HUMAN FACTORS STUDIES OF CONTROL CONFIGURATIONS FOR ADVANCED TRANSPORT AIRCRAFT

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ABSTRACT

This research investigated the threshold levels of display luminance contrast which were required to interpret static, achromatic, integrated displays of primary flight information. A four-factor within-subjects design was used to investigate the influences of type of flight variable information, the level of ambient illumination, the type of control input, and the size of the display symbology on the setting of these interpretability thresholds. A three-alternative forced choice paradigm was used in conjunction with the method of adjustments to obtain a measure of the upper limen of display luminance contrast needed to interpret a complex display of primary flight information. The pattern of results and the absolute magnitudes of the luminance contrast settings were found to be in good agreement with previously reported data from psychophysical investigations of display luminance contrast requirements.

INTRODUCTION

Technological growth in many disciplines has lead to the widespread development of complex, integrated displays of flight information. As avionic designers endeavor to apply the power of the computer and the flexibility of advanced display media, there continually appear new, innovative flight displays in which data are centrally located to the pilot, new forms of symbology are used to encode the data, and new flight facts are incorporated with old ones. The source of considerable potential benefits for cockpit design, integrated displays have flourished in applications to general, civil, and military fixed-wing and rotary-wing aircraft, spacecraft, and flight training simulators. Across these applications, the goals to reduce cockpit "clutter," enhance data presentations, and reconfigure the displayed information are being achieved; thus, it is widely held that safer flight, reduced pilot workloads, and a substantially improved man-machine interface are within the grasp of designers.

Among the various types of integrated displays available is the important subset of displays that present primary flight command and control information. The primary flight display (PFD) has received considerable attention from display designers because it provides the most fundamental information that is used to control the aircraft. Consequently, there has developed a widely diversified set of displays which are greatly varied in the degree of information synthesis, the amount of information presented, and the type of data acquisition and display system elements used to format and display the information. Carel (1965) and Roscoe and Eisele (1980) point out that primary command and control displays can range from literal presentations of the visual scene, to full-bodied and skeletal analog representations, to abstract presentations of alphanumerics and symbolic indicators. Each of these different types of PFDs requires system components that are different in capabilities and cost.

The cost-benefit tradeoff faced by the avionic display system manufacturer is critically important and is weighted by a potential for damaging or fatal consequences should wrong choices be made in the selection of display system elements. On one hand, the cost of system elements must be minimized simply because flight quality components have a very high unit cost. For example, a single display unit used for the PFD in the F-15 fighter cockpit costs in excess of $40,000; similarly, highly expensive color cathode-ray tubes (CRTs) are being used in the new generation Boeing 757/767 civil aircraft. Thus, based on sheer economic considerations, the avionic system manufacturer must select display system components which are minimally acceptable in terms of job performance. However, if system elements are chosen without regard to the requirements and limitations of the human operator, then it is possible that disastrous consequences could result should the display system become unusable during flight. These two conflicting sets of criteria, the cost of display system components and the human operator's needs, can only be resolved through a careful analysis of the display system operational environment, the operator task environment, a consideration of the visual limitations of the pilot, and a knowledge of the influence of various display design parameters on the visual information processing capacity of the human operator.

With the proliferation of integrated flight displays appearing in operational and near-term service aircraft, it is imperative that the influence of specific display system characteristics for flight control be understood with respect to realistic piloting tasks and flight conditions. Concerning the pilot/display interface, designers require information in which performance-based assessments of the pilot's visual requirements are related to components of design in the display system. For realistic piloting tasks and flight conditions, this type of information is virtually non-existent. For example, many standard guidelines sources (e.g., McCormick and

Sanders, 1982; and Van Cott and Kinkade, 1972) provide human performance-based design recommendations for graphics and alphanumerics that are drawn largely from psychophysical threshold detection and recognition studies in which laboratory conditions and tasks are not easily transferred to those found in the avionic application environment. As a result, avionic display designers frequently pick and choose among design options with little understanding about how their decisions impact the usability of the display. Consequently, there is a clear and definite need for practical design recommendations.

The intent of this research was to contribute to the determination of a set of display system requirements for integrated flight control displays. These requirements are derived from psychophysical visual performance data that have been collected during a realistic piloting task under conditions which are likely to occur in the operational environment. There were three objectives to this research. First, the research determined, for various conditions of ambient illumination, the minimum contrast ratios required by a pilot to interpret a display of complex information. Second, the study investigated the influences of size of the display symbology, type of flight variable, and type of control input on setting these interpretability thresholds. Third, the research determined the accuracy of control inputs for each of the experimental factors at these interpretability thresholds.

METHOD

Experimental Design

A four factor 4x3x2x2 (flight variable x illumination x size of symbology x control input) within-subjects design was used for the study. Within each illumination condition, the size of symbology, the type of flight variable, and the type of control input were combined factorially to provide a set of 16 static display stimulus conditions. Thus, each subject served in 48 experimental trials. A randomized order of presentation for the 16 stimulus formats within an illumination condition was developed for each subject. Additionally, the presentation order of the illumination conditions was randomized for each subject. A description of the independent factors and the dependent measures is detailed below.

