197525

R & D CATALOG FORM

DATE 7 January 1965

1. PROJECT TITLE/CODE NAME
Attitude Determination System

2. SHORT PROJECT DESCRIPTION
An horizon camera system with statoscope and statoscope recorder.

3. CONTRACTOR NAME [redacted]

4. LOCATION OF CONTRACTOR [redacted]

25

5. CLASS OF CONTRACTOR
Manufacturer

6. TYPE OF CONTRACT
CPFF

7. FUNDS
FY 19 65 $ [redacted]
FY 19 $
FY 19 $

X1

8. REQUISITION NO.
NA

9. BUDGET PROJECT NO.
NP-0-1

10. EFFECTIVE CONTRACT DATE *(Begin - end)*
11 August 1964 - 31 Dec. 64

11. SECURITY CLASS.
A. A. - SECRET
T. - SECRET
W. - SECRET

12. RESPONSIBLE DIRECTORATE/OFFICE/PROJECT OFFICER TELEPHONE EXTENSION
DDI/NPIC/P&DS/[redacted]

X1

13. REQUIREMENT/AUTHORITY This requirement was established by a request from NPIC/P&DS to DD/S&T/OSA for proposals concerning an attitude determination device for a specific high-altitude aerial reconnaissance system.

14. TYPE OF WORK TO BE DONE
Engineering development

15. CATEGORIES OF EFFORT

MAJOR CATEGORY	SUB-CATEGORIES
Other	Photogrammetry Photo Reconnaissance Recorders

16. END ITEM OR SERVICES FROM THIS CONTRACT/IMPROVEMENT OVER CURRENT SYSTEM, EQUIPMENT, ETC.
An horizon camera system and a statoscope that includes the statoscope recorder. No instrumentation is presently available for this reconnaissance system.

17. SUPPORTING OR RELATED CONTRACTS *(Agency & Other)*/COORDINATION
Both OSA and NPIC approved the proposal submitted [redacted], and have selected that company as sole bidder. Other flight recording systems which were available were not applicable to the specific needs of this particular reconnaissance system. NPIC shall assume financial responsibility and OSA will

25

18. DESCRIPTION OF INTELLIGENCE REQUIREMENT AND DETAILED TECHNICAL DESCRIPTION OF PROJECT *(Continue on additional page if required)* The requirement for a recording vertical reference unit presents design criteria different from that associated with conventional camera stabilization systems. Its function in a high performance reconnaissance aircraft is to provide accurate and smoothed attitude data in order to permit geometric corrections to photographs taken from fixed cameras. The problems of short term stability for the duration of exposure now becomes one of long-term steadiness or smooth-tracking of aircraft motions. This performance requirement is best met by a platform having inherent gyroscopic stability rather than only the inertial

19. APPROVED BY AND DATE

OFFICE	DEPUTY DIRECTOR	DDCI

R & D CATALOG FORM (Continued)

17. handle contracting, following transfer of funds.

18. stability usually supplied by the camera; for the inertial stability of such a reference unit is small compared to that of the camera mount. Such a platform will provide long-term stability and will also be capable of driving suitable angular position transducers which can then be read out through a remote data recording system.

The function of the data recording system is to monitor and record the vehicle's attitude in roll, pitch, azimuth, absolute time and altitude -- all at the same instant as the exposure command signal to the camera. Mission requirements for the acquisition of a large number of photographs dictate that, in order to minimize weight, data is to be recorded only on command and that the system be completely automatic to insure the highest degree of reliability.

TRANSMITTAL SLIP

DATE

TO:

NPIC/P&DS/DB

ROOM NO.

4N 411

[redacted]

REMARKS:

Contract File Copy.

FROM:

ROOM NO.	BUILDING	EXTENSION

FORM NO. 241
1 FEB 55

REPLACES FORM 36-8
WHICH MAY BE USED.

☆ GPO : 1957—O-439445

(47)

#5021

SECRET

NPIC D-172-64
2 NOV 1964

MEMORANDUM FOR: Assistant Deputy Director (Intelligence) for Management

SUBJECT : Research and Development Project Approval Request for an "Attitude Determination System"

REFERENCE : DDCI Memorandum ER 63-88121, dated 23 December 1963: Approval of Research and Development Activities

In compliance with paragraph 5.b. of the reference, it is requested that the "Attitude Determination System" project in the amount [redacted] as outlined in Annex "A" be approved.

25X

[redacted]

25X

ARTHUR C. LUNDAHL
Director,
National Photographic Interpretation Center

APPROVED:

X1

[redacted]

Paul A. Borel
Assistant Deputy Director (Intelligence) for Management

5 Jan 64
Date

Distribution:
- Orig & 1 - LB SS NPIC
- 2 - Director, NPIC
- 1 - A DD I (Mgmt)
- 2 - P&DS DB/NPIC

SECRET

GROUP 1
Excluded from automatic downgrading and declassification

X1

NPIC/P&DS/DB [redacted] (15 October 1964)

ANNEX A

Research and Development Project Approval Request

I. Identification

The proposed project, designated "Attitude Determination System," is provided for in NPIC's FY 65 financial plan at the [redacted] level under Object Class 700, Category 6 "Other Projects." 25X1

The proposed development is of joint interest to DD/S&T/OSA and NPIC, since a need exists for attitude and altitude determination with the 112B camera.

II. Objectives

The objective is to determine from horizon exposures the pitch and roll of the vehicle at the instant of exposure, and to determine the altitude of the vehicle by employing a statoscope and its recorder.

III. Technical Specifications

The system would consist of two pieces of equipment -- an horizon camera system and a statoscope that includes the statoscope recorder.

The system concept will be based upon the minimization of weight and, to insure high reliability, will use proven components throughout. The system will be completely automatic and will respond and record at the instant of the exposure command to the main reconnaissance camera. By recording only on command -- in lieu of continuous recording -- weight can be held to a minimum.

The acquired data will subsequently be processed on the ground for visual and/or computer readout -- for photo reduction and interpretation.

IV. Background

In March 1964 a proposal was received through DD/S&T/OSA by NPIC/P&DS 25X1 from [redacted] At NPIC's request and because the 112B system does not have benefit of an horizon camera, DD/S&T/OSA had been seeking proposals for an attitude determination device. The [redacted] 25X1 proposal was sent to NPIC for information and evaluation only, for at that date no contractual action was anticipated: a contract was to be pursued when the availability of an airplane could be depended on in advance. (Such a contract would require the contractor to assume responsibility for installing the equipment in a vehicle.)

An airplane has become available, and no other contract exists which would cover the project.

V. Contractor and Financial Arrangements

Because the need for attitude determination has implications for the exploitation process -- in calculating geometry of photographs -- it was agreed that NPIC would assume financial responsibility based upon its part of the need. OSA would handle the contracting, following transfer of funds.

X1 Both OSA and NPIC jointly approved of the proposal submitted by [redacted] and have selected that company as sole bidder.

X1 [redacted] for the development.

VI. Security

X1 The contract will be [redacted] and association with the Agency will be classified at the SECRET level.

staff. [illegible] requirement.

go both ways.

