FIXATIONS DURING DAY AND NIGHT GCA APPROACHES USING AN EXPERIMENTAL INSTRUMENT PANEL ARRANGEMENT

The seventh of a series of reports
on
EYE FIXATIONS OF AIRCRAFT PILOTS

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FOREWORD

This report was prepared by the Psychology Branch of the Aero Medical Laboratory, Research Division, Wright Air Development Center, under a project identified by Research and Development Order No. 694-31, Principles of Instrument Presentation with Capt. Milton acting as Project Engineer. Capt. McIntosh and Maj. Cole assisted in the analysis of the data and writing of the report. T/Sgt. Morris was the photographer on all flights, edited the film, and prepared the reference slides.

Special acknowledgement is also due to the following organizations and individuals for valuable assistance in conducting the experiments. The Special Photographic Service Branch which did the photographic work; the instructors of the United States Air Force Instrument Pilot School who were subjects; Mr. Charles Simon, Mr. James Randolph and a number of students at Antioch College who read the film and did the basic statistics; and Mr. David R. Craig for the many helpful suggestions regarding the report.

ABSTRACT

This report is the seventh in a series of investigations of eye movements of pilots during instrument flight. The frequency, duration, and sequence of eye fixations made by 15 pilots when flying day and night GCA approaches with a new panel arrangement are summarized. For purposes of comparison, data previously obtained with the standard Air Force panel arrangement during GCA approaches under day conditions are included. All conditions investigated showed that the air speed, directional gyro, gyro horizon and vertical speed are the most used instruments.

Significantly more fixations were made during day GCA than during night GCA. The average length of all fixations was shorter during the day although not significantly so. The average length of fixation on some of the individual instruments, however, were significantly shorter during day GCA. The total number of fixations and the average length of all fixations were approximately the same for both the standard and the new panels. There were significant differences between numbers of fixations on some of the individual instruments. The length of fixations did not vary significantly for any of the instruments. Considering the results of this study and the results of other studies which show that the optimal spacing between instruments is short and horizontal, and that instruments in the top row tend to be fixated first and more frequently, the standard panel appears to represent a better panel arrangement for GCA approaches.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Robert H. Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Research Division

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The seventh of a series of reports
on
Eye Fixations of Aircraft Pilots

I. PURPOSE OF THE STUDY

This report is the seventh in a series of investigations of pilots' eye movements during instrument flight. Measurements were made of the frequency, duration, and sequence of eye movements during day and night GCA approaches using a new instrument panel arrangement. These data were desired for the purpose of investigating (1) the differences between day and night conditions, and (2) the effects of relocation of the instruments. For the latter investigation the data of the present study were supplemented by similar data collected previously under day conditions using the standard Air Force instrument panel (5). The experimental panel, with the relocation of the instruments, is shown in Figure 1. The results for GCA only are presented in this report. Data collected on ILAS approaches while using the experimental panel have already been published (7). Data on maneuvers such as turns and straight and level flight will be presented in future reports. Similar data obtained while using the standard panel are covered in reports already published (1, 5). For purposes of comparison some of the standard panel data are included in this report.

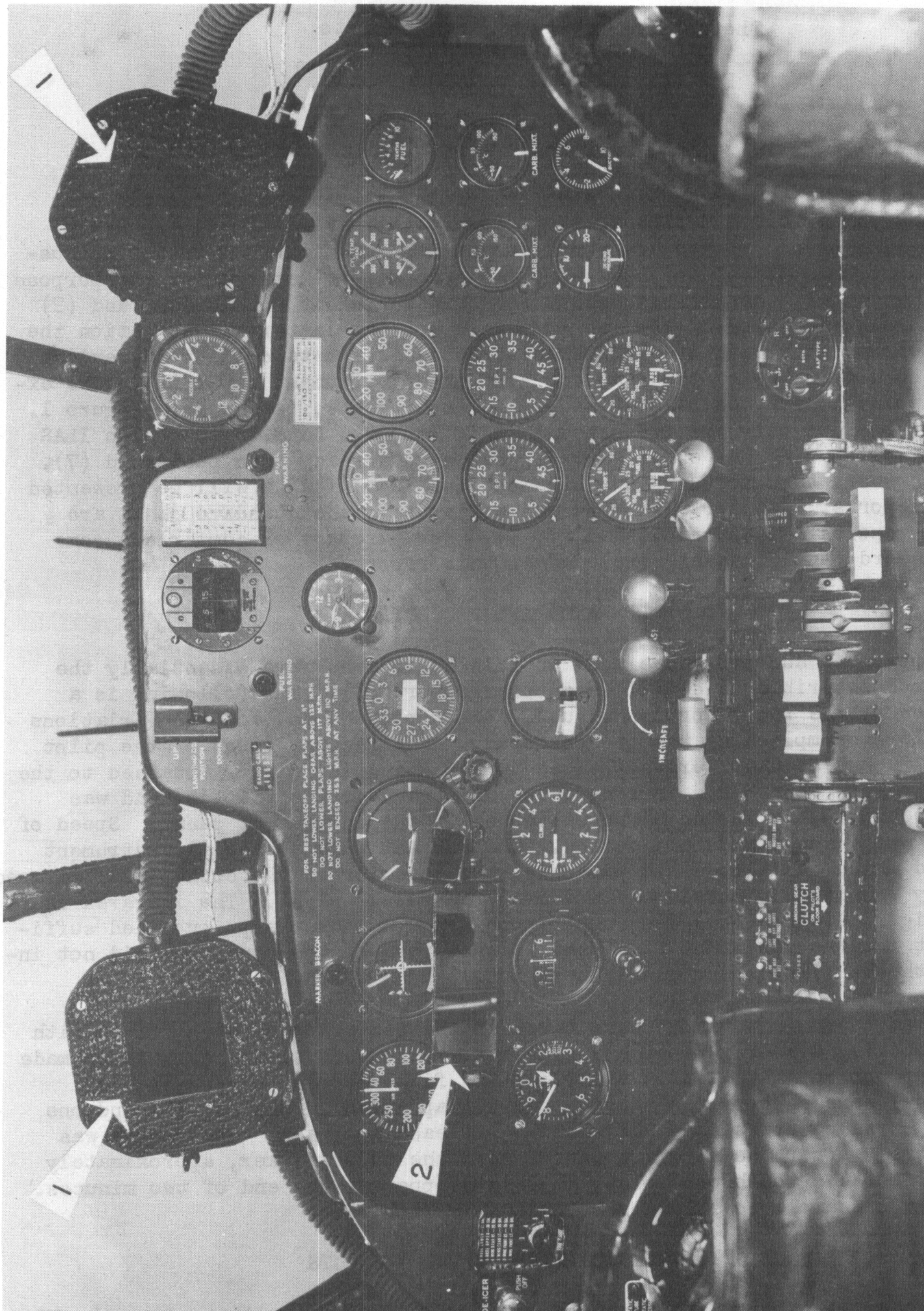
II. APPARATUS AND PROCEDURE

The apparatus and procedure used in this experiment were essentially the same as those described in detail in another report (3). The following is a brief review of the recording techniques, flight procedures, and the variations necessary for accomplishing the present study. The face and eyes of the pilot were photographed as they were reflected in a rectangular mirror attached to the instrument panel (Figure 2). A stop watch mounted near the pilot's head was photographed through a second mirror attached to the instrument panel. Speed of the camera was eight frames per second. The subject wore a special instrument flying hood which restricted his vision to the interior of the cock-pit. Infrared photography was used to obtain eye movement records at night. The infrared lamps shown in Figure 1 were focused on the pilot's face. These lamps provided sufficient light for the very fast film used in this part of the study but did not interfere with the pilot's normal night vision.

Flight Procedures: Photographs were taken at the beginning of each flight with the pilot looking directly at each instrument. Reference slides were later made from these photographs to aid in analyzing the film records. Each pilot's eye movements were photographed during one GCA approach in the daytime and one at night. A two minute sample was obtained of each approach. The camera was started shortly after the aircraft passed over the outer marker, approximately four miles from the touchdown point, and was stopped at the end of two minutes. This two minute sample covered almost the entire approach.

