# *Analysis of the Panoramic Aerial Photograph* †*

JOHN LE RESCHE, *Photo Interpreter,*
*U. S. Naval Photographic Interpretation Center,*
*Washington, D. C.*

ABSTRACT: *An examination of the panoramic aerial photograph reveals certain points of interest to the photo interpreter. Each photograph covers a narrow, horizon-to-horizon strip transverse to the flight line. The photo is vertical along its principal x-axis and oblique elsewhere with the tilt angle increasing along the principal y-axis. The horizon-to-horizon view has advantages to the photo interpreter where a broad expanse of terrain is desired, such as in charting or reconnaissance. However, the panoramic photograph must be rectified to recover essential elements of the photo image, namely, the position, alignment and dimensions. At first glance, the photo interpreter may feel that the problems involved in rectifying a photograph with a constantly increasing tilt-angle makes its use impractical.*

*The problems of rectification may be simplified, however, by utilizing certain advantages inherent in the geometry of the panoramic photograph. Each photograph can be considered a segment of a cylinder which has been projected onto a plane. Consequently, the principal y-axis (or principal line) of the photograph is a segment of a circle rather than a straight line. Therefore, each light ray intersects each point along the principal line at right angles. It is suggested that this property of the panoramic photograph may lead to the use of radian measurements rather than linear measurements in its rectification, thereby achieving the simplification desired.*

RECENT reports in various publications describe a panoramic aerial camera now on the market. This camera is capable of photographing a strip transverse to the flight line, extending from horizon to horizon (Figure 1).

It is realized that, in addition to this camera, several other panoramic-type cameras are under investigation or in various stages of development by other companies. However, for simplicity, this discussion is limited to the image produced by one optical system. Principles developed herein should be applicable to various types of panoramic photography.

This horizon-to-horizon coverage is achieved through the use of a rotating scanning-prism and a fixed-lens assembly. The optical rays are projected line-by-line through a focal-plane shutter onto a moving strip of film, instead of onto an entire exposure simultaneously. The resultant photograph has the geometrical character of a cylinder, each projected line having a different tilt-angle as the prism rotates through an arc of constantly changing tilt-angles. The general effect is produced is produced in a manner analogous to a newspaper printed from a cylindrical platen. Since the prism rotates across the flight line, a series of exposures gives a continuous view that can be examined stereoscopically.

The manufacturer recommends that this camera be used for tracking and indexing photography where its horizon-to-horizon coverage could be used to the greatest advantage. However, it seems applicable for other purposes. Among the uses that have been suggested are geological surveying, preliminary explorations of unpopulated areas, and highway planning.[1] Photography so used, and especially for tracking, is apt

[1] "Horizon-to-Horizon Camera Is Developed for Aircraft," *Aviation Week*, Sept. 16, 1957, p. 76.

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† This paper has been cleared for publication by the U. S. Naval Photographic Interpretation Center. The opinions expressed herein are the author's and do not necessarily reflect those of the U. S. Naval Photographic Interpretation Center, the Navy or the Department of Defense.

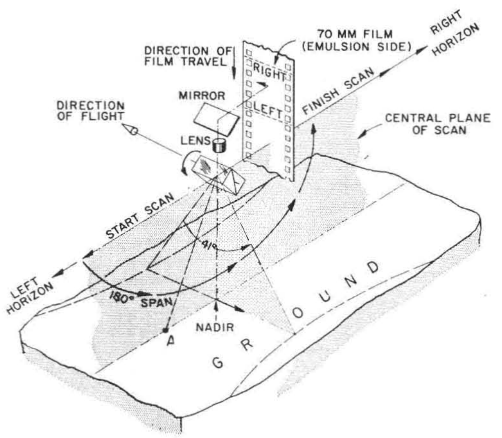


FIG. 1. Schematic of the optical system of the Perkin-Elmer model 501 lightweight panoramic camera. (Courtesy of Perkin-Elmer Corp.)

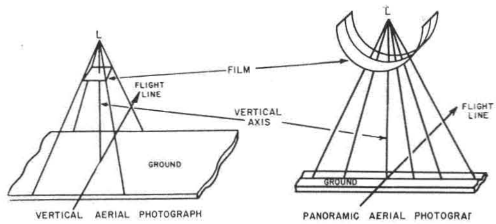


FIG. 2. Comparison of the geometry of the panoramic aerial photograph with the vertical aerial photograph.

to be found to be the only photographic coverage of an area of interest. Therefore, it is probable that soon the photo interpreter will be asked to prepared detailed interpretations from this kind of photography.

