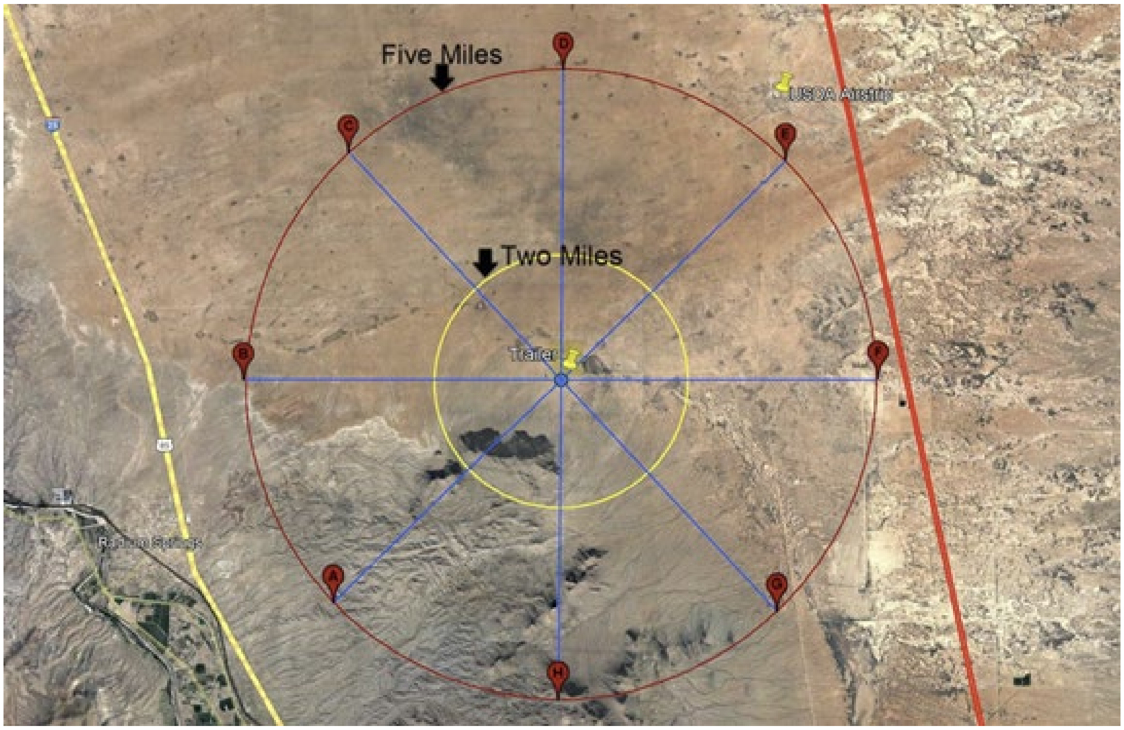


Figure 2. Bird-eye view of the operational location for the NMSU A46 event.

The encounter geometries provided are referred to as "wagon wheel" crossings. The encounters were laid out around the compass rose centered where the VOs were situated (Figure 2). Encounters started at a distance beyond the visual line of sight of the VOs. Nominally, for these tests, the encounters started at 5 miles. The intruder came in from one of the depicted starting points. The sUA flew various patterns within a .25 nautical mile (NM) radius of the bullseye. The intruder then exited this location by aligning along the defined exit vector. The exit direction was aligned to minimize the flight time outside the 5-mile diameter ring. Each subsequent intruder crossing was along a different random "spoke of the wheel." Dedicated visual observers were posted on the ground and in the crewed aircraft to maintain safety.

For more details on each encounter, please see the associated test cards. Appendix E presented the finalized test cards prepared for the New Mexico flights.

As noted above, the initial flight test plan was developed for the first round of testing conducted in New Mexico. KSU used the lessons learned from this testing when developing the flight test plan for Task 4.

3.3.3 Task 3-3: Draft Data Analysis Plan

This section summarizes key elements of the data analysis plan, which is a part of the experiment plan provided in Appendix C. The research team identified the main dependent and independent variables for the initial flight testing. The primary dependent variable was the intruder detection distance. The finalized variables are listed and discussed in Section 3.4.5.1 of this report.

The proposed list of data collected in the experiment is consistent with the previous work done at New Mexico State University's UAS test site (Dolgov, 2016 & Dolgov et al., 2012). The data collection initially proposed in the data analysis plan was slightly altered before the start of flight testing. The finalized data collected before and during flight tests is listed below:

- Test Site Information
    - Test Area Dimensions, Dates and Times of Experiments, Latitude and Longitude coordinates of the test area
    - Test Site Weather (Temperature, Dew Point, Barometric Pressure, Wind Speed and Direction, Rainfall Rate)
    - Test Site Ambient Light Level
    - Test Site Ambient Noise Level
- VO Information
    - Background
    - Aviation Experience
    - Visual Acuity and Hearing Levels
    - Fatigue Levels
- Audio and Video Recordings
    - VO and Remote Pilot in Command (RPIC) Communications
    - Video recording of the Ground Control Station (GCS) areas
    - Photographs (GCS and test area, test setup, crewed aircraft)
- VO-Specific Responses
    - Acknowledgment of visual acquisition of intruder aircraft
    - The suggestion of a maneuver to RPIC if a potential collision is identified.
- **Crewed and Uncrewed Aircraft Information and Global Positioning System (GPS) data:**
    - Latitude, Longitude, Altitude, Speed, Heading at a minimum frequency of 1 Hz.

Wichita State University developed scripts and algorithms to process the raw data, compute the quantitative parameters of interest, and perform graphical and statistical analysis on the quantitative parameters. The steps involved in the processing and analysis of the data are listed below:

- Obtain the intruder aircraft GPS and flight data from the Garmin-1000, ForeFlight, or GPS Puck logs.
- Obtain the sUA GPS and flight data from the Mission Planner software logs.
- Identify the start and end times of useful “runs” based on a 4.5-mile distance between the intruder aircraft and VO locations.
- Compute the horizontal and vertical distances between Intruder aircraft and UA, Intruder aircraft and VO locations, sUA and VO locations (Distances are based on geodesic arc lengths between points defined on the WGS84 ellipsoid).
- Compute the unmitigated flight path for the sUA.
- Compute the unmitigated and mitigated CPA and corresponding horizontal and vertical miss distances:
    - CPA occurs at the smallest slant distance between the intruder aircraft and sUA for a given run.
    - Slant distance is the Euclidean distance between the intruder aircraft and sUA.

- Determine Well Clear (2000 ft x 250 ft) and near mid-air collision (NMAC) (500 ft x 100 ft) violations for both mitigated and unmitigated flight test encounters.
- Determine the intruder's distance, altitude, speed, and heading from the GPS data during VO detection.
- Determine the ambient light and noise levels during VO detection.
- Determine the response times to initiate and complete an avoidance maneuver when performed.
- Compute the intruder's visual angle and angular visual area at the time of VO detection.
- Compute descriptive statistics and percentile distribution curves for the relevant dependent variables.
- Compute statistical relationships and correlations between the relevant dependent and independent variables using common methods like Analysis of Variance (ANOVA), Regression model fit, and Spearman's correlation test.

The ANOVA analysis used in this study was the one-way method. A one-way ANOVA analysis determines whether different groups of a single independent variable affect a dependent variable differently. The ANOVA analysis is useful for both numeric and categorical independent variables.

The Spearman correlation test is a bivariate analysis that measures the strength and direction of a linear relationship between two variables. Positive values of the correlation coefficient close to 1 indicate a strong positive relationship, and negative values relative to -1 indicate a strong negative relationship. The Spearman correlation test was preferred in this study over the Pearson correlation test (one of the most widely used correlation statistics) since the Pearson test assumes both variables to be normally distributed. The Spearman correlation is a non-parametric statistic with no requirement of normality.

The data processing and statistical analysis methodologies described in this section are consistent with several of the VO performance-related experiments mentioned in the literature review (Dolgov, 2016; K. W. Li et al., 2019a., K. W. Li et al., 2019b, Li et al., 2020; Vance et al., 2017; Woo et al., 2020).

3.3.4 Task 3-4: Test and Data Analysis Plan Review

Task 3-4 consisted of the data analysis plan discussed in Section 3.3.4. The detailed Data Analysis Plan can be found in Appendix C.

3.3.5 Task 3-5: VO Training PowerPoints

Task 3-5 involved creating VO Training PowerPoint slides intended to train the participants on their role of the VO during the flight testing. The team created two training versions while building the requisite PowerPoint presentations; the first focuses on training the VO participants on the topics most applicable to the flight testing in a condensed 30-minute training. The second version is an extended version of the training provided to the FAA with a PowerPoint that encompassed the topics needed to train a VO for safe EVLOS operation. Appendix F provides the PowerPoint slides for the condensed version, and Appendix G provides the extended version.

The performing team used four different training courses to identify the most pertinent topics needed for this training: (1) New Mexico State University's FAA UAS Flight Test Site Training,

(2) the Alaska Center for Unmanned Aircraft Systems Integration Training, (3) Kansas State University Salina's Applied Aviation Research Center Training, and (4) the Public Safety Unmanned Response Team Training. This section offers an overview of the topics included in the training PowerPoints.

- Federal Aviation Requirements (General Knowledge)
  - FAR § 107.3 – Definitions
  - FAR § 107.31 – Visual Line of Sight Aircraft Operation
  - FAR § 107.37 – Operation Near Aircraft; Right of Way Rules
  - FAR § 107.39 – Operation Over Human Beings
  - FAR § 107.51 – UAS Operating Limits
  - FAR § 107.17 – Medical Conditions
  - FAR § 107.23 – Hazardous Operations
  - FAR § 107.27 – Alcohol and Drugs
  - Federal Aviation requirements (VO Specific)
- Airspace Knowledge
  - FAR § 107.33 – Visual Observer
  - FAR § 107.33a – Effective Communication
  - FAR § 107.33b – See the aircraft throughout the flight and accurately determine UAS altitude and direction.
  - FAR § 107.33c – Coordination
- UAS Part107 Operating Limitations
  - Operating Requirements
- Team Composition and Reporting
  - Definition of mission support teams' roles and responsibilities
    - Remote Pilot in Command (RPIC)
    - Flight Team (VO, Team Leader, Air Boss)
  - Defined reporting structure
  - Responsibilities of RPIC
    - Clearly define the roles and responsibilities of the entire support team
- Responsibilities for Primary Observer
  - Deployed at launch/landing site
  - UAS Tracking
  - Late-game collision avoidance
  - External pilot assistance
  - Interface between VO and other personnel
  - Interference with non-participants
- VO Placement
  - Geography
- Communications
  - Hand-held radios
  - Call signs
  - Observer to pilot
    - Aircraft tracking information
    - Maneuver recommendations

- Pilot to Observer
    - Heads up for inbound traffic
    - No factor aircraft calls
    - Communication Procedures
- Phraseology
    - Object name "Intruder aircraft."
    - Object heading "Cardinal direction."
    - Object heading relative to the UA (toward, away, parallel, etc.)
    - Object altitude relative to the UA (high, co-altitude, low altitude)
    - Maneuver (maintain, climb, descent, turn)
    - Example callouts:
        - "Intruder aircraft, headed south, toward UA, high, maintain."
        - "Intruder aircraft, headed southeast, toward UA, co-altitude, recommended descent."
        - "Intruder aircraft, headed southeast, toward UA, low altitude, recommend climb."
- Communication standards (phonetic alphabet, figures/numbers, altitudes and flight levels, direction, speed, time)
- Emergency terminology

- Situational Awareness
    - Know your directions.
- UAS Observer Issues
    - Size and orientation of the UA
    - Paint schemes and lights
    - Engine noise (or lack of)
    - Environmental and terrain effects
        - Sun, clouds, haze, dust
        - Mountains in the background
    - Accurate altitude and distance estimates for non-participating aircraft
- Spatial Disorientation
    - Visual Illusions
    - Autokinesis
    - Flicker Vertigo
    - False Perceptions
    - False Horizons
    - Lost Horizons
    - Black Hole Syndrome/ Black Hole Approach
- Techniques
    - Scanning Technique 1
        - 10-degree sectors through the area of responsibility
        - Horizon to operating altitude.
    - Engine noise may be the first indication.
    - Compass Use
        - N, S, E, W, not "left" and "right."

        - Give bearing from our location.
- Emergency Procedures
    - Follow "Air Boss's" Instructions

3.3.6 Task 3-6: Completed Initial Flight Test and Data Collection

Task 3-6 consisted of the final round of initial flight testing. The conclusion of initial flight testing and data collection informed the methodology for subsequent flight test activities and was derived from lessons learned in Task 2. NMSU conducted two rounds of flight testing as outlined above. The sections below discuss the initial flight testing completed by New Mexico State University and the subsequent flight testing by Kansas State University.

3.3.6.1 *NMSU Flight Testing*

An initial round of flight tests took place at the Jornada Experimental Range (JER) near Las Cruces, NM, from September 21 to 23, 2022. This first round of testing ran through the planning, training, and execution of the designed test protocols. Eight VO test subjects were part of the testing over three days. The objectives were to gather data and validate test protocols. The three sections below cover the flight's set-up and execution, collected data, and the lessons learned.

3.3.6.2 *NMSU Flights and Data Collection*

Tasks 3-4 of the proposed work required NMSU to complete initial flight testing and data collection. All tests had a similar plan, timing, and set-up procedure. Four static locations were set up. The team established a central command and control location where the test subjects were given their VO training, shown in Figure 3. All test subject locations were approximately 200 feet from this central location. The other three static locations were located in the East, North, and South of the central location, as shown in Figures 4, 5, and 6. Figure 7 presents images of the VO location setup. Figures 8, 9, 10, and 11 present broader views of the testing area. One can see clearly that the test area is flat and offers few obstructions, maximizing visibility. The images below were from Wednesday, September 21, 2022.

Figure 3. NMSU Visual Observer Training in the Field.

Figure 4. Visual Observer East Location.

Figure 5. Visual Observer South Location.

Figure 6. Visual Observer North Location.

Figure 7. Visual Observer Location Set-Up and Reference Notes.

Figure 8. View From VO North Location. The east location is to the left of the image, and the Central and South Locations are visible to the right.

Figure 9. sUAS Pilot and VO During the Testing and Data Collection.

Figure 10. View to the Northeast.

Figure 11. View to the Northwest.

The intruder for these tests was a CTLS Light Sport aircraft. The NMSU team employed four systems for collecting the intruder aircraft's GPS coordinates to ensure accuracy. These systems consisted of two self-contained GPS Pucks, GPS data from a device onboard the CTLS running the ForeFlight application, and a Garmin GPS recording device.

Figure 12 below shows the approximate location of the VO's during the testing. All VOs were approximately 200-230 feet away from each other. The approximate GPS positions of the VO test subjects were as follows:

North VO: 32.596904° -106.740488°
East VO: 32.596735° -106.739860°
South VO: 32.596287° -106.740274°

Figure 12. VO locations are marked with yellow pins (all are near the center crossing of the dirt runway).

Flight plots for each day are shown below in Figures 13 through Figure 21. There were three flight images for each day of flight testing. The first image in each set shows the entire flight of the intruder with the aircraft taking off from the Las Cruces International Airport. Figure 14 presents an overview of the crossing patterns, and Figure 15 depicts a close-up view of the crossing area to show the dispersion of the flights and just how close the aircraft approached the center of the target area. The red line to the right in the images represents the boundary for the White Sands Missile Range restricted airspace where the intruder aircraft could not fly. That is why all the approaches turned before reaching this limit.

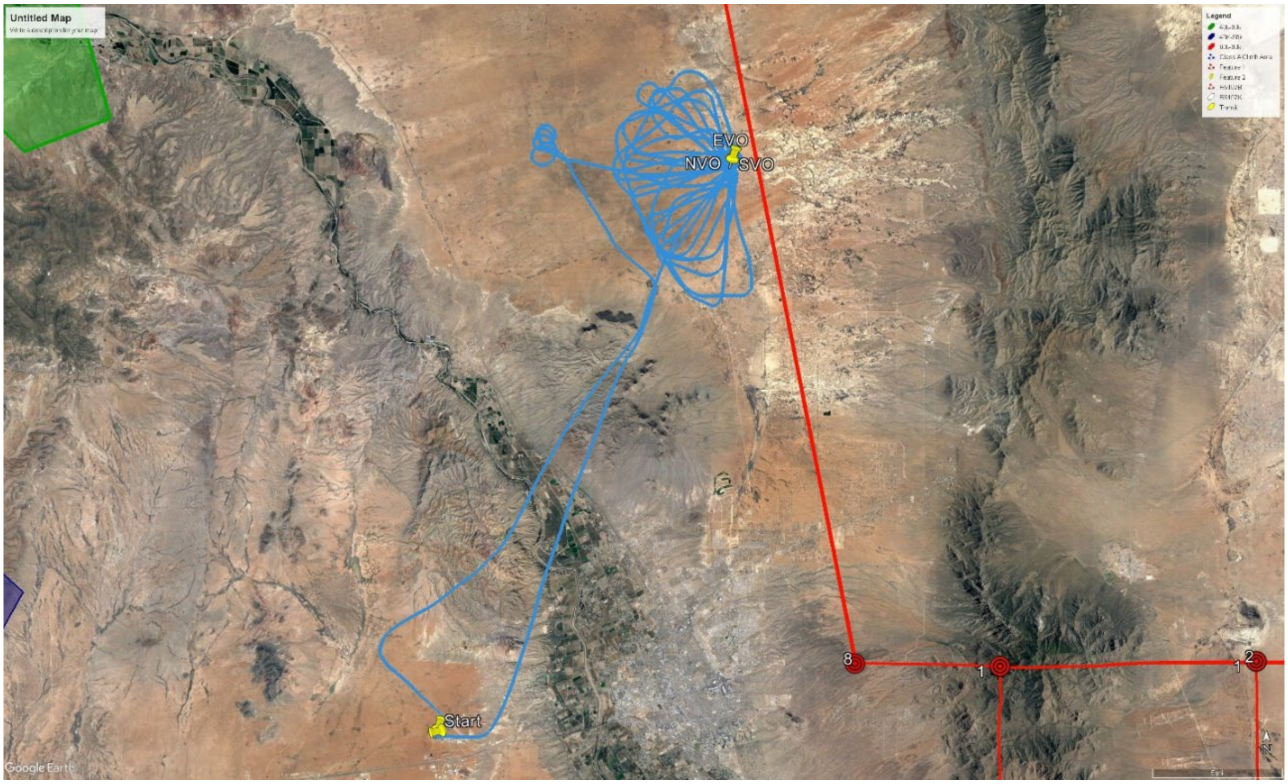


Figure 13. Full Flight Path for September 21, 2022.

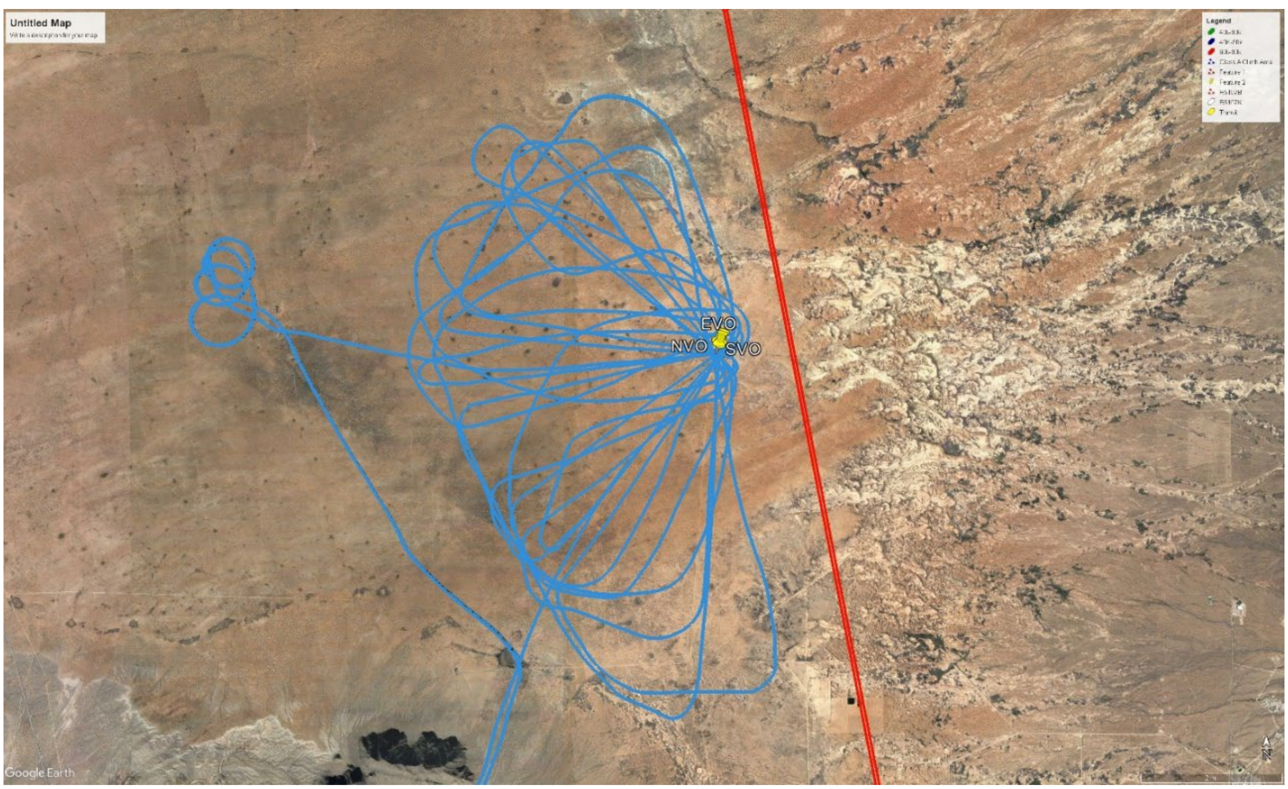


Figure 14. Flight Path Crossing for September 21, 2022

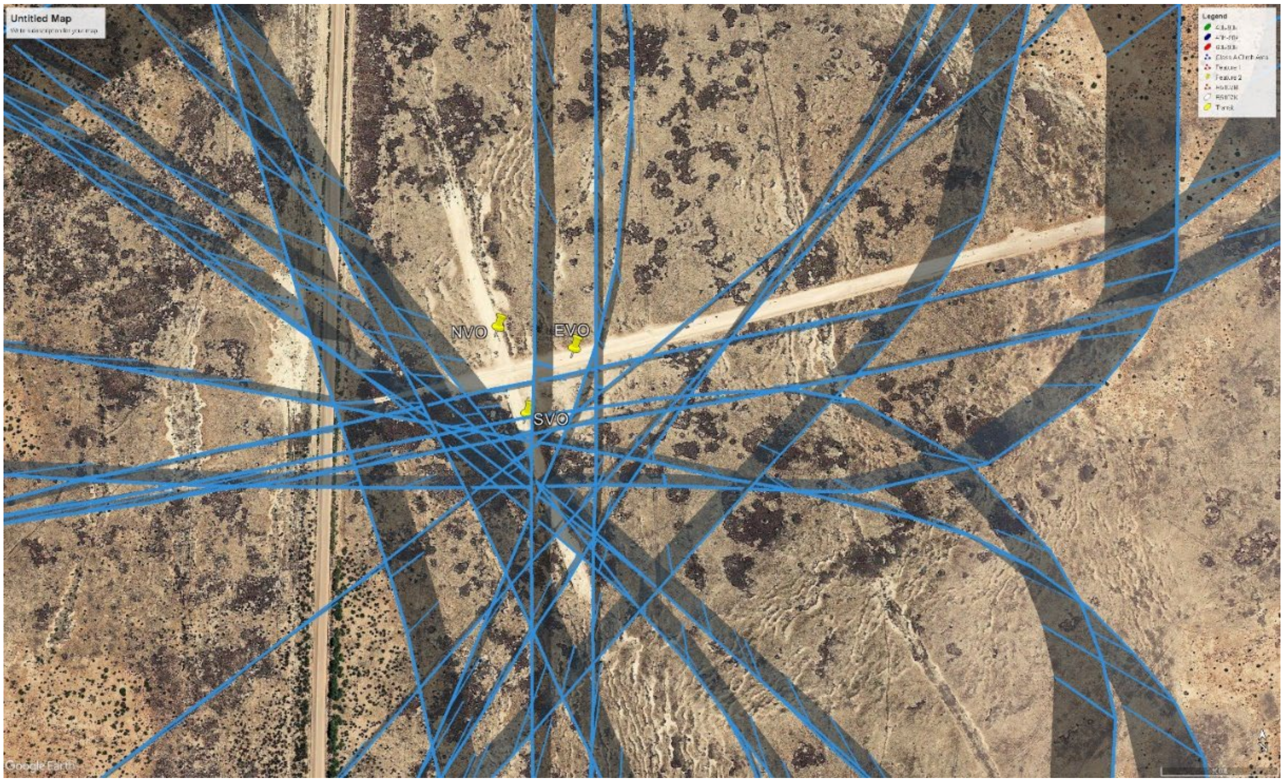


Figure 15. Close-up view of the flight path crossings on September 21, 2022.

