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EYE FIXATIONS OF AIRCRAFT PILOTS

III. Frequency, Duration, and Sequence Fixations When Flying Air Force Ground-Controlled Approach System (GCA)

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FOREWORD

This is the third of a series of reports describing the results of a number of related investigations conducted under Expenditure Orders 694-28 and 694-31 by the Psychology Branch, Aero Medical Laboratory, Engineering Division, Air Materiel Command. The purpose of these investigations is to provide basic data regarding pilots' eye movements during instrument flight. Such background research provides the answers to many questions encountered in designing aircraft instruments and instrument panels on which a large number of instruments must be arranged in the most effective way.

Capt. Jones and Lt. Milton were responsible for all flight work, and supervised the film reading and analysis of the data. Sgt. Morris was the photographer on all flights, edited the film and prepared the reference slides. Dr. Fitts assisted in planning the study and advised on various details of experimental procedures and data analysis.

The authors wish to express their appreciation to a number of individuals for valuable assistance in conducting the project: to the Special Photographic Services Branch which did the photographic work; to the personnel of the United States Air Force Instrument Pilot School, Barksdale Air Force Base, the All Weather Flying Division, Clinton County Air Force Base, and the Wright-Patterson Air Force Base Instrument School, who volunteered as subjects; and to Mr. P. J. Kirchmer who prepared the illustrations. Special acknowledgment is due to Mr. Charles Simon and a number of students from Antioch College who assisted in reading the film records and in analyzing the data.

ABSTRACT

This report is the third in a series dealing with the measurement of eye movements of pilots during instrument flight. The frequency, duration, and sequence of eye fixations made by forty USAF pilots when flying GCA approaches are summarized. Fixations on the primary instruments vary from 33 per minute on the directional gyro to 3 per minute on the turn and bank indicator. Over three-fourths of all fixations are made on three instruments—the directional gyro, the gyro horizon and the airspeed indicator. The length of fixations vary from an average of 0.90 second on the directional gyro to 0.36 second on the turn and bank indicator. Approximately one-half of the pilots' time is spent observing the directional gyro and an additional four-tenths of their time is spent observing the gyro horizon and airspeed indicator. Among these pilots, flying experience did not have any significant relation to rate of eye fixation. Eye Movement Link Values between all instruments are presented. From these data an optimum arrangement of instruments on the panel can be determined. Since this arrangement varies for different maneuvers, recommendations on this point are withheld pending the completion of similar analyses for other maneuvers.

PUBLICATION APPROVAL

For the Commanding General:

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I. PURPOSE OF THE STUDY

The present report covers part of the data obtained during a series of investigations of how pilots use their eyes during instrument flight. These studies were conducted to determine the answers to such questions as the following: How much of the instrument panel do pilots observe "at a glance"? How often is each instrument checked during particular maneuvers? How much time is required to check each instrument? What percentage of the total time available is spent in seeking information from each of the different instruments? How are the frequency and duration of eye fixations influenced by factors such as pilot experience, instrument arrangement, instrument lighting, and the particular maneuver being flown at the time?

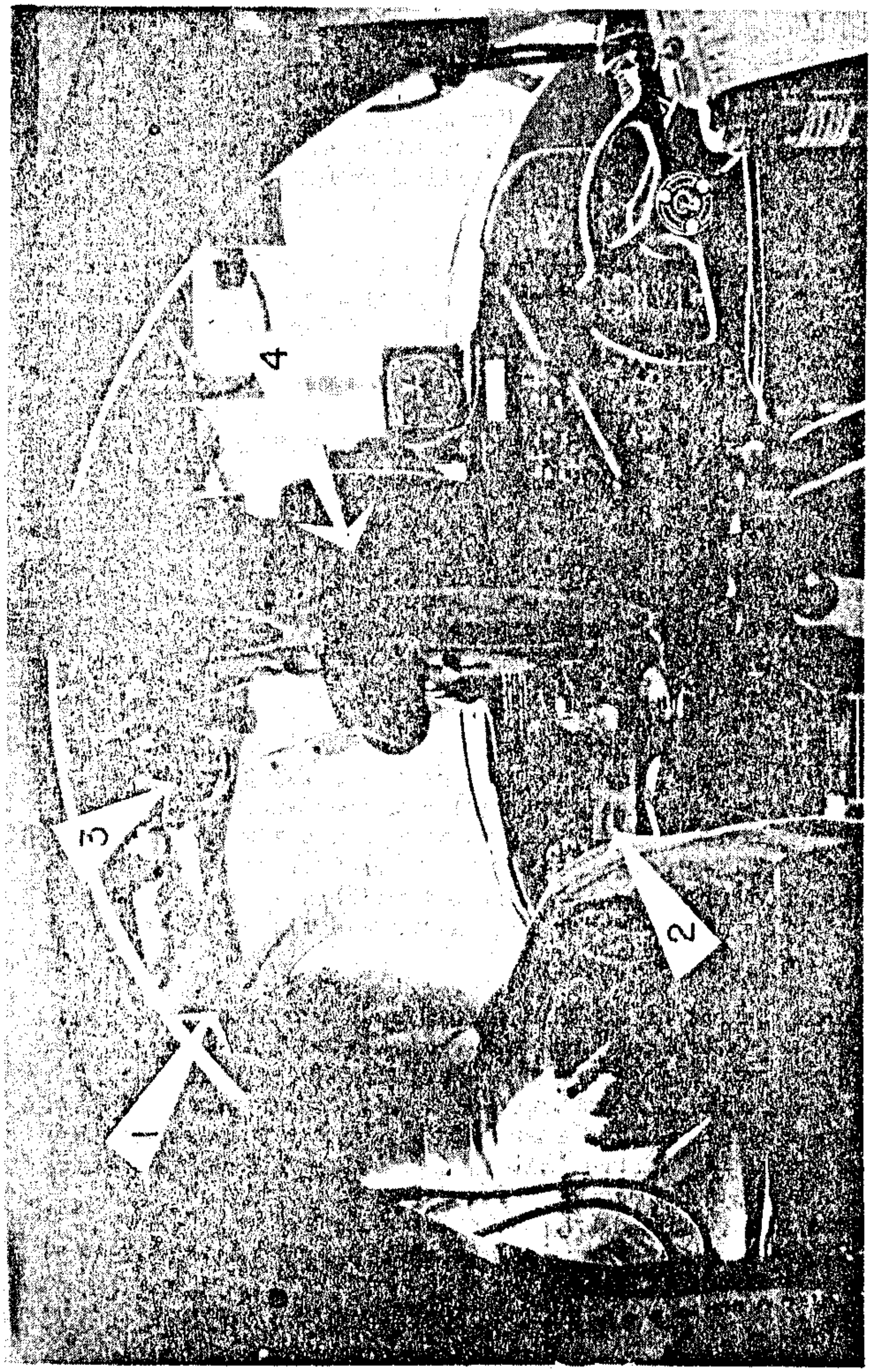
The results for GCA approaches are summarized in the present report. Data on eye movement during ILAS approaches, during maneuvers flown at altitudes, during contact landings and take-offs and during night flights are presented in other reports in this series.