For Contract File -DB/PHS

HORIZON CAMERA SYSTEM

FOR

TILT MEASUREMENT

Prepared by

X1 [redacted]

N64-11

March 5, 1964

TABLE OF CONTENTS

[redacted] 25X

LIST OF FIGURES

1.0 Introduction

When measurements are to be made on aerial photographs, it is essential to have some technique for orienting them. The usual processes of photogrammetry permit the orientation by providing adequate ground control in each picture. In areas where ground control is sparse or lacking, some substitute must be provided. Over the years, many such substitutes have been tried with varying degrees of success. The subject of this proposal is the provision of a method of supplying the elements of angular orientation. In the past, techniques from vertical gyros to inertial platforms and from sun and star photos to horizon photographs have been used. Of these, perhaps the oldest is the technique of horizon photography.

2.0 General Requirements

Some of the limitations of horizon photography are obvious in that it requires reasonably flat country and meterological conditions which permit viewing the horizon. As will be seen, some of these limitations are not quite so stringent as at first sight they may appear. Let us first consider some of the general requirements to be met in the design of such a system.

2.1 Horizon Dip.

The location of the horizon in an aircraft is somewhat below the horizontal. This is shown in Figure 1 where we observe that in the geometric case (rays travelling along straight lines) the horizon falls below the tangent to the geoid by an angle δ . This is easily computed to be

$$\delta = 1.07\sqrt{H}$$

where δ is in minutes of arc and H is the aircraft altitude in feet. But in point of fact, light rays are refracted by the atmosphere so as to follow the path shown. This reduces the "dip" of the apparent horizon to:

$$\delta = 0.98\sqrt{H}$$

The values of this apparent horizon dip are plotted in Figure 2 where it is seen that it has an appreciable range going to 3.66° for an altitude of 50,000 feet.

2.2 Choice of Scale and Coverage.

The factors of scale, coverage, size and precision are all mutually dependent. Some of the considerations which affect the choice of focal length and format size are described in this section.

2.2.1 Angular Range.

The provision of the angular coverage for horizon photography must be very carefully done since for a given measuring accuracy the system size will grow as the range is increased. One factor contributing to the range has already been discussed, and that is the variation of dip with the altitude range of the missions. If, for example, we must consider flights from 10,000 to 50,000 feet, the dip varies from 1.63 to 3.66 degrees. The other factor to be considered is the range of roll and pitch motions. If the horizon camera is to be attached to a stabilized prime vertical camera the range can be made quite small. In commercial mapping missions it is usual to fly with sufficient care and sufficient references to permit restriction of aircraft roll and pitch motions to less than 1.5 degrees. Under these conditions quite good accuracy is obtainable with very small cameras. In military missions it has been customary to design for roll and pitch motions of up to ± 8 degrees. Under these conditions the range of angular coverage to be provided for is 6.37 degrees above the horizontal to 11.66 degrees below the true horizontal. This is a total range of 18.03 degrees.

2.2.2 Scale and Accuracy.

Several investigations[1] of the use of horizon photography have shown that it is capable of accuracies of about 2 minutes of arc. If we desire to provide the possibility of attaining this accuracy with low cost measuring equipment, we must permit the measurement of 2 minutes of arc with instruments having errors of about 0.001 inches. This may be conveniently provided by any of the micrometer types of equipments since the measuring range will not overlarge. The tentative scale will then be about 1 minute of arc per .001 inches. This is attained with a focal length of the order 3.4 inches.

3.0 Possible Horizon Camera Designs

Since the idea of horizon photography is not new, there are many designs that have been suggested for the ap-

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[1] Zarzycki, Photogrammetric Engineering, Volume XXIX No. 4

plication. Before selecting a particular type, we might profitably examine a few of these techniques. One requirement common to most of these is a small protrusion from the aircraft.

3.1 Toroidal Lens Camera.

This type of lens and camera produces an image as shown in Figure 3. The picture is an annulus with the sky appearing on the exterior. The horizon then appears as a circle which is centered on the axis when the aircraft is level. The advantage of this type of instrument lies in the simplicity of the display. The display is much like a circular level bubble except that the horizon circle changes in diameter with altitude as a result of dip. Another disadvantage is the poor tangential resolution of the picture, limiting its use to the horizon itself. One great advantage is the display of the entire horizon permitting the selection of useful portions of it for measurement. This technique may be quite useful in a low accuracy system.

Another notation should be made on this system. The optical characteristics require a cylindrical window. This cylinder forms an essential part of the optics and must be maintained in the proper orientation relative to the toroidal lens. Thus, the system is only useful when applied to rigid, fixed mount systems. If applied to stabilized or soft mount systems, the horizon image will become distorted and difficult to reduce to roll and pitch data, since the distortion will be a function of roll and pitch.

3.2 Conical Mirror System.

This system has the advantage of requiring ordinary optics, except for the simple and inexpensive conical mirror. It has all the advantages and disadvantages of the previous system. It differs from that system in permitting a simpler installation and a cheaper instrument. Pictorially, the display is identical except that the sky is inside and the ground outside the horizon circle. The system appears in Figure 4.

3.3 High Oblique Cameras.

Orientation may be obtained from a single high oblique aerial photograph which includes the horizon. The geometry of such a photograph is shown in Figure 5. The details of the derivation are not given but it can be shown that for small deviations from level flight the pitch and roll angles of the aircraft are obtainable as follows. We measure the angle ϕ on the photograph and the linear distance $\overline{OA}$. From these two measurements and from the known nominal position of the camera we can find:

$$\overline{OD} = f \tan \theta$$

$$\overline{OC} = f \tan \theta \cos \phi$$

$$\overline{AB} = \delta \frac{(\overline{OA}^2 + f^2)}{f}$$

$$r = f \frac{(\overline{OC} - \overline{AB} - \overline{OA})}{(\overline{OA}^2 + f^2)}$$

$$p = \tan \phi \sin \theta$$

where θ = nominal angle of obliquity, i.e. angle between the axis of the prime vertical and the axis of the oblique camera.

δ = dip angle in radian measure

f = oblique camera focal length

r = aircraft roll in radian measure

p = aircraft pitch in radian measure.

The above geometry is basic to the use of most of the conventional horizon cameras. It may be noted that any single photo corresponds to a single determination of roll and pitch. If high accuracy is desired, or if we wish to protect the mission against meteorological obscuration on a part of the horizon, or if there may be mountainous conditions on some part of the horizon, it is necessary to provide a view of as many portions of the entire horizon as possible. As a matter of fact, systems using two views of the horizon have been used, commonly, especially under the trimetrogon arrangement.

3.4 Four Lens Camera.

One form of horizon camera which has found some practical use is a form using four lens viewing the horizon in four directions along mutually perpendicular lines. The resulting camera has four pictures of an angle of obliquity of 90 degrees. The system is excellent and has performed very well, However, the camera has a restricted angular range and is quite expensive as a result of the complex optics between the camera body and the four lenses.

3.5 Single Lens With Pyramid Prism.

This system combines the advantages of the four lens system of the previous paragraph with an inexpensive unit capable of being adapted to many cameras. The pyramid prism is essentially an attachment to a standard camera. Since this is the system that is proposed, a detailed examination of its characteristics will be made in the following section.

4.0 Proposed Horizon Camera.

The proposed horizon camera utilizes the system described in the last section (Par. 3.5). The installation is pictured in Figure 6 where a type P2 camera with 50 ft. magazine is illustrated with a prism. The focal length is 3 inches on a 70 mm format. The required projection from the aircraft is 5 inches and the window consists of a rectangular parallelepiped 5 X 8 1/4 each face (note that a 100 ft. magazine is also available).

