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EYE FIXATIONS OF AIRCRAFT PILOTS, I. A REVIEW OF PRIOR EYE-MOVEMENT STUDIES  
AND A DESCRIPTION OF A TECHNIQUE FOR RECORDING THE FREQUENCY, DURATION,  
AND SEQUENCES OF EYE FIXATIONS DURING INSTRUMENT FLIGHT

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## ABSTRACT

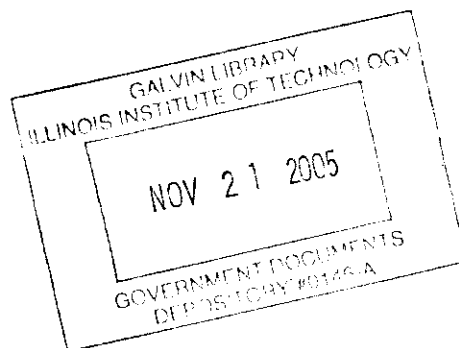
This report is the first in a series dealing with the measurement of the eye movements of pilots during instrument flight. The literature on eye movements during reading and related visual tasks is summarized and one previous experiment dealing with the recording of eye movements during instrument flight is reviewed. The apparatus and techniques employed in the present series of studies, the flight procedures, and the methods used in analyzing eye-movement records are described in detail. Eye fixation data obtained by these procedures are shown to be reliable.

## PUBLICATION APPROVAL

For the Commanding General:

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## FOREWORD

This is the first report describing the results of a series of related investigations conducted 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. This 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 of the 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. Kirchmer 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.

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## EYE FIXATIONS OF AIRCRAFT PILOTS, I. A REVIEW OF PRIOR EYE-MOVEMENT STUDIES AND A DESCRIPTION OF A TECHNIQUE FOR RECORDING THE FREQUENCY, DURATION, AND SEQUENCES OF EYE FIXATIONS DURING INSTRUMENT FLIGHTS.

### I. NEED FOR INFORMATION REGARDING THE EYE MOVEMENTS OF AIRCRAFT PILOTS

Aircraft instruments are designed to provide pilots with information needed to control aircraft in flight--information such as the attitude of an aircraft with respect to the ground, its location in three-dimensional space, and the rate of change of its attitude and location vectors. Knowledge of how pilots use their eyes when they are flying on instruments, i.e., how they obtain data from separate instruments in order to combine bits of discrete information into a total picture of "what the aircraft is doing", is fundamental to a basic understanding of the function served by aircraft instruments. Such knowledge should guide the engineer in designing functional instruments. It can form a scientific basis for improving the design of aircraft instruments, increasing the efficiency of pilots, and simplifying the task of instrument flying.

The present series of studies of eye movements of pilots was undertaken to answer such questions as the following: How often is each instrument checked during particular maneuvers? How much time is required to check each instrument? What percentage of the total time available during critical maneuvers is spent in obtaining information from each of the different instruments? How are the frequency and duration of eye fixations influenced by factors such as instrument design, instrument arrangement, instrument lighting, pilot experience, and the particular maneuver being flown at the time?

The answers to some of these questions can be inferred from the results of studies that psychologists have already conducted on eye movements. Before describing the present investigations, it seems worthwhile to summarize some of the facts that are known about how the eyes are used in reading and in related visual tasks and to review one previous study in which pilot's eye movements were recorded during instrument flight. (The reader who is familiar with the eye-movement literature or who is interested only in the techniques employed in the present series of investigations, may want to omit the following section and continue on Page 13).

### II. REVIEW OF SOME PREVIOUS EYE MOVEMENT STUDIES

#### Techniques for Recording Eye Movements.

Since the beginning of research on eye movements over fifty years ago, many techniques have been employed for recording the activity of the eyes in reading and in other tasks. The two techniques that are now used most frequently are (1) photographic and (2) electrical.

Dodge (16), using a falling plate, is believed to have made the first photographic record of eye movements in 1899. At present the most commonly used photographic method is that of corneal reflection. A small beam of light is directed onto the cornea of the eye, and the reflected light focused by a suitable lense system on a stationary or moving film. By means of variations in this arrangement it is possible to record both the vertical and the horizontal components of eye movements, to record the patterns of fixations employed by individuals when they look at pictures or advertisements, and to record simultaneously both eye movements and speech during oral reading (see references 7 and 39). The ophthalmograph, a commercially available eye movement camera, utilizes the corneal-reflection method and provides records of the horizontal movements of both eyes and of eye-movement and eye-fixation times.

Some electrical recording techniques make use of the fact that the back of the eyeball, which contains the sensitive light receptor cells, is electrically negative relative to the front of the eyeball. Since changes in corneo-retinal potentials are closely proportional to the sine of the angle of rotation of the eye it is possible, with a proper electrode placement and amplifying system, to record eye movements electrically. Another electrical method consists of recording photographically the action currents generated by the extrinsic eye muscles. These methods yield results that are similar to those obtained with the conventional photographic techniques (42). One serious limitation of both the electrical and the corneal reflection methods is that the reader's head must be immobilized while the recording is being made.

### Some Typical Eye Movement Measures.

The fixation pause: When an individual inspects an array of visual objects his eyes usually make a succession of quick (saccadic) movements and separate fixation pauses. Perception usually occurs during the fixation pause and not during the time when the eyes are actually in motion. Only when the eyes are smoothly following a moving object are they capable of resolving visual patterns while in motion. Arnold and Tinker (4) report that an average fixation pause of 0.157 seconds is required to identify a letter, after the eyes have made a 12 degree movement. In reading the mean pause duration varies from about 0.2 to 0.4 seconds. Fixation pauses in reading probably are longer than those made in discriminating sample objects because more time is required for comprehension and assimilation of the meaning of material that is read than is required for mere discrimination. Pause duration increases as the difficulty of the reading material increases (42).

It should be noted that the eye can detect a light stimulus that lasts for less than a millisecond (0.001), provided it is sufficiently intense. However, it is thought that in any continuous activity a minimum of about 0.1 second is required for a well-cleared-up perception.

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Regressive eye movements: Boyle (5) analyzes the regressive pause (the pause that follows a backward eye movement within a line of print) into the following six patterns: (1) adjustment after the first fixation in a line, (2) adjustment within a line when the span of vision is overreached, (3) regressions for verification, (4) regressions during word analysis, (5) regressions for phrase analysis, and (6) regressions for re-examination of a whole line. He points out that regressions are necessary in analytical reading. The number of regressive movements varies widely for different individuals and for reading matter of different levels of difficulty.

