A Quantitative Measurement of Presence in Flight Simulators

Javier (Jeff) Covelli
Northrop Grumman Corporation (NGC)
Orlando, Florida
Jeff.Covelli@1983.usna.com

Jannick Rolland
CREOL, College of Optics and Photonics, University of Central Florida (UCF)
Orlando, Florida
jannick@odalab.ucf.edu

Peter Hancock
Institute for Simulation & Training (IST)
Orlando, Florida
phancock@pegasus.cc.ucf.ed

ABSTRACT

Virtual Reality (VR) and Augmented Reality (AR) Head Worn Display (HWD) technology is being considered as a novel alternative for low cost, wide Field of Regard (FOR), deployable simulators. There are inherent differences in display characteristics among different HWDs and between HWDs in general with conventional displays. For example, the effective Field of View (FOV) in most HWDs is no more than 60º horizontal and 45º vertical, which is far narrower than the human eye's 200º horizontal and 135º vertical FOV. Developing a HWD with a wide 200º horizontal FOV is expensive. Current HWD flight simulator implementations provide limited effective FOV that reduces the pilot's visual stimulus, perception, sense of presence and overall training effectiveness. To successfully utilize a VR or AR HWD in a simulator, we hypothesize the user must have the same or even a higher mental immersion experience as compared with the conventional simulator experience with unrestricted FOV. Attempts to measure mental immersion or presence from VR simulations were normally conducted with questionnaires. Although more convenient, the validity of measuring the continuous experience of presence with post experience questionnaires has been challenged (e.g., Slater, 2004). Here, a quantitative approach to measure presence in relation to mental image processing and performance is proposed. This paper presents experimental methods involving measurement and analysis of normal head and eye movement patterns of experienced pilots while accomplishing specific tasks in a conventional flight simulator with a 170° horizontal x 75° vertical FOR. The paper outlines metrics taken using head and eye tracking equipment, and results of pilot head and eye movement patterns between different Areas of Interest (AOIs) inside and outside the cockpit. The experimental results are analyzed with regard to task performance and five different pilot effective FOV conditions. A summary of findings, experiment limitations, lessons learned and potential areas for future research are also presented.

ABOUT THE AUTHORS

Javier (Jeff) Covelli is a Sr. Software / Systems Engineer and Program Manager for Northrop Grumman Corporation (NGC), a Certified Modeling and Simulation Professional (CMSP) and has been working in the Live, Virtual and Constructive military simulation and training field for over 20 years. While on active duty, he was a Navy Carrier pilot and served as Training and Safety Officer for various squadrons and for the Flight Deck and Combat Information Center (CIC) aboard the U.S.S. George Washington (CVN-73), where he earned Officer of the Deck (OOD) and Tactical Action Officer (TAO) qualifications. For the past four years he has worked as a technical lead on the Army sponsored Future Combat Systems (FCS) Training Common Component (TCC) and Common Training Instrumentation Architecture (CTIA) program. He holds a B.S. Ocean Engineering Degree from the United States Naval Academy (USNA), an M.S.E.E. degree from the Naval Postgraduate School (NPS), an M.S.I.E. (Simulation and Training) from the University of Central Florida (UCF) and is currently finishing his Ph.D. degree in Modeling and Simulation from UCF.

Jannick Rolland received a Diploma from the *Institut D'Optique, Graduate School* in France in 1984, and the Ph.D. degree in Optical Science from the University of Arizona in 1990. She is a Professor of Optics at the University of Central Florida with joint appointments in Computer Science and Modeling and Simulation. After completing a Postdoctoral Fellowship, she joined the Research Faculty at UNC-Chapel Hill in 1992 and headed the Vision Research Group 1992-1996. She holds 13 patents, wrote 6 book chapters, and has over 60 peered review publications related to optical design, augmented reality, vision, and image quality assessment. Professor Rolland served on the editorial board of the *Journal Presence* (MIT Press) 1996-2006, and as Associate Editor of *Optical Engineering* 1999-2004. She is a Guest Editor for a special issue of the IEEE Journal of Display Technology on medical displays. She is a Fellow of the Optical Society of America, and a member of SPIE, IEEE, and SID.

Peter Hancock is Provost Distinguished Research Professor in the Department of Psychology, the Institute for Simulation and Training, and in the Department of Civil and Environmental Engineering at the University of Central Florida. In his previous appointment, he founded and was the Director of the Human Factors Research Laboratory at the University of Minnesota. Professor Hancock is the author of over five hundred refereed scientific articles and publications as well as the editor of numerous books. In 1999 he was the Arnold Small Lecturer of the Human Factors and Ergonomics Society and in 2000 he was awarded the Sir Frederic Bartlett Medal of the Ergonomics Society of Great Britain for lifetime achievement. In 2001 he won the Franklin V. Taylor Award of the American Psychological Association as well as the Liberty Mutual Prize for Occupational Safety and Ergonomics from the International Ergonomics Association. In association with his colleagues Raja Parasuraman and Anthony Masalonis, he was the winner of the Jerome Hirsch Ely Award of the Human Factors and Ergonomics Society for 2001, the same year in which he was elected a Fellow of the International Ergonomics Association. He was awarded a Doctor of Science (D.Sc.) degree from Loughborough University in December, 2001. In 2002, he was awarded the Jastrzebowski Medal of the Polish Ergonomics Society for contributions to world ergonomics and in the same year was named a Fellow of the Ergonomics Society of Great Britain. In 2003 he won the Liberty Mutual Medal of the International Ergonomics Association, a world-wide competition for innovative advances in occupational safety and ergonomics. In 2006 he won the Norbert Wiener Award of the Systems, Man and Cybernetics Society of the IEEE. His current experimental work concerns the evaluation of behavioral response to high-stress conditions. His theoretical works concern human relations with technology and the possible futures of this symbiosis. He is a Fellow of and past President of the Human Factors and Ergonomics Society. He collects and studies antique maps and is a committed Ricardian.

