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EFFECT OF PICTORIAL DISPLAY CONFIGURATION ON THE FREQUENCY OF CONTROL REVERSALS DURING AIRCRAFT LANDING APPROACHES

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EFFECT OF PICTORIAL DISPLAY CONFIGURATION ON THE FREQUENCY OF CONTROL REVERSALS DURING AIRCRAFT LANDING APPROACHES

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ABSTRACT

Twelve airline pilots participated in a fixed-base simulator study to determine the effect of increased pictorial display realism on the frequency of control reversals made with an inside-out landing display. Display conditions included the effects of collimation and scale (head-up versus head-down presentation), horizon symbology (simple line versus white-black sky-ground surfaces), and ground plane realism (computer generated perspective versus a TV picture of a realistic model).

The number of control reversals was moderately high on all displays. Control reversals to roll disturbances occurred nearly twice as frequently as reversals to either pitch or lateral rate disturbances. Though there were no significant differences among the numbers of small control reversals for the different displays, there was some evidence that this conclusion may not apply to large control reversals. Pilots who were prone to make control reversals made considerably more large control reversals when using the two displays which did not have the white-black sky-ground surfaces; however, due to the low occurrence of large reversals, this observation was not amenable to statistical test.

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INTRODUCTION

Despite the apparent similarity in the perceived features of a pilot's view of the earth during visual flight and the characteristics of an "inside-out" pictorial representation of the earth, relatively frequent control reversals are made even by experienced pilots controlling fixed base aircraft simulators with the aid of such displays. These control reversals have been systematically observed in studies of various displays employed in fire control systems (Weisz, et al, 1960; Bauerschmidt and Roscoe, 1960) and incidentally observed in studies of pictorial displays designed to assist pilots performing landing approaches. In one sample 12 airline pilots who participated in a series of simulator landing display studies, (Palmer and Wempe, 1971), one-half showed a marked tendency to operate a two-axis hand controller in a direction the reverse of that required for proper control. Four of these pilots learned to overcome this tendency, although they sometimes made an occasional control reversal at critical moments. When these four pilots made a control reversal they would rapidly correct their initial incorrect response. The other two pilots appeared absolutely unable to overcome their strong tendency to make control reversals even after four hours of practice. After making a control reversal, these pilots would sometimes lose control of the simulated aircraft.

It is not known whether the observed control reversals were more closely related to the somewhat unrealistic simulator cab and hand controller employed in that study, or to deficiencies in the perceptual quality of the information presented on the pictorial landing display. It seemed reasonable to assume, however, that performance would improve if pilots were provided with a familiar wheel control located in a more realistic cockpit simulator. Consequently, the present study is concerned with the effect of variation in only the perceptual aspects of the pictorial landing display itself.

The objective of this study was to determine if the frequency of control reversals would be influenced by increased realism in the pictorial representation of the horizon, and by the presentation of the pictorial display in a head-up or head-down mode. For purposes of comparison, a head-down display involving a simulated earth view of an approach to an airport was also included.

METHOD

Task Simulation

A block diagram of the simulation is shown in Figure 1. The pictorial display was generated by a digital computer using computer graphic techniques while the dynamics of a DC-8 aircraft were simulated on an analog computer according to the equations described by Jackson and Snyder (1966). Pilots were seated in the cockpit shown in Figure 2. In addition to the information presented on the central pictorial display, radio and barometric altitude, rate of climb, heading, air speed, and trim instruments were provided.