The fixation span: The fixation span (sometimes called span of perception) is the amount of material that can be perceived in one eye fixation. Buswell (10) states that width of span is a measure of maturity of reading habits. On the basis of this conclusion, many attempts have been made to discover training methods that will increase the fixation span. It has been pointed out, however, that other factors besides reading experience affect fixation span. For example, Luckiesh and Moss (26) and Paterson and Tinker (33) find that span decreases slightly in going from medium to large-size type. Dockeray (15) reports that the span of distinct vision for letters in 10-point type at a distance of 35 cm from the eyes is 20 to 22 mm on either side of the fixation point. Applying this visual angle to 28 inches, the distance of the instrument panel from the pilot's eyes, gives 1.6 inches on either side of the fixation point as the span of clear vision for comparable stimulus conditions. Other investigators report that the distance between fixations in reading varies from 10 mm to 20 mm. Thus it seems that the fields of distinct vision overlap in successive fixations.

Eye movement time: The time taken to move the eyes between fixations is relatively small and varies somewhat with the material read. Tinker (43) reports that movement time constitutes from 5.3 to 9.6 percent of the total time consumed in reading, with a mean of about 7 percent. Quick movements to the right made in reading a line of print cover from 1 to 4 degrees on the average and require from about 0.01 to 0.02 seconds. The longer return sweep from the end of one line to the beginning of the next, which usually covers from 21 to 20 degrees, requires from 0.04 to 0.045 seconds.

The delay time ("reaction time") of the eye in responding to a new stimulus is approximately the same as that for the hand or foot. Travis (46), for example, states that when a step function of rate is imposed on a stationary target, the eye requires about 0.2 second to initiate its following motion.

## Validity and Reliability.

Validity: Imus, Rothney, and Baer (19) report that comprehension of material read has little or no correlation with most eye movement measures. Anderson (1) and Broom (9) report that the correlation between eye movement measures during reading and scores on reading tests is low. Tinker (41) shows that when material read before the camera is strictly

comparable to that read in a comprehension test, the correlations between fixation frequency and perception time (fixation frequency times pause duration) and performance test scores are high, ranging from 0.80 to 0.99. He states that pause duration by itself is not a valid measure of reading performance.

Reliability: Imus, Rothney, and Baer (19), using 50-word samples of text, find relatively low reliability ( $r = 0.59$  to  $0.72$ ) for eye movement measures. Anderson (2) and Broom (9) using the ophthalmograph, note similar low reliability. Tinker (41) reports low reliability when using short samples of from 5 to 15 lines of text. However, when the size of the sample is increased to from 20 to 40 lines, the reliability is approximately 0.8. He concludes that when only group comparisons are involved, short samples are adequate, but that for individual evaluation, a sample of at least 20 lines of text should be used.

Other evaluations: Tinker (41) states that reading performance is the same before the camera as when working at a table. This finding is confirmed by Gilbert (17) with the reservation that the subject must be adapted to the laboratory situation. Stromberg (37) cautions that there is not a specific minute fixation point but a fixation area and that the two eyes do not necessarily coordinate in fixating. In general, the evidence indicates that under adequate experimental conditions, eye movement records are adequate and reliable measures of reading performance.

## Effects of Stimulus and Physiological Variables.

Peripheral vision: La Grone (22) has used tachistoscopic exposures to study the relation of peripheral vision and eye movements. He reports that high perception scores in the left peripheral field accompany fast reading, few fixations, and short pause durations and that high perception scores in the right peripheral field accompany slow reading, more fixations and longer pause durations. It is known that peripheral vision aids in the making of an accurate series of fixations.

Illumination: In general the eye is able to adapt to very wide variations in illumination with negligible evidence of direct changes in efficiency. There is considerable controversy over whether there is any real advantage in using levels of illumination above about 10 foot-candles. Very little work has been done on reading or other visual tasks at very low levels of illumination, such as those used in aircraft cockpits at night.

Type pattern: Many typographic factors, such as size of type, color of print and background, length of lines, space between lines, and all capitals versus lower case letters influence the duration and frequency of fixations. Eye movements can be expected to vary considerably with different stimulus configurations.

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Emotion: Several investigators have studied the effect of emotion on eye movements. There are indications that some changes in eye movements are associated with emotion, although the evidence is rather inconclusive and the changes are not large.

Visual fatigue: The data regarding the effect of visual fatigue on eye movements do not provide a clear-cut answer to the question of visual fatigue, since differing results are reported by different investigators.

Hoffman (18) reports that the number of fixations per line, the number of eye blinks and the speed of reading show significant changes after four hours of reading and that the number of fixations per line shows a significant increase in variability after two hours of reading. Dearborn (14) states that after a long day of visual work speed of reading is reduced. Kurtz (21) claims that eye movement records reveal fatigue after 30 minutes of severe visual exertion. McFarland, Holway and Hurvich (29) believe that a device yielding a precise measure of fixation and binocular coordination would provide a measure of visual fatigue but that fixation and regression frequency and pause duration would remain unchanged.

Clark and Warren (12) report no significant trends in variation of fixation, regression and pause duration for eye movements in reading during a 65-hour period, although sporadic changes occur for certain individuals. The most extensive study of visual fatigue in reading that has yet been reported is that of Carmichael and Dearborn (11). They had individuals read continuously for six hour periods during which time they obtained continuous electrical recordings of eye movements. Despite changes in general attitudes and in feelings of fatigue on the part of the subjects, the investigators conclude that individuals can read continuously for six hours without undue signs of fatigue.

Anoxemia: McFarland, Knehr and Berns (30, 31) find significant increases in reading and eye movement time, and increases in fixations per line in oxygen concentrations corresponding to 15,000 to 18,000 feet of altitude. Qualitative variation of ocular movements, unsteadiness, nystagmoid tendencies, and an accentuation of abnormalities are also reported.

Miscellaneous factors: Simpson (34, 35) reports no significant correlation between eye movement measures and time spent in leisure reading. He reports correlations of  $-.38$  to  $-.52$  between fixation and regression frequency versus college achievement and mental ability, but no correlation between pause duration and achievement or ability. Leavell and Sterling (23) report low to moderate correlations between eye movement measures and intelligence. A number of investigators have attempted to determine the effects of such things as maturity level, reader proficiency, stuttering, and deafness. Results of these studies are not definitive or clear-cut.

