CONVERGENT LOW OBLIQUE PHOTOGRAPHY AND ITS APPLICATION TO THE TWINPLEX*

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ABSTRACT

An excellent and elementary presentation of the significant principles of convergent low oblique photography and its application to the Twinplex. The paper should be of interest to all Society members inasmuch as the principles outlined are pertinent to the fields of governmental, military, and commercial mapping.

The following is a summary of comparable data between vertical and 20° convergent low oblique photography:

Characteristic	*Vertical*	*Convergent*
Flight line overlap	60%	100%
Base-height ratio	0.63	1.23
Width-height ratio	1.15	1.27

The ground area covered by convergent photography is 6 times greater than vertical photography when the flying height is adjusted on the basis of a 1,000 *C*-factor for the convergent system and a 600 *C*-factor for the vertical system.

The advantages and disadvantages of convergent photography are presented in a simple straightforward manner.

The present Multiplex projectors have been adapted to compile convergent photography by the addition of a simple inexpensive bracket.

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IN THE countinuing search for greater economy and efficiency in making topographic maps from aerial photographs, it may be well to reconsider the very basic phase of the photogrammetric operation, namely the taking of the aerial picture. The vertical photograph is, of course, the most widely used today. Instruments designed for verticals have been refined to a point where maximum utilization of this type of photography is being approached. Unless aerial camera lenses of substantially wider angular coverage are made available in the very near future, and this does not appear likely, the answer to the problem of better photogrammetric mapping methods must be found elsewhere. Such an answer may be found in convergent low oblique photography.

As used in this paper, the term "convergent low oblique" defines photography taken with a simple twin-camera arrangement consisting of a pair of wide-angle precision aerial cameras coupled rigidly together so that their respective optical axes lie in a common plane anf form an angle of 20° with a plumb line and 40° with each other (Figure 1). The 20° angle was chosen because it gives the greatest amount of stereoscopic coverage (100% in the line of flight) with the least amount of obliquity and the most favorable air base. The expression "low oblique" has no reference to the flying height and is used as commonly defined, meaning an oblique in which the horizon does not appear. The convergent orientation of the cameras results in a total angle of net coverage of 114° in the plane containing the optical axes if a 6-inch focal length and 9-inch square format are used. The two cameras are exposed simultaneously. Such a camera system can be oriented in two ways—along the flight line, and transversely, at a 90° angle to the flight line.

For precision topographic mapping the orientation along the flight line is used. When exposures are taken so that the coverage of the forward-looking

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camera from one exposure station overlaps the coverage of the backward-looking camera from the next exposure station by 100%, the effective ratio of the base between exposures to the flying height (base-height ratio) is 1.23 and the effective ratio of the width of the strip to the flying height (width-height ratio) is 1.27 (Figure 2). The comparable values for vertical photography are base-height ratio=0.63 and width-height ratio=1.15. This doubling of the base-height ratio is one of the important advantages of convergent low oblique photography. Von Gruber has shown mathematically that when the base-height ratio is doubled, the errors in relative orientation and the deformations in the stereoscopic model are only half as great.[1] Furthermore, the increase in the base gives a more exaggerated stereoscopic impression of relief, making vertical measurements easier to determine. Because of the stronger intersection of conjugate image rays, the operator of a stereoscopic plotting instrument using this photography is more positive that his "floating mark is on the ground." These advantages, attributable to the increase in the base-height ratio, are strong contributors to the *C*-factor (ratio of flying height to the least contour interval that may be plotted accurately)—the contribution being such that it can be safely said that the *C*-factor of a precise instrument using convergent low oblique photography is substantially increased (probably doubled) over its *C*-factor when using vertical photography.

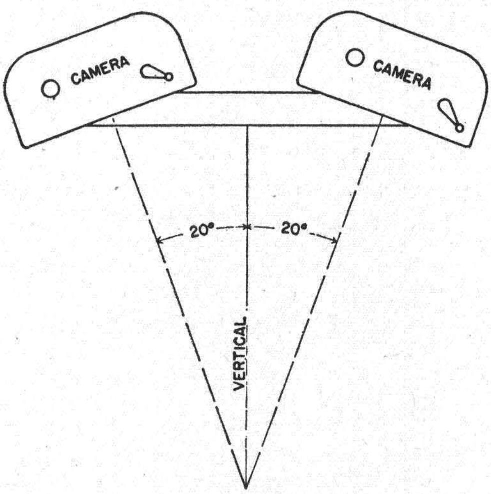

FIG. 1. Camera couple.