A Quantitative Measurement of Presence in Flight Simulators

Javier (Jeff) Covelli
Northrop Grumman Corporation (NGC)
Orlando, Florida
Jeff.Covelli@1983.usna.com

Jannick Rolland
CREOL, College of Optics and Photonics, University of Central Florida (UCF)
Orlando, Florida
Jannick@odalab.ucf.edu

Peter Hancock
Institute for Simulation & Training (IST)
Orlando, Florida
phancock@pegasus.cc.ucf.ed

INTRODUCTION

When a unit deploys, reaching and maintaining a certain level of proficiency is required. It is common knowledge in the aviation community that a decrease in training leads to a decrease in proficiency, which contributes to an increase in accident rate and decrease in combat effectiveness (Shappell and Wiegmann, 2000). In an effort to cut costs and improve pilot proficiency, the military has plans to decrease actual flight hours and increase flight training reliance on simulators (French, 2003).

Conventional flight simulators consist of an emulated cockpit, instruments and controls with a virtual environment display ranging in sophistication (and price) from a simple flat computer monitor to the wide 360° Field of Regard (FOR) dome screens with bulky projectors and digital image blending techniques. We refer to Field of View (FOV) as the instantaneous subtenant visual angle of the scene at the eye. The FOR refers to the overall FOV of the simulated scene one can perceive via head movements. The FOR, typically measured in degrees, is basically the amount of virtual environment the simulator image generator (IG) can render per cycle. For military simulator training, the simple Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD) monitors are practical in deployed situations but the high fidelity simulator dome display systems provide more immersion (Ames, 2005). This simple display FOR is much smaller than a normal human's FOV of about 200º horizontal (h) and 135º vertical (v) (Arthur, 2000). So this limited FOR will create a small human effective FOV, roughly the same as the FOR.

For a flight simulator, the limited effective FOV of a single computer monitor might suffice for cockpit familiarization but is impractical for providing realistic Out-The-Window (OTW) display and situation awareness (SA) for advanced pilot training. The desktop PC simulation approach is also impractical for providing realistic crew coordination training for aircrews (Stewart, Dohme & Nullmeyer, 2002). However, it is neither practical nor feasible to deploy a conventional wide FOR dome screen flight simulator with aviation units to maintain pilot proficiency. This is especially true for cockpits with side-by-side seating, for which the display system is inherently large. Operational Flight Trainers (OFTs) are the most practical way to keep proficient but are impractical when needed in tight spaces or with limited budgets.

Head-Worn Display (HWD) technology is normally associated with fully immersive Virtual Reality (VR) simulation. Additionally, Augmented Reality (AR) HWD technology is being considered as a novel new display alternative to provide operational cockpit Heads Up Display (HUD) and also embedded training in a low-cost, wide FOR, deployable simulator. However, there are inherent differences in display characteristics among different HWDs and between AR displays in general with conventional displays (Cakmakci and Rolland, 2006). For example, the FOV in most HWDs are less than 60º h x 45º v (assuming a 4:3 format), which is far narrower than the human's normal FOV of about 200º h x 135º v (Arthur, 2000). A pilot will normally use peripheral vision during a flight but developing an HWD with a wide 200º h x 135º v FOV is expensive. Therefore, current flight simulator implementations use HWDs with an effective 60º h x 45º v FOV. However, this reduced effective FOV can reduce the pilot's visual stimulus, perception, sense of presence and training effectiveness (Azuma, Baillot, Behringer, Feiner, Julier and MacIntyre, 2001).

To successfully utilize a VR or AR display device in a simulator, the user must have the same or an even higher mental immersion experience and presence as compared with the simulator experience of unrestricted FOV in a conventional wide FOR simulator. A distinction is made between immersion and presence by many researchers. Immersion is a description of overall fidelity in relation to physical reality provided by the display and interaction systems. Presence is the subjective experience of being in one place or environment, even when one is physically situated in another (Witmer and Singer, 1998). Attempts to measure presence were historically conducted with questionnaires (Witmer and Singer, 1998) (Biocca, Harms and Burgoon, 2003). Although more convenient, the validity of measuring the continuous experience of presence with post experience questionnaires has been challenged (e.g., Slater, 2004). Generally, the use of continuous indicators of behavioral or physiological response is considered more sensitive and valid. The major argument is that after-the-event questionnaire-based measures cannot in principle rule out the possibility that the reported "presence" was called into being simply by its having been asked about. To prove this, Slater made up an arbitrary concept ("colorfulness of the experience"), constructed a questionnaire to "measure" this phenomenon, and showed how results are obtained that mirror results with presence questionnaires.

A fundamentally different view offered by Zahoric & Jenison (1998), Flach & Holden (1998) is that presence is "tantamount to successfully supported action in the environment." What is important in this approach is action (i.e. how things are done) and the affordances offered in the virtual environment, rather than just appearances. In other words, the sense of "being there" is grounded on the ability to "do" there. A scientific basis for "presence" as it is usually understood in virtual environments research cannot be established solely on the basis of post-experience presence questionnaires alone. Therefore, a quantitative approach to measure presence and immersion in relation to mental image processing from AR data is needed. A methodology needs to be developed that quantitatively measures and compares the display system effect on the pilot's visual perception and presence.

RESEARCH SUMMARY

This research paper describes a quantitative approach to measure presence in relation to mental image processing and performance, illustrated in the context of a human factors study. The goal of this study was to accurately measure head and eye movement patterns for experienced pilots during turning and landing tasks, while varying the pilot's effective FOV. Task performance was also recorded, with the additional goal of determining the optimum effective FOV requirements for satisfactory completion of these tasks.

