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EYE FIXATIONS OF AIRCRAFT PILOTS, II. FREQUENCY, DURATION AND SEQUENCE OF FIXATIONS WHEN FLYING THE USAF INSTRUMENT LOW APPROACH SYSTEM (ILAS)

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FOREWORD

This is the second 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. Kirchner who prepared the illustrations. Special acknowledgment is due to a number of students from Antioch College who assisted in reading the film records and in analyzing the data.

ABSTRACT

This report is the second 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 ILAS approaches are summarized. Fixations on the primary instruments vary from thirty per minute on the cross-pointer to one per minute on the turn and bank indicator. Over half of all fixations are made on two instruments—the cross-pointer and the directional gyro. The length of fixations vary from an average of 0.86 second on the cross-pointer to 0.34 second on the turn and bank indicator. Two instruments, the cross-pointer and directional gyro, are looked at during approximately two-thirds of all the time available to a pilot during an ILAS approach. More experienced pilots make slightly more fixations per minute (hence slightly shorter fixations) than do less experienced pilots. 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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EYE FIXATIONS OF AIRCRAFT PILOTS, II. FREQUENCY, DURATION, AND SEQUENCE OF FIXATIONS WHEN FLYING THE USAF INSTRUMENT LOW APPROACH SYSTEM (ILAS)

I. PURPOSE OF THE STUDY

The present report covers one of 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? During critical maneuvers, 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?

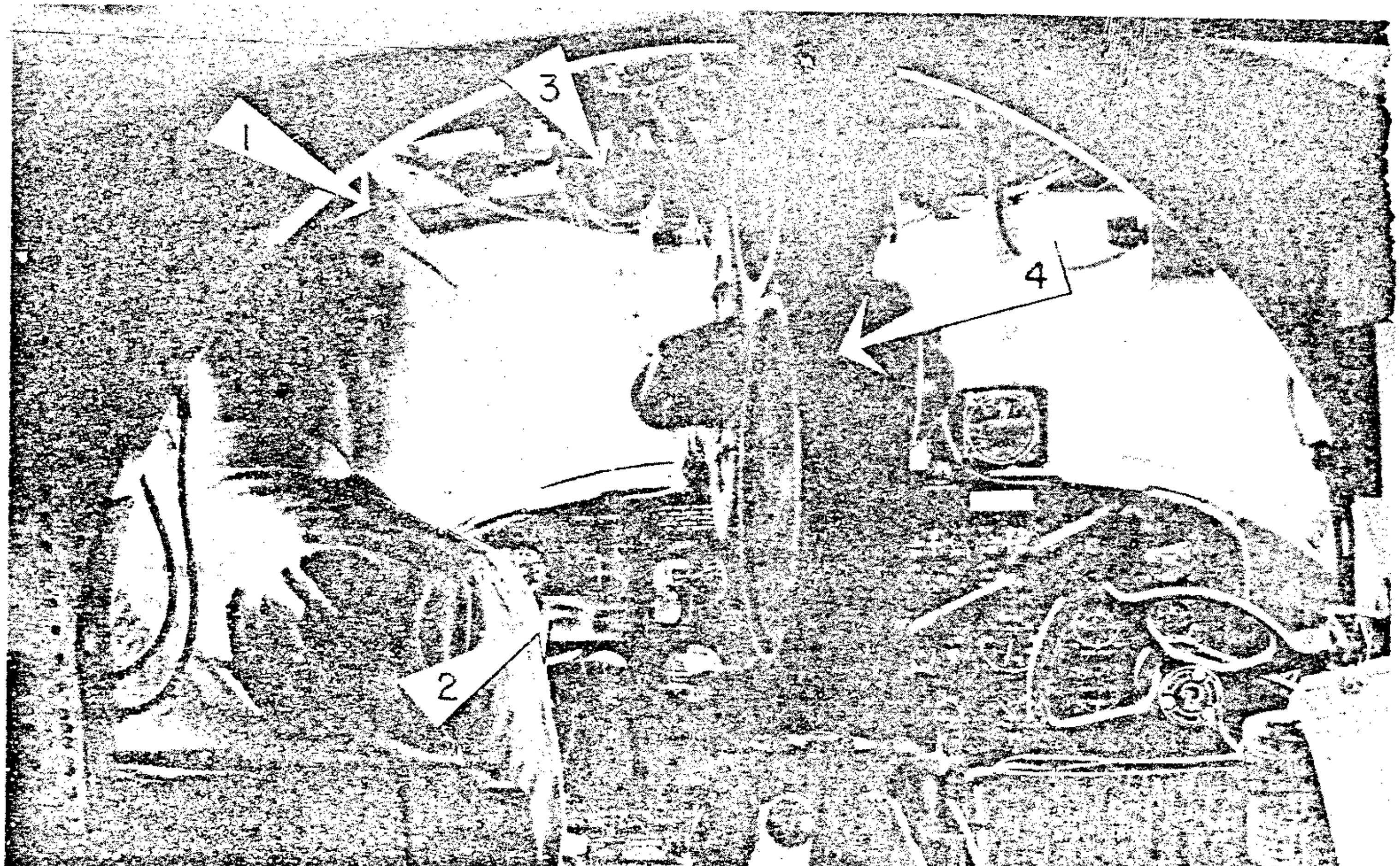
The results for ILAS approaches are summarized in the present report. Data on eye movements during GCA approaches, during maneuvers flown at altitude, during contact landings and takeoffs, and during night flights will be presented in subsequent reports.

