

PC-Based Desktop Display versus Immersive Head-Mounted Display Flight Simulator Performance

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ABSTRACT

In the last five years, there has been an increased emphasis on the use of 2D and 3D PC-based flight simulators for flight training. Flight simulators allow users to practice certain skills and to stay current between flights in real aircraft. In addition, affordable PC-based flight simulators may be a viable, cost-effective alternative for actual aircraft flight time or fully immersive, high fidelity simulators in the future. The research reported in this study examined the differences between flight simulator training on a limited field-of-view desktop monitor and training with an immersive virtual reality head-mounted display (HMD). A between-subjects design was used with thirty participants. Half of the participants performed designated flight protocols using the desktop monitor trainer and the other half performed the same flight protocols on the HMD immersive trainer. Participants using the desktop monitor performed significantly better than those in the HMD condition on tasks that involved maintaining altitude, pitch, bank, and heading. Possible explanations for these results include the “heads-up” nature of an HMD, resulting in less time viewing the aircraft instruments, and less familiarity with an HMD. Further research is needed to study performance differences between simulators with varying levels of fidelity. Research is also needed to study longitudinal effects of flight simulator training on real aircraft flight performance.

ABOUT THE AUTHORS

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INTRODUCTION

There has been a recent shift of focus toward the use of PC-based programs and flight simulators in flight training. One question that is facing researchers is whether there are any performance differences between flight simulator training using a desktop computer and monitor versus training with an immersive virtual reality head-mounted display (HMD). Both displays have advantages and disadvantages associated with them. The two-dimensional desktop screen is less complex and more affordable than the HMD. The HMD has a smaller footprint allowing it to take up less space than the desktop display. In the past, desktop screens have typically had higher resolution, but HMD technology is quickly shortening this technological gap with smaller displays with higher resolutions.

The skill level of the user has also been shown to play a role in the effectiveness of various fidelities used in flight simulation. Noble (2002) found that among experienced users a higher level of fidelity is positively correlated with a higher level of performance in the real aircraft. However, for novice users, increasing fidelity does not necessarily transfer to improved performance in the real aircraft. The highest transfer of skills between simulators and real-world operations occurs when experts use high fidelity simulators.

Traditional full-sized flight simulators with high fidelity controls and displays are large and expensive. In addition, these simulators require well-trained people to maintain the system and instruct users on how to operate them. Commercial airlines have already begun determining which tasks can be trained using PC-based programs (Nordwall, 2001). Several studies have shown that PC-based simulators are useful in teaching simple introductory level flying skills (Dennis & Harris, 1998), for practicing navigation and IFR skills (Armstrong, 2005), and for providing Instrument Proficiency Checks (Taylor, Talleur, Rantanen, & Emanuel, 2004).

During an interview concerning the release of Microsoft Flight Simulator 2002, Armstrong (2005) highlighted some of the notable problems with flight simulators. These problems included low levels of fidelity that caused students to develop bad flight handling habits and technological shortcomings that prevented some existing simulators from behaving like real aircraft.

Research concerning field-of-view is particularly relevant for this study. A field-of-view larger than 60 degrees was shown to be optimal for difficult navigation tasks performed in a flight simulator. Smaller fields of view were sufficient for less difficult tasks associated with final approach. (Keller, Schnell, Lemos, Glaab, & Parrish, 2003).

While flight simulators may never replace time spent behind the controls of a real aircraft, they can be used to teach specific tasks for which their use is appropriate. They can be used to augment real flight training, reduce the amount of hours spent in a real cockpit (Taylor et al., 2004), and reduce the amount of resources the Air Force invests on fully immersive flight simulators.

The purpose of this experiment was to determine whether there was a significant difference between flight simulator task performance when using a desktop display (Desktop Display Group) compared to using an HMD simulator (HMD Group). We hypothesized that participants assigned to the HMD Group would perform better on tasks requiring a larger field-of-view (i.e., navigation) as opposed to tasks requiring a smaller field-of-view (i.e., changing altitude).

METHOD

Participants

Thirty cadets from the United States Air Force Academy, all volunteers, between the ages of 18 and

23 years old took part in the experiment after completing a flight experience survey. The survey was sent out to 50 interested cadets via e-mail. Individuals whose answers demonstrated a lack of experience and/or knowledge concerning flying (e.g., did not know how to read altitude from an altimeter) were not allowed to participate. Volunteers who demonstrated that they were over-qualified (e.g., private pilots) were not allowed to participate. After the surveys were evaluated, 30 participating cadets were randomly assigned to one of the two groups: Desktop Display Group or HMD. Three participants were excused from the experiment due to their inability to follow flight profiles, and three more participants were recruited to replace them.

Equipment

The Desktop Display Group used a flight simulator workstation consisting of an AMD Athlon 64 FX53 processor running at 2.4GHz and 2GB memory. CH Products Flight Sim Yoke and Pro Pedals were used as the control devices. The image was presented on a Dell 19" color LCD flat panel monitor. Audio was presented on two Dell PC speakers (see Figure 1).



