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Development of Instrumentation for the Study of Pilots' Eye Movements in Army Helicopters

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by

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DEVELOPMENT OF INSTRUMENTATION FOR THE STUDY OF PILOTS' EYE MOVEMENTS IN ARMY HELICOPTERS

SUMMARY

As part of a program to establish cockpit visibility requirements for Army helicopters, a method of instrumentation was established to record photographically pilots' eye movements in various helicopters during flight in order to determine visual windshield usage. Two methods of recording pilots' eye movements were considered, namely, (1) the use of a camera located behind the pilot which viewed his eyes through a mirror located ahead of him on the instrument panel, and (2) the use of a camera located in front of the pilot. The second method was selected.

Accuracy of reading or interpreting the photographic data obtained from the instrumentation was established through the conduct of tests performed in the H-13 and H-21 helicopters, which were selected as being representative of various types of Army helicopters. These tests revealed that it was possible to determine the actual location of the area of the windscreen through which the pilot was looking, within 10° vertically and horizontally during at least 72 per cent of the time for the H-13 helicopter, and 60 per cent of the time for the H-21 helicopter.

INTRODUCTION

The need for improved cockpit visibility in aircraft has been receiving an increasing amount of attention in both military and civil aviation, and minimum requirements for transport-type, fixed-wing aircraft have been established.[1] Considerable work also has been accomplished to determine visibility requirements for small fixed-wing aircraft,[2] and some preliminary work has been carried on for helicopters.[3]

[1]Thomas M. Edwards and Wayne D. Howell, "Recommendations on Cockpit-Visibility Standards for Transport-Type Aircraft," CAA Technical Development Report No. 275, February 1956.

[2]Eugene E. Pazera, "Cockpit Visibility Requirements for Army Fixed-Wing Liaison-Reconnaissance-Type Airplanes, Part I - Pilot Opinion and Tolerance Study," CAA Technical Development Report No. 369, September 1958.

[3]Rollin E. Farrand, "A Pilot Questionnaire Study of Cockpit Visibility Requirements for Army Helicopters," CAA Technical Development Report No. 350, June 1958.

Although the smaller helicopters provide nearly hemispherical visibility in the forward area, the areas of the windshields in larger helicopters have been reduced, such that basic work is urgently required to establish minimum visibility requirements for such aircraft. In fact, preliminary work in this connection[3] has indicated that several of the larger type helicopters now in operation do not meet minimum requirements. This work included a pilot questionnaire study and an analysis of flight paths and flight attitudes of helicopters during various critical maneuvers.

This report describes the development of instrumentation required for the measurement of pilot-look directions during flight. The results of the pilot eye-movement study will be published in a later report.

DEVELOPMENT OF INSTRUMENTATION

Two methods of recording pilot eye movements were considered, namely, (1) with a movie camera located behind the pilot's seat, photographing the reflected image of the pilots' eyes from a mirror located in front of the pilot on the instrument panel, and (2) with a movie camera located in front of the pilot, photographing the pilots' eyes directly.

The first method presents less obstruction to the pilot's vision than the second method and is more useful in the limited confines of a small cockpit where there is not sufficient room between the pilot and available camera location to develop the necessary field of view. However, it requires additional space behind the pilot for camera and photographer.

The size of the mirror used in the first method is governed by the amount of the pilots' head and body movements, that is, the greater the movement, the larger the mirror necessary to encompass the field. A small mirror can be located at the normal eye-level directly in front of the pilot, providing a desirable frontal view of the pilot. A large mirror would have to be mounted in a less desirable oblique location because it would constitute a visual obstruction.

After due consideration, the second method, the direct photographic recording of the pilots' eyes, was selected for this study because of the limited space behind the pilot in the H-13 and H-21 helicopters and because of the magnitude of head and body movements by the pilots, which could not be contained within the limited field of view of a mirror of reasonable size.

Initially, three helicopters were chosen for the conduct of the pilot eye-movement study as being representative of the various

[3] Rollin E. Farrand, op. cit.

classes and types of helicopters being used by the Army. The H-13 was selected as the light, reconnaissance-type helicopter. Both the H-21 and H-34 were selected as typical light, cargo-type helicopters due to differences in their flight characteristics.

Camera mounts were designed and fabricated for each helicopter and flight tested. No vibrational problems were encountered during the tests and the quality of film data proved satisfactory. Two cameras were used in the H-13 due to extreme head and body movements encountered during initial flight tests. The final camera arrangements for each type of helicopter and sample film frames are shown in Figs. 1, 2, and 3. In the H-13, shown in Fig. 1, one camera was mounted at a point 5° right and 20° down from the zero reference point, which is straight ahead of the pilot's eyes. The other camera was located at a point 30° right and 15° down from zero reference. In the H-21, shown in Fig. 2, the camera was located 42° to the left of zero reference and 38° down. In the H-34, shown in Fig. 3, the camera was located 35° left of zero reference and 53° down. Since the camera locations for the H-21 and H-34 are similar, film-analysis accuracy tests were conducted only for the H-13 and H-21 helicopters.

FILM-ANALYSIS ACCURACY

Test Procedure.

To establish limits of accuracy in "reading," or analyzing pilot windshield use from these films, three steps were taken.

1. Subject pilots were photographed while looking at individual, well-defined points located on the windscreen.

2. Each point was located accurately, and angularly with respect to a normal pilot-eye position.

3. The test films from step 1 were analyzed by film readers and the angular readings were compared with the actual locations of the points determined in step 2.

Approximately 500 "fixation" points were located on the windscreen of the helicopter in which the tests were conducted. The points were located in easily identified rows and numbered consecutively in each row. The number of rows varied, depending on the helicopter being considered. For the H-13, shown in Fig. 4, nine rows were used.

