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PRELIMINARY STUDY OF HEAD-UP DISPLAY ASSESSMENT TECHNIQUES.

I. VIEWING DURATION OF INSTRUMENT PANEL AND HUD SYMBOLOGY USING A RECALL METHODOLOGY

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SUMMARY

Eight commercial pilots were shown 50 colored, high fidelity slides of a standard instrument panel (IP) with the needle positions of each instrument varying from slide to slide and then 50 slides of a head-up display (HUD) symbology format which contained an equivalent amount of flight-related information as the instrument panel slides. All stimuli were presented under controlled, static viewing conditions that allowed the measurement of the speed and accuracy with which one randomly selected flight parameter on each slide could be read. The subject did not know which parameter would be requested and, therefore, had to remember the total set of information in order to answer the question correctly. The results showed that: (1) from 6.6 - 8.7 sec total viewing time was required to correctly extract altitude, airspeed, heading, VSI, or ADI from the IP slides and from 6.1 to 7.4 sec for the HUD slides, the mean difference being significant at $p < 0.025$ level of confidence; (2) slide viewing duration continued to decrease over the course of the 50 trials suggesting that learning or a change in information extraction strategy had occurred. An adjunct investigation on two subjects given 200 trials showed that mean viewing duration continued to occur after 200 viewing trials; and (3) the present experimental method is considered adequate for those viewing situations in which the visual information is static and the subjects are already familiar with the format and meaning of the information. An alternative methodology is presented that allows statements to be made regarding information extraction during direct viewing rather than on a recall basis. A review of the literature on display format and content, integration of information from several sources, and symbol interpretability and evaluation techniques is presented in an appendix.

INTRODUCTION

It has been suggested that instrument panels in today's commercial aircraft have not been designed to facilitate the transfer of information to the pilot. Most panel indicators, it is said, employ different logic and scaling so that the pilot must make mental interpolations or transpositions when critically comparing (cross-checking) one flight parameter with another. The fact that a different indicator is usually used to display one flight parameter requires the pilot to scan each instrument in some order that may or may not be optimal in terms of remembering (storing) or using (throughput) the information directly. And, since the indicators are located below the glare shield, a head-up transition is necessary in order to obtain meaningful information from the outside scene during the final segment of an approach. Finally, the fact that the present panel indicators are relatively near to the eyes calls for a rapid refocus (accommodative response) to the apparent distance of the runway upon going head-up.

The head-up display (HUD) has been proposed as one means of reducing or eliminating altogether most of these perceptually related problems (refs. 1,2). The HUD should make it possible to present necessary and sufficient flight information to the pilot in an integrated manner that incorporates a consistent logic for its derivation and presentation and which is located where he finds it of most utility during an approach; namely, superimposed over his external field of view. Reviews of the literature on HUD technology (refs. 2-4) show that, with a few notable exceptions (refs. 5-7), there is very little empirical data available to substantiate most of these claims. As Sampson et al. (ref. 8) point out:

> Data are also required on the most appropriate ways to split up the information processing burden by assigning portions of it to both man and machine. While studies have investigated detection tasks as versus other tasks (e.g., decision-making), it is surprising that no writers have suggested that complex activities be split up into their elemental components each being carried out with essentially its own favored display. It would appear that something could be done in this particular area to examine critically detection tasks, judgmental tasks, information processing tasks, and decision-making tasks to determine whether the greatest payoff for each will come from treating display content and/or display format. It may turn out that detection tasks could be improved most by treating the format whereas decision-making would profit most by manipulating the content of displays.

A literature review of information processing performance is presented in appendix A. Three basic subjects are reviewed: display format and content, integration and combination of information from several sources, and symbol interpretability and evaluation techniques. This review is included for its relationship to the present investigation and for future reference.

This exploratory investigation was conducted as a part of the laboratory and simulator studies of the joint FAA/NASA Head-Up Display Concept

Evaluation Project.[1] One objective of these studies was to develop sensitive techniques for measuring information transfer from the head-up display to the pilot. A series of controlled laboratory studies would be conducted in which the basic visual parameters (stimulus luminance, size, shape(s), contrast, viewing duration(s), color, and other characteristics) could be systematically varied and the resulting perceptual processing performance monitored. The questions of primary interest for this study were those of speed and accuracy of extracting information from photographs of standard instrument panel indicators and photographs of an integrated, symbolic "analog" of this same flight-related information. The format of a thin symbolic "analog" display is suitable for generation by microprocessor and display on a head-up display (HUD). Hereafter, this second type of symbolic information will be called "HUD" information. To effectively control for possible performance differences arising from differences in the location of the two sets of information within the pilot's field of view, each was viewed sequentially in the same location. (Other issues related to switching attention from the instrument panel to the HUD and the outside scene are discussed in detail in ref. 10.) That is, the field of view within which the pilot saw the flight-related information was the same for both the instrument panel (IP) photographic slides and the HUD slides.

I wish to thank Patrick Ted Jensen and Richard Giroux for the able assistance they provided in collecting most of the data, and Robert Hodges, Joy Hamerman, and Donna Miller for valuable technical support during the conduct of this study.

METHOD

Apparatus and Procedure

All stimuli consisted of 35-mm slides presented in a three-channel tachistoscope[2] shown in figure 1. Two types of slides were used: IP and HUD symbology. Each was viewed separately and for as long as the pilot subject (S) desired, to a maximum of 10 sec. All slides were back-projected onto a ground glass screen. Viewing distance to this screen was 89 cm for both the IP and the HUD channel. The third channel was used to maintain a fixed, constant light adaptation level between trials when both the IP and HUD projectors were off. In this case the viewing screen of the third channel was illuminated at the same level as was present during the stimulus slide trials. All stimuli were exposed by means of an electromechanical shutter with 3-msec opening and 1-msec closing time. The events of each trial were

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[1]Task Order DOT-FA77WAI-725 to Interagency Agreement NASA-NMI 1052.151, dated March 9, 1977. A detailed overview of the program plan is presented elsewhere (ref. 9).

[2]Iconix model 6137. A channel refers to an individual optical display screen and beam-splitting mirror to allow for precise superimposition of visual images or temporal sequencing of two or more images.