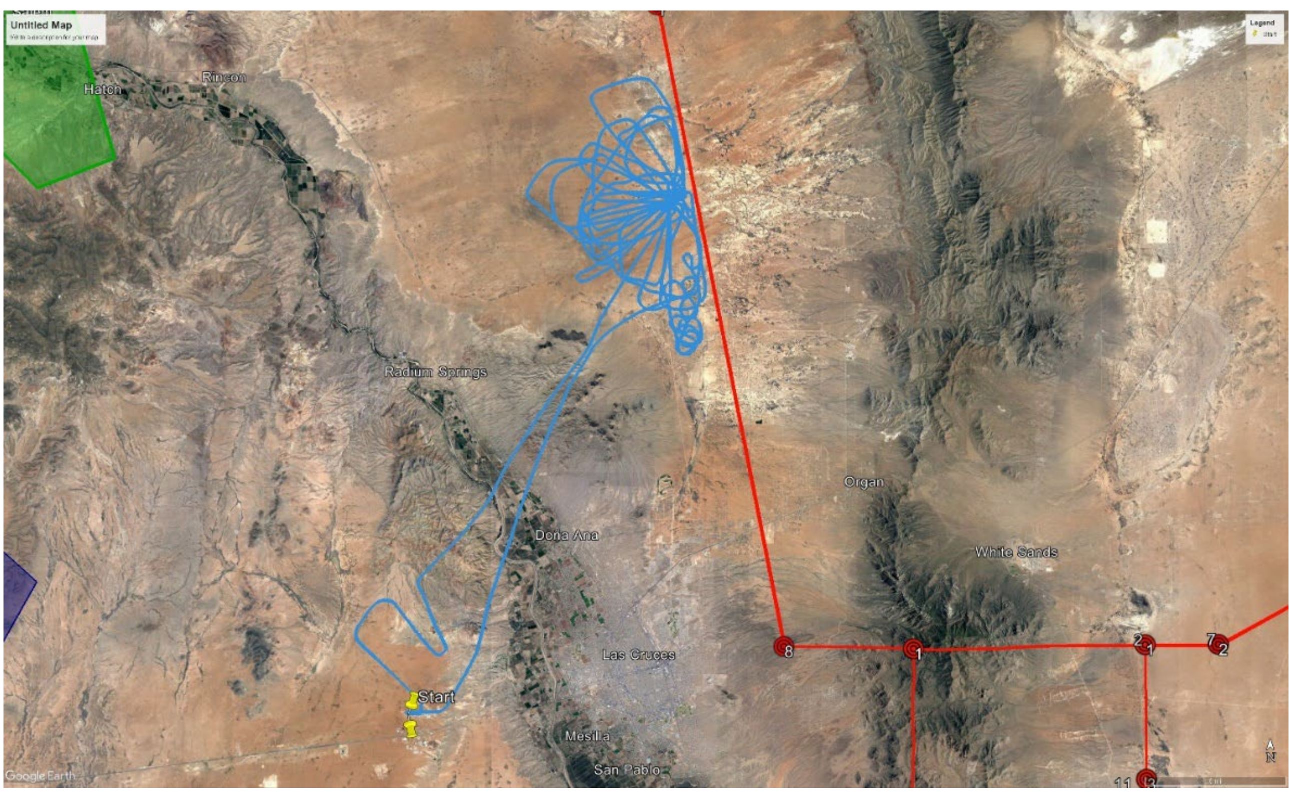


Figure 16. Full Flight Path for September 22, 2022.

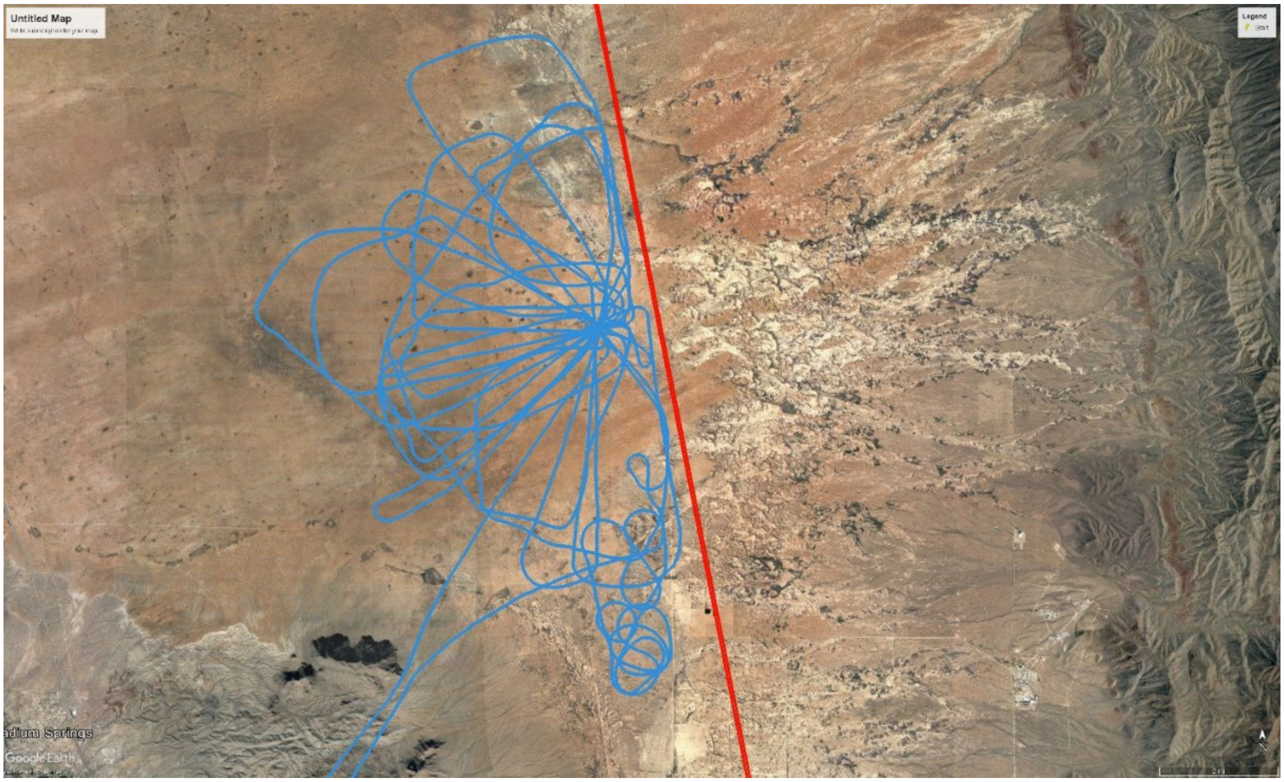


Figure 17. Flight Path Crossings on September 22, 2022.

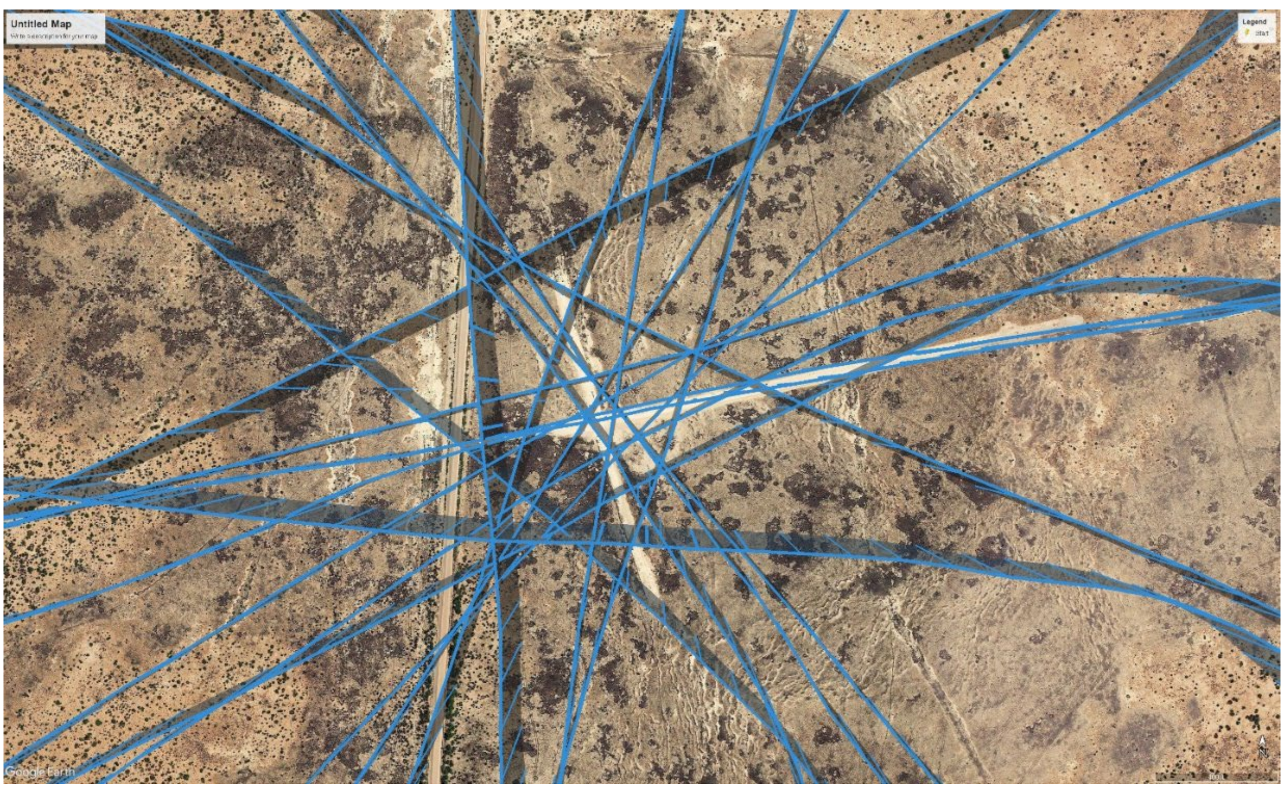


Figure 18. Close-up View of the Flight Path Crossings on September 22, 2022.

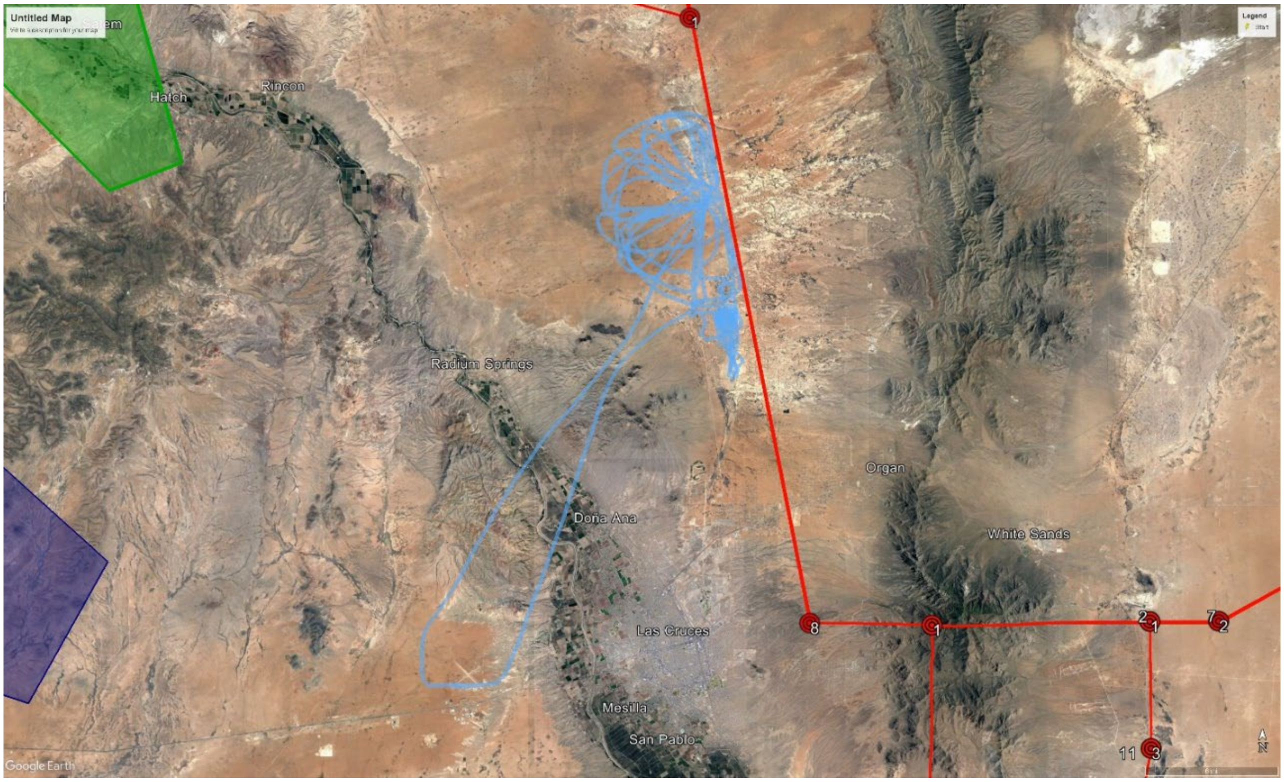


Figure 19. Full Flight Path for September 23, 2022.

Figure 20. Flight Path Crossings on September 23, 2022.

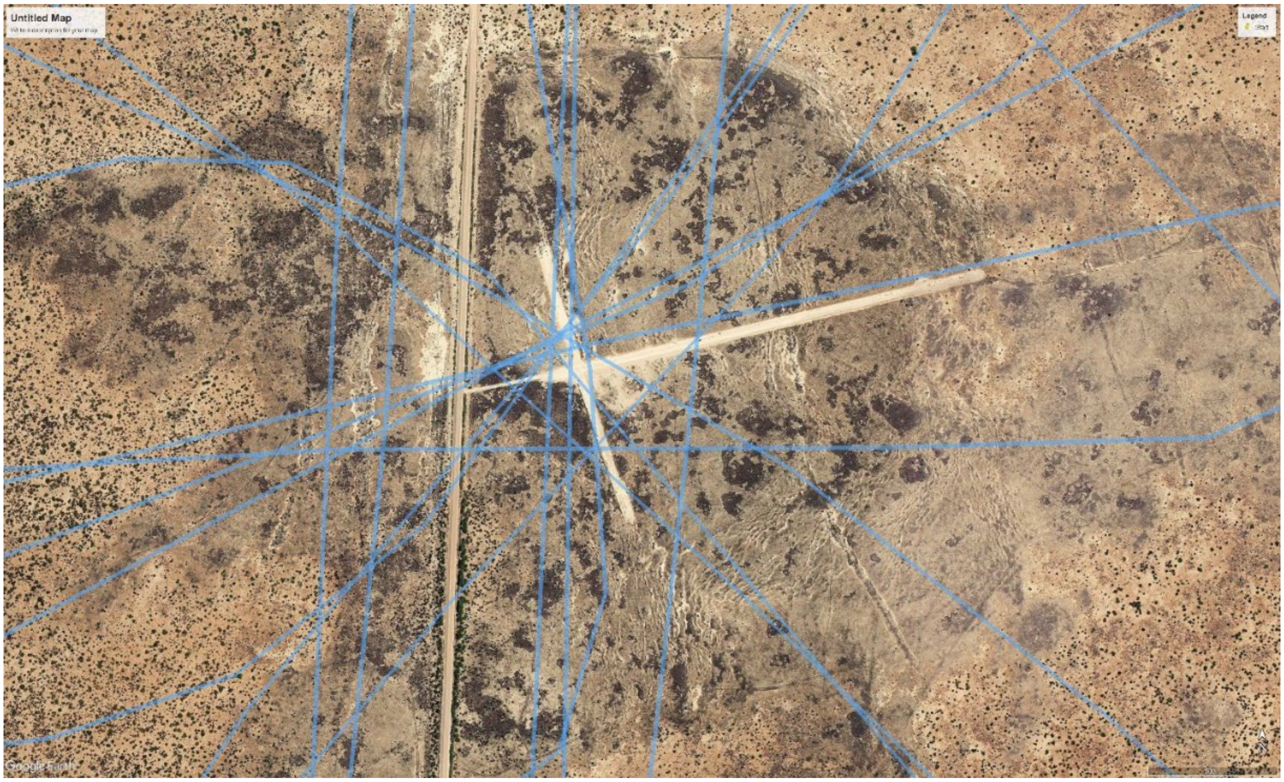


Figure 21. Close-up View of the Flight Path Crossings on September 23, 2022.

Over the three days of testing, there were a total of 143 runs, which were broken down as follows:

- 9/21: 3 subjects, 18 runs each = 54 potential data points
- 9/22: 2 subjects, 19 runs each = 38 potential data points
- 9/23: 3 subjects, 17 runs each = 51 potential data points

The initial runs were set with a start point of 5 miles out, but it was clear that the aircraft could not be seen at this distance. The starting point was moved to 4 miles out.

3.3.6.3 *NMSU VO Subject Data Collection*

A total of eight ground-based VOs served as participants in the initial flight testing at NMSU. Each operating station included an RPIC, a researcher, and a single ground-based VO. Table 2 shows the participants' IDs, visual acuity, aviation experience, and fatigue levels.

Table 2. NMSU Subject Data

Participant ID	Snellen Test (Best Eye)	Aviation Experience	Fatigue Level
D1P1	20/20	None	Well-rested
D1P2	20/20	None	Well-rested
D1P3	20/30	None	Well-rested
D2P1	20/20	None	Well-rested
D2P2	20/25	None	Neutral
D3P1	20/30	None	Neutral
D3P2	20/20	None	Well-rested
D3P3	20/20	None	Well-rested

3.3.6.4 *NMSU Flight and Testing Lessons Learned*

The NMSU team consolidated their initial notes and lessons learned from this testing event and provided them to the KSU team before subsequent flight testing occurred. The notes provided below are unfiltered items collected during post-testing. The entire test team provided inputs to the list below. Items listed run the gamut of recommendations, ranging from specific actions to general impressions and feelings arising from testing. Researchers did not attempt to resolve conflicting comments, thoughts, or impressions. The feedback and notes sometimes represented points that contrasted with the overall testing plan. The listing below represents the raw feedback from the NMSU team. Some items are germane to the New Mexico testing, and some are to the overall effort.

All the following points were reviewed and discussed before the round of testing at KSU. If necessary, KSU revised the test planning and execution. The items below are in no specific order and are grouped by topic area.

- Logistics
    - Participants met the research team at a local business and followed the research team to the testing site, guaranteeing no participants got lost.
    - All participants and research team members were encouraged to use the facilities before entering the field, as no restroom facilities were on site.
    - The drive from the local business to the testing site was approximately 30 minutes.
- Setup
    - Generators used in the field should be placed far enough away from the group/lecture/presentation area to not interfere with the talks/discussions.
    - Take photos of all areas for the test setup for reference - staged with team personnel and not with participants.

- A dedicated weather station on site for the sound and light meters is essential to ensure a sterile data collection environment.
- Copies of the desired callouts were taped to each table by the VOs – Note: several subjects asked for a compass to help with cardinal directions. Thus, a picture of a compass was taped to the VO tables for the KSU flight testing.
- Flight simulations were set for a takeoff point at each VO location.
- In the future, and in the interest of the flight crew's safety, do not set up a monitoring station in the middle of the east-west runway. If the intruder aircraft had a problem at the low altitudes they were flying, that would be the emergency runway. The aircraft may not always be within gliding distance of JER, but they were for a good part of the time.

