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A STUDY OF PILOT EYE MOVEMENTS DURING VISUAL FLIGHT CONDITIONS IN ARMY FIXED-WING LIAISON-RECONNAISSANCE-TYPE AIRCRAFT

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SUMMARY

To obtain further substantial information for establishing minimum angles of vision from the cockpits of Army liaison-reconnaissance-type fixed-wing aircraft, motion pictures were taken of pilots' eye movements with a newly developed head-mounted camera while each of a group of Army pilots performed various normal and tactical flight maneuvers. The head-mounted camera recorded both the field of view in the pilot's look direction and the eyes and forehead on each photographic frame.

It was possible to determine through which portion of the windshield the pilot was looking within 3.3°. The resulting data are presented for all conventional and tactical maneuvers performed in the Cessna L-19 "Bird Dog" aircraft in terms of the percentage of photographic frames to show the use of the available windshield area.

The windshield area used by the pilots during the pilot eye-movement study substantiates, to a considerable extent, the conclusions drawn from a pilot questionnaire study of windshield use reported previously

INTRODUCTION

There has been a growing interest in cockpit visibility in recent years. The Office of the Chief of Army Transportation requested that the Technical Development Center (TDC) of the Civil Aeronautics Administration conduct a program to determine cockpit visibility requirements for the satisfactory performance of all necessary maneuvers of Army liaison-reconnaissance-type fixed-wing aircraft The first phase of this program, a questionnaire study of pilot opinion concerning the quality of existing visibility in which a preliminary windscreen outline was determined, has been completed.[1]

This report covers a phase of the cockpit visibility study, the specific aim of which is the determination of areas of the windshield and visual angles actually used by the pilots in performing various conventional and tactical maneuvers. The conventional maneuvers were takeoff, landing, and cruise, and climbing, level, and gliding turns. The tactical maneuvers

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

included short-field takeoffs and landings, message pickups and drops, artillery spotting, road and object reconnaissance, supply drops, formation flying, and wire laying.

TEST PROCEDURE

Previous eye-movement studies involving other types of aircraft were performed by placing a motion picture camera in front of the pilot to record his eye movements, or by photographing the reflection of the pilot's eyes in a mirror placed in front of the pilot. These methods were not suitable in the L-19 airplane, however, because there was not sufficient space to mount a camera where it would not interfere with existing visibility. The use of mirrors in an L-19 also was impractical because of the range of pilot head and body movements which made it impossible to keep his eye images in the field of view of any reasonable arrangement of mirrors.

It was decided, therefore, that a new method of recording pilot eye movements should be devised Specifications were prepared for a head-mounted camera that would record the eyes and forehead of the pilot, as well as the field of view in the look direction on each frame of movie film. The camera,[2] shown in Fig 1, was designed and fabricated by PAR Products of Hollywood, Calif. It uses a 100-foot roll of 16 mm movie film. The film is exposed at a rate of 4 frames per second and records about 16 minutes of flight. The camera has a 9 5 mm lens which gives a field of view of about 43° horizontally and vertically. The camera is operated by a 24-28 volt d-c motor from a battery pack or the aircraft electrical system. Typical photographic frames taken with the camera are shown in Fig. 2.

Tests performed with the camera showed that a subject's direction of sight can be determined within an average accuracy of plus or minus 3.3°. This means that the actual point on the L-19 windshield through which the pilot looked at any particular moment was determined within an average of 1.4 inches of the true point.

The L-19 aircraft windshield, side, and top windows were marked, using a semaphoric code system to aid in identifying the portion of the windshield being used by the pilot when the surrounding structure is not visible in the field of view of a particular photographic frame. Black electrical tape about 1/8-inch wide and 1 inch long was used to mark those transparencies. These marks then were photographed with a binocular cockpit visibility camera.[3] The angular location of every mark on the windshield thus was obtained as shown in Fig. 3. These semaphoric code marks, or tick

[2] Eugene E. Pazera, "Development of a Head-Mounted Camera for Recording Pilots' Eye Movements," unpublished Technical Development Report.

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

marks, were placed every 6 inches horizontally and vertically on the windshield and 4 inches apart on the side and top windows.

Some doubt had been expressed about the effect of the weight of the camera, 4.5 pounds, on the pilot's normal performance of visual tasks. However, after the first few minutes of flight, the pilots became well accustomed to the camera, and all of them stated that it had no effect on their search habits.

The pilots who served as subjects for this study, as well as other operational support, were provided by the Army Aviation School, Fort Rucker, Ala. The data secured from three pilots performing 19 separate maneuvers are included in this report. Each pilot made three or four flights, each of which lasted about 1 hour, providing 14 to 16 minutes of actual data. All maneuvers were performed under actual field conditions; for example, artillery spotting was performed during the conduct of an actual field training problem; supply drops were performed using training bundles under each wing, and so forth. The subject pilot was required to perform each maneuver without the aid of an observer. An engineer normally flew with the subject pilot in the observer's seat to operate the camera and record the sequence of maneuvers during each flight. The only exception was artillery spotting, when an Army officer flew with the pilots to control artillery fire.

FILM ANALYSIS

Four individuals were trained to analyze the head camera films. The analysts then were divided into two teams. Each team worked in a projection room 10 feet long and 10 feet wide. The rooms were painted a flat grey and lighted with a single fluorescent tube which had been covered with strips of various colored cellophane to provide a uniform, low level of lighting of a neutral tone. The films were projected through a motion picture image rectifier, shown in Fig. 4, to rotate the projected image 90° so that the picture would appear upright for the analysts. The movie screen was located on one wall directly opposite the motion picture image rectifier, as shown in Fig. 5. Each analyst was provided with a chair with writing desk attached, so that the windshield outline of an L-19 showing the tick marks could be placed directly in front of the analyst.

The titles of the maneuvers were recorded on the film by having the pilot aim the head camera at a card held on the side window. However, in cases where the pilot failed to get such a record, it was possible to determine the maneuver by observing the aircraft attitude or by other means, such as following the sequence of maneuvers as recorded by the photographer.

It was the analyst's function to determine the direction in which the pilot's eyes were fixed and to locate a similar point in the field of view which represented the pilot's line of sight. To accomplish this, the direction of the eye fixation and field of view were correlated by having the subject pilot hold his head in a predetermined position and fixate his eyes on a series of targets distributed throughout the field of view prior to each test flight, as shown in Fig. 6. These reference photographs then were used to draw a correlation grid on the projection screen, as shown in Fig 7

The single rows of vertical and horizontal targets were used to prepare a complete overlay grid. Vertical grid lines were prepared from fixations on the horizontal row of targets, Fig. 7A, and horizontal grid lines from fixations on the vertical targets, Fig 7B, thereby providing coverage of the entire field of view, Fig. 7C The distance between each grid line was selected arbitrarily as 5 units to permit interpolation. These units are relative and do not represent inches, degrees, or any other unit of measure.

Working independently, each analyst "read" the films in the following manner:

1. The analysts looked at the pilot's eyes, each separately, and obtained a reading for each, for example, right eye 10 up and 7 left, and for the left eye, 10 up and 9 left.

2. These two readings were averaged and the resulting point was recorded as the apparent line of sight. In this example, the average was 10 up and 8 left.

3. A vertical correction then was applied for parallax. The lens of the camera is located about 1 1/4 inches above the pilot's eyes. The correlation of the direction of the pilot's eye fixation and field of view was done with the pilot focusing at 50 feet to eliminate the need for correcting the eye readings for normal eye convergence when looking at close objects. Therefore, at 50 feet, there is no parallax error. For readings nearer the pilot eye position, parallax error will increase progressively to a maximum of 1 1/4 inches. At the windshield, the parallax error was about 1 inch. The correction was applied by lowering the apparent point by 1 inch on the windshield This was done by estimating the distance with the known spacing of the tick marks for reference

4. The point on the windshield through which the pilot actually was looking then was found by relating the structure and tick marks on the screen to similar references on the binocular cockpit visibility photograph

5. The analysts also recorded all frames in which the pilot was looking at instruments simply as instrument panel fixations. Frames in which the pilot moved his head and/or eyes rapidly, causing a blurred image, and frames in which sun glare caused the loss of the image on the film, were recorded as unusable frames

It should be emphasized that throughout the entire analysis, the two analysts in each team worked independently of each other. They did not at any time discuss with each other their judgments of any photographic frame.

PRESENTATION OF DATA

The mean values of estimated angular location of looks were transferred to tabulation sheets which were representations of a sphere divided horizontally and vertically into 5° increments. Superimposed on these sheets was the outline of the L-19 windshield as it appeared to the average pilot. For each maneuver, and for all pilots, the total number of frames that showed the pilots looking through a particular square were noted in that square on the tabulation sheets.

The total number of looks in a particular square then were divided by the total number of usable frames for a particular maneuver and the resulting percentages were transferred to an identical set of grid tabulation sheets. Thus, the data for individual maneuvers are presented to the nearest 1 per cent Squares containing less than 0.5 per cent of the usable looks were marked with plus signs. Results from all maneuvers also were added and tabulated. The data for the tabulation sheet containing all maneuvers are given to the nearest 0.1 per cent with plus signs referring to values of less than 0.05 per cent of the total looks, since the total looks for all maneuvers are distributed more evenly. Therefore, smaller variations in percentage values increase in importance

Each of Figs. 8 to 27, inclusive, contains two curves. The solid curve represents the distribution of windshield fixations in the vertical direction, and the dashed curve represents the distribution of fixations in the horizontal direction The height of the vertical fixation curve for each 5° increment of vertical arc is the sum of the percentages of each 5° block in that horizontal column. Similarly, the height of the horizontal eye-movement curve for each 5° of horizontal arc is the sum of the percentages of each 5° block in that vertical column. The grid lines were used for plotting scales, each increment representing 2 per cent of the total usable photographic frames.

The horizontal zero reference line shown in Figs. 8 to 28 is an imaginary line on the aircraft directly ahead of the pilot and coincident with the horizon when the aircraft is in level flight attitude. The vertical zero reference is directly in front of the pilot and coincident with the aircraft centerline. The curves are intended to show the general characteristics of the data. Both graphical and numerical data for each maneuver are shown so that a better evaluation and understanding can be made of the interrelationship among upward, downward, left, and right fixations.

In the discussion of the data which accompanies each tabulation sheet, there is mention of aircraft attitude, velocity, rate of climb, and so forth, for each maneuver. These data were obtained from movies used in the reduced visibility tolerance studies conducted at Fort Knox, Ky. These data represent the average performance of 11 pilots performing each maneuver twice.

DISCUSSION

Taxi See Fig. 8.

Pilot eye movements were recorded while taxiing either from the ramp to the active runway before takeoff or from the runway to the ramp after landing The aircraft attitude was about 12° nose up during taxi Data for three pilots were recorded for a total of 698 photographic frames.

The solid curve shown in Fig 8 shows that the primary use of the windshield is between 5° and 20° below the zero reference. This corresponds to a region 7° above and 8° below the horizon

The broken curve shown in Fig. 8 shows that the pilots used the area from 45° left to 45° right of the aircraft centerline predominantly.

Takeoff. See Fig. 9.

Recording of pilot's eye movements during takeoff began when the throttle was opened for takeoff and ended when the pilot completed his straight climb-out. The aircraft attitude during takeoff roll and climb-out varied between 11° and 15° nose up The ground run averaged 23 seconds and the break-ground indicated air speed (IAS) was 61 miles per hour (mph). Climb-out IAS averaged 71 mph and the average rate of climb was 660 feet per minute (fpm). The climb-out was straight until an altitude of about 450 feet was reached. Three pilots are represented for a total of 992 photographic frames.

The solid curve shown in Fig 9 shows the major windshield usage was 10° to 15° below the zero reference. In view of the climb-out attitude, this indicates that the pilot's principal point of interest was either the horizon or some object directly in line with the horizon.

The dashed curve shows a peak usage in the 10° left to 5° right sector of the windshield, indicating that the pilots were interested primarily in seeking visibility straight ahead The moderate scanning between 130° left and 140° right probably was due to the pilot searching for other aircraft in the pattern during climb-out.

Cruise. See Fig. 10.

Pilot eye movements during cruise were recorded during straight and level flight while the aircraft was en route between maneuvering areas. The average aircraft attitude was 3° nose up and the average speed was 90 mph. Three pilots are represented for a total of 856 photographic frames.

The solid curve shown in Fig. 10 shows major interest in the windshield area 10° above to 20° below the zero reference. When accounting for the aircraft attitude, this indicates that the pilots were interested in a strip of windshield 7° above to 23° below the horizon.

The dashed curve shows a peak between 0° and 10° left of the centerline of the aircraft. The relatively high percentages in the 0° to

10° right sector resulted from one of the pilots tending to cruise with his vision on the right side of the aircraft centerline.

Landing - Downwind Leg See Fig. 11

Pilot eye movements during the downwind leg of a normal landing were recorded from the beginning of the turn onto downwind to the middle of the turn onto base leg. All landings followed a left-hand traffic pattern. There are no data available on the aircraft performance or attitude during this phase of landing. Three pilots are represented for a total of 575 photographic frames.

The solid curve shown in Fig. 11 shows a peak between 5° and 20° below, with a secondary peak occurring from 0° to 10° above the zero reference Two pilots tended to divide their concentration of looks between these two areas, whereas the third pilot tended to look below the zero reference during the entire maneuver. The concentration of looks below the zero reference is due to the pilot scanning for other traffic in the pattern that might be dangerous to his planned descent and landing and to his observations of the landing area. The concentration of looks above the zero reference is due to the pilots scanning for other aircraft that might be descending in such a way as to be on a collision course.

The dashed curve does not show a definite peak in any one area. The heavier concentration of fixations on the left is due to the left-hand traffic pattern and the left turns. The lack of a definite peak probably is due to the pilots' increased scanning of the airport and surrounding sky due to congested traffic around the airport.

Landing - Base Leg. See Fig. 12.

Pilot eye movements during flight on the base leg were recorded from the middle of the turn onto base leg to the end of the turn onto final approach. All traffic patterns were left-hand patterns. The aircraft attitude varied between 0° and 5° nose down. The average rate of descent was 660 fpm. The turn onto final approach was initiated at an altitude of about 225 feet. The maximum angle of bank during the turn was 21°. Three pilots are represented for a total of 349 photographic frames.

The solid curve shown in Fig. 12 shows a peak occurring between 0° and 5° above the zero reference. When considered with aircraft attitude, this indicates that the pilots tend to watch the horizon and/or some object on the same plane during flight on the base leg.

The dashed curve shows a definite tendency to use the left side of the aircraft windshield This is due partially to the turns onto base leg and final approach, and to the pilot's watching the active runway to obtain visual cues necessary for initiating his turn onto final approach.

Landing - Final Approach. See Fig 13.

Pilot eye movements during the final approach were recorded from the end of the turn onto final approach to the end of the landing roll During final approach, the aircraft attitude varied between 3° nose down and

10° nose up. The final approach IAS varied between 48 and 72 mph. The average rate of descent was 540 fpm and the average touchdown velocity was 48 mph. Three pilots are represented for a total of 481 photographic frames.

The solid curve shown in Fig. 13 shows that the area of the windshield used by the pilots was between 5° above and 15° below the zero reference. When aircraft attitude is considered, it is apparent that the pilots were interested in seeing slightly below the horizon, perhaps the end of the runway.

The broken curve shows a heavy concentration of fixations between 5° and 15° left of the aircraft centerline. This is due to the pilots obtaining visual cues on the ground to land the aircraft safely.

Short-Field Takeoff. See Fig. 14.

Pilot eye movements during short-field takeoffs were recorded from the moment the throttle was opened until the pilots began their turn after climb-out. The aircraft attitude varied between 11° and 15° nose up. The ground run averaged 22 seconds, the break-ground IAS was 55 mph, and the climb-out IAS averaged 63 mph. The climb-out was straight at a rate of 780 fpm. Three pilots are represented with a total of 577 photographic frames.

The solid curve in Fig. 14 indicates that the pilots' interest was between 5° and 15° below the zero reference. When this is considered with the fact that the aircraft was in a 11° to 15° nose-up attitude, it is apparent that the pilots were looking at or slightly below the horizon. This probably is due to the pilots observing the treetops to check for adequate clearance. The fixations between 15° and 20° above the zero reference are the result of the pilots scanning the area ahead of them for any low-flying aircraft that might interfere with their climb-out.

The broken curve indicates a strong tendency of the pilots to look between 5° right and 5° left of the aircraft centerline. Note the looks of the pilots up and to the rear to check for aircraft that might be flying into the field. The looks to the side and rear, as shown by the broken curve, are due to the pilots scanning for other aircraft as they climbed above the treetops.

Short-Field Landing. See Fig. 15.

Pilot eye movements during short-field landings were recorded from the beginning of the final approach to the end of the landing roll. The aircraft attitude varied from 3° nose down to 12° nose up. The average IAS was 53 mph and the average rate of descent was 480 fpm. Three pilots are represented for a total of 1,117 photographic frames.

The solid curve in Fig. 15 shows that the primary use of the windshield was between 5° and 15° below the zero reference. This corresponds to 12° above and 8° below the horizon, assuming that the average nose-up attitude of the aircraft was 7°.

The broken curve indicates that the pilots used the area of the windshield from 20° left to 45° right of the aircraft centerline. The peak in the curve that occurs between 5° and 10° left of the aircraft centerline is the area actually used in landing the aircraft. Note the similarity between this peak and the peak in the broken curve in Fig. 13. The main difference in these curves is that in the final approach to an airstrip with a control tower, the pilots concentrated more on the landing strip than they did when they came into an uncontrolled field where they had to check their own clearance of the area in order to avoid other aircraft.

High Reconnaissance of Field Landing Strip. See Fig. 16.

