College Note No. 26

THE COLLEGE OF AERONAUTICS

CRANFIELD

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INVESTIGATION OF EYE MOVEMENTS OF AN AIRCRAFT PILOT UNDER BLIND APPROACH CONDITIONS

by

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SUMMARY

Eye movement patterns were obtained of a pilot in an aircraft fitted with a standard R.A.F. blind flying panel on several approaches under Standard Beam Approach conditions.

These patterns were obtained by photographing the reflection of the pilot's eyes in a mirror attached to the instrument panel.

The results show the

(1) Proportion of time spent on each instrument,
(2) Duration of the fixation time on each instrument,
(3) Frequency of the eye fixations,
(4) Sequence of eye movements.

It was originally intended to investigate the eye movements on an I.L.S. approach using the Zero Reader and I.L.S. Cross Pointer independently. Unforseen difficulties and delays, however, prevented the completion of this part of the investigation.

This Note is based on a thesis submitted by A.F.A. Watts in partial fulfillment of the requirements for the Diploma of the College of Aeronautics.

MEP

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1. Introduction

One of the greatest problems of commercial and military aviation is the landing of aircraft on a given airfield under unfavourable weather conditions.

The problem of visibility affects all forms of transportation to some degree, but unlike surface vehicles, an aircraft is compelled to land regardless of weather conditions after a specific time.

This landing procedure is performed by pilots with the assistance of various radio and radar aids, but it must be emphasised that it is the pilot who lands the aircraft and not the equipment, however good it may be.

No effort has been spared to ensure wherever possible that the pilot has at his disposal the latest and most reliable navigational aids in order to make his work less arduous and complex.

Several attempts have been made to land an aircraft solely with the use of radio and servo mechanisms, and in one case the Atlantic Ocean was crossed successfully by an aircraft taking off and landing without any human actuation of the controls. While this was a remarkable feat it has a limited scope at present due to the bulkiness of the equipment required.

It may be accepted that the equipment available to the pilot for navigation and blind approaches is technically sound and functions consistently well providing the equipment is adequately maintained.

A problem still remains, however, in ensuring that the individual flying the aircraft functions as consistently and as well.

Most commercial pilots and certainly all service pilots have been trained to fly to a strict and rigorous training programme in an attempt to eliminate inconsistencies as far as possible.

Each pilot will, however, tend to fly an aircraft either visually or by instruments according to his own particular style, and the differences between trained pilots may even be apparent and measureable.

When flying under visual flight rules these differences may be ignored but when flying under instrument flight rules, any idiosyncrasy, especially on an approach, may have a disastrous effect.

/The ...

The physiological and psychological reactions of human beings while flying have received considerable attention at the R.A.F. Institute of Aviation Medicine, the U.S.A. Air Materiel Command and the Applied Psychology Unit at Cambridge.

The need for instruments which can convey the correct information in the shortest time has been realised by the instrument manufacturers, but it is very doubtful if aircraft designers seriously consider the movements of pilots' eyes when arranging instruments on the instrument panel.

It is felt that consideration should be given to the link values of eye movement between instruments for all critical manoeuvres before deciding on a new instrument layout.

2. Description of Procedure for Recording Eye Movements

(a) Selection of Procedure

The method selected in this investigation was that suggested by Dodge and Cline, that is by direct photography of the eyes.

This method is comparatively simple and is adequate for such cases where there is no necessity to record such small eye movements as 10 minutes of arc.

Because of the difficulty in mounting a camera directly in front of the pilot, the reflection of the pilot's eyes in a mirror was photographed.

No trouble was experienced from vibration in the particular aircraft used for the investigations and the photographs were quite sharp.

Alternative methods of measuring eye movements are given in Appendix 1.

(b) Aircraft and Equipment

An Anson Mk 1 was fitted with an R.A.F. standard blind flying panel as shown in Fig. 1.

A mirror to reflect the pilot's eyes was mounted on the inside of the cowling above and to the left of the blind flying panel and adjusted so that the pilot's eyes were reflected directly into the camera.

/Fig. 3 ...