- VO Briefing/Training
    - The VO training was difficult to conduct outside because of noise and glare on the computer screen, making the PowerPoint hard to see. Based on this observation, KSU presented the VO training PowerPoint inside their sUAS command trailer.
    - The initial VO brief took ~30 minutes.
    - Specific notes from the briefer who did all the VO training:
        - An individual with no experience will struggle with the PowerPoint presentation. It lacked materials for them to be successful.
        - Provide an array of scanning options for detecting aircraft. The slides suggest there are more options, so they should be provided.
        - Provide deviations in communication from VO to RPIC. There is no singular way to articulate an intruder aircraft.
        - Include an order of precedence if an intruder aircraft goes unnoticed in a rapid communications process. "Drop altitude NOW, Intruder aircraft." When the aircraft is safe, then relay additional information.
        - When the VO has no experience, specific steps in communication should be listed as optional. The main information that needs to be divulged is stating intruder, relative location, heading towards/away/no factor, and altitude.
        - When the VO has no experience, how can you expect them to recommend a maneuver accurately? The suggested maneuver is a dangerous metric to measure by. It is simulated, but putting this idea into a beginner's mind could form a hazardous habit.
        - When the VO has no experience, describing the altitude of an aircraft has no real meaning. They do not know what 500ft above ground looks like.
    - Provide a large sample of photos, video, and audio that characterizes an intruder aircraft.
        - A low-flying aircraft flying directly towards the VO. What does the profile of the plane look like? What does an aircraft sound like at 500 ft? What does a plane look like at 500ft, 1000ft, 1500ft, etc.?
    - Provide more practice slides or quizzes with actual videos of intruder aircraft. This can be a video of the open sky spanning several minutes to show what "normal" looks like while training.

    - Keep other support personnel and radio traffic away from the briefing area and impose a buffer zone.

Based on these observations by NMSU, KSU adjusted the training slides to include more practice slides for VOs. The research team member presenting the slides also quizzed each participant multiple times on these slides to gauge whether they had a grasp of the information presented. The VO trainer also utilized a local cell tower and power lines to demonstrate different heights. The local power lines are approximately 16 feet tall, whereas the cell tower is approximately 120 feet tall. While this was not the most pertinent comparison, it allowed the participants to attain a real-world view of what 120 feet looked like so they could grasp what the sUA operational height of 400 feet looked like.

- Communications
    - Utilizing two sets of radios allows for (1) communication linking all ground personnel and (2) communication linking the test director to the intruder aircraft. The VO teams could not hear the communication between the test director and the intruder aircraft.
    - For future testing, a better practice is not to have individuals carrying both sets of radios to ensure that aircraft radio calls do not get out to the VOs and ground team (and vice versa). We had no issues but realized splitting the two radio roles was best.
    - Each VO test location needs a unique identifier – NMSU used North, South, and East.
- Flight Test Execution
    - Test operational planning requires the test team to go through an entire practice session to ensure they know how to start the tests, record data, end the test, store test materials, etc. Practicing these procedures multiple times before the first test day ensured streamlined data collection.
    - The test cards had to be modified in real time due to the shorter test subject time. All flights were at 120 meters (~394 feet) AGL.
    - Timestamps were called out on the radio at 15-minute intervals and were captured on the three computers recording data in attempts to ease post-processing.
    - Aircraft range after crossing:
        - The aircraft were sent to 5 nm out for the first two crossings.
        - Team leads assessed the loss of aircraft visibility at ~3.5 to 4 miles out.
        - After the first two runs, the distance was changed to 4 miles out. The shorter distances decreased the cycle time between runs.
        - Post-testing, the VOs said they could not see the aircraft after each run except in one run by one person at a specific orientation. It appears that for our testing with this specific aircraft, 4 miles out was sufficient for a reset for the subsequent runs under these conditions.
        - See Table 3; the average time for the 4 miles out runs was ~6 minutes between passes.
    - During participant debriefing, participants voiced that they knew the sUA was a simulation and that it was easy to recognize the pattern as the aircraft was flying

at a constant altitude. Future testing would benefit from deviating the altitude during testing.

- Deviate the flight paths to have offset flybys. An example of alternating the wagon wheels' center points is shown in Figure 23.
- Once the participants realized the aircraft would fly only to this fixed point at a certain altitude, it created a high error margin.
- Conceptually, this does not simulate normalcy. The crewed aircraft incursions typically do not occur back-to-back. The VO is on edge, specifically watching for a specific intruder aircraft, which does not reflect typical operations.
- For example, runs on Wednesday, September 21, 2022, cross-over point to the center of the test area – aircraft directly overhead, approximate times between crossings. This "cycle time" meant approximately ten runs per hour.

Table 3. CLTS Run Time for September 21, 2022

Run	Time of Day	Distance	Time Between Runs
Run 1	2:22 PM		
Run 2	2:32 PM	5 miles out	0:10 minutes
Run 3	2:37 PM	4 miles out	0:05 minutes
Run 4	2:42 PM	4 miles out	0:05 minutes
Run 5	2:47 PM	4 miles out	0:05 minutes
Run 6	2:54 PM	4 miles out	0:07 minutes
Run 7	2:59 PM	4 miles out	0:05 minutes
Run 8	3:01 PM	4 miles out	0:02 minutes
Run 9	3:13 PM	4 miles out	0:12 minutes
Run 10	3:19 PM	4 miles out	0:06 minutes
Run 11	3:24 PM	4 miles out	0:05 minutes
Run 12	3:30 PM	4 miles out	0:06 minutes
Run 13	3:36 PM	4 miles out	0:06 minutes
Run 14	3:44 PM	4 miles out	0:08 minutes
Run 15	3:51 PM	4 miles out	0:07 minutes
Run 16	3:57 PM	4 miles out	0:06 minutes
Run 17	4:03 PM	4 miles out	0:06 minutes
Run 18	4:08 PM	4 miles out	0:05 minutes
		Average Run Time	0:06 minutes

A rough sketch of the approach orientations from the 18 runs completed on September 21 is detailed below in Figure 22. Figure 22 shows how random the approaches were; subsequent days were equally random.

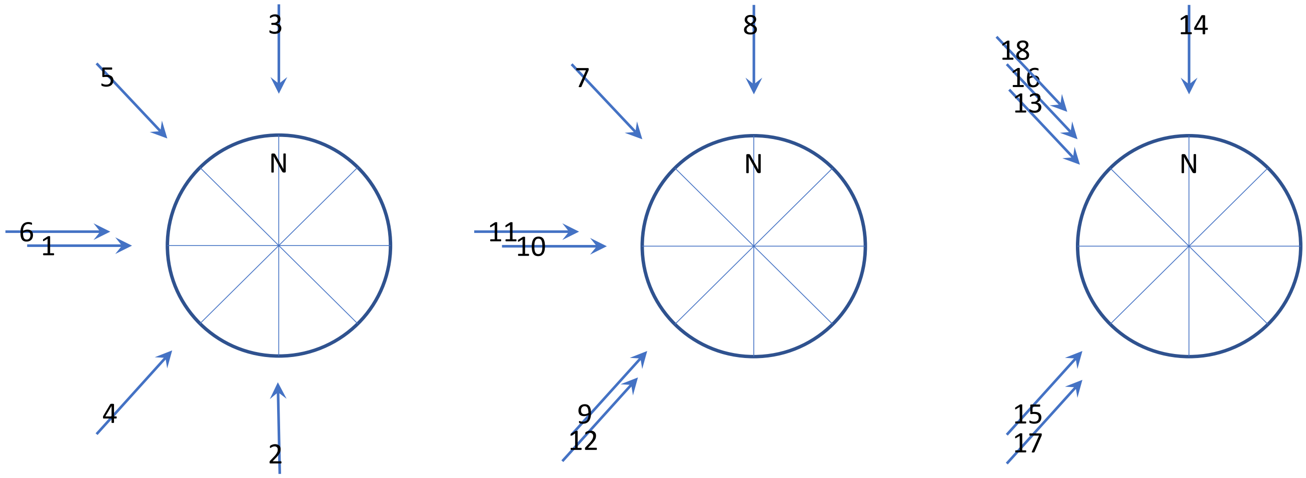


Figure 22. Example of the Random Intruder Approaches on Day 1 of NMSU testing.

- Post Testing
  - Closedown procedures for post-flight are essential to ensuring all recording devices are stopped and all data is captured.
  - A crewed aircraft is about 75 dB(A) when flying overhead.
  - Lay the lux meter and sound level meter on a flat surface away from other structures and noise sources. Use the Slow, Low Range, dB(A) settings on the sound level meter.
  - Put a blank for the time on the post-run RPIC questionnaires. This will help to identify associations between responses and given runs.
  - Work with the RPICs to standardize interactions with the subjects and their responses on the post-run questionnaires as much as possible.
  - Consider completing the VO training immediately before subjects complete the flight tests. They will forget some of the details otherwise.
  - Pin a mic to the subject to ensure you get a clear audio recording of their responses. Participants will not always be standing near the RPIC's laptop when making responses, so recording audio with the laptop's mic is not always ideal.

- Perceptual Testing
  - The hearing screening is initiated at 30 dB, with octave frequencies from 250 to 8000 Hz. If the subject has trouble with an ear/frequency combination at 30, boost in 5 dB steps until they can hear it, then record the stimulus level. Start with the right ear, then do the left. Subjects are seated in a sound-attenuated booth with the door open.
  - A quiet, indoor facility is necessary for hearing and vision testing. At NMSU, the ambient noise in the sound-attenuated booth with an open door is 19 dB(A).
  - The Snellen chart was used, with subjects located 20 feet away.
  - The Ishihara 38-plate booklet was utilized to determine color deficiency. Subjects went through the booklet and read out the numbers they saw on the plates.

- Post-test, additional inputs from participants were collected.
  - VOs asked when to reset as the intruder aircraft turned near the test area.

- VOs stated they could not predict the incoming direction. Restricted airspace did help them narrow this down.
- Subjects said they always heard the aircraft before they saw it, but they only responded when they saw the aircraft.
- Many participants were confused about the altitude part of the response. Participants said the aircraft's altitude was low relative to where airplanes usually are, so they always responded low.
- Subjects said that based on the VO Training, they knew the UA should never be above the crewed aircraft; thus, the command prompt "climb" did not apply to the operation.
- The tear-down for flight testing took 30 minutes.

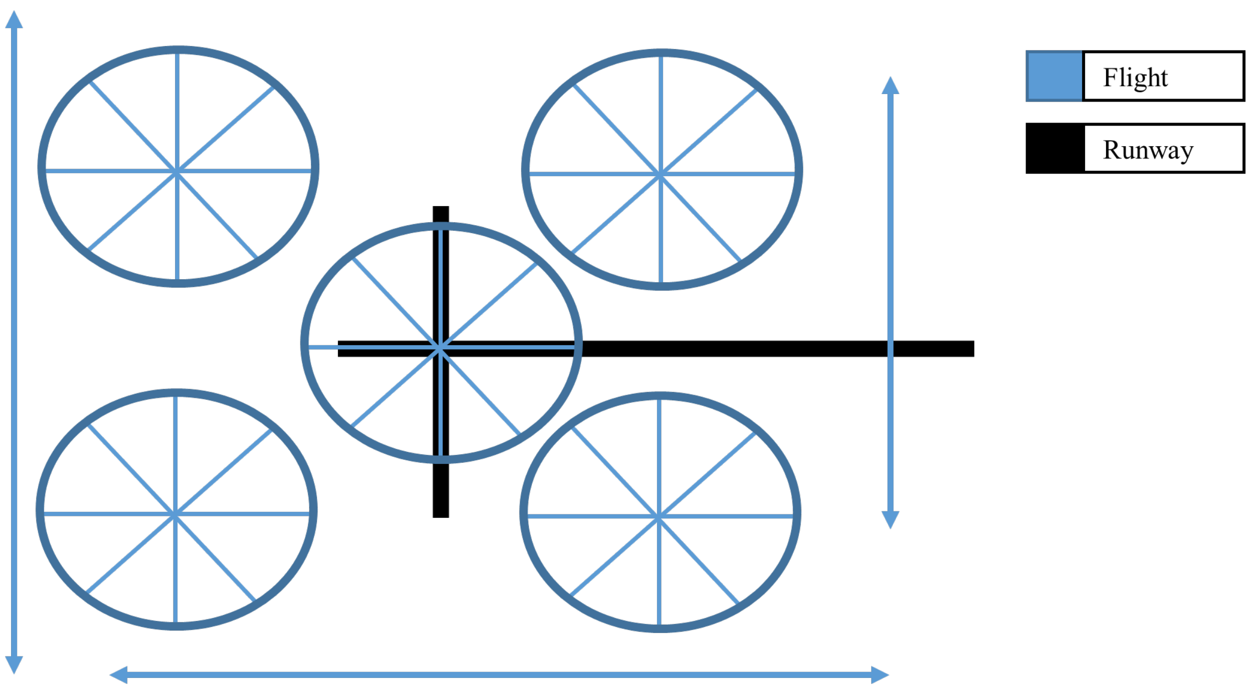


Figure 23. Potential Alternative Intruder Flight Paths.

3.3.6.5 *NMSU Flight Test Results*

This section provides results for the intruder detection distance, intruder speed at detection, and intruder position at detection for the initial flight tests.

Table 4 provides the descriptive statistics for intruder detection distance calculated for the NMSU flight test encounters with the CTLS intruder aircraft. The detection distances were computed for all 143 runs. The VOs detected the CTLS intruder aircraft at an average distance of 1.14 miles. This is an improvement over the average visual detection distance of 0.79 miles obtained by Dolgov (2016). In his study, Dolgov (2016) obtained visual acquisition distances of the CTLS aircraft in daytime conditions with 3 participants acting as VOs for 67 trials.

Table 4. Descriptive Statistics for Intruder Detection Distance Calculated for the NMSU Flight Test Encounters.

Intruder Detection Distance (miles)				
Intruder Aircraft: CTLS, Sample Size = 143 runs				
Min.	Max.	Mean	Median	Std. Deviation
0.05	3.49	1.14	1.06	0.50

Figure 24 shows the percentile distribution for intruder detection distance calculated for the NMSU encounters with the CTLS intruder aircraft. The VOs detected the intruder aircraft at a distance of at least 1 mile in 57.1% of the runs, at least 2 miles in 5.6% of the runs, and at least 3 miles in 0.9% of the runs.

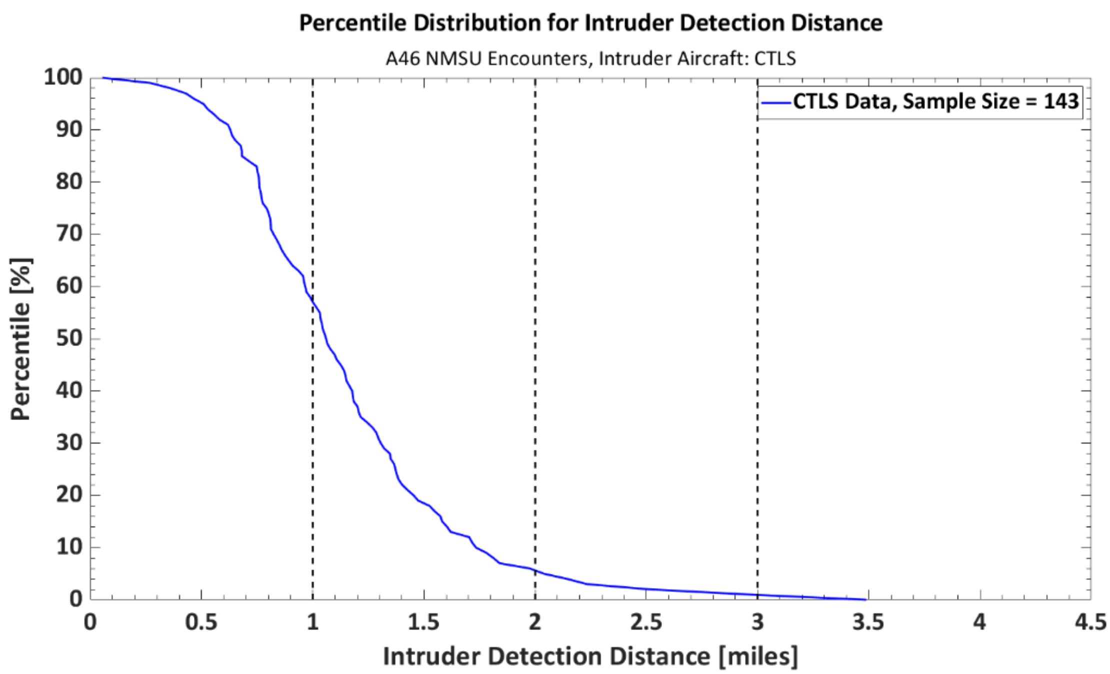


Figure 24. Percentile Distribution for Intruder Detection Distance Calculated for the NMSU Flight Test Encounters.

Table 5 provides the descriptive statistics for intruder speed at detection for the CTLS intruder aircraft used in the NMSU flight tests. The intruder aircraft speed was only available for 127 out of 143 runs in the flight data logs. The average speed at detection for the CTLS intruder aircraft was 95.8 kts.

Table 5. Descriptive Statistics for Intruder Speed at Detection for the NMSU Flight Test Encounters.

Intruder Speed at Detection [kts]				
Intruder Aircraft: CTLS, Sample Size =127 runs				
Min.	Max.	Mean	Median	Std. Deviation
68.2	113.6	95.8	97.7	9.2

Figure 25 shows the positions of the intruder aircraft at detection, VO stations, and the mission flight path for the NMSU flight test encounters. The center of the wagon wheel for the intruder aircraft tracks was directly above the VO locations. Figure 25 shows that most intruder detections were evenly distributed in all directions except in the east direction.

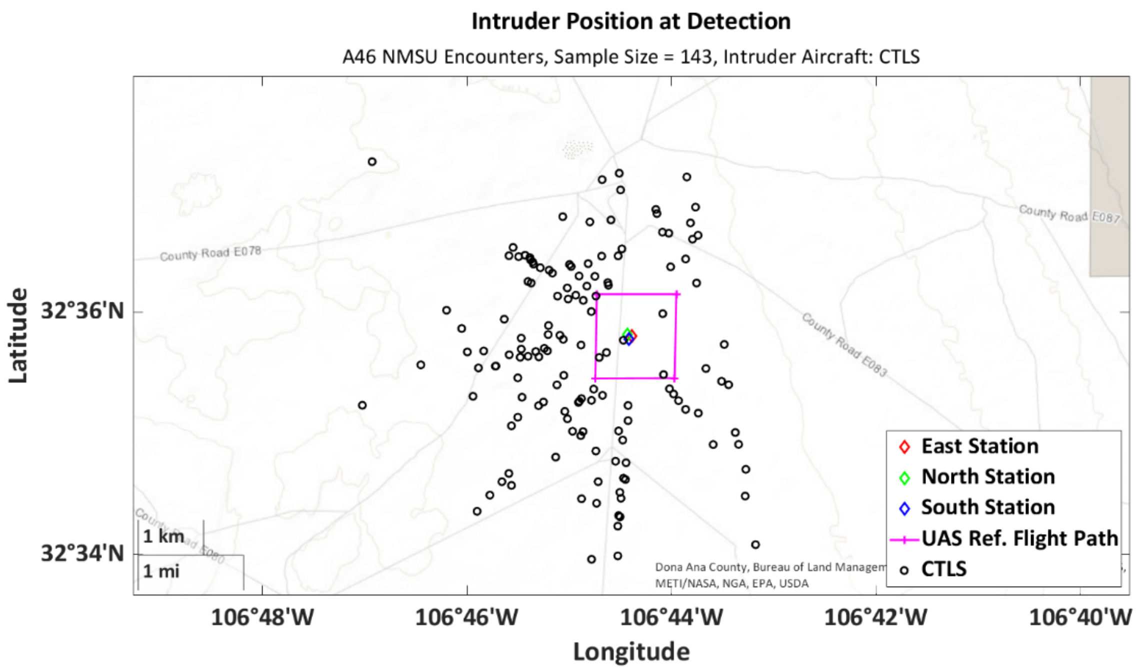


Figure 25. Positions of the Intruder Aircraft at Detection on a Map for the NMSU Flight Test Encounters.

3.3.7 Analysis of Aircraft Projected Area for NMSU and KSU Aircraft

Researchers used three different intruder aircraft between two rounds of VO testing. These were a CTLS Light Sport, a Cessna 172 Skyhawk, and a Cirrus Design SR20. These aircraft are distinctly different in size and shape, resulting in perceptible differences by observers. Since the size of the aircraft differed from every viewing angle, researchers attempted to provide general approximations of the shape, profile, and projected area an observer may see. Approximations accounted for the projected area when viewing the aircraft from the front, top, and side. These approximations are not intended to be exact. Still, they provided a relative value to assess how much the aircraft may fill the observers' field of view at different ranges (i.e., subtended arc within the field of view).

The approach used to estimate the projected areas is one that the research team has used in the past for estimating balloon flight payload impact areas and safety analysis. There are several methods to do this, and three different methods have been used for previous analyses. The three different approaches are "Blocks, Bubbles, and Bulk" techniques, all requiring a reference measurement.

- Blocks – estimation by grid overlay (what was used here).
- Bubbles – tracing the entire area in a computer-aided design program and looking at the resulting area of the generated shape. There are challenges with this approach based on the image quality and optics used to create the images (perspective and depth).
- Bulk – also called the "paper doll" method, where one prints two sheets of paper with the image. After carefully cutting out the image on one sheet, one weighs the entire sheet and the "paper doll cut out." This can be converted into an area based on the mass ratio.

The block grid estimation is appropriate for this analysis. Previous efforts have shown that results using all three approaches are comparable. The block area approach allows one to go back easily and further estimate component areas (e.g., wing area from a top-down view or fuselage area only from the front if you eliminate the wing area). One must count the blocks for the desired area towards a mathematical conclusion.

A simple description of the approach used was to (1) find a graphic of aircraft with measurements; (2) place on a grid overlay of known dimensions of aircraft for all three orientations (front, side, and top); (3) identify which blocks were at least 50% overlay of the aircraft; (4) count the number of blocks; and (5) calculate. The assessments of the projected areas of NMSU's CTLS from the side view are shown below in Figures 26 to 30. The projected areas for the CTLS from the side and top view and the C-172 and SR20 from the top, side, and front angle can be found in Appendix H.

Figure 26. NMSU's CTLS Light Sport Aircraft.