II. PROCEDURES FOLLOWED IN OBTAINING EYE-FIXATION RECORDS DURING ILAS APPROACHES

The procedures followed in the present study 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 are 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.

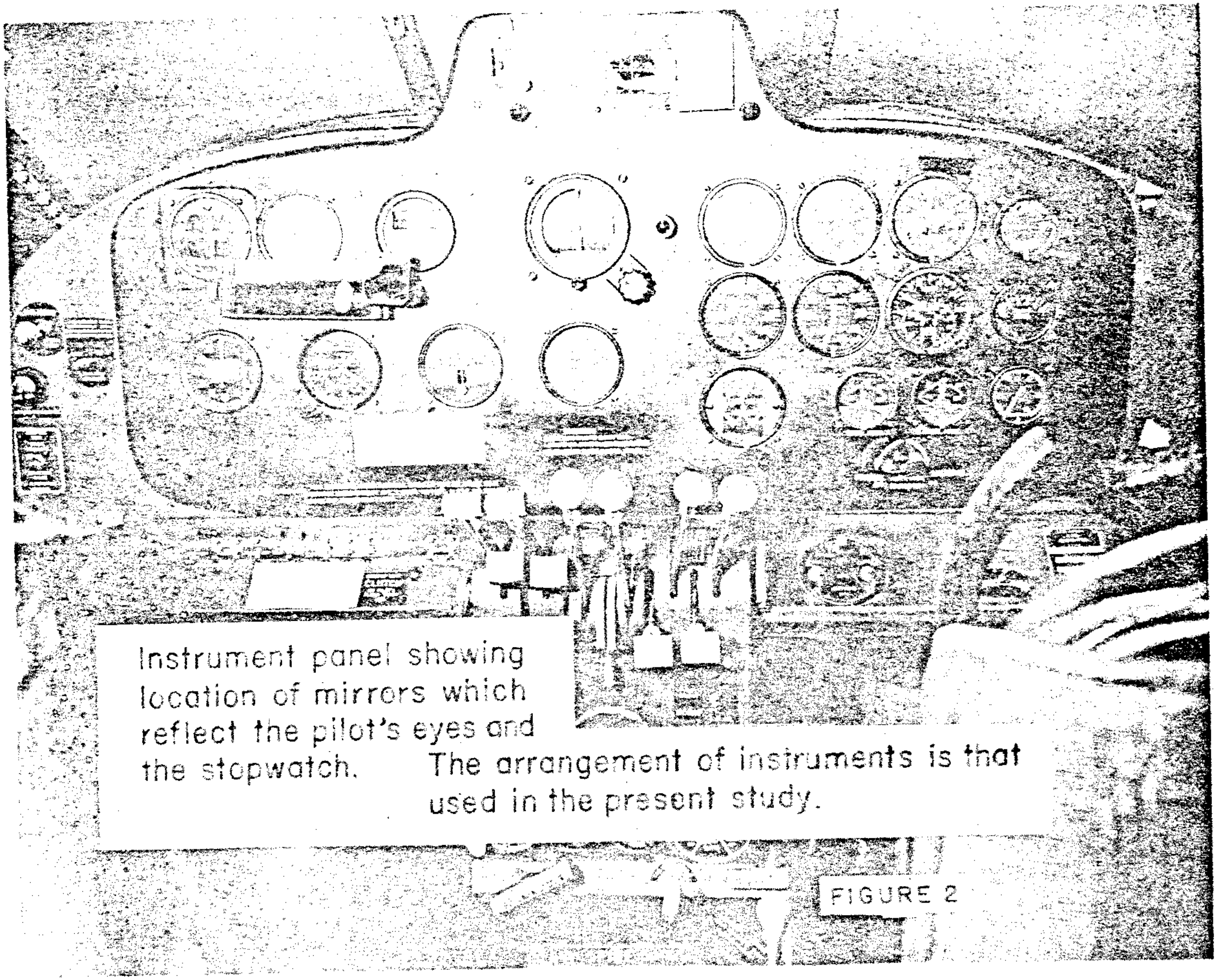
Flight procedures. Each of forty USAF pilots made two approaches for a landing using standard ILAS procedure under simulated instrument conditions. The camera was started as the aircraft passed over the outer marker (OM), approximately 4 1/2 miles from the touchdown point, and a 30-second sample of eye fixations was obtained. The camera was started again as the aircraft passed over the middle marker (MM), approximately 1 1/2 miles from the touchdown point, and a second 30-second sample of eye fixations was obtained.



ARRANGEMENT OF EXPERIMENTAL EQUIPMENT IN THE COCKPIT

1. Blind Flying Hood 3. Stop Watch
2. Mirror 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 independently, frame-by-frame, by two scorers. Standard reference photographs were taken at the beginning of each flight with the pilot looking directly at each instrument. These were made into slides and employed in analyzing the film records.

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.

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 rest of the group was made up of less experienced pilots attending the Instrument School at Barksdale Air Force Base and stationed at Wright-Patterson Air Force Base.

The forty pilots who served as subjects ranged in age from 23 to 35 years with an average of 27 years. Their total flying time varied from 700 to 5000 hours, with an average of slightly over 2000 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 plus actual (natural instrument conditions) ILAS approaches that had been flown by different pilots varied from 0 to 375. Thirteen of the pilots had made less than 25 ILAS approaches, both practice and actual. The record of flying experience for all subjects is given in Table I.