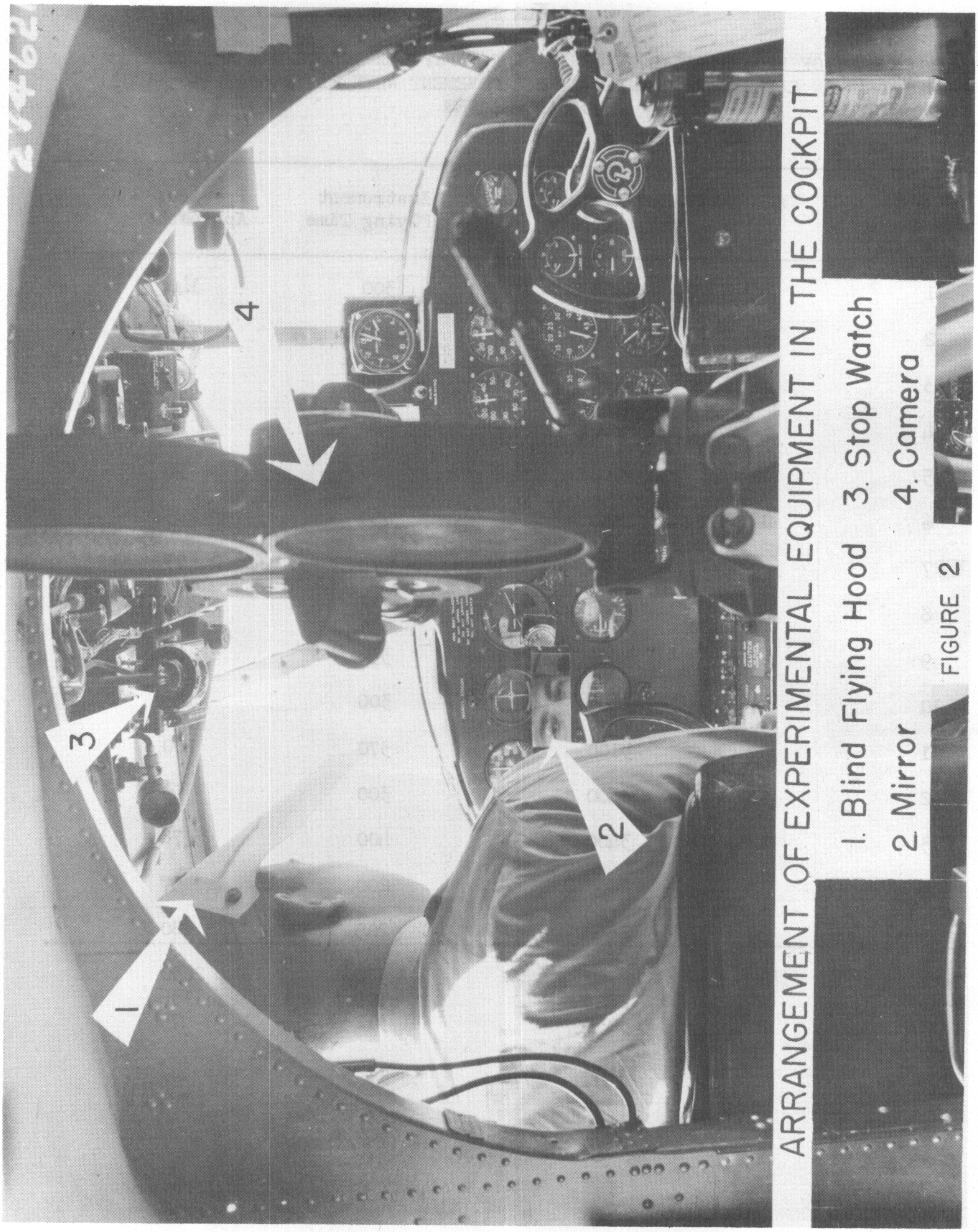
III. DESCRIPTION OF THE SUBJECTS

The subjects in this experiment were fifteen instructor pilots from the USAF Instrument Pilot School then located at Barksdale Air Force Base, Louisiana. The record of flying experience for these subjects is given in Table I. The average age of the pilots was 29. Their total flying time averaged 2848 hours and instrument flying time (hood plus weather) averaged 305 hours. They had an average of 135 (practice plus actual) GCA approaches.



5609-A INSTRUMENT PANEL ARRANGEMENT USED IN THE SECOND SERIES OF EXPERIMENTS
1. LAMPS WITH INFRA-RED FILTERS FOR NIGHT PHOTOGRAPHY
2: MIRRORS WHICH REFLECT THE PILOT'S EYES AND THE STOPWATCH

FIGURE 1



ARRANGEMENT OF EXPERIMENTAL EQUIPMENT IN THE COCKPIT

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

FIGURE 2

TABLE I

SUMMARY OF BIOGRAPHICAL INFORMATION FOR FIFTEEN PILOTS WHO SERVED AS SUBJECTS IN AN EXPERIMENT TO MEASURE EYE MOVEMENT WHEN FLYING DAY AND NIGHT GCA APPROACHES

Subject	Age	Total Hours Flying Time	Instrument Flying Time	Previous GCA Approaches
1	28	2500	300	140
2	27	2500	330	593
3	32	3000	400	82
4	30	2250	250	58
5	34	1760	200	56
6	27	1850	400	283
7	28	3400	275	77
8	29	3300	300	235
9	27	3800	350	48
10	27	3100	300	53
11	34	3100	370	100
12	26	3400	300	90
13	29	3400	400	78
14	30	2800	200	57
15	31	2560	205	80
Total	439	42720	4580	2030
Mean	29.2	2848	305.3	135
Median	29.5	3039	312	75

IV. RESULTS

A. Film Analysis:

All film records were read independently, frame by frame, by two people. Table II shows the number of frames of photography that were read identically by the two film scorers. When the records were read independently agreement was 90.4 per cent on the day film and 90.3 per cent on the night film. Most of the disagreement involved film that was difficult to read because of poor photography, or the few frames of film which showed the pilots' eyes in the process of moving from one instrument to another. The two scorers together viewed the parts of the film on which they were in disagreement. After this second analysis the scorers reached agreement on 99.3 per cent of the day film and 99.7 per cent of the night film.

A tabulation of the groups of successive frames identified as a fixation on a given instrument provided the number of fixations made on that instrument during the two minute period. This number was converted to fixations per minute using as the divisor the time interval within which the fixations actually occurred. The total number of frames involved in movement to and fixation on a given instrument was divided by the number of fixations in order to find the average time per fixation cycle. An average number of fixations per minute and an average time per fixation cycle were thus derived for each subject with respect to each instrument. These individual subject means were used as the "raw scores" from which the statistics presented in this report were calculated. In other words, the means presented here are the means of subject means, etc.

B. Day and Night GCA Approaches with the New Panel:

Number of Fixations. Means, standard deviations (root mean square variations), "t" ratios and correlation coefficients of number of fixations per minute are summarized in Table III and Figures 3 and 4. Of the 99 fixations per minute made by the average pilot during day GCA approaches, 84 were on the directional gyro, vertical speed, gyro horizon, and air speed. The altimeter, engine instruments, and cross-pointer were fixated an average of 5, 3, and 1 times respectively. The turn and bank indicator was fixated an average of less than 1 time per minute.

During the night GCA approaches the directional gyro, vertical speed, air speed, and gyro horizon were again the most looked at instruments receiving 63 of the total of 81 fixations. The altimeter was fixated an average of 6 times per minute, the cross-pointer 2 times, the engine instruments 1 time, and the turn and bank less than 1 time per minute.

With the exception of the cross-pointer and altimeter all instruments were fixated more often during the day GCA than at night. The "t" ratio for the total of all fixations, the directional gyro, the vertical speed and the engine instruments are significant at the 1 per cent level of confidence. The "t" for the gyro horizon is significant at the 5 per cent level of confidence while the "ts" for the remaining instruments are not significant. Correlation coefficients for air speed, directional gyro, and turn and bank are significant at the 1 per cent level of confidence and correlations for vertical speed and total fixations are significant at the 5 per cent level.

TABLE II

PER CENT OF PHOTOGRAPHIC FRAMES READ IDENTICALLY BY TWO READERS FIRST INDEPENDENTLY AND THEN TOGETHER

	GCA DAY		GCA NIGHT	
Subject	Independent	Together	Independent	Together
1	64.1	97.0	88.5	100.0
2	92.6	97.3	91.3	99.8
3	85.6	98.6	94.3	99.5
4	80.2	99.1	84.9	99.6
5	93.6	98.9	93.6	100.0
6	96.4	100.0	96.5	100.0
7	92.6	99.4	78.9	99.4
8	93.0	100.0	92.2	99.7
9	96.6	99.8	90.7	100.0
10	96.9	100.0	89.0	100.0
11	94.7	100.0	94.3	99.6
12	94.6	100.0	91.7	100.0
13	93.0	100.0	94.9	99.7
14	92.2	99.5	88.4	98.8
15	89.5	99.7	84.9	99.9
M	90.4	99.3	90.3	99.7

TABLE III

MEANS, STANDARD DEVIATIONS, "t" RATIOS, AND CORRELATION COEFFICIENTS OF NUMBER OF FIXATIONS PER MINUTE ON EACH INSTRUMENT DURING DAY AND NIGHT GCA APPROACHES (N = 15)

Instrument	Day	Night	"t"	"r"
Air Speed				
Mean	13.4	12.6		
SD	6.1	6.8	.66	.70**
Cross-Pointer				
Mean	1.4	1.9		
SD	1.8	1.6	.75	.01
Gyro Horizon				
Mean	17.2	9.2		
SD	13.7	6.7	2.24*	.24
Engine Instruments				
Mean	3.1	1.4		
SD	2.1	1.9	3.04**	.44
Altimeter				
Mean	4.9	5.6		
SD	5.9	5.4	.44	.47
Directional Gyro				
Mean	31.1	23.9		
SD	8.8	8.5	4.00**	.67**
Vertical Speed				
Mean	22.7	17.3		
SD	10.1	6.0	3.21**	.56*
Turn and Bank				
Mean	.15	.02		
SD	.32	.07	1.81	.72**
Total Fixation (1)				
Mean	99.2	80.7		
SD	24.0	15.4	3.47**	.52*

(1) The total fixations are based on all frames of photography including those few fixations that were on objects other than the instruments.