Figure 1. Desktop Display Simulator Workstation

The HMD workstation consisted of a Dell 8400 with a Pentium IV processor running at 3.4GHz with 1GB memory, Virtual Research V8 HMD with 2D speakers, Intersense Inertia Cube head tracker, and CH Products Flight Sim Yoke and Pro Pedals (see Figure 2; the monitor shown was only used for researcher observations and interface, and was not used by the HMD participants).



Figure 2. HMD Simulator Workstation

Both workstations ran Microsoft Flight Simulator 2004 using the same aircraft (Cessna 172), time of day, and weather settings. The experiment was conducted in the Human Computer Interaction Lab at the United States Air Force Academy.

Experimental Design

The design was a straightforward between groups comparison. Manipulation of the flight simulator display served as the independent variable. One group trained with the Desktop display, whereas the other group trained using an HMD.

Procedure

Prior to the start of the experiment participants were given a brief overview of the workstation's flight controls, the relevant flight instruments, and acceptable deviations for the flight instruments during experiment trials. Participants assigned to the Desktop Display Group were trained on the view, or "pan" feature (i.e., a toggle on the yoke of the control could be pressed to change views). Similarly, participants assigned to the HMD Group were allowed time to orient themselves in the virtual cockpit while wearing the HMD.

The experiment consisted of the following three sessions: familiarization, turn profile, and landing profile (see descriptions below). The three sessions were identical for the two groups with the exception being the type of display through which participants viewed the simulation. Familiarization took approximately 30 minutes while the turn profile and landing profile took another 30 minutes to complete.

Familiarization

During the familiarization session, participants were asked to complete take-off, turn, climb, decent, and landing tasks. Participants were given verbal commands and were asked to notify the experimenter when they had reached the desired settings. Following is a familiarization command example:

“Now you will turn right to a heading of 1-5-0 and descend to an altitude of 1000 feet. Once you have leveled out, maintain airspeed of 75 knots and say ‘I’m there.’”

Participants’ performance was not measured during the familiarization session, although they were asked to fly within predefined performance parameters (see Measures). A pilot study determined that asymptotic simulator performance was reached in 20 minutes of practice, therefore the familiarization session lasted 20 minutes.

Turn Profile

Following the familiarization session and a short break, participants completed a turn profile. During this task participants were required to turn to various headings while either maintaining an altitude, climbing, or descending. Commands were provided in the same manner as the familiarization session.

Landing Profile

Following the turn profile the participants attempted to land the aircraft. The landing profile began with participants flying the downwind leg of a right traffic pattern at 800 ft above the ground. Participants were guided to various waypoints in the traffic pattern (i.e., altitudes and airspeeds) using commands, but were asked to keep the aircraft lined up with the runway using either their view toggle (Desktop Display Group) or the HMD (HMD Group) to view their relationship to the runway.

Measures

Data were collected for every second of simulator time. Four measures of performance were extrapolated from the Microsoft Simulator: altitude, pitch, bank, and

heading. The Mean Square Error (MSE) for each measure was calculated each second, and the average MSE for each trial was calculated. Participants were asked to fly within performance parameters according to the following private pilot check-ride requirements: altitude +/- 200 feet, heading +/- 15 degrees, airspeed +/- 5 knots, and vertical climb rate +/- 100 feet/min. However, error calculations were made using any deviation from the directed altitude, heading, airspeed, or climb rate. For example, if a participant was directed to fly at 1700 feet, error was calculated as any altitude other than 1700 feet for each second of flight.

RESULTS

Treatment of Data

Data for the turn and landing profiles were first separated and then analyzed independently. A one-way analysis of variance (ANOVA) was utilized to analyze the data. Graphs showing MSE results are in feet for the altitude, degrees for heading, knots for airspeed, and feet/min for the vertical climb rate.

Turn Profile

Participants using the desktop display performed significantly better than those using the HMD when maintaining altitude [$F(1,28) = 4.837, p=.036$], pitch [$F(1,28) = 22.523, p=.0001$], and heading [$F(1,28) = 4.283, p=.048$]. Figure 3 compares the Desktop Display and HMD conditions using the overall MSE for each group. (Perfect simulator performance results in a MSE of zero.)

Landing Profile

During the landing profile participants using the desktop display performed significantly better than those using the HMD when maintaining pitch [$F(1,28) = 7.102, p=.013$], bank [$F(1,28) = 4.541, p=.042$], and heading [$F(1,28) = 8.045, p=.008$]. Figure 4 compares the Desktop Display and HMD conditions using MSEs.

