2006

Effect Of Operator Control Configuration On Unmanned Aerial System Trainability

John Neumann
University of Central Florida

Part of the Navigation, Guidance, Control and Dynamics Commons

Find similar works at: https://stars.library.ucf.edu/etd

University of Central Florida Libraries http://library.ucf.edu

This Doctoral Dissertation (Open Access) is brought to you for free and open access by STARS. It has been accepted for inclusion in Electronic Theses and Dissertations, 2004-2019 by an authorized administrator of STARS. For more information, please contact STARS@ucf.edu.

STARS Citation
https://stars.library.ucf.edu/etd/970
EFFECT OF OPERATOR CONTROL CONFIGURATION ON UNMANNED AERIAL SYSTEM TRAINABILITY

by

JOHN L. NEUMANN

B.B.A. Florida Atlantic University, 1993
M.S. University of Central Florida, 2004

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Modeling and Simulation in the College of Sciences at the University of Central Florida Orlando, Florida

Fall Term
2006

Major Professor: J. Peter Kincaid
ABSTRACT

Unmanned aerial systems (UAS) carry no pilot on board, yet they still require live operators to handle critical functions such as mission planning and execution. Humans also interpret the sensor information provided by these platforms. This applies to all classes of unmanned aerial vehicles (UAV’s), including the smaller portable systems used for gathering real-time reconnaissance during military operations in urban terrain. The need to quickly and reliably train soldiers to control small UAS operations demands that the human-system interface be intuitive and easy to master. In this study, participants completed a series of tests of spatial ability and were then trained (in simulation) to teleoperate a micro-unmanned aerial vehicle equipped with forward and downward fixed cameras. Three aspects of the human-system interface were manipulated to assess the effects on manual control mastery and target detection. One factor was the input device. Participants used either a mouse or a specially programmed game controller (similar to that used with the Sony™ Playstation 2 video game console). A second factor was the nature of the flight control displays as either continuous or discrete (analog v. digital). The third factor involved the presentation of sensor imagery. The display could either provide streaming video from one camera at a time, or present the imagery from both cameras simultaneously in separate windows. The primary dependent variables included: 1) time to complete assigned missions, 2) number of collisions, 3) number of targets detected, and 4) operator workload. In general, operator performance was better with the game controller than with the mouse,
but significant improvement in time to complete occurred over repeated trials regardless of the device used. Time to complete missions was significantly faster with the game controller, and operators also detected more targets without any significant differences in workload compared to mouse users. Workload on repeated trials decreased with practice, and spatial ability was a significant covariate of workload. Lower spatial ability associated with higher workload scores. In addition, demographic data including computer usage and video gaming experience were collected and analyzed, and correlated with performance. Higher video gaming experience was also associated with lower workload.
ACKNOWLEDGMENTS

I sincerely appreciate all the help I have received over the course of my academic career at the University of Central Florida. My committee members deserve special thanks: Dr. Paula Durlach has been instrumental in my development as a researcher at the U.S. Army Research Institute for the Behavioral Sciences. Thanks to Dr. Peter Kincaid, who worked as my advisor and program chair. Dr. Mustapha Mouloua and Dr. Robert Kennedy provided expert guidance in class as well as with this report. I would also like to thank Dr. Randall Shumaker for his interest in this project. This mix of committee members has provided me with unparalleled expertise in the field, as well as valuable insight toward achieving my long-term career goals.

Additionally, I would like to acknowledge the support I received from many others over the past 4 years, including all of the senior researchers at the Army Research Institute. Several of my professors and fellow students also contributed to this achievement. Special thanks go out to Julie Waller and Dr. Bob Ruskin of the Consortium of Research Fellows Program for sponsoring my fellowship at ARI, and last but not least, to my family for all their love and support.
TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................ viii
LIST OF FIGURES ........................................................................................................ ix
INTRODUCTION ........................................................................................................... 1
  Preliminary UAV Control Interface Research ......................................................... 3
LITERATURE REVIEW ............................................................................................... 7
  Navigation and Travel in Virtual Environments ....................................................... 7
  Input Devices ........................................................................................................ 10
  Movement Control ............................................................................................... 14
  Interface Design and Display Configuration ......................................................... 15
  Sensory Awareness ............................................................................................... 21
  Individual Differences ......................................................................................... 24
  Purpose of Investigation ...................................................................................... 28
METHOD ..................................................................................................................... 30
  Equipment: Hardware .......................................................................................... 30
  Equipment: Input Devices .................................................................................... 31
  Equipment: Control Interface ................................................................................ 31
  Equipment: Sensor Imagery Display .................................................................... 33
  Experiment: Session 2 .......................................................................................... 38
  Measures ............................................................................................................. 41
RESULTS .................................................................................................................... 44
  Pre-screening of Data .......................................................................................... 44
Performance Measures: Time to Complete ........................................................ 45
Performance Measures: Targets Detected ......................................................... 49
Performance Measures: Collisions ................................................................. 50
Workload ............................................................................................................ 50
Usability Ratings and Demographics................................................................. 52
Video Gaming Experience ............................................................................. 54
Spatial Ability ................................................................................................. 55
DISCUSSION ................................................................................................. 58
Input Device .................................................................................................... 58
Video Gaming and Controller Experience ..................................................... 59
Selection of the Mouse as an Input Device .................................................... 61
Workload and Performance .......................................................................... 61
Spatial Ability and Performance .................................................................... 63
Camera View Configuration and Control Interface ..................................... 64
Usability Ratings ............................................................................................ 66
Future Work .................................................................................................. 67
APPENDIX A  PARTICIPANT TRAINING MANUAL ........................................... 70
APPENDIX B  IRB APPROVAL LETTER ......................................................... 85
APPENDIX C  POST EXPERIMENT USABILITY QUESTIONNAIRE .................... 87
APPENDIX D  OCU INTERFACE TRAINING EVALUATION ............................... 92
REFERENCES .............................................................................................. 94
LIST OF TABLES

Table 1. Taxonomy of Travel Technique Options............................................................ 9
Table 2. Correlation Matrix of Spatial Ability Test Battery ............................................ 37
Table 3. Test Phase Missions with Descriptions .......................................................... 40
Table 4. Video Game Experience Factor Correlations ............................................... 54
Table 5. Spatial Test Correlations ............................................................................... 57
LIST OF FIGURES

Figure 1. MAV Prototypes from Honeywell and Allied Aerospace ...................................... 2
Figure 2. The OCU interface with 2 camera views and overhead map display .......... 16
Figure 3. Logitech Dual thumbstick Game Controller ................................................................. 31
Figure 4a. Discrete Input Control Pad ......................................................................................... 32
Figure 4b. Continuous Input Control Pad .................................................................................... 32
Figure 5a. Dual Camera View Configuration .............................................................................. 34
Figure 5b. Alternating Camera View Configuration ................................................................. 34
Figure 6a. Westbound Flight with Target in South Parking Lot ..................................... 36
Figure 6b. Northeast-bound Flight with Target in South Parking Lot .......................... 36
Figure 7. Mean Time to Complete Manual Control Missions over Repeated Trials ...... 45
Figure 8. Repeated Trials by Course ......................................................................................... 46
Figure 9. Input Device by Game Controller Interaction ....................................................... 47
Figure 10. Mean NASA TLX Workload Scores by Mission .................................................. 51
Figure 11. Workload Scores over Repeated Missions .......................................................... 51
INTRODUCTION

The idea of using robots to perform dangerous jobs is not new. General Motors helped pioneer this technology in 1961 with the aid of a working robot that was responsible for dropping red-hot car parts into a cooling liquid (Mickle, 2005). Nearly half a century later, the technology now exists that makes the use of robotics and unmanned systems practical in a variety of contexts. The military has invested heavily in the development of several robotic and uninhabited platforms designed to perform tasks that might otherwise be dangerous or physically taxing to humans. Although these platforms are uninhabited, they still require a substantial level of involvement from human operators in order to function properly and efficiently. One of the more high-profile systems currently in use by the military is the Predator Drone. This is a large fixed-wing unmanned aerial vehicle (UAV) that can survey large geographic areas for extended missions. Video images transmitted from the vehicle back to the control station provide near real-time reconnaissance without risking the life of a pilot. Predators have been actively engaged in the hunt for Osama Bin Laden, and in some cases they have been used to track and eliminate high value targets. Unmanned systems are not limited to aerial vehicles. The Talon and PackBot are land-based robots that see constant action in Iraq. These robots assist military personnel in disposing of improvised explosive devices, otherwise known as roadside bombs. Disposal experts who employ these systems typically receive 4 to 5 calls per day in areas surrounded by insurgents (Magnuson, 2006).
The military is continually working to expand its UAV and robotic arsenal. The Defense Advanced Research Projects Agency (DARPA) sponsored an advanced concept technology demonstration program to develop the technologies needed to field an operational micro-unmanned aerial vehicle (MAV). This type of unit is designed for use on reconnaissance tasks by platoon-level soldiers for military operations in urban terrain (MOUT). The unit is much smaller than fixed-wing systems like the Predator, which allows it to be transported in a backpack and deployed quickly. Another unique characteristic of the MAV is its ducted-fan design. This incorporates vertical take-off and landing capability with the ability to hover in one location as it transmits video and sensor data back to its operator. This imagery is displayed on a portable computer that also serves as the operator control unit (OCU). Figure 1 shows 2 of the prototype MAV systems developed by Honeywell and Allied Aerospace.

Figure 1. MAV Prototypes from Honeywell and Allied Aerospace
Development of these systems is nearing the final stages. Working prototypes are being tested, and better control interface designs are emerging. Still there are several unknowns with regard to how operators will be trained. The Army intends that a Class I UAV operator be designated, not dedicated. So any platoon member should be able to operate the vehicle. This means that MAV operation must be easily taught without requiring a great deal of specialized knowledge. For this type of system, there has been little research on the most efficient way to conduct training, to assess training success, or to design the OCU to facilitate mastery. Beginning this process, we developed a configurable OCU and flight simulation for MAV operator training. Taking a user-centered approach, our current research goal was to determine how different MAV input control methods and display configurations could affect operator performance, workload, and training efficiency. In addition, we investigated operator spatial ability to determine if this was a reliable predictor of key flight performance criteria.

Preliminary UAV Control Interface Research

In April 2004, The U.S. Army Research Institute’s (ARI) Simulator Systems Research Unit began evaluating prototype control interfaces used for piloting a simulated UAV within a synthetic terrain database. The first system examined at ARI was developed for DARPA by Northrop Grumman and incorporated a simulation engine created by NASA-Ames. Following initial testing done with the Northrop Grumman system, we began evaluation of another prototype OCU developed by Honeywell. Both
systems used touch-screens as the primary input method. In the case of the Northrop Grumman OCU, operators could manually control the flight path of the UAV by touching directly on the sensor image.

A total of 3 studies were scheduled using the original Northrop Grumman interface. The first was a comprehensive usability evaluation. In this study, a group of 7 human factors practitioners and research psychologists conducted heuristic and formative evaluations with the system. Among the highest priority usability concerns was the lack of salience of critical displays such as the altimeter. The OCU also provided little or no feedback on the MAV’s velocity and heading, and it was often difficult for operators to determine if their inputs had registered (Durlach, Neumann, & Bowens, 2006). The simulation and flight model were the real strengths of the system, but the OCU was lacking from a usability standpoint. Hix, et al. (1999) attributes the generally poor interface design of most simulation applications using virtual environments (VE) to the fact that a majority of research efforts in the field are focused on visual quality and rendering efficiency. Typically, much less attention is paid to how well the design effectively fits the intended user.

Aside from usability issues, the most notable operator concern reported in this study was difficulty with manual control. Because participants cited manual control as the most difficult and frustrating portion of the first evaluation, we completed a second study with the Northrop Grumman OCU that focused primarily on relevant manual control tasks. In this experiment, users completed a series of 4 missions that required each operator to manually pilot the MAV within a synthetic terrain database (modeled
after the U.S. Army McKenna MOUT training site). Each mission was designed to test
different skills such as target identification, low altitude and precision flying, avoiding
obstacles, and landing in designated landing areas.

Unlike the first study where one camera image was displayed on the OCU at a
time, the view angle and configuration of the camera images in the second study were
manipulated. Three images were now being displayed simultaneously – a forward view,
a downward view, and a satellite map view. The angle of the downward camera was the
independent variable and varied between 30, 60, and 90 degrees from horizontal. Each
participant completed the NASA TLX workload assessment at the end of every mission.
The results of this study did not yield many significant effects of camera angle; however,
mission 1 (a ranged target detection task) was accomplished more quickly with the 30-
degree camera configuration (Durlach, Neumann, & Bowens, 2006). Of greater interest
was the ability of operators to complete the final mission, which required a rather difficult
landing on a rooftop. All but 1 crash in the entire experiment happened during the last
mission, and half of the ten total crashes came in the 30-degree condition. The 60 and
90-degree conditions produced 2 and 3 crashes, respectively. Mean workload ratings
were also significantly higher for missions 3 and 4 (55.32 and 58.89) compared to
missions 1 and 2 (40.41 and 41.44); $F(3, 99) = 23.76, p<.01$. This was not unexpected
based on the increasing difficulty of the trials.

