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**IN-FLIGHT PERFORMANCE EVALUATION OF
EXPERIMENTAL INFORMATION DISPLAYS**

By

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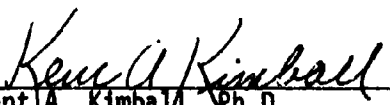
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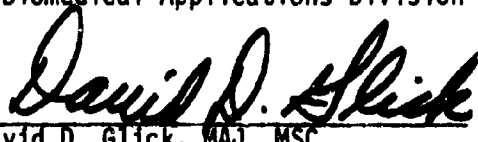
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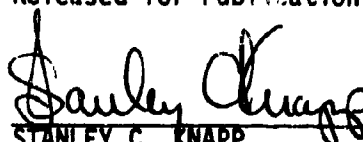


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The objective of this investigation was to evaluate a method of displaying information which permits rapid transmission of flight data to the operator under three viewing conditions: (1) day flights with the unaided eye, (2) night flights with the unaided eye, and (3) night flights using the AN/PVS-5 night vision goggles (40° field of view focused at infinity). Information obtained from the analyses of aviator performance data demonstrated the potential of presenting flight information to the aircrew via prototype displays for all viewing modes.		

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INTRODUCTION

Because of potential battlefield threat conditions, tactical helicopter flight will extensively utilize terrain flight profiles for both day and nighttime flights. Terrain flight requires aviators to maintain the major portion of their visual attention out of the cockpit to avoid terrain obstacles and to maintain concealment. Certain mission phases require the pilot to shift his attention into the cockpit for necessary flight information. Any factor which degrades the pilot's ability to rapidly adjust to the vision within the cockpit enhances the probability of disorientation and obstacle collision.

This information transfer is further compounded when wearing night vision goggles (NVG) because they require a manual refocus to achieve near vision within the cockpit. This, of course, not only increases the time needed to obtain the desired information, but also requires removing one or both hands from the controls. Because of these time delays inherent in the use of NVG, the aviator often chooses to go without the information he desires, or he must ask the copilot to provide it, or he must risk obstacle collision by coming inside and refocusing to obtain the required information.

The AN/PVS-5 Night Vision Goggles represent the state-of-the-art applied technology for head-mounted night vision systems. Thus, any reduction in the time required to transfer flight information must involve changes in the flight instrument displays. Improvements in the flight displays should incorporate features that allow for unrestricted viewing by the unaided eye during day and night flights. Improved displays must also allow the crewmembers to obtain information without refocusing the NVG.

The objective of the current investigation was to evaluate one method of displaying information that allows the rapid transmission of flight information under three primary viewing conditions: (1) day flights with the unaided eye; (2) night flights with the unaided eye; and (3) night flights using the AN/PVS-5 Night Vision Goggles (40° field of view focused at infinity).

A potential technique to resolve the information transfer problem was developed by mounting active light displays, focused at infinity, in a position convenient for use by the pilot. Such displays have the potential for quickly relaying certain parameters of key interest to the pilot at a low dollar cost. They also permit the transmission of directional information to the copilot/navigator from current or future navigation systems.

Currently the nonbifocal night vision goggles must be initially focused for inside instrument viewing and then refocused at infinity for viewing outside the cockpit. Thus, cockpit instruments or information display devices that are collimated at infinity provide the aviator with the capability of quickly looking inside for flight and engine information without manually refocusing the NVG's. The primary question addressed in this project was whether or not this method of displaying flight instruments provided adequate information during all three primary visual conditions referenced above.

METHODOLOGY

SUBJECTS

Subjects for this investigation were four rotary wing Army aviators from Fort Rucker, Alabama. These aviators had extensive experience in rotary wing flight, having flown an average of 1030 hours in UH-1 rotary wing aircraft. All aviators possessed previous experience with the AN/PVS-5 Night Vision Goggles (average total flight hours with NVG was 21.7 with an average of 257 night flight hours).

