PILOT RESPONSE TO PERIPHERAL VISION CUES DURING INSTRUMENT FLYING TASKS

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I. Introduction.

Flying an aircraft by visual reference to the ground or horizon is a relatively natural function compared to flying by sole reference to the cockpit instruments. During instrument flying, stimuli produced in the inner ear and deep muscles of the lower torso are often in conflict with visual cues provided by the flight instruments. When this conflict occurs, the pilot may disregard his visual sense in favor of the strong sensations of balance and feel, and inadvertently place his aircraft in an abnormal or hazardous attitude.

In order to minimize the chances of such an occurrence, instrument flight training stresses the requirement for absolute dependence on the visual senses, with almost total disregard for the sensations of balance and kinesthesia. This complete dependence on vision requires nearly continuous scanning of the flight instruments to assure constant input of attitude information. Because of this conflict between the senses, instrument flying can be considered, from the physiological point of view, as an "unnatural" human function. To overcome the effects of this conflict requires a great deal of initial training,* followed by periodic—recurrent—training.** In fact, ATR (Air Transport Rating) pilots employed by scheduled airlines must also undergo an instrument flight check every six months to demonstrate an acceptable level of performance in flying safely by sole reference to their instruments (US FAR 121.441(b)(24)). Also, it may well be that the additional time and expense involved in learning to fly by instrument has been a major factor in deterring most private pilots from seeking this additional training, for according to the FAA, less than 3% of all U.S. private pilots held instrument ratings as of December 31, 1965.[13]

The principal instruments used by a pilot to control his aircraft during actual or simulated instrument flight consist of six dial-type indicators (Figure 1) which provide information on airspeed, attitude, altitude, vertical speed (rate of climb/descent), magnetic heading, and rate of turn. Of the six instruments, the attitude indicator (Figure 2) is the most important because it is the only instrument that provides simultaneous information on both the pitch and bank attitude of the aircraft.

However, the scanning of these flight instruments must be expanded periodically to include other instruments such as fuel flow meters, temperature gauges, etc. Also, the scanning may be interrupted for several seconds periodically to study navigational charts, change radio frequency, copy an ATC clearance and to perform other tasks not directly associated with controlling the attitude of the airplane.

Because of the nature of contemporary instrument design,[19,28] little useful information can be obtained from these displays unless direct vision is employed. In present day cockpits, the pilot must look *directly at* each indicator to obtain accurate information. Because of this, minimal scanning of the instruments is almost a full-time job, even during routine IFR conditions.

Response of the pilot to visual stimuli requires at least 1/5 second;[29] in some cases, the time required to react muscularly may be as high as two seconds.[30] Thus, when two or three instruments are viewed in succession, three to six seconds may elapse from the time the pilot begins to scan the instruments until the aircraft starts to respond to the pilot's manual input. In severe turbulence

* "An applicant for an instrument rating must have at least 40 hours of instrument time under actual or simulated conditions, including time acquired in a synthetic trainer. That time must include at least 20 hours of flight time of which at least 15 hours must be instrument flight instruction given by a flight instructor with an appropriate instrument rating on his flight instructor certificate." (US FAR 61.35,(c) Amendment #24).

** "A pilot may not act as pilot-in-command of an aircraft under IFR (Instrument Flight Rules) or in weather conditions less than prescribed VFR (Visual Flight Rules) minimums unless, in the preceding six calendar months, he has had at least six hours of instrument time under actual or simulated instrument conditions. . . ." (US FAR 61.47(d)).

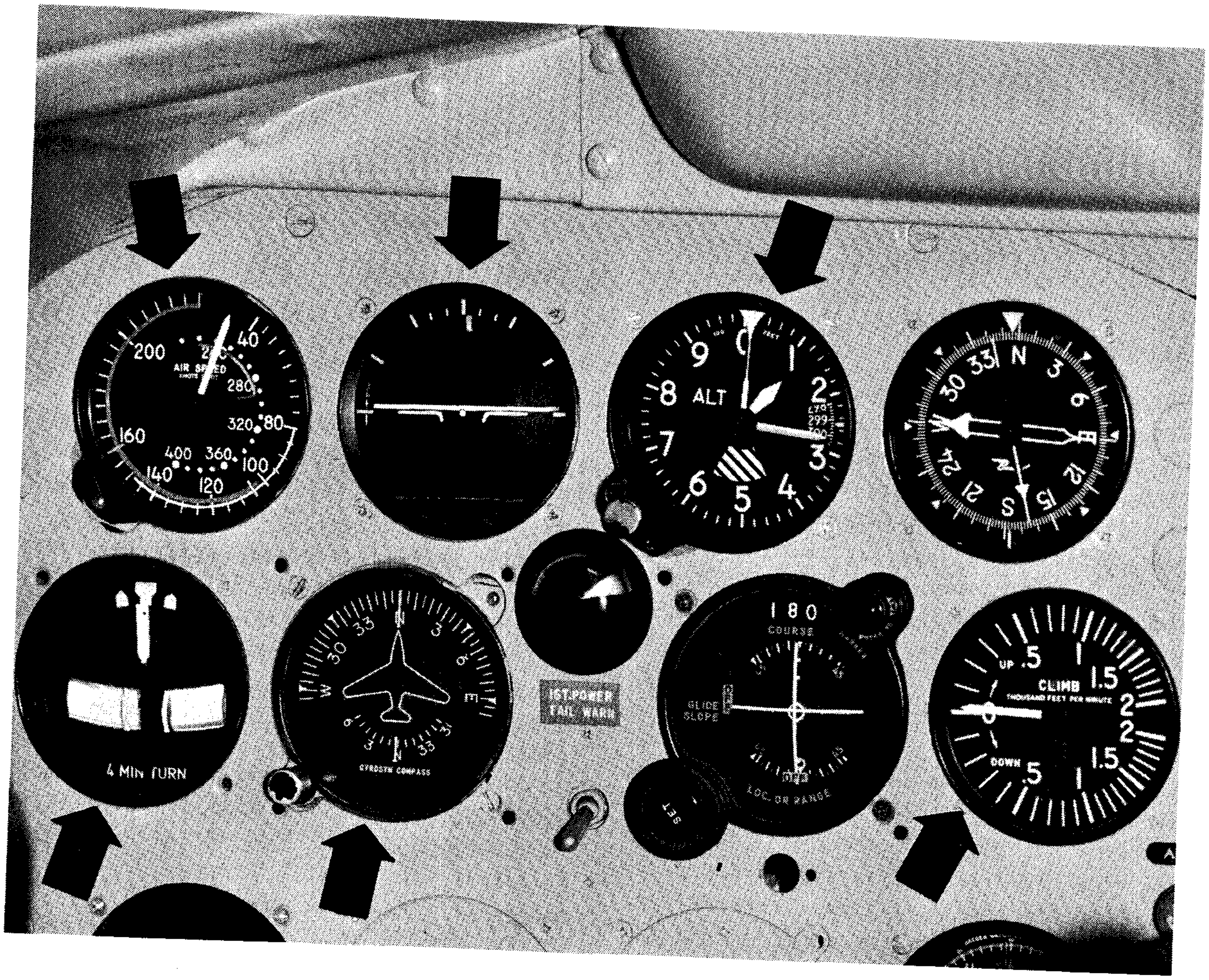

FIGURE 1. Flight instrument layout in Convair 340 airline type aircraft. Arrows point to pilot's primary flight instruments (co-pilot has duplicate set on right side of panel). Attitude indicator is under top-center arrow.

where the aircraft may be subjected to high rates of roll, this lapse of time can result in excessive bank angles if the pilot is delayed in resuming his scan pattern after performing some other task in the cockpit. For this and other reasons, some private plane owners spend relatively large sums of money (as much as $13,000) to install automatic flight control devices in their aircraft. However, since only a small percentage of lightplanes are equipped with these devices, most private pilots must keep their aircraft "right-side-up" during turbulent IFR conditions by manual means alone.

The attitude indicator is the only instrument capable of providing pitch and roll cues simultaneously. It has a fixed, symbolic aircraft with a moving horizontal bar that represents the real horizon; these depict the angular relationship between the actual horizon and the real aircraft. If the attitude indicator is not observed every few seconds—virtually to the exclusion of many of the other flight instruments—it is difficult to maintain desired aircraft attitude, particularly in rough air. This is due to the roll characteristics of many aircraft; even in smooth air, few airplanes will fly "hands-off" for any length of time without banking to one side or the other.

