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FIXATIONS DURING ZERO-READER APPROACHES IN A JET AIRCRAFT

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

JOHN L. MILTON, CAPTAIN, USAF
AERO MEDICAL LABORATORY

FRED J. WOLFE, MAJOR, USAF
ALL-WEATHER FLYING SECTION

FEBRUARY 1952

WRIGHT AIR DEVELOPMENT CENTER

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John L. Milton, Captain, USAF
Aero Medical Laboratory

Fred J. Wolfe, Major, USAF
All-Weather Flying Section

February 1952

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Dayton, Ohio

FOREWORD

This report was prepared by Captain Milton of the Psychology Branch, Aero Medical Laboratory, Research Division, in cooperation with Major Wolfe of the All-Weather Flying Section, Flight Test Division, under a project identified by Research and Development Order No. 694-31, Principles of Instrument Presentation. Captain Milton acted as project engineer. Major Wolfe assisted in planning the study, coordinated the test schedule, and supplied many helpful suggestions regarding this report. Members of the Flight Research Unit in the Psychology Branch assisted with the statistical work and prepared the report for final publication. T/Sgt W. G. Morris was the photographer on all flights, edited the film, and prepared the reference slides.

The project engineer gratefully acknowledges the assistance rendered by the following organizations and individuals: The Special Photographic Services Branch which provided a photographer and camera equipment, and developed the film; the pilots of the All-Weather Flying Section who were subjects in the study; Dr. Virginia Senders who directed a group of Antioch College students in the analysis of the film; and Mr. David R. Craig for the many helpful suggestions regarding the preparation of the report.

ABSTRACT

This report covers one of a series of investigations of eye movements of pilots during instrument flight. The frequency, duration, and sequence of eye fixations made by 10 pilots during Zero Reader approaches under simulated instrument conditions are summarized. Comparisons are made between results obtained on Zero Reader approaches and results obtained on ILAS approaches using a somewhat similar instrument panel arrangement.

During Zero Reader approaches the Zero Reader Instrument, the Air Speed and the Gyro Horizon are the most used instruments. The Zero Reader, which includes directional gyro information and cross-pointer information, receives the same amount of attention during Zero Reader approaches as the Directional Gyro and Cross-pointer receive during ILAS approaches. The optimal arrangement of the instrument panel for Zero Reader Approaches (using frequency and length of eye movements as the Criteria) would call for location of the Zero Reader in the top center position with the Gyro Horizon and Air Speed located adjacent and horizontal.

PUBLICATION REVIEW

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

FOR THE COMMANDING GENERAL:



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

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I. PURPOSE OF THE STUDY

The purpose of this experiment was to obtain pilot eye movement data during Zero Reader approaches in a jet aircraft. An analysis of these data provided the average number of fixations per minute on each instrument, the average length of those fixations, and the sequence with which the pilots checked the various instruments during Zero Reader approaches. These results add to the knowledge obtained from previous experiments concerned with the manner in which pilots use their instruments during various phases of instrument flight. The results of this series of studies should aid in determining better instrument presentations and better panel arrangements. The results obtained and the conclusions drawn in this report are based on Zero Reader approaches only, and not on other maneuvers that are possible with the Zero Reader.

For purposes of comparison, data obtained during ILAS approaches using a similar instrument panel arrangement (6) are included in this report.

