

# Enhanced spatial state feedback for night vision goggle displays

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## ABSTRACT

A preliminary study was conducted to investigate the use of visual flow cues as an aid to ground and vertical drift awareness during helicopter flight and targeting while using night vision goggles (NVG's). Three displays were compared: 1) *NVG* display: simulated NVG image of cockpit and external environment; 2) *Overlay* display: NVG image with an overlay of a flow cue field and a surrounding wire-frame globe; 3) *Cut-out* display: same as the *Overlay* display but with symbology removed from the central region (leaving an unobscured 20 degree field-of-view of the NVG image). Three levels of contrast were also compared using each display type. The visual scenery was displayed to subjects using a helmet-mounted virtual reality device that had a 40 X 50 degree field-of-view liquid crystal display

The study involved six pilots. Three tasks were given: 1) Search task: designate enemy targets with a helmet-mounted sight (no flight control inputs); 2) Hover task: null out all translational and yaw rates while in a hover; 3) Search/Hover task: perform both Search and Hover tasks simultaneously. These tasks were conducted in a fixed-based helicopter simulator which used the dynamics of a small-scale model helicopter. The following performance measures were collected: 1) Pilot ability to detect and recognize targets (Search and Search/Hover tasks); 2) Pilot ability to null translational and yaw rates (Hover and Search/Hover tasks); 3) Time scanning the instrument panel (Hover and Search/Hover tasks). Subjects also rated displays for efficacy in completing the three tasks.

Target detection scores conducted during the Search and Search/Hover tasks were highest using the NVG display, followed by the *Cut-out* display. Root-mean-square (RMS) drift rate error was comparable for all display types in the Hover and Hover/Search tasks, however RMS control input activity in all the translational axes was significantly higher in both rate-cueing displays (*Overlay* and *Cut-out*) than with the NVG display. From the control input and drift rate time histories it appears that the motion cues were more compelling in the *Overlay* and *Cut-out* displays than those perceived in the NVG display. A significant decrease in instrument-scanning time (both Hover and Search/Hover tasks) was observed for both the *Overlay* and *Cut-out* displays compared to the NVG display, with pilots flying essentially head-out-of-cockpit while using the rate-cueing displays. Contrast was not observed to have a significant effect on hover performance in any of the displays.

**Keywords:** helmet mounted displays, 3-D flow cueing

## 1. INTRODUCTION

Rotorcraft night operation in close ground proximity is a difficult problem which requires two concurrent tasks: object recognition (for mission tasks and obstacle avoidance), and vehicle orientation. The motivation for this paper is based on studies of night-vision-goggle (NVG)-related helicopter mishaps, from which four major areas of perceptual difficulty were identified. These were: altitude, sink rate, horizontal ground drift, and attitude. This evidence, coupled with anecdotal reports, implies that the visual feedback mechanisms which impart perception of these states during day unaided vision can be unreliable or absent during NVG viewing. Attempts to improve the field-of-view (FOV) and enhance image resolution may improve the situation, but perceptual problems with image-sensing systems are likely to remain areas of concern.

The approach adopted for addressing these perceptual issues was: 1) Identify the functional requirements to provide visual feedback in a rotorcraft helmet-mounted display (HMD), including the perceptual requirements to support flight control feedback loops; 2) Identify methods to provide required feedback which are consistent with current understanding of visual perception; 3) Develop prototype HMD displays which employ the identified feedback mechanisms; 4) Preliminary testing and evaluation of display options using potential helicopter mission profiles.

Based on current work including the NVG mishap studies and several prior surveys,<sup>1,2,3</sup> three major areas have been identified as contributing to NVG visual feedback problems: 1) Loss of peripheral or off-axis visual cues due to narrow FOV in current HMD's; 2) Sensor resolution and noise causing degradation of spatial cues; 3) Motion ambiguity created by head-tracked motion of the sensor.

From the functional requirements analysis, visual flow cueing has been identified as a major area of opportunity for improving performance. Anderson and Dyre<sup>4</sup> conducted an experiment in which subjects were given a circular 15 degree FOV and immersed in a three-dimensional field of dots. The subjects were then moved through this field (visually simulated) and their body sway measured to observe the sensation of self-motion. The results showed that central vision can be stimulated to produce strong sensations of motion both parallel and normal to the viewer's line-of-sight (LOS). As a powerful tool for stimulating motion perception within and near central vision, flow cues can be a method of conveying rate feedback. It is proposed that presenting these cues on the image periphery will: 1) Leave the primary visual task largely unobstructed; 2) Provide compelling and useable rate-cueing for tasks requiring spatial awareness.

## **2. EXPERIMENTAL DESIGN**

### **2.1 Overview**

This experiment investigated the effects of three different display designs and three contrast levels on target detection and hover performance. The baseline display simulated a night-vision-goggle (NVG) image as seen from the pilot's perspective. The *Overlay* display superimposed three-dimensional (3-D) symbology on an NVG image to cue vehicle rate to the pilot, and the *Cut-out* display combined the 3-D rate cues with a decluttering strategy while viewing an NVG image. Subjects conducted these tasks in a fixed-based helicopter simulator, with visual scenery displayed to subjects using a helmet-mounted virtual reality device that had a 40 X 50 degree FOV liquid crystal display. The cockpit airframe seen from the pilot's perspective matched the dimensions of the AH1 Cobra helicopter. Head motion was tracked by an ultra-sound system with a resolution of approximately 0.1 degrees. Subjective ratings for each display type were also collected.

### **2.2 Display Design**

#### **2.2.1 NVG display**

The NVG display is shown in Fig. 1. The pilot is looking out the forward cockpit with the head pitched down 10 degrees, so that the upper portion of the instrument panel visible. Panel instruments included aircraft heading, radar altimeter, attitude gyro, and total horizontal ground speed. The NVG image (mountains, terrain, trees, airframe and targets) was rendered monochromatic green, with object intensity mapped from its approximated wavelength.<sup>5</sup> A pair of targeting crosshairs was fixed to the screen's center (line of sight) for all displays.