Having witnessed the ability of some operators to successfully anticipate arrival
over the designated landing zones with the 60-degree camera view, and noting a trend
that the fewest total crashes occurred in the same condition, we began a third and final
study with the Northrop Grumman OCU. In this experiment, the camera image display configuration was returned to the setup used in the initial evaluation. This means a single image was displayed on the OCU, but the operator had the ability to switch between the forward view and a downward view. Once again the downward view angle was the manipulated IV (70-degrees or 90-degrees). Participants completed the same 4 missions and workload assessments used in the previous study. By returning to the alternating camera setup, we hoped to determine how manually switching camera views affected operator workload. Also, we still had not determined if the 90-degree camera view was sub-optimal. The 70-degree condition would help us to see if there was any advantage to allowing users to anticipate the designated landing zone. Results gave us little to go on, as no significant effects of camera angle were observed for this experiment. In addition, operators had serious difficulty with the camera switching procedure due to mis-mapping of the camera control icon and certain auto-switch functions that were hard to manage.

To overcome the problems we observed during the previous experiments, it was decided that future research should use a more reliable interface with superior data collection capabilities. So a new interface was developed with the aid of programmers from the University of Central Florida’s Institute for Simulation and Training. By taking into account the lessons learned from the earlier studies, this OCU improved on previous designs, offered more flexibility with the user interface and terrain database, and provided the data collection tools needed to make research more manageable. This system was the one used for the main experiment described in this report.
LITERATURE REVIEW

There are several factors that can influence an operator’s ability to pilot a UAV using the type of laptop-based control units being developed. Most of the relevant issues associated with using these systems are addressed somewhere within the fields of human-robot or human-computer interaction (HCI). Some areas of research in HCI include cognition, memory, perception, learning, usability, hardware and software development, speech recognition, graphics, ergonomics, displays, navigation, virtual environments, input devices, output devices, and interface design. This list is not exhaustive, and within many of these focus areas exist even more sub-categories that attract a great deal of attention from the research community. The areas of navigation in virtual environments, input devices, displays, interface design, usability, and perception play a significant role with regard to the current study and were examined closely. In addition, there are unique issues involved with the teleoperation of remote vehicles that have direct implications for this research.

Navigation and Travel in Virtual Environments

Bowman, Koller and Hodges (1997) proposed a taxonomy for navigation in virtual environments (VE) and identified the most important factors influencing a user’s ability to travel within them. The authors first distinguish between navigation and travel and provide working definitions for both concepts. Accepting their definitions, we describe navigation as the process of determining a path through the VE to reach a
goal. This is also referred to as wayfinding. Travel refers to the control of user viewpoint motion. This viewpoint could be either a first person rendering or one where the user’s viewpoint is attached to the camera point in the VE. We use the term teleoperation to describe the latter condition, and this illustrates a viewpoint that an operator would experience piloting the MAV through a synthetic terrain database like the one used in this study. This can be characterized as an egocentric viewpoint (Hughes & Lewis, 2005). Bowman, Koller and Hodges’ (1997) research focused primarily on travel, and identified seven factors affecting travel in VE’s including:

- Speed
- Accuracy
- Spatial awareness
- Ease of learning
- Ease of use
- Information gathering
- User comfort

Experimental factors can also influence travel performance. These include the task chosen, the environment, the user, and system characteristics. Furthermore, the authors categorize different components of travel technique. They propose 3 high-level categories of travel technique including:

- Direction/Target selection
- Velocity/Acceleration selection
- Input conditions
Each category of travel technique is then broken down into different options. For example, *direction and target selection* can be controlled by gaze-directed steering, pointing in the environment, discrete selection (such as from a menu), or pointing on a 2D display. *Velocity and acceleration control* can be constant, discrete, gesture based, scaled, or automatic/adaptive. *Input conditions* can also vary from constant travel with no user input, to continuous input, start and stop inputs, and automatic starting and stopping. Table 1 summarizes each travel technique with options. This structure provides a framework for our current research, which incorporates some of the different input and control methods.

Table 1

<table>
<thead>
<tr>
<th>Direction and Target Selection</th>
<th>Velocity and Acceleration Selection</th>
<th>Input Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaze-directed steering</td>
<td>Constant</td>
<td>Constant with no input</td>
</tr>
<tr>
<td>Pointing within VE</td>
<td>Discrete</td>
<td>Continuous inputs</td>
</tr>
<tr>
<td>Discrete selection (menu)</td>
<td>Gesture-based</td>
<td>Start and stop inputs</td>
</tr>
<tr>
<td>Pointing 2D display</td>
<td>Scaled</td>
<td>Automatic starting and stopping</td>
</tr>
</tbody>
</table>
Input Devices

Existing prototype Class I UAV operator control units have used touch screens, with a stylus as the primary input device. However, our previous research with these systems showed that users complained about the reliability of the touch screen inputs. In particular, users had difficulty distinguishing between failed touches (touches that did not register) and successful touches that had delayed effects (Durlach, Neumann, and Bowens, 2006). With this in mind, an objective of the current research was to evaluate alternatives to the touch screen setup. Card, English and Burr (1978) completed a study that compared a mouse and joystick with the stylus, as well as with text keys and step keys on a text-selection task. Citing the stylus (or finger pointing if possible) as the optimal input device, the mouse was only 5% slower. The joystick was 83% slower than the stylus. The text and step keys were 107% and 239% slower, respectively. The authors predicted positioning time of the mouse and joystick using Fitts’ Law (1954), which is governed by the magnitude and distance of the target being selected. In a later study, MacKenzie, Sellen and Buxton (1991) compared the mouse and trackball to the stylus on both pointing and dragging tasks, and found only a 1% difference between the mouse and stylus on the pointing task (mean time to complete). The mouse was approximately 10% faster on the dragging task. The trackball finished a distant 3rd in both cases. Therefore, with the reliability issues we observed in previous research with the stylus, the mouse would appear to be a viable replacement.
In addition to developing a taxonomy on travel in VE’s, Bowman encourages the evaluation of all interaction techniques relating to immersive VE testbeds, which includes the different types of input devices (Bowman, Johnson, & Hodges, 1999). The authors provide another taxonomy for categorizing the performance of these techniques. However, because this particular body of work utilized head mounted displays in truly immersive VE’s, they assumed a mouse (and keyboard) could not be used effectively as input devices and eliminated them from the taxonomy. Because the control systems that are being developed for piloting MAV’s are designed with portable computers in mind, a mouse (either touch-glide or standard) and keyboard are obviously available input options. In fact, the authors claim that these flat surface-based (2-dimensional) input devices improve performance in controlling multiple degrees of freedom in VE’s, thus giving the user an advantage over interacting in a volume (3-dimensional) capacity. It could be argued then that the mouse would offer the UAV operator some advantages over alternative input devices. Due to the relative ease of using commercially available computer systems and input devices like the mouse, developers can (and do) leverage the fact that most people are familiar with this kind of hardware when designing the control interface. By using common hardware instead of creating a new control device, the MAV should, theoretically, be easier to learn how to fly.

In addition to standard PC platforms, video game consoles such as the Sony™ PlayStation and Microsoft™ XBOX are also very popular, especially with the military recruiting demographic. Market studies by the NPD Group revealed a total of $7.3 billion
dollars in video game sales in 2004, with a large majority of gamers being under 40 years old (NPD, 2005). Millions of people are playing these games and several of the most popular games require users to navigate through 3D virtual environments on both the vertical and horizontal planes. These gaming consoles differ from the standard PC in that they include a unique dual-joystick game controller instead of a mouse and keyboard. Manufacturers of computer peripheral hardware like Logitech™ have been marketing similar game controllers for use with standard computer platforms as well, so the technology is not limited to game-only systems. With the enormous success these products have demonstrated in the marketplace, it is possible that this type of game controller could be adapted for use with the MAV control interface and would work well for MAV operators who are familiar with the device. This would involve eliminating the use of the joystick component of the controller for selection tasks, as the Card (1978) study showed a significant deficiency on selection tasks when compared to using a mouse. Fortunately, the game controller is equipped with buttons that can be programmed to automatically select options from the control interface. Considering the NPD group statistics for gamers under 40, and the overwhelming majority of enlisted men and women in this age group, we can expect a large percentage of them to have had at least some experience with a game controller. But what about operators who have not used the device before? This becomes an issue, especially if the device is not easily trainable. This type of controller may appear complex to a novice user when compared to a mouse or stylus, and such perceived complexity could create unwanted...
stress on the operator and affect workload. In a military operations setting, this is clearly undesirable.

Microsoft claims that thousands of hours of usability testing were involved in the development of the XBOX game controller, but finding published journal studies or technical reports with empirical measures of performance has proven difficult. It is possible these in-house usability studies are proprietary and can only be obtained directly from the manufacturers. Other research is also limited on the subject of input devices for teleoperation. Hoff and Lisle (2003) compared a primitive 3-degree of freedom game controller to a data glove and found that the data glove outperformed the game controller when manipulating entities in the VE, but on a visualization-identification task there was no difference between the two devices. This finding could benefit developers of uninhabited ground platforms like the Talon, which has a large robotic arm used for manipulating hazardous objects such as roadside bombs, but may not generalize to aerial vehicle control.

Even without a wealth of empirical data, we do know a lot about the capabilities of game controllers. The devices contain two small joysticks that are manipulated by the user’s thumbs, as well as a variety of pressure-sensitive buttons that can be programmed to allow both discrete and continuous movement (a.k.a. digital v. analog). When used to control flight, the dual joystick configuration means the user can seamlessly manipulate all 6-degrees of freedom within the VE. The extra buttons on the device also allow the on-screen functions of the OCU to be mapped directly to the controller. This could actually make certain selection tasks more efficient than the
mouse. So the game controller appears to offer certain advantages to MAV operators. For example, computer-based flight simulators exist whereby pilots can control vehicle flight and weapons systems in parallel, which is inherently more efficient than clicking on display or control options in series.

Reasonable suggestions have been made that both the mouse and game controller may be well suited as input devices for the OCU. The MAV testbed used in this study was configured for use with both of these devices. This made possible a direct comparison of the two. According to Hancock (1996), the influence of input devices is of practical concern because the choice of device can affect interaction dependent on task control. Hancock also cites the Card (1978) study which made an additional finding relevant to our research – that devices that offered users continuous control performed faster than key operated (step-wise) devices. So an added benefit of the mouse and game controller was being able to investigate continuous vs. discrete control methods.

Movement Control

Strommen (1993) found that young children preferred discrete movements (jumping from location to location) to continuous movement when locating targets in a 3D environment while using game controller from Nintendo.™ Because the mean age of Strommen’s participants was only 3 years, the results may not be applicable to an adult population; but they do pose an interesting question regarding user preferences.
Referring back to the Bowman taxonomy on travel within VE’s, discrete movement and continuous movement are two of the sub-categories of velocity and acceleration control. So regardless of the type of input device used, examining the performance differences between adult operators using different movement control methods could make a valuable contribution to developers of human-machine interfaces for teleoperated systems. Because existing systems had used both continuous (Northrop Grumman) and discrete (Honeywell) movement control schemas, we incorporated both types of control into our OCU in order to determine which method trainees found least taxing and operated most efficiently.

**Interface Design and Display Configuration**

Beyond the type of input device and control technique used, there are issues with the design of the interface that could affect operator performance while piloting the MAV. In preparing the OCU testbed for this study, we combined the lessons learned from the usability evaluations of previous systems with knowledge of interface design principles in an effort to minimize operator workload. Nielsen (1993) proposed a popular set of usability guidelines that calls on developers to do whatever possible to minimize the user’s memory load, in addition to incorporating effective error messages, error prevention and recovery measures, consistency, and feedback. Many of the principles that were violated with the Northrop Grumman and Honeywell interfaces have been corrected in the design of the new OCU. A few of the notable changes involved the
creation of salient displays and alarms. The altimeter was redesigned in line with the findings of Sanders and McCormick (1993), who suggest that an integrated vertical display provides the best representation for the operator and resulted in the fewest errors during testing. The design of the airspeed indicator (digital) and the heading indicator (horizontal tape display) also followed their recommendations. In addition, the display area is configurable to suit the preferences of the operator. Figure 2 shows the interface configured for 2 locked camera views and the overhead map view.

