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EYE FIXATIONS OF AIRCRAFT PILOTS, IV. FREQUENCY, DURATION, AND SEQUENCE OF FIXATIONS DURING ROUTINE INSTRUMENT FLIGHT

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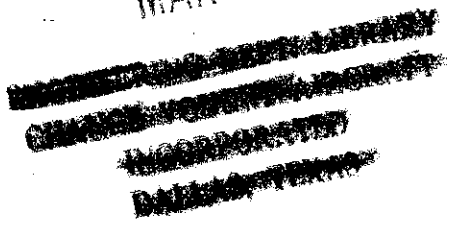

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FOREWORD

This is the fourth in 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 appreciation to the following individuals for valuable assistance in conducting the project: the Special Photographic Services Branch, which did the photographic work; the personnel from the United States Air Force Instrument Pilot School at Barksdale Air Force Base, from the All Weather Flying Division at Clinton County Air Force Base, and from the Wright-Patterson Air Force Base Instrument School, who volunteered as subjects; and 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 fourth in a series dealing with the measurement of pilot's eye movements during instrument flight. The frequency, duration, and sequence of eye fixations made by 36 USAF pilots when flying five maneuvers frequently performed during routine instrument flight are summarized. There is relatively little variation in the average rate of fixation and in the average length of fixation on specific instruments from maneuver to maneuver. Fixations per minute on the primary instruments made by the average pilot during routine maneuvers vary from about 25 on the directional gyro and on the gyro horizon to about 5 on the turn and bank indicator. Approximately two-thirds of all fixations are made on three instruments - the airspeed indicator, the directional gyro, and the gyro horizon. The average length of a fixation cycle during routine maneuvers may be as long as 0.70 second on the gyro horizon and as short as 0.34 second on the turn and bank indicator. Approximately two-thirds of all the time available during routine maneuvers is spent in looking at three instruments - the airspeed indicator, the directional gyro and the gyro horizon. Within the experience range studied, frequency and duration of eye-fixation are not related to pilot experience. Eye-movement link values between all instruments are presented. From these data an optimum arrangement of instruments on the panel can be determined. Since these values are affected by the particular arrangement being studied, recommendations on this point are withheld pending the completion of similar analyses for other arrangements.

PUBLICATION APPROVAL

For the Commanding General:

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LIST OF ILLUSTRATIONS

I. PURPOSE OF THE STUDY

The present report covers one of a series of investigations of how pilots use their eyes during instrument flight. The results for five specific maneuvers performed during routine instrument flight are summarized in the present report. Data on eye movements during ILAS approaches, during GCA approaches, during contact landings and takeoffs, and during night flights are covered in other reports.

II. PROCEDURES FOLLOWED IN OBTAINING EYE-FIXATION RECORDS

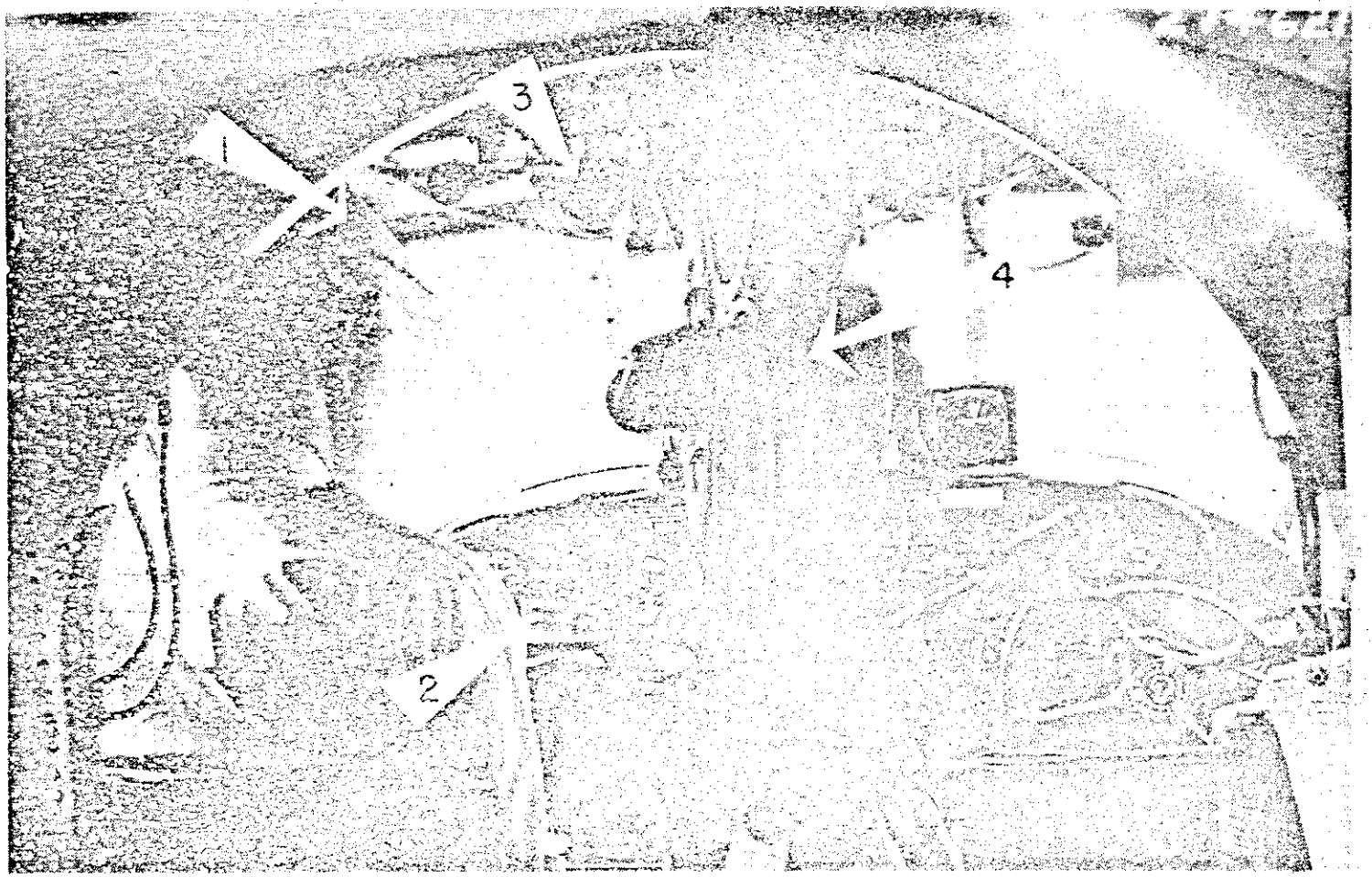
The procedures followed in the present report were described in detail in USAF Air Materiel Command Technical Report No. 5837. The description covered recording techniques, film analysis procedures, and the reliability of the resulting data. Briefly these procedures were as follows:

Photographic Recording. A 35-mm camera was installed in a C-45 aircraft, so that the eyes of a pilot could be photographed as they were reflected in a small rectangular mirror attached to the instrument panel, in the center of the flight instrument group. Photographic records were taken at eight frames per second during selected maneuvers. A special blind flying hood was used to restrict the pilot's vision to the instrument panel. A view of the recording camera and mirror is shown in Figure 1. The instrument-panel arrangement used in the present study is shown in Figure 2.

Flight Procedures. Each of 36 USAF pilots made an instrument flight during which he flew the aircraft through the following five maneuvers: 1) a climb (constant heading), 2) a descent (constant heading), 3) a level turn, 4) a climbing turn, and 5) a descending turn. A one-minute sample of each pilot's eye fixations was obtained during each maneuver. All pilots performed the maneuvers in the sequence listed above.