APPARATUS

AN/PVS-5 Night Vision Goggles

The 40° field-of-view (FOV) AN/PVS-5 NVG's were focused at infinity throughout the study. The NVG's are self-contained, battery powered, second generation, passive, binocular devices. The NVG's weigh approximately 1.9 pounds, and for their airborne application mount to the SPH-4 aviator helmet with snaps and velcro attachments.

Helicopter

The test vehicle used throughout this study was the USAARL JUH-1H helicopter. This aircraft has been specially instrumented to provide measures of the pilot control inputs and aircraft position, rates, and accelerations to the Helicopter In-Flight Monitoring System (HIMS). HIMS measures changes in the aircraft's attitude in all six degrees of freedom while simultaneously recording cyclic, collective and pedal inputs and aircraft flight status values. These data were recorded in real time using an on-board incremental digital recorder. Continuous information from twenty pilot and aircraft monitoring channels was

recorded for all flights. A more detailed description of HIMS can be found in USAARL Report No. 72-11.¹

Prototype Displays

The displays used for this evaluation were mounted on the left side of the JUH-1H instrument panel directly in front of the left seat (Figures 1 and 2). The displays were located so as to allow the pilot complete freedom of control movement. Figures 3 and 4 show details on the location of the displays and the internal lenses, cross-polarized lenses and Wratten filters. The displays were mounted at the forward end of two, light-tight rectangular boxes with the display facing the subjects. One box housed the numeric LED display which presented information; the other box housed the circular gas discharge light display. Two display scales, mounted directly over the circular gas discharge light, were interchanged to provide either airspeed information or radar altitude information. Plano convex lenses were placed at their focal length from the displays between the light displays and the subject's eye. Two plano convex lenses were used on the airspeed and radar altitude displays. A 559mm focal length, 102mm diameter lens was used to collimate the displays at infinity for the first two subjects tested. A second lens was used to present the airspeed and radar altitude information to the last two subjects. This lens had a 571mm focal length with a 86mm diameter. A 571mm focal length, 86mm diameter plano convex lens was used for all four subjects on the LED numeric heading display.

A Burroughs circular neon orange gas discharge analog display was utilized to provide the airspeed and radar altitude information. The diameter of the circular gas discharge display was 2.48 inches. An airspeed scale (0-90 knots) was placed over the circular bar graph for the flight profile test phase while a radar altitude scale (0-100 ft. AGL) was placed over the bar graph for the hover testing phase.

A three digit light emitting diode (LED) matrix (1" wide X 1/4" high) numeric display was used to provide heading information during both the flight profile and hover test phases. Minor adjustments in the two display housings were used to focus clear images during the day and night flights.

Cross-polarized lenses were installed between the displays and the collimating lenses during the NVG's testing conditions to reduce the light output of the displays to luminance levels compatible with the NVG's. Wratten filters were inserted at an angle into the aft end of the display housing during the daytime flights in an effort to reduce the reflections from the subject's face.

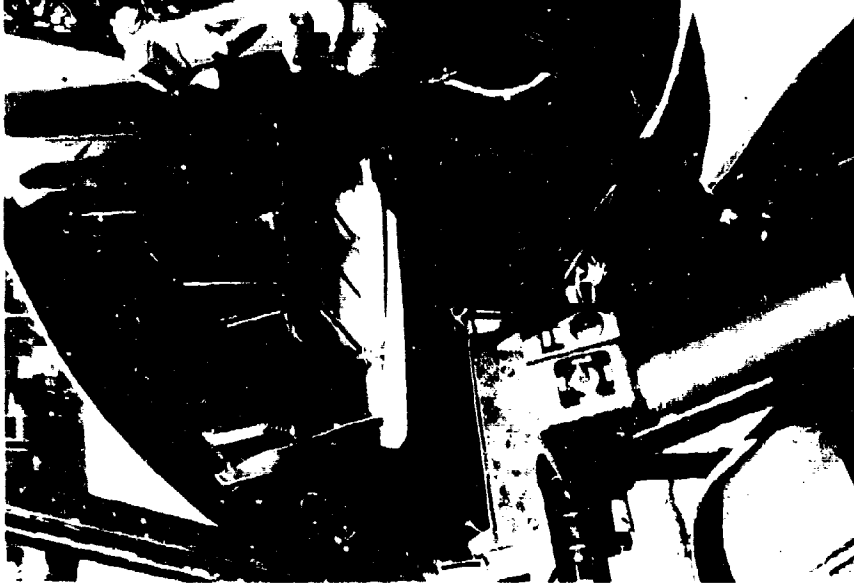


FIGURE 2. Experimental Display Housings.