4.1 Character of the Photographs.

Approximately 20 degrees of horizon in each of four directions is portrayed on each frame. The geometry of these photographs and methods of reducing data are discussed in this section.

4.1.1 Geometry.

The appearance of the photographs is shown in Figure 7, with indications of the direction of deflection of the horizon for a particular roll and pitch condition. The geometry of each photograph is exactly similar to that of the single oblique, except that the angle of obliquity now exceeds 90 degrees. If fiducial marks are provided (as they will be) at the nominal horizon, the equations previously given will change somewhat in detail but remain basically the same.

In this case the measured quantities become ϕ and $\overline{DE}$ (referring back to Figure 5). The reduction equations now become:

$$\overline{OD} = f \tan \theta$$

$$\overline{OC} = f \tan \theta \cos \phi$$

$$\overline{OA} = \overline{OC} - \overline{DE}$$

$$\overline{AB} = \delta \frac{(\overline{OA}^2 + f^2)}{f}$$

$$R = f \frac{\overline{DE} - \overline{AB}}{(\overline{OC}^2 + f^2)}$$

$$\rho = \phi \sin \theta$$

One interesting facet of this system is its ability to be used even when the horizon is obscured or broken by mountains. This application will supply only changes in orientation from frame to frame, but these data can be quite useful if precisely bridged forward. The technique consists of using two successive frames. In the first frame we select two conveniently spaced features as close to the obscured horizon as possible, i.e. as far away as possible. The coordinates of these two points are measured and recorded. In the second frame, we identify and measure the same two features. By appropriate computation we can now determine the difference in roll, pitch and yaw of the aircraft. The method depends on the fact that the points being measured are so distant that the parallax caused by aircraft translations are negligible. As a result the change in coordinates is purely a function of the rotations of the aircraft.

The results of analysis of the geometry give for small angles, the following results when referring to Figure 8.

$$\Delta \psi = \frac{\Delta y_A \Delta x_B - \Delta x_A \Delta y_B}{\Delta x_A \Delta x_B + \Delta y_A \Delta y_B}$$

$$\Delta p = \Delta \psi \sin \theta$$

$$\Delta r = f \frac{y_B - y_A - \Delta \psi x_B}{\left[\frac{f}{\cos \theta} + y_A + \Delta \psi x_B \right]^2}$$

where the nomenclature is derived from Figure 8 or previous definitions.

4.1.2 Methods of Data Reduction.

After collection of the photography, we are faced with the problem of converting the photographs into the desired data of Δr and $\Delta \psi$ or r and p. The attitude, or attitude changes, may be obtained by the use of the analytical methods, actually making the indicated measurements and using the equations for reduction by a computer. For somewhat lower accuracies, or for methods of reduction not involving computer time, the following suggestions may be made.

a) Oblique Tiltometer. This little instrument of a design suggested [redacted] can be constructed at very little cost for measuring horizon photos. After setting the attitude scale (to insert dip), the instrument reads directly in roll and pitch. When measuring a side view the rotation scale will be found to be calibrated directly in pitch angle while the displacement scale will read roll angle directly. The procedure is to align the horizon fiducials with the corresponding fiducials on the picture. By manipulating the rotation and displacement controls one aligns the horizon cursor with the horizon image. Reading the scales will then give roll and pitch directly. In a front or rear view the rotation scale reads roll, while the displacement scale will read pitch directly.

X1

b) Projection Type Instrument. If a photographic projector is mounted in a pair of gimbals and has a pyramid prism mounted in front of its lens, it forms an exact analog of the aircraft-horizon camera system. By providing fixed mirrors to reflect the four horizon views to the horizontal easel, a convenient instrument is produced to measure roll and pitch angles. Readout is by means of encoders on the gimbals and the operation may be described as follows. A set of mutually concentric squares is provided on the horizontal easel. The operator manipulates the gimbals until the four horizon lines are aligned with the sides of a single square. Then a button is pushed to read out the encoders to a paper tape or direct to a computer, as desired.

c) Plotting Instrument. Finally, in the case of obscured horizons, the reduction is now limited to and . These may be measured analytically or the pair of views may be put into a simple stereoscopic microscope with a parallax bar measuring provision. A greatly simplified resection can then be performed. The projection type instrument can also be used to read differences into tape.

4.1.3 Limitations.

Of course, the previously described system is limited by factors affecting the horizon. Thus, in the event that there is a 3000 foot difference in ground elevation between opposite horizons, the greatest error that can result depends upon the altitude. Remembering that the values of roll and pitch are the mean of measurements on four photos:

at 10,000 ft. the error is 45 minutes;
50,000 ft. the error is 3.4 minutes;
80,000 ft. the error is 2.7 minutes.

In the event of obscuration, the differences in orientation may be measured as described. These may be bridged forward over short distances but, of course, errors will accumulate. On the other hand, differences of orientation can be used to strengthen measurement quite apart from their use to accumulate the orientation numbers.

4.2 Proposed System Description.

The proposed system will consist of the following items to be supplied by the contractor:

X1 a) One [redacted] Model P2, 70 mm camera with 100 ft. magazine modified to incorporate additional fiducial marks and a frame count indication between frames.

b) One horizon prism (pyramid) with mounting hardware and mounted to the above camera with proper alignment and providing for 5,000 to 50,000 feet altitudes and ± 8 degrees in pitch and roll.

c) Window and window structure suitable for aircraft mounting. Retracting mechanism for withdrawing windows to flush position.

d) Mounting provisions and electrical interface provisions for operation with the prime vertical mapping camera.

e) Data Reduction device for direct reading of roll and pitch from horizon pictures, as described previously (oblique tiltometer).

The basic dimensions of this system are shown in Figure 6. The window dimensions and the projection below the aircraft skin depends very directly on the desired scale of the pictures. The present scale is about 0.001 inch per minute of arc. If a lower scale can be accepted - making data reduction somewhat more difficult for a given level of accuracy - the size of the prism and the window would reduce proportionately, reducing the projection.

Another factor tending to make the size large is the requirement for covering the wide range of horizon positions. If the altitude range and roll and pitch range were reduced to the size of the window and projection would be reduced proportionately. Thus, if the roll and pitch range were ± 4 degrees and the altitude restricted to 40,000 to 60,000 feet, the size of window and projection would reduce by more than half.

4.2.1 Alternate System.

An alternate system giving about one half the scale of the above on a 1 X 1 inch format (35 mm film) is illustrated in Figure 10 (at the same scale as Figure 6). In this case, the distance from the prism to the lens becomes rather small. A decision on the suitability of such a setup must await further knowledge of the details of the structure around the mounting area and the shape of the aircraft skin. If the range of roll and pitch were reduced, the distance from lens to the prism may be increased permitting a more convenient mounting. The cost of this arrangement would be almost the same as that of the previously described one unless the window retraction can be dispensed with.

