*NavScan: A Dual Purpose Panoramic Camera**

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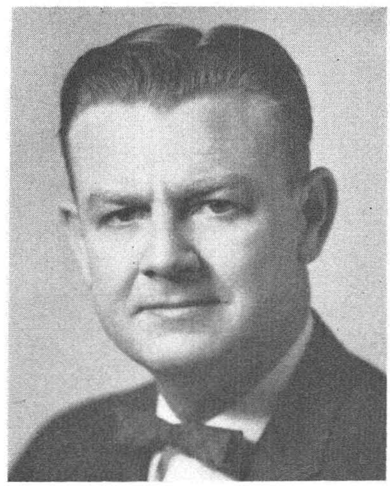
(*Abstract is on next page*)

THE NavScan panoramic camera, coined from the words "Navy" and "Scan," was designed and developed by Photogrammetry, Inc., under the sponsorship of the U. S. Navy. The dual purpose of the NavScan panoramic camera is to produce highly resolved and dimensionally precise photographic records of horizontal panoramic views from a ground exposure station. NavScan photography provides wide-angle recordings from which the permanently stored information can be verbalized into qualitative and quantitative intelligence. The optico-mechanical design principles of the NavScan are compatible for both quality and metrical photography.



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A fundamental principle common to many panoramic cameras is the rotation of the lens about the rear nodal point. The position of that point can be determined in the optical laboratory by means of a nodal slide. This slide is a mechanical device that permits a lens to be moved back and forth along its optical axis until rotation of the lens about a vertical axis does not cause a shift in the image. The nodal slide principle is similar to that utilized in some panoramic cameras.

In Figure 1 the solid lines represent lens position 1. The front nodal point is designated N_1 and the rear nodal point N_2. AN_1 is a chief ray from an infinite object-point to the front nodal point. The ray N_2B emerges from the lens parallel to AN_1.

The dotted lines represent lens position 2 after rotation about the rear nodal-point. The front nodal-point is now located at N_1'. Since A and A' represent the same infinite object-point, the chief ray of $A'N_1'$ is parallel to AN_1 through the front nodal-point N_1'. The ray N_2B emerges from the lens parallel to $A'N_1'$. No shift of the emergent chief rays occur if the lens is rotated about a vertical axis through the rear nodal-point.

In the most elementary form of panoramic camera (Figure 2) the lens rotates about the rear nodal-point. The distance from that point to the focal-plane is equal to the focal-length. The advantage of this design is that the film remains stationary during the time of exposure. The disadvantage is the limited horizontal coverage of less than 180°.

Horizontal coverage of 360° can be obtained by moving the film past the slit in the opposite direction to that of the lens-slit-magazine assembly as shown in Figure 3. The film moves 2π focal-lengths per revolution. The disadvantage of this system for precise metrical data is the exacting requirement to synchronize the movement of the image and film.

In the "photographic plane table" design

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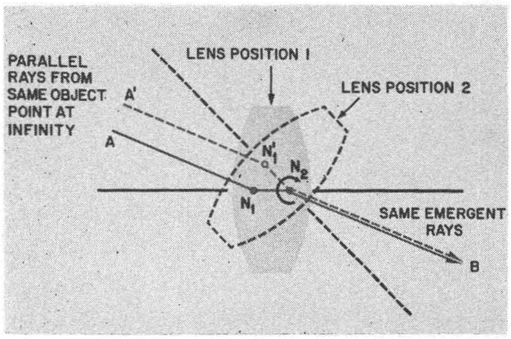

FIG. 1. The nodal slide principle is similar to that utilized in some panoramic cameras.

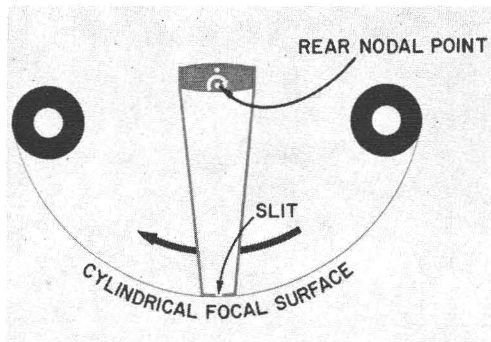

FIG. 2. The elementary form of panoramic camera.

