FIG. 1. Fairchild field rectifier for 3-inch focal-length panoramic photography.

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A Panoramic Rectifier for Tactical Field Use

The same principles used in this simple, portable, quick-response device might also be applied to longer focal lengths.

(*Abstract on next page*)

OVER THE PAST FEW years panoramic aerial photography has gained ever wider acceptance in the field of aerial reconnaissance. This acceptance follows from the very real advantages of photographic system—simplicity, reliability, and compactness—which are coupled with extended area coverage in the panoramic type of system. Typical examples of such panoramic cameras are the Fairchild KA-56 and KA-60 three-inch focal length cameras which have been produced in quantity.

In spite of the many plus factors favoring tactical panoramic photography, some relatively minor drawbacks remain. These include difficulty in determining distance between objects on the ground, the lack of an immediate sense of relative position and orientation of subjects in the scene, and a degree of difficulty in obtaining suitable

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stereoscopic vision of stereo pairs if the objects of interest are far from the flight path. Also, due to panoramic distortion, mosaics cannot be satisfactorily put together to form crude charts.

All of these disadvantages are eliminated if the *panoramic distortion* is taken out by rectification because after rectification, a panoramic negative takes on the appearance and characteristic of a wide-angle *frame-camera* photograph.

surements may be made directly, and which may be viewed stereoscopically and combined into mosaics for purposes of photointerpretation and chart making.

The principles of static rectifications are disarmingly simple, and may be seen from the basic geometry of rectification shown in Figure 2. Here, a panoramic negative is formed into a cylinder which has a radius of curvature equal to the focal length of the taking lens. This effectively reconstructs the

ABSTRACT: *The static rectification of 3-inch focal length wide-angle panoramic photographs has been achieved by effectively reconstructing the geometry under which the original pictures were taken. A special lens, which images from a cylinder to a plane, was developed to accomplish this task. The rectifier incorporating this lens has proved to be a versatile tactical device for the production of stereo pairs and mosaics from rectified panoramic photographs. The presentation of the principles of operation of the rectifier includes an example of a rectified photograph.*

Several highly complex general-purpose panoramic rectifiers have been built, some of which are capable of excellent performance. These, however, because of their sophistication and complexity, do not fill the need for a tactical type of device which can give rectified prints of adequate quality for the quick reaction evaluation of a rapidly changing tactical situation.

THE FIELD RECTIFIER described here was designed to fill this need for a simple, portable, quick-reaction rectifier for KA-56, KA-60 and other 3-inch focal-length panoramic photography (Figure 1). It has been designed for operation under field conditions and for maximum adaptability to the tactical situation. Necessary features incorporated include:

- Operation from either 28 VDC (using an accessory motor generator) or 115 volt, 60 cycle, single phase
- Table-top mounting
- Ease of portability
- Simplified print stock feed
- Easy processing.

Operating on a principle which allows the panoramic negatives to be rectified statically (no motions of optical or mechanical components are required during exposure of a print), it optically corrects the distortion introduced into panoramic photography due to the fact that the aiming point of the panoramic camera changes as the camera scans. Removal of this distortion provides photographic prints from which rectilinear mea-

geometry of the *taking* situation in which a flat plane is imaged onto a real (fixed-film, moving-lens camera) or effective (moving-film, fixed-lens camera) cylinder. An imagined point source located at the center of the negative will project a fully rectified image onto a plane tangent to the cylinder at its midpoint. Unfortunately, such point-source projection is impractical. Not, as might first be imagined, because it is unrealistic to make a *point* source small enough, but because diffraction drastically limits resolution in the

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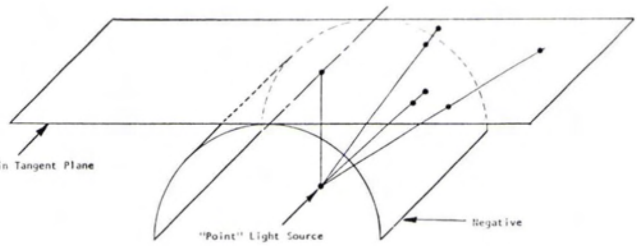

FIG. 2. Basic geometry of rectification of a panoramic photograph.

outer portions of the field to about 2 lines per millimeter.

