USSAMCOM TR 00-D-20

U.S. ARMY AVIATION
AND MISSILE COMMAND

DISPLAY OF AIRCRAFT STATE INFORMATION FOR AMBIENT VISION PROCESSING USING HELMET MOUNTED DISPLAYS

THOMAS J. SHARKEY, ROBERT T. HENNESSY, AND THOMAS W. MARLOW

MONTEREY TECHNOLOGIES, INC.
24600 SILVER CLOUD COURT, SUITE 103
MONTEREY, CA 93940-6536

SEPTEMBER 2000

FINAL REPORT

Prepared for

AVIATION AND MISSILE COMMAND RESEARCH, DEVELOPMENT & ENGINEERING CENTER (AMCOM RDEC) (PROVISIONAL)
AEROFLIGHTDYNAMICS DIRECTORATE

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
09 – 09 - 2000	Final Technical Report	December 1997 to September 2000

4. TITLE AND SUBTITLE
Display of Aircraft State Information for Ambient Vision Processing Using Helmet Mounted Displays

5a. CONTRACT NUMBER
DAAH10-98-C-0020

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Thomas J. Sharkey, Robert T. Hennessy and Thomas W. Marlow

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Monterey Technologies, Inc.
24600 Silver Cloud Court, Suite 103
Monterey, CA 93940-6536
(831) 648-0190

8. PERFORMING ORGANIZATION REPORT NUMBER
MTI 20.972904

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Aviation & Missile Command
AeroflightDynamics Directorate
AMSAM-AR-A-B, MS 211-2
NASA Ames Research Center
Moffett Field, CA 94035-1000

10. SPONSOR/MONITOR'S ACRONYM(S)
AMCOM - AFDD

11. SPONSOR/MONITOR'S REPORT NUMBERS
USSAMCOM TR 00-D-20

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report describes the work performed by Monterey Technologies, Inc. under a Phase 2 Small Business Innovation Research (SBIR) contract. The goal of the work was the development and evaluation of a novel head mounted display (HMD) that provide helicopter pilots aircraft state information in a way that allows processing by the ambient visual system. A generic helicopter simulator was built for use as a testbed. Ambient displays were presented in the pilot's peripheral field of view while the pilots performed a series of low speed flight maneuvers. The characteristics of the ambient displays were manipulated in three separate evaluations. The first evaluation focused on the size, shape, and density of the objects in the ambient display. The second experiment focused on the relationship between longitudinal motion of the aircraft and motion of the ambient objects across the display. The third experiment examined the effect of providing a horizon. In general, the presence of the ambient displays resulted in improved performance for some, but not all, flight tasks. Detailed results of these studies and recommendations for future research on the effects of ambient displays on pilot performance are presented.

15. SUBJECT TERMS
Helicopter, Helmet-Mounted Displays, Vision, Flight Displays, Ambient Vision

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Robert T. Hennessy
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	323	(831) 648-0190

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the following people:

Mr. Zoltan Szoboszlay of the U.S. Army AeroflightDynamics Directorate at NASA Ames Research Center served as the Contracting Officer's Representative (Technical). His continuous support of this program is greatly appreciated.

Mr. George Tucker of NASA Ames Research Center recruited and assisted in scheduling pilots for each of the studies.

Mr. Ian McDowell of FakeSpace for developing and fabricating the modifications to the Proview 30 used in the first experiment.

The authors are indebted to the pilots who participated in these studies. The names of these pilots are not contained here in an attempt to insure the confidentiality of the data. Without their patience, efforts, and thoughtful comments we would not have been able to accomplish as much as we have.

Display of Aircraft State Information for Ambient Vision Processing Using Helmet Mounted Displays

ABSTRACT

This report describes the development and evaluation of a novel head mounted display (HMD) that provide helicopter pilots aircraft state information in a way that allows processing by the ambient visual system. This work was performed by Monterey Technologies, Inc. under a Phase 2 Small Business Innovation Research (SBIR) contract. A generic helicopter simulator was built for use as a testbed. Ambient displays were presented in the pilot's peripheral field of view while the pilots performed a series of low speed flight maneuvers. The characteristics of the ambient displays were manipulated in three separate evaluations. The first evaluation focused on the size, shape, and density of the objects in the ambient display. The second experiment focused on the relationship between longitudinal motion of the aircraft and motion of the ambient objects across the display. The third experiment examined the effect of providing a horizon. In general, the presence of the ambient displays resulted in improved performance for some, but not all, flight tasks. The results of these studies and recommendations for future research into the effects of ambient displays on pilot performance are presented.

Display of Aircraft State Information for Ambient Vision Processing Using Helmet Mounted Displays

INTRODUCTION

TWO VISUAL SYSTEMS

The ambient and focal modes of processing visual information by humans were first hypothesized by Held (1968) based on physiological work done on hamsters by Schneider (1967). Schneider showed that distinctly different visual capabilities, i.e., object recognition and spatial localization, were mediated by the visual cortex and optic tectum respectively. A large amount of physiological work (see Leibowitz and Post, 1982) has both confirmed the reality of the ambient and focal modes of visual information processing, and characterized the distinctive features of the two modes or systems.

The focal mode is a "what" system that is directed by attention and serves detail resolution object detection, recognition, identification and alignment. The ambient system is a "where" system that serves spatial awareness, self-orientation, self-motion, and gaze stability. Superficially, the distinction appears to be the familiar peripheral-foveal receptor difference, but the dissimilarity is more profound.

The Ambient Visual System

The two visual systems differ physiologically and functionally in several ways. The ambient system is more primitive in evolution, and has neural connections directly to the vestibular and somato-sensory systems, and receives input from the whole retina. The ambient system responds more vigorously with increasing size of the retinal area stimulated. This makes sense, because in natural viewing a person's self-motion causes changes in the optic array over the entire retina. The ambient system works at a reflexive level, neither requiring attention, nor easily overcome by conscious volition. Functionally, the ambient system operates by the principal of mass action; the greater the area of the retina stimulated the greater and faster the response. Anyone who has stood inside a domed simulator has experienced the mass action and reflexive nature of the ambient system as their body jerked automatically when the pilot performed an abrupt maneuver. Also, ambient function is not affected by luminance level and is not spatial frequency dependent. The ambient system operates without decrement down to near the absolute threshold for light detection and is insensitive to optical blur. This has significant implications for the cost and sophistication of the display technology required for ambient presentations. In short, the ambient system and mode of processing visual information in gross, and robust. It operates independently of gaze direction and does not impose an attentional or cognitive load.

The Focal Visual System

In contrast, the focal system is a more recent development in evolution; it receives input from only the central portion of the retina and neurologically it is confined to the geniculo-corticate pathway. The focal system is what we normally think of as our main visual ability. Functionally, the focal system is controlled by attention, is highly directional, and has great resolving power under optimal conditions and is primarily responsible for object detection and recognition. However, achieving good performance requires adequate luminance level, good optical focus, fixation accuracy, and gaze stability. Focal system performance is easily disrupted by darkness, obscurants, vibration, and blurring of the foveal image. The focal system and mode of processing visual information is highly refined and delicate.

WHY HAVEN'T AMBIENT VISUAL DISPLAYS BEEN USED BEFORE?

The artificiality and difficulty of using conventional flight instruments has been recognized for a long time. Conventional aircraft displays require conscious attention, and must be fixated by the pilot. Visual and cognitive workload and visual clutter are high, and adding additional information to conventional displays will exacerbate the problem. These problems were recognized and, beginning in the 1960s, several displays intended to be observed peripherally have been developed. These displays include the Smith Para-Visual Director (Magendie, 1960) and the Peripheral Visual Horizon Display, more commonly known as the Malcolm Horizon (Money, Malcolm, and Anderson, 1976; Malcolm, 1984).

The Para-Visual Director was developed to provide command attitude information through the use of "barber poles". These "barber poles" were positioned to the sides and above the glareshield. The movement of the helical stripes on the "barber poles" indicated the commanded changes to aircraft's bank and pitch. This display was intended to be easy to use, and to be viewed at least partially using peripheral vision.

The Malcolm Horizon was an extended horizon line that extended across most of the interior of the cockpit. Motion of the Malcolm Horizon was conformal to the natural horizon. The horizon line was generated by reflecting a light onto the interior of the cockpit via a gimbal mounted, rotating mirror. Movement of the Malcolm Horizon indicated changes in aircraft pitch and roll. The standard attitude indicator, which is based on a design that had been introduced in the 1920's, forces the pilot to fixate a small instrument which presents an artificial horizon line only 2 or 3 degrees in visual angle. The Malcolm Horizon extends this fragment of visual information by a factor of twenty or more to provide a horizon visible through peripheral vision.

These devices never became commercially successful although both showed sufficient promise to be flight tested. The Para-Visual Director was a "craft" produced device. That is, its design was not specifically derived from knowledge of visual sensory and perceptual processes. It was developed on the common sense notion that peripheral vision and motion vaguely akin to the streaming of the visual scene could be exploited for the flight control device. The Malcolm horizon was actually designed to deliberately take advantage of the concept of the ambient mode of visual information processing. Early evaluations indicated that the design was successful. The device received high praise on some flight tests by pilots of both fixed- and rotor-wing aircraft. Unfortunately, the actual implementation of the device for in-flight tests appears to have suffered from some technical problems. Poor visibility of the horizon in bright conditions and glare produced on the instrument panel were two of the problems reported. To the best of our knowledge the Malcolm Horizon has never been implemented operationally.

For an extensive review of the ambient-focal distinction and prior peripheral displays see the appendix by D. Alfred Owens and Jeffery T. Andre in Hennessy and Sharkey (1997).

HELICOPTER SIMULATOR

DEVELOPMENT AND EVALUATION SYSTEM

A low fidelity helicopter simulator was developed for use in this research program. This simulator is named the Development and Evaluation System (DAES). DAES was designed to be operated in one of two modes; a desktop mode and a HMD mode. These modes are described below.

Figure 1 is a schematic diagram of DAES.

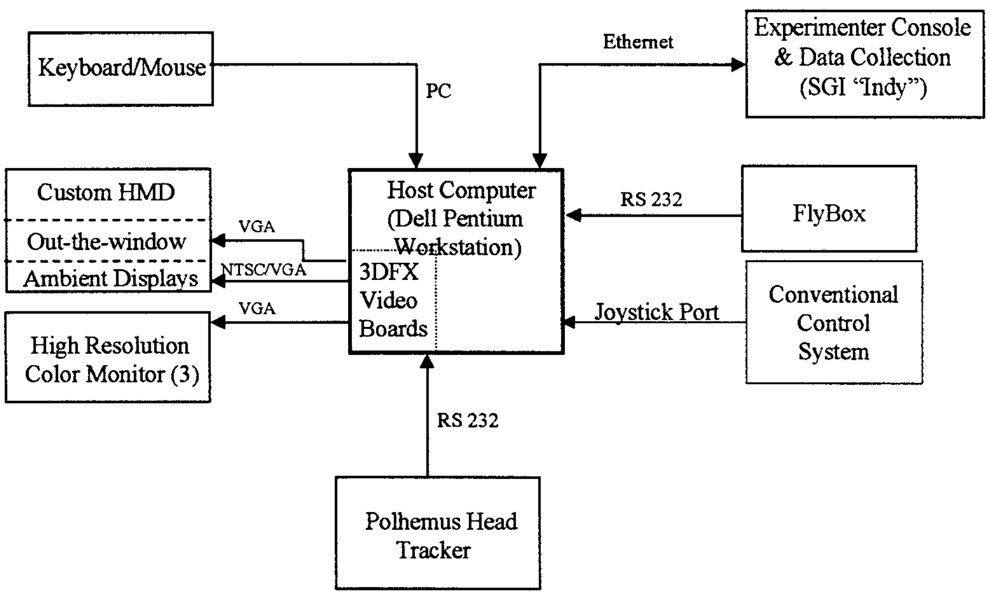


Figure 1. Schematic diagram of the Development and Evaluation System (DAES).

Desktop Configuration

In the desktop mode the visual scene is presented on three CRT arranged in a semicircle. The out-the-window scene is displayed on the monitor in front of the pilot, and the ambient displays are presented on the displays located to either side. Head tracking is not required, or available, in this mode. Figure 2 shows the arrangement of the monitors in the desktop configuration.

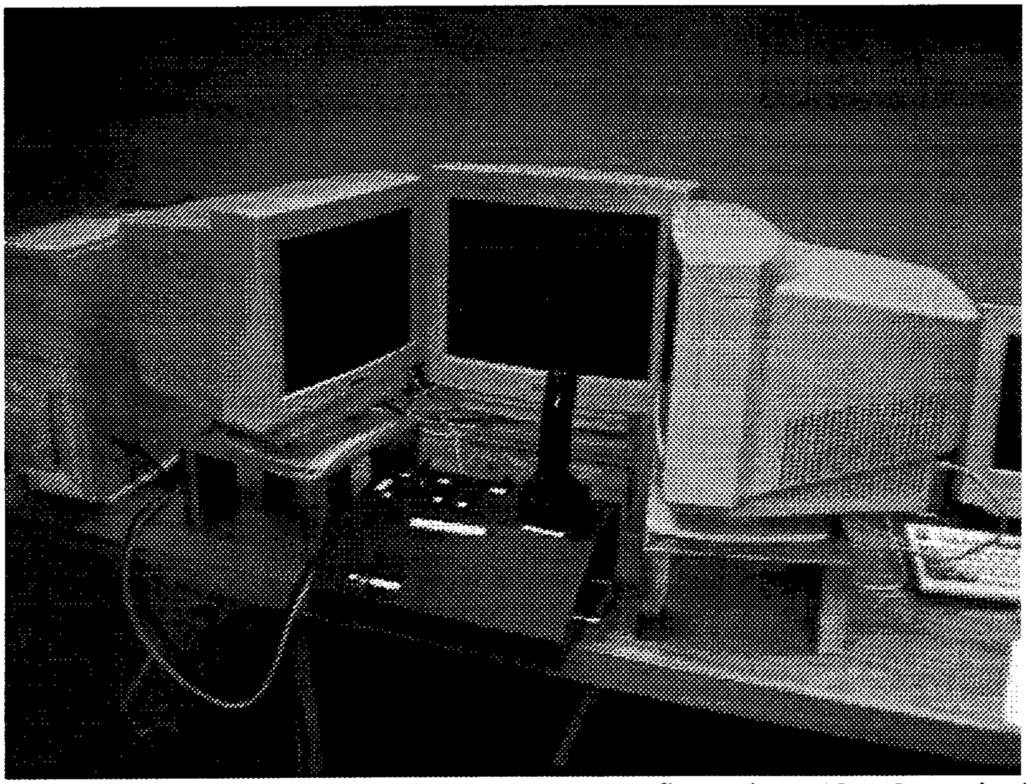


Figure 2. Arrangement of monitors in the desktop configuration. Also shown in the 3-axis joystick used to fly the simulated aircraft.

Pilots may either "fly" the simulator, or the simulator can move along pre-specified routes without requiring pilot inputs. The latter mode was intended to support psychophysical research into the ambient system's sensitivity to motion.

Head Mounted Display Configuration

The visual scene was presented in a head mounted display (HMD). Two HMDs were used during the course of this program; A modified Proview 30 and an unaltered Proview 100. Both of these HMDs were manufactured by Kaiser Electro-Optics (Carlsbad, CA). Figure 3 shows modified Proview 30. The Proview 30 HMD was modified by the addition of two displays located peripherally. These displays were used to present the ambient displays and, in the daylight control condition, an out the window scene.

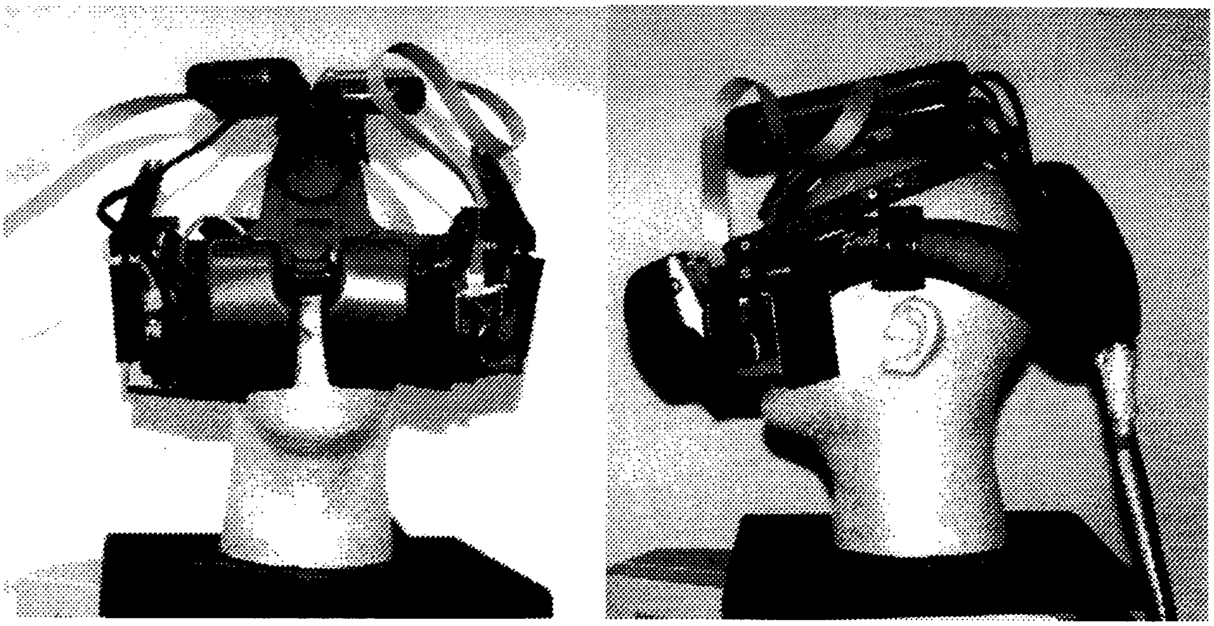


Figure 3. The modified Proview 30 Head Mounted Display used to examine ambient displays. The peripheral displays on which the ambient displays were presented were added to a Proview 30 HMD. The left panel shows a front view of the HMD, and the right panel shows a side view.

The modified Proview 30 HMD has four display surfaces. The out-the-window scene was presented biocularly on the two inboard display surfaces. These displays are full color, and have VGA resolution. The outboard channels, which were added to the Proview 30 for this program, are full color displays with NTSC resolution. The drive electronics for the outboard displays are mounted on the top of the HMD.

The second HMD used in this program is a Proview 100. The Proview 100 HMD has four display surfaces; two outboard and two inboard. All of the displays are full color displays with VGA resolution. The out the window scene was presented biocularly on the two inboard display surfaces. The ambient displays were presented on the two outboard display surfaces. Figure 4 shows the Proview 100 HMD.

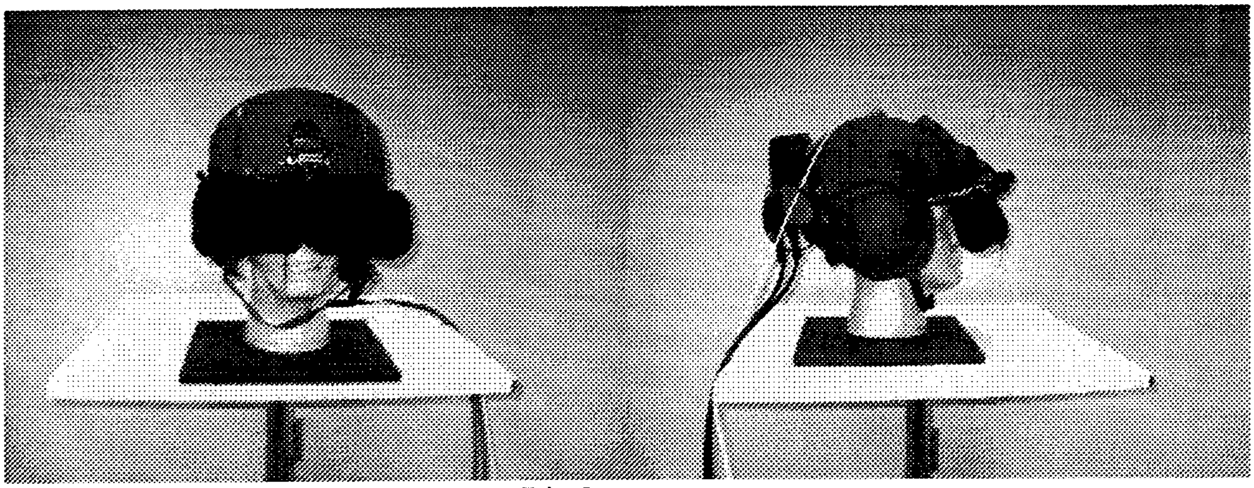


Figure 4. Proview 100 head Mounted Display.

The Proview 30 HMD was used during initial development work and in experiment 1. The Proview 100 HMD was used in experiments 2 and 3.

Head Tracking

The pilot's head position was tracked using a Fastrack position sensor (Polhemus, Inc., Colchester, VT). The transmitter was attached to the HMD, and the receiver was mounted to the seat behind pilot's head. The head position was used to update the pilot's out-the-window view and to move the ambient objects on the display surfaces.

Aircraft Controls

Two control systems are available in DAES. The first is a Flybox (BG Systems, Palo Alto, CA). The second is a set of conventional helicopter controls (Flight Link, Chico, CA).

Flybox

The Flybox is used primarily for development work; it was not used by the pilots to control the simulated helicopter in any of the experiments conducted during this program. The programmer is able to use the Flybox to control the simulated helicopter from the computer. This has been found to be more convenient than using the conventional control system.

The Flybox can also be used to fly the simulated helicopter in the desktop mode. Pilots fly the simulated aircraft using Flybox (BG Systems, Palo Alto, CA) control system. This controller is in the foreground in Figure 2. This control system contains a 3-axis joystick, two levers, and a momentary and discrete pushbuttons. One of the levers is used as a collective. The three axis joystick is serves the functions performed by the cyclic and the anti-torque pedals.

Conventional Control System

All of the ambient symbol evaluations were conducted using a set of conventional helicopter controls (Flight Link, Chico, CA). These controls attach to the host compute through the PC's joystick port. This system was modified slightly based on input received from pilots using the controls during integration. Specifically, the seat was raised approximately 2 inches so that the pilots could rest their forearms on their thighs while flying, and a heel rest approximately 3 inches tall was added so that the balls of the pilot's feet were on the anti-torque pedals. The control system is shown in Figure 5.

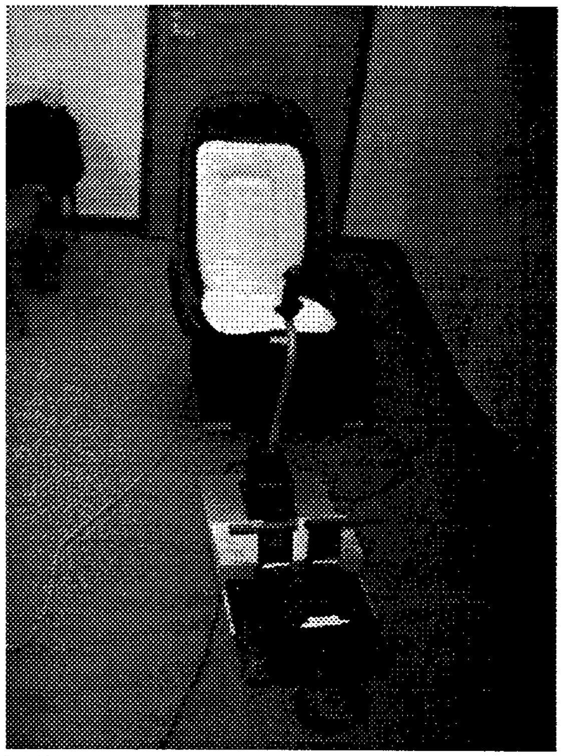


Figure 5. Conventional helicopter control system.

<u>Cockpit Instrumentation</u>

Cockpit instrumentation was displayed on a simulated head-up display (HUD) located above a cockpit mask. The instruments were limited to digital readouts of the aircraft's heading, radar altitude, barometric altitude, and forward airspeed. These were augmented by a turn ball and a tape indicating collective position. Figure 6 shows the layout of the instrumentation. During experiment 1, a secondary task consisting of three random digits was also presented on the HUD. The secondary task display was not used in experiments 2 and 3

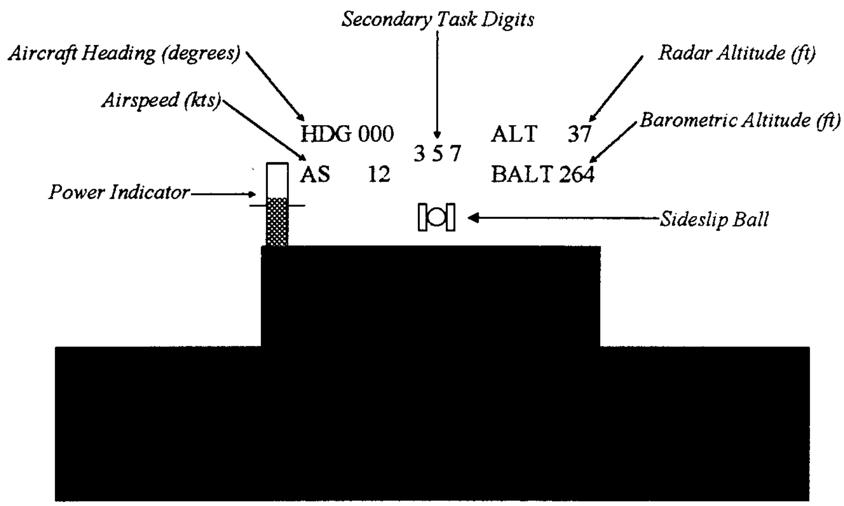


Figure 6. Aircraft instrumentation. The symbols and alphanumerics were presented as if they were on a head up display attached to the aircraft. The large black area represents the cockpit mask.

Gaming Area

The gaming area simulated the Monterey, CA area. This terrain data base, which is distributed by Multi-Gen (San Jose, CA) and SGI (Mountain View, CA), was modified to include the ground markings (e.g., cones) needed to support the flight maneuvers described in Aeronautical Design Standard – 33 (ADS-33) (U.S. Army, 1996).

Aircraft Model

The Enhanced Stability Derivative (ESD) software model was used in this simulation. The ESD software simulates a generic, light-weight helicopter. ESD was made available for this program by the U.S. Army Aeroflightdynamics Directorate at NASA Ames Research Center.

SIMULATOR OPERATION

Appendix 1 contains operating instructions for DAES.

AMBIENT SYMBOLOGY DEVELOPMENT

DISPLAY METAPHOR

The ambient objects were presented using a bill board metaphor. In this metaphor, the ambient objects appeared as if they were painted on infinitely long, infinitely tall billboards located to the sides of the aircraft. This metaphor is shown in Figure 7.

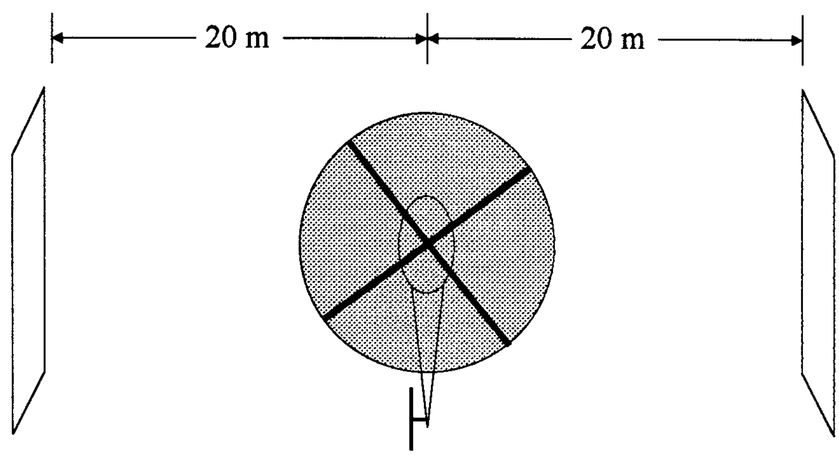


Figure 7. Schematic representation of the bill board metaphor used to display ambient objects. The bill boards appeared to be infinitely long and infinitely tall from the pilot's view.

Pilot testing showed that for the low speed tasks used in the experiments that were used in these evaluations, placing the bill boards at a distance of 20 meters to the side of the aircraft resulted in acceptable motion. If the bill boards were much closer to the aircraft than 20 meters, then the angular rates of the ambient objects became so high that the objects appeared to be unacceptably blurred, and were often distracting. If the bill boards were at a greater distance, then the motion of the ambient objects was difficult to detect at very low airspeeds.

EXPERIMENTAL EVALUATIONS

Three formal evaluations were conducted during this program.

Experiment 1 examined the size, shape and density of ambient objects. Experiment 2 examined the effects f different drive laws relating the aircraft's forward and aft velocity to the velocity of the ambient objects across the display surfaces. Experiment 3 examined alternative methods of presenting artificial horizon information.

FLIGHT TASKS

The core set of maneuvers flown were:

- Bob up
- Acceleration – Deceleration
- Constant speed, constant rate of descent approach to landing
- Precision hover
- Pirouette
- Slalom

All of these tasks are adaptations of tasks described in ADS-33, with the exception of the Constant speed, constant rate of descent approach to landing task. The precision hover task was flown during experiment 1, but was not flown during experiments 2 and 3.

Bob-Up

The bob-up task was initiated with the aircraft on the ground in the center of two concentric squares. The pilot's task was to maintain the aircraft directly over the initial position while climbing to an altitude of 50 ft (15.2 m), performing a pedal turn of 180°, and then descending to a landing.

Acceleration - Deceleration

This task began on the ground with the aircraft looking down a course. Cones placed on the ground indicated the left and right sides of the course. At the far end of the course was a pair of concentric squares. The pilot's task was to come up to a stable hover at 30 ft (9.1 m) AGL. Once at a stable hover the pilot accelerated quickly to 15 kts IAS and then decelerated so as to come to hover over the center of the boxes on the far end of the course. During the acceleration and deceleration, the pilot was to remain between the left and right edges of the course and to maintain 30 ft (9.1 m) altitude.

Constant Speed, Constant Rate of Descent Approach to Landing

In this task the aircraft was initialized on the ground. The pilot then climbed straight up to an altitude of 300 ft (91.4 m) AGL. Directly ahead of the aircraft was a runway. The pilot accelerated to an airspeed of 20 kts, and initiated a constant rate descent that would result in the aircraft landing at the threshold of the runway. During the descent, the pilot was to maintain 20 kts and a constant rate of descent until reaching an altitude of 50 ft (15.2 m) AGL. This task was chosen for inclusion here due to its similarity with the approach flown by Navy helicopter pilots approaching air capable ships. This task is the only one in this battery that is not contained in ADS-33.

Precision Hover

The precision hover course was composed of two types of markers; those that provided ground position information and those that provided altitude information. The ground position markers consisted of an "X" on the ground. The "X" was at about a 45° angle to the forward right of the aircraft when it was in its initial position. Near the "X" were a number of cones. These cones were arranged so that when the aircraft was directly over the "X" they appeared to be aligned from the pilot's vantage point. The altitude information markers consisted of a ball mounted atop a pole. At some distance beyond the ball was a bill board. When the pilot was over the "X" and at the proper altitude, the ball appeared to be in the center of the bill board. The pilots task was to bring the aircraft to an altitude of 20 ft (6.1 m) AGL over the initial position, and then side slip forward and to the right until the aircraft was over the "X" and the ball appeared centered in the bill board.

Pirouette

The pirouette course consists of a 100 ft (30.5 m) ring on the ground. A cone marked the center of this circle. The aircraft was initialized with the pilot directly over the ring. The pilot began the task by climbing to an altitude of 20 ft (6.1 m) AGL. Once at the desired altitude, the pilot side slipped the aircraft around the circle while keeping the nose of the aircraft pointed towards the center.

Slalom

The slalom was performed at an altitude of 50 ft (15.2 m) AGL and 20 kts over a runway. The pilot's task was simply to perform a series of alternating left and right turns so that the aircraft passed in the gaps between the lines painted on the centerline of the runway while going out at least as far as the edges of the runway during each turn.

EXPERIMENT 1

Experiment 1 examined the effects of the shape, size, and density of ambient objects on pilot performance. Appendix 1 contains a complete report of this study.

EXPERIMENTAL DISPLAY CONDITIONS

Shapes of the Ambient Objects

Two shapes were examined in this study; squares and circles. The rationale behind the selection of these shapes was to determine if the high spatial frequency content indicating vertical and horizontal present in the squares (because of the sharp vertical and horizontal edges) lead to better aircraft control than was possible in the absence of this information. The pattern formed by symbols of both shapes provided vertical and horizontal information, with the energy at lower spatial frequencies.

Sizes of Ambient Objects

Two sizes of ambient objects were examined, large and small. The large size squares were 4 meters per side and the small squares 1 meter per side. The diameter of the large circles was 4 meters and the diameter of small circles was 1 meter. These objects were presented at a distance of 20 meters.

Densities of the Ambient Objects

Two object densities were examined. In the high density condition the squares occupied 50% of the display. In the low density condition, the squares occupied 12.5% of the display area. The circles were positioned so that their centers were at the same location as the center of the square would have been in the corresponding size-density condition. However, the circles actually covered about 78% or the area covered by the squares.

RESULTS

Performance Measures

Bob-Up

In the bob-up task, the average altitude did not differ between the ambient conditions or between the ambient conditions and the control conditions. The variability of altitude during the 180° pedal turn was reduced by the presence of the ambient displays compared to the Day scene and NVG control conditions. This reduction ranged from approximately 19% to 37%. The altitude variability was greater when the ambient objects were large than when they were small, although the difference is only marginally statistically reliable. We interpret these results as indicating that the pilots were able to use the altitude information provided by the ambient displays to quickly detect and counter changes in the aircraft's altitude. This ability was better when there were more ambient objects in the field of view than when there were fewer objects. The absence of differences in altitude variability in most of the other tasks suggests that the pilots were not able to detect changes when the movement of the ambient objects on the displays was more complex. In the pedal turn portion of the bob-up task, vertical motion of the ambient objects, which indicated a change in the aircraft's altitude, was readily detected as the only other ambient motion was limited to translation across the screen due to the change in aircraft heading. In most of the other tasks, the aircraft motion, and consequently the motion of the ambient objects, involved more axes.

The turn rate during the pedal turn portion of the bob-up task was effected by the shape of the ambient objects. Pilots turned the aircraft at a faster rate when the objects were grids (6.6 deg/sec) than when they were circles (5.4 deg/sec). The standard deviation of the turn rate was smaller when the ambient objects were small (2.4 deg/sec) than when they were large (2.1 deg/sec). Not only were there more objects visible at any one time when the objects were small, edges of the ambient objects entered and exited the ambient display as the aircraft turned more frequently, possibly providing cues that allowing the pilots to quickly detect changes in the turn rate.

An interaction between the shape and size of the ambient objects was also found in the standard deviation of turn rate in the bob-up task. Examination of this interaction shows that the turn rate was more variable when the ambient objects were large squares (turn rate = 2.9 deg/sec) than when the they were small squares (turn rate = 1.9°/sec) or either large or small circles (turn rate = 2.1 deg/sec).

Acceleration - Deceleration

The average heading during the acceleration - deceleration task was unaffected by the display conditions. The standard deviation of the aircraft's heading was smaller when the displays were sparse than when they were dense (sd = 0.80° and 1.52°, respectively). The standard deviation of altitude was also larger when the ambient objects were densely distributed (sd =10.5 ft [3.3 m]) than when sparsely distributed (sd = 8.5 ft [2.6 m]). Based on comments from the pilots, we interpret this result as indicating that when there was aircraft motion in multiple axes simultaneously the dense displays were distracting at worst, and too busy to be processed by the ambient system at the minimum, when a large number of objects were present in the field of view.

Constant Speed, Constant Rate of Descent Approach to Landing

The descent rate was affected by the shape of the ambient objects, being faster when the ambient objects were circles (313 ft/min [95.4 m/min]) than when they were squares (280 ft/min [85.3 m/min]). There was also a significant interaction between the shape and density of the ambient objects. When the ambient objects were distributed densely the rate of descent was approximately the same for both circles and squares (about 305 ft/min [93.0 m/min]). In contrast, when the ambient objects were distributed sparsely the average rate of descent was about 250 ft/min(76.2 m/min) for squares and 325 ft/min (99.0 m/min) for circles. These results suggest that the high spatial frequency components present in squares may have lead to the perception of excessive vertical velocity which the pilots counteracted by slowing their rate of descent.

Average airspeed and the standard deviation of airspeed during the approach were both affected by the interaction between the size and density of the ambient objects. The average airspeed when the ambient objects were large and distributed sparsely was about 24.3 kts (45.0 kph) compared to airspeeds between 23.0 and 23.4 kts (42.6 and 43.3 kph) for small, sparsely distributed ambient objects and both large and small densely distributed ambient objects, respectively. The standard deviation of airspeed was greatest when the ambient objects were large and densely distributed (6.3 kts [11.7 kph]), and smallest when the ambient objects were small and densely distributed (3.5 kts [6.5 kph]). The standard deviation was nearly identical for large and small ambient objects when sparsely distributed (4.7 kts [8.7 kph]).

Precision Hover

The pilot's ability to maintain a constant heading in the precision hover task was best when the ambient objects were circles rather than squares. The ideal heading was 315°, and the average headings for circles and squares were 316.8° and 318.2°, respectively. This finding suggests that in this task, in which the pilot's gaze was often to the right of the aircraft's center line, the pilots were more quickly able to detect changes in heading and take corrective action when the ambient objects were circles. An interaction between the shape and density of the ambient objects was also found. The average heading for the sparse square condition was farther from the ideal heading (320°) than in the dense square, of sparse and dense circle conditions where the average heading was nearly identical at 317°.

Not surprisingly, the standard deviation of heading shows a similar picture. Heading variability was greater when the ambient objects were squares (5.2°) than when they were circles (3.6°). There was also an interaction between the shape and density of the ambient objects. Heading was most variable when the ambient objects were sparsely distributed squares (7.6°) and least variable when they were sparse circles (3.1°). The standard deviation of the aircraft's heading was about 4.0° for both the dense square and dense circle.

Pirouette

The standard deviation of the aircraft's the bank angle during the pirouette was larger when the ambient objects were large (2.2°) than when the objects were small (2.4°). There is also an interaction between the size and shape of the ambient objects on the standard deviation of the bank angle. The standard deviation of bank angle was 2.0° with small squares and 2.5° with large squares. With circles of both sizes the standard deviation of the bank angle was approximately 2.3°. These result suggests that the horizontal edges of the squares were of some use when the squares and the gaps between them were small. The horizontal edges had no effect when the gaps were larger.

Slalom

The ideal altitude in the slalom task was 50 ft (15.2 m) AGL. The average altitude was significantly closer to the target altitude in the NVG and day control conditions than it was when ambient displays were present. Additionally, the standard deviation of altitude was smaller in the day condition than in the NVG or ambient display conditions. The ambient objects did not improve performance in terms of maintaining a constant altitude compared to a NVG scene as anticipated. These results suggest that when the motion of the ambient objects is in multiple axes simultaneously, the ambient objects are not interpreted as effectively as is a natural scene occupying a wide field of view.

Average airspeed was affected by the size of the ambient objects. Pilots tended to fly faster than the 20 kt target airspeed when the ambient objects were small (27.5 kts [50.9 kph]) than when they were large (25.7 kt [47.6 kph]). The standard deviation of airspeed was affected by the interaction between the size and density of the ambient objects. When the objects were distributed sparsely, the standard deviation of airspeed was about 6.8 kt (12.6 kph) for both sizes of objects. Airspeed variability increased to about 7.3 kt (13.5 kph) for large ambient objects as the density increased. In contrast, the standard deviation of airspeed decreased to about 6.3 kt (11.7 kph) as the density increased for small ambient objects.

Subjective Reports

Following each flight pilots completed a questionnaire in which they rated the effectiveness of the ambient display and the acceptability of that display on 7-point scales. The questionnaire consisted of 29 separate items. The questionnaire also contained a number of open ended questions which gave the pilots the opportunity to comment on any items not covered in the questionnaire.

Awareness of Aircraft Attitude and Changes in Aircraft Attitude

One group of questions was aimed at determining whether or not the pilots felt ambient displays aided them in maintaining awareness of aircraft attitude or to detect changes in aircraft attitude. Responses to these questions generally indicated that all of the ambient displays had either a small beneficial effect or no effect at all. The exception was in terms of the pilot's awareness of vertical speed and changes in vertical speed. Here, pilots consistently indicated that the ambient objects were quite helpful. Comments made by the pilots indicate that the beneficial effect is most apparent when the aircraft's motion in other axes is small or at a slow rate. When the aircraft was maneuvering or had considerable longitudinal velocity, in which chase the ambient objects "flowed" across the screen at a rate proportional to the velocity, then it was more difficult for the pilot to extract vertical motion of the ambient objects from the background motion.

There were very few instances where one of the ambient display conditions was judged to have a deleterious effect, and in those cases the effect average ratings suggest the impact was small. This is important because it suggests that even when the pilot's felt that they were not able to extract and use the attitude and motion information from the ambient displays, the displays were not capturing focal attention or competing for the same cognitive resources needed to fly the aircraft using the focal displays and out-the-window scene.

Display Characteristics

Pilots also rated the level of visual clutter on the ambient displays. In all cases, pilots rated the displays with square ambient objects as being more visually cluttered than the circles at the same size and density. Displays consisting of small ambient objects were rated as being more cluttered than displays consisting of larger ambient objects. The displays in which the distribution of ambient objects was sparse were rated as being less cluttered than the displays in which the ambient objects were more densely distributed.

Generally, the displays consisting of square ambient objects were rated as being less cluttered than displays consisting of circles at the corresponding levels of size and density. This finding was somewhat unexpected. We had anticipated that because of the presence of greater levels of high spatial frequency content in the squares and the slightly greater amount of display area the squares occupy that the squares would be perceived as being more cluttered. The increased clutter of the circles was attributed to the greater difficulty pilots had interpreting the motion of the circles. One pilot described the motion of an ambient displays made up of circles as appearing to be similar to a "disco ball". Apparently, the vertical and horizontal edges of the squares gave the pilot orientation cues that were useful in interpreting the motion of the ambient fields.

Generally, the ratings indicate that displays with small ambient objects were judged as having too many objects visible at any one time. The displays with the large size ambient objects were judged to have about the right number, or not enough objects visible. The exception to this generalization is the large, dense circles which were rating as having too many objects on the screen.

Pilots rated the size of the ambient objects directly. The ratings indicate that the small ambient objects were too small. This probably reflects the poor acuity of the peripheral retina. The large size ambient objects were rated as being about the right size when densely distributed, and as being too large when sparsely distributed. These ratings indicate that the ambient objects need to be big enough to be perceived as distinct objects even when their images are moving over the retina, but not so large and far apart that only a very few are in the visual field.

Ratings of the amount of space between the ambient objects indicates that the gap was inadequate in the small, densely distributed conditions. Ratings of the spacing of the ambient objects in the small, sparsely distributed display conditions and in conditions in which the ambient objects were large indicate that the spacing was "about right".

Taken together, these results indicate that sizes of the ambient objects used here are not ideal; the small ambient objects are too small, and the large ones too large. The results also indicate that the densities are lower and higher than ideal.

Workload

Pilots rated the effect of the ambient displays on their workload relative to that encountered when performing the task using NVGs for each of the six flight maneuvers. Reductions in workload were reported for the bob-up and the constant speed – constant rate of descent approach for all of the ambient displays. These maneuvers differ from the other maneuvers in that the motion of the aircraft is generally confined to one or two dimensions. This "simple" motion made it easier for the pilots to detect changes in the flow of the ambient objects that were indicative of unintended deviations from desired parameters. In contrast, in the other maneuvers the flow of the ambient objects was almost always in more dimensions simultaneously. Pilots found it more difficult to identify changes in ambient motion against this more complex visual background motion.

At least some, but not all, of the ambient displays were judged to increase the pilot's workload in the precision hover, pirouette, and slalom tasks. In the precision hover task the workload ratings depended on the density of the ambient objects. With the exception large circles, the workload was rated as being greater than when using NVGs when the ambient objects were sparse than when they were dense.

In the pirouette task, the workload was judged to be about the same as with NVGs when the ambient displays consisted of large squares and large, sparsely distributed circles. The workload was higher than with NVGs for all other ambient display conditions. The workload was rated as being higher for densely distributed ambient objects than for sparsely distributed objects when the objects were small. When the objects were large, the workload was rated as higher when the ambient objets were sparsely distributed than when distributed densely.

In the slalom task the workload was rated as being about the same as when flying with NVGs in the small, dense circle, large dense grid, and large sparse circle conditions. In all other conditions the workload was judged to be higher than with NVGs.

Ability to Perform Tasks

The pilots rated their ability to perform the bob-up, the acceleration – deceleration, the constant speed, constant rate of descent approach, and the precision hover flight tasks as being enhanced by the ambient displays. The pirouette and slalom were rated as being adversely affected by presence of ambient displays except when the ambient objects were large, densely distributed squares where performance was rated as being improved.

EXPERIMENT 2

In experiment 2, the relationship between the forward and rearward speed of the aircraft and the speed of the ambient objects across the display surface was varied. This experiment is fully described in Appendix 3.

EXPERIMENTAL DISPLAY CONDITIONS

Five different drive laws relating the airspeed of the helicopter to the longitudinal speed of the ambient objects across the displays were examined in this study. These experimental conditions are described below.

Linear

The longitudinal velocity of the ambient objects was directly related to the longitudinal velocity of the aircraft.

No longitudinal motion

The ambient objects remained stationary on the display regardless of the velocity of the aircraft.

Non-linear

The change in velocity of the ambient objects per unit change in aircraft velocity was an logarithmic function of aircraft velocity. This had the effect of amplifying changes in the velocity of the ambient objects at low airspeeds, and attenuating the change at higher airspeeds.

Acceleration

The motion of the ambient objects was driven by the aircraft's acceleration, rather than velocity. When the aircraft was accelerating, the ambient objects moved rearwards on the display. The rate of the motion of the ambient objects was related to the rate of acceleration

Time decay

Motion of the ambient objects was "washed out" over a 5 sec period. When the aircraft reached a constant speed, motion of the ambient objects was smoothly reduced until they were stationary on the display. Subsequent changes in airspeed moved the ambient objects as if the constant speed was the set point (e.g., accelerating [decelerating] after maintaining a constant airspeed caused the ambient objects to move rearwards [forwards] on the display

RESULTS OF OBJECTIVE MEASURES OF PILOT PERFORMANCE

Bob up

The pilot's ability to maintain position was similar in the NVG control condition and in the acceleration and time decay drive law experimental conditions (15.0 to 16.2 ft [4.6 to 4.9 m]). The amount of drift was somewhat greater in the linear drive law condition (21.2 ft [6.5 m]), and was considerably greater in no longitudinal motion and non-linear experimental conditions (30.4 and 32.9 ft [9.3. and 10.0 m], respectively).

The average turn rate was fastest in the no longitudinal motion, acceleration, and time decay experimental conditions (6.9 to 7.7 deg/sec), and lowest in the non-linear motion condition (3.3 deg/sec). Turn rate was intermediate in the linear motion and NVG control conditions (5.4 to 5.6 deg/sec).

The variability in turn rate during the bob-up is smallest in the NVG control condition (0.9 deg/sec) and greatest in the linear drive law condition (2.8 deg/sec). The standard deviation of the turn rate is intermediate in the other four conditions (1.7 to 2.4 deg/sec).

The largest error in average altitude occurred in the linear motion condition (6.4 ft [2.0 m]), and the smallest error occurred in the acceleration motion condition (0.3 ft [0.1 m]). The magnitude of the altitude error was similar in the no longitudinal motion, non-linear motion, and NVG control conditions (1.5 to 2.1 ft [0.4 to 0.6 m]). However, the average altitude was less than the 50 ft target altitude in the non-linear motion condition, the only condition in which the altitude was below the target in this task. The altitude error in the time decay condition was 3.2 ft (1.0 m).

The standard deviation of altitude during the bob-up task was smallest in the no longitudinal motion, acceleration, and time decay conditions (4.7 to 6.0 ft [1.4 to 1.8 m]). The standard deviations were larger in the linear and non-linear motion conditions and in the NVG control condition (7.1 to 7.7 ft [2.2 to 2.3 m]).

Acceleration - Deceleration

The average altitude in each condition during the acceleration/deceleration maneuver were all equal to or above the target altitude of 30 ft AGL (9.1 m). The average altitudes in the no longitudinal motion, time decay, and NVG control conditions were all within about a foot of the target altitude (30.0 to 31.1 ft [9.1 to 9.5 m]). The average altitude was highest in the non-linear motion condition (38.4 ft [11.7 m]), and was intermediate in the linear and acceleration conditions (32.8 and 32.9 ft, respectively [10.0 m])

The altitude was less variable in the linear, acceleration, and NVG conditions (3.8 to 4.4 ft [1.2 to 1.3 m]) than in the no longitudinal motion, non linear, and time decay conditions (5.8 to 6.4 ft [1.8 to 2.0 m]).

Constant speed, constant rate of descent approach

Pilots flew constant speed, constant rate of descent approach faster than the 20 kts (37 kph, 23 mph) target airspeed in the acceleration condition. In all other conditions the average airspeed ranged from 19.6 kts (36.3 kph, 22.6 mph) to 21.4 kts (39.6 kph, 24.6 mph).

Airspeed was least variable in the NVG only condition (1.8 kts [3.3 kph, 2.1 mph]). Airspeed was most variable in the linear and non-linear motion conditions (3.0 kts [5.6 kph, 3.4 mph] and 2.9 kts [5.4 kph, 3.3 mph]). In the other three display conditions airspeed variability was approximately 2.5 kts (4.6 kph, 2.9 mph).

Pilots had digital and radar altimeter data available, along with information from the forward, out-the-window scene and from the ambient displays, on which to judge their rate of descent. They did not have a vertical speed indicator. The average rate of descent from the point at which the aircraft reached 20 kts (37 kph, 23 mph) of airspeed until the aircraft reached 50 ft AGL (15.2 m). The rate of descent was greatest in the acceleration condition (317.3 ft/min [96.7 m/min]). The average rate of descent in all of the other display conditions was similar, ranging from a low of 256.3 ft/min (78.1 m/min) to a high of 274.3 ft/min (83.6 m/min).

The standard deviation of the rate of descent was smallest in the no longitudinal motion condition (115.3 ft/min [35.1 m/min]) and was intermediate in the acceleration condition (139.5 ft/min [42.5 m/min]). The standard deviation was larger in the remaining four conditions, where it ranged from 150.3 ft/min (45.8 m/min) to 161.4 ft/min (49.2 m/min).

Pirouette

The average altitude was higher than the target altitude of 20 ft (6.1 m) in all conditions. The average altitude was closer to the target altitude in the time decay condition (21.5 ft [6.6 m]) than in any of the other conditions. The altitude error was greatest in the linear condition (28.4 ft [8.6 m]). In the other conditions the average altitude ranged from 24.7 ft (7.5 m) to 26.1 ft (8.0 m).

The altitude variability was least in the NVG and time decay conditions (6.26 and 6.81 ft [1.9 and 2.1 m], respectively. The altitude variability was greatest in the acceleration and linear conditions, with standard deviations of 10.0 ft (10.05 m) and 9.7 ft (2.96 m), respectively.

The average bank angle during the pirouette was smallest in the time decay condition (0.6°). The average bank angle was slightly greater than this in the NVG and linear conditions (0.9°). The bank angle was still greater in the non linear (1.1°) and acceleration (1.2°) conditions, and was greatest in the no longitudinal motion condition (1.5°).

The standard deviation of the aircraft's bank angle was greatest in the linear and acceleration conditions (3.2° and 3.0°, respectively). In the other conditions, the standard deviations were similar and ranged from 2.3° to 2.4°.

During the pirouette, pilots attempted to maintain a 100 ft (30.5 m) distance from the center of the circle. The average error was greatest in the acceleration and linear display conditions (13.0

and 12.6 m [42.6 and 41.3 ft], respectively). In the other conditions the average errors are similar, ranging from 8.3 m (27.2 ft) to 10.9 m (35.8 ft).

The variability in the distance between the aircraft and the center of the circle was smallest in the non linear, time decay, and NVG display conditions (5.1 to 5.4 m (16.7 and 17.7 ft) and greatest in the acceleration condition (8.4 m [27.6 ft]). In the linear and no longitudinal motion conditions the standard deviations of the distance between the aircraft and the center of the circle were 6.4 and 6.6 m (21.0 and 21.6 ft), respectively.

Slalom

In the slalom task the pilot attempted to maintain 20 kts (37 kph, 23 mph) airspeed. In all cases the average airspeed was farthest from the target of 20 kts in the NVG condition (24.7 kts [45.7 kph, 28.4 mph]). In the ambient display conditions the average airspeed ranged from 19.5 kts (36.1 kph, 22.4 mph)to 22.8 kts (42.2 kph, 26.2 mph).

The standard deviation of airspeed was smallest in the linear display condition (4.6 kts [8.5 kph, 5.3 mph]) and was greatest in the no longitudinal motion condition (6.6 kts [12.2 kph, 7.6 mph]). In the other display conditions the standard deviation of airspeed was between 5.2 kts (9.6 kph, 6.0 mph) and 5.7 kts (10.6 kph, 6.6 mph).

In the slalom task the pilot attempted to maintain an altitude of 50 ft AGL (15.2 m). In all cases, the average altitude was higher than 50 ft. The average altitude was closest to the target in the no longitudinal motion, acceleration, and time decay conditions, where it ranged from 54.5 ft (16.6 m) to 56.2 ft (17.1 m). The highest average altitude was in the linear display condition (63.6 ft [19.4 m]). The average altitude was intermediate in the non-linear and NVG conditions (59.8 and 58.5 ft [18.2 and 17.8 m], respectively.

The smallest standard deviation in the aircraft's altitude during the slalom task is in the acceleration condition (10.6 ft [3.2 m]). Intermediate performance is seen in the no longitudinal motion and time decay conditions, where the standard deviations were both 13.0 ft (4.0 m). Performance in the other conditions was more variable, with standard deviations ranging from 14.4 ft (4.4 m) to 15.6 ft (4.8 m).

SUBJECTIVE DATA

Overall, pilot ratings and comments indicated that the workload was lowest with the linear drive law. The time decay drivel law, in which motion of the ambient objects was "washed out" over a period of 5 seconds, was rated as second best.

It appears that the linear drive law worked best in those maneuvers performed at or near hover airspeeds. At higher airspeeds the velocity of the ambient objects as they moved from the front to the rear of the display surfaces masked changes in airspeed. The flow of the ambient objects also appears to have masked changes in the positions of the ambient objects caused by changes in the other aircraft attitude. For example, at a hover pilots found it easier to detect a positive rate of climb based on the motion of the ambient objects than they did when the aircraft was flying forwards at 15 to 20 kts. This masking effect was most apparent in the slalom, where the aircraft is moving in multiple axes simultaneously.

Pilot performance was similar with the acceleration and time decay drive laws. However, pilots pointed out that the direction that the ambient objects flowed on the displays was, on occasion, in the opposite direction to that expected from the motion of the aircraft. This drawback was evident in cases where the pilot attempted to stop a drift. As an example, consider a situation where the only aircraft motion is a constant speed forward drift. With the acceleration based drive law, the ambient objects would be stationary on the displays. As the pilot pulls back on the cyclic and the aircraft begins to slow the ambient objects will begin to move forwards on the display (showing deceleration, not the direction that the aircraft is translating.) If the constant rate of deceleration persists, the aircraft will slow to a zero airspeed and then begin translating rearwards. Even though the direction of the aircraft's motion changes, the motion of the ambient objects would remain the same. This inconsistency between the direction of ambient object motion and the direction of aircraft motion is unsatisfactory at low airspeeds because the pilot could misperceive the ambient motion as showing a change in the position of the aircraft. In a worst-case scenario, this misperception could cause the pilot to make a control input that would cause the aircraft to strike an obstacle.

The non-linear drive law was rated highly in terms of allowing the pilots to easily detect changes in the aircraft's direction, forward or aft, and in terms of allowing the pilots to detect changes in airspeed in the rage from 0 to 5 kts. However, the workload was high when using this drive law. We feel that the high workload was largely due to the amplification of the ambient motion at airspeeds which are so low as to be negligible from the pilot's standpoint. The amplified motion caused the pilots to "chase" the display in an attempt to null out the motion. Because helicopters drift forwards and rearwards slightly, even in a stable hover, the pilots were never able to eliminate the ambient motion for even a few seconds. Consequently, the pilot's were always forced to make control inputs. With the other display drive laws, very low rate drifts were undetected and placed no manual control burden on the pilots.

At higher airspeeds, pilots report that the level of display clutter is reduced by eliminating the constant flow of the ambient objects across the displays. This reduction in clutter, coupled with the tendency of the constant motion of the ambient objects in one axis to mask changes in other axes, suggests that different control laws, each tailored to a particular flight regime, will better serve the needs of the pilots than a single drive law.

EXPERIMENT 3

In experiment 3, the effects of alternative methods of depicting an artificial horizon were examined. This experiment is fully described in Appendix 4.

EXPERIMENTAL DISPLAY CONDITIONS

In this study four ambient displays, and a no ambient control condition, were examined. The four experimental conditions were:

- Full field ambient display
- Full field ambient display plus an artificial horizon
- Ambient objects below the horizon only
- Artificial horizon only

Examples of ambient displays on one of the outboard display surfaces are shown in Figure 8. The aircraft is in a straight and level attitude in each panel.

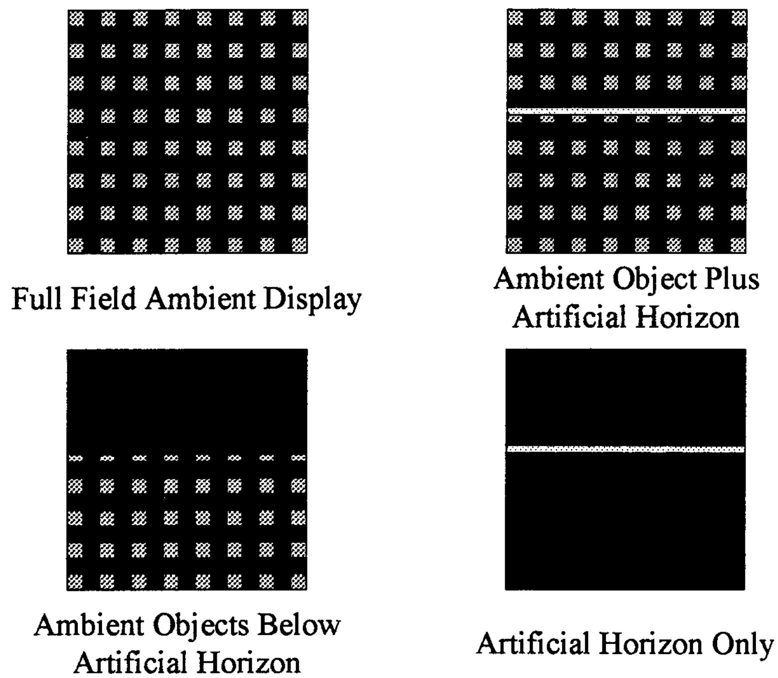


Figure 8. Examples of the ambient displays used in Experiment 3. Each panel shows the positions of the ambient objects and/or the artificial horizon when the aircraft is straight and level.

In all cases, the ambient objects (i.e., the squares) were portrayed as being 2 meters per side and being at a distance of 20 meters. Ambient objects covered 25% of the outboard display surfaces, when the entire display was filled. In the condition where ambient objects were displayed below the horizon only, the density of the objects below the horizon was 25% and the density above the horizon was 0%..

The artificial horizon, or the edge of the ambient objects at the horizon, represented a level plan through the pilot's eye point. The horizon did not take the altitude of the aircraft into account so, strictly speaking, it was not conformal. However, at the altitudes flown during these tasks the difference in the position of a "local level" line and a conformal horizon line are negligible.

A linear drive law between the aircraft's longitudinal velocity and the longitudinal velocity of the ambient objects was used in all of the display conditions.

OBJECTIVE MEASURES OF PILOT PERFORMANCE

Bob Up

The distance the aircraft drifted was significantly greater in all four of the experimental conditions than in the no ambient display control condition. This unexpected result may indicate that an ambient display, even one as simple and uncluttered as an artificial horizon only, distracts the pilot to the extent that the drift cues in the forward, focal scene are ineffective. Alternatively, it may be that the presence of the ambient displays caused the pilots to believe that they were able to detect drift from the ambient cues, when in fact the cues were not used effectively.

Differences in the turn rate between display conditions were generally small. The slowest turn rate was in the artificial horizon only condition. This result suggests that the pilots were accustomed to having the ambient objects flow across the outboard displays when performing a pedal turn, and were somewhat more cautious when they relied on the NVG scene without any additional cueing. However, it is also clear that the presence of an edge representing the horizon, resulted in increased variability in the turn rate..

The presence of ambient objects (i.e., the squares) allowed the pilots to maintain a more consistent altitude in this task. Variability was reduced by 20% to 60% compared to the NVG condition. Altitude variability was greater when an artificial horizon alone was displayed than in the control condition or in any of the conditions where ambient objects were displayed.

Acceleration - Deceleration

The average altitude held by the pilots was closer to the target altitude of 30 ft in all four of the experimental conditions than in the NVG only control condition. However, the altitude variability was higher in all of the experimental conditions than in the control condition. These effects appear to be related to the display of information on the outboard displays; there is no difference between displays containing only an artificial horizon and those containing ambient objects.

One possible interpretation of this pattern of results is that the presence of ambient displays gave the pilots a feeling of confidence in their altitude awareness that allowed them to fly a bit lower than without the displays. This confidence may not be justified; the data indicates that the pilots were able to detect and correct altitude deviations better without the ambient displays. One possible explanation may be that when the ambient displays were present the pilot tended to make use of that information and consequently, to make less use of the radar altitude displayed on the HUD than they did when no ambient objects were present.

Constant speed, Constant Rate of Descent Approach

It was predicted that pilots would be able to detect changes in the flow rate of the ambient objects to better maintain the target airspeed of 20 kts. The data indicate that in all display conditions, with the exception of the horizon plus ambient objects condition, the pilots maintained the target airspeed within the accuracy of the digital readout. The average airspeed was slightly higher in the horizon plus ambient objects condition.

The data indicate that airspeed variability was small, and essentially the same in all of the display conditions. It had been expected that the pilots would detect changes in the rate of ambient object movement and be able to use that information to make speed adjustments more accurately than when they relied on the digital airspeed readout alone.

The variability in the rate of descent was lowest in the full field ambient object condition. In the other ambient display conditions the variability was greater than in the NVG control condition. This suggests that the presence of an artificial horizon indication and the absence of the ambient objects (i.e., the artificial horizon only condition) had an adverse effect on the pilot's ability to detect changes in the rate of descent.

Pirouette

The pilots were able to maintain a more consistent bank angle in this task when a full field of ambient objects was presented than when the ambient objects filled only part of the field, or when only an artificial horizon was displayed. This result was surprising in that the artificial horizon symbol was expected to allow the pilot to judge changes in bank angle.

The target altitude for this task was 20 ft AGL. The greatest average altitude error was found in the ambient objects below the horizon condition, where the average altitude was approximately 22 ft AGL. In all of the other experimental conditions, and in the NVG control condition, the average altitude was approximately 22 ft AGL.

It was expected that the vertical flow of the ambient objects would allow the pilot to more accurately maintain a constant altitude than in the NVG control condition or in the artificial horizon only condition. The data did not fully support this prediction, as the standard deviation of altitude was lowest in the NVG control condition. The presence of ambient objects did result in smaller altitude variability than in the artificial horizon only condition.

Ideal performance of the pirouette task would result in the aircraft being directly over the 100 meter diameter circle on the ground. The average error was smallest and least variable in the full field ambient object display condition. The average errors were greatest when ambient objects were combined with an artificial horizon or when ambient objects were presented blow the horizon.

Slalom

In the slalom pilots attempted to maintain an airspeed of 20 kts and an altitude of 50 ft AGL. The results show an inverse relationship between the average error and the altitude variability. The average altitude error was smallest and the altitude variability greatest in the horizon only display condition. Altitude error was greater, and the standard deviation of altitude was smaller, in all of the conditions containing ambient objects than in the NVG control condition. These data show that pilots were not able to effectively use the vertical flow of the ambient objects to detect altitude changes. It may be that the longitudinal flow of the ambient objects masked the vertical motion of the objects, making it difficult for the pilot to detect the changes in vertical position of the ambient objects.

An inverse relationship between the error in average airspeed and the standard deviation of airspeed was found. The average airspeed was closer to the target of 20 kts, and the variability of airspeed larger, in all of the experimental conditions than in the NVG control condition. Since the artificial horizon only condition does not convey any information about airspeed, the performance difference between this condition and the NVG only condition was not anticipated.

SUBJECTIVE DATA

Vertical and Longitudinal Speed

Pilots rated the experimental display conditions containing ambient objects as increasing their awareness of both vertical and longitudinal speed compared to the NVG only condition. They also rated these displays as improving their ability to detect changes in airspeed and altitude. The experimental condition containing only an artificial horizon was rated as providing equivalent awareness of speed and altitude to the NVG only condition.

Aircraft Roll

Pilots rated the ambient displays as being equivalent, or slightly inferior, to the NVG only condition both in terms of maintaining awareness of the aircraft's roll angle and in allowing detection of changes in the roll angle. It was expected that ambient displays containing an artificial horizon or presenting ambient objects below the horizon would be rated as improving the pilot's awareness of aircraft bank angle.

Aircraft Heading

It was expected that displays containing ambient objects would improve the pilot's awareness of heading and improve their ability to detect changes in heading. These expectations were partially borne out. Pilots did rate their ability to detect heading changes as being improved by displays containing ambient objects. However, these displays were rated as being equivalent to the NVG control condition in terms of providing an awareness of heading.

Pilot comments suggest that the reason the displays were not rated superior to the control condition was because the ambient objects do not contain absolute information about the aircraft's heading. That is, the ambient objects do not provide information that allows the pilot to distinguish between a heading of 270° and 180°, for example. All the ambient objects merely indicate a constant heading or the direction and rate of a heading change.

Visual Clutter

Pilot ratings of visual clutter indicate that all of the displays containing ambient objects were rated as being more cluttered than the NVG only condition. The ambient display containing only an artificial horizon was rated as being less cluttered than the NVG only condition. Based on the present data, it is not possible to determine whether the differences in ratings between the conditions are due to the proportion of the outboard displays occupied by ambient symbols (i.e., the area filled with the horizon line plus the squares), the different motion characteristics of the artificial horizon and the squares, or both.

Workload

Pilots the rated the effects of the ambient displays on their workload in each of the five flight tasks. In all tasks except the slalom, all of the displays were rated as having no effect or slightly reducing the workload compared to the NVG only control condition. The largest reductions in workload were found with the displays containing ambient objects in the bob up and acceleration-deceleration tasks.

Comments made by the pilots indicates that in the bob up, the ambient objects reduced the workload associated with monitoring altitude. Once at 50 ft, the pilots were able to detect changes in altitude from the vertical motion of the ambient objects; they did not have to monitor the digital readout of altitude.

In the acceleration-deceleration task the workload reduction was attributable primarily to the ambient objects providing cues indicating that the aircraft was drifting backwards. (The digital readout of airspeed simulated a pitot-static system, and read 0 (zero) when the aircraft was drifting backwards regardless of speed. Also, the velocity cues in the out-the-window scene were generally inadequate due to the sparseness of objects in the vicinity, particularly considering the aircraft's nose-up attitude during the deceleration.) Pilots were able to use the motion of the ambient objects to detect and stop backwards drift when decelerating to a stop.

In the slalom, all of the displays containing ambient objects were judged as increasing the pilot's workload. The artificial horizon only condition was judged to have no effect. In the slalom, the motion of the aircraft was relatively complex and, therefore, the motion of the ambient objects was also complex. The increased workload is due to the difficulty pilots had relating the motion of the ambient objects on the displays to the motion of the aircraft.

Ability to Perform Flight Tasks

The pattern of pilot's ratings of the effect of the ambient displays on their ability to perform the flight tasks was similar to the pattern of workload ratings. In all tasks except the slalom, all of the displays were rated as having no effect or slightly enhancing the pilot's ability to perform the maneuver compared to the NVG only control condition.

Overall Acceptability

Two of the ambient displays were rated as being minimally acceptable for flight testing by the pilots; the artificial horizon only and the display with ambient objects below the horizon. The other two displays, the artificial horizon plus the ambient objects and the full field of ambient objects, were rated just below the acceptable level.

DISCUSSION

PROGRAM ACCOMPLISHMENTS

Simulator Development

A generic light helicopter simulator, called the Development and Evaluation System (DAES) was developed specifically for use in this program. The host computer is a single CPU Pentium machine containing three high-end video boards. These video boards drive the displays viewed by the pilots.

DAES has a built in data collection capability. During an experimental session, data is sent from the host computer to another computer (an SGI Indy) which serves as an experimenter station and data collection machine. Ethernet is used to connect the computers. All aircraft position and orientation data, pilot head position and orientation, and control positions are collected at a 10 Hz rate by default. The data collection list can be modified through code.

The simulator can be operated in two modes; desk top and HMD modes. In the desktop mode the center channel presents an out-the-window scene, and the outboard channels present either ambient displays or a wide field of view out-the-window scene. In the HMD mode the inboard displays are used to present the out-the-window scene biocularly. The outboard channels can be used to present ambient displays or out-the-window scenes.

One of the unique features of this simulator is its ability to display ambient symbology. Algorithms developed during the course of this program allow ambient symbols to be displayed as if they are located on bill boards located to the sides of the aircraft. From the pilot's perspective, these bill boards appear to be infinitely long and infinitely tall; there are no discontinuities in the field of ambient objects as the aircraft moves through space or as the pilot moves his or her head.

There have been no breakdowns with DAES during the course of this experiment. However, due to an experimenter's error a small number of data files were lost during experiment 1.

Unfortunately, the amount of time, effort, and program resources required to develop DAES far exceeded our expectations. This had a negative effect on the progress of this program, and limited the range and scope of research and development that could be ultimately accomplished.

HMD Development

Two HMDs have been used in this program. The first HMD was a modified version of a COTS Proview 30. Modifications featured the addition of display surfaces located outboard to the OEM displays, and the addition of a head position and orientation tracker.

The outboard displays are based on COTS displays. These displays have NTSC resolution, and measure approximately 2-1/2 inches diagonally. No failures of the modified components occurred during this study.

The COTS HMD did fail multiple times during this study. All of the failures were of the backlights for the LCDs. Although the manufacturer was cooperative and fixed the failures under warrantee, the HMD was not available for use in research for several months due to the failures.

The second HMD used was a COTS Proview 100. This display attaches to the center NVG mount on a SPH-4 aviator's helmet. A head position and orientation tracker was attached to the SPH-4.

No failures or breakdowns of the Proview 100 were experienced. However, towards the end of the third study the left outboard display began to separate from the rest of the display module. Repairs to the HMD are recommended if it is to be used in future research.

Experimental Evaluations

During this study, three separate experiments were conducted. The first experiment explored the effects of the shape, size, and density of ambient displays on pilot's ability to perform helicopter flight maneuvers.

The results of experiment suggest that squares were more effective than circles as ambient stimuli. This, we believe, is attributable to the high spatial frequency content provided by the vertical and horizontal edges of the squares being processed by the ambient visual system. These results suggested that squares 4 meters per side were larger than optimal, and that squares 1 meter per side were smaller than ideal. The drawback to the larger squares seems to have been that there were too few edges visible at any point in time to be an effective stimulus. In the case of the small objects, there were simply too may visible at any time. This gave pilots the sensation that they were seeing a "disco ball" (to use one pilot's description). Finally, densities of 12.5% appeared to have so much area between the objects that the pattern of motion was hard to detect. At the higher density (i.e., 50% in this study) the ambient field was considered distracting. Based on the conclusions reached in this study, subsequent experiments used ambient displays consisting of squares 2 meters on a side, covering 25% of the ambient display area.

The second experiment examined the effect of different drive laws relating longitudinal motion of the aircraft to longitudinal motion of ambient objects. There goal was to look at methods of minimizing the distracting, and possibly fatiguing, effects of high velocity longitudinal flow of the ambient objects while allowing the pilot to still detect changes in the velocity and direction of the helicopter, even at speeds near a hover. The results indicate that a drive law based on acceleration is not acceptable because it can mislead the pilot as to the direction of drift. A drive law based on a log function of airspeed worked well in terms of both making changes in aircraft direction obvious and attenuating the velocity of the ambient motion at higher airspeeds. However, this implementation was judged to be unsatisfactory because of the very high workload imposed on the pilot when attempting to null the display motion when attempting to maintain a stable hover over a ground point. The best control laws overall were the linear control law (which was used in experiment 1) and a control law that washed out the motion of the ambient objects over time when the airspeed was constant. However, neither of these was found to be sufficient for the entire range of airspeeds encountered during normal helicopter operations. The conclusion reached based on the results of experiment 2 are that (a) if only one control law is used, then it should be either a linear drive law or a drive law that washes out the motion of the ambient objects across the display over time, and (2) an implementation where different control laws are used for different flight regimes should be developed and tested prior to flight testing.

The third study completed during this program examined the effectiveness of alternative methods of displaying an artificial horizon for ambient system processing. It was expected that an artificial horizon covering a large angle in the pilot's peripheral field of view would be a very effective and easy to use cue. Four experimental displays were examined. These were

- Full field ambient display
- Full field ambient display plus an artificial horizon
- Ambient objects below the horizon only
- Artificial horizon only

This experiment showed that the artificial horizon had an effect only in selected tasks. The artificial horizon cueing was useful when coupled with ambient objects showing vertical and longitudinal motion and rotational motion of the aircraft, and then only in conditions where the aircraft's maneuvers were relatively benign. In tasks with more aggressive, multiple axis aircraft motion (e.g., the slalom maneuver) the artificial horizon was found to be somewhat of a hindrance.

RECOMMENDATIONS FOR FUTURE RESEARCH

During this program a test environment tailored to examining the effectiveness of ambient displays on helicopter pilot performance was developed and experimental evaluations of important characteristics of ambient displays were conducted. While the results indicate the potential of ambient displays, there are other display techniques that, while considered by us to be potentially useful, could not be evaluated within this program. Some of these are described briefly here.

ALTERNATIVE DISPLAY METAPHORS

Throughout this program, ambient objects were presented using a "bill board" display metaphor. This metaphor has been shown to be an effective means for presenting longitudinal drift and altitude change information. It has not proven to be an effective approach to presenting pitch, roll, or yaw information, particularly when the aircraft is moving in multiple axes simultaneously. Presentation of lateral drift is problematic using this display metaphor.

Flat plane

This display metaphor would result in a visual scene that would be similar to that encountered when flying over flat ground or over water. Ambient objects would be "painted" on the surface. This display could be augmented by including 3-D objects of constant size throughout the scene. We expect that this approach may be more useful to pilots in judging aircraft roll and pitch, and than are displays using the bill board metaphor. This display metaphor would also allow an intuitive representation of the aircraft's lateral drift, cues that are not easily presented using a bill board metaphor. However, pilot's judgement of altitude and longitudinal drift may not be as well supported as with the bill board metaphor.

Valley

The valley metaphor attempts to combine the best features of the bill board and flat plane metaphors. From the pilot's view point, the scene would resemble being in a valley or river bed. The surface directly below the aircraft would be flat. To either side of the aircraft would be surfaces that slope upwards from the flat plane, or rise vertically from the plane. These surfaces would have ambient objects "painted" on them, but the objects on the horizontal surface would not necessarily be the same as those on surfaces rising up from the plane.

ALTERNATIVE DRIVE MODES

Deviations from commanded airspeed

In the three studies conducted during this program, the longitudinal velocity of the ambient objects was generally a function of the airspeed. The faster the airspeed, the faster the ambient objects moved across the display. (The exceptions were one condition in which the longitudinal motion of the ambient objects washed out over time and a condition where the ambient objects position on the display was unaffected by the airspeed.) This approach is not suitable for tasks where the airspeed is higher due to the visual blurring of the ambient objects and the subjective discomfort caused by the constant motion. An alternative approach would be to drive the ambient objects based on the difference between a commanded airspeed and the actual speed of the aircraft. For example, consider the situation where the pilot is attempting to maintain an airspeed of 80 kts. When the aircraft's velocity matches the target speed, within some tolerance, then the ambient objects would be stationary on the displays. When the airspeed is grater than the commanded airspeed, say 84 kts, then the ambient objects would appear to flow from the front to the rear of their display. If the aircraft was below the commanded airspeed, 76 kts for instance, then the ambient objects would appear to flow from the rear to the front of the displays. The rate of the flow would be a function of the difference between the actual and target airspeeds. For example, at an airspeed of 84 kts the rate that the ambient objects flow rearward on the display would be lower than if the aircraft were traveling at 88 kts. With this type of ambient object drive law, the pilot's task is simply to null out the motion. This approach would be better suited to contour and up and away flight regimes than to the hover regime examined in this program.

Deviations from commanded altitude

The effectiveness of drive laws based on deviations from the commanded altitude should also be examined. These drive laws would be analogous to those based on airspeed. As the aircraft descends below the commanded altitude, the ambient objects would go upwards on the display, and when the aircraft climbs above the commanded altitude, the ambient objects would move downwards on the display.

This approach could be extended for use in cueing the pilot to maintain the proper altitude on complex glide paths. For example, consider a glide path where the aircraft first descends and then maintains a constant altitude. As the pilot intercepts the first portion of our hypothetical glide slope the ambient objects appear to mover downwards on the display. The pilot nulls out this motion by decreasing the aircraft's altitude. As the aircraft moves along the descending portion of the glide path, the pilot maintains a sink rate that keeps the ambient objects stationary on the display. When the constant altitude portion of the glide slope is intercepted, then the ambient objects would begin to move upwards on the display, assuming that the aircraft was still descending. As the pilot detects the upwards motion of the ambient objects, the pilot brings the sink rate back to zero to null the ambient motion. This would allow the pilot to fly complex vertical profiles without requiring constant monitoring of altitude and position; all of the information needed to accurately follow the glide path vertically would be contained in the ambient display.

Depiction of radar altitude rather than barometric altitude

Throughout this program, the vertical position of the ambient objects has been a function of the aircraft's barometric altitude. As the maneuvers were flown over level ground, this has had no practical effect. However, for other flight tasks where a constant terrain clearance over uneven ground is desired, Nap-of-the-Earth (NOE) flight for instance, ambient displays may be driven using radar altitude data. Consider, for example, a case where the pilot wishes to fly at an altitude of 10 ft above the terrain. As the pilot flies over level ground at 10 ft, the ambient objects would remain in a constant vertical position on the display. As the aircraft comes to a down slope, the radar altitude would begin to increase. As the radar altitude increases, the ambient objects would move downwards on the display. The pilot would perceive the motion of the ambient objects and initiate a descent. Once the aircraft descends enough to reach the desired altitude then the ambient objects would again have no vertical motion on the display. This use of ambient displays would allow the pilot to remain "eyes out" while still having radar altitude information available.

TERRAIN PROXIMITY

Change visible characteristics of ambient objects when altitude AGL is below a predetermined level.

One of the shortcomings of the displays examined in this program is that they provide only relative altitude information; they don't cue the pilot as to the height above the ground. We recommend that ambient displays containing absolute altitude information be developed and their effectiveness examined.

One method of displaying absolute altitude information is to change the appearance of the ambient objects at a predetermined altitude. Consider an ambient display where the ambient objects flow upwards on the display as the aircraft's altitude above the ground decreases. As the aircraft descends through a preset altitude (e.g., 20 ft AGL) the characteristics of the ambient objects entering the display from the bottom would be altered. For example, the objects could be a different shape, color, and/or brightness. These objects would then move up the screen as the aircraft descends until at the point the skids or wheels contact the ground, the entire ambient display is filled. This information would, in theory, contain enough information to allow the pilot to land the aircraft in conditions such as brown outs and white outs; conditions where other displays (e.g., NVGs, PNVGS) cannot provide a view of the terrain.

Change visible characteristics when the aircraft's altitude and rate of descent indicate ground contact within a predetermined time.

This approach to presenting altitude information would be very similar to the approach described above. However, instead of using the distance between the aircraft and the terrain, the time until ground contact would be used to position the ambient objects vertically. For example, ambient objects that differ from the "normal" ambient objects would begin to flow upwards into the display when the aircraft is some number of seconds from contacting the ground at the current sink rate. As the time to contact decreases, the ambient objects move upwards until, when ground contact is imminent, the entire display is filled with the new ambient objects.

This approach could be used with drive laws based on sink rate, or with drive laws containing higher order components of vertical velocity, such as vertical acceleration.

MODE CONTROL

Automated Mode Control

The results obtained in this program and the impressions we have from using the ambient displays informally in a variety of flight tasks have lead us to the conclusion that a single drive law is not sufficient for the entire flight envelope of a helicopter. The difficulties associated with rapid longitudinal flow of the ambient objects at high speed have been noted and discussed previously. In other aircraft axes, the motion of the ambient objects needs to be tailored to the flight task. It is unlikely, for example, that the pilot is terribly interested in an altitude change of 2 or 3 ft in up-and-away flight. Altitude changes of 2 or 3 ft can make an important difference in hover mode. It may be that drive laws on the vertical and longitudinal axes can be developed that are appropriate to specific flight regimes.

Assuming that different drive laws can be developed, then it would be useful to develop and test an automated mode control system. An automated mode control system is desirable because of the potential to reduce or eliminate the workload associated with manual control in normal conditions. For instance, an automated system could select the appropriate drive law for hover, transition, and up-and-away flight without requiring the pilot to perform any actions at all. In addition, an automated mode control could be extended to cue the pilot in emergency conditions. For instance, in the event of a loss of power, an automated mode control system could alter the vertical and longitudinal flow of the ambient displays so that when the motion is nulled, the aircraft is at its best airspeed and rate of descent.

Pilot Mode Control

Several pilots have commented that ambient displays would be useful in one or more situations, but that they don't believe that they would want them present during an entire flight. For instance, one helicopter pilot who has flown Emergency Medical Services (EMS) missions mentioned that ambient displays would be useful when trying to maintain position when attempting to hoist a person from a confined area or off the side of a hill at night or in conditions of reduced visibility. Another pilot mentioned that an ambient display would be useful when attempting to maintain a stable hove position while delivering mechanical equipment (e.g., an air conditioner unit) to the roof of a high rise building.

These tasks suggest that there may be some value in allowing pilots to select and deselect ambient displays manually.

INTEGRATION OF AMBIENT DISPLAYS WITH PANORAMIC NIGHT VISION GOGGLES

Panoramic Night Vision Goggles (PNVG) provide pilots a much wider field of view (FOV) than is available with conventional NVGs. One of the major advantages of the wider FOV is that the motion of objects in the displays provides aircraft orientation cues that can be processed by the ambient system. This is not only due to the PNVGs stimulating the peripheral retina (recall that the ambient system receives input from the entire retinal), but due to he increased retinal area being stimulated. There are, however, situations where PNVGs will not be able to provide visual cues to the pilot. White-outs and brown-outs are two examples of situations where PNVGs, or normal, unaided vision for that matter, are ineffective. Other conditions where the information available from PNVGs will be insufficient are flights in impoverished cue conditions, such as at high altitude over smooth water at night or in IMC conditions. We believe that the effective operating envelope of PNVGs can be extended to these conditions, or at the very least safety will be enhanced when these conditions are encountered, by the integration of ambient cueing.

Integrating ambient cueing into PNVGs can be accomplished relatively easily using the same approach as the ANVIS HUD. That is, a symbol generator can be placed on the objective end of the peripheral display tubes of the PNVGs. Ambient symbols would be presented on these display surfaces, rather than the focal symbols presented on the ANVIS HUD. From the pilot's point of view, the ambient symbology would appear superimposed on the PNVG display of the out-the-window scene. In order to properly position the ambient symbols, the pilot's head position would need to be measured. This adds some measure of complication, but air worthy head tracking systems are beginning to be available from several sources.

CONCLUSIONS

This program has demonstrated that ambient displays can be effective as sources of aircraft orientation information in some instances. There are limitations on the range of tasks and conditions where ambient objects are useful. Pilots were better able to use ambient displays when the aircraft maneuvering was limited to one or two dimensions than when the maneuvering involved simultaneous changes in all six degrees of freedom.

The experiments conducted during this program were able to identify the ranges of size, shape, and density of the ambient objects that were most effective and acceptable to pilots, at least when presented using a bill board display metaphor. The research also showed that a linear drive law relating airspeed to the longitudinal flow of the ambient objects across the display was generally preferred at low speeds. At higher speeds display drive laws that reduced the motion of the ambient objects when the airspeed was constant were also acceptable. In all cases, displays which the aircraft's acceleration (vice airspeed) was used to drive the ambient objects across the displays was unacceptable due to the potential to mislead the pilot as to the direction of the aircraft's motion. Artificial horizons extending across the peripheral displays were generally not effective in terms of improving pilot performance on the flight task used in these experiments unless the horizon was accompanied by ambient objects driven by aircraft orientation and translation. It may be that a horizon alone would be beneficial in other tasks, possibly up-and-away flight tasks.