The development of an optimized effective FOV stereoscopic AR-based display system to perform such tasks requires an understanding of FOV effects in relation to the function of different visual pathways such as (a) dorsal stream functioning related to spatial orientation, heading control, sense of immersion and visual-motor tasks requiring a wide FOV and (b) ventral stream functioning related to targeting, object recognition, and visual-motor tasks requiring a more narrow FOV (Winterbottom, Patterson and Pierce, 2006). In this study, pilots were tested in a flight simulator further described under method with varying amount of FOV to simulate the future use of HWDs.

It was hypothesized that depending on the task, limiting the pilot effective FOV will impose additional workload and stress due to the limited peripheral image data. To be more specific, as the pilot's effective FOV is artificially reduced, eye movement range (in radians) will decrease proportional to the decrease in effective FOV. Additionally, as the effective FOV is decreased, head movement range (in degrees) and head rate of movement (in degrees/second) will increase to compensate for the reduced peripheral visual data.

It was further hypothesized that a threshold exists, while decreasing the effective FOV, where the pilot can no longer compensate sufficiently to maintain an adequate cognitive mental image and that there will be a measurable decrease in task performance. Somewhere between the onset of a measured increase in normal head and eye movement range and velocity and the measured decrease in task performance, negative training becomes a concern. These FOV effects will provide insight into AR or VR HWD device FOV design for this type of flight simulation application.

The results from this research provide a methodology to, in the future, quantitatively measure presence during normal task simulation using an HWD that limits the pilot's effective FOV. This study will facilitate the determination of optimum effective FOV specifications needed by an AR or VR HWD system to conduct these types of tasks.

Method

Pilot Participants

Bristow Academy provided a group of experienced Bell 206 certified instructor pilot volunteers. The reason for using certified instructor pilots was their experience and expected level of aircraft familiarity. Student pilot skills can be unpredictable but mostly it was the intent to not disrupt student pilots and their training while at Bristow Academy.

Equipment and Materials

Bristow Academy provided a Bell 206 flight simulator, the Aero Simulators Flight Navigation Procedure Trainer (FNPT) II, for this experiment. The FNPT II has a 170° horizontal x 75° vertical wrap-around FOR, rear-projected display. The entire helicopter simulator depicted in Figure 1 is supplied in a self-contained 18 foot trailer classroom, complete with instructor station.

Figure 1 - Aero Simulators FNPT II

The University of Central Florida (UCF) Optical Diagnostics and Applications Lab (ODALab) provided an InterSense IS-1200 VisTracker for head orientation tracking. The Institute for Simulation and Training (IST) provided an Arrington Research ViewPoint EyeTracker® system and EyeFrame Hardware demonstration unit for this research (Arrington and Geri, 2000). Effective FOV masks were created and custom fit to attach to the EyeTracker goggles as demonstrated by the pilot participants in Figure 2.

Figure 2 - Pilot wearing Head/Eye Tracking System, with and without an effective FOV mask

Experimental Design

A single group, within-subject repeated measures design was used with experienced pilots having relatively similar flight experience and skills. The reason for this design was the limited number of experienced instructor pilots available. The independent variable was the pilot's effective FOV, which varied by a fraction of 100% for each consecutive test run. As the effective FOV was reduced, a measurable difference in the dependent variables (i.e. head and eye movement patterns) were predicted, and a measurable difference in performance was also expected.

Experiment Procedure

Experiments were conducted after hours, when the simulator was available and not scheduled for training. The pilot volunteers were briefed on the experiment procedures and the head/eye tracking system used in the simulator. Each volunteer pilot was asked to read and sign an informed consent form before the experiment.

All simulation test runs began with a pilot initialized at the base leg of a Visual Flight Rule (VFR) pattern, 600 ft. and 85 kts as depicted in Figure 3. The pilot wore a helmet with the VisTracker camera and the ViewPoint EyeTracker goggles with or without a mask with a pre-determined effective FOV. The pilot maneuvered to make a coordinated turn to line up with the runway, while descending to land at the runway intersection. Time to land, flight path over the ground and descent path were recorded for each run. Each pilot conducted a total of five simulation runs. The pilot effective FOV was also changed for each simulation run.

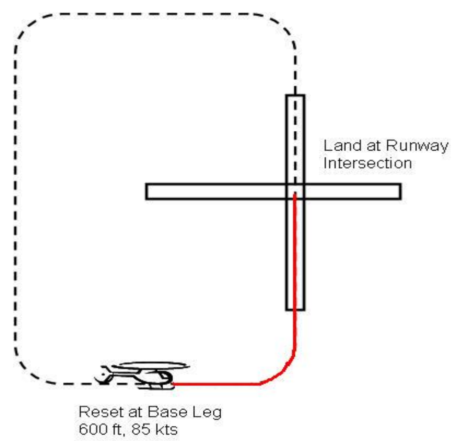
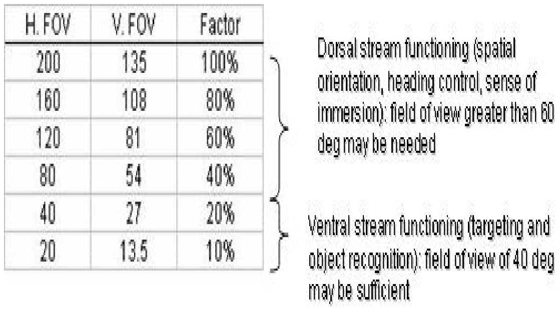


Figure 3 - Simulation VFR Pattern

A counter-balanced Latin Square Design was used to determine the sequence of simulator test runs the pilot participants conducted and to prevent asymmetric transfer effects (Lowry, 2007).

The independent variable levels for each simulation test run was the pilot's effective FOV as a percentage factor of normal 200º h x 135º v FOV, which can be one of six possible conditions as indicated in Figure 4.