* Significant at the 5 per cent level of confidence.

** Significant at the 1 per cent level of confidence.

NEW PANEL

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING DAY GCA APPROACHES

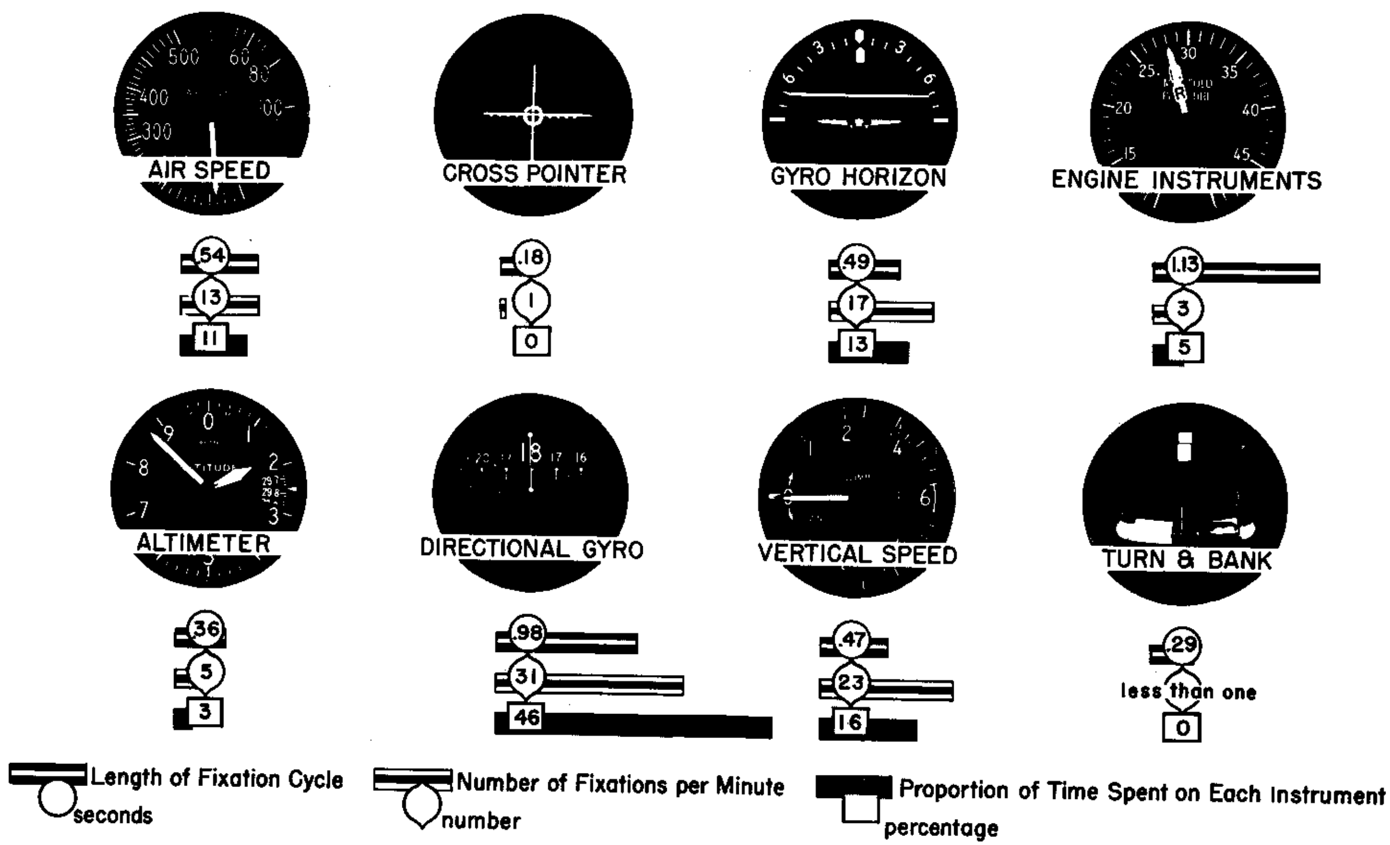


Fig 3

NEW PANEL

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING NIGHT GCA APPROACHES

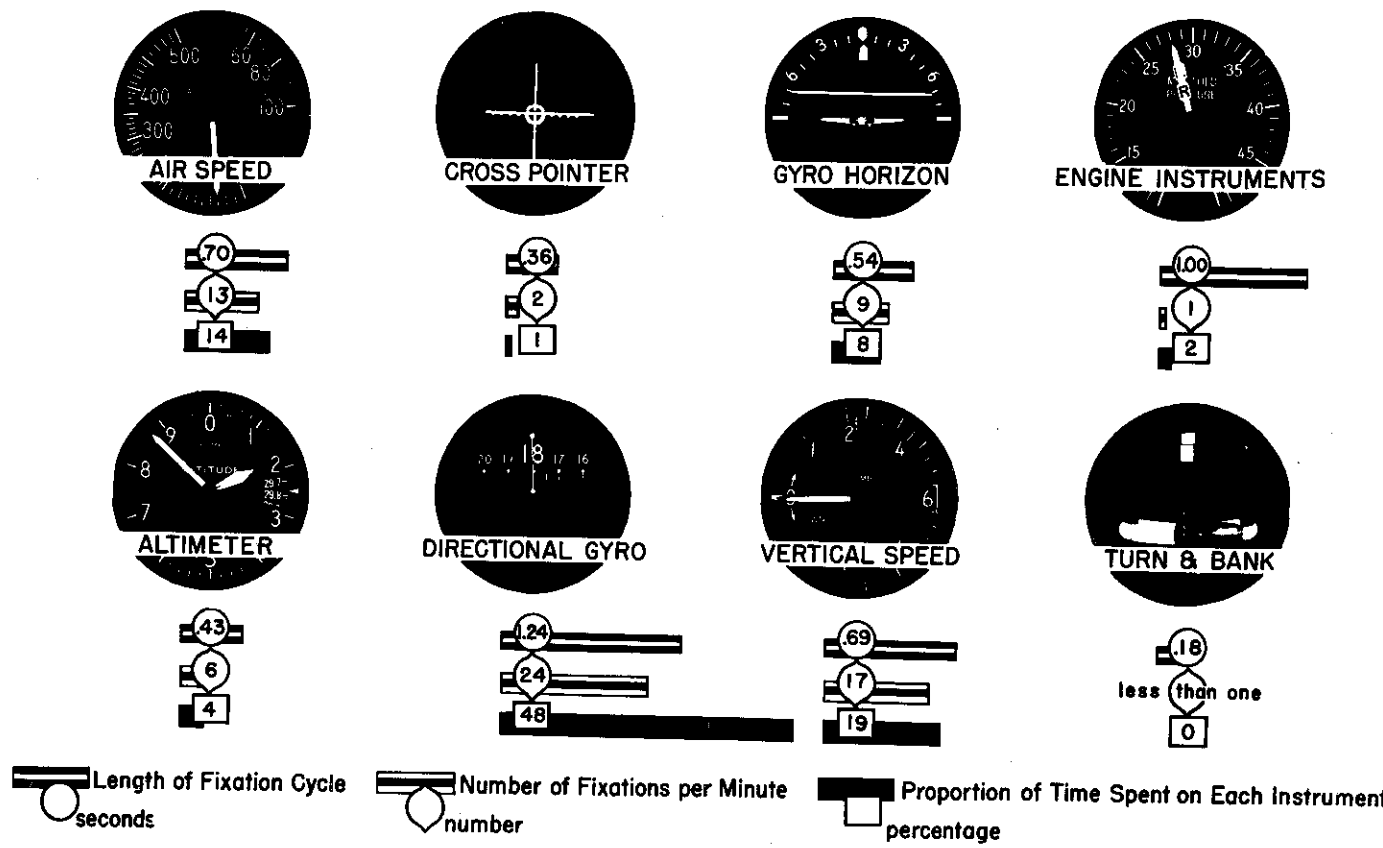


FIGURE 4

Length of Fixation Cycle. Means and standard deviations for average length of fixation cycle on each instrument are given in Table IV and Figures 3 and 4.

In the remainder of this report the terms "fixation cycle" , "fixation time" and "length of fixation" will be considered synonymous. Table IV presents the mean duration of the Fixations which were made on each instrument. Subjects who did not fixate a given instrument were not included in the calculation of the mean fixation time for that instrument.