Figure 2. The OCU interface with 2 camera views and overhead map display

**Workload**

If a good interface design will help reduce operator workload, then what other factors exist that might affect workload when piloting a UAV? Although workload can mean different things to different people, most human factors practitioners accept the
work of Wickens (1984) and McCloy, Derrick, and Wickens (1983) as a framework for studying workload. The general concept states that human operators have a limited amount of resources from which to draw upon when executing a task. Affecting workload can then be achieved by either altering the amount of resources available to the person or altering the task requirements (Sanders & McCormick, 1993). For example, altering available resources could be achieved by not allowing the operator to sleep for more than 24 hours. Altering task requirements can be achieved in many ways. In their discussion on human-centered design for UAV control, Mouloua, Gilson, and Hancock (2003) describe 5 factors that will affect operator workload in most UAV scenarios:

1) Number of flight parameters controlled by a single operator
2) Degree of operator involvement in obstacle or threat avoidance
3) Number of total vehicles controlled by a single operator
4) Difficulty of target search and recognition
5) Difficulty of situation assessment (such as distinguishing friend from foe)

In addition, the level of available operator resources depends on five key issues:

1) The level of training and experience
2) Time on task
3) Attentional skills
4) Support by backup personnel or systems
5) Situation awareness (SA)
Per the issues influencing available resources and workload, much of the work done on the OCU interface used in this study was focused on maximizing the operator’s environmental awareness. This resulted from the fact that most vehicle crashes in our previous experiments were a result of poor situational awareness (SA). Recall that we studied different camera angles and configurations, but the interface lacked salience of critical mission displays like altitude and heading. Results were mixed. We did find that workload increased with task difficulty as the missions became progressively harder, but very little was found with regard to effects of camera angle. The fact that workload increased with task difficulty confirmed the findings of Warm, Dember, Gluckman and Hancock (1991). Warm also found that performance diminished with increased workload. This was somewhat evident in our previous research where the mean experimenter ratings were inversely related to workload measures. This meant that participants who received lower scores from the experimenter reported higher workload scores. However, there are instances where workload and performance disassociate (Yeh & Wickens, 1988), and the direct link between task difficulty and workload level is broken (Derrick, 1988, Eggemeier; et al, 1982). These findings were cited by Hancock (1996), who offers an in-depth discussion of these circumstances, and explores the concept further by evaluating the link between workload and performance over extended practice. Because an overarching goal of the current research is developing efficient and effective training methods for MAV operators, practice and learning are of great interest. So in line with Hancock’s research, we examined operator performance concurrently with workload to directly examine the association between the two.
With regard to the optimal display of sensor imagery, the issue surrounding the
best camera image configuration remains uncertain. By taking advantage of the
freedom to manipulate camera views more effectively with the new OCU, we may be
able to determine if an optimal configuration exists that reduces workload. Mainly, there
are two camera views we are concerned with – the forward camera and the downward
view. Would operators benefit more from having both images displayed
simultaneously, or is it better to alternate between the two? Because of the limited view
area of the screen, presenting both images at the same time reduces the maximum size
of each image. Displaying 1 view at a time increases the available image size, but
requires the user to manually switch between views. Tan, Czerwinski and Robertson
(2006) found that wider fields of view using large displays improved virtual navigation
found that participants performed better on spatial orientation tasks using larger
displays when navigating in 2D (2003) and 3D (2004) settings. These conclusions
suggest that offering a larger image to the operator may improve UAV navigation and
travel within either a 2D or 3D virtual environment. However, there is no way of knowing
if these results would be replicated if the user had to monitor an additional display, such
as the downward camera view of the MAV. Each scenario raises questions with regard
to attention and resources. For example, if the user has both views to monitor at one
time, then it is reasonable to think that the two images will compete for the operator’s
attention. Sanders and McCormick (1993) state that divided attention consumes
resources and the number of potential sources of information should be minimized.
Tsang and Wickens (1988) state that time-sharing 2 tasks in the same modality is less efficient than if they were in different modes. This could relate to monitoring 2 visual images simultaneously. However, switching between the two views by issuing a command through the interface introduces an additional input task that can easily take the operator’s attention away from the sensor imagery, and also removes an element that contributes to the operator’s situation awareness, i.e. when the operator switches to the down camera view they have no forward view from which to navigate. Eliminating the downward view in lieu of a forward-only camera setup is likely not the solution, as we observed in our first MAV manual control study where half of all crashes occurred when the secondary camera was angled at just 30-degrees from horizontal. This is only a 15-degree change from the forward view angle, which is typically set at 15-degrees from horizontal for MAV operation – regardless of the OCU or vehicle type.

One factor with regard to camera placement and view angle that we did not investigate – but should be noted – is the ability of the camera to be panned across the viewing area. Because current restrictions limit the use of motors on MAV cameras, the MAV testbed was configured with both cameras locked in place. However, Hughes and Lewis (2004) found that allowing operators to control an independent camera improved search performance. The authors also discuss 2-camera displays and present a question for future research in that if one image is dominant, then a picture-in-picture configuration may be optimal. Although not specifically examined in the present study, it would make sense to investigate performance with the picture-in-picture configuration should we determine that operators primarily use one camera view for certain missions.
The OCU developed by Honeywell employs this setup and would provide a good testbed for the research. Recalling the 2nd study with the Northrop Grumman OCU, we observed participants relying heavily on the overhead map view and, in some cases, flying an entire mission while attending solely to this display (Neumann & Durlach, 2005). This mission was type-specific, whereby the operator was essentially tracking the MAV along a designated flight path with no concern for obstacle avoidance or target detection. In a more realistic setting, executing a MAV mission solely from a satellite view would be impractical. If the only objective for the mission was to adhere to a designated flight path, then the operator would be advised to fly the MAV in autonomous mode. However, this example does illustrate how operators are prone to developing a strategy for completing each mission, and this could involve relying almost entirely on a single display – regardless of whether or not additional imagery or instrumentation are available within the interface.

**Sensory Awareness**

When piloting the MAV under manual control, awareness of the environment surrounding the traveling entity is critical for successful navigation, obstacle avoidance, and target detection. Controlling the vehicle remotely compounds the challenge for achieving these objectives. During teleoperation, there is a decoupling of perception and action that contributes to the difficulty of maneuvering a remote vehicle on the basis of a video feed from a fixed camera (Peruch & Mestre, 1999; Woods, Tittle, Feil, & Roesler, 2004). This is likely because a human moving through space has several
sources of information besides straight-ahead-vision, and these may be absent or
distorted when navigating through video input. This can interfere with judgment of scale,
depth, and velocity. In addition, people moving through space make anticipatory head
and eye movements toward the position they are approaching; they don’t just look
straight ahead (Ryzberczyk, Gallerne, Hoppenot, Colle, & Mestre, 2001). This is not
possible with a fixed camera. Prototype Class I UAV’s employ fixed cameras to keep
both operator workload and payload weight to a minimum.

Other important discussions of operator awareness in the literature focus on
factors such as optical flow and field of view (FOV). People experience optical flow as
the pattern of light hitting the retina changes as they move through an environment.
When coupled with internal (proprioceptive) perception of motion, this allows us to
perceive both the structure of the environment and our movement within it (Tan,
Czerwinski & Robertson, 2006; Duffy, 2000; Klatzky, Loomis, Beall, Chance, &
Golledge, 1998). Optical flow is also a significant aid in travel/wayfinding when
landmarks and other environmental cues are not present, (Kirschen, Kahana, Sekuler,
& Burack, 2000). However, some researchers suggest only the central FOV is
The latter study does not account for peripheral optical flow cues due to the use of
computer displays with narrow FOVs. Because MAV operators use computer-based
control interfaces, these results seem applicable to the current research. In addition,
landmarks and other environmental cues will most likely be present for MAV pilots who
are operating the vehicles over short-range missions, especially in urban terrain
settings. These factors may diminish the role of optical flow and its affect on navigation and travel when teleoperating the MAV (via computer display) in both simulated and real environments. The impact of field of view is also limited by the size of the OCU screen. The portable computers that display the control interface and sensor imagery for MAV operators are no more than 19" wide, and from a comfortable viewing distance there is limited opportunity to make significant changes in operator view area or to display larger sensor imagery that could trigger peripheral cues. Although current MAV prototypes can carry more than 1 camera, only 1 camera view is typically available to the operator at a time, or both are displayed in a picture-in-picture arrangement. This latter setup substantially reduces the secondary image in size, and this image occludes the corresponding portion of the main image. As mentioned, the current OCU was designed with the ability to display either 1 camera view (with the operator manually alternating between views), or the forward and downward views simultaneously. We know the available screen area limits the resolution of each image, so the dual-camera configuration in our study was designed to fill the identical amount of on-screen space (in pixels) as the alternating view setup. Therefore, the dual-camera configuration effectively cuts the size of each image in half. This poses a question regarding image resolution and an operator’s ability to process environmental cues and detect targets within the VE. Stelzer and Wickens (2006) found that display size reduction diminished estimates of flight path changes and control performance in fixed-wing aircraft pilots using complex cockpit displays, but these pilots were able to adapt to display size changes for search and surveillance tasks. This suggests that MAV operators who
navigate primarily from the main video image (the forward camera) would suffer degradation in manual flight control performance when using the dual camera setup. However, it is unknown whether the addition of the downward view would help compensate for the lower resolution of the forward view. With regard to target detection, Stelzer and Wickens’ findings suggest there may be no impact of display size.

One important note regarding this entire discussion is that we are assuming operators will be stationary when completing MAV flight tasks. A recent article by Muth, Walker and Fiorello (2006) makes the point that military personnel are beginning to control uninhabited vehicles from inside moving vehicles. If this were to apply to MAV operators, it would introduce a whole new set of issues for successful mission completion. As we might expect, the authors found that performance on an uncoupled driving task was significantly degraded while the command and control vehicle was in motion. Measures of operator motion sickness also increased. With the addition of a target detection task, the OCU display configuration and image resolution might be of even greater importance as users would need to constantly adjust their line of sight to maintain focused attention on the relevant display area.

**Individual Differences**

It is worth noting that the impact of display configuration may be mitigated by individual differences. Waller, Knapp, and Hunt (2001) found that for some tasks (particularly those involving controlled mental effort), individual differences can be much
more influential on performance than differences in the appearance of the training system. Investigating the impact of individual differences can lead down many paths. In general, it is advisable to attempt to control for differences in cognitive abilities and related computer experience when designing any computer-based training system. This takes effort. That being said, a substantial amount of the research reviewed for this manuscript made mention of gender differences, particularly with regard to navigation in virtual environments and spatial ability. It was not the purpose of this study to focus on gender as a factor, but we did record measures of both spatial ability and video gaming experience, which previous research tells us often exhibit gender differences. Turnage, Kennedy and Lane (1996) published a compelling review that addresses the topic of gender differences in detail. In this article, there is particular focus on spatial ability, and the impact this has for men and women who live in a world increasingly dominated by technology. The world of computing, in particular, is inherently dominated by males, and the more computers are used for training the greater the expected advantage will favor the male population. The authors posit that skill-acquisition can be influenced by practice, but if the tasks are continually male-oriented endeavors there will be little change in the status quo. To change course, the authors propose that where gender differences do exist, it would better serve the entire population by structuring practice and skill-acquisition tasks that are of interest to each gender. In early 2006, Gamedaily.com reported that according to the Consumer Electronics Association, women gamers age 25-34 outnumber men (Brightman, 2006). This study included popular action and sports games, but also puzzle and card games like Solitaire,
Sudoku, and Tetris. The latter group makes up the majority of games played by females. Tetris, specifically, requires mental rotation of geometric figures. Mental rotation is widely considered one on the 3 subsets of spatial ability, so this holds promise for developers interested in narrowing perceived gender gaps in spatially relevant skill acquisition tasks. Linn and Petersen (1985) observed large effect size differences only on measures of mental rotation. So if it is true that training with similar tasks can improve spatial ability, we may see improvement in female mental rotation scores should the current game playing trends continue. Because our current research uses a computer-based display with a gaming system peripheral device, we can expect to observe at least some gender bias. However, as quoted in the Turnage (1996) article, Holden (1991) states that “this area of research is something of a political minefield.” With this in mind, we looked at possible gender effects, but only to the extent that the original scope and purpose of this research would not be altered to a large degree.

Spatial Ability and Video Game Experience

Prior research has shown spatial ability is a factor in a variety of navigational and other tasks. Dissertation studies by Bailey (1994) and Darken (1996) cited by Waller, Knapp and Hunt (2001) conclude that there is evidence that spatial ability, as assessed by paper-and-pencil psychometric tests, has moderate significant predictive validity for spatial knowledge acquisition in virtual environments. Many tests, both paper-based and computer-based, have been developed with the purpose of reliably measuring spatial
ability. Most of these tests are designed to test different aspects of spatial ability. For example, the Hidden Figures and Hidden Patterns Tests from Educational Testing Services (ETS) measure flexibility of closure (cf), also known as field independence. This involves picking out specific patterns or shapes embedded within distracting information. The Cube Comparison Test from ETS and the Vandenberg Test of Mental Rotation (VTMR) examine the ability to rotate images in the mind. Other tests, like the adapted Cardinal Direction Test (Gugerty, Brooks and Treadway, 2005) used in our study, examine spatial orientation. For the purposes of this report, we elected to administer a battery of different tests to measure all 3 different aspects of spatial ability. This would afford the opportunity to discriminate between the different subsets during analysis.

Additional research has focused on computer and video gaming experience and how this relates to performance in VE’s. De Lisi and Cammarano (1996) concluded that computer experiences (including game playing) and spatial ability were related. When administering the VTMR, the authors observed a gender effect favoring males during the pre-test. This was not unexpected, as the VTMR typically exhibits the largest gender effect size (Collins & Kimura, 1997; Voyer, Voyer & Bryden, 1995; Linn & Petersen, 1985). However, on the post-test VTMR, both males and females in each group who had played a game requiring rotation of geometric figures called Blockout outperformed males who played only Solitaire. This implies that practice with the rotation task contributed to improved scores on the post-test, so experience with spatially demanding video games may offer advantages to trainees regardless of gender.
Purpose of Investigation

The overall purpose of this research is to influence the development of future UAV operator control systems. We are most concerned with operator training. By comparing available input devices, interface configurations, and control schemas, we are on the road to determining which setups are most efficient and effective.

Simulation provides us the ability to manipulate the environment, and it also permits us to easily change the control configuration of the interface. We took full advantage of the newly developed OCU in this regard. There are 3 main categorical factors examined in this study. The first is the input device where we are comparing the mouse and game controller. Next is the dual-camera imagery being presented simultaneously versus individually with alternating views. The final manipulation was the movement control method as either continuous or discrete. In addition to the stated IV’s, we are also measuring the affect the different control configurations and devices have on operator workload. Lastly, we want to determine the predictive value of several different tests of spatial ability, and other notable factors like computer and video gaming experience.

There are certain theoretical issues that make the formation of several hypotheses possible for this research, but for some of the areas we are looking into a hypothesis was not formulated. The single versus dual camera configuration represents a case where no hypothesis was formed, and this can be regarded as exploratory research. Evidence suggests a wider display is better for pilots (as would be in the
single camera display condition), but working with portable computer screens makes this research hard to compare to the current system. In addition, our previous studies were inconclusive in this area.