SIMULATION CONFIGURATION

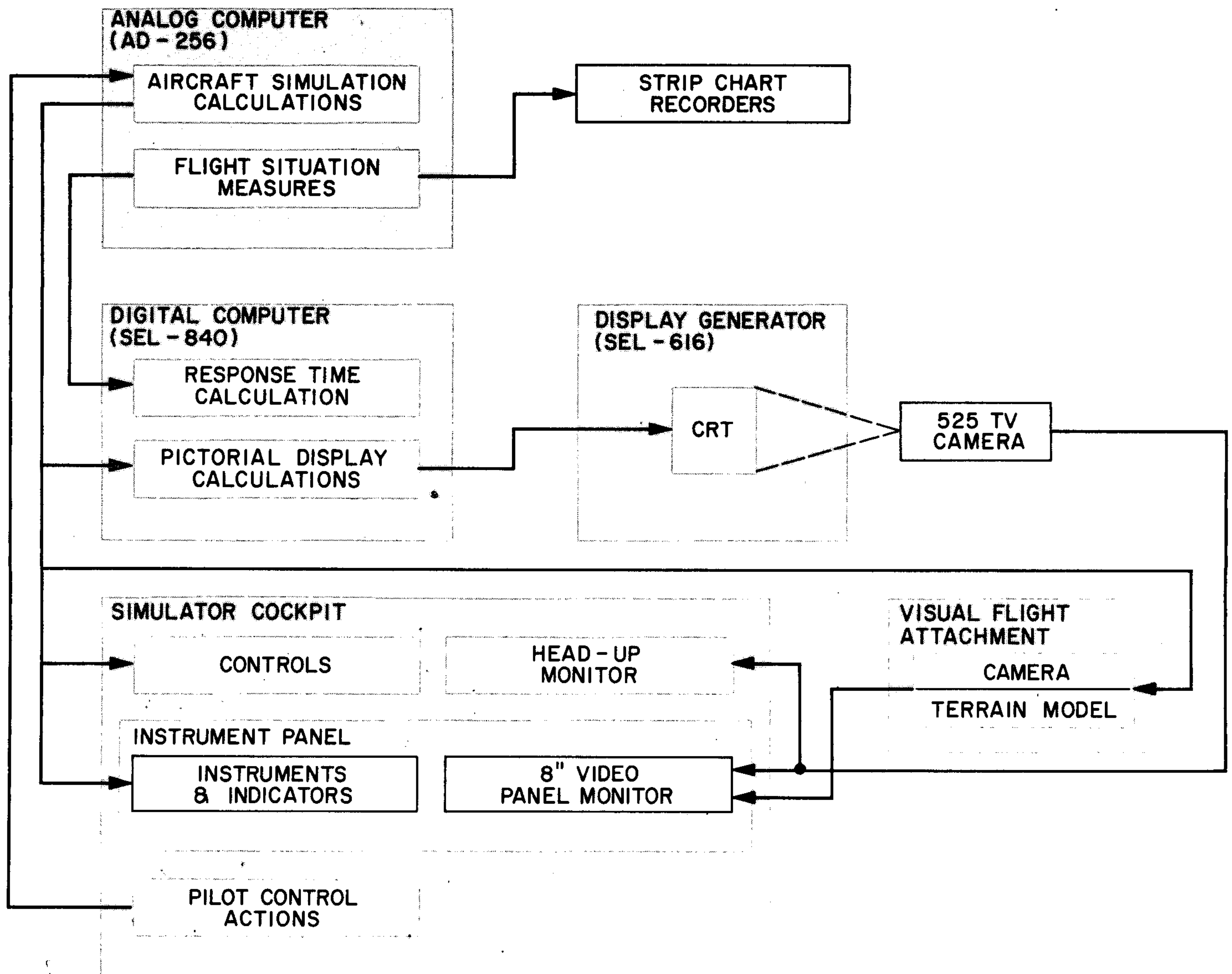

FIGURE 1

FIGURE 2. PILOT'S DISPLAYS AND CONTROLS

Display Conditions. The major characteristics of the four displays tested are shown in Table 1. The letters A, B, C, and D designate the

	PICTORIAL		EARTH VIEW	
	HEAD UP	HEAD DOWN	HEAD UP	HEAD DOWN
Horizon Bar	A	B	X	X
Light Sky	X	C		D

Table 1. Combinations of display conditions tested. (The blank cells were not tested in the study. The crossed-out cells describe illogical combinations.

displays tested. The basic pictorial display (display B, shown in Figure 3) is identical, except for a slight reduction in magnification, to one of the displays investigated by Palmer and Wempe (1971). In the head-down mode this display appeared on a 20 cm television monitor with 525 lines of resolution. As compared with the real world the monitor display represented a .25 magnification of the runway while presenting a .7 rad. by a .7 rad. perspective view of that runway. In the collimated head-up mode (display A) the same pictorial information was displayed at unity magnification as a virtual image at an apparent distance of 10 meters.

On display C, shown in Figure 2, the horizon bar of display B was replaced by a representation of a light colored sky and dark ground. This arrangement of contrasting surfaces was expected to provide realism not present in display B in which the ground and the sky were both dark and the horizon was represented by a contrasting bar.

The earth display (display D) was presented to the pilots on the same head-down monitor used for the pictorial display. The visual scene viewed by the pilots was derived from a model of Dulles International Airport mounted on a moving belt driven past a five degree of freedom TV camera and optical probe. The picture displayed to the pilots was in black and white. This system is described in a report by Chase (1970). This display represents the maximum degree of realism attainable on a head-down pictorial display. A photograph of the pilot's view of display D is shown in Figure 4.

