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A Preliminary Study of Head-Up Display Assessment Techniques. II. HUD Symbology and Panel Information Search Time

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SUMMARY

Twelve commercial pilots were shown 50 high-fidelity slides of a standard aircraft instrument panel with the airspeed, altitude, ADI, VSI, and RMI needles in various realistic orientations. Fifty slides showing an integrated head-up display (HUD) symbology containing an equivalent number of flight parameters as above (with flight path replacing VSI) were also shown. Each subject was told what flight parameter to search for just before each slide was exposed and was given as long as needed (12 sec maximum) to respond by verbalizing the parameter's displayed value. The results for the 100-percent correct data indicated that: (1) there was no significant difference in mean reaction time (averaged across all five flight parameters) between the instrument panel and HUD slides; (2) a statistically significant difference in mean reaction time was found in responding to different flight parameters ($p \leq 0.001$). Extraction of altimeter information from the instrument panel produced the longest reaction time (2.3 sec), with a mean accuracy of 93 percent. Extraction of airspeed information from the HUD symbology produced the shortest reaction time (1.5 sec), with a mean accuracy of 97 percent; (3) a statistically significant reduction in mean reaction time was found over the course of the study ($p \leq 0.025$), suggesting that the subjects were still learning how best to extract the required information; and (4) mean reaction time differed significantly ($p \leq 0.001$) between subjects. The same instrument panel and HUD slides, viewing time, and other stimulus characteristics were used in the present study as were in an earlier study (ref. 1). The fact that there was no significant difference in mean reaction time between the two types of displays in the present study, a finding in disagreement with the previous study, is most likely due to methodological differences used. Specifically, mean reaction time differences to the two types of displays do not occur when a subject knows which specific flight parameter to search for and remember for subsequent verbalization, but the reaction times differ when he must memorize all five flight parameters and then recall one required parameter. A direct reading technique of assessing the speed and accuracy of information extraction from different types of displays is considered a more adequate methodology than a memorization-recall technique since the former depends primarily

on visibility factors (that may be precisely measured and controlled), while the latter involves many complex cognitive variables known to vary widely between individuals and which are less precisely controlled. In addition, the former technique is nearer to the procedures pilots actually use in the cockpit.

INTRODUCTION

A recent study conducted in this laboratory (ref. 1) indicated that pilots can extract flight information faster from slides of an integrated display of flight information (hereafter referred to as HUD symbology) than from slides of a standard aircraft instrument panel when both types of displays contain an equivalent number of flight parameters. However, the interpretation of these results is complicated by the fact that. (1) the rate at which the information was extracted was actually the time taken by the pilots to *memorize* (to a subjective criterion) five kinds of flight information (i.e., airspeed, altitude, heading, attitude, and vertical speed or flight-path angle), and (2) the accuracy levels obtained actually reflect the pilot's ability to *recall* from memory one of the five flight parameters after a slide had been removed from sight. It might be argued that this relatively complex memorization/recall task is not equivalent to the task pilots normally face of searching for and then reading a given flight parameter from its appropriate display.

This study was designed to determine whether the format of information depicted in one of the above two types of displays enables pilots to search out and *read* a given flight parameter faster and/or more accurately than does the format depicted in the other set of slides. Another objective was to compare the influence of the two experimental methodologies on performance, while the other variables remain constant.

Basically, the approach taken was as follows. Each pilot was asked to determine the value of a specific flight parameter. A test slide was then presented and his task was to locate the appropriate instrument or symbol within the display and read the indicated value. The slide was removed from a subject's view as soon as he started to verbalize his reading of the instrument.

METHOD

Subjects

Twelve male airline pilots who did not participate in the memorization-recall study (ref. 1) served as paid voluntary subjects. They ranged in age from 38 to 57 years, with a mean age of 43. Five of the subjects held the rank of Captain and the other seven were First Officers. As a group, their flying experience averaged 2098 hours and ranged from 200 to 6500 hours. One subject was currently assigned to a DC-9 type of aircraft, the remaining 11 flew the B-727 model. All subjects possessed 20:15 binocular distance acuity or better (A-O Snellen broken ring pattern), normal visual field limits, normal color perception, and most had an accommodative near point of 34 cm or less. (The oldest pilot (57 years) possessed a near point of 45 cm in each eye and the second oldest (49 years), 40 cm in each eye.)

Apparatus

The sound-proof chamber and three-channel tachistoscope described by Haines (ref. 1) were used to present the 50 slides of the instrument panel and the 50 slides of the HUD symbology. These 100 stimulus slides were identical to those used and described by Haines (ref. 1), except for the following change. For the present study, only one instrument panel slide had an instrument panel indicator needle missing, and only one HUD slide had a scale indicator missing. (In the previous study, three instrument panel and three HUD slides had the attitude indicator needle missing.) In both cases, the missing flight parameter was altitude. In both studies, the subjects were only questioned once for each type of display slide about a flight parameter that corresponded to a missing flight parameter.