With regard to the input device and control method, we can predict that the game controller and continuous control method will be more efficient, thus we expect faster mission times for operators in these conditions. Although the game controller offers more efficient (parallel) control, it also places a heavy tax on working memory, so workload may be greater for users of this device versus the mouse:

H₁: Mean times to complete manual control flight tasks will be faster for users in the game controller conditions over the mouse.
H₀: Mean times to complete manual control flight tasks will be equal for users of the game controller and the mouse.

H₁: Mean times to complete manual control flight tasks will be faster for users with the continuous input control method than the discrete input method.
H₀: Mean times to complete manual control flight tasks will be equal for operators using the continuous and discrete input control methods.

H₁: Workload scores will be greater for users of the game controller compared to those using the mouse.
H₀: Workload scores will be equal for both game controller and mouse users.
METHOD

Participants

72 participants from the UCF area completed the entire experiment. Three other participants did not satisfy training requirements and were excused. Everyone recruited was at least 18 years old and had normal color vision. Participation was voluntary and compensation was $20 or UCF course credit, at the participant’s discretion. Each participant completed an informed consent form that explained the scope of the study prior to any testing.

Equipment: Hardware

The simulation consisted of a network of 3 computers. The OCU, the MAV simulation, and the synthetic terrain database all ran on one machine. This unit was networked with another computer running OneSAF Testbed (OTB version 2.5), which allowed the experimenter to introduce dismounted soldiers and ground vehicles into the terrain database. The terrain database was modeled after an Army urban training site at Fort Polk, Louisiana. A third laptop ran the *Dismounted Infantry Virtual After Action Review System* (DIVAARS). This program records missions in real-time for playback and analysis. A separate off-network tablet PC running Windows 2000 was used to administer the NASA TLX developed by Hart & Staveland (1988).
Equipment: Input Devices

There were two possible input devices used with the OCU. One was a standard 2-button/1-wheel Dell optical mouse with a USB connector placed on a common 0.25” mouse pad, and the other device was the Logitech dual-thumbstick game controller shown in Figure 3 – also with a USB connector.

![Logitech Dual thumbstick Game Controller](image)

Figure 3. Logitech Dual thumbstick Game Controller

Equipment: Control Interface

There were 2 possible control interfaces, shown in Figures 4a and 4b. The first was the discrete input control pad, which used arrow icons for operator inputs. When using the mouse, operators clicked on the arrow that corresponded to the desired movement. Clicking on a different icon canceled the previous input and the MAV immediately began executing the new command.
The alternate control pad (figure 4b) allowed operators to mimic joystick control on a 2-D point and click surface. To accelerate the MAV, operators could click and drag the green dot located inside the gray circle in the direction they wanted the MAV to travel, or they could just click a point on the control surface and the green dot would automatically move there and achieve the same results. To adjust heading, operators moved the green dot located in the arc at the top of the display, and moving the green dot within the vertical bar on the right-hand side of the display controlled altitude. Dragging the dot further away from the center point proportionately increased velocity, so operators had air speed control to the hundredths of Knots.
Operators using the mouse interacted directly on the control interface by clicking on it to register an input or flight command. Game controller users made all inputs directly from the controller. For both devices, the control surfaces provided visual feedback for the action they initiated. For example, if the MAV was moving horizontally to the left, the leftward pointing arrow of the discrete control surface illuminated, or the dot in the circle of the continuous control moved to the left.

**Equipment: Sensor Imagery Display**

Half of the participants were presented with a dual camera image display (the forward view and the down view simultaneously). The rest could view only 1 image at a time. In order to see the alternate view, they could manually switch which view was displayed. To switch views, mouse users clicked on the icon corresponding to the camera they wished to activate. Game controller users pressed one of the programmable buttons (labeled number 2) located on the device, and then used the controller’s directional pad to select the desired camera view. Both camera configurations used the same amount of on-screen viewing area (in pixels) for the video images. Figures 5a and 5b illustrate the differences in the 2 camera image display configurations. The overhead satellite map was always visible to all participants. Although the screen shot in figure 5b shows the overhead map view at full-zoom and the continuous control pad in the lower right corner of the interface, during the experiment the overhead map image was the identical aspect ratio for all conditions. The input control pad was also moved and docked in the same location as in figure 5a.
Figure 5a. Dual Camera View Configuration

Figure 5b. Alternating Camera View Configuration
Design and Procedure

Each participant completed 2 sessions on separate days. In session 1, which lasted about an hour, participants completed a demographics questionnaire and 4 tests of spatial ability. The demographic survey contained questions on each user's computer usage and video game playing habits, as well common demographic data like gender, age, and education. The spatial ability tests included the Hidden Figures and Hidden Patterns Tests (1975), and the Cube Comparison Test (1976) from Educational Testing Services (ETS), as well as a computer-based test adapted from the Cardinal Direction Test developed by Gugerty, Brooks, and Treadway (2005). The latter test required users to ascertain the location of a target in relation to a building. This square-shaped building appeared in all trials with parking lots on all 4 sides. The target always appeared in 1 of these parking lots. Users were hypothetically placed in the cockpit of an airplane that appeared in an image approaching the building from 1 of 8 directions. These included the 4 Cardinal Directions, as well as the 4 Primary Inter-Cardinal Directions. In an adjacent image, users were shown the view from the cockpit of the plane along with the target in relation to the building. This required users to rotate the right-side image in their mind to determine the correct location of the target. Figures 6a and 6b illustrate examples of the plane approaching from both the Cardinal and Inter-Cardinal Directions. The left-side image always assumed the plane was traveling from the bottom toward the top, so when rotated each of the targets in the following examples is located in the South parking lot.
Each of the spatial ability tests was examined for reliability. The Hidden Figures and Hidden Patterns tests contained parts A and B that correlated with $r = .69$ and $r = .68$, respectively. With approximately 50% of the variance shared, scores from both parts of these 2 tests were combined to strengthen the overall reliability. Multiple split-half correlations were performed with the adapted Gugerty Cardinal Direction test. When correlating the Cardinal directional scores (based on number correct) with the Inter-Cardinal scores, $r = .77$. Another split-half correlation using odd and even trials yielded $r = .78$. The Cube Comparison test is a one-part test containing 21 trials.
Although the Cube Comparison Test has been in use for roughly 30 years and is certified by ETS, we reviewed previous research to determine a minimum level of reliability. By taking published correlations of this test with other tests and transforming the scores using the Fisher z-transform equation, a minimum test reliability could be determined by converting the average Fisher z-score back to $r$. Based on the research reviewed for this study, the result was $r = .27$. A correlation matrix of the entire 4-test battery appears in Table 2.

Table 2
Correlation Matrix of Spatial Ability Test Battery

<table>
<thead>
<tr>
<th></th>
<th>Cube Test</th>
<th>Hidden Figures</th>
<th>Hidden Patterns</th>
<th>Gugerty Adapted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube Test</td>
<td>1.00</td>
<td>.361*</td>
<td>.381*</td>
<td>.247*</td>
</tr>
<tr>
<td>Hidden Figures</td>
<td>1.00</td>
<td>.405*</td>
<td>.149</td>
<td></td>
</tr>
<tr>
<td>Hidden Patterns</td>
<td>1.00</td>
<td></td>
<td>.248*</td>
<td></td>
</tr>
<tr>
<td>Gugerty Adapted</td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

* indicates significance at alpha < .05

Based on this matrix, the resulting $r$-figures indicate that the test battery does a fairly good job of measuring different factors. The fact that the Hidden Figures and adapted Gugerty tests are not significantly correlated is a plus in this instance, and this test never shares more than 6 ¼ % of the variance with any of the other tests.
MAV operator training took place during the 2nd session. This portion of the study lasted approximately 2 hours. For this session, participants were semi-randomly assigned to 1 of 8 conditions determined by a 2 x 2 x 2 between-groups design, where the 3 factors were equipment conditions. These IV’s included: 1) input device, 2) control interface, and 3) number of camera views. Each operator completed the training facilitated by a printed manual and an experimenter (this author). Once participants had reviewed the instruction portion of the training manual and familiarized themselves with the on screen controls and the input device, the experimenter administered and graded a short exam that was designed to test the operator’s knowledge of all the commands and interface components required for the study. This training evaluation worksheet is reprinted in Appendix D. Upon successful completion of this test, each participant began a series of 6 practice exercises. We required operators to perform these exercises without crashing the MAV, and to a temporal criterion. In prior related experiments, MAV flight dynamics were unfamiliar to the operator. At times, the MAV would lapse into large oscillations depending on the movement commands it was given. In order to avoid such problems during this experiment, we limited the speed at which the MAV could travel to 6 knots.

Each participant was allowed 5 attempts to successfully complete each of the 6 practice exercises. Participants who could not finish the exercises within 5 attempts were dismissed from the experiment before the test phase (there were 3 instances).
After finishing the practice exercises, participants began a new series of 6 missions. Mission 1 required operators to pilot the MAV for 1 lap around an oval-shaped roadway and then land on top of a marked rooftop landing zone (LZ). This mission had been performed as one of the final 2 practice exercises, with the aid of route waypoints displayed on the overhead map display. When performed as Mission 1, these waypoints were not visible. Mission 2 was the first of 2 tactical missions, and involved flying to a pre-designated building (a church) and identifying the occupants as seen through the windows. Participants needed to observe the church from several vantage points at close range to successfully determine how many soldiers and enemy infantry were inside. Mission 3 was a slalom-type obstacle course, which had also been completed as the final practice exercise. Six 125-foot poles were imported into the database and operators had to weave through them while avoiding other obstacles such as trees and buildings. Poles sequentially alternated in color between green and red. At the end of the course, each participant photographed the command vehicle located near the start/finish line. As with Mission 1, route waypoints that had been displayed during practice were not displayed during the test phase.

Mission 4 was a reconnaissance sortie, and the last of the 2 tactical missions. Twelve entities (8 vehicles and 4 dismounted infantry) were imported into the database and operators were given 7 minutes to successfully photograph as many them with the MAV's onboard camera as possible. At the 7 minute mark, participants were ordered back to the launch site. This mission included a debriefing session where each operator was asked to recall the type and location of entities observed during the flight. This was
done by marking directly on a scale map of the terrain database. This post-test was
later graded by the experimenter who used a transparent overlay to determine correctly
marked entity locations. Scores were determined as follows: markings located within
.625” of the correct location of the entity (inside a 1.25” diameter circle traced on the
overlay) received 2 points. Entities marked within 1” of the actual location (within a 2”
diameter circle) received 1 point. Correctly labeling an entity’s orientation also earned a
point. Orientation for vehicles was always North.

Mission 5 was a repeat of Mission 1 – a lap around the oval roadway, and
Mission 6 was a repeat of Mission 3 – the slalom course. At set points during certain
missions, participants were asked questions designed to assess their situation
awareness. Table 3 summarizes the 6 test-phase missions in order.

Table 3
Test Phase Missions with Descriptions

<table>
<thead>
<tr>
<th>Mission #</th>
<th>Mission Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Complete 1 lap around oval roadway, land on designated rooftop LZ</td>
</tr>
<tr>
<td>2</td>
<td>Tactical exercise, locate and identify hostages and enemy soldiers</td>
</tr>
<tr>
<td>3</td>
<td>Complete slalom-type obstacle course, then photograph C2 vehicle</td>
</tr>
<tr>
<td>4</td>
<td>Tactical exercise, locate and photograph multiple entities within 7:00</td>
</tr>
<tr>
<td>5</td>
<td>Repeat of Mission 1</td>
</tr>
<tr>
<td>6</td>
<td>Repeat of Mission 3</td>
</tr>
</tbody>
</table>
Measures

Several measures of performance were collected for each trial, with some variation depending on mission. These included time-to-complete, number of collisions, number of targets observed (mission 2) or detected and photographed (mission 4), and workload. To measure workload, operators completed the NASA Task Load Index once before training, once after completing the practice trials, and then again after each individual mission in the test phase. This totaled 8 workload measures per participant. Results were computed for each of the 6 workload factors and exported into a Microsoft Excel file, where the composite workload score was computed. As each participant completed the workload assessment, the experimenter simultaneously rated the performance of each operator (per mission) on the same 6 factors as the NASA TLX, thus formulating an non-weighted experimenter rating of workload.

During and after certain missions, the experimenter would ask specific questions designed to assess the operator’s current level of situation awareness. For example, once each operator had reached the North side of the target building containing the hostages in mission 2, they were asked which direction they would fly to return to the pre-designated landing zone (LZ). The correct answer was always South. This LZ was marked by a large letter H located inside a circle on the rooftop of a 3 story building near the launch site, and was used as the designated LZ for practice mission 5, as well as test-phase missions 1, 2, and 5. In another example of assessing situational awareness, operators were asked to recall the orientation of the H immediately after landing (at the conclusion of mission 1).
Mission 4 was unique in that participants also completed a post-mission exercise where they were asked to recall the type and location of entities they observed during flight. A scale map of the terrain database was used for this purpose, and participants used a single-letter coding scheme to designate the particular entity type they saw. Location was determined by marking the corresponding letter directly on the scale map. An additional point could be earned if the operator could also correctly recall an entity’s orientation. Operators were advised they would be asked to recall this information before beginning the mission, and were allowed to refer to a handout that showed pictures of all entity types with their associated code. At the conclusion of the study, everyone completed the comprehensive usability survey found in Appendix C, which contained 32 items formatted using a 10-point Likert scale.