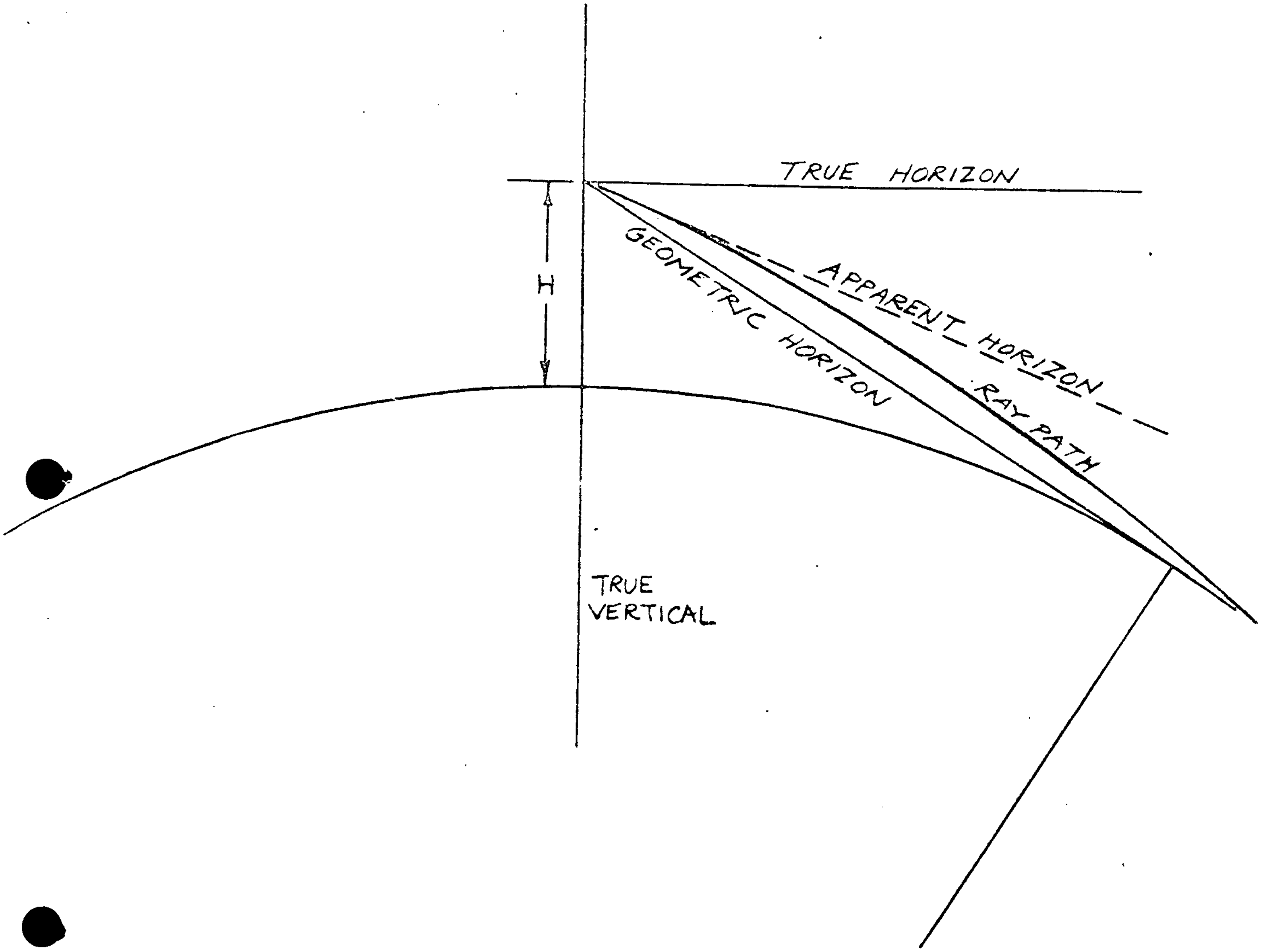
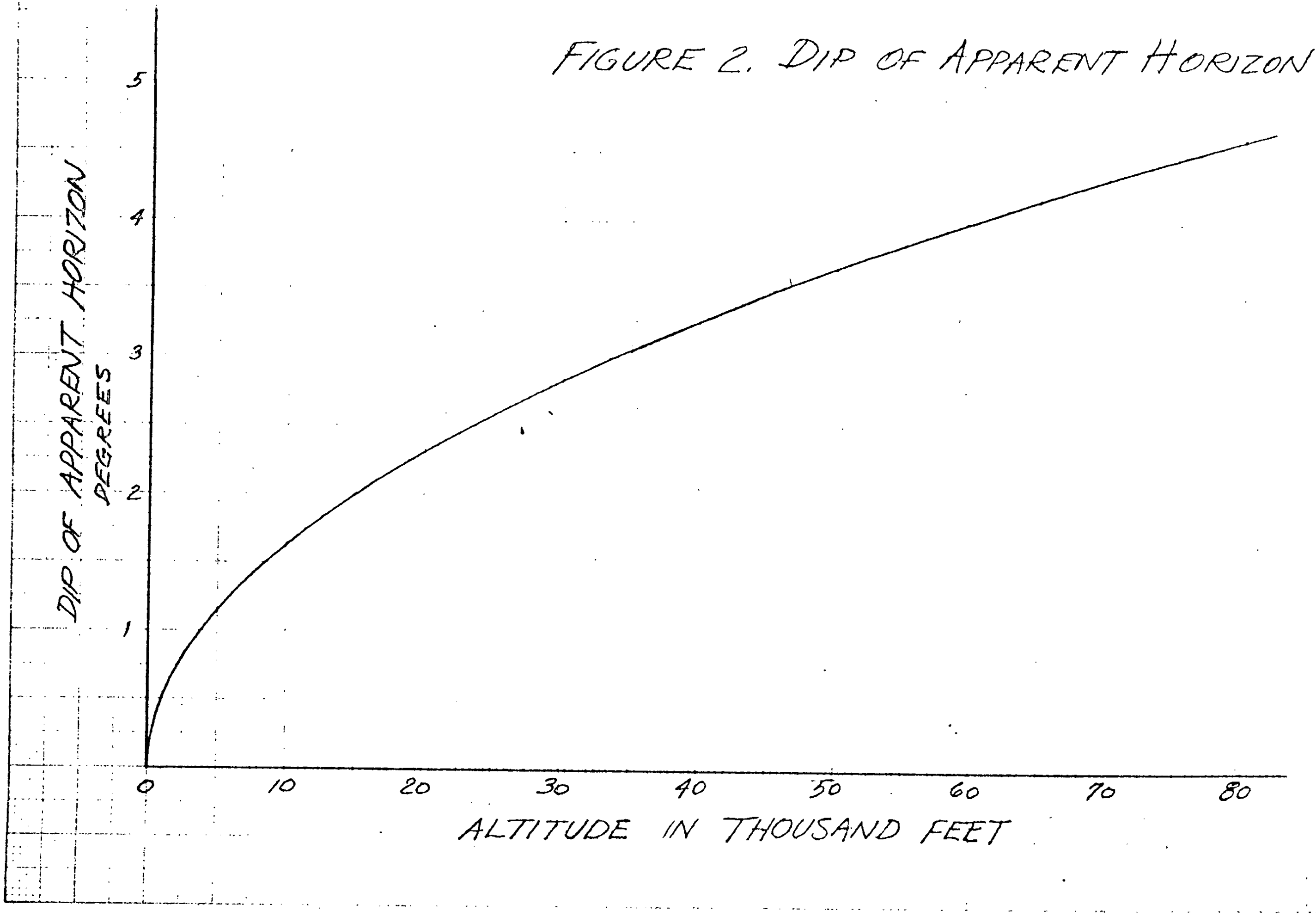