During day GCA the longest fixation time, 1.13 seconds, was on the engine instruments, and the next longest fixation, 0.98 second was on the directional gyro. The air speed, gyro horizon, and vertical speed were next averaging approximately 0.50 second. Fixations on the remaining instruments were somewhat shorter. The average fixation on the altimeter was 0.36 second, the turn and bank 0.29 second, and the cross-pointer 0.18 second. The average of all fixations was 0.66 second.

During night GCA the directional gyro with 1.24 seconds was fixated longest, and the engine instruments were next with 1.00 second. The average fixation time on the air speed was 0.70 second, and 0.69 second on the vertical speed. The remaining fixation times were 0.54 second on the gyro horizon, 0.43 second on the altimeter, 0.36 second on the cross-pointer, and 0.18 second on the turn and bank. The average length of all fixations during night GCA was 0.77 second.

Comparisons of day and night approaches are shown in Table V. Number of subjects, mean length of fixation times, and standard deviations for some of the instruments differ from those shown in Table IV. For comparison purposes "t" ratios and correlation coefficients were computed for only those subjects who fixated an instrument during both day and night conditions.

Fixation time on the engine instruments was longer during day GCA than during night GCA. All of the remaining fixation times were longer at night. The "t" ratios for air speed, cross-pointer and vertical speed are significant at the 1 per cent level of confidence.

Correlation coefficients for each of the instruments are also shown in Table V. The correlation for gyro horizon is significant at the 1 per cent level. The remaining correlations are not significant.

Total Time Allotted to Each Instrument. The percentage of the total available time that was spent in looking at each instrument was calculated by using the length of fixation time and the number of fixations on each instrument. During both day and night GCA, the pilots spent more of the available time observing the directional gyro and the vertical speed than any of the other instruments. (Figures 3 and 4) These two instruments accounted for 62 per cent of the available time during the day GCA and 67 per cent at night. The order of relative importance of the instruments according to the amount of time spent on each during day GCA is as follows: (1) directional gyro, (2) vertical speed, (3) gyro horizon, (4) air speed, (5) engine instruments, (6) altimeter, (7) cross-pointer,

TABLE IV

MEANS, STANDARD DEVIATIONS, AND "t" RATIOS OF LENGTH OF FIXATIONS ON EACH INSTRUMENT DURING DAY AND NIGHT GCA APPROACHES (1)

Instrument	Day	Night
Air Speed		
N	15	15
Mean (seconds)	.54	.70
SD (seconds)	.10	.20
Cross-Pointer		
N	11	11
Mean (seconds)	.18	.36
SD (seconds)	.07	.13
Gyro Horizon		
N	14	15
Mean (seconds)	.49	.54
SD (seconds)	.16	.25
Engine Instruments		
N	15	11
Mean (seconds)	1.13	1.00
SD (seconds)	.48	.30
Altimeter		
N	14	13
Mean (seconds)	.36	.43
SD	.12	.11
Directional Gyro		
N	15	15
Mean (seconds)	.98	1.24
SD (seconds)	.58	.32
Vertical Speed		
N	15	15
Mean (seconds)	.47	.69
SD (seconds)	.08	.27
Turn and Bank		
N	3	1
Mean (seconds)	.29	.18
SD (seconds)	.13	0
Average, All Fixations (2)		
N	15	15
Mean (seconds)	.66	.77
SD (seconds)	.27	.13

(1) The number of subjects varies because some of the pilots did not look at all of the instruments.

(2) The average of all fixations is based on all frames of photography including those few fixations that were on objects other than the instruments.

TABLE V

MEANS, STANDARD DEVIATIONS, "t" RATIOS, AND CORRELATION COEFFICIENTS OF LENGTH OF FIXATIONS ON EACH INSTRUMENT DURING DAY AND NIGHT GCA APPROACHES (1)

Instrument	Day	Night	"t"	"r"
Air Speed				
Number	15	15		
Mean (seconds)	.54	.70	3.40**	.48
SD (seconds)	.10	.20		
Cross-Pointer				
Number	9	9		
Mean (seconds)	.19	.37	3.44**	-.02
SD (seconds)	.07	.14		
Gyro Horizon				
Number	14	14		
Mean (seconds)	.49	.54	1.20	.76**
SD (seconds)	.16	.26		
Engine Instruments				
Number	11	11		
Mean	1.09	1.00	.60	.32
SD	.53	.30		
Altimeter				
Number	13	13		
Mean (seconds)	.36	.43	1.17	.52
SD (seconds)	.13	.11		
Directional Gyro				
Number	15	15		
Mean (seconds)	.98	1.24	1.86	.42
SD (seconds)	.58	.32		
Vertical Speed				
Number	15	15		
Mean (seconds)	.47	.69	3.59**	.42
SD (seconds)	.08	.27		
Average, All Fixations (2)				
Number	15	15		
Mean (seconds)	.66	.77	1.67	.43
SD (seconds)	.27	.13		

(1) The number of subjects varies because some of the pilots did not look at all of the instruments.

(2) The average of all fixations is based on all frames of photography including those few fixations that were on objects other than the instruments.

** Significant at the 1 per cent level of confidence.

and (8) turn and bank. The order for night GCA is the same except that air speed and gyro horizon exchange positions and altimeter and engine instruments exchange positions in the order.

Relation Between Frequency of Use and Speed of Checking Instruments. Table VI shows the correlation coefficients for number of fixations versus length of fixations for each instrument under both day and night conditions. For both day and night GCA the correlations for the directional gyro and the total are significant at the 1 per cent level of confidence. Also, for night GCA correlations for the cross-pointer and the gyro horizon are significant at the 5 per cent level of confidence. These correlations indicate that pilots who made more fixations on the directional gyro during the day GCA and on the cross-pointer and directional gyro during night GCA also made significantly shorter fixations on those instruments. Conversely, pilots who made more total fixations during both day and night and more fixations on the gyro horizon during night GCA also made significantly longer fixations than did pilots who made fewer fixations.

The correlation between average number and average length of fixation for all instruments combined is not - 1.0 because fractional fixations at the ends of record samples were not considered.

Fixation Sequence and Eye Movement Link Values. The frequencies of eye movements between instruments that occurred during GCA approaches are listed by pairs in Table VII for day and Table VIII for night GCA approaches. Four fixation sequences (both directions between two instruments) accounted for the majority of all eye movements made under either day or night conditions. These sequence pairs (between directional gyro and vertical speed, between directional gyro and gyro horizon, between directional gyro and air speed, and between vertical speed and gyro horizon) accounted for 68 per cent of the eye movements during day approaches and 64 per cent of the eye movements during night approaches. The greatest frequency of eye movements occurred between the directional gyro and vertical speed which accounted for 29 per cent of the 2722 eye movements during day approaches and 31 per cent of the 2034 eye movements during night approaches.

The strength of the bond (eye movement link value) between any two instruments based on the percentage of eye movements in either direction between the instruments is shown in Figure (5) for day and Figure (6) for night approaches. The relative strength of the bonds among the instruments is about the same for both day and night approaches. The outstanding difference is a strengthening of the directional gyro - air speed bond during night approaches mainly at the expense of the directional gyro-gyro horizon bond. This increased emphasis on the air speed at night was also found to be true during ILAS approaches (8).

TABLE VI

CORRELATION COEFFICIENTS BETWEEN NUMBER OF FIXATIONS PER MINUTE AND AVERAGE LENGTH OF FIXATIONS FOR BOTH DAY AND NIGHT GCA APPROACHES (1)

Instrument	Day		Night	
	N	r	N	r
Air Speed	15	.020	15	.240
Cross-Pointer	11	.107	11	-.648*
Gyro Horizon	14	.193	14	.518*
Engine Instruments	15	-.500	15	-.481
Altimeter	14	.021	14	.401
Directional Gyro	15	-.644**	15	-.788**
Vertical Speed	15	-.049	15	-.367
Total Fixations	15	.914**	15	.959**

(1) A negative correlation indicates a tendency for the number of fixations to increase as the length of fixations decreases.

** Significant at the 1 per cent level of confidence.

* Significant at the 5 per cent level of confidence.

