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Small Unmanned Aircraft Systems: Operator Workload and Situation Awareness Utilizing First Person View Techniques

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Small Unmanned Aircraft Systems: Operator Workload and Situation Awareness Utilizing First Person View Techniques

Ross Lucas Stephenson, Jr.

Dissertation Submitted to the College of Aviation in Partial Fulfillment of the

Requirements for the Degree of Doctor of Philosophy in Aviation

Embry-Riddle Aeronautical University

Daytona Beach, Florida

April 2023

Small Unmanned Aircraft Systems: Operator Workload and Situation Awareness Utilizing First Person View Techniques

By

Ross L. Stephenson, Jr.

This dissertation was prepared under the direction of the candidate's Dissertation Committee Chair, Dr. Dothang Truong , and has been approved by the members of the dissertation committee. It was submitted to the College of Aviation and was accepted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Aviation.

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Abstract

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Title: Small Unmanned Aircraft Systems: Operator Workload and Situation Awareness Utilizing First Person View Techniques

Institution: Embry-Riddle Aeronautical University

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The small, unmanned aircraft systems (sUAS) sector within the aviation industry is experiencing unprecedented growth. However, the regulatory guidance for the safe integration of sUAS into the National Airspace System (NAS) has not kept pace with this technological growth within the market. Current regulatory limitations of line-of-sight operations may have an impact on the establishment of an equivalent level of safety for sUAS operations as maintained by manned aircraft. The focal point of the discussion of line-of-sight operations has been the ability of the sUAS pilot to see and avoid all obstacles and other aircraft in a safe and timely manner. The purpose of this dissertation study was to examine whether the use of first-person view (FPV) techniques while piloting sUAS within the NAS would have an effect on the operator's workload and if FPV techniques affect the operator's Level 1 situation awareness (SA). More specifically, this study examined sUAS operator workload and Level 1 SA while using three visual acuity techniques: visual-line-of-sight, FPV with a 21-in. liquid crystal display monitor, and the use of FPV head-mounted goggles.

A preliminary experiment was designed and conducted to collect the required data for analysis. Participants were randomly assigned to one of three visual acuity technique groups and were required to navigate an sUAS, DJI Inspire 1 quadcopter, on a flight course. Participants completed a demographic survey, the Ishihara color blindness test, and two post-experiment tests. The post-experiment tests included the National Aeronautical and Space Administration Task Load Index (NASA TLX) questionnaire and a Level 1 SA test used to assess the participants' perceived workload during the experiment based on their assigned visual acuity technique and their recall of elements within the flight course environment, respectively. ANOVA and ANCOVA tests were conducted to test the hypotheses. The results indicated no statistically significant differences between the three groups' scores for perceived workload or SA.

The preliminary results of the experiment provided a foundation for further analysis using a UAS dataset retrieved from NASA's Aviation Safety Reporting System database, where the primary aircraft was listed as a UAS. SA was identified as the most prevalent causal factor among the human factor elements within the event reports. A comparison between SA and non-SA groups was constructed using the Chi-square statistical test. The results indicated there was a statistically significant association between the event reports where SA was listed as a causal factor and the event's geographic region listed within the report. Additional Chi-square analysis showed a statistically significant association between the human factor elements of SA and time pressure within event reports where the geographic region was not indicated within the report. Aviation organizational safety managers must continually analyze their safety management system performance to ensure the effectiveness of their risk mitigation measures. This dissertation study provides information helpful to operational managers and their selection of risk mitigation processes.

Dedication

I dedicate this endeavor to my Lord and Savior, Jesus Christ, whose guidance, direction, and comfort carried me through this formidable task during extraordinary times. And to my wife, Susan, for without her support and guidance, I would not have been able to sustain the effort needed to reach this goal.

Acknowledgments

Without the help, support, friendship, and collaboration of countless individuals this endeavor would have ended many years ago. I would like to specifically acknowledge the following:

- Dr. Dothang Truong, who provided discerning wisdom, guidance, and inspiring counsel that kept me going throughout this process.
- The dissertation committee: Dr. Thropp, Dr. Pugh, and Dr. Myers, whose suggestions improved the research and my knowledge.
- The members of Ph.D. in Aviation Cohort 5 and other friends; specifically, students Dave Carroll, Nicole Bier, Robert Allen, and Tanya Gatlin for their unyielding support and timely advice.
- Captain Matt Tuohy, the director of Jacksonville University's School of Aviation, whose sage guidance and humble approach has talked me off the ledge on multiple occasions.
- To my loving wife of 32 years, Susan, whose love and support kept me going when failure, frustration, and endless challenges seemed overwhelming.

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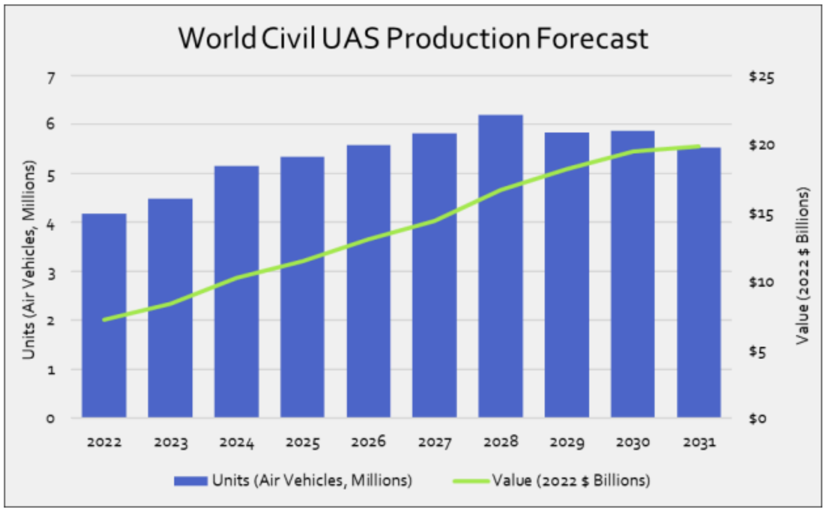
Chapter I: Introduction

The unmanned aircraft systems (UAS) sector within the aviation industry continues to experience rapid growth on an exponential scale (Carroll & Stephenson, 2015). This specific niche within the aviation industry is capitalizing on a myriad of business opportunities among the many viable applications of UAS technology (Gertler, 2022). The Teal Group's "2022/2023 World Civil Unmanned Aerial Systems Market Profile and Forecast" predicts the worldwide UAS market will total $139 billion over the next 10 years (Gertler, 2022). In addition, the Teal Group forecast on worldwide UAS growth states that civil UAS production "promises to be one of the most dynamic sectors for the next decade, emerging from a $7.2 billion market in 2022 to more than triple to $19.8 billion by 2031" (Gertler, 2022, p. 1). World civil UAS production forecast is depicted in Figure 1.

Figure 1

World Civil UAS Production Forecast

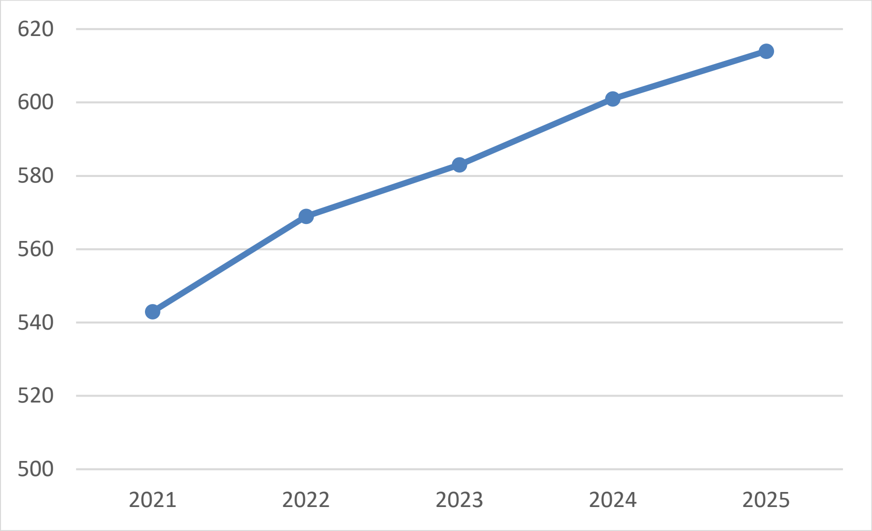


Note. Adapted from "2022/2023 World Civil Unmanned Aerial Systems Market Profile and Forecast" by J. Gertler, 2022, p. 1. Copyright 2022 by the Teal Group Corporation.

According to the forecast, the U.S. will account for 32% of the worldwide projected spending on UAS within the civil market in 2022 (Finnegan, 2020). The U.S. Department of Transportation's projected growth of commercial sUAS within the U.S. is depicted in Figure 2.

Figure 2

Department of Transportation Commercial sUAS Projections 2021–2025



Note. Graph depicts total commercial fleet numbers in thousands. Adapted from "FAA Aerospace Forecast: Fiscal Years 2021–2041" by the Federal Aviation Administration, 2021 (https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2021-41_FAA_Aerospace_Forecast.pdf). In the public domain.

While technological development within the UAS sector has occurred at a rapid rate, regulatory guidance for the safe integration of UAS into the National Airspace System (NAS) has not kept pace with the velocity of growth within the market (Dalamagkidis et al., 2011; Degarmo, 2004). The Federal Aviation Administration (FAA) Modernization and Reform Act of 2012 (FMRA) was initiated by Congress in efforts to encourage the FAA to expedite the formulation of regulatory policy for the safe integration of UAS into the NAS (Schlag, 2013). The sUAS rulemaking process was completed in June of 2016.

Timeline of UAS Integration into the NAS

In 2005, General Atomics received the first FAA issued airworthiness certificate for a civil operated unmanned aircraft vehicle (FAA, 2005). This provided the FAA the opportunity to collaborate with industry stakeholders, collecting necessary technical and operational data to facilitate the development of a regulatory process for safe integration of UAS into the NAS. In 2008, Congress recommended the FAA and DOD form an executive committee to develop techniques and procedures to permit safe operations of UAS in the NAS (FAA, 2005). In 2010, the NextGen Integration and Evaluation Capability research platform was established to “explore, integrate, and evaluate NextGen concepts through simulations resulting in concept maturation and requirements definition” (FAA, n.d.a, p.1). This research platform ran simulations on UAS integration into the NAS. Later that year, the FAA entered an agreement with Insitu Inc, a subsidiary of Boeing, to conduct research on the integration of UAS into the NAS utilizing air-traffic-control simulations (FAA, 2005). Insitu provided the FAA with a ScanEagle UAS for operational research. The ScanEagle has a 3 m (9 ft 10 in.) wingspan and weighs approximately 44 lb (20 kg), and has an average operating speed of 48 kt (88.9 kph) (Hodgson et al., 2013).

In 2013, as directed by the FAA Modernization and Reform Act of 2012, the FAA began a multi-year program to establish six UAS test sites to conduct research on integrating UAS into the NAS (FAA, 2005; FAA, n.d.c). Additionally, the Act directed the study of the human factors associated with operating UAS (Fern et al., 2012). The test sites were established in Griffiss International Airport, NY, New Mexico State University, NM, North Dakota Department of Commerce, ND, State of Nevada, NV, Texas A&M University Corpus Christi, TX, University of Alaska Fairbanks, AK, and Virginia Polytechnic Institute and State University, VA (FAA, n.d.e). These test sites were to provide the operational environment to verify safe operations of public and civil UAS and navigation parameters prior to the integration of UAS into the NAS (FAA, n.d.c). The FAA test site locations are depicted in Figure 3.

Figure 3

FAA Test Site Program Locations

Note. FAA = Federal Aviation Administration. Adapted from “UAS Test Site Program” by the Federal Aviation Administration, n.d. (https://www.faa.gov/uas/programs_partnerships/test_sites/). In the public domain.

In July of 2013, the FAA issued the first restricted category type certificates to two companies, Boeing’s Insitu for their SanEagle and AeroVironment for their Puma sUAS (Bellamy, 2013; FAA, 2005). Prior to the issuance of restricted type certificates, operators of UAS had to conduct flights within the experimental category, which prohibits flights for commercial operations (Bellamy, 2013). The restricted category type certificates allowed the operators to conduct flight operations for commercial purposes. Later that year, the FAA would grant a certificate of authorization allowing the California Air National Guard to operate an MQ-1 over the wildfire in Yosemite National Park (FAA, 2005; FedWeek, 2013).

Again in 2013, the FAA released its first annual UAS integration roadmap "Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS Roadmap)" (FAA, 2013). The purpose of the roadmap was to provide the aviation stakeholders a guide to understanding the operational goals and challenges faced by the industry while emphasizing aviation safety (FAA, 2013).

In 2014, the FAA entered into an agreement with the Academy of Model Aeronautics (AMA), providing a venue for working toward continued safety of model aircraft within the NAS (FAA, 2005; Hanson, 2014). This memorandum of understanding between the FAA and AMA facilitated the requirement to establish the Special Rule for Model Aircraft as directed within the FAA Modernization and Reform Act of 2012 (Hanson, 2014). Later that year, the FAA published their interpretation of the Special Rule for Model Aircraft within the Federal Register for comment (FAA, 2005).

In 2015, the FAA proposed the 14 C.F.R. Part 107 framework of regulations for comment within the Federal Register (FAA, 2005). The Part 107 framework included remote pilot in command certification and responsibilities, operational limitations, and aircraft requirements. The Department of Transportation and the FAA finalized the Part 107 operational rules in 2016 (FAA, 2016). Additionally, in 2016, the FAA Extension, Safety, and Security Act (2016) was passed, amending provisions within the FAA

Modernization and Reform Act (2012). These amended provisions established the requirement for UAS remote identification (FAA, 2005). The remote identification requirement would allow for the electronic remote identification of UAS during operation, very similar to the operations of a transponder in a manned aircraft.

In 2016, the FAA granted a certificate of authorization (COA) for the first UAS beyond-visual-line-of-sight (BVLOS) operations to support research and development activities at the Northern Plains UAS Test Site. The COA allows the test site to conduct testing and validation of detect and avoid systems of the UAS necessary to mitigate collision hazards while operating within the NAS (Fang et al., 2018).

In December of 2017, the National Defense Authorization Act for Fiscal Year 2018 was signed into law. While the act contained provisions primarily focused on U.S. Department of Defense appropriations, it also delineated the requirement for UAS to be registered with the FAA and that individual UAS must be visibly marked with the FAA registration number (FAA, 2005). The registration number was required to be displayed on the aircraft effectively on February 25, 2019 (FAA, 2005; National Defense Authorization Act for Fiscal Year 2018, 2018).

In 2018, the FAA Reauthorization Act of 2018 was signed into law enacting legislation including provisions to support the safe integration of UAS into the NAS (FAA, 2005). The act included the requirement for the Secretary of the U.S. Department of Transportation to update the comprehensive plan for developing the concept of operations for safe integration of UAS into the NAS. In addition, the act delineated provisions for UAS test range operations, operations of UAS in the Arctic, UAS safety standards, public use UAS, and special use of UAS within the NAS prior to completion of the comprehensive plan and subsequent rulemaking (FAA Reauthorization Act of 2018).

Small UAS Background

UAS classifications vary by government agencies and civilian organizations (U.S. Army, 2010). They have been classified by factors such as range, size, weight, and performance (Penn State, n.d.). Table 1 illustrates the UAS classifications defined by the U.S. Department of Defense. The FAA defines an sUAS as an aircraft weighing less than 55 lb (24.9 kg), including payload and equipment attached, that can be flown without aircrew onboard (FAA, 2016a; FAA, 2016b).

Prior to the advent and growth in demand for commercial off-the-shelf (COTS) multirotor sUAS, most unmanned aircraft flying within the NAS were radio controlled (RC) model aircraft flown by hobbyists (Gettinger & Michel, 2015). The AMA was established in 1936, providing RC model aircraft hobbyists (i.e., recreational users) a community venue for establishing the rules and general practices for safe and enjoyable operations (Gettinger & Michel, 2015).

Table 1
UAS Classification by the U.S. Department of Defense

Category	Size	Maximum Gross Takeoff Weight (lb)	Normal Operating Altitude (ft)	Airspeed (kt)
Group 1	Small	0–20	< 1,200 AGL [a]	<100
Group 2	Medium	21–55	< 3,500	<250
Group 3	Large	< 1320	< 18,000 MSL [b]	<250
Group 4	Larger	> 1320	< 18,000 MSL	Any airspeed
Group 5	Largest	> 1320	> 18,000	Any airspeed

Note. [a] AGL = above ground level. [b] MSL = mean sea level. Adapted from “U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035” by the U.S. Army, 2010, p. 12 (https://rosap.ntl.bts.gov/view/dot/18249). In the public domain.

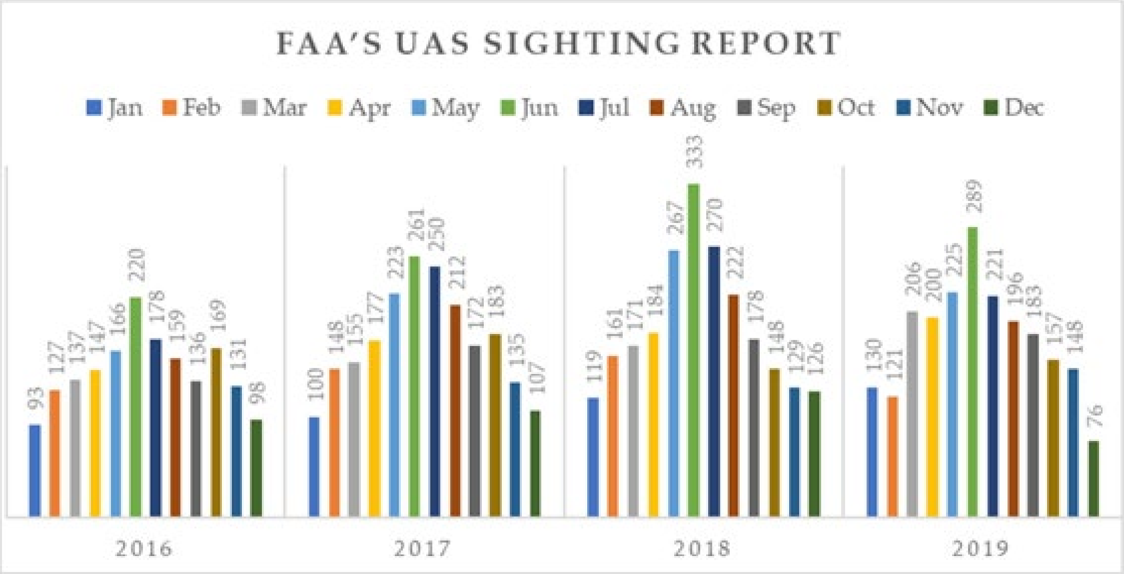
The AMA was a self-regulating organization, operating without government regulation until 1981 (Gettinger & Michel, 2015). In 1981, the FAA issued an advisory circular, AC91-57, that established more formal guidelines for RC model aircraft operation (Gettinger & Michel, 2015). Prior to 1981, the AMA's rules and general practices were the sole source of guidance for operators flying, within the NAS, models that would be considered by today's definition unmanned aircraft.

Safe integration of sUAS into the NAS is of great concern to the FAA. Organizations such as the AMA and multiple sUAS vendors have collaborated on their efforts to provide educational campaigns to sUAS operators so they may navigate their sUAS within the NAS with an equivalent level of safety as present in manned aircraft (Woo, 2017). Although extensive efforts have been taken to educate model aircraft and sUAS operators on safety concerns for operations within the NAS, improper operation of sUAS continues to be reported by manned aircraft and various observations from the ground (FAA, 2017; Gettinger & Michel, 2015; Woo, 2017).

The sUAS sightings and near midair collisions with manned aircraft have become all too common (Wallace et al., 2018; Wallace et al., 2019). These incidents continue to present a formidable challenge for the FAA and aircrew of manned aircraft (Woo, 2017). Sightings have continued to increase each year, with peak sightings occurring during the warmer months. The sUAS sightings reported to the FAA for the period of January 2016 to December 2019 are depicted in Figure 4. It should be noted that while the overall number of sightings has increased year over year, not all sUAS sightings presented a significant risk of collision (Gettinger & Michel, 2015).

Figure 4

Reported UAS Sightings by Month 2016–2019

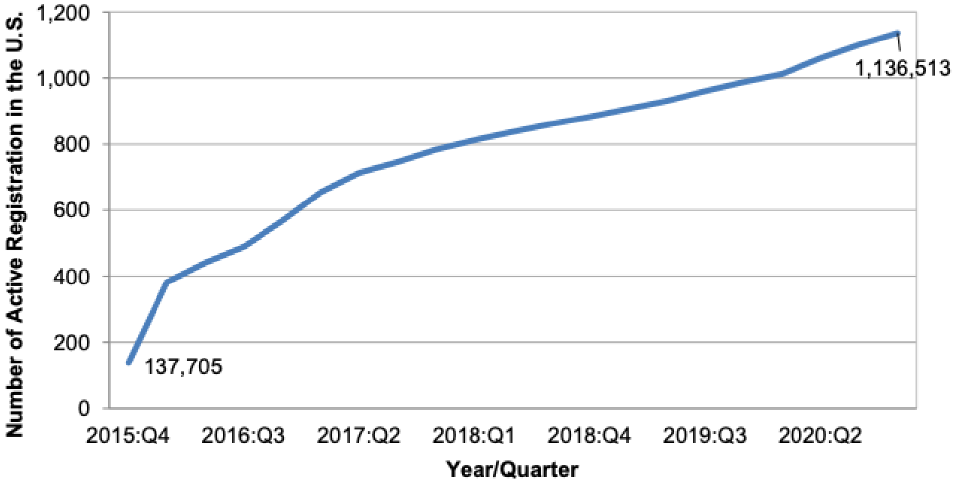


Note: Adapted from "Defending Airports from UAS: A Survey on Cyber-Attacks and Counter-Drone Sensing Technologies" by G. Lykou, D. Moustakas, D., and D. Gritzalis, 2020, *Sensors*, *20*(12), p. 6.

An ongoing challenge for the FAA has been enforcing compliance with sUAS operational and safety regulations (Loffi et al., 2016; Woo, 2017). To establish a means of accountability for sUAS operations, the FAA required all sUAS operators to register their aircraft with the FAA and to display the assigned registration number on the sUAS (Registration and Marking Requirements for Small Unmanned Aircraft, 2015; Woo, 2017). Recreational model aircraft registrations by year are depicted in Figure 5, and non-model registrations of sUAS aircraft by year and quarter are depicted in Figure 6.

Figure 5

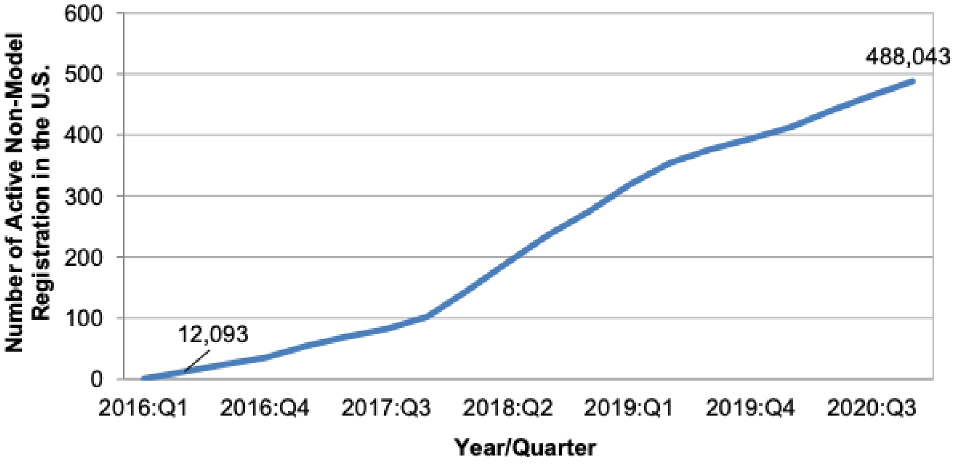
Recreation Model Aircraft Registrations by Quarters/Years (Cumulative)



Note. Adapted from "FAA Aerospace Forecast Fiscal Years 2021-2041" by the Federal Aviation Administration, 2021 (shorturl.at/fwDLS). In the public domain.

Figure 6

Registrations of sUAS by Quarters/Year (Cumulative)



Note. Adapted from "FAA Aerospace Forecast Fiscal Years 2021-2041" by the Federal Aviation Administration, 2021 (shorturl.at/jtO14) In the public domain.

The purpose of the requirement is clearly stated in the Interim Final Rule of Registration and Marking Requirements for Small Unmanned Aircraft (2015):

> Registration will provide a means to quickly identify these small unmanned aircraft in the event of an incident or accident involving the sUAS. ... Aircraft registration is necessary to ensure personal accountability among all users of the NAS. ... Aircraft registration also allows the FAA and law enforcement agencies to address non-compliance by providing a means by which to identify an aircraft's owner and operator. ... As more small unmanned aircraft enter the NAS, the risk of unsafe operations will increase without a means by which to identify these small unmanned aircraft in the event of an incident or accident. (80 FR 78593, 2015, p. 1)

Additionally, the sUAS registration requirement provides the FAA an opportunity to address and educate new sUAS operators on procedures and regulations inherent to safe operation of unmanned aircraft within the NAS (Loffi et al., 2016; Registration and Marking Requirements for Small Unmanned Aircraft, 2015). Providing sUAS operators information concerning safe operation of sUAS within the NAS implements a baseline of risk mitigation measures necessary given the vast and ever-increasing number of sUAS operations (Loffi et al., 2016; Morris & Thurston, 2015). Continuing their efforts to educate sUAS operators, the FAA introduced an iOS application, B4UFLY, which is a simple decision-making tool that provides real-time data concerning laws, regulations, and airspace restrictions for specific geographic locations (FAA, 2016d; Loffi et al., 2016).

In June of 2016, the FAA issued Advisory Circular 107-2, Small Unmanned Aircraft Systems, which amended its regulations to make provisions for integration of sUAS into the NAS (FAA, 2016a). In February of 2021, the FAA issued Advisory

Circular 107-2A, Small Unmanned Aircraft Systems, which made changes to the areas of sUAS remote identification requirements, aircraft registration, and operations of sUAS over people (FAA, 2021a). This initiative was the FAA's primary measure to address safe integration of sUAS into the NAS, specifically with an emphasis on three crucial areas of interest: "personnel, equipment, and operations" (FAA, 2021a, p. 3-1). The new regulation addresses each area of interest individually and collectively to mitigate the risks of operating sUAS within the NAS primarily dominated by manned aircraft operations (FAA, 2021a). A summary of Part 107 operating regulations is provided in Table 2.

Table 2

Summary of Part 107 Operating Regulations

sUAS must weigh less than 55 pounds, including payload
Operate within class G airspace [a]
sUAS operated within visual line-of-sight [a]
Fly during daylight or civil twilight [a]
Operate at airspeed less than 100 miles per hour [a]
Yield right-of-way to manned aircraft [a]
No flight conducted directly over people [a]
No operation of sUAS from a moving vehicle, unless in sparsely populated area [a]

Note. [a] These rules are subject to waiver. Adapted from "Fly Under the Small UAS Rule" by the Federal Aviation Administration, 2016. (https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107). In the public domain.

Unlike other FAA airman certificates, it is relatively simple to acquire the FAA remote pilot certificate. While most applicants for the remote pilot certificate may have had some experience operating sUAS prior to applying for the certificate, no experience or training is necessary. In addition, no formal operational proficiency check or FAA medical certificate is required. A formal operational proficiency check and FAA medical certificates are required for other FAA airman certificates. 14 CFR §107.17 states:

> No person may manipulate the flight controls of a small-unmanned aircraft system or act as a remote pilot in command, visual observer, or direct participant in the operation of the small unmanned aircraft if he or she knows or has reason to know that he or she has a physical or mental condition that would interfere with the safe operation of the small unmanned aircraft system. (para. 1)

The requirements for the remote pilot certificate are listed in Table 3. Once the remote pilot certificate has been obtained, it must be readily available by the sUAS remote pilot during all operations (FAA, 2018, 2020). The remote pilot certificate is valid for a 2-year period (FAA, 2018, 2020). Certificate holders must pass recurrent training or a knowledge test every 2 years to maintain the certificate (FAA, 2018, 2020). Part 107 remote pilot certificates active by year is depicted in Figure 7.

Table 3

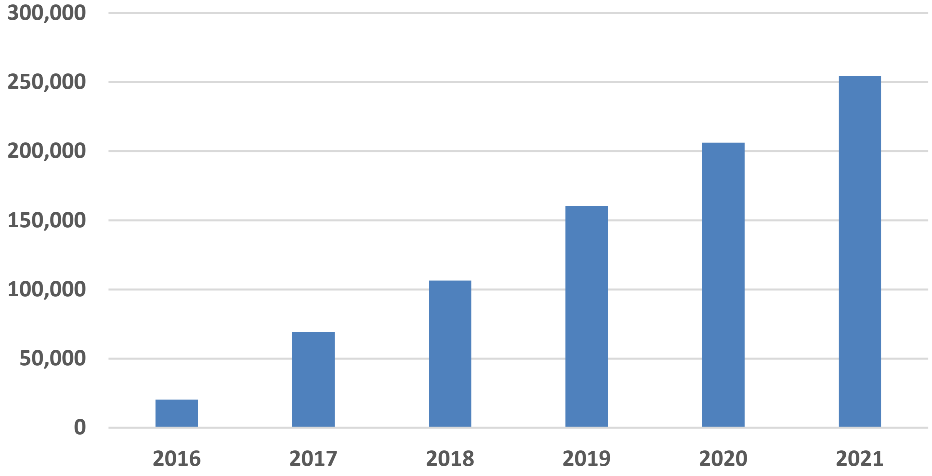
FAA Remote Pilot Certificate Requirements

Minimum age 16 years old
Able to read, speak, write, and understand English
Physically and mentally able to safely operate sUAS
Pass FAA aeronautical knowledge exam

Note. Adapted from “Requirements and Process for Becoming a Pilot” by the Federal Aviation Administration, 2018. (https://www.faa.gov/uas/getting_started/part_107/remote_pilot_cert/). In the public domain.

Figure 7

Estimated Part 107 Remote Pilot Certificates Held by Year



Note. Adapted from “FAA Regional Active Airmen Totals” by the Federal Aviation Administration, 2021b (https://registry.faa.gov/activeairmen/M70_Active_Pilots_Summary.pdf). In the public domain.

Current FAA restrictions on sUAS operations to line-of-sight prohibit efficient use of UAS capabilities within a myriad of applications (FAA, 2016a). While a process is in place to request a waiver to the Part 107.31 regulation, VLOS Aircraft Operation, as of October 2021, only 80 BVLOS waivers have been issued by the FAA (FAA, 2021c). The technology that exists within the sUAS industry provides the ability to safely control sUAS from a distance far greater than the limitations of the unaided human eye (Stevenson et al., 2015). The focal point of the discussion on visual-line-of-sight (VLOS) operations has been the ability of the sUAS pilot to see and avoid all obstacles and other aircraft in a safe timely manner.

Piloting an aircraft is a dynamic task, which requires vigilance in the monitoring of multiple situational variables (Gugerty & Tirre, 2000). It is stressed that SA is comprised of both perceptual and cognitive processes, which includes visual acuity

(Endsley, 1995a). Vision is the primary sense utilized in the piloting of sUAS and the primary means for obstacle avoidance as established by 14 C.F.R. Part 107 (FAA, 2016c).

The FAA's 2021 regulation on the operation of sUAS does not provide a defined visual acuity standard referencing maximum distances allowed between the sUAS and the operator (FAA, 2021a). However, to establish an equivalent level of safety for unmanned operations as those that exist for manned operations, the FAA has established operational parameters that limit sUAS operational distances to that of the operator's unaided visual acuity (FAA, 2021a). That is, each individual sUAS operator must maintain the aircraft to always have direct line-of-sight contact with it during flight operations (FAA, 2021a). To initiate an environment for operating sUAS within see and avoid parameters and to mitigate risk, the FAA has mandated that all sUAS pilots must always maintain visual-line-of-sight (VLOS) with their sUAS during UAS operations. Furthermore, this regulation prohibits the use of electronic or optical aids to enhance the pilot's visual acuity during flight operations (FAA, 2021a).

The sUAS have many similar characteristics to aircraft flown within the RC model aircraft community. Many of the aircraft used by RC aircraft hobby enthusiasts have been modified for use within the parameters of operations defined by the FMRA (FAA, 2019).

In an effort to enhance the RC flying experience, first-person-view (FPV) goggles were designed to provide the pilot a virtual flight environment as if the pilot were in the cockpit of the aircraft. While it is a novel technique for enhancing the flight experience and aircraft control, it is not a new concept. The use of FPV techniques to create a virtual environment for aircraft pilots has been used for both military fixed and rotary wing operations (Warnke, 2017). The main purpose for the military use of FPV techniques has been to enhance single pilot and multi-pilot aircrew SA.

Background on First-Person Vision

The ability to provide high-definition real-time video feed from a remote location in a first-person perspective has become commonplace with a multitude of applications (Betancourt et al., 2015; Kanade & Hebert, 2012). More common applications include medicine, space exploration, construction management, and wartime use (Almeida et al., 2017). Cameras mounted on teleoperated vehicles provide real-time video feed from the vehicle's onboard systems to the vehicle's operator remotely, providing the operator the sense of being onboard the vehicle firsthand (Almeida et al., 2017). The operators receive the real-time video transmission on head mounted displays (HMDs), which incorporate two small video screens, one for each eye, or one large viewing screen within the display (Paes et al., 2017). These HMDs are often referred to as FPV goggles or glasses. First-person vision or first-person view has become the most frequently used term for visual acuity perspective, but other terms such as egocentric vision or ego-vision have also been used (Betancourt et al., 2015). FPV technology became popular in the late 1990s as innovative designs began to grasp the idea of multi-modal computing, providing users a visual interface that could display text and images in an immersive manner (Betancourt et al., 2015).

The application of FPV through telepresence has created specialty niches within the field of medicine (Mailhot, 1996). Teleoperations via FPV has created new specialties such as teleradiology, telehealth, telepsychiatry, and tele imaging to name a few (Mailhot, 1996). The use of FPV techniques has provided doctors and surgeons the ability to extend their practice beyond their present locale while creating the perception that the patient is right “in front of him/her” (Mailhot, 1996, p. 321).

Space exploration began with a series of automated robots that were teleoperated, such as the Mariner, Ranger, and Surveyor spacecraft but presented no sense of telepresence to the operators (Pedersen et al., 2003). While real-time video feed from the Mars exploration assets such as the rover Opportunity is not possible with current technology, teleoperations of unmanned assets on the planet by manned spacecraft in Mars orbit is possible (Craig et al., 2015). Real-time video transmission from Earth’s orbit can provide teleoperation from an FPV perspective and have been used for missions such as in-space assembly, in-space inspections, and human extravehicular space activities interaction (Craig et al., 2015).

Teleoperation of robotic equipment on the construction site utilizing FPV visual acuity techniques is not new (Skibniewski, 1992). The John Deer Excavator, Model 690C, is a teleoperated excavator used for rapid airport and runway repair (Skibniewski, 1992). The micro-tunneling machine and the remote work vehicle both provide the operator an FPV perspective of the operated equipment as if the operator was present within the vehicle itself during operation (Skibniewski, 1992). The use of teleoperated vehicles also allows the operator to be present within an environment which may be hazardous to human health. Mobile rescue robots were used during emergency response at the Fukushima nuclear power plant, providing the operators an FPV perspective of the accident site (Nagatani et al., 2013).

Statement of the Problem

The FAA Modernization and Reform Act of 2012 fostered the demand for integration of sUAS into the NAS (Fern et al., 2012). While the FAA Modernization and Reform Act of 2012 set the groundwork for a plan of sUAS integration into the NAS by 2015, the challenge of implementing the necessary aircraft collision avoidance systems remains. Current FAA regulations limit the use of FPV techniques while piloting sUAS within the NAS operating under 14 C.F.R. Part 107 regulations, specifically §107.31. The regulation states that FPV use is limited unless provisions of the section can be exercised by “the remote pilot in command and the person manipulating the flight controls or a visual observer” (para. b1 & b2). This paragraph provides for the operation of the unmanned aircraft utilizing FPV techniques by the pilot in command and the person manipulating the flight controls if the visual observer is meeting the requirements of §107.31 and §107.33. Does this limitation affect sUAS operator workload and SA?

Much has been done in the development of ground control system (GCS) traffic displays for sUAS operators, providing sUAS operators real-time awareness of airborne traffic within the sUAS’s area of operations (Ruseno et al., 2022; Segor et al., 2010). GCSs have evolved from merely displaying live video feed from onboard aircraft cameras to transponder-equipped and more current Automatic Dependent Surveillance-Broadcast (ADS-B)-equiped aircraft, to include sUAS (Segor et al., 2010; Reseno et al., 2022). In addition, the industry has developed multiple promising aircraft collision hazard avoidance systems utilizing electro-optical, radar, audible, and IR sensors. The fusion of data available from electro-optical, acoustic, and infrared sensors can provide the sUAS operator a complete picture of the operational environment, thus increasing SA

(Segor et al., 2010). These systems will facilitate autonomous sUAS BVLOS operations (Ferguson, 2018a). However, the challenge of detecting and maintaining aircraft separation in the event of failure of autonomous systems remains the sUAS operator's responsibility. Little research exists on sUAS operator workload and SA during operations utilizing FPV techniques. A review of the published literature found no documentation on research that has been conducted on how the utilization of FPV techniques enhances or degrades the sUAS operator's Level 1 SA and workload. Therefore, the current study addresses an important gap in the literature.

Purpose Statement

The purpose of this study was to determine if the use of FPV visual acuity techniques effects the sUAS pilot-in-command's (PIC) workload and Level 1 SA. In addition, this research examined SA as a human factor within event reports where the primary aircraft was listed as a UAS as maintained within the NASA Aviation Safety Reporting System (ASRS) database to determine the prevalence of FPV effects upon recent incidents in the NAS.

Significance of the Study

In May of 2018, the FAA began to approve certain waivers for sUAS BVLOS operations (Finnegan, 2020). Inherent in these systems is the requirement for a robust GCS that provides visual and audible data and alerts to the operator, including FPV live video feed from the sUAS (Ferguson, 2018a). These BVLOS operations have been approved for the conduct of research and development for autonomous sense-and-avoid sUAS systems to be employed during BVLOS operations (Ferguson, 2018a; Ferguson, 2018b). While Ferguson's (2018a; 2018b) research appears promising, failure of sense-and-avoid systems during sUAS BVLOS operations requires the operator to take control of the sUAS and maintain aircraft collision avoidance manually. A better understanding of sUAS operator workload can provide aircraft collision avoidance systems developers additional supporting data on the human-machine interface (HMI) between the operator and the sUAS. Additionally, this HMI supporting data can provide developers insight into GCS design requirements as it applies to minimum detection thresholds of hazards, whether airborne or ground based. In addition, this study fills a gap in the existing literature by examining the effects of FPV usage on sUAS remote pilot Level 1 SA during operations. The evidence produced from the current study will also provide insight into the development of more robust FPV systems to be included in future sUAS ground control stations.

Research Questions and Hypotheses

The current study examined how the use of FPV techniques during the operation of sUAS affected the operator's workload and Level 1 SA during execution and completion of a mission flight task objective. Post-task operator subjective workload was assessed by the NASA TLX questionnaire. Post-task Level 1 SA was assessed using a Level 1 SA assessment questionnaire. The mission flight task objective was to complete the experiment course of flight expediently while safely navigating the course. Three conditions of visual acuity for piloting a sUAS were utilized within the methodology of the experiment: (a) VLOS operation, (b) electronic aided piloting with FPV technique utilizing a 21-in. LCD screen, and (c) electronic aided piloting with FPV techniques utilizing visual immersion goggles. The current study investigated two research questions (RQ) and corresponding hypotheses (H).

RQ1

What effect will the utilization of FPV techniques have on the sUAS operator's perceived workload?

H_1

sUAS pilot subjective workload will be lower in the LCD screen condition than the VLOS condition.

H_2

sUAS pilot subjective workload will be lower in the visual immersion goggle condition than the VLOS condition.

H_3

sUAS pilot subjective workload will be lower in the visual immersion goggle condition than the LCD screen condition.

RQ2

What effect will the utilization of FPV techniques have on the sUAS operator's Level 1 SA?

H_4

sUAS pilot post-task Level 1 SA will be better in the LCD screen condition than the VLOS condition.

H_5

sUAS pilot post-task Level 1 SA will be better in the visual immersion goggle condition than the VLOS condition.

H_6

sUAS pilot post-task Level 1 SA will be better in the visual immersion goggle condition than the LCD screen condition.

Delimitations

The current study evaluated FPV visual acuity techniques to determine which techniques used within the study provided the sUAS operator the optimal means for identifying the presence of obstacles while completing a task. However, the current study did not intend to evaluate the participants' learning ability during the experiment.

Study participants were solicited from a heterogeneous group of undergraduate and graduate students, staff, and faculty members from Jacksonville University, the Jacksonville Fire and Rescue Department, the Jacksonville chapter of the Association of Uncrewed Vehicle Systems International (AUVSI), and a local U.S. Navy helicopter squadron. This limited sample group was necessary due to Covid-19 restrictions. Participants possessed various degrees of skill and experience that may have modulated their individual performances in the experiment. The participants who volunteered predominantly originated from an undergraduate university setting, which limits the generalizability of the study findings to other university settings with similar demographics.

It was not within the scope of this research to evaluate how using FPV visual acuity techniques would affect all three levels of sUAS operator SA. This research only evaluated the participants' Level 1 SA. Observation of the elements within the aircraft's domain is paramount to the development of SA. The current study attempted to identify which FPV visual acuity technique would provide the UAS operator the most expedient means of observing obstacles within the UAS's airspace that require an operator induced deviation from the present course of flight. No factors outside the scope of evaluating FPV visual acuity techniques that impact sUAS operator workload and Level 1 SA were discovered during the research process. It was not within the scope of the study to examine patterns of mistakes that could be made by the participants while operating the sUAS during the experiment. No patterns of mistakes were observed or identified. Therefore, no items were identified as covariates to be considered during the analysis of results. Further, while recent regulations have been promulgated concerning the operation of UAS within the NAS, this research did not address the regulations pertaining to the operation of UAS in regard to hazards of midair collisions.

Multiple types of off-the-shelf FPV goggles on the market may be purchased. However, only one brand and type of FPV goggles were used during the current study. The current study did not intend to evaluate which brand of FPV goggle provides optimal workload relief and Level 1 SA during the experiment. The DJI FPV goggles were used in the current study to determine if there would be a statistically significant difference in the UAS operator's workload and Level 1 SA as observed under the three levels of treatment. The DJI FPV goggles were selected for use due to their designed interoperability with the DJI Inspire 1 sUAS, which was the sUAS brand and model utilized during the experiment. Other brands of FPV goggles were not utilized or evaluated.

Analysis of the ASRS dataset was conducted to examine the elements of SA and workload as contained within the event reports submitted. While other human factor elements are contained within the reports, this study focused on the prevalence of SA and workload being listed as a human factor element and did not examine other human factors. Additionally, this study did not examine the details within the event reports that might shed light on why SA was listed within the report as a causal factor.

Limitations and Assumptions

Limitations

Human operator reaction times to stimuli have ranged from 150 to 300 ms (Stevenson et al., 2015). While operator reaction times of 250 ms are typical, factors such as fatigue and fitness level can affect reaction time. Factors such as medications and food and beverage taken soon before participating in an experiment can affect the results of the experiment (Lowette et al., 2015). Fatigue, fitness levels, and food and beverage intake of the participants were not controlled or assessed during the experiment.

The results of the current study could be affected if the participants shared information concerning the location of the boxes and shared information concerning the Level 1 SA assessment questionnaire at the end of the experiment. Therefore, participants were briefed not to disclose the details of their participation and results of the experiment during the study. Violation of this control measure could affect the validity of the measured outcomes during the study.

