

3D Immersive Environment Using X-Plane for Depth Perception Research

**Dr. Logan A. Williams, Charles T. Bullock, Dr. Marc D. Winterbottom,
Dr. James P. Gaska, Dr. Steven C. Hadley**

**711th Human Performance Wing, United States Air Force School of Aerospace Medicine
Wright-Patterson AFB, OH**

{Logan.Williams; Charles.Bullock.1; Marc.Winterbottom; James.Gaska.1; Steven.Hadley.8} @us.af.mil

**Dr. Charles J. Lloyd
Visual Performance LLC
Ellisville, MO**

Charles.Lloyd@VisualPerformance.us

**Dr. Michael P. Browne
SA Photonics
Los Gatos, CA
M.Browne@SAphotonics.com**

ABSTRACT

Game-based flight simulation software has been shown to provide a reliable, low-cost, virtual environment able to facilitate a wide range of training and research objectives. In this work, which is part of the U.S. Air Force School of Aerospace Medicine Operational Based Vision Assessment program, game-based simulation software was used to render an immersive three-dimensional constructive environment within a helmet mounted display (HMD) for weapons platform specific vision research and to quantify the impact of aircrew vision on selected operational tasks. In this work, an operationally relevant MH-60 call-to-landing task was simulated to provide data relevant to the applicability of U.S. Air Force Flying Class III depth perception standards. The specific simulation system consisted of a high-resolution (1920x1200) 55° field-of-view binocular HMD with infrared head tracking, in which two instances of X-Plane were stereoscopically rendered to the HMD using separate PCs, both incorporating Intel i7 processors and Quadro K4200 video cards with Quadro Sync. This paper details the overall design, implementation, and validation of the virtual environment used to simulate the MH-60 call-to-landing task, including stereoscopic rendering using game-based simulation software, hardware/software stereo rendering limitations, HMD warping, and head-tracker integration. The minimum perceived stereo threshold capabilities of this system are also quantified, including discussion of its applicability to simulated tasks requiring precise depth discrimination. This work will provide an example simulation framework for future stereoscopic virtual immersive environments applicable to both research and training.

ABOUT THE AUTHORS

Dr. Logan Williams is a senior research engineer at the U.S. Air Force School of Aerospace Medicine at Wright-Patterson AFB, Ohio, and currently leads technology development for the Operational Based Vision Assessment laboratory. Previously, he has led multiple lines of research in various fields such as human effectiveness, immersive environments, visual display system design, and distributed simulation for aircrew training. He has served as the lead systems engineer for F-16, A-10, and KC-135 aircrew training systems and has two decades of experience in analog and digital circuit design, networked control systems, optical & electro-optical system design, computer programming, and physics-based modeling and simulation. He has earned a PhD in Electro-Optics, ME and BS degrees in Electrical Engineering, as well as a BS in Physics.

Charles (Tommy) Bullock is a software engineer within the U.S. Air Force School of Aerospace Medicine's Operational Based Visual Assessment laboratory at Wright-Patterson AFB, Ohio. He is responsible for custom image generator hardware/software design, as well as software development for visual research, including task-specific scenario programming to evaluate the correlation between visual capabilities and operational performance in operationally relevant scenarios. He has 12 years of experience in software development, including previous experience in the bioinformatics field processing large data sets and population genetics. He has earned MS and BS degrees in Computer Science from the University of Kentucky.

Dr. Marc Winterbottom is a senior research psychologist supporting the Operational Based Vision Assessment Laboratory at the U.S. Air Force School of Aerospace Medicine, Wright-Patterson AFB, Ohio. His most recent research focuses on U.S. Air Force vision standards and modernization of vision screening practices. His prior research focus at the Warfighter Readiness Research Division, Mesa, Arizona, was on visual perception, particularly as it related to display technologies for simulation and training applications. He received an MS in Human Factors Psychology from Wright State University (2000) and a BA degree in Psychology from Purdue University (1996). He was awarded a DoD SMART Scholarship in 2010 and recently completed a PhD in Human Factors Psychology at Wright State University.