Pilot eye movements during high reconnaissance were recorded from the time the pilots positioned the aircraft in line with the landing field to the point where they turned away from the field. The purpose of such a reconnaissance is for the pilot to observe certain conditions, including obstructions such as power lines, wire fences, and so forth, which might prevent an aircraft from landing. The aircraft attitude was 3° nose up, the average speed was 84 mph, and the maneuver was performed at an average altitude of 85 feet. Three pilots are represented for a total of 777 photographic frames.

The solid curve shown in Fig 16 indicates that the pilots' primary zone of interest was between 10° above and 10° below the zero reference. All points above 3° below the zero reference are above the horizon, and were the areas actually used to fly the aircraft and/or check for other traffic. Those points below 3° below the zero reference are below the horizon, and were the areas actually used in reconnaissance of the landing field and/or keeping the aircraft clear of treetops.

The dashed curve shows the primary zone of interest to be between 20° and 90° left of the aircraft centerline. All high reconnaissance maneuvers were performed to the right of the field; therefore, in order that the pilots can observe the landing area, they must use the left portion of their windshield and their left side window.

Low Reconnaissance of Field Landing Strip. See Fig. 17.

Pilot eye movements during low reconnaissance were recorded from the point where the pilots aligned their aircraft with the landing field to the point where the pilots began to turn away from the field after climbout. The purpose of such a reconnaissance is for the pilot to observe the landing strip at very low altitude for hazards such as logs, rocks, extremely rough surface, and to observe any peculiar conditions which might affect the landing characteristics of an aircraft, such as abnormal wind currents and thermals. The average attitude during this maneuver was 2° nose up and the maneuver was performed at an average speed of 68 mph at an altitude of 2 to 5 feet. Three pilots are represented for a total of 738 photographic frames.

The solid curve shown in Fig. 17 indicates that the pilots were interested primarily in visibility between 5° above and 10° below the zero reference This corresponds to a region 3° above to 12° below the horizon.

The points above the horizon are those areas of the windshield used in checking for clearance above treetops and to check on air traffic during climb-out. The area below the horizon is the area used to observe the landing field and to check clearance above the ground

The dashed curve shows a peak zone of windshield use between 10° and 40° left of the aircraft centerline. All low reconnaissance maneuvers were performed with the aircraft flying to the right of the landing field.

Message Pickup. See Fig. 18.

Pilot eye movements during message pickups were recorded from the beginning of the straight descent for the low pass to the end of the climb-out after the pickup was made. The attitude of the aircraft varied from 6° nose down during the approach through 1° nose up during the pickup to 15° nose up during the climb-out. The average rate of descent during the approach was 720 fpm and the average rate of ascent during climb-out was 780 fpm. The speed of the aircraft varied from 73 mph during the approach and climb-out to 66 mph during the low pass for the pickup. Three pilots are represented for a total of 922 photographic frames.

The solid curve shown in Fig. 18 indicates a primary use of windshield between 10° above and 10° below the zero reference, with a peak occurring at 0° to 5° below the zero reference.

The dashed curve shown in Fig. 18 shows a definite peak between 5° and 10° left of the aircraft centerline. This peak probably is due to the pilots judging their alignment on the message pickup apparatus through this sector of the windshield

Message Drop. See Fig. 19.

Pilot eye movements during message drops were recorded from the time the pilots began their straight descent to the drop area and continued until the pilots began their climb-out after the message drop. No information is available on the aircraft attitude during the maneuver. Three pilots are recorded for a total of 755 photographic frames.

The solid curve shown in Fig. 19 indicates a primary use of the windshield in a zone from 5° above to 10° below the zero reference. This probably is due to the pilots watching the horizon and/or treetops during this maneuver. The broken curve indicates pilots' use of the windshield from 15° right to 80° left.

Wire Laying. See Fig. 20.

Pilot eye movements during the wire-laying mission were recorded from the time the wire was paid out until the wire separated from its container during this maneuver. Due to a shortage of wire-laying "donuts," only one pilot flew this mission. There is no information available on the aircraft attitude during this maneuver. One wire bundle consisting of five wire "donuts" was used on the right wing bundle rack One pile is represented for a total of 176 photographic frames.

The solid curve shown in Fig. 20 indicates a definite need for visibility below the zero reference. This is the area of the windshield used to follow the wire-laying course and to keep the aircraft from colliding with treetops.

The broken curve shown in Fig. 20 shows three definite peaks, all occurring between 30° left and 20° right of the aircraft centerline. The peaks on either end of the curve are due to the right and left turns performed by the pilot as he followed the wire-laying course. The center peak is the result of the straight flight between turns in the wire-laying course. The points between 55° and 80° right are caused by the pilot glancing at the wire bundle under his right wing.

Road Reconnaissance. See Fig. 21.

Pilot eye movements during road reconnaissance were recorded from the time the pilots started their reconnaissance maneuver and continued for a period of about 45 seconds to 1 minute. The aircraft attitude was 2° nose up and the maneuver was performed at an average speed of 85 mph. The average altitude for performing this mission was about 375 feet. Three pilots are recorded for a total of 583 photographic frames.

The solid curve shown in Fig. 21 indicates that the area of primary importance was between 0° and 25° below the zero reference, a definite peak occurring between 10° and 15° below the zero reference.

The broken curve indicates two primary zones of use, one occurring from 15° to 40° left, the other occurring between 15° and 30° right. These two peaks show the areas of the windshield used. The pilot's choice of window area was dependent on which side of the road he was flying.

Bridge Reconnaissance. See Fig. 22.

Pilot eye movements during the bridge reconnaissance missions were recorded after the pilots began their reconnaissance and continued for a little over a minute The aircraft attitude averaged 2° nose up. The aircraft was flown at an average speed of 78 mph and at an average altitude of 270 feet. Three pilots are represented for a total of 824 photographic frames.

The solid curve shown in Fig 22 indicates the primary windshield use was between 5° above and 10° below the zero reference. The broken curve shows that the pilots positioned their aircraft in such a way that they could observe the bridge 25° to 90° left of the aircraft centerline.

Supply Drop. See Fig. 23

Pilot eye movements during supply drops were recorded from the moment the pilots began their low pass for the drop and continued until after the drop was completed and the pilots began their climb-out. No specific information is available on the aircraft performance during a supply drop Three pilots are represented for a total of 946 photographic frames.

The solid curve shown in Fig. 23 indicates a definite tendency of the pilots to concentrate windshield use in a region between 5° above and 10° below the zero reference

The broken curve indicates that there is no definite windshield zone used by pilots during this maneuver. The primary windshield usage is overwhelmingly to the left of the aircraft centerline. The reason for this is unknown, as the aircraft was symmetrically loaded with one supply bundle attached to each wing, and the maneuver was performed in an airspace having no apparent hazard to safe flight on either side. It is reasonable to assume, therefore, that the pilots performing this maneuver favored the left side of the windshield for some reason other than for satisfactory performance of this maneuver.

Formation Flying. See Fig. 24.

Pilot eye movements during formation flying were recorded from the time the pilots began to fly into formation and continued for about 3 minutes. No specific data are available on aircraft performance during this maneuver. Three pilots are represented for a total of 1,951 photographic frames.

The solid curve shown in Fig. 24 shows the primary zone of windshield use to be between 5° and 20° below the zero reference.

The broken curve indicates a very definite use of the windshield between 15° and 30° to the left of the aircraft centerline. It should be noted that in all cases the lead plane was to the left of the subject pilots' aircraft. Visibility during formation flying is not a critical problem because the pilots will tend to position their aircraft in such a manner as to view the other aircraft through available windshield area.

Artillery Spotting. See Fig. 25.

Pilot eye movements during artillery spotting were recorded from the approach to the target to the destruction of that target. During this maneuver, a qualified observer controlled the fire from the rear seat and he directed the pilots as necessary. During artillery spotting, the aircraft was flown with a nose-up attitude of 4°, at an average speed of 70 mph, and at an average altitude of 2,000 feet. Three pilots are represented for a total of 3,821 photographic frames.

The solid curve shown in Fig. 25 indicates primary use of the windshield area between 5° above and 15° below the zero reference, with moderate interest shown as high as 10° above and 20° below the zero reference. This would indicate that the pilots want to see between 6° above and 24° below the horizon.

The broken curve does not show any definite peak, indicating that the pilots use the available visibility between 95° left and 100° right of the aircraft centerline.

Turns. See Fig. 26.

Pilot eye movements were recorded during 12 left-hand turns for each pilot, six 90° turns and six 180° turns. They were climbing, level, and gliding turns. These turns were recorded as either normal or maximum performance. Normal turns were performed as the pilots normally would perform a turn while cruising Maximum-performance turns were performed as the pilots might perform the turns in a combat situation where the maximum performance of the aircraft would be required. The angle of bank varied between 22° and 87°, and the nose-up attitude varied from 25° nose up to 52° nose down. The IAS ranged from 61 to 105 mph See Table I for a complete breakdown of aircraft attitude for each of the 12 turns. Three pilots are represented with a total of 3,752 photographic frames.

TABLE I

AIRCRAFT PERFORMANCE DURING 12 DIFFERENT TURNS
(AVERAGE PERFORMANCE OF 11 ARMY PILOTS)

Maneuver	Angle of Bank (deg.)	Maximum Nose-Up Attitude (deg.)	Speed into Turn (mph)	Speed Out of Turn (mph)	Average Rate of Climb or Descent (ft./min.)
90° Climbing Turn Normal	27	12	91	78	540
Level Turn Normal	33	2	90	86	000
Gliding Turn Normal	22	5	86	93	-600
180° Climbing Turn Normal	30	14	90	81	600
Level Turn Normal	33	2	87	87	000
Gliding Turn Normal	24	- 5	61	91	-600
90° Climbing Turn Maximum	55	26	86	78	840
Level Turn Maximum	69	1	92	95	000
Gliding Turn Maximum	71	-37	90	105	-1020
180° Climbing Turn Maximum	60	25	87	77	600
Level Turn Maximum	66	0	89	94	000
Gliding Turn Maximum	87	-52	86	104	-1620

The solid curve shown in Fig. 26 shows the vertical distribution of horizontal scanning for all turns. The pilots' primary windshield use was in the region 10° above and 15° below the zero reference.

The dashed curve shows that the pilots primarily were using the left side of the windshield, actually from 10° right to 35° left of the aircraft centerline. This is to be expected when performing left-hand turns.

All Maneuvers. See Fig. 27.

The percentage of looks in each 5° square for all pilots performing all maneuvers is shown in Fig. 27 for a total of 20,896 photographic frames.

The peak of the solid curve indicates that the pilots tend to concentrate their use of the windscreen between 20° above and 25° below the zero reference. The region above 20° is used primarily to search for other traffic. No doubt considerable air search is performed in the lower regions of the aircraft windshield, but these fixations are intermingled with those for the actual performance of the maneuvers and are indistinguishable.

The dashed curve shows a primary use of the windshield in the region from 10° right to 50° left of the aircraft centerline with an additional peak between 60° and 90°. The cockpit of the L-19 aircraft is symmetrical. The major concentration of fixations are located to the left of the centerline because all maneuvers requiring the pilots to favor one side of the aircraft, such as high and low reconnaissance, turns, and the like, were performed in a manner which required the pilots to use the left side so that the resulting data would be consistent.

GENERAL DISCUSSION

The distribution of looks or photographic frames for all pilots during all maneuvers is shown in Fig. 28. The dashed outline superimposed on this figure represents the minimum cockpit visibility requirements determined in the previous study.[4] Actual frame counts were used in this case in lieu of percentages since it is desired to discuss the details of the distribution of looks. It is believed that if only one pilot makes just one glance to search for visual guidance while flying an airplane, the importance of that glance must be considered.

It can be seen that some observations fall outside the average L-19 windshield outline. Some of the reasons for this are:

1. The variation in aspect to the windshield and windows due to varied seated heights and/or fore and aft seat adjustments. The windshield outlines used during data analysis corresponded to the true angular presentation of the windshield as seen by the pilot whose looks were being analyzed.

2. The pilots' use of peripheral vision to look into certain areas while unconsciously fixating on structure. This is particularly true in looking through the top windows. The pilots appeared to be looking at the radio panels in the wing roots while actually gleaning information from the windows both above and below the wing roots.

3 At some moments, a pilot's eyes must pass over some areas which are not windshield

4. There are some normal reading inaccuracies.

[4]Eugene E. Pazera, op. cit.

The minimum cockpit visibility requirements determined from the questionnaire study were based on an assumption that the aircraft configuration for liaison-reconnaissance work would be similar to the Cessna L-19; that is, single-engine, high-wing, and conventional landing gear, with the pilot and observer seated in tandem. With this configuration, the preliminary requirements appear to be entirely adequate, if not over-generous in some areas. The need for visibility downward beyond 90° to the side is extremely limited At the same time, the wing root imposes a limitation to badly needed visibility upward at 90° to the side. Increasing the minimum requirement for upward visibility at 90° to the side beyond 8° for a high-wing aircraft similar to the Cessna L-19 would gain very little since the wing itself imposes the primary restriction to upward visibility. The need expressed for visibility above the wing in the questionnaire study is substantiated further in this study. Such visibility should extend horizontally from 60° to 120° and vertically from 30° to 60°. The vertical angular obstruction to vision caused by the wing root should be kept to a minimum to allow easy passage from side window to top window. If a greater degree of freedom in the selection of future aircraft configurations is permissible, there is sufficient evidence from this study to suggest that the design of an aircraft incorporate the seating of the pilot slightly forward of the leading edge of the wing to eliminate its interference with the pilot's vision. Also, by locating the average pilot eye height just below the level of the wing chord, the obstruction to rearward visibility will be minimized.

Extensive use also is made of all available visibility down over the nose of the aircraft. It would appear that additional downward visibility would be used if available. However, the highest concentration of looks occur at 5° to 10° to the left of the centerline of the aircraft and 5° to 10° below the horizon. Below 10°, a progressive decrease in looks to the sides is noticeable where visibility down to 40° below the horizon is available. It is believed, therefore, that downward visibility over the nose to 17° below the horizon will provide minimum adequate visibility for all maneuvers where the presence of an engine in front of the cockpit will tend to impose design limitations, and that 30° below the horizon will provide excellent visibility where the design configuration of the aircraft will permit such an increase.

A windscreen outline relating the preliminary minimum windscreen requirements developed in the questionnaire and reduced vision tolerance study to the desired changes determined from the pilot eye-movement study is shown in Fig. 29.

CONCLUSIONS

It is concluded that:

1. The three pilots taking part in the pilot eye-movement study during the performance of the prescribed maneuvers focused their attention on an area equivalent to 54 per cent of the total available area of visibility from

the L-19 airplane. The average total available visibility from the L-19 airplane is 5.36 steradians, or 43 per cent of the theoretical available visibility from the center of a sphere.

2. The areas on the windshield that show high percentages of usage generally are the areas through which the pilots obtain visual cues necessary to operate their aircraft and not the areas of the windshield which are used to search the airspace for other aircraft.

3. Use of the area of available visibility beyond a 90° azimuth angle on either side of the pilot represents less than 5.5 per cent of the total usage of available visibility.

4. The windshield area used by the pilots during the pilot eye-movement study substantiates, to a considerable extent, the conclusions drawn from the pilot questionnaire study.

5. Visibility is needed in the area of the obstruction to vision caused by the wing.

ACKNOWLEDGMENT

Acknowledgment is made to the personnel of the Army Aviation School, Fort Rucker, Ala., who gave every possible assistance in obtaining aircraft, pilots, and supporting services for TDC personnel conducting this study; to Lt. O'Connor, who was assigned to this project at Fort Rucker as Liaison Officer; and to Lts. Jenkins, Joyce, McCready, Morton, Schull, and Sink, who flew during their off-duty hours as subject pilots.

