Development and Testing of a Virtual Reality Aviation Illusion Trainer

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ABSTRACT

In flight, pilots will experience visual illusions that, in some cases, can be severe enough to cause an accident. Recreating visual illusions for pilots to experience in a controlled training environment can be difficult as these illusions require specific conditions to exist. Researchers at Embry-Riddle Aeronautical University's Daytona Beach campus have leveraged Virtual Reality (VR) technology to develop the VR Aviation Illusions Trainer (VRAIT). VRAIT is comprised of six immersive training scenarios that will provide narrated training and examples of aviation visual illusions. The goal of this research is to determine the effectiveness of the VRAIT application in training pilots on illusion recognition, recovery, and prevention/mitigation techniques. The methodology used a series of surveys and knowledge tests to collect data on the student knowledge gain, self-efficacy change, realism/presence, simulator sickness, satisfaction, and usability. Data collection for the project is currently underway.

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INTRODUCTION

In flight, sensory conflicts and illusions can cause pilots to experience visual illusions that, in some cases, can be severe enough to cause an accident. When in an aircraft, maintaining proper spatial orientation can be a challenge. Between 5-10% of all general aviation accidents can be attributed to spatial disorientation (SD) and illusions, of which 90% are fatal. Teaching illusions to student pilots is paramount (FAA, n.d.). Currently, pilot training for the private pilot certificate requires introducing illusions that can lead to SD as well as illusions during the final approach to landing. Knowledge of illusions and SD is tested during the Federal Aviation Administration (FAA) Private Pilot Airplane Knowledge Test and is demonstrated to an examiner during the Private Pilot Practical Test. However, giving a student a true illusion experience is not always possible in the flight environment. Recreating visual illusions in Virtual Reality (VR) for pilots to experience in a controlled training environment can be difficult as these illusions require specific meteorological or geographical conditions to exist. Researchers at Embry-Riddle Aeronautical University's (ERAU) Daytona Beach campus have leveraged VR technology to develop the VR Aviation Illusions Trainer (VRAIT). VRAIT is comprised of six immersive training scenarios that provide narrated training and examples of aviation visual illusions. The goal of this research is to determine the effectiveness of the VRAIT application in training pilots on illusion recognition, recovery, and prevention/mitigation techniques. The methodology used a series of surveys and knowledge tests to collect data on the student knowledge gain, self-efficacy change, realism/presence, simulator sickness, satisfaction, and usability. Data collection for the project is ongoing.

REVIEW OF RELEVANT LITERATURE

Spatial Disorientation

Many pilots have tragically lost their lives after becoming disorientated in flight. Disorientation accidents date back to the early days of human flight and, unfortunately, continue to be a contributor to fatal aircraft accidents today. "The day the music died" in 1959 resulted in the death of singers Buddy Holley, Ritchie Valens, and JP Richardson and pilot Roger Peterson. A contributing factor to the accident was the disorientation of the pilot due to his "unwise decision to embark on a flight which would necessitate flying solely by instruments when he was not properly certificated or qualified to do so" (CAB, 1959). The 1999 fatal crash that killed John F. Kennedy Jr. after several erratic maneuvers is also attributed to spatial disorientation that was likely caused by continued flight into darkening conditions with limited ground-based lighting and the absence of an instrument rating (NTSB, 2000). Additionally, the recent crash of the helicopter carrying Kobe Bryant and friends is yet another example of the deadly results that can come from the pilot's inability to properly control the aircraft when flying from VFR conditions into IFR conditions without the proper training and experience necessary (NTSB, 2021). There are numerous other accidents resulting from spatial disorientation which illustrates the great need to find new and effective ways to train pilots to reduce spatial disorientation accidents.

Spatial orientation is the body's natural ability to maintain orientation and/or posture in relation to the surrounding environment at rest and during motion. While in flight, it can be difficult for the pilot to maintain proper orientation because of the numerous sensory stimuli. These stimuli come from the visual, vestibular, and proprioceptive senses and vary in magnitude, direction, and frequency. Any differences between the sensory inputs can lead to illusions and spatial disorientation (Antunano, n.d.). Flight conditions that deprive the pilot of visual references that help maintain orientation like clouds, fog, haze, darkness, terrain, or sky backgrounds with indistinct contrast cause spatial disorientation (AOPA, 2004). The loss of visual cues often causes spatial disorientation and renders the pilot incapable of properly handling the aircraft when these visual cues are limited or non-existent. When a pilot suffers from spatial disorientation, the result is typically an unconscious misapplication of the flight controls by the pilot (Stott, 2013).