Flight Conditions. For each flight the simulated aircraft was positioned at an altitude of 70 meters, 1000 meters from the runway threshold on a .052 radian (3 degree) glideslope to a point 330 meters down the runway. The aircraft was trimmed such that if there were no wind conditions it would proceed down the proper flight path at a sink rate of 4 meters per second with air speed maintained by an auto throttle.

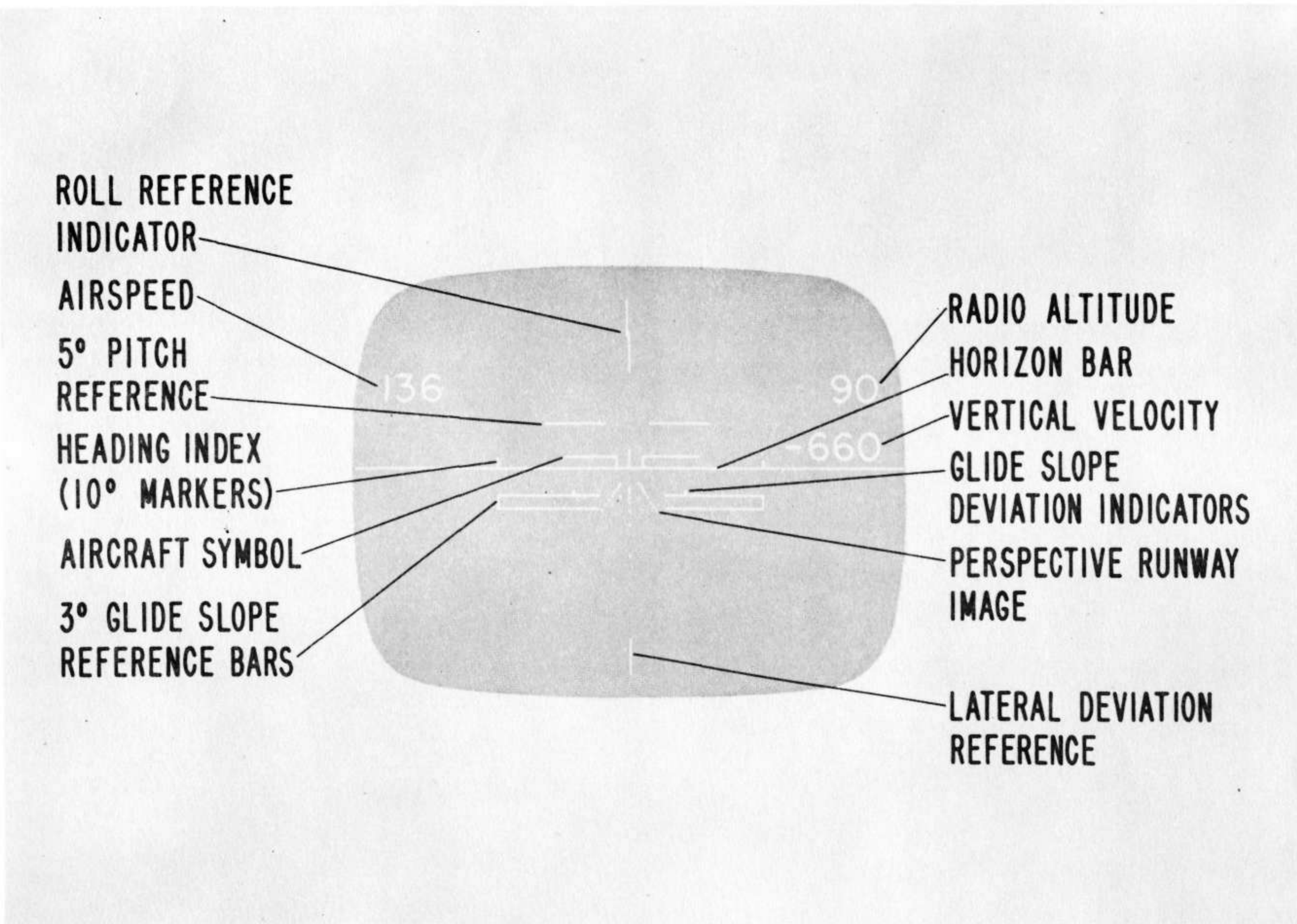

FIGURE 3. DISPLAY ELEMENTS OF THE PICTORIAL DISPLAY

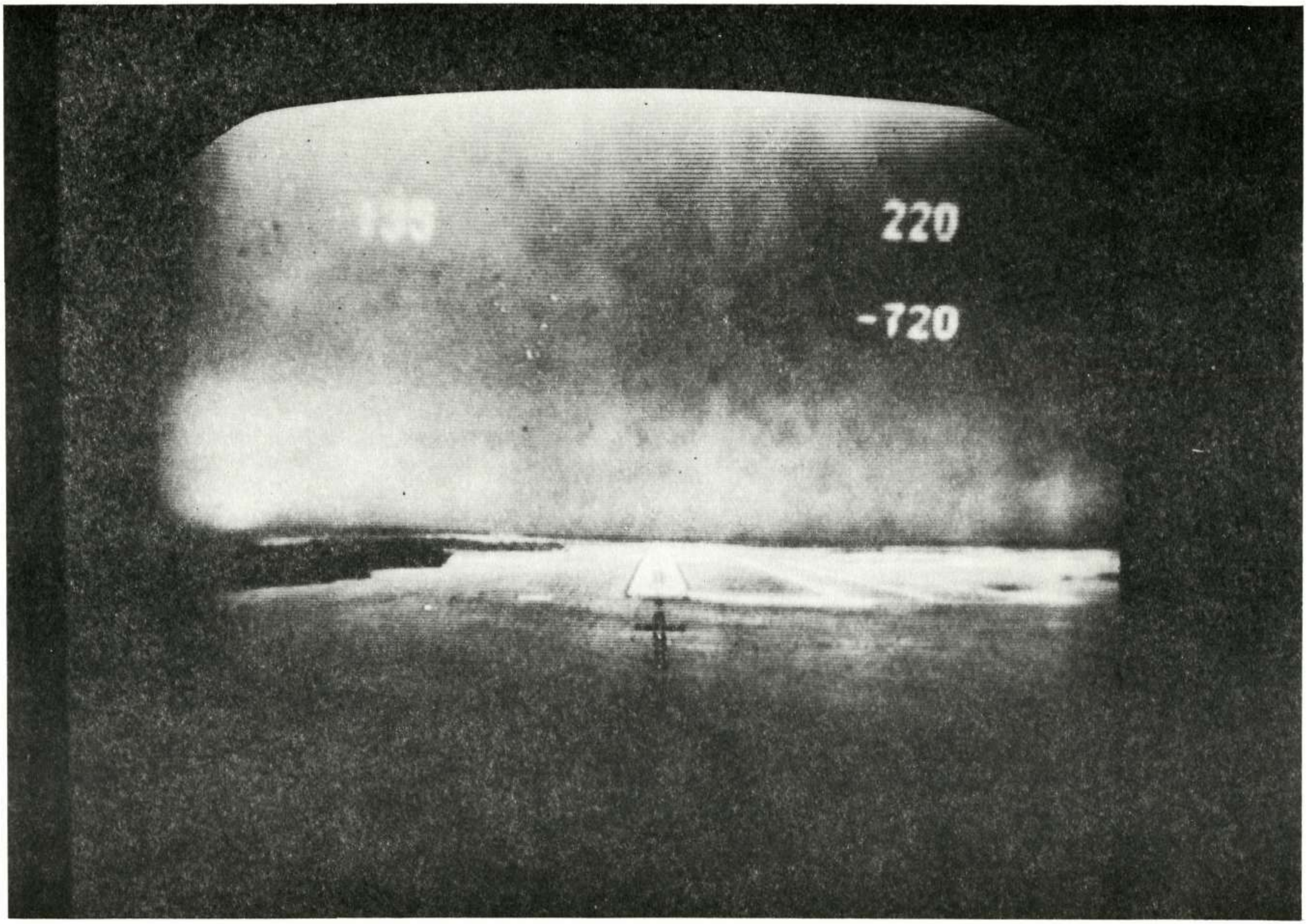

FIGURE 4.   HEAD DOWN EARTH VIEW DISPLAY (DISPLAY D)

Within 5 sec. after the start of a trial run, the simulated aircraft was subjected to a single pitch, roll, or lateral rate disturbance. The pitch and roll rates were .087 rad./sec. and .26 rad./sec., respectively. The lateral rate disturbance produced a 5 meter/second step in lateral velocity. The pilot's task was to correct for the disturbance as rapidly as possible by means of the appropriate control movements. A trial was terminated when the altitude reached 20 to 30 meters.

Pilot Subjects

Twelve airline pilots with extensive experience in instrument flying participated in the present experiment. All twelve of the pilots had previously been observed in an experiment by Palmer and Wempe (1971) in which they were required to operate a two axis hand-controller in conjunction with a display with features resembling display B. On the basis of these earlier observations, pilots were first ranked by those experimenters with regard to their tendency for making control reversals and then classified into three categories reflecting the level of their reversal proneness.

