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Evaluation of Helmet Mounted Display Alerting Symbology

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INTRODUCTION

The present research is aimed at developing tools to support the NASA Safe All-weather Flight Operations Research (SAFOR) program. The goal of our part of this program is to make dramatic reductions in the rate and severity of civil rotorcraft accidents through reduction in pilot error. This research is also supported by a cooperative agreement between the Army Aeroflightdynamics Directorate and NASA Ames Research Center.

A major factor in pilot error is the failure to apprehend critical information or to integrate isolated facts into a coherent concept that can guide correct behavior. An important tool for improving pilot situation awareness is the helmet mounted display. In its earliest implementations, the helmet display was used primarily as a weapon pointing device. With the addition of sensor imagery it came to be an aid to flight in limited visibility.

The benefit from a helmet mounted display increases when the pilot has a lessened requirement to look back into the cockpit. Ultimately it is desirable to make the helmet display the primary flight instrument. In fact the Army's RAH-66 Comanche will have the helmet display as its primary flight display. The helmet display needs to be well integrated with the panel instruments when used in this way. It needs to present as much information as possible without being cluttered or obscuring the out-the-window view. It also needs to permit an easy transition back into the cockpit when this is needed.

Pilots face purely mechanical problems in shifting from the helmet display to the panel display. They must refocus and reconverge their eyes from infinity to under 31 inches (Hawkins, 1997, p 246). They must also adapt to a different display brightness. These problems compound the biggest problem, that of switching attention from the out-the-window task to the in-cockpit task. Switching from one task to another can be a slow process. It can take as much as two to three seconds to switch from one attention demanding task to another demanding task. Switching time can be reduced substantially by effective alerting (De Maio, 1976).

The research used two approaches to increasing the effectiveness of alerts. One was to increase the ability of the alert to attract attention by using the entire display surface. The other was to include information about the required response in the alert itself.

In the full screen alert, a flashing alert symbol appears at the bottom of the helmet display. In addition to this flashing symbol, all of the nominal symbology on the display flashes until the pilot were to acknowledge the alert. Stimulating a large area of the retina with the flashing alert can stimulate the part of the visual system that operates without attention. This ambient visual system (Hennessey and Sharkey, 1997) is primarily involved in postural control and orienting, but it may also serve to alert the viewer to movement in the periphery of the visual field. This system is relatively insensitive to the attentional demand of the primary task. Thus ambient alerting can pull attention from that task even when alerts are rare and the primary task has a high attentional demand.

Adding task information to the alert should aid the pilot in transitioning from the flying task to the alert response task. It should not affect the alerting quality of the display. The information about the alert task allows the pilots to begin thinking about the task even while their eyes are still directed at the helmet display. Partial information about the response has been shown to speed responding in choice reaction time tasks (Leuthold et al, 1996). In addition, the information manipulation works by improving the visual momentum between the helmet display and the panel display. Visual momentum refers to the ease with which the viewer can transfer attention smoothly from one display to the other (Woods et al, 1987).

The helmet display evaluation was conducted along with a test of workload and situation awareness measures. The present report contains a summary of the test method. The details are presented in a separate report (De Maio and Hart, 1999).

METHOD

Apparatus

Helicopter Simulation - The investigation was conducted using the NASA Ames Research Center's six-degree-of-freedom vertical motion simulator (VMS) with a rotorcraft cockpit. The VMS is unique among flight simulators in its large range of motion. This large motion capability provides high quality flight cues to the pilot.

A simulated rotorcraft cabin, the RCAB, was configured as a single-pilot cockpit with a four-window computer generated display, consisting of three forward view, CRT displays, spanning 27° X 147° and one CRT chin window on the right side (26° X 22°). The out-the-window imagery was generated using an Evans and Sutherland ESIG 3000 image generator.

The primary inputs to the motion base are the aircraft translational and rotational accelerations calculated by the math model for the pilot position. Appendix A contains a summary of the motion gains. The simulated aircraft was a UH-60A, Black Hawk. Rotor, engine, and transmission sounds were simulated. Conventional helicopter controls were used. The stick-to-visual throughput time delay was approximately 72 msec. In addition there was a 20 msec math model cycle time.

Panel instruments were displayed on two 14 in diagonal color CRTs. The right CRT displayed generic, basic flight instruments (see Figure 1). The left CRT displayed a moving map of the visual database (see Figure 2). The map showed major terrain features and major roads, drawn in light blue. The planned course was displayed in red. A compass rose was displayed in the upper right hand corner. A gray square overlaid the high resolution area at the center of the data base. In the visual database, this area was a high definition rendering of a small village, which was not represented on the map. A digital range indicator in the lower left corner indicated the size of the displayed area in nautical miles. When the alert task was presented, the required input and the pilot's response were overlaid at the bottom of the map. The helmet mounted display system consisted of the helmet, helmet display unit and head position sensing system of the AH-64 integrated helmet and display sight system.

Helmet Display Symbology - Helmet display symbology (see Figure 3) was based on the AH-64's pilot night vision system (PNVS), cruise mode symbology. This symbology includes a compressed 120° compass at the top of the display, digital torque and airspeed on the left, digital altitude and analog, radar altitude and vertical speed on the right. A dashed line gives an indication of pitch and roll, referenced to the display frame. A diamond indicating the position of the aircraft's nose is the only head slaved PNVS symbology. Symbology was added for the course director indicator (CDI), Waypoint, and alert displays. In the simulator, altitude was above ground level for both digital and analog displays.

Alert Task Symbology – There were five alert type conditions. A No-alert condition provided a flying performance baseline. Alert flash (Localized and Full-Screen) was crossed with alert information content (No-Info and Partial-Info) to yield four experimental conditions (see Table 1). The alert was presented

solely on the helmet mounted display, with a digit entry task to simulate the procedural response presented on the panel.
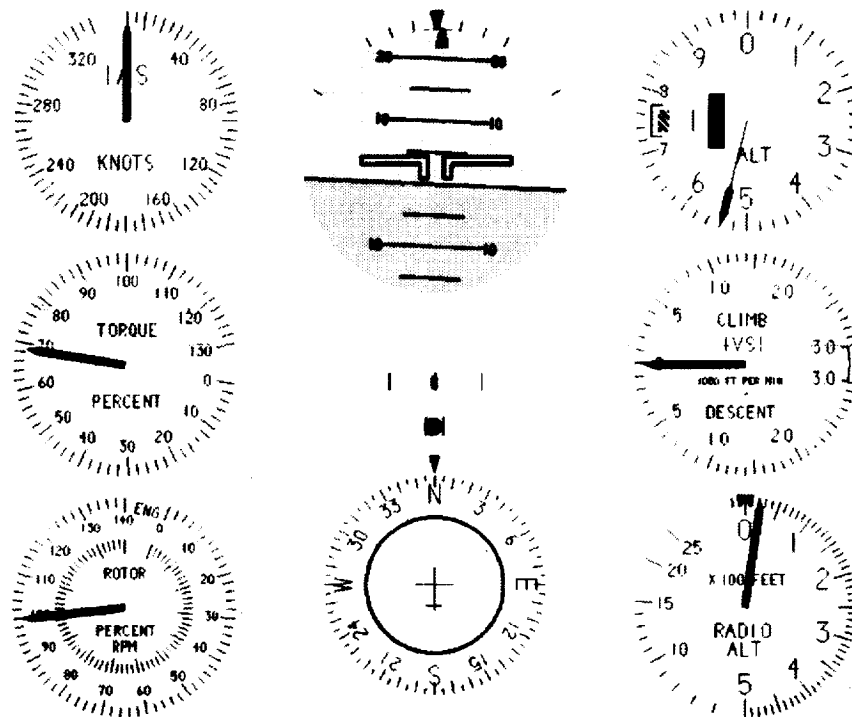

Figure 1. Simulated instrument panel. Instruments consisted of white and colored graphics on a black background. Color scheme has been revised for better printing.

