FIXATIONS DURING ZERO-READER APPROACHES IN A JET AIRCRAFT

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

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FEBRUARY 1952

WRIGHT AIR DEVELOPMENT CENTER

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

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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.

WADC TR 52-17
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
TABLE OF CONTENTS

I. Purpose of the Study ................................................. 1

II. The Zero Reader ..................................................... 1

III. Procedures .......................................................... 1
    Flight Procedures .................................................. 1
    Photographic Recording .......................................... 3

IV. Results .............................................................. 3
    Film Analysis ....................................................... 3
    Number of Fixations .............................................. 3
    Length of Fixation Cycle ......................................... 6
    Total Time Allotted to Each Instrument .......................... 6
    Relation Between Frequency of Use and Speed of Checking Instruments ........................................ 6
    Fixation Sequence and Eye Movement Link Values ............... 6

V. Discussion of Results ............................................... 6

VI. Summary ............................................................. 14
    Bibliographical References ....................................... 15

WADC TR 52-17
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.
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

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

WADC TR 52-17
LENGTH OF EYE FIXATIONS AND NUMBER OF FIXATIONS ON AIRCRAFT INSTRUMENTS DURING ZERO READER APPROACHES

**Figure 2**

- **Air Speed**
  - Fixation cycle: 52 seconds
  - Number of fixations: 10, 30

- **Zero Reader**
  - Fixation cycle: 129 seconds
  - Number of fixations: 16, 13

- **Cross Pointer**
  - Fixation cycle: 25 seconds
  - Number of fixations: 1

- **Gyro Horizon**
  - Fixation cycle: 48 seconds
  - Number of fixations: 1

- **RPM**
  - Fixation cycle: 66 seconds
  - Number of fixations: 4

- **Altimeter**
  - Fixation cycle: 42 seconds
  - Number of fixations: 2

- **Turn & Bank**
  - Fixation cycle: 70 seconds
  - Number of fixations: 2

- **Vertical Speed**
  - Fixation cycle: 45 seconds
  - Number of fixations: 3

- **Slave Gyro**
  - Fixation cycle: 50 seconds
  - Number of fixations: 1

- **Exhaust Temp.**
  - Fixation cycle: 48 seconds
  - Number of fixations: 1

Legend:
- Fixation cycle: Length of fixation cycle measured in seconds
- Number of fixations: Number of fixations per minute
- Proportion of time spent on each instrument: Percentage of time spent on each instrument
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 122 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)

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>r</th>
<th>N**</th>
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<td>-.78*</td>
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<td>CROSS-POINTER</td>
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<td>TURN AND BANK</td>
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<td>9</td>
</tr>
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<td>VERTICAL SPEED</td>
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<td>10</td>
</tr>
<tr>
<td>SLAVE GYRO</td>
<td>-.49</td>
<td>6</td>
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<tr>
<td>EXHAUST TEMP.</td>
<td>-.39</td>
<td>5</td>
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<tr>
<td>SEARCH</td>
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<td>10</td>
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<tr>
<td>TOTAL</td>
<td>-.97</td>
<td>10</td>
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</tbody>
</table>

(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>
<thead>
<tr>
<th></th>
<th>ZR - GH</th>
<th>131</th>
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<th>ZR - ZR 127</th>
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<td>VS - ZR 16</td>
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<td>VS - TB 4</td>
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<td>VS - TB 4</td>
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### TABLE III (Cont’d)

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<td>O - AS - ET</td>
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<tr>
<td>36.</td>
<td>ET - ALT - 1</td>
<td>O - ALT - ET</td>
</tr>
<tr>
<td>37.</td>
<td>ET - TB - 1</td>
<td>O - TB - ET</td>
</tr>
</tbody>
</table>

**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

WADC TR 52-17
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
ZERO READER APPROACHES

- AIR SPEED: 24%
- ALTIMETER: 4%
- TURN & BANK: 3%
- VERTICAL SPEED: 5%
- CROSS POINTER: 38%
- GYRO HORIZON: 6%
- SLAVE GYRO: 3%
- RPM: 3%
- EXHAUST TEMP: 0%

---

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 maneuver-
ing 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 informa-
tion, 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-455 aircraft. This aircraft had 
an instrument panel arrangement similar to the one in the T-33 used in the present 
study. The C-455 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 air-
craft, the differences between a Zero Reader approach and a Cross-pointer approach, 
or other factors that might be involved. There are, however, some interesting ob-
servations that can be made.

In both types of approaches the Cross-pointer and the Directional Gyro infor-
mation 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 fixa-
tions on the Cross-pointer and Directional Gyro in the ILAS approaches. The aver-
age 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 in-
struments that were fixated next most frequently. Fixations on these two instru-
ments were approximately equal for both types of approaches. Fixations on the 
remaining instruments differed slightly during the two types of approaches. How-
ever, 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 AIRCRAFT INSTRUMENTS DURING DAY ILAS APPROACHES

Air Speed: 49, 9, 7

Gross Pointer: 76, 57, 45

Gyro Horizon: 37, 18, 11

Engine Instruments: 89, 2, 4

Altimeter: 39, 4, 2

Directional Gyro: 54, 23, 20

Vertical Speed: 39, 9, 5

Turn & Bank: 

- Length of Fixation Cycle: seconds
- Number of Fixations per Minute: number
- Proportion of Time Spent on Each Instrument: percentage

Figure 4
EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
DAY I.L.A.S.

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.