Dr. James P. Gaska received a Ph.D. degree in Biopsychology from Syracuse University and from 1981 to 2000 worked at UMASS Medical School where he used single cell electrophysiological and computational techniques to explore and model the representation of the world in the visual cortices of primates. From 1995 to 2010, Dr. Gaska worked as a contractor to the Air Force and used vision science and visual performance models to aid in the design of camouflage, laser eye protection, and flight simulation technologies. He is currently Senior Scientist for OBVA at the USAF School of Aerospace Medicine at WPAFB.

Dr. Steven C. Hadley is the programmatic lead and principal subject matter expert for the Operational Based Vision Assessment Program. He is a board certified Ophthalmologist, Operational Pilot-Physician, Aeromedical Specialist, Special Operations Consultant, Commander and Subject Matter Expert with 34 years of active duty military experience, including 19 years working with the US Army and 15 years working with the US Air Force. He has served as a chief flight surgeon and command USAF helicopter instructor pilot with over 4000 flight hours, and is qualified in eight different military aircraft. He is a West Point graduate and completed his M.D. at Uniformed Services University of the Health Sciences (USUHS), Bethesda, MD.

Dr. Charles J. Lloyd is president of Visual Performance LLC where he addresses research and development challenges relating to training display system design, requirements, metrics, and measurements. He has 28 years of experience in display systems and applied vision research at such organizations as Honeywell's Advanced Displays Group, The Lighting Research Center, BARCO Projection Systems, FlightSafety International, and the Air Force Research Laboratory. Charles has published more than 75 papers in this arena.

Dr. Michael P. Browne is the general manager of vision products at SA Photonics in San Carlos, California. He has a PhD in Optical Engineering from the University of Arizona's Optical Sciences Center. He has been involved in the design, test, and measurement of head-mounted display systems since 1991. At Kaiser Electronics, he led the design of numerous head-mounted display and rear-projection display systems, including those for the F-35 Joint Strike Fighter. He leads SA Photonics' efforts in the design and development of person-mounted information systems, including body-worn electronics, head-mounted displays, and night vision systems.

3D Immersive Environment Using X-Plane for Depth Perception Research

Dr. Logan A. Williams, Charles T. Bullock, Dr. Marc D. Winterbottom,
Dr. James P. Gaska, Dr. Steven C. Hadley

711th Human Performance Wing, United States Air Force School of Aerospace Medicine
Wright-Patterson AFB, OH

{Logan.Williams; Charles.Bullock.1; Marc.Winterbottom; James.Gaska.1; Steven.Hadley.8} @us.af.mil

Dr. Charles J. Lloyd
Visual Performance LLC
Ellisville, MO

Charles.Lloyd@VisualPerformance.us

Dr. Michael P. Browne
SA Photonics
Los Gatos, CA

M.Browne@SAphotonics.com

INTRODUCTION

In recent years game-based visualization technologies have proven able to provide a wide range of graphical display capabilities (Smith & Denise, 2007) for military simulation at a fraction of the cost of traditional image generators and are often supported by robust software development kits (SDKs) and active user communities. The use of X-Plane, specifically, as a highly versatile game-based simulation tool has been widely demonstrated (e.g. Garcia & Barnes, 2010; Eidman, Lisa, Kam, Pohl, Rogers, & Mitchell, 2009; Williams, Lisa, Eidman, Kam & Pohl, 2009; Allsop & Gray, 2014; Williams, Littman, Folga & Patterson, 2014). In 2015, the U.S. Air Force School of Aerospace Medicine Operational Based Vision Assessment (OBVA) program implemented a unique three-dimensional (3D) immersive environment for the evaluation of weapons platform specific vision research to quantify the impact of aircrew vision on selected operational tasks. X-Plane was selected, primarily due to its expansive software development community and relatively low cost, to render an immersive 3D constructive environment using a helmet-mounted display (HMD) to perform Flying Class III (FCIII) aircrew depth perception research using a simulated, operationally relevant MH-60 call-to-landing task, as shown in Figure 1.

This paper details the overall design, implementation, and validation of the virtual environment used to simulate the MH-60 call-to-landing task, including stereoscopic rendering using game-based simulation software, hardware/software antialiasing, HMD warping, and head-tracker integration. The minimum perceived stereo threshold capabilities of this system are also quantified, including discussion of its applicability to simulated tasks requiring precise depth discrimination. The simulation framework described herein may be used to guide the implementation of future stereoscopic virtual immersive environments applicable to both research and training. However, the use of X-Plane to conduct this work is not an endorsement of this product by the U.S. Government.