II. PROCEDURES FOLLOWED IN OBTAINING EYE FIXATION RECORDS DURING GCA APPROACHES

The procedures followed in the present study are described in detail in USAF Air Materiel Command Technical Report No. 5837. The description covers recording techniques, film analysis procedures, the various maneuvers flown, and the reliability of the resulting data. Briefly, these procedures were as follows:

Photographic Recording. A thirty-five millimeter camera was installed in a C-45 aircraft so that the face and eyes of the pilot could be photographed as they were reflected in a rectangular mirror attached to the instrument panel at the center of the flight instrument group. Photographic records were made at 8 frames per second during critical maneuvers. A special blind flying hood was used to limit the pilot's vision to the instrument panel. A view of the recording camera and mirror is shown in Figure 1.

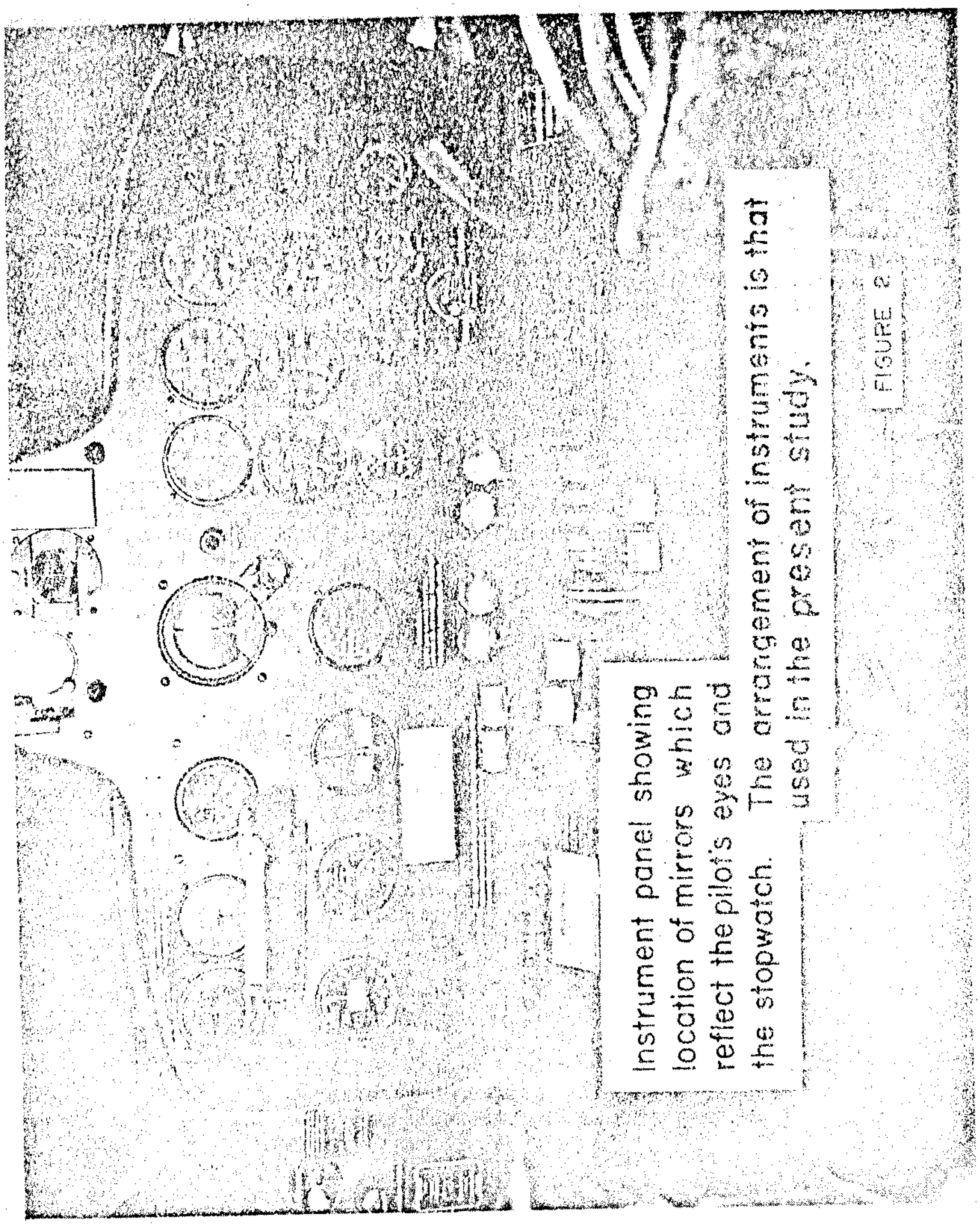
Flight Procedures. Each of 40 USAF pilots made two approaches for a landing using standard GCA procedures under simulated instrument conditions. The camera was started as the aircraft passed over a point (OM) approximately 4 1/2 miles from touch-down and a thirty-second sample of eye fixations was obtained. The camera was again started as the aircraft passed over a point (MM) approximately 1 1/2 miles from touch-down and a second thirty-second sample of eye fixations was obtained. In altitude and distance from touch-down, these two points correspond to the location of the outer marker and middle marker beacons of the USAF Instrument Low Approach System (ILAS).