FIGURE 1. DIP OF THE HORIZON

FIGURE 2. DIP OF APPARENT HORIZON



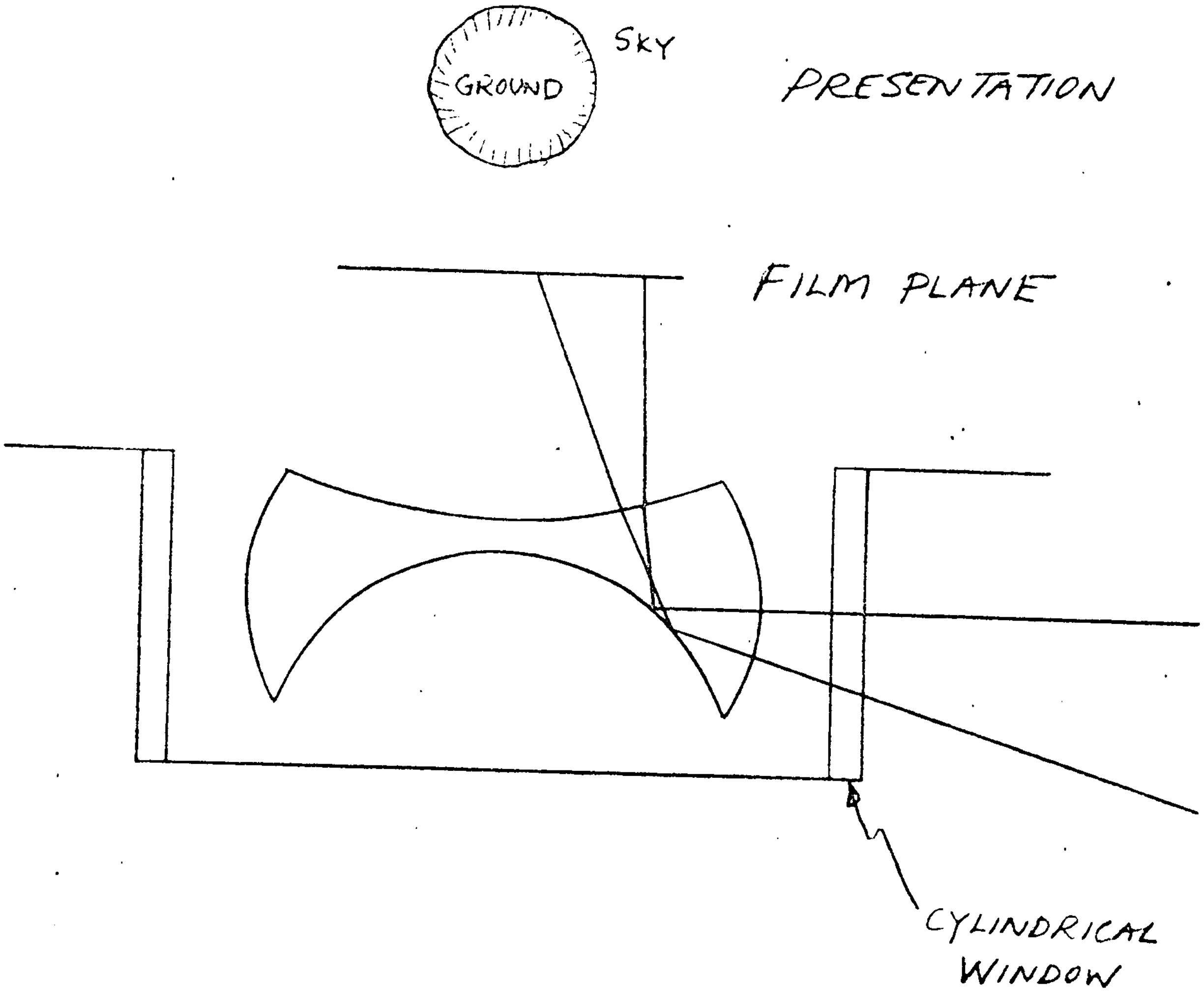


FIGURE 3. TOROIDAL LENS SYSTEM