#### **2.2.2 Overlay display**

The *Overlay* display in Fig. 2 shows a 3-D lattice of cubes (surfaces shaded blue) surrounding the helicopter. Due to computational constraints the lattice extended three layers beyond the helicopter in any direction. The lattice was positionally fixed relative to the ground, so that helicopter motion was sensed by a flow of cubes in the opposite direction. As the helicopter overran a plane of cubes along a given axis, a third distant plane of cubes would appear. As the helicopter built up translational speed, the cubes elongated parallel to the vehicle flight path, so that during translation each elongated block (its c.g. fixed inertially) would rotate in the direction of the flight path vector. Fig. 2 also shows members of a wire-frame globe (colored white) which was centered on the helicopter c.g. and surrounded the vehicle. The globe had lines of longitude at 30 degree increments of azimuth, and lines of latitude at 20 degree increments of elevation. Azimuth is numerically depicted at 10 degree intervals along the horizon.

#### **2.2.3 Cut-out display**

Fig. 3 shows the *Cut-out* display, which is identical to the *Overlay* display but with the central symbology removed (except for the targeting crosshairs, which were required for the experiment). As the pilot's head attitude changed, overlaid

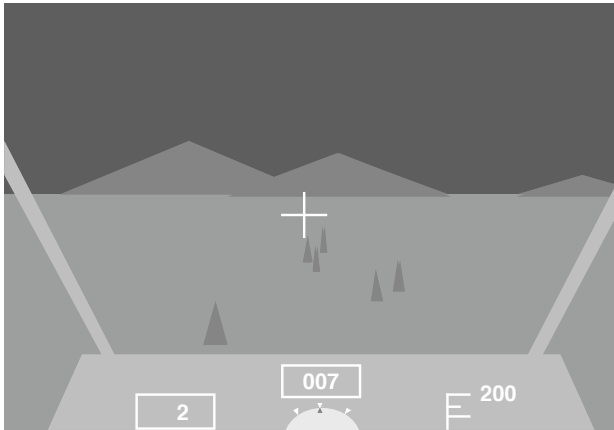


Fig. 1 NVG Display

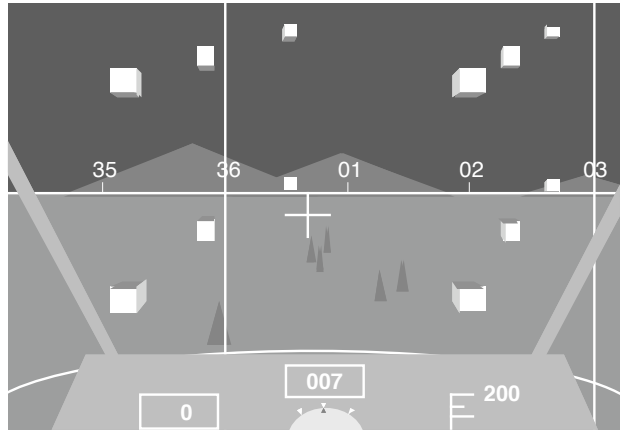


Fig. 2 Overlay Display (Steady Hover)

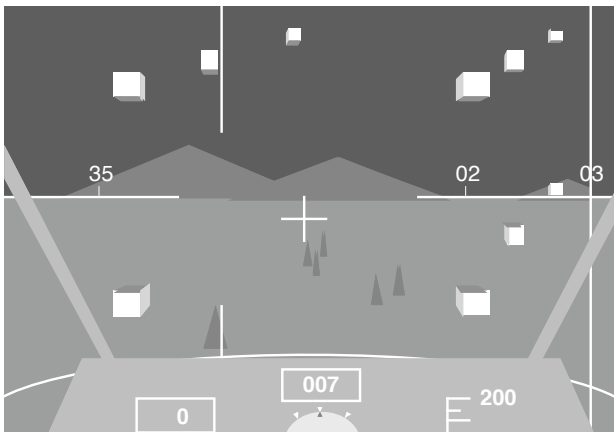


Fig. 3 Cut-out Display (Steady Hover)

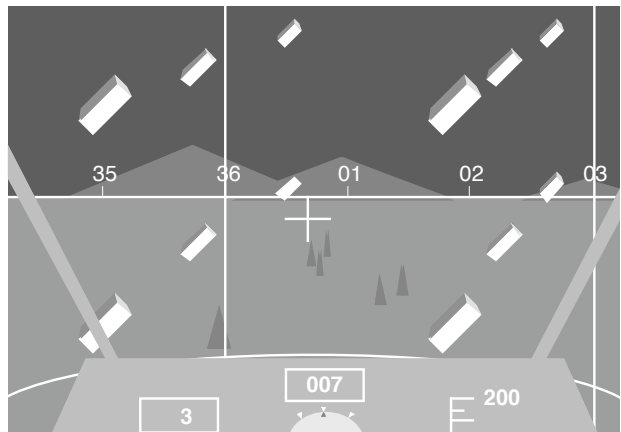


Fig. 4 Overlay Display (Descending Left Motion)

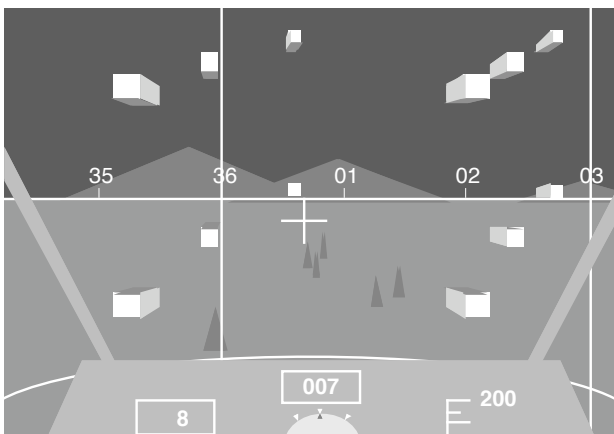


Fig. 5 Overlay Display (Forward Motion)