Research has documented that experimental bias may influence experiment results when participants attempt to answer study questionnaires in an attempt to provide the researcher with what the participants believe will support the researcher’s expected results (Holman et al., 2015; Hróbjartsson et al., 2013). Therefore, each participant was instructed to complete the NASA TLX questionnaire and the Level 1 SA test without regard to their vision of the researcher’s expected results.

The target population for this research included all personnel eligible to apply for a Part 107 remote pilot certificate within the state of Florida., which may limit the generalizability of the current study's findings to states with similar demographics.

The obstacles used during the experiment were stationary in nature. sUAS operators should expect to encounter moving obstacles as well as stationary within operations in the NAS. This study was limited to the encounter of stationary obstacles only.

The ASRS provides a means for aviation stakeholders to document the occurrence of hazardous events in order to prevent future occurrence. However, event reporting is completely voluntary, and therefore, may not capture all events occurring within the NAS. In addition, purposeful or unintentional omission of data within the event report decreases the fidelity of the report.

Assumptions

This research experiment was conducted under several assumptions. First, it was assumed all participants answered truthfully on their demographic, gaming, and RC model hobby enthusiast pre-experiment questionnaire. Second, that the participants did not significantly vary in fatigue and fitness levels. Third, that the familiarization training established and verified that each participant was competent in their sUAS piloting skills, performed to their greatest ability level during the trials, and had sufficient visual acuity to pilot the sUAS during the experiment. Fourth, the participants did not disclose the details of their participation of the experiment during the study. Fifth, the weather was consistent among all treatment groups. The experiment was conducted under similar conditions for all participants. Lastly, the participants did not tailor their answers to the

NASA TLX questionnaires and the Level 1 SA assessment questionnaire based on their perception of desired experimental outcomes.

The ASRS analysis was conducted under a couple of assumptions. First, it was assumed that the submitters of the event reports provided accurate and complete information within the report regarding the incident or unsafe condition. Second, that the event reports had been reviewed by a subject matter expert that accurately categorized the human factor elements within the reports.

Definitions of Terms

Attention allocation	Allocation of attention to a specific task for an optimal duration of time, given consideration of expected cost to the performance of other required tasks (Wickens, 2002a).
Channelized attention	For the purpose of this study, channelized attention refers to the intense focus of attention on one element within the environment with disregard to other elements.
Command and control	For this study, command and control refers to the ability of the UAS operator to electronically manipulate the operation of the UAS while actively verifying and correcting the UAS's response to the electronic signals sent by the

	operator during the conduct of achieving a task (DeGarmo, 2004).
Commercial off-the-shelf components	For this study, commercial off-the-shelf components refers to UAS components that can be readily acquired within the retail markets (Wheatley, 2006).
Communications line-of-sight	The propagation of transmission and reception of data between two communication nodes that are within unobstructed view of each other. These communication nodes are absent of obstacles between them that would hinder the transmission of the electromagnetic energy used to communicate (Freeman, 1981).
Dynamic eyepoint	For this research, dynamic eyepoint refers to the real-time image captured by the UAS's on-board camera as displayed to the UAS operator for the purpose of controlling the UAS to accomplish a task. Two of the three visual acuity techniques examined in this research were used to observe the dynamic eyepoint: (a) Dell 21-inch LCD monitor, and (b) the FPV goggles. The term was adapted from

	Terwilliger (2012) and is essential to the outcome of this research.
Egocentric viewpoint	FPV vantage point from the UAS mounted camera, providing the operator the virtual representation of piloting the UAS from the cockpit of the UAS (Williams, 2007).
Exocentric viewpoint	The third person perspective of the UAS within its environment as displayed on a ground control station or aircraft's multifunction display (Williams, 2007).
Fatigue	For this research, fatigue refers to the human physiological condition of being tired due to excessive periods of work without rest, disruptions of circadian rhythms, insufficient sleep, and unpredictable events that disrupt normal periods of operational work (Caldwell, 2005).
Field of view	The angular dimension of the visual area in which information can be observed (Ball et al., 1988). For this research, FOV can refer to the visual area observed by a camera lens or the human eye.

FPV techniques	First-person-view techniques which provide the UAS operator real-time video feed from the aircrafts onboard camera to an electronic visual display such as a computer screen or head worn goggles.
Ground control station	For this research, the ground control station is the machine interface that allows the UAS operator the ability to exercise command and control of the UAS (Walter et al., 2004).
Human error	For this research, errors associated with the human element of UAS operations (Manning et al., 2004).
Human factors	Factors that relate to actions attributed to qualities inherent in human composition, capabilities, and behavior (Manning et al., 2004).
Human machine interface	The interaction between the human element and the machine during command and control of the UAS.
Man in the loop	For this research, this term refers to the human element within the UAS during the decision-making process of command and control (Ibrahim et al., 2004).

Reaction time	The time to respond to an incoming stimulus, measured from the moment the stimulus is first perceptible to the moment a response is made (McGrew, 2009).
Simulation	For this research, this term refers to the creation of an environment and events that would attempt to replicate its real-world counterpart.
Situation awareness	The cognitive process of observing and understanding elements within the environment and using that information to complete a task (Endsley, 1995b).
Spatial disorientation	The inability to ascertain one's direction of motion and position in time and space with reference to a fixed coordinate system (Previc & Ercoline, 2004).
Static eyepoint visual interaction method	The UAS operator's visual interaction method to receive live streaming video feed from a fixed camera mounted on the UAS that is immovable; thereby providing a static eyepoint (Terwilliger, 2012).
Task overload	Degradation in performance associated with a high demand task that exceeds the maximum

	capacity of skill possessed by the operator (Young & Stanton, 2002).
Task underload	Degradation in performance associated with a low demand task. The operator underutilizes their maximum capabilities due to accommodation of the reduced workload of the low demand task (Young & Stanton, 2002).
Teleoperation	The operation of a task utilizing a machine remotely controlled by a human operator that is not physically located at the area of operation (Draper, 1995).
Telepresence	The appearance of being present at the location of a remote-controlled vehicle operation while the operator is physically located elsewhere in control of the vehicle with a control station (Riley, 2001).
Unmanned aircraft system	System of elements comprised of an unmanned aircraft, human element, command and control element, data communication link, launch and recovery element, and possibly a payload (Barnhart, 2011). A sUAS is an aircraft that weighs less than 55 lb (24.9 kg) (FAA, 2016a).

Unmanned aerial vehicle	An aerial vehicle that is controlled remotely or autonomously and does not carry a human operator (U.S. Department of Defense, 2002).
Visual depiction	Imagery data received from the UAS camera that is depicted on the UAS operator’s method of FPV visual display Terwilliger (2012). Two types of FPV visual display used for this research were: (a) 21-in. Dell LCD monitor, and (b) full visual immersion goggles.
Visual line-of-sight	For this study, visual line-of-sight refers to the unobstructed observation of a target by the unaided human eye.

List of Acronyms

AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
ATC	Air Traffic Control
CFR	Code of Federal Regulations; also C.F.R.
COTS	Commercial Off-The-Shelf
DOD	Department of Defense
DOT	Department of Transportation
DVR	Digital Video Recorder
EFV	Enhanced Flight Visibility

EFVS	Enhanced Flight Vision System
EV	Enhanced Vision
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FLIR	Forward Looking Infra-Red
FMC	Flight Management Computer
FMRA	FAA Modernization and Reform Act
FMS	Flight Management System
FOV	Field of View
FPM	Feet Per Minute
FPV	First Person View
GPS	Global Positioning System
GS	Ground Speed
HDD	Head-Down Display
HDMI	High-Definition Multimedia Interface
HF	High Frequency
HGS	Head-up Guidance System
HUD	Head-Up Display
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
INS	Inertial Navigation System
KIAS	Knots Indicated Airspeed
LF	Low Frequency

MAA	Maximum Authorized Altitude
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NM	Nautical Mile
NMAC	Near Mid-Air Collision
NO A/G	No Air-to-Ground Communication
NOTAM	Notice to Airmen
NTSB	National Transportation Safety Board
OAT	Outside Air Temperature
PFD	Primary Flight Display
PIC	Pilot In Command
SA	Situation Awareness
SATNAV	Satellite Navigation
SOP	Standard Operating Procedure
SVS	Synthetic Vision System
TCAS	Traffic Alert and Collision Avoidance System
TLX	Task Load Index
UAS	Unmanned Aircraft System
UAS	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USAF	United States Air Force
VFR	Visual Flight Rules

VHF	Very High Frequency
VLOS	Visual line of sight
VMC	Visual Meteorological Conditions
VO	Visual Observer

Chapter II: Review of the Relevant Literature

UAS pilot reaction time to obstacles encountered during flight is imperative to ensure an equivalent level of safety as maintained by manned aircraft. As technology advanced within the UAS market, a myriad of sensors and systems were developed to transcend beyond the “See and Avoid” rules of flight defined by 14 C.F.R. Part 91.113: Right-of-Way-Rules: Except Water Operations (2004). All these technological enhancements promise to assist the UAS pilot in safely operating their platform within the airspace shared with other aircraft. The purpose of this chapter is to provide a review of the literature, beginning with a discussion of the theoretical framework guiding this study and then elaborating on the focal concepts relevant to the research question (e.g., visual perception/acuity, field of view, teleoperations). Additional review of current literature on aircraft collision hazard detection, sUAS see-and-avoid, beyond-line-of-sight, and sense-and-avoid technologies is presented for context.

Theoretical Framework

A wide array of disciplines requires operators to observe and comprehend vast amounts of data, often constrained by temporal demands, during mission operations. Technological innovations during the mid-1980s and continuing through the 1990s fostered an increased interest in SA, as new automation tools were developed to assist operators with traditional tasks that were previously manual in nature (Endsley & Garland, 2000). These newly developed tools provide operators with a plethora of data, most of which are changing at a rapid pace. The traditional aircraft cockpit provided pilots elementary information concerning the aircraft’s airspeed, altitude, pitch, yaw, and direction via round “steam gauge” type instrumentation. The modern automation available on today's flight deck provides pilots more information to perceive and process, as displayed on what appears to be small computer screens as opposed to the traditional instrumentation. These systems provide an overwhelming amount of data for aircrew on the aircraft's status internally and its external environment to include satellite weather data, ADS-B aircraft positioning, flight plan management, aircraft systems status, and GPS satellite reception and frequency integrity, to name a few.

Although offering several advantages, these innovations in automation may overwhelm the operator at times with a large amount of information to be perceived and processed. The large amounts of data provided through these systems must be perceived, filtered, and processed diligently by the operator in order to provide utility for the mission task. By design, these automated systems provide the operator with the data necessary to acquire and maintain SA (Endsley & Jones, 2011).

Accordingly, the theoretical framework for the current study is based on the theoretical model of SA proposed by Endsley (1995a; 1995b). Simply stated, SA is being aware of what is happening around you (Endsley & Garland, 2000). Endsley (1995b) provides a model of SA within the role of the operator's decision-making process, explicitly stating that SA is a state of knowledge derived from the processes utilized "to achieve that state" (p. 36). The process of acquiring the necessary information to achieve and maintain SA is defined as situation assessment (Endsley, 1995b).

Endsley further breaks SA down into three levels. Level 1 SA refers to the operator's perception of the elements within the operational environment (Endsley, 1988a; Endsley, 1988b). Prior to processing and understanding the elements within the operational environment, operators must first observe these elements within time and space as they appear relative to the operator's position. These observations are temporal, given the observations are acquired over time within a dynamic environment. Perception is the fundamental factor in developing SA (Endsley & Garland, 2000). Level 2 SA refers to the operator's comprehension of the elements observed within time and space and how those elements impact the operator's current state of operations (Endsley, 1988a; Endsley, 1988b). This synthesis of level 1 elements provides the operator "an understanding of the significance of those elements in light of pertinent operator goals" (Endsley, 1995b, p. 37). Lastly, level 3 SA is the ability of the operator to project the state of the elements as perceived into a future scenario and assesses the impact of those future states on the operator's mission task (Endsley, 1988a; Endsley, 1988b).

Each of the three levels of SA are influenced by individual factors such as the operator's training, experience level, working memory, and the specific goals of the mission task (Rebensky, 2020). Additional factors such as the operator's health, workload, and human-machine interface design can have an influence on the operator's ability to perceive and process the information necessary to develop and maintain SA (Avanzini et al., 2021; Rebensky, 2020). SA is an integral part of the decision-making process. However, it should be noted that Wickens (2002) and Endsley (1988b) both state that the construct of SA, while an important input in the decision-making process, is separate from the act of decision-making.

Wickens (2002) further expands the concept of SA by presenting three components of SA: spatial awareness, system awareness, and task awareness. *Spatial awareness* refers to the act of successfully piloting an aircraft through the hazard-filled three-dimensional (3-D) space of the NAS (Wickens, 2002). The pilot must meet the challenge of flying his aircraft, which is the top priority of flying within a three-tiered hierarchy of Aviate, Navigate, and Communicate (Morris & Leung, 2006). The pilot is first met with the challenge of controlling and monitoring the status of aircraft orientation—pitch, roll, and yaw—and the position of the aircraft—altitude, lateral flight path deviation, and position along the flight path (Wickens, 2002). Subsequently, all these variables are interrelated in the dynamics of flight; changes in pitch, roll, and yaw will change the future altitude and position of the aircraft along its planned flight path. Pilots create a mental model of these anticipated effects of the control movements by relying on condition-action rules of aerodynamics stored in long-term memory (Doane et al., 2004; Wickens, 1999). These mental models facilitate the pilots' ability to 'stay ahead of the aircraft' (Rankin et al., 2013).

Wickens (2002) second component of SA is *system awareness*. The modern aircraft provides the pilot a suite of automated flight-control systems, all designed to reduce the pilots' workload. Traditional analog gauges have been replaced with onboard computers displaying a multitude of data to the pilot within the cockpit in an effort to increase SA. Often, the complexity of the systems, in addition to poor design, increases the pilots' ability to perceive the necessary data available for processing (Wickens, 2002). While these systems have been designed to ease the pilots' workload, increased diligence is required to maintain awareness of the multitude of information provided to aircrew. Coupled with modern aviation automation is the requirement to train aircrew on system operations and the ability to filter or shed unnecessary information to develop an accurate mental picture of the aircraft within its operational airspace.

Wickens' (2002) third component of SA, *task awareness*, includes two additional tasks beyond aviating and navigating the aircraft. The additional tasks include communicating and monitoring the aircraft systems. Pilots maintain continuous channels of communication before, during, and after flight with other aircrew, air traffic control, other aircraft, aircraft maintainers, and other stakeholders in order to safely accomplish their mission. In the same fashion as the pilot maintains diligence in monitoring the flight-control automated systems, other systems such as electrical, hydraulic, fuel, and environmental systems command equal diligence in monitoring. The busy pilot exercises diligence in their awareness of the tasks to be performed within a flexible hierarchy (Wickens, 2002). The pilot has the ability to adapt to the ever-changing environment, prioritizing aircrew actions in order to safely navigate the NAS.

Understanding the extensive number of tasks to be accomplished by aircrew, aircraft designers have provided proceduralized checklists for aircrew to facilitate complete execution of the steps required for specific tasks. Often, aircrew must perform multiple tasks simultaneously, with no guidance on task priorities within the checklists (Wickens, 2002). This requires pilots to rely upon their training, experience, and judgement to prioritize tasks.

SA for Unmanned Aircraft Systems

While unmanned vehicle operators are not onboard their remotely operated vehicle, the requirement to acquire and maintain SA like their manned counterparts remains the same (Endsley & Jones, 2011). Unlike manned aircraft navigating within the NAS, sUAS operators remotely pilot their aircraft via ground control stations (GCS). The remote status of operation of the sUAS poses unique challenges for the operator, specifically in acquiring and maintaining SA. The requirements for SA during sUAS operations will vary by mission and operational goals (Endsley & Jones, 2011). Specific tasks such as search and rescue operations, orthomosaic mapping, and battlefield surveillance all have mission specific informational requirements for the sUAS itself, but also sensor-related information regarding the operational environment of the sUAS (Endsley & Jones, 2011).

Drury and Scott (2008) discuss a framework of human-machine interface (HMI) design requirements to facilitate successful UAS operations. While the term UAS categorizes the aircraft as “unmanned”, the human element is very much present. The UAS mission is determined, planned, and controlled by the human operator via the HMI. The HMI allows the human operator the ability to communicate and coordinate the actions of the UAS. In order to mitigate distraction, miscommunications, and information overload, HMI design must provide the operator with sufficient information for development of an appropriate level of SA for the specific mission at hand.

Drury and Scott’s (2008) Human-UAV Awareness Framework is an effort to inform system designers of UAS HMI requirements that would provide the operators’ the necessary information to develop the accurate mental picture of the UAS’s operational status within its operating environment. In order to do so, Drury and Scott (2008) begin with three benchmark requirements of human-UAV awareness:

- “accommodate the asymmetrical information needs of people and UAVs,
- be independent of any particular instantiation of a UAV,
- be specific to the types of information needed in the UAV domain" (p. 4).

Drury and Scott's (2008) framework assume the UAV employs a typical level of automation, such as waypoint following, and programmable capabilities, such as land immediately and return to home functions. The framework consists of three elements: 1) the understanding or awareness the operator has about the UAV, 2) the knowledge the UAV has about the operator, and 3) the operator's overall awareness of the mission. The first element, human-UAV awareness, is the most extensive of the three elements. This element consists of the operator's understanding of the UAV's current position, altitude, velocity, and its 4D spatial relationship to the vehicle's launch and recovery point, the relation to other aircraft, the proximity to natural or man-made obstacles, the proximity to the intended target, operational threats to the UAV, and the UAV's intended flight path (Drury & Scott, 2008). Additionally, the UAV's capabilities are also considered, such as onboard sensors, communications links, performance limitations, and pre-programmed contingency logic, that is, the operator should possess an understanding of how the UAV will respond to various conditions such as low battery power or obstacle encounters. This also includes the UAV's levels of consumables, the airworthiness of the UAV, current mode of autonomy and sensor use, and status of current communication strength and fidelity (Drury & Scott, 2008). Current and forecasted weather conditions must also be considered.

The second element, UAV-human awareness, includes the information the UAV needs to know about the operator (Drury & Scott, 2008). This includes the course and altitude to navigate, the velocity, sensors to deploy and when, and to what degree of autonomy to operate (Drury & Scott, 2008). The UAV must also maintain information concerning pre-programmed modes of operation for contingencies or command noncompliance (Drury & Scott, 2008).

Lastly, the third element involves the operator's overall awareness of the mission itself. This will include the purpose and goals of the mission, the customer, other stakeholders, a chronological understanding of the mission progress, time constraints, critical mission decision points, and other related or follow up missions (Drury & Scott, 2008).

Visual Perception

Rapid and accurate visual cue perception is paramount in aviation for determining spatial orientation and control of the aircraft within its operational environment (Gibb & Gray, 2016). Perception is a process that links the observer with their environment and creates a cognitive representation of this environment (Sekuler & Blake, 2006; Boonsuk et al., 2012). This process includes obstacle detection and avoidance in flight. Accurate visual cue perception is affected by the aircraft operator's visual acuity, motion perception, and depth perception (Gibb & Gray, 2016). Visual acuity is commonly assessed using a Snellen chart, which tests the degree of sharpness of vision observed by the human eye of a static chart with high-contrast letters from a distance of 20 ft (6.1 m); normal visual acuity is 20/20 (Gibb & Gray, 2016; Sekuler & Blake, 2006; The American Heritage Dictionary of Medicine, 2015). Visual acuity can be subcategorized into near acuity, far acuity, dynamic visual acuity, static visual acuity, and monocular and binocular visual acuity.

Near acuity generally describes the visual acquisition of objects within 3 ft 4 in. (1 m) in fine detail, and far acuity refers to the detailed observation of objects farther away (Gibb & Gray, 2016). The FAA requires aviation medical examiners to conduct near, intermediate, and distant visual acuity tests on personnel requesting an FAA medical certificate (Nakagawara et al., 2009). FAA vision standards by certificate class are presented in Table 4.

Table 4

FAA Vision Standards by Certificate Class

Certificate Class Flight Category	First Class Air Transport and Second Class Commercial	Third Class Private
Distant Vision	20/20 or better in each eye separately, with or without correction.	20/40 or better in each eye separately, with or without correction.
Intermediate Vision	20/40 or better in each eye separately, with or without correction at age 50 and over, as measured at 32 in.	No requirement
Near Vision	20/40 or better in each eye separately, with or without correction, as measured at 16 in.	20/40 or better in each eye separately, with or without correction, as measured at 16 in.

Note. Adapted from “Evaluation of Next-Generation Vision Testers for Aeromedical Certification of Aviation Personnel” by V. B. Nakagawara, R. W. Montgomery, and K. J. Wood, 2009. Civil Aeromedical Institute, Federal Aviation Administration (https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200913.pdf). In the public domain.

Dynamic visual acuity (DVA) is defined as “an observer’s ability to resolve a target when there is relative motion between the observer and that target” (Long & Rourke, 1989, p. 443). Target perception and resolution are inversely related with resolution deteriorating at velocities greater than 30 to 40 degrees per second (Long & Rourke, 1989). Resolution refers to the observer’s “ability to distinguish spatial details of an object” (Sekuler & Blake, 2006, p. 579). Additionally, DVA refers to the relative motion associated with the position and point of view of the observer and its effect on the observer’s optical processing of the operating environment (Mestre, 2016). It is this process of visual input and optical processing that provides the observer with the sense and "control of self-motion" (Mestre, 2016, p. 1).

A pilot's ability to perceive and resolve another aircraft in flight during the targets progression across the horizon is an example of dynamic visual acuity (Nakatsuka et al., 2006). However, human physiology and target characteristics can affect an observer's DVA (Hoffman et al., 1981; Nakatsuka et al., 2006). Human physiological factors include age, sex, peripheral acuity, oculomotor abilities, and other psychological factors (Ishigaki & Miyao, 1994; Long & Crambert, 1990; Nakatsuka et al., 2006). Target characteristics that can affect DVA include target reflectivity, velocity, size, and available duration of observation by the observer (Nakatsuka et al., 2006). Long and Rourke (1989) observed that DVA can be improved with training.

Jun (2011) studied the effects of composite display visual acuity in comparison to the visual acuity provided by FPV view techniques during the operation of tele-robotic vehicles. He noted that operator SA was a key element within the rapid decision-making process required in tasks such as flying aircraft and is congruent with Endsley's (1995a) theory of SA. That is, SA is dependent on the vehicle operator's perception, comprehension, and projection of the operational environment (Endsley, 1995b).

Jun's (2011) experiment in an indoor controlled environment required the participants within two groups to remotely control a telerobotic vehicle on an experimental track. The participants were required to navigate the telerobotic vehicle around the obstacles on the experimental track in order to locate specific objects and then return to their starting position. One group of participants navigated the telerobotic vehicle utilizing a combination of first- and third-person view perspective while the second group solely utilized FPV via a computer monitor. The first group was referred to as the CP group, while the second group was referred to as the FPP group, respectively. During the experiment, participants within the CP group could utilize the live visual feed from the telerobotic vehicle's onboard camera as displayed on the computer monitor in addition to utilizing line-of-sight visual observation of the vehicle during operation. Participants within the FPP group were limited to navigating the telerobotic vehicle solely utilizing the live video feed from the vehicle's onboard camera as displayed by the computer monitor.

Jun's experimental design consisted of one independent variable of "available point of view" (2011, p. 18) with two levels: the CP and FPP perspectives. There were three dependent variables observed in the study:

1. Operator SA as assessed by the Situation Awareness Global Assessment Technique (SAGAT),
2. Operator workload as assessed by the NASA-TLX, and
3. Task performance as defined as the number of objects located by the participant and glance activity.

The participants' glance activity was recorded utilizing an eye tracking system. Glance activity recorded the number of times the participant looked away from the live video feed as displayed by the computer monitor and focused their observation of the vehicle itself. He analyzed the data collected to identify if variations existed between the two levels of the independent variable and operator performance and to identify if a correlation existed in participants' perceived workload at the two levels of the independent variable. Results found a significant difference in performance between the

CP and the FPP groups but no significant differences in SA levels. In addition, no correlation was found between participants' SA scores and the number of glances the participant made to acquire line-of-sight with the telerobotic vehicle during operation, nor between the participants' SA scores and performance. Also, no correlation was found between the participants' perceived workload and point of view. He found operator development of SA while operating a tele-robotic vehicle occurred more rapidly while utilizing a combination of FPV and third-person-view techniques to create a virtual environment. Jun concluded that utilizing FPV techniques provided the operator the conduit to receive more visual data relative to the position of the tele-robotic vehicle within its operational environment, thus providing the operator more information to process.

Burg (1966) studied the visual acuity of both static and moving targets within the closed experimental environment. This study is relevant in that it substantiates the earlier discovery of the measure of visual capability of DVA, which is a key factor when discussing the benefits of FPV visual acuity techniques. Burg defines DVA as "the ability to discriminate an object when there is relative movement between the observer and the object" (Burg, 1966, p. 460). Object or obstacle to flight discrimination is essential in the safe operation of UAS and is a key element in the UAS operator's sustained SA. DVA is a key element within this study because it is hypothesized the DVA will be enhanced with UAS operator utilization of FPV visual acuity techniques.

Air-to-Air Target Detection. Federal Aviation Regulations have mandated that all pilots should exercise diligent lookout procedures in flight regardless of the aircraft type (FAA, 1998; FAA, 2016e). It is the pilot's responsibility to possess the ability to recognize other aircraft operating within the NAS to establish and maintain safe visual separation at all degrees of workload and environmental conditions (FAA, 2016e; Graham & Orr, 1970; Kephart & Braasch, 2010). While the development of autonomous traffic avoidance systems for sUAS is well underway, see-and-avoid practices are the primary means of midair collision avoidance for all aircraft operating within the NAS (Curtis-Brown et al., 2017).

The see-and-avoid concept is a synergistic relationship between a pilot's acquired airmanship, vigilant lookout doctrine, and proper preflight planning (FAA, 2016e). While there may be no finite definition of airmanship, it has been generally accepted as the pilot's degree of professionalism and performance as demonstrated in the aeronautical decision-making process (Nergård, 2014; Nergård et al., 2011). This degree of airmanship has an unquantifiable effect on the success of a vigilant lookout doctrine. Research by Graham and Orr (1970) and Catalano and McKown (1963) demonstrated that failures of the see-and-avoid concept originate conclusively from the inability to see obstacles in flight (as cited in Graham, 1989). Preflight planning provides airmen the opportunity to acquire necessary information pertaining to the intended route of flight such as projected aircraft congestion density, meteorological conditions, and Special Use Airspaces that may be encountered, to name a few (FAA, 2016e). However, traffic detection and avoidance rely solely on the pilot's ability to visually acquire traffic movements within the pilot's field of vision (FAA, 2016e).

Data presented within the FAA's Aviation Circular 90-48D (2016e) reports findings from previous research that states average pilot reaction time to obstacles detected in flight to be 12.5 s. Reaction times are presented in Table 5. Detection of airborne obstacles to flight are often hindered by background clutter such as the meteorological conditions of cloud formations, ground terrain features, and bodies of water (Gandhi et al., 2003). In addition, the target's position, and the velocity in relation to the host aircraft is key in the target's detection (Gandhi et al., 2003; Kwag et al., 2006; Morris, 2005). Research by Wallace et al. (2018) assessed that sUAS operators could reliably detect a small unmanned quadcopter at ranges up to 528 ft (161 m).

Table 5

Aircraft Identification and Reaction Times

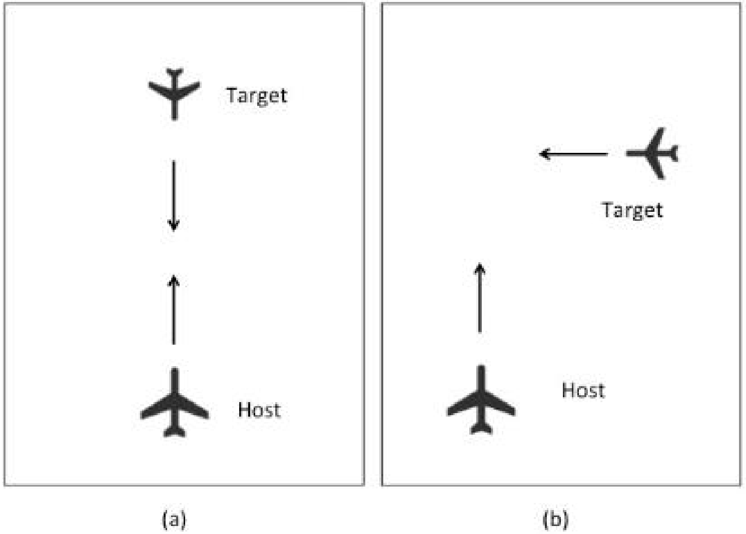
Event	Seconds
See object	0.1
Recognize Target	1.0
Become aware of collision course	5.0
Decision to turn left or right	4.0
Muscular reaction	0.4
Aircraft lag time	2.0
Total	12.5

Note. Adapted from "Pilots' Role in Collision Avoidance" by the Federal Aviation Administration [AC 90–48D], 2016, p. 2 (https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/1029428) In the public domain.

Discrimination of the target from background clutter during perpendicular flight trajectories of the target in relation to the host aircraft, as illustrated in Panel b of Figure 8, are more easily detected than direct oncoming flight trajectories, as illustrated in Panel a of Figure 8 (Gandhi et al., 2003). Targets with a trajectory depicted in Panel b that appear to present a possible collision course will present a stationary image of 2D quality (Krause, 1995).

Figure 8

Detection of Flight Trajectories



Note. Panel a: Target aircraft on oncoming collision course aspect. Panel b: Target aircraft on perpendicular collision course aspect. Adapted from "Detection of Obstacles in the Flight Path of an Aircraft" by T. Gandhi, M.-T. Yang, R. Kasturi, O. Camps, L. Coraor, and J. McCandless, J., 2003, *IEEE Transactions on Aerospace and Electronic Systems, 39*(1), p. 177. (https://doi.org/10.1109/TAES.2003.1188902). Copyright 2003.

These targets present an image that appears static in nature than the targets originating from a perpendicular trajectory which present characteristics that appear more dynamic. An additional discrimination characteristic of the detected target with the oncoming flight trajectory is the increase in the visual target's image expansion relative to the time to collision (Gandhi et al., 2003). Target image expansion increases at a greater rate for objects with oncoming flight trajectories relative to the host aircraft, as shown in Panel a of Figure 8 than for objects with a more perpendicular nature as those with trajectories to the host aircraft as depicted in Panel b (Gandhi et al., 2003).

Research conducted by Watson et al. (2009) developed the concept of a pattern visibility metric that could provide visibility predictions of aircraft imagery. The Watson et al. prediction model incorporated target and host aircraft variables including aircraft size, shape, coloration, visual search field, pilot's field of view, aircraft speed and angle of approach, and target detectability. Detectability refers to the ability of the aircrew to detect the airborne target within the aircrew’s field of view (Andrews, 1977). Andrews found the factors affecting detectability include target size and shape, target and host aircraft velocity and relative azimuths, and target contrast with the predominant background.

Watson et al. (2009) developed a metric to determine aircraft detectability. Their intent was to construct a model that would examine aircraft size, shape, distance from the host aircraft, and target coloration to predict detectability. In addition, their model included variables such as the aircrew’s visual search field, the aircrew’s field of view, and the velocity and azimuth of the target in relation to the host aircraft. As mentioned in their study, reflected electromagnetic energy from airborne targets provides an image of the target upon the aircrew’s retinas. While the authors examined the shape and size of many aircraft types, the crux of their findings determined that the target’s degree of visual angle and its luminance in contrast to the background environment determines a contrast threshold, which provides a threshold at which the target may be detected.

A text by Terwilliger et al. (2017) adopted the work of Howett (1983) to derive an approximate calculation of VLOS for UAS operations:

> An approximate calculation of VLOS can be made using Howett’s equation by assuming that an object must subtend one minute of visual arc to be detectable by a human with normal 20/20 vision. An estimate of the VLOS distance for operation of the sUAS, based on the distance in feet (ft) for identifying and detecting an object with the human eye for a PIC or VO with 20/20 vision and typical visual acuity (see Figure 129), could be calculated with the following

> equation: Visible Distance (ft) = 3438 x Side View Height of sUAS (in.) Ex., A sUAS with a side view height (profile size) of 10-in.: Visible distance = 3438 x 10 = 34,380 ft. (p. 178)

Field of View

The unaided human field of view (FOV) is approximately 200º (Boonsuk et al., 2012; Sekuler & Blake, 2006). Given this limitation, humans must turn their heads and eyes to see objects within their environment that are outside their FOV (Sekuler & Blake, 2006). The FAA has institutionalized a specific scan pattern to systematically search for obstacles to flight (Colvin et al., 2005; FAA, 1998). It is recommended that pilots shift their focus of fixation outside the cockpit every second while shifting their focus no more than 10 degrees of view with each fixation to observe the entire FOV possible (Colvin et al., 2005; FAA, 1998).

Visual perception theory proposes that an internal representation of the elements within our visual sphere of perception is created by multiple discrete fixations within our FOV (Alfano & Michel, 1990; Sekuler & Blake, 2006). Increasing the FOV of the UAS operator maximizes the virtual presence of the operator within the virtual environment, and therefore enhances the operator's ability to safely control their aircraft within the operating airspace (Knapp & Loomis, 2004; Lin et al., 2002; Prothero & Hoffman, 1995). The motor output of the UAS operator during teleoperations is dependent upon the acquisition and processing of sensory input, primarily from the operators FOV (Goodale, 2008). The cognitive transformation of the data acquired through the sensory input of the eye provides the operator an internal representation of the external operating area (Goodale, 2008; Boonsuk et al., 2012).

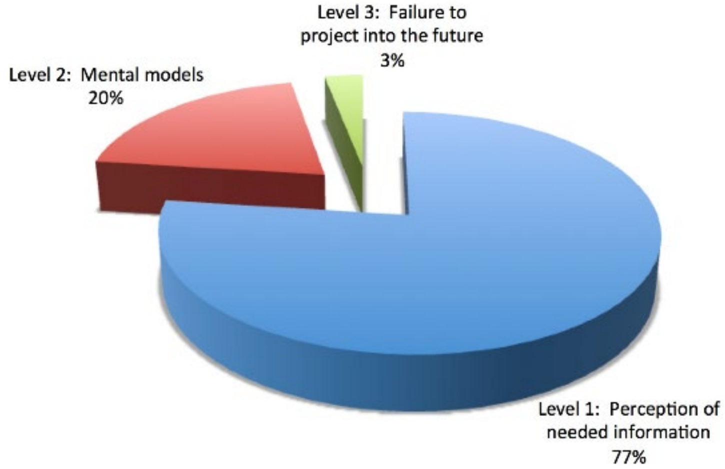
The neuronal process of the eye transforms the electromagnetic energy contained within the visible spectrum of light into neural energy referred to as the transduction procedure. Human perception of the environment and of the elements therein, are a product of our brain's cognitive processing of this neural energy. This visual processing is a crucial element in providing aircraft operators their awareness of the aircraft's position in time in space, awareness of other elements within this operating space, and the understanding of these elements in this dynamic environment (Endsley, 1995a; Tirre & Gugerty, 1999).

While many aircraft within the NAS are equipped with Traffic Collision Avoidance Systems (TCAS) and the Next Generation Air Transportation System (NextGen) plans to incorporate Automatic Dependent Surveillance-Broadcast systems (ADS-B) for collision avoidance, the primary detection process employed by manned aircraft is see and avoid (Colvin et al., 2005). The FAA and the Airline Operators and Pilot's Association (AOPA) have taken measures to institutionalize a scanning procedure to identify targets outside of the cockpit (FAA, 1998; Wynbrandt, 2001). However, due to the physical location of the UAS operator in relation to the physical position of the controlled aircraft, the ability to observe and detect elements within the aircraft's operating airspace differs greatly relative to that of manned aircraft.

Research conducted by Jones and Endsley (1996) discovered that approximately 77% of human errors in aviation accidents and incidents occur from difficulties acquiring the information necessary to safely operate the aircraft as shown in Figure 9.

Figure 9

Errors in Aviation Associated with Situation Awareness



Note. Adapted from “A Neuroergonomic Experiment: Predictors of Situation Awareness and Display Usability with USAF Pilots While Performing Complex Tasks” by S. D. Harbour and J. C. Christensen, 2015. Copyright 2015 by SPIE. https://doi.org/10.1117/12.2180324

Studies have estimated that perception originating from our sense of vision consist of 80%–85% as compared to the other senses (Gillen, 2008). Jones and Endsley (1996) noted that failures to perceived information could originate from a failure of monitoring or observing data, a misperception of data, or simply that the data was difficult to detect. Of these three reasons for failing to perceive information within an aircraft’s operational area, failure to monitor or observe the data was the largest percentage of the three, accounting for 35% of the errors studied (Jones & Endsley, 1996).

It has been discovered that obstacle to flight detection for manned aircraft varies from distances of 3.4 to 5.4 miles (Colvin et al., 2005). The vantage point of a manned aircraft pilot’s FOV originates from the cockpit of the aircraft. This is not the case of the UAS operator’s FOV. However, with the increased distance between the UAS operator and the UAS's position in its operational airspace, the vantage point of UAS operator's FOV would not be collocated with the aircraft's position. The UAS operator's position on the ground would render the operator's FOV unable to detect/differentiate static/dynamic movement of objects relative to the position of the aircraft.

Providing the UAS operator an electronically enhanced FOV through FPV visual acuity techniques may increase the operator's ability to detect and react to obstacles encountered during flight. Research conducted by the University of Washington, the State of Nevada's Office of Economic Development, the Nevada Institute for Autonomous Systems, and the FAA's UAS Test Site in Nevada states that FPV systems available can provide the UAS operator a greater FOV than the unaided human eye (FAA, 2016a).

Alfano and Michel (1990) studied the effect of restricting the FOV of participants and the subsequent loss of performance and perception of the participants within their operational environment. The authors proposed that human perception of the visual world in which we operate is constructed of a myriad of specific fixations of the eye on elements within the environment to create a mental mosaic of reality within this process. Their emphasis was on the information contained within our peripheral vision as we conduct the process of mosaicking our mental picture of reality. Within the constructs of their research, the peripheral vision of the research participants was incrementally restricted to gauge the degree of effect this would have on the participants' performance during walking, reaching, and their development of a cognitive map of an unfamiliar floor plan.

The results of the Alfano and Michel (1990) study demonstrated that the ability of their participants to create a cognitive map began to decay with incremental increases in the restriction of the participants' peripheral vision. Similarly, during the participants' task of walking, the degree of errors in navigating the test path increased during the incremental increase in the participants' peripheral vision. During the reaching task, participants again were found to have a decreased ability to perform as their eye-hand coordination decreased within the task as their peripheral vision was incrementally decreased. To this end, the authors concluded that as field of view is restricted, there would be corresponding decreases in performance and perception recall.

Research has shown that the FOV from teleoperated vehicles employing mounted cameras can provide a real-time video feed of the observed area that is narrower than the normal FOV of the vehicle operator, creating what has become known as the soda straw effect (Fong & Thorpe, 2001; Lewis et al., 2009). Regardless of this limitation, human controlled teleoperations utilizing real-time video feed provided by vehicle mounted cameras has been the preferred means of operating remote vehicles (Fong & Thorpe, 2001).

Pazuchanics (2006) conducted research on the effects of the camera perspective on mounted teleoperated vehicles on the operator's performance during navigation of a virtual environment. Pazuchanics proposed that the soda straw effect could be mitigated during teleoperation by two techniques: increasing the FOV of the vehicle-mounted camera and including the vehicle within its operational environment with a third-person perspective for view by the vehicle operator. The researcher mounted a camera on the rear of the teleoperated vehicle to provide the third-person view to the operator. The researcher provided three hypotheses: (a) increasing the FOV of the vehicle mounted camera would provide a greater improvement in operator performance; (b) providing a third-person perspective of the vehicle to the operator during teleoperations would increase performance; and (c) increasing the FOV of the vehicle mounted camera would provide a greater improvement in operator performance than providing a third-person perspective of the vehicle to the operator.

Pazuchanics' (2006) experiment required participants to navigate through an obstacle course while teleoperating a robotic vehicle within a virtual environment. Performance of operation would be examined with the following variables: (a) total completion time to navigate the virtual course; (b) number of collisions with obstacles that occurred during navigation through the virtual course; (c) number of turnarounds required due to poor navigation on the course; and (d) operator comfort during navigation with the associated FOV and perspective as assessed by a questionnaire administered after each condition of the experiment. During the experiment, the camera perspective of the vehicle-mounted camera was varied with two conditions: FPV and third-person view. In addition, the FOV was varied with two conditions: 30º FOV and 60º FOV.

The results of the experiment supported Pazuchanics' (2006) first hypothesis that an increase in the operator's FOV would increase performance. The experiment condition with the 60º FOV resulted in an increase in performance in all the variables measured and facilitated the greatest degree of comfort while navigating the obstacle course with the virtual vehicle. In testing of the author's second hypothesis, it was discovered that the third-person view perspective resulted in a decrease in total time to navigate the obstacle course, a decrease in the number of turnarounds required, and an increase in the operator's comfort during operations. However, use of the third-person perspective did not significantly reduce the number of collisions that occurred during navigation. In testing the third hypothesis, Pazuchanics discovered that the wider FOV facilitated greater operator performance than the third-person perspective condition. Time to complete navigation of the obstacle course was faster using the increased FOV versus the third-person perspective. The number of collisions with obstacles was less utilizing the increased FOV versus the use of the third-person perspective. The number of turnarounds utilizing the increase FOV was also less than those that occurred utilizing the third-person perspective. However, operator comfort was not significantly different between the two conditions.

Pazuchanics' (2006) concluded that the increase in the operator's FOV would increase performance as compared to providing a third-person perspective during teleoperations. However, it was noted that if the ability to increase the FOV of the vehicle mounted camera was not available, the provision of a third-person perspective would provide added benefits to navigation.

Bateman et al. (2000) studied the effect of vehicle operator performance utilizing FPV techniques within the virtual environment of automobile driving simulations. Their study demonstrated that the enhanced FOV provided by FPV devices provided greater visual acuity and increased operational performance. The use of FPV techniques increased the operator's FOV from the vehicles studied and thus had resulted in an increase in operator performance. It was also concluded that FPV techniques provide a conduit for providing additional navigational information to the operator within the 3-dimensional workspace environment, thus enhancing the data available for the operator during the decision-making process.

Human-Machine Interface Predictive Models

Understanding the dynamics of the human-machine interface (HMI) during teleoperations of UAS is of utmost importance if an equivalent level of safety as experienced by manned aircraft is to be achieved. Imperative to this present research is the understanding of limitations and constraints that create the binding synergy attained in this human-machine relationship. To better understand HMI, predictive models have been formulated to assist in assessing human psychomotor behavior (MacKenzie, 1992). Therefore, it is important to review the relevant literature for the following HMI predictive models:

- Fitts' law
- Steering law
- Cornering law

Fitts' Law

Fitts (1954) experimented with human sensory, perceptual, and motor functionality to examine human performance in controlled environments to determine if performance would be limited by the subject's motor system capacity. To control for learning behavior, controlled environments were designed and employed to isolate external stimuli and to hold all other experimental conditions constant. This created the conditions to provide an environment where the subject's own activity could be self-monitored, in isolation of other factors, providing the subject "visual and proprioceptive feedback loops" (Fitts, 1954, p. 381). The loops provided the subject information necessary to regard responses to the experimental stimulus as adequate based on the force, direction, and amplitude of the variation of the subject's movement in response to the stimuli. Fitts hypothesized that the subjects motor system capacity could be inferred from the variation in repeated responses of the subjects during the experiment.

Fitts' (1954) conducted three experiments to test the hypothesis that performance would be limited by the subject's motor system capacity. First, subjects were asked to execute the movement of tapping two rectangular metal plates with a stylus with equal amplitude. Conditions of the experiment were varied to change the weight of the stylus used, to increase the distance between the metal plates, and to increase the width of the target area to be tapped within the metal plates. Total time for task completion was recorded, with emphasis on subject speed and accuracy. Errors that occurred during the execution of the experimental task were permitted and recorded.