The MAV simulation was programmed to collect and record a majority of the desired data automatically for every mission. This included measures of time to complete, collisions, and photographs taken. All events were time-stamped and recorded in a log file. Rules and procedures were developed to maintain consistency of measurement of certain factor. The experimenter hand-recorded data for each mission to ensure accuracy of the log files. For example, time to complete was observed, recorded manually, and then checked against the log file. The experimenter would mark an observed time such as 3 minutes and 25 seconds, and then review the log file which contained an exact time like 203.64 seconds. No major discrepancies were detected for this measure.
Collisions were a little more difficult to quantify, because there were times a participant would get caught on an obstacle (such as a tree branch) and the log file would show a series of low-impact collisions only milliseconds apart. Because the experimenter also recorded collisions observed, it was possible to eliminate extraneous collisions from the log file and ascertain the proper total. As a rule, any recorded collision that occurred less than one second from the previous recorded impact, and with an impact magnitude < .9, would be discarded.
RESULTS

Pre-screening of Data

Before performing any formal analysis, data were screened for issues that could impact the robustness of the results. Tests were run for normality looking at outliers, skewness, and kurtosis. Outliers were treated uniformly. After verifying the data were correctly entered, each outlier score was transformed to 1-unit outside of the most extreme score (either positive or negative) that fell within +/-2 Sd of the mean (Tabachnick & Fidell, 1996). For the spatial tests, this unit was based on number correct. For timed flight performance measures, the unit was 1 second. In the case of multiple outliers, the adjusted scores were in increments corresponding to the level of the raw score, beginning with the score closest to the mean. There were very few outliers among the spatial test scores. Spatial scores were then converted to standard scores.

There were 2 instances of missing data: 1 male and 1 female participant incorrectly completed a single spatial test. These data were replaced by using the mean test score grouped by gender. Gender was selected for grouping to reduce the impact of the decrease in overall variance inherent when substituting mean scores for incomplete data. Finally, A composite (standard) score was formulated for video gaming experience by adding and averaging the standard scores of each participant's self-rated video game skill with the number of hours played per day and the number of days played the previous week.
Performance Measures: Time to Complete

Manual flight skills were the main requirement for the oval and slalom courses, which were completed to criterion during practice and then twice more each during the test phase of the experiment. We observed significant overall improvement in time to complete these missions over the 3 repeated trials, $F(2, 128) = 59.55, p = .000$. Figure 7 illustrates the reduction in mean times across missions.

![Graph showing mean time to complete manual control missions over repeated trials](image)

**Figure 7. Mean Time to Complete Manual Control Missions over Repeated Trials**

These results indicate learning occurred with fairly consistent improvement over trials, and the final attempts yielded the fastest times.
Furthermore, we observed main effects of Course. Mean time to complete the Oval Course was 196.42 seconds, compared to 222.36 seconds to complete the Slalom Course, $F(1, 64) = 170.16, p = .000$. There was also a Course by Trial interaction, $F(2, 128) = 9.8720, p = .0001$. Figure 8 illustrates the interaction between Course and Repeated Trials. Although it was technically possible to complete both courses in less than 180 seconds, instances were rare for the Slalom Course due to the extra turns (including a 180-degree U-turn) required when navigating the obstacles.

![Figure 8. Repeated Trials by Course](image)
Analysis also yielded a main effect of Input Device, where operators using the Game Controller completed the manual control missions significantly faster, 202.45 seconds, than those using the mouse, 216.33 seconds, $F(1, 64) = 18.48, p = .00006$. In addition, we found an interaction of Input Device by Control Interface (the continuous vs. discrete control method), $F(1, 64) = 4.6085, p = .0356$. t-tests revealed that the mouse with the discrete control interface differed (longer times to complete) from both the mouse with the continuous interface, $p = .0196$, and the game controller with the discrete control interface, $p = .0001$. Figure 9 illustrates this.

![Figure 9. Input Device by Game Controller Interaction](image-url)
Interpreting this interaction suggests the mouse with discrete control was the least optimal setup for completing the manual control missions. There was no main effect of Control Interface on time to complete for the 2 control interface configurations.

Two other multi-way interactions were noted in the analysis of manual control missions: Trial x Camera Views x Control Interface, $F(2, 128) = 3.3716, p = .0374$, and Trial x Course x Input Device x Control Interface, $F(2, 128) = 3.9981, p = .0206$. Very little could be discerned from these interactions.

Mission 2 was timed. This was 1 of the 2 missions that were not repeated during the experiment. These 2 missions were analyzed separately from the manual control missions (Course), and were categorized as tactical missions. Neither tactical mission was practiced during training. Mission 2 required operators to thoroughly examine the contents of a building (from the outside) in order to successfully complete the task. Operators were instructed in a pre-mission briefing to locate the building (a church), and observe it from all sides in order to determine how many occupants were inside. Only 48 of the 72 total participants (66%) successfully completed mission 2; that is, they correctly identified all 4 occupants (2 friendly soldiers and 2 enemy infantry). Most of those who did not succeed did not follow the instructions from the pre-mission briefing, and only observed the building from the front. Thus, they did not identify the soldier in the back of the church and, as a result, had shorter flight times than those who correctly circled the entire building. Because of this, only flight times for the 48 successful pilots were analyzed for time to complete.
We found 2 main effects for time to complete mission 2. The first was an effect of Input Device. Mean time to complete was faster with the Game Controller, 279.79 seconds, than with the Mouse, 345.63 seconds, $F(1, 40) = 10.89, p = .002$. There was also an effect of Camera Views. Mean time to complete was faster with 1 camera view than with 2 views displayed simultaneously; 287.53 seconds vs. 337.90 seconds, respectively, $F(1, 40) = 6.3780, p = .0156$.

Performance Measures: Targets Detected

Mission 4 was the 2nd tactical mission, and required operators to employ a variety of control techniques to achieve success. Twelve entities were imported into the terrain database. Operators had 7 minutes to locate and photograph as many of these targets as possible. A full point was issued for taking pictures of an entity with both the forward and down cameras ($\frac{1}{2}$ point each). During the pre-mission briefing, participants were not told how many targets were available, or the exact time limit. This was done to reduce the desire to rush towards the end of the mission, which may have induced careless mistakes. Participants completed the Mission 4 post-test during the debriefing session. There was a main effect of Input Device for targets detected. Again, operators with the Game Controller outperformed those using the mouse. Mean targets detected were 8.97 (game controller) vs. 6.96 (mouse), $F(1, 64) = 21.07, p = .00002$. Two operators detected all 12 targets – both with the game controller. One operator in the mouse condition detected 11 targets. There were no main effects with the post-test.
Performance Measures: Collisions

Additional analysis was run on the measure of number of collisions. We failed to observe any effects of Input Device, Control Interface, or number of Camera Views. Number of collisions also did not correlate inversely with time to complete. This suggests that speed-accuracy tradeoffs were not evident in the current study. Although collisions were a seemingly valid measure, these data were severely positively skewed due to a floor effect, and did not provide a very reliable performance measure overall.

Workload

Workload was measured at the conclusion of training using the NASA TLX, and measured again after every mission in the test phase. There was a main effect of Mission, $F(5, 320) = 28.540, \ p = .000$. A Tukey post-hoc analysis showed that Mission 4 differed from all other missions. Missions 2 and 3 did not differ from each other, but did differ from Missions 1, 5, and 6. Missions 3 and 6 (the repeated Slalom course) differed, suggesting workload decreased as operator experience with the task increased. Figure 10 plots the mean workload scores across the 6 test-phase missions.
Figure 10. Mean NASA TLX Workload Scores by Mission

Figure 11. Workload Scores over Repeated Missions
Looking at workload over the repeated trials, we observed a main effect of repetition. Figure 11 displays the differences in workload across repeated trials. Mean workload scores were 36.51 for missions 1 (Oval) and 3 (Slalom), compared to 32.25 for missions 5 (Oval) and 6 (Slalom), $F(1, 64) = 9.8690, p = .0025$. Because time to complete decreased across repeated trails as well, it suggests workload may have decreased as performance improved. To check this relationship, average workload scores for Missions 1 and 3 were computed, as well as for Missions 5 and 6. Then we computed average time to complete scores for the same pairs of missions and checked for significant correlations. All factors correlated, including within subjects scores across missions, so we cannot assume performance was the only factor relating to the decrease in workload scores.

There was also a main effect of course, with operators reporting higher workload scores for the Slalom Course, 35.87, than the Oval Course, 32.89, $F(1, 64) = 5.4624$, $p=.0226$.

Usability Ratings and Demographics

Participants completed a 32-item usability survey at the conclusion of the experiment. 31 items were rated using a 10-point Likert scale. Item 32 asked about previous remote control vehicle (RC) experience. Lower usability ratings were favorable, and higher ratings indicated difficulty or dissatisfaction with a component of the system. A factorial analysis was computed using the averages from all 31 responses. This
showed a significant main effect of Input Device, with mean ratings of 2.32 for the Game Controller and 2.79 for the Mouse condition, $F(1, 64) = 6.1553, p = .0157$.

Significant interactions revealed certain items on the survey were rated more favorably for certain conditions, so a separate ANOVA was run for each individual survey item. There were main effects on Input Device for 11 items. Ten of these were rated more favorably for the Game Controller condition. Among these was the first item, which rated the system as a whole. Also included were ease of use, and maintaining awareness of individual mission objectives. In addition, game controller users rated 2 different aspects of feedback provided by the system more favorably, as well as 2 items pertaining to their expectations of how the MAV would react to operator inputs. They also rated the system more favorably for taking both novice and experienced user needs into account, found the camera easier to center over targets, and mistakes easier to correct. There was only one item where game controller users rated the system less favorably (or more favorably for the mouse) – whether the system speed was fast enough. This implies game controller users were prepared to move faster.

There were 4 items that users in the dual-camera view configuration rated more favorably than the single view, alternating camera setup. These included: organization of information on screen, learning how to operate the system, and being able to perform tasks in a straight-forward manner. The last item was also the system speed, which was rated as being fast enough. There were no instances where 1 camera was more favorably rated. We also did not find any significant preferences based on the type of control interface (continuous vs. discrete).
Video Gaming Experience

In addition to the planned IV’s, we correlated video gaming experience with performance, workload, and usability ratings. A composite score for video gaming experience (VGE) was formed from responses to 3 items in the demographic survey that each participant completed during session 1 of the study. These included self-rated video game skill, hours played per day, and number of days played in the previous week. Standard scores were created and then combined and averaged to form the score for VGE. The rationale for combining these 3 factors into 1 score was the high correlation between them. By combining scores that share a large amount of variance (typically 50% or more) we strengthen the overall reliability of the measure. Table 4 lists the original r-scores for the 3 video game factors that make up the VGE score.

Table 4

<table>
<thead>
<tr>
<th></th>
<th>VG Skill</th>
<th>Days play per week</th>
<th>Hours per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>VG Skill</td>
<td>1.00</td>
<td>.665*</td>
<td>.737*</td>
</tr>
<tr>
<td>Days played</td>
<td>1.00</td>
<td></td>
<td>.887*</td>
</tr>
<tr>
<td>Hours per day</td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

* All significant at alpha < .05
Using the composite measure, the largest effect was between VGE and gender, \( r = .75 \). There was a medium sized effect, \( r = .55 \), between VGE and experience with RC vehicles. Beyond this, there were significant correlations with 3 of the usability survey items, and with 7 of the 8 recorded workload measures. Higher VGE was associated with more favorable usability ratings on 2 of 3 items, as well as being associated with lower workload scores in every instance. VGE was favorably associated with system ease of use, and with participant confidence in being ready to operate a real air vehicle after finishing the training. The only negative correlation with usability occurred on item 10 – adequacy of status messages when taking off, landing, and grounded.

We ran VGE regressions and correlations with the primary dependent measures in this study. VGE was a significant predictor of Targets Detected (photographed) in Mission 4, \( R = .371 \) (adjusted \( R^2 = .125 \), \( p = .001 \)); and of scores on the Mission 4 post-test, \( R = .381 \) (adjusted \( R^2 = .133 \), \( p = .001 \). We also observed significant correlations with targets detected and the Mission 4 post-test scores; \( r = .44 \) and \( r = .38 \), respectively. VGE was inversely correlated with total collisions, \( r = -.29 \). The regression with VGE and collisions returned a \( p \)-value of .08. We did not find an association between VGE and the total time to complete the repeated Oval and Slalom courses.

**Spatial Ability**

To examine the predictive value of the 4 spatial tests, linear regressions were run with the main dependent variables. None of the tests were significant predictors of time
to complete the manual control missions; however, 3 of the tests were predictors of the number of targets identified (photographed) during Mission 4. These were the Cube Comparison test, $R = .260$ \((adjusted \, R^2 = .054), p = .027;\) the Hidden Figures test, $R = .266$ \((adjusted \, R^2 = .058), p = .024;\) and the Hidden Patterns test, $R = .41$ \((adjusted \, R^2 = .157), p = .000.\) Additional analysis was run with split samples in an attempt to cross-validate these results. Two groups \((N = 36)\) were formed by Input Device, and when the regressions were repeated the Hidden Patterns test remained a significant predictor of targets detected in both groups at alpha < .05. The Cube test was predictive for both groups at alpha < .10. The Hidden Figures test did not hold up to cross-validation for targets detected. In the main sample \((N = 72)\), the Hidden Patterns test was also a predictor of fewer collisions, $R = .299$ \((adjusted \, r^2 = .077), p = .011.\) However, cross-validation with this factor yielded an $R = .41$ \((p = .014)\) in group Game Controller, but an $R = .21$ \((p = .226)\) in the Mouse group. So another split-sample regression was run with participants 1-36 and 37-72 as the 2 groups. This analysis reported slightly better \(p\)-values, but did not reach significance at alpha < .05 or .10 for both groups.