The same geometry, reversed, would function if the *point* source were replaced with a *pinhole*, and the arrangement used as a *pinhole* camera. Again, however, diffraction would limit the resolution to the same 2 lines per millimeter at the edge of the field.

IF A TYPICAL flat-fielded, wide-angle lens is substituted for the pinhole, diffraction is still the largest error for very small aperture systems. The effects of this diffraction increase as the working aperture of a lens decreases in substantial agreement with the expression

$$\text{Resolution (lines/mm)} = \frac{1600}{\text{working } f/\text{No.}} \qquad (1)$$

In order, for example, to have a resolution capability of 16 lines/mm. the working f/number must be at least as small as $f/100$.

On the other hand, the depth of focus or Focal Range of an objective is determined from the formula:

$$\text{F.R.} = .000088\ (\text{working } f/\text{No.})^2 \qquad (2)$$

In the wide-angle small-aperture case, the arrangement would be as shown in Figure 3. Here, the required focal depth is $1\frac{1}{2}$ inches.

This requires

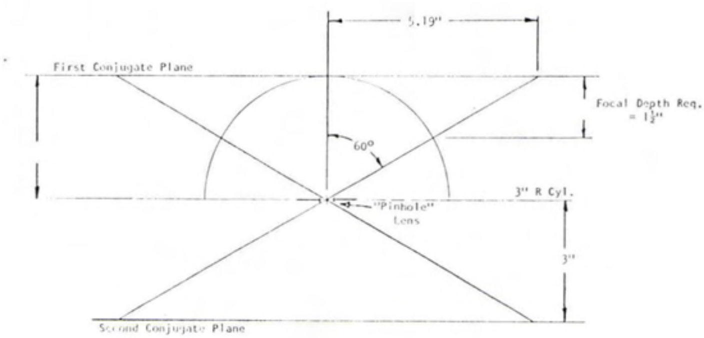

FIG. 3. Geometry for wide-angle, small-aperture case of panoramic rectification.

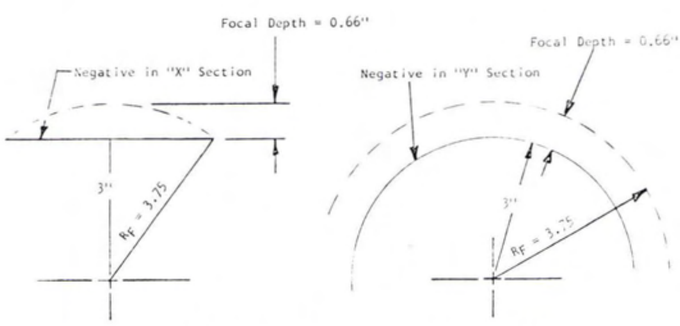

FIG. 4. Relation of the lens to the cylindrical surface.

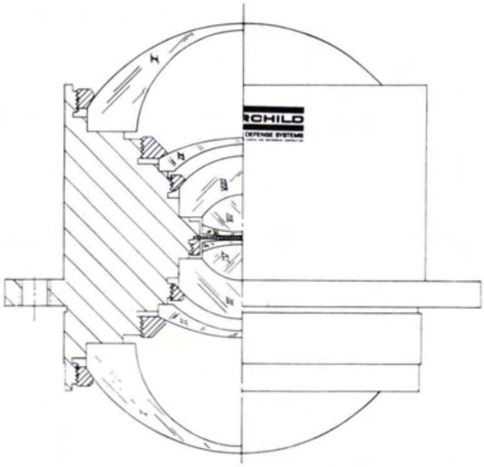

FIG. 5. The special lens has 10 elements symmetrically arranged.

$$\text{F.R.} = 1.5 = .000088\,(f/\text{No.})^2 \quad \text{or,}$$
$$\text{Working } f/\text{No.} = 130.$$

This would resolve (aerially) approximately 12 lines per millimeter, and could be expected to produce a print with the order of 5–8 lines per millimeter referred to the negative surface.