Figure 27. CTLS Shown from Different Angles.

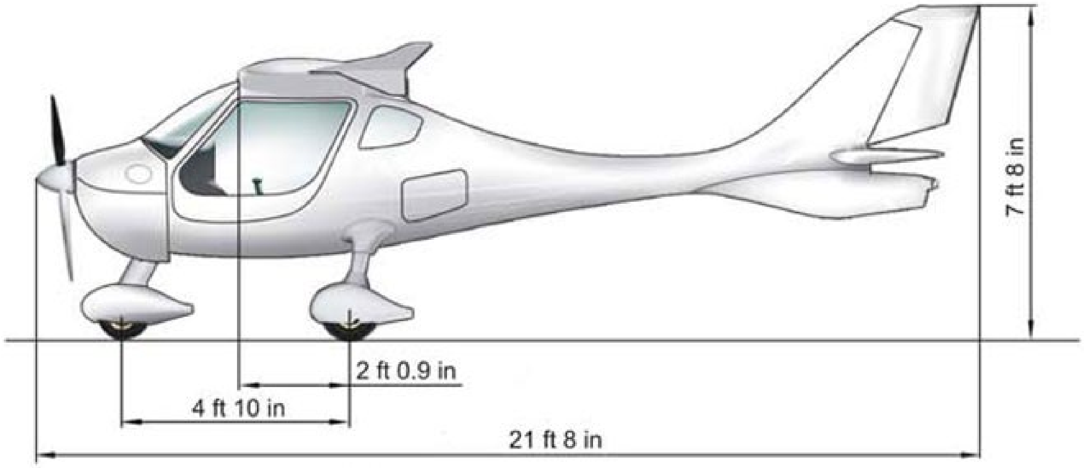


Figure 28. Side View of CTLS Used for Projected Area Assessment.

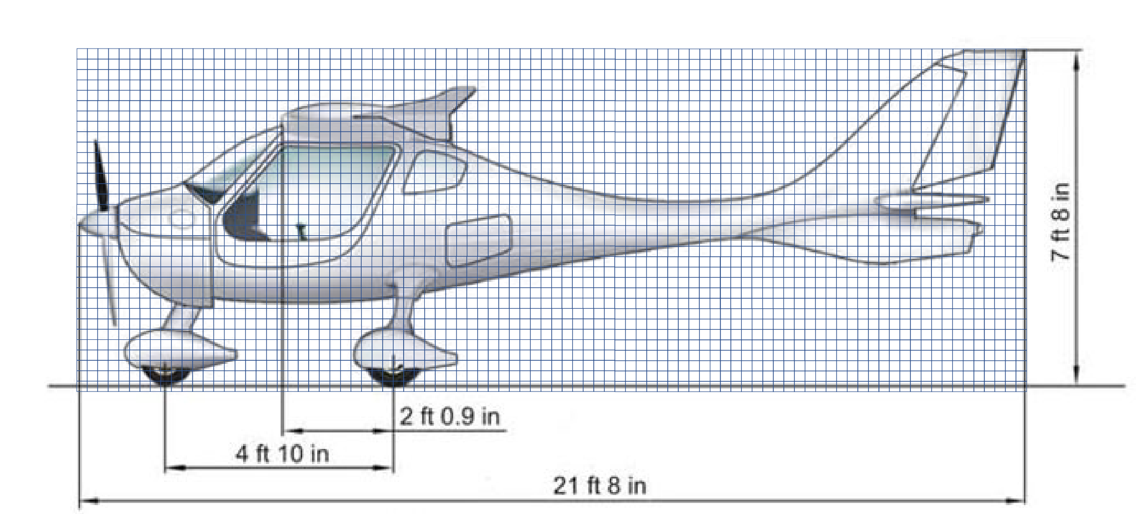


Figure 29. Grid Overlay of Side View of the CTLS.

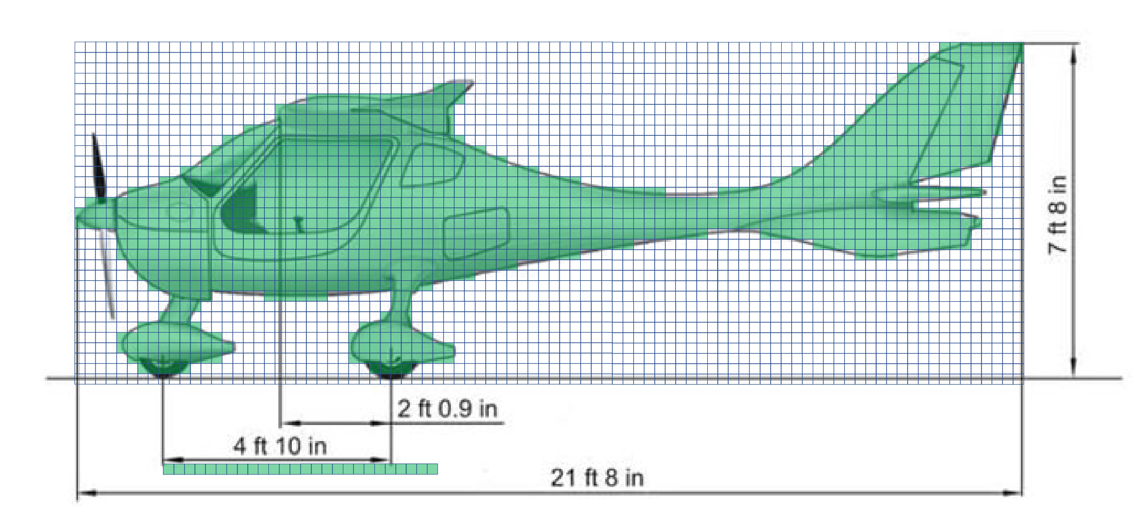


Figure 30. CTLS Side View Grid Overlay with Estimated Area. Each Block is 2.7 inches square or 7.34in^2. There are 1,126 blocks.

The estimated projected areas in both inches squared and feet squared were made using the estimated block sizes for each view and counting the total number of blocks. Further estimates were made for the wings, body, tail, and landing gear for the front profile. This was done because the wings are long, thin, and often not as easy to see when viewing the aircraft head-on.

The aircraft's body section presents the most straightforward element to see visually. Table 6 summarizes the estimated projected areas for all three aircraft.

Table 6. Estimated Projected Area for the CTLS, Cessna 172 Skyhawk, and Cirrus Design SR20 Aircraft.

Aircraft	View	Section	Block side dimension (in)	Area of each Block (in^2)	Number of Blocks	Area (in^2)	Area (ft^2)
CTLS	Side	N/A	2.71	7.34	1126	8,269.46	57.43
	Front	All	2.91	8.47	762	6,452.69	44.81
	Front	Wings	2.91	8.47	305	2,582.77	17.94
		Body			327	2,769.07	19.23
		Tail			44	372.60	2.59
		Landing Gear			86	728.26	5.06
	Top		5.64	31.81	684	21,757.77	151.10
172S	Side		3.684	13.57	1157	15,702.64	109.05
	Front	All	3.646	13.29	652	8,667.24	60.19
	Front	Wings and struts	3.646	13.29	318	4,227.27	29.36
		Body			214	2,844.77	19.76
		Tail			59	784.31	5.45
		Landing Gear			61	810.89	5.63
	Top		6.261	39.20	984	38,572.92	267.87
Cirrus Design SR20	Side		5.47	29.92	486	14,541.56	100.98
	Front	All	5.41	29.27	284	8,312.14	57.72
	Front	Wings and struts	5.41	29.27	129	3,775.58	26.22
		Body			102	2,985.35	20.73
		Tail			25	731.70	5.08
		Landing Gear			28	819.51	5.69
	Top		5.6	31.36	1150	36,064.00	250.44

These estimated projected areas serve only as general references. Observers seldom see an aircraft precisely from these perspectives. The actual view from the observer will be a blend of these perspectives. The size difference between the three aircraft is also noteworthy. The CTLS is smaller than the Cessna 172 Skyhawk and the Cirrus SR20. The Cessna 172 Skyhawk and the Cirrus SR20 are similar in size. A comparison of the aircraft sizes based on projected areas in Table 5 considers the three perspectives as follows:

- The side view projected area of the Cessna 172S is ~190% greater than the CTLS.
- The front view projected area of the Cessna 172S is ~134% greater than the CTLS.
- The top view projected area of the Cessna 172S is ~177% greater than the CTLS.

- The side view projected area of the Cirrus SR20 is ~176% greater than the CTLS.
- The front view projected area of the Cirrus SR20 is ~128% greater than the CTLS.
- The top view projected area of the Cirrus SR20 is ~166% greater than the CTLS.

- The side view projected area of the Cessna 172S is ~108% greater than the Cirrus SR20.
- The front view projected area of the Cessna 172S is ~104% greater than the Cirrus SR20.
- The top view projected area of the Cessna 172S is ~107% greater than the Cirrus SR20.

The size difference may correlate to the resulting detection distances and may be used to extrapolate the detection distance of aircraft smaller or larger than these three.

3.4 Task 4 – Flight Testing and Data Analysis

Following the development and initial testing of the experimental plan within Task 3, the research team carried out the designated experiments in Task 4. At the conclusion of this task, the research team consolidated data from the final flight testing at KSU to capture the results. This section offers an overview of the data and results. A database with the relevant parameters for all valid flight test encounters was generated and is provided in Appendix I.

3.4.1 KSU Aircraft

KSU flight tests used two aircraft types for the intruder aircraft: a Cessna 172 Skyhawk and a Cirrus SR20. Using two distinct aircraft platforms allows for comparisons of VO performance as a function of aircraft size and speed, as the Cessna 172 and the SR20 have different cruise speeds, wingspans, heights, and lengths, as broken down below. The simulated sUA was a Great Shark 330 simulated using Mission Planner Software; participants reviewed the specifications of this aircraft during the VO Training.

3.4.1.1 *Cessna 172 Skyhawk*

Figure 31 depicts the Cessna 172 Skyhawks in the KSU fleet. The Cessna 172 has a wingspan of 36 feet, a length of 27.17 feet, and a height of 8.92 feet. The cruise speed was 90 knots, and the altitude for this flight testing was 500 feet AGL.

Figure 31. KSU Cessna 172 Skyhawk.

3.4.1.2 *Cirrus SR20*

Figure 32 displays one of the Cirrus SR20s in the KSU fleet. The Cirrus SR20 has a wingspan of 38.3 feet, a length of 26 feet, and a height of 8.9 feet. The cruise speed is 110 knots, and the altitude for this flight testing was 500 feet AGL.

Figure 32. KSU Cirrus SR20.

3.4.1.3 *Great Shark 330*

Figure 33 displays the Great Shark 330 with a wingspan of 11 feet, a cruise altitude of 400 feet AGL, and a cruise speed of 45 knots.

Figure 33. KSU Great Shark 330.

3.4.2 KSU Participant Breakdown

A total of 19 ground-based VOs served as participants in this study. Each participant was assigned an ID based on the test day and their operating station. Each operating station included an RPIC, a researcher, and a single ground-based VO. A minimum of two operating stations were active on any given test day. Three operating stations were active on three out of the eight test days. The participants' assigned ID, test day and date, Snellen test results (visual acuity), aviation experience, fatigue levels, and hearing test results are reported in Table 7. The participants on the first four days detected the Cessna 172 aircraft, and the participants on the remaining four days detected the SR20 aircraft.

Table 7. KSU Participants' Snellen Test Results, Aviation Experience, and Fatigue Levels

ID	Test Day and Date	Snellen Test Results (R and L)		Aviation Experience	Fatigue Level	Hearing Test Results (Best Ear)
D1P1	Day 1 (11/01/22)	20/15	20/15	None	Not reported	All Frequencies at 30dB
D1P2	Day 1 (11/01/22)	20/20	20/20	Remote Pilot	Well rested	All Frequencies at 35dB
D2P1	Day 2 (11/10/22)	20/20	20/25	Remote and Private Pilot	Neutral	All Frequencies at 30dB
D2P2	Day 2 (11/10/22)	20/15	20/15	Remote Pilot	Well rested	All Frequencies at 30dB
D2P3	Day 2 (11/10/22)	20/13	20/13	Remote and Private Pilot	Extremely well rested	All Frequencies at 30dB
D3P1	Day 3 (03/28/23)	20/15	20/15	Remote and Private Pilot	Well rested	All Frequencies at 30dB

D3P2	Day 3 (03/28/23)	20/13	20/13	Remote Pilot	Well rested	All Frequencies at 30dB except 8kHz on the Left Ear
D4P1	Day 4 (04/10/23)	20/30	20/15	Student Pilot	Well rested	All Frequencies at 30dB
D4P2	Day 4 (04/10/23)	20/13	20/15	None	Well rested	All Frequencies at 30dB
D5P1	Day 5 (07/10/23)	20/13	20/13	None	Neutral	All Frequencies at 30dB
D5P2	Day 5 (07/10/23)	20/13	20/20	None	Neutral	All Frequencies at 30dB
D5P3	Day 5 (07/10/23)	20/15	20/13	None	Neutral	All Frequencies at 30dB
D6P1	Day 6 (07/20/23)	20/30	20/13	None	Neutral	All Frequencies at 30dB except 8 kHz on the Left Ear
D6P2	Day 6 (07/20/23)	20/20	20/20	None	Not rested	All Frequencies at 30dB
D7P1	Day 7 (07/31/23)	20/25	20/20	None	Well rested	All Frequencies at 30dB except 0.25kHz on the Left Ear
D7P2	Day 7 (07/31/23)	20/13	20/20	None	Not rested	All Frequencies at 35dB except 0.25kHz on the Left Ear
D7P3	Day 7 (07/31/23)	20/13	20/20	None	Neutral	All Frequencies at 35dB
D8P1	Day 8 (08/11/23)	20/13	20/13	None	Well rested	All Frequencies at 35dB
D8P2	Day 8 (08/11/23)	20/13	20/30	None	Well rested	All Frequencies at 35dB except 4 and 8 kHz on the Left Ear

3.4.3 *Location of VO Stations and UAS Reference Path*

The VOs were located at predetermined stations. A minimum of two and a maximum of three operating stations were active on a given test day. Researchers gave the operating stations (also referred to as VO stations) the following IDs: P1, P2, and P3. The three VO stations were located approximately 200 ft apart from each other. Figure 34 shows the locations of the operating stations along with the reference UA flight path. The UA flight path was a box pattern defined using four waypoints, as shown in Figure 34. The box pattern's center was about 1.25 miles north of the VO stations. The simulated UA operated at a constant speed of 45 knots and a constant altitude of 400 ft AGL throughout its mission flight path.

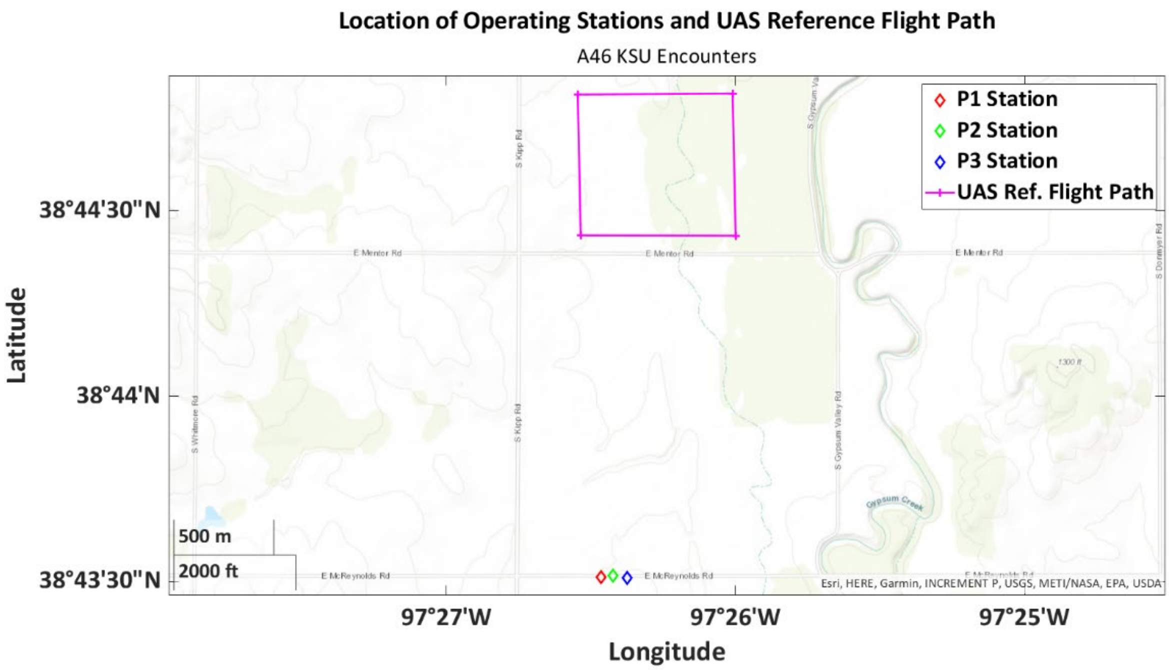


Figure 34. Location of Operating Stations and UA Reference Flight Path for the KSU Flight Test Encounters.

3.4.4 *KSU Flight Test Results*

3.4.4.1 *Dependent and Independent Variables*

Table 8 lists the dependent and independent variables of interest for this study. The primary dependent variable of interest was the intruder detection distance. This variable was used to determine the detection performance of VOs. The dependent variables, including (1) the VO-suggested maneuvers and (2) the Mitigated and Unmitigated CPAs, were used to determine the effectiveness of VOs and RPICs in maintaining the separation between the UA and the intruder aircraft. Other dependent variables, including (1) the response times to initiate the UA avoidance maneuvers and (2) to complete the avoidance maneuvers, were used to quantify the breakdown of reaction times involved in the detection and avoidance sequence by human subjects. The RPIC maneuvered the UA in the vertical domain, as suggested by the VOs. However, the maneuvers in the horizontal domain and the start and end times for the maneuvers were determined and implemented by the RPIC.

Table 8. Dependent and Independent Variables

Dependent Variables	Independent Variables
Intruder Detection Distance	Ambient Light Levels
VO Suggested Maneuver	Ambient Noise Levels
Response Time to Initiate an Avoidance Maneuver	VO Aviation Experience
Response Time Complete an Avoidance Maneuver	VO Visual Acuity
Closest Point of Approach, Horizontal and Vertical Miss Distances for Mitigated Encounters	Intruder Aircraft Speed
Closest Point of Approach, Horizontal and Vertical Miss Distances for Unmitigated Encounters	Intruder Aircraft Size (Projected Visual Area/Visual Angle)

The independent variables of interest in this study included (1) ambient light and ambient noise levels, (2) the participant's aviation experience and visual acuity, and (3) the intruder aircraft characteristics, including the speed and the visual angle/projected visual area. The ambient light and noise levels were confounding to a certain extent. For example, the ambient light levels varied with the days' time and the amount of cloud cover. While the time of day could be controlled in this experiment, the variation in cloud cover was out of the research team's control. This also resulted in a secondary confounding variable – the contrast between the intruder aircraft and the background sky. Similarly, the ambient noise levels were confounding due to noise pollution by high winds and gusts on certain testing days. The intruder aircraft's speed was a function of the type of intruder aircraft. The target groundspeed during the encounters was 90 kts for the Cessna 172 intruder aircraft and 110 kts for the SR20 intruder aircraft. The following sections discuss the descriptive statistics analysis for the dependent variables. The relationship between the intruder detection distance and the independent variables is also discussed in these sections.

3.4.4.2 *Intruder Detection Distance Descriptive Statistics*

Table 9 provides the descriptive statistics for intruder detection distance calculated for the KSU flight test encounters with the Cessna 172 intruder aircraft, the SR20 intruder aircraft, and the combined dataset. The VOs detected the intruder aircraft (Cessna 172 & SR20) at an average distance of 1.67 miles. The VOs detected the Cessna 172 intruder aircraft at an average distance of 1.90 miles and the SR20 intruder aircraft at an average of 1.46 miles. The results from this study are comparable with the Vance et al. (2017) study that conducted 49 flight test encounters with 10 participants acting as VOs and the Cessna 172 aircraft as intruders. The study's established visual detection distance for intruder aircraft was 0.31 miles to 3.87 miles, with an average of 1.63 miles.

Table 9. Descriptive Statistics for Intruder Detection Distance Calculated for the KSU Flight Test Encounters.

Intruder Detection Distance (miles)				
Intruder Aircraft: Cessna 172 & SR20, Sample Size = 340 runs				
Min.	Max.	Mean	Median	Std. Deviation
0.05	4.24	1.67	1.54	0.70
Intruder Aircraft: Cessna 172, sample Size = 157 runs				
Min.	Max.	Mean	Median	Std. Deviation
0.05	4.24	1.90	1.69	0.81
Intruder Aircraft: SR20, sample Size = 183 runs				
Min.	Max.	Mean	Median	Std. Deviation
0.22	3.90	1.46	1.45	0.51

Figure 35 shows the percentile distribution for intruder detection distance calculated for the KSU encounters with the Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The VOs detected the intruder aircraft (Cessna 172 & SR20) at a distance of at least 1 mile in 89.5% of the runs, a distance of at least 2 miles in 22.6% of the runs, and a distance of at least 3 miles in 3.3% of the runs. The VOs detected the Cessna 172 intruder aircraft at a distance of at least 1 mile in 90.8% of the runs, a distance of at least 2 miles in 37% of the runs, and a distance of at least 3 miles in 9.2% of the runs. The VOs detected the SR20 intruder aircraft at a distance of at least 1 mile in 88.3% of the runs, at least 2 miles in 10.5% of the runs, and at least 3 miles in 1% of the runs.