TABLE VII

FREQUENCY OF OCCURRENCE OF EYE MOVEMENTS BETWEEN PAIRS OF INSTRUMENTS WHILE FLYING DAY GCA APPROACHES WITH THE NEW PANEL

1.	D/G	-	V/S	398	390	V/S	-	D/G
2.	D/G	-	G/H	227	218	G/H	-	D/G
3.	D/G	-	A/S	165	154	A/S	-	D/G
4.	D/G	-	ALT	84	73	ALT	-	D/G
5.	D/G	-	E/I	18	42	E/I	-	D/G
6.	D/G	-	X/P	2	17	X/P	-	D/G
7.	D/G	-	T/B	2	3	T/B	-	D/G
8.	G/H	-	A/S	127	65	A/S	-	G/H
9.	G/H	-	V/S	111	189	V/S	-	G/H
10.	G/H	-	X/P	21	4	X/P	-	G/H
11.	G/H	-	E/I	14	4	E/I	-	G/H
12.	G/H	-	ALT	10	12	ALT	-	G/H
13.	A/S	-	V/S	112	29	V/S	-	A/S
14.	A/S	-	E/I	25	16	E/I	-	A/S
15.	A/S	-	ALT	23	39	ALT	-	A/S
16.	A/S	-	X/P	14	15	X/P	-	A/S
17.	V/S	-	E/I	28	15	E/I	-	V/S
18.	V/S	-	ALT	14	17	ALT	-	V/S
19.	V/S	-	X/P	2	5	X/P	-	V/S
20.	V/S	-	T/B	2	0	T/B	-	V/S
21.	E/I	-	ALT	10	2	ALT	-	E/I
22.	E/I	-	X/P	2	0	X/P	-	E/I
23.	E/I	-	T/B	0	1.	T/B	-	E/I
24.	ALT	-	X/P	1	0	X/P	-	ALT

Legend

X/P Cross-Pointer
A/S Air Speed
D/G Directional Gyro
G/H Gyro Horizon
E/I Engine Instruments
ALT Altimeter
V/S Vertical Speed
T/B Turn and Bank

TABLE VIII

FREQUENCY OF OCCURRENCE OF EYE MOVEMENTS BETWEEN PAIRS OF INSTRUMENTS WHILE FLYING NIGHT GCA APPROACHES WITH THE NEW PANEL

1.	D/G	-	V/S	315	306	V/S	-	D/G
2.	D/G	-	A/S	171	188	A/S	-	D/G
3.	D/G	-	G/H	89	68	G/H	-	D/G
4.	D/G	-	ALT	73	77	ALT	-	D/G
5.	D/G	-	E/I	18	16	E/I	-	D/G
6.	D/G	-	X/P	4	16	X/P	-	D/G
7.	V/S	-	G/H	116	58	G/H	-	V/S
8.	V/S	-	A/S	32	77	A/S	-	V/S
9.	V/S	-	ALT	27	31	ALT	-	V/S
10.	V/S	-	E/I	10	10	E/I	-	V/S
11.	V/S	-	X/P	3	2	X/P	-	V/S
12.	G/H	-	A/S	87	38	A/S	-	G/H
13.	G/H	-	X/P	30	9	X/P	-	G/H
14.	G/H	-	ALT	14	10	ALT	-	G/H
15.	G/H	-	E/I	5	2	E/I	-	G/H
16.	A/S	-	ALT	27	38	ALT	-	A/S
17.	A/S	-	X/P	16	24	X/P	-	A/S
18.	A/S	-	E/I	5	2	E/I	-	A/S
19.	A/S	-	T/B	1	0	T/B	-	A/S
20.	E/I	-	ALT	11	2	ALT	-	E/I
21.	E/I	-	X/P	1	2	X/P	-	E/I
22.	X/P	-	ALT	1	1	ALT	-	X/P
23.	T/B	-	V/S	1	0	V/S	-	T/B

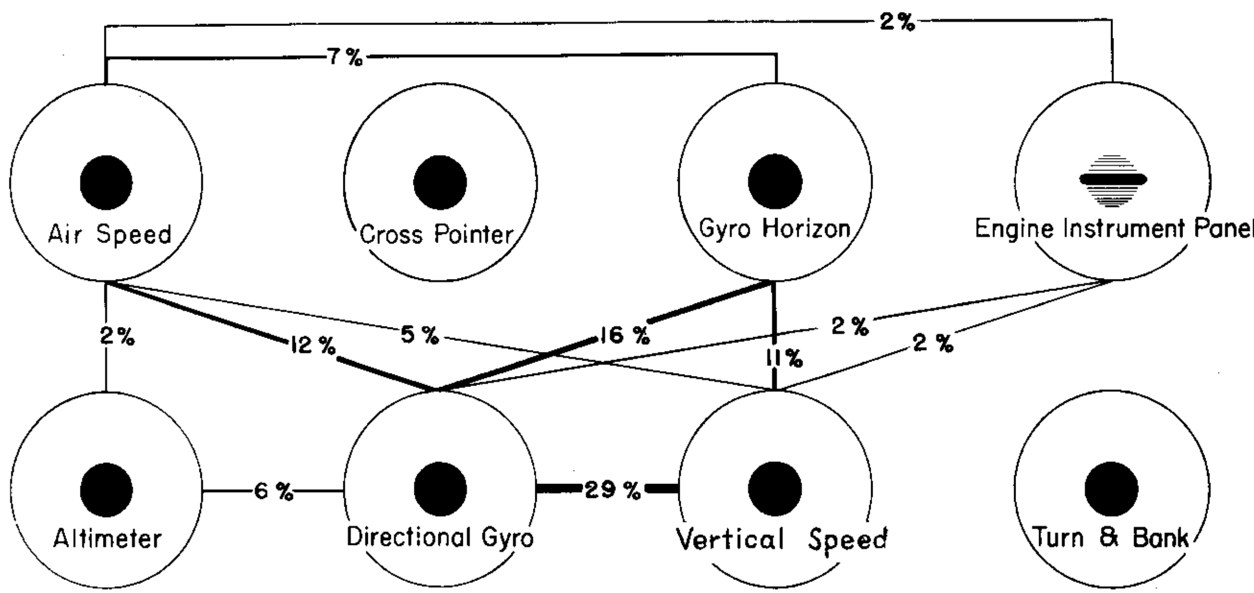
Legend

X/P - Cross-Pointer
A/S - Air Speed
D/G - Directional Gyro
G/H - Gyro Horizon
E/I - Engine Instruments
ALT - Altimeter
V/S - Vertical Speed
T/B - Turn and Bank

NEW PANEL

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

DAY GCA



LINK VALUES BASED ON 15 PILOTS — VALUES LESS THAN 2% OMITTED

FIGURE 5

NEW PANEL
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
NIGHT GCA

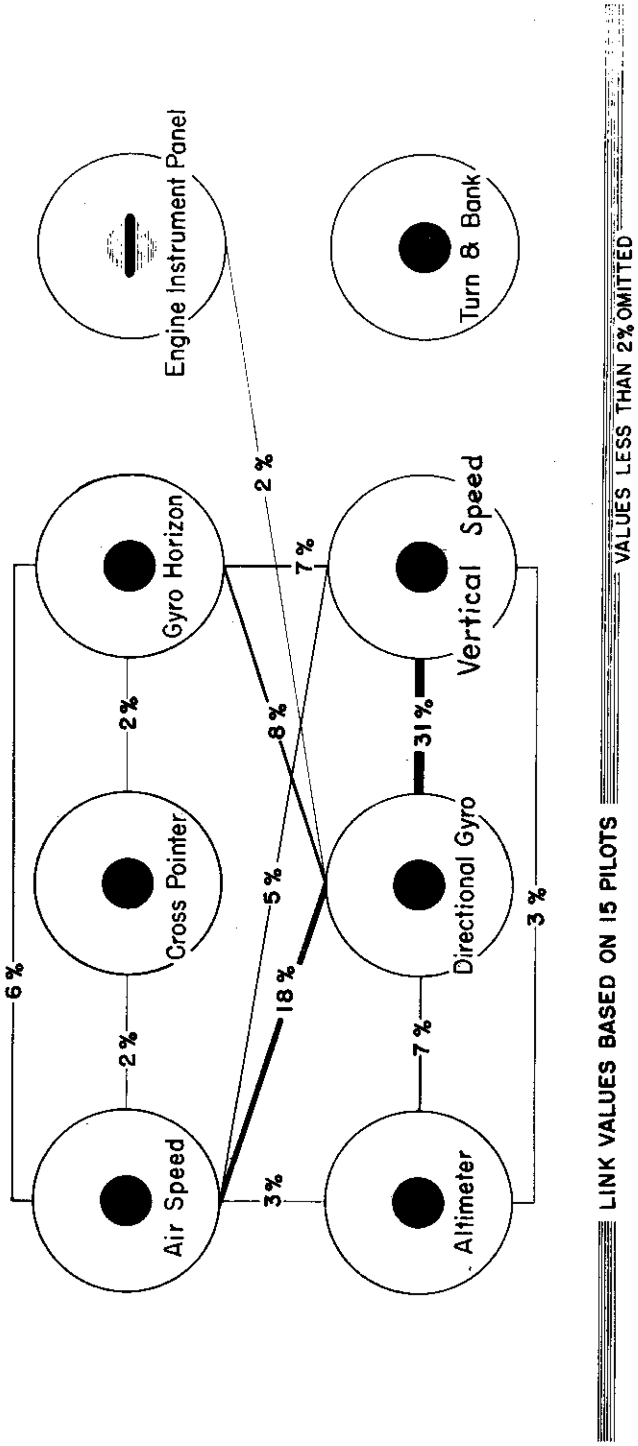


FIGURE 6

Effect of Experience on Eye Movement Measures. The relationship between total hours of flying time and number and length of fixations for both day and night GCA approaches are summarized in Tables IX and X. None of the correlations between total flying time and number of fixations are significant. Correlations for length of fixations were significant for two instruments, the altimeter and the engine instruments. During day approaches the more experienced pilots made significantly shorter fixations on the altimeter and during night approaches they made significantly shorter fixations on the engine instruments.