Figure 1: Game-based rendering of the simulated call-to-landing task.

RESEARCH DESCRIPTION

Although detailed discussion of the FCIII depth perception research scenario is not the specific goal of this paper, a brief description will aid the reader in understanding the design and development of this simulation system. Under various operational MH-60 landing conditions, the flight engineer (FCIII aircrew) is responsible for calling out distance to ground to estimate altitude and avoid obstacles. The flight engineer typically leans far outside the aircraft (side window) to make estimations of relative distance between various ground obstacles and aircraft components (e.g., landing gear). The motivation of the OBVA team was to replicate these visual estimation tasks in a simulated, operationally similar virtual environment to determine the importance of stereoscopic vision in

performing accurate calls to landing. The simulated system, therefore, employs a high-resolution, head-tracked stereo HMD, which allows the subject to view a scene similar to that encountered by FCIII aircrew during a call to landing task.

SYSTEM DESIGN

The 3D virtual environment system uses two instances of X-Plane software to stereoscopically render a head-tracked, out-the-window visualization during a simulated MH-60 call-to-landing task. These two software instances are operated on two separate PCs, each incorporating Intel i7 processors and Nvidia Quadro K4200 video cards with Quadro Sync to ensure 60-Hz rendering synchronization between each channel of the stereoscopic visualization. Inadequate synchronization between stereo channels may render moving content in slightly different locations (e.g., a frame ahead or behind), resulting in inaccurate depth estimation. A custom plug-in was written in C++, using the X-Plane SDK (Supnik, 2003), to allow control of various rendering parameters, such as setting rendering frustums to specify interpupillary distances (IPDs) for various stereoscopic viewing conditions. Additionally, the PilotView plug-in (Barbour, 2013), readily available within the development community, was utilized to perform various 3D geometrical operations to control HMD gaze direction relative to the ownship flight path.

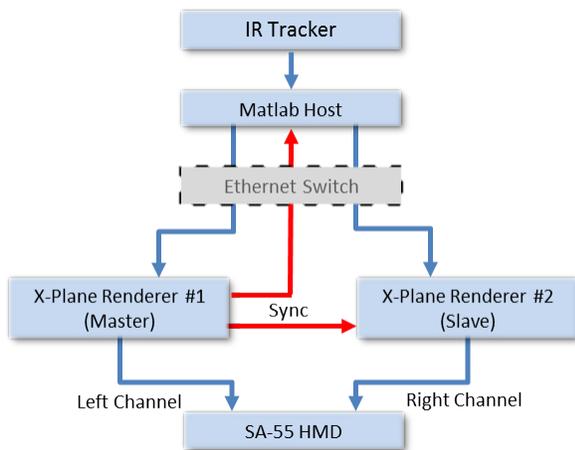


Figure 2. Network/system diagram.

host and the rendering machines was implemented using UDP multicast packets containing the relevant control parameters (e.g., aircraft position, etc.). The overall network/system diagram is shown in Figure 2.

HMD Configuration

The native optics of the SA-55 HMD produce significant pincushion distortion; therefore, the Brown-Conrady model for radially symmetric image warping (Brown, 1966) was implemented to minimize optical distortion while adding negligible latency. The model parameters were determined empirically by subjective evaluation of the final image geometry. However, this reduces the active horizontal FOV to 44° due to the loss/deactivation of pixels near the image borders, as shown in Figure 3. However, the modified FOV is still within the 40° FOV typical of NVGs. A custom 3D printed rigid body constellation, containing five IR reflectors, was mounted to the HMD for integration with the OptiTrack system, as shown in Figure 4.

The primary stereoscopic display system consisted of an SA-55 binocular HMD, composed of two 1920x1200 opaque organic light emitting diode displays with 100% overlap, 55° horizontal field-of-view (FOV), 4 meter virtual image distance, and capable of motion blur reduction (variable pixel hold time). This HMD was selected in part because it is one of the highest resolution, largest FOV HMDs currently available. Previous work (Lloyd, 2012) suggested that a relatively high resolution was needed to adequately display stereo imagery. The FOV limitation of the HMD is operationally similar to performing the call-to-landing task using night vision goggles (NVGs, ~40° FOV) and was thus not considered to be a significant system limitation. Head tracking was performed via a NaturalPoint OptiTrack (Motive:Tracker) infrared (IR) tracking system, utilizing seven Flex-13 cameras, with tracking latency of approximately 8.3 ms. The simulation control host was written in Matlab (MathWorks, 2014) by the OBVA team and operated from a third, separate PC. Communication between the Matlab



Figure 3. Simulation of SA-55 HMD image distortion and correction: native distortion (left), Brown-Conrady correction (center), and corrected image (right).