Experimental Design

The experimental plan was carried out in two phases. In the first phase, the four displays were compared by means of an experimental design chosen to eliminate uncontrolled transfer effects and minimize experimental error with a small number of pilots. Table 2 is a diagram of this design. Eight pilots were grouped with regard to their previously observed level of low or medium reversal proneness. Each pilot flew 120 flights that were

	TYPE OF DISPLAY			
LEVEL OF REVERSAL PRONENESS	A TRIAL BLOCKS	B TRIAL BLOCKS	C TRIAL BLOCKS	D TRIAL BLOCKS
LOW	1	3	5	7
MEDIUM	2	4	6	8

Table 2. Experimental design for Phase I. (The numbers in the cells represent pilots).

divided into ten blocks of twelve trials each. Within every block, two disturbances involving right and left rolls, right and left cross winds, and up and down pitch angles were introduced in a different random sequence. Only one disturbance appeared in a trial, and each pilot worked with only one of the four displays. Prior to the test flights, pilots were permitted one practice approach, intended to familiarize the pilots with the display and the dynamics of the aircraft.

Table 3 diagrams the experimental design for Phase II. The two pilots

LEVEL OF REVERSAL PRONENESS			
LOW		HIGH	
SUBJECT		SUBJECT	
9	10	11	12
Display	Display	Display	Display
B A C D	D C A B	C B D A	A D B C

Table 3. Experimental design for Phase II. (Each subject received three blocks of 12 trials with each display).

with high proneness for control reversals and two pilots with low reversal proneness who had not participated in Phase I flew each of the four displays in Phase II. As in Phase I, test runs were divided into blocks of twelve trials, each including two randomly arranged samples of the six disturbances. All pilots completed three blocks of twelve trials with each display.

Performance Measurements

The principal measure of performance was the number of control reversals initiated by the pilots in response to the programmed disturbances. Control reversals were detected by examining strip chart recordings of aileron and elevator position as well as pitch and roll angle and angular rate. Two classes of control reversals were distinguished. The first, referred to as a reversal error, was defined as a control motion in a direction that increased position error and was of a magnitude exceeding 5 mm on the strip chart (5 mm = .052 rad. elevator and a .026 rd. aileron). The second class, referred to as a confusion error was defined as a control motion in the wrong direction exceeding 1 mm on the strip chart. As defined, then, all reversal errors were also counted as confusion errors.

The time elapsing between the initiation of a disturbance and the first control response to exceed a magnitude of .03 radians was automatically calculated to the nearest 0.05 sec. and recorded. Some inaccuracies were introduced in measuring response latencies by this means since no distinction was made between correct and incorrect responses, and responses smaller than the .03 radian tolerance limit were not included in the measurements.

RESULTS

Phase I - Confusion and Reaction Time Data

Errors - The numbers of trials in which confusion and reversal errors were produced are shown in Table 4 for all four displays and for both levels

TYPE OF ERROR	DISPLAY A (PIC-U) PRONENESS LOW		B (PIC) PRONENESS LOW		C (LT-SKY) PRONENESS LOW		D (EARTH-V) PRONENESS LOW	
	LOW	MED	LOW	MED	LOW	MED	LOW	MED
CONFUSION	18	27	11	19	20	13	17	20
REVERSAL	5	19	4	12	5	2	6	5

Table 4. Number of trials involving confusion and reversal errors in Phase I. (N = 120 per condition).

of reversal proneness. The numbers presented in Table 4 are intended to provide only an indication of the considerable magnitude of the problem since an analysis of variance performed on the confusion errors showed no significant differences either for type of display or level of reversal proneness. For this analysis the number of control reversals accumulated within each block of trials was transformed according to the relationship $X = \sqrt{x + .5}$.

An analysis of confusion errors according to the type of disturbance showed a very consistent pattern both for displays and subjects. The number of confusion errors was much greater for the roll disturbance than for either the pitch disturbance or the crosswinds. These differences are tabulated in Table 5.

DISTURBANCE	DISPLAY A (PIC-U) PRONENESS			B (PIC) PRONENESS			C (LT-SKY) PRONENESS			D (EARTH-V) PRONENESS			
	LOW	MED	Σ	LOW	MED	Σ	LOW	MED	Σ	LOW	MED	Σ	ΣΣ
PITCH	1	1	2	3	5	8	3	0	3	3	7	10	23
ROLL	13	20	33	5	13	18	13	11	24	12	9	21	96
LATERAL RATE	4	6	10	3	1	4	4	2	6	2	4	6	26

Table 5. Number of confusion errors associated with pitch, roll and wind disturbances in Phase I. (N = 120).

<u>Time</u> - the results of the analysis of response latencies are shown in Table 6 which presents response delays in terms of the mean number of seconds elapsing between the introduction of a disturbance and the occurrence of any response larger than the established threshold value.

