The average RMSEz was $h/10{,}000$.

To assist in arriving at some definite conclusions on this important but controversial subject, the Corps of Engineers is planning a series of significant investigations, with emphasis on aerial triangulation. The Research and Development Laboratories, Fort Belvoir, Virginia, has recently procured complete coverage of the Arizona Test Area with KC-1, Planigon lens, 6 inch focal-length cameras at an altitude of 10,000 feet. This coverage involves 20 degree convergent simultaneous with vertical photography and equal altitude 15 degree convergent photography. An analysis of these test data should provide significant additional information concerning the merits of the three types of photography.

### VI. Conclusions

The test results to date are conflicting. Additional testing is mandatory before definite conclusions can be formulated, and this testing should obviously include 120 degree photography, as it becomes available. Undoubtedly, some as yet undiscovered proportioning of resolution, distortion, scale and Base:Height ratio will be the answer.

# *The Significance of Reseau Photography in Triangulation Operations**†*

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### I. Introduction

In recent years, with the development of large capacity electronic computors, there has been a significant advancement of analytical aerial triangulation methods. Great strides have also been made in the development of a better photographic image with the manufacture of camera option, shutters, and platens nearing perfection. Similarly, such advancements have also been made in the precision of the measuring instruments until one believes that the ultimate has been reached. However, there is a third material link in the photogrammetric chain—that is the film. One might ask, "Have equal strides been made in the development of the film? Does the film truly record and preserve this record of image excellence to the same precision obtained with the aerial cameras and measuring instruments?" Even though there have been great improvements with aerial film, it is feared that the answers to these questions will be negative. Since it can hardly be expected that any more accuracy in the values obtained from the measuring instruments exists than in the film itself, there is an urgent need to do something about strengthening this link in the photogrammetric chain. Thus there will be provided an increased accuracy in aerial triangulation, an area where such is sorely needed. In several ways, the use of reseau photography would be of value in this critical area.

### II. Background

Reseau, a word of French origin, means a network or a grid, and this grid superimposed upon film produces what is referred to as reseau photography. The first use of such photography may well be obscured in the volumes of publications and books on photogrammetry and its

* Information contained in this treatise does not necessarily represent the official views of the Corps of Engineers or the Department of Army.—The Author.

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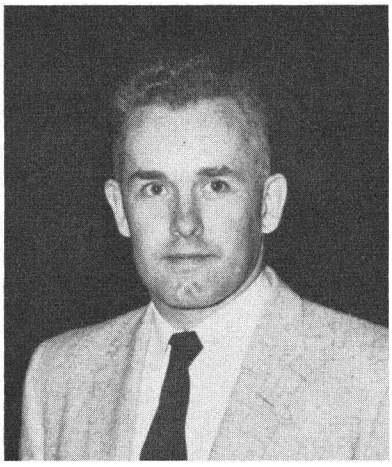

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allied fields, for the limited attempt to obtain this information resulted only in failure. However, reseau photography has had a number of application, both past and present. One of the earlier applications of reseau photography was in the field of astronomy for the purpose of facilitating measurements of star images on a photographic plate.

In 1926 and 1927, Dr. von Gruber used the reseau in his investigation to determine the amount of systematic and random shrinkage of the first stable photogrammetric films developed.[1] He obtained his results by measuring the differences between the grid on the film with reference to the grid of the original reseau by aid of the lateral and altitudinal parallex screws of the stereocomparator.

The British Ordinance Survey, prior to World War II, started an air triangulation program to tighten the horizontal control network in England.[2] For this purpose the British analytical method was developed by Col. Thompson. The areas involved were photographed with reseau equipped cameras, and the resulting photography measured on the Cambridge Stereocomparator. At first only a few British Ordinance Survey cameras were equipped with a reseau, but since World War II they have all been so equipped.

[1] Reference: *Photogrammetry*, Collected Lectures & Essays edited by O. von Gruber.

[2] Reference: *The Photogrammetric Record*, September 1953. "The Use of the Cambridge Stereocomparator for Air Triangulation," by Brigadier H. A. L. Shewell.