Software Implementation

A custom plug-in was written in C++ using the X-Plane Plugin SDK. The SDK permits the use of rendering callback functions, which allow the plug-in to execute custom code either directly before or directly after a specified rendering phase. Prior to the first rendering phase of each frame, the plug-in registers a callback function, which parses all pending control packets from the simulation host to specify the various rendering parameters (e.g., ownship and object locations, weather, time of day, etc.). This is done only once per frame to ensure parameters controlled by the plug-in remain consistent throughout the rendering of the entire frame.

Due to the plug-in being designed for a task in which the observer has no control over the aircraft, the plug-in also disables the simulation's native flight dynamics for the ownship by setting an override DataRef. Instead, the flight paths are generated remotely and provide 6 degree of freedom (6-DOF: x, y, z, roll, pitch, yaw) location information to the plug-in on a frame-by-frame basis. In this sense, the game software is being used simply as an image generator. To synchronize each frame of the rendering machines with the external Matlab host, the host requests a frame synchronization packet to be sent from the plug-in after each drawn frame. This packet is sent by a rendering callback function directly after the last accessible rendering phase. The frame synchronization functions were implemented in Matlab using a .NET library created in C#.

To render the observer's point of view within the HMD, and to implement stereo, the plug-in interfaces with the publically available PilotView plug-in. PilotView enables the camera to be placed at an arbitrary 6-DOF offset from the aircraft model's center of gravity. The plug-in receives external head-tracking data sent via UDP multicast by a custom application written using the NatNet SDK provided by OptiTrack. This information is fed into PilotView by setting DataRefs, first to enable external tracking data and then to populate 6-DOF offsets from the PilotView camera position, which are a combination of the tracking data received from the OptiTrack system as well as an additional offset to represent the IPD of the observer and enable stereo. The IPD offset is a simple calculation that is found by multiplying a distance vector of half the IPD length by a rotation matrix representing the 6-DOF position of the head tracker. The resulting vector is added to the head-tracker positional offset. The final portion of the plug-in utilizes a GLSL shader to apply the Brown-Conrady image warping algorithm to the rendered frame.

The flight paths were externally modeled in Matlab using a set of parametric functions to determine the 6-DOF ownship coordinates as a function of time. Each component of the flight path was first specified using several control points, then completed via bicubic interpolation and/or polynomial fit, using 16.67-ms (60-Hz) time increments, as shown in Figure 5.



Figure 4. SA-55 HMD configured with 3D printed IR reflective rigid body.

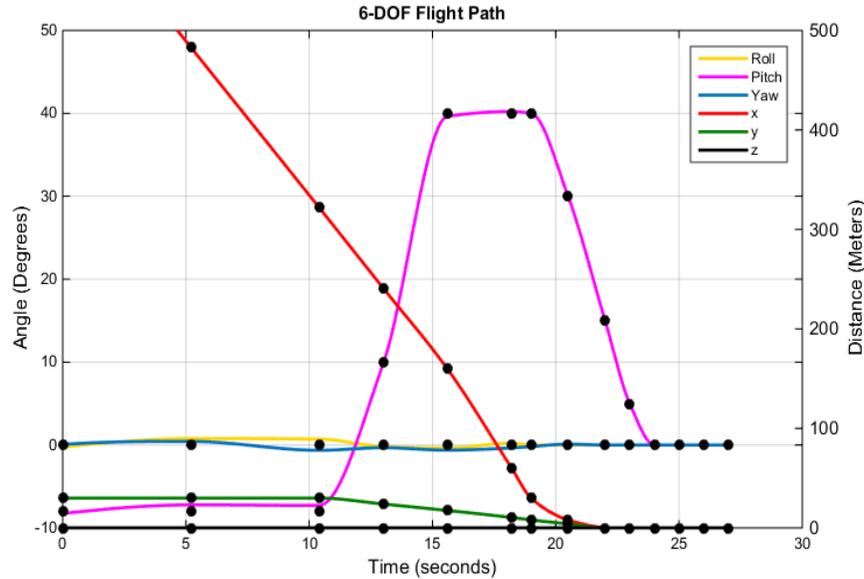


Figure 5. Typical parametric flight path for call-to-landing, illustrating control points and interpolation with random variation. Note that X-Plane assigns altitude to the y-coordinate, with transverse coordinates x and z.