	DISPLAY							
	A (PIC-U)		B (PIC)		C (LT-SKY)		D (EARTH-V)	
	PRONENESS		PRONENESS		PRONENESS		PRONENESS	
	LOW	MED	LOW	MED	LOW	MED	LOW	MED
	1.14	1.16	1.22	1.32	1.21	1.41	1.55	1.92
GRAND MEAN	1.15		1.27		1.31		1.74	

Table 6. Mean response times in seconds in Phase I.

An analysis of variance of response times shows that the effects of displays, reversal proneness, and their interaction are all significant at the .01 level. Most of the display difference appears to be associated with display D, a result that may largely reflect mechanical lags inherent in the simulator required to produce that display.

Phase II - Confusion and Reaction Time Data

The results obtained in Phase II of the study in general confirm the principal findings of Phase I. Exceptions to this statement will be noted where appropriate in the remainder of the report.

Errors - Confusion and reversal errors are indicated in Table 7 in terms of the number of trials in which they occurred. Again, an analysis of variance of the confusion errors showed that there was no significant overall difference

	DISPLAY							
	A (PIC-U)		B (PIC)		C (LT-SKY)		D (EARTH-V)	
	PRONENESS		PRONENESS		PRONENESS		PRONENESS	
TYPE OF ERROR	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
CONFUSION	6	16	7	17	4	11	5	13
REVERSAL	0	5	1	7	1	2	1	2

Table 7. Number of trials involving confusion and reversal errors in Phase II. (N = 72 per condition).

associated with the displays for this measure. There was a significant interaction ($p<.05$) between subjects within groups and displays which suggested

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that between the subjects within the proneness groups there was an inconsistency with regard to performance with the various displays. There was also a significant effect ($p<.05$) for reversal proneness which reflects the expectation that the subjects in Phase II would show a greater degree of divergence than the subjects who participated in Phase I.

With regard to the type of disturbance that produced confusion errors, Phase I and II results are in agreement. Again roll errors were far more frequent, as indicated in Table 8.

DISTURBANCE	DISPLAY A (PIC-U) PRONENESS LOW	HIGH	Σ	B (PIC) PRONENESS LOW	HIGH	Σ	C (LT-SKY) PRONENESS LOW	HIGH	Σ	D (EARTH-V) PRONENESS LOW	HIGH	Σ	ΣΣ
PITCH	2	2	4	1	5	6	0	4	4	0	3	3	17
ROLL	4	10	14	6	4	10	4	6	10	4	7	11	45
LATERAL RATE	0	4	4	0	8	8	0	1	1	1	3	4	17

Table 8. Number of confusion errors associated with pitch, roll, and wind disturbances in Phase II. (N = 72).

Time - Mean response times for Phase II are indicated in Table 9. Inspection of Table 9 does show that response times were once more significantly

	DISPLAY A (PIC-U) PRONENESS LOW	HIGH	B (PIC) PRONENESS LOW	HIGH	C (LT-SKY) PRONENESS LOW	HIGH	D (EARTH-V) PRONENESS LOW	HIGH
	1.54	1.64	1.91	1.53	1.56	1.74	1.98	1.61
GRAND MEAN	1.59		1.72		1.65		1.79	

Table 9. Mean response times in seconds in Phase II.

different ($p<.05$) with the slowest responses made with display D, a result consistent with the data of Phase I. However, the reaction time differences among the displays were not as large despite the fact that their absolute values are considerably higher than those of Phase I.

Phase I and Phase II - Reversal Data

It is evident from the data of Table 4 and Table 7 that the occurrences of control reversals, by the criteria of this study, were too meager for statistical analysis. Even a grouping of the Phase I and Phase II data for all pilots by each display, as was done to produce Figure 5, was not amenable to statistical analysis because of the lack of independence of the data (each pilot made more than one trial with each display). Nevertheless, it is believed that observations relative to Figure 5 are appropriate since it does suggest some relationships that should be investigated further.

It is recalled that the pilot-subjects were graded according to prior performance on a display similar to B of this study. It is noteworthy that the low proneness group evidenced less than one-third as many reversals for that display as the medium and high proneness group, which is consistent with the raters' opinions of prior performance.

Prior to the experiment, it was the opinion of the authors that the high proneness group would have fewer reversals if Display B were shown head-up and collimated -- as was done to produce Display A. Figure 5 lends no support to that opinion and even suggests that there may have been some decrement in performance as averaged among the pilots.

