Panoramic Progress—Part II

ITEK LABORATORIES,
Lexington 73, Mass.

EDITOR'S NOTE: Panoramic Progress is the title of a brochure by Itek Laboratories. Appreciating the value of this brochure and how helpful the contents would be to photogrammetrists, approval to reprinting was solicited and graciously given by Itek Laboratories. Thanks are extended to Itek Laboratories and also to its representative Howard J. Hall. Part I with main headings of "The Advantages of Panoramic Photography" and "The Design of Panoramic Cameras" was published in the December 1961 issue of this JOURNAL (Vol. XXVII, No. 5, pp. 747–754). Part II, in the current issue, with the main headings of "Technical Analysis of Panoramic Photography" and "Instrumentation for Use of Panoramic Photographs" contains the balance of the brochure. Information has been received that a second and expanded version of Panoramic Progress is now available from Department 1–120, Itek Laboratories, Lexington 73, Mass.

TECHNICAL ANALYSIS OF PANORAMIC PHOTOGRAPHY

GENERAL DESCRIPTION AND DEFINITIONS

PANORAMIC aerial photography involves several types of image displacement which are not inherent in frame or strip photography. Three terms and their preliminary definitions are listed below in order to clarify the following discussion:

1. *Panoramic Distortion:* The displacement of images of ground points from their expected perspective due to the cylindrical shape of the negative film platen and the sweeping action of the lens.
2. *Sweep Positional Distortion:* The displacement of the images of ground points from their expected cylindrical position due to the forward motion of the aircraft during the sweep time of the lens. This distortion is in addition to, and modifies, the position of points due to panoramic distortion.
3. *Image Motion Compensation (IMC) Distortion:* The displacement of images of ground points from their expected cylindrical position due to the translation of the lens or focal plane which is used to compensate for image motion during exposure time. This distortion is in addition to, and modifies, the position of points due to both panoramic distortion and sweep positional distortion.

SCALE FACTORS

The rectification or transformation of aerial photography is primarily a consideration of correct scale factors. Therefore, prior to any consideration of transforming panoramic photography, we must define and specify the unique scale factors.

Figure 6 is a schematic of the panoramic photograph. The following derivations are separated into the basic scale factor areas as they are affected by the distortions defined above. In all of these derivations and relations, the following definitions apply.

- x and y—Coordinates of any image point in the plane of the photograph. The $+x$ axis is in the direction of flight.
- x_p—Panoramic distortion component
- x_s—Sweep distortion component
- x_{im}—IMC distortion component
- X and Y—Coordinates of any point in the ground datum plane
- f—Camera focal-length
- H—Flying height above datum
- α—Camera sweep-angle
- ω—Angular velocity of the camera sweep-arm
- m—Magnification of photographic printer
- t—Sweep-time of the camera
- V—Velocity of the aircraft
- v—Velocity of image in the focal-plane

PANORAMIC EFFECT

The following derivations consider a camera stationary in space. From Figure 7.

$$y_p = f\alpha$$

$$\alpha = \tan^{-1}\frac{Y}{H}$$

$$y_p = f\tan^{-1}\frac{Y}{H} \tag{1}$$

$$x_p = \frac{f}{H}X\cos\alpha \tag{2}$$

If we consider a grid network on the ground of 100-foot increments in X and Y, the resultant photograph will appear as shown in Figure 8. In all of the figures illustrating the

