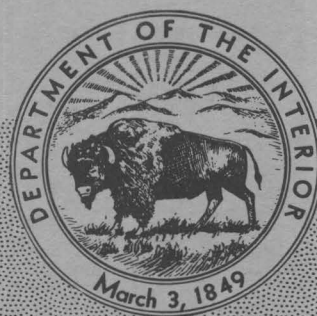# TWIN LOW-OBLIQUE PHOTOGRAPHY
AND THE TWINPLEX PLOTTER

Prepared by Topographic Division
Research and Technical Control Branch
Section of Photogrammetry

GEOLOGICAL SURVEY CIRCULAR 222

TWIN LOW-OBLIQUE PHOTOGRAPHY AND THE TWINPLEX PLOTTER

The text of this circular is an adaptation
and combination of the following papers:

1. Hopkins, B. T., 1951, The Twinplex
plotter for low-oblique photography. [Un-
published.]
2. Radlinski, W. A., 1952, Convergent low-
oblique photography and its application to
the Twinplex; Photogrammetric Engineering,
vol. 18, no. 3, pp. 591-597.
3. Thompson, M. M., 1950, The Twinplex, a
new stereoplotting instrument; U. S. Geo-
logical Survey Circ. 82.

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ILLUSTRATIONS

TWIN LOW-OBLIQUE PHOTOGRAPHY AND THE TWINPLEX PLOTTER

INTRODUCTION

During recent years, the technical procedures of topographic mapping have been profoundly altered by the use of aerial photographs as one of the basic source materials for map compilation. An aerial photograph, however, does not in itself constitute a map. Because of variations in ground elevations, tilting of the camera, and other phenomena, the aerial photograph gives a distorted picture of the terrain; furthermore, a single aerial photograph affords no means of measuring variations in ground elevation. For converting the information contained in the photographs into accurate topographic maps, various plotting instruments have been developed. These instruments range from relatively simple devices, used for the production of maps of relatively low accuracy, to elaborate plotting machines designed for mapping to a high standard of precision. The plotting instruments that have been devised are, in general, increasingly complex as a higher degree of precision is attained.

In 1950, the Geological Survey completed the prototype model of a new plotting instrument of moderate complexity, called the "Twinplex," that embodies an unusual approach to the diverse problems of precision and reconnaissance mapping. The Twinplex instrument is designed to accommodate low-oblique photography taken by twin cameras, whereas most of the existing techniques for precision aerial mapping utilize vertical photography (taken with the optical axis of the single camera in a vertical or near-vertical position). A low-oblique photograph is defined as a photograph taken with the optical axis intentionally deviated from the vertical, but not sufficiently to include the horizon in the exposure.

This report discusses the objectives of twin low-oblique photogrammetry, the geometry of twin low-oblique photography, and techniques for utilizing low-oblique photography in the Twinplex and other plotting instruments.

OBJECTIVES

The objectives of photogrammetric techniques utilizing twin low-oblique photography are as follows:

1. Decreasing the over-all cost of mapping.

2. Increasing the accuracy of mapping operations.

3. Making possible the use of higher flying with no departure from standard accuracy.

4. Allowance of greater latitude in the positioning of flights.

5. Decreasing the flying time required for photography over a given area.

The Twinplex plotting instrument was developed by the Geological Survey under the direction of Russell K. Bean, with the following objectives:

1. Providing an instrument that accommodates twin low-oblique photography readily and is capable of exploiting the advantages of such photography.

2. Providing a versatile instrument suitable for aerial triangulation, precision mapping, and reconnaissance mapping.

GEOMETRY OF
TWIN LOW-OBLIQUE PHOTOGRAPHY

Camera arrangement

Twin low-oblique photography is obtained with a special twin-camera arrangement consisting of a pair of wide-angle precision aerial cameras coupled rigidly together. The respective optical axes of the cameras lie in a common vertical plane and form an angle of 20° with a plumb line (assuming no tilt) and 40° with each other (fig. 1). The 20° angle was chosen because it gives the greatest amount of stereoscopic coverage (100 percent in the line of flight) with the least amount of obliquity and the most favorable air base. This arrangement gives a total angle of net coverage of 114° in the plane containing the optical axes for a 6-inch focal length and 9-inch square format. The shutters are synchronized so that simultaneous exposures are made with both cameras of the coupled pair. The camera system may be oriented in two ways:

1. Along the flight line (that is, the vertical plane containing the optical axes also contains the flight line). This orientation gives convergent low-oblique photography that is suitable for precision mapping.

2. Transverse to the flight line (that is, the vertical plane containing the optical axes is normal to the flight line). This orientation is suitable for reconnaissance mapping.

Convergent low-oblique photography

When exposures are taken with the twin cameras oriented along the flight line, the exposure in the forward-looking camera at one exposure station is convergent with the exposure in the backward-looking camera at the next exposure station (figs. 2 and 3, see pages 4 and 5). If the exposure stations are so spaced that the convergent photographs overlap each other by 100 percent, the effective ratio of the base between exposures to the flying height (base-height ratio) is 1.23. For an efficient spacing of such flights, the effective ratio of the width of the strip to the flying height (width-height ratio) is 1.27. The comparable values for vertical photography are: base-height ratio = 0.63 and

width-height ratio = 1.15. The 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 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.

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 necessity 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 that is 2.2 times the area of a corresponding model from vertical photography assuming equal flying heights; however, inasmuch as 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 (fig. 4, see page 7). By way of illustration, an area of 66