THIS LEVEL OF resolution was not considered satisfactory, even though experiments showed some advantages from the use of rectified prints even at that low resolution level.

What was needed was a lens which could image from the *cylinder*, formed by the panoramic negative, to the *plane*, represented by the photographic print paper. The use of cylindrical optics for this purpose was investigated and abandoned after it became clear that, although the design of a lens of

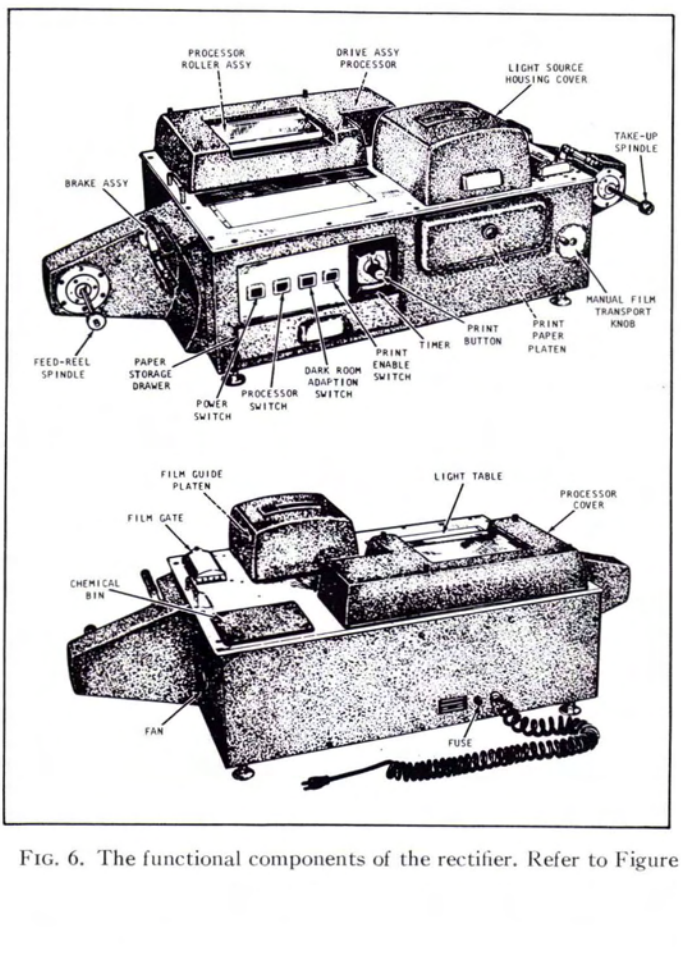

FIG. 6. The functional components of the rectifier. Refer to Figure 1.

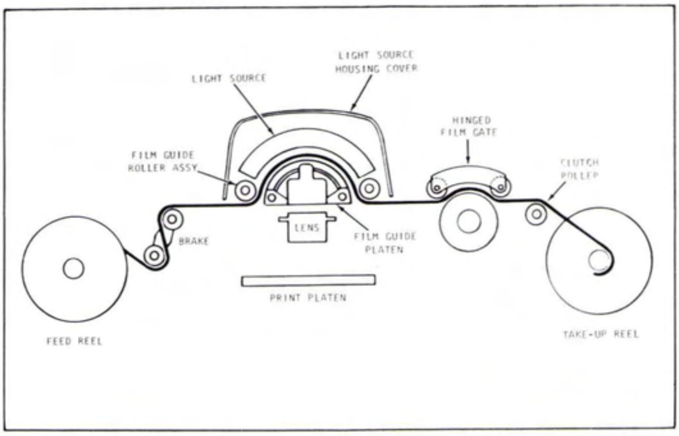

FIG. 7. The film is threaded over the cylindrical platen.

this type was possible, its uncorrectable aberrations would limit its resolution to something of the same order of 2 lines per millimeter provided by a simple *pinhole* camera.