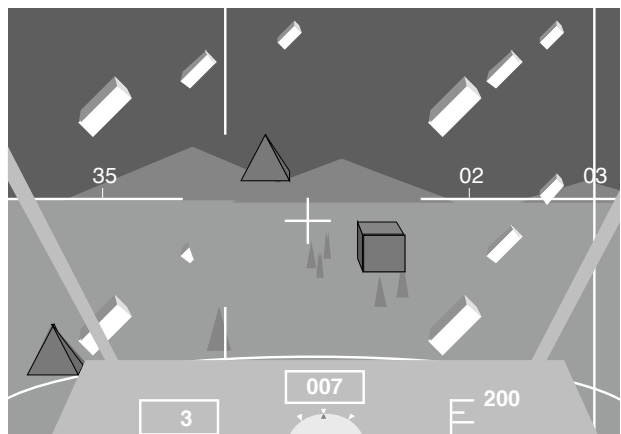


Fig. 6 Cut-out Display with Targets Shown

symbology entering the blanking zone would disappear, and (blanked) symbology exiting the zone would reappear. In Fig. 4 the *Overlay* display is seen during descending and left vehicle translation - the static picture can indicate either left and downward or right and upward motion, but viewing the cues in motion removes this ambiguity. Fig. 5 depicts forward helicopter motion seen using the *Overlay* display. Fig. 6 again shows left and descending motion seen with the *Cut-out* display (note the absence of central cues). Targets (part of the NVG imagery, hence monochromatic green) are shown in Fig. 6.

### **2.3 Contrast**

Three contrast levels were used with each display type: 1) High: nominal object color intensities; 2) Medium: all intensities reduced to 60% of nominal intensities (NVG image, cube lattice, globe); 3) Low: all intensities reduced to 40% of nominal.

### **2.4 Tasks**

#### **2.4.1 Search Task**

Ten targets appeared in the external scene when the subject depressed a cyclic button. Five were intended targets shaped as cubes (green since part of the NVG image), and five were distracter targets shaped as pyramids. The objective was to maximize the capture of intended targets. Target capture was performed by head-pointing the display crosshairs over a target and depressing a cyclic trigger switch, subsequently the target would disappear. Every ten seconds a new set of random targets would replace the previous set. Targets appeared within  $\pm 60$  degrees of the aircraft heading in nominal increments of 30 degrees, and actual target azimuth varied randomly  $\pm 5$  degrees from the nominal. Target elevation was randomly generated from -15 degrees (to avoid airframe obscuration of target) to +40 degrees relative to the horizon. Once targets appeared they remained fixed relative to the ground. A run lasted 60 seconds (six target sets) during which the helicopter was fixed in space at an altitude of 50 feet, requiring no control inputs from the pilot.

#### **2.4.2 Hover Task**

The helicopter was automatically positioned and trimmed for a steady-state 50-foot hover. Upon depressing a cyclic button, flight control was transferred to the subject and turbulence initiated. The turbulence model was Gaussian, zero-mean, with maximum gusts of  $\pm 1$  ft/sec in the north, east and vertical directions. Task objective was to null out all translational and yaw rates that developed using any of the available cues (terrain features, panel instruments, artificial flow cues). A run finished after 60 seconds of flight.

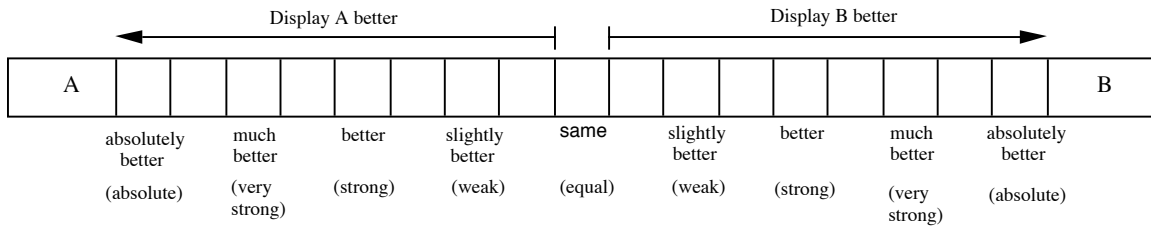
#### **2.4.3 Search/Hover Task**

The subject conducted both the Hover and Search tasks simultaneously, with the primary objective being helicopter control and stabilization. Each run was 60 seconds in duration.

### **2.5 Protocol and Data Analysis**

All references to significance refer to a 95% confidence level ( $p < .05$ ). The order of tasks each subject received was Search, Hover and Search/Hover. Prior to each task the subject was briefed on scenarios and objectives. A warm-up session of three target sets was given using each display/contrast combination (9 combinations). For the Hover task, pilots practiced flying with each display until they felt comfortable with both the vehicle dynamics and displays. Familiarization times ranged from 20 minutes to 45 minutes. A similar warm-up period was given for the Search/Hover task. Following each warm-up, nine 'live' runs were recorded, one for each display/contrast combination (orders were counterbalanced), and subject evaluations collected.

The Analytic Hierarchy Process<sup>6</sup> (AHP) was used to obtain subjective preferences for the three displays for each task. AHP breaks up multiple options into a series of paired comparisons which are then recombined to produce an overall weighted ranking. The scale given to subjects is a measure of dominance of one alternative over the other, shown in Fig. 7.