It is also interesting to note that the complete working model of convergent low oblique photography is contained within a 75° angle of camera coverage. By eliminating the need to work beyond this limit, the present problems of model "fall-off," which frequently occur in the outer areas for the wide-angle metrogon lens, are also eliminated.

Another very important advantage of convergent low oblique photography is the extent of the ground area covered. The orientation of the cameras along the flight line provides working-model coverage which is 2.2 times the area of a corresponding model from vertical photography assuming equal flying heights; however, since the *C*-factor of convergent low oblique photography is greater, the comparison of ground covered should take into account the higher flying height possible with convergent photography. On the basis of a 1,000 *C*-factor for the convergent system as compared to a 600 *C*-factor for a vertical system, the ground area covered by convergent photography is 6 times greater (Figure 3). By way of illustration, an area of 66 square miles, which is slightly greater than the area of an average $7\frac{1}{2}$ minute quadrangle, can be compiled with 20-foot contours using only 3 convergent low oblique models as compared to about 18 models for comparable 600 *C*-factor vertical photography. The advantages of having to compile only $\frac{1}{6}$ as many models are obvious; more important still is the considerable saving in time and money resulting from the requirement of only $\frac{1}{6}$ as many control points.

[1] *Photogrammetry*, Otto Von Gruber, American Photographic Publishing Co., C 1942, page 47.

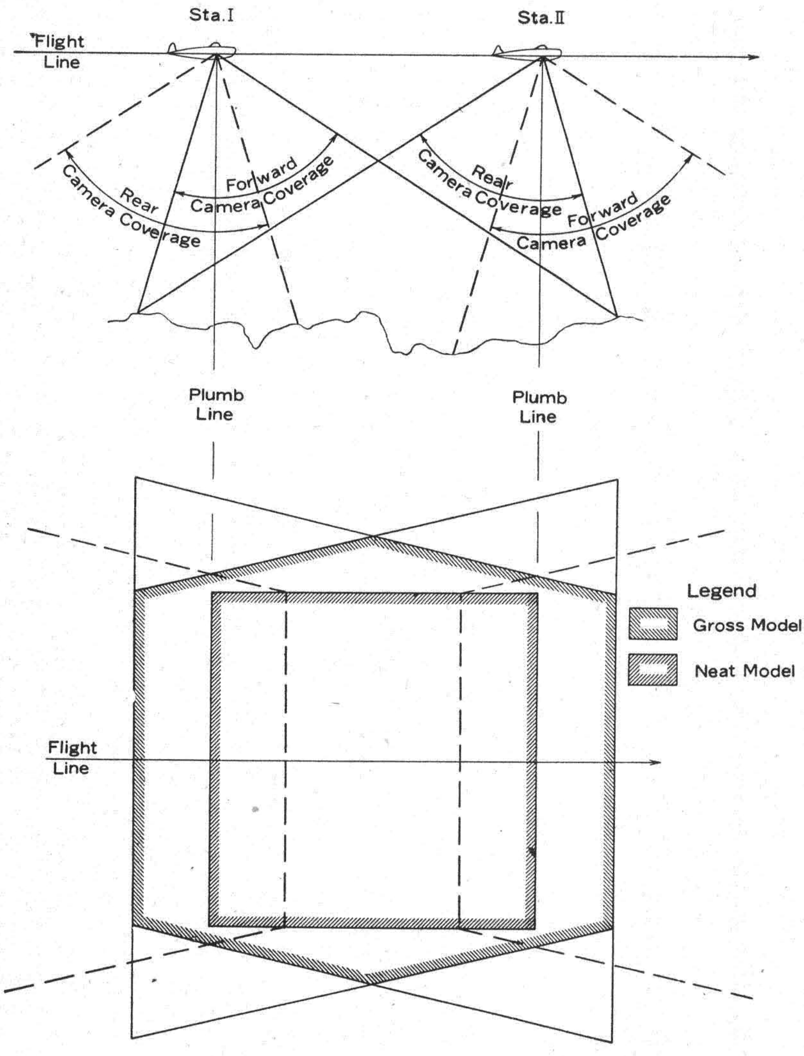

FIG. 2. Convergent coverage.

As a further consideration, it is noteworthy that 43% of the gross stereoscopic model falls outside the working model limits, that is, the gross stereo model is 1.7 times as great as the working model. This feature permits greater leeway in supplemental control planning and simplifies the task of the aerial photographer by allowing him more tolerance in the positioning of his exposures.