The second experiment tested the subject's ability to move plastic washers between two fixed pins on a board. It required the subject to conduct two ranges of movement, one while moving a washer from one pin to the other, with the subsequent movement executed empty handed while moving to acquire the next washer to be moved. The condition of this experiment varied the distance between the pins and the diameter of the holes in the washers, thus producing 16 experimental conditions. Total time for task completion was recorded, with emphasis on subject speed and accuracy. The tasks executed during this experiment did not permit errors.

The third experiment examined the subject's ability to move metal pins between holes on a board, while the diameter of the pins and the distance between the holes were varied throughout the experimental conditions. The size of the holes was twice the diameter of the pins used during each condition of the experiment. Total time for task completion was recorded, with emphasis on subject speed and accuracy. The tasks executed during this experiment did not permit errors.

The results of Fitts' (1954) experiments demonstrated that a subject's rate of performance during the execution of the tasks observed remained constant throughout a varied range of movement amplitudes and tolerance limits. A level of optimum performance was determined for the three experiments. However, performance degradation was observed within the three experiments when the rate of performance fell outside this level. Specifically, Fitts concluded a relationship exists that can model the inverse relationship between speed and accuracy within the aimed movements of the experiment test subjects (Plamondon & Alimi, 1997; Zhai et al., 2004).

In Equation 1, Fitts law (MacKenzie, 1992) provides a derived index of difficulty for the acquisition of a target:

$$ID = \log_2(2A/W) \tag{1}$$

where:

ID = Index of difficulty

A = Movement distance between targets.

W = Width of the target to be acquired which is analogous to the position in which the movement ends.

To facilitate the index of difficulty greater than zero for all the conditions in his experiments, Fitts, utilized a factor of two in the logarithm (Fitts, 1954, p. 388; MacKenzie, 1992). In Equation 2, the formula is rewritten to determine movement time (*MT)* between the targets, providing a linear regression equation that can be used to observe the correlation (r) for goodness of fit:

$$MT = a + b \text{ x } \log_2(2A/W) \tag{2}$$

where:

MT = Movement time,

a = Intercept of the linear regression (describes the delay), and

b = Slope of the linear regression (describes the acceleration) (Soukoreff & MacKenzie, 2004, p. 758).

Steering Law

Accot and Zhai (1997) took Fitts' work a step further to apply his pointing task theory to trajectory-based tasks used in human-computer interfaces. Accot and Zhai proposed that Fitts' theory was sufficient to address simple pointing tasks of target acquisition but was not a practicable means of addressing the mechanics of subsequently tracking an acquired target with trajectory-based movements of the human-computer interface mechanism.

To evaluate their theory, Accot and Zhai (1997) conducted a series of four experiments that required the test subjects execute steering tasks with human-computer interface devices. Each experiment required the test subjects to navigate a stylus pointer through a series of computer-generated constraints with various length and width boundaries. The initial two experiments closely resembled the mechanics of Fitts' tapping experiments, and the inverse relationship between speed and accuracy was highly correlated. However, the narrowing constraints of the third experiment and the spiraling tunnel constraints of the fourth experiment introduced trajectory navigation requirements that were not present in the first two experiments.

In Equation 3, the steering law provides a model that describes the relationship between total completion time and the constraints of the steering task:

$$T = a + b \times ID \tag{3}$$

where:

T = completion time,

a and *b* = constants that depend on the choice of input device, and

ID = index of difficulty of the task (Accot & Zhai, 1999, p. 467).

The index of difficulty may be determined by Equation 4:

$$ID = \int \frac{ds}{W(s)} \tag{4}$$

where:

ID = index of difficulty of the task,

s = curvilinear abscissa, and

W(*s*) = path width at *s* (Accot & Zhai, 1997, p. 467).

Accot and Zhai (1997) concluded that within the experiments, the time to navigate the stylus pointer on the computer-generated display was linearly correlated to the degree of difficulty of the task. Their research moved beyond the essence of Fitts' law and examined other possible symmetries in movement tasks.

Cornering Law

Like Fitts' law and the steering law, the cornering law proposes to model the performance of cornering-based tasks based on a degree of difficulty of the constraints of the required task (Helton et al., 2013; Pastel et al., 2007). In examination of the cornering law, Helton et al. (2013) observed operator workload while piloting teleoperated unmanned ground vehicles (UGVs) while utilizing both third-person and FPV visual acuity techniques.

Pastel et al. (2007) developed the theory of the cornering law in their examination of operator workload while piloting computer simulated virtual vehicles around corners of varying degree and through apertures of various widths. The researchers utilized the third-person visual acuity technique for their experiments. They hypothesized that the degree of difficulty (*ID*) in negotiating a corner would increase as the size of the vehicle increased relative to the width of the corner, as shown in Equation 5:

$$ID \sim \frac{1}{w-p} \tag{5}$$

where:

ID = index of difficulty of the task,

w = width of the corner, and

p = vehicle size (Pastel et al., 2007, p. 491).

Theorizing differences in the cornering law applicability to real world conditions, Helton et al. (2013) continued to examine the theory of cornering law with real teleoperated UGVs, utilizing both third-person and FPV visual acuity techniques. As remarked by Bateman et al. (2011), differences in virtual task performance were discovered utilizing over-head, third-person, and FPV visual acuity techniques.

Helton et al. (2013) designed their experiments to measure UGV operator travel time between the constraints of the travel path obstacles, the rate of collisions made during navigation, and the UGV operators' perceived workload as measured by the NASA TLX questionnaire, while completing a 90º cornering turn within the constraints of the obstacles. Two experiments were conducted during the study consisting of five blocks per experiment. Experiment 1 utilized a third-person visual acuity technique, and Experiment 2 utilized a FPV technique. The other experimental conditions remained the same for both experiments. During each of the five blocks per experiment, the participants were required to navigate the UGV via teleoperation with the goal of completing the travel path without colliding with any of the obstacles. The aperture width of the travel path within the constraints of the obstacles was reduced with each subsequent block to increase the degree of difficulty. Participants completed each experimental trial utilizing third-person and FPV visual acuity techniques while teleoperating the UGV. Workloads for each block were subjectively evaluated by each participant utilizing the NASA TLX questionnaire.

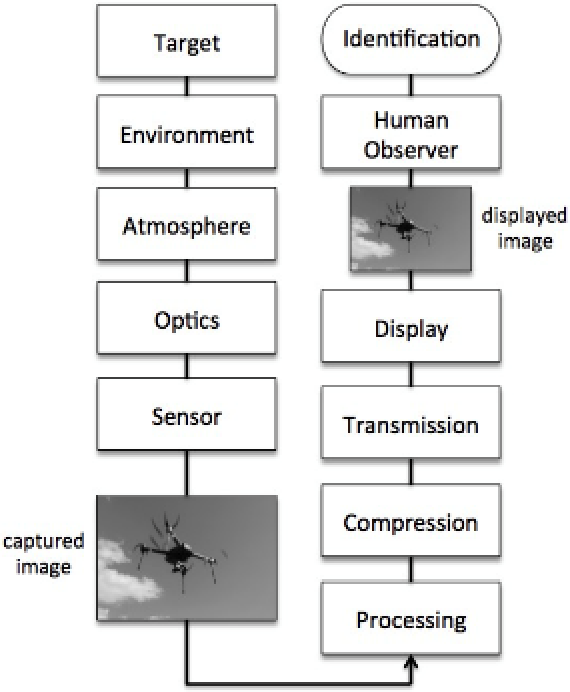
The results of Experiment 1 utilizing third-person view demonstrated participant performance improved with each subsequent block due to the learning effect (Helton et al., 2013). In addition, participants perceived a decreasing temporal demand with each subsequent block, as noted on the NASA TLX questionnaires. Similarly, the results from Experiment 2 utilizing FPV demonstrated participant performance improved with each subsequent block due to the learning effect. Again, as done in Experiment 1, participants perceived a decreasing temporal demand with each subsequent block, as noted on the NASA TLX questionnaires. Helton et al. (2013) discovered that during both experiments, the cornering law successfully predicted participant performance while teleoperating the UGVs within the constraints of the aperture widths created by the obstacles.

Telepresence

In the context of this present study, *telepresence* is defined as the appearance of being present at the location of a RC vehicle operation while the operator is physically located elsewhere in control of the vehicle with a control station (Riley, 2001). Telepresence provides the human operator the virtual sensation that they are present within the environment of the remotely controlled vehicle. Key component sub-systems of telepresence systems incorporate audiovisual sensors to suffice the two main human senses used during interpersonal communication of hearing and vision (Johanson, 2015). Integrated imaging systems, commonly used in telepresence operations, are a system of smaller component systems that utilize optics and sensors to capture data from the target area to be processed. After processing, the data is transmitted to a ground-based control station (GCS) where a visual representation of the data collected by the sensors is displayed for view by the human observer. This process is depicted in Figure 10.

Figure 10

Obstacle Detection Process



Note. Reprinted from "Up Periscope! Designing a New Perceptual Metric for Imaging System Performance" by A. B. Watson, 2016. *Electronic Imaging, 13*, p. 1 (https://ntrs.nasa.gov/api/citations/20160001862/downloads/20160001862.pdf). In the public domain.

Righetti et al. (2007) studied the effects of FPV techniques on UAS pilot SA while piloting surveillance aircraft. Their study created a virtual environment in which the UAS became a "natural extension" (Righetti et al., p. 159) of the operator. This was an application of telepresence as utilized by an airborne surveillance aircraft. The aircraft used was a blimp that was controlled by the operator in response to the current real-time flight condition of the aircraft. The researchers' concept was to provide the human operator a virtual reality-based telepresence experience while operating the remotely controlled aircraft.

Righetti et al. (2007) designed a telepresence system that provided the remotely controlled aircraft operator a machine interface to the aircraft. The interface provided accurate real-time data of the observed area using the aircraft's onboard sensors. The researchers proposed that human operator's speed of observation and comprehension of the environment observed by the aircraft through the onboard sensors would enhance the operator's reaction time.

The system was designed to provide the human operator a natural and realistic interface with the remotely controlled aircraft (Righetti et al., 2007). It included a haptic interface consisting of a vibro-tactile belt that provided the operator real-time feedback on the direction and the strength of the wind and its effect on the aircraft. In addition, the system provided the operator live video feed from the aircraft's onboard camera via an operator-worn head mounted display (HMD). Inertial sensors within the HMD sensed the head movements of the operator. The aircraft's onboard camera replicated the head movements of the operator via a two-axis gimbal. Real-time audio sensors provided the operator audible sensing of the aircraft's environment via the use of a pair of headphones.

The tests were found to provide the operator a natural virtual reality experience (Righetti et al., 2007). The first tests were conducted in a static fashion without the control of an aircraft to ensure operability of the system. The second tests integrated the system with the aircraft. Test subjects were required to pilot the aircraft while counting parked cars in a parking lot.

The researchers concluded that natural feedback, which included FPV visual data, provided the operator a greater ability to understand the airborne status of the aircraft and, thus, an ability to react accordingly to changes within the flight environment with greater speed.

According to Ferland et al. (2009), Human-to-machine interfaces used to create telepresence can greatly enhance the performance and SA of the operator. The interface is the key component of a telerobotic system. The interface provides the operator the necessary connection with the remote environment to interact within this environment to accomplish the intended task. It also provides the visual display of the environment to the robotic system operator, as illustrated in Figure 10. Visual modalities within robotic systems often combine other information relative to its operation within the environment to decrease the operator's workload and increase SA.

Egocentric Versus Exocentric Viewpoints. Visualization viewpoints may be either egocentric or exocentric (Ferland et al., 2009). The *egocentric viewpoint* provides the robotic system operator a view of the environment from the perspective of the robot itself, while the *exocentric viewpoint* provides the robotic system operator a view of the robot within its environment from an external point of view (Ferland et al., 2009; Slater et al., 1996). The egocentric viewpoint provides the operator an optimum perspective for navigation, target detection, and obstacle avoidance, while the exocentric viewpoint provides the robotic system operator a greater awareness of the robot's presence and interaction within the intended environment (Ferland et al., 2009; Saitoh et al., 2006).

Teleoperations

In the context of this present research, *teleoperation* is defined as the operation of a task utilizing a machine remotely controlled by a human operator that is not physically located at the area of operation (Draper, 1995). Boonsuk et al. (2012) studied the impact of 360º visual interfaces to evaluate optimal human-machine interface process for use in teleoperation of remote systems. Their work investigated the visual acuity of operators provided with an enhanced FOV of the environment, which minimized the perceptual distortion of spatial information that can occur without the use of the increased FOV techniques. These techniques provided the operators a greater distribution of attention and greater situational awareness.

Boonsuk et al. (2012) focused their attention on mobile surveillance systems incorporated within a virtual moving ground vehicle. Their objective was to provide the remotely piloted vehicle operator an immersive system that displayed a 360º panorama view of the operating area. Three specific design interfaces for this display were used with respect to the operator's egocentric perspective:

- 4 x 90º views with front, left, right, and rear,
- 2 x 180º views with front and rear, and
- 1 x 360º panoramic view.

The virtual cameras attached to the virtual remotely piloted ground vehicle provided transformation of the 3D environment to a 2D display as observed on standard 22-in. computer monitor displays (Boonsuk et al., 2012). The 360º design of the system allowed the operator the ability to acquire targets of interest in all directions during remote piloted vehicle operation. However, the authors noted that the transformation of the 3D panoramic view into a 2D display could produce errors in judgment during determination of egocentric direction to the targets of interest.

Utilizing the three design interfaces, the goal of the Boonsuk et al. (2012) study was to examine the spatial task performance of the participants to determine the optimal display interface used within the virtual environment. Each participant conducted three separate phases: Phase 1 familiarization, Phase 2 target acquisition, and Phase 3 map reproduction. The familiarization provided the participants the opportunity to become acquainted with the keyboard controls to be used for navigation and vehicle control within the virtual environment. During the acquisition phase, participants were provided 10 min to locate and select 10 targets within the virtual environment. During the map reproduction phase, participants were required to navigate the virtual environment to locate targets and subsequently mark the target locations on an overhead map. Participants conducted the three phases for each type of visual interface. At the completion of each interface session, the participants completed a questionnaire regarding their satisfaction utilizing each specific interface.

Boonsuk et al. (2012) reported the frequency distributions of the participants' performance of the target acquisition task revealed participants were more likely to select targets when they were near the center of the interface display (see the target acquisition rates in Table 6). Differences in target acquisition distributions for the three specific display interfaces indicated that participant focus of attention was broadest with the 360º display and narrowest with the series of 90º displays.

Boonsuk et al. (2012) predicted the distance of the targets relative to the participants' perspective within the virtual reality space, as depicted by each of the interfaces, would not affect target acquisition in terms of selection of the target with the pointing device. However, the time to select the target within the virtual space was positively correlated to the position of the target within the virtual space and the relative distance of the target from the participants' perspective. They concluded this indicated the participants processed the data within a 3D environment rather than the mere 2D projected images within each interface.

Table 6

Target Acquisition Distributions

Interface	Degrees of Interface Display Center	Targets Selected (%)
90° x 4	45	52
180° x 2	45	50
360° x 1	45	41
90° x 4	15	31
180° x 2	15	23
360° x 1	15	15

Note. Adapted from "The Impact of Three Interfaces for 360-Degree Video on Spatial Cognition" by W. Boonsuk, S. B. Gilbert, and J. W. Kelly, 2012. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/2207676.2208647

Boonsuk et al. (2012) logged the participants' reaction times throughout the experiment for each interface. Time intervals of one per second were used to record the participants' directions and positions throughout the virtual environment of the experiment. Observation of the recorded data allowed analysis of the participants' time from target acquisition to target selection. Utilizing a one-way, repeated-measures ANOVA, they analyzed the reaction times to determine the effect of each interface type and found interface type did not significantly affect participants' reaction times.

They analyzed the participants' pointing errors during the experiment to evaluate the ability to reference the egocentric target directions relative to the participants' position within the virtual environment of the experiment (Boonsuk et al., 2012). Utilizing a one-way repeated-measures ANOVA, the researchers reported there were no significant differences between the 90º interface and the 180º interface, but that pointing error was significantly greater utilizing the 360º interface.

A mapping task required participants to locate the targets within the virtual environment of the experiment and then mark the target locations on an overhead map (Boonsuk et al., 2012). Target placements on the overhead map varied greatly among participants. The researchers analyzed the participants' mapping task performance with each interface and found no significant differences in the participants' mapping task performance affected by interface type.

A survey was conducted after each interface to record the participants' interface preferences (Boonsuk et al., 2012). The participants responded to four questions regarding their: (a) preferred interface, (b) most natural feel for navigation, (c) most accurate interface for pointing task, and (d) most accurate interface for the mapping task. The survey data augmented the results of the pointing error performance analysis as the results from the first three questions supported the significantly degraded performance of the participants while utilizing the 360º interface. The participants' responses to Item 3 indicated they preferred the 90º interface; however, as noted in the analysis of pointing error, performance was not significantly different while utilizing the 180º interface. Participants' response to Item 4 indicated no difference in preference by interface.

Among their findings, Boonsuk et al. (2012) concluded image segmentation—a facet of the tested FOV techniques—affects the operator's spatial allocation of attention; thus, affecting the operator's situational awareness. It was hypothesized that this would also affect operator reaction time to obstacles encountered in flight.

Aircraft Collision Hazard Detection

One of the most challenging issues faced by the FAA and sUAS operators is the integration of sUAS into the NAS while implementing measures to prevent midair collisions between manned and unmanned aircraft (Dolgov, 2016). Although numerous methods are being developed to include onboard sense and avoid systems, visual line-of-sight is the primary means of midair collision avoidance for sUAS (Consiglio et al., 2012; Dolgov, 2016; Lacher et al., 2010). Automated sense and avoid systems have demonstrated a higher level of accuracy and reliability than the primary VLOS method of midair collision avoidance during testing (Dolgov, 2016; Lacher et al., 2010). A key facet of these sense and avoid systems is the integration of algorithm intense software that presents trajectory predictions for autonomous sUAS navigation based on optically acquired aircraft positions relative to the sUAS (Kang et al., 2017). These systems are extremely costly and remain in the research and development and testing phases.

The requirement for the establishment and maintenance of an equivalent level of safety for sUAS operations as that which is maintained by manned aircraft within the NAS has been the catalyst for development of autonomous sense and avoid systems for sUAS (Kang et al., 2017; Woo, 2017). Recent studies on manned aircraft pilots' difficulties in maintaining see and avoid techniques for sUAS are practically non-existent (Loffi et al., 2016; Woo, 2017). In addition, challenges exist for the sUAS operator to implement sufficient see and avoid techniques to provide sufficient airspace separation between manned aircraft operating at low altitudes. This challenge is amplified by the numerous obstacles to flight encountered at the low altitudes typically flown by sUAS such as tall vegetation and buildings (Woo, 2017). Indeed, this limited visibility challenge of the sUAS operator has fostered the necessity for the development of sUAS autonomous sense and avoid systems (Woo, 2017).

Clothier et al. (2017) examined the suitability of human see and avoid capabilities as an acceptable means for UAS midair collision avoidance. They noted the development and implementation of detect and avoid (DAA) systems is paramount for safe operation of UAS and manned aircraft within non-segregated airspace within the NAS (Clothier et al., 2017). A *detect and avoid system* is defined as "the capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action to comply with the applicable rules of flight" (International Civil Aviation Organization [ICAO], 2015 p. xv). Clothier et al. (2017) utilized human factors modelling to identify and analyze the many performance-influencing factors (PIFs) that are comprised within the human see and avoid (SAA) task. In addition, the researchers explored the specific task of visual detection, which is "a Level I Situational Awareness (SA) task" (Clothier et al., 2017, p. 2).

Airborne target detection, time spent during the SAA task, and the effectiveness of the visual detection task may be influenced by a multitude of PIFs as shown in Tables 7, 8, and 9. Clothier et al. (2017) utilized the Harris 5M model in their classification of identified PIFs, as it includes the identified elements of the human-machine interaction of the system and its environment. The classification of PIFs include the human, machine, mission, medium, and management (Clothier et al., 2017, p. 5). The human element includes the aircrew and their interaction during flight; the machine element includes the own aircraft and the identified target conflict aircraft; the medium element consists of the airspace environment; the management element includes applicable “policies, procedures, culture, and norms” (Clothier et al., 2017, p. 5).

Table 7

5M Model PIF for Visual Detectability of Target Aircraft

Classification	Performance Influencing Factors		
Human	Number of own aircraft aircrew		
Machine	Own aircraft attitude	Own aircraft velocity vector	Own aircraft cockpit visibility
	Own aircraft cockpit windshield	Target aircraft size	Target aircraft apparent size
	Target aircraft inherent contrast	Target aircraft patterns and markings	Target aircraft lights
	Target aircraft velocity vector	Target aircraft maneuvering	Line of sight range
Mission	Mission phase	Altitude	Time of operations
Medium	Terrain	Meteorological conditions	Sun position/glare
	Clutter	Glint	Turbulence

Note. PIF = performance influencing factors. Adapted from “Human See and Avoid Performance and Its Suitability as a Basis for Requirements for UAS Detect and Avoid Systems” by R. A. Clothier, B. P. Williams, K. Cox, and S. Hegarty-Cremer, 2017. *17th AIAA Aviation Technology, Integration, and Operations Conference*, p. 12. https://doi.org/10.2514/6.2017-4387

Table 8

5M Model PIF for Time Spent Performing SAA

Classification	Performance Influencing Factors		
Human	Pilot workload	Pilot experience	Pilot knowledge of airspace environment
	Pilot training	Pilot fatigue	Pilot stress
	Pilot psychological state	Overreliance on automation	Complacency
	Crew resource management		
Machine	Traffic alerting devices	Cockpit design	
Mission	Complexity	Phase of mission	Mission duration
Medium	Turbulence	Air Traffic Services	Known airspace users

Note. PIF = performance influencing factors; SAA = human see and avoid. Adapted from "Human See and Avoid Performance and Its Suitability as a Basis for Requirements for UAS Detect and Avoid Systems" by R. A. Clothier, B. P. Williams, K. Cox, and S. Hegarty-Cremer, 2017. *17th AIAA Aviation Technology, Integration, and Operations Conference*, p. 13. https://doi.org/10.2514/6.2017-4387

Table 9

5M Model PIF for Effectiveness of Visual Detection Task

Classification	Performance Influencing Factors		
Human	Pilot workload	Physiological performance of the eye	Permanent physiological conditions
	Temporary physiological conditions	Pilot experience in SAA	Pilot knowledge of airspace environment
	Pilot stress	Pilot training	Pilot fatigue
	Pilot psychological state	Pilot distraction	Location in visual field of regard
	Crew resource management		
Machine	Traffic alerting devices	Cockpit design	
Mission	Complexity	Phase of mission	Mission duration
Medium	Turbulence	Air Traffic Services	Temperature
	Airspace		

Note. PIF = performance influencing factors; SAA = human see and avoid. Adapted from "Human See and Avoid Performance and Its Suitability as a Basis for Requirements for UAS Detect and Avoid Systems" by R. A. Clothier, B. P. Williams, K. Cox, and S. Hegarty-Cremer, 2017. *17th AIAA Aviation Technology, Integration, and Operations Conference*, p. 14. https://doi.org/10.2514/6.2017-4387

Clothier et al. (2017) concluded an alternative means of determining the functional requirements of DAA systems would be to use the pilot's ability to see and avoid as a benchmark for design. Through their literature review, they discovered that while models exist that characterize the human pilot's ability to detect airborne targets, models that comprehensively take into consideration all the PIFs examined in their study are non-existent. Clothier et al. (2017) stated when designing DAA systems, the use of the human pilot's ability to see and avoid should be considered the "lower bound on the DAA sensor design space" (p. 11). Lastly, the authors concluded that manned aircraft unequipped with traffic alerting devices would not be able to visually detect a sUAS and possess sufficient time to execute the process of midair collision.

sUAS See-and-Avoid

Kephart and Braasch (2010) conducted a study to compare the abilities of a manned aircraft pilot to detect obstacles and airborne traffic to the abilities of a UAS operator. The researchers addressed the fact that most mid-air collisions occur with low-time pilots at the controls during daylight hours in VMC; therefore, they conducted a study to examine how low-time pilots' traffic detection ranges vary from that of UAS operators. They noted that although the FAA does not address the visual search area and target detection range, AC 25.773-1 provides detailed cockpit visibility guidelines. Specifically, "search area azimuth guidelines range from ± 60° up to ± 120°, and elevation guidelines range from no guidelines up to + 37° and – 25°" (Kephart & Braasch, 2010, p. 37).

Previous research reviewed by Kephart and Braasch (2010) as conducted by the Air Force Research labs calculated detection ranges between 1.7 and 2.3 mi (2.74 and 3.7 km) for pilots alerted to traffic by a traffic warning system. Additional research reviewed as conducted by the MIT Lincoln Laboratory identified the detection range for the un-alerted pilot to be 1.14 and 1.61 mi (1.84 and 1.87 km) for the alerted pilot in attempts to detect a Cessna 421 (Kephart & Braasch, 2010).

Kephart and Braasch (2010) utilized a Piper Saratoga as their test aircraft and a Piper Warrior III as the target aircraft. To simulate live video feed from a UAS, they mounted three cameras on the Piper Saratoga and recorded the flights used during the manned aircraft range detection phase of the study. The video feed recorded during the manned aircraft range detection phase was then replayed for the UAS operator test subject, notionally as live video feed from a UAS. Two aircraft conflict trajectories were presented to the manned and unmanned aircraft test subjects. The first aircraft conflict trajectory was at a 90° angle intersect to the heading of the test aircraft, and the second was on a head-on/oncoming trajectory.

Kephart and Braasch (2010) reported the manned aircraft mean detection range for the aircraft conflict trajectory of 90° was 1.511 mi (2.43 km) and the mean detection range for the head-on/oncoming aircraft conflict trajectory was 1.038 mi (1.67 km). The simulated UAS operator range detection distances were considerably less than those of the manned aircraft. The simulated UAS operator mean detection range for the aircraft conflict trajectory of 90° was 0.651 mi (1.05 km), while the mean detection range for the head-on/oncoming aircraft conflict trajectory was 0.417 mi (0.67 km). The manned aircraft succeeded in detecting airborne targets at further ranges than the simulated UAS operator.

See and avoid discipline requires vigilance on the part of all aircrew and sUAS pilots operating both manned and unmanned aircraft within the NAS. Title 14 C.F.R. §107.33 provides specific guidance on utilizing a visual observer during sUAS operation. However, the use of a visual observer during sUAS operations is not a requirement. Noting the lack of current research on the effectiveness of utilizing a visual observer to assist the sUAS operator in traffic detection and collision avoidance, Vance et al. (2017) conducted human factors research to examine the visual observer's ability to detect airborne collision hazards.

Ten participants acting as visual observers during sUAS operations were required to indicate when they immediately detected an aircraft collision hazard, and once it was visually acquired, they were to estimate the aircraft collision hazard's distance, altitude, and rate of closure to the sUAS (Vance et al., 2017). In addition, the visual observers were required to estimate the lateral distance between the sUAS and the aircraft collision hazard at the closest point of the two aircraft's flight paths. A DJI Matrice 100 (equipped with 50 mAh STROBON navigation strobe lights) was used during sUAS operations and a Cessna 172/S was used as the aircraft collision hazard.

Vance et al. (2017) used scripted aircraft collision hazard intercepts of the Cessna 172/S (see Table 10). The experiment consisted of 40 scheduled intercepts, of which, 39 datasets were usable for audio detection, and 38 datasets were usable for visual detection, respectively. Multiple global positioning system (GPS) data points were acquired from both the DJI Matrice and the Cessna for comparison of aircraft position and visual observer's estimations throughout the study. The percentage and number of participants per initial modality of detection are presented in Table 11.

Table 10

Scripted Intercepts of Aircraft Orientation

Intercept	Aircraft Orientation
Control	Cessna flew inbound to sUAS flight location, sUAS not airborne
1	sUAS oriented slightly left of Cessna course
2	sUAS oriented slightly right of Cessna course
3	sUAS conducted a repeating lateral maneuver directly in front of Cessna
4	sUAS flew a head-on convergence course with the Cessna

Note. Adapted from "Detecting and Assessing Collision Potential of Aircraft and Small Unmanned Aircraft Systems (sUAS) by Visual Observers" by S. M. Vance, R. J. Wallace, J. M. Loffi, J. D. Jacob, J. C. Dunlap, and T. A. Mitchell, 2017. *International Journal of Aviation, Aeronautics, and Aerospace, 4*(4), p. 7.

Table 11

Intercept Initial Detection Modality

Mode of Detection	%	*n*
Audible	30.5	18
Visual	27.1	16
Simultaneous Visual/Audible	32.0	19

Note. "Detecting and Assessing Collision Potential of Aircraft and Small Unmanned Aircraft Systems (sUAS) by Visual Observers" by S. M. Vance, R. J. Wallace, J. M. Loffi, J. D. Jacob, J. C. Dunlap, and T. A. Mitchell, 2017. *International Journal of Aviation, Aeronautics, and Aerospace, 4*(4), p.10.

Intercept initial detection by the participants sensory modality was quickly followed by the second modality (Vance et al., 2017). Data collected revealed that the participants detected the aircraft collision hazard audibly at a mean range of 8605.4 ft (2623 m) and visually at a mean range of 8,618.6 ft (2627 m) (Vance et al., 2017, p. 17), approximately 1.6 mi (1.39 km) for each modality. Other factors that may influence the observer's visual performance include "aircraft size or surface area, aspect angle, aircraft reflectivity, light level, relative sun position or glare, sky contrast, visual obstructions, and external aircraft lighting" (Vance et al., 2017, p. 17) in addition to the observer's physiological limitations. Likewise, the observer's audible sensory modality may be affected by factors such as "aircraft engine type, power setting, altitude, wind direction and speed, ambient noise" (Vance et al., 2017, p. 17), in addition to the observer's physiological limitations.

Vance et al. (2017) concluded that performance of the observers to accurately estimate the distance and altitude between the sUAS and the aircraft collision hazard was poor, with the observers overestimating distance by 2.5 times more than underestimating the distance between the aircraft. The purpose of the study was to determine if the information presented to the sUAS operator, including the margin of error in actual versus perceived closure rates, was sufficient for the operator to perform evasive to prevent the midair collision. The authors concluded that the visual observer's tendency to overestimate the closure rates during the intercepts would not provide the operator sufficient margin of error in terms of time to initiate a change in the sUAS profile to avoid the midair collision.

Research conducted by the FAA has determined that it takes a minimum of 6.1 s for a pilot to detect an aircraft collision hazard, understand how that hazard poses a risk to the pilot's own aircraft (FAA, 2016e; Vance et al., 2017). Additionally, the pilot's subsequent actions to include the determination of the appropriate own aircraft flight profile modifications to avoid a midair collision, pilot muscle reaction time, and aircraft maneuvering lag time will account for approximately 6.4 s (FAA, 2016e; Vance et al., 2017).

Vance et al. (2017) proposed that while the remote pilot aircraft identification and reaction time process would be similar as the same process for the manned aircraft, the introduction of a visual observer in the process may increase the total time for aircraft hazard collision avoidance. However, the authors concluded midair collision may be avoided provided the visual observer communicates clearly and in a timely manner the information concerning the potential hazard to flight (Vance et al., 2017). They also recommended further research on this topic.

Beyond-Line-of-Sight and Sense and Avoid Technologies

The ability to conduct sUAS BVLOS operations presents an incredible opportunity for remote pilots, while at the same time, creating what may appear to be a formidable challenge for the FAA (Ferguson, 2018a). BVLOS operations are conducted with the sUAS beyond the VLOS of the operator. They significantly increase the economic potential and ability to conduct a myriad of missions; including construction monitoring, inspecting powerline, assessing agricultural crops, and surveilling disaster areas, to name a few (Ferguson, 2018a).

There are multiple benefits to employing sUAS in BVLOS operations. Every sUAS flight requires some degree of transit time to the area of operation from the take-off and landing area that is unrecoverable data collection time (Ferguson, 2018a). Employing BVLOS operations cuts down on that lost time by minimizing the number of launch and recovery evolutions necessary for mission accomplishment. This efficiency is amplified using sUAS, which cost significantly less than the traditional use of manned fixed-wing and rotary aircraft.

BVLOS can provide higher quality results than traditional data collection methods. Traditional long-range data collection employed manned aircraft and orbital spacecraft, which are restricted to higher altitudes than the lower altitudes that can be flown by sUAS (Ferguson, 2018a). The lower altitudes available for sUAS BVLOS operations are optimum for high-resolution data collection. The BVLOS ability of this type of data collection provides enhanced utility when timing of the data collection is crucial (Ferguson, 2018a).

The decreased risk to the human element in aviation is also a benefit of BVLOS operations (Ferguson, 2018a), because removing the human from the cockpit or hazardous environment reduces the risk of bodily harm. In addition, BVLOS operations may allow the operator to observe an area considerably beyond convenient ground access which is outside the VLOS operational envelope (Ferguson, 2018a).

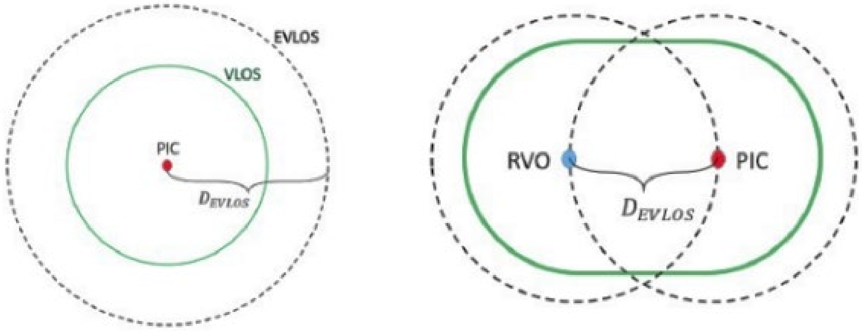
In 2015, the FAA began a collaborative research and development program titled Pathfinder Focus Area 2 (Ferguson, 2018b). The purpose of this program is to identify and define the requirements for sUAS operations within a subset of BVLOS operations, defined as localized BVLOS operations (Ferguson, 2018b).

sUAS operations conducted within a defined local area but outside the Part 107 regulations on VLOS are considered localized BVLOS operations (Ferguson, 2018b). Distance limits to define the term local vary by mission and will be determined by the mission's concept of operations. PrecisionHawk—a manufacture of sUAS hardware and software and provider of BVLOS business solutions—was the primary industry contractor conducting the research and development for the FAA's BVLOS protocols during the Pathfinder Focus Area 2 study and was the first recipient of the Part 107 waiver by the FAA to conduct BVLOS operations (Sondgeroth, 2018).

The FAA is currently accepting applications for Part 107 waivers for BVLOS operations and has received over 1,200 to date (Sondgeroth, 2018). However, PrecisionHawk reported that 99% of the applications have been rejected due to specific concept of operations failure to demonstrate “acceptable levels of safety” (Sondgeroth, 2018, p. 40). Figure 11 provides an illustration of the FAA’s approved concept of localized BVLOS visual surveillance (VS) operations.

Figure 11

FAA Concept of Localized BVLOS Visual Surveillance Operations



Note. BVLOS = beyond visual line-of-sight; D_{EVLOS} = detection line-of-site distance; EVLOS = extended visual line-of-sight; FAA = Federal Aviation Administration; PIC = pilot-in-command; RVO = remote visual observer; VLOS = visual line-of-sight. Left image: BVLOS-VS operations without remote visual observer. Right image: BVLOS-VS operations with optional RVO to expand operational area. Adapted from “Pathfinder Focus Area 2: Phase III Report” by A. Ferguson, 2018b, p. 5. Copyright 2018 by PrecisionHawk, Inc.

In Figure 11, the diagram on the left illustrates the BVLOS-VS model where the PIC is solely responsible for operating the sUAS while maintaining vigilance in SA to determine the entrance into the operating area by an intruder aircraft (Ferguson, 2018b). D_{EVLOS} area is the maximum distance at which the PIC can detect a manned intruder. The operating area will be less this distance by a reasonable buffer. The EVLOS area defines the effective visual line-of-sight distance in which the PIC may visually acquire an intruder aircraft entering the sUAS operating area. With this model, the PIC may operate the sUAS beyond the VLOS envelope but no further than the area in which the PIC can visually detect an intruder.

The diagram on the right of Figure 11 illustrates the BVLOS-VS model where the PIC is assisted in visual observation of the sUAS operating area with the assistance of a remote visual observer (Ferguson, 2018b). In this model, sUAS operations may be conducted without either the PIC or the RVO maintaining VLOS contact with the sUAS. The sUAS operating area for this model encompasses the entire area in which the PIC and the RVO can visually detect an intruder. This concept is called “observer-augmented BVLOS-VS” (Ferguson, 2018b, p. 6).

The necessary components required for FAA approval of BVLOS operations include three major components (Ferguson, 2018a). First, the sUAS must contain the necessary hardware and software to detect and identify cooperative and non-cooperative intruder aircraft entering the sUAS area of operations (Ferguson, 2018a). It is also important that this component of the system provide the operator sufficient indication of system malfunction or degraded functionality. Second, the sUAS operator must be fully aware of the airspace environment for the sUAS operations to include airspace boundaries, limitations, and possible temporary flight restrictions. In addition, the sUAS operator must conduct a thorough preflight of the sUAS hardware and software components. Lastly, the sUAS PIC must possess a sufficient level of experience operating sUAS by type, rotary wing or fixed wing sUAS, and complete specific BVLOS training, including a practical check flight evaluation to ensure operator competency.

The Pathfinder initiative has established a framework and process in which sUAS operators may petition and attain a waiver for BVLOS operations from the FAA (Ferguson, 2018a, 2018b; Sondgeroth, 2018). Now that the framework is in place, the sUAS industry appears more willing to make the appropriate investments in research and development to improve existing hardware and software components required for sUAS BVLOS operations, unlocking the full potential of sUAS operations (Ferguson, 2018a; Sondgeroth, 2018).

Current See and Avoid Versus Sense and Avoid

The Federal Aviation Regulation (FAR) Part 91 General Operating Rules requirement for all aircraft to see-and-avoid traffic as a means of collision avoidance fosters one of the key challenges to BVLOS operations for sUAS within the NAS (Argrow & Frew, 2017; Dolph et al., 2017). While sUAS aircraft collision avoidance systems exist, standard procedures and protocol development by industry and the FAA are still ongoing (Mcfadyen & Mejias, 2016; Woo, 2017). While sUAS applications are many, Glaab et al. (2018) claims a substantial increase in applications will occur as sense and avoid technology comes online.

The see-and-avoid process may be subdivided into specific functions: detect, decide, act; or observe, orient, decide, and act (Hutchings et al., 2007; Mcfadyen & Mejias, 2016). The sUAS sense-and-avoid systems must be able to replicate the human see-and-avoid process and autonomously detect aircraft collision hazards, determine alternate course of actions to prevent midair collision with the detected hazard, and execute the changes determined to the existing flight profile, and then return to the previous flight profile prior to the aircraft collision hazard detection (Dolph et al., 2017; Mcfadyen & Mejias, 2016).

Technological solutions for manned and sUAS collision avoidance are divided into two types of systems: cooperative and uncooperative (Glaab et al., 2018; Woo, 2017; Yu & Zhang, 2015). A list of cooperative and uncooperative systems is depicted in Table 12 (Woo, 2017, p. 22). Cooperative systems transmit and receive information between the airborne aircraft providing aircraft position in time and space and can calculate collision hazard probabilities based on aircraft velocities and trajectories (Glaab et al., 2018; Williamson & Spencer, 1989; Yu & Zhang, 2015). Traffic collision avoidance system (TCAS) and automatic dependent surveillance-broadcast (ADS-B) are examples of cooperative systems (Glaab et al., 2018; Woo, 2017; Yu & Zhang, 2015). Currently TCAS size and weight precludes its use within the sUAS airframe (Glaab et al., 2018). Current ADS-B systems have been designed for the sUAS and are available commercially. However, the ADS-B system was designed to meet the aircraft separation requirements of commercial and general aviation aircraft (Glaab et al., 2018) and ADS-B bandwidth is limited (Glaab et al., 2018; Schnell et al., 2014). The influx of high numbers of sUAS within the NAS is forecasted to overload the ADS-B bandwidth, which renders the use of ADS-B as an unviable solution (Glaab et al., 2018).

Table 12

Aircraft Collision Avoidance Systems

Technology	Type	Function
TCAS	cooperative	detection/alert
ADS-B	cooperative	detection/alert
Network meshing	cooperative	communication bandwidth management
LIDAR	non-cooperative	sense-and-avoid
SAR	non-cooperative	sense-and-avoid
EO systems	non-cooperative	sense-and-avoid
Acoustic sensing systems	non-cooperative	sense-and-avoid
GBSAA	non-cooperative	sense-and-avoid
Geo-fencing	non-cooperative	airspace restriction

Note. ADS-B = automatic dependent surveillance–broadcast; EO = electro-optical; GBSAA = ground-based sense-and-avoid; LIDAR = laser detection and ranging; SAR = synthetic aperture radar; TCAS = traffic collision avoidance system. Adapted from "Visual Detection of Small Unmanned Aircraft: Modeling the Limits of Human Pilots" by G. S. Woo, 2017. [Doctoral dissertation, Embry-Riddle Aeronautical University]. Scholarly Commons, p. 22. https://commons.erau.edu/edt/350

Frew and Brown (2008) explored the utility of using meshed communications networks to facilitate the quick and reliable exchange of sUAS data for aircraft collision avoidance within the NAS. By using a series of networking nodes, sUAS may be operated beyond its traditional single command and control node (Frew & Brown, 2008; Shirani et al., 2012). Like the concept of ADS-B ground-based nodes, flight profile data from the sUAS is transmitted to the node and is then transferred to another node within the meshed communications network. This information is then transmitted to other sUAS within the network and processed onboard other sUAS within the network's airspace for aircraft collision avoidance. A unique feature of this network is that the node may be ground-based or use another UAS as the node platform (Frew & Brown, 2008; Shirani et al., 2012). This provides mobility and flexibility for the communications network (Frew & Brown, 2008).

Meshed network sensing systems would require an infrastructure very much like the one for the cellular telephone network (Frew & Brown, 2008). However, the current cellular network is not designed for communicating with sUAS within the NAS (Argrow & Frew, 2017). Therefore, a specific sUAS cellular architecture would be required (Frew & Brown, 2008). There are several advantages to the use of a cellular network dedicated for sUAS. First, multiple ground-based cellular nodes would provide extended area coverage (Frew & Brown, 2008). sUAS could transit from station to station during operations. Second, redundancy in the network provides for one station that may be providing poor coverage to be picked up by another. Thirdly, overextending bandwidth is not of concern since bandwidth may be reused as sUAS operators go off-line after completing a mission. Lastly, this type of ground-based cellular network may be shared by many different UAS types to differ the cost of the infrastructure (Frew & Brown, 2008).

Unlike the cooperative systems such as TCAS, ADS-B, and meshed communications networks, the non-cooperative systems listed in Table 12 do not transfer collision avoidance data between the aircraft (Woo, 2017). LIDAR is one of the most common components of sUAS for mapping and navigation (Scott & Jerath, 2018). LIDAR operates by emitting laser light from the laser scanner and then measures the time for the reflected energy of that light to return to its source (Behroozpour et al., 2017). Information scanned by the sUAS onboard LIDAR creates an “occupancy grid” (Scott &

Jerath, 2018, p. 6) that is used by the sUAS navigation system to navigate from point to point, avoiding obstacles to flight on the grid.

Like LIDAR, the EO system utilizes a laser to determine the range to an obstacle detected in flight (Kim et al., 2010). However, the obstacle is first identified by the EO camera sensor as an anomaly within the field of view of the sensor, then the distance to the sensor is determined by the range finding feature of the laser (Kim et al., 2010). Identified target signatures are defined by azimuth and elevation angles (Jamoom et al., 2016). Algorithms within the sUAS software determine if the identified targets present a potential midair collision hazard and adjusts the flight profile as necessary. It should be noted that LIDAR is superior to EO systems in detection and avoidance of long-range obstacles (Jamoom et al., 2016; Scott & Jerath, 2018).