**Fig. 7. Dominance scale used for paired comparison of two display options**

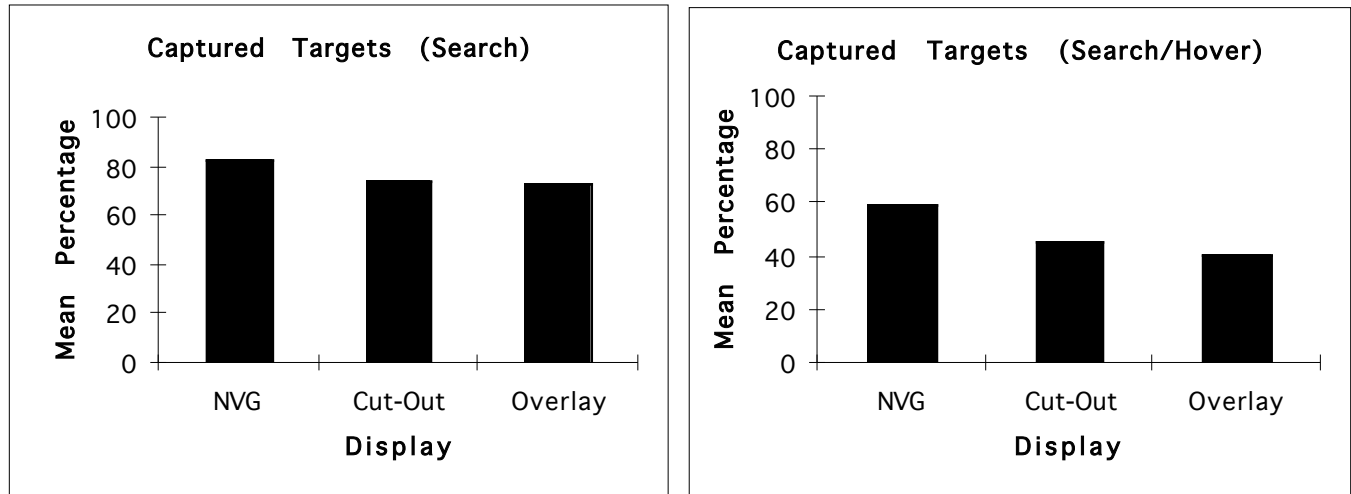
## 2.6 Subjects

Six subjects participated in the experiment. All had actual or simulator helicopter flight experience, ranging from 0-1900 hours actual (mean 950), and 0-75 hours simulator (mean 17). Three subjects were helicopter instructors, all but one had commercial pilot ratings, with the remaining holding a private pilot license. None had flight experience using an HMD. Subject ages ranged from 25 to 42, and all were male.

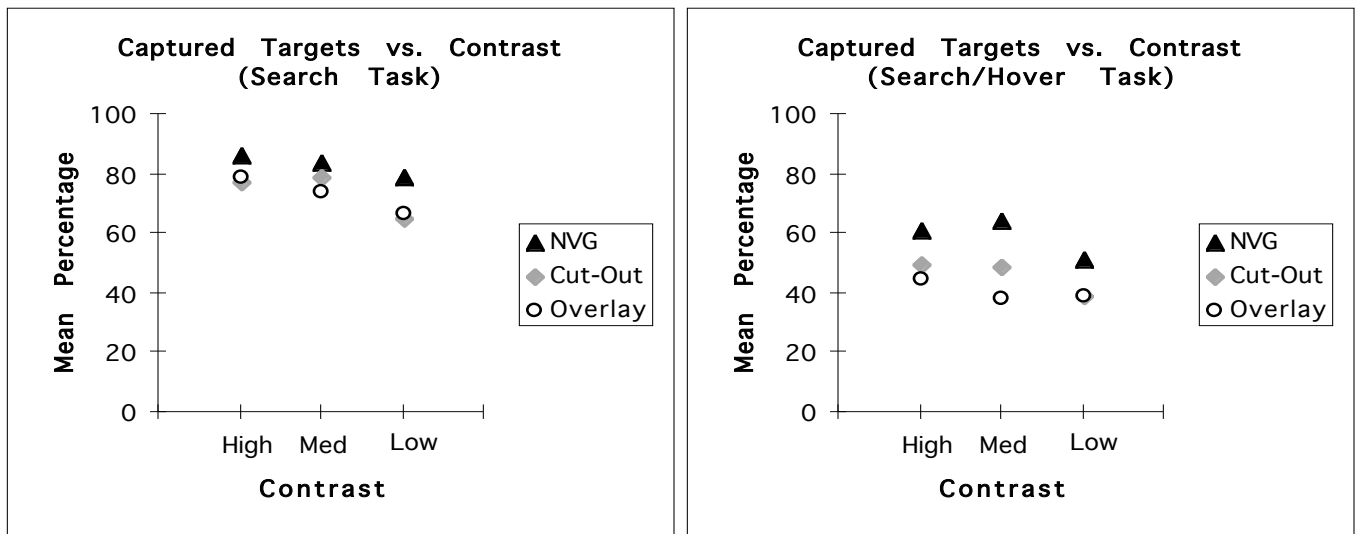
## 3. RESULTS

### 3.1 Target detection

Target detection results are presented in Fig. 8. For both the Search and Search/Hover tasks the NVG display had higher detection scores than the other displays. Search/Hover task scores were significantly lower compared to the Search task scores for all displays. Fig. 9 shows the effect of contrast on target detection. For the NVG and *Cut-out* displays scores were essentially the same going from the High to Medium contrast. At Low contrast both the *Cut-out* and *Overlay* displays yielded similar scores within each task.

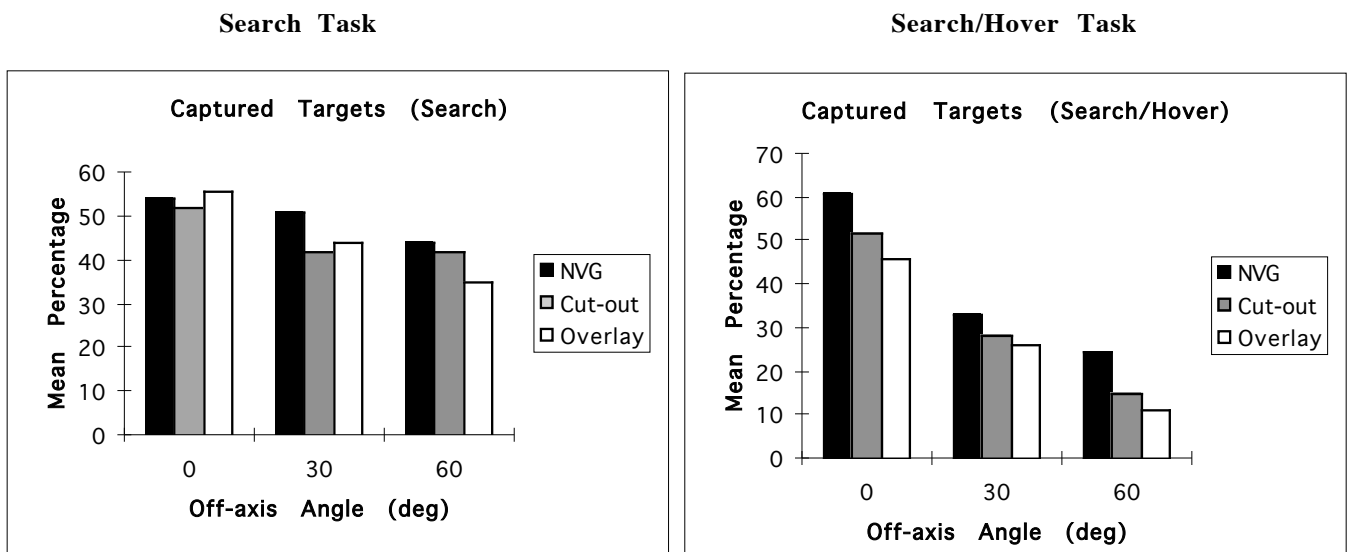


**Fig. 8 Target detection scores for Search and Search/Hover tasks**



**Fig. 9 Target detection scores vs. contrast for Search and Search/Hover tasks**

Fig. 10 shows detection performance for three zones of detection: 0 deg ( $\pm 15$  degrees off the nose), 30 deg (15 to 45 degrees off the nose, both directions), and 60 deg (greater than 45 degrees off the nose, both directions). It is seen that the addition of the high workload Hover task to the Search task results in decreasing detection scores as off-axis angle increases.