IV. RESULTS

Number of Fixations. Means and standard deviations (root mean square variations) for number of fixations per minute and duration 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 looking at that instrument before the eyes move on.) From inspection of these tables it can be seen that the cross-pointer and the directional gyro were fixated far more often than were any of the other instruments. Of the 106 fixations per minute made by the average pilot in the group, 58 were on these two instruments. Four instruments--the cross-pointer, the airspeed indicator, the directional gyro, and the gyro horizon--were fixated 91 times. This was approximately 87 per cent of all fixations or 91 per cent of the fixations that could be attributed to the basic flight and engine instruments.

TABLE I

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

Subject	Age	Total hours flying time	Instrument flying time	Simulated ILAS Approaches Total	Simulated ILAS Approaches Current*	Actual ILAS Approaches Total	Actual ILAS Approaches Current*
1	27	2500	500	300	25	75	5
2	30	2500	200	40	2	0	0
3	23	1300	400	100	0	10	0
4	31	2500	300	18	4	0	0
5	31	2100	300	40	0	0	0
6	28	3200	350	30	20	12	0
7	23	2200	215	34	2	10	0
8	26	2700	205	14	4	0	0
9	37	5000	250	8	0	0	0
10	27	2800	300	80	25	0	0
11	33	1350	100	30	0	0	0
12	28	1600	180	22	8	0	0
13	26	1350	156	65	0	1	0
14	27	3400	275	40	3	0	0
15	26	2100	300	55	15	10	5
16	28	2450	170	70	15	4	0
17	33	1500	150	20	15	0	0
18	29	2300	300	0	0	0	0
19	28	2150	100	7	7	0	0
20	33	1500	70	30	25	10	10
21	26	1450	150	40	0	0	0
22	27	1800	200	55	20	15	3
23	29	1300	100	55	20	0	0
24	24	2300	280	120	22	50	6
25	27	900	70	5	5	0	0
26	29	1950	250	55	16	10	5
27	27	900	100	6	2	0	0
28	26	2100	300	110	23	30	2
29	26	850	150	2	0	0	0
30	25	2650	300	12	4	15	0
31	28	1650	200	2	0	0	0
32	--	1900	200	87	7	10	9
33	28	2100	200	7	6	0	0
34	26	1700	120	16	10	0	0
35	26	1800	100	32	26	3	0
36	28	2000	300	8	6	0	0
37	25	1500	95	10	0	0	0
38	35	4300	200	18	0	0	0
39	28	700	65	55	14	0	0
40	24	1300	280	75	27	3	3
Total	1088	81650	8481	1773	378	268	28
Mean	27.9	2041	212	44	9	7	1
Median	27.5	1975	200	31	6	0	0

* Made in the 90 days preceding the experimental flight.

TABLE II

Means and Standard Deviations of Number of Fixations Per Minute on Each of the Basic Instruments During an ILAS Approach
(N = 40)

	First Approach		Second Approach		All Data Combined
	OM_1	MM_1	OM_2	MM_2	
Cross-Pointer					
Mean	28.7	30.2	28.9	30.7	29.6
SD	7.6	8.1	6.2	8.3	6.3
Air Speed					
Mean	16.8	15.4	16.9	15.1	16.0
SD	7.3	7.4	6.4	5.8	5.0
Directional Gyro					
Mean	27.9	26.0	29.9	28.0	28.0
SD	9.2	10.1	8.9	12.8	8.9
Gyro Horizon					
Mean	17.4	16.8	16.7	16.9	16.9
SD	8.8	10.0	10.8	12.0	8.9
Altimeter					
Mean	3.3	2.4	2.5	2.4	2.7
SD	2.6	2.2	3.2	2.2	1.8
Turn and Bank					
Mean	0.9	0.8	0.7	1.0	0.9
SD	1.5	1.4	1.1	1.6	1.1
Vertical Speed					
Mean	3.5	3.1	4.3	3.3	3.5
SD	3.4	3.2	4.2	3.9	3.0
Engine Instrument Panel*					
Mean	2.1	1.5	2.4	0.9	1.7
SD	2.0	2.1	2.7	1.4	1.5
Total Fixations, All Instruments**					
Mean	107.2	104.2	108.0	104.4	105.8
SD	19.4	23.1	22.4	26.6	19.5

* At times more than one engine instrument may have been checked during a fixation cycle on the engine instrument panel.

** Includes those miscellaneous frames of photography (about 6 percent of the total) that could not be attributed to any particular instruments.

