ASSURE A46 – Validation of Visual Operation Standards for Small Unmanned Aircraft Systems (sUAS)

Task 3 – Experiment Plan

June 9, 2022

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AGL   Above Ground Level
ANOVA   Analysis of Variance
CPA   Closest Point of Approach
dB   Decibel
ES3   Earscan 3
EVLOS   Extended Visual Line of Sight
FAA   Federal Aviation Administration
GCS   Ground Control Station
Hz   Hertz
IRB   Institutional Review Board
KSU   Kansas State University
NIST   National Institute of Standards and Technology
NM   Nautical Miles
PII   Personally Identifiable Information
PSURT   Public Safety Unmanned Response Team
RPIC   Remote Pilot in Command
SDT   Signal Detection Theory
sUAS   Small Uncrewed Aircraft System
UAS   Uncrewed Aircraft System
VAD   Visual Acquisition Distance
VMC   Visual Meteorological Conditions
VO   Visual Observer
VTOL   Vertical Take-off and Landing

1 INTRODUCTION

This document presents the methodology and procedures applied to investigate the visual operation capabilities of Visual Observers (VOs) for small-Uncrewed Aircraft Systems (sUAS). The Federal Aviation Administration's (FAA) proposed sUAS rule suggests the use of a dedicated VO to help aid the Remote Pilot In Command (RPIC) in see and avoid to meet VO requirements established under the auspices of (Title 14 CFR §107.33, 2021). This research aims to address gaps in knowledge in an attempt to quantify VO performance and identify human performance limitations regarding visual detection. The results from this study may be used to inform future policy and training standards for Extended Visual Line Of Sight (EVLOS) operations with the use of VOs. Nine research questions have been identified for this study. These questions have been derived through careful analysis regarding the findings of the literature review articulated for this work and capture constructs provided by the FAA in technical interchange discussions. The nine questions include:

1. What is the visual detection time for a ground-based visual observer?
2. At what point does the visual observer 1) see the intruder aircraft, 2) alert the RPIC, and 3) 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 make a decision regarding the suggested avoidance maneuver?
5. How long does it take to complete the avoidance maneuver?
6. How does the 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?
8. What can be done to improve VO performance? This will be answered anecdotally based on subject matter expertise input.
9. What was the Closest Point of Approach (CPA) for each trial (see Section 3.7 for the Data Analysis)?

2 METHODOLOGY

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

1. the time it takes for a participant to visually detect a Cessna-172 intruder aircraft,
2. the time for the participant to decide whether an avoidance maneuver is required to ensure safe separation between aircraft,
3. the time it takes the RPIC to confirm the avoidance maneuver decision,
4. the time it takes for the RPIC to initiate the maneuver, and
5. the time it takes for the maneuver to be completed.

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

1. Enabling the research team to evaluate the accuracy of detection of a conventional aircraft by the VO and the RPIC;
2. Exploring the capacity for VOs and RPIC to use visual references for avoidance;
3. Identifying challenges associated with VO/RPIC communications;
4. And, exploring the capacity for the RPIC to give way to the conventional aircraft.

The experimental design will also afford the research team to collect general information that may impact VO detection performance, such as ambient noise, light levels, and individual physiological differences related to visual acuity, color deficiency, and hearing capabilities. This information could serve as a baseline for considerations toward the development of future training criteria for VOs and RPICs. A series of preliminary test runs of the experiment design will be conducted in New Mexico in advance of the final data collection flights in Kansas. This initial testing will be used to assess personnel layout, data collection methods, flight path geometries, data gathering approaches, and other testing elements to ensure successful testing with participants in Kansas. These initial tests are designed to maximize the experimental design when flight testing occurs. All lessons learned from the New Mexico flights will be applied to the data collection flight tests conducted in Kansas. What follows is an overview of the specific data collection methods and instruments, a description of participants (sampling), data analysis, and other considerations that drive the overall experiment design.

3   EXPERIMENT DESIGN

A mixed methods design utilizing a triangulated approach will be established for this research to capture both quantitative and qualitative data simultaneously and in an equally weighted manner during the data collection phase of this study. The primary advantage of implementing a mixed methods experimental design is to counterbalance the weaknesses of each method. For instance, this method leverages the strengths of the qualitative data (e.g., data about the context) to offset the weakness of the quantitative data (e.g., ecological validity). Likewise, the strengths of the quantitative data (e.g., generalizability) offset the weakness of the qualitative data (e.g., context dependence; Mills & Gay, 2012). As such, the research team believes this design is well suited to investigate the parameters associated with VO effectiveness.

The rationale for choosing a mixed methods design resides on the basis that quantitative data gathered via the Cessna-172 flight logs, the Ground Control Station (GCS) operating the simulated sUAS, the detection distance along with the ambient noise and light levels will be collected simultaneously with the qualitative data from the VO participants on their perceptions and maneuver choice. While the quantitative and qualitative data will be gathered at the same time, the analyses will be performed separately; after both analyses are complete, the results will be compared to draw overall conclusions.

3.1   Purpose
The purpose of this experimental design is to gather data regarding VO performance related to the accuracy of detection of a conventional aircraft during a sUAS flight operation utilizing a flight test campaign. As part of this flight test campaign, the research team will (1) identify any communication challenges between the VO and RPIC, (2) explore the capacity of the VO to suggest the correct avoidance maneuver, and (3) record the time it takes for the RPIC to confirm and complete the avoidance maneuver.

3.2 Sample Population

Participants will be selected using a convenience sample and will consist of undergraduate students across various departments at Kansas State University (KSU). This will allow the research team to examine if basic training given to them prior to the start of testing is sufficient for them to perform their role. For this study, VO participants will be over the age of 18.

3.2.1 Sample Population Selection and Recruitment

The research team will recruit participants through verbal solicitation, campus news alerts and emails, flyers, and social media channels (e.g., LinkedIn and/or Facebook). The target number for the sample is estimated to be between 25 and 50 participants. Of the 15 sUAS detection studies reviewed during the literature review task of this project, only four studies had 20 or more participants (Loffi et al., 2016; Li et al., 2019a; Li et al., 2019b; Li et al., 2020). The lack of participants in those studies was identified as a gap in the literature that we aim to fill by gaining a larger sample size.

3.3 Evaluation Procedure

The following section describes the evaluation procedures of this experimental design, including the participant demographics, physiological testing, and a breakdown of the flight test campaign. The experiment consists of two sessions. In the first, the participant will provide informed consent, answer a demographic survey, undergo perceptual testing, and complete VO training. The main experiment will take place during the second session. The participant is tasked with monitoring the location of the sUAS on the display at the GCS while scanning the airspace to ensure safe separation from any "intruder" aircraft. An intruder aircraft will enter the airspace according to pre-planned flight trajectories that are unknown to the participant. Details about each session follow.

Session one will begin with the participant reviewing and signing the informed consent form (see Appendix E). Once consent is given, the participant will fill out a demographics survey (see Appendix A). The participant will then undergo physiological testing, including the Snellen Eye Chart (see Appendix B), the Ishihara Color Deficiency test (see Appendix C), and a hearing screening (see Appendix D). The physiological data will be utilized to better understand the relationship between a test participant's visual acuity, color vision, hearing capability, and their ability to detect an intruder aircraft. These tests will not be used to approve or deny participants' participation. After the physiological data is collected, participants will undergo an approximately one-hour VO training presentation to provide insight into their roles and responsibilities during the flight test campaign. Following the collection of physiological data, the participants will complete the visual observer training (see Appendix F), conducted by a KSU flight operations team member. The training will outline the purpose of the flight operation with details on the system, flight path, altitude, speed, and the participants' roles and responsibilities as VOs. Participants will also be briefed on the call outs required during the testing when they detect the intruder aircraft (example phrases are detailed in Appendix F) and make an avoidance maneuver (descend, climb, maintain, or turn). The required callout information includes the object name, the object heading, the object heading relative to the UA, the object altitude relative to the UA, and the maneuver. These five items will be listed on a sign at the VO workstation to ensure they remember the required information needed for a callout. Upon completion of the VO training

presentation, the first session will conclude. This session will last approximately an hour and a half.

