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DESCRIPTION AND FLIGHT TESTS OF AN OCULOMETER

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16. Abstract

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SUMMARY

A remote-sensing oculometer has been successfully operated during flight tests with an NASA experimental Twin Otter aircraft at the Langley Research Center. Even though the oculometer was designed primarily for the laboratory, these tests demonstrated that it was able to track the pilot's eye-point-of-regard (lookpoint) consistently and unobtrusively in the flight environment. Specifically, it was demonstrated that (1) the oculometer equipment operates effectively in the presence of appreciable vibration and that (2) the flight instrument being monitored at any time can be instantly determined. The instantaneous position of the lookpoint was determined to within approximately 1°.

Data were recorded on both analog and video tape. Enough data were obtained to indicate a general scan pattern and the most frequently monitored information during instrument landing system (ILS) landing approaches under simulated instrument flight rules (IFR) conditions. An insufficient number of test runs were made during the flight program to support a general statistical analysis. The video data consisted of continuous scenes of the aircraft's instrument display and of a superimposed white dot (simulating the lookpoint) dwelling on an instrument or moving from instrument to instrument as the pilot monitored the display information during the landing approaches.

INTRODUCTION

At the Langley Research Center, a nonintrusive, eye-measuring device called an oculometer has been used to measure a pilot's look direction and to determine his associated lookpoint during instrument landing system (ILS) landing approaches. Lookpoint is defined in this paper as the point where the pilot's instantaneous line of sight intersects the instrument panel. The oculometer flight tests were made primarily to demonstrate that the oculometer equipment would operate consistently and accurately under actual flight conditions (or alternately, to identify any unexpected problems which might prevent use of such equipment in flight). A secondary objective of the tests was to obtain eye-point-of-regard data as the pilot shifted his attention from instrument to instrument during ILS landing approach. Both objectives were accomplished even though the flight program was abbreviated and, for that reason, only a limited amount of data was obtained.

The information cues used by a pilot during the approach and landing phase of airplane flight are not very well understood. When visibility conditions become marginal, the understanding of cues received and processed by the pilot takes on primary importance.

Previous techniques (see ref. 1) for determining a pilot's look direction have involved the use of motion-picture film records and electro-optical sensing devices attached to the pilot's head. These systems were difficult to correlate in real time with the pilot's eye movement or look direction, and with aircraft control inputs and response.

The oculometer is a noninstrusive device that does not require mechanical or electrical attachments to the pilot. Eye lookpoint, eye movement, and eye detail are recorded in real time simultaneously with associated aircraft and situation parameters.

The oculometer was developed for the Langley Research Center by the Honeywell Radiation Center of Lexington, Massachusetts. Several prototype oculometer configurations have been built and tested under laboratory conditions (refs. 2 to 6). One configuration requires that the translational movements of the pilot's eye be restricted to approximately 1-cu-in. volume. This configuration has been tested in a moving-base simulator at the Langley Research Center. (See ref. 7.) A later version of the oculometer configuration permits freedom of eye movement within a volume of approximately 1 cu ft; this system is also described in reference 7. The logic equations for the oculometer are based on U.S. Customary Units. As a result of the laboratory and simulator testing, it was concluded that an oculometer does not distract a pilot from his normal routine and provides useful and valid data on eye movement and pupil diameter.

Flight tests were made with the 1-cu-in. configuration: (1) to ascertain whether these conclusions remained valid in an actual instrument flight rules (IFR) landing approach situation and (2) to determine whether the oculometer equipment would operate effectively in a typical flight environment. Some of the flight tests took place in considerable turbulence caused by the onset of a late evening thunderstorm. The results of these flight tests are reported in this paper.

SYMBOLS AND DEFINITIONS

To facilitate international usage of the data presented, dimensional quantities are presented in both the International System of Units (SI) and in U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

a_i,b_i coefficients in equations (A1) and (A2), respectively (i = 1,2,3,4)

a_0,b_0 constants in x- and y-linearization equations (eqs. (A1) and (A2))

L1,L2,L3,L4 lenses (see fig. 2)

x,y	transverse and vertical components, respectively, of eye lookpoint with respect to established "null point" in plane of instrument panel
x_c,y_c	corrected x- and y-values, respectively (see eqs. (A1) and (A2))
x_{TV}	position along TV raster line as determined by digital counter (reset to zero at beginning of each raster line)
y_n	typical raster scan line (see fig. 6)
y_{TV}	TV raster line number as determined by digital counter (reset at beginning of each field)

Axis systems:

X,Y	orthogonal coordinates of subject's lookpoint with origin at established null point
X_{TV},Y_{TV}	digital coordinates with origin at top left corner of monitor displaying video signal from electro-optical sensor unit

Abbreviations:

IFR	instrument flight rules
ILS	instrument landing system
IR	infrared
MM	middle marker
OM	outer marker
RMI	remote magnetic indicator
TV	television
V	volts
Vdc	volts of direct current
VSI	vertical speed indicator
μm	micrometers ($m \times 10^{-6}$)

DESCRIPTION OF OCULOMETER SYSTEM

The primary function of the oculometer is to measure the look direction of a subject's eye without interfering with his assigned activities. Secondary information such as pupil diameter and blink rate can also be obtained. The principal application during the flight tests was to indicate continuously which instrument the pilot was observing during ILS landing approaches under simulated IFR conditions.

The basic oculometer system consists of a sensing subsystem (electro-optical) and a video-signal processor. Additional electronics and optics were added during the flight tests to aid the oculometer operator and to combine the eye data with a closed-circuit TV view of the pilot's instrument panel. These components are described in the following sections of this paper.

Sensing Subsystems

The function of the sensing subsystem is to provide special illumination for the subject's eye and to obtain continuous information about its orientation (i.e., where it is looking). A near-infrared (IR) illumination source and an IR-sensitive TV camera are used in combination to obtain a video signal containing pertinent details of the eye. Relatively high levels of near-infrared illumination cause no physical discomfort to the eye and do not cause the diameter of the pupil to decrease appreciably. (If pupil diameter contracts to less than 3 mm, the eye movement cannot be tracked with the oculometer.)

The subsystem is housed in a single unit which contains the illumination source, the TV camera, and suitable illumination and collection optics. Figure 1 is a photograph of the sensing unit with its covers removed. A diagram of the arrangement of the components in this unit is shown in figure 2. A 100-watt tungsten lamp is the illumination source, and filters in the optical path restrict the transmitted light to a 0.8- to 0.9-μm bandwidth. Lenses L3 and L4 then collimate the near-invisible light into a circular beam which appears to the subject as a dull red glow and does not interfere with his normal vision. In fact, the subject is usually unaware of this light unless he looks directly at the fixed mirror where he sees a "round red disk." The IR beam has uniform intensity over a cross-sectional area of approximately 6.45 cm^2 (1 in^2) at the pilot's eye. The image of the eye remains in focus for a translational depth of approximately 2.54 cm (1 in.) along the optical path. Thus, an effective volume of 1 cubic inch is defined as the operational "eyespace" for this oculometer. This eyespace volume is a compromise providing sufficient resolution at the sensor while at the same time allowing slight head movements. A beam splitter (see fig. 2) is used to combine the illumination and collection optical paths. Thus, when the eye is located within the illumination beam, its enhanced image is focused onto the face of the vidicon tube in the camera. Additional details of the sensing subsystem are described in reference 2.

The TV camera in the sensing unit is a self-contained, 525 line-rate camera with a silicon-matrix vidicon tube. The silicon-matrix tube is essential to the oculometer sensing unit; its maximum response is in the near-infrared region. The tube is efficient in low ambient light levels; it is structurally rugged and is not readily damaged by high ambient light levels. An additional advantage of this 525 line-rate camera is its compatibility with readily available TV equipment such as closed-circuit monitors, recorders, and signal-conditioning equipment.

The basis for the oculometer data is the output video signal from the TV camera in the sensing unit. During the flight tests, this signal (1) was recorded directly for postflight analysis, (2) was used as the data input to a signal processor, and (3) was displayed on a TV monitor. The displayed signal appeared as a bright disk (pupil) with a superimposed small bright spot (reflection of light source) as shown in figure 3. By displaying the signal on this monitor, the oculometer operator could visually determine where the pilot's eye was within the eyespace. When the pilot's eye was not approximately centered, the operator could instruct the pilot, by way of the intercom, which way to move his head to return his eye to the approximate center of the eyespace. Very few corrections, however, were required during the flight tests.

Principle of Operation

When a subject's eye is within the eyespace, it is illuminated uniformly by the IR beam. Some of the rays enter the eye through the pupil, and some are reflected by the cornea. The rays entering the eye are reflected from the retina, effectively backlighting the pupil so its image appears as a bright disk on the TV tube. On the other hand, the rays reflected by the cornea produce a virtual image of the illumination source located halfway between the vertex and the center of curvature of the cornea. The image appears as a small bright spot (hereinafter called "corneal reflection") as illustrated in figure 4. Figure 4 also shows the relative position of the corneal reflection with respect to the pupil for several typical eye positions.

The basic measurement made by an oculometer is the displacement of the corneal reflection relative to the center of the pupil. All the information required for this measurement is contained in the video signal from the sensing unit. Adjusting the blanking level of the TV camera can eliminate all eye details except the "bright pupil" and the corneal reflection from the video signal. (See fig. 3.) Low contrast areas such as facial skin, iris, and sclera (white of the eye) are thus blanked out, and the corneal reflection appears brighter than the pupil. The video signal goes to a signal processor which makes the measurement just mentioned.

Video-Signal Processor

The signal processor consists of a commercially available minicomputer with two specialized interface circuit boards. A photograph of this unit is shown in figure 5. The minicomputer has a memory capability of 16 000 sixteen-bit words. A teletype keyboard with a papertape punch and reader is used to load the oculometer program into memory and to communicate with the minicomputer. The teletype unit is not necessary for operation of the oculometer after initial setup. (It was not carried onboard the aircraft during the flight tests.)

The upper half of figure 6 is an enlargement of the eye detail from figure 3. The horizontal line y_n is a typical raster line which intersects both the pupil and the corneal reflection. Below the photograph, a signal proportional to the light intensity along y_n is shown. The abrupt changes in signal level occur at the edges of the pupil and the corneal-reflection images (i.e., at "boundary points" A, B, C, and D). The boundary points are detected in the interface section of the signal processor by comparing the light level with fixed threshold levels.