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[1] Von Gruber, Otto, 1942, Photogrammetry, collected lectures and essays; translated by G. T. McCaw and F. A. Cazalet; Boston, American Photographic Publishing Co., pp. 47-48.
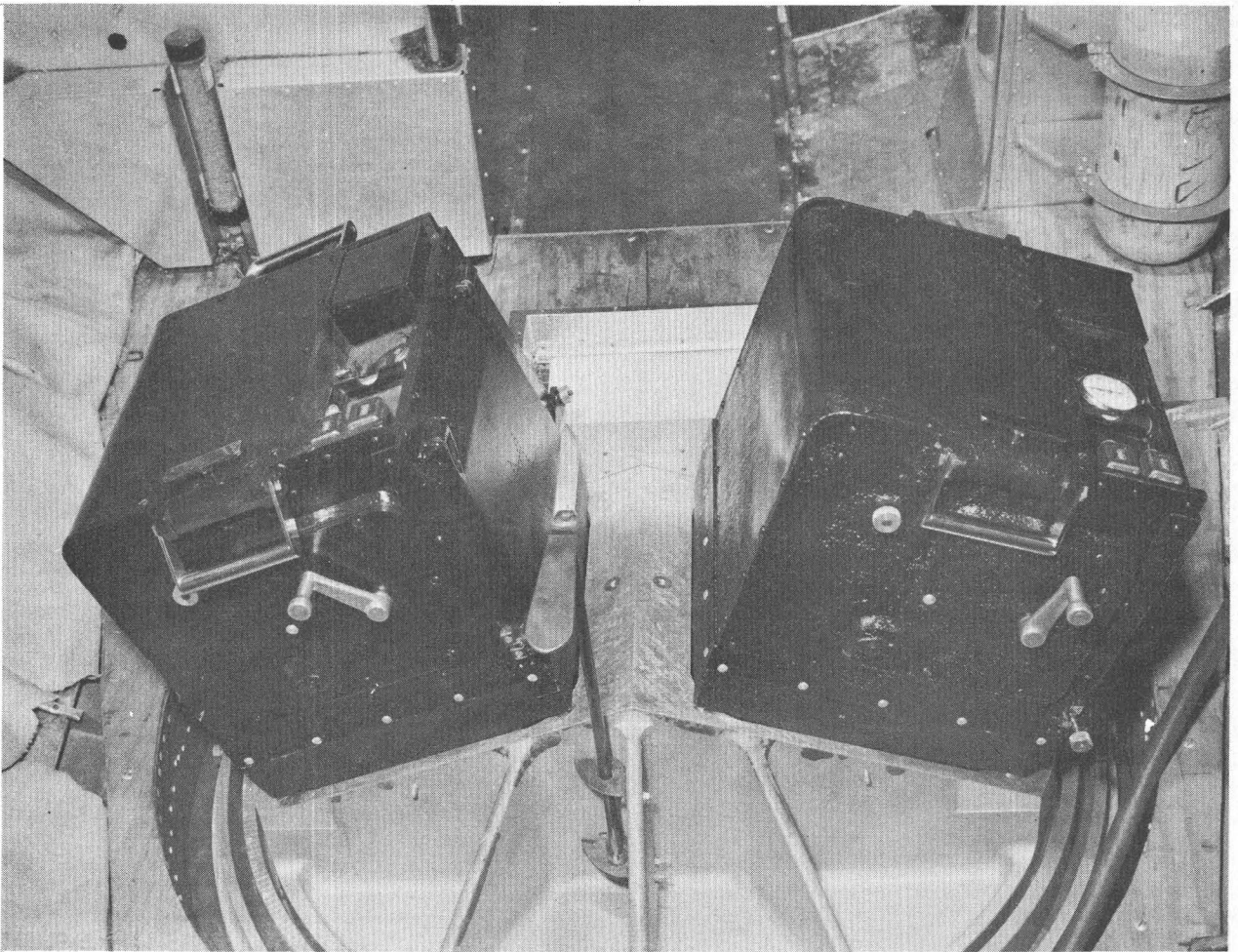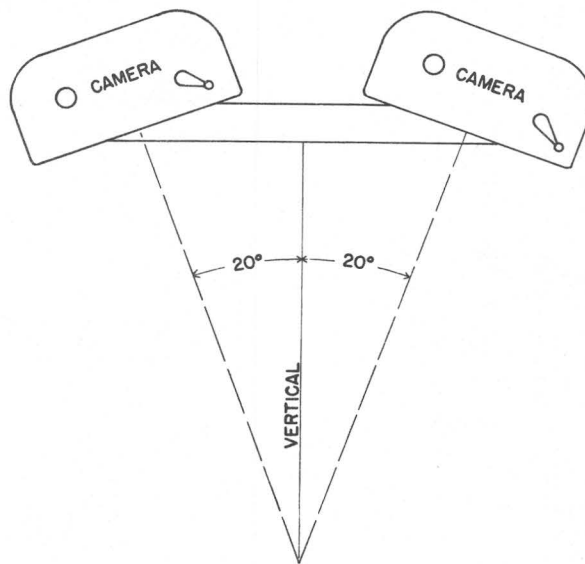
Figure 1. --Twin camera arrangement. Lower view shows two 6-inch precision aerial cameras installed in an aircraft modified for twin low-oblique photography. (Photograph by courtesy of Mark Hurd Mapping Co.) Upper view is a schematic representation of the coupled cameras.
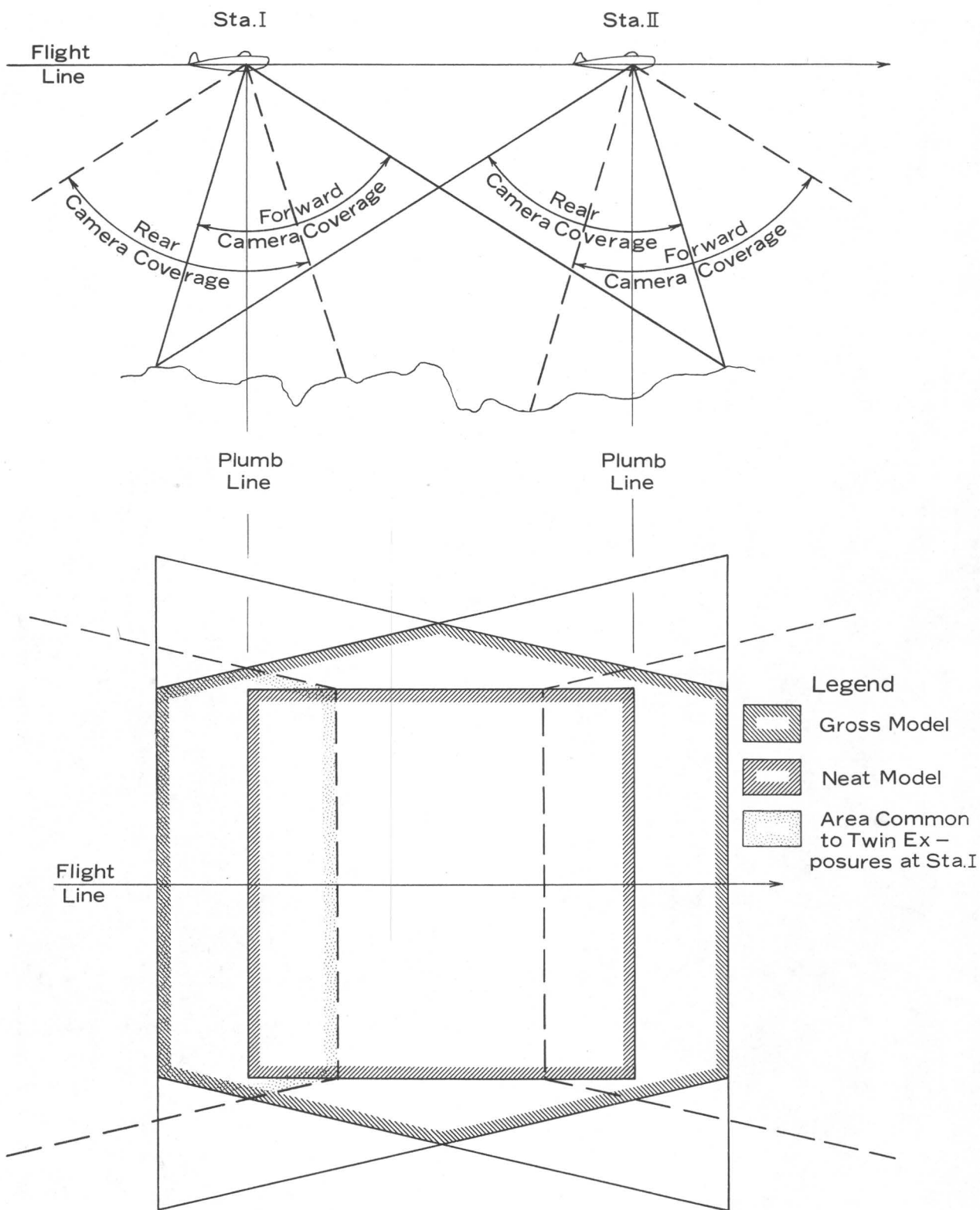
Figure 2. --Convergent low-oblique coverage.

For H = 12,000, area of neat model = 8.1 sq.mi., $\dfrac{B}{H}$ = 1.23, $\dfrac{W}{H}$ = 1.27

area of gross model = 14.1 sq.mi., $\dfrac{B}{H}$ = 1.23, $\dfrac{W}{H}$ = 1.41

Total forward overlap = 1.84 H.

Neat model area A = 5.6×10^{-8} H²   Gross model area A = 9.82×10^{-8} H²
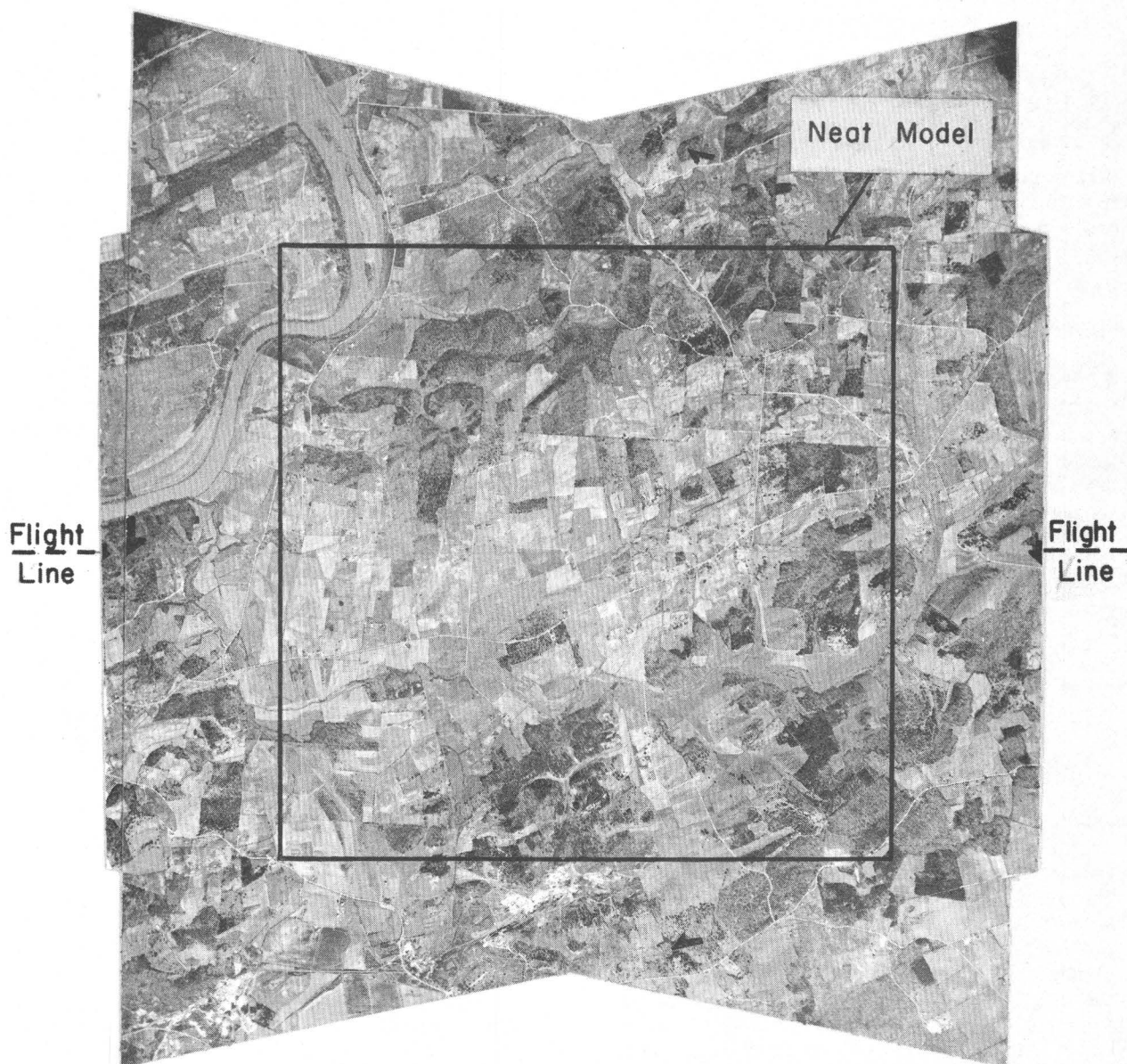
Figure 3. --Convergent stereoscopic pair. (Photographs rectified to demonstrate coverage of the overlapping exposures from two successive stations. The divergent exposures are not shown.)