II. THE ZERO READER

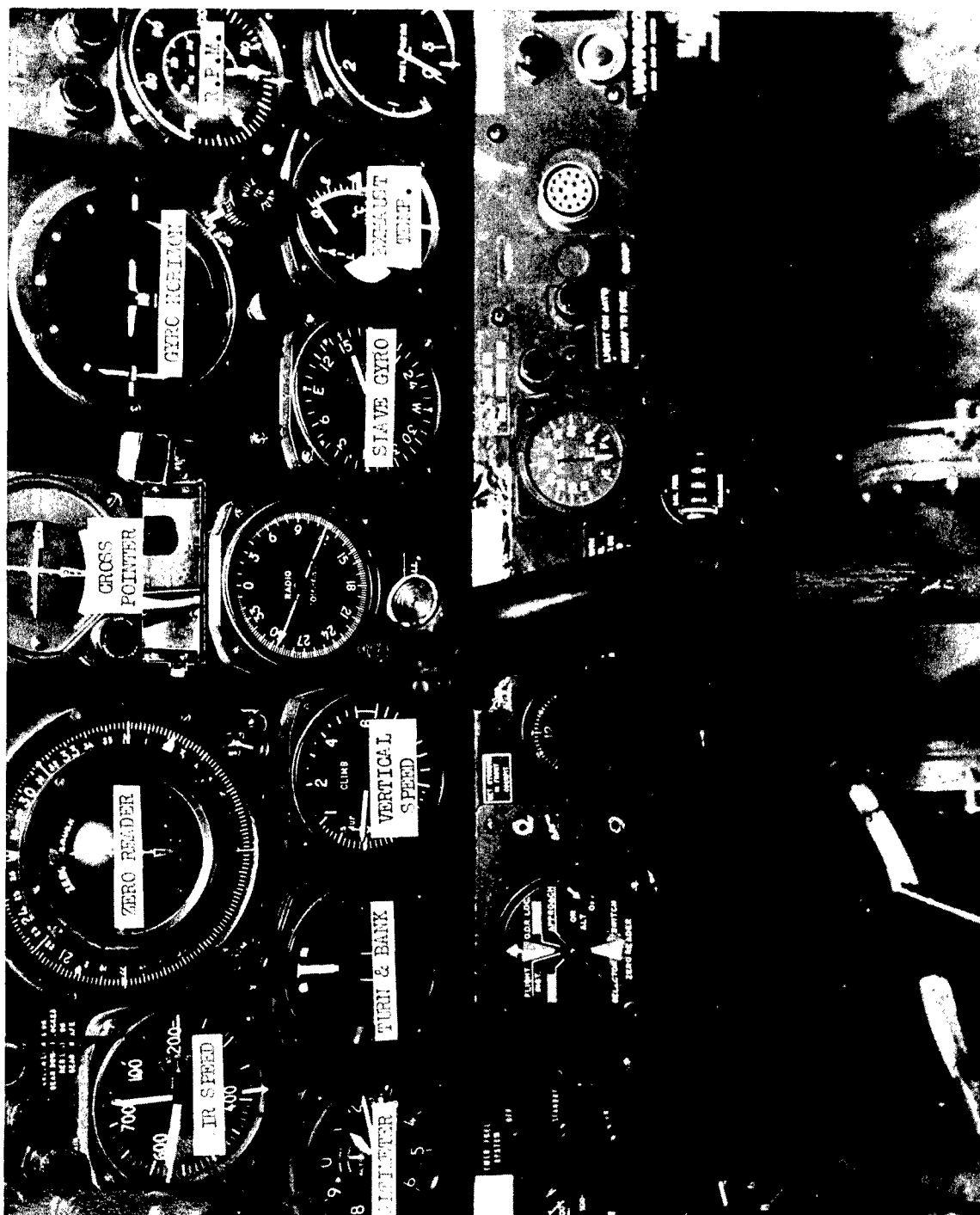
The following is a brief description of the Zero Reader. A more detailed account of this instrument may be obtained from another report (1) published by the All Weather Flying Division who developed and tested the instrument.

The Zero Reader consists of the Combined Indicator, the Control, the Selector Switch, and the Inverter. (The instrument as it appears on the pilot's instrument panel is shown in Figure 1.) Heading signals are essential to the operation of the Zero Reader. These signals can be obtained from a slaved gyro magnetic compass or a modified gyro fluxgate compass. Angular displacement error signals from the localizer receiver or VOR receiver and glide path receiver are essential to the operation of the Zero Reader when flying ILAS, VAR, or VOR. By proper adjustment of the Heading Selector and the Selector Switch the pilot can select heading, altitude, and radio signal to establish a required flight plan. When these signals are combined in the Zero Reader control with pitch and roll signals from the Zero Reader gyro, the resulting indications presented on the Zero Reader Indicator show the aircraft control movements necessary for flight along this established flight plan. Some of the ways in which this instrument may be used are: For climbs and letdowns, for constant altitude flight, for VAR flight plans, for VOR flight plans, and for approaches on ILAS.

III. PROCEDURES

The procedures followed in the present study are essentially the same as those employed in previous eye movement studies and are described in detail in another report (4). A brief review of the flight procedure, regarding technique, film analysis, and the variations necessary for accomplishing the present study follows:

Flight Procedures. Ten pilots assigned to the All Weather Flight Division were used as subjects. Each pilot made one practice Zero Reader approach and made a second approach during which his eye movements were photographed. The subject flew the aircraft from the rear cockpit of a T-33. Another pilot sat in the front cockpit and acted as a safety observer.