Of the three axes around which an aircraft can rotate, control of the roll axis (bank angle) is usually the most critical and the most important in relation to control of speed and heading. During VFR* (contact) flight, when visual reference to the real world outside the cockpit is constantly

* "Visual Flight Rules." A commonly used term meaning that the weather conditions permit flight by visual reference to the ground or natural horizon.

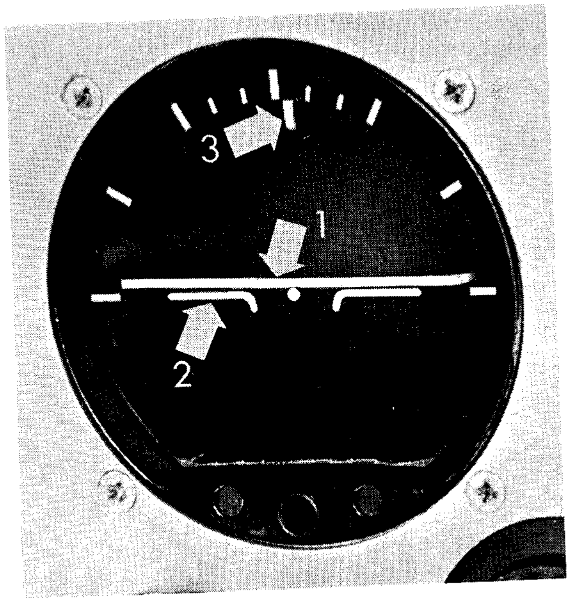

FIGURE 2. The attitude indicator (artificial horizon) provides pitch and roll information simultaneously. The horizon bar (arrow #1) moves vertically in relation to the fixed aircraft symbol (arrow #2) to indicate an up or down nose (pitch) attitude. The bar rotates to the left or right to show bank (roll). Angle of bank is shown by relationship of the moving pointer (arrow #3) to the fixed indices on the periphery of the instrument face.

available, a pilot has no trouble in keeping his aircraft on an even keel, even when diverting his attention to tasks within the cockpit. Apparently, some visual reference is maintained peripherally with the outside world, providing the pilot with information to correct any undesired change in the aircraft's roll or pitch attitude. (Although the degree to which peripheral vision cues are used to correct or maintain aircraft attitude during "contact" weather is unknown, some preliminary research information recently obtained in this laboratory has demonstrated that controlling aircraft attitude by visual reference to the outside world becomes more difficult when the pilot's peripheral vision is restricted to a subtended angle of less than 5°). Unlike contact flying, peripheral cues are nonexistent during instrument flight conditions, due to loss of reference to the outside world—and because of the nature of contemporary instrument design. This forces the pilot to depend on central vision to obtain accurate roll and pitch information from the attitude indicator.

From the foregoing, it is apparent that instrument flying involves two sets of visual tasks that are basically in conflict with each other; i.e., (1) obtaining continuous information on aircraft attitude by use of foveal vision, and (2) performing other cockpit duties that also require use of foveal vision. Obviously, any major variation in apportionment of visual attention may detract from the total efficiency of the overall flight task. If an emergency occurs, such as failure of an engine, attention probably will be diverted from the flight instruments, further randomizing the attitude data received through the pilot's eyes. As the acquisition of these discrete data becomes less frequent, the pilot's response may become erratic, further complicating the task of flying the aircraft in a smooth and safe manner.

Ideally, the solution to the problem may be to cue the pilot continuously—rather than intermittently—on all functions of the aircraft. From a practical point of view, this would appear to be an impossibility. However, if none other than *roll* data were absorbed continuously, this alone would serve to make the flight task easier and less fatiguing.

There are several ways in which continuous roll information could be fed to the pilot: e.g., by aural signals; presure against the body (such as on the side of the shoulders or hips, or against the legs or feet); rotary or lateral displacement of the control wheel or stick; differential expansion of the hand grips on the wheel or stick; and/or visual signals acting peripherally and/or foveally. Since, as mentioned previously, pe-

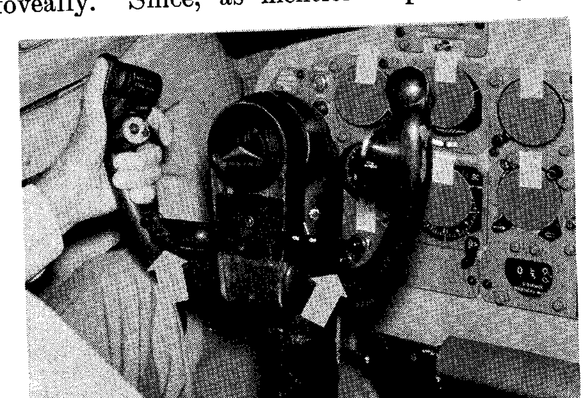

FIGURE 3. Pilot response to peripheral vision cues was studied using two sets of small colored lights attached to pilot's control wheel in aircraft simulator. Upper bulbs were red, lower ones green. (Installation shown here is in Boeing 720 simulator.)

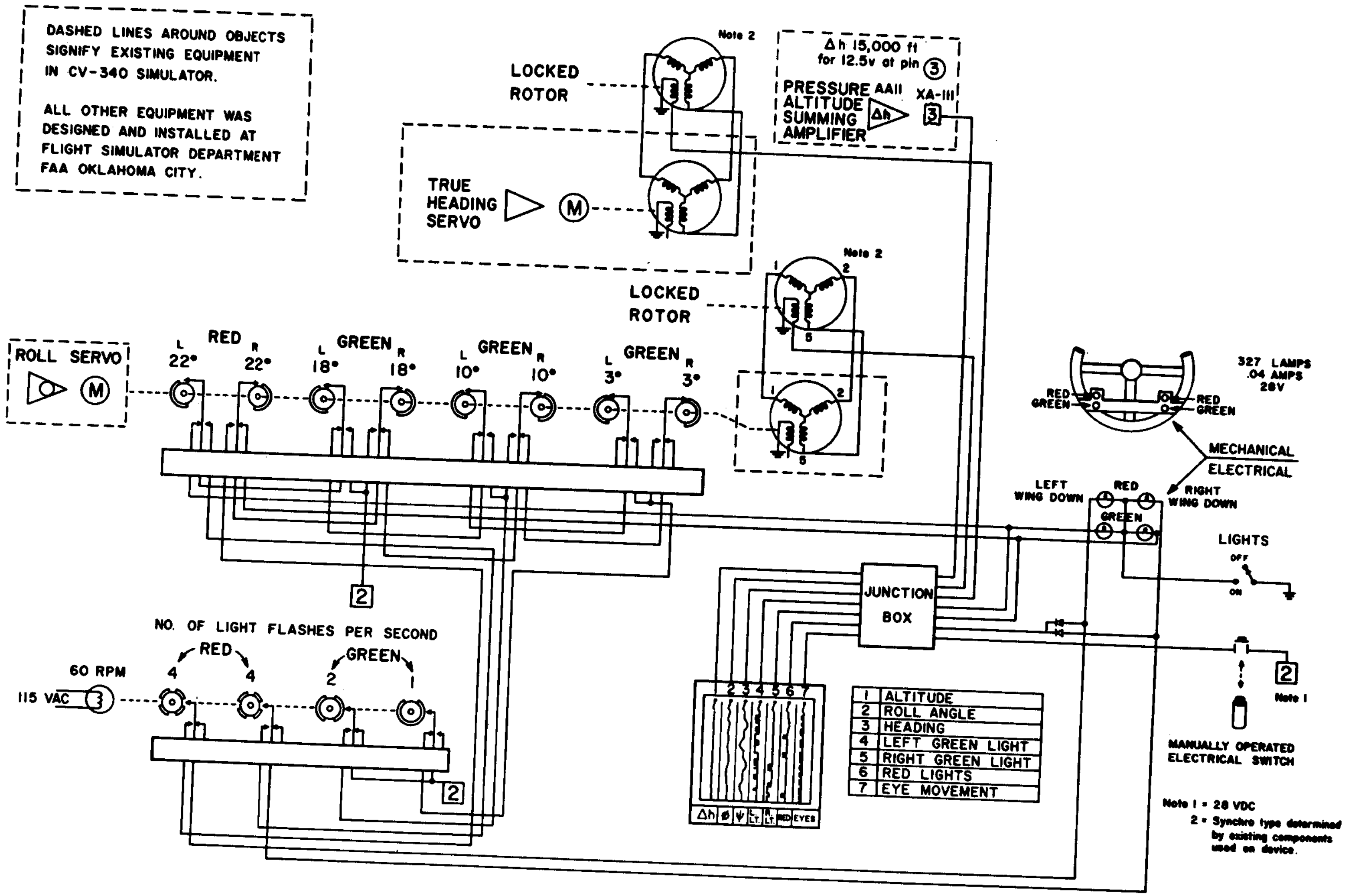

Figure 4. Schematic diagram of electrical circuitry used to activate cue lights in relation to aircraft simulator bank (roll) angle.

ripheral vision is used routinely during "contact" or good-weather flying, it was decided to conduct a study of pilot response to this type of visual function as it might relate to controlling aircraft roll attitude during instrument flight conditions.