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square miles, which is slightly greater than the area of an average 7½-minute quadrangle, can be compiled with 20-foot contours using only 3 convergent low-oblique models compared with about 18 models for comparable 600 C-factor vertical photography. The advantages of having to compile only one-sixth as many models are obvious; more important still is the considerable saving in time and money resulting from the requirement of only one-sixth as many control points.

It is noteworthy that 43 percent 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 low-oblique 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 stereoplotting instruments wherein the exact conditions of exposure can be recaptured at model scale without any rectification of diapositives being necessary. After orientation in the stereoplotting 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 presented by vertical photography as the method of projection in both cases is identical. Because the low-oblique 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 because the bases of objects are more readily identifiable for the selection and plotting of control points. Prints required by the fieldman and stereo-operator for stereoscopic examination purposes can be made on a fixed rectifier. This process need not be precise inasmuch as the rectification is necessary only to facilitate the verification of imagery and the identification of control by stereoscopic means.

The second argument against convergent low-oblique 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 the present vertical photography that 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 is based on vertical accuracy), and low-oblique convergent photography provides us with the desirable increase.

The third argument against convergent low-oblique photography is the hidden ground caused by relief. It should be pointed out, however, that hidden ground also occurs in vertical photography as theoretically the only point at which high relief would not obscure detail is 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 value compares with 0.85 times the change in relief for the corresponding point in the model from wide-angle vertical photography. 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 as the vertical model 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 taken of the 6 times greater area coverage offered by convergent photography, consideration must be given during the planning stage

COMPARISON OF WORKING NEAT MODEL AREAS
FOR
20 FT. CONTOURING
WITH
WIDE ANGLE PHOTOGRAPHY

C=1,000; CONVERGENT LOW OBLIQUES
22.4 SQ. MI.

TWINPLEX (EXPECTED)

C=1,000; VERTICALS
10.3 SQ. MI.

C=850; VERTICALS
7.4 SQ. MI.

C=750; VERTICALS
5.8 SQ. MI.

C=600; VERTICALS
3.7 SQ. MI.

(MULTIPLEX)

IF EQUAL C-FACTORS ARE CONSIDERED, THE RATIO OF THE AREA COVERED BY TWINPLEX PHOTOGRAPHY TO VERTICAL PHOTOGRAPHY IS 2.2 TO 1.

$$C = C\text{-FACTOR} = \frac{\text{FLIGHT HEIGHT}}{\text{CONTOUR INTERVAL}}$$

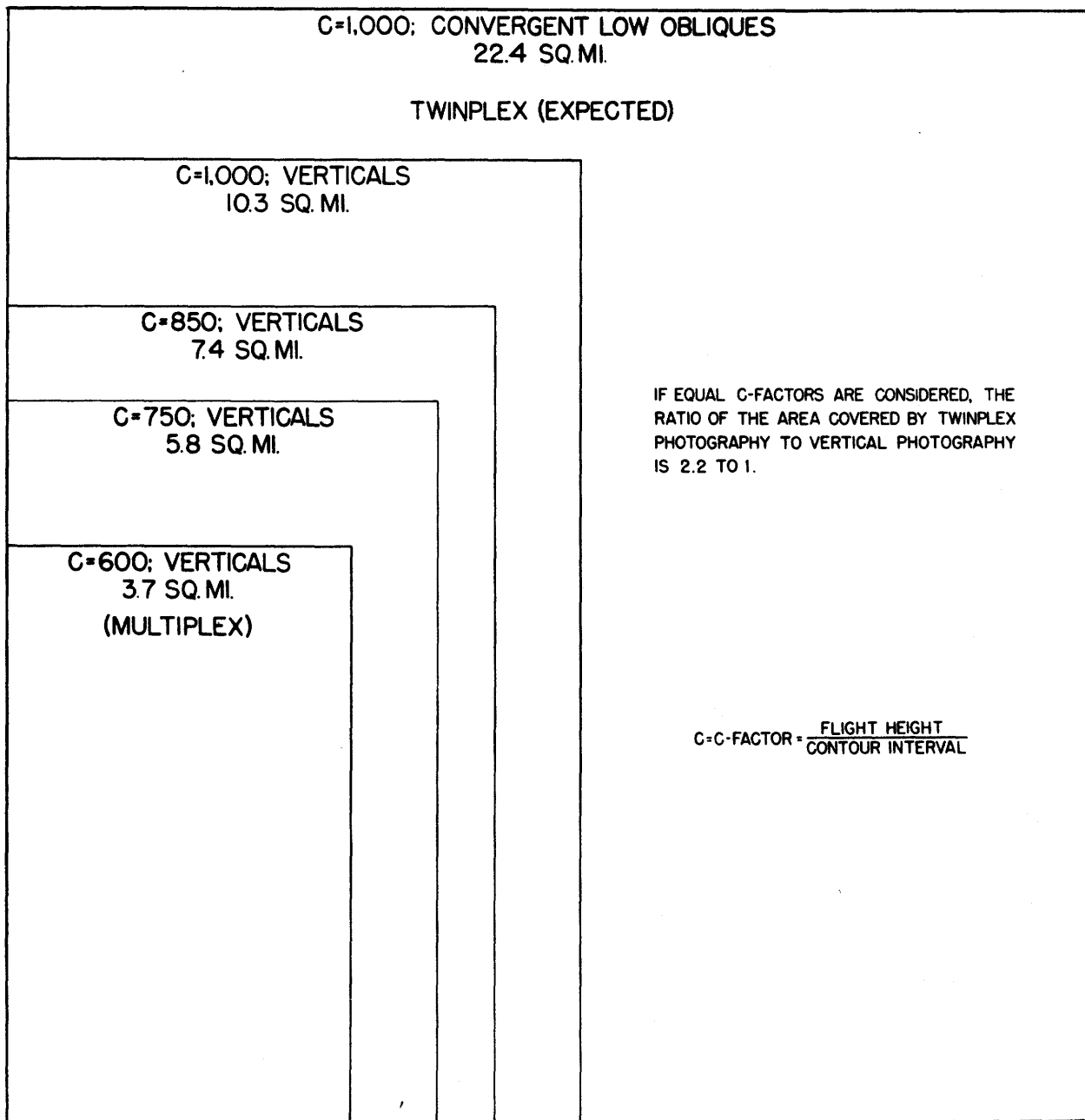Figure 4.--Comparison of areas covered per stereoscopic neat model.