During this program a helicopter simulator tailored to the unique requirements of presenting and testing ambient displays was developed. Unfortunately, this development consumed considerably more resources than anticipated. This had the effect of reducing the resources available to explore the effects changes in the characteristics of ambient displays have on pilot performance. A number of important research issues that should be addressed have been identified. It is our hope that this device will be used to continue the research started in this program.

References

Held, R. (1968). Dissociation of visual function by deprivation and rearrangement. *Psychologische Forschung*, 31, 338-348.

Hennessy, R.T. and Sharkey, T.J.(May, 1997). *Display of Aircraft State Information for Ambient Vision Processing Using Helmet Mounted Displays* (USAATCOM TR 97-D-5). U.S. Army Aviation and Troop Command, Aviation Research, Development & Engineering Center. Ft. Eustis, VA.

Leibowitz, H.W. and Post, R.B. (1982). The two modes of processing concept and some implications. In J. Beck (Ed.), *Organization and Representation in Perception* (p. 343-363). Hillsdale, NJ: Erlbaum.

Majendie, A.M.A. (1960). The para-visual director. *The Journal of the Institute of Navigation*, 13, 447-454.

Malcolm,. R.E. (1984). Pilot disorientation and the use of a peripheral vision display. *Aviation, Space, and Environmental Medicine*, (March 1984), 231-238.

Money, K.E., Malcolm, R.E., and Anderson, P.J. (1976). *The Malcolm Horizon*. AGARD Conference Proceedings No. 201.

Schneider, G.E., (1967). Contrasting visuomotor functions of tectum and cortex in the golden hamster. *Psychologische Forschung*, 31, 52-62.

US Army Aviation and Troop Command (10 May 1996). *Aeronautical Design Standard: Handling Qualities Requirements for Military Rotorcraft (ADS-33D-PRF)*. St. Louis, MO: Aviation Research, Development, and Engineering Center.

APPENDIX 1

Operating Instructions for the Development and Evaluation System (DAES)

OPERATING INSTRUCTIONS FOR AMBIENT FOCAL PHASE II SIMULATION

I. Equipment Operation

1.0) Power Up The Computers and Equipment

1.1 - Apply power to the simulation host computer (the Dell Dimension P166v as of this writing). Turn on power to the host computer monitor.

1.2 - Apply power to the three remote monitors.

1.3 - Apply power to the head tracker (Polhemus 3SPACE FASTRAK). Verify that the transmitter cable is inserted into the transmitter connector at the front of the FASTRAK unit. Verify that the headtracker receiver is connected to the appropriate receiver connector (connector two as of this writing) on the front of the FASTRAK unit. Wait for the green status light on the front to stabilize (in the green state), before moving to the next step.

1.4 - Apply power to the FlyBox.

2.0) Bringing Up The GUI

2.1 – Apply power to the Indy and wait for IRIX to boot.

2.2 – Log in to 'ahmd', by selecting the 'ahmd' icon and double clicking. Enter 'ahmd99' at the password prompt and depress the return key. This should get you to the IRIX command line prompt, in the /usr/AHMD directory. Enter 'pwd' at the command line prompt to confirm that you are in the correct directory. Entering 'ls' at the command line will list all the files in the directory. Executable files are indicated by appending a '*' to the last character of the file name. There should be a file called 'ahmdctrlxx' where the 'xx' is a version number.

2.3 – If able to confirm that you are in the correct directory and the executable exists, enter the name of the current GUI executable, and follow it with a <cr>. As of this writing, the current executable is 'ahmdctrl12'.

2.4 – To exit from the GUI after completing your simulation runs, move the cursor to the upper left of the GUI window and click on the small square box with the horizontal bar. Select exit from the drop down window.

3.0) Start The Simulation Executable

3.1 - Double click the icon labeled 'ahmd.exe' on the Win95 desktop.

3.2 - A Win95 shell will be created, initialization messages will appear, and the screen will darken. Wait 10 seconds after the screen goes black, and toggle the trigger on the FlyBox. One or more of the three remote monitors will display the data base.

3.3 - The sim is now in an operational state.

4.0) Performance

4.1 - The sim has been tuned for optimum performance with the head tracker powered up. It does not have to be logically operational, but does need to have power applied. If power has not been applied, the sim may run slightly slower than it is capable of running.

5.0) Tuning the user configurable parameters

5.1 - The file 'user_parms.inc' can be modified to tune the simulation. This file is found in the 'c:\AHMD\dev' directory. A standard text editor can be used to make modifications. Tunable parameters are shown below in upper case letters, following the #define compiler directive. Comments are shown following the double slash (//). Blank lines are ignored and included for readability.

II. User Enabled Functions

```
//
//      user_parms.inc
//
//      This file contains all the 'user enabled' conditions
//
//      Author:     Tom Marlow
//      Date:       7/17/98
//      Version:    1.0
//

//
//---------------------------------------------------------------------------------------------------------
//
//      HUD display control
//

#define b_ALT  TRUE        // TRUE or FALSE to control display of baro altitude HUD
#define HDG    TRUE        // TRUE or FALSE to control display of heading HUD
#define AS     TRUE        // TRUE or FALSE to control display of airspeed HUD
#define r_ALT  TRUE        // TRUE or FALSE to control display of radar altitude HUD

//
//-----------------------------------------------------------------------------------------------
//
//      Head Tracker Control variable. Use this to enable or disable the
//      head tracking hardware. When disabled, it is safe to remove power
//      from the head tracker i.e. it will not degrade performance if the power
//      is set to off. When enabled (HT_ON set to TRUE), power must be applied to the
//      head tracker to avoid a performance penalty.
//

#define HT_ON          TRUE          // TRUE or FALSE to control head tracker operations

//
//-------------------------------------------------------------------------------------------------------------
//
//      Secondary Task control variables
//

#define SECONDARY  TRUE          // TRUE or FALSE to control secondary task
#define DELAY      1000          // initial delay for 'numbers' display, units TBD
#define DISPLAY    500           // amount of time that the digits are displayed, units TBD
```

```
//
//-----------------------------------------------------------------------------------------------------
//
//      The following initialization coordinates need to be obtained
//      from the Realibase being used for the simulation.
//

//#define INIT_X        (float)-6800.00         // starting X in Realibase helisim
//#define INIT_Y        (float)-6000.00         // starting Y in Realibase helisim
//#define INIT_Z        (float) 200.00          // starting Z in Realibase helisim
#define INIT_X          (float)  101293.00      // starting X in Realibase Monterey
#define INIT_Y          (float)  141721.00      // starting Y in Realibase Monterey
#define INIT_Z          (float) 200.00          // starting Z in Realibase Monterey

#define INIT_H          (float)  180.0          // starting ownship heading in degrees

//#define INIT_AMBO_Y           (float) -65.0   // starting elevation for 3D ambient
//#define INIT_AMBO_X           (float) 100.0   // starting X for 3D ambient
//#define INIT_AMBO_Z           (float) 100.0   // starting Z for 3D ambient
#define INIT_AMBO_Y             (float) 0.0     // starting elevation for 2D ambient
#define INIT_AMBO_X             (float) 0.0     // starting X for 2D ambient
#define INIT_AMBO_Z             (float) 0.0     // starting Z for 2D ambient


//
//-----------------------------------------------------------------------------------------------------
//
//      The following crosswind variables are used to add crosswinds to the sim
//
//      There is no wind model in the simulation math model.  By adding winds, the
//      experimenter is adding offsets to the aircraft coordinate system (X, Y, Z).
//      The winds (offsets) are summed, so that winds defined for the X and Z axis,
//      will move the aircraft along a ray between the X and Z axis'.  The direction
//      of the ray will be a function of the magnitude of the 'wind' defined for the
//      X and Z axis.
//
//      A positive X value will push the aircraft to the East, i.e. winds are out of the West
//      A positive Z value will push the aircraft to the North, i.e. winds are out of the South
//      A positive Y value will push the aircraft 'up', i.e. away from the terrain
//
//      Use the CROSS_WIND variable to turn the 'winds' on and off.  CROSS_WIND
//      set to TRUE with the XWIND_X, XWIND_Y, and XWIND_Z set to 0.0, is functionally
//      equivalent to CROSS_WIND set to FALSE.  The XWIND_X, Y, and Z values are
//      ignored when the CROSS_WIND variable is set to FALSE.
//
```

```
#define CROSS_WIND FALSE                // TRUE or FALSE to control Cross winds

//#define XWIND_X        (float)0.5     // roughly 50 knot xwind
#define XWIND_X          (float)0.25    // roughly 25 knot xwind
#define XWIND_Y          (float)0.0
#define XWIND_Z          (float)0.0

//
//-----------------------------------------------------------------------------------
//
//      The AC_PHI value defines the camera rotation from the center, of
//      the left and right displays. Rotation is in degrees clockwise (right
//      display) and counterclockwise (left display).
//

#define AC_PHI           50.0F

//
//-----------------------------------------------------------------------------------
//
//      The Height Of Terrain (HOT) is used as an offset for landing the
//      airframe when ownship is located near the airbase in the Monterey
//      visual data base.
//

#define HOT              61.0F

//
//-----------------------------------------------------------------------------------
//
//      Use the 'control condition' variable to determine which data base to
//      to load, and which lighting conditions to display. TRUE = 3
//      channel OTW, FALSE = ambient side channels.
//

#define CONTROL_CONDITION      FALSE      // TRUE or FALSE
```

```
//
//------------------------------------------------------------------------------------------------
//
//      The following parameters can be used as factors in the
//      equations of motion for the ambient fields.
//

#define MIN_AS          (float) 0.0       // limit range of ambient motion
#define MAX_AS          (float) 100.0     // limit range of ambient motion
#define AS_SCALE        (float) 0.005     // scale the raw AC airspeed value
#define MIN_ALT         (float) 0.0       // limit range of ambient motion
#define MAX_ALT         (float) 2000.0    // limit range of ambient motion
#define ALT_SCALE       (float) 0.7       // scale the raw AC altitude value
#define YAW_SCALE       (float) 20.0      // scale the raw AC yaw value
#define PITCH_SCALE     (float) 1.0       // scale the raw AC pitch value
#define ROLL_SCALE      (float) 0.07      // scale raw AC roll value
#define MOV_SCALE       (float)  0.25     // scale raw AC longitudinal flow
#define LOOM_SCALE      (float) 0.25      // scale raw 'looming' value

//
//------------------------------------------------------------------------------------------------
//
//      The following can be used as scale factors in the equations of motion
//      for the movement of the horizon. The horizon(s) is separate geometry that
//      moves according to it's own set of drive laws, that are independent of
//      any other geometry in the scene. These scale factors can be used to
//      fine tune the movement of the horizons, without influencing the movement
//      of the ambient displays.
//
//      The variables preceded by the 'HT_' are used as scale factors for the
//      movement that the head tracking mechanism adds to the movement of the
//      horizon.
//

#define HORIZON         TRUE              // display horizon, T or F
#define H_ROLL_SCALE    (float) 5.0       // horizon roll scale factor
#define H_PITCH_SCALE   (float) 1.0       // horizon pitch scale factor

#define HT_ROLL_SCALE   (float)  10.0     // head tracker horizon scale factor
```

```
//
//---------------------------------------------------------------------------------------------------------
//
//        Use the 'collect' variable to toggle data collection.  If COLLECT = TRUE, data
//        will be collected.  If COLLECT= FALSE, data will not be collected.  The set of
//        variables being  collected is static and embedded  in the 'C' code of the main routine.
//
//        SCREEN_PRINT controls the screen dump of the data collection
//        variables as the simulation is exiting.
//

#define COLLECT              FALSE        // TRUE or FALSE
#define SCREEN_PRINT         FALSE        // TRUE or FALSE

//
//---------------------------------------------------------------------------------------------------------
//
//        The following parameters introduce different drive laws to the simulation.  Each degree
//        of freedom has it's own drive law(s).  Only one drive law will be enabled at any given
//        time, for each degree of freedom.  If multiple drive laws, for a specific degree of freedom
//        are mistakenly enabled (set to TRUE), only the first will be acted upon.  For example, if
//        five drive laws have been defined for PITCH, and all five have been mistakenly enabled
//        (set to TRUE), only the first of the five will be acted upon.  It is a good practice to set all
//        drive laws that are not intended to be used to FALSE.
//
//        A value of TRUE will enable a specific drive law equation.  Each equation will animate
//        the ambient fields in a specific degree of freedom.  Degrees of freedom are as follows:
//
//        LOOM        - movement along the lateral axis of motion (left and right)
//        PITCH       - movement in pitch of the aircraft
//        ALT         - movement in altitude (movement along Realimation Z axis)
//        AS          - movement along the longitudinal axis of motion (front to rear)
//        YAW         - movement in aircraft yaw (heading)
//        ROLL        - movement in roll of the aircraft
//

#define LOOM_DL1      FALSE              // looming function

#define PITCH_DL1     FALSE              // pitch = change in altitude
#define PITCH_DL2     FALSE              // pitch += change in altitude
#define PITCH_DL3     FALSE              // pitch = roll

#define ALT_DL1       FALSE              // alt = delta Y

#define AS_DL1        TRUE               // as = delta X + delta Z

#define YAW_DL1       FALSE              // yaw = delta heading

#define ROLL_DL1      FALSE              // roll = roll
```

```
//
//------------------------------------------------------------------------------------------
//
//      Use the following switch to control the display of the ambient displays.
//      The ambient displays are independent of the horizon display.  It is
//      possible to display the ambients without the horizon, or display the
//      horizon without the ambients, by setting the respective display flags
//      TRUE and FALSE.  It is also possible to display both horizon
//      and ambients by setting both display flags TRUE or display neither by
//      setting both display flags FALSE.
//
//      if (AMBIENT)
//              display ambient patterns
//      else
//              display black background
//

#define AMBIENT         FALSE           // TRUE or FALSE
```

III Data Collection

```
//
//      The following algorithm is used to collect data from a simulation run.  The discrete list of
//      variables shown below is used to determine which variables to collect.

//
//      Data Collection
//
// Get time and write to data file
//

ltime = timeGetTime();                                  // get system time in milliseconds

  if (d_collect) {
        frame_data[loop_count].x = x_position_north;   // rbs co-ordinates (meters in Monterey.rbs)
        frame_data[loop_count].y = y_position_east;    // ownship y
        frame_data[loop_count].z = z_position_down;    // ownship z
        frame_data[loop_count].pitch = ac_pitch;       // ownship pitch in deg radians
        frame_data[loop_count].roll = ac_roll;         // ownship roll in deg
        frame_data[loop_count].yaw = ac_yaw;           // ownship yaw heading in deg
        frame_data[loop_count].as = u_airspeed;        // ownship forward airspeed in knots
        frame_data[loop_count].a_agl = -12;            // temp value for now

        frame_data[loop_count].trk_pitch = ht_offset.pitch;    // head tracker pitch, radians
        frame_data[loop_count].trk_roll = ht_offset.roll;      // head tracker roll, radians
        frame_data[loop_count].trk_yaw = ht_offset.yaw;        // head tracker yaw, radians
        frame_data[loop_count].wind_vel_x = XWIND_X;           // wind velocity in X
        frame_data[loop_count].wind_vel_y = XWIND_Y;           // wind heading in Y
        frame_data[loop_count].wind_vel_z = XWIND_Z;           // wind heading in Z

        frame_data[loop_count].rand_left     = i_p1;           // left random digit, sec task
        frame_data[loop_count].rand_mid      = i_p2;           // middle random digit, sec task
        frame_data[loop_count].rand_rht      = i_p3;           // right random digit, sec task
        frame_data[loop_count].exp_control = -12;              // temp value
        frame_data[loop_count].fb_long = longitudinal_cyclic_in; // stick raw input, longitudinal
        frame_data[loop_count].fb_lat = lateral_cyclic_in;     // stick raw input, lateral
        frame_data[loop_count].fb_coll = collective_in; // collective raw input
        frame_data[loop_count].fb_rudder = rudder_in; // rudder raw input
        frame_data[loop_count].kill          = sw11;           // kill sim switch
        frame_data[loop_count].pause         = sw12;           // pause sim switch
        frame_data[loop_count].mom_left      = mom1;           // momentary switch 1
        frame_data[loop_count].mom_right     = mom2;           // momentary switch 2
        frame_data[loop_count].count  = loop_count;            // loop count

    //          spare1 and spare2 changed on 16 September 1999
        frame_data[loop_count].spare1 = (int) -12;     // spare integer – RADAR ALTITUDE in ft
```

```
        frame_data[loop_count].spare2 = (int) -12;      // spare integer - BARO ALTITUDE in ft

        frame_data[loop_count].spare3 = (float) -12;            // spare float
        frame_data[loop_count].spare4 = (float) -12;            // spare float
        frame_data[loop_count].time = ltime;                    // system time
        if (loop_count >= DATA_BUFFER-1) d_collect = FALSE;
        loop_count += 1;
}

//
//      stop data collection when end of buffer is reached, or when sim is terminated
//

if (loop_count >= DATA_BUFFER-1) d_collect = FALSE;
        loop_count += 1;
}
```

IV. Changing Camera Rotation Angle

To change the rotation angle of the camera for the left and right displays, it is necessary to invoke the Realimation Space and Time Editor (STE). The STE is used to manipulate the visual data base on an off-line basis. While it is possible to add dynamic features to the data base, this STE function is not used in the AHMD simulation. Static changes such as changing the camera rotation angle are made by the STE, and dynamic movements are done in the program algorithms.

To change the camera rotation angle, perform the following sequence of steps;

1. Invoke the STE by double clicking on the AHMD data base icon. As of this writing, the icon is labeled 'mon_2space.rbs'. It is located in the C:\AHMD\dev\sim\data directory.

2. Verify that the 'Views' window is open.

If it is not open, move the mouse cursor to the topmost (of nine) icons on the right hand edge of the STE GUI. If the cursor is held stationary over this icon, it should display a tiny window in yellow with the text 'toggle views'. Depress the left mouse button to toggle the 'views' window. If the views window is the only window open (excepting the GUI itself), toggling it closed, will effectively unload the data base. If this occurs, go back to step 1.

If the 'Views' window is open, there will be three views displayed. They are labeled Main View, LeftAmbientView, and RightAmbientView.

3. Click the mouse cursor on the + (yellow plus sign) to the left of the LeftAmbientView. This will change the plus sign to a - (minus sign) and expand the component geometry of the LeftAmbientView.

4. Double click on the 'leftCam' line item. This will bring up a window with camera controls in it. Click on the 'Offset' tab, if it is not already displayed. This will give you control of the position and orientation of the camera associated with the left ambient display.

5. Change the yaw field to the desired camera angle of rotation. A yaw value of 0 positions the camera at 90 degrees to the ambient billboard (looking out 90 degrees to the longitudinal axis of ownship). Increasing the yaw value swings the camera forward until it is parallel to the longitudinal axis of ownship. After making changes to the yaw value, click on the 'Apply' button in the bottom of the leftCam window.

6. Click on the File|Save at the upper left corner of the STE GUI.

This completes the procedure to make a static change to the left view of the data base. The right view is changed in the same way. To change the right view, change all references to LeftAmbientView to RightAmbientView in the procedure above. Changes to the yaw value for the right camera should be the mathematical negative of the left channel e.g. a left view change of 45 degrees should be matched with a right view change of –45 to achieve the desired effect in the movements of the ambients. To view the change dynamically (if appropriate), it is necessary to bring up the simulation. This is done by following the procedure 2.0 in the Equipment Operation section of this manual.

V. Creating or Replacing Ambient Grids

Before proceeding with the following procedure, be forewarned that the end result may be a data base that is no longer compatible with the program algorithms that are necessary to animate the grids. BEFORE CONTINUING, MAKE A COPY OF THE DATA BASE.

To an ambient grid for the left and right displays, it is necessary to invoke the Realimation Space and Time Editor (STE). The STE is used to manipulate the visual data base on an off-line basis. While it is possible to add dynamic features to the data base, this STE function is not used in the AHMD simulation. Static changes such as creating an ambient grid are made by the STE, and dynamic movements are done in the program algorithms.

To replace an ambient grid, perform the following sequence of steps;

1. Invoke the STE by double clicking on the AHMD data base icon. As of this writing, the icon is labeled 'mon_2space.rbs'. It is located in the C:\AHMD\dev\sim\data directory.

2. Verify that the 'Views' window is open. You will need to add the grid to the view after it is created.

If it is not open, move the mouse cursor to the topmost (of nine) icons on the right hand edge of the STE GUI. If the cursor is held stationary over this icon, it should display a tiny window in yellow with the text 'toggle views'. Depress the left mouse button to toggle the 'views' window. If the views window is the only window open (excepting the GUI itself), toggling it closed, will effectively unload the data base. If this occurs, go back to step 1.

If the 'Views' window is open, there will be three views displayed. They are labeled Main View, LeftAmbientView, and RightAmbientView.

3. Click the mouse cursor on the + (yellow plus sign) to the left of the LeftAmbientView. This will change the plus sign to a - (minus sign) and expand the component geometry of the LeftAmbientView.

4. Locate the grid that you will be replacing in the left view. As of this writing, there are two candidate grid placements: upGridLeft, and leftGrid_1. As an example, to replace the left grid, click on the yellow + (plus sign) to the left of the leftGrid_1 placement. This will reveal a green cube and the graphical representation of the grid geometry. You can view the grid geometry (not necessary) by double clicking on leftGrid1. If you view the grid geometry, close out the window with the rotating grid geometry before proceeding.

5. Highlight the left grid geometry by clicking once, then use the scissors icon (STE GUI at the top) to cut(delete) the grid from the view.

6. Move the mouse cursor to the create function at the top of the STE GUI. Click on Create|Shape|Grid.

7. The grid creation tool will open. You will now need to create the grid in your own image and likeness (so to speak). Be sure to create the grid with 80 X squares and 40 Z squares. Beyond that limitation, you are on your own.

8. After creation, the grid will be represented by a line item (label of your choice, assigned during creation) in the 'shapes' window. Find your shape (newly created shapes are always added at the end of the list) and add it to the placement where the original shape was deleted (step # 5). Add your newly created shape to the old placement, by dragging it with the mouse.

9. Click on the File|Save at the upper left corner of the STE GUI.

This completes the procedure to make a static change to the left view in the data base. The right view is changed in the same way. To change the right view, change all references to LeftAmbientView to RightAmbientView in the procedure above. To view the change dynamically (if appropriate), it is necessary to bring up the simulation. This is done by following the procedure 2.0 in the Equipment Operation section of this manual.

VI. Moving the Ambient Camera Near or Far To/From The Grid

To change the distance of the camera from the left and right displays, it is necessary to invoke the Realimation Space and Time Editor (STE). The STE is used to manipulate the visual data base on an off-line basis. While it is possible to add dynamic features to the data base, this STE function is not used in the AHMD simulation. Static changes such as moving the viewing distance of the camera are made by the STE, and dynamic movements are done in the program algorithms.

To change the camera viewing distance, perform the following sequence of steps;

1. Invoke the STE by double clicking on the AHMD data base icon. As of this writing, the icon is labeled 'mon_2space.rbs'. It is located in the C:\AHMD\dev\sim\data directory.

2. Verify that the 'Views' window is open.

If it is not open, move the mouse cursor to the topmost (of nine) icons on the right hand edge of the STE GUI. If the cursor is held stationary over this icon, it should display a tiny window in yellow with the text 'toggle views'. Depress the left mouse button to toggle the 'views' window. If the views window is the only window open (excepting the GUI itself), toggling it closed, will effectively unload the data base. If this occurs, go back to step 1.

If the 'Views' window is open, there will be three views displayed. They are labeled Main View, LeftAmbientView, and RightAmbientView.

3. Click the mouse cursor on the + (yellow plus sign) to the left of the LeftAmbientView. This will change the plus sign to a - (minus sign) and expand the component geometry of the LeftAmbientView.

4. Double click on the 'leftCam' line item. This will bring up a window with camera controls in it. Click on the 'Camera' tab, if it is not already displayed. This will give you control of the position, orientation, clipping, and field of view of the camera associated with the left ambient display.

5. Change the Y field (in the position) to the desired viewing distance. Units are in meters. Changing the viewing distance will also change the angular speed of the camera across the grid, thus you will probably want

to change the multipliers in the drive laws as well, if you change the viewing distance. Then click on the 'Apply' button in the bottom of the leftCam window.

6. Click on the File|Save at the upper left corner of the STE GUI.

This completes the procedure to make a static change to the left view of the data base. The right view is changed in the same way. To change the right view, change all references to LeftAmbientView to RightAmbientView in the procedure above. To view the change dynamically (if appropriate), it is necessary to bring up the simulation. This is done by following the procedure 2.0 in the Equipment Operation section of this manual.

VII. Data Base Design

Several Realimation data base files have been created to work with the AHMD simulation. All of the data bases developed share a common architecture. Any newly developed data bases, if they are to work with the AHMD simulation are required to share the same architecture, as it is defined below. The names of the views and top level placements need to be strictly adhered to. Names of the underlying geometry (or shapes in the Realibase paradigm) can be of your own choosing. This description is valid for all the working data bases for the AHMD program, as of this date. In order of development from first to last, they are ahmd_v1.rbs, ahmd_v2.rbs, and ahmdvdb.rbs. They can be found in the c:\AHMD\dev\sim\data directory.

There are three views in the AHMD data base. A main view, which is the out-the-window view, a left view, and a right view, which correspond to the left and right ambient view. The description contained herein, contains only the first three levels of the architecture, a view, a placement, and a shape. Although this is enough of a description to ensure that any data base will work properly with the AHMD code, it does not describe the entire data base. In the Realimation paradigm, a shape can consist of placements, which can consist of shapes etc. Thus the lowest level of the main view described herein, may consist of placements within shapes, within placements etc. The left and right views are less complicated, as of this writing. The possibility remains that additional complexity will be embedded in the future.

1.0 Main View Architecture

View: Main View - this view contains the Monterey terrain

placement: - Terrain
shape: N36_45_0W121_30_0.flt

placement: - Placement of ADS hover
shape: ??????

placement: - Player
shape: camo net (ownship)
camera: main view camera

atmospherics: - main view atmospherics

camera: - main view camera

2.0 Left Ambient View Architecture

View: LeftAmbientView

placement: - Left Horizon
shape: leftHorizonG

placement: - LeftGrid_1
shape: leftGrid1

placement: - LeftGrid_2
shape: leftGrid2

placement: - UpGridLeft
shape: upGridLt

atmospherics: - main view atmospherics

camera: - left cam

3.0 Right Ambient View Architecture

view: RightAmbientView

placement: - Right Horizon
shape: rightHorizonG

placement: - RightGrid_1
shape: rightGrid1

placement: - RightGrid_2
shape: rightGrid2

placement: - UpGridRight
shape: upGridRt

atmospherics: - main view atmospherics

camera: - right cam

VIII. Data File Manipulation

The data collection function is performed by the 'ahmdctrlxx' process, that executes on the Indy. Data files can be moved directly into a spreadsheet program such as MS Excel, using the following procedure.

1.0 After a simulation run, note the file name that the GUI uses to save the collected data. Bring the simulation down (on the PC), and bring up a DOS window.

2.0 From the DOS window, type 'ftp views3' and <cr>. Views3, is the current name of the Indy running the GUI executable. If this name changes, the 'ftp views3' command will have to change to the appropriate new name for the Indy. The ftp program will display the following prompt: 'User (views3.mti.com:(none)):'. You will need to enter ahmd (the directory name on the indy) and a <cr>. FTP will then prompt for a password. Enter the current password for the ahmd directory on the Indy. As of this writing, the password is 'ahmd99' without the quotes. FTP will respond with 'user ahmd logged in'.

3.0 From the ftp command line, enter 'cd Data'. This command is case sensitive. FTP will respond with 'CWD command successful'. Then enter 'ls'. FTP will respond with a list of files in the 'usr/AHMD/Data' directory on the Indy. One of the files should be the file name that you remembered (from step 1.0).

4.0 Enter 'get *filename*' , where *filename* is the name of the data file you are importing to the PC, at the ftp prompt. This command is case sensitive. Pay particular attention to any upper case characters in the file name. The 'get' command will move the file from the Indy, to the PC into the directory where the ftp program was originally started. By default, this is C:\WINDOWS. NOTE: All of the data files on the Indy will have a ".dat" suffix. The files with a ".cfg" suffix are configuration files. The configuration files contain the values shown in the GUI when data collection was terminated.

5.0 Enter "quit" at the ftp command line prompt. This will cause the ftp program to exit, and return you to the C:\WINDOWS directory (by default). The data file is now on the PC. The data file is a comma separated file with a header that labels all the columns. The name of the file conforms to the DOS convention of eight (8) characters with a three (3) character suffix.

SUMMARY OF KEYSTROKES (all entered on the simulation host computer)

ftp views3<cr>
ahmd<cr>
ahmd99<cr>
cd Data<cr>
ls<cr>
get *filename*<cr> the default *filename* is Base_Default.dat
quit<cr>

APPENDIX 2

Experiment 1 Report

Evaluation of Displays Presenting Aircraft State Information for Processing by the Ambient Visual System: Effects of the Density, Shape, and Size of the Ambient Objects on Pilot Performance

SBIR Phase II
Contract Number DAAH10-98-C-0020

25 February 2000

Prepared For:

U.S. Army Aviation & Missile Command
Aviation Applied Technology Directorate
Fort Eustis, VA 23604-5577

Prepared By:

Monterey Technologies, Inc.
24600 Silver Cloud Court
Suite 103
Monterey, CA 93940

EXECUTIVE SUMMARY

This report describes the method and results of the first in a series of planned experiments being conducted to develop effective displays for presenting aircraft state information in a format that is processed by the ambient visual system. Four very experienced helicopter pilots flew a series of maneuvers in a low to moderate fidelity simulator. The out-the-window scene was presented biocularly in a commercial head mounted display (HMD). The HMD was modified by the addition of two peripheral displays, one located to each side of the forward scene. Display presenting information for processing by the ambient visual system was displayed in the two peripheral displays. The presentation of the ambient objects used a "bill-board" metaphor. The ambient objects were presented as if they were painted on stationary bill-boards located at a distance of 20 meters to each side of the aircraft.

In this experiment two levels of the size, shape, and density of the objects presented in ambient displays were manipulated parametrically The two sizes of the ambient objects were small and large. Small grids were 1 meter per side, and large grids were 4 meters per side. The small circles were 1 meter in diameter and the large circles were 4 meters in diameter. The two shapes of ambient objects were grids and circles. The edges of the grids provide cues t the direction of the vertical and horizontal planes. The circles, not having straight edges at right angles, do not provide this same information. In the high density conditions ambient objects occupied 50% of each peripheral display. In the low density condition 12.5% of the area was occupied by ambient objects. There were two control conditions used in this study; a night vision goggle (NVG) simulation and a wide field of view, full daylight scene.

Pilots performed a series of six flight tasks with each combination of display factors in a helicopter simulator and with the two control conditions. These flight tasks were:

- Bob-Up
- Acceleration / Deceleration
- Constant Speed, Constant Rate of Descent Approach
- Precision Hover
- Pirouette
- Slalom

All these tasks, with the exception to the constant speed, constant rate of descent approach task, are variations of the flight tasks described in ADS-33D, *Handling Qualities Requirements for Military Rotorcraft*.

During each flight, aircraft position and attitude information, the position of the aircraft's controls, and the pilot's head position were collected automatically. After completing the flights in which ambient displays were used, the pilot completed a questionnaire. This questionnaire included items relating to the effect of the ambient displays on:

- the pilots ability to maintain awareness of, and detect changes in, aircraft attitude,
- the perceived clutter of the display
- the workload experienced by the pilot,
- the ability of the pilot to perform each of the flight tasks

Pilots also rated the overall acceptability of the displays.

The results indicate that the ambient displays were most effective when the aircraft was moving in only one or two dimensions and the translation rates were low. In these cases, pilots were able to use the information being displayed to improve their performance. In cases where the aircraft was moving in multiple dimensions simultaneously, and in cases where the translation rates were high, pilots were not able to interpret and use the information in the ambient displays to improve their performance. This result suggests that drive laws tailored to the task or flight regime are needed.

The empirical data indicates that small ambient objects lead to better performance in tasks where the rate being controlled is low. When the task involved higher rates, then larger ambient objects lead to better performance. This interaction between aircraft rate and the size of the ambient object is likely due to the ambient system not being able to detect or process the high frequency components. The high frequency components in the display are lost due to the poor resolution on the periphery of the retina. At slow rates, the ambient objects are distinguishable from one another even when they are small and densely distributed. At higher rates, the small ambient objects are not distinguished and are, therefore, less effective than are the larger, still distinguishable, ambient objects.

The rating data indicates that pilots generally found the larger ambient objects to be superior to the smaller ambient objects in terms of the workload experienced, their ability to perform the flight tasks. The larger ambient objects were rated has being less likely to intrude into the pilot's conscious attention.

Few differences in pilot performance attributable to the difference in the shape of the ambient objects were found. Pilots rated the grids as being better than circles bot in terms of the workload experienced during the task and on the pilots's ability to perform the task. Pilots were divided as to whether grids or circles better allowed them to maintain awareness of the aircraft's attitude and to detect changes in attitude.

Very few measures of pilot performance were found to be sensitive to the density of the ambient objects. Not surprisingly, the sparse distributions of ambient objects were judged to be less cluttered than were the dense distributions. There is no clear difference between the pilot ratings of the dense and sparse distributions of ambient objects in terms of workload, the ability to perform the flight tasks, or in the pilot's ability to maintain awareness of or to detect changes in the aircraft's attitude.

Based on these results, it was determined that a grid shape leads to better performance and improved pilot acceptance than did the circular shape. The best density and size are not so clear. It appears that small sizes are most useful only when they are moving slowly on the ambient display. In most cases, performance with large objects is comparable, and is more acceptable to the pilots because of the reduced clutter. However, in some cases the number of large objects visible in the scene was small, making it more difficult for the pilot to get a sensation of the direction and magnitude of the motion. Therefore, ambient objects whose size is between the small and large ones used in this study is recommended for future use.

Like size, the results with regard to the density of the ambient objects is somewhat ambiguous. The sparse distribution is perceived to be preferable in terms of clutter and the amount of space between the objects. However, in the sparse conditions there were too few objects visible, particularly when the rates were low, for the information in the ambient displays to be useful to the pilot. Therefore, a density on the order of 25% is expected to result in a better tradeoff between the number of objects visible and the presence of an adequate number of objects over a larger range of aircraft rates than either of the densities used here.

INTRODUCTION

This report describes the methods, results, and conclusions of an experiment conducted to identify an effective combination of shape, density, and size of objects presented in peripheral displays for use in subsequent evaluations. These objects are intended to provide helicopter pilots information about aircraft attitude in a manner that allows that information to be processed by the ambient visual system.

There are two functionally and anatomically distinct portions of the human visual system. These are the focal and the ambient systems. The focal system has been characterized as a "what" system. The focal system receives its input only from the foveal region. Operation of the focal system requires a higher level of image quality, luminance level, and contrast than does the ambient system. The fine spatial resolution of the retinal image allows the person to see the details needed to identify objects using focal information. In addition, processing information acquired via the focal system places demands on conscious information processing resources. Virtually all existing flight symbology has been designed to be perceived and processed by the focal system.

The ambient system has been described as a "where" system. The ambient system provides information regarding the observer's position, orientation, and movement in space. The ambient system, which receives input from the entire retina, begins to operate at lower levels of luminance and contrast than does the focal system. Processing of information by the ambient system is done at a subconscious level, and does not compete with the focal system for cognitive resources. Ambient displays operate on the principle of mass action. The more of the retina stimulated by ambient displays the more effect on the perception of self orientation.

Little is known regarding the relationships between the density, shape, and size of objects and their effectiveness. This experiment was conducted to identify symbols that would be effective for future research.

Two levels each of size, shape, and density of ambient objects were combined parametrically in this study. The levels of size and density were selected to include what appeared to be the effective range based on informal evaluations conducted previously. The two levels of shape, squares and circles, where selected to examine the effect of having high spatial frequency vertical and horizontal components (in the squares) on the effectiveness of the ambient displays.

The maneuvers flown in this study, with one exception, were based on the flight maneuvers described in the Aeronautical Design Standard for Handling Qualities Requirements for Military Rotorcraft, ADS-33. The exception was a constant speed, constant rate of descent approach to a landing area. This task was selected as it is similar to the approach made by Navy helicopters to ships. The approach to shipboard landing is a difficult because of the lack of visual cues. It is anticipated that ambient displays would be an aid to pilots when making this type of an approach.

METHOD

PILOTS

Five pilots, all men, participated in this experiment. One pilot was became unavailable due to schedule conflicts after completing only a single familiarization flight. The data reported here is from the remaining four pilots.

The pilots participating in this experiment were highly experienced. Two were civilian test pilots based at NASA Ames Research Center, one was an active duty Army pilot assigned to the US Army Aeroflghtdynamics Directorate at NASA Ames Research Center, and the fourth was an active duty Navy helicopter pilot assigned to the National Rotorcraft Technology Center. They had an average of over 2800 hours (standard deviation =1376 hours) as pilot in command (PIC) of rotary wing aircraft, and an average of over 1400 hours (standard deviation =1546 hours) as PIC of fixed wing aircraft. The average age of the pilots was 44 years. Three of the four pilots wore glasses or contact lenses.

All of the pilots were briefed on the purpose of this study, the tasks that they would be performing, and on the known risks of participating in this study.

SIMULATOR

FLIGHT CONTROLS

The Development and Evaluation System (DAES) was used in this experiment. DAES is a low fidelity helicopter simulator. DAES uses a conventional helicopter control arrangement (i.e., cyclic, side mounted collective, anti-torque pedals). The control hardware is from Flight Link (Chico, CA).

HEAD MOUNTED DISPLAY

The visual scene is presented in a modified Kaiser Electro-Optics Proview 30 (Carlsbad, CA) head mounted display (HMD). The modifications to the HMD consist of adding two 2.5 inch NTSC displays; one to the right and the other to the left of the Proview 30 displays. On these displays the ambient scene is presented in experimental conditions and the peripheral view of the out-the window display is presented in the daylight, full field of view control condition. In the NVG only control condition the additional displays are blank.

FLIGHT SYMBOLOGY

A limited set of flight information was presented digitally. The information consisted of:

- Radar Altitude (ft)
- Barometric Altitude (ft)
- Forward Airspeed (kts)
- Aircraft Heading (degrees)

In addition to the digital information, a turn coordination ball and a collective position indicator were displayed. All of this information was presented as if it were on a Head-Up Display fixed to the cockpit in front of the pilot.

GAMING AREA

The terrain model in DAES represents the Monterey, CA area. This model, which is made available without charge from SGI and Multigen, was modified with the addition of markers on the ground used in the performance of flight tasks described in ADS-33.

AMBIENT DISPLAY CONDITIONS

In the experimental conditions, ambient objects were presented in the left and right peripheral displays. The ambient object were varied parametrically in terms of the size (1 meter, 4 meter), the shape(rectangle, circle), and the density (50%, 12.5%) of the objects. Figure 1 shows the ambient display conditions.

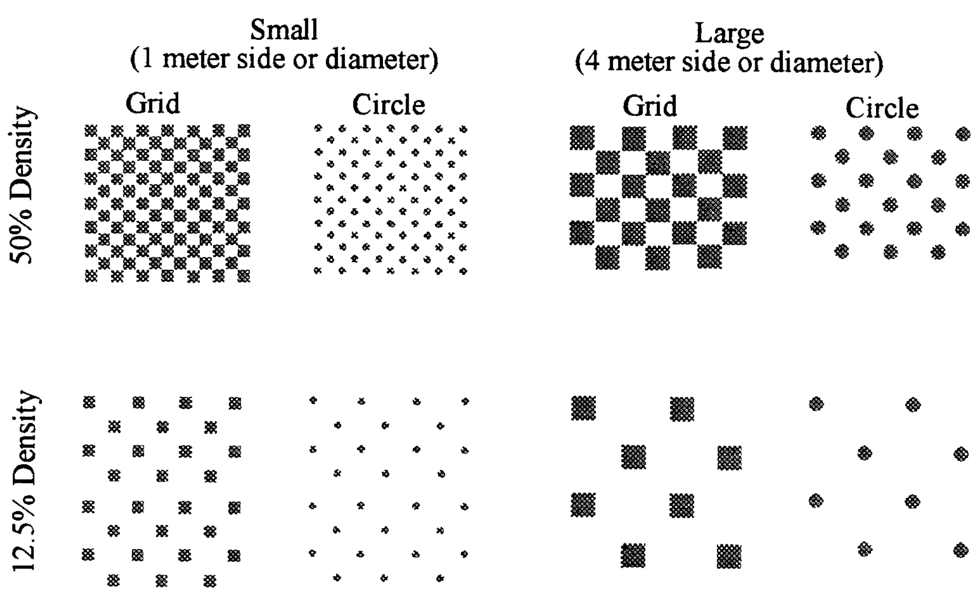


Figure 1. Ambient Display Conditions Presented In Experiment 1.

CONTROL CONDITIONS

Two control conditions were used; a full daylight, wide FOV condition and a NVG only condition. In the daylight control condition a daylight scene was displayed in the forward visual channels as well as in the peripheral displays. In the NVG only condition the forward scene was presented only in the two forward displays; the peripheral displays were blank. Both control conditions were flown after all of the experimental conditions had been completed.

TEST MANEUVERS

Six test maneuvers were performed in each of the experimental and control conditions. These maneuvers were:

- Bob-Up, Turn to Target
- Acceleration/Deceleration
- Constant Speed and Rate of Descent Approach to Landing
- Precision Hover
- Pirouette
- Slalom

The maneuvers are described below. All of these maneuvers, with the exception of the Constant Speed and Rate of Descent Approach to Landing, are variations of the maneuvers described in ADS-33.

BOB-UP, TURN TO TARGET

This maneuver begins with the aircraft on the ground in the center of a pair of concentric squares. The pilot's task is to climb to 50 ft AGL, make a 180 degree pedal turn while maintaining 50 ft AGL, and then descend and land while remaining over the center of the concentric circles.

ACCELERATION/DECELERATION

The aircraft is initially on the ground in the center of a pair of concentric circles. Directly ahead of the aircraft and on the ground are course markers. At the far end of the course is another pair of concentric squares. The squares on the far end of the course define the end position for the maneuver. While remaining over the starting position, From the starting position with the aircraft on the ground, the pilot climbs to an altitude of 30 ft AGL. While maintaining 30 ft AGL, the pilot accelerates the aircraft up to an altitude of 15 kts, and then decelerates so as to come to a stop over the center of a pair of concentric rectangles at the far end of the course. After coming to a stop, the pilot then lands the aircraft.

CONSTANT SPEED AND RATE OF DESCENT APPROACH TO LANDING.

The aircraft is positioned on the ground. Directly ahead of the aircraft is a runway. The pilot brings the aircraft straight up to an altitude of 300 ft AGL. Once at 300 ft, the pilot accelerates the aircraft to a speed of 20 kts IAS. Once at 20 kts, the pilot was to select and maintain a rate of descent that would lead to landing at the runway's threshold while maintaining 20 kts of airspeed.

PRECISION HOVER

The precision hover began with the aircraft on the ground. At approximately a 45 degree angle to the right of the aircraft there was an "X" on the ground. This "X" indicated the desired end position. A series of cones to the side of the "X" appeared to be in alignment when the aircraft was directly over the "X". In front of the "X" was a ball on a pedestal. Beyond the ball was a rectangle. When the aircraft was over the "X" on the ground and at the ideal altitude the ball appeared to be centered in the rectangle.

The pilot's task was to climb straight up to 20 ft AGL while maintaining the aircraft's heading. Once at 20 ft AGL the pilot slide-slipped the aircraft until it was directly over the "X" on the ground. While side slipping, the pilot adjusted the aircraft's altitude so that the ball would appear to be centered vertically and laterally in the rectangle.

PIROUETTE

The aircraft was initially positioned on the ground on a 100 ft radius circle. The aircraft was positioned so that a cone at the center of the circle was directly ahead. The pilot began the maneuver by first climbing straight up to an altitude of 20 ft AGL. Once at 20 ft AGL the pilot side-slipped the aircraft so that it remained over the circle on the ground, maintained 20 ft AGL, and so the nose of the aircraft remained pointed at the cone in the center of the circle.

SLALOM

The aircraft was positioned just before the threshold of a runway on centerline. The pilot began the maneuver by climbing straight up to an altitude of 50 ft AGL. Once at 50 ft AGL the pilot accelerated along the centerline until reaching an airspeed of 20 kts. Once at 20 kts the pilot began a series of turns going from one edge of the runway to the other edge and passing through successive gaps in the runway's centerline. During the turns the pilot was to maintain 20 kts and 50 ft AGL.

DESIGN AND PROCEDURE

Prior to flying DAES the pilots were briefed on the purpose of the experiment, their tasks, and known risks of participating in the study. The first flight in DAES was a familiarization flight. This flight was performed in the full daylight, wide FOV control condition. During this flight the pilot was allowed a period of free-flight in which to explore the handling and performance of the simulator. Following the free flight period, the pilot practiced each of the six experimental tasks. Generally, each task was performed twice during the familiarization flight. On a number of occasions, pilots were allowed to perform a maneuver more than twice. No data was recorded during the familiarization flights.

Following the familiarization flight each pilot flew a series of eight flights with ambient displays. A different ambient display was presented on each flight. The orders of ambient display conditions were determined randomly for pilots 1 and 2. These orders were reversed for pilots 3 and 4.

After completing the flights with the ambient displays, each pilot performed the tasks in the daylight, wide FOV and then in the NVG only control conditions. The order of the controls conditions was the same for all pilots.

In all cases, flights were separated by at least 1 hour. However, because of equipment failures during the course of this experiment, up to 1 month elapsed between flights. When the time between flights exceeded 1 week, the pilot was allowed to practice each task prior to collection of data.

During each flight, each maneuver was performed twice. The data used in the analyses are the average of the two performances.

RESULTS

Two types of ANOVAs were performed on each dependent measure. The first type of ANOVA is a 3 factor, repeated measures ANOVA. The factors are shape (grid, circle), size (1 meter, 4 meters), and density (50%, 12.5%). These analyses were done to identify statistically reliable differences in pilot performance attributable to these factors or to the interactions between factors.

The second ANOVA is a one-factor ANOVA with repeated measures. The single factor is display condition. The ten levels of the factor are:
Small Grid 50% Ambients
Small Grid 12.5% Ambients
Small Circle 50% Ambients
Small Circle 12.5% Ambients
Large Grid 50% Ambients
Large Grid 12.5% Ambients
Large Circle 50% Ambients
Large Circle 12.5% Ambients
Daylight, Wide FOV Control Condition
NVG Only Control Condition

The second type of ANOVA was used to identify statistically reliable differences between the experimental and/or control conditions.

BOB-UP, TURN TO TARGET

AVERAGE ALTITUDE

The target altitude for the 180 degree turn potion of the bob up maneuver was 50 ft AGL. The ambient displays used in this experiment present information regarding changes in altitude; information about absolute altitude is not displayed. Consequently, it was expected that the average altitude would not be affected by the presence of ambient display, nor would there be any difference in altitude between ambient display conditions. The average altitude (± 1 standard deviation) during the turn in each experimental condition and in the control conditions is shown in Figure 2.

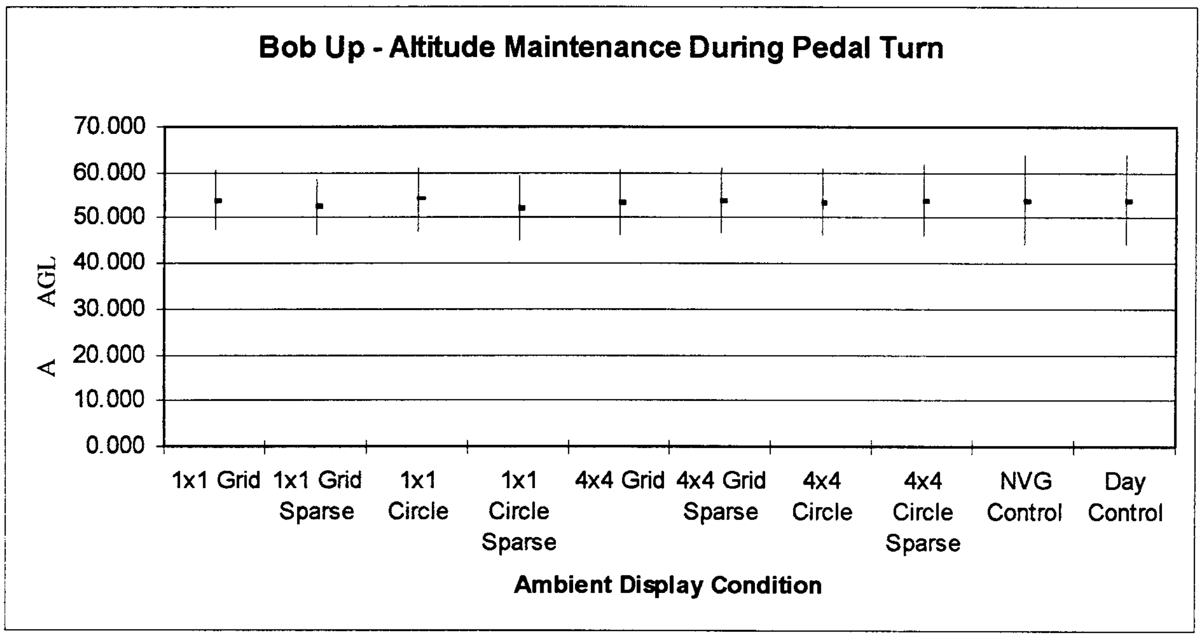


Figure 2. Average Altitude (AGL) +/- 1 Standard Deviation During Turn Portion Of The Bob-Up Maneuver.

Table 1 summarizes the one-factor repeated measures ANOVA performed on the average altitude data. This table shows that the average altitudes in the control and experimental conditions are not reliably different.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	14.672	9	1.6302	0.146	NS
Error	301.928	27	11.1825		

Table 1. Summary Of A Single Factor ANOVA On The Average Altitude During The Pedal Turn Portion Of The Bob-Up Maneuver.

Table 2 summarizes the 3-factor repeated measures ANOVA performed on the average altitude data. Inspection of Table 2 shows that the differences between the ambient display conditions are not statistically reliable. Inspection of this table also shows that the interactions between the size, shape and density of the ambient displays are not statistically significant.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	1.367	1	1.367	0.252	NS
Error $_{size}$	16.248	3	5.416		
Shape	0.016	1	0.016	0.005	NS
Error $_{shape}$	9.793	3	3.264		
Density	3.539	1	3.539	0.649	NS
Error $_{density}$	16.361	3	5.454		
Size x Shape	0.023	1	0.023	0.002	NS
Error $_{size\ x\ shape}$	43.714	3	14.571		
Size x Density	7.734	1	7.734	1.917	0.2603
Error $_{size\ x\ density}$	12.105	3	4.035		
Shape x Density	0.086	1	0.086	0.031	NS
Error shape x density	8.390	3	2.797		
Size x Shape x Density	0.008	1	0.008	0.000	NS
Error $_{size\ x\ shape\ x\ density}$	61.061	3	20.354		

Table 2. Summary Of ANOVA Performed On Average Altitude Data From The Pedal Turn Portion Of The Bob-Up Maneuver.

STANDARD DEVIATION OF ALTITUDE

It was expected that the ambient displays would allow the pilot to detect changes in altitude more quickly than the change would be detected in either of the control conditions. Quicker detection of changes would allow the pilot to reduce variability in altitude. The standard deviation of altitude in each display condition is shown in Figure 3.

Table 3 summarizes the one way ANOVA that includes the control conditions. There is an indication that there is a difference between two or more of the display conditions.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	56.765	9	6.307	2.014	0.0773
Error	84.565	27	3.132		

Table 3. Summary of a One-Way ANOVA Performed on Standard Deviation of Altitude Data From the Pedal Turn Portion of the Bob-Up Maneuver.

Figure 3 shows that the results of the ANOVA shown in Table 3 are due to the reduction in altitude variability between the control conditions and the small, grid, 12.5% density ambient display condition. On the average, the presence of ambient displays reduced altitude variability by 28% compared to the control conditions. The reduction ranged from 37% in the small, grid 12.5% density ambient object condition to 19% in the large, circle, 12.5% density ambient object condition.

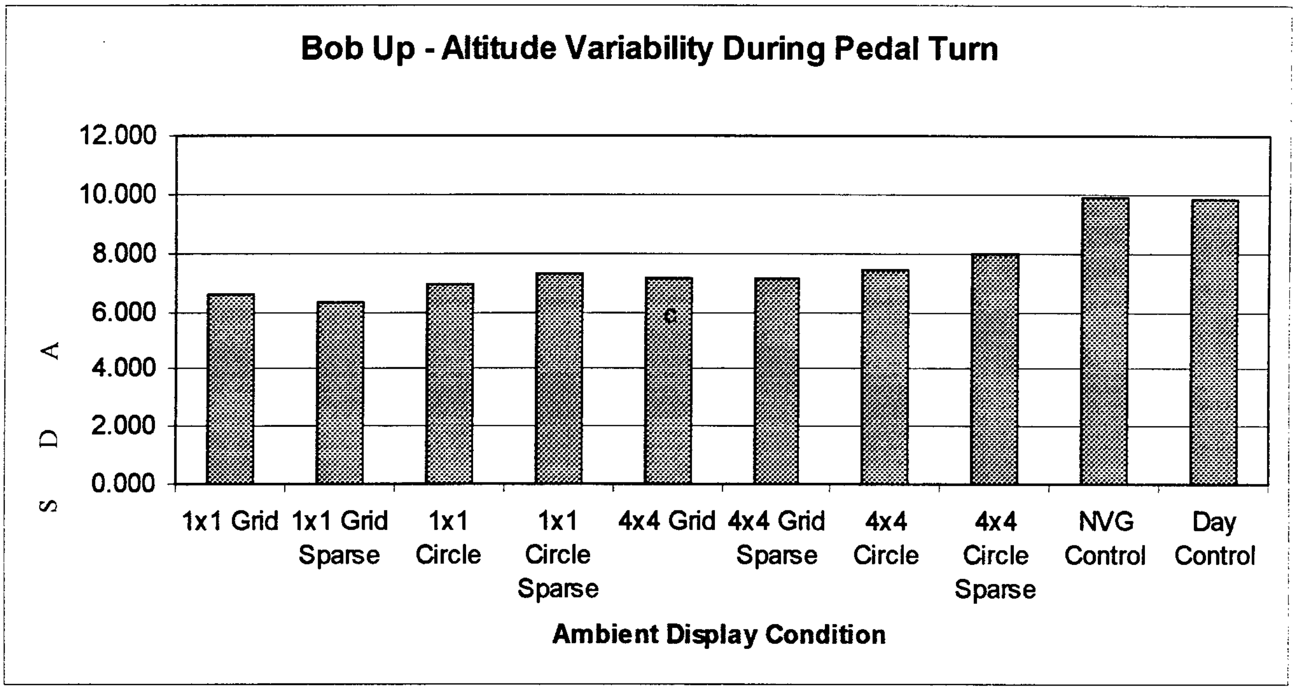


Figure 3 . Altitude Variability During Pedal Turn Portion Of The Bob-Up Maneuver.

Table 4 summarizes a three-factor ANOVA performed on the standard deviations of the altitude during the turn portion of the bob-up maneuver. Inspection of this table indicates that using the conventional 0.05 level of probability that none of the factors or interactions is statistically significant. There is a suggestion that the size of the ambient objects displayed may have an effect on the variability of altitude. The mean standard deviation is 6.787 ft when small ambient objects were displayed and 7.441 ft when large ambient objects were displayed; altitude variability is approximately 13% smaller when small ambient objects were displayed than when large objects were displayed.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	3.421	1	3.421	3.676	0.1508
Error size	2.792	3	0.931		
Shape	3.076	1	3.076	1.850	0.2671
Error shape	4.987	3	1.662		
Density	0.192	1	0.192	0.040	NS
Error density	14.403	3	4.801		
Size x Shape	0.027	1	0.027	0.011	NS
Error size x shape	7.162	3	2.387		
Size x Density	0.134	1	0.134	0.025	NS
Error size x density	16.046	3	5.349		
Shape x Density	0.744	1	0.744	0.101	NS
Error shape x density	22.196	3	7.399		
Size x Shape x Density	0.022	1	0.022	0.029	NS
Error size x shape x density	2.267	3	0.756		

Table 4. ANOVA Comparing Effects Of Ambient Display Conditions On Altitude Variability During The Pedal Turn Portion Of The Bob-Up Task.

AVERAGE TURN RATE

The turn rate was computed from the point at which the aircraft began to turn until the aircraft turned through 180 degrees or, in the few instances where the pilot did not turn a full 180

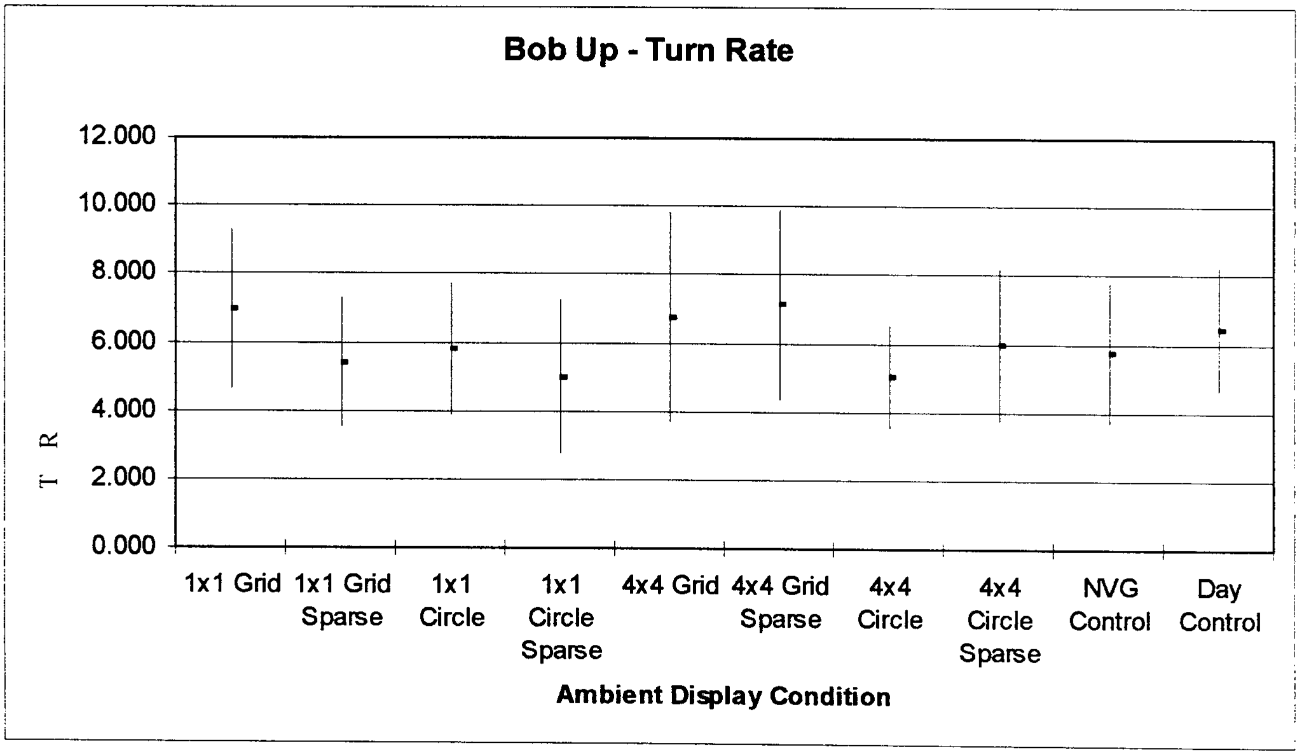


Figure 4. Average Turn Rate (+/- 1 Standard Deviation) in the Bob-Up Task.

degrees, until the aircraft stopped turning and began to descend. The average turn rates (± 1 standard deviation) in each condition are shown in Figure 4.

Table 5 summarizes a one way ANOVA performed on the turn rate data from the Bob-Up task. This table shows that the differences between the conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	21.695	9	2.411	1.483	0.2042
Error	43.877	27	1.625		

Table 5. One way ANOVA performed on the average turn rate data from the Bob-Up task.

Table 6 summarizes the three factor ANOVA performed to identify differences between the experimental conditions.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	1.437	1	1.437	0.697	NS
$\text{Error}_{\text{size}}$	6.188	3	2.063		
Shape	10.152	1	10.152	4.800	0.1157
$\text{Error}_{\text{shape}}$	6.345	3	2.115		
Density	0.560	1	0.560	0.601	NS
$\text{Error}_{\text{density}}$	2.794	3	0.931		
Size x Shape	0.848	1	0.848	3.950	0.1407
$\text{Error}_{\text{size x shape}}$	0.644	3	0.215		
Size x Density	6.768	1	6.768	1.790	0.2735
$\text{Error}_{\text{size x density}}$	11.340	3	3.780		
Shape x Density	0.859	1	0.859	1.996	0.2527
$\text{Error}_{\text{shape x density}}$	1.291	3	0.430		
Size x Shape x Density	0.012	1	0.012	0.009	NS
$\text{Error}_{\text{size x shape x density}}$	3.946	3	1.315		

Table 6. Summary of Three Factor ANOVA Performed On Turn Rate Data from the Bob-Up Task.

The main effect of the shape of the ambient objects approached statistical significance. Examination of the data shows that the pilots turned the aircraft faster when the ambient objects were grids (6.6 degrees/second) than when the objects were circles (5.4 degrees/second).

The interaction between the size and the shape of the ambient objects also approached statistical significance. This interaction is shown in Figure 5. The average turn rate for the large grid was about 0.7 degrees/second faster than for the small grid, while the average turn rates were nearly identical for the large and small circles.

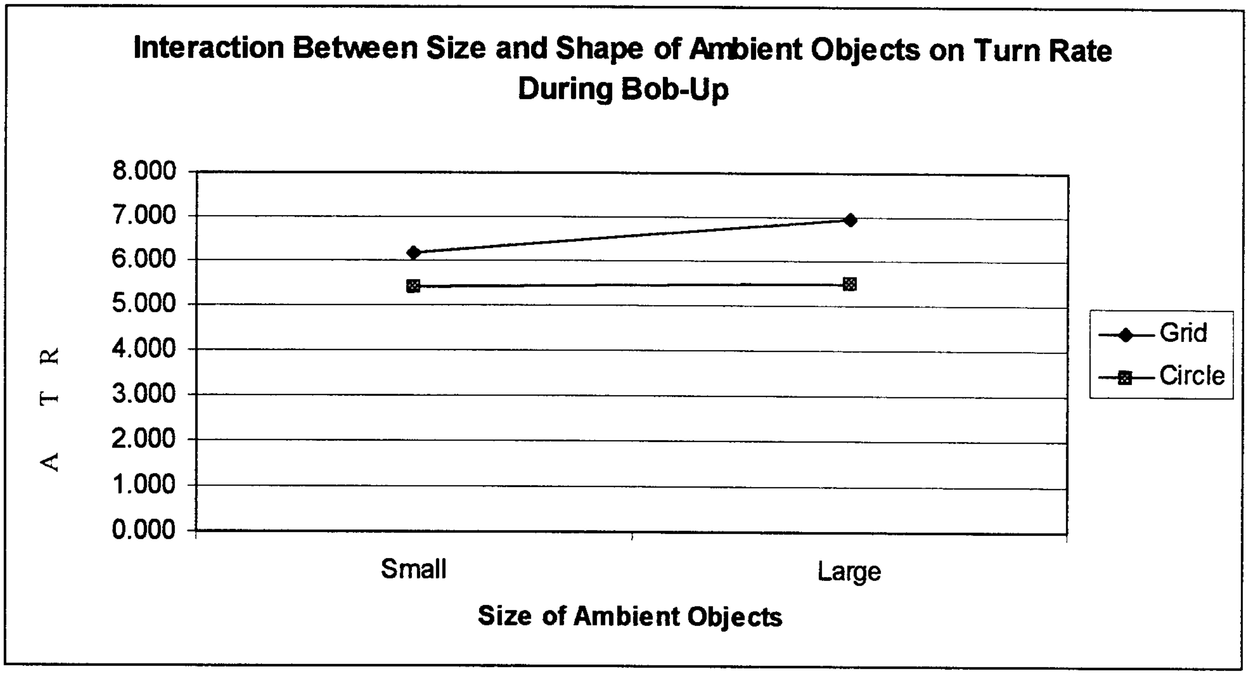


Figure 5 . The Effects of Size and Shape on Turn Rate in the Bob-Up Task.

TURN RATE VARIABILITY

The standard deviation of the turn rate in each condition is shown in Figure 6.

Table 7 contains the summary of a one-way ANOVA performed on the standard deviations of turn rate in the Bob-Up task. The differences between the conditions are not statistically reliable. There is no evidence that turn rate is effected by the presence of the ambient displays

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	7.649	9	0.850	1.167	0.3538
Error	19.658	27	0.728		

Table 7. Summary of a One-Way ANOVA on the Standard Deviations of Turn Rate in the Bob-Up Task.

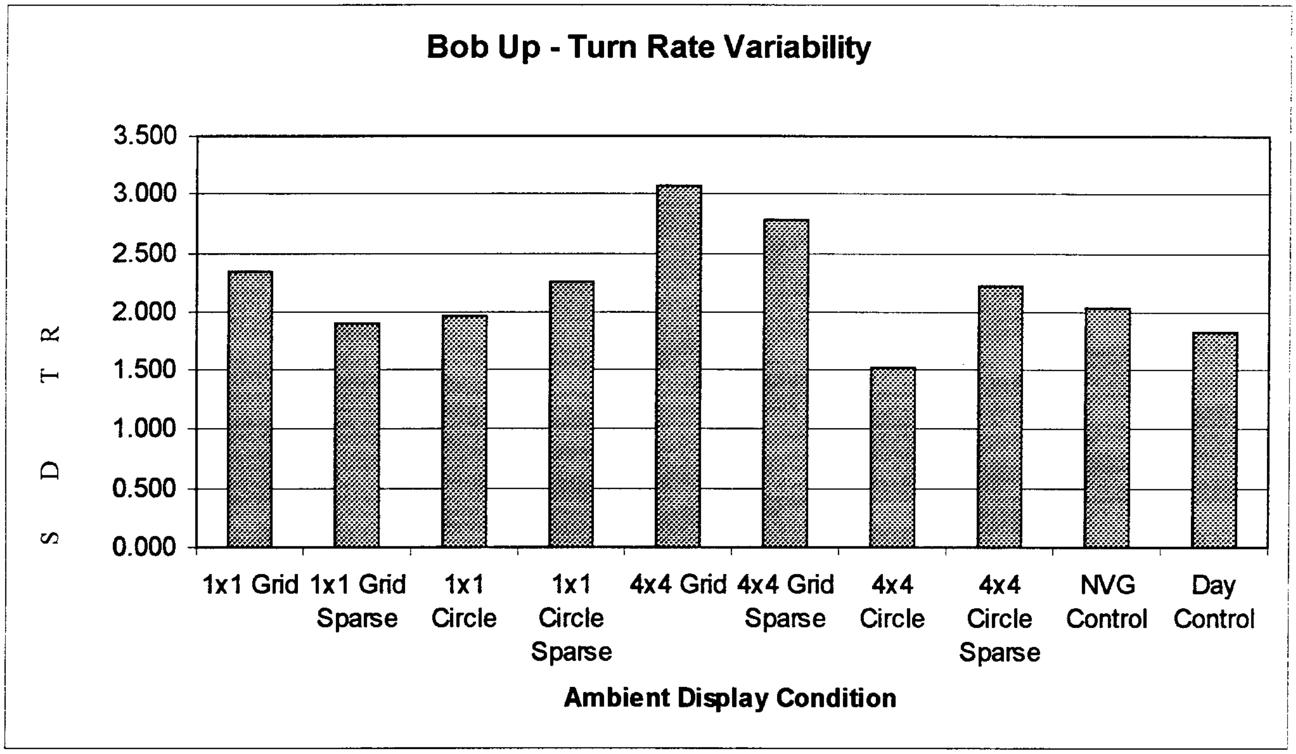


Figure 6. Standard Deviation of Turn Rate in the Bob-Up Task.

Table 8 summarizes a three-factor ANOVA performed on the standard deviations of turn rate. This table shows that turn rate variability was effected by the size of the ambient objects and that size and shape of the ambient objects interacted to effect turn rate.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.670	1	0.670	10.255	0.0477
Error $_{size}$	0.196	3	0.065		
Shape	2.298	1	2.298	3.192	0.1718
Error $_{shape}$	2.160	3	0.720		
Density	0.039	1	0.039	0.027	NS
Error $_{density}$	4.379	3	1.460		
Size x Shape	2.211	1	2.211	16.139	0.0259
Error $_{size\ x\ shape}$	0.411	3	0.137		
Size x Density	0.167	1	0.167	0.164	NS
Error $_{size\ x\ density}$	3.056	3	1.019		
Shape x Density	1.478	1	1.478	2.749	0.1958
Error $_{shape\ x\ density}$	1.613	3	0.538		
Size x Shape x Density	0.028	1	0.028	0.016	NS
Error $_{size\ x\ shape\ x\ density}$	5.223	3	1.741		

Table 8. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Turn Rate in the Bob-Up Task.

The standard deviation of turn rate averaged 2.1 degrees with the small ambient objects and 2.4 degrees with the large ambient objects.

The interaction between the size and shape of the ambient objects is shown in Figure 7.

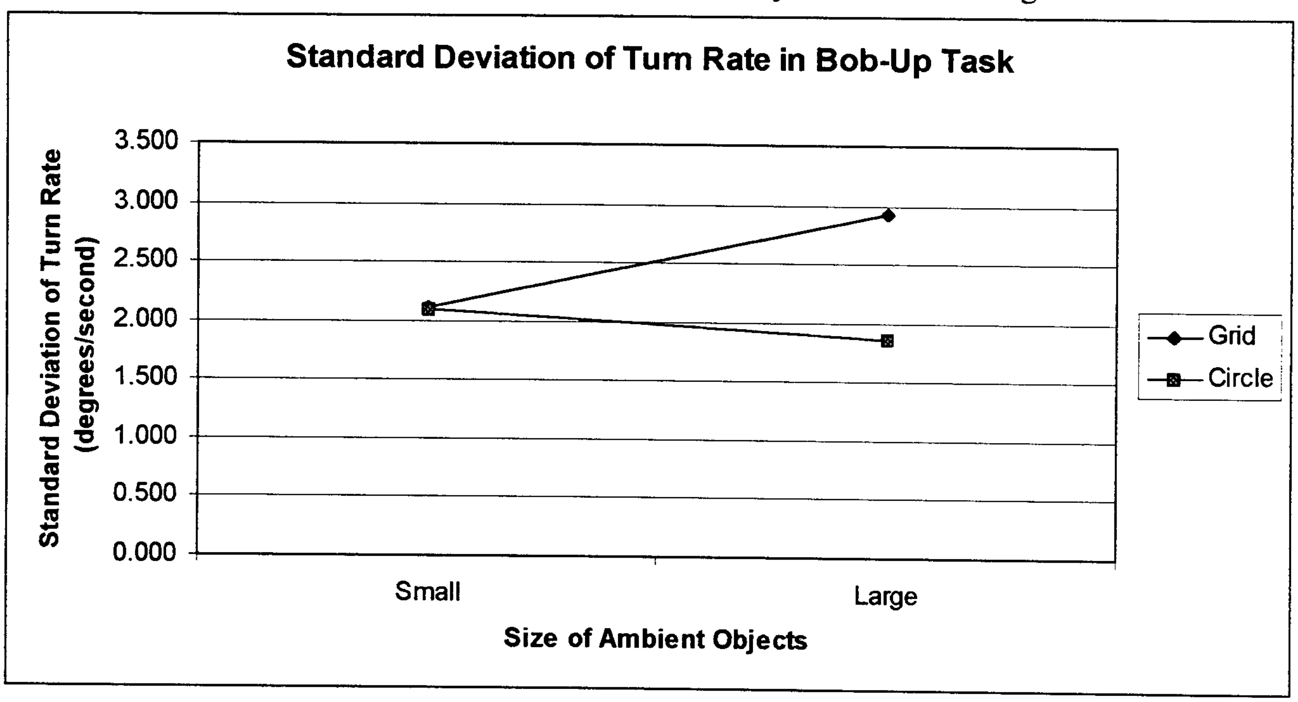


Figure 7. Interaction Between the Size and Shape of Ambient Objects on Aircraft Turn Rate in the Bob-Up Task.

Inspection of this figure shows that the interaction is largely due to the increase in variability when the ambient displays contained grid patterns as the size increased coupled with a decrease in variability of the circle pattern as size increased.

ACCELERATION/DECELERATION MANEUVER

AVERAGE AIRCRAFT HEADING

The average heading of the aircraft (± 1 standard deviation) during the acceleration/deceleration maneuver is shown in Figure 8.

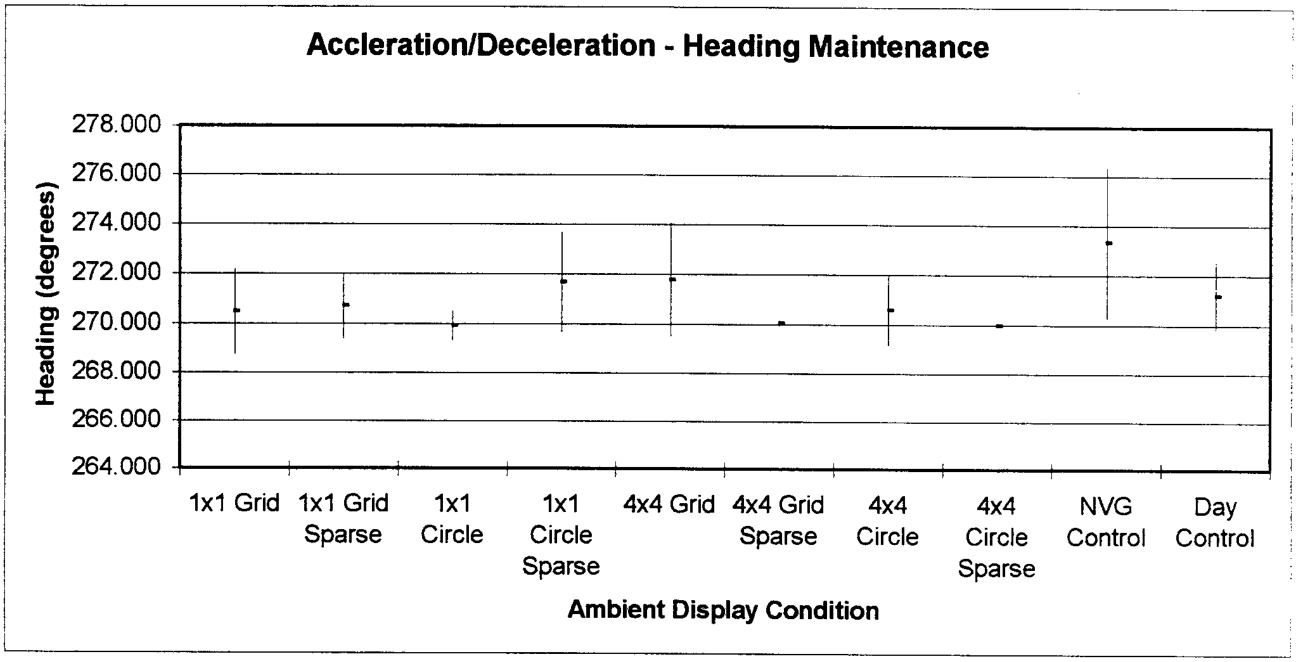


Figure 8. Average Heading (+/- 1 standard deviation) in the Acceleration Task.

A one-way ANOVA indicates that the differences between conditions are not statistically significant. This ANOVA is summarized in Table 9.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	40.719	9	4.524	1.282	0.2908
Error	95.259	27	3.528		

Table 9. Summary of a One-Way ANOVA on the Average Aircraft Heading During The Acceleration/Deceleration Task.

Table 10 summarizes a three-factor ANOVA performed to identify the effects of ambient size, shape, and density. This ANOVA indicates that neither the differences between the factors nor the interactions between the factors has a statistically reliable effect on aircraft heading.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.250	1	0.250	1.716	0.2820
$Error_{size}$	0.437	3	0.146		
Shape	0.500	1	0.500	2.664	0.2009
$Error_{shape}$	0.563	3	0.188		
Density	1.250	1	1.250	0.322	NS
$Error_{density}$	11.656	3	3.885		
Size x Shape	0.000	1	0.000	0.000	NS
$Error_{size\ x\ shape}$	1.188	3	0.396		
Size x Density	9.500	1	9.500	1.317	0.3352
$Error_{size\ x\ density}$	21.641	3	7.214		
Shape x Density	3.500	1	3.500	0.642	NS
$Error_{shape\ x\ density}$	16.359	3	5.453		
Size x Shape x Density	0.000	1	0.000	0.000	NS
$Error_{size\ x\ shape\ x\ density}$	4.906	3	1.635		

Table 10. ANOVA Summarizing the Effects of Ambient Size, Shape, and Density on Aircraft Heading During the Acceleration/Deceleration Task.

STANDARD DEVIATION OF AIRCRAFT HEADING

Figure 9 shows the standard deviation of the aircraft's heading during the acceleration/deceleration maneuver.

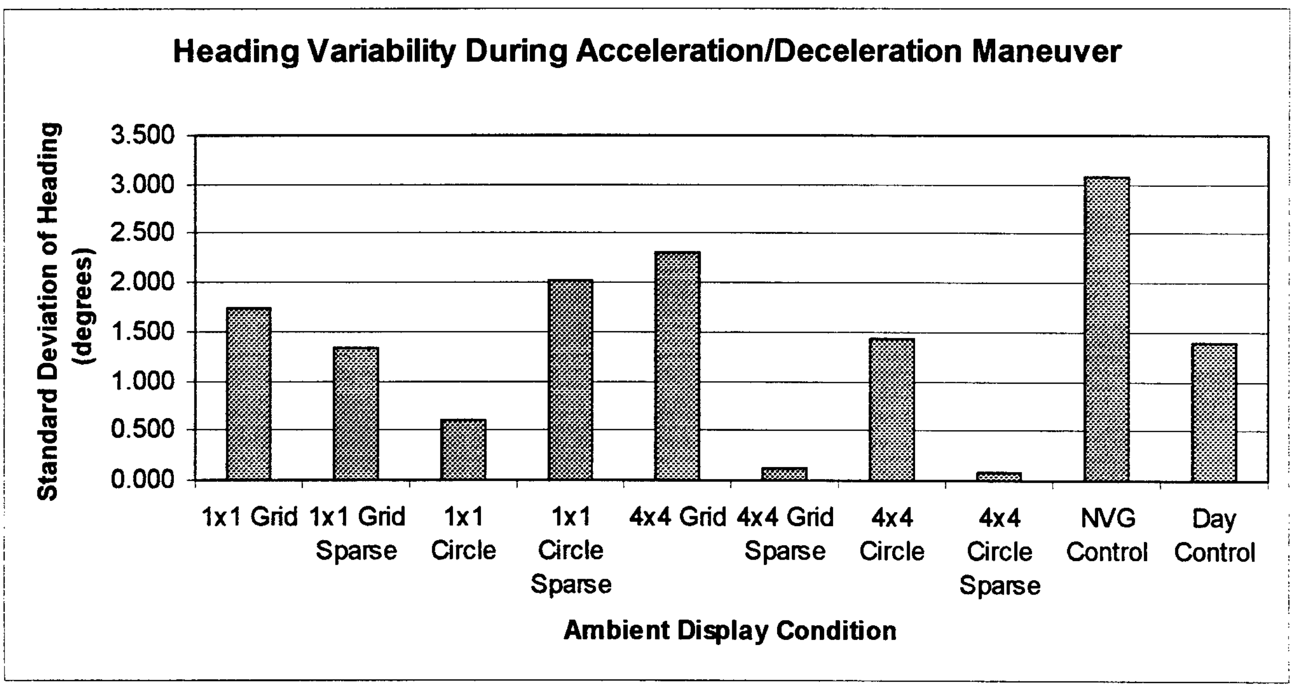


Figure 9. Standard Deviation of Heading During Acceleration/Deceleration Task.

A one-way ANOVA on these data indicates that the differences between the conditions are not statistically reliable. This ANOVA is summarized in Table 11.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	32.549	9	3.617	1.235	0.3154
Error	79.064	27	2.928		

Table 11. One-way ANOVA on the Standard Deviation of Aircraft Heading in the Acceleration/Deceleration Task.

A three-factor ANOVA on the standard deviation of the aircraft's heading during the acceleration/deceleration task is summarized in Table 12.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	1.559	1	1.559	2.092	0.2439
$Error_{size}$	2.236	3	0.745		
Shape	0.897	1	0.897	0.818	NS
$Error_{shape}$	3.289	3	1.096		
Density	3.262	1	3.262	69.404	0.0030
$Error_{density}$	0.141	3	0.047		
Size x Shape	0.094	1	0.094	0.042	NS
$Error_{size\ x\ shape}$	6.697	3	2.232		
Size x Density	10.355	1	10.355	1.201	0.3544
$Error_{size\ x\ density}$	25.866	3	8.622		
Shape x Density	3.485	1	3.485	0.782	NS
$Error_{shape\ x\ density}$	13.373	3	4.458		
Size x Shape x Density	0.492	1	0.492	0.633	NS
$Error_{size\ x\ shape\ x\ density}$	2.330	3	0.777		

Table 12. Summary of Three Factor ANOVA Performed on the Standard Deviation of Aircraft heading in the Acceleration/Deceleration Task.

This ANOVA indicates that the standard deviation of heading is effected by the density of the ambient objects. The standard deviation of heading is smaller with sparse ambient displays than with the dense displays (0.886 degrees vs. 1.524 degrees, respectively). No other factor or interaction between factors is statistically reliable.

AVERAGE ALTITUDE

The average altitude (± 1 standard deviation) during the acceleration/deceleration task is shown in Figure 10.

A one-way ANOVA on the average altitude data is summarized in Table 13. This ANOVA shows that the differences in average altitude are not statistically significant.

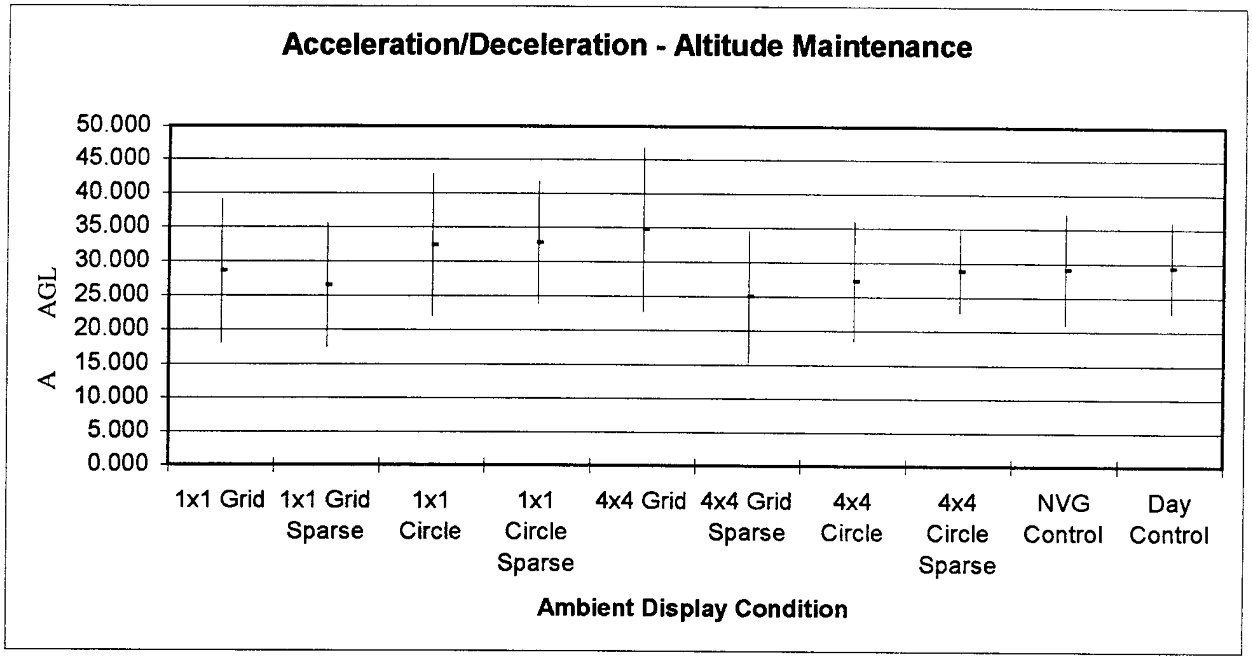


Figure 10. Average Altitude (+/- 1 standard deviation) in the Acceleration/Deceleration Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	333.435	9	37.048	1.263	0.3008
Error	792.113	27	29.338		

Table 13. Summary of an ANOVA Performed on Average Altitude in the Acceleration/Deceleration Task.