The coordinates (X_{TV},Y_{TV}) of the boundary points for every raster line intersecting the pupil and/or corneal-reflection images are determined by the interface section. The Y_{TV}-coordinate is simply the TV scan line number obtained from a counter which is reset to zero at the beginning of each field. The X_{TV}-coordinate for each point is obtained from a second counter which is started at the beginning of each scan line. (The x-counter measures position along the raster line as a function of time.) The coordinates are then converted to 10-bit digital words which are written into the memory of the minicomputer.

The minicomputer calculates the X_{TV},Y_{TV}-coordinates of the center of the pupil and the center of the corneal reflection, their relative displacement, and the diameter of the pupil. (Pupil diameter was recorded but not analyzed in this study.) The azimuth and elevation angles of a subject's line of sight and the X,Y-coordinates of his lookpoint on the instrument panel are calculated from the X_{TV},Y_{TV}-coordinates.

The lookpoint is a function of the azimuth and elevation angle of the subject's instantaneous line of sight with respect to a selected zero reference point (referred to in this paper as "null point") on the instrument panel. The azimuth and elevation angles are in turn proportional to the measured relative displacements of corneal reflection and of the center of the pupil. The signal processor has four output channels. Three channels are analog signals with a range of ±5 Vdc, and the fourth channel is a logic voltage (track/no-track signal) telling whether the eye is in or out of track. One of the analog channels outputs a voltage proportional to the pupil diameter, and the other two analog channels give voltages proportional to the x- and y-components of the subject's lookpoint on the instrument panel. For this study, the four output signals were recorded on an onboard aircraft instrumentation recorder. Three of the output signals were also used for inputs to a scan converter described later.

Peripheral Electronics and Optics

A scan converter is tied in with the basic oculometer to combine the video signal from a second TV camera with a pair of analog signals. The result is a video scene with a superimposed electronic dot which moves with respect to the video scene. The dot is synthesized from the x- and y-components of the lookpoint. The scan converter and a second TV camera were used in the present study to generate an annotated TV scene consisting of the simulated lookpoint (viz, the dot) superimposed on a video scene of the instrument panel.

The scan converter also has provisions for a blanking input signal and a memory feature. The blanking feature allows the electronic dot to be eliminated from the scene under certain conditions. For example, in the present study when the track/no-track signal from the signal processor was used as the blanking input, the operator (watching a TV monitor) was able to tell that the pilot's eye was not being tracked when the dot disappeared from the annotated scene. (Without such a blanking feature, an operator might think that a subject was staring at one spot on the instrument panel when, in fact, his eye was "out of track.") The memory feature on the scan converter is similar to that of a storage oscilloscope (or "Memoscope"). When in the "storage mode," the dot traces out the subject's scan pattern as shown by the example on the monitor in figure 7. The oculometer operator can erase the pattern as often as desired.

The only output from the scan converter is an annotated video signal which is recorded on video tape. With the memory feature inactive, the recording shows the dot moving from instrument to instrument as the subject scans the instrument panel. However, with the memory feature active, scan patterns such as those shown in figure 7 can be recorded as they are being generated.

SYSTEM PERFORMANCE

The present tracking range of the oculometer covers a viewing field of $\pm 30^\circ$ in azimuth and -10° to $+30^\circ$ vertically (referenced to the pilot's line of sight to the fixed mirror). Laboratory tests have indicated (ref. 5) that the average error in tracking a subject's eye within this field is less than 1°. The average error in tracking the pilot's eye during the present flight tests was calculated to be 1.02° over the field spanned by the 17 test points used for the linearization process. (See appendix.) However, the average error for the 11 points that covered only the flight-instrument area (excluding the clock) was 0.93° (the largest errors were on the left side of the panel beyond the instrument area). A 1° error corresponds to approximately a 1.27-cm (1/2-in.) lookpoint error.

DESCRIPTION OF TEST AIRCRAFT

The airplane used for this test was an NASA experimental Twin Otter which is a fixed gear, high-wing monoplane powered by two single-stage, free-power turbine engines. The airplane is shown in figure 8. The Twin Otter is a passenger/cargo airplane which carries a pilot, copilot, and up to 19 passengers. The airplane has a wing span of 19.81 m (65 ft) and a fuselage length of 15.77 m (51.75 ft). The maximum take-off weight is 5252.23 kg (11 579 lb) and the maximum landing weight is 5171.04 kg (11 400 lb). Take-off speed is approximately 65 knots, normal cruise is 130 to 150 knots, and the landing approach speed is approximately 90 knots.

OCULOMETER INSTALLATION

Equipment constraints dictated that the copilot side of the cockpit be used for these tests. The flight instruments on the copilot panel consisted of the nine instruments shown in figure 9.

Installation of the oculometer components in the Twin Otter did not require any major modification of the airplane or functional changes to the oculometer itself. The sensing unit of the oculometer was secured to the floor between the copilot seat and the rudder pedestal post. (See fig. 10.) The unit as installed did not interfere physically with the copilot or with his use of the rudder pedals. The fixed mirror was attached to the sensing unit rather than to the instrument panel in order to minimize vibration differences between the sensing unit illumination source and the mirror. A headrest (two pads shown above the copilot seat) served as a physical point of reference for the pilot rather than as a head restraint. When the pilot maintained an approximate head contact with the headrest, his eye would be in or very near the designated eyespace. A TV camera was mounted in the cockpit doorway to provide a view of the instrument panel. This camera view (i.e., video signal) was used as an input to the scan converter for the composite scene as shown in figure 7. The instrument panel as seen from the approximate location of this TV camera is shown in figure 11.

The remainder of the oculometer and TV equipment required for the flight tests was located in the passenger compartment as shown in figure 12. The components were fastened to a shock-mounted pallet which was attached to the holddown points normally used for the passenger seats. The components consisted of two 9-in. TV monitors, a camera control unit for the TV camera mounted in the doorway, a scan converter, the signal processing unit, associated electronics, and a video-tape recorder. The oculometer operator's seat was located immediately to the rear of the video tape recorder and faced the 9-in. TV monitors. From this position, the oculometer operator could monitor the pilot's eye position relative to the designated eyespace.

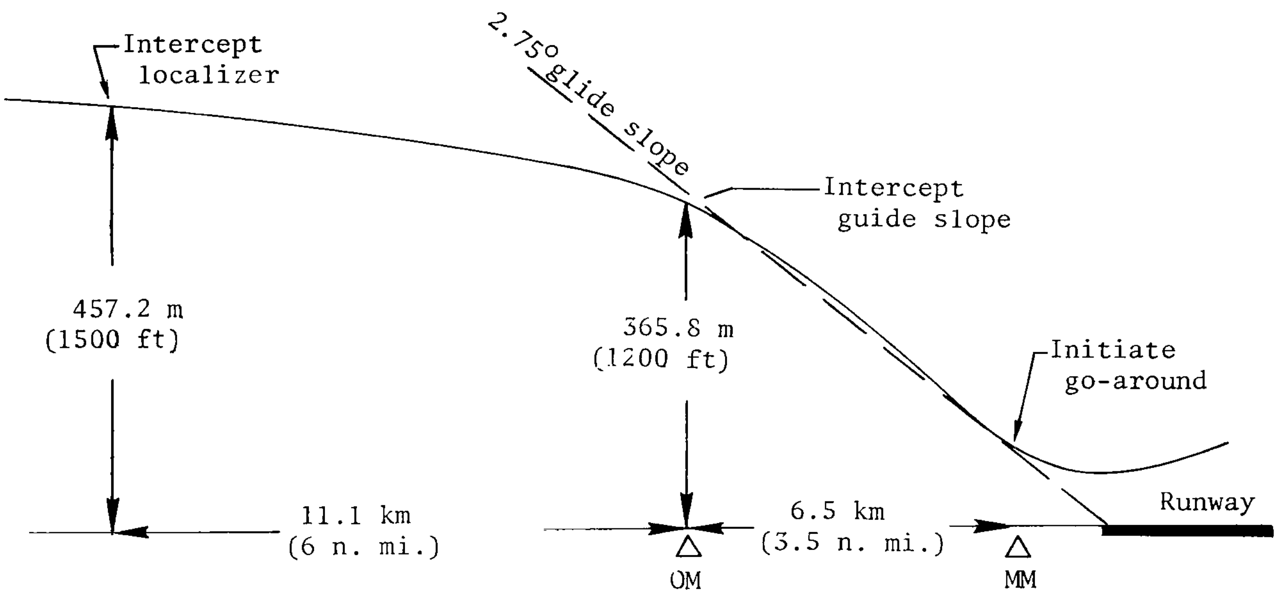
A 110-V, 60-cycle rotary inverter (driven by one of the airplane's 100-ampere dc generators) was added to supply power for the oculometer components. The inverter was located in the rear section of the airplane. The total equipment weight (oculometer, cameras, recorders, and inverter) added to the aircraft for these tests was approximately 145.15 kg (320 lb).

The test aircraft was chosen for the oculometer flight test because it already contained instrumentation to sense and record a variety of flight parameters. The oculometer signals were recorded on this system together with the flight parameters. Thus, data for pilot eye position can be correlated with the airplane situation and the control data. The instrumentation is shown in the lower right corner of figure 12.

TESTS AND RESULTS

Prior to the data flights, the engines of the aircraft were run up to maximum revolutions per minute (rpm) on the flight line to produce a severe vibrational environment (much more severe than subsequently experienced in the flight tests). A subject's eye was tracked successfully during this exercise, although there was a noticeable jitter in the video output signal from the electro-optical sensor unit. (This was caused partly by equipment vibration, predominately in the vertical axis of the fixed mirror, and partly by vibrations of the subject's head with respect to the sensing unit.) The amplitude of the jitter was estimated to be a maximum of 0.5° peak-to-peak in the output signal of the signal processor. Next, a successful shakedown flight was made to verify operation of the equipment in flight and especially to verify successful operation during the touchdown.

Two data flights were made. Each data flight consisted of a series of nighttime ILS landing approaches at Langley Air Force Base under simulated IFR conditions. Five of these approaches provided usable data. A profile of a typical ILS landing approach at Langley Air Force Base is shown in sketch (a).