ARRANGEMENT OF EXPERIMENTAL EQUIPMENT IN THE COCKPIT

1. Blind Flying Hood
2. Mirror
3. Stop Watch
4. Camera

FIGURE 1



Instrument panel showing location of mirrors which reflect the pilot's eyes and the stopwatch. The arrangement of instruments is that used in the present study.

FIGURE 2

Film Analysis. All film records collected in the present study were read frame by frame. Standard reference photographs, taken at the beginning of each flight, with pilots looking directly at each instrument, were made into slides and used as a reference by the film readers.

A detailed discussion of the reliability of the film analysis procedure is included in AF Technical Report No. 5837 (see reference 2).

III. DESCRIPTION OF SUBJECTS

It was decided to obtain eye-fixation data for a group of subjects that was fairly typical of post-war USAF pilots, for example, men whose experience level would range from moderate to expert. Some of the most proficient pilots at the United States Air Force Instrument Pilot School, Barksdale Air Force Base; at Wright-Patterson Air Force Base Instrument School; and at the All Weather Flying Division, Clinton County Air Force Base, were included in the group. Less experienced subjects included pilots attending the Instrument School at Barksdale and pilots stationed at Wright-Patterson. The 40 pilots who served as subjects ranged in age from 23 to 37 years with an average of 28 years. Their total flying time varied from 700 to 5,000 hours, with an average of approximately 2,000 hours. Their instrument flying time (hood plus weather) varied from 65 to 500 hours, with an average of approximately 200 hours. The number of practice and actual GCA approaches which they had made varied from 0 to 375. Seventeen of the pilots had made less than 25 GCA approaches, both practice and actual. Of these 17, only 2 had no experience with GCA. The summary of flying experience for each pilot in the group is given in Table I. Thirty-eight of these were the same pilots employed in the study of ILAS approaches (see reference 4).

IV. RESULTS

Means and standard deviations (root mean square variations) for number of eye fixations per minute and for length of fixation cycle on each instrument are summarized in Tables II and III. (A fixation cycle is defined as the time required to move the eyes to an instrument plus the time spent in looking at that instrument.) The data are presented separately for the two periods of photographic recording (OM and MM) as well as for the two approaches made by each subject.

Number of Fixations. During a GCA approach the typical pilot in this group made an average of 93 fixations per minute. Of these, 33 were on the directional gyro (heading indicator), 21 were on the gyro horizon (attitude indicator), and 18 were on the airspeed indicator. Thus, approximately 77 percent of all fixations were made on these three instruments. No other instrument was fixated more than 6 times per minute.

TABLE I

Summary of Biographical Information for the 40 Pilots Who Served as Subjects in an Experiment to Measure Eye Movements When Flying GCA Approaches

Subject	Age	Total Hours Flying Time	Instrument Flying Time	Simulated GCA Approaches Total	Simulated GCA Approaches Current	Actual GCA Approaches Total	Actual GCA Approaches Current
1	27	2500	500	300	25	75	5
2	30	2500	200	100	40	40	10
3	23	1300	400	150	15	30	5
4	31	2500	300	15	5	2	1
5	31	2100	300	18	13	0	0
6	28	3200	350	75	60	2	2
7	23	2200	215	100	15	2	0
8	26	2700	205	30	6	4	0
9	37	5000	250	15	0	10	0
10	27	2800	300	100	25	5	0
11	33	1350	100	8	3	0	0
12	28	1600	180	15	5	2	0
13	26	1350	156	50	0	0	0
14	26	2100	300	54	20	20	10
15	28	2450	170	70	30	20	2
16	30	3200	225	50	5	10	1
17	33	1500	150	20	10	0	0
18	29	2300	300	0	0	0	0
19	28	2150	100	4	4	1	1
20	33	1500	70	32	32	10	10
21	26	1450	150	20	5	0	0
22	27	1800	200	27	12	1	1
23	29	1300	100	205	30	0	0
24	24	2300	280	104	31	25	5
25	27	900	70	6	0	0	0
26	25	2850	400	90	16	14	2
27	29	1950	250	155	42	10	5
28	27	900	100	6	3	0	0
29	26	2100	300	130	40	75	50
30	26	850	150	0	0	0	0
31	25	2650	300	10	10	0	0
32	28	1650	200	1	0	0	0
33	—	1900	200	20	12	3	0
34	28	2100	200	25	15	0	0
35	26	1700	120	17	11	2	0
36	26	1800	100	12	12	0	0
37	28	2000	300	75	75	0	0
38	25	1500	95	1	0	0	0
39	35	4300	200	5	0	0	0
40	28	700	65	40	10	0	0
Mean	28	2075	214	54	16	9	3
Median	28	1975	200	26	11 1/2	1 1/2	0

TABLE II

Means and Standard Deviations of Number of Fixations per Minute On Each Instrument During GCA Approaches (N = 40)

	First Approach		Second Approach		All Samples Combined
	OM_1	MM_1	OM_2	MM_2	
Airspeed					
Mean	19.4	18.4	17.2	18.0	18.2
S.D.	9.0	9.9	8.2	10.2	8.0
Directional Gyro					
Mean	32.2	32.8	33.5	34.7	33.3
S.D.	8.9	10.1	7.5	9.9	7.9
Gyro Horizon					
Mean	21.3	20.8	20.9	19.5	20.6
S.D.	8.6	12.3	9.8	13.1	9.5
Altimeter					
Mean	5.4	3.9	5.0	4.4	4.7
S.D.	4.1	3.8	4.6	5.6	3.4
Turn - Bank					
Mean	3.8	3.1	3.0	3.0	3.2
S.D.	5.5	5.8	4.3	5.3	4.7
Vertical Speed					
Mean	7.1	5.4	6.4	6.2	6.2
S.D.	6.7	6.2	6.3	6.9	5.7
Engine Instrument Panel					
Mean	3.1	2.3	2.9	1.9	2.6
S.D.	3.2	2.9	3.4	2.5	2.3
Total Fixations, All Instruments*					
Mean	96.4	91.2	92.8	91.7	93.0
S.D.	20.0	24.3	16.9	27.5	18.7

* Includes those miscellaneous fixations (about 4 percent of the total) that could not be attributed to any of the primary instruments.

