

PERIPHERAL VISION CUES: THEIR EFFECT ON PILOT PERFORMANCE DURING INSTRUMENT LANDING APPROACHES AND RECOVERIES FROM UNUSUAL ATTITUDES

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I. Introduction.

A recent study¹ showed that peripheral vision cues displayed in the cockpit of an aircraft simulator significantly improved pilot performance while flying high altitude holding patterns. In considering other operational phases, the question arises as to whether such cues would be useful *as an aid* in achieving the more precise control required in making instrument approaches through a 200-foot cloud ceiling. To answer this question, a study was conducted in a jet-engine air transport simulator. Also included in the study was a test to determine if such cues could be used *solely* for bank angle control—during instrument approaches—as a safety “backup” in case of failure of the attitude indicator (artificial horizon). Also, since severe turbulence has, on occasion, prevented flight crews from focusing on their instruments—resulting in loss of control—the pilot-subjects were tested to determine if they could safely recover from unusual attitudes with *no instrument display* other than the peripheral cue lights.

II. Equipment and Methodology.

Research Device. A Boeing 720 aircraft simulator with two degrees of freedom (pitch and roll movement capability) was utilized; the instrument panel (Figure 1) was typical of that in many airline aircraft.

Peripheral Cue Lights. Two pairs of small lights were used as cueing devices; each pair consisted of a red light positioned vertically above a green one. One pair was installed near each of the lower corners of the pilot's control wheel. (Figure 2). Activated by relays and a switch card connected to the roll servo of the simulator computer, the left-hand lights illuminated when the left wing was down more than $1\frac{1}{2}^\circ$, and the

right-hand ones illuminated when the right wing was banked more than $1\frac{1}{2}^\circ$ below the horizontal.

Operation of the lights was as follows: during wings-level flight (between $1\frac{1}{2}^\circ$ left bank and $1\frac{1}{2}^\circ$ right bank) the lights did not illuminate; between $1\frac{1}{2}^\circ$ and 10° of bank, the green light on the appropriate side flashed once per second; from 10° to 22° the green light rate doubled to two flashes per second. To signify a standard rate turn, the green light illuminated steadily in the 4° range between 22° and 26° of bank. From 26° to 90° the green light was extinguished and the red light flashed three times per second. Flash durations, with equal nonillumination periods between, were approximately as follows:

Green—(1 flash/sec.) = 0.50 second

Green—(2 flashes/sec.) = 0.25 second

Red—(3 flashes/sec.) = 0.166 second

The bulbs used for the cue lights were G.E. #327's using 0.04 amps at 28 volts, D.C., inserted in Dialco #25-101-3830 transparent colored units of 0.5-inch diameter. Luminance measurements of the cue light sources indicated a maximum of +1.4 log ft.-lamberts for the green bulbs and +1.7 log ft.-lamberts for the red. See Appendix for details of cue light circuitry.

Cockpit Illumination. General luminance within the cockpit was the same for all subjects but varied by areas ranging from approximately -0.7 log ft.-lamberts at the instrument panel to +1.1 log ft.-lamberts at the windshield.

Data Recorded. Two Sanborn 850 recorders were interconnected to appropriate simulator circuitry to provide a record of the following data: airspeed, altitude, roll (bank) angle, magnetic (compass) heading, control wheel rotation (in degrees), control column movement (fore and aft), path of aircraft relative to glide slope and localizer “beam,” flash rates and durations of

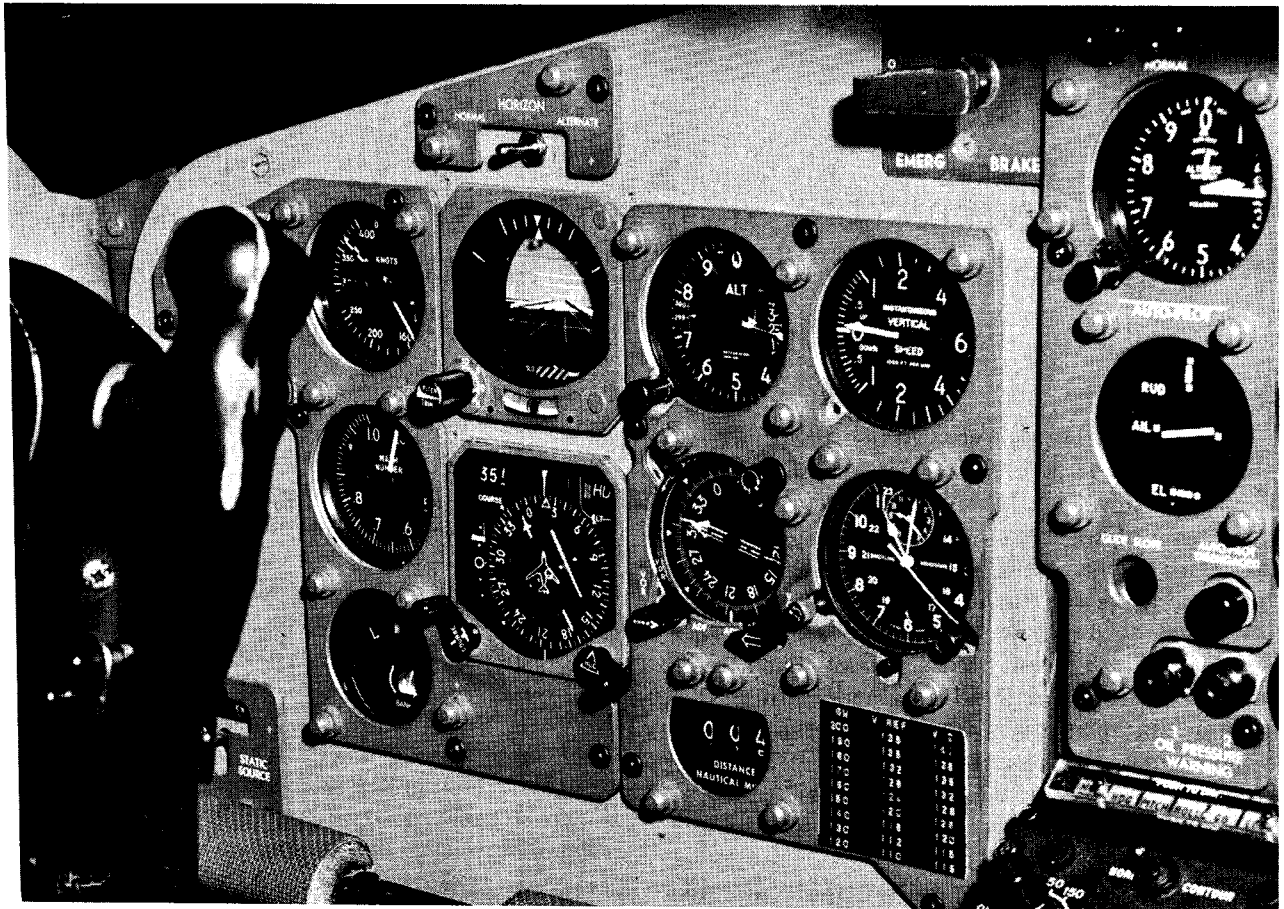


FIGURE 1. The instrument panel in the B-720 simulator used for the study of pilot response to peripheral vision cues is typical of that in many airline aircraft.

left/right green and red (cue) light illumination, and time of passage over outer and middle markers (geographical points along the approach path).

