TABLE 1

LIST OF DATA FOR 30^g AND 44.5^g CONVERGENT PHOTOGRAPHY BASED UPON A PHOTO-SCALE IN THE MODEL CENTER OF 1:50,000

	30^g *Convergent Photography*	44.5^g *Convergent Photography*
Picture size *Focal-length*	9″×9″ (23×23 cm.) 6″ (15 cm.)	9″×9″ (23×23 cm.) 6″ (15 cm.)
Flying Height h *Base b* *Base-ratio b:h*	23,200 ft. (7,100 m.) 4.16 miles (6.7 km.) 0.94	21,800 ft. (6,650 m.) 5.1 miles (8.2 km.) 1.24
Width of Flight Strip	5.15 miles (8.7 km.)	4.65 miles (7.5 km.)
Useful Model Area	21.2 miles² (55 km.²)	23.6 miles² (61 km.²)
Angle of View ν in Model Corner	47^g	40.3^g
Dead Spaces in Model Corner	$1.09 \cdot \Delta h$	$1.35 \cdot \Delta h$
Maximum Angle γ of Homologous Rays	56^g	70^g
Variation of γ over Entire Model	13^g	18^g

*Universal Photogrammetric Electronic Rectifier**

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ABSTRACT: *An electronic line scanning machine is described which will line scan an oblique aerial photograph and produce a rectified print automatically. The machine incorporates optical-mechanical scanning and reproduces by means of an ultrasonic light modulator. The rectifier will handle camera formats up to 9″×18″, focal lengths from 3″ to 100″ and tilt angles up to 80 degrees. Scanning is done at 500 lines per minute.*

The basic theory of line scanning for aerial image rectification is discussed and the development of the equations for the computer required for the machine is given.

FOR many years various progressive individuals involved in the rectification of oblique aerial photographs have considered an electronic line scanning technique for the rectification of such photographs. In this technique each elemental area in the oblique photograph would be scanned point by point as a series of lines and each line would be reproduced with dimensions distorted according to the mathematical relationship

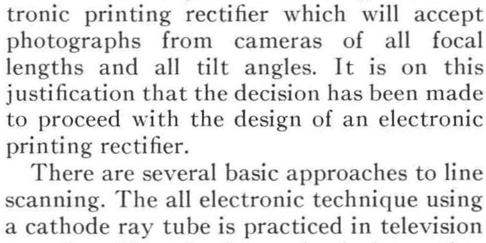
* Acting for the authors, this paper was read at the Society's 24th Annual Meeting by Mr. John Freda of the Rome Air Development Center.

between oblique and rectified photographs. In the past it has been thought that "the state of the art" had not progressed to the point where it was feasible to design such a machine. With recent advances in electronic computers, light modulators, and line scanning techniques, as exemplified by television and facsimile machines, it is felt that this barrier no longer pertains.

On first consideration of the problem one immediately wonders why a line scanning rectifier would be advantageous. Present optical rectifiers perform a satisfactory transformation of the oblique copy to rectified print. In order to handle the complete range of aerial photographs from various cameras and the tilt angles and scales involved, a large number of rectifiers is required for any complete installation. In addition, unusually long focal-length cameras require a special rectifier for high tilt angles and it is necessary in some instances to go through intermediate stages of rectification in order to completely process a photograph.

It should be possible to design an electronic printing rectifier which will accept photographs from cameras of all focal lengths and all tilt angles. It is on this justification that the decision has been made to proceed with the design of an electronic printing rectifier.