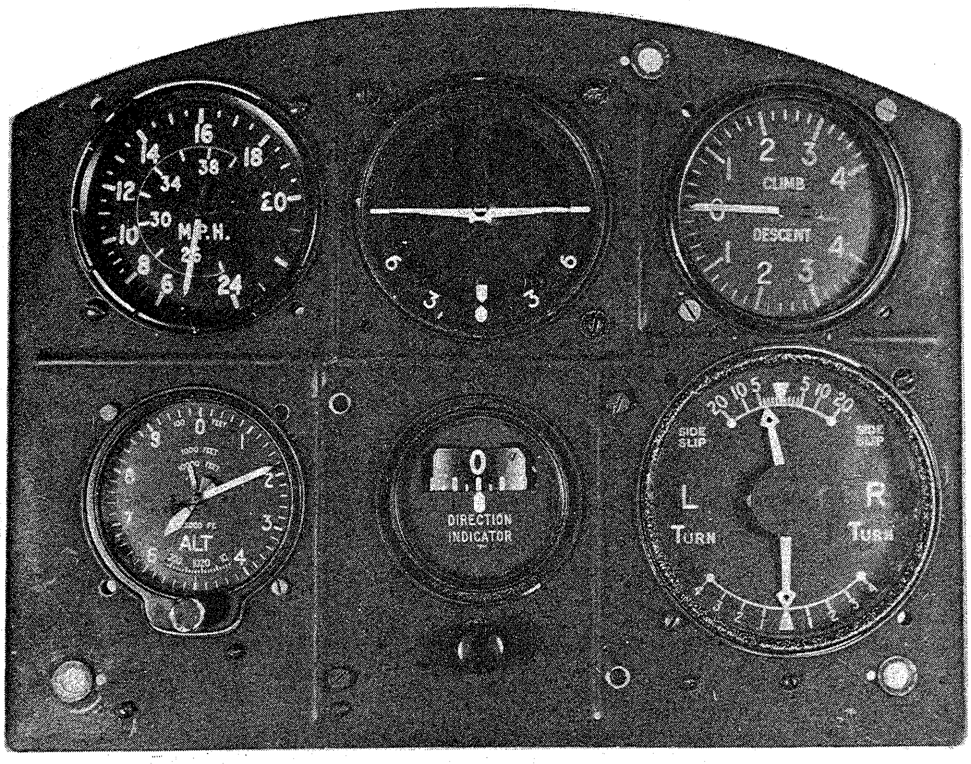


FIGURE 1. R. A. F. STANDARD BLIND FLYING PANEL

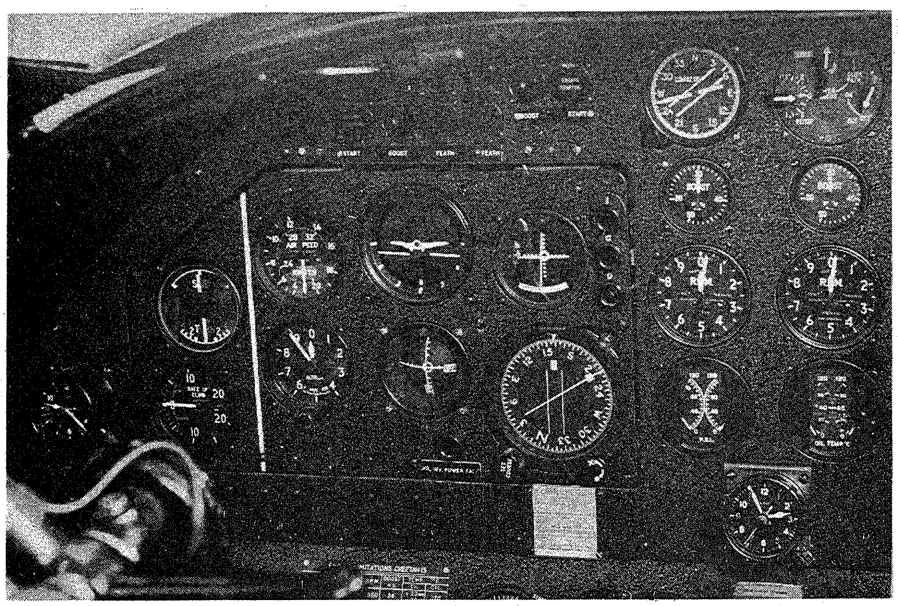


FIGURE 2. B. O. A. C. AND B. E. A. PANEL

Fig. 3 shows a view of the pilot with the mirror in position, and Fig. 4 shows the mounting of the camera.

The camera, a Paillard Bolex 16 mm. ciné camera fitted with a 3 inch f 3.5 Dallmeyer telepho lens, was fixed on a tripod between the main and rear spars.

The tripod was mounted on three floor brackets and tied down to the floor with bunjy to a central bracket.

It was originally intended that the floor brackets for the tripod should contain hard rubber inserts to eliminate vibration during flight. These inserts were eventually removed however, because although the rubber served as an excellent shock absorber, it did not eliminate the vibration, on the contrary it enhanced it considerably.

In order to simulate blind approach conditions without restricting the photography of the eyes, the pilot was fitted with a hood similar to an arc welder's shield.

The hood comprised a wire frame attached to the helmet and covered with fabric, and was adjusted so that the pilot could see all the aircraft instruments without difficulty. Any attempt on the part of the pilot to see outside the cockpit would result in the head having to be tilted in a very awkward manner.

It was found that there was no necessity for artificial lighting inside the cockpit, and although the photography took place on a dull morning with overcast sky there was sufficient light available to photograph with a stop of f 5.6 at a speed of 10 frames per second.

Kodak Super XX panchromatic reversible ciné film was used having a Scheiner of 32°.

(c) Flight Procedure

Five runs were made on the Standard Beam Approach (S.B.A.) under simulated instrument conditions and a photographic record was made of the pilot's eye movements.

A description of the Standard Beam Approach is given in Appendix II.

The Bolex ciné camera was started at a speed of 10 frames per second as the aircraft passed over the Outer Marker and a continuous record of the eye movements was taken until the aircraft passed over the Inner Marker, a distance of 9,250 feet and a flying time of approximately 70 seconds.

/It was ...