Appendix A lists the content of all 50 instrument panel slides; Appendix B is a similar listing for the 50 HUD slides. The presentation frequency of all values of the flight parameters for both types of display slides is given in Appendix C.

In addition to the 100 display slides, a fixation slide consisting of four small medium grey dots at the corner of an imaginary square subtending 3° of arc on a side was used before each trial. The background of this slide was selected to approximate the average luminance of each display slide to help maintain a relatively constant state of retinal light adaptation. The subject was instructed to look at the center of these dots while the slide was present. Six cueing or "question" slides were also used. Each contained a key word(s) that described the type of flight parameter the subject was supposed to extract from a display slide shown afterward. The key words — airspeed, altitude, heading, vertical speed, attitude, and flight path — were printed in medium grey capital letters centered on the slide. To help control for retinal light adaptation constancy, the background of each of these slides was also the same as used on the fixation slide.

The presentation and removal of the slides from the T-scope screen was controlled by the experimenter or the subject, depending on the nature of the slide. The fixation slide automatically appeared at the start of each trial, but was removed by a push-button switch operated by the experimenter. When this switch was actuated, a question slide appeared immediately. The viewing duration of the question slides was controlled by a voice-actuated switch located in front of the subject's mouth. When the subject's vocal response removed a question slide, the fixation slide automatically came into view a second time for 1.0 sec, followed immediately by a display slide. The removal of the display slide was also controlled by the subject through the above-mentioned voice-actuated switch.

Finally, a set of earphones connected to a white noise generator was used to isolate the subject from the potentially distracting auditory cues produced by movement of the slide projector trays. Once the first set of experimental trials began, the amplitude of the white noise remained constant for the rest of that subject's participation, and the experimenter communicated with the subject by having him remove the earphones whenever he felt the experimenter touch his arm.

Procedure

Initially, the subject was given a brief description of the overall HUD project. Following this, the subject was introduced to a laboratory technician who administered the battery of vision tests.

Instrument panel slide familiarization— Each subject was shown a photograph of a typical cockpit instrument panel, and the scale divisions for each of the five instruments present were then reviewed (cf. Appendix D). Concurrently, the subject was told that the degree of accuracy required of his readings was as follows: (a) pitch attitude to the nearest degree, (b) airspeed to the nearest 10 knots, (c) altitude to the nearest 20 ft, (d) heading to the nearest 5°, and (e) vertical speed to the nearest 100 ft/min. However, he was also advised that if a reading seemed to "jump out at him" (i.e., seemed in sharper focus or darker) and it was more precise than the accuracy levels cited above, he was not to waste time rounding off the value to meet these requirements.

With regard to reporting attitude information, the subjects were instructed to obtain both pitch and roll information. Pitch readings were to consist of the number of degrees of pitch and its (nose up/down) direction. In reporting roll, the subjects were told simply to state whether the display indicated a right turn, left turn, or level flight. The subjects were also instructed to report the magnitude and direction of the pitch reading first and the indicated roll second. For nonlevel flight, roll could be reported as either a right (or left) turn, (b) right (or left) bank, or (c) right wing up (or down) so long as the subject was consistent in such usage.

Due to the anticipated difficulty in being able to discriminate the scale markings of the airspeed indicator, the experimenter also instructed each subject to learn, during the practice trials, to read this instrument by referring to the "clock position" of its needle. To facilitate this task, the subject's attention was directed to the airspeed indicator pictured in the instrument panel photograph, and the experimenter then pointed out that: (a) a reading of 130 knots occurs at the 3 o'clock position, (b) the major scale divisions are at 10-knot intervals, (c) only the even-numbered divisions are labelled, and (d) the range of airspeed readings would be from 100 to 180 knots. Therefore, if the needle should cover a numbered division, the reading would be 100, 120, 140, 160, or 180 knots, depending on the location of the needle with reference to the 3 o'clock position.

Because some of the altitude readings were so great that the radio altimeter needle was not visible behind a shield, the subjects were instructed to use only the barometric pressure altimeter to determine altitude. To ensure familiarity with this particular type of altimeter, each subject was directed to first use the counter reading that appeared in the "window" of this indicator to establish the altitude in thousands of feet, and then to complete the reading by adding the value indicated by the needle position covering the range of 0 to 999 ft.

The final instruction specific to the instrument panel indicators was that to obtain heading information the subject was to use the needle position of the compass and ignore the counter reading displayed in the RMI window. This instruction was given to reduce the possibility that a subject would discover that the needle position and counter indicated identical readings for each value of heading.