TABLE III

Means and Standard Deviations of Length of Fixation on Each of the Basic Instruments During ILAS Approaches*

	First Approach OM_1	First Approach MM_1	Second Approach OM_2	Second Approach MM_2	All Data Combined
Cross-Pointer					
N	40	40	40	40	40
Mean	.84	.95	.80	.92	.86
SD	.29	.64	.28	.48	.31
Air Speed					
N	40	40	40	40	40
Mean	.38	.38	.38	.37	.38
SD	.10	.10	.14	.16	.09
Directional Gyro					
N	40	40	40	40	40
Mean	.57	.54	.59	.55	.56
SD	.14	.13	.12	.12	.08
Gyro Horizon					
N	39	40	29	26	40
Mean	.52	.53	.52	.50	.52
SD	.14	.19	.20	.16	.13
Altimeter					
N	33	29	25	29	37
Mean	.40	.40	.32	.38	.38
SD	.16	.16	.11	.12	.11
Turn and Bank					
N	15	15	15	16	27
Mean	.36	.37	.35	.34	.34
SD	.17	.17	.16	.14	.13
Vertical Speed					
N	29	27	30	27	39
Mean	.39	.41	.43	.39	.39
SD	.11	.19	.16	.13	.12
Engine Instrument Panel					
N	27	18	27	16	36
Mean	.89	.84	.80	.79	.79
SD	.47	.43	.39	.47	.34
Average, All Fixations**					
N	40	40	40	40	40
Mean	.58	.62	.58	.62	.59
SD	.10	.20	.12	.23	.12

* The number of subjects varies for different instruments because a few pilots did not look at a particular instrument during one of the 30-second periods.

** This average is based on all frames of photography, including those that could not be assigned to any of the primary instruments.

Length of Fixation Cycle. The instrument that required the longest fixation time was the cross-pointer, with 0.86 second. It was followed by the engine instrument panel with 0.79 second. (Usually when pilots looked at the engine group they checked only one instrument, the manifold pressure indicator.) The remaining six instruments fell into two groups so far as length of fixation cycle was concerned. One group, composed of the directional gyro and the gyro horizon, had an average length of fixation cycle slightly in excess of 0.5 second. The other group, composed of the airspeed indicator, the altimeter, the turn and bank indicator, and the vertical speed indicator, had an average length of fixation cycle of slightly less than 0.4 second.

Total Time Allotted to Each Instrument. It is possible to determine from the eye-movement films the percentage of the total time available that was spent in observing each instrument. (See Figure 3.) Approximately 41 per cent of the available time was spent in looking at the cross-pointer, and 25 per cent in looking at the directional gyro. Thus, this group of pilots spent approximately two-thirds of their time observing the two instruments on which they made approximately one-half of their fixations. They spent 91 per cent of their time observing the four instruments on which they made 85 per cent of their fixations (cross-pointer, air speed indicator, directional gyro, and gyro horizon). In general, then, those instruments that were looked at most frequently were also looked at for longer periods of time.

When the instruments are ranked according to the amount of use each received during the ILAS approaches the order of relative importance is as follows: 1) cross-pointer, 2) gyro compass, 3) gyro horizon, 4) airspeed indicator, 5) engine instrument panel, 6) vertical speed indicator, 7) altimeter, and 8) turn and bank indicator.

Agreement Between Different Eye-Movement Samples. Means and standard deviations (Tables II and III) were computed separately for each period of measurement, i.e. outer marker and middle marker on both first and second approaches. Table IV shows the differences between means, the correlations, and the "t" ratios for length of fixation on the four major instruments and for average fixations, for the four different periods of recording. None of the "t" ratios are significant at even the 0.05 level of confidence. All of the correlation coefficients are positive and 18 are significant at the 0.01 level of confidence. Only 7 of the 30 correlations fail to be significant at the 0.05 level of confidence. This is sufficient evidence to justify the conclusion that there is genuine homogeneity among the different samples with regard to length of fixation cycle. Accordingly, the data from the four periods of photography have been combined for all other analyses included in the present report.

Table V shows the differences, correlations, and "t's" for number of fixations for all instruments at the different periods of sampling. It can be noted that in Table V the number of cases (N) is 40, whereas in Table IV the number of cases is 36. This fact can be explained as

