FIXED-BASE SIMULATOR INVESTIGATION OF DISPLAY/SCAS REQUIREMENTS FOR ARMY HELICOPTER LOW-SPEED TASKS

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Abstract

A piloted simulation was conducted to investigate the effect of presenting flight symbology on a panel-mounted display (PMD) versus a head-up display (HUD) for different levels of augmentation and turbulence while performing low-speed tasks representative of the scout helicopter mission. A secondary objective was to investigate the advantages of using a collective kinesthetic-tactual display (KTD) for altitude control during a precision hover task. The experiment was conducted on a NASA-Ames fixed-base simulator using a camera-model TV system, single-window visual display, and trainer-type aviator's night-vision imaging-system goggles. Two pilots performed a total of 169 evaluations, including 54 evaluations of the KTD for the precision hover task. The results show that the display symbology from either the HUD or PMD improved the pilot ratings for low levels of augmentation. One pilot generally gave lower ratings for the PMD than the HUD for the approach to a hover and departure tasks and significantly lower ratings for the PMD in the bob-up/precision hover task segment in low turbulence. Display medium (HUD vs PMD) generally had little effect on the other pilot's ratings. These differences between the two pilots' ratings were attributed to differences in the individual pilot's control strategy. Only one pilot rated the bob-up/precision hover task in low turbulence as satisfactory, and this required the HUD and velocity command augmentation. Both pilots were able to control altitude during the precision hover within ±1 ft with altitude hold augmentation, both with and without turbulence. Altitude drift increased for reduced levels of augmentation. The KTD helped the pilot reduce altitude drift during the precision hover task for the low to mid augmentation levels, but it had little effect on pilot ratings.

Introduction

The current and future generation Army aeroscout helicopters will be required to operate worldwide under a variety of environmental and threat conditions. Specific requirements for the scout mission include the capability to operate in day, night, adverse weather, and obscured battlefield conditions. The scout mission also requires nap-of-the-earth (NOE) flight and the acquisition/designation of targets at standoff distances using terrain masking to enhance survivability. Precision hover is required for effective utilization of the aircraft weapon systems. This task can place an extremely high workload on the pilot operating in a confined area at night using night-vision goggles, and operating under adverse environmental conditions. Pilot workload may be reduced by increasing aircraft augmentation and/or by improvement of the flight data presentation via displays. Reference 1 reported the results of a simulator investigation of control system and display variations for an attack helicopter mission which included night hover, using a flight symbology superimposed over a forward looking infrared display (FLIR). The study concluded that for the hover and bob-up task in moderate turbulence, a horizontal velocity command system and augmentation of the vertical axis were required for satisfactory handling qualities.

The primary objective of this experiment was to investigate the effect of presenting flight symbology on a PMD versus a HUD for different levels of augmentation and turbulence while performing low-speed tasks representative of the scout helicopter mission. The principal issue of concern was that a pilot alternating from looking out of the cockpit through the night-vision goggles, to looking at the PMD (by looking "under" the goggles) would experience difficulties in aircraft control and, possibly, disorientation.

A secondary objective was to investigate the advantages of using a KTD for altitude control during a precision hover task. The Reference 2 study suggested that a KTD might be used to increase the pilot workload capability. As inferred, this may be achieved through a possible reduction in visual scanning, and would include additional sensory or cognitive benefits.

Experimental Design

Facility

The experiment was conducted on the NASA-Ames fixed base simulator, Chair 6, in conjunction with Visual Flight Attachment

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(VFA) 2, which provided a 35° × 48° field-of-view from outside the cockpit (Fig. 1). Flight symbology (Fig. 2) was presented on either a HUD or a 9 in. PMD. The center of the PMD was located to the left of the pilot's centerline to simulate a possible configuration of a scout helicopter's instrument panel (Fig. 1). During the experiment, the standard cockpit instruments were covered, leaving either the PMD, or the HUD, and the VFA to provide information to the pilot. Standard helicopter controls consisting of the cyclic, collective, and pedals were used. Aural cueing was not available for the simulation. The use of night-vision goggles was simulated by the pilot wearing trainer-type Aviator's Night-Vision goggles with a simple filter instead of the light intensification tubes (Fig. 3).

This experiment utilized the Reference 3 small-perturbation advanced-attack helicopter model which has the full non-linear set of kinematic terms in 6 DOF-equations of motion, and includes ground-effects. Rotor and/or engine dynamics are not included.

The environmental conditions consisted of either no wind or a low level of disturbance composed of a wind shear varying linearly with altitude to 10 knots steady wind at the 70 ft reference altitude, plus 1.6 knots rms horizontal gusts and 0.8 knots rms vertical gusts.

Two Army pilots served as evaluation pilots for the experime t:

Pilot A: An experimental test pilot with 3,200 flight hours, 1,000 of which were in rotary wind aircraft, 1 hr night vision goggles, 52 hr Pilot Night Vision System (42 evaluations).

Pilot B: An Army pilot with 900 flight hours in rotary wing aircraft, 50 hr night vision goggles, NOE qualified (73 evaluations).

Task

The experimental tasks were implemented to simulate specific segments of the scout helicopter mission while operating within the constraints imposed by the simulator. The mission scenario and specific tasks are illustrated in Figure 4. All three tasks were used to investigate the effects of presenting flight symbology on a HUD or on a PMD. Only subtasks five, six, and seven of task B were used to investigate the effects of using the KTD to control altitude drift.

Variables

The mission task was performed using the VFA real-world display alone, or performed with the HUD or the PMD. The display symbology developed and tested for the advanced attack helicopter (AAH) mission[1,4] was utilized in the HUD and PMD (Fig. 2).

During the simulation it was observed that the two pilots who participated in the evaluation flew the tasks with different control strategies. Pilot A chose to rely more on the visual system cues when levels of augmentation would not afford him the time to conduct a cross check utilizing the PMD. That is, primarily visual cues were used to get the aircraft under control (achieve a certain level of stability) and then primarily PMD cues were used to minimize altitude/attitude deviations. Pilot B attempted to conduct the maneuvers as quickly and as precisely as he could without spending a considerable amount of visual dwell time for obstacle clearance. That is, the visual cues were used to establish initial obstacle avoidance and then the PMD cues were almost entirely used throughout the remainder of the task in order to maximize performance.

A KTD device, consisting of an electromechanical slide mounted flush in the collective control handgrip, was used to display altitude error from a reference precision hover. Movement of the slide, from its flush-with-the-handgrip position, would indicate the direction and magnitude of the altitude error. Installation of the collective KTD did not alter the nominal collective control function. The KTD was implemented using the procedures discussed in Reference 5, and the installation is shown in Figure 5.

The levels of augmentation utilized was the same as that developed in the experiments cited in References 1 and 3. The stabilization systems varied from the basic helicopter model with no augmentation to pitch/roll inertial-velocity command-position hold, yaw-rate command-heading hold, and vertical-rate command-altitude hold. These augmentation systems are summarized in Table 1. A summary of augmentation systems versus the display formats that were evaluated, i.e., HUD, PMD, No Display, and KTD, is shown in Table 2. The numbers assigned to the augmentation levels are for ease of discussion and do not imply an increasing hierarchy of augmentation.

Results

The results of this experiment are discussed in relation to the task, augmentation, flight symbology, and KTD. Pilot comments and standard Cooper-Harper ratings were obtained for each segment of the task. Averaged individual pilot ratings shown are for illustration of trends only, and the statistical accuracy is not implied. Specific remarks were recorded on simulation data sheets in addition to cassette tapes. Aircraft state and trajectory data were recorded on strip charts and X-Y plotters for real-time analysis. Post run performance-criteria data was available from a line printer. All data were recorded on digital tapes for post simulator flight processing.

HUD/PMD/No Display

Figures 6, 7, and 8 present the individual pilot rating data for HUD, PMD, and no display formats as a function of augmentation system for task segments A, B, and C. Figures 6a, 7a, and 8a are data from Pilot A and Figures 6b, 7b, and 8b are data from Pilot B.

Pilot A generally rated the PMD lower than the HUD for the entire range of augmentation and wind conditions. The PMD pilot ratings were significantly worse than the HUD ratings for Pilot A during task segment B in a low level of turbulence (Fig. 7a). For Pilot B the choice of display medium (HUD vs PMD) had little effect on ratings for the range of augmentation and wind conditions investigated.