TABLE III

Means and Standard Deviations of Length of Fixations on Each Instrument During GCA Approaches *

	First Approach		Second Approach		All Data Combined
	OM_1	MM_1	OM_2	MM_2	
Airspeed					
N	39	39	39	40	40
Mean	.64	.54	.55	.51	.57
S.D.	.26	.18	.16	.20	.17
Directional Gyro					
N	40	40	40	40	40
Mean	.81	1.00	.85	1.01	.90
S.D.	.25	.40	.22	.40	.26
Gyro Horizon					
N	40	38	39	37	40
Mean	.53	.54	.60	.60	.56
S.D.	.18	.26	.35	.36	.21
Altimeter					
N	35	29	34	29	40
Mean	.40	.38	.39	.37	.39
S.D.	.25	.18	.12	.18	.11
Turn - Bank					
N	28	22	23	23	35
Mean	.40	.30	.44	.34	.36
S.D.	.21	.19	.11	.20	.16
Vertical Speed					
N	27	25	27	27	35
Mean	.50	.43	.47	.43	.47
S.D.	.16	.20	.19	.16	.12
Engine Instrument Panel					
N	23	17	21	18	31
Mean	.97	.71	.96	.68	.88
S.D.	.61	.23	.40	.32	.31
Average, All Fixations**					
N	40	40	40	40	40
Mean	.65	.71	.67	.71	.67
S.D.	.14	.19	.12	.20	.14

* The number of subjects varies because some pilots did not look at a particular instrument during one of the sampling periods.

** Includes those miscellaneous fixations that could not be attributed to any of the primary instruments.

Although the total number of fixations per minute during GCA approaches is less than that discovered during ILAS approaches (see reference 4), the frequency of checking each instrument is higher. This is possible since there is one less instrument to check. The extra time available during a GCA approach (which results from not having to check the cross-pointer) seems to be fairly equitably distributed among all the instruments. Every instrument is checked at least one time per minute more, and no instrument is checked over five times per minute more, than during an ILAS approach.

Length of Fixation Cycle. The average length of fixation cycle for this group of pilots was 0.67 second. The instrument that required the longest time for fixation was the directional gyro, with 0.90 second. Lengths of fixation cycle for the remaining instruments were as follows: engine instrument panel - 0.88 second, airspeed indicator - 0.57 second, gyro horizon - 0.56 second, vertical speed indicator - 0.47 second, altimeter - 0.39 second, and turn-bank indicator - 0.36 second.

Comparing the present GCA data with those reported elsewhere for ILAS (see reference 4), it can be noted that the length of fixation cycle is longer for all instruments during GCA approaches than during ILAS approaches. For the altimeter, turn and bank indicator, and gyro horizon the differences are small and not particularly consistent. Only slightly more than half the pilots made longer fixations on these instruments during the GCA approaches than they did during the ILAS approaches. For the directional gyro and the airspeed indicator the differences are large and consistent. Over 90 percent of the 38 subjects common to both groups made longer fixations on these instruments during the GCA approaches than they did during the ILAS approaches.

Total Time Allotted to Each Instrument. It is possible to express the time that was spent in observing each instrument as a percentage of the total time available to the pilot during an approach. (See Figure 3.) The average pilot spent approximately 49 percent of the time available to him in looking at the directional gyro, 19 percent in looking at the gyro horizon, and 17 percent in looking at the airspeed indicator. Thus, during a GCA approach, these three instruments were observed during 85 percent of all the time available during the last four and one-half miles preceding touchdown. No one of the remaining instruments was observed for more than 5 percent of the time.

If the instruments are ranked according to the amount of use received during a GCA approach, the order of relative importance is as follows: 1) directional gyro, 2) gyro horizon, 3) airspeed indicator, 4) vertical speed indicator, 5) engine instrument panel, 6) altimeter, and 7) turn and bank indicator. Considering the instruments that are common to both, this order differs from thst discovered for ILAS approaches (4) in only one respect. During an ILAS approach the engine instrument panel received slightly more attention (less than 1 percent more) than did the vertical speed indicator. In interpreting these data it should be remembered that a safety pilot was present. If this relieved the pilot who was flying the aircraft of some anxiety about flying into the ground,