There are several basic approaches to line scanning. The all electronic technique using a cathode ray tube is practiced in television scanning. There is the mechanical scanning technique as used in facsimile and wirephoto transmission. In addition, line-by-line reproduction in a conventional optical rectifier can be utilized as a means of rectification. All of these techniques were considered and a mechanical scanning method was selected on the basis that it was the only practical approach having the possibility of producing the required accuracy and resolution of reproduction. It is not feasible with presently available components to obtain



ELECTRONIC PRINTING RECTIFIER
FIGURE 1

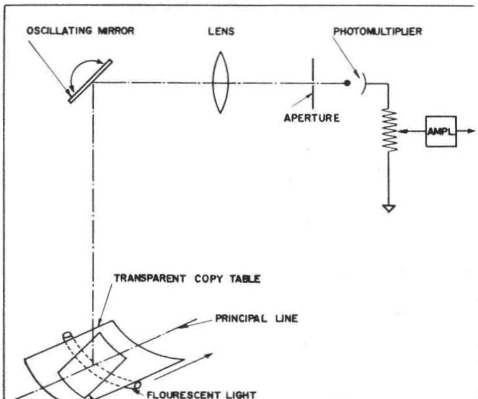


FIG. 2
RECTIFIER SCANNER

the required accuracy and resolution in an all electronic scanning machine.

As is well known in an oblique aerial photograph, there is no change of scale along a line perpendicular to the principal line. If advantage is taken of this characteristic, a machine designed to scan along a direction perpendicular to the principal line will have linear motion. This is a definite simplification. The Electronic Printing Rectifier design requires that the principal line of the photograph be placed on the copy holder so that the scanning mechanism operates in a direction perpendicular to the principal line.

A sketch of the machine is shown in Figure 1. Copy is placed on the transparent, cylindrical copy carriage at the left of the machine with the principal line parallel to the axis of the copy carriage. The transparency is illuminated by a curved blue fluorescent tube underneath the copy carriage. Scanning is accomplished by an oscillating mirror placed above and on the axis of the copy holder. As the oscillating mirror scans a line, the copy carriage advances and thus the entire photograph is scanned line-by-line. The information from the scanning mirror is passed to a photomultiplier light detector and the light energy converted to an electronic signal. This electronic signal is modified as required and actuates an ultrasonic light modulator mounted on a carriage which moves parallel to the axis of the recording cylinder.

The schematic of this system is shown in more detail in Figures 2 and 3. In Figure 2,

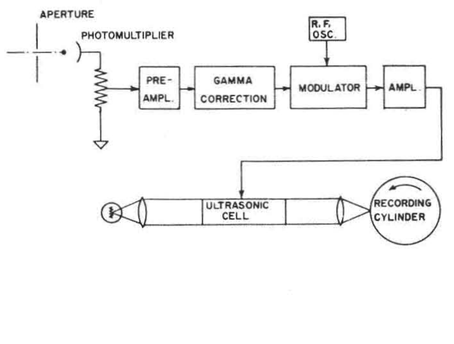


FIG. 3
SCAN AND RECORD ELECTRONICS

the copy is shown on the cylindrical copy carriage with the principal line parallel to the axis of the copy table. The lens focuses the copy image on an aperture plate in front of a photomultiplier tube. As the oscillating mirror moves across the copy perpendicular to the principal line, the image being viewed is passed across the aperture plate, and the information equivalent to a small spot on the copy passes through the aperture to the photomultiplier tube. The greater the amount of light passing through the copy at any given point, the greater will be the electrical signal from the photomultiplier.

There is a certain "dead" time on the recording cylinder where the photosensitive recording paper is attached to the cylinder. During this part of the cycle the scanning mirror "flies back." It can thus be seen that the copy is scanned line-by-line and recorded on a rotating cylinder line-by-line as the copy carriage moves into the machine.

The electronic scanning and recording system is given schematically in Figure 3. The signal from the photomultiplier is amplified and is then "gamma" corrected using non-linear circuits. This "gamma" correction compresses the relatively large density range of the negative to the density range required for recording on paper. The video signal thus obtained passes into the ultrasonic light modulator system.

The ultrasonic light modulator has the ability to produce a light signal whose intensity varies directly as the electrical signal input. The video signal and an R.F. Signal generated in an oscillator mix in a modulator and the resultant signal is amplified to operate an ultrasonic cell. The modulated light from this ultrasonic cell exposes photosensitive paper on the recording cylinder.