To establish, angularly, the points on which the pilots fixate, a binocular vision cockpit visibility camera[4] was used to

[4]Thomas M. Edwards, "Development of an Instrument for Measuring Aircraft Cockpit Visibility Limits," CAA Technical Development Report No. 153, January 1952.

photograph fixation points, shown in Fig. 4, as they appeared on the helicopter windscreen. The photograph in Fig. 5 was taken with this camera. Grids superimposed on the photographs by the camera permit accurate angular measurements of any point shown in the picture. The nine rows of fixation points in Fig. 5 have been accentuated to illustrate their location.

All eye-fixation photographs were recorded while the helicopter was in actual flight, since the manner in which the pilot will look at a particular point depends upon pressures imposed upon him while manipulating the flight controls and observing certain important instruments.

To eliminate the possibility of the readers becoming preinformed as to what fixation photograph was being analyzed, a system of control numbers was used which permitted the fixation photographs to be recorded at random. A control number was used, rather than the actual point number, to indicate which series of points were being filmed. An appropriately numbered card (control number) was recorded on the film prior to photographing the pilot looking at a particular series of points. A series of points included all the points assigned the same number in each row. Therefore, it was possible to have nine points in a series since there are nine rows. Fixation photographs within a series were separated by flashing a plain white card in front of the camera.

As the pilot acknowledged that a point in a particular row could be seen by him, the cameraman placed a C-mark in the appropriate column on a control sheet and then photographed the pilot looking at that point. If the point was not visible to the pilot, the cameraman simply placed an X-mark in that column and proceeded to the next point.

The following is a sample of the control sheet used.

		Particular Rows of Numbers on Cockpit Bubble								
Control[1] Number	Point[2]	Front Center	Side Center	Horiz. Center	Front Left	Side Front	Horiz. Bottom	Front Right	Side Back	Horiz. Top
44	27	C	C	C	C	C	C	C	C	C
45	56	C	C	C	X	X	X	X	X	C
46	52	C	C	C	C	C	X	C	X	C

[1] Identifies the series.
[2] The point number on the cockpit bubble.
X - Indicates the pilot's inability to see a fixation point.
C - Indicates the pilot's ability to see a fixation point.

The final step, analyzing the films, was accomplished by employing three analysts to read the films. Each analyst was furnished a control chart showing 29 individual fixation photographs of pilots looking at points chosen from those on the cockpit bubble. Control charts are composed of fixation photographs placed on an angular grid (Mercator projection) at their proper angular location as determined through use of the binocular vision cockpit visibility camera. Figure 6 is a typical control chart. The fixation photographs are selected to provide uniform coverage of the area of available visibility. It was the analysts' objective to compare each frame of the 16-mm film data with the photographs on the control chart and thereby determine the pilot's direction of sight.

The film analysts were situated in a room in the manner shown in Fig. 7. A time- and motion-study projector was used to permit the film to be studied, one frame at a time. For the first six fixation points on each helicopter, the readers were told the actual reading and were permitted to discuss the location freely to develop their estimating ability. No discussion of the remaining points was permitted until each reader had recorded the location he believed correct. The reading error was determined by comparing the actual angular location of the point with the mean value of the estimated angular location determined by the reading team of three persons.

Results of Reading Accuracy - H-13 Helicopter.

Attempts were made, both visually and graphically, to subdivide the average reading error into areas representing equal numerical errors. This proved impractical due to the random location of points of equal value. Originally, it was thought that the reading error would increase in some direct relationship with the distance from the zero reference point. This was expected because the pilot made such extreme movements of his head, body, and eyes when looking at points which were far distant from the zero reference point. In some movements, the pilot's eyes were totally obscured from the camera, making analysis virtually impossible. These movements are more difficult to analyze than those used when the pilot was looking nearly straight ahead. While there is some evidence of increased errors at the extremities, there is no direct linear relationship between reading error and distance from the zero reference point.

Charts were prepared showing the numerical value of the average reading error for angular sectors 45° on each side of the zero reference. See Fig. 8. The arithmetical mean of the reading error in degrees is shown for each sector. Table I is a summary of the results of the H-13 reading accuracy.

Results of Reading Accuracy - H-21 Helicopter.

Charts, similar to those in Fig. 8, were prepared for the H-21 helicopter. These show the horizontal and vertical reading errors for windscreen sectors in increments of 45°. See Fig. 9. Figure 9 indicates that the reading accuracy for film data showing the pilot looking ahead or to the left in the H-21 helicopter is comparable to the accuracy achieved in the H-13 helicopter. It is only in the area beyond 112.5° to the right that the accuracy decreases. In order to look beyond 112.5° to the right, it was necessary for the pilot to turn his head in such a manner that his eyes were hidden from the camera lens. The analysts then were forced to rely on only the head and body positions to determine the angular line of sight, which accounts for this decrease in accuracy. Table II is a summary of the H-21 helicopter reading accuracy.

CONCLUSIONS

It is concluded that.

1. For the H-13 helicopter, the readings of the photographic frames were accurate within 5° for at least 42 per cent of the horizontal readings and 44 per cent of the vertical readings, while 72 per cent of the photographic frames read were accurate within 10° horizontally and 76 per cent were accurate within 10° vertically.

2. For the H-21 helicopter, 39 per cent of the photographic frames read were within 5° horizontally and 38 per cent were read within 5° vertically, while at least 60 per cent of the photographic frames read were accurate within 10° horizontally and 62 per cent were read within 10° vertically.

3. The accuracies obtained are sufficient evidence that film analysis of pilots' eye movements as described in this report is adequate for the purpose of this study. Since the pilot eye-movement study is designed to determine general areas of the windscreen which are used most frequently by pilots, greater accuracies are not necessary.