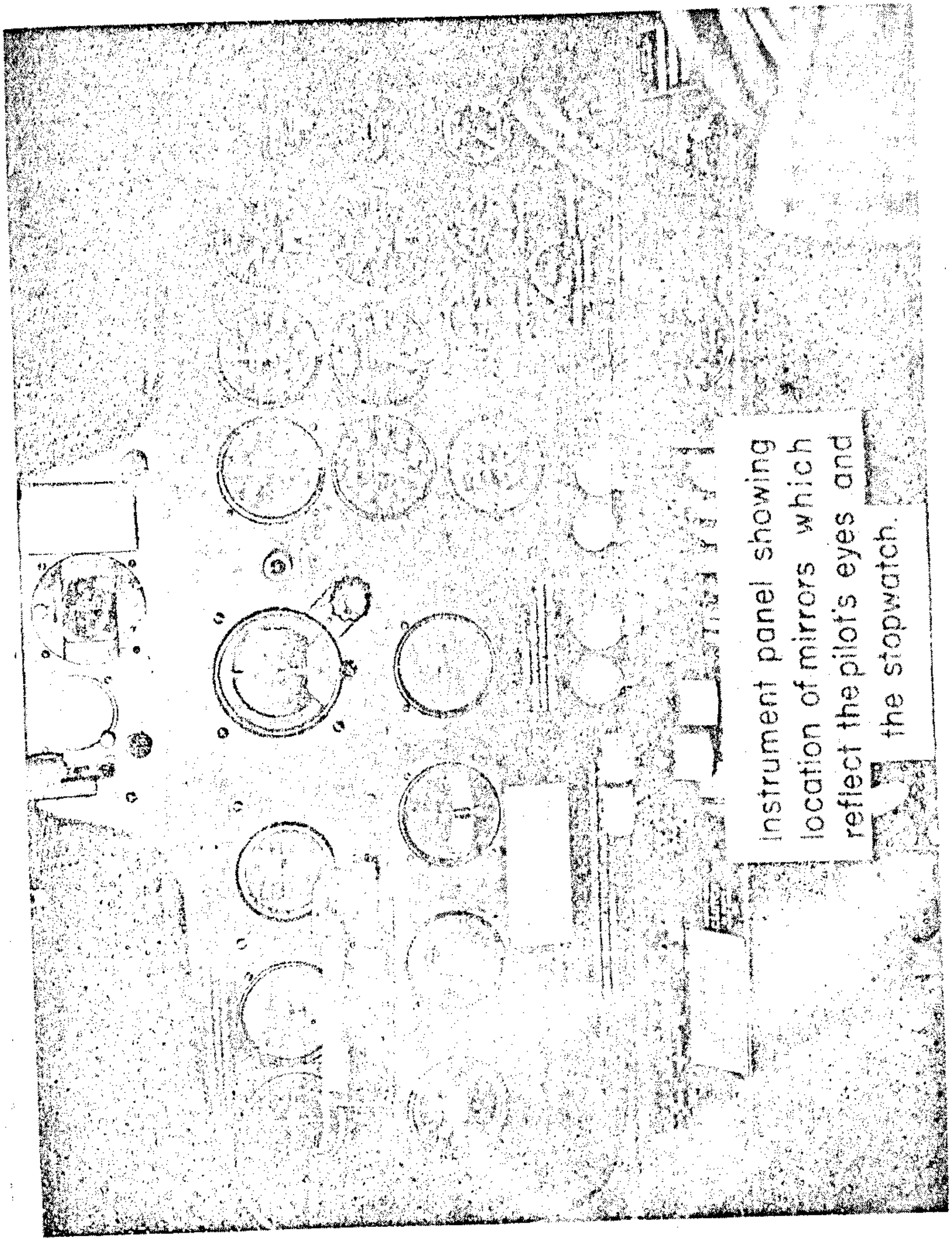
Film Analysis. All film records collected in the present study were scored by looking at each frame of photography and determining the instrument which the pilot was fixating at the time the photograph was made. Standard reference photographs taken at the beginning of each flight with the pilot looking directly at each instrument, were used to assist the scorer in making these judgments.

A detailed discussion of the reliability of the film analysis procedure was included in USAF Technical Report No. 5837. It was concluded that the recording and analysis technique was satisfactory from the point of view of reliability.



ARRANGEMENT OF EXPERIMENTAL EQUIPMENT IN THE COCKPIT

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



Instrument panel showing location of mirrors which reflect the pilot's eyes and the stopwatch.

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, i.e. whose experience level ranged from moderate to expert. The more experienced subjects included instructor pilots of the USAF Instrument Pilot School, Barksdale Air Force Base; instructor pilots of the Base Instrument School, Wright-Patterson Air Force Base; and pilots of the All Weather Flying Division, Clinton County Air Force Base. About half of the pilots belonged in this group. The other half of the group was made up of less experienced pilots attending the Instrument School at Barksdale Air Force Base or stationed at Wright-Patterson Air Force Base.

The 36 pilots who served as subjects ranged in age from 23 to 35 years with an average of 28 years. Their total flying time varied from 700 to 5000 hours, with an average of approximately 2100 hours. Their instrument flying time (hood plus weather) varied from 65 to 500 hours, with an average of approximately 200 hours. Among the 36 pilots were 35 who served as subjects during the maneuvers reported in USAF Technical Report No. 5839 and 5967.

IV. RESULTS

Number of Fixations. Means and standard deviations (root mean square variations) for number of fixations per minute on each instrument for each of the maneuvers are summarized in Table II. From inspection of this table, it can be seen that the total number of fixations per minute is relatively constant from maneuver to maneuver and that the instruments which are fixated most often during one maneuver tend to be fixated most often during the remaining maneuvers. There are, however, scattered differences which will be discussed later.

The pilots in this group averaged 105.6 fixations per minute during the descending turn, 106.0 fixations per minute during the climbing turn, 106.3 fixations per minute during the descent on a constant heading, 109.6 fixations per minute during the climb on a constant heading, and 109.7 fixations per minute during the level turn. They made approximately equal numbers of fixations on the two instruments which were checked most frequently - the directional gyro (heading indicator) and the gyro horizon (attitude indicator). The gyro horizon was checked most frequently during the climbs and descents on constant headings, while the directional gyro was checked most frequently during the turns. However, the largest difference between the averages for the two instruments during any maneuver is only 1.5 fixations per minute. From 45 to 48 percent of all fixations were made on these two instruments.

The airspeed indicator was the third most frequently checked instrument during all maneuvers except the level turn. During that maneuver the altimeter was checked slightly more frequently than was the airspeed indicator. From 62 to 67 percent of all fixations were made on the directional gyro, gyro horizon, and airspeed indicator combined.

TABLE I

Summary of Biographical Information for 36 Pilots Who Served as Subjects in an Experiment to Measure Eye Movements During Routine Instrument Flight

SUBJECT	AGE	TOTAL FLYING TIME	INSTRUMENT FLYING TIME
1	27	2500	500
2	30	2500	200
3	23	1300	400
4	31	2500	300
5	31	2100	300
6	28	3200	350
7	23	2200	215
8	26	2700	205
9	37	5000	250
10	27	2800	300
11	33	1350	100
12	28	1600	180
13	26	1350	156
14	27	3400	275
15	28	2450	170
16	33	1500	150
17	29	2300	300
18	28	2150	100
19	33	1500	70
20	27	1800	200
21	29	1300	100
22	24	2300	280
23	26	2100	300
24	26	850	150
25	25	2650	300
26	25	1000	200
27	28	1650	200
28	—	1900	200
29	28	2100	200
30	26	1700	120
31	26	1800	100
32	28	2000	300
33	25	1500	95
34	35	4300	200
35	28	700	65
36	24	1300	280
Mean	28	2093	217
Median	28	2100	202

TABLE II

Means and Standard Deveiations of Number of Fixations Per Minute on Each of the Basic Instruments During Five Maneuvers Performed in Routine Instrument Flight
(N = 36)

	Climbing, Constant Heading	Descending, Constant Heading	Climbing Turn	Descending Turn	Level Turn
			Airspeed		
Mean	22.3	22.0	17.4	18.8	14.8
S.D.	7.6	7.5	7.4	8.6	9.2
			Directional Gyro		
Mean	23.9	24.5	26.1	25.4	26.7
S.D.	9.7	10.4	8.9	7.1	8.4
			Gyro Horizon		
Mean	25.8	25.0	24.6	24.7	26.3
S.D.	9.7	10.2	8.4	7.5	7.5
			Altimeter		
Mean	9.6	8.7	10.3	8.9	15.1
S.D.	5.2	5.6	5.4	5.4	6.3
			Vertical Speed		
Mean	11.9	10.7	10.0	9.0	9.4
S.D.	8.1	5.8	6.5	5.8	7.4
			Turn and Bank		
Mean	5.0	3.8	6.4	6.7	8.0
S.D.	4.6	4.1	5.7	6.6	5.9
			Engine Instrument Panel		
Mean	5.3	6.4	5.3	5.5	2.5
S.D.	3.0	3.3	3.4	3.1	3.1
			Total, All Fixations*		
Mean	109.6	106.3	106.0	105.6	109.7
S.D.	22.3	19.6	19.9	17.9	21.0

* Includes those miscellaneous fixations (about 5 percent of the total) that could not be attributed to any of the primary instruments.

The most apparent differences among the different maneuvers are the decreased frequency with which the airspeed was checked during the turns, especially the level turn, and the increased frequency with which the altimeter was checked during the level turn.

Length of Fixation Cycle. The average length of fixation cycle (all fixations included) varied from 0.57 second during the level turn and the straight climb to 0.59 second during the climbing turn. However, between different maneuvers, there was considerable variation in length of fixation cycle for the individual instruments. Considering only flight instruments, during the climb and descent on a constant heading the longest fixation (0.67 second) was on the airspeed, while during the turns the longest fixation (0.70 second) was on the gyro horizon.