On the basis of post-test questioning of more than half the subjects, the RMI counter readings were ignored throughout the instrument panel test trials, and the subjects were able to learn how to read the airspeed indicator by the end of the practice session for these slides.

HUD symbology familiarization— Upon completing the above briefing on the instrument panel slide information, each subject was instructed in the meaning and use of HUD symbology. Specifically, a drawing of a HUD slide was presented and the experimenter identified each scale, explained how it was to be interpreted, and indicated where the scale marker would be located for different values of the associated flight parameter. The subject was also informed of the potential in-flight use of flight-path angle and its relationship to pitch angle and angle of attack.

In terms of reading the scales of the HUD symbology slides, each subject was instructed to use the same levels of precision as prescribed for the instrument panel indicators, except that, instead of having to obtain vertical speed information, they would be asked to determine flight-path angle to the nearest degree. They were also told to locate and report attitude information in the same format as for the instrument panel slides (i.e., magnitude and direction of pitch followed by type of turn).

Test instructions— The final step in briefing each subject was to have him read the test instructions (appendix E). Briefly, the instructions stated that there would be 20 practice and 50 test trials for each type of display, and that the slides would be presented in the following sequence: fixation slide, question slide, fixation slide, and display slide. The instructions also indicated that the question and display slides would remain in view until the subject *started* to make a vocal response, but that the display slide would automatically be removed if he failed to respond within a fixed time period. (In practice, the experimenter removed the display slide from view within 10 to 12 sec after its onset.) Each subject also read that on some trials the instrument or (HUD) scale reading would be missing altogether; when this occurred, he was to respond by saying "missing." Finally, the instructions stated that each subject's task was simply to focus his attention on the center of the fixation slide whenever it appeared, read the question slide to himself and then aloud, and then obtain the requested information from the display as quickly and accurately as he could. After answering any questions, the experimenter then led the subject to the test chamber to undergo a 5-min-long period of light adaptation before the first session began.

During the adaptation period, the experimenter verified that the apparatus was ready, reviewed the sequence of events for the subject, and instructed the subject that he was to say "ready" at the start of each trial after he had focused his attention on the fixation slide and was prepared to view the question slide. (During the experimental trials, the experimenter controlled the viewing duration (5 ± 1 sec) of the pre-question fixation slide for all subjects.)

Sessions— Four slide-presentation sessions were conducted per subject; the briefing and test sessions were carried out within one day over a 2- to 3-hr period for every subject. The first and third sessions were practice sessions, and the second and fourth, for experimental trials. All slides in any one session had one format only (e.g., HUD), and the format presented in an experimental session was the same as the one that appeared in the practice session immediately preceding. The order in which the two types of slides were presented (i.e., HUD slides first vs. IP slides first) was randomly assigned and counterbalanced across the 12 subjects.

Practice trials— The two practice sessions consisted of 20 trials each, and were administered in the following sequence: (1) 10 slides of one format (e.g., HUD); (2) a 3-min rest period, during which questions were answered and feedback was provided regarding the subjects' total number of correct responses; (3) 10 more slides of the same format; and (4) another 3-min rest period with accuracy feedback. With regard to feedback, the subjects were also told what the correct response was immediately after they gave an incorrect response.

Experimental trials— Upon completing a brief post-practice rest period, the subject was told that the experimental trials would use the same slide-presentation sequence as in the practice trials. He also was told that a 2-min rest period would come at the end of the first and second block of 20 trials, and that he would not be provided with any feedback regarding his performance.

Each 50-trial experimental session contained slides of only one format, and included the 20 slides used in the immediately preceding practice session. As was the case in Haines' study (ref. 1), both sets of 50 slides contained the same "target" values (i.e., the value of the requested flight parameter for that trial) for the four common flight parameters, except in five instances (c.f., appendix B, slides numbered 1, 3, 37, 39, and 47). Unlike the previous study, however, the subjects in this study did not view each set of slides in the same random order. Instead, two random orders were used, counterbalanced across the two types of displays.