TABLE I

A SUMMARY OF READING ACCURACY
IN THE H-13 HELICOPTER

Front Camera

Error	Horizontal Reading		Vertical Reading	
Degrees	Number of Points	Per Cent of Total	Number of Points	Per Cent of Total
0 - 4.9	83	42	96	49
5.0 - 9.9	65	33	54	28
10.0 - 14.9	17	9	28	14
15.0 - 19.9	14	7	8	4
20.0+	17	9	10	5
Totals	196	100.0	196	100.0

Side Camera

Error	Horizontal Reading		Vertical Reading	
Degrees	Number of Points	Per Cent of Total	Number of Points	Per Cent of Total
0 - 4.9	87	45	109	56
5.0 - 9.9	54	28	46	24
10.0 - 14.9	27	14	23	12
15.0 - 19.9	16	8	8	4
20.0+	11	5	9	4
Totals	195	100.0	195	100.0

TABLE II

A SUMMARY OF READING ACCURACY
IN THE H-21 HELICOPTER

Error Degrees	Horizontal Reading Number of Points	Horizontal Reading Per Cent of Total	Vertical Reading Number of Points	Vertical Reading Per Cent of Total
0 - 4.9	123	39	121	38
5.0 - 9.9	68	21	78	24
10.0 - 14.9	47	15	50	16
15.0 - 19.9	35	11	38	12
20.0+	45	14	31	10
Totals	318	100.0	318	100.0

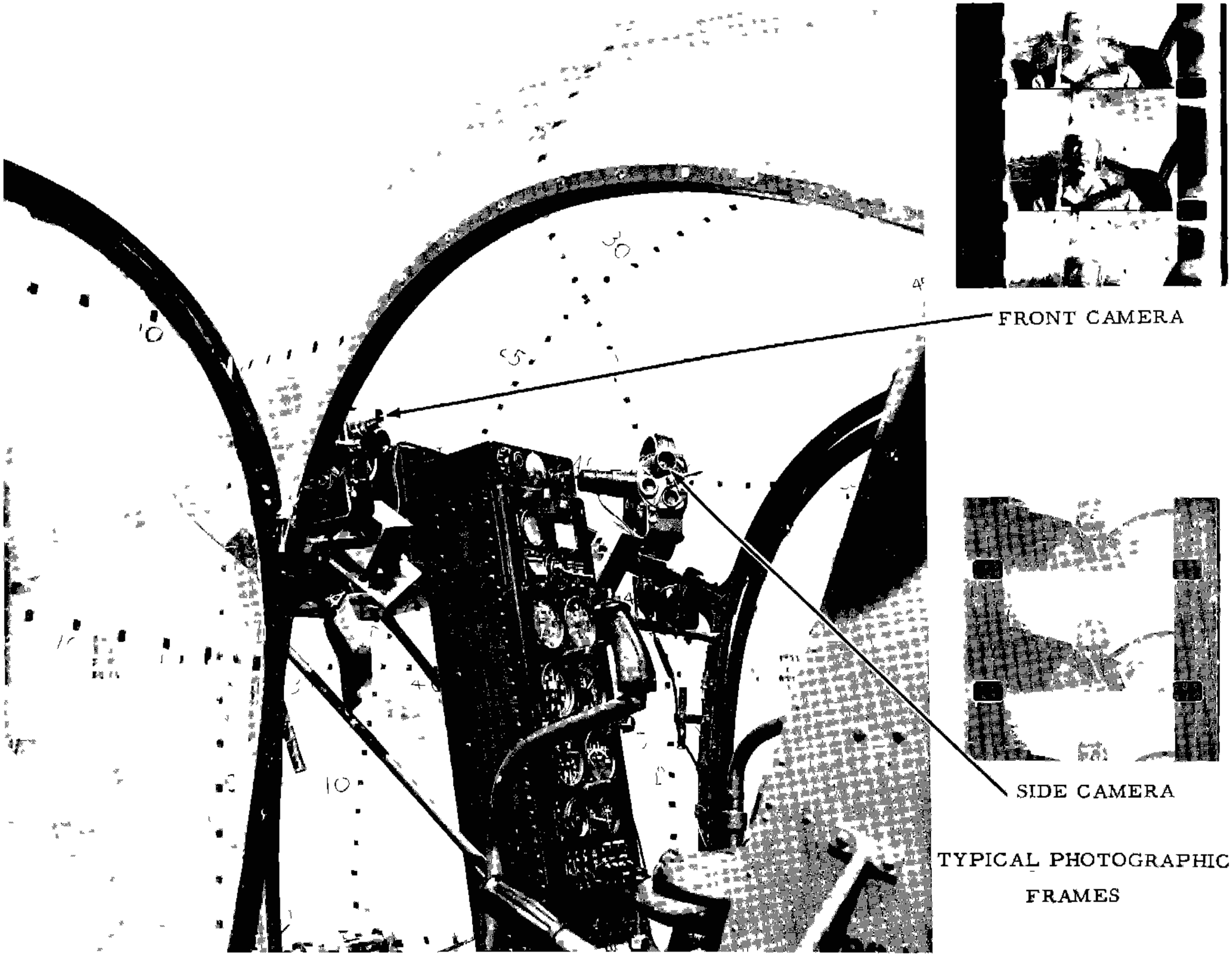
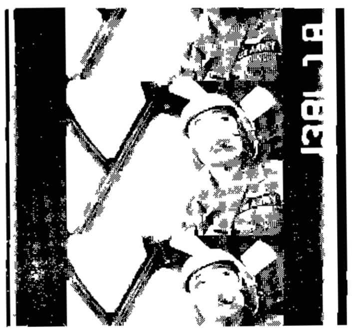