In all Alert Task conditions, a flashing letter was presented in the bottom center of the display, the position corresponding to the TADS field of view box (see Figure 4). The letter was approximately 3° tall. In the Localized alert condition, this symbol constituted the entire alert. In the Full-Screen alert condition, all symbology flashed. Flashing alternated between the center and periphery of the display, that is, when the center brightness was high, the periphery was low and vice versa. Central symbology consisted of the horizon line, nose diamond, alert letter, and the waypoint when it was present. All other symbology was peripheral. "High" brightness was the brightness set by the pilot. "Low" brightness voltage was 30% of high. This design ensured that some symbology would always be fairly bright and that no symbology would ever be completely off. Flash rate was set to be noticeable but not disturbing, at three Hz with a linear ramp up and down. Three alert symbols were used. In the No-Information condition, an upper case "N" indicated an alert. In the Part-Information condition, an "L" indicated an alert and that numbers were to be entered left-to-right, while an "R" indicated right-to-left entry.
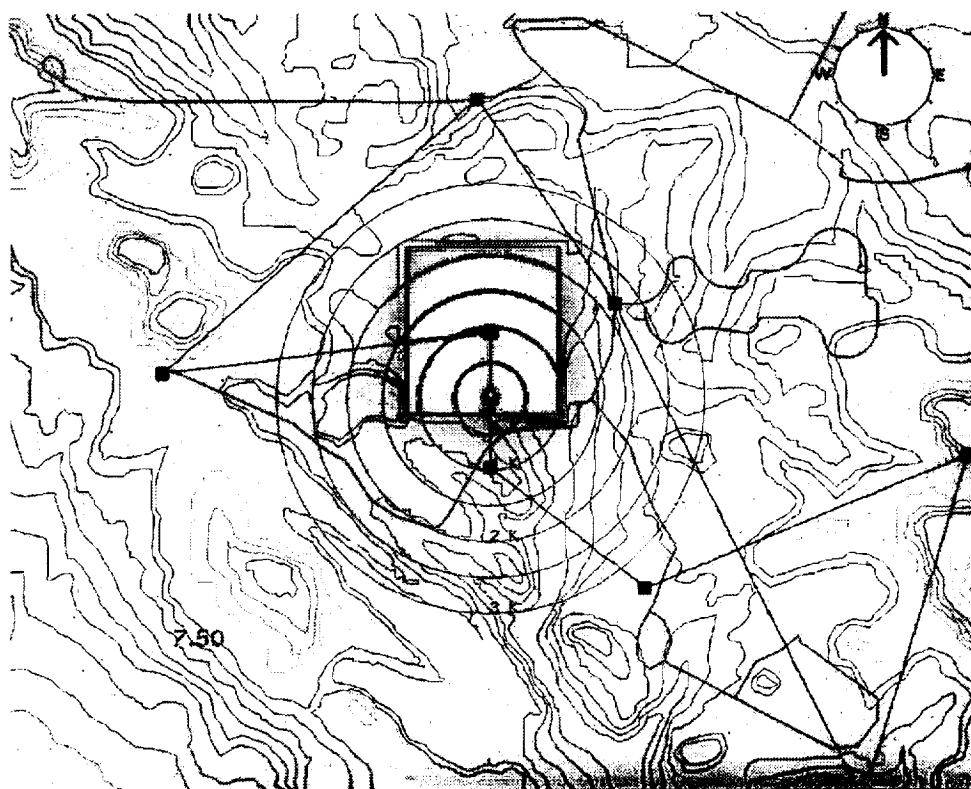
Figure 2. Map display. Terrain contours consisted of colored lines on a black background. Roads were teal. Planned route was red. Color scheme has been revised for better printing.

Navigation Symbology – There were three navigation display conditions. A baseline "Visual" navigation condition used the basic PNVS symbology without the waypoint symbol on the compass display. A "Waypoint" condition used a waypoint marker superimposed on the visual scene. The "CDI" condition incorporated symbols into the compass display indicating bearing to waypoints and course deviation. Data were collapsed across these conditions for the alert display analysis.

Table 1. Alert conditions.

	No Alert	No Information	Partial Information
No Alert	**Baseline**		
Localized Alert		X	X
Full-Screen Alert		X	X

The two aided displays included an arrival time clock in the upper right that showed the pilot's instantaneous arrival time error, up to +/-99 sec. Arrival time

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error was simply the difference between the target arrival time and the arrival time computed from current speed and distance remaining. In an actual mission planned speed would vary on each navigation leg, and so arrival time would be needed for each leg. In the simulation, planned speed was constant across legs, so only segment arrival time was displayed.

Waypoint Symbology - The Waypoint symbology consisted simply of a pennant displayed at the geographical location of each waypoint and the altitude of the aircraft. The pennants were maintained as moving models by the image generation system but were displayed by the Silicon Graphics computer that drove the helmet display. Each pennant was shaped like an arrow that pointed toward the next waypoint (see Figure 5). Because the pennants were maintained as part of the visual data base, all were displayed continuously, and their size decreased with distance from the pilot's eye position.
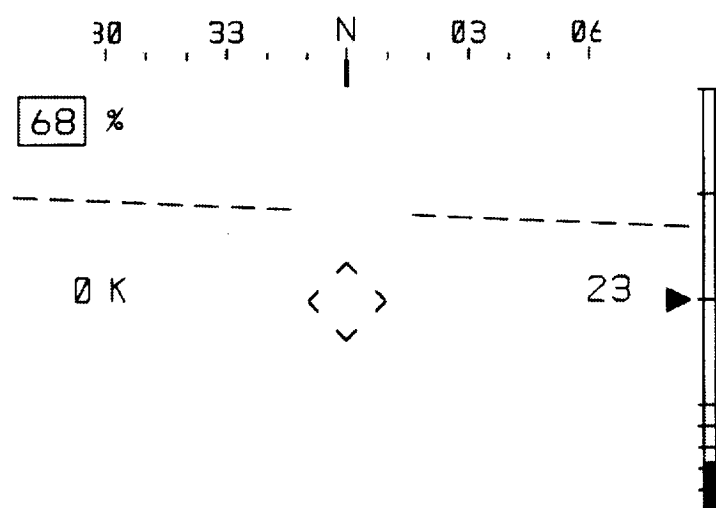
Figure 3. Basic helmet display symbology.

CDI Symbology - The CDI symbology mimicked a conventional, panel mounted, course deviation indicator (CDI) (see Figure 6). A tail beneath the compass lubber line pivoted to point toward the planned course. A carat (^) indicated the heading to the current waypoint (as in the basic PNVS). A circle (o) indicated the heading to the next waypoint. Both waypoint symbols edge limited.

Alert Task Operator Interface – The pilot reacted to the alert symbol on the helmet mounted display by performing a response task overlaid on the map display using a keypad. The keypad was located on a console adjacent to the collective lever and contained a button to allow the pilot to acknowledge the alert along with a 10-key numeric pad. When the pilot acknowledged the alert, the helmet display symbology ceased flashing, but the alert symbol remained present. Acknowledgement also caused the task display to appear

superimposed on the map display. The task display consisted of three lines of text. The top line was the word "LEFT" or "RIGHT," indicating the direction in which the pilot was to enter numbers using the 10-key pad. The second line showed five digits, selected randomly with replacement, which the pilot was to enter. The third line showed five blanks, corresponding to the five digits to be entered. As the pilot entered each correct digit, it was displayed in the appropriate blank. Incorrect entries were ignored. Once the pilot entered the fifth correct digit, both the map and helmet mounted displays returned to the nominal state.
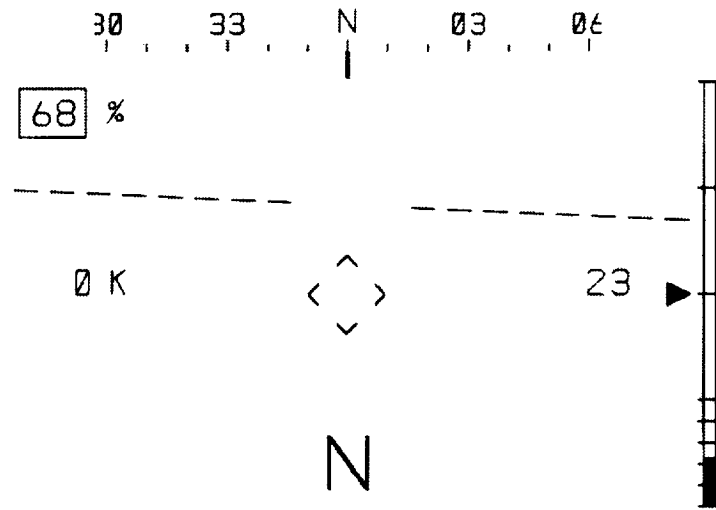