Session two will begin as participants are escorted to their assigned stations for the main experiment. Several participants will be seated at separate stations and will complete session two simultaneously. Each station will be separated by 100 - 200 yards to ensure the participants cannot hear one another. Each VO participant will be paired with an RPIC at a designated workstation with a ground control station that the RPIC will control. Remote pilots will be trained and certified members of KSU Salina's staff. Flight testing will utilize a simulated sUAS controlled by a RPIC via Mission Planner software. The VO participants will be tasked with monitoring the location of the sUAS on the display at the GCS while scanning the airspace to ensure safe separation from intruder aircraft.
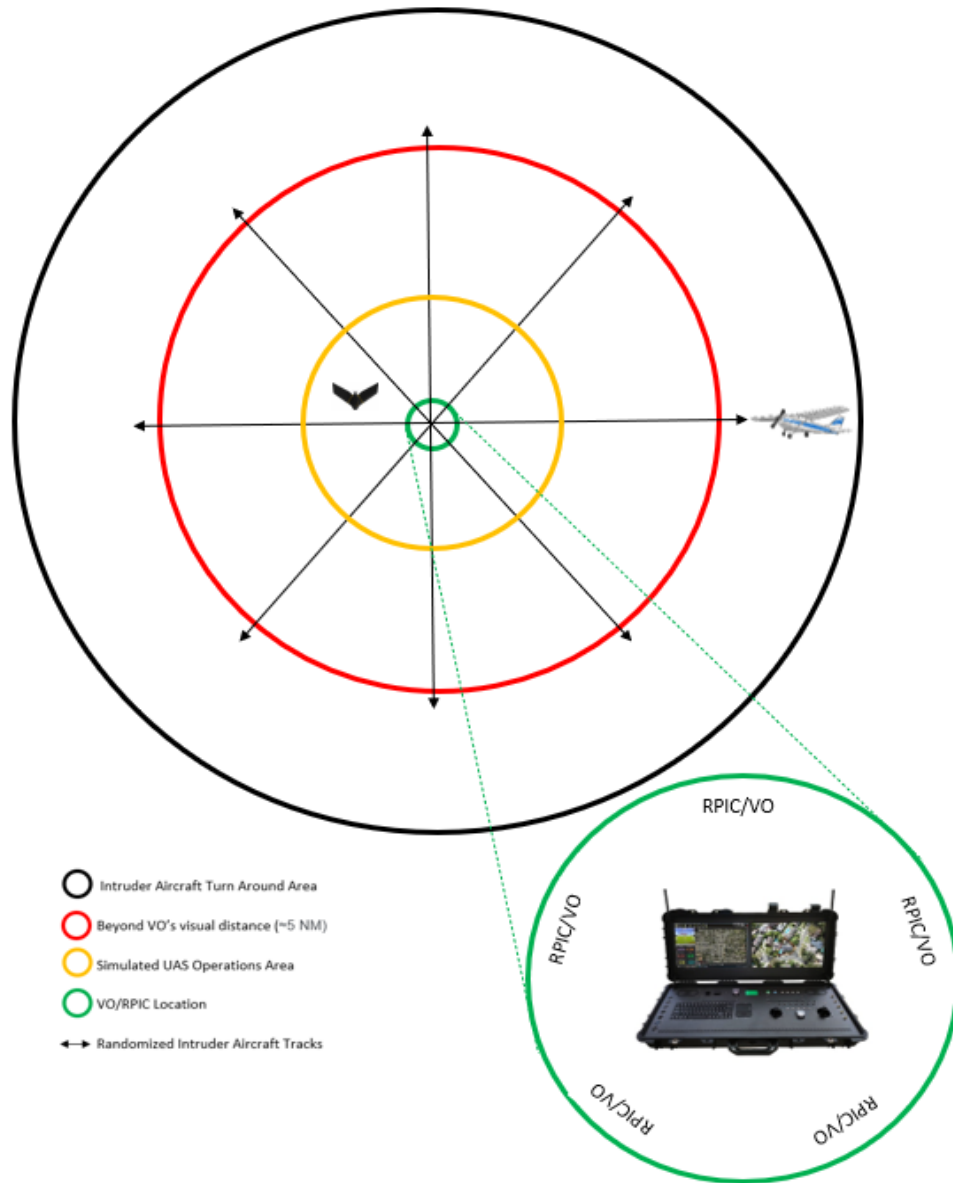
Figure 1. Conventional Aircraft Flight Paths.

Figure 1 1 represents the intruder aircraft's flight paths over the sUAS flight experiment area. Working from the center out, the green circle shows the location of the VO participants, the workstations, and the RPICs. Final spacing between these participants will be determined during the trials at New Mexico to ensure interdependences of the groups. The yellow circle represents the simulated sUAS operational area. The red circle will have a five-mile diameter and represents a distance beyond the visual range of the VOs. Areas outside the red circle and within the black circle will be used for intruder aircraft reset for the following test runs.

It should be noted that the five-mile range is an arbitrary line, and past flight testing has shown that the intruder aircraft may not be able to be seen at two to three miles out. The further this distance, the longer the runs will take, and the fewer tests will be able to be completed in a day.

This test "start line" of five miles will be reviewed as part of the testing to see if it can be made smaller to increase the number of tests completed.

The Cessna-172 approach paths will enter the UAS operations area at 500 feet Above Ground Level (AGL) with a ground speed of 90 knots. The intruder aircraft's approaches will consist of pseudo-random trajectories that cross over or are tangent to, the area where the small uncrewed aircraft will be operating. The pseudo-random trajectories will be a pre-defined list of approaches that the pilot of the Cessna-172 will know and choose from and communicate the planned approach to the "Air Boss" on the ground. This will be a double-blind experiment where neither the experimenters nor the participants will have contact with the intruder aircraft.

A trial will begin when the Cessna-172 is five Nautical Miles (NM) away from the experiment area. The VO will monitor the airspace and respond verbally when they see an intruder aircraft. They will have the option to provide a suggested avoidance maneuver to the RPIC as well. The RPIC will evaluate the suggested avoidance maneuver, and based on their experience, they will make the final decision on the correct avoidance maneuver, initiating the chosen maneuver at the ground station. If the RPIC chooses to make a different avoidance maneuver than what the VO suggested, the RPIC will complete a post-run questionnaire on why they chose a different maneuver (see Appendix J). These post-run questionnaires will be located on the RPIC workstation. When the RPIC rotates stations after each run, they will take a questionnaire, fill it out, and give it to the experimenter located at the next RPIC station. Once the aircraft has completed its maneuver, if any, and the Cessna-172 is out of the experiment area's airspace by three NM, the trial will be complete. RPIC reaction times and times to complete maneuvers will be recorded as well. Participants will complete between four and eight trials depending on the time it takes for the Cessna-172 to get back into position for a new approach. Session two will take approximately two hours to complete.

VO participants will also be recorded using a head-mounted GoPro Max to capture their callouts to the RPIC, while capturing a video recording of the experimental area.

All trials will be completed during daylight hours between 8 am and 5 pm during Visual Meteorological Conditions (VMC), where the weather will be clear from clouds with a minimum visibility of 10 statute miles.

3.3.1 Counterbalancing

Due to the level of experience required of an RPIC to conduct a sUAS mission safely and effectively, the experimental design will utilize KSU Salina's UAS Flight Operations Department Team Members, who are trained and experienced sUAS operators to act as RPICs for this testing. The KSU Salina UAS Department has a fixed number of flight operations team members who will be able to participate in the flight-testing campaign portion of the experimental design. Thus, to minimize the possibility of the RPICs experiencing a rehearsal effect from repeated trials and days of participating in the flight testing, the RPICs will be rotated between each VO station after the conclusion of a run and before the start of the next run. Furthermore, the RPICs will also not be aware of the approach path the intruder aircraft will take to ensure a more naturalistic response.

3.4 Measurement and Instrumentation

Prior to data collection, participants will complete a demographics form, found in Appendix A, and will complete Visual Observer Training instructed by a KSU flight operations team member. An outline of this training can be found in Appendix F.

This experiment will use the following data collection tools during the flight test:

1. A Snellen Eye Test for visual acuity (see Appendix B),
2. An Ishihara Test chart for color deficiency (see Appendix C),
3. An Audiometer to evaluate hearing levels (see Appendix D),
4. Audio recordings to capture participant's verbal callouts, and video recording of the airspace and the Cessna- 172's flight path over the experimental area (see Appendix H),
5. A Lux meter to measure the ambient light levels (see Appendix I),
6. A sound level meter to measure ambient noise level (see Appendix J),
7. The Cessna-172 flight logs, including the GPS, speed, altitude, and heading,
8. And Mission Planner simulation software for the sUAS simulated GPS, speed, altitude, and heading.

Table 1 categorizes the nine data collection tools into four types of data, (1) physiological data, (2) environmental data, (3) flight data, and (4) communications data. The data collection tools will be time-synced daily.

Table 1. Data Collection Tool Types.

Physiological Data	Environmental Data	Flight Data	Communications Data
Snellen Eye Test	Lux Meter	Cessna-172 Flight Logs	Audio Recordings
Ishihara Color Deficiency Test	Decibel Meter	Mission Planner Simulation Logs	
Audiometric Evaluation	Video Recordings		

Table 2. Experimental Design Matrix.

Dependent Variables	Independent Variables	Confounding Variables
Maximum visible distance	Light and noise levels	Contrast between the intruder aircraft and its background
Response time to initially see intruder aircraft	Flightpath of intruder aircraft	Presence of non-participating conventional aircraft near operational area
Response time to suggest a maneuver to deconflict/avoid intruder aircraft, if any response is given	VO experience	
Time to evaluate and "confirm" maneuver	Visual acuity and other physiological factors	
Maneuver performed, if any		
Time for maneuver to be completed, if any performed		

Data will be collected for six dependent variables, which include: (1) the maximum visual distance, (2) the response time to initially see the intruder aircraft, (3) the response time to suggest a maneuver to deconflict/avoid the intruder aircraft, (4) the time for the RPIC to evaluate and "confirm" the maneuver, (5) the maneuver performed, and (6) the time to complete the avoidance maneuver. The confounding variables over which we may have no control include the contrast between the intruder aircraft and its background, and the presence of non-participating conventional aircraft near the operational area.

3.4.1 Time Synching Instrumentation Tools
The procedure for time synching all the data collection tools is outlined below.

All clocks will be synchronized at the beginning of the testing day (assuming internet access):
1. Synchronize/verify each station laptop is synced with time.gov
   a. Go to time.gov to check the time (look at the right-hand panel to compare the computer clock).
   b. If off by more than +/- 0.500 seconds, right-click on the taskbar clock.
      - Click "Adjust date/time."
      - Click the "synchronize clock" button.
      - The National Institute of Standards and Technology (NIST) clock page should automatically refresh to show the results.
   a. Sometimes the server is wrong, or it won't work; try it manually:
      - Run a command prompt as administrator.
      - Enter an upcoming time via "time HH:MM:SS AM/PM" and wait to hit "Enter."

- Watch the NIST time seconds tick and hit "Enter" at the exact time the NIST clock matches what you've typed.
- Try again if the panel indicates the clock is off by more than +/- 0.500 Seconds.