However, the factor of constantly changing tilt-angles will likely cause the photo interpreter to reject the panoramic photograph for detailed interpretation. This is because any such interpretation of photography requires taking measurements. Elements of the photo-image essential to its interpretation which require measurements are its true shape, dimensions, orientation and position. The photo interpreter is accustomed to determining them either directly from vertical photographs or by rectifying oblique photographs. The oblique photograph to which he is accustomed is a plane which has a constant tilt-angle and can be rectified by using standard mathematical or graphical methods. However, the tilt-angles change constantly over the panoramic photograph. Therefore, every point to be rectified could have a different tilt-angle. As a result, it may be necessary to rectify the panoramic aerial photograph by performing a separate tilt analysis and rectification of each of a series of points (Figure 2).

It seems, then, that the photo interpreter needs a workable method of rectifying this kind of photograph. Such a method should be simple to use and as accurate as the standard methods of rectifying oblique photographs. The author believes that such a method will be found.

Since this report is prepared prior to any general usage of this kind of photography, it is in the nature of a preliminary investigation. It is believed that such an investigation can best meet the requirements of the photo interpreter, as stated above, by presenting an over-simplified approach to the geometrical concepts involved. The scope of this report is, therefore, limited by the assumptions that the camera platform is level, and that the ground datum is a plane.

These assumptions are justified on the following grounds. Since this kind of photography is not yet in general use, it is too soon to anticipate all the problems that could arise. Certain refinements, such as the considerations of $x$- and $y$-tilt of the camera platform, displacement due to relief, and the curvature of the earth, do not really change the basic approach to the problem.

The geometry of the panoramic aerial photograph can best be analyzed by rolling it along the $y$-axis into a half cylinder so that its surface agrees with its perspective. The surface of the photograph can then be considered as the curved surface of a segment of a right circular cylinder whose radius is equal to the focal-length of the lens. Pertinent elements of the panoramic aerial photograph can then be defined in terms of this cylinder.

The principal $y$-axis of the photograph lies along the directrix of the cylinder, and marks the interesection of a plane and the curved surface of a right circular cylinder (Figure 3). It is thus a segment of a circle whose radius is the focal-length of the lens. Consequently the focal-length is constant along the principal $y$-axis and the optical rays intersect all points on that axis at right angles. Therefore, all points on the principal $y$-axis have a characteristic possessed only by the principal point of a planar photograph.

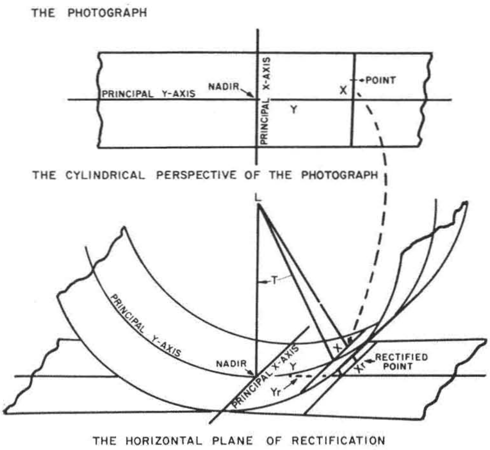


FIG. 3. Geometric concepts involved in rectification of the panoramic aerial photograph.

All $x$-axes of the photograph are rulings of the cylinder and thus are straight lines, intersecting the principal $y$-axis at right angles. The principal $x$-axis is that ruling where the photograph is tangent to a horizontal plane. The nadir of the photograph is located at the intersection of the principal axes. The nadir is also the principal point of the panoramic photograph.

These characteristics make possible rectifying image-points on the panoramic photograph by projecting them onto a horizontal plane tangent to the photograph. Each can be located by describing it in terms of $x$ and $y$ coordinates. These coordinates are set up on the photograph, taking the principal $x$- and $y$-axes as the coordinate axes and the nadir as the origin.

The rectified $x$- and $y$-coordinates of any point are functions of the tilt-angle of that point, and the determination of the tilt-angle is fundamental to the rectification. The relationship between the position of a point on the photograph and its tilt-angle can best be expressed in radians.

The $y$-coordinate of a point on the photograph is the length of the intercepted arc of the tilt-angle of that point. The radian for a panoramic aerial photograph can be established by its definition as being equal to the focal-length of the lens. Therefore, a standard radian formula can be used to determine the $y$-coordinate (distance along the principal $y$-axis of the photograph from the nadir) subtended by a tilt-angle of one degree. This value is constant for the photograph.