The relationship between instrument flying time and number and length of fixations is summarized in Tables XI and XII. The only significant correlation is the one for the engine instruments. The more experienced pilots made shorter fixations on those instruments during night GCA approaches.

Correlations between flying experience and number and length of fixations revealed no clear cut tendencies. Throughout this series of experiments ILAS approaches using the standard panel was the only case where more experienced pilots made significantly more and shorter fixations.

C. GCA Approaches With the Standard Panel and With the New Panel:

The standard panel is the standard Air Force arrangement of instruments established by Technical Order No. 01-0-160 (Figure 7). The results of the eye fixation experiment in which the standard panel was used are presented in a previous report (1).

Comparisons of the number of fixations and length of fixations made by subjects who used the standard panel for day GCA approaches and by those who used the new panel for day GCA approaches are provided in Tables XIII and XIV. Means and the significances of the difference between means are presented for each instrument.

Number of Fixations. There were significantly more fixations on the standard panel on two instruments, the turn and bank and the air speed. The t's for these two instruments are significant at the 1 per cent level of confidence in the case of the turn and bank, and at the 5 per cent level in the case of the air speed. The vertical speed is the only instrument that was fixated significantly (at the 1 per cent level of confidence) more often on the new panel.

TABLE IX

THE RELATION BETWEEN TOTAL FLYING TIME AND NUMBER OF FIXATIONS WHEN FLYING BOTH DAY AND NIGHT GCA APPROACHES. CORRELATION COEFFICIENTS WERE COMPUTED FROM DATA COLLECTED ON FIFTEEN PILOTS. (1)

Instrument	Day	Night
Air Speed	.150	-.352
Cross-Pointer	.019	.055
Gyro Horizon	.018	.337
Engine Instruments	.135	.122
Altimeter	.161	.324
Directional Gyro	.276	-.221
Vertical Speed	.204	-.199
Turn and Bank	-.050	.207
Total	.338	.006

(1) A positive correlation indicates a tendency for the number of fixations to increase as the total flying time increases. A negative correlation indicates a tendency for the number of fixations to decrease as the total flying time increases.

TABLE X

THE RELATION BETWEEN TOTAL FLYING TIME AND LENGTH OF FIXATIONS WHEN FLYING BOTH DAY AND NIGHT GCA APPROACHES. CORRELATION COEFFICIENTS WERE COMPUTED FROM DATA COLLECTED ON FIFTEEN PILOTS. (1)

Instrument	Day	Night
Air Speed	-.393	.105
Cross-Pointer	.077	.495
Gyro Horizon	.215	.329
Engine Instruments	-.373	-.770**
Altimeter	-.546*	.486
Directional Gyro	-.425	.100
Vertical Speed	.060	.303
Turn and Bank	0	0
Average, All Fixations	-.436	.104

(1) A positive correlation indicates a tendency for the length of fixations to increase as the total flying time increases. A negative correlation indicates a tendency for the length of fixations to decrease as the total flying time increases.

** Significant at the 1 per cent level of confidence.

* Significant at the 5 per cent level of confidence.

TABLE XI

THE RELATION BETWEEN INSTRUMENT FLYING TIME AND NUMBER OF FIXATIONS WHEN FLYING BOTH DAY AND NIGHT GCA APPROACHES. CORRELATION COEFFICIENTS WERE COMPUTED FROM DATA COLLECTED ON FIFTEEN PILOTS. (1)

Instrument	Day	Night
Air Speed	.062	.034
Cross-Pointer	.037	-.204
Gyro Horizon	-.164	.115
Engine Instruments	-.022	.315
Altimeter	-.221	.312
Directional Gyro	-.299	-.111
Vertical Speed	.219	.003
Turn and Bank	.291	-.021
Total	-.130	.178

(1) A positive correlation indicates a tendency for the number of fixations to increase as instrument flying time increases. A negative correlation indicates a tendency for the number of fixations to decrease as the instrument time increases.

TABLE XII

THE RELATION BETWEEN INSTRUMENT FLYING TIME AND LENGTH OF FIXATIONS WHEN FLYING BOTH DAY AND NIGHT GCA APPROACHES. CORRELATION COEFFICIENTS WERE COMPUTED FROM DATA COLLECTED ON FIFTEEN PILOTS. (1)

Instrument	Day	Night
Air Speed	-.414	-.116
Cross-Pointer	.340	-.118
Gyro Horizon	-.203	-.332
Engine Instruments	-.259	-.639*
Altimeter	.280	.071
Directional Gyro	.371	.078
Vertical Speed	.268	.004
Turn and Bank	0	0
Total	.279	-.007

(1) A positive correlation indicates a tendency for the length of fixations to increase as instrument flying time increases. A negative correlation indicates a tendency for the length of fixations to decrease as the instrument time increases.

* Significant at the 5 per cent level of confidence.

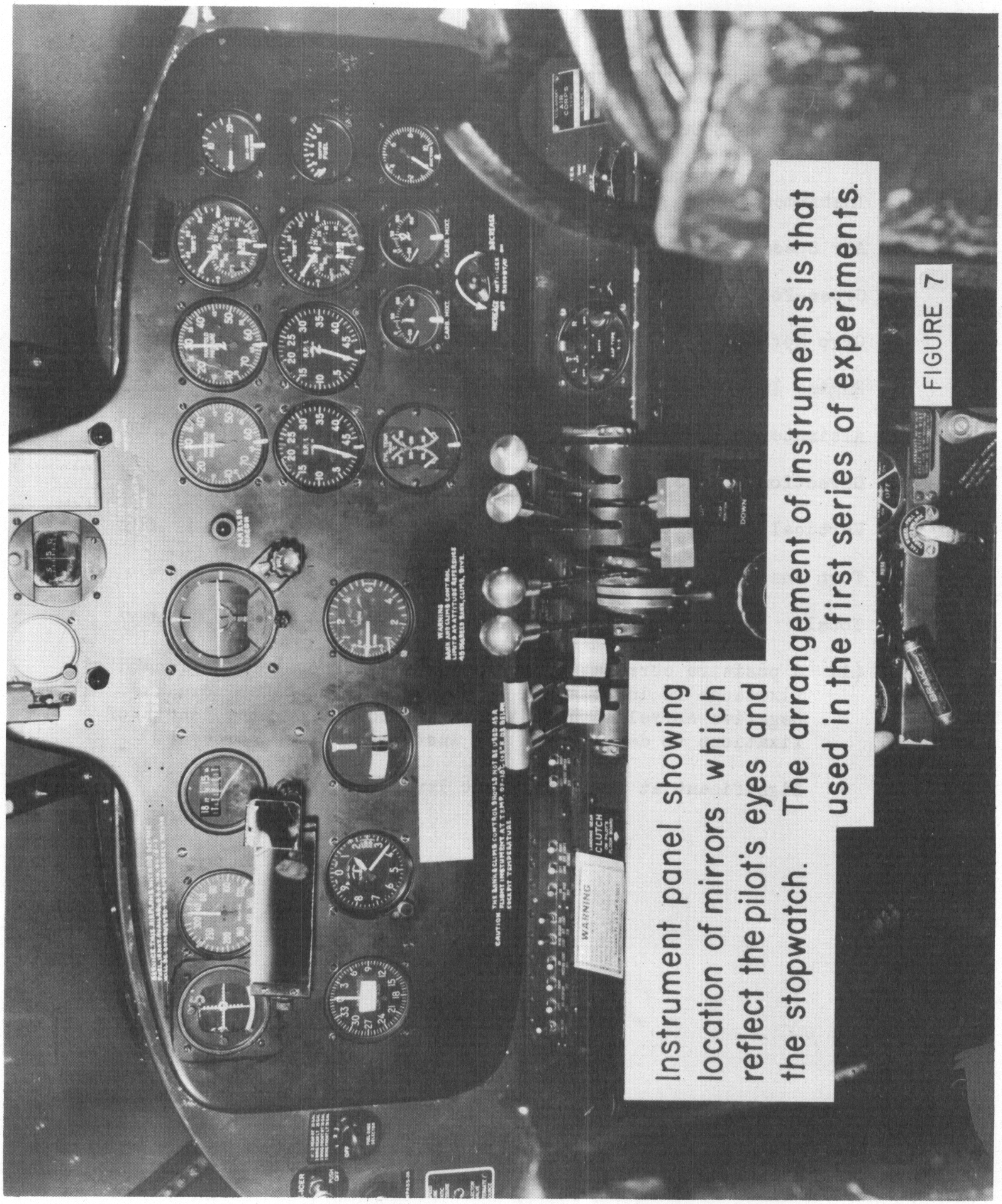


FIGURE 7

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

TABLE XIII

MEANS, STANDARD DEVIATIONS, AND "t" RATIOS OF NUMBER OF FIXATIONS PER MINUTE ON BOTH THE STANDARD AND THE NEW PANEL DURING DAY GCA APPROACHES

Instrument	(N = 40) Standard	(N = 15) New	"t"
Air Speed			
Mean	18.2	13.4	
SD	8.0	6.1	2.32*
Cross-Pointer (1)			
Mean		1.4	
SD		1.8	
Gyro Horizon			
Mean	20.6	17.2	
SD	9.5	13.7	
Engine Instruments			
Mean	2.6	3.1	
SD	2.3	2.1	.75
Altimeter			
Mean	4.7	4.9	
SD	3.4	5.9	.12
Directional Gyro			
Mean	33.3	31.1	
SD	7.9	8.8	.82
Vertical Speed			
Mean	6.2	22.7	
SD	5.7	10.1	5.79**
Turn and Bank			
Mean	3.2	.15	
SD	4.7	.32	4.01**
Total Fixations (2)			
Mean	93.0	99.2	
SD	18.7	24.0	.88

(1) The cross-pointer was not fixated on the standard panel, therefore, no comparison can be made.