In addition to the regression analysis, all 4 tests of spatial ability were correlated with the main performance measures, as well as other factors in the analysis like VGE and demographics. Table 5 summarizes these findings. The Cube Comparison test and Hidden Figures test were significantly associated with targets detected, \(r = .26\) and \(r = .30,\) as was the Hidden Patterns test, \(r = .45.\) The Hidden Patterns test and total collisions were also associated, \(r = .33.\) Only the Hidden Figures test correlated with the Mission 4 post-test, \(r = .25.\) We observed gender effects with spatial ability, but notably
gender did not correlate with the Cube Comparison test. For the other tests the effects were relatively small; Hidden Figures test, $r = .27$, Hidden Patterns test, $r = .24$, and the Gugerty test, $r = .29$. Spatial ability correlated with age on 2 of the tests, where older participants scored better on the Hidden Figures, $r = .29$, and Gugerty tests, $r = .32$.

Table 5
Spatial Test Correlations

<table>
<thead>
<tr>
<th>Test Type</th>
<th>VGE</th>
<th>Age</th>
<th>Gender</th>
<th>Time to Complete</th>
<th>Targets ID</th>
<th>Collisions</th>
<th>M4 post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube Test</td>
<td>-.076</td>
<td>.088</td>
<td>.103</td>
<td>.067</td>
<td>.261*</td>
<td>-.158</td>
<td>.208</td>
</tr>
<tr>
<td>Hidden Figures</td>
<td>.150</td>
<td>.289</td>
<td>-.268*</td>
<td>-.159</td>
<td>.303*</td>
<td>-.108</td>
<td>.255*</td>
</tr>
<tr>
<td>Hidden Patterns</td>
<td>.198</td>
<td>.187</td>
<td>-.242*</td>
<td>-.152</td>
<td>.451*</td>
<td>-.325*</td>
<td>.222</td>
</tr>
<tr>
<td>Adapted Gugerty</td>
<td>.201</td>
<td>.316</td>
<td>-.296*</td>
<td>-.114</td>
<td>.153</td>
<td>-.121</td>
<td>.171</td>
</tr>
</tbody>
</table>

* = significant to $p < .05$
DISCUSSION

Input Device

The most robust findings involved operator performance when using the game controller over the mouse. We observed several significant main effects with this device, including time to complete (efficiency) and targets detected (search). One reason for the apparent superiority of the game controller might have been that it allowed more focused attention on the sensor imagery compared to the mouse. Once operators learned how to use the game controller, they rarely needed to shift their attention off the sensor image. In contrast, mouse users had to look at where they were “clicking” on the control interface – so they had to constantly shift their attention away from the camera imagery. Another advantage of the game controller in this study is that it allowed users to manipulate all 6 degrees of freedom in parallel. With the mouse, all user inputs had to be completed in series. Although 1 of the 2 available control interfaces provided operators with continuous speed and directional control, regardless of input device, it still required sequential inputs from the mouse. In this regard, the game controller is more efficient, provided users have the resource capacity to execute these kinds of flight maneuvers simultaneously. It appears from both our results and observation that human operators have little trouble with this kind of parallel processing. However, there are other circumstances that may have been working together to achieve the results we observed. So we examined additional factors to get a better understanding of our findings.
Video Gaming and Controller Experience

The first issue we examined was how much previous experience our participants have had playing video games, particularly with the type of dual-thumbstick game controller used in this study. Participants were primarily college students in their late teens or early 20’s. We collected demographic data from all participants, and they were asked to report the types of gaming consoles they have owned or used recently, as well as their video gaming habits. Many of our participants had several hours of experience with a similar game controller, so they had essentially trained themselves on its operation. Popular games like HALO and flight simulators require operators to have good working command of the controller to accomplish anything substantial within the scope of the game. Compared to the speed and cognitive demands of these games and simulations, MAV operation (at a maximum speed of 6 knots) might have appeared almost mundane.

We found that video gaming experience (VGE) significantly correlated with certain performance measures, like targets detected and collisions, but it did not correlate with time to complete. At this stage, we needed to be sure that the significant performance differences observed with the game controller were not solely the result of prior experience with the device. Approximately 70% of all participants had previously used a similar game controller, but this measure did not take into account how much time each participant had spent using one. So we ran a series of correlations and ANOVAs to examine the relationships between prior experience with the device and other measures like VGE and the primary dependent variables. Experience with the
game controller correlated with VGE, and other results mimicked those found when using the VGE measure. There was only 1 factor where we didn’t observe an effect of VGE that existed with game controller experience, and that was the number of collisions ($r = .30$). ANOVA revealed a main effect of experience with the controller, but no interactions. It is very interesting to note that an examination of the means showed the ratio of collisions for participants with previous game controller experience was similar to those who had never used the device across conditions. Participants in the Mouse condition with no prior game controller experience had approximately 1.57 collisions for every 1 collision by an operator who had used a game controller before. For participants in the Game Controller condition, the ratio was 1.68 : 1. So this suggests some transfer to other input devices is possible. Based on what we see here, it appears the effects we observed with the game controller were not conditional on having previous experience with the device.

After examining the other factors in the demographic data as we did with game controller experience, we can feel reasonably comfortable that the composite VGE metric is the most reliable choice for our analysis. It seemed logical then to look at VGE as a covariate of the primary IV’s. For total time to complete the repeated Oval and Slalom courses, VGE was a significant covariate, but we found the same main effect of input device and no significant interactions. It was the same story for targets detected. As with the original analysis, there were no main effects with collisions. So while VGE was predictive (per the regression analysis) of some DV’s it is clearly not the only reason operators performed better in general with the game controller.
Selection of the Mouse as an Input Device

Operator control units we have previously examined used a touch-screen and stylus as the primary input method, which requires a shift of attention to the control interface for entering commands to the OCU. This was an issue of concern in this study as well when using the mouse. In prior MAV studies, we found that uncertainty about whether a touch input actually registered was a consistent source of frustration and confusion to users (Durlach, Neumann, and Bowens, 2006). Consequently, we used the mouse rather than a touch screen in this experiment to avoid this issue. Based on the Card, English and Burr (1978) study, we knew that the mouse would be fairly equivalent to a touch screen in terms of cognitive demands and efficiency, given most people’s familiarity with the device. Basically, we wanted to keep the system as close cognitively to the systems currently being tested by the military. By using the mouse instead of the stylus, we eliminated one detracting factor (missed inputs) without introducing any major changes to the way operators would normally interact with the OCU.

Workload and Performance

Knowing the stylus was convention for MAV operators, our main concern with introducing an alternate input device like the game controller would be that it would increase cognitive demand and operator workload. Operators would need to learn finger-button mappings and how to simultaneously operate the 2 thumb-sticks. We could expect that experienced video gamers would adapt to the controller, but there
would also be participants who had never used the device. The question would then become if the device was easily trainable or not. However, in this study we did not pick up any differences in workload ratings between the mouse and game controller conditions. We observed that workload decreased over repeated trials as experience on task increased, which confirms the findings of Warm et al (1991).

We also did not observe any significant differences in collisions. In addition, during mission 4 (the target ID and reconnaissance scenario), participants located and photographed significantly more targets in 7 minutes with the game controller. This figure worked out to over 33% more targets, which is substantial considering current MAV systems operate with relatively short flight times. Because of this, it is critical to get the most out of the vehicle during its limited time in the air. Mission 4 also solicited the highest workload ratings of all missions. It was programmed to be the culminating mission, where operators would need to employ all the skills they had learned throughout training. Even with the increased cognitive demands of the mission, performance with the game controller significantly exceeded that with the mouse. This suggests operators had the attentional capacity and resources to manage the operation. That brings up a point about the attentional capacity of video game players. In a highly publicized study, Green and Bavelier (2003) conducted a series of experiments that concluded action video game players exhibited increased attentional capacity. We observed a significant main effect of VGE on targets detected in mission 4 (in addition to Input Device), so it is plausible to suggest their findings have merit, but there is nothing to confirm that our results were due solely to VGE, or that attentional capacity
was a contributing factor. In addition, there is no evidence that any attempts to replicate the Green and Bavelier study have been fruitful. There is clearly a relationship between VGE and performance in our research, but more experiments would need to be run to investigate specific factors that could be contributing to the observed differences.

Spatial Ability and Performance

Another major focus of this research was on operator spatial ability. Higher spatial ability scores were associated with lower workload ratings. Thus, people with higher spatial ability felt less taxed. Some of the tests of spatial ability proved to be a significant predictor of measures like fewer collisions (Hidden Patterns test) and number of targets detected (Hidden Patterns, Hidden Figures, and Cube Comparison tests). In addition, the ability of operators to correctly recall the location and orientation of the targets on the Mission 4 post-test was predicted by the Hidden Figures test. Cross-validation attempts weakened the regression analysis, but the Hidden Patterns test in particular was robust as a predictor of performance on the tactical missions, 2 and 4. For targets detected during Mission 4, this test held up to cross-validation at alpha < .05. In addition (although not reported in the results), the Hidden Patterns test was predictive of flight time on Mission 2 at alpha = .07, just missing the .05 cutoff. This is interesting because the missions where spatial ability acted as a predictor of performance were the same missions that presented tactical scenarios to the operator. These missions did not follow the more rigid structure of the Slalom and Oval course.
missions, where operators had much less freedom to improvise from the assigned flight path and mission requirements. With the church mission and the target ID mission, participants could take virtually any flight path and adopt a variety of strategies for completing the tasks.

Although not the focus of this study, we did observe gender differences on 3 of the 4 spatial tests. This was not unexpected, but it was surprising to find the Cube Comparison test was the 1 test that did not produce a gender effect. The Linn and Petersen (1985) study discussed 3 aspects of spatial ability, and mental rotation was the area where the largest gender differences were observed. This was not the case in our research. It is a bit of a stretch to assume at this point that the gender gap is closing 20 years later, but with the increase in female video game players cited previously it would not be surprising to see this happen in the near future. It is also important to note that our participant pool was made up primarily of college students, who may not be representative of the general population. Even so, it is reasonable to think that if training with spatially demanding exercises can improve performance on computer skill-acquisition tasks, then as more females are assimilated into the mainstream computer and gaming culture their spatial abilities may improve.

Camera View Configuration and Control Interface

There were very few effects of either the number of camera views or the type of control interface. There was 1 instance worth noting, however, and this is the main
effect of camera views observed during mission 2. This was the mission where operators had to fly to a church on the North end of the database and locate enemy soldiers and friendly hostages that were inside the building. After excluding those who did not complete the mission successfully, the single camera view condition performed better on time to complete. This means they identified all occupants and returned to the landing area faster than those using 2 camera views. Recall that in the single view condition the resolution of each image was twice that of the dual-camera configuration. Because search was the primary task, this suggests that the increased resolution may have made the job easier. Operators were required to peer through windows and doors to see who was inside, and it is possible the increased magnitude of the targets (who were often obstructed) made identification easier. Also, because this mission required the MAV to be flown only a few feet off the ground – the church was a 1 story building – there was little or no need to ever switch to the downward camera view. Doing so would have offered no new information to the operator. Not having to switch camera views to execute a mission saves time and conserves attentional resources. However, this mission was unique, and there were no other cases where significant differences of camera views surfaced. It is possible that other factors that were not present in this study diminished the role of the video imagery. Most notably is the issue of latency. Real-world operators must cope with delays from input to execution inherent to the system. In addition, wind and other environmental factors could influence flight dynamics and affect operator perception of flight path, as well as their perception of speed and distance. This could lead to more reliance on the video feed.
Usability Ratings

Usability ratings were affected both by the input device and by the number of camera views. More positive usability ratings came from users of the game controller (10 items) than the mouse, with one notable exception. Those using the game controller rated the system as not being fast enough. That is, they were generally prepared to go faster. There were also some observed preferences of having 2 camera views, despite no observed significant main effects on performance. Operators reported more favorable system usability scores on 4 items in the dual-camera display condition, compared to none with the single view. No effects of control interface were found regarding usability in either condition.

When combined with the performance results, the overwhelming user preference with the game controller suggests that this input device is well adapted for MAV operation. There is the possibility that a novelty factor contributed to the more favorable usability ratings, but 2/3 of our participants had used the device before making this a weak argument for explaining the differences in ratings on 10 of 31 items. Considering the success this controller has realized in the commercial sector, it stands to reason that this is due to an exceptional balance of functionality, control, and trainability.
Future Work

It would certainly be interesting to apply some of the findings in this report to a live setting to determine if there is any transfer to real-world MAV operation. It would not be difficult to incorporate the game controller as an input device for the systems currently being tested and examine operator performance. With the overwhelming improvement in both flight (time) efficiency and target detection using the device, it seems logical to test it with a physical system.

We also observed significant improvement in completion time across the repeated missions (the Oval and Slalom courses), regardless of condition. This indicates either that flight skill was continuing to improve or that participants were learning to use cues in the synthetic environment to guide their flight control inputs. Hence, operators could have merely been adopting a particular navigation strategy to improve their course run times. A more complex experiment using a novel environment for a transfer test would be required to choose between these possibilities. That way flight skill could be assessed in the absence of learned cues.