A small degree of random variation was applied to each flight path (between trials) to both enhance realism and eliminate frequent repetition of rendering artifacts that might be used as improper cues by the observer during the call to landing experiment. Each simulated flight path was evaluated for operational plausibility by an MH-60 aircrew subject matter expert, with Figure 6 illustrating the view of the rear wheel touch down, as seen by the flight engineer.

STEREOSCOPIC EVALUATION

The utility of any display system for stereo perception research is dependent upon the minimum stereo threshold that may be accurately represented, which ideally will be less than or equal to the minimum stereo threshold of the observer. Such a system is said to be “eye limited” rather than “display limited” in stereo acuity. Unfortunately, analytical determination of the absolute stereo threshold of a stereoscopic display system is not straightforward and often depends upon several factors that are unknown, unquantifiable, or reconfigurable by the user.

In addition to relatively straightforward parameters such as pixel pitch and horizontal parallax, the stereo threshold of the system can be affected by various effects that are more difficult to quantify, such as antialiasing or pixel interpolation methods and/or image warping (as in this case), as well as the effect of human perception. Based simply upon a 1-pixel disparity between left/right images, the stereo threshold of the SA-55 would be equal to the pixel pitch of the display, which is 1.72 arcmin. However, human stereo perception tends to employ an integrating effect over the extended range of the target, not a single pixel, and stereo thresholds far below the pixel pitch are routinely realized (Ferwerda & Greenberg, 1988; McKee, Welch, Taylor, & Browne, 1990). Additionally, rendering effects that smooth edges (e.g., antialiasing) are expected to improve the stereo threshold,



Figure 6. Rendered view of rear wheel touchdown during call-to-landing, as seen by FCIII aircrew.

while effects that discard or collapse pixels (e.g., image warping) are expected to degrade the stereo threshold (Lloyd, 2012; Bach, Schmitt, Kromeier & Kommerell, 2001). Therefore, it becomes necessary to quantify the stereo threshold of the display system in the “as-built” configuration using psychometric measures. Using observers with good stereo acuity, it is then possible to determine if the system is either display or eye limited for the intended stereo application.

Evaluation Method

To quantify the stereo threshold of the display, the well-accepted Ψ (psi) method was adopted to estimate a psychometric function using a simple two-alternative forced-choice experiment for stereoacuity (Lu & Doshier, 2013; Kingdom & Prins, 2010). The experimental stimuli consisted of two static cross-shaped objects placed $d = 10$ m from the observer (within the virtual environment), with one object slightly closer than the other, as shown in Figure 7. The subject is forced to choose the closer of the two, and the discrepancy Δd between objects is altered by the Ψ algorithm after each trial, based upon the observer’s previous response. Each cross is randomly rotated after each trial. The Ψ method was implemented with 30 trials per block, with at least 10 blocks per antialiasing condition, across five available antialiasing conditions, under both stereo and non-stereo rendering conditions, with identical Brown-Conrady image warping implemented across all trials. Stereo images were rendered using each observer’s measured IPD, whereas non-stereo images were rendered with IPD = 0, which produces identical centered images for each eye. A typical Ψ estimate of the psychometric function is shown in Figure 8, as well as the manner in which the stimulus is altered by the Ψ algorithm between each trial. Note that the Ψ algorithm tends to converge rather quickly. Typically, at $d = 10$ m, observers with excellent stereo



Figure 7. Screenshot of stimulus used to determine stereo threshold of the display. Note that the relative sizes reveal which object is closer in the absence of stereo cues.