Independent Factors

Type of flight variable. Four types of symbolic flight variables were investigated in the study. The flight variables tested in the integrated formats included glideslope and localizer deviation indicators, pitch, and roll or bank angle. These flight variables were represented by the indicators shown in Figure 1. As can be seen in this figure, the glideslope and localizer deviation indicators are located at the right side and bottom of the display, respectively. The aircraft pitch was represented by the series of lines crossing the center of the display. Each line represented an increment of 2.5 deg in pitch. Aircraft pitch was referenced to the top of the aircraft symbol which remained fixed in the center of the display. A zero-degree pitch angle was represented by the alignment of the horizon line, which bisected the display horizontally, with the top of the aircraft symbol. Finally, aircraft bank angle was presented at the top of the display. Increments of five degrees in bank angle were displayed with this indicator. Each flight variable indicator used the conventional inside-out format.

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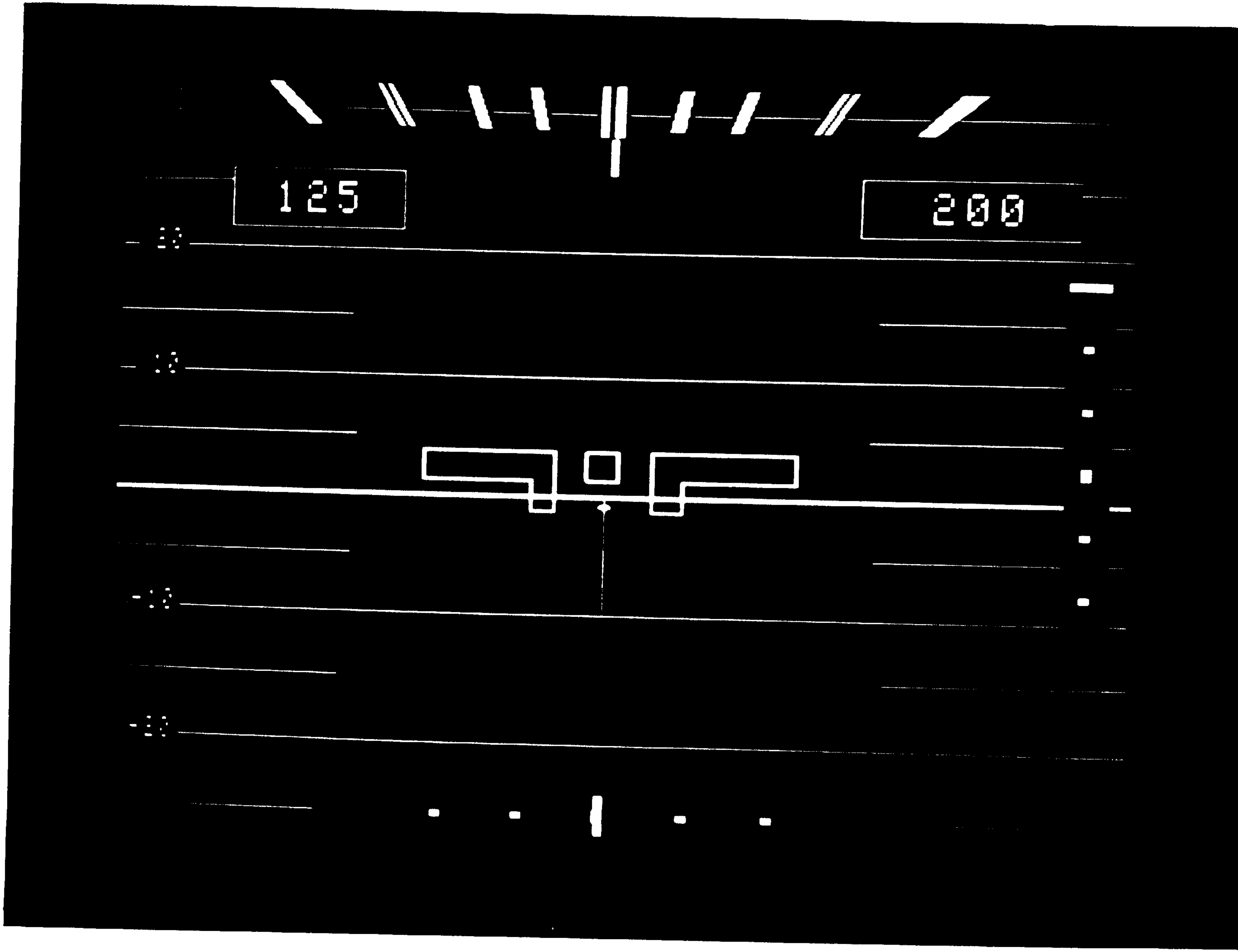

Figure 1. An example of one of the eight experimental primary flight displays used in the study.