There was a large amount of data collected during this experiment, covering many areas of human performance and cognition. Several areas could be studied more closely or on an individual basis. One obvious thread to follow would be examining the apparent gender effects. There have been many studies that have attempted to address this issue in general, so any future work done in this area could be focused on teleoperation and/or human-machine control interfaces to add relevance to the current
project. In addition to spatial ability, there was a strong relationship between gender and VGE in our research. This topic deserves more attention. In particular, the De Lisi and Cammarano (1996) study showed that females improved on the VTMR with practice on a spatially demanding video game. It was somewhat unexpected to find that video game experience did not significantly correlate with any of the spatial tests administered in our experiment. We administered several tests of spatial ability prior to MAV training, but did not give spatial post-tests. It would be interesting to see if there is improvement on the spatial tests after completing the 2-hour MAV operator training or after a follow up session where participants flew a series of tactical missions. Many of the spatial tests we used were predictive of performance on these types of missions (number 2 and 4), so it is possible that experience in this domain could, in turn, train people to improve their own spatial abilities through practice. Instead of just looking at mental rotation, we could also test other spatial factors like field independence. This played the most significant role in our research based on the regression analysis with the Hidden Patterns test. It is likely that a pre-test post-test design is not possible with the same paper-based tests used in this study, because the individual items don’t change in either content or the order in which they are presented. However, reliable randomized tests could be used or developed for this purpose. The relationship between video gaming experience and spatial ability has important implications for training – especially in simulation – so it warrants further investigation. The OCU developed for our research makes a good testbed to use for future experiments. The control interface is similar to a computer-based flight simulator, and functions much like a video game without the
extraneous graphics or scoring components. It is also a flexible program, allowing for almost total manipulation of display. In addition, camera views can be added or subtracted, zoomed, and panned. There are also other available functions designed for identification and tracking that could be activated and used in future studies.
Introduction to the Micro-Unmanned Aerial Vehicle Study

The US Army is undergoing a major transformation. One element of the transformation is the introduction of a new class of military platforms known as unmanned air and ground vehicles (called UAV’s and UGV’s). A major benefit of these unmanned vehicles is that they can perform reconnaissance missions and survey areas contaminated with radiological, chemical or biological agents without risk to human life. They can also survey the battlefield and provide real-time video feedback.

We are investigating the design of operator control systems for micro-unmanned aerial vehicles that can perform these kinds of reconnaissance missions. In addition, we are investigating operator training requirements. In this experiment you will be trained on how to fly a simulated micro-UAV (MAV) and then you will complete a set of missions that will test your ability to maneuver the MAV and locate various targets. After each mission you will be given a short questionnaire that asks you to rate certain aspects of the task you performed.

It takes approximately 90 - 120 minutes to complete the experiment. No previous flight experience is necessary to participate in this study.

Confidentiality

Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in an electronic file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

If you are prepared to participate in this experiment, please read and sign the Consent Form and Voluntary Agreement. Please also indicate on that form your preferred method of compensation. We offer cash payment or course credit. Also, please feel free to ask the experimenter any questions. Keep in mind that you do have the right to withdraw from this experiment at any time, for whatever reason.

When you have finished reading and signed the voluntary consent form, begin by reading the following section titled ‘Overall Description of the MAV Simulation’ on the following page. You are not required to memorize all the information contained here, but if you have any questions on the material please feel free to ask the experimenter for clarification.
Overall Description of the MAV Simulation

You will be working with a simulation for flying a micro unmanned aerial vehicle. The micro-UAV itself will be referred to from now on as “the MAV”. This is not a fixed-wing aircraft like most airplanes are; rather it is a small rotary craft with an internal fan and duct design (see prototype photos below). An operator controls the MAV using a laptop computer equipped with an input device such as a mouse or joystick controller. This interface is referred to as the OCU – Operator Control Unit. This is a dismounted control unit, as it is envisioned that a dismounted soldier (on foot, rather than in a vehicle) will be controlling the MAV.

MAV prototypes from Honeywell and Allied Aerospace

Introduction to the OCU and MAV Camera System

The MAV is equipped with a dual camera system. When the vehicle flies through the simulated environment you will be able to view video images sent back to the OCU. You will be instructed on how to operate the cameras as well as how to use the OCU interface and controllers to pilot the MAV. You will also have an opportunity to practice some manual flight/piloting techniques before beginning the actual experiment. After basic instruction, a training session will take place; then you will move on to the assigned pilot mission tasks where performance data will be recorded. Be sure that you understand the objective of each mission before starting a trial. The experimenter is available to answer your questions before you begin each task, so please ask for help if you are unsure of any requirements. Unless instructed otherwise, it is important that you complete each task as quickly and efficiently as possible.

At the end of the training session and at the end of each mission you will complete a short computer-based questionnaire. In the first section you will rate different aspects of the task you performed; then you will be asked to choose between a pair of items that
Training Session

The goal of training is to familiarize you with the flight characteristics of the MAV, and to give you an opportunity to practice piloting the MAV in manual mode. We will begin by reviewing the features of the OCU and then proceed to a series of practice exercises. The experimenter will facilitate this training session and provide instruction on how to complete the assigned tasks.

OCU Layout and on-screen controls

Below you will see a sample layout of the OCU. On the left side of the screen is the video sensor imagery (camera views), and in the upper-right you will find an overhead map view of the terrain database. Just below the map view there is a control pad that is used for issuing flight commands to the MAV. The control pad will be examined in greater detail throughout training. There is an altimeter along the left border area of the OCU display, as well as a task bar along the top that contains various icons. You will be instructed on how to use all of the relevant gauges and icons during training.
The experimenter will handle tasks such as loading mission files and scenarios, so you only need to focus on learning how to operate the MAV itself. Before beginning the flight training exercises, we will learn about the function of the OCU in more detail.

**Understanding the Task Bar Icons**

The upper task bar (below) includes the take-off (and landing), mission mode, and camera control buttons. There is also a mission timer located on the far right of this task bar. For this study, you will need to know how to use the take-off icon and the camera control icons.

![Task Bar Icons](image.png)

**Take-off & Landing icon**

You can take off and land by activating the task bar icon for take-off and landing. This is done by pressing button (10) on the joystick controller. Once the take off button is pressed the MAV will automatically climb to an altitude of approximately 60 feet above the ground level. At this time you may pick up the joystick and execute the take-off command. You will see the red stop sign icon illuminate when you have reached take-off altitude. Pressing button 10 on the joystick will now execute the land command. You may land the MAV now.

**Activating Camera Views and taking Snapshot photos**

These camera buttons allow the operator to switch between the available camera images. This study uses a 2 camera setup. On the OCU, camera image #1 is the view from the MAV’s forward camera and camera image #2 displays the view from the downward camera.

One of the unique features of the OCU is the ability to take snapshots with either camera. Before taking a snapshot, you will need to activate the camera that you want to take the picture. The active camera image will always have a blue border on the top of the view frame, as well as a ( ) overlay in the center of the image. The corresponding icon on the task bar will also illuminate. To change the active camera view you must use the joystick to activate the group of icons on the task bar and select the camera you want.
To activate a camera view: This is done by pressing and holding joystick button #2 while you scroll through the available camera views with the directional pad. The experimenter will demonstrate this feature now.

If not already airborne, try taking off and switching the camera view. Snapshots of targets can now be taken using the (9) button on the game controller/joystick.

**Main Window Components:**

**Altimeter** (See vertical bar on the left side of this page)

The ruler-like markings on the altimeter display the altitude of the MAV in feet above sea level. Red tabs may be visible on the upper or lower regions of the display if the experimenter has chosen to activate the altitude alarm system. The red areas simply mark the altitudes that will activate the alarm if the MAV passes into this “red zone”.

< The white triangle cut-out (left) points to the current altitude of the MAV. In this case, the MAV is approximately 82 feet above sea level.

The light brown column at the lower end of the bar marks the altitude of the nearest surface below the OAV (this is the current ground level).

**Note!~** In the current example, the MAV is approximately 82 feet above sea level, but the ground level is approximately 22 feet. This means the MAV is only 60 feet above ground!

**Manual Input Control Pad** (Discrete Mode):

This manual input control pad lets you control the position of the MAV manually. For this display, 9 buttons are used as the interface to the MAV. The four straight-arrow icons represent forwards, backwards, left, and right. The curved arrow icons in the
upper corners show rotation of the MAV left and right. The lower corner icons move the MAV up and down. The middle X icon stops the MAV. Your airspeed is also shown here in knots. Max speed is 6 knots. You will issue these commands to the MAV by using the joystick. Joystick training is next.

**Note on Input Controller Feedback**

Because you are using the joystick to control the MAV, the control display will activate when an input is received. The display provides feedback in this way to the operator that a command has been issued and is being executed. Arrow icons on the discrete control pad will illuminate when that command has been entered, i.e. when you push forward on the joystick, the forward arrow will illuminate. The brighter the icon gets, the faster you are traveling.

**Joystick / Game Controller**

The joystick/game controller is shown below, and by now you have at least performed some basic tasks with this device. We will now go over how to use the joystick for all of the tasks required during this experiment.

Controlling MAV movement with the Joystick:

The **left thumb stick** controls movement forward, backward, and sideways (or at angles), but the MAV heading never changes when the left thumb stick is used. Pushing up on this thumb stick moves the MAV forward. Pulling down on the stick moves the MAV backwards. Moving the stick from side to side moves the MAV right or left without altering heading.

The **right thumb stick** controls altitude and heading/rotation. Pushing up on the stick increases the MAV’s altitude, and pulling down decreases altitude. Moving the right thumb stick from side to side rotates the MAV in place.
It is possible (and expected) to use both sticks simultaneously to rotate, change altitude, and move at the same time. At this time, you may take-off and practice manipulating the thumb sticks for approximately 1 -2 minutes.

**Using the Joystick to activate icons from the task bar:**

The buttons on the right-hand side of the joystick (# 1 – 4) are used to highlight groups of icons on the task bar. Once a group of icons is highlighted, the directional pad of the left-hand side of the controller is used to select the individual icon you wish to activate.

**To select a camera view:** hold down button #2 on the controller. While holding the button, use your left thumb to press the directional pad to scroll through the different camera icons. When the camera view (marked I or II) is highlighted, release button #2 to activate the window. Note that the upper border of the active camera view window will also turn blue.

**Heading Tape**

Note that each camera view window has a heading tape located along the top edge of the frame. This number indicates the current heading (based on 360 degrees) of the vehicle with regard to that camera image. Because the cameras have been locked in place for this experiment, the participant can assume that the forward camera view heading is the same as the MAV heading. So if the heading tape reads “270” then you know the MAV is facing due west.
0-degrees is the same as due North on a regular compass. 90-degrees = East; 180-degrees = South; 270-degrees = West.

Important Note!! ~ The downward camera view is locked at 90 degrees from horizontal (this is essentially straight down). However, when the MAV is in motion the vehicle tilts in a similar manner to a moving helicopter. This tilting will cause the downward camera to point slightly backwards, thus giving the operator a heading reading that is opposite of the forward camera view. i.e. if the forward camera heading is 0-degrees, then the downward camera heading will read 180-degrees only while the MAV is in motion.

Practice Time: Now that you have learned all the functions of the OCU and the flight controls, we will complete a series of practice exercises beginning on the next page.
Practice Exercises

These exercises will give you a chance to practice the various tasks required to complete the missions in this study.

Warm up
Start this warm up session by executing a take-off and briefly practicing the following maneuvers. You will notice that inertia comes into play when trying to stop the MAV, so you will need to learn to estimate things like stopping distances and rotational velocity carry-over.

1) Move the right thumb stick up and down to make the MAV ascend and descend.
2) Move the right thumb stick side to side to rotate the MAV.
3) Move the left thumb stick up and down to make the MAV fly forward and backwards.
4) Move the left thumb stick side to side to move the MAV laterally. Note that the heading only changes when you rotate the MAV with the right thumb stick.
5) Activate camera 1 and then activate camera 2. Now switch back to camera 1 and take a snapshot.
6) Land the MAV.

Next you will complete a series of timed practice exercises. The experimenter will observe these exercises and determine if you have met the time requirement before allowing you to proceed to the next exercise. All mission and properties files needed for these exercises will be loaded by the experimenter.

Practice Exercise 1

1) Press OK (button 10) to start the simulation and timer.
2) Execute the Take-off command.
3) When the Red Stop icon illuminates, execute the Land command.
4) This exercise must be completed in 30 seconds (:30) or less.

Practice Exercise 2

1) Press OK to start the simulation and timer
2) Execute the Take-off command.
3) At or before the completion of take-off, activate the view window for Camera 1 (forward view).
4) Take a snapshot with camera 1.
5) Activate the view window for camera 2 (down view).
6) Take a snapshot with camera 2.
7) Execute the Land command.
8) This must be completed in 40 seconds (:40) or less.
Practice Exercise 3 (with alarm active)

1) The upper altitude alarm will be set at 150 feet and activated.
2) Press Ok to start the simulation and timer.
3) Execute the Take-off command.
4) Ascend to 150 feet and trigger the alarm.
5) Immediately descend to 50 feet or below without hitting the ground.
6) Ascend back up to 100 feet but less than 150 feet.
7) Rotate the MAV 360-degrees without dropping below 100 feet. It is required that the heading tape shows the number “0” after completing 1 rotation with the MAV. The “0” must remain in the forward camera view window before landing.
8) Execute the Land command.
9) This exercise must be completed in 1 minute 35 seconds (1:35) or less.

Practice Exercise 4: rapid command execution

For this exercise you will follow a series of oral commands issued by the experimenter. After take-off and as soon as the Red Stop icon illuminates, you will immediately begin to hear a series of flight commands. Commands will be given as fast as you can correctly comply. Once the correct feedback is observed from the OCU the experimenter will proceed to the next command.