2. Synchronize the Sound and Light sensors by connecting via the USB cable.
   a. Press the "Set Time" button on the software interface.
   b. Verify the date/time on the device LCD matches the NIST readout by comparing side-by-side.
3. Synchronize the GoPro MAX Date/Time:
   a. Press the Power/Mode button to get to the "Setup" menu.
   b. Press the Shutter/Select button to Enter.
   c. Press the Power/Mode button to scroll down to the date/time icon (the icon looks like the top half of a calendar or an upside-down keyboard).
   d. Press the Shutter/Select button to Enter.
   e. Verify the correct date (Shutter/Select changes and Power/Mode Scrolls).
   f. Watch the NIST time webpage and set the GoPro time to an upcoming minute (wait).
   g. Push the Power/Mode button to scroll down to "DONE" and hit the Shutter/Select button about 10 seconds BEFORE the NIST clock catches up with what is entered (MM-1):50.
   h. Select "BACK" and "EXIT" to go back to the video recording mode.
   i. Take a quick video recording of the NIST website time to determine the offset for potential post-processing correction.
4. For any other clocks that need to be synced manually, pull up time.gov (on a phone, etc.) and sync by direct comparison.

3.5   Validity and Reliability

Maximizing internal validity and reliability is essential to this research in examining VO and RPIC performance and human performance limitations regarding visual detection during an sUAS flight operation. Mills and Gay (2012) described internal validity as the degree to which observed differences in the dependent variable result solely from the manipulation of the independent variables and not from any uncontrolled extraneous variables. Of foremost importance is to collect data in a manner that is credible and reliable to minimize any threat to the internal validity of this experiment (Mills & Gay, 2012). Lazar, Feng, and Hochheiser (2010) suggest that establishing internal validity corresponds to the development of a multi-faceted argument that supports the interpretation of collected data. Thus, instituting standardized procedures, a fixed location, and consistent data collection methods will be utilized to enhance this study's internal validity.

In attempts to enhance internal validity, this experimental design uses a double-blind procedure in which the VO participants, RPIC staff, and researchers do not know the chosen flight path. Only the C-172 pilot and an "Air Boss" on the ground will know the chosen flight paths with no interaction with the participants. Double-blind procedures help to minimize the possible effects of participant and research bias (Frey, 2018). Enhancing the internal validity of the study will, in turn, enhance the external validity of the results, allowing the results to serve as a baseline representation of the types of data needed to be collected 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, et al., 2012). To enhance the reliability of this study, experienced RPICs with FAA Remote Pilot Certificates and years of hands-on flight experience were utilized to evaluate VO participant performance. The construction, planning, and testing of all instruments were also documented and described, and the researchers' relationship with the groups and setting were detailed.

3.6   Environment, Setting, and Apparatus

The research team has access to a 2000-acre farm in Gypsum, Kansas, roughly 20 miles from KSU-Salina's campus, which will be used as the flight-testing environment.

The sUAS flights will be simulated using the Mission Planner Software as the control station depicted in Figure 2. The simulation sUAS profile will be a fixed-wing hybrid Vertical Takeoff and Landing (VTOL) UAS flown with the following parameters:

- Cruise Altitude: 400 feet AGL
- Cruise Speed: 45 Knots Indicated
- Max Pitch Angle: 25 Degrees
- Min Pitch Angle: -20 Degrees
- Max Bank Angle: 30 Degrees

sUAS flight paths will be established greater than one mile from the RPIC/VO locations to simulate the EVLOS environment. Flight data of the sUAS position will be provided to the VO by means of a secondary monitor. Mission Planner can provide hundreds of data points related to the sUAS flight (e.g., position, altitude, speed, time, etc.).

Figure 2. Mission Planner Software Display.

The Cessna-172 is an S model with a Garmin-1000. The Cessna-172 will be flown with the following parameters:

- Cruise Altitude: 500 feet AGL

- Cruise Speed: 90 Knots Ground Speed

The Garmin-1000 will record pertinent flight data (e.g., position, altitude, speed, time, etc.). The intended encounter trajectories for the intruder aircraft are detailed in Appendix K.

3.7 Data Analysis

This section identifies all the data that will be collected prior to and during flight tests, equipment used to measure and collect the data, steps involved in data processing, and statistical and other quantitative analyses of the data.

3.7.1 Data Collection
- 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 Astronomical Data
    - Test Site Illuminance
    - Test Site Ambient Noise Level
- VO and RPIC Information:
    - Background
    - Visual Acuity and Hearing Levels
    - Experience
    - Location on the test site in terms of Latitude and Longitude coordinates
- Audio and Video Recordings
    - Flight Communications
    - VO and RPIC Communications
    - Video recording of the GCS areas
    - Photographs (GCS and test area, test setup, intruder aircraft, flight simulator)
- Specific VO responses:
    - Acknowledgment of visual acquisition of intruder aircraft
    - Acknowledgment of loss of visual sight of intruder aircraft after the initial acquisition
    - The suggestion of a maneuver to RPIC if a potential collision is identified
- Specific RPIC responses:
    - Acknowledgment of maneuver suggested by the VO, if any
    - Confirmation of go/no-go to the suggested maneuver, if any
    - Override to the suggested maneuver, if any
    - Acknowledgment of completion of the maneuver, if any
- Intruder and UA Information and GPS data:
    - Minimum flight parameters: latitude, longitude, altitude, speed, heading at a minimum frequency of 1 Hz

3.7.2 Equipment used to measure and collect data
A brief description of all the equipment used to measure and collect the data is provided in Appendices D, G, H, I, and J.

3.7.3 Data Processing

The flight paths of the intruder aircraft will be mined from the GPS recorder located onboard the aircraft. The flight paths of the simulated UA will be traced from the logs of the flight simulator software. These flight paths will be based on the GPS recorder position of the aircraft in terms of Latitude, Longitude, and Altitude.

The recorded VO and RPIC responses will be coded with the timestamps obtained from the GCS area laptop(s). The VO and RPIC coded responses will be chronologically aligned with the GPS tracks.

MATLAB and Microsoft Excel will be used to process the data collected. Other mapping visualization tools like Google Maps and ArcGIS may also be used for the visualization of flight encounters.

3.7.4 Quantitative Results, including Statistical Analysis

The following quantitative parameters will be computed from the processed data:

- o Visual Acquisition Distance (VAD) (calculated based on GPS data at the time of detection by VO),
- o The altitude of intruder aircraft at the time of detection,
- o The apparent size of intruder aircraft at the time of detection in visual arcs,
- o Response time to initially visually acquire the intruder aircraft,
- o Response time to suggest a maneuver to deconflict/avoid intruder aircraft,
- o Time to evaluate and "confirm" maneuver,
- o Time for maneuver to be completed, if any performed, and
- o Encounter Parameters:
  - Closest Point of Approach (CPA)
  - Horizontal Miss Distance
  - Vertical Miss Distance
  - Status of Well Clear and near midair collision violation

The statistical analysis will include computation of the probability of detection curves, univariate and multivariate Analysis of Variance (ANOVA), and Signal Detection Theory (SDT) analysis. The independent and dependent variables are listed in Section 3.4. The probability of detection curve will be obtained as a function of the following variables: the apparent size of the intruder aircraft, VAD, time of day or ambient light levels, ambient noise levels, and flight path of the intruder aircraft. A multivariate ANOVA will be used to study the effect of the independent variables on the dependent variables and the interactions within independent variables and within dependent variables.

SDT will be used to measure the ability of VOs to correctly suggest an avoidance maneuver as a function of the independent variables. For this SDT test, the number of hits will correspond to the number of times the VOs suggest a correct maneuver, the number of misses will correspond to the number of times the subjects suggest an incorrect maneuver, and false alarms will correspond to instances when VOs suggest a maneuver when none is required, and correct rejections will correspond to instances when VOs correctly identify that no maneuver is required.

SDT will also be used to assess the likelihood of RPICs overriding the maneuvers suggested by the VOs. For this SDT test, the number of hits will correspond to the number of times the RPICs correctly override the VO suggested maneuver, the number of misses will correspond to the number of times the RPICs incorrectly override the VO suggested maneuver, and false alarms will correspond to instances when RPICs override the VO suggested maneuver when not is required, and correct rejections will correspond to instances when RPICs correctly override the VO suggested maneuver.

MATLAB and Microsoft Excel will be used to compute the quantitative results, including statistical analysis of the processed data, and generate plots to visualize the results effectively.

3.8 Presentation of Results

The presentation of results will highlight the time it takes VOs to detect the intruder aircraft, and at what distance and altitude, the time it takes the VO to announce an avoidance maneuver, the time for the RPIC to confirm the avoidance maneuver, and the time it takes to complete the maneuver. Statistical analysis and SDT results will also be presented along with the primary quantitative parameters of interest to help infer the relationships between the different variables involved in the experiment.

Furthermore, data and results from the experiment methodology will be presented within technical reports to the project sponsor, supporting organization(s), and/or presented at industry conferences/symposia.

3.9 Limitations and Assumptions of Methodology

The following limitations were considered when developing this methodology. They predominately stem from (1) individual human performance limitations, (2) the potentially limited participant pool, and (3) the variability in sUAS flight operations that may limit the applicability of our results to future sUAS flights.

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

Limitation 2: Since participants have no VO experience, conclusions about VO performance may not generalize to VOs with more experience.

Limitation 3: Kansas State University Salina has a smaller campus population there may be limited participants.

Limitation 4: The short time available for this task may limit the ability to recruit and schedule participants.

Limitation 5: This flight test will be simulating a fixed-wing hybrid VTOL UAS thus, the time it takes for this system to initiate and complete an avoidance maneuver will vary compared to other UAS platforms. Therefore, the results may not generalize operations utilizing other UAS platforms.