The best approximation that could be obtained was one employing a lens possessing a spherical field on one side of the stop, and a flat field on the other. The cylinder formed by the film cuts this sphere in two circular lines. If the radius of curvature of field of the transfer lens is so adjusted during design that these intersection lines lie 70 percent of the way between the center line of the negative and its edge, an optimum mean focus will be obtained.

Figure 4 shows two views relating the lens and cylindrical surface. The optimum conjugate for the lens equals its field curvature in the object space and is 3.375 inches in this instance. The total *focal depth* represented by the ± 0.375 inches is 0.75 inches.

Returning to the expression for calculation of usable working f/number we find:

$$\text{F.R.} = 8.8 \times 10 - 5\ (Wf/\text{No.})^2 \tag{3}$$

from which

$$Wf/\text{No.} = \frac{.75}{8.8 \times 10 - 5} \tag{4}$$

or, in this case,

$$Wf/\text{No.} = \sqrt{85 \times 10^2} = f/90 \text{ (working)} \tag{5}$$

With the lens operating at an axial magnification of 1:1, this corresponds to an in-

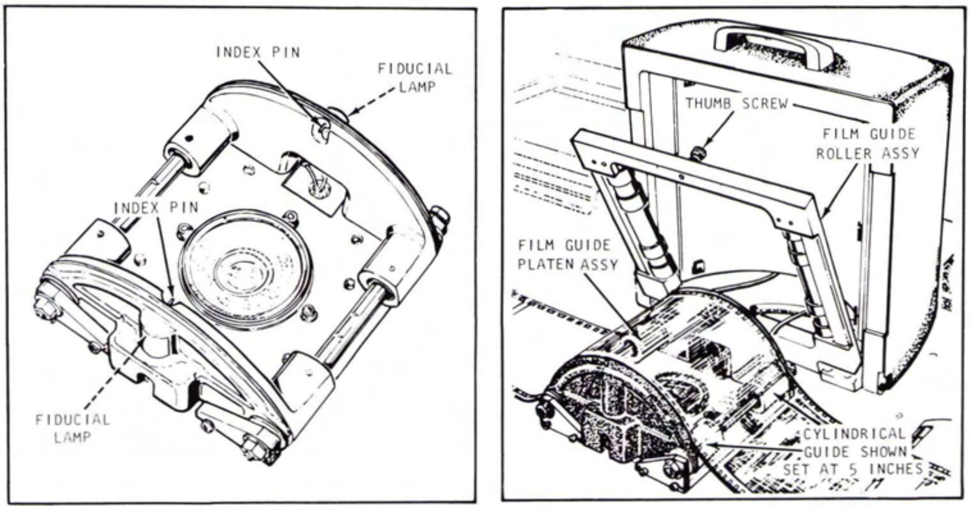

FIG. 8. Illustrations of the film feed.