It would be imprudent to discuss the merits of convergent photography without also considering the arguments against it. In the main, these are: the variation in scale due to obliquity, reduction in horizontal accuracy, and hidden ground due to relief. The first of these, variation in scale, would be a serious drawback if compilation were to be accomplished from the prints, but such is not the case. To be successful, convergent photography must be compiled in stereo-plotting instruments wherein the exact conditions of exposure can be recaptured at model scale without any rectification of diapositives being necessary. After orientation in the stereo-plotting instrument, there *is no* scale variation in the model. It has also been said that convergent photography gives a "poor" perspective. Actually the perspective of the model is no different than that which is presented by vertical photography since the method of projection in both cases is identical. Because the convergent exposure embraces a larger ground area than the vertical exposure, it necessarily includes lower angles of view in the added area—but this can be an advantage in that the bases of objects are more readily identifiable for the selection and plotting of control points. Prints required by the field man and stereo operator for stereo examination purposes can be made on a fixed rectifier. This process need not be precise since the rectification is necessary simply to facilitate the verification of imagery and the identification of control by stereo means.

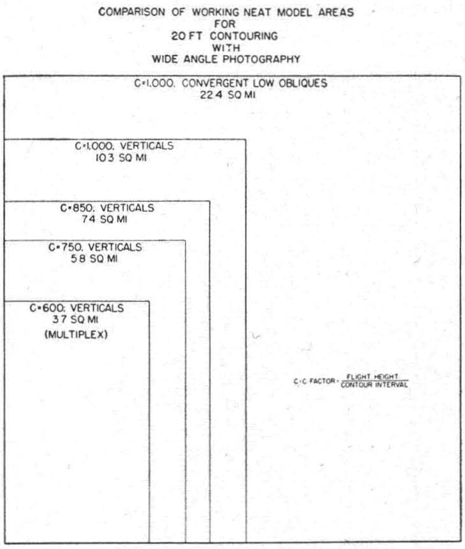

FIG. 3. Comparison of areas covered per stereoscopic neat model.

The second argument against convergent photography, the reduction in horizontal accuracy, is outweighed by the more important result of greater vertical accuracy. The ideal condition for equal horizontal and vertical accuracies occurs when the base-height ratio is 1.0. Convergent photography, which is flown at a base-height ratio of 1.23, is closer to the ideal value of 1.0 than is present vertical photography which is flown at a base-height ratio of 0.63. When the base-height ratio is greater than unity, the vertical positioning is favored; conversely, when it is less than unity, the horizontal positioning is favored; however, horizontal positioning is not nearly as critical as vertical positioning. Consider a 5-foot horizontal error on a 1:7,200 compilation—it is less than a pencil-line width. Yet a vertical error of 5 feet at this scale could represent a half contour interval and would therefore be serious. The aim is to increase vertical accuracy (*C*-factor after all is based on vertical accuracy) and convergent photography provides us with the desirable increase.

The third argument against convergent photography is the hidden ground caused by relief. It should be pointed out, however, that hidden ground also occurs in vertical photography since theoretically the only relief which would *not* obscure detail would lie directly at the nadir point. At the extreme corner of the full working model of convergent photography, the horizontal component of the hidden ground is 1.4 times the change in relief. This figure compares to .85 times the change in relief for the corresponding point in the model from wide-angle vertical photography. It must be remembered that while the possibility of having additional hidden ground in the convergent model is increased, there is also an increase in the ground area covered. On the basis of equal *C*-factors the convergent model covers the same area that the vertical model covers without any increase in the hidden ground—plus an added coverage of 1.2 times. Taking advantage of the increased *C*-factor (hence higher flying) the convergent model covers 3.7 times the area of a 600 *C*-factor vertical model without any increase in the amount of hidden ground—plus an added coverage of 2.3 times wherein the amount of hidden ground may be slightly increased. It is therefore true that if full advantage is to be taken of the 6 times greater area coverage offered by convergent photography, consideration would have to be given during the planning stage to the type of terrain. For precipitous country, the base-height and width-height ratios may have to be reduced. In most cases it would be desirable to take the risk of obtaining some blind areas in favor of other advantages.

What about stereo equipment to compile convergent photography—will complete new instruments be required? The answer is no. Through the addition of a simple inexpensive bracket, the present Multiplex projectors have been adapted to compile convergent photography; Kelsh plotters have likewise been modified without major design changes to accommodate convergent photography. Although not necessary, a further modification besides the addition of the bracket, is desirable. When projectors are tilted 20° from the vertical for convergent photography, the plane of optimum focus is not horizontal. This is remedied by canting the projector lens slightly to satisfy the Scheimpflug condition of having the planes of the object, the image, and the lens intersect on a common line.