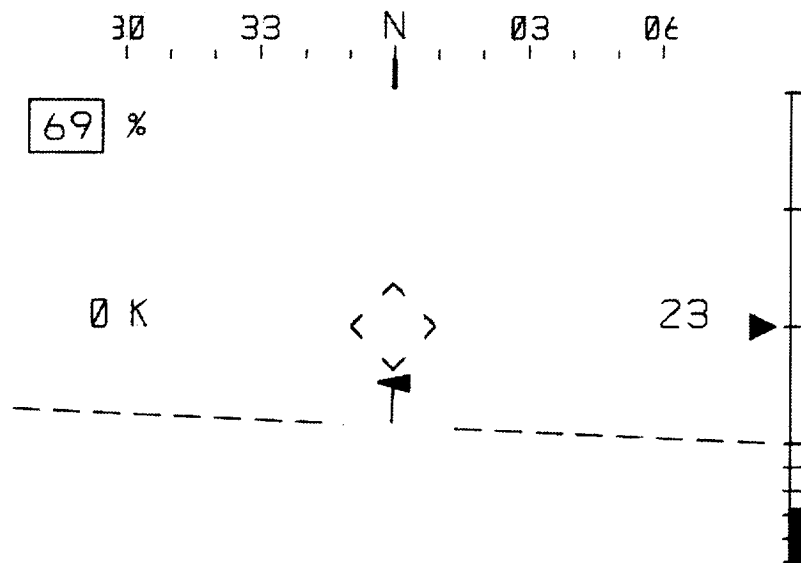Figure 4. Helmet display alert symbol

Figure 5. Waypoint navigation symbol.

This task captured the salient aspects of a procedural task. These include a structured sequence of actions, determination of required response, and making the required response. For this task the sequence was first to acknowledge alert, second to determine direction of digit input (left or right), and last to input five digits. Unlike an actual flight procedure, this task had no consequence for the flight.
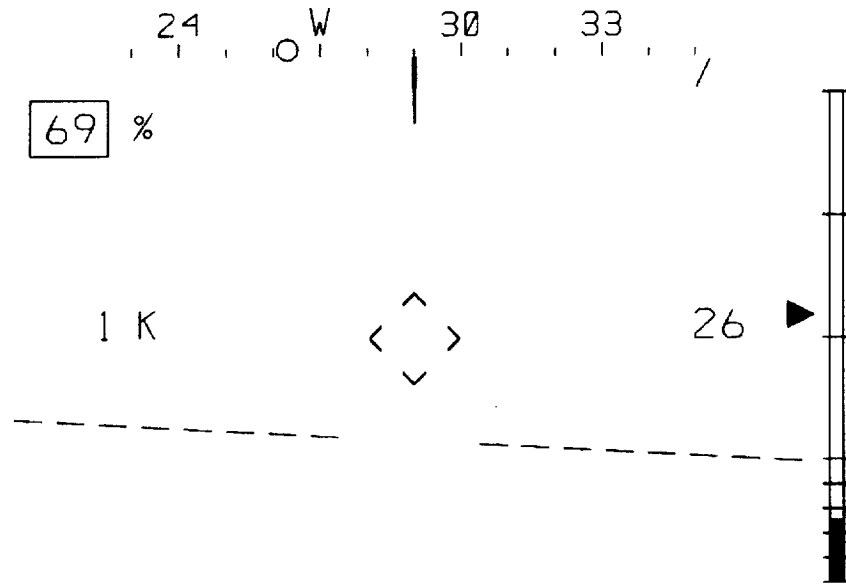

Figure 6. "CDI" navigation symbology. Current waypoint symbol is edge limited on right.

Experimental Tasks – A standardized mission was developed, that consisted of 11 legs. The mission included four tasks: cross-country navigation, track following, bob-up and reconnaissance for tanks. This mission is described in De Maio and Hart (1999).

Procedure

Pilots participated in pairs. Each pilot performed one to three missions and then took a break while the other pilot flew. The duration of each pair's simulation period was four days. Missions lasted about 30 min. Following each mission the pilot gave his workload and performance self-evaluation ratings without receiving any feedback on his performance. Pilots received written instructions explaining the objectives of the research and the tasks that they would perform (see Appendix B). They then performed familiarization flights until they were ready to begin practicing the experimental tasks.

Pilots received paper maps that duplicated the cockpit map in order to familiarize themselves with the mission before hand. They were also allowed to make a list of the waypoints for each mission to take into the cockpit. As the pilots passed each waypoint, they were to depress the microphone switch and state the waypoint name.

Three practice missions were provided. These missions had no tanks present, and the pilots did not perform reconnaissance. The pilots flew practice missions in each of the navigation display and alert conditions until they and the experimenter felt that they were ready to proceed to the experimental trials. Pilots gave no workload or self-evaluation ratings of the practice runs.

The order of presentation of the navigation display conditions for data collection was balanced by a Latin Square (n = 12). Presentation of alert conditions was balanced to control for first order effects. Pilots flew three to six experimental missions per day for a total of 12 experimental missions.

Data collected for each experimental mission included workload ratings and performance self-evaluations, mission time of waypoint passage reports, mission time of reconnaissance reports, reconnaissance reports, and automatically recorded flight performance data. The pilots gave workload ratings and performance self-evaluations orally over the intercom, and the experimenter transcribed them into a log, at the end of each mission.

It became clear during data collection that the bob-up task would not provide usable data. Therefore a single task condition was added. The task was performed in the cockpit on flight freeze. This condition is more like a classical reaction time task in that the subject only monitored the helmet display for the alert symbol. When the alert symbol appeared, the subject performed the alert task just as in the flying condition. This condition is a logical extension of the process of increasing the frequency of alerts. Unfortunately it was not included in the original design. Some of the pilots had completed their tenure in the study and were no longer available to participate in the reaction time task. Therefore one of the experimenters and a simulation engineer served as subjects.

RESULTS

Problems with the timing of the bob-up task made it impossible to gather usable data from that task. Only the track following and cross-country tasks provided usable data for evaluating the alerts. The reaction time presentation of the alert task also provided usable data, although the subjects in that task were not the pilots who had participated in the simulation.

The first question was whether the alert and information manipulations provide enough benefit to render average alert response latency shorter. An effect on the mean might be expected if the manipulations had a beneficial effect on both long and short response latencies. At least in the case of the full-screen alerting, the author did not expect this to be the case. Rather the author expected that the full-screen alert would provide a benefit primarily when the pilot's attention was held strongly by another task, that is, in instances when very long response latency might be expected. Therefor the alert manipulation should have more effect on the variance than on the mean.

On the other hand, one might expect that the information manipulation would affect both long and short responses. Since the partial information alert affects the transfer of attention between displays, and not from the flying task to the alert task, it should affect long and short responses equally.

The data analysis was a 2 (Info) X 2 (Alert) X 2 (Subject) analysis of variance for the reaction time data and a 2 (Info) X 2 (Alert) X 8 (Subject) analysis of variance for the simulation data. Mean response latencies are shown in the tables below. Three responses were examined, as follows: the first response, to acknowledge the alert; the second response, to enter the first digit; and the last response, to enter the fifth digit. Analysis of variance tables are shown in Appendix C.

Three responses were use to describe the pilots' responses to the alert. Their first response was to depress a button acknowledging the alert and turning off the helmet display alert symbology. Their second response was to begin the digit entry task. Their last response was to enter the final digit of the sequence. Intermediate digit entries were not examined. Table 2 shows the effect of the alert and information manipulations on response latency in the reaction time task. The manipulations produced reliable differences for the two digit entry responses. The effect of the alert format was unexpected. The full-screen alert produced a longer average latency for all three responses, and this difference was statistically significant for the second and last responses. In the reaction time task, the subjects' response was degraded by the full-screen presentation. The data were more in line with expectations for the partial information symbol. Both of the responses involving digit entry were made more quickly when the alert symbol provided partial information about the task. The initial response, to acknowledge the alert, was non-significantly longer when partial information was presented.

It would seem that any manipulation that increases the complexity of the alert, either by adding information or by making the alert symbology more complex, slows the initial response. One cannot say whether this result of this slowing persists in subsequent responses. If so, the positive effect of partial information on subsequent responses offsets this negative effect. On the whole, however, the

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full-screen alert does not speed responding in a reaction time task, while the partial information alert does speed responses that require use of that information.

Table 2. Mean response latency (sec) for reaction time task. "*" Indicates a reliably (p<0.05) shorter latency for that condition.