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR-CRAFT INSTRUMENTS DURING I.L.A.S. APPROACHES

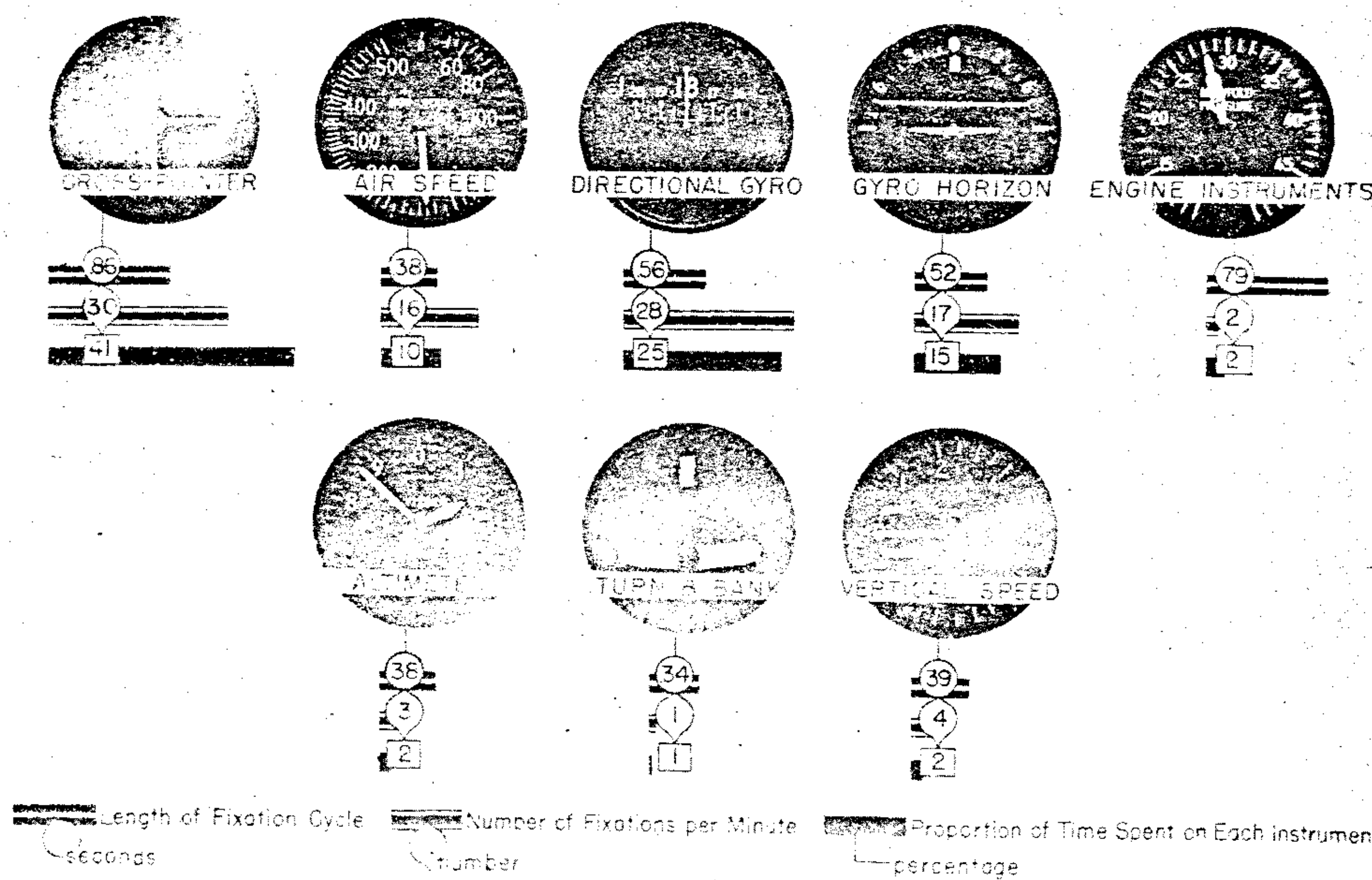


Fig 3

TABLE IV

Mean Differences in Lengths of Fixations, Correlation Coefficients, and "t" Ratios for Two Different Segments of Each of Two ILAS Approaches. Comparisons are Between 30-Second Samples Begun at the Outer Marker (OM) and at the Middle Marker (MM).
(N = 36)

	MM_1			OM_2			MM_2		
	diff.*	r	t	diff.*	r	t	diff.*	r	t
Cross-Pointer									
OM_1	.11	.569**	.616	-.04	.664**	1.728	.08	.557**	.131
MM_1				-.14	.508**	1.485	-.02	.587**	.532
OM_2							.12	.623**	1.708
Air Speed									
OM_1	.00	.340*	—	.00	.393*	—	-.01	.381*	.172
MM_1				.00	.022	—	-.01	.658**	.092
OM_2							-.01	.137	.250
Directional Gyro									
OM_1	-.03	.326	.820	.02	.431**	.504	-.02	.038	.772
MM_1				.05	.377*	1.517	.01	.183	.160
OM_2							-.04	.435**	1.646
Gyro Horizon									
OM_1	.01	.205	.109	-.01	.451**	1.172	-.02	.321	1.110
MM_1				-.02	.486**	1.194	-.03	.537**	1.300
OM_2							-.01	.475**	.011
Average, All Instruments									
OM_1	.04	.635**	.662	.00	.498**	—	.04	.555**	.110
MM_1				-.04	.398*	1.218	.00	.642**	—
OM_2							.04	.664**	.987

* Significant at the five per cent level of confidence.
** Significant at the one per cent level of confidence.
\+ Figures in this column occasionally differ ±0.1 from that which would be expected by subtracting the means shown in Table II. This is the result of rounding to one decimal place in both tables.

TABLE V

Mean Differences in Number of Fixations, Correlation Coefficients, and "t" Ratios for Two Different Segments of Each of Two ILAS Approaches. Comparisons are Between 30-Second Samples Begun at the Outer Marker (OM) and at the Middle Marker (MM).

(N = 40)