The tilt-angle of any point on the photograph can be calculated by dividing its $y$-coordinate by the constant derived above. This relationship can be expressed as:

$$t = \frac{y}{\left(k = \frac{\pi f}{180}\right)} .^{2}$$

The rectified $x$- and $y$-coordinates are functions of the tilt-angle of any point on the photograph, and can be described in terms of a right triangle relating the focal point on the lens to the $y$-axis of the horizontal plane of rectification which is tangent to the photograph at the nadir. This triangle is formed by a line along the $y$-axis between the intersections of two lines projected from the focal-point of the lens. The angle between these lines is the tilt-angle, one of the lines being perpendicular to the $y$-axis at the nadir of the photograph. The length of this line is fixed, being the focal-length of the lens. The slant distance along the other line between the focal-point and its intersection with the $y$-axis and the length of the line along the $y$-axis are determined by the tilt-angle.

Since the length of the line along the $y$-axis is the rectified $y$-coordinate of the point being rectified, it can be determined by the relationship: $y_r = f \tan t$.

The $x$-coordinate of a point on the photograph is the distance between it and the principal $y$-axis of the photograph. Therefore the relationship between that coordinate and its rectified $x$-coordinate is the same as the relationship between the scale of the photograph along the $x$-coordinate and the scale along its principal $x$-axis through the nadir. Since the focal-length of the panoramic aerial photograph is constant along its principal $y$-axis, the scale of the $x$-coordinate is determined by the slant distance between the focal-point and its ground datum and the focal-length. As the triangle described above, relating the focal-point to the points on the horizontal plane of rectification tangent to the photo-

[2] The symbols and abbreviations used in this and succeeding formulas are identified as follows: $t$ is the tilt-angle; $k$ is the constant relationship between a distance along the principal $y$-axis of the photograph subtended by a tilt-angle of one degree; $f$ is focal length of the lens; $y$ is $y$-coordinate on the photograph; $y_r$ is the rectified $y$-coordinate on the horizontal plane of rectification; $x$ is the $x$-coordinate; and $x_r$ is the rectified $x$-coordinate.

graph, is similar to the right triangle relating the focal-point to the ground datum of these points, the relationship between the scales of the $x$-coordinate and its rectification is similar to the ratio between the focal-length and the slant distance. Thus, the proportion between the two can be expressed as: $x_r = x/\cos t$.

It is the opinion of the author that the photo interpreter should be prepared to use any and all kinds of photography available over an area of interest. The apparent objection to the use of the panoramic aerial photograph is the difficulty of obtaining accurate measurements because of the constantly changing tilt angle over the photograph.

It is hoped that this report will create interest in developing methods of coping with this problem. Such methods would have to be a unified process for rectifying the entire photograph and would have to satisfy certain requirements of simplicity and accuracy.

To the author, it seems that the methods of rectification can be devised to meet these requirements. The concept of the perspective being the curved surface of a cylinder appears to be as usable as that of a tilted plane for the oblique photograph. The three suggested formulas should enable the photo interpreter to rectify a panoramic aerial photograph onto a horizontal plane using simple, straightforward procedures. The formulas are purposely stated so that calculations can be performed either on a slide-rule or by using a book of standard mathematical tables.

# *Stereoscopic Profile-Scanning for Contour Line Information**†

LEO V. STREES, *Cartographer,*
*U. S. Navy Hydrographic Office,*
*Washington, D. C.*

ABSTRACT: *Contours are used to express both the physiographic character of the terrain and to accurately locate the continuum of points of equal elevation. The use of the profile-scan technique to obtain contours in the latter sense is discussed. A method of converting the Stereoplanigraph into an interim scanning instrument for determining contour information is described. Applications of profile-scanning to mapping systems are briefly discussed.*

## I. INTRODUCTION

PHOTOGRAMMETRY, by its very nature, is concerned with the cartographic representation of terrestrial features and their spatial relationships. With stereoscopic plotting instruments these spatial relationships are recreated, at a greatly reduced scale, in the form of the stereo-model. The major photogrammetric task generally is to transform this three dimensional stereo-model into the two dimensional map sheet.

Many recent technical developments in photogrammetry have been directed toward developing equipment and techniques to map the stereo-model more accurately and efficiently.

One of the techniques recently advocated has been that of obtaining contour line information from the stereo-model by profile-scanning(1).

Profile-scanning, that is moving the floating mark over the surface of the stereo-

* The opinions expressed herein do not necessarily represent those of the Navy Department.—*The Author.*

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