These differences between the Pilot A and B ratings of the PMD and HUD may be attributed to the individual pilot control strategies. If Pilot A could not quickly interpret the PMD symbology, apply the necessary control corrections, and observe the symbology excursions shrinking in the right directions he would transition momentarily back to the visual scene to ensure obstacle avoidance and start the process over. This alternating from looking out of the cockpit to looking at the PMD (under the goggles) resulted in various degrees of confusion depending upon the augmentation level and wind conditions. In general, Pilot A felt that mental workload increased and predictability of control inputs was degraded with the PMD. Alternatively, the control strategy preferred by Pilot B was to establish initial obstacle avoidance with the visual cues then transition almost entirely to the PMD cues thus making the evaluation a tracking task to minimize excursions. This type of control strategy reduced the disorientation or confusion associated with alternating visually in-and-out of the cockpit and was used during the bob-up maneuver. But, during the conduct of task A, Pilot B also was forced to increase outside visual dwell time and could not comfortably perform an in-and-out cross scheck while applying the necessary control corrections. Thus he too became visually disoriented for lower levels of augmentation.

As the level of augmentation increases to the inertial velocity command configurations (augmentation 5 through 8) Pilot B no-display pilot ratings approach the HUD and PMD data with no turbulence. For all tasks, the no-display data with turbulence is very similar to the HUD and PMD ratings with turbulence. These no-display pilot rating trends may have existed for Pilot A also but insufficient data was obtained. In general, the effect of turbulence for all display formats was to degrade the pilot evaluations by one to three ratings for all tasks.

Independent of the display format, the inertial velocity command configurations were generally required for Level 1 (satisfactory) pilot ratings under calm conditions. However, each task segment did receive a few Level 2 pilot ratings.

The Level 2 ratings for the PMD and augmentation system 6, task B (shown in Fig. 7), resulted from the pilot's complaints regarding interaxis control sensitivity disharmony, i.e., the collective being too sensitive. Augmentation systems 2 through 4 (three-axis SCAS through attitude hold) generally produced adequate but unsatisfactory (Level 2) pilot ratings. The complete mission scenario could not be accomplished with augmentation systems 1 or 2 for the no display format.

The relatively good pilot ratings which were obtained for task segment C (Fig. 8), using augmentation systems 2 and 3, and using either the HUD or the PMD, were primarily due to the decreasing confinement as the task progressed and hence less precision was needed in task performance.

Figure 9 shows virtually no difference in horizontal circular error radius (CER) between the HUD and PMD with and without turbulence for the precision hover subtask of task segment B. CER is the radius within which the vehicle is maintained for 50% of the time. Note that only the no turbulence conditions HUD and PMD with augmentation systems 5 and above were able to achieve a CER of less than one foot.

Figures 10 and 11 present the altitude drift data for the precision hover subtask of task segment B. These figures indicate that there were only small differences in altitude drift using the HUD verses PMD for the range of augmentation systems examined. The general trend for both pilots illustrated that the altitude drift with no turbulence was slightly decreased by using the HUD for augmentation levels 2 through 5.

This trend was not visible with turbulence. For augmentation levels 6 through 8 there was no significant differences in altitude drift between the two displays with or without turbulence. With turbulence the overall effect was to increase altitude drift during the precision hover for augmentation levels 3 through 6. No consistent trend was evident as to the direction of the altitude drift during the precision hover, although for Pilot B under calm conditions there was usually an upward drift.

Collective Kinesthetic-Tacutal Display (KTD)

In addition to the data obtained for the complete mission scenario, limited data were obtained primarily from Pilot B by using a collective KTD to control altitude drift during just the precision hover subtask numbers 5, 6, and 7.

The pilot comments indicated a narrow range of conditions within which the collective KTD device was considered useful in maintaining altitude during the precision hover. This useful range was a function of the augmentation system, the type of display (HUD, PMD, No Display) used in conjunction with the KTD device, and the environment conditions. As shown in Fig. 12, with highly augmented configurations the pilots felt that the KTD device was not needed to control altitude drift within ±1 ft during the precision hover. With no augmentation, or with minimum augmentation, the pilot either could not perform the precision hover, or could not effectively use the KTD device because of the large altitude excursions exceeding its full-scale range or because of the limited bandwidth (0.4 Hz) of the KTD. Between these extremes, the pilot reported that the KTD was useful, depending on whether an additional display HUD or PMD) was used, and on the selected wind condition. For the less augmented configurations, the pilot reported that although the KTD as implemented provided an indication of altitude drift, it did not provide information on how much collective control was required to cancel the drift. The pilot would typically apply too much collective control, resulting in an overshoot of the reference hover altitude. Thus, the pilot would control height within an altitude band about the reference position rather than at the precise reference altitude.

Conclusions

A piloted simulation was conducted to investigate the effects of presenting flight symbology on a PMD or a HUD for different levels of helicopter augmentation, and for turbulence while performing low-speed tasks representative of the scout helicopter mission. Data were obtained from two pilots using simulated night-vision goggles while flying a fixed-base simulator with a single-window visual display of the outside world. Additional data were obtained from one pilot to investigate the advantages of using a collective KTD for altitude control during the precision hover task. The following conclusions are based on the pilots' subjective evaluations and on measured performance data:

1) Pilot A generally rated the PMD worse than the HUD. For task segment B (bob-up/precision hover) in a low level of turbulence Pilot A gave significantly worse ratings for the PMD than the HUD. Pilot B rated both display mediums (HUD or PMD) about the same. These differences in pilot ratings are attributed to the control strategies used, i.e., Pilot A relied primarily on visual cues if stability was inadequate to ensure terrain avoidance, whereas, Pilot B used the visual cues for initial obstacle avoidance then transitioned almost entirely to the PMD.

2) For a high level of augmentation (inertial velocity-command configurations) the no display pilot ratings are similar to the HUD and PMD pilot handling qualities for all the tasks. As the level of augmentation is decreased from the inertial velocity-command configurations the degradation of the no display pilot ratings from the HUD and PMD pilot rating becomes more pronounced. Because this was a fixed-base simulation, the added display cues (PMD, HUD) compensated somewhat for the lack of motion cues which may be more important at the lower augmentation levels.

3) The different types of augmentation systems within each display case did significantly affect the handling qualities ratings for that particular display. It was generally observed that for all three displays higher levels of augmentation were preferred by the pilots.

4) For the bob-up/precision hover task (segment B) in low turbulence, satisfactory handling qualities were achieved only with the HUD and the velocity command systems.

5) For the precision hover task in low turbulence, altitude variations of less than ±1 ft were obtained only with the velocity command system and altitude hold in the vertical axis.

6) Pilot B considered the collective KTD useful in controlling altitude drift during precision hover for the low to mid levels of augmentation examined, i.e., three-axis SCAS with heading-hold and the attitude-hold configuration. Although the

KTD, as implemented, provided an indication of altitude drift, it did not provide information on how much collective control was required to cancel the drift. The KTD had little effect on pilot ratings.

References

[1]Aiken, E. W. and Merrill, R. K., "Results of a Simulator Investigation of Control System and Display Variations for an Attack Helicopter Mission." Preprint No. 80-18, 36th Annual Forum, American Helicopter Society, Washington, D.C., May 1980.

[2]Jagacinski, Richard J., et al., "Performance Evaluation of a Kinesthetic-Tactual Display." AHS/NASA Specialists' Meeting on Helicopter Handling Qualities, Ames Research Center, Moffett Field, CA, NASA CP-2219, April 1983.

[3]Aiken, E. W., "A Mathematical Representation of an Advanced Helicopter for Piloted Simulator Investigations of Control System and Display Variations." NASA TM-81203, May 1980.

[4]Aiken, E. W. and Blanken, Christopher L., "Piloted Simulation of the YAH-64 Backup Control System Engagement." NASA TM-81293, July 1981.

[5]Lebacqz, J. V. and Aiken, E. W., "A Flight Investigation of Control, Display, and Guidance Requirements for Decelerating Descending VTOL Instrument Transitions Using the X-22A Variable Stability Aircraft." Vol. 1, Calspan Report Number AK-5336-F-1, Sept. 1975.

Table. 1. Augmentation systems.

Command stabilization level	Pitch	Roll	Yaw	Vertical
1. No augmentation	Basic A/C	Basic A/C	Basic A/C	Basic A/C
2. AAH SCAS, three-axis	Pitch rate and attitude feedback control quick	Shaped roll rate feedback control quick	Washed-out yaw rate feedback control quick	Basic A/C
3. AAH SCAS RCHH yaw	Same as above	Same as above	Rate command heading hold (RCHH)	Basic A/C
4. Attitude hold + RC-heave	Control quick removed	Control quick removed	SCAS with different shaping of r	Rate command (RC)
5. IVC RCHH-yaw RC-heave	Inertial velocity command (IVC)	Inertial velocity command (IVC)	RCHH	RC
6. IVCPH RCHH-yaw RC-heave	Inertial velocity command-position hold IVCPH	Inertial velocity command-position hold IVCPH	RCHH	RC
7. IVC RCHH-yaw RCAH-heave	IVC	IVC	RCHH	RCAH Altitude-hold
8. IVCPH RCHH-yaw RCHH-heave	IVCPH	IVCPH	RCHH	RCAH

Table 2. Summary of configurations evaluated.