FIGURE 3. VIEW SHOWING MOUNTING OF MIRROR AND PILOT FITTED WITH HOOD

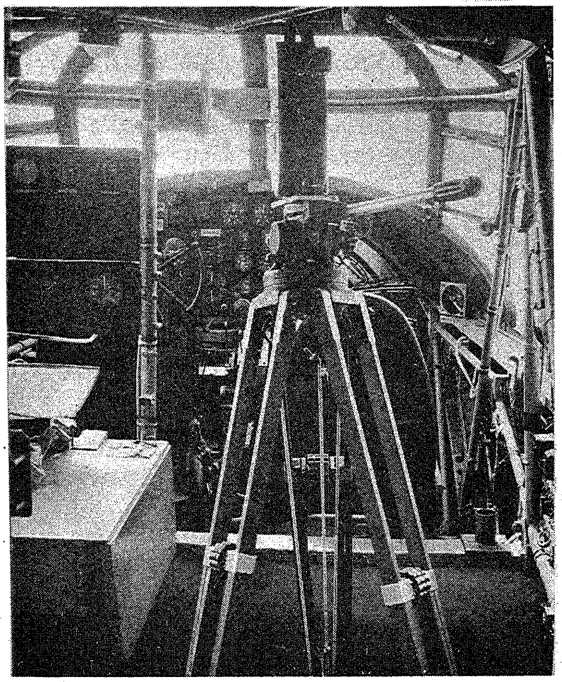


FIGURE 4. VIEW SHOWING AXING OF CAMERA IN AIRCRAFT

It was found necessary from safety considerations to fly with a safety pilot as other low flying aircraft were often in the vicinity.

(d) Film Analysis

For analysing the film frame by frame a small Specto projector was used.*

Before the flights commenced, sample frames were taken of the eye positions of the pilot when looking at each of the specific flight instruments.

These frames constituted a series of instrument location reference photographs.

Two projectors were set up, adjacent to each other, one projecting the reference photographs and the other the film taken in flight. Each frame was then examined and compared with the reference photographs to determine which instrument was being viewed, the time base being obtained by counting the frames.

3. Results of Film Analysis

(a) Proportion of time spent on each instrument

The two instruments on which most time was spent were the Artificial Horizon and the Air Speed Indicator. For the five flights the average time spent on both these instruments comprised 62 per cent of the total time.

Although the general patterns of the proportions were similar on the individual flights, there were appreciable variations in the cases of some of the instruments.

In flight 1 the proportion of time spent on the Air Speed Indicator was as high as 42.4 per cent at the expense of the Artificial Horizon, but this dropped in flight 2 and remained substantially constant for the other flights.

The reason for this high proportion in the first flight is not clear. It may have been due to the pilot feeling his way or more probably that the pilot was accustomed to flying aircraft that were undergoing some form of flight test where it is imperative that the air speed should be consistent.

/In flight ...

* A suitable projector with a counter fitted to enable the number of frames to be read directly is now manufactured by the Specto Company of Windsor.

In flight 2 more time was spent on the Rate of Climb indicator than in the other four flights.

This may have been due to a bumpy approach where the rate of descent changed with each bump, although this would seem unlikely as all the observations were completed in one hour and the other flights do not seem to be similarly affected.

Table I gives the proportion of time spent on each instrument for each flight, and also the averages for the five flights.

Fig. 5 shows the results in graphical form.

Table II gives the analysis on the basis of seven periods of ten seconds duration during each flight.

In flight 1 it will be noticed that there is a tendency for the time spent on the Air Speed Indicator to increase during the flight, while in Flight 5 there was a tendency to decrease. No such trends occurred in the other flights.