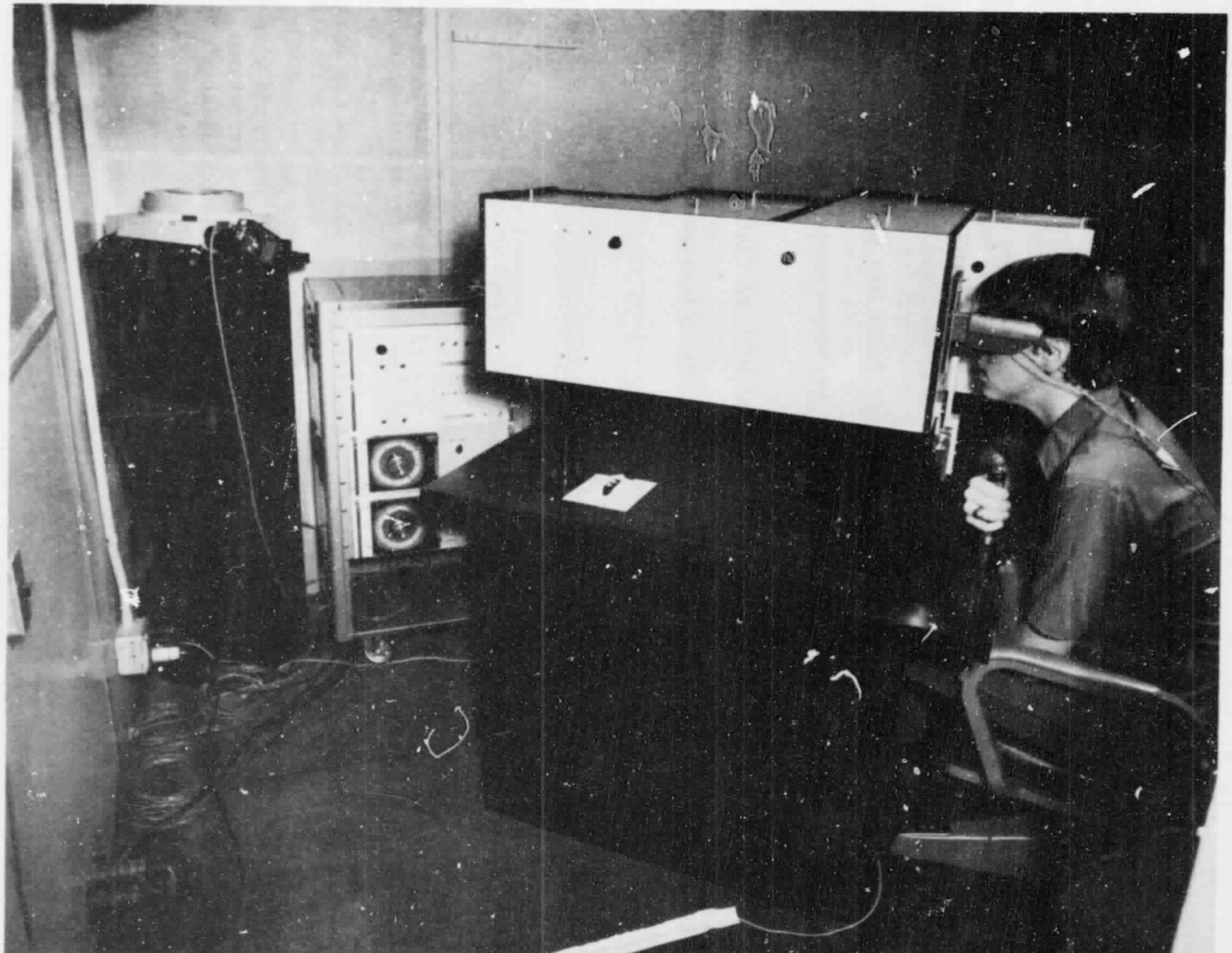


Figure 1. - Photograph of tachistoscope, control equipment, and subject.

controlled by the subject by means of a finger button held in his right hand. The first time the button was pressed, a slide was exposed and a timer started (1-msec accuracy). The second time the button was pressed, the shutter closed and the timer stopped. If the second button press did not occur within 10 sec, the shutter closed automatically and 10 sec was recorded for that trial.

Immediately following each viewing period the subject was asked what specific value was present on a certain panel instrument indicator, or in the case of the HUD symbology, the "value" of one of the flight parameters. (The subject did not know which parameter would be requested and, therefore, had to remember all of the information presented.) In the case of IP slides, a different combination of needle positions was used in each slide. In 3 of the 50 slides one of the needles was made invisible by masking, in which case the subject was supposed to have reported that that parameter was "missing" if he noticed it. (The flight parameter missing on all three HUD slides was attitude. On two of these slides heading was the flight parameter requested and airspeed on the other.) Figure 2 is a photograph of one of the IP slides.

Due to the size of the projection screen of the tachistoscope upon which the slides of the instrument panel and HUD symbology were projected, somewhat smaller visual angles were subtended by the numerals and reference scales than would be found in an actual cockpit. Measurements showed that the smallest number that had to be discriminated to yield a correct response still exceeded the angular size required to satisfy the 20:20 acuity criterion by a factor of at least 6; that is, the smallest visual angle subtended by any numeral was 6.92' arc (airspeed numbers on panel instrument slides). Compared to the airspeed indicator on a B747 aircraft instrument panel, the stimulus' image size of the airspeed numerals was about 60% that of the airspeed numerals in a B747. The high visual contrast of these stimulus slides — because they were back-projected — and the amount by which the numerals, needles, tick marks, etc. exceeded the visual acuity limit of the subjects, explains why no subject had any particular difficulty perceiving the stimulus information.

In the case of the HUD slides (fig. 3), the spatial arrangement of the reference scales and spacing between ticks was held constant throughout all 50 slides. Different numeric values were inserted on the vertical airspeed scale (left), altitude scale (right), or heading scale (horizontal). The arrow-head pointers also changed location from slide-to-slide as did the vertical location of the flight path symbol (double triangle and dot) relative to the 5°-arc-separated pitch-ladder symbols laying above and below the horizon. Thus, for both the IP and HUD slides there were five possible flight parameters to be scanned and remembered for subsequent recall. It is important to note that this particular symbology was selected not because it necessarily represented a potentially attractive format but only because it allowed for control of all of the relevant visual stimulus variables of line width and length, numeral size, etc.