Table 14 contains the summary of a three-factor ANOVA performed on the average altitude data.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	10.139	1	10.139	0.223	NS
Error $_{size}$	136.479	3	45.493		
Shape	20.504	1	20.504	2.537	0.2093
Error $_{shape}$	24.242	3	8.081		
Density	49.621	1	49.621	1.115	0.3699
Error $_{density}$	133.495	3	44.498		
Size x Shape	96.539	1	96.539	1.248	0.3463
Error $_{size\ x\ shape}$	232.020	3	77.340		
Size x Density	21.404	1	21.404	2.397	0.2192
Error $_{size\ x\ density}$	26.785	3	8.928		
Shape x Density	94.884	1	94.884	6.434	0.0841
Error $_{shape\ x\ density}$	44.241	3	14.747		
Size x Shape x Density	39.607	1	39.607	0.891	NS
Error $_{size\ x\ shape\ x\ density}$	133.356	3	44.452		

Table 14. Summary of a Three-Factor ANOVA Performed on Average Altitude Data From the Acceleration/Deceleration Task.

Table 14 reveals that there is an interaction between the shape and density of the ambient objects. This interaction is shown in Figure 11. The average altitude is greater with large grids than with small grids. In contrast, the average altitude was lower with large circles than with small circles.

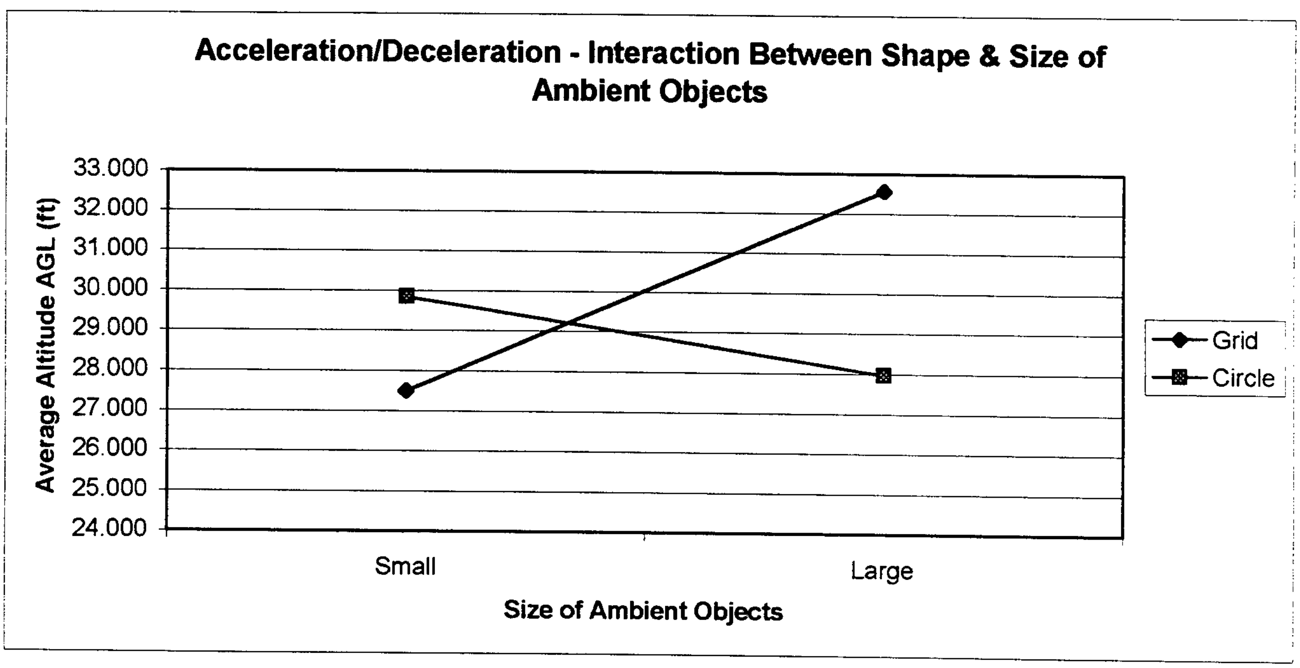


Figure 11. Interaction Between the Shape and Size of Ambient Objects on Average Altitude in the Acceleration/Deceleration Task.

STANDARD DEVIATION OF ALTITUDE

The standard deviations of altitude in each condition are shown in Figure 12.

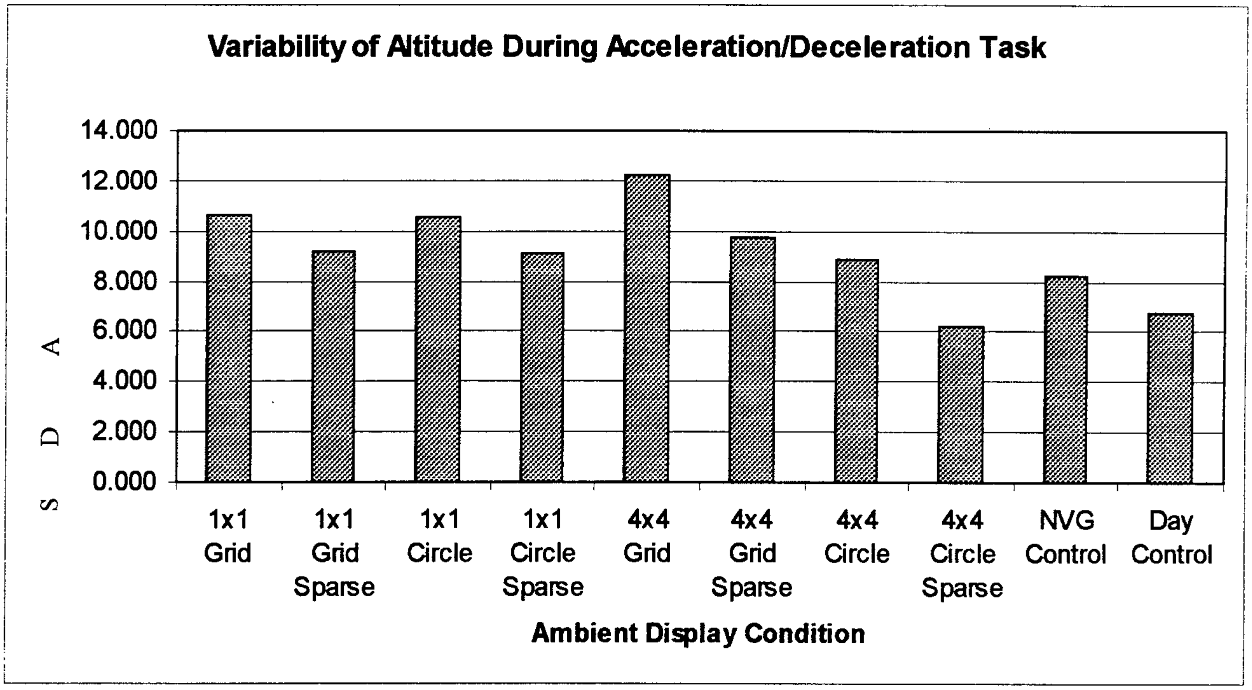


Figure 12 Standard Deviation of Altitude AGL in the Acceleration/Deceleration Task.

A one-way ANOVA performed on the standard deviation of altitude is shown in Table 15. This ANOVA indicates that the differences between conditions are not statistically significant.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	116.337	9	12.926	1.371	0.2491
Error	254.547	27	9.428		

Table 15. Summary of a One-Way ANOVA on the Standard Deviaiton of Altitude in the Acceleration/Deceleration Task.

Table 16 contains the summary of a three-factor ANOVA performed on the standard deviations of altitude.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	2.798	1	2.798	0.239	NS
Error $_{size}$	35.128	3	11.709		
Shape	25.106	1	25.106	1.310	0.3363
Error $_{shape}$	57.490	3	19.163		
Density	32.365	1	32.365	4.105	0.1355
Error $_{density}$	23.650	3	7.883		
Size x Shape	22.378	1	22.378	2.300	0.2266
Error $_{size\ x\ shape}$	29.187	3	9.729		
Size x Density	2.528	1	2.528	0.597	NS
Error $_{size\ x\ density}$	12.709	3	4.236		
Shape x Density	0.014	1	0.014	0.006	NS
Error $_{shape\ x\ density}$	6.532	3	2.177		
Size x Shape x Density	0.015	1	0.015	0.002	NS
Error $_{size\ x\ shape\ x\ density}$	20.743	3	6.914		

Table 16. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Altitude in the Acceleration/Deceleration Task.

Examination of Table 16 shows that the only factor or interaction that approached statistical significance is density. The standard deviation of altitude is greater when the ambient objects are dense than when they are sparse (10.5 ft vs. 8.5 ft, respectively).

CONSTANT SPEED, CONSTANT RATE OF DESCENT APPROACH

AVERAGE VERTICAL SPEED

The average vertical speeds in ft/min during the approach task (± 1 standard deviation) are shown in Figure 13. Negative values indicate a descent.

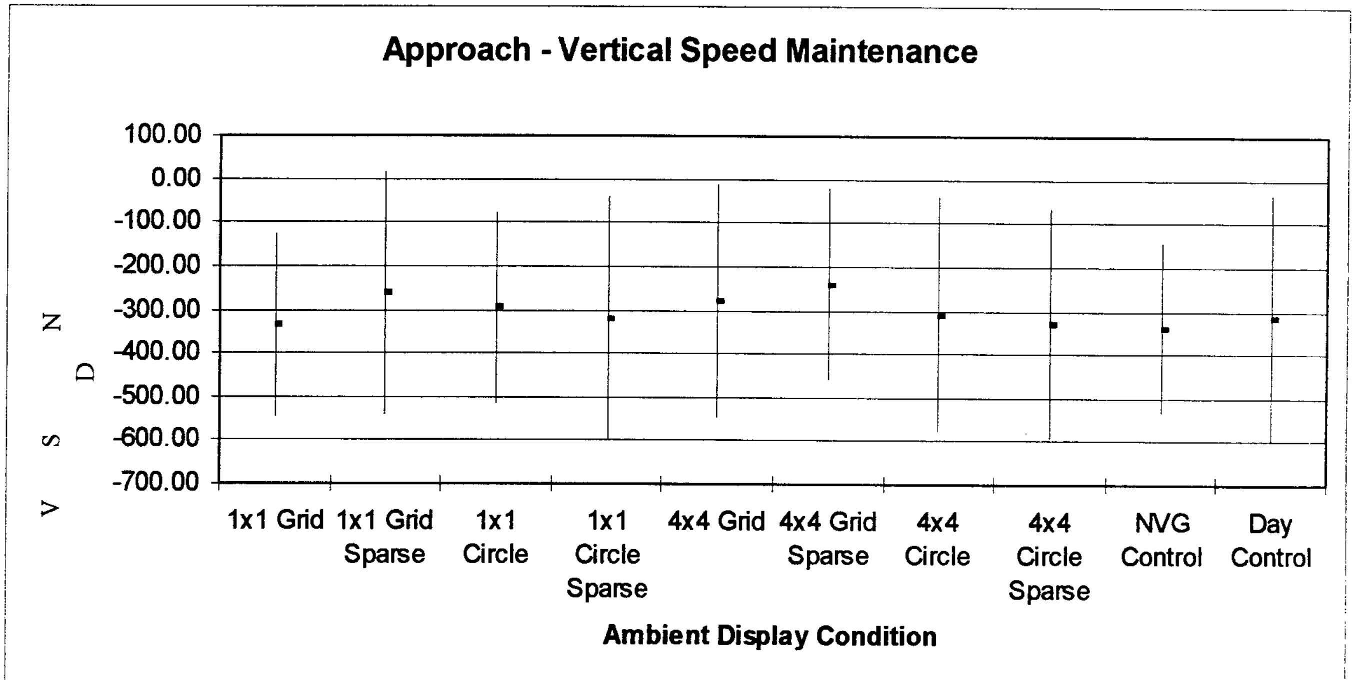


Figure 13. Average Vertical Speed in the Constant Speed, Constant Rate of Descent Approach Task.

Table 17 is the summary of a one-way ANOVA performed on the average vertical speed data. This ANOVA suggests that the differences between conditions are marginally significant.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	39509.055	9	4389.895	1.709	0.1356
Error	69336.719	27	2568.027		

Table 17. Summary of a One-Way ANOVA Performed on the Average Vertical Speed Data from the Approach Task.

Table 18 contains the summary of a three-factor ANOVA performed on the average vertical speed data.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	2544.250	1	2544.250	2.762	0.1950
Error $_{size}$	2763.311	3	921.104		
Shape	6705.250	1	6705.250	5.095	0.1087
Error $_{shape}$	3948.312	3	1316.104		
Density	1307.750	1	1307.750	0.941	NS
Error $_{density}$	4168.188	3	1389.396		
Size x Shape	3465.750	1	3465.750	0.499	NS
Error $_{size\ x\ shape}$	20837.363	3	6945.788		
Size x Density	1168.500	1	1168.500	0.461	NS
Error $_{size\ x\ density}$	7609.689	3	2536.563		
Shape x Density	15406.500	1	15406.500	8.463	0.0609
Error $_{shape\ x\ density}$	5461.354	3	1820.451		
Size x Shape x Density	241.500	1	241.500	0.154	NS
Error $_{size\ x\ shape\ x\ density}$	4719.031	3	1573.010		

Table 18. Summary of a Three-Factor ANOVA Performed on Average Vertical Speed in the Approach Task.

The main effect of size is marginally significant. The rate of descent was faster with small ambient objects than with large ambient objects (303 ft/min vs. 290 ft/min rates of descent, respectively).

The average rate of descent was faster when the ambient objects were circles than when they were grids. When circles were displayed the average rate of descent was 313 ft/min compared to 280 ft/min when grids were displayed.

There is also and interaction between the shape and density of the ambient objects. This interaction is shown in Figure 14.

Inspection of Figure 14 shows that when the pattern was dense, the rate of descent was about the same for both grids and circles. When the pattern was spares, the rate of descent was faster when the ambient objects were circles than when they were grids.

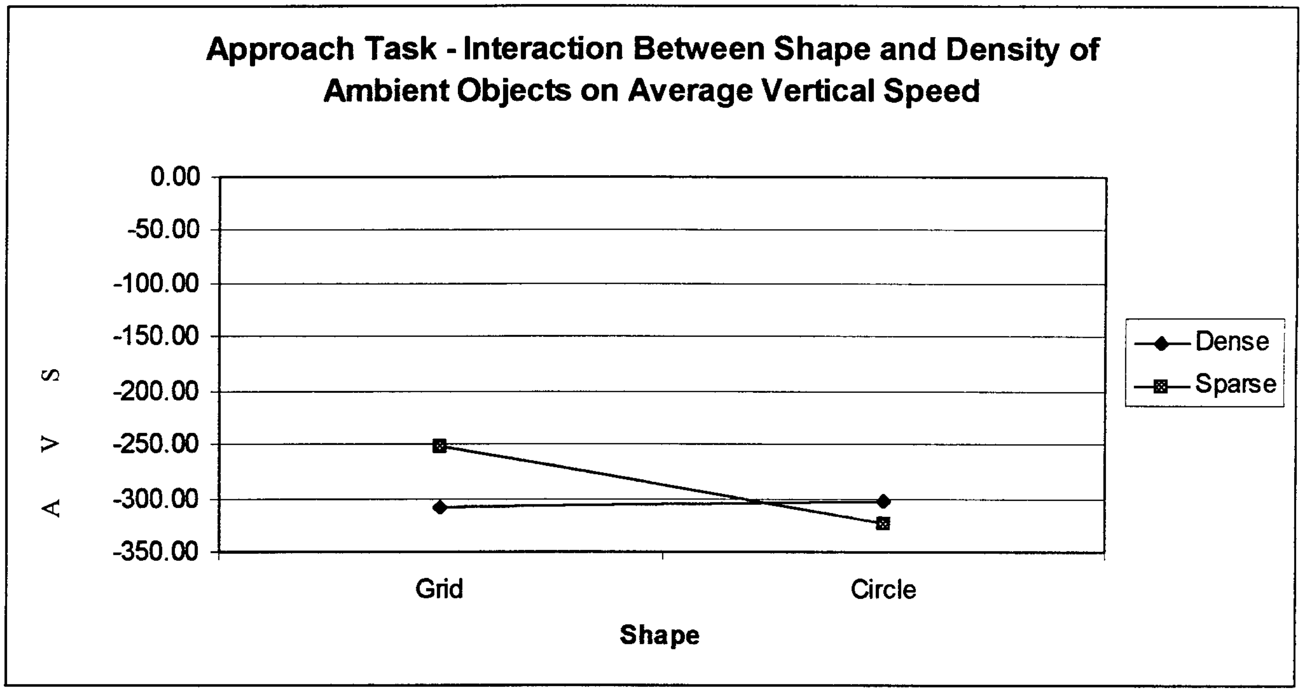


Figure 14. Interaction Between Shape and Density of Ambient Objects on vertical Speed in the Approach Task.

STANDARD DEVIATION OF VERTICAL SPEED.

Figure 15 shows the standard deviation of vertical airspeed in the approach task.

Table 19 is the summary of a one-way ANOVA performed on the standard deviation of vertical speed. This analysis indicates that the differences between conditions are not statistically significant.

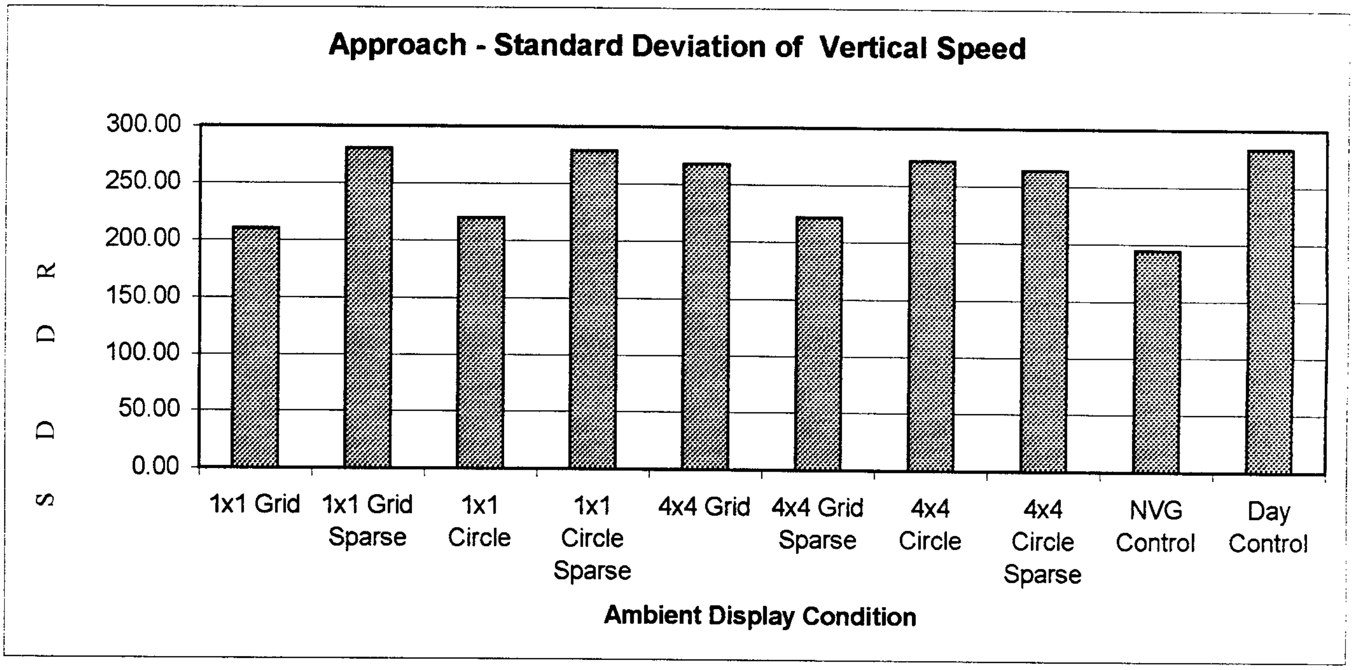


Figure 15. Standard Deviation of Vertical Speed in the Constant Speed, Constant Rate of Descent Approach Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	40111.859	9	4456.873	0.752	NS
Error	160014.219	27	5926.453		

Table 19. Summary of the One-Way ANOVA Performed on the Standard Deviation of Vertical Speed Data from the Approach Task.

Table 20 summarizes the three-factor ANOVA performed on the standard deviation of vertical speed data. This ANOVA indicates that none of the factors or interactions are statistically significant.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	418.750	1	418.750	0.036	NS
Error $_{size}$	34526.469	3	11508.823		
Shape	1166.000	1	1166.000	0.270	NS
Error $_{shape}$	12964.184	3	4321.395		
Density	3311.750	1	3311.750	0.389	NS
Error $_{density}$	25508.191	3	8502.730		
Size x Shape	510.500	1	510.500	0.120	NS
Error $_{size\ x\ shape}$	12785.098	3	4261.699		
Size x Density	15836.625	1	15836.625	2.864	0.1890
Error $_{size\ x\ density}$	16586.512	3	5528.837		
Shape x Density	560.750	1	560.750	0.290	NS
Error $_{shape\ x\ density}$	5793.731	3	1931.244		
Size x Shape x Density	1594.500	1	1594.500	2.759	0.1952
Error $_{size\ x\ shape\ x\ density}$	1733.938	3	577.979		

Table 20. Summary of the Three-Factor ANOVA Performed on the Standard Deviation of Vertical Speed Data from the Constant Speed, Constant Rate of Descent Approach Task.

AVERAGE AIRSPEED

During the constant speed, constant rate of descent approach task, pilots attempted to maintain a forward airspeed of 20 kts. Figure 16 shows the average airspeed during the approach in each condition.

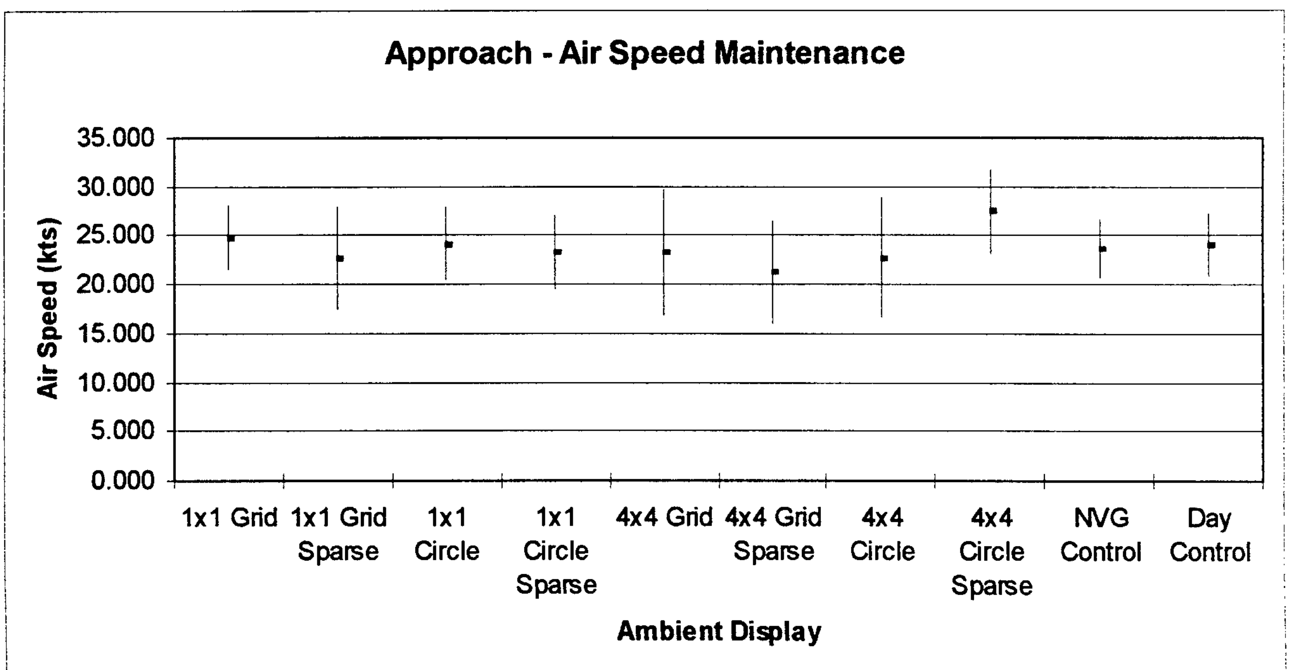


Figure 16. Average Airspeed in the Constant Speed, Constant Rate of Descent Approach Task.

The one-way ANOVA performed on the average airspeed data is summarized in Table 21. Examination of Table 21 shows that the differences between conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	108.727	9	12.081	1.580	0.1716
Error	206.469	27	7.647		

Table 21. Summary of the One-Way ANOVA Performed on the Average Airspeed Data from the Constant Speed, Constant Rate of Descent Approach Task.

A three-factor ANOVA on the average airspeed data is summarized in Table 22. This ANOVA reveals a significant interaction between size and density of the ambient objects. This interaction is shown in Figure 17

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.713	1	0.713	0.278	NS
Error $_{size}$	7.692	3	2.564		
Shape	11.908	1	11.908	1.369	0.3272
Error $_{shape}$	26.095	3	8.698		
Density	0.412	1	0.412	0.061	NS
Error $_{density}$	20.399	3	6.800		
Size x Shape	10.213	1	10.213	0.513	NS
Error $_{size\ x\ shape}$	59.747	3	19.916		
Size x Density	22.654	1	22.654	14.097	0.0313
Error $_{size\ x\ density}$	4.821	3	1.607		
Shape x Density	40.857	1	40.857	3.251	0.1690
Error $_{shape\ x\ density}$	37.704	3	12.568		
Size x Shape x Density	21.053	1	21.053	3.410	0.1617
Error $_{size\ x\ shape\ x\ density}$	18.520	3	6.173		

Table 22. Three-Factor ANOVA on the Average Airspeed in the Approach Task.

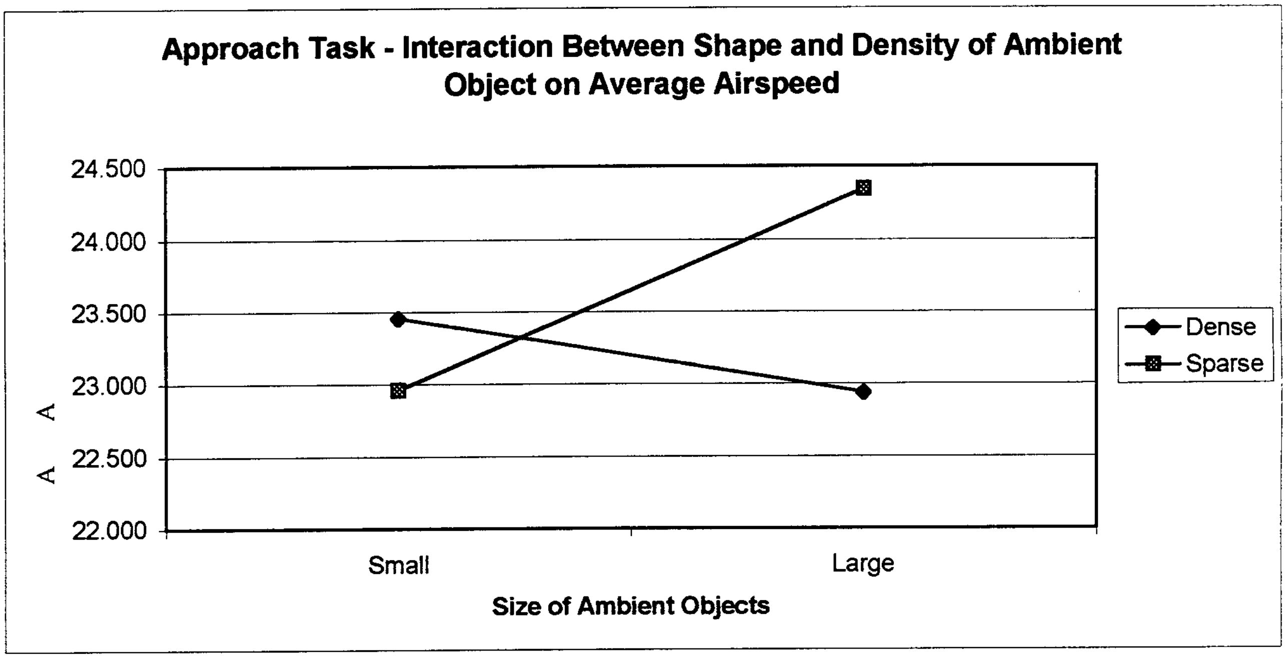


Figure 17. Interaction Between the Size and Shape of the Ambient Objects on Average Airspeed in the Approach Task.

Examination of Figure 17 shows that for the sparse distribution of ambient objects the average airspeed was greater when the ambient objects were larger than when the objects were small. When the ambient objects were more densely distributed the average airspeed was greater

STANDARD DEVIATION OF AIRSPEED

The standard deviation of airspeed in each of the display conditions is shown in Figure 18.

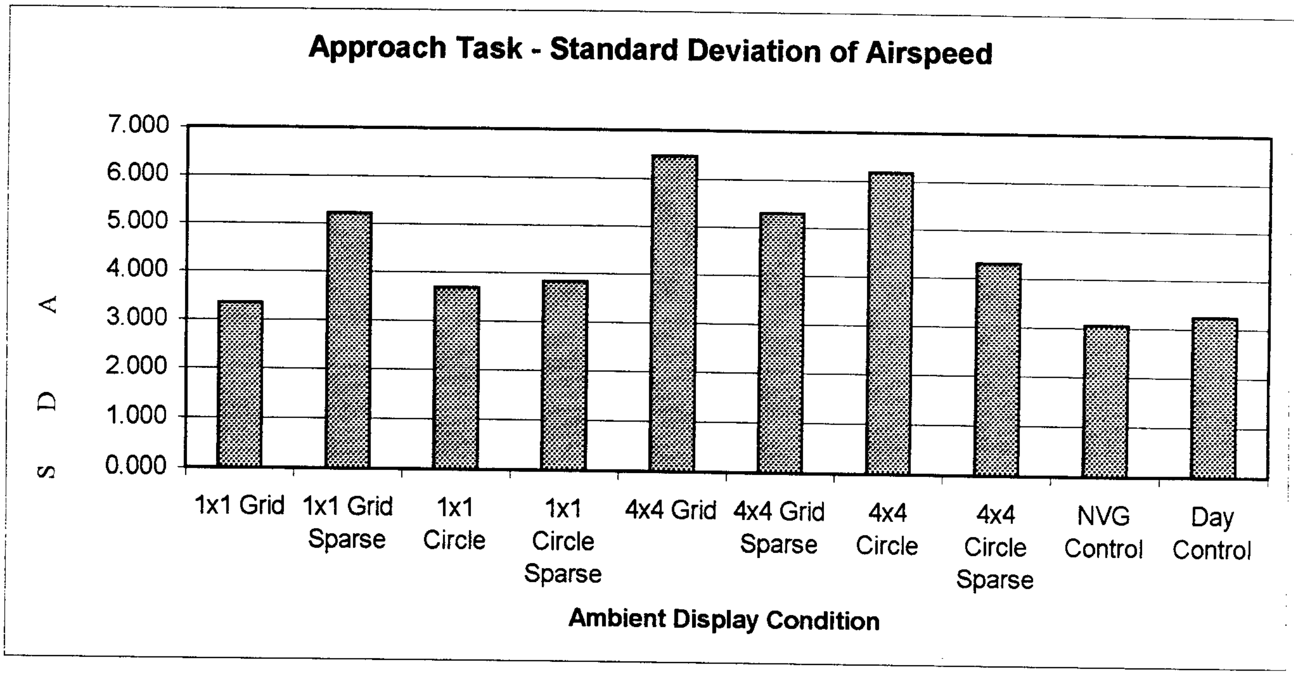


Figure 18 Standard Deviation of Airspeed in the Constant Speed, Constant Rate of Descent Approach Task.

A one-way ANOVA on the standard deviation of airspeed in the approach task is shown in Table 23. This ANOVA indicates that the difference between conditions is marginally significant. Examination of Figure 18 indicates that variability with the large, dense ambient objects is more variable than it is in the control conditions.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	56.977	9	6.331	1.881	0.0988
Error	90.861	27	3.365		

Table 23. Summary of the One-Way ANOVA Performed on the Standard Deviation of Airspeed from the Approach task.

Table 24 is the summary of the three-factor ANOVA performed on the standard deviation of airspeed data from the approach task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	19.425	1	19.425	12.146	0.0383
Error $_{size}$	4.798	3	1.599		
Shape	2.578	1	2.578	0.700	NS
Error $_{shape}$	11.041	3	3.680		
Density	0.565	1	0.565	0.279	NS
Error $_{density}$	6.067	3	2.022		
Size x Shape	0.016	1	0.016	0.002	NS
Error $_{size\ x\ shape}$	22.538	3	7.513		
Size x Density	13.220	1	13.220	3.452	0.1599
Error $_{size\ x\ density}$	11.490	3	3.830		
Shape x Density	3.079	1	3.079	0.977	NS
Error $_{shape\ x\ density}$	9.453	3	3.151		
Size x Shape x Density	0.480	1	0.480	0.221	NS
Error $_{size\ x\ shape\ x\ density}$	6.525	3	2.175		

Table 24. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Airspeed Data from the Approach task.

The pilots maintained a more constant airspeed when the ambient objects were small than when they were large. The mean standard deviation f airspeed was 4.0 kts with the small ambient objects and 5.6 kts with the large ambient objects.

The standard deviation of airspeed was also effected by an interaction between the size and density of the ambient objects. This interaction is shown in Figure 19. Airspeed variability was larger when the small ambient objects were distributed sparsely than when distributed densely. The variability was greater when the large ambient objects were distributed densely than when sparsely distributed.

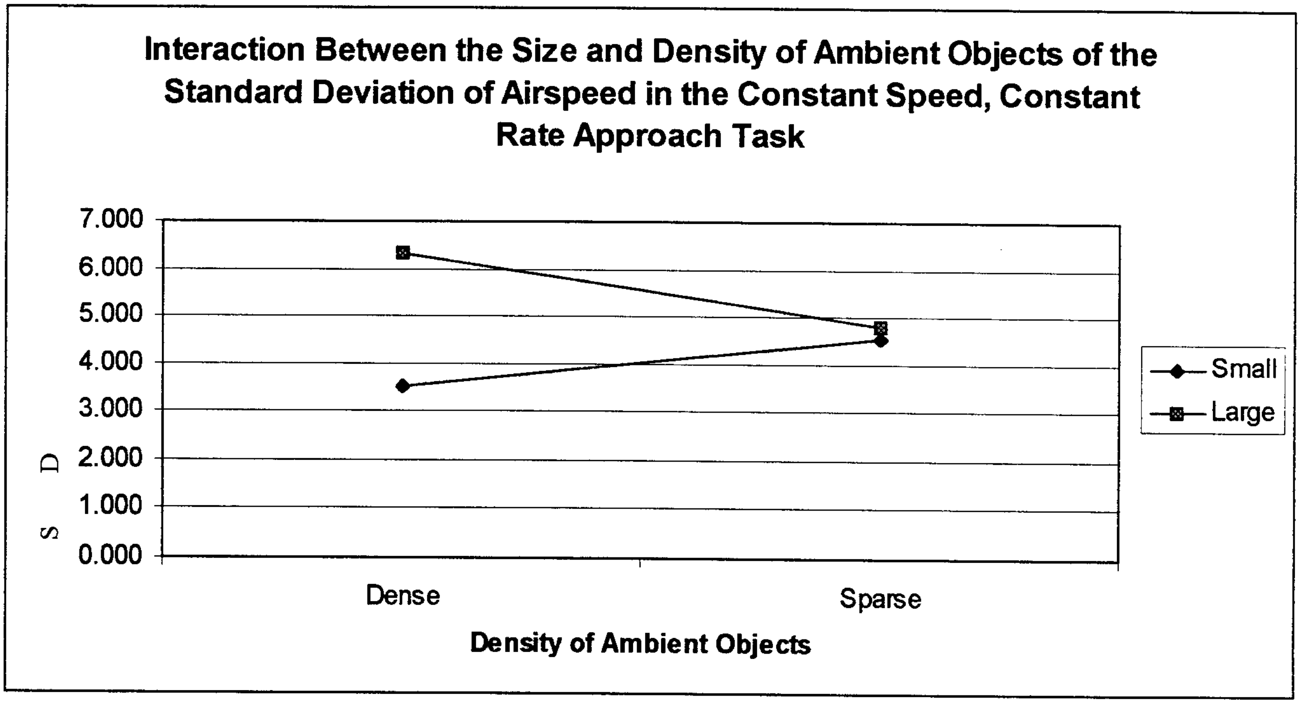


Figure 19. Interaction between the Size and Density of Ambient Objects on the Standard Deviation of Airspeed in the Constant Speed, Constant Rate of Descent Task.

PRECISION HOVER TASK

AVERAGE HEADING

Pilots attempted to maintain their initial heading of 315 degrees throughout the precision hover maneuver. The average heading in each condition (± 1 standard deviation) is shown in Figure 20.

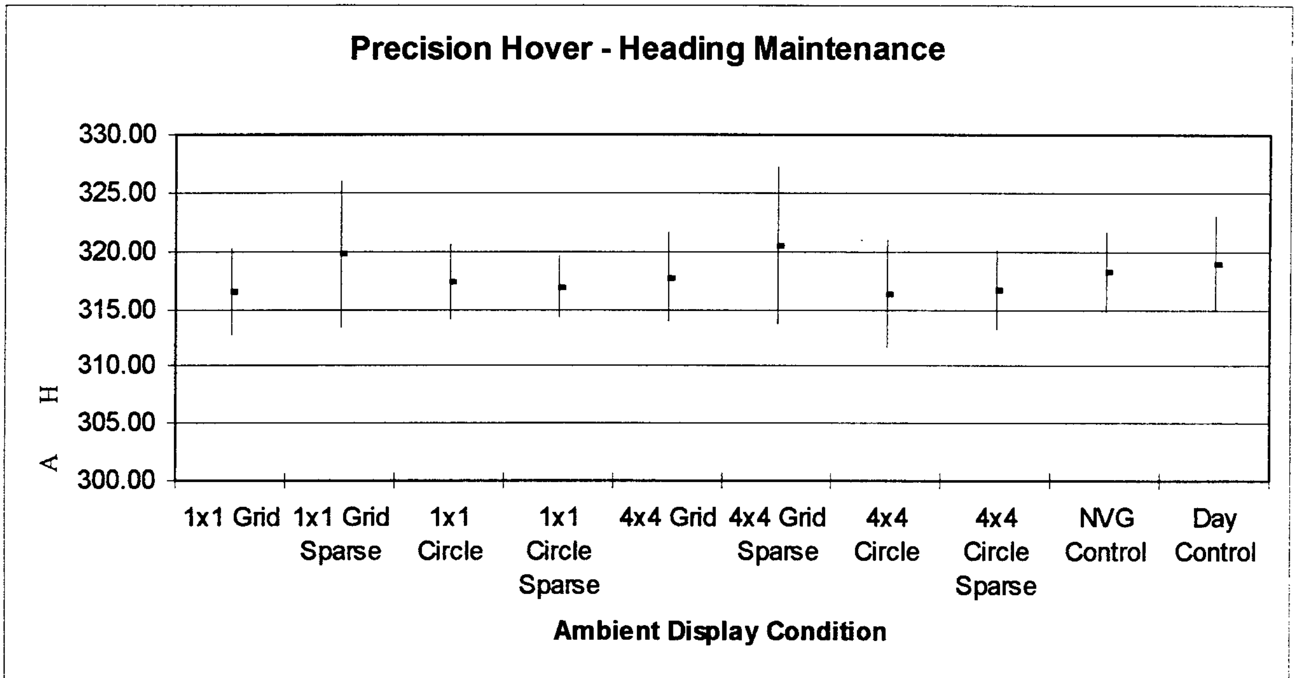


Figure 20. Average Heading (+/- 1 standard deviation) in the Precision Hover Maneuver .

A one-way ANOVA performed on the heading data is summarized in Table 25. This summary indicates that the differences between the conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	74.625	9	8.292	1.565	0.1762
Error	143.013	27	5.297		

Table 25. Summary of a One-way ANOVA Performed on the Average Heading Data From the Precision Hover Task.

Table 26 summarizes a three-factor ANOVA performed on the average headings in each of the experimental conditions. Examination of this table shows that the difference in average heading between grids and circles is statistically reliable. When the ambient objets were circles the average heading was 316.8 degrees, and when the objects were grids the average heading was 318.6 degrees. Pilots maintained their average heading better with circles than with grids.

Table 26 also shows that the interaction between the shape and density of ambient objects had a marginally reliable effect on the average aircraft heading during this maneuver. This interaction is shown in Figure 21.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.500	1	0.500	0.090	NS
Error $_{size}$	16.750	3	5.583		
Shape	26.250	1	26.250	11.053	0.0434
Error $_{shape}$	7.125	3	2.375		
Density	17.500	1	17.500	2.754	0.1955
Error $_{density}$	19.062	3	6.354		
Size x Shape	5.500	1	5.500	0.344	NS
Error $_{size\ x\ shape}$	48.016	3	16.005		
Size x Density	0.000	1	0.000	0.000	NS
Error $_{size\ x\ density}$	8.922	3	2.974		
Shape x Density	18.750	1	18.750	3.879	0.1432
Error $_{shape\ x\ density}$	14.500	3	4.833		
Size x Shape x Density	0.500	1	0.500	0.160	NS
Error $_{size\ x\ shape\ x\ density}$	9.375	3	3.125		

Table 26. Summary of a Three-Factor ANOVA on the Average Heading in the Precision Hover Task.

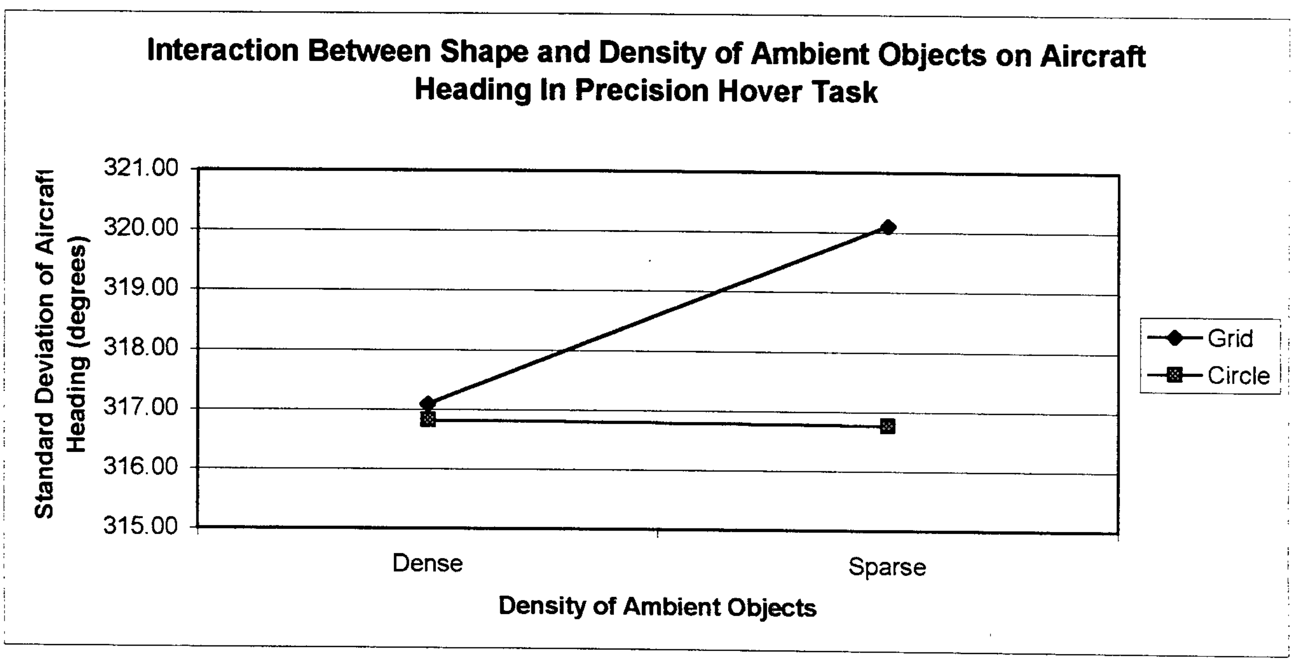


Figure 21. Effect of the Interaction Between the Shape and Density of Ambient Objects on Average Heading in the Precision Hover Task.

STANDARD DEVIATION OF AIRCRAFT HEADING

The standard deviation of the aircraft heading in condition during the precision hover task are shown in Figure 22.

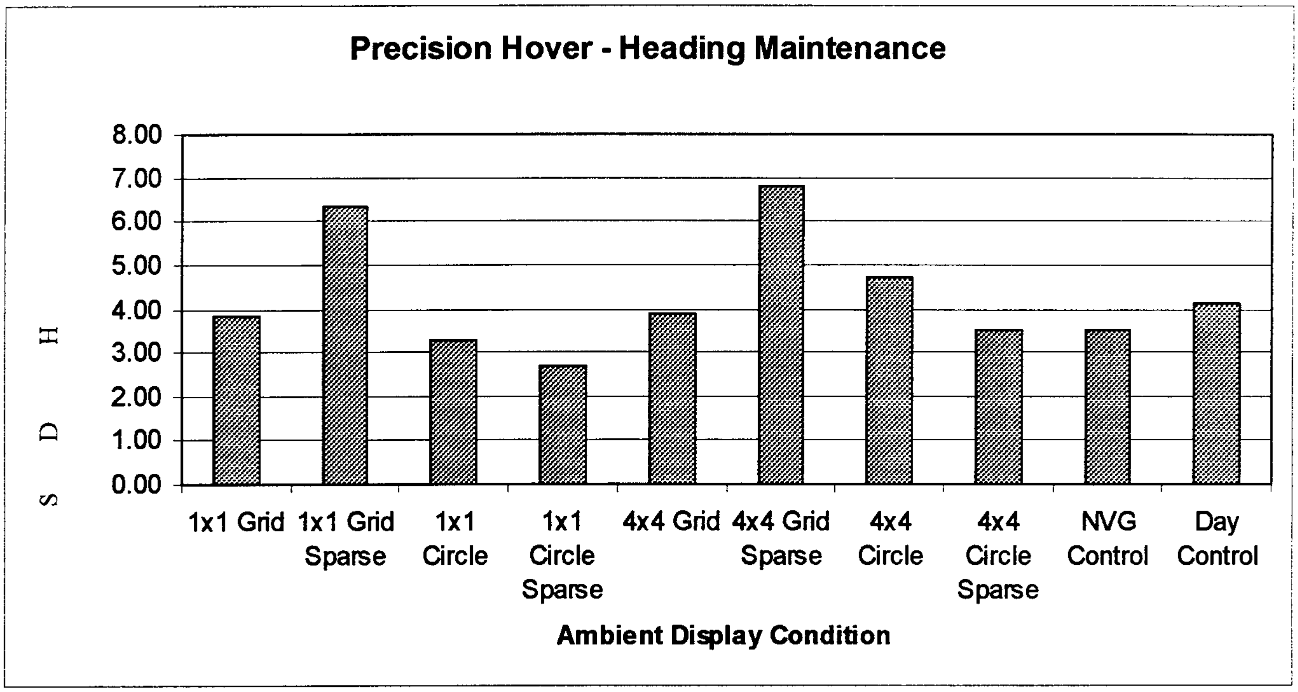


Figure 22. Standard Deviation of Aircraft Heading in Each Condition During the Precision Hover Task.

A summary of a one-way ANOVA performed on the standard deviation of aircraft heading is summarized in Table 27. This table shows that the differences between display conditions are not statistically reliable.

Table 28 contains the summary of a three-factor ANOVA performed on the standard deviation of aircraft heading in the experimental conditions. This ANOVA shows that the difference in the standard deviation of aircraft heading when the ambient objects were grids (5.2 degrees) and when the objects were circles (3.6 degrees) is marginally significant.

Table 28 also shows that the interaction between the shape and density of the ambient objects is marginally significant. This interaction is shown in Figure 20. Examination of Figure 20 shows that the density of the ambient objects had no effect on average heading when the ambient objects were circles. When the ambient objects were grids, then the average heading was farther from the ideal (315 degrees was the target heading) when the objects were sparse than when they were dense.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	63.201	9	7.022	1.067	0.4177
Error	177.770	27	6.584		

Table 27. Summary of a One-Way ANOVA performed on the Standard Deviation of Aircraft Heading in the Precision Hover Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	3.740	1	3.740	0.383	NS
$Error_{size}$	29.290	3	9.763		
Shape	22.095	1	22.095	4.600	0.1209
$Error_{shape}$	14.410	3	4.803		
Density	6.525	1	6.525	0.634	NS
$Error_{density}$	30.882	3	10.294		
Size x Shape	1.495	1	1.495	0.140	NS
$Error_{size\ x\ shape}$	32.127	3	10.709		
Size x Density	0.020	1	0.020	0.003	NS
$Error_{size\ x\ density}$	18.390	3	6.130		
Shape x Density	26.089	1	26.089	5.065	0.1093
$Error_{shape\ x\ density}$	15.451	3	5.150		
Size x Shape x Density	0.574	1	0.574	0.147	NS
$Error_{size\ x\ shape\ x\ density}$	11.698	3	3.899		

Table 28. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Aircraft Heading in the Precision Hover Task.

Table 28 also shows that the standard deviation of aircraft heading was effected by the interaction between the shape and density of the ambient objects. This interaction is shown in Figure 23. This figure shows that the standard deviation of aircraft heading was approximately the same for both grids and rectangles when they were distributed densely in the scene. When distributed sparsely, the standard deviation of aircraft heading increased when the objects were grids, and decreased when the objects were circles.

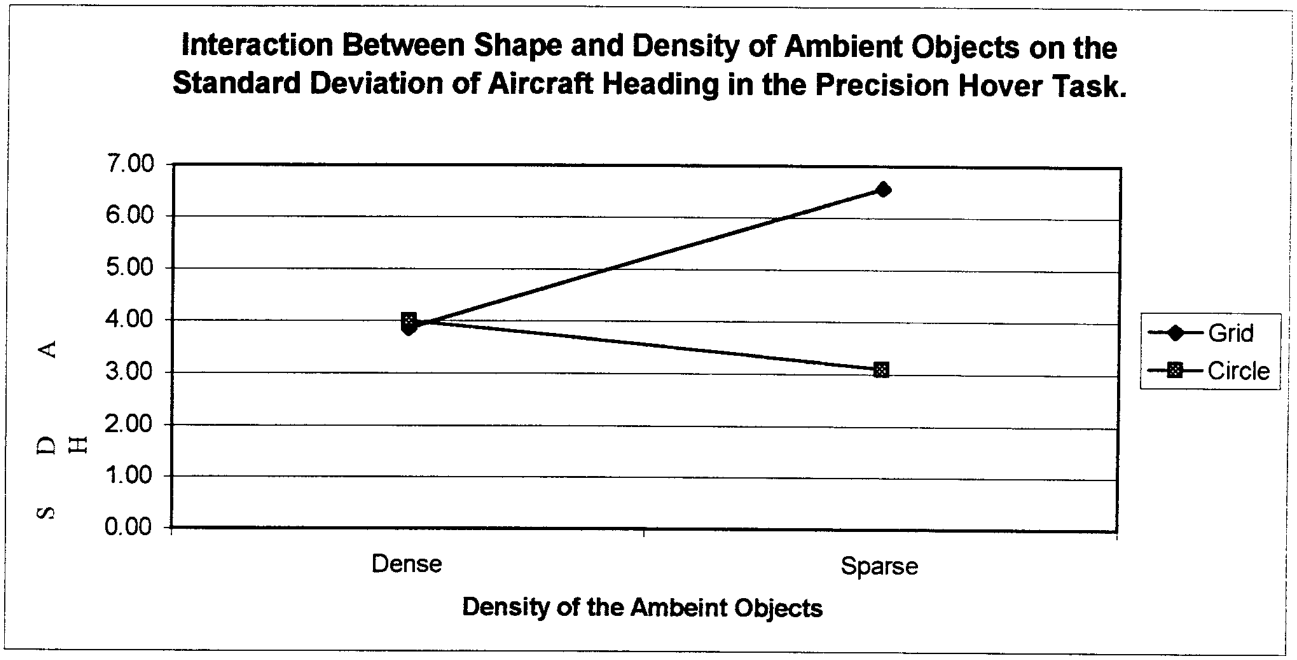


Figure 23. Interaction Between the Shape and Density of Ambient Objects on the Standard Deviation of Aircraft Heading in the Precision Hover Task.

PIROUETTE

AVERAGE ALTITUDE

The average altitude (± 1 standard deviation) in each of the display conditions during the pirouette task is shown in Figure 24.

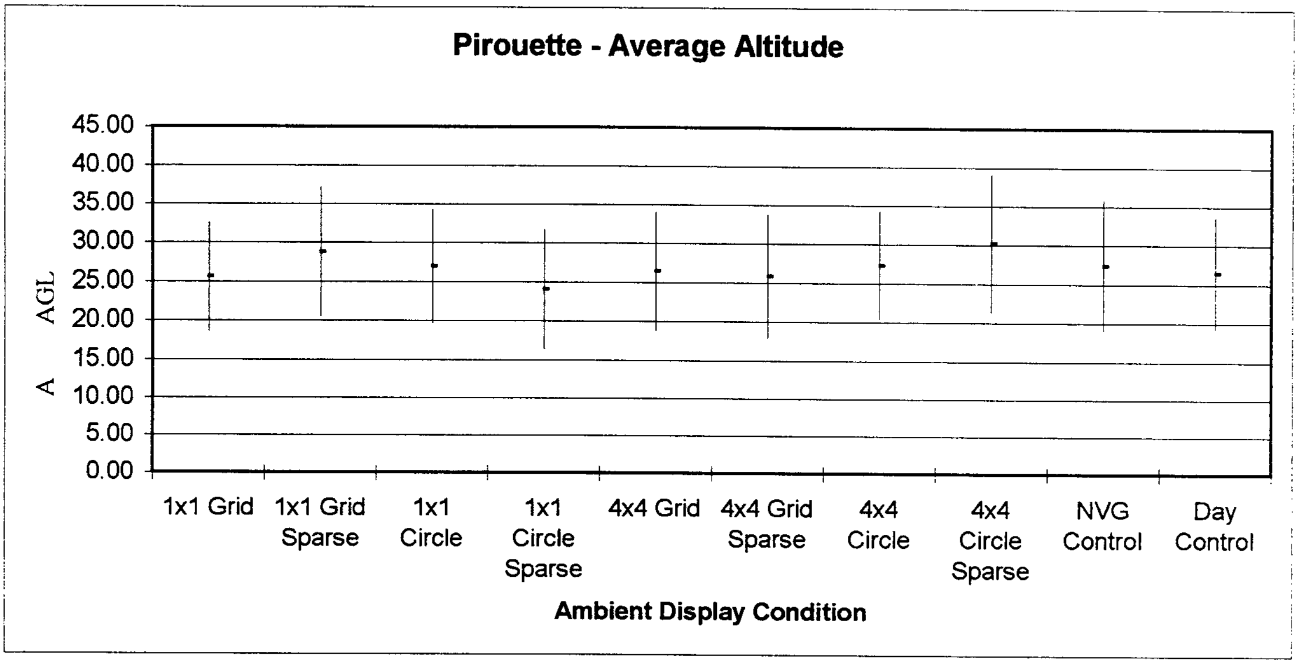


Figure 24 Average Altitude (+/- 1 standard deviation) in the Pirouette Task.

Table 29 contains the summary of a one-way ANOVA performed on the average altitude data from the pirouette task. This ANOVA shows that the differences between display conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	107.198	9	11.911	0.497	NS
Error	647.067	27	23.965		

Table 29. Summary of a One-Way ANOVA Performed on the Average Altitude Data from the Pirouette Task. The Target Altitude was 20 ft AGL.

Table 30 summarizes a three-factor ANOVA performed on the average altitude data from the pirouette task. This ANOVA shows that none of the main effects or interactions between ambient display factors had a statistically significant effect on the average altitude during this task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	10.061	1	10.061	0.998	NS
Error_{size}	30.242	3	10.081		
Shape	1.830	1	1.830	0.028	NS
Error_{shape}	197.806	3	65.935		
Density	3.326	1	3.326	1.773	0.2754
$\text{Error}_{density}$	5.628	3	1.876		
Size x Shape	38.105	1	38.105	0.842	NS
$\text{Error}_{size\ x\ shape}$	135.722	3	45.241		
Size x Density	1.973	1	1.973	0.116	NS
$\text{Error}_{size\ x\ density}$	51.043	3	17.014		
Shape x Density	3.445	1	3.445	0.225	NS
$\text{Error}_{shape\ x\ density}$	45.919	3	15.306		
Size x Shape x Density	46.578	1	46.578	1.165	0.3607
$\text{Error}_{size\ x\ shape\ x\ density}$	119.924	3	39.975		

Table 30. Summary of Three-Factor ANOVA Performed on Average Altitude Data from the Pirouette Task.

STANDARD DEVIATION OF ALTITUDE

The standard deviation of aircraft altitude in each display condition during the pirouette task is shown in Figure 25.

Table 31 contains a summary of the one-way ANOVA performed on these data. This table indicates that the differences between the conditions are not statistically reliable.

A three-factor ANOVA performed on the standard deviation of altitude data from the pirouette task is shown in Table 32. None of the main effects of the factors, or the interactions between the factors has a statistically significant effect on the standard deviation of aircraft altitude in this task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	15.501	9	1.722	0.292	NS
Error	159.368	27	5.903		

Table 31. Summary of a One-Way ANOVA Performed on the Standard Deviation of Altitude Data From the Pirouette Task.

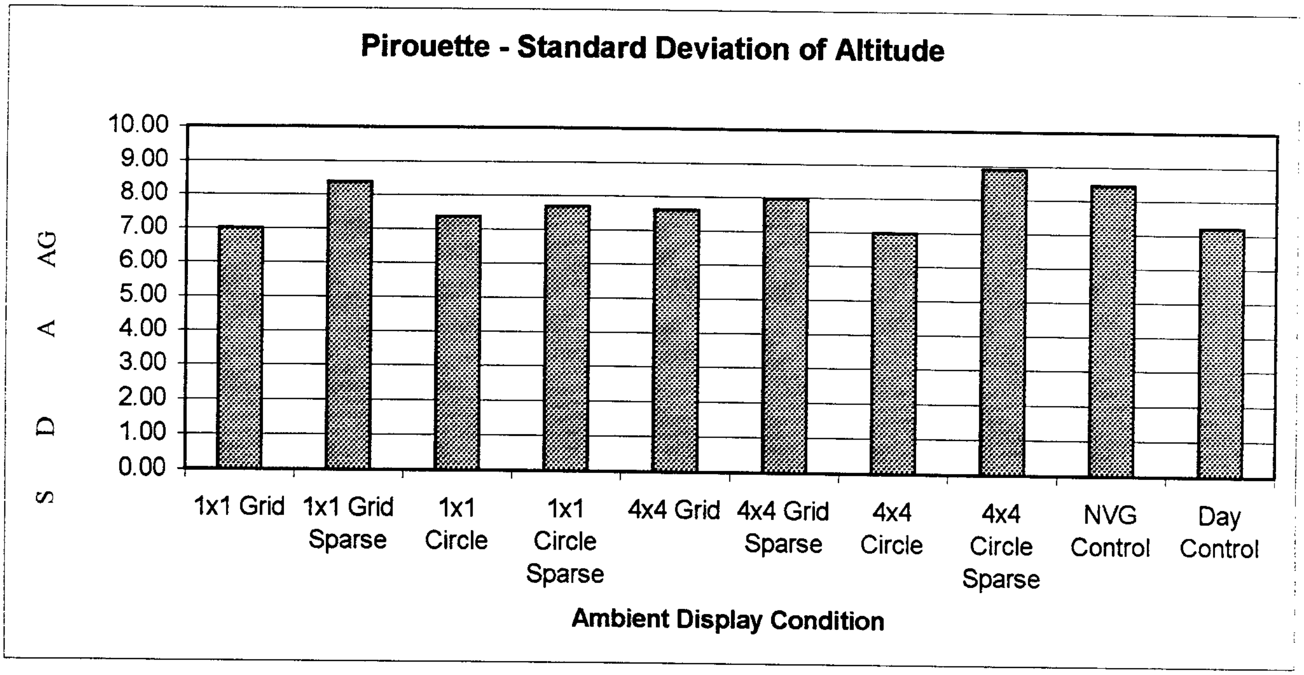


Figure 25. Standard Deviation of Altitude in Each Display Condition During the Pirouette Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.557	1	0.557	0.151	NS
Error $_{size}$	11.037	3	3.679		
Shape	0.000	1	0.000	0.000	NS
Error $_{shape}$	55.474	3	18.491		
Density	7.957	1	7.957	2.338	0.2237
Error $_{density}$	10.210	3	3.403		
Size x Shape	0.198	1	0.198	0.018	NS
Error $_{size\ x\ shape}$	32.193	3	10.731		
Size x Density	0.181	1	0.181	0.047	NS
Error $_{size\ x\ density}$	11.504	3	3.835		
Shape x Density	0.143	1	0.143	0.074	NS
Error $_{shape\ x\ density}$	5.801	3	1.934		
Size x Shape x Density	3.383	1	3.383	0.340	NS
Error $_{size\ x\ shape\ x\ density}$	29.847	3	9.949		

Table 32. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Altitude Data from the Pirouette Task.

AIRCRAFT BANK ANGLE

AVERAGE AIRCRAFT BANK ANGLE

The average bank angle of the aircraft (± 1 standard deviation) in each of the display conditions during the pirouette maneuver is shown in Figure 26

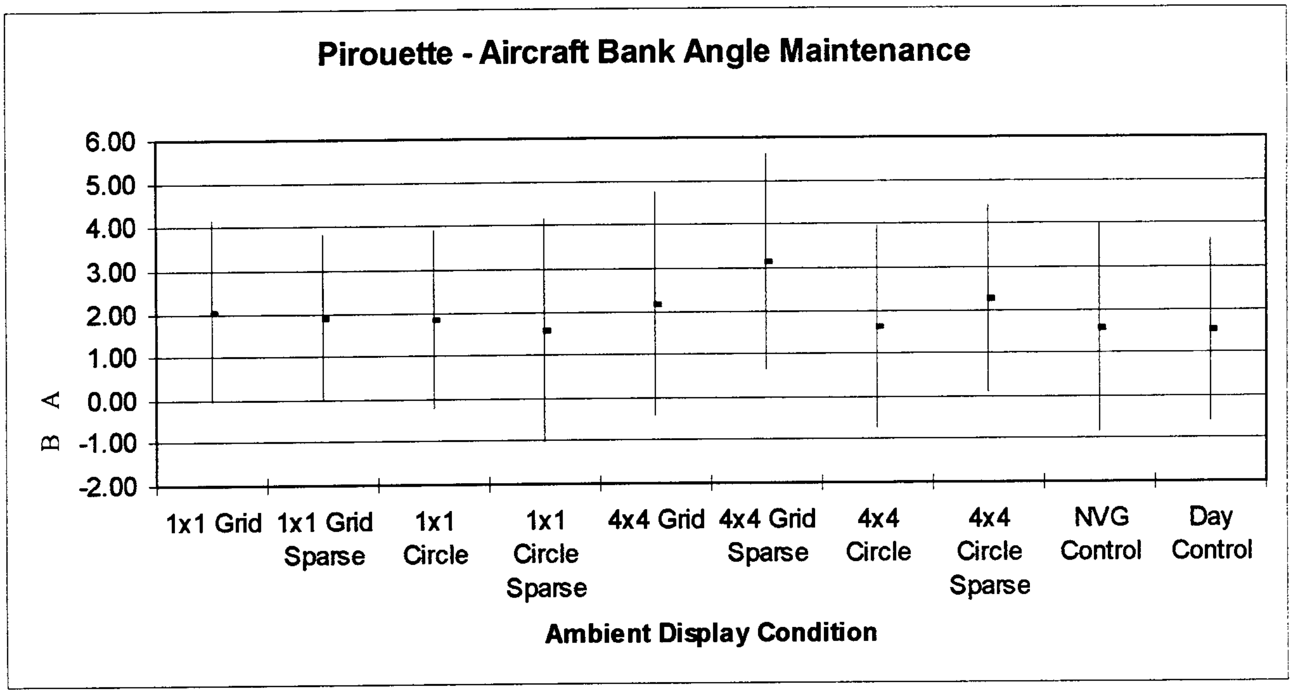


Figure 26. Average Aircraft Bank Angle (+/- 1 standard deviation) in Each Display Condition During the Pirouette Task.

Table 33 contains a summary of a one-way ANOVA performed on the average bank angle data from the pirouette task. This table shows that the differences between the conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	8.739	9	0.971	0.876	NS
Error	29.917	27	1.108		

Table 33. Summary of a One-Way ANOVA Performed on the Average Bank Angle Data from the Pirouette Task.

The summary of a three-factor ANOVA performed on the average aircraft bank angle is contained in Table 34. This table shows that none of the main effects or interactions between the factors has a statistically reliable effect on the bank angle.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	1.663	1	1.663	2.820	0.1916
Error $_{size}$	1.769	3	0.590		
Shape	1.986	1	1.986	0.630	NS
Error $_{shape}$	9.452	3	3.151		
Density	0.696	1	0.696	0.968	NS
Error $_{density}$	2.156	3	0.719		
Size x Shape	0.404	1	0.404	0.220	NS
Error $_{size\ x\ shape}$	5.512	3	1.837		
Size x Density	2.090	1	2.090	1.482	0.3111
Error $_{size\ x\ density}$	4.232	3	1.411		
Shape x Density	0.107	1	0.107	0.508	NS
Error $_{shape\ x\ density}$	0.632	3	0.211		
Size x Shape x Density	0.012	1	0.012	0.015	NS
Error $_{size\ x\ shape\ x\ density}$	2.473	3	0.824		

Table 34. Summary of a Three-Factor ANOVA Performed on the Average Bank Angle Data from the Pirouette Task.

STANDARD DEVIATION OF AIRCRAFT BANK ANGLE

Figure 27 shows the standard deviation of the aircraft's bank angle in each display condition during the pirouette task. Table 35 summarizes a one-way ANOVA performed on these data.

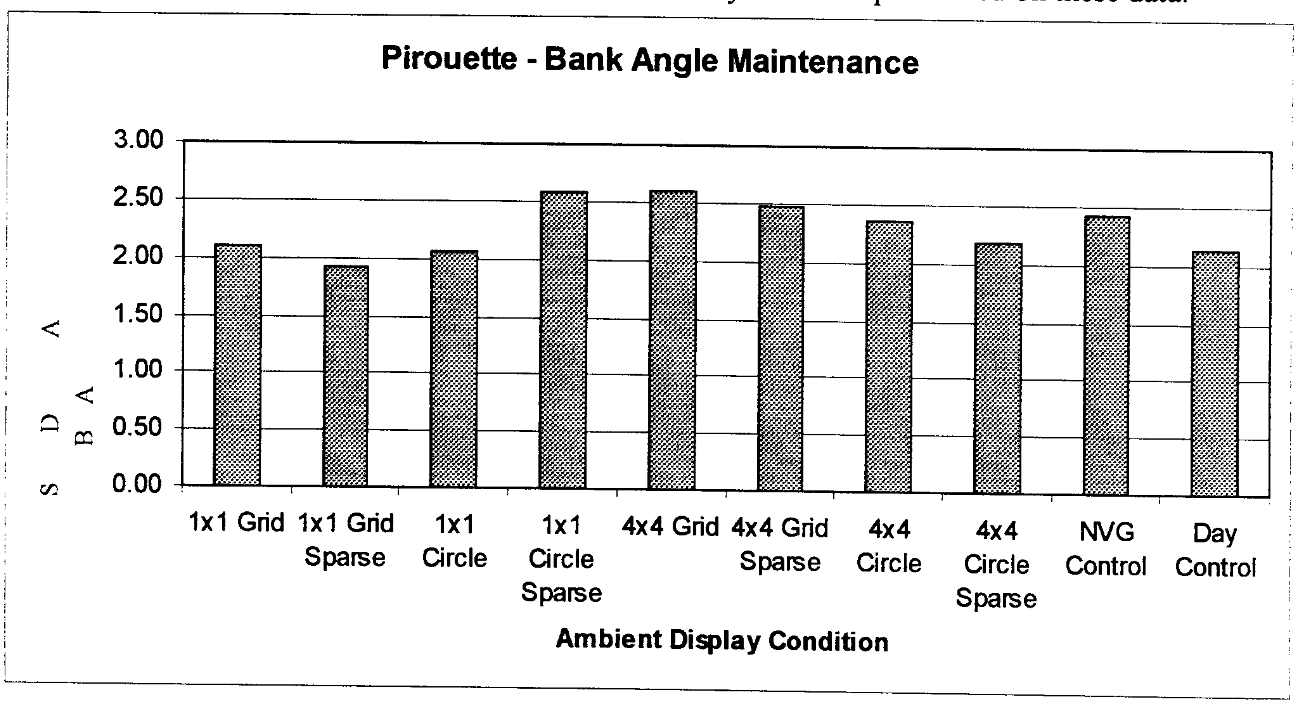


Figure 27. Standard Deviation of Aircraft Bank Angle in Each Display Condition During the Pirouette Task.

Table 35 shows that the differences between the display conditions are not statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	2.023	9	0.225	0.526	NS
Error	11.531	27	0.427		

Table 35. Summary of a One-Way ANOVA Performed on the Standard Deviation of Aircraft bank Angle During the Pirouette Task.

Table 36 summarizes a three-factor ANOVA performed on the standard deviation of aircraft bank angles in the ambient display conditions. This ANOVA shows that there is an effect of the size of the ambient objects. The standard deviation of the aircraft's bank angle was greater when the ambient objects were large than when they were small (2.4 degrees vs. 2.2 degrees, respectively).

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	0.454	1	0.454	5.383	0.1024
$Error_{size}$	0.253	3	0.084		
Shape	0.004	1	0.004	0.003	NS
$Error_{shape}$	3.611	3	1.204		
Density	0.002	1	0.002	0.003	NS
$Error_{density}$	1.793	3	0.598		
Size x Shape	0.675	1	0.675	3.456	0.1598
$Error_{size \times shape}$	0.586	3	0.195		
Size x Density	0.200	1	0.200	0.259	NS
$Error_{size \times density}$	2.317	3	0.772		
Shape x Density	0.216	1	0.216	0.497	NS
$Error_{shape \times density}$	1.304	3	0.435		
Size x Shape x Density	0.293	1	0.293	3.232	0.1700
$Error_{size \times shape \times density}$	0.272	3	0.091		

Table 36. Summary of a Three-Factor ANOVA Performed on the Standard Deviations of the Aircraft's bank Angle During the Pirouette Task.

There is some suggestion that the interaction between the size and shape of the ambient objects effects the variability of the aircraft's bank angle. Figure 28 shows that when the objects are small, the standard deviation was greater for circles than grids. For large ambient objects the standard deviation was greater for grids than circles.

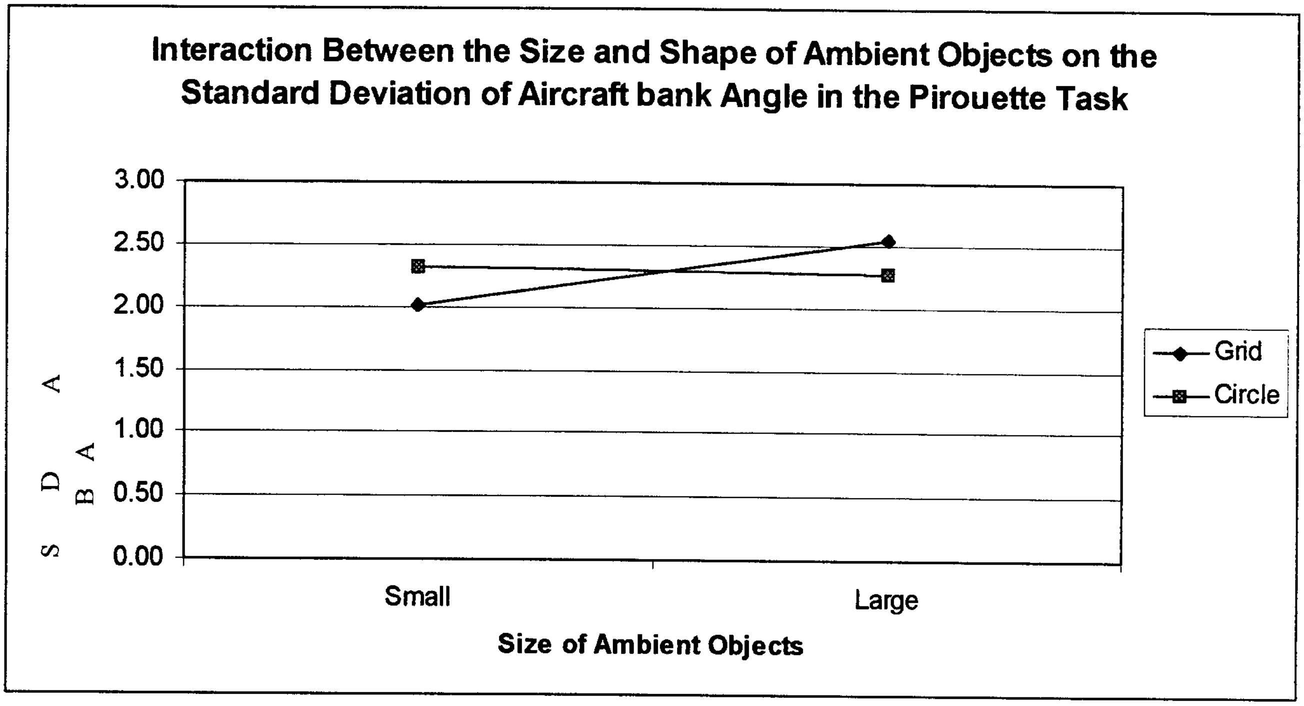


Figure 28. Effect of the Interaction Between the Size and Shape of Ambient Objects on the Standard Deviation of the Aircraft's Bank Angle During the Pirouette Task.

SLALOM

AVERAGE ALTITUDE

During the slalom, pilots attempted to maintain an altitude of 50 ft AGL. Figure 28 shows the average altitude (± 1 standard deviation) in each of the conditions.

Examination of Figure 29 shows that the average altitude was closest to the target altitude of 50 ft AGL in the NVG and Daylight control conditions. On eht average, pilots flew higher than desired in all conditions in which ambient objects were displayed.

Table 37 summarizes a one-way ANOVA performed on the average altitude data from the slalom task. This ANOVA indicates that the difference between the highest and lowest altitude is significant. Examination of Figure 26 shows that lowest average altitude is just over the 50 ft target altitude in the NVG only condition. The highest average altitude is in the small, sparse grid condition.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	1516.925	9	168.547	1.911	0.0935
Error	2381.109	27	88.189		

Table 37. Summary of a One-Way ANOVA Performed on Average Altitude Data from the Slalom Task.

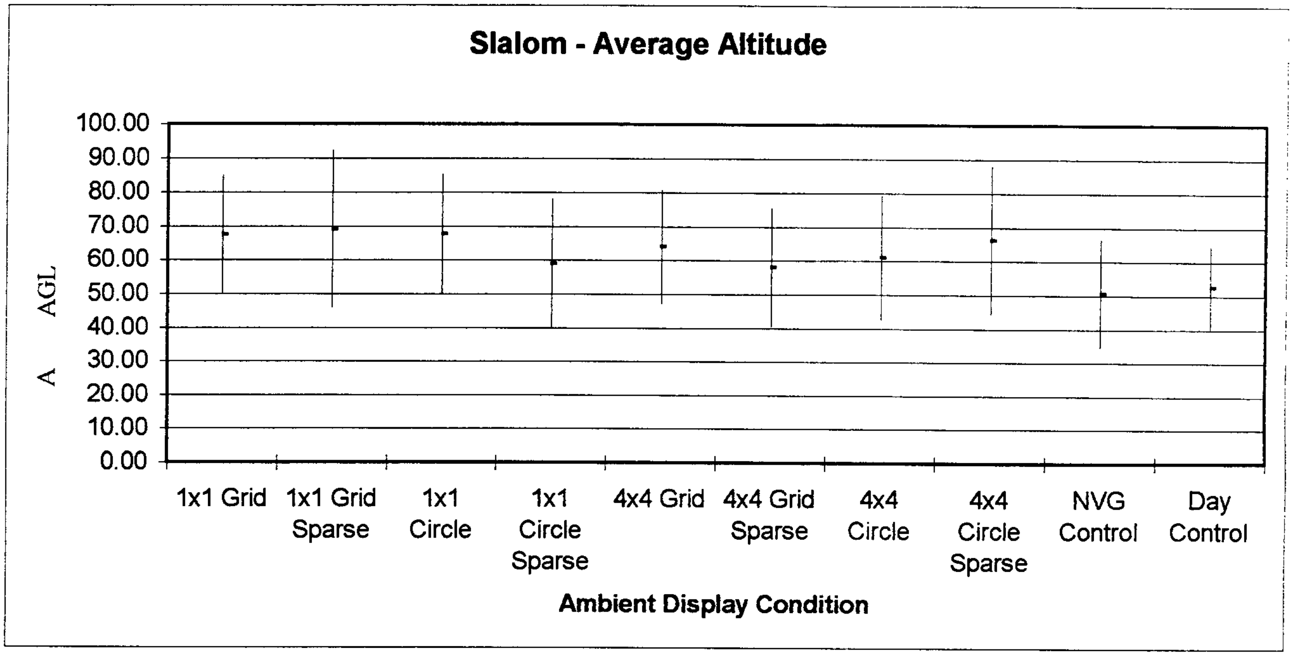


Figure 29. Average Altitude (+/- 1 standard deviation) in the Slalom Task.

Table 38 contains a summary of a three-factor ANOVA performed on the average altitude data from the slalom task. None of the main effects or two way interactions are statistically significant. The three way interaction between the size, shape and density of the ambient objects was statistically reliable. This interaction is shown in Figure 30.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	99.016	1	99.016	1.768	0.2760
Error $_{size}$	168.059	3	56.020		
Shape	12.109	1	12.109	0.244	NS
Error $_{shape}$	148.852	3	49.617		
Density	31.359	1	31.359	0.096	NS
Error $_{density}$	978.203	3	326.068		
Size x Shape	116.813	1	116.813	1.926	0.2594
Error $_{size\ x\ shape}$	181.977	3	60.659		
Size x Density	20.734	1	20.734	0.102	NS
Error $_{size\ x\ density}$	608.960	3	202.987		
Shape x Density	0.609	1	0.609	0.048	NS
Error $_{shape\ x\ density}$	37.981	3	12.660		
Size x Shape x Density	229.672	1	229.672	6.005	0.0909
Error $_{size\ x\ shape\ x\ density}$	114.734	3	38.245		

Table 38. Summary of Three-Factor ANOVA Performed on Average Altitude Data from the Slalom Task.

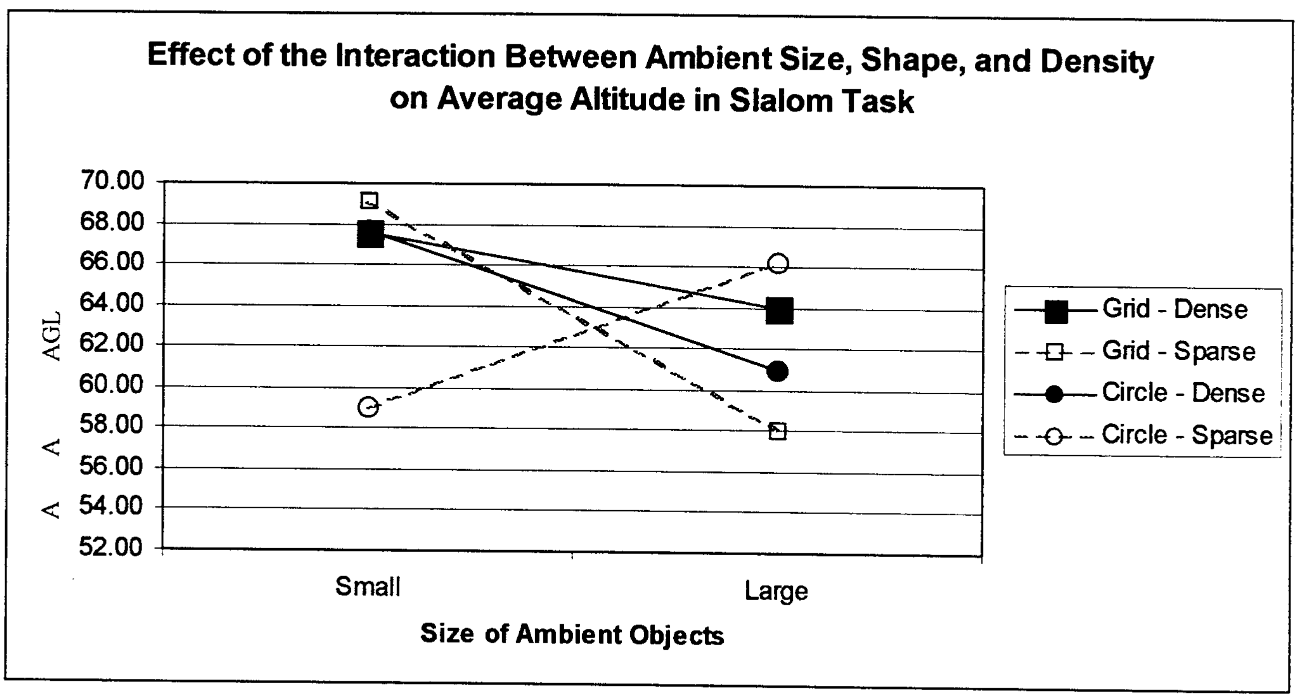


Figure 30. Effect of the Interaction Between the Size, Shape, and Density of the Ambient Objects on Average Altitude in the Slalom Task.

Examination of Figure 30 shows that the average altitude increasing as the size of the ambient increases for sparse circles. For dense grids and circles, and for sparse grids, the average altitude decreases as the sizes of the objects increase.

STANDARD DEVIATION OF ALTITUDE

The standard deviation of altitude in each condition of the slalom task is shown in Figure 31. Inspection of this figure shows that the altitude variability was greater in all ambient conditions compared to both the NVG only and the Day control conditions.

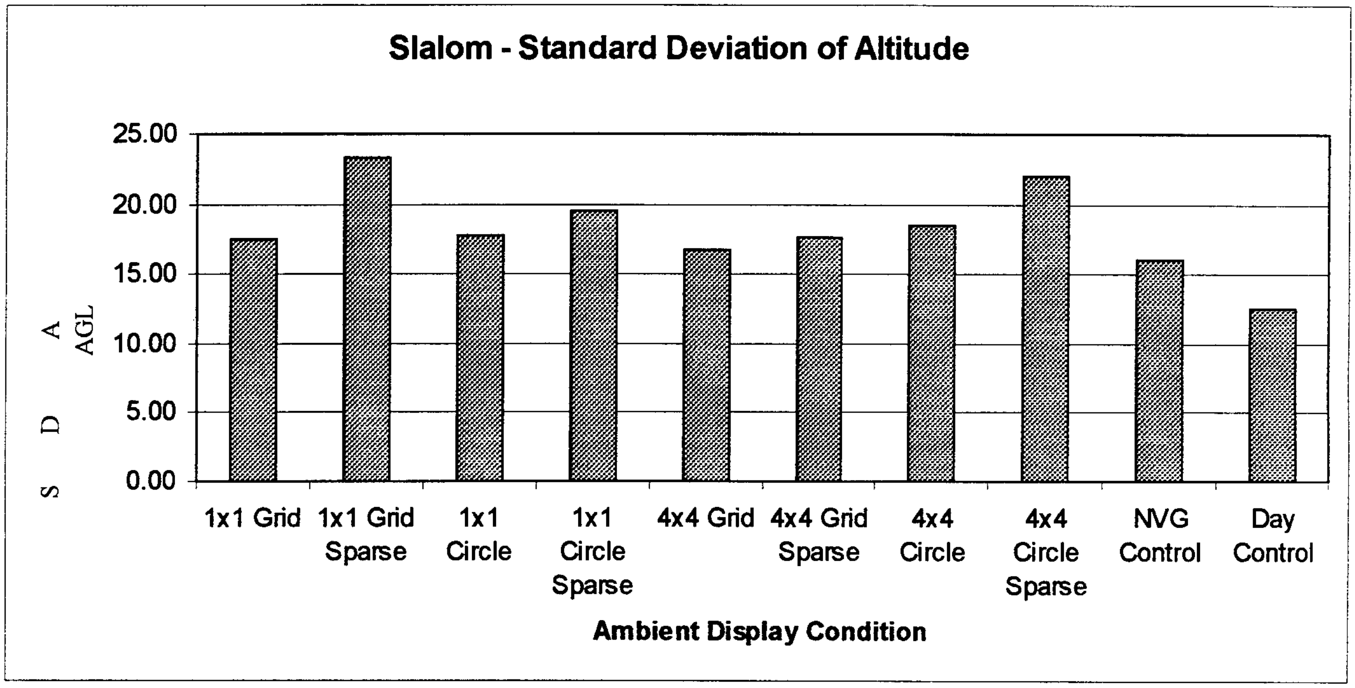


Figure 31. Standard Deviation of Altitude in the Slalom Task.

Table 39 contains a summary of the one-way ANOVA performed on the standard deviation of altitude data. This table shows that the difference between display conditions is statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	322.640	9	35.849	3.114	0.0108
Error	310.848	27	11.513		

Table 39. Summary of a One-Way ANOVA performed on the Standard Deviation of Altitude Data from the Slalom Task.