Limitation 6: The flight operations used for this experiment were limited to daytime operations under VMC conditions performing a beyond visual line of sight sUAS flight operation. The results from this study may not apply to operations being conducted under different conditions, such as nighttime operations.

Limitation 7: The data collected for the time it takes 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.

This experimental design and subsequent flight test campaign are driven by the ensuing assumptions.

Assumption 1: Experienced VOs would perform differently, but what constitutes experience?

Assumptions 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 understand the roles and responsibilities of a VO during a sUAS operation.

Assumption 4: Participants will follow the processes they are given during the VO training to include, using the correct callouts, and using the specified scanning technique.

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

Assumption 6: Participants will 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 will not scan the airspace and give inadvertent clues to the participants as to where the intruder aircraft is located.

3.10 IRB Considerations
The nature of these tests requires the use of human subjects to assess their performance as visual observers. If human test subjects are used, then a review and approval from an Institutional Review Board (IRB) is required. The research team will submit this experiment plan to their respective IRBs prior to engaging in research activity. Given the nature of this research and mechanisms for data collection, it is anticipated that this research will pursue an expedited IRB process; however, due to the nature of this study, there may be delays in getting IRB approval as revisions may be needed.

Prior to beginning this research, the research team will ensure that all necessary university participants are current with their respective IRB certification procedures as required by their respective institutions – e.g., Collaborative Institutional Training Initiative on human subjects' research. All research team members involved in this research will ensure all survey data and potential Personally Identifiable Information (PII) remains secure, ensuring the confidentiality and anonymity of all participants. The following measures will be taken to ensure the protection of all participant data PII that may result from this research.

1. Access to raw data sets will be limited to research team members with a need to access the data. In this case, it will be limited to those identified by the lead university (KSU) as (1) flight test developers, or (2) data analysts.
2. All data collected for this research will be anonymized and coded such that the identity of survey participants cannot be identified. The research team will use a unique coding scheme that cannot be correlated to survey or interview participants' personal information.

3. Physical records of the demographic information and physiological data will be kept in a secure office in a locked file cabinet. Informed consent and digital survey notes will be controlled via (1) locked storage, and/or (2) password protection.

This study will be utilizing an element of deception for safety purposes. The participants will be told that the sUAS will be flying in an area beyond their line of sight, and the participants will have a ground control station at their disposal that displays the sUAS flight path, location, and altitude on the screen. However, the sUAS will not be a real aircraft, Mission Planner software will be used to simulate the sUAS flight path and location onto the ground control station, no sUAS will be in the air. This is being done to eliminate the risk of a midair collision between the conventional aircraft and the sUAS. The participants will be debriefed after the trials are over that the sUAS was a simulation (see Appendix L).

4 REFERENCES

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APPENDIX A – DEMOGRAPHICS FORM

The following outline represents the demographics form for this study. Additionally, it will outline the measurement scales and other metrics for use in performing data analysis and quantifying the results.

Demographics Form

- Please enter today's date
  - (fill in the blank)
- Enter your participant ID given to you by the experimenter
  - (fill in the blank)
- What is your age?
  - 18 – 24
  - 25 – 34
  - 35 – 44
  - 45 – 54
  - 55 +
  - Prefer not to answer
- What is your gender identity?
  - Male
  - Female
  - Transgender
  - Do not identify as male, female, or transgender
  - Prefer not to answer
- What category best describes you?
  - American Indian or Native American
  - Asian
  - Black or African American
  - Hispanic/Latinx
  - Native Hawaiian or Other Pacific Islander
  - White
  - Other (Fill in the blank)
  - Prefer not to answer
- What is your highest level of education completed?
  - Less than a high school diploma
  - High school degree or equivalent (e.g., GED)
  - Vocational/Trade Certification
  - Some college, no degree
  - Associates degree (e.g., AA, AS)
  - Bachelor's degree (e.g., BA, BS)
  - Master's degree (e.g., MA, MS)
  - Professional degree (e.g., MD, DDS, DVM)
  - Doctorate (e.g., PhD, EdD)
  - Prefer not to answer

- Do you have any prior aviation experience?
  - Yes
    - Sport Pilot
    - Private Pilot
    - Commercial Pilot
    - Airline Transport Pilots
    - Remote Pilot
    - Other (fill in the blank)
  - No
  - Prefer not to say
- Do you have any documented visual or auditory issues (e.g., strabismus, deafness)
  - Yes
    - If yes, please explain
  - No
- Are you currently taking any medications that may affect your vision or reaction time?
  - Yes
    - If yes, please explain
  - No
- How many hours of sleep did you get last night?
  - Fill in the blank
- How does the amount of sleep you got last night compare to your usual number of hours of sleep?
  - More than I usually get
  - About the same as I usually get
  - Less than I usually get
- How fatigued do you feel right now?
  - Extremely well-rested
  - Well-rested
  - Neutral
  - Not Rested
  - Extremely not rested
- Are you presently experiencing any other conditions or physical effects that may affect your reaction time?
  - Yes
    - If yes, please explain
  - No
- Do you have any additional information you want to share related to supporting this effort?

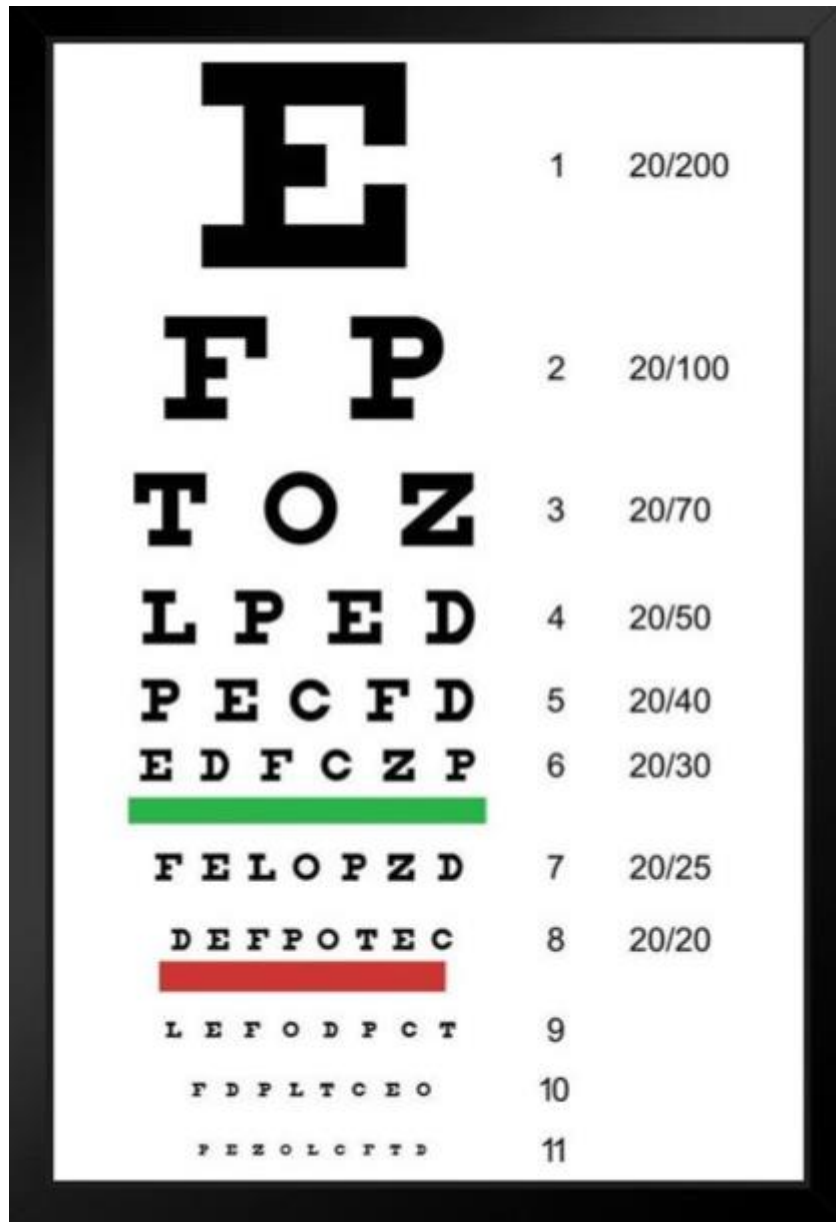**APPENDIX B – SNELLEN EYE CHART**

Figure 3. Snellen Eye Chart (Snellen Eye Chart, n.d.).

Figure 3 is the Snellen Eye Chart that will be used to evaluate the participant's visual acuity. The eye chart will be placed on a wall or stationary background with the participant stationed 10 feet away. The following are the instructions that will be given to the participants when administrating the Snellen Eye test:

1. Cover one eye with your hand so that you cannot see out of that eye, but do not apply pressure to the covered eye.
2. Identify a line on the chart you can comfortably read. Read the letters on that line aloud.
3. Continue trying to read the letters on each successively smaller line. Do not squint.

4. Stop when you can no longer read the successively smaller line.
5. Switch to the other eye and repeat (Snellen Eye Chart, n.d.).

The administrator will record the participant's visual acuity for each eye by noting the line for which they correctly identified either:

1. More than half the letters on that line but not all of them,
2. Or all letters on that line, plus a few letters (less than half) on the next line.

Some examples of visual acuity results would be if you correctly identified five of the seven letters on the 20/32 line, your visual acuity for that eye would be $20/32^{-2/7}$. Whereas if you correctly identified all seven letters on the 20/32 line and three of the eight letters on the 20/25 line, your visual acuity in that eye is $20/32^{+3/8}$ (Snellen Eye Chart, n.d.).