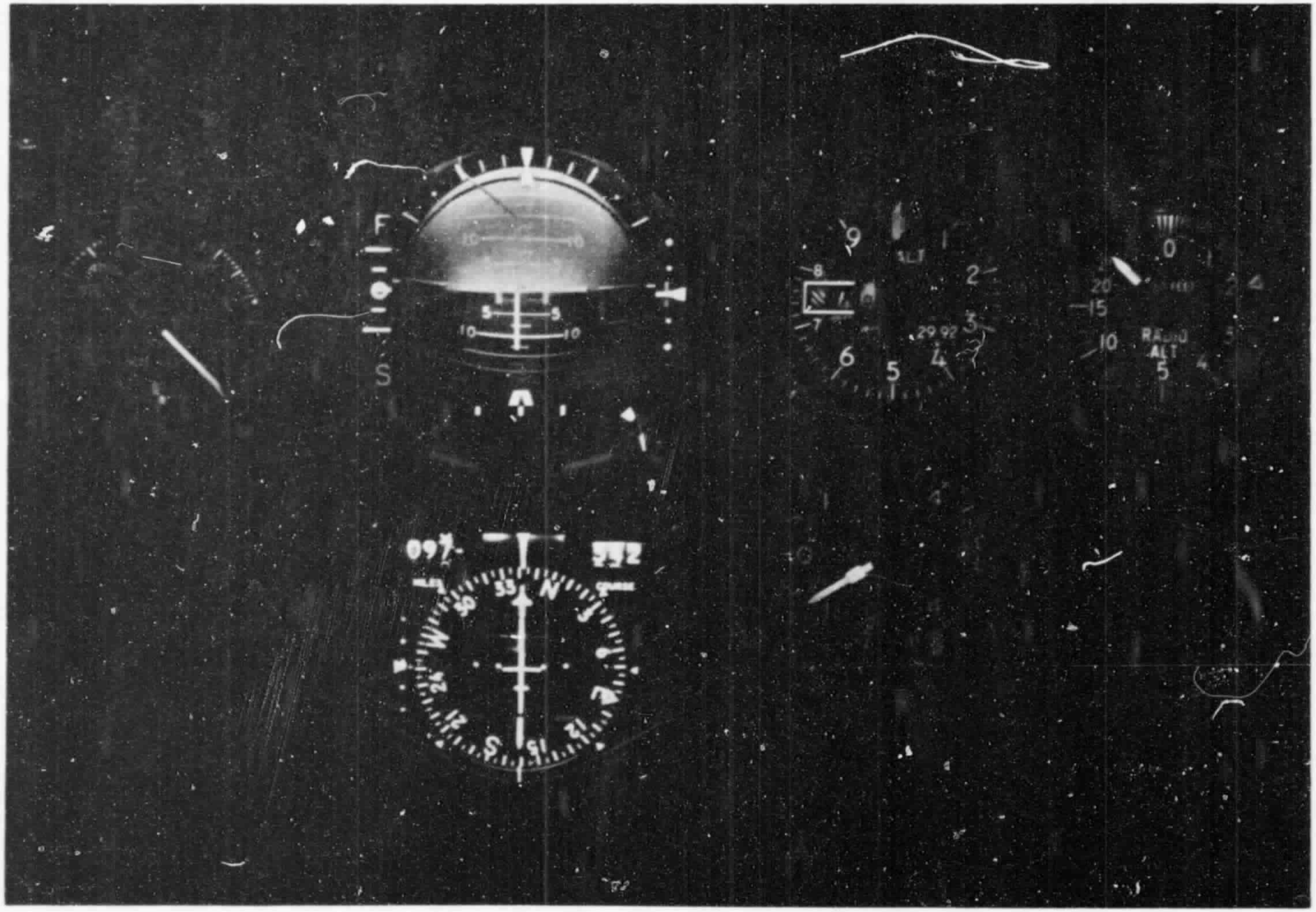


Figure 2. - Illustration of typical instrument panel stimulus slide.

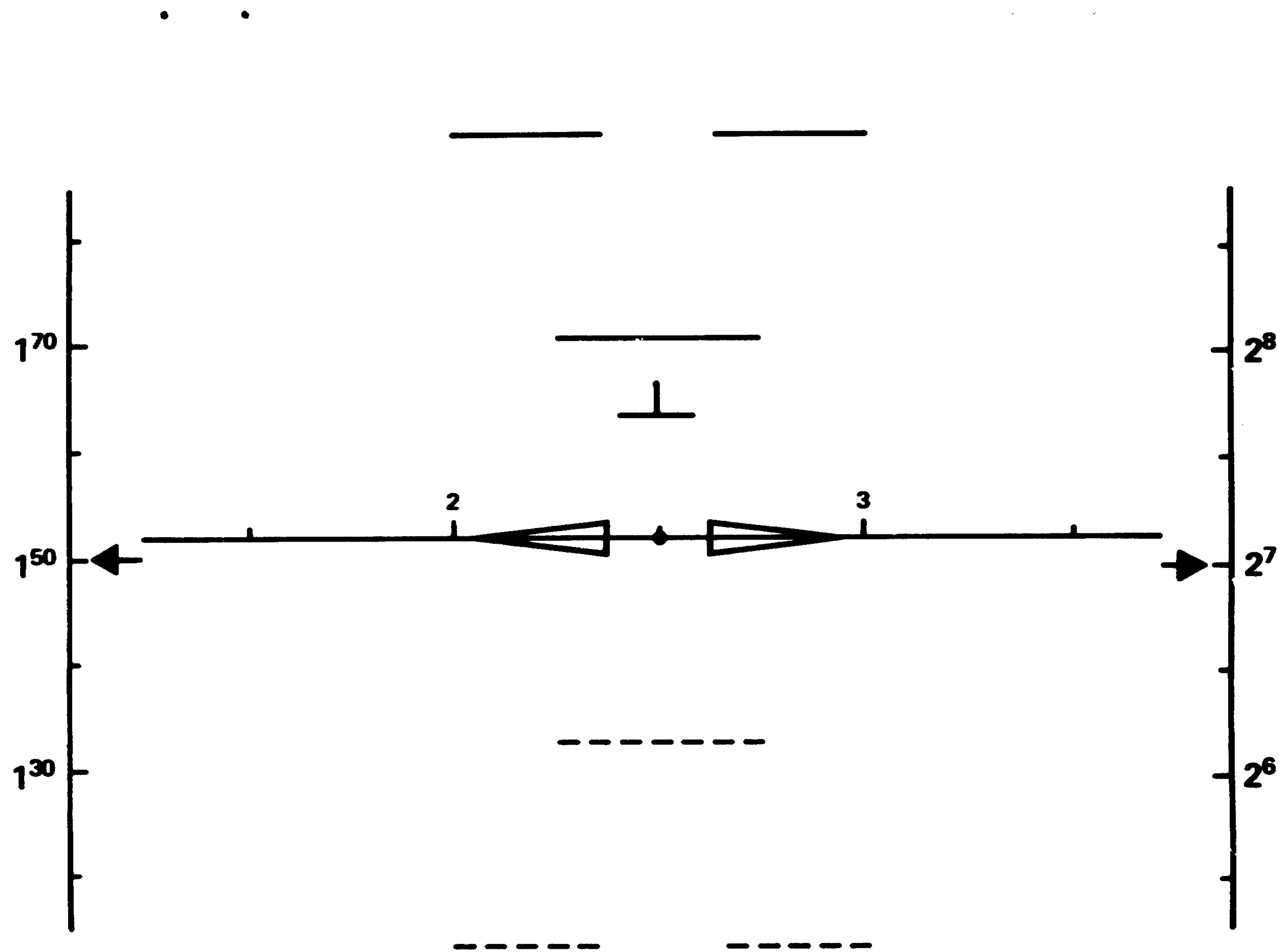


Figure 3. - Illustration of typical head-up display symbology stimulus slide.

Since only one of the subjects had seen a head-up display type symbology before, it was necessary to carefully explain each of the symbols. All of the subjects quickly grasped the details of the altitude, airspeed, horizon, heading, and pitch-ladder scale. Several subjects had some difficulty understanding the flight path and pitch attitude symbols and their interrelationship. The most effective way to explain these two symbols was to draw a diagram which showed the aircraft in a given pitch-up attitude, ground plane with runway touchdown point, and flight-path line connecting the aircraft to the touchdown point. It was then pointed out that the aircraft symbol (inverted T) indicated the angle that the aircraft was pitched up relative to the horizon. The flight-path symbol represented the angular depression, measured on the pitch attitude scale, along which the aircraft was actually flying. The subject was told that if the flight path symbol overlayed the horizon the aircraft was flying level and also that the pitch attitude minus angle of attack equalled the flight-path angle. This explanation sufficed.