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR-CRAFT INSTRUMENTS DURING G.C.A. APPROACHES

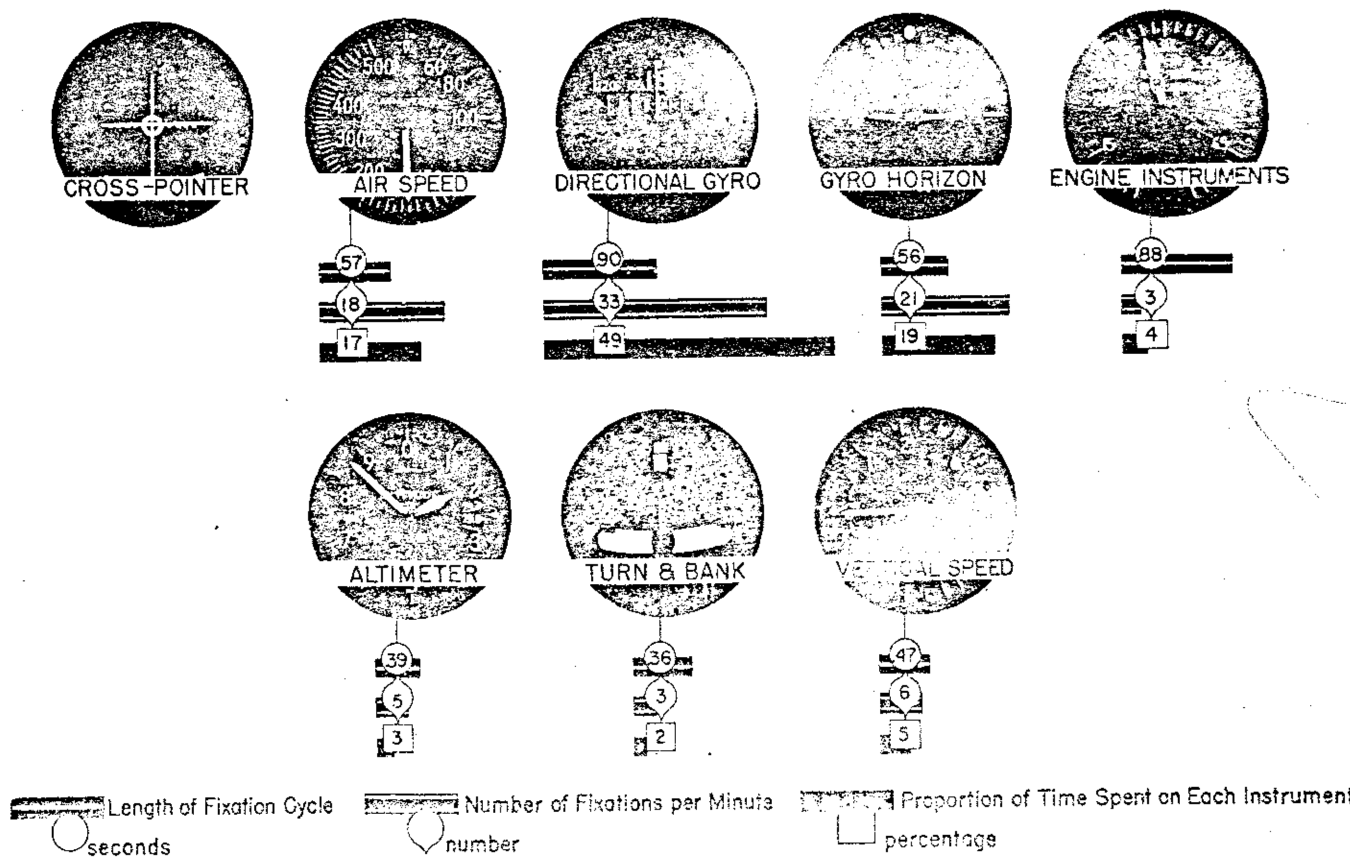


FIGURE 3

it may have led, in some cases, to less frequent use of the altimeter than would be true for an instrument approach under actual "weather" conditions.

Agreement Between Different Eye Movement Samples. Means and standard deviations were computed separately for each period of measurement, i.e. 'outer marker' and 'middle marker' on both first and second approaches. Table IV shows, for each instrument, differences, correlations, and "t" ratios between the means of number of fixations per minute made during each sample. None of the 48 "t" ratios are significant at the 0.01 level of confidence and only three are significant at the 0.05 level of confidence, a condition which would be expected to arise by chance. Only one of the 48 correlation coefficients fails to be significant at the 0.05 level of confidence and 41 are significant at the 0.01 level of confidence. This is sufficient evidence to justify the conclusion that there is genuine homogeneity among the different samples insofar as number of fixations is concerned.

Table V summarizes comparable data for length of fixation cycle for the three instruments on which the pilots spent 85 percent of their time, and for the average length of fixation cycle for all instruments combined. Here 5 of the 24 "t" ratios are significant at the 0.01 level of confidence and 5 additional ones are significant at the 0.05 level of confidence.

The length of fixation on the airspeed indicator at 4 1/2 miles from touch-down point on the first approach was significantly longer than during any of the three remaining samples. This is difficult to explain since there are no significant differences between the three remaining samples.

The data for length of fixation on the directional gyro reveal that subjects consistently made shorter fixations at 4 1/2 miles from touch-down point than they did at 1 1/2 miles from touch-down point. In other words, as they neared touch-down point the amount of time spent in checking the directional gyro each time it was looked at, became longer. This change was of similar magnitude during both approaches. To assume, simply, that pilots concentrate more on heading as they get closer to the runway does not completely explain this difference since the increase in number of fixations on this instrument is very small. It seems more reasonable to accept the hypothesis that as the pilot approaches the runway he attempts to hold his assigned heading to smaller and smaller tolerances. This means he must read the directional gyro more exactly; this could reasonably be expected to increase the difficulty of reading the instrument and the time required for reading. This agrees with the supposition that length of fixation is an index of the difficulty of reading an instrument.

It is obvious that relatively large differences in length of fixation on the directional gyro (which is the most-frequently-checked instrument), at different positions on the GCA approach, affect the length of the mean fixations. In two instances this effect is sufficient to make these differences significant.

TABLE IV

Mean Differences in Number of Fixations, Correlation Coefficients, and "t" Ratios for Two Different Segments of Each of Two GCA Approaches. Comparisons are Between 30-Second Samples Begun at 4 1/2 miles (OM) and at 1 1/2 miles (MM) From Touch-Down Point.
(N = 40)