	Full-screen Alert	Localized Alert	Partial Information Symbol	No Information Symbol
First Response	2.23	2.20	2.27	2.18
Second Response	4.10	3.89*	3.58*	4.38
Last Response	7.98	7.43*	7.26*	8.12

Tables 3 and 4 show response latency data for the track following and cross-country tasks, respectively. While none of the differences was statistically reliable, there were some intriguing trends. First, the general trend for the partial information alert was similar to that obtained in the reaction time task, as was expected, since the partial information affects task performance and not the alerting quality of the symbology. Second, the full-screen alert showed a non-significant trend toward faster responding. This trend was most pronounced for the cross-country task, in which the alerts were least frequent. This trend shows that the full-screen alert may be more effective in pulling attention from a primary flying task to a rare event.

Table 3. Mean response latency (sec) for track following task. No differences between means were statistically reliable.

	Full-screen Alert	Localized Alert	Partial Information Symbol	No Information Symbol
First Response	3.21	3.51	3.31	3.41
Second Response	7.15	7.58	6.85	7.77
Last Response	11.82	12.47	11.54	12.65

These results suggest that both the full-screen alert and the partial information alert might provide better alerting than do current, localized, uninformative alerts.

These results are not, however, as compelling as they might be. The magnitude of the effects is at least as great as is seen in typical, single-task experiments on partial information alerting (e.g., Rosenbaum, 1980; Reeve and Proctor, 1984). In some cases the speed improvements exceeded one second, but the statistical power is low. Part of the problem is that it was not possible to collect the large amount of data usually collected in laboratory reaction time experiments. Another part of the problem is that response latency data are not normally distributed and that at least one of the manipulations may affect long latency responses differentially. There is a need to perform analyses that focus more on the long latency responses.

Table 4. Mean response latency (sec) for cross-country flight task.
No differences between means were statistically reliable. "†"
indicates $p < 0.069$.

	Full-screen Alert	Localized Alert	Partial Information Symbol	No Information Symbol
First Response	4.06†	7.08	4.98	4.61
Second Response	11.10	11.94	10.14	11.37
Last Response	16.50	16.75	14.73	16.95

Differential effects on long latency responses affect the variance and skewness of the distribution of responses much more than they do the mean. Appendix D shows the distribution of responses for the various flight tasks and alert conditions. All the distributions are skewed and that the degree of skewness increases when alerts are less frequent.

The author used two statistical tools to examine the effect of the experimental manipulation on the shape of the data distributions. The first, momental skewness is a descriptive measure of the skewness of a distribution (Beyer, 1966, p 3). It does not allow inferences about the magnitude of the difference in skewness between two distributions, but it does allow us to quantify such differences. The second, an F test for equality of variance is generally used to ensure the suitability of data for analysis of variance (Hayes, 1963, p 351). In this use, it measures the likelihood of a large deviation from normality, that is, significant skewness. It has also been used to discriminate between differently shaped data distributions (Hart and McPherson, 1976; Meyers, 1971).

Momental skewness was greater for the full-screen alert condition than for the localized alert condition for the first response on the RT task but smaller for the later responses (see Table 5). Skewness was greater for the localized alert condition in both the flying task conditions, reflecting the effect of fewer long latency responses in the full-screen alert condition. This effect moderated for later responses, and even reversed for the last response on the cross-country flight task.

Table 5. Momental skewness as a function of alert type. Greater momental skewness indicates more long latency responses. The condition having lower momental skewness, and fewer long latency responses, is shown in bold.

	1st Response		2nd Response		Last Response	
	Full-screen	Localized	Full-screen	Localized	Full-screen	Localized
RT	5.94	**1.56**	**1.39**	1.83	**3.25**	5.06
TRK	**4.29**	5.06	**2.41**	3.07	**1.17**	2.44
CC	**3.21**	6.68	**3.01**	5.41	3.66	**2.42**

The partial information alert condition showed lower skewness across the board, the only exception being the last response in the cross-country flight task condition (see Table 6). For the most part, the partial information alert did reduce long latency responses.

Table 6. Momental skewness as a function of alert information content. Greater momental skewness indicates more long latency responses. The condition having lower momental skewness, and fewer long latency responses, is shown in bold.

	1st Response		2nd Response		Last Response	
	Part Info	No Info	Part Info	No Info	Part Info	No Info
RT	**3.53**	7.89	**2.00**	4.49	**2.24**	3.92
TRK	**4.03**	5.46	**1.79**	3.01	**1.59**	2.64
CC	**3.29**	7.48	**3.16**	4.82	6.20	**1.72**

The F-test for equality of variance showed that for the most part both the full-screen alert (see Table 7) and the partial information alert (see Table 8) improved latency performance, in the sense that they significantly reduced variance. The effect of the partial information alert was weakest for the first response. The first response showed more variability in two of the three task conditions. Variability of the later responses was consistently reduced by the partial information alert.

Table 7. F- test for equality of variance of alert type data distributions. "*" indicates $p < 0.05$. "†"1st response data contained one very long latency; without it $F(94, 102) = 4.05$.
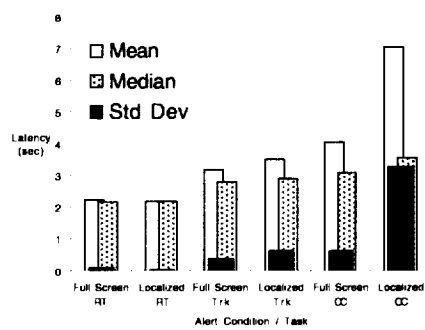
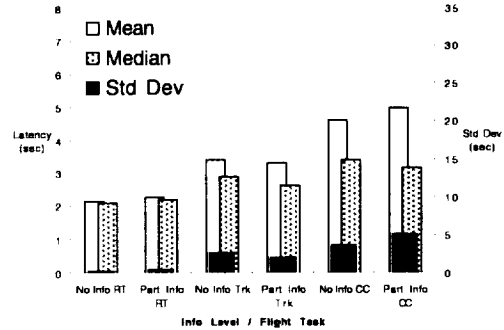|	1st Response	2nd Response	Last Response
$F_{VAR}(n_1, n_2)$ RT	0.1	1.5*	2.9*
$F_{VAR}(n_1, n_2)$ Trk	2.4*	1.7*	1.7*
$F_{VAR}(n_1, n_2)$ CC	26.5* †	1.8*	1.2

Table 8. F- test for equality of variance of alert information data distributions. "*" indicates $p < 0.05$; negative sign indicates larger partial information variance.

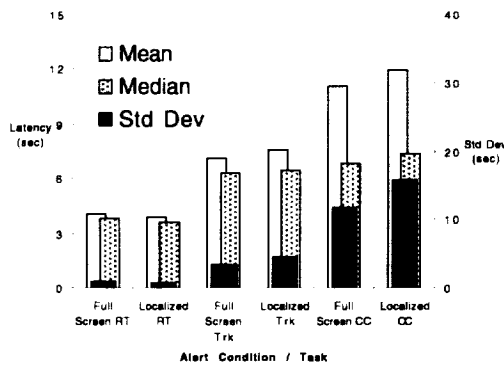|	1st Response	2nd Response	Last Response
$F_{VAR}(n_1, n_2)$ RT	-2.2*	1.6*	1.2
$F_{VAR}(n_1, n_2)$ Trk	1.7*	2.3*	1.7*
$F_{VAR}(n_1, n_2)$ CC	-2.1*	1.7*	3.7*

Figure 7 presents a graphical summary of the latency data. There are trends toward faster responding (mean latency), reduced skewness (difference between mean and median), and reduced variability with the full-screen alert and with partial alert information. The full-screen alert had its greatest impact on the first response in the cross-country task. The effect diminished for later responses, and the full-screen alert provided less benefit as the frequency of alerting increased. The partial information content alert had its greatest effect on the later responses, and may even have had a deleterious effect on the first response. Its effect was roughly the same in all task conditions.
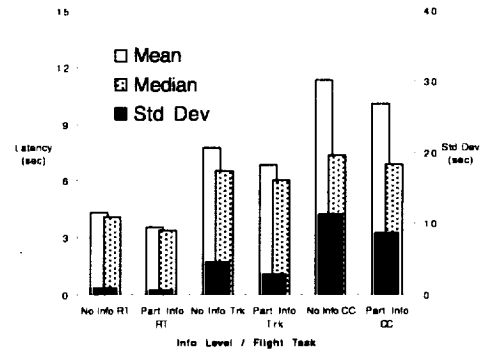
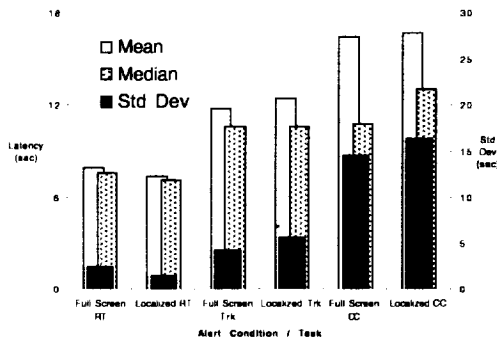A. Alert Type – First Response   D. Alert Information – First Response
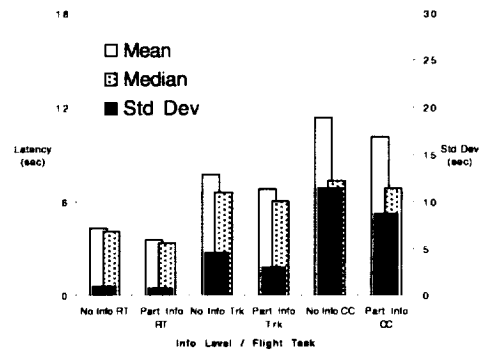
B. Alert Type – Second Response   E. Alert Information – Second Response