A Tukey Post-Hoc test revealed that the 1x1 Grid Sparse differed from the Day control condition at the 0.01 level of probability, and that the 4x4 Circle Sparse condition differed from the Day control condition at the 0.05 level.

Table 40 summarizes a three-factor ANOVA performed on the standard deviation of altitude data. Examination of Table 40 shows that there is a significant three-way interaction. None of the main effects of two-way interactions are statistically reliable. Figure 32 shows the three-way interaction.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	4.303	1	4.303	0.345	NS
Error size	37.455	3	12.485		
Shape	3.395	1	3.395	0.273	NS
Error shape	37.342	3	12.447		
Density	70.807	1	70.807	2.820	0.1915
Error density	75.316	3	25.105		
Size x Shape	46.166	1	46.166	2.679	0.2001
Error size x shape	51.707	3	17.236		
Size x Density	4.842	1	4.842	0.616	NS
Error size x density	23.569	3	7.856		
Shape x Density	1.139	1	1.139	0.149	NS
Error shape x density	22.987	3	7.662		
Size x Shape x Density	22.109	1	22.109	5.957	0.0917
Error size x shape x density	11.134	3	3.711		

Table 40. Summary of Three-Factor ANOVA Performed on Standard Deviation of Altitude Data from the Slalom Task.

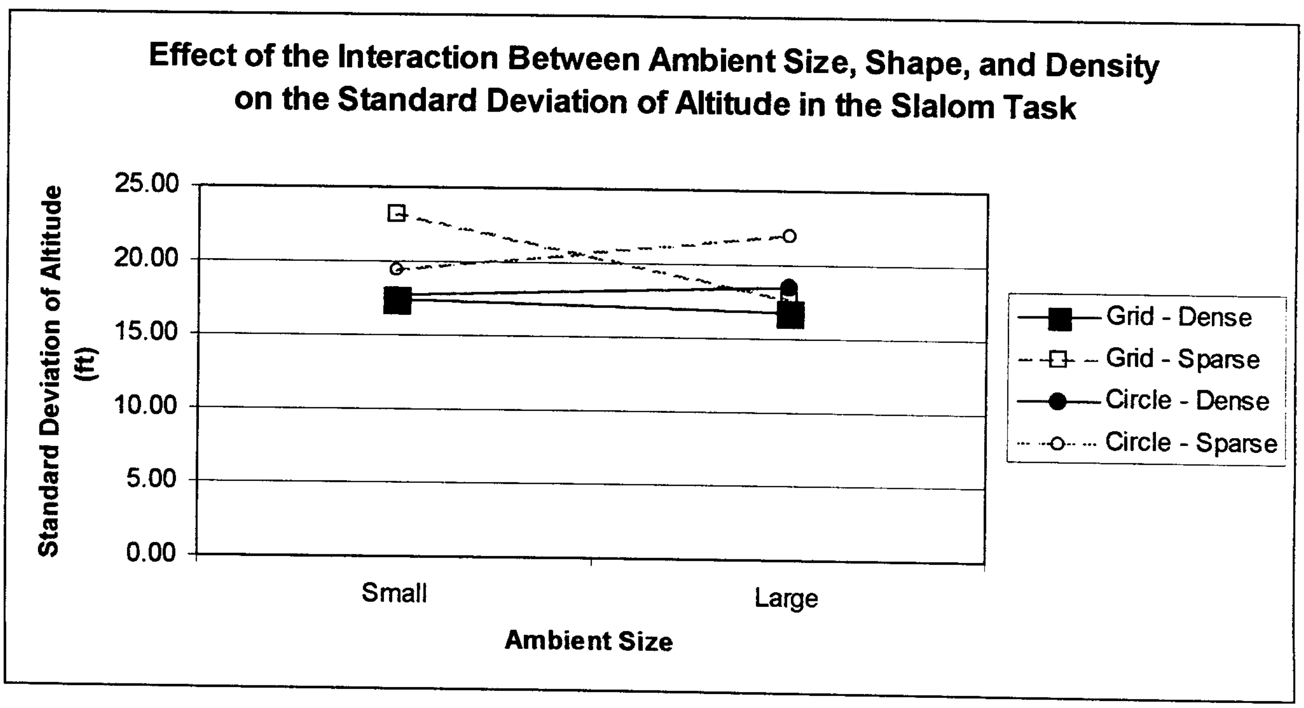


Figure 32. Effect of the Interaction between Ambient Size, Shape, and Density on the Standard Deviation of Altitude in the Slalom Task.

Examination of Figure 31 shows that the altitude variability increases as the size increases when the ambient objects are sparse circles. In the other combinations of factors, the variability decreases or, in the case of dense circles, increases only slightly.

AVERAGE AIRSPEED

The target airspeed in the slalom task was 50 kts. Figure 33 shows the average airspeed (± 1 standard deviation) in each of the display conditions.

Table 41 contains the summary of a one-way ANOVA performed on the average airspeed data from the slalom task. This analysis shows that the differences between display conditions are not statistically reliable.

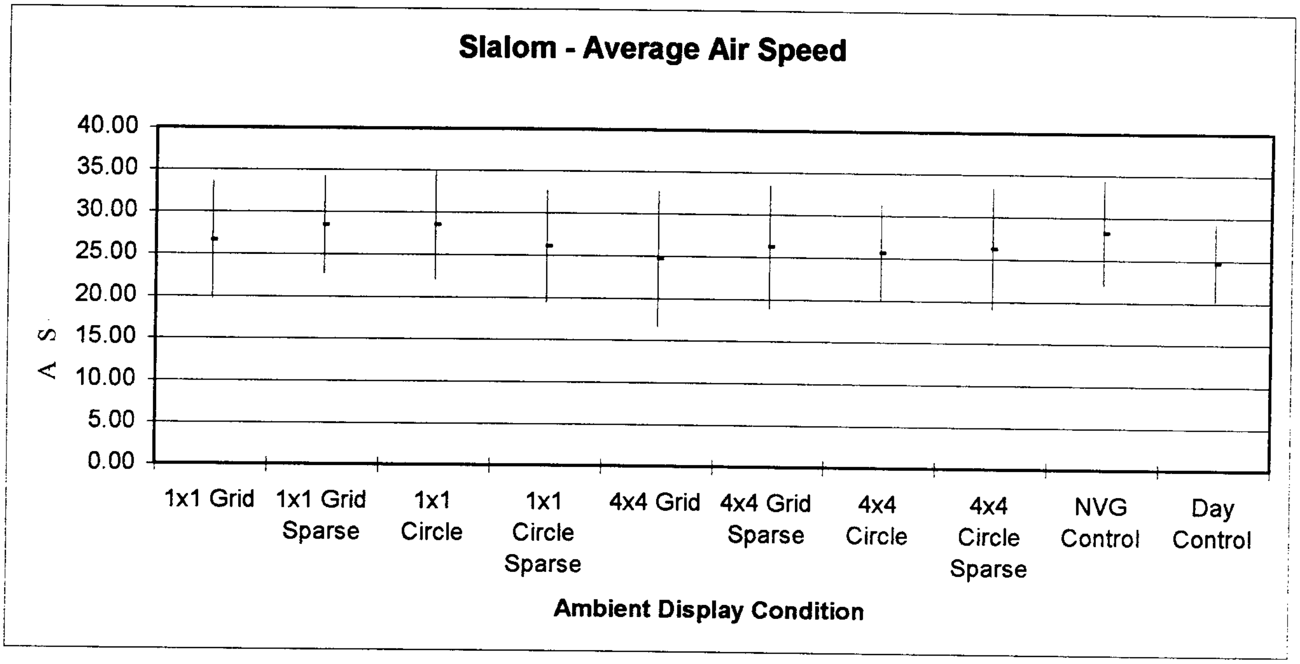


Figure 33. Average Airspeed (+/- 1 standard deviation) in Each Display Condition in the Slalom Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	74.306	9	8.256	1.055	0.4255
Error	211.307	27	7.826		

Table 41. Summary of a One-Way ANOVA Performed on the Average AIrspeed Data From the Slalom Task.

Table 42 summarizes a three-factor ANOVA performed on the average airspeed data from the slalom task. Inspection of this table shows that the main effect of the size of the ambient objects is statistically significant. The average airspeed was 25.7 kts when the ambient objects were large, and 26.6 kts when the ambient objects were small. No other main effect or interaction is statistically reliable.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	24.314	1	24.314	8.087	0.0643
Error $_{size}$	9.020	3	3.007		
Shape	0.105	1	0.105	0.018	NS
Error $_{shape}$	17.521	3	5.840		
Density	1.094	1	1.094	0.094	NS
Error $_{density}$	35.033	3	11.678		
Size x Shape	0.982	1	0.982	0.386	NS
Error $_{size\ x\ shape}$	7.637	3	2.546		
Size x Density	3.830	1	3.830	0.239	NS
Error $_{size\ x\ density}$	48.107	3	16.036		
Shape x Density	13.184	1	13.184	2.153	0.2386
Error $_{shape\ x\ density}$	18.370	3	6.123		
Size x Shape x Density	5.756	1	5.756	0.993	NS
Error $_{size\ x\ shape\ x\ density}$	17.386	3	5.795		

Table 42. Summary of a Three-Factor ANOVA Performed on the Average Airspeed Data from the Slalom Task.

STANDARD DEVIATION OF AIRSPEED

The standard deviation of airspeed in each display condition is shown in Figure 34. A one-way ANOVA, which is summarized in Table 43, shows that the differences between conditions are not statistically reliable.

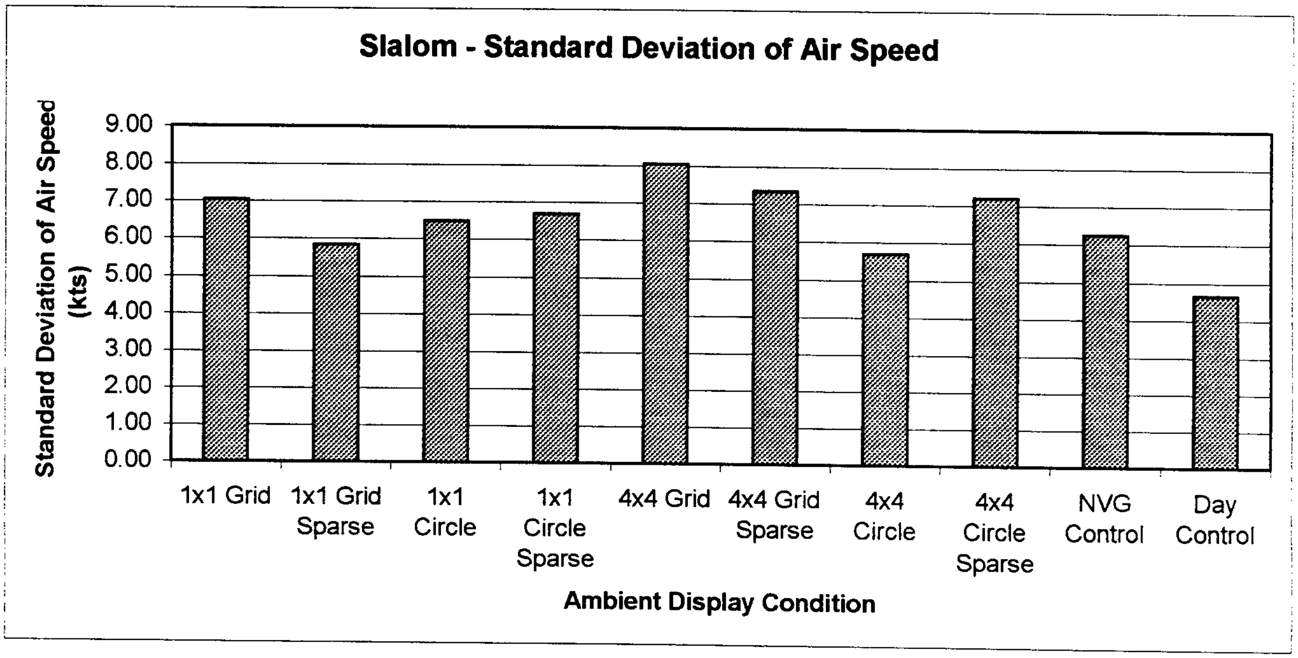


Figure 34. Standard Deviation of Airspeed in the Slalom Task.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Ambient Condition	33.778	9	3.753	1.420	0.2285
Error	71.354	27	2.643		

Table 43. Summary of a One-Way ANOVA Performed on Standard Deviation of Altitude Data from the Slalom Task.

Table 44 summarizes the three-factor ANOVA performed on the standard deviation of airspeed data from the slalom task. This ANOVA indicates that there is a marginally reliable effect of the interaction between the size and density of the ambient objects on airspeed variability.

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	p
Size	2.542	1	2.542	0.464	NS
$Error_{size}$	16.441	3	5.480		
Shape	2.339	1	2.339	0.772	NS
$Error_{shape}$	9.090	3	3.030		
Density	0.016	1	0.016	0.004	NS
$Error_{density}$	11.180	3	3.727		
Size x Shape	3.872	1	3.872	0.996	NS
$Error_{size\ x\ shape}$	11.660	3	3.887		
Size x Density	1.587	1	1.587	3.558	0.1555
$Error_{size\ x\ density}$	1.338	3	0.446		
Shape x Density	6.539	1	6.539	1.970	0.2551
$Error_{shape\ x\ density}$	9.957	3	3.319		
Size x Shape x Density	0.319	1	0.319	0.173	NS
$Error_{size\ x\ shape\ x\ density}$	5.537	3	1.846		

Table 44. Summary of a Three-Factor ANOVA Performed on the Standard Deviation of Airspeed in the Slalom Task.

The effect of the interaction between the size and shape of the ambient objects on airspeed variability is shown in Figure 35. Examination of this figure shows that the airspeed variability increases as the density of the ambient objects decreases for small ambient objects. For large ambient objects, airspeed variability increases as the density of the objects in the scene decreases.

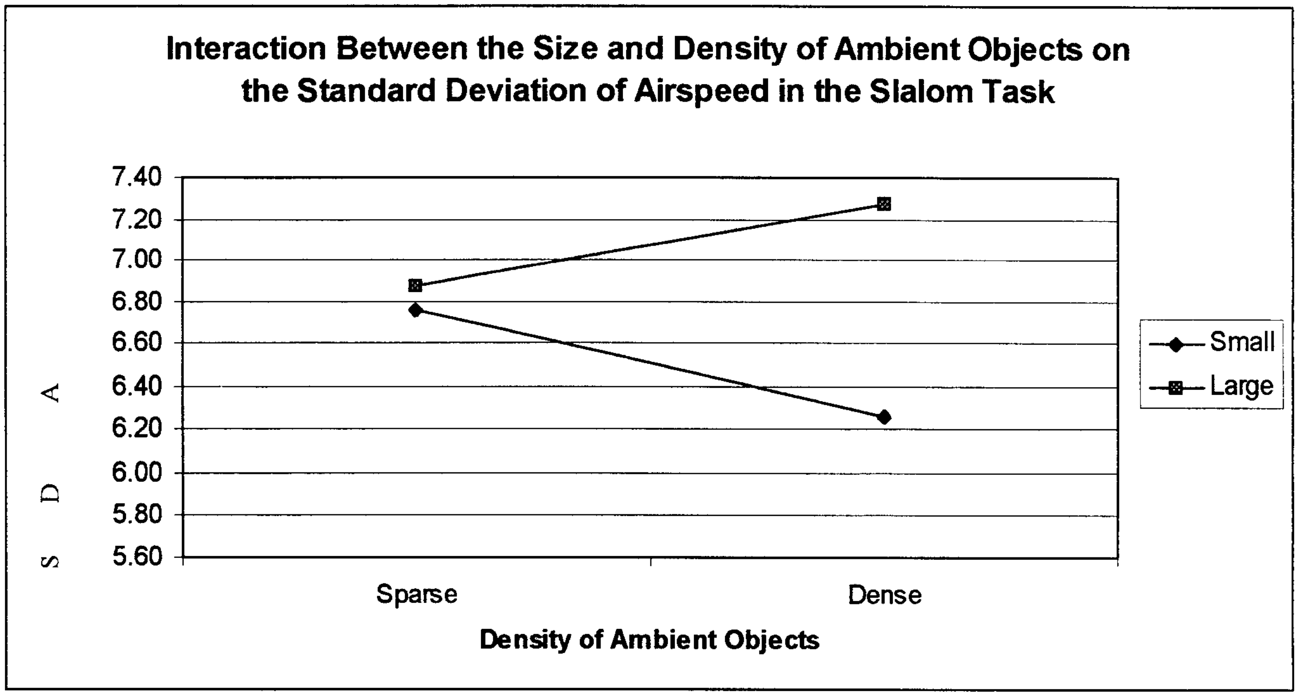


Figure 35. The effect of the Interaction Between the Size and Density of Ambient Objects on the Standard Deviation of Airspeed in the Slalom Task.

SUBJECTIVE RESULTS

BACKGROUND

Pilots completed a questionnaire following completion of each flight using ambient displays. This questionnaire consisted of 29 items to be rated by the pilot and seven open-ended questions. This questionnaire is contained in appendix 1.

RATINGS

Pilot responses were made on a 7-point scale. The average ratings to each question are presented here. The verbal anchors for each rating scale are shown parenthetically.) Due to the small sample size, inferential statistics were not computed on the average rating data.

Rating 1. Did the ambient display help you maintain awareness of the aircraft's pitch angle? (1 = It interfered with my awareness of aircraft pitch, 4 = No effect on my awareness of pitch, 7 = It was invaluable in helping me maintain awareness of aircraft pitch.)

Figure 36 shows the average ratings regarding pilot awareness of pitch. These ratings indicate that the effect of ambient displays was quite small, but generally positive. Circles were judged more favorably than grid when the ambient objects were small, and grids were judged preferable to circles when the ambient objects were large. Dense distributions of ambient objects were rated slightly better than sparse distributions when the ambient objects were small, while sparse distributions of ambient objects were preferred when the objects were large.

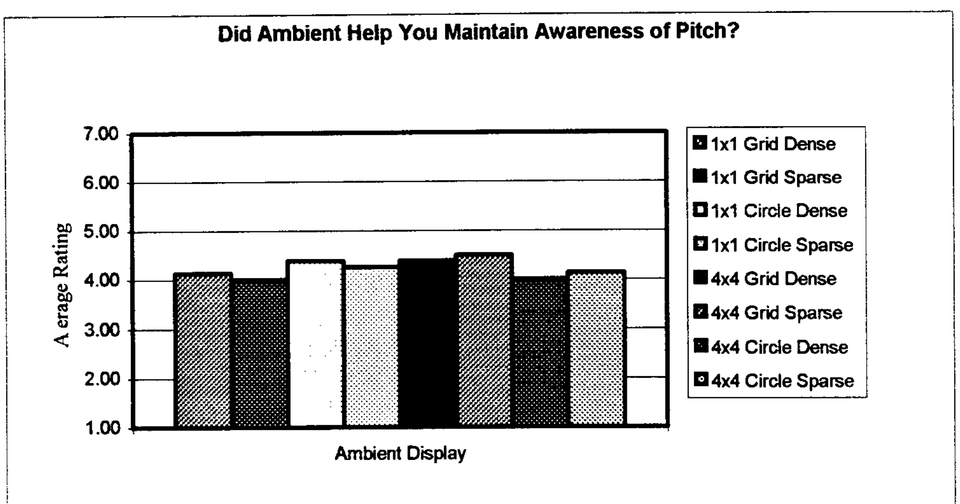


Figure 36. Average Pilot Ratings of Ability to Maintain Awareness of Pitch in Each of the Ambient Display Conditions.

Rating 2. Did the ambient display effect your ability to detect CHANGES in the aircraft's pitch angle? (1 = It interfered with my ability to detect pitch changes, 4 = No effect on my awareness of pitch changes, 7 = It was invaluable in helping me detect pitch changes.)

Figure 37 shows the average ratings of the effect of the ambient displays on the pilot's ability to detect pitch changes. With the exception of the small-grid-dense condition, the ambient displays were judged to have a positive effect. Small circular ambient objects were rated best. For small ambient objects, circles were preferred to grids, and sparse distributions were preferred to dense distributions. For large ambient objects, the dense and sparse distributions of large grids were judged as having equivalent effects. When the display consisted of large circles, pilots rated the dense distribution as being preferred to the sparse distribution.

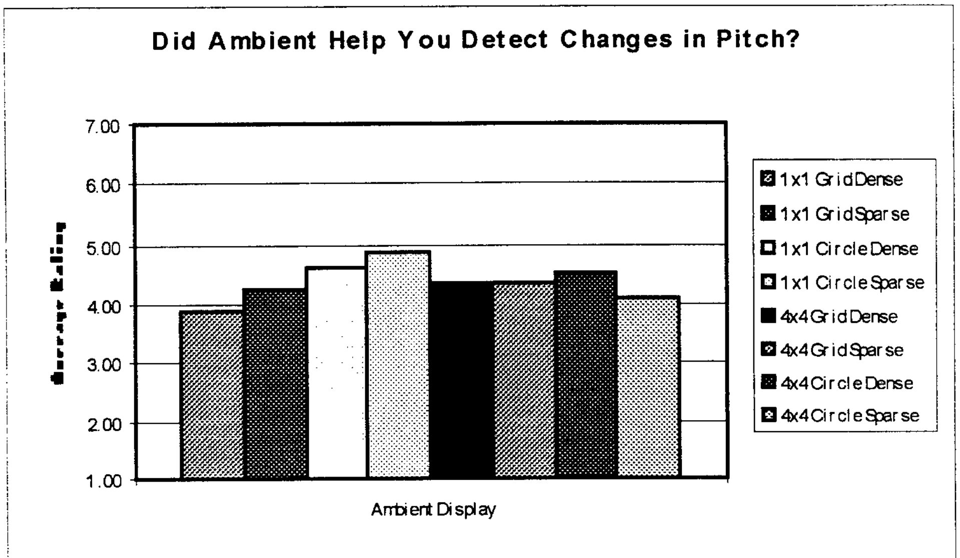


Figure 37. Average Pilot Ratings of Ability to Detect Changes in Pitch in Each of the Ambient Display Conditions.

Rating 3. Did the ambient display help you maintain awareness of the aircraft's roll angle? (1 = It interfered with my awareness of aircraft roll, 4 = No effect on my awareness of roll, 7 = It was invaluable in helping me maintain awareness of aircraft roll.)

Figure 38 shows the average ratings of the effect of the ambient displays on the pilot's awareness of aircraft roll. All of the conditions were rated as having a small beneficial effect. The highest rated displays consisted of small-dense and large-sparse circles. Examination of this figure shows that when the ambient objects are small, sparse distributions are preferred. Hen the ambient objects are large, then the dense distributions were preferred.

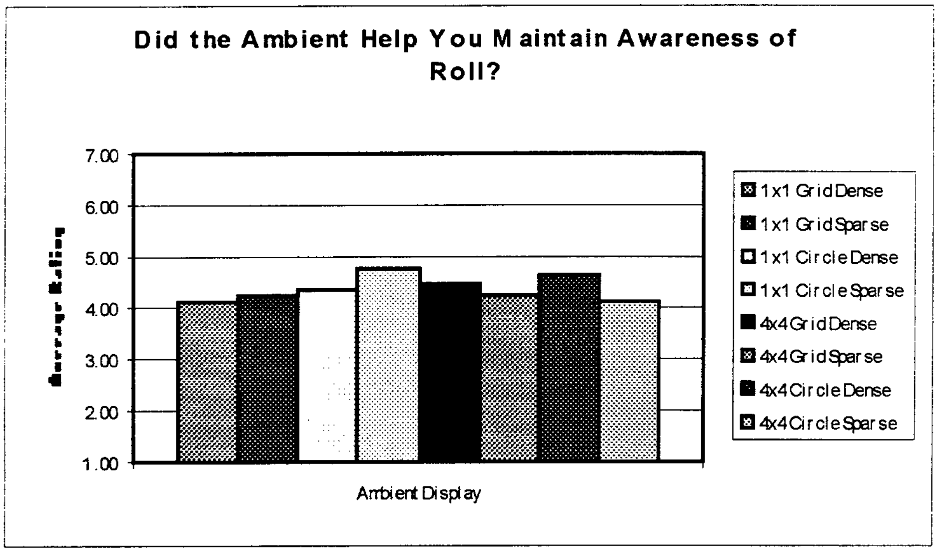


Figure 38. Average Pilot Ratings of Ability to Maintain Awareness of Aircraft Roll in Each of the Ambient Display Conditions.

Rating 4. Did the ambient display effect your ability to detect CHANGES in the aircraft's roll angle? (1 = It interfered with my ability to detect roll changes, 4 = No effect on my awareness of roll changes, 7 = It was invaluable in helping me detect roll changes.)

The ratings of the ambient display's effect on the pilot's ability to detect changes in the aircraft's roll angle are shown in Figure 39. The large-grid-dense condition was judged to be most useful by the pilots. When the ambient objects were circles, pilots rated the dense displays higher than the sparse displays. The –small-grid-dense condition and the large-grid-sparse conditions were judged to have a detrimental effect; all of the other ambient displays were judged to have a positive effect.

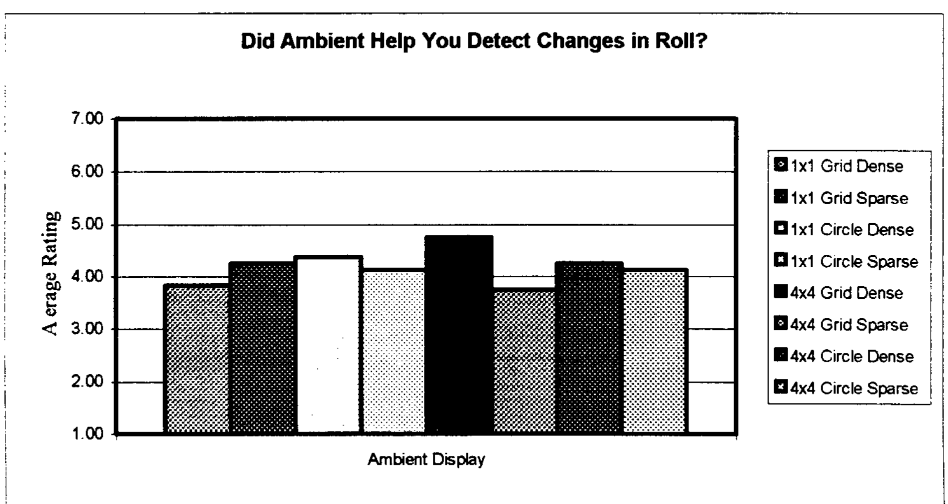


Figure 39. Average Pilot Ratings of Ability to Detect Changes in Roll in Each of the Ambient Display Conditions.

Rating 5. Did the ambient display help you maintain awareness of the aircraft's vertical speed? (1 = It interfered with my awareness of vertical speed, 4 = No effect on my awareness of vertical speed, 7 = It was invaluable in helping me maintain awareness of vertical speed.)

All of the ambient displays were judged to have a beneficial effect on the pilot's awareness of vertical speed. These ratings are shown in Figure 40. On the whole, grid patterns were rated a bit higher than circular patterns. This is probably due to the presence of horizontal line segments at the top and bottom of each element of the grid. These horizontal elements provide a strong sensation of vertical motion. Sparse distributions of the grid pattern were preferred over the dense patterns regardless of the size of the grid elements.

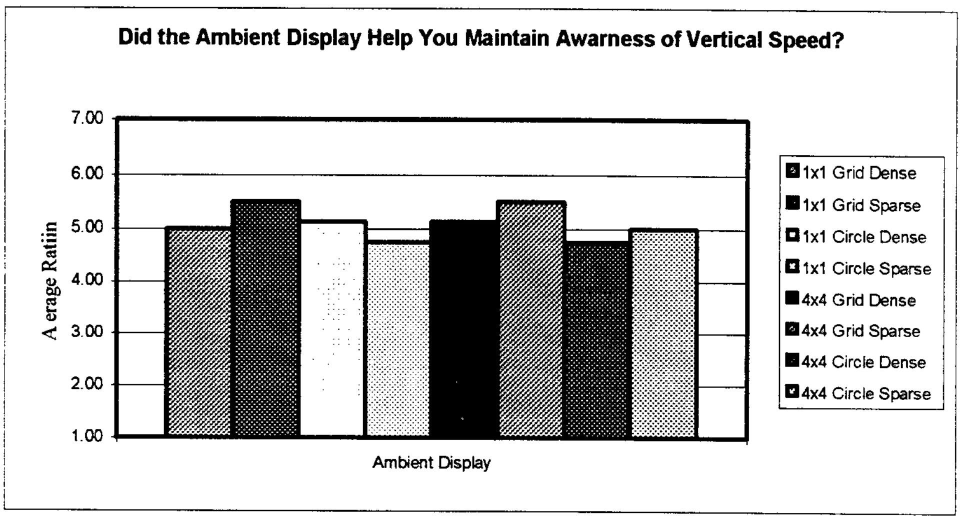


Figure 40. Average Pilot Ratings of Ability to Maintain Awareness of Vertical Speed in Each of the Ambient Display Conditions.

Rating 6. Did the ambient display effect your ability to detect CHANGES in the aircraft's vertical speed? (1 = It interfered with my ability to detect changes in vertical speed, 4 = No effect on my awareness of vertical speed changes, 7 = It was invaluable in helping me detect changes in vertical speed.)

The average ratings of the effect of the ambient displays on the pilot's ability to detect changes in vertical speed are shown in Figure 41. All of the ambient displays as having a beneficial effect on the detection of changes in vertical speed. The highest rated display was the large-circle-sparse condition. The lowest rated display was the large-circle-sparse condition. When the ambient objects were small, pilots rated the sparse distributions over the dense distributions. When the ambient objects were large the dense distributions were rated higher than the sparse distributions.

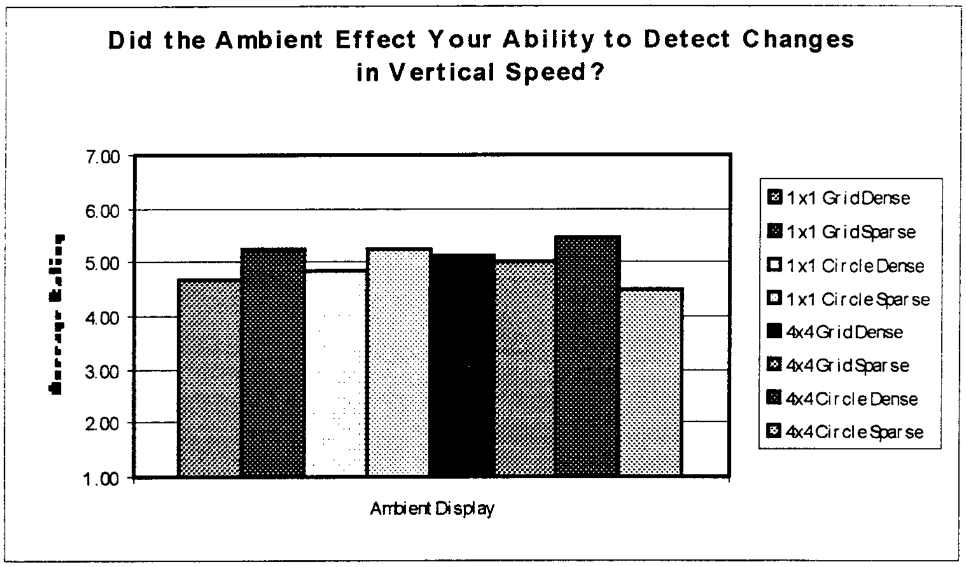


Figure 41. Average Pilot Ratings of Ability to Detect Changes in Vertical Speed in Each of the Ambient Display Conditions.

Rating 7. Did the ambient display help you maintain awareness of the aircraft's heading? (1 = It interfered with my awareness of heading, 4 = No effect on my awareness of heading, 7 = It was invaluable in helping me maintain awareness of heading.)

Figure 42 shows the average ratings of the pilot's ability to maintain awareness of the aircraft's heading with each of the ambient displays. All of the ambient displays, with the exception of the large-circle-dense condition, were judged to be helpful in terms of maintaining awareness of aircraft heading. The large grids were rated highest. For all grids, the sparse distributions were judged to be more useful than the dense distributions. Similarly, for all the large sizes of ambient objects sparse distributions were preferred to dense distributions.

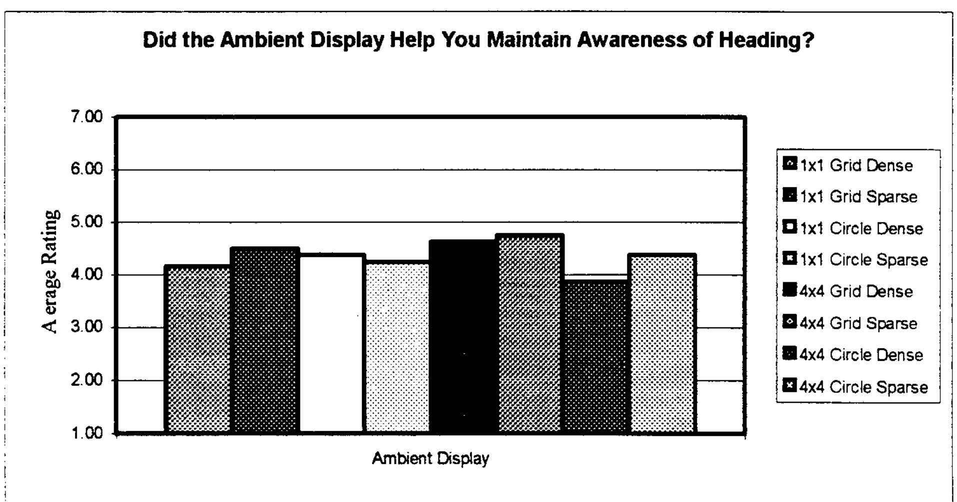


Figure 42. Average Pilot Ratings of Ability to Maintain Awareness of Aircraft Heading in Each of the Ambient Display Conditions.

Rating 8. Did the ambient display effect your ability to detect CHANGES in the aircraft's heading? (1 = It interfered with my ability to detect heading changes, 4 = No effect on my awareness of heading changes, 7 = It was invaluable in helping me detect heading changes.)

The ratings of the ability of the pilot's to detect changes in heading with each of the ambient displays is shown in Figure 43. All of the ambient displays were rated as having a positive effect on the pilot's ability to detect heading changes. The ambient displays rated highest were the small-circle-sparse and large-grid-sparse conditions. When the ambient objects were small, the sparse distributions were rated higher than the dense distributions. The difference in ratings as a function of density when the ambient objects were large was negligible. Sparse grids were preferred over dense grids regardless of the size of the grids.

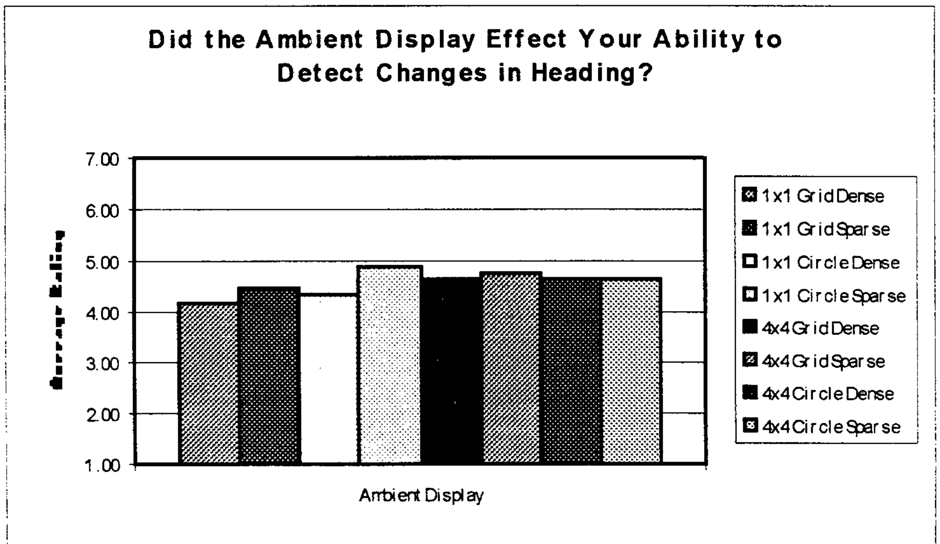


Figure 43. Average Pilot Ratings of Ability to Detect Changes in Heading in Each of the Ambient Display Conditions.

Rating 9. How visually cluttered was the ambient display? (1 = So cluttered it was distracting, 4 = Acceptable, 7 = No Noticeable Clutter.)

The average rating of each ambient display's visual clutter is shown in Figure 44. The large-sparse-circle displays was rated best in terms of visual clutter. Two other conditions, the large-grid-sparse and large-grid-dense conditions, were judged to be acceptable. None of the conditions using small ambient objects were judged to be acceptable; all were considered distracting.

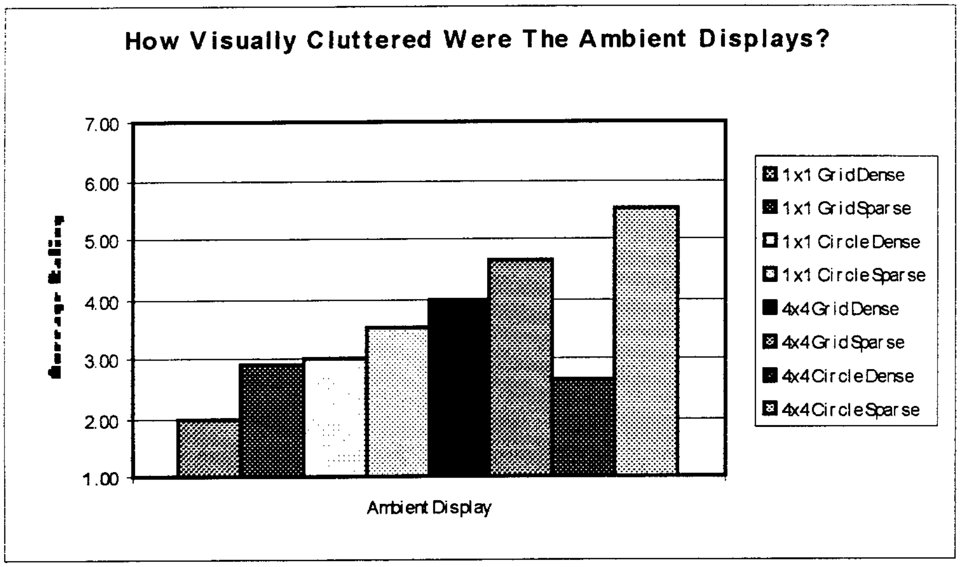


Figure 44. Average Ratings of Visual Clutter in Each of the Ambient Display Conditions.

Rating 10. Were there too many or not enough ambient symbols on the display at any one time? (1 = Too many ambient symbols visible at any one time, 4 = About the right number of ambient symbols on the display, 7 = Not enough ambient symbols visible at any one time.)

The ratings of whether the number of ambient objects on the display was acceptable are shown in figure 45. On this rating scale, a value of 4 indicates that the number of ambient objects visible in the display was "about right". All of the other displays conditions were considered to have either too few or too many objects visible.All of the displays with small ambient objects and the display with the large circles distributed densely were judged to have too many objects visible at any one time. The large-grid-sparse and large-circle-sparse conditions were rated as not having enough objects visible.

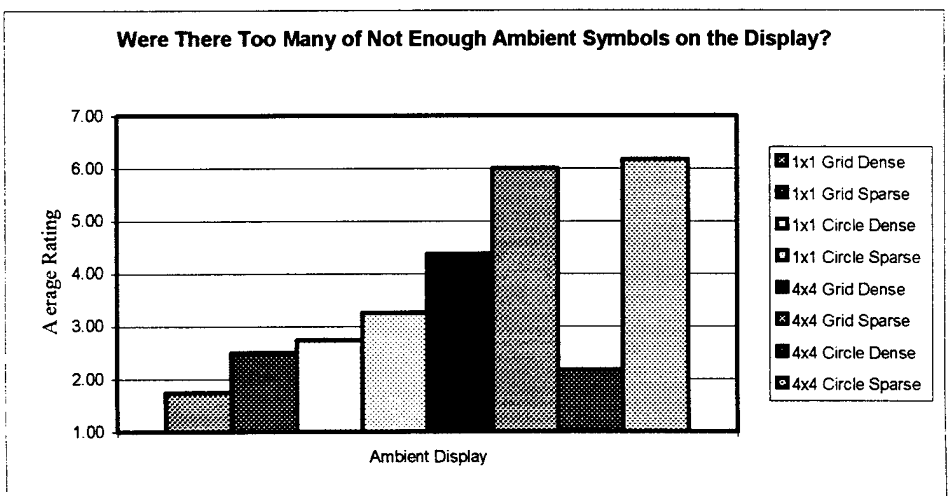


Figure 45. The Average of Whether or Not the Number of Ambient Objects on the Display Was Acceptable.

Rating 11. Were the ambient symbols too large or too small? (1 = Ambient symbols were too small, 4 = Size of ambient symbols was about right, 7 = Ambient symbols were too large.)

Average ratings of the suitability of the size of the ambient objects are shown in Figure 46. Pilots rated the size of the ambient objects as being "about right" in two conditions: dense-grid-large and dense-circle-large. This figure shows that in all cases pilots rated the ambient object higher numerically when it was distributed sparsely than when distributed densely. This indicates that the subjective impression of size suitability is dependent on the density of objects displayed.

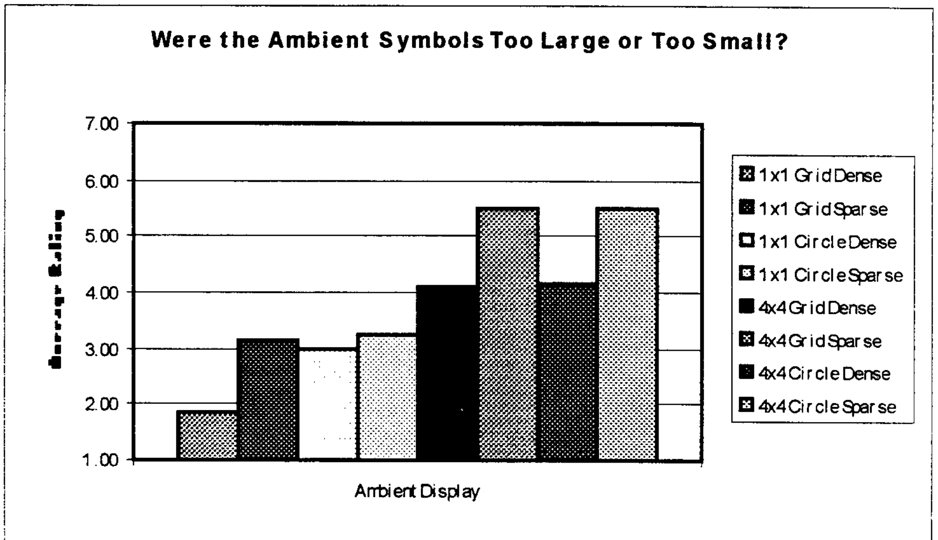


Figure 46. Average Rating of the Size of the Ambient Objects.

Rating 12. Was there too much or not enough space between the ambient symbols? (1 = Not enough space; the ambient symbols need to be a lot farther apart, 4 = About right, 7 = Too much space; the ambient symbols need to be a lot closer together.)

The average ratings of the amount of space between ambient objects are shown in Figure 47. The ambient objects was judged to bee too large in the large-circle-sparse condition. The amount of space between ambient objects was judged to be inadequate in the small-grid-dense and small-circle-dense conditions. In all other conditions the amount of space between ambient objects was judged to be in the acceptable range.

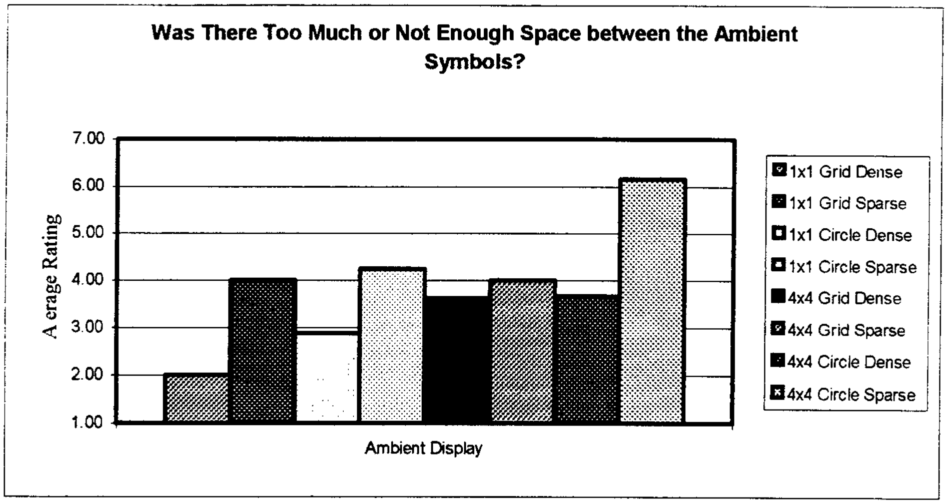


Figure 47. Average Rating of the Amount of Space Between the Ambient Objects in Each Display Condition.

Rating 13. Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the bob up – turn towards target task. (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

The average ratings of the effect of the ambient displays on pilot workload in the bob up task are shown in Figure 48. Three conditions were judged to reduce the workload associated with performing this task compared to the workload with a NVG only scene; small-grid-sparse, large-grid-dense and large-grid-sparse. The other ambient displays conditions was judged to have no effect on workload.

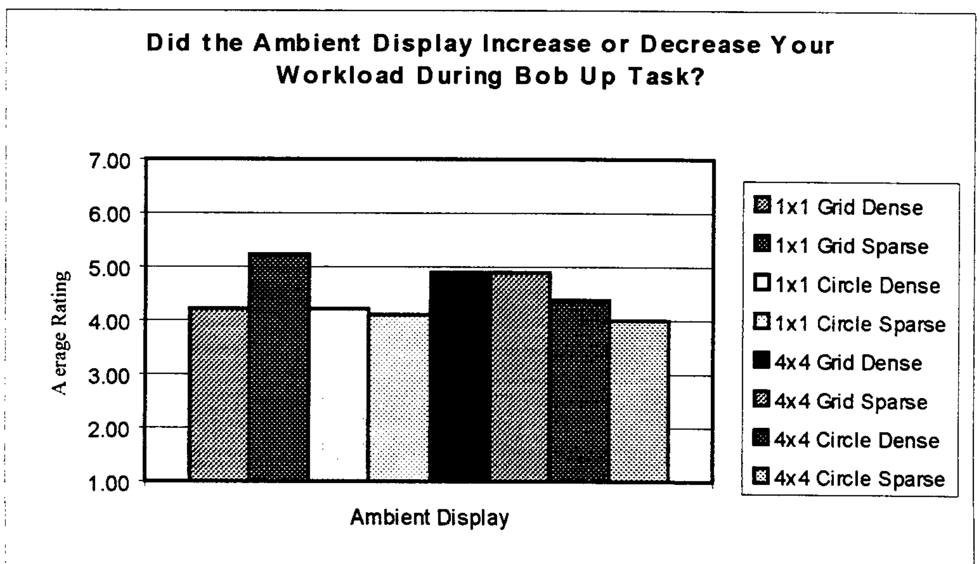


Figure 48. Average Rating of the Effect of the Ambient Display Condition on Workload in the Bob-Up Task.

Rating 14. Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the acceleration/deceleration task. (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

The effects of the ambient displays on workload in the acceleration/deceleration task are shown in Figure 49. These ratings indicate that the pilot's workload was relatively unaffected by the ambient displays. None of the ambient displays were judged to reduce workload a great deal. Two conditions, small-grid-dense and small-grid-sparse, were judged to cause a small increase in workload.

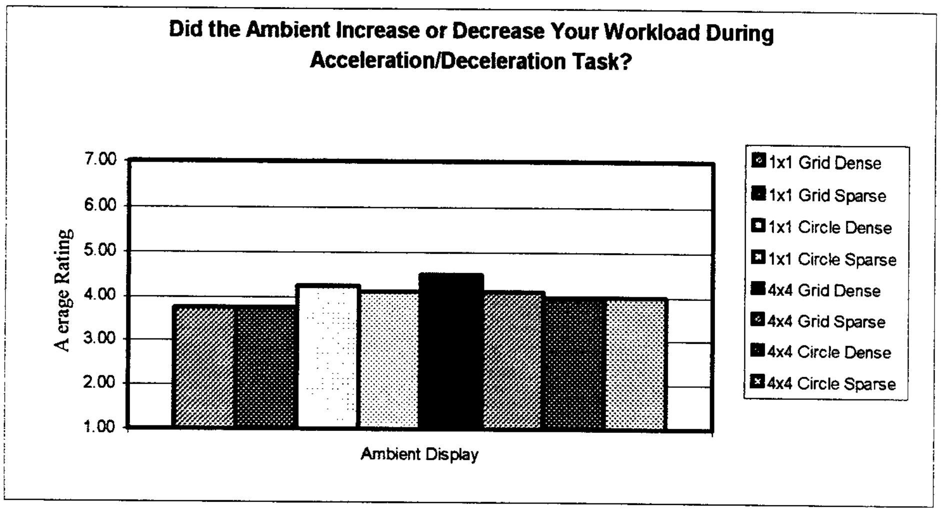


Figure 49. Average Rating of the Effect of the Ambient Displays on Workload in the Acceleration/Deceleration Task.

Rating 15. When flying the constant speed and rate of descent approach to landing task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene? (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

The ratings of workload in the constant speed, constant rate of descent approach task are shown in Figure 50. The pilots rated the small-grid-sparse condition as reducing workload an appreciable amount. All of the other ambient displays were rated as reducing workload a small, amount.

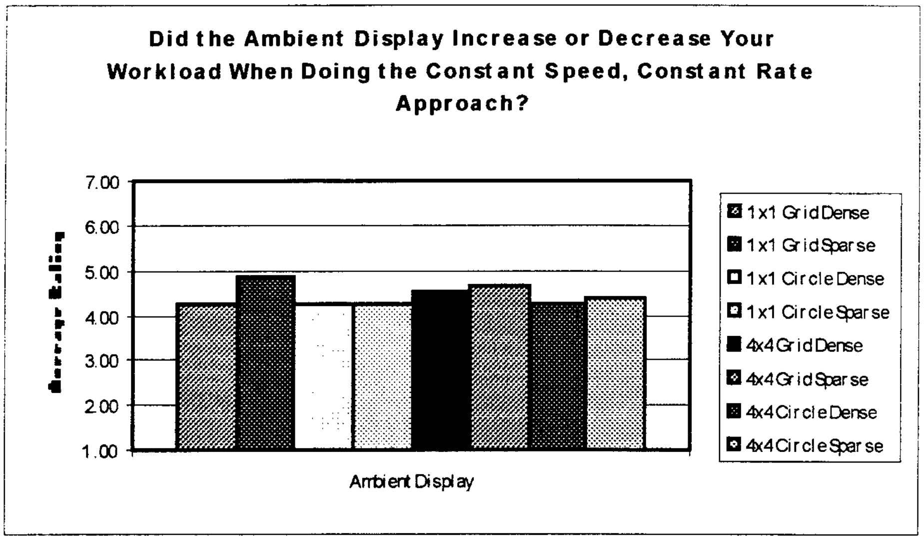


Figure 50 Average Rating of the Effect of the Ambient Displays on Workload in the Constant Speed, Constant Rate of Descent Approach Task.

Rating 16. When flying the precision hover task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene? (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

Figure 51 contains the ratings of workload in the precision hover task. Only the large-grid-dense condition was judged to reduce pilot workload relative to the NVG only condition in this task. Two other conditions, small-grid-dense and small-circle-dense, were rated as having a very minor effect The five remaining conditions were judged to have a detrimental effect on pilot workload in this task.

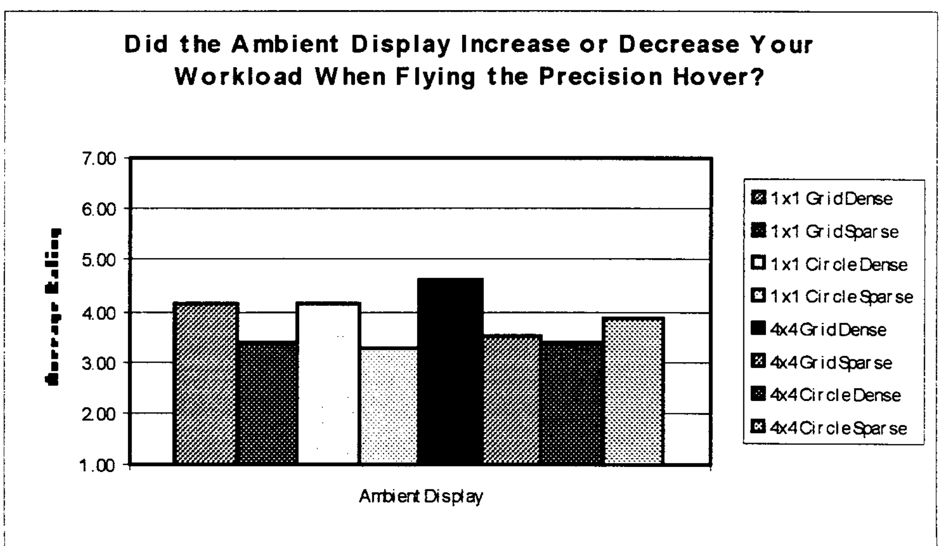


Figure 51 Average Rating of the Effect of the Ambient Displays on Workload in the Precision Hover Task.

Rating 17. When performing the pirouette task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene? (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

The average ratings of the effect of the ambient displays on pilot workload in the pirouette task are shown in Figure 52 All of the small ambient object conditions and the large-circle-dense condition, were judged to increase the workload. The other three conditions, all large ambient objects, were judged to have essentially no effect on workload.

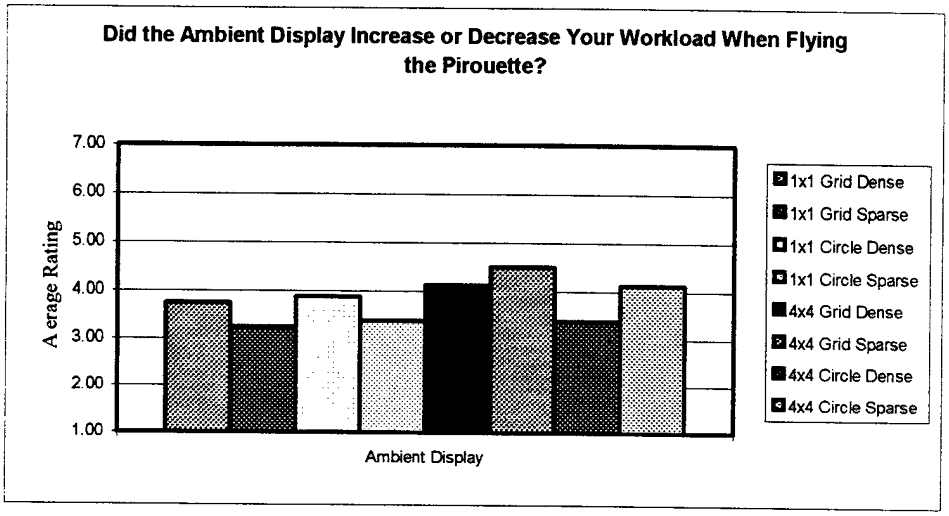


Figure 52 Average Ratings of the Effect of the Ambient Display on Workload in the Pirouette Task.

Rating 18. When flying the slalom task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene? (1 = Ambient displays caused a large increase in workload, 4 = About the same, 7 = Ambient displays caused a large reduction in workload.)

Figure 53 shows the average ratings of the effect of the ambient displays on workload in the slalom task. In this task, the best of the ambient display conditions were judged to have no effect on workload, and most of the ambient displays were judged to cause a large increase in workload.

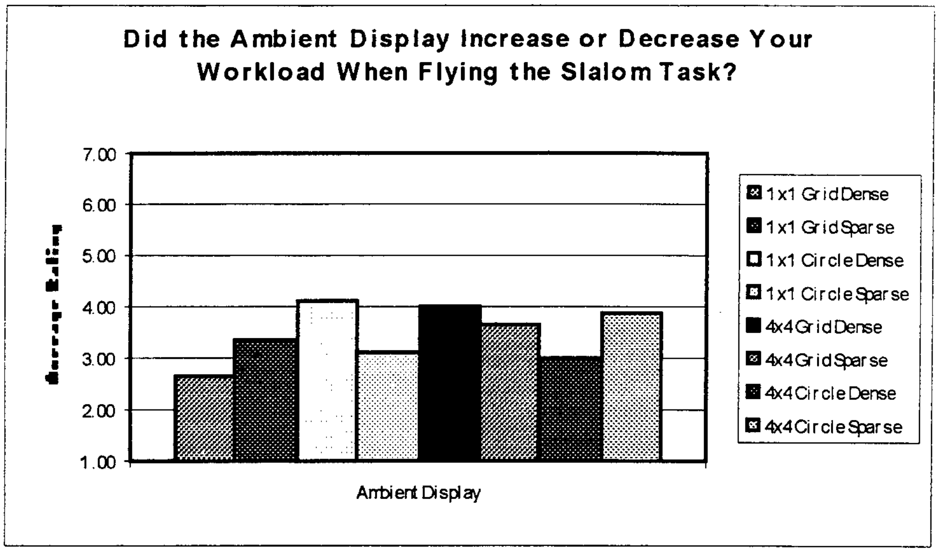


Figure 53 The Average Rating of the Effect of Ambient Display on Workload in the Slalom Task.

Rating 19. Did the ambient displays improve or harm your ability to perform the bob up – turn towards target task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

Average ratings of the effect of the ambient displays on the pilot's ability to perform the bob-up maneuver are shown in Figure 54 Performance was judged to be improved, compared to performance in a NVG only condition, when the ambient objects were grids. This is likely due to the effectiveness of the grids in cueing pilots to changes in altitude.

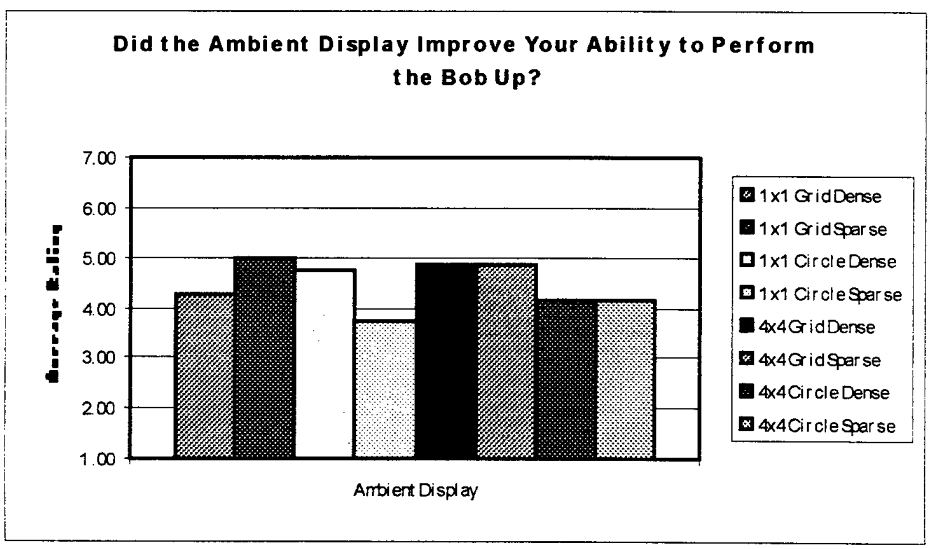


Figure 54. Average Rating of the Pilot's Ability to Perform The Bob-Up Task With Each of the Ambient Displays.

Rating 20. Did the ambient displays improve or harm your ability to perform the acceleration/deceleration task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

Figure 55 shows the average ratings of the effect of the ambient displays on the pilot's ability to perform the acceleration/deceleration task. Pilots rated their ability to perform this task as better when the ambient objects were large grids. None of the other ambient conditions were judged to have an effect on performance.

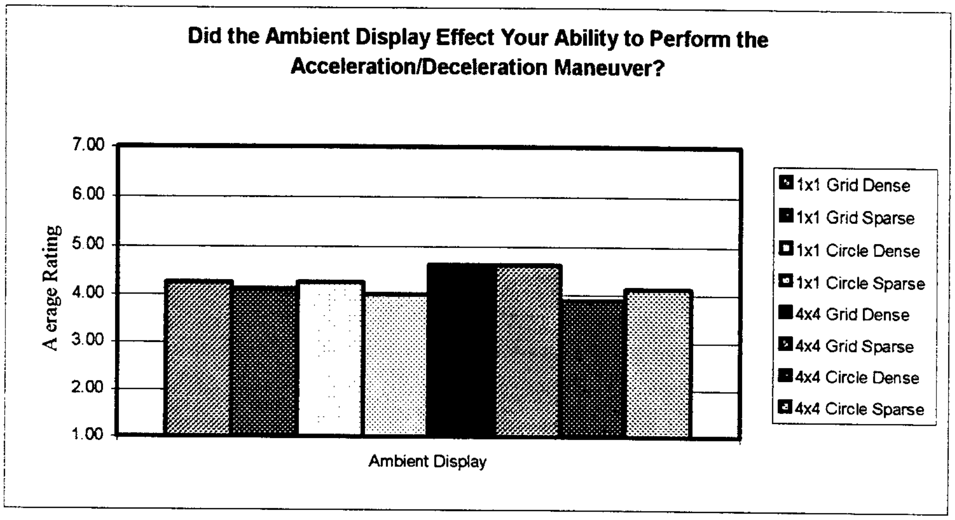


Figure 55. The Average Rating of the Pilot's Ability to Perform the Acceleration/Deceleration Maneuver In Each of the Ambient Display Conditions.

Rating 21. Did the ambient displays improve or harm your ability to perform the constant speed and rate of descent approach to landing task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

Average pilot ratings of the effect of the ambient displays on their ability to perform the constant speed, constant rate of descent approach task are shown in Figure 56. Pilots indicated that when the ambient objects were large grids their ability to perform this task was improved compared to a NVG only condition. None of the other ambient display conditions was judged to have an impact on performance.

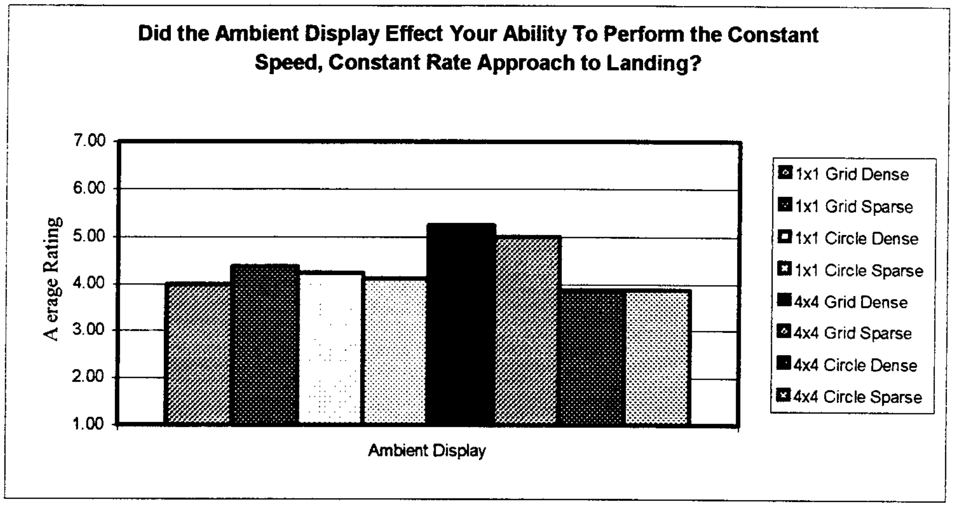


Figure 56. Average Ratings of the Pilot's Ability to Perform the Constant Speed, Constant Rate of Descent Approach to Landing in Each of the Ambient Display Conditions.

Rating 22. Did the ambient displays improve or harm your ability to perform the precision hover task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

The ratings of the effect of the ambient displays on pilot's ability to perform the precision hover task are shown in Figure 57. Only the large-grid-dense condition was judged to improve performance relative to an NVG only condition. Two conditions, small-circle-sparse and large-circle-dense, were judged harmful to pilot performance. None of the other ambient display conditions were judged to have an impact on performance.

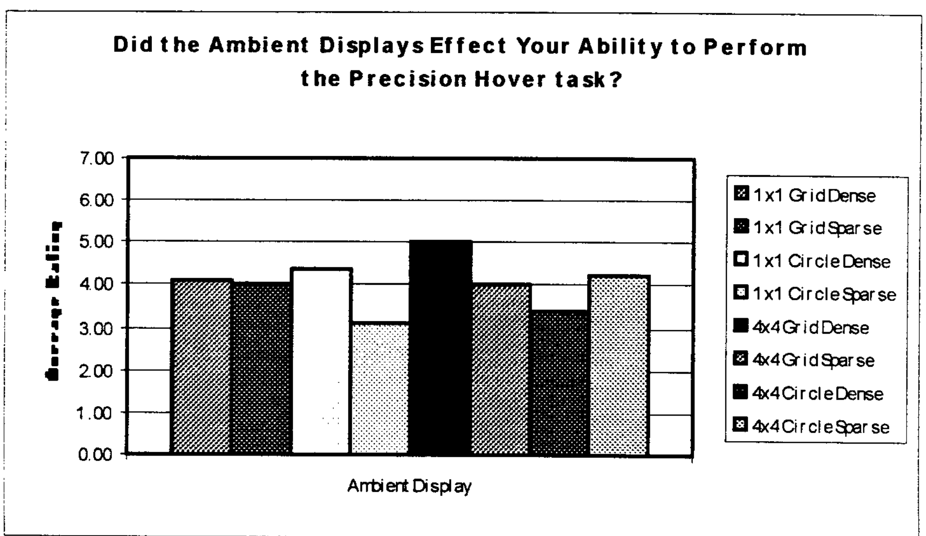


Figure 57. Average Ratings of the Pilots Ability to Perform the Precision Hover Task In Each of the Ambient Display Conditions

Rating 23. Did the ambient displays improve or harm your ability to perform the pirouette task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

Figure 58 shows the average ratings of the effect of the ambient display conditions on the pilot's ability to perform the pirouette maneuver. Only the large-grid-dense display was judged to improve performance. Three of the display conditions were judged to have essentially no effect. These conditions are small-circle-dense, large-grid-sparse, and large-circle-sparse. The other conditions were judged to have a negative effect on pilot performance in this task.

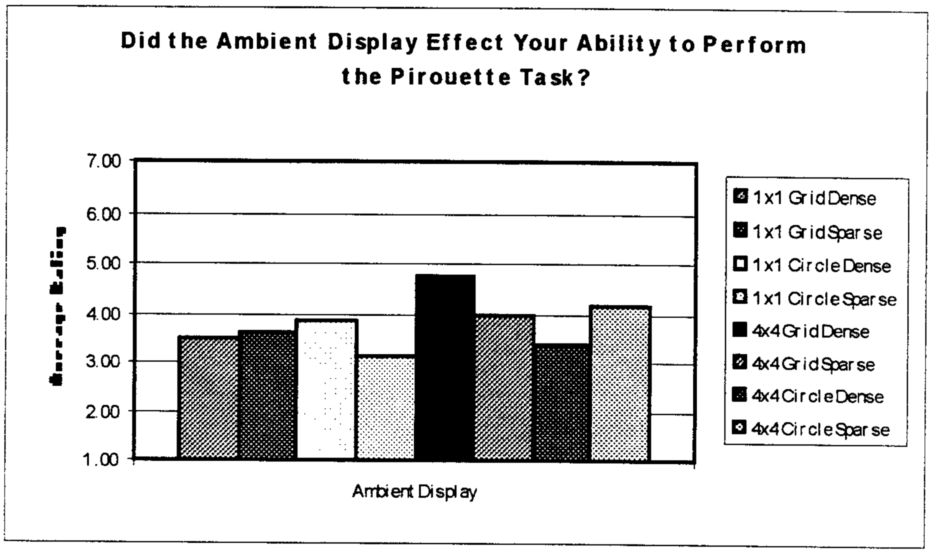


Figure 58. The Average Ratings of the Pilot's Ability to Perform the Pirouette Task in Each of the Ambient Display Conditions.

Rating 24. Did the ambient displays improve or harm your ability to perform the slalom task, compared to what you expect when flying with a NVG only scene. (1 = Ambient displays hurt performance, 4 = About the same, 7 = Ambient displays improved performance.)

Ratings of the effect of the ambient displays on the pilots ability to perform the slalom task are shown in Figure 59. The only the large-grid-dense ambient display condition was judged to have a positive effect on performance. The small-circle-dense, large-grid-sparse, and large-circle-sparse conditions were rated as having essentially no effect on the ability of the pilot to perform this task. All of the other ambient displays were rated as having a large, adverse effect on pilot performance in this task.

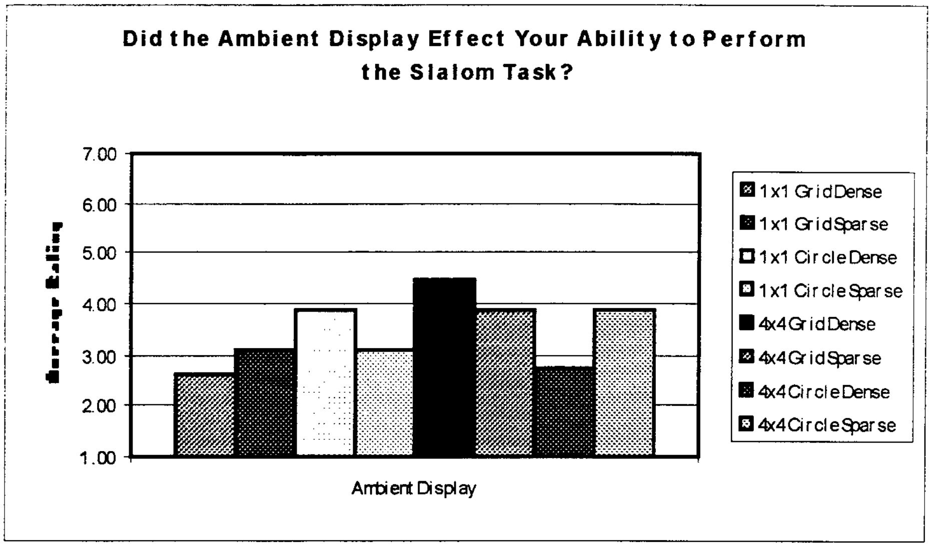


Figure 59. The Average Ratings of the Pilot's Ability to Perform the Slalom Task in Each of the Ambient Display Conditions.

Rating 25. Overall, how acceptable was this ambient symbol set? (1 = Not acceptable as is; major changes are needed before flying with this symbol set, 4 = Minimally acceptable. Some improvements needed before this symbol set can be flown, 7 = Acceptable as is; no changes are needed in order to fly with this symbol set.)

The average ratings of the overall acceptability of each of the ambient displays are shown in Figure 60. These ratings clearly show that none of the ambient symbol sets used in this experiment was considered to be acceptable for use in flight without significant improvement.

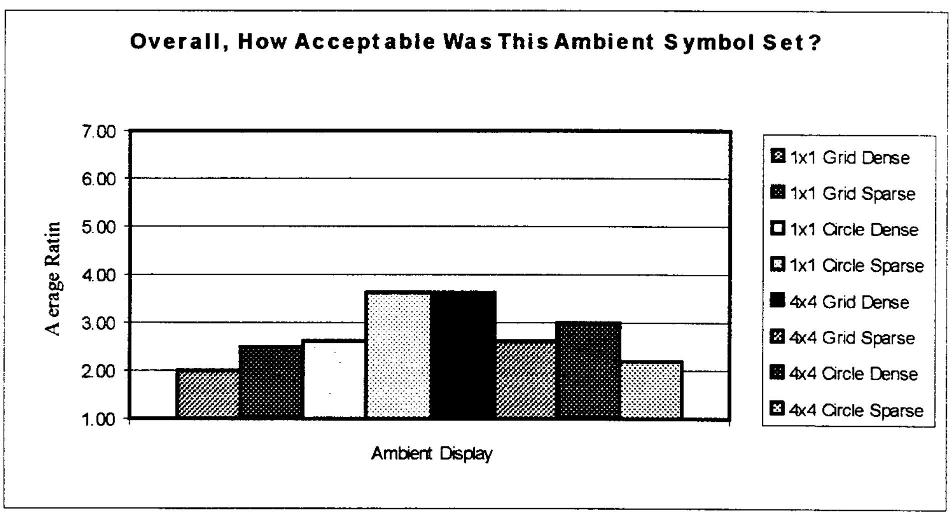


Figure 60. Average Ratings of Overall Acceptability of Each of the Ambient Display Conditions

Rating 26. How consciously aware were you of the ambient displays? (1 = I was always aware of the ambient displays, 4 = I was aware of the ambient displays about half the flight, 7 = I never noticed the ambient displays.)

Ideally, displays presenting information for processing by the ambient visual system will no more intrude on the pilot's consciousness than does the horizon. The information is processed at a subconscious level. The ratings in Figure 61 indicate that pilots were aware of the ambient displays during most of the flights. This suggests the possibility that the information was often being processed by the focal system, rather than by the ambient visual system

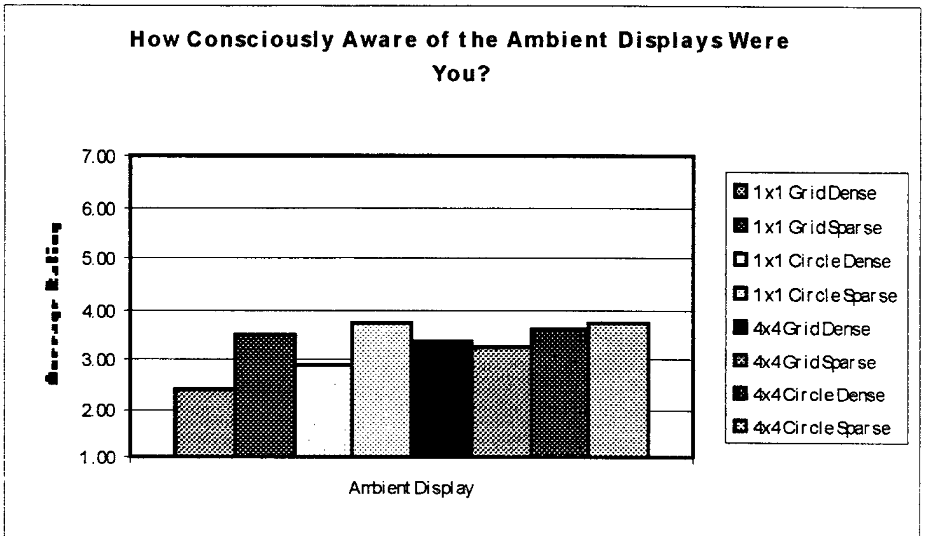


Figure 61. Average Ratings of How Consciously Aware the Pilot Was of the Ambient Display in Each Condition.

Rating 27. How much attention did you pay to the ambient displays? (1 = I was always paying attention to the ambient displays, 4 = I paid attention to the ambient displays about half the flight, 7 = I never paid attention to the ambient displays.)

One of the appeals of displays that present information in a way that allows for processing by the ambient visual system is that they do not compete for the pilot's focal resources. If pilots are consciously aware of the display, then the displays are not living up to this potential. Figure 62 shows the pilot's ratings of the amount of time they paid attention to the ambient displays.

Examination of Figure 62 shows that pilots generally were paying attention to the ambient displays during half or more of the flight in seven of the eight conditions. The exception is the large-circle-sparse condition. This may indicate that the ambient displays were capturing the selective attention of the pilots. This could be due to display characteristics, or may simply be a novelty effect.

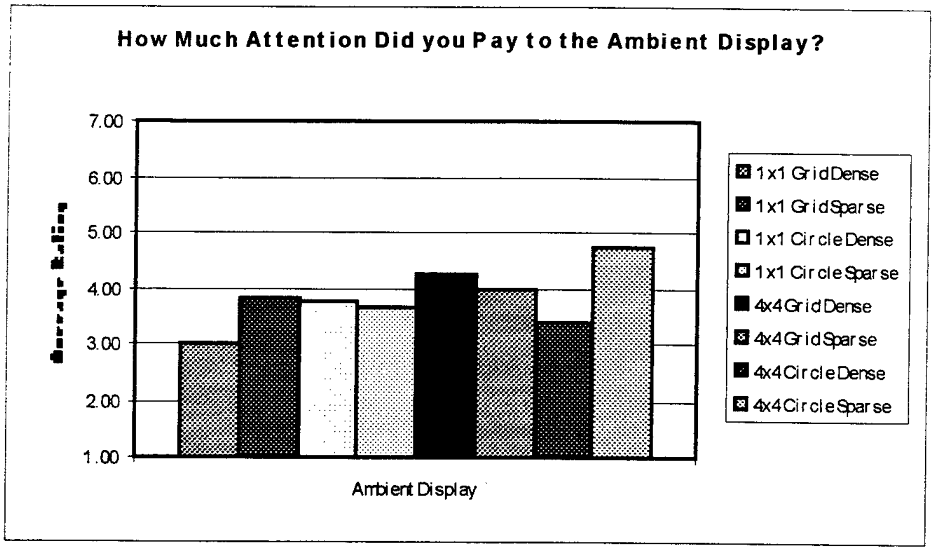


Figure 62. Average Rating of the Amount of Attention the Pilot Paid to the Ambient Display in Each Condition.

Rating 28. Was the horizontal velocity of the ambient symbols on the display appropriate given the velocity of the aircraft? (1 = The ambient symbols moved too slowly given the speed of the helicopter, 4 = The ambient symbols moved at the right speed, 7 = The ambient symbols moved too quickly given the speed of the helicopter.)

The average ratings of the suitability of the relationship between the horizontal velocity of the aircraft and that of the ambient objects is shown in Figure 63. (Recall that all of the ambient displays were driven using the same drive law. This drive law the ambient objects movement on the HMD screens was consistent with objects painted on a "bill-board" located at a distance of 20 meters to the side of the aircraft.).

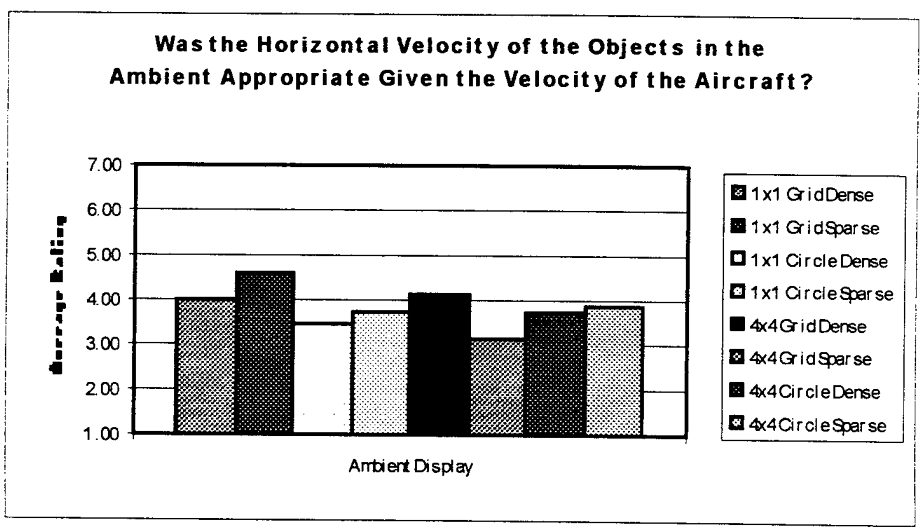


Figure 63. The Average Rating of the Match Between the Horizontal Motion of the Ambient Objects and the Velocity of the Aircraft.

This figure shows that, with two exceptions, pilots rated the horizontal motion of the ambient objects to be roughly consistent with what they expected given the velocity of the aircraft. The first exception is the small-grid-sparse condition, which was rated as moving somewhat faster than anticipated. The other exception is the large-grid-sparse condition which was rated as moving more slowly than appropriate given the speed of the aircraft. The reasons that pilots found the motion of these two conditions less than appropriate has not been determined.

Rating 29. Was the horizontal acceleration of the ambient symbols on the display appropriate given the acceleration of the aircraft? (1 = The ambient symbols moved too slowly; they seemed to lag behind the helicopter, 4 = The ambient symbols accelerated at the right rate as the helicopter accelerated, 7 = The ambient symbols accelerated too quickly; they seemed to jump ahead of the helicopter.)

Figure 64 shows the average ratings of the appropriateness of the horizontal acceleration of the ambient objects as a function of aircraft acceleration. Pilots rated the acceleration of the ambient objects as being about right in most conditions. In two conditions the ratings indicate that the pilots perceived the ambient objects as accelerating more slowly than the aircraft. (Again, the same drive law was used in each ambient condition.)

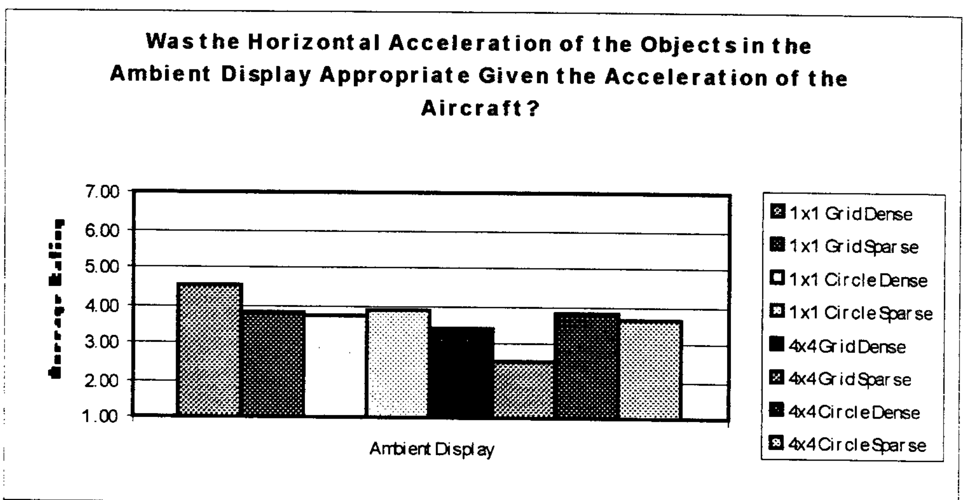


Figure 64. The Average Rating of the Match Between the Horizontal Acceleration of the Ambient Objects and the Acceleration of the Aircraft.

OPEN ENDED QUESTIONS

Following completion of each flight in which ambient displays were used pilots completed a questionnaire. This questionnaire contained a number of ratings made on 7-point scales as well as a series of open ended questions soliciting written responses. The results of the ratings are given in the preceding section. The questionnaire also contained a small number of open ended questions. These questions and the pilot's responses are reproduced below. The questions from the questionnaire appear in **bold face**. The responses are grouped by ambient display condition.

Only minor editing has been done to enhance readability has been done. Editing has been limited to spelling out abbreviations and acronyms, correcting spelling errors, and minor grammatical corrections. The comments of the editor are italicized.

1X1 (SMALL)GRID DENSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No.
P2. Not positive on orientation, but more usefully vertical velocity in the hover.
P4. Yes, except precision hover and slalom.
P5. Again, Bob-Up, Accel/Decel, and Constant Rate Approach seemed to be helped whereas Precision Hover, Pirouette, and Slalom (were) not (helped) so much

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Only vertical.
P2. Low speed translational velocity and low climb and descent rates.
P4. Vertical speed.
P5. Provided additional forward and vertical speed cues. Rate cueing in one axis was very noticeable.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Yes, all lateral maneuvers because of the blinder effect.
P2. No. It was however useless in the pirouette. I also found it a _____ (illegible) in the Accel/Decel task.
P4. Yes. Slalom. Just an overwhelming distraction on either side.
P5. No. Somewhat distracting in Slalom.

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. Blinder effect. No lateral orientation.
P2. None that I was aware of.
P4. Again, an overwhelming distraction. (It was) very hard not to pay attention to the ambient displays.
P5. *No response.*

5. What did you most DISLIKE about this set of ambient symbols?

P1. The strobe effect.
P2. When the translational rates are sufficient to cause the symbols to blur they (the ambient displays) are a nuisance.
P4.. Appeared to rotate and spin at varying rates. During a turn and altitude change this was very distracting.
P5. Too much movement and information, especially as rates and speeds picked up.

6. What did you most like about this set of ambient symbols?

P1. Nothing.
P2. They help neutralize vertical acceleration from level constant altitude.
P4. *No response.*
P5. Small deltas were noticeable quickly.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Yes, horizontal movement made the information misleading. Horizontal (fore & aft) and (left & right).
P2. Never misleading but sometimes, especially at high rates, just a lot of visual noise.
P4. Yes. As before, there was no relation to lateral acceleration, which is extremely important information for low airspeed maneuvers.
P5. Not too bad. Maybe too much information again during slalom.