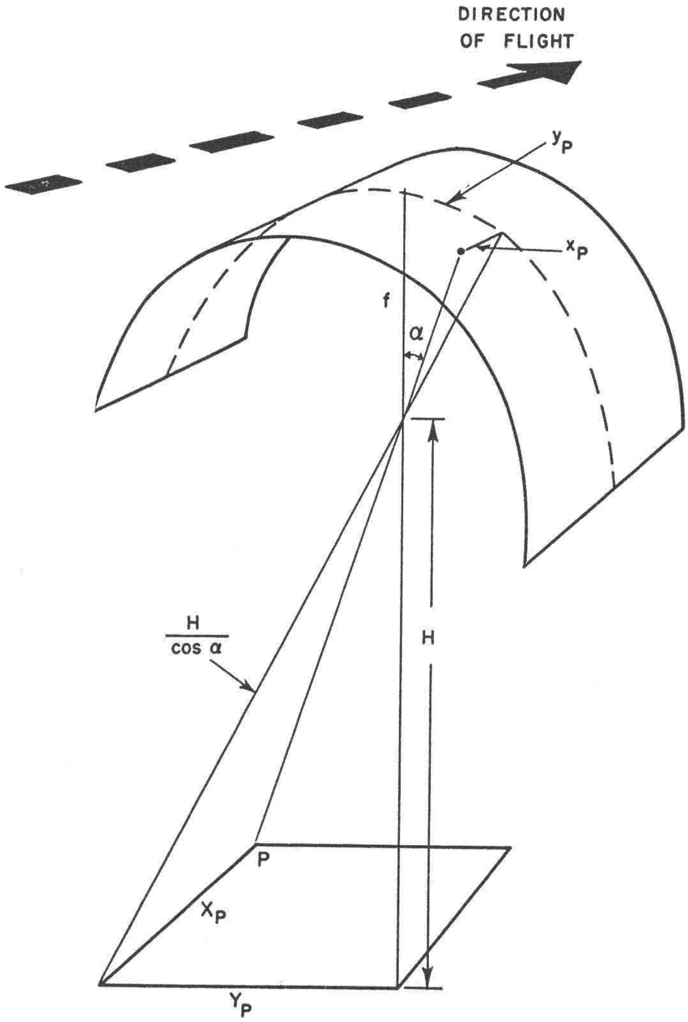

FIG. 6. Schematic of a panoramic photograph.

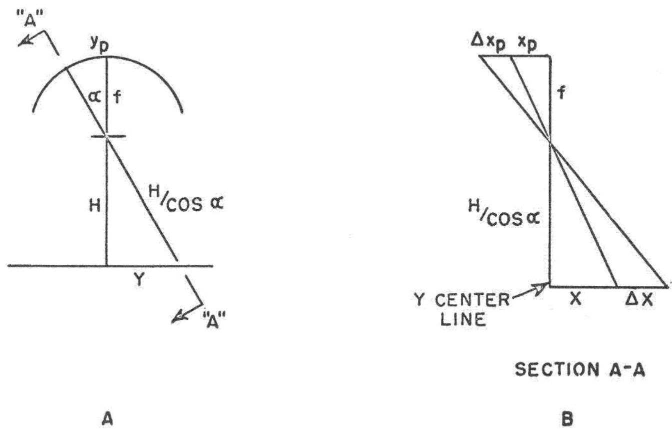

FIG. 7. Panoramic geometry.

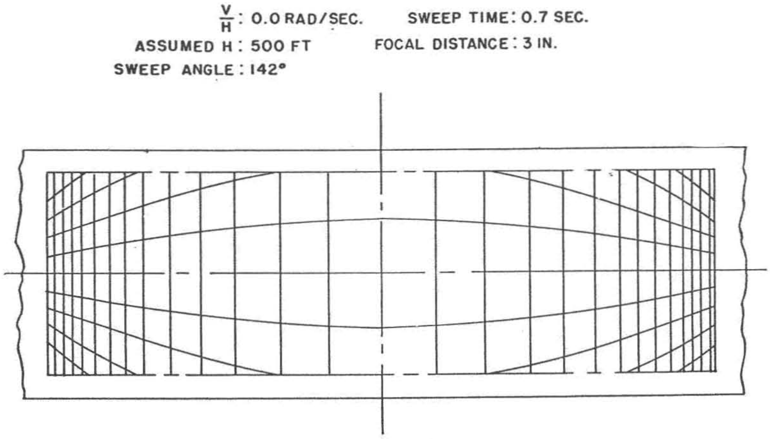

FIG. 8. Panoramic effect.

various panoramic distortions, the factors of focal-length and altitude are maintained constant.

SWEEP POSITIONAL EFFECT

We now consider the condition wherein the camera is moving in a direction normal to the sweep axis. From Figure 9:

$$x_s = \frac{f}{H} Vt \cos \alpha$$

From the equation for angular velocity,

$$t = \frac{\alpha}{\omega} \tag{3}$$

Therefore,

$$x_s = \frac{Vf}{H\omega} \alpha \cos \alpha$$

The y_s distortion is not affected by the vehicle velocity and therefore remains the same as the y_p distortion as previously stated in Equation 1.