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. When choosing the maximum permissible base length in this type of country, consideration must also be given to this condition: objects cannot be plotted stereoscopically if they are in a surface that, if extended, will intersect the air base. [2]

Transverse low-oblique photography

Orientation of the camera couple normal to the flight line results in transverse low-oblique photography (figs. 5 and 6, see pages 10 and 11) in which each model is composed of the four exposures taken at two successive exposure stations (two at each station). A half-model is formed by the overlap of the right-hand exposure of station I with the right-hand exposure of station II. Similarly, another half-model is formed by the left-hand exposures at the same exposure stations. In the transverse neat model, the base-height ratio is 0.63 and the width-height ratio is 2.31. The extreme width-height ratio would permit coverage of an area having a reduced number of flight lines; however, the base-height ratio would probably not permit a C-factor greater than 600 for standard map accuracy. A stereoplotting instrument accommodating transverse low-oblique photography would permit reconnaissance mapping of large areas at relatively low cost. For instance, by flying at 30,000 feet and assuming a contour interval of 50 feet or greater, a full 15-minute quadrangle could be compiled from one flight of five models. For a single flight, the net stereoscopic gain per model is approximately a rectangular area whose length is equal to the air base and whose width extends to the limits of the photographic coverage normal to the flight line. The reduction in the number of flight lines permits a decrease in the number of ground-control points required and a decrease in flying time and distance, factors which are especially important in military operations. To date, the Geological Survey has not had an

[2] Zeller, Dr. M., 1952, Textbook of photogrammetry; translated by E. A. Miskin and R. Powell; London, H. K. Lewis & Co., Ltd., p. 116.

opportunity to test this system of photography, but an extensive test project is in the planning stage.

THE TWINPLEX PLOTTER

Principles of construction and operation

The Twinplex stereoplotting instrument is based on the principle of double projection and recreates the spatial model by anaglyphic means in a manner similar to the multiplex and the Kelsh plotter. Diapositives, at a reduced scale, are printed without rectification from the oblique photography obtained from either the convergent orientation of the camera couple or the transverse orientation. The instrument makes use of sets of twin projectors enclosed in a cage. Each set of projectors is analogous to the camera couple in the airplane and may be swung into proper position to accept either the convergent photography (fig. 7, see page 12) or the transverse photography (fig. 8, see page 13).

The two diapositives in a set of twin projectors correspond respectively to the two exposures made at one camera station. In the convergent low-oblique system one projector projects the exposure of the forward-looking camera and its twin projects the exposure of the backward-looking camera at a given exposure station. In operation, one projector of a set forms a model with the convergent projector of the adjacent set along the flight line.

The two cameras used for the twin photography are so mounted that their respective lenses are separated in space by a certain fixed distance. This separation is a matter of inches and is negligible if considered in relation to the flying heights in normal use. Therefore, at mapping scales, the positions of the two lenses can be considered as occupying the same point. The pair of exposures at a given exposure station do not make a stereoscopic model; each exposure must be paired with an exposure from an adjacent exposure station to obtain stereoscopic coverage. For single model compilation there is no mechanical problem connected with the spatial positioning of the projectors. An instrument designed for stereotriangulation, however, must provide a series of sets of projectors so mounted that their respective optical axes can assume an angle with each

other that corresponds to the angle in the camera installation. It must also be possible to swing each projector cage into proper position to accommodate either convergent or transverse low-oblique photography. It is obviously impossible for two projectors of a set to occupy the same position in space at the same time. Therefore, it becomes a basic requirement of an instrument designed for bridging that means be provided to bring each projector of a set, in turn, into the proper position for forming a model with the appropriate projector of the adjacent set. It is a further requirement that such movement of the projectors should be accomplished without disturbing the orientation, either relative or absolute, of the models. Therein lies a critical mechanical problem in the design and construction of the Twinplex plotting instrument. In either orientation, only one projector of each set is used at any one time. For convergent photography the convergent pair from camera stations I and II are oriented to form Model I-II. For the orientation of the adjacent Model II-III, the projector at station II, which was convergent with a projector at station I, is swung out of projecting position and its twin swung into its previously calibrated projecting position so that it will be convergent with a projector at station III. Model II-III can now be formed by the relative orientation of the projector set at station III, and can be brought to the same scale as Model I-II by adjustment of the air base of the second model. Any projector can be swung into or out of its projecting position at will.

In the camera couple for the twin low-oblique photography, the camera mounts would, under ideal conditions, be so calibrated that a vertical plane containing the optical axes also contains a pair of fiducial marks for each camera. It would therefore be necessary, in the interior orientation procedure for each projector set, not only to center each diapositive with respect to the optical axis of each projector, but to orient each diapositive so that a vertical plane through the optical axes of the two projectors will contain the corresponding pairs of fiducial marks.

Under conditions likely to be encountered in military use, it is doubtful that such precise calibration of the cameras in their mount can be attained. With this in mind the camera obliquity

was designed to provide an overlap between the twin exposures at each station amounting to six-tenths of the flight height (figs. 2 and 5). The correct azimuthal relation of the two diapositive plates of a set can be determined by observing common image points, within this overlap area, as projected alternately by the two projectors of a set. Simple observation of these common points projected alternately on the tracing table will show any lack of agreement between them. Appropriate adjustments to the plates will bring the common image points into coincidence and thus recover the correct azimuthal relation. A strong check of the interior orientation is obtained by observing the coincidence of the common image points at upper and lower positions of the tracing-table platen.

Stereotriangulation

The two cameras used in twin low-oblique photography are coupled rigidly together, and are simultaneously subject to tilt, crab, and other deviations that may be expected in normal aerial photography. As the Twinplex is designed to permit stereotriangulation through bridging techniques, it is so constructed that the various relative orientation adjustments are made to each twin-projector set as a unit. If a pair of single projectors is used for compilation, this requirement is unnecessary.

Horizontal and vertical stereotriangulation can be accomplished with either orientation of the projector sets; however, accuracy is greater with the use of convergent low-oblique photography. Considering equal contour intervals, it is theoretically possible to span one $7\frac{1}{2}$-minute quadrangle with one bridge of three models as compared with four bridges of five or six models each, required with the multiplex. The use of transverse low-oblique photography, while not as accurate, permits considerable reduction in the number of basic horizontal-control points inasmuch as the number of flights and models for a given area is decreased.

Ellipsoidal reflector projectors

In the prototype Twinplex instrument, using multiplex-type projectors, the illumination of the models is rather weak. An improved Twinplex
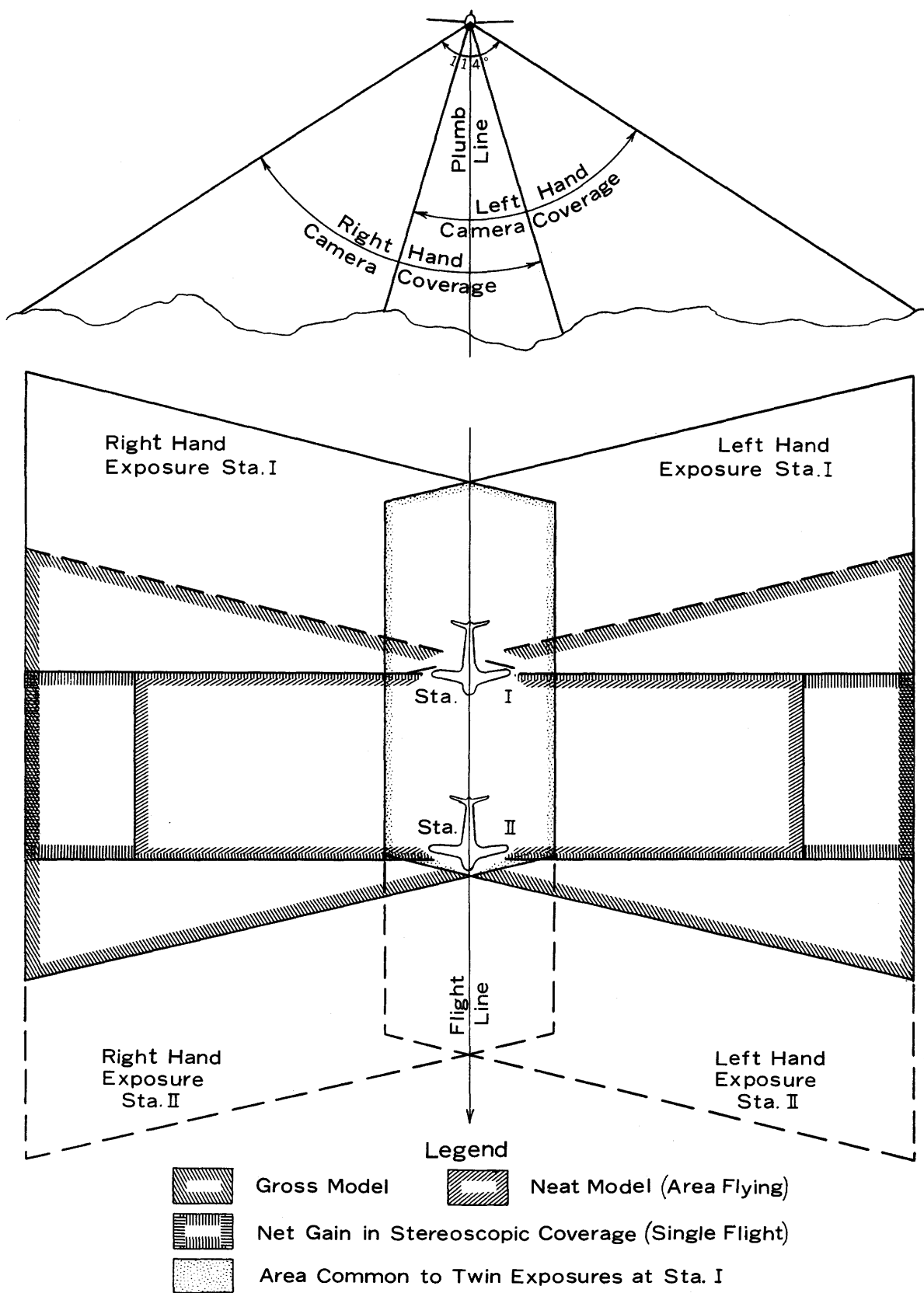
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Figure 5.--Transverse low-oblique coverage.