	MM_1			OM_2			MM_2		
	diff.	r	t	diff.	r	t	diff.	r	t
Airspeed									
OM_1	-1.0	.62**	.79	-2.2	.55**	1.72	-1.5	.34*	.84
MM_1				-1.2	.48**	.81	-0.4	.72**	.37
OM_2							0.8	.78**	.75
Directional Gyro									
OM_1	0.5	.71**	.47	1.3	.73**	1.32	2.5	.63**	1.92
MM_1				0.8	.76**	.73	1.9	.53**	1.26
OM_2							1.2	.64**	.97
Gyro Horizon									
OM_1	-0.6	.66**	.38	-0.5	.53**	.34	-1.9	.51**	1.0[illegible]
MM_1				0.1	.66**	.05	-1.3	.80**	1.03
OM_2							-1.4	.67**	.91
Altimeter									
OM_1	-1.6	.55**	2.69*	-0.5	.37*	.60	-1.0	.24	1.06
MM_1				1.1	.34*	1.42	0.5	.35*	.62
OM_2							-0.6	.41**	.64
Turn - Bank									
OM_1	-0.7	.79**	1.15	-0.8	.76**	1.42	-0.8	.73**	1.29
MM_1				-0.1	.73**	.23	-0.1	.95**	.49
OM_2							—	.90**	—
Vertical Speed									
OM_1	-1.7	.74**	2.30*	0.7	.78**	.97	-0.9	.66**	.32
MM_1				1.0	.61**	1.16	0.8	.69**	.98
OM_2							-0.2	.67**	.26
Engine Instrument Panel									
OM_1	0.8	.46**	1.51	-0.1	.49**	.26	-1.1	.41**	2.25
MM_1				0.6	.67**	1.50	-0.4	.35*	.79
OM_2							-1.0	.38*	1.85
Total Fixations, All Instruments									
OM_1	-5.2	.63**	1.69	-3.5	.60**	1.33	-4.7	.54**	1.25
MM_1				1.6	.55**	.50	0.5	.62**	.13
OM_2							-1.2	.79**	.42

* Significant at the .05 level of confidence.

** Significant at the .01 level of confidence.

TABLE V

Mean Differences in Length of Fixation, Correlation Coefficients, and "t" Ratios for Two Different Segments of Each of Two GCA Approaches. Comparisons are Between 30 Second Samples Begun at 4 1/2 Miles (OM) and at 1 1/2 Miles (MM) From Touch-Down Point.

	MM_1			OM_2			MM_2		
	diff.	r	t	diff.	r	t	diff.	r	t
Airspeed (N = 37)									
OM_1	-.10	.32	2.25*	-.09	.25	2.04*	-.12	.15	2.40*
MM_1				.01	.59**	.38	-.02	.45**	.65
OM_2							-.03	.40*	.97
Directional Gyro (N = 40)									
OM_1	-.19	.59**	3.73**	.04	.46**	.99	.20	.45**	3.48**
MM_1				-.15	.62**	3.03**	.01	.69**	.24
OM_2							.16	.70**	3.49**
Gyro Horizon (N = 36)									
OM_1	.02	.71**	.80	.05	.70**	2.06*	.06	.53**	1.26
MM_1				.03	.70**	1.08	.04	.55**	.81
OM_2							.01	.40*	.19
All Instruments Combined (N = 40)									
OM_1	.06	.73**	2.92**	.02	.59**	1.06	.06	.64**	2.51*
MM_1				-.04	.51**	1.53	.00	.70**	—
OM_2							.04	.62**	1.67

* Significant at the .05 level of confidence.
** Significant at the .01 level of confidence.

These statistics seem to indicate that insofar as length of fixation on the directional gyro is concerned, there is a lack of homogeneity between the data collected at 4 1/2 miles from touch-down point and that collected at 1 1/2 miles from touch-down point, although the data from a particular position on the first approach is homogeneous with that taken at the same position on the second approach. Therefore, the mean and standard deviation shown in Table II in the column headed "All Data Combined" do not adequately describe the length of fixation on the directional gyro during a GCA approach. However, it is felt that the differences between instruments are so large as to be affected only slightly by the interaction with distance from touch-down point. This can be illustrated by ranking the instruments in terms of length of fixation at the outer marker and the middle marker and computing a rank order correlation. This correlation is 0.96 for approach one and 0.93 for approach two.

It will be noted that in Tables II and IV the number of cases (N) is 40 whereas in Tables III and V the number of cases varies. This occurs because all subjects did not look at all instruments during each sampling period. When that happened, the number of fixations for such subjects on certain instruments was zero. This is a measure which can be used in calculations involving number of fixations (Tables II and IV). However, when number of fixations is zero, no measure of length of fixation is available, so data for such subjects must be omitted from all calculations involving length of fixation (Tables III and V).

Relation Between Frequency of Use and Speed of Checking Instruments. Table VI shows the correlation coefficients for length of fixation vs. number of fixations on each instrument. These correlations are significant for three of the instruments. Pilots who made a large number of fixations on the directional gyro tended to make shorter fixations than did pilots who made fewer fixations. Conversely, pilots who made a large number of fixations on the altimeter and vertical speed indicator tended to make longer fixations than did pilots who made fewer fixations on these instruments. (The correlation between average number and average length of fixation for all instruments combined is not -1.00 because samples were drawn over a fixed period of time, and different subjects made different total numbers of fixations during this time.)

Weighting. Table VII shows the length of fixation for each instrument when the averaging is with regard for fixations instead of subjects. This was calculated by the formula

$$\frac{\text{Total Frames for an Instrument}}{\text{Total Fixations on the Instrument}} = \text{Time per frame}$$

which weights each eye fixation equally. This procedure gives the most weight to the subject who made the most fixations. At all other places in this report averages were computed in such a way as to weight equally the data contributed by each subject.

TABLE VI

Correlations* Between Length of Fixation and Number of Fixations Made on the Primary Instruments by USAF Pilots Flying GCA Approaches

Instrument	N	"r"
Air Speed	40	-.09
Directional Gyro	40	-.64
Gyro Horizon	40	-.10
Altimeter	40	.32
Turn and Bank	35	.30
Vertical Speed	35	.49
Engine Instrument Panel	31	-.19
All Instruments Combined	40	-.98

* A negative correlation indicates that the pilots who make longer individual fixations on an instrument tend to check that instrument less frequently.

TABLE VII

Average Length of Fixation on Each Instrument During GCA Approaches

Instrument	Average Length of Fixation (seconds)	
	Weighted by fixations	Weighted by subjects
Air Speed	.56	.57
Directional Gyro	.87	.90
Gyro Horizon	.53	.56
Altimeter	.41	.39
Turn and Bank	.42	.36
Vertical Speed	.50	.47
Engine Instrument Panel	.83	.88
Average Fixation, All Instruments	.64	.67

Fixation Sequences (Eye Movement Link Values). Any discussion of the pattern of eye movements, or the eye fixation sequences, revealed by this study should be prefaced by the statement that the pattern of eye movements was, no doubt, considerably affected by the arrangement of instruments on the panel. These data were collected on pilots who were using the instrument arrangement established by Technical Order 01-1-160. This was the standard Air Force arrangement at the time the study was made (See Figure 2).