Figure 10 shows the effect of this distortion on the center line of the imaged grid. For clarity, the other lines of the grid are not shown.

IMC EFFECT

When image motion is compensated for by movement of either the lens or the film platen, a third distortion is introduced. The direction of the lens motion (and therefore of this distortion) in order to obtain zero relative velocity of the image must be opposite to the direction of travel of the vehicle. The derivation of this distortion follows from Figure 11.

$$v = \frac{dx_{im}}{dt} = \frac{f}{H} V \cos \alpha$$

$$dx_{im} = \frac{fV \cos \alpha \, dt}{H}$$

From the equation for angular velocity,

$$dt = \frac{d\alpha}{\omega}$$

$$x_{im} = -\frac{Vf}{H\omega} \sin \alpha \tag{4}$$

The effect of this distortion on the center line of the grid is also shown in Figure 10.

RESULTANT IMAGE

There is only one image of the grid which is recorded by the panoramic camera, and this

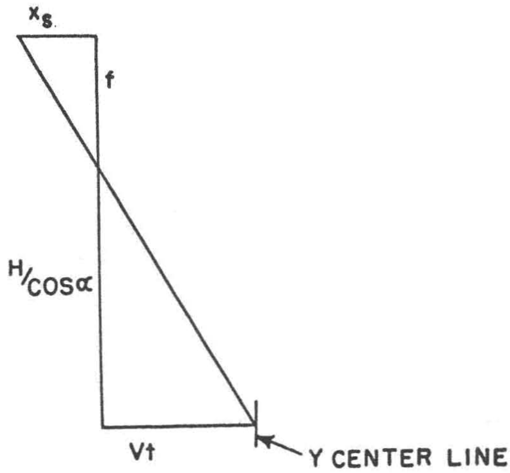

FIG. 9. Sweep positional geometry.

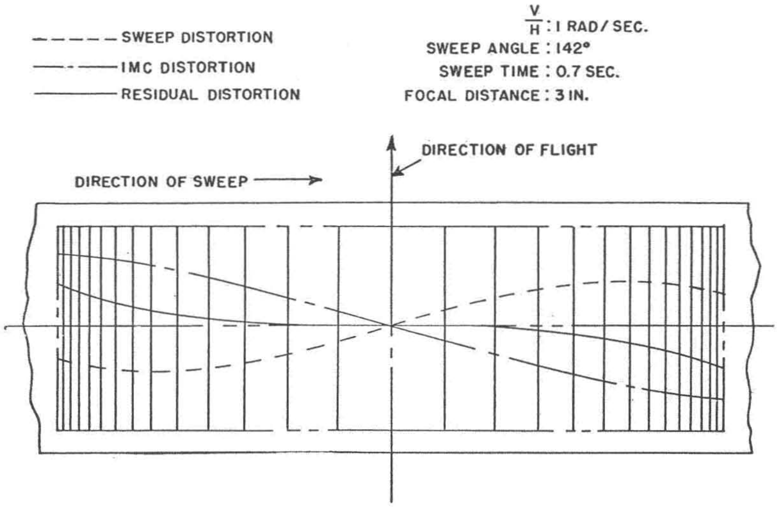

FIG. 10. Center-line displacement.

image embodies all of the factors which have been derived above. The residual center-line displacement is the algebraic sum of the two residual distortions. The IMC distortion, always being larger, is dominant. The resultant x displacement is given by:

$$x = x_p + x_s + x_{im}$$

$$x = \frac{f}{H} \times \cos\alpha + \frac{Vf}{H\omega}(a\cos\alpha - \sin\alpha) \qquad (5)$$