1X1 (SMALL)GRID SPARSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Noticed that vertical motion was sensed better with the ambient, especially (during the) bob up. This was especially effective as long as there was no roll input involved.
P2. No.
P4. Yes, Bob-Up.
P5. Yes. In particular the constant speed descent, accel/decel and precision hover. Somewhat in the pirouette and bob-up. Less in the slalom.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Vertical speed and vertical deviation or trend information.
P2. Fine grained vertical speed.
P4. Altitude, vertical speed.
P5. Again, rate was most significant. Attitude changes were less significant.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Yes, in the lateral field of view. It was like flying with blinders on. Pirouette, hover, accel/decel.
P2. No.
P4. Yes, Slalom.
P5. During slalom the rapid motion (of the ambient symbols) was somewhat confusing. "Saturation."

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. Again, the blinder effect severely reduced the pitch attitude and ground reference.
P2. None.
P4. Became disoriented as you go into multi-axis maneuvers.
P5. At higher rates, too much movement/cueing.

5. What did you most DISLIKE about this set of ambient symbols?

P1. It was like flying next to a movie marquee. The flashing was disorienting at times.
P2. No opinion good or bad.

P4. TOO SMALL. They become useless and actually distracting at higher speeds (vertical and forward).
P5. As above.

6. What did you most like about this set of ambient symbols?

P1. Being able to accurately determine vertical position and vertical rate of change.
P2. No opinion good or bad.
P4. *No response.*
P5. At lower rates with uni-axial changes this (ambient symbol) set seemed to give good data.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. It became misleading when you changed more than one axis at a time. If you could maintain the other axes steady you could determine what was causing the change. However, when tow or more are changing look out!!
P2. I am not very aware of the ambient display motion so I don't find it misleading.
P4. At higher airspeeds, symbols become distracting. They tend to appear to "flash" and if you involve more (than one) axis, they rotate in different directions.
P5. Too much/cluttered information with higher rates, multi-directional speed changes, and multi-directional rates.

1X1 (SMALL) CIRCLE DENSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No.
P2. Anywhere inertial hover hold is crucial. Better for vertical cueing than translational.
P4. Yes. All but precision hover and slalom.
P5. Again, seemed to help the most during Bob-Up, Accel/Decel, and Constant Rate Approach (non multi-axis maneuvers?). Less with Precision Hover, Pirouette, and Slalom.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Vertical speed. It (the ambient display) did not provide or allow for any better control.
P2. Showed translational rate.
P4. Vertical speed.
P5. Again. Speed changes were more noticeable in ambient displays (vertical and airspeed).

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No.
P2. No.
P4. No.
P5. Not really. Maybe distracting in Slalom.

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. No lateral view Like having blinders on.
P2. None.
P4. None.
P5. *No response.*

5. What did you most DISLIKE about this set of ambient symbols?

P1. The movement. As ground speed picked up, they (the ambient display) began to strobe in the opposite direction.
P2. As speed starts to increase I find the delta speed difficult to evaluate with the ambient display.
P4. Circles are more difficult (compared to squares) to pick up motion and attitude changes.

P5. Almost too much. Especially with any significant rate on the aircraft either yaw, horizontal, or vertical.

6. What did you most like about this set of ambient symbols?

P1. Nothing.
P2. *No response.*
P2. None.
P5. Could pick up small changes quickly.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Yes, when it began to strobe.
P2. It seems in the diagonal translation in the precision hover that the ambient cues seem to stand still. Didn't seem to be very useful.
P4. None.
P5. When one display stops and the other moves rapidly, i.e., Slalom, can be somewhat peculiar. You may be able to get used to it with practice.

1X1 (SMALL) CIRCLE SPARSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No effect on awareness of A/C position. Orientation (heading) in steady state (was) somewhat better.
P2. *No response.*
P4. Yes, Bob-Up.
P5. Improved Bob-Up and Accel/Decel quite dramatically. Precision Hover improved a little. Pirouette and Slalom not too much. (In the) slalom a little distracting as speed got fast.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Vertical speed and vertical height. In bob-up turn height was more difficult to see changes.
P2. *No response.*
P4. Altitude reference.
P5. Additional forward speed and vertical speed cues.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Lateral positioning during all maneuvers at altitude.
P2. *No response.*
P4. Yes, Slalom.
P5. *No response.*

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. Lack of peripheral vision.
P2. *No response.*
P4. "Disco Ball" effect becomes distracting at higher speeds or multi-axis.
P5. See comment RE: slalom, above.

5. What did you most DISLIKE about this set of ambient symbols?

P1. Once the ambient symbology started moving the flicker (like a movie marquee) was distracting. Also, collective and lateral cyclic movement causes uneasy feeling.
P2. *No response.*
P4. Shape. Circles don't provide enough information for attitude changes.

P5. See comment RE: slalom, above.

6. What did you most like about this set of ambient symbols?

P1. Height control and vertical rate.
P2. *No response.*
P4. *No response.*
P5. Spacing seemed to help at lower speed, controlled maneuvers to cue rate changes.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Roll and collective; unable to filter out what was moving the symbology.
P2. *No response.*
P4. Yes. In multi-axis maneuvers, the counter-rotating symbols becomes very distracting.
P5. *No response.*

4X4 (LARGE) GRID DENSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Vertical position in bob-up, precision hover.
P2. Ambient display was very helpful in accomplishing the deceleration toa hove in the accel/decel. This is the first time I've been able to keep from going backwards while stabilizing.
P4. Yes. All but precision hover.
P5. Yes. In particular, constant speed descent, accel/decel, and pirouette. Somewhat in the bob-up, precision hover, and slalom.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Vertical speed during bob-up.
P2. Possibly vertical rate and longitudinal translational rate.
P4. Vertical speed.
P5. Rate seemed to be a primary indication via the ambient display – either in pitch, roll, or yaw, or the display helped control rate!. Better in yaw and roll, I think, than pitch.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Yes, accel/decel maneuver made you feel like you were in a tunnel.
P2. No.
P4. No.
P5. I don't think so!

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. Roll attitude and pitch attitude could not be precisely determined. Yaw changes could not be sensed.
P2. No response.
P4. None.
P5. I don't think they did reduce awareness.

5. What did you most DISLIKE about this set of ambient symbols?

P1. They felt like "bug eyes". Made me feel like I was enclosed with only a little window to peer through.
P2. No response.
P4. Change in airspeed above about 20 kts, symbols are difficult to see/use.
P5. The inability to have a clear/focused view of them. I think clearer would be better. Not sure.

6. What did you most like about this set of ambient symbols?

P1. Size and spacing. Made them (the ambient displays) more useable than the smaller number.
P2. I was able see them more clearly and to interpret their motion a greater portion of the time. field.
P4. Vertical speed information/cues.
P5. Rate cueing provided.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Sensation of pitch and roll were misleading when more than one axis was activated.
P2. No.
P4. Yes. Roll acceleration is very misleading. You see the attitude change, but you don't pick up and lateral acceleration cues until you see it in the front screen.
P5. Unsure. I don't think so.

4X4 (LARGE) GRID SPARSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No.
P2. *No response.*
P4. Yes. All except the precision hover and slalom.
P5. Yes. Constant speed descent and bob-up. Somewhat in the precision hover, pirouette, and accel/decel. Less in the slalom.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Slightly in regards to vertical speed.
P2. *No response.*
P4. Vertical speed.
P5. Rate or delta.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Any maneuver requiring more than one axis to be moving.
P2. *No response.*
P4. No.
P5. Slalom seemed slightly more difficult this time.

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. They were very sparse and have a tendency to bloom during rotation and horizontal translation.
P2. *No response.*
P4. None.
P5. *No response.*

5. What did you most DISLIKE about this set of ambient symbols?

P1. Sparseness and the blooming effect. They were disorienting during any pitch or roll change.
P2. *No response.*
P4. No roll or lateral cues sufficient to arrest acceleration in lateral axis.
P5. A little too big and too spaced out.

6. What did you most like about this set of ambient symbols?

P1. Vertical height control was easier to maintain.
P2. *No response.*
P4. Altitude seemed to be easier to maintain.
P5. *No response.*

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Accel/decel, pitch attitude changes were misleading. Pirouette, roll attitudes were misleading.
P2. *No response.*
P4. Misleading in that you are looking to them for lateral acceleration cues and you don't get them. You don't see lateral acceleration until it shows up on center screen (overshoot).
P5. Not sure.

4X4 (LARGE)CIRCLE DENSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Bob-up: good vertical cues.
P2. I don't recall getting any cues from the symbology that I directly depended upon.
P4. Yes. Bob-Up.
P5. Somewhat during Bob-Up, Accel/Decel. Constant Rate Appeoach, and Precision Hover. Not so much for Pirouette and Slalom.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Vertical velocity and position.
P2. Rearward velocity.
P4. Altitude reference.
P5. Additional forward speed and vertical speed cues were provided with ambient displays.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Horizontal positioning nearly impossible. Precision hover and Pirouette.
P2. None.
P4. Yes. Slalom and Pirouette.
P5. (I) don't think so.

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. They would move differentially. This was confusing. Pirouette.
P2. I don't have any sense that that the displays are degrading my awareness.
P4. Still get the "Disco Ball" effect when you involve higher speed or mulit-axis (motion).
P5. *No response.*

5. What did you most DISLIKE about this set of ambient symbols?

P1. Obstruction of peripheral vision. This required me to turn my head which caused me to loose control of heading and altitude.
P2. Nothing in particular.
P4. The shape doesn't provide sufficient information. You don't see attitude changes fast enough.
P5. With their size and spacing I think cues were not as easily picked up.

6. What did you most like about this set of ambient symbols?

P1. Vertical rate and height control.
P2. Nothing in particular.
P4. *No response.*
P5. The limited additional cueing they did provide.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. During precision hover when a lateral cyclic movement (was made) the A/C model rolled a great deal before translating. When collective was moved motion of the ambient displays was aggravated.
P2. I don't find myself consciously using the ambient displays. They work best at very low speed in low velocity translation but there are usually other cues in those environments that are perceived to be better for me.
P4. Yes, during the slalom task ambient symbols rotate in different directions, causing disorientation.
P5. *No response.*

4X4 (LARGE) CIRCLE SPARSE

1. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. No, the ambient display did not give me any benefit, only confusion.
P2. No.
P4. Yes. All but precision hover and slalom.
P5. Yes. Less so than the blocks, I believe. Did particularly well on the pirouette, but I'm not sure why. Other maneuvers degraded slightly over blocks, I think.

2. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

P1. Some vertical position. Speed vertical could not be determined.
P2. Some indication of vertical rate.
P4. Vertical speed.
P5. Primarily rates and changes.

3. Did the ambient symbology reduce your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

P1. Most of the maneuvers were hindered by the ambient symbology. It was like having blinders on.
P2. No.
P4. No.
P5. No.

4. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

P1. Could not see laterally without turning your head. Of course, you lost control of the front scene when that happened.
P2. *No response.*
P4. None.
P5. *No response.*

5. What did you most DISLIKE about this set of ambient symbols?

P1. Having it there. It was disorienting when more than one axis activated.
P2. Balls were too large.
P4. They (the ambient symbols) were too large and far apart.
P5. Too sparsely spaced, or not enough definition as the blocks.

6. What did you most like about this set of ambient symbols?

P1. *No response.*
P2. *No response.*
P4. *No response.*
P5. Pirouette better, I'm not sure why.

7. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

P1. Information was misleading when more than 2 axes were activated.
P2. No.
P4. No.
P5. Yes, one time. A combination of yaw and drift caused left ambient display to appear motionless. This was deceiving.

DISCUSSION AND RECOMMENDATIONS

AMBIENT DISPLAY CHARACTERISTICS

SIZE OF THE AMBIENT OBJECTS

Two sizes of ambient objects were examined; small and large. The small objects were squares 2 meters per side or circles 2 meters in diameter. The large objects were squares 4 meters per side or circles 4 meters in diameter. The angular extent of the small objects was approximately 2.8 degrees and the maximum extent of the large objects was approximately 11.4 degrees.

Altitude maintenance was better with the smaller ambient objects in the bob-up task. The frequency of edges crossing the boundary of the display area was much greater with small objects than with large objects. These edge crossings are more easily detected than are changes in the absolute position of the ambient objects or changes in the relative positions of the edges of the ambient objects and the edges of the screen. Consequently, pilots were able to identify changes in altitude and take corrective action more quickly with the smaller ambient objects.

Small ambient objects resulted in less variability in the turn rate during the bob-up task. The frequency at which the edges of the ambient objects crossed the edges of the screen provided the pilots more information on rate simply because the edge crossings occurred so much more often with the small ambient objects than with the larger ones. However, the interaction between the size and density of the ambient objects on the standard deviation of airspeed shows that performance is better when the objects are distributed sparsely. That is, performance is best for large ambient objects when the frequency of edge crossings is reduced. In contrast, which small ambient objects performance is best in the dense condition which has the highest frequency of edge crossings.

During the pirouette task, the standard deviation of the aircraft's bank angle was smaller when the ambient objects were small than when the objects were large. Again, we suspect that the proximity of the edges of the ambient objects to the edge of the screen and the frequency of the ambient object's edges crossing the screen edges allowed the pilots to identify changes more rapidly than when the edges of the ambient objects crossed the edges of the screen less frequently and were generally farther from the screen edges.

In the slalom task the average airspeed was closer to the target airspeed when the ambient objects were large than when they were small. Because of the intense, multi-axis motion in this task, the small ambient displays were judged by the pilots to be disorienting. The smaller ambient objects had a large number of objects "whirling" on the display during this task. A smaller number of larger objects on the display may have been less distracting, thereby allowing the pilots to better focus on keeping the aircraft within parameters.

Pilot ratings show that the workload was lower with larger ambient objects than with the small objects for all six of the flight tasks. Ratings also indicate that they were better able to perform each of the six tasks with the large ambient than they were with the small ambient objects. The ratings also that the number of ambient objects displayed at any one time, the size, and spacing of the large ambient objects was better than the small objects. Finally, the ratings of the visual clutter of the ambient displays indicate a preference for the larger ambient objects.

Taken together, these data indicate that the larger size ambient objects is more acceptable to pilots than are the smaller ambient objects. There is a performance penalty with the ambient objects as large as those used in this experiment compared to the smaller ambient objects. An intermediate size, 2x2 meters or 3x3 meters, may be a better size in terms of trading off performance against pilot preference.

Shape of the Ambient Objects

Two shapes of ambient objects were examined in this study, rectangular grids and circles. Relatively few performance differences between the shapes of the ambient objects were found.

In the bob-up task, the average turn rate was faster with grids than circles (6.6 degrees/sec vs. 5.4 degrees/second). The reason why pilots turned the aircraft at a higher rate when the ambient objects were grids is unclear.

The vertical speed in constant speed, constant rate of descent task was faster with circles than grids (313 ft/min vs. 280 ft/min). This indicates that the pilots reached an altitude of 50 ft AGL (the point at which they were free to slow the aircraft's forward and vertical speed in preparation for landing) more quickly when the ambient objects were circles. It may be that the sharp edges of the grids entering and leaving the ambient field of view were more effective stimuli for the perception of rate. If this is correct, then pilots would perceive their rate of descent as being faster when grids are displayed than when circles are displayed for the same rate of motion of the objects.

The heading that was to be maintained in the precision hover task was 115 degrees. The average heading was closer to the initial heading when the ambient objects were circles (116.8 degrees) than when the ambient objects were grids (118.6 degrees). The standard deviation of the aircraft's heading during this task was smaller when the ambient objects were circles (3.6 degrees) than grids (5.2 degrees).

Pilots judged their workload to be less with grids than circles in the bob-up, constant speed approach, precision hover, and pirouette tasks. They also rated the grids as improving their ability to perform all of the tasks higher than they did the circles. The grids were rated as being better than circles in terms of the number of symbols, but worse in terms of display clutter, symbol size and symbol spacing.

Density of the Ambient Objects

The ambient objects were displayed at two levels of density. In the dense condition 50% of the rectangular area was filled with ambient objects. In the sparse condition 12.5% of the area was filled with ambient objects. (The diameter of the circles was equal to the height and width of the grids. Therefore, circles actually filled an area that was about 79% that filled by the grids.)

The only differences in performance between the dense and sparse distributions of the ambient objects were found in the acceleration/deceleration task. In this task, the standard deviation of aircraft heading was smaller when the ambient objects were distributed densely (0.89 degrees) than when the objects were distributed sparsely (1.52 degrees). However, the standard deviation of altitude was smaller when the ambient objects were distributed sparsely (8.5 ft) than when densely distributed (10.5 ft).

The sparse distributions of ambient symbols were preferred in terms of display clutter, the number of symbols, the size of the symbols, and the size of the gaps between symbols. The ratings do not show a clear preference between the two densities in terms of the ability to perform the tasks, or the workload in the tasks.

Selection of Ambient Displays for Use in Future Studies

These results suggest that a grid pattern provides the best balance of performance as measured objectively, pilot ratings of ability to perform maneuvers and workload during the maneuvers, and acceptability to the pilots. In this experiment, the larger ambient objects were generally less distracting than the smaller objects.

Large objects were judged to be less distracting than smaller objects. However, the large objects either filled up more area than acceptable or failed to provide enough of a stimulus to be effective. Simultaneously, sparse distributions were less distracting and were more acceptable to the pilots than dense distributions, particularly with the smaller objects. These considerations lead us to recommend that the ambient objects should be a bit smaller than the large size used in this study, perhaps 2x2 meters or 3x3 meters at the simulated distance of 20 meters used in this study.

At the large size, the sparse distribution resulted in too few ambient objects being in the pilot's field of view while the dense distribution seemed to capture the pilot's attention and caused the pilots to feel closed in by walls. When the small ambient objects were displayed, the high density condition did result in a marked improvement in the pilots ability to maintain altitude, at least when the aircraft motion was constrained to two axes. However, when the aircraft moved in multiple axes or when one or more translational velocities was large, the small, dense ambient displays ceased to be interpretable, let alone effective. Therefore, we recommend that an intermediate level of density be considered for use in subsequent evaluations.

Figure 66 shows the recommended ambient display. The objects in this display are squares 3 meters per side. The pattern is 25% filled. Also shown in this figure, for comparison, are the grid patterns used as ambient displays in this experiment.

AMBIENT DRIVE LAWS

The ambient displays appeared to improve pilot performance only when the aircraft's motion was limited to one or two degrees of freedom. For example, the ambient display's effect on performance was most apparent in pedal turn portion of the bob-up task. During this portion of the task, the ambient objects were translating horizontally across the screen. Only when the aircraft was gaining or losing altitude was the motion of the ambient objects at a slant. This change from pure horizontal motion to diagonal motion was readily detected and interpreted by the pilots.

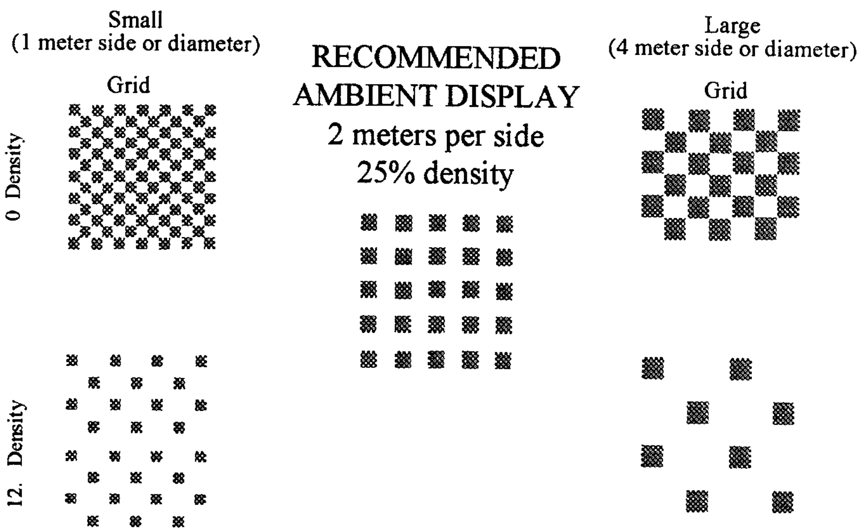


Figure 66. Ambient display recommended for use in future work. Also shown, for comparison, are selected examples of the ambient displays used in this study.

In contrast, most of the other maneuvers required the aircraft be maneuvered in multiple degrees of freedom simultaneously. Consider the slalom task. In this task the aircraft was translating, changing heading, pitch, and roll angles simultaneously in order to maintain the nominal altitude and airspeed (i.e., 50 ft AGL and 20 kts). These translational and angular motions were combined, along with pilot head motions, to drive the ambient symbols on the displays. Pilots did not find this multi-axis motion to be helpful. They reported being able to detect that the ambient objects were moving in the display, but being unable to relate the motion in the display to aircraft motion. Not infrequently, the motion of the ambient objects on the display was distracting. One pilot described the effect as being similar to having "rotating disco balls" in his peripheral field of view.

While it is interesting to speculate as to whether or not pilots would find physical billboards painted with grids or circles distracting while flying the maneuvers, the fact is that the ambient displays did not lead to improved performance in these conditions. Restricting the motion of the ambient displays to enhance their interpretability is in order.

One approach to restricting the motion of the ambient displays is to limit the changes in aircraft position that are used to drive the ambient objects. For example, one could drive the ambient objects using only the aircraft's rotations as inputs. This would have the benefit of eliminating the constant streaming of the ambient objects across the display when the aircraft is translating longitudinally, laterally, or vertically. The principal drawback to this approach is that the cues that the pilot can use to determine whether or not the aircraft is hovering over a spot or has began translating forward or aft or vertically will be eliminated. Another drawback to this approach is that the motion of the ambient objects on the screen will not be consistent with the motion that would occur if real objects were visible.

A second approach is to use non-linear or non-continuous drive laws to control translation of the ambient objects on the screen. For example, the square root of forward airspeed could be used to drive the ambient objects across the screen This type of control law would continuously vary the relationship between the aircraft's velocity and the resulting motion on the screen. At low aircraft speeds the motion of the ambient objects would be reduced by a smaller amount than at higher airspeeds. A non-continuous control law would apply a different gain to the relationship between the aircraft's velocity and the motion of the ambient objects on the screen. For instance, the gain could be near 1.0 when the aircraft is in hover mode so that changes are easily detected. In transition mode the gain might be on the order of 0.5. This would still allow the pilot to detect changes in airspeed but would not allow the ambient objects to simply become a "blur" across the screen. Finally, in cruise mode the gain might be 0.2. This low gain would allow the pilot to detect rather large changes in airspeed while small changes of a few knots would go unnoticed without letting the velocity of the ambient objects across the screen reach the point at which they are indecipherable "blurs".

Another approach to limiting motion is to have the ambient objects move in response to changes in the aircraft state. In steady state conditions the ambient objects would be stationary on the display. For example, imagine an aircraft moving forward at a constant velocity and altitude. In this case, the ambient objects would be stationary on the display. As the aircraft accelerates from the steady state speed the ambient objects would begin to flow across the display. Once a new steady state speed was reached then the motion of the ambient objects would attenuated over time until they became stationary. This approach is attractive because it eliminates motion of the ambient objects across the display surfaces that tends to obscure changes in other axes (e.g., the flow of the ambient objects caused by the forward motion of the aircraft masks changes in other axes.) The disadvantage is that the visual motion of the ambient objects will not be similar to the visual flow that occurs due to aircraft motion when viewing the natural environment.

AIRCRAFT HANDLING

The simulator used in this experiment limited the ability of the pilots to perform the maneuvers precisely. One weakness is the sensitivity of the collective. Pilots found that the collective was too sensitive to allow normal control of altitude. Specifically, very small movements of the collective around the hover position resulted in rates of climb or descent found unacceptable by the pilots. (Note that in the bob-up task the ambient displays appear to have provided the pilot information that resulted in significant improvements in altitude control compared to the performance exhibited in the control conditions.) In order to improve the quality of the simulation a non-linear control law will be developed and implemented. This control law will require larger movements of the collective to cause a change in power near the hover position than at the extremes of collective motion.

SCENE QUALITY

The ambient scenes were presented on LCDs with NTSC resolution. System testing prior to the start of this experiment showed that the ambient objets were too blurred to be effective. Therefore, Fresnel lenses were incorporated into the optical system to improve the focus. A significant amount of distortion near the edge of the Fresnel lenses was evident. In future evaluations, improved optical quality will be necessary. Two approaches are being pursued. The first is the (a) development of new mounting system for the ambient displays that will include improved lenses and an improved method of positioning the lenses. The second is the use of wide field of view HMD with the same display resolution in the forward and peripheral scenes.

AMBIENT BRIGHTNESS

Another weakness in the ambient display systems was the mismatch in brightness between the ambient displays and the forward scene. The ambient displays were brighter than the forward scene and brighter than necessary given that the performance of the ambient system is stable even light levels only slightly above threshold. The brightness of future ambient displays will be reduced to more closely match the brightness of the forward scene.

DISPLAY HARDWARE

The HMD used in this experiment was developed with flexibility in mind. This flexibility allowed us to explore options for positioning the displays. Unfortunately, this flexibility made it difficult to reposition the ambient displays reliably for each pilot throughout the experiment. Two paths have been pursued in order to rectify this shortcoming. First, alternative mounting designs for the ambient displays have been developed. These mounting designs, if implemented, would utilize the existing HMD and ambient display hardware. The second alternative being investigated is the use of a wide field of view HMD developed by Aberdeen Proving Grounds. This HMD allows presentation of three channels of video distributed horizontally. In the case of ambient display work, the left and right peripheral display areas would be used to present ambient objects. The center channel would be used to present either the NVG or daylight forward scenes.

The experiment was interrupted twice due to failures of the HMD used to display the forward scene. These interruptions lasted for several weeks while the HMD was returned to the manufacturer's service facility for repair. Due to limited program resources, it is not feasible to obtain a spare HMD for use in the event of failure. The manufacturer of the HMD, Kaiser Electro-Optics, performed the repairs to the HMD under warrantee, and even provided a HMD for use during the second interruption. Unfortunately, the replacement HMD also failed quickly. The failure of the "loaner" HMD points out that even having a spare HMD available would not prevent interruptions.

APPENDIX 1

Subjective Rating Form

POST EXPERIMENT QUESTIONNAIRE

PILOT CODE: ____________________ DATE: __________________________

Listed below are all of the display conditions. Please rank order these from best to worst in terms of how well the display supported your ability to maintain awareness of the aircraft's position and orientation. (1 = best, 10 = worst)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

Did you find any of the ambient symbol sets to be particularly useful? If so, which symbol set or sets stand out? What about the symbol set or sets was useful and in what conditions?

Did you find any of the ambient symbol sets to be a hindrance or to interfere with flying the helicopter? If so, which symbol set or sets were a hindrance and under what conditions did the problem occur? What could be done to remedy this problem?

Which symbol set made it easiest for you to maintain awareness of the aircraft's pitch attitude? (Select one)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

Which symbol set made it easiest for you to maintain awareness of the aircraft's roll attitude? (Select one)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

Which symbol set made it easiest for you to maintain awareness of the aircraft's heading changes? (Select one)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

Which symbol set made it easiest for you to determine when there was a change in the aircraft's forward or backward velocity? (Select one)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

Which symbol set made it easiest for you to determine when there was a change in the aircraft's vertical speed? (Select one)

_____ Daylight 3- Channel Out the Window Scene
_____ Narrow Field Of View Night Vision Goggle Scene
_____ 1 m by 1 m Dense Grid
_____ 1 m by 1 m Sparse Grid
_____ 1 m by 1 m Dense Circles
_____ 1 m by 1 m Sparse Circles
_____ 4 m by 4 m Dense Grid
_____ 4 m by 4 m Sparse Grid
_____ 4 m by 4 m Dense Circles
_____ 4 m by 4 m Sparse Circles

At what point did you feel comfortable flying the simulator? The first flight? The last flight? Never?

Please provide any other comments, favorable or unfavorable, regarding the ambient symbols.

Please provide any recommendations you have for improving the ambient symbol sets.

Are there any flight tasks that you believe would be valuable additions to a test battery for future work on ambient symbols? If, what are those tasks?

Please provide any comments on the simulator you care to make. We are particularly interested in recommendations that will make the simulator a better test bed for future symbology research.

APPENDIX 3

Experiment 2 Report

EVALUATION OF ALTERNATIVE DRIVE LAWS FOR PRESENTATION OF AIRCRAFT STATE INFORMATION IN AMBIENT DISPLAYS

SBIR Phase II
Contract Number DAAH10-98-C-0020

01 May 2000

Prepared For:

US Army Aviation and Missile Command
Aviation Applied Technology Directorate
Fort Eustis, VA 23604-5577

Prepared By:

Monterey Technologies, Inc.
24600 Silver Cloud Court
Suite 103
Monterey, CA 93940

EVALUATION OF ALTERNATIVE DRIVE LAWS FOR PRESENTATION OF AIRCRAFT STATE INFORMATION IN AMBIENT DISPLAYS

EXECUTIVE SUMMARY

This report describes the methods and results of the second in a series of studies being conducted to develop effective displays for presenting aircraft state information to pilots in a format that is processed by the ambient visual system. The first study in this series examined the size, density and shape of the ambient objects. This study examines the drive laws relating longitudinal motion of the aircraft to the longitudinal motion of the ambient objects on the displays.

The ambient objects were presented as if painted on infinitely long, infinitely tall bill boards located 20 meters (66 ft) on either side of the aircraft. Motion of the aircraft in pitch, roll, yaw, vertical translation and longitudinal translation, and pitch, roll, and yaw motion of the pilot's head, caused the ambient objects to appear to move. Lateral translation of the aircraft had no effect on the ambient displays; they remained as if at a distance of 20 meters. In all cases the ambient objects represented squares 2 meters (6.6 ft) on a side. 25% of the ambient display area was occupied by the squares. In a control condition, no ambient objects were displayed.

Five drive laws relating longitudinal motion of a simulated helicopter to motion of the ambient objects on the displays were examined. In all cases the motion of the ambient objects on the display were driven using a 1 to 1 relationship between aircraft and the motion of the ambient objects in all axes other than longitudinal. These control laws are described

- Linear - the longitudinal velocity of the ambient objects was directly related to the longitudinal velocity of the aircraft.
- No longitudinal motion- the ambient objects remained stationary on the display regardless of the velocity of the aircraft.
- Non-linear – the change in velocity of the ambient objects per unit change in aircraft velocity was an exponential function of aircraft velocity where the exponent was less than 1.0. This had the effect of amplifying changes in the velocity of the ambient objects at low airspeeds, and attenuating the change at higher airspeeds.
- Acceleration – the motion of the ambient objects was driven by the aircraft's acceleration, rather than velocity. When the aircraft was accelerating, the ambient objects moved rearwards on the display. The rate of the motion of the ambient objects was related to the rate of acceleration
- Time decay – motion of the ambient objects was "washed out" over a 5 sec period. When the aircraft reached a constant speed, motion of the ambient objects was smoothly reduced until they were stationary on the display. Subsequent changes in airspeed moved the ambient objects as if the constant speed was the set point (e.g., accelerating [decelerating] after maintaining a constant airspeed caused the ambient objects to move rearwards [forwards] on the display

Pilots flew a series of maneuvers with each drive law in a fixed base, "virtual reality" helicopter simulator. Pilots interacted with the simulator through a set of conventional aircraft controllers (Flight Link, Chico, CA) The out-the-window view, a view of the cockpit and instruments, and the ambient displays were presented on a Proview 100 helmet mounted display (HMD) (Kaiser Electro-Optics, Carlsbad, CA). The Proview 100 has four display surfaces. These surfaces are arranged in a horizontal row. Ambient displays were presented on the two outboard surfaces. A NVG scene was presented biocularly in the two inboard channels.

The maneuvers flown were a bob up, an acceleration/deceleration, a constant speed, constant rate approach to a landing point, a pirouette, and a slalom. All of these maneuvers, with the exception of the constant speed approach, were variants of the maneuvers described in ADS-33.

Overall, the best performance and lowest pilot workload occurred in the linear drive law condition. However, on some tasks performance with the linear drive law was surpassed with other drive laws. Examination of the pattern of results indicates that the linear drive law condition worked best at very low airspeeds. At higher airspeeds the rate of motion of the ambient objects tended to mask changes in ambient motion in other dimensions. This was most apparent in the slalom task, where the aircraft was also moving in multiple dimensions simultaneously.

At higher airspeeds, performance in the time decay and acceleration conditions was similar, and better than in all other conditions. This suggests that providing the pilot information about changes in airspeed is sufficient. The collateral benefit is that reducing or eliminating continuous longitudinal flow of the ambient objects allows the pilot to more easily identify changes in other dimensions. Pilot comments indicate the acceleration condition was not providing the information needed at hover speeds. Specifically, in this regime the pilot is more interested in the direction and velocity of any drift. The motion of the ambient objects when using the acceleration drive law did not coincide with the direction that the aircraft was moving . (For example, consider an aircraft drifting forwards at 3 kts. When the pilot pulls back on the cyclic to stop the drift, the aircraft decelerates from 3 to 2 kts. With the acceleration drive law, this causes the ambient objects to move forwards on the display. However, the aircraft is still moving forwards.)

These results suggest that multiple ambient display drive laws may be superior to a singe drive law. The low speed drive law should emphasize the direction and velocity of the aircraft's motion. At higher airspeeds, the drive law should be tailored to make it easy for pilots to identify changes in airspeed while minimizing the continuous flow of the ambient objects over the display.

EVALUATION OF ALTERNATIVE DRIVE LAWS FOR PRESENTATION OF AIRCRAFT STATE INFORMATION IN AMBIENT DISPLAYS

INTRODUCTION

This report describes the methods and results of the second in a series of studies being conducted to develop effective displays for presenting aircraft state information to pilots in a format that is processed by the ambient visual system. The first study in this series examined the size, density and shape of the ambient objects. This study examines the drive laws relating motion of the aircraft to motion of the ambient objects on the displays.

The results of the first study in this series showed that improvements in the dynamics of the ambient displays are needed. In that study, the ambient objects represented stationary objects located 20 meters (66 ft) to the side of the aircraft. As the aircraft flew forward, the ambient objects flowed to the rear across the display surfaces. Similarly, as the aircraft's altitude increased the ambient objects flowed downwards on the displays. Rotational motion of the aircraft (i.e., pitch, roll, and yaw) was also portrayed in the ambient displays. In the first study it was found that at higher rates of aircraft longitudinal motion (e.g., above 20 kts) the flow of the ambient objects across the screen made it difficult for the pilot to extract motion in the other axes from the ambient displays. At the other extreme, the motion of the ambient objects near a stationary hover was not always of sufficient rate to allow pilots to detect low rate drift.

This study was designed to investigate alternative relationships between aircraft longitudinal motion and motion of the ambient objects across the displays.

EQUIPMENT

SIMULATOR

The Development and Evaluation System (DAES) was used to conduct these tests. DAES is a low cost, PC-based helicopter simulator. The helicopter model is the Enhanced Stability Derivative (ESD) model. It is tuned to represent a generic, light weight helicopter.

The pilot flies DAES using a set of commercially available controllers (Flight Link, Chico, CA). The collective control law has been modified since the first study in this series to reduce the sensitivity around the hover position. Additionally, minor tuning of the parameters in the ESD software has been done to improve directional handling qualities. This tuning was aimed at improving fly-ability in the slalom task

DISPLAY

The out-the-window scene and the ambient displays were presented on a Kaiser Proview 100 HMD (Kaiser Electro-Opics, Carlsbad, CA). In the previous study, a Proview 30 was used to display the out-the-window scene and the ambient objects were shown on custom displays attached to the periphery of the Proview 30's displays. In all cases the forward, out-the-window scene was presented biocularly in the two center channels. The ambient objects were displayed in peripheral channels.

AMBIENT DISPLAYS

The ambient display consisted of squares 2 meters per side viewed from a distance of 20 meters (66 ft). The squares occupied 25% of the display area.

EXPERIMENTAL CONDITIONS

There were six conditions in this study; a NVG only control condition and five experimental conditions. In the experimental conditions, different control laws relating longitudinal motion of the aircraft to flow of the ambient objects on the display were evaluated. These control laws were:

a) Linear
b) No Longitudinal Motion
c) Non-Linear (exponential)
d) Acceleration
e) Time Decay

Vertical translation and pitch, roll, and yaw of the aircraft drove the ambient displays in a 1:1 ratio to aircraft motion. Lateral translation was not depicted in the ambient displays.

The sequence of experimental conditions was determined randomly for one of the pilots. This sequence was reversed for the other pilot. The NVG only control condition was always flown last.

LINEAR CONTROL LAW

The linear control law used in this study was the same as the control law used in the first experiment. The rate of longitudinal motion of the ambient objects across the displays was equivalent to the rate of longitudinal motion of the aircraft. The motion of the ambient objects was in the opposite direction as that of the aircraft; as the aircraft flew forwards the ambient objects moved from the front to the rear of the displays.

NO LONGITUDINAL MOTION

In this condition, motion of the ambient objects on the screen was independent of the aircraft's longitudinal motion. At a constant heading, altitude, and bank angle the ambient objects appeared to be stationary on the display regardless of airspeed.

NON-LINEAR CONTROL LAW

The velocity of the ambient objects on the displays was a non-linear function of the aircraft's longitudinal airspeed. The formula used to relate aircraft longitudinal translation rate to motion of the ambient objects on the display was:

****
XXX get C and E values, and consider putting in a plot
****

$V_{ambient} = (C * V_{aircraft})^E$

where
$V_{ambient}$ = velocity of the ambient object across the display
$V_{aircraft}$ = longitudinal velocity of the aircraft (i.e., airspeed)
C = Constant (= 1.0)
E = Exponent (= XX)

This control law had the effect of reducing the change in the velocity c.f the ambient objects caused by changes in the aircraft's velocity more at higher airspeeds than at lower airspeeds.

ACCELERATION

This control law relates the speed of the ambient objects on the display to the acceleration of the aircraft rather than to the aircraft's velocity. When the aircraft is accelerating, the ambient objects flow from the front towards the rear of the displays regardless of the velocity or direction (forward/backwards) of the aircraft's longitudinal motion. When the aircraft is decelerating the ambient objects flow from the rear towards the front of the displays. The rate of motion of the ambient objects was related to the acceleration of the aircraft. The faster the aircraft accelerates or decelerates, the faster the ambient objects move on the display.

TIME DECAY

This control law reduced the longitudinal motion of the ambient objects on the screen over a time whenever the aircraft's speed was constant. The motion of the ambient objects decayed to zero over a 5 second period. Changes in the direction and velocity of the ambient objects were relative to the change in aircraft velocity from the constant airspeed. For example, consider aircraft is flying at a constant 20 kts (37 kph, 23 mph) that decelerates to 15 kts (28 kph, 17 mph). While the airspeed is constant the ambient objects will remain stationary on the display. As the aircraft begins to decelerate, the ambient objects will flow from the rear towards the front of the display. The rate of flow being proportional to the difference in the aircraft's current speed from 20 kts. As the aircraft reaches and then maintains 15 kts, the velocity of the ambient objects on the display will be reduced until after 5 seconds at 15 kts they are again stationary.

FLIGHT TASKS

Five flight tasks were performed in each of the experimental and control conditions. These tasks were:

a) Bob-up
b) Acceleration/Deceleration
c) Constant Speed, Constant Rate of Descent Approach to Landing
d) Pirouette
e) Slalom

All of the tasks, with the exception of the constant speed, constant rate of descent approach to landing, are slightly modified versions of tasks described in ADS-33. These tasks are described below.

BOB-UP

In the bob-up task the pilot attempted to maintain the aircraft's ground position while climbing to an altitude of 50 ft AGL (15.2 meters). Once at 50 ft, the pilot performed pedal turn of 180 degrees while maintaining the altitude. After completing the turn, the pilot descended and landed.

ACCELERATION/DECELERATION

This task required the pilot to accelerate from a stop up to 15 kts (28 kph, 17 mph) and then to decelerate and come to a stop over a square marked on the ground. During this maneuver, the aircraft was to maintain an altitude of 30 ft AGL (9.1 meters) and maintain a straight ground track.

CONSTANT SPEED, CONSTANT RATE OF DESCENT APPROACH TO LANDING

From an initial position of 300 ft AGL (91.4 meters) and 0 kts airspeed the pilot accelerated up to 20 kts (37 kph, 23 mph) and initiated a constant rate of descent towards a landing area. During the approach, the pilot was to maintain the aircraft's heading as well as airspeed and rate of descent until reaching an altitude of 50 ft AGL (15.2 meters), at which time the pilot could make initiate changes in preparation for landing.

PIROUETTE

In the pirouette, the pilot attempted to side-slip the aircraft around a 100 ft (30.5 meter) diameter ring. While maintaining the distance from the center of the ring, the pilot was to maintain an altitude or 20 ft AGL (6.1 meters) and to keep the nose of the aircraft aimed towards the center of the ring.

SLALOM

The slalom was performed over a runway. The pilot's task was to make a series of left and right hand turns so that the aircraft passed through the gaps in the runway's center line. Each turn was to be made so that the outside of the turn was at or beyond the lines on the edges of the runway. The target parameters for the slalom were 50 ft AGL (15.2 meters) and 20 kts (37 kph, 23 mph).

METHOD

PILOTS

Two experienced helicopter pilots participated in this experiment. Both these pilots had participated in the previous experiment and were familiar with flying DAES.

PROCEDURE

Prior to flying DAES instructions were read to the each pilot. These instructions described the flight maneuvers that would be required and the display conditions that were being investigated. The pilots were advised that their data would be de-identified, and that they had the right to withdraw from the study at any time without incurring any cost or negative consequence.

Before each session, the drive law being used was explained to the pilot and any questions about the drive law answered. The pilot then performed two replications of each of the five maneuvers. Each flight session required between about 35 and 45 minutes to complete.

Following each flight in which ambient displays were presented, the pilot completed a rating form. This rating form is contained in Appendix A.

Following all of the flights, the pilot completed a form in which the various display conditions were judged relative to each other. This rating form is contained in Appendix B.

RESULTS FROM AUTOMATICALLY RECORDED DATA

BOB-UP

AVERAGE DISTANCE DRIFTED

The distance that the aircraft drifted during the pedal turn portion of the bob-up maneuver is shown in Figure 1. Inspection of this figure shows that the pilot's ability to maintain position was similar in the NVG control condition and in the acceleration and time decay drive law experimental conditions (15.0 to 16.2 ft [4.6 to 4.9 meters]). The amount of drift was somewhat greater in the linear drive law condition (21.2 ft [6.5 meters]), and was considerably greater in no longitudinal motion and non-linear experimental conditions (30.4 and 32.9 ft [9.3. and 10.0 meters], respectively).

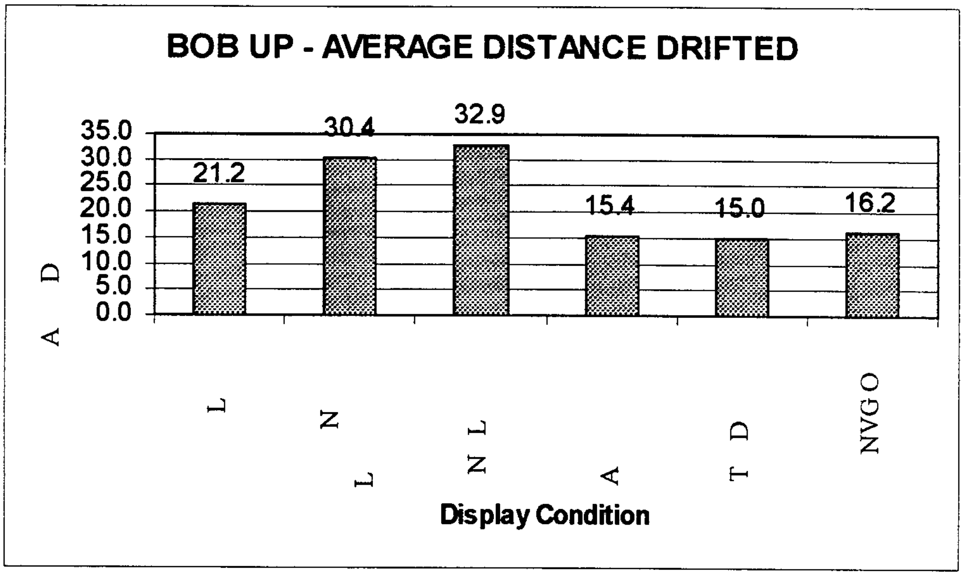


Figure 1. Average distance aircraft drifted during the pedal turn portion of the bob-up maneuver.

AVERAGE TURN RATE

The average turn rates during the pedal turn portion of the bob-up maneuver are shown in Figure 2. The average turn rate was fastest in the no longitudinal motion, acceleration, and time decay experimental conditions (6.9 to 7.7 deg/sec), and lowest in the non-linear motion condition (3.3 deg/sec). Turn rate was intermediate in the linear motion and NVG control conditions (5.4 to 5.6 deg/sec).

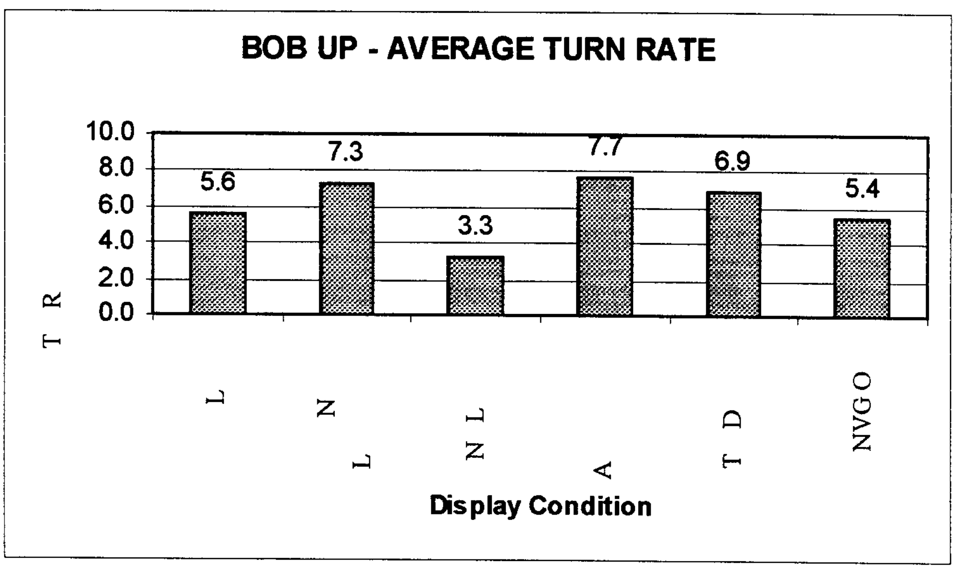


Figure 2. Average turn rate during the pedal turn portion of the bob-up maneuver.

STANDARD DEVIATION OF TURN RATE

Figure 3 shows the standard deviation of turn rate in each of the display conditions. The variability is smallest in the NVG control condition (0.9 deg/sec) and greatest in the linear drive law condition (2.8 deg/sec). The standard deviation of the turn rate is intermediate in the other four conditions (1.7 to 2.4 deg/sec).

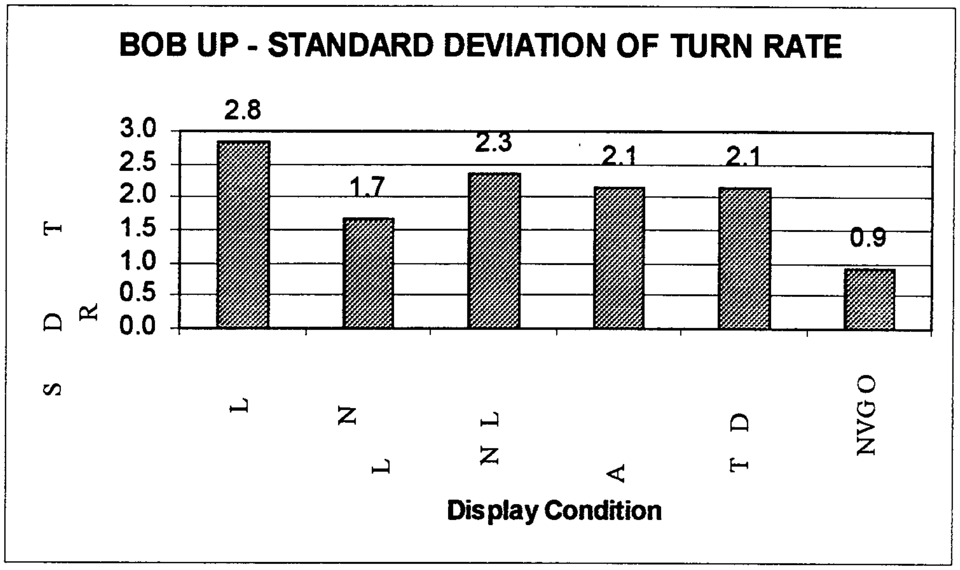


Figure 3. Standard deviation of turn rate during the pedal turn portion of the bob-up maneuver.

AVERAGE ALTITUDE

The absolute value of altitude error is shown in Figure 4. The largest error occurred in the linear motion condition (6.4 ft [2.0 meters]), and the smallest error occurred in the acceleration motion condition (0.3 ft [0.1 meters]). The magnitude of the altitude error was similar in the no longitudinal motion, non-linear motion, and NVG control conditions (1.5 to 2.1 ft [0.4 to 0.6 meters]). However, the average altitude was less than the 50 ft target altitude in the non-linear motion condition, the only condition in which the altitude was below the target in this task. The altitude error in the time decay condition was 3.2 ft (1.0 meters).

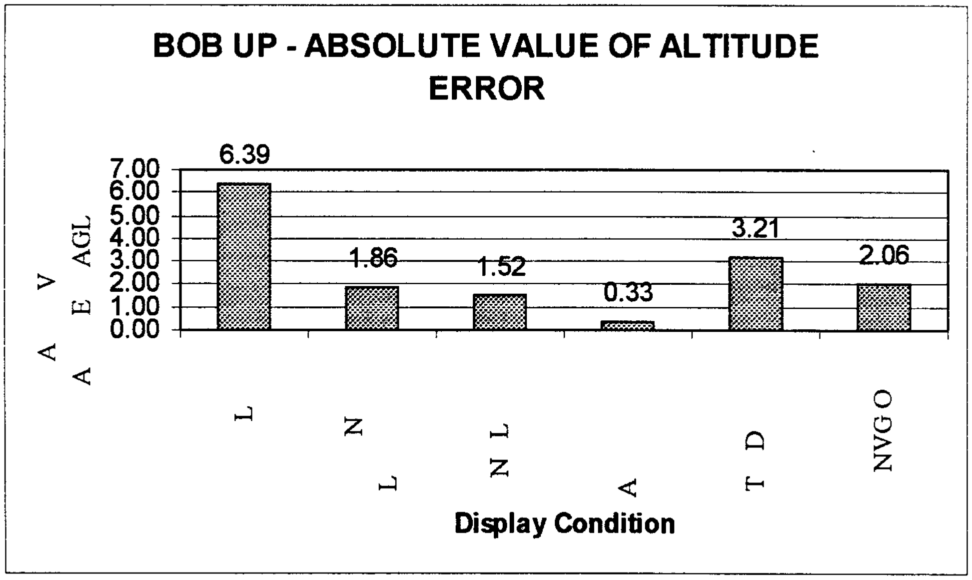


Figure 4. Absolute value of altitude error.

ALTITUDE VARIABILITY

The standard deviation of altitude during the bob-up task was smallest in the no longitudinal motion, acceleration, and time decay conditions (4.7 to 6.0 ft [1.4 to 1.8 meters]). The standard deviations were larger in the linear and non-linear motion conditions and in the NVG control condition (7.1 to 7.7 ft [2.2 to 2.3 meters]). Figure 5 shows the standard deviations of altitude in each of the conditions in the bob-up maneuver.

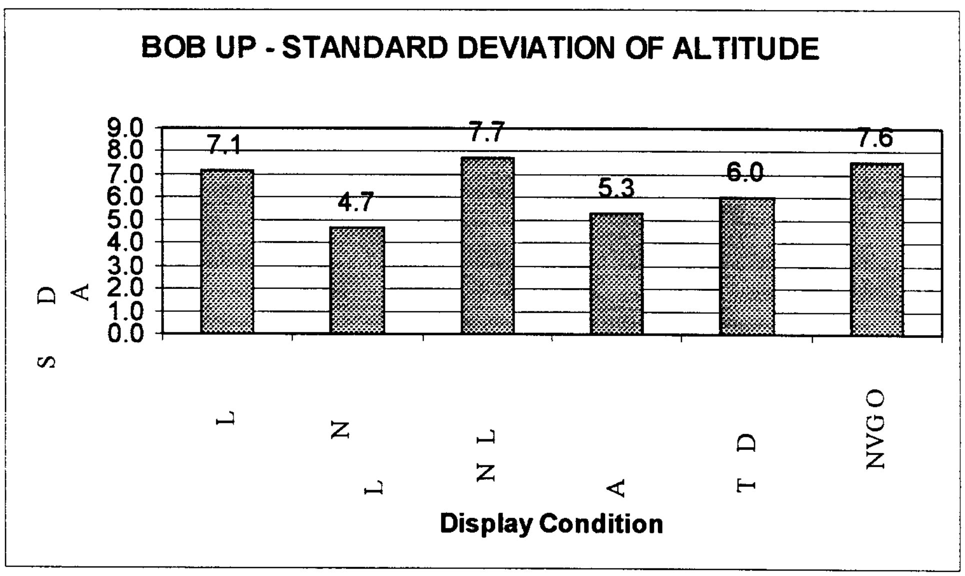


Figure 5. Standard deviation of altitude in the bob-up maneuver.

ACCELERATION/DECELERATION

AVERAGE ALTITUDE

The average altitude in each condition during the acceleration/deceleration maneuver is shown in figure 6. This figure shows that the average altitudes were all equal to or above the target altitude of 30 ft AGL (9.1 meters). The average altitudes in the no longitudinal motion, time decay, and NVG control conditions were all within about a foot of the target altitude (30.0 to 31.1 ft [9.1 to 9.5 meters]). The average altitude was highest in the non-linear motion condition (38.4 ft [11.7 meters]), and was intermediate in the linear and acceleration conditions (32.8 and 32.9 ft, respectively [10.0 meters])

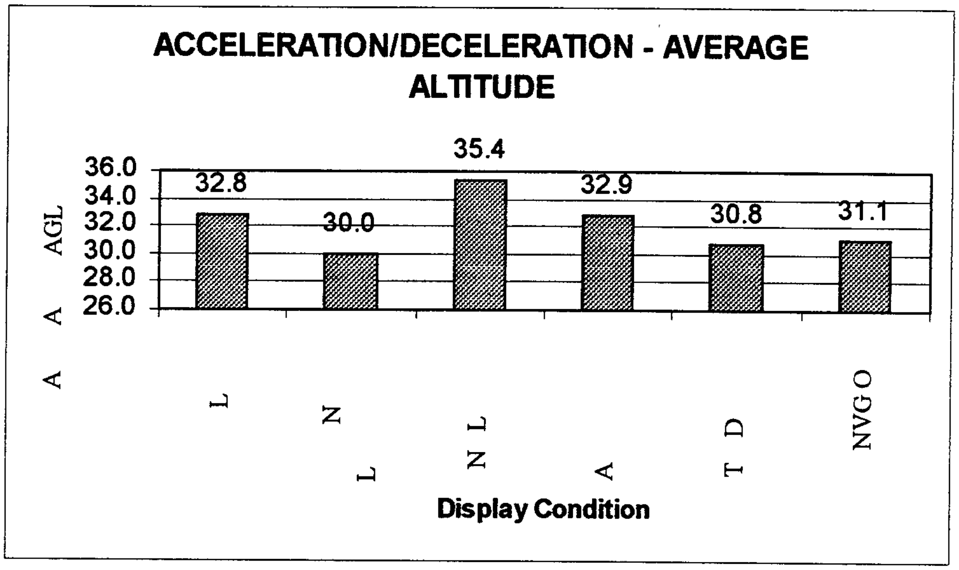


Figure 6. Average altitude in the acceleration/deceleration task. The target altitude was 30 ft AGL.

ALTITUDE VARIABILITY

Figure 7 shows the standard deviation of altitude in the acceleration/deceleration task. The altitude was less variable in the linear, acceleration, and NVG conditions (3.8 to 4.4 ft [1.2 to 1.3 meters]) than in the no longitudinal motion, non linear, and time decay conditions (5.8 to 6.4 ft [1.8 to 2.0 meters]).

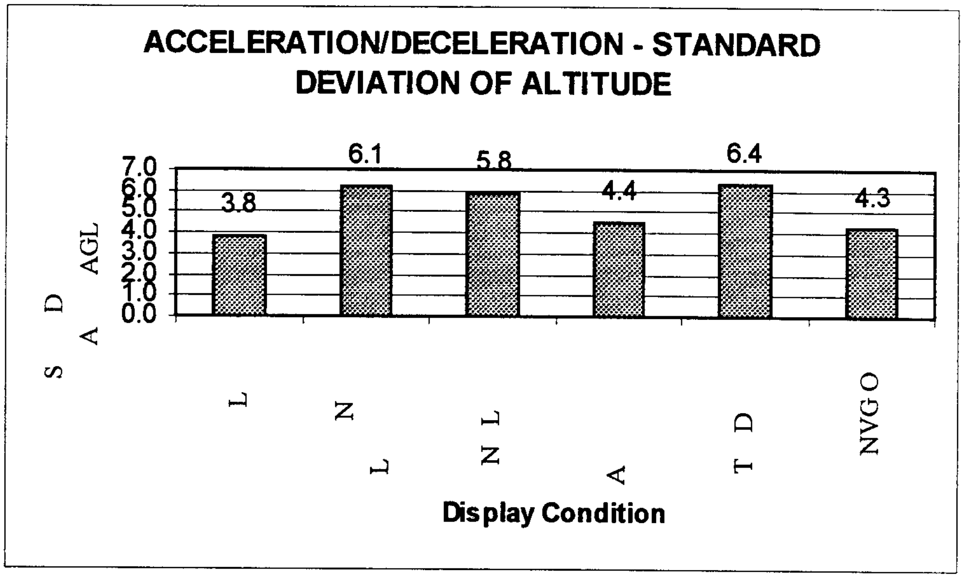


Figure 7. Standard deviation of altitude in the acceleration/deceleration task.

CONSTANT SPEED, CONSTANT RATE OF DESCENT APPROACH

AVERAGE AIRSPEED

Pilots flew the approach faster than the 20 kts (37 kph, 23 mph) target airspeed in the acceleration condition. In all other conditions the average airspeed ranged from 19.6 kts (36.3 kph, 22.6 mph) to 21.4 kts (39.6 kph, 24.6 mph) The average airspeeds are shown in figure 8.

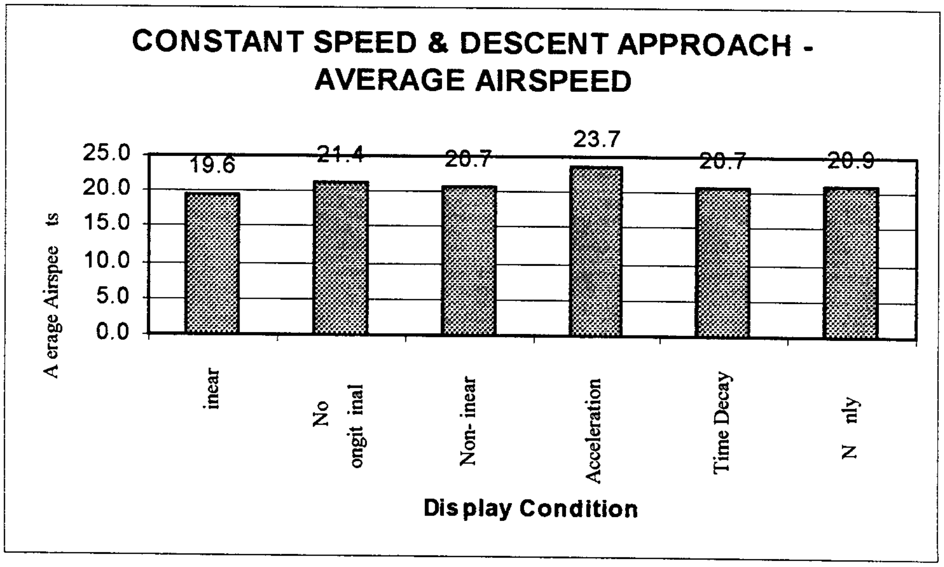


Figure 8. Average airspeed in the constant speed, constant rate of descent approach.

AIRSPEED VARIABILITY

Figure 9 shows the standard deviation of the airspeed in each of the display conditions in the constant speed, constant rate of descent approach task. Airspeed was least variable in the NVG only condition (1.8 kts [3.3 kph, 2.1 mph]). Airspeed was most variable in the linear and non-linear motion conditions (3.0 kts [5.6 kph, 3.4 mph] and 2.9 kts [5.4 kph, 3.3 mph]). In the other three display conditions airspeed variability was approximately 2.5 kts (4.6 kph, 2.9 mph).

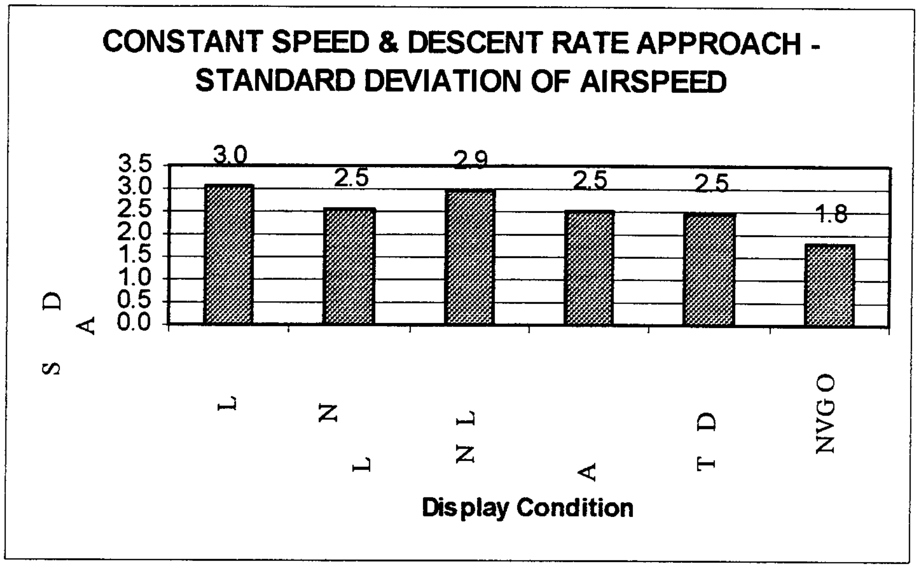


Figure 9. Standard deviation of airspeed during the constant speed, constant rate of descent approach to landing task.

AVERAGE RATE OF DESCENT

Pilots had digital and radar altimeter data available, along with information from the forward, out-the-window scene and from the ambient displays, on which to judge their rate of descent. They did not have a vertical speed indicator. Figure 10 shows the average rate of descent from the point at which the aircraft reached 20 kts (37 kph, 23 mph) of airspeed until the aircraft reached 50 ft AGL (15.2 meters). The rate of descent was greatest in the acceleration condition (317.3 ft/min [96.7 meters/min]). The average rate of descent in all of the other display conditions was similar, ranging from a low of 256.3 ft/min (78.1 meters/min) to a high of 274.3 ft/min (83.6 meters/min).

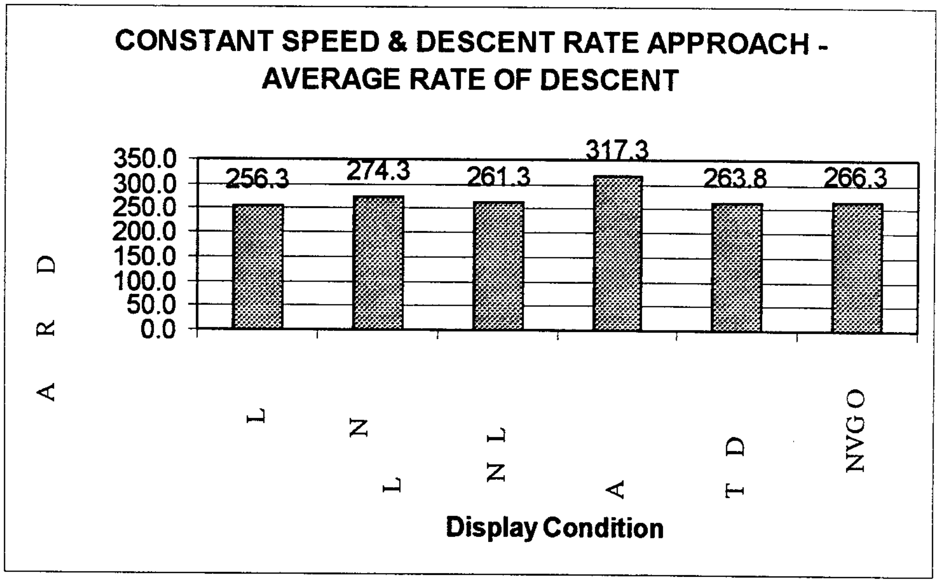


Figure 10. Average rate of descent in the constant speed, constant rate of descent approach task.

VARIABILITY OF RATE OF DESCENT

The standard deviation of the rate of descent in each display condition is shown in figure 11. This figure shows that the smallest variability is in the no longitudinal motion condition (115.3 ft/min [35.1 meters/min]) and was intermediate in the acceleration condition (139.5 ft/min [42.5 meters/min]). The standard deviation was larger in the remaining four conditions, where it ranged from 150.3 ft/min (45.8 meters/min) to 161.4 ft/min (49.2 meters/min).

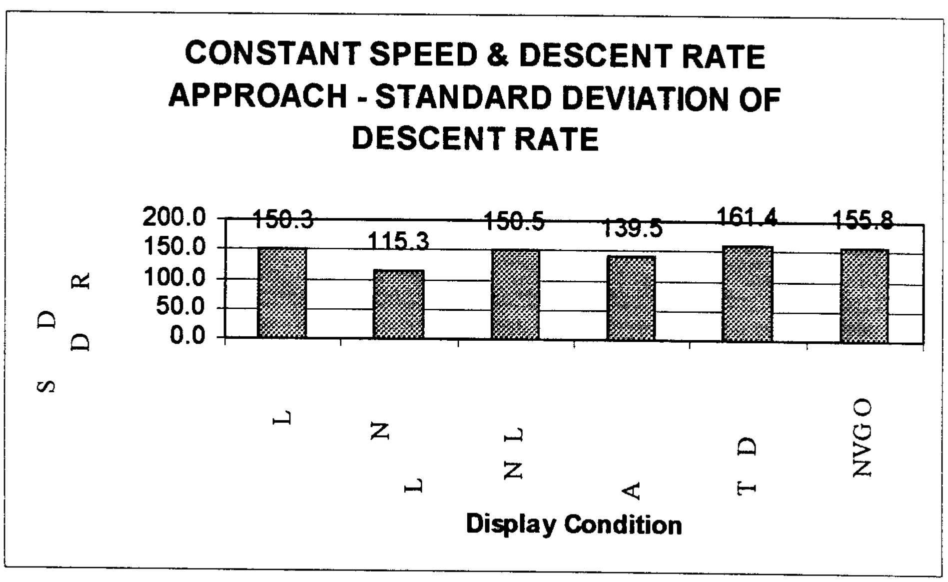


Figure 11. Standard deviation of rate of descent in the constant speed, constant rate of descent approach task.

PIROUETTE

AVERAGE ALTITUDE

The average altitude was higher than the target altitude of 20 ft (6.1 meters) in all conditions. The average altitude was closer to the target altitude in the time decay condition (21.5 ft [6.6 meters]) than in any of the other conditions. The altitude error was greatest in the linear condition (28.4 ft [8.6 meters]). In the other conditions the average altitude ranged from 24.7 ft (7.5 meters) to 26.1 ft (8.0 meters). The average altitudes are shown in figure 12 for each of the display conditions.

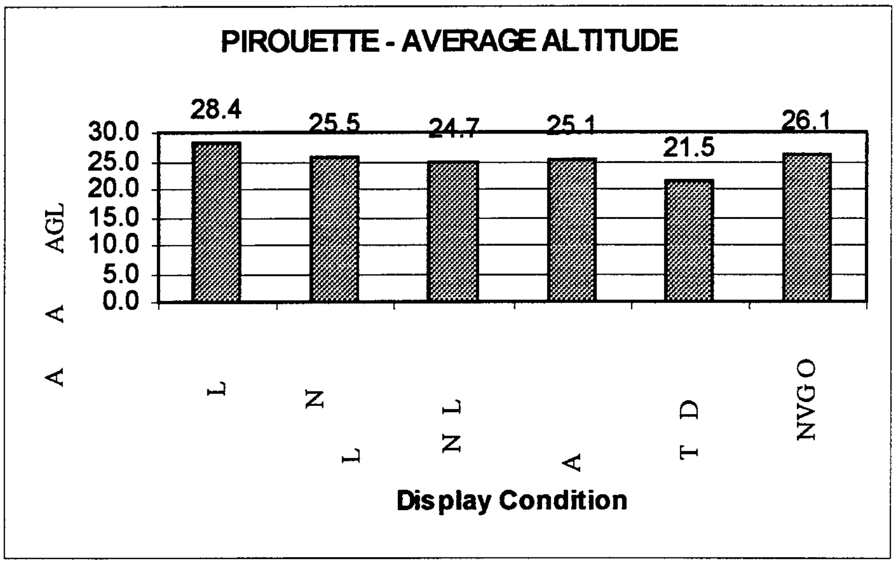


Figure 12. Average altitude in the pirouette task.

ALTITUDE VARIABILITY

The standard deviations of altitude in each display condition during the pirouette task are shown in figure 13. The variability was least in the NVG and time decay conditions (6.26 and 6.81 ft [1.9 and 2.1 meters], respectively. The altitude variability was greatest in the acceleration and linear conditions, with standard deviations of 10.0 and 9.7 ft, respectively (3.0 meters)

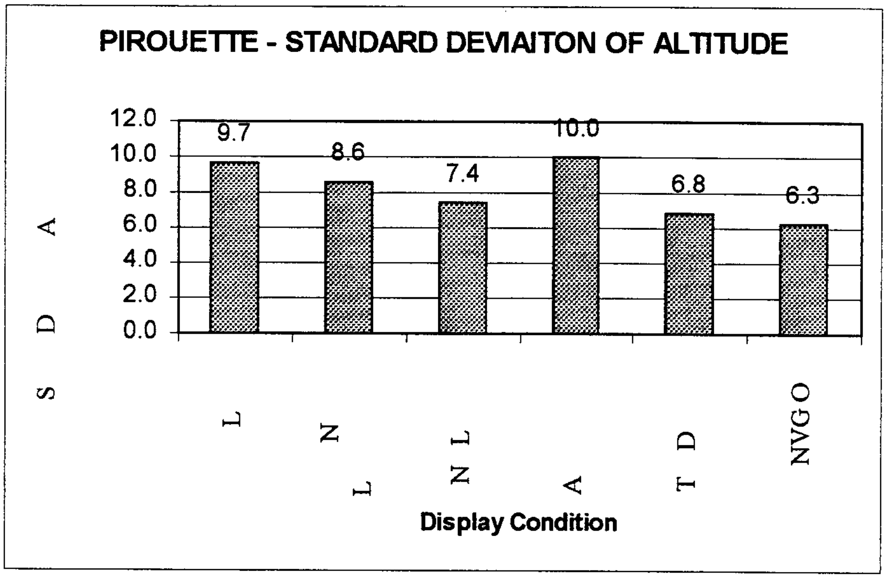


Figure 13. Standard deviation of altitude in the pirouette task.

AVERAGE AIRCRAFT BANK ANGLE

The average bank angle of the aircraft during the pirouette task are shown in figure 14. The average bank angle during the pirouette was smallest in the time decay condition (0.6 deg) The average bank angle was slightly greater than this in the NVG and linear conditions (0.9 deg). The bank angle was still greater in the non linear (1.1 deg) and acceleration (1.2 deg) conditions, and was greatest in the no longitudinal motion condition (1.5 deg).

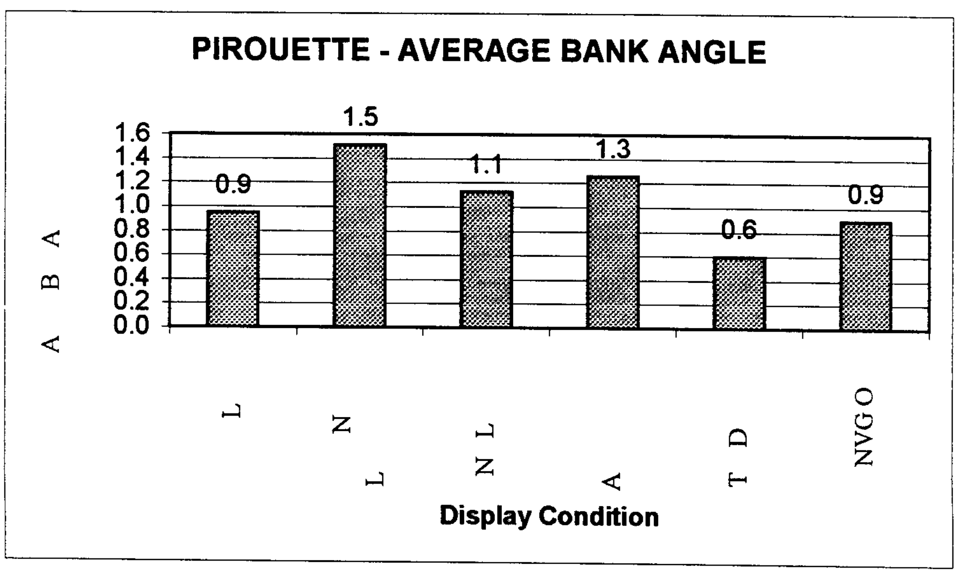


Figure 14. Average aircraft bank angle during the pirouette task.

VARIABILITY OF AIRCRAFT BANK ANGLE

The standard deviation of the aircraft's bank angle was greatest in the linear and acceleration conditions (3.2 and 3.0 deg, respectively). In the other conditions, the standard deviations were similar and ranged from 2.3 to 2.4 degrees. Figure 15 shows the standard deviation of bank angle in each display condition.

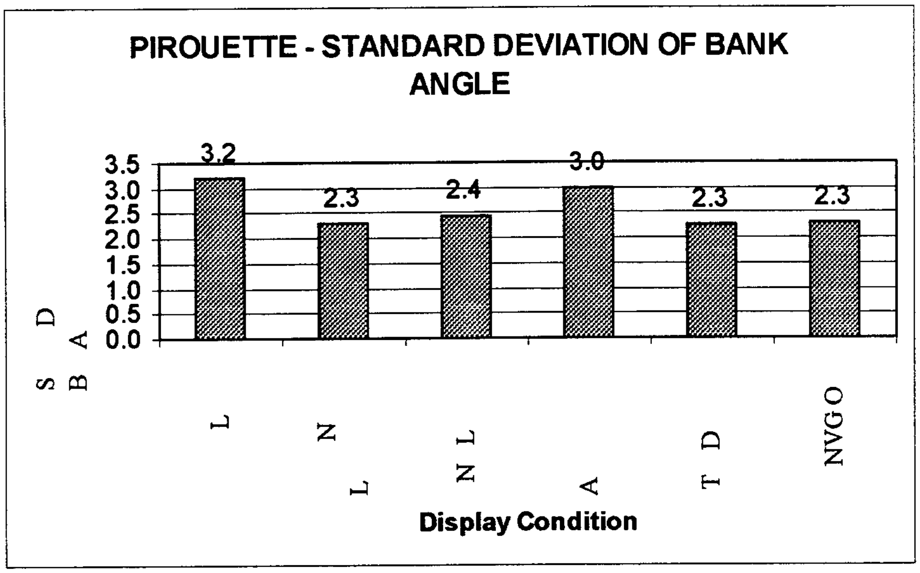


Figure 15. Standard deviation of aircraft bank angle in the pirouette task.

DISTANCE FROM THE CENTER OF THE CIRCLE

During the pirouette, pilots attempted to maintain a 100 ft (30.5 meter) distance from the center of the circle. Figure 16 shows the average error in this distance. (Positive values indicate distances greater than 100 ft from the circle's center.) The average error was greatest in the acceleration and linear display conditions (13.0 and 12.6 meters [42.6 and 41.3 ft], respectively). In the other conditions the average errors are similar, ranging from 8.3 meters (27.2 ft) to 10.9 meters (35.8 ft).

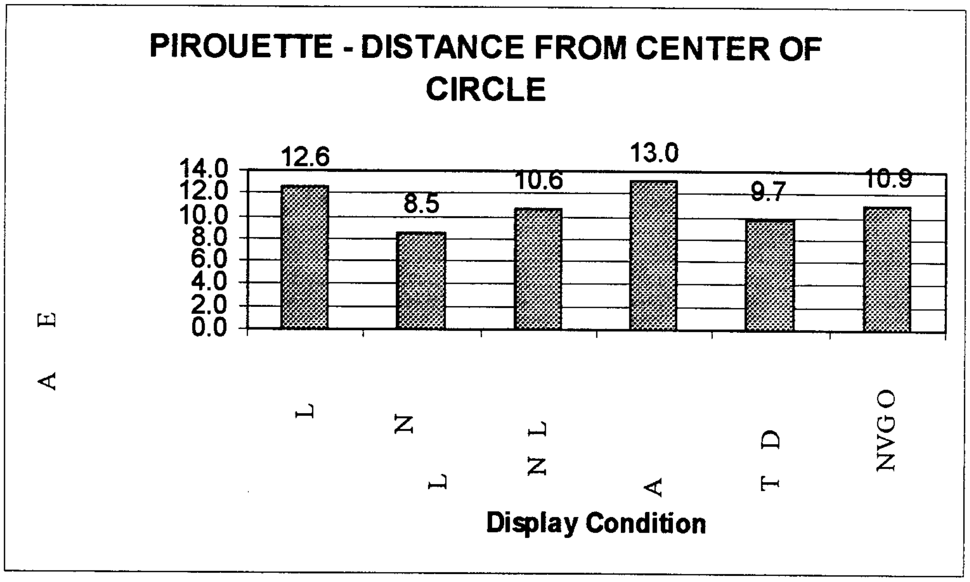


Figure 16. Average error in distance from the center of the circle in the pirouette task. Positive values indicate that the aircraft was outside the circle.

VARIABILITY IN DISTANCE FROM THE CENTER OF THE CIRCLE

The variability in the distance between the aircraft and the center of the circle is shown in figure 17. Variability was smallest in the non linear, time decay, and NVG display conditions (5.1 to 5.4 meters (16.7 and 17.7 ft) and greatest in the acceleration condition (8.4 meters [27.6 ft]). In the linear and no longitudinal motion conditions the standard deviations of the distance between the aircraft and the center of the circle were 6.4 and 6.6 meters (21.0 and 21.6 ft), respectively.

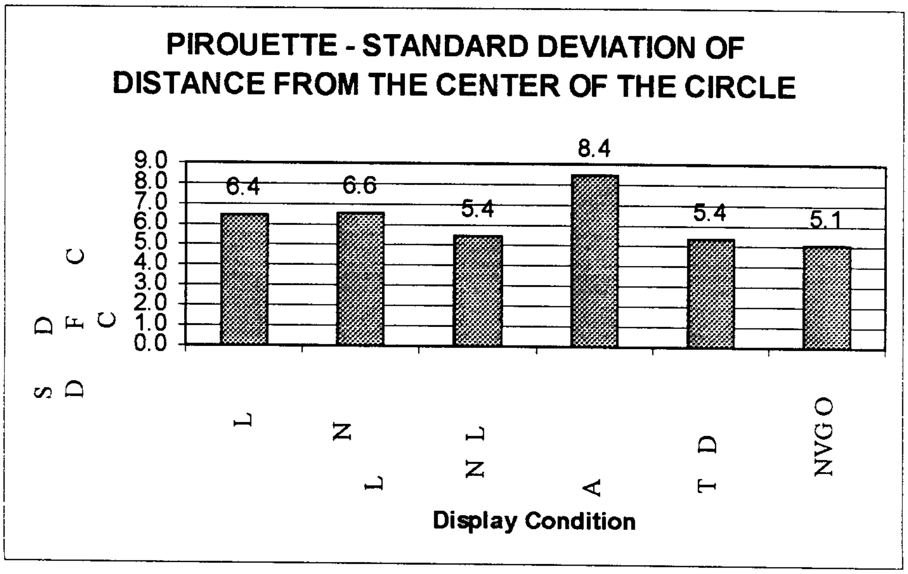


Figure 17. Standard deviation of the distance between the aircraft and the center of the circle in the pirouette task.

SLALOM

AVERAGE AIRSPEED

In the slalom task the pilot attempted to maintain 20 kts (37 kph, 23 mph) airspeed. The average airspeed in each display condition is shown in figure 18. In all cases the airspeed was farthest from the target of 20 kts in the NVG condition (24.7 kts [45.7 kph, 28.4 mph]). In the ambient display conditions the average airspeed ranged from 19.5 kts (36.1 kph, 22.4 mph)to 22.8 kts (42.2 kph, 26.2 mph).

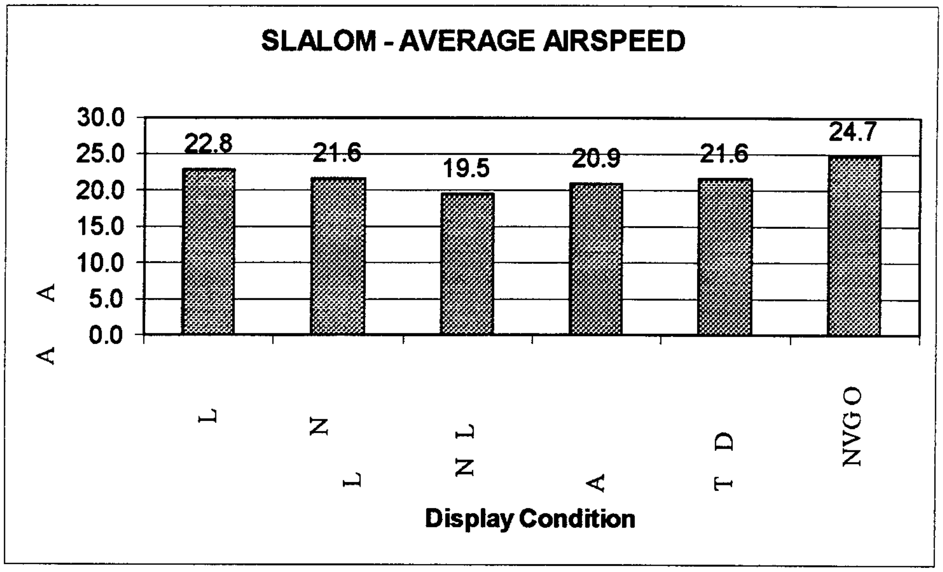


Figure 18. Average airspeed in the slalom task.

VARIABILITY OF AIRSPEED

Figure 19 shows the variability of airspeed in the slalom. The standard deviation of airspeed was smallest in the linear display condition (4.6 kts [8.5 kph, 5.3 mph]) and was greatest in the no longitudinal motion condition (6.6 kts [12.2 kph, 7.6 mph]). In the other display conditions the standard deviation of airspeed was between 5.2 kts (9.6 kph, 6.0 mph) and 5.7 kts (10.6 kph, 6.6 mph).

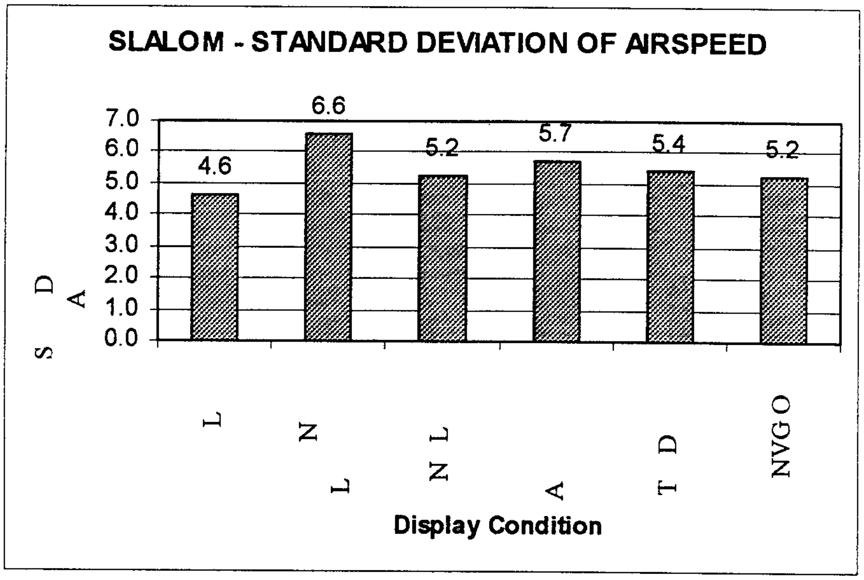


Figure 19. Standard deviation of airspeed in the slalom task.

AVERAGE ALTITUDE

In the slalom task the pilot attempted to maintain an altitude of 50 ft AGL (15.2 meters). Figure 20 shows the average altitude in each of the display conditions. In all cases, the average altitude was higher than 50 ft. The average altitude was closest to the target in the no longitudinal motion, acceleration, and time decay conditions, where it ranged from 54.5 ft (16.6 meters) to 56.2 ft (17.1 meters). The highest average altitude was in the linear display condition (63.6 ft [19.4 meters]). The average altitude was intermediate in the non-linear and NVG conditions (59.8 and 58.5 ft [18.2 and 17.8 meters], respectively.