instrument, completed in 1952, (fig. 9, see page 14), utilizes a new type of projector designed to give greatly improved model illumination. This projector, designated as ER-55, makes use of an ellipsoidal reflector to direct the rays from the light source, at one focus of the ellipsoid, to the projecting lens at the other focus (fig. 10, see page 15). It can be used with either vertical or low-oblique photography. The proper color filter and the diapositive are appropriately placed in the lighting system for projection of the image. The principal distance in the new projector is 55 millimeters, the projection distance is 500 millimeters and the diapositive format is approximately 110 by 110 millimeters as compared with 64 by 64 millimeters for the multiplex. Consequently, less reduction is required from the aerial negative to the diapositive; also, the magnification is less from the diapositive to the projected model. The first ellipsoidal reflector projector was delivered in August 1952 and initial tests disclosed that it gives very brilliant and evenly distributed illumination (fig. 11, see page 16).

For H = 12,000, area of neat model = 7.6 sq.mi., $\frac{B}{H}$ = .63, $\frac{W}{H}$ = 2.31

area of gross model = 23.4 sq.mi., $\frac{B}{H}$ = .63, $\frac{W}{H}$ = 3.07

Total forward overlap = 0.77 H

Neat model area A = 5.22 x 10^{-8} H^2 Gross model area A = 16.3 x 10^{-8} H^2
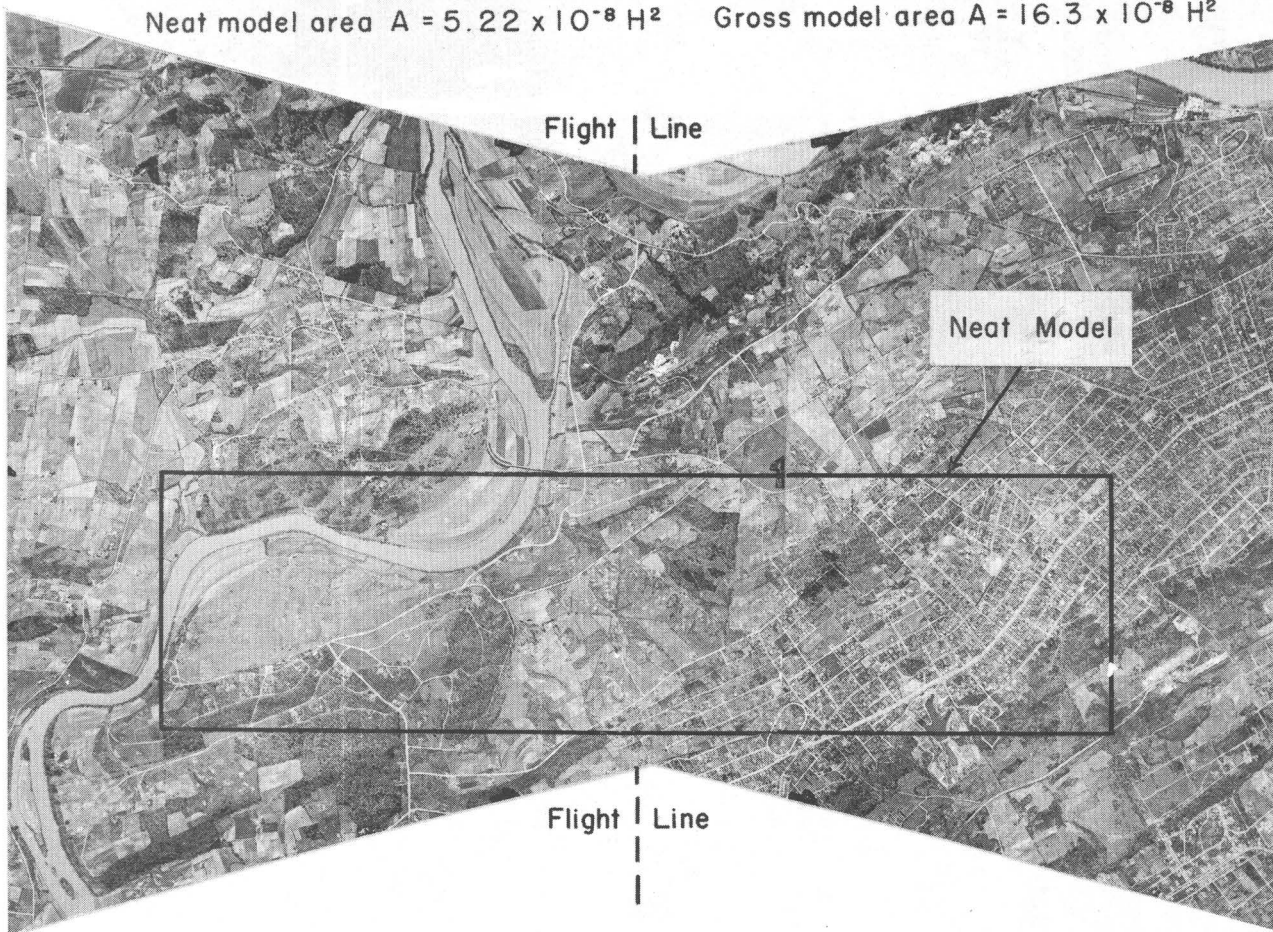

Figure 6. --Transverse coverage at a single station. (This is not a stereoscopic pair; the adjacent exposures that overlap this coverage are not shown.)
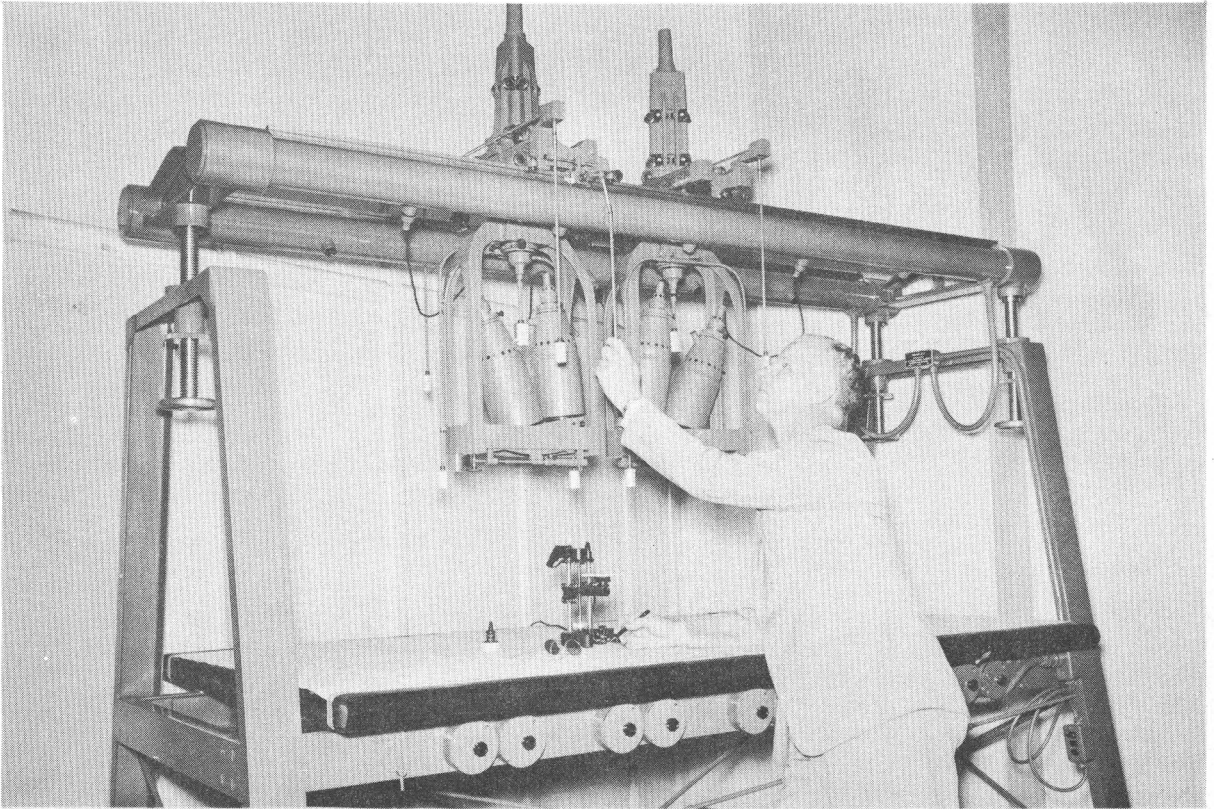
Figure 7. --Prototype Twinplex - convergent orientation.