Subjects. Twenty pilots, all with air transport ratings (ATR's) with flight time ranging from 5,600 hours to 19,500 hours were used as subjects (Table 1). Ten were qualified in the Boeing 720 airplane; the rest were qualified either in the Convair 580 (turbo-prop model) or in the Lockheed Electra L-188. Fourteen of the 20 subjects reportedly had no familiarity with the particular attitude indicator (Collins 108 with "V" command bar) installed in the simulator.

Instrument Display Modes. The instrument approaches were flown alternately in three display modes:

Mode A. "Full" instrument panel* (including

*The turn and slip indicator (T&B) was covered during the entire experiment.

"command" bar in attitude indicator) but with peripheral vision cue lights *deactivated* (Figure 3a).

Mode B. Full instrument panel* (*excluding* command bar), with functioning peripheral cue lights (Figure 3b).

Mode C. "Partial" instrument panel* (*without attitude indicator*) with the peripheral cue lights as the only source of bank angle information (Figure 3c).

Attitude Indicator and Course Deviation Indicator Instruments. The attitude indicator in the simulator was a Collins FD 108 (Figure 4). In instrument display mode A, the inverted "V" bar (arrow #1) provided the pilot with "command" information; i.e., in the "glide slope" mode, "mating" of the delta aircraft symbol (arrow #2) with the V bar by appropriate manual control pressure and displacement keeps the real aircraft on, or close to, the centerline of the localizer and glide slope.

TABLE 1. Age and total flying time of 20 subjects. [Mean age, standard error (S.E.), and standard deviation (S.D.) were 45.7 years, ± 0.95 , and 4.26. Mean Flying Time, S.E., and S.D. were 9,795 hours, ± 895.4 , and 4,002.5, respectively.]

<i>Subject</i>	<i>Age</i>	<i>Total flight time</i>
1.....	43	8,000
2.....	47	7,000
3.....	48	18,400
4.....	45	9,000
5.....	48	6,800
6.....	45	12,000
7.....	53	11,000
8.....	48	8,000
9.....	34	7,200
10.....	43	12,000
11.....	45	7,000
12.....	44	8,000
13.....	49	12,000
14.....	47	5,700
15.....	46	8,200
16.....	48	5,600
17.....	54	19,500
18.....	43	15,000
19.....	44	9,500
20.....	41	6,000

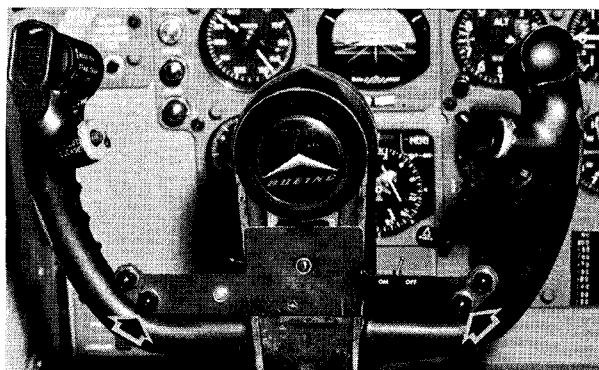


FIGURE 2. Various flash rates (or steady state illumination) of green cue light (arrows) were used to indicate different ranges of bank angle; flashing red light (located above green bulb) indicated any bank angle in excess of 26° . Right turns (banks) were indicated by illumination of a right-hand light and left turn by a left-hand light.

In display mode B, the V bar was deactivated, requiring use of the Collins 331A-7 course deviation indicator (CDI) to determine the relationship between the real aircraft and the localizer and glide slope. See Figure 5.

In mode C, the attitude indicator was covered, necessitating use of the airspeed instrument (a),

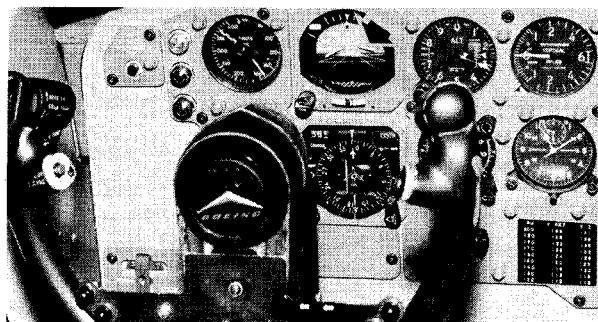


FIGURE 3a. In mode A, the peripheral cue lights were deactivated and the primary flight instruments shown here (including the "V" command bar (arrow)) were utilized during the ILS approaches.

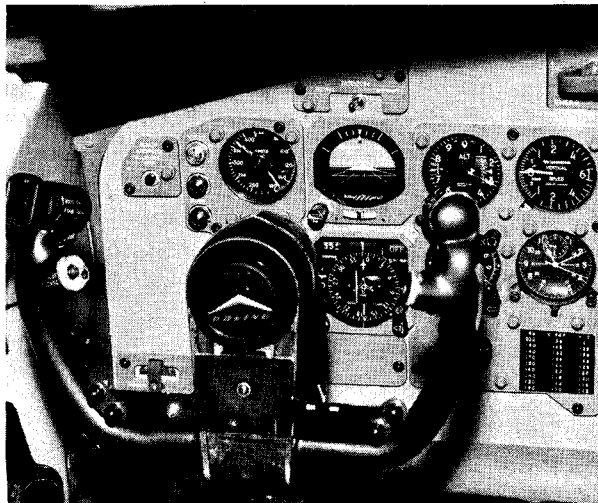


FIGURE 3b. In mode B, the peripheral cue lights were available with the instruments shown (note that "V" command bar was not available in this display mode).

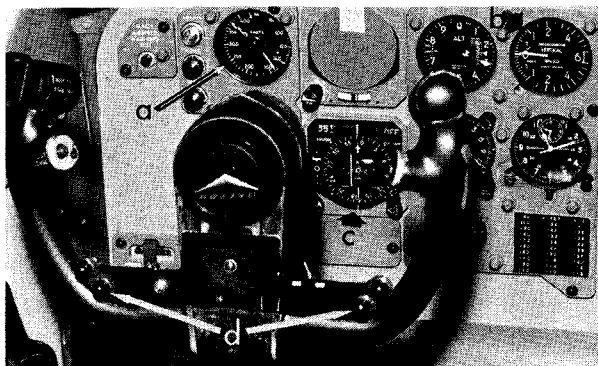


FIGURE 3c. The attitude indicator was covered in mode C necessitating use of airspeed (a), and the vertical speed indicator (b) for pitch information, and the CDI (c) for glide slope and localizer data; the peripheral vision cue lights (d) provided the only available information on bank angle.

Figure 3c), and the vertical speed indicator (b) for pitch information, the CDI (c) for glide slope and localizer data, and the peripheral cue lights (d) for bank angle information.

The CDI was available for use in all three display modes, providing glide slope, localizer, and heading information. The "bulls-eye" and the two dots above and below on the left side of the instrument (Figure 5) are used to indicate the relationship of the real aircraft to the centerline of the glide slope "beam." As shown in Figure 5, the glide slope needle (arrow #1) indicates the aircraft is below glide slope by one dot. The localizer on-course "bulls-eye" and off-course "dots" on either side of the bulls-eye are at the center of the instrument; the localizer needle position (arrow #2) indicates the aircraft is to the right of centerline by one dot. The relationship of instrument readings to the physical position of an aircraft with regard to magnitude of deviation from glide slope and localizer is discussed in the results and discussion section.