After the subject had completed a battery of vision tests, he was given typed instructions to read (appendix B). He was then taken to the soundproof testing room and adapted to the ambient illumination for at least 10 min during which time the experimenter (E) discussed the various response procedures required and answered questions. Each test period lasted about 25 min with two short rest breaks given during this period.

Following the data collection period, the subject was asked to indicate the order in which he scanned both the five panel indicators and the five HUD flight parameters. This order was based on the eye scan pattern, once the pattern had become fairly stable according to the subjective opinion of the subject.

Subjects

Eight male, commercial-rated pilots took part. They ranged in age from 33 to 49 (mean = 40.1) years and had from 700 to 3,200 hr (mean = 1,932 hr) of pilot-in-command time in the most recently flown aircraft type (707, 727, 737, 747, and DC-9). Three subjects were captains and five were first officers. All subjects possessed 20:15 binocular distance acuity and 20:20 near acuity (Orthorater-Landolt broken ring and A-O Snellen broken ring); normal visual motility and field limits; normal color perception; and accommodative near-point of 30 cm or less. One subject had an accommodative near-point of 32 cm and 47 cm for his right and left eyes, respectively, but his performance was not noticeably different from that of the others. Another subject had served in a previous HUD investigation at Ames in which a variety of HUD symbologies was presented; however, an analysis of his data indicated that it was not significantly different from that of other subjects.

RESULTS

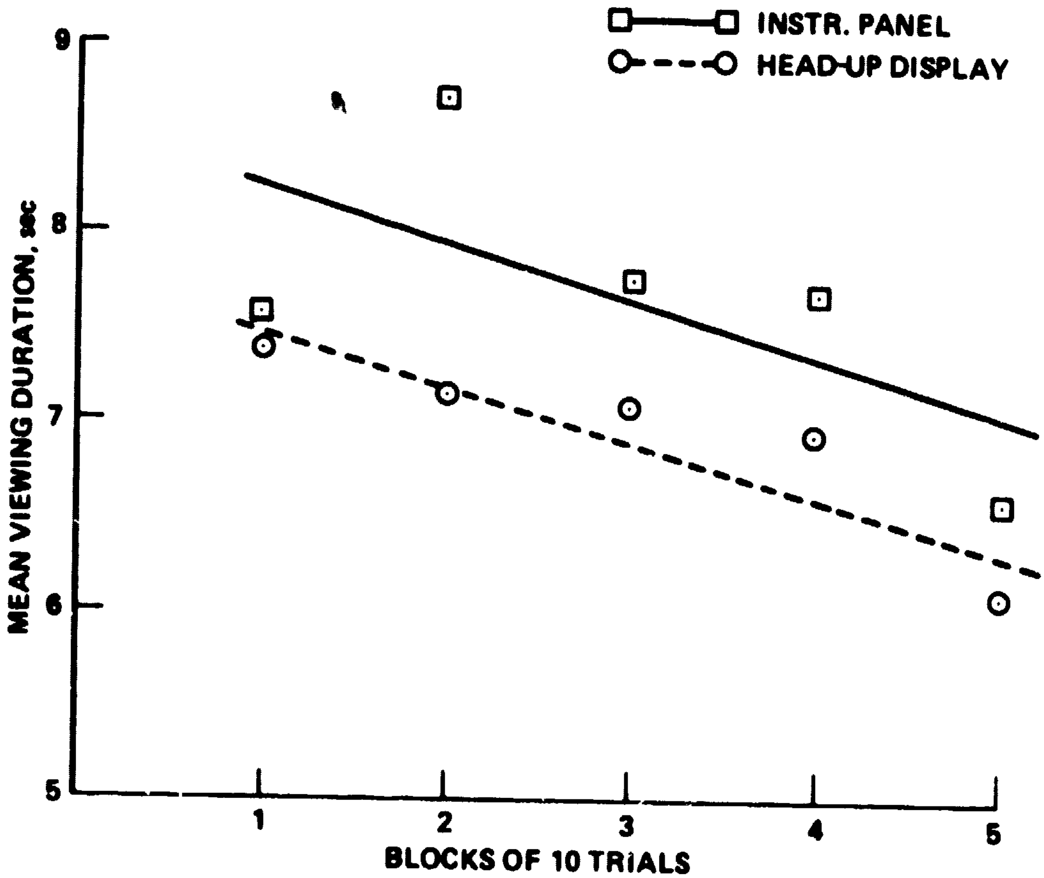
Mean Viewing Time Results

The mean time to scan the IP and HUD slides for five consecutive blocks of 10 trials is shown in figure 4. These data, averaged across all subjects, show that the IP slides required nearly 0.5 sec longer than did the HUD symbology slides ($p < 0.025$) [$F(1,7) = 8.61$]. All values of statistical significance were determined by analysis of variance (ref. 11) with the relevant F values cited immediately following the level of confidence. As shown in figure 4, mean viewing time for both the IP and HUD slides was still decreasing after 50 trials, suggesting that these subjects either were still learning how best to obtain the required flight parameter or were changing their response "criterion" of what constituted acceptable performance. It should be noted that no feedback was given regarding the accuracy of the subjects' responses. The difference in "learning rate" between these two types of displays was significant at the $p < 0.001$ level of confidence [$F(4,28) = 23.94$] with the IP showing a somewhat faster rate. The statistical main effect of "nesting" the 50 trials into five blocks of 10 trials each was also significant at the $p < 0.001$ level of confidence [$F(45,315) = 3.05$].

Since these mean data are calculated across all of the separate flight parameters, they could mask important differences between individual flight-related parameters. Consequently, these data were also analyzed by the percentage of correct responses for each flight parameter separately within each of the two basic information sources (IP and HUD). Table 1 presents these mean percentages. It can be seen that: (1) IP indicators displaying altitude, attitude, and heading are read more accurately than the comparable flight parameters displayed by HUD symbology, and (2) airspeed is read more accurately from the HUD symbology than from the IP indicator. The vertical speed indicator (VSI) on the IP slides cannot be compared directly with the flight path information on the HUD slides because each parameter calls for a different type of visual and cognitive processing.

An analysis was also made of mean scan time for those responses that were 100% correct relative to information displayed on IP and HUD slides. This was done to determine if a particular flight parameter was contributing more than another to a mean reduction in slide viewing time. This analysis showed that, over the course of the 10 viewing trials on which heading information was supposed to have been "extracted," viewing duration decreased more for the HUD than the IP slides. These mean data were best fit by a linear regression of the form $y = 8.76 + 0.21x$ with a coefficient of determination of $r^2 = 0.47$. (An index of the degree of "fit" achieved by the regression. The r^2 statistic may be referred to significance tables, e.g., table V.A., p. 209, ref. 12.)