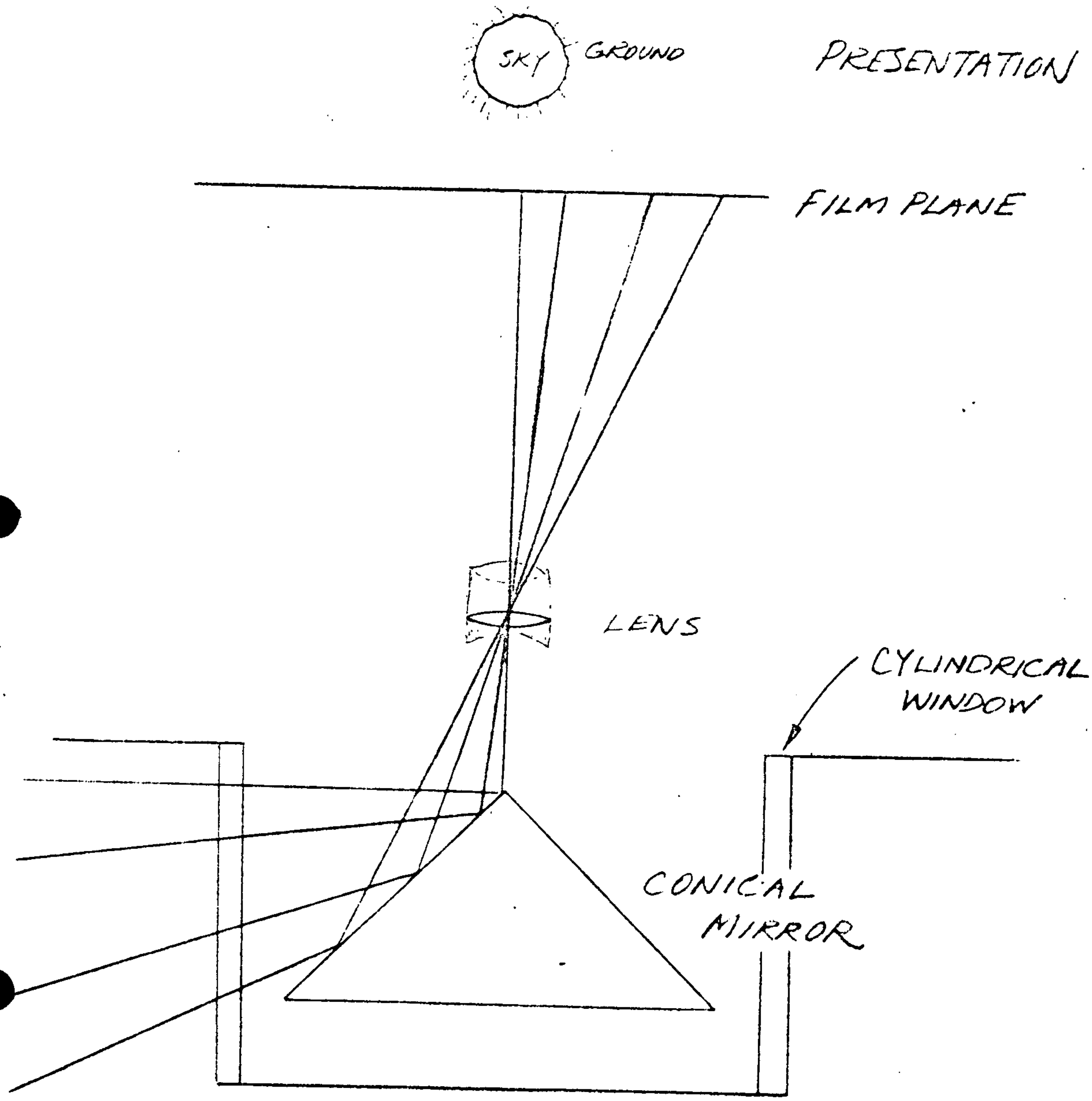


FIGURE 4. CONICAL MIRROR SYSTEM

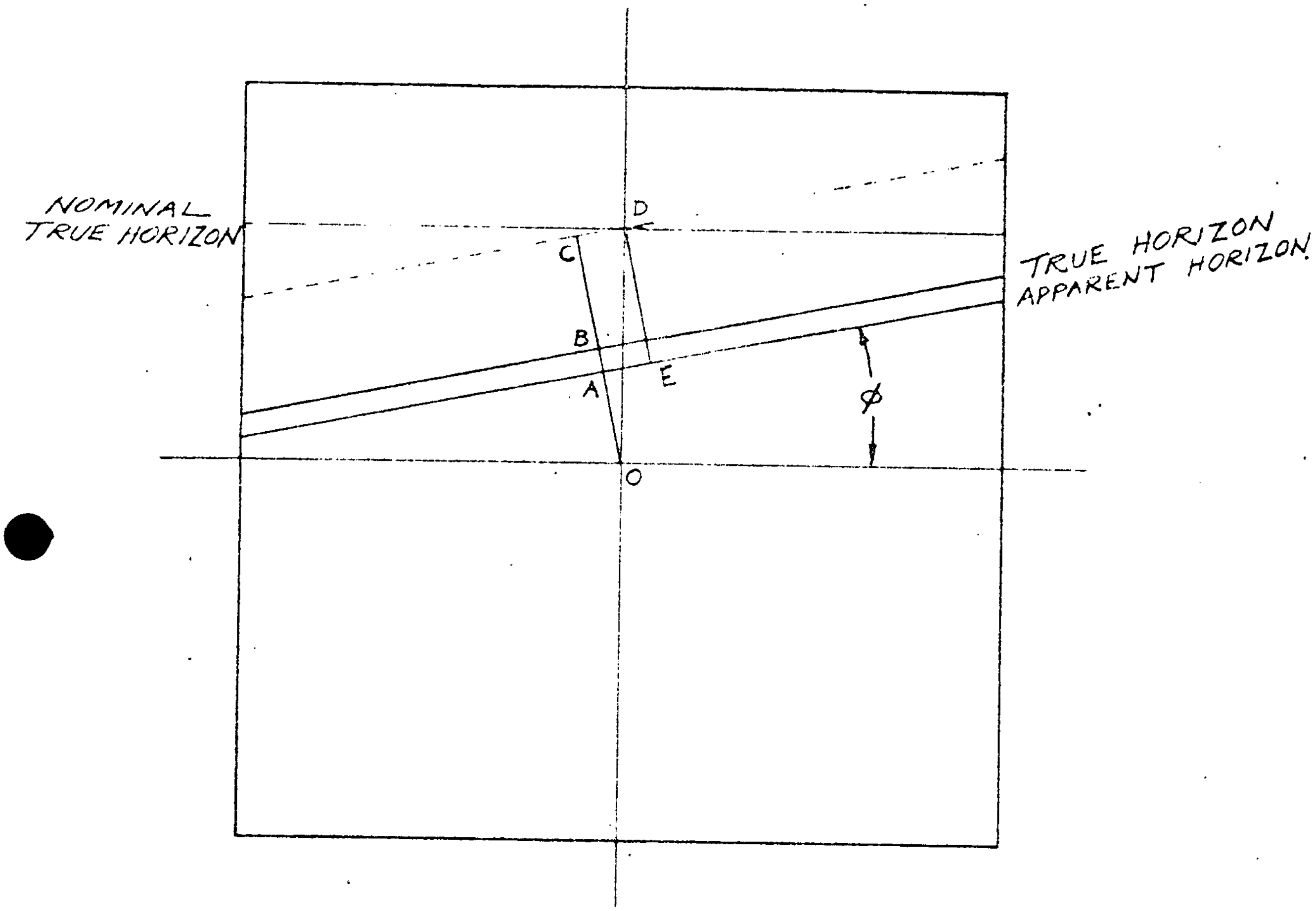


FIGURE 5. GEOMETRY OF OBLIQUE PHOTOGRAPHS