(2) The average of all fixations is based on all frames of photography including those few fixations that were on objects other than the instruments.

** Significant at the 1 per cent level of confidence.

* Significant at the 5 per cent level of confidence.

TABLE XIV

MEANS, STANDARD DEVIATIONS AND "t" RATIOS OF LENGTH OF FIXATION ON BOTH THE STANDARD AND THE NEW PANEL DURING DAY ILAS APPROACHES (1)

Instrument	Standard	New	"t"
Air Speed			
Number of Pilots	40	15	
Mean	.57	.54	.81
SD	.17	.10	
Cross-Pointer (2)			
Number of Pilots		11	
Mean		.18	
SD		.07	
Gyro Horizon			
Number of Pilots	40	14	
Mean	.56	.49	1.21
SD	.21	.16	
Engine Instruments			
Number of Pilots	31	15	
Mean	.88	1.13	1.77
SD	.31	.48	
Altimeter			
Number	40	14	
Mean	.39	.36	.81
SD	.11	.12	
Directional Gyro			
Number of Pilots	40	15	
Mean	.90	.98	.50
SD	.26	.58	
Vertical Speed			
Number of Pilots	35	15	
Mean	.47	.47	
SD	.12	.08	
Turn and Bank			
Number of Pilots	35	3	
Mean	.36	.29	.73
SD	.16	.13	
Average, All Fixations (3)			
Number of Pilots	40	15	
Mean	.67	.66	.13
SD	.14	.27	

(1) The number of subjects varies because some of the pilots did not look at all of the instruments.

(2) The cross-pointer was not fixated on the standard panel, therefore no comparison can be made.

(3) The average of all fixations is based on all frames of photography including those few fixations that were on objects other than the instruments.

STANDARD PANEL

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING G.C.A. APPROACHES

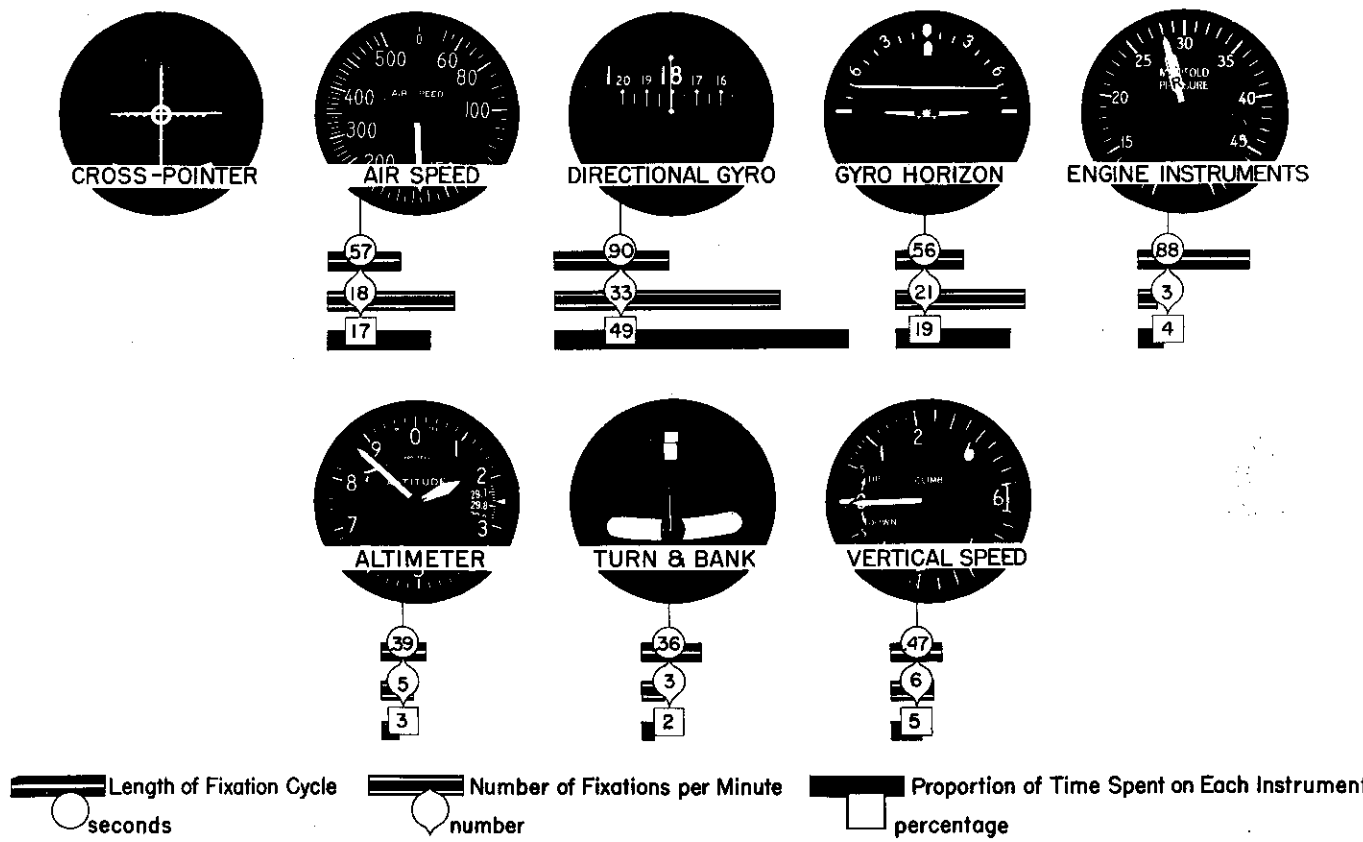


FIGURE 8

STANDARD PANEL

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS

GROUND CONTROL APPROACH

G.C.A.

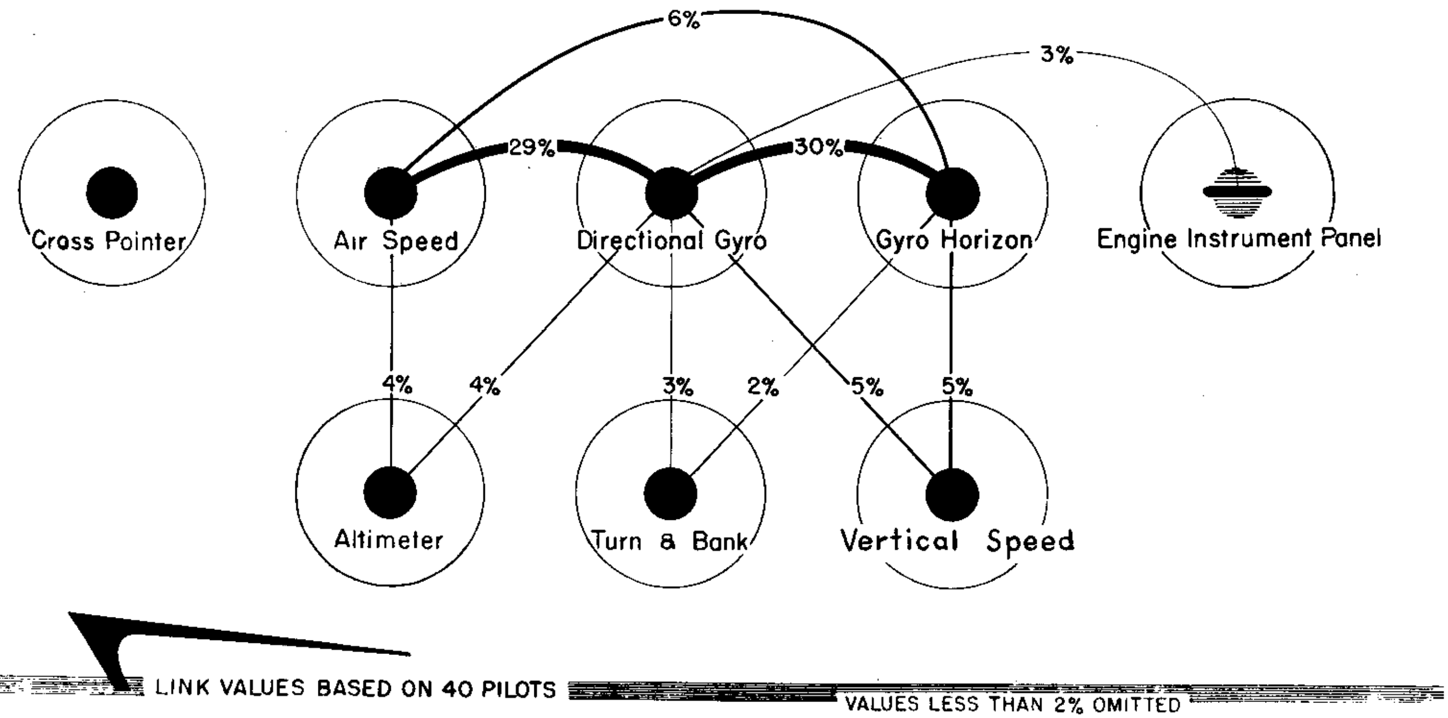


FIGURE 9

TABLE XV

A COMPARISON OF THE IMPORTANT LINK VALUES ON THE STANDARD PANEL WITH THE CORRESPONDING VALUES ON THE NEW PANEL.

