*Orthophotography—Its Techniques and Applications**

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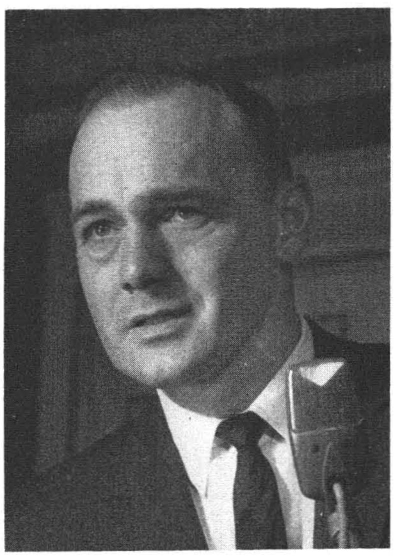
ABSTRACT: *A system for producing orthophotographs (photographs which are the equivalent of orthographic photographs) has been developed by the U. S. Geological Survey so as to be compatible with its integrated photogrammetric system. These orthophotographs, made on the Orthophotoscope, have been furnished to field geologists and field topographic mapping personnel for operational testing under varying conditions of terrain, vegetation, and field control. Valuable experience is being gained in the proper and economical use of orthophotographs under field conditions. Experimental projects are planned utilizing orthophotographs with superimposed contours and orthophotographs with spot evaluations in areas of interest. A different system of accomplishing the same objective has been developed commercially and reports indicate that it is also very successful. The Geological Survey recently completed the design of a new model Orthophotoscope which will allow more efficient and comfortable operation and will yield a much improved product.*

FOR the past five years, the U. S. Geological Survey has been engaged in a program designed to develop the best instrumentation and production techniques to attain the goal of a uniform-scale photograph.



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To those who are unfamiliar with the need for orthographic or uniform-scale photographs, a brief explanation is in order. Stereoscopic photogrammetry has achieved success largely because of a factor called parallax. Parallax is defined by the American Society of Photogrammetry as "the apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation." This "apparent displacement of the position of a body" is the keystone of the arch of stereoscopic photogrammetry, but under its alias of "relief displacement" it is one of the major villains, of the single perspective photograph. In other words, images of objects at varying distances from a datum are displaced differently, and the result is a perspective representation of the shape and position of features that distorts the scale of the single photograph and makes it unsuitable as a medium for direct measurement (Figure 1).

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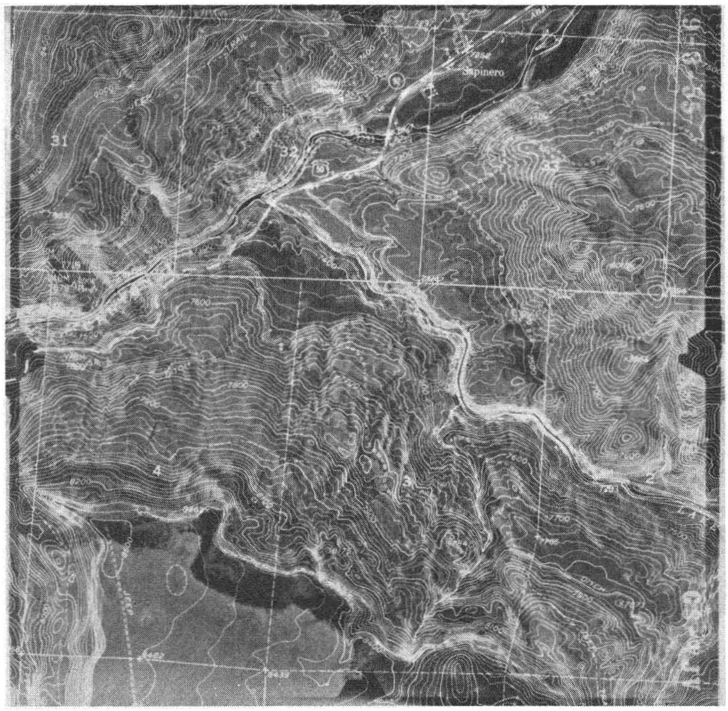

FIG. 1. Perspective aerial photograph with superimposed U.S.G.S. map. The scale of the map overprint is equal to that of the photograph at the datum of the river (upper left corner). Note the lack of scale uniformity of the photograph as exhibited by the discrepancies between the photographic features and their plotted positions on the map.

Although this same perspective photography is used to make topographic maps, complex instruments, such as stereoscopic plotting machines, are required. Out of this seeming paradox grew the Geological Survey system of orthophotography which combines the geometric integrity and photographic intelligence value of the oriented stereoscopic model in a single product (Figure 2).