RESULTS AND DISCUSSION

Table 1 presents the mean viewing time (hereafter called "reaction time"), standard deviation, and mean percent correct for each flight parameter presented on the instrument panel and HUD slides. The statistical significance in mean reaction time for the 100-percent correct data for these variables was tested by analysis of variance using a 2 × 3 × 5 × 12 repeated measures design (ref. 2). Appendix F gives the summary table of this analysis. It was found that: (1) There was a statistically significant difference ($p < 0.001$) in mean reaction time required to read one flight parameter versus another. However, this difference is related to whether the parameter was displayed on the instrument panel or the HUD type of display. Figures 1(a) and 1(b) show the mean data for each of the five blocks of ten trials each. (2) The instrument

TABLE 1.- MEAN REACTION TIME (SEC) AND PERCENT CORRECT RESULTS

Flight parameter	Type of information					
	Instrument panel			Head-up display		
	Mean[a]	S.D.[a]	Mean percent correct	Mean[a]	S.D.[a]	Mean percent correct
Attitude	2.22	0.60	95.8	2.14	0.62	94.2
Airspeed	1.71	.36	99.2	1.52	.46	96.7
Altitude	2.32	.71	92.5	2.16	.56	93.3
Heading	1.85	.41	100	2.14	.57	97.5
Vertical speed	1.54	.30	94.2			
Flight-path angle				1.73	.60	99.2
Mean of first four parameters	2.02			1.99		

[a]Each value is based on a mean of 10 reaction time values per subject for 12 subjects.

panel altimeter information took the greatest amount of time on the average to extract (2.3 sec), while the HUD airspeed information took the least (1.5 sec). (3) A small but significant ($p < 0.025$) reduction in mean reaction time occurred over the course of these five blocks of trials for attitude, airspeed, and flight-path symbology displayed on the HUD slides. A smaller (nonsignificant) reduction in mean reaction time occurred over the five blocks of trials for airspeed and vertical speed information displayed on the instrument panel slides. The statistically significant ($p < 0.001$) trial blocks by flight parameter interaction suggest that these subjects learned how to extract the required information at different rates for different flight parameters. A

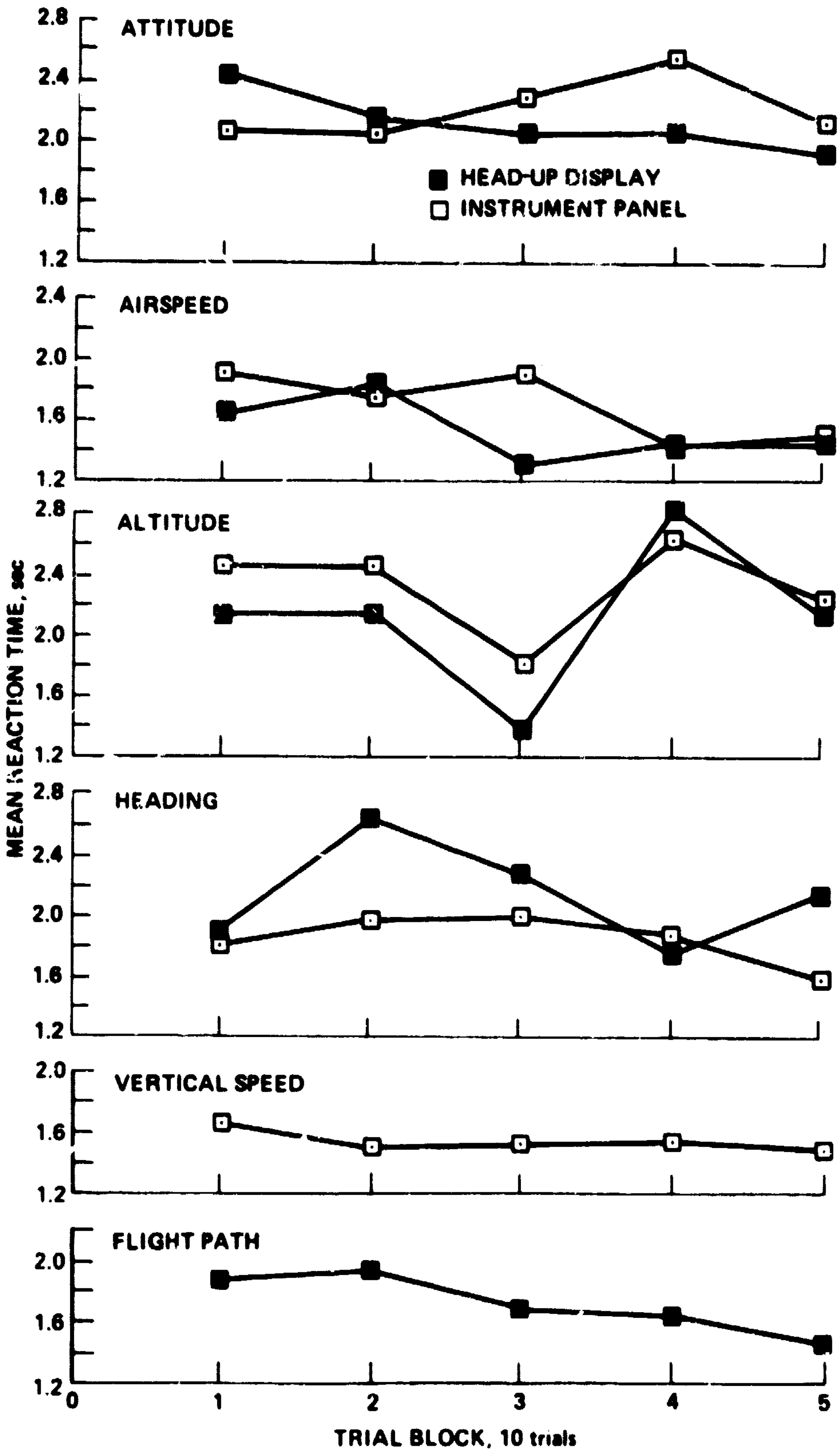

Figure 1.- Grand mean reaction time results across trial blocks.