II. Methodology.

Peripheral Cue Lights. Two sets of small lights were used as cueing devices (Figure 3); each set consisted of a red bulb and a green bulb. One set was installed near the lower left corner of the pilot's control wheel; the other was near the right-hand corner. Activated by a camming device connected to the roll servo of an aircraft simulator computer (Figure 4), the left-hand lights illuminated during left turns, and the right-hand ones operated during right turns.

In contemplating the use of lights for peripheral cues, several factors are evident; first, the lights should not add to the pilot's perception problems; second, their operation should not produce an irritating effect except when such an effect is desired as a warning; and third, they should produce the desired response as a relatively *natural* function. Based on this, a "negative" cue (lack of any cue light illumination) was used to inform the pilot when he was in relatively *level* flight. To prevent continuous operation of the cue lights during level flight in rough air, the non-illumination range involved a total roll-angle range of six degrees—from zero to 3°, left or right. Between 3° and 10° of roll, the green light was set to flash once per second; from 10° to 18° the green light rate was doubled to two flashes per second. To provide for turns in the holding patterns, the green light illuminated *steadily* in a 4° range from 18° to 22° of bank. From 22° to 90° of bank, the green light was extinguished and the *red* light flashed four times per second.[12]

Flash durations of the lights were as follows:

Green—(1 flash/sec.) = 0.185 sec. duration per flash.

Green—(2 flashes/sec.) = 0.125 sec. duration per flash.

Red—(4 flashes/sec.) = 0.100 sec. duration per flash.

Thus, when the green light was flashing at a rate of one flash per second, about 1/5 of each second involved incandescence (exclusive of nigrescence); when the flash rate was two per second, the bulb was lit for 1/4 of each second. When the red light flashed, light radiation was apparent for almost 1/2 of the total time (Figure 5).

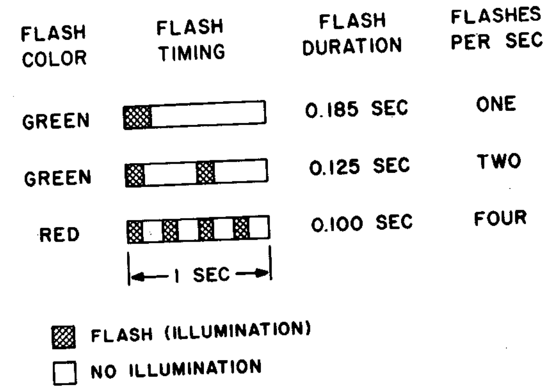

FIGURE 5. Flash timing and duration of cue light illumination was controlled by electro-mechanical camming device installed in simulator computer equipment.

Cockpit Illumination. General luminance within the cockpit was the same for all subjects but varied by areas, ranging from approximately −.2 log. foot lamberts (ft.−L.) at the instrument panel (under the glare shield) to .8 log. ft.−L. at the windshield. At the center of the cockpit the luminance was about −.1 log ft.−L. and at the side window it was .75 log. ft.−L. In the pilot's lap area it was about .2 log. ft−L. The bulbs used for the cue lights were G. E. #327's, using 0.04 amps at 28 volt, 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 2.6 log. ft.−L. for the green bulb and 3.2 log. ft.−L. for the red.

Research Apparatus. A Curtis-Wright Dehmel Convair 340 flight simulator was used. In order to obtain performance charactertistics similar to those of a light twin, such as a Cessna 310 or Beech Twin Bonanza, the simulator's speed and flight characteristics were altered by appropriate changes in flap and power settings.

Data Recorded. Data recorded during the flights consisted of the following, in relation to time: (a) altitude—(feet), (b) bank angle (left or right), in degrees, (c) magnetic heading—(degrees), (d) duration, flash rate and left/right indication of green light, (e) duration, flash rate and left/right indication of red light, (f) eye movements (up or down) of subject, and (g) number and accuracy of mathematical problems completed. All but the last item were recorded on a Sanborn 800 recorder; these data were then transferred to punch cards for statistical analyses.

Subjects. Since pilots of widely varying flying experience are involved in weather accidents, thirty pilots with flight time ranging from 52 hours (this subject had only 1½ hours of instrument flight training) to 12,000 hours were used as subjects (Table 1). Sixteen of the 30 were qualified to fly by sole reference to instruments; the others met only "visual flight rules" requirements. Eleven held private licenses, another eleven were commercial pilots, and the remaining eight held ATR ratings. All had a normal field of vision as well as normal color vision according to their FAA physical examination records. Chosen in as random a manner as practicality permitted, the group was divided almost equally between pilots with less than 1,000 hours flying experience and pilots with more than 1,000 hours. The youngest subject was 19 years of age; the eldest was 60 (mean, 38.6 years; standard deviation, 10.8) resulting in a range of 27.8 to 49.4 years for ⅔ of the subjects. This compares favorably with the mean age and standard deviation of all airmen certificated by the FAA in 1966 (35.1 and 10.8 years, respectively) of whom approximately 66% ranged between 24.3 and 45.9 years.[5]

TABLE 1. Total flight hours of 30 subjects used to study pilot response to peripheral vision cues in aircraft simulator.

Subject number	*Hours*	*Subject number*	*Hours*
1	50	16	900
2	54	17	1,200
3	55	18	1,400
4	115	19	1,500
5	145	20	2,500
6	154	21	4,600
7	160	22	4,000
8	170	23	7,000
9	200	24	7,400
10	221	25	7,900
11	250	26	8,000
12	300	27	9,000
13	350	28	9,000
14	400	29	8,950
15	550	30	12,500

Each subject was given an identical one-hour familiarization flight in the simulator; during this time and while the subject flew the aircraft in moderately banked turns and level flight, maintaining an altitude of approximately 4,000′, the observer (in the co-pilot's seat) described the use of the peripheral cue light system. At appropriate times during the familiarization flight, the instrument panel and peripheral lights were used in the same three combinations (or modes) subsequently used during the test runs; i.e., (a) normal instrument panel with *no* lights, (b) normal panel with lights, and (c) panel with lights but *without the attitude indicator* (Figure 6). Just before the end of the familiarization flight, the simulator was flown for five minutes by sole use of the peripheral lights—*with all of the flight instruments covered.*

Simulator Test Standards. Prior to each flight, all control functions and settings of the simulator were standardized. Center of gravity, gross weight, outside air temperature, barometric pressure, flap angle, power and rpm, oil cooler shutter position, trim tab settings, and all other adjustments that might effect the aircraft's performance and feel were set the same for each subject. Also, longitudinal trim was adjusted so the aircraft would not normally diverge through a range of more than 600 feet of altitude and/or 20 knots of airspeed during "hands-off" flight. In addition, the pilot seat was adjusted so that each subject's eye position was at about the same point in space.

Flight Patterns. Each subject was given two tasks: (1) to fly 15 holding patterns within certain desired limits, and (2) to solve a series of mathematical problems while flying nine of the 15 patterns. These patterns consisted of the standard "race-track" holding type involving (a) an approximate one-minute inbound leg, (b) a 180° change of direction (using a 20° angle of bank), (c) a one-minute outbound leg, and (d) another 180° change of direction with 20° of bank. Because of the speed (140 kts) and bank angle, each turn required approximately 90 seconds (when performed optimally); thus each pattern consumed about five minutes—or a total of about one hour and 15 minutes for all 15 patterns.