The average length of fixation cycle for the gyro horizon varied from 0.70 second to 0.54 second, that for the airspeed indicator from 0.67 second to 0.52 second, that for the directional gyro from 0.60 second to 0.51 second, that for the altimeter from 0.50 second to 0.44 second, that for the vertical speed indicator from 0.49 second to 0.39 second, and that for the turn and bank indicator from 0.48 second to 0.34 second. Fixations on the engine instrument panel were considerably longer, ranging from 1.25 seconds during the straight glide to 0.93 second during the level turn.

Table IV presents the average length of fixation cycle for each instrument with the weighting made according to fixations. These values were calculated by the following formula:

$$\frac{\text{Total frames observing one instrument}}{\text{Total fixations on the instrument}} \times \text{Time per frame.}$$

This procedure, which weights each eye fixation equally, gives the most weight to the subject who made the most fixations. If these fixation cycle values are compared with those derived from the calculations which weighted each subject equally, it can be seen that the differences are very small. In only 4 of the 40 instances are the differences larger than 0.04 second. At all other places in this report the computations were made in such a way as to weight equally the data contributed by each of the thirty-six subjects.

Total Time Allotted to Each Instrument. It is possible to determine from the eye-movement films the percentage of the total time available to the pilot that was spent in observing each instrument. These data are presented in Figures 3, 4, 5, 6, and 7, and are summarized in Table V. Inspection of Table V reveals that, although the proportion of time allotted to each instrument varies from maneuver to maneuver, in all cases approximately two-thirds of the time was spent in observing three instruments--the gyro horizon, the directional gyro, and the airspeed indicator. When climbing and descending on a constant heading the relative importance of the different instruments, as judged by the amount of time devoted to each, was as follows: 1) airspeed indicator,

TABLE III

Means and Standard Deviations of Length of Fixation on Each of the Basic Instruments During Five Maneuvers Performed in Routine Instrument Flight*

	Climbing, Constant Heading	Descending, Constant Heading	Climbing Turn	Descending Turn	Level Tu
			Airspeed		
N	36	36	36	36	35
Mean	.67	.67	.58	.61	.52
S.D.	.19	.21	.14	.14	.11
			Directional Gyro		
N	36	36	36	36	36
Mean	.51	.54	.56	.59	.60
S.D.	.13	.13	.13	.12	.15
			Gyro Horizon		
N	36	36	36	36	36
Mean	.59	.54	.70	.63	.70
S.D.	.20	.15	.28	.18	.20
			Altimeter		
N	36	35	36	35	36
Mean	.47	.48	.44	.45	.50
S.D.	.13	.12	.07	.12	.15
			Vertical Speed		
N	34	36	33	35	32
Mean	.47	.49	.48	.46	.39
S.D.	.14	.14	.12	.11	.12
			Turn and Bank		
N	32	31	32	32	36
Mean	.39	.34	.48	.46	.44
S.D.	.14	.19	.15	.13	.14
			Engine Instrument Panel		
N	35	34	30	34	23
Mean	1.13	1.25	1.11	1.13	.93
S.D.	.57	.76	.37	.42	.54
			Average, All Fixations**		
N	36	36	36	36	36
Mean	.57	.58	.59	.58	.57
S.D.	.11	.11	.13	.10	.12

* Number of cases varies because some pilots did not look at a particular instrument during some of the maneuvers.

** Based on all fixations, including those that could not be attributed to any of the primary instruments.

TABLE IV

Average Length of Fixation for Different Instruments During Different Maneuvers

Instrument	Average Length of Fixation (Seconds) Weighted by fixations	Weighted by subjects
	Climbing, constant heading	
Airspeed	.66	.67
Directional Gyro	.48	.51
Gyro Horizon	.58	.59
Altimeter	.47	.47
Vertical Speed	.47	.47
Turn and Bank	.43	.39
Engine Instrument Panel	1.09	1.13
Average, all fixations	.55	.57
	Descending, constant heading	
Airspeed	.68	.67
Directional Gyro	.52	.54
Gyro Horizon	.53	.54
Altimeter	.49	.48
Vertical Speed	.49	.49
Turn and Bank	.44	.34
Engine Instrument Panel	1.12	1.25
Average, all fixations	.57	.58
	Climbing Turn	
Airspeed	.60	.58
Directional Gyro	.53	.56
Gyro Horizon	.67	.70
Altimeter	.43	.44
Vertical Speed	.47	.48
Turn and Bank	.48	.48
Engine Instrument Panel	1.09	1.11
Average, all fixations	.56	.59
	Descending Turn	
Airspeed	.62	.61
Directional Gyro	.58	.59
Gyro Horizon	.62	.63
Altimeter	.45	.45
Vertical Speed	.48	.46
Turn and Bank	.46	.46
Engine Instrument Panel	1.07	1.13
Average, all fixations	.57	.58
	Level Turn	
Airspeed	.52	.52
Directional Gyro	.58	.60
Gyro Horizon	.68	.70
Altimeter	.50	.50
Vertical Speed	.41	.39
Turn and Bank	.46	.44
Engine Instrument Panel	.85	.93
Average, all fixations	.55	.57

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR-CRAFT INSTRUMENTS DURING INSTRUMENT FLIGHT

CLIMBING (CONSTANT HEADING)

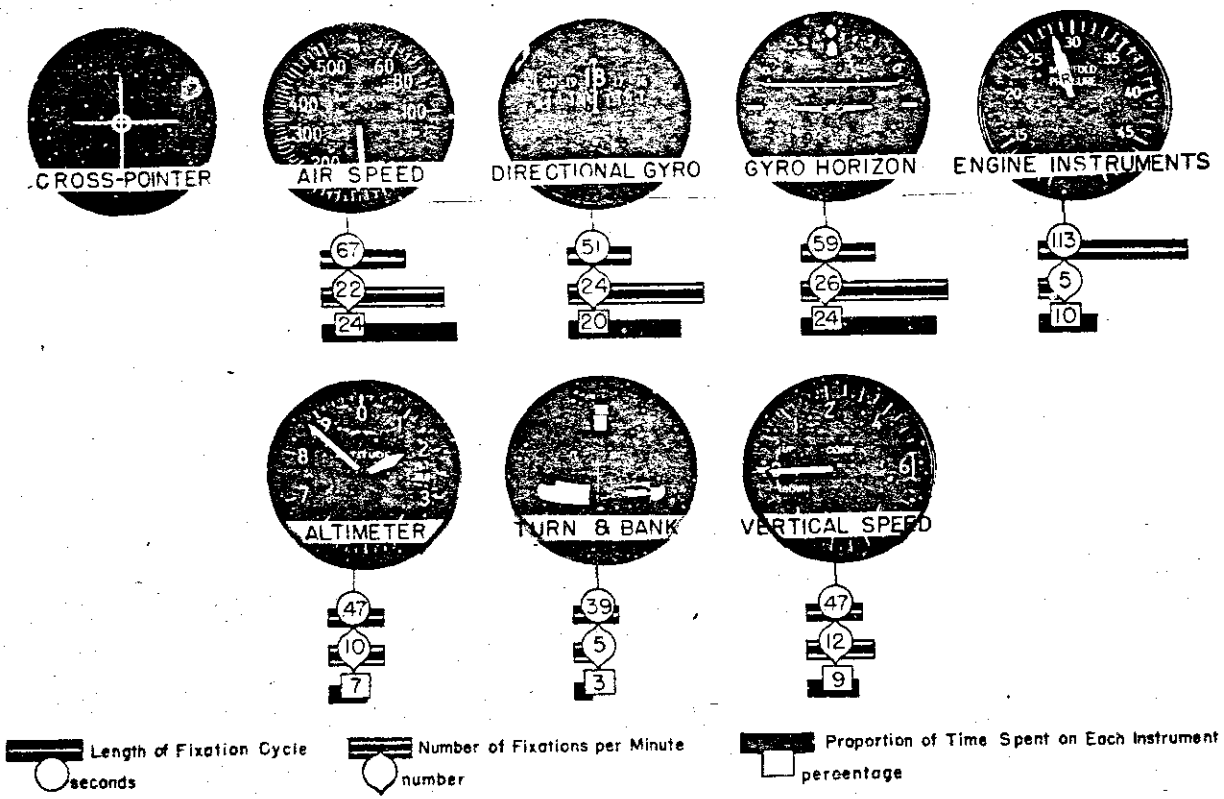


FIGURE 3

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING INSTRUMENT FLIGHT

DESCENDING (CONSTANT HEADING)