FIG 1 HEAD-MOUNTED CAMERA WORN BY AN ARMY PILOT

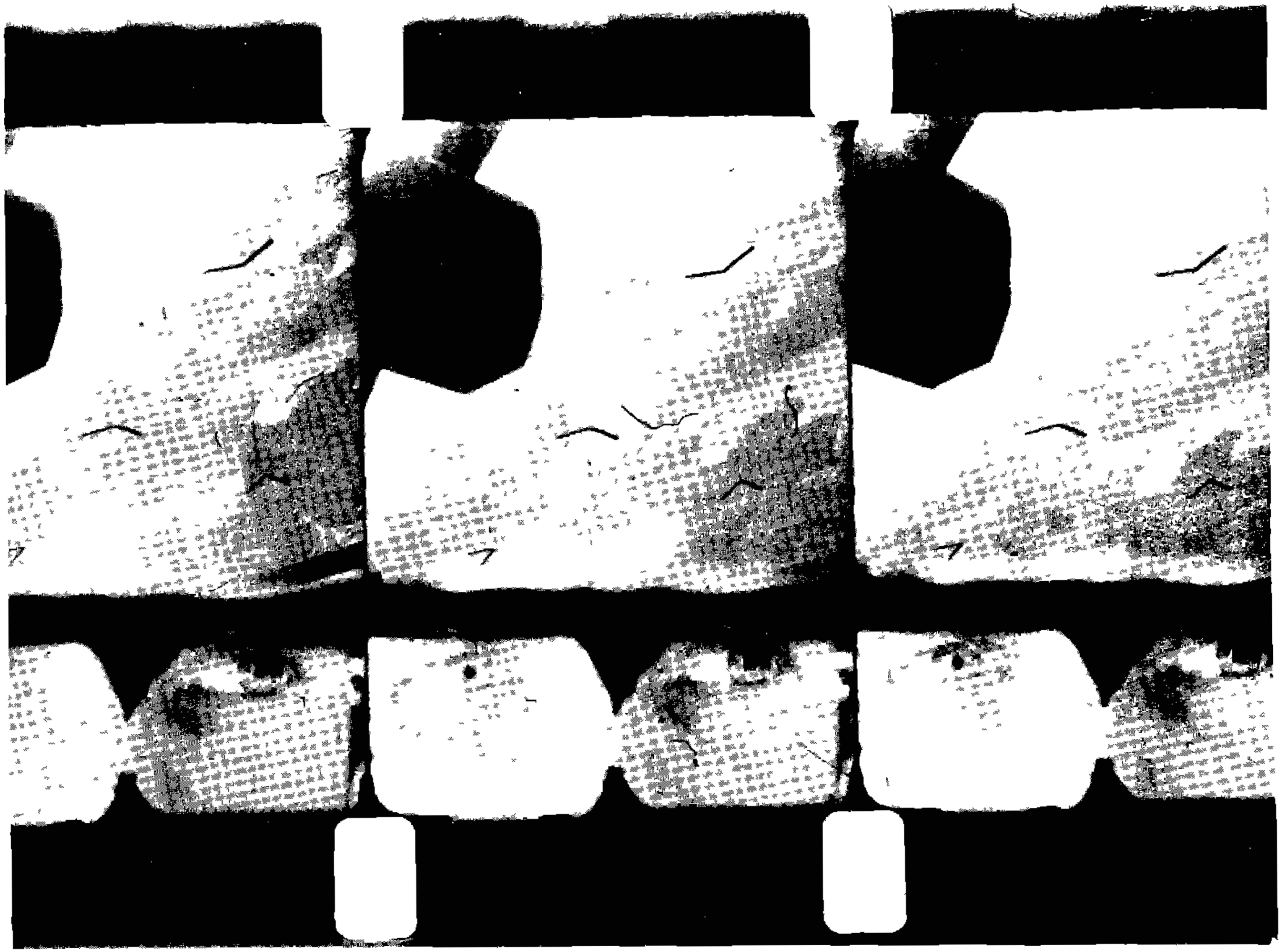


FIG 2 TYPICAL PHOTOGRAPHIC FRAMES TAKEN WITH THE HEAD-MOUNTED CAMERA

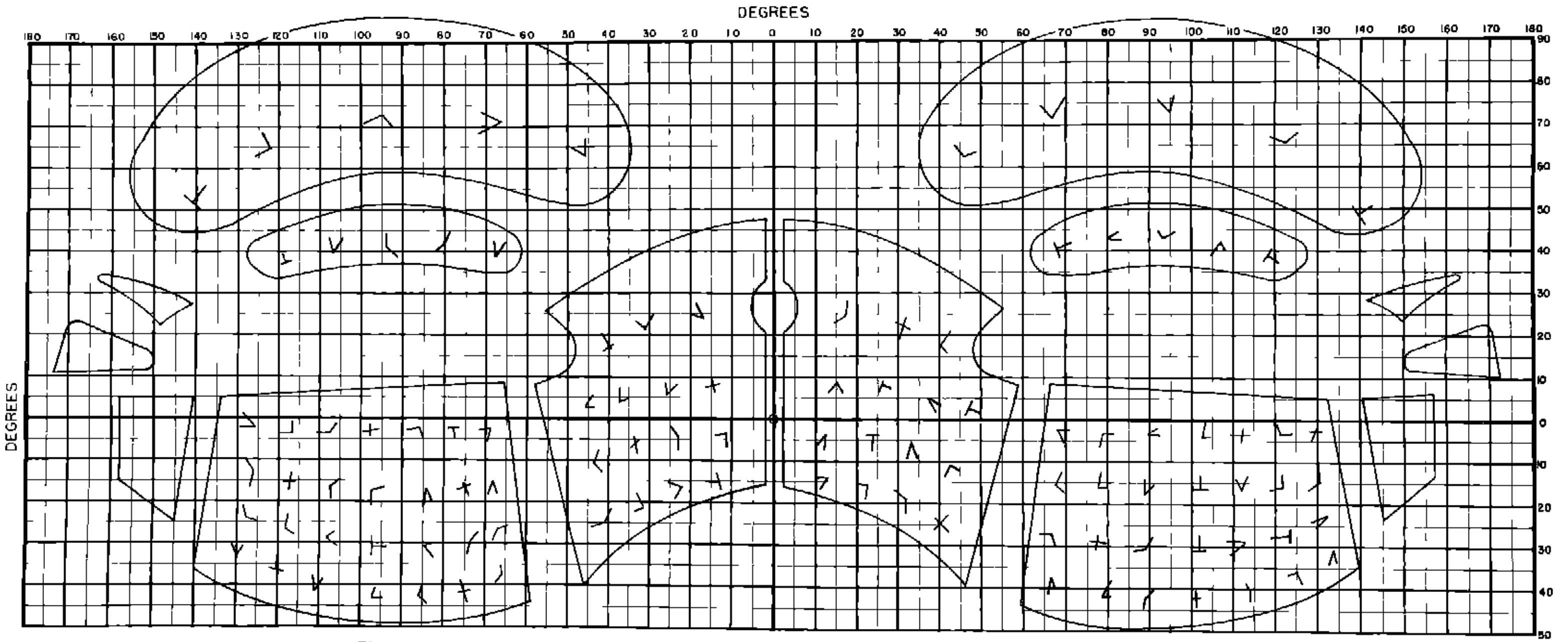


FIG 3 L-19 COCKPIT VISIBILITY OUTLINE SHOWING THE LOCATION OF THE TICK MARKS

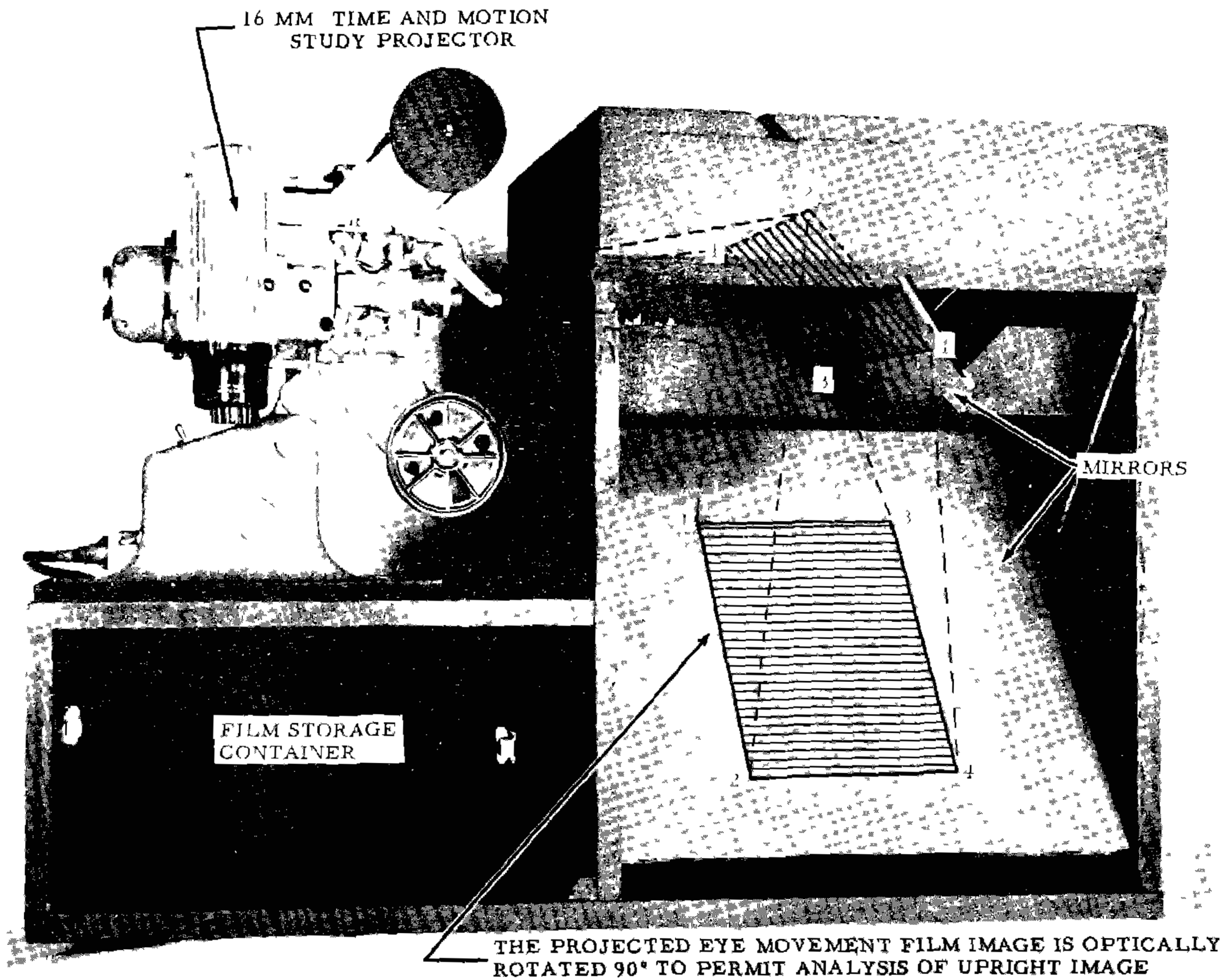


FIG. 4 MOTION PICTURE IMAGE RECTIFIER

FIG 5 FILM ANALYSIS ROOM SHOWING ACTUAL ANALYSIS

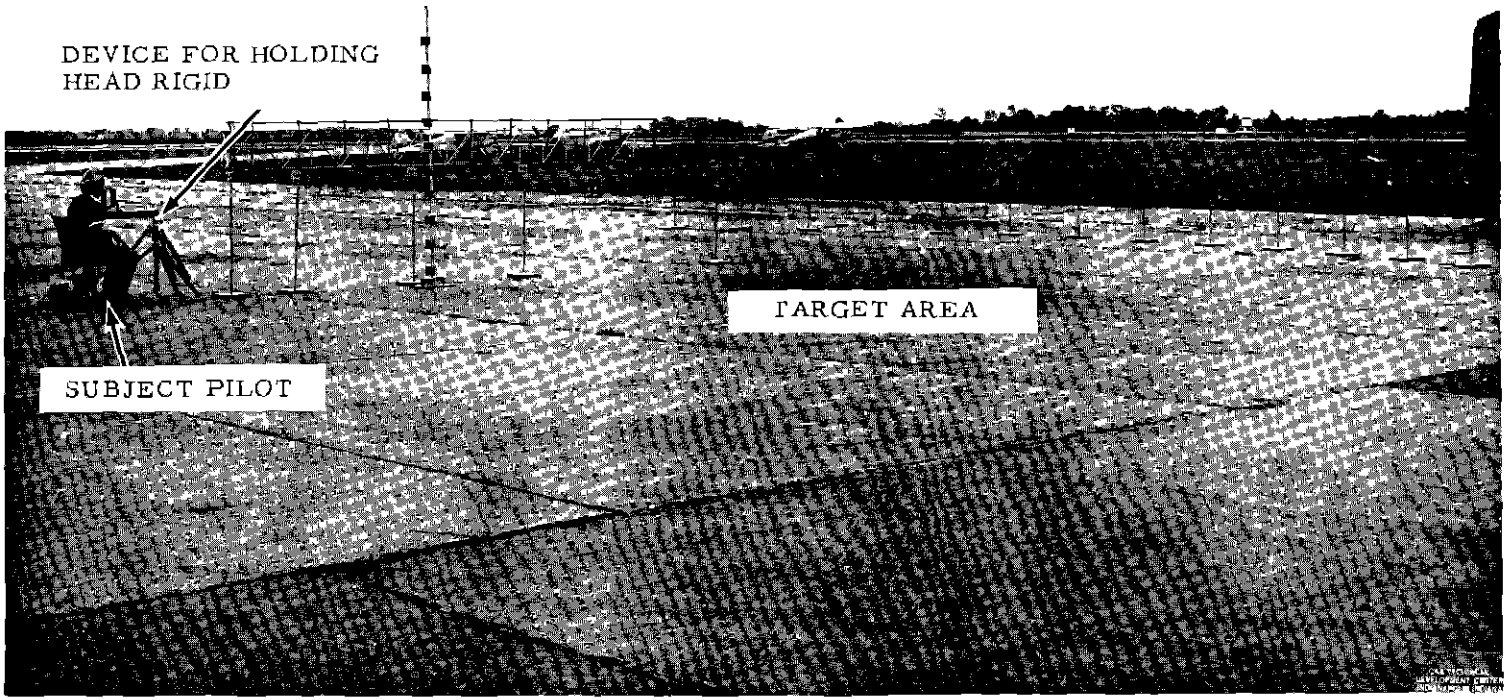


FIG 6 TARGET ARRANGEMENT FOR CORRELATING EYE AND VIEW FIELDS

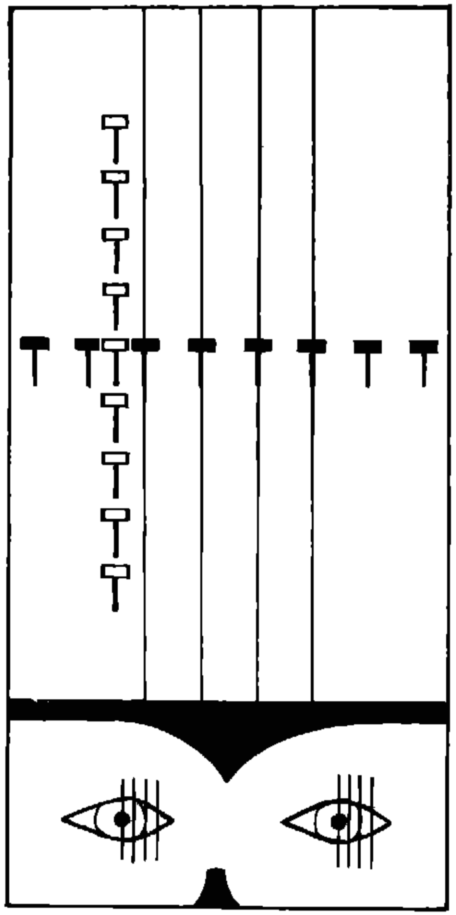


FIG 7A
CONSTRUCTION OF THE VERTICAL GRID LINES

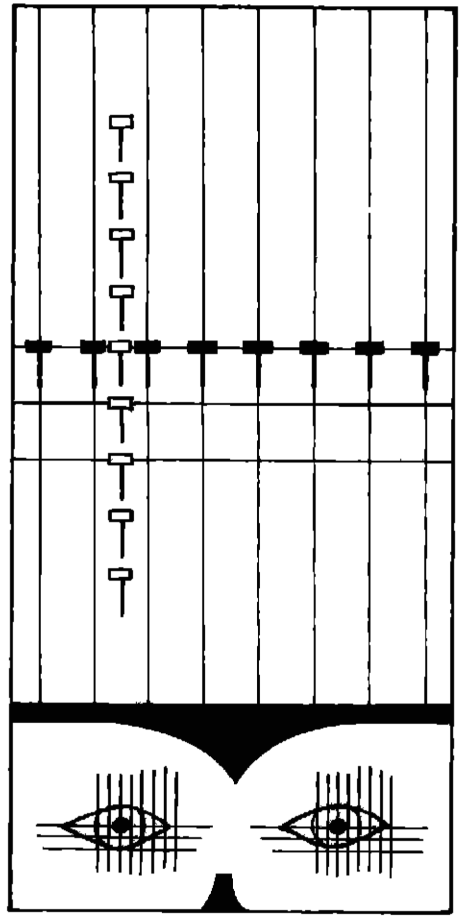


FIG 7B
CONSTRUCTION OF THE HORIZONTAL GRID LINES

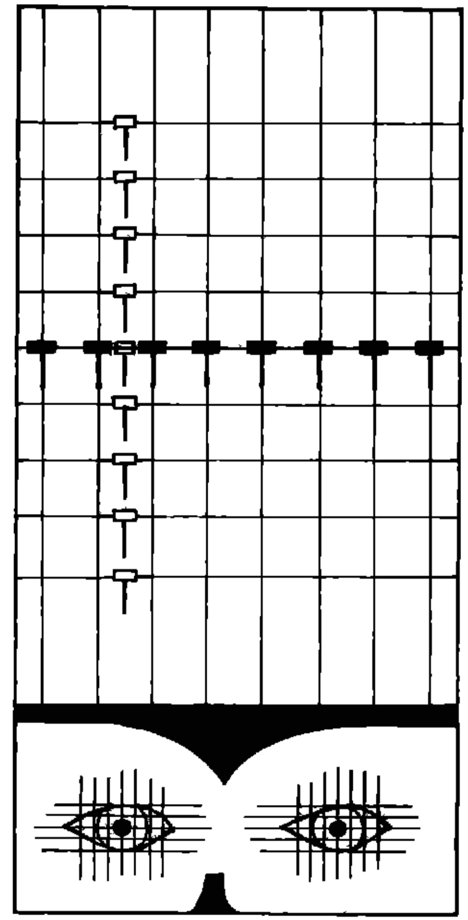