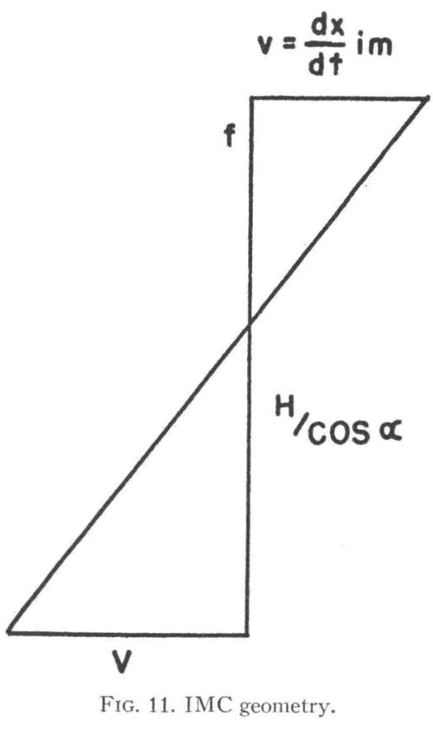

FIG. 11. IMC geometry.

Again, the y component is not affected by IMC and remains as stated in Equation 1.

A reduced scale sketch of the grid negative, including all of the factors derived above, is shown in Figure 12.

INSTRUMENTATION FOR USE OF PANORAMIC PHOTOGRAPHS

There are two basic methods by which panoramic photographs may be corrected.

1. *Transformed prints* may be made of the panoramic negative. In these prints all portions of the image will be to the same scale, and a rectangular grid on the ground will appear as a rectangular grid on the print.
2. *Contact prints or the original negative* may be viewed in a panoramic mensuration viewer. The image in this viewer will contain the typical panoramic distortion; however, the true distance (in feet or yards) between any two points of a frame may be measured and displayed by means of a built-in analog computer.

PANORAMIC TRANSFORMING PRINTER

Itek Laboratories has designed and fabricated several types of transforming printers, one of which is shown in Figure 13. This and other printers of recent vintage have been designed on the basis of geometrical equivalence of the taking conditions in order to transform the panoramic scenes to rectified photographs.

Transformation of Distortions

The distorted negative is transformed by duplicating in reverse the taking system. The

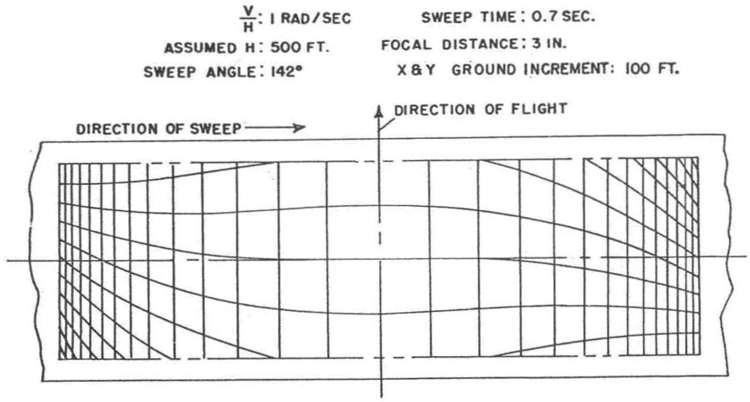

FIG. 12. Composition ground pattern.

light-slit sweeps across the negative platen and projects the image through a lens onto the easel-mounted printing material. In coincidence with this operation, the easel and platen translate in relation to each other to correct for relative displacement and IMC during the camera sweep.

Easel Motion

The displacement of the easel must proportionally duplicate the relative ground displacement during the time of sweep.

From Figure 14 it is seen that:

$$X_s' = \frac{qX}{H}$$

as before,

$$X = \frac{Vt}{H} \quad \text{and} \quad t = \frac{\alpha}{\omega}$$

Therefore,

$$X_s' = q\frac{V}{H}\frac{\alpha}{\omega}$$

where X'_s = easel displacement.
q, the image distance, $= mf$.