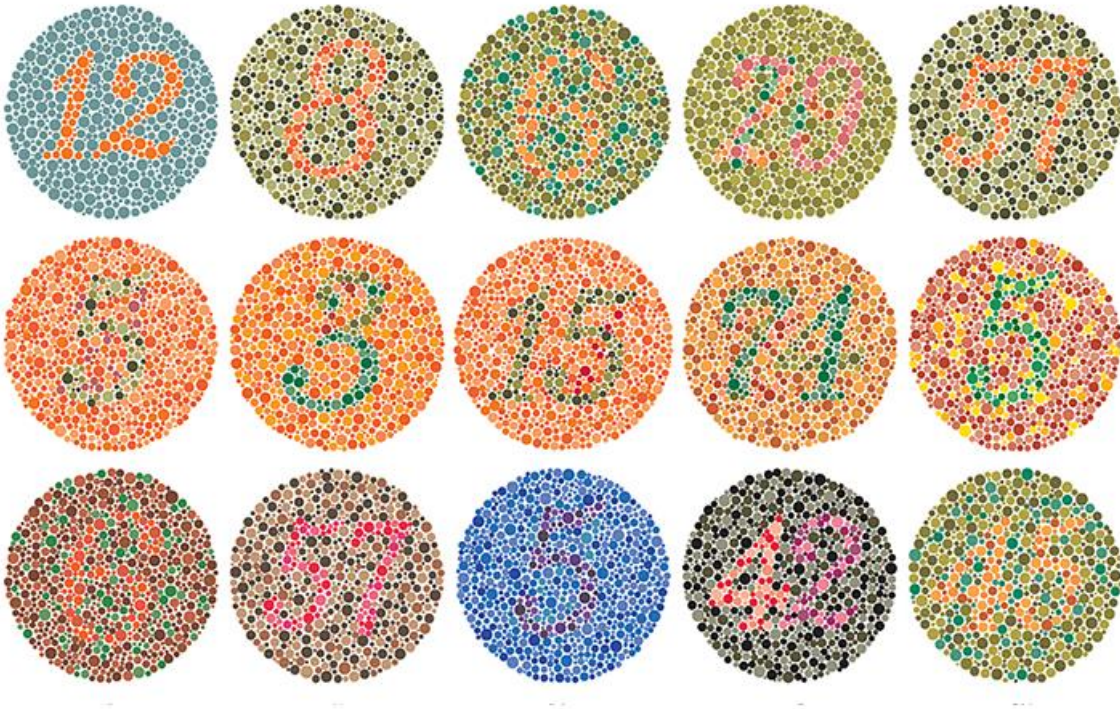**APPENDIX C - ISHIHARA COLOR DEFICIENCY TEST**

Figure 4. Ishihara Color Deficiency Test Examples (American Optometric Association, n.d.).

Figure 4 depicts examples of the Ishihara Color Deficiency Test plates used to detect red-green color deficiencies.

Participants will be seated inside the KSU hanger and presented with the booklet and a test sheet number 1 – 24, participants will write the number, shape, or letter seen on their test sheet and hand to the administrator when complete. The numerals seen on the plates are stated, and each answer should be given without more than a three-second delay. The number stated by the participant will be recorded. The test plate with the figure "12" is used as an example plate to explain the test processes to the participants and will be read correctly by those with and without color deficiencies.

Examples of the interpretation of the plates are below:

- Participants without deficiencies will read "8," and those with red-green deficiencies will read "3",
- Participants without deficiencies will read "29," and those with red-green deficiencies will read "70",
- Participants without deficiencies will read "74," and those with red-green deficiencies will read "21" (Stanford University, n.d.).

Participants will be presented with 11 plates, and an assessment of the readings of plates 1 to 11 determines the normality or defectiveness of the participant's color vision. If ten or more plates are read correctly, the color vision is regarded as normal/without deficiencies. If a participant reads seven or fewer plates correctly, the color vision is regarded as deficient.

APPENDIX D – AUDIOMETER/HEARING TEST

Figure 5. Earscan 3 Screening Audiometer (Earscan, n.d.).

Figure 5 shows the Earscan 3 (ES3) Screening Audiometer that will be used to evaluate participants' hearing levels. Rather than a full-scale hearing test, we will conduct a screening to determine that the participant meets the minimum requirements for hearing. The screening protocol is as follows:

1. Test setup. The screening will be conducted in an indoor area with minimal background noise, and the participant will be seated in a chair facing away from the experimenter. The headphones will be fitted to the participant, placing the red headphone on the right ear. They will be given the response button and told that their task is to press the button when they hear a quiet tone in either ear.

2. All test tones will be presented at 30 (decibel) dB Hearing Level, meaning 30 decibels above the normal hearing threshold in quiet. This level was chosen because we anticipate that screenings will be conducted in environments with some background noise.

3. The experimenter will begin the test by presenting a 250 hertz (Hz) tone to the right ear. They will confirm that the participant detected the tone by watching for the button press indicator on the ES3 display. If the participant does not detect the tone, it will be presented again. This frequency/ear combination will be marked as a 'miss if the tone is still undetected.'

4. This process will be repeated in the right ear for tones at 500, 1000, 2000, 4000, and 8000 Hz. The experimenter will vary the timing of tone presentation during the screening.

5. Steps 3 and 4 will be repeated for the left ear.

Participants will not be told the results of the screening and will participate in the study regardless of the outcome. However, only participants that detected all frequencies in both ears will be included in the data analysis.

APPENDIX E – INFORMED CONSENT

Below is the outline for the Informed Consent.

PROJECT TITLE:

PROJECT APPROVAL DATE:		**PROJECT EXPIRATION DATE:**		**LENGTH OF STUDY:**	

PRINCIPAL INVESTIGATOR:

CO-INVESTIGATOR(S):

CONTACT DETAILS FOR PROBLEMS/QUESTIONS:

IRB CHAIR CONTACT INFORMATION:

PROJECT SPONSOR:

PURPOSE OF THE RESEARCH:

PROCEDURES OR METHODS TO BE USED:

BIOLOGICAL SAMPLES COLLECTED (Describe procedure, storage, etc.):

[Select a statement from the drop down menu]

[Select a statement from the drop down menu]

ALTERNATIVE PROCEDURES OR TREATMENTS, IF ANY, THAT MIGHT BE ADVANTAGEOUS TO SUBJECT:

RISKS OR DISCOMFORTS ANTICIPATED:

BENEFITS ANTICPATED:

EXTENT OF CONFIDENTIALITY:

[Select a statement from the drop down menu]

IS COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS? ☐ Yes ☐ No

PARENTAL APPROVAL FOR MINORS:

PARENT/GUARDIAN APPROVAL SIGNATURE: [blank] **DATE:** [blank]

Terms of participation: I understand this project is research, and that my participation is voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits, or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form, and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed and dated copy of this consent form.

(Remember that it is a requirement for the P.I. to maintain a signed and dated copy of the same consent form signed and kept by the participant).

PARTICIPANT NAME: [blank]

PARTICIPANT SIGNATURE: [blank] **DATE:** [blank]

WITNESS TO SIGNATURE: **(PROJECT STAFF)** [blank] **DATE:** [blank]

APPENDIX F - VISUAL OBSERVER TRAINING

The following components of the visual observer training were found to be the most pertinent to this flight test operation, based on a review of four different VO training courses, 1) New Mexico State University's FAA UAS Flight Test Site, 2) the Alaska Center for Unmanned Aircraft Systems Integration, 3) Kansas State University Salina's Applied Aviation Research Center, and 4) the Public Safety Unmanned Response Team (PSURT). The various institutions have different names for the same basic training, including "Visual Observer Training," "Observer Training," and "VO/Communication Training." With different names, all have the same and associated core elements required to safely perform the VO tasking.

- 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 Part 107 Operating Limitations
  - Operating Requirements
- Team Composition and Reporting
  - Definition of mission support teams' individual 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 call outs:
      - "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 UAS
  - 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
  - Spatial Disorientation Definition
    - Visual Illusions
    - Autokinesis
    - Flicker Vertigo
    - False Perceptions
    - False Horizons
    - Lost Horizons
    - Black Hole Syndrome/ Black Hole Approach

- - PSURT Materials regarding eyes/vision
    - Specifically, "rods" and "cones"
    - Mesopic vision
      - Fixation and fascination
- 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 bearings from our location
- Emergency procedures
  - Follow "Air Boss's" Instructions

APPENDIX G – POST RUN QUESTIONAIRE WITH RPIC

RPIC Identifier: __

VO Identifier: __

Trial: __

Run: __

Questions:

What was the suggested avoidance maneuver by the VO?

Did you agree/disagree with he suggested avoidance maneuver?

If you disagreed with the VOs suggested avoidance maneuver, what was your suggested avoidance as the RPIC?

As the RPIC, why did you choose to perform a different avoidance maneuver other than the one suggested by the VO?

APPENDIX H – AUDIO AND VIDEO RECORDING

Figure 6. GoPro Max (User Manual - GoPro, n.d.).

Figure 6 shows the GoPro MAX, which will be used to capture audio of the VO and RPIC, and video footage of the airspace to determine if the VOs are using the scan technique demonstrated in the VO training, and to see whether their intruder aircraft sighting is of an actual aircraft. The GoPro Max has 6K video, 360-degree field of view shots at a 5.6k resolution, 6 mics, and GPS capabilities. The recording protocol for the GoPro Max is below:

1. With the camera off, unlock the door, slide it down, and flip it open to insert the SD card with the label facing the battery compartment.
2. Insert the battery and slide the door all the way up until there is no gap, and then lock it.
3. Press the Mode button to turn on the GoPro Max.
4. Swipe left or right to mode you want (HERO mode for video).
5. Choose the desired orientation (landscape).
6. Press the shutter button to start recording (User manual - GoPro, n.d.)