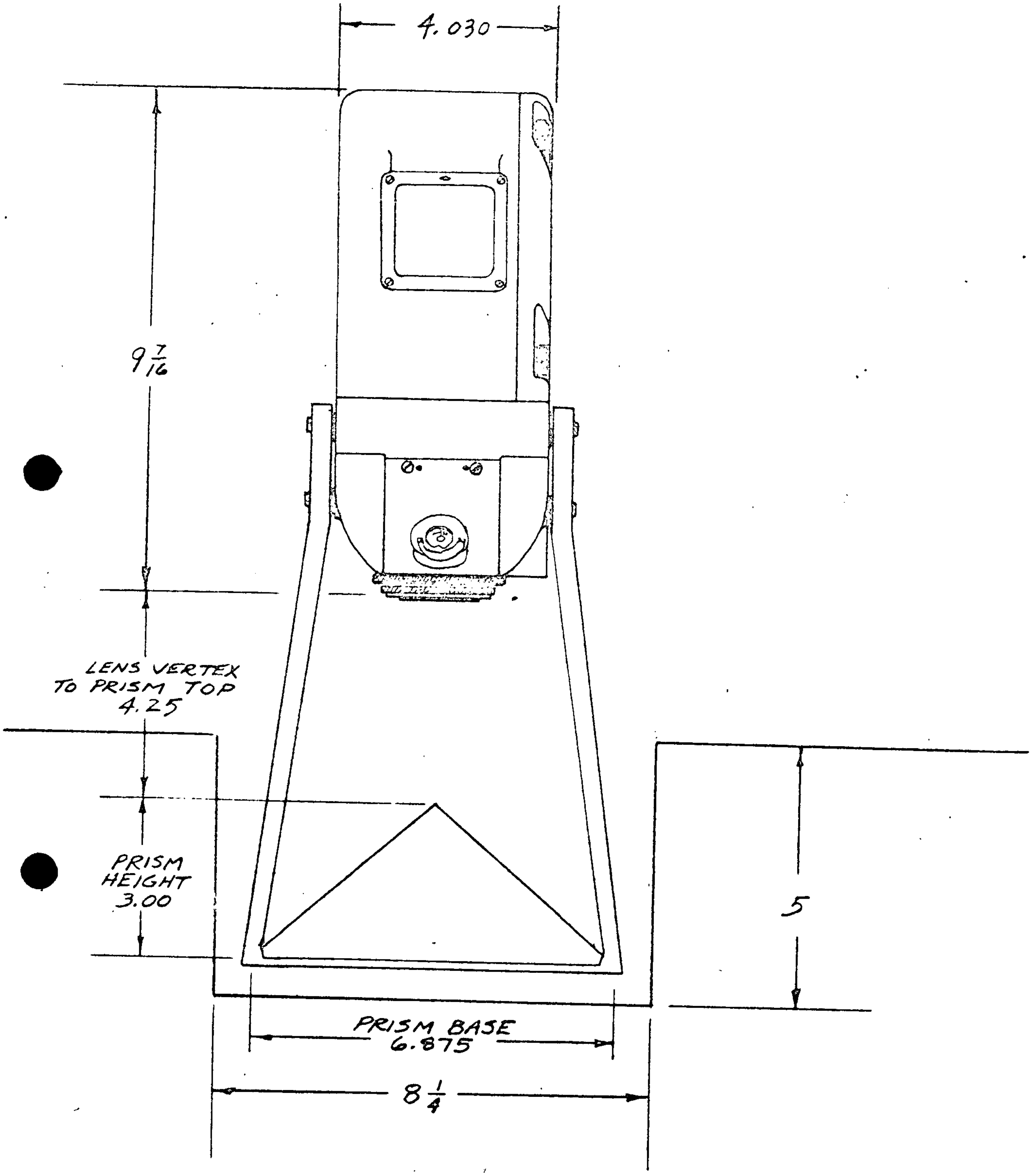


FIGURE 6. P2 CAMERA - PYRAMID PRISM SYSTEM

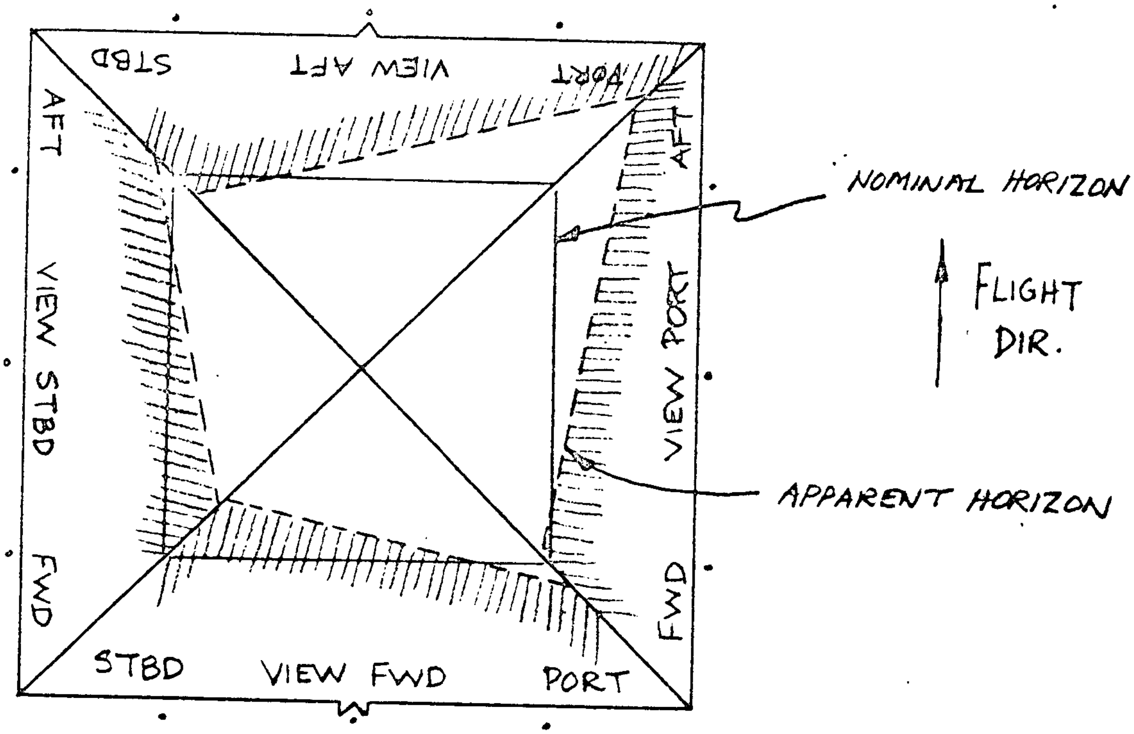
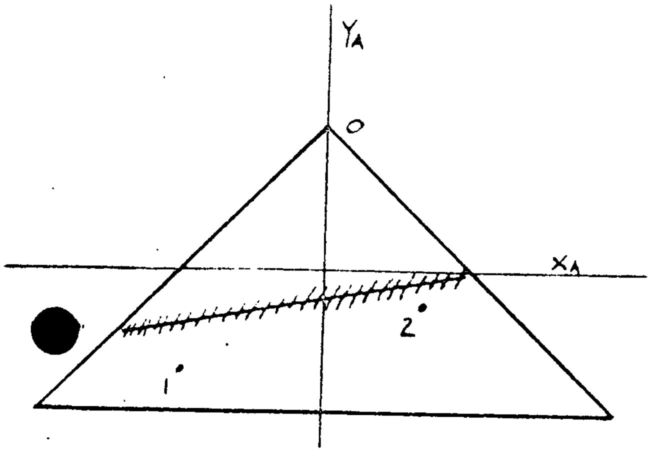