T-33 INSTRUMENT PANEL

FIGURE 1

Photographic Recording. A 16mm camera was mounted behind and to the right of the subject's head. A small rectangular mirror was attached to the center of the instrument panel. The pilot's face and eyes were photographed as they were reflected in the mirror. Speed of the camera was 16 frames per second. Photographs were taken before 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.

During the approach the camera was turned on by the observer pilot in the front cockpit at the time when the aircraft intercepted the glidepath, and the camera was turned off automatically by an intervolumeter attachment to the camera itself. The subject did not know the exact time his eye movements were being photographed. A one minute sample was obtained of each subject's eye movements. This one minute sample covered almost the entire period from the point where the glidepath was intercepted to the point of touchdown on the runway.

IV. RESULTS

Film Analysis. All film records were read independently, frame by frame, by two people. The reference slides mentioned above were used as criteria by the film readers in determining the instrument being fixated.

There was 87.5 per cent agreement between the two readers when all the frames were read independently. The two film scorers viewed together the frames on which they disagreed and reached agreement on 100 per cent of the frames of photography after this second analysis. Most of the disagreement involved fixations on objects other than the flight instruments. The fixations that could not be identified with a particular instrument were placed in a category called Search. Search includes the following: (1) fixations on objects outside of the cockpit, (2) fixations on controls or switches inside the cockpit, (3) the few frames of photography that were blurred or showed the subject's eyes blinking, and (4) fixations on a point between two instruments. The Search category accounts for an average of 20 fixations per minute and is included in Table I. In previous eye movement studies Search accounted for so few fixations that it was not included as a separate category in the reports.

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 one minute period. 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.

Number of Fixations. Means and standard deviations for number of fixations per minute are summarized in Table I and Figure 2. The 10 pilots averaged 92 fixations during the one minute test period. The majority of these fixations were on three instruments. The Zero Reader was fixated an average of 30 times; the Flight Indicator 16 times and the Air Speed 10 times. None of the remaining flight instruments were fixated as often as five times per minute.

TABLE I

MEANS AND STANDARD DEVIATIONS OF NUMBER
OF FIXATIONS PER MINUTE AND LENGTH OF
FIXATION CYCLE ON EACH INSTRUMENT DURING
ZERO READER APPROACHES

INSTRUMENT	N	<u>Mean Number of Fixations Per Minute</u>		N	<u>Mean Length of Fixation Cycles (In Seconds)</u>	
		MEAN	SD		MEAN	SD
AIR SPEED	10	10.1	6.5	10	.52	.13
ZERO READER	10	30.5	11.1	10	1.29	.56
CROSS-POINTER	10	1.3	1.4	6	.25	.24
FLIGHT INDICATOR	10	16.4	9.2	10	.48	.23
RPM	10	4.4	2.6	10	.66	.22
ALTIMETER	10	2.2	1.2	9	.42	.20
TURN AND BANK	10	2.4	1.3	9	.70	.82
VERTICAL SPEED	10	2.9	1.6	10	.45	.26
SLAVE GYRO	10	1.0	.91	6	.50	.20
EXHAUST TEMP.	10	.8	.8	5	.48	.11
SEARCH	10	19.9	7.8	10	.25	.23
TOTAL	10	91.8	26.7	10	.72	.21