similar learning effect was found in our earlier study as well (ref. 1). To determine if the curves in figure 1(a) and 1(b) were sufficiently consistent across the five trial blocks in terms of slope linearity, which would indicate a reliable learning effect, each curve was fit using a linear least-squares equation. Only two of the ten curves could be fit with an acceptably high ($p \leq 0.05$) degree of fit as indicated by the coefficient of determination (r^2) as discussed elsewhere (ref. 3, table V.A., p. 209); viz., HUD-presented attitude [$y = 2.46 + (-0.11)$; $r^2 = 0.85$], and HUD-presented flight path [$y = 2.08 + (-0.12)$; $r^2 = 0.89$]. (4) No statistically significant difference in mean reaction time was found between the instrument panel and HUD slides, averaged across all other experimental variables. Nevertheless, the analysis of variance showed that there was a significant difference in mean reaction time for these test subjects (mean reaction time ranged from 1.60-2.29 sec for these 12 subjects) ($p < 0.001$) and for the information type (e.g., instrument panel) by the subjects interaction ($p < 0.001$), suggesting that some subjects were better able than others to extract the required information from one type of information source.

Figure 2 shows that the mean percent accuracy of response, averaged across the attitude, airspeed, altitude, and heading data, was higher for the instrument panel display than for the HUD slides for four of the five trial blocks. Nevertheless, the possibility that the subjects were still increasing their familiarity with the HUD information display format throughout part or all of the study might explain why the mean percentage of correct responses tended to increase during testing to a value slightly greater than that for the instrument panel by the last trial block.

When the mean percentage of correct responses was plotted over the five trial blocks for each flight parameter, no clear-cut trend was found except for attitude displayed on the instrument panel. The mean percent accuracy of this parameter was 92, 96, 96, 96, and, finally, 100% for trial blocks 1 through 5 respectively. Table 1 shows that there is no evidence of a reaction time/accuracy tradeoff in these mean data.

In our earlier study (ref. 1), the pilots used a memorization-recall technique to give the correct value of a required flight parameter. This methodology led to the finding that the instrument panel slides required an almost 0.5-sec longer viewing time than did the HUD slides in order for the subjects to recall any of the five possible flight parameters. In the present study, on the other hand, no such HUD vs. instrument panel viewing time difference was found, presumably because the subjects knew the required flight parameter, that is, because they did not have to scan all the information displayed. The present findings show that no significant viewing time difference exists in order to extract information from the instrument panel and HUD symbology information (to the same level of accuracy) when the entire display does not have to be scanned.

In our earlier study, the total viewing times for the display of five instrument panel parameters ranged from about 7.5 sec at the beginning of testing to about 6.6 sec at the end. Thus, assuming that each flight parameter required approximately the same amount of time to memorize and recall, each