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Illumination. The three levels of ambient illumination were high, medium, and low diffuse lighting conditions. The high ambient (41,000 lux) is representative of bright sunshine. The second level (21,500 lux) is similar to a condition of bright indirect illumination. Lastly, the low ambient condition (0.1 lux) is similar to flight conditions during night flight. In this condition, the primary contributors to the ambient environment are cockpit lamps, the reflected radiance from the display screen, and reflectance from the flight desk and cabin structure. Each of these illumination conditions was measured at the pilot's display desk with a cosine-corrected illuminometer (Minolta, Model T-1H). The corresponding background display screen luminances which resulted from the reflection of the diffuse ambients at the display surface were photometrically measured by a hand-held photometer (Tektronix Model J-16 configured with a J6523 1-deg narrow angle luminance probe) and were found to be 0.03 cd/m^2; 1,164.78 cd/m^2; and 2,247.34 cd/m^2 for the low, medium, and high illumination conditions, respectively. An angle of incidence was selected for the luminaires so as to avoid specular glare reflections at the display screen surface during testing.

Display size. Two differently sized experimental integrated PFD formats were used in the study. Figure 1 illustrates the larger of two formats tested. The smaller display format was a scaled down version (magnification factor 0.5) of the larger display. In keeping generally within the minimum design recommendations for recognition of alphanumerics and graphics (i.e., 12-24 arcminutes), a minimum angular subtense of 7.7 arcminutes was maintained for the localizer and glideslope deviation needles used in the smaller display. The horizontal and vertical visual angles subtended by these and other display elements of interest to the study are presented for both displays in Table 1.

Table 1. Visual angles subtended by (1) the overall size of the integrated primary flight displays (in degrees of visual angle) and by (2) the flight variable indicators tested in each of the display formats (in minutes of arc of visual angle).

	DISPLAY SIZE			
	LARGE		SMALL	
DESCRIPTION	LENGTH	WIDTH	LENGTH	WIDTH
OVERALL SIZE	16.4	22.0	8.2	11.0
FLIGHT VARIABLE INDICATORS				
GLIDESLOPE	521.8	61.4	260.9	30.7
GLIDESLOPE DEVIATION NEEDLE	61.4	15.4	30.7	7.7
LOCALIZER	521.8	61.4	260.9	30.7
LOCALIZER DEVIATION NEEDLE	61.4	15.4	30.7	7.7
PITCH GRID LINES				
LONG	1319.8	15.4	659.9	7.7
SHORT	306.9	15.4	153.5	7.7
BANK ANGLE	1181.7	61.4	590.9	30.7
BANK ANGLE INDICATOR NEEDLE	61.4	30.7	30.7	15.4
AIRCRAFT SYMBOL	491.1	92.1	245.6	46.1

Type of control input. One of two types of control input was required for each presentation of the eight display formats. The control inputs which were required for each format included an indication that a corrective control input was necessary or, alternatively, that a "situation ok" set of circumstances was present. Corrective action inputs were obtained by the subject's adjustment of the control stick to null the presence of an erroneous flight variable. An indication of "situation ok" was obtained when the subject depressed one of the buttons on top of the control stick. Control input selection was based upon the match between an instructed flight profile and the flight profile that was presented in the display format. When matched flight profiles occurred, a "situation ok" input was to be performed; alternatively, if a mismatch existed between the flight profiles a corrective pitch or roll input was to be performed.

Dependent Measures

The two dependent measures collected were the contrast ratio at the interpretability threshold and the percent of correct control input responses.

Contrast ratio. The contrast ratios (CRs), which were determined through photometric assessment of the target display luminance and background display luminance level, are defined to be the upper limens of the luminance contrast which is needed to interpret the aircraft situation. The CR is given by the formula,

$$CR = Lmax / Lmin \tag{1}$$

where Lmax, the greater of the two display luminances, is the sum of the emitted symbol luminance and the background display luminance. Lmin is the background display luminance.

Percent of correct response. The percent of correct response for control inputs was defined to be the number of correct input responses, collected at the interpretability threshold, divided by the total number of control inputs across the experimental session and multiplied by 100.

Subjects

Three male volunteers served as participants in the study. Each subject was experienced in flying simulated landings with the integrated PFD used in the study. Furthermore, two of the subjects had previously held general aviation aircraft licenses for fixed-wing aircraft. During the experimental session, subjects were encouraged to take rest breaks between trials when needed. However, subjects were not allowed to leave the simulator cockpit except upon the completion of an illumination condition. In this way, visual adaptation levels for the illumination conditions were maintained.

Task and Procedure

At the start of the experimental session, each subject was seated in the first officer's flight chair and allowed to assume a comfortable position. The center-of-display to pilot-eye distance was adjusted to 66 cm. The neck support on the flight chair was placed against the back of the subject's head to insure that this display-eye distance was maintained. Additionally, the display-eye distance was checked periodically throughout the session between experimental trials. A 10-minute adaptation period was provided at the beginning of each illumination condition to allow the subject to become accustomed to the ambient light level. During the first illumination condition, the subject was provided with practice trials to acquaint him with the experimental process. During this practice period, the subject was allowed to ask questions and clarify the conditions of the task.

At the end of an illumination condition, the subject was allowed to leave the cockpit and rest. During this rest period, the experimenter set up the next illumination condition. After the rest period the subject was light adapted to the new illumination condition, the display-eye distance was re-established, and the subject performed the next block of trials. Following the completion of the experimental session, the subject was debriefed and dismissed.