**Fig. 10 Off-axis target acquisition results for Search and Search/Hover tasks**

### 3.2 Hover performance

Fig. 11 shows typical plots for the *NVG* and *Overlay* displays for drift rate and control input for the three axes of translation (Hover task). In general, lateral and vertical motion appeared to be less oscillatory while using the *NVG* display than with the other two rate-cueing displays. The *NVG* display also resulted in significantly lower control activity in the longitudinal and lateral axes for both the Hover and Search/Hover tasks. Collective activity was also lower with the *NVG* display than with the rate-cueing displays. RMS control input rates are shown in Fig. 12. From this data it appears that the rate cues of both the *Overlay* and *Cut-out* displays imparted stronger motion sensation than occurred using the *NVG* display. RMS drift rates, shown in Fig. 13, were comparable for all three displays for the Hover and Search/Hover tasks.

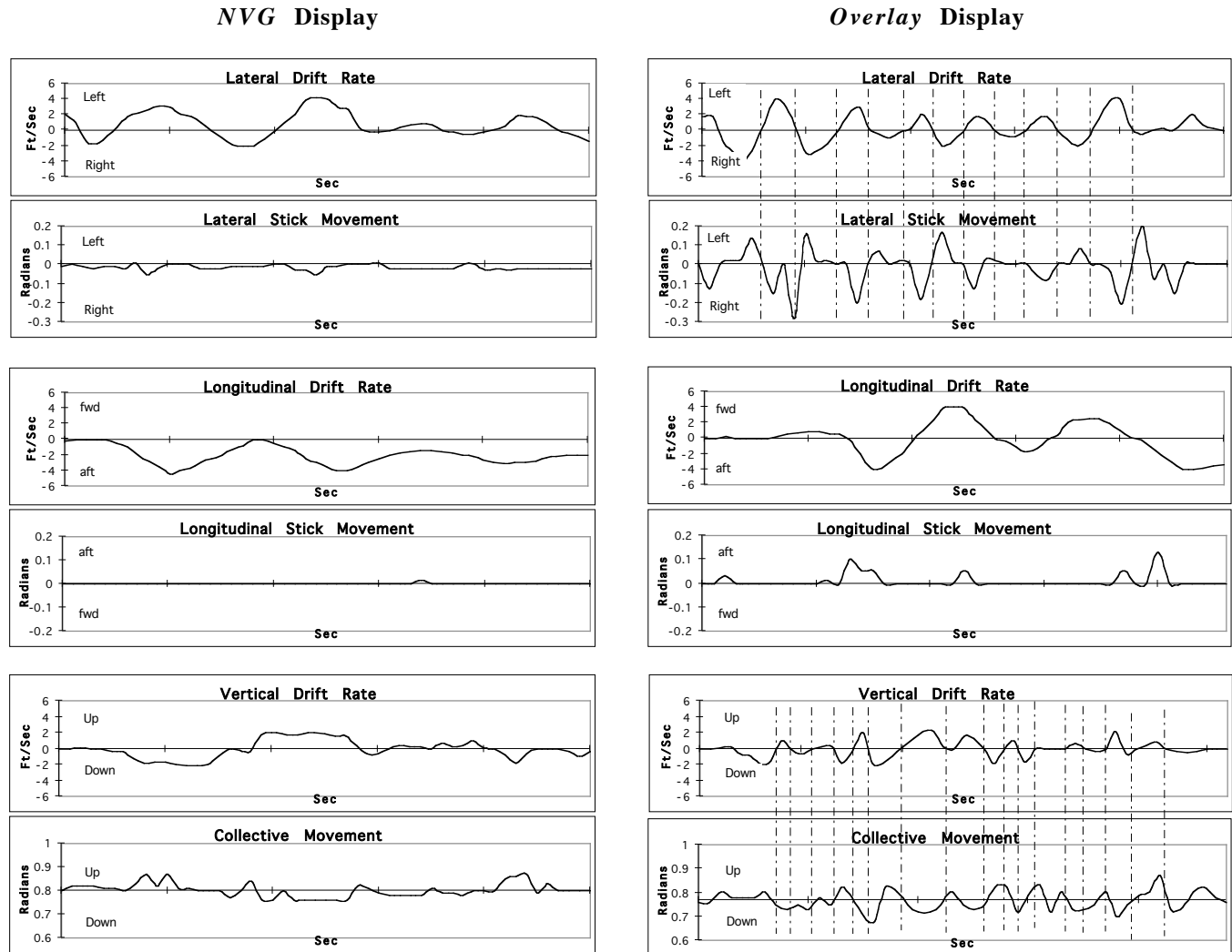
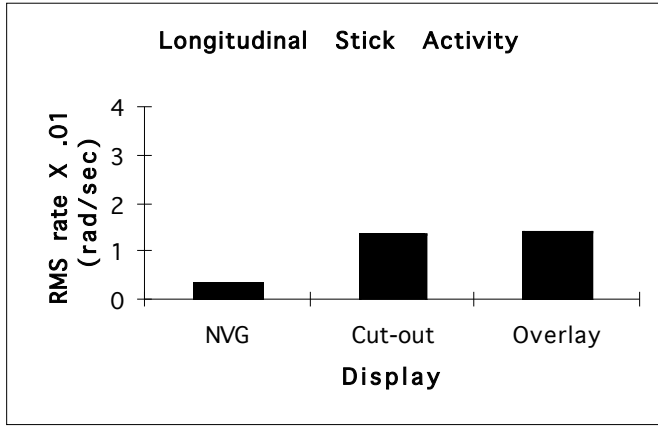
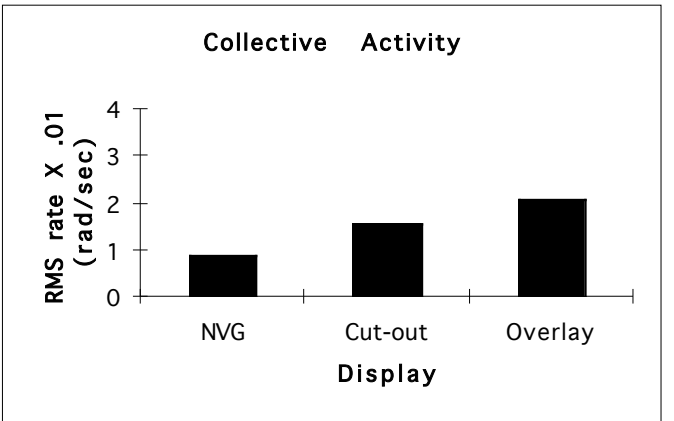
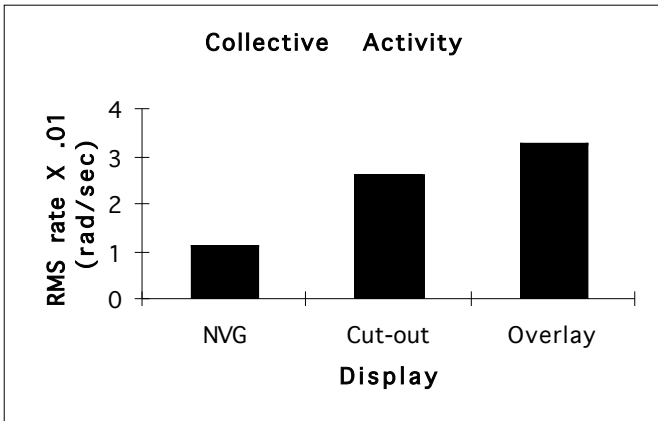
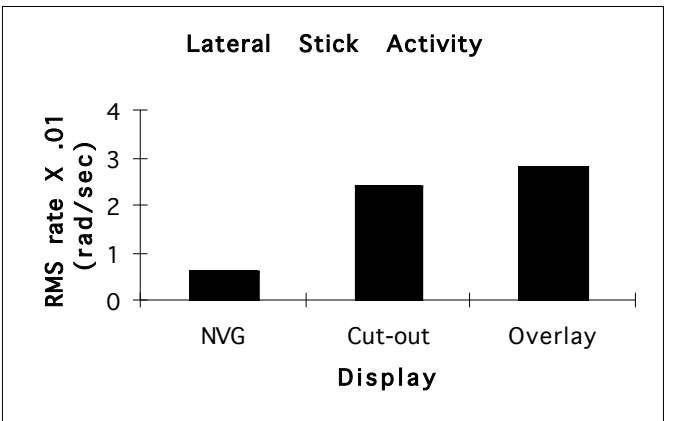
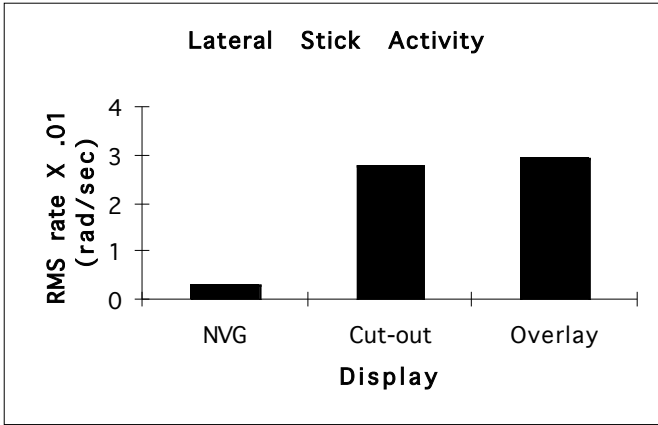
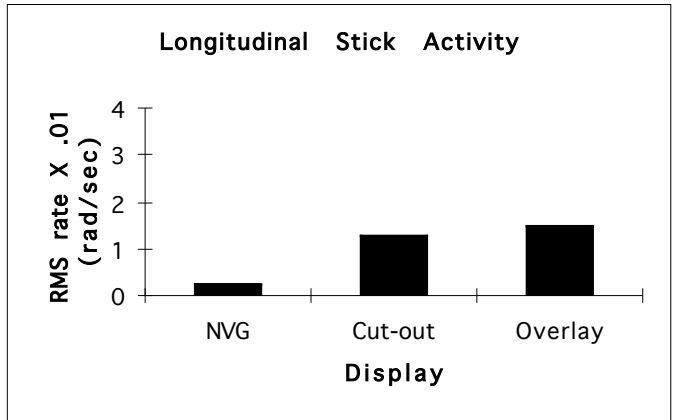


Fig. 11 Case example of Hover task drift rates and control inputs for *NVG* and *Overlay* displays, same pilot (60 sec run)