C. Alert Type – Last Response   F. Alert Information – Last Response

Figure 7. Effects of experimental manipulations on mean response latency, median response latency, and standard deviation of response latency.

DISCUSSION

The general trend in the data points to a small benefit from both the full-screen alert and the partial information alert. The pattern of benefit varies for the two manipulations. The full-screen alert provides its greatest benefit on the first response, to acknowledge the alert, when alerts are infrequent. The partial information alert provides its benefit on the execution of the alert task procedure, independent of alert frequency. The measurement of these effects was somewhat problematic, both because of the small size of the effects and because the effects themselves significantly change the variance of the response latency distribution. Yet these benefits come at virtually no cost, since they involve only modest formatting and display of information readily available.

Full-Screen Alert

The full-screen alert has its largest effect on the time required for the pilot to make an initial response to an infrequent alert. In this case the alert must pull the pilot's attention from the flying task. Attracting the pilot's attention becomes more difficult the less frequent the alerts. In the simulation alert frequency was always very high compared to what might be expected in actual flight. In the bob-up task, which did not produce usable data, three alerts were presented in about 30 sec. In the track following task, alerts were presented about once per minute. In the cross-country task one alert was presented in a 15 to 20 minute segment. The benefit of the full-screen alert was greater in the cross-country task. One might expect a substantially greater benefit in actual flight, when the interval between alerts would typically be measured in hours or missions.

The magnitude of the full-screen alert effect declined over the course of execution of the alert task. The initial benefit was swamped by other variability in task performance. In actual flight the effect might be more persistent for a number of reasons. The benefit might be larger; overlearned procedures should be less variable; and performance of the alert procedure would be a higher priority for the crew. So one might expect a substantial benefit from full-screen alerting in actual flight.

A concern prior to the simulation was that the full-screen alert would be too annoying and might even be disorienting. Intense strobe lights can degrade motor control and orientation. The author did not expect this to be a problem for a variety of reasons. The luminance of the alert symbology was low. Usually undesirable effects occur with more intense stimuli. The symbology was never fully off, and the display brightness was relatively constant, so that the eye was never in darkness. Finally the flash rate was well below that at which disorientation occurs. In the event, the pilots reported no difficulty of any sort with the full-screen alert.

Partial Information Alert

The purpose of the partial information alert was to forewarn the pilots about what response they were to make. This forewarning should have facilitated task execution (Rosenbaum, 1980; Leuthold et al, 1996). In fact the partial alert did facilitate performance of the alert task procedure both in the reaction time context and in the flying context. This benefit persisted throughout the full

execution of the task. Partial information did slow the initial response to acknowledge the alert somewhat, but this slowing was more than offset by the improvement in task execution speed. The procedural task used was both less complex and less rehearsed than actual aircraft emergency procedures, and that its impact on aircraft operation was nil.

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APPENDIX A

MOTION GAINS

*** SLOW GAINS

GXS=.4
GYS=.8
GZS=.5
GPS=.05
GQS=.05
GRS=.5

*** SLOW CORNER FREQUENCIES

OMEGXS=1.5
OMEGYS=.6
OMEGZS=.3
OMEGPS=.5
OMEGQS=.7
OMEGRS=.5

*** FAST GAINS

GXF=.4
GYF=.6
GZF=.9
GPF=.5
GQF=.8
GRF=.4

*** FAST CORNER FREQUENCIES

OMEGXF=1.5
OMEGYF=.6
OMEGZF=1.4
OMEGPF=.85
OMEGQF=.85
OMEGRF=.7

*** DAMPING RATIO

ZETAX=.707
ZETAY=.707
ZETAZ=.707
ZETAP=.707
ZETAQ=.707
ZETAR=.707

*** SLOW AND FAST "SPEEDS" FOR INTERPOLATION OF SLOW AND FAST GAINS

VGFAST=10.
VGSLOW=0.

*** SLOW AND FAST "SPEEDS" FOR INTERPOLATION OF SLOW AND FAST CORNER
FREQUENCIES

VWFAST=10.
VGWLOW=0.

*** TC FORWARD PATH GAINS

GXTC=1.
GYTC=1.

*** TC FEEDBACK GAINS

GKTCFB=.1

*** RESIDUAL TILT CORNER FREQUENCIES. DAMPING RATIO, AND GAINS

*** CORNER FREQ. OF LARGE AXIS RT LOWPASS FILTER

OMEGLRT=2.

*** CORNER FREQ. OF SMALL AXIS RT LOWPASS FILTER

OMEGSRT=2.

*** DAMPING RATIO OF LARGE AXIS RT LOWPASS FILTER

ZETAR1=.707
ZETAR2=.707

*** ROLL AND PITCH RT GAINS

GPRT=1.
GQRT=1.

GKTCFB=0.5

Appendix B

Pilot Instructions

Introduction and Instructions to Experimental Pilots

This experiment is the start of a program of research, conducted jointly by the Army and NASA, to develop principles for the presentation of symbolic information on a helmet mounted display. The current work uses a production AH-64 IHADSS, but the goal is to extend the work with an advanced color, wide field of view, binocular display system. The research is conducted on NASA's Vertical Motion Simulator, the largest motion based simulation in the world.

The research will examine presentation of two types of information on the helmet display, alert information and navigation information. Alert information will be presented in two modes. In a one mode a flashing letter presented at the bottom of the HMD will indicated that you should come into the cockpit to perform a procedural task. In the second mode the flashing letter will be accompanied by flashing of all HMD symbology. Two navigation display conditions will be used. In one waypoint data will be presented by markers on the HMD that have been located and scaled to fit into the visual scene. In the second an "instrument" located at the top of the HMD will present waypoint information. The test conditions for both experimental questions will be embedded in a simulated cross-country flight mission of about 20 minutes duration.

Cross-Country Flight

Prior to each flight, you will receive a map showing the route you are to fly. You will maintain an altitude of 100 ft agl and an airspeed of 80 kt. At each waypoint you will make a radio call to inform us that you have reached the waypoint. You should make a list of the waypoints and headings to aid you in the cockpit. Along the route you will perform two experimental flight tasks, that are not part of the cross-country flight. These tasks are a track following tasks and a bob-up. Your flight time from the take-off to the track and from the track to the bob-up position will be specified for each mission. You will also be asked to reconnoiter two areas of interest along each route and report back the number of tank platoons in each area. Performance specifications are given in the table at the end of this document.

Track Following Task

You will follow a track on the ground maintaining a comfortable and an altitude of 100 ft AGL.

Bob-up Task

You will establish a stable hover at 10 ft AGL in position in front of the bob-up tree. At this point make your radio call to tell us that you have reached the waypoint. This call will initiate the task. You will then climb to and altitude of 50 ft AGL and hover for 10 sec. Mark the start and end of the hover and the end of the task by pressing the "xmit" switch. Performance specifications are given in the table at the end of this document.

Procedural Tasks and Alert Displays

We have developed a laboratory task which is intended to demand your attention as would an inflight procedure. This task will be presented on the left panel CRT, which normally displays the moving map. The task requires you to enter five digits on the numeric keypad located on the side console. The word "Left" or "Right" displayed above the number indicates whether they are to be entered from left to right or from right to left. The system will only respond to correct entries, which will be displayed on the panel. After you have entered all five digits, the map display will reappear.