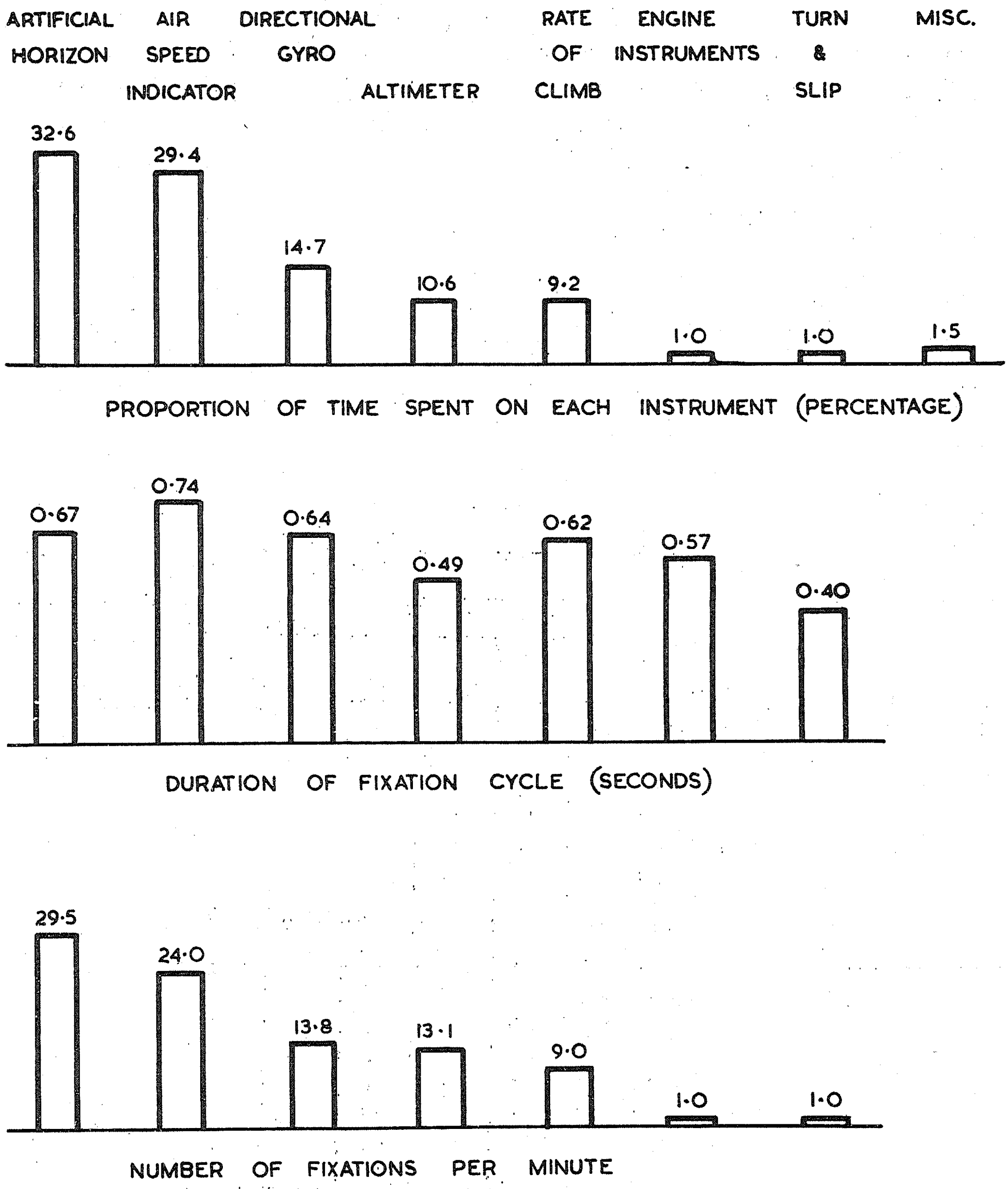
TABLE I

Proportion of Time Spent on Each Instrument

(1 Frame = 1/10 second)

INSTRUMENT	FLIGHT 1		FLIGHT 2		FLIGHT 3		FLIGHT 4		FLIGHT 5	
	No. of frames	%	No. of frames	%	No. of frames	%	No. of frames	%	No. of frames	%
HOR	173	25.0	261	37.4	224	31.8	245	35.2	235	33.8
ASI	293	42.4	185	26.4	172	24.4	214	30.8	166	23.9
D/G	77	11.1	56	8.0	142	20.1	96	13.8	144	20.7
Alt	78	11.2	41	5.9	87	12.3	81	11.6	85	12.2
R/C	26	3.8	137	19.6	63	8.9	45	6.5	52	7.5
ENG.	11	1.6	8	1.1	5	0.7	6	0.9	4	0.6
T/S	12	1.7	4	0.6	4	0.5	2	0.3	2	0.3
MISC.	22	3.2	7	1.0	9	1.3	6	0.9	7	1.0
	692	100.0	699	100	706	100	695	100	695	100

/AVERAGE ...



PROPORTION OF TIME, DURATION, & FREQUENCY OF FIXATIONS ON AIRCRAFT INSTRUMENTS.

(AVERAGES OF 5 FLIGHTS) FIG. 5.

AVERAGE OF FIVE FLIGHTS

INSTRUMENTS			PERCENTAGE
HOR	-	Artificial Horizon	32.6
ASI	-	Air Speed Indicator	29.4
D/G	-	Directional Gyro	14.7
Alt	-	Altimeter	10.6
R/C	-	Rate of Climb Indicator	9.2
ENG	-	Engine Instrument	1.0
T/S	-	Turn and Slip Indicator	1.0
MISC	-	Miscellaneous (blinking, etc.)	1.5
			100.0

TABLE II

TIME SPENT ON EACH INSTRUMENT

(In periods of 10 secs. duration of flight)

	PERIOD 10 sec. intervals	NUMBER OF FRAMES (1 Frame = 1/10 sec.)								
		HOR	ASI	D/G	Alt	R/C	ENG	T/S	MISC.	TOTAL
FLIGHT 1	1	23	38	15	8	7	0	9	0	100
	2	26	36	13	11	5	7	0	2	100
	3	24	47	14	7	0	0	0	8	100
	4	22	31	19	11	10	4	0	3	100
	5	32	44	5	12	0	0	3	4	100
	6	30	44	7	14	0	0	0	5	100
	7	16	53	4	15	4	0	0	0	92
	TOTAL	173	293	77	78	26	11	12	22	692
FLIGHT 2	1	64	10	5	3	6	8	4	0	100
	2	41	33	3	6	17	0	0	0	100
	3	31	31	6	12	20	0	0	0	100
	4	35	33	11	5	14	0	0	2	100
	5	39	27	13	0	21	0	0	0	100
	6	24	22	13	0	41	0	0	0	100
	7	27	29	5	15	18	0	0	5	99
	TOTAL	261	185	56	41	137	8	4	7	699
FLIGHT 3	1	29	26	14	15	16	0	0	0	100
	2	44	11	28	13	4	0	0	0	100
	3	40	28	22	3	0	5	0	2	100
	4	19	22	19	18	18	0	4	0	100
	5	30	26	30	2	12	0	0	0	100
	6	34	38	10	16	0	0	0	2	100
	7	27	21	14	20	13	0	0	5	100
		1		5						6
	TOTAL	224	172	142	87	63	5	4	9	706