Two of the desired limits of operation were purposely made rather "loose" to accommodate the assumed lesser flying ability of those subjects

FIGURE 6. Attitude indicator was covered (arrow) during five of the 15 patterns. The two other instruments shown covered (an extra heading indicator and a remote radio compass indicator) were not essential to instrument flight and were not used during the study. In this photo, subject is maintaining level flight while performing mathematical task.

who had little or no instrument experience (the subject with the least amount of flying time, for example, also had no experience using an attitude indicator). These limits consisted of maintaining the inbound and outbound headings within plus or minus 10 degrees, and altitude within 300′± of the 4,000′ desired cruising altitude; an approximate bank angle of 20° was designated for the turns.

During a rest period in the cockpit (after the familiarization flight and prior to flying the 15 patterns) each subject was given a page of simple mathematical problems to solve (number facility test forms #16, #17, #18, and #19 of the Louis J. Moran Repetitive Measurements Battery); each paper sheet, on a clip board, was kept on the subject's lap during this task. He was instructed to solve the problems at his normal working rate. Data from these pre-flight sheets were used during subsequent analyses to compare error and working rates with those of similar tasks accomplished while flying the aircraft.

Instrument Display Modes. The patterns were flown alternately in three instrument display modes (Figure 7):

(a) Five patterns in which the full instrument panel (including the attitude indicator) was available, but *in which the peripheral lights were deactivated.*

(b) Five patterns in which the full instrument panel (including the attitude indicator) was available *and in which the peripheral lights also provided bank angle information*, and

(c) Five patterns in which only a "partial" instrument panel (*without the attitude indicator*) was available and in which the *peripheral lights were the only source of information on bank angle.*

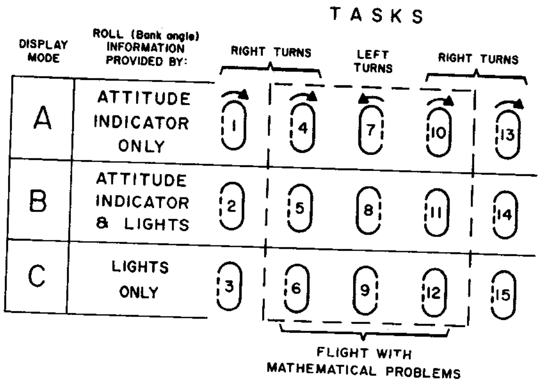

FIGURE 7. Experimental design. Each subject flew 15 "race-track" holding patterns in the direction and in the numbered sequence shown. The three types of bank angle cues available to the subjects are shown at the left and are referred to in the text as Modes A, B, and C. Mathematical problems were worked simultaneously while flying the aircraft in Patterns 4 through 12.

The turn and slip indicator was covered during the entire experiment, since this instrument is not routinely used by most instrument pilots.

Twelve of the 15 patterns involved turns to the right; the remainder (Nos. 7, 8, and 9) were to the left. During the first three and last three patterns the subjects were *not* required to accomplish any mathematical task in conjunction with the flight task. Thus, the first three patterns (No. 1, 2, 3) were utilized primarily to establish a minimum flight performance baseline; data from the last three (Nos. 13, 14, 15) were used to obtain the end point of any learning curve that might become evident. The middle nine patterns (Nos. 4, 5, 6, 7, 8, 9, 10, 11, and 12) provided data on the ability of the subjects to perform the flight and mathematical tasks *simultaneously.*

Experimental Procedure. The patterns were flown in the order shown in Figure 8. Each pattern consisted of four parts: (1) a 60-second inbound leg* in which the aircraft was flown on a north heading and at an altitude of 4,000 feet, (2) a level turn (a turn in which a given altitude is maintained), utilizing approximately 20 degrees of bank and involving a 180 degree change of direction, (3) a 60 second outbound leg on a south heading, and (4) a final, 20° banked turn, with another 180° change of direction.

At the completion of the last turn of each pattern, the alterations necessary to change from one instrument display mode to another were made rapidly by the observer; the peripheral cue lights were activated for patterns No. 2, 3, 5, 6, 8, 9, 11, 12, 14, and 15 by operation of a switch located at the right of the observer's seat, and the attitude indicator was covered with an adhesive plate for patterns No. 3, 6, 9, 12, and 15.

Also, the clip board with the appropriate mathematical test sheet was handed to the subject by the observer during the first (inbound) leg of patterns No. 4 through 12. The subject worked as many problems as he felt he could do safely while flying the aircraft through the first turn, the southbound leg, and the final turn. After completion of the last turn of each pattern, the subject handed the clip board back to the observer for attachment of the appropriate sheet to be used in the next pattern. Sheet No. 17 was used for patterns No. 4, 7, and 10; sheet No. 18 for Nos. 5, 8, and 11, and sheet No. 19 for patterns No. 6, 9, and 12.

For a record of eye movement (and unbeknownst to the subjects) the observer maintained constant visual surveillance on the subjects' eyes; when their gaze was directed toward the work sheet, the observer depressed a concealed switch button, activating the recorder stylus. The same individual was used to record the data on all 30 subjects.

After completion of the last pattern (No. 15), each subject was required to recover from steep turns in each of two display modes; i.e., (a) using the normal panel (including attitude indicator) but without the peripheral cue lights, and (b) using only the cue lights (with all instruments covered). In each instance, the subject kept his hands off the control wheel and his eyes closed until, after placing the aircraft in a bank of at least 80° (direction of turn was unknown to the subject), the observer rapidly centered the control wheel, removed his hands from the wheel and instructed the subject to take control. The subject then endeavored to place the aircraft in a level flight attitude. These recoveries completed the subject's tasks; no subject was used more than once in the study.

* Data recorded from this segment of each pattern were *not* used because this portion of the pattern was utilized to stabilize the simulator at the proper airspeed, heading, and altitude prior to entry into the first turn.

Performance Criteria. The primary criterion used for appraisal of flight performance was the amount of time each subject was able to maintain the desired bank angle in relation to the total time available. For example, if the time available for maintaining the desired bank angle in the two turns and the southbound leg was a total of 180 seconds (excluding "roll-in" and "roll-out" time, i.e., the time used to roll from level flight to the desired bank angle of 20° and then, near the end of the turn, to return to level flight), and the subject maintained the desired bank angle for a total of 120 seconds, his flight performance for that pattern would be 66.6% (120/180=0.666). Additional factors available for further modification of the flight performance scores included variations of heading, altitude, airspeed, and excessive bank angles.

Secondary Task Criterion. Secondary task performance during the middle nine patterns was based on the number of mathematical problems completed in each pattern, corrected to a baseline time period.

TABLE 2. Mean flight performance scores, standard errors, standard deviations, and observed ranges of 30 subjects for each of the 15 holding patterns.

Display mode	*Pattern*	*Mean Standard error*	*Standard deviation*	*Range*
A	1	71.7 ± 2.70	14.86	46.5–94.0
B	2	83.9 ± 1.89	10.39	59.2–99.5
C	3	65.5 ± 2.77	15.23	30.9–90.7
A	4*	51.8 ± 2.54	13.96	26.3–80.3
B	5*	66.3 ± 2.52	13.85	38.3–90.5
C	6*	61.8 ± 3.19	17.55	18.5–96.0
A	7*	56.9 ± 2.15	11.83	36.9–84.9
B	8*	68.5 ± 2.46	13.54	42.2–91.2
C	9*	67.6 ± 2.59	14.24	44.9–94.1
A	10*	54.9 ± 2.28	12.57	33.3–75.2
B	11*	66.8 ± 2.70	14.86	34.2–88.0
C	12*	63.8 ± 3.08	16.97	29.8–91.9
A	13	74.5 ± 2.45	13.49	45.2–98.1
B	14	85.3 ± 1.45	8.00	66.4–99.5
C	15	71.6 ± 2.54	13.96	35.6–89.4

*Patterns involving flight *and* mathematical tasks.