The subjects used the upward method of adjustments in conjunction with a three-alternative forced choice paradigm to set the display luminance contrast and provide control inputs for each static presentation of the stimulus display formats. At the start of each trial, the subject was presented with a set of flight instructions (located on the left of two CRTs situated in front of the subject) which described an aircraft situation. The subject acknowledged his understanding of these instructions by initiating the procedure to manipulate luminance contrast.

In the procedure to set the luminance contrast, the pilot was required to use a side-arm controller to incrementally increase luminance contrast and input pitch, roll, or "situation ok" inputs. To set the luminance contrast, the trigger on the side-arm controller was used. For the first trigger activation, a temporally constrained stimulus format was presented on the CRT located directly in front of the subject in which the maximum luminance contrast was below detection threshold. The stimulus field presentation was temporally constrained to 3.0 s for each increment of luminance. Following a procedure similar to that used by Beaton (1984) at each temporal increment, the display was modulated upwards to maximum luminance contrast, stabilized at the peak luminance contrast for approximately 1.0 s, and then was sequentially de-modulated below the detection threshold. This procedure was followed to avoid iconic image effects due to a sharp onset or removal of luminance in the visual field. Additionally, it was desirable to control the time of display presentation to reduce guessing by the subjects as to the required control input. With repeated activation of the trigger, the subject was able to incrementally increase the display luminance contrast to a point at which he was able to evaluate the aircraft's situation against the situation given in the flight instruction display. At this point, the subject could perform either a pitch, roll, or "situation ok" control input. The initiation of one of these inputs served as an end-of-trial indication. Subsequent to this input, the accuracy of control input, and the A/D bit values for the display luminance were recorded in a subject raw data file. This entire process was controlled through the VAX-ADAGE computer system which is described below.

Apparatus

Flight simulator facility. The fixed-base advanced display evaluation cockpit (ADEC) which was used in this study was located in the Crew Station Systems Research Laboratory (CSSRL) of the Cockpit Systems Branch (CSB) of the National Aeronautics and Space Administration's Langley Research Center (NASA LARC). As illustrated in Figure 2, the cockpit is a representative example of a generic advanced concepts cockpit for the 1990s wide-body transport aircraft. As can be seen in this figure, the cockpit is equipped with three large-screen, in-line gun, color shadow-mask CRTs. The two CRTs on the right-hand side of the simulator (Conrac Model 7211, 13-in. diagonal) were used in the experiment. Each of these CRTs is a studio quality, high resolution (1024 x 1024 pixels) display monitor. Additionally, the cockpit is equipped with a 6-inch diagonal experimental electroluminescent flat panel display, a multifunction programmable keyboard, an in-house constructed automatic flight guidance and control system located near the top of the flight desk, and a yellow experimental flight desk which houses the displays. The pilot's primary flight controls were a pistol-grip side-arm controller for pitch and roll inputs. The two pushbuttons located on top of the controller and the trigger imbedded in the front of the pistol grip were placed under software control. The use of these controls in the present study was discussed above. Additionally, throttles located between the two flight chairs, pedals for simulated rudder control, simulated banks of overhead pilot controls, humidity and temperature controls, and a removable experimenter station with a data link to the VAX computer were provided.

Ambient lighting simulator. The ambient lighting simulator consisted primarily of two metal-halide (HMI) luminaires, and diffusion material spread over the windscreen of the cockpit.