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR-CRAFT INSTRUMENTS DURING ZERO READER APPROACHES

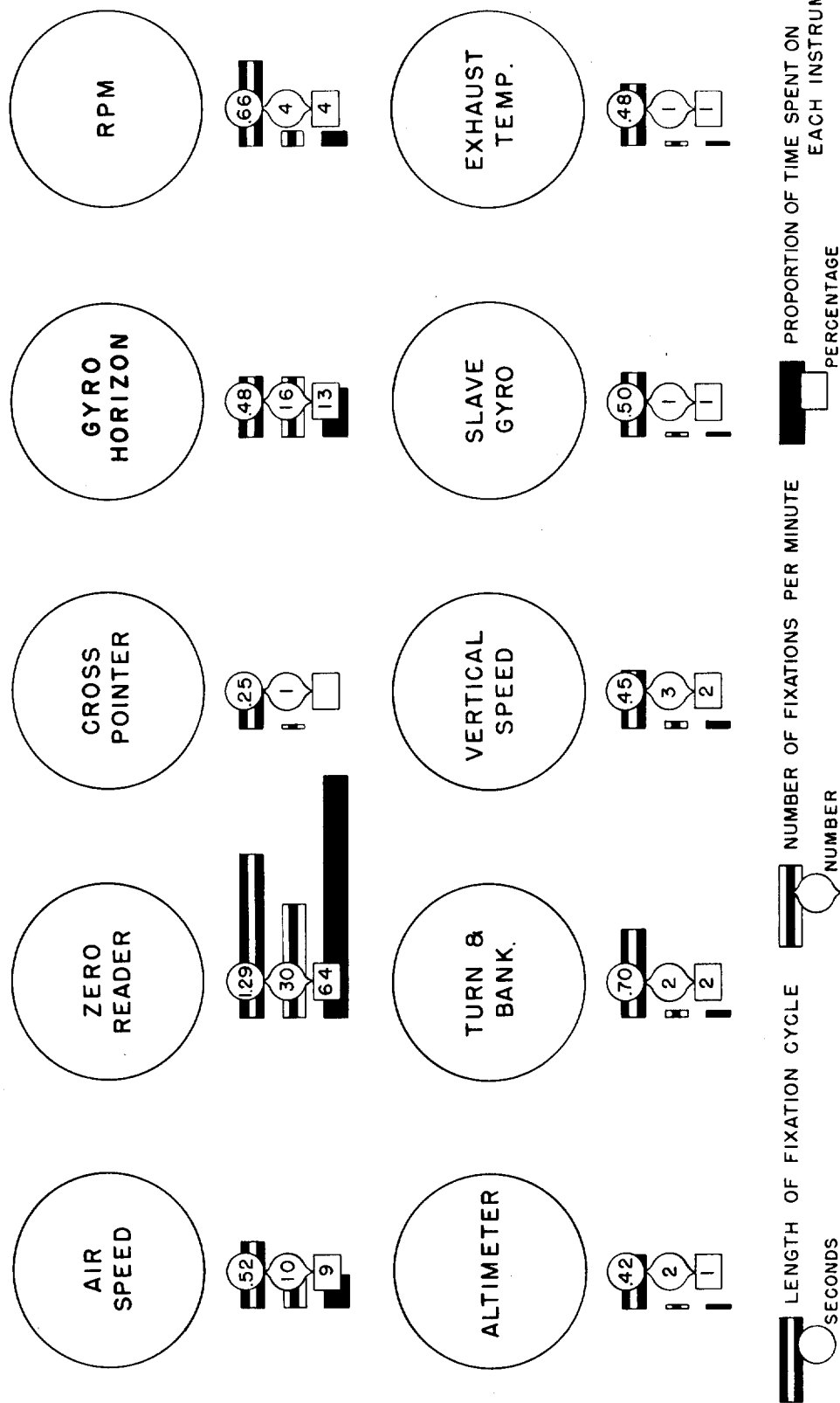


FIGURE 2

Length of Fixation Cycle. Means and standard deviations for average length of fixation on each instrument are also summarized in Table I and Figure 2. The longest fixation time, 1.29 seconds, was on the Zero Reader. This time includes the fixation times on both the cross-pointer and the directional gyro parts of the Zero Reader since it was not possible to distinguish between the two fixations. The next longest fixation times were on the Turn and Bank which was 0.70 second and the R.P.M. which was 0.66 second. The remaining fixations averaged approximately 0.50 second with the exception of Cross-pointer and Search fixations which averaged 0.25 second.

Total Time Allotted to Each Instrument. Fixations on the Zero Reader amounted to 64 per cent of the total time available to the pilot. Fixations on the Flight Indicator accounted for 13 per cent of the time and fixations on the Air Speed accounted for 9 per cent of the time. Fixations on each of the remaining instruments accounted for less than 5 per cent of the total available time. About 8 per cent of the time was spent on fixations placed in the Search category.

Relation Between Frequency of Use and Speed of Checking Instruments. Table II shows the correlation coefficients between length of fixations and number of fixations for each instrument. The negative correlation for the Zero Reader is significant at the 1 per cent level of confidence which indicates that those pilots who made more fixations on that instrument also made significantly shorter fixations. The correlation between the total number of fixations and the average length of fixation for all instruments 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 that occurred during Zero Reader approaches are listed by pairs in Table III. The most frequent sequences (both directions between two instruments) occurred between the Zero Reader and the Gyro Horizon and between the Zero Reader and the Air Speed. These two fixation sequences accounted for 422 eye movements out of a total of 676 made by the 10 pilots.