ABSTRACT: *The NavScan panoramic camera was designed to produce highly resolved and dimensionally precise photographic reproductions of panoramic views. The optico-mechanical design principles of the NavScan are compatible for both quality and metrical photography, without a compromise of either type. The basic reasons for this extremely favorable feature are:*

a. The effective positions of the front and rear nodal points of the lens fall on the axis of rotation. This design principle precludes image-movement or smear resulting from eccentricities of image and object space perspective-centers relative to the axis of rotation and thereby increases the photographic quality.

b. The film is stationary and held firmly in a cylindrical focal surface during the entire exposure.

c. Fiducial dots, spaced every 10 degrees, are recorded on the film for later use in determining angular measurements. A simple linear measurement represents a horizontal angle. Data reduction procedures are compatible with established military training courses in navigation, surveying, and artillery fire.

The Appendix is confined to the derivation of the general formula for the determination of the magnitude of image-movement as a function of the eccentricities of front and rear nodal points, slit width, and scale.

(Figure 4) developed in 1858 by Chavallier of France, the focal-surface is planar and the rear nodal-point is not on the axis of rotation. The photographic format is an annulus (See MANUAL OF PHOTOGRAMMETRY, 1952, p. 7). Vertical lines in object space are radial from the center of the annulus.

Figure 5a illustrates a pan camera design with the lens optical axis vertical and two parallel mirrors. The horizontal coverage is slightly less than 360° to allow for the entrance and exit of film. The rear nodal point is on the axis of rotation but the front nodal point is not. The fact that the latter point is not on the axis of rotation is of no consequence when the object is located at infinity. However, in close-up photography the resulting image-movement owing to the front nodal point not being on the axis of rotation may become appreciable.

Figure 5b is a schematic design of the NavScan panoramic camera. This design is

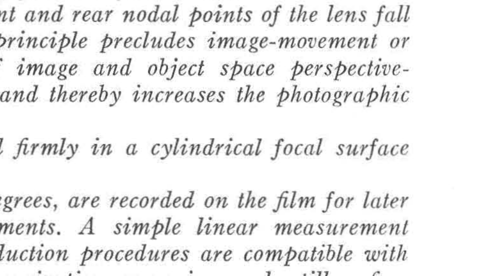

FIG. 3. Obtaining 360° horizontal coverage by moving the slit in the opposite direction to that of the lens-slit-magazine assembly.

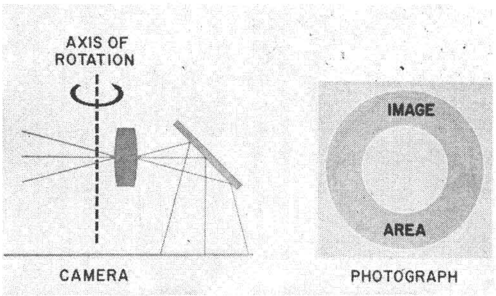

FIG. 4. "Photographic plane table" panoramic camera developed in 1858 by Chavallier of France.

similar to that illustrated in Figure 5a except that the top mirror is replaced by a roof prism facing the opposite direction. The purpose of the roof prism is to place the apparent position of the front nodal point on the axis of rotation and to reverse the image in the horizontal plane.

The optical configurations of NavScan "without dome" and "with dome" is illustrated in Figure 6. In the "without dome" configuration, light rays from object space enter the front face of the roof prism and are reflected from the roof of the prism down-