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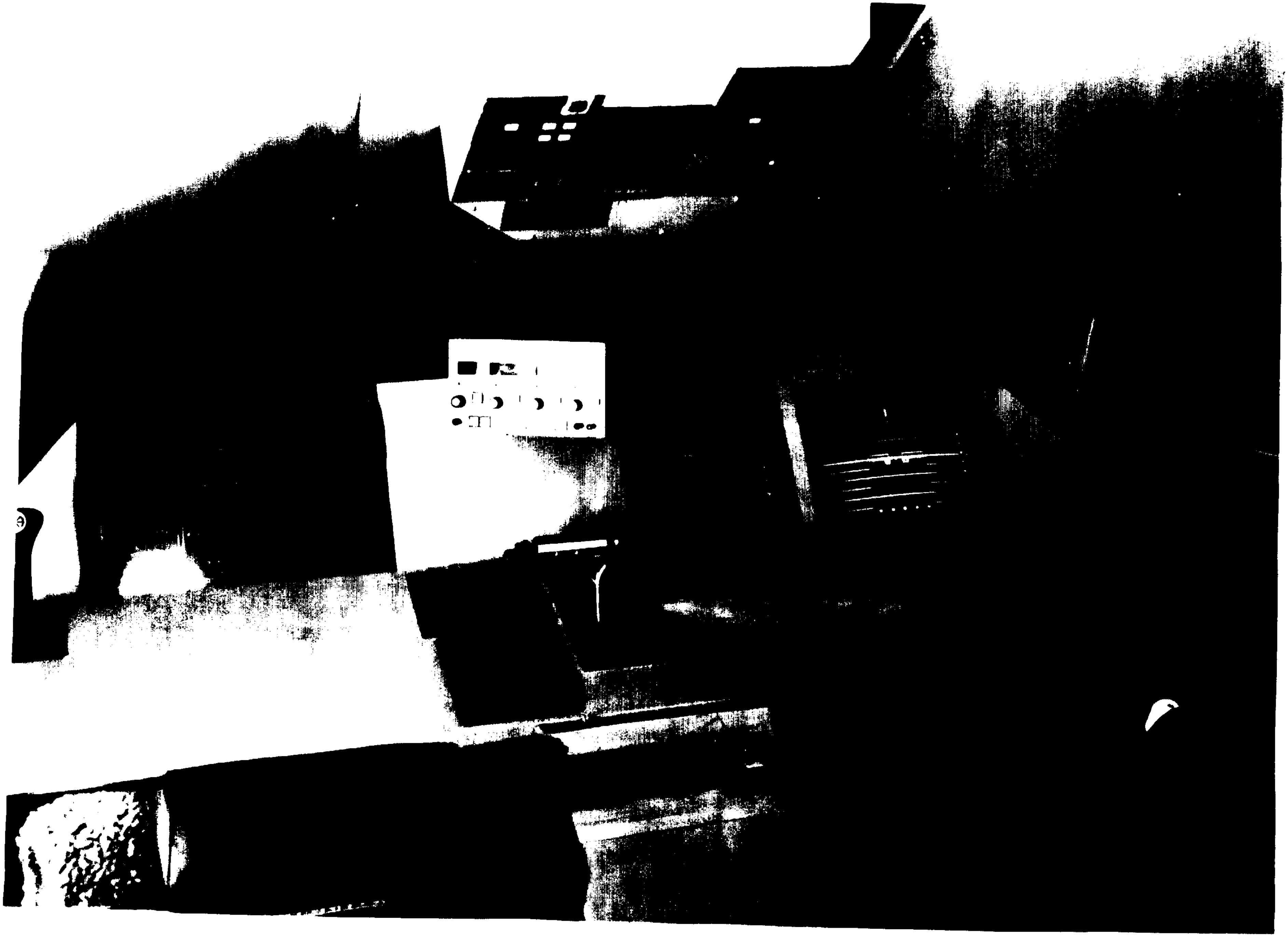
Figure 2. Illustration of the advanced display experimental cockpit (ADEC) used in the study.



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Specifically, a 4KW HMI system (Strand Century Inc., Model 3790) was located in a bay forward of the ADEC windscreen. This lamp illuminated the cockpit through the forward windscreen. Diffusion material (Roscoe Inc., Tufsilk) was spread across the windscreen to provide a bright diffuse lighting condition. The second HMI source (Strand Century Inc., Model 3680) was a 2.5KW system. This system was positioned at the rear of the ADEC simulator and was directed so as to illuminate the displays and the pilot's flight desk. Silk gauze material was positioned in front of each source to control the intensity of the light and to provide additional diffusion during the medium and high ambient lighting conditions. During the low lighting condition, both lamps were turned off.

Computer facility/graphics display generator. A detailed description of this facility has been provided by Montoya, Lane, Turner, and Hatfield (1983); however, an overview summary of the system is provided here. A VAX (DEC, Model 780) serves as the host computer which controls all input/output (I/0) for various experimental activities. The VAX computer consists of the 11/780 central processing unit (CPU), a floating point accelerator (FP780), 2 Mbytes of ECC MOS core memory, 4 Gbytes of virtual memory, and uses the VMS (Version 3.5) operating system. In addition, two 67-Mbyte disk drives and a 9-track tape drive are linked to the VAX via massbus architecture and are used for storage of controlling software and data files. Peripheral device I/O to pilot controls and displays and to experimenter computer consoles is enabled through the laboratory peripheral accessory package (DEC, Model LPA-11) which contains 64 12-bit analog-to-digital (A/D) converters, 4 10-bit digital-to-analog (D/A) converters, and 16 discrete parallel 32-bit channels.

The ADAGE 3000 graphics display generator is a high performance, raster scan, color, programmable display generator (PDG). It allows user control over the number of television (TV) lines per frame, the refresh rate, interlace, resolution mode, color selection, 3-D coordinate transformation of a display format, and alphanumeric character generation. An in-depth description of the capabilities of this system is provided by Montoya, England, Hatfield, and Rajala (1981).

The display formats and controlling software were developed using the FORTRAN-77 programming language available on the VAX computer. The display formats were assembled, compiled, and downloaded to the ADAGE 3000 PDG via serial data link. Following the collection of all data sources, the data were transformed and analyzed using the Biomedical statistical analysis package (BMDP, Version 3.1) which was resident on a personnel computer (PC) system (SPERRY, Model 400) configured with a 20 Mbyte hard-disk, 640 Kbytes of random access memory (RAM) and using the DOS (Version 2.1) operating system.

RESULTS

To transform the raw data of the luminance contrast settings into meaningful descriptions of the subject's performance, the following procedure was used. First, the luminance output of the display as a function of the digital-to-analog ramp in the ADAGE display system was determined for each of the 256 steps of digital memory. This data set was generated by measuring the luminance intensity at the center of the display for each increment of digital memory.

Next, the luminance data were regressed upon digital value. A second- order regression was found to provide a good fit to the data (R^2 = .98). The requirement for the second order term in the regression was investigated by inspection of a plot of the raw data. From this plot it was determined that a slight nonlinearity, a slight downward turn, occurred near the extreme low end of the observed function. Consequently, the second-order term was required to account for this change in the function. Following the development of the mapping function between digital value and luminance output, each subject's response data were transformed from the recorded digital value into equivalent luminance output.