From this description of the machine it can be seen that a piece of photographic copy which is placed on the cylindrical copy table will be reproduced on the recording cylinder in a line scan fashion.

This rectification transformation requires distortion of the two dimensions of the photograph. This means that the line scanning mechanism must be controlled by one computer and the motion of the recording carriage by a second computer. This is accomplished in the machine as indicated schematically in Figure 4. It has been pointed out previously that the oscillating scanning mirror goes through a cycle for each revolution of the recording cylinder. If the angle of scan is increased, the speed of scanning the copy is higher and the recorded line is thereby reduced in size. By varying the angle through which the scanning mirror oscillates and keeping the total cycle time constant, a distortion in the direction of scan is obtained. This is accomplished in the Electronic Printing Rectifier by solving the transformation functions relating the oblique aerial photograph to the rectified photograph using computers. The information so computed actuates a servo drive to adjust the mirror scanning mechanism. Information that must be fed into these computers is resultant tilt angle, focal-length of the taking camera, and the scale factor.

Rectification in a direction along the principal line is obtained by varying the rate at which the recording carriage advances relative to the copy carriage. The copy

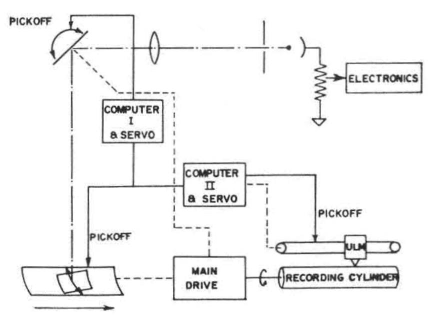


FIG. 4
SCHEMATIC OF EPR

table advances at a constant rate. The recording carriage advances at a varying rate for each line and this is determined by solution of the transformation equations.

In the design of the Electronic Printing Rectifier it was necessary to make a choice between constant advance of the copy carriage and changing advance of the recording carriage, or varying advance of the copy carriage and constant advance of the recording carriage. The decision to advance the copy table at a constant rate was based on two factors. In an oblique aerial photograph the foreground has the highest ground resolution and the background the lowest ground resolution; this, of course, is due to the geometry of oblique photography. However, the resolution in lines per millimeter remains the same. Advancing the copy table at a uniform advance rate maintains this relationship in regard to resolution, with the foreground having the greater number of lines per inch recorded in the rectified image and the background having a lesser number of lines per inch recorded. This variation in resolution in no way degrades the rectified image, but only maintains the same relationship in detail definition as exists in the original photograph.

From an electronic and photographic standpoint, design problems are minimized by using the constant table advance scheme. With this system the dimensions of the aperture of the photomultiplier tube remain constant. The recording aperture must vary in dimension according to the change in line advance. In the direction of recording, the aperture size remains constant for uniform exposure. In a direction perpendicular to recording, the aperture changes in size according to the change in line advance. If this scheme were not used, the aperture of the photomultiplier would have to be varied in size and in addition, the sensitivity of the photomultiplier tube would have to be changed to conform to the change in size of the aperture.

The design specifications for the Electronic Printing Rectifier are as follows:

1. Camera focal lengths—3″ to 100″.
2. Tilt angles—0° to 80°.
3. Tip angles—0° to 15°.
4. Resolution—500 lines per inch.
5. Copy size—up to 9″×18″.
6. Maximum reproduction size—36″×48″.
7. Change of scale range—enlarge or reduce 3 to 1.
8. Recording material—standard photographic paper.