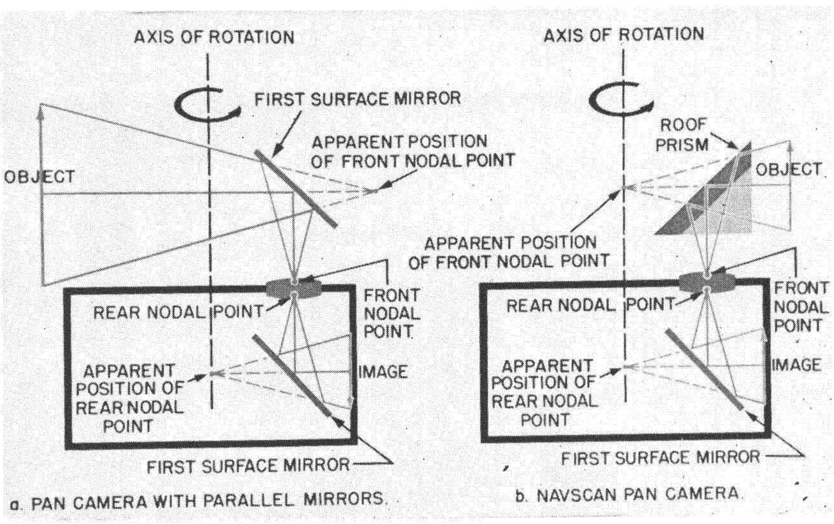

FIG. 5. Schematic comparison of two panoramic camera configurations.

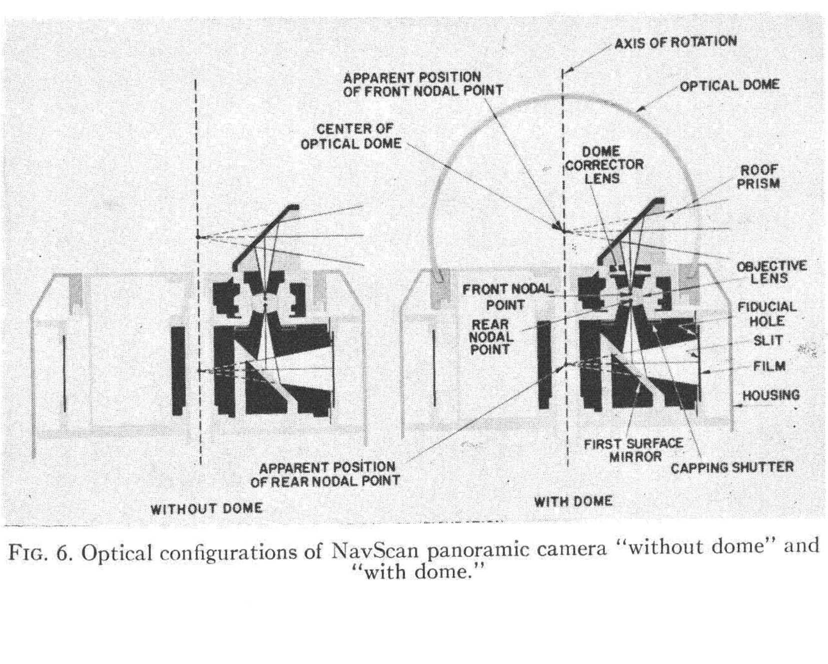

FIG. 6. Optical configurations of NavScan panoramic camera "without dome" and "with dome."

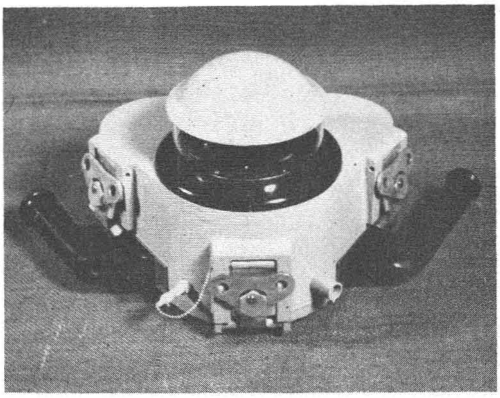

FIG. 7. Photograph of NavScan LO, a manually-controlled model.

ward onto the 60 mm f/6.8, Goerz Dagor lens. The rays, after transmission through the lens, are reflected from the first surface mirror onto the film plane. Note that the apparent positions of the front and rear nodal points fall on the axis of rotation. This design principle eliminates image-movement or smear resulting from eccentricities of image and object-space perspective centers relative to the axis of rotation and thereby enhances the photographic quality. The film is stationary and is held firmly in a cylindrical focal-surface during the complete exposure. There is no compression or elongation of the photographic image owing to a lack of synchronization since the film is not moved during exposure.