Augmentation system	Head-up display	Panel mounted display	No display	KTD
1. Basic aircraft	○			
2. Three-axis SCAS	○	△		◆
3. Three-axis SCAS plus RC heading hold	○●	△▲	□	◆
4. Attitude hold RC-heave	○●	△▲	□■	◆
5. IVC RC-heave	○●	△▲	□■	◆
6. IVCPH RC-heave	○●	△▲	□■	◆
7. IVC RCAH-heave	○●	△▲	□■	◆
8. IVCPH RCAH-heave	○●	△▲	□■	◆

● Solid symbol — turbulence
○ Open symbol — calm

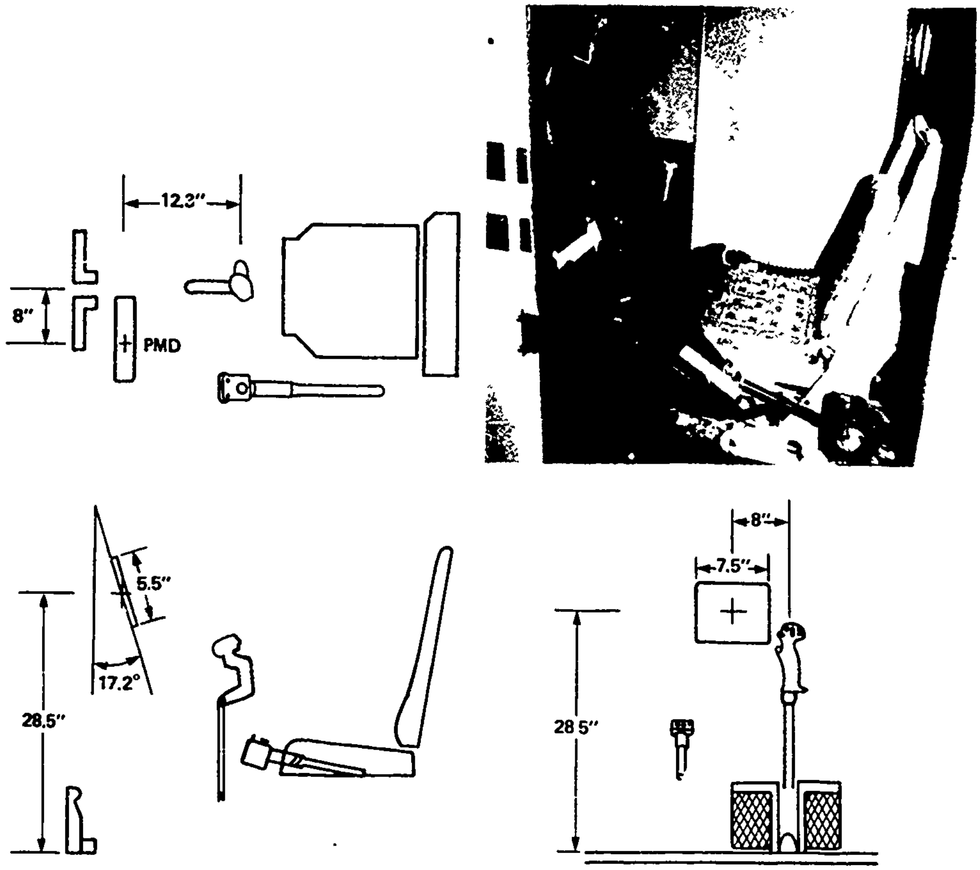
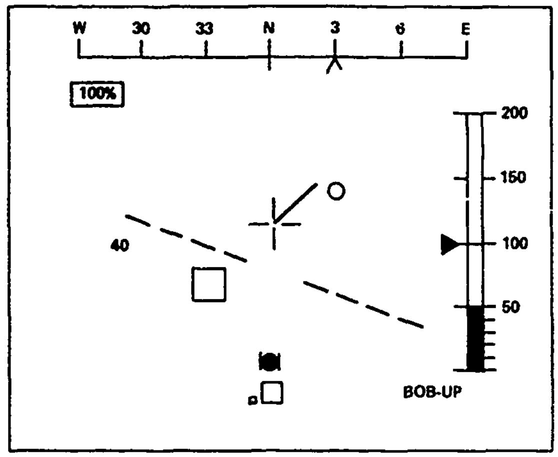
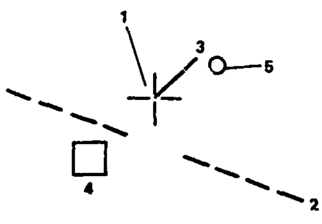


Figure 1. Cockpit general arrangement.



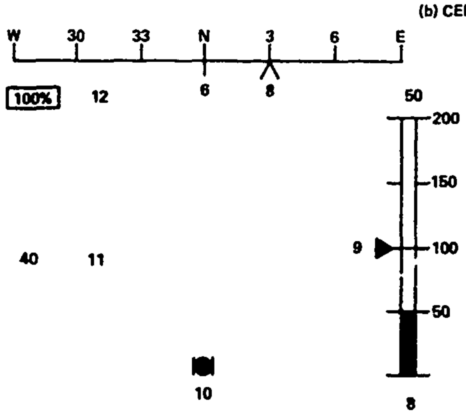
(a) BASELINE DISPLAY FORMAT



(a)

SYMBOL	INFORMATION
1. Aircraft reference	Fixed reference for horizon line, velocity vector, hover position, cyclic director, and fire control symbols
2. Horizon line (cruise mode only)	Pitch and roll attitude with respect to aircraft reference (indicating nose-up pitch and left roll)
3. Velocity vector	Horizontal Doppler velocity components (indicating forward and right drift velocities)
4. Hover position	Designated hover position with respect to aircraft reference symbol (indicating aircraft forward and to right of desired hover position)
5. Cyclic director	Cyclic stick command with respect to hover position symbol (indicating left and aft cyclic stick required to return to designated hover position)

(b) CENTRAL SYMBOLOGY



SYMBOL	INFORMATION
6. Aircraft heading	Moving tape indication of heading (indicating North)
7. Heading error	Heading at time bob-up mode selected (indicating 030)
8. Radar altitude	Height above ground level in both analog and digital form (indicating 50 ft)
9. Rate of climb	Moving pointer with full-scale deflection of ±1,000 ft/min (indicating 0 ft/min)
10. Lateral acceleration	Inclinometer indication of side force
11. Airspeed	Digital readout in knots
12 Torque	Engine torque in percent

(c) PERIPHERAL SYMBOLOGY

Figure 2. Display mode symbology (Ref. 1).