Simulator Test Standards. Prior to each flight, all applicable aircraft functions and settings were standardized. Such variables as cen-

ter of gravity, gross weight, outside air temperature, barometric pressure, fuel quantity, flap angle, and power and trim settings were initially set the same for each subject. The pilot's seat was also adjusted so that each subject's eye position was at about the same point in space.

Familiarization Procedure. Each subject flew the "aircraft" for one hour prior to the simulated instrument landing approaches. The "flight" was conducted at an altitude of 3,000 feet above the ground at approximately 170 knots; power was 1.8 engine pressure ratio (EPR) and the flaps were extended 30°. The landing gear remained retracted. Flight maneuvers were divided about equally between level flight and turns with bank angles up to 30°. The first portion of the flight was conducted purely for familiarization purposes with instrument and peripheral vision cue light displays as follows:

1. Ten minutes *without* the peripheral cue lights, divided equally between use of the attitude indicator with and without the "V" command bar.
2. Twenty minutes *with* peripheral cue lights. This was subdivided into:
 - a. Five minutes using the attitude indicator *without* the "V" bar.
 - b. Five minutes with the attitude indicator covered.

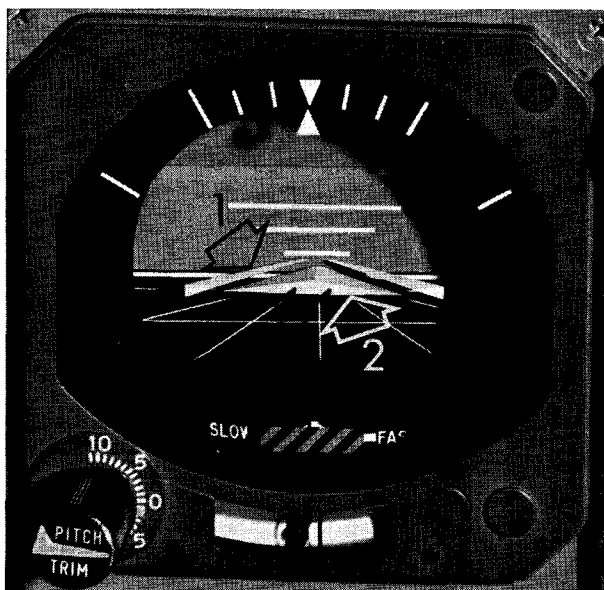


FIGURE 4. The "V" bars (arrow #1) in the Collins FD 108 attitude indicator provide the pilot with "command" information; i.e., "mating" the delta aircraft symbol (arrow #2) with the "V" bars by appropriate pressure and displacement keeps the real aircraft close to, or on, the centerline of the localizer and glide slope.



FIGURE 5. The Collins 331A-7 course deviation indicator (CDI) provides glide slope, localizer, and heading information. According to the positions of the glide slope needle (arrow #1) and the localizer needle (arrow #2), the aircraft is below glide slope and to the right of the localizer by one dot.

c. Ten minutes with the attitude indicator covered and the pilot reading text material held on the lap. This was done while simultaneously flying the aircraft and making all bank angle corrections only by means of the peripheral vision cue lights.

The last portion of this familiarization flight consisted of flying six standard holding patterns while using the three instrument display modes described earlier. While flying the last three patterns, each subject also performed the secondary task of solving and writing answers to a series of mathematical problems. These problems were on a clipboard held on the subject's lap.

Experimental Procedure. After completion of the last pattern of the familiarization flight, each subject was given a 5-minute rest period while the copilot-observer positioned the aircraft 9 nautical miles from the outer compass locator on the localizer path, in preparation for the instrument landing approaches.

Nine ILS approaches were performed by each subject in the sequence shown in Figure 6, with each of the instrument/cue light display modes used during the previous holding patterns. No landings were made; instead, after descending to an altitude of between 100 and 150 feet, the subject executed a "go-around," climbing up to the original approach altitude. The aircraft was then immediately "backed-up" by a simulator technician to the original starting point for the next approach.

After completing the approaches, each subject attempted to recover from a series of four steeply-banked turns, in each of two instrument/cue light display modes; i.e., (a) with all flight instruments available (including the attitude indicator) but *without the peripheral cue lights*, and (b) using *only* the cue lights (*all flight instruments covered*). In each case, while the aircraft was being put into the unusual attitude by the observer, the subject kept his hands and feet free of the controls, and his eyes closed and covered. After the control wheel was quickly centered by the observer—without decreasing the bank angle—the subject was told to take control. He then attempted to roll the aircraft into level flight attitude as rapidly as possible.

The sequence and details of the four recovery maneuvers are as follows:

Power: 1.8 EPR.

Flaps: 30°.

Landing Gear: Retracted.

Recovery #1. Initiated from an attitude of:

Left wing down 60°

Nose up 10°.

Recovery #2. Initiated from an attitude of:

Right wing down 80°

Nose level.

Recoveries #1 and 2 made with all instruments available (*no peripheral vision cue lights*).

Recovery #3. Initiated from an attitude of:

Right wing down 60°

Nose up 10°.

Recovery #4. Initiated from an attitude of:

Left wing down 80°

Nose level.

Recoveries #3 and 4 made by sole use of peripheral vision cue lights (*all instruments covered*).

These recovery maneuvers completed the tasks. No subject was used more than once in the study.

Performance Criteria. Three flight performance measures were used to compare the effects of the three different instrument display modes on pilot performance during the instrument approaches. These criteria were: (1) glide slope deviation (2) localizer path deviation and (3) bank angle—from the outer marker to the middle marker. Flight time between these two geographical points was approximately 80 seconds for each ILS approach.

For purposes of analysis, variation of performance on each criterion was categorized as follows:

(1) Glide slope:

(a) "On course."

(b) Above glide slope, to 1st dot.

(c) Below glide slope, to 1st dot.

(d) Between 1st and 2nd dot (above or below glide slope).

(e) Beyond 2nd dot (above or below glide slope).

(2) Localizer:

(a) "On course."

(b) Left or right of "on course" to 1st dot.

(c) Left or right between 1st and 2nd dot.

(d) Beyond 2nd dot (left or right).

(3) Wing attitude (bank angle):

(a) "Level" (not more than 1½° of bank, left or right).

(b) Between 1½° and 10° of bank, left or right.




DISPLAY MODE:	CONVENTIONAL FLIGHT INSTRUMENTS WITH:	ILS APPROACH SEQUENCE		
		1	4	7
A	 ARTIFICIAL HORIZON WITH V COMMAND BAR (no peripheral vision cue lights.)	2	5	8
B	 ARTIFICIAL HORIZON WITH PERIPHERAL VISION CUE LIGHTS	3	6	9
C	 PERIPHERAL VISION CUE LIGHTS ONLY (no artificial horizon)			

FIGURE 6. Nine ILS approaches were flown by each of the 20 subjects in the sequence shown, using three different instrument/cue light displays.

- (c) Between 10° and 22° of bank, left or right.
- (d) Between 22° and 26° of bank, left or right.
- (e) Beyond 26° of bank, left or right.