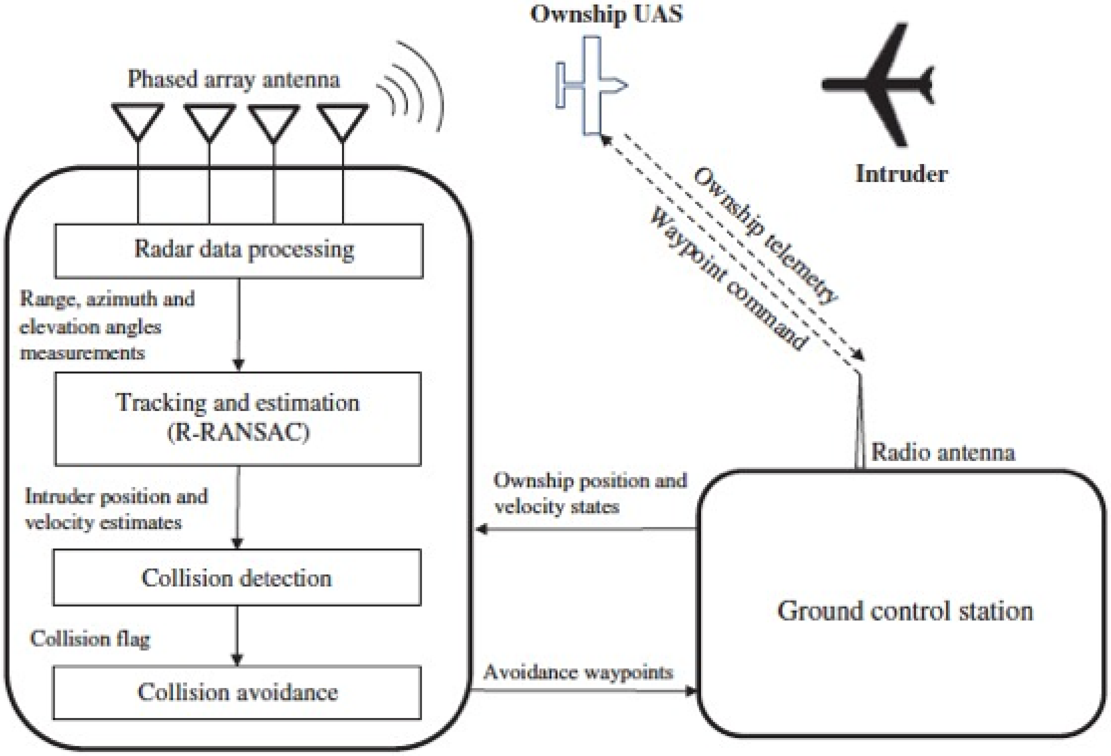
Synthetic aperture radar (SAR) uses a series of multiple radar pulses to create an image from the return of the reflected energy from the transmitted pulses as they reflect off the surface of the target (Yu & Zhang, 2015). The fidelity of SAR allows it to determine airborne target location, velocity, azimuth, and elevation. One of the key characteristics of SAR is its ability to penetrate clouds and storms. In addition to its use as an aircraft collision hazard detection device, SAR is employed on sUAS for terrain mapping, surveillance, border patrol, agricultural surveys, and many others (Majewski et al., 2018). It should be noted that EO systems create a rendition of the targeted area of a higher fidelity than that created by SAR (Yu & Zhang, 2015).

Acoustic sensing systems utilize the specific narrowband tone from the sound of other aircraft for identification within the sUAS operating area (Siewert et al., 2018; Yu & Zhang, 2015). Acoustic sensing systems can be installed directly on the sUAS for target detection, or the acoustic sensing systems may be installed as a series of ground-based nodes to create a detection array (Siewert et al., 2018). Acoustic sensing systems are cost effective detection and very capable of locating and tracking airborne traffic. However, SAR and EO systems are superior in long range capability (Yu & Zhang, 2015).

Ground-based sense-and-avoid systems utilize ground-based radar to identify and track airborne targets (Sahawneh et al., 2018). Estimation, collision-detection, and collision-avoidance algorithms are used by this system to produce aircraft traffic deconfliction solutions. The ground-based sense-and-avoid system structure is depicted in Figure 12. A phased-array radar antenna is used to acquire aircraft within the area of interest and once targets are acquired, the algorithms evaluate position and velocity metrics to derive deconfliction solutions (Sahawneh et al., 2018). These systems can ensure airborne traffic maintain sufficient separation for safety.

Figure 12

Ground-Based Sense and Avoid System



Note. From "Ground-Based Sense-and-Avoid System for Small Unmanned Aircraft" by L. R. Sahawneh, J. K. Wikle, A. Kaleo Roberts, J. C. Spencer, T. W. McLain, K. F. Warnick, and R. W. Beard, 2018. *Journal of Aerospace Information Systems*, 1–17, p. 3. In the public domain.

Geofencing is an alternative to sense-and-avoid aircraft collision avoidance systems. Much like a normal fence observed on the ground, the geofence contains the sUAS within the confines of a georeferenced area (Stevens et al., 2015). The GPS equipped navigation system of the sUAS ensures that the aircraft does not breach the boundary of the geofenced area. The georeferenced area may define a geofence for horizontal and lateral limits of operation of the sUAS. The sUAS guidance system anticipates encroachment upon the boundaries of the geofence and adjusts the flight profile of the sUAS to remain within the confines of the georeferenced area (Stevens et al., 2015).

Summary

Human factors associated with aircraft operator visual perception and acuity have been considered while formulating regulations and policies to govern the integration of UAS into the NAS (Dalamagkidis et al., 2011). This would require consideration of the same human factors during the design of individual unmanned aircraft control systems (Carrigan et al., 2008; Terwilliger, 2012). Previous research examined operator performance during teleoperations of unmanned vehicles with various visual display control interfaces (Boonsuk et al., 2012; Burg, 1966; Jun, 2011). As UAS operations is expected to continue rapidly expanding, outpacing manned aircraft operations, technologies must be developed to provide UAS the equivalent level of safety as that of manned operations (Bedford, 2014; Clothier et al., 2007; Dalamagkidis et al., 2008).

Human-machine interface predictive models have furthered the understanding of teleoperated unmanned vehicle operator performance (Accot & Zhai, 1997; Fitts, 1954; MacKenzie, 1992). The Fitts law, steering law, and cornering law have established a baseline for determining operator speed and accuracy during remote vehicle navigation and target acquisition (Accot & Zhai, 1997; Fitts, 1954; MacKenzie, 1992). Research has shown that increasing operator DVA increases speed and accuracy experimental settings (Burg, 1966; Jun, 2011). In addition, research has shown that optimal scanning patterns have produced significant increases in reaction time performance in virtual reality environments (Shapiro & Raymond, 1989). It may be found that operator DVA may also be affected by the specific type of visual scanning technique utilized.

The review of the literature covered the current states of target detection, see-and-avoid versus sense-and-avoid techniques, BVLOS operations, and aircraft collision hazard avoidance. Future developments in sense-and-avoid technologies are forecast to be adopted and become commonplace within the NAS. While some sense-and-avoid technologies have been approved for BVLOS operations within the NAS, they are few in numbers and most are only approved to conduct research and development on those systems. Therefore, the onus remains on the sUAS operator to detect and maintain aircraft collision hazard avoidance. This present research augments the research conducted in previous studies on manned and unmanned aircraft collision hazard detection ranges and fills the gap in the existing literature on sUAS operator workload during visual line-of-sight operations and during operations utilizing FPV visual acuity techniques. In addition, this research fills a gap in existing literature by investigating the effects of FPV usage on sUAS remote pilot Level 1 SA during operations.

Chapter III: Methodology

This research aims to gain a deeper understanding of small UAS operator workload and level 1 SA while utilizing FPV visual acuity techniques. A experiment was conducted utilizing three visual display interfaces in addition to analysis of event reports as contained within the ASRS database where the primary aircraft was listed as a UAS. This chapter describes the research method selection, the population and sample, data collection process, and the analysis of the ASRS database.

Research Method Selection

Quantitative data for analysis was collected during a experiment. No empirical data exists regarding UAS pilot workload and Level 1 SA while utilizing FPV techniques, thus posing the need for data collection through this experiment. A experiment differs from a true field experiment in that it replicates “to some degree” (Vogt et al., 2012, p. 348) the conditions that exist in an experiment conducted in a real-world setting. The experiment design employed in this study provided the opportunity to conduct the experiment in a controlled environment that was not hindered by the impracticalities and logistical burden of conducting the experiment in a natural setting (Jaikumar, n.d.). While the experimental design may not replicate the realness of the natural environment, strict control of the variables under observation increases the internal validity of the research (Jaikumar, n.d.). In addition, the experiment lacks the “random assignment of participants to an experimental and control group” (Babbie, 2015, p. 367). This method of research was selected over alternative methods based on the impracticality of conducting this research within the NAS in observation of real time sUAS operations. Therefore, an artificial flight environment was used for this experiment. The artificial flight environment for the experiment was constructed within the confines of the fenced-in outdoor tennis courts and unimproved (undeveloped) area adjacent to the tennis courts located at Jacksonville University, Florida.

Population/Sample

Population and Sampling Frame

The target population for this research included all personnel eligible to apply for a Part 107 remote pilot certificate within the state of Florida. The state of Florida has the third largest number of FAA-issued remote pilot certificates in the U.S., with California and Texas having the first and second largest number of remote pilot certificates issued, respectively (FAA, 2021b). According to the FAA's U.S. Civil Airmen Statistics for January 2022, there are 25,942 remote pilot certificates issued within California, 23,414 issued within Texas, and 21,258 issued within Florida (FAA, 2021b). The FAA collects minimal identifiable demographic data on remote pilot certificate applicants, limiting the data to gender, age, and county and state of applicant. No other information is collected such as previous FAA airman certificates issued, education level, prior UAS flight experience, or training. Due to the lack of identifiable demographic data beyond gender and age on individuals issued remote pilot certificates, this present research was limited to these two demographic characteristics to identify the representativeness of the sample to the population.

Random selection of participants from the population for this research was not practical. Participants for this present research were solicited from the sampling frame which included the student, faculty, and staff population at Jacksonville University, members of the Jacksonville Autonomous Unmanned Vehicle Systems International chapter, members of a local Navy helicopter squadron, and members of the city of Jacksonville's Fire and Rescue Department. Pre-experiment screening questionnaires were utilized to identify potential participants for this research and to collect demographic data. Participants were older than 18 years of age, possessed no obvious physical or mental characteristic that would restrict the operation of the DJI Inspire 1 sUAS while utilizing the FPV goggles, and met the physical qualifications as defined in 14 C.F.R. §107.17 (see the Small UAS Background section in Chapter I).

Sample Size

A priori power analysis was conducted in the *G*Power* software to determine requisite sample size. Conducting a power analysis on the one-way analysis of variance (ANOVA) with one independent variable at three levels, a power of 0.8, an alpha level of .05, and a medium effect size ($f^2 = .4$), required a sample size of 66 (Cohen, 1988; Faul et al., 2007).

Sampling Strategy

The sampling strategy selected participants from the sampling frame. Recruitment of participants included the Jacksonville University Institutional Review Board (IRB) approved email notification. The recruitment email provided a brief description of the research, minimum requirements for eligibility, associated risks to participation, expected total time of participation, and compensation. Participants were recruited from undergraduate and graduate students, staff, and faculty members from Jacksonville University, the Jacksonville Fire and Rescue Department, the Jacksonville chapter of the Association of Uncrewed Vehicle Systems International, and a local U.S. Navy helicopter squadron. The prescreening and scheduling of all participants was conducted via face-to-face communication solely with this researcher to ensure each participant met the minimum requirements for eligibility. Personally sensitive participant information was maintained through a password protected account on Jacksonville University's server.

Data Collection Process

Design and Procedures

Participants were required to fly a sUAS in a controlled outdoor environment within the confines of a specific flight course (see Appendix C). The atmospheric conditions were equivalent during the experiment for all participants; temperature 80-85 degrees Fahrenheit, winds S-SW 3-5 knots, with solar luminance unobstructed by clouds. The mission flight task objective was to complete the experiment course of flight expeditiously and in a manner to safely navigate the course. Upon arrival, the participants were briefed on the details of the experiment and their participation. The participants were then given time to read and complete the informed consent form and then complete a pre-test demographic survey (see Appendix B1). The pre-test demographic survey facilitated identification of potential outliers, non-qualified participants, and potential bias existing among participants. Controls for these potential threats to internal validity are presented in the Potential Threats to Internal Validity section in this chapter. After completing the pre-test demographic survey, applicants that were not disqualified at this point were administered the Ishihara color vision test to verify no color blindness. The color vision test may be found in Appendix F. Color vision is a requirement as it was assessed during the post-test Level 1 SA assessment questionnaire (see Appendix B2). Those that passed the color vision assessment were qualified to participate in the study. Each individual participant was provided familiarization training on sUAS operation in a practice area adjacent to the experiment test area. Then they were escorted from the sUAS practice area to the experiment test area, where they received further instructions and completed their experiment flight. Upon completing their flight, the participants completed a Level 1 SA assessment questionnaire, followed by the NASA TLX questionnaire (see Appendix B3). The timeline for the experiment is presented in Table 13.

Table 13

Approximate Experiment Timeline

Activity	Time (min)
Informed Consent Form	5
Demographic Questionnaire	5
Color Vision Test	5
Initial sUAS Familiarization Training	15
Experimental Testing	10
Level 1 SA Assessment Questionnaire	5
NASA TLX Questionnaire	5
Total Time	50–60

Note. Additional 10 minutes within total time added for participant transit to and from experiment activity locations.

sUAS Familiarization Training. All participants were given the same initial sUAS familiarization training to establish minimum piloting abilities. It was conducted in a practice area adjacent to the Jacksonville University tennis court area. Given the proximity of the practice area to the flight course on the tennis courts, a heavy-duty solid green windscreen material was installed to prevent participants from prematurely viewing the flight course environment. Premature viewing of the flight course environment by participants could create bias in the Level 1 SA assessment questionnaire results. The operational test plan was submitted and approved by the Embry-Riddle Aeronautical University Safety Review Board (see Appendix D for the approval letter).

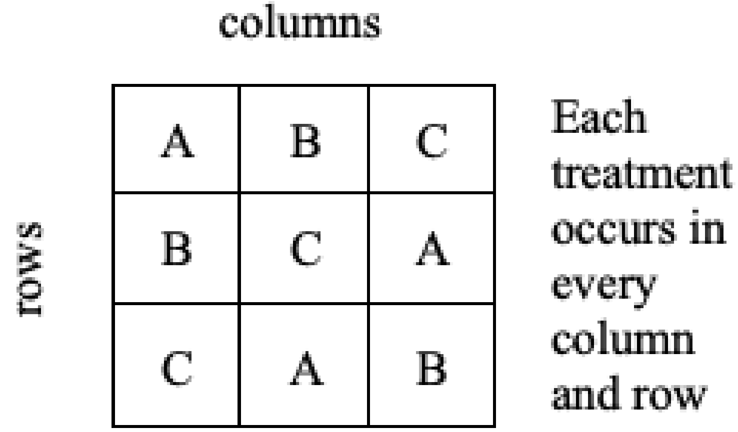
The participants were instructed to gather at a canopy tent within the practice area adjacent to the university tennis courts on the day of their scheduled drone flight for familiarization training. All participants were given a familiarization brief on operating the sUAS that included basic quad-copter aerodynamics, detailed instructions on how to control the sUAS with the remote controller, safety procedures, and details on their practice flight. Upon completion of the familiarization brief, each participant received hands-on instruction flying the sUAS within the practice area. The participants were instructed to fly the sUAS on a flight path that was delineated by orange traffic cones within the practice area. The traffic cones were arranged to define a corridor of 100 ft (30 m) long and 4 ft (1.2 m) in width, with a 90º right turn at the end of the 100 ft (30 m) corridor, continuing with a corridor of 50 ft (15 m) in length and 4 ft (1.2 m) in width.

The participants were instructed to fly the sUAS within the corridor of traffic cones to the end of the 100 ft (30 m) stretch, execute a 90º right turn, then continue to the end of the 50 ft (15 m) stretch of corridor. Upon reaching the end of that corridor, the participants were instructed to execute a 180º turn and fly the sUAS within that corridor and return to the starting point. The participants were instructed to fly the sUAS between 4 and 7 ft (1.2 and 2.13 m) above the ground during the practice flight. Participants were not provided the opportunity to conduct a practice flight on the flight course.

Assignment to the Three Treatment Groups. The Latin squares technique was used for the assignment of participants to the three treatment groups. Use of the Latin square technique minimizes the impact of the extraneous factors that may have a confounding effect on the treatment results associated with treatment group composition (Perret et al., 2011; Ryan & Morgan, 2007). The Latin square is table that is composed of the treatments utilized within the experimental design (Gao, 2005). The treatments will occur only once in each line of the table and only once in each column (Gao, 2005). Therefore, the Latin square as depicted in Figure 17 was used for this experiment to assign the participants to the three treatment groups, which consisted of: (a) visual line-of-sight pilot operation; VLOS group, (b) electronic aided piloting with FPV techniques utilizing a 21-in. LCD screen; LCD group, and (c) electronic aided piloting with FPV techniques utilizing full visual immersion goggles; GOGS group. The participants were assigned to their respective treatment group as the treatment occurs within the table sequentially, row by row (Gao, 2005).

Figure 17

Latin Square Participant Assignment



A	B	C
B	C	A
C	A	B

Note. A=VLOS group. B=LCD group. C=GOGS group.

Experiment sUAS Flights. Upon completion of the familiarization training, the participants were escorted one at a time onto the tennis court from the practice area and were directed to the operating position designated by this researcher. This operating position remained the same for all participants operating the sUAS by visual line-of-sight and the participants utilizing the FPV goggles. The operating position was approximately

6 ft (1.83 m) behind the beginning of the flight course. Participants operating the drone by visual line-of-sight were instructed to stand while conducting their flight from the operating position. Participants operating the drone utilizing the FPV goggles were required to sit in a chair at the operating position. Participants operating the sUAS with the FPV technique utilizing the 21-in. LCD screen were escorted to a 6 ft (1.3 m) tall dome tent adjacent to the operating position. The 21-in. LCD screen was on a table inside the dome tent. Participants were required to sit in a chair at the table inside of the tent while operating the sUAS on the flight course. The 21-in. LCD displayed high-definition live video feed from the sUAS's onboard FPV camera during the participant's operation of the sUAS. The dome tent shielded the participant's view of the flight course during the participant's operation of the sUAS.

A diagram of the flight course is provided in Appendix C, but it is not to scale. The course center flight path was constructed of two segments:

Segment 1: consists of a 100 ft (30 m) flight segment

Segment 2 consists of a 50 ft (15 m) flight segment

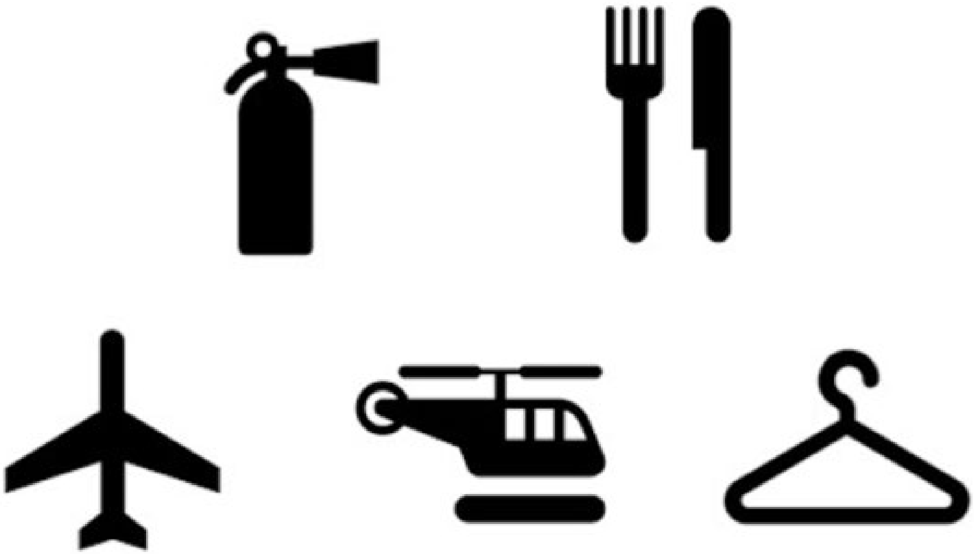
The 100 ft flight segment contained a white centerline flight path bounded on each side by a checkered hazard area. The 100 ft (30 m) flight segment was constructed of a 40 in. (102 cm) wide white vinyl sheet, bounded by a 40 in. (102 cm) wide white and black checkered vinyl sheet on each side. The 50 ft (15 m) flight segment was attached to the end of the 100 ft (30 m) flight segment to introduce a required 90º right turn on the flight course. The 50 ft (15 m) flight segment was constructed in the same manner as the 100 ft (30 m) flight segment. The participants were instructed to fly on the centerline of the white flight path at an altitude between 4 and 7 ft (1.2 and 2.13 m) above the ground. The checkered areas provided the participants visual guidance markers for the boundary of the primary intended flight path.

The participants were informed that an obstacle to flight would be introduced to the flight path from any of the white boxes positioned on the flight course centerline. Additionally, the participants were informed that each box contained a helium filled balloon that may be released in the flight path of the sUAS at any time. The vantage point of the participant's operating position for the visual line-of-sight participants provided viewing of the tops of the balloons inside the white boxes. In addition, the participants that utilized FPV techniques could also view the tops of the balloons inside the white boxes as the vantage point of the sUAS FPV camera progressed from the beginning to the end of the flight course. However, none of the balloons were ever released into the flight path of the sUAS for any participant. The intent of the possible release of a balloon obstacle was to direct the participants' attention towards obstacle avoidance during flight. The cardboard boxes were white in color and measured 14 x 14 x 14 in. (35.6 x 35.6 x 35.6 cm), matching the surface color of the flight course to not distract participants during flight. The cardboard boxes were positioned on the flight course centerline at an interval of every 15 ft (4.57 m) as depicted on the flight course diagram in Appendix C. Participants were instructed to deviate left or right of course immediately upon detecting a balloon to avoid the obstacle.

Additional obstacles were placed within the flight course. These flight course obstacles were constructed from cardboard boxes measuring approximately 2 x 2 x 4 ft (0.61 x 0.61 x 1.22 m) and were placed to the left and right of the planned flight course tangent to the boxes containing balloons on the flight course centerline as depicted in the flight course diagram in Appendix C. The flight course obstacles were painted in fluorescent colors; green, orange, yellow, blue, and pink. Each flight course obstacle displayed a large pictogram on each side of the obstacle that could be viewed by the participant from their operating position on the experimental flight course, as displayed in Figure 18. The participants were instructed not to deviate from the planned flight track on the side of the obstacle in the event a tethered balloon was released in the path of the sUAS. In this case, the sUAS would deviate to the side of the planned flight course opposite the additional obstacle.

Figure 18

Flight Course Obstacle Pictograms



Note. Pictogram height and width: fire extinguisher 20 x 10 in.; fork and knife 20 x 10 in.; airplane 14 x 19 in.; helicopter 14 x 16 in.; and coat hanger 15 x 16 in.

Participants were escorted back to the tent canopy in the practice area after completing their flight on the flight course and instructed not to discuss details of their participation until the conclusion of the experiment. At the tent, participants were seated at a table and were required to complete a Level 1 SA post-test questionnaire, assessing their recollection of the flight course environment. Participants were asked to identify the number of additional obstacles they recall observing during their flight, the position and color of the additional obstacles, and to identify the pictograms located on the obstacles and their sequential order of appearance.

Upon completing the Level 1 SA assessment questionnaire, the NASA TLX assessment questionnaire (Hart, 2006; Hart & Staveland, 1988) was administered to the participants to gauge their perceived workload. Unlike the SAGAT assessment questionnaire, the NASA TLX assessment questionnaire does not require the task or simulation to be suspended to provide the test subject an opportunity to be queried. Therefore, the NASA TLX was chosen in lieu of the SAGAT. The NASA TLX assessed subjective workload ratings for perceived mental, physical, and temporal demand, performance, effort, and frustrations levels during each of the FPV techniques utilized during this research. Analysis of these factors was used to identify if an asymmetric transfer between the FPV conditions occurred and if overall performance was affected by the associated workload perceptions (Hancock, 1989). After completing each flight, the NASA TLX assessment questionnaire was administered to each participant via the iPad NASA-TLX application.

Apparatus and Materials

The sUAS used in this research was a component of systems that included the vehicle, an RC with remote joysticks, an Apple® iPad Air2 display attached to the RC platform, and the iOS DJI GO application installed on the iPad that provided the interoperability between the sUAS and the RC. The DJI Inspire 1 was chosen for this research due to the sUAS's ease of use, GPS stabilization, and the ability to use two remote controllers. Utilizing two remote controllers provided the opportunity for the participant to pilot the sUAS during the experiment, while enabling the primary investigator acting as the observer the ability to override the participants' inputs and take control of the sUAS at any time. The DJI Inspire 1 incorporated two optical sensors and one sound navigation and ranging (SONAR) sensor to maintain stability indoors where GPS reception is not accessible. The DJI Inspire 1 incorporates a 3-axis brushless gimbal that maintains the FPV camera orientation with respect to the surface of the testing environment despite the sUAS's forward and lateral pitch during flight. The camera attached to the 3-axis gimbal provided the live video feed to the FPV display utilized by the participants and is referred to as the FPV camera for this research.

The FPV techniques utilized a Dell 21-in. LCD monitor and the DJI Goggles FPV headset. Real time streaming high-definition video was provided to the Dell LCD monitor and to the FPV headset from the quadcopter RC via a mini high-definition multimedia interface (HDMI) cable from the HDMI output on the RC to each FPV display during the respective treatment condition. The HDMI output of the RC was 720 pixels at 60 frames per second. The Dell LCD monitor resolution was 1920 x 1080 pixels and the FPV headset was 1920 x 1080 pixels, with each display type having a refresh rate of 60 Hz.

Materials necessary to conduct this experiment included:

- DJI Inspire 1 quadcopter (sUAS),
- DJI Goggles FPV headset,
- Dell 21 in. LCD monitor,
- 4 x 150 ft (1.23 x 45.72 m) white vinyl tablecloth,
- 4 x 150 ft (1.23 x 45.72 m) black/white checkered tablecloth,

- (5) 2 x 2 x 4 ft (0.61 x 0.61 x 1.23 m) colored boxes for obstacles,
- (9) 14 in. (35.56 cm) square white cardboard boxes,
- Apple® iPads for administration of the NASA-TLX questionnaires,
- Computer with IBM® SPSS® Version 27 software, and
- Stopwatch.

Sources of the Data

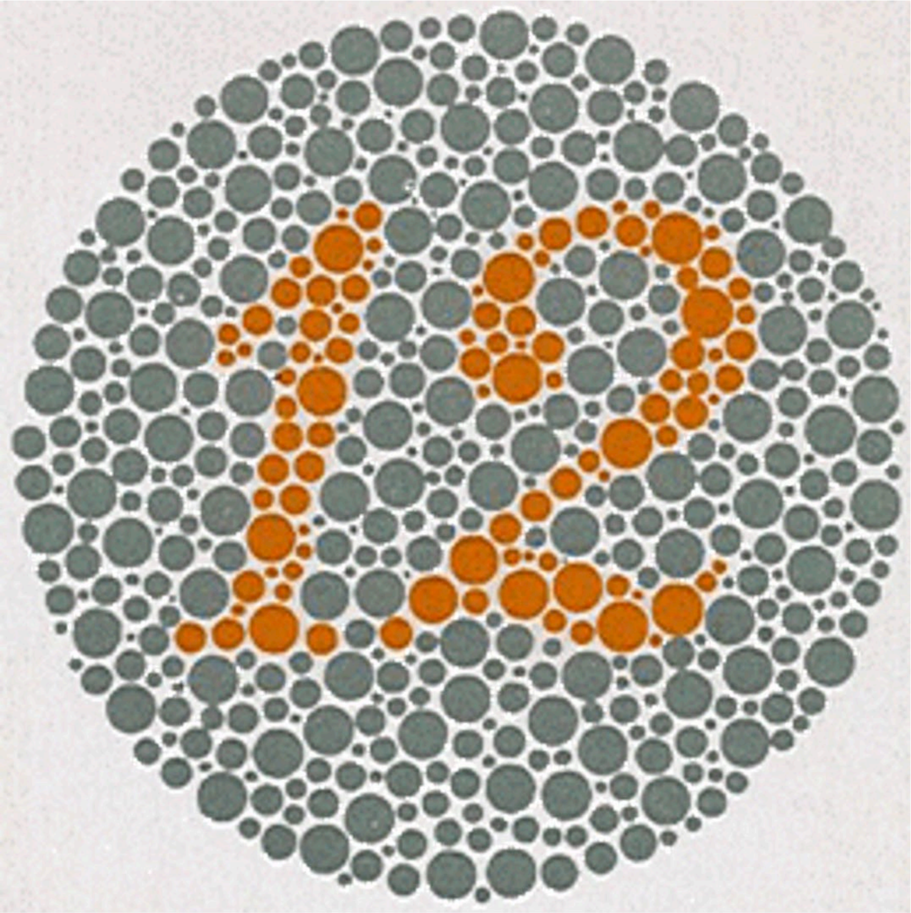
All data examined were generated from the experiment and were collected using the following data collection instruments:

1. Color blindness test
2. Demographic questionnaire
3. NASA-TLX questionnaire
4. Level 1 SA assessment questionnaire

Color Blindness Test. The Ishihara color blindness test was administered prior to the administration of the demographic survey to verify the prospective participants met the requirements for the study. The Ishihara test is the commonly used test of color sensitivity within the aviation industry and is frequently used in other occupational specialties (Rodriguez-Carmona et al., 2012). The Ishihara test utilizes pseudoisochromatic plates under static luminance conditions to measure the test subject's ability to isolate chromatic contrasts. The test reveals the loss of red-green chromatic sensitivity in the test subject. A sample of an Ishihara test pseudoisochromatic plate is presented in Figure 19.

Figure 19

Sample Ishihara Test Pseudoisochromatic Plate



Note. The image depicts the number "12" in various size orange dots surrounded by various size gray dots.

Demographic Questionnaire. Upon verification that the participants possessed no color vision impairment as assessed by Ishihara Test, the participants completed a demographic questionnaire (see Appendix B1). The pre-test demographic survey provided the researcher a systematic process of collecting information from the experiment participants to quantitively compare the descriptive characteristics of the sample with that of the population from which they were drawn (Wolf et al., 2016). The pre-test demographic survey included queries regarding age, gender, visual acuity, sUAS flight experience, RC aircraft flying experience, computer gaming experience, and FAA certificate possession. Additionally, the pre-test demographic survey facilitated identification of potential outliers, non-qualified participants, and potential bias existing among participants.

NASA-TLX Questionnaire. The participants completed the NASA-TLX questionnaire after completion of their sUAS flight on the flight course (see Appendix B3). The NASA-TLX workload assessment questionnaire provided a subjective assessment by the participants on their perceived workload during a prescribed task (Grier, 2015). The participants were required to rate six subscales from 0 to 100 on mental demand, physical demand, temporal demand, frustration, effort, and performance. A global workload score was calculated using the weighted mean of the six subscales after the participants made a series of paired comparisons of all the combinations of the six subscales (Grier, 2015).

Level 1 SA Assessment Questionnaire. The Level 1 SA assessment post-test questionnaire was used to assess the participants' recall of the elements present within the testing environment after the completion of their flight. Immediately following the flight course, the participants were escorted to a post-test survey area where they were asked to complete the Level 1 SA assessment questionnaire. The questionnaire presented the test participant with a graphical depiction of the experimental flight course on which they were required to indicate their recollection of the location of the five colored flight course obstacles (see Appendix B2). The participants were required to draw a box on the questionnaire diagram indicating the location of the obstacle. In addition to identifying the location of the obstacles on the experimental flight course, the participants were also required to record the color of the obstacle and include the pictogram on the box (see

Figure 17). Scores were calculated for each participant based on their accurate recollection of (a) the number of obstacles identified, (b) the color of the obstacles, (c) the pictograms on the obstacles, (d) the order of the pictograms, (e) the order of the obstacle colors as encountered on the flight course, and (f) the correct association of the pictogram with its respective colored obstacle. Scores were calculated as follows: correct number of boxes = 5 points, correct colors of boxes = 5 points, correct pictograms on the boxes = 5 points, correct location of the boxes = 5 points, correct order of the symbols = 5 points, correct order of the colored boxes = 5 points, correct pictogram on color of box = 5 points. For instance, if the participant correctly recalled 4 of the 5 pictograms on the obstacles, they would receive 4 out of 5 points. The total possible score for the SA test was 35 points.

Ethical Consideration

This dissertation research consisted of an experimental design requiring human participants and therefore abided by ethical duties regarding voluntary participant consent, doing no harm, and maintaining data privacy and confidentiality. An application to conduct research with human subjects was submitted to and approved by the Jacksonville University IRB under a memorandum of understanding from Embry-Riddle Aeronautical University's IRB (see Appendix A). All participation in this research was voluntary. The participants were verbally briefed on their role of participation in this research and provided with a written informed consent form containing a detailed description of the research purpose and design to enable their decision to participate with informed consent.

Risks to participants inherent to the conduct of the experiment were defined in the operational test plan. Risk mitigation measures were also contained within the operational test plan. One risk identified and not addressed within the operational test plan was the possibility that one or more of the participants could have experienced symptoms like simulator sickness, which usually arises after extended periods of time within a full-motion flight simulator (Johnson, 2005). However, it was possible that due to the spatial limitations of the FPV goggles, the participants could perceive discrepancies between their vestibular and ocular senses while piloting the sUAS during the experiment (Lin, 2002). This type of motion sickness associated with operations in a virtual environment has been noted by the U.S. Army as cue conflict theory (Kolasinski, 1995). Participants were instructed to inform the experiment investigator if they experienced any dizziness or symptoms of motion sickness during the experiment. This researcher did not witness any indication of dizziness or symptoms of motion sickness during the experiment, nor was it indicated by any of the participants.

The participants' personal information and other identifiable demographics were maintained in a confidential manner. Participants were informed of the confidentiality of their data, and every effort was be made to answer all their questions about the experiment and research truthfully. Data created during the experiment process were maintained in this researcher's office at Jacksonville University, with this researcher maintaining sole access to the data.

Measurement Instrument

This study utilized four data collection instruments:

- Ishihara color blindness test,

- Pre-experiment demographics questionnaire,
- Level 1 SA assessment post-test questionnaire, and
- NASA-TLX questionnaire.

Total flight time by each participant to complete the course was recorded by a stopwatch. It was calculated as the time the UAS crossed the start line of the flight course and terminates when the UAS crossed the finish line of the flight track. The NASA TLX questionnaire was used to collect the subjective workload of each participant after each flight. The Level 1 SA assessment post-test questionnaire was used to assess the participants' recall of the elements present within the testing environment after the completion of their flight. The NASA TLX index scores, flight times, and Level 1SA assessment scores were originally recorded on a Microsoft® Excel spreadsheet prior to import into IBM® SPSS® Version 27 for analysis.

Data Analysis Approach

Reliability Assessment Method (Instrument reliability)

The instrument used for data collection should provide consistency of a measure across multiple usages (Babbie, 2015), so that when the measure is repeated and achieves similar results, the instrument is said to be reliable. Studies have been conducted demonstrating collected stopwatch times to be reliable with differences reported between 0.04 and 0.41 s (Hetzler et al., 2008; Lundquist, 2007; Mayhew et al., 2010). The Level 1 SA assessment questionnaire was evaluated utilizing a known answer key to ensure consistency in measurement. Participants' responses on the NASA-TLX were scored following the instructions provided by the instrument's developers (Hart & Staveland, 1988). The reliability and validity of the NASA-TLX has been demonstrated as more reliable than alternative workload assessment instruments (Hoonakker et al., 2011).

Validity Assessment Method

Assessment instruments are considered valid if they accurately measure the data they are intended to measure (Babbie, 2015). The data collection instruments used in the current study have provided valid results in previous studies. Hart and Staveland (1988) developed the NASA-TLX to formalize the evaluation of subjective workload as performed in a variety of tasks. The NASA-TLX has been successfully used to assess operator workloads for the past 32 years (Hart, 2006) and has a history of proven validity (Xiao et al, 2005). Subjective workload for most tasks could be represented by a combination of variables including “mental, physical, and temporal demands, frustration, effort, and performance” (Hart, 2006, p. 904). The NASA-TLX is the benchmark of workload assessments and has been used to assess workload for aircrew, operating room staff, and nuclear power plant control rooms, to name a few (Hart, 2006).

The Level 1 SA data collection instrument is an objective assessment designed to collect the participants’ recollection of the obstacles encountered within the experimental testing environment. The Level 1 SA test was developed in reference to the study by Lindemann et. al. (2018), where the test participants were queried by a variation of a SAGAT test that contained questions that assessed the participants’ recall of their testing environment on all three of Endsley’s levels of SA. However, during this study, the task was not paused; the participants were queried on their recall of the testing environment post-task. The use of this type of questionnaire allowed for a direct measurement of the participants’ perceptions of the testing environment rather than their subjective assessment of how well they performed (Endsley, 1995a). A dedicated rubric was used to score the Level 1 SA tests upon completion. The Level 1 SA data collection instrument was developed in coordination with a human factors and HMI expert.

Potential Threats to Internal Validity. Several potential threats to internal validity were identified. First, it was expected that participants that have previous experience playing video games, flying RC model aircraft, or piloting sUAS or UAVs would perform better during the experiment than participants lacking that experience. This bias could affect the outcome of the manipulations of the independent variable. The Latin square design was used to eliminate the noise created by such bias. Second, it is possible that compensatory rivalry could be an issue in two ways. Participants may view the selection to the line-of-sight group as not as challenging, thus rewarding, as the participants chosen to fly with the FPV techniques. This perception may have biased their performance. To address this issue, participants were asked not to reveal which visual acuity method they were assigned during the experiment until after the conclusion of the research. This researcher personally conducted all the testing during this research, thus eliminating confounding variables that may have arisen from use of additional researchers (Thomas, 2018), and ensuring standardization of the testing procedures during the research.

Data Analysis Process/Hypothesis Testing

Demographic Questionnaire and Descriptive Statistics

The descriptive statistics included the participants' age, gender identification, employment/education status, corrective eye lens use, geographic home city and state, previous video game experience, previous sUAS piloting experience, previous RC model aircraft flying experience, FAA airman certificate holders, and data concerning previous and recent flight experience and frequency. In addition, descriptive statistics collected from the results of the experiment included the participants' total time to complete the flight course, and the participants' score on the NASA TLX workload and the Level 1 SA post-test assessment questionnaires.

Hypothesis Testing

A one-way ANOVA was used to statistically compare the participant flight performance, workload, and Level 1 SA utilizing the three levels of treatment. The one-way ANOVA was used to test for any statistically significant differences of the mean values of the dependent variable between the groups of the independent variable (Field, 2013; Lund & Lund, 2013). Six assumptions were considered to complete the one-way ANOVA test. The first three of the six were met in the design of the research study: (a) one dependent variable that is measured at the continuous level, (b) one independent variable that consists of two or more categorical, independent groups, and (c) independence of observations (Field, 2013; Lund & Lund, 2013). The other three assumptions were tested using IBM® SPSS® Version 27software: (d) no significant outliers in the groups of the independent variable in terms of the dependent variable, (e) the dependent variable is approximately normally distributed for each group of the independent variable, and (f) homogeneity of variances (Field, 2013; Lund & Lund, 2013). Boxplots were produced to identify univariate outliers. Univariate outliers can be present due to data entry error, measurement error, or from a generally unusual value collected (Field, 2013; Lund & Lund, 2013). The Shapiro-Wilk test and Q-Q plots were used to identify whether the data collected were normally distributed. Levene's test of equality of variances was used to identify if the assumption of homogeneity of variances was met or violated (Field, 2013; Lund & Lund, 2013).

The one-way ANOVA test in IBM® SPSS® Version 27 software was used to test for statistically significant differences between the three visual acuity techniques used. The participants in this research were randomly assigned to one of the three treatment levels of the independent variable. The independent variable was the visual acuity technique used, consisting of the line-of-sight technique, the FPV with the 21-LCD screen technique, and the FPV goggle technique. The effects of the manipulation of the independent variable on the dependent variables were observed and recorded by this researcher. The dependent variables observed included the participants' score on the NASA TLX workload assessment questionnaire and the participants' score on the Level 1 SA assessment questionnaire.

Summary

This research employed a experimental design and selected participants from the Jacksonville area who represented the population of Part 107 eligible individuals within the State of Florida. The experiment implemented a between-groups design with a Latin square design to mitigate possible differences in experiment group composition. Data on two dependent variables were collected: Level 1 SA and perceived workload.

Statistical analysis was conducted to test for variability of the composition of the three experimental groups with regard to age, computer gaming experience, Part 107 certificate possession, and private pilot certificate possession. Initial analysis was planned to utilize the multivariate analysis (MANOVA) method. However, a MANOVA was not used due to the lack of correlation between the dependent variables. The hypotheses were tested using the one-way ANOVA statistical analysis process. Two separate one-way ANOVAs were performed, one for each dependent variable (i.e., perceived workload, Level 1 SA), consistent with the literature showing they are two distinct constructs (Durso et al., 1999; Endsley, 1993; Vidulich, 2000; Vidulich & Tsang, 2015).

Chapter IV: Results

The purpose of this research was to determine the effects of FPV techniques on small-unmanned aircraft system operator's Level 1 SA and perceived workload. Experimental data were collected from participants eligible for the Part 107 remote pilot certificate. Participants were assigned to fly the flight course within three groups utilizing one of the three visual acuity techniques: (a) VLOS pilot operation, (b) electronic aided piloting with FPV techniques utilizing a 21-in. LCD screen, and (c) electronic aided piloting with FPV techniques utilizing full visual immersion goggles. A randomized block design method was used to assign participants within each group. One-way ANOVAs were conducted to determine if statistically significant differences existed between the groups of dependent variables for each treatment group.

Experimental Results

Demographic Information

A demographic survey was administered to all prospective participants to ensure they met the requirements of the study. The sample consisted of 24 adults, 8 participants per group. All participants were 18 years or older and there were 17 males and 7 females. Twenty participants were university students, and 4 participants were from a Navy helicopter squadron in Jacksonville. Table 14 provides the age and gender data for each group.

The previous chapter identified a required sample size of 159 participants which was not met. Conduct of the experiment was greatly hindered by two tropical depressions that traveled through the immediate Jacksonville, Florida area. On both occasions, experimental testing was ceased due to the destruction of the flight course by the depression's high winds and rain. Shortly after reconstruction of the flight course following the second tropical depression, the COVID-19 pandemic became an unwelcomed reality. The advent of COVID-19 brought about the cessation of all face-to-face research involving human participants by the JU IRB for approximately six months. However, after the JU IRB ended the moratorium on research involving human participants, reluctance to participate in the experiment peaked as the COVID-19 pandemic continued to spread across the globe. The fear and uncertainty created by the COVID-19 pandemic greatly affected continued participation in the research experiment.

Table 14

Age and Gender Demographics by Group

Group	*N* = 24	Age		Male	Female
	n	*RNG*	*M* (*SD*)	*n* (%)	*n* (%)
VLOS	8	19 - 30	21.00 (3.62)	5 (62.5)	3 (37.5)
LCD	8	19 - 25	21.00 (2.10)	7 (87.5)	1 (12.5)
GOGS	8	20 - 30	23.00 (3.66)	5 (62.5)	3 (37.5)

Note. GOGS = goggles (FPV); LCD = liquid crystal display; RCA = radio controlled aircraft; VLOS = visual line of sight; RNG = range.