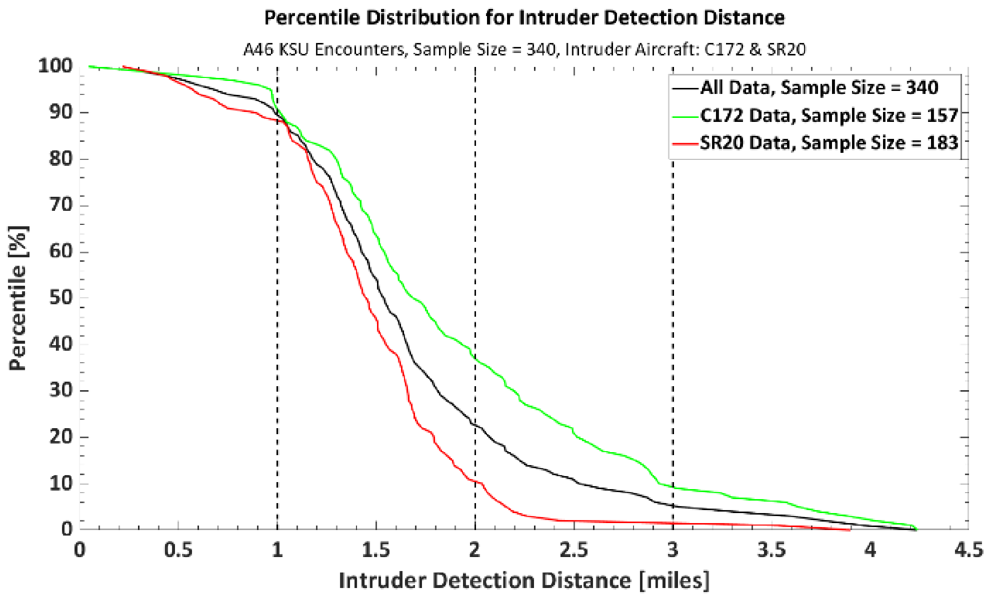


Figure 35. Percentile Distribution for Intruder Detection Distance Calculated for the KSU Flight Test Encounters.

Figure 36 shows the positions of the intruder aircraft at detection, VO stations, and the UA flight path for the KSU flight test encounters. The intruder positions shown in Figure 36 closely follow the intruder aircraft tracks along the wagon wheel described in the experiment plan. The center of this wagon wheel in the KSU flight test encounters was in the same area as the UA flight path and, therefore, offset from the VO stations. It can be observed from Figure 36 that most of the detections occurred in the direction north of the VO stations. The complete set of intruder flight paths plotted on a map for the eight days of testing is provided in Appendix J.

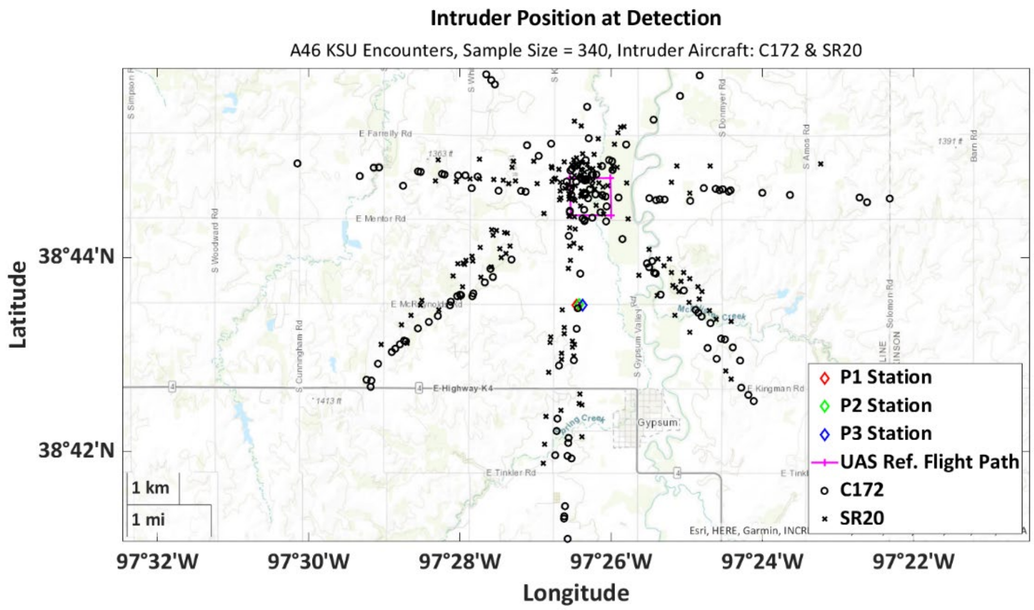


Figure 36. Positions of the Intruder Aircraft at Detection on a Map for the KSU Flight Test Encounters.

3.4.4.3 *Intruder Detection Distance as a Function of the Ambient Light Levels*

The research team evaluated the statistical relationship between the intruder detection distance and the independent variables described in section 3.4.5.1. The first independent variable investigated was the ambient light levels at the time of detection. The ambient light levels depend on the time of the day as the sun's position varies over time. The ambient light levels also depend on the amount of cloud cover and the scattering of the light in the atmosphere. The subsequent sections discuss the variation of the ambient light levels with the time of the day and the relationship between the intruder detection distance and the ambient light levels.

3.4.4.3.1 Variation of Ambient Light Levels with the Time of Day

Figure 37 shows the variation of the ambient light levels at detection with the local time of the day at detection for the eight test days. Two light meters were active during testing and located at designated weather stations between the first (P1) and second (P2) stations and the second and third (P3) stations. For the test days with a third VO station active, the light levels corresponding to this station were obtained by averaging the light meter readings corresponding to the first and second VO stations. Figure 37 shows that the two light meters had different readings for the same time and day on most test days. For example, the first light meter readings on the Day 3 (March 28, 2023) tests were close to 75,000 lux, while the second light meter readings were close to 100,000 lux. This difference could be due to one or a combination of the following factors: the positioning of the sensors of the light meters, the cloud cover variation in the sky, and the sun's position.

The ambient light level intensity at the time of detection was 13,000 to 116,000 lux for the KSU flight tests. Testing conducted by Bharathwaj and Srinivasan (2009) showed that ambient light levels with intensity values less than 40,000 lux indicate an overcast sky, and values greater than 100,000 lux indicate a bright, clear sky condition-based on their testing.

The main observations from Figure 37 are (1) light intensity levels during 09:00-10:00 hours were lower (< 80,000 lux) and peaked during 12:00-13:00 hours, and (2) most of the light intensity level readings for the Day 2 (November 10, 2022) tests were < 40,000 lux indicating overcast conditions. Appendix K provides a detailed breakdown of the meteorological conditions for each testing day.

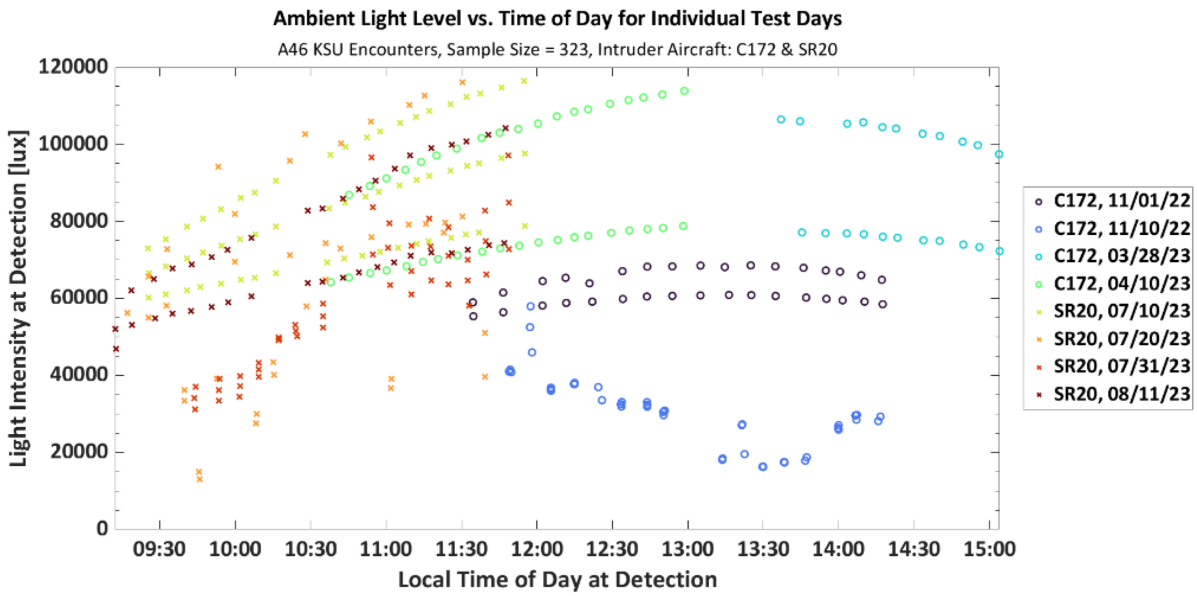


Figure 37. Scatter Plot for Intruder Aircraft Detection Distance vs. Light Intensity Levels at Detection for the KSU Flight Test Encounters.

3.4.4.3.2 Variation of Intruder Detection Distance with the Ambient Light Levels

Figure 38 shows the relationship between the intruder detection distance values and the ambient light levels at the time of detection. A linear regression model was computed for this data (shown in Figure 38). The coefficient of determination (R^2) value for the regression model is very low (< 1), indicating a high spread for the data. The Spearman correlation (r_s) value was computed at -0.17 for this data, showing a weak negative correlation between the intruder detection distance and the ambient light level. The Spearman probability (p_s) value was computed to be 0.022 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the ambient light level.

The two main observations from Figure 38 are (1) detection distances were significantly higher for ambient light intensity values < 40,000 lux (overcast conditions), and (2) the majority of the lower detection distance values (< 1 mile) occurred for ambient light intensity values > 60,000 lux (partly cloudy or bright sunny conditions).

Figure 39 shows the relationship between the intruder detection distance values and the ambient light level at the time of detection color-coded for the individual test days. The main observation from Figure 39 is that the higher detection distance values (> 3 miles) corresponded to the lower light intensity values (< 40,000 lux) that occurred during Day 2 (November 10, 2022) tests. Figure 40(a) shows an image of the Cessna 172 intruder aircraft captured from a GoPro camera mounted on the head of a VO during one of the runs with overcast conditions. Here, the contrast between the intruder aircraft and the background sky was high, thereby increasing the intruder aircraft's visibility. On the other end of the spectrum, Figure 40(b) shows an image of the test site captured from a GoPro camera mounted on the head of a VO during one of the runs with bright sunny conditions. Here, the VO was facing east, with the sun positioned closer to the horizon. The bright background sky resulted in a poor contrast with the intruder aircraft, thereby decreasing the intruder aircraft's visibility.

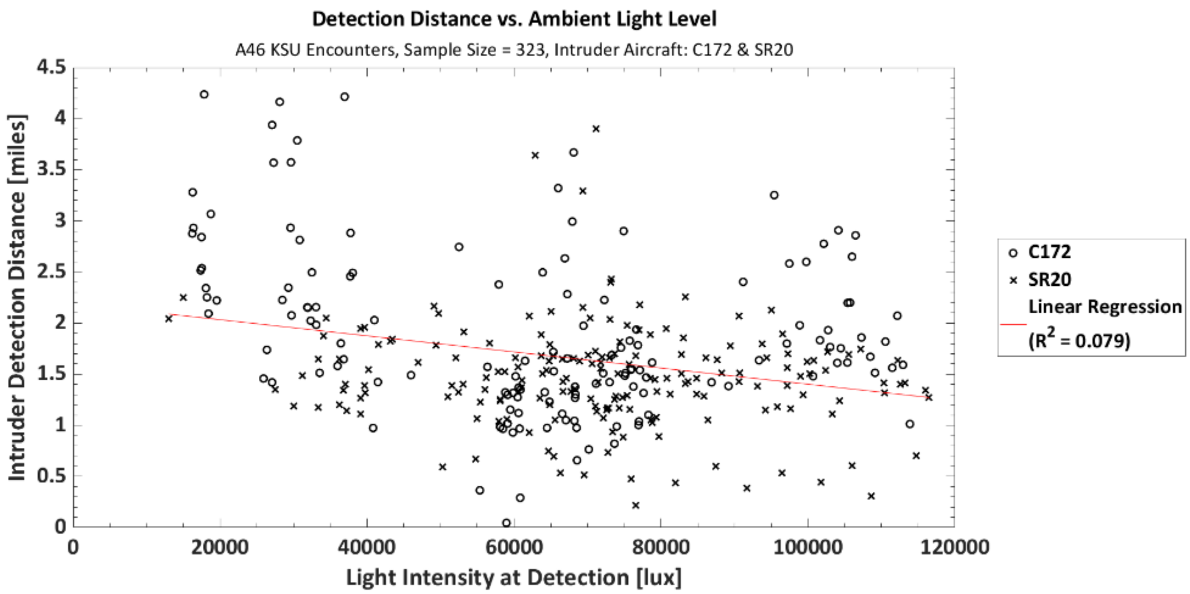


Figure 38. Scatter Plot for Intruder Detection Distance vs. Light Intensity at Detection for the KSU Flight Test Encounters.

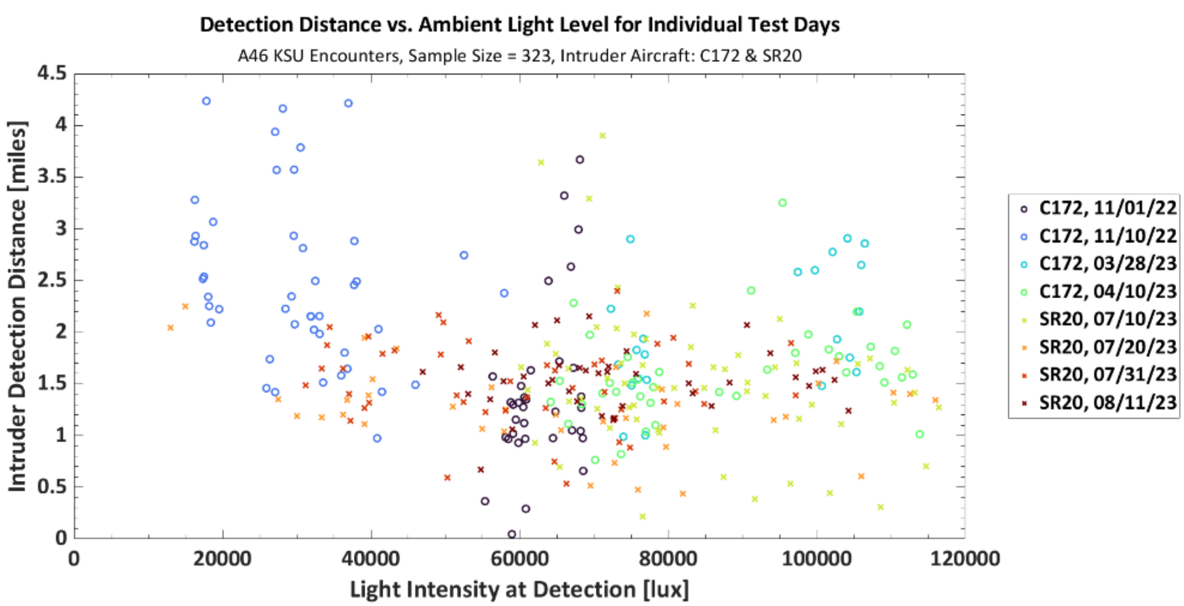


Figure 39. Scatter Plot for Intruder Detection Distance vs. Light Intensity at Detection for the KSU Flight Test Encounters.

(a) (b)

Figure 40. Images from GoPRO camera mounted on the VOs during the KSU flight test encounters (a) one of the runs from Day 2 tests with overcast conditions, and (b) one of the runs from Day 6 tests with bright sunny conditions.

3.4.4.4 *Intruder Detection Distance as a Function of the Ambient Noise Levels*

The second independent variable the research team investigated was the ambient noise levels at the time of detection. Figure 41 shows the relationship between the intruder detection distance values and the ambient noise levels at the time of detection, adjusted for outliers. Most of the noise level readings shown in Figure 41 range from 30 to 60 dB. The outlier data included noise level readings from the Day 2 tests in the 60 to 90 dB range. Table 10 lists the average wind speeds and direction and maximum gust speeds for the duration of the tests. The average wind speed was 16 mph during the Day 2 tests. The higher wind speeds and the wind direction on the Day 2 tests could contribute to the higher noise level readings compared to the rest of the data.

Table 10. Wind and Gust Speeds, Direction for the Eight KSU Flight Test Days.

Test Day	Avg. Wind Speed	Max. Gust Speed	Wind Direction
Day 1 (11/01/22)	~20 mph	31 mph	From SW
Day 2 (11/10/22)	~16 mph	0 mph	From NW
Day 3 (03/28/23)	~5 mph	0 mph	From NE & SW
Day 4 (04/10/23)	~7 mph	0 mph	From NW
Day 5 (07/10/23)	~14 mph	22 mph	From SW
Day 6 (07/20/23)	~11 mph	21 mph	From NE
Day 7 (07/31/23)	~9 mph	0 mph	From SE
Day 8 (08/11/23)	~10 mph	0 mph	From SW

Researchers removed the outlier data for statistical analyses. Figure 41 shows a linear regression model computed for the new data and adjusted for the removed outliers. The coefficient of determination (R^2) value for the regression model is very low (< 1), indicating a high spread for the data. The Spearman correlation (r_s) value was -0.198 for this data, indicating a weak negative correlation between the intruder detection distance and the ambient noise level. The Spearman probability (p_s) value was 0.011 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the ambient noise level.

Unlike the ambient light levels, the ambient noise levels did not directly impact the VO detection performance. Based on anecdotal evidence, most KSU participants reported seeing the intruder aircraft before hearing its noise signature. Therefore, the statistical relationship presents as follows: lower values of intruder detection distance resulted in higher noise level readings at the time of detection. This intuitively makes sense. When the aircraft was closer to the VO stations (sound meters were located near them), its noise signature was louder, resulting in a higher noise level reading.

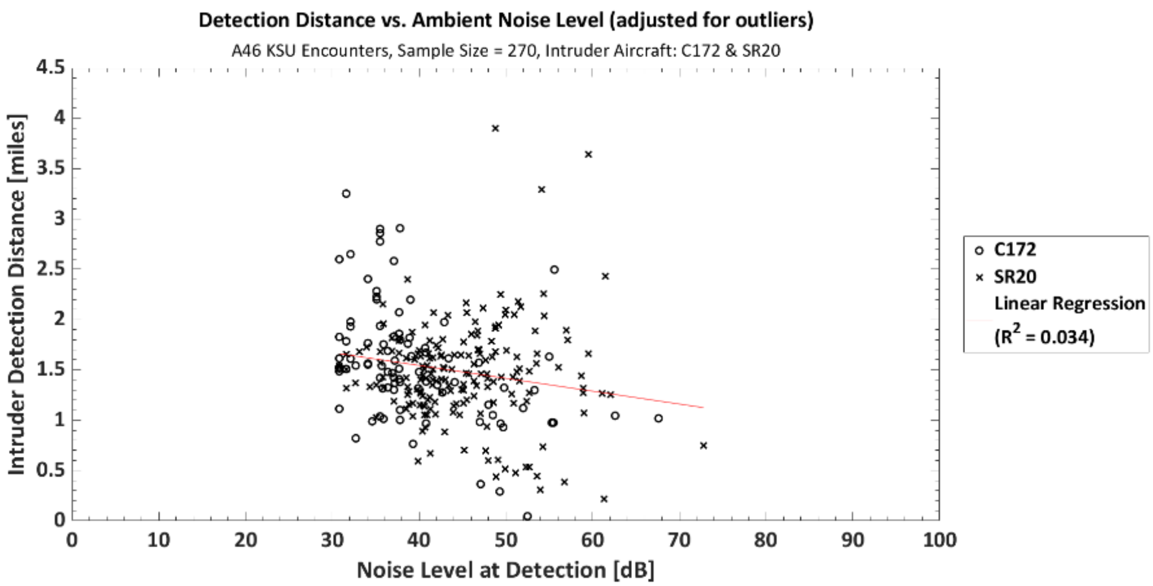


Figure 41. Scatter plot for Intruder Detection Distance vs. Noise Level at Detection (Adjusted for outliers) for the KSU Flight Test Encounters.

3.4.4.5 *Intruder Detection Distance as a Function of the VO Aviation Experience Level*

The third independent variable investigated was the VO Aviation Experience level. The research team defined three VO Aviation Experience level categories: Low, Medium, and High. VOs with no prior aviation experience were categorized as Low. VOs that were remote pilots or student pilots were categorized as Medium. VOs that had completed their private pilot certification were categorized as High. Figure 42 shows the percentile distribution for the intruder detection distance as a function of the VO Aviation Experience categories. The analysis of variance (ANOVA) statistical test proved inconclusive in determining this independent variable's statistical significance. One possible reason for this could be the insufficient number of runs for the Medium (71) and High (49) categories in comparison with the Low (220) category.

It can be observed from Figure 42 that VOs in the High category had a better detection performance compared to the VOs in the Low and Medium categories. For example, VOs in the High category detected the intruder at a distance of at least 2 miles in about 65% of their runs. In comparison, VOs in the Medium and Low categories detected the intruder at a distance of at least 2 miles in only about 30% and 10% of their runs, respectively. The VOs for the SR20 intruder aircraft flight test encounters all belonged to the Low category. Therefore, the VO Aviation Experience level could partly be responsible for the deterioration in the VO detection performance observed in Figure 35 for the SR20 intruder aircraft runs.

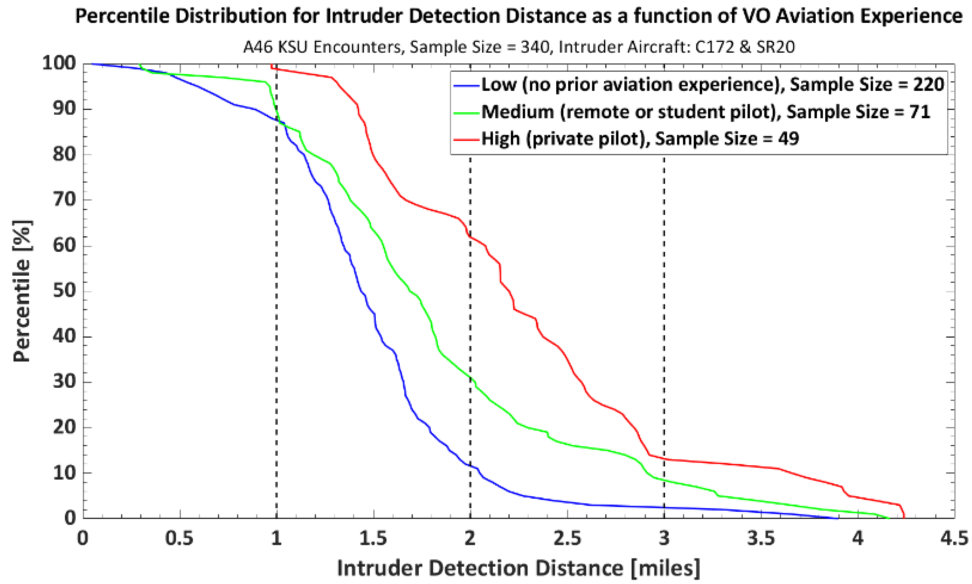


Figure 42. Percentile Distribution of Intruder Aircraft Distance as a Function of the VO Aviation Experience Categories for the KSU Flight Test Encounters.