The solution of weatherproofing or waterproofing the camera simply consists of installing a spherical optical dome on an *O*-ring to a watertight housing, and inserting a corrector lens between the objective lens and roof prism. The concentric optical dome is a

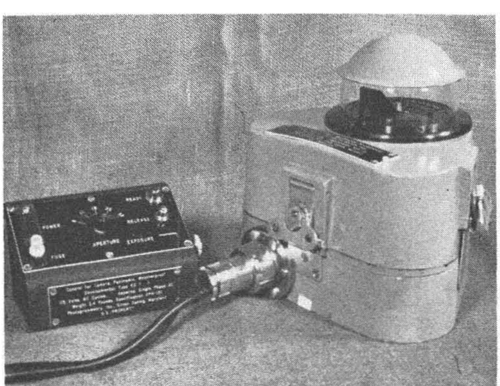

FIG. 8. Photograph of NavScan HI, a remote-controlled model.

negative lens of relatively long focal-length or low diopter power. The dome corrector lens is a positive lens of the same focal-length as the concentric dome. The positive dome corrector lens therefore nullifies the power of the negative concentric dome, and the optical effect is equivalent to photographing through a plane parallel port. The dome is installed so that the center of the dome falls on the apparent position of the front nodal point.

Two models of the NavScan camera have been designed, one for manual operation and one for electrically controlled operation. In the NavScan LO, manually operated model (See Figure 7), the camera housing is an aluminum casting, chemically impregnated for the purpose of watertightness. The mechanical connections on the housing for motor wind and aperture setting are *O*-ring sealed. The scan motor consists of four Negator springs and is governor-controlled. The motor is wound and the film advanced in the same operation. When the spring motor is released, a 350° exposure is scanned during a time interval of 1.3 seconds. The shutter is a simple device that consists of a 1.8° slit width located near the focal-plane. The shutter efficiency is 99% and the shutter exposure time is fixed at 1/150 second. The film capacity is 70 exposures on a 100-foot roll of 35 mm. film.

In the NavScan HI, electrically controlled model, (See Figure 8) heating pads and thermostats are installed to maintain a workable inside temperature under adverse weather conditions. The remote control box has a pushbutton to actuate the camera, a selector switch for aperture setting, and a counter to record the number of exposures.

The film and format dimensions are annotated on Figure 9. There are 36 fiducial dots spaced at 10° intervals. The total horizontal angular coverage is 350° and the vertical 20°. The center-line on the negative, representing the true horizon line, is an optional feature and is easily produced by securing a very small diameter fiber or hair on the rotating slit. Intervals of 90° are notched under the fiducial dots. The 10° shortage for complete 360° horizon coverage is due to the space requirement for film lead-in and lead-out; the equivalent space is used to start and stop the slit assembly.

A measuring microscope (Figure 10) is used to determine the horizontal and vertical angles of a point by direct interpolation between fiducial dots of larger known angles. Reference marks on the reticle are aligned with the fiducial dots on the negative, and the

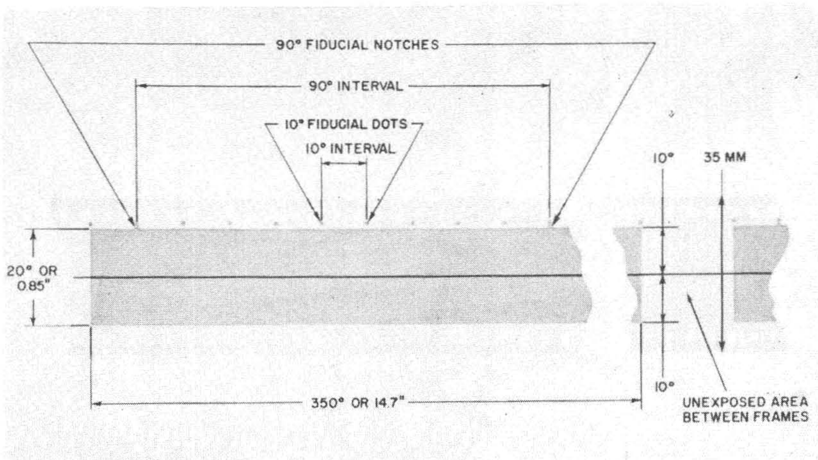

FIG. 9. Film and format dimensions of the NavScan panoramic camera.

horizontal and vertical angles are interpollated on the grid pattern of the reticle.