	MM_1 diff.+	MM_1 r	MM_1 t	OM_2 diff.+	OM_2 r	OM_2 t	MM_2 diff.+	MM_2 r	MM_2 t
Cross-Pointer									
OM_1	1.5	.639**	1.398	0.2	.437**	.130	2.0	.585**	1.753
MM_1				-1.3	.495**	1.140	0.5	.682**	.524
OM_2							1.9	.646**	1.849
Airspeed Indicator									
OM_1	-1.4	.362*	1.024	0.2	.402**	.147	-1.7	.240	1.286
MM_1				1.5	.359*	1.226	-0.3	.579**	.314
OM_2							-1.8	.601**	2.133*
Directional Gyro									
OM_1	-1.8	.737**	1.582	2.1	.607**	1.265	0.2	.730**	.116
MM_1				3.8	.652**	3.027**	1.9	.682**	1.286
OM_2							-1.9	.752**	1.424
Gyro Horizon Indicator									
OM_1	-0.6	.689**	.541	-0.8	.441**	.463	-0.5	.596**	.343
MM_1				-0.1	.662**	.093	0.1	.719**	.081
OM_2							0.2	.739**	.178
Altimeter									
OM_1	-0.9	.545**	2.410*	-0.8	.352*	1.542	-0.9	.346*	1.985
MM_1				0.1	.320*	.146	—	.239	—
OM_2							-0.1	.447**	.112
Turn and Bank Indicator									
OM_1	-0.1	.307*	.399	-0.2	.513**	.745	0.2	.485**	.618
MM_1				—	.344*	—	0.3	.407**	1.008
OM_2							0.3	.551**	1.445
Rate of Climb Indicator									
OM_1	-0.4	.470**	.735	0.9	.366*	1.265	-0.1	.462**	.233
MM_1				1.3	.708**	2.680	0.3	.740**	.614
OM_2							-1.0	.705**	2.046*
Engine Instrument Panel									
OM_1	-0.6	.405**	1.707	0.3	.477**	.855	-1.2	.420**	4.009**
MM_1				0.9	.587**	2.645*	-0.6	.465**	1.993
OM_2							-1.5	.400**	3.901**
Total - All Instruments									
OM_1	-3.1	.670**	1.109	0.8	.496**	.228	-2.8	.555**	.778
MM_1				3.8	.573**	1.158	0.3	.739**	.107
OM_2							-3.5	.740**	1.237

* Significant at the five per cent level of confidence.

** Significant at the one per cent level of confidence.

\+ Figures in this column occasionally differ ±0.1 from that which would be expected by subtracting the means shown in Table II. This is the result of rounding to one decimal place in both tables.

follows: If during a particular sample a subject failed to make any fixations on an instrument, his number of fixations is zero, and the zero can be used in calculating the averages given in Table V. However, when number of fixations is zero, no measure of length of fixation is available, so data for that subject must be omitted in calculating the averages given in Table IV.

Of the 54 values of "t" shown in Table V three are significant at the 0.01 level of confidence. Two of these three occur for the engine instrument panel, which is fixated very infrequently. Four additional "t" ratios are significant at the 0.05 level of confidence. Of these four, only one occurs for the four instruments which account for 91 per cent of the total fixations. Thus the distribution of the values of "t" does not differ greatly from that expected to occur by chance, especially for the more reliable data. These findings justify combining data on number of fixations from all four samples for any further statistical computations which must be made. This is done in the present report and will be done in subsequent reports in this series. It can be concluded that pilots use their eyes in essentially the same way on successive approaches and on different segments of the same approach.

Relation Between Frequency of Use and Speed of Checking Instruments. Table VI shows the correlation coefficients for length of fixations vs. number of fixations for each instrument. The correlation is significant for the cross-pointer. Pilots who made a large number of fixations on this instrument tended to make significantly shorter fixations than did pilots who looked at the instrument less often. This was not true to any appreciable extent for the other instruments. (The correlation between average number and average length of fixation for all instruments combined is not -1.0 because the samples drawn were for a given time, not a given number of fixations.

Weighting. In Table VII is shown the length of fixation for each instrument with the weighting made according to fixations instead of subjects. This was calculated by the following formula:

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

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 the data contributed by each of the forty subjects equally.

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, without doubt, considerably affected by the arrangement of instruments on the panel. The data here reported were collected on pilots who were using the instrument arrangement established in Technical Order 01-1-160. This was the Standard Air Force arrangement at the time of this study.

TABLE VI

Correlations Between Length of Fixations and Number of Fixations on Various Instruments

Instrument	Number	Correlation*
Cross-Pointer	40	-.57
Air Speed	40	.02
Directional Gyro	40	-.25
Gyro Horizon	40	.00
Altimeter	37	.05
Turn and Bank	27	.27
Vertical Speed	39	.01
Engine Instruments	36	.21
Miscellaneous	40	.02
Average, All Fixations	40	-.97

* A negative correlation indicates that pilots who made more fixations made fixations of shorter duration.

TABLE VII

Average Length of Fixation for Different Instruments

Instrument	Average Length of Fixation (seconds)	
	Weighted by fixations	Weighted by subjects
Cross-Pointer	.82	.86
Air Speed	.38	.38
Directional Gyro	.55	.56
Gyro Horizon	.52	.52
Altimeter	.40	.38
Turn and Bank	.37	.34
Vertical Speed	.39	.39
Engine Instruments	.84	.79
Miscellaneous	.19	.19
Total fixations, all instruments	.57	.59