FIG 1 INSTRUMENT ARRANGEMENT IN THE H-13C



TYPICAL PHOTOGRAPHIC FRAMES

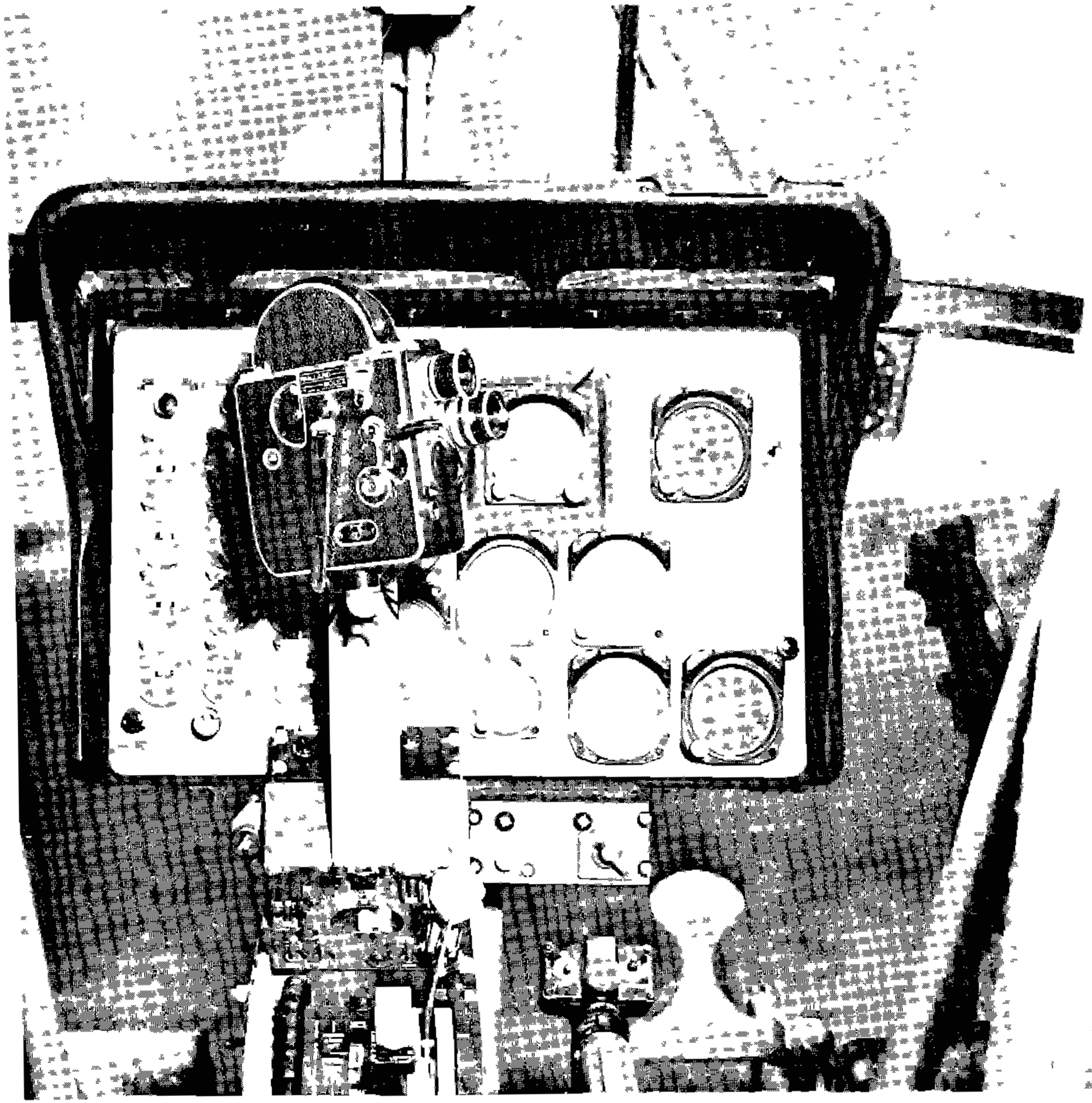


FIG 2 INSTRUMENT ARRANGEMENT IN THE H-21

FI[illegible] 4 [illegible]OGRAPHIC