An extremely attractive feature of the measuring microscope is the capability of correcting for film shrinkage or expansion. Magnification of the microscope can be varied $\pm 5\%$. The interval between fiducial dots is 10° regardless of the magnitude of shrinkage or enlargement. The magnification of the microscope is varied until the distance between fiducial dots on the negative are superimposed on the corresponding reference marks on the reticle. If there are full 10° intervals between points no correction for film shrinkage or expansion is required because the intervals between fiducial dots on the film rails at the instant of exposure were 10°. This is an extremely simple procedure to correct for the dimensional change of film.

A panoramic plotter and stereo viewer (Figure 11) is proposed for reducing quantitative and qualitative information. The precision instrument is used as a plotter for determining the horizontal positions and vertical elevations of points. The radial arms are disconnected when the device is used as a stereoscopic viewer for photographic interpretation.

A schematic drawing of a refined plotter is shown in (Figure 12). This is designed for the continuous tracing of contours instead of the point-by-point procedure illustrated in Figure 11. In addition, the utilization of the Zeiss parallelogram principle allows for a variation in the plotting scale.

Figure 13 represents an artist's conception of the NavScan, Model 190. The primary objective of this proposed design is to reduce to a practical minimum the size and weight of the NavScan LO and HI panoramic cameras without altering the optical system and thereby maintaining the same photographic scale. The metrical characteristics of the camera do not compromise its utilization for photographic interpretation functions. The photo interpreter has the opportunity of using highly resolved black-and-white or color stereo photography.

The significant features of the NavScan Model 190 are:

a. The front and rear nodal points of the lens fall on the axis of rotation.
b. The axis of the optical plummet and the axis of rotation coincide. The optical plummet is used to conveniently center

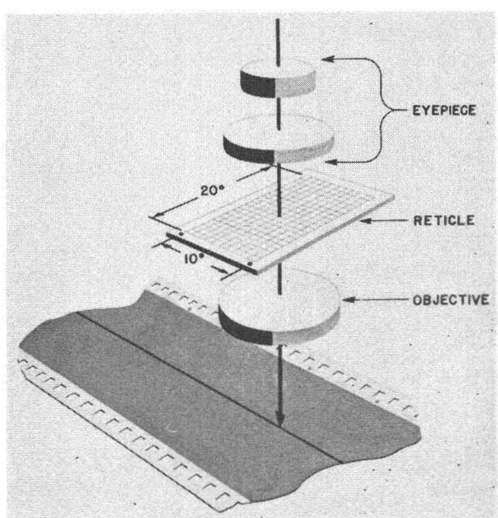

FIG. 10. Measuring microscope for the determination of horizontal and vertical angles from NavScan photography.

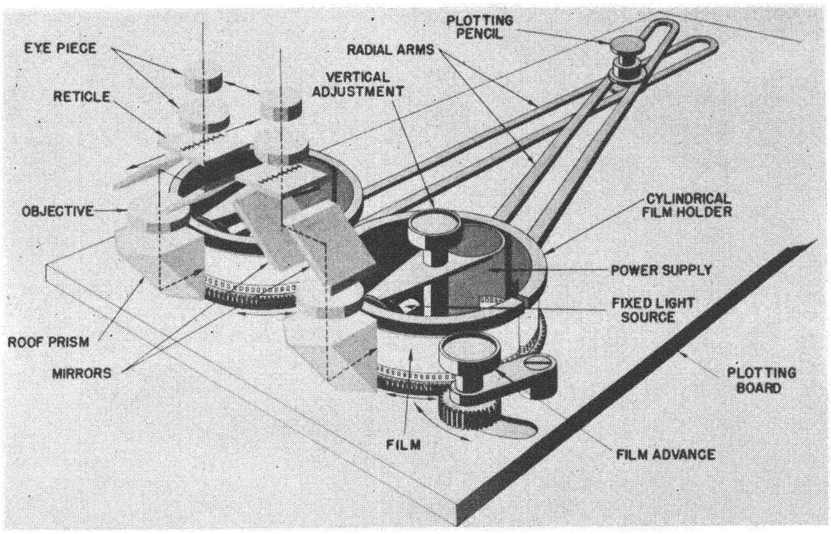

FIG. 11. A point-by-point plotter and stereoscopic viewer for NavScan photography.