The eye movement link values, based on the percentage of eye movements in both directions between any two instruments, are shown in Figure 3. The largest link value, 38 per cent, is between the Zero Reader and the Gyro Horizon. The next largest, 24 per cent, is between the Zero Reader and the Air Speed. The remaining links are comparatively small. With the exception of the link between Gyro Horizon and R.P.M., all of the link values connect the Zero Reader with some other instrument.

V. DISCUSSION OF RESULTS

The results of this study indicate the relative importance of the Zero Reader during a Zero Reader approach. This instrument accounted for 30 fixations out of a total of 72 instrument fixations made during a one minute sample, and for 64 per cent of the total time available to the pilot. The Gyro Horizon and Air Speed are the next most important instruments from the standpoint of number of fixations and amount of time spent in looking at them. It is also apparent that the Cross-pointer instrument is used very infrequently (approximately 1 per cent of the total avail-

TABLE II

PRODUCT MOMENT CORRELATION COEFFICIENTS BETWEEN NUMBER OF FIXATIONS PER MINUTE
AND AVERAGE LENGTH OF FIXATIONS DURING ZERO READER APPROACHES (1)

<u>INSTRUMENT</u>	<u>r</u>	<u>N</u> **
AIR SPEED	-.01	10
ZERO READER	-.78*	10
CROSS-POINTER	.40	6
FLIGHT INDICATOR	.45	10
RPM	-.27	10
ALTIMETER	.28	9
TURN AND BANK	-.48	9
VERTICAL SPEED	-.35	10
SLAVE GYRO	-.49	6
EXHAUST TEMP.	-.39	5
SEARCH	-.39	10
TOTAL	-.97	10

(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.

** N = Number of Subjects.

TABLE III

FREQUENCY OF OCCURRENCE OF EYE MOVEMENTS BETWEEN PAIRS OF INSTRUMENTS DURING ZERO READER APPROACHES

1. ZR - GH - 131	127 - GH - ZR
2. ZR - AS - 85	79 - AS - ZR
3. ZR - RPM - 19	20 - RPM - ZR
4. ZR - VS - 16	16 - VS - ZR
5. ZR - ALT - 9	15 - ALT - ZR
6. ZR - TB - 11	9 - NB - ZR
7. ZR - XP - 5	5 - XP - ZR
8. ZR - SG - 5	4 - SG - ZR
9. ZR - ET - 2	4 - ET - ZR
10. GH - RPM - 12	6 - RPM - GH
11. GH - VS - 3	2 - V/S - GH
12. GH - AS - 2	2 - AS - GH
13. GH - XP - 1	5 - XP - GH
14. GH - ALT - 1	2 - ALT - GH
15. GH - TB - 1	3 - TB - GH
16. GH - SG - 1	1 - SG - GH
17. GH - ET - 1	1 - ET - GH
18. AS - RPM - 7	1 - RPM - AS
19. AS - ALT - 7	3 - ALT - AS
20. AS - TB - 4	3 - TB - AS
21. AS - XP - 1	2 - XP - AS
22. AS - VS - 0	2 - VS - AS
23. RPM - XP - 6	0 - XP - RPM
24. RPM - ET - 4	0 - ET - RPM
25. RPM - SG - 2	1 - SG - RPM
26. RPM - VS - 1	1 - VS - RPM
27. TB - ALT - 4	1 - ALT - TB
28. TB - VS - 2	4 - VS - TB
29. TB - XP - 1	0 - XP - TB
30. SG - VS - 3	1 - VS - SG
31. SG - ET - 1	0 - ET - SG
32. ALT - VS - 2	1 - VS - ALT
33. ALT - RPM - 1	0 - RPM - ALT
34. ALT - SG - 1	0 - SG - ALT

TABLE III (Cont'd)