The 42 eye movements or "links" between the six flight instruments and the engine instrument panel that are possible with this arrangement are listed in Table VIII in descending order of frequency of occurrence. The strength of the bonds between pairs of instruments (Eye Movement Link Values), based on the frequency of eye movements in both directions between two instruments, is shown in Figure 4.

It can be seen from an inspection of Table VIII that there were four very important eye movements made by these pilots. These are: 1) from the gyro horizon to the directional gyro, 2) from the directional gyro to the airspeed indicator, 3) from the directional gyro to the gyro horizon, and 4) from the airspeed indicator to the directional gyro. Each of these movements occurred more than 1,000 times out of the total of 7,382 eye movements classified. Together they accounted for 59 percent of all eye movements made during the GCA approaches.

Movements to the right and movements to the left between pairs of instruments occurred with approximately equal frequency. This indicates that there was no carry-over of the reading habit in which short movements tend to be made to the right, and long ones to the left. It also indicates that there was little tendency for pilots to check several instruments in a fixed sequence.

As was stated in a previous report, "On a priori grounds it seems that a good instrument panel arrangement would be one on which the most frequent eye-movement paths are short and are horizontal", (4). There is a limited amount of experimental evidence to support this assumption (1). Inspection of Figure 4 reveals that the panel arrangement used in the present study meets these conditions exceptionally well. However, it should be emphasized that the particular instrument arrangement studied may have influenced the data shown in Figure 4 to a considerable degree. A different instrument arrangement might produce somewhat different Link Values. This problem will be covered in a subsequent report.

Effect of Experience on Eye Movement Measures. The relations between flying experience, as represented by total flying time, and 1) number of fixations per minute and 2) duration of fixation cycle, are summarized in Table IX.

It is interesting to note that the correlation coefficient for total fixations on all instruments, although too small to be significant, varies in the same direction as was true for ILAS approaches (see reference 4). However, none of the 16 correlation coefficients are significant at the 0.05 level of confidence. Hence, for the forty pilots in this group, it must be concluded that flying experience, as measures by total hours flying

TABLE VIII

Frequency of Occurrence of Eye Movements Between Pairs of Instruments in Flying GCA Approaches

1. G/H to D/G - 1169
2. D/G to A/S - 1097
3. D/G to G/H - 1093
4. A/S to D/G - 1025
5. A/S to G/H - 239
6. V/S to G/H - 206
7. G/H to A/S - 200
8. D/G to V/S - 192
9. V/S to D/G - 165
10. D/G to Alt - 151
11. A/S to Alt - 146
12. Alt to D/G - 141
13. G/H to V/S - 139
14. E/I to D/G - 122
15. D/G to T/B - 118
16. Alt to A/S - 115
17. T/B to D/G - 101
18. G/H to E/I - 88
19. T/B to G/H - 85
20. D/G to E/I - 79
21. A/S to V/S - 69
22. Alt to V/S - 63
23. G/H to T/B - 61
24. V/S to A/S - 51
25. G/H to Alt - 50
26. E/I to G/H - 45
27. Alt to T/B - 44
28. Alt to G/H - 43
29. V/S to E/I - 39
30. T/B to A/S - 38
31. A/S to T/B - 36
32. V/S to Alt - 33
33. E/I to A/S - 30
34. T/B to Alt - 21
35. E/I to V/S - 18
36. A/S to E/I - 17
37. T/B to V/S - 16
38. V/S to T/B - 15
39. T/B to E/I - 11
40. E/I to A/S - 5
41. Alt to E/I - 3
42. E/I to T/B - 3

Legend

A/S - Air Speed Indicator
D/G - Directional Gyro
G/H - Gyro Horizon
E/I - Engine Instrument Panel
Alt - Altimeter
T/B - Turn and Bank Indicator
V/S - Vertical Speed Indicator

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
GROUND CONTROL APPROACH
G.C.A.