the camera over the station point. A plumb bob (easily deflected by wind) is not required.

c. Fiducial dots are recorded on the film every 10° of horizontal angle.
d. The horizon line, $\pm 10°$ vertical angle line, and $-10°$ vertical angle line are recorded on the film.
e. Each exposure covers 20° vertically and 190° horizontally. Two exposures are required to cover the 360° horizon. Therefore, each end of the film will contain a 10° overlap.
f. The camera accommodates the standard 36 exposure roll of 35-mm. film that is available at most drug stores.
g. The capacity of the roll of 35-mm. film is 5 exposures.
h. If necessary, the film can be processed in daylight loading tanks.
i. A supplementary lens is furnished to copy a data card supported against the cylindrical wall of the camera housing. If two exposures each are made from two stations, the fifth exposure can be used to record the written data pertaining to the four previously exposed horizontal photographs.
j. The two photographs required to cover the complete horizon can be oriented so that one receives maximum exposure and the other minimum exposure. This technique allows the aperture setting to be changed for a more uniform exposure of the complete horizon.
k. Two 30-second level bubbles at right angles to each other are used to level the camera.
l. The *f*-number settings are: 6.8, 8, 11, 16,

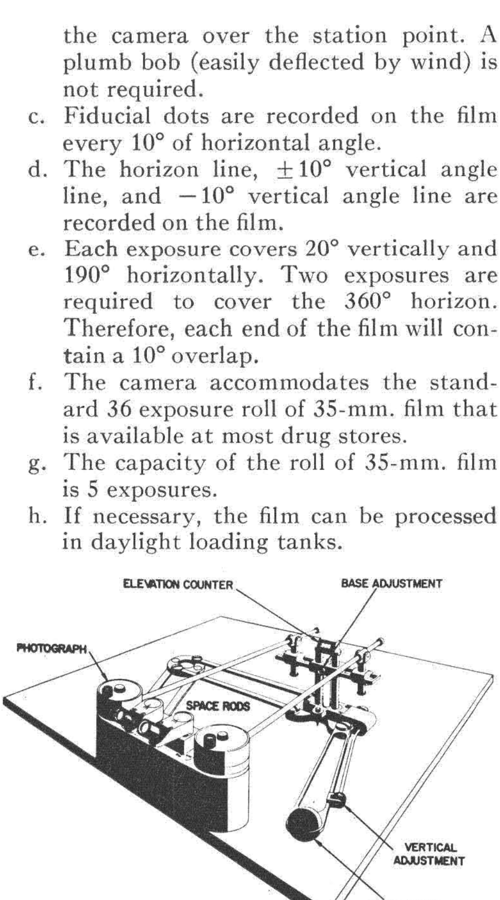

FIG. 12. An elaborate plotter for the continuous tracing of contours from NavScan photography.