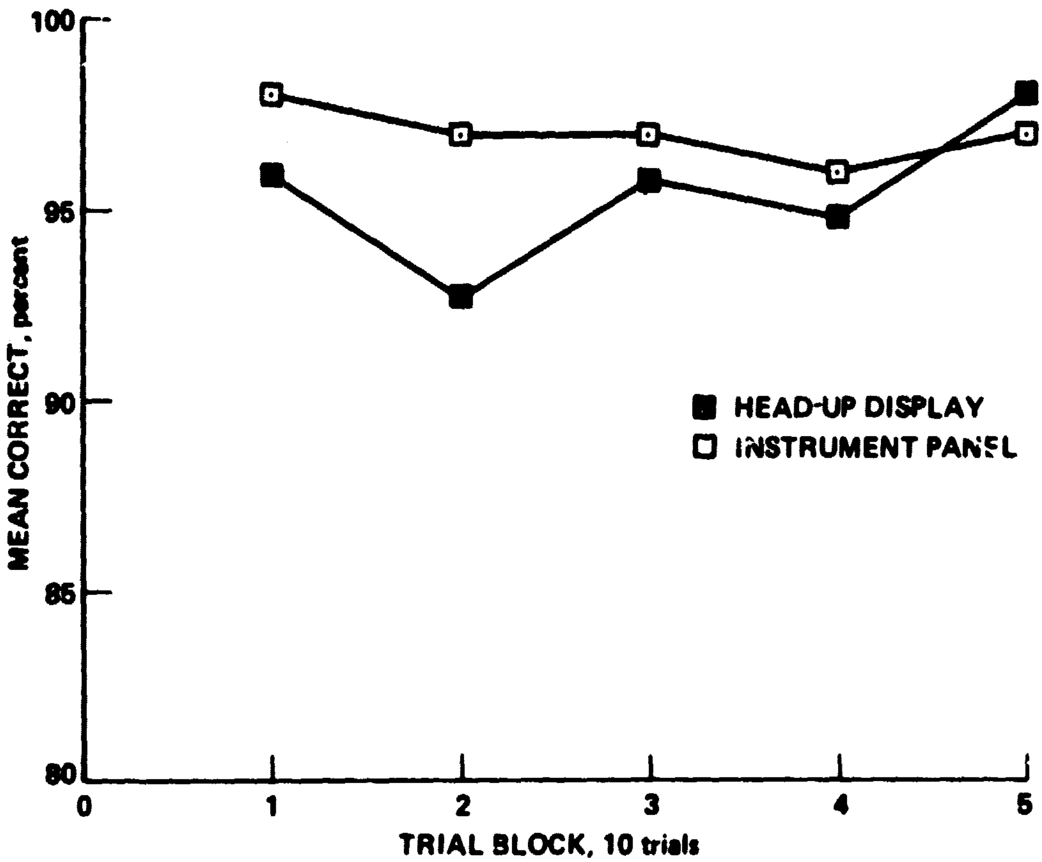

Figure 2.- Grand mean correct responses across trial blocks.

required about 1.5 sec at the beginning of testing to about 1.3 sec at the end. These viewing durations are slightly shorter than those found in the present study, as shown in table 1 (Instrument Panel column). Likewise, since there were five HUD flight parameters to remember in the earlier study and total viewing time ranged from about 7.4 sec at the beginning of testing to about 6.1 sec at the end, to correctly extract from memory the correct information, each parameter required about 1.5 sec at the beginning and 1.2 sec at the end. These durations are also slightly shorter than those found in the present study (table 1, Head-up display column).

Regarding the experimental methodologies used in the earlier and present studies, it appears reasonable to say that a direct reading technique of assessing the speed and accuracy of information extraction from different types of displays is preferable to a memorization-recall technique since the former depends primarily on visibility factors that can be precisely measured and controlled while the latter involves a host of complex cognitive variables that are known to vary widely from one person to the next and which are less precisely controllable. Equally important, the former technique is more similar to procedures pilots actually use in the cockpit. A follow-on study is underway to investigate information processing between these two types of displays in which the HUD symbology contains missing or erroneous information compared to the instrument panel information presented immediately before.

CONCLUSIONS

This study has shown that the present direct viewing methodology, in which the pilot knows which flight parameter to search for before being shown the display, is adequate for evaluating speed and accuracy of information transfer performance from static, high-fidelity slides of instrument panel and HUD symbology displays. The present data also provide an estimate of the performance that may be expected of pilots under good viewing conditions since the viewing environment was stable, nondistracting, and the stimulus slides were high-fidelity, high-contrast photographs of an actual instrument panel and a simplified HUD symbology. Future research is called for in which the present methodology is employed in a cockpit using dynamic displays.

APPENDIX A

CONTENT OF INSTRUMENT PANEL SLIDES

Attitude is cited in terms of pitch angle and direction. Roll attitude is given (following the semicolon) in terms of right wing orientation (D = down, L = level, U = up).

Asterisks indicate the reading the subject was asked to make for this slide.

Slide no.	Flight datum				
	Attitude	Airspeed	Altitude	Heading	Vertical speed
1	3D, L	140*	2700	342	725D
2	3D, L	130*	2700	342	725D
3	3D, L*	130	4000	342	725D
4	0, U	130	4000*	342	725D
5	0, U	160	4000	342	725D*
6	0, L	160	4000	342	725D*
7	0, L	160	4000	342*	0
8	0, L	140	4000	342*	0
9	3U, L	140	4000	342	0*
10	3U, L	140	4000*	342	400U
11	3U, L*	140	290	342	400U
12	3U, L	140	290	342*	325D
13	3U, U	140	290	342	325D*
14	3U, U	150*	290	342	325D
15	3U, L	150*	2700	025	0
16	3U, L	150	2700*	025	325D
17	0, L	150	2700*	025	325D
18	3U, D*	150	2700	025	325D
19	3U, L	150	3200	025*	325D
20	3U, L	150	3200	025	400U*
21	3U, L	160*	3200	025	400U
22	3U, L	160*	3200	025	325D
23	0, D*	160	3200	025	325D
24	3D, L	160	3200	025*	775D
25	3D, L	130	3200	025*	775D
26	3D, L	130*	290	025	775D
27	3D, L*	140	290	025	775D
28	3D, L	130*	1700	285	775D
29	3D, L	120	1700*	285	775D
30	0, L*	120	1700	285	775D
31	0, L*	120	1700	285	0
32	0, D	120	1700*	285	0
33	3U, D	120	1700	285	0*