An HMD alert will signal when you are to perform this task. This signal will consist of a flashing letter at the bottom of the HMD. In on condition, only this letter will flash. In a second condition, all HMD symbology will flash. The symbol may provide some information about the task to be performed. In one condition, the letter, "L" or "R" will indicate left-to-right or right-to-left entry. In a second condition, the letter "N" will indicate only that the number entry task is to be performed. Prior to beginning the number entry task, you must "clear" the alert by pushing the "Cancel" button next to the numeric pad.

The sequence of events for this task is as follows:

1. HMD flashes and number entry task replaces moving map

2. Pilot "clears" alert by pushing "Clear" button

3. Pilot enters five numbers on keypad

4. Panel display reverts to moving map.

Navigation Displays

There are two HMD navigation displays.

A "lollipop" display indicates the location of the current waypoint by a symbol floating above its location. The symbol will point left or right depending on the direction of turn required after passing the waypoint. A timer will track your on-time performance. A time of arrival error counter located in the upper right portion of the HMD tells how many seconds early (+) or late (-) you are.

A "CDI" display shows your deviation from the route, heading to the current waypoint, heading to the next waypoint, and on-time status. Deviation is indicated by a pointer located below the lubber line. This pointer indicates the direction to the course. Maximum scaled deviation is 2000 ft when the pointer is 60 degrees from vertical. The current waypoint is indicated by a carat on the compass scale. The next waypoint is indicated by a circle on the compass scale. These symbols edge limit if the waypoint is off scale. On-time status is indicated as on the "Lollipop" display.
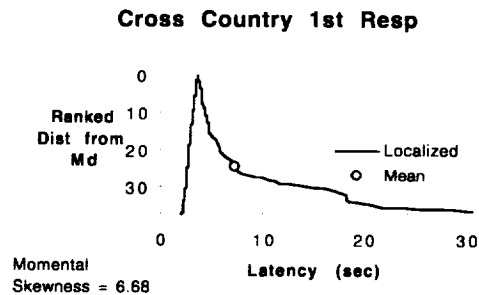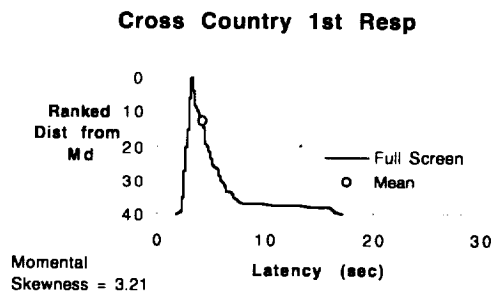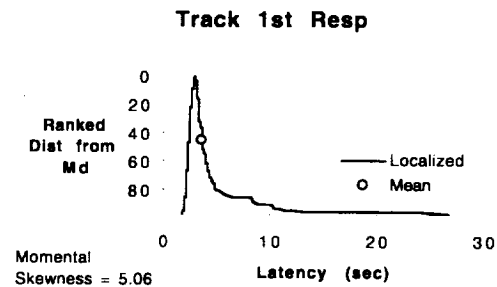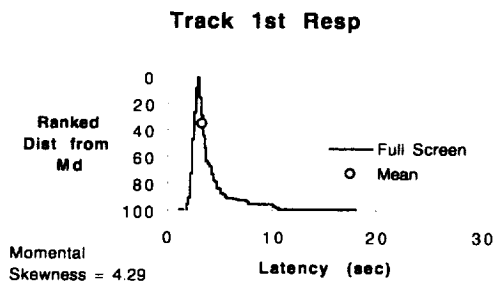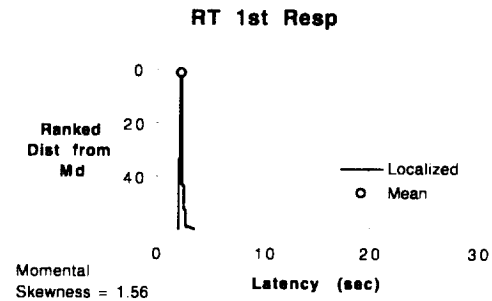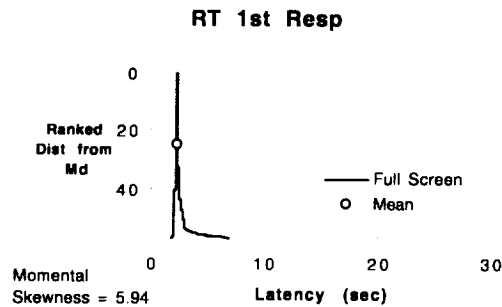
Performance Criteria and Workload

You will be asked to evaluate your performance against the criteria in the table below. You will be asked to rate your workload on six phases of the mission. Your ratings will be made on a scale from 1 to 100. Ratings will be made for "Input," that is, gathering information, "Central," that is, thinking about the task, "Output," that is, making control inputs or other actions, and "Time" pressure.
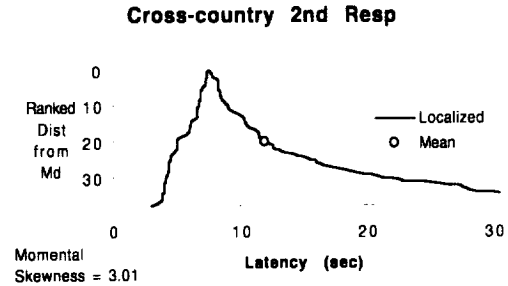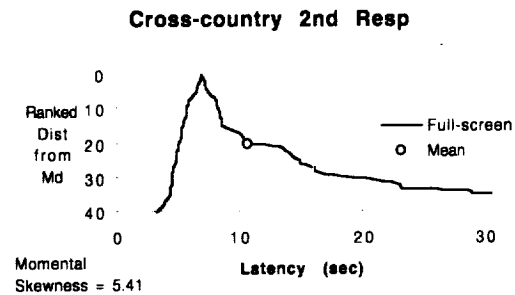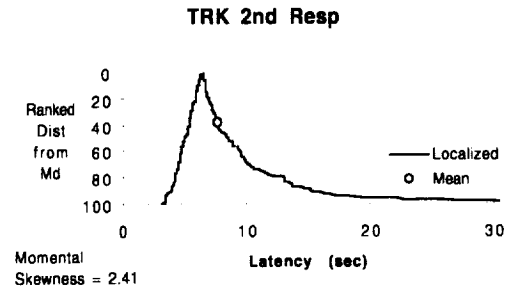
		D (Desired)	A (Acceptable)	O (Outside Acceptable)
Recon	Accuracy (% tanks detected)	>90%	75% - 90%	<75%
	Timeliness (report time after first detection)	<20 sec	20 - 40 sec	>40 sec
Navigation	Accuracy (maximum deviation from course)	<100 ft	100 - 200 ft	>200 ft
	Timeliness (at track and bob-up)	+/- 10 sec of assigned time	+/- 20 sec of assigned time	>+/- 20 sec of assigned time
Bob-up	Height	+/- 3 ft	+/- 6 ft	>+/- 6 ft
	Time	+/- 4 sec	+/- 6 sec	>+/- 6 sec
	Position	+/- 6 ft	+/- 10 ft	>+/- 10 ft

Performance criteria.

APPENDIX C

DISTRIBUTION OF REACTION TIMES

RT 1st Resp

Ranked Dist from Md

Full Screen
○ Mean

Momental Skewness = 5.94

Latency (sec)

RT 1st Resp

Ranked Dist from Md

Localized
○ Mean

Momental Skewness = 1.56

Latency (sec)

Track 1st Resp

Ranked Dist from Md

Full Screen
○ Mean

Momental Skewness = 4.29

Latency (sec)

Track 1st Resp

Ranked Dist from Md

Localized
○ Mean

Momental Skewness = 5.06

Latency (sec)

Cross Country 1st Resp

Ranked Dist from Md

Full Screen
○ Mean

Momental Skewness = 3.21

Latency (sec)

Cross Country 1st Resp

Ranked Dist from Md

Localized
○ Mean

Momental Skewness = 6.68

Latency (sec)

<u>Distribution of Response Latencies for First Response as a Function of Display</u>. Positive skewness is evident in the tail of long latency responses and in the displacement of the mean relative to median. Mean will be displaced to a higher valued when distribution is more highly skewed. Greater value of momental skewness statistic indicates greater skewness.