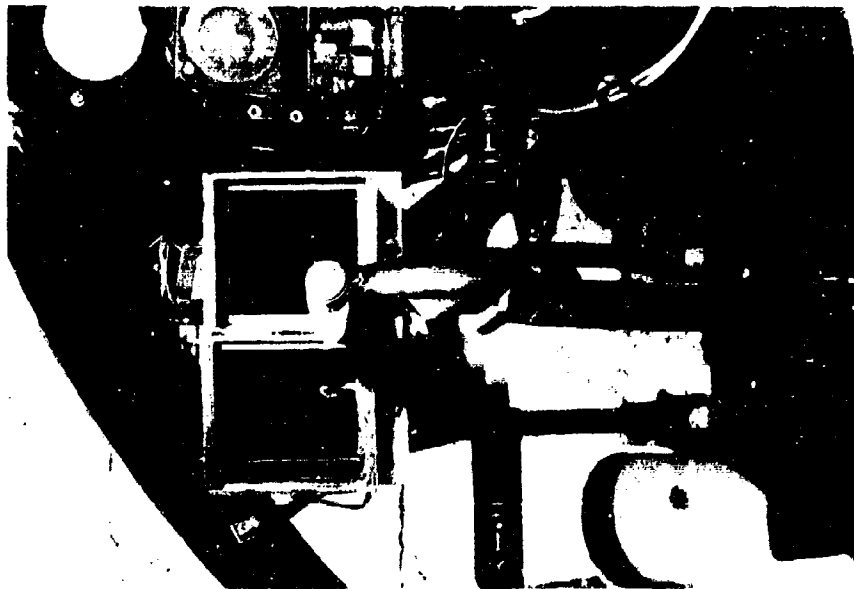


FIGURE 1. Experimental Display Housings.

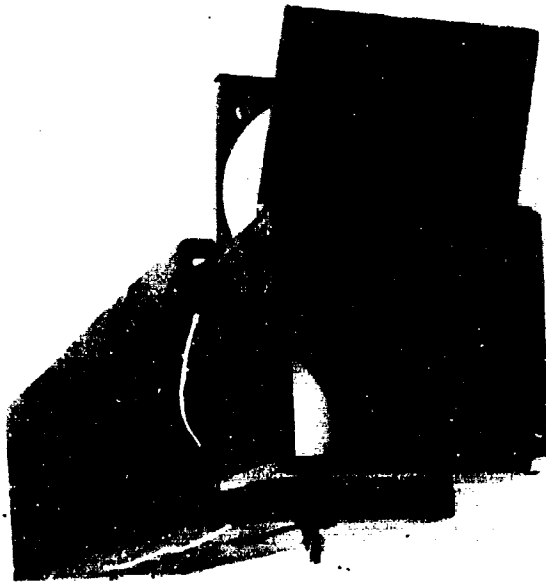


FIGURE 3. Experimental Display Housing Showing Wratten Filter, Collimating Lens and Neutral Density Filter.