COMPILATION WITH PAIRS OF SINGLE PROJECTORS

If extensive operations are planned using twin low-oblique photography, it is contemplated that the Twinplex stereoplotting instrument will be used primarily for stereotriangulation. Compilation can be accomplished by means of pairs of single projectors, either multiplex, Kelsh, or ER-55 (fig. 12, see page 17). The multiplex and Kelsh require a minor adaptation. Multiplex projectors are adapted for a 20° obliquity, in either orientation, by means of simple wedge-shaped pieces fitted between the bracket and the gimbal mount. The Kelsh projectors are adapted for convergent photography by providing a 20°-step tilt in addition to the present slow Y-tilt motion.

EXPERIMENTAL COMPILATION PROJECT

Geometry of the test models

The prototype Twinplex stereoplotting instrument, (see fig. 7), using two pairs of multiplex-type projectors, was completed early in 1950. In order to evaluate the performance characteristics of this instrument, a test project was set up consisting of the compilation of a $7\frac{1}{2}$-minute quadrangle, Miamisburg SE, Ohio, at a scale of 1:10,000 with 20-foot contours on the slopes and 10-foot contours in the flats.

The available convergent photography for this area did not meet the theoretically most efficient values for base-height and width-height
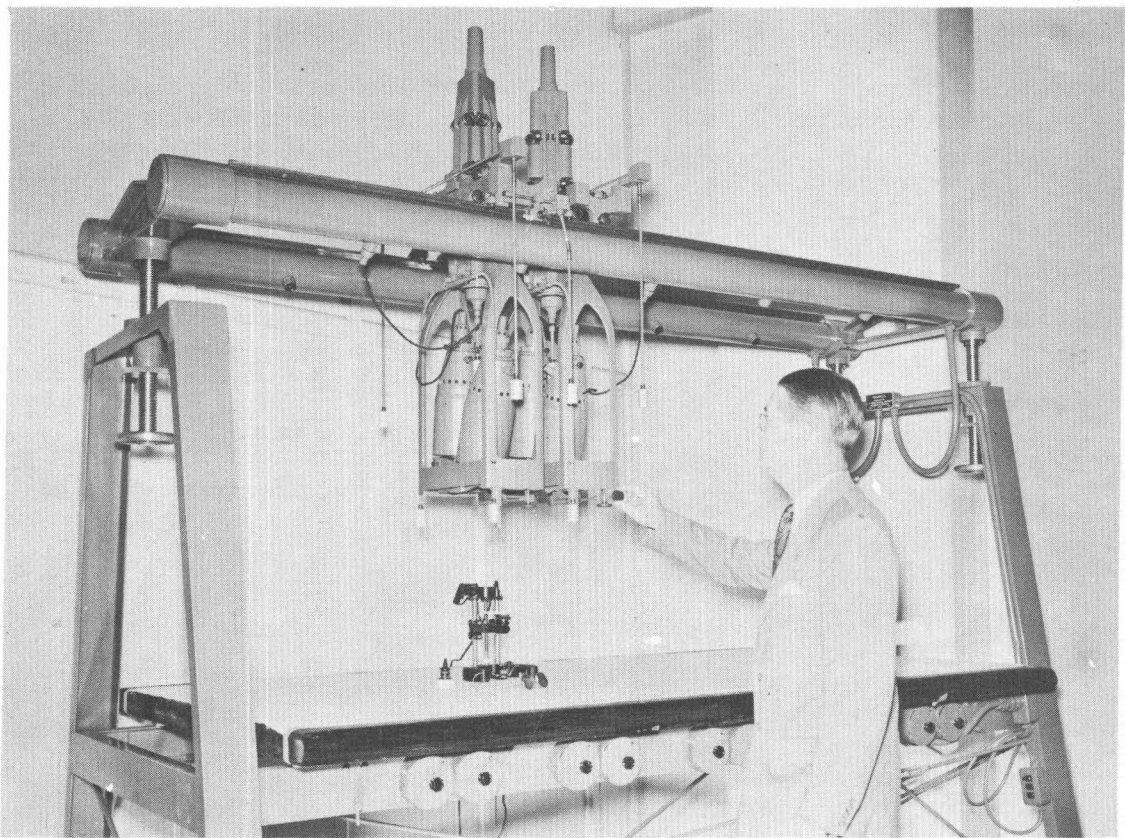
Figure 8. --Prototype Twinplex - transverse orientation.

ratios. The values actually obtained were 1.16 for base-height ratio and 0.92 for width-height ratio, resulting in an excess of side lap. Four flights of three models each covered the entire quadrangle. The flight height was approximately 12,000 feet above mean-ground elevation.

In the prototype model of the Twinplex instrument, the principal distance of the convergent projectors of the two pairs was changed from 30 millimeters to 29.64 millimeters. This change increased the optimum projection distance from 360 millimeters to approximately 400 millimeters, thus providing for the increased length of the rays due to the 20° inclination. There was no noticeable improvement in the models as a result of this change, although theoretically such a change was desirable.

As a projected image ray from the horizon side of any diapositive of a convergent model is extremely long (approximately 500 millimeters at a scale of 1:10,000), there is a definite advantage in compiling at smaller scales when using multiplex-type projectors. The quality of a test model was noticeably better at a scale of 1:12,000 than at 1:10,000. The smaller scale probably could not be accommodated in the prototype Twinplex because of interference of the projector cages. However, in using a pair of multiplex-type projectors for single-model compilation, with appropriate wedges to allow the 20° convergent tilt, there would be no interference and the smaller scale could be accommodated.
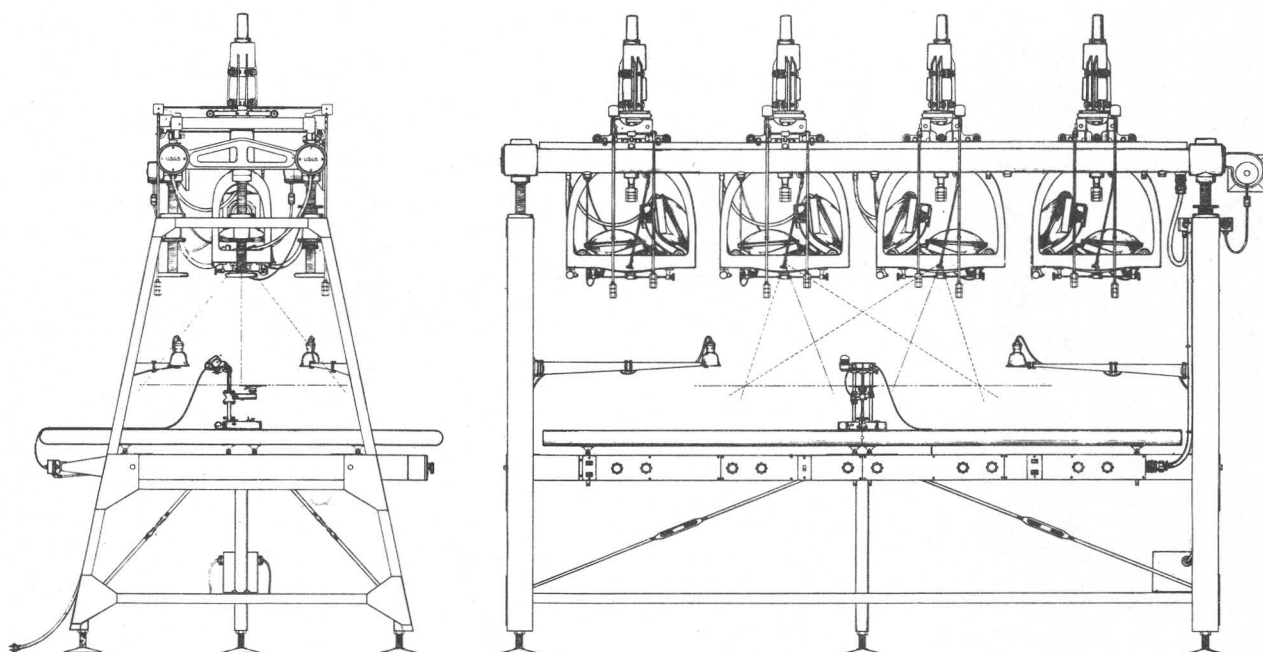
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Figure 9. --Improved Twinplex with ellipsoidal-reflector projectors.