TABLE VIII

Frequency of Occurrence of Eye Movements in Flying ILAS Approaches

1. X-Pt - D/G - 1206
2. D/G - X-Pt - 1123
3. A/S - X-Pt - 659
4. D/G - G/H - 609
5. X-Pt - A/S - 592
6. G/H - D/G - 571
7. X-Pt - G/H - 449
8. D/G - A/S - 447
9. A/S - D/G - 425
10. G/H - X-Pt - 386
11. G/H - A/S - 163
12. V/S - G/H - 137
13. A/S - G/H - 133
14. G/H - V/S - 128
15. G/H - E/I - 87
16. Alt - X-Pt - 80
17. A/S - Alt - 66
18. E/ I - X-Pt - 57
19. G/H - A/S - 56
20. X-Pt - G/H - 50
21. V/S - X-Pt - 50
22. X-Pt - V/S - 42
23. D/G - V/S - 39
24. V/S - D/G - 38
25. D/G - Alt - 36
26. E/I - A/S - 33
27. Alt - V/S - 30
28. D/G - E/I - 26
29. E/I - G/H - 26
30. E/I - D/G - 23
31. V/S - Alt - 23
32. Alt - D/G - 20
33. Alt - G/H - 20
34. G/H - Alt - 19
35. V/S - A/S - 19
36. D/G - T/B - 18
37. A/S - V/S - 16
38. T/B - Alt - 16
39. T/B - X-Pt - 15
40. X-Pt - E/I - 14
41. X-Pt - T/B - 14
42. A/S - E/I - 14
43. T/B - V/S - 13
44. Alt - T/B - 13
45. T/B - D/G - 12
46. G/H - T/B - 11
47. T/B - A/S - 9
48. T/B - G/H - 9
49. V/S - E/I - 8
50. A/S - T/B - 6
51. V/S - T/B - 2
52. Alt - E/I - 2
53. E/I - Alt - 1
54. E/I - V/S - 1
55. E/I - T/B - 0
56. T/B - E/I - 0

Legend

X-Pt - Cross-Pointer
A/S - Air Speed Indicator
D/G - Gyro Compass (directional gyro)
G/H - Gyro Horizon
E/I - Engine Instrument Panel
Alt - Altimeter
T/B - Turn and Bank Indicator
V/S - Vertical Speed Indicator

The 56 eye movements between the seven flight instruments and the engine panel that were possible with this instrument panel arrangement are listed in Table VIII 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 Figure 4.

The most common eye movement was that from the cross-pointer to the directional gyro, which accounted for 1,206 of a total of 8,060 eye movements recorded. The reverse movement from the directional gyro to the cross-pointer was second most common and occurred 1,123 times. It is interesting to note that more than one-fourth of the total eye movements were made between these two instruments. The third most frequent eye movement was that from the airspeed indicator to the cross-pointer, which occurred 659 times; and the fourth, that from the directional gyro to the artificial horizon, which occurred 609 times.

It seems likely that the location of the airspeed indicator along the path of the most frequent eye movement between the cross-pointer and directional gyro was responsible for at least part of the eye movements from the cross-pointer to the airspeed indicator and from the directional gyro to the airspeed indicator (i.e. pilots sometimes fixated the airspeed indicator briefly while moving their eyes from the cross-pointer to the directional gyro or vice versa). It would be possible to check this hypothesis by reversing the positions of the airspeed indicator and the cross-pointer, and determining whether or not the frequency of fixation on the airspeed indicator is reduced.

On a priori grounds it seems that a good instrument-panel arrangement would be one in which the most frequent eye-movement paths are short and are horizontal. 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 dual pursuit task (1). From data such as those shown in Figure 4, an optimum arrangement can be determined for any group of instruments, for any maneuver, and for any class of pilots. The arrangement used here is obviously a poor one for ILAS approaches. However, it should be emphasized again that the data shown in Figure 4 may have been influenced by the particular instrument arrangement studied. Link values may change somewhat for other arrangements. This question 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, is summarized in Table IX. The correlation between total number of fixations per minute and total hours flying time is 0.35. This figure is significant at between the 0.05 per cent and the 0.01 per cent levels of confidence. The correlation between average duration of fixation cycle and total hours flying time is -.30. This figure is significant at between the 0.05 and the 0.10 levels of confidence. Thus it seems probable that more experienced pilots make more eye fixations per minute during critical maneuvers than do less experienced pilots.

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

INSTRUMENT LANDING APPROACH SYSTEM (I.L.A.S.)