Note: it is not important that the MAV travels any considerable distance. The purpose of this exercise is to allow you to learn the mapping of all buttons and icons and their corresponding functions. The experimenter is looking mainly for the correct feedback from the OCU control pad located in the lower right of the display.

Rapid command execution - Part A

1) Press OK to start the simulation and timer.
2) Execute Take-off.
3) The first series of commands after take-off will be: 9 commands.
4) This exercise must be completed in 1 minute 5 seconds (1:05) or less.

The experimenter will now reload the properties file and reset the timer.

Rapid command execution - Part B

5) Press OK to start the simulation and timer.
6) Execute take-off.
7) The second series of commands after take-off should be: 14 commands.
8) This exercise must be completed in 1 minute 25 seconds (1:25) or less.
The next 2 exercises involve flying the MAV over longer distances and following pre-determined mission parameters. These will be similar to the missions you will complete during the remainder of the experiment.

**Practice Exercise 5**

In this exercise you will pilot the MAV around the main roadway that forms an oval inside the terrain database. Waypoints will be visible in the overhead map view window. Waypoints are used to determine the correct flight path of the MAV. The experimenter will explain this to you in more detail while the MAV completes the mission autonomously.

1) The experimenter will load and run this mission autonomously and will point out the Landing Zone (LZ) on the (H) building.
2) After the autonomous mission finishes, the simulation will be reset.
3) You must now manually pilot the MAV around the gray pathway while remaining to the left of the 4 red poles and landing in the correct LZ.
4) When ready, press OK to start the timer.
5) Execute the Take-off command.
6) Complete one lap around the 4 red poles and stay over the gray path.
7) Land on the (H) building.
8) This exercise must be completed in 3 minutes 50 seconds (3:50) or less.

**Practice Exercise 6 – obstacle course**

In this exercise you have obstacles to navigate. You will also take 2 snapshots at the end of the run. Complete the mission by flying through the series of red and green poles and then return to your start point to take the snapshots.

1) The experimenter will load and run this mission autonomously with waypoints visible. Observe how the MAV passes to the right of all green poles and to the left of all red poles.
2) At the end of the run, you will see the C2 vehicle parked on the sidewalk. (This is you! You control the MAV from this position inside the vehicle.)
3) You must now complete the course manually with a few additional instructions: *After you finish navigating around the poles you will need to take snapshots of the C2V with both cameras.*
4) When ready, press OK and then execute Take-off.
5) Complete the obstacle course.
6) Take snapshot from camera 1
7) Take snapshot from camera 2.
8) Land – but do NOT land on the C2 vehicle!
9) This exercise must be completed in 5 minutes (5:00) or less.
You will now complete a short computer-based questionnaire. The experimenter will explain this and give you instructions at this time. Then you will begin a series of 6 missions.

**Mission Protocol for ARI/IST MAV Experiment 1**

There will be 6 missions for you to complete during this portion of the study. The experimenter will instruct you on mission requirements and provide any documentation necessary. If you are unsure of any of these requirements please ask for clarification. Once you begin a mission, the experimenter will have very limited interaction with you. He/she will not be able to answer questions on mission requirements once you execute the take-off command, so please ask beforehand.

**Mission 1**

This mission is a repeat of practice exercise #5 where you piloted the MAV around the gray pathway while remaining to the left of the 4 red poles.

1) You will manually pilot the MAV around the gray pathway while remaining to the left of the 4 red poles and landing on the (H) building.
2) When ready, press OK to start the timer.
3) Execute the Take-off command.
4) Complete one lap around the 4 red poles and stay over the gray path.
5) Land on the (H) building.

**Complete the computer-based questionnaire at this time and then proceed to Mission 2.**

**Mission 2**

This mission involves using the MAV to do reconnaissance work. You will get a handout titled “Mission 2 Intel & Recon”. Review this with the experimenter and then complete the required tasks. The experimenter may ask you for situational updates at different points during this mission.

1) Read the “Mission 2 Intel & Recon” handout.
2) When ready the experimenter will load the mission scenarios.
3) Press OK to start the mission timer.
4) Execute Take-off.
5) Locate the church.
6) Use the MAV to observe the church from all sides.
7) Determine who or what is occupying the church.
8) Pilot the MAV to the landing zone.
9) Complete the debriefing with the experimenter.
Mission 3

This mission repeats practice exercise #6 where you navigated a series of red and green poles. You will also take 2 snapshots of the C2 vehicle at the end of the run. Complete the mission by flying through the series of red and green poles and then return to your start point to take the snapshots of the C2V.

1) You must complete the obstacle course manually.
2) After you finish navigating around the poles you will need to take snapshots of the C2V with both cameras.
3) When ready, press OK and then execute Take-off.
4) Complete the obstacle course.
5) Take snapshot of the C2V with camera 1
6) Take snapshot of the C2V with camera 2.
7) Land – but do NOT land on the C2 vehicle!

Complete the computer questionnaire at this time and then proceed to Mission 4.

Mission 4

This mission involves using the MAV to do more reconnaissance work. You will get a handout titled “Mission 4 Intel & Recon”. Review this with the experimenter and then complete the required tasks. This is primarily a target identification mission. Once again, the experimenter may ask you for situational updates during this mission.

1) Review the “Mission 4 Intel & Recon” handout.
2) The experimenter will load the mission files and scenario.
3) You will have a limited time to identify as many targets as possible within the terrain database.
4) Positive ID can only be achieved by taking snapshots of each entity with both the forward and down cameras, and each entity must be centered in the frame so that the center ( ) overlay is touching part of the entity.
5) When ready, press OK to begin the mission and start the timer.
6) Immediately begin looking for entities to identify via the camera.
7) The experimenter will tell you to stop when time has expired.

Complete the computer-based questionnaire at this time.

Mission 5: Repeat mission 1 – This is your final attempt to make the best time possible. (Then complete the computer-based questionnaire.)

Mission 6: Repeat mission 3 – This is your final attempt to make the best time possible. When finished you may proceed to your final debriefing session.
APPENDIX B
IRB APPROVAL LETTER
January 15, 2004

Paula J. Durlach, Ph.D.
U.S. Army Research Institute
Simulator Systems Research Unit
ATTN: TAPC-ARI-IF [Durlach]
12350 Research Parkway
Orlando, FL 32826

Dear Dr. Durlach:

With reference to your protocol entitled, "Learning to Fly a Simulated Unmanned Micro Aerial Vehicle," I am enclosing for your records the approved, executed document of the UCIRB Form you had submitted to our office.

Please be advised that this approval is given for one year. Should there be any addendums or administrative changes to the already approved protocol, they must also be submitted to the Board. Specifically, you will need to submit any changes made after you receive the equipment required to conduct this research, since you were unable to give all of the details at this time. Changes should not be initiated until written IRB approval is received. Adverse events should be reported to the IRB as they occur. Further, should there be a need to extend this protocol, a renewal form must be submitted for approval at least one month prior to the anniversary date of the most recent approval and is the responsibility of the investigator (UCF).

Should you have any questions, please do not hesitate to call me at 823-2901.

Please accept our best wishes for the success of your endeavors.

Cordially,

Chris Grayson
Institutional Review Board (IRB)

Copies: Eduardo Salas
IRB File
MAV USABILITY QUESTIONNAIRE (IMROC-OCU EXP: 1 Joystick)

Circle the number that best describes your reaction between the 2 extremes given.

1) The system I worked with was
   
   wonderful
   
   1  2  3  4  5  6  7  8  9  10
terrible

2) The system I worked with was
easy
   
   1  2  3  4  5  6  7  8  9  10
difficult

3) I found this experience
   
satisfying
   
   1  2  3  4  5  6  7  8  9  10
frustrating

4) The system I worked with seemed
   
   Capable of doing the
   
   exercises
   
   1  2  3  4  5  6  7  8  9  10
Unable to do the
   
   exercises

5) I found this experience
   
   stimulating
   
   1  2  3  4  5  6  7  8  9  10
dull

6) The system I worked with was
   
   flexible
   
   1  2  3  4  5  6  7  8  9  10
rigid

7) The functions of the on-screen manual control buttons (on the control pad) were
   
   clear
   
   1  2  3  4  5  6  7  8  9  10
confusing

8) The functionality of the buttons for switching between camera views was
   
   clear
   
   1  2  3  4  5  6  7  8  9  10
confusing

9) Organization of information on the video display screen was
   
   clear
   
   1  2  3  4  5  6  7  8  9  10
confusing
10) Current status (such as Taking off, Landing, Grounded) messages were adequate

1  2  3  4  5  6  7  8  9  10

11) When controlling the MAV in flight using the joystick, the device was easy to use
difficult to use

1  2  3  4  5  6  7  8  9  10

12) As I progressed through the missions using the joystick, my hands and/or wrists became fatigued
Never Always

1  2  3  4  5  6  7  8  9  10

13) When using the joystick to enter flight commands to the MAV, maintaining awareness of individual mission objectives was easy difficult

1  2  3  4  5  6  7  8  9  10

14) When using the LEFT thumb stick (forward, back, left & right movements) to move the air vehicle while in manual control, the air vehicle reacted as I expected.
always never

1  2  3  4  5  6  7  8  9  10

15) Using the RIGHT thumb stick (up, down & rotation) to move the air vehicle while in manual control, the air vehicle reacted as I expected.
always never

1  2  3  4  5  6  7  8  9  10

16) When using the joystick to stop the motion of the air vehicle while in manual control, the air vehicle reacted as I expected.
always never

1  2  3  4  5  6  7  8  9  10

17) When using the joystick to switch between camera views (highlighting the camera icon located on the task bar), the display reacted as I expected.
always never

1  2  3  4  5  6  7  8  9  10

18) While using the camera to take snapshots of targets, centering the target so it was aligned with the ( ) overlay was easy difficult

1  2  3  4  5  6  7  8  9  10
19) When piloting the MAV in manual control, determining the current heading of the MAV from the 360-degree directional heading tape was clear 1 2 3 4 5 6 7 8 9 10 confusing

20) It was clear when the air vehicle had landed always 1 2 3 4 5 6 7 8 9 10 never

21) The system provided adequate feedback when I issued a command to the MAV always 1 2 3 4 5 6 7 8 9 10 never

22) The OCU interface keeps you informed about what it is happening always 1 2 3 4 5 6 7 8 9 10 never

23) Learning to operate the system was easy 1 2 3 4 5 6 7 8 9 10 difficult

24) Remembering names and use of commands was easy 1 2 3 4 5 6 7 8 9 10 difficult

25) Tasks could be performed in a straightforward manner always 1 2 3 4 5 6 7 8 9 10 never

26) Training materials were clear 1 2 3 4 5 6 7 8 9 10 confusing

27) After this training, I am ready use this system to fly a real air vehicle very confident 1 2 3 4 5 6 7 8 9 10 not at all confident

28) The system speed was fast enough 1 2 3 4 5 6 7 8 9 10 too slow
29) System reliability was
reliable    unreliable
1     2     3     4     5     6     7     8     9     10

30) Correcting your mistakes was
easy    difficult
1     2     3     4     5     6     7     8     9     10

31) Both experienced and inexperienced users’ needs were taken into consideration
always    never
1     2     3     4     5     6     7     8     9     10

32) Do you have any previous Remote Control R/C experience? YES / NO (circle one)

If you answered yes, please briefly describe:
______________________________________________________________________________
______________________________________________________________________________.
APPENDIX D

OCU INTERFACE TRAINING EVALUATION
To ensure that you have a basic grasp of the MAV pilot interface and the available flight commands, please complete the following exercise.

Each of the critical features of the user interface are labeled above with letters A – N. Every letter must be used, so choose the best answer. Enter the corresponding letter in the blank following each of the item descriptions below:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter</td>
<td></td>
</tr>
<tr>
<td>Mission Timer</td>
<td></td>
</tr>
<tr>
<td>Rotational Velocity Control</td>
<td></td>
</tr>
<tr>
<td>Heading Tape</td>
<td></td>
</tr>
<tr>
<td>Satellite MAP View</td>
<td></td>
</tr>
<tr>
<td>Current MAV Altitude</td>
<td></td>
</tr>
<tr>
<td>Camera 2 Image</td>
<td></td>
</tr>
<tr>
<td>Camera Selection Icons</td>
<td></td>
</tr>
<tr>
<td>Vertical Velocity Control</td>
<td></td>
</tr>
<tr>
<td>Take-off &amp; Land Icon</td>
<td></td>
</tr>
<tr>
<td>Horizontal Velocity Control</td>
<td></td>
</tr>
<tr>
<td>MAV Location on Map</td>
<td></td>
</tr>
<tr>
<td>Ground Level Indicator</td>
<td></td>
</tr>
<tr>
<td>Air Speed Indicator</td>
<td></td>
</tr>
</tbody>
</table>

93


development of robot human-like behaviour for an efficient human-machine co-
operation. *Proceedings of the 6th European Conference for the Advancement of
Assistive Technology, 10*, 274-279.

Sanders, M., & McCormick, E. J. (1993) *Human factors in engineering and design. 7th

Strommen, E. (1993). Is it easier to hop or walk? Development Issues in Interface

flow cues and narrow the gender gap in 3-D virtual navigation. *Human Factors,
vol 48*, (2), 318-333.

improve path integration in 3D virtual navigation tasks. *Proceedings of CHI 2004,
April 24-29*, Vienna, Austria.

Lauderdale, Florida.

Tsang, P., & Wickens, C. (1988). The Structural Constraints and Strategic Control of

Turnage, J., Kennedy, R. S., & Lane, N. E., (1996). Gender differences in human
abilities: can practice moderate results? *Journal of the Washington Academy of
Sciences, vol 84 (2)*, 111-129.