Slide no.	Flight datum				
	Attitude	Airspeed	Altitude	Heading	Vertical speed
34	3U, L	120	1700	285	0*
35	3U, L*	120	1700	285	400U
36	3U, L*	120	530	285	400U
37	3U, L	120	530*	285	400U
38	3U, L	130*	530	285	400U
39	3U, L	130	530*	285	775D
40	3D, L	130	530	285	775D*
41	3D, L	120	Missing*	285	775D
42	3U, L	160	3200	025	400U*
43	3D, L	130	1700	285*	775D
44	3D, L*	140	290	025	775D
45	3D, L	130	3200	025*	775D
46	3D, L	120	1700	285*	775D
47	3D, L	130	290*	025	775D
48	3D, L	130	2700	342*	725D
49	3U, L	150*	3200	025	325D
50	3D, L	160	3200	025	775D*

APPENDIX B

CONTENT OF HEAD-UP DISPLAY SLIDES

See notes for appendix A. Missing values indicate that the value of that flight parameter is the same as given in appendix A for the instrument panel slide of the same number.

Slide no.	Flight datum				
	Attitude	Airspeed	Altitude	Heading	Vertical speed
1		120*			4D
2		*			4D
3	3U, L*				4D
4			*		4D
5			2700		4D*
6					4D*
7				*	2D
8				*	0
9					0*
10			*		2U
11	*		280		2U
12		120	280	*	2D
13			280		2D*
14		*	280		2D
15		*			0
16			*		2D
17			*		2D
18	*				2D
19				*	2D
20			2700		2U*
21		*			2U
22		*			2D
23	*				0
24	3U, L			*	4D
25				*	3D
26		*	280		3D
27	*		280		3D
28		*			3D
29			*		3D
30	*				3D
31	*	160			0
32			*		0
33					0*
34					0*
35	*				2U
36	*	140	525		2U

Slide no.	Flight datum				
	Attitude	Airspeed	Altitude	Heading	Vertical speed
37	3U, U		525*		2U
38		*	520		2U
39			520*		3D
40	0, L		520		4D*
41			*		3D
42					2U*
43				*	3D
44	*		280		3D
45		140	520	*	4D
46				*	3D
47			280*		3D
48				*	4D
49		*	280	342	2D
50	3U, L				4D*

APPENDIX C

TOTAL FREQUENCY OF INSTRUMENT PANEL AND HEAD-UP DISPLAY SLIDE READINGS AND FREQUENCY OF DESIRED "TARGET" READINGS

Flight parameter	Indicated reading	IP		HUD	
		Total f[a]	Target f[b]	Total f[a]	Target f[b]
Attitude[c] (deg)	0, U	2	0	2	0
	0, L	6	2	7	2
	0, D	2	1	2	1
	3U, U	2	0	3	0
	3U, L	18	3	20	4
	3U, D	2	1	2	1
	3D, L	18	3	14	2
	Totals	50	10	50	10
Airspeed (knots)	120	11	0	11	1
	130	13	4	12	4
	140	9	1	9	0
	150	8	3	8	3
	160	9	2	10	2
	Totals	50	10	50	10
Altitude (ft)	Missing	1	1	1	1
	280	0	0	9	1
	290	8	1	0	0
	520	0	0	4	1
	525	0	0	2	1
	530	5	2	0	0
	1700	10	2	10	2
	2700	7	2	9	2
	3200	11	0	8	0
	4000	8	2	7	2
	Totals	50	10	50	10
Heading (deg)	025	19	4	18	4
	285	16	2	16	2
	342	15	4	16	4
	Totals	50	10	50	10

Flight parameter	Indicated reading	IP		HUD	
		Total f[a]	Target f[b]	Total f[a]	Target f[b]
Vertical speed[c] (ft/min)	400U	9	2		
	0	8	3		
	325D	10	1		
	725D	7	2		
	775D	16	2		
	Totals	50	10		
Flight path[c] (deg)	0			8	3
	2U			9	2
	2D			10	1
	3D			12	0
	4D			11	4
	Totals			50	10

[a]Total frequency is the number of times the designated reading appeared during the 50 experimental trials for each type of display.