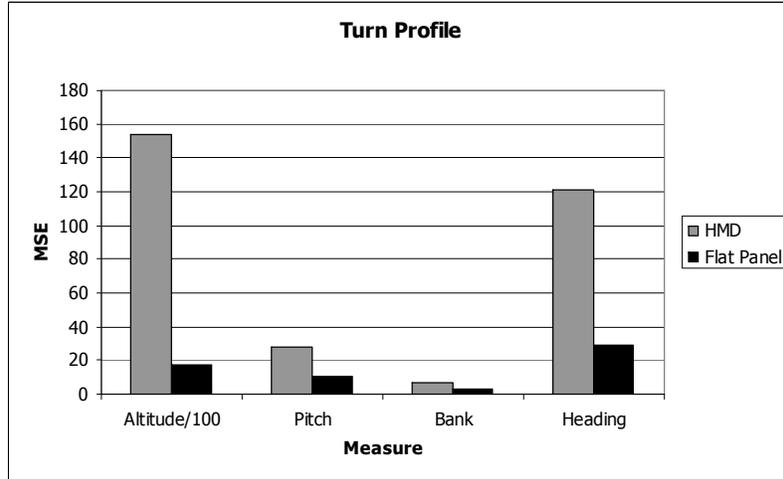


Figure 3. Turn Profile Results

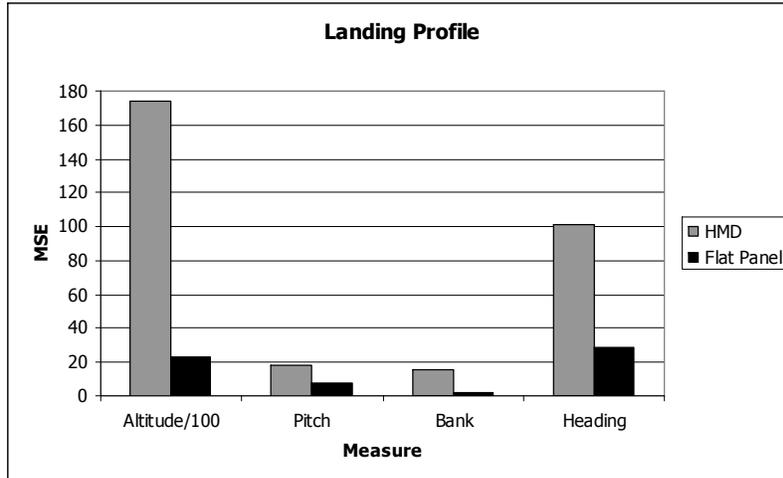


Figure 4. Landing Profile Results

DISCUSSION

As hypothesized, there was a difference in simulator performance between the two display types. However, the authors expected the HMD display to be easier to use and, thus, yield better performance. The data reflect, in general, that the Desktop Display Group performed with fewer errors when flying the flight simulator. One possible cause for this is the tendency for novice pilots to maintain a “heads-down” technique when asked to fly within specific flight parameters. In other words, when asked to fly within +/- 200 feet, a novice pilot has a tendency to monitor the cockpit instruments (i.e., altimeter and vertical velocity

indicator) instead of using external queues (i.e., wings and nose position relative to the horizon).

The authors also expected flight simulator performance to be better for the HMD Group during tasks like landing that require a larger field-of-view. To exacerbate this effect, the landing profile was constructed with the participants beginning on a right-traffic downwind leg to necessitate looking out the right window to maintain position with the runway. One theory for the superior Desktop Display Group performance in the landing profile is that these participants were more likely to be fixated on the aircraft instruments as opposed to the outside world,

resulting in better performance in the four chosen measures. Researcher observations supported this assertion. Researcher observations also indicated a general trend for the HMD Group participants to spend much of their time looking around the virtual world as opposed to their instruments. This was probably due to the fact that it was natural to look around with the HMD combined with their lack of experience establishing a disciplined cross-check of their instruments.

Another possible explanation for superior Desktop Display Group performance when compared to the HMD Group is the participants' unfamiliarity with the HMD. Both groups were given equal time (20 minutes) to familiarize themselves with their respective flight simulators and displays. However, we submit that most computer users are more familiar with desktop computer monitors than they are with HMDs.

Although it appeared that participants had an easier time maintaining altitude, pitch, bank, and heading using a desktop display, it is still uncertain which simulator display is better when measuring other factors like position (relative to a landmark or runway), situation awareness, and navigation performance. Future research is needed to investigate display differences when measuring these and other variables.

It is important to note that this study measured the effects of different simulator displays on *simulator* performance. These results do not imply any advantages these simulator displays might have on real flight performance. Future research is needed to investigate the differences these two display types, in addition to other training platforms, have on real-flight performance.

CONCLUSION

Although support was found in this study for differences in performance between the type of simulator displays used (HMD versus Desktop Display) and the types of profiles trained (turning versus landing), there were no clear-cut explanations for why these differences existed. Some possible explanations for these differences were described, but further empirical evidence is needed to answer specifically why students perform better on some training platforms and during certain training profiles.

Another area for study would be the effect of increasing the number of experimental conditions for the display variable. This could be done by using

different numbers of desktop monitors (e.g., three instead of just the one that was used in this study), or using different HMDs of varying levels of fidelity. These different research designs could potentially assist the Air Force in selecting training platforms that further increase real-flight performance at a lower cost.

Results from this experiment have real world application in that they can be used to help the Air Force determine the types of training tasks that can be performed, or supplemented with flight simulators, as opposed to in-flight training. It can also help to indicate the best types of simulators for specific types or classes of tasks. If higher fidelity flight simulators do not result in better flight performance than the use of lower fidelity ones, then the Air Force may save money by investing in lower fidelity flight simulators for appropriate tasks.

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