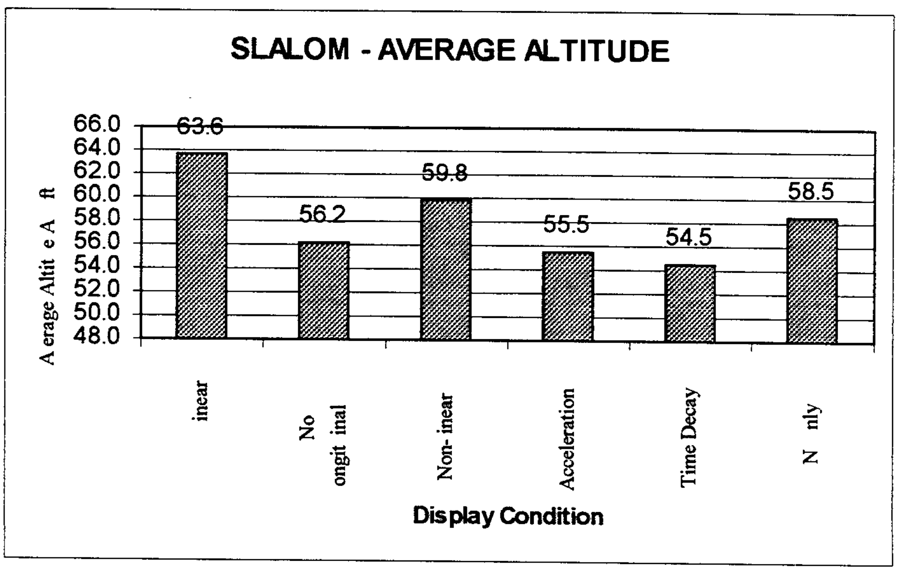


Figure 20. Average altitude in the slalom task.

ALTITUDE VARIABILITY

Figure 21 shows the variability of aircraft altitude during the slalom task. The smallest standard deviation is in the acceleration condition (10.6 ft [3.2 meters]). Intermediate performance is seen in the no longitudinal motion and time decay conditions, where the standard deviations were both 13.0 ft (4.0 meters). Performance in the other conditions was more variable, with standard deviations ranging from 14.4 ft (4.4 meters) to 15.6 ft (4.8 meters).

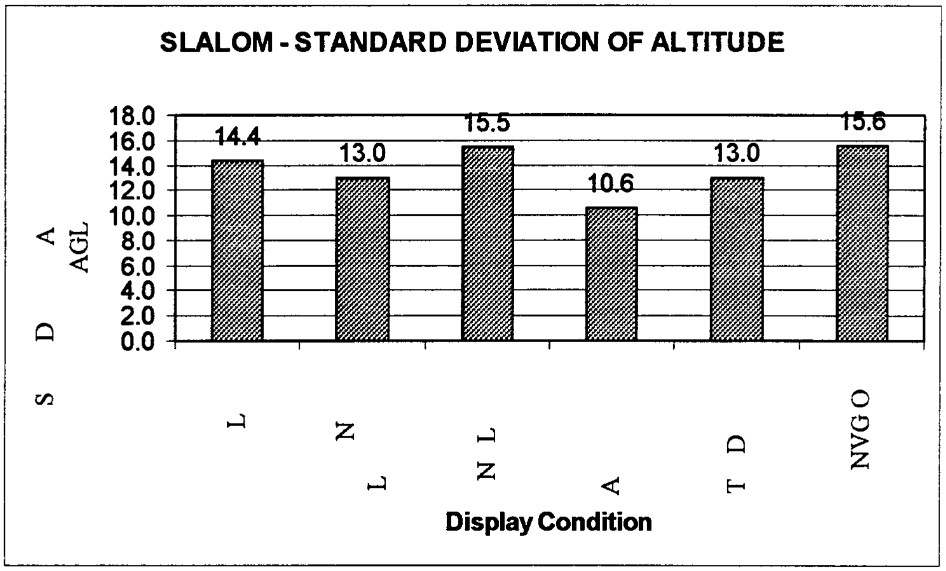


Figure 21. Standard deviation of altitude during the slalom task.

POST FLIGHT RATINGS AND COMMENTS

Following each flight using one of the ambient displays the pilots were asked to complete an evaluation form. This form had the pilots rate the display on each of 27 questions and to answer a series of open ended questions.

POST FLIGHT RATINGS

Each rating was made on a 7-point scale. The average ratings of the pilots are given below. The verbal anchors for each of the questions are shown parenthetically.

<u>Question 1. Did the ambient display help you maintain awareness of the aircraft's fore and aft speed?</u> (1 = It interfered with my awareness of speed; 7 = It was invaluable in helping me maintain awareness of speed.)

The ratings of the pilot's ability to maintain awareness of the aircraft's longitudinal motion are shown in figure 22. All of the displays, except the no longitudinal motion condition, were judged to provide some benfit. The no longitudinal motion condition did not provide information about the direction or velocity of the aircraft's motion. It would not, therefore, be expected to be an improvement over the NVG control condition. There was a possibility that the stationary ambient objects would tend to cause the pilots to feel that they were stationary when they were actually moving. These ratings suggest that this effect is small enough not to be a bother to the pilots.

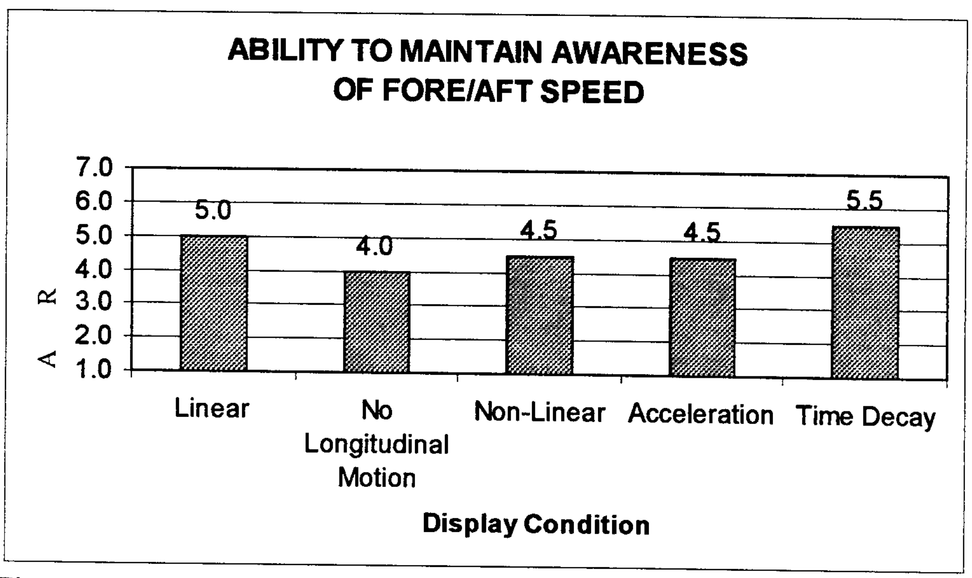


Figure 22. Average rating of pilot's ability to maintain awareness of the aircraft's fore/aft speed.

The display drive law rated best on this question was the time decay. This control law behaved in the same manner as the linear drive law when airspeed was constantly changing. It had the added benefit of becoming stationary when the aircraft's speed was constant, which made it relatively easy to detect any change in speed.

Question 2. Were the changes in longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed between 0 and 5 kts? (1 = Change too small to ever be noticed; 7 = Changes were easily detected.)

Figure 23 shows the average ratings of the ability of the pilot to detect changes in airspeed around hover with each of the ambient displays. Three of the ambient display drive laws were judged as improving the pilot's ability to detect changes in airspeed at hover speeds. All of these drive laws moved the ambient objects in the opposite direction of aircraft motion. The acceleration drive law was judged to be relatively ineffective. The no longitudinal motion drive law was rated as interfering with the pilot's ability to detect changes in airspeed in this regime. This is most likely because the stationary ambient objects actually provide a visual stimulus that is consistent with the aircraft being stationary.

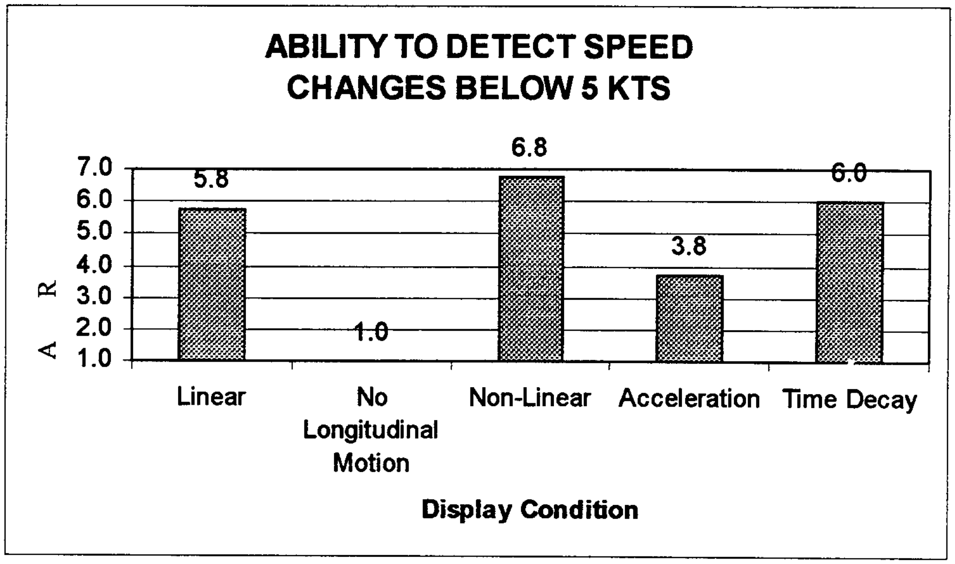


Figure 23. Average ratings of the pilots ability to detect changes in the aircraft's airspeed in the flight regime between 0 and 5 kts.

Question 3. Were the changes in longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed between 5 and 10 kts? (1 = Change too small to ever be noticed; 7 = Changes were easily detected.)

The average ratings of the pilot's ability to detect airspeed changes in the regime between 5 and 10 kts are shown in figure 24. The contribution of the ambient displays was rated as either providing a modest improvement or having little effect for all display conditions except the no longitudinal motion drive law. The no longitudinal motion condition was rated as hindering the pilot's ability to detect airspeed changes. As in the low speed regime, this is probably due to the display providing cues that the aircraft is not translating forwards or rearwards regardless of the actual motion.

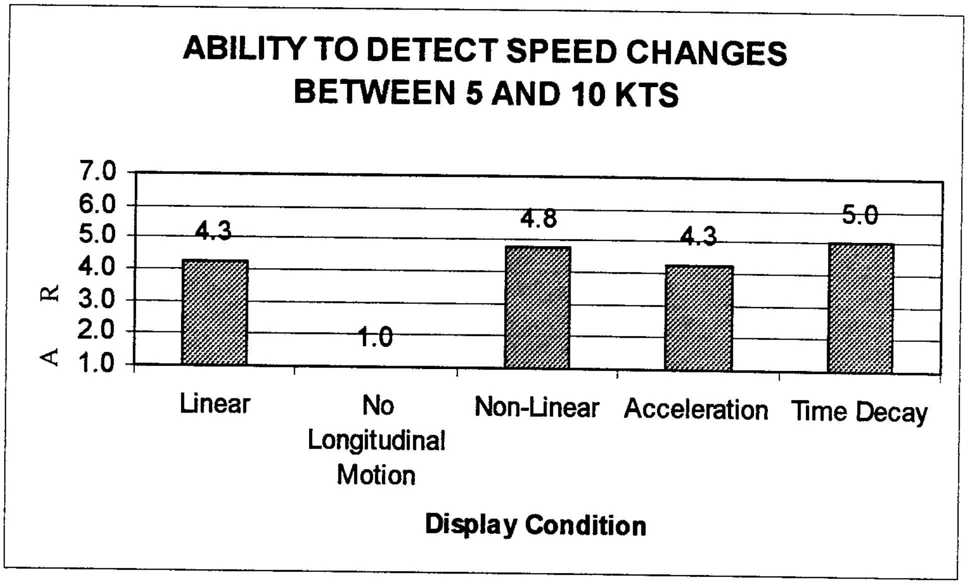


Figure 24. Average ratings of the pilot's ability to detect airspeed changes in the regime between 5 and 10 kts.

Question 4. Were the changes in longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed over 10 kts? (1 = Change too small to ever be noticed; 7 = Changes were easily detected.)

At airspeeds above 10 kts, only the time decay drive law was rated as providing a beneficial effect. The no longitudinal motion display drive law was again rated as hindering pilot's perceptions of airspeed changes. The other three drive laws were rated as having little or no effect. The average ratings are shown in Figure 25.

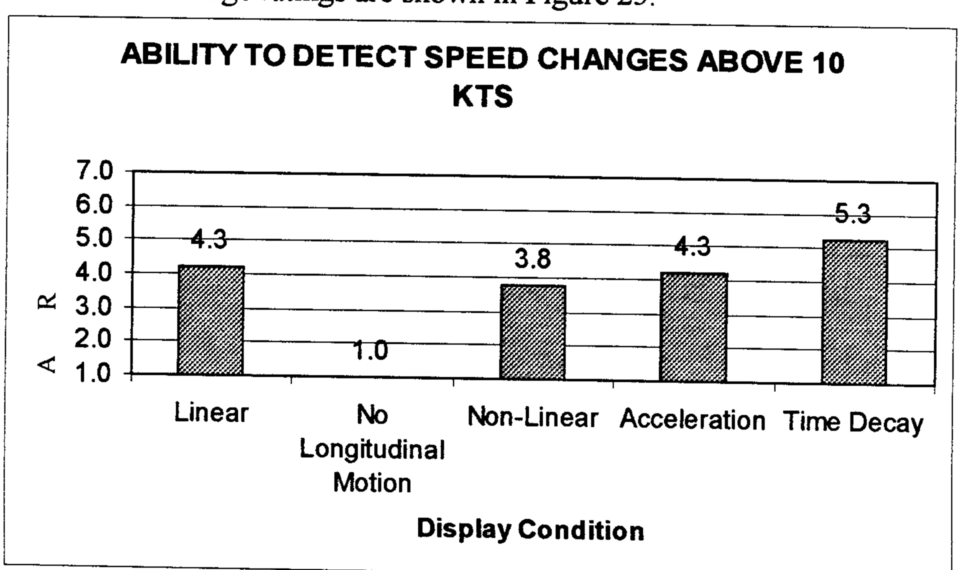


Figure 25. Average ratings of the pilot's ability to detect changes in airspeed in the regime above 10 kts.

Question 5. Did the ambient display effect your ability to detect changes in the direction of the aircraft's fore and aft motion (i.e., to tell you when you began to drift backwards or forwards)? (1 = It interfered with my ability to detect direction changes; 7 = It was invaluable in helping me detect direction changes.)

Figure 26 shows the average ratings of the pilot's ability to detect changes in the direction of the aircraft's drift. The non-linear drive law was rated as making it very easy to detect changes in the direction of movement. This is not surprising since the drive law caused the display to change directions quite abruptly when the direction of the aircraft changed. The magnitude of the cue, while being impossible to miss, was considered objectionable by the pilots.

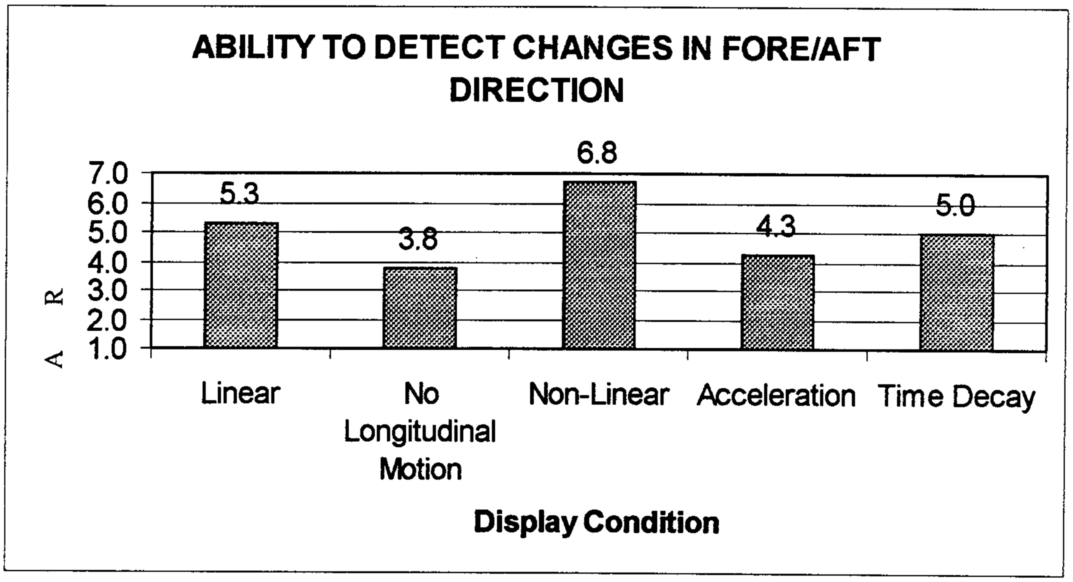


Figure 26. Average ratings of the pilot's ability to detect changes in the direction of the aircraft's drift

The linear and time decay drive laws were rated as being beneficial. When the aircraft's speed was not constant over several seconds, these drivel laws caused the ambient displays to behave in a way that is virtually identical.

It is somewhat surprising that the acceleration based drive law was judged to have little effect. With this drive law the direction of the aircraft is not shown in the ambient display; the ambient objects move forwards (aft) on the display when the aircraft is decelerating (accelerating) regardless of the direction that the aircraft is moving. It was expected that pilots would find the independence of the aircraft's direction and the motion of the ambient objects to be disrtacting.

Question 6. Did the ambient display help you maintain awareness of the aircraft's vertical speed? (1 = It interfered with my awareness of vertical speed; 7 = It was invaluable in helping me maintain awareness of vertical speed.)

The average ratings of the contribution of the ambient displays to pilot's awareness of vertical speed are shown in figure 27. As the drive law for this axis was identical in all cases, differences reflect the pilot's ability to extract information about motion in this direction from the display. It was expected that displays in which longitudinal motion was eliminated or reduced would make it easier for pilots to detect motion in the other axes. These data suggest that this hypothesis is correct. Pilot's rated the display with no longitudinal motion as being best, followed by the time decay drive law. Both these have no longitudinal motion of the ambient objects at constant airspeeds, and the no longitudinal motion condition eliminates motion in this dimension form the display regardless of aircraft motion.

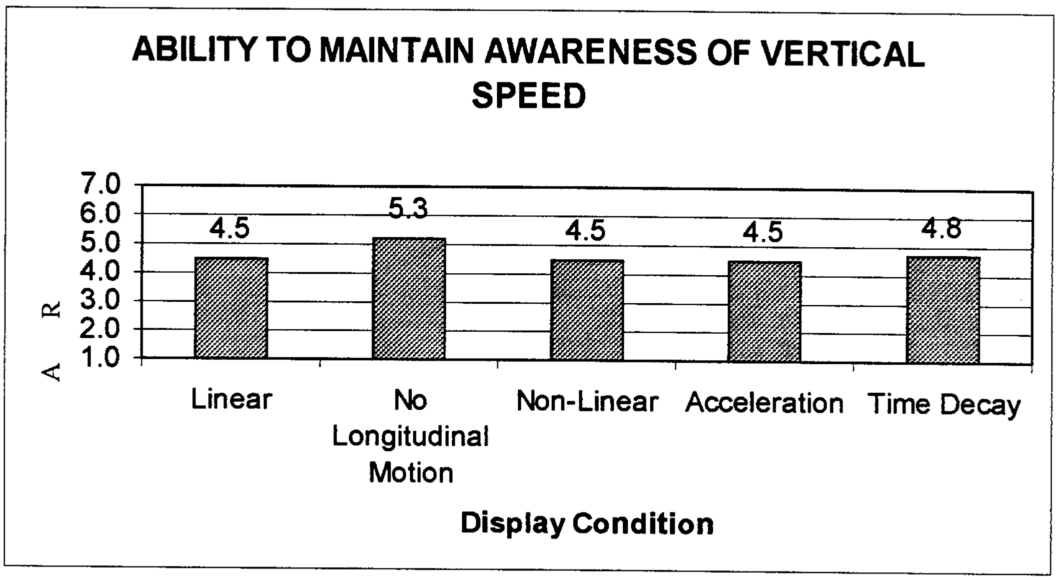


Figure 27. Average ratings of the contribution of the ambient displays to pilot's awareness of vertical speed

The other display conditions were judged as providing some assistance to the pilot in terms of vertical speed. This suggests that even in the presence of longitudinal flow pilots are able to extract information about the aircraft's vertical speed from the pattern of ambient object motion.

<u>Question 7. Did the ambient display effect your ability to detect CHANGES in the aircraft's vertical speed?</u> (1 = It interfered with my ability to detect changes in vertical speed; 7 = It was invaluable in helping me detect changes in vertical speed.)

Figure 28 shows the average ratings of the pilots ability to detect changes in the aircraft's vertical speed from the ambient displays. All drive laws were judged as providing a small improvement. The differences between conditions are smaller than in the case of maintaining an awareness of vertical speed.

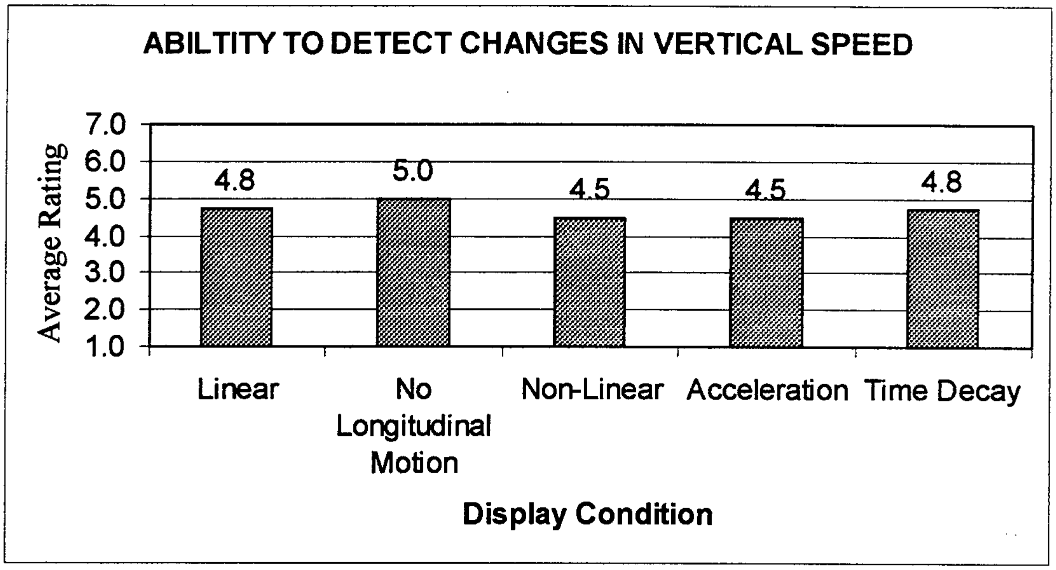


Figure 28. Average ratings of the pilot's ability to detect changes in vertical speed with each of the display drive laws.

Question 8. Did the ambient display help you maintain awareness of the aircraft's pitch angle? (1 = It interfered with my awareness of aircraft pitch; 7 = It was invaluable in helping me maintain awareness of aircraft pitch.)

The average ratings of the pilot's ability to maintain awareness of the aircraft's pitch angle are shown in figure 29. These ratings suggest that the contribution of the ambient displays is, at best, modest. This was somewhat unexpected since the regular pattern of the ambient objects and the sharp vertical and horizontal edges of the squares provide, in principle, good cues to the aircraft's pitch attitude. One possibility is that the because the ambient displays provide vertical velocity information, pilots were unable to extract and use the information about aircraft pitch. Another possibility is that the position of the displays themselves were rather far forward and, therefore, the information in the ambient displays was not more helpful that was he image of the horizon as shown in the NVG scene.

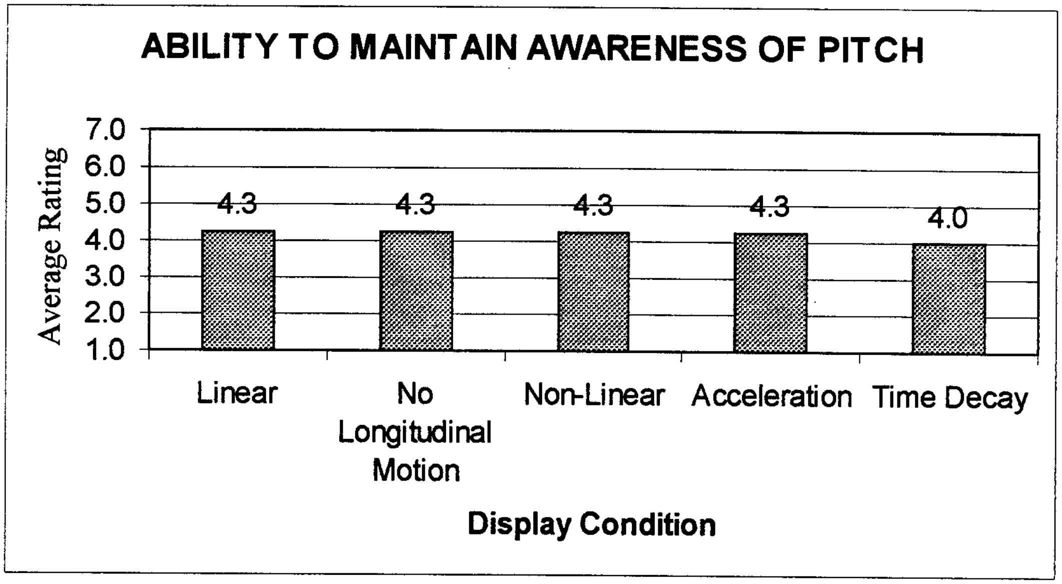


Figure 29. Average ratings of the pilot's ability to maintain awareness of the aircraft's pitch angle.

Question 9. Did the ambient display effect your ability to detect CHANGES in the aircraft's pitch angle? (1 = It interfered with my ability to detect pitch changes; 7 = It was invaluable in helping me detect pitch changes.)

Figure 30 shows the average ratings of the pilot's ability to detect changes in aircraft pitch. The ratings indicate that the ambient displays had little or no effect.

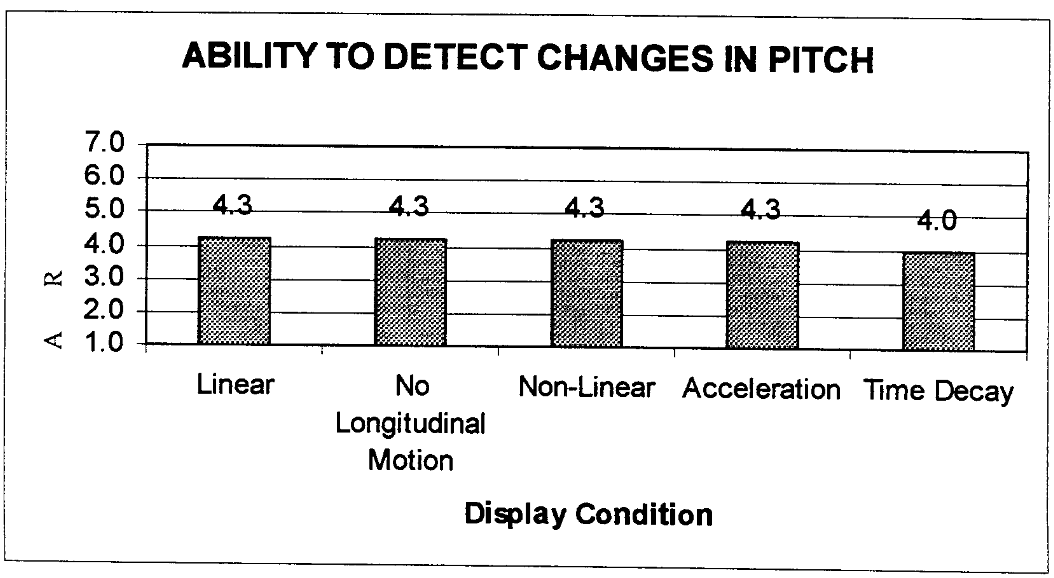


Figure 30. Average ratings of the pilot's ability to detect changes in aircraft pitch.

It was expected that the absence of longitudinal flow in the ambient displays would make it easier for the pilots to detect roll. These ratings indicate that the longitudinal flow did not interfere with the detection of roll. It may be that the pattern of the ambient objets coupled with the straight edges of the objects is sufficient to allow the pilots to detect movement of one ambient field upwards while the other moves downwards regardless of the flow of the objects in other directions.

Question 10. Did the ambient display help you maintain awareness of the aircraft's roll angle? (1 = It interfered with my awareness of aircraft roll; 7 = It was invaluable in helping me maintain awareness of aircraft roll.)

The average ratings of the ambient display's ability to help a pilot maintain awareness of the aircraft's roll angle are shown in figure 31. There is a suggestion that the ambient displays provided a marginal benefit to the pilot. The reason that the time decay condition is rated slightly lower than the other conditions is not readily apparent.

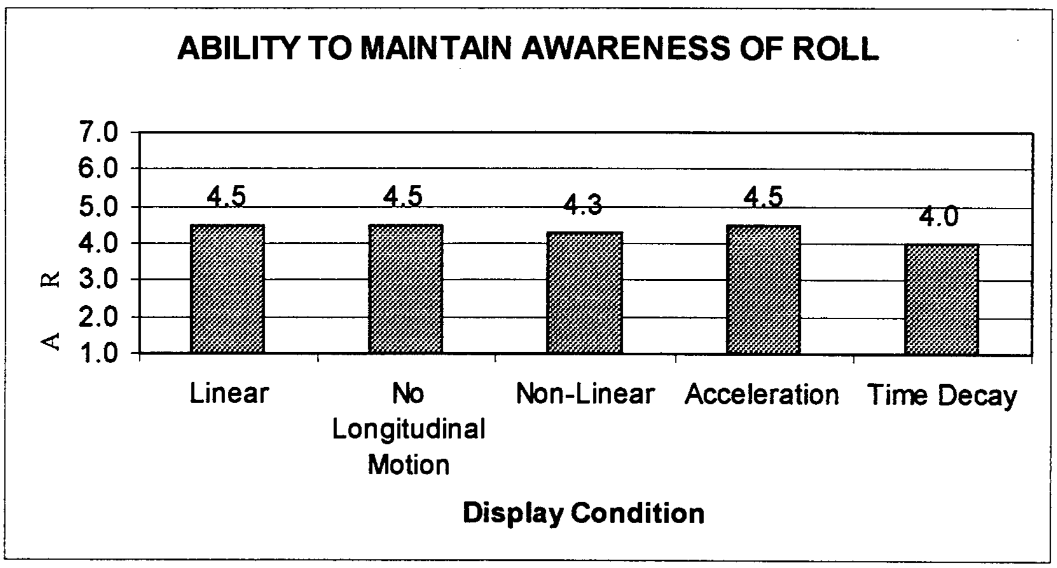


Figure 31. Average rating of the pilot's ability to maintain awareness of the aircraft's roll angle.

Question 11. Did the ambient display effect your ability to detect CHANGES in the aircraft's roll angle? (1 = It interfered with my ability to detect roll changes; 7 = It was invaluable in helping me detect roll changes.)

Figure 32 shows the average ratings of the pilot's ability to detect roll angle changes. All of the displays, except the those using the time decay drive law, were judged to slightly improve the pilot in detecting changes in the aircraft's roll angle. It is unclear why the time decay condition was not rated as assisting the pilot since the movement of the ambient objects would be similar to that of the linear, non-linear, and acceleration conditions when the aircraft's speed was changing, and similar to the non longitudinal motion and acceleration conditions at constant airspeeds. The display with no longitudinal motion was rated best, although the differences between the conditions was small. It was expected that pilots would more easily detect changes in roll angle from the ambient display when the objects were not flowing across the display.

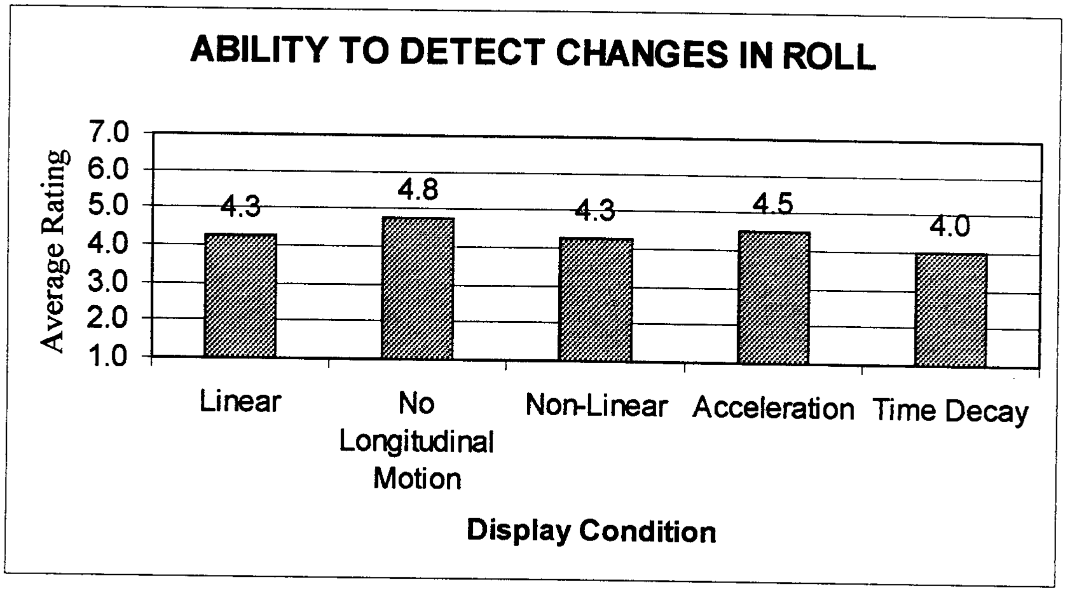


Figure 32. Average rating of the pilot's ability to detect changes in the aircraft's roll angle.

<u>Question 12. Did the ambient display help you maintain awareness of the aircraft's heading?</u> (1 = It interfered with my awareness of heading; 7 = It was invaluable in helping me maintain awareness of heading.)

The average ratings of the pilot's ability to maintain awareness of the aircraft's heading in each of the ambient display conditions are shown in figure 33. It had been expected that displays without longitudinal flow of the ambient objects (i.e., the non longitudinal flow condition and the acceleration and time decay conditions during flight segments at a constant velocity) would make it easier for the pilots. The results indicate that the pilots were best able to maintain awareness of heading in the linear and time decay drive law conditions, suggesting that the flow in the displays did not have a large, adverse effect the pilots ability to detect heading changes. As in the case of detection of other rotational motions, it may be that the shape and pattern of the ambient objects was sufficient to allow the information to be used by the ambient visual system.

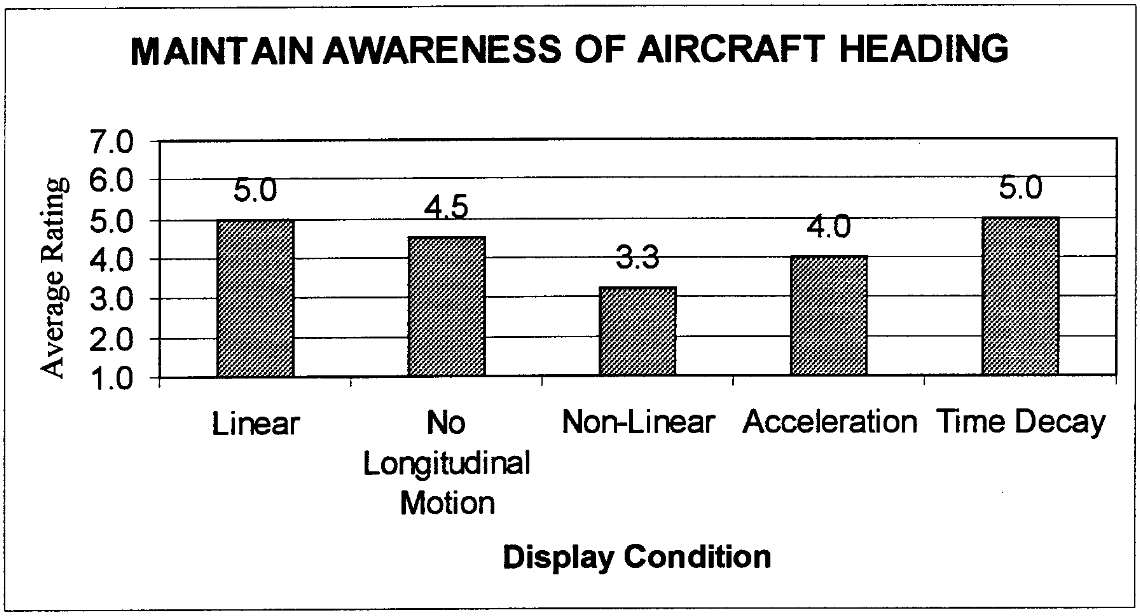


Figure 33. Average ratings of the pilot's ability to maintain awareness of the aircraft's heading.

Figure 33 shows that the non-linear condition was rated as interfering with heading awareness. This is possibly due to the rather abrupt changes in the direction of the ambient objects as the direction of the aircraft's drift changed form forward to rearwards or vice versa. These changes in direction may have masked the changes in heading during hovering tasks, such as the bob up.

<u>Question 13. Did the ambient display effect your ability to detect CHANGES in the aircraft's heading?</u> (1 = It interfered with my ability to detect heading changes; 7 = It was invaluable in helping me detect heading changes.)

The average ratings of the pilot's ability to detect changes in aircraft heading are shown in figure 34. The non-linear and acceleration drive law conditions were rated as having no effect. The other three ambient display conditions were judged to have small, beneficial effects. These ratings are consistent with the ratings for heading awareness, except in the case of the non-linear drive law. It may be that pilots detected that their heading changed in spite of changes in the overall ambient flow, but had difficulty determining the direction of that change from the ambient displays.

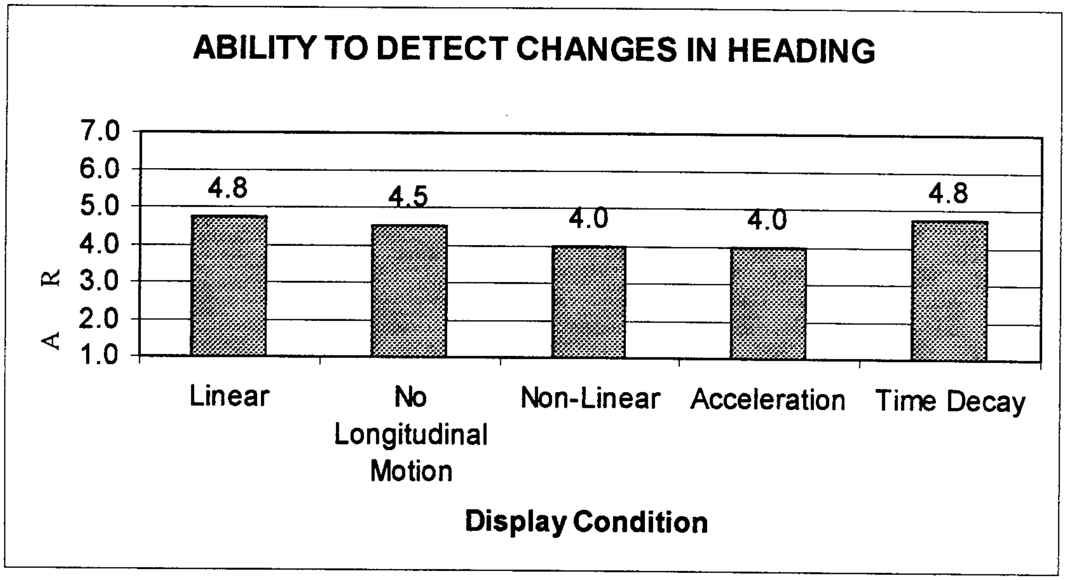


Figure 34. Average ratings of the pilot's ability to detect changes in aircraft heading.

Question 14. How visually cluttered was the ambient display? (1 = So cluttered it was distracting, 4 = Acceptable level of clutter; 7 = No noticeable clutter.)

Figure 35 shows that all of the ambient displays were rated as being more cluttered than acceptable. The displays rated as being least visually cluttered used the non-longitudinal motion and the time decay drive laws. These displays did not use continually moving ambient objects to represent constant airspeed. The acceleration drive law also eliminated the flow of the ambient objects at a constant airspeed. The low rating of this display condition may be due to the motion of the ambient field being considered inconsistent with motion of the aircraft, particularly in the hover regime. For example, when decelerating the ambient objects flowed rearwards on the display regardless whether the aircraft is moving forwards or aft.

The displays containing continual longitudinal flow or changes in the direction of the flow of the ambient objects considered to be abrupt were rated as being the most cluttered. This indicates that showing steady state motion reduces the acceptability of the displays

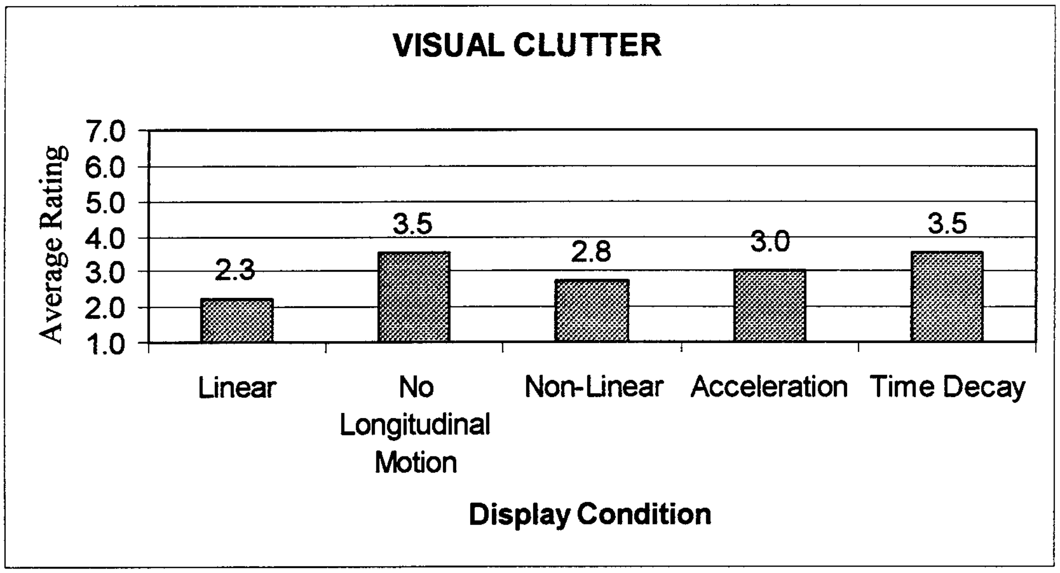


Figure 35. Average ratings of ambient display clutter.

Question 15. Did the ambient displays increase or decrease you workload, compared to what you expect when flying a NVG only scene, when performing the bob up-turn towards target task? (1 = Ambient displays caused a large increase in workload; 4 = About the same; 7 = Ambient displays caused a large reduction in workload.)

Throughout the bob up task the pilot attempts to keep the aircraft over a point on the ground. In an ideal performance the airspeed remains zero. (Since there were no winds in this simulation air- and ground speed are equivalent.) Therefore, the pilot attempts to detect and correct for any drift that occurs. The average workload ratings for this task are shown in figure 36.

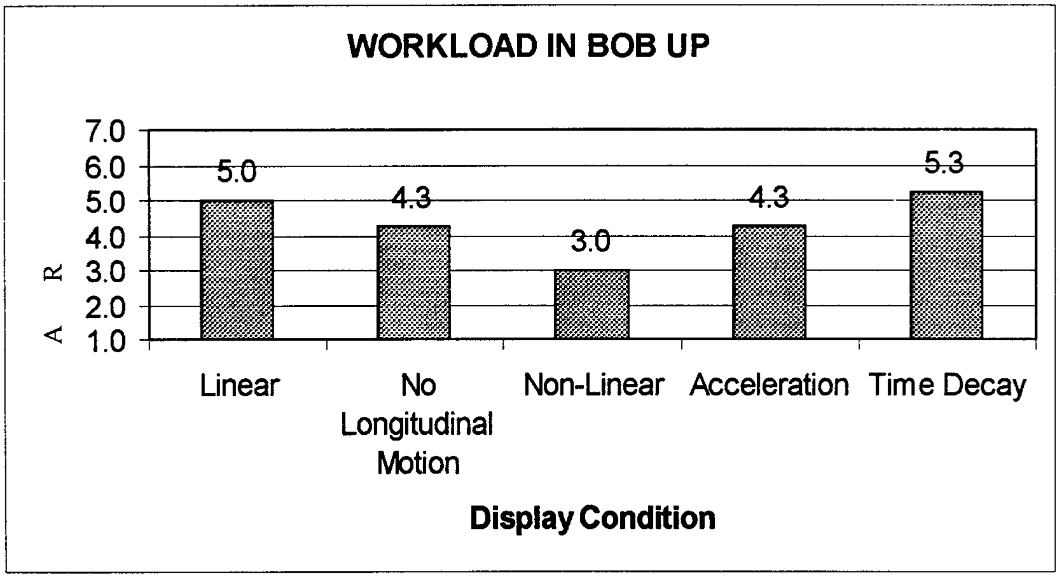


Figure 36. Average rating of pilot workload during the bob up maneuver.

The workload was rated highest in the non-linear motion condition. This is almost certainly due to the fact that drift rates the pilot would normally ignore due to the low rate caused the ambient displays to flow across the screen at a rate that was easily detected Consequently, the pilots had to work particularly hard in an attempt to keep the motion nulled out.

The workload was rated lowest in the linear and time decay motion conditions. In these conditions the longitudinal rate of flow was always quite low (airspeeds seldom exceeded 1 kt). Pilots found it easy to detect and correct drift rates that materially altered the position of the aircraft. They also found it easy to ignore drift rates they considered inconsequential and, therefore, didn't expend effort trying to null out drifts that they considered immaterial.

The no longitudinal and acceleration drive laws were rated as causing a small reduction in workload compared to the NVG only condition.

Question 16. Did the ambient displays increase or decrease you workload, compared to what you expect when flying a NVG only scene, when performing the acceleration/deceleration task? (1 = Ambient displays caused a large increase in workload; 4 = About the same; 7 = Ambient displays caused a large reduction in workload.)

Figure 37 shows the average ratings of pilot workload in the acceleration/deceleration task. The pilots rated the workload as lowest in the linear and time decay motion conditions. Because the aircraft was always accelerating or decelerating during this task, and never maintained a constant speed for long, the motion of the ambient displays in these conditions is similar. The no longitudinal motion and the acceleration conditions were rated as having a higher workload than in the linear and time decay conditions, but still as being less than in the NVG condition. This suggests that pilots were aided by having information about the aircraft's velocity more than by acceleration information. It also suggests that acceleration information was not used, nor was it a distraction. Pilots rated the workload as being greatest in the non-linear condition. This is due to the abrupt changes in direction of the ambient objects when the aircraft changes directions. This was a distraction as the aircraft maintained position prior to the start of the maneuver and when the aircraft decelerated to a stop following the deceleration portion of the maneuver.

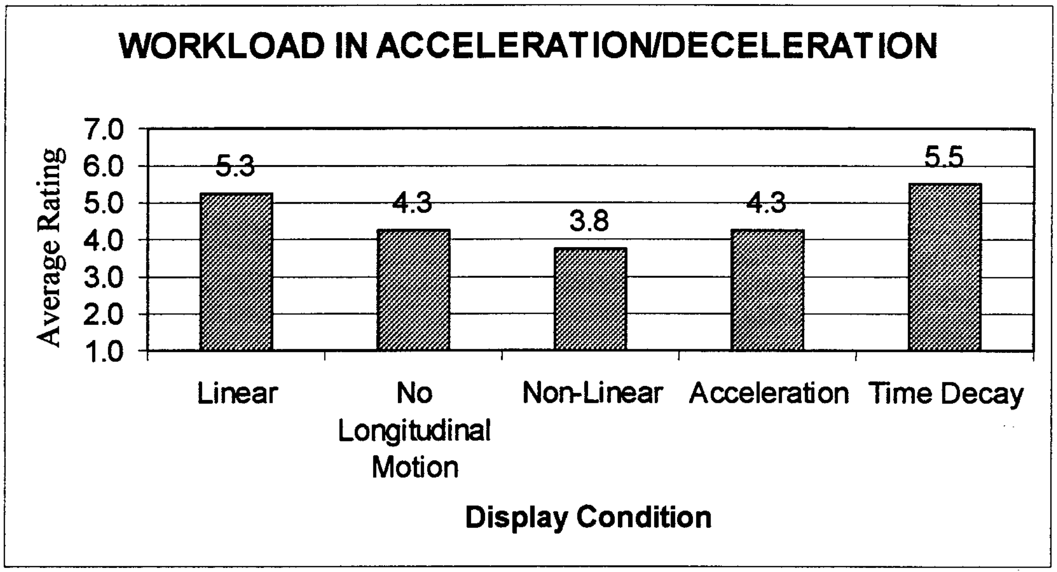


Figure 37. Average ratings of pilot workload in the acceleration/deceleration task.

Question 17. When flying the constant speed and rate of descent approach to landing task did the ambient displays increase or decrease your workload, compared to what you expect when flying a NVG only scene? (1 = Ambient displays caused a large increase in workload; 4 = About the same; 7 = Ambient displays caused a large reduction in workload.)

Figure 38 shows the average rating of workload in the constant speed, constant rate of descent approach task. The airspeed was held constant throughout the majority of this task

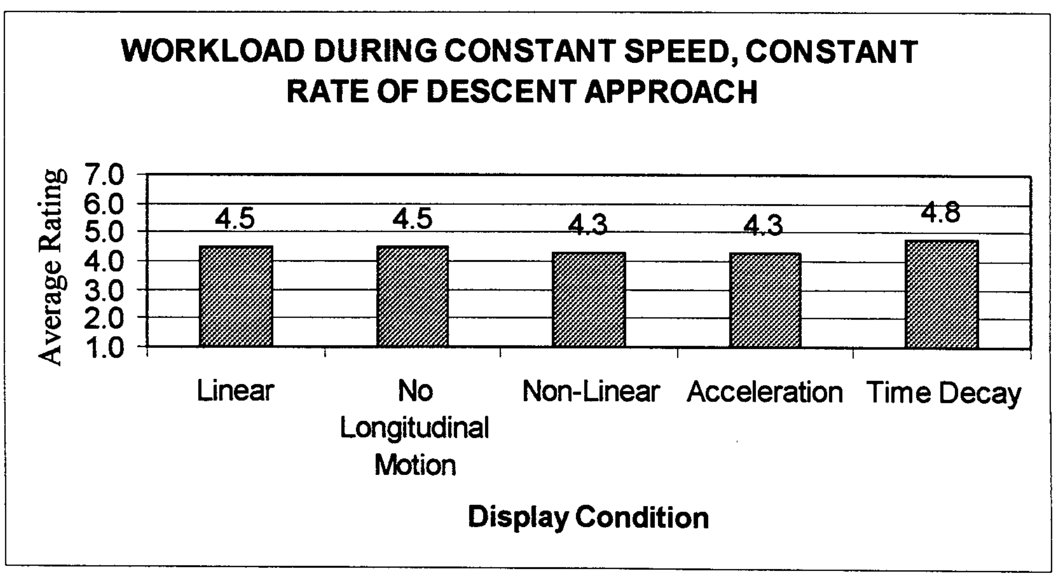


Figure 38. Average ratings of workload in the constant speed, constant rate of descent approach task.

The workload was reduced somewhat in each of the ambient display conditions relative to the NVG condition. The largest reduction was in the time decay condition. In this condition, the longitudinal motion of the ambient displays ceased during the descent so long as the speed was constant. If the aircraft changed speed, the direction of the longitudinal flow of the ambient objects indicated the direction of the speed change and the rate of the flow indicated the magnitude of the speed change. This made it easy for the pilots to detect speed changes and, because the ambient objects were normally not moving longitudinally, easy for them to monitor rate of descent.

The linear and no longitudinal motion conditions were rated equally in terms of reducing the pilot's workload. In the linear condition, the longitudinal flow of the ambient objects provided information about airspeed. In contrast, airspeed had no effect on the ambient objects in the no longitudinal motion condition. These ratings suggest that the masking effect associated with presenting information about airspeed in the linear condition was roughly equivalent to the increased ease of monitoring vertical speed when longitudinal motion is surpressed.

<u>Question 18. When flying the pirouette task did the ambient displays increase or decrease your workload, compared to what you expect when flying a NVG only scene?</u> (1 = Ambient displays caused a large increase in workload; 4 = About the same; 7 = Ambient displays caused a large reduction in workload.)

Figure 39 shows the average ratings of pilot workload in the pirouette task. Only the linear and time decay conditions were rated as reducing the workload in this task. Like the bob up, the longitudinal airspeed in this task was near zero. Therefore, high rates of longitudinal flow of the ambient objects on the display were seldom possible.

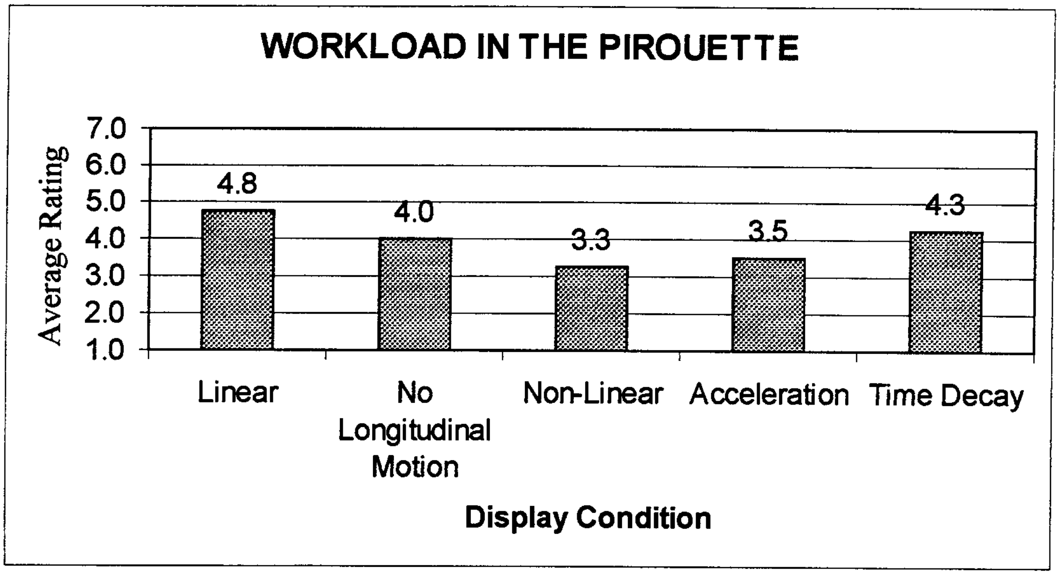


Figure 39. Average workload in the pirouette task.

The workload was rated lowest in the linear and time decay motion condition. In both these conditions, the ambient displays would represent forward and rearward drift faithfully. (It is unlikely that a drift could be maintained for a long enough time for the motion to go to be significantly reduced or to go to zero in the time decay condition.) Detection and correction of drift is critical to the successful performance of this task, and the cueing provided by the ambient displays is likely responsible for the reduced workload.

The non-linear and acceleration conditions were rated as causing an increase in workload. In the non-linear condition this is likely due to the inability of pilots to ignore very low drift rates and the abrupt change in the direction of the ambient objects as the aircraft changed its direction (fore/aft). In the case of the acceleration condition the increased workload is probably due to the inconsistency between the direction of aircraft motion and the direction the ambient objects move on the screen. This suggests that at low speeds, pilots prefer to have information about their direction than about the direction and rate of their acceleration.

Question 19. When flying the slalom task did the ambient displays increase or decrease your workload, compared to what you expect when flying a NVG only scene? (1 = Ambient displays caused a large increase in workload; 4 = About the same; 7 = Ambient displays caused a large reduction in workload.)

The average ratings of pilot workload in the slalom task are shown in figure 40. In all cases, except the acceleration condition, the ambient displays were judged to provide a small reduction in workload. No real difference between these conditions is evident.

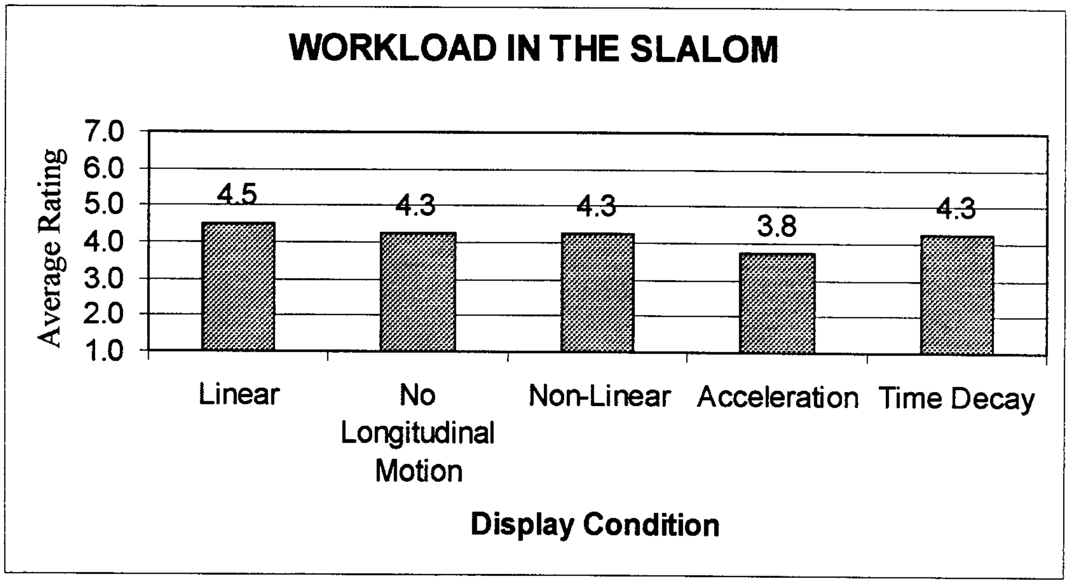


Figure 40. Average ratings of pilot workload in the slalom task.

The workload was rated as being greater in the acceleration condition than in the NVG condition, or in any of the other ambient display conditions. This is probably due to the direction of the ambient objects changing repeatedly as the aircraft speed up and slows down during this maneuver.

In all the other conditions, the motion of the ambient objects was generally in the same direction throughout the task. The pilot ratings of these four ambient display conditions indicates that the displays caused a small reduction in workload. No differences are obvious between the conditions.

<u>Question 20. Did the ambient displays improve or harm your ability to perform the bob up-turn towards target task, compared to what you expect when flying a NVG only scene?</u> (1 = Ambient displays hurt performance; 4 = About the same; 7 = Ambient displays improved performance.)

The average ratings of the effect of the ambient displays on the pilot's ability to perform the bob up are shown in figure 41. The linear and time decay were rated as improving the pilot's ability to perform this task. In this task the motion of the ambient objects on the display are very similar; the duration of drifts is not long enough for the time decay drive law to "wash out" motion and the velocity of any drift is typically very low. The short duration of drifts made it easy for the pilot to detect translational motion and the low velocity of drift allowed the pilot to identify altitude changes easily.

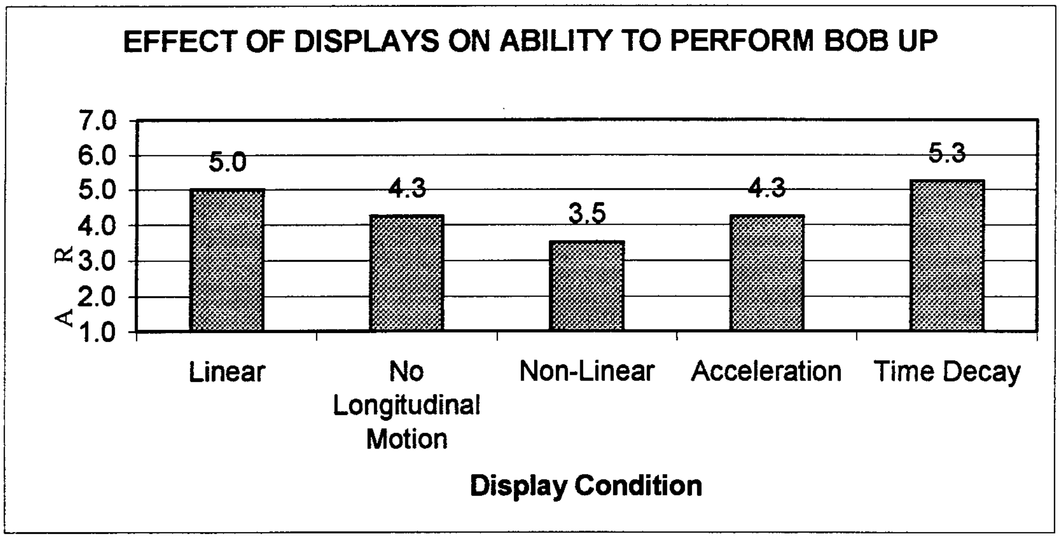


Figure 41. Average ratings of the effect of the ambient displays on the pilot's ability to perform the bob up.

The no longitudinal motion condition and acceleration drive law conditions were rated as providing a small improvement. In the no longitudinal motion condition we suspect that because the ambient objects did not respond to airspeed the pilot was aided by the ease in detecting altitude changes. However, this improved ease did not offset the advantage of having drift information presented in this task. In the acceleration drive law condition pilots were also able to easily detect altitude changes. However, at low airspeeds acceleration information is more difficult for the pilot to use than is velocity information.

The non-linear drive law condition was rated as harming the pilot's ability to perform the bob up. We suspect this is due to the rather abrupt change in the motion of the ambient objects as the aircraft reversed directions.

Question 21. Did the ambient displays improve or harm your ability to perform the acceleration/deceleration task, compared to what you expect when flying a NVG only scene? (1 = Ambient displays hurt performance; 4 = About the same; 7 = Ambient displays improved performance.)

Figure 42 shows the average ratings of the display conditions on the pilot's ability to perform the acceleration/deceleration task. All of the conditions were rated as aiding the pilot.

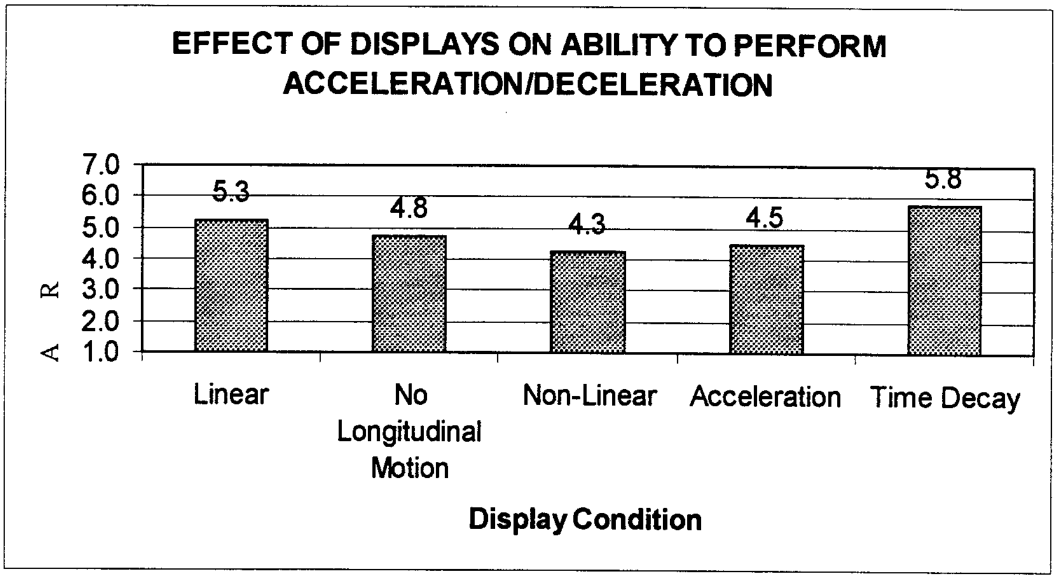


Figure 42. Average ratings of the pilot's ability to perform the acceleration/deceleration task

The time decay and linear drive law conditions were rated best. Because little time in this task is spent at a constant speed the motion of the ambient objects in the time decay condition would not get "washed out". Therefore, motion of the ambient displays in the two conditions would be nearly identical.

The next best rated was the no longitudinal motion condition. In this condition changes in the aircraft's altitude would be more easily detected by the pilot than in the other conditions.

Rated as only slightly less beneficial than the no longitudinal motion conditions were the non-linear and acceleration display conditions. The non-linear condition may have been rated lower than the other conditions due to the abrupt change in the direction of the ambient object's motion as the aircraft's direction changed. The rating in the acceleration condition seems to reflect the pilot's preference for velocity information over acceleration information.

<u>Question 22. Did the ambient displays improve or harm your ability to perform the constant speed and rate of descent approach to landing task, compared to what you expect when flying a NVG only scene?</u> (1 = Ambient displays hurt performance; 4 = About the same; 7 = Ambient displays improved performance.)

Figure 43 shows that all of the displays were rated as improving the pilot's ability to perform the constant speed, constant rate of descent approach. The small differences between the ratings of the conditions do not appear to be particularly meaningful in this task. This suggests that the presence of airspeed information and the manner in which it was presented in the ambient display did not have a large effect on the pilot's ability to perform this task. This is particularly interesting since it shows that for flight segments where airspeed is constant over an extended period , washing out the motion or showing acceleration rather than velocity are equivalent to the pilot.

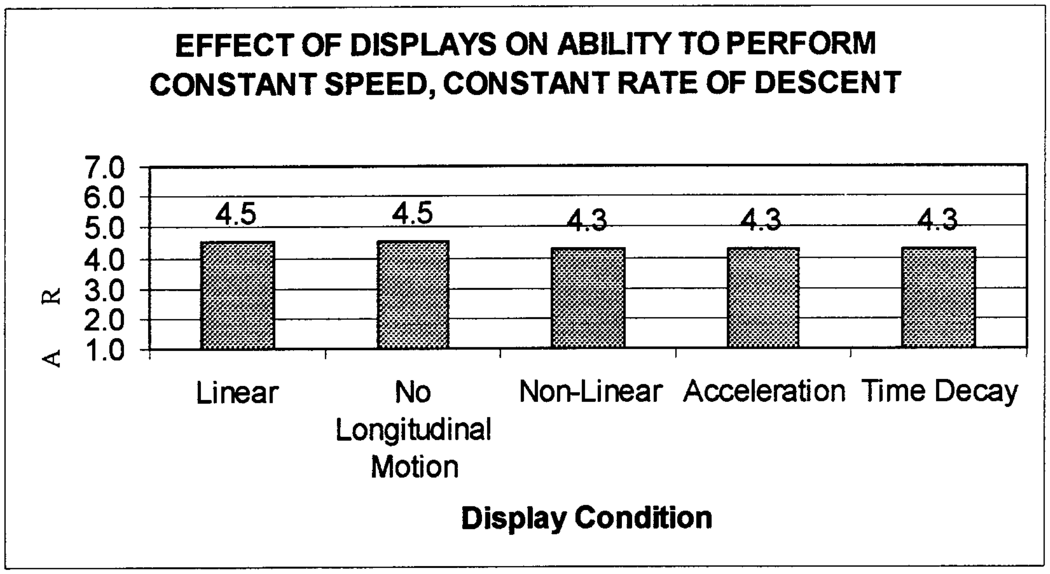


Figure 43. Average ratings of the effect of the ambient displays on the pilot's ability to perform the constant speed, constant rate of descent approach task.

Question 23. Did the ambient displays improve or harm your ability to perform the pirouette task, compared to what you expect when flying a NVG only scene? (1 = Ambient displays hurt performance; 4 = About the same; 7 = Ambient displays improved performance.)

The average ratings of the pilot's ability to perform the pirouette task in each of the ambient display conditions are shown in figure 44. The linear drive law condition was rated best. It is not clear why this condition was rated as being better than the time decay drive law (which was rated as second best) since the appearance of these two conditions would be similar in this task. Drift information coupled with the altitude information is likely the combination of information needed by pilots to successfully perform this maneuver.

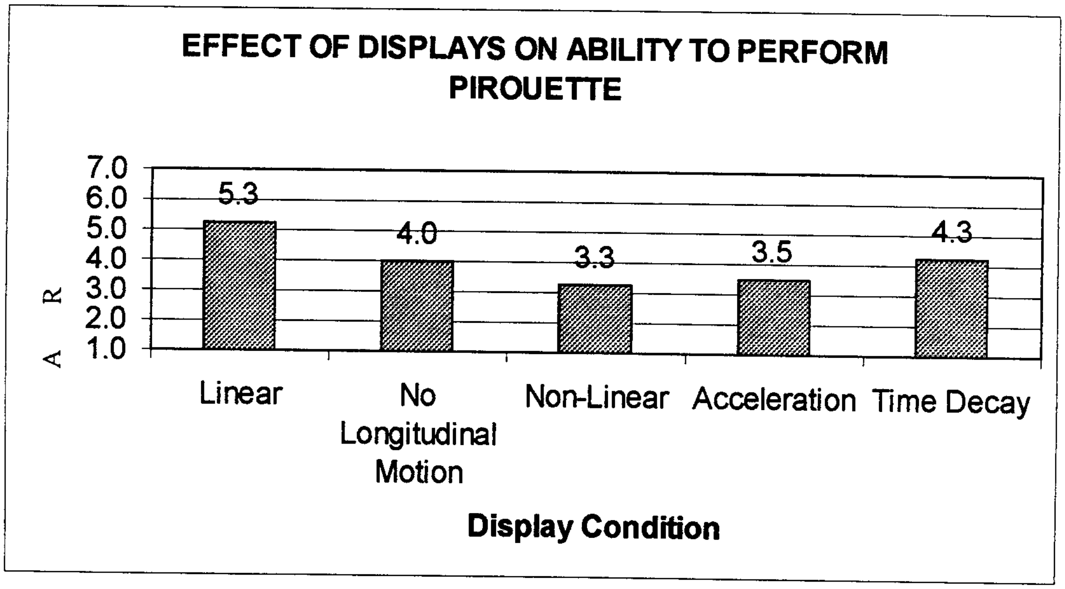


Figure 44. Average ratings of the effect of the ambient displays on the pilot's ability to perform the pirouette task.

The ratings of the non-linear and acceleration drive law conditions indicates that these had an adverse effect on a pilot's ability to perform this task. In the case of the non-linear control law this is probably a response to the abrupt reversals in the direction of the ambient objects as the aircraft's direction changed. In the pirouette changes in direction were quite common as the pilot attempted to maintain a constant distance from the center of the circle. The reason that the acceleration drive law was rated as having an adverse impact on the pilot's ability to perform this task is that the ambient displays did not show the direction of the aircraft's longitudinal translation. In this case the pilot's needed information as to whether they were moving towards or away from the center of the circle. The acceleration rate was not particularly valuable in terms of task performance, and in those cases where the direction of the ambient objects on the display was not consistent with the direction of that the aircraft was moving the displays were a hindrance.

Question 24. Did the ambient displays improve or harm your ability to perform the slalom task, compared to what you expect when flying a NVG only scene? (1 = Ambient displays hurt performance; 4 = About the same; 7 = Ambient displays improved performance.)

Figure 45 shows the average ratings of the pilots' ability to perform the slalom task with each of the ambient displays. With the exception of the acceleration drive law condition, all of the displays were rated as improving the pilot's ability to perform this task. The differences between these four display conditions do not appear to be meaningful.

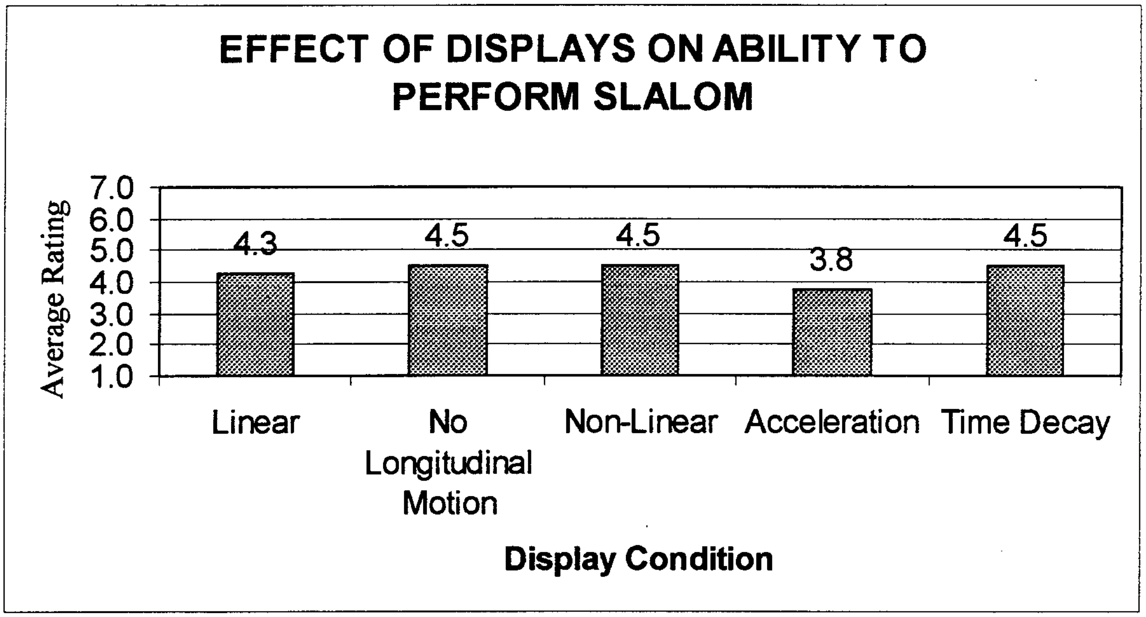


Figure 45. Average rating of the effect of the ambient displays on the pilot's ability to perform the slalom task.

The motion of the ambient objects on the display in the acceleration drive condition differed from the other conditions in that the ambient objects were often flowing rearwards (indicating that the aircraft was decelerating) even though the aircraft was flying forwards. This direction difference was easily perceived by the pilots, and appeared to interfere with performance of this task.

Question 25. Overall, how acceptable was this ambient symbol set? (1 = Not acceptable as is; major changes are needed before flying with this symbol set, 4 = Minimally acceptable. Some improvements needed before this symbol set can be flown; 7 = Acceptable as is; no changes are needed in order to fly with this symbol set.)

The average ratings of the overall acceptability of the ambient display conditions are shown in figure 46. Only the time decay drive law condition was rated as being above minimally acceptable. This rating indicates that in tasks where the velocity of the aircraft is constantly changing the display provides aircraft velocity information in a manner virtually identical to that of the linear drive law. This was useful in the bob up and pirouette tasks. In tasks where aircraft velocity was relatively constant for extended periods of time, such as the constant speed, constant rate of descent approach and slalom tasks, the longitudinal flow of the ambient objects was reduced making it easier for the pilot to detect changes in the other axes. Additionally, in these tasks the time decay condition made it relatively easy for the pilot to detect changes for the established airspeed.

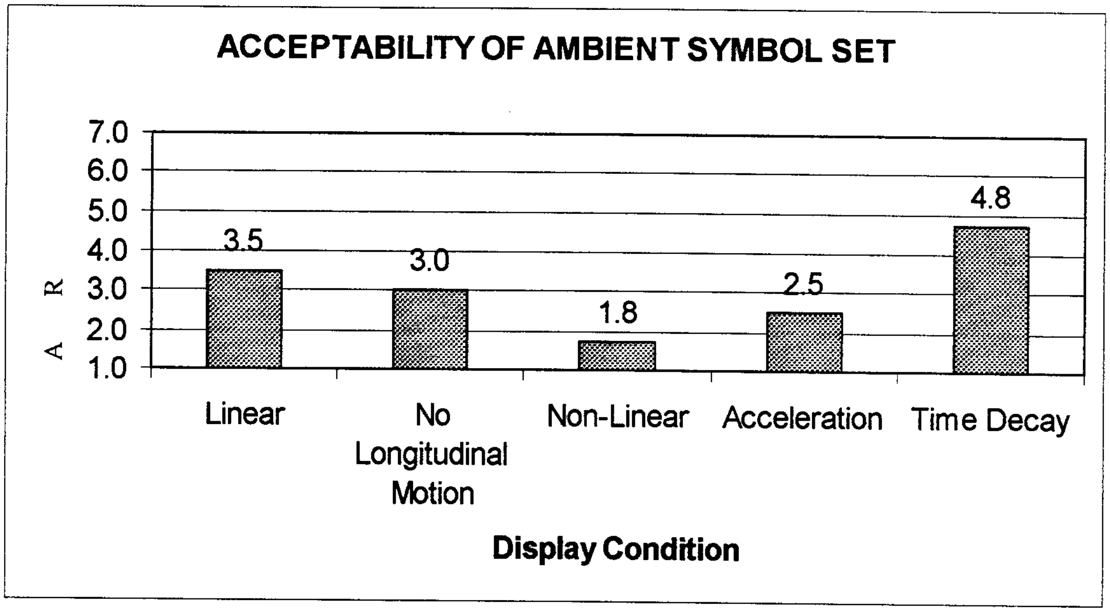


Figure 46. Average ratings of the acceptability of the ambient display conditions.

The next highest rated display used the linear drive law. This condition was rated lower than the time decay condition because the longitudinal flow of the ambient objects masked changes in other axes increasing the difficulty of identifying changes in heading, pitch, bank angle, or altitude. At higher, constant speeds it was more difficult to identify changes in airspeed in the linear drive condition than with the time decay condition.

The no longitudinal motion condition was rated as being the third best. In this case, the absence of longitudinal flow in the display made it easier for pilots to detect changes in the aircraft's heading, pitch, bank angle, or altitude. However, the absence of longitudinal flow eliminated the ability of the ambient displays to support an awareness of airspeed or changes in airspeed altogether.

The acceleration drive law was rated as next to last. This indicates that the pilots found velocity information more useful than acceleration information. In fact, the difference between the direction of aircraft travel and the direction of the ambient object's motion interfered made it more difficult to fly with the ambient displays than without them.

Finally, the display condition rated lowest was the non-linear drive law condition. While this display provided good information regarding the direction that the aircraft was traveling, it was judged to change direction so abruptly that it drew the pilot's attention away from flying the aircraft. Another difficulty with this display condition is that changes in the speed of the ambient objects moving across the display became smaller as the airspeed increased. At some point, the pilot's were unable to detect changes in the flow rate of the ambient objects that were caused by meaningful changes in airspeed. These problems indicate that the specific drive law implemented in this study did not lead to a display that supported the pilots.

Question 26. How consciously aware were you of the ambient displays? (1 = I was always aware of the ambient displays; 4 = I was aware of the ambient symbols about half the flight; 7 = I never noticed the ambient displays.)

The average ratings of the amount of time the pilots were consciously aware of the ambient displays is shown in figure 47. To the extent that the displays captured or required the conscious attention of the pilot they are not fully exploiting the ambient visual system and are, instead, competing with the focal visual system. The ratings indicate that the only display that the pilots report being aware of less than half the time was the no longitudinal motion condition. This seems to indicate that continuous or intermittent longitudinal flow of the ambient objects was causing pilots to be aware of the displays.

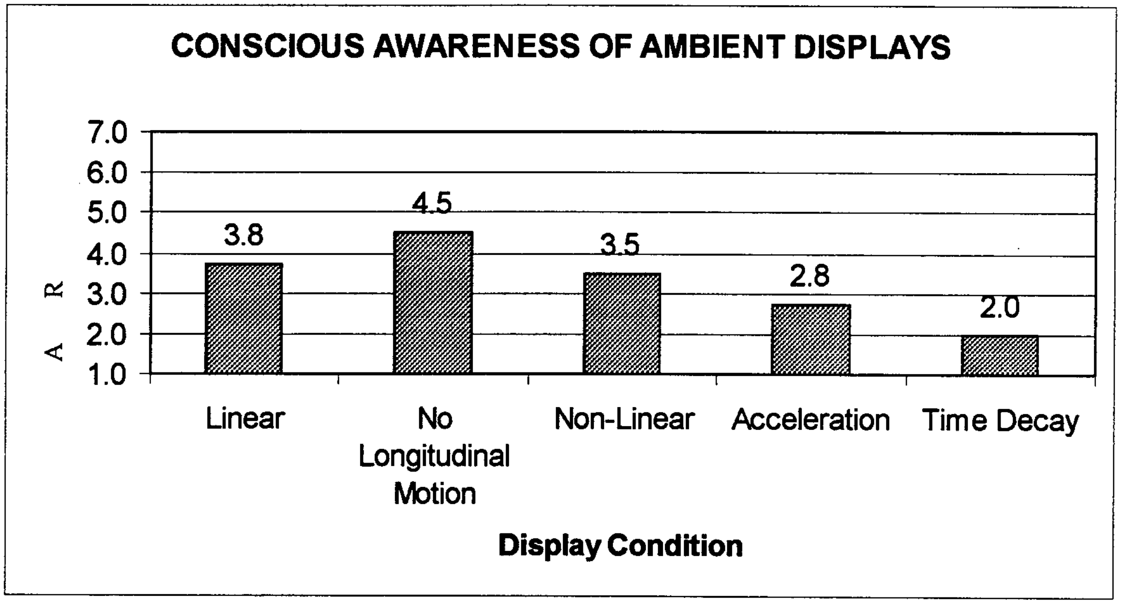


Figure 47. Average ratings of the amount of time the pilots were consciously aware of the ambient displays.

Question 27. How much attention did you pay to the ambient displays? (1 = I was always paying attention to the ambient displays; 4 = I paid attention to the ambient symbols about half the flight; 7 = I never paid attention to the ambient displays.)

The average ratings of the conscious attention the pilots paid to the ambient displays are shown in figure 48. These ratings show that pilots paid the least conscious attention to the displays in the no longitudinal motion condition. This indicates that the longitudinal flow of the ambient objects in the other conditions causes the pilots to attend to the displays.

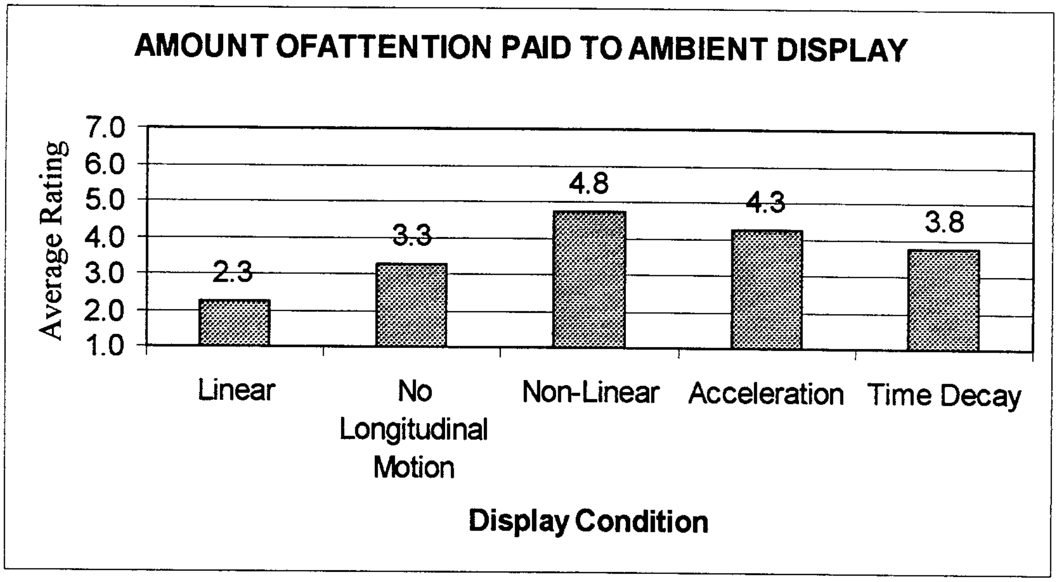


Figure 48. Average rating of the attention pilot's paid to the ambient displays.

POST FLIGHT PILOT COMMENTS

The display evaluation form, which is contained in Appendix A, contained a series of open ended questions. The pilot's answers to these questions are given below. The answers are grouped by display condition.

LINEAR DRIVE LAW

Question 1. Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?
Pilot A – Slightly distracting during pirouette and slalom.
Pilot B – Generally a help for slow rotations at the top of the bob up and in the deceleration to hover portion of the acceleration/deceleration. Movement longitudinally at 15 kts in the acceleration/deceleration was distracting.

Question 2. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Helpful during slow speed, uni-directional flight; bob up, acceleration/deceleration, and constant speed approach.
Pilot B – Heading change at the top of the bob up. Deceleration to hover in the acceleration/deceleration.

Question 3. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Slightly during pirouette and slalom.
Pilot B – *no response.*

Question 4. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.
Pilot A – *no response*
Pilot B – In one pure longitudinal translation task the squares were going by, aft, so quickly they were a distraction.