Stimulus material other than print: Brandt (6, 8) states that in observing non-printed material horizontal excursions of the eyes are more frequent and extensive than are vertical movements; that 66 percent of the



fixations are in the left half of the visual field and 61 percent are above the mid-line; that one-third of the time is spent in the upper left, slightly less in the upper right, less in the lower left, and least in the lower right. Corkill and Lythgoe (13) present data which indicate that starting from a stationary fixation point the eyes can look toward and recognize objects to the right and left more rapidly and easily than objects below, and those below more easily than those above. White (49), who studied eye movements in check reading mock-ups of engine instrument panels reports that the top rows of instruments are fixated more often than the bottom rows, and that there are more fixations on the top left than on the top right side of a panel.

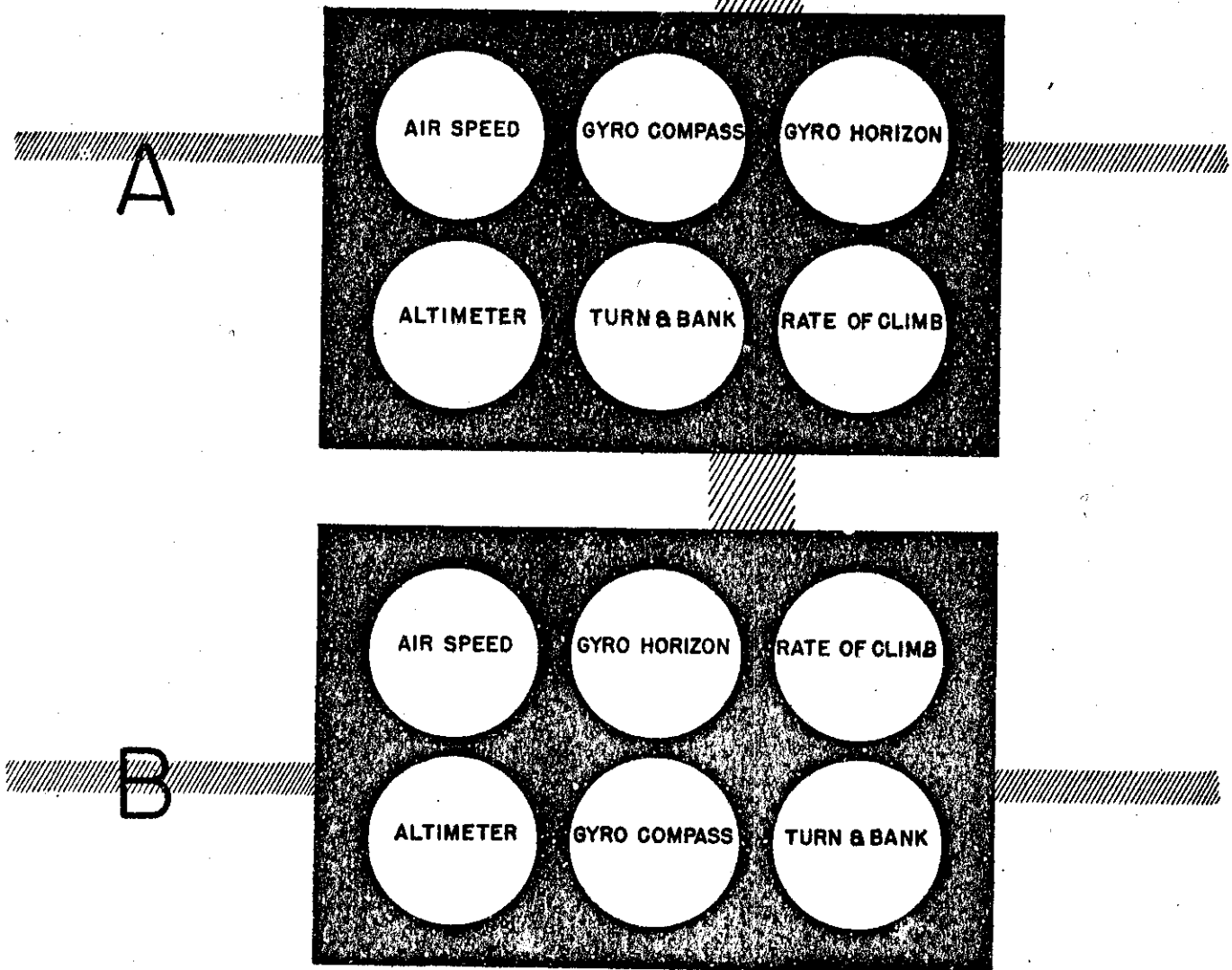
Training eye movements: Many procedures for training eye movements result in modified oculomotor patterns which seem to indicate improved reading efficiency. However, motivated reading has often been found to result in improvement as great as the more formal eye-movement training procedures. Tinker (42) believes that it is probable that motivating factors, and not the eye movement training as such, result in the increased reading ability and that an over-emphasis on mechanics may decrease flexibility and adaptability of reading habits. It seems reasonable that eye movements merely reflect efficient or poor reading performance rather than cause it. Although many experiments in the training of eye movements have been based on the assumption that peripheral factors are the important determinants of reading performance, Anderson (1), Traxler (47), Sisson (36), and others have concluded that the central processes are much more important.

## Summary.

Changes in eye movements occur with variations in reading purpose or attitude and with the difficulty of comprehension. Oculomotor patterns are a means of achieving the perceptual sequences necessary for apprehension and assimilation. Since they are extremely flexible they are thought to reflect any variation in the process of perception, apprehension, and assimilation. Usually clear apprehension and rapid assimilation produce few fixations and regressions, while ineffective perception and confused apprehension produce many fixations and regressions. Many fixations and frequent regressions also occur during analytical reading where it is necessary to examine the text to work out relationships. (42)

It is reasonable to assume that eye movement patterns reflect to some extent the blocks or difficulties that occur in the orderly sequence of thought processes.