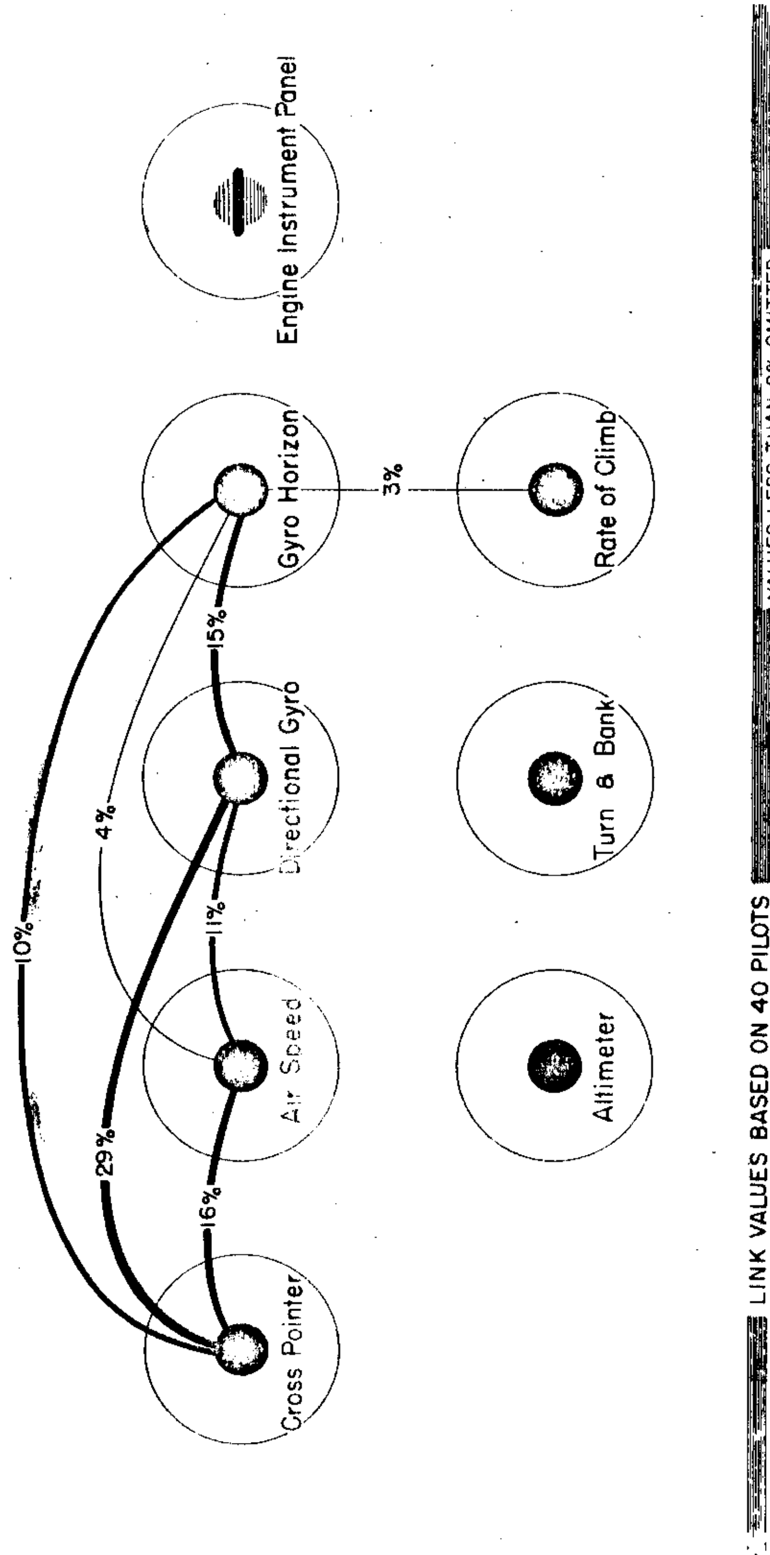


Figure 4

Since there is a significant correlation (0.47) between total flying time and instrument time, the relations between total flying time and eye fixation measures generally hold true for instrument time.

This finding regarding the relation between experience and length of fixation is in agreement with the inferences which have been drawn from the work of McGehee (3) (See TR No. 5837.)

When the pilots who acted as subjects in this experiment are divided into two equal groups on the basis of total flying time the least experienced group averages 100 fixations per minute and the most experienced group 112 fixations per minute. When the division is on the basis of instrument time the least experienced group averages 102 fixations per minute and the most experienced group 110 fixations per minute. The grouping is almost identical with either method of division, there being a shift of only six subjects depending on whether total flying time or instrument time is used as a basis for classification.

The extent of previous ILAS experience shows a definite relationship with the frequency and duration of fixations on the cross-pointer. This can be illustrated by comparing the least experienced and most experienced quartiles, selected on the basis of number of ILAS approaches each subject had flown. The ten pilots with most ILAS experience (over 65 ILAS approaches each) average 34 fixations per minute on the cross-pointer while the ten pilots with least ILAS experience (ten or fewer ILAS approaches each) average only 27 fixations per minute on that instrument. The average length of fixation cycle on the cross-pointer is only 0.64 second for the most experienced quartile but is 1.02 seconds for the least experienced quartile. Similarly, the most experienced group averages 120 total fixations per minute while the least experienced group averages only 96 total fixations per minute.

Although more experienced pilots probably fly better than less experienced pilots, it cannot be concluded, from these data, that rapid eye fixations are the cause of better flying. Nor does it necessarily follow that by forcing himself to move his eyes more rapidly over the instruments a pilot will improve his flying skill, because it is quite possible that eye movements merely reflect the speed with which a pilot interprets the meaning of instrument indications, i.e. how rapidly he thinks.

V. SUMMARY

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

2. Fixations on the primary instruments varied from an average of thirty per minute on the cross-pointer to one per minute on the turn and bank indicator. Over half of all fixations were made on the cross-pointer or on the directional gyro.

TABLE IX

The Relation Between Total Flying Time and Eye Movement Measures When Flying ILAS Approaches. Correlation Coefficients Were Computed from Data Collected on 40 Pilots.

Instrument	No. Fixations per Minute (1)	Duration of Fixation Cycle (2)
Cross-Pointer	.200	-.265
Air Speed Indicator	-.267	-.373
Directional Gyro	.017	-.145
Gyro Horizon	.352*	.093
Altimeter	-.011	-.261
Turn and Bank Indicator	-.236	.030
Rate of Climb Indicator	.185	-.253
Engine Instrument Panel	-.040	.118
Total Fixations (all instruments)	.352*	-.296

* Significant at the five per cent level of confidence.

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

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

3. The length of fixations varied from an average of 0.86 second on the cross-pointer to 0.34 on the turn and bank indicator.

4. The cross-pointer and the directional gyro together were looked at during approximately two-thirds of all the time available to a pilot during an ILAS approach.

5. More experienced pilots made slightly more fixations per minute (hence had slightly shorter fixation times) than did less experienced pilots.

6. Eye-Movement Link Values between all instruments were determined. From these values it is possible to determine an arrangement of instruments on the panel that is optimum from the point of view of eye movements. This 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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