Because the British Ordinance Survey has had apparent success in the use of reseau photography, the Engineer Research and Development Laboratories at Fort Belvoir, Virginia, initiated a "Test of Analytical Extensions with the Use of Reseau Photography." This is being conducted at the Army Map Service. Two reseau equipped cameras were used in this test. A Williamson F.49 Mark II six-inch focal-length reseau-equipped camera was loaned by the Ordinance Survey, and a reseau was specially installed in a Fairchild T-11 camera. Both cameras were used to obtain photography over the Arizona Test Area. This photography is now being measured on a Cambridge Stereocomparator. The resulting measurements, after being corrected for lens distortion, are being processed in the UNIVAC-programmed Herget analytical triangulation method.

## III. DISCUSSION

The reseau, for the purpose of this paper, is represented by a system of intersection ticks rather than continuous lines. These ticks are two millimeters in length, spaced at ten-millimeter intervals, and are ten microns wide. The center tick is four millimeters in length. The specified interval here is standard, but if greater precision is necessary, a smaller interval between the ticks can be made. Each of these intersections has established coordinates through the calibration of the reseau prior to installation in the camera.

A few statistics might be noted here, before describing the theory and application of reseau photography, to show the relative accuracies of the camera, instrument and film. The accuracies of the camera and instruments exceed that of the film by three to four times. In the camera, error has been reduced to approximately one part in 15,000, and in the measuring instrument one part in 20,000, But in the film the error is one part in 5,000. In camera tests with the metrogon, planigon and avigon lenses, film accuracy was determined with an error of one part in 5,000, while in the case of the RC-7 plate an error of one part in 7,000 was determined. In order to get some indication of the magnitude of the random film change, and distortion, 129 reseau ticks of one F.49 plate were measured on a Mann Comparator that measures to an accuracy

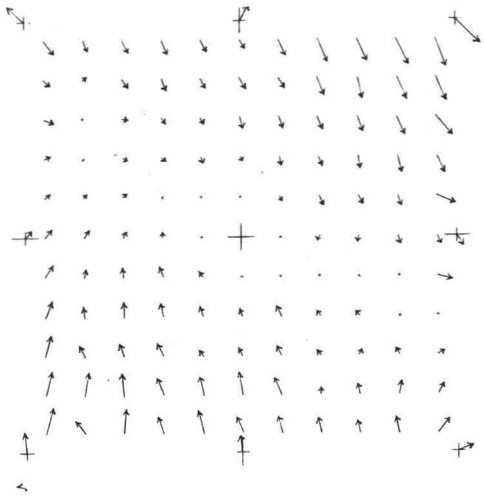

FIG. 1. This illustration shows the direction and magnitude of the film change displacement of each reseau intersection. Linear corrections, based on the outside intersections along each axis, have been applied. One-tenth of an inch represents ten microns, and residuals of less than five microns are not indicated with vectors.

of $\pm 3u$. Linear film change corrections were determined and applied to each reseau intersection. The resulting residuals ranged from $-42u$ to $+39u$ in $y$ and $-25u$ to $+38u$ in $x$. (Figure 1). The RMSE's were $9u$ in $y$, $19u$ in $x$, and $21u$ in the resultant direction. Assuming like RMSE's, combining the two horizontal displacements, and propogating them into the $z$ coordinate, there is obtained a RMSE in $z$ of approximately $44u$. Assuming a focal length of 153 mm., the result is a probable error in terms of the projection distance, of one part in 3,500—this being due to film change and/or distortion. It is obvious that the measurement of one plate should not be considered as conclusive, but it does provide an indication. These statistics indicate the obvious need for strengthening the accuracy of the film.

The theory behind placing a reseau in the focal plane of the camera is quite simple. At the moment of exposure, the reseau as well as the imagery is permanently recorded on the film enabling any point on the photograph to be referenced directly to an intersection within five millimeters in either the $x$ or $y$ directions. With this system, a point need only be measured from the nearest intersection. To obtain the coordinates of a point, the $x$ and $y$ values, measured between the point and the intersection, are added to or subtracted from the calibrated coordinates of the intersection. Regardless of any film changes or distortion, the calibrated coordinates of each intersection are used in determining a point's position.