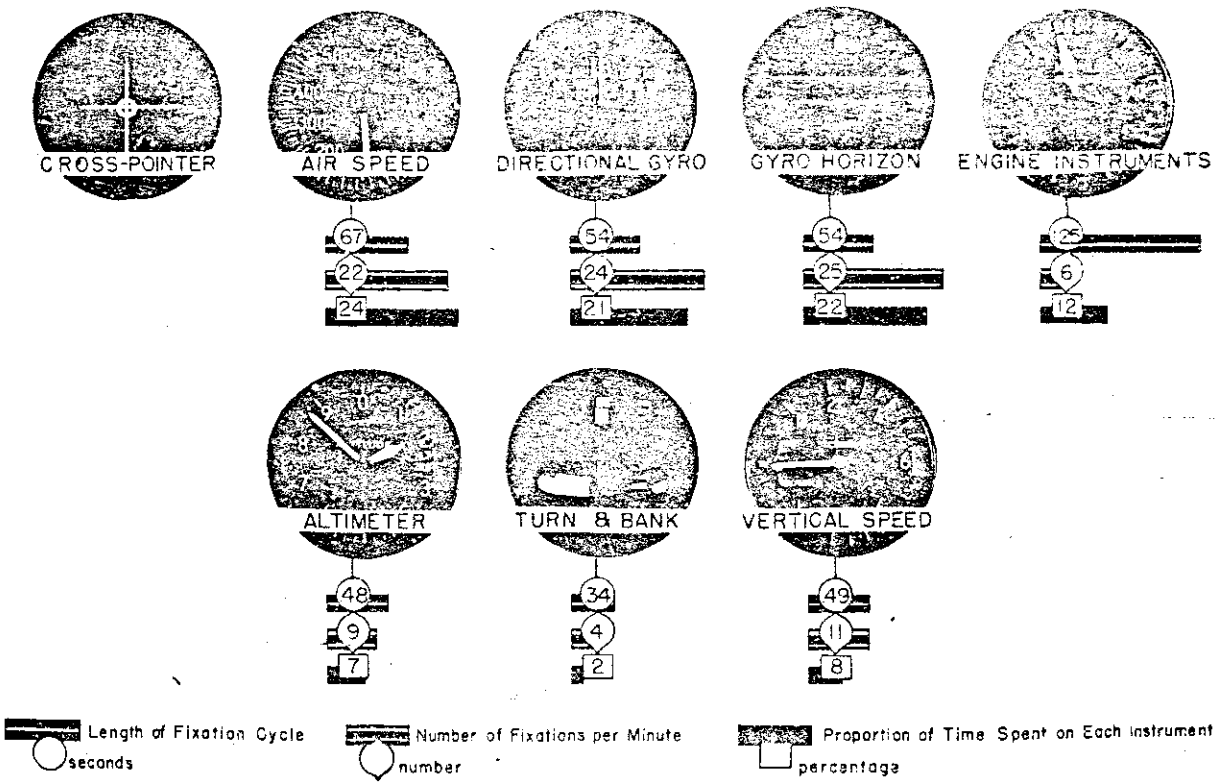


FIGURE 4

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING INSTRUMENT FLIGHT

CLIMBING TURN

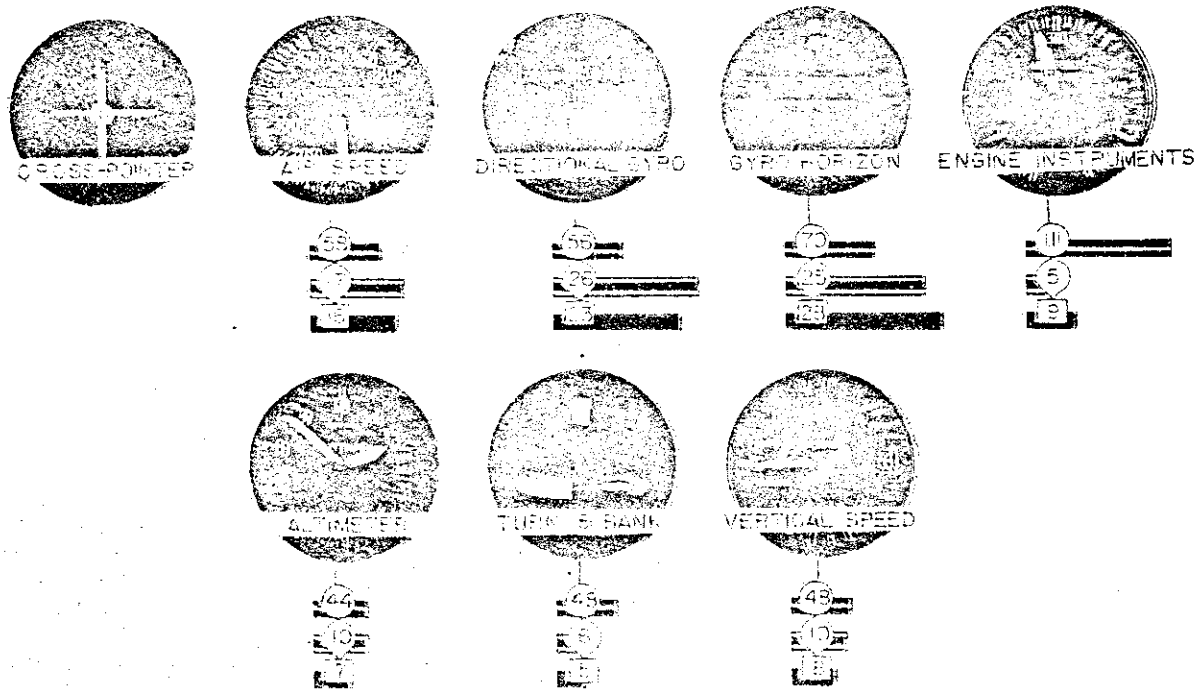


FIGURE 5

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR-CRAFT INSTRUMENTS DURING INSTRUMENT FLIGHT

DESCENDING TURN

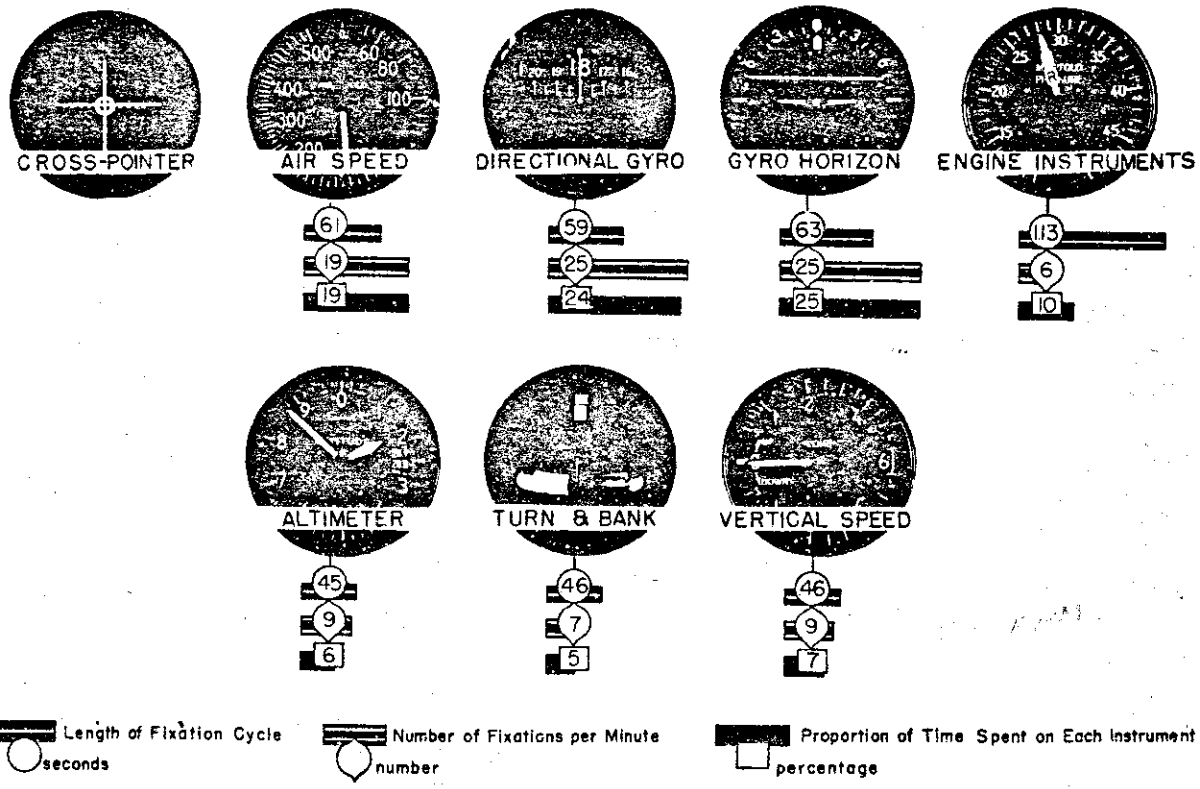


FIGURE 6

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING INSTRUMENT FLIGHT

LEVEL TURN

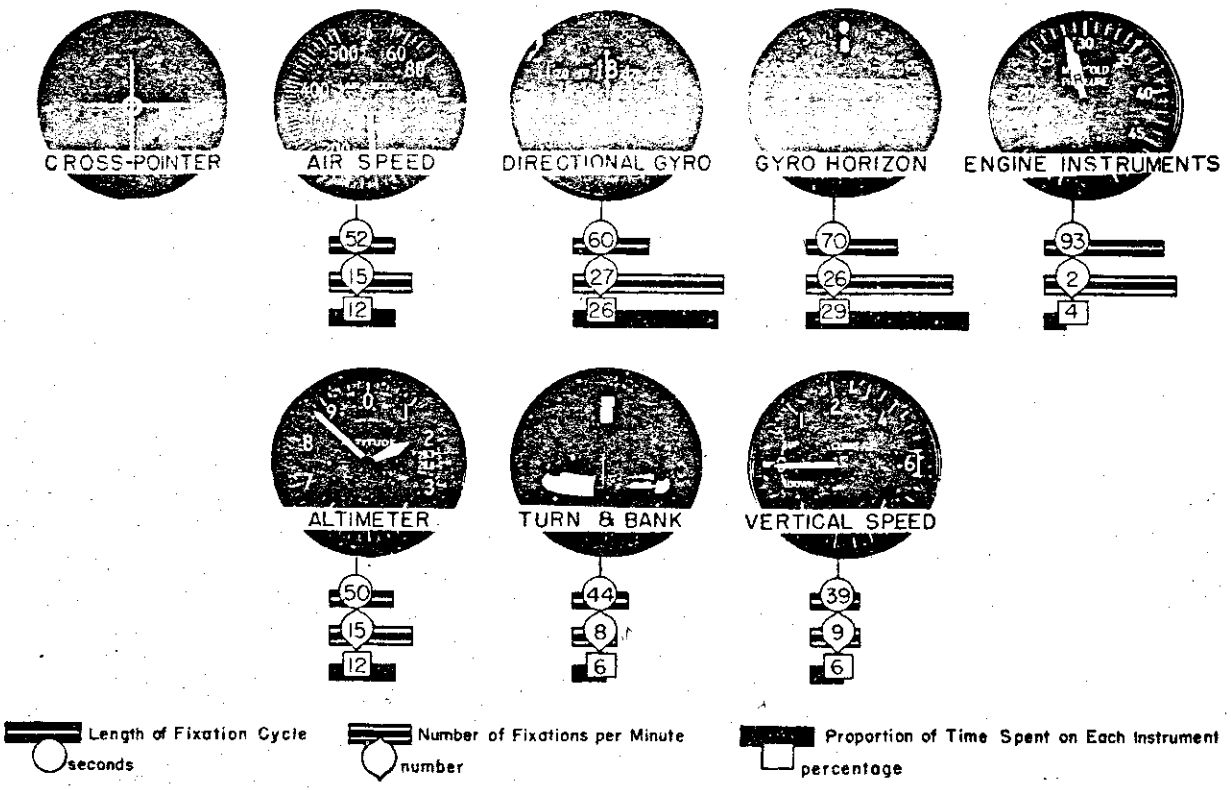


FIGURE 7

2) gyro horizon, 3) directional gyro, 4) engine instrument panel, 5) vertical speed indicator, 6) altimeter and 7) turn and bank indicator. During climbing and descending turns the order of relative importance was 1) gyro horizon, 2) directional gyro, 3) airspeed indicator, 4) engine instrument panel, 5) vertical speed indicator, 6) altimeter, and 7) turn and bank indicator. During level turns the order of relative importance was: 1) gyro horizon, 2) directional gyro, 3-4) airspeed indicator tied with altimeter, 5-6) vertical speed indicator tied with turn and bank indicator, and 7) engine instrument panel.

It is interesting to note that although the specific order is somewhat different, the three instruments on which the pilots spent about two-thirds of their time when flying routine maneuvers are the same three instruments on which it was previously discovered they spent 85 percent of their time when flying GCA approaches (1) and 50 percent of their time when flying ILAS approaches (5).

Relation Between Frequency of Use and Speed of Checking Instruments. Table VI shows the relation between length of fixation and number of fixations made by these pilots on various instruments during the five maneuvers investigated. During all maneuvers there is, for the directional gyro, a significant negative relationship between the two measures. In other words, the fixations on this instrument, of pilots who checked it often were of shorter duration than were those of pilots who checked it less frequently. The lack of similar negative correlations for the gyro horizon discredits the hypothesis that a rather high frequency of fixations on an instrument accounts for this relation.

Fixation Sequence (Eye-Movement Link Values). Any discussion of the pattern of eye movements or the 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. The instrument arrangement used in this study had been established by Technical Order 01-1-160 and was the accepted Air Force arrangement at the time of the study (see Figure 2).

The 42 eye movements, between the six flight instruments and the engine instrument panel, that are possible with this arrangement are listed in Tables, VII, VIII, IX, X, and XI, in descending order of importance. The strength of the bond (Eye-Movement Link Value) between any two instruments, based on the frequency of eye movements, in both directions between the instruments, is shown in Figures 8, 9, 10, 11, and 12.

For three of the five maneuvers the most frequent eye movement was from the gyro horizon to the directional gyro and the second most frequent was from the directional gyro to the gyro horizon. For the two remaining maneuvers the same two eye movements were most frequent but the order was reversed. This Link Value was very strong since 21 to 25 percent of all the eye movements made during each maneuver were between these two instruments.

TABLE V