Twelve participants (50.0%) indicated prior flight experience with sUAS, 9 (37.5%) indicated some previous experience flying radio-controlled (RC) aircraft as a hobby, 7 (29.1%) possess a current Part 107 Remote Pilot certificate, 16 (66.6%) possess a current Private Pilot certificate, and 5 (20.8%) possess current FAA certificates beyond the Private Pilot certificate. FAA certificates beyond the Private Pilot certificate include the Commercial Single and Multiengine certificate, the Certified Flight Instructor Certificate, the Certified Flight Instructor-Instrument certificate, and the Airline Transport Pilot certificate. Thirteen participants (54.1%) indicated they were active computer gamers. The demographic breakdown of participants age and FAA pilot certificate type by experimental group assignment is shown in Table 15.

Table 15

Frequencies of FAA Pilot Certificates within Each Group

Group	FAA Certificate Type		
	Remote Pilot [a]	Private Pilot	Beyond Private [b]
	n	*n*	*n*
VLOS	2	5	2
LCD	3	5	1
GOGS	2	6	2

Note. Categories are not mutually exclusive. FAA = Federal Aviation Administration; GOGS = goggles (FPV); LCD = liquid crystal display; VLOS = visual line of sight.
[a] Part 107 certificated sUAS pilot. [b] Commercial Single Engine, Certified Flight Instructor, Certified Flight Instructor-Instrument, or Airline Transport Pilot certificate.

An ANOVA between the three experimental groups found no significant difference in the participants' age, $F(2, 21) = 1.357, p = .279$; no significant difference in the participants' possession of a Part 107 certificate, $F(2, 21) = .179, p = .837$; and no significant difference in the participants' possession of a Private Pilot certificate, $F(2, 21) = .167, p = .848$.

The demographic data for the participants' computer gaming and RCA flying hobby experience are presented in Table 16. The participants' computer gaming experience ranged from 0 to 17.5 hours a week with a mean of 3.23. The participants' RCA flying experience ranged from 1 to 7 on a Likert scale with 1=low experience level and 7=high experience level with a mean of 1.41.

Table 16

RCA Flying and Computer Gaming Experience within Each Group

	RCA Flying Experience		Computer Gaming Experience	
	n	Mean Experience Level	*n*	total hours/week
VLOS	2	2.00	5	33.50
LCD	4	4.00	2	19.50
GOGS	3	5.33	6	24.50

Note. GOGS = goggles (FPV); LCD = liquid crystal display; RCA = radio controlled aircraft; VLOS = visual line of sight.

A summary of participant mean gaming hours per week and RCA flying experience levels is presented in Table 17. An ANOVA between the three experimental groups found no significant difference in the participants' total gaming hours per week, *F*(2, 21) = .279, *p* = .759. Additionally, an ANOVA between the three experimental groups found no significant difference in the participants' RCA experience levels, *F*(2, 21) = 1.125, *p* = .343.

Table 17

Group Mean Gaming Hours Per Week and RCA Flying Experience

Group		Computer Gaming	RCA Flying
	n	*M* (*SD*)	*M* (*SD*)
VLOS	8	4.19 (4.34)	0.5 (0.93)
LCD	8	2.44 (6.13)	2.0 (2.51)
GOGS	8	3.06 (3.34)	2.0 (2.98)

Note. GOGS = goggles (FPV); LCD = liquid crystal display; RCA = radio controlled aircraft; VLOS = visual line of sight.

Descriptive Statistics

Descriptive statistics are provided for the experiment participants' NASA TLX questionnaire scores and SA test scores, reflecting the participants' perceived workload and Level 1 SA during their sUAS flight on the flight course in Table 18. The participants' total time to navigate the flight course ranged from 33 to 142 s with a mean time of 83.96 s (*SD* = 31.56).

Table 18

Descriptive Statistics of the NASA TLX and SA Tests Results

	Group	*M*	*SD*	*Mdn*	Min.	Max.
NASA TLX	VLOS	59.08	10.94	59.17	39.00	78.33
	LCD	57.04	12.05	56.83	34.00	70.33
	GOGS	56.02	19.18	60.33	25.67	82.67
SA Test	VLOS	14.75	7.48	13.50	5	31
	LCD	12.13	4.19	12.00	4	18
	GOGS	13.88	4.52	15.00	6	18

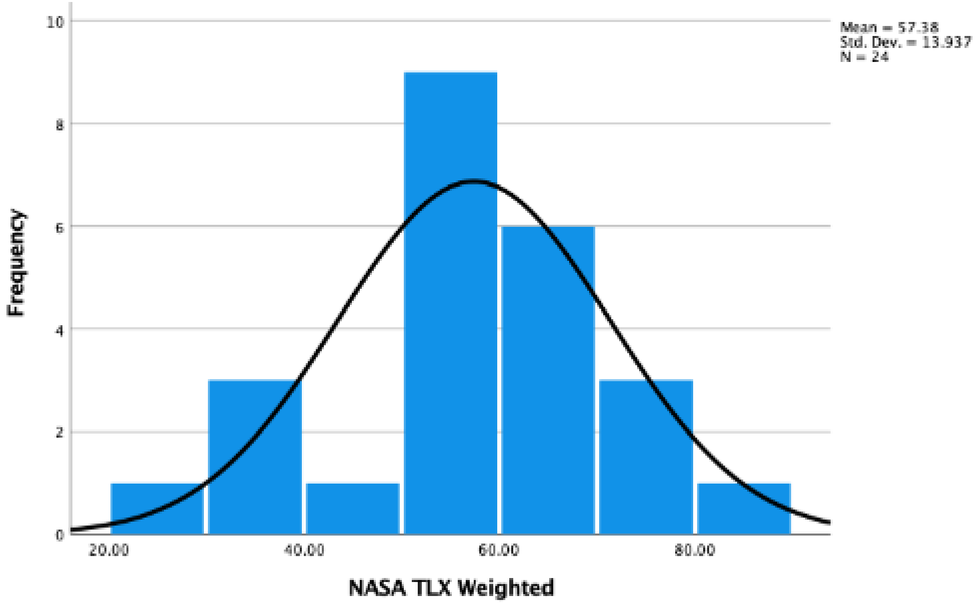
Note. GOGS = goggles (FPV); LCD = liquid crystal display; RCA = radio controlled aircraft; VLOS = visual line of sight.

NASA TLX Questionnaire Scores

The NASA TLX assessment questionnaire was administered to each participant after the conduct of each flight via the Apple® iPad NASA-TLX application. The participants' weighted NASA TLX questionnaire scores ranged from 25.67 to 82.67 with a mean score of 57.38 (*SD* = 13.94). The frequency distribution of the participants' weighted NASA TLX questionnaire scores is presented in Figure 20. Unweighted ratings by group may be found in Appendix E.

Figure 20

Weighted NASA TLX Questionnaire Score Frequencies

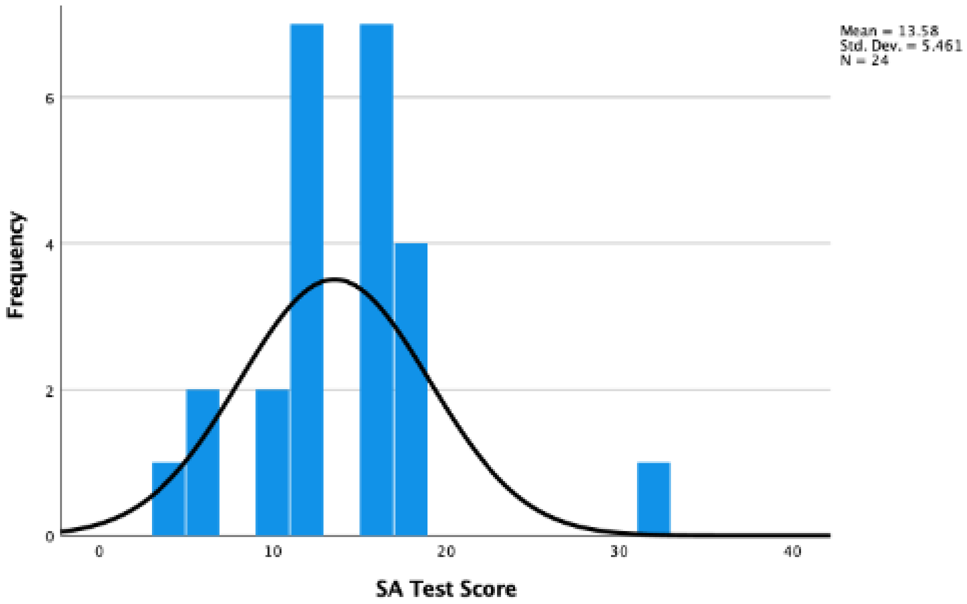


Situation Awareness Test Scores

The participants' SA test scores ranged from 4 to 31 with a mean score of 13.58 (*SD* = 5.46). The frequency distribution of the participants' SA scores is shown in Figure 21.

Figure 21

SA Test Score Frequencies



Hypothesis Testing

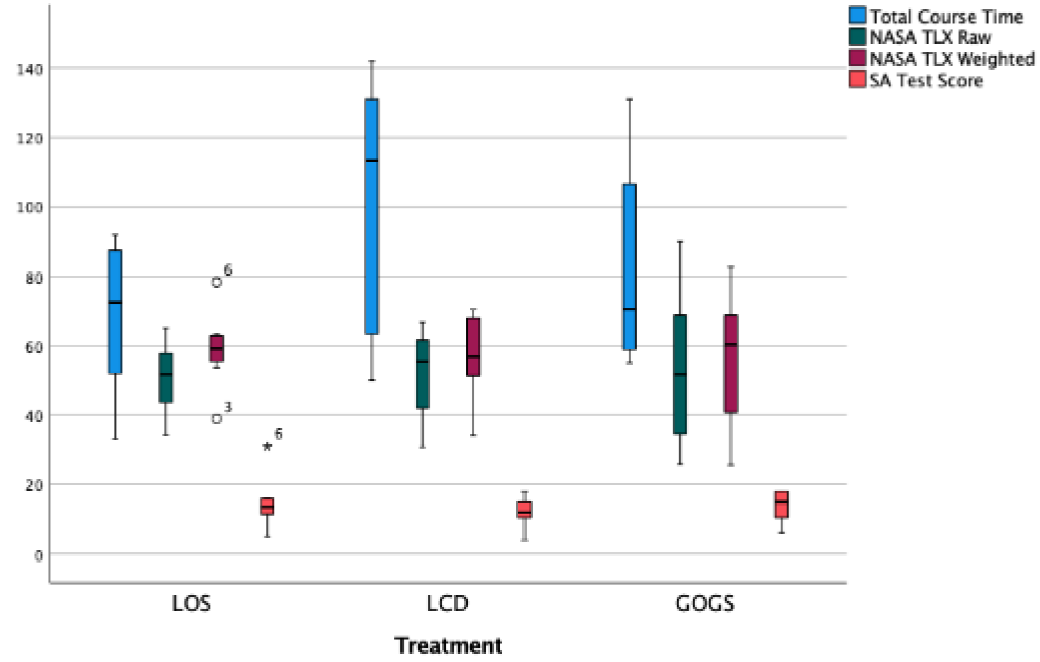
One-way ANOVA tests were conducted to test the hypotheses for subjective workload and Level 1 SA accuracy. If the probability value was ≤ 0.05, the null hypothesis was rejected. Six assumptions were considered to complete the one-way ANOVA test. The first three of the six were met in the design of the research study: (a) one dependent variable that is measured at the continuous level, (b) one independent variable that consists of two or more categorical, independent groups, and (c) the independence of observations. The following section addresses the remaining three assumptions.

Testing for Outliers

The fourth assumption proposes that there are no significant outliers within the independent variable group's effect on the dependent variable. The straightforward method of using boxplots was used to identify the presence of outliers within the data. The boxplot for the dependent variables as grouped by the three treatments is depicted in Figure 22. Three data points within the VLOS treatment group were located more than 1.5 box lengths from the edge of their respective boxes and were classified as outliers. However, further examination of the data determined that the outliers were not due to data entry error or measurement error but were merely genuinely unusual values as compared to the data within their respective dependent variable. ANOVA tests were conducted for each DV including the outliers and without the outliers.

Figure 22

Boxplots of Dependent Variable Scores by Group



Note. LCD = liquid crystal display; LOS = Line of sight (VLOS); GOGS = goggles (FPV); NASA = National Aeronautics and Space Administration; SA = Situation Awareness; TLX = task load index. o^{3} = participant 3; o^{6} = participant 6; $*^{6}$ = participant 6.

Testing for Normality

The fifth assumption considered was the normality of the dependent variable, i.e., whether the data were normally distributed within their respective independent variable group. The Shapiro-Wilk test and Q-Q plots were used to test the dependent variables for normality. All the data points for each dependent variable within their respective treatment group were approximately normally distributed, as indicated by the results from the Shapiro-Wilk test presented in Table 19 and confirmed with Q-Q plots.

Table 19

Shapiro-Wilk Test of Normality for NASA TLX and SA Test Results

	Group	Statistic	*df*	*p*
NASA-TLX Results	VLOS	.928	8	.499
	LCD	.916	8	.399
	GOGS	.964	8	.851
SA Test Results	VLOS	.844	8	.084
	LCD	.941	8	.621
	GOGS	.871	8	.156

Note. GOGS = goggles (FPV); LCD = liquid crystal display; RCA = radio controlled aircraft; NASA = National Aeronautics and Space Administration; SA = situation awareness; TLX = task load index; VLOS = visual line of sight.

Testing for Homogeneity of Variances

The sixth assumption considered for the ANOVA procedure was if the variance of each group of the independent variable was the same. Results for the testing for homogeneity of variances is presented in Table 20. The results of the Levene's tests were not significant ($p > 0.05$), indicating the error variance of the dependent variables was not significantly different across the three treatment groups. Therefore, the assumption of homogeneity of variances was met.

Table 20

Levene's Test of Equality of Variances for NASA TLX and SA Test Results

	Levene's Statistic	*df*1	*df*2	*p*
NASA-TLX Results	2.005	2	21	.160
SA Test Results	.478	2	21	.627

Note. NASA = National Aeronautics and Space Administration; SA = situation awareness; TLX = task load index. *df*1 = g – 1: where g is the number of groups; *df*2 = *N* – g: where *N* is the sample size of all groups combined and g is the number of groups. *N* = 24.

Subjective Workload (Hypotheses 1, 2, and 3)

The ANOVA procedure was conducted to test hypotheses 1, 2, and 3 to examine the effect of the independent variable, the three visual acuity techniques, on the dependent variable, the participants' perceived workload as assessed by the NASA TLX while piloting the sUAS on the flight course. Hypotheses 1, 2, and 3 state:

H_1: sUAS pilot subjective workload will be lower in the LCD screen condition than the VLOS condition.

H_2: sUAS pilot subjective workload will be lower in the visual immersion goggle condition than the VLOS condition.

H_3: sUAS pilot subjective workload will be lower in the visual immersion goggle condition than the LCD screen condition.

Two separate one-way ANOVAs were conducted to test H_1. The first ANOVA was conducted including the two outliers within the VLOS treatment group for the NASA TLX weighted scores. The second ANOVA was conducted with the two outliers removed from the VLOS treatment group for the NASA TLX weighted scores.

ANOVA for NASA TLX Weighted with Outliers. The data were normally distributed for each treatment group, as assessed by Shapiro-Wilk test ($p > 0.05$), as depicted in Table 19. The homogeneity of variances assumption was met as assessed by Levene's test of homogeneity of variances ($p = .160$), as the results show in Table 20. Results of the one-way ANOVA indicated that the NASA TLX weighted scores increased from the GOGS ($M = 56.02$, $SD = 19.17$), to LCD ($M = 57.04$, $SD = 12.04$), to VLOS ($M = 59.08$, $SD = 10.94$) treatment groups, in that order. The one-way ANOVA results presented in Table 21 indicate the differences between the visual acuity techniques utilized and the participants' perceived workload as assessed by the NASA TLX were not statistically significant, $F(2, 21) = .092$, $p = .912$.

Table 21

One-Way ANOVA Statistics for the NASA TLX Results

	Sum of Squares	*df*	M^2	*F*	*p*
Between Groups	38.903	2	19.451	.092	.912
Within Groups	4428.606	21	210.886		
Total	4467.509	23			

Note. ANOVA = analysis of variance; NASA = National Aeronautics and Space Administration; TLX = task load index.

Welch ANOVA for NASA TLX Weighted Without Outliers. Two outliers were removed from the VLOS group. As presented in Table 22, the data were normally distributed for each treatment group as assessed by Shapiro-Wilk test ($p > 0.05$). However, the homogeneity of variances assumption was not met as assessed by Levene's test of homogeneity of variances ($p = .023$); therefore, the Welch ANOVA was used. Results of that ANOVA test indicated that the NASA TLX weighted scores increased from the GOGS group ($M = 56.02$, $SD = 19.17$) to the LCD group ($M = 57.04$, $SD =$

12.04) to VLOS group (*M* = 59.22, *SD* = 3.58), in that order, but the differences between these visual acuity techniques were not statistically significant: Welch's *F*(2, 10.625) = .197, *p* = .824.

Table 22

Shapiro-Wilk Test of Normality for NASA TLX Results

	Group	Statistic	*df*	*p*
NASA TLX Results	VLOS	.975	6	.925
	LCD	.916	8	.399
	GOGS	.964	8	.851

Note. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); NASA = National Aeronautics and Space Administration; SA = situation awareness; TLX = task load index. Two outliers were removed from VLOS group.

Both ANOVA tests conducted on the NASA TLX weighted scores, both with and without outliers removed, found no statistically significant differences between the use of the three visual acuity techniques for piloting the sUAS on the flight course. Therefore, the ANOVA test results failed to support hypotheses 1, 2, and 3.

Situation Awareness (Hypotheses 4, 5, and 6)

The ANOVA procedure was conducted to test Hypotheses 4, 5, and 6 to examine the effect of the levels of the independent variable (three visual acuity techniques) on the dependent variable (participants' Level 1 SA) as assessed by the SA test (see Appendix B2). Hypotheses 4, 5, and 6 state:

H_4: sUAS pilot post-task Level 1 SA will be better in the LCD screen condition than the VLOS condition.

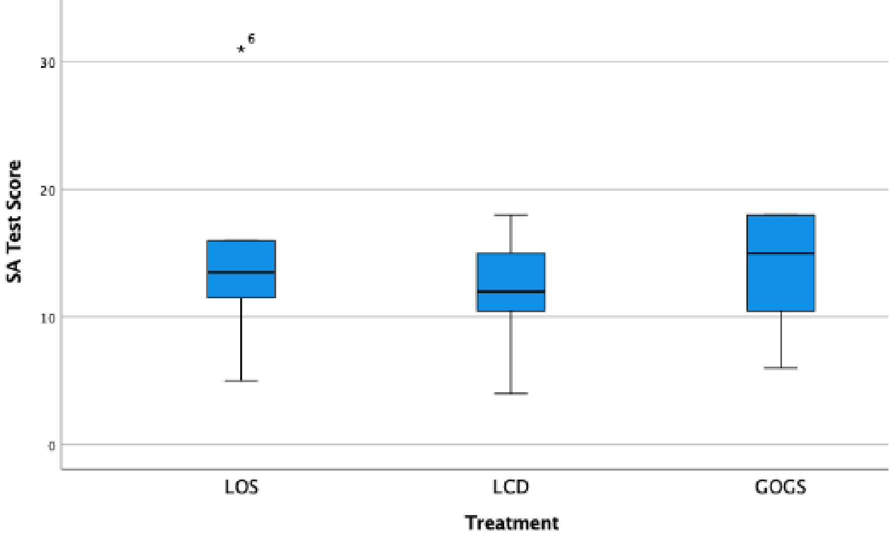
H_5: sUAS pilot post-task Level 1 SA will be better in the visual immersion goggle condition than the VLOS condition.

H_6: sUAS pilot post-task Level 1 SA will be better in the visual immersion goggle condition than the LCD screen condition.

Examination of the box plots for the SA test scores identified an outlier within the VLOS treatment group (see Figure 23). The first ANOVA was conducted including the one outlier within the VLOS treatment group SA test scores. The second ANOVA was conducted with the outliers removed from the VLOS treatment group SA test scores.

Figure 23

Boxplots of Mean SA Test Results with VLOS Group Outlier



Note. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); SA = situation awareness; VLOS = visual line of sight. $*^6$ = case 6.

ANOVA for SA Test Scores with Single VLOS Group Outlier. The Shapiro-Wilk test results in Table 23 show the data were normally distributed for each treatment group ($p > .05$). The homogeneity of variances assumption was met as assessed by Levene's test of homogeneity of variances ($p = .627$).

Table 23

Shapiro-Wilk Test of Normality for SA Test Results with VLOS Outlier

	Group	Statistic	*df*	*p*
	VLOS	.844	8	.084
SA Test Results	LCD	.941	8	.621
	GOGS	.871	8	.156

Note. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); SA = situation awareness; VLOS = visual line of sight.

Table 24 presents the results of the ANOVA. The SA test scores increased from the LCD group (*M* = 12.13, *SD* = 4.19) to the GOGS group (*M* = 13.88, *SD* = 4.52) to the VLOS group (*M* = 14.75, *SD* = 7.48), respectively, but the difference between the visual acuity techniques was not statistically significant, *F*(2, 21) = .457, *p* = .640.

Table 24

ANOVA Statistics for SA Test Results with VLOS Outlier

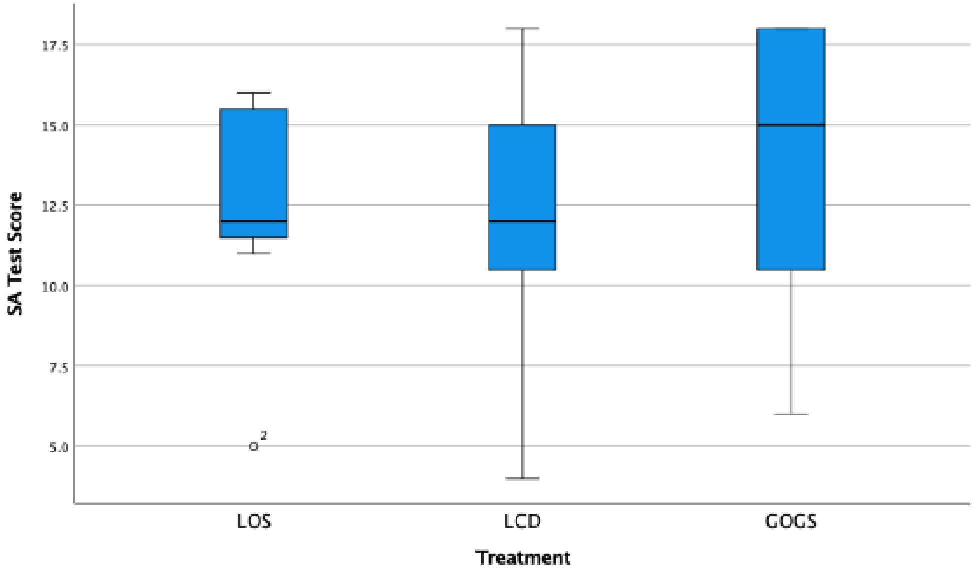
	Sum of Squares	*df*	M^2	*F*	*p*
Between Groups	25.583	2	14.292	.457	.640
Within Groups	657.250	21	31.298		
Total	685.833	23			

Note. ANOVA = analysis of variance; SA = situation awareness; VLOS = visual line of sight.

ANOVA for SA Test Results with the Single VLOS Group Outlier Removed. The outlier shown in Figure 24 was removed prior to conducting the ANOVA test with the SA scores. The outlier was the highest value in the VLOS SA data set, so its removal resulted in a new outlier that was the lowest value in that data set (see Figure 24).

Figure 24

Boxplots of the SA Test Results with New Outlier



Note. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); SA = situation awareness; VLOS = visual line of sight. O^2 = case 2.

This outlier was also removed prior to the ANOVA test. The data were normally distributed for each treatment group, as assessed by the Shapiro-Wilk test (p > .05) as presented in Table 25. The homogeneity of variances assumption was met, as assessed by Levene's test of homogeneity of variances (*p* = .399). Results of the ANOVA indicated the SA test scores, as shown in Table 26, increased from the LCD group (*M* = 12.13, *SD* = 4.19) to the VLOS group (*M* = 13.67, *SD* = 2.25) to the GOGS group (*M* = 13.88, *SD* = 4.52), respectively, but the differences between the visual acuity techniques was not statistically significant, *F*(2, 21) = .463, *p* = .636.

Table 25

Shapiro-Wilk Test of Normality for SA Test Results without Outliers

	Group	Statistic	*df*	*p*
SA Test Results	VLOS	.836	6	.121
	LCD	.941	8	.621
	GOGS	.871	8	.156

Note. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); SA = situation awareness; VLOS = visual line of sight.

Table 26

ANOVA Statistics for SA Test Results without VLOS Outlier

	Sum of Squares	*df*	M^2	*F*	*p*
Between Groups	14.189	2	7.095	.463	.636
Within Groups	291.083	19	15.320		
Total	305.273	21			

Note. ANOVA = analysis of variance; SA = situation awareness; VLOS = visual line of sight.

Both ANOVA tests conducted on the SA test scores, both with and without outliers removed, found no statistically significant differences between the three visual acuity techniques for piloting the sUAS on the flight course. Therefore, the ANOVA test results failed to support Hypotheses 4, 5, and 6.

Additional Analysis

The one-way analysis of covariance (ANCOVA) was used to statistically compare the effect of the three levels of the independent variable (visual acuity technique) on the participants' workload and Level 1 SA with consideration for the differential effect of demographic variables. The existence of continuous predictor variables, also known as covariates, can have an influence upon the dependent variables (Vogt et al., 2012; Field, 2013). The random assignment of the participants to their respective experimental groups typically balances out the possible bias of the covariates “within the bounds of probability” (Vogt et al., 2012, p. 175). However, research involving smaller cases, as in this research, requires additional measures to control for the bias of covariates (Vogt et al., 2012). Therefore, in order to eliminate the bias of the covariates outside of the experimental manipulation of the independent variable, the effect of the covariates are removed during analysis with the ANCOVA test (Field, 2013). The one-way ANCOVA was used to test for any statistically significant differences of the mean values of the dependent variable between the groups of the independent variable (Field, 2013; Lund & Lund, 2013).

Ten assumptions were considered to complete the one-way ANCOVA test. The first four of the six were met in the design of the research study: (a) one dependent variable that is measured at the continuous level, (b) one independent variable that consists of two or more categorical, independent groups, (c) a continuous covariate variable, and (d) independence of observations (Field, 2013; Lund & Lund, 2013). The other six assumptions were tested using IBM® SPSS® Version 27software: (e) the covariate should be linearly related to the dependent variable at each level of the independent variable, (f) homogeneity of regression slopes, (g) normality of the dependent variables, (h) homoscedasticity, (i) homogeneity of variances, and (j) no significant outliers (Field, 2013; Lund & Lund, 2013).

Linearity Assumption

The effect the visual acuity technique has on the participants’ workload and Level 1 SA may vary, to some degree, based on the amount of time the participants play video games during the week and the participants' RCA experience levels. Therefore, the participants' total gaming time and RCA experience levels are considered covariate variables. Scatterplots were used to test for whether there is a linear relationship between the covariates and the dependent variables. There was a linear relationship between total gaming hours and RCA experience levels for each treatment group, as assessed by visual inspection of the scatterplots.

Homogeneity of Regression Slopes Assumption

This assumption determines if there is a statistically significant interaction between the covariate and the levels of each treatment group. In order to determine if there is homogeneity of regression slopes, specific interaction terms were created between the covariates and the dependent variables. The interaction terms are presented in Table 27.

Table 27

Interaction Terms between Covariates and NASA TLX and Level 1 SA Test Results

	Covariate	*F*	*df*	*p*
NASA-TLX Results	Total Gaming Time	.101	2	.905
	RCA Experience Level	.087	2	.917
SA Test Results	Total Gaming Time	3.664	2	.046
	RCA Experience Level	1.336	2	.288

Note. NASA = National Aeronautics and Space Administration; TLX = task load index; RCA = radio-controlled aircraft; SA = situation awareness.

The homogeneity of regression slopes was not violated as both the covariates for the NASA TLX results were not statistically significant ($p > .05$). Additionally, for the Level 1 SA test results, the homogeneity of regression slopes was not violated with the RCA experience level covariate ($p > .05$). However, the homogeneity of regression slopes for the Level 1 SA test results was violated with the total gaming time covariate (*p* < .05). Proceeding with the ANCOVA for Level 1 SA test results with the total gaming time covariate was not continued due to the possibility of erroneous results (Johnson, 2016).

Subjective Workload

ANCOVA for NASA TLX Results with Total Gaming Hours Covariate. The Shapiro-Wilk test was used to test for normality using within-group residuals. Standardized residuals within their respective treatment group were approximately normally distributed, as assessed by Shapiro-Wilk test (*p* > .05), as presented in Table 28 and confirmed with Q-Q plots.

Table 28

Shapiro-Wilk Test of Normality for NASA TLX Standardized Residuals for Total Gaming Hours Covariate

	Group	Statistic	*df*	*p*
NASA-TLX Results	VLOS	.902	8	.299
	LCD	.890	8	.236
	GOGS	.975	8	.935

Note. GOGS = goggles (FPV); LCD = liquid crystal display (FPV); NASA = National Aeronautics and Space Administration; TLX = task load index; VLOS = visual line of sight.

The assumption of homoscedasticity was tested by creating a scatterplot of the standardized residuals against the predicted values by treatment group. There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values. The homogeneity of variances assumption assumes the variance of the standardized residuals for each group of the independent variable are the same. Results for the testing for homogeneity of variances is presented in Table 29. The results of the Levene's tests were not statistically significant ($p > .05$), indicating the error variance of the dependent variable was not significantly different across the three treatment groups. Therefore, the assumption of homogeneity of variances was met.

Table 29

Levene's Test of Equality of Variances for NASA TLX Standardized Residuals for Total Gaming Hours Covariate

	Levene's Statistic	*df*1	*df*2	*p*
NASA-TLX Results	2.298	2	21	.125

Note. NASA = National Aeronautics and Space Administration; SA = situation awareness; TLX = task load index. *df*1 = g – 1: where g is the number of groups; *df*2 = *N* – g: where *N* is the sample size of all groups combined and g is the number of groups. $N = 24$.

The residuals were examined for significant outliers within the treatment groups. There were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations. Results of the one-way ANCOVA indicated that unadjusted mean ± standard deviation of the NASA TLX weighted scores increased from the GOGS ($M = 56.02$, $SD = 19.17$), to LCD ($M = 57.04$, $SD = 12.04$), to VLOS ($M = 59.08$, $SD = 10.94$) treatment groups, in that order. The adjusted mean ± standard error of the NASA TLX weighted scores increased from the GOGS ($M = 55.85 \pm 5.28$ gaming hours/week), to LCD ($M = 56.53 \pm 5.32$ gaming hours/week), to VLOS ($M = 60.38 \pm 5.41$ gaming hours/week) treatment groups, in that order. Adjusted and unadjusted NASA TLX weighted score means and variability are presented in Table 30. After adjustment for participants' gaming hours per week, there was not a statistically significant difference in NASA TLX weighted score results, $F(2, 18) = .101$, $p = .905$.

Table 30

Adjusted and Unadjusted NASA TLX Mean Scores and Variability for Total Gaming Hours Covariate

		Unadjusted		*Adjusted*	
Group	*N*	*M*	*SD*	*M*	*SE*
VLOS	8	59.08	10.94	60.38	5.41
LCD	8	57.04	12.05	56.53	5.32
GOGS	8	56.02	19.08	55.85	5.28

Note. NASA = National Aeronautics and Space Administration; TLX = task load index; GOGS = goggles (FPV); LCD = liquid crystal display; VLOS = visual line of sight; N = number of participants, M = Mean; SD = Standard Deviation; SE = Standard Error. Total gaming hours measured in gaming hours/week.

NASA TLX Results with RCA Experience Levels Covariate. The Shapiro-Wilk test was used to test for normality using within-group residuals. Standardized residuals within their respective treatment group were approximately normally distributed, as assessed by Shapiro-Wilk test (*p* > .05), as presented in Table 31 and confirmed with Q-Q plots.

Table 31

Shapiro-Wilk Test of Normality for NASA TLX Standardized Residuals with RCA Experience Levels Covariate

	Group	Statistic	*df*	*p*
NASA-TLX Results	VLOS	.856	8	.108
	LCD	.912	8	.369
	GOGS	.955	8	.762

Note. GOGS = goggles (FPV); LCD = liquid crystal display (FPV); NASA = National Aeronautics and Space Administration; TLX = task load index; VLOS = visual line of sight.

The assumption of homoscedasticity was tested for by creating a scatterplot of the standardized residuals against the predicted values by treatment group. There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values. The homogeneity of variances assumption assumes the variance of the standardized residuals for each group of the independent variable are the same. Results for the testing for homogeneity of variances is presented in Table 32. The results of the Levene's tests were not statistically significant ($p > .05$), indicating the error variance of the dependent variable was not significantly different across the three treatment groups. Therefore, the assumption of homogeneity of variances was met.

Table 32

Levene's Test of Equality of Variances for NASA TLX Standardized Residuals with RCA Experience Levels Covariate

	Levene's Statistic	*df*1	*df*2	*p*
NASA-TLX Results	2.229	2	21	.133

Note. NASA = National Aeronautics and Space Administration; SA = situation awareness; TLX = task load index. $df1 = g - 1$: where g is the number of groups; $df2 = N - g$: where N is the sample size of all groups combined and g is the number of groups. $N = 24$.

The residuals were examined for significant outliers within the treatment groups. There were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations. Results of the one-way ANCOVA indicated that unadjusted mean ± standard deviation of the NASA TLX weighted scores increased from the GOGS ($M = 56.02$, $SD = 19.17$), to LCD ($M = 57.04$, $SD = 12.04$), to VLOS ($M = 59.08$, $SD = 10.94$) treatment groups, in that order. The adjusted mean ± standard error of the NASA TLX weighted scores increased from the GOGS ($M = 55.82 \pm 5.61$ RCA experience rate), to VLOS ($M = 56.70 \pm 8.43$ RCA experience rate), to LCD ($M = 56.96 \pm 5.64$ RCA experience rate), treatment groups, in that order. Adjusted and unadjusted NASA TLX weighted score means and variability are presented in Table 33. After adjustment for participants' RCA experience levels, there was not a statistically significant difference in NASA TLX weighted score results, *F*(2, 18) = .087, *p* = .917.

Table 33

Adjusted and Unadjusted NASA TLX Mean Scores and Variability for RCA Experience Levels Covariate

		Unadjusted		*Adjusted*	
	N	*M*	*SD*	*M*	*SE*
VLOS	*8*	*59.08*	*10.94*	*56.70*	*8.43*
LCD	*8*	*57.04*	*12.05*	*56.96*	*5.64*
GOGS	*8*	*56.02*	*19.08*	*55.82*	*5.61*

Note. NASA = National Aeronautics and Space Administration; TLX = task load index; GOGS = goggles (FPV); LCD = liquid crystal display; VLOS = visual line of sight; N = number of participants, M = Mean; SD = Standard Deviation; SE = Standard Error. Total gaming hours measured in gaming hours/week.

Situation Awareness

ANCOVA for SA Test Results with RCA Experience Levels Covariate. The Shapiro-Wilk test was used to test for normality using within-group residuals. Standardized residuals within the GOGS and LCD treatment groups were approximately normally distributed, as assessed by Shapiro-Wilk's test (*p* > .05), as presented in Table 34 and confirmed with Q-Q plots. However, the standardized residuals within the VLOS group were not approximately normally distributed, as assessed by Shapiro-Wilk's test (p < .05).

Table 34

Shapiro-Wilk Test of Normality for SA Test Standardized Residuals with RCA Experience Levels Covariate

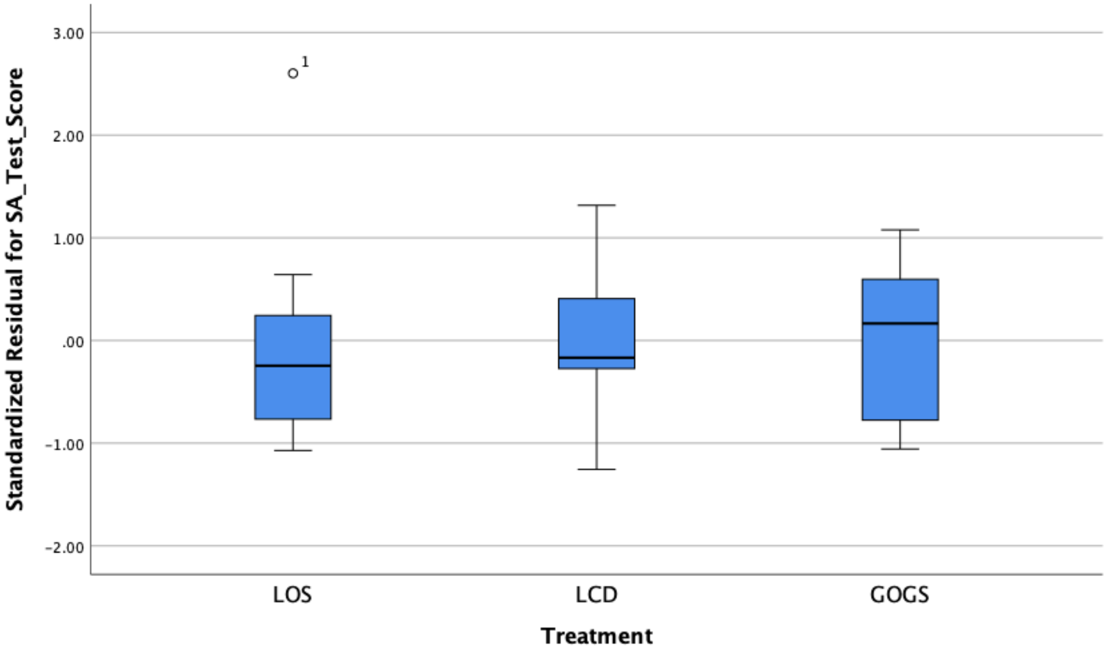
	Group	*Statistic*	*df*	*p*
NASA-TLX Results	*VLOS*	*.810*	*8*	*.037*
	LCD	*.944*	*8*	*.656*
	GOGS	*.920*	*8*	*.429*

Note. GOGS = goggles (FPV); LCD = liquid crystal display (FPV); NASA = National Aeronautics and Space Administration; TLX = task load index; VLOS = visual line of sight.

Examination of the box plots for the standardized residuals for SA test scores identified an outlier within the VLOS treatment group (see Figure 25). After removal of the outlier within the LOS group identified in Figure 25, an additional Shapiro-Wilk test was conducted. The standardized residuals within their respective treatment group were approximately normally distributed, as assessed by the subsequent Shapiro-Wilk's test (p > .05), as presented in Table 35 and confirmed with Q-Q plots.

Figure 25

Box Plots of Standardized Residuals for SA Test Results



Note. SA = situation awareness; GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); VLOS = visual line of sight. O[1] = case 1.

Table 35

Shapiro-Wilk Test of Normality for SA Test Standardized Residuals with RCA Experience Levels Covariate With VLOS Outlier Removed

	Group	Statistic	*df*	*p*
SA Test Results	VLOS	.946	7	.690
	LCD	.944	8	.656
	GOGS	.920	8	.429

Note. GOGS = goggles (FPV); LCD = liquid crystal display (FPV); NASA = National Aeronautics and Space Administration; TLX = task load index; VLOS = visual line of sight.

The assumption of homoscedasticity was tested for by creating a scatterplot of the standardized residuals against the predicted values by treatment group. There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values. The homogeneity of variances assumption assumes the variance of the standardized residuals for each group of the independent variable are the same. Results for the testing for homogeneity of variances is presented in Table 36. The results of the Levene's tests were not statistically significant ($p > .05$), indicating the error variance of the dependent variable was not significantly different across the three treatment groups. Therefore, the assumption of homogeneity of variances was met.

Table 36

Levene's Test of Equality of Variances for SA Test Standardized Residuals with RCA Experience Levels Covariate

	Levene's Statistic	*df1*	*df2*	*p*
SA Test Results	*.574*	*2*	*20*	*.573*

Note. SA = situation awareness; RCA = radio-controlled aircraft. *df*1 = g – 1: where g is the number of groups; *df*2 = *N* – g: where *N* is the sample size of all groups combined and g is the number of groups. *N* = 23.

The residuals were examined for significant outliers within the treatment groups. There were no outliers in the data, as assessed by no cases with standardized residuals greater than ±3 standard deviations. Results of the one-way ANCOVA indicated that unadjusted mean ± standard deviation of the Level 1 SA test scores increased from the LCD (*M* = 12.13, *SD* = 4.19), to VLOS (*M* = 12.43, *SD* = 3.87), to GOGS (*M* = 13.88, *SD* = 4.56) treatment groups, in that order. The adjusted mean ± standard error of the Level 1 SA test scores increased from the VLOS (*M* = 9.70 ± 2.33 RCA experience rate), to LCD (*M* = 12.31 ± 1.50 RCA experience rate), to GOGS (*M* = 56.96 ± 14.06 RCA experience rate), treatment groups, in that order. Adjusted and unadjusted NASA TLX weighted score means and variability are presented in Table 37. After adjustment for participants' RCA experience levels, there was not a statistically significant difference in Level 1 SA test score results, *F*(2, 17) = .846, *p* = .447.

Table 37

Adjusted and Unadjusted SA Test Mean Scores and Variability for RCA Experience Levels Covariate

		Unadjusted		*Adjusted*	
Group	*N*	*M*	*SD*	*M*	*SE*
VLOS	*7*	*12.43*	*3.87*	*9.70*	*2.33*
LCD	*8*	*12.13*	*4.19*	*12.31*	*1.50*
GOGS	*8*	*13.88*	*4.52*	*14.06*	*1.48*

Note. NASA = National Aeronautics and Space Administration; TLX = task load index; GOGS = goggles (FPV); LCD = liquid crystal display; VLOS = visual line of sight; N = number of participants, M = Mean; SD = Standard Deviation; SE = Standard Error.

ASRS Data Analysis

The results of the preliminary experiment provided a foundations from which a comparison could be made on a dataset retrieved from the ASRS database. Characteristics of event reports where the primary aircraft was a UAS were explored in addition to a comparison of event reports where SA was listed as a causal factor and event reports where SA was not listed as a causal factor.

The ASRS database was implemented in 1976 through a memorandum of agreement between the FAA and NASA (Billings et al., 1976). The reporting system provides aviation industry operators and stakeholders a venue for voluntary reporting of an incident and underlying conditions that may have contributed to the incident's occurrence (Billings et al., 1976). The reports contain descriptive metadata such as the aircraft operator, state of incident occurrence, environmental conditions, aircraft type, and includes areas for the reporter to provide a narrative description of the event (Billings et al., 1976). The system provides the reporter the opportunity to share pertinent details about an aviation incident in order to increase awareness of factors that may have led to the event occurrence. One key feature of the system is that it provides the reporter a non-punitive means of sharing their experience with other aviation stakeholders without fear of reprisal (Billings et al., 1976)

Reports filed are processed by ASRS subject matter experts that review and codify the human factor elements within the event reports. Those human factor elements include but are not limited to workload, SA, HMI, training, and distraction to name a few (Reynard, 1986). Codified reports are then added and maintained within the ASRS database, available for data retrieval and review (Corrie, 1997).