3.4.4.6 *Intruder Detection Distance as a Function of the VO Visual Acuity*

The fourth independent variable investigated was VO Visual Acuity. The research team defined two categories for VO Visual Acuity – Low and High. VOs with vision worse than 20/20 (corrected) in either eye were categorized as low. VOs with 20/20 vision or better for both eyes were categorized as High. Figure 43 shows the percentile distribution for the intruder detection distance as a function of the VO Visual Acuity categories. The ANOVA test p-value was 0.6140 (> 0.05), indicating a statistically insignificant relationship between the intruder detection distance and the VO Visual Acuity. Figure 43 shows that VO detection performance was similar for the Low and High categories of VO Visual acuity. The total number of runs was 69 for the Low category and 271 for the High category.

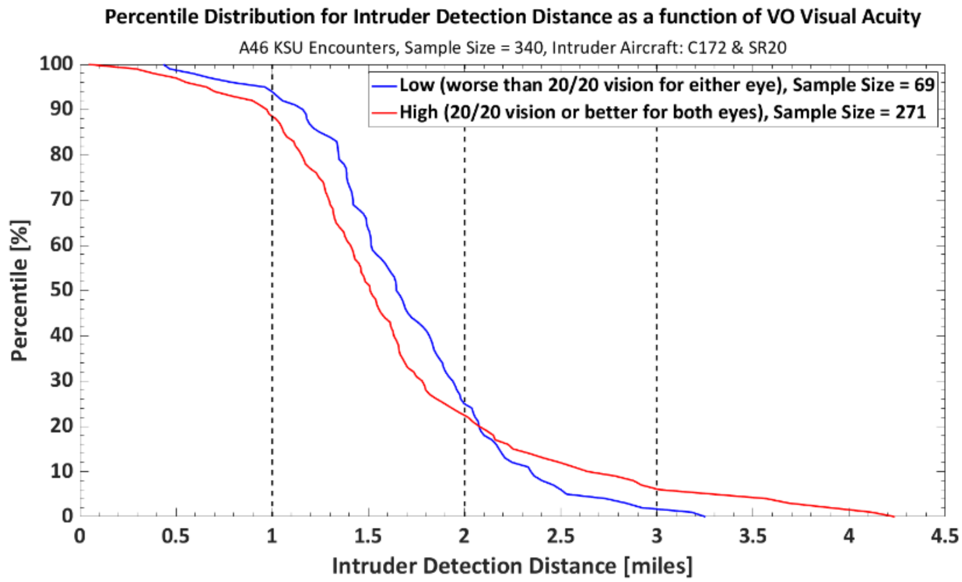


Figure 43. Percentile Distribution of Intruder Detection Distance as a Function of the VO Visual Acuity Categories for the KSU Flight Test Encounters.

3.4.4.7 *Intruder Detection Distance as a Function of the Intruder Aircraft Speed*

The fifth independent variable investigated was the intruder aircraft speed. Figure 44 shows the relationship between the intruder detection distance values and the intruder aircraft speed at the detection time. Figure 44 shows a linear regression model computed for this data. The coefficient of determination (R^2) value for the regression model is very low (< 1), indicating a high spread for the data. The Spearman correlation (r_s) value was -0.18 for this data, indicating a weak negative correlation between the intruder detection distance and the intruder aircraft speed. The Spearman probability (p_s) value was 0.001 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the intruder aircraft speed.

The average speed at detection was 111.1 kts for the SR20 intruder aircraft and 94.2 kts for the Cessna 172 intruder aircraft. Table 11 provides the descriptive statistics for the Cessna 172 and SR20 intruder aircraft speed at detection. The average speed for the SR20 intruder aircraft was 18% higher than the average speed for the Cessna 172 intruder aircraft. The statistical analysis indicates that a higher intruder aircraft speed could deteriorate the VO detection performance, as pictured in Figure 35 for the SR20 intruder aircraft runs.

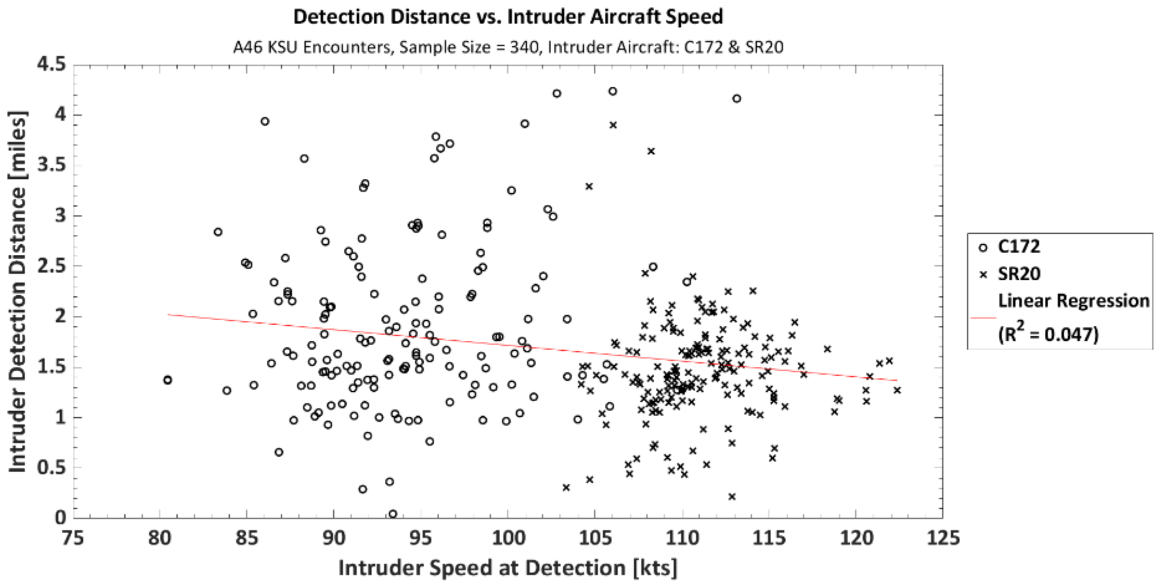


Figure 44. Scatter Plot for Intruder Detection Distance vs. Intruder Speed at Detection for the KSU Flight Test Encounters.

Table 11. Descriptive Statistics for Intruder Speed at Detection for the KSU Flight Test Encounters.

Intruder Speed at Detection [kts]				
Intruder Aircraft: Cessna 172, Sample Size = 157 runs				
Min.	Max.	Mean	Median	Std. Dev.
80.4	113.1	94.2	93.7	5.9
Intruder Aircraft: SR20, Sample Size = 183				
Min.	Max.	Mean	Median	Std. Dev.
103.3	122.4	111.1	110.6	3.6

3.4.4.8 *Intruder Detection Distance as a Function of the Intruder Aircraft Size*

The sixth independent variable investigated was the size of the intruder aircraft. The intruder aircraft size was determined using (1) projected visual area and (2) visual angle. The following sections describe how the research team defined the visual area of the intruder aircraft, explored detection distance as a function of visual area, and accounted for visual (viewing) angles.

3.4.4.8.1 Projected Visual Area of the Intruder Aircraft

This section describes the methodology for computing the projected visual area of the intruder aircraft at the time of detection. The projected visual area for a given aircraft is a function of the aircraft's position and direction of flight with respect to the VO location. Section 3.4.2 provides the visual area for different viewing angles of the intruder aircraft used in this study. Table 12 provides the side and front projected areas that were the most relevant for the calculations again for clarity. The front and side visual areas of the Cessna 172 and SR20 aircraft are almost identical.

The front visual area of the CTLS aircraft is 74.4% of the front visual area of the Cessna 172. The side visual area of the CTLS aircraft is 52.7% of the side visual area of the Cessna 172.

Table 12. Projected Visual Area (Front and Side) for the KSU and NMSU aircraft.

Intruder Aircraft	**Visual Area – Front [sq. ft]**	**Visual Area – Side [sq. ft]**
NMSU - CTLS	44.81	57.43
KSU - Cessna 172	60.19	109.05
KSU - SR20	57.72	100.98

A wagon wheel with the center of the wagon wheel at an offset from the VO location defined the intruder aircraft flight paths for the KSU flight test encounters. The projected visual area was primarily a function of the aircraft flight path angle with respect to the center of the wagon wheel. The flight path angle was calculated with respect to the first quadrant. A linear interpolation method approximates the projected visual areas for oblique detections. Figures 45 through 48 show an example of an encounter flight path with different intruder aircraft flight path angles. When the flight path angle was close to 0°, the projected visual area was equal to the front area (Figure 45). When the flight path angle was close to 90°, the projected visual area was approximately equal to the side area (Figure 46). The projected visual areas were calculated using linear interpolation for the flight path angles between 0° and 90° (Figures 47 and 48). The effect of altitude offset between the aircraft and the VO, and the effect of aircraft roll and pitch angles on the projected visual area were assumed to be negligible in the calculations.

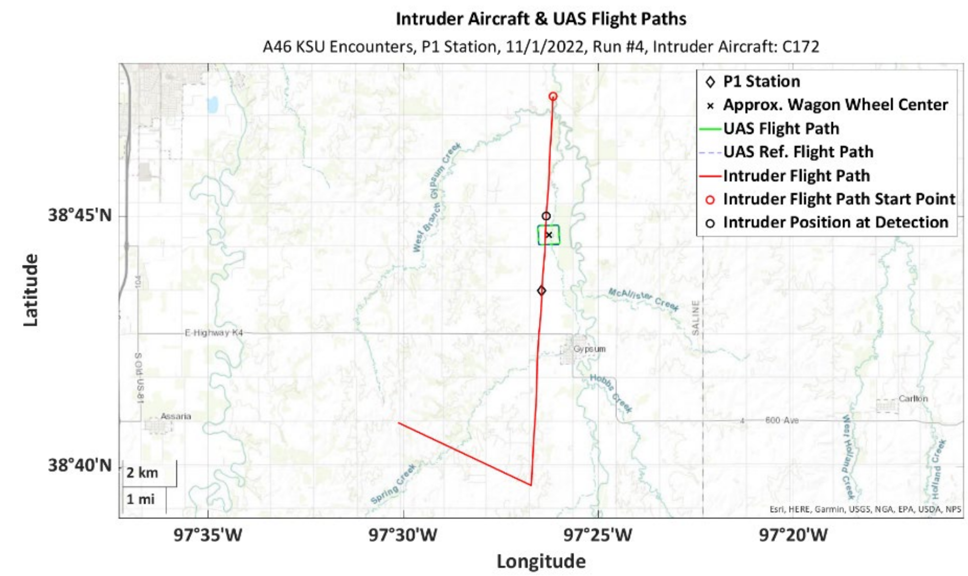


Figure 45. Example KSU Encounter Flight Paths with Different Intruder Flight Path Angles (P1 VO Station, Day 1 - 11/01/22), Run #4.

In Figure 45, the flight path angle is 3.8°, and the projected visual area is 62.24 sq. ft (~ equal to the front area). In Figure 46, the flight path angle is 87.9°, and the projected visual area is 107.90 sq. ft (~ equal to the side area).

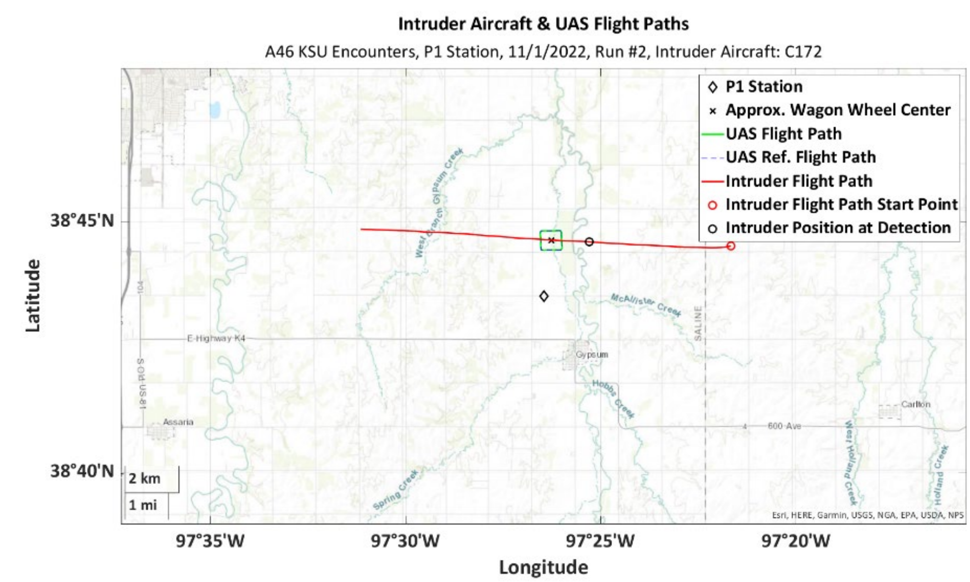


Figure 46. Example KSU Encounter Flight Paths with Different Intruder Flight Path Angles (PI VO Station, Day 1 - 11/01/22), Run #2.

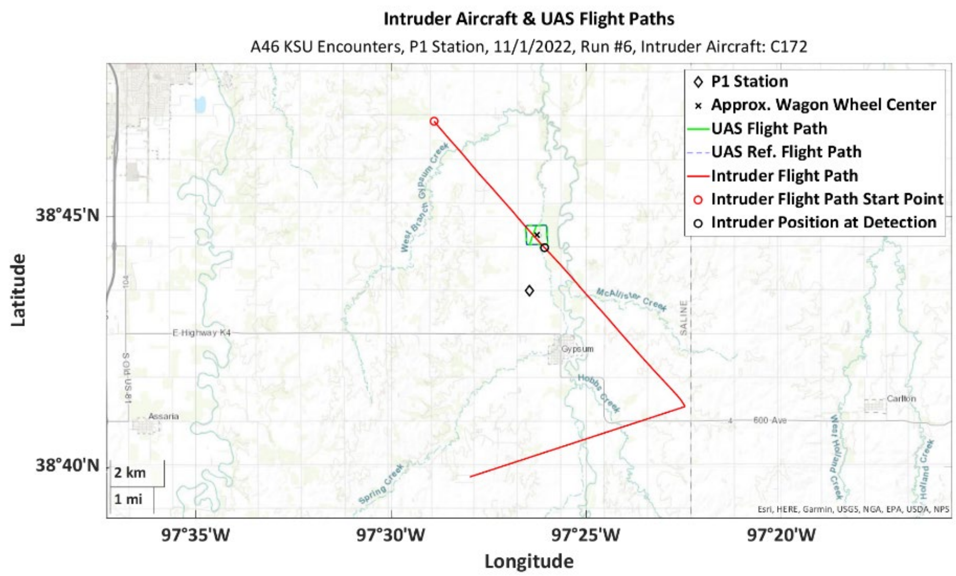


Figure 47. Example KSU Encounter Flight Paths with Different Intruder Flight Path Angles (P1 VO Station, Day 1 - 11/01/22), Run #6.

Figure 47 shows the flight path angle = 32.2°, and the projected visual area is 77.68 sq. ft (~ halfway between front and side area). In Figure 48, the flight path angle is 49.2°, and the projected visual area is 86.90 sq. ft (~ halfway between front and side area).

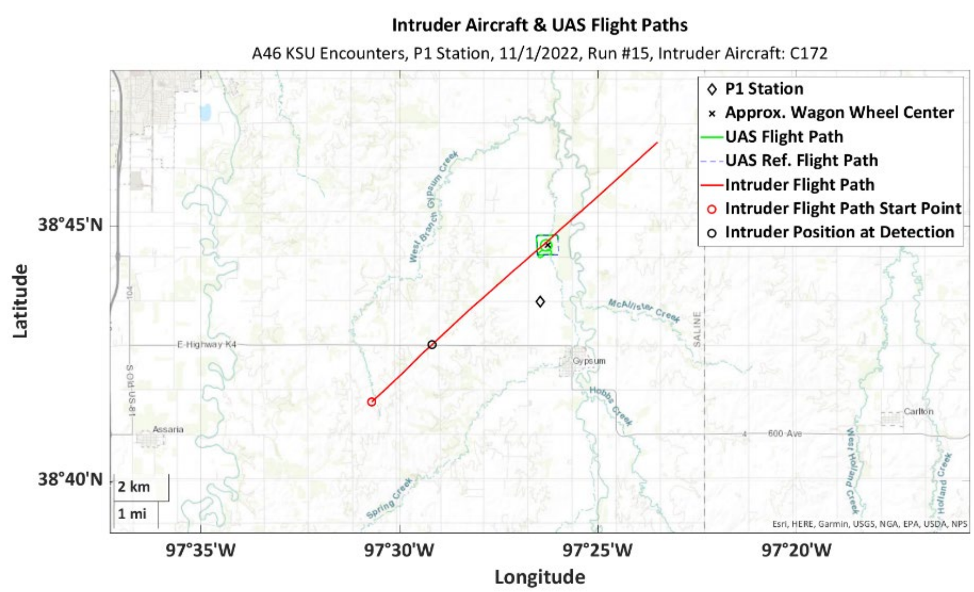


Figure 48. Example KSU Encounter Flight Paths with Different Intruder Flight Path Angles (P1 VO Station, Day 1, 11/01/22), Run #15.

For the NMSU flight test encounters, the center of the wagon wheel was co-located with the VO location. Therefore, all flight path angles were close to 0°, and the projected visual area was approximately equal to the front area (Figure 49 and Figure 50).

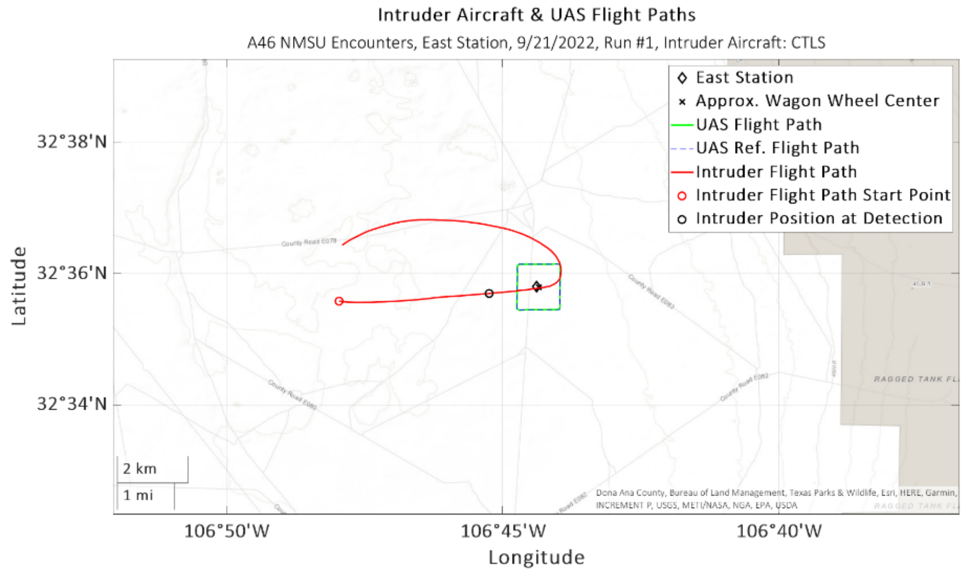


Figure 49. Example NMSU Encounter Flight Paths with Different Intruder Flight Path Angles (East VO Station, Day 1 - 09/21/22), Run #1.

In Figure 49, the flight path angle is 0.7°, and the projected visual area is 44.91 sq. ft (~ equal to the front area). In Figure 50, the flight path angle is 2.2°, and the projected visual area is 45.12 sq. ft (~ equal to the front area).

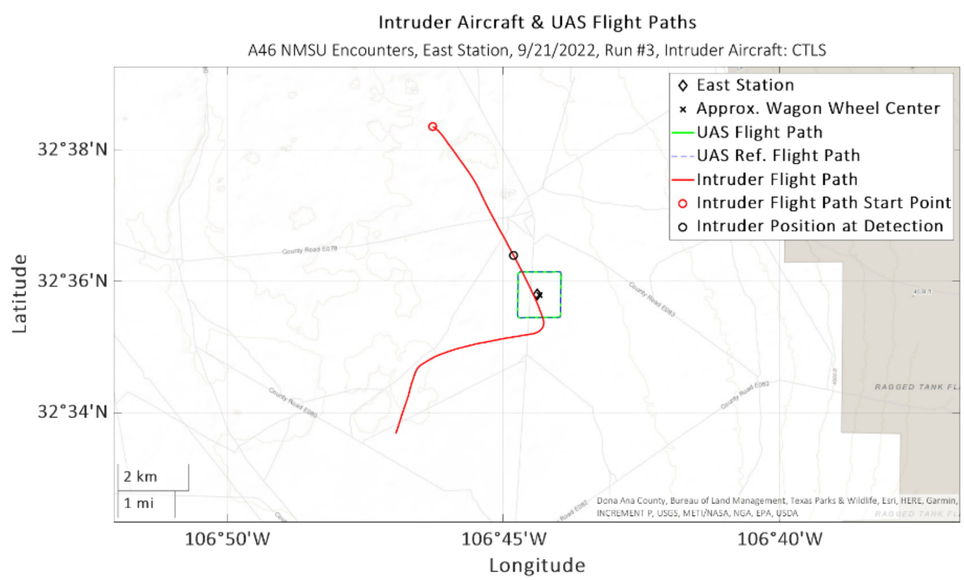


Figure 50. Example NMSU Encounter Flight Paths with Different Intruder Flight Path Angles (East VO Station, Day 1 - 09/21/22). Run #3.