Percent of Time Spent in Observing Each Instrument During Different Maneuvers Performed in Routine Instrument Flight

	Climbing, Constant Heading	Descending, Constant Heading	Climbing Turn	Descending Turn	Level Turn
Airspeed	24	24	16	19	12
Directional Gyro	20	21	23	24	26
Gyro Horizon	24	22	28	25	29
Altimeter	7	7	7	6	12
Vertical Speed	9	8	8	7	6
Turn and Bank	3	3	5	5	6
Engine Instrument Panel	10	12	9	10	4
Miscellaneous	3	3	4	4	5

TABLE VI

Correlations Between the Average Length of Fixation and the Average Number of Fixations for Individual Pilots on Various Instruments During Different Maneuvers Performed in Routine Instrument Flight

	Climbing, Constant Heading		Descending, Constant Heading		Climbing Turn		Descending Turn		Level Turn	
	N	r	N	r	N	r	N	r	N	r
Airspeed	36	-.30	36	.02	36	.20	36	-.04	35	-.08
Directional Gyro	36	-.45**	36	-.33*	36	-.52**	36	-.46**	36	-.55**
Gyro Horizon	36	-.13	36	-.08	36	-.18	36	-.05	36	-.21
Altimeter	36	.06	35	.07	36	-.13	35	.01	36	-.17
Vertical Speed	34	-.01	36	.01	33	-.39*	35	.17	32	.30
Turn and Bank	32	.31	31	.49**	32	.10	32	.10	36	.25
Engine Instrument Panel	35	-.06	34	-.37*	30	-.06	34	-.23	23	0

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

For all maneuvers the third most frequent eye movement was from the directional gyro to the airspeed indicator and the fourth most frequent was from the airspeed indicator to the directional gyro. From 13 to 18 percent of all eye movements made during the several maneuvers were between these two instruments.

It is interesting to note that from 43 to 49 percent of all eye movements made by this group of pilots while flying these maneuvers were between the three indicators located in the top row of flight instruments. These are the airspeed indicator, the directional gyro and the gyro horizon. It should be remembered that these are the same three instruments on which the pilots made from 45 to 48 percent of their fixations and spent from 67 to 68 percent of the time available to them during the maneuvers.

In a previous report it was stated, "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" (5). This hypothesis is supported by the data of Fitts and Simon who investigated the effect of both vertical and horizontal displacement of indicators on performance of a dual pursuit task (2). Inspection of Figures 8, 9, 10, 11, and 12 reveals that the panel arrangement used in this study meets this criterion exceptionally well for the maneuvers investigated. However, it should be remembered that these data may have been influenced by the particular instrument arrangement studied and that some of the Link Values may change somewhat for other arrangements. This question will be investigated in a subsequent study.

Effect of Experience on Eye Movement Measures. The relation between rate of fixation (number of fixations per minute) and flying experience as represented by 1) total flying time and 2) instrument flying time is summarized in Table XII. None of the correlations approach significance. Therefore, the present results fail to demonstrate any relationship between flying experience and rate of fixation during the performance of these instrument flight maneuvers. This does not necessarily mean that there is no relation - only that the relation, if it exists, is sufficiently small that in a sample of 36 cases individual differences between pilots outweigh any influence due to experience alone.