FIGURE 7. HORIZON PHOTOGRAPH LOOKING AT BASE

STARBOARD WING DOWN } ATTITUDE
NOSE DOWN



HORIZON PHOTO A

MEASURED VALUES

x_{A1}, y_{A1}

x_{A2}, y_{A2}

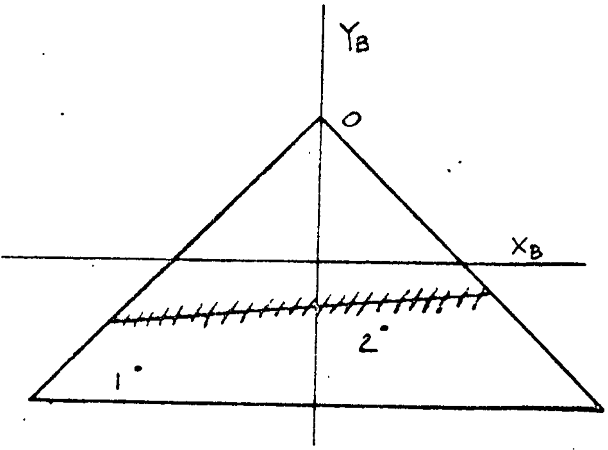
DEFINED VALUES

$\Delta x_A = x_{A2} - x_{A1}$

$\Delta y_A = y_{A2} - y_{A1}$

$$x_A = \frac{x_{A2} + x_{A1}}{2}$$

$$y_A = \frac{y_{A2} + y_{A1}}{2} - y_0$$



HORIZON PHOTO B

MEASURED VALUES

x_{B1}, y_{B1}

x_{B2}, y_{B2}

DEFINED VALUES

$\Delta x_B = x_{B2} - x_{B1}$

$\Delta y_B = y_{B2} - y_{B1}$

$$x_B = \frac{x_{B2} + x_{B1}}{2}$$

$$y_B = \frac{y_{B2} + y_{B1}}{2} - y_0$$

FIGURE 8. HORIZON PHOTO GEOMETRY

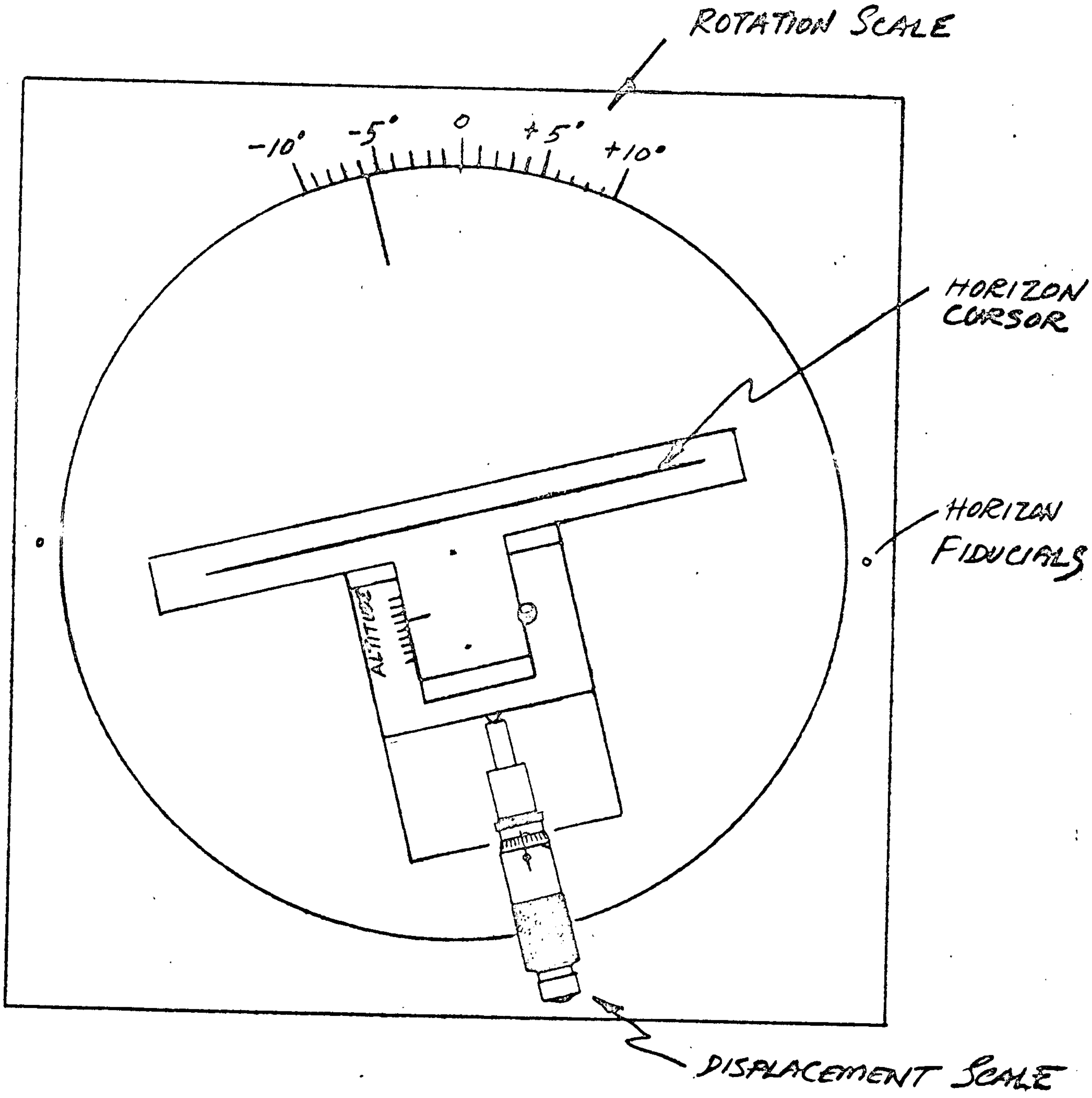
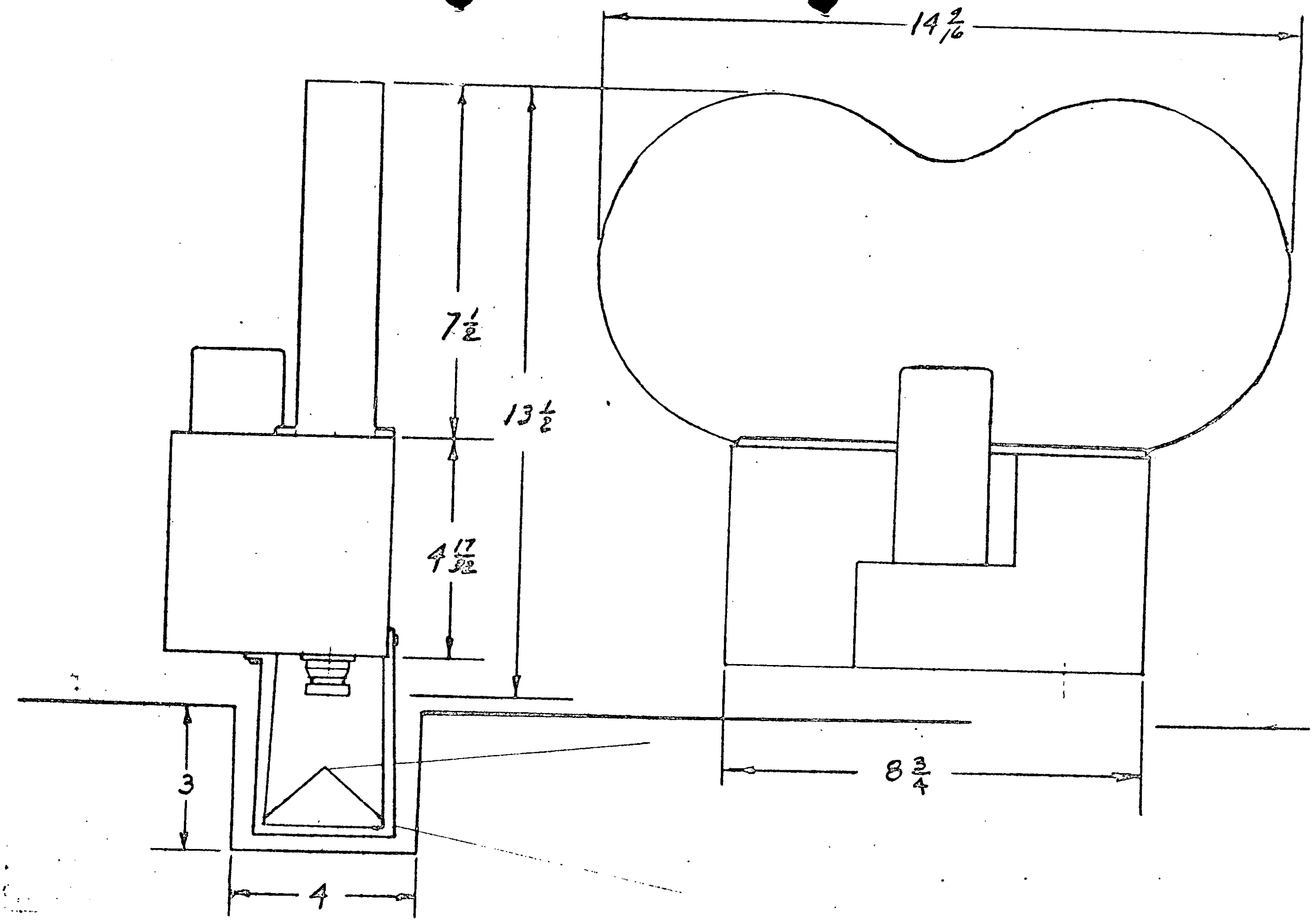


FIGURE 9. OBLIQUE TILTOMETER

FIGURE 10. CONFIGURATION WITH TRAID MODEL G-1D 35mm



Research and Development
Project Approval Request

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25X1 [redacted] has quoted [redacted] for the development.

VI. Security

25X1 The contract will [redacted] and association with the Agency will be classified at the SECRET level.