APPENDIX I – LUX METER

Figure 7. Digital Lux Meter (Lux/Light Meter, n.d.).

Figure 7 illustrates the TekcoPlus LUX29TK Digital Light Lux Meter with a data logging function and can detect lux levels from 0 to 200,000 lux. The recording protocol is detailed below:

1. Use the CD provided in the set to install the software.
2. Double click the "LuxMeter Communication Tool" to open the software.
3. Install batteries and turn the meter on, then connect it to the computer with the USB cable.
4. Click "Communication," then click "Connect."
5. Once it is ready to use, the phrase "Connected to the device: OK!" will display, and real-time data should appear on the left-hand side of the screen.
6. Click the "Set Time" button to set the current date/time.
7. IMPORTANT: The recording Parameters must be set up, otherwise the meter will not record. Press "Set Param" before recording. Set the Recording Interval to 1 Sec, Total Records to 21000 (maximum), Lux Unit to "Lux" and Click "OK" when ready.
8. The maximum recording time with the above settings is about 5 hours and 50 minutes. If the recording time finishes, "Full" will be displayed at the bottom right-hand corner of the screen, and the device will turn off automatically after 10 minutes at idle.
9. To start recording, press the "REC" button on the meter. The recorded data sample count should be displayed in the lower right-hand corner of the screen. Press "REC" on the device again or click the "Stop Recording" button via the software interface if you want to stop recording manually.
10. While recording, you can disconnect the meter from the computer and position it as needed for measurement. It can be powered externally via the USB interface.
11. When you are done, reconnect the meter to the computer to synchronize the data to the software and download it. Click "Data Download" and save the .rec file to the computer.
12. To Export the data, click "File" then "Export" to save the data in Excel Format.

APPENDIX J – DECIBEL METER

Figure 8. Sound Level Meter (Sound Level Meter, n.d.).

Figure 8 displays the TekcoPlus SLM25TK Sound Level meter with a data logging function for dB between 30 and 130. The recording protocol is described below:

1. Use the CD provided in the set to install the software.
2. Double click the "Noise Logger Communication Tool" to open the software.
3. Install batteries and turn the meter on, then connect it to the computer with the USB cable.
4. Click "Communication," then click "Connect."
5. Once it is ready to use, the phrase "Connected to the device: OK!" will display, and real-time data should appear on the left-hand side of the screen.
6. Click the "Set Time" button to set the current date/time.
7. IMPORTANT: The recording Parameters must be set up, otherwise the meter will not record. Press "Set Param" before recording. Set the recording interval to 1 Sec, total records to 32512 (maximum), sample level to Slow, and noise level to A. Click "OK" when ready.
8. The maximum recording time with the above settings is about 9 hours. If the recording time finishes, "Full" will be displayed at the bottom right-hand corner of the screen, and the device will turn off automatically after 10 minutes at idle.
9. Recording example: 100 records at 5-second recording intervals will record for 8 minutes 20 seconds before stopping.
10. To start recording, press the "REC" button on the meter. The recorded data sample count should be displayed in the lower right-hand corner of the screen. Press "REC" on the device again, or via the software interface, click the "Stop Recording" button to stop recording manually.
11. While recording, you can disconnect the meter from the computer, and position it as needed for measurement. It can be powered externally via the USB interface.
12. When you are done, reconnect the meter to the computer to synchronize the data to the software and download it. Click "Data Download" and save the .rec file to the computer.

To Export the data, click "File" then "Export" to save the data in Excel Format. (Sound Level Meter, n.d).

APPENDIX K – INTRUDER ENCOUNTERS

Table 3: Intruder Aircraft Encounter Approaches.

	Direction	Radial	Altitude (AGL)*	Altitude (MSL)**
A	East to West	270°	485'	1700'
B	Southeast to Northwest	315°	985'	2200'
C	Southwest to Northeast	045°	485'	1700'
D	West to East	090°	485'	1700'
E	North to South	180°	485'	1700'
F	Northwest to Southeast	135°	985'	2200'
G	Northeast to Southwest	225°	485'	1700'
H	South to North	360°	485'	1700'

*AGL is MSL altitude minus the elevation of the ground at the UAS site (1215' MSL).

**MSL is rounded to the nearest hundredth and based upon the current KSLN METAR.

Figures 9-16 depict the intended approach paths of the intruder aircraft outlined in Table 3.
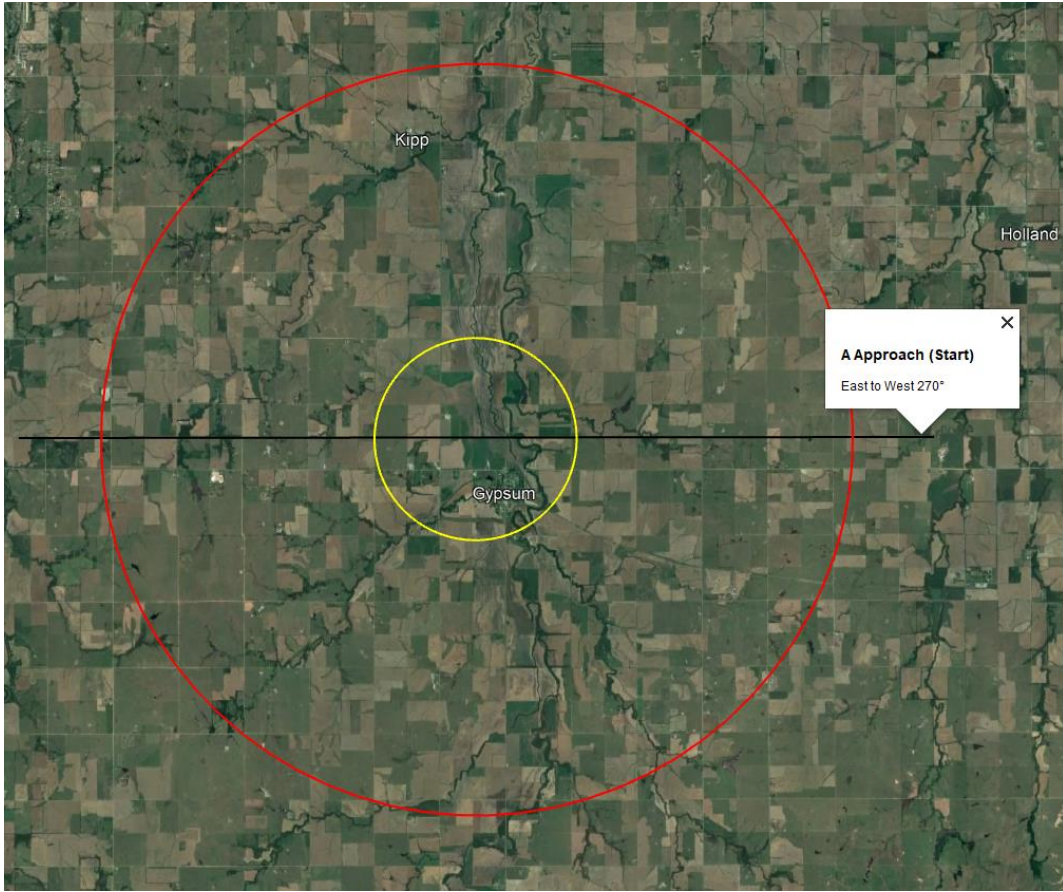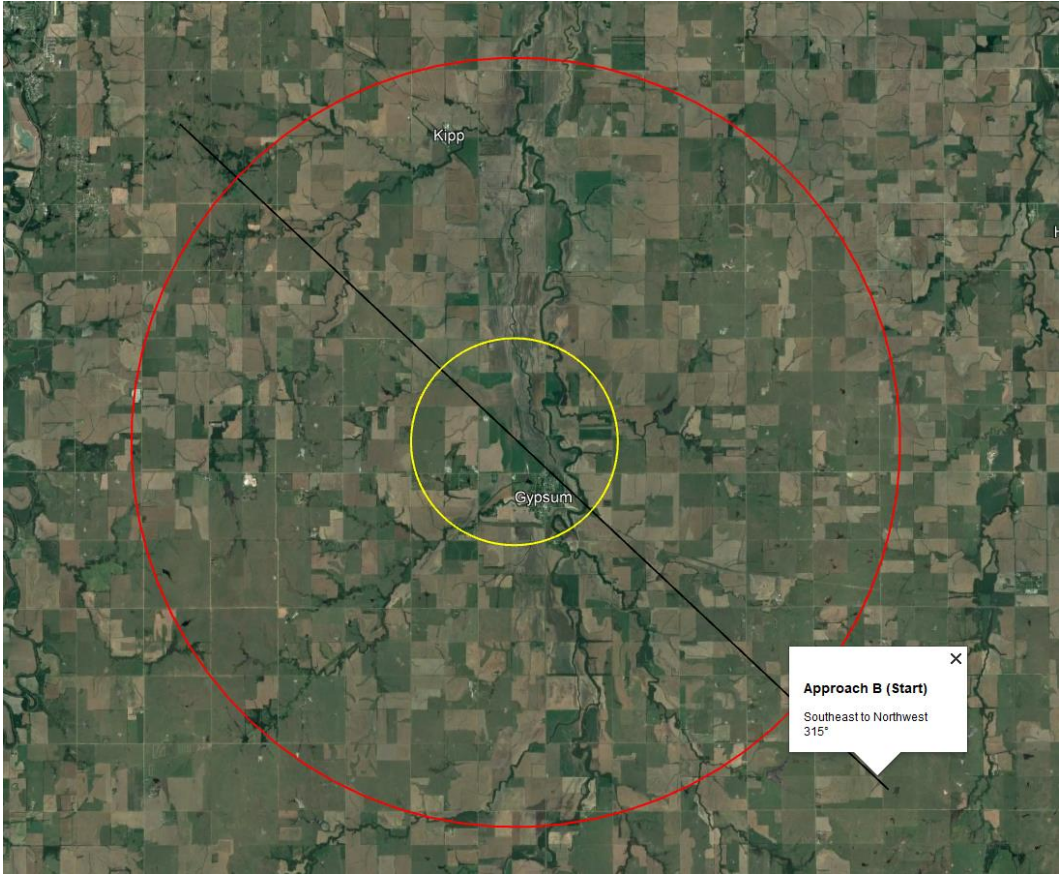
Figure 9. Approach A East to West.
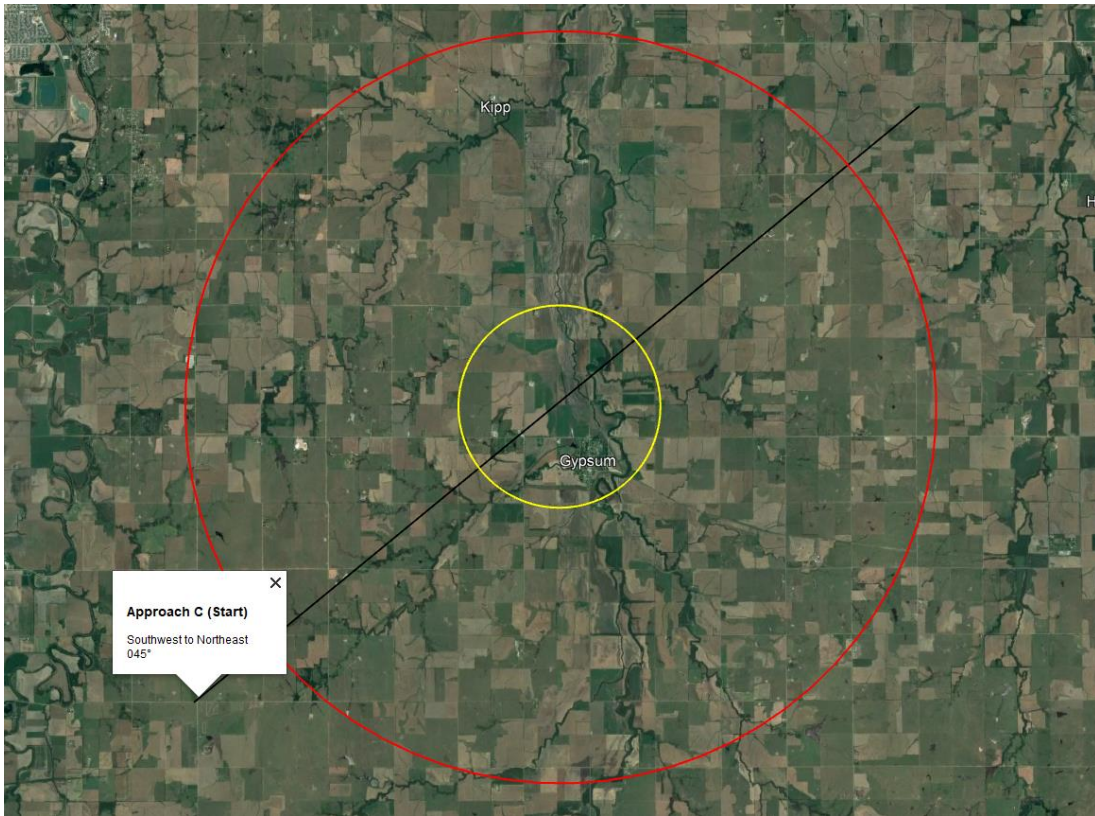
Figure 10. Approach B Southeast to Northwest.