Scaling procedure

As the prototype model of the Twinplex consisted of only two sets of projectors, it was necessary to adopt a system of scaling suitable to a single-model instrument. It was decided to use the stereo-templet system developed by M. B. Scher of the Geological Survey for control bridging with the Kelsh plotter. This is a variation of the conventional slotted-templet system, in which pass points are picked and templets prepared from horizontalized models. Since the models are leveled before the picking of pass points, there are no tilt or relief displacements in the templets and the only function of the templets is to bring all models to a common scale.

The stereo-templets were prepared by pricking onto the templet material the location of the pass points selected from the horizontalized model. This was accomplished by using a needle point in place of the pencil on the tracing table. Duplicates were prepared from each templet by pricking the location of each pass point through the original onto the duplicate.

Inasmuch as the pass points are located on the templet from horizontalized models, it is not necessary that the slots radiate from the isocenter. Therefore, any pass pass point on the templet may be used as a pivot point. In order to obtain a strong azimuth line for each templet, a pass point in one corner of the original templet was selected as a pivot point, and a second pivot point was selected in the diagonally opposite corner of the duplicate templet. Slots were cut radially from each pivot point and the templet laydown assembled in the usual way.

Model quality

In the prototype model of the Twinplex, using multiplex-type projectors, the plane of best focus of any projector, being normal to the principal axis of the projector, is inclined approximately 20° to the horizontal plane of the slate table and the Scheimpflug condition[3] is not satisfied. As the model is viewed on planes parallel

[3]Scheimpflug condition: Images are in sharp focus if the planes of the object, the image, and the lens intersect on a common line.

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TOP VIEW
WITH REFLECTOR REMOVED

CROSS SECTION

DIAPOSITIVE PLATE

BOTTOM VIEW

PICTORIAL VIEW

SWING BRACKET, LOCK SCREW, AND
CALIBRATION PIN MOUNTED FOR TWINPLEX ASS'Y.
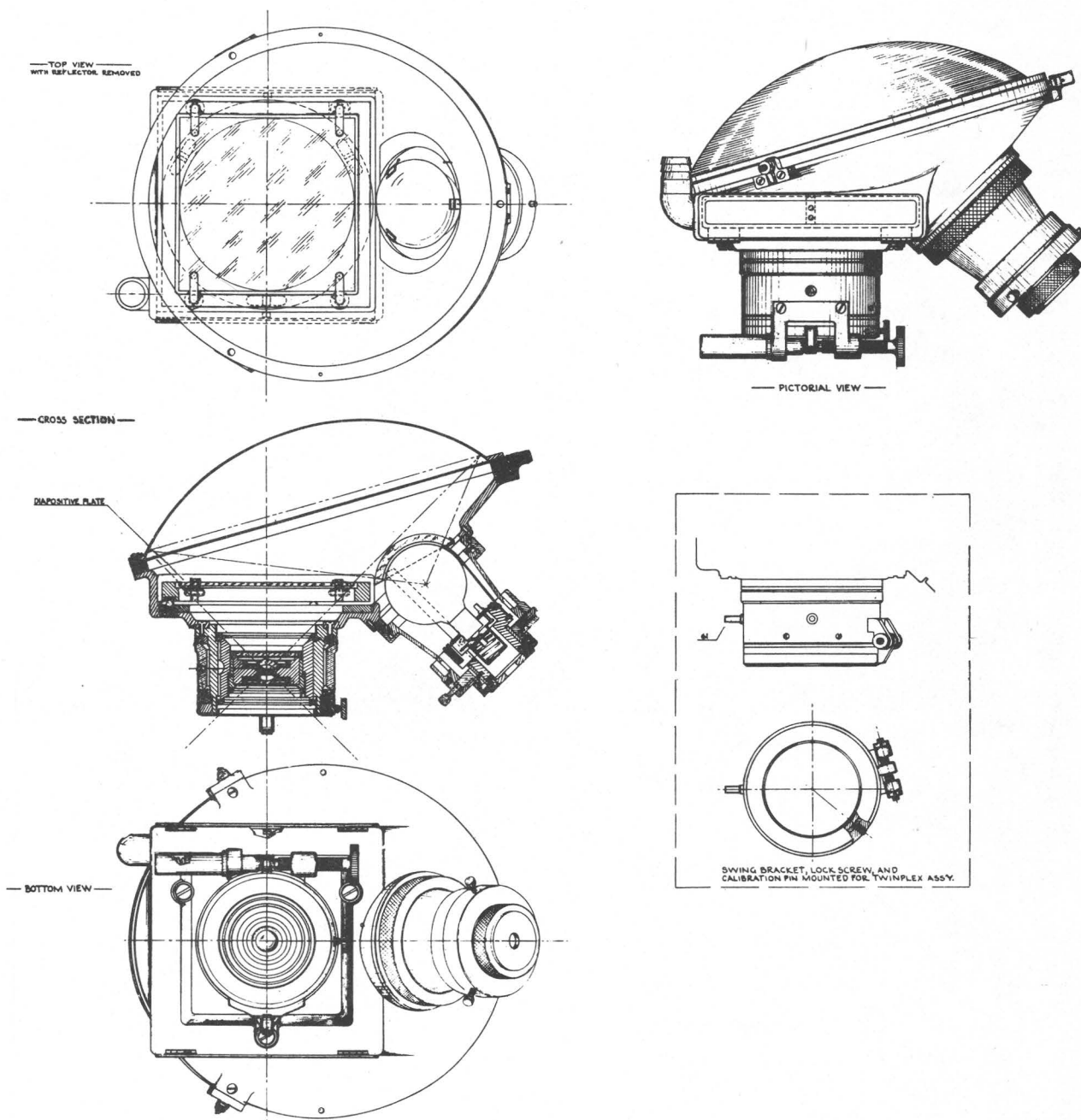
Figure 10.--General assembly--ellipsoidal-reflector projector.

to the slate table, it is obvious that very little of the model area is observed at the optimum focus. In the design of the new projectors for the Twinplex instruments, the Scheimpflug condition is satisfied by canting the projector lens slightly, about $1\frac{1}{2}°$, with respect to the principal axis of the projector.

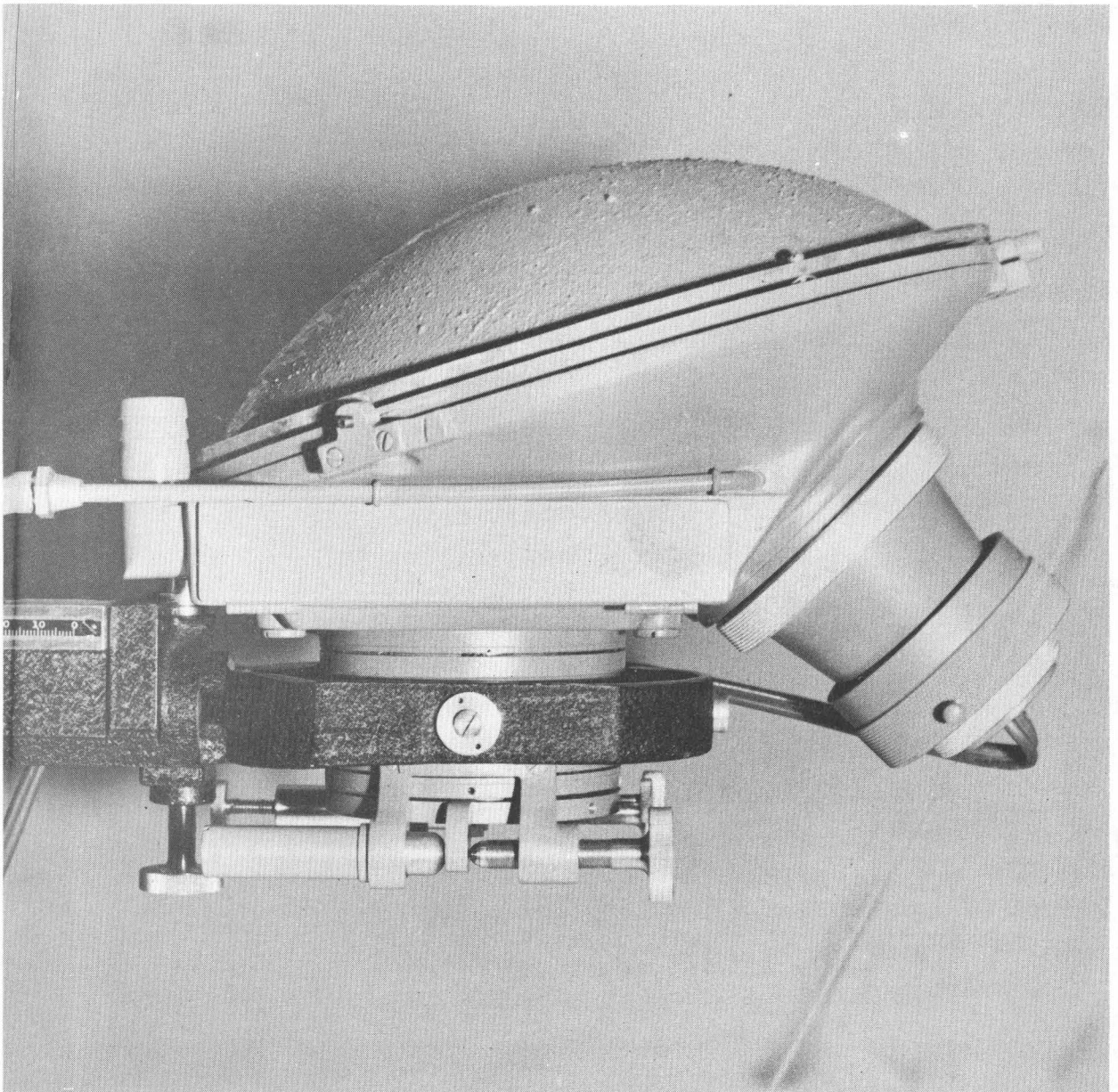The illumination of the model in the prototype Twinplex, as projected by the multiplex-type