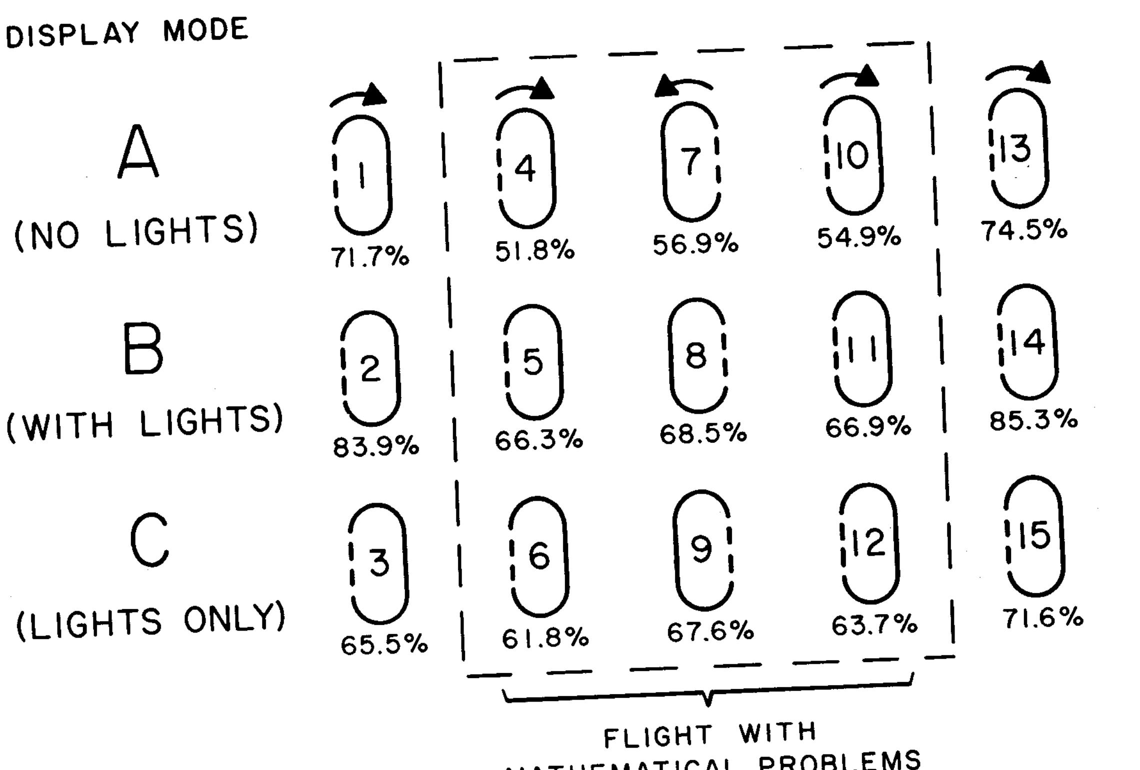

FIGURE 8. Mean flight task scores (percent of time at desired bank angle) of 30 subjects, each of whom flew the 15 holding patterns in the numerical sequence shown

Eye Movement Data. "Eye-down" time (subjects' eyes directed downward toward the mathematical task) in the various patterns was calculated as a percentage value of the total time used for all three segments of each pattern.

III. Results and Discussion.

Flight Performance. The mean flight performance scores, standard errors, standard deviations, and observed ranges for each of the 15 patterns are shown in Table 2. To determine whether learning was a significant factor in producing the flight performance scores shown in Figure 8, appropriate F tests and t tests were conducted on the scores for patterns 1 and 13; 4 and 7; 4 and 10; 2 and 14; 5 and 11; 3 and 15; 6 and 9; 6 and 12; and 9 and 12. No significant differences were found; thus, no learning factor appeared to be present.

Tests were then applied to the differences between patterns 4 and 6; 4 and 12; 10 and 5; 10 and 6; 10 and 11; 10 and 12; and 13 and 14. All patterns in which the peripheral cue lights were available demonstrated performance scores significantly better ($p=.05$ or greater) than those without the lights (Table 3). The difference between patterns 6 and 10 was particularly interesting since the subject was confronted for the first time in pattern 6 with the task of flying the aircraft *with only the cue lights for bank angle information* while simultaneously solving arithemetical problems. In pattern 10, on the other hand, the subject had already flown two similar patterns *while using the attitude indicator for roll angle data.* Despite his familiarity, flight performance was better in No. 6 (with cue lights) than in pattern 10 (without cue lights), further indicating that learning was not a significant factor.

Although the scores for the patterns involving turns to the left (Nos. 7, 8, and 9) were slightly better than for the adjoining right-hand patterns (perhaps due to roll bias in the simulator), the differences were not statistically significant. The data from both turns sets (Nos. 4, 7, 10; 5, 8, 11; and 6, 9, and 12) were thus combined within the three respective display modes; this resulted in mean scores for the patterns involving the additional mathematical task of 55.9% for Mode A, 67.2% for Mode B, and 64.3% for Mode C.

TABLE 3. Pattern comparisons, "t" ratios and level of statistical significance of flight performance of 30 subjects.

Pattern comparisons	"*t*"	*Significance*
1–13	.86	---
3–15	1.61	---
4–6	2.44	.05
4–7	1.52	---
4–10	.90	---
4–12	2.99	.01
5–10	3.33	.01
5–11	.13	---
6–9	1.40	---
6–10	1.75	.05
6–12	.44	---
9–12	.93	---
10–11	3.35	.01
10–12	2.30	.05
13–14	3.76	.01
13–15	.80	---
14–2	.58	---

Similarly, for those patterns in which no additional task was performed, data from patterns 1 and 13, 2 and 14, and 3 and 15 were grouped together in their respective display modes. The resulting mean scores for these were 73.1% for Mode A, 84.6% for Mode B and 68.5% for Mode C.

These scores, shown in Figure 9, disclose a decrement in flight performance when another task (one that takes the pilot's visual attention away from his instrument panel) is added to the flight task. In Mode A, for example, flight performance decreased 23.5%; in Mode B (light cues plus the attitude indictor), flight performance decreased 20.6%. However, in Mode C (cue lights only), flight performance decreased only 6.1%. In fact, this performance was only 8.8% less than that when the subjects had only the single task of flying the aircraft and could devote continuous visual attention to the flight instruments.

The effect of the use of peripheral cues on flight performance for a given task mode is further demonstrated in Figure 10. When the single task of flying the aircraft is examined, it is evident that flight performance was improved by 15.7% when the cue lights were utilized. When the mathematical task was added to the flight

Instrument Panel and Cue Light Display Mode:	Flight Performance		Difference	Percent Reduction In Flight Performance
	Without Extra Task	With Extra Task		
A (No Lights)	73.1	55.9	17.2	(17.2 / 73.1) 23.5%
B (With Lights)	84.6	67.2	17.4	(17.4 / 84.6) 20.6%
C (Lights Only)	68.5	64.3	4.2	(4.2 / 68.5) 6.1%

FIGURE 9. Flight performance as a function of additional task requirement.

Task Mode:	Flight Performance Scores — Normal Instrument Panel Display And:		Difference	Percent Increase In Flight Performance
	No Cue Lights	With Cue Lights		
WITHOUT EXTRA TASK	73.1	84.6	11.5	(11.5 / 73.1) 15.7%
WITH EXTRA TASK	55.9	67.2	11.3	(11.3 / 55.9) 20.2%

FIGURE 10. Flight performance as a function of use of peripheral cue lights.

task (lower line of chart) the use of peripheral cues improved flight performance by 20.2%.

Mathematical Task Performance. As shown in Figure 11, the means for the mathematical task scores for display Modes A, B, and C were 22, 28, and 27, respectively. With cue lights added to the normal panel (Mode B), task performance improved 27.2% ($p=0.01$) over that for Mode A; when roll information was provided solely by the lights, task performance improve-

Instrument Panel and Cue Light Display Mode:	Average Number Of Problems Worked	Difference	Percent Increase In Problems Worked
A (No Lights)	22		
B (With Lights)	28	(28 − 22) 6	(6 / 22) 27.2%
C (Lights Only)	27	(27 − 22) 5	(5 / 22) 22.7%

FIGURE 11. Mathematical task performance as a function of use of peripheral cue lights.

ment was 22.7% ($p=0.01$). Also, there was a direct correlation between flight performance and number of computations completed; the correlation of mean scores was .866.

Instrument Panel and Cue Light Display Mode:	Percent Time* Foveal Vision on Extra Task	Percent Difference: B – A C – A	Percent Increase of Time Foveal Vision Devoted to Extra Task
A (No Lights)	49.3		
B (With Lights)	65.6	16.3	(16.3/49.3) 33.0%
C (Lights Only)	65.3	16.0	(16.0/49.3) 32.4%

* Percent of total time available.

FIGURE 12. Visual attention to extra task as a function of use of peripheral cue lights.

Direction of Visual Attention. The amount of time the subjects' eyes were directed toward the mathematical task, (as compared to time looking elsewhere), is shown in Figure 12; the means are 49.3%, 65.6%, and 65.3% for display Modes A, B, and C, respectively. Statistical analyses indicated that significantly ($p=0.05$) more time was spent looking elsewhere (primarily at the instrument panel) in Mode A as compared with Mode B and Mode C; the latter two did not differ significantly from each other.