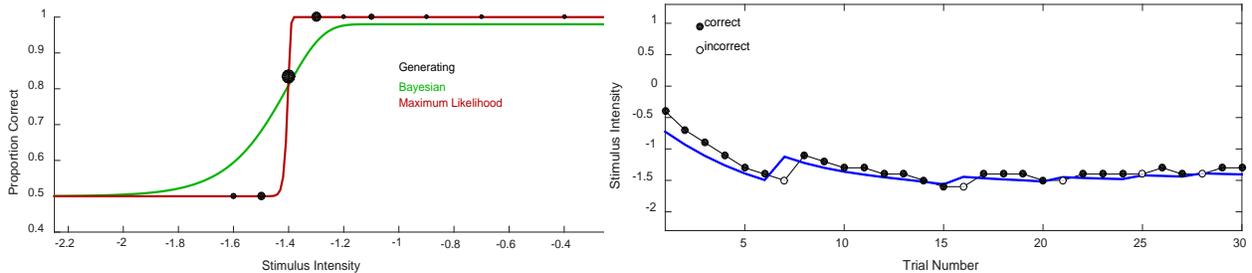


Figure 8. Typical estimate of the psychometric function given by the Ψ method (left) and convergence action of the adaptive algorithm (right). The red fitted curve is the most likely psychometric function to fit the given generating data, whereas the green curve represents a Bayesian threshold function. The blue curve is the Ψ algorithm’s current estimate of the observer’s threshold and is updated with each correct or incorrect response. The stimulus intensity units are given as $\log(\Delta d)$.

acuity and a typical IPD of 65 mm are able to discriminate real-world differences between objects of about $\Delta d \sim 3.7$ cm (~ 5 arcsec). Therefore, it is desirable that the stereoscopic display system be able to replicate this performance within the virtual environment. The stereoacuity required to discriminate between two objects, with longitudinal spacing Δd , at a distance d is given by the minimum angle of binocular disparity $\Delta\theta$:

$$\Delta\theta(\text{binocular disparity in arcsec}) = 3600 \cdot \tan^{-1} \frac{IPD \cdot \Delta d}{d^2} \quad (1)$$

Table 1. Comparison of Stereo Threshold Results at Various Antialiasing Multiples

Observer	Red	Blue	Green
IPD	66mm	65mm	63mm
Clinical Stereoacuity	3.7"	6.0"	3.0"
Stereoacuity at 0x	8.0"	14.3"	8.7"
Stereoacuity at 2x	7.6"	12.2"	9.8"
Stereoacuity at 4x	7.3"	11.2"	10.4"
Stereoacuity at 8x	6.8"	11.8"	7.6"
Stereoacuity at 16x	6.2"	10.3"	8.9"

Three observers with good stereoacuity participated in the experiment, with results detailed in both Table 1 and Figure 9. The baseline “clinical” stereoacuity threshold of each observer was measured (average of five measurement blocks) using the high-fidelity OBVA stereo test battery, which isolates stereo cues by employing constant-size concentric ring stimuli. The OBVA stereo test battery is modeled after the Freiburg Stereoacuity Test (Bach, Schmitt, Kromeier, & Kommerell, 2001), albeit using concentric ring stimuli similar to the well-known Titmus/Randot graded circle test (Precision Vision, 2015).

Inspection of Figure 9 reveals several interesting characteristics of the “as-built” HMD system. The first is that this system generally preserves the stereoacuity of the observer (Figure 9, solid lines). Second, the effect of antialiasing on stereo threshold in this system is relatively minor, although it trends somewhat toward better stereo threshold with increased antialiasing (Figure 8, solid lines). The observer with the best stereoacuity was able to resolve stereo imagery within ~6 arcsec (at 16x antialiasing), which, although still near the limit of human performance, falls somewhat less than the clinical measure. This slight discrepancy is likely due to the differences in stimuli between the two methods. Rather than spatially collocated concentric circles, the simulated stimuli (“cross” objects) are spatially separated, extended objects (as opposed to spatially localized, thin lines), with 3° of separation from center to center, and ~1° to ~1.3° between nearest edges, depending on the angle of rotation. This increases the eccentricity of the stimuli, when viewed by a human observer, by placing the retinal images farther from the fovea (which subtends ~1°), thus degrading the measured stereo threshold, as shown by Westheimer & McKee (1980). It has also been shown that stereoacuity measurements may be strongly affected by learning on the part of the observer, with well-practiced observers showing substantial improvement over novice observers for identical measurement tasks, especially with electronic displays (Fahle & Henke-Fahle, 1996; McKee & Taylor, 2010). Although each observer was considered to be well practiced at this task, this may also account for some variability in the data.