Visual Illusions

The FAA defines several visual illusions in the Pilot's Handbook of Aeronautical Knowledge (PHAK) and Aeronautical Information Manual (AIM) that pose potential hazards to pilots while in flight (FAA, 2016; FAA 2021).

Runway Width Illusion: The Runway Width Illusion causes the pilot to fly an abnormally high or low approach to landing. A pilot's previous experience of landing at a similar size runway repeatedly can cause this illusion. The pilot flying at an average width runway will become accustomed to the sight of the runway image as it appears on the aircraft windshield/windscreen. If the runway normally appears to span half of the windshield, the tendency is for the pilot to fly a traffic pattern and approach that makes all runways span half of the windshield. Thus, if the pilot approaches an airport with a very narrow runway, the tendency is for the pilot to fly a lower approach and traffic pattern so that the narrower runway will cover the same amount of windshield to which the pilot is accustomed. Conversely, if the pilot approaches an airport with a wider runway, the tendency is for the pilot to fly a higher approach and traffic pattern so that the wider runway will cover the same amount of the windshield to which the pilot is accustomed. The correct pilot action is to rely on one's instruments to provide accurate data of altitude since visual cues are askew (FAA, 2016, p. 17-10 to 17-12; FAA, 2021, p. 8-1-6).

Runway Slope Illusion: Similar to the Runway Width Illusion, the Runway Slope Illusion occurs because of a pilot's previous experience. The normal sight picture experienced by a pilot predisposes that individual to make certain assumptions regarding aircraft attitude, height, and distance from objects and/or terrain. A pilot who normally flies their approaches and traffic patterns into relatively flat runways will have a predetermined impression of what appears to be "normal" regarding the height above the runway. An up-sloping runway creates the illusion that the aircraft is higher than it actually is and creates a tendency for the pilot to fly a lower approach and pattern. Flying too low can cause impact with terrain or obstacles. Conversely, a down-sloping runway creates the illusion that the aircraft is lower than it actually is and creates a tendency for the pilot to fly a higher-than-normal approach. A higher-than-normal approach may cause overshooting of the runway (FAA, 2016, p. 17-10 to 17-12; FAA, 2021, p. 8-1-6).

Black Hole Illusion: The Black Hole Illusion, also known as the Featureless Terrain Illusion, can cause the pilot to fly a dangerously low approach. This generally occurs when the pilot is flying without reference to instruments on very dark nights with no moon or star lights, over featureless terrain, and no ground lights between the aircraft and the runway. (FAA, 2016, p. 17-10; FAA, 2021, p. 8-1-6). A series of studies on black hole conditions were conducted in the 1960's using a flight simulator. Without the aid of an altimeter or glide slope information, a majority of the very experienced instructor pilots who participated in the study flew too low of an approach and many crashed short of the runway (SKYbrary Aviation Safety, n.d.)

False Horizon Day Illusion: Sloping clouds, haze, obscured horizons, and any features that cause an inability to correctly determine the aircraft attitude in relationship to the earth's horizon can cause a false horizon illusion. The tendency, without the aid of an attitude indicator, is for the pilot to alter the flight attitude of the aircraft to "match" what appears to be the horizon by changing the aircraft's bank angle. This bank angle causes a loss of lift which causes the aircraft to descend. The inability to correctly align the aircraft with the earth's horizon can lead to, at best, unusual attitudes and, at worst, catastrophic consequences (FAA, 2016, p. 17-8; FAA, 2021, p. 8-1-6).

False Horizon Night Illusion: As with the False Horizon Day Illusion, the inability to correctly determine the aircraft's attitude in reference to the earth's horizon can be caused by any lights that are not parallel with the earth's horizon. Some potential causes are lights ascending the slope of a mountain, a pattern of stars, and certain geometric patterns of ground lights. The tendency is for the pilot to position the aircraft such that the wings appear to be level with the false horizon usually resulting in a loss of lift and a reduction in altitude. As with other illusions, reliance on one's instruments will help the pilot maintain a proper attitude in relationship to the earth's horizon (FAA, 2016, p. 17-26; FAA, 2021, p. 8-1-6).