TABLE II (Continued)

TIME SPENT ON EACH INSTRUMENT
(In periods of 10 secs. duration of flight)

	PERIOD 10 secs. intervals	NUMBER OF FRAMES (1 Frame = 1/10 sec.)								
		HOR	ASI	D/G	Alt	R/C	ENG	T/S	MISC.	TOTAL
FLIGHT 4	1	32	31	19	16	0	0	0	2	100
	2	37	34	8	10	11	0	0	0	100
	3	35	16	31	2	16	0	0	0	100
	4	32	30	5	11	14	6	0	2	100
	5	33	26	15	21	1	0	2	2	100
	6	20	43	18	16	3	0	0	0	100
	7	56	34	0	5	0	0	0	0	95
	TOTAL	245	214	96	81	45	6	2	6	695
FLIGHT 5	1	30	31	13	13	8	1	2	2	100
	2	31	29	18	13	3	3	0	3	100
	3	34	30	22	14	0	0	0	0	100
	4	26	30	17	11	16	0	0	0	100
	5	43	14	27	6	10	0	0	0	100
	6	40	14	14	24	8	0	0	0	100
	7	31	18	33	4	7	0	0	2	95
	TOTAL	235	166	144	85	52	4	2	7	695

/(b) ...

(b) Duration of eye fixations

The duration of a fixation cycle has been taken as the time required to move the eyes to the instrument plus the time spent in looking at the instrument before the eyes make the next movement.

Table III gives the average durations of the fixations for each flight and the average for five flights while Fig. 5 shows the results in chart form.

The instrument with the longest fixation time was the Air Speed Indicator with 0.74 second, while the Artificial Horizon, Direction Gyro, and Rate of Climb Indicator followed closely with 0.67, 0.64 and 0.62 seconds respectively.

It may be of interest to note that the fixation times for the Altimeter and Turn and Slip Indicator are substantially lower than for the other instruments.

(c) Frequency of eye fixations

The number of fixations per minute of flight for each instrument is shown in Table IV and the averages for five flights are also shown in chart form in Fig. 5.

From Fig. 5 it is seen that the Artificial Horizon, the instrument on which most time was spent, also had the largest number of fixations per minute, although the duration of fixations was lower than that of the Air Speed Indicator.

From Table IV it is seen that a fairly constant pattern was followed in flights 3,4, and 5.

Table I shows that the proportion of time spent on the Artificial Horizon in flight 1 was lower than in the other flights. The number of fixations per minute for this instrument however was highest in this flight (Table IV) and the duration of fixation the lowest (Table III).

(d) Link values between instruments

Table V is an analysis on a sequential basis of the number of eye movements occurring between the various combinations of two instruments.

/Table III ...

TABLE III

AVERAGE DURATION OF EYE FIXATIONS

INSTRUMENT	FLIGHT 1		FLIGHT 2		FLIGHT 3		FLIGHT 4		FLIGHT 5	
	No. of Fix.^{n}	Av. per Fix.^{n}	No. of Fix.^{n}	Av. per Fix.^{n}	No. of Fix.^{n}	Av. per Fix.^{n}	No. of Fix.^{n}	Av. per Fix.^{n}	No. of Fix.^{n}	Av. per Fix.^{n}
ASI	35	0.84	27	0.68	24	0.72	27	0.79	26	0.64
HOR	37	0.46	31	0.84	33	0.68	34	0.72	36	0.65
D/G	14	0.55	12	0.47	17	0.83	15	0.64	22	0.65
R/C	5	0.64	21	0.65	7	0.90	8	0.56	11	0.47
ENG	2	0.55	1	0.80	1	0.50	1	0.60	1	0.40
Alt	19	0.41	10	0.41	17	0.51	14	0.58	16	0.53
T/S	2	0.60	1	0.40	1	0.40	1	0.20	1	0.20
	114		103		100		100		113	

AVERAGE OF FIVE FLIGHTS

INSTRUMENTS			No. of Fixations	Average Time per Fixation (secs)
ASI	-	Air Speed Indicator	139	0.74
HOR	-	Artificial Horizon	171	0.67
D/G	-	Directional Gyro	80	0.64
R/C	-	Rate of Climb Indicator	52	0.62
ENG	-	Engine Instrument	6	0.57
Alt	-	Altimeter	76	0.49
T/S	-	Turn and Slip Indicator	6	0.40
			530	

/Table IV ...