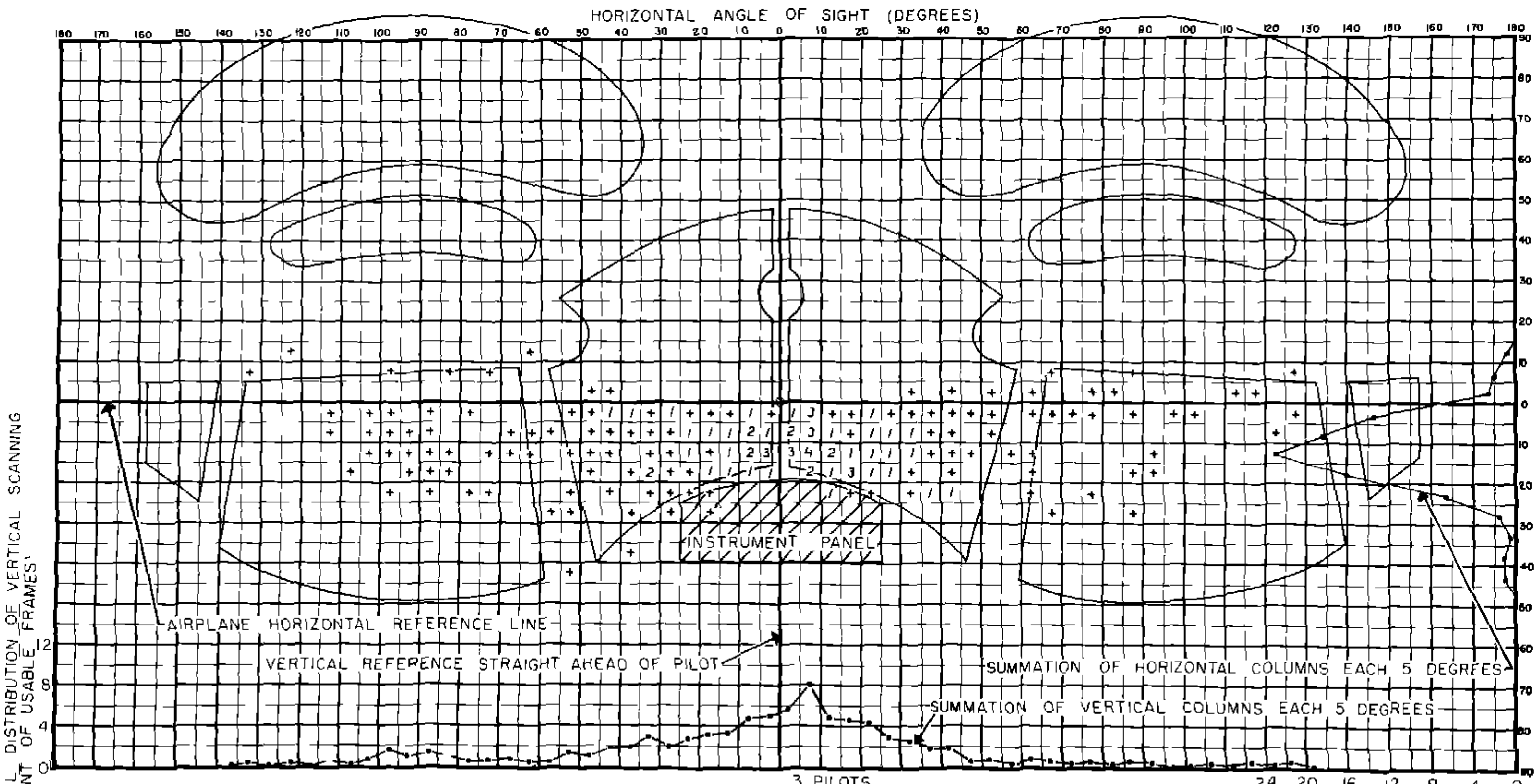


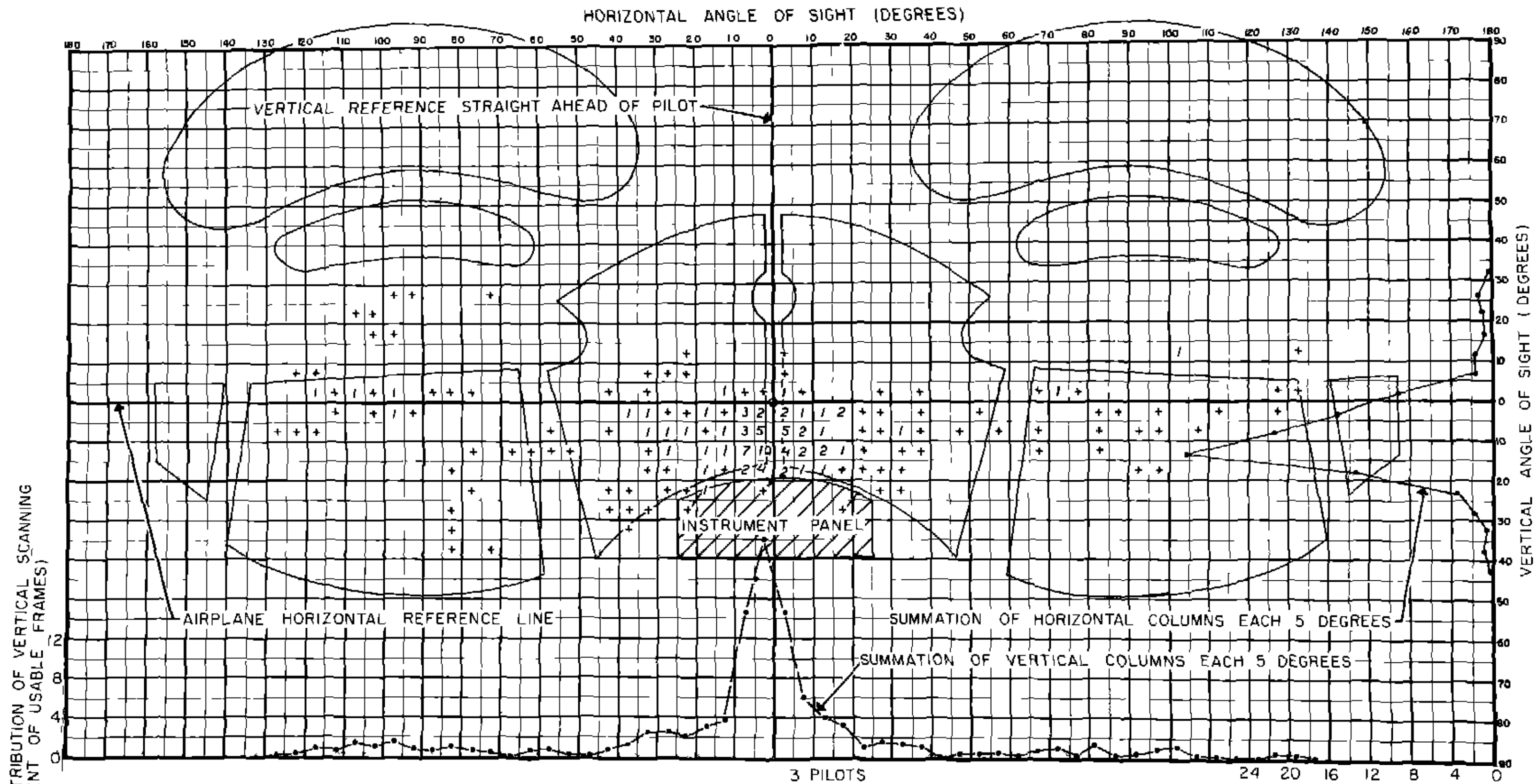
FIG 7C
COMPLETED GRID

FIG 7 CONSTRUCTION OF THE OVERLAY GRID FOR ANALYZING HEAD CAMERA FILM.



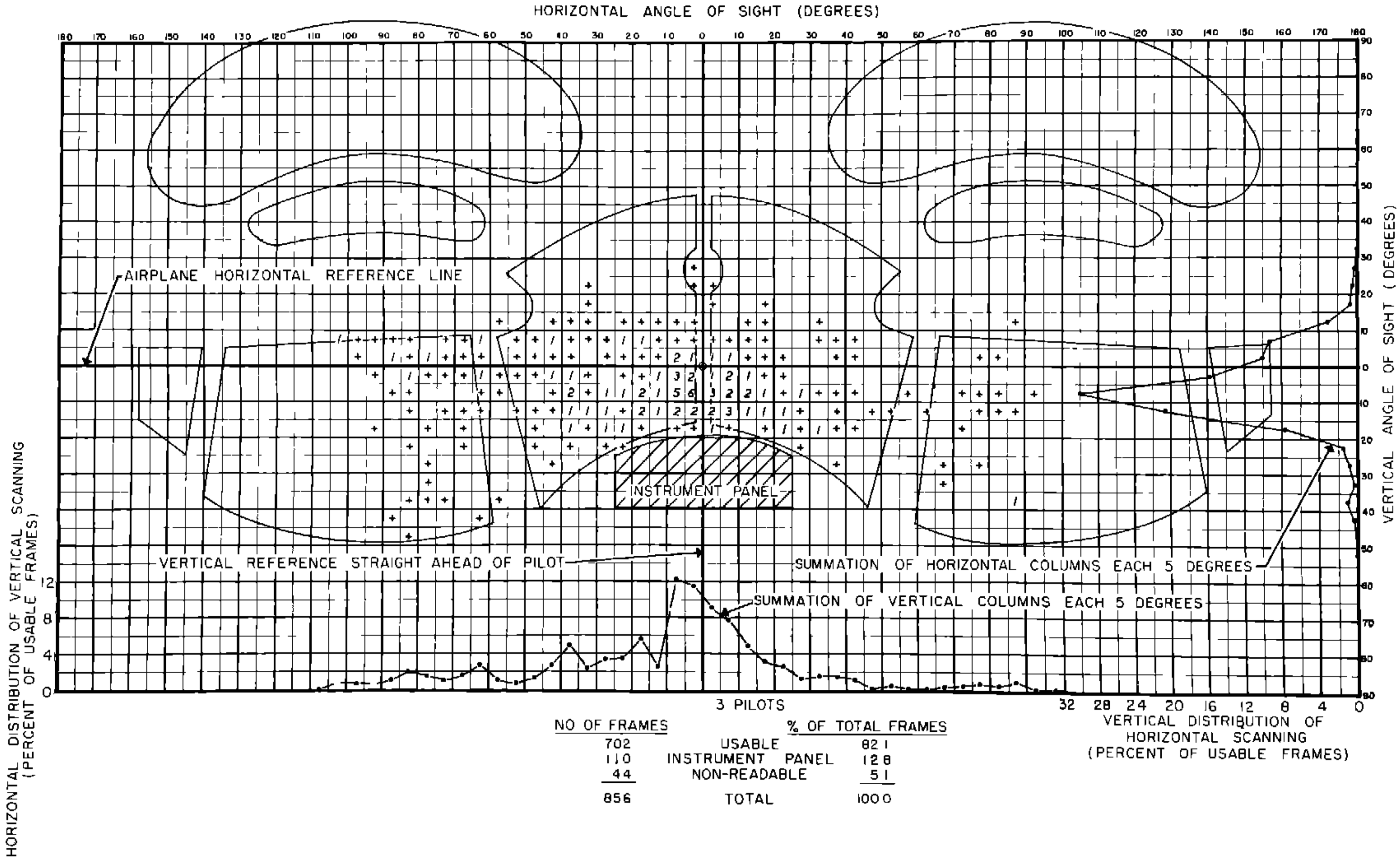
NO OF FRAMES		% OF TOTAL FRAMES
579	USABLE	83 0
57	INSTRUMENT PANEL	8 2
62	NON-READABLE	8 8
698	TOTAL	100 0

FIG 8 WINDSHIELD USE DURING TAXI



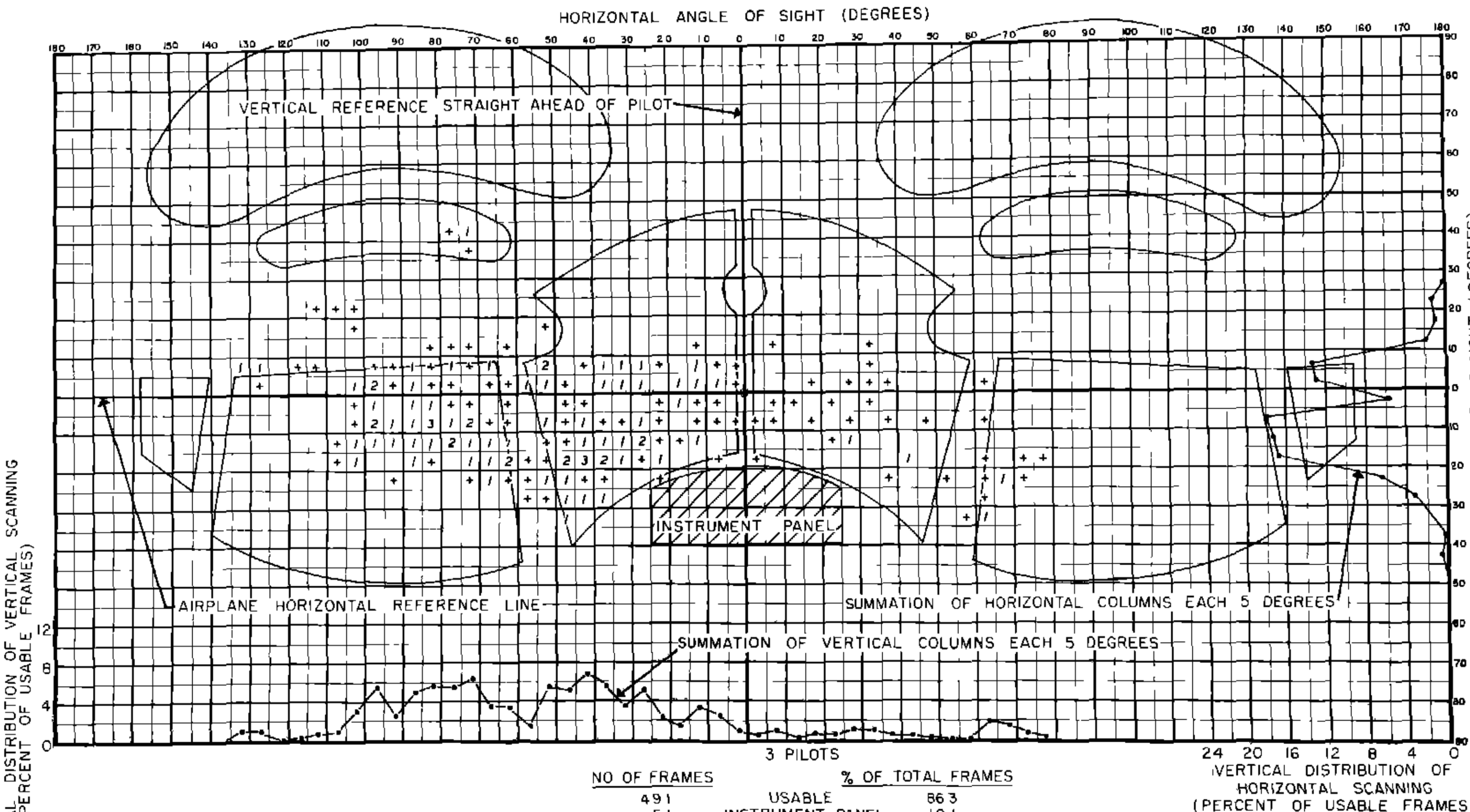
NO OF FRAMES		% OF TOTAL FRAMES
694	USABLE	70 0
189	INSTRUMENT PANEL	19 0
109	NON-READABLE	11 0
992	TOTAL	100 0

FIG 9 WINDSHIELD USAGE DURING NORMAL TAKE-OFF



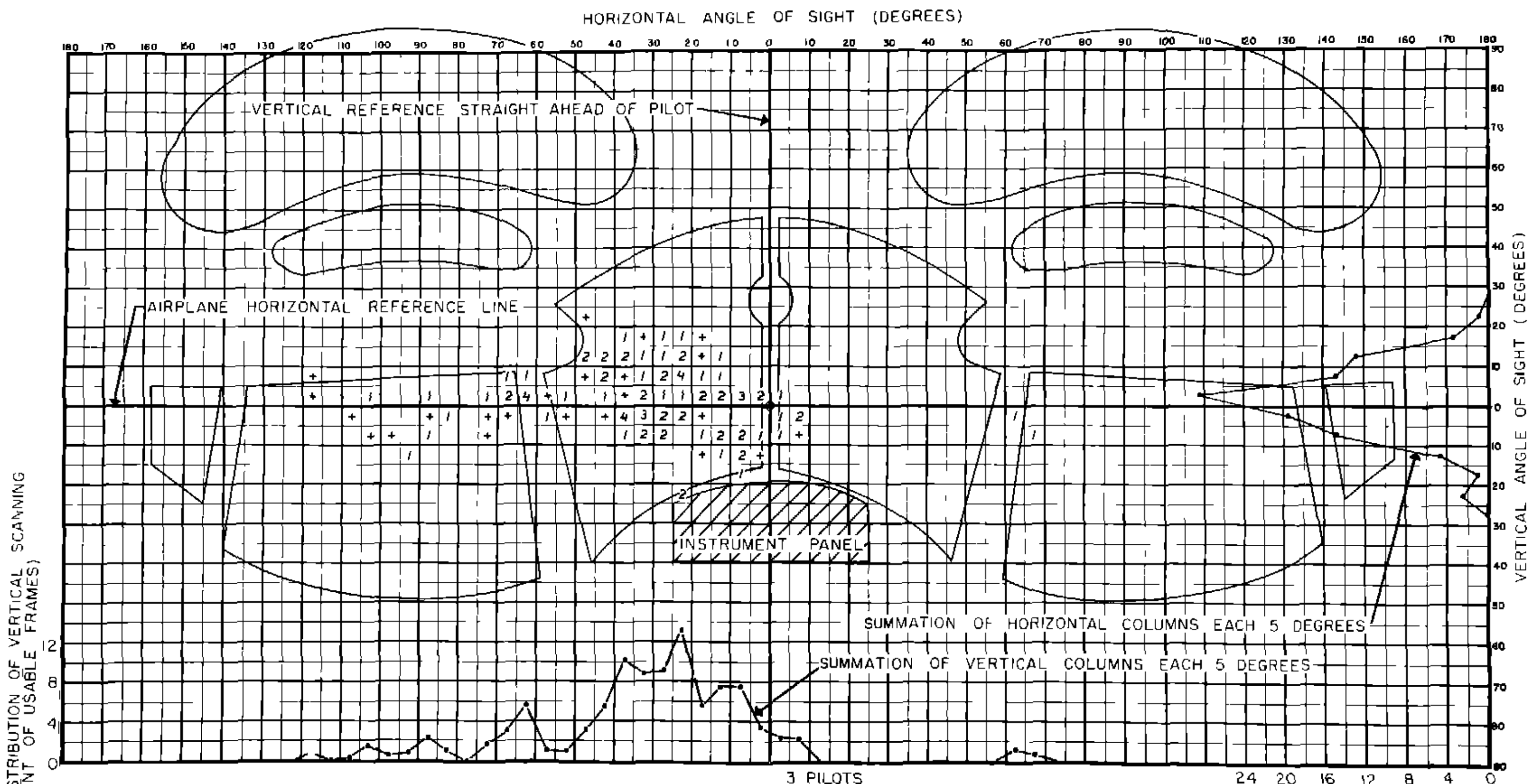
NO OF FRAMES		% OF TOTAL FRAMES
702	USABLE	82 1
110	INSTRUMENT PANEL	12 8
44	NON-READABLE	5 1
856	TOTAL	100 0