Therefore,

$$X_s' = \frac{V}{H}\frac{mf}{\omega}\alpha = P \tag{6}$$

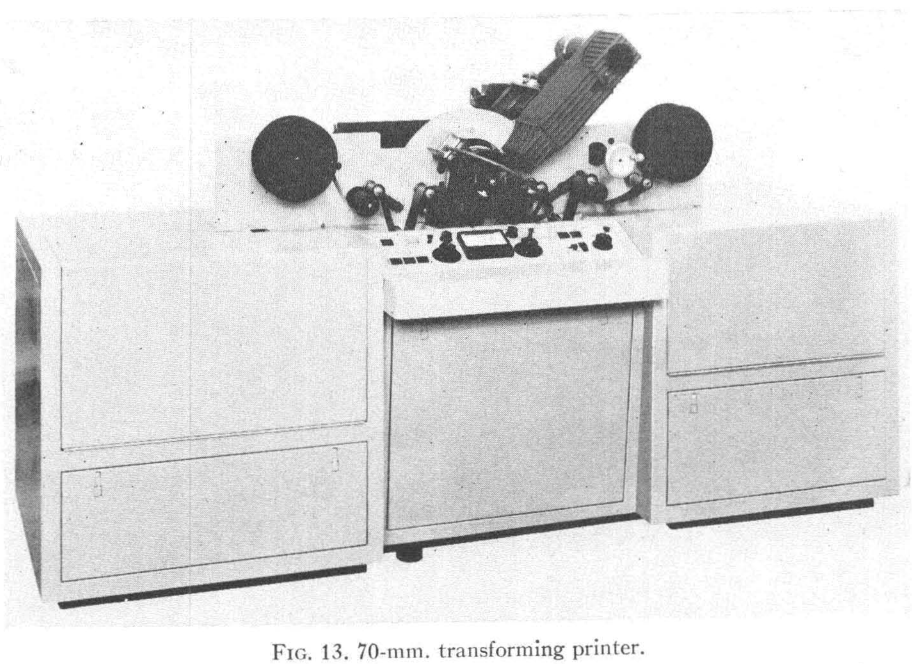

FIG. 13. 70-mm. transforming printer.

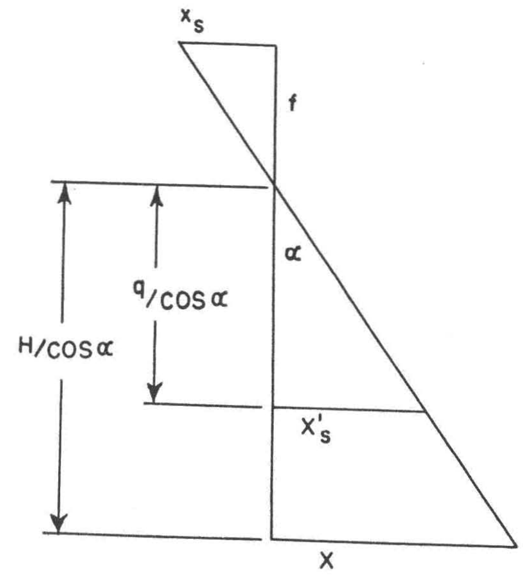

FIG. 14. Easel displacement geometry.

As noted from this equation, the easel displacement is a linear function, proportional to the angle of sweep α, whose range of magnitude varies as the parameter V/H.

Platen Motion

The platen displacement must duplicate the displacement introduced into the camera as a result of IMC. Because the platen geometry is theoretically identical to the camera geometry, no q/H proportionality exists. The platen displacement, therefore, is the same as the camera displacement due to IMC as derived in Equation 4.

$$x_{im} = -\frac{Vf}{H\omega}\sin\alpha$$

During rectification, the platen translates as a function of sin α, and the easel translates as a function of α, but in the opposite direction. In order that no relative motion will exist between the projected image and the easel, and in order for the projected image of the center-line residual distortion to coincide with the displaced easel center line, the projected displacement between the IMC distortion and the center-line residual distortion must be equal to the easel displacement.

This is shown by Figure 15, in which the platen is displaced by the amount x_{im}, so that the curve lies on the optical center line. It should be noted that this curve does not actually exist as a trace on the negative. The residual center line, which physically exists on the negative, is now displaced from the optical center line by the amount X_s.

Upon projecting this displacement onto the easel, the projected image, P, is derived as follows:

$$P = \frac{x_s m}{\cos\alpha}$$

From equation 3

$$x_s = \frac{Vf}{H\omega}\alpha\cos\alpha$$

Therefore,

$$P = \frac{Vmj}{H\omega}\alpha \qquad (7)$$

which is identical to the easel displacement, X'_s, from Equation 6.