At the heart of the Geological Survey system is the machine known as the Orthophotoscope. This instrument has been the subject of two papers in Photogrammetric Engineering.[1,2] These papers describe the fundamental principles underlying the orthophotograph and the instrumental means of implementing those principles. It is the intent of the author to pick up where these papers left off, commenting in turn on the extent to which the potential of the art has been developed, current procedures of production, and new instrumentation which will further refine operation and production.

GEOLOGIC APPLICATIONS

Mr. Russell K. Bean, the inventor of the Orthophotoscope, had set forth the possibilities of such a machine over a decade ago, but due to the press of other developmental effort, no steps were taken towards construction. However, shortly after the formation by the Geological Survey of the Interdivision Committee on Photogrammetric Techniques in Geology and Hydrology, that body expressed an acute need for uniform-scale photography for geologic use. Spurred on by the urgency of this need, the Research and Development Unit of the Geological Survey's Staff Photogrammetry Section built a workable experimental model (Figure 3). As this machine was being tested, an engineered

[1] Bean, Russell K., "Development of the Orthophotoscope," PHOTOGRAMMETRIC ENGINEERING, Vol. XXI, No. 4, September 1955.

[2] Bean, Russell K. and Thompson, Morris, M., "Use of the Orthophotoscope," PHOTOGRAMMETRIC ENGINEERING, Vol. XXIII, No. 1, March 1957.

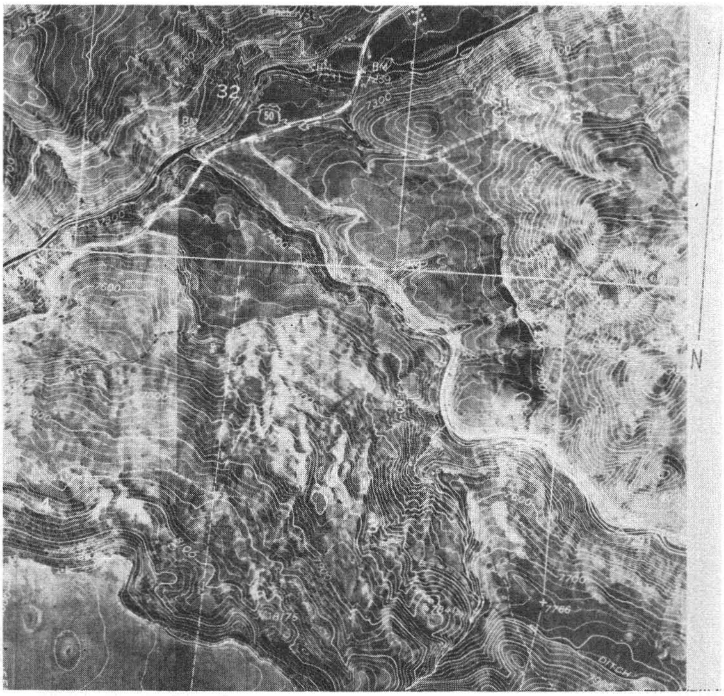

FIG. 2. Orthophotograph with same superimposed map as that used in Fig. 1. The scale of the map is equal to the scale of the orthophotograph at the datum of the river (upper left corner). Note that the photographic features agree closely with their plotted positions on the map, throughout the area.

prototype (Figure 4) was designed and constructed making use of the knowledge gained on the so-called "bread board" model. In the summer of 1956, the engineered model was placed in production at the Special Maps Branch of the Geological Survey, and has been in operation since that time. Field geologists were informed

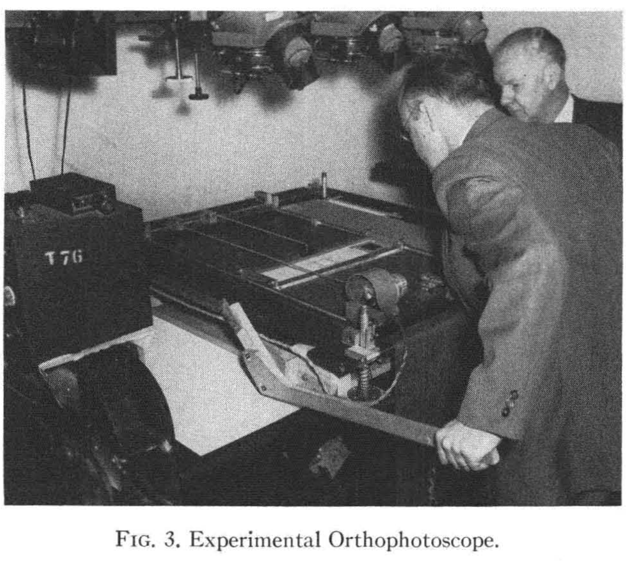

FIG. 3. Experimental Orthophotoscope.