[illegible]LS

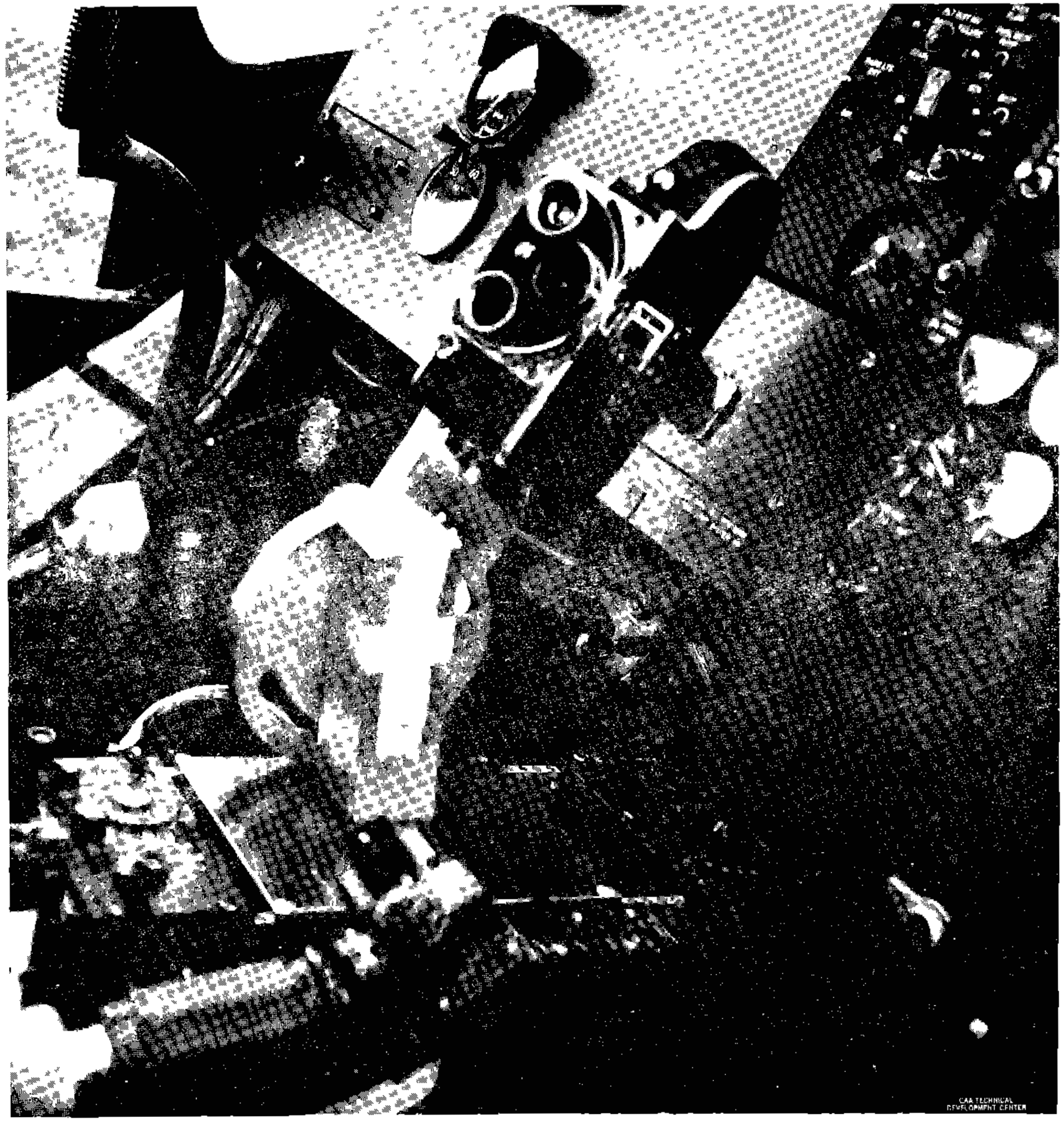


FIG 3 INSTRUMENT ARRANGEMENT IN THE H-34

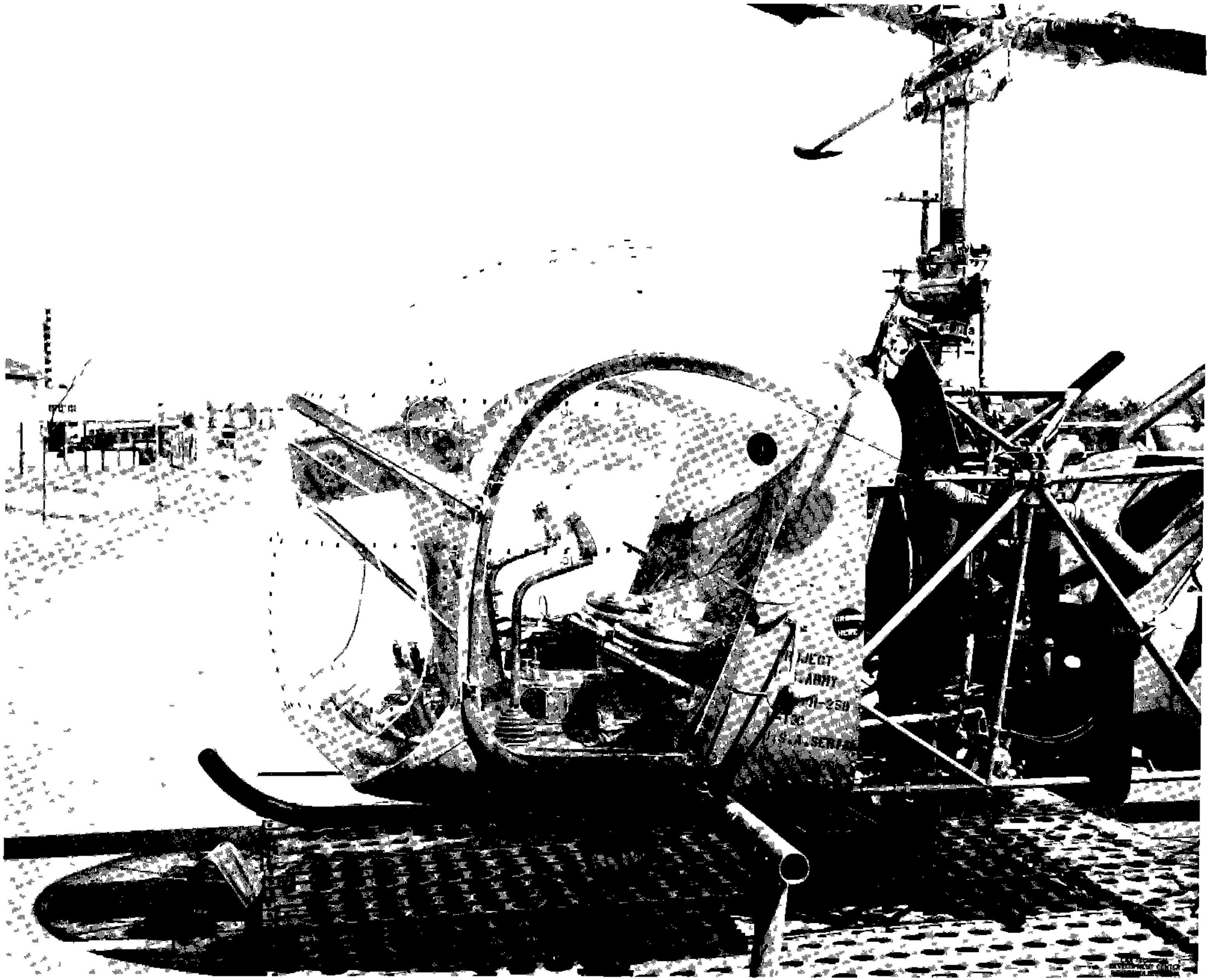


FIG 4 H-13 HELICOPTER INSTRUMENTED WITH FIXATION POINTS