FIG 10 WINDSHIELD USAGE DURING CRUISE



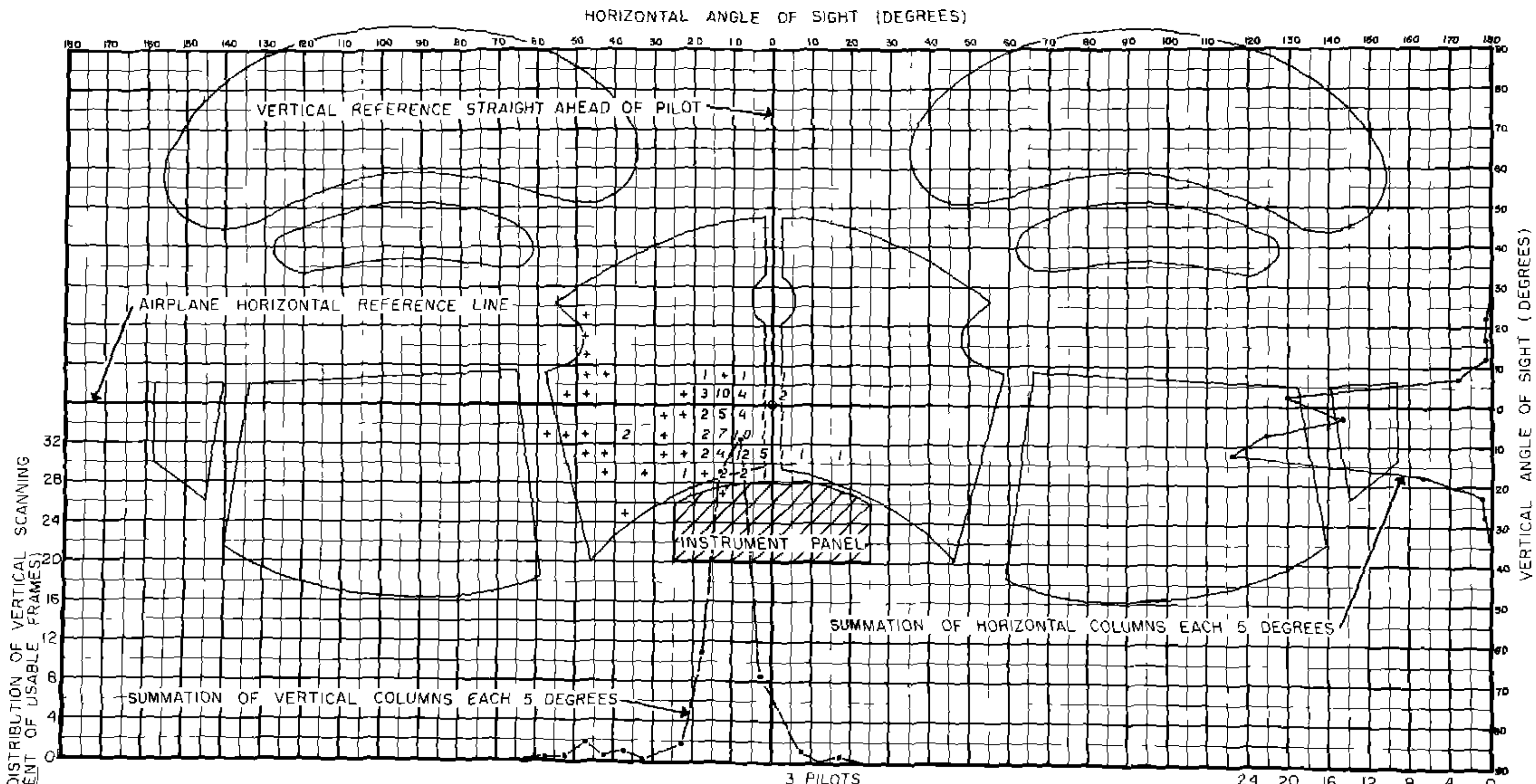
NO OF FRAMES		% OF TOTAL FRAMES
491	USABLE	86 3
51	INSTRUMENT PANEL	10 1
26	NON-READABLE	4 6
568	TOTAL	100 0

FIG 11 WINDSHIELD USAGE DURING NORMAL LANDING – DOWN WIND LEG



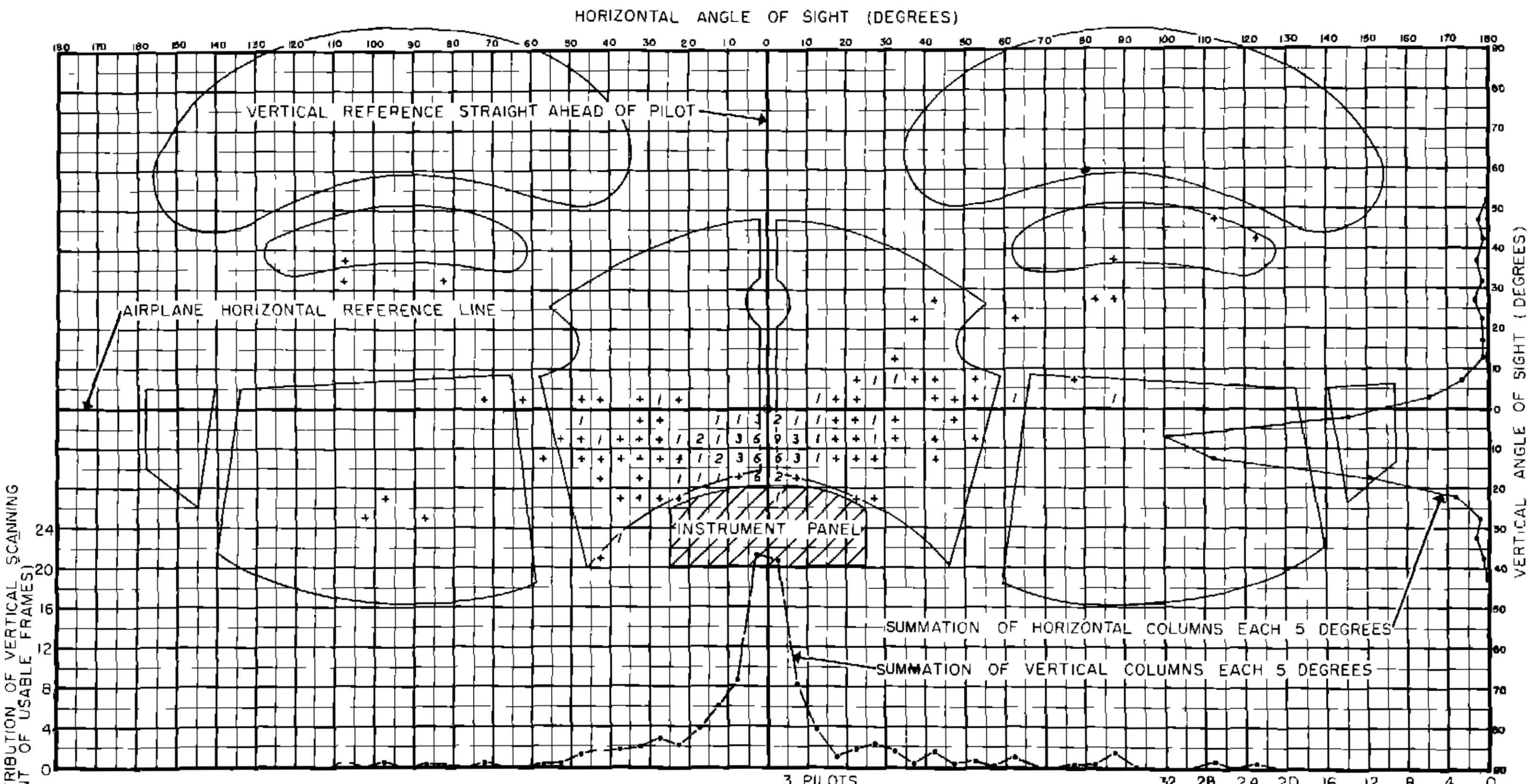
NO OF FRAMES		% OF TOTAL FRAMES
279	USABLE	80.0
34	INSTRUMENT PANEL	9.7
36	NON-READABLE	10.3
349	TOTAL	100.0

FIG 12 WINDSHIELD USAGE DURING NORMAL LANDING - BASE LEG



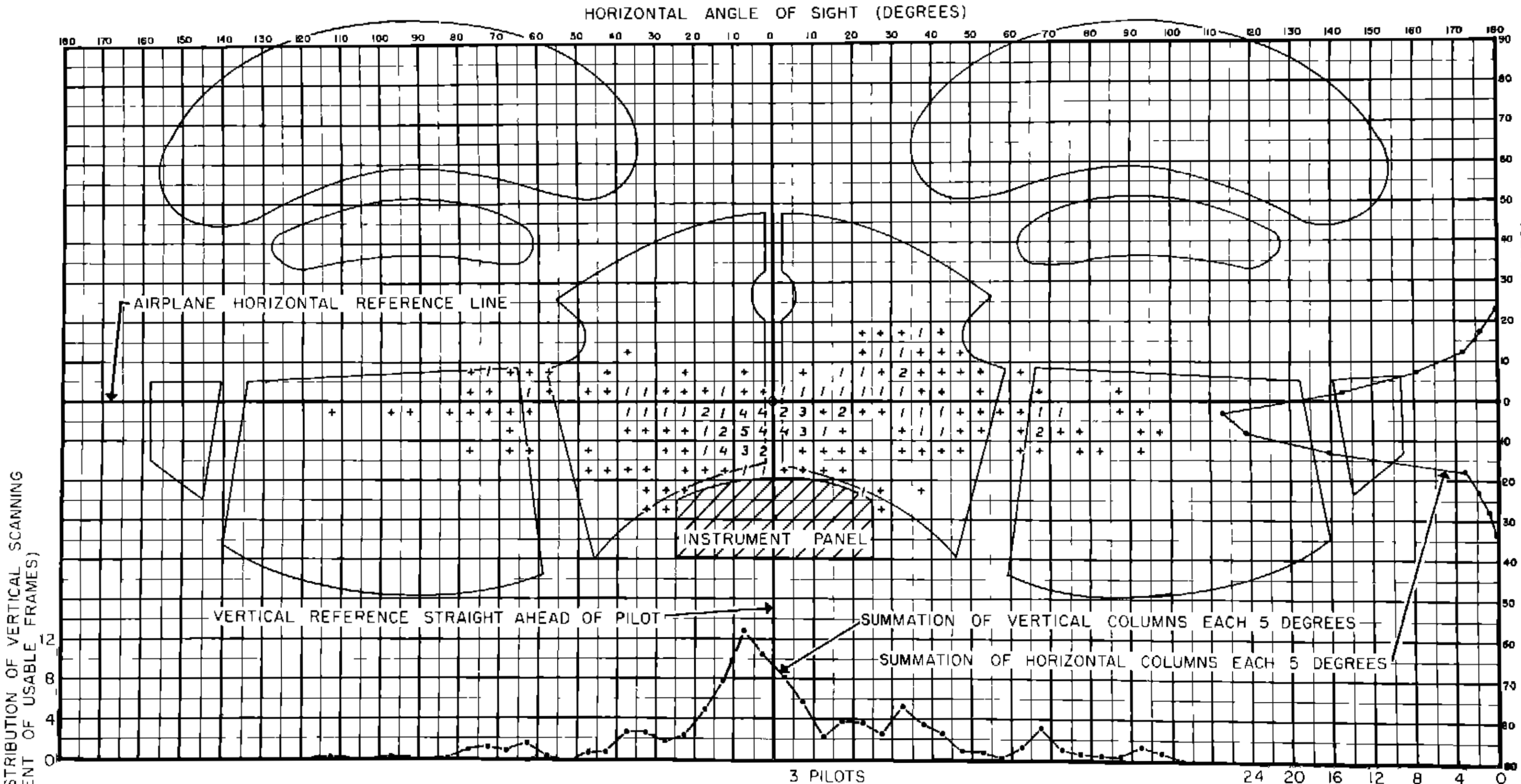
NO OF FRAMES		% OF TOTAL FRAMES
448	USABLE	93 2
7	INSTRUMENT PANEL	1 4
26	NON READABLE	5 4
481	TOTAL	100 0

FIG 13 WINDSHIELD USAGE DURING NORMAL LANDING - FINAL



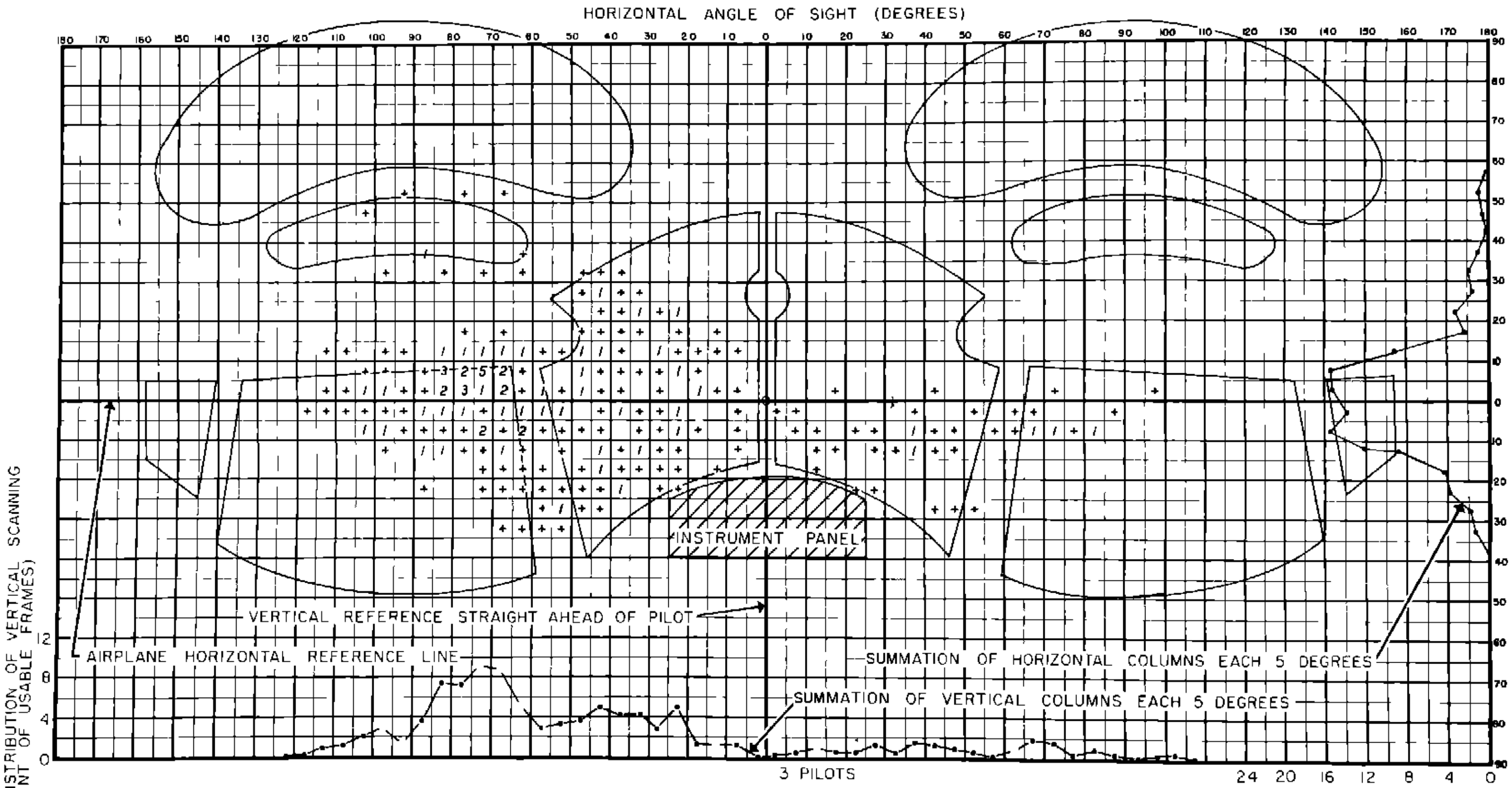
NO OF FRAMES		% OF TOTAL FRAMES
476	USABLE	82 5
70	INSTRUMENT PANEL	12 1
31	NON-READABLE	5 4
577	TOTAL	100 0