H. FOV	V. FOV	Factor
200	135	100%
160	108	80%
120	81	60%
80	54	40%
40	27	20%
20	13.5	10%

Figure 4 - Effective FOV Reduction Factors

Masking portions of the EyeTracker goggles restrict the effective FOV to the six reduction factor conditions indicated in Figure 4. The order in which a pilot participant used an effective FOV reduction factor condition can be selected at random from a possible six-factorial (6!) or 720 possible sequences. Consequently, before the simulation test runs each pilot participant was randomly assigned a sequence of effective FOV conditions per run as indicated in Table 1.

Table 1 - Example Participant (P) simulation run effective FOV reduction factor sequence

	Sequence					
	FOV1	FOV2	FOV3	FOV4	FOV5	FOV6
P1	80%	20%	100%	60%	40%	10%
P2	40%	100%	60%	20%	10%	80%
P3	60%	10%	40%	100%	20%	80%
:	80%	20%	10%	100%	40%	60%
Pn	10%	20%	100%	40%	60%	80%

The different horizontal and vertical effective FOV openings of the mask were calculated based on an eye to mask distance of 15 mm. The following Table 2 summarizes the mask H x V opening dimensions in millimeters.

Table 2 - Effective FOV Mask Openings

H FOV (deg.)	V. FOV (deg.)	Factor	H (mm)	V (mm)
200	135	100%		
160	108	80%	170.1	41.3
120	81	60%	52.0	25.6
80	54	40%	25.2	15.3
40	27	20%	10.9	7.2
20	13.5	10%	5.3	3.6

In the FNPT II simulator, the 100% effective FOV is limited to essentially 80% by the 170° h x 75° v simulator FOR. Therefore each pilot completed only a total of five test runs, taking roughly 4 minutes for each run. This short VFR base leg to landing simulation run was planned to prevent the pilot from spending more than a half hour in the simulator for all five simulation runs.

Determining Sample Size

It was anticipated that no more than 12 certified pilot instructors would be available to volunteer given the limited number of instructors at Bristow Academy and their extremely busy schedule. Given this anticipated limitation, a limited sample size was predicted to be at best 10 to 12 pilots times 6 effective FOV conditions providing a maximum of 72 effect observations. To ensure this sample size and predicted mean are adequate to represent a larger population mean, the method used to determine adequate sample size was to determine an acceptable margin of error (difference between sample and population mean) based on a normally distributed population.

Using a horizontal head movement sample as an example, to ensure detection of an effect between 40% and 80% effective FOVs, the calculated additional head movement required by the 40% effective FOV condition should require a maximum of 20º additional movement, which is the predicted population standard deviation. For 95% confidence that the sample mean is within 6º of the population mean, the sample size must be 43, which can be satisfied with nine (9) pilot participants.

Measurement Procedures

Head and/eye movement patterns were categorized based on the three factors that influence where a pilot looks: Information, Effort, and Importance (Wickens, Xu, Hellenberg, Carbonari and Marsh, 2000).

For *Information* expectancies, the pilot's Areas of Interest (AOIs), where the pilot can gather visual information, are defined in Figure 5. The number of pilot's eye fixations, defined as dwells greater than 100 ms per AOI within a 0.5º radius from the edge (Guest and Rolland, 1999), was a metric collected as Dwell Frequency per AOI (DFA). The 0.5º radius corresponds to half the eyetracker angular accuracy. Also, how long a pilot fixated in an AOI was a metric collected as the Mean Dwell Duration (MDD) in an AOI (Poole, Ball, Phillips, 2004). These eye dwell metrics were collected to provide an indication of pilot scan pattern changes during the VFR approach and landing phase as the effective FOV was varied.

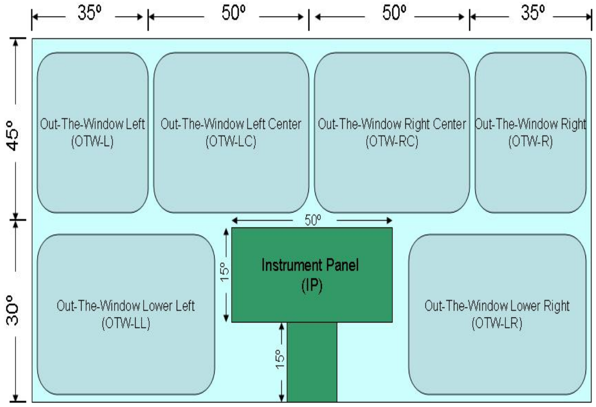


Figure 5 - Bell 206 Cockpit AOIs

Inside the cockpit, certain Instrument Panel (IP) gauges were important for communication of information during different phases of the simulated flight. As a result, the transitions in and out of the IP were recorded. Likewise, in the OTW, different AOIs provided the needed information during various phases of the simulated flight. The OTW was divided into six large AOIs, evenly distributed to the left and likewise to the right of the simulator. All pilots were seated in the right seat for the simulation runs.

For *Effort* expectancies, the eye and head movements were recorded to understand pilot effort in gathering visual data from one AOI to another. The rationale for such Effort metric definition is that vertical eye movement requires more effort than horizontal because it takes more muscular effort to move the eye vertically than horizontally. Head movement requires use of larger neck muscles and therefore requires greater effort (Wickens et. al., 2000). The head movements (in degrees) relative to the simulator were recorded and plotted for each pilot during each sequence. Likewise, the eye movements relative to the head were recorded and plotted for each pilot during each sequence. A rotating Cartesian coordinate system depicted in Figure 6 was used for measuring the head and eye rigid body rotations. (Agrawal, 1986).