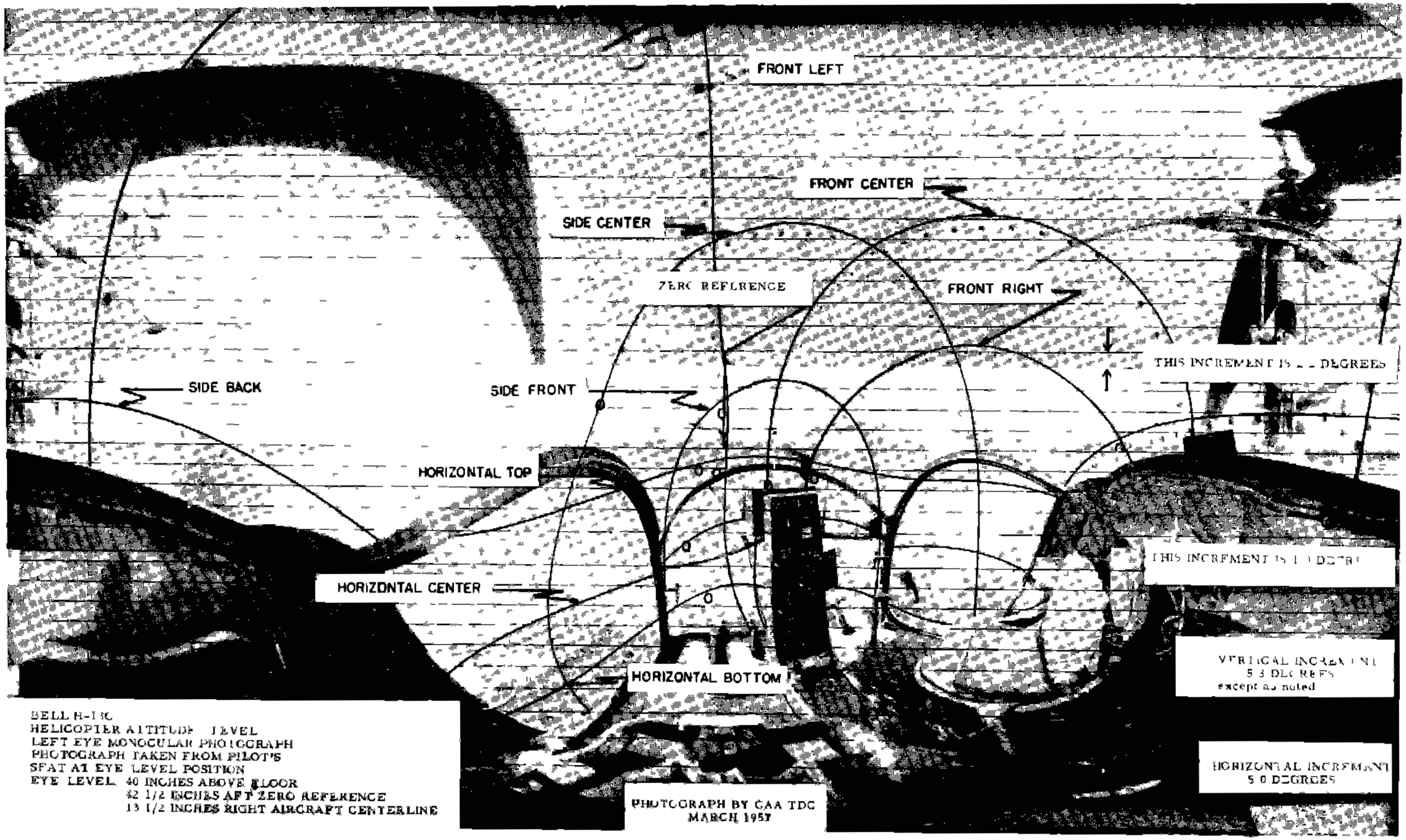


FIG 5 FIXATION POINTS FOR THE H-13 INSTRUMENTATION STUDY

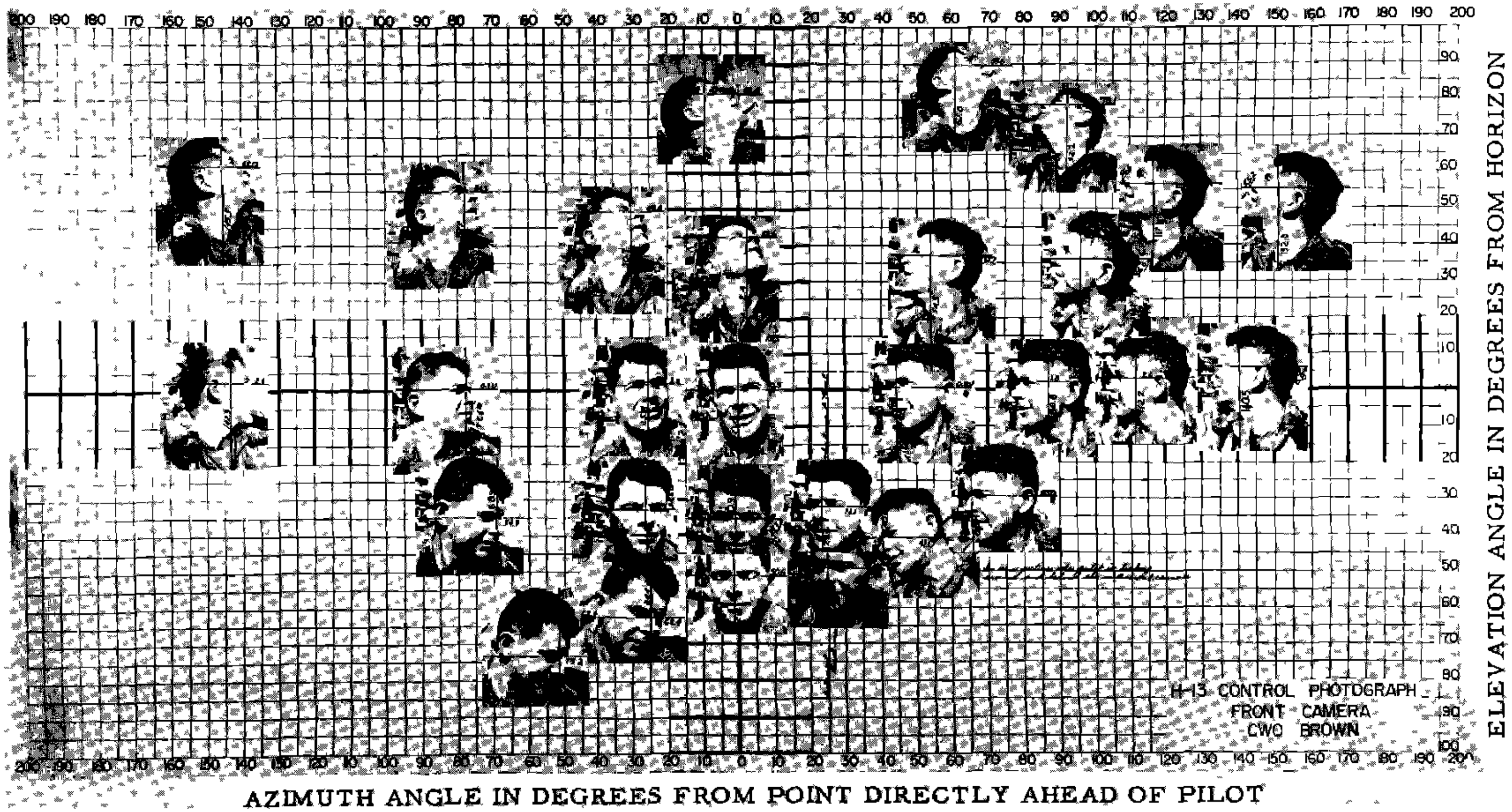