In the final steps to form the interpretability contrast ratios, the equivalent symbol luminance for each trial, obtained in the previous steps, was summed with the appropriate level of background display luminance and then divided by this background luminance level. Following the formation of the interpretability contrast ratios, each of the independent factors was related to these contrast settings by an analysis of variance (ANOVA). Post hoc analyses of significant effects included using simple effects F-tests to probe significant interactions, and using the Newman-Keuls range test to probe significant main effects.

A check of the raw data for control input errors revealed that, across the total set of observations, only six control input errors, each of which occurred in a different combination of conditions, were present in the data set. Given that the overall accuracy of the control input settings was 96 percent and that there was no apparent consistency in the performance of these errors, it was decided that further analysis of these error data would not provide meaningful insight about the subject's performance. Consequently, no additional analyses were performed on these data. These findings suggest that the subjects, as per the experimenter's instructions, attempted to maximize accuracy over speed when performing their control input selection.

The results of the ANOVA which was performed on the luminance contrast data revealed that the main effects of illumination condition and flight variable were statistically significant ($p = 0.0104$ and $p = 0.0352$, respectively). Furthermore, the two-way illumination condition by flight variable interaction was also statistically significant ($p = 0.0141$). The remaining main effects of display size and control input, as well as all other interactions were not statistically important ($p > 0.05$). A description of the statistically significant findings is detailed below.

Figure 3 illustrates the main effect of illumination condition. As shown in this figure, the mean contrast ratio required to interpret the integrated information in the displays was significantly higher ($p < 0.05$) for the low illumination condition than for either the medium or high illumination conditions. No significant difference was found in the contrast levels required to interpret the displayed information during the medium and high illumination conditions.

In the main effect of flight variable (Figure 4), higher luminance contrast ($p < 0.05$) was required to interpret the pitch angle indicator than was required to interpret the roll angle indicator. No other statistically important differences were found in the contrast settings between other flight variable pairs.

In the two-way illumination condition by flight variable interaction, shown in Figure 5, it was found that the luminance contrast needed to interpret each of the flight variables was greater ($p < 0.05$, for all variables) during the low illumination condition than during the medium or high illumination conditions. In the medium and high illumination conditions a similar level of luminance contrast was required to interpret the various flight variables. For the low illumination condition, a similar finding as occurred with the main effect of flight variable was found; generally, the pitch and localizer deviation indicators required a greater amount of luminance contrast to be interpreted than did the glideslope and bank angle indicators.

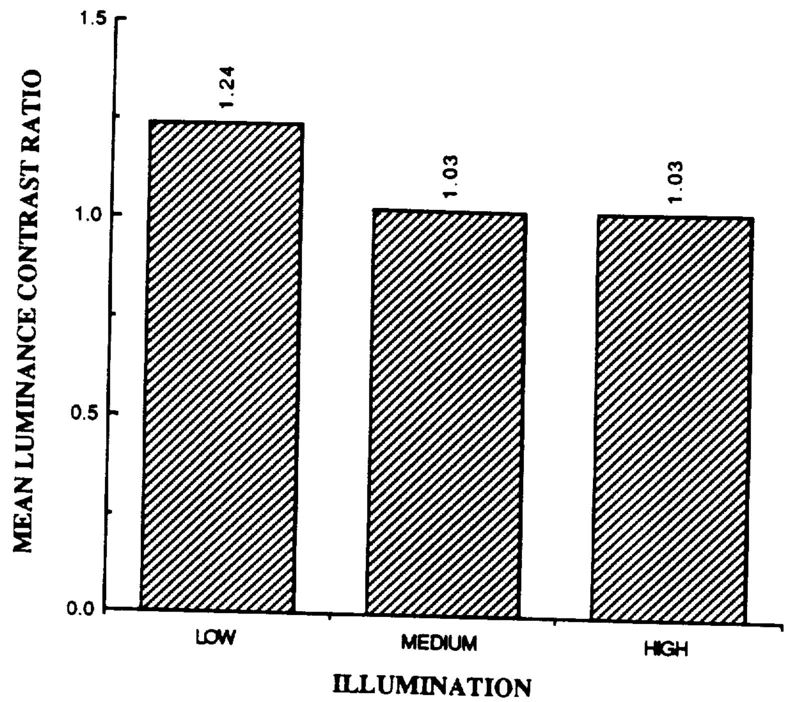

Figure 3. The effect of illumination.