Sketch (a)

Two pilots were used on each data flight. A "safety pilot" flew the landing patterns and maneuvered the aircraft into the vicinity of the localizer about 18.52 km (10 n. mi.) out. Here, the "oculometer pilot" assumed control; he acquired the localizer and set up a slow descent to the outer marker (OM) where he acquired the 2.75° glide slope, and continued to the middle marker (MM). The aircraft reached the 61-m (200-ft) altitude minimum near the middle marker where the safety pilot reassumed control and executed a go-around.

In general, data were recorded only during the profile segment from OM to MM. Oculometer signals were recorded on both video tape and on the test aircraft's special onboard instrumentation recorder. (See fig. 12.) The signals recorded on this magnetic tape system were the four outputs from the oculometer's signal processor unit. (See fig. 5.) A number of aircraft parameters were also simultaneously recorded on the magnetic tape for correlation to the oculometer data. Two types of video recordings were made: (1) a "raw" video signal from the oculometer's electro-optical unit and (2) a video composite consisting of the synthesized x- and y-components (viz, an "electronic dot") of the pilot's look direction superimposed on a live view of his instrument panel obtained from a second TV camera. Thus, a viewer of the composite picture can watch the "dot" travel from instrument to instrument as it traces out the pilot's scan pattern in real time. The viewer can also follow the progress of the ILS approach by monitoring the aircraft instruments and by listening to the voice channel tied into the aircraft's intercom system.

A preliminary look at the magnetic tape data (played back on a strip chart recorder) and a review of the video tapes showed clearly that the oculometer had tracked the pilot's eye movement satisfactorily and that data were successfully recorded. The pilot stated that the cockpit components of the oculometer did not interfere with the flight situation. The jitter in the oculometer output signals was more than had been experienced in the laboratory but less than the 0.5° amplitude observed in the system checkout during ground runup of the airplane engines. This jitter caused no problem in determining the particular instrument being monitored at any given time. The instantaneous lookpoint on the face of an instrument was determined to within approximately 1° or about 1.27 cm (0.5 in.).

Next, the x- and y-output signals were analyzed to obtain dwell times on and transitions among the six most used flight instruments during the landing approaches. Results for the first approach of the test series on the second flight are shown in table I. The instrument names appear in the same order in the row and column headings; thus, each instrument name intersects itself along the table diagonal. Data entries along this diagonal are percents of total tracking time (157 sec) spent observing the respective instruments. Off-diagonal entries are the number of one-way transitions between the various instruments. Mean dwell times per observation (and standard deviation) for each instrument are listed at the bottom of the appropriate column.

The data show that the pilot spent over two-thirds of the test time monitoring the ILS instrument and that each observation was usually longer than 1 sec. Only a modest amount of time (3 to 5 percent) was spent monitoring airspeed, attitude, and altitude, respectively, and very little time was spent on the RMI and VSI. Total time on instruments adds up to approximately 82 percent; the remaining 18 percent involves transition time between instruments or time glancing at switches and the safety pilot. This same general trend held for subsequent approaches although the percentages varied somewhat.

The number of transitions between any two instruments can be determined from table I as follows: select the "from" instrument from the row headings and follow this row across to the column of the desired "to" instrument; the number of one-way transitions is listed at the intersection. The number of transitions in the opposite direction is obtained by interchanging the labels of the "to" and "from" instruments and repeating the process. For example, the number of transitions from the ILS to the altimeter is listed as 7, and the number of returns was 14.

Although the pilot was not accustomed to flying simulated IFR approaches in this aircraft (especially from the right-hand seat), this unfamiliarity had no effect on accomplishing the primary objective of the mission. (The copilot panel in the test airplane had the required instruments for making an ILS approach.) The values in table I generally agree with those obtained on a simulator for other aircraft (e.g., see ref. 6), and thus, offer further evidence that the oculometer and all recording equipment were functioning satisfactorily during the flight tests.

CONCLUDING REMARKS

A remote-sensing oculometer has been successfully operated during flight tests using an NASA experimental Twin Otter aircraft. Although the flight program was abbreviated, all objectives of the program were accomplished. The oculometer was able to track the pilot's eye-point-of-regard (lookpoint) consistently and unobtrusively in the flight environment. It was demonstrated that the equipment operates effectively in the presence of appreciable vibration and that the flight instrument being monitored by the pilot at any instant can be identified.

Enough data were obtained to indicate a general scan pattern and the instrument information most frequently monitored by the pilot during the instrument landing system landing approaches. The instantaneous lookpoint on the face of an instrument was determined to within approximately 1.27 cm (0.5 in.), a measurement which corresponds to a look direction of about 1.0°. These data were in agreement with the values obtained with the oculometer during a similar piloting task on a simulator.

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APPENDIX

CALIBRATION AND LINEARIZATION

Accessory routines in the minicomputer program provide semiautomatic procedures for the calibration and linearization of the output signals. These procedures must be performed for each subject because of differences in eye characteristics. In fact, the output signals for the left and right eyes of any given subject may differ significantly because of a difference in the individual's eye geometry.

The calibration process for this study had the pilot fixate in turn on three selected points on the instrument panel. A point on the instrument panel was selected as the null point which then became the origin of the X,Y-axis system. This point was at the approximate center of the turn-and-slip indicator. This selection, although arbitrary, conveniently established a null point which was close to the optical path between the eye and the sensing unit. Next, an x-calibration point was selected about 20° to the right (or to the left) of the null point, and a y-calibration point was established about 20° above the null point. For convenience, these two points were located on the X- and Y-axes, respectively. The coordinates of all three points were entered into the memory of the minicomputer together with a desired output voltage for each. The minicomputer was then placed in the "calibration mode," and the pilot was instructed to fixate on each of the three points. At each fixation, the operator pressed a switch to capture a digital number related to the distance between the corneal reflection and the center of the pupil. The minicomputer then automatically adjusted the x- and y-output voltages to the assigned values; thus the calibration was established.

The linearization process is used to remove distortions from the output data caused by equipment anomalies and by subject-to-subject eye variations. The relationship between the position of the corneal reflection relative to the pupil center and to eye direction is approximately linear for look angles up to 10° or 20° away from the reference line of sight. However, significant nonlinearities exist at 30°. These nonlinearities are caused, in part, by the method used to determine the position of the center of the pupil and, in part, by the geometry of the eyeball and the test setup.

Nonlinearities are corrected in the oculometer by polynomial equations which introduce equal and opposite nonlinearities. The following polynomial equations were used for linearization in this study:

$$x_c = a_0 + a_1x + a_2xy + a_3xy^2 + a_4y \tag{A1}$$

$$y_c = b_0 + b_1y + b_2(y^2 - x^2) + b_3yx^2 + b_4x \tag{A2}$$

where x_c and y_c are the corrected values for the lookpoints, and the terms on the right were developed empirically according to the types of distortion noted in oculometer measurements using test arrays. (A nominal array is shown in fig. 13.) Examples of distortion patterns and associated linearizing terms are shown in table II.

The coefficients of these polynomials are chosen by the minicomputer to yield the minimum root-mean-square (rms) error over the array of fixation test points. To utilize this feature, the subject looks at each test point in figure 8, and its fixation value is stored in the minicomputer memory when the operator moves a switch. (A typical set of measured fixation values is shown in fig. 14.) After all the test-point fixations have been stored, the computer automatically adjusts the linearizing coefficients to achieve a minimum rms error (fig. 15). The linearizing coefficients for up to nine subjects can be stored in the minicomputer memory.

REFERENCES

1. Young, Laurence R.: Measuring Eye Movements. Amer. J. Medical Electron., vol. 2, no. 4, Oct.-Dec. 1963, pp. 300-307.

2. Merchant, John: Laboratory Oculometer. NASA CR-1422, 1969.

3. Mason, Kenneth A.; and Merchant, John: Design of a Breadboard Remote Oculometer. NASA CR-1459, 1970.

4. Merchant, John; Wilson, Ronald; and Mason, Kenneth A.: System Design Study for an Optimal Remote Oculometer for Use in Operational Aircraft. NASA CR-1562, 1970.

5. Davis, P. W.; Lutz, J. S.; Warner, A.; and Iannini, A. A.: Design and Construction of a Portable Oculometer for Use in Transportation Oriented Human Factors Studies. DOT-TSC-OST-71-13, Aug. 1971.

6. Merchant, J.; and Morrissette, R.: A Remote Oculometer Permitting Head Movement. AMRL-TR-73-69, U.S. Air Force, Nov. 1973. (Available from DDC as AD 776 075.)

7. Spady, Amos A., Jr.; and Waller, Marvin C.: The Oculometer, a New Approach to Flight Management Research. AIAA Paper No. 73-914, Sept. 1973.

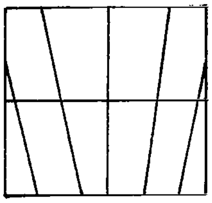
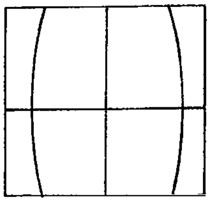
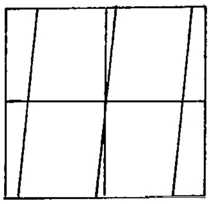
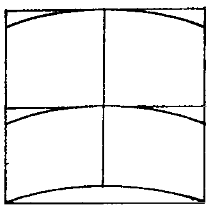
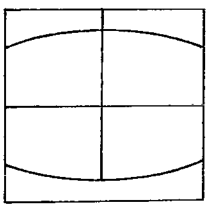
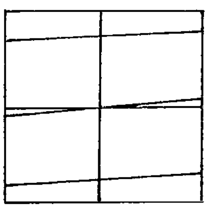
TABLE I.- PILOT PATTERN OF MONITORING INSTRUMENTS DURING INITIAL LANDING APPROACH IN DHC-6 TWIN OTTER

[Percent values indicate percent time spent on each instrument; total percentage does not equal 100 percent of test time because of time spent by eye in transition between instruments. Numbers represent number of transitions between instruments.]