FIG 14 WINDSHIELD USAGE DURING SHORT FIELD TAKE-OFF



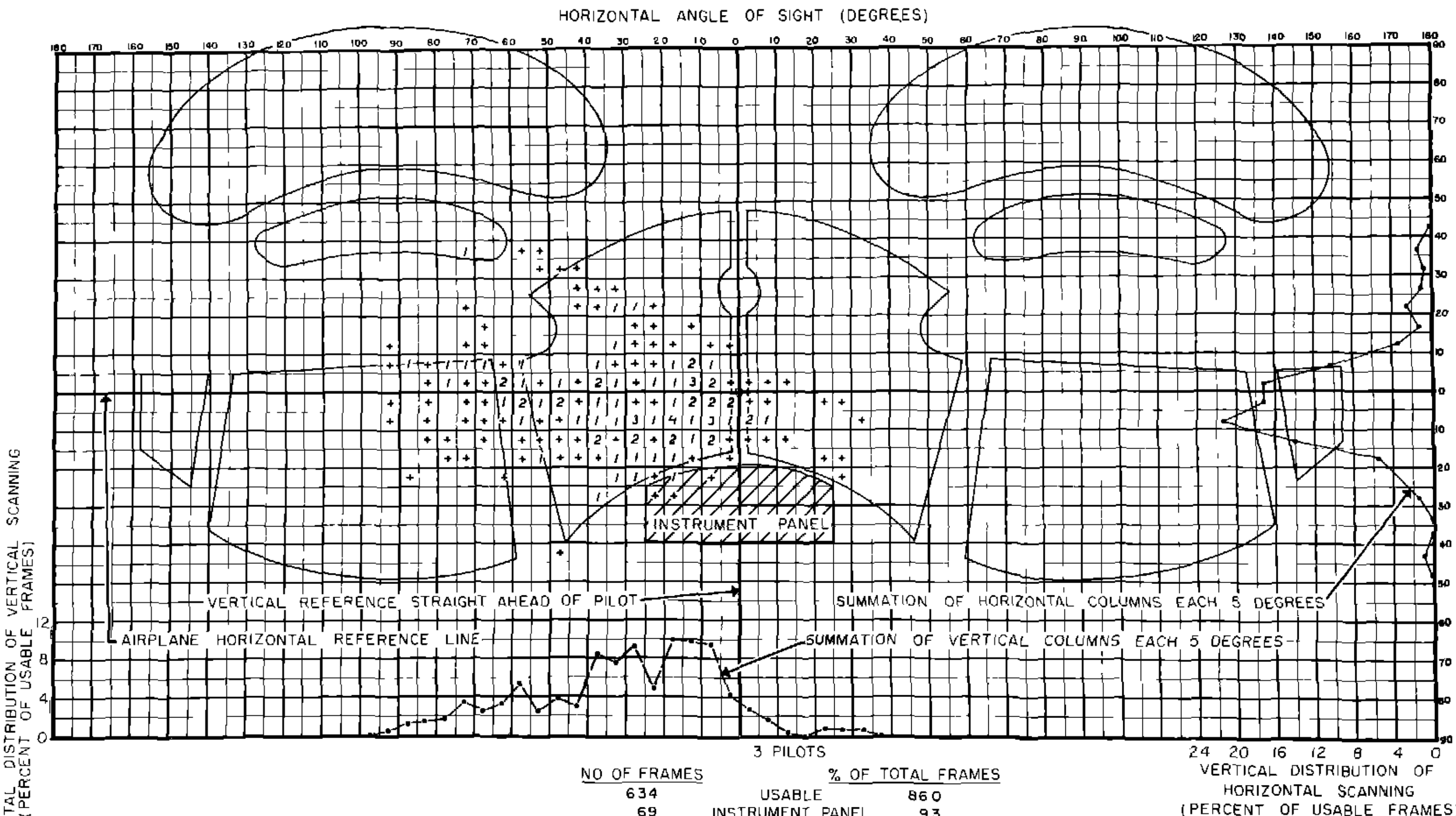
NO OF FRAMES		% OF TOTAL FRAMES
872	USABLE	78 1
171	INSTRUMENT PANEL	15 3
74	NON-READABLE	6 6
1117	TOTAL	100 0

FIG 15 WINDSHIELD USAGE DURING SHORT FIELD LANDING - STRAIGHT IN APPROACH



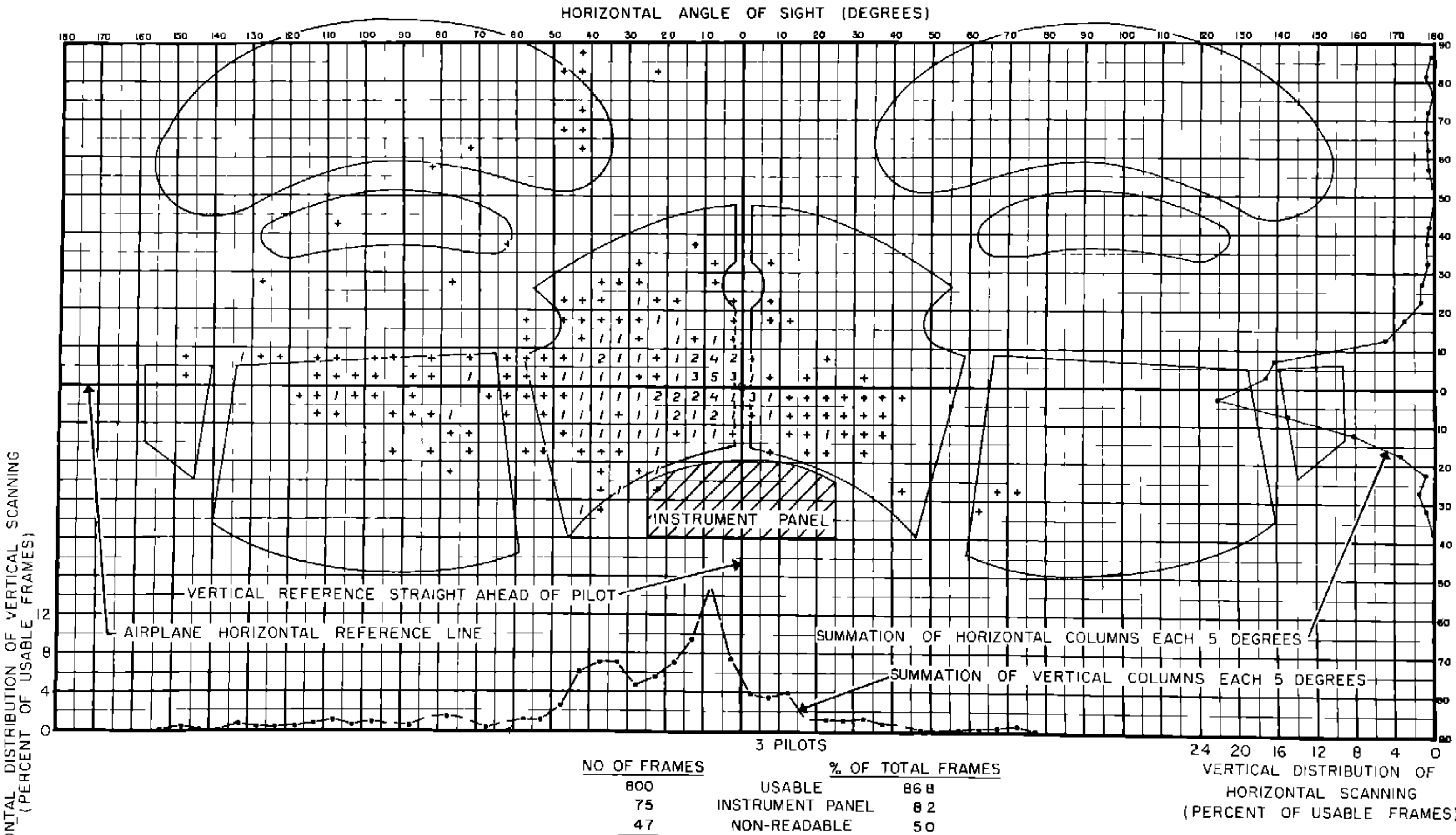
NO OF FRAMES		% OF TOTAL FRAMES
673	USABLE	86 5
36	INSTRUMENT PANEL	4 7
68	NON-READABLE	8 8
777	TOTAL	100 0

FIG 16 WINDSHIELD USAGE DURING HIGH RECONNAISSANCE OF FIELD STRIP



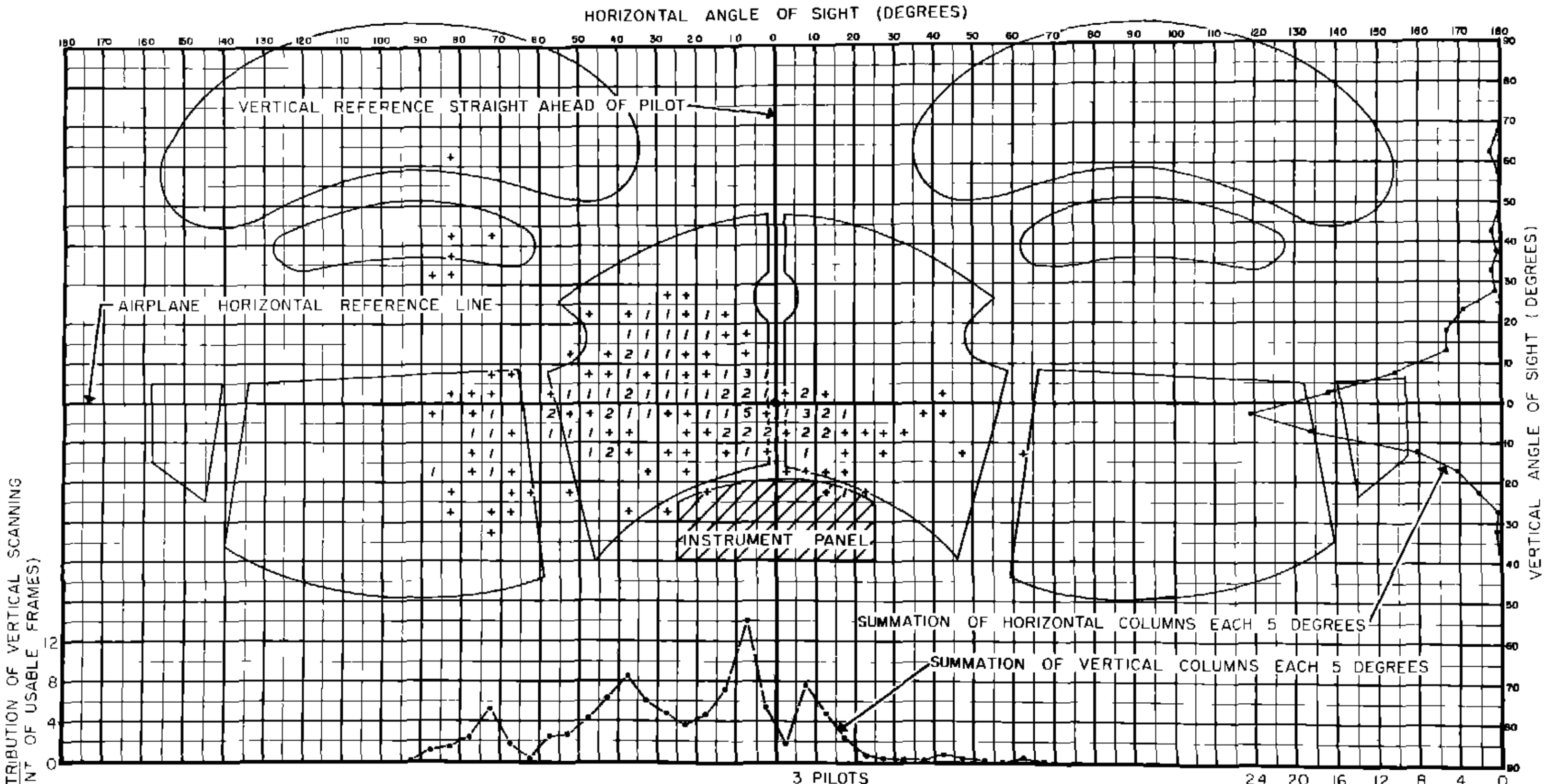
NO OF FRAMES		% OF TOTAL FRAMES
634	USABLE	86 0
69	INSTRUMENT PANEL	9 3
35	NON-READABLE	4 7
738	TOTAL	100 0

FIG 17 WINDSHIELD USAGE DURING LOW RECONNAISSANCE OF FIELD STRIP



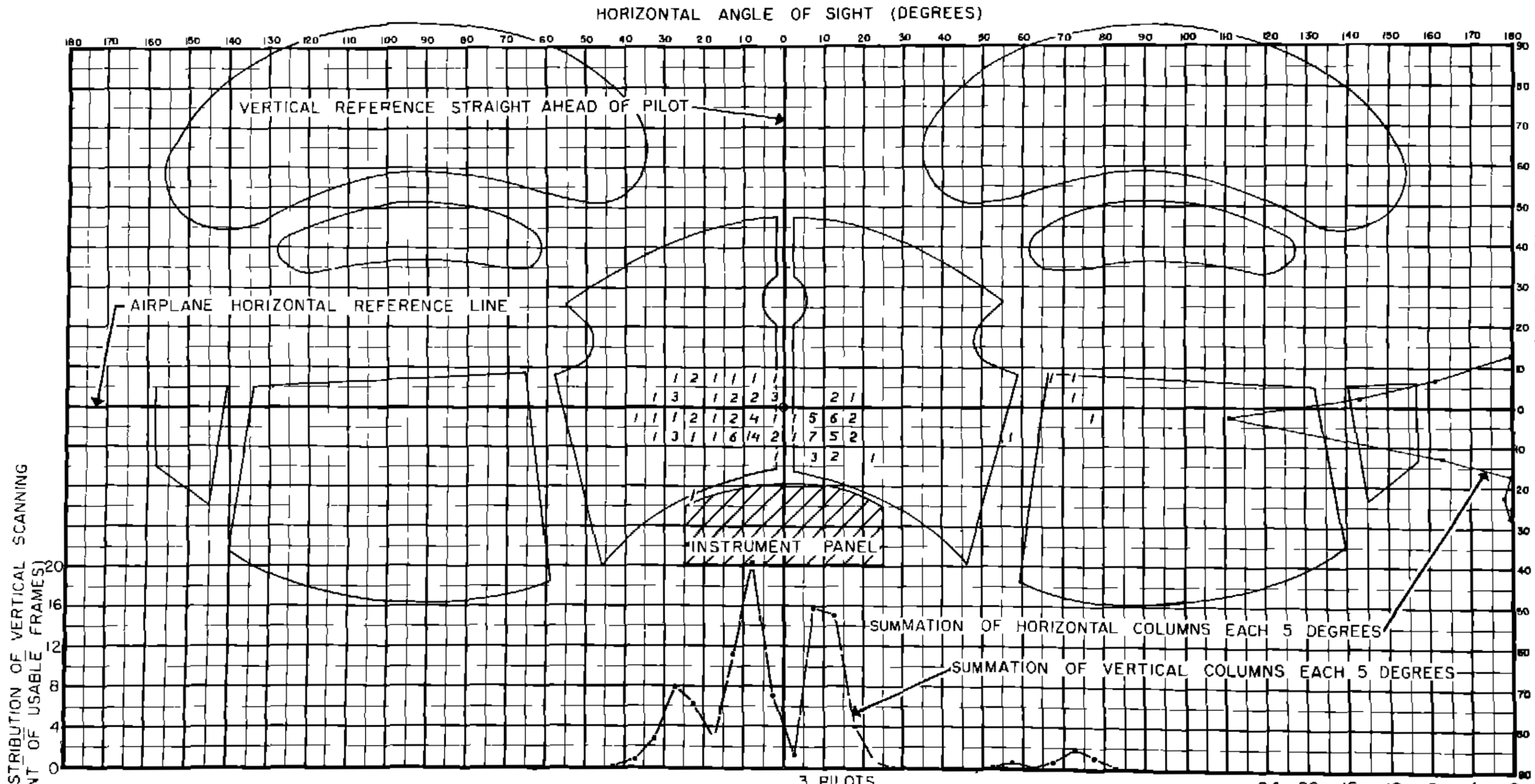
NO OF FRAMES		% OF TOTAL FRAMES
800	USABLE	86.8
75	INSTRUMENT PANEL	8.2
47	NON-READABLE	5.0
922	TOTAL	100.0