Tables XIII and XIV summarize the relation between length of fixation cycle for the three instruments which pilots spend two-thirds of their time observing and 1) total flying time and 2) instrument flying time. Since none of these correlations are significant, the present evidence again fails to support the idea that length of fixation on these three instruments is related to flying experience.

SUMMARY

1. The frequency, duration and sequence of eye fixations made by 36 USAF pilots when flying five maneuvers performed during routine instrument flight were recorded.

TABLE VII

Frequency of Occurrence of Eye Movements During Maneuvers Performed in Routine Instrument Flight - Climbing, Constant Heading

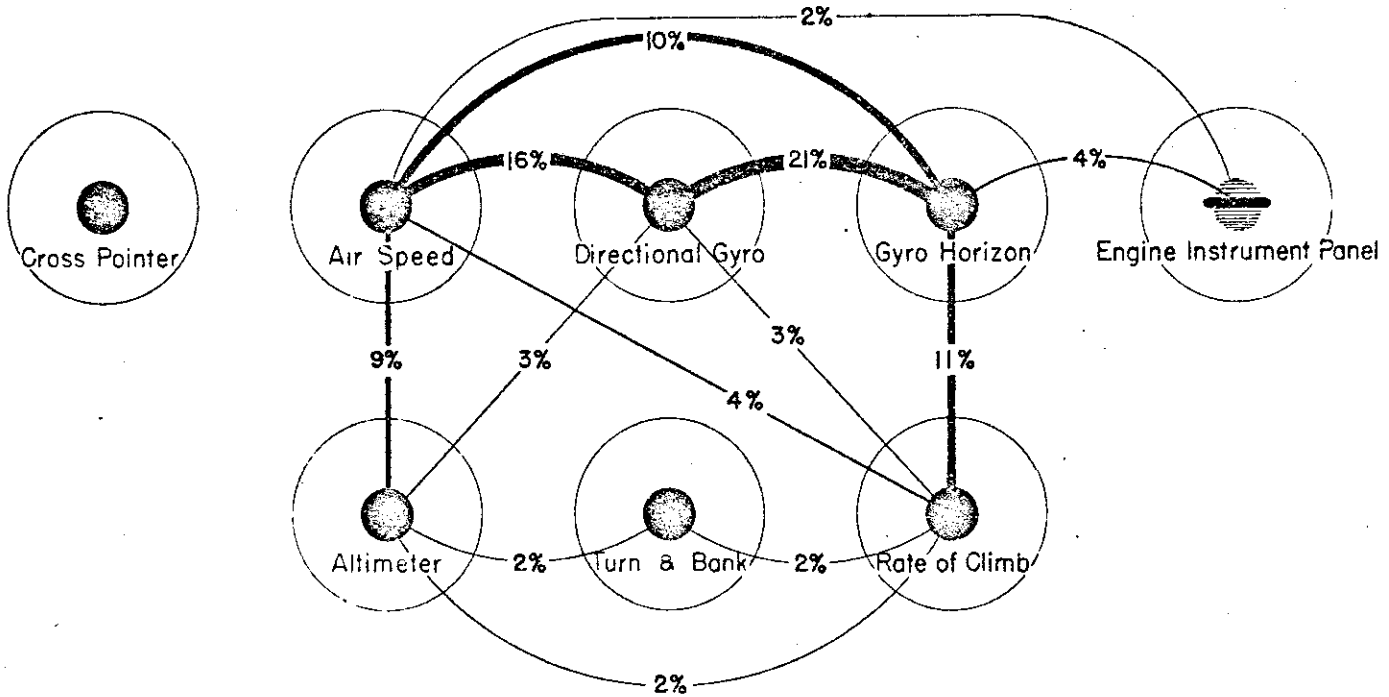
G/H - D/G	415	Alt - G/H	45
D/G - G/H	369	V/S - D/G	40
D/G - A/S	324	T/B - G/H	39
A/S - D/G	259	E/I - G/H	38
V/S - G/H	221	V/S - Alt	38
A/S - G/H	212	A/S - T/B	37
A/S - Alt	197	D/G - E/I	33
G/H - V/S	190	T/B - Alt	33
G/H - A/S	163	G/H - T/B	33
Alt - A/S	139	T/B - A/S	30
G/H - E/I	92	V/S - T/B	30
V/S - A/S	74	V/S - E/I	28
E/I - D/G	70	A/S - E/I	26
A/S - V/S	66	D/G - T/B	26
T/B - V/S	58	G/H - Alt	25
E/I - A/S	56	T/B - D/G	13
Alt - D/G	54	E/I - V/S	10
Alt - T/B	54	E/I - Alt	9
D/G - V/S	51	Alt - E/I	6
Alt - V/S	51	E/I - T/B	6
D/G - Alt	47	T/B - E/I	6

Legend

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

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

CLIMBING (CONSTANT HEADING)



LINK VALUES BASED ON 36 PILOTS

VALUES LESS THAN 2% OMITTED

FIGURE 8

TABLE VIII

Frequency of Occurrence of Eye Movements During Maneuvers Performed in Routine Instrument Flying - Descending, Constant Heading

G/H - D/G	402	T/B - G/H	39
D/G - G/H	356	T/B - V/S	38
D/G - A/S	345	Alt - T/B	38
A/S - D/G	307	D/G - E/I	37
V/S - G/H	198	A/S - E/I	37
A/S - G/H	190	V/S - Alt	36
A/S - Alt	170	G/H - T/B	35
G/H - A/S	166	G/H - Alt	33
G/H - V/S	138	V/S - D/G	31
G/H - E/I	129	D/G - T/B	27
Alt - A/S	105	T/B - D/G	24
V/S - A/S	84	V/S - E/I	22
E/I - D/G	77	A/S - T/B	19
A/S - V/S	70	T/B - Alt	19
E/I - A/S	68	V/S - T/B	16
E/I - G/H	68	T/B - A/S	14
Alt - V/S	66	E/I - V/S	14
D/G - V/S	57	Alt - E/I	7
D/G - Alt	55	E/I - Alt	5
Alt - G/H	54	E/I - T/B	4
Alt - D/G	48	T/B - E/I	3

Legend

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

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
DESCENDING (CONSTANT HEADING)

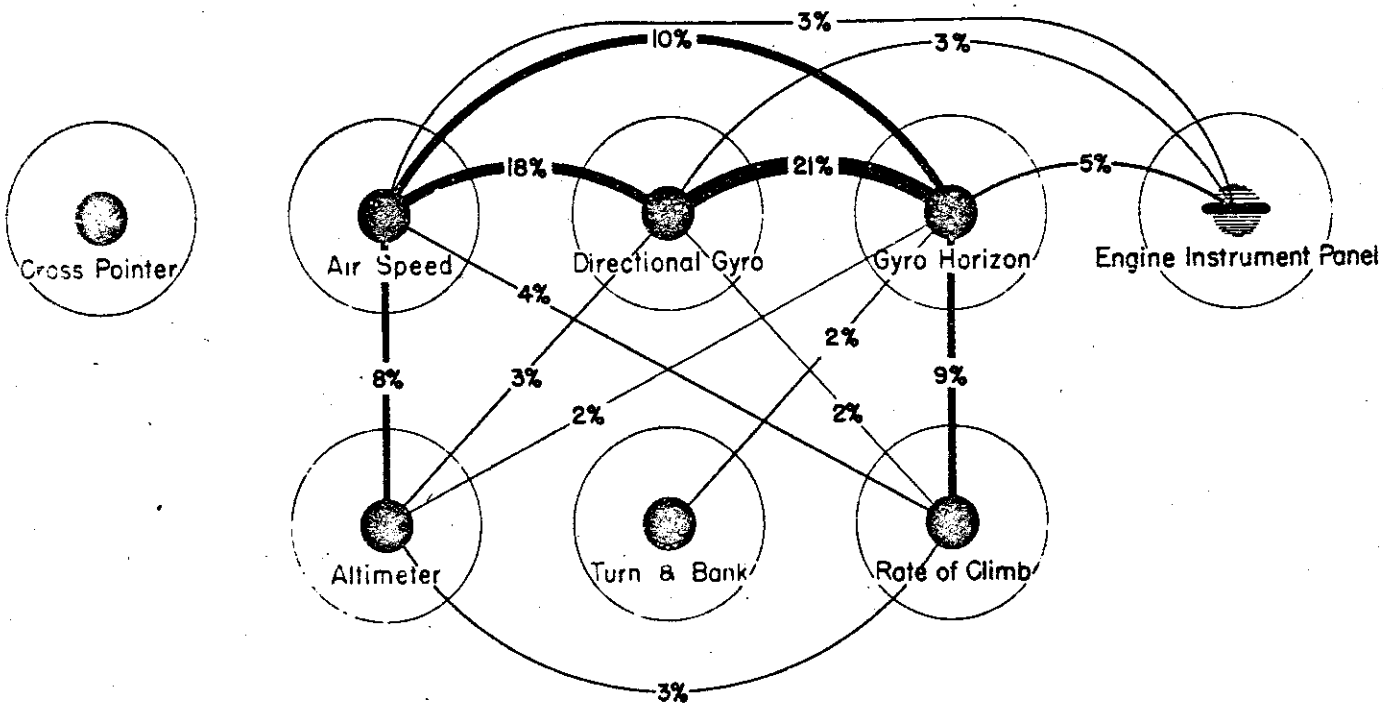


FIGURE 9

TABLE IX

Frequency of Occurrence of Eye Movements During Maneuvers Performed in Routine Instrument Flight - Climbing Turn