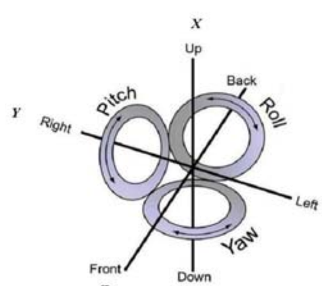


Figure 6 - Head and Eye Coordinate System

For *Importance*, how quickly pilots moved their head and eyes to gather visual data measured as the rates of movement (degrees/second) for the eyes and head were calculated from the eye and head movement data and plotted for each pilot during each simulation run. Also, the pilot was video taped from the left seat to validate head tracking data during the entire simulation run. During and after each simulator sequence, the pilot was asked for feedback regarding their discomfort level and perceived performance. After all sequence runs for the pilot were complete, a post-flight debrief documented any overall FOV effects perceived by the pilot.

RESULTS AND DISCUSSION

The data extracted from the Head and Eye Tracker measurements were based on the previously described factors that influence where a pilot looks: Information, Effort, and Importance. For each simulation run, the simulator recorded aircraft course over ground and elevation. The results described here represent an analysis of measured head and eye movement trend and aircraft track performance as the effective FOV was changed for each simulation run.

Information

Table 3 contains the average DFA for all the pilots tested, listed by effective FOV.

Table 3 – Average Dwell Frequency per AOI (DFA)

Avg	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	3.57	13.86	14.43	0.14	20.43		0.29
20%	3.00	17.57	9.14	0.29	19.71		0.14
40%	2.71	16.57	7.57	0.14	16.14		0.43
60%	1.43	16.86	6.86	0.29	15.14		0.14
80%	1.14	15.29	7.43		12.86		

The data shown in Table 3 indicate that the pilots tended to mainly look outside left of center (OTW-LC) and also outside right of center (OTW-RC), as well as the instrument panel (IP) for flight information, with some glances outside at far left (OTW-L), outside far right (OTW-R) and outside lower right (OTW-LR) when landing. Recall that all pilots were seated in the right seat of the simulator. Also, the data indicate that the average DFA significantly increases for the OTW-L, OTW-RC and IP AOIs as the effective FOV is decreased. It is to be noted that this average DFA was the combined value for the base course, turn and final approach phases. To analyze this effect during each phase of the simulated flight, the DFA data was processed separately for each phase of the simulation run. The results are reported in Table 4.

Table 4 – Average DFA per phase

Base	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	1.00	3.14	1.14		2.43		
20%	1.43	4.29	0.86		2.71		
40%	0.71	3.00	0.57		2.71		
60%	0.43	3.00	1.43		2.43		
80%	0.71	3.86	1.57		2.00		
Turn	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	2.57	6.71	0.86		6.14		
20%	1.57	6.43	1.14		6.71		
40%	2.00	6.71	1.00		4.86		
60%	1.00	4.71	1.86		4.14		
80%	0.43	4.43	1.14		3.43		
Apch	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%		3.57	12.14	0.14	11.71		0.29
20%		5.71	7.14	0.29	10.29		0.14
40%		6.86	6.00	0.14	8.57		0.43
60%		11.43	5.86	0.29	9.71		0.43
80%		7.00	4.71		7.43		

The data in Table 4 indicate that except for the OTW-RC and IP, the average DFA do not significantly increase with decreasing effective FOV. However, during the turn phase, the average DFA does increase for OTW-L, OTW-LC and IP with a decreasing effective FOV. This finding reflects on the turn phase requiring the pilot to gather spatial orientation to the runway and heading control information in preparation for the approach phase. During the approach phase the average DFA tends to increase for OTW-RC and IP as the effective FOV decreased. This finding reflects the approach phase requiring the pilot to gather increased spatial orientation data with regard to the runway landing area (i.e. runway intersection). It is also interesting to note during the approach phase the average DFA decreased for OTW-LC with decreasing effective FOV. This may be explained by the increased information required from the OTW-RC and IP AOIs.

Table 5 contains the average MDD for the AOIs that registered any dwell time, for all the pilots tested, listed by effective FOV.

Table 5 – Average Mean Dwell Duration (MDD)

Avg	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	1.25	2.03	3.32	1.08	1.27		0.99
20%	0.98	2.23	4.14	0.57	1.12		5.33
40%	1.15	2.95	7.46	0.70	0.97		4.56
60%	2.32	2.96	8.80	0.70	0.88		3.13
80%	0.66	3.55	7.60		0.98		

The data in Table 5 indicate a trend of pilot MDD decreasing for OTW-LC, OTW-RC and IP AOIs as the effective FOV is decreased. When the MDD was processed for each phase, the following MDD trends listed in Table 6 stood out.

Table 6 – Average MDD per phase

Base	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	1.16	0.93	0.91		1.46		
20%	0.99	1.13	1.80		1.16		
40%	1.18	1.42	0.98		1.18		
60%	0.85	1.74	2.71		0.90		
80%	0.89	1.76	2.68		1.30		
Turn	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%	1.35	1.61	1.79		1.57		
20%	0.87	1.99	1.26		1.16		
40%	1.10	1.88	2.22		0.85		
60%	2.90	3.33	2.74		0.85		
80%	0.77	4.71	1.35		0.79		
Apch	OTW-L	OTW-LC	OTW-RC	OTW-R	IP	OTW-LL	OTW-LR
10%		3.36	3.96	0.43	1.08		0.57
20%		2.60	7.32	0.57	1.13		5.33
40%		5.16	11.14	0.70	0.93		4.56
60%		3.44	17.23	0.52	1.02		4.86
80%		4.87	21.58		0.90		

The data in Table 6 indicate that during the base leg phase and turn phase, the OTW-LC MDD decreased while the IP MDD increased with a decreasing effective FOV. After a close analysis of the Scene Camera video during these phases, with varying effective FOV, it appears that the pilots tended to revert to Instrument Meteorological Condition (IMC) visual scan behavior in setting up for the approach phase, requiring more information from the IP AOI and less from the OTW-LC. Once on approach phase, the pilots tended to revert back to Visual Meteorological Condition (VMC) visual scan behavior, as indicated by the comparably large MDD values for OTW-RC, which also decreased with a decreasing effective FOV. We infer that during the approach phase, as the effective FOV is decreased, the pilot tends to compensate for a lack of peripheral vision by dwelling more on the limited horizon with more frequent checks of the instruments (i.e. airspeed indicator and altitude) to gather information for a smooth landing.