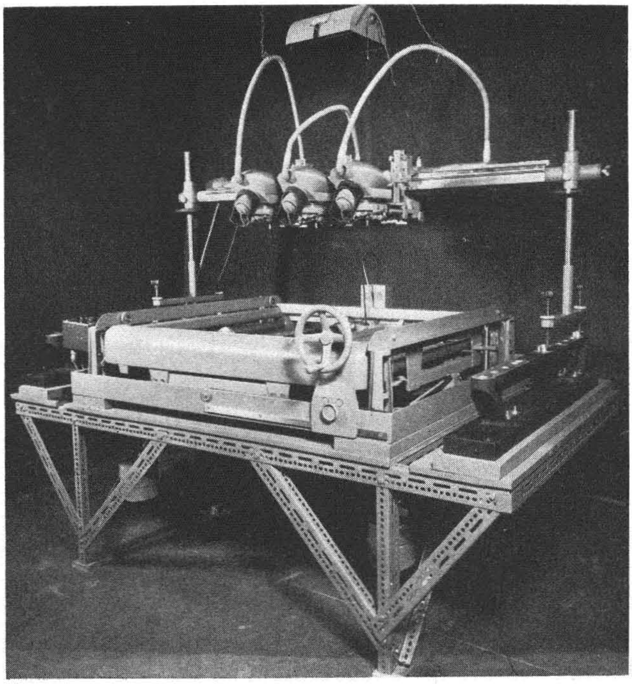

FIG. 4. 1956 Model Orthophotoscope with ER-55 projectors.

of the potential of the new process and were urged to consider the use of orthophotographs for their projects.

Early in 1956, the Interdivision Committee prepared a list of possible applications of orthophotographs in geology. Some of the suggested uses were as follows:

1. A planimetric base for delineating geologic detail.
   a. A base for compiling surficial geologic features, particularly geologic contacts.
   b. A base on which structure contours can be built, correlating dip and strike data, topographic contours and elevations.
   c. A base for isopachous (equal thickness) lines in areas where outcroppings are visible and bed thickness can be measured.
2. A substitute for a conventional planimetric map.
3. A base for use in field studies in an area where no map is available.
4. A geologic map to accompany a geologic report in areas where topographic maps are not available.

Most of these uses and many others can be generalized under a consideration of the recurring problem encountered by field geologists: this is, the problem of correlating detail visible both on the ground and on the perspective photography, to a map base. (This problem is not, of course, unique to geologists.) At this early stage of experience, there are several opinions as to the most efficient way of using orthophotographs. A discussion of these methods follows:

METHODS OF USE

DIRECT USE OF ORTHOPHOTOGRAPHS

In the summer of 1957, experimental orthophotographs were used effectively in geologic studies in Lee and Scott counties, Virginia. This experience indicated that excellent results could be obtained by plotting geologic detail directly on the unmosaicked orthophotographs. The geologist was able to locate himself better on the orthophotograph because more detail was visible than on the topographic map, and because resections were more effective due to better position accuracy.

In addition to the orthophotographs, a 1:24,000-scale topographic map on a stable base, and contact perspective prints of 4-inch Zeiss P-10 photography were furnished. Contours on the topographic map were used to plot geologic features at their correct elevations, and to obtain data for slope computation. The perspective photography was used stereoscopically to enhance interpretations of features. Unmosaicked orthophotographs were used because it was believed that the straight lines made by mosaic edges detracted from and confused geologic detail on the medium. It may be desirable to furnish field geologists with (a) photographic detail in orthographic position, (b) contours on a transparent overlay and (c) contact prints for stereoscopic viewing.

INDIRECT USE OF ORTHOPHOTOGRAPHS

Many field geologists prefer to plot geologic detail first on the perspective photographs and later to transfer this detail to the orthophotograph. Inasmuch as imagery on perspective photographs is generally sharper than that on orthophotographs, they believe interpretation of detail is improved. Further, they believe that the orthophotograph furnishes the necessary bridge between the perspective photographs and the topographic map.

USING PERSPECTIVE PHOTOGRAPHY AND ORTHOPHOTOGRAPHY IN COMBINATION

Some of the experimental photographs requested by field geologists have been prepared at scales approximating those of the perspective photography covering the area being studied. The intention was to use one perspective print and the corresponding orthophotograph as parts of a stereoscopic pair, the perspective furnishing relief displacements and the orthophotographs furnishing accurate relative position. Theoretically, as the geologist views this pair he can plot geologic detail on the orthophotograph, which can later be transferred to a conventional map base or to an orthophotograph mosaic. This process of quasi-stereoscopic viewing should be performed with caution, as the apparent relief is inconsistent and can be misleading.

Needless to say, there are other methods of applying orthophotographs to geologic studies which represent compromises between the three principal techniques mentioned above. The factors involved in choosing the best method for a specific project, will be discussed.

Factors Affecting Techniques

QUALITY OF SOURCE PHOTOGRAPHY

If the conventional photography is of good quality, the orthophotographs made from it will very likely be good