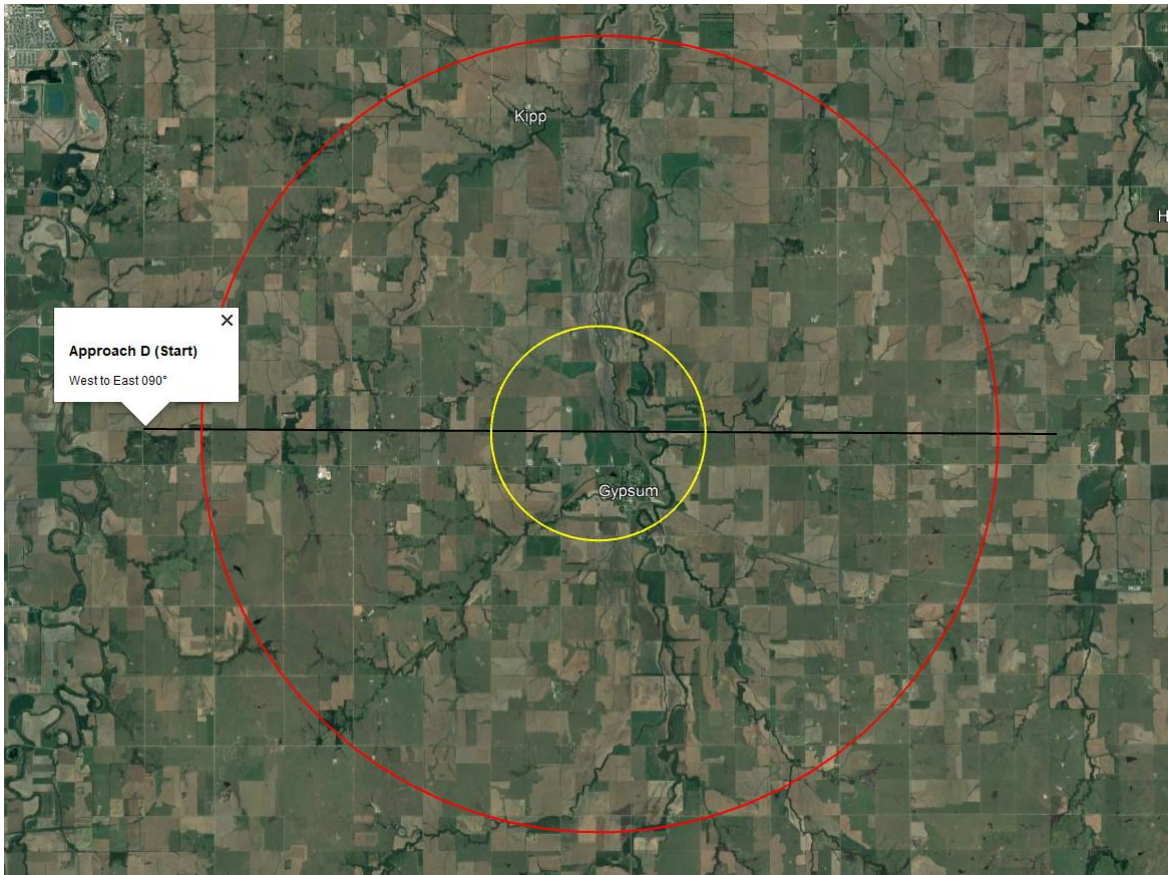Figure 11. Approach C Southwest to Northeast.
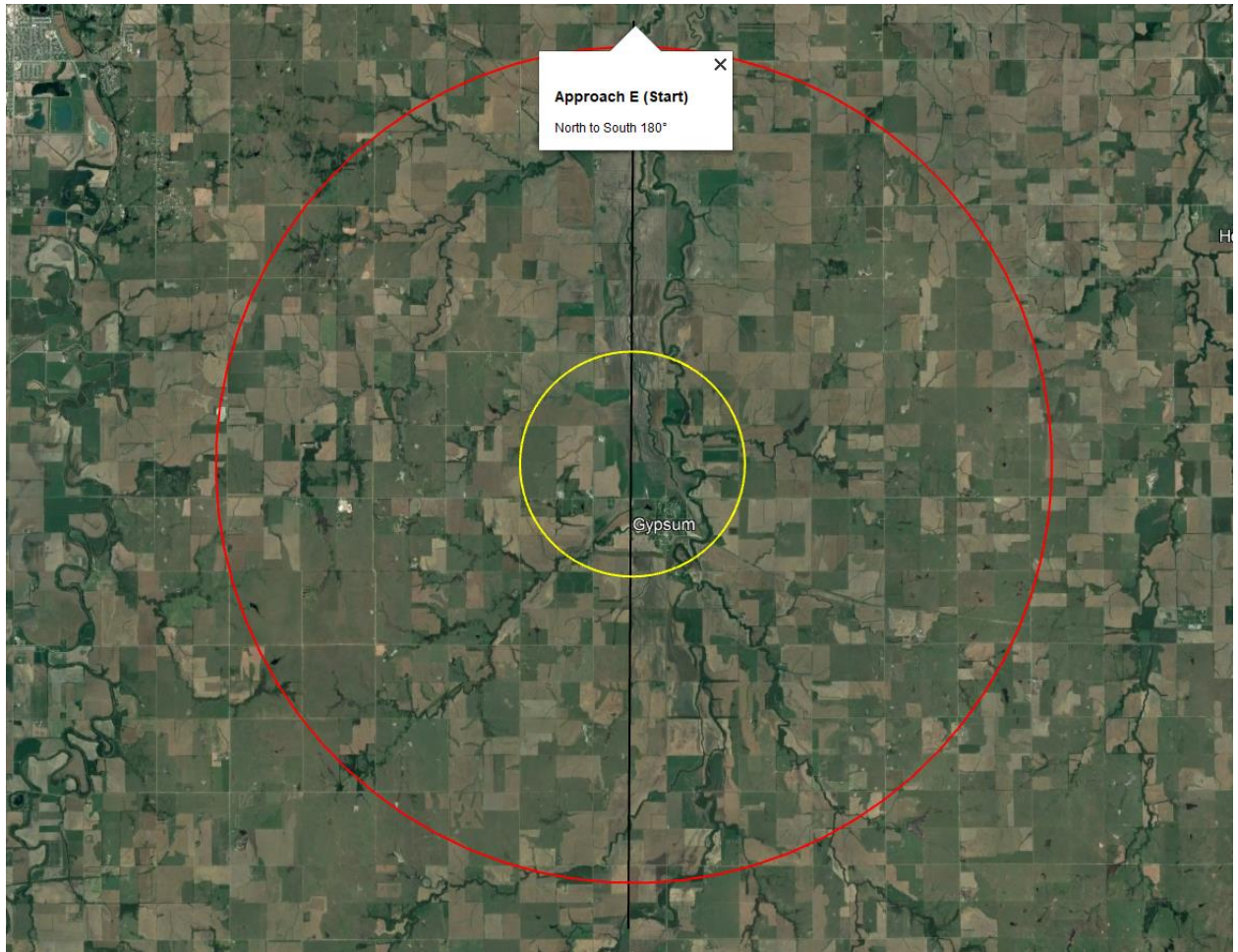
Figure 12. Approach D West to East.