Measures are expressed as a percent of the total transition time between the outer marker and middle marker. Performance during recovery from the unusual attitudes (steeply-banked turns) was related to the actual time required to roll the aircraft to less than $11\frac{1}{2}^\circ$ of bank.

III. Results and Discussion.

The ILS Approach. In a perfectly executed ILS (instrument) approach, an aircraft descends along the line of intersection of the localizer beam and glide path³ (Figure 7). Also, assuming no cross wind, the wings would remain level and the aircraft's heading would not vary from the localizer heading.

However, few pilots can consistently execute an instrument approach this perfectly because of variations in pilot technique and experience, fatigue, delays in aircraft response to control inputs, and other such variables. Because of these variables, a wide range of pilot performance levels may be observed which are measurable as

deviations above, below, and to either side of the center of the localizer/glide-slope path.

For purposes of analysis, pilot performance was evaluated in categories that would be meaningful to pilots as well as to designers of instrument display systems. For example, the ability to hold the aircraft in a relatively wings-level attitude (not more than $11\frac{1}{2}^\circ$ of bank) is indicative of better performance than if the pilot allows bank angle to vary widely and often; similarly, a majority of the time spent "on glide slope" constitutes better performance than if most of the time is used flying above or below glide slope. Also, flight above glide slope is more desirable than flying an equal distance below glide slope, because the latter places the aircraft closer to the ground. Flight within one dot on either side of the localizer centerline is preferable to flying beyond one dot. Even less desirable would be operation beyond the two-dot range, for at the middle marker, the aircraft would be too far to the side of the runway to be landed successfully. Similarly, two dots above glide slope might require a go-around, loss of time, and another approach attempt. Two dots below glide slope, on the other hand, places the airplane about 150 feet above ground at the middle marker—lower than desirable and less safe. The

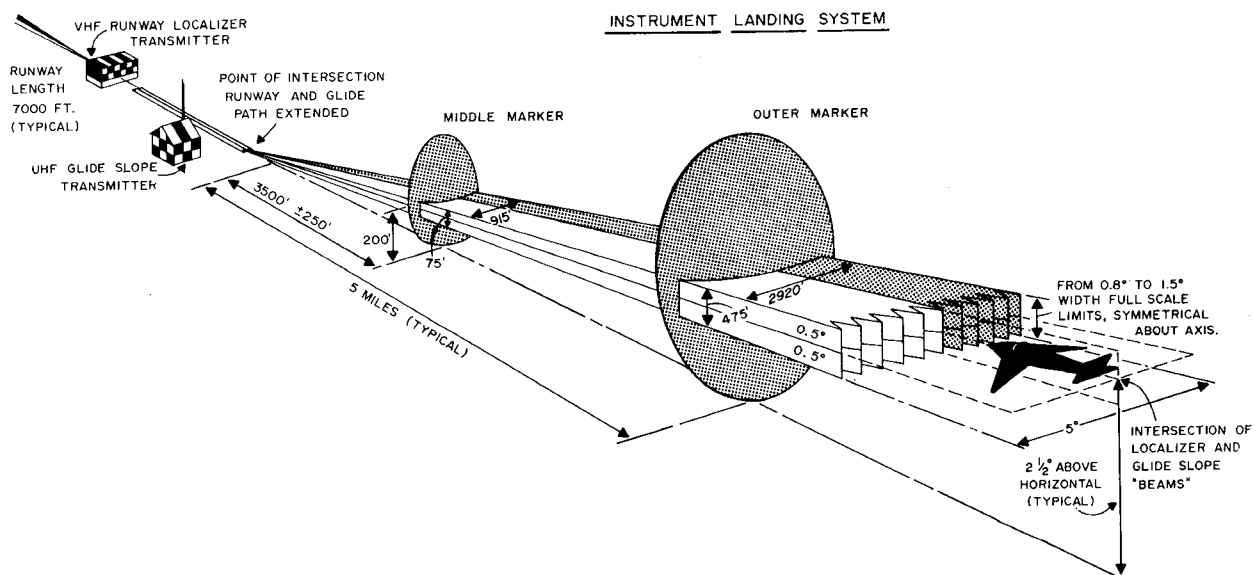


FIGURE 7. Typical instrument landing system configuration.³ Approach data used in study was obtained in area between middle and outer markers.

relationship of these one- and two-dot "categories" of performance to distance from the centerline of the localizer and glide slope is shown in Figure 8, where a vertical "slice" of a typical localizer/glide slope "beam" is depicted at the middle marker (about 3,500 feet from the runway threshold). Here the beam is approximately 920 feet wide and 80 feet deep with its "floor" about 150 feet above ground (the beam is approximately 2,920 feet wide, 475 feet deep and 1,200 feet above runway elevation about 4 miles further out from the runway). At the middle marker, there are only 80 feet vertically between the points represented by two dots above glide slope and two dots below.

If a pilot keeps his aircraft within "tighter" limits, such as between one dot above and one dot below glide slope, his deviation would amount to less than 40 feet vertically at the middle marker. At the outer marker, the same deviation would involve about 240 feet.

The two hatched blocks in the beam in Figure 8, show the areas used in this study for comparison of pilot performance while flying the ILS approaches. The center (dark) hatching represents the approximate range of "on" localizer, "on" glide slope performance. The lighter hatching shows the limits of the one-dot performance range.

Bank Angle Performance. Comparison of the percentage of time the aircraft was flown in a wings-level attitude during the nine instrument approaches (Figure 9, Tables 2 and 3), indicates there might be significant differences between subsequent runs in each of display modes A and C (1 vs. 4 vs. 7 and 3 vs. 6 vs. 9). In fact, at first glance, it would seem that learning was definitely related to the differences between approaches 3 and 6 in mode C, since use of the peripheral cue lights, as the only available means of ascertaining bank angle, was a relatively unfamiliar task. Also, there appears to be a large