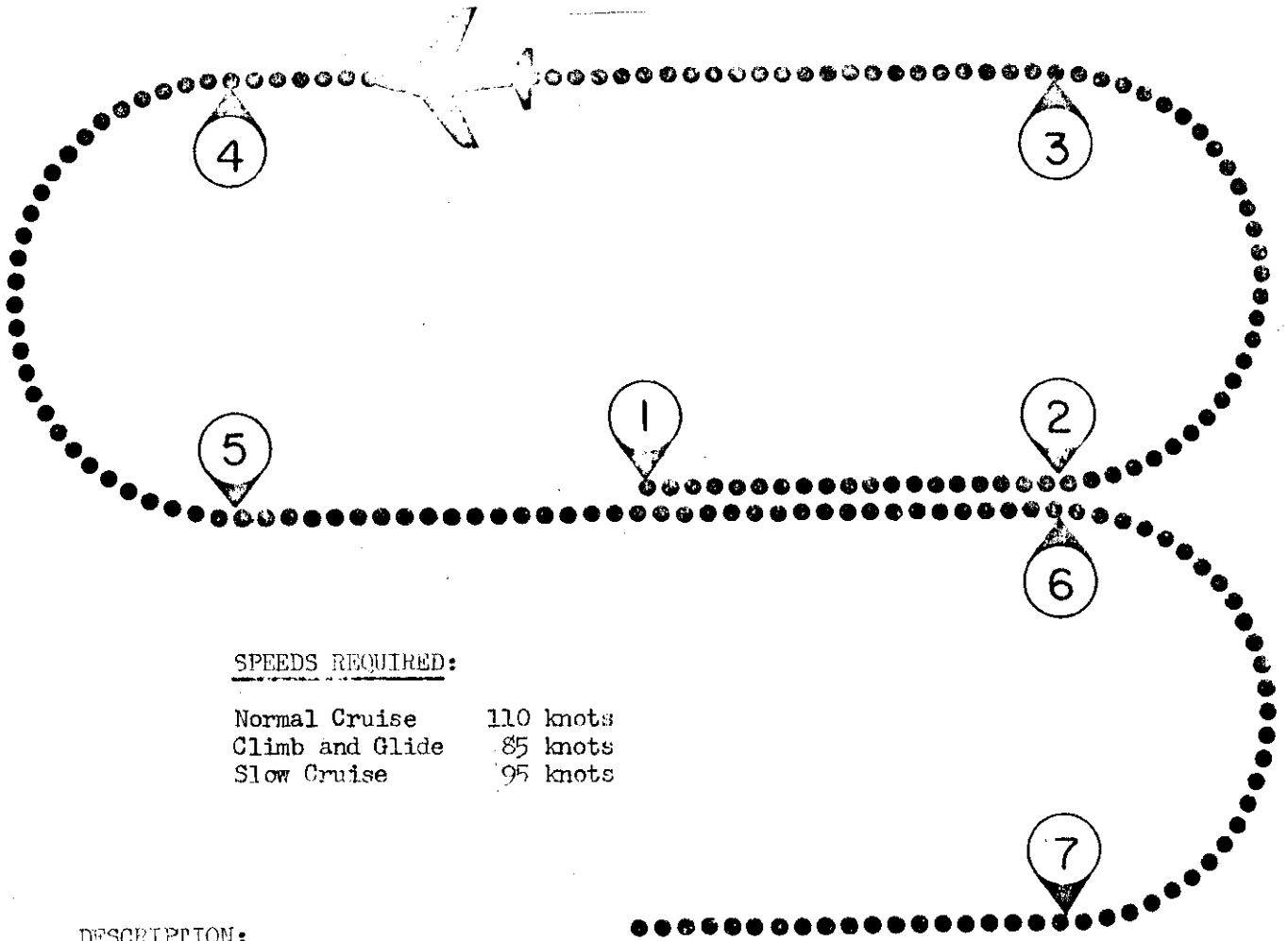
Eye movements during instrument flight should exhibit many of the same characteristics shown in reading print. The eyes should move in quick jerks separated by periods of relatively steady fixation. The length of fixation should vary considerably depending on the difficulty of the instrument-reading task. Small refixation and adjustive movements should take place during the examination of a single instrument. Such secondary factors as lighting, vibration, instrument size and instrument arrangement should affect eye fixation patterns.



Instrument Panel Arrangements used by Mc Gehee in an experiment to investigate pilot's eye movements during flight under simulated instrument conditions.

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FIGURE 1



#### SPEEDS REQUIRED:

Normal Cruise	110 knots
Climb and Glide	85 knots
Slow Cruise	95 knots

#### DESCRIPTION:

1. The pilot flies straight and level, changing from normal cruise speed to slow cruise in thirty seconds.
2. He makes a 180° standard rate gliding turn to the left. He descends 300 feet during the turn at the rate of 300 feet per minute.
3. He continues to descend, at the rate of 500 feet per minute, for one minute in straight flight, holding the heading established at the end of the 180° left turn. The descent is made at gliding speed.
4. He makes a 180° standard rate level turn to the left at slow speed.
5. He flies one minute straight and level at slow speed on the heading established at the end of the 180° standard rate level turn to the left.
6. He makes a 180° standard rate turn to the right, climbing with high power at slow speed.
7. He climbs for thirty seconds at slow speed on heading established at the end of the 180° right climbing turn. He then levels off after the thirty seconds straight climb and resumes normal cruising speed.

## Standard Flight Pattern

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FIGURE 2

\* Reproduced from Final Report,  
Project TED No. ATL-R 601,  
by Lt. Wm. McGehee, U. S. Navy.

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Several important differences between the task of the eyes in reading and in instrument flying should be mentioned. In one case the information obtained is verbal or ideational, and no immediate motor response is required. In the other case the information obtained is quantitative or spatial, and often an immediate motor response is required. In instrument flying it is usually not desirable to look at instruments in any fixed sequence, but rather to cross-check instruments in a sequence most appropriate to the immediate situation. In reading, eye fixation sequences are highly stereotyped. In both cases, however, the sequence of fixations probably reflects to some extent the sequence of thought processes.

### III. PREVIOUS STUDIES OF EYE FIXATIONS DURING INSTRUMENT FLIGHT

As part of a study that was concerned with the arrangement of the instrument panel, McGehee (28) recorded pilots' eye movements during flights made under simulated instrument conditions. He used two different instrument panel arrangements. These two arrangements are shown in Figure 1.

Six relatively inexperienced Naval pilots and eight relatively experienced Air Force pilots flew a PB7-5A aircraft through one three-hour flight using Panel A and one three-hour flight using Panel B. At three specified times during each flight (early, midway and late) they flew a relatively complex six-minute pattern (see Fig. 2) during which their eye movements were photographed. This recording was used as a work-sample for comparing eye movements for the two panels.