"From" instrument	"To" instrument					
	ILS	Airspeed indicator	Attitude indicator	Altimeter	RMI	VSI
ILS	68.44%	16	9	7	1	0
Airspeed indicator	9	5.32%	8	1	1	0
Attitude indicator	8	2	3.32%	9	1	0
Altimeter	14	0	2	3.19%	0	1
RMI	1	1	0	0	1.03%	1
VSI	1	0	1	0	0	0.25%
Mean dwell time, sec	1.801	0.17	0.110	0.283	0.587	0.025
Standard deviation, sec	2.611	0.280	0.176	0.330	0.832	0.000

TABLE II.- EXAMPLES OF DISTORTION PATTERNS

AND ASSOCIATED LINEARIZING TERMS

Distortion pattern	Linearization term
	xy
	xy^2
	y
	y^2-x^2
	yx^2
	x

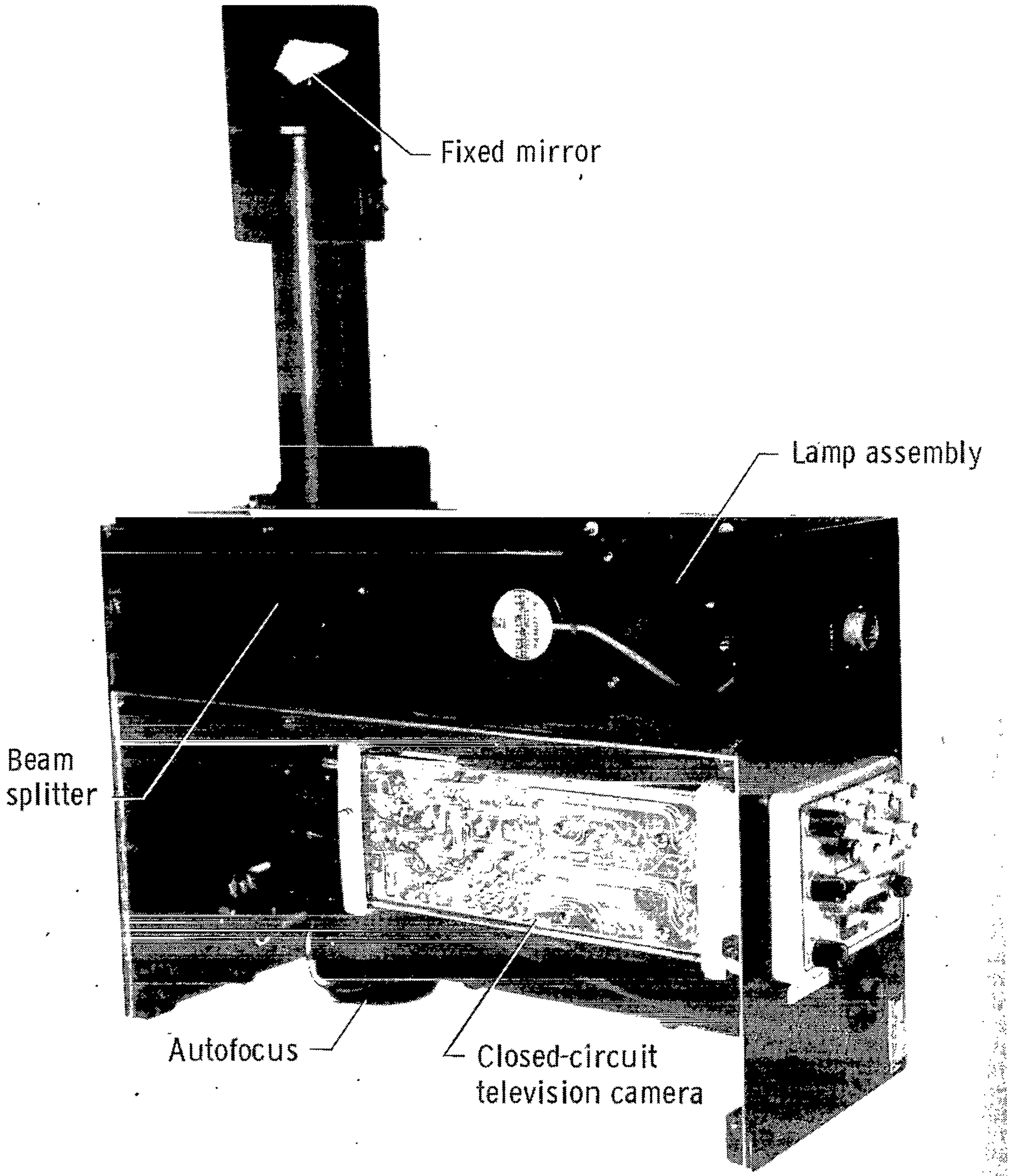


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Figure 1.- Electro-optical sensing unit with covers removed.

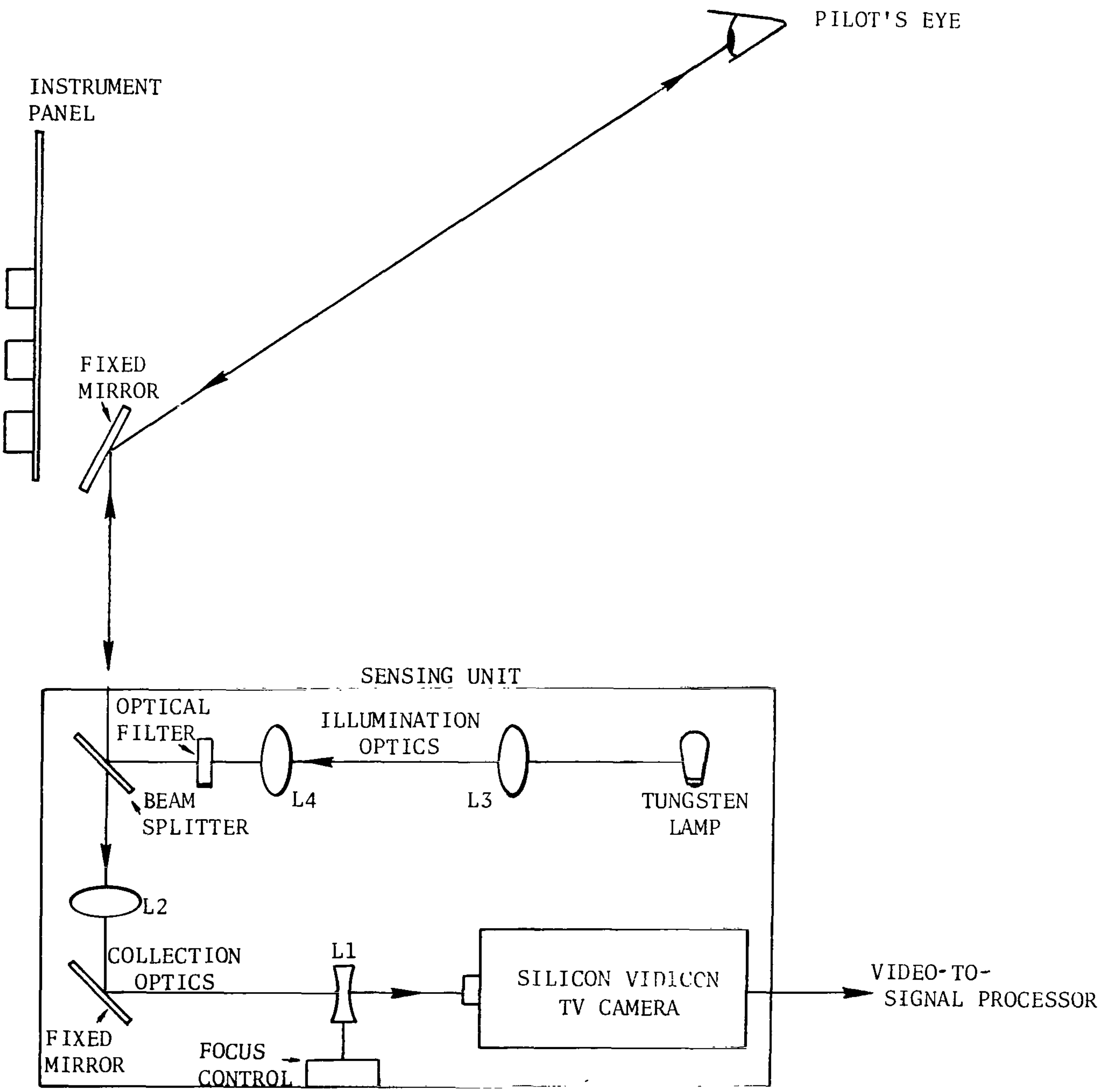
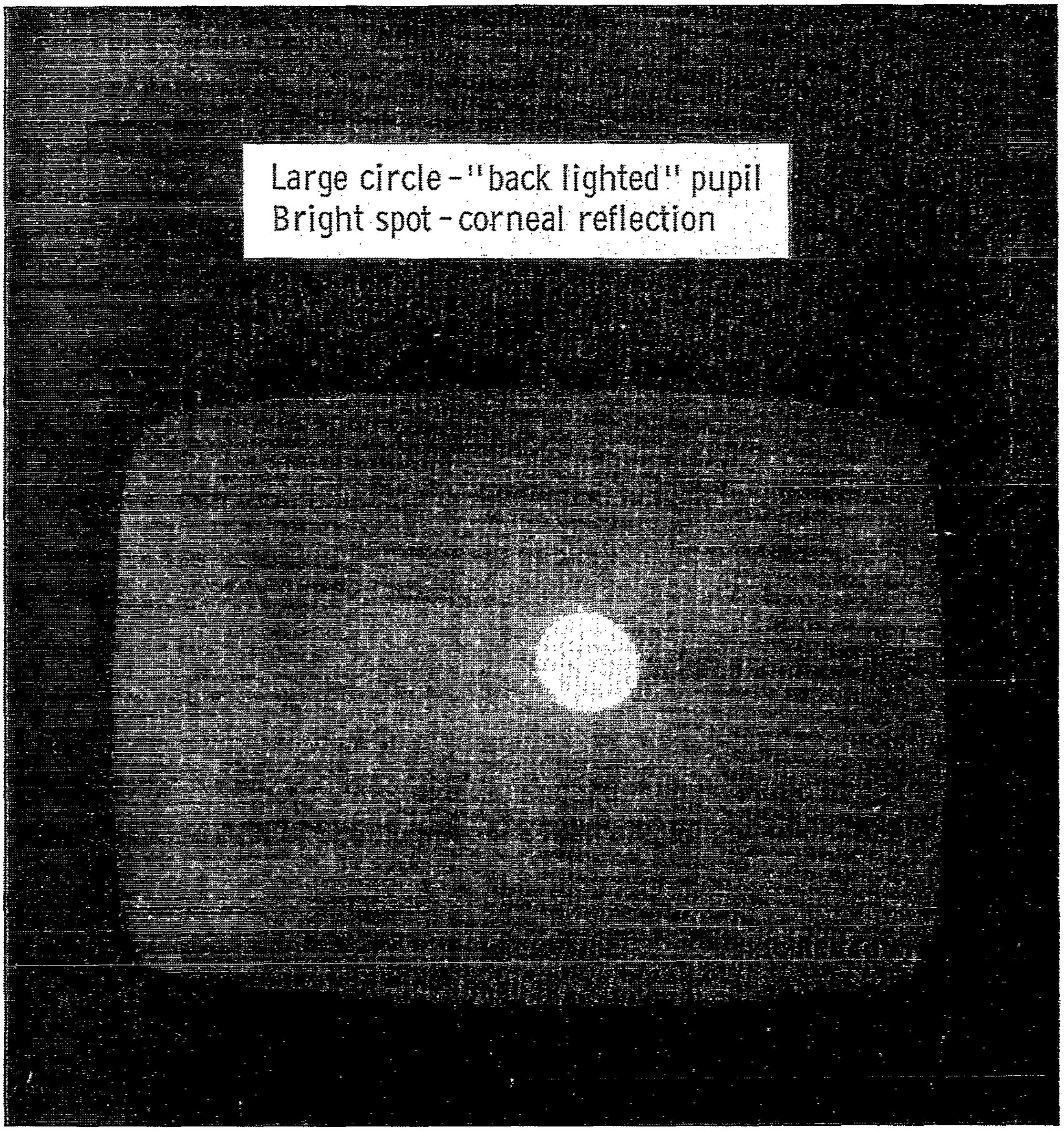
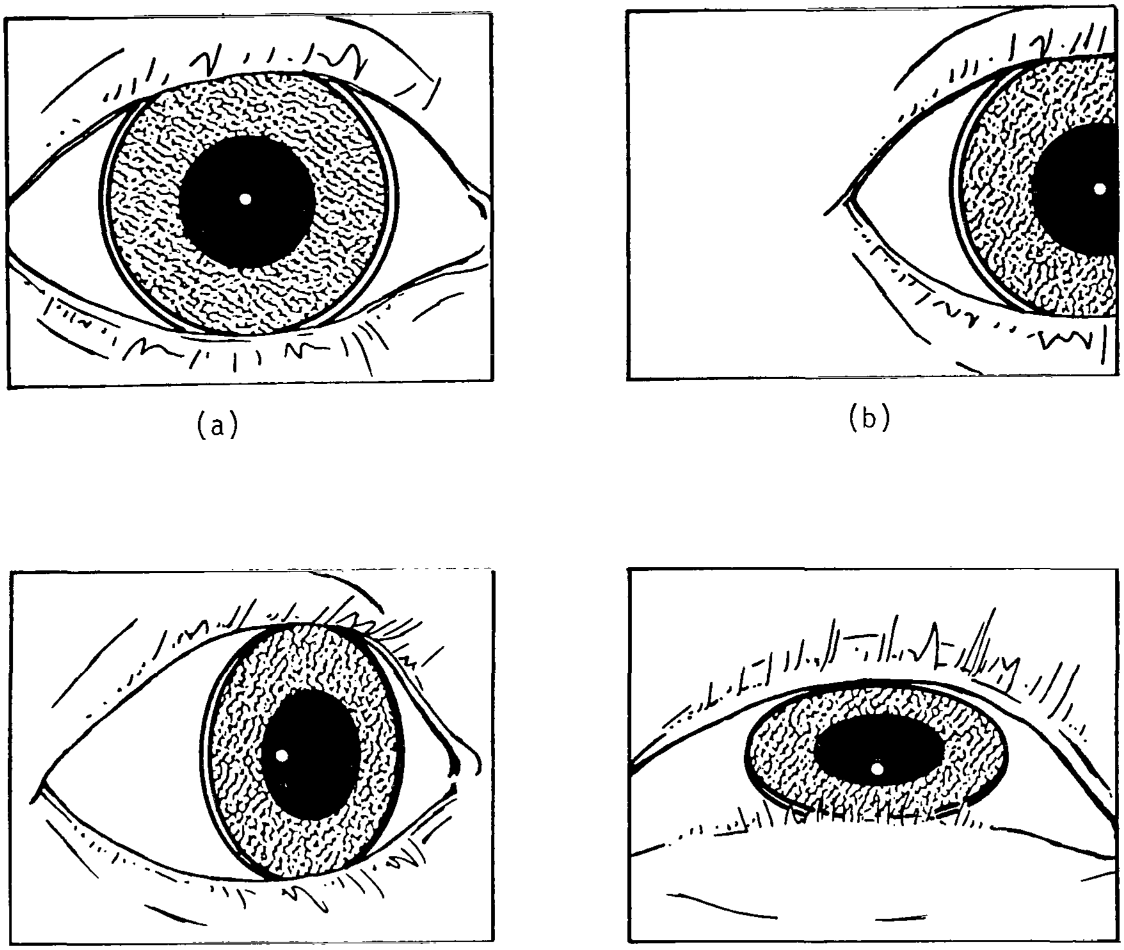