The easel displacement is a linear function of the sweep angle α, which agrees with the expression for the ground displacement relative to the camera. The easel displacement, as a function of the projected distortion y_p, is derived as follows:

$$\tan\alpha = \frac{y_p}{mf}$$

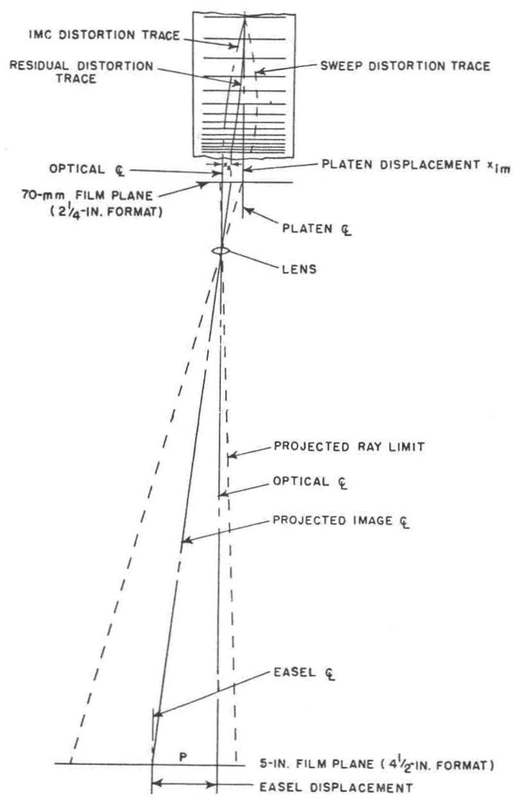

FIG. 15. Panoramic rectification geometry.

$$\alpha = \tan^{-1}\frac{y_p}{mf} \tag{8}$$

By solving Equation 6 for α and substituting

$$X_s' = \frac{V}{H}\frac{mf}{\omega}\tan^{-1}\frac{y_p}{mf} \tag{9}$$

By comparing this displacement of the optical axis ground trace, it is seen that a proportionality exists in the ratio of mf/H.

Roll Compensation

Although roll cannot be considered an inherent distortion, failure to eliminate it in the rectifier will result in both a tan α and cos α distortion. A means of aligning the negative nadir mark coincident with that of the rectifier optical center line must be provided. Upon rectification, however, the amount of roll is subtracted from the angular sweep projection; that is, the roll is $+2°$, the projected image will cover $+68°$ and $-72°$.

Multiple Camera Inputs

The focal-length of the taking camera is a major factor in defining the motions which the printer must encompass for complete transformation. Further, the platen for the negative film is a casting designed as a function of the camera parameters modified by the factors of the projected lens. Therefore, for each different camera to be accommodated, the platen and the motion controls must be different and of rigid design. These can be made as replaceable subassemblies so that the same basic printer can be used.

Other Approaches to Transformation

Another method of solving the transformation equations by opto-mechanical means that has been investigated by Itek Laboratories is the concept of the continuous enlarging printer with a variable printing ratio. In this instrument the negative is driven past a slit while the printing material is driven past another slit or over a printing stage at a synchronous rate. The lens and easel stages must be moved at a programmed rate to accomplish the scale changes required. To compensate for the differential rate of change of x and y scales, two of the three projection elements must be tilted during the scan of the negative. While these motions are compensating for the panoramic distortion, the easel slit and the printing stage must be translated normal to the direction of the film drive to compensate for the sweep positional and IMC distortions.

It is obvious that so many interrelated nonlinear motions are extremely difficult to generate accurately. In the case of a film having a resolution of 100 lines per millimeter, for instance, the total accumulated error would have to be kept to less than 0.01 mm, or 0.0004 inch. This implies that each component would have to be kept to tolerances many times finer. It is for this reason that transformers based on geometrical duplication of original taking conditions, like those built by Itek, have been preferred.

PANORAMIC MENSURATION VIEWER

The Itek 70-mm Mensuration Viewer (See Figure 16) enables the operator to view any portion of a panoramic transparency at optimum magnification, and to measure distances between any two points on the image. Measurements can be made directly from unrectified panoramic photography with the use of the self-contained analog computer which accurately reads out ground distance onto a digital display. This is possible because of the relationship shown in Figure 17.