Question 5. Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – *no response*
Pilot B – Good for very low speed maneuvering fore and aft.

Question 6. Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – During the pirouette, and possibly during the slalom.
Pilot B – No.

Question 7. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?
Pilot A – Aircraft rates in the acceleration/deceleration. Descent rate in the constant speed approach.
Pilot B – Indicating very low translation or rotational rates.

Question 8. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Better, I believe, in the acceleration/deceleration. A little better in the bob up.
Pilot B – Deceleration to a hover in the acceleration/deceleration.

Question 9. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Pirouette, slightly. Possibly to a small degree during the slalom.
Pilot B – No.

Question 10. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?
Pilot A – Movement of the ambient displays. The closeness to the forward scene. (Ambient symbols) running into the forward scene. Too much cue as aircraft got too fast during slalom, but this could be used to indicate that you need to slow down.
Pilot B – None.

Question 11. What did you find most useful about this set of ambient symbols?
Pilot A – Slow speed, slow rate change maneuvers. Not multi-axis maneuvers.
Pilot B – Slow speed translation.

Question 12. What did you find least useful this set of ambient symbols?
Pilot A – Pirouette and slalom to some degree.
Pilot B – Very distracting at moderate forward airspeed.

NO LONGITUDINAL TRANSLATION

Question 1. Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?
Pilot A – No, not significantly.
Pilot B – No.

Question 2. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Not position, but altitude/vertical speed (constant speed approach, acceleration/deceleration, bob up, and slalom).
Pilot B – Perhaps yaw motion in the bob up.

Question 3. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Position reference/drift rate more difficult to pick up in the bob up and pirouette, particularly.
Pilot B – No.

Question 4. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.
Pilot A – Not significant.
Pilot B - :Lack of longitudinal ambient motion may have been misleading.

Question 5. Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Not applicable.
Pilot B – Not applicable.

Question 6. Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Not applicable.
Pilot B – Not applicable.

Question 7. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?
Pilot A – Vertical speed was most significant.
Pilot B – Small amounts of yaw rate.

Question 8. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Not position but altitude/vertical speed (constant speed approach, acceleration/deceleration, bob up, and slalom).
Pilot B – No.

Question 9. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Yes (pirouette and bob up). Drift longitudinally.
Pilot B – No.

Question 10. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?
Pilot A – No longitudinal drift cues.
Pilot B – None.

Question 11. What did you find most useful about this set of ambient symbols?
Pilot A – Vertical speed/altitude maintenance cueing.
Pilot B – Yaw rate indication.

Question 12. What did you find least useful this set of ambient symbols?
Pilot A – No longitudinal drift cues.
Pilot B – Lack of longitudinal motion seems at cross purposes with the rest of the display.

NON-LINEAR DRIVE LAW

Question 1. Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?
Pilot A – During maneuvers near zero speed the changes (in direction of the ambient display) were distracting. Too much movement. This made the bob up and pirouette more difficult.
Pilot B – Around hover the ambient display was far too sensitive.

Question 2. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Seemed to improve the acceleration/deceleration and slalom slightly.
Pilot B – Yes, it clearly indicated longitudinal translation but may have been misleading as to the absolute amount of translation.

Question 3. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Seemed to hinder the bob up and pirouette, especially the pirouette.
Pilot B – Yes, the "cross field of view" motion of the ambient symbology was at odds with the actual longitudinal motion.

Question 4. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.
Pilot A – Confusing during the pirouette. Too much sensitivity during the bob up.
Pilot B – Yes, the "cross field of view" motion of the ambient symbology was at odds with the actual longitudinal motion.

Question 5. Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Improved the acceleration/deceleration, and possibly the slalom.
Pilot B – No.

Question 6. Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Pirouette was much more difficult.
Pilot B – No.

Question 7. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?
Pilot A – Ground speed, yaw rate seemed to be helpful in the slalom.
Pilot B – Showed actual translation rate which might not have been detected without the ambient. (Rates) were very clear in the ambient.

Question 8. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Possibly in the acceleration/deceleration and slalom.
Pilot B – No.

Question 9. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Definitely in the pirouette, and somewhat in the bob up.
Pilot B – No.

Question 10. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?
Pilot A – Too much movement or information.
Pilot B – No.

Question 11. What did you find most useful about this set of ambient symbols?
Pilot A – Longitudinal speed cueing for the acceleration/deceleration, constant speed approach, and slalom.
Pilot B – As a detection of small longitudinal translations.

Question 12. What did you find least useful this set of ambient symbols?
Pilot A – Too much sensitivity.
Pilot B – The longitudinal motion of the ambient around hover were far too sensitive.

ACCELERATION DRIVE LAW

Question 1. Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?
Pilot A – During deceleration (this display) could be deceptive. Have to cue airspeed so as not to chase acceleration. Hard to fly the pirouette and slalom – multi-axis tasks.
Pilot B – Not that I'm aware of.

Question 2. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Slightly in the acceleration/decelerations and constant speed approach.
Pilot B – It assisted in achieving zero speed at the end of the acceleration/deceleration.

Question 3. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Pirouette and slalom. Slightly in the bob up.
Pilot B – No.

Question 4. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.
Pilot A – Pirouette and slalom. Slightly in the bob up.
Pilot B – No.

Question 5. Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – I don't think so.
Pilot B – No.

Question 6. Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Pirouette and slalom. Slightly in the bob up.
Pilot B – No.

Question 7. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?
Pilot A – Vertical speed was best. Useful in the constant speed approach and acceleration/deceleration.
Pilot B – It provides a stronger indication of motion in a given axis. Not sure that the effect is beneficial

Question 8. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – In the constant speed approach and in the acceleration/deceleration.
Pilot B – No.

Question 9. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Pirouette and slalom. Slightly in the bob up.
Pilot B – No.

Question 10. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?
Pilot A – Too much movement/information from the ambient displays.
Pilot B – None.

Question 11. What did you find most useful about this set of ambient symbols?
Pilot A – Steady state, during constant speed approach.
Pilot B – Assist in determining zero acceleration at zero speed.

Question 12. What did you find least useful this set of ambient symbols?
Pilot A – Too much motion from the displays.
Pilot B – The fact that it comes to rest at some forward speed after the deceleration to this speed – contradictory cues.

TIME DECAY DRIVE LAW

Question 1. Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?
Pilot A - At the bottom of the constant speed approach I decelerated and the ambient display went aft. This was distracting. During the pirouette and slalom when one display moves and the other stops – dependent on yaw and longitudinal motion – distracting.
Pilot B – May have been a distraction in the constant airspeed, constant rate of descent task at the very end on short final.

Question 2. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Yes. During the bob up, acceleration/deceleration, and constant speed approach. (This display was) OK in the pirouette and slalom.
Pilot B – Seemed better in the hover bob up and the acceleration/deceleration.

Question 3. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?
Pilot A – Not too bad. Problems as noted above.
Pilot B – No.

Question 4. Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.
Pilot A - As described above. Bottom of the constant speed approach and a little during the pirouette.
Pilot B – The decay of cues at a constant forward airspeed may have had a negative effect.

Question 5. Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Not sure.
Pilot B – No.

Question 6. Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?
Pilot A – Not sure.
Pilot B – No.

Question 7. What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?
Pilot A – Bob up – Helped me hold position and minimize drift while maintaining minimum ambient display movement.
Pilot B – End deceleration in the acceleration/deceleration task.

Question 8. Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Bob up and constant speed approach were probably best.
Pilot B – Acceleration/deceleration.

Question 9. Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?
Pilot A – Bottom of constant speed approach. Pirouette, a little.
Pilot B – No.

Question 10. In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?
Pilot A – Distracting.
Pilot B – No.

Question 11. What did you find most useful about this set of ambient symbols?
Pilot A – Constant speed approach, OK. Bob up, OK.
Pilot B – Confirmation of zero speed in deceleration to hover.

Question 12. What did you find least useful this set of ambient symbols?
Pilot A – Aft movement (of the ambient symbols) during a deceleration.
Pilot B – Conflict between aft acceleration cue from the ambient when airspeed indicator was zero in aft translation.

POST EXPERIMENT RATINGS AND COMMENTS

After completing all of the flights with the ambient displays and the flight using the NVG forward scene without any ambient display, the pilots rank ordered the displays and the NVG only control condition in terms of their usefulness on each of the flight maneuvers and overall workload and usefulness. The pilots then provided written responses to several open ended questions.

RANK ORDER

The pilots rank ordered each of the display conditions from best to worst a total of seven times; once in terms of usefulness on each of the maneuvers, and then in terms of workload and overall usefulness. The rank orders assigned by each of the pilots were averaged. These averages are reported below. Also reported below is the correlation between the rank orders assigned each display condition by the two pilots.

Question 1. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the bob up task.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	1.0
No Longitudinal Motion	4.5
Non-Linear	5.5
Acceleration	3.0
Time Decay	3.5
NVG Only Control	3.5

Pilots found the linear drive law condition to be the most useful display in the bob up task. This reflects the benefit of drift and altitude cues in this task.

The acceleration drive law was rated as second best, just slightly ahead of the time decay and NVG control conditions. The differences between the average rank orders are not considered meaningful.

The no longitudinal motion and the non-linear display conditions were ranked below the NVG control condition. The low rating assigned the no longitudinal motion condition reflects the value of aircraft drift information in this task. Because of the low translational velocities in this task, the continual flow of the ambient objects in some of the other conditions outweighed the possibility of changes in other axes being masked.

The non-linear display condition was rated lowest. This indicates that even though drift information is important to perform this task well, the velocity of the ambient objets and the abruptness of their direction change as the aircraft changed direction disrupted pilot performance.

The correlation between the rank orders assigned the display conditions by the two pilots is 0.314.

Question 2. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the acceleration/deceleration task.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	2.0
No Longitudinal Motion	5.0
Non-Linear	5.0
Acceleration	2.0
Time Decay	2.0
NVG Only Control	5.0

Again, the linear motion condition was ranked as being one of the best. Considered equally useful were the acceleration and time decay conditions. In this task, the motion of the ambient objects would be similar in the time decay and linear. The aircraft never maintains a constant velocity for an extended period so 'washout" of the motion in the time decay condition is unlikely. The motion of the ambient objets in the acceleration condition would differ from the motion in the other two conditions, primarily during the deceleration phase. In the deceleration phase, the motion of the ambient objects in the acceleration condition would be in the opposite direction as in the other two conditions. It may be that because the pilot was focused on slowing the aircraft that the acceleration information was as useful as velocity information.

The no longitudinal motion and non-linear motion conditions were rated as being equivalent to the NVG only condition. All three of these conditions were rated worse than the three ambient display conditions discussed previously. The ratings of the no longitudinal motion condition and the NVG condition indicate that presenting longitudinal translation information is valuable in this task. The low rating of the non-linear condition again reflects the disruption caused by the abrupt direction reversal around hover airspeeds.

The correlation between the rank orders assigned the display conditions by the two pilots is 0.543.

Question 3. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the constant speed, constant rate of descent approach to landing task.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	1.5
No Longitudinal Motion	5.0
Non-Linear	5.0
Acceleration	2.5
Time Decay	3.0
NVG Only Control	4.0

The linear control law condition was rated as being best in the constant speed, constant rate of descent approach task. This indicates that the pilots felt that they could use the display to monitor the aircraft's vertical translation and its orientation even in the presence of relatively fast longitudinal flow of the ambient objects. The acceleration and time decay conditions were ranked about the same; both being considered more useful than the NVG only scene. This indicates that it is possible to eliminate the constant longitudinal flow from the ambient displays during constant speed flight segments while still providing airspeed information to the pilot in a useful manner.

The no longitudinal motion and non-linear motion conditions were rated as being worse than the NVG condition in this task. In the case of the no longitudinal motion condition, the low rating reflects the importance of airspeed information in this task. It seems that the presence of aircraft vertical speed and orientation information is not adequate to compensate for the absence of airspeed information. In the case of the non-linear condition, the ratings reflect both the tendency of the ambient objects to abruptly change direction as the aircraft drifts forwards and aft while climbing to the point at which the approach begins and the low gain between changes in airspeed and changes in the rate of ambient flow at the higher airspeeds. This low gain meant that the airspeed change had to be considerable before the pilots were able to detect a change in the velocity of the ambient objects.

The correlation between the rank orders assigned the display conditions by the two pilots is 0.143.

Question 4. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the pirouette task.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	3.0
No Longitudinal Motion	3.0
Non-Linear	6.0
Acceleration	4.5
Time Decay	2.0
NVG Only Control	2.5

The pirouette is the only task in which the linear condition was not ranked best. In this task, the time decay condition was the only ambient display rated better than the NVG control condition. It is unclear why the time decay would be rated ahead of the linear condition, since the motion of the ambient objects would be very similar.

In this task, the ambient displays were presented in location that the pilots would have liked to look. That is, the pilots would have liked to have been able to see the circle on the ground using their peripheral vision. However, the ambient displays were displayed at that location. This may have given the gave pilots the impression that the ambient displays were blocking their view of the scene. This impression is erroneous because the ambient displays were presented outside the field of view of the NVGs. Therefore, even if the ambient were not there the pilots would not have been able to see the circle without turning their heads so that the circle was in the NVG's field of view. None-the-less, pilots felt as if the ambient displays were acting like blinders in this task.

The correlation between the rank orders assigned the display conditions by the two pilots is 0.257.

Question 5. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the slalom task.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	2.0
No Longitudinal Motion	3.0
Non-Linear	5.5
Acceleration	3.0
Time Decay	4.0
NVG Only Control	3.5

In this task ,he correlation between the rank orders assigned the display conditions by the two pilots is -0.200. This shows a marked lack of agreement in their assessments of the usefulness of the different display conditions. This may be due to the pilots adopting different strategies for flying this task, or because they attended to different aspects of the ambient motion.

It is worth noting that in spite of the relatively complex motion of the ambient objects on the display in this task three of the ambient display conditions were rated as being more useful than the NVG control condition. This indicates that although the motion was in multiple axes pilots felt that some aspects of the ambient display were providing useful and usable information.

Question 6. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of workload.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	1.0
No Longitudinal Motion	3.5
Non-Linear	6.0
Acceleration	4.5
Time Decay	2.5
NVG Only Control	3.5

The linear drive law condition was rated better in terms of workload than the NVG only condition and all of the other ambient display conditions when all of the tasks were considered. The time decay condition was rated as being second best. This indicates that ambient displays can provide information that the reduces pilot workload. We believe that the linear condition was rated best is, in part, attributable to the high proportion of the tasks performed at near hover speeds. If more of the time using the ambient displays had been in cruise conditions (i.e., tasks where maintaining a constant airspeed is important) then the difference between the time decay and linear conditions may have been smaller.

The no longitudinal motion condition was rated the same as the NVG condition in terms of workload. This can be interpreted as indicating that longitudinal translation information is needed in order for the ambient display to reduce the pilot's workload; the availability of vertical translation and rotational information is not enough to aid to justify the display. This may be due to the pilot interpreting the stationary ambient display as indicating that the aircraft was stationary even when it was moving, and having to expend effort to keep track of the airspeed alone using focal processing.

The correlation between the rank orders assigned the display conditions by the two pilots is 0.657. This indicates that the pilots were generally in agreement regarding the displays when considering them overall, rather than in the context of the individual tasks.

Question 7. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of overall usefulness.

DISPLAY CONDITION	AVERAGE RANK ORDER
Linear	1.0
No Longitudinal Motion	3.5
Non-Linear	6.0
Acceleration	4.0
Time Decay	2.5
NVG Only Control	4.0

The pilots were in general agreement regarding the usefulness of the displays overall. The correlation between the rank orders assigned the display conditions by the two pilots is 0.600.

The linear condition was ranked as being the most useful. As for many of the specific tasks, this shows that the presence of longitudinal translation information is valuable. The second highest ranked condition is the time decay. In many of the tasks, the motion of the ambient objects in this condition was very similar to the motion in the linear condition. It is only when the aircraft maintains a constant airspeed for a number of seconds that the appearance differed. Both of these display conditions were ranked as being more useful to the pilot than the NVG control condition.

The differences between the overall rankings of the no longitudinal motion, acceleration, and NVG display conditions are small. This indicates that an effective ambient display needs to provide the pilot longitudinal velocity information. If this information is omitted the display does not provide the pilot the support that it could. If a surrogate for longitudinal velocity is used, it must be in terms that are meaningful to the pilot. In this case, the data indicate that acceleration is not adequate, but that washing out velocity over time is a useful approach.

The ranking of the non-linear display condition indicates that it is not considered useful to the pilots. The unsatisfactory rating of this condition is largely due to the pilots perceiving the change in the direction of the ambient objects when the aircraft changed direction as being too abrupt.

PILOT ANSWERS TO POST EXPERIMENT QUESTIONS

1. WHICH DISPLAY CONDITION BEST SUPPORTED YOUR ABILITY TO PERFORM THESE MANEUVERS. WHAT ABOUT THIS DISPLAY CONDITION WAS PARTICULARLY USEFUL?

Pilot A – Again, This is dependent on the task!

Linear, non-multi-axis motion (of the aircraft)	Seemed to be aided by linear air speed and longitudinal motion cue.
Multi-Axis motion (of the aircraft)	Speed/acceleration, etc. (gave me) too much information. No speed cue or no ambient was better

Pilot B - My sense is that the linear model is the best overall.

2. WHAT ASPECT OF THE AMBIENT MOTION DID YOU FIND MOST DISRUPTIVE? IN WHICH DISPLAY CONDITION OR CONDITIONS DID YOU EXPERIENCE THIS PROBLEM?

Pilot A – Non-linear at low speed (was) too sensitive.

Pilot B – No motion in longitudinal the worst. Non-linear second worst.

3. DID THE MOTION EVER CONFUSE YOU? IF IT DID, WHAT WERE THE CIRCUMSTANCES AND IN WHAT MANNER WAS IT CONFUSING?

Pilot A - Yes. Non-linear and acceleration during the pirouette.

Pilot B – Non-linear and no longitudinal motion were the worst in relating cues to reality.

4. DID YOU EXPERIENCE ANY DIFFICULTIES DUE TO THE AMBIENT DISPLAYS BEING SO CLOSE TO THE FORWARD SCENE? IF SO, WHAT WERE THE DIFFICULTIES AND UNDER WHAT CIRCUMSTANCES DID THEY OCCUR?

Pilot A – Yes. Primarily during the pirouette. Sometimes during the slalom as well.

Pilot B - Yes. 1) Ambients with good rate on course conflict at the intersection line. 2) Longitudinal motion in ambient display is almost orthogonal to longitudinal motion caused problems in real forward and aft motion.

SUMMARY AND RECOMMENDATIONS

These data have shown that ambient displays can improve some facets of pilot performance, and are that pilots recognize the beneficial effect of the displays. However, not all of the displays examined in this study improved performance.

Overall, the linear drive law condition lead to the best performance, and lowest pilot workload. It was also rated as being most useful by the pilots. However, on some tasks the linear drive law condition fell short of some of the other conditions. In looking at the pattern of results, it appears that the linear drive law worked best in maneuvers performed at or near hover. At higher airspeeds, which were still modest, the velocity of the longitudinal flow of the ambient objects across the display made it difficult for the pilots to identify changes in airspeed. The rapid flow also appears to have masked changes in the position of the ambient objects caused by aircraft changes in other axes. This was most apparent in the slalom, where the target airspeed was at the high end of speeds encountered in this study and the aircraft was maneuvering in multiple axes simultaneously.

The differences in the performance between the time decay and acceleration drive law conditions makes it difficult to determine which is better. However, as the pilots pointed out, the acceleration condition often resulted in the flow of the ambient objects being opposite the direction that would be expected from motion of the aircraft. In this flight regime, the acceleration information does not support the pilot as well as does velocity or position information, and was misleading. Consequently, we feel that the time decay drive law is better suited to low speed tasks. At higher airspeeds (e.g., in the constant speed, constant rate of descent approach, the slalom, and the acceleration/deceleration) the performance differences are too small and inconsistent to distinguish between the drive laws. In these higher speed tasks, perceived clutter was reduced by eliminating the constant flow of the ambient objects that occurred with the linear drive law. This, coupled with the tendency of the constant flow of the ambient objects to mask changes in other axes, leads us to conclude that a drive law like the acceleration or time decay drive laws would be a better choice at speeds above those characteristic of hover or transition flight regimes.

One of the biggest problems still faced in developing a usable ambient display is scaling the motion of the ambient objects to cover the entire flight envelope. All of the tasks in this experiment are flown at airspeeds of 20 kts (37 kph, 23 mph) or less. Even at these modest airspeeds, the rate at which the ambient objects flow across the screen is too high. This experiment attempted to explore this issue through the use of drive laws relating the airspeed to the motion of the ambient objects. The three drive laws that attempted to improve the ambient display's ability to cue the pilot to low speed drift and of changes in velocity at higher speeds were the non-linear, the acceleration, and the time decay.

It appears that the acceleration and time decay drive laws were most useful in the constant speed, constant rate of descent approach task. In this task, in contrast to the slalom which was also performed with a target airspeed of 20 kts, the amount of maneuvering was very small. Any changes in the display indicated a deviation from the steady state parameters set up by the pilot. However, when the pilot slowed the aircraft in preparation for landing at the end of this maneuver, the acceleration cue was not providing the pilot the information needed to stop the aircraft and maintain position over a specific ground position. In fact, pilots indicated that when decelerating the rearward motion of the ambient objects across the displays was cocfusing. In this part of the maneuver the linear drive law was preferred. This suggests that an acceleration and time decay based drive laws are useful when the aircraft's longitudinal motion will remain in the same direction, and is not useful in flight regimes where changes in the aircraft's direction of travel are occurring or where the pilot desires to maintain position over a point on the ground.

What appears to be needed are different drive laws operating at different airspeeds. One possibility is a linear drive law at hover airspeeds, a linear drive law with a different gain at transition airspeeds, and a drive law based on acceleration or a time decay of the ambient motion at up and away (i.e., cruise) airspeeds. This approach would better match the motion of the ambient objects to the information needs of the pilots in the different flight regimes.

Another area where the ambient displays can be improved is in providing pilots an enhanced awareness of the horizon. In the displays used in this and the preceding study, the horizon was not depicted unambiguously. The pilots could infer the location of the horizon from the vertical relationship between objects in the left and right displays. However, in some situations the location of the horizontal plane could easily be misinterpreted by the pilot. For instance, as the aircraft rolled so that it was no longer level, the ambient objects on one side would move upwards on the display while those on the other side moved downwards. If the aircraft happened to roll to the point at which the row of objects on one side was aligned with either the row above or below it on the other side, it would be possible for the pilot to become disoriented. In order to avoid this possibility, displays containing an indicator of the local level are being developed. These displays include:

- Extended artificial horizon only (no other ambient objects)
- Extended artificial horizon superimposed over ambient displays
- Ambient objects displayed below horizon only

It is worth noting that with these displays the information about horizon will be independent of the aircraft's vertical velocity. The horizon line will not move vertically on the screen as the aircraft ascends or descends. (Currently, all of the ambient objects move across the display vertically as the aircraft changes altitude.)

APPENDIX A

Post Flight Rating Form

POST FLIGHT RATING FORM

PILOT CODE AND DISPLAY CONDITIONS

PILOT CODE: ____________________ DATE: __________________________

EXPERIMENTAL CONDITION:

- Linear Drive Law
- No Longitudinal Translation
- Non-Linear Drive Law
- Acceleration Drive Law
- Time Decay Drive Law
- NVG Control (No Ambient Displays)

PILOT RATINGS

Did the ambient display help you maintain awareness of the aircraft's fore and aft speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of speed	No effect on my awareness of speed	It was invaluable in helping me maintain awareness of speed

Were the changes in the longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed between 0 and 5 kts?

|---------------|---------------|---------------|---------------|---------------|---------------|

Change too small to ever be noticed	Noticeable about half the time	Changes were easily detected

Were the changes in the longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed between 5 and 10 kts?

|---------------|---------------|---------------|---------------|---------------|---------------|

Change too small to ever be noticed	Noticeable about half the time	Changes were easily detected

Were the changes in the longitudinal speed of the ambient objects large enough for you to notice changes in your airspeed over 10 kts?

|---------------|---------------|---------------|---------------|---------------|---------------|

Change too small to ever be noticed	Noticeable about half the time	Changes were easily detected

Did the ambient display effect your ability to detect changes in the direction of the aircraft's fore and aft motion (i.e., to tell when you began to drift backwards or forwards)?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect direction changes	No effect on my awareness of direction changes	It was invaluable in helping me detect direction changes

Did the ambient display help you maintain awareness of the aircraft's vertical speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of vertical speed	No effect on my awareness of vertical speed	It was invaluable in helping me maintain awareness of vertical speed

Did the ambient display effect your ability to detect CHANGES in the aircraft's vertical speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect changes in vertical speed	No effect on my awareness of vertical speed changes	It was invaluable in helping me detect changes in vertical speed

Did the ambient display help you maintain awareness of the aircraft's pitch angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of aircraft pitch	No effect on my awareness of pitch	It was invaluable in helping me maintain awareness of aircraft pitch

Did the ambient display effect your ability to detect CHANGES in the aircraft's pitch angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect pitch changes	No effect on my awareness of pitch changes	It was invaluable in helping me detect pitch changes

Did the ambient display help you maintain awareness of the aircraft's roll angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of aircraft roll	No effect on my awareness of roll	It was invaluable in helping me maintain awareness of aircraft roll

Did the ambient display effect your ability to detect CHANGES in the aircraft's roll angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect roll changes	No effect on my awareness of roll changes	It was invaluable in helping me detect roll changes

Did the ambient display help you maintain awareness of the aircraft's heading?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of heading	No effect on my awareness of heading	It was invaluable in helping me maintain awareness of heading

Did the ambient display effect your ability to detect CHANGES in the aircraft's heading?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect heading changes	No effect on my awareness of heading changes	It was invaluable in helping me detect heading changes

How visually cluttered was the ambient display?

|---------------|---------------|---------------|---------------|---------------|---------------|

So cluttered it was distracting | Acceptable level of clutter | No noticeable clutter

Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the bob up – turn towards target task.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload | About the same | Ambient displays caused a large reduction in workload

Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the acceleration/deceleration task.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload | About the same | Ambient displays caused a large reduction in workload

When flying the constant speed and rate of descent approach to landing task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload | About the same | Ambient displays caused a large reduction in workload

When performing the pirouette task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload | About the same | Ambient displays caused a large reduction in workload

When flying the slalom task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

Did the ambient displays improve or harm your ability to perform the bob up – turn towards target task, compared to what you expect when flying with a NVG only scene.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the acceleration/deceleration task, compared to what you expect when flying with a NVG only scene.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the constant speed and rate of descent approach to landing task, compared to what you expect when flying with a NVG only scene.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the pirouette task, compared to what you expect when flying with a NVG only scene.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the slalom task, compared to what you expect when flying with a NVG only scene.

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Overall, how acceptable was this ambient symbol set?

|---------------|---------------|---------------|---------------|---------------|---------------|

Not acceptable as is; major changes are needed before flying with this symbol set	Minimally acceptable. Some improvements needed before this symbol set set can be flown	Acceptable as is; no changes needed are needed order to fly with this symbol set

How consciously aware were you of the ambient displays?

|---------------|---------------|---------------|---------------|---------------|---------------|

I was always aware of the ambient displays	I was aware of of the ambient symbols about half the flight	I never noticed the ambient displays

How much attention did you pay to the ambient displays?

|---------------|---------------|---------------|---------------|---------------|---------------|

I was always paying attention to the ambient displays	I paid attention of the ambient symbols half the flight	I never paid attention to the ambient displays

QUESTIONS

Did the difference, if any, between the motion of the ambient objects and the motion in the forward scene interfere with your ability to fly the maneuvers or distract you in any way?

Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?

Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, in which maneuver or maneuvers?

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

Did the longitudinal motion of the ambient objects, if any, improve your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?

Did the longitudinal motion of the ambient objects, if any, harm your ability to detect changes in aircraft orientation or motion in any other axis? If so, in which maneuver or maneuvers?

What information (e.g., pitch, forward velocity, vertical speed) did the ambient display provide you that was unavailable in the forward scene?

Did the ambient symbology improve your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

Did the ambient symbology harm your ability to maintain awareness of the aircraft's position and orientation during any of the maneuvers? If so, which maneuver or maneuvers?

In what way did the ambient displays reduce your awareness of the aircraft's position or orientation?

What did you most useful about this set of ambient symbols?

What did you most find least useful this set of ambient symbols?

APPENDIX B

Post Experiment Rating Form

POST EXPERIMENT QUESTIONNAIRE

In this experiment you used six different displays. These displays varied the relationship between longitudinal motion of the simulated aircraft and motion of the ambient objects across the display screens. To help you remember the display conditions, the relationship between aircraft motion and motion of the ambient objects are described briefly, below. The order of the conditions in this list may not be the same as the order in which you used them during your simulated flights.

Condition 1 - Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects. In this condition, the ambient objects moved across the screen as if they were painted on bill boards located at a distance of 20 meters from the aircraft. As the aircraft speed doubles, the velocity of the ambient objects on the screen doubles.

Condition 2 - No Longitudinal Translation of the Ambient Objects. In this condition, the aircraft's forward and rearward speed had no effect on the positions of the ambient objects on the screen. The positions of the ambient objects was affected by the pitch, roll, yaw, and vertical motion of the simulated aircraft.

Condition 3 - Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects. The motion of the ambient objects on the screen was a non-linear function of the aircraft's speed. At low speeds, the velocity of the ambient objects on the screen changed more per unit of aircraft speed change than at higher airspeeds.

Condition 4 - Motion of the Ambient Objects Related to Aircraft Acceleration. The motion of the ambient objects on the screen was a function of the aircraft's acceleration, not its' velocity. If the aircraft was at a constant speed the ambient objects were stationary on the screen. When the aircraft was accelerating forwards the ambient objects flowed rearwards on the screen at a rate proportional to the acceleration rate. When the aircraft decelerated the ambient objects flowed forwards at a speed proportional to the deceleration rate.

Condition 5 - Motion of the Ambient Objects Decays Over Time At A Constant Airspeed. Whenever the aircraft was accelerating or decelerating the motion of the ambient objects on the screen reflected the changing speed. When the aircraft reached a constant speed the motion of the ambient objects declined to zero over a period of approximately 5 seconds.

Condition 6 - No Ambient Displays. In this condition only the simulated NVG scene was visible; no ambient objects were displayed.

RANK ORDERING OF THE DISPLAY CONDITIONS

1. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the bob-up task.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

2. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the acceleration-deceleration task.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

3. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in constant speed, constant rate of descent approach to landing task.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

4. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness during the pirouette task.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

5. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of their usefulness in the slalom task.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

6. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of workload.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

7. Rank order the ambient drive laws from best to worst (1 = best, 6 = worst) in terms of overall usefulness.

___ Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ No Longitudinal Translation of the Ambient Objects
___ Non-Linear Relationship Between Airspeed and Longitudinal Motion of the Ambient Objects
___ Motion of the Ambient Objects Related to Aircraft Acceleration
___ Motion of the Ambient Objects Decays Over Time At A Constant Airspeed
___ No Ambient Displays

Which display condition best supported your ability to perform these maneuvers? What about this display condition was particularly useful?

What aspect of the ambient motion did you find most disruptive? In which display condition or conditions did you experience this problem?

Did the ambient motion ever confuse you? If it did, what were the circumstances and in what manner was it confusing?

Did you experience any difficulties due to the ambient displays being so close to the forward scene? If so, what were the difficulties and under what circumstances did they occur?

APPENDIX 4

Experiment 3 Report

EVALUATION OF METHODS FOR PRESENTING AIRCRAFT STATE INFORMATION FOR PROCESSING BY THE AMBIENT VISUAL SYSTEM: ALTERNATIVE METHODS FOR PRESENTING AN ARTIFICIAL HORIZON

SBIR Phase II
Contract Number DAAH10-98-C-0020

26 July 2000

Prepared for:

U.S. Army Aviation & Missile Command
Aviation Applied Technology Directorate
Fort Eustis, A 23604-5577

Prepared By:

Monterey Technologies, Inc.
24600 Silver Cloud Court
Suite 103
Monterey, CA 93940

TABLE OF CONTENTS

LIST OF FIGURES

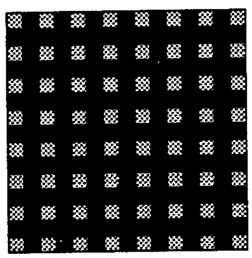
LIST OF TABLES

EVALUATION OF METHODS FOR PRESENTING AIRCRAFT STATE INFORMATION FOR PROCESSING BY THE AMBIENT VISUAL SYSTEM: ALTERNATIVE METHODS FOR PRESENTING AN ARTIFICIAL HORIZON

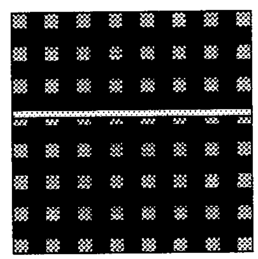
EXECUTIVE SUMMARY

This experiment reports the results of the third in a series of experiments examining the use of ambient displays to present aircraft attitude information to helicopter pilots. This study focuses on alternative methods of presenting an artificial horizon either in addition to or instead of ambient displays such as those used in studies conducted previously in this program. In the first study in this program, the size, shape, and density of the ambient objects on pilot performance was examined. The second study examined alternative drive laws relating longitudinal motion of the aircraft to motion of the ambient objects on the display.

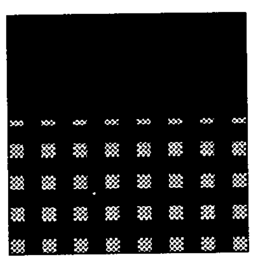
Two experience helicopter pilots flew a series of maneuvers in each of four experimental display conditions and then in a NVG only control condition. The experimental display conditions are shown below.



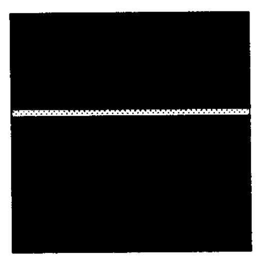
Full Field Ambient Display



Ambient Object Plus Artificial Horizon



Ambient Objects Below Artificial Horizon



Artificial Horizon Only

These displays were presented to the outboard sides of an "out-the-window" scene that simulated NVGs. All of the displays were presented on a head mounted display.

The maneuvers flown in this study were:

- Bob-up
- Acceleration/Deceleration
- Constant Speed, Constant Rate of Descent Approach to Landing
- Pirouette
- Slalom

Aircraft position and attitude were collected during each flight. These data were analyzed to identify differences in pilot performance between display conditions. Subjective measures were also collected and analyzed.

It was found that pilots rated the ambient displays as being more acceptable and useful than a NVG only scene. Objective data indicates that there are instances where ambient displays allow the pilot to perform maneuvers more precisely. However, not all maneuvers benefited from the availability of ambient displays. Maneuvers which require simultaneous multi-axis changes (e.g., a slalom) benefit less from ambient displays than maneuvers which are more benign. The "best" display in terms of performance and acceptability to the pilots consisted of an artificial horizon plus a full field of ambient objects (i.e., squares).

Suggested areas for future research include examining alternative display metaphors, using ambient displays to provide ground proximity information, and using the ambient objects to aid in flight maintaining a constant altitude AGL (i.e., contour flight).

EVALUATION OF METHODS FOR PRESENTING AIRCRAFT STATE INFORMATION FOR PROCESSING BY THE AMBIENT VISUAL SYSTEM: ALTERNATIVE METHODS FOR PRESENTING AN ARTIFICIAL HORIZON

INTRODUCTION

This experiment reports the results of the third in a series of experiments examining the use of ambient displays to present aircraft attitude information to helicopter pilots.

In the first study in this program, the effects of the size, shape, and density of the ambient objects on pilot performance were examined. The results of the first study in this series indicated:

- Squares are more effective than circles as stimuli for the ambient system
- Squares 4 meters/side were too large and squares 1 meter/side were too small given a presentation distance of 20 meters
- Ambient objects displayed over 50% of the display were too dense, and at 12.5% density the ambient objects were too sparse

Based on these results, the ambient stimuli in experiments 2 and 3 consisted of 2 meter/side squares displayed at a density of 25%. Experiment 1 was conducted using a head mounted display (HMD) that suffered from reliability problems. This HMD was replaced in experiments 2 and 3 with a different HMD. The replacement HMD positioned the ambient displays at a different location than was used in experiment 1, and featured a higher display resolution in the peripheral display channels.

The second study examined alternative drive laws relating longitudinal motion of the aircraft to motion of the ambient objects on the display. The experimental conditions were:

- Linear drive law - 1:1 relationship between longitudinal motion of the aircraft and motion of the ambient objects on the display
- No longitudinal motion of the ambient objects
- Logarithmic – the velocity of the ambient objects across the display was a log function of the aircraft's velocity
- Acceleration – motion of the ambient objects across the display was related to the aircraft's longitudinal acceleration, not its velocity
- Time Decay – longitudinal motion of the ambient objects "washed out" over 5 seconds when the aircraft maintained a constant velocity.

The results of the second study indicated that for the flight tasks, and velocities attained while performing those tasks, a linear drive law was more acceptable to the pilots than the others and resulted in the best level of performance. Therefore, a linear drive law was employed throughout the present study.

This study focuses on alternative methods of presenting an artificial horizon either in addition to or instead of ambient displays such as those used in studies conducted previously in this program. The goals of this study are (a) to determine whether or not presenting an artificial horizon as part of an ambient display leads to improve pilot performance, and (b) to identify a means of presenting an artificial horizon that minimizes display clutter while still supporting pilot performance.

METHOD

HELICOPTER SIMULATOR

The simulator used in this experiment simulated a generic, light weight helicopter. This simulator has been used in previous studies conducted as part of this program, and is described briefly here.

The pilot controlled the helicopter through a set of conventional controls (i.e., a cyclic, a collective, and anti-torque pedals.) The controls are commercial, off-the-shelf (COTS) items (Flight Link, Chico, CA). The simulation was hosted on a single CPU Pentium computer running the Windows 95 (Microsoft, Redmond, WA) operating system.

The Enhanced Stability Derivative (ESD) mathematical model of the helicopter was used in this simulation. ESD was provided by the NASA Ames Research Center for use in this research program.

Symbology was limited to numerical readouts of forward airspeed, heading, radar altitude, and barometric altitude. Also displayed were a turn coordination ball and a collective position indicator tape. All of these symbols were displayed as if on a head-up display (HUD) fixed to the aircraft. The HUD was positioned below the pilot's normal line of sight, just above an opaque mask in the scene. This mask represented fixed structure in the cockpit. This position was selected to minimize the obscuration of the out-the –window scene while keeping the symbology in a location where it was easily viewed by the pilot.

HEAD MOUNTED DISPLAY

A COTS Head Mounted Display (HMD) was used to present the symbology, the out-the – window scene, and the ambient displays to the pilot. This HMD, a Proview 100 (Kaiser Electro-Optics, Carlsbad, CA) has four separate visual channels arranged horizontally. The two outboard channels were used to display the ambient objects and/or the artificial horizon. The inboard channels were used to display the simulated HUD symbology and the out-the-window scene. The pilots viewed the center channels biocularly.

PARTICIPANTS

Two experienced helicopter pilots participated in this study. The aviation experience of these pilots is summarized in Table 1. Both pilots had participated in one or both of the preceding studies in this program.

Type of Aviation Experience	Pilot A	Pilot B	Average
Helicopter Pilot-in-Command (hours)	3500	2000	2750
Fixed Wing Pilot-in-Command (hours)	3000	0	1500
Night Vision Goggle Use (hours)	50	280	165
HMD Symbology Use (hours)	50	10	30

Table 1. Aviation experience of the participating pilots.

FLIGHT TASKS

Pilots performed two repetitions of each of five flight tasks in each display condition. These tasks were:

- Bob-up – beginning on the ground, ascend to 50 ft AGL while maintaining position over the starting point. Once at 50 ft, turn the aircraft 180°, and then descend and land.
- Acceleration/Deceleration – beginning at an altitude of 30 ft AGL, accelerate in a straight line to an airspeed of 15 kts. Then slow and come to a stop over the center of a square on the ground.
- Constant Speed, Constant Rate of Descent Approach to Landing – beginning at an altitude of 300 ft AGL, initiate an approach to a landing zone. During the approach maintain 20 kts airspeed and a constant rate of descent.
- Pirouette – at an altitude of 20 ft AGL, side slip around a 100 meter diameter circle painted on the ground, keeping the aircraft over the circle. During the maneuver, keep the nose of the aircraft pointed towards a marker located at the center of the circle.
- Sialom – while maintaining 20 kts airspeed and 50 ft AGL, perform a series of turns while going down a runway. The outside of the turns should be over or outboard of the runway's edges and each turn should take the aircraft over the gap between the dashed lines in the runway's centerline.

These tasks, with the exception of the Constant Speed, Constant Rate of Descent Approach to Landing, are based on the tasks described in ADS-33. All of these tasks were used in the preceding two studies conducted as part of this research program.

DISPLAY CONDITIONS

During this experiment, each pilot flew the maneuvers using each of four experimental displays and when using a NVG only (no ambient display) control condition. The four experimental display conditions were:

- Artificial Horizon only
- Ambient objects (i.e., squares) throughout the peripheral channels
- Artificial Horizon over a full field of ambient objects
- Ambient Objects below the horizon; the portion of the field above the horizon was blank

Figure 1 shows one of the outboard channels in each of the experimental display conditions. In this figure, the aircraft is straight and level.

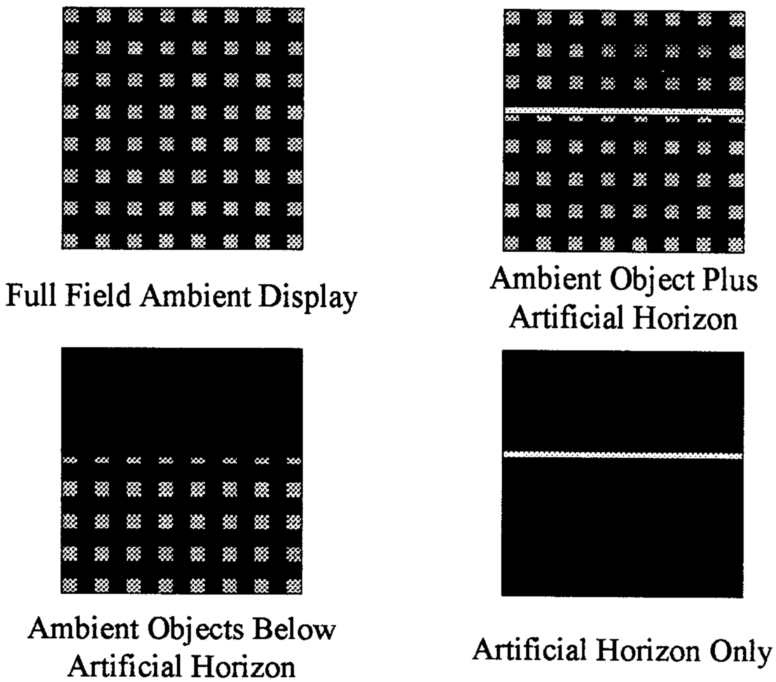


Figure 1. Ambient Displays Used In Experiment 3.

The ambient objects simulated squares 2 meters per side. The objects were positioned as if painted on infinitely long, infinitely tall bill-boards located 20 meters to the sides of the aircraft. In this display metaphor, the ambient objects were driven by motion of the aircraft in five degrees of freedom; pitch, roll, yaw, vertical translation, and longitudinal translation. Lateral translation of the aircraft did not effect the position of the ambient objects on the display. The ambient objects were also driven by the pitch, roll, and yaw of the pilot's head. Translation of the pilot's head did not effect the position of the ambient objects on the display. The artificial horizon was driven by the pitch and roll of the aircraft and of the pilot's head.

In addition, each pilot flew the maneuvers in a control condition consisting of the out-the-window scene only. The two outboard channels in the HMD were blank in the control condition.

PROCEDURE

Pilots were read instructions describing the nature and purpose of the experiment and the tasks they would be asked to fly. The instructions described known short term hazards (i.e., the potential for developing "hot spots" from wearing the HMD, the possibility of developing simulator induced sickness), and that no long term hazards from participating had been identified. The pilots were also told that the data would be de-identified so as to protect their privacy. As part of these instructions, pilots were informed of their right to terminate their participation at any time without adverse consequences.

After reading the instructions and answering any questions that the pilots had, data collection commenced. One of the pilots had very recently completed another study using the same simulator, tasks, and HMD so no practice was necessary to refamiliarize him with the simulator. The other pilot, although experienced with the simulator from participating in research conducted earlier, had not flown this simulator for several months. This pilot was allowed to practice each of the tasks during the first session prior to initiating data collection for that task.

The pilots always flew the tasks in the same order in each display condition. This order was:

- Bob-up
- Acceleration/Deceleration
- Constant Speed, Constant Rate of Descent Approach to Landing
- Pirouette
- Slalom

The sequence of display conditions was determined randomly for the first pilot, with the exception that the NVG only control condition was flown last. The order of the experimental display conditions was reversed for the second pilot. Again, the second pilot flew the NVG only control condition last. This sequence makes it impossible to attribute superior performance with one or more of the ambient displays to increased practice flying the simulator compared to the amount of practice before the control condition.

Following each flight with one of the ambient displays, the pilots completed a questionnaire. This questionnaire is contained in Appendix 1. The post flight questionnaire allowed the pilot to rate the display's usefulness, and the effect on workload and task performance. The questionnaire also contained a number of open ended questions.

Appendix 2 contains the post experiment questionnaire. This questionnaire was completed by the pilot after completing all flights (i.e., after flying with the NVG only display condition.) This form primarily asked the pilots to rank order all five of the display conditions; the four experimental conditions and the control condition. This questionnaire also contained a number of open ended questions allowing the pilots to elaborate on their experience using the ambient displays.

RESULTS OF PERFORMANCE MEASURES

This study was conducted with only two pilots. Because of this small sample size no inferential statistics have been computed. The data presented here consists of descriptive statistics; arithmetic means and standard deviations.

BOB-UP

Drift Distance

The average distance drifted while performing the pedal turn portion of this maneuver is shown in Figure 2.

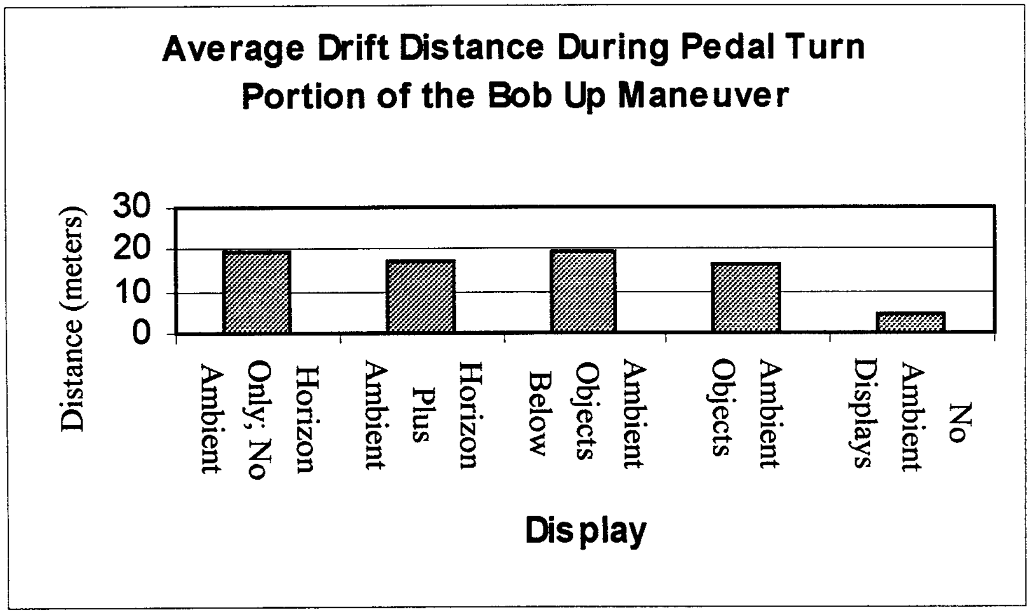


Figure 2. Average Distance Drifted During the Pedal Turn from the Aircraft's Position at the Start of the Turn.

These data indicate that the presence of an ambient display had an adverse impact on the pilot's ability to maintain the aircraft's position over a specific geographic position while performing this maneuver. It does not appear that this deficit is due to the flowing of the ambient objects over the displays as the aircraft turned. The aircraft drifted over three times as far regardless of whether the ambient display contained objects that moved across the display as the aircraft turned, or remained fixed (i.e., the artificial horizon only condition). We believe that this result may show that the pilot was unable to use the cues available in the out-the –window scene whenever an ambient display was present. This may be due to a distracting effect from the ambient display, or it could be that the pilot's were overly confident that they could use the ambient displays to help them detect and eliminate drift.

Turn Rate

Figure 3 shows the average turn rate during the pedal turn portion of the bob up maneuver. The differences between display conditions are small, indicating that the ambient displays did not harm or hinder the pilot's ability to turn the aircraft. The pilot's did tend to turn more slightly slowly in the horizon only condition. This result may be due to the pilot's expecting to "see" visual flow correlated to their turn rate in the out-board displays, and being more conservative when receiving ambient stimulation not consistent with their prior experience. (That is, when the pilots turned in all other experimental display conditions, or when they turn in the natural environment with a full field of view, flow of the images across the retina is expected whenever objects are visible.

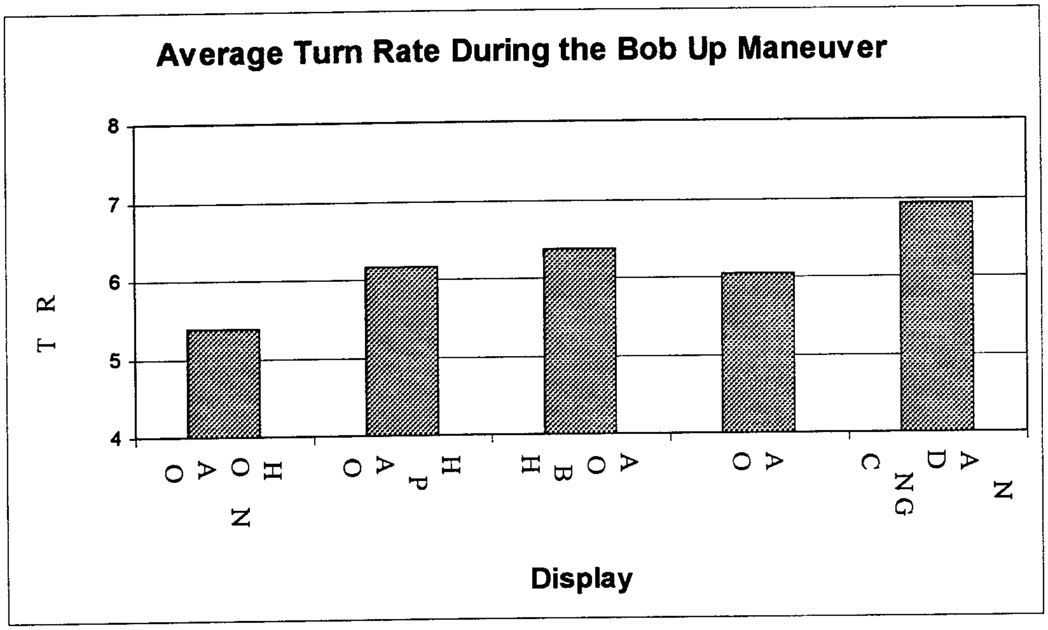


Figure 3. Average Turn Rate During the Pedal Turn Portion of the Bob Up Maneuver.

Variability of Turn Rate

The flow rate of the ambient displays changes as the aircraft's turn rate changes. It was expected that this information would allow the pilots to maintain a more constant turn rate than when they were forced to rely on the narrow out-the-window scene and the HUD symbology alone. The standard deviation of the turn rate in each display condition is shown in Figure 4.

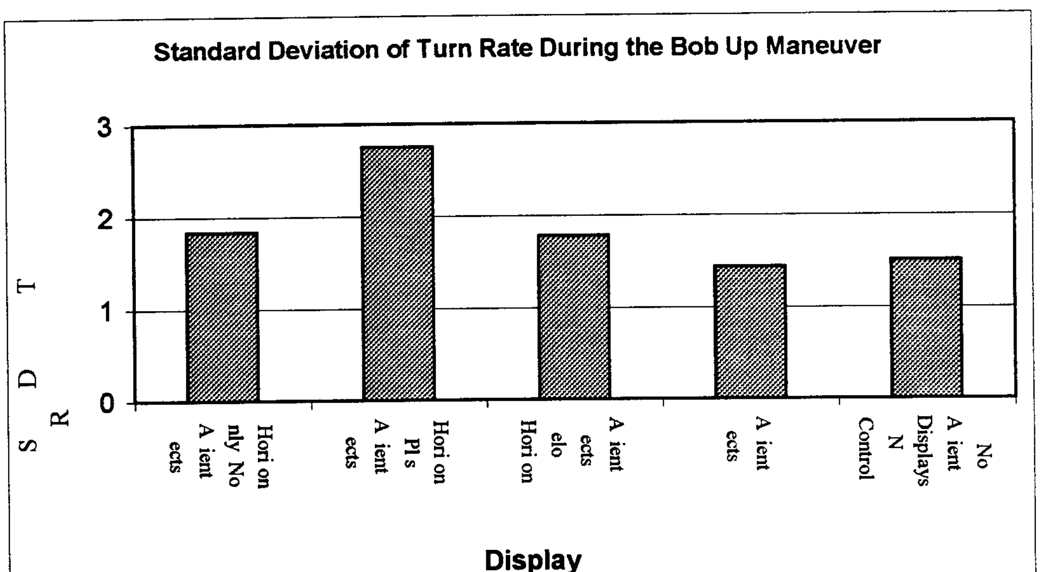


Figure 4. Standard Deviation of Turn Rate During the Pedal Turn Portion of the Bob Up Maneuver.

Examination of this figure shows that the ambient displays did not allow the pilots to maintain a more constant turn rate. Further, the presence of a horizon line, or an edge indicating the location of the horizon, seems to have had a detrimental effect as the variability is increased.

Average Altitude

The target altitude for this task was 50 ft AGL. Figure 5 shows the average altitude during the pedal turn in each display condition.

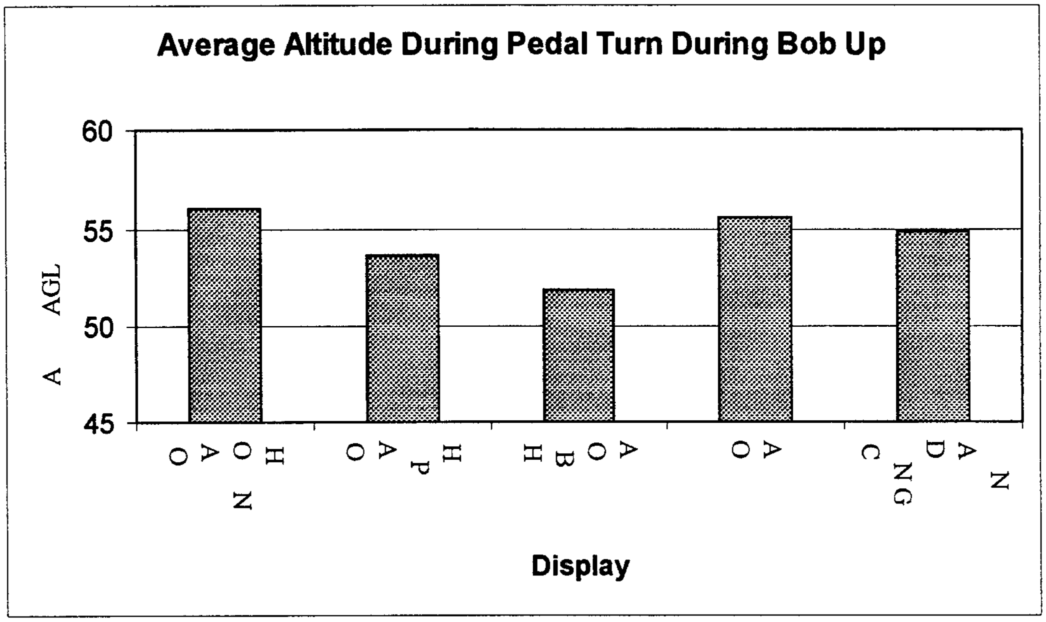


Figure 5. Average Altitude During the Pedal Turn Portion of the Bob Up Maneuver.

These data show that the ambient displays did not have a systematic effect. The ambient objects do not show absolute altitude. Rather, their vertical motion shows the direction and rate of altitude changes. It was expected that once the aircraft was stabilized at 50 ft AGL and began the pedal turn, the pilot could use the ambient displays to detect and correct deviations from the target altitude. In contrast to the ambient objects (i.e., the squares), the horizon alone does not provide information about vertical motion of the aircraft and, therefore, was not expected to improve altitude maintenance. The horizon only shows the plane perpendicular to the gravity vector; the position of the artificial line on the display is unaffected by altitude changes.

It appears that only the combination of an artificial horizon with ambient objects improved altitude holding. This may be attributable to the horizon line providing a reference against which motion of the ambient objects can be readily detected. This would allow the pilots to make corrective control inputs sooner than in those cases where no such reference is available.

Altitude Variability

It was expected that the vertical motion of the ambient objects would improve the pilot's ability to detect changes in the aircraft's altitude. Improved detection of altitude changes should reduce the variability of altitude. Figure 6 shows the standard deviation of the aircraft's altitude during the pedal turn portion of the bob up maneuver. These data suggest that the presence of ambient objects reduce the altitude variability 20 to 60% compared to a NVG scene. Altitude variability was increased relative to the NVG condition when the ambient display consisted of an artificial horizon without ambient objects showing changes in the aircraft's altitude.

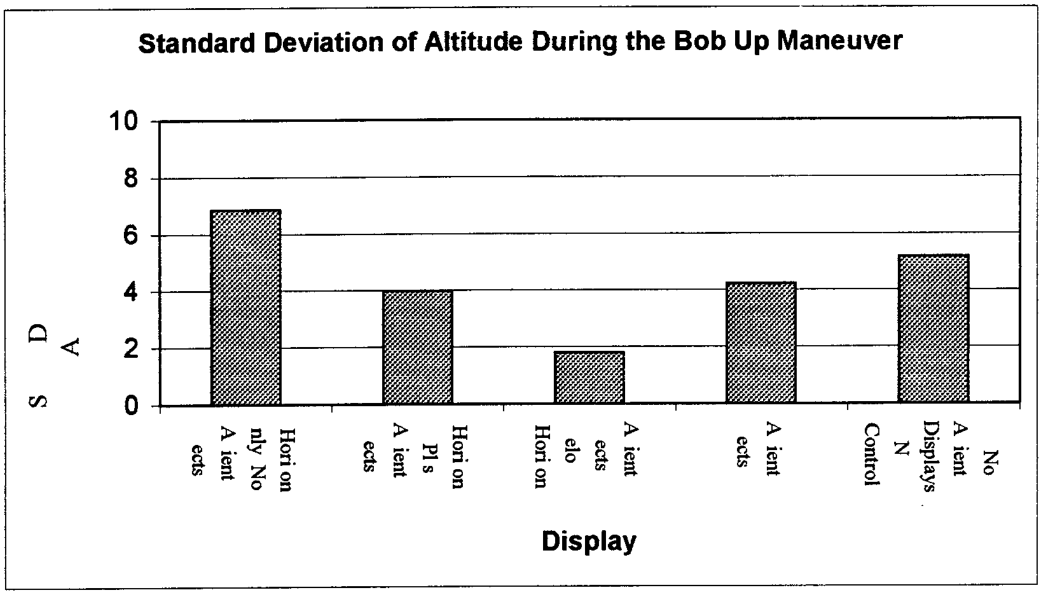


Figure 6. Standard Deviation of the Aircraft's Altitude During The Pedal Turn Portion of the Bob Up Maneuver.

ACCELERATION/DECELERATION

Average Altitude

During the acceleration/deceleration task, pilots attempted to maintain an altitude of 30 ft AGL. Figure 7 shows the average altitudes in each of the display conditions.

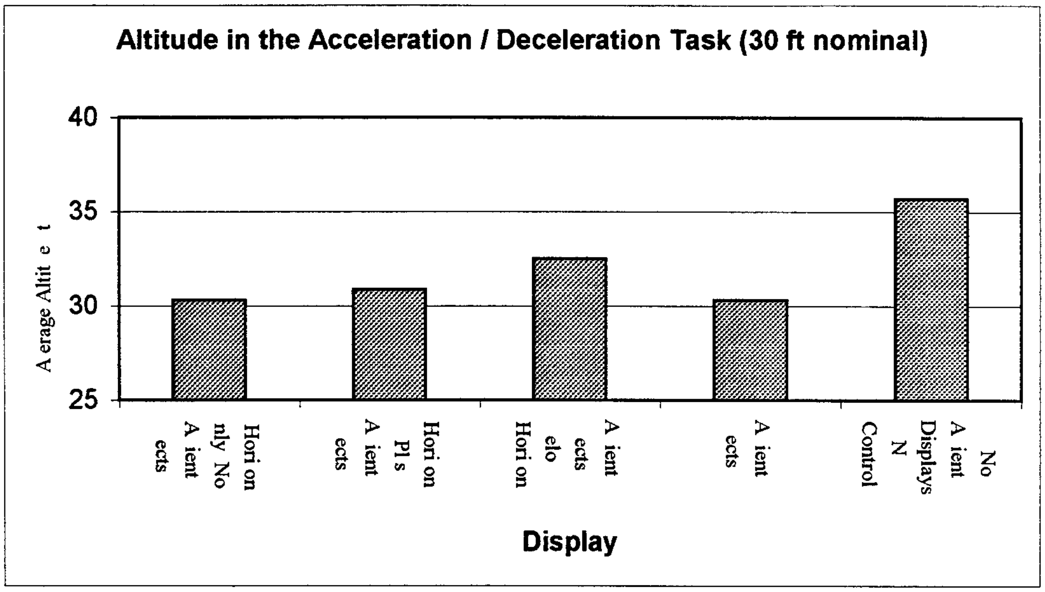


Figure 7. Average altitude During the Acceleration/Deceleration Task.

This figure shows that the average altitude during this maneuver was closer to the target altitude when ambient objects were present, and when an artificial horizon alone was displayed.

<u>Altitude Variability</u>

Figure 8 shows that the variability of the aircraft's altitude. Contrary to our expectations, the altitude variability was greater when ambient displays were presented compared to the NVG only condition. This increase occurred both when ambient objects were in the scene and when the ambient display consisted only of an artificial horizon.

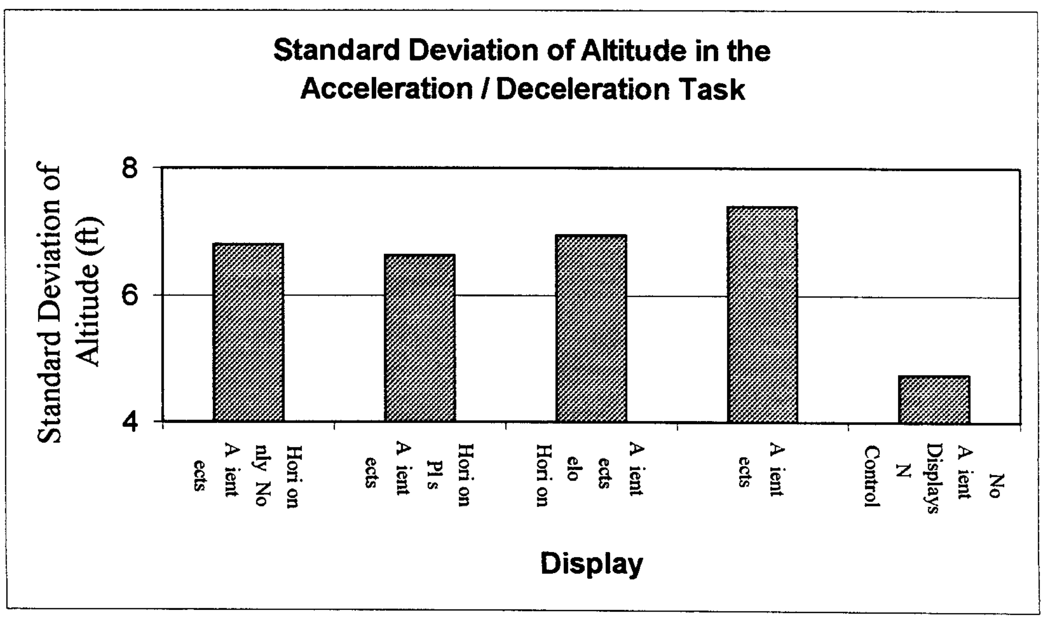


Figure 8. Altitude Variability During the Acceleration/Deceleration Task.

CONSTANT SPEED, CONSTANT RATE OF DESCENT APPROACH TO LANDING

Average Airspeed

In this task, pilots were instructed to maintain an airspeed of 20 kts during the descent. Figure 9 shows the average airspeed in each of the display conditions. In general, it appears that pilots did maintain the target airspeed as well as possible given the resolution of the digital readout on the HUD in all conditions except the artificial horizon plus ambient objects condition.

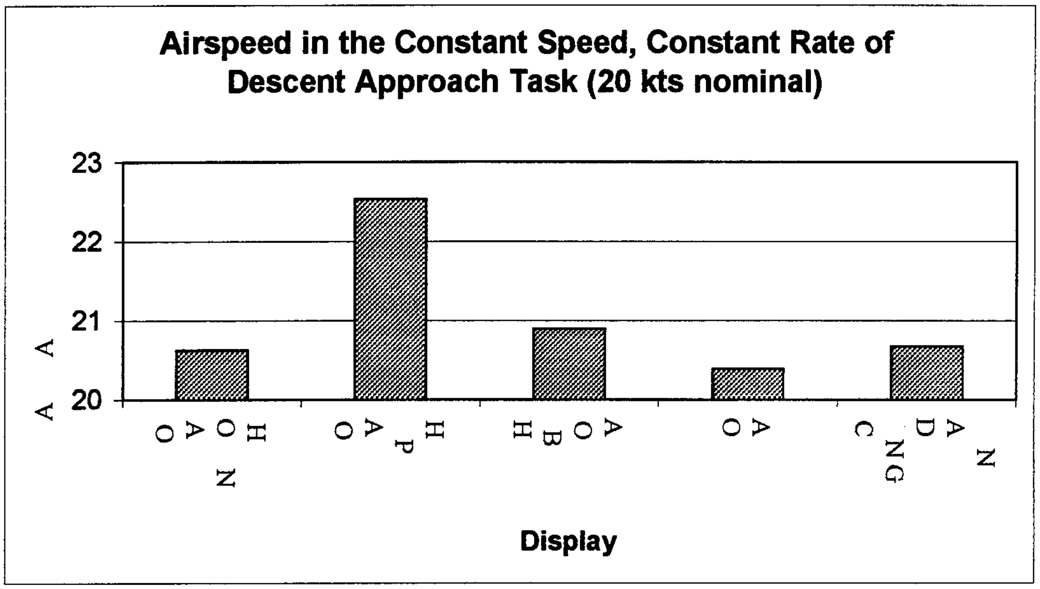


Figure 9. Average Airspeed in the Constant Speed, Constant Rate of Descent Approach.

Airspeed Variability

If pilots can detect changes in the rate of longitudinal flow of the objects in the ambient displays, then they should be able to maintain a constant airspeed more accurately. Figure 10 shows the standard deviation of airspeed during the approach task. These data indicate that the flow of the ambient objects did not have a beneficial effect on airspeed maintenance.

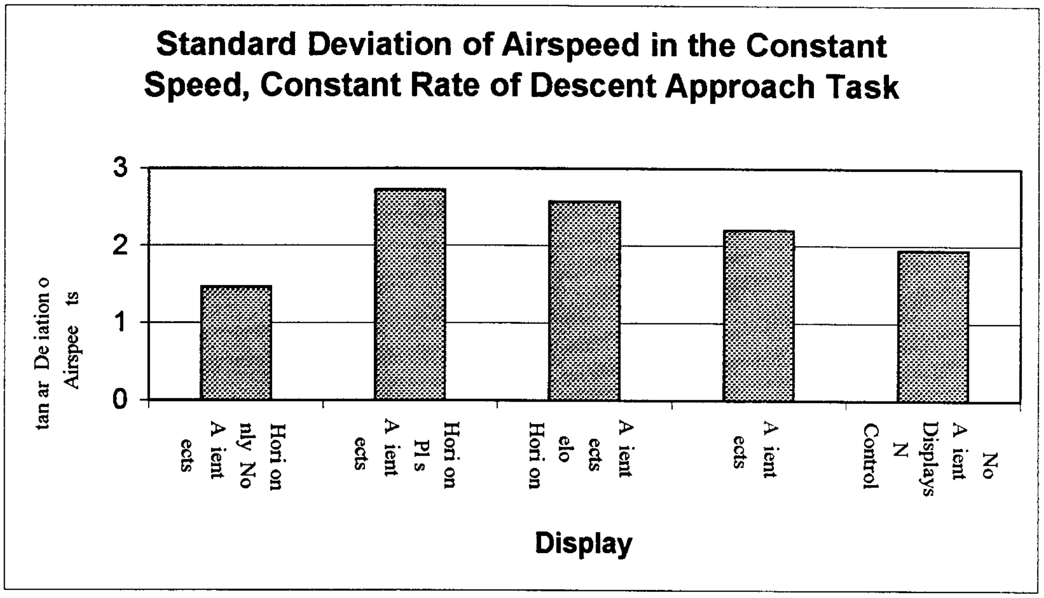


Figure 10. Standard Deviation of Airspeed in the Constant Speed, Constant Rate of Descent Approach Task.

<u>Rate of Descent</u>

The average rate of descent in each display condition is shown in Figure 11. There was no "target" or "ideal" rate of descent in this task; the pilot selected the rate of descent that would result in a constant glideslope towards the landing area.

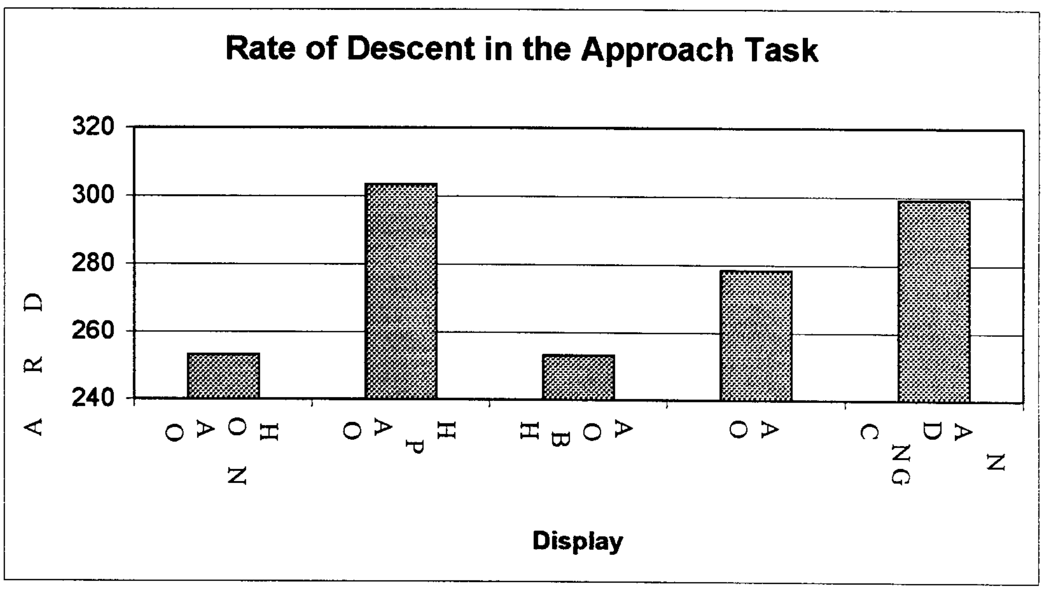


Figure 11. Average Rate of Descent in the Constant Speed, Constant Rate of Descent Approach Task.

Rate of Descent Variability

The standard deviation of the aircraft's rate of descent in each display condition is shown in Figure 12. This figure suggests that the addition of an artificial horizon, either alone or in conjunction with ambient objects, slightly impairs the pilot's ability to maintain a constant rate of descent relative to the NVG without ambient displays condition. However, ambient objects alone appear to reduce the variability.

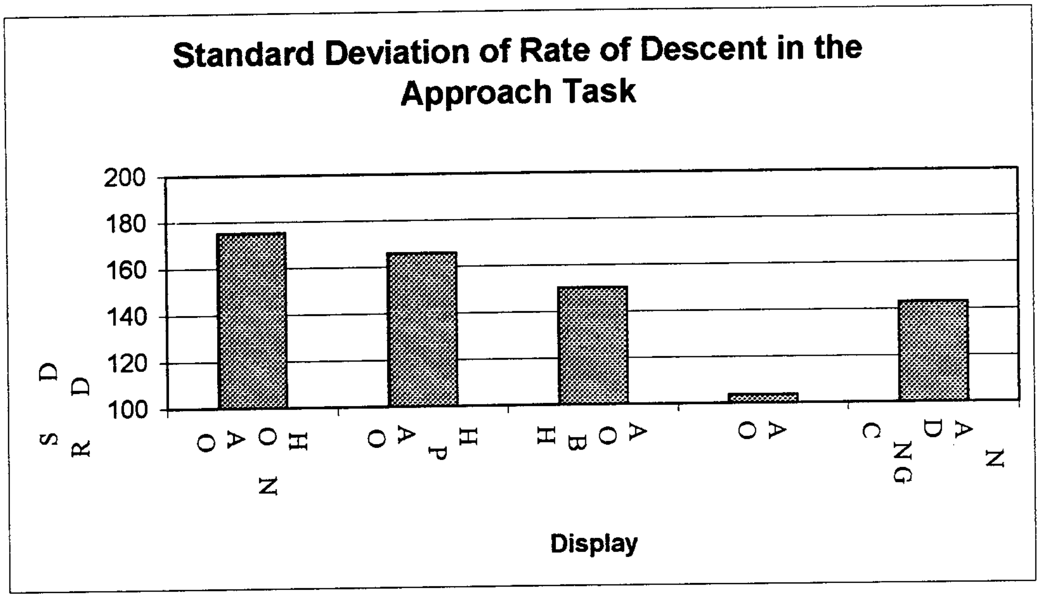


Figure 12. Standard Deviation of Rate of Descent in the Constant Speed, Constant Rate of Descent Approach Task.

PIROUETTE

Standard Deviation of Bank Angle

In the pirouette, pilots attempt to maintain a constant side slip rate and accompanying turn rate to smoothly fly over the circle. In order to maintain a constant side slip rate, the aircraft's bank angle would remain constant. Figure 13 shows the standard deviation of the aircraft's bank angle in each display condition. This figure shows that the bank angle was held more constant when a full field of ambient objects was displayed than when the ambient objects filled only part of the field, only an artificial horizon was presented, or when the scene consisted of a NVG only display. This is surprising as it was expected that the artificial horizon cue would be beneficial in and of itself.

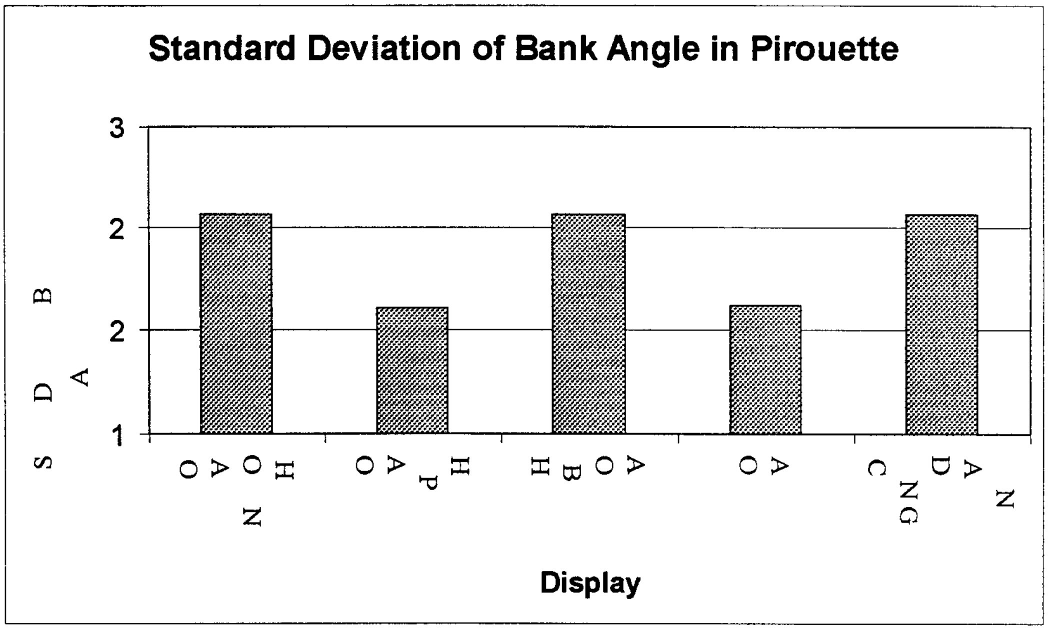


Figure 13. Standard Deviation of the Aircraft's Bank Angle in the Pirouette Maneuver.

Average Altitude

In the pirouette task, pilots attempted to maintain an altitude of 20 ft AGL. As can be seen in Figure 14, the average altitude was about 22 ft AGL in all display conditions except the condition with ambient objects only below the horizon, where the average altitude was approximately 24 ft AGL.

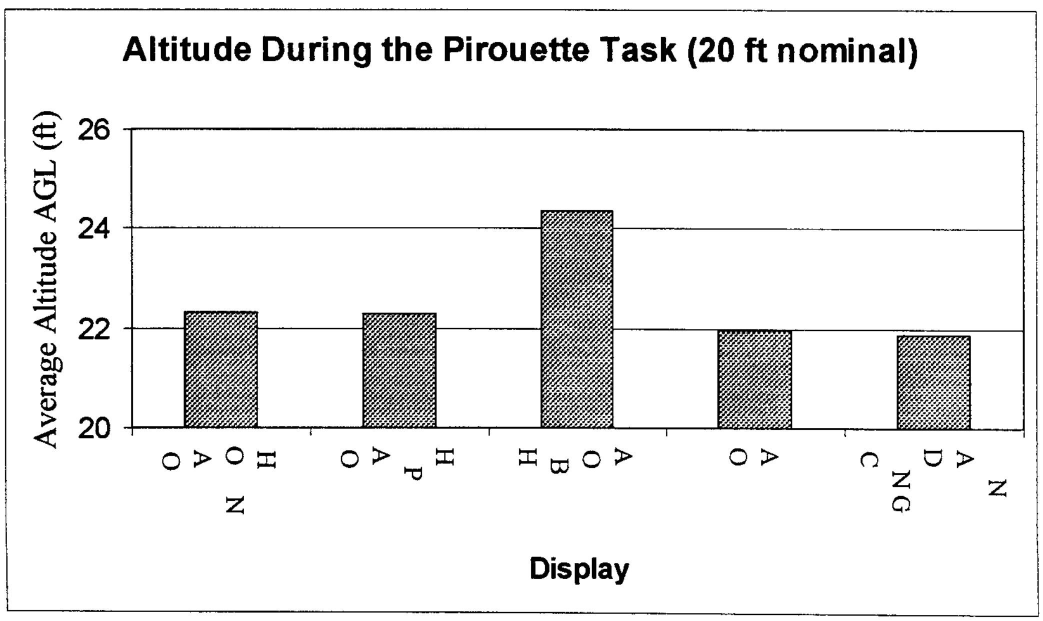


Figure 14. Average Altitude in the Pirouette Task.

Altitude Variability

The standard deviation of the aircraft's altitude is shown in Figure 15. It was expected that the vertical flow of the ambient objects as the aircraft's altitude changed would allow pilots to take corrective action in a more timely fashion and thereby reduce the altitude variability. No effect of the artificial horizon alone was anticipated. The data show that the vertical velocity movement of the ambient objects did not allow the pilots to maintain altitude more consistently than they could without the ambient displays.

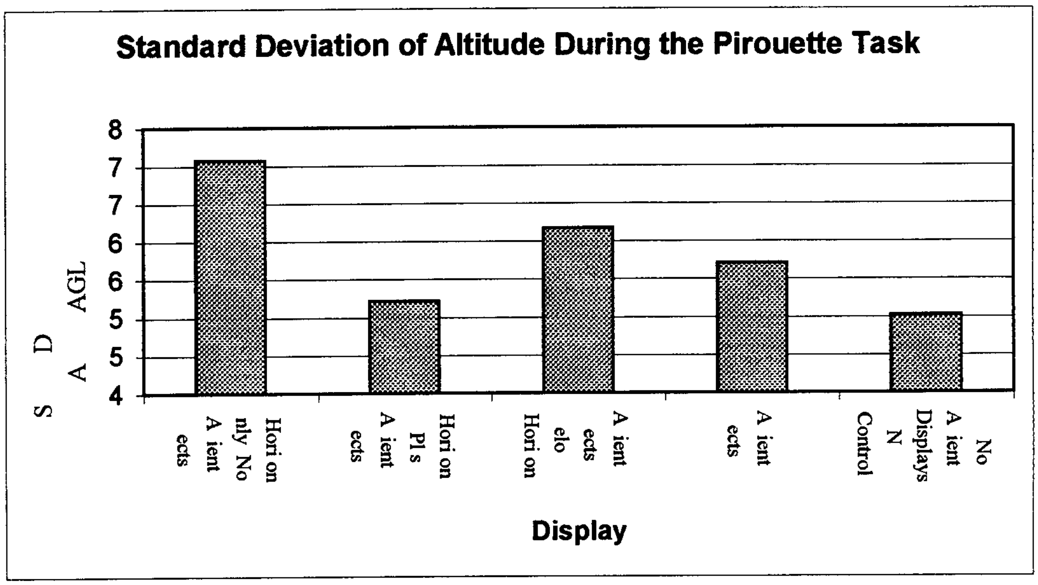


Figure 15. Standard Deviation of Altitude in the Pirouette Task.

Average Distance Error

During the pirouette task pilots attempted to keep the helicopter directly above a circle marked on the ground. This circle was 100 meters in diameter. Figure 16 shows the average position error relative to the circle. In all cases, the pilots tended to be outside the circle during this maneuver.

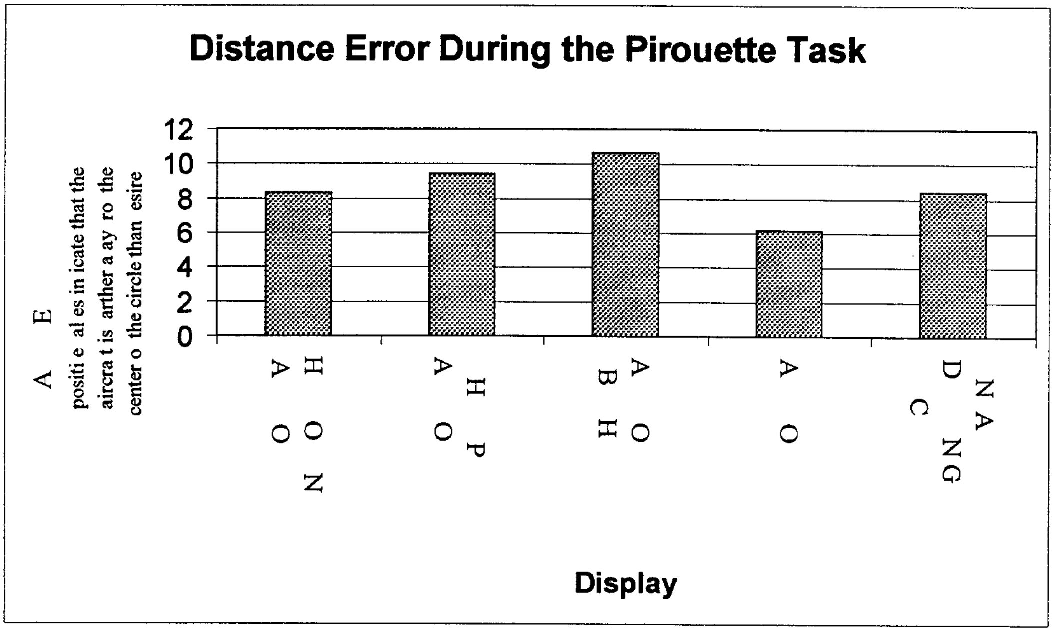


Figure 16. Average Distance Error in the Pirouette Task.

Variability of Distance Error

It had been expected that the longitudinal flow of the ambient objects caused by the aircraft drifting forwards or backwards would allow pilot to reduce the variability of the aircraft's position error. Figure 17 shows the standard deviation of the aircraft's distance from the circle in all of the display conditions. These data indicate that the flow of the ambient objects did not improve the pilot's ability to maintain a constant distance from the circle compared to the NVG only condition. This figure also shows that performance deteriorated when the artificial horizon alone was presented.