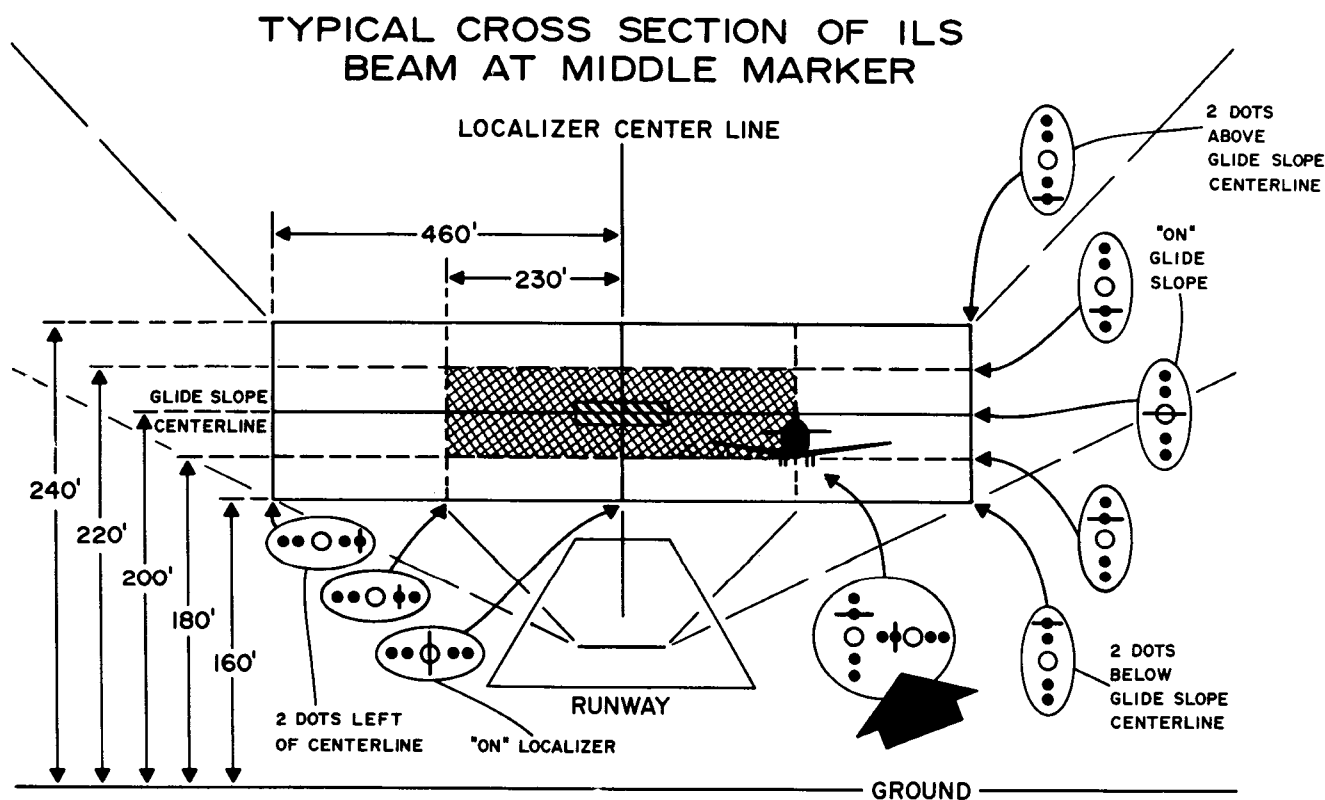


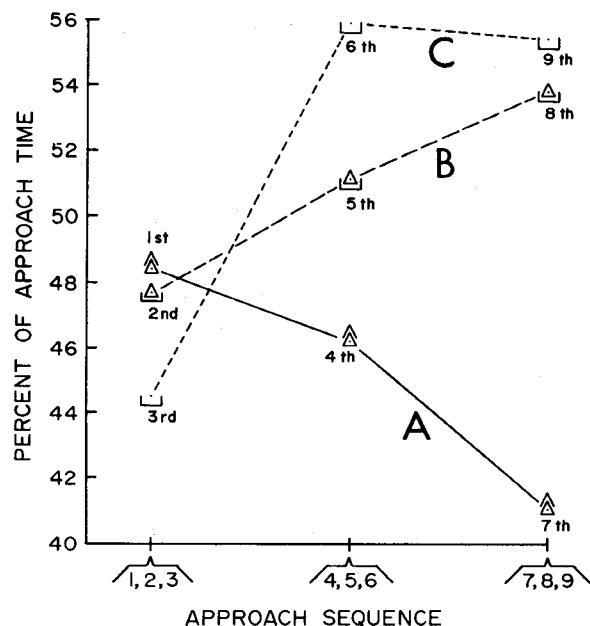
FIGURE 8. Glide slope and localizer CDI display indications are shown relative to various locations within the ILS "beam." At the middle marker, the aircraft shown here is approximately 20 feet below and 230 feet to the right of the glide slope/localizer centerline; the CDI display for this location indicates a one-dot deviation (large arrow).

reduction in performance in approach 7, as compared to approach 1 (in which the most sophisticated instrument display equipment was available to the pilot). However, appropriate *t* tests indicate there was no significant difference between the scores in any one display mode at the $p < .05$ probability level. Therefore, it is assumed that learning did *not* contribute significantly to the variation in scores in mode C, nor could any significance be attributed to the apparent decrease in performance shown in mode A.

However, statistically significant differences do appear when the performance scores for the different instrument display modes are compared

TABLE 2. Means, standard errors, and standard deviations for level flight (zero°–1.5°) between the outer and middle markers during nine ILS approaches.

Approach number and display mode	Mean and standard error (secs.)	Standard deviation
1A-----	48.5 ± 2.93	13.13
2B-----	47.7 ± 4.58	20.48
3C-----	44.6 ± 5.74	25.69
4A-----	46.3 ± 2.98	13.32
5B-----	51.2 ± 4.21	18.82
6C-----	55.9 ± 4.56	20.40
7A-----	41.1 ± 3.83	17.15
8B-----	53.8 ± 3.95	17.66
9C-----	55.5 ± 4.46	19.97



LEGEND: ARTIFICIAL HORIZON WITH "COMMAND" BAR (no cue lights).
 ARTIFICIAL HORIZON WITH CUE LIGHTS.
 CUE LIGHTS ONLY (no artificial horizon).

FIGURE 9. Mean scores of time in level flight (zero to 1½° of bank) resulting from use of three different display modes. Although there appears to be wide differences between scores for approaches #3 and #6 in mode C, #2 and #8 in mode B, and #1 and #7 in mode A, the differences within any one display mode were not statistically significant. There were, however, significant differences between modes; i.e., between approaches #7 and #8, and between #7 and #9.

TABLE 3. Inter- and intra-display mode comparisons of level flight performance (zero°–1.5° bank angle).

Approach and display mode comparisons	" <i>t</i> "	Significance Level
3C-6C-----	1.55	---
9C-3C-----	1.49	---
6C-4A-----	1.77	.05
9C-7A-----	2.44	.05
8B-7A-----	2.30	.05
6C-7A-----	2.49	.05
5B-7A-----	1.77	.05
4A-7A-----	1.07	---
1A-7A-----	1.53	---
5+8B-4+7A-----	1.68	---
6+9C-4+7A-----	2.11	.05
6+9C-5+8B-----	0.53	---

with each other (Figure 10). For example, there is a significant difference ($p < .05$) between the scores for "level" flight in approach #4, mode A with no cue lights (46.3%), and approach #6, mode C with cue lights only (55.9%). The same holds for approach #7 mode A (41.1%) and #9 mode C (55.5%). Also, significant differences are found between approach #7 mode A (41.1%) and approaches #5 mode B (51.2%) and #8 mode B (53.8%)—in which the peripheral cue lights were added to the attitude indicator display.

It is apparent that, on the average, the pilots were able to maintain a bank angle of less than







MEAN BANK ANGLE SCORES								
INSTRUMENT DISPLAY MODE :	BANK ANGLE (DEGREES)	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	COMBINED MEANS (%) (4 thru 9)
(A) 	(a) 0 - 1 1/2 (b) 1 1/2 - 10 (c) 10 - 22 (d) 22 - 26 (e) 26 +	1	48.5 51.4 0.1 0.0 0.0	4	46.3 53.5 0.2 0.0 0.0	7	41.1 58.4 0.5 0.0 0.0	43.70 55.95 0.35 0.00 0.00
(B) 	(a) 0 - 1 1/2 (b) 1 1/2 - 10 (c) 10 - 22 (d) 22 - 26 (e) 26 +	2	47.7 49.5 2.5 0.3 0.0	5	51.2 46.9 1.9 0.0 0.0	8	53.8 44.5 1.7 0.0 0.0	52.50 45.70 1.80 0.00 0.00
(C) 	(a) 0 - 1 1/2 (b) 1 1/2 - 10 (c) 10 - 22 (d) 22 - 26 (e) 26 +	3	44.6 48.8 6.0 0.3 0.3	6	55.9 40.5 3.2 0.2 0.2	9	55.5 41.1 3.4 0.0 0.0	55.70 40.80 3.30 0.10 0.10
LEGEND :  ARTIFICIAL HORIZON WITH V COMMAND BAR (no peripheral cue lights)  ARTIFICIAL HORIZON WITH CUE LIGHTS  CUE LIGHTS ONLY (no artificial horizon)								

FIGURE 10. Mean percentages of time flown at various bank angles during ILS approaches are shown in relation to three different instrument/cue light display modes.