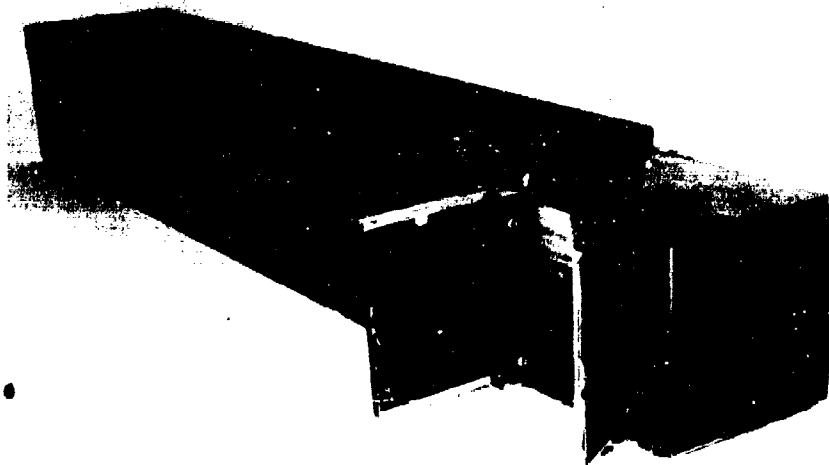


FIGURE 4. Experimental Display Housing Showing Wratten Filter, Lens, and Natural Density Filter.

The luminance values for each display were measured in the laboratory using a Photo-Research Pritchard Photometer Model 1980. For the LED, a dot on the matrix was measured; for the gas discharge display the brightest ends of a standard and elongated bar were measured using the inserted airspeed scale. These luminance values are presented in Table 1.

Pilot Questionnaire

A questionnaire was constructed to determine the aviators' opinions about the experimental displays during the different test conditions, as well as comparisons of these displays to the standard flight instruments.

PROCEDURE

All subjects were given approximately 15 minutes to familiarize themselves with the displays during the flight from Cairns Army Airfield to the test site, Highfalls Stagefield. Upon reaching the test site, the subjects completed a practice maneuver to aid in their familiarization with the displays.

Each subject flew two test maneuvers: (1) a 30-foot AGL hover into the wind at a constant heading for 2 minutes; and (2) a flight profile lasting approximately 6 minutes which included one standard rate turn and two straight segments of approximately 3.8 nautical miles per segment. During the straight segments of this profile, the pilots were instructed to maintain a constant heading and airspeed. Each maneuver was accomplished under four different test conditions: (1) a baseline flight during the day with the unaided eye using the standard flight instruments; (2) day flight with the unaided eye using the test displays; (3) night flight with the unaided eye using the test displays; and (4) night flight with the AN/PVS-5 NVG's using the test displays. The 30-foot AGL hover and the flight profile maneuvers were flown twice by each subject under each test condition. The order of testing was counterbalanced to prevent a learning bias from influencing the data. Night testing was conducted under .96 to zero percent moon illumination. Each subject's total flight involvement was approximately 4½ hours, half of that occurring at night and half during the daylight hours.

Among the substantial number of flight evaluations that have been conducted, only a small minority actually measure changes in the man-helicopter system performance and utilize numerical data to discriminate between testing conditions. One result is that a numerical description of standard flight performance is not within common aviation knowledge. For this investigation standard daytime flights using the normal flight

TABLE 1
LUMINANCE VALUES¹ OF THE EXPERIMENTAL DISPLAYS

	Heading Display ²	Airspeed/Radar Altitude Display ³	
		Standard Unit Bar	Elongated Bar
Display Alone	7.44	9.28	5.96
With Lense & Wratten Filter	4.20	.61	1.37
With Lense - Wratten Filter & Neutral Density Filter ⁴	.0788	.0102	.0229
Neutral Density Values	1.7268 ND	1.7760 ND	1.7760 ND

¹ All luminance values are presented in Footlamberts.

² Description: LED Matrix, measured matrix dot.

³ Description: Burroughs Circular Analog Gas Discharge, measured bright end of illuminated airspeed scale bars.

⁴ Values with Neutral Density (ND) filter were calculated rather than directly measured.

instruments were included to obtain a numerical description of standard flight conditions that could be compared against those results obtained from flights using the experimental displays. Thus, for this investigation the unaided daytime flights are considered as representing standard, or baseline, flight performance.

At the conclusion of testing, the information obtained from the HIMS was processed and analyzed. Measures of error for heading, airspeed, and radar altitude were selected to determine changes in man-helicopter system performance between the three experimental conditions and the baseline flights.