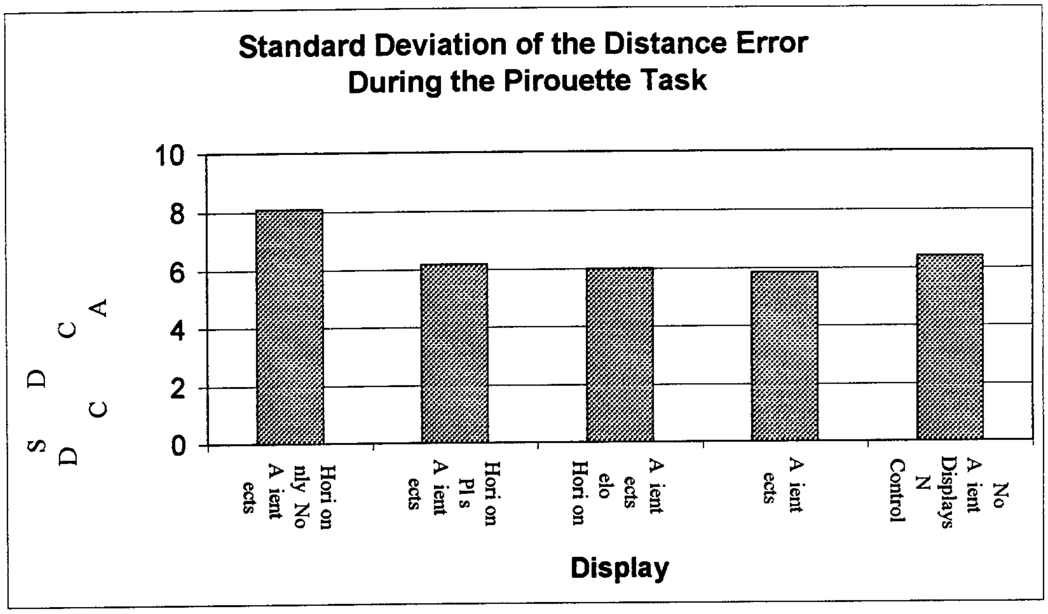


Figure 17. Variability of Distance Error in the Pirouette Task.

SLALOM

Average Altitude

Pilots attempted to maintain an altitude of 50 ft AGL during the slalom. Figure 18 shows the average altitude in each of the display conditions. The altitude error was smallest in the artificial horizon only condition. The altitude error was greater in all conditions where the display contained ambient objects than in the NVG control condition.

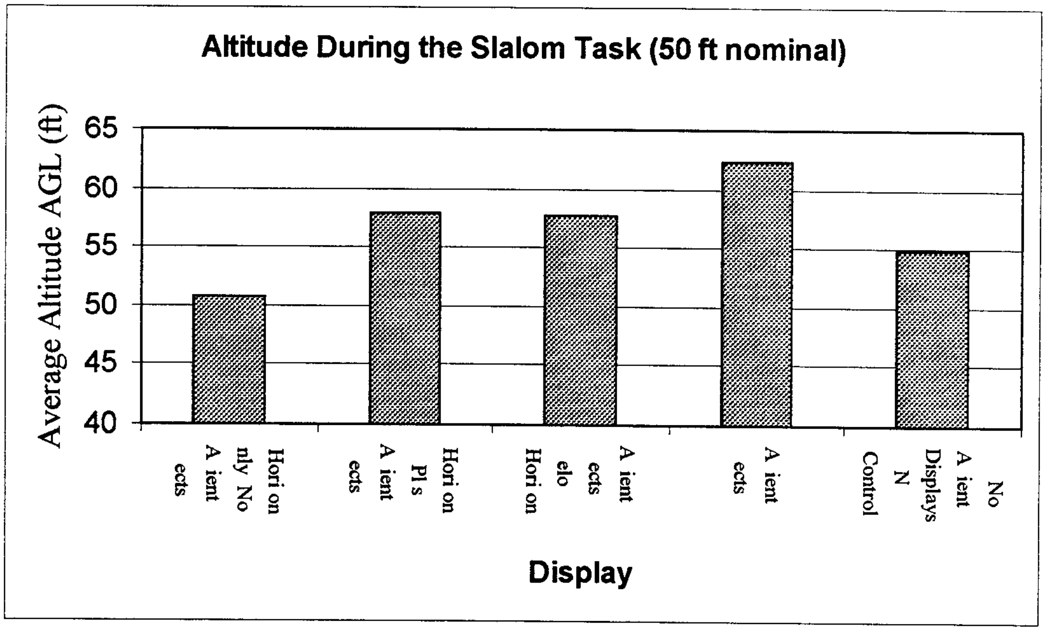


Figure 18. Average Altitude in the Slalom Task.

Altitude Variability

Vertical motion of the ambient objects was expected to provide the pilot information about changes in the aircraft's altitude. If the pilot is able to use this information, the altitude variability should decrease. Figure 19 shows the standard deviation of altitude in all of the display conditions.

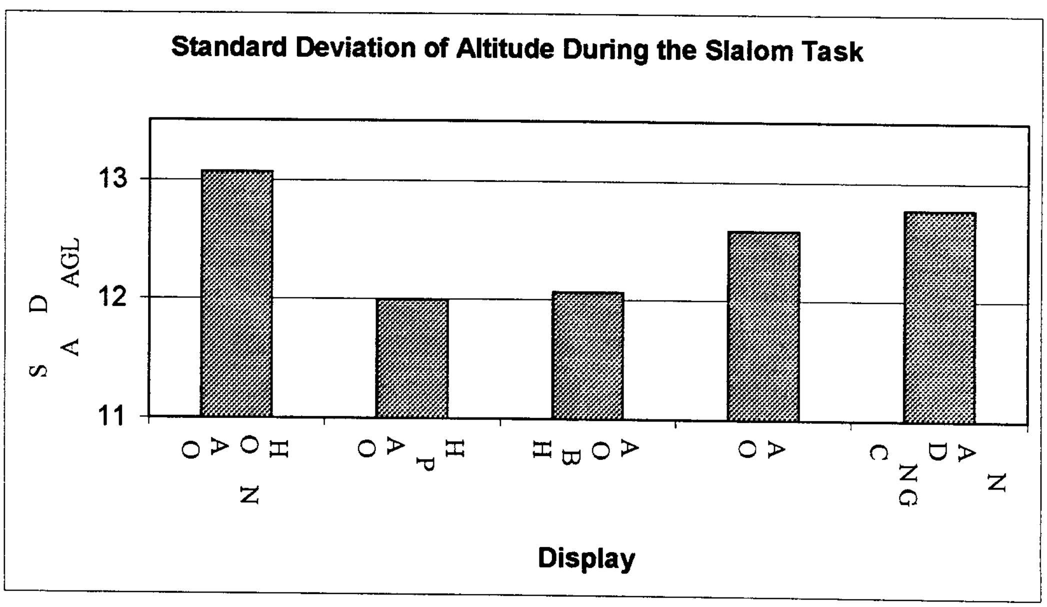


Figure 19. Standard Deviation of Altitude in the Slalom Task.

These data show that neither ambient objects by themselves nor an artificial horizon by itself improved performance relative to the NVG only condition. However, the combination of an artificial horizon with ambient objects did allow the pilots to maintain a slightly more consistent altitude.

Average Airspeed

The target airspeed during the slalom was 20 kts. The average airspeed in each display condition is shown in Figure 20.

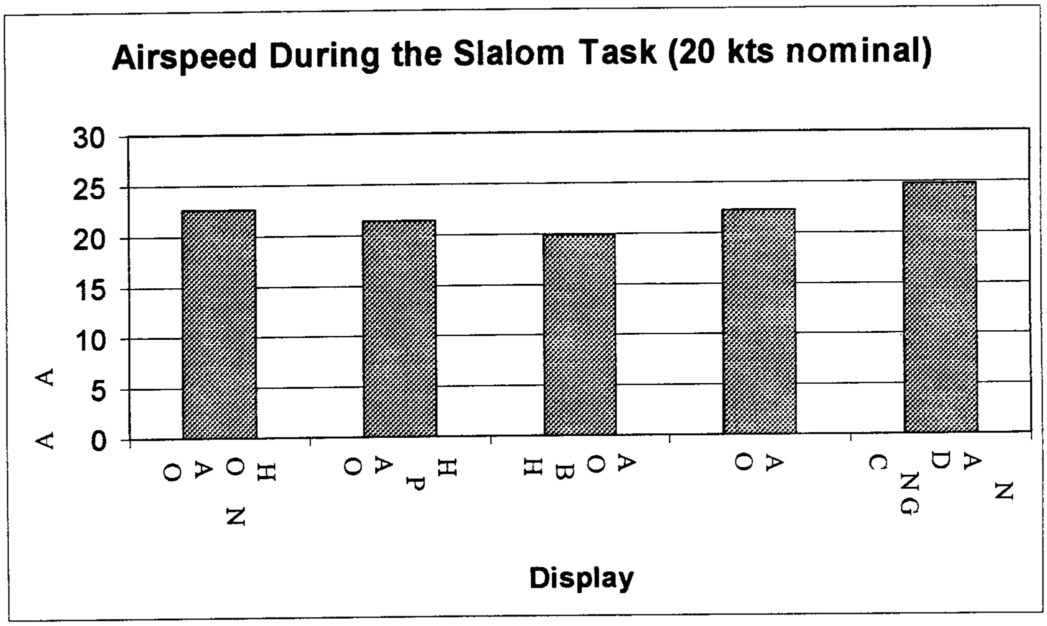


Figure 20. Average Airspeed in the Slalom Task.

Maintaining a constant airspeed using the information contained in the flow rate of the ambient objects requires that the pilot develop a "sight picture" of what the flow is at the desired airspeed. It also requires the pilot to detect and correct deviations from the target airspeed.

Inspection of Figure 20 shows that the average speed was closer to the 20 kt target in all ambient display conditions than in the NVG only condition. Since the artificial horizon does not convey any information about the airspeed, performance in the artificial horizon only condition was not expected to differ from the NVG only condition.

Airspeed Variability

If the pilot is able to identify changes in airspeed from changes in the flow rate of the ambient objects and initiate corrections faster than is possible when performing the task with a NVG only scene, then the variability of airspeed should be smaller when ambient objects are displayed. Figure 21 shows the standard deviation of airspeed in the slalom task.

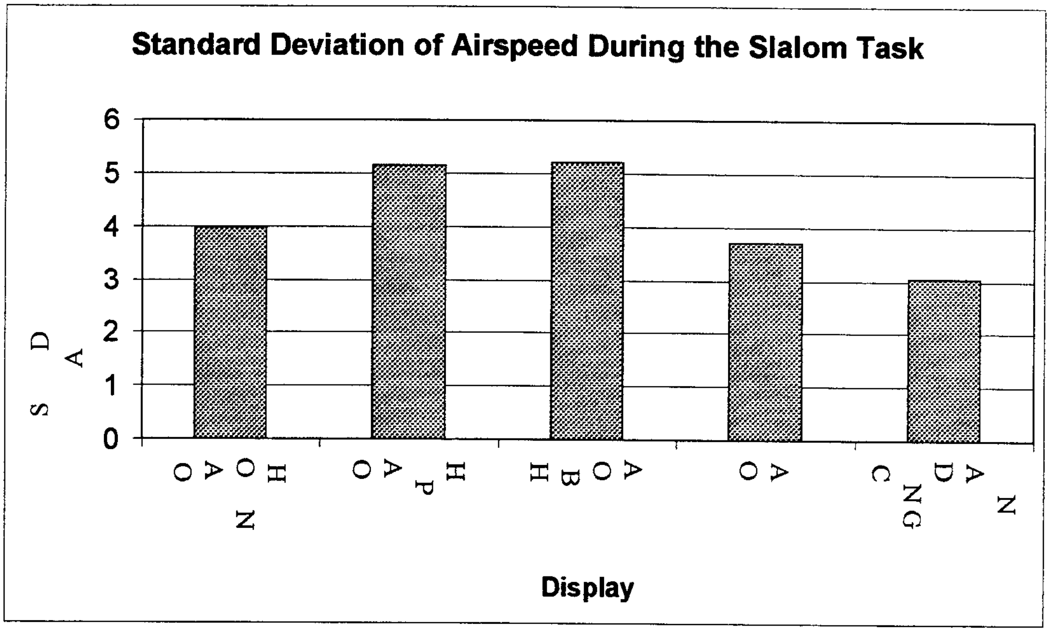


Figure 21. Standard Deviation of Airspeed in the Slalom Task.

These data show that the variability in airspeed was larger when ambient displays were available. This result suggests that pilots were not able to used the information in the flow rate of the ambient objects to better maintain speed.

SUBJECTIVE DATA

Pilots completed two types of questionnaires during this study. The first type of questionnaire was completed after each simulated flight in which the pilot used one of the ambient displays. The data obtained from this questionnaire compare the four experimental display conditions against each other. This questionnaire appears in Appendix 1.

The second type of questionnaire was completed following the final flight, which was always the NVG only control condition. This questionnaire allows comparisons between the four experimental conditions and the NVG only control condition. This questionnaire appears in Appendix 2.

POST FLIGHT QUESTIONNAIRE

In this questionnaire pilots responded to a series of 24 questions by responding on 7-point scales. The questions were phrased so that a rating of "4" indicates that the display was equivalent to a NVG only display. Ratings greater than "4" indicate that the ambient display was judged to be superior to a NVG only display, and ratings less than "4" indicated that the ambient display was inferior.

Awareness of Fore-Aft Speed

The average ratings of the effects of the ambient displays on the pilot's ability to maintain awareness of the aircraft's fore and aft motion are shown in Figure 22. Pilots rated the display containing ambient objects filling the entire field as being best. The displays containing both ambient objects and an artificial horizon were judged to be better than the NVG only display. The ambient display containing only an artificial horizon was rated as being equivalent to the NVG scene along this dimension.

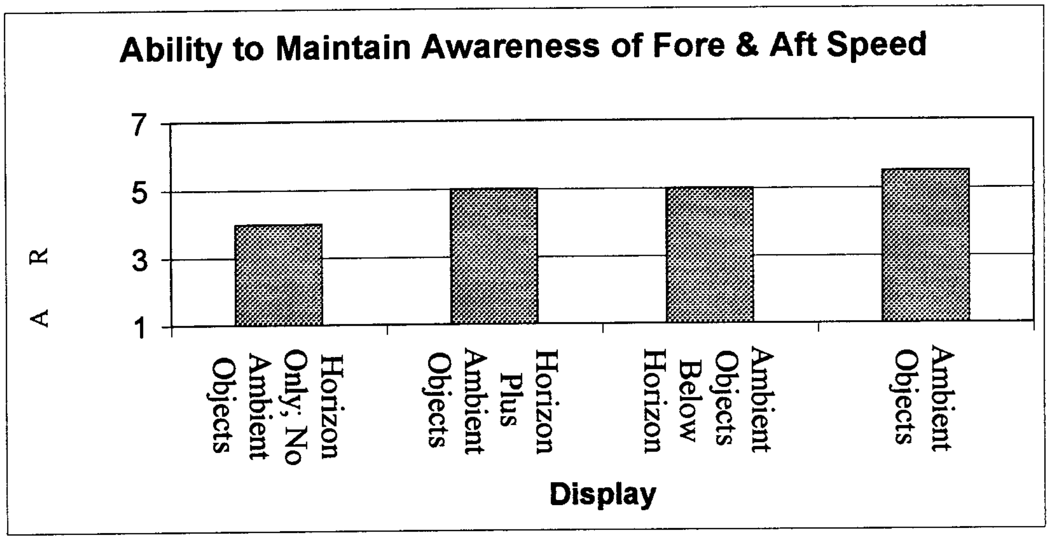


Figure 22. Average Rating of the Effects of the Ambient Displays on the Pilot's Ability to Maintain Awareness of the Aircraft's Fore and Aft Motion.

Ability to Detect Changes in Fore-Aft Motion

The average ratings of the effect of the displays on the pilot's ability to detect changes in fore and aft motion are shown in Figure 23. The displays containing a full fields of ambient objects were rated superior to the display containing only a partial field of ambient objects. This suggests that the motion in the full field was noticed more readily than when the motion was below the horizon only. In part, this may be due to the fact that in the deceleration portion of the acceleration/deceleration task the pilots view of the area below the horizon was limited by the nose-up pitch of the aircraft and the vestigial cockpit structure.

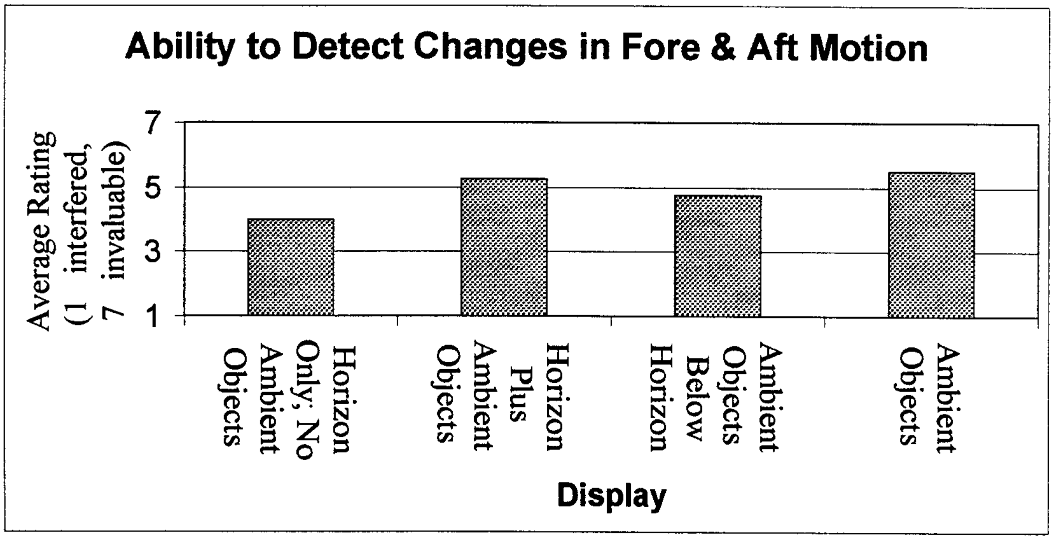


Figure 23. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Detect Changes in Fore and Aft Motion of the Aircraft.

Ability to Maintain Awareness of Vertical Speed

Figure 24 shows the average ratings of the effect of the ambient displays on the pilot's ability to maintain awareness of the aircraft's vertical speed. The full field display of ambient objects was rated as being better than the other displays, and better than a NVG only scene. The other tow displays containing ambient objects were rated as being roughly the same, and both were judged to be better than a NVG only scene. The ambient display containing only an artificial horizon was rated as being the same as a NVG scene.

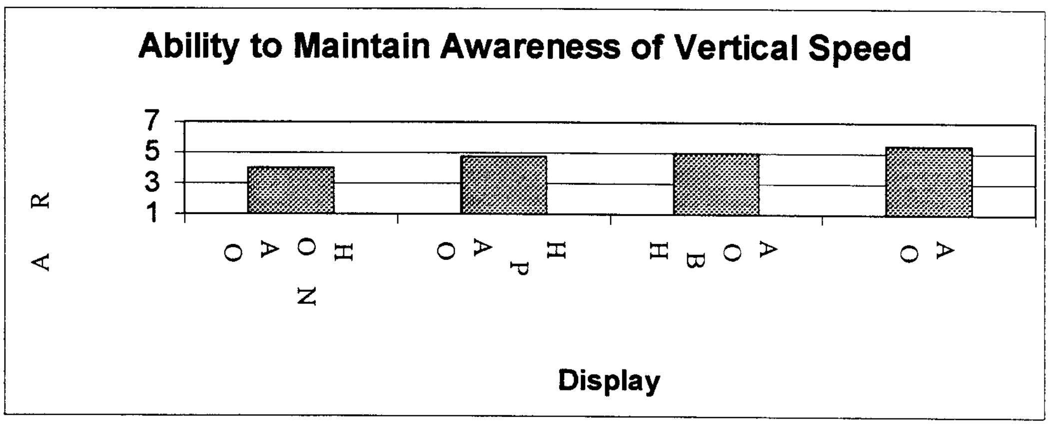


Figure 24. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Maintain Awareness of the Aircraft's Vertical Speed.

Ability to Detect Changes in the Aircraft's Vertical Speed

The average ratings of the effect of the displays on the pilot's ability to detect changes in the aircraft's vertical speed are shown in Figure 25. All of the displays containing ambient objects were rated as being approximately equivalent, and all were judged better than a NVG only scene. The display containing only an artificial horizon was rated as being roughly the same as a NVG only scene.

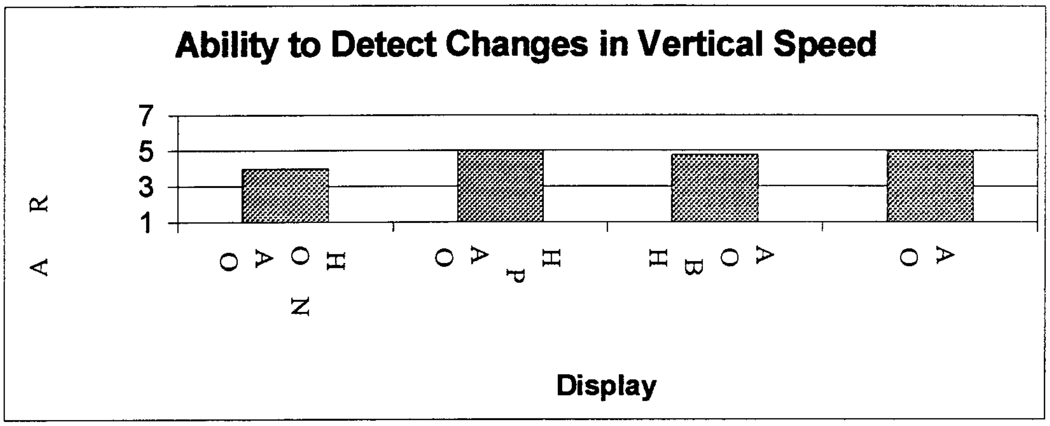


Figure 25. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Detect Changes in the Aircraft's Vertical Speed

Ability to Maintain Awareness of Pitch

The average ratings of the ambient displays on the pilot's ability to maintain awareness of the aircraft's pitch angle are shown in Figure 26. These ratings indicate that the pilots were not obtaining useful information about the aircraft's pitch angle from the motion or orientation from the ambient objects. Instead, the pilot's were using the artificial horizon to obtain information about aircraft pitch attitude. However, the pilots rated the display with an artificial horizon as being only a slight improvement over a NVG scene.

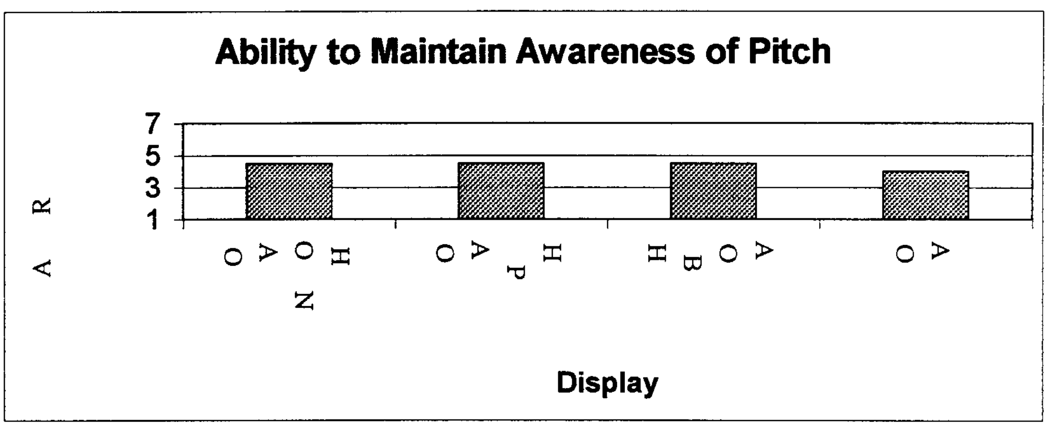


Figure 26. Average Ratings of the Ambient Displays on the Pilot's Ability to Maintain Awareness of the Aircraft's Pitch Angle.

Ability to Detect Changes in Aircraft Pitch

All of the displays containing an artificial horizon were rated as slightly improving the pilot's ability to detect changes in aircraft pitch compared to a NVG only scene. The ambient display without an artificial horizon was rated as being equivalent to a NVG scene. The average ratings are shown in Figure 27.

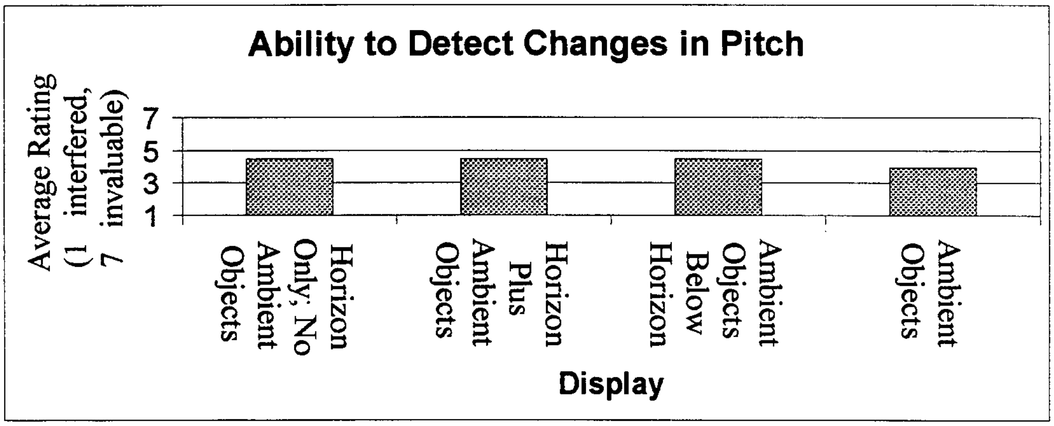


Figure 27. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Detect Changes in Aircraft Pitch

Ability to Maintain Awareness of Roll

The average ratings of the pilot's ability to maintain awareness of roll are shown in Figure 28. The displays containing an artificial horizon only and ambient objects below the horizon were rated as improving the pilot's ability to maintain awareness of aircraft roll compared to a NVG only scene. The display combining ambient objects and an artificial horizon was judged to be equivalent to a NVG scene, and the display with ambient objects but no horizon information was judged to be slightly inferior to a NVG only scene.

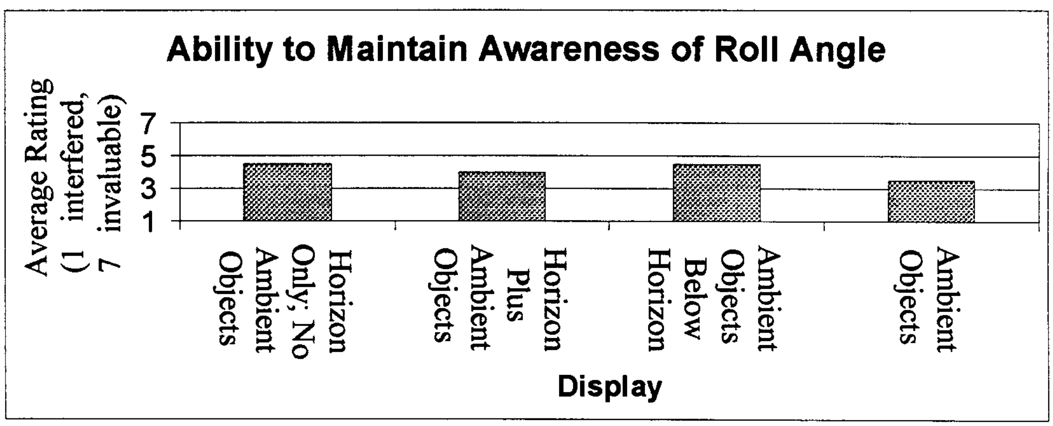


Figure 28. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Maintain Awareness of Roll.

Ability to Detect Changes in Roll

The average ratings of the pilot's ability to detect changes in roll with each of the ambient displays are shown in Figure 29. As in the case of awareness of roll, the displays with artificial horizon only and with ambient objects below the horizon were rated as being a moderate improvement over a NVG only scene. The display combining ambient objects throughout the field with an artificial horizon was rated as being equivalent to a NVG only scene. The display containing only ambient objects but no artificial horizon was rated as being somewhat worse than a NVG only scene.

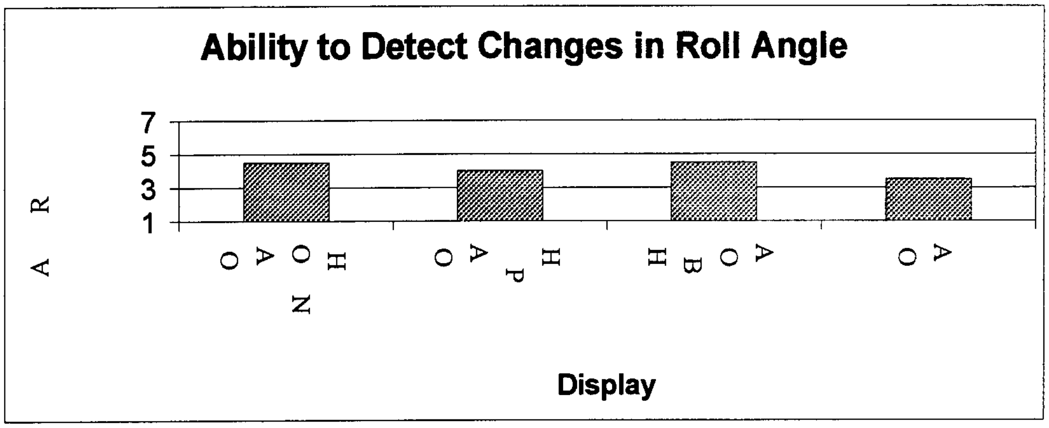


Figure 29. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Detect Changes in Roll

Ability to Maintain Awareness of Heading

The average ratings of the effect of the ambient displays on the pilot's ability to maintain awareness of the aircraft's heading are shown in Figure 30. The display containing only an artificial horizon was rated as being roughly the same as a NVG only scene. This is not surprising since the artificial horizon was invariant with respect to changes in aircraft heading. All of the displays containing ambient objects were rated as improving the pilot's awareness of heading, with the display combining an artificial horizon with a full field of ambient objects being rated best.

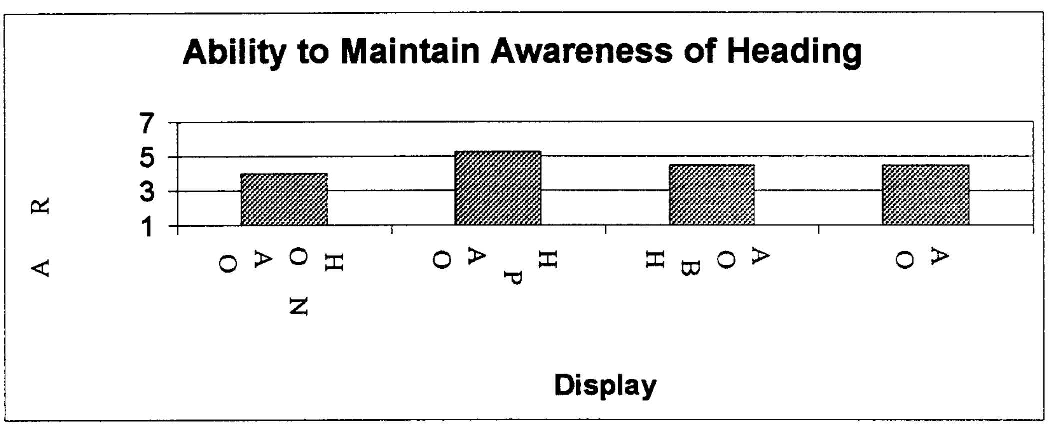


Figure 30. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Maintain Awareness of Aircraft Heading.

Ability to Detect Changes in Heading

The average ratings of the ambient displays on the pilot's ability to detect changes in the aircraft's heading are shown in Figure 31. All of the displays containing ambient objects were rated as being better than a NVG only scene. The differences between these three conditions is small. The artificial horizon only condition was rated as being similar to a NVG only scene.

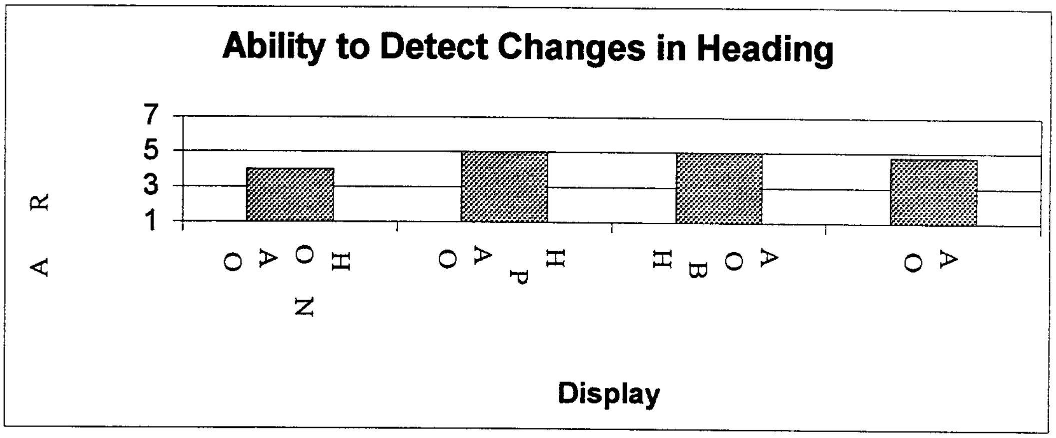


Figure 31. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Detect Changes in Aircraft Heading.

Visual Clutter

Pilots rated all of the displays containing ambient objects as being slightly more cluttered than a NVG only display. The ambient display containing only an artificial horizon was rated as being a good deal less cluttered than a NVG only display. Figure 32 shows the average ratings of display clutter.

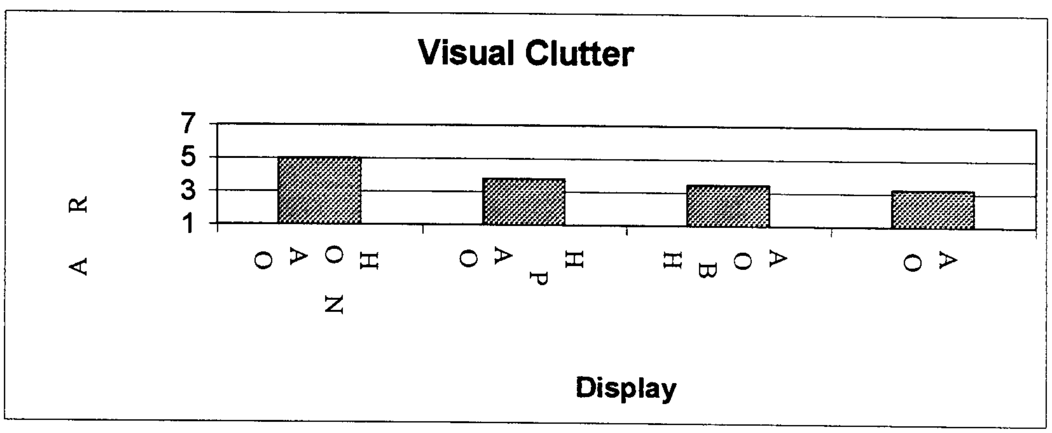


Figure 32. Average Ratings of the Visual Clutter With Each of the Ambient Displays.

Effect on Workload in the Bob Up Task

The average ratings of the effect of the ambient displays on the pilot's workload in the bob up task are shown in Figure 33. The ratings indicate that a combination of ambient objects and an artificial horizon decrease the pilot's workload. Displays with either ambient objects or an artificial horizon alone were rated as having no effect on workload compared to a NVG only scene.

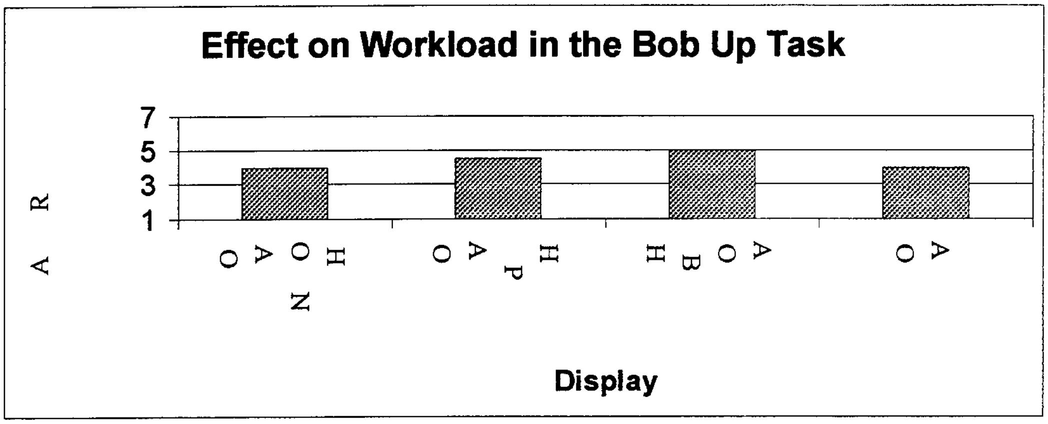


Figure 33. Average Ratings of Pilot Workload in the Bob Up Task With Each of the Ambient Displays.

Effect on Workload in the Acceleration/Deceleration Task

The presence of ambient objects reduced the pilot's workload in the acceleration/deceleration task. An ambient display with only an artificial horizon had no effect on the pilot's workload in this task. Figure 34 shows the average workload ratings with each of the ambient displays.

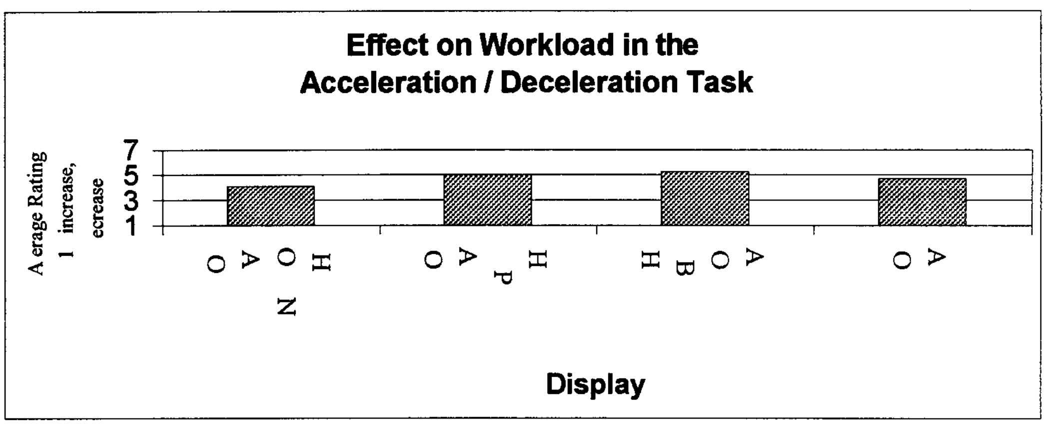


Figure 34. Average Ratings of Pilot Workload in the Acceleration/Deceleration Task With Each of the Ambient Displays.

Effect on Workload in the Constant Speed, Constant Rate of Descent Approach Task

The average ratings of the displays in terms of their effect on workload in the constant Speed, constant rate of descent approach task are shown in Figure 35. All of the displays were rated as not altering the pilot's workload relative to the workload when performing the task with a NVG only scene.

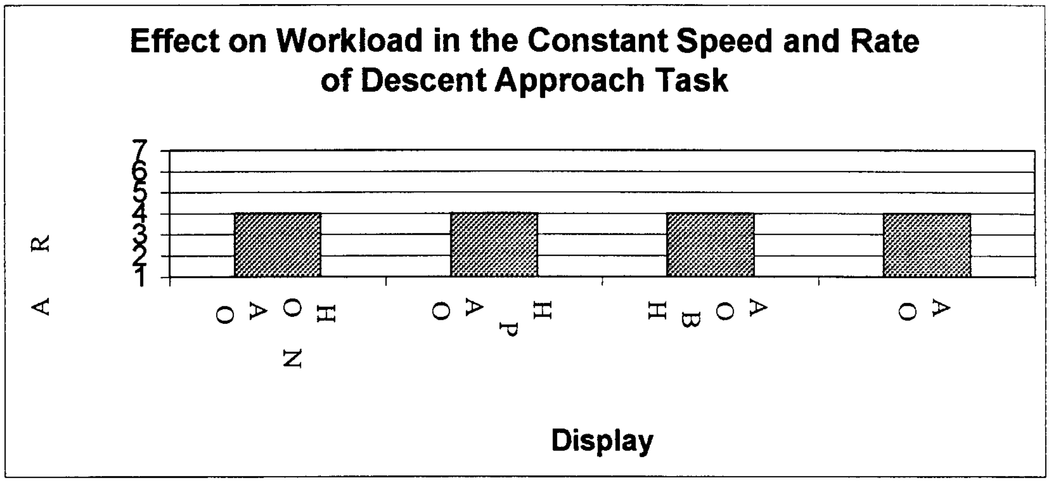


Figure 35. Average Ratings of Pilot Workload in the Constant Speed, Constant Rate of Descent Approach Task With Each of the Ambient Displays.

Effect on Workload in the Pirouette Task

All of the displays containing ambient objects were rated as causing a small reduction of workload in the pirouette task. The ambient display containing an artificial horizon was rated as having no effect on workload in this task. Figure 36 shows the average workload ratings in the pirouette task for each of the displays.

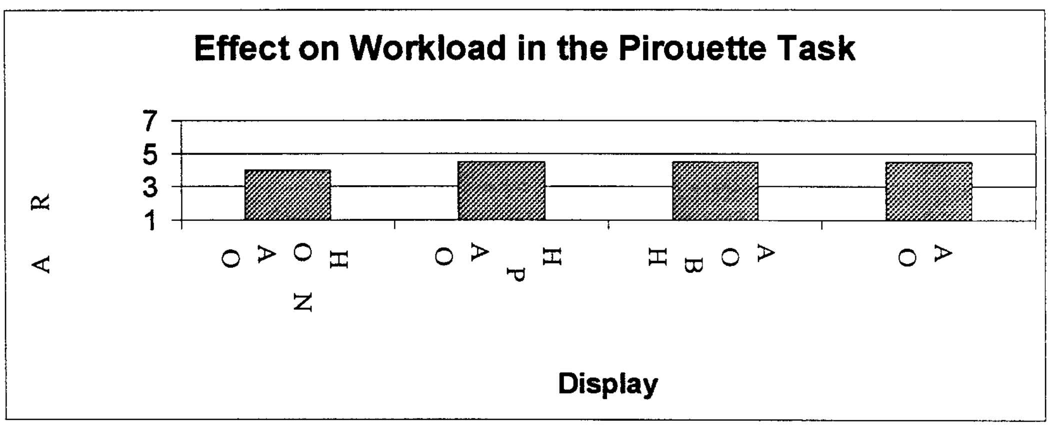


Figure 36. Average Ratings of Pilot Workload in the Pirouette Task With Each of the Ambient Displays.

Effect on Workload in the Slalom Task

All of the displays containing ambient objects were rated as increasing the pilot's workload during the slalom maneuver. The most detrimental in terms of workload is the display combining a full field of ambient objects and an artificial horizon. Displays with ambient objects below the horizon and full field ambient objects without an artificial horizon were rated worse than a NVG only scene, but not as poorly as the artificial horizon-full field ambient display. The display containing only an artificial horizon was rated as having no effect on workload. The average ratings of pilot workload in the slalom maneuver are shown in Figure 37.

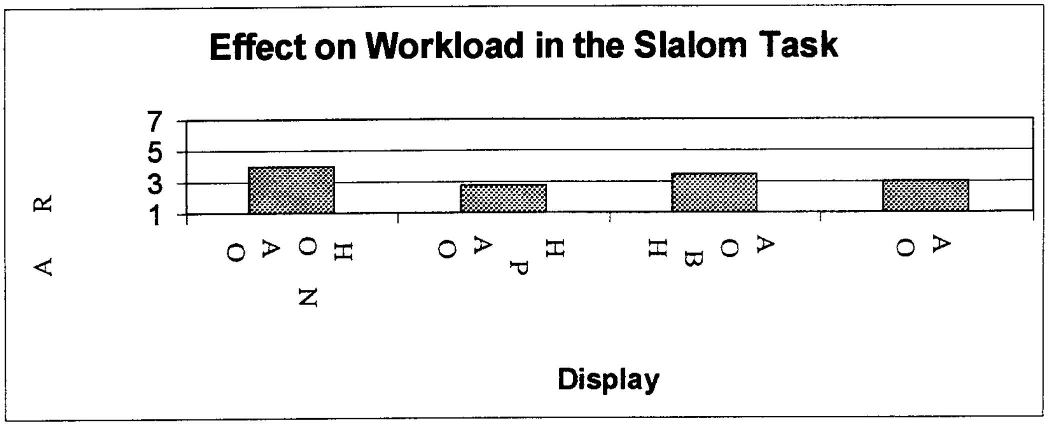


Figure 37. Average Ratings of Pilot Workload in the Slalom Task With Each of the Ambient Displays.

<u>Effect on the Pilot's Ability to Perform the Bob Up Maneuver</u>

The pilot's rated the displays combining an artificial horizon with ambient objects as having a small, but positive, effect on their ability to perform the bob up task. Displays with ambient objects but no artificial horizon and with an artificial horizon but no ambient objects were judged to have no impact on the pilot's ability to perform this task. The average ratings are shown in Figure 38.

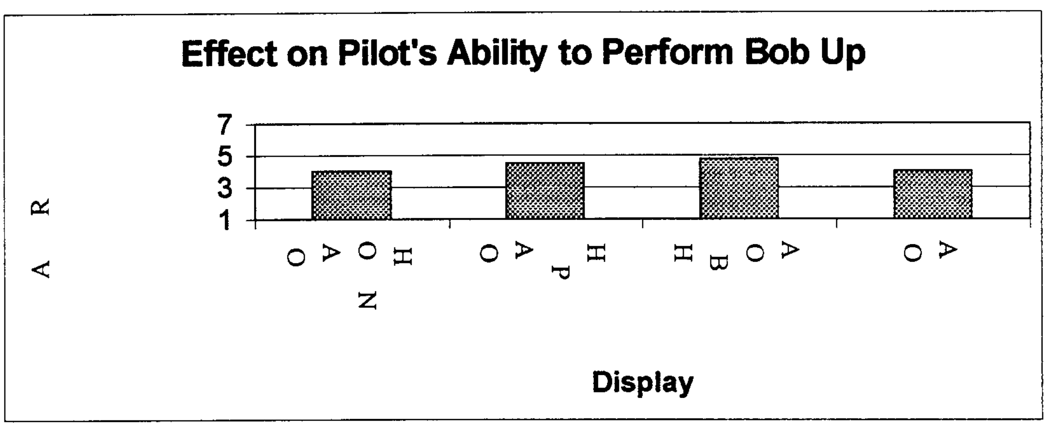


Figure 38. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Perform the Bob Up Maneuver

<u>Effect on the Pilot's Ability to Perform the Acceleration/Deceleration Maneuver</u>

The average ratings of the effects of the ambient displays on the pilot's ability to perform the acceleration/deceleration maneuver are shown in Figure 39. The display with ambient objects throughout the full field was rated as having the greatest positive effect on the pilot's ability to perform this maneuver. Displays which combined an artificial horizon and ambient objects were also rated as being beneficial, although inferior to the display containing only ambient objects.

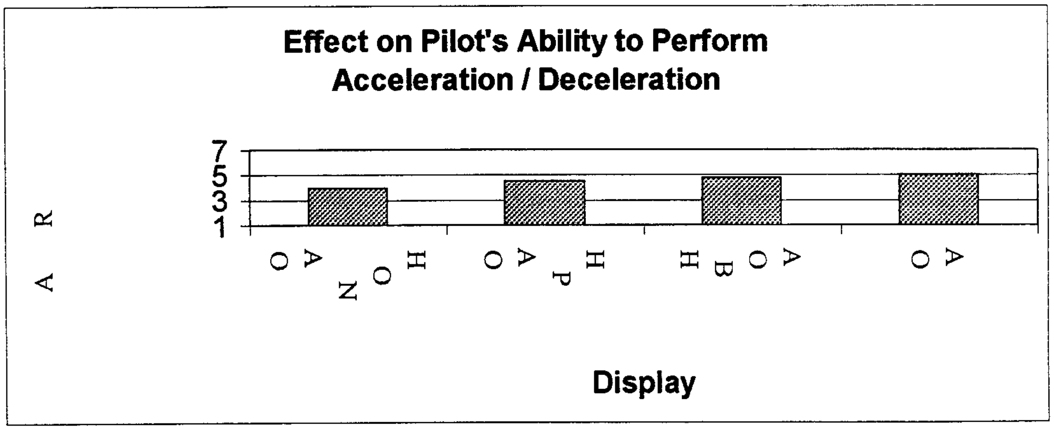


Figure 39. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Perform the Acceleration/Deceleration Maneuver.

<u>Effect on the Pilot's Ability to Perform the Constant Speed, Constant Rate of Descent Approach Maneuver</u>

Figure 40 shows the average ratings of the effect of the ambient displays on the pilot's ability to perform the constant speed, constant rate of descent approach task. All of the ambient displays were rated as having no effect on the pilot's ability to perform this task.

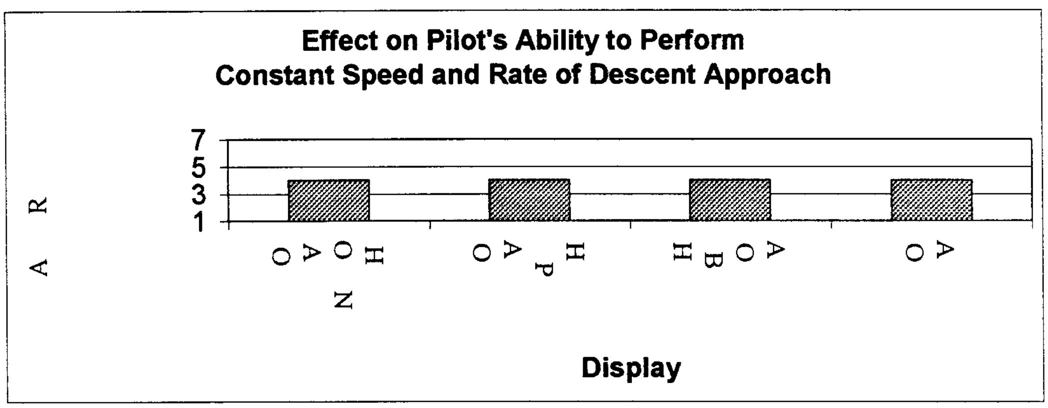


Figure 40. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Perform the Constant Speed, Constant Rate of Descent Approach Maneuver

<u>Effect on the Pilot's Ability to Perform the Pirouette Maneuver</u>

The displays containing ambient objects were all rated as having a small, positive effect on the pilot's ability to perform the pirouette maneuver. The addition of an artificial horizon did not add or subtract from the effect of the ambient objects. An artificial horizon alone had no effect on the pilot's ability to perform this maneuver compared to a NVG only condition. The average ratings of the effect of the ambient displays on the pilot's ability to perform the pirouette are shown in Figure 41.

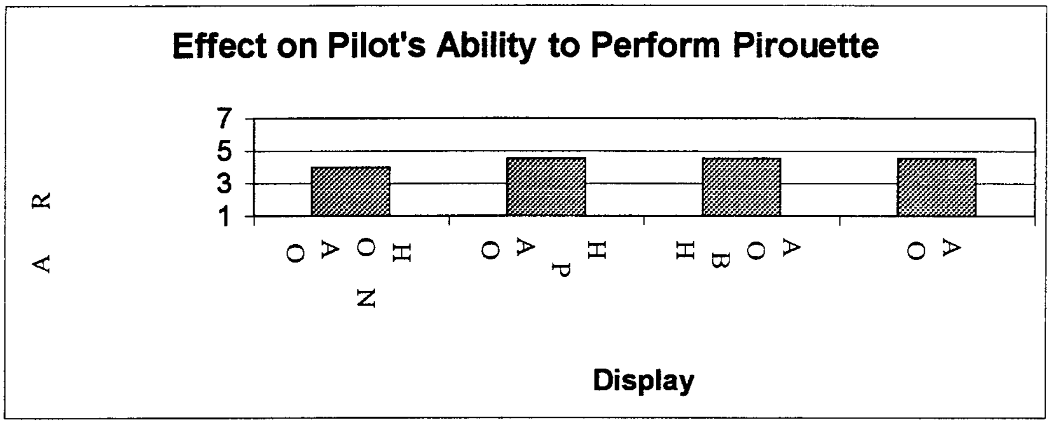


Figure 41. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Perform the Pirouette Maneuver.

Effect on the Pilot's Ability to Perform the Slalom Maneuver.

The average ratings of the effect of the ambient displays on the pilot's ability to perform the slalom task are shown in Figure 42. Only the artificial horizon only condition was judged to have a positive effect. All of the other conditions were judged to harm the pilot's ability to perform the slalom.

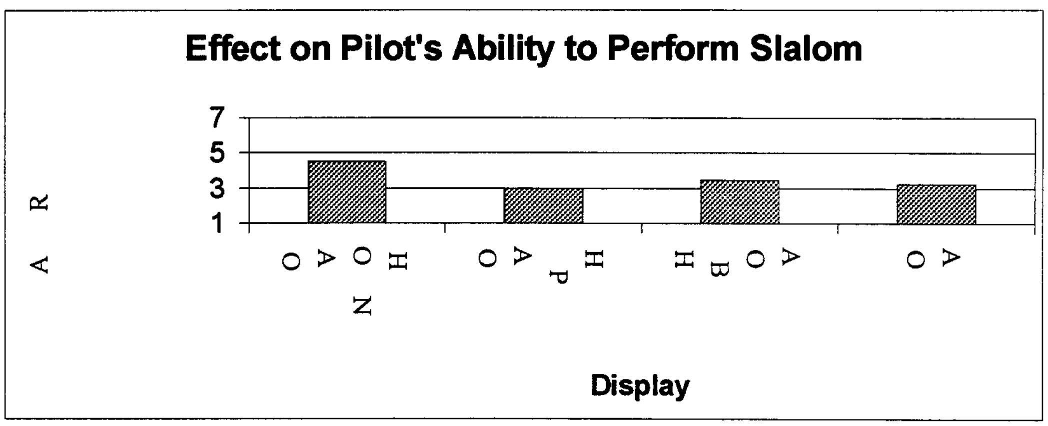


Figure 42. Average Ratings of the Effect of the Ambient Displays on the Pilot's Ability to Perform the Slalom Maneuver.

Overall Acceptability of the Ambient Displays

The displays consisting of the artificial horizon only and the ambient objects below the horizon were rated as being minimally acceptable to fly with in an aircraft. The display consisting of a full field of ambient objects was rated as being only slightly below the acceptable level. The display combining a full field of ambient objects with an artificial horizon was rated as being below the acceptable level. The average ratings of overall acceptability are shown in Figure 43.

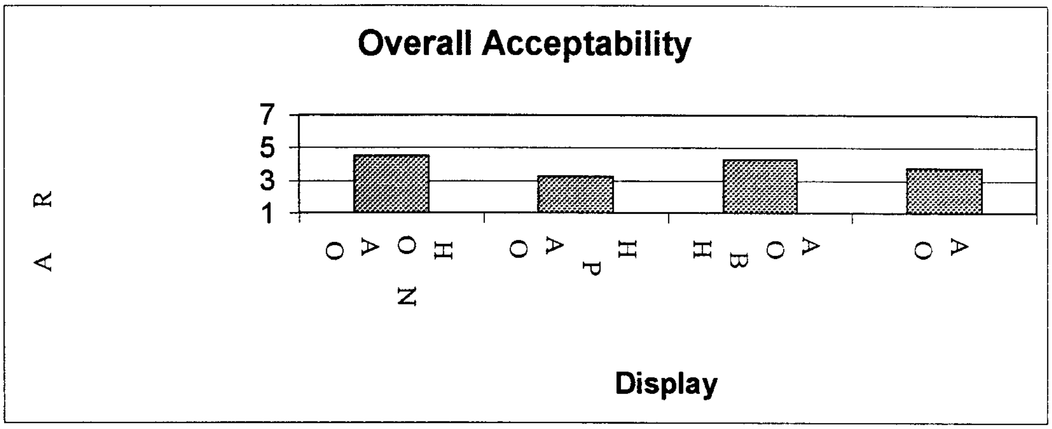


Figure 43. Average Ratings of Overall Acceptability of Each of the Ambient Displays.

Conscious Awareness of Ambient Displays

The average ratings of the amount of time the pilots were consciously aware of the ambient displays are shown in Figure 44. The display containing only an artificial horizon is the only display pilots report being aware of consciously over half of the time. The ratings indicate that pilots were aware of the display containing the artificial horizon plus ambient objects and the display containing only ambient objects slightly less than half of the time. The proportion of time the pilots were aware of the display consisting of ambient objects below the horizon was smallest.

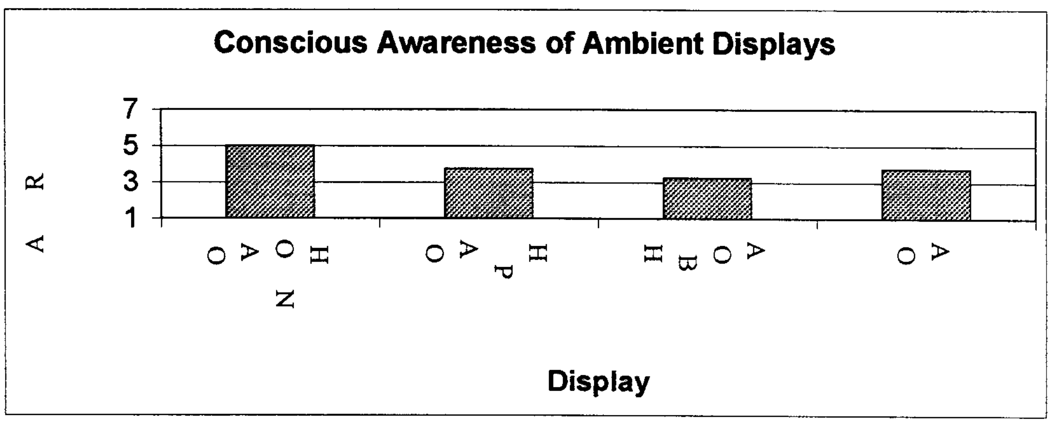


Figure 44. Proportion of Time Pilots Were Consciously Aware of the Ambient Display.

Amount of Attention Paid to the Ambient Displays

Figure 45 shows that pilots paid attention to the display containing only the artificial horizon the least of all the displays by a large margin. They also report paying attention to the display with

Aircraft Roll

The pattern of average rank orders of the displays in terms of providing the pilots awareness of the aircraft's roll and awareness of roll changes are identical. These rank orders are shown in Table 4. The rank orders indicate that all of the ambient displays were an improvement over the NVG only display.

	Artificial Horizon Only; No Ambient Objects	Artificial Horizon Plus Ambient Objects	Ambient Objects Below Horizon	Ambient Objects Throughout the Display	No Ambient Displays (NVG Control)
Awareness of Aircraft Roll	3.5	1.5	3.5	2.5	4.0
Awareness of Roll Changes	3.5	1.5	3.5	2.5	4.0

Table 4. Average rank orders of how well the displays supported the pilot's ability to maintain awareness of aircraft roll and their ability to detect changes in roll.

The display containing an artificial horizon plus ambient objects was rated best, followed by the display containing ambient objects throughout. The display containing an artificial horizon and the display with ambient objects below the horizon were rated equally. Again, it had been expected that pilots would find a clear indication of the horizon to be more helpful than the field of ambient objects. This expectation is not supported by these data.

Visual Clutter

The average rank orders of visual clutter are shown in Table 5. Not surprisingly, the NVG control condition was rated as being least cluttered. This is simply due to the absence of any symbols in the peripheral displays. Interestingly, the two ambient displays rated as being least cluttered , the artificial horizon only and the artificial horizon plus ambient objects, are very different in terms of the proportion of the peripheral screens occupied by "symbols". Also interesting is the fact that the display containing ambient objects below the horizon (which has the second smallest proportion of the display area occupied by "symbols") was rated as being most cluttered.

	Artificial Horizon Only; No Ambient Objects	Artificial Horizon Plus Ambient Objects	Ambient Objects Below Horizon	Ambient Objects Throughout the Display	No Ambient Displays (NVG Control)
Visual Clutter	3.0	3.0	4.5	3.5	1.0

Table 5. Average rank orders of the visual clutter of the displays.

Overall Usefulness

The average rank orders of the overall usefulness of the display are shown in Table 6. All of the ambient display conditions were rated as being more useful than the NVG only display. The ambient displays containing an artificial horizon plus ambient objects and the display, both of which contain an indication of the horizon and of the aircraft's vertical and longitudinal translation, were judged to be most useful. The displays containing only an artificial horizon or only ambient objects were rated as being less useful than displays containing both.

	Artificial Horizon Only; No Ambient Objects	Artificial Horizon Plus Ambient Objects	Ambient Objects Below Horizon	Ambient Objects Throughout the Display	No Ambient Displays (NVG Control)
Overall Usefulness	4.0	1.5	2.0	3.0	4.5

Table 6. Average rank orders of the overall usefulness of each of the displays.

Overall Acceptability

The average rank orders of the overall acceptability of the displays are shown in Table 7. All of the ambient displays were rated as being more acceptable than was the NVG only scene. The ambient display containing an artificial horizon plus ambient objects was rated best. All of the other ambient displays were rated equally, but as being less acceptable than display consisting of an artificial horizon plus ambient objects.

	Artificial Horizon Only; No Ambient Objects	Artificial Horizon Plus Ambient Objects	Ambient Objects Below Horizon	Ambient Objects Throughout the Display	No Ambient Displays (NVG Control)
Overall Acceptability	3.0	1.5	3.0	3.0	4.5

Table 7. Average rank orders of the overall acceptability of each of the displays.

Open-Ended Questions

The rating form completed by the pilots at the conclusion of the experiment contained a series of open-ended questions, along with the ratings discussed above. The questions and the pilot's responses appear in Appendix 4.

DISCUSSION

The effects of the adding the artificial horizon were mixed. In some cases the horizon improved pilot performance. For example, average altitude was closer to the target altitude of 50 ft AGL when the ambient display consisted of an artificial horizon alone than when the ambient display contained either an artificial horizon alone or an artificial horizon coupled with ambient objects. In other cases, presenting an artificial horizon enhanced performance only when coupled with ambient objects. The standard deviation of altitude in the slalom and bob up tasks being examples of tasks where the combination of objects in the ambient displays was needed. There were several instances where the artificial horizon had an adverse impact on pilot performance, airspeed variability in the slalom being an example. However, in most tasks the effect of presenting an artificial horizon was negligible.

Subjective data from the pilots is less equivocal. There is a clear pattern in the ratings showing that the pilots found an artificial horizon useful when combined with ambient objects, particularly when the ambient objects were throughout the entire field rather than just below the horizon. An artificial horizon by itself was not considered to be a major improvement over the NVG scene. The slalom task was an exception.

In the slalom pilots reported that the ambient displays, including the condition with only the artificial horizon, were a hindrance. During the slalom the aircraft was often moving in a six degrees of freedom simultaneously. This motion was more complex than in any of the other maneuvers flown in this experiment. The complexity of the aircraft's motion was reflected in the motion of the ambient objects. Pilots report that they had difficulty interpreting the motion of the ambient objects and in determining what control movements to make that would allow them to fly the maneuver better. Presumably, the artificial horizon alone should have been easier for the pilot's to interpret. However, it seems that the pilots did not find the pitch and roll information conveyed by the artificial horizon to be useful. Consequently, the display was merely visual clutter to them.

All of the other tasks were less dynamic than the slalom. Pilot preference for ambient displays combining an artificial horizon with other ambient objects reflects the demands placed on them by the maneuvers. Several of these maneuvers required the pilot to detect and correct drift from a specific position. The bob up and the terminal phase of the acceleration/deceleration maneuvers being the best examples. In these cases the artificial horizon provided a useful cue to aircraft attitude. This cue, coupled with information about drift rate and direction from the other ambient objects, allowed pilots to better anticipate future drift of the helicopter when making control inputs.

The combination of an artificial horizon and ambient objects facilitated pilot perception of vertical motion. Without an artificial horizon it can be very difficult to determine it the aircraft is maintaining a constant altitude, or if the altitude is changing slowly. This discrimination is made much easier when a benchmark is present. The artificial horizon provides this benchmark; the pilot can see the ambient objects being occluded by the artificial horizon as the aircraft's altitude changes. This was useful in the bob up, acceleration/deceleration, and pirouette tasks.

In all of the maneuvers, with the exception of the slalom, the aircraft bank angles required to perform these maneuvers were modest. Similarly, large pitch angles were not required except in the slalom and in the acceleration/deceleration maneuvers. For the other maneuvers, the pilots seem to have obtained aircraft attitude information from the out-the-window scene with sufficient accuracy and certainty that the incremental improvement caused by the artificial horizon was unimportant.

The pilots did not rate the display condition containing ambient objects below the horizon as highly as either the full field of ambient objects or as highly as the combination of ambient objects with an artificial horizon. The display with ambient objects below the horizon has the same information as the display combining an artificial horizon with ambient objects, but is less cluttered. None the less, pilots rated the later display superior to the former. This may indicate that the display with ambient objects below the horizon did not stimulate enough of the retina to allow longitudinal or vertical drift to be detected without conscious, focal processing.

It is worth noting that the display with ambient objects below the horizon is the only ambient display in this set that provides cues as to which direction is up, and which is down. Providing the pilot an intuitive indication of up and down may be more applicable for fixed wing aircraft than helicopters in day-to-day operations. However , this information would be critical in the event of entering inadvertent IMC or when recovering from an unusual attitude, which is applicable to both fixed- and rotor-wing aircraft. These conditions were not examined in this study, but should be considered before eliminating this display from further consideration.

Taken together, these results indicate that the most useful and acceptable ambient display consists of an artificial horizon superimposed on a full field of ambient objects. This indicates that pilots can make use of the information about the location of the horizon even while performing relatively benign maneuvers.

The manner in which the pilots used the horizon information isn't fully understood. It may be that the pilots used the artificial horizon to help determine the attitude of the aircraft. In this simulation, none of the instruments provided attitude information (e.g., bank angle, pitch angle). Furthermore, the visual scene did not contain information about the rotor's tip path plane, so it was difficult for the pilot to predict attitude changes. The artificial horizon could have been used to obtain information normally available from other sources. The artificial horizon could also have been useful as a visual benchmark against which pilots could judge altitude changes indicated by the vertical flow of the ambient objects. At low rates of altitude change, it is difficult to detect the vertical motion of the ambient objects, particularly when the ambient objects are moving due continuous motion of the aircraft. (For instance, when the aircraft is moving forward at some airspeed, say 20 kts, the ambient objects continuously move from the front of the display to the rear of the display). Continuous motion in one or more axes tends to make it more difficult to detect motion in other axes. These two ways of employing the information available from the artificial horizon are not mutually exclusive.

Pilots in this and in the preceding studies have commented that the ambient displays were most useful when they were attempting to hold a position and the visual cues available from the out-the-window scene were inadequate. This is consistent with the performance data which shows the ambient displays help most in tasks such as the bob up and the terminal phase of the acceleration/deceleration task. This suggests that allowing the pilot to select the points during a flight where ambient displays are available may be a reasonable implementation approach. It would be likely that pilots would not desire a full ambient display during up and away flight. In this regime, the pilot may elect to have the ambient displays blank, or perhaps display only an artificial horizon, depending on the cues that are available. In other flight regimes, for example when attempting to maintain a hove in an impoverished visual environment, the pilot might elect

POST FLIGHT RATING FORM

PILOT CODE AND DISPLAY CONDITIONS

PILOT CODE: ____________________ DATE: __________________________

EXPERIMENTAL CONDITION:

Artificial Horizon Only; No Ambient Objects
Ambient Objects Only; No Horizon
Artificial Horizon and Ambient Objects
Ambient Objects Below Horizon
NVG Control (No Ambient Displays)

PILOT RATINGS

Did the ambient display effect your ability to maintain awareness of the aircraft's fore and aft speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of speed	No effect on my awareness of speed	It was invaluable in helping me maintain awareness of speed

Did the ambient display effect your ability to detect changes in the direction of the aircraft's fore and aft motion (i.e., to tell when you began to drift backwards or forwards)?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect direction changes	No effect on my awareness of direction changes	It was invaluable in helping me detect direction changes

Did the ambient display effect your ability to maintain awareness of the aircraft's vertical speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of vertical speed	No effect on my awareness of vertical speed	It was invaluable in helping me maintain awareness of vertical speed

Did the ambient display effect your ability to detect CHANGES in the aircraft's vertical speed?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect changes in vertical speed	No effect on my awareness of vertical speed changes	It was invaluable in helping me detect changes in vertical speed

Did the ambient display effect your ability to maintain awareness of the aircraft's pitch angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of aircraft pitch	No effect on my awareness of pitch	It was invaluable in helping me maintain awareness of aircraft pitch

Did the ambient display effect your ability to detect CHANGES in the aircraft's pitch angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect pitch changes	No effect on my awareness of pitch changes	It was invaluable in helping me detect pitch changes

Did the ambient display effect your ability to maintain awareness of the aircraft's roll angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of aircraft roll	No effect on my awareness of roll	It was invaluable in helping me maintain awareness of aircraft roll

Did the ambient display effect your ability to detect CHANGES in the aircraft's roll angle?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect roll changes	No effect on my awareness of roll changes	It was invaluable in helping me detect roll changes

Did the ambient display effect your ability to maintain awareness of the aircraft's heading?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my awareness of heading	No effect on my awareness of heading	It was invaluable in helping me maintain awareness of heading

Did the ambient display effect your ability to detect CHANGES in the aircraft's heading?

|---------------|---------------|---------------|---------------|---------------|---------------|

It interfered with my ability to detect heading changes	No effect on my awareness of heading changes	It was invaluable in helping me detect heading changes

How visually cluttered was the ambient display?

|---------------|---------------|---------------|---------------|---------------|---------------|

So cluttered it was distracting	Acceptable level of clutter	No noticeable clutter

Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the bob up – turn towards target task?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

Did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene, when performing the acceleration/deceleration task?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

When flying the constant speed and rate of descent approach to landing task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

When performing the pirouette task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

When flying the slalom task did the ambient displays increase or decrease your workload, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays caused a large increase in workload	About the same	Ambient displays caused a large reduction in workload

Did the ambient displays improve or harm your ability to perform the bob up – turn towards target task, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the acceleration/deceleration task, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the constant speed and rate of descent approach to landing task, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the pirouette task, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Did the ambient displays improve or harm your ability to perform the slalom task, compared to what you expect when flying with a NVG only scene?

|---------------|---------------|---------------|---------------|---------------|---------------|

Ambient displays hurt performance	About the same	Ambient displays improved performance

Overall, how acceptable was this ambient symbol set?

|---------------|---------------|---------------|---------------|---------------|---------------|

Not acceptable as is; major changes are needed before flying with this symbol set	Minimally acceptable. Some improvements needed before this symbol set set can be flown	Acceptable as is; no changes needed are needed order to fly with this symbol set

How consciously aware were you of the ambient displays?

|---------------|---------------|---------------|---------------|---------------|---------------|

I was always aware of the ambient displays	I was aware of of the ambient symbols about half the flight	I never noticed the ambient displays

How much attention did you pay to the ambient displays?

|----------------|----------------|----------------|----------------|----------------|----------------|

I was always paying attention to the ambient displays	I paid attention of the ambient symbols half the flight	I never paid attention to the ambient displays

QUESTIONS

How did the ambient display effect your ability to maintain your awareness of the aircraft's pitch angle? In what flight conditions was your awareness improved or degraded?

Were you ever unable to determine the aircraft's pitch angle? If so, under what conditions did this occur?

How did the ambient display effect your ability to maintain your awareness of the aircraft's roll angle? In what flight conditions was your awareness improved or degraded?

Were you ever unable to determine the aircraft's roll angle? If so, in what flight conditions did this occur?

When changing the aircraft's altitude the squares in the ambient displays (in those conditions where the squares were displayed) flowed upwards or downwards on the displays while the artificial horizon (either the line or the upper limit of the area in which the squares were displayed) remained visually aligned with the horizon. Did you find the motion of the squares relative to the horizon to be disorienting or difficult to interpret? If so, in what flight conditions was did the problem occur?

If the motion of the squares appeared to be inconsistent with the motion of the artificial horizon, please describe the inconsistency and the flight conditions under which it occurred.

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

What did you most useful about this set of ambient symbols?

What did you most find least useful this set of ambient symbols?

Were you able to distinguish between the horizon and the other objects presented in the ambient field?

APPENDIX 2: POST EXPERIMENT QUESTIONNAIRE

POST EXPERIMENT QUESTIONNAIRE

PILOT CODE: ____________________ DATE: ________________________

AMBIENT DISPLAY RATINGS

Rate the ambient displays (1 = best, 5 = worst) in terms of their usefulness in the bob up task.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their usefulness in the acceleration/deceleration task.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their usefulness in the constant speed, constant rate of descent approach to landing task.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their usefulness in the pirouette task.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their usefulness in the slalom task.

____ No Ambient Objects Displayed
____ Ambient Objects Only
____ Ambient Objects Below Horizon (no horizon indicator displayed)
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of how well they supported your ability to maintain awareness of the aircraft's pitch attitude.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of how well they supported your ability to detect changes in the aircraft's pitch attitude.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of how well they supported your ability to maintain awareness of the aircraft's roll attitude.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of how well they supported your ability to detect changes in the aircraft's roll attitude.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their visual clutter.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their overall usefulness.

____ No Ambient Objects Displayed
____ Ambient Objects Only (no horizon indicator displayed)
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

Rate the ambient displays (1 = best, 5 = worst) in terms of their overall acceptability.

____ No Ambient Objects Displayed
____ Ambient Objects Only
____ Ambient Objects Below Horizon
____ Horizon Line Only
____ Horizon Line Plus Ambient Objects

QUESTIONS

Which ambient display condition best supported your ability to perform these maneuvers?

What about this display condition was particularly useful?

Did you ever find the ambient displays misleading in terms of judging the aircraft's pitch and/or roll attitude? If so, please describe the conditions in which this problem occurred.

Were there any situations where there were not enough ambient objects visible to allow you to determine the aircraft's pitch and/or roll attitude? If so, please describe the conditions in which this problem occurred.

Please use the space below to comment on any aspect of the ambient displays you used in this experiment.

APPENDIX 3: PILOT RESPONSES TO THE OPEN-ENDED QUESTIONS ON THE POST FLIGHT QUESTIONNAIRE

ARTIFICIAL HORIZON ONLY

How did the ambient display effect your ability to maintain your awareness of the aircraft's pitch angle? In what flight conditions was your awareness improved or degraded?

Pilot A: No noticeable change over the other ambient scenes so far.
Pilot B: Did not effect awareness of pitch angle.

Were you ever unable to determine the aircraft's pitch angle? If so, under what conditions did this occur?

Pilot A: Yes. During the acceleration/deceleration with the nose in the air. I can tell generally that I'm level but not with sufficient detail to control drift.
Pilot B: No.

How did the ambient display effect your ability to maintain your awareness of the aircraft's roll angle? In what flight conditions was your awareness improved or degraded?

Pilot A: No.
Pilot B: Not much awareness in roll. Slight improvement during slalom.

Were you ever unable to determine the aircraft's roll angle? If so, in what flight conditions did this occur?

Pilot A: Again, the outside world usually provides a general sense of roll attitude.
Pilot B: No.

When changing the aircraft's altitude the squares in the ambient displays (in those conditions where the squares were displayed) flowed upwards or downwards on the displays while the artificial horizon (either the line or the upper limit of the area in which the squares were displayed) remained visually aligned with the horizon. Did you find the motion of the squares relative to the horizon to be disorienting or difficult to interpret? If so, in what flight conditions was did the problem occur?

Pilot A: N/A
Pilot B: N/A this flight.

If the motion of the squares appeared to be inconsistent with the motion of the artificial horizon, please describe the inconsistency and the flight conditions under which it occurred.

Pilot A: N/A
Pilot B: N/A this flight.

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

Pilot A: Concurrent yaw and lateral translation in the pirouette.
Pilot B: No.

What did you find most useful about this set of ambient symbols?

Pilot A: Nothing.
Pilot B: Only an increased awareness of the horizon during limited maneuvers.

What did you find least useful this set of ambient symbols?

Pilot A: There wasn't much there and I didn't use what was there.
Pilot B: No drift information.

Were you able to distinguish between the horizon and the other objects presented in the ambient field?

Pilot A: N/A
Pilot B: Yes

AMBIENT OBJECTS ONLY; NO ARTIFICIAL HORIZON

How did the ambient display effect your ability to maintain your awareness of the aircraft's pitch angle? In what flight conditions was your awareness improved or degraded?

Pilot A: Don't think they had any effect.
Pilot B: No significant effect in pitch. Awareness degraded in slalom due to multi-axis "confusion" in the ambient display.

Were you ever unable to determine the aircraft's pitch angle? If so, under what conditions did this occur?

Pilot A: Never really know what the attitude is, but get relative pitch orientation from the scene
Pilot B: No.

How did the ambient display effect your ability to maintain your awareness of the aircraft's roll angle? In what flight conditions was your awareness improved or degraded?

Pilot A: It did not.
Pilot B: No significant effect on awareness of roll angle.

Were you ever unable to determine the aircraft's roll angle? If so, in what flight conditions did this occur?

Pilot A: Always had a reference to the outside world but never know what the absolute attitude is.
Pilot B: No.

When changing the aircraft's altitude the squares in the ambient displays (in those conditions where the squares were displayed) flowed upwards or downwards on the displays while the artificial horizon (either the line or the upper limit of the area in which the squares were displayed) remained visually aligned with the horizon. Did you find the motion of the squares relative to the horizon to be disorienting or difficult to interpret? If so, in what flight conditions was did the problem occur?

Pilot A: N/A
Pilot B: Not disorienting until you go into multi-axis maneuvers like the slalom.

If the motion of the squares appeared to be inconsistent with the motion of the artificial horizon, please describe the inconsistency and the flight conditions under which it occurred.

Pilot A: N/A
Pilot B: Consistent.

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

Pilot A: In sideward flight in the pirouette.
Pilot B: No.

What did you find most useful about this set of ambient symbols?

Pilot A: Good for fore and aft translation control.
Pilot B: Altitude reference and vertical speed reference.

What did you find least useful this set of ambient symbols?

Pilot A: Roll attitude information
Pilot B: Multi-axis rotations became distracting at times.

Were you able to distinguish between the horizon and the other objects presented in the ambient field?

Pilot A: N/A
Pilot B: Yes.

ARTIFICIAL HORIZON AND AMBIENT OBJECTS

How did the ambient display effect your ability to maintain your awareness of the aircraft's pitch angle? In what flight conditions was your awareness improved or degraded?

Pilot A: I was never aware that it entered my awareness of pitch at all.
Pilot B: No effect in pitch.

Were you ever unable to determine the aircraft's pitch angle? If so, under what conditions did this occur?

Pilot A: I virtually never know what the actual attitude is. I was sensitive to the horizon line when I first sat down for this set of runs but quickly lost track of it. I depended on scene elements for pitch attitude and rate.
Pilot B: No.

How did the ambient display effect your ability to maintain your awareness of the aircraft's roll angle? In what flight conditions was your awareness improved or degraded?

Pilot A: I was never sensitive to the display as a source of roll information.
Pilot B: No significant effect in awareness of roll angle. Change in roll angle is initially noted, but you don't have an awareness of a "current" roll angle.

Were you ever unable to determine the aircraft's roll angle? If so, in what flight conditions did this occur?

Pilot A: I never knew exactly what the roll attitude was, but was never uncomfortable with it.
Pilot B: No.

When changing the aircraft's altitude the squares in the ambient displays (in those conditions where the squares were displayed) flowed upwards or downwards on the displays while the artificial horizon (either the line or the upper limit of the area in which the squares were displayed) remained visually aligned with the horizon. Did you find the motion of the squares relative to the horizon to be disorienting or difficult to interpret? If so, in what flight conditions was did the problem occur?

Pilot A: No. I was never sensitive to the relative motion.
Pilot B: The only disorientation occurred during the slalom maneuver. The ambient display goes into a distracting mode when you introduce multi-axis motion.

If the motion of the squares appeared to be inconsistent with the motion of the artificial horizon, please describe the inconsistency and the flight conditions under which it occurred.

Pilot A: *no response*
Pilot B: No inconsistency.

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

Pilot A: In the pirouette the differential fore and aft motion in the ambient display was obvious and very hard to interpret at times.
Pilot B: No.

What did you find most useful about this set of ambient symbols?

Pilot A: Their use as a longitudinal translation cue.
Pilot B: Altitude and vertical speed references were very useful.

What did you find least useful this set of ambient symbols?

Pilot A: It seems roll information.
Pilot B: Multi-axis maneuvers become distracting and disorienting when ambient symbols rotate in different directions.

Were you able to distinguish between the horizon and the other objects presented in the ambient field?

Pilot A: Yes, when I consciously looked at the ambient display.
Pilot B: Yes.

AMBIENT OBJECTS BELOW ARTIFICIAL HORIZON

How did the ambient display effect your ability to maintain your awareness of the aircraft's pitch angle? In what flight conditions was your awareness improved or degraded?

Pilot A: Pitch angle cue was very hard for me to pick up consciously. I don't know that it helped me at all.
Pilot B: No real improvement for pitch angle.

Were you ever unable to determine the aircraft's pitch angle? If so, under what conditions did this occur?

Pilot A: The end of the acceleration/deceleration is particularly difficult to pick up pitch attitude when you go nose high and lose the horizon. However, you can put your nose down to the point where you can see the grid cues and still be able to stop the rearward deceleration.
Pilot B: No.

How did the ambient display effect your ability to maintain your awareness of the aircraft's roll angle? In what flight conditions was your awareness improved or degraded?

Pilot A: I don't believe it did.
Pilot B: No improvement for roll angle.

Were you ever unable to determine the aircraft's roll angle? If so, in what flight conditions did this occur?

Pilot A: I seem to be able to get sufficient roll information from the visual scene.
Pilot B: No.

When changing the aircraft's altitude the squares in the ambient displays (in those conditions where the squares were displayed) flowed upwards or downwards on the displays while the artificial horizon (either the line or the upper limit of the area in which the squares were displayed) remained visually aligned with the horizon. Did you find the motion of the squares relative to the horizon to be disorienting or difficult to interpret? If so, in what flight conditions was did the problem occur?

Pilot A: No disorientation.
Pilot B: Disorienting during slalom. Multi-axis maneuvers are more distracting than others.

If the motion of the squares appeared to be inconsistent with the motion of the artificial horizon, please describe the inconsistency and the flight conditions under which it occurred.

Pilot A: *no response*
Pilot B: N/A

Did you ever find that the information presented in the ambient displays was misleading? If so, please describe the situation and how the information was misleading.

Pilot A: I still find the display for the pirouette task to be confusing laterally and yawing simultaneously.
Pilot B: No.

What did you find most useful about this set of ambient symbols?

Pilot A: As a cue to longitudinal translation.
Pilot B: Altitude and vertical speed were more easily maintained with this ambient display set.

What did you find least useful this set of ambient symbols?

Pilot A: Pitch and roll information.
Pilot B: Roll axis or multi-axis maneuvers became more difficult with this ambient set.

Were you able to distinguish between the horizon and the other objects presented in the ambient field?

Pilot A: I really wasn't aware of the horizon cue formed by the top of the squares – unless I looked directly at it.
Pilot B: Yes.

APPENDIX 4: PILOT RESPONSES TO THE OPEN-ENDED QUESTIONS ON THE POST EXPERIMENT QUESTIONNAIRE

POST EXPERIMENT QUESTIONNAIRE

Which ambient display condition best supported your ability to perform these maneuvers?

Pilot A: Square plus horizontal line.
Pilot B: Ambient objects below the horizon.

What about this display condition was particularly useful?

Pilot A: Not sure. Horizon line is perhaps a visual ridge in the display.
Pilot B: Having an additional horizon in addition to ambient objects helps improve overall situational awareness.

Did you ever find the ambient displays misleading in terms of judging the aircraft's pitch and/or roll attitude? If so, please describe the conditions in which this problem occurred.

Pilot A: No. They were useless for pitch and roll.
Pilot B: No.

Were there any situations where there were not enough ambient objects visible to allow you to determine the aircraft's pitch and/or roll attitude? If so, please describe the conditions in which this problem occurred.

Pilot A: No ambients is probably better than horizon line by itself. No ambient totally takes away attitude information.
Pilot B: Yes, although I'm not sure the issue is whether there were enough. Rather, there may be a different set of symbols which would produce an awareness of pitch and roll attitude. In the bob-up maneuver, drift correction is the most difficult portion. The acceleration/deceleration was the same for the final portion of the task.

Please use the space below to comment on any aspect of the ambient displays you used in this experiment.

Pilot A: All squares plus horizon line good for longitudinal translation – but even then I occasionally have to double think about what I'm seeing as an indication of fore or aft motion.
Pilot B: I found that a no-ambient symbol condition was much easier for the slalom task. The slalom seemed to be the only task that was distracting or disorienting due to the ambient symbols. The ambient symbols have proven to be useful primarily in altitude hold/position, and low velocity vertical position information. Beyond those two things, the ambient symbols don't provide much additional awareness.