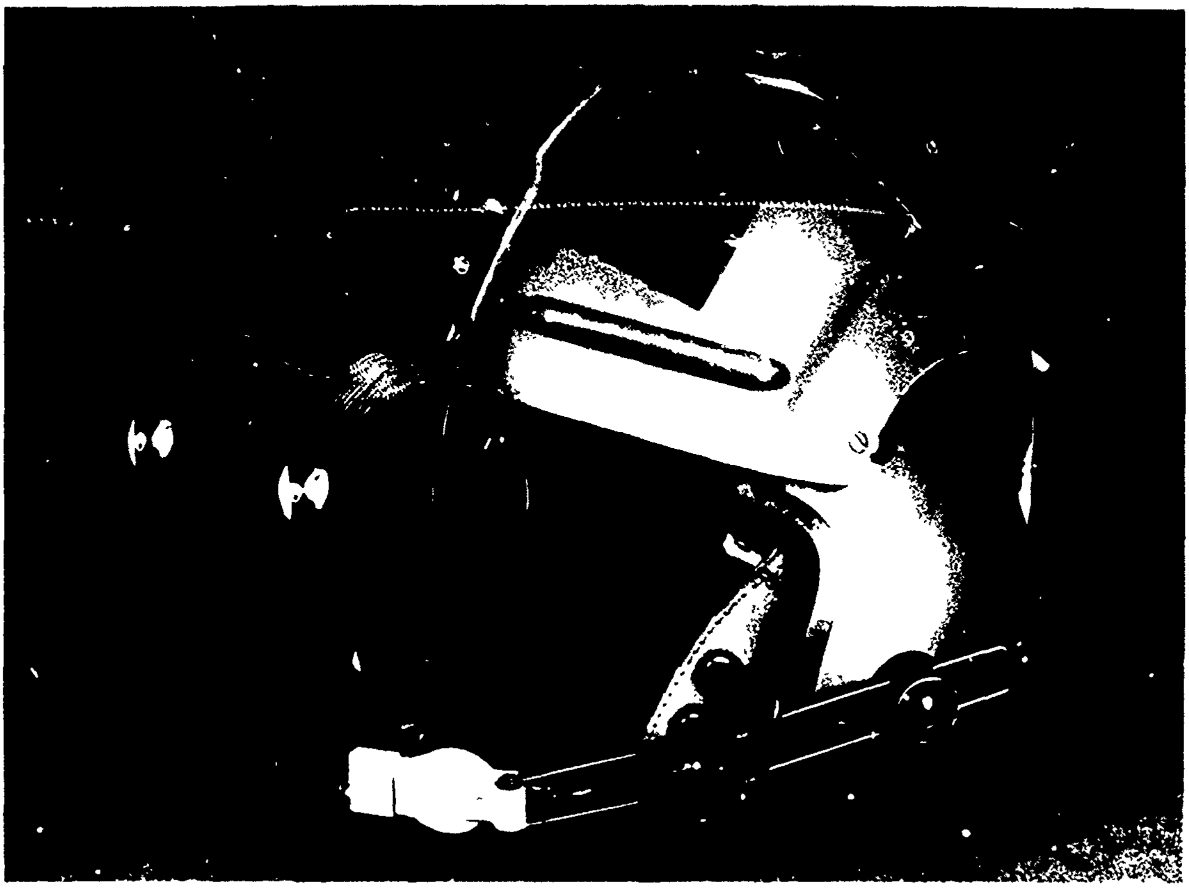


Figure 3. Trainer-type aviator's night vision goggles and helmet.

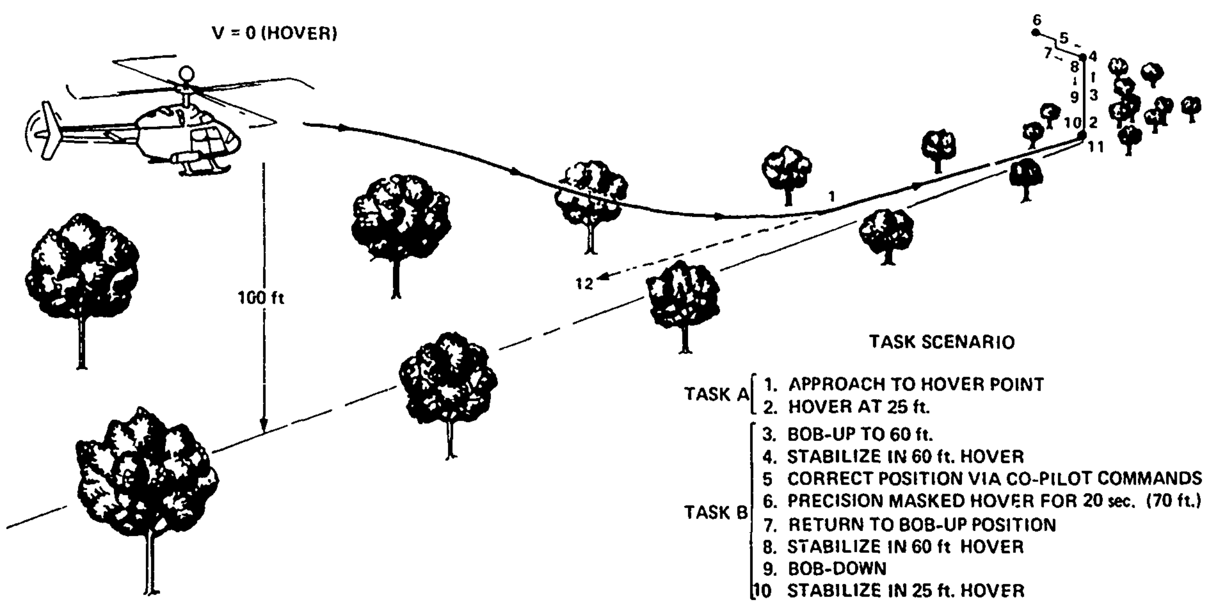


Figure 4. Simulation task – prescribed course.