None of the mean scanning times for the remaining flight parameters could be "fit" to a statistically acceptable criterion ($p < 0.05$), indicating



INSTR. PANEL
HEAD-UP DISPLAY
MEAN VIEWING DURATION, sec
9
8
7
6
5
1
2
3
4
5
BLOCKS OF 10 TRIALS

TABLE 1. - MEAN PERCENTAGE OF CORRECT RESPONSES FOR EACH

FLIGHT PARAMETER AND SOURCE OF INFORMATION

Type of flight information	Scoring criterion[a]	Source of information[b]	
		Instrument panel indicator	Head-up display
Airspeed	±8 knots	67%	76%
Altitude	±20 ft	85%	79%
Attitude[c]	±1°	75%	71%
Heading	±10°	85%	79%
VSI	±90 ft/min	62%	(d)
Flight path	±1°	(d)	90%

[a]These values were used to determine if the response was to be scored as correct or incorrect.

[b]Each mean percentage is based on 80 data points.

[c]For the IP slides, S had to estimate pitch attitude by comparing the aircraft symbol location relative to the labeled pitch lines (5° arc apart) and shorter, unlabeled lines (2.5° arc apart). For the HUD symbology, S had to estimate the relative position of the aircraft symbol (inverted T) with respect to the pitch attitude scale lines (solid above the horizon or dashed below) which were 5° arc apart.

[d]The VSI could be read directly from the IP slide. The interpretation of the HUD flight path required making an estimate of its angular separation from the (stabilized) pitch attitude scale.

that no particular flight parameter contributed to the overall mean reduction in scanning time for the 100% correct data. Individual response differences of these subjects were very large, suggesting that a variety of information extraction strategies was being used.

Flight Parameter Scanning Order Results

Table 2 presents the order in which each subject thought he had scanned each of the five flight parameters on the IP and HUD slides. It should be noted that a relatively consistent order of scan was indicated by most of the eight subjects for the IP slides, probably due to their prior experience with similar displays and recognition of the need for a consistent scan pattern. Far less scan order consistency was indicated for the HUD symbology, however. While airspeed was indicated as being the first parameter scanned on the IP slides by seven of the eight subjects, only two said that they looked at the HUD's airspeed symbol first. The greatest degree of intra-subject consistency of (subjectively estimated) scan order on the HUD symbology was and aircraft reference, with seven of the eight subjects indicating that they thought they scanned it second. Very little consistency of scan order was indicated in the remainder of these HUD data.

TABLE 2. - ORDER IN WHICH INSTRUMENT PANEL AND HUD SYMBOLOGY

WERE JUDGED TO HAVE BEEN SCANNED

Flight parameter \ Pilot	1	2	3	4	5	6	7	8
Instrument panel								
ADI	2	2	2	2	2	2	2	1
Airspeed	1	1	1	1	1	1	1	4
Altitude	3	3	3	3	3	3	3	3
VSI	4	4	4	5	4	4	4	2
Compass	5	5	5	4	5	5	5	5
Head-up display								
Aircraft ref.	2	2	2	2	2	2	2	1
Airspeed	5	1	3	4	1	3	3	4
Altitude	1	3	5	1	4	1	4	2
Velocity vector	3	4	1	5	5	4	1	3
Heading	4	5	4	3	3	5	5	5

DISCUSSION

In the present investigation total viewing time on any given trial is assumed to reflect the relative ease with which the subject was able to extract all of the flight-related information from that slide. Because the basic visibility of either type of slide was the same, it is reasonable to assume that differences in total scanning time reflect differences in the relative interpretability of each kind of flight information (e.g., altitude, airspeed, heading) within each of the two sources of information (IP or HUD). Since mean viewing time decreased by about 1.3 sec over the 50 trials, it is likely that these subjects were still learning how best to extract the required information from each type of display. It may be that the present information processing task is different from that encountered in the aircraft cockpit since one would expect stable performance on IP information extraction because of its highly over-learned nature. Further research is called for in which the same response measures are used both in the vision laboratory and the cockpit.

An exploratory study also was conducted as a part of the present investigation to determine if, by increasing the number of trials, the learning effect would decrease to an acceptable level or cease altogether. Two previously untested pilots were presented 200 trials each of IP and HUD slides using the same procedures as before. These results showed no evidence of an asymptote after 200 trials. One reason for this relatively long learning effect might be that the unfamiliarity with the HUD symbology and the static nature of both types of slides may have inhibited these subjects from developing a rapid, consistent eye scan pattern.

Although the present study required the subject to remember all five flight-related parameters, because he did not know which one would be requested, a follow-on study is planned that will instruct the pilot which parameter to look for before the stimulus slide appears. This follow-on study should help indicate whether the process of storing this type of HUD and IP information in short-term memory is more or less accurate than is a direct visual search technique. It should also indicate an approximate asymptotic time for information extraction from these two basic information sources.

The investigative approach used here is considered to be useful for evaluating static displays. Further work is planned along this line using HUD hardware which will allow a variety of dynamic symbol formats.

APPENDIX A

INFORMATION PROCESSING: AN ABBREVIATED LITERATURE REVIEW

This review concentrates on human processing of symbolic (alphanumeric, scales, and other "synthetic" representations of system "state" variables) information. Howell and Briggs (ref. 13), Attneave (ref. 14), and Quastler (ref. 15) have prepared bibliographies of such research and the reader should consult them for further detailed information. Three main subjects are reviewed here: (1) display format and content, (2) integration and combination of information from several sources, and (3) symbol interpretability and evaluation techniques.

Display Format and Content

It is only where the relative location of one symbol to another and the total content of symbolic information can be shown to produce an effect on pilot performance that these characteristics become important to the designer of displays. Unfortunately, relatively little has been done to relate specific display formats and individual symbolic elements to how effectively a pilot can "fly them" (ref. 16). Egan and Goodson (ref. 17) remark that, "Human factors knowledge has not kept pace with the proliferating uses of HUDs and the expansion of HUD technology. Consequently, the majority of existing Human Factors specifications for HUDs are based on expert opinion rather than empirical data." The present author echoes this opinion.

Regarding the location of symbols on a HUD display, the pilot's visual search behavior plays a central role in determining the effectiveness of the format. While research by Mackworth (ref. 18) has shown the importance of symbols[1] presented in the visual periphery as determiners of where pilots will look next, the fact remains that central vision mediates the best visual recognition performance (refs. 19,20). A study by Baker, Morris, and Steedman (ref. 21) quantified both speed and accuracy of form recognition as a function of: (1) distortion between the reference and "target" symbol (the symbol searched for), (2) the number of irrelevant symbols in the display, (3) various design properties of the symbol, (4) practice, and (5) location of the symbol in the display. Both search time and errors were found to increase as a function of the number of irrelevant forms in the display[2] and an

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[1]Hereafter, whenever the term symbol is used it may be taken as being synonymous with the more common psychological term "stimulus."

[2]The question may be raised concerning what constitutes irrelevant symbols in a well designed HUD symbology. While no symbol should be irrelevant at the time it is needed by the pilot (which could be almost any instant), from an information processing point of view any symbol not immediately providing usable flight-control/monitoring information is irrelevant and even potentially distracting.

increase in the amount of blurring between the target and the background symbols. Practice was found to be most effective when blurring differences were greatest between the two types of symbols. Also, symbols located in the periphery required more time to find than more centrally located symbols.