Figure 2.- Diagram showing sensing unit components.



L-77-177

Figure 3.- TV monitor display of video signal from sensing unit.



(a) (b) (c) (d)

(a) Eye looking straight ahead (at illumination source); corneal reflection at center of pupil.

(b) Eye looking straight ahead but laterally displaced; corneal reflection still at center of pupil.

(c) Eye looking to side; corneal reflection displaced horizontally from pupil center.

(d) Eye looking up; corneal reflection displaced vertically from pupil center.

Figure 4.- Relative locations of pupil and corneal reflections for several eye orientations.

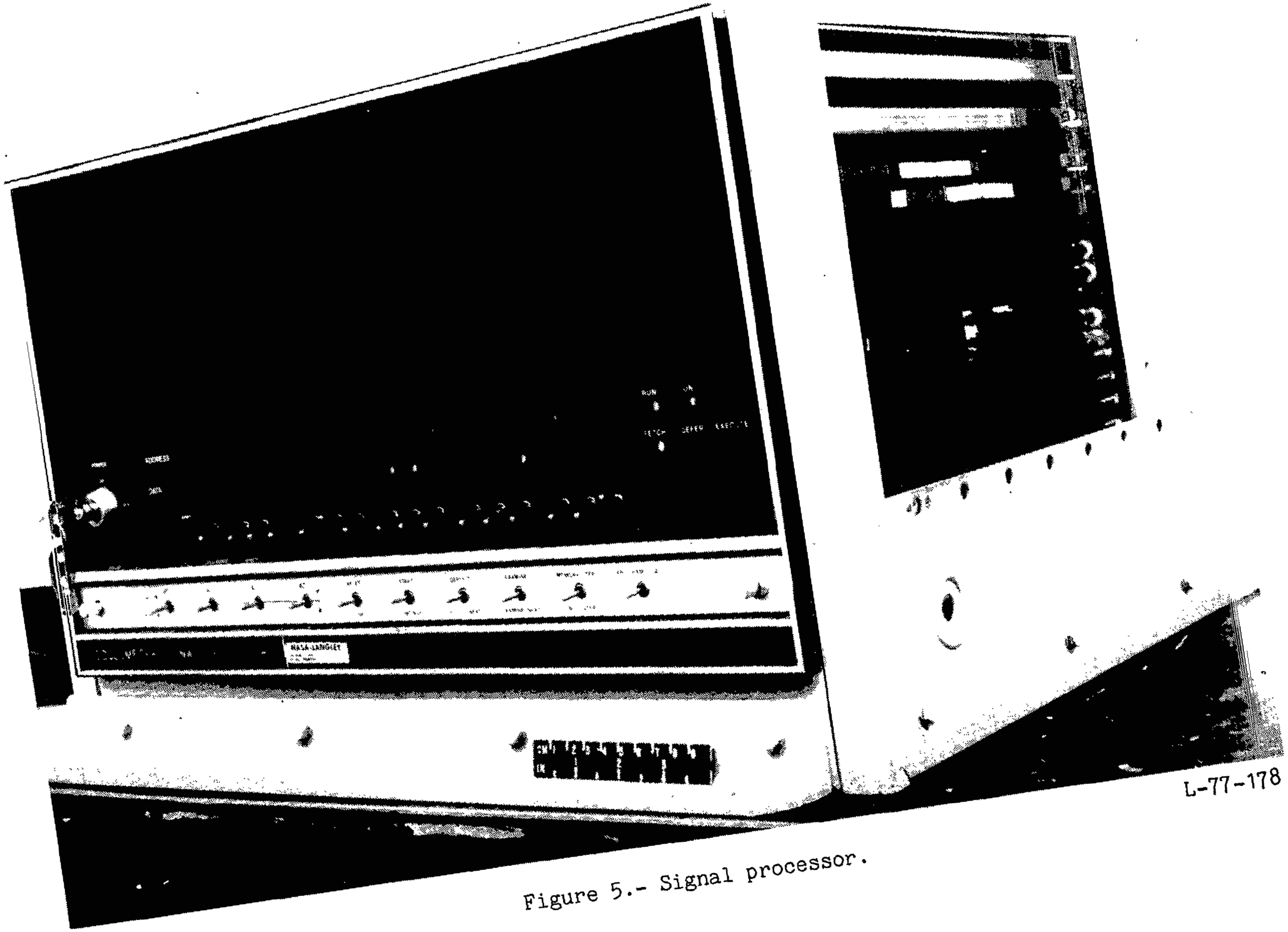


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Figure 5.- Signal processor.