Eye fixations were photographed by a 16-mm. motion picture camera that was installed behind the instrument panel of the aircraft.

The amount of time spent on each instrument by Air Force and Navy pilots for the two panels is shown in Table I. These results indicate differences between the six flight instruments, between the two different panels, and between the Navy and Air Force pilots.

Statistically significant differences were found to exist for the time spent on individual instruments when instruments were located on the two different panels. McGehee states, "Differences between the time spent on the various instruments in the two panel arrangements may be explained by the hypothesis that pilots tend to spend more time on the centrally located instruments, and particularly on the instrument located in the top center position. While not definite, this finding suggests that instrument panel designs should place the most important instrument for instrument flight in the top center position of the panel, and the next most important instrument in the lower center position". This hypothesis agrees in general with Brandt's (6, 8) findings regarding the area of most frequent fixation, on pictures and advertisements, and with White's results (49) on the points of most frequent fixation in checking instrument panels.

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TABLE I

Percent of Total Time Devoted to Each Instrument During Six  
Minutes of Maneuvers. \*

<u>Air Force Pilots</u>	<u>Panel "A" Flown First</u>		<u>Panel "B" Flown First</u>	
	<u>Panel A</u>	<u>Panel B</u>	<u>Panel A</u>	<u>Panel B</u>
Gyro Horizon	17.9	18.4	21.8	24.0
Directional Gyro	22.6	19.6	21.9	17.4
Altimeter	8.2	12.6	8.9	12.4
Air Speed Indicator	21.5	23.9	24.2	23.6
Turn-Bank Indicator	7.6	6.6	5.8	3.7
Rate of Climb Indicator	2.4	2.7	2.5	3.0
 <u>Navy Pilots</u>				
Gyro Horizon	25.4	27.4	26.9	34.2
Directional Gyro	22.8	15.2	22.3	15.6
Altimeter	7.1	7.1	6.8	7.5
Air Speed Indicator	12.9	15.2	14.5	12.4
Turn-Bank Indicator	5.8	6.5	3.7	1.5
Rate of Climb Indicator	5.4	5.5	3.2	5.1

\* Calculated from information contained in a letter report to the Commandant, School of Aviation Medicine, Randolph Field, Texas, by Col. Arthur W. Melton, 1 November 1944.

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TABLE II

Average Duration of Fixation in Seconds.\*

<u>Group</u>	<u>N</u>	<u>Gyro Horizon</u>	<u>Directional Gyro</u>	<u>Altimeter</u>	<u>Turn- Bank</u>	<u>Air Speed</u>	<u>Clock</u>	<u>Vertical Speed</u>
A	15	.58	.54	.51	.51	.51	.52	.43
B	14	.56	.47	.45	.48	.56	.56	.35
C	10	.50	.45	.47	.50	.53	.60	.37

TABLE III

Percent of Total Time Devoted to Each Instrument During

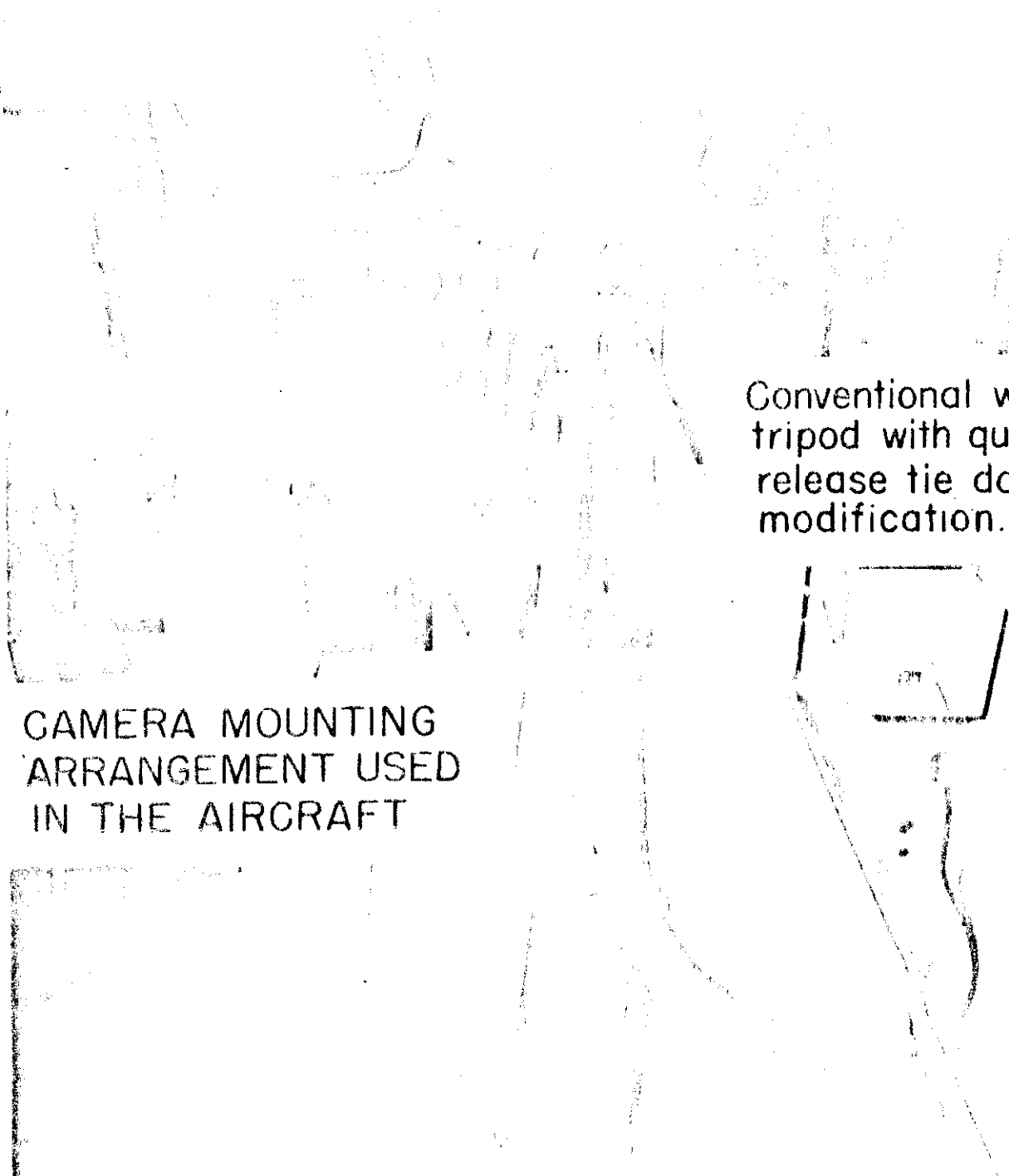
4 Minute Flight.\*\*

<u>Group</u>	<u>N</u>	<u>Gyro Horizon</u>	<u>Directional Gyro</u>	<u>Altimeter</u>	<u>Turn- Bank</u>	<u>Air Speed</u>	<u>Clock</u>	<u>Vertical Speed</u>
A	15	33.8	22.4	11.1	10.1	9.9	7.9	1.4
B	14	38.2	23.1	11.7	7.5	7.3	9.8	3.0
C	10	26.4	22.1	14.2	9.1	10.0	12.5	3.0