1 1/2° for substantially longer periods of time when peripheral cue lights were available for bank angle indication, than when using the attitude indicator with the "V" command bar. For example, the improvement in performance in approach #8 compared to that for approach #7 is 30.9%; performance in approach #9 (cue lights only) compared to approach #7 is even greater, 35.0%. (Figure 11).

The reason for this becomes apparent when the two systems are compared in relation to requirements for visual discrimination. The conventional system in mode A requires the use of central (foveal) vision for discrimination of changes in bank angle. If the aircraft begins to bank inadvertently while the pilot is looking at other instruments, or is otherwise distracted, the increase in bank angle will not be detected until the pilot focuses directly on the attitude indicator; by this time the bank angle may be excessive. On the other hand, in modes B and C, flashing of a peripheral cue light at banks in excess of 1 1/2° causes the pilot to initiate corrective action regardless of where his vision may be directed at the moment.

The scores related to bank angles between 1 1/2° and 10° (b, Figure 10) also demonstrate major




"LEVEL" FLIGHT PERFORMANCE AS FUNCTION OF INSTRUMENT DISPLAY MODE				
DISPLAY MODE :	APPROACH SEQUENCE NUMBER	TIME IN "LEVEL" FLIGHT (%)	DIFFERENCE (%)	INCREASE (%)
A 	7	41.1		
B 	8	53.8	(53.8-41.1)	(12.7/41.1)
C 	9	55.5	(55.5-41.1)	(14.4/41.1)

FIGURE 11. Time in level flight (bank angles less than 1 1/2°) increased with use of peripheral vision cues.

differences; i.e., significant differences ($p < .01$) appear between the scores for 7b and 8b (58.4% vs. 44.5%), and 7b and 9b (58.4% vs. 41.1%). This strongly suggests that the peripheral cue lights were useful in reducing the amount of time the aircraft operated at bank angles between 1 1/2° and 10°.

For banks in excess of 10°, mean time was less than 1 second in mode A and 2.8 seconds in mode C (Figure 12).

Glide Slope Performance. The mean percentage scores of time flown "above," "on," and "below" glide slope during the nine approaches are shown in Figure 13. As with the roll angle data, only information from the last six ap-

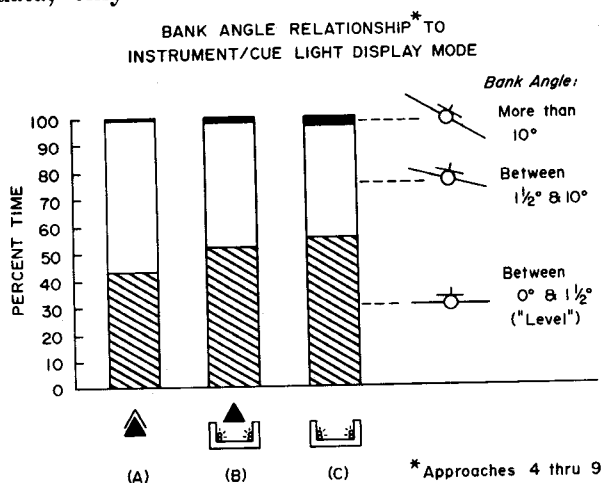


FIGURE 12. As expected, time in excess of 10° bank was greatest when attitude instrument was unavailable for reference. However, total time in excess of 1 1/2° of bank was least in display mode C, indicating peripheral vision cues were useful in maintaining "level" flight.

proaches (No. 4 through 9) was used for statistical analysis of differences between display modes.

The combined mean scores for *on* glide slope (maintaining the aircraft close enough to the centerline of the glide slope to keep the cross pointer needle within the "bulls-eye" circle on the instrument) are 25.20%, 13.85%, and 11.55% for modes A, B, and C, respectively. The differences between A and C, and A and B are statistically significant ($p < .01$); there was no significant difference between modes B and C.

Similarly, when the scores for within "one-dot-above," "on," and within "one-dot-below" (c+d+e) are combined, significant differences again appear between modes A and C (95.45% vs. 76.15% - $p < .01$), and modes A and B (95.45% vs. 85.95% - $p < .05$). As before, no significant difference was found between modes B and C. These differences represent a 9.9% performance decrement for mode B (compared to A) and 20.2% for mode C. Comparing B and C with each other, we find that C was 11.4% less than mode B. This indicates that use of the "V" command bar with the attitude indicator resulted in better glide slope performance

MEAN GLIDE SLOPE SCORES								
INSTRUMENT DISPLAY MODE :	POSITION "ABOVE" "ON" & "BELOW" GLIDE SLOPE	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	COMBINED MEANS (%) (4 thru 9)
(A)	(a) (b) (c) (d) (e) (f) (g)	1	1.9 2.8 <u>27.5</u> <u>18.1</u> 47.5 1.6 0.6	4	1.6 2.4 <u>28.5</u> <u>24.8</u> 42.7 0.0 0.0	7	0.9 1.8 <u>25.4</u> <u>25.6</u> 43.9 2.4 0.0	1.25 2.10 <u>26.95</u> <u>25.20</u> 43.30 1.20 0.00
(B)	(a) (b) (c) (d) (e) (f) (g)	2	3.6 3.0 <u>17.4</u> <u>10.9</u> 53.2 10.1 1.8	5	1.5 6.9 <u>33.1</u> <u>13.4</u> 38.1 5.9 1.1	8	0.6 4.8 <u>32.5</u> <u>14.3</u> 40.5 6.8 0.5	1.05 5.85 <u>32.80</u> <u>13.85</u> 39.30 6.35 0.80
(C)	(a) (b) (c) (d) (e) (f) (g)	3	3.1 2.2 <u>15.6</u> <u>8.1</u> 50.0 13.9 7.1	6	2.1 16.5 <u>30.3</u> <u>13.2</u> 34.3 3.6 0.0	9	1.1 17.8 <u>36.7</u> <u>9.9</u> 27.9 6.6 0.0	1.60 17.15 <u>33.50</u> <u>11.55</u> 31.10 5.10 0.00

LEGEND:

- 2 DOTS ABOVE GLIDE SLOPE
- 1 DOT
- ON
- 1 DOT BELOW
- 2 DOTS
- ARTIFICIAL HORIZON WITH V COMMAND BAR (no peripheral cue lights)
- ARTIFICIAL HORIZON WITH CUE LIGHTS
- CUE LIGHTS ONLY (no artificial horizon)

FIGURE 13. Mean scores of time flown above, on, and below glide slope in relation to use of three different instrument/cue light display modes during nine ILS approaches. As expected, time "on" glide slope was greatest while using the flight director "V" bar (mode A). Surprisingly, time spent *below* glide slope was least in mode C (36.20% versus 44.50% in mode A).

than did the other two display systems. However, the lack of any statistically significant difference between the scores for modes B and C suggests that use of peripheral vision cues, *with or without availability of the attitude indicator*, provides comparable glide slope performance. In the latter case, control of the aircraft's pitch attitude had to be based on the pilot's integration of data obtained visually from three instruments—the airspeed indicator, the vertical speed indicator, and the glide slope/localizer indicator.