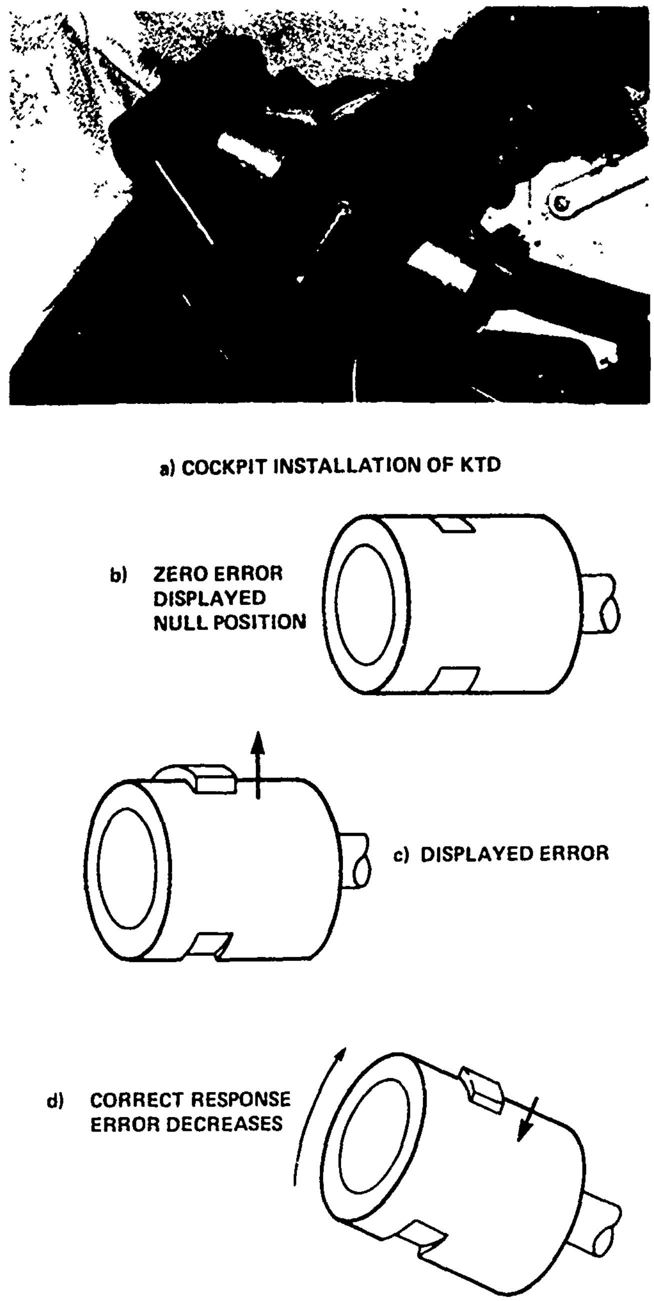
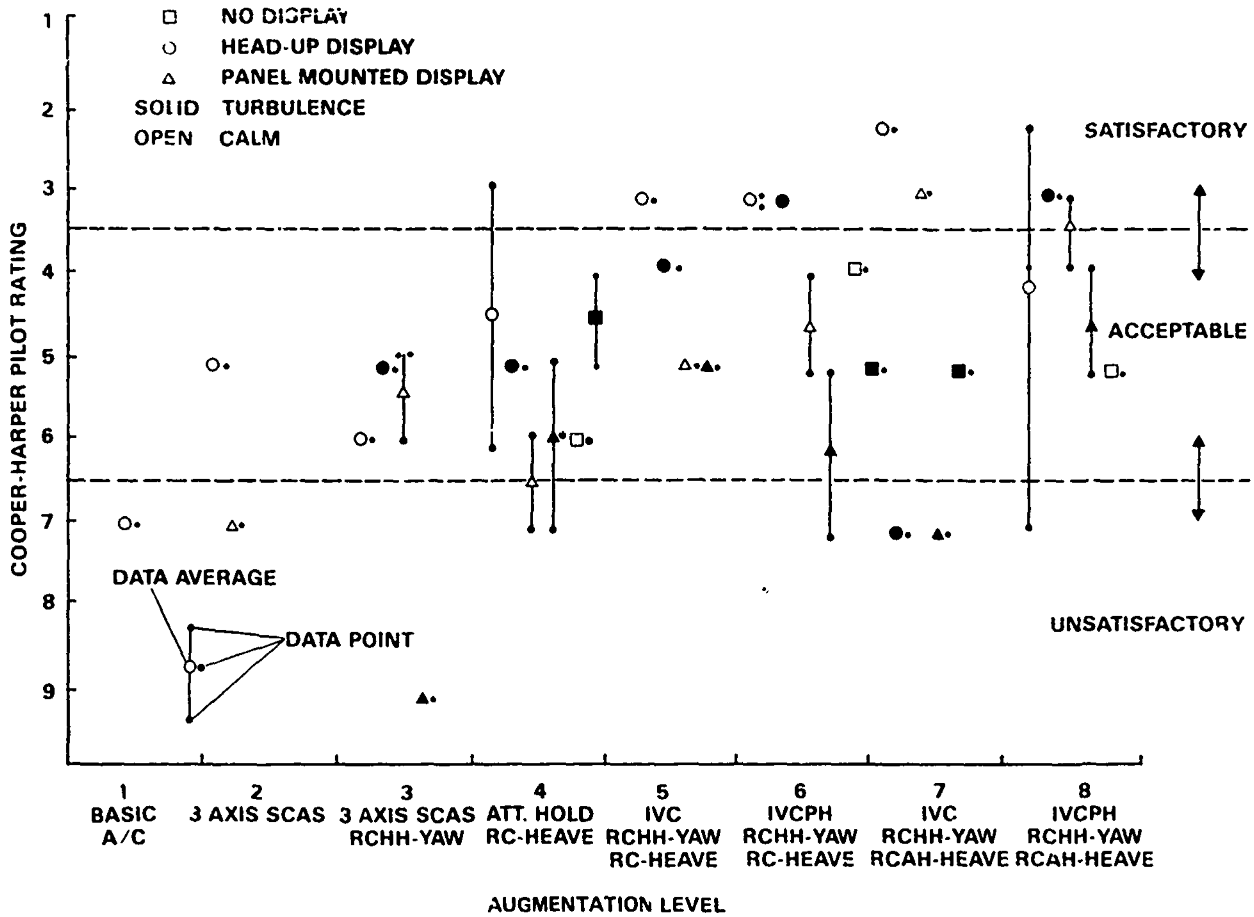
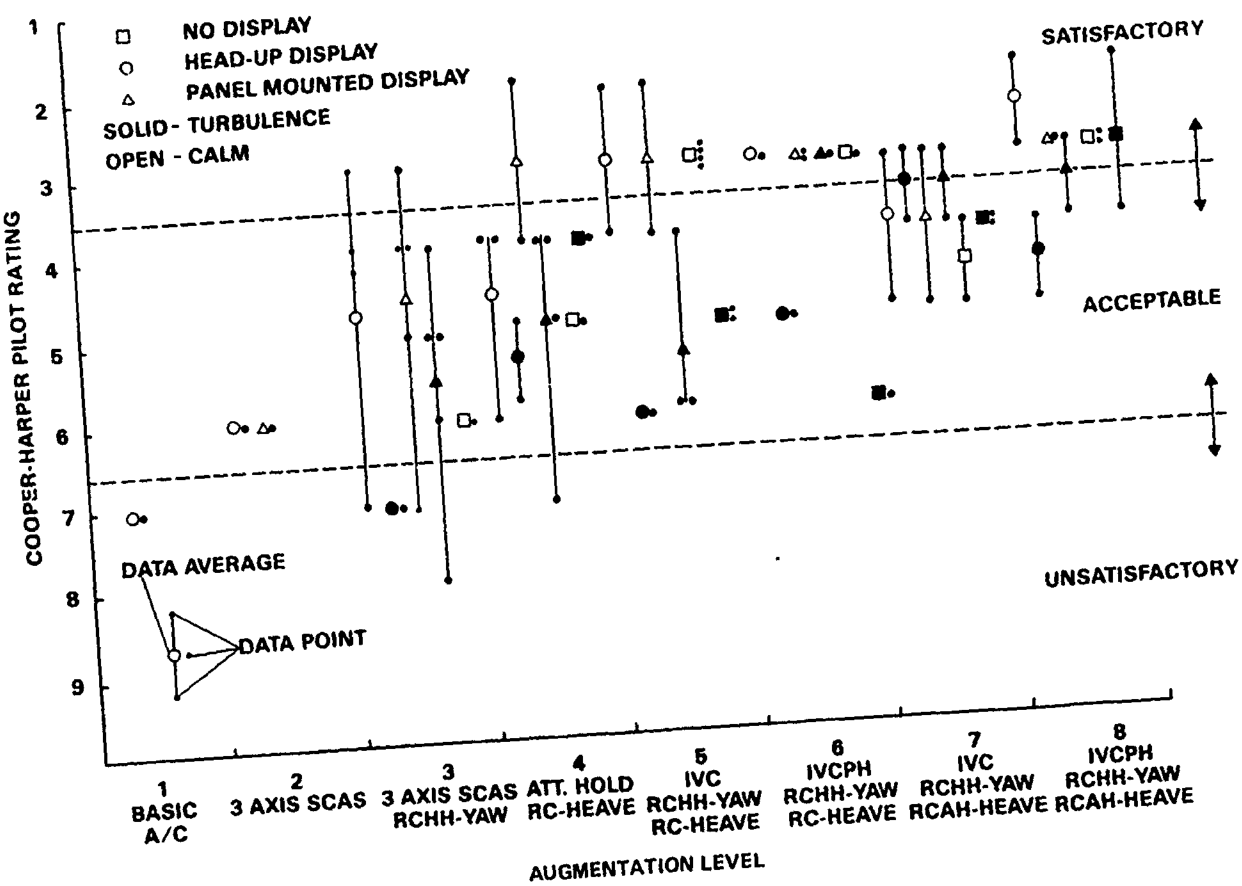


Figure 5. Installation and control-display relationship for collective KTD.



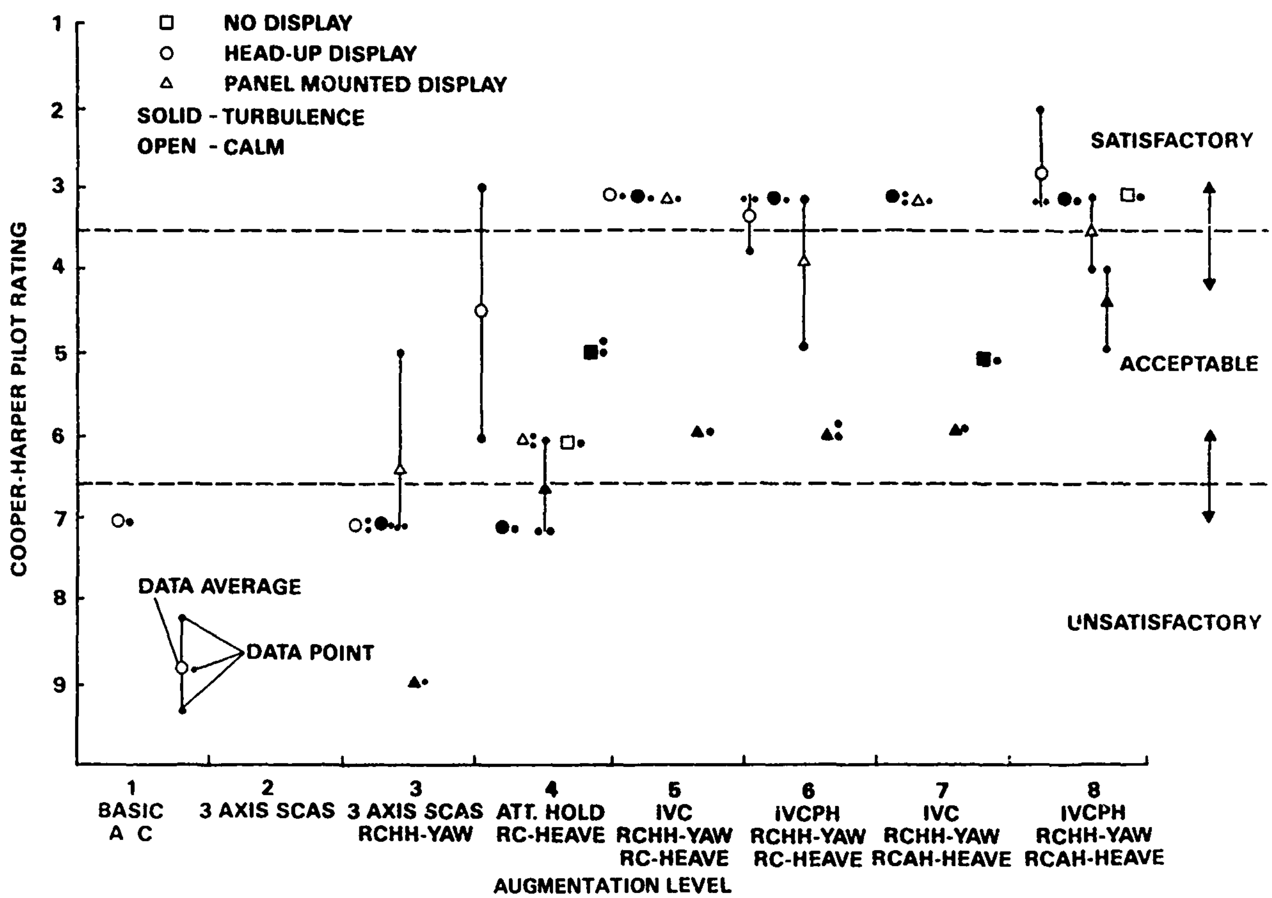
(a) Pilot A.