FIG 18 WINDSHIELD USAGE DURING MESSAGE PICK-UP



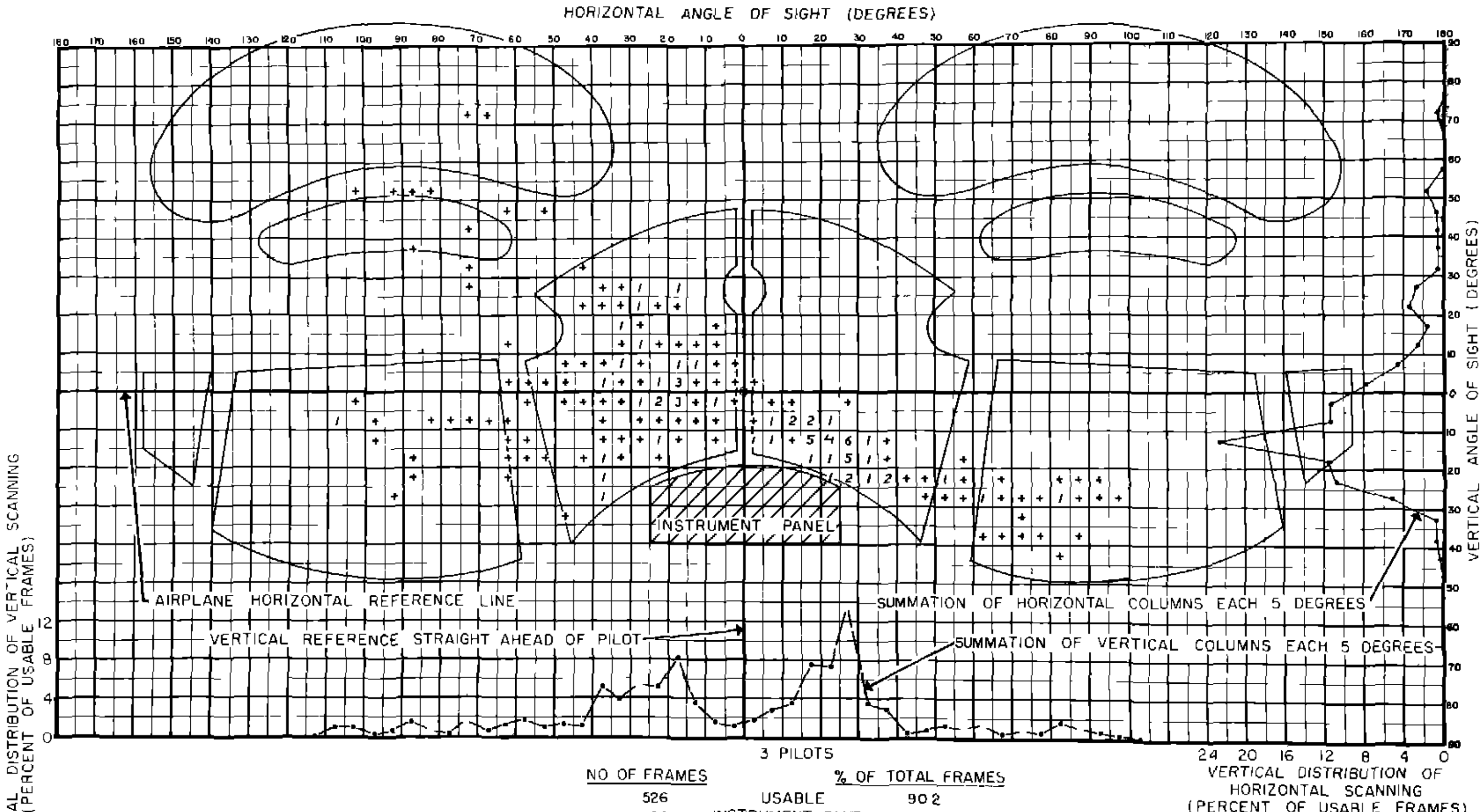
NO OF FRAMES		% OF TOTAL FRAMES
713	USABLE	94 4
24	INSTRUMENT PANEL	3 2
18	NON-READABLE	2 4
755	TOTAL	100 0

FIG 19 WINDSHIELD USAGE DURING MESSAGE DROP



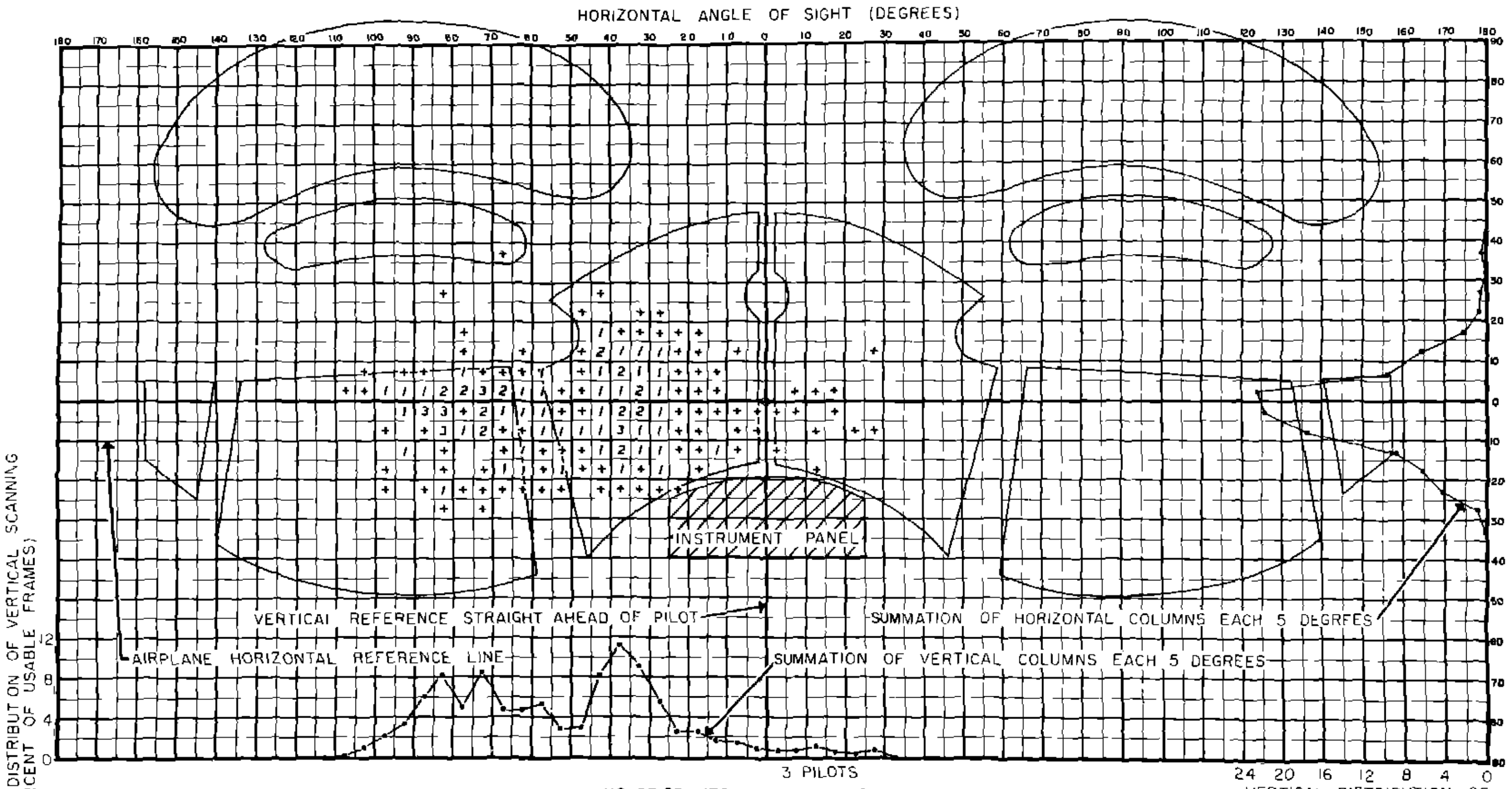
NO OF FRAMES		% OF TOTAL FRAMES
176	USABLE	100.0
0	INSTRUMENT PANEL	0.0
0	NON-READABLE	0.0
176	TOTAL	100.0

FIG 20 WINDSHIELD USAGE DURING WIRE LAYING



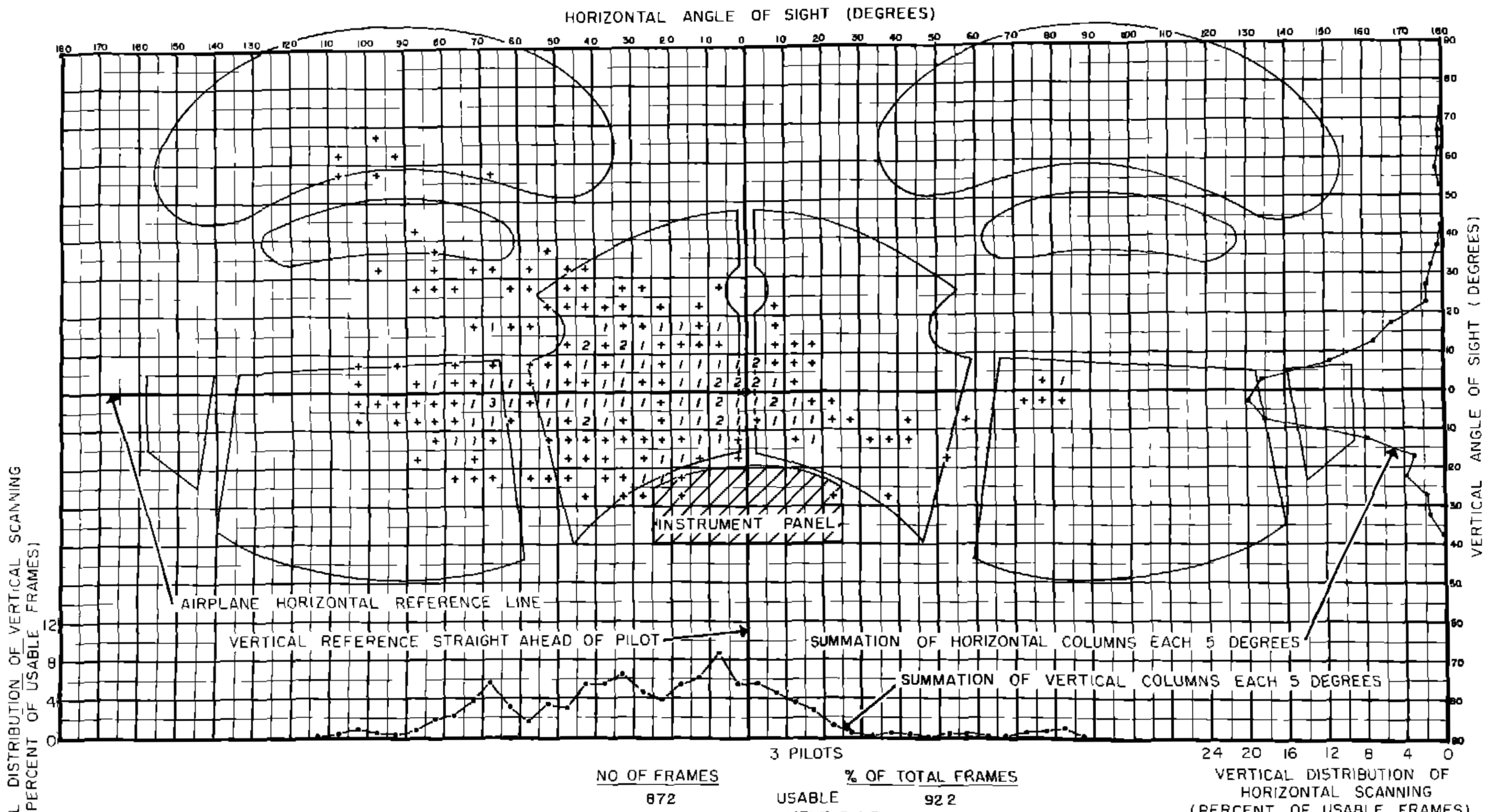
NO OF FRAMES		% OF TOTAL FRAMES
526	USABLE	90 2
28	INSTRUMENT PANEL	4 8
29	NON-READABLE	5 0
583	TOTAL	100 0

FIG 21 WINDSHIELD USAGE DURING ROAD RECONNAISSANCE



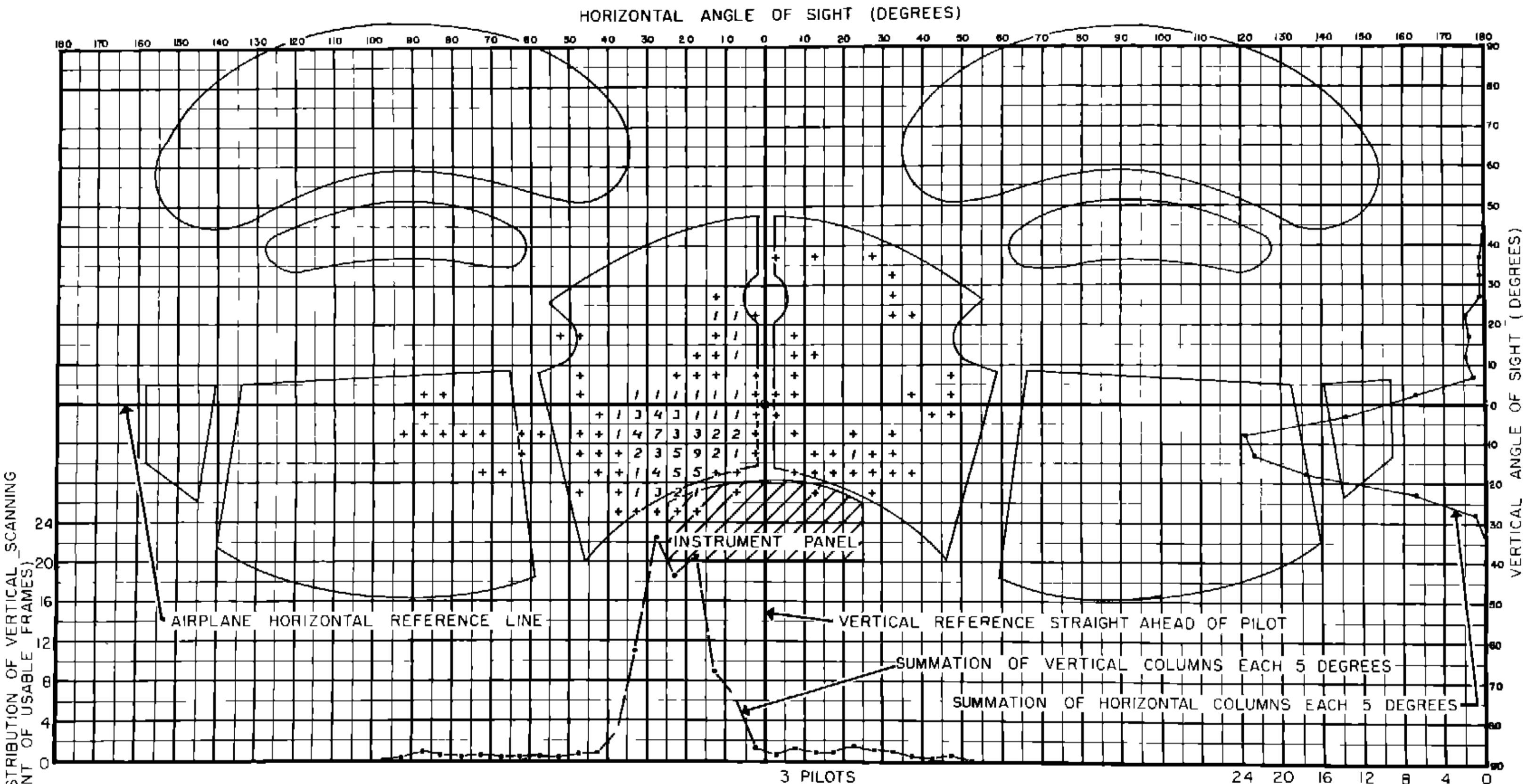
NO OF FRAMES		% OF TOTAL FRAMES
725	USABLE	88.0
47	INSTRUMENT PANEL	5.7
52	NON-READABLE	6.3
824	TOTAL	100.0

FIG 22 WINDSHIELD USAGE DURING OBJECT (BRIDGE) RECONNAISSANCE



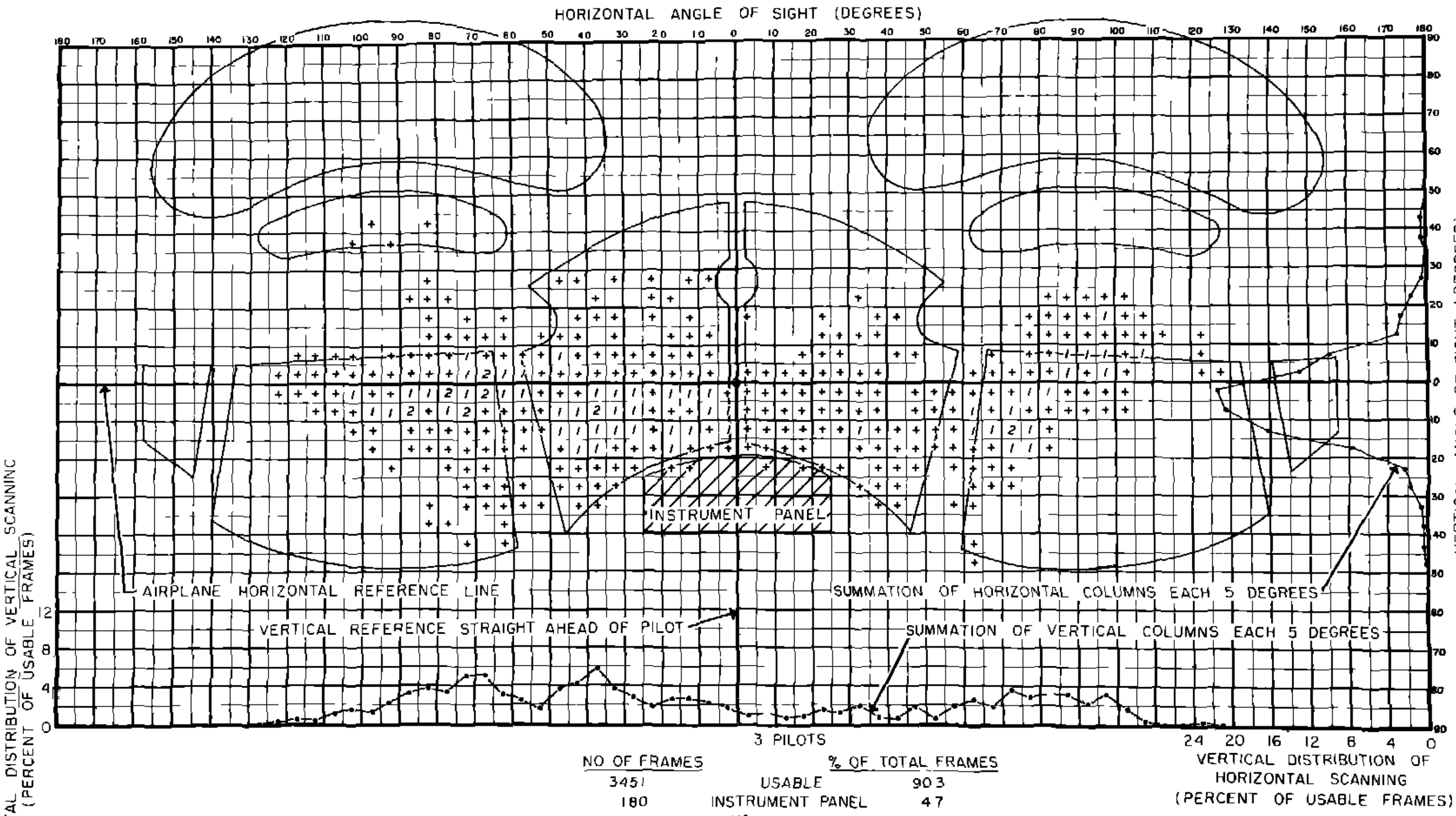
NO OF FRAMES		% OF TOTAL FRAMES
872	USABLE	92.2
40	INSTRUMENT PANEL	4.2
34	NON-READABLE	3.6
946	TOTAL	100.0