ANALYSIS AND RESULTS

PERFORMANCE DATA

The primary purpose of this investigation was to determine if the prototype displays provided adequate information for each of the three primary visual conditions. In addition, the flights using the prototype displays were compared to the baseline performance using standard flight displays to determine if there was a general improvement in flight performance using the prototype displays.

Measures of performance error were used to evaluate changes between the baseline flights and the day, night, and night vision goggles (NVG) prototype display (PD) flights. For the low level flights, measures of heading error and measures of airspeed error were examined. For the hover flights, measures of heading error and radar altitude error were used. In each case these measures were selected because they correspond directly to the types of information displayed on the prototype display during each type of flight profile.

For each of these performance measures, four aspects of error were initially examined: (1) standard deviation (SD), (2) average constant error (ACE) from standard values specified by the experimenters during the test flights, (3) average absolute error (AAE), and (4) root mean square error (RMSE). The initial phases of the analyses demonstrated that for maintenance of a constant radar altitude, the measures of average absolute error and root mean square error were completely redundant with the measures of average constant error. As a result, these error scores were deleted from further consideration for each of the performance measures of airspeed, heading, and radar altitude, to insure consistency of data between each of these primary performance measures. The final analyses of performance change utilized the measures of standard deviation and average constant error. The analyses were conducted using a two-factor repeated measures multivariate analysis of variance (Cramer 1974).²

The results from the overall tests of performance differences between the four experimental conditions, for the low level flights and for the hover flights are presented in Table 2A and B. Each of these overall comparisons were significant indicating that for both the hover and low level flights at least one pair of experimental conditions had significant error performance differences. Further analyses were conducted to compare each experimental condition with all other conditions to determine exactly where the changes in performance were apparent.

Results obtained from examination of the low level flights (Table 3A) demonstrate that all test conditions showed significantly different performance errors, except when the baseline performance was compared to that obtained during the NVG's PD flights. When each pair of hover flight test conditions were evaluated (Table 3B) it was determined that there were significant differences when the baseline, day, and night flights were compared with the NVG's PD flights. No significant change in performance error was found between the baseline flights and the night PD flights or between the day and night PD flights. Further discussion of the apparent significant difference between the baseline and the day PD flights occurs in a following section.

The average error values for each of the performance error measures are presented in Table 4. The standardized discriminant function coefficient, found at the top of each variable column in Table 4, shows the relative contribution of each variable in providing the maximum possible discrimination between the experimental conditions. The discriminant score contrasts for each experimental condition, found in parenthesis next to the labels of the experimental conditions, provide the most important information found in Table 4. These values are estimates of the composite performance error for each experimental condition when all variables are considered simultaneously and are graphically displayed in Figure 5. Since all performance measures used in this analysis were measures of error, the highest discriminant score contrasts (.712 for the day PD low level flights and 1.230 for the NVG's PD hovers) represent the highest levels of performance error.

The discriminant score contrasts for the low level flights (Figure 5 and Table 4A) demonstrate that the best overall low level flight performance was observed during the night PD flights. Progressively more performance error was observed during the NVG's PD flights and the baseline flights. The largest performance error was found during the day PD flights. Previous analyses have determined that the differences between the second ranked NVG's flights and the third ranked baseline flights were not significant. These results obtained from the low level testing suggest that pilots most effectively utilized the PD during night flight. When the night vision goggles were employed the aviators may have attended more to visual cues outside the cockpit, thus losing a

TABLE 2
 MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY TESTS OF SIGNIFICANT DIFFERENCES
 BETWEEN THE FOUR EXPERIMENTAL FLIGHT CONDITIONS

Source	F Ratio	Means Squares Tested ¹	Degrees of Freedom for Hypothesis	Degrees of Freedom for Error	P Less Than
A. LOW LEVEL FLIGHTS					
Experimental Conditions	2.012	C/CS+MC	12.00	143.16	.027*
Subjects	4.714	S/MC	12.00	119.35	.001*
B. HOVER FLIGHTS					
Experimental Conditions	3.047	C/CS+MC	12.00	58.49	.002*
Subjects	2.867	S/MC	12.00	34.69	.008*

* Significant beyond the .05 level.