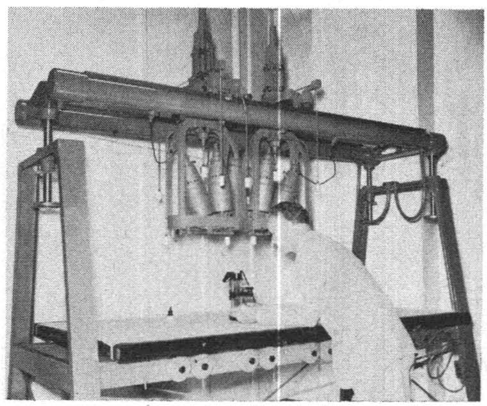

FIG. 4. Twinplex orientation along the flight line.

An instrument, the Twinplex, especially designed to use oblique photography both for compilation and stereo-triangulation was exhibited by the Geological Survey at the January 1950 meeting of the American Society of Photogrammetry (Figure 4). Mr. R. K. Bean of the Geological Survey received the Photogrammetric Award in 1951 for the development of this instrument. The prototype model of the Twinplex utilizes standard Multiplex projectors; however a special type of projector known as the ER-55 is now being fabricated and will incorporate many desirable changes in stereo projectors. The lighting system will be greatly improved through the use of a special reflector which is designed to increase the over-all light passing through the lens and to intensify the light rays which travel the farthest, that is, to the corners of the model. This projector can be used with both vertical and convergent photography; however for convergent photography, the lens will be canted so as to satisfy the Scheimpflug conditions. The projection distance of the ER-55 will be 500 mm. (as compared to 360 mm. for Multiplex) and the diapositive size will be approximately four times the present Multiplex size.

Because of the considerable cost of manufacturing a complete Twinplex instrument, it is not proposed to use them in the production of topographic maps primarily as a compilation instrument, but rather as a stereo-triangulation instrument much as the present 14-foot Multiplex bar is now used. Compilation would be accomplished with paired Multiplex, Kelsh, or ER-55 projectors, mounted with adapter brackets on standard Mutliplex bars.

Another versatile feature of the Twinplex is its ability to utilize oblique photography taken with the camera-couple oriented normal to the flight line (Figure 5). This type of photography has the advantage of wide coverage (over twice that of present vertical) with comparable accuracy, and is particularly suitable for reconnaissance mapping and when flying time is limited over a given area. For example, on the basis of equal *C*-factors and 50-foot contour accuracy, the transverse coverage will include an area of 225 square miles, comparable to a 15 minute quadrangle, with one flight and 6 models as compared to 2 flights and 12 models for vertical coverage. The military should find this characteristic of the Twinplex especially appealing.