3.4.4.8.2 Intruder Detection Distance as a Function of the Projected Visual Area

Figure 51 shows the relationship between the intruder detection distance values and the intruder aircraft projected visual area at the time of detection. NMSU included the data from the flight tests with the CTLS intruder aircraft here for comparison with flight test data from KSU. Researchers computed a linear regression model for the KSU data (Figure 47). The coefficient of determination (R^2) value for the regression model is very low (< 1), indicating a high spread for the data. The regression model did not include the data from NMSU since the projected visual areas at detection were almost identical for all the runs. The Spearman correlation (r_s) value was computed to be 0.19 for this data, indicating a weak positive correlation between the intruder detection distance and the projected visual area. The Spearman probability (p_s) value was 0.0029 (< 0.05), indicating a statistically significant relationship between the intruder detection distance and the projected visual area.

The main observations from Figure 47 are – (1) the majority of the lower detection distances (< 1 mile) for the KSU flight test encounters occurred for close to head-on detections (visual area was the lowest), (2) higher detection distances (> 3 miles) for the KSU flight test encounters occurred for all main orientations of the intruder aircraft at detection – head-on, side & oblique, and (3) projected visual area was likely not a contributing factor in the VO detection performance for the NMSU flight test encounters since majority of the detections were for head-on orientations.

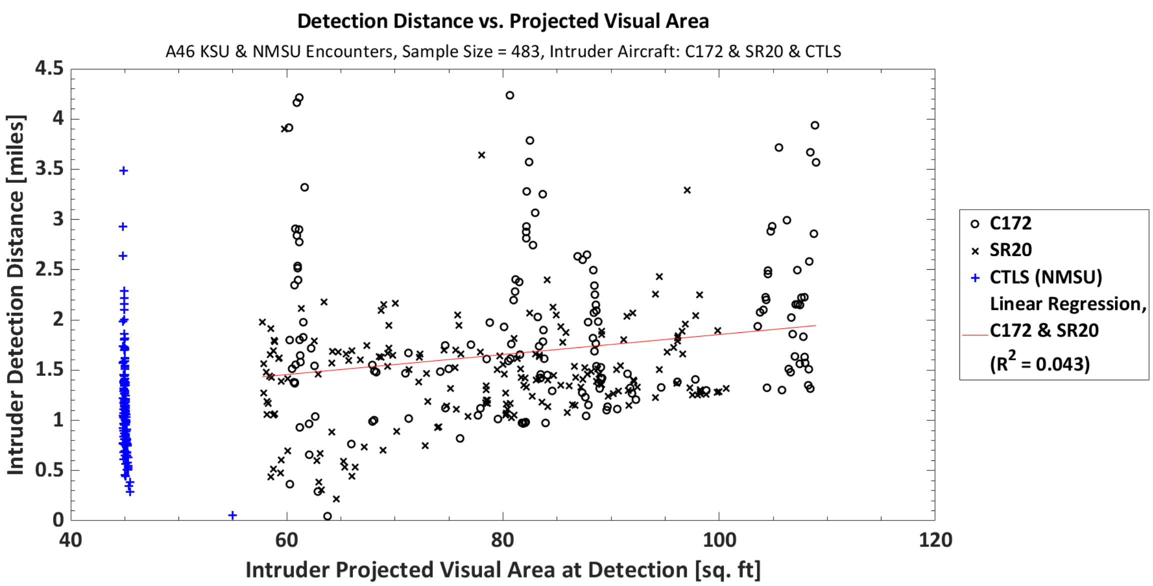


Figure 51. Scatter Plot for Intruder Detection Distance vs. Projected Visual Area for the KSU and NMSU Flight Test Encounters.

Researchers compared the NMSU data to the Cessna 172 aircraft data to evaluate the effect of the smaller size of the CTLS aircraft on the detection distance. The Cessna 172 and CTLS aircraft had similar average speeds at detection. The comparison only included the head-on detections for the Cessna 172 runs, limiting the sample size to 33. Figure 53 shows the percentile distribution for intruder detection distance calculated for the CTLS and the Cessna 172 aircraft (head-on detections only). Figure 53 shows that VO detection performance was significantly better for the Cessna 172 aircraft compared to the CTLS aircraft, even when comparing only head-on detections. The smaller visual area of the CTLS aircraft contributes to this. The front area is 74.4% of the Cessna 172 aircraft front area. The detection distances for the CTLS aircraft were scaled up by this factor (divided by 0.744, the ratio of the front area of the CTLS and Cessna 172 aircraft). Figure 52 shows the resulting percentile distribution plot. While scaling the CTLS detection distances improves the correlation with the Cessna 172 data compared to the unscaled data, the differences are still significant. This implies that other variables in the experiment, including the ambient light and noise levels, sun glare, VO experience, etc., may have contributed to the observed differences.

Another factor that may have contributed to the differences between the CTLS and the Cessna 172 detection distances is the visual scan area. The evidence for the visual scan area contributing to the differences in the NMSU and KSU results is anecdotal. For the NMSU encounters, the center of the wagon wheel was directly above the VO locations. Therefore, the VOs had to scan 360° of the sky, as the intruder aircraft for the subsequent runs would be just as likely to be behind them as in front of them. For the KSU encounters, the center of the wagon wheel was offset from the VO locations. This allowed the VOs to spend most of their time looking in one direction (toward the center of the wagon wheel), as there was a considerable chance that the intruder aircraft would be visible in that direction. One of the key findings of the literature review was that a reduction in the size of the visual scan area can speed up visual detection.

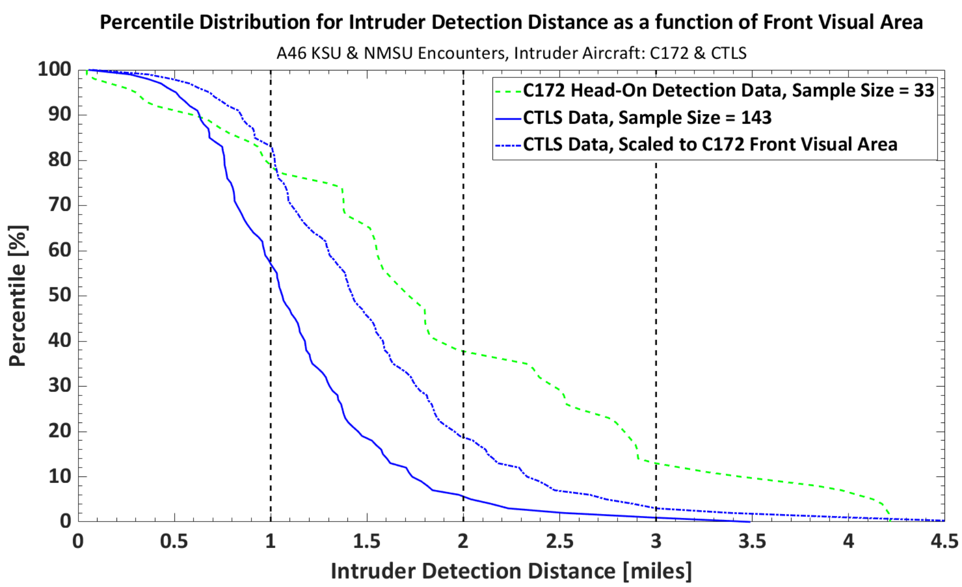


Figure 52. Percentile Distribution for Intruder Detection Distance Calculated for the CTLS Aircraft and Cessna 172 head-on Detection Runs.

3.4.4.8.3 Intruder Detection Distance as a Function of the Visual Angle

The projected visual area does not take depth into account. Visual angle measures the image an object casts on the retina. The size of objects varies relative to the distance from an observer. Objects closer to the eye will have a larger visual angle.

The aircraft wingspan was a key variable for calculating the visual angle in this study. For head-on encounters, the visual angle calculated with respect to the aircraft wingspan may not truly indicate the detectable size since the wings may not be visible until the aircraft is much closer to the observer. If the fuselage cross-sectional diameter is used to calculate the visual angle instead of the wingspan, the resulting visual angle will be significantly lower for the same distance.

The National Transportation Safety Board (NTSB) states that for an aircraft to have a reasonable chance of being visually recognized, it must subtend at least 12 minutes of visual arc (NTSB, 1987). For the Cessna 172 and SR20 aircraft (wingspan in the range of 36 to 38 ft), 12 arc-minutes is equivalent to ~2 miles. For the CTLS aircraft (wingspan equal to ~28 ft), 12 arc-minutes equals ~1.5 miles.

Figure 53 shows the percentile distribution for the visual angle subtended by the intruder aircraft at detection for the KSU and NMSU flight test encounters. It can be seen from Figure 49 that a visual angle of at least 12 arcminutes was subtended in only ~38% of the runs for the Cessna 172 aircraft, ~8% of the runs for the SR20 aircraft, and ~14% of the runs for the CTLS aircraft.

The Australian Transport Safety Bureau suggests that an aircraft should subtend a visual arc of 24 to 36 minutes under sub-optimal visual conditions to have a reasonable chance of being visually recognized (Hobbs, 1991). For the Cessna 172 and SR20 aircraft (wingspan in the range of 36 to 38 ft), 36 arc-minutes is equivalent to ~0.65 miles. For the CTLS aircraft (wingspan equal to ~28 ft), 36 arc-minutes equals ~0.5 miles.

Figure 49 illustrates that a subtended visual angle of at least 36 arcminutes in > 90% of the runs for all three aircraft. The results of this study support the claim that the visual angle threshold of an aircraft is in the range of 24 to 36 arcminutes.

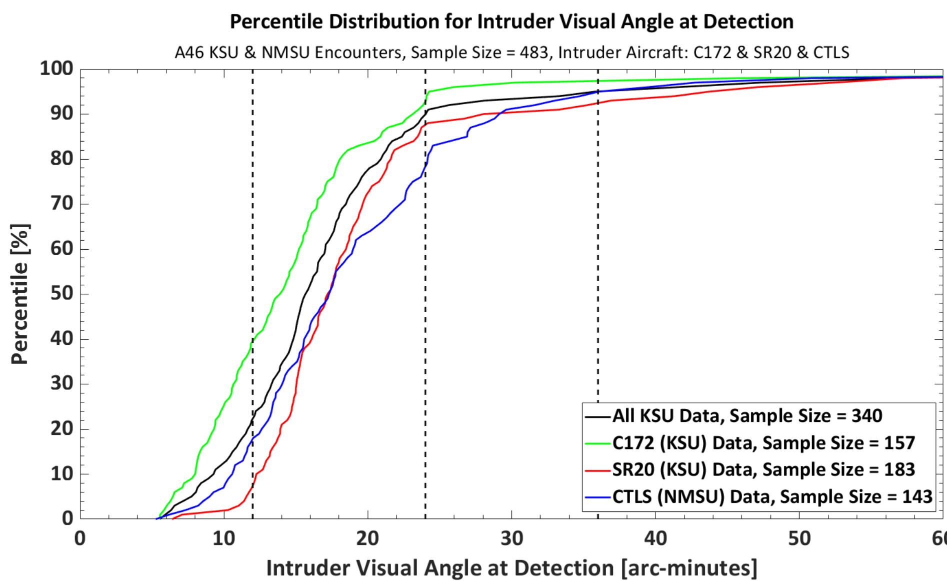


Figure 53. Percentile Distribution for Intruder Visual Angle at Detection Calculated for the KSU and NMSU Flight Test Encounters.

3.4.4.9 *VO Suggested Maneuvers*

This section provides the breakdown of avoidance maneuvers suggested by the VOs for the KSU flight test encounters with the Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The experiment limited avoidance maneuvers to the vertical domain and included options for the UA to descend, climb, or maintain its current altitude. The participants acting as VOs determined the avoidance maneuvers based on their estimate of the intruder aircraft's altitude. The participants were aware that the UA operating altitude was 400 ft AGL. The participants had no sight of the simulated sUA as it had an apparent operating area approximately 1.25 miles north of the VO stations.

Figure 45 depicts the breakdown of the avoidance maneuvers suggested by the VOs for the KSU flight test encounters. VOs determined that no avoidance maneuver was required and that the UA could maintain its altitude in 57.1% of the trials. VOs suggested a descend avoidance maneuver in 34.1% of the trials and a climb avoidance maneuver in 8.8%. Figure 55 (a) and (b) depict the breakdown for the avoidance maneuvers separately for the Cessna 172 and SR20 intruder aircraft, respectively. VOs determined avoidance maneuvers unnecessary in 48.4% and 64.5% of the Cessna 172 and SR20 intruder aircraft trials, respectively. VOs suggested a climb avoidance maneuver in 15.9% of the trials for the Cessna 172 intruder aircraft and only in 2.7% of the trials for the SR20 intruder aircraft. VOs suggested a descend avoidance maneuver in a similar percentage of trials for intruder aircraft – 35.7% for the Cessna 172 and 32.7% for the SR20. Subsequent sections discuss the effectiveness of the VO-suggested avoidance maneuvers in maintaining separation between the UA and the intruder.

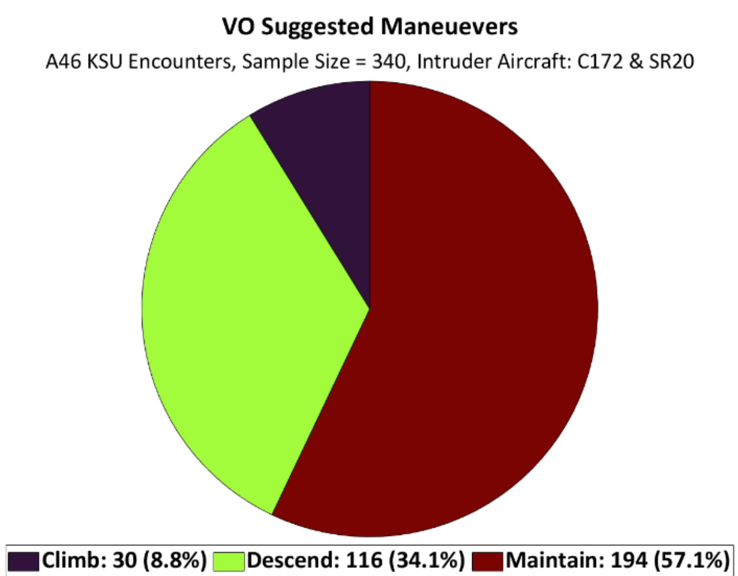
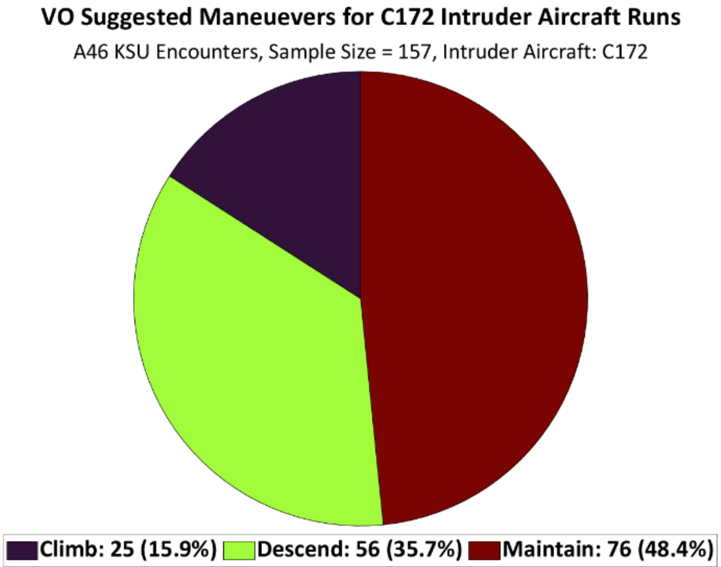
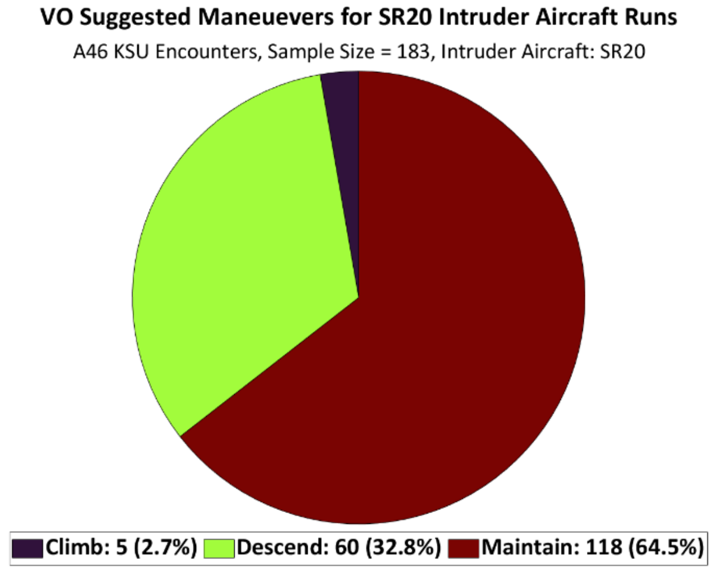


Figure 54. Breakdown of Avoidance Maneuvers Suggested by the VOs for the KSU Flight Test Encounters.



(a)



(b)

Figure 55. Breakdown of avoidance maneuvers suggested by the VOs for the KSU flight test encounters separately for each intruder aircraft (a) Cessna 172 and (b) SR20.

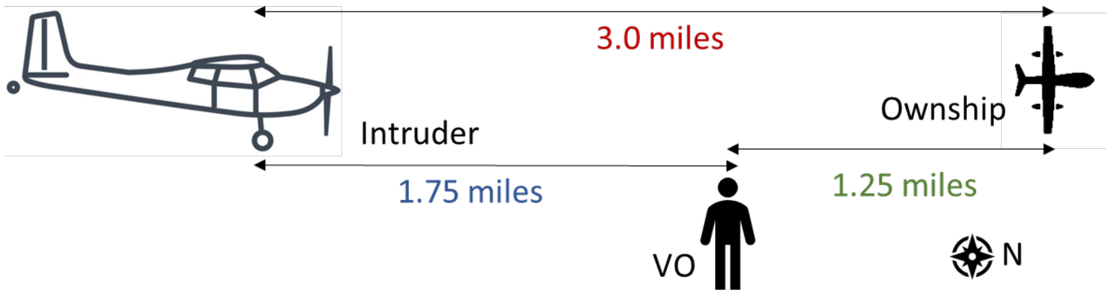
3.4.4.10 *Response Time to Suggest, Initiate, and Complete Avoidance Maneuvers*

This section discusses the response times for the VOs to suggest avoidance maneuvers to the RPIC and for the RPICs to initiate and complete the maneuvers.

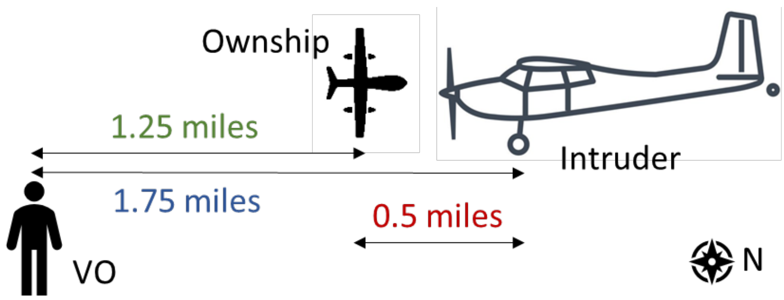
The research team manually recorded the VO callout time stamps for intruder detection. The VOs called out the avoidance maneuvers within 1 to 3 seconds after their detection callout. Since the time between the two callouts was so small, manually recording both during the experiment with high precision was challenging. The research team, therefore, did not record the avoidance maneuver callout time stamps. In summary, while a precise breakdown of the response time for the VOs to suggest avoidance maneuvers is not available, the research team believes an average value of 2 seconds is reasonable based on anecdotal evidence.

The response times to initiate the maneuver were determined during the post-processing of the flight data. Flight test encounters consisted of 146 maneuvers. In the case of 2 out of the 146 runs, the RPIC maneuvered the UA before the VO called out the intruder detection. The research team removed these data points from the analysis, resulting in a sample size of 144 for the response times to initiate and complete the avoidance maneuvers.

The research team determined that the maneuver start time was a function of (1) the distance between the intruder and UA at the time of detection and (2) the intruder detection distance. The flight test encounters in this study were representative of an EVLOS operation where the VOs were located approximately 1.25 miles from the UA mission area. Figure 56 depicts two example cases with the same intruder detection distance but different positions of the intruder with respect to the UA at the time of detection. In the first case (Figure 47(a)), the UA operates 1.25 miles north of the VO, and the intruder detection distance is 1.75 miles. The intruder is located south of the VO at 3 miles from the UA. In the second case (Figure 56 (b)), the intruder is located north of the VO at 0.5 miles from the UA. The UA position and the intruder detection distance are the same for both cases.



(a)



(b)

Figure 56. Example of the Relationship between Detection Distance and Position of the Intruder and UA in EVLOS Operations: (a) Intruder far away from the UA, and (b) Intruder near the UA.

The response times to initiate the avoidance maneuver ranged from 6 to 98 seconds from the time of detection. The RPICs in this study determined the maneuver start times based on their estimate of the position of the intruder aircraft with respect to the UA. For most trials, the RPICs maneuvered the UA once the distance between the intruder and the UA became less than 1.5 miles. This was the primary reason the response times to initiate the maneuver exceeded 20 seconds in more than half of the runs.

Figure 48 depicts the relationship between the response times to initiate the maneuver with respect to the time of detection and the distance between the intruder and the UA at the time of detection. Figure 48 shows a linear regression model computed for this data. The coefficient of determination (R^2) value for the regression model is low (< 1), indicating a high spread for the data. The main observation from Figure 57 is that the response times to initiate the maneuver were longer for more considerable distances between the intruder and the UA at the time of detection.