D/G - G/H	424	E/I - G/H	50
G/H - D/G	397	Alt - T/B	48
D/G - A/S	276	T/B - G/H	47
A/S - D/G	273	V/S - T/B	47
G/H - V/S	172	T/B - V/S	46
V/S - G/H	157	Alt - V/S	46
A/S - G/H	144	T/B - Alt	44
A/S - Alt	135	V/S - Alt	44
Alt - A/S	131	E/I - A/S	44
G/H - A/S	107	A/S - V/S	44
G/H - E/I	101	V/S - A/S	41
D/G - Alt	87	D/G - E/I	34
E/I - D/G	77	T/B - A/S	26
Alt - G/H	71	A/S - E/I	23
D/G - T/B	70	V/S - E/I	22
Alt - D/G	68	A/S - T/B	8
T/B - D/G	65	E/I - Alt	8
G/H - Alt	58	Alt - E/I	8
G/H - T/B	57	E/I - T/B	7
V/S - D/G	55	E/I - V/S	7
D/G - V/S	50	T/B - E/I	4

Legend

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

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
CLIMBING TURN

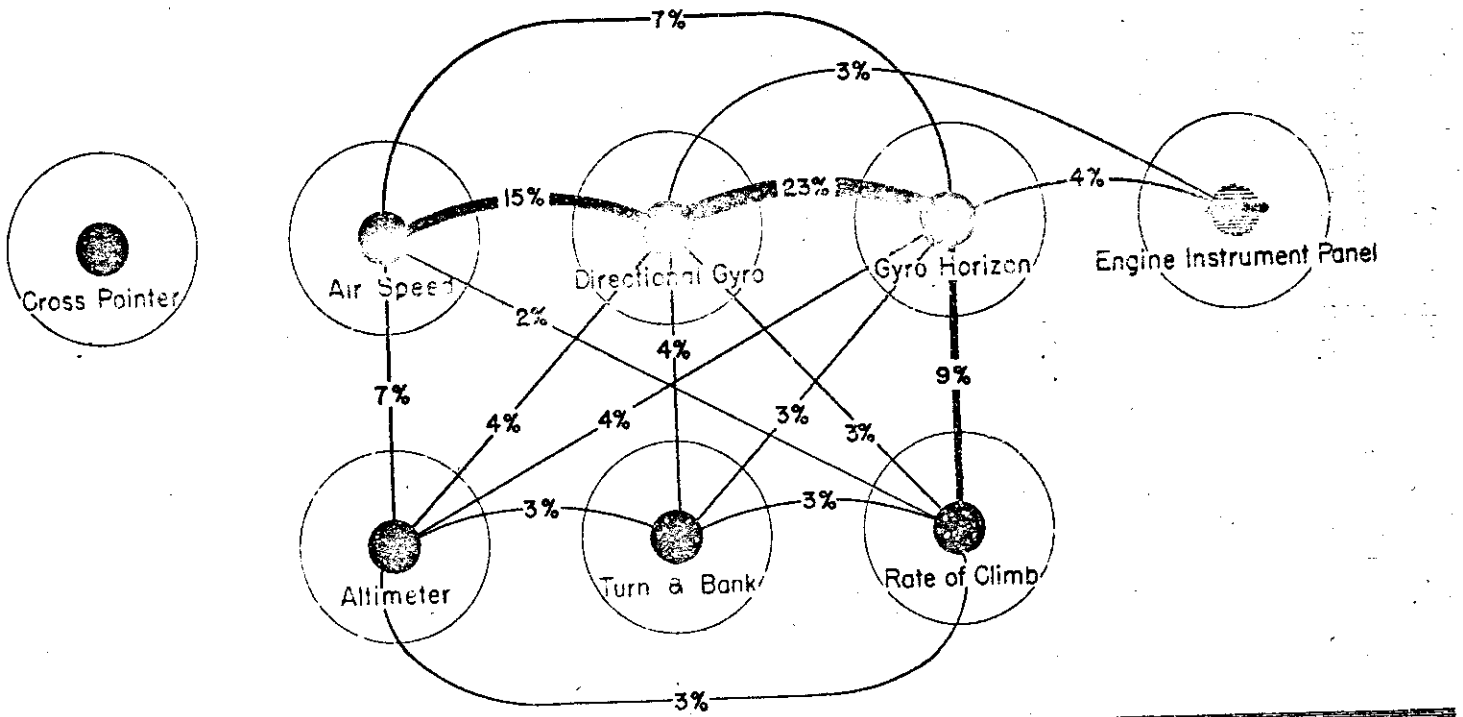


FIGURE 10

TABLE X

Frequency of Occurrence of Eye Movements During Maneuvers Performed in Routine Instrument Flight - Descending Turn

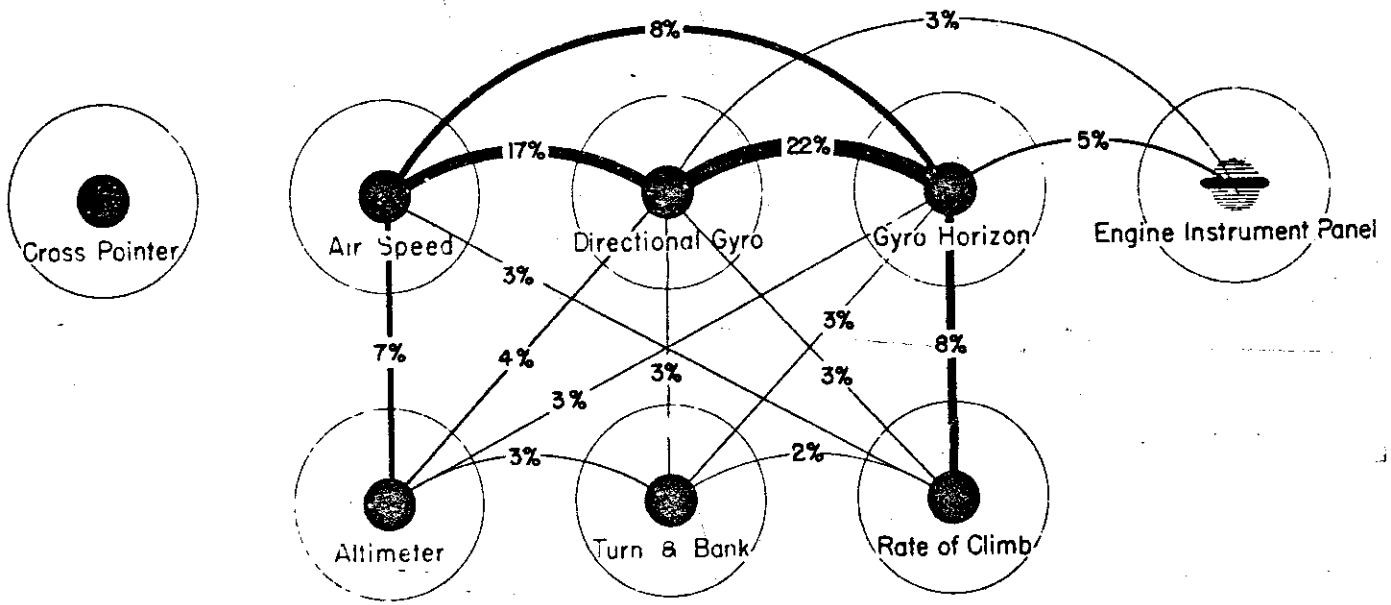
D/G - G/H	415	V/S - A/S	55
G/H - D/G	392	D/G - V/S	55
D/G - A/S	306	G/H - Alt	55
A/S - D/G	288	T/B - V/S	55
A/S - G/H	155	V/S - D/G	55
V/S - G/H	151	Alt - G/H	55
A/S - Alt	143	Alt - V/S	55
G/H - A/S	140	E/I - A/S	55
G/H - V/S	140	T/B - A/S	55
Alt - A/S	119	V/S - T/B	55
G/H - E/I	116	T/B - G/H	55
E/I - G/H	75	V/S - Alt	55
D/G - Alt	70	A/S - E/I	55
E/I - D/G	70	A/S - T/B	55
Alt - D/G	60	V/S - E/I	55
T/B - D/G	60	D/G - E/I	55
G/H - T/B	59	Alt - E/I	55
T/B - G/H	58	E/I - T/B	55
D/G - T/B	57	T/B - E/I	55
Alt - T/B	55	E/I - Alt	55
A/S - V/S	55	E/I - V/S	55