The theory of rectification by line scanning was developed by use of Figure 5. The horizontal plane represents the ground. The photograph plane is projected back to the ground plane so that the principal point in

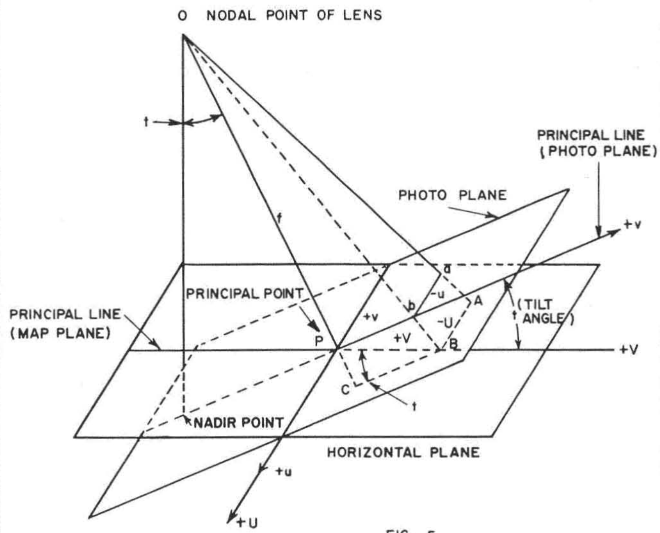
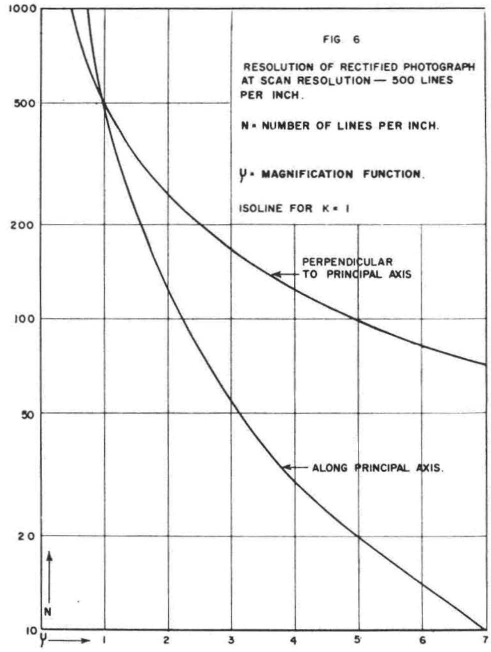


FIG. 5
OBLIQUE PHOTOGRAPHY GEOMETRY



the photograph coincides with its position on the ground. This configuration of the geometry simplifies the derivation of the mathematical relationships. From this figure the transformation equations become:

$$U = \frac{uf \cos t}{f \cos t - v \sin t}$$

$$V = \frac{fv}{f \cos t - v \sin t}$$

Where U is a dimension in the map plane perpendicular to the principal axis, u is the corresponding distance in the photo plane perpendicular to the principal axis. V is a distance in the map plane along the principal axis. v is the corresponding distance in the photographic plane. f is the focal-length of the camera and t is the resultant tilt angle. By proper manipulation of these equations it can be shown that the magnification in the direction perpendicular to the principal line is given by u and the magnification in the direction along the principal line is given by the function μ^2 where μ is the magnification factor and is given by the relationship:

$$\mu = \frac{a}{ab - v}$$

In this equation

$$a = \frac{f}{\sin t}$$

and

$$b = \cos t.$$

An interesting graph showing the change of resolution in an oblique aerial photograph is given in Figure 6. The plot of change of resolution along the principal axis is described by the function $N = 500/\mu^2$ and the change of resolution perpendicular to the principal axis is given by the function $N = 500/\mu$. This plot is very revealing in that it shows the deterioration of resolution in an oblique aerial photograph due to the geometry of oblique photography.

Visualizing an airplane taking oblique photographs from the side, above the isoline the resolution will be better in a direction parallel to the line of flight, and below the isoline the resolution will be better in a direction perpendicular to the line of flight. This plot also indicates the fast deterioration of the photograph. If the numerical values assigned are deleted, these plots are indicative of the characteristics of oblique aerial photographs regardless of the means of rectification.