Autokinesis: This illusion is a nighttime illusion that is caused by staring at a static light for several seconds. The pilot will perceive the light to move around causing a tendency for the pilot to continually adjust the aircraft's attitude in an attempt to align the light with the aircraft. This disorientation may cause a complete loss of control of the aircraft (FAA, 2016, p. 17-8, 17-26; FAA, 2021, p. 8-1-6).

Each of these illusions are those in which pilots of all experience levels fall prey when relying solely on one's physical senses to determine aircraft control. Since all humans are susceptible to these illusions, knowledge and training can help pilots develop an awareness of each and establish procedures to help combat the tendency to fall victim to these illusions.

Current SD and VR implementations in flight training

At the time of publication, the FAA does not allow for VR training to count as simulator time towards a certificate or rating (FAA, n.d.). VR is considered an extra training activity that can be done to help prepare students for future flight lessons. Some examples of this type of training include procedural/checklist training and VR flight simulators. Extra visual illusion and SD training can be offered by flight schools, where the student uses a simulator to experience illusions and SD first-hand. This training experience is typically only available at a small subset of medium to larger sized flight training schools due to the limited availability of resources and simulator cost. VR training in this fashion is not standardized and is completed solely at the discretion of the training location where the lessons take place (Cavaliere, 2021).

Another avenue for training is by requesting a scheduled visit to the FAA's Civil Aerospace Medical Institute (CAMI) training center in Oklahoma City. CAMI Airman Education Programs are 1-day courses that offer pilots training on a variety of aviation topics that include a course on spatial disorientation training with demonstrations. These training sessions are free, but capacity limits training slots and student must provide their own travel costs to get to and from CAMI (FAA, 2019).

A recent study by Thomas et al. (2021) provided positive indications about the use of Virtual Reality as a training aid. Participants from varying age groups and flight experience viewed the runway-width illusion scenario, and evaluated their experiences on factors such as usability, faithfulness, general reactions, and physiological symptoms. The overall scores on the Post-Training Survey used in the study from both the low-time and highly experienced pilot groups indicated good usability, high fidelity, and effectiveness of the VRAIT as a learning and training tool. The study acted as a proof of concept when it came to utilizing Virtual Reality as a learning and training tool in the flight training environment, and the development and testing of the VRAIT and its six comprehensive visual illusion scenarios is the expansion from that proof of concept (Thomas et al., 2021).

METHODOLOGY

VR Facility and Equipment

ERAU Spatial Disorientation Lab and Extended Reality (XR) Lab undertook the creation of VRAIT to update the SD and illusion training offered to students at ERAU. By using a VR based trainer, the Spatial Disorientation Lab will be able to provide students with an opportunity to experience in flight illusions using a commercial off-the-shelf (COTS) VR headset and computer. In this case, a VR computer with a high-end graphics card and a Valve Index VR headset and hand controls capable of running flight simulation software and other standalone VR applications was chosen (Figure 1) (Steam, 2022).

Figure 1. VR computer station with Valve VR headset and controls

Development and Testing of VRAIT

The development plan was to create a series of narrated VR experiences that explain and demonstrate aviation illusions. Research on visual illusions was conducted by subject matter experts (SME) who were certificated flight instructors and professors at ERAU. The SMEs chose six visual illusion scenarios that were described in the FAA's reference material like the PHAK. From the reference material, the SMEs developed scripts for the six illusions. These scripts were given to the XR lab developers to create immersive VR worlds with narrated examples of the illusions.

Development of the VRAIT started in 2020 with a period of rapid prototyping and design using the Unity game engine. In Unity, the developer has the freedom to create a controlled virtual environment for the VR user to experience, and access to several built-in tools and plugins to hasten each iteration of the software. One such plugin is World Composer, which uses satellite imagery from Microsoft's Bing Maps to create a terrain that's both easy to work with and enables the developer to generate an updated map should the specified areas change over time. In addition to this plugin, the built-in animation system in Unity was indispensable in creating an automated step-by-step procedure for the training, and allowed for efficient changing of 3D movement, voice over lines, and special effects.

Tests and iterations for the VRAIT software took place throughout the development cycle, and each new build was rigorously reviewed by both developers and SMEs. After the core application design was identified, every build was tested and reviewed, with key items marked for iteration. The scripts written by the SMEs were edited using this iterative design process, and changes were quickly reflected in the software application for a more polished and effective learning experience.