Instruments	Standard Panel (Per cent)	New Panel (Per Cent)
Directional Gyro - Gyro Horizon	30	16
Directional Gyro - Air Speed	29	12
Directional Gyro - Vertical Speed	5	29
Gyro Horizon - Vertical Speed	5	11

TABLE XVI

THE RELATION BETWEEN TOTAL FLYING TIME AND EYE MOVEMENT MEASURES WHEN FLYING GCA APPROACHES WITH THE STANDARD PANEL

Instrument	No. Fixations per Minute (1) N = 40	Duration of Fixation Cycle (2) N = 40
Air Speed	.03	.15
Directional Gyro	.05	-.24
Gyro Horizon	.11	.17
Altimeter	.06	.01
Turn and Bank	.08	-.03
Vertical Speed	-.01	-.13
Engine Instrument Panel	-.20	.28
Total Fixations, All Instruments	.12	-.13

(1) A positive correlation indicates a tendency for the number of fixations to increase as the total flying time increases. A negative correlation indicates a tendency for the number of fixations to decrease as the total flying time increases.

(2) A positive correlation indicates a tendency for the length of fixations to increase as the total flying time increases. A negative correlation indicates a tendency for the length of fixations to decrease as the tot- flying time increases.

Length of Fixations. The differences between means of the lengths of fixations on the two panels are not significant for any of the instruments. As was true in the case of the comparison of ILAS approaches (8) the averages of all fixations on both panels were approximately the same, being 0.66 second on the new panel and 0.67 second on the standard panel. Mean number and length of fixations, and mean proportion of time spent on each instrument on the standard panel are shown in Figure (8).

Link Values. The link values between instruments on the standard panel are shown in Figure (9) and may be compared with those on the new panel shown in Figure (5). The largest link values on the standard panel are between the directional gyro and the air speed, and between the directional gyro and the gyro horizon accounting for 59 per cent of the total eye movements. These two link values account for only 28 per cent of the eye movements on the new panel. The greatest difference in link value between any two instruments occurs between the directional gyro and the vertical speed. This link represents 29 per cent of the eye movements on the new panel but only 5 per cent of the eye movements on the standard panel. The important link values for the two panels are presented in Table XV for purposes of comparison.

Effect of Experience on Eye Movement Measures. The correlation coefficients of total hours of flying time with number of fixations and length of fixations on the standard panel are presented in Table XVI. None of the correlations are significant. Similar information on the new panel is presented in Tables IX and X. On the new panel the more experienced pilots exhibited a slight tendency to make shorter fixations on the altimeter. The correlation is significant at the 5 per cent level of confidence. None of the other correlations for the new panel during day GCA were significant at either the 1 or 5 per cent level of confidence.

V. DISCUSSION OF RESULTS

A. Day and Night GCA.

Comparison of the overall results for day and night GCA approaches reveals, in general, approximately the same differences as those obtained under similar conditions during ILAS approaches (8). The pilots made significantly more fixations during day GCA than during night GCA. With the exception of the engine instruments, fixation times on each of the instruments and the average for all fixations were shorter during day approaches. The differences for the air speed, vertical speed and cross-pointer are significant. As was pointed out in the ILAS report (8), one probable reason for this difference is that the low level of illumination in the cockpit at night makes it necessary for pilots to fixate the instruments longer in order to interpret them. Within a definite time period an increase in the length of fixations must result in a decrease in the number of fixations.

The data presented in Figures 3 and 4 indicate no important changes in the distribution of time among the various instruments between night and day conditions. The same instruments which received the greatest emphasis during day GCA, the air speed, gyro horizon, directional gyro, and vertical speed, also received the greatest emphasis at night. The link values between the directional gyro and the air speed, the directional gyro and the gyro horizon, and the directional gyro and the vertical speed further indicate the importance of these four instruments during GCA approaches.

These results coupled with the findings that the optimal spacing between the most frequently used instruments is short and horizontal (2), and that in rapid check reading of an instrument group the upper instruments tend to be fixated first, and more frequently (7), would indicate that this panel arrangement could be improved on for GCA approaches. It is also true that the control column in most aircraft interferes with the pilot's view of some of the instruments on the lower part of the panel.

It is interesting to note that the cross-pointer instrument, which was not operative during GCA, still received a few short fixations. This can probably be accounted for by the fact that the cross-pointer was located directly in front of the pilot and between the air speed and gyro horizon which were fixated frequently.

B. GCA Approaches When Using Both the Standard and New Panels.

On the basis of the two experiments reported herein it would seem that the same four instruments would be the primary ones for GCA approaches regardless of limited changes in the way those instruments are arranged on the panel. The position of the instruments, however, does appear to determine to some extent the relative use that each will receive. This finding was true also in the case of ILAS approaches (8). The fact that during GCA approaches the air speed and turn and bank were fixated significantly more often on the standard panel is probably because of the favorable locations of those instruments on the standard panel. On the standard panel the air speed was located adjacent to and on the same horizontal line as the directional gyro, which, as revealed by the link values, is the most frequent cross-check between the air speed and other instruments. The turn and bank receives relatively few fixations in either case, and when it is moved to the extreme lower right position among the flight instrument group on the new panel the pilots fixate it less than 1 time per minute. The increased number of fixations on the vertical speed on the new panel may be the result of training techniques as well as its location adjacent to and on a horizontal line with the most frequently fixated instrument, the directional gyro. During the period between the completion of the study using the standard panel and the study using the new panel, the Air Force Instrument School put increased emphasis on the use of the vertical speed indicator. The instrument instructors at the school who were subjects in both experiments predicted that the vertical speed would be used more often in the second study.

Considering the results of other studies which show that the optimal spacing between the most used instruments is short and horizontal (2), and that in rapid check reading the upper instruments tend to be fixated first and more frequently (7), the standard panel represents a better panel arrangement for GCA approaches than the new panel. The results of the ILAS study (8) showed the new panel was an excellent arrangement for that type approach. The favorable position of the cross-pointer on the new panel is probably not justified considering that it is not operative during CGA and instrument flight at altitude. The new panel would probably be an excellent arrangement of instruments if there were wide spread use of an instrument of the Zero Reader type which would be substituted for the cross-pointer and used for instrument flight at altitude as well as for approaches. A current eye movement study using the Zero Reader will reveal the amount of attention given to the instrument during certain maneuvers.

VI. SUMMARY

Records were obtained of the frequency, duration, and sequence of eye fixations of fifteen USAF pilots while flying GCA approaches under simulated instrument conditions. Comparisons were made between fixation patterns produced during day approaches and night approaches and between fixation patterns produced while using the standard panel arrangement and a new panel arrangement. It was found that:

1. Fixations involving the same four instruments (the air speed, directional gyro, the gyro horizon, and the vertical speed) accounted for over 85 per cent of the available time during GCA regardless of which condition was being investigated.

2. The relative amount of use received by each of these four instruments was not affected by the difference between day and night conditions but was affected by the difference between panel arrangements.

3. The difference between day and night conditions significantly affected the number of fixations on certain individual instruments as well as the total number of fixations. Night conditions produced fewer fixations than day conditions. With the exception of engine instruments night conditions produced longer fixations for each instrument and the average length of all fixations.

4. The difference between the standard panel and the new panel produced no significant change in the total number of fixations although there were signif-

icant differences in the case of some of the individual instruments. Differences in lengths of fixations between the standard panel and the new panel were not significant in any case.

5. For all conditions investigated the cross-checking pattern, which is revealed by the eye movement link values, showed that the strongest links were between the four most used instruments.

6. On the basis of the findings of this experiment and from the results of other instrument reading experiments, the standard panel appears to represent a better arrangement of instruments than the new panel for GCA approaches.

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