A summation of the flight and mathematical task performance is shown in Figure 13. When the peripheral cue lights were added to the normal instrument panel display (top line), flight performance for a given task mode was better than for the other display modes. Extra task performance, as revealed by the vertical bars at the bottom of the chart, demonstrates the variations in improvement as they relate to various display modes and use of the peripheral cue lights.

The means, standard deviations, and observed ranges of flight performance are shown in Figures 14 and 15 for patterns 10/11, and 13/14, respectively. As indicated by the shift of the lower bars to the right in each diagram, the addition of peripheral cue lights improved performance in both task modes. When the task was confined solely to flying the aircraft, the performance range was condensed by addition of the cue lights, reducing the spread between the lowest and highest scores.

Heading Variation. Although a maximum heading variation of 20° was considered an appropriate performance "target" during flight on the outbound legs of the patterns, 385 (85.5%) of the 450 patterns were flown within a smaller range of 10 degrees. Eleven percent involved a variation from 11 to 20 degrees; about 2½% deviated as much as 30°. Less than 1% (the remainder) exceeded 31 degrees of heading variation.

The number of legs involving heading variations in excess of 10° is shown in Figure 16; in each case, it is evident that the least number of deviations occurred in patterns in which the peripheral cue lights were available for use with the normal instruments (patterns 2, 5, 8, 11, and 14). In the 11°–20° and the 21°–30° ranges, deviations occurred 39% and 20% less often, respectively, in Mode B (with cue lights) than in Mode A.

The number of legs in which deviation in excess of 10° occurred averaged 6.5 for the single task (flight only) patterns and 17.3 in the two-task (flight and mathematical tasks) patterns. However, almost 80% of the latter were in Mode A in which the peripheral cue lights were *not* available.

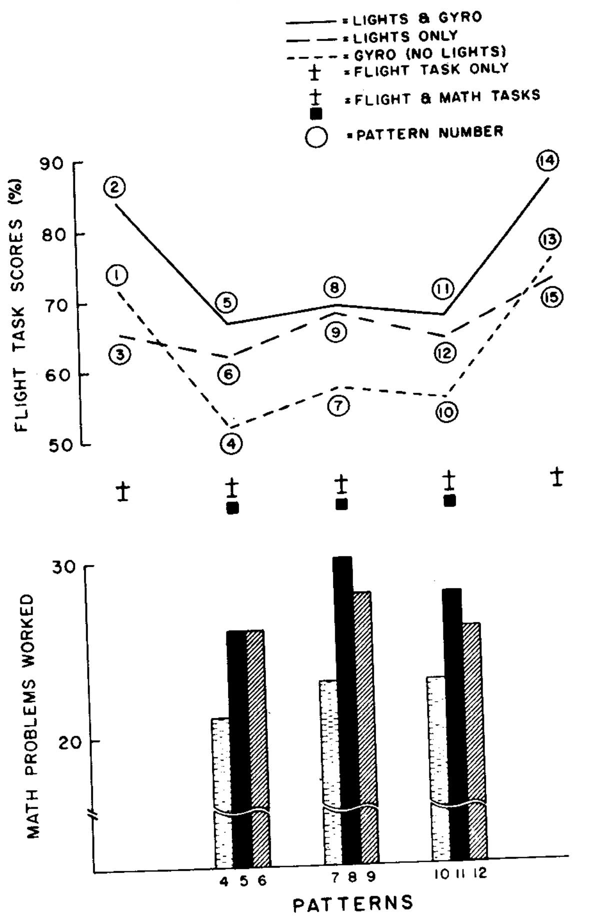

FIGURE 13. Flight and mathematical task performance relationship; flight performance (solid and dashed lines) decreased with addition of mathematical task (bars). Least relative decrement occurred when peripheral cues were used solely for roll angle information (middle line). Mathematical task performance was lowest with conventional panel (no peripheral cues) in Patterns 4, 7, and 10. (The word "gyro" as used herein refers to attitude indicator instrument.)

Altitude Variation. Twenty-four of the 30 subjects remained within an altitude range of 200 feet throughout all patterns; the remaining six (20%) exceeded this range a total of nine times but stayed within a range of 400 feet. Of these nine events, seven occurred in turns, indicating that level flight was less conducive to altitude variation.

Flight Performance and Instrument Flying Qualification. Of the 30 subjects, 18 (60%) were qualified to fly solely by use of their normal flight instruments without visual reference to the

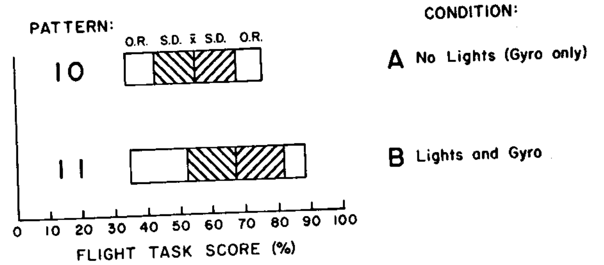

FIGURE 14. Means, standard deviations, and observed ranges of subjects' flight task score while visual attention divided between two tasks. ("Gyro" refers to attitude indicator.)

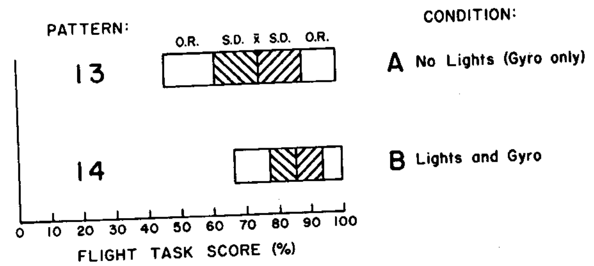

FIGURE 15. Means, standard deviations, and observed ranges of subjects' flight task score while visual attention devoted solely to flight task. ("Gyro" refers to attitude indicator.)

ground or horizon. The remaining 12 did not possess this qualification. The flight performance scores of these two groups are shown in Table 4. Although there appears to be several notable differences between the flight performance of the two groups in several patterns (No. 6. 11, 13, and 15), no conclusions are drawn at this time because of the small size of the sample and the need for further study of other factors which might bias the performance capabilities of two such diverse groups.

Flight Performance and Total Flying Time. The total flying time of each subject is shown in Table 1. To obtain a clean division between so called "low-time" and "high-time" pilots and still maintain equal sample numbers, data for subjects No. 15 and 16 were removed. This resulted in a range of 50–400 hours for the low-time group and 1,200–12,500 hours for the high-time group.

The flight performance scores for these two groups are displayed in Table 4. Again, the small size of the sample and the division of the subjects into two arbitrary flight time groups calls for additional study before any conclusions might be drawn from the differences shown.

TABLE 4. Mean scores of pilot flight performance in each of 15 holding patterns arranged according to qualification for instrument flight and total flight hours.

Display mode	*Pattern*	*Qualified for instrument flying* (N=16)	*Not qualified for instrument flying* (N=14)	*Total flying hours*	
				1,200–12,500 "High Time"	*50–400 "Low Time"*
A	1	73.4	69.1	71.7	70.2
B	2	85.3	81.8	86.1	80.0
C	3	64.5	67.2	61.4	68.9
A	4	51.2	52.8	49.4	52.9
B	5	65.2	68.1	64.8	67.8
C	6	58.7	66.3	57.9	67.1
A	7	57.4	56.1	56.4	58.1
B	8	67.0	70.7	65.1	70.1
C	9	67.3	68.1	64.0	71.5
A	10	54.8	54.9	54.2	54.6
B	11	62.4	73.4	60.3	72.4
C	12	63.7	64.0	62.3	67.2
A	13	77.3	70.5	76.8	72.4
B	14	86.5	83.5	86.7	83.3
C	15	69.2	75.2	67.4	75.7

General Discussion. Many studies[4,9,21,22,23] have documented the large number of eye movements which occur in instrument flying; the average qualified instrument pilot may, at times, make 100 or more eye movements per minute during routine IFR flight. Another study[16] indicates that about 50% of a pilot's eye movements relate primarily to viewing two instruments, the attitude indicator and the heading indicator. Still another report[30] shows that, on the average, more than 23% of a pilot's total fixation time is spent on one instrument, the attitude indicator (artificial horizon—Table 5). It seems rather obvious from these findings that the average pilot has little time for additional visual duties during routine instrument flight, and when non-routine tasks such as unexpected loss of power require the pilot's attention, his visual channels can become overburdened. If this occurs, the pilot's overall performance may deteriorate.