Steedman and Baker (ref. 22) reported that forms must be larger than 12 min arc to be picked out of a complex display with the greatest efficiency; they should also be in sharp focus. Of course both the size (subtended visual angle) and placement of stationary and moving HUD symbols are interacting variables that must be evaluated through a variety of simulator and aircraft flight trials.

Boynton and Bush (ref. 23) presented rectilinear forms viewed against confusion forms. Background luminance, contrast, exposure duration, and location of the forms were also varied or controlled by each of the nine subjects. Their task was to locate and identify the "critical" target form from among a varying number of confusion forms or to indicate that no critical form was present. The results showed that as the exposure time is decreased, the rate at which identification accuracy falls off increases as a function of the number of forms presented. On only 4.4% of all trials was a critical form reported when there was none. In the case of a HUD the background scene will be that of the runway environment after breakout from IMC flight. Fisher (ref. 10) has conducted a preliminary investigation of the degree to which a background scene affects information transfer from a HUD symbology and vice versa. Since this technical report is published as one of the present series of papers it will not be reviewed here except to point out that no significant degradation of either the background scene upon HUD information extration or HUD information upon background scene information extraction was found for the 12 pilot subjects. A report by Eriksen (ref. 24) showed that symbols that differ from other symbols in a complex display in terms of their color or form are located more effectively than those that differ in terms of their size or brightness.

Visual recognition requires a discrimination between two or more features of a stimulus array and is integrally related to proper design of symbology format and content. A technique that is commonly used to quantify recognition is that of sorting stimuli into same or similar categories. Another technique is that of feature reproduction by the subject. Sleight (ref. 25) reported that the swastika, circle, crescent, airplane, cross, and star are all reliably discriminated and posses high "attention-getting" value. In another study Bowen et al. (ref. 26) reported that crosses were best and triangles poorest (compared with others tried) in terms of ease of discrimination. Klemmer and Loftus (ref. 27) had subjects reproduce symbols that had been exposed visually and then taken away. Familiar forms (numerals) were compared with nonsense forms and found to be no more recognizable. The objective of a series of studies by Harcum et al. (ref. 28) was to quantify differences in recognition of display elements as a function of their location in the visual field. Generally, fewest errors of reproduction were found for stimuli imaged along a horizontal (retinal) meridian and most along the vertical meridian.

Regarding the important subject of alphanumerics in displays, it may be pointed out that Cornog and Rose's reference handbook (ref. 29) contains over 200 studies on various alphabetic and numeral shapes and sizes. A font known as NAMEL was developed during the 1950's; it has (since) been standardized by the armed services in MIL-M-18012 and MS 33558. MS 33558 applies to numerals and letters for aircraft instrument dials. The interested reader is referred to Ketchel and Jenney (ref. 6, pp. 148-154) for further discussion of this subject.

Integration and Combination of Information from Several Sources

In its broadest sense, display integration refers to those techniques by which the pilot is relieved of the need to integrate information. In short, the system does it for him. Workload should decrease and system efficiency should improve with proper integration of information. Information integration usually takes the form of correction, transformation, filtering, quickening, lagging, referencing, or other means of making it more directly usable. The aircraft flight director is an example of an integrated display.

A second way that displays are said to be integrated is through proper formating and zoning of the symbols present. Some of the research discussed in the preceding section is related to this type of integration. One way of organizing this subject of information integration is to consider two separate but related aspects: display integration, and internal system integration.

Concerning display integration, it may be said that grouping symbolical information into functionally useful sets or groupings of information is the approach taken by most people. Nevertheless, Ritchie and Bamford (ref. 30) rightly point out that complex displays cannot be made by simply combining simple displays. Information grouping must be done in such a manner that a new parameter is generated; this parameter must be useful to the pilot in that it must suggest to him what he needs to know about his aircraft in order to best control it. Ritchie and Bamford feel that this parameter(s) should be in the form of the equations of motion for the aircraft being flown. They propose two principles of integration. The first, called "check reading," is illustrated by experiments in which the pilot must quickly scan a group of instruments each with needle orientations that may or may not align in a given pattern. If a needle is misaligned with others in its group, discrimination is facilitated. The second principle is called "pointer matching" and refers to the type of display in which one needle displays raw data, such as altitude, while its rate of change is displayed beside it. By keeping the two needles matched, a correct or desired flight performance is achieved. In both of these principles a certain measure of increased usefulness is achieved over what would have been available if the displays had not been properly grouped. The interested reader should consult references 31 and 32 for examples of display integration of an altimeter in which these principles are taken into account.

Blair and Kaufman (ref. 33) reported an investigation in which the display elements were closely grouped and the controls were spaced widely apart. They also tested the opposite conditions. They found no difference between these two conditions which suggests that merely grouping controls close to each other does not automatically insure that the information will be better integrated.

Concerning internal system integration, an example of this type of integration is found in an angle-of-attack system. The angle-of-attack air vane deflection response time and possible (aircraft) side-to-side air flow asymmetries require that the output signal be "integrated" or "conditioned" so as to present a single, usable needle indication. An improper choice of the time constants or other parameters of the system could render the displayed value unusable. Thus, a comprehensive knowledge of the dynamics both of the pilot's response capabilities and the aircraft's control loop(s) is necessary in order to best integrate displays.

The application of microcomputers in aviation has made it possible to process several (raw data and processed) parameters very rapidly to yield "predictor" information. Predictor information is another example of an internal system integration. Dynamic equations of motion and current "state" values are used to predict future flight path. Obviously, such displays allow the pilot to make control inputs that are based on whether the system is going to do what he wants it to. Thus, predicted errors may be corrected before they actually occur (cf. refs. 34,35).

Display quickening is another means of integrating a display. It refers to processing a signal before it reaches the display so as to make the pilot's tasks easier; it involves feeding derivative information back to the system's input. It may be performed in systems where the signal from the pilot's control and the aircraft's response (output) are one or more derivatives apart. In a study in which subjects had to try to track squares moving over the face of a CRT with two joystick-operated spots, Birmingham, Kahn, and Taylor (ref. 36) found that the subjects can carry on a larger number of control tasks simultaneously when the control system is quickened. Rund et al. (ref. 37) studied the effect of quickening on a binary type of display versus a continuous display. A binary display presents only the direction of the error while a continuous display gives the size, direction, and velocity of the error. They investigated three quickening rates and found that when control information and error velocity information were used (highest level of quickening) in a binary display, tracking performance was almost equivalent to that obtained with a partially-quickened continuous display. That is, the error velocity term (used with the highest level of quickening) did not improve performance with a continuous display.