35. ET - AS - 1
 36. ET - ALT - 1
 37. ET - TB - 1

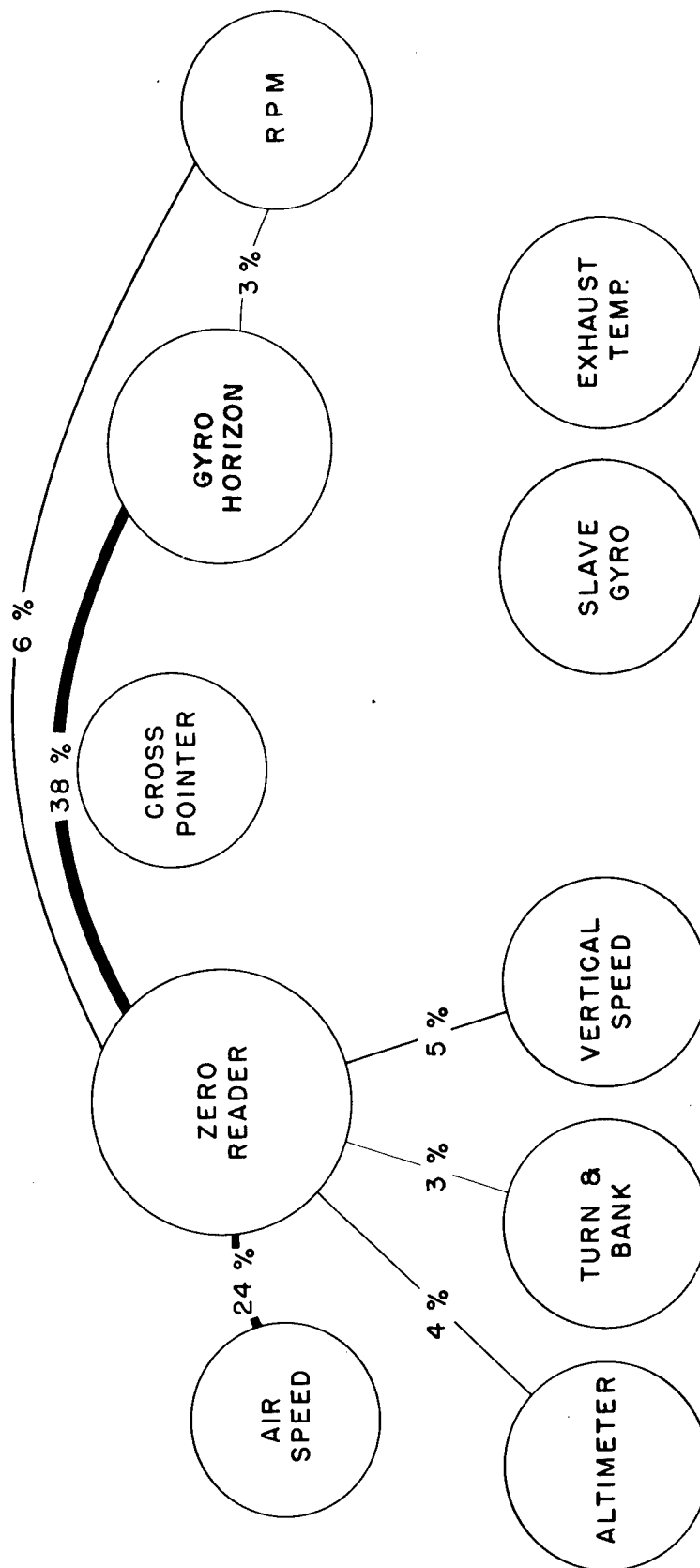
O - AS - ET
 O - ALT - ET
 O - TB - ET

LEGEND

AS - Air Speed
 ZR - Zero Reader
 XP - Cross-Pointer
 GH - Gyro Horizon
 RPM - Revolutions Per Minute

ALT - Altimeter
 TB - Turn and Bank
 VS - Vertical Speed
 SG - Slave Gyro Compass
 ET - Exhaust Temperature

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS ZERO READER APPROACHES



LINK VALUES BASED ON 10 PILOTS VALUES LESS THAN 2 % OMITTED

FIGURE 3

able time) although it is probably fixated much more often during the maneuvering to intercept the approach beam. Except for the location of the Cross-pointer the instrument panel arrangement used in this study appears to be a good one for Zero Reader approaches. It is known, from other instrument reading studies that short, horizontal eye movements are the most efficient (2). It also appears that the top center position of an instrument panel is the most favorable. In order to meet the above criterion the Zero Reader should be located in the top center position on the panel with the Gyro Horizon and Air Speed adjacent and horizontal. The Cross-pointer, to be used efficiently, should be viewed with a minimum of parallax. During a Zero Reader approach, panel space permitting a better location for the Cross-pointer would appear to be above or above and to the side of the Zero Reader. It is interesting to note that three of the subjects who had a lot of experience with the Zero Reader averaged only 5 fixations per minute on the Gyro Horizon, while the seven relatively inexperienced pilots averaged 21 fixations per minute. Since the Zero Reader indirectly gives attitude information, the more experienced pilots might not have felt the need for cross-checking the Gyro Horizon as often.