**Search Task**

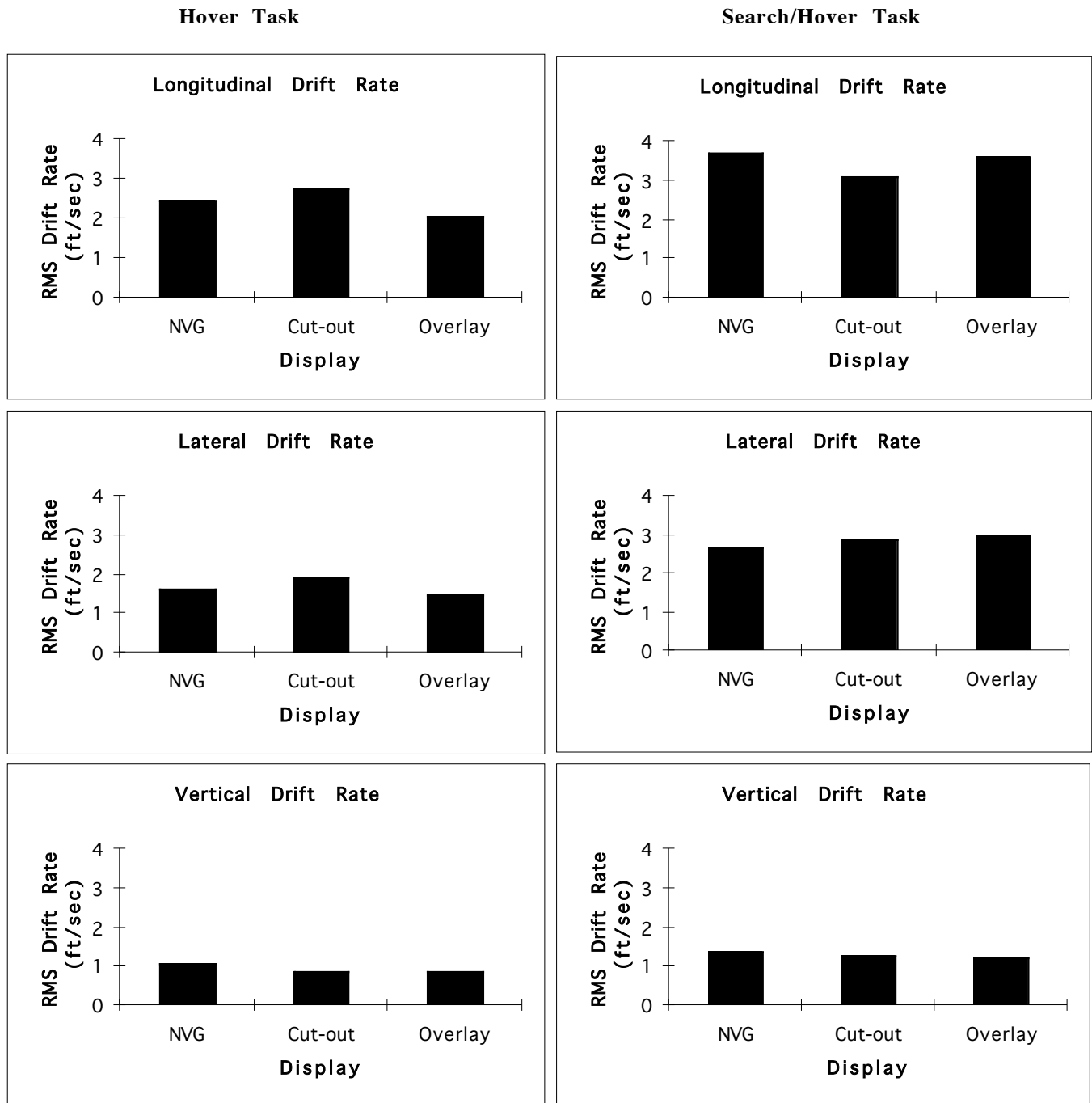


**Search/Hover Task**



**Fig. 12 Control input activity for Search and Search/Hover tasks**





**Fig. 13 Hover and Search/Hover task drift rates**

A significant decrease in head-down time (Fig. 14) was observed for both the *Overlay* and *Cut-out* displays compared to the *NVG* display (Hover and Search/Hover tasks). Head-down time using the *NVG* display decreased going from the Hover to Search/Hover task, but there was little difference between the tasks for the two rate-cueing displays.

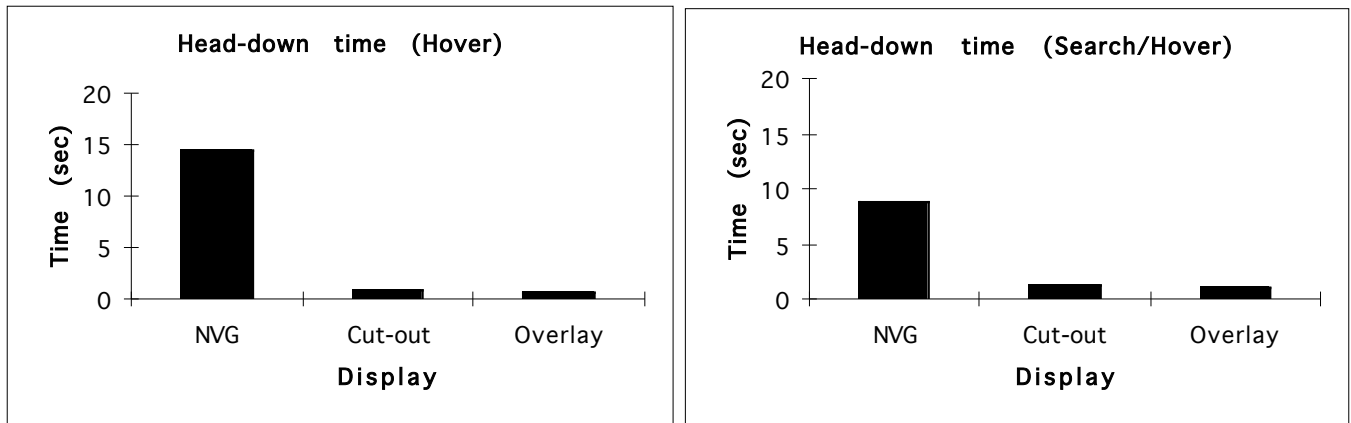


Fig. 14 Mean head-down time for Hover and Search/Hover tasks (60 sec flight time)

### 3.3 Subjective rankings of displays

The AHP results are shown in Fig. 15. For the Search task, the *NVG* display was preferred over the other two displays, which agrees with the better detection performance it produced. For the Hover task the *Overlay* was preferred, and for the Search/Hover task the *Cut-out* display was preferred.