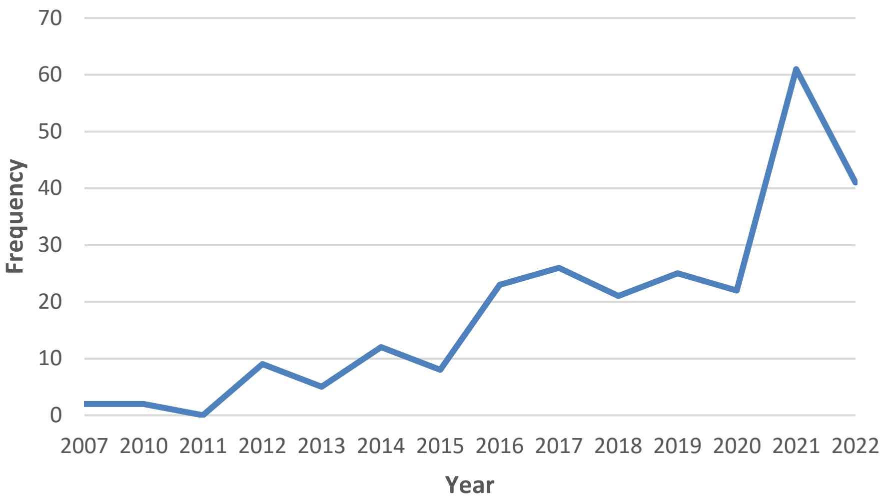
A search of the entire database was conducted for any narrative containing “UAS” or “UAV” within the narrative and synopsis portion of the reports. The search yielded 754 reports, submitted between July 2002 and September 2022. The retrieved dataset was downloaded in Microsoft Excel format for analysis. The focus of the analysis was upon event reports which listed the primary aircraft as a UAS. Therefore, the primary aircraft field within the report titled “Make Model Name” was filtered to include only aircraft identified as a UAS. Nomenclature contained within the “Make Model Name” field included 32 types of identifiers to indicate the primary aircraft was a UAS. The identifiers included names such as “DJI Spark”, “UAV-Unpiloted Aerial Vehicle”, “Large UAS, Fixed Wing”, “Skydio 2” and many others, all of which identified the aircraft as a UAS. The resulting filtered dataset contained 284 event reports where the primary aircraft was listed as a UAS. Twenty seven reports were removed from the dataset due to missing data fields within the event report, resulting in a working dataset for analysis of 257 (34%) reports. The other 497 (66%) reports submitted consist of incidents where manned aircraft were listed as the primary aircraft which had encountered a UAS during operations. Categorical data analysis was conducted on the dataset of 257 records where the primary aircraft was listed as an unmanned aircraft system.

Characteristics of Reported Events

Frequency of Reported Events by Year. As depicted in Figure 26, an increase in reports filed can be seen from the earliest report recorded in 2007. An increase in UAS operations can be seen to begin around 2014-2016 associated with the FAA's issuance of Section 333 waivers for UAS operations, followed by the finalization of the Part 107 operational rules in 2016.

Figure 26

Frequency of Reported Events by Year

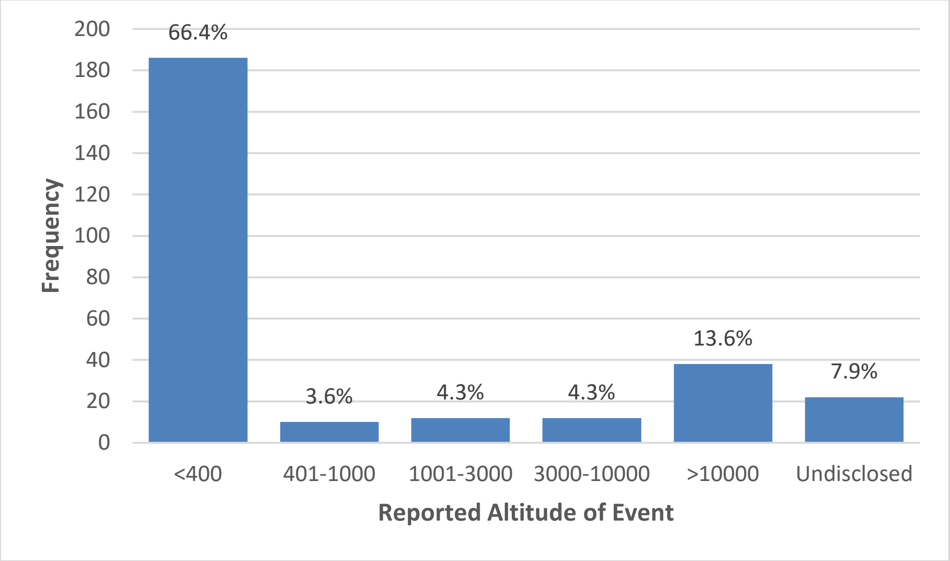


Note. Last report depicted from September 2022.

Reported Events by Altitude. As depicted in Figure 27, approximately 92% of the reported events included the altitude of the event. Approximately 66.4% of the events were reported as 400 feet and below, with 13.6% of the events reported as occurring over 10,000 feet.

Figure 27

Frequency of Reported Events by Altitude



Note. Event reports with the altitude omitted from the report are categorized as unreported.

Reported Events by Region. The ASRS event filing process requests the submission to include the geographic location of the event including the state of the occurrence. States were consolidated by geographic region, as depicted in Table 38, to facilitate the illustration of the reported events as can be seen in Figure 28. It should be noted that the top three regions by reported events, North-Central, Northeast, and Southwest all contain at least one FAA test site within their region. Two test sites are located within the Northeast region in Virginia and New York, and two test sites are located within the Southwest region in New Mexico and Nevada. This existence of the test sites within the region may account for the increased reported events within those regions.

Table 38

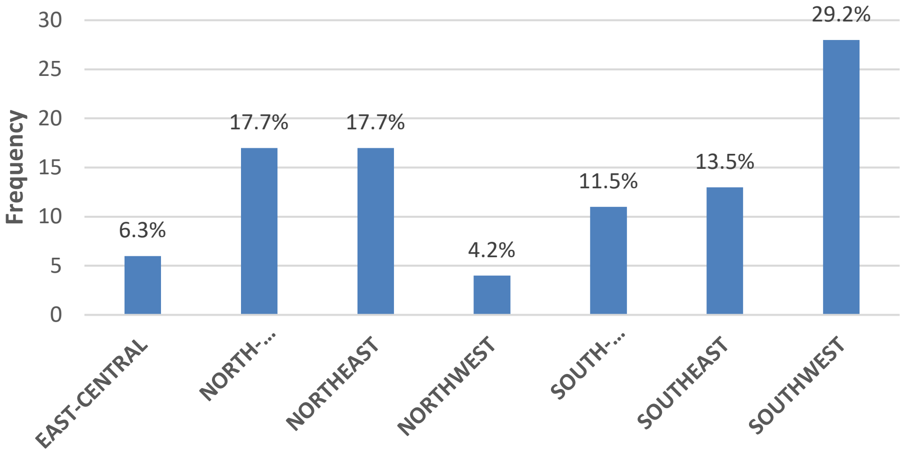
Consolidation of State by Geographic Region

Geographic Region	State
East-Central	Illinois, Indiana, Michigan, Ohio, Wisconsin
North-Central	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia
Northwest	Idaho, Montana, Oregon, Washington, Wyoming
South-Central	Arkansas, Louisiana, Mississippi, Oklahoma, Texas
Southeast	Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee
Southwest	Arizona, California, Colorado, Nevada, New Mexico, Utah

Note. One event was recorded within Alaska but was not included in analysis due to missing data within the report. No reports indicating the event occurred in Hawaii. Therefore, Alaska and Hawaii are not included above.

Figure 28

Reported Events by Region

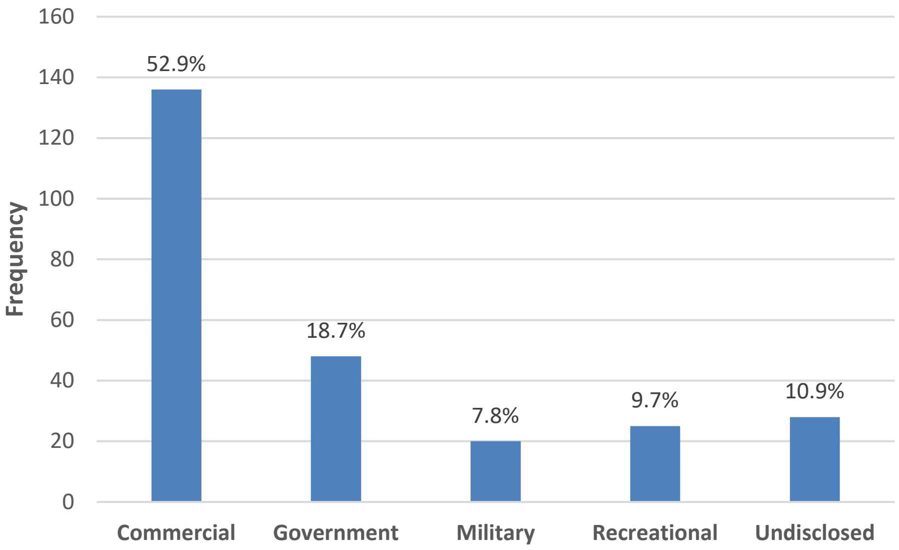


Note. 161 reports did not include the state of occurrence and were omitted from this figure.

Reported Events by Operator. ASRS reports include the type of operator for both primary and secondary aircraft within the report fields such as commercial, government, military, and recreational. Reports within the dataset where the operator field was omitted were categorized as undisclosed. The reported events within the dataset are depicted by operator in Figure 29.

Figure 29

Reported Events by Operator

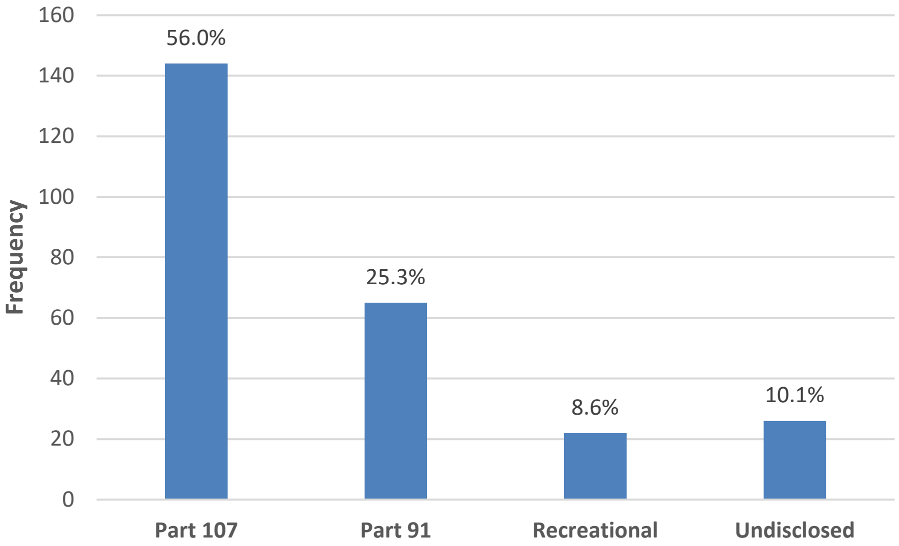


Note. Event reports with the type of operator omitted from the report are categorized as undisclosed.

Reported Events by FAR Part. Federal Aviation Regulations (FARs) are separated into parts which outlines the specific requirements for operations. Figure 30 depicts the reported events submitted by FAR part. Approximately 56% of the reports submitted indicate the operation was conducted under Part 107. It should be noted that the Part 107 rule became effective August 2016.

Figure 30

Reported Events by FAR Part



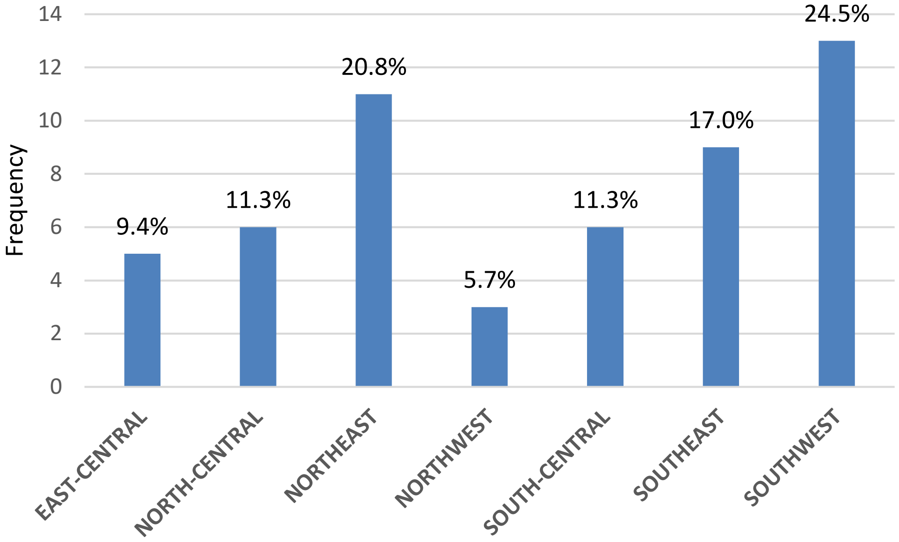
Note. Event reports with the FAR Part omitted from the report are categorized as undisclosed.

The majority of the event reports, approximately 56%, were conducted under Part 107 operations occurred within the Southwest region as depicted in Figure 31. Approximately 24.5% of the 161 event reports where the region was disclosed within the report occurred within the Southwest region, closely followed by the Northeast region at 20.8%.

Figure 32 depicts the total Part 107 remote pilot certificates held by region. The Southeast region contains the largest number of Part 107 remote pilot certificates followed by the Southwest region. Both the Southwest and Southeast regions contain the states with the largest number of Part 107 remote pilot certificates, specifically California with 30,798 certificates and Florida with 25,274, respectively.

Figure 31

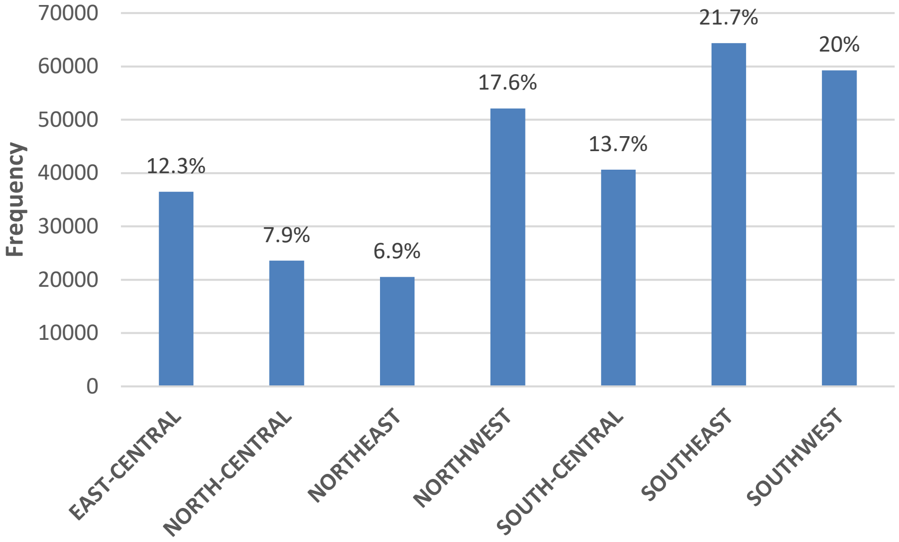
Part 107 Reported Events by Region



Note. Event reports with the region undisclosed (*n*=91) are not depicted.

Figure 32

Remote Pilot Certificates Held by Region

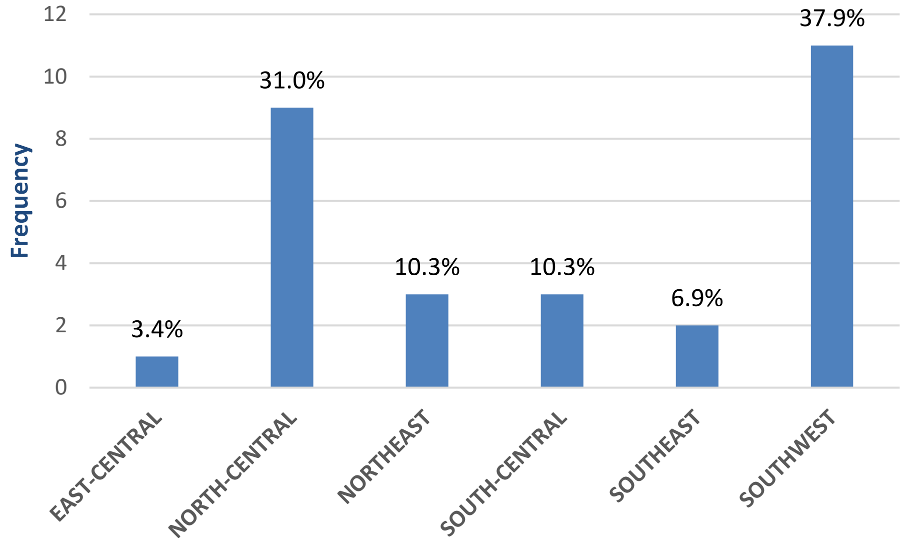


Note. Graph depicts total remote pilot certificates held as of December 31, 2022. Adapted from "2022 Active Civil Airman Statistics" retrieved from https://www.faa.gov/data_research/aviation_data_statistics/civil_airmen_statistics. In the public domain.

The reported events conducted under Part 91 operations were less than half of the total operations conducted under Part 107 as depicted in Figure 33. The Part 91 operations were conducted predominantly by government and military operators. The majority of Part 91 operations were conducted within the Southwest and North-Central regions, with the Southwest region accounting for 37.9%, and the North-Central region accounting for 31%, respectively.

Figure 33

Part 91 Reported Events by Region

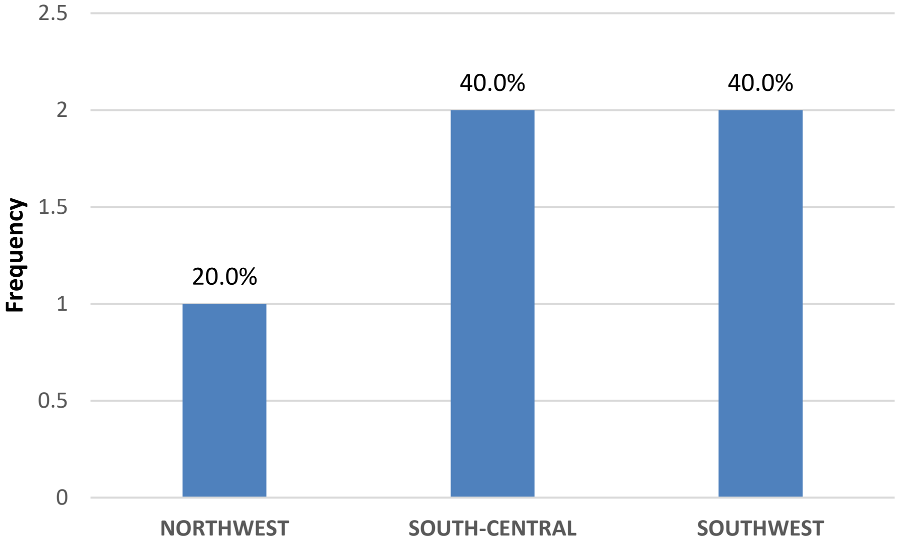


Note. Event reports with the region undisclosed (*n*=35) are not depicted.

Only 5 of 22 event reports listed as conducted under recreational operations disclosed the state of the event occurrence, as depicted in Figure 34. It should be noted that while there are no federal requirements to obtain an airman’s certificate to operate a UAS recreationally, the FAA requires all recreational operators to take the Recreational UAS Safety Test and register all recreational UAS over 0.55lbs (FAA, 2022).

Figure 34

Recreational Operations by Region

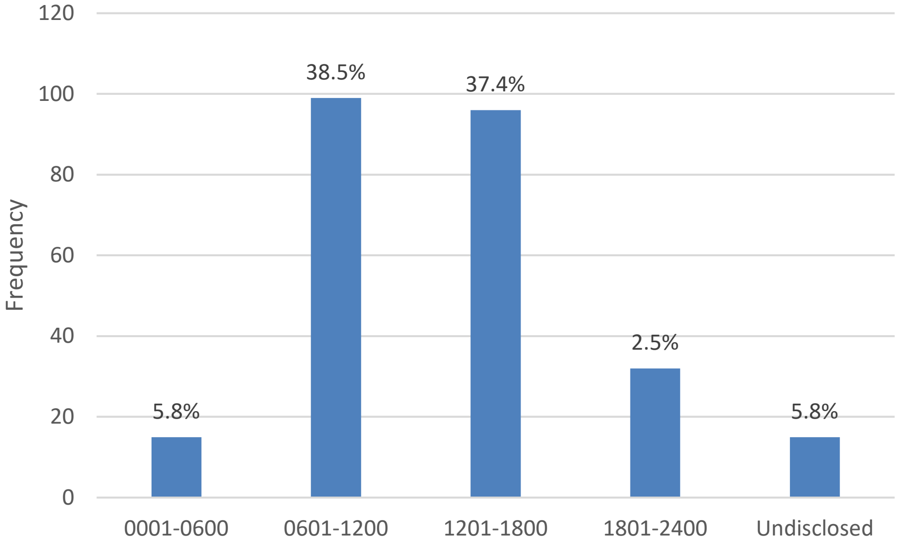


Note. Event reports with the region undisclosed (*n*=16) are not depicted.

Reported Events by Time of Day. Most of the event reports indicate that operations were primarily conducted during daylight hours. Approximately 76% of the flights were conducted during the day, with 18.3% conducted at night. Only 5.8% of the reports did not indicate the time of day for the event. The reported events by time of day are depicted in Figure 35.

Figure 35

Reported Events by Time of Day

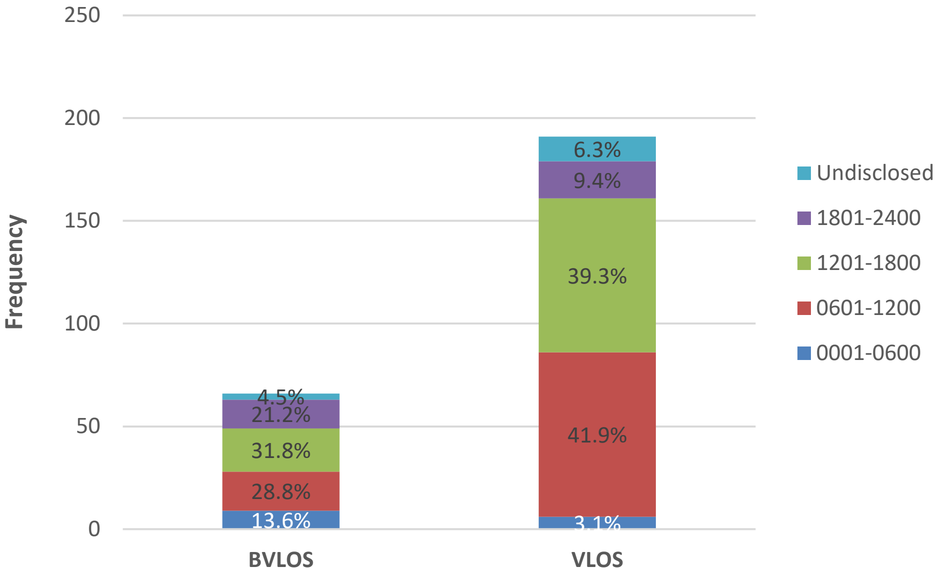


Note. Event reports with the time of day omitted from the report are categorized as undisclosed.

Reported Events by Mode of Operation. Most of the reported events were conducted under VLOS operations, approximately 75%, with approximately 25% of the reported events conducted under BVLOS operations. Figure 36 depicts the reported event mode of operation and is delineated by time of day. Of the total BVLOS operations, 60.6% were during daylight hours, with 34.8% conducted during night operations. Total VLOS operations included 81.2% of the reported events conducted during daylight hours, with 9.4% conducted during night operations. The largest portion of BVLOS flight operations occurred during the 1201-1800 time period, in contrast to VLOS operations, where 41.9% of operations occurred during the 0601-1200 time period.

Figure 36

Reported Event Mode of Operation by Time of Day

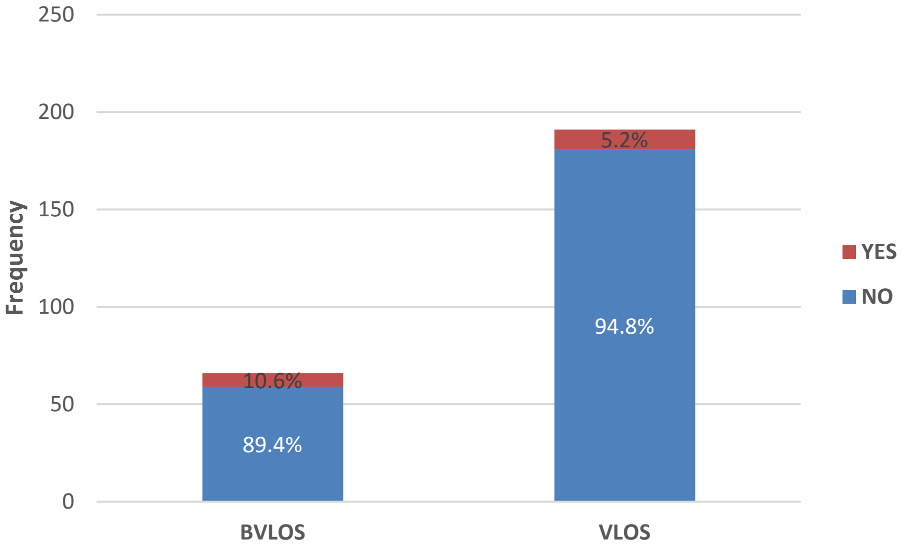


Note. The time of day is segmented into four 6-hour segments including one segment where the time of day was undisclosed within the report. BVLOS=beyond visual line of sight. VLOS=visual line of sight. Data point labels within each time-of-day segment indicate percentage of reports within that respective segment.

Workload Comparison; BVLOS and VLOS. A comparison of the workload human factor element as found within the dataset of 257 event reports, and further separated by BVLOS or VLOS operations, can be seen in Figure 37. Approximately 5.2% of all the event reports conducted under VLOS operations listed workload as a human factor element as compared to 10.6% for the event reports conducted under BVLOS operations.

Figure 37

Workload Comparison; BVLOS and VLOS

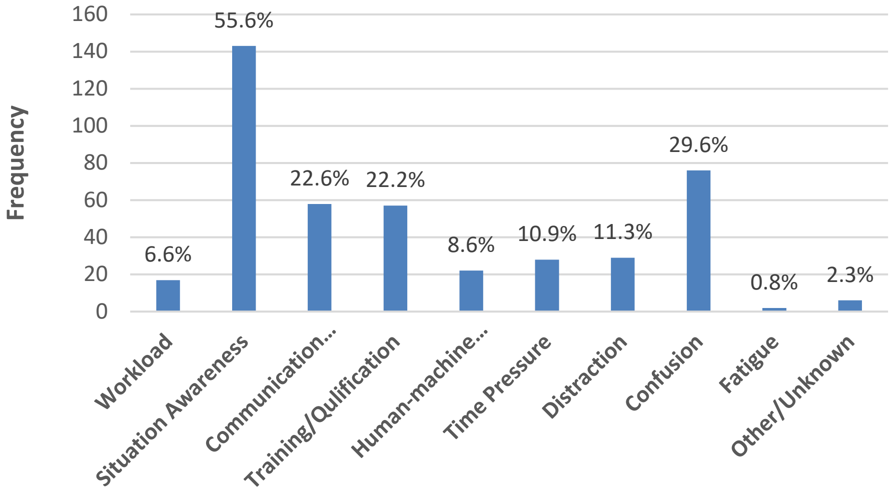


Note. BVLOS = beyond visual line of sight. VLOS = visual line of sight.

Reported Events by Human Factor Elements. There are 10 primary human factor elements identified by subject matter experts within the ASRS dataset; workload, SA, communication breakdown, training/qualification, HMI, time pressure, distraction, confusion, fatigue, and other/unknown. The human factor elements identified within the dataset of 257 reports submitted are depicted in Figure 38. The dataset of 257 reported events where the primary aircraft was listed as an unmanned aircraft system was further examined, specifically the reported events where SA was noted as a causal factor. The subset of the 257-report dataset where the human factor element of SA was identified as a causal factor contained 143 event reports. The additional human factor elements identified within the subset of 143 event reports is depicted in Figure 39.

Figure 38

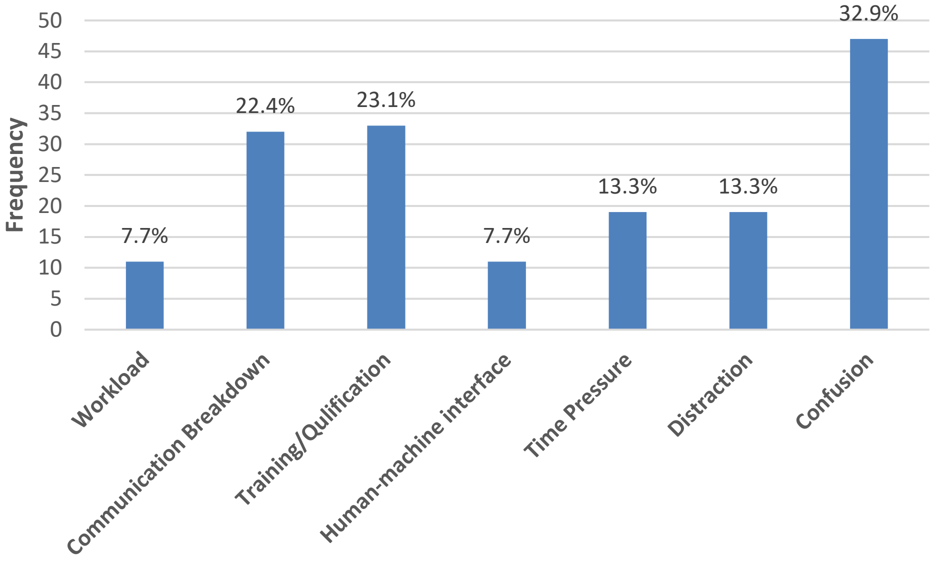
Human Factor Elements



Note. Data labels for each human factor element indicate percentage of element within the dataset of 257 reports.

Figure 39

Additional Human Factor Elements



Note. Data labels for each human factor element indicate percentage of element within the subset of 143 reports where situation awareness was identified as a causal factor.

Comparison Analysis – SA Subset

This section provides a comparison of the event reports within the downloaded ASRS dataset where the primary aircraft was listed as a UAS. Specifically, the comparison between event reports where SA was listed as a causal factor and event reports where SA was not listed as a causal factor. The purpose was to explore the characteristics of the reported events to identify specific factors that may be similar or unique to each group. The following figures within this subsection illustrate the characteristics of the subset of 257 event reports where the primary aircraft is listed as a UAS in relation to the 143 event reports within the 257 event reports where SA was identified as a causal factor.

Chi-Square Analysis. Chi-square tests were used to compare the characteristics of the reported events where SA was listed as a causal factor and the reported events where SA was not listed as a causal factor. The chi-square test results are depicted in two tables. The results for the baseline characteristics are depicted in Table 39 and the results for the human factor elements are depicted in Table 40. One hundred forty-three of the 257 reported events (55.6%) listed SA as a causal factor. The indicated region of the reported event was the only independent variable that had a significant relationship with SA being listed as a causal factor at a $p < 0.05$. There was a statistically significant association between the reported event's region and SA being listed as a causal factor, X^2 $(7) = 18.229$, $p = .011$. However, 5 cells (31.3%) had an expected count less than 5, therefore not meeting one of the required assumptions of the Chi-square test.

Table 39

Comparisons of Baseline Characteristics by SA Causal Factor Group

Characteristic	Overall Sample	SA noted as causal factor	SA not noted as causal factor	Chi square test of independence
Region				
Northeast	17 (6.6)	12 (8.5)	5 (4.4)	X^2 *(7)=18.229*^{a}
Southeast	13 (5.1)	7 (4.9)	6 (5.3)	*p*=0.011
North-Central	17 (6.6)	13 (9.2)	4 (3.5)	φ=0.267
South-Central	11 (4.3)	9 (6.3)	2 (1.8)	*n*=257
East-Central	6 (2.3)	5 (3.5)	1 (0.9)	
Southwest	28 (10.9)	20 (14.1)	8 (7.0)	
Northwest	3 (1.2)	1 (0.7)	2 (1.8)	
Undisclosed	161 (62.9)	75 (52.8)	86 (75.4)	
Time of Day				
0001-0600	15 (5.8)	6 (4.2)	9 (7.9)	X^2 *(4)=4.372*
0601-1200	99 (38.5)	55 (38.5)	44 (38.6)	*p*=0.358
1201-1800	96 (37.4)	55 (38.5)	41 (36.0)	φ=0.130
1801-2400	32 (12.5)	21 (14.7)	11 (9.6)	*n*=257
Undisclosed	15 (5.8)	6 (4.2)	9 (7.9)	
Aircraft Operator				
Commercial	86 (33.5)	48 (33.6)	38 (33.3)	X^2 *(4)=7.133*
Government	47 (18.3)	19 (13.3)	28 (24.6)	*p*=0.129
Military	21 (8.2)	15 (10.5)	6 (5.3)	φ=0.167
Recreational	75 (29.2)	45 (31.5)	30 (26.3)	*n*=257
Undisclosed	28 (10.9)	16 (11.2)	12 (10.5)	
Mode of Operation				
BVLOS	66 (25.7)	35 (24.5)	31 (27.2)	X^2 *(1)=0.245*
VLOS	191 (74.3)	108 (75.5)	83 (72.8)	*p*=0.62
				φ=0.31
				n=257
FAR Part				
Part 91	64 (24.9)	38 (26.6)	26 (22.8)	X^2 *(4)=7.174*^{b}
Part 107	139 (54.1)	83 (58.0)	56 (49.1)	*p*=0.129
Public	5 (1.9)	1 (0.7)	4 (3.5)	φ=0.167
Recreational	22 (8.6)	9 (6.3)	13 (11.4)	*n*=257
Undisclosed	27 (10.5)	12 (8.4)	15 (13.2)	

Note. a. 5 cells (31.3%) have expected count less than 5. B. 2 cells (20.0%) have expected count less than 5. BVLOS = beyond visual line of sight. VLOS = visual line of sight.

Table 40

Comparisons of Human Factor Elements by SA Causal Factor Group

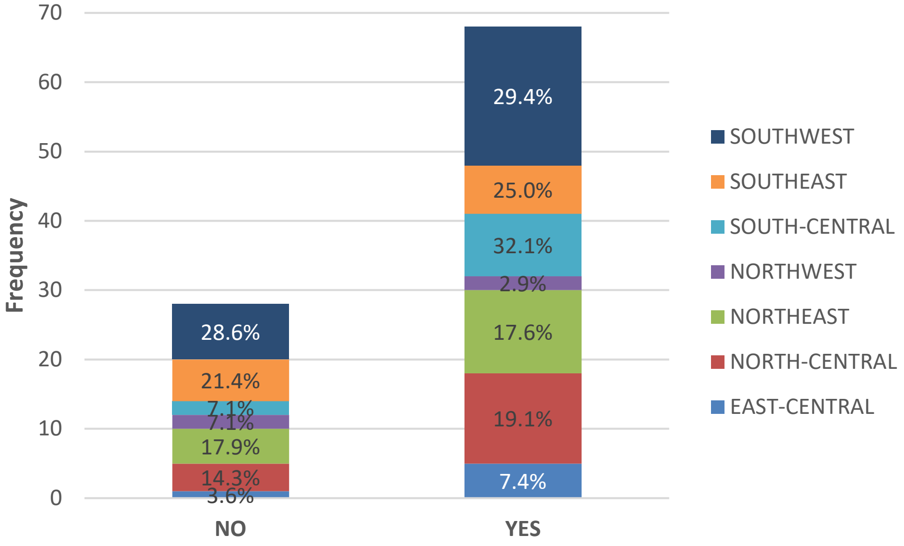
Characteristic	Overall Sample	SA noted as causal factor	SA not noted as causal factor	Chi square test of independence
Workload	17	11	6	X^2 (1)=0.606 p=0.436 φ=0.049 n=257
Communication Breakdown	58	32	26	X^2 (1)=0.007 p=0.935 φ=0.005 n=257
Training/Qualifications	57	33	24	X^2 (1)=0.151 p=0.698 φ=0.024 n=257
Human Machine Interface	22	11	11	X^2 (1)=0.310 p=0.577 φ=0.035 n=257
Time Pressure	28	19	9	X^2 (1)=1.90 p=0.168 φ=0.086 n=257
Distraction	29	19	10	X^2 (1)=1.292 p=0.256 φ=0.071 n=257
Confusion	76	47	29	X^2 (1)=1.681 p=0.195 φ=0.081 n=257
Fatigue	2	0	2	X^2 (1)=2.528[a] p=0.112 φ=0.099 n=257
Other/Unknown	6	3	3	X^2 (1)=0.079[a] p=0.778 φ=0.018 n=257

Note. a. 2 cells (50%) have expected count less than 5.

Comparison by Region; SA Listed as Causal Factor. The subset of 257 event reports was separated into two groups, one where SA was listed as a causal factor and the other where SA was not listed as a causal factor. These two groups are depicted in Figure 40 by group with 55.6% of the event reports listing SA as a causal factor and 44.4% not listing SA as a causal factor. Figure 40 further separates the two groups by region. It should be noted that 161 of the 257 event reports do not indicate the state of the event occurrence and are not depicted within the figure.

Figure 40

Comparison by Region; SA Listed as Causal Factor

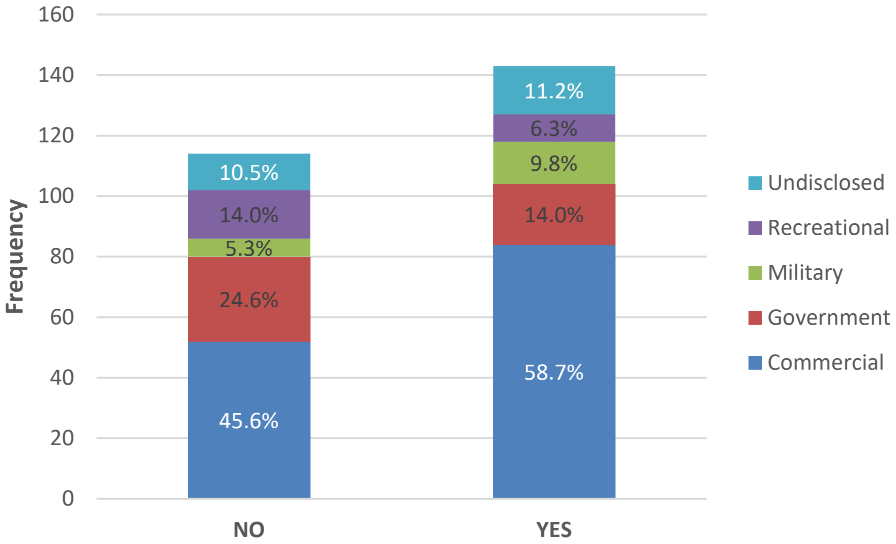


Note. Subset of 257 event reports where the primary aircraft is listed as a UAS. The NO column depicts the event reports where SA was not listed as a causal factor. The YES column depicts the event reports where SA was listed as a causal factor.

Comparison by Operator; SA Listed as Causal Factor. The event reports are categorized by operator to include military, government, commercial, and recreational. All event reports where the operator field was omitted were categorized as undisclosed. There were 28 of 257 records where the aircraft operator was categorized as undisclosed. The reported events are presented in two groups, where SA was listed as a causal factor and where SA was not listed as a causal factor with group composition delineated by operator in Figure 41. Additionally, Figure 41 depicts the reported events by operator with respective percentage of events within the SA listed as a causal factor group.

Figure 41

Reported Events by Operator; SA Listed as Causal Factor

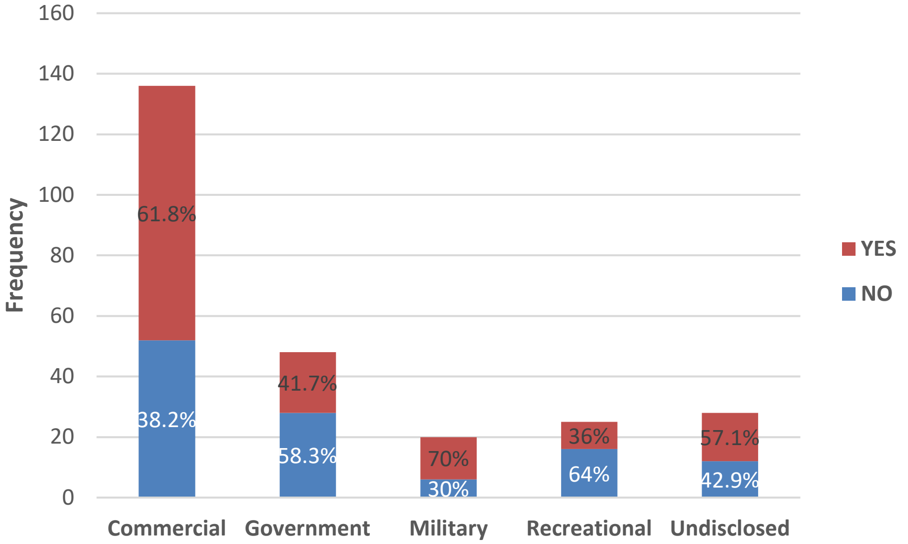


Note. Subset of 257 event reports where the primary aircraft is listed as a UAS. The NO column depicts the event reports where SA was not listed as a causal factor. The YES column depicts the event reports where SA was listed as a causal factor.

The majority of the 257 event reports listed SA as a causal factor across all categories of aircraft operator except the event reports for government and recreational operations as depicted in Figure 42. Approximately 60% of the event reports for government operations and 64% of the event reports for recreational operations listed SA was not a causal factor, respectively.

Figure 42

Situation Awareness Factor by Operator; All 257 Records

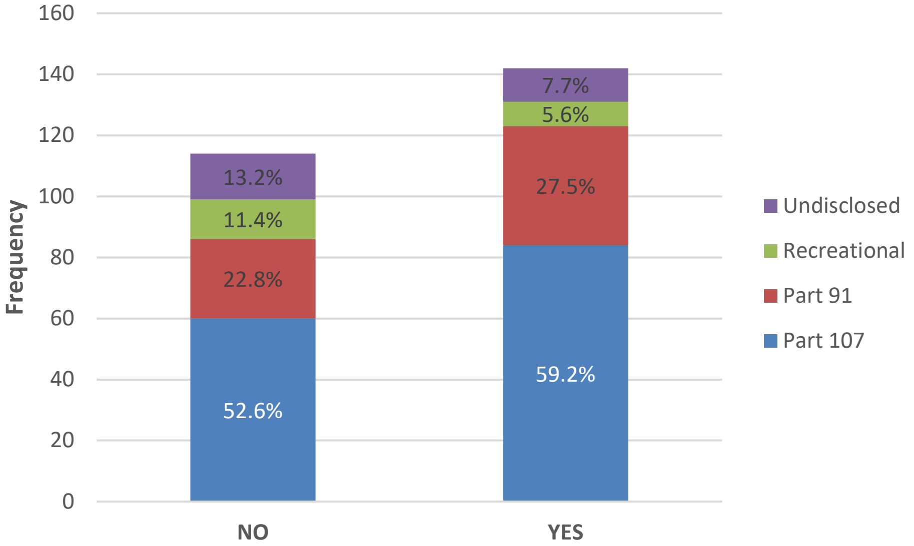


Note. Yes/no columns represent event reports where SA was/was not listed as causal factor. Percentages shown are in reference to the operator's proportion of yes to no event reports.

Comparison by FAR Part; SA Listed as Causal Factor. Most reported events were operating under FAR Part 107 regulations. Over 50% of all operations, regardless of SA being listed as a causal factor or not within the event reports, were FAR Part 107 operations as depicted in Figure 43.