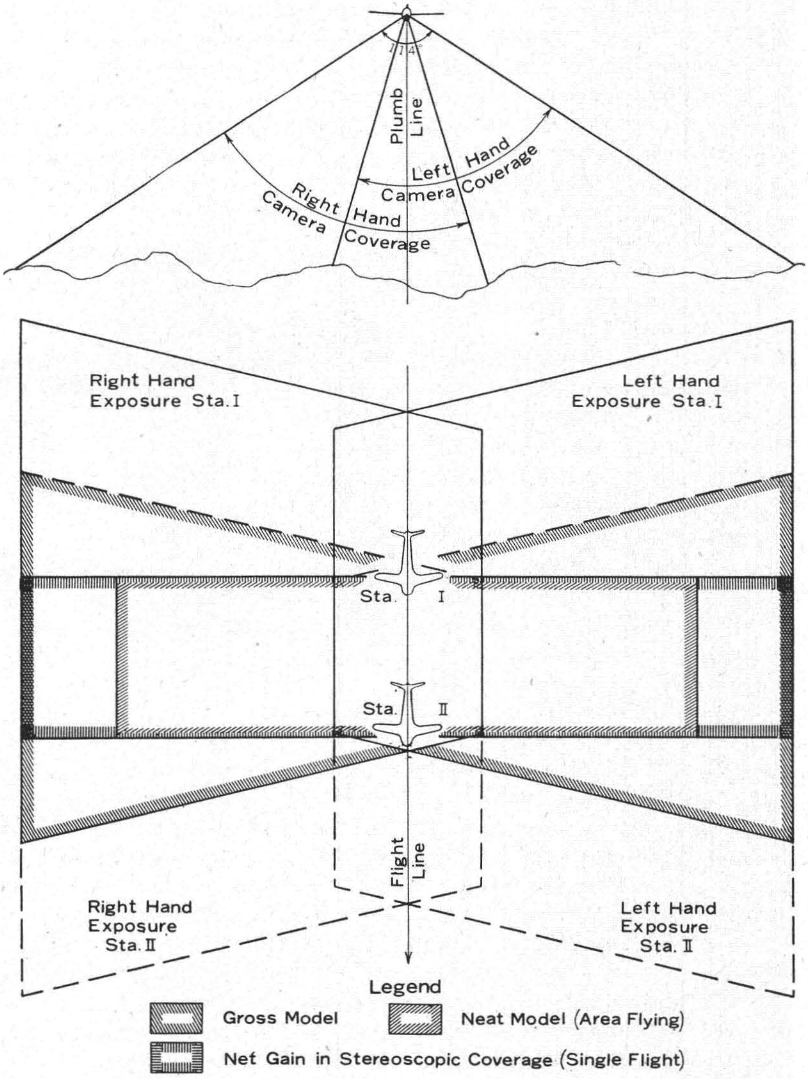

FIG. 5. Transverse coverage.

While it is not within the scope of this paper to go into the details of compilation with the Twinplex, certain general features should be pointed out. Once the model is set up in the Twinplex, there are no moving parts to contend with. Plotting is accomplished with the standard tracing table in the same manner as it is worked in the Multiplex and Kelsh systems. Yet the *C*-factor of Twinplex is comparable to that of more complicated plotters. Because of the wide area coverage, a 15-mile bridge for 20-foot contour accuracy can be accomplished with only 4 models (as compared to 11 models for a 600 *C*-factor vertical system), thereby reducing control costs and bridging weaknesses. The repeatability of readings with the instrument is excellent and even the less experienced operator can duplicate his elevation readings with considerable accuracy and comparative ease.

To verify the theory of the Twinplex and convergent low oblique photography, the Geological Survey has compiled a $7\frac{1}{2}$ minute quadrangle in the vicinity of Miamisburg, Ohio, at a compilation scale of 1:10,000 (12,000-foot flying height) with 20-foot contours on the slopes and 10-foot contours in the flats. The prototype model of the Twinplex using standard Multiplex projectors with uncanted lenses was used and therefore the conditions were not ideal. The operator found that because of the strong intersection of conjugate image rays and the increase in stereoscopic depth, the contouring was relatively simple. A rigid field test of the compiled manuscript was made, with the following results:

1. Seventy-three spot heights were checked by stadia lines—the average error was 2 feet; only 2 points were in error by 5 feet, one point by 6 feet, and one point by 7 feet. The average spot height reading error, expressed as a fraction of the flight height, was 1/6,000.

2. Accuracy test lines were checked by plane-table traverse, the field elevation for each point being checked against the elevation of the same point as interpolated from the contours. Of 106 points tested, the average error was 2 feet; 59 points were within 1 foot; only one point was found to be in error by more than 10 feet and 7 points were in error by more than 5 feet.

While no definite general conclusions can be drawn from only one test, the check of the initial Twinplex compilation substantiates convergent photography and Twinplex theory. Further and more extensive tests will be conducted during the coming year using the new ER-55 projectors and modified Kelsh and Multiplex projectors. Other governmental and private organizations are known to be conducting similar investigations with very promising results.

There is no claim being made that convergent low oblique photography and the Twinplex will solve all photogrammetric problems. No one system or instrument can do that because of the varying conditions and objectives confronting the map-maker. On the other hand, photogrammetrists should not be indifferent toward the investigation of convergent low oblique photography as a more efficient means of meeting the growing demands for topographic maps by military and civilian users. In theory, it is desirable; in practice, it has worked successfully; and now instruments are available to compile with it.

NEWS OF PHOTOGRAMMETRISTS

On May 29 Carroll E. Dobbin received the honorary degree of Doctor of Engineering at the Colorado School of Mines, Golden, Colo. He has been a geologist in the U. S. Geological Survey since 1918. His specialty has been the geology of coal, petroleum and natural gas in the West.

The many friends of Past-President Talbert Abrams will be pleased at his being given the honorary degree of Doctor of Science by the Michigan College of Mining and Technology, Houghton, Michigan. Details have not been received.

The Four Corners Geologic Society of Arizona, Colorado, New Mexico, and Utah, has appointed Dr. *Sherman A. Wengerd*, Associate Professor of Geology University of New Mexico, as Editor of its Geologic Symposium to be published in the late summer or early fall. The symposium will cover the geology of oil and gas fields; regional geology, stratigraphy, structure, and exploration in the vast Four Corners Region. The symposium will have 24 contributors who are company and independent geologists active in the search for oil and gas in the area.