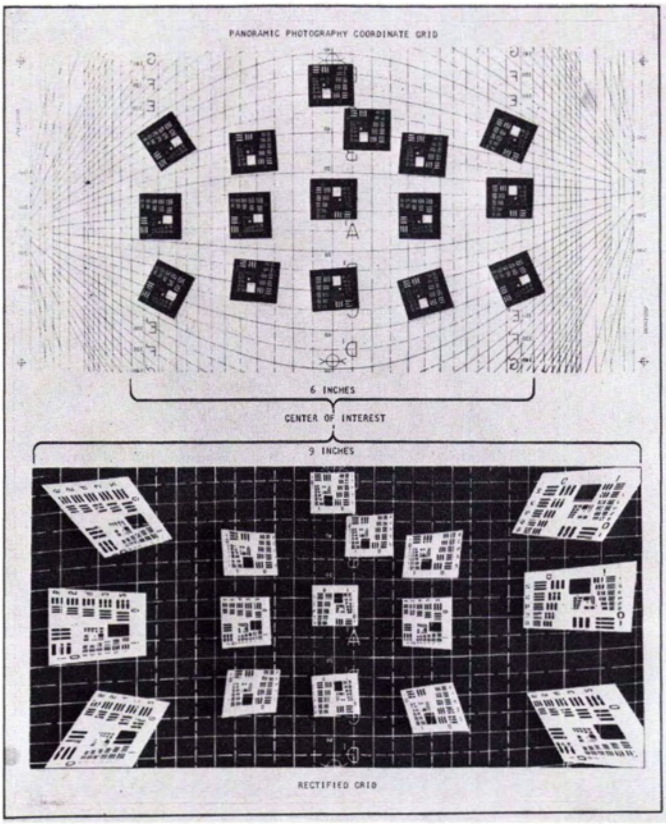

FIG. 9. For test purposes, resolution diagrams were placed on a panoramic grid.

finity f/No. of $f/45$. Such a lens should give approximately 20 lines per millimeter aerial image resolution (referred to the cyclindrical negative surface). This was considered entirely adequate for the specific use intended for the tactical rectifier.

A SPECIAL LENS of these characteristics was designed. A compromise between depth of focus and aberration correction dictated that the working f/number could be opened up to $f/64$ corresponding, as above, to an infinity $f/32$. The resultant increase in speed was obtained without resolution loss in the *real world* case. A sectional view of this lens is shown in Figure 5. It is of 10-element symmetrical form in which the field expander shells introduce considerable pupil coma so that the relative illumination is much better than the $\cos^4$ value usually expected.

After the lens design was complete, one significant problem area remained before a practical device could be designed and constructed. This was the problem of illumination. Even though the lens form exhibits much pupil coma, the illumination fall-off at 60 degrees off axis required some kind of compensation if uniformly exposed prints were to be produced. The use of anti-vignetting coatings, such as those used on mapping lenses to even-out similar illumination problems, was not possible due to the small size of the lens pupil (small irregularities in the coating would show up in the print) and the fact that the illumination fall-off was not radially symmetrical. The problem was finally solved by using additive layers of diffusing material interposed between the cylindrically-wound cold-cathode light source and the negative surface.

THE IMPLEMENTATION of the design principle resulted in the instrument shown in Figure 1 Figure 6 shows the functional components of the unit.

Operational features designed into the rectifier with the intention of augmenting its tactical utility include:

★ Employment of an ektomatic print paper system coupled with—

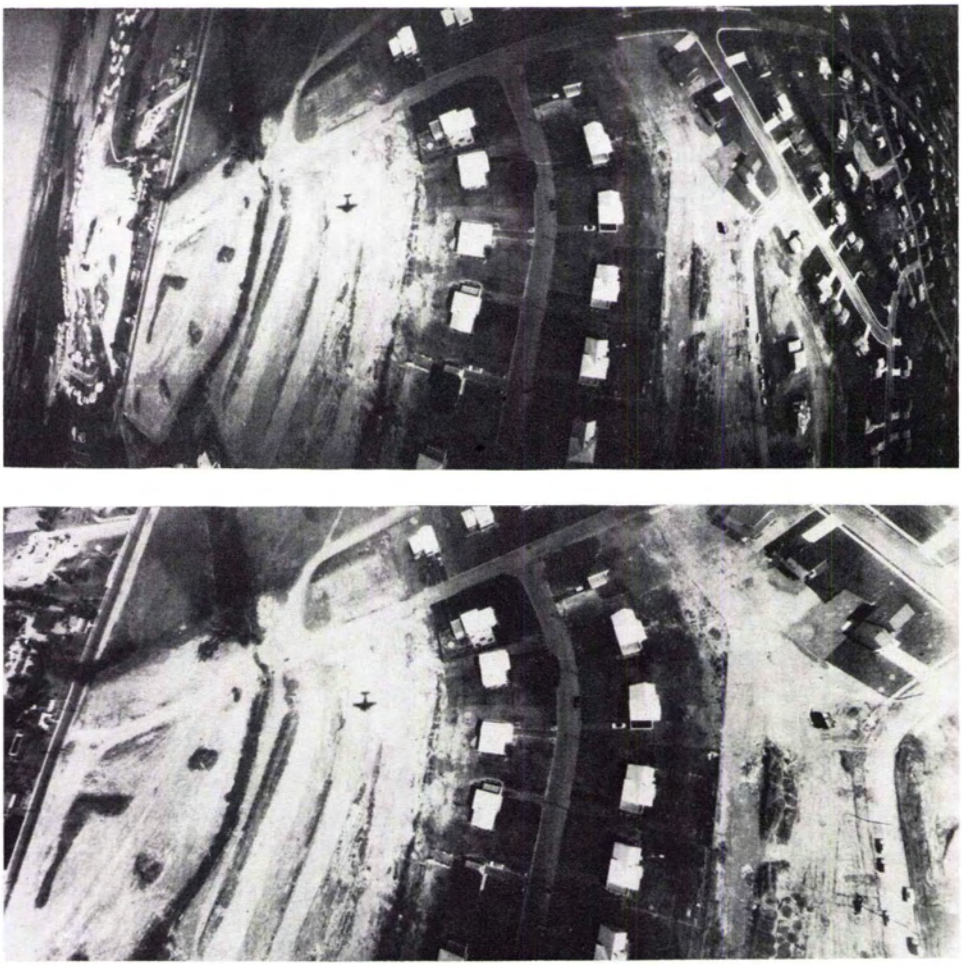

FIG. 10. The top view is an unrectified contact print with the corresponding rectified print below.

- ★ A rapid automatic print processor
- ★ A *previewer* section through which a given frame may be viewed before rectification
- ★ A *darkroom adaptation* switch which alters the previewer illumination from "white" to red light under which the printing paper may be safely handled in the dark room
- ★ A set of *variable contrast* filters for use with negatives of different contrast
- ★ Quick rewind capability.

The sequential operation of the rectifier is briefly described as follows:

For rectifying a frame of 3-inch panoramic photography, the film is fed through the cylindrical platen as shown in Figures 7 and 8. Exposures, of from about 5 seconds to 3 minutes, (depending on negative density) are initiated by setting the timer and subsequently activating the print-enable and print switches. During exposure, the manually introduced single sheet of print paper is held flat by an automatically sequenced vacuum hold-down system. The exposed print is immediately passed through the rapid processor, and the procedure repeated on the next frame of interest.

THE RESOLUTION achieved by the system is in excess of 15 lines per millimeter anywhere in the $4\frac{1}{2} \times 9$-inch rectified format (referred to the original negative). The rectification process gives accuracies of ± 2.5 mm. anywhere within the rectified field of view, limited only by the *S*-curve introduced by the camera's forward-motion compensation (FMC). At a photographic scale of 1:2,000, this corresponds to a ground accuracy of approximately ± 15 feet. At this same scale, the the diagonal of the rectified print covers nearly 1,800 feet so that the rectification accuracy, discounting FMC errors, is approximately ± 1 percent.