Legend

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

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DESCENDING TURN



LINK VALUES BASED ON 36 PILOTS

VALUES LESS THAN 2% OMITTED

FIGURE 11

TABLE XI

Frequency of Occurrence of Eye-Movements During Maneuvers Performed in Routine Instrument Flight- Level Turn

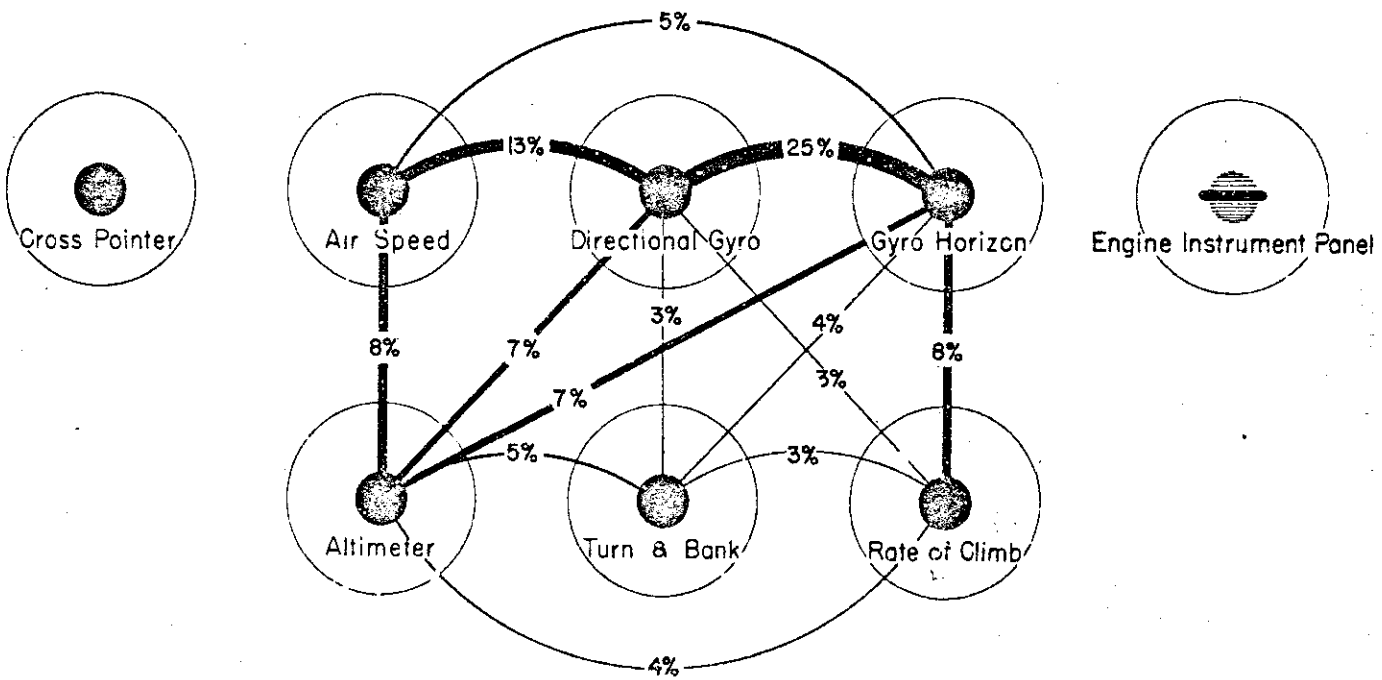
G/H - D/G	456	V/S - D/G	53
D/G - G/H	441	T/B - V/S	48
D/G - A/S	253	D/G - V/S	46
A/S - D/G	216	D/G - T/B	44
A/S - Alt	171	V/S - T/B	42
V/S - G/H	154	G/H - E/I	39
G/H - V/S	140	E/I - D/G	28
Alt - G/H	135	E/I - G/H	25
D/G - Alt	128	V/S - A/S	23
Alt - D/G	119	T/B - A/S	23
Alt - A/S	106	D/G - E/I	21
G/H - Alt	105	E/I - A/S	18
G/H - A/S	100	A/S - V/S	18
Alt - T/B	98	A/S - E/I	13
A/S - G/H	93	A/S - T/B	13
G/H - T/B	87	E/I - V/S	8
T/B - Alt	84	V/S - E/I	8
Alt - V/S	77	E/I - Alt	5
T/B - G/H	73	Alt - E/I	4
T/B - D/G	59	E/I - T/B	2
V/S - Alt	55	T/B - E/I	2

Legend

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

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

LEVEL TURN



LINK VALUES BASED ON 36 PILOTS

VALUES LESS THAN 2% OMITTED

FIGURE 12

TABLE XII

Relation Between Flying Experience and Average Rate of Eye Fixations
(N = 36)

Maneuver	Correlation of No. fixations per minute with Total Flying Time	Instrument Flying Time
Climbing, Constant Heading	.090	.203
Descending, Constant Heading	.070	.039
Climbing Turn	-.045	-.041
Descending Turn	-.052	.034
Level Turn	.057	-.023

TABLE XIII

Relation Between Total Flying Time and Length of Fixation on Three Flight Instruments During Five Maneuvers
(N = 36)

Maneuver	Correlation Between Total Flying Time and Length of Fixation on Airspeed	Directional Gyro	Gyro Horizon
Climb, Constant Heading	-.07	-.23	.05
Descent, Constant Heading	-.08	-.02	-.09
Level Turn	-.25	-.12	.10
Climbing Turn	-.23	.12	.20
Descending Turn	-.25	-.02	.08

TABLE XIV

Relation Between Instrument Flying Time and Length of Fixation on Three Flight Instruments During Five Maneuvers
(N = 36)

Maneuver	Correlation Between Instrument Flying Time and Length of Fixation Airspeed	Directional Gyro	Gyro Horizon
Climb, Constant Heading	-.07	-.23	.05
Descent, Constant Heading	-.08	-.02	-.09
Level Turn	-.25	-.12	.10
Climbing Turn	-.23	.12	.20
Descending Turn	-.25	-.02	.08

2. The average numger of fixations per minute varied from 105 to 109 depending on the maneuver. The directional gyro and gyro horizon were each fixated about 25 times per minute. Approximately two-thirds of all fixations were on these two instruments and on the airspeed indicator.

3. The average length of fixation cycle varied only slightly (from 0.57 second to 0.59 second) from one routine maneuver to another. For some maneuvers, average length of fixation on the gyro horizon was as long as 0.70 second while for other maneuvers average length of fixation on the turn and bank indicator was as short as 0.34 second. Average fixations on the engine instruments usually exceeded one second in duration.

4. Approximately two-thirds of all the time available was spent in observing three instruments - the directional gyro, the gyro horizon, and the airspeed indicator.

5. In this group of pilots, amount of flying experience had no relation to the average length of fixation or to the rate of fixation shown by individual pilots.

6. Eye-movement link values between all instruments were determined. From these values it is possible to specify an optimum panel arrangement for these maneuvers. Although the arrangement established by Technical Order 01-1-160 is very good for the five maneuvers studied, recommendations on this point are withheld pending similar analyses for other maneuvers and of other instrument panel arrangements.

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2. P. M. Fitts and C. W. Simon. Effect of pointer position and of horizontal vs. vertical instrument separation on performance on a dual pursuit task. USAF Air Materiel Command Technical Report No. 5832, 1949.

3. R. E. Jones, J. L. Milton, and P. M. Fitts. Eye fixations of aircraft pilots, I. A review of prior eye movement studies and a description of a technique for recording the frequency, duration and sequence of eye fixations during instrument flight. USAF Air Materiel Command Technical Report No. 5837, 1949.

4. W. McGehee. Comparative study of pilot fatigue resulting from extended instrument flights using the standard AAF and British instrument panels. Final Report, Project TED No. ATL-K601, U. S. Navy.

5. J. L. Milton, R. E. Jones, and P. M. Fitts. Eye fixations of aircraft pilots, II. Frequency, duration and sequence of fixations when flying the USAF instrument low approach system (ILAS). USAF Air Materiel Command Technical Report No. 5839, 1949.