TABLE 5. Percentage of eye fixation time devoted to individual instruments under various flight conditions.

Instrument	*Flight conditions*							
	Straight and level	*Level turn*	*Climb*	*Climb turn*	*Descent*	*Descending turn*	*ILAS approach*	*GCA approach*
Directional Gyro	37	26	20	23	21	24	25	49
Gyro Horizon	25	29	24	28	22	25	15	19
Airspeed	7	12	24	16	24	19	10	17
Altimeter	13	12	7	7	7	6	2	3
Rate of Climb	5	6	9	8	8	7	2	5
Turn and Bank	3	6	3	5	2	5	1	2
Engine Instruments	2	4	10	9	12	10	2	4
ILS Cross Pointer	----------	----------	----------	----------	----------	----------	41	----------

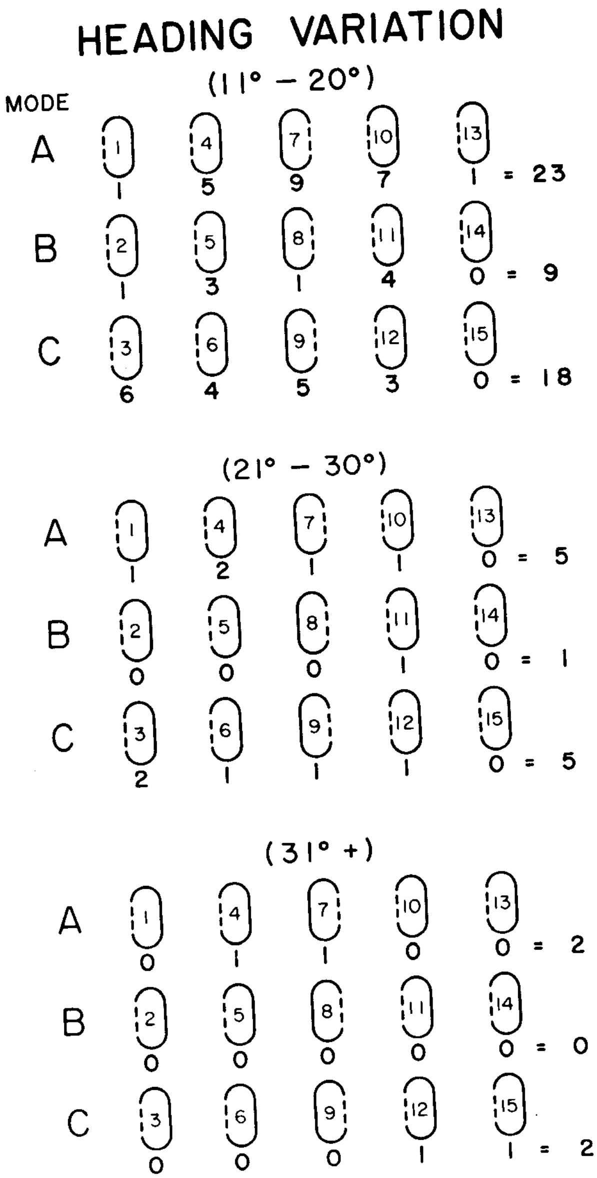

FIGURE 16. Number of heading variation events in excess of 10 degrees during flight on outbound leg is shown on the right. The least number of deviation events occurred in Mode B (peripheral cues added to normal instrument display).

The dependence on vision for effective manual control of aircraft during instrument flight—or when precise but non-automatically stabilized flight is required—has necessarily centered on the use of central vision. The reason for this is evident upon examination of any instrument panel in the average commercial airliner, general aviation plane or military aircraft. Because of design features, small size, and color and contrast combinations, precise information can be obtained from aircraft instruments only by use of central vision. In fact, only a portion of an instrument dial can normally be perceived clearly during a single fixation because of the decrease in visual acuity at angles increasingly divergent from the central axis of the eye.[6,17,18] For example, relative acuity is decreased by about 50% at an angle of five degrees to the central axis, and about 90% at 20°. At 40°–50° it is only about 5% of central acuity.[30]

In recognition of the pilot's visual discrimination problem, some proposals have been made for the use of auditory[14] and pressure[2] (touch) signals as possible means of reducing the visual burden of the pilot. However, little attention has been given to the possible use of peripheral vision as a sensory aid for instrument flying except by (a) Vallerie[25] who studied the use of peripheral vision as a means of eliminating time normally spent switching fixations between various instruments, (b) the development of the British-Collins "Barber Pole" system now used in some highly sophisticated business aircraft, and (c) a proposed device[27] that projects a lighted image of a large horizon bar across the instrument panel.

As the present study shows, use of peripheral vision not only permitted a reduction in the workload imposed on the pilot's central vision, but also may have simplified the act of discrimination of direction of turn to a relatively automatic function. This may be of operational significance, when one considers the proportion of time pilots normally spend looking at various instruments during instrument flight; in a study involving climbs while holding constant headings, by Cole et al.,[4] 48% of the pilots' visual attention was devoted to looking at only two instruments—the heading indicator and the attitude indicator. Since heading change is a function of bank angle for a given speed, it becomes obvious that if bank angle control can be maintained with reasonable accuracy without the necessity of looking at the attitude indicator, the proportion of visual attention normally given to the heading indicator may also be reduced. Also, if the premise is accepted that a stabilized heading induces constant airspeed—for a given power and trim condition—it may be assumed that the airspeed indicator would require less attention. As shown by Cole's study[4] three instruments (air-

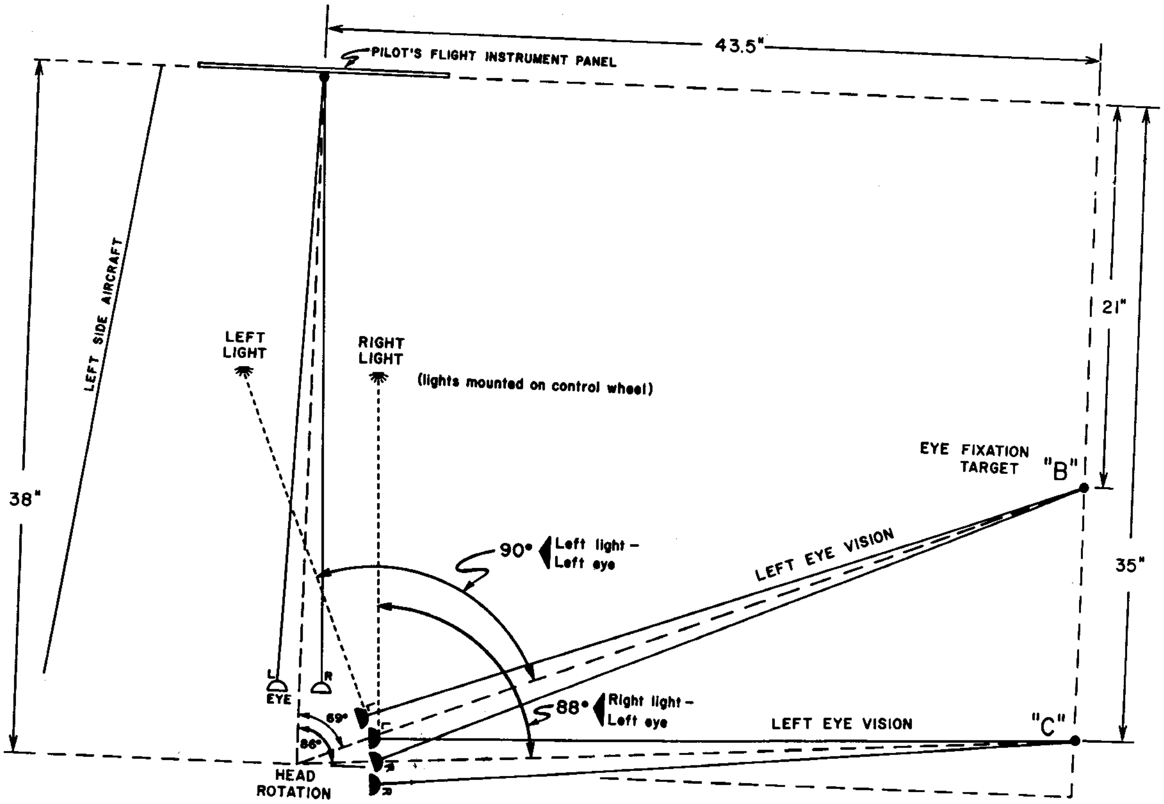

FIGURE 17. Head rotation and angles of peripheral cue discrimination (left eye); testing of lateral discrimination of peripheral cues indicated cues were recognizable by the left eye at a maximum of 90° when central vision was fixated to the right.

speed, heading indicator, and attitude indicator) occupied more than ⅔ of the pilots' visual attention. Thus, it is possible that with experience in the use of peripheral cues for bank angle control, pilots might reduce their fixation time on the instrument panel by at least half.