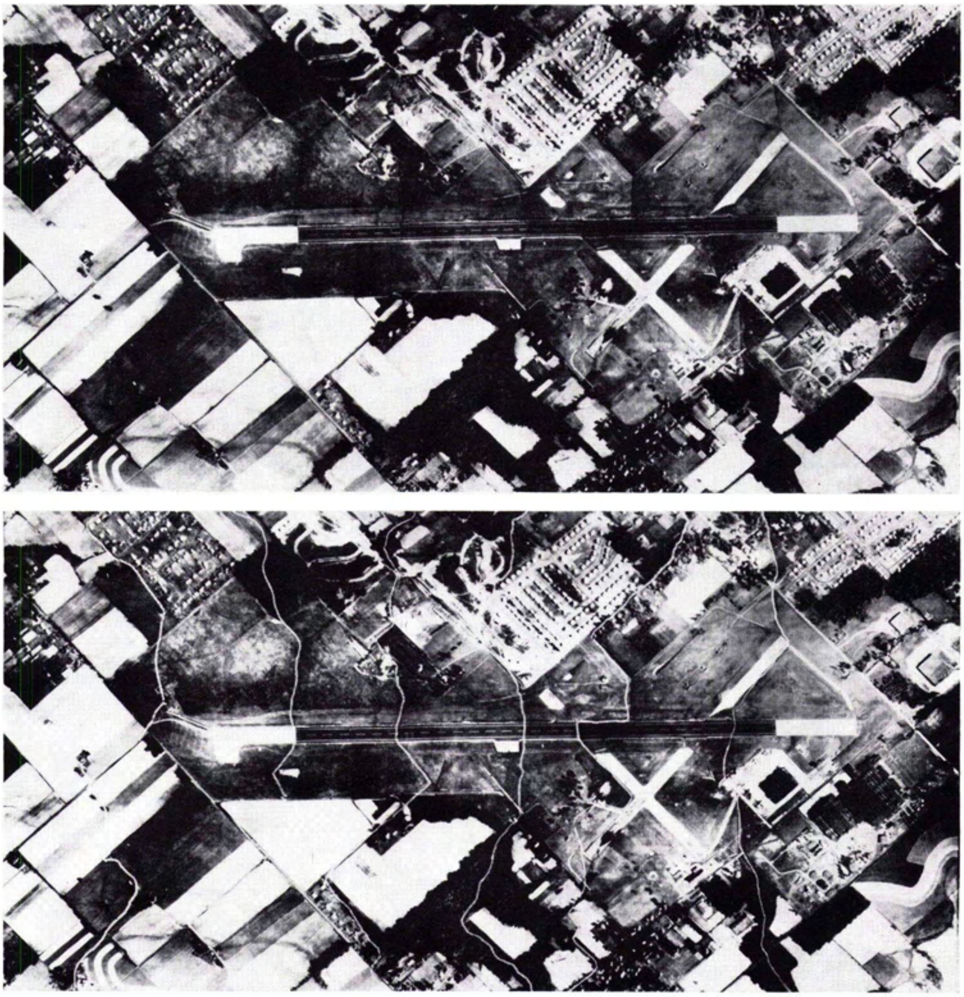

FIG. 11. A mosaic of seven rectified prints. The lower view is included to accentuate the *feather* lines of the assembly.

The lens theoretically has zero distortion because of its symmetry. These properties are typically tested by photographing a panoramic grid onto which resolution targets have been introduced as illustrated in Figure 9.

Figure 10 illustrates a typical rectified print, referenced to the before-rectification photograph from which it was made. From prints of this quality, stereoscopic examination of fields of interest is entirely practical, to the extremes of the rectified field. Also, mosaics can be readily produced to yield low-accuracy charts (roughly the same as equivalent coverage vertical-frame photographs) of the area photographed. Such a mosaic, comprised of seven rectified prints, is presented in Figure 11. The *feather* lines of the mosaic are accentuated in the lower view.

IN SUMMARY, by application of straight-forward geometry and optical art it has proved practical to synthesize a simple reliable and practical field tactical rectifier for 3-inch focal length panoramic photography. The same principle could, undoubtedly, be applied to longer focal lengths, with higher resolving power results, because the depth of focus problem for narrower angle (along flight) coverage would be quadratically less severe.