Figure 43

Reported Events by FAR Part; SA Listed as Causal Factor

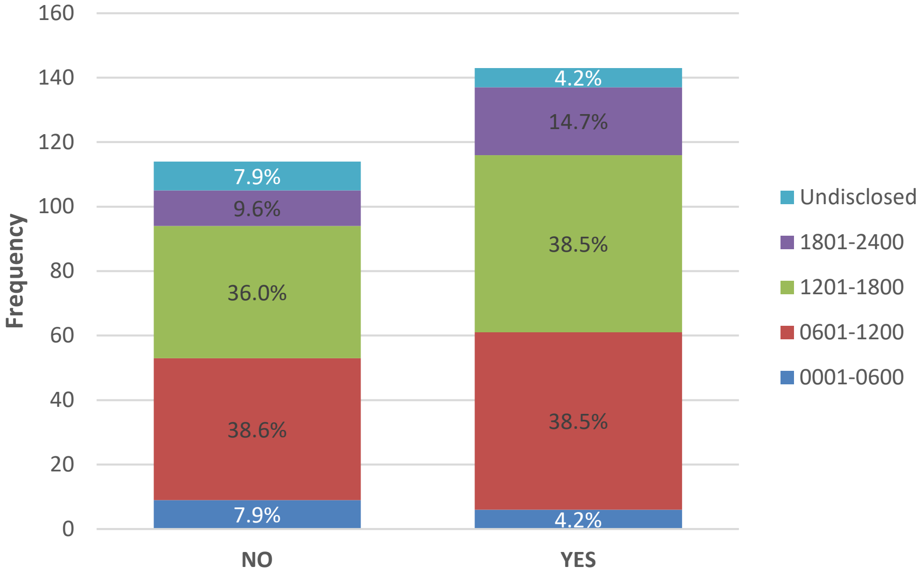


Note. Subset of 257 event reports where the primary aircraft is listed as a UAS. The NO column depicts the event reports where SA was not listed as a causal factor. The YES column depicts the event reports where SA was listed as a causal factor

Comparison by Time of Day; SA Listed as Causal Factor. Most of the reported events were listed as occurring between 0601-1800, during daylight hours. Only 18.5% of the reported events where SA was not listed as a causal factor were conducted during the night. Similarly, 18.9% of the reported events where SA was listed as a causal factor were conducted at night, as depicted in Figure 44.

Figure 44

Reported Events by Time of Day; SA Listed as Causal Factor



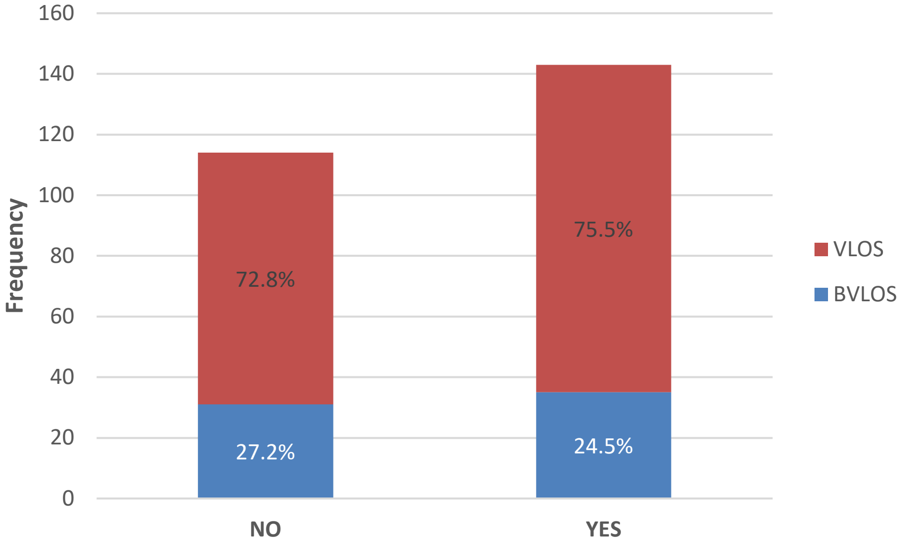
Note. Subset of 257 event reports where the primary aircraft is listed as a UAS. The NO column depicts the event reports where SA was not listed as a causal factor. The YES column depicts the event reports where SA was listed as a causal factor.

Comparison by Mode of Operation; SA Listed as Causal Factor.

Approximately 74% of the 257 reported events where the UAS was listed as the primary aircraft were conducted during VLOS operations as depicted in Figure 45. In addition, 53% of the reported events listed as BVLOS operations had SA listed as a causal factor, whereas 56.5% of the reported events listed as VLOS operations had SA listed as a causal factor.

Figure 45

Mode of Operation; SA Listed as Causal Factor

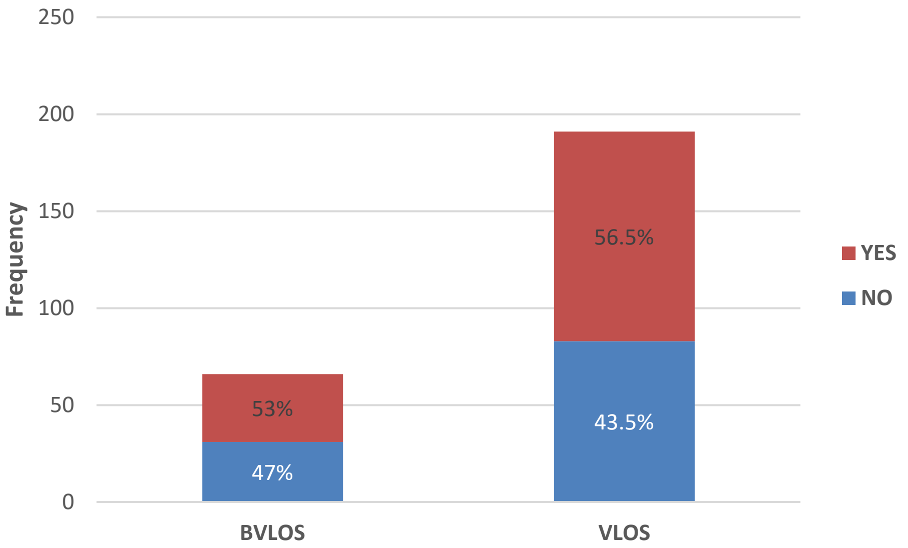


Note. Subset of 257 event reports where the primary aircraft is listed as a UAS. The NO column depicts the event reports where SA was not listed as a causal factor. The YES column depicts the event reports where SA was listed as a causal factor. BVLOS = beyond visual line of sight. VLOS = visual line of sight.

A comparison of the SA human factor element as found within the dataset of 257 event reports, and further separated by BVLOS or VLOS operations, can be seen in Figure 46. SA was listed as a human factor element in 53% of the event reports conducted under BVLOS operations and 56.5% of the event reports conducted under VLOS conditions, respectively.

Figure 46

Situation Awareness Comparison; BVLOS and VLOS

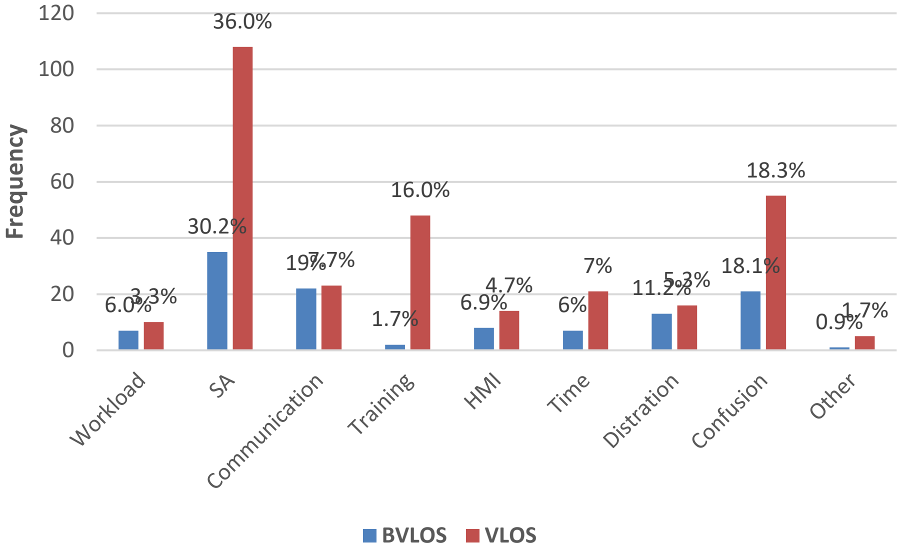


Note. BVLOS = beyond visual line of sight. VLOS = visual line of sight.

SA was the leading human factor element identified as a causal factor within the 257 event reports for both BVLOS (30.2%) and VLOS (36%) operations as depicted in Figure 47. For BVLOS operations, the second leading human factor element was communication (19%) followed closely by confusion (18.1%). For VLOS operations, the second leading human factor element was confusion (18.3%) followed by training (16%). While the training human factor element was listed as a causal factor in 16% of the event reports for VLOS operations, only 1.7% of the event reports for BVLOS operations listed the training human factor element as a causal factor.

Figure 47

Human Factor Elements by Mode of Operation

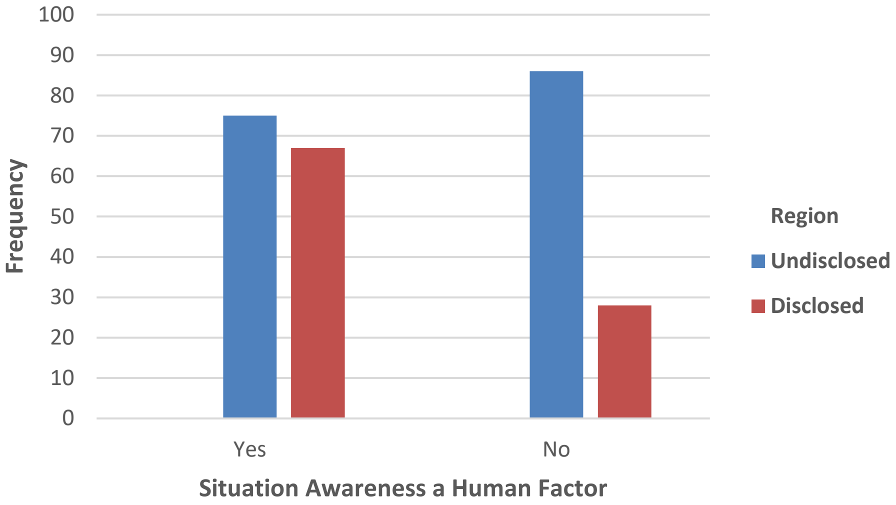


Note. Values at top of columns represent percentage of total reported human factor element for the respective mode of operation. SA = situation awareness. HMI = human-machine interface. BVLOS = beyond visual line of sight. VLOS = visual line of sight.

To further explore the association between the region variable and SA, the region variable categories were collapsed to address the low expected cell counts to re-run the Chi-square test. The region variable was recategorized to include two categories, disclosed and undisclosed. All event reports where the reporter listed the state of occurrence were categorized as disclosed, and reports which omitted the state of occurrence remained categorized as undisclosed. The test was re-run and all expected cell frequencies were greater than 5. There was a statistically significant association between the reported event's region and SA being listed as a Causal factor, X^2 (1) = 13.865, p <.001. Graphical presentation of the association is depicted in Figure 48.

Figure 48

Chi-square Test of Association; SA and Region

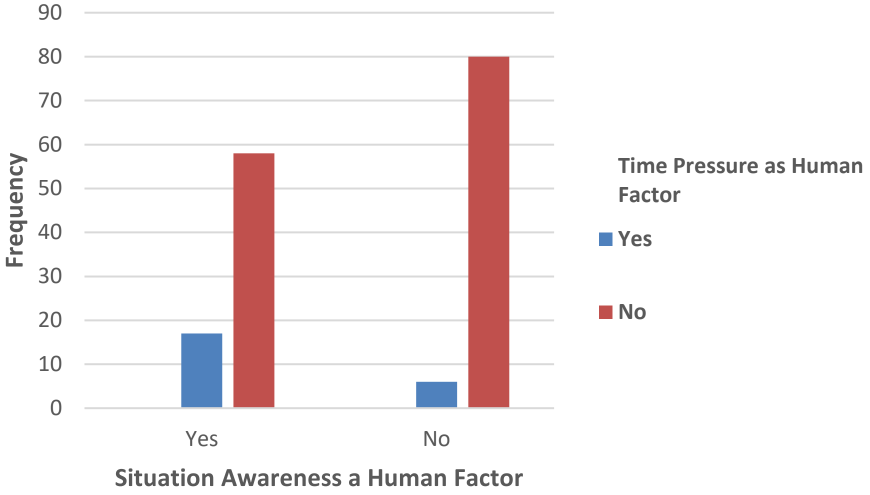


Note. Event reports with the state of occurrence listed within the event report are categorized as disclosed. Event reports with the state of occurrence omitted from the event report are categorized as undisclosed.

In an effort to understand if there was a specific region responsible for the significant association between the region variable and SA being listed as a causal factor, each individual region was filtered out of the dataset and the Chi-square test was again conducted. There were no statistically significant associations identified within the results of the Chi-square tests conducted on each individual region. However, 161 of the 257 event reports did not identify the state of the event occurrence and were coded in the region variable as undisclosed. The Chi-square test was conducted on the subset of 161 event reports where the region was undisclosed. All expected cell frequencies were greater than five. The results indicated there was a statistically significant association between the human factor element of time pressure and SA within the event reports, X^2 (1) = 8.054, p =.005. A visual representation of this relationship is depicted in Figure 49.

Figure 49

Chi-square Test of Association; SA and Time Pressure

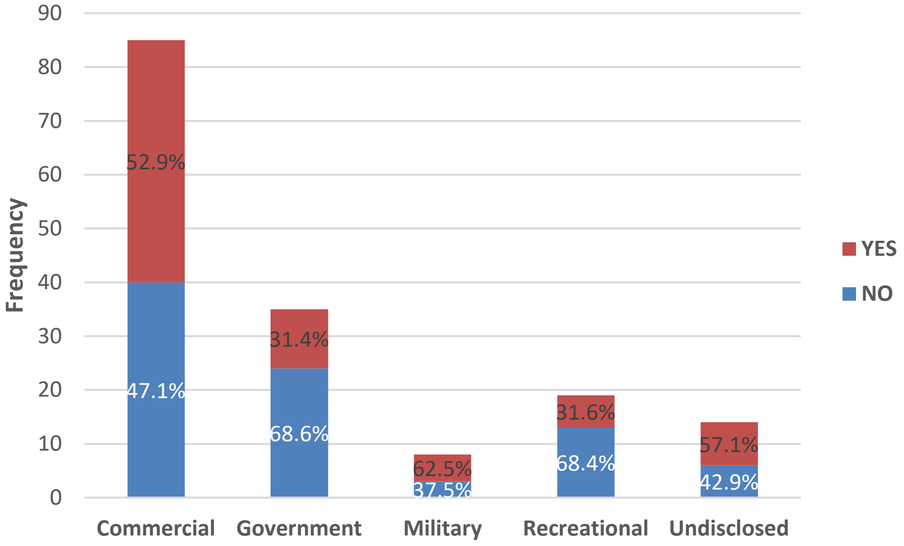


Note. Subset of 161 of 257 event reports where the region was undisclosed.

The omission of the state of occurrence within 161 event reports fostered additional examination to identify the characteristics of the reports where the state was reported versus not reported. As seen in Figure 50, most of the event reports listed SA as a causal factor within the event report except the event reports for government and recreational operations, which listed SA as a causal factor in only 31.4% and 31.2% of the reports submitted, respectively. Commercial operators event reports were almost split with approximately 48% of the event reports listing SA as a causal factor. Further, examination of the 95 event reports out of the 257, where the event report included the state of event occurrence, illustrates that SA was listed as a causal factor in most event reports across all aircraft operator categories as depicted in Figure 51.

Figure 50

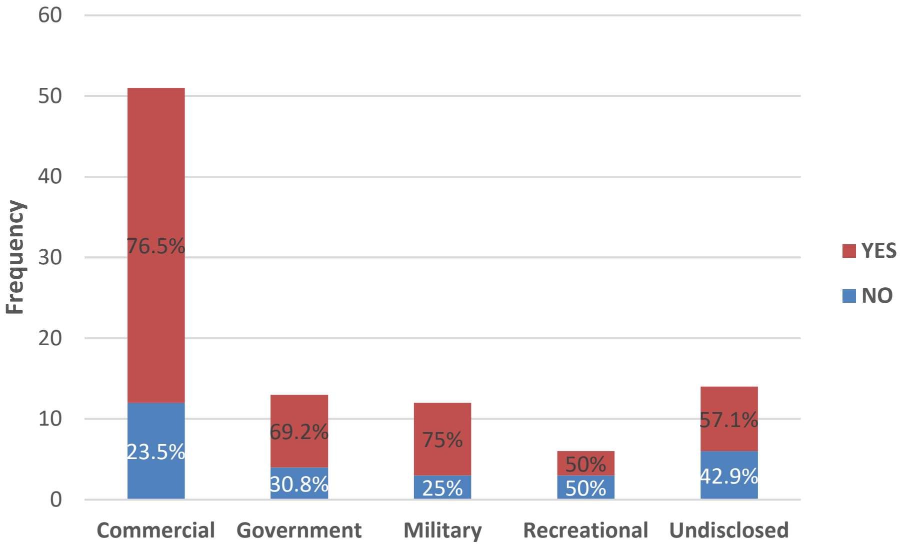
Situation Awareness Factor by Operator; 161 Undisclosed Records



Note. Yes/no columns represent event reports where SA was/was not listed as causal factor. Percentages shown are in reference to the operator's proportion of yes to no event reports.

Figure 51

Situation Awareness Factor by Operator; Disclosed Region 95 Records



Note. Yes/no columns represent event reports where SA was/was not listed as causal factor. Percentages shown are in reference to the operator's proportion of yes to no event reports.

Summary

Statistical analyses were conducted to test for variability between the three experimental groups. The ANOVA test results found no statistically significant differences between the three experimental groups in reference to age, computer gaming experience, Part 107 certificate possession, and private pilot certificate possession. Two separate ANOVA test procedures were conducted for the two dependent variables because the literature (Durso et al., 1999; Endsley, 1993; Vidulich, 2000) showed perceived workload and SA are two distinct constructs. The results indicated there were no statistically significant differences between the three experimental groups for both participants' SA and perceived workload scores. The additional analysis with the ANCOVA procedure did not result in any significant differences. Further exploratory analysis was conducted on a dataset retrieved from NASA's ASRS database. Specifically, event reports where the primary aircraft was listed as a UAS. SA was identified as the most prevalent causal factor among the human factor elements within the event reports.

Chapter V: Discussion, Conclusions, and Recommendations

The operation of sUAS in an expanding array of civil applications introduces a host of challenges for the integration of unmanned operations of aircraft within the NAS in both controlled and uncontrolled airspace (Avanzini et al., 2021). While regulations and infrastructure continue to develop toward the utilization of a traffic management system that supports autonomous operations of sUAS within the NAS, the human-autonomy interaction will remain, commanding operator attention to workload and SA (Politowicz et al., 2021). The SA and workload of sUAS operators must be considered before, during, and after sUAS flight operations to establish and maintain the required equivalent level of safety for unmanned aircraft. See-and-avoid operations of sUAS are impacted by numerous factors such as "variability of pilot visual acuity and air-to-air visibility, target size and aspect, target contrast, back-ground complexity, crew workload, and search patterns, and sun position" (Graham, 1989, p. 6; see also Woo et al., 2020).

Discussion

The current study explored the effects of the utilization of FPV visual acuity techniques on sUAS operator perceived workload and SA. In this study, one independent variable with three levels (i.e., VLOS, FPV LCD, and FPV GOGS) was used to determine what effect these levels had on sUAS operator perceived workload and SA. The VLOS group of participants operated the sUAS on the flight course without the use of any visual acuity enhancing device and solely relied on piloting the sUAS via direct visual line-of-sight. The FPV LCD group of participants operated the sUAS on the flight course utilizing a Dell 21-in. LCD monitor to view the live video feed transmitted from the sUAS's onboard camera. The FPV GOGS group operated the sUAS on the flight course utilizing DJI FPV goggles to view the live video feed transmitted from the sUAS's onboard camera. Twenty-four participants were recruited to produce a sample that represented the population of personnel eligible to apply for a Part 107 remote pilot certificate within the state of Florida. The sample included participants with and without formal flight training in manned aircraft and included participants with and without sUAS flight experience. In this study, the participants piloted a sUAS on an experimental flight course within a controlled setting utilizing one of three visual acuity techniques to measure sUAS operator perceived workload and SA. The study was guided by two research questions focused on sUAS operator workload and Level 1 SA.

RQ1 - What effect will the utilization of FPV techniques have on the sUAS operator's perceived workload?

Hart and Staveland (1988) defined workload as "a hypothetical construct that represents the cost incurred by a human operator to achieve a particular level of performance" (p. 2). This definition inherently focuses on the human element as opposed to the task at hand. In addition, workload is a composite of an operator's perceived experience, as derived from the interaction between the task objectives, the environment and conditions of operations, and the operator's abilities and level of skill (Hart & Staveland, 1988). Research question 1 was investigated with consideration of this definition of workload.

The research hypotheses derived from this research question posited that utilizing different FPV techniques (using a FPV LCD screen and FPV goggles) during operation of sUAS will have a differential effect on the operator's perceived workload when compared to the perceived workload under VLOS operational conditions. The null hypothesis for this research question states that utilizing FPV techniques during operation of sUAS will not have a differential effect on the operator's perceived workload, as compared to VLOS. The results from this experiment found no statistically significant difference in the sUAS operator's perceived workload as assessed by the NASA TLX questionnaire scores for each level of the visual acuity techniques (VLOS, FPV LCD, and FPV GOGS).

The findings revealed operating the sUAS via the FPV goggles did not produce a statistically significant difference in perceived workload among the participants, as assessed by the NASA TLX questionnaire scores, from piloting the sUAS via the FPV technique utilizing the LCD monitor or from piloting the sUAS via VLOS. In addition, the findings revealed no statistically significant difference in perceived workload between the two groups utilizing the FPV techniques (i.e., goggles or the LCD monitor). These findings suggest that utilizing FPV techniques as used in this study would neither increase nor decrease the apparent sUAS operator workload beyond what is experienced when operating a sUAS via direct line-of-sight. This lends support to the recent work by Rebensky (2020) in which the researcher found no statistically significant difference in the UAS operators perceived workload while using one of two visual acuity techniques: using two LCD screens displaying the environment and the UAS flight parameters or combining the UAS flight parameters into a HUD utilizing only one screen.

One plausible explanation for this result can be found in research on eye movement. Bellenkes et al. (1997) who examined the connection between increased mental workload and eye movements and Wickens et al. (2004) and Causse et al. (2011) examined the connection between eye movements and aircrew's mental workload. In these latter two studies, it was discovered that the duration of the aircrew's fixation was the first parameter to change with increased levels of stress within the cockpit. Extending this earlier research, Škvareková et al. (2020) measured aircrew workload based on the eye movements of their test subjects. As discussed in Škvareková et al. (2020), during periods of increased cognitive demands, aircrew eye movements tended to fixate, experiencing extended periods of eye dwelling on specific targets, thus focusing on one of many elements of the spatial array of the environment on the fovea.

Similarly, in this research, the participants within each group experienced the increased cognitive demand, i.e., increased "demand for controlled information processing" (Kool et. al., 2010, p. 1), of operating the sUAS within an environment inherent with equal levels of flight safety risk, as each group flew at the same altitude relative to the known flight course obstacles and the type, number, and position of flight course obstacles were identical for each group. This increased cognitive demand may have channeled the participants' fixation on the aircraft itself as flight progressed from start to finish on the flight course. One plausible explanation is that the aircraft's immediate proximity to the threat of impact with the ground and the known flight course obstacles may have 'locked' the participants' fixation on the aircraft itself from flight start to finish. This visual fixation on the aircraft, and likely on the white boxes along the flight course path center where balloons (flight obstacles) might be released, has similarities with the research by Škvareková et al. (2020) and Bellenkes et al. (1997) in that increased workload rate tended to elicit increased eye fixation rates. Based on the similar Level 1 SA scores across all treatment groups, it can be inferred that all three groups experienced a relatively similar level of workload during the experiment, which could indicate similar levels of eye fixation in terms of target location within the participants’ spatial array and target dwell time. This could be a plausible explanation for the approximately equivalent levels of perceived workload and Level 1 SA results for all treatment groups.

Another plausible explanation for a lack of statistically significant differences in perceived workload between the groups is that the nature of the central task demand was identical for all participants. While the VLOS group had direct visual contact of the spatial array of the flight course, both FPV groups (LCD and GOGS) also had visual contact of the spatial array of the flight course, albeit their visual field of view (FOV) was electronically reproduced. Additionally, cognitive areas in the brain that exhibit preferential activity (e.g., memory storage) for objects closest to where a person is looking (Goldstein & Brockmole, 2016) could also explain why the participants from each group shared the relatively same perception of mental workload.

Analysis of the ASRS dataset identified UAS operator workload as one of the least frequently occurring human element factors present within the event reports. In reference to Figure 37, workload is listed as the third least frequent occurring human factor element within the 257 event reports, occurring in 6.6% of the reports. Only fatigue and other/unknown human factor elements were lower, at 0.8% and 2.3%, respectively.

In reference to Figure 36, only 5.2% of all the event reports conducted under VLOS operations listed workload as a human factor element as compared to 10.6% for the event reports conducted under BVLOS operations. The small differences in event reports listing the human factor element of workload within the BVLOS and VLOS operational groups in Figure 36 is congruent with the experiment findings where there were no statistically significant differences between the experimental groups perceived workload as captured within the NASA TLX scores.

In observation of the experiment findings and the analysis of the ASRS dataset, it does not appear that the additional system automation requirements for BVLOS operations increased the operator workload significantly beyond that experienced during VLOS operations. However, while studies have shown that reductions in operator workload can be experienced with system automation, this benefit is mostly associated with routine operations. In cases of unexpected events or emergency situations, workload levels may be increased by the demands of automation (Lin et al., 2018; Liu et al., 2009). The level of impact automation will have on operator workload depends on various factors such as the HMI design of automation, operator training and proficiency on the systems, and specific task parameters for the mission (Lin et al., 2018). While automation requirements can decrease the UAS operator's workload, poor design and improper use of the automation may fail to reduce workload as intended (Lin et al., 2018).

RQ2 - What effect will the utilization of FPV techniques have on the sUAS operator's Level 1 SA?

The participants' Level 1 SA was recorded as assessed by the Level 1 SA test administered immediately after the participants exited the flight course area. The test assessed the participants' short term memory recall of the elements present within the flight course environment, specifically, the obstacles on the flight course, the position of the obstacles on the flight course, and their color and pictogram shape.

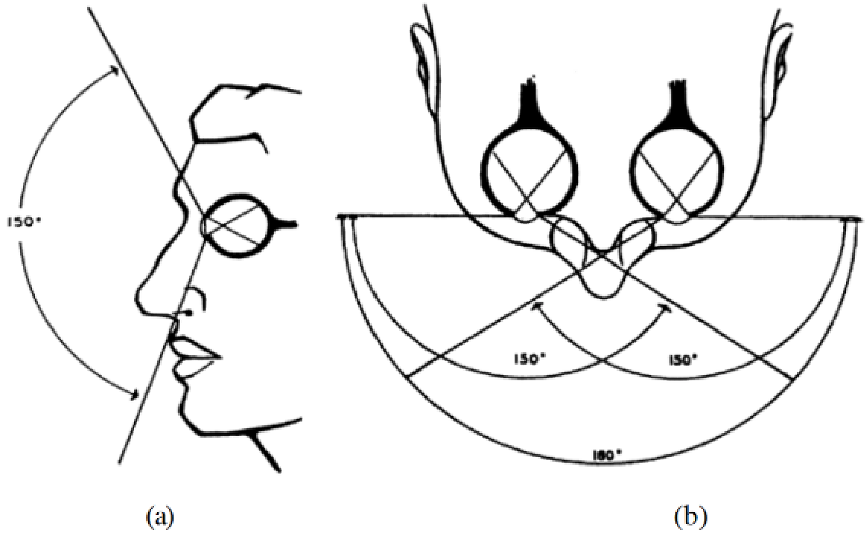
Regarding research question 2, there was not a statistically significant difference between the VLOS group SA scores and the two FPV visual acuity technique groups. This finding suggests that operating a sUAS utilizing FPV goggles or using a ground-control station with an LCD monitor for visual acuity would provide the equivalent level of SA as operating the sUAS via direct line-of-sight.

While the VLOS group benefited from a greater FOV as compared to the two FPV techniques, the reduction in the FOV did not appear to influence the participants' Level 1 SA. The participants' Level 1 SA, as assessed by the SA test, consisted of their recall of the elements they perceived within the research testing environment. Their Level 1 SA was their perception of the flight course and established obstacles within the environment of the flight course while piloting the sUAS. The VLOS group's perception of the flight course environment was with the unaided, their naked eyes. The FPV groups, utilizing the FPV goggles and the FPV LCD screen for visual acuity, both experienced electronic enhancement of the flight course as they viewed the course via live streaming video as it was broadcast through the onboard camera of the sUAS.

The VLOS group operated the sUAS from a stationary vantage point solely with unaided eyes. Therefore, these participants were subject to the physiological limitations of the human eyes while viewing the flight course. The FOV of the unaided human eye is comprised of two, separate monocular FOVs, but the brain combines them into one binocular FOV. Each monocular FOV is made up of a nasal FOV of approximately 60º from the vertical meridian of each eye and a temporal FOV of approximately 107º from the vertical meridian (Walker et al, 1990). The total binocular FOV encompasses 180º along the horizontal meridian (Strasburger & Pöppel, 2002). The horizontal and vertical fields of view are depicted in Figure 52.

Figure 52

Human Eye Field of View



Note. Panel a: Vertical field of view of the human eye. Panel b: Horizontal field of view of the human eye. Adapted from "Virtual Reality-History, Applications, Technology and Future" by T. Mazuryk and M. Gervautz, 1999, p. 16 (https://www.cg.tuwien.ac.at/research/publications/1996/mazuryk-1996-VRH/TR-186-2-96-06Paper.pdf). Copyright by Computer Science.

The camera on the Inspire 1 sUAS has a FOV of 94º. The lens is 20 mm with a f/2.8 focus that focuses on both the horizontal and vertical points at the same time. The DJI Goggles have a single screen FOV of 85º that reduced the participants' view of the Inspire FOV of 94º by 9º. The data collected from the two FPV visual acuity groups did not support the hypotheses that there was a statistically significant difference in the Level 1 SA test scores. Therefore, it can be inferred that the 9º difference between the two FPV group's FOV had no statistically significant effect on the participants' perception of the elements within the flight course environment.

Fixations and Peripheral Acuity. Visual operations throughout normal daily life consists of a myriad of eye fixations in a multitude of patterns of various durations of time that are specific for every task (Shinoda et al., 2001). Physical activities such as cricket, table tennis, driving, and making tea and sandwiches have demonstrated that specific fixation patterns can be associated with the specific task (Shinoda et al., 2001). "Fixation is defined as a condition in which an individual visually collects and interprets information available in the foveal range of the eye, over a period of time that is longer than 80 ms" (Škvareková et al., 2020, p. 68; see also Homqvist et al., 2011). While various tasks may have similar visual stimuli, the performance goals of the viewer can be quite different, and this certainly holds true for the participants in this study as well. The successful navigation of the sUAS on the flight course demanded a series of very precise eye fixations on the part of each participant, regardless of the modality of visual acuity. The participants' task–to safely navigate the flight course without hitting the obstacles known to exist within the environment of the flight course–was the participants' primary cognitive goal. However, the unpredictability of additional visual input, such as the unexpected release of a balloon into the flight path of the sUAS, directed the participants' foveal target to the sUAS and the associated flight course boxes that could introduce a balloon into the flight path of the sUAS. The lack of significant differences in the results using the design of experimental flight course would suggest that participants from all three treatment groups may have conducted some "pre-attentive analysis" (Shinoda et al., 2001, p. 3536) of the flight course environment upon first viewing the course immediately prior to their flight task. Specifically, such analysis would have identified potential threats to the sUAS on the flight course and associated levels of risk for each threat. In addition, as the participants' image of the environment changed as the sUAS progressed from the start to finish of the course, this required the participant to continue to direct their attention to the sUAS and its relation to the remaining balloon boxes and known flight course obstacles. This lends support to research by Folk et al. (1992) that proposed participants "adopt an 'attentional control setting' that determines which features will control the deployment of attention in any given task" (p. 3536).

Retinotopic Map. As the participants were introduced to the environment of the flight course, reflected light from objects within the participants' visual space began to penetrate their retina, becoming a vast number of electrical signals sent to specific areas within the striate cortex of the brain (Goldstein & Brockmole, 2016). An interesting characteristic of this process is that the retinal image, as it is processed and mapped within the brain, is not allocated equally, so that representation of the total image on the cortex is distorted (Goldstein & Brockmole, 2016). The portion of the retinal image that receives the primary focus is centered on the fovea, unlike objects in the periphery of the retina (Goldstein & Brockmole, 2016). This map of the retinal image transformed into electrical signals on the cortex is called the retinotopic map. The result of this retinotopic mapping is more cortical brain activity for the main fixation task, as when focusing on the sUAS in flight, compared to objects that are within the peripheral FOV, such as the course obstacles. Therefore, the lack of statistically significantly different Level 1 SA scores for the participants within each group can be explained by similar target fixation on the sUAS while navigating the flight course, thus, similar retinotopic mapping. This plausible explanation suggests that more space was allocated on the cortex for the retinal image that passed through the fovea, the central fixation on the sUAS during flight, than was allocated for the known obstacles on the flight course positioned on the periphery of the participants' retinal area.

Useful Field of View. The sUAS operator faces a complex set of visual demands. Safely operating a sUAS occurs within a visually cluttered environment requiring the operator to process both central and peripheral vision simultaneously while accomplishing the primary central task demand. Visual information observed by the participants during the experiment was obtained by the participants' individual eye movements and their *useful field of view* (UFOV), defined by Ball et al. (1988) as "the total visual field area in which useful information can be acquired without eye and head movements (i.e., with one eye fixation)" (p. 2210). Measuring UFOV includes detecting, locating, or identifying objects against complex visual backgrounds. Ball et al. (1993) found at a minimum an individual's UFOV is a function of the target of their central task demand, the degree of complexity of a secondary task, if assigned, and the salience of existing peripheral targets (p. 3112). Research by Ikeda and Takeuchi (1975), Williams (1982), Drury and Clement (1978), and Seya et al. (2013) found that reductions in UFOV would occur with the simple presence of a foveal stimulus. In addition, the researchers also discovered that the detection of peripheral objects would be further impaired by increasing the central task demand. This reduction in the UFOV could also be applied to the participants within this study, as their central task demand was high as they operated the sUAS. It is plausible that the intensity of the participants' central task demand decreased their UFOV, thus impairing their detection of peripheral objects, the known obstacles on the flight course. The lack of statistically significant differences in the Level 1 SA scores suggests this reduction in UFOV was experienced similarly across all three groups. Similarly, research by Mackworth (1976) on UFOV identified that objects can be detected at 58º from the central fixation point and can be identified at 10−15º from the central fixation point. Additionally, Mackworth's (1965) and (1976) research found the UFOV will contract in order prevent overloading of the visual system and referred to this overloading as *tunnel vision*. Such tunnel vision would account for lower Level 1 SA test score results shared by all participants within the three groups. It is also plausible that identification of the obstacles on the flight course was hindered because the known obstacle's location relative to the participants central fixation point on the aircraft would only be within the 10−15º for a small fraction of the time it took the participant to complete the flight course. This would occur while the aircraft was adjacent to the nearest obstacle. It should be noted that tunnel vision studied by Mackworth is not the same physiological tunnel vision effects on the eye experienced in individuals due to hypoxia. Mackworth's definition refers to the cognitive overload created by the increased demands of visual stimuli on the fovea.

ASRS Analysis. In reference to Figure 35, the majority of the event reports indicate that operations were primarily conducted during daylight hours. Flights conducted during daylight hours provide numerous benefits: operators can more easily maintain visual contact with the UAS, photographs and photogrammetry yield higher resolution given the increased levels of ambient light during the daytime, and airborne traffic and other obstacles to flight are more easily detectable, to name a few (Cardosi & Lennertz, 2017). In addition, operations during daylight hours would preclude the requirement for a waiver from the FAA for night operations.

Analysis of the ASRS dataset identified UAS operator SA as the most prevalent human factor element listed within the dataset of 257 event reports. In reference to Figure 45, the differences in the percentage of event reports within the BVLOS and VLOS operational groups where SA is listed as a human factor element are negligible. This is congruent with the experiment results where there were no significant differences between the three visual acuity technique groups for SA.

The Chi-square test of association identified the association between the event reports' indicated region and SA being listed as a causal factor at a $p < 0.05$. To better understand the relationship between SA and the indicated regions of the event reports, and more specifically, which region was contributing to the association, each region was individually filtered out of the dataset prior to subsequent conduct of the Chi-square test.

There were no statistically significant associations identified within the results of the Chi-square tests conducted on each individual region. However, it was noted that 161 of the 257 event reports did not identify the state of the event occurrence. Further comparative analysis was conducted between the event reports where the region was disclosed and the event reports where the region was not disclosed.

A comparison of SA by operator, as seen in Figure 50 and Figure 51, revealed an interesting observation. There was a notable increase in SA listed as a human factor element within the reports where the geographic region was listed within the event report. Approximately 95 of the 143 reports where SA was listed as a human factor element included the geographic region within the report. The increase in SA being listed as a human factor element within the event report can be seen in the comparison of the reports where the region was disclosed and undisclosed in Table 41.

Table 41

Comparison of Disclosed and Undisclosed Reports by Operator

	Commercial %	Government %	Military %	Recreational %
Disclosed (n=95)	76.5	69.2	75.0	50.0
Undisclosed (n=161)	52.9	31.4	62.5	31.6

Note. ASRS dataset where SA is listed as a human factor element within the event report.

In all operator categories, the percentage of SA being listed as a human factor element within the event report is greater within the group of reports where the reporter disclosed the geographic location of the event. While the omission of the region within the report may have been a result of oversight on the part of the reporter, willful omission of the geographic location of the event is a plausible explanation for the lower percentages within the undisclosed event reports. Specifically, reporters may have willfully omitted inclusion of the event location out of fear of prosecution for a possible FAR violation. The ASRS provides immunity from prosecution for events of non-criminal intent that resulted from human error (Eisenbraun, 1981). It is the incentive of immunity from prosecution that encourages operators to self-report events. This has been a fundamental concept responsible for the success of the ASRS (Eisenbraun, 1981).

Conclusions

The focus of this present research was on understanding the effects of using FPV techniques while operating sUAS on the operator's Level 1 SA and perceived workload. One independent variable with three treatment levels was used to examine the three visual acuity techniques: (a) visual line-of-sight pilot operation, (b) electronic aided piloting with FPV techniques utilizing a 21-in. LCD screen, and (c) electronic aided piloting with FPV techniques utilizing full visual immersion goggles. Additionally, the human factor elements of SA and workload were examine as contained within event reports within the ASRS database where the primary aircraft was listed as a UAS. Findings from this study offer potential insights on the understanding of how the increased demands of a central task during sUAS operations reduces the operator's UFOV.

Theoretical Contributions

Previous studies on aircrew fixation during central task demands and the associated effects on useful field of view have been oriented on pilot helmet-mounted display, and heads-up-displays (HUDs) in the cockpit. Similar studies have examined the use of HUDs during sUAS operations and the effects on workload and SA (Rebensky, 2020). While similar studies have found that utilization of a HUD can improve SA, such as research by Yoon et al. (2017) focused on surgical procedures, and research conducted within the automotive domain by Lindermann et al. (2018), this present study examined the effects of the three visual acuity modalities on Level 1 SA. Further examination of the results beyond the initial design of this study recognized the relationship between the physiological characteristics of the human eye as it perceives the spatial array of elements within the operating environment, and the subsequent translation of the photons to electrons and their stimulation of areas within the striate cortex. In other words, the results of this study inferred that the relationship between the participants' central task demand and eye dwell or fixation had more impact on Level 1 SA than the visual acuity modality utilized based on the amount of space allocated for memory within the brain of the elements perceived. More research is warranted within this area to understand how to design the best interface that would facilitate the allocation of more cortex to elements that are required for optimum memory recall to enhance SA; thus, improving flight safety.

Practical Contributions

Utilizing FPV techniques to operate sUAS may offer practical benefits to aviation safety and human performance. Specifically, FPV techniques provide sUAS operators live video feed of the sUAS's airspace and surroundings. Using FPV techniques during sUAS operations virtually transports the operator within the environment of the robotic aircraft providing an immersive enhanced awareness as if the operator were present within the aircraft's environment. This concept is referred to as "sense of presence" (Paes et al., 2017, p.2). This sense of presence provides the sUAS operator access to the geographic environment of the robotic aircraft and to the real-time spatial array of the visual environment, thus enhancing the sUAS operator's SA with information that would not have been available without using FPV techniques. Utilizing FPV techniques provides the potential to enhance human performance by decreasing operator reaction time during operations, accelerating the decision-making process; thus, enhancing safety. In addition, the findings of this research provide support that the benefits of FPV techniques on human performance occur without a detrimental increase in the operator's mental workload.

Implementation of BVLOS operations within the NAS have progressed at a considerably slow pace due to the inherent risk associated with operating unmanned aircraft within the FAA's current regulatory framework (FAA, 2021). Regulators continue to work together with the UAS community to develop strategies that will support the viability and sustainability of this rapidly expanding aviation sector. The FAA recently created the UAS Beyond Visual Line-of-Sight Aviation Rulemaking Committee "to inform the FAA on performance-based criteria to enable safe, scalable, economically viable, and environmentally advantageous BVLOS operations in the NAS" (FAA, 2021d, p. 2). Absent from the committee's charter is the task to examine the human factors element, and more specifically, the human-machine interface inherent in BVLOS operations.

Findings from this research suggest potential similarities in operator workload and Level 1 SA in sUAS operations utilizing either VLOS or BVLOS. Analysis of the quantitative research data collected revealed no statistically significant difference in perceived workload and Level 1 SA scores between the VLOS group and the LCD and GOGS groups utilizing FPV techniques. Additionally, no statistically significant difference was found between the LCD and GOGS group's perceived workload and Level 1 SA. This finding suggests utilization of FPV techniques may not affect sUAS operator workload or Level 1 SA. However, due to the static nature of the experimental flight course navigation requirements outside of the normal traffic density and complexity of the NAS, this conclusion should be interpreted with caution. Continuing this line of research will help fill the gap in understanding the human factors element and may subsequently facilitate the committee's task of developing minimum human factor operating requirements for safe BVLOS operations within the NAS.

The analysis of the ASRS dataset uncovered potential bias in event reporting, which is not a new phenomenon (Haslbeck, 2015). This research encountered potential reporting bias within the event reports' data fields that hindered the development of a clearer understanding of the event details. This included the geographic location of the event and the human factor element of SA. NASA ASRS managers should examine the propensity to omit information within the reports and potential bias in order to increase the fidelity of the ASRS.

Limitations of the Findings

While promising, conclusions drawn from this study are subject to several limitations. First, all the obstacles were within the FOV of the participants as they entered the experiment area, and therefore could be briefly observed prior to the conduct of the experiment. However, all participants were exposed to the experiment area for the same duration and the duration was very brief, only a few seconds. Thus, this brief observation would not be expected to bias participants. Nonetheless, consideration should be given to conducting the experiment with the obstacle's introduction after the commencement of the experiment so the participants cannot see them first. Additionally, the obstacles within the experiment were stationary. UAS operators will encounter airborne obstacles during flight operations. Recommendations for further research include conducting the experiment with airborne obstacles.

Second, the flight course was within a controlled setting eliminating the traffic density and complexity of the NAS. The confines of the tennis courts provided a sterile airspace environment to conduct a small research study of this scale. In every-day operations within the NAS, sUAS operators are required to cope with a vast unsegmented spatial array, in contrast to the easily segmented visual field created for the experimental conditions of this research. UFOV limitations for sUAS operators were identified and discussed but were limited to the scale of the operating environment outside routine air traffic within the NAS. Since traffic density is one of the primary concerns with sUAS integration into the NAS, a more realistic experimental setting is warranted to address this potential confounding variable.