Figure 6. Pilot rating results – task A.



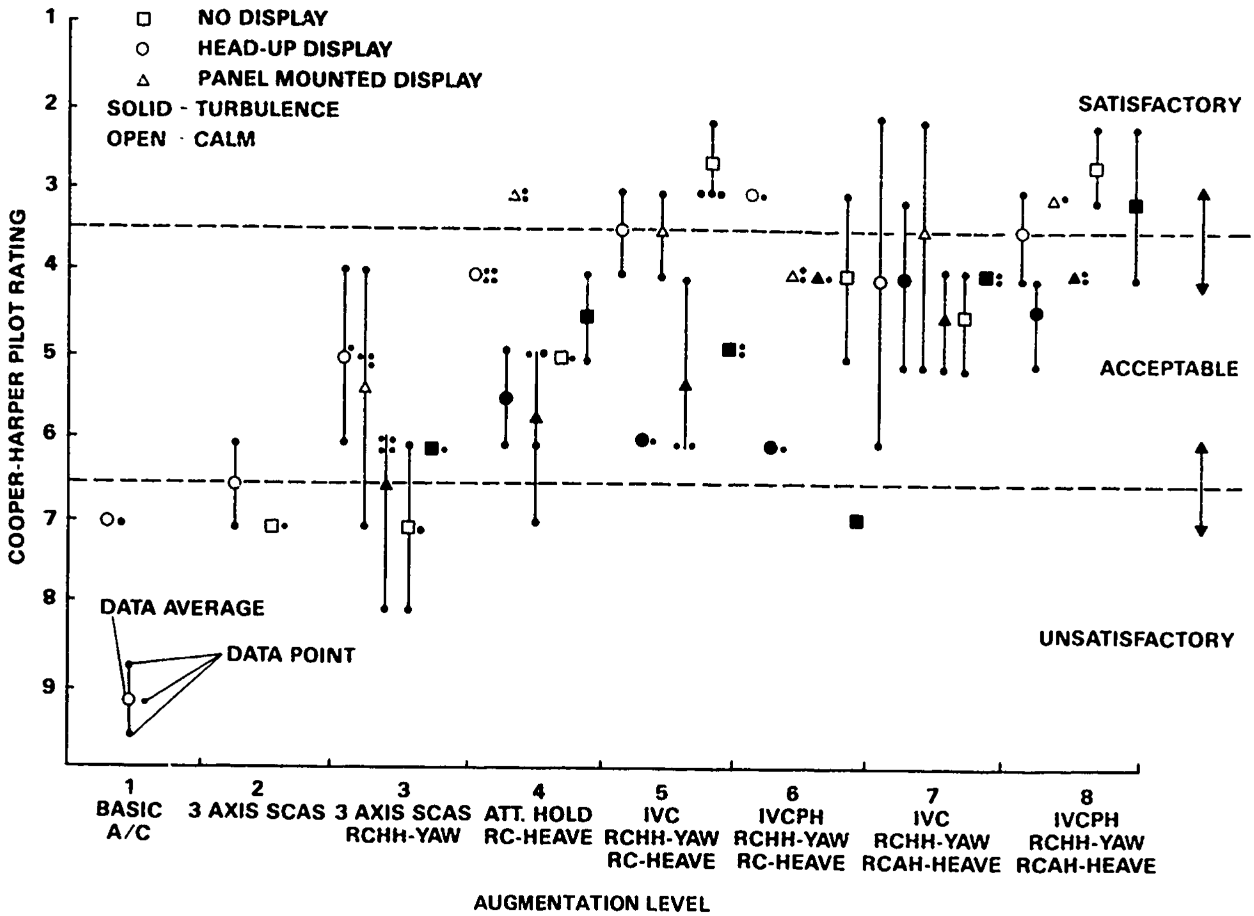
(b) Pilot B.

Figure 6. Concluded.



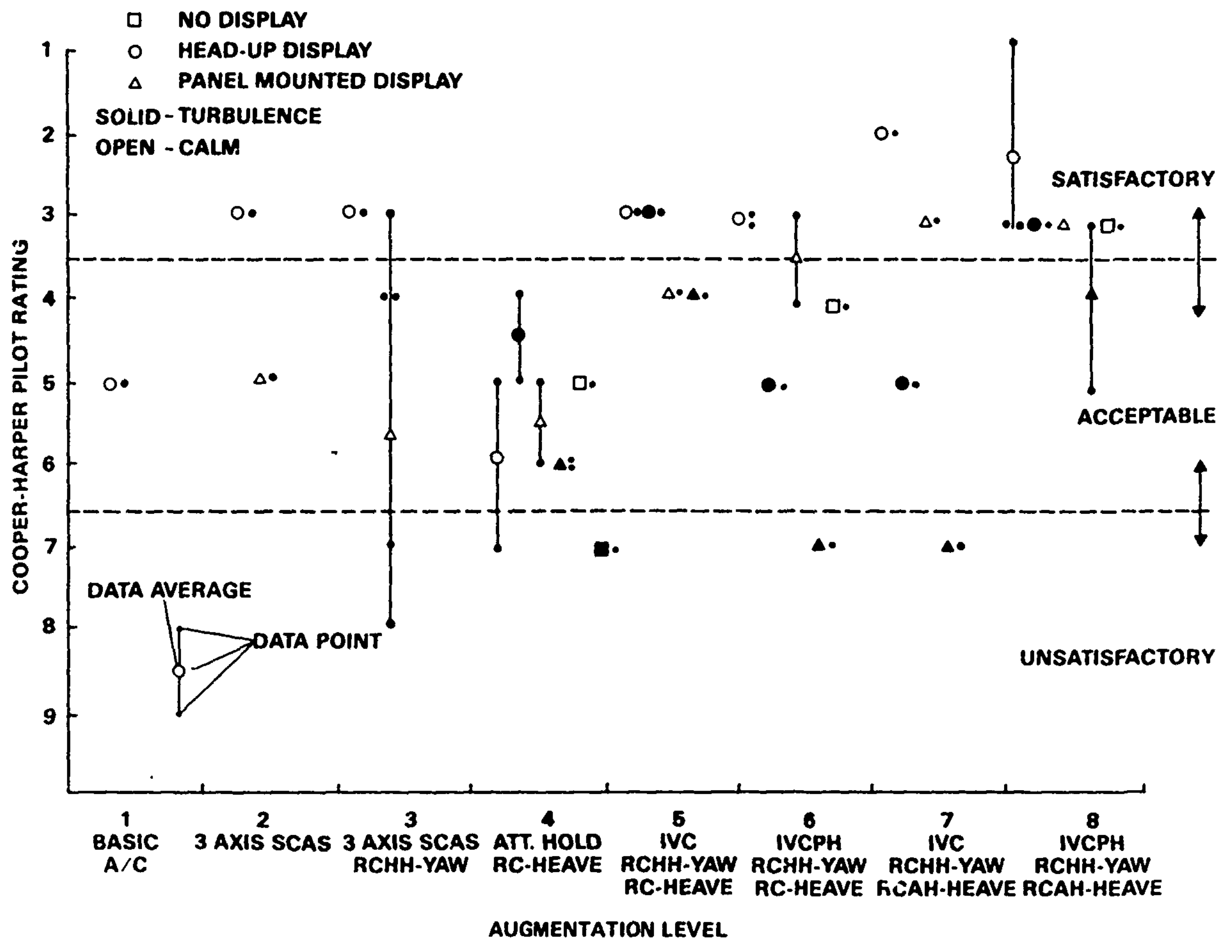
(a) Pilot A.

Figure 7. Pilot rating results — task B.