FIG 23 WINDSHIELD USAGE DURING SUPPLY DROP



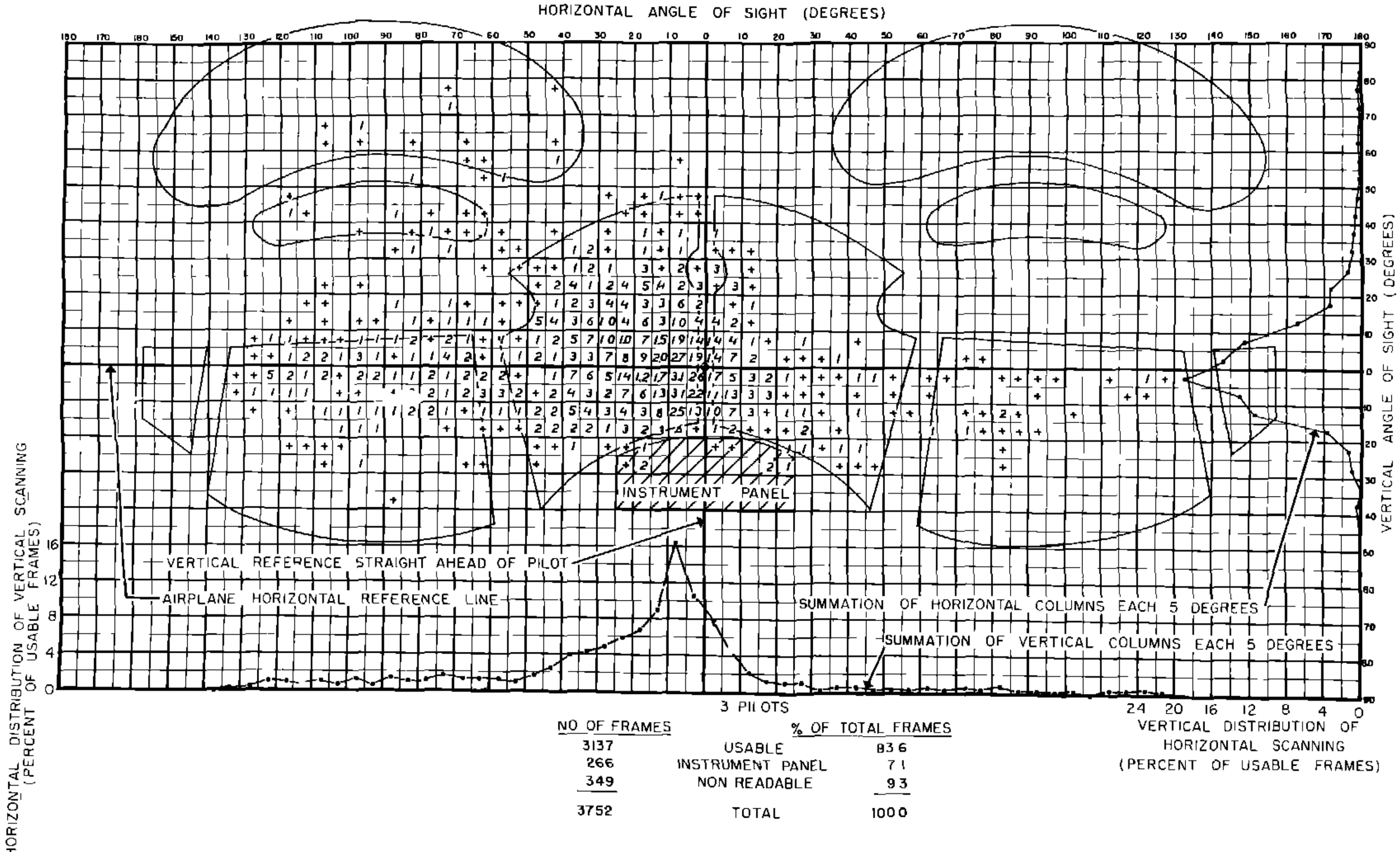
NO OF FRAMES		% OF TOTAL FRAMES
725	USABLE	88 0
47	INSTRUMENT PANEL	5 7
52	NON-READABLE	6 3
824	TOTAL	100 0

FIG 24 WINDSHIELD USAGE DURING FORMATION FLYING



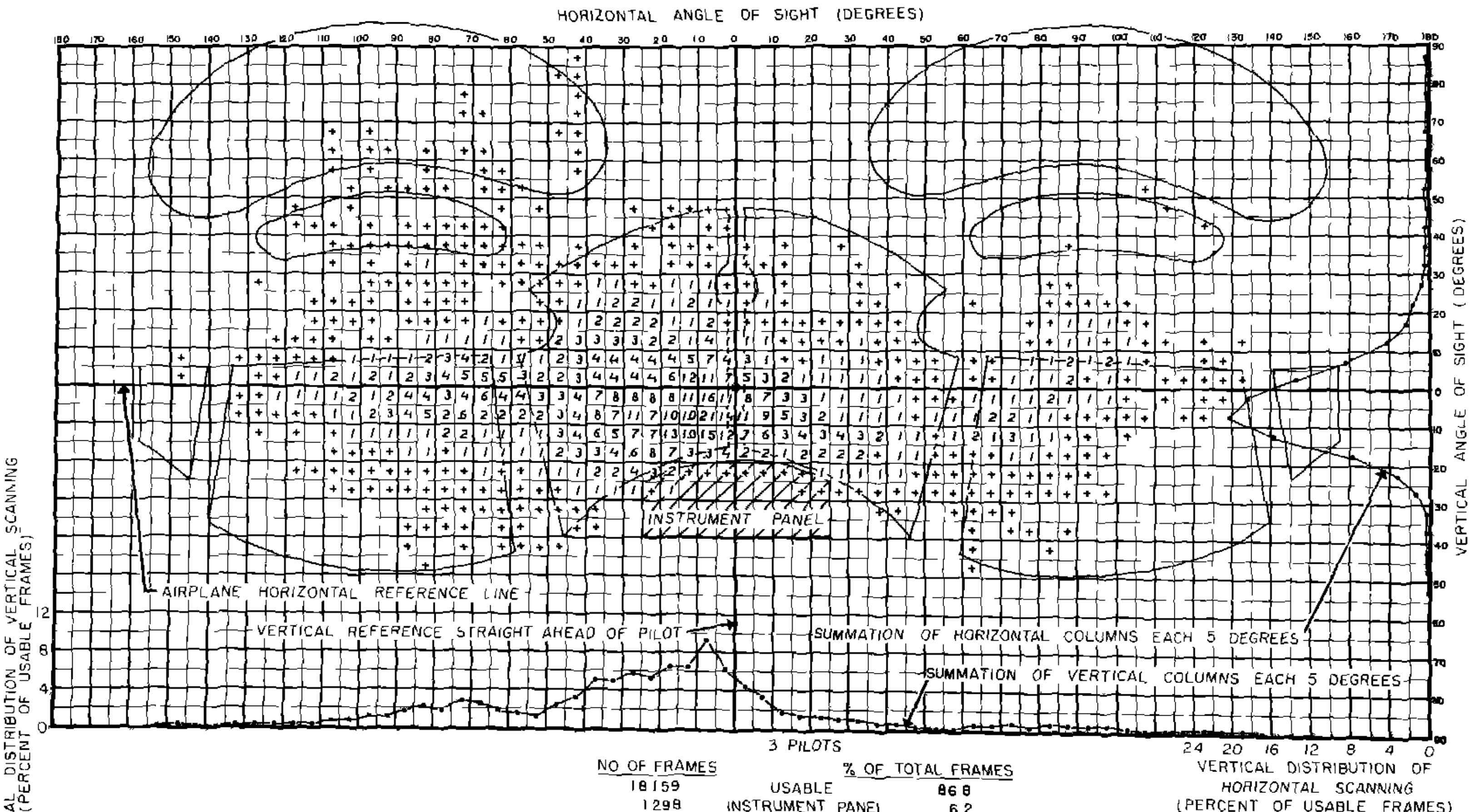
NO OF FRAMES		% OF TOTAL FRAMES
3451	USABLE	90 3
180	INSTRUMENT PANEL	4 7
190	NON-READABLE	5 0
3821	TOTAL	100 0

FIG 25 WINDSHIELD USAGE DURING ARTILLERY SPOTTING



NO OF FRAMES		% OF TOTAL FRAMES
3137	USABLE	83 6
266	INSTRUMENT PANEL	7 1
349	NON READABLE	9 3
3752	TOTAL	100 0

FIG 26 WINDSHIELD USAGE DURING TURNS



3 PILOTS

NO OF FRAMES		% OF TOTAL FRAMES
18159	USABLE	86 8
1298	INSTRUMENT PANEL	6 2
1439	NON-READABLE	7 0
20 896	TOTAL	100 0

FIG 27 WINDSHIELD USAGE DURING ALL MANEUVERS IN ARMY L-19 LIAISON-RECONNAISSANCE TYPE AIRCRAFT

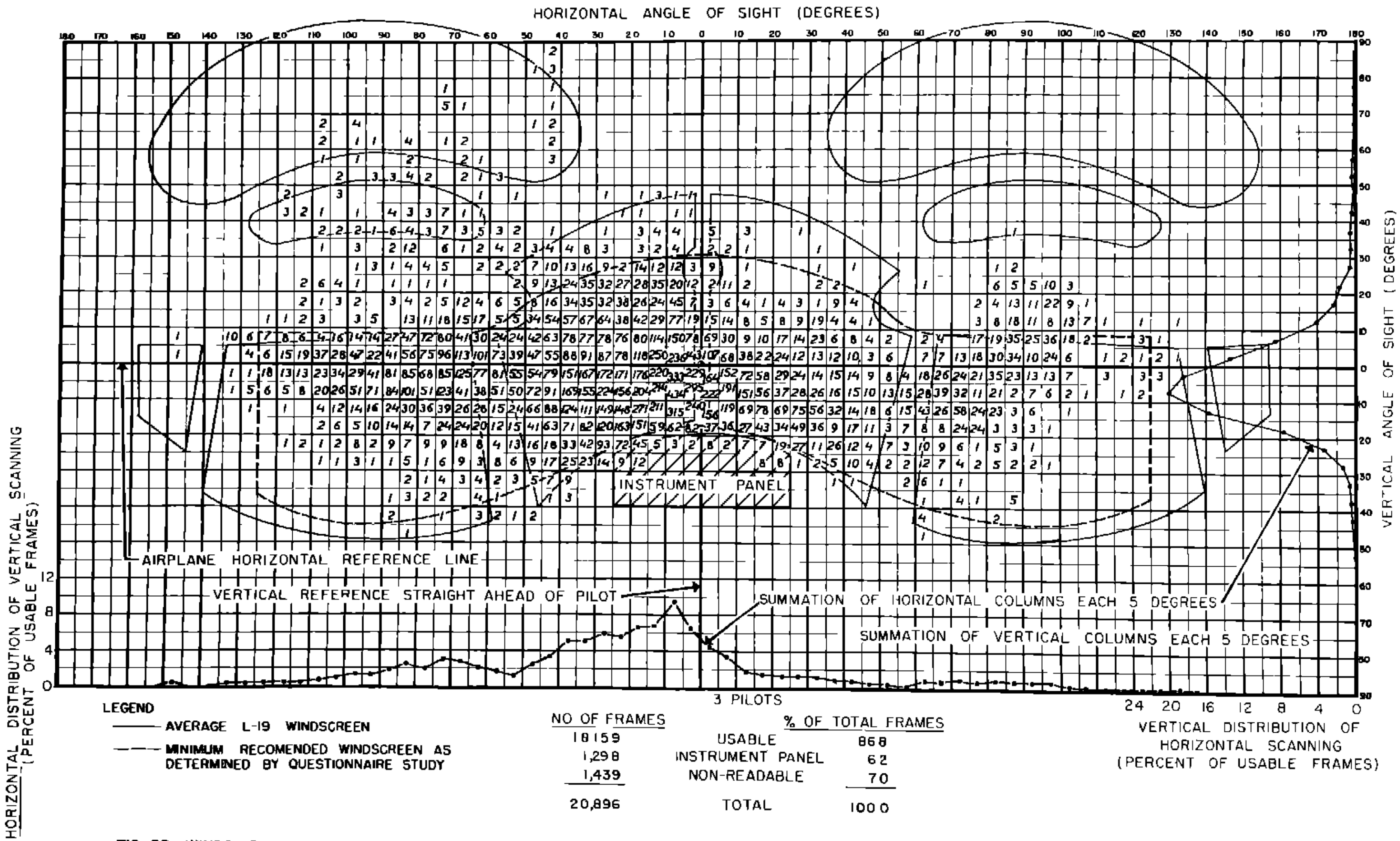


FIG 28 WINDSHIELD USAGE DURING ALL MANEUVERS IN ARMY L-19 LIAISON-RECONNAISSANCE TYPE AIRCRAFT BY ACTUAL FRAME COUNT

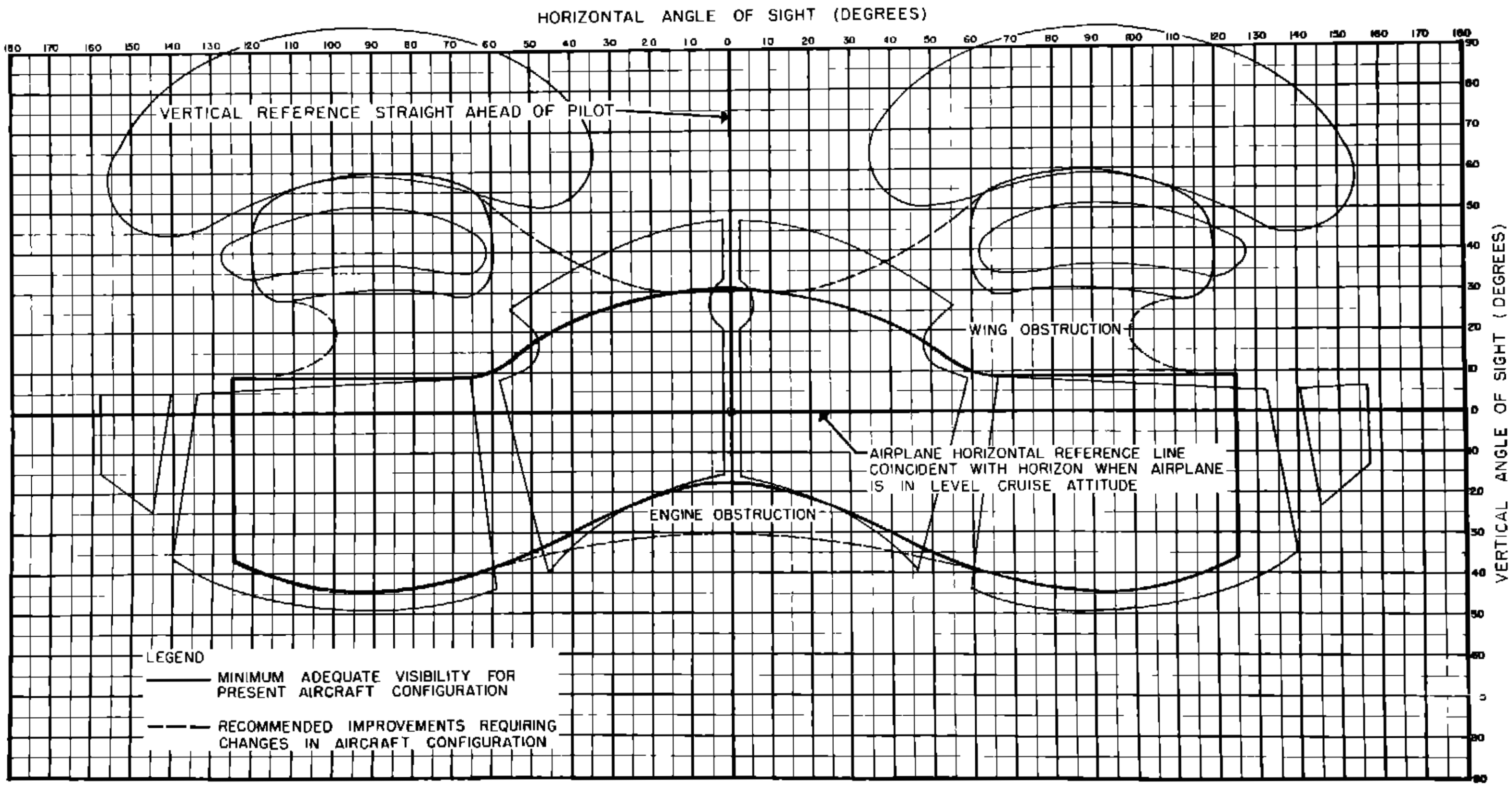


FIG 29 EXAMPLE OF VISIBILITY ANGLES AS DETERMINED FROM THE PILOT EYE-MOVEMENT STUDY