Still another approach to display integration within the system (as opposed to only at the output of the system) is that of combining the display with the control. Such systems are best suited to manual controls where vision is not involved at all. Thus, the rotary control knob that is turned through kinaesthetic and (sometimes) auditory feedback cues is an example of such an integrated system. Such systems may or may not require a visual confirmation of their position. In the case of an aircraft's rudder, stabilizer, or other trim control, the manual input may be displayed on a special panel instrument. An annotated bibliography on this topic has been prepared by Andreas and Weiss (ref. 38). A study by Norris and Spragg (ref. 39) deals with different planes of rotation of cranks, another study by Morin and Grant (ref. 40) deals with the spatial correspondence between lights and the switches that control them, and a study by Adams (ref. 41) deals with pedal controls. Although most work to date on the subject of integration follows a pragmatic and empirical approach, there has been some control-operator and systems modeling in an attempt to discover if new mathematical models will point toward new and more effective control techniques (e.g., ref. 42).

Symbol Interpretability and Evaluation Techniques

In its broadest definition, interpretability refers to how effectively pilots are able to use displays for the purposes for which they were designed. Use of such a definition requires that each symbol standing for a given flight parameter such as airspeed, glide slope, or altitude, be well designed in and of itself as well as in relation to all of the other symbols present. The present review concentrates on the relationship between display symbology and methods of evaluation (rather than upon pilot performance as was treated above).

Numerous techniques have been used to evaluate symbol interpretability. They may be divided into two general categories: time and accuracy measures. Studies of symbol conspicuity generally relate to how rapidly one can detect the presence (or change) of some symbol. Brandt (ref. 43) discusses the importance of display borders, size, and color in displays for attracting attention to a display. He reported that the time spent viewing photographs of different sizes increased as the square root of the increase in area viewed and that motion implied by certain symbols in a photograph intended to direct attention in the direction of the motion. In a study conducted as part of the present HUD project, Haines and Guercio (ref. 44) presented both HUD symbology and aircraft instrument panel photographs to pilots using a tachistoscope where field of view, image luminance, and viewing time could be controlled. The pilot was told which flight parameter to search for before he saw the photograph. Speed was the principal response criterion. Accuracy of recall of various kinds of visual material, such as graphs, pictorial charts, maps, and photographs, was investigated by Vernon (ref. 45). The technique involved presenting the subject with each type of material, taking it away, and then asking for a written or oral report on its content. He found that the average number of questions answered correctly was about the same for all kinds of visual material when the questions had to be answered on the basis of the material. Better educated subjects preferred graphs and less educated charts.

Response accuracy is the second general category that has been used to evaluate symbol interpretability. Connell (ref. 46) studied the relative effectiveness of presenting numerical data by scales and graphs where single interpolation (i.e., independent variable only) and double interpolation (both a dependent and an independent variable) were called for. Tables were found to yield the best performance because interpolation was unnecessary, scales were slightly better than graphs where no interpolation was required, and scales and graphs were about equally good and were better than tables when interpolation is required. The reader is also referred to reference 47 for an investigation of the interpretability of information plotted on polar coordinate displays which were static black and white photographs. The dependent variables included: number of "tracts" within each 120° sector, past time history of the tracts, and coordinate face sectors. Among the many findings reported were: that interpretation time increased almost logarithmically as tracts are added and increasing the number of sectors to be searched did not lead to a significant change in interpretation accuracy.

APPENDIX B

TEST INSTRUCTIONS

The objective of this study is to find out how quickly and accurately you can obtain information from aircraft cockpit displays. You will be asked to view slides of a standard array of aircraft cockpit instruments and also slides of an integrated display called a head-up display. You will be given sufficient training to make you familiar with the two basic types of information to report the information presented. You will view the slides in a darkened room using a special vision apparatus which allows all of the viewing conditions to be controlled. Once the test is ready to begin you will hear a signal (I will say "ready"). This means that you may press your finger button at any time thereafter; this will present the first slide. Your task is to look at the slide and determine the particular values shown on all of the instruments (in the case of the instrument panel slides) and all of the head-up display symbolic information so you can correctly answer one specific question I will ask you about a particular instrument or symbol setting. Try to do this as quickly as you can; speed is important. As soon as you feel you can report to me this information press the response button a second time. If you do not press the button after a certain length of time the slide will be automatically extinguished. Once the slide is off, I will immediately ask you to report one item of flight-related information that was seen on the slide (from memory). If a particular piece of information was missing altogether, just respond by saying "missing." Do you have any questions?

REFERENCES

1. Naish, J. M.: A System for Presenting Steering Information During Visual Flight (the Head-up Display), Royal Aircraft Establishment, Technical Note, IAP1132, Oct. 1961.

2. Jenney, L. L.; Malone, T. B.; and Schweickert, G. A.: Head-up Displays: A Study of Their Applicability in Civil Aviation. The Matrix Research Div., Falls Church, Virginia, NASA Contract NASW-1940, Jan. 1971.

3. Shrager, J. J.: Head-up Displays: A Literature Review and Analysis with an Annotated Bibliography. FAA-RD-78-31, April 1978.

4. Kane, R. S.: Study and Analysis of Requirements for Head-up Display (HUD). NASA CR-66912, Mar. 1970.

5. Gold, T.; and Hyman, A.: Visual Requirements Study for Head-up Displays. Final report — phase I, JANAIR Report No. 680712, Mar. 1970.

6. Ketchel, J. M.; and Jenney, L. L.: Electronic and Optically Generated Aircraft Displays: A Study of Standardization Requirements. JANAIR Report No. 680505, May 1968.

7. Chatelier, P. R.; and Hemingway, J. C.: Abstracts of Control and Display Related Human Factors Engineering Research and Development Efforts — June 1977. Naval Air Systems Command, Washington, D.C. June 1977.

8. Sampson, P. B.; Wade, E. A.; Anderson, E.; Johnson L.; and Soifer, N.: Literature Survey on Human Factors in Visual Displays. Rome Air Development Center, Air Research and Development Command, Griffiss AFB, New York, RADC TR 61-95, June 1961.

9. Haines, R. F.: Evaluating Fundamental Issues of Head-up Displays for Commercial Aviation — the NASA Testing Program. Proceedings of International Head Up Display Symposium, Vancouver, B.C., Canada, Sept. 7-9, 1977, pp. 82-91.

10. Fisher, E.: Information Transfer Effectiveness of Head-up Display: A Systems Approach. M.A. Thesis, San Jose State University, Aug. 1978.

11. Dixon, W. J., ed.: BMD: Biomedical Computer Programs. School of Medicine, University of California, Los Angeles, 1975.

12. Fisher, R. A.: Statistical Methods for Research Workers. Tenth ed. Edinburgh, Oliver and Boyd, 1948.

13. Howell, W. C.; and Briggs, G. E.: Information Input and Processing Variables in Man Machine Systems: A Review of the Literature. Contract N61339-508, Tech. Report NAVTRADEVCEN 508-1, 26 Oct. 1959, U.S. Naval Training Devices Center, Port Washington, N.Y.

14. Attneave, F.: Some Informational Aspects of Visual Perception. Psychol. Review, vol. 61, 1954, pp. 183-193.

15. Quastler, H.: Human Performance in Information Transmission. Part I: General Remarks. Report R-62, Bio Systems Group, Control Systems Laboratory, Univ. of Illinois, Urbana, Ill. Mar. 1955, p. 16.