As

$$\overline{AB} = \sqrt{(\Delta X)^2 + (\Delta Y)^2}$$

and

$$X = \frac{H}{f}\frac{x}{\cos\alpha}$$

$$Y = H\tan\alpha$$

Therefore, the following expression shows the relationship between the actual ground distance of any line AB and its X and Y computer coordinates.

$$\overline{AB} = \left[H^2(\tan\alpha_B - \tan\alpha_A)^2 + \left(\frac{H}{f}\right)^2(X_B\sec\alpha_B - X_A\sec\alpha_A)^2\right]^{1/2}$$

All of the optical, mechanical, and electrical components of the viewer are housed in one console; on the forward face of this cabinet is a rear-projection screen 28 inches wide and 20 inches high. All controls and read-out meters are located in an instrument panel directly below the screen.

The optical system comprises the condenser assembly, the projection lens, the mirror assembly, and the screen. The condenser assembly is of conventional design; it contains three plano-convex lenses, two heat filters, a 1,000-watt projector bulb, and a spherical mirror behind the lamp.

Each frame of photography contains oblique views in two directions which are

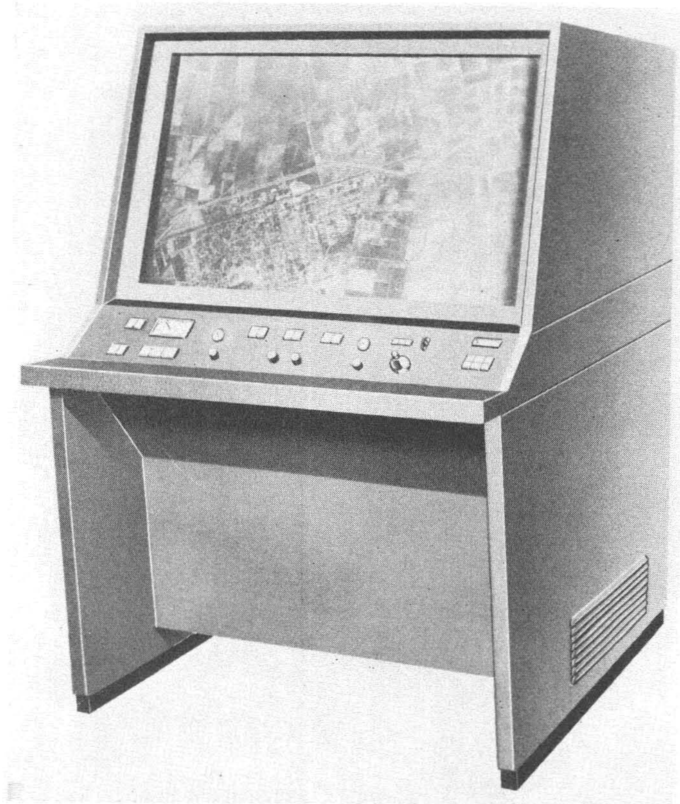

FIG. 16. Panoramic Mensuration Viewer.

difficult to interpret when presented in an orientation unfamiliar to a human observer. For this reason, a mirror system was designed so that the image can be rotated to present horizons at the top of the screen. The mirrors are made of $\frac{1}{2}$- or 1-inch plate glass, ground and polished to a flatness of $\frac{1}{20}$ wavelength over the effective lens aperture. They are aluminized on the front surface, and overcoated with silicon monoxide.

To remain in accurate focus, the film must be held flat within ± 0.003 inch. A specially designed glass vacuum platen solves this problem.