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Figure 11.--Ellipsoidal-reflector projector arranged for vertical photography.

projectors, was very uneven. This was offset by printing diapositives each of which varied in density from fairly dark on the side containing the nadir point to light on the opposite side. It is expected that this procedure will not be necessary with the new projectors using the ellipsoidal reflectors.

Compilation and tests

During the compilation, each oriented model was leveled on the four elevations in the corners of the model, and the points controlling the center of the model were then read. Two models read 0.2 millimeter high on these points; the
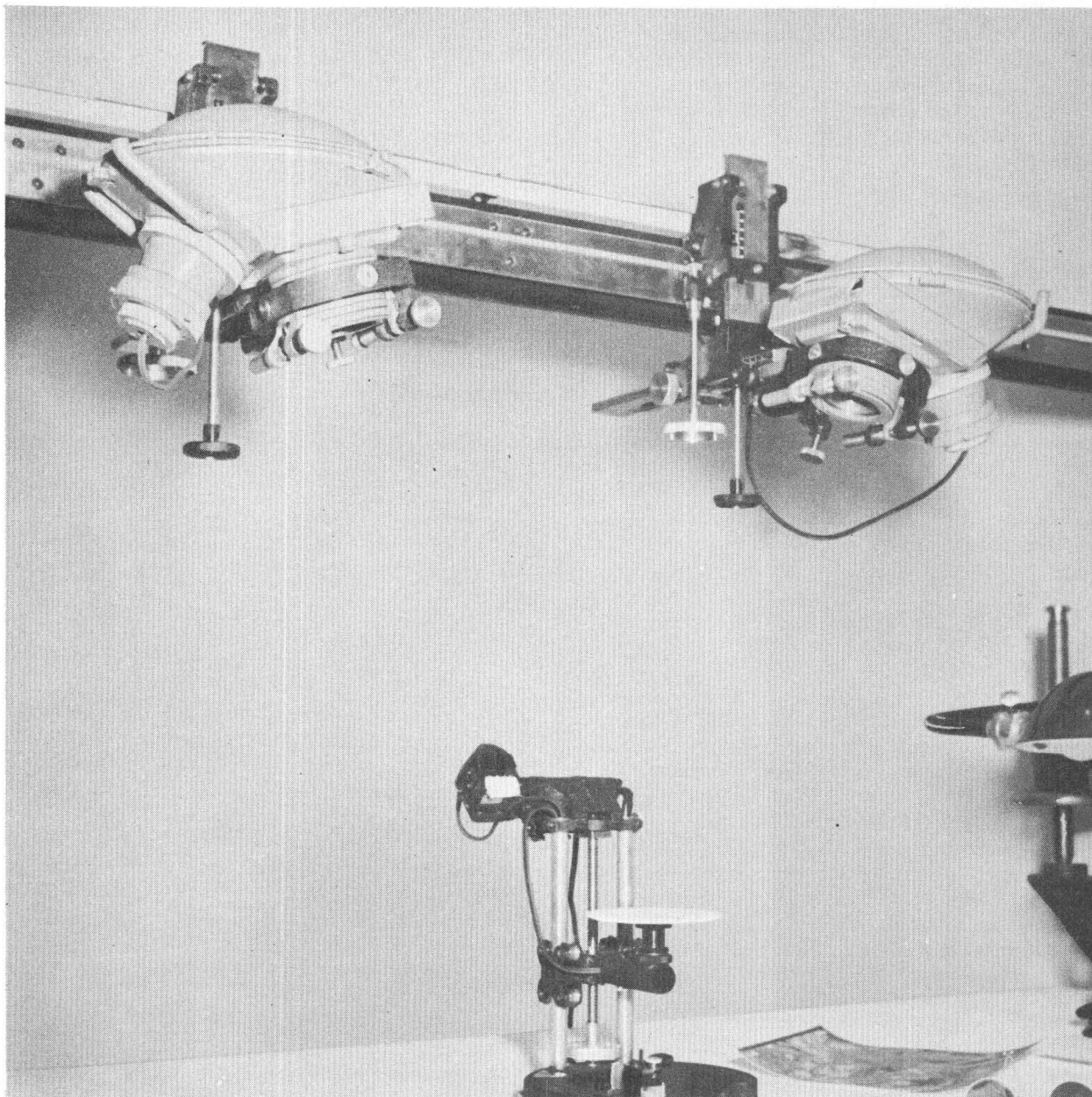
16

Figure 12.--Ellipsoidal-reflector projectors mounted on standard multiplex bar
for single-model compilation of convergent photography.

remaining ten models read flat. This indicates a very strong Y-tilt parallax solution. The compilation procedure for the quadrangle followed the standard practice adopted for the multiplex. Contouring was relatively easy due to the strong intersection of the conjugate image rays.

The contact prints from the convergent oblique photography were not suitable for stereoscopic examination because of the difference in scale between the nadir side and the horizon side. Accordingly, a set of rectified prints was required. This rectification, which need not be precise, was

readily accomplished by tilting the easel of the rectifier 20° in the plane containing the flight line. The prints were larger than the conventional 9-inch contact prints, and somewhat inconvenient to use with a pocket stereoscope. A mirror-type stereoscope with a binocular eyepiece proved satisfactory for observing the rectified prints.

As part of the compilation procedure, spot elevations were read on easily recoverable planimetric features within the quadrangle, and recorded on the manuscript. These elevations were checked by stadia lines during the field-completion survey with the following results: Of 73 points read and checked, the mean error was 2 feet. Two points were 5 feet in error, one was 6 feet in error, and one was 7 feet in error. These points were read from the oriented model using a Williamson direct-reading tracing table with a least graduation of 5 feet, and were selected to provide an over-all test for each model. Wherever possible, points most favorable for reading were used. The average spot-height reading error for this test project, expressed as a fraction of the flight height, was $H/6,000$.

The specifications for compilation of the quadrangle called for 20-foot contours, with the addition of 10-foot intermediate contours in the flats. During the compilation, it was considered that the 10-foot contours might be below standard as the area in the valley bottoms was generally very flat and not suitable for contouring by the usual stereoscopic methods. The bulk of the corrections to contours made during the field-completion survey was in these flat areas; however, the differences in elevation as expressed by the contour changes were generally less than one-half the 10-foot contour interval.

Accuracy-test lines were laid out on the north and south halves of the quadrangle and were run by the field-completion engineers, using the method of plane-table traverse. Of 106 points tested, the mean error was 2 feet and the standard deviation was 3 feet; one point was found to be in error more than one-half the 20-foot contour interval (16 feet). The field elevation for each point was checked against the elevation of the same point as interpolated from the contours.

CONCLUSION

While no general conclusions can be drawn from only one test, the check of the initial Twinplex compilation appears to substantiate the theory of low-oblique convergent photography and the Twinplex instrument. Further and more extensive tests are contemplated using the new ER-55 projectors and modified Kelsh and multiplex projectors.

It is not claimed that convergent low-oblique photography and the Twinplex instrument will solve all photogrammetric problems. No one system or instrument can do that, because of the varying conditions and objectives confronting the mapmaker. 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 have been developed that take advantage of its possibilities.