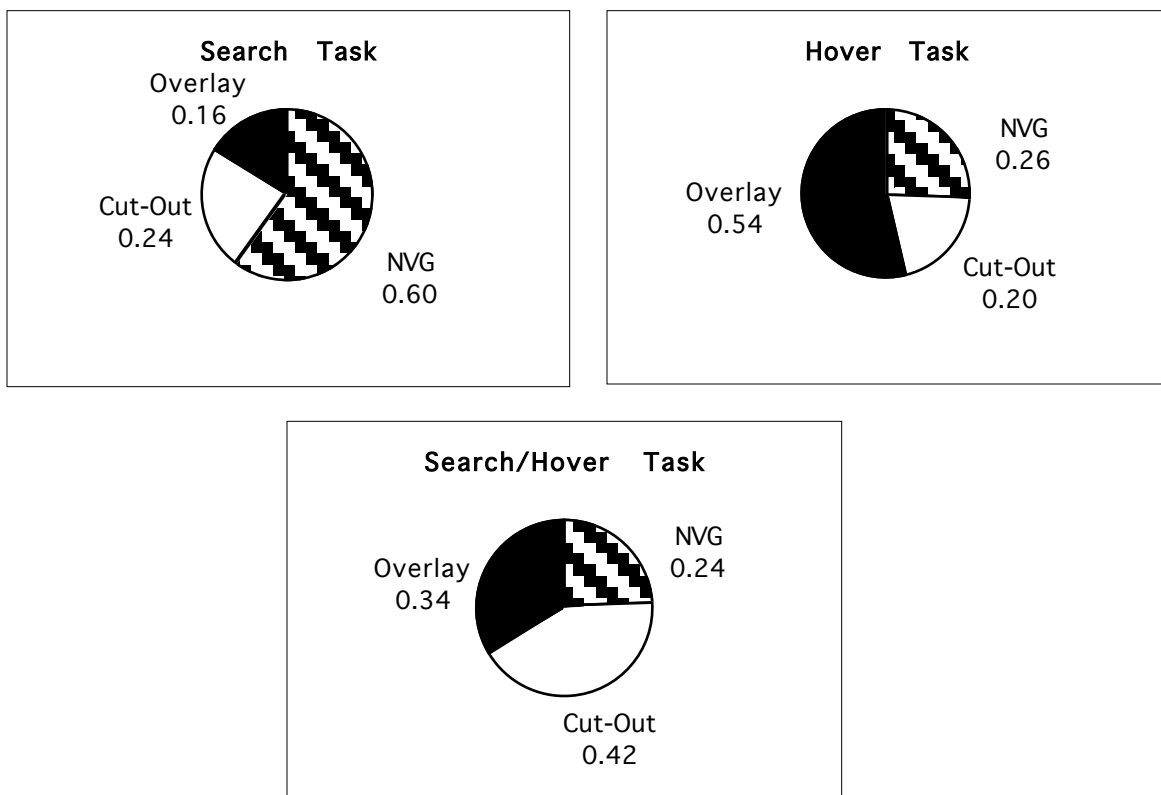


Fig. 15. Weighted ranking of displays using AHP

## 4. CONCLUSIONS

### 4.1 Summary of results

- All three displays produced similar drift rate errors in the three translational axes, but control input activity was higher with the rate-cueing displays. From the control input and drift rate time histories it appears that the motion cues were more compelling in the *Overlay* and *Cut-out* displays than those perceived in the *NVG* display. A significant decrease in head-down time was observed for both the *Overlay* and *Cut-out* displays compared to the *NVG* display (Hover and Search/Hover tasks). Contrast was not observed to have a significant effect on hover performance in any of the displays.
- Target detection scores were highest with the *NVG* display, followed by the *Cut-out* display. Introduction of the Hover task to the Search task resulted in a significant decrease in target detection scores, this effect being more marked with the rate-cueing displays. Target detection scores during the Search/Hover task were progressively lower with increasing off-axis target angle for all displays.
- Subjective scores indicated a preference for the *NVG* display with the Search task, a preference for the *Overlay* display with the Hover task, and a preference for the *Cut-out* display with the Search/Hover task.

### 4.2 Remarks on results

The hover performance data showed comparable RMS drift rates, but inspection of the control inputs histories revealed that subjects were more sensitive to drift rates while using the rate-cueing displays than with the *NVG* display, notably in the vertical and lateral axes. The lateral rate behavior using the *Overlay* and *Cut-out* displays is consistent with a control strategy that responds primarily to rate. Bank angle serves as a predictor of lateral rate, and degradation of bank angle sensing in the presence of strong rate feedback could produce results similar to what were observed in this experiment. Seen with a reduced FOV, the Cobra cockpit offers very few markers for cockpit reference, and most of the subjects did comment that there was an uncomfortable lack of visible airframe reference while looking out of the cockpit. It is possible that improved cockpit reference cues could reduce some of the drift rate oscillation and high stick activity observed with the rate-cueing displays, and it is also possible that this hover performance was to some extent an artifact of the cueing design itself.

For the Search task the target detection scores for all three displays were comparable. During the Search/Hover task subjects were essentially flying head-out-of-cockpit with the rate-cueing displays, so one might have expected their detection scores to be comparable to if not higher than the *NVG* display's scores for the same task. A possible explanation why this did not occur is that the artificial rate cues were so compelling that they diminished the effect of and attention given to other visual stimuli. Removal of the *Overlay* display's central flow cues did not appear to have an effect on hover performance, although the subjective scores for the Hover task indicated preference for having the entire cue field in sight. The target detection scores indicated a benefit to having a central declutter zone when using the rate-cues. Subjective ratings favored the *Cut-out* display when conducting the Search/Hover task, indicating that of the three displays subjects thought it balanced best the trade-off between external object and drift rate awareness.

## 5. ACKNOWLEDGMENTS

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## 6. REFERENCES

1. J. Crowley, C. Rash, R. Stephens. "Visual illusions and other effects with night vision devices," *SPIE*, Vol. 1695, Helmet Mounted Displays III, 1992.
2. E. Bachelder and R. J. Hansman. "Issues in simultaneous HMD display of multi-reference frames for helicopter applications," *SPIE Proceedings: Enhanced and Synthetic Vision*; Paper No. 2736-23.
3. J. Morey and D. Leedom. "Superimposing instrument symbology on a night vision goggle display during simulated contour flight," *Dynamics Research Corporation*, Contract #MDA-903-92-D-0025, 1993.
4. G. Anderson and B Dyre. "Spatial orientation from optic flow in the central visual field," *Perception and Psychophysics*, Vol. 35, 453-458 1989.
5. R. Miller and T. Tredici. "Night vision manual for the flight surgeon," *Ophthalmology Branch, Armstrong Laboratory*, Report AL-SR-1992-0002, 1992.
6. L. Yang and R. J. Hansman. "Application of the analytical hierarchy process for making subjective comparisons between multiple automation/display options," *6th IFAC/IFOR/IEA Symposium*, 1995.