The film transport mechanism performs three major functions: It slews film at a rapid rate (about 250 feet per minute) so that a particular frame may be selected for viewing; it runs the film at a variable, slower rate (from $\frac{1}{2}$ to 5 feet per minute) so that the frames may

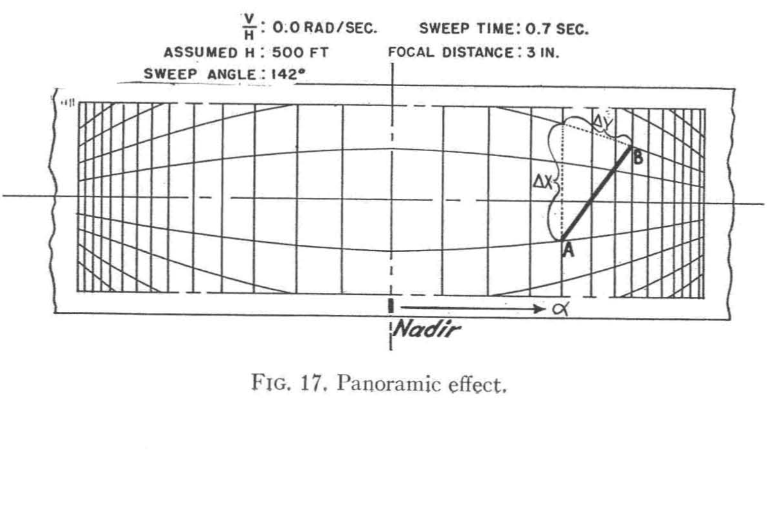

FIG. 17. Panoramic effect.

be scanned for selection of a particular area on a frame; and it operates under manual control so that the film may be precisely positioned for study and mensuration purposes. The film transport will handle reels containing up to 500 feet of film.

... AND THE FUTURE

The field of panoramic aerial photography has made great strides in the past decade, and the future holds promise of dramatic new applications. Recently, the work being done in the mathematical aspects of image displacement has been extended by applying analytical photogrammetric approaches to panoramic photography. This will broaden the application of high-resolution, wide-coverage photography to mapping and charting operations requiring very precise measurements.

The fruits of many other scientific fields are being applied to all aspects of panoramic aerial photography. Inter-disciplinary research is being conducted to combine the potentials of electronics, optics, photography, and other sciences in order to overcome the limitations imposed by each and to increase the over-all information gathering capabilities of the system.

Today, panoramic aerial photography finds its major application in gathering information about the earth; tomorrow it will take its place as a valuable contributor to the exploration of space.

*Seasonal Changes in Light Reflectance from Forest Vegetation**‡

CHARLES E. OLSON, JR., and RALPH E. GOOD,**
Assistant Prof. of Forestry and Graduate Asst. in Botany, respectively, Univ. of Illinois, Urbana, Ill.

ABSTRACT: *During the 1960 growing season, light reflectance from foliage of nine species of trees was measured weekly with a G.E. recording spectrophotometer. Hardwood foliage reflected more light than pine foliage in almost all wave-lengths during all parts of the growing season. Differences in reflectance between hardwood and pine foliage decreased steadily from May to the beginning of the hardwood color change in September and October. During the fall color change reflectance from hardwood foliage varied erratically by species.*

A PHOTOGRAPH is nothing more nor less than a graphic record of energy intensity. The characteristics of reflected energy strongly influence images recorded in the camera. Despite this fact very little is known about the reflecting characteristics of objects we photograph.

One of the first major works in spectral reflectance from natural formations was completed by E. L. Krinov prior to 1939, although publication of his results was delayed by World War II (Krinov, 1947). Studies of spectral reflectance from natural and man-made objects have been completed at the U. S. National Bureau of Standards (Keegan and O'Neill, 1951; Keegan, Schleter, and Hall, 1955; Keegan *et al.*, 1955, 1956), and several other investigators have reported spectral reflectance studies (Schulte, 1951; Bäckström and Welander, 1953; Colwell, 1954, 1956; Belov and Areybašev, 1957; Hindley and Smith, 1957; Steen and Little, 1959).

In 1959 the University of Illinois initiated studies of spectral reflectance characteristics of forest vegetation. A pilot study was conducted during the fall of 1959 to test equipment and sampling procedures; the sampling design for the 1960 growing season was based on the results of this pilot study. This report summarizes results for the 1960 growing season.

* This report summarizes work supported by the Office of Naval Research, U. S. Navy, as Contract 1834 (31), Project NR 387-025.

‡ A partial revision of paper presented at the 27th Annual Meeting, The Shoreham Hotel, Washington D. C., March 19–23, 1961.

** Mr. Good is now at Botany Dept., Rutgers Univ.