SMEs tested out scenarios to see if the illusions appeared real as if they would out in the real world. Other flight training students and pilots were also given the opportunity to provide comments and feedback on each scenario. Updates and iterations were made as needed until each scenario was deemed ready by the SMEs for use and research.

At the end of development, six different visual illusion scenarios were created:

1. Runway Width (Figure 2)
2. Sloped Runway (Figure 3)
3. False Horizon Day
4. False Horizon Night
5. Black Hole Approach
6. Autokinesis

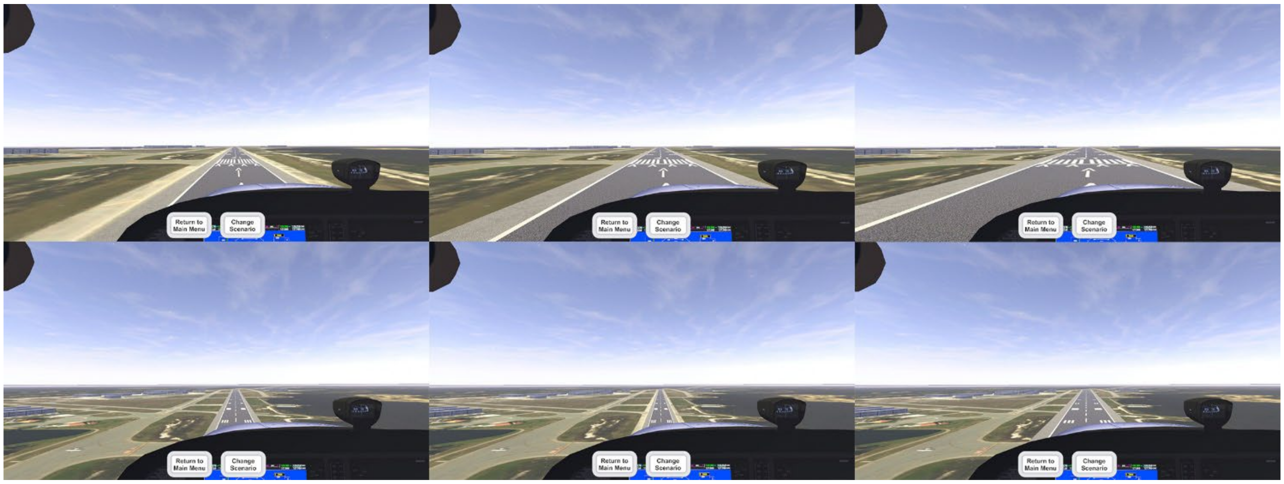

Figure 2. Progression of Approaches to Runways of Various Widths During Runway Width Scenario