27

RT 2nd Resp

0
20
Ranked Dist
from Md 40

———— Full Screen
O Mean

0   10   20   30

Momental
Skewness = 1.83

Latency (sec)

RT 2nd Resp

0
20
Ranked Dist
from Md 40

————Localized
O Mean

0   10   20   30

Momental
Skewness = 1.39

Latency (sec)

TRK 2nd Resp

0
Ranked 20
Dist 40
from 60
Md 80
100

———— Full-screen
O Mean

0   10   20   30

Momental
Skewness = 3.07

Latency (sec)

TRK 2nd Resp

0
Ranked 20
Dist 40
from 60
Md 80
100

————Localized
O Mean

0   10   20   30

Momental
Skewness = 2.41

Latency (sec)

Cross-country 2nd Resp

0
Ranked 10
Dist
from 20
Md 30
40

———— Full-screen
O Mean

0   10   20   30

Momental
Skewness = 5.41

Latency (sec)

Cross-country 2nd Resp

0
Ranked 10
Dist
from 20
Md 30

————Localized
O Mean

0   10   20   30

Momental
Skewness = 3.01

Latency (sec)

<u>Distribution of response latencies for second response as a function of display</u>. Positive skewness is evident in the tail of long latency responses and in the displacement of the mean relative to median. Mean will be displaced to a higher valued when distribution is more highly skewed. Greater value of momental skewness statistic indicates greater skewness.

RT 3rd Resp

Ranked Dist from Md

Full-screen
○ Mean

Momental
Skewness = 3.66

Latency(sec)

RT 3rd Resp

Ranked Dist from Md

Localized
○ Mean

Momental
Skewness = 2.24

Latency (sec)

TRK 3rd Resp

Ranked Dist fom Md

Full-screen
○ Mean

Momental
Skewness = 1.17

Latency (sec)

TRK 3rd Resp

Ranked Dist from Md

Localized
○ Mean

Momental
Skewness = 2.44

Latency (sec)

Cross-country 3rd Resp

Ranked Dist from Md

Full-screen
○ Mean

Momental
Skewness = 3.25

Latency (sec)

Cross-country 3rd Resp

Ranked Dist from Md

Localized
○ Mean
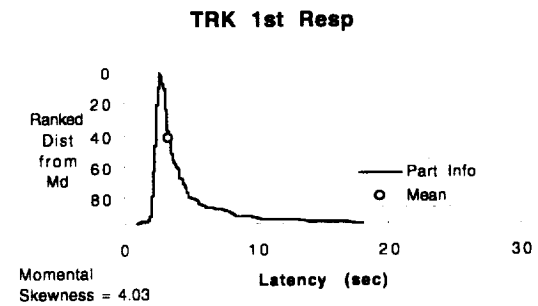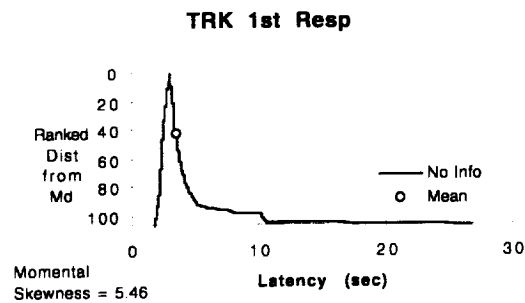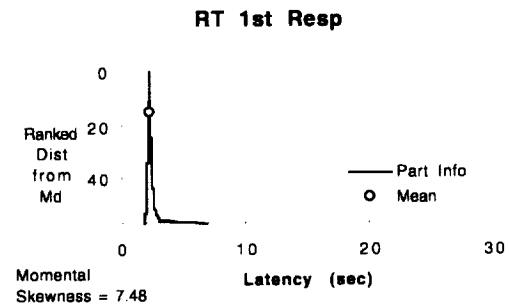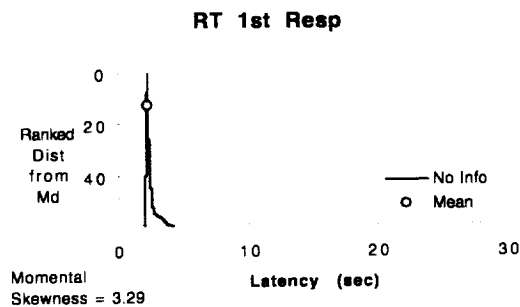
Momental
Skewness = 5.06

Latency (sec)

<u>Distribution of response latencies for third response as a function of display</u>.
Positive skewness is evident in the tail of long latency responses and in the
displacement of the mean relative to median. Mean will be displaced to a higher
valued when distribution is more highly skewed. Greater value of momental
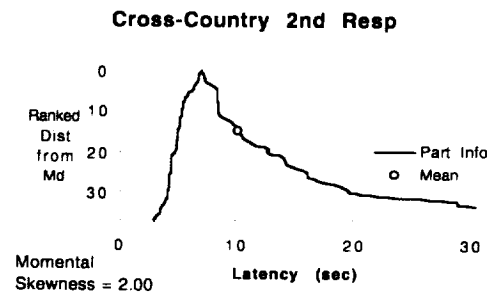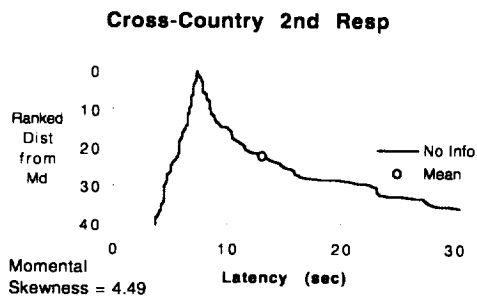skewness statistic indicates greater skewness.

RT 1st Resp

Ranked Dist from Md

——— No Info
○ Mean

Latency (sec)

Momental
Skewness = 3.29

RT 1st Resp

Ranked Dist from Md

——— Part Info
○ Mean

Latency (sec)

Momental
Skewness = 7.48

TRK 1st Resp

Ranked Dist from Md

——— No Info
○ Mean

Latency (sec)

Momental
Skewness = 5.46

TRK 1st Resp

Ranked Dist from Md

——— Part Info
○ Mean

Latency (sec)

Momental
Skewness = 4.03

Cross-Country 1st Resp

Ranked Dist from Md

——— No Info
○ Mean

Latency (sec)

Momental
Skewness = 7.89

Cross-Country 1st Resp

Ranked Dist from Md

——— Part Info
○ Mean

Latency (sec)

Momental
Skewness = 3.53

<u>Distribution of response latencies for first response as a function of information.</u>
Positive skewness is evident in the tail of long latency responses and in the
displacement of the mean relative to median. Mean will be displaced to a higher
valued when distribution is more highly skewed. Greater value of momental
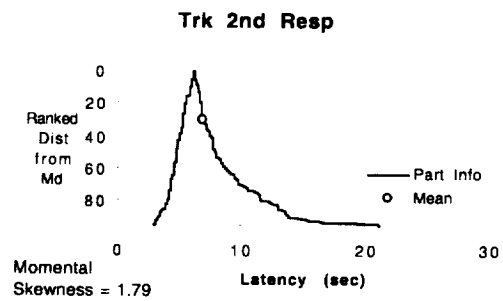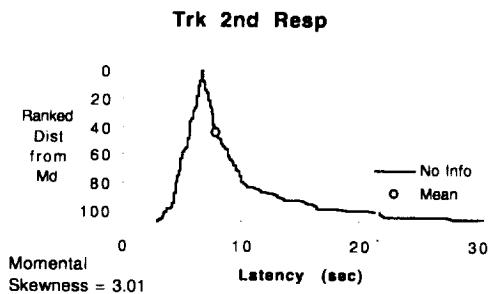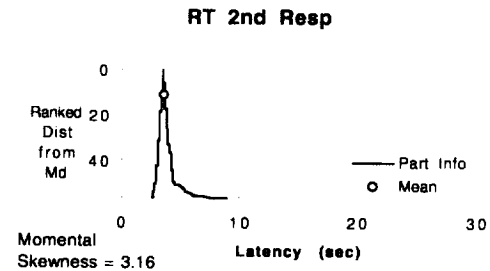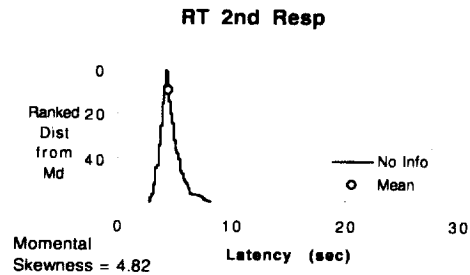skewness statistic indicates greater skewness.