When stereo rendering was disabled (Figure 9, dashed lines), the stereo threshold of these observers appears to have increased to a range of approximately 20” to 40”, though it would be predicted to be much worse. However, this is simply due to the nature of the stimuli. The simulated stimuli are representative of “real-world” depth scenes, in which the stereo cue is combined with several other depth cues to provide an overall perception of depth. The most notable of these additional cues is object size. For depth inequalities of $\Delta d > 15$ cm at $d=10$ m, the relative size of the two objects becomes a dominant depth cue, allowing these observers to accurately judge depth with stereo rendering disabled, based solely upon non-stereo cues, to within a 20” to 40” range. This is readily illustrated by Figure 7, in which the object on the left appears larger (thus closer), even in the absence of stereo cues (i.e., Figure 7 is a 2D image). Additionally, the stereo acuity values obtained using this HMD/simulation apparatus were very comparable to those obtained using a real world model of the same cross-shaped stimuli viewed at 10 m.

The fact that individual differences are preserved within the stereo cuing range (i.e., below ~20”, prior to size cue dominance), rather than converging to some common performance level, is the primary figure of merit in determining the eye-limiting stereo performance of the system. If the system were display-limited, individual

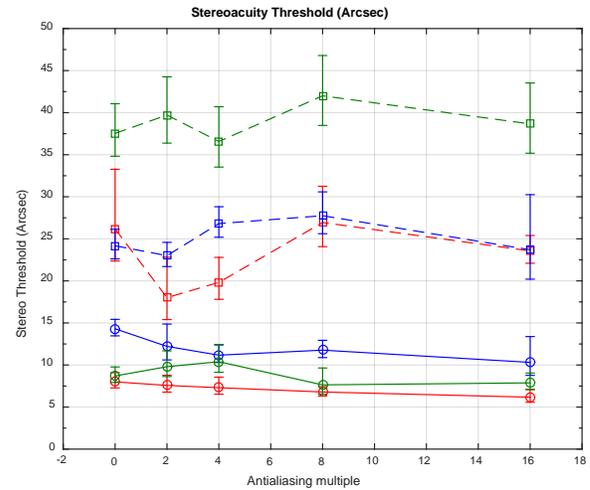


Figure 9. Stereo/depth thresholds of three observers (red, blue, green) at various antialiasing multiples, with (solid) and without (dashed) stereo enabled.

differences in stereo threshold would collapse to some common minimum threshold at some or all antialiasing conditions. Since this does not occur, this system can be said to be “eye limited” with regard to stereoacuity.

It should be noted that all observers judged the antialiasing levels of 4x and greater to be the most comfortable for stereo viewing. Low, or no, antialiasing (0x, 2x) produced noticeable “jaggies” at the edges of each object, which were not well correlated between the left and right eye images, resulting in a “shimmering” effect at the edges. Although this had minimal effect on performance, it was judged to be distracting by all observers.

RESEARCH & TRAINING APPLICATIONS

In this work, which specifically pertains to depth perception research using a relatively aggressive call-to-landing scenario, the observer had no control over the flight path and was not permitted to “free-fly” the aircraft. However, this work is intended to provide an example simulation framework for further development of stereoscopic virtual immersive environments applicable to both research and training. Such stereoscopic HMDs and verification processes can be adapted to a wide range of simulation systems to fulfill a broad spectrum of research and training requirements where accurate stereo representation proves to be a necessary requirement. Although the authors consider this device to be “eye-limited”, it should also be noted that a stereoscopic display that provides less than “eye-limited” stereo performance may still be adequate for a particular task, so long as it can provide a “useful” amount of stereo cuing.

CONCLUSION

This research has demonstrated that game-based simulation software provides a viable alternative to traditional image generators for operationally relevant depth perception research. Additionally, the use of high-resolution HMDs can provide a fully immersive stereoscopic virtual environment without significantly limiting the operational FOV (assuming a similar FOV to NVGs) or the stereo acuity of the user. The display system described herein permits stereo resolution dramatically lower than the display pixel pitch while providing a useful (eye-limited) degree of stereo for the call-to-landing scenario under study.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of Casey Wimsatt of SA Photonics, who initially prototyped the stereo X-Plane concept and implemented the Brown-Conrady distortion correction algorithm, as well as the efforts of Sandy Barbour, the developer of the Pilot View plug-in. The views expressed are those of the authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense, or the U.S. Government.