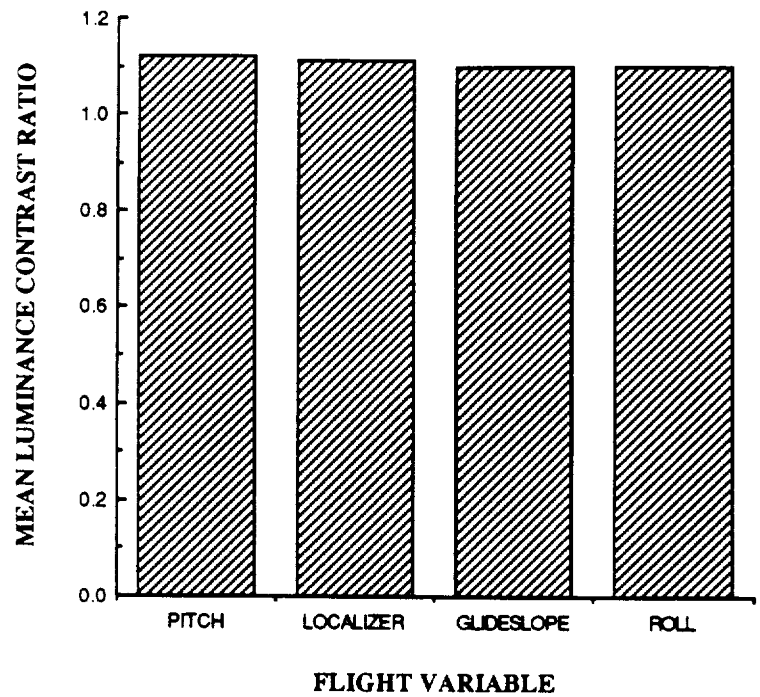

Figure 4. The effect of type of flight variable.

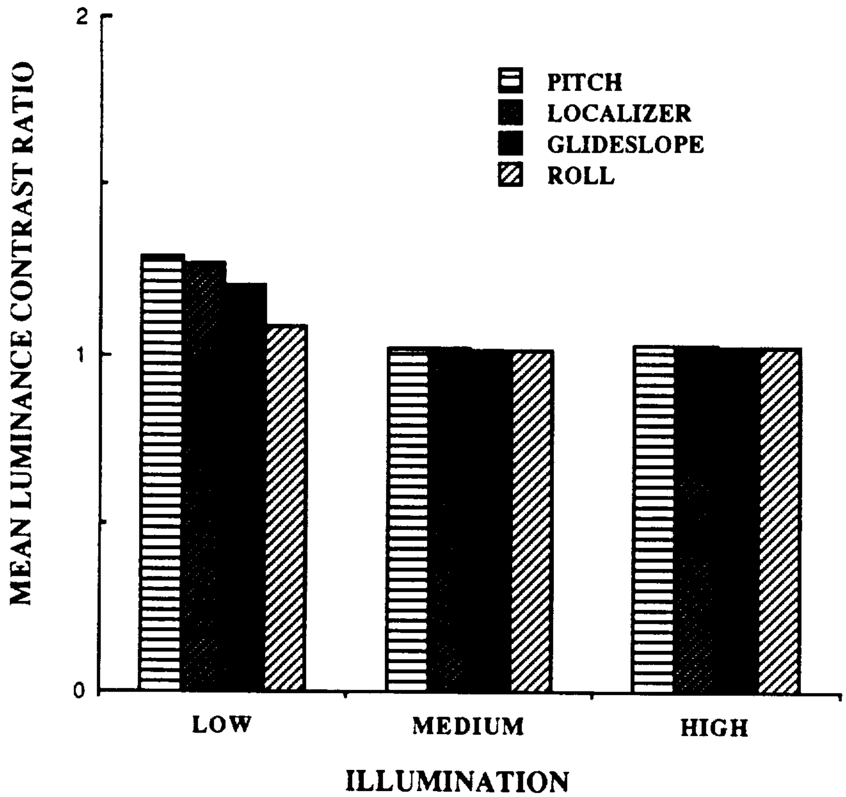

Figure 5. The illumination by flight variable interaction.

DISCUSSION

The analysis of the luminance contrast data revealed that three consistent trends occurred in the data. The first trend seen in these results concerns the requirement that greater luminance contrast was needed during the low illumination condition than was needed during either the medium or high illumination conditions to interpret the displayed information. The second trend which is seen to occur is that during the low illumination condition greater luminance contrast was required to interpret the pitch angle and localizer flight variable indicators than was needed to evaluate the glideslope and bank angle displays. Finally, the third trend which is evident in the data concerns the consistent lack of an effect for the size of the displayed symbology and the type of control input. A discussion of each of these trends is presented below.

As shown throughout Figures 3-5, it is interesting that a higher luminance contrast was required to interpret the displayed information during the low illumination condition than during the medium and high illumination conditions. This finding is consistent with the results found in previous studies which have investigated luminance contrast requirements. In the present study, the pattern of luminance contrast settings and the absolute levels of luminance contrast needed to interpret the displayed information conform closely to the data of Blackwell (1946). Blackwell found that luminance contrast settings ranged between 1.01:1 and 1.1:1 for a target identification task when display luminance levels and subtended visual angles were comparable to those used in the present study; furthermore, he found that as the display luminance level was increased, while visual angle was held constant, a lower luminance contrast was required to identify the target.