Summarizing the effective FOV effect on Information behavior, the pilot tends to focus more on the horizon and less on the instruments, especially during the turn and approach phase. We infer a greater pilot need for aircraft orientation (i.e. horizon) information as the effective FOV is reduced.

Effort

All pilots tested had a tendency to increase their head movement ranges in pitch and yaw as the effective FOV was decreased. The following Table 7 contains the calculated average pilot head pitch and yaw movement range values by effective FOV for each phase.

Table 7 - Average Pilot Head Pitch and Yaw Movement Range

Eff FOV	Pitch (base)	Pitch (turn)	Pitch (apch)
10%	45.40	70.94	34.08
20%	32.44	42.83	19.66
40%	24.32	29.51	19.74
60%	24.18	20.14	19.90
80%	20.66	21.07	14.32
Eff FOV	Yaw (base)	Yaw (turn)	Yaw (apch)
10%	22.42	35.66	39.95
20%	15.06	19.51	24.15
40%	12.47	12.88	22.18
60%	11.76	7.51	13.28
80%	12.49	8.14	11.47

The data in Table 7 indicate that the original hypothesis of increased head movement to compensate for limited peripheral data was correct for all phases of the simulation runs. We infer that pilot effort to gather visual data tends to increase with a decreasing effective FOV in all phases of the simulation run.

Importance

Every pilot tested had a tendency to increase the range of head pitch and yaw rates of movement as the effective FOV was decreased. The following Table 8 contains calculated average pilot head pitch and yaw rates of movement by effective FOV for each phase.

Table 8 - Average Pilot Head Pitch and Yaw Rates of Movement

Eff FOV	Pitch (base)	Pitch (turn)	Pitch (apch)
10%	236.63	485.27	197.58
20%	172.55	222.43	76.53
40%	100.64	143.59	78.97
60%	92.28	62.64	66.91
80%	72.88	54.14	45.23
Eff FOV	Yaw (base)	Yaw (turn)	Yaw (apch)
10%	140.47	199.78	184.84
20%	65.78	90.74	124.92
40%	47.73	54.13	77.49
60%	38.85	22.84	33.76
80%	38.05	24.24	28.97

The data in Table 8 indicate that the original hypothesis of increased head rates of movement to compensate for limited peripheral data was correct for all phases of the simulation runs. We infer that pilot urgency to obtain visual data tends to increase with a decreasing effective FOV in all phases of the simulation run. It is to be noted that all head movement patterns seemed to show the greatest increase for 40% and lower effective FOV.

Average vs. Peak Values across Simulation Phases

When comparing data across simulation run phases shown in Tables 7 and 8 to the raw data (not reported here except a sample data in Figure 7), results show that the highest average head movement range value and the highest average head rate of movement value do not indicate the highest number of peak values in that phase. For example, looking at the data in Table 8, for a 40% effective FOV the average head yaw rates of movement increase from base (47.73), turn (54.13) and finally land (77.49) phase. However, looking at pilot head tracking raw data shows that there are only a few large peaks in the base leg, with more medium to large size peaks in the turn phase and finally many small peaks in the land phase. This finding is illustrated in Figure 7, which is a representative sample of one pilot simulation run with a 40% effective FOV.

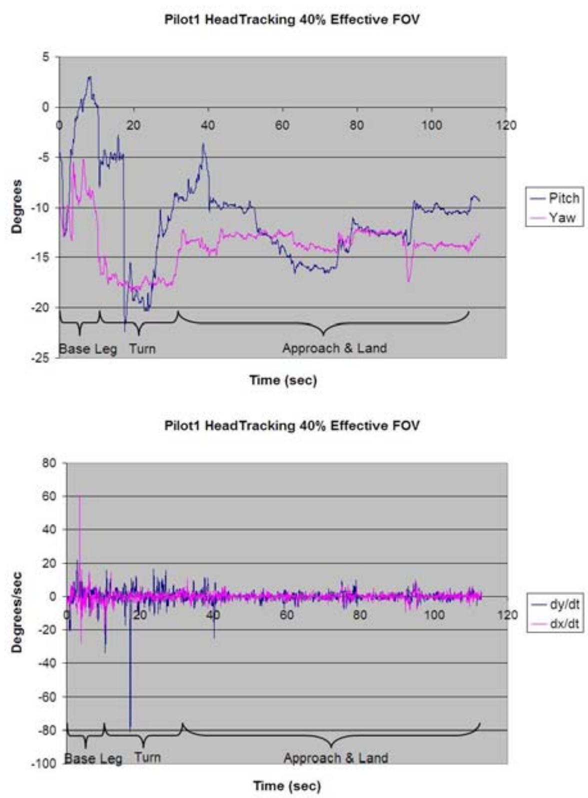


Figure 7 – Sample Pilot Head Tracking Data

The base phase (approximately 10 seconds) indicates very few large peaks when the pilot is determining the best time to start the turn. The turn phase (approximately 20 seconds) indicates more medium size peaks, when the pilot has more need for gathering horizon and runway visual data. On the straight approach (approximately 90 seconds), the movement settles to very frequent small peaks, when the pilot is maintaining lineup and making quick checks on airspeed while calculating the descent to the landing spot.

Performance
Figure 8 and Figure 9 depict the aircraft course over ground (top portion) and the rate of descent (lower portion), which are representative of the majority of the pilot performance measurements from best performance (Figure 8) to worst (Figure 9). The green triangle represents a window for maintaining a safe instrument assisted approach. For a visual approach, it serves as a guide to analyze performance. The red ellipse in the top portion is where a pilot should be during an instrument approach so they may transition to visual approach and landing on the runway. It was used to determine proper start after the turn phase. Since the pilot was instructed to land at the runway intersection, they will normally maintain a glide slope just above the green triangle on the lower portion.