Below Glide Slope. A rather unexpected finding shows up with respect to time flown within one dot below glide slope in the three display modes; these were 43.30% in mode A, 39.30% in mode B, and 31.10% in mode C. The mode C time was significantly less (28%) than the time flown below glide slope while using the command bar/attitude indicator display in mode A. In examining this difference of “below-glide-slope” performance between modes A and C, it is interesting to note there is little difference between the times flown within one dot *above* versus one dot *below* glide slope (c vs. e) in modes B and C (Figure 13). The scores are 32.80% (above) and 39.30% below in mode B, and 33.50% above and 31.10% below in mode C. On the other hand, there is a large, statistically significant difference between the two in mode A—26.95% above vs. 43.30% below.

Constant observation of the subjects' eye movements during the approaches showed a reduced scan rate of the instrument panel in mode A compared to mode C. In mode A, the subjects tended to fixate on the command bar/attitude indicator to the exclusion of other instruments. In mode C appreciable visual attention was devoted to the vertical speed indicator, the glide slope/localizer needles, the direction indicator, and the airspeed.

A factor that may have accounted in part for the extra time spent below glide slope in mode A is the relatively large mass of the Boeing 720 (in this case, 170,000 pounds) in combination with the relative movement between the command bar and the aircraft symbol in the attitude indicator. When this large mass descends below the intended flight path the pilot must raise the real aircraft's nose for an appreciable time to arrest the unwanted descent until the aircraft again intercepts the glide slope. Such a pitch change

increases drag, slows the aircraft, and causes nose “heaviness;” this, in turn, causes the aircraft to gradually pitch downward unless the pilot holds sufficient back-pressure on the control wheel to counteract this pitching moment. If he fails to do so, the aircraft again descends below the desired flight path. The difficulty of accurately perceiving the small amount of pitch change required to hold a proper pitch attitude (sometimes as little as $\frac{1}{16}$ inch relative movement between the small symbolic aircraft and the command bar) may contribute to this error in performance. On the other hand, movement of the glide slope needle and vertical speed indicator needles—necessarily used for pitch reference in mode C—are much larger, permitting quicker visual recognition of developing errors in pitch control, thereby perhaps inhibiting excessive descents below glide slope.

The means, standard errors, and standard deviations for glide slope performance are shown in Table 4.

TABLE 4. Means, standard errors, and standard deviations of glide slope performance relative to maintaining aircraft within a total range of one-dot-deviation above and below glide slope centerline.

Pattern	$\bar{x} \pm S.E. \bar{x}$ (secs.)	S.D.
1-----	93.1 \pm 3.13	13.98
2-----	81.5 \pm 4.58	20.46
3-----	73.6 \pm 7.71	34.47
4-----	96.0 \pm 1.45	6.50
5-----	84.6 \pm 4.07	18.18
6-----	77.7 \pm 7.43	33.22
7-----	94.9 \pm 1.91	8.55
8-----	87.4 \pm 4.28	19.14
9-----	74.5 \pm 5.93	26.49

Localizer Performance. Performance related to localizer path adherence is shown in Figure 14. As indicated in the column labeled “Combined Means,” the average time “on” localizer* in mode A was 58.25%; values for modes B and C were 29.00% and 34.70%, respectively. The differences between A and B, and A and C were significant at the .01 level of confidence. There was no significant difference between modes B and C.

*Localizer needle within confines of “bulls-eye” circle on instrument face.

Differences between standard deviations for on localizer performance were small, ranging from a high of 24.37% (approach 6—mode C) to a low of 20.93% in approach 9—mode C.

Maintenance of the aircraft within the confines of one dot on either side of the localizer path (including time "on" course) was accomplished with no significant difference between the three display modes. However, as shown in Table 5, there were wide variations in standard deviation. In approaches 4 and 7 (mode A) there was no variation but in approaches 5 and 8, (mode B) the standard deviations were 7.14 and 11.87, respectively. In 6 and 9 (mode C) standard deviations were 2.68 and 4.78, about one-third of those in mode B in which the attitude indicator without the "V" bar was utilized.

Recoveries from Unusual Attitudes. Time required to return the aircraft from 60° and 80° banks to a wings-level attitude is shown in Table 6. When the conventional instrument display was used (without assistance of peripheral cues) the mean recovery time was 20.6 seconds with a standard deviation of 5.5 seconds. A significantly lesser time ($p < .01$) was required for recoveries

from similar bank angles while using the peripheral cue lights as the only flight display; mean time for all subjects was 16.9 seconds with a standard deviation of 2.8 seconds.

Of even greater interest was the fact that no reversals (attempting to recover in the wrong direction due to incorrect interpretation of available cues) occurred while using the peripheral

TABLE 5. Means, standard errors, and standard deviations of localizer performance relative to maintaining aircraft within a total range of one-dot-deviation on either side of localizer centerline.

Pattern	$\bar{x} \pm S.E. \bar{x}$ (secs.)	S.D.
1-----	99.6 \pm 0.40	1.79
2-----	92.4 \pm 4.69	20.97
3-----	88.3 \pm 6.23	27.87
4-----	100.0 \pm 0.00	0.00
5-----	97.3 \pm 1.59	7.14
6-----	99.4 \pm 0.59	2.68
7-----	100.0 \pm	0.00
8-----	96.5 \pm 2.65	11.87
9-----	98.9 \pm 1.06	4.78




MEAN LOCALIZER SCORES								
INSTRUMENT DISPLAY MODE :	POSITION OF A/C "LEFT", "ON", "RIGHT" OF LOCALIZER CENTERLINE	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	APPROACH SEQUENCE	MEANS %	COMBINED MEANS (%) (4 thru 9)
(A) 	(a) LEFT	1	0.0	4	0.0	7	0.0	0.00
	(b) LEFT		0.4		0.0		0.0	0.00
	(c) LEFT		13.5		13.5		13.9	13.70
	(d) LEFT		<u>54.4</u>		<u>55.6</u>		<u>60.9</u>	<u>58.25</u>
	(e) RIGHT		31.7		30.9		25.2	28.05
	(f) RIGHT		0.0		0.0		0.0	0.00
	(g) RIGHT		0.0		0.0		0.0	0.00
(B) 	(a) LEFT	2	3.5	5	0.0	8	0.0	0.00
	(b) LEFT		4.1		0.0		0.7	0.35
	(c) LEFT		22.2		38.8		31.5	35.15
	(d) LEFT		<u>36.4</u>		<u>25.7</u>		<u>32.3</u>	<u>29.00</u>
	(e) RIGHT		33.8		32.8		32.7	32.75
	(f) RIGHT		0.0		2.7		2.8	2.75
	(g) RIGHT		0.0		0.0		0.0	0.00
(C) 	(a) LEFT	3	0.0	6	0.0	9	0.0	0.00
	(b) LEFT		8.9		0.6		0.0	0.30
	(c) LEFT		33.0		37.9		34.3	36.10
	(d) LEFT		<u>29.7</u>		<u>35.8</u>		<u>33.6</u>	<u>34.70</u>
	(e) RIGHT		26.1		25.7		31.0	28.35
	(f) RIGHT		2.9		0.0		1.1	0.55
	(g) RIGHT		0.0		0.0		0.0	0.00
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FIGURE 14. Mean scores of time flown "on" and to either side of the localizer centerline in relation to use of three instrument/cue light display modes. Time spent "on" localizer was significantly less in modes B and C, but scores for flight within the confines of one dot to either side of center were close in all three display modes; i.e., mode A—100.00%; mode B—96.90%; and mode C—99.15%.