A difference between the present study and the study by Blackwell suggests that an-other conclusion can be drawn from the results of the present study. In this study, different surround luminance levels were used to control the adaptive state of the eye; however, in Blackwell's study, no explicit manipulations to the adaptive state of the eye were performed. Yet, even though these differences existed between the two studies, the results of the two studies are quite similar. This finding suggests that, for the conditions used in this study, luminance contrast was set independently of the adaptation state of the eye. An explanation for this finding can be obtained from previously reported research. In earlier studies (Carel, 1965; Ireland, Kinslow, Levin, and Page, 1967) it has been found that luminance contrast requirements remain relatively constant when the background surround luminance (the eye adaptive state) does not exceed ten times the display luminance level. The ratios of background surround luminance to the display luminance level used in the present study are within this ten-times criterion. Thus, even though differences in the adaptive state of the eye were present between the two studies, the magnitude of these differences was not substantial enough to be an important determinant in the setting of display luminance contrast; rather, as with Blackwell's study, the setting of luminance contrast was dependent upon the display luminance level and the visual angles subtended by the targets.

As shown in Figures 4 and 5, in the low illumination condition higher luminance contrast was required to interpret the aircraft pitch and localizer deviation displays than was required to interpret the guideslope and bank angle displays. These differing requirements may to some degree reflect differences in the level of difficulty required to interpret the various types of information. For example, judgements of pitch angle were made upon an analysis of the cues presented by the relative position of the aircraft symbol between two different pitch grid lines, whereas judgements of bank angle could have been based upon cues which resulted from both the position of the bank angle indicator and the angle made between the horizon line and the aircraft symbol. Concerning the localizer deviation indicator, it is possible that its location (see Figure 1) in the display combined with its smaller relative size to the pitch and bank angle indicators influenced the subjects to adjust upwardly their settings of luminance contrast to insure that their interpretation of the displayed information was correct.

Finally, the third trend in the data concerns the consistent lack of an effect for the size of the display symbology and the lack of an effect for the type of control input. With respect to the size of the display symbology, it is possible that two experimental factors contributed to a lack of a size of display symbology effect. Concerning the first of these factors, it may be that the overall sizes of the indicators used for the flight variables were not selected at extreme enough levels to provide statistically significantly differences for this factor. In particular, the sizes of the various display indicators were based upon maintaining a minimum visual angle for the deviation needle used in the localizer and glideslope indicators, and upon maintaining a constant scaled ratio for all display elements contained in the two differently sized display formats. Consequently, in satisfying these two criteria, the overall size of the various flight variable indicators was implicitly selected for each indicator contained in each of the display formats. It is possible that the range of relative sizes for the various indicators which resulted from these procedures was not adequate to influence the luminance contrast levels required to interpret the information presented in these displays.

The second factor which may have contributed to the lack of a size of symbology effect concerns the task requirement used in the study. Unlike a simple experimental paradigm in which a detection or identification threshold is established for a target, this study required subjects to select a level of display luminance contrast at which information contained in the display could be interpreted. The requirement to interpret the displayed information may have conditioned the subjects' responses in the following way. The subjects, in setting luminance contrast levels at which meaningful information could be obtained from the displayed flight variable indicators, may have selected luminance contrast levels at which the overall configuration of the various flight variables could be analyzed and compared to the instructed flight profile. Consequently, it may be the case that the overall sizes of the displayed symbology were not as important to the setting of display luminance contrast as was the relative configuration of the flight variables and the information transmitted to the subject by each of the variables.

The lack of a statistically significant finding for the type of control input suggests that the display luminance contrast levels needed to interpret each of the flight variables were not influenced by the type of mismatched information presented in the information and PFD displays. That is, the interpretation of flight variable indicator information, with respect to the flight information presented in the instruction display, was performed at a display luminance contrast level which was set independent of whether or not the flight variable was involved in the mismatch of information between the two displays.

CONCLUSION

This study investigated the levels of display luminance contrast which were needed to simultaneously interpret multiple sources of information presented in a static, achromatic, integrated display of primary flight information for three different conditions of illumination, two different types of control input, and two different sizes of the display symbology. The multiple sources of information which were required to be interpreted included glideslope and localizer deviation, and aircraft bank angle. A three-alternative, forced choice paradigm was used in conjunction with the method of adjustments to obtain a measure of the threshold luminance contrast which was needed to interpret the displayed information. The experimental task performed by the subjects, that of assessing and making judgements about the current status of the aircraft's flight profile, is similar to the types of tasks which occur in the operational task environment.

It was found in this study that the levels of luminance contrast required to interpret the displayed information conformed closely to the levels which have been reported in previous studies of display luminance contrast requirements. In general, it was found that very low levels of luminance contrast are required to interpret and make decisions about a display of complex information. Furthermore, for the conditions in this study, it was found that the display luminance level, and to some degree the format of the information, were important factors in the setting of display luminance contrast.

It is interesting to note that the agreement of the results among studies which have investigated display luminance contrast requirements is quite good. This agreement has occurred despite the fact that widely different experimental conditions and tasks have been used to assess display luminance contrast requirements in these studies. Based on this good agreement of results, and in light of the findings of the present study, it is believed that the general recommendations for display luminance contrast which are provided in various display design handbooks are, in general, satisfactory for the design of displays to be used in an operational task environment.

Lastly, the recent advancement of color shadow mask CRT technology into the aircraft cockpit suggests that future research on display design parameters should be directed towards an evaluation of color contrast, its contributions to display legibility, and its impact on the levels needed for other display design elements (i.e., display luminance and display resolution) to satisfy the visual requirements of the user.

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