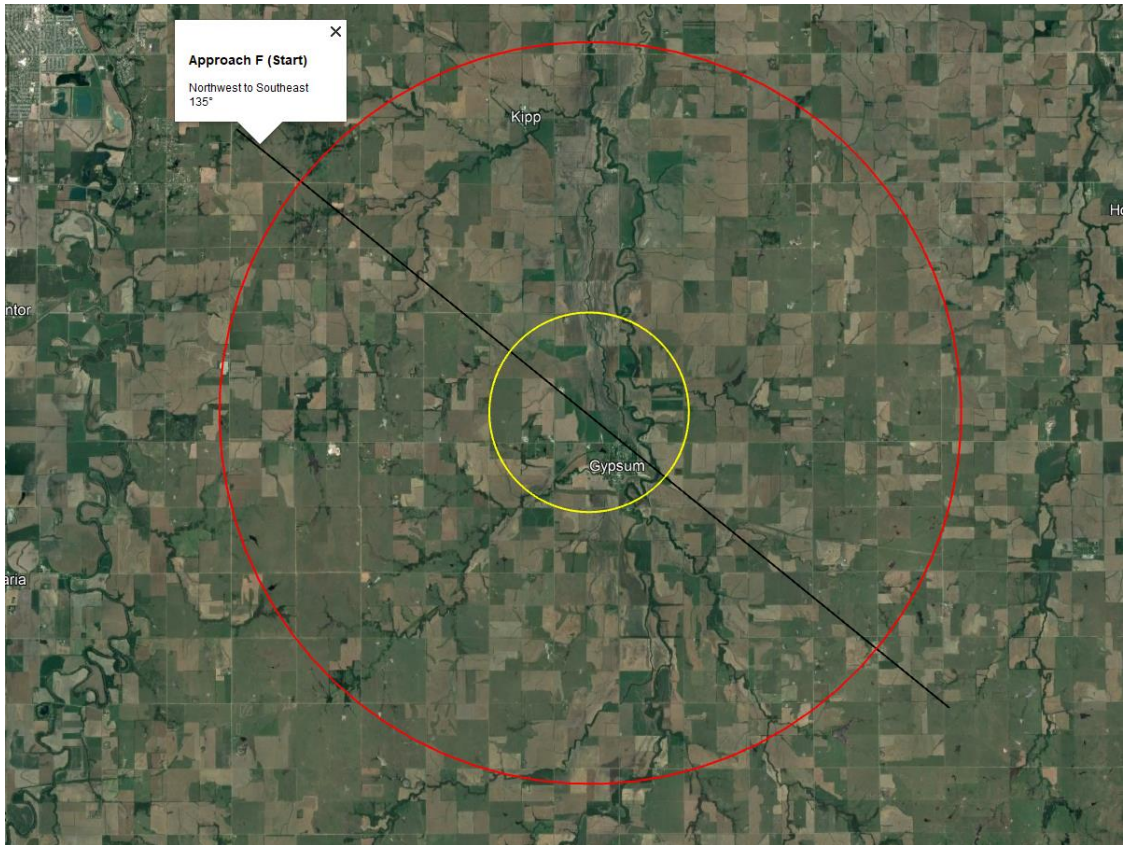Figure 13. Approach E North to South.

Figure 14. Approach F Northwest to Southeast.
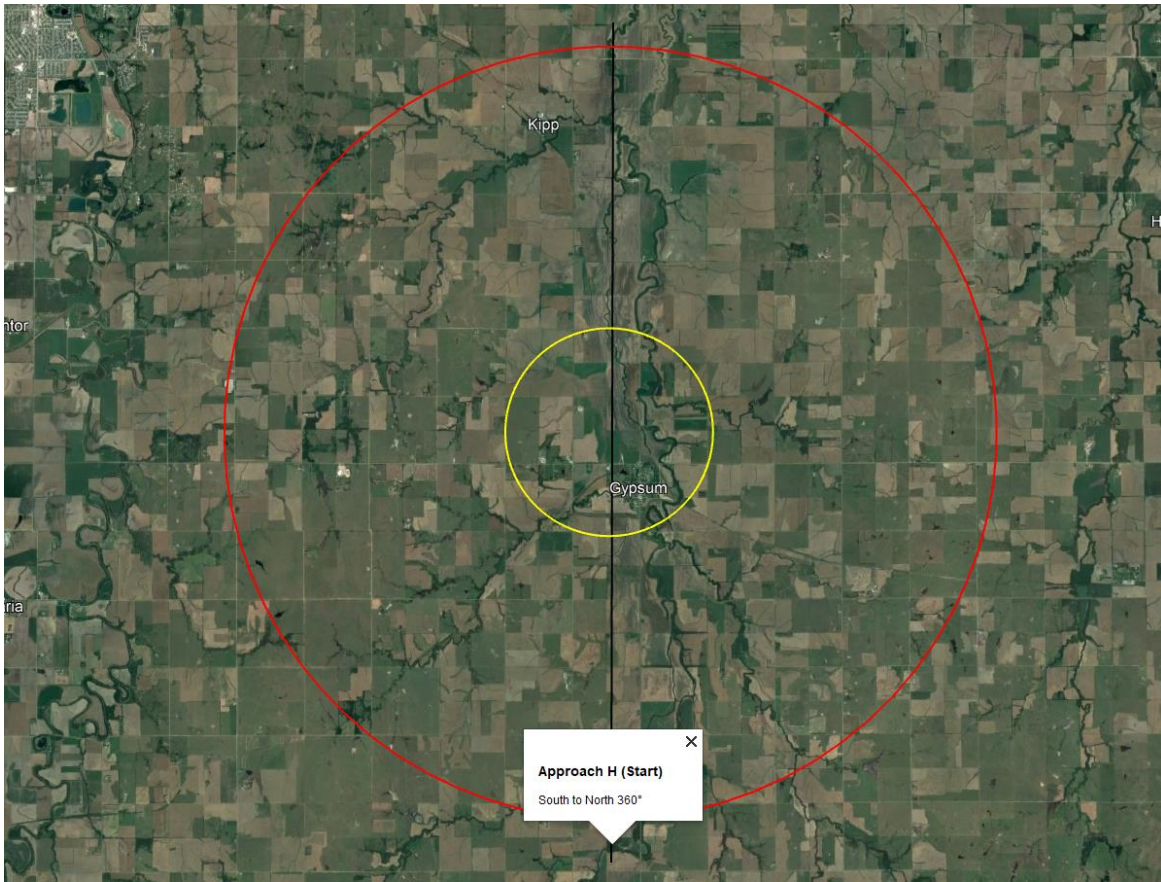
Figure 15. Approach G Northeast to Southwest.

Figure 16. Approach H South to North.

APPENDIX L – PARTICIPANT DEBRIEF

Thank you for participating in our study.

Purpose of the study:

Earlier in our consent form, we informed you that the purpose of the study was to evaluate and capture data on a visual observer's ability to detect intruder aircraft in an uncrewed aircraft's operational area and give way to the conventional aircraft.

Unfortunately, in order to properly test the ability to give way to the conventional aircraft, we could not provide you with all of the details prior to your participation. This ensures that your reactions in this study were spontaneous and not influenced by prior knowledge about the purpose of this study. You were told that the experiment would utilize a uncrewed aircraft (UA), however, we utilized a simulation tool called Mission Planner to display a flight on the ground control station, but no UA was flown. This was done to maximize your safety and the safety of the aircraft. If we had told you the uncrewed aircraft was simulated, this could have impacted your response time and/or your suggested maneuver, additionally, if your response time was too long or if your suggested maneuver was not correct, this could have led to a mid-air collision between the uncrewed aircraft and the conventional aircraft. We regret the deception, but we hope you understand the reason for it.

Confidentiality:

Please note that although the aircraft used in this study has changed from the originally stated aircraft, everything else on the consent form is correct. This includes the ways in which we will keep your data confidential.

Now that you know the true purpose of our study and are fully informed, you may decide that you do not want your data used in this research. If you would like your data to be removed from the study and permanently deleted, please let Tom Haritos know.

Please do not disclose research procedures to anyone who might participate in this study in the future, as this could affect the results of the study.

Useful Contact Information:

If you have any questions about this study, please contact Tom Haritos, at (785)-284-9731 or tharitos@ksu.edu. If you have any questions about your rights as a research participant, please contact the IRB Chair at 785-532-3224 or rscheidt@ksu.edu.

*** Please keep a copy of this form for your future reference. Once again, thank you for your time and participation in this study.***