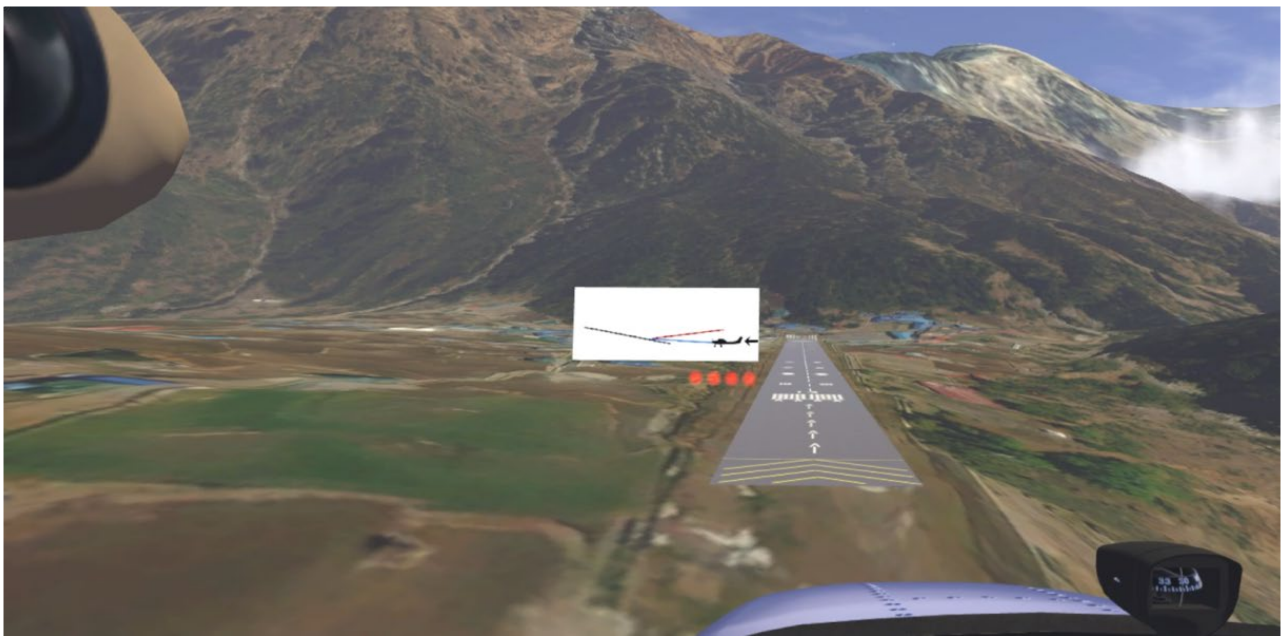

Figure 3. Dangerously Low Approach to Up-Sloping Runway During Runway Slope Scenario

RESEARCH PLAN AND DATA COLLECTION

Data collection instruments

The research design is an experimental within-subject research design. Data will be collected on participant knowledge gain, self-efficacy, simulator sickness, presence in the virtual environment, usability, and satisfaction. Knowledge gain will be measured pre- and post-training by using a short multiple-choice test on topics that includes defining the illusion, recognizing the illusion, how to prevent/mitigate the effects of the illusion, and performing corrective action when experiencing the illusions. Self-efficacy will be measured utilizing a pre- and post-training participant self-efficacy questionnaire asking participants to rate their confidence levels on being able to define the illusions, recognize the illusions, and apply the proper corrective actions in flight.

The survey tool used to measure simulator sickness pre- and post-training is the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. (1993). The scores will serve as an indicator to enhance the system and determine the comfortability of participants using the system.

The igroup Presence Questionnaire (IPQ) survey is used to measure the sense of presence sensed in the virtual environment. Its development and wide use in the industry serves as a tool to identify how well the software makes the participant feel spatial presence, attention, and involvement with the experience and the subjective experience of realism (igroup, 2016).

The System Usability Scale (SUS) is the survey tool used to measure perceived usability; developed in the 1980s, it quickly became the recommended tool to measure perceived usability (Lewis, 2018). The SUS is used to measure the perceived usability of the VRAIT to gain perspective on the systems controls and interaction of the user with the software/ hardware.

Lastly, the College of Aviation faculty and staff developed the Training Satisfaction survey. An analytical review of a wide range of satisfaction surveys created the Training Satisfaction survey in early 2021. Currently, limited testing has been conducted on the loading factors of the survey and is used as a method of measuring satisfaction with the training scenarios in the VRAIT.

FUTURE RESEARCH PLANS

A study has been approved by the ERAU IRB for testing the VR visual illusions as outlined and data collection is currently underway. After a complete analysis of the data, revisions will be made to the training scenarios as appropriate. A concurrent effort is underway to use a motion platform to put the student in a chair with 4-axis movement to add to the realism and attempt to make the scenarios more immersive. Developing VR training on vestibular illusions scenarios to include the Leans, Graveyard Spiral, Coriolis illusions, and more are also underway.

CONCLUSION

The FAA has produced several publications on spatial disorientation to educate pilots on the causes, as well as methods that can help one avoid becoming disoriented in flight (Antunano, n.d.). These educational products provide a solid basis for pilot education but, in addition to knowledge, there is a need to help pilots develop the skills necessary to properly counteract spatial disorientation. Technology has advanced such that tools and programs can be crafted and created to provide spatial disorientation training for pilots that will allow one, using virtual reality, to experience first-hand various aspects and types of spatial disorientation. The goal is that through experiential simulation training, pilots will be able to learn experientially causes for and reactions to various spatial disorientation factors.

The development of the VRAIT serves as the foundation for current and future research into the usability of virtual reality as an immersive and effective training tool. The data collected in the coming months will be analyzed to understand the impact of the visual illusion scenarios contained in the VRAIT, which will allow the research teams to build upon this foundation and create a comprehensive Spatial Disorientation training tool complete with both visual and vestibular illusion scenarios.

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