REFERENCES

- Allsop, J. & Gray, R. (2014). Flying under pressure : Effects of anxiety on attention and gaze behavior in aviation. *Journal of Applied Research in Memory and Cognition*, 3, 63-71.
- Bach, M., Schmitt, C., Kromeier, M., & Kommerell, G. (2001). The Freiburg Stereoacuity Test: automatic measurement of stereo threshold. *Graefes Archive for Clinical and Experimental Ophthalmology*, 239, 562-566.
- Barbour, S. (2013) Pilot View [Computer software]. Retrieved from http://www.xpluginsdk.org/pilot_view.htm
- Brown, D. C. (1966). Decentering distortion of lenses. *Photogrammetric Engineering*, 32(3), 444-462.
- Eidman, C., Lisa, M., Kam, C., Pohl, A., Rogers, B., & Mitchell, D. (2009). Leveraging gaming technology for military training. *Proceedings of the Society for Applied Learning Technology, New Learning Technology 2009 Conference*.
- Fahle, M. & Henke-Fahle, S. (1996). Interobserver variance in perceptual performance and learning. *Investigational Ophthalmology & Visual Science*, 5(37)

- Ferwerda, J. A., & Greenberg, D. P. (1988). A psychophysical approach to assessing the quality of antialiased images. *IEEE Computer Graphics and Applications*, 8(5), 85-95.
- Garcia, R., & Barnes, L. (2010). Multi-UAV simulator utilizing X-Plane. *Journal of Intelligent & Robotic Systems*, 57, 393-406.
- Kingdom, F., & Prins, N. (2010). *Psychophysics: a practical introduction*. Elsevier, London: Academic Press
- Lloyd, C. J. (2012). *Effects of spatial resolution and antialiasing on stereoacuity and comfort* (paper no. 4572). Paper presented at the AIAA Modeling and Simulation Technologies Conference, Minneapolis, MN.
- Lu, Z., & Doshier, B. (2013). *Visual psychophysics: from laboratory to theory*. Cambridge, MA: The MIT Press.
- Mathworks (2014), Matlab R2014b [Computer Software]. Retrieved from <http://www.mathworks.com/>
- McKee, S. P. & Taylor, D. (2010) The precision of binocular and monocular depth judgments in natural settings. *Journal of Vision*, 10(10), 1-13.
- McKee, S. P., Welch, L., Taylor, D. G., & Browne, S. F. (1990). Finding the common bond: stereoacuity and the other hyperacuties, *Vision Research*, 32(6), 879-891.
- Precision Vision (n.d.). Randot Stereo Test [Computer software]. Retrieved from <http://precision-vision.com/products/stereo-vision-tests/randot-stereo-test.html>
- Smith, P. Sciarini, L., & Nicholson, D. (2007). *The utilization of low cost gaming hardware in conventional simulation* (paper no. 7256). Paper presented at the Interservice/Industry Training, Simulation and Education Conference 2007, Orlando, FL.
- Supnik, B. (2003). The X-Plane plugin software development kit (SDK)[Computer software]. Retrieved from <http://www.xsquawkbox.net/>
- Westheimer, G., & McKee, S. P. (1980). Stereogram design for testing local stereopsis. *Investigative Ophthalmology & Visual Science*, 19(7), 802-809.
- Williams, L. A., Lisa, M., Eidman, C., Kam, C., & Pohl, A. (2014). Evaluation of game-based visualization tools for military flight simulation (Technical Report AFRL-RH-WP-TR-2014-0004). Retrieved from <http://www.dtic.mil/get-tr-doc/pdf?AD=ADA594585>
- Williams, H. P., Littman, E. M., Folga, R. V., & Patterson, F. R. (2014). Field of View Evaluation for Flight Simulators Used in Spatial Disorientation Training (No. NAMRU-D14-41). Office of the Assistant Secretary Of Defense (Health Affairs), Washington DC.