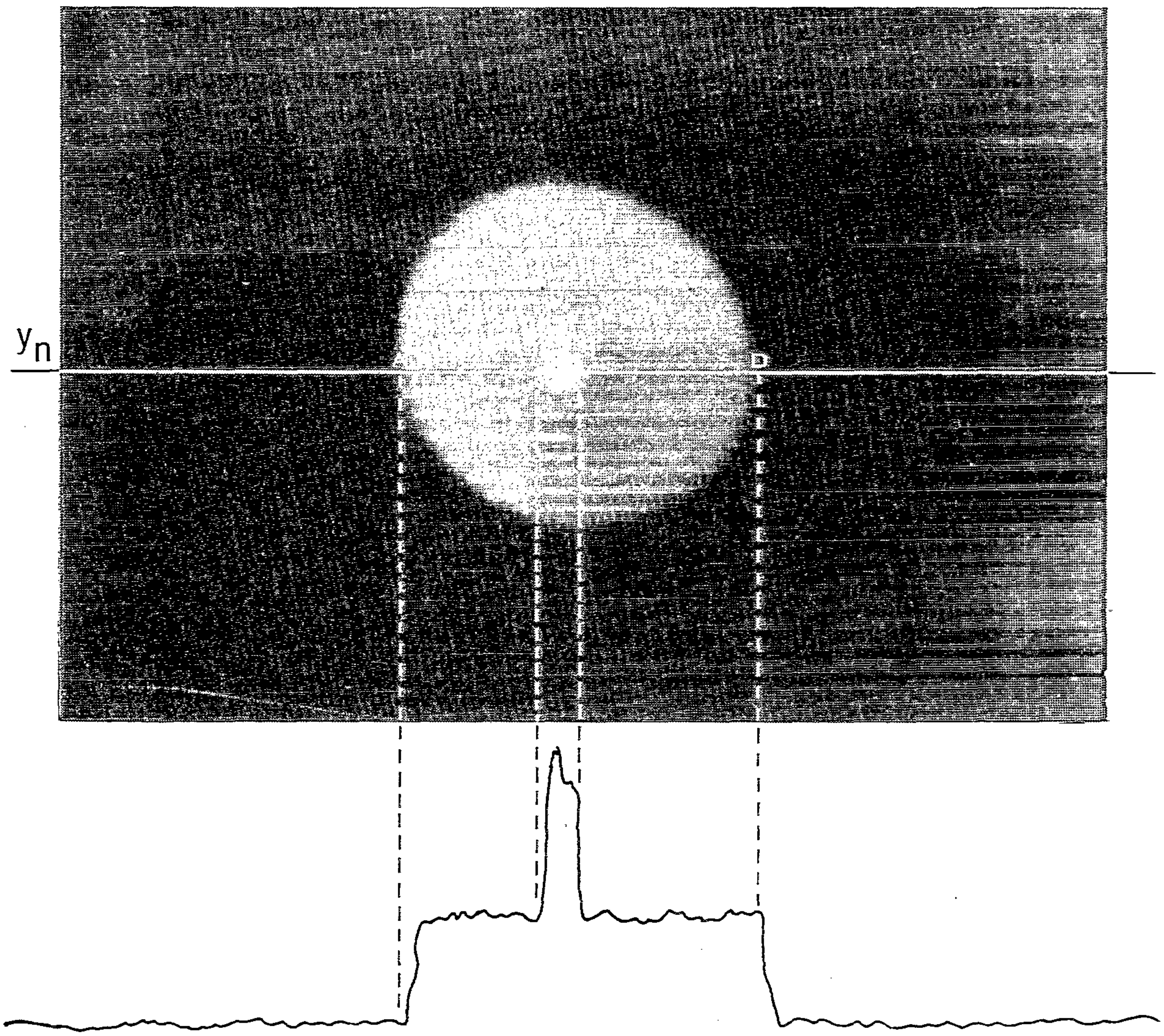

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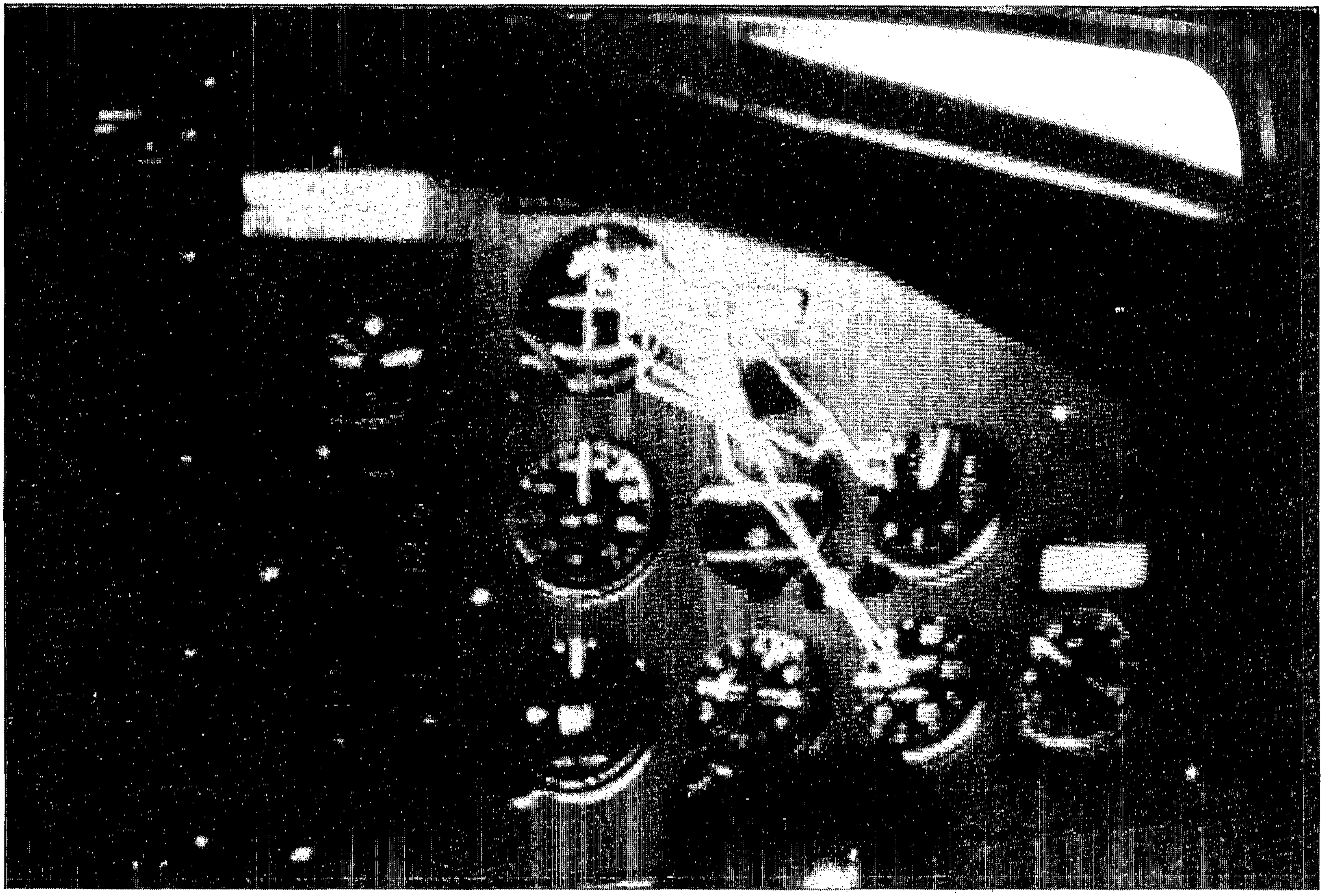
Figure 6.- Light intensity analysis of typical raster line y_n by signal processor. A, B, C, and D are contrast boundary points.



L-73-5546

Figure 7.- Timelapse video record of pilot's scan pattern.

L-73-6350

Figure 8.- Test airplane.

L-73-5803.1

Figure 9.- Flight instruments on copilot panel.

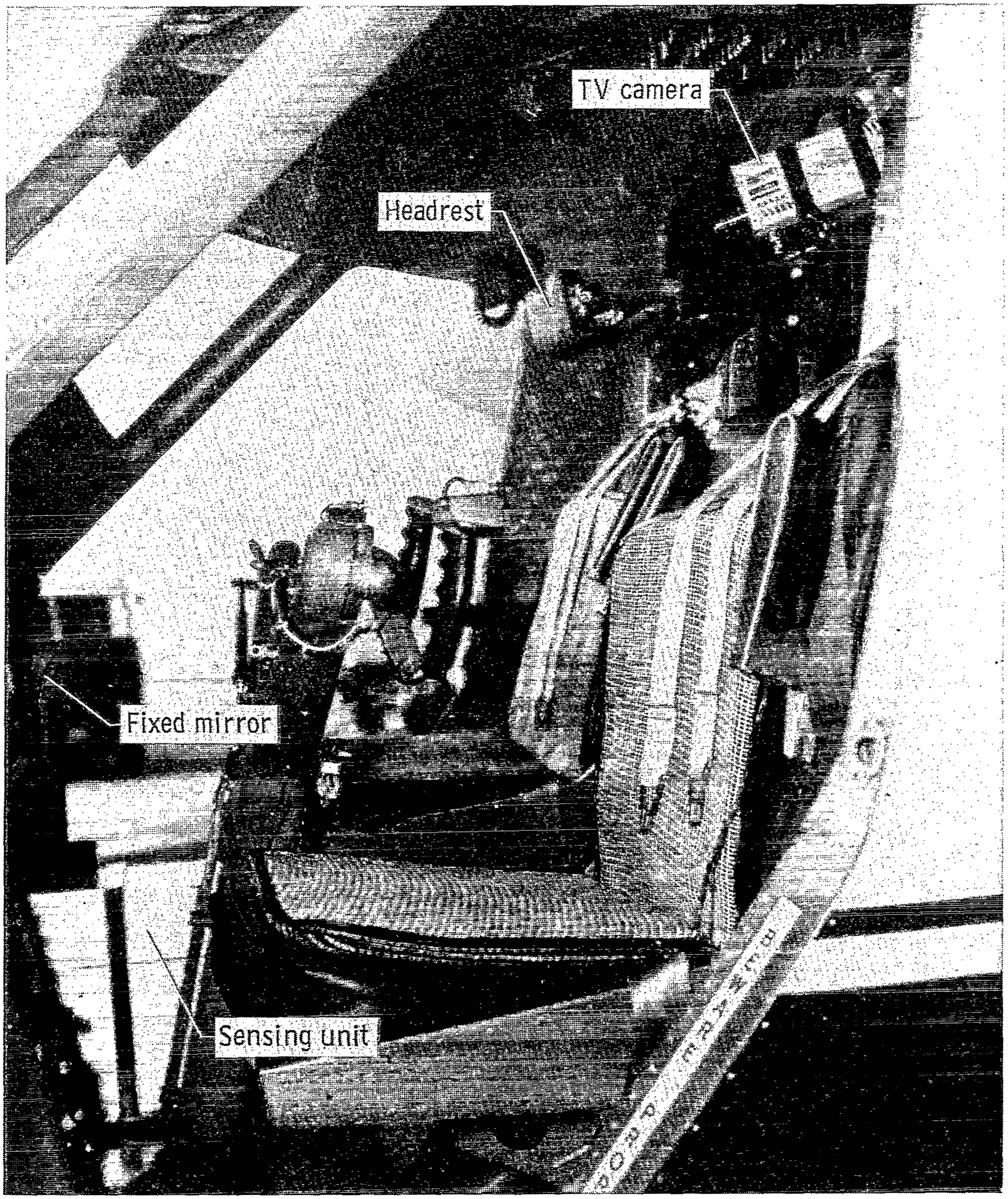


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Figure 10.- Cockpit equipment added for oculometer flight tests.