RT 2nd Resp

Ranked Dist from Md

No Info
○ Mean

Momental Skewness = 4.82

Latency (sec)

RT 2nd Resp

Ranked Dist from Md

Part Info
○ Mean

Momental Skewness = 3.16

Latency (sec)

Trk 2nd Resp

Ranked Dist from Md

No Info
○ Mean

Momental Skewness = 3.01

Latency (sec)

Trk 2nd Resp

Ranked Dist from Md

Part Info
○ Mean

Momental Skewness = 1.79

Latency (sec)

Cross-Country 2nd Resp

Ranked Dist from Md

No Info
○ Mean

Momental Skewness = 4.49

Latency (sec)

Cross-Country 2nd Resp

Ranked Dist from Md

Part Info
○ Mean

Momental Skewness = 2.00

Latency (sec)

<u>Distribution of response latencies for first response as a function of information</u>. Positive skewness is evident in the tail of long latency responses and in the displacement of the mean relative to median. Mean will be displaced to a higher valued when distribution is more highly skewed. Greater value of momental skewness statistic indicates greater skewness.
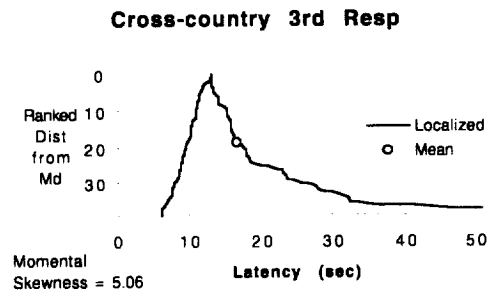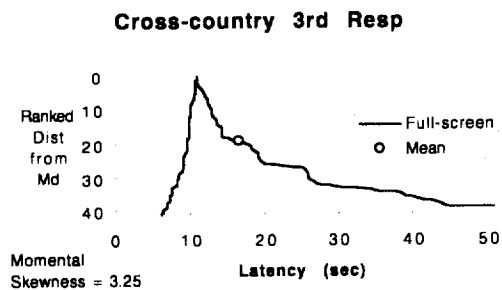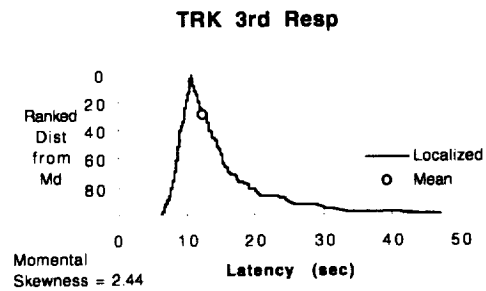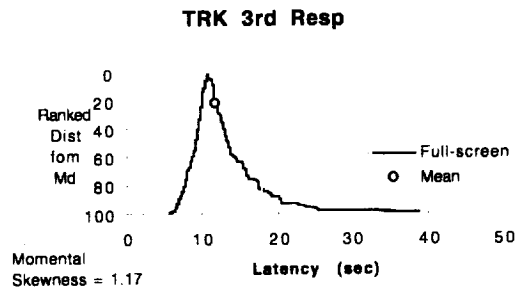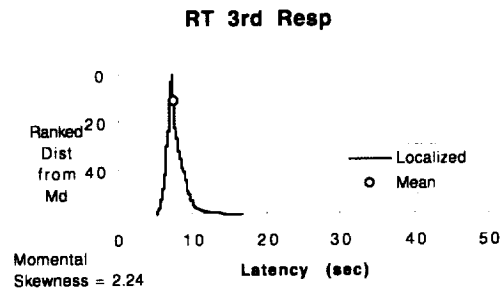
RT 3rd Resp

Ranked Dist from Md

Momental Skewness = 3.66

Full-screen
o Mean

Latency(sec)

RT 3rd Resp

Ranked Dist from Md

Momental Skewness = 2.24

Localized
o Mean

Latency (sec)

TRK 3rd Resp

Ranked Dist fom Md

Momental Skewness = 1.17

Full-screen
o Mean

Latency (sec)

TRK 3rd Resp

Ranked Dist from Md

Momental Skewness = 2.44

Localized
o Mean

Latency (sec)

Cross-country 3rd Resp

Ranked Dist from Md

Momental Skewness = 3.25

Full-screen
o Mean

Latency (sec)

Cross-country 3rd Resp

Ranked Dist from Md

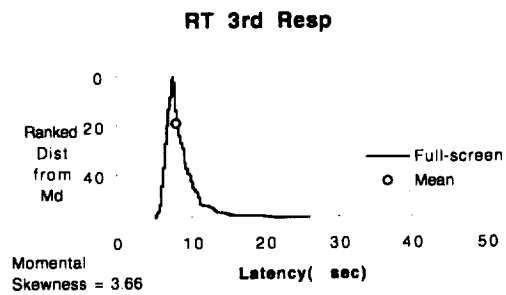Momental Skewness = 5.06

Localized
o Mean

Latency (sec)

<u>Distribution of response latencies for first response as a function of information.</u>
Positive skewness is evident in the tail of long latency responses and in the
displacement of the mean relative to median. Mean will be displaced to a higher
valued when distribution is more highly skewed. Greater value of momental
skewness statistic indicates greater skewness.

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APPENDIX D

ANALYSIS OF VARIANCE TABLES

General Linear Models Procedure

Dependent Variable: Time to First Response, RT Task

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.228	0.743	4.53	0.004
Error	209	34.238	0.164		
Corrected Total	212	36.466			

R-Square	C.V.	Root MSE	C Mean
0.061	18.13	0.405	2.232

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PILOT	**1**	**1.792**	**1.792**	**10.94**	**0.0011**
ALERT	1	0.0026	0.0026	0.02	0.90
INFO	1	0.499	0.499	3.05	0.082

General Linear Models Procedure

Dependent Variable: Time to Second Response, RT Task

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	54.31	18.103	22.42	0.0001
Error	210	169.598	0.807		
Corrected Total	213	223.908			

R-Square	C.V.	Root MSE	C Mean
0.24	22.51	0.899	3.992

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PILOT	**1**	**8.135**	**8.135**	**10.07**	**0.0017**
ALERT	**1**	**3.604**	**3.604**	**4046**	**0.0358**
INFO	**1**	**40.962**	**40.962**	**50.72**	**0.0001**

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General Linear Models Procedure

Dependent Variable: Time to Last Response, RT Task

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	118.651	39.550	9.68	0.0001
Error	210	858.143	4.086		
Corrected Total	218	976.793			

R-Square	C.V.	Root MSE	C Mean
0.12	26.16	2.021	7.726

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PILOT	**1**	**31.998**	**31.998**	**7.83**	**0.0056**
TASK	**1**	**23.844**	**23.844**	**5.84**	**0.0166**
PILOT*TASK	**1**	**57.392**	**57.392**	**14.04**	**0.0002**

General Linear Models Procedure

Dependent Variable: Time to First Response, Cross-Country

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	349.49	36.832	2.50	0.0107
Error	157	2439.88	15.541		
Corrected Total	166	2789.36			

R-Square	C.V.	Root MSE	C Mean
0.12	84.23	3.94	4.68

Source	DF	Type III SS	Mean Square	F Value	Pr > F
PILOT	7	285.71	31.998	2.63	0.0136
TASK	1	52.18	23.844	3.36	0.0688
PILOT*TASK	1	0.25	57.392	0.02	0.8996

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13. ABSTRACT (Maximum 200 words)

Proposed helicopter helmet mounted displays will be used to alert the pilot to a variety of conditions, from threats to equipment problems. The present research was performed under the NASA SAFOR, supported by a joint Army/NASA research agreement. The purpose of the research was to examine ways to optimize the alerting effectiveness of helmet display symbology. The research used two approaches to increasing the effectiveness of alerts. One was to increase the ability of the alert to attract attention by using the entire display surface. The other was to include information about the required response in the alert itself. The investigation was conducted using the NASA Ames Research Center's six-degree-of-freedom vertical motion simulator (VMS) with a rotorcraft cockpit. Helmet display symbology was based on the AH-64's pilot night vision system (PNVS), cruise mode symbology. A standardized mission was developed, that consisted of 11 legs. The mission included four tasks, which allowed variation in the frequency of alerts. The general trend in the data points to a small benefit from both the full-screen alert and the partial information alert.

14. SUBJECT TERMS

Helmet display, Pilot alerting, Partial information, MHD

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Evaluation of Helmet Mounted Display Alerting Symbology

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