TABLE IV

NUMBER OF FIXATIONS PER MINUTE

INSTRUMENT	FLIGHT 1		FLIGHT 2		FLIGHT 3		FLIGHT 4		FLIGHT 5	
	No. of Fixa-tions	No. per min.	No.of Fixa-tions	No. per min.	No.of Fixa-tions	No. per min.	No.of Fixa-tions	No. per min.	No.of Fixa-tions	No. per min.
HOR	37	32.0	31	26.6	33	22.6	34	29.3	36	31.0
ASI	35	30.3	27	23.1	24	20.4	27	23.3	26	22.4
D/G	14	12.1	12	10.3	17	14.4	15	12.9	22	19.0
Alt	19	16.5	10	8.6	17	14.4	14	12.1	16	13.8
R/C	5	4.3	21	18.0	7	5.9	8	6.9	11	9.5
ENG	2	1.7	1	0.9	1	0.8	1	0.7	1	0.9
T/S	2	1.7	1	0.9	1	0.8	1	0.7	1	0.9
	114	98.6	103	88.4	100	79.3	100	85.9	113	97.5

AVERAGE OF FIVE FLIGHTS

INSTRUMENT		No. of Fixations	No. of Fixations per minute
HOR	- Artificial Horizon	171	29.5
ASI	- Air Speed Indicator	139	24.0
D/G	- Directional Gyro	80	13.8
Alt	- Altimeter	76	13.1
R/C	- Rate of Climb Indicator	52	9.0
ENG	- Engine Instrument	6	1.0
T/S	- Turn and Slip Indicator	6	1.0
		530	91.4

/Table V ...

TABLE V

SEQUENCE OF EYE MOVEMENTS

INSTRUMENTS	FLIGHTS 1	2	3	4	5	Total of 5 Flights
ASI-HOR	25	17	15	15	20	92
HOR-ASI	17	16	16	15	10	74
HOR-D/G	11	8	7	7	15	48
Alt-ASI	12	4	5	9	10	40
D/G-HOR	6	4	9	9	11	39
HOR-Alt	7	3	8	5	4	27
ASI-Alt	8	2	6	7	3	26
HOR-R/C	3	4	3	7	6	23
R/C-HOR	2	8	3	5	2	20
Alt-HOR	3	1	6	5	3	18
R/C-ASI	1	6	0	1	4	12
D/G-R/C	1	5	2	1	3	12
ASI-D/G	3	0	3	5	1	12
D/G-Alt	2	2	1	0	6	11
D/G-ASI	3	1	3	2	2	11
ASI-R/C	1	9	0	0	1	11
R/C-D/G	0	4	2	2	2	10
Alt-D/G	0	0	4	1	4	9
R/C-Alt	1	3	2	0	2	8
ASI-ENG	0	1	0	1	1	3
Alt-R/C	0	2	1	0	0	3
T/S-R/C	0	0	1	0	1	2
ENG-Alt	0	0	0	1	1	2
D/G-T/S	0	0	1	1	0	2
T/S-Alt	1	0	0	1	0	2
HOR-T/S	0	1	0	0	0	1
ASI-T/S	1	0	0	0	1	2
Alt-T/S	1	0	0	0	0	1
Alt-ENG	1	0	0	0	0	1
D/G-ENG	1	0	0	0	0	1
T/S-ASI	1	0	0	0	0	1
T/S-HOR	0	1	0	0	0	1
ENG-ASI	1	0	0	0	0	1
ENG-HOR	1	0	0	0	0	1
ENG-D/G	0	0	1	0	0	1
ENG-R/C	0	1	0	0	0	1
HOR-ENG	0	0	1	0	0	1
	114	103	100	100	113	530