¹ CS = Condition subject interaction mean squares. MC is the within cells error mean squares.

TABLE 3

MULTIVARIATE ANALYSIS OF VARIANCE SUMMARY
COMPARISON OF EXPERIMENTAL CONDITIONS

Source	F Ratio	Means Squares Tested ¹	Degrees of Freedom for Hypothesis	Degrees of Freedom for Error	P Less Than
A. LOW LEVEL FLIGHTS					
Baseline Vs. Day	2.944	Cx-Cy/CS+MC	4.00	54.00	.028*
Baseline Vs. Night	3.950	Cx-Cy/CS+MC	4.00	54.00	.007*
Baseline Vs. NVG's	.803	Cx-Cy/CS+MC	4.00	54.00	.529
Day Vs. Night	2.705	Cx-Cy/CS+MC	4.00	54.00	.040*
Day Vs. NVG's	73.608	Cx-Cy/CS+MC	4.00	54.00	.001*
Night Vs. NVG's	95.358	Cx-Cy/CS+MC	4.00	54.00	.001*
B. HOVER FLIGHTS					
Baseline Vs. Day	3.511	Cx-Cy/CS+MC	4.00	22.00	.023*
Baseline Vs. Night	1.748	Cx-Cy/CS+MC	4.00	22.00	.175
Baseline Vs. NVG's	3.797	Cx-Cy/CS+MC	4.00	22.00	.017*
Day Vs. Night	2.292	Cx-Cy/CS+MC	4.00	22.00	.092
Day Vs. NVG's	12.050	Cx-Cy/CS+MC	4.00	22.00	.001*
Night Vs. NVG's	22.327	Cx-Cy/CS+MC	4.00	22.00	.001*

* Significant beyond the .05 level.

¹ CS = Condition subject interaction mean squares. MC is the within cells error mean squares.

TABLE 4
AVERAGE ERROR SCORES FOR EACH EXPERIMENTAL CONDITION

A. LOW LEVEL FLIGHTS				
	Heading S.D. (-.013)*	Heading A.C.E. (-.542)*	Airspeed S. D. (.641)*	Airspeed A.C.E. (-.563)*
1. Baseline (.338)**	2.50	.19	2.16	-.29
2. Day (.712)**	3.02	-.80	2.33	.03
3. Night (-.853)**	1.72	.60	1.79	1.29
4. NVG's (-.197)**	2.52	.68	1.93	-.02
B. Hover Flights				
	Heading S.D. (-.233)*	Heading A.C.E. (-.340)*	Radar Alt S.D. (.765)*	Radar Alt A.C.E. (-1.035)*
1. Baseline (-1.137)**	2.23	-.71	3.98	4.93
2. Day (-.767)**	1.86	.43	1.78	.03
3. Night (.674)**	3.01	-1.01	5.32	-.78
4. NVG's (1.230)**	2.97	-1.84	4.66	-3.13

* Standardized Discriminant Function Coefficients.

** Discriminant Score Contrasts. Units of measure are degrees for heading, knots for air-speed and feet for altitude.

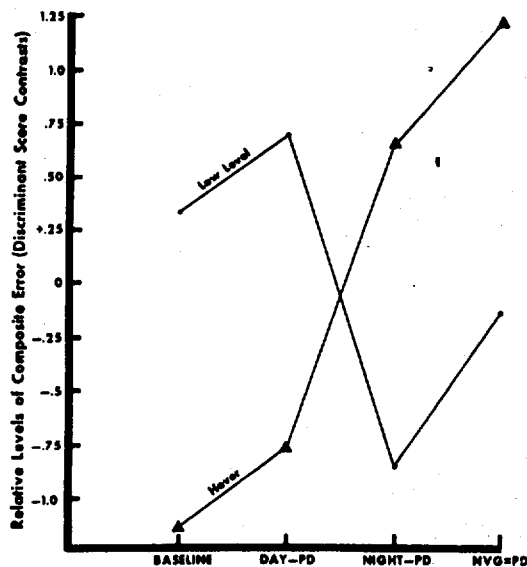


FIGURE 5. Relative Performance Error for Baseline Flights and Experimental Conditions.