cue lights. On the other hand, six (30%) of the 20 subjects rolled the airplane in the wrong direction while using the conventional instrument display without peripheral cue lights. One of these six maintained the wrong direction of roll for such an extended period of time he would have crashed inverted, had he been in an actual airplane. This is particularly significant when the experience and skill level of the subjects are considered.

IV. Summary and Conclusions.

To provide information on the effect of peripheral vision cues on pilot performance during instrument flight, 20 ATR pilots flew nine ILS (instrument) approaches in a Boeing 720 jet aircraft simulator using three different instrument displays; i.e., (1) all instruments* including flight director system ("command" bar with attitude indicator), (2) peripheral vision cue

lights with all instruments*, including attitude indicator but without "command" bar, and (3) peripheral cue lights—as sole source of bank angle information—with all instruments* *except the attitude indicator*.

The three principal performance categories investigated during the ILS approaches were aircraft deviation from: (1) wings-level flight, (2) glide slope centerline, and (3) localizer centerline.

Effects of peripheral cue lights on pilot performance in recovering from steeply banked, unusual attitudes were also investigated; recoveries were made with (1) all instruments* available (no cue lights), and (2) with peripheral vision cue lights only.

The performance data obtained during these recoveries included: (1) time required to recover

*With exception of turn and slip indicator which was covered during entire study.

TABLE 6. Recovery to a wings-level attitude from 60- and 80-degree left and right banks was accomplished significantly faster when using only peripheral vision cues. Maneuvers #1 and #4 were to the left with 60° and 80° banks respectively; #2 and #3 were to the right at 80° and 60°, respectively. (All times given in seconds.)

Subject	Conventional instruments		Total time	Peripheral cues only		Total time
	1*	2*		3*	4*	
1.....	5.5	10.0	15.5	5.0	6.5	11.5
2.....	11.5	15.0	26.5	9.0	10.0	19.0
3.....	8.0	12.5	20.5	7.0	9.0	16.0
4.....	6.0	5.5	11.5	6.0	11.0	17.0
5.....	14.0	11.0	25.0	5.5	12.0	17.5
6.....	5.5	9.0	14.5	6.5	5.5	12.0
7.....	7.5	7.0	14.5	7.0	8.5	15.5
8.....	12.5	10.0	22.5	12.0	9.5	21.5
9.....	6.0	6.5	12.5	7.0	8.5	15.5
10.....	5.0	19.5	24.5	5.5	6.5	12.0
11.....	10.0	12.5	22.5	7.0	7.5	14.5
12.....	9.5	10.5	20.0	12.0	7.5	19.5
13.....	8.5	17.0	25.5	10.0	9.0	19.0
14.....	13.0	21.5	34.5	7.5	8.0	15.5
15.....	11.0	7.0	18.0	7.0	9.0	16.0
16.....	10.5	8.0	18.5	8.0	10.0	18.0
17.....	8.0	12.0	20.0	9.0	11.0	20.0
18.....	10.0	10.0	20.0	7.5	12.5	20.0
19.....	11.0	14.0	25.0	11.5	7.5	19.0
20.....	10.0	11.5	21.5	10.5	8.5	19.0
Means.....	9.1	11.5	20.6	8.0	8.9	16.9
Standard errors.....	0.59	0.94	1.23	0.48	0.41	0.64
Standard deviations.....	2.67	4.24	5.50	2.17	1.84	2.87

*Maneuver sequence number (recovery from unusual attitudes).

to wings-level flight, and (2) pilot reaction, recovery technique and direction of initial and subsequent recovery attempts.

Statistical tests of the data showed that use of peripheral vision cue lights resulted in:

1. Improved performance in maintaining wings-level flight;

2. Less time flown below glide slope as compared to that when all instruments (including the command bar function of the Collins 108 system) were used;

3. Comparable performance in maintaining position within one dot of the localizer/glide slope centerline, with or without the attitude indicator;

4. Safe instrument approaches with a "failed" attitude indicator using vertical speed indicator primarily for pitch control; and

5. Improved performance in recoveries from unusual attitudes with smoother control application, less pitch oscillation, reduced airspeed and altitude variation and less time required to return to a wings-level attitude, with no reversals.

The improved performance in maintaining a wings-level attitude during the instrument approaches was not unexpected, since the peripheral vision cue lights alert the pilot to inadvertent banks sooner than would normally occur while using the conventional attitude indicator. This, of course, serves to reduce variations in heading, and in turn, allows more visual time to be devoted to other instruments.

The findings that a disproportionate amount of time was spent *below* glide slope while using the complete "108" instrument display system was surprising and may have been due, in part, to a lack of complete familiarity with the 108 instrument. Further investigation of this problem in flight might be desirable to determine whether this occurs during actual instrument approaches with pilots who are completely familiar with the display system.

The close similarity of performance in the two display modes utilizing the peripheral vision cues—with and without the attitude indicator—presents several interesting questions. Since the peripheral cues relate directly to bank angle only, how were the subjects able to consistently make

safe ILS approaches without the customary pitch angle cues normally obtained from the attitude indicator? It may be assumed that this was accomplished by using information obtained from either the vertical speed indicator, the glide slope needle, the air-speed, or all three. Could the same results have been achieved with cues from only one of these three instruments? Additional research will be in order to answer these and other closely related questions for, in the opinion of these investigators, much remains to be done in developing a display system that more closely fits the psychophysiological demands made on the pilot. Certainly, it is most interesting that pilots with little or no previous experience in making ILS approaches without an attitude indicator were able to do so—easily and safely—by use of a relatively strange display system.

Lack of reversals while using only peripheral vision cues for recoveries from unusual attitudes (compared to the occurrence of reversals with the conventional instrument display) suggests a human factors design deficiency in present day attitude indicators, even in those with a marked color differentiation between sky and ground on the face of the instrument. In addition, the demonstrated lack of hesitation in recovering in the proper direction when using peripheral vision cues implies a very definite need for improving present methods of providing the pilot with aircraft attitude information.

Also, it is of interest that when the subjects were concerned only with rolling the airplane to a wings-level attitude (by use of the peripheral cues and without the necessity of monitoring pitch attitude, airspeed, and altitude) recovery technique was smoother with less "manhandling" of the controls.

In final summation, it may be said that this study has demonstrated that peripheral vision cues can be a useful aid in making instrument approaches and recovering from unusual attitudes.

V. Recommendation.

It is recommended that further research be conducted to find means of more fully utilizing the peripheral vision capabilities of flight crew members.

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