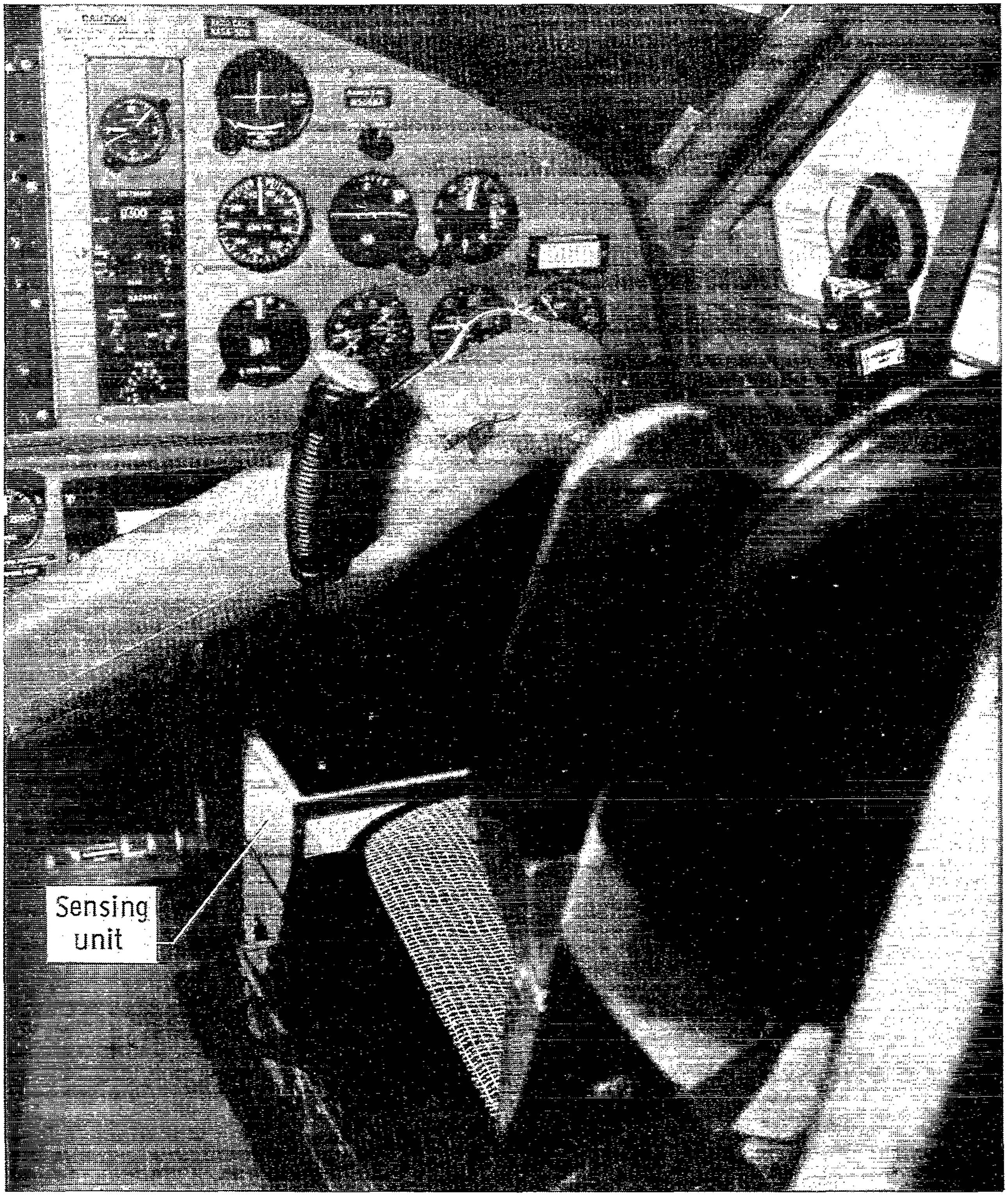

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Figure 11.- View of copilot instrument panel from location of TV camera.

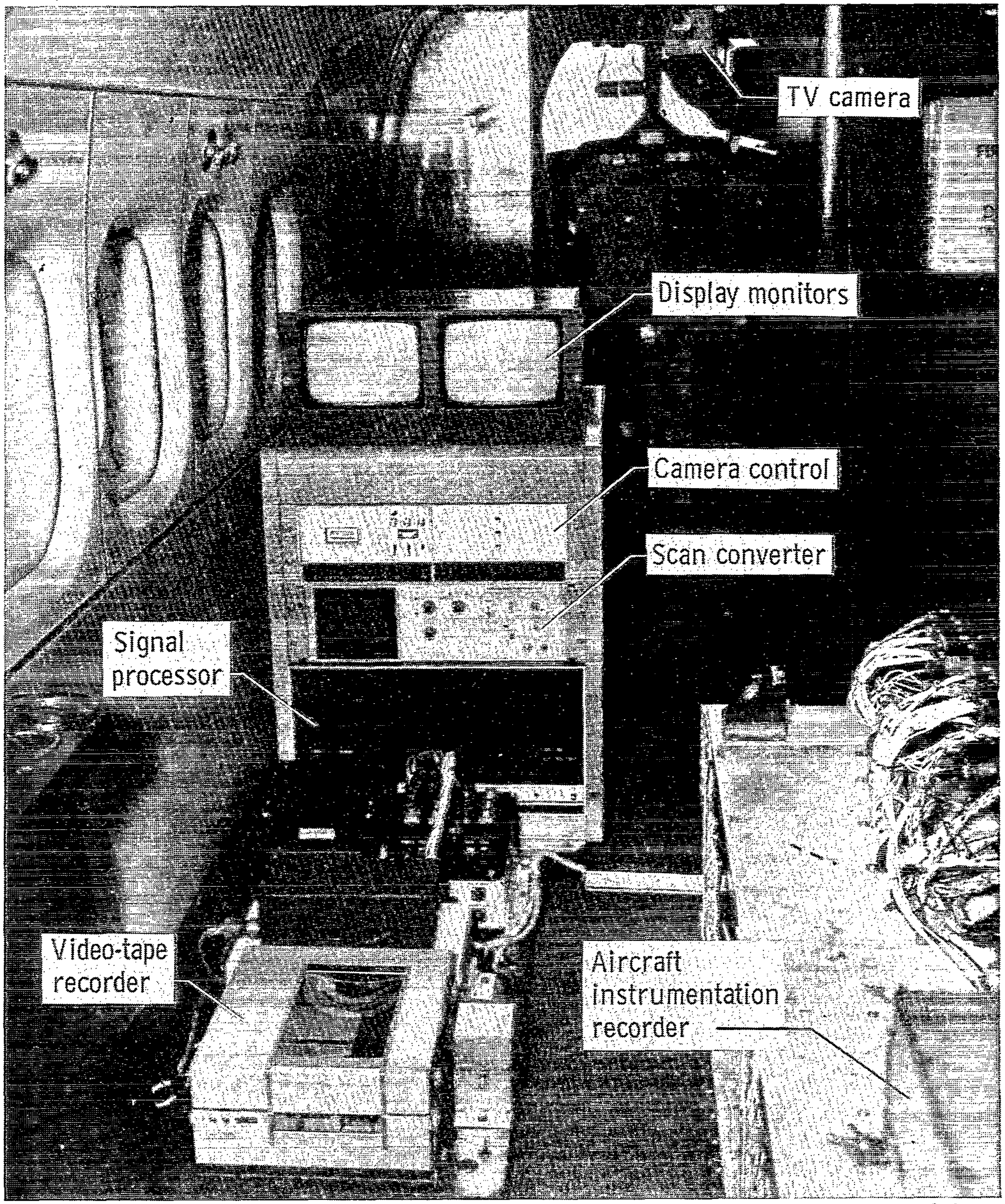

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Figure 12.- Oculometer components located in passenger compartment.