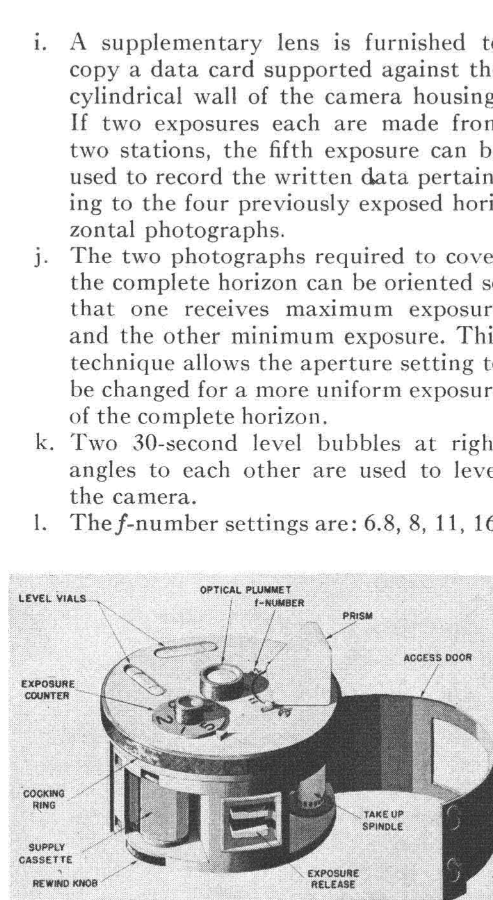

FIG. 13. NavScan Model 190, a relatively small and light weight version for 190° horizontal coverage.

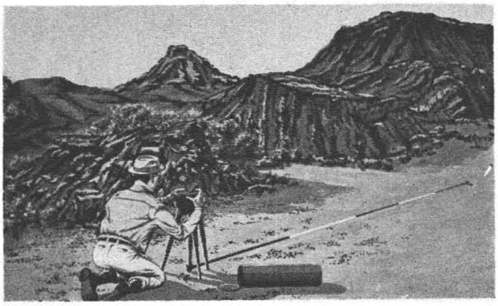

FIG. 14. Photographic Surveying.

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m. All optical air-glass surfaces are low-reflectance hard-coated.
n. The shutter exposure time is fixed at 1/100 second.
o. The shutter efficiency is 99%.
p. The scan time of each exposure is approximately one second.
q. The camera operates between a temperature range of +120°F. to −5°F.
r. The accuracy of the horizontal and vertical angles is ±1 minute of arc after corrections listed in the calibration report.
s. The camera is furnished with a calibration report.
t. A 100-foot tape, without individual foot graduations, is furnished to lay off a base line of known length. The 100-foot tape is graduated in alternately black and white 20-foot lengths. A surveying pin is permanently attached to one end of the tape while another surveying pin is adjustable to the division of the 20-foot intervals. One pin is inserted into the other for storage on the collapsible rod.
u. A collapsible tripod of relatively short extended length is furnished with built-in collapsible rod to establish a constant height of the instrument.
v. A watertight case is furnished so that the camera can be conveniently transported under adverse conditions.
w. The camera is secured to the tripod at all times for expeditious operation.

A photographic surveying operation is depicted in Figure 14. The estimated time to record photographically the complete horizon at both terminals of the base line, including set-up and break-down time, is approximately 30 minutes.

The purpose of Figure 15 is to extend sincere acknowledgements and a tip of the Tam o'Shanter to all the fine laddies who have contributed to the successful development of the NavScan panoramic cameras and the proposed date reduction instrumentation.

APPENDIX

The general formula for the determination of the magnitude of image movement resulting from the eccentricity of nodal points is derived as follows:

Since a/2 in Figure 16 is a common arc, it can be stated that the following is a close approximation when θ is relatively small:

$$\alpha f = \frac{\theta}{2}(f + E_2)$$
$$\alpha = \frac{\theta}{2} + \frac{\theta E_2}{2f}. \qquad (1)$$

Applying the law of sines

$$\frac{\sin(\beta + \theta/2 - \alpha)}{E_1} = \frac{\sin\alpha}{D}$$
$$\beta + \frac{\theta}{2} - \alpha = \frac{\theta}{2}\left(1 + \frac{E_2}{f}\right)\left(\frac{E_1}{D}\right). \qquad (2)$$

When E_2 is relatively small compared to f, the following is a close approximation:

$$1 + \frac{E_2}{f} = 1. \qquad (3)$$

Substituting equations (1) and (3) into equation (2) and multiplying equation (2) by $2/\theta$

$$\frac{2\beta}{\theta} = \frac{E_1}{D} + \frac{E_2}{f}$$
$$\beta = \frac{\theta}{2}\left(\frac{E_1}{D} + \frac{E_2}{f}\right). \qquad (4)$$