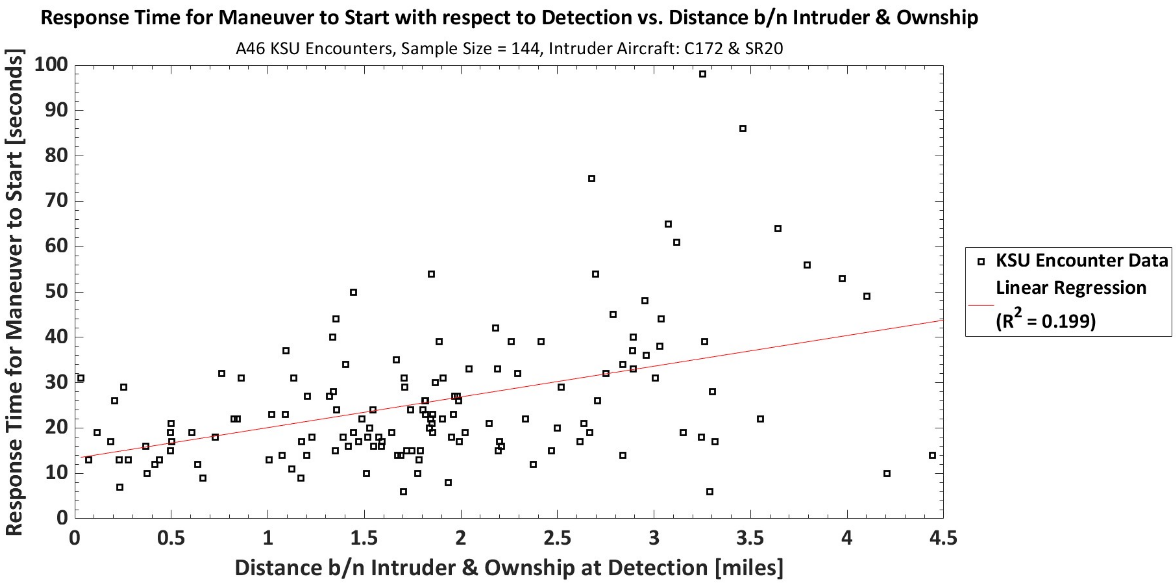


Figure 57. Scatter Plot for Response Times to Initiate the Avoidance Maneuver vs. Distance Between the Intruder and the UA at Detection for the KSU Flight Test Encounters

The research team proposed an approach to apply the data for the response times to initiate the avoidance maneuver towards VLOS operations by utilizing only the data where the distance between the intruder and the UA at the time of detection was less than 1.25 miles (i.e., the distance between the VO station and UA mission flight path). A sample size of 37 flight test encounters that meet this criterion was available in this study. Table 13 provides the descriptive statistics for this sample size. The average response time to initiate the avoidance maneuver was determined to be ~19 seconds with respect to detection and ~17 seconds with respect to avoidance maneuver callout.

Table 13. Descriptive Statistics for Response Times to Initiate the Avoidance Maneuver.

Response Times to Initiate Avoidance Maneuver [seconds]				
Distance b/n Intruder & UA at Detection ≥ 1.25 miles, Sample Size = 37 runs				
Min.	Max.	Mean	Median	Std. Dev.
7	37	18.73	17	7.54

The response times to complete the avoidance maneuver were determined from the post-processing of the flight data and were based on the time the UA took to maneuver to its new target altitude. The new target altitude of the UA was 200 to 300 ft higher or lower than the operating altitude based on the type of maneuver (climb or descend). The average response time to complete the maneuver was determined to be ~22 seconds. The response time to complete the avoidance maneuver is a function of the vertical velocity of the UA. The UA's average vertical velocity (climb/descend rate) during the avoidance maneuver was determined to be ~624 ft/min.

According to the FAA AC 90-48D (FAA, 2016b), detecting and recognizing an intruder aircraft, assessing its collision potential, making an avoidance decision, and initiating and completing an avoidance maneuver take a crewed aircraft pilot at least 12.5 seconds. Table 14 provides the reaction times determined in this study for specific collision avoidance procedure tasks. These findings are consistent with results from the Vance et al. (2017) study, which suggest that RPs could take longer than the 12.5-second estimate to follow required procedures for collision avoidance.

Table 14. Average Reaction Time for Collision Avoidance Procedure Tasks

Collision Avoidance Procedure Tasks	Average Reaction Time
Making an Avoidance Decision	2 seconds
Initiating an Avoidance Maneuver	17 seconds
Completing an Avoidance Maneuver	22 seconds

3.4.4.11 *Closest Point of Approach for Mitigated & Unmitigated Encounters*

The research team computed the CPA for both mitigated and unmitigated flight paths. The unmitigated flight path was calculated based on the assumption that the UA operated at a constant speed of 45 knots and a constant altitude of 400 ft AGL throughout its mission flight path. At the start of every run, the position of the actual UA flight path was used to determine the start position for the unmitigated flight path. Figure 58 shows the mitigated (actual) and unmitigated (reference) flight paths for the UA.

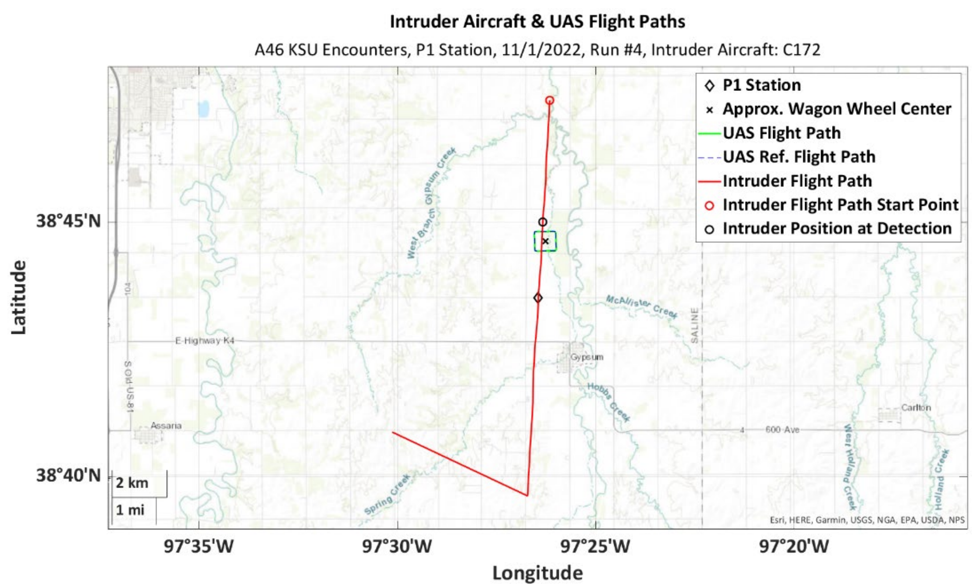


Figure 58. Example Encounter Flight Paths for the UA and Intruder (P1 VO Station, Run #4, Day 1- 11/01/22).

The change in CPA between mitigated and unmitigated encounters is a sound measure of the effectiveness of an avoidance maneuver. A positive value change in CPA indicates increased separation between the intruder and the UA. The CPA represents the slant distance between the UA and the intruder. The research team utilized the components of the CPA slant distance –

horizontal and vertical miss distances to gain more insight into the effectiveness of maneuvers in both the horizontal and vertical domains.

Figure 59 shows the percentile distribution for the change in CPA slant and horizontal distances for the KSU encounters with Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The actual UA flight path deviated significantly from its original mission flight path in 4 out of the 340 runs. The research team removed these data points from their analysis, resulting in a sample size of 336.

Maneuvering the UA increased horizontal separation between the intruder and the UA in 52.8% of the trials. The research team defined a criterion for a maneuver to be effective in the horizontal domain when it resulted in a change in the horizontal miss distance of greater than 500 ft. The value of 500 ft also represents the radius of the cylinder used to define the NMAC boundary. The maneuvers were effective in the horizontal domain in 14.8% of the runs for the combined dataset, 10.1% with the Cessna 172 intruder aircraft, and 18.7% with the SR20 intruder aircraft. The research team also defined a criterion for a maneuver to be detrimental in the horizontal domain when it resulted in a change in horizontal miss distance of less than -500 ft (Figure 55). The maneuvers were detrimental in the horizontal domain in 16.2% of the runs for the combined dataset, 16.8% with the Cessna 172 intruder aircraft, and 15.9% with the SR20 intruder aircraft.

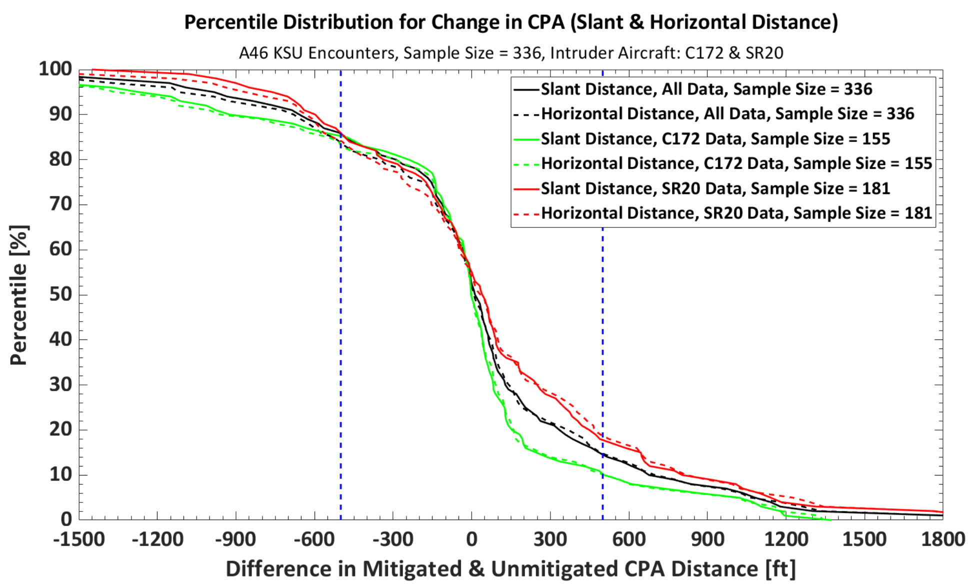


Figure 59. Percentile distribution for change in CPA (slant & horizontal distance) calculated for the KSU flight test encounters.

Figure 60 shows the percentile distribution for the change in CPA (vertical distance) for the KSU encounters with Cessna 172 intruder aircraft, SR20 intruder aircraft, and the combined dataset. The maneuvers increased the vertical separation between the intruder and the UA in 55.3% of the runs. The criterion for a maneuver to be effective in the vertical domain was set to a change in the vertical miss distance of greater than 100 ft. The value of 100 ft also represents the height of the cylinder used to define the NMAC boundary. The maneuvers were effective in the vertical domain in 30.9% of the runs for the combined dataset, 35.2% of the runs with the Cessna 172 intruder aircraft, and 27.1% of the runs with the SR20 intruder aircraft. The criterion for a maneuver to be detrimental in the vertical domain was a change in the vertical miss distance of less than -100 ft. The maneuvers were detrimental in the vertical domain in 0.7% of the runs for the combined dataset, 1.6% of the trials with the Cessna 172 intruder aircraft, and 0% of the runs with the SR20 intruder aircraft.

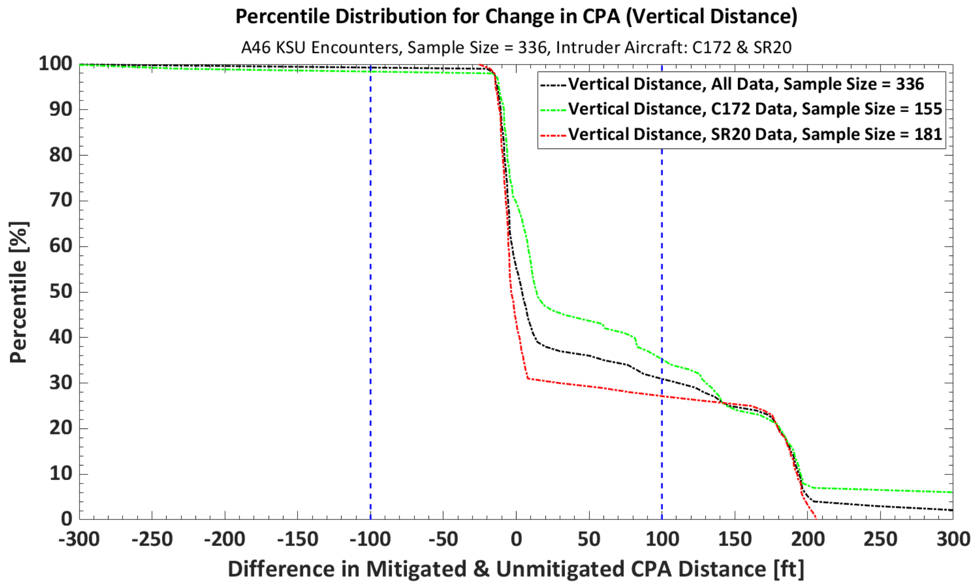


Figure 60. Percentile Distribution for Change in CPA (vertical distance) calculated for the KSU Flight Test Encounters.

Table 15. Well Clear and NMAC Violations for Mitigated and Unmitigated encounters in the KSU flight tests

Intruder Aircraft: Cessna 172 & SR20, sample Size = 336 runs			
Well Clear Violations		**NMAC Violations**	
Unmitigated	193	Unmitigated	54
Mitigated	165	Mitigated	22
% reduction	14.5	% reduction	59.3
Well Clear Violations (No Maneuver Performed - Maintain)		**NMAC Violations (No Maneuver Performed - Maintain)**	
Unmitigated	90	Unmitigated	22
Mitigated	90	Mitigated	18
% reduction	0	% reduction	18.2
Well Clear Violations (Maneuver Performed – Climb or Descend)		**NMAC Violations (Maneuver Performed – Climb or Descend)**	
Unmitigated	103	Unmitigated	32
Mitigated	75	Mitigated	4
% reduction	27.2	% reduction	87.5

Table 15 provides the Well Clear and NMAC violations count and the breakdown of the type of maneuver performed for the KSU flight test encounters. There were 193 unmitigated Well Clear violations out of the 336 valid encounters. The VOs and RPICs executed avoidance maneuvers to mitigate 14.5% of the Well Clear violations. There was no reduction in the Well Clear violations count for the encounters without an avoidance maneuver. For the encounters with an avoidance maneuver, there was a reduction of 27.2% in the Well Clear violations count.

There were 54 unmitigated NMAC violations out of the 336 valid encounters. The VOs and RPICs executed avoidance maneuvers to mitigate 59.3% of the NMAC violations. There was a reduction of 18.2% in the NMAC violation count for the encounters without an avoidance maneuver. For the encounters with an avoidance maneuver, there was a reduction of 87.5% in the NMAC violations count.

An important observation from this data was that the VOs determined that no avoidance maneuver was necessary in 22 out of 54 (~41%) encounters with NMAC violations. Based on these data, VOs were ineffective in estimating collision potential between an intruder and the UA when they did not have a visual sight of the UA. This is consistent with the Crognale (2009) study's findings, where the VOs could not accurately determine collision potential unless they saw the intruder and the UA simultaneously.

3.5 Task 5 – Lessons Learned Document

Task 5 consisted of developing a Lessons Learned Document, which captured experience gained during the initial flight testing conducted at NMSU and the final flight testing at KSU. Appendix L provides the completed Lessons Learned Document; recommendations were formulated from the lessons learned.

- It is imperative to perform a dry run of the flight testing beforehand. A dry run will ensure that all those involved with the flight testing understand their assignments and essential workflows.
- During the dry run, the lead researcher should take pictures of the test stations to guarantee consistency during setup for each day of flight testing.
- Perform all perceptual testing inside a well-lit room with minimal noise. While this was the initial plan, the perceptual testing was moved outside due to limitations onsite at the test location. Performing such tests inside will reduce potential errors in perceptual data collection and reduce strain on the participants.
- Providing a visual example of a 500 ft distance during VO testing, such as a tower, pole, or building, could increase participants' understanding and improve their performance when perceiving objects at a distance. This could be especially helpful to novice individuals and/or those with little or no VO experience.
- Conducting this research in a simulated environment would mitigate the need for a 5-hour block of time from participants and staff. A simulation would also permit a team to conduct more runs, allowing a team to study additional variables quantitatively. The ability to analyze more variables in a more controlled environment would contribute to a more robust understanding of the performance effectiveness of VOs in different conditions.

4 CONCLUSIONS

The ASSURE A46 research team investigated the effectiveness of VO performance for EVLOS operations. More specifically, the A46 research team explored methods to quantify VO performance with intruder distance as the primary dependent variable and subsequent dependent variables such as lighting conditions on eyesight and visual acuity. As the primary dependent variable, intruder detection distance, this variable informed the overall detection performance of VOs.

For the initial tests at NMSU, the VOs detected the intruder aircraft (CTLS) at an average distance of 1.14 miles for 143 runs. For the KSU flight tests, the VOs observed the intruder aircraft (Cessna 172 and SR20) at an average distance of 1.67 miles for 340 runs. The VOs detected the Cessna 172 intruder aircraft at an average distance of 1.90 miles for 157 runs and the SR20 intruder aircraft at an average of 1.46 miles for 183 runs. These results were comparable with the average detection distance of 1.63 miles obtained by Vance et al. (2017), with 49 trials, 10 participants acting as VOs, and the Cessna 172 aircraft serving as the intruder aircraft.

For the KSU flight tests, the VOs detected the intruder aircraft (Cessna 172 and SR20) at a distance of at least 1 mile in 89.5% of the runs, a distance of at least 2 miles in 22.6% of the runs, and a distance of at least 3 miles in 3.3% of the runs suggesting that performance significantly degrades as the distance between the intruder aircraft and VO increases. For the NMSU flight tests, the VOs detected the intruder aircraft (CTLS) at a distance of at least 1 mile in 57.1% of the runs, a distance of at least 2 miles in 5.6% of the runs, and a distance of at least 3 miles in 0.9% of the runs.

With regard to the impact of ambient light levels on detection, the intruder detection distance and the ambient light levels exhibited a weak, negative, statistically significant correlation. The detection distances were higher for ambient light intensity values < 40,000 lux (overcast conditions). The majority of the lower detection distance values (< 1 mile) occurred for ambient light intensity values > 60,000 lux (partly cloudy or bright sunny conditions). The bright background sky and the sun's glare were responsible for decreasing the intruder aircraft's visibility. The average speed at detection for the SR20 intruder aircraft (111.1 kts) was 18% higher than the average speed for the Cessna 172 intruder aircraft (94.2 kts). The faster-moving SR20 intruder aircraft resulted in less effective VO detection performance compared to the slower-moving Cessna 172 intruder aircraft.

With regard to ambient noise levels, the ambient noise levels did not directly impact VO detection performance. The majority of the participants in the NMSU flight tests heard the intruder aircraft noise signature before visually detecting it. This trend was the opposite of the KSU flight tests, where the majority of the participants visually detected the intruder aircraft before hearing the aircraft noise signature. One possible explanation for this qualitative finding is that the detection distances in the NMSU flight tests were lower compared to the KSU flight tests, resulting in the intruder aircraft being closer to the VO stations and, therefore, a louder noise signature. A study by Vance et al. (2017) revealed that it is possible for visual and auditory means to result in an even distribution of detections. In the Vance et al. (2017) study, participants initially detected the intruder in 30.5% of the trials by auditory means and 27.1% of the trials by visual means. The participants detected the intruder simultaneously by visual and auditory means in 32% of the trials. Further research is deemed necessary in this domain.

With regard to the manuever call out’s, the VOs called out the avoidance maneuvers almost instantaneously (within 1 to 3 seconds, an average of 2 seconds) after their detection callout. The average response time to initiate the avoidance maneuver scaled to VLOS operations was determined to be ~17 seconds. The average response time to complete the maneuver was determined to be ~22 seconds. The response time to complete the avoidance maneuver is a function of the vertical velocity of the UA. The UA's average vertical velocity (climb/descend rate) during the avoidance maneuver was determined to be ~624 ft/min. VOs determined no avoidance maneuver was necessary in 22 out of 54 (50%) encounters with NMAC violations.

Additionally, the avoidance maneuvers were effective in increasing the vertical separation between the intruder aircraft and the UA in only 30.9% of the runs. This value indicates that VOs are not effective in estimating collision potential between the intruder and the UA. This is consistent with Crognale (2009), where the VOs could not accurately determine collision potential unless both the intruder and the UA were present in the visual field simultaneously.

In closing, the research team computed the statistical relationships and correlations between the independent variables and the intruder detection distance. A closing summary of the key findings of this research are provided below:

- Ambient light levels had an impact on the VO detection performance. The bright background sky and the sun's glare were responsible for decreasing the intruder aircraft's visibility. Overcast conditions increase the aircraft's visibility by providing an enhanced contrast between the aircraft and the background sky.
- Ambient noise levels did not directly impact the VO detection performance. Most of the VOs in the KSU flight tests visually detected the intruder aircraft before hearing its noise signature. This observation is based on anecdotal evidence and requires further investigation in future studies.
- VOs' aviation experience had an impact on the detection performance. VOs with no aviation experience had poorer detection performance than VOs with prior aviation experience. VOs with a private pilot certification had better detection performance than those VOs with a remote pilot certificate or VOs enrolled as student pilots. Future studies should investigate the impact of various levels of piloting experience with regard to VO performance.
- VOs' visual acuity did not impact the detection performance.
- Aircraft speed had an impact on the VO detection performance. The faster-moving intruder aircraft (SR20) resulted in less effective VO detection performance than the slower-moving intruder aircraft (C172).
- The aircraft's projected visual area had an impact on the VO detection performance. Most of the lower detection distances for the larger intruder aircraft (C172 & SR20) were associated with head-on and close-to-head-on encounters (that resulted in the smallest projected visual area).
- Scaling the detection distances with the projected visual area for the smaller intruder aircraft (CTLS) to the larger intruder aircraft (C172) (for head-on encounters) did not result in a similar percentile distribution curve between the two detection distance datasets.
- A visual angle of at least 36 arc-minutes was subtended in > 90% of the runs for all three aircraft at detection. The visual angle was computed using the aircraft wingspan for all encounters.

The ASSURE A46 research team investigated the effectiveness of VO performance in an EVLOS operational paradigm. In actual trial runs at KSU, participants were only effective at 89.5% within 1 mile with a significant degradation in performance effectiveness to 22.6% at 2 miles, and 3.3% at 3 miles. These findings ascertain that VOs may not be reliable as an effective source for collision avoidance. The initial test runs at NMSU also highlighted the effectiveness of using VOs with detection performance at 57.1% within 1 mile, 5.6% within 2 miles, and 0.9% within 3 miles. It is imperative to note that NMSU had a smaller sample size of participants for the initial test runs. Nonetheless, the safety concerns implicated based on the results of this study suggest that humans are prone to cognitive/perceptual errors in cognitive/perceptual tasks such as EVLOS operations. Caution should be used when assigning VOs as a safety mitigation strategy for collision avoidance in flight operations conducted beyond visual line of sight.

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