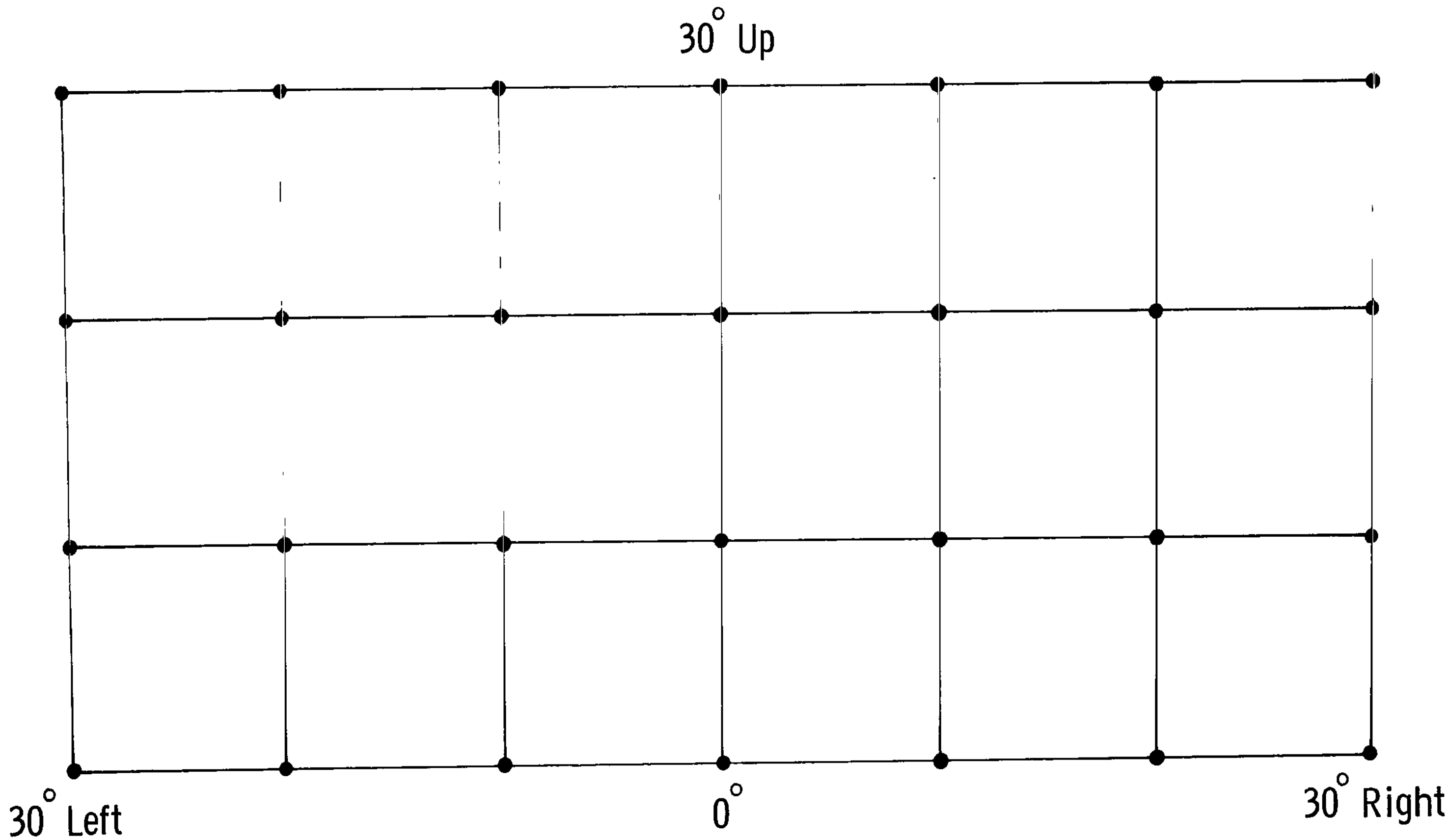

Figure 13.- Coordinates of array of nominal fixation points.

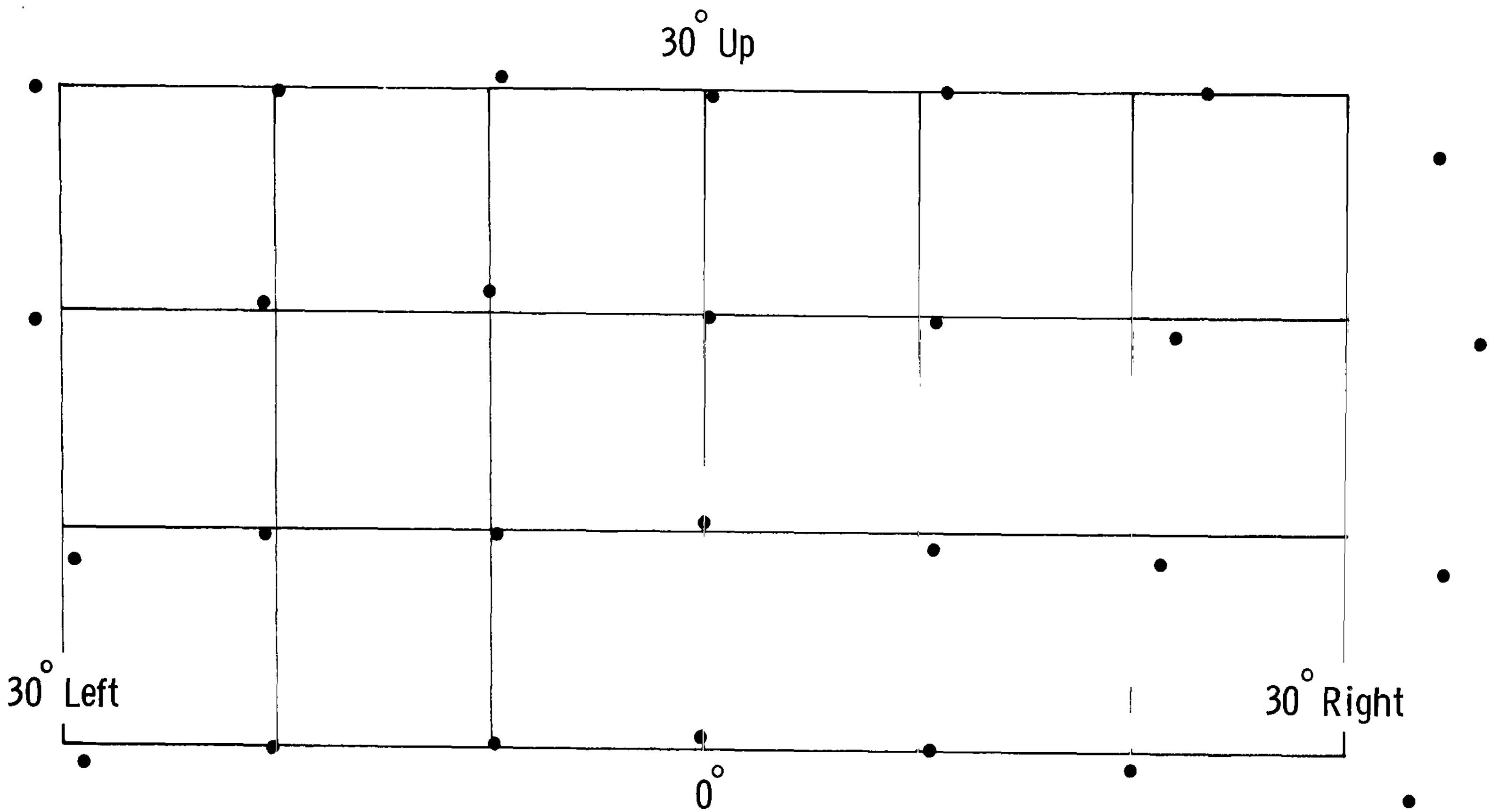

Figure 14.- Coordinates of typical uncorrected fixation-point values as measured by oculometer.

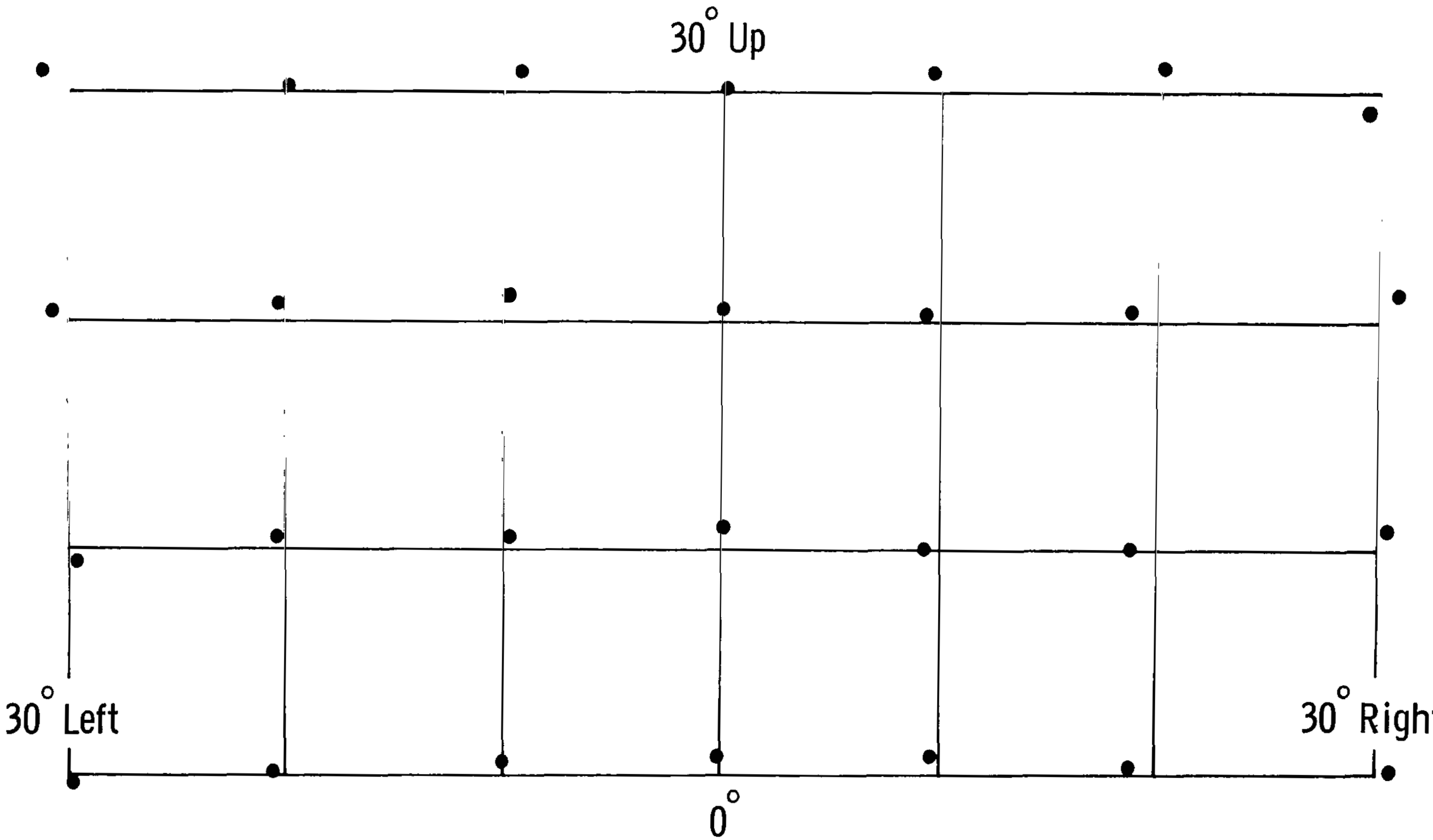

Figure 15.- Coordinates of measured fixation-point values after linearization.

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