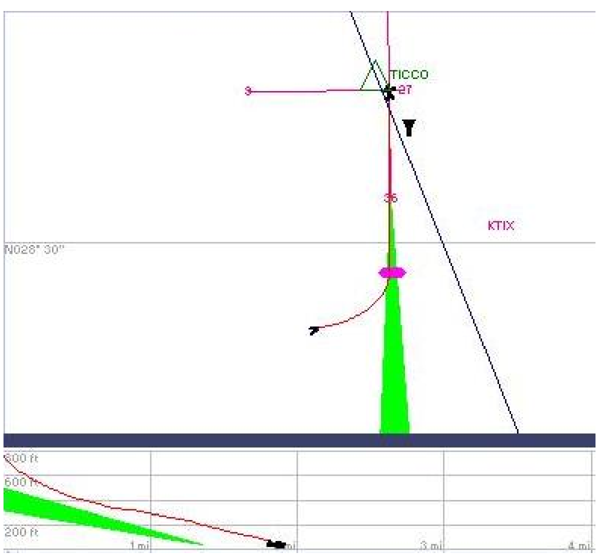


Figure 8 - Example of good pilot performance

The pilots are taught in such scenarios to maintain base heading until at the position to make a standard left turn to approach. The decreasing effective FOV clearly shows most started their turn too early, as seen in Figure 9 course over ground indicating a poor start for the straight-in approach, had trouble with runway lineup and also took less time to land by shortening the normal base leg turn. While struggling with lineup, the pilot also had trouble maintaining a steady rate of descent. Their normal visual approach scan pattern was disrupted by the restricted effective FOV, as measured by the head tracker.

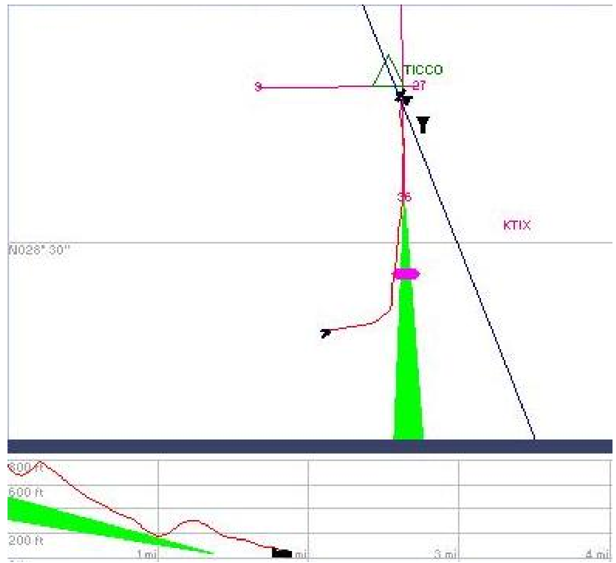


Figure 9 – Example of poor pilot performance

SUMMARY AND FUTURE WORK

Behavior and Performance Summary
Based on the Information, Effort and Importance behavior metrics taken while varying the pilot effective FOV, we infer that a pilot will alter their normal visual scan pattern and head/eye movement pattern to compensate for a limited effective FOV. We also infer that task performance decreases significantly as the effective FOV is decreased below 40% effective FOV.

By limiting the pilot effective FOV, additional workload and stress is experienced by the pilot, measured by Information, Effort and Importance behavior changes. As the effective FOV was decreased, head movement range (in degrees) and head rate of movement (in degrees/second) increased to compensate for the reduced peripheral visual data.

It was also demonstrated, while decreasing the effective FOV, that pilots have a noticeable threshold where they can no longer compensate sufficiently to maintain an adequate cognitive mental image to complete their VMC pattern tasks. As the effective FOV was decreased, the pilot visual workload increased to such an unrealistic level, the sense of "being there" or "Presence" also decreased, measured by the pilot's eventual inability to "do" there.

Quantitative Measurements

By measuring changes in pilot head/eye movement patterns, categorized by Information, Importance and Effort, one can quantify pilot presence while performing a simulator task. Pilot head movement patterns, correlated with task performance indicate that an effective FOV of 40% or more is required for the experimental tasks. This implies that an AR display for these types of flight simulator tasks will need to have an effective FOV display greater than 80° h x 54° v.

Lessons Learned

Although it was estimated that a minimum of nine participants were required to detect an effect between effective FOVs of 40% and 80%, the seven volunteer pilots provided clear head and eye movement pattern change caused by the effective FOV effect.

The Arrington ViewPoint Scene Camera was extremely helpful in confirming the Intersense VisTracker head movement pattern effective FOV effects, and also ensured that good MDD and DFA data were recorded for each simulation run. The ViewPoint EyeTracker software allowed one to define Region of Interest (ROI) boxes to automatically gather Information data like MDD and DFA. Although the effective FOV masks were easy to change in between simulation runs, they interfered some with the ViewPoint EyeTracker camera and caused a slight offset to the calibration. Thus, the ViewPoint Scene Camera option was used, providing AVI recording of each run to track gaze position on the real world scene video being captured. Consequently, each of the 35 runs (7 participants, 5 effective FOVs) was painstakingly analyzed for roughly one hour each, one by one and scene by scene, to ensure accurate MDD and DFA collection.

The Arrington ViewPoint EyeTracker Video Capture Card required a tower computer with an empty Peripheral Computer Interface (PCI) slot. So using a laptop was not an option for easy daily equipment setup and breakdown when the simulator was available for the experiment. The tower, keyboard and monitor had to be set up in the very limited space offered in the instructor station.