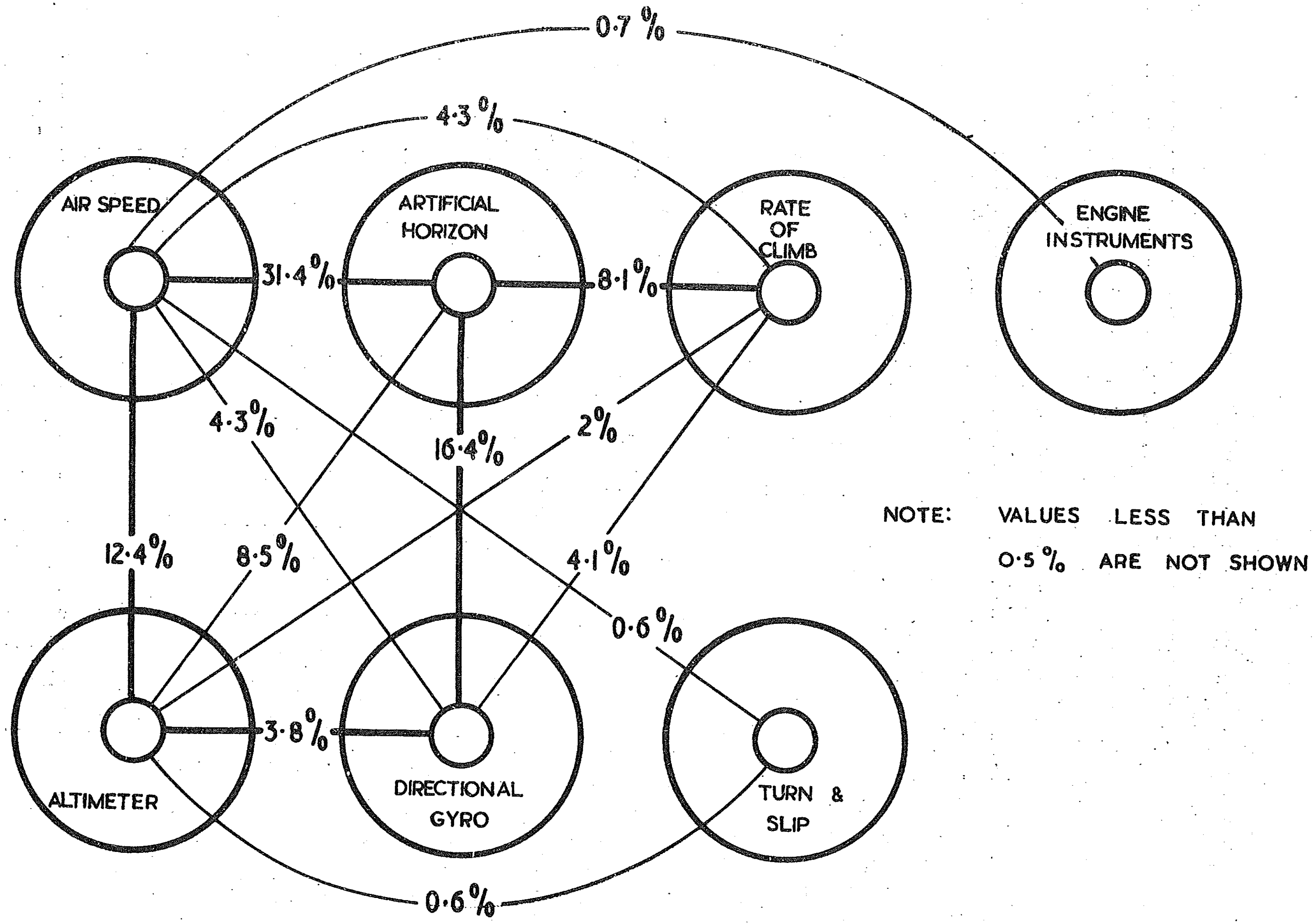
The movements most frequently occurring were those between the Air Speed Indicator and the Artificial Horizon, a total of 92 movements during the five flights. Next in order of magnitude were the movements from the Artificial Horizon to the Air Speed Indicator with 74 occurrences.

From Table V the link values between the various combinations of two instruments have been compiled and are given in Table VI.

A link value between any two instruments is the total number of times that eye movements occurred between the two instruments. For example in flight 1 the number of movements between the Air Speed Indicator and the Artificial Horizon was 25, and from the Artificial Horizon to the Air Speed Indicator 17, so that the link value between these two instruments is taken as the sum of these movements, i.e. 42.

The relative link values are shown in Fig. 6 expressed as a percentage average for five flights, from which it is seen that the instruments with the highest link values are the Air Speed Indicator and the Artificial Horizon with a percentage of 31.4.

/Table VI ...



EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS ON STANDARD BEAM APPROACH

(MEAN OF 5 FLIGHTS)

FIG. 6.

TABLE VI

LINK VALUES BETWEEN INSTRUMENTS

	Number of Fixations						
	FLIGHTS					Total of 5 Flights	Percentage of Total
	1	2	3	4	5		
ASI-HOR and HOR-ASI	42	33	31	30	30	166	31.4
HOR-D/G and D/G-HOR	17	12	16	16	26	87	16.4
Alt-ASI and ASI-Alt	20	6	11	16	13	66	12.4
HOR-Alt and Alt-HOR	10	4	14	10	7	45	8.5
HOR-R/C and R/C-HOR	5	12	6	12	8	43	8.1
R/C-ASI and ASI-R/C	2	15	0	1	5	23	4.3
D/G-R/C and R/C-D/G	1	9	4	3	5	22	4.1
ASI-D/G and D/G-ASI	6	1	6	7	3	23	4.3
D/G-Alt and Alt-D/G	2	2	5	1	10	20	3.8
R/C-Alt and Alt-R/C	1	5	3	0	2	11	2.0
ASI-ENG and ENG-ASI	1	1	0	1	1	4	0.7
T/S-R/C and R/C-T/S	0	0	1	0	1	2	0.4
ENG-Alt and Alt-ENG	1	0	0	1	1	3	0.6
D/G-T/S and T/S-D/G	0	0	1	1	0	2	0.4
T/S-Alt and Alt-T/S	2	0	0	1	0	3	0.6
HOR-T/S and T/S-HOR	0	2	0	0	0	2	0.4
ASI-T/S and T/S-ASI	2	0	0	0	1	3	0.6
D/G-ENG and ENG-D/G	1	0	1	0	0	2	0.4
ENG-HOR and HOR-ENG	1	0	1	0	0	2	0.4
ENG-R/C and R/C-ENG	0	1	0	0	0	1	0.2
	114	103	100	100	113	530	100.0

/4. ...