Two interesting aspects of the study were (a) the quick manner in which the subjects adapted to the use of peripheral vision cues and (b) the angles within which the light cues were recognizable (Figures 17, 18, and 19). However, despite these and other apparent advantages of using this "secondary" visual sense, research should be conducted in actual flight to determine whether any in-flight factors (e.g., acceleration) might significantly change the results found in the present study. If such factors do not prove to be a problem, consideration might then be given to adding a peripheral vision cue system to the pilot's information display.

IV. Summary.

1. During contact (or good weather) (VFR) flight, many of the visual cues used by a pilot to control his aircraft are received through his peripheral vision receptors.

2. During instrument flight, on the other hand, central vision is used to obtain discrete data, necessitating numerous eye movements and fixations.

3. Obtaining discrete data intermittently through central vision—as compared to receiving continuous data through peripheral vision—produces a decrement in flight performance when additional tasks are introduced.

4. When peripheral vision cues are added to the instrument display environment, flight performance is improved, particularly when additional tasks are added to the pilot's flight duties.

V. Recommendation.

Additional research should be undertaken to explore more effective means of utilizing human sensory capabilities for the reception and use of aircraft orientation information.

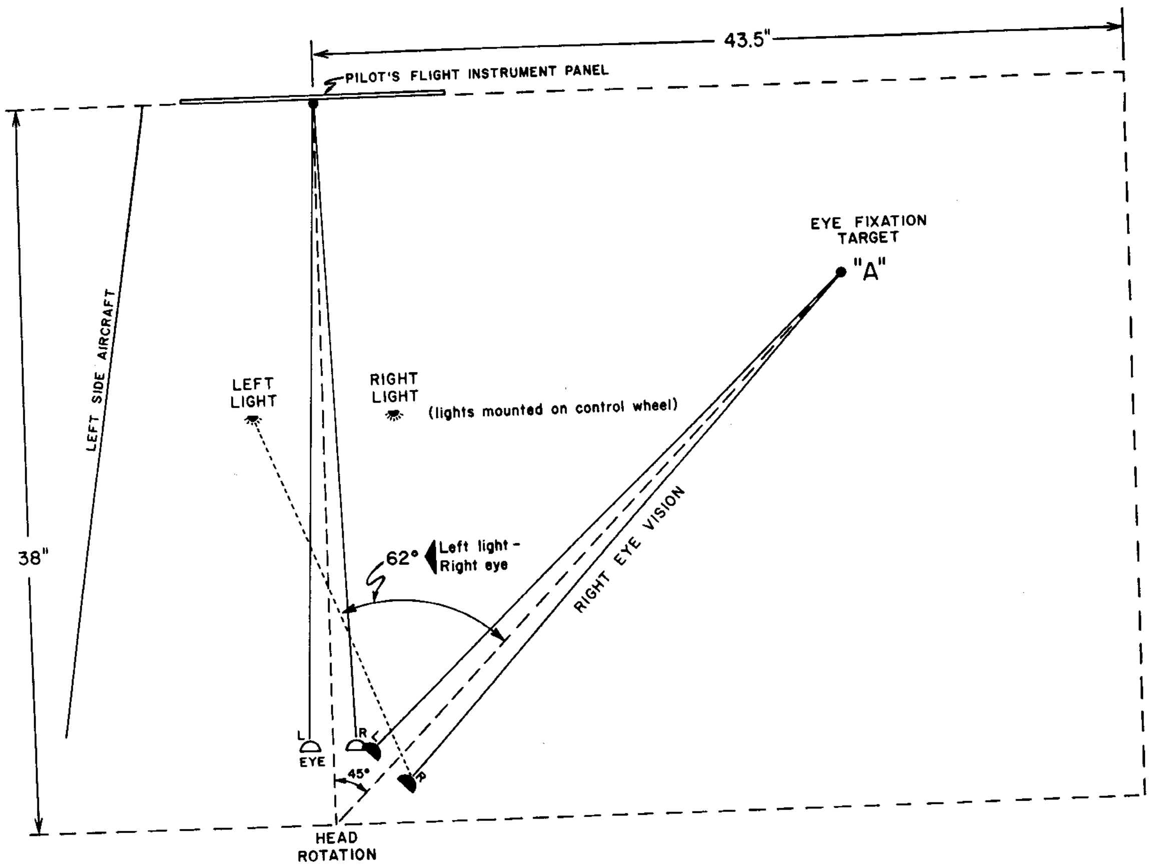

FIGURE 18. Head rotation and angle of peripheral cue discrimination (right eye); lateral discrimination of peripheral cues (Figure 17) was a maximum of 62° for the right eye when fixated to the right.

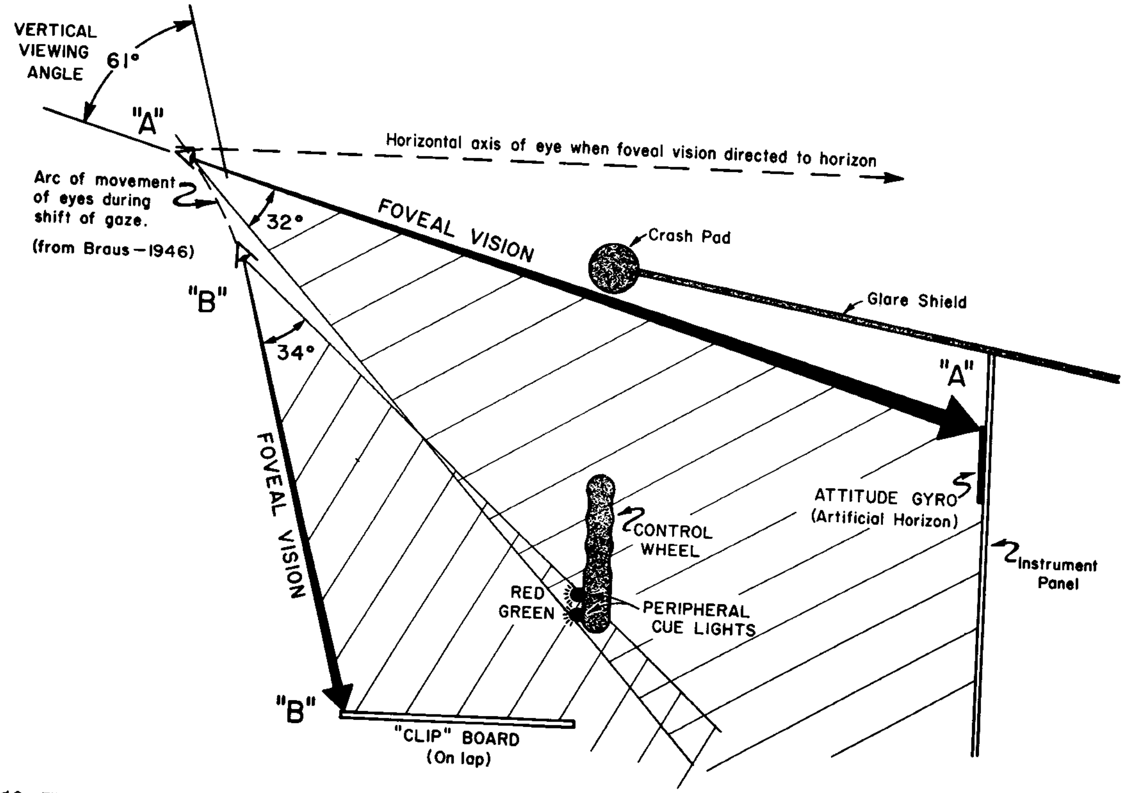

FIGURE 19. Vertical viewing angles associated with performance of "two-task" patterns—flying aircraft and solving mathematical problems on a lap-supported clip board. Cue lights were within vertical angles of 32–34 degrees.

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