Further examination of Figure 5 suggests that the low proneness group had about the same propensity to make reversal errors on each of the displays, whereas, the medium and high proneness group appeared to have a relatively high propensity to make reversals on Displays A and B but did not appear to differ from the low proneness group on Displays C and D. This observation is meaningful in that Displays A and B had only a line for a horizon; whereas, Displays C and D had a distinctly different shading for the sky as compared to the ground plane.

Because the foregoing observations seem to be in conflict with the analyses of the confusion data (where no significant differences were noted among the displays), Figure 6 was prepared. Here it is noted that with the reversals removed from the confusion data, there still does not appear to be any differential performance among the displays. Thus in view of the data of this experiment, it is logical to suspect that the tendency to make confusion errors may not be the same from pilot to pilot as the tendency to make reversal errors.

CONCLUSIONS

Consideration of the results leads directly to two major conclusions, each supported by the results of both phases of the experiment. (1) The frequency of control reversals made by airline pilots in a relatively realistic fixed base cab simulator is high enough to be of practical importance. Although the value of motion cues (which were absent) is not known, the variations in display symbology and appearance which were employed in this study did not significantly alter the number of small control

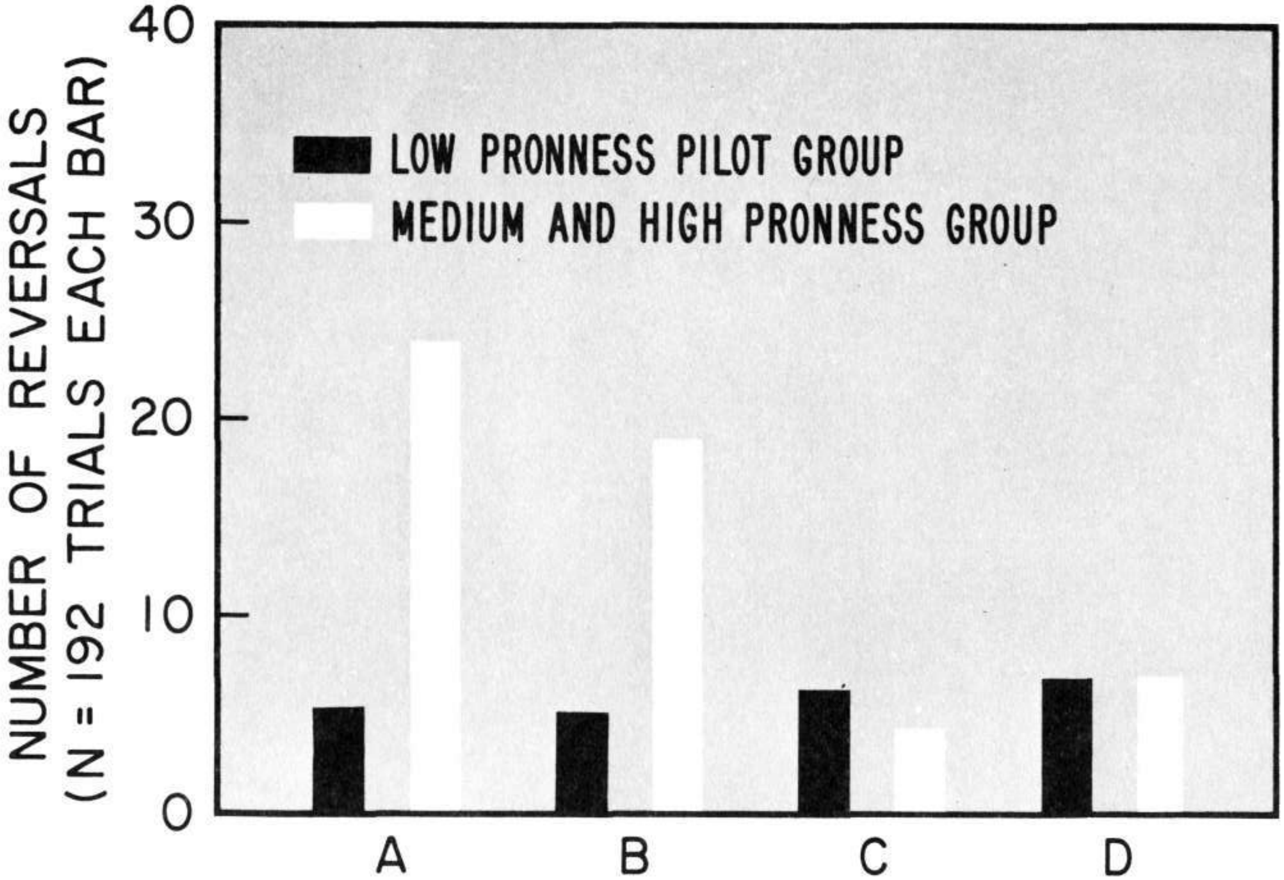

FIGURE 5. CONTROL REVERSALS - PHASE I AND PHASE II DATA COMBINED

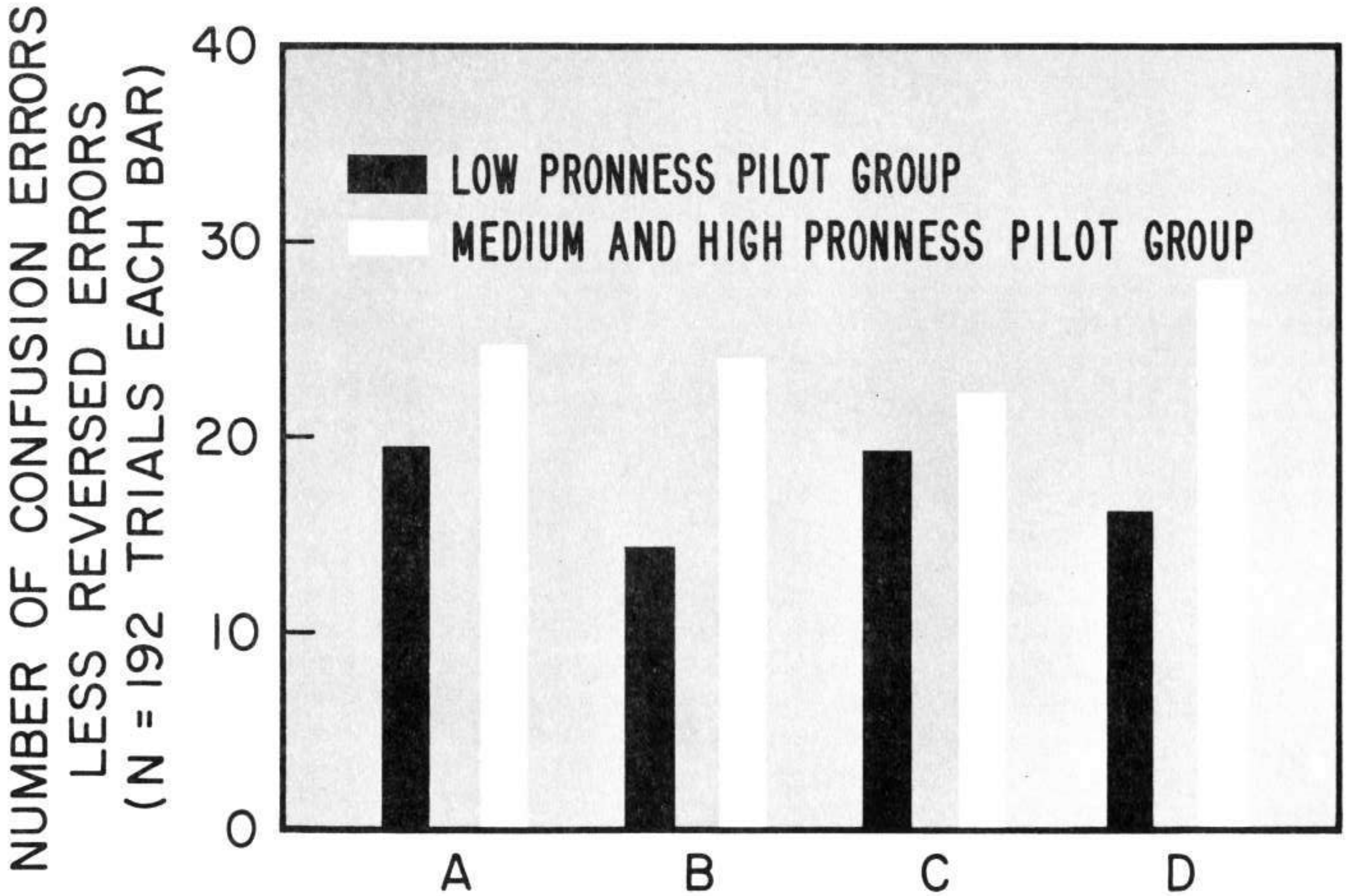

FIGURE 6. SMALL CONTROL REVERSALS ONLY - PHASE I AND PHASE II DATA COMBINED

reversals (confusion errors - reversal errors). This was true both for "head-up" and "head-down" displays. However, the pilots who seemed most prone to make control reversals made several times more large control reversals when confronted with the displays that lacked a differentiation between sky and ground. This last observation was not subjected to statistical test due to the low overall occurrence of large reversals.
(2) In the absence of motion cues, pilots had far more difficulty correcting roll disturbances than in reducing pitch and wind perturbations.

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