portion of their flight precision. Since NVG's flight demonstrated slightly, although not significantly, lower performance error, it can be assumed that the PD did provide effective supplementary information. The relatively high performance error scores for the day PD flights suggest that aviators, all who have many hours of VFR contact flight experience, were not able to effectively utilize the PD information as a supplement to the normal attitude cues. In fact, it would appear that the pilots may have been distracted from attending to their normal sight picture and thus provided more performance error.

Performance on the hover flight maneuvers showed different results than did the low level flights. For the hover maneuver, flights during the baseline conditions provided the lowest composite error scores, followed by the day PD flights and the night PD flights. The NVG's PD flights provided the highest measures of performance error and thus the worst performance. Re-examination of Table 3B shows that there were no significant differences between the baseline and night PD flights or the day and the night PD flights. The estimate of the composite error value for the day PD flights (Figure 5 and Table 4B) would suggest that the significant differences between the baseline and day PD flights reported in Table 3B are spurious and result from the reduced information available within the individual pairwise comparisons. The estimates of composite performance error suggest there were no statistically significant differences between the baseline day and night PD hovers.

These results suggest that for the hover maneuver the information required by the pilot to maintain the aircraft's attitude comes primarily from outside cues. In addition, requirements to come inside to view the PD, or the restrictions in the normally available field-of-view encountered when using the night vision goggles, serve to slightly degrade the hover performance. However, it should be noted that the differences in the obtained error scores, although statistically significant in some cases, are probably not practically different.

QUESTIONNAIRE DATA

In general, most subjects felt that the displays were adequate for use with the unaided eye and extremely desirable for use with the night vision goggles. Several points concerning the use of the current photo-type displays were raised. Nearly all subjects experienced problems with glare during certain sun angles even though the Wratten filter had been introduced to reduce this problem. When using the night vision goggles it was determined that the pilots had to engage in unfamiliar head movements to see both displays. This was primarily due to the spacing between the NVG's light intensification tubes which require the pilots to look at any particular display with only one eye. Several pilots commented that the heading display provided substantial assistance in maintaining orientation during NVG's low level flights. Pilots indicated that during the hover there was a tendency to engage their attention on the displays resulting in more than normal drift from the hover point.

CONCLUSIONS

The analyses of the performance errors measured during the four types of visual display experimental test conditions provide four primary conclusions:

(1) The use of the prototype displays during NVG's, day, and night flights has demonstrated potential for improving the aviator's mission performance.

(2) The final analysis of the low level flight profile was conducted with heading error (standard deviation and average constant error) and airspeed error (standard deviation and average constant error) as the primary discriminators of performance. These measures were chosen because of their direct relationship to the flight information presented. The use of the PD significantly reduced heading and airspeed error for the unaided eye during low level flights at night and when

using the night vision goggles. Less performance error was observed during the NVG's PD flight as compared to the normal day VFR flight (baseline) condition although this difference was not statistically significant.

(3) The displayed information regarding altitude and heading did not improve the ability of aviators to maintain a precision hover. However, it may be possible that there are other types of information or displays which could improve the aviators' ability to perform an extremely precise hover.

(4) The consensus of subjects was that the experimental displays provided adequate information to the unaided eye during the day and night and were highly desirable for use with the NVG's, particularly during low level flight.

This investigation has demonstrated the potential utility of the prototype display in presenting necessary flight information to the pilot and copilot/navigator during all three types of primary viewing conditions (day, night, and when using the night vision goggles). The combination of a long darkened display housing which provided a clear image during high illumination daylight flights and a collimating lense to focus the image at infinity for use with the night vision goggles was particularly effective in providing information during forward flight. This method of information display utilized commonly available components and has a demonstrated potential to provide low cost, readily available flight information to the Army aviator.

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