\* Reproduced from a letter report to Commandant, School of Aviation Medicine, Randolph Field, Texas, by Col. Arthur W. Melton, 1 November 1944.

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CAMERA MOUNTING  
ARRANGEMENT USED  
IN THE AIRCRAFT

Conventional wooden  
tripod with quick-  
release tie down  
modification.



FIGURE 3

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In a second study by McGehee, the eye movements of three groups of Navy pilots were photographed in a Howard airplane. The first group (A) was composed of 15 aviation cadets who were in an intermediate squadron and who had approximately 15 hours of instrument time. The second group (B) was composed of 14 pilots who had completed the advanced instrument course and who had approximately 33 hours of instrument flying. Eleven of these 14 pilots had been tested previously in Group A. The third group (C) was composed of 10 officers who were instructors at the U. S. Naval Air Station, Atlanta, and who had 100 or more hours of instrument flying time. In Tables II and III are shown the average duration of visual fixations and the percent of total time spent in fixations on each of seven instruments during 4 minutes of instrument flight.

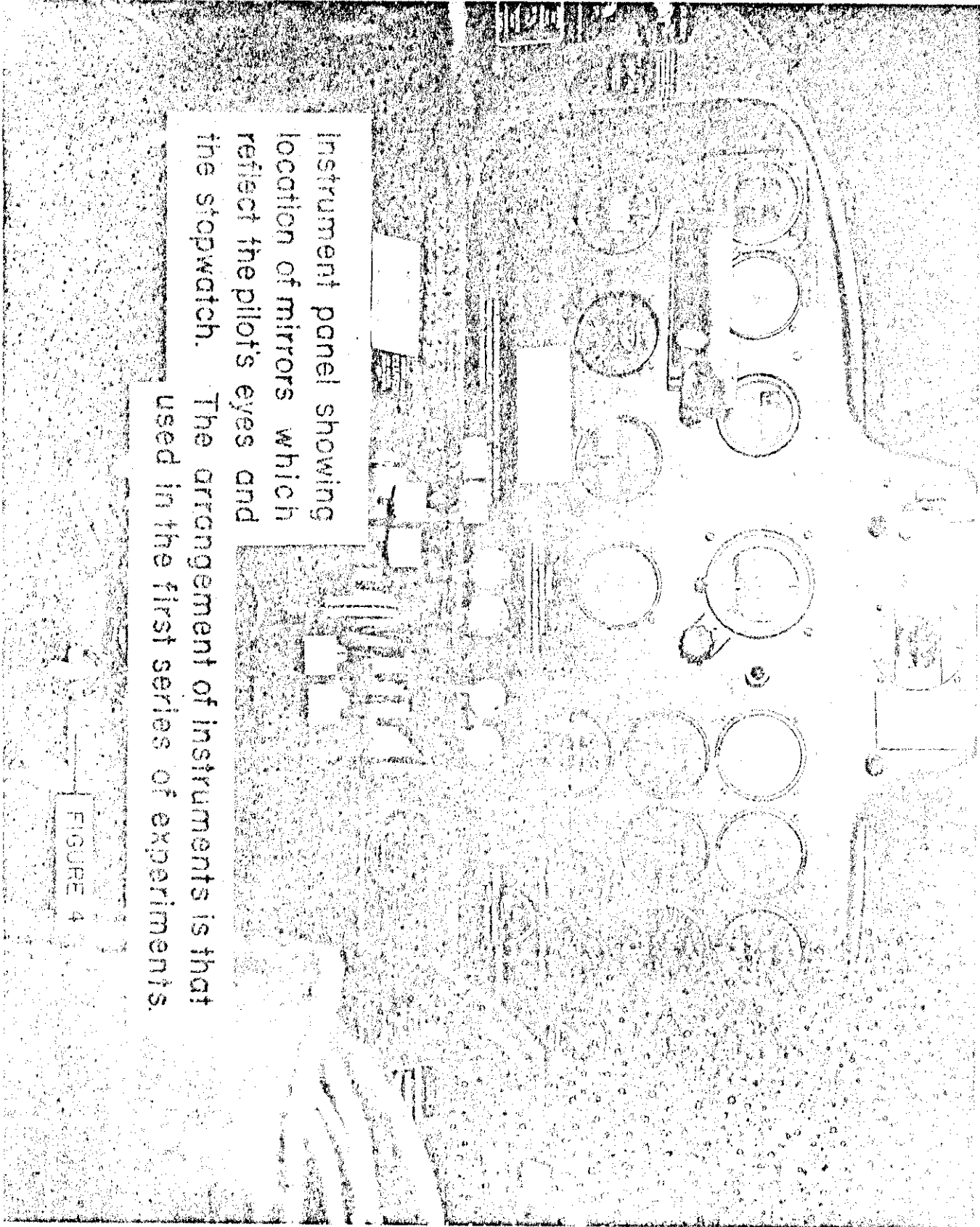
It can be seen from Tables I, II, and III that there were very large differences in the amount of time devoted to each instrument. This time varied from roughly 25 percent to 3 percent for different instruments. The two groups of pilots emphasized different instruments. The group of Air Force pilots, for example, watched air speed more than the Navy pilots, while the latter watched the attitude gyro more than did the former. Such differences are to be expected in view of the different training of the two groups. The average length of fixation was approximately one-half second. Further reference will be made to these data in discussing the results obtained in the present studies.

#### IV. APPARATUS AND PROCEDURE EMPLOYED IN THE PRESENT SERIES OF INVESTIGATIONS OF EYE MOVEMENTS.

In recording a pilot's eye movements during instrument flight it is essential that no artificial restriction be imposed that might change the nature of his eye movements or interfere with his control of the aircraft. For this reason any recording apparatus that immobilizes a pilot's head is unsatisfactory. This fact rules out the use of most of the standard eye movement cameras that employ a beam of light reflected from the cornea of the eye. It also renders impractical the use of electrical recordings of muscle action potentials or of retinal polarity, since these records cannot be interpreted if the pilot moves his head during the period of recording. It is highly desirable that any equipment used permit the recording of eye movements in the air for relatively long periods of time without landing. Ease of installation and suitability for use in various types of aircraft are further considerations in the choice of apparatus.

In view of these requirements it seems best to photograph directly the pilot's head and eyes as reflected in a small mirror located on the instrument panel. The apparatus used in the present series of investigations includes the following components: (1) a 35-millimeter motion picture camera with an F-8 lens and a magazine capacity of 400 feet of film, (2) a small (approximately 1 1/2 by 5 1/2 inches) mirror which is mounted on the aircraft instrument panel, (3) a specially devised blind flying hood for excluding the pilot's vision outside





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.

FIGURE 4

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the cockpit and (4) a stopwatch which is photographed in the same frames that show the position of the eyes. The major problem encountered in mounting the camera in the aircraft is vibration. After trying various special mounting arrangements, it was discovered that vibration is minimized by mounting the camera on a conventional wooden tripod that is secured to the deck of the aircraft by a quick release mechanism (see Figure 3). This arrangement allows the cameraman easy access to his equipment for focusing, changing film, etc.

The mirror used to reflect the pilot's eyes is mounted on the instrument panel. The arrangement used in several studies is shown in Figure 4. In this case the location is approximately in the center of the flight instrument group midway between the top and bottom rows of instruments. The angle of the mirror can be adjusted in two dimensions until the pilot's eyes are reflected directly into the camera.

In order to simulate instrument flight it is necessary to limit the pilot's vision to the inside of the cockpit. Meanwhile it is desirable to permit as much light as possible to enter the cockpit in order to obtain good photographs. The device finally selected as meeting both these conditions is worn on the pilot's head. It resembles a welder's shield and consists of a strip of sandblasted plexi-glass attached to a tight fitting harness. The shield can be adjusted so that the pilot is able to see all the aircraft instruments but is unable to see outside the cockpit unless he tilts his head back in a very awkward manner. Since no obstruction is placed on the windshield, this arrangement permits the safety pilot maximum visibility. A view of the pilot seated in the aircraft and wearing this special blind flying hood is shown in Figure 5. The camera and the mirror on the panel can also be seen in this photograph. The motion picture camera is located slightly behind and to one side of the pilot, just above shoulder height.

The stop watch is mounted near the pilot's head at the same distance from the camera lens as the pilot's face and is reflected in a small mirror placed next to the one that provides the reflection of the pilot's eyes. Since the stopwatch appears on each frame of exposed film, it is possible to determine to the nearest tenth of a second the interval covered by any period of photography and to calculate a time value which can be assigned to each frame. Such a timing procedure is necessary because of variability in camera speed due to changes of temperature and other uncontrollable factors during flight.

The initial series of studies was conducted in a C-45 type aircraft in which the manufacturer's instrument panel was replaced by one on which the instruments were arranged in accordance with USAF Technical Order No. 01-1-160. The instrument lay-out specified in this Technical Order represents the "standard" Air Force Instrument Panel arrangement in use at the time the experiment was conducted. This instrument panel is shown in Figure 4. Later studies have been conducted with other instrument-panel arrangements.

ARRANGEMENT OF EXPERIMENTAL EQUIPMENT IN THE COCKPIT

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



FIGURE 5

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## V. FLIGHT PROCEDURES

Before takeoff the following standard instructions are read to each pilot who serves as a subject in the investigations:

"The flight we are about to make is for the purpose of photographing your eye movements during various maneuvers while flying on instruments. It is not a "check" in any sense of the word and your name will not be connected with the data that are collected. We believe that the information obtained will be valuable in the design of new instruments, the arrangement of instruments on the panel, and perhaps the development of new techniques for instrument flying.

"The safety pilot will make the take-off and climb to the assigned altitude. At this time you will change to the pilot's seat and the hood, mirror, and camera will be properly adjusted. Then, we will take some pictures of your eyes while you are looking at the various flight instruments. These photographs are used as 'calibration samples' in scoring the records that are taken during the flight."

At this point the pilot is told what maneuvers he is to fly. The instructor pilot then adds:

"Your task will be to fly the aircraft as you normally would during an actual instrument flight. Records may not be taken of complete maneuvers but only for a part of each maneuver. It is likely that you will not know when we are photographing. For that reason it is important that once a maneuver is started you do not move your head other than the amount you would normally move it to see all of the instruments. This is so that your eyes will be in the range of the camera at all times. Further instructions will be given in the air before each maneuver."

In all cases the take-off is made by the safety pilot. When the assigned altitude is reached the subject is instructed to change to the pilot's seat and to adjust the hood. At this time reference photographs are taken with the pilot looking at each instrument in turn. These sample photographs are labeled by photographing the name of the instrument at which the pilot is looking. Typical photographs of a pilot looking at three different flight instruments are shown in Figure 6. These photographs of reference fixations are made into slides that can be compared with any questionable fixations during the scoring of the actual record of the pilot's eye movements.

## VI. PROCEDURE EMPLOYED IN ANALYZING FILM RECORDS

The records obtained are analyzed in the following manner.<sup>1</sup> The time (on the stopwatch) is noted at the beginning of the film strip and at the

<sup>1</sup> The method described has been developed after considerable experience and is recommended for use by others. Minor variations of this method were used in early studies in the series.



AIR SPEED INDICATOR



VERTICAL SPEED INDICATOR



GYRO HORIZON

Three frames of photography reproduced from the film recording of one subject's eye movements to illustrate the ease with which the instrument the pilot is fixating can be determined.

FIGURE 6

end of the film strip. The number of frames in the strip is counted and the amount of time to be assigned to each frame is calculated. The film scorer, using a Moviola, examines each frame of photography and determines the instrument on which the pilot was fixating when that frame was exposed. In cases where the film reader is uncertain as to what instrument the pilot is looking at, the film reader refers to the slide which has been made from the reference fixation photographs of each pilot for each instrument. These slides are arranged on a viewer located adjacent to the Moviola so that it is easy to select the reference slide that matches the test frame. The film reader counts and records the number of frames comprising each fixation and records the instrument on which that fixation was made. Eye blinks, when shown on the test film, are noted in the scoring. If a blink occurs during the fixation on an instrument the sequence is recorded as a single fixation and a single blink. However, most blinks occur between fixations. If the pilot looks about the cockpit this also is noted.

The camera speed of 8 frames per second was selected because it was felt that eye fixations of less than  $1/8$  second would occur very infrequently, and that most fixations would be considerably longer. In those infrequent cases when a particular eye-position is recorded on a single frame of photography this single-frame record is treated in the same manner as a fixation lasting through several frames.

All eye fixations that cannot be assigned by the film readers to a particular instrument are classified in a miscellaneous category. Eye-blinks that occur between fixations and fixations on other parts of the cockpit are examples of data that must be so classified.

In Figure 6 is shown a sample of the type of record provided by this scoring method. It will be noted that this record provides data on the frequency, the duration, and the sequence of eye fixations.

In order to insure basic accuracy each section of film is read independently by two different persons. The individual readings are then compared to determine the number of frames read identically. All frames on which the two readers do not agree are marked. Both scorers, working together, check each film and attempt to reach agreement on as many of their former differences as possible. Any film record is discarded if the photography is so poor that after re-examination there is not at least 95 percent agreement.

## VII. RELIABILITY OF THE SCORING PROCEDURE

An exacting test of the reliability of the film-analysis procedure is the percentage of frames of film that are read identically by two scorers working independently. The results of several completed studies provide data for this test of reliability. The first records scored were the ILAS approaches of 40 pilots. Of these, 91 percent of a total of over 40,000 frames was read identically by two different scorers. Most of

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Subject: "K" Page 2 of 2  
 Maneuver: 125 #1, Middle Marker Scored by: QJM  
 Beg. time: 4.4 End. time: 37.3 Time/frame: .140

x/pt.	a/s.	d/g.	g/h.	alt.	t/b.	v/s.	e/l.	misc.	total frames	
6								Blink	6	
			3						1	
		4							3	
7									4	
		3							7	
3									3	
				3					3	
4									3	
	3	4							4	
4									4	
		3							3	
			4						4	
	2							Radio Comp.	2	
				2					2	
6									2	
					2				6	
								1	1	
									2	
3								1	1	
		3							3	
			3						3	
								Blink	3	
4									1	
	1								4	
									1	
		4					5		5	
5									4	
			4						5	
4									4	
			4						4	
									4	
<b>Totals:</b>	108	15	54	34	5	2	6	5	7	236
frames	26	6	16	10	2	1	2	1	6	70
fixations	4.15	2.50	3.88	3.40	2.50	2.00	3.00	5.00	1.17	3.87
length fix. (in sec.)	.58	.35	.47	.48	.35	.29	.42	.70	.16	.47

43

Totals:

frames  
 fixations  
 length fix.  
 (in sec.)

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Part of one subject's eye movement record illustrating the manner in which fixations and frames per fixation on each instrument are recorded. [REDACTED]

USAF-TR-5837 [REDACTED] FIGURE 7 [REDACTED]

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the disagreement between scorers involved the records of a few pilots whose eye photographs were not as clear as would have been desirable. In a 1,500 frame sample selected at random from the records of 40 pilots who performed maneuvers at altitude, 95 percent of the frames were read identically.

Another indication of reliability is the correlation between various average scores obtained by the two film readers. These coefficients are summarized in Table IV which shows the extent of agreement before re-examination of the film.

It can be noted from Table IV that the reliability of scoring for number of fixations per minute is generally higher than for the average duration of the fixation cycles. Determination of the number of fixations is the simpler of the two scoring operations. The lower reliability of fixation cycle data is probably a function of the additional possibilities for errors (differences between the two readers) in counting the number of frames per fixation and in rounding during the calculations which must be made in arriving at length of fixation. As would be expected, the reliability coefficients are highest for the most frequently checked instrument (cross-pointer) and lowest for the least frequently checked instrument (turn and bank indicator).

Considering the data on number of fixations per minute during ILAS approaches, the reliability coefficients are 0.97 or above for the three instruments on which pilots spend more than 80 percent of their total time (cross-pointer, directional gyro and gyro horizon), and 0.80 or above for all instruments except the one on which they spend less than 1 percent of their total time (turn and bank indicator).

Considering the data on length of fixation cycle during ILAS approaches, the reliability coefficients are 0.89 or above for the two instruments on which pilots spend 66 percent of their total time (cross-pointer and directional gyro) and 0.67 or above for all instruments except the one on which they spend less than 1 percent of the total time (turn and bank indicator).

The scoring of single frames of photography is an especially troublesome item and a probable source of some unreliability. Despite identical training procedures, some film readers tend to assign most single frames to the miscellaneous category, others tend to assign them to particular instruments. However, single frames occur infrequently and their scoring has only a small bearing on overall results.

When the results obtained by two independent readers are compared on the basis of instruments ( $N = 8$ ) instead of subjects ( $N = 40$ ) the coefficients of correlation between the two sets of data are very high. The correlation between average length of fixation on the eight instruments, as determined by the two readers, is 0.991, and between average number of fixations per instrument is 0.999. From this it can be concluded that,



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TABLE IV

Reliability (Correlation) Coefficients for the Independent Results  
Obtained by Two Recorders Scoring Eye Movement Records of Pilots  
Flying Landing Approaches Under Simulated Instrument Conditions.  
Two Minutes of Film Record Were Secured on Each of 40 Pilots.

*Test Approaches*

<u>Instrument</u>	<u>Average</u> <u>No. of fixations per min.</u>	<u>Average</u> <u>Length of fixation</u>
Cross-pointer	.98	.99
Directional Gyro	.97	.89
Gyro Horizon	.98	.69
Air Speed Indicator	.80	.67
Altimeter	.86	.71
Turn and Bank Indicator	.53	.39
Vertical Speed Indicator	.93	.72
Engine Instrument Panel	.80	.72
Miscellaneous Category	.93	.69
All Instruments (Combined)	.96	.96

# Contrails

provided the interest of the experiment is in a comparison of instruments, rather than in a comparison of individual pilots, a representative sample of considerably less than 40 pilots will probably be adequate and the present film-analysis procedures will be entirely satisfactory.

The general conclusion regarding the reliability of the film reading procedure is that it is adequate for the purposes of the present series of investigations.

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