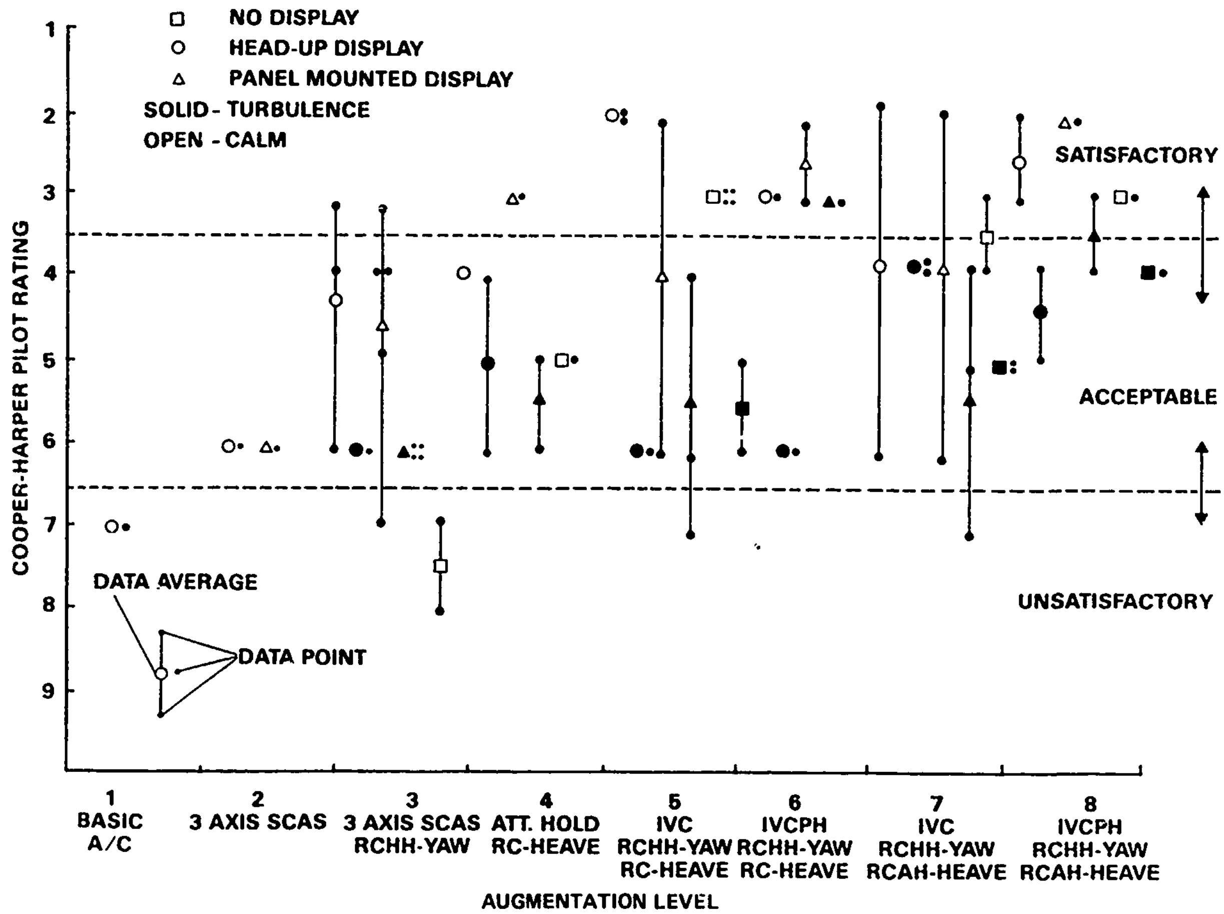
(b) Pilot B.

Figure 7. Concluded.



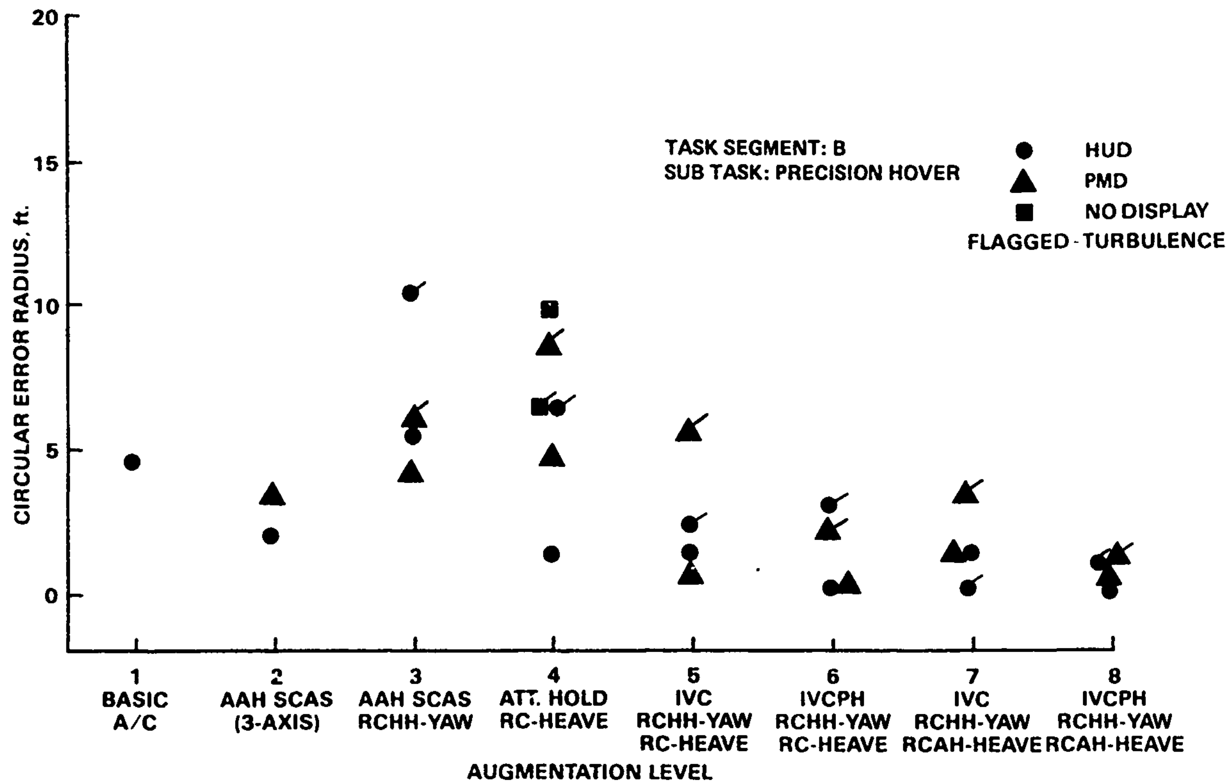
(a) Pilot A.

Figure 8. Pilot rating results – task C.



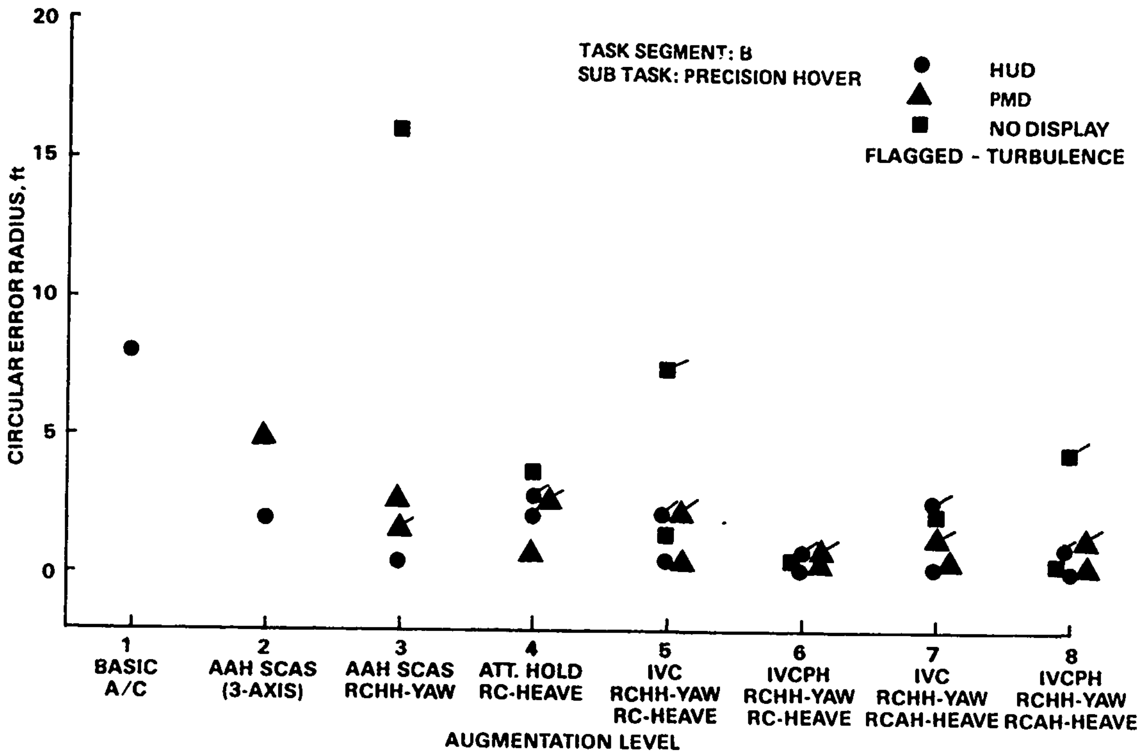
(b) Pilot B.