Probably the most significant application of reseau photography is the virtual elimination of the error effect of film change or shrinkage. Since the reseau image is recorded on the film, any film change after the moment of exposure will displace a terrain image and its nearest reseau intersection by approximately the same amount. Since the change over a five millimeter measuring distance is negligible in either the $x$ or $y$ direction, the virtual elimination of the error effect of film change is quite apparent. At the same time, the ratio of the scale of the calibrated focal length to that of the photography is maintained at 1:1. Without the use of the reseau, all points would have to be referenced to the center of the photograph, requiring the application of quite inferior film change corrections to the measured values of each point.

Although not as significant as film change, film flatness may at times introduce error that should be corrected. The determination of the magnitude of such an error presents a difficult problem, but, by the same principle as in film change, this error is nearly eliminated with the use of reseau. It is obvious that the image will be displaced if the film is warped away from the focal plane, and it is the author's belief that it is equally obvious that the projection of the reseau intersection in the vicinity of that image will be displaced in the same manner and approximately the same amount. Here again the differential error between the point and the intersection is normally negligible.

It is quite evident that reseau photography will not eliminate lens distortion or refraction, but its use does have an indirect effect. To insure true correction of these two types of errors, the position of a point at the time of exposure must be known; this requirement is met when the point is measured on reseau photography.

The advantages of the reseau are not confined to the elimination of film errors, for the comparator to be used in measurements would not require the same over-

all preciseness as it would for non-reseau photography. A precision screw that would measure over the distance of the reseau interval is all that is required. The differential expense incurred in a comparator for reseau photography, over a comparator for regular photography, cannot be determined here.

The question of time required to use the reseau system may well be in your thoughts. At this time there are no comparative data of the observation time between the use of reseau and non-reseau photography. Only assumptions can be made. It is anticipated, however, that the operation of combining the measurement of the point from the nearest intersection and the value of that intersection on reseau photography is as fast if not faster than measuring the same point on non-reseau photography and applying film change correction. The time involved here is not a significant factor in the use of the reseau system.

The reseau does not necessarily end its usefulness as a tool in measuring photography for aerial triangulation procedures. It also lends itself as a possible asset in film inspection. Presently, by measuring the $AB$, $CD$ distances, and comparing these values with the original $AB$, $CD$ values, over-all lateral, longitudinal, and differential film shrinkage is determined. This does not tell the whole story, however, since random and possible systematic quadratic film or change still remain unknown factors with the present method. Use of the reseau provides a convenient tool for rapidly determining such distortions.

Some technologists might consider as a disadvantage the time and work required to equip and calibrate the camera with a reseau. The author does not so consider it. In 1951, the Photographic Interpretation Center obtained some reseau photography with a CA-8 camera to investigate the effect of processing on film distortions. However, so far as known by the author, only the Fairchild T-11 camera used in the Army Map Service test has been so equipped for triangulation in the United States. To equip the T-11 camera a reseau had to be engraved on a special glass plate. This engraving was performed by the Max Levy Company and the reseau calibrated by the Fairchild Camera and Instrument Corporation prior to installation of the plate in the camera. The plate was then installed in the camera by the Wright Air Development Center with the reseau in the focal plane, and the center intersection in coincidence with the principal point. The camera with the reseau plate installed was then calibrated by the Fairchild Camera and Instrument Corporation.

## IV. Conclusion

The apparent advantages of the use of reseau photography as covered in this paper are briefly summarized as follows:

(a) Displacement error due to film change is essentially eliminated with the use of the reseau, and the 1:1 scale ratio is maintained between the calibrated focal length and the photography.

(b) Error due to lack of flatness of the film in the camera at the time of exposure would also be virtually removed.

(c) Less stringent specifications are required of the comparator used in measuring the photography.

(d) The use of the reseau is an excellent tool for the purpose of film inspection to determine systematic and random film changes.