16. Egan, D. E.: Research Toward Improving Performance of Pilots Using Head-up Displays. Paper presented at Carrier Landing Performance Conference, Naval Safety Center, Naval Air Station, Norfolk, Va. 14 April 1976.

17. Egan, D. E.; and Goodson, J. E.: Human Factors Engineering for Head-up Displays: A Review of Military Specifications and Recommendations for Research. Aerospace Psychology Department, Naval Aerospace Medical Research Laboratory, Pensacola, Florida, April 1976.

18. Mackworth, N. H.: Some Suggested Uses for the Optiscan - A Head-Mounted Eye Camera. Paper presented at ADME meeting, New York, N.Y., Dec. 1960.

19. Haines, R. F.: A Review of Peripheral Vision Capabilities for Display Layout Designers. Proceedings of the Society for Information Display, vol. 16, no. 4, 1975, pp. 238-249.

20. Low, F. N.: Peripheral Visual Acuity. Arch. Ophthal., vol. 45, 1951, pp. 80-99.

21. Baker, C. A.; Morris, D. F.; and Steedman, W. C.: Target Recognition on Complex Displays. Human Factors, vol. 2, no. 2, May 1960, pp. 51-61.

22. Steedman, W. C.; and Baker, C. A.: Target Size and Visual Recognition. Human Factors, vol. 2, no. 3, Aug. 1960, pp. 120-127.

23. Boynton, R. M.; and Bush, W. R.: Recognition of Forms Against a Complex Background. J. Opt. Soc. America, vol. 46, 1956, pp. 758-764.

24. Eriksen, C. W.: Location of Objects in a Visual Display as a Function of the Number of Dimensions on Which Objects Differ. J. Exp. Psychol., vol. 44, 1952, pp. 56-60.

25. Sleight, R. B.: The Relative Discriminability of Several Geometric Forms. J. Exp. Psychol., vol. 43, 1952, pp. 324-328.

26. Bowen, H. M.; Andreassi, J.; Truax, S.; and Orlansky, J.: Optimum Symbols for Radar Displays. Dunlap and Associations, Inc., Stamford, Conn., Contract NONR2682(00), Sept. 1959.

27. Klemmer, E. T.; and Loftus, J. P.: Numerals, Nonsense Forms and Information. Operational Applications Laboratory, AFCRC, ARDC Proj. 7682, Feb. 1958.

28. Harcum, E. R., et al.: Visual Recognition Along Various Meridians of the Visual Field I to XII. Vision Research Lab., Univ. of Michigan, Ann Arbor, Michigan, Project Michigan, June 1957 to Sept. 1958.

29. Cornog, D. Y.; and Rose, F. C.: Legibility of Alphanumeric Characters and Other Symbols. National Bureau of Standards, Washington, D.C., Report No. 262-2, Feb. 1967.

30. Ritchie, M. L.; and Bamford, H. E., Jr.: Investigations of Instrument Integration. In symposium on USAF flight control display integration program, WADC, Wright-Patterson AFB, Ohio, Feb. 1958.

31. Simon, C. W.; Slocum, G. K.; Hopkins, C. O.; and Roscoe, S. N.: Altimetry Studies: I. An Experimental Comparison of Three Pictorial and Three Symbolic Displays of Altitude, Vertical Speed, and Altitude Commands. Weapons Systems Development Laboratories, Hughes Aircraft Co., Culver City, California, Tech. Memo 425, Jan. 1956.

32. Simon, C. W.; and Roscoe, S. N.: Altimetry Studies: II. A Comparison of Integrated versus Separated, Linear versus Circular, and Spatial versus Numerical Displays. Hughes Aircraft Co., Culver City, California, Tech. Memo. 435, May 1956.

33. Blair, W. C.; and Kaufman, H. M.: Command Control. I: Multiple Display Monitoring. II: Control-Display Spatial Arrangement. General Dynamics Corp., Electric Boat Division, E. B. Tech. Report SPD 59-082, Nov. 1959.

34. Kelly, C. R.: The Predictor Instrument. Human Control Dynamics in Air and Space Craft, B. J. Smith, ed. Flight Safety Foundation, Inc. 468 Fourth Avenue, N. Y., Nov. 1958.

35. Fogel, L.: A New Concept: The Kinalog Display System. Human Factors, vol. 1, no. 2, April 1959, pp. 30-37.

36. Birmingham, H. F.; Kahn, A.; and Taylor, F. V.: A Demonstration of the Effects of Quickening in Multiple-Coordinate Control Tasks. N.R.L., Washington, D.C., N.R.L. Report 4380, 1954

37. Rund, P. A.; Birmingham, H. P.; Tipton, C. L.; and Garvey, W. D.: The Utility of Quickening Techniques in Improving Tracking Performance with a Binary Display. Engineering Psychology Branch, Applied Research Division, Naval Research Laboratory, Washington, D.C., NRL Report 5013, 1957.

38. Andreas, B. G.; and Weiss, B.: Review of Research on Perceptual-Motor Performance Under Varied Display-Control Relationships. Rome Air Development Center, Rome, New York. (Univ. of Rochester), Contract AF30(602)-200, May 1954.

39. Norris, E. B.; and Spragg, S. D. S.: Studies in Complex Coordination. I. Performance on the Two-Hand Coordinator as a Function of the Planes of Operation of the Controls. Special Devices Center, Port Washington, N.Y., Tech. Report SDC241-6-3, 1950.

40. Morin, R. E.; and Grant, D. A.: Spatial Stimulus-Response Correspondence. WADC, Wright-Patterson AFB, Ohio, WADC Tech. Report 53-292, 1953.

41. Adams, J. A.: Psychomotor Response Acquisition and Transfer as a Function of Control-Indicator Relationships. J. Exp. Psychol., vol. 48, 1954, pp. 10-14.

42. Clement, W. F.; Jex, H. R.; and Graham, D.: A Manual Control-Display Theory Applied to Instrument Landings of a Jet Transport. IEEE Transactions on Man-Machine System, vol. MMS-9, no. 4, Dec. 1968.

43. Brandt, H. F.: Advertising Analyzed by Ocular Photography. The Psychology of Seeing. Philosophical Library, New York, 1945.

44. Haines, R. F.; and Guercio, J.: Preliminary Study of Head-up Display Assessment Techniques. II. Instrument Panel and HUD Symbology Search Time During Direct Viewing. (In preparation)

45. Vernon, M. D.: The Use and Value of Graphical Methods of Presenting Quantitative Data. Occupational Psychol. (Univ. of Reading), vol. 26, Jan. 1952, pp. 22-34.

46. Connell, S. C.: The Relative Effectiveness of Presenting Numerical Data by the Use of Scales and Graphs. AMC Engineering Div. Memo Report TSEAA-8/sec/me . Wright Field, Ohio, Dec. 1947.

47. Gebhard, J. W.; de Groat, S. G.; and Glickman, R. W.: The Interpretability of Plotted Information on Polar-Coordinate Displays. ONR, Washington, D.C., JHU Report 166-1-152, 14 July 1952.