Figure 8. Concluded.



(a) Pilot A.

Figure 9. Circular error radius results – precision hover.



(b) Pilot B.

Figure 9. Concluded.

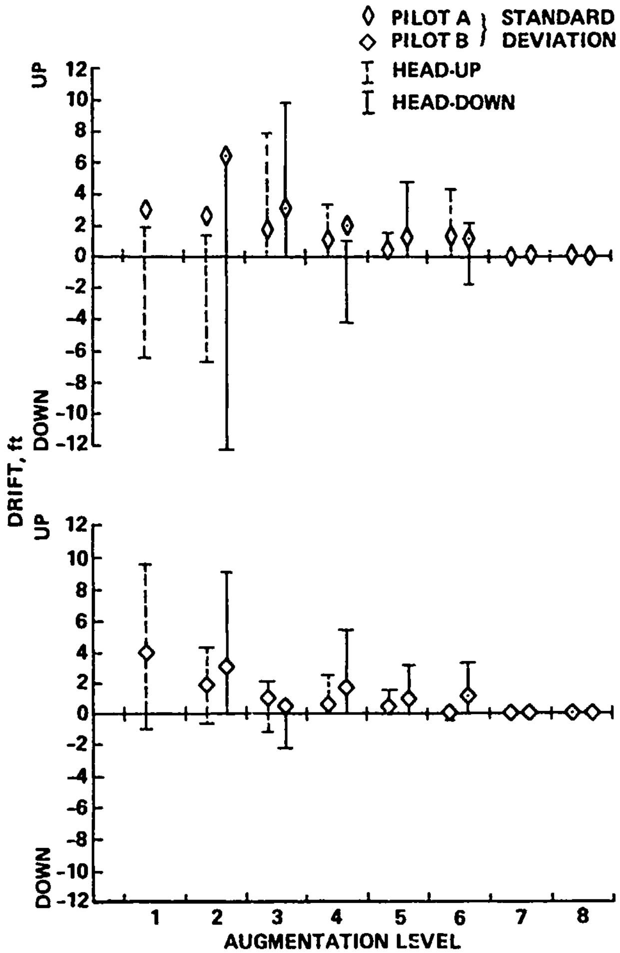


Figure 10. Altitude drift results — no turbulence.

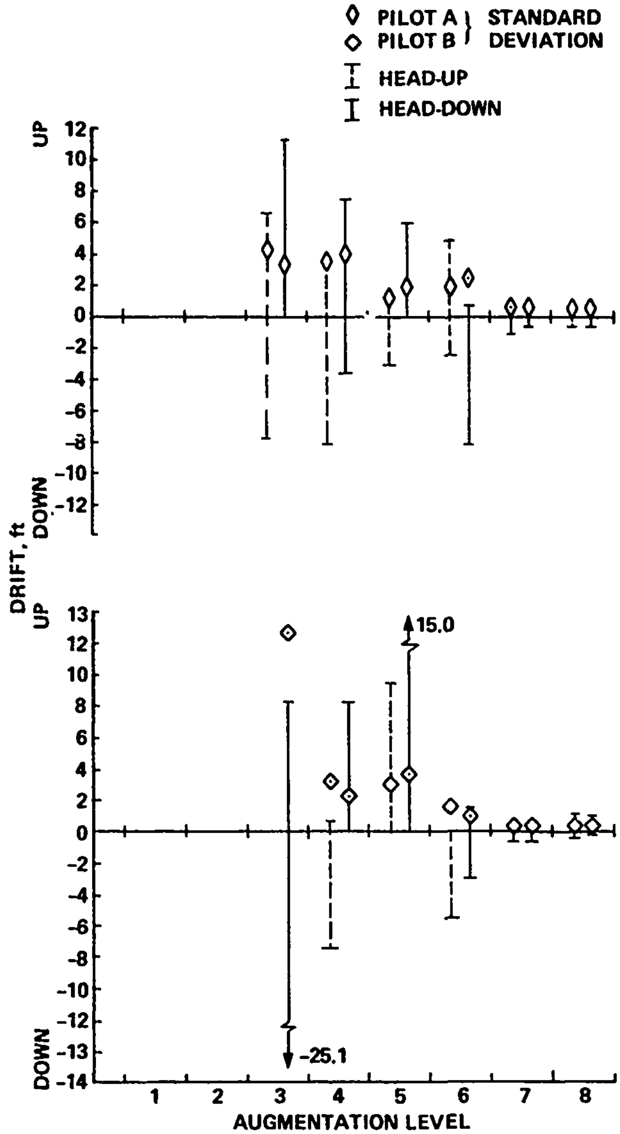


Figure 11. Altitude drift results — turbulence.

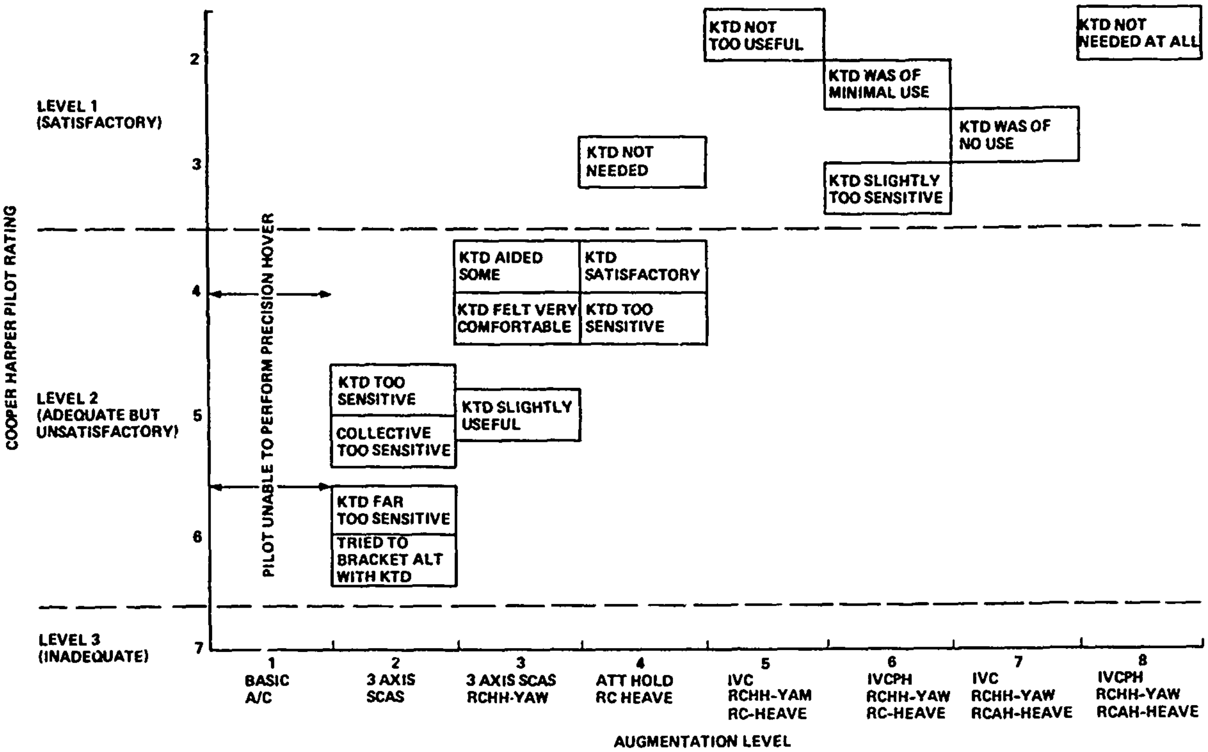


Figure 12. Pilot rating trends using PMD and KTD.