FIG 6 TYPICAL H-13 CONTROL CHART

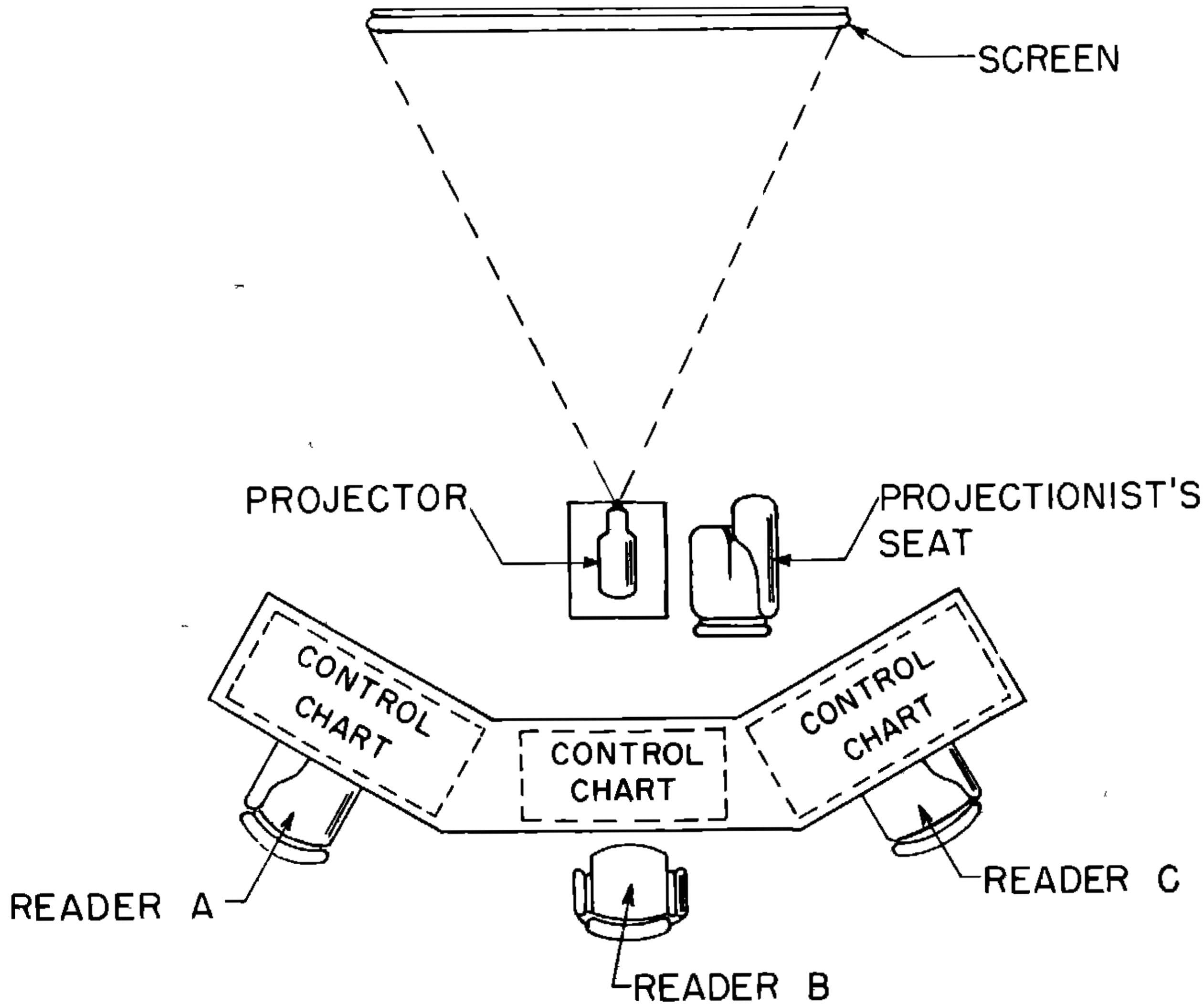


FIG 7 READING ROOM ARRANGEMENT FOR THE PILOT EYE-MOVEMENT FILM ANALYSIS

←VERTICAL REFERENCE (DIRECTLY IN FRONT OF PILOT)