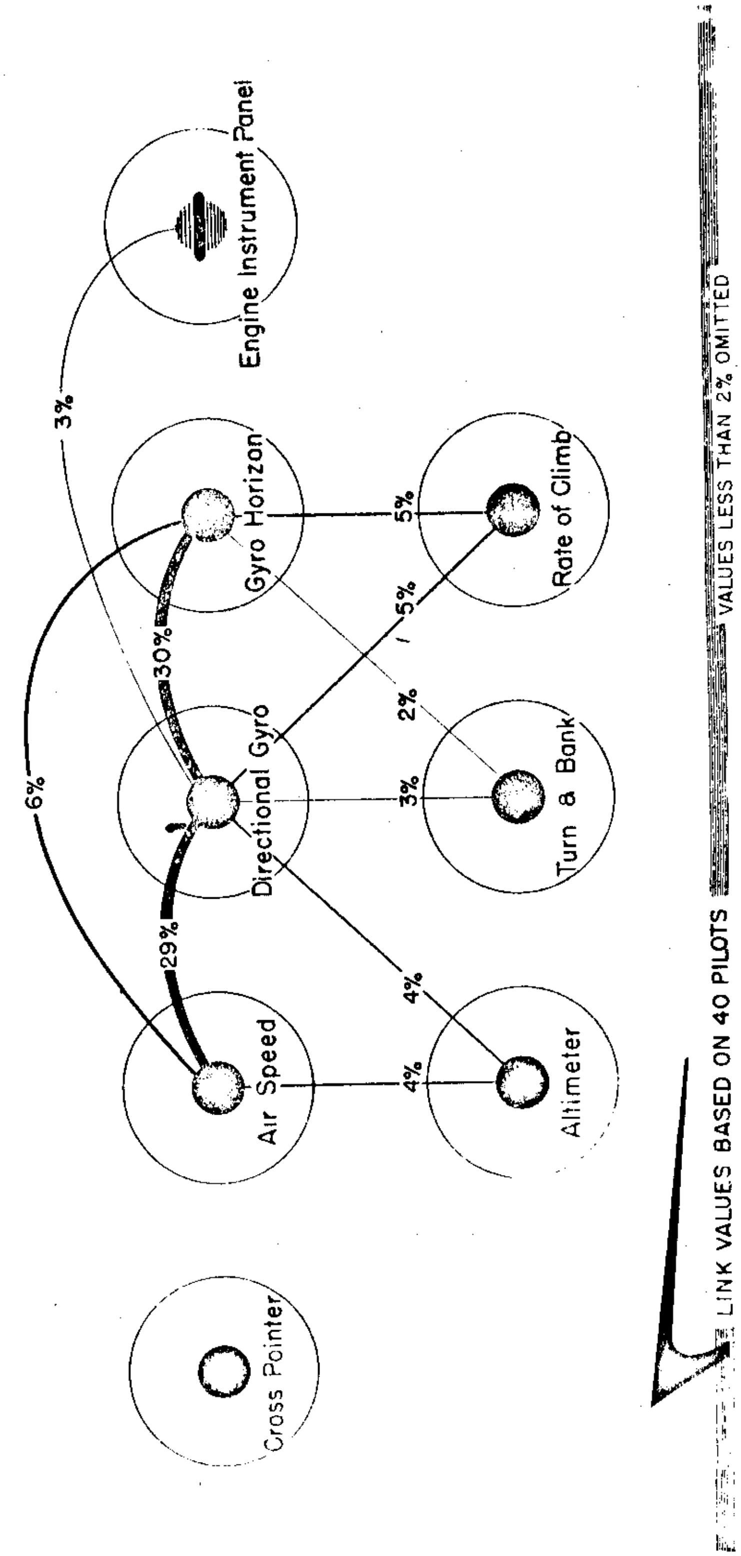


FIGURE 4

TABLE IX

The Relation Between Total Flying Time and Eye-Movement Measures Made During GCA Approaches

Instrument	N	No. Fixations per Minute*	Duration of Fixation Cycle**
Air Speed	40	.03	.15
Directional Gyro	40	.05	-.24
Gyro Horizon	40	.11	.17
Altimeter	40	.06	.01
Turn and Bank	35	.08	-.03
Vertical Speed	35	-.01	-.13
Engine Instrument Panel	31	-.20	.28
Total Fixations, All Instruments	40	.12	-.13

* A positive correlation indicates that more experienced pilots checked an instrument more often; a negative correlation that they checked it less often.

** A positive correlation indicates that more experienced pilots made longer fixations; a negative correlation that they made shorter fixations.

time, has no significant relation to length of fixation and number of fixations per minute.

The relation between eye-movement measures and instrument flying time is similar to that discussed above. The coefficient of correlation between total number of fixations per minute and hours of instrument (hood plus weather) time is 0.16. The correlation between length of the average fixation and hours of instrument flying experience is -0.16. This is to be expected since, for this group of subjects, there is a significant relation (r = 0.46) between total flying time and instrument flying time.

The effect of total amount of previous GCA experience on the rate of fixation is summarized in Table X. If the group is divided into four equal sub-groups, using as the criterion number of GCA approaches which have been flown by each subject, the mean number of fixations per minute is somewhat lower for the least experienced sub-group. However, the differences between individuals within each group are so large that the differences between group means are not significant.

The effect, on rate of fixation, of GCA experience during the 90 days preceding the experimental flight is shown in Table XI. There is a suggestion that the less experienced subjects may make somewhat fewer fixations per minute (hence, fixations of longer duration); but again, the individual differences are so large that the differences between the sub-group means are not statistically significant and are of no practical importance.

It must be concluded that this group of subjects fails to demonstrate any significant relation between rate of fixation and flying experience as measured by total flying hours, by instrument flying hours, or by number of GCA approaches flown by each pilot.

V. SUMMARY

1. The frequency, duration, and sequence of eye fixations made by forty USAF pilots when flying GCA approaches were recorded.

2. Fixations on the primary instruments varied from an average of 33 per minute on the directional gyro to 3 per minute on the turn and bank indicator. The group of pilots averaged 93 fixations per minute; over three-fourths of these were on the directional gyro, gyro horizon, and airspeed indicator.

3. The length of fixation cycle varied from an average of 0.90 second on the directional gyro to 0.36 second on the turn and bank indicator. Length of the average fixation was 0.67 second.

4. The average pilot spent approximately one-half of his time looking at the directional gyro and an additional four-tenths of his time looking at the gyro horizon and airspeed indicator.

TABLE X

Relation Between Total Previous GCA Experience and Rate of Eye Fixation When Flying GCA Approaches

Sub-Group	Experience (No. of Approaches)	N	No. Fixations Per Minute Range	Mean	S.D.
I	0 - 10	10	68-108	83.9	12.5
II	11 - 25	10	63-129	95.1	22.1
III	26 - 90	10	73-122	96.1	21.7
IV	91 - or more	10	59-125	96.2	15.5

TABLE XI

Relation Between Current GCA Experience (90 Days Preceding the Study) and Rate of Eye Fixation When Flying GCA Approaches

Sub-Group	Experience (No. of Approaches)	N	No. Fixations Per Minute Range	Mean	S.D.
I	0 - 3	10	68-108	86.8	12.2
II	4 - 11	10	63-129	92.2	21.9
III	12 - 27	9	74-125	100.9	19.5
IV	28 - or more	11	59-122	92.2	19.0

5. Among these forty pilots flying experience did not have any ificant relation to rate of eye fixation.

6. Eye Movement Link Values between all instruments were determined. From these values it is possible to specify an arrangement of instruments on the panel that is optimum from the point of view of eye movements. The arrangement used in this experiment (see Figure 2) is an excellent one for use during GCA approaches; however, the optimum arrangement will differ for different maneuvers. Therefore, recommendations on this point are withheld, pending the completion of similar analyses for other maneuvers and other instrument panel arrangements.

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