Potential Future Work

Although expensive, validation of this data could be accomplished by duplicating the experiment in actual helicopter flights. The effective FOV masking process would be similar to Instrument Flight Rule (IFR) check flight procedures where a student pilot wears a mask that only allows them to see the IP during navigation and approach, while the instructor pilot observes and can take over the controls during flight for safety.

ACKNOWLEDGEMENTS

We thank Dr. Kincaid and the Institute for Simulation and Training (IST) for providing a research grant necessary to allow purchase of the head-worn EyeTracker system used in the research. We thank Frank Biocca for stimulating discussions regarding current measures of Presence. W extend some deep thanks to Patrick Corr, Senior VP of Bristow Group Inc., Jens Jehnes, Chief Flight Instructor, and Ben Kao of Bristow Academy (formerly Helicopter Adventures Inc.) for the use of their flight simulator and their extremely professional flight instructor staff that graciously volunteered for all the experiments. We acknowledge support by the National Science Foundation (NSF) grant IIS/HCI 03-07189.

REFERENCES

Agrawal, B. N. (1986). Design of Geosynchronous Spacecraft. Prentice-Hall Inc. Engelwood Cliffs, NJ. P. 106-112.

Ames, B. (2005). Streamlined Databases Drive Military Simulation, Military & Aerospace Electronics, November.

Arthur, K. (2000). Effects of Field of View on Performance with Head-Mounted Displays, Ph.D. Dissertation, Department of Computer Science, University of North Carolina at Chapel Hill

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., MacIntyre, B., (2001, Nov/Dec). Recent Advances in Augmented Reality, IEEE Computer Graphics and Applications, Vol. 21, 6 p 34-47

Cakmakci, O., Rolland, J. (2006). Head-Worn Displays: A Review, Journal of Display Technology, Vol. 2, Issue 3, pp.199-216.

Biocca, F., Harms, C. & Burgoon, J.K. (2003). Towards a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria. Presence, 12(5), 456-480

Flach, J. M., & Holden, J. G. (1998). The reality of experience: Gibson’s way. Presence: Teleoperators and Virtual Environments, 7(1), 90–95.

French, M. (2003). U.S. Navy to use more Simulation Training, Federal Computer Week, 6 November.

Guest, M., Rolland, J.P. (1999). Search Strategies when Masses are Missed in Mammography, Technical Report TR99-007, University of Central Florida (1999).

How to determine sample size (n.d.). Retrieved 5 February, 2007 from http://www.isixsigma.com/library/content/c000709a.asp

Lowry, R. (2007). Orthogonal Latin Square Designs with n = j2, Retrieved August 3, 2006, from http://faculty.vassar.edu/lowry/lsqtext.html

Pausch, R., Crea, T., & Conway, M. (1992). A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. Presence, 1(3), 344-363

Poole, A., Ball, L. J., & Phillips, P. (2004). In search of salience: A response time and eye movement analysis of bookmark recognition. In S. Fincher, P. Markopolous, D. Moore, & R. Ruddle (Eds.), People and Computers XVIII-Design for Life: Proceedings of HCI 2004. London: Springer-Verlag Ltd.

Shappell, S. A. and Wiegmann, D. A. (2000). The human factors analysis and classification system - HFACS. Technical Report DOT/FAA/AM-00/7, FAA, Feb. 2000

Slater, M. (2004). How Colorful Was Your Day? Why Questionnaires Cannot Assess Presence in Virtual Environments, Presence: Teleoperators & Virtual Environments, Aug2004, Vol. 13 Issue 4, p484-493

Stewart, J. E., Dohme, J. A., & Nullmeyer, R. T. (2002). U.S. Army Initial Entry Rotary-Wing Transfer of Training Research, International Journal of Aviation Psychology, (12) 4, 359-375

Wickens, C. D., Xu, X., Hellenberg, J. R., Carbonari, R., & Marsh, R. (2000). The Allocation of Visual Attention for Aircraft Traffic Monitoring and Avoidance: Baseline Measures and Implications for Freeflight, (Technical Report ARL-00-2/FAA-00-2) Savoy, IL: University of Illinois, Aviation Research Lab

Winterbottom, M., Patterson, R. & Pierce, B.P. (2006) Visual suppression of monocularly presented symbology against a fused background in simulation and training environment. Accepted for presentation to the meeting of the Society for Photo-Electronic Instrumentation Engineering, Defense and Security Symposium, Orlando, FL, April 17-21, 2006.

Witmer, B.G. & Singer, M.J. (1998). Measuring presence in virtual environments: A Presence Questionnaire. Presence: Teleoperators and Virtual Environments, 7, 225-240.

Zahoric, P., & Jenison, R. L. (1998). Presence and being-in-the-world. Presence: Teleoperators and Virtual Environments, 7(1), 78–89.

Glossary of Acronyms

AOI	Area of Interest
AR	Augmented Reality
CRT	Cathode Ray Tube
DFA	Dwell Frequency per AOI
FNPT	Flight Navigation Procedure Trainer
FOR	Field of Regard
FOV	Field of View
H	Horizontal
HUD	Heads Up Display
HWD	Head Worn Display
IFR	Instrument Flight Rules
IG	Image Generator
IMC	Instrument Meteorological Condition
IP	Instrument Panel
IST	Institute for Simulation and Training
LCD	Liquid Crystal Display
MDD	Mean Dwell Duration
ODALab	Optical Diagnostics and Applications Lab
OFT	Operational Flight Trainer
OTW	Out the Window
OTW-L	Out the Window - Left
OTW-LC	Out the Window - Left of Center
OTW-LL	Out the Window - Lower Left
OTW-LR	Out the Window - Lower Right
OTW-R	Out the Window - Right
OTW-RC	Out the Window - Right of Center
PCI	Peripheral Computer Interface
UCF	University of Central Florida
V	Vertical
VFR	Visual Flight Rules
VMC	Visual Meteorological Condition
VR	Virtual Reality