	180°–135° (LEFT)	135°–90° (LEFT)	90°–45° (LEFT)	45°–0° (LEFT)	0°–45° (RIGHT)	45°–90° (RIGHT)	90°–135° (RIGHT)	135°–180° (RIGHT)
90°–45°	1 PT 14 7-V 37 3-H	1 PT 22 8-V 29 3-H	2 PTS 1 2-V 2 2-H	7 PTS 5 9-V 16 4-H	2 PTS 13 3-V 36.2-H	6 PTS 6 0-V 7 3-H	2 PTS 6 6-V 20 3-H	1 PT 26 9-V 77 1-H
45°–0°	3 PTS 9 3-V 1 9-H	2 PTS 6 0-V 3 7-H	6 PTS 8 6-V 7 8-H	15 PTS 10 1-V 5 6-H	14 PTS 3 9-V 5 8-H	11 PTS 6.3-V 10 7-H	13 PTS 7 2-V 14 0-H	2 PTS 1 7-V 5 9-H
0°–45°	0 PTS	3 PTS 20 5-V 8 0-H	5 PTS 13 3-V 8 1-H	26 PTS 7 6-V 4 6-H	33 PTS 4 7-V 4 2-H	25 PTS 4 8-V 8 3-H	4 PTS 1 6-V 4 7-H	0 PTS
45°–90°	0 PTS	0 PTS	8 PTS 10 0-V 12 2-H	4 PTS 5 2-V 2 1-H	0 PTS	0 PTS	0 PTS	0 PTS

PILOTS EYE LEVEL (at 0°)

LEFT RIGHT

V = VERTICAL ERROR

H = HORIZONTAL ERROR

FRONT CAMERA

FIG 8 THE AVERAGE H-13 READING ERROR IN DEGREES FOR ANGULAR WINDSCREEN SEGMENTS IN INCREMENTS OF 45°

← VERTICAL REFERENCE (DIRECTLY IN FRONT OF PILOT)

	LEFT 180°–135°	LEFT 135°–90°	LEFT 90°–45°	LEFT 45°–0°	RIGHT 0°–45°	RIGHT 45°–90°	RIGHT 90°–135°	RIGHT 135°–180°
90°–45° (above)	1PT 1 4-V 0 7-H	1PT 17 1-V 0 0-H	2PTS 1 5-V 4 1-H	7PTS 9 6-V 17 3-H	2PTS 5 9-V 5 6-H	6PTS 7 0-V 10 8-H	2PTS 2 9-V 1 1-H	1PT 1 3-V 2 1-H
45°–0° (above)	3PTS 5 4-V 5 0-H	2PTS 7 6-V 4 1-H	6PTS 4 0-V 4 5-H	15PTS 3 8-V 10 3-H	14PTS 5 8-V 4 0-H	11PTS 9 2-V 7 6-H	12PTS 8 9-V 10 3-H	2PTS 19 6-V 21 1-H
0°–45° (below)	0PTS	3PTS 13 3-V 39 7-H	5PTS 3 8-V 6 0-H	26PTS 5 1-V 5 5-H	34PTS 5 2-V 4 8-H	24PTS 5 6-V 6 8-H	4PTS 4 6-V 12 6-H	0PTS
45°–90° (below)	0PTS	0PTS	8PTS 10 5-V 6 6-H	4PTS 5 1-V 7 9-H	0PTS	0PTS	0PTS	0PTS

PILOTS EYE LEVEL ↑ (at 0° line)

LEFT | RIGHT

SIDE CAMERA

FIG 8 (CONTINUED) THE AVERAGE H-13 READING ERROR IN DEGREES FOR ANGULAR WINDSCREEN SEGMENTS IN INCREMENTS OF 45°

←VERTICAL REFERENCE (DIRECTLY AHEAD OF THE PILOT)

	180°–112 5°	112 5°–67 5°	67 5°–22 5°	22 5°–0°–22 5°	22 5°–67 5°	67 5°–112 5°	112 5°–157 5°	157 5°–180°
90°–67 5°	NO POINTS	0 PTS	1 PT 10 1-V 16 8-H	2 PTS 6 3-V 15 0-H	2 PTS 15 6-V 22 7-H	3 PTS 16 8-V 24 9-H	1 PT 11 5-V 27 0-H	NO PTS
67 5°–22 5°		6 PTS 9 6-V 5 9-H	10 PTS 12 4-V 9 9-H	16 PTS 54-V 70-H	6 PTS 4 2-V 8 1-H	5 PTS 13 3-V 14 5-H	10 PTS 13 8-V 24 7-H	
22 5°–0°–22 5° (PILOT EYE LEVEL)		41 PTS 7 2-V 6 1-H	35 PTS 4 8-V 7 9-H	19 PTS 55-V 70-H	6 PTS 4 2-V 5 8-H	12 PTS 7 8-V 7 9-H	13 PTS 10 6-V 13 5-H	
22 5°–67 5°		9 PTS 10 1-V 4 0-H	13 PTS 9 7-V 6 7-H	46 PTS 10 2-V 77-H	12 PTS 13 3-V 6 6-H	17 PTS 14 5-V 8 7-H	15 PTS 11 4-V 20 7-H	
67 5°–90°		0 PTS	0 PTS	0 PTS	12 PTS 15 5-V 8 1-H	6 PTS 13 1-V 16 1-H	0 PTS	

LEFT — RIGHT

V = VERTICAL ERROR

H = HORIZONTAL ERROR

FIG 9 THE AVERAGE HORIZONTAL AND VERTICAL READING ERRORS IN DEGREES ON THE H-21 FOR ANGULAR WINDSCREEN AREAS 45° SQUARE