[b]Target frequency is the number of times the designated reading was the reading the subject had to make during the 50 experimental trials for each type of display.

[c]U = right wing up; D = right wing down; L = wings level.

APPENDIX D

INSTRUMENT PANEL DISPLAY SCALE DIVISIONS AND RANGE

I. Airspeed

IP: numbered every 20 knots; minimum division is 2 knots for 100-450 and 10 knots for 60-100 knots. Range: 60-450 knots.

HUD: numbered every 20 knots; minimum division is 10 knots. Range: 60 knots, with three numbered divisions.

II. Attitude (pitch)

IP: numbered at 5°, 10°, and 20°; minimum division is 2.5°. Range visible on slides: -20° to +20°.

HUD: not numbered, but one line equals 5°, two lines equals 10°, and three lines equals 15°. No other markings. Range: -15° to +15°.

III. Altitude

IP: (pressure type) numbered every 100 ft as 1, 2, etc.; minimum division is 20 ft. Range for dial: 0 to 1000 ft; Counter-Range: 0 to xxxxx ft.

HUD: numbered every 100 ft; minimum division is 50 ft. Range: 300 ft, with three numbered divisions.

IV. Heading

IP: numbered every 30° as 3, 6, etc.; minimum division is 5°. Range: 0 to 360°.

HUD: numbered every 10° as 1, 2, etc.; minimum division is 5°. Range: 20°, with two numbered divisions.

V. Vertical Speed

IP: numbered in 1000 ft/min as 0, 0.5, 1, 2, 4, and 6; minimum division is 100 ft/min for 0-1000 and 500 ft/min for 1000-6000. Range: -6000 to +6000 ft/min.

VI. Flight-Path Angle

HUD: same scale as for HUD pitch attitude.

APPENDIX E

TEST INSTRUCTIONS

The purpose of this study is to determine how quickly and accurately you can obtain information from slides of a standard cockpit instrument panel and from slides of a head-up display. The slides will be presented in a T-scope apparatus over four testing sessions. All four sessions will be conducted today. The first and third sessions will consist of 20 practice trials each; the second and fourth sessions, 50 test trials each.

At the beginning of each trial, you will be asked to focus your attention on the midpoint of a "fixation slide" by looking at the center of the area outlined by four dots on the slide. After a brief interval, the fixation slide will disappear automatically and will be replaced by a "question slide" presenting one of the following words: attitude, airspeed, altitude, heading, and either vertical speed or flight path. You are to read the "question slide" to yourself and, when you are sure of its content, tell the experimenter what you have read. Your vocal response will remove the question slide, so be sure that you are aware of what it says *before* you start to speak. You may take as long as you like to read the question slide.

When the question slide is removed, the fixation slide will reappear. As before, it is important that you look directly at the center of the area outlined by the four dots.

After a brief interval, the fixation slide will automatically be replaced by one of the display (test) slides. Your job then will be to locate and read the instrument, or scale, which indicates the value of the flight parameter mentioned on the question slide. When you are sure of the reading, relate it to the experimenter. Your vocal response will then remove the display slide and replace it with the fixation slide for the start of the next trial.

Please note that if you do not report the instrument or scale reading to the experimenter after a certain length of time, the display slide will disappear automatically. Therefore, you should try to obtain an *accurate* reading as *quickly* as possible. Also, on some trials, the instrument or scale reading will be missing altogether. When this occurs, respond by saying "missing."

To summarize, your task is simply to focus your attention on the center of the fixation slide whenever it appears, read the question slide to yourself and aloud, and report the requested information from the display slide as quickly and accurately as you can. Do you have any questions?

APPENDIX F

ANALYSIS OF VARIANCE SUMMARY OF MEAN REACTION TIME DATA

Source of variance	df	SS	MS	F	p<
Information type (Instrument panel; HUD) [I]	1	0.0057	0.0057	0.0062	
Flight parameter (e.g., altitude) [F]	4	82.561	20.640	22.50	0.001
Trial blocks [B]	4	11.187	2.796	3.04	.025
Subjects [S]	11	62.622	5.693	6.20	.001
I × F	4	10.568	2.642	2.88	.025
I × B	4	4.260	1.065	1.16	
F × B	16	40.150	2.509	2.73	.001
I × S	11	46.039	4.185	4.56	.001
F × S	44	54.156	1.230	1.34	
B × S	44	27.732	.630	.68	
I × F × B	16	13.513	.844	.92	
I × F × S	44	64.558	1.467	1.59	.025
I × B × S	44	25.679	.583	.63	
F × B × S	176	93.790	.532	.58	
I × F × B × S	176	119.754	.680	.74	
[I × F × B × S] Replications	600	550.306	.917		
Mean	1	4464.426	4464.426		

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