For purposes of comparison Figures 4 and 5 show eye movement data on ILAS approaches obtained in a previous study in a C-45 aircraft. This aircraft had an instrument panel arrangement similar to the one in the T-33 used in the present study. The C-45 had no Zero Reader, but the basic instruments were arranged in somewhat the same manner as in the T-33. It is not possible to determine how much of the differences in the two sets of data are due to the differences between aircraft, the differences between a Zero Reader approach and a Cross-pointer approach, or other factors that might be involved. There are, however, some interesting observations that can be made.

In both types of approaches the Cross-pointer and the Directional Gyro information is the most important. The average length of fixations on the Zero Reader, 1.29 seconds is almost exactly the same as the combined average length of fixations on the Cross-pointer and Directional Gyro in the ILAS approaches. The average length of fixations on these two instruments combined totaled 1.30 seconds. The proportion of the total amount of time available to the pilot that was spent in obtaining directional gyro and cross-pointer information was almost exactly the same for both types of approaches. This time amounted to 64 per cent of the time during the Zero Reader approaches and 65 per cent of time during ILAS approaches.

In both types of approaches the Gyro Horizon and the Air Speed were the instruments that were fixated next most frequently. Fixations on these two instruments were approximately equal for both types of approaches. Fixations on the remaining instruments differed slightly during the two types of approaches. However, there were very few fixations on those instruments in either case.

The method of cross-checking the instruments, as shown by the eye movement link values, further reveals the importance of cross-pointer and directional gyro information, as well as air speed and gyro horizon information during both types of approaches.

LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIR- CRAFT INSTRUMENTS DURING DAY ILAS APPROACHES

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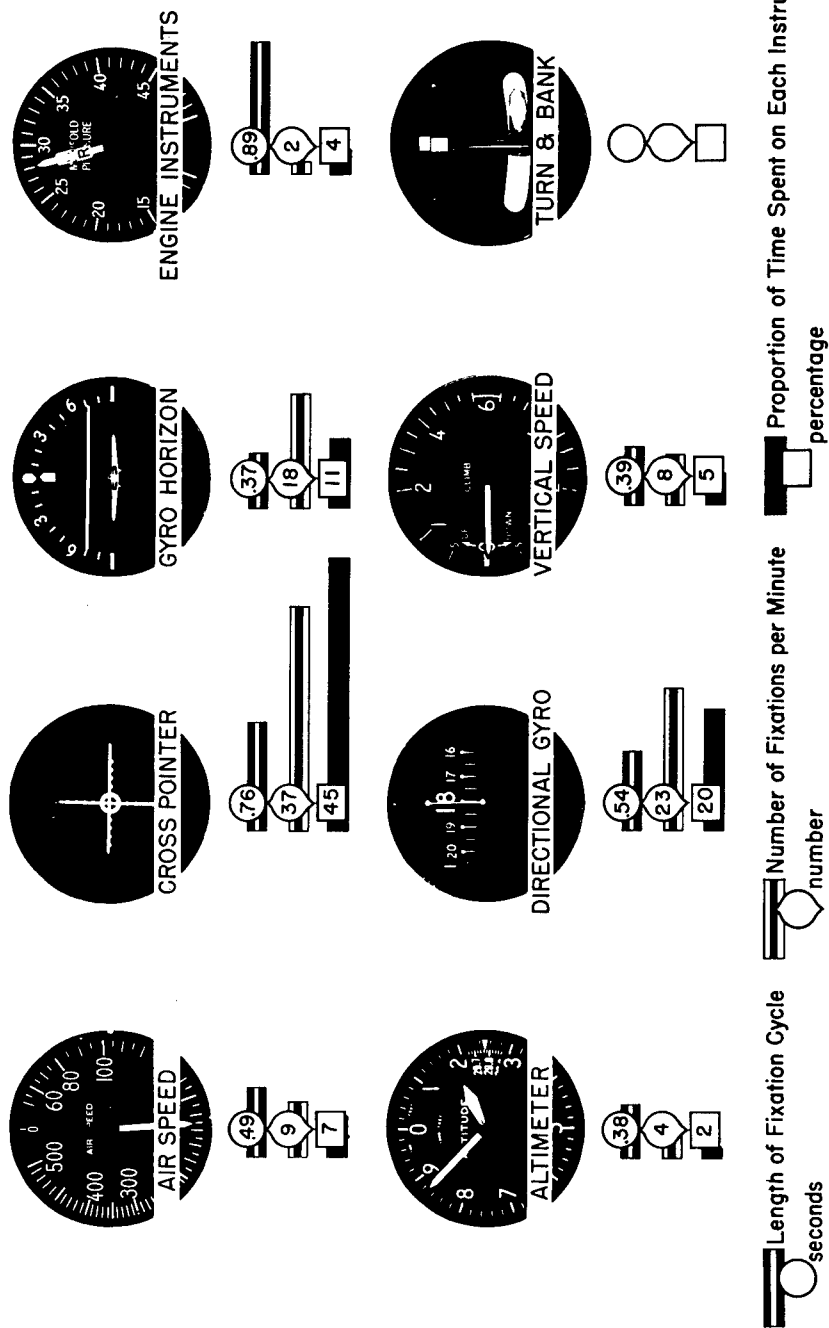
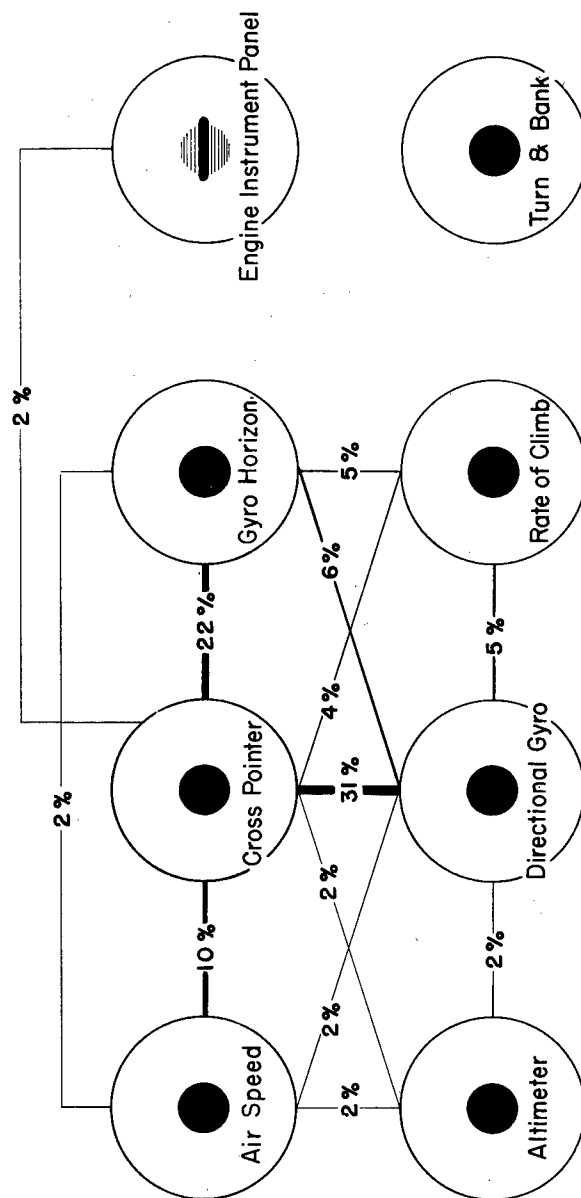


FIGURE 4

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS DAY I.L.A.S.

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

FIGURE 5

VI. SUMMARY

Records were obtained of the frequency, duration, and sequence of eye fixations of 10 All Weather Flying Division pilots while flying Zero Reader approaches under simulated instrument conditions. Comparisons were made between fixation patterns produced during Zero Reader approaches and fixation patterns produced during ILAS approaches using the standard cross-pointer instrument. It was found that:

1. The Zero Reader is the most used instrument during Zero Reader approaches. The Cross-Pointer and Directional Gyro are the most used instruments during ILAS approaches. The Zero Reader was used almost exactly the same amount of time during the Zero Reader approaches as the Cross-Pointer and Directional Gyro were used during ILAS approaches. These instruments accounted for the greatest number of eye movements in their respective studies. In both types of approaches the Gyro Horizon and Air Speed are the instruments used next most frequently.
2. The Cross-Pointer is used very infrequently during Zero Reader approaches. However, the Cross-Pointer is considered an essential instrument in addition to the Zero Reader for VOR and VAR flight plans.
3. The optimal arrangement of the instrument panel for Zero Reader approaches (using frequency and length of eye movements as the criteria) would call for location of the Zero Reader in the top center position with the Gyro Horizon and Air Speed located adjacent and horizontal.

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