Also it can be seen that

$$\frac{c}{2} = (f + E_2). \qquad (5)$$

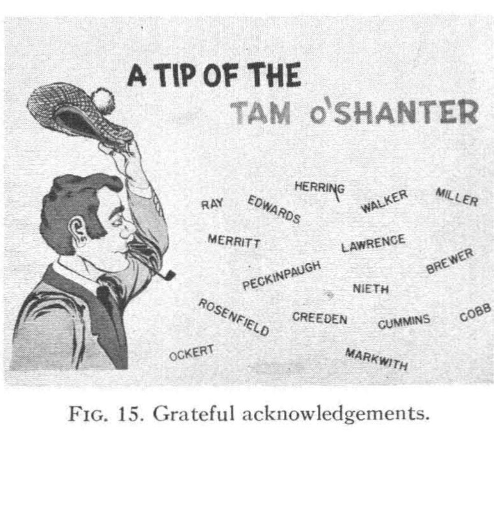

FIG. 15. Grateful acknowledgements.

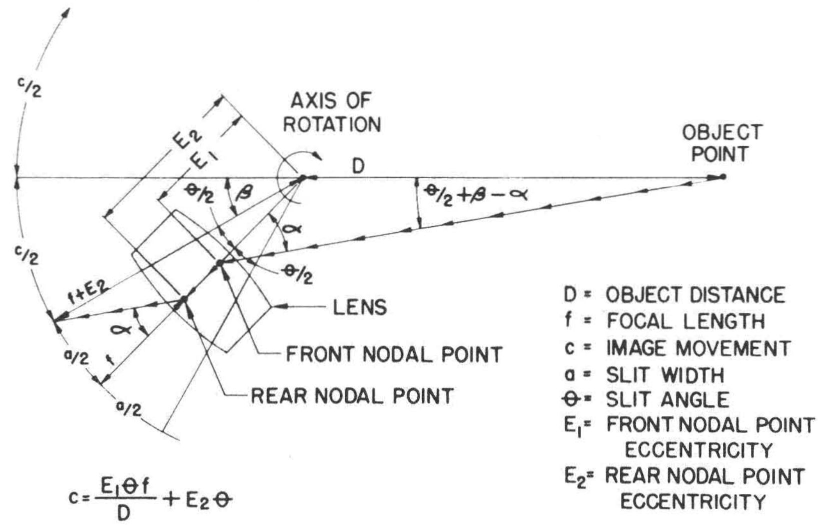

FIG. 16. Image-movement resulting from the eccentricity of nodal points.

When E_2 is small compared to f, the following is a close approximation:

$$f + E_2 = f. \tag{6}$$

Substituting equations (4) and (6) into equation (5)

$$c = \theta f\left(\frac{E_1}{D} + \frac{E_2}{f}\right)$$

$$c = \frac{\theta E_1 f}{D} + \theta E_2. \tag{7}$$

It is apparent from the above formula that there is no image-movement or blur when (1) the front and real nodal points are on the axis of rotation ($E_1 = E_2 = 0$), or (2) the rear nodal point **is** on the axis of rotation ($E_2 = 0$) and the object is located at infinity ($D = \infty$).

When the front nodal point is on the axis of rotation ($E_1 = 0$) or when the object is located at infinity ($D = \infty$), the image-movement formula reduces to the simplified form

$$c = \theta E_2.$$

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Patent No. 2,794,379 dated June 4, 1957.

*A Tilted Line Approach to Photogrammetric Determinations of Volume**

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INTRODUCTION

THE usual scheme of computing earthwork volumes for highway, railroad, and canal projects is the cross-section method. This has been used for many decades, and must be accepted as a time-tested approach to the problem of volume determination. In brief, this "standard" method consists moving along the proposed centerline of the highway, and taking cross-sections at regular intervals so as to determine the shape of the original ground surface at these intervals. If the ground surface changes abruptly, special cross-sections are taken at the critical places.

This standard method is a logical outgrowth of the "field" approach. It represents a convenient solution to several problems encountered by the instrumentman. Since brushing is commonly required, it makes good

* This paper was submitted in 1960 in competition for Wild Heerbrugg Instruments, Inc. Photogrammetric Award in honor of Dr. h. c. A. J. Schmidheini.

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