Finally, the sample size and population for this study involved only on participants who volunteered to participate, and who predominantly originated from an undergraduate university setting, which limits the generalizability of the study findings to other university settings with similar demographic characteristics. Collection of data from a larger sample was preferred but was hindered during the research process by two tropical depressions, one in May 2019 and another in September 2019. Both storms destroyed the flight course on the Jacksonville University tennis courts requiring two additional purchases of material and installation of the new flight course. In addition, the Jacksonville University IRB halted all face-to-face research interaction on campus on March 16, 2020, because of the COVID-19 pandemic and did not rescind the moratorium until September 2020. Regardless, after the lifting of the moratorium on face-to-face interaction for research, continued recruitment of prospective participants was not successful. One plausible explanation is that prospective participants were reluctant to unnecessarily expose themselves to the risk of contracting COVID-19 during participation in a research study. A more robust study with multiple test locations could examine the dependent variables with a broader participant base. Future studies could be conducted utilizing sUAS simulation software which would decrease the logistical constraints required for such an experiment and decrease the time required for participation, which may increase the number of qualified study participants.

The ASRS provides a means of collecting self-reported details concerning aviation safety related events and incidents in order to improve operational procedures, training, and equipment (Corrie, 1997). Event reports contain various data concerning the event details which is reviewed by subject matter experts in order to categorize the type of operation and to categorize the human factor elements that were present within the event (Corrie, 1997). However, incomplete data due to willful or unintended omission of data fields during the reporting process degrades the fidelity of the report. Some criticisms of the ASRS include the lack of participation of stakeholders, underreporting, and bias in reporting to name a few (Haslbeck et al., 2015). This research encountered a notable number of event reports where the geographic location of the event was either willfully or inadvertently omitted from the report. In addition, the analysis of the event reports within the dataset where the geographic region was and was not disclosed appeared to be biased, providing a skewed picture of the human factor element of SA associated within the event reports.

Recommendations

The results of this study inferred that sUAS operator perceived workload and SA may be influenced more by the amount of area allocated for memory recall within the statia cortex than by the visual acuity method utilized by the operator. Developments in UAS technology and applications have far outpaced the human factors research associated with sUAS operations. This creates multiple challenges within the human factors arena as there are clear human congnitive performance limitations that were identified in this research that should be further examined. For example, recent work by Hallenbeck et al. (2021) suggests that distracting visual tasks may disrupt the visual perceptions of the retinal image, creating biases in memory errors that would manifest in a subject's working memory, as represented by "internal representations of information no longer available within the environment" (p. 2). The central task demand of operating a sUAS within the NAS environment is riddled with a myriad of irrelevant visual stimuli, representing opportunity for the sUAS operator to become distracted. Policy makers should focus additional efforts on examining the human cognitive and physiological constraints that may effect the human-machine interface and command and control of sUAS operations to foster the development of evidence-based safety risk mitigation procedures.

Recommendations for Future Research

The known obstacles on the flight course were static, and therefore present at the time the experiment participants were introduced to the flight course. A possible variation warranting further research would include a similar experimental environment with stationary and airborne obstacles introduced after the navigation of the sUAS had begun and introduced in sequence as the operator progresses on the course. This research could explore sUAS operator stress and the "startle effect."

It is unclear if the effects of the central task demand on the participants' UFOV, specifically the decrease in UFOV, were equally distributed within the participants' peripheral vision. A research design should be employed to examine if manipulation of the cognitive load of the central task demand would affect peripheral perception equally within the participants' field of view. This is congruent with future research suggested by Williams (1982).

Knowledge of how increased demands of a central task for any telepresence operation reduces the operator's UFOV could be used in the design of telepresence displays that could automatically reduce the gain on the amount of information that is displayed to the teleoperator during periods of increased demand. One such example is the Garmin 1000 Primary Flight Display (PFD). During unusual aircraft attitudes, the PFD will display large red arrows in order to focus the pilot on bringing the nose of the aircraft in the direction of the arrows (Garmin, 2011). Simultaneously, the PFD will decrease the amount of system functionality information displayed such as wind direction, selected altitude, true airspeed, nearest airports, and others that system designers removed in order to facilitate focus by the pilot on resolving the unusual attitude. Likewise, PFDs for teleoperations could be designed with the operator's decreased UFOV in mind; PFDs designed to automatically reduce the unnecessary system functionality information displayed during periods of increased central task demands.

The foundation of Endsley's universally accepted theory on SA rests on the operator's perception and understanding of the elements within their environment (Endsley, 1995a). Endsley proposes that these elements are specific within certain context and may not be relevant across disciplines (Endsley, 1995a). Hawkins further development of the original *SHEL* model, named after the first letter of the individual components, Software, Hardware, Environment, and Livewire, identified the elements observed as found within the interaction between the individual components of the SHEL model (Hawkins, 1984). Further research is recommended to examine this interaction as it applies to BVLOS operations for UAS.

The safe integration of UAS into the NAS will require continued vigilance on behalf of all stakeholders in identification of current and future operational risks and mitigation procedures. The NASA ASRS database provides a suitable source of data regarding the conditions evident during incidents reported within voluntarily submitted event reports. In addition, the FAA catalogs more than 100 reports per month regarding reports of UAS sightings from pilots, citizens, and law enforcement and publishes this data quarterly within the FAA UAS Sightings Report. Further research is warranted to examine UAS SA and workload within these two resources to facilitate the development of mitigation techniques, procedures, and protocols for the safe integration of UAS into the NAS.

While not explored in this present study, future research is warranted to investigate the need for sUAS operational proficiency flight reviews. This would involve the categorization of sUAS minimum required operator skills and abilities for safe operation within the NAS. Much as in manned aircraft, the sUAS industry continues to grow, as does the ever expanding necessity of establishing an equivalent level of safety for sUAS operations as maintained by manned aircraft.

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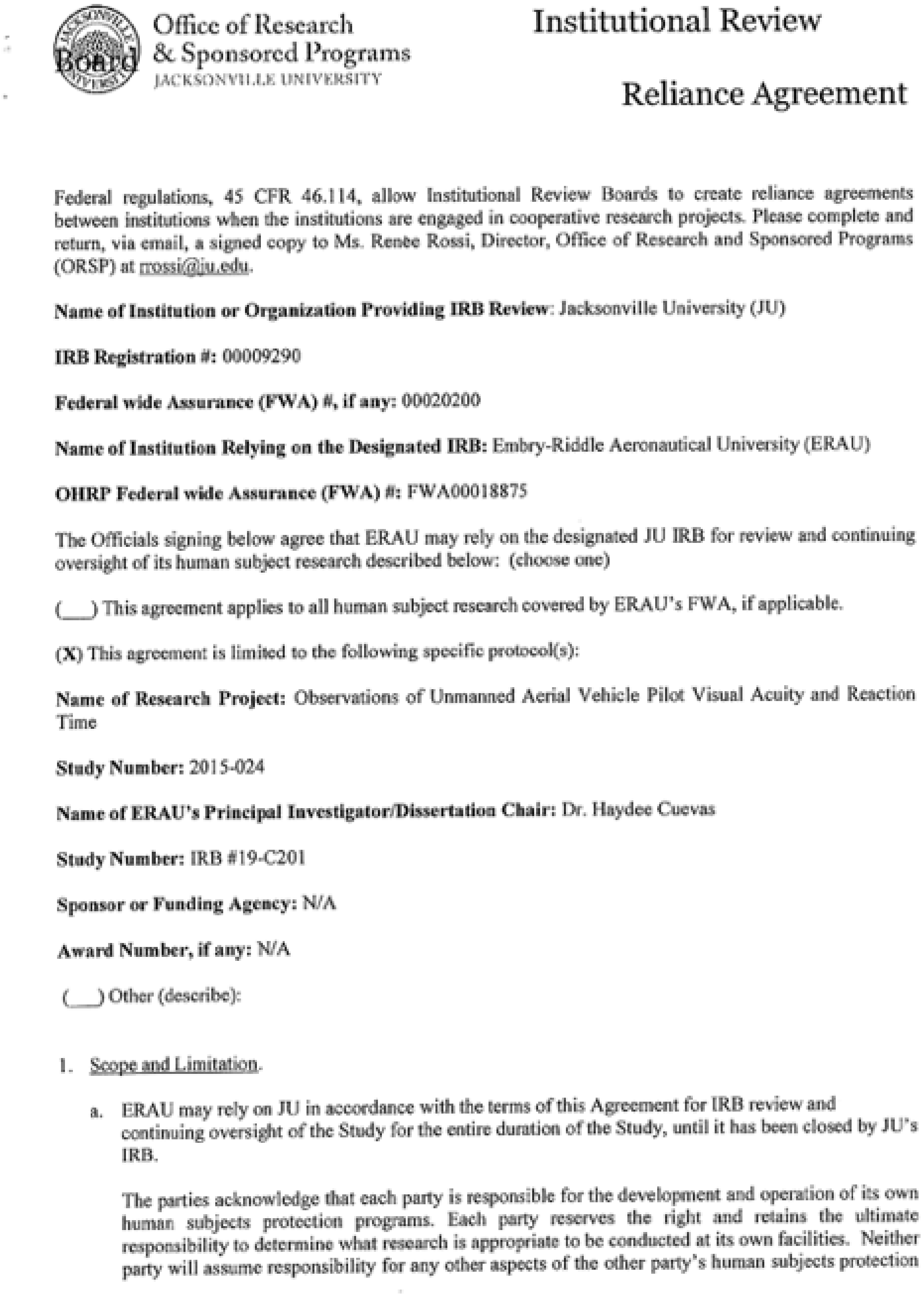
Appendix A

Permission to Conduct Research



Office of Research
& Sponsored Programs
JACKSONVILLE UNIVERSITY

Institutional Review Board

Reliance Agreement

Federal regulations, 45 CFR 46.114, allow Institutional Review Boards to create reliance agreements between institutions when the institutions are engaged in cooperative research projects. Please complete and return, via email, a signed copy to Ms. Renee Rossi, Director, Office of Research and Sponsored Programs (ORSP) at rrossi@ju.edu.

Name of Institution or Organization Providing IRB Review: Jacksonville University (JU)

IRB Registration #: 00009290

Federal wide Assurance (FWA) #, if any: 00020200

Name of Institution Relying on the Designated IRB: Embry-Riddle Aeronautical University (ERAU)

OHRP Federal wide Assurance (FWA) #: FWA00018875

The Officials signing below agree that ERAU may rely on the designated JU IRB for review and continuing oversight of its human subject research described below: (choose one)

(___) This agreement applies to all human subject research covered by ERAU's FWA, if applicable.

(X) This agreement is limited to the following specific protocol(s):

Name of Research Project: Observations of Unmanned Aerial Vehicle Pilot Visual Acuity and Reaction Time

Study Number: 2015-024

Name of ERAU's Principal Investigator/Dissertation Chair: Dr. Haydee Cuevas

Study Number: IRB #19-C201

Sponsor or Funding Agency: N/A

Award Number, if any: N/A

(___) Other (describe):

1. Scope and Limitation.

    a. ERAU may rely on JU in accordance with the terms of this Agreement for IRB review and continuing oversight of the Study for the entire duration of the Study, until it has been closed by JU's IRB.

    The parties acknowledge that each party is responsible for the development and operation of its own human subjects protection programs. Each party reserves the right and retains the ultimate responsibility to determine what research is appropriate to be conducted at its own facilities. Neither party will assume responsibility for any other aspects of the other party's human subjects protection programs or human subjects research operations. Each party will remain responsible for ensuring its own compliance with applicable Federal, State, and local laws regarding human subjects research.

b. ERAU will retain responsibility of the protection of human subjects at its location, including:
   i. Safeguarding the rights and welfare of human subjects;
   ii. Educating the members of its research community in order to establish and maintain a culture of compliance with federal, state and local regulations and its own policies relevant to the protection of human subjects; and
   iii. Implementing appropriate oversight mechanisms to ensure compliance with the determinations of the JU IRB.

2. Compliance with Law.
   a. During the term of this Agreement, each party will maintain an approved Federalwide Assurance (FWA) of compliance with the Office for Human Research Protections (OHRP), and upon request, provide a copy of its FWA to the other party, and abide by the terms and conditions of their respective FWA and this Agreement. In the event a party's FWA is amended in a manner that impacts this reliance agreement, such party will notify the other party and promptly supply a copy of the amended FWA to the other party. For research covered by this agreement, each party agrees to comply with requests for information in its possession that is necessary for oversight by the other IRB.

   b. JU shall perform all of the functions required under applicable federal, state, and local laws and regulations, whether foreign or domestic, for reviewing and approving human subjects research in connection with the Study, including, without limitation, 45 CFR 46 and 21 CFR 50 and 56. JU's review and approval shall also be conducted in accordance with all relevant institutional policies regarding human subjects research. The investigators of ERAU will abide by all conditions and determinations made by JU in connection with its review and approval of the Study.
      i. ERAU will not conduct the Study if it has not been reviewed and approved by JU.
      ii. ERAU will obtain review and approval from JU IRB prior to the implementation of any amendments to the Study.
      iii. ERAU will not conduct the Study if it is suspended or terminated by JU IRB.

   c. Both parties shall ensure adherence to this agreement and shall ensure that its employees, investigators, and agents adhere to the applicable federal, state, and local laws, regulations and policies regarding the conduct of human subjects research, including but not limited to, 45 CFR part 46 and 21 CFR parts 50 & 56 and other applicable governmental regulations and guidance.

3. Liability. Each party JU and ERAU shall only be responsible, to the extent permitted by law, for actions or claims arising from or caused by willful, reckless, or negligent acts or omissions of its respective officers, employees, and agents thereof.

4. Reporting and Notification.
   a. Each party shall immediately notify the other, at the contact listed below, in writing, of any serious or continuing non-compliance issues involving the Study.

   b. Each party shall immediately notify the other, in writing (within not more than five (5) working days), if and when an oversight agency or organization initiates any action regarding such noncompliance.

   c. JU shall immediately report, in writing, to ERAU any determinations made by the JU IRB of suspension or termination of IRB approval involving the Study.

d. Each party shall immediately notify the other, in writing, if any investigator or other employee or research personnel involved in the Study is suspended, debarred, or receives any other restriction of any duties whether clinical or research related.

e. Each party shall immediately notify the other, at the contact listed below, any information which it may acquire about the Study that may be relevant to a determination of non-compliance, unanticipated problems involving risks to subjects or others (including adverse events), or suspension or termination of the research by JU IRB.

5. Termination. Either party may terminate this Agreement (1) immediately upon written notice to the other party in the event of a breach of this Agreement by the non-terminating party or (2) with or without cause upon thirty (30) calendar days' prior written notice of termination to the other party.

6. Confidentiality/HIPAA
   a. Individual information: The parties agree to maintain strict confidentiality of all information received or obtained in connection with the performance of this Agreement (whether or not such information involves the Study) which relates to or identifies a particular research subject or any other specific individual, including but not limited to, the name, address, medical treatment, or condition, financial status, or any other personal information which is deemed to be confidential or private in accordance with applicable local, State, or Federal law whether foreign or domestic (including, without limitation, the Health Insurance Portability and Accountability Act of 1996 and any regulations and official guidance thereunder) and standards of professional ethics. The parties will notify their respective employees, contractors, agents, and representatives of this confidentiality requirement and require them to maintain the confidentiality of such information. ERAU shall not send to JU any documents containing identifiable patient information unless requested by JU for audit purposes.

   b. JU shall promptly (within no more than forty-eight (48) hours) notify ERAU of any unauthorized use, loss or disclosure of individually identifiable patient or human subject information or violations of information security laws, regulations, or policies whether foreign or domestic.

7. Documentation. ERAU shall maintain all documents reviewed by ERAU in connection with the Study, including any communication with investigators, and make those documents available to JU upon written request. When informed consent is required, the investigators will maintain in his/her files signed consent forms associated with the Study in accordance with the JU Records Retention Policy. Upon written request, JU IRB shall make available to ERAU all IRB minutes concerning the Study. If any governmental or regulatory authority notifies ERAU that it will inspect JU's records, facilities, or procedures, or otherwise take action related to the Study ERAU shall promptly notify JU and provide JU with copies of any reports issued by the investigating authority, including any response by ERAU.

8. Assignment and Binding Effect. Neither party shall assign, subcontract, or transfer any of its rights or obligations under this Agreement to a third party without prior written consent of the other party. If any assignment, subcontract, or transfer of rights does occur in accordance with this Agreement, this Agreement shall be binding upon and inure to the benefit of the parties hereto and their respective authorized successors or assigns.

9. Independent Contractor. Each party shall be considered to be an independent party and shall not be construed to be an agent or representative of the other party, and therefore, shall have no ability to bind the other party or have any liability for the acts or omissions of the other party. In addition, neither party, nor any of its employees, agents, or subcontractors, shall be deemed to be employees or agents of the other party. Therefore, neither party nor any of its employees, agents or subcontractors, shall be entitled to compensation, workers' compensation, or employee benefits of the other party by virtue of this Agreement.

10. Amendment, Modification and Waiver. This Agreement shall not be altered or otherwise amended except pursuant to an agreement, in writing, signed by each of the parties. A waiver, by either party, of a breach of any provision of this Agreement must be in writing and shall not operate or be construed as a waiver of any subsequent breach. The failure of a party, in any instance, to insist upon the strict performance of the terms of this Agreement shall not be construed to be a waiver or relinquishment of any of the terms of this Agreement, whether at the time of the party's failure to insist upon strict performance or at any time in the future, and such term or terms shall continue in full force and effect unless amended or waived in writing in accordance with this Agreement.

11. Survival. The provisions of this Agreement relating to confidentiality and documentation of records shall survive the termination of this Agreement.

Signature of Signatory Official Jacksonville University

Renee Rossi

Ms. Renee Rossi
Director, Office of Research and Sponsored Programs (ORSP)
Jacksonville University
2800 University Blvd., North
Jacksonville, FL 32211
P: (904) 256-7458
E: rrossi@ju.edu

Date: 2/11/19

Signature of Signatory Official Embry-Riddle Aeronautical University

Charlie Sevastos
Vice President and General Counsel
600 South Clyde Morris Boulevard
Daytona Beach, Florida

Contact Information:
Teri Gabriel
IRB Director
386.226.7179
Teri.gabriel@erau.edu

Date: 2/6/19

Appendix B

Data Collection Devices

Appendix B1
Demographic Survey

Participant Number: _________________

1. Which gender do you most closely identify with?
a. Female
b. Male
c. Other
d. Prefer not to answer

2. What is your current age? _____

3. Are you a student, faculty, or staff?
a. student
b. faculty
c. staff

4. Do you wear correctable eye lenses?
  a. Yes
  b. No

  If Yes to question 4, is your vision correctable to 20/20?
    a. Yes
    b. No

4. Do you have any experience flying unmanned aircraft systems / drones?
a. Yes
b. No

If yes, how many years and months experience__________________

Please rate your expertise level flying drones with 1=low and 7=high: _____

How frequently do you fly drones?
  a. Daily
  b. Couple times a week
  c. 3-5 times a week
  d. Couple times a month
  e. Few times a year; please note how many times a year

5. Do you have any experience flying radio-controlled aircraft as a hobby?
  a. Yes
  b. No

  If yes, how many years and months experience__________________

Please rate your expertise level flying radio-controlled model aircraft with 1=low and 7=high:________

How frequently do you fly radio-controlled aircraft as a hobby?
a. Daily
b. Couple times a week
c. 3-5 times a week
d. Couple times a month
e. Few times a year; please note how many times a year_______________

5. Do you hold a Part 107 Remote Pilot Certificate?
a. Yes
b. No

6. Do you play video games regularly to include flight simulation?
a. Yes
b. No

If you answered yes, please list your games by name below and rate your expertise for each game played (1 = low, 7 = high)

Also indicate your average HOURS/WEEK in that category for the past year. For example, if you play 1.5 hrs/week, mark "1+ to 3"

Game #1 ___________________

Expertise

1	2	3	4	5	6	7

Hours Played Per Week

Never 0+ to 1	1+ to 3	3+ to 5	5+ to 10	10+

Game #2 ___________________

Expertise

1	2	3	4	5	6	7

Hours Played Per Week

Never 0+ to 1	1+ to 3	3+ to 5	5+ to 10	10+

Game #3 ___________________

Expertise

1	2	3	4	5	6	7

Hours Played Per Week

Never 0+ to 1	1+ to 3	3+ to 5	5+ to 10	10+

Game #4 _________________

Expertise

1	2	3	4	5	6	7

Hours Played Per Week

Never 0+ to 1	1+ to 3	3+ to 5	5+ to 10	10+

---

7. Do you have an FAA airman's certificate?

a. Yes
b. No

If you answered Yes to question 7, please answer the following questions.

8. Approximately what is your total flight time?___________________

9. Specify approximately how many hours do you fly a week ________, month________, and year________.

10. Which region did you complete the majority of your total flight hours (e.g., Northwest for Oregon; Southwest for Arizona)?

a. Northwest – (Idaho, Montana, Oregon, Washington, Wyoming)
b. Southwest – (Arizona, California, Colorado, Nevada, New Mexico, Utah)
c. North-Central – (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota)
d. South-Central – (Arkansas, Louisiana, Mississippi, Oklahoma, Texas)
e. East-Central – (Illinois, Indiana, Michigan, Ohio, Wisconsin)
f. Northeast – (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, West Virginia)
g. Southeast – (Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee)
h. Alaska
i. Hawaii
j. Not in the United States

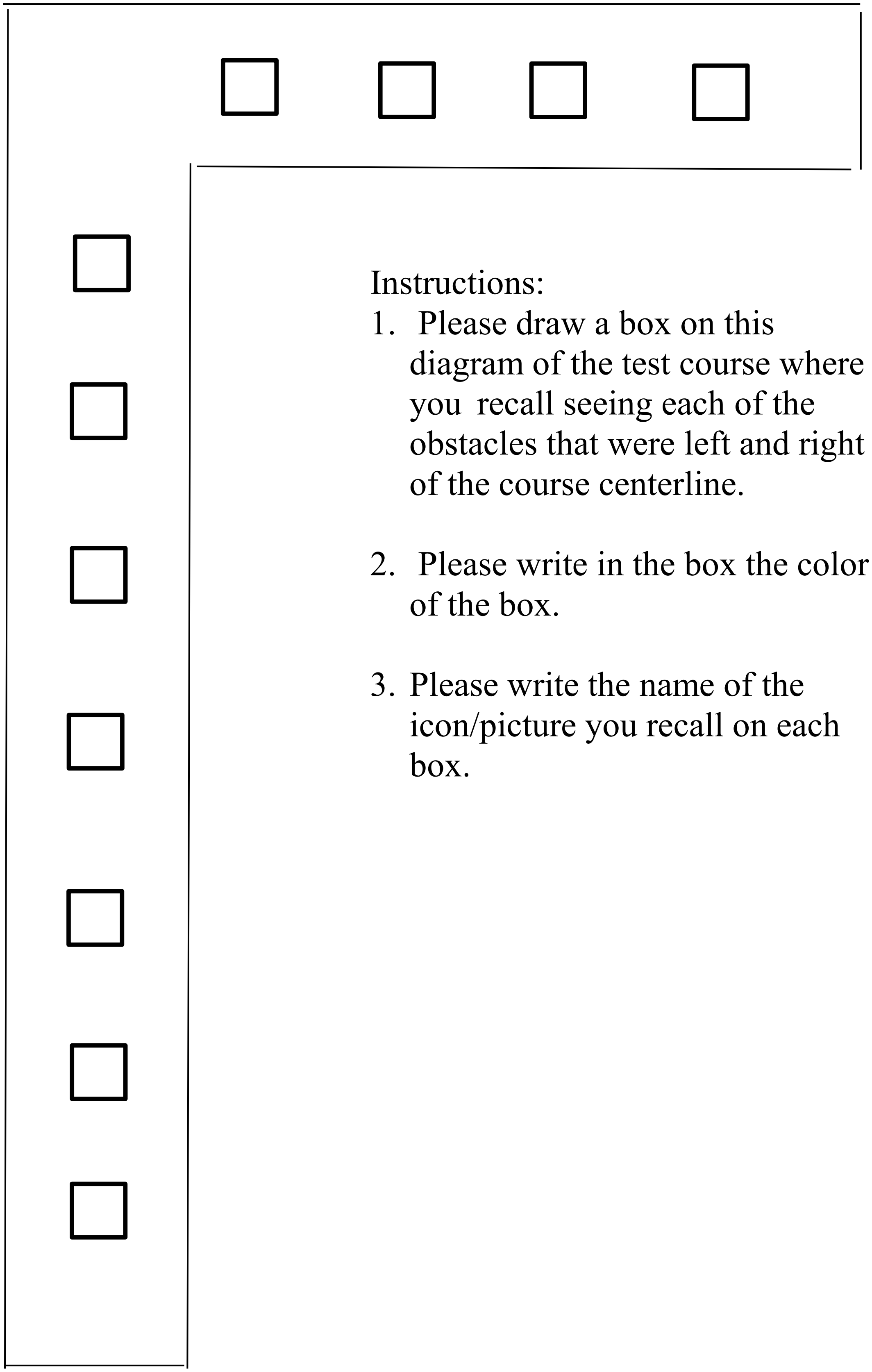
9. Approximately how many years have you been flying? ______

10. What is your city and state of residency?______________________________

Appendix B2

Level 1 SA Assessment

Participant ID______________



Instructions:

1. Please draw a box on this diagram of the test course where you recall seeing each of the obstacles that were left and right of the course centerline.

2. Please write in the box the color of the box.

3. Please write the name of the icon/picture you recall on each box.

Appendix B3

NASA TLX

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

NASA TLX Scoring Sheet

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Good Poor

EFFORT

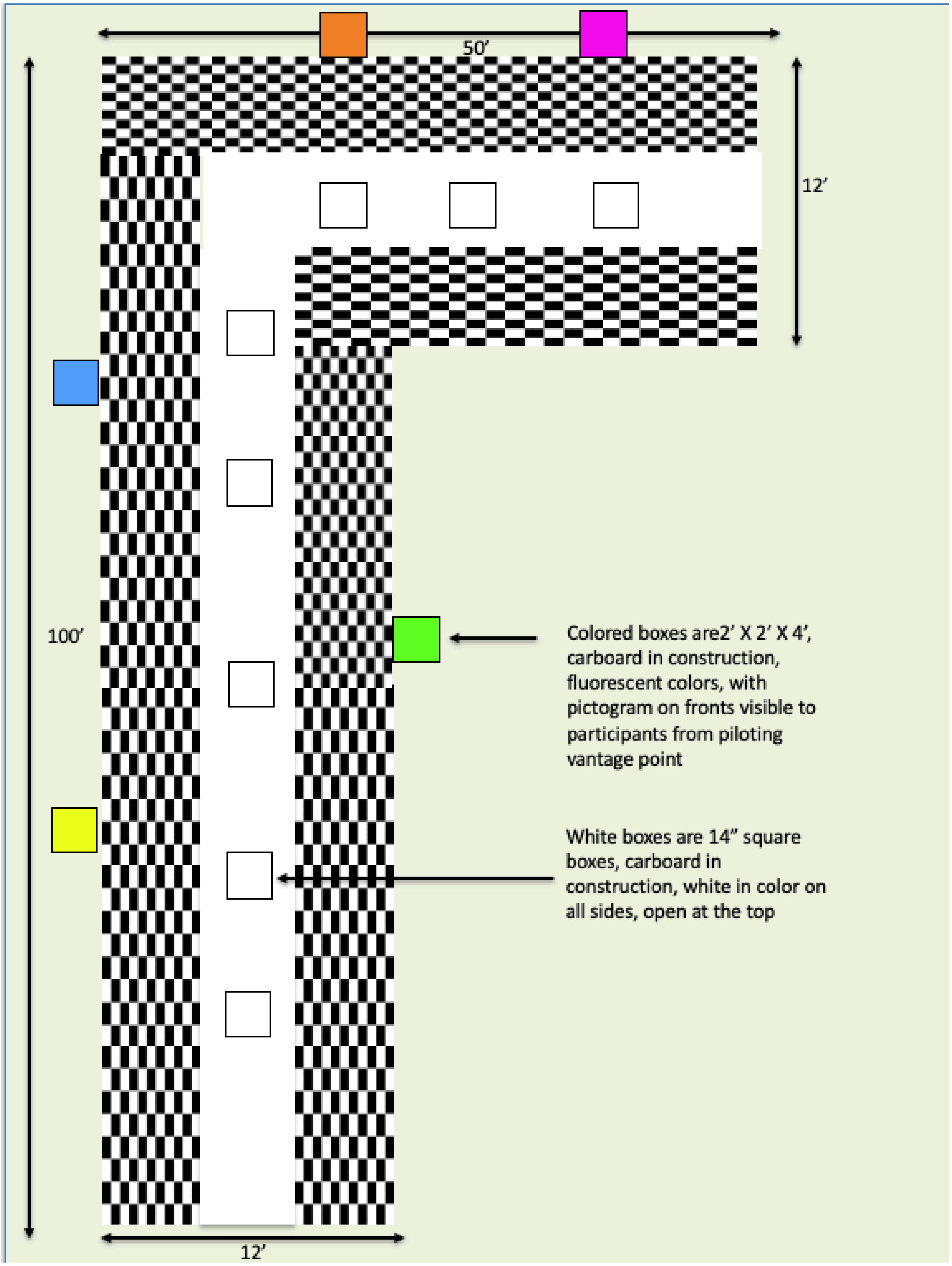
Low High

FRUSTRATION

Low High

Appendix C

Experiment Flight Course Diagram

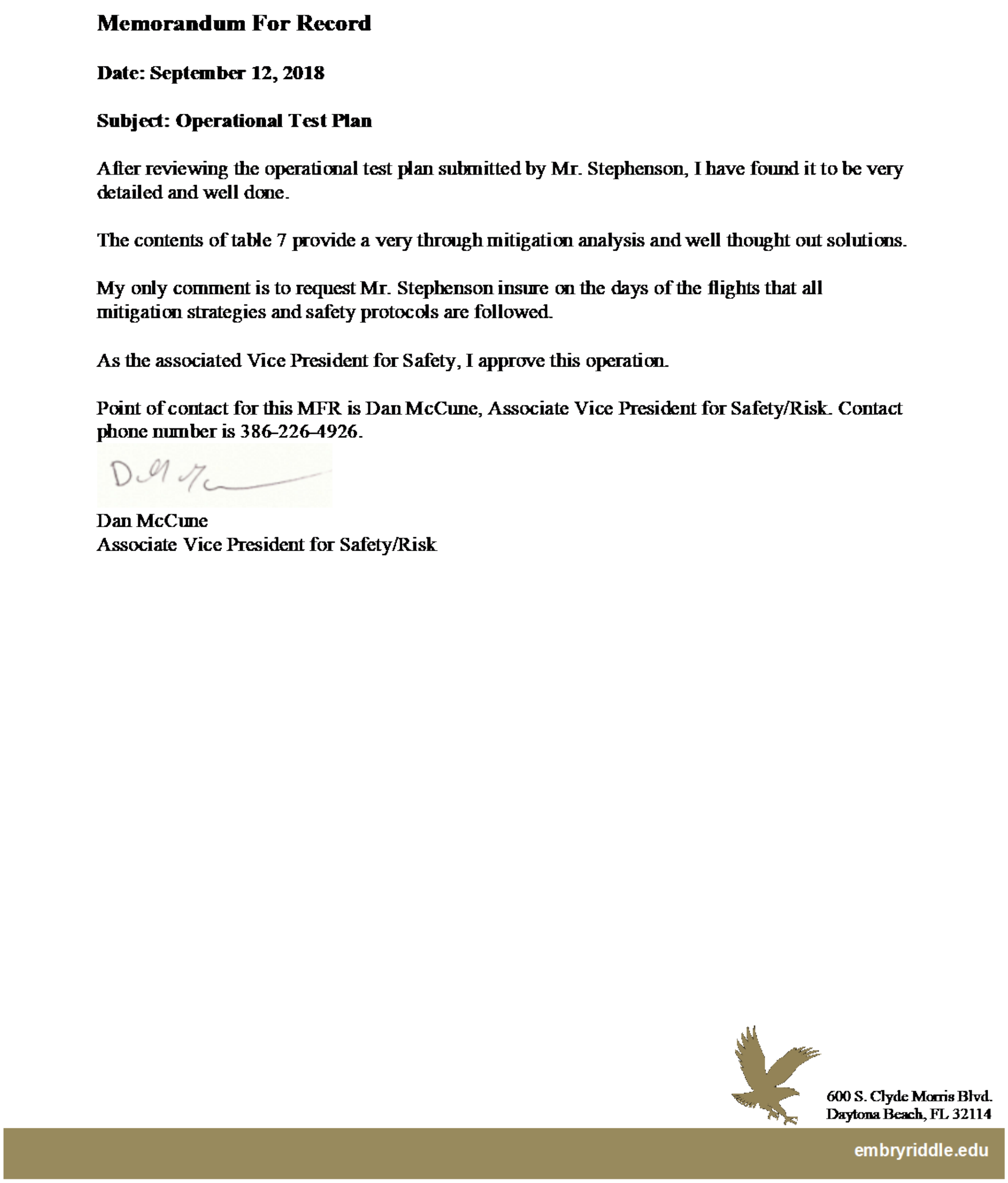


Colored boxes are2' X 2' X 4', carboard in construction, fluorescent colors, with pictogram on fronts visible to participants from piloting vantage point

White boxes are 14" square boxes, carboard in construction, white in color on all sides, open at the top

Appendix D

Operational Test Plan Approval



Memorandum For Record

Date: September 12, 2018

Subject: Operational Test Plan

After reviewing the operational test plan submitted by Mr. Stephenson, I have found it to be very detailed and well done.

The contents of table 7 provide a very through mitigation analysis and well thought out solutions.

My only comment is to request Mr. Stephenson insure on the days of the flights that all mitigation strategies and safety protocols are followed.

As the associated Vice President for Safety, I approve this operation.

Point of contact for this MFR is Dan McCune, Associate Vice President for Safety/Risk. Contact phone number is 386-226-4926.

Dan McCune
Associate Vice President for Safety/Risk

600 S. Clyde Morris Blvd.
Daytona Beach, FL 32114
embryriddle.edu

Appendix E

Average NASA TLX Unweighted Ratings

Average NASA TLX Unweighted Ratings by Group

	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
VLOS	72.5	20.63	65.63	66.88	62.5	55.0
LCD	63.75	38.75	54.38	46.25	65.63	59.38
GOGGS	59.38	18.75	51.88	35.0	55.63	31.88

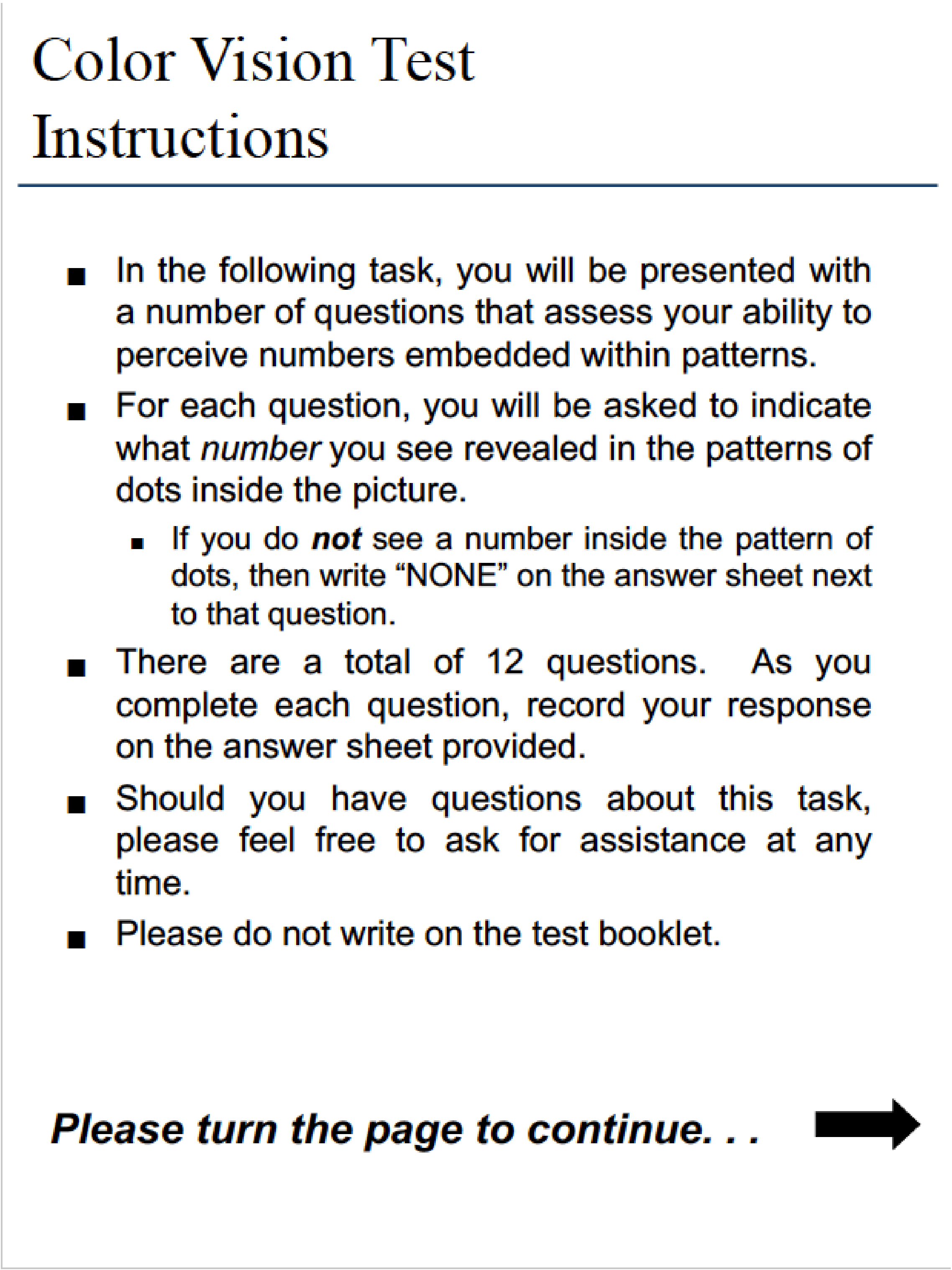
Note. Average unweighted ratings from NASA TLX questionnaires. GOGS = goggles (FPV); LCD = liquid crystal display; LOS = visual line of sight (VLOS); SA = situation awareness; VLOS = visual line of sight.

Appendix F

Ishihara Color Vision Test

Color Vision Test

Please wait until the instruction is given before turning the page to begin. . . ➡



Color Vision Test Instructions

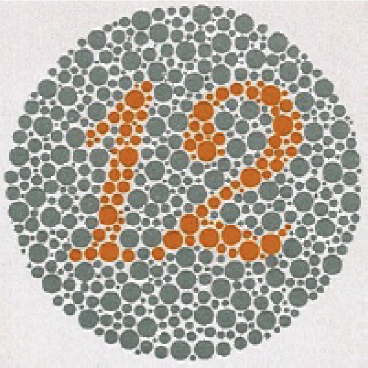
- In the following task, you will be presented with a number of questions that assess your ability to perceive numbers embedded within patterns.
- For each question, you will be asked to indicate what *number* you see revealed in the patterns of dots inside the picture.
  - If you do ***not*** see a number inside the pattern of dots, then write "NONE" on the answer sheet next to that question.
- There are a total of 12 questions. As you complete each question, record your response on the answer sheet provided.
- Should you have questions about this task, please feel free to ask for assistance at any time.
- Please do not write on the test booklet.

Please turn the page to continue. . . ➡

Color Vision Test
Sample Item

Here is a sample item of the task you will perform. Please look at the picture below. What number do you see revealed in the pattern of dots below?

Sample Item



You should see the number "12" inside the pattern of dots. So, you would write "12" on the answer sheet on the space next to that question. Please make sure to complete all items. And please remember not to make any marks on the test booklet.

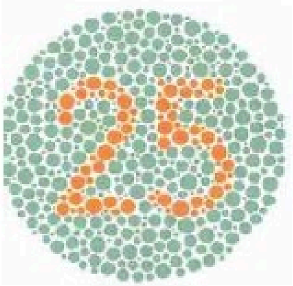
If you have any questions, please ask now. Otherwise, let the experimenter know that you are ready to begin.

Please wait until the instruction is given before turning the page to begin. . . ➡

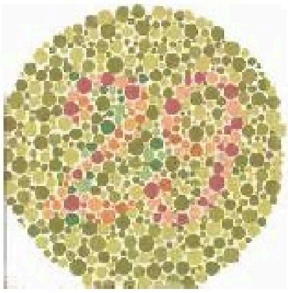
Color Vision Test

What numbers do you see revealed in the patterns of dots below? Please record the number on the answer sheet or, if you do not see a number, write “NONE.”

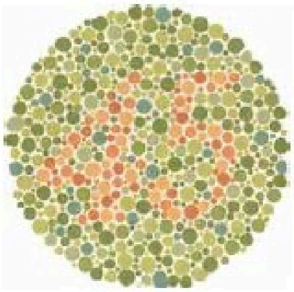
Question 1



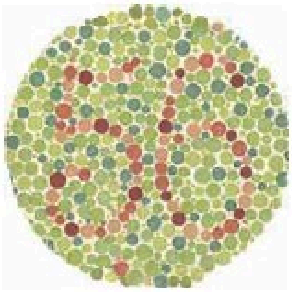
Question 2



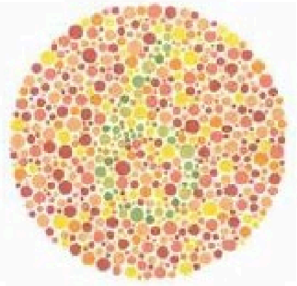
Question 3



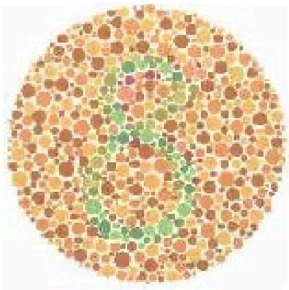
Question 4



Question 5



Question 6

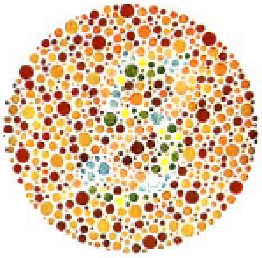


Please turn the page to continue. . .

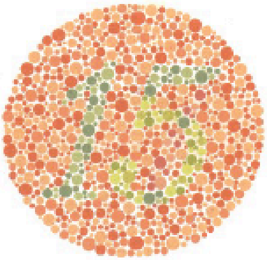
Color Vision Test

What numbers do you see revealed in the patterns of dots below? Please record the number on the answer sheet or, if you do not see a number, write "NONE."

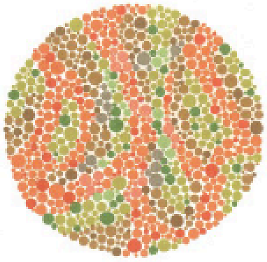
Question 7



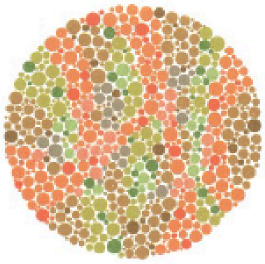
Question 8



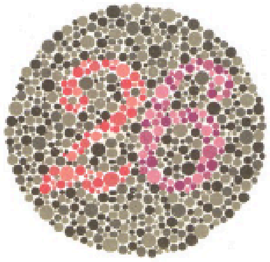
Question 9



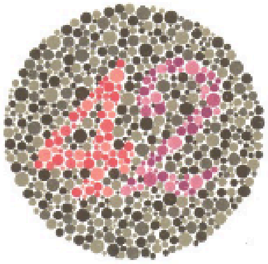
Question 10



Question 11



Question 12



Please stop here.