4. Suggested Procedure for Future Investigations

The results of this investigation were obtained for the last two miles of each of the five approaches, which, while being the most critical section, represents only part of the approach.

As data for establishing statistical relationships they must be considered incomplete and can only serve as a guide for subsequent experiments.

Extension of the observations over a longer flight period would require some modifications of the procedure. With the type of camera used in this investigation, the maximum length of film which could be run through using the spring motor was 20 feet. This is equivalent to 800 frames and which if exposed at the rate of 10 per second would give a run of 80 seconds duration.

As it is not possible to rewind during filming, it would be necessary to either crank the camera by hand, or attach an electric motor to the drive of the camera if longer filming time is required.

With this modification the filming time could be increased to the capacity of the camera, in this case 100 feet, which would give a filming time of 6.6 minutes at a speed of 10 frames per second.

Unforseen circumstances prevented the investigation being extended to the eye movements on an I.L.S. approach using the Zero Reader and I.L.S. Cross Pointer independently.

/Appendix I ...

APPENDIX I

METHODS OF MEASURING EYE MOVEMENTS

Various methods have been employed to measure eye movements, a brief summary of which is appended.

(i) Direct visual observation of the eyeball

Javal (1879) made a study of eye movement by direct observation, and in an attempt to reduce the distraction of the experiment, a mirror was placed in front of the subject so that the reflection of the eye movements could be recorded behind the subject.

(ii) Counting techniques

Landolt (1891) determined what he considered was the smallest angle through which the eye could move voluntarily by viewing a recurring pattern at various distances. The distance between the patterns was 13 mm. and he increased the distance of view until the number of patterns could only just be counted. The angular separation between the patterns was then found to be about five minutes of arc.

(iii) Photographic methods

Dodge and Cline (1901) using a falling plate, appear to be the first to make a photographic study of eye movements. Karslake (1940) brought this method up to date for work on the attention value of advertisements and notices.

Judd, McAllister and Steele (1905) attached to each cornea a flake of Chinese white, and by means of a ciné camera achieved considerable success. The subject's head was clamped at the back and sides and he was required to bite a rigid piece of wood in order to eliminate any head movements.

In addition, two small steel balls were attached to a spectable frame and worn by the subject, so that when the eyes were photographed, the movement of the flake of Chinese white relative to the steel ball image was an indication of the eye movement, the steel balls being a head datum. It was claimed by this method that the maximum error did not exceed $7\frac{1}{2}$ minutes of arc. (Experiments on steady fixation showed that movements of the eyes of at least 30 minutes of arc took place.)

Dodge (1907) passed light from an A.C. operated arc lamp through a blue glass filter and a vertical slit onto the cornea of the eye, and the image formed by the reflected light

/was then ...

was then photographed through a horizontal slit on to a falling plate. Thus, a record of side to side movements of the corneal reflex was obtained, and since the arc was A.C. operated, the record was broken and gave a time scale also. Again it was necessary to clamp the subject's head to eliminate any movement.

Taylor (1937) designed the ophthalmograph which was made by the American Optical Company to meet the need for a commercial eye camera. This camera is used for research on the saccadic nature of the movements in reading and the fixation pauses but again it is necessary to clamp the subject's head securely.

(iv) Mechanical recording

Ohm (1914) used a lever attached to one end of the eyelid near the outer cornea, and as the eye moved the lever was raised or lowered and the movement recorded on a revolving drum.

Other workers have placed capsules over the eyeball and any movement of the cornea under the capsule produced a change in air pressure which was recorded and calibrated.

(v) Photo-electric recording

Rotations of the eye as small as one minute of arc were detected by the photoelectric method as described by Lord and Wright (1948). An ultra-violet beam of wave length 3650Å was reflected onto the subject's eye in such a direction that it fell on the blind spot when the subject was viewing the fixation target. With the assistance of photo-electric cells, a single stage balanced D.C. amplifier, a cathode ray oscillograph and other items, the eye movements were recorded with the above accuracy. As on previous experiments, the subject was obliged to bite a dental block to obviate head movements as far as possible.

(vi) Recording of the corneal retinal potential difference

Carmichael and Dearborne (1948) are the greatest exponents of this method which measures the eye movements by means of the potential change that occurs around the eye. Since changes in corneal-retinal potentials are closely proportional to the sine of the angle of rotation of the eye it is possible, with correct positioning of the electrodes and amplifying system, to record eye movements electrically.

/Appendix II ...

APPENDIX II

STANDARD BEAM APPROACH

In the Standard Beam Approach the Main Beacon transmits two beam morse signals (.-) A, and (-.) N, which enable the pilot to determine on which side of the beam approach he is flying.

When the pilot is flying in the narrow section where the two beams overlap he receives a continuous note.

There are two Markers, the Outer Marker and Inner Marker situated at 10,000 feet and 750 feet respectively from touchdown.

The Outer Marker transmits signals at two dashes per second while the Inner Marker transmits dots at the rate of six per second.

The pilot passes the Outer Marker at 1,000 feet and then descends to 150 feet at 600 feet per minute. This height is maintained until the Inner Marker is heard, by which time the runway should be visible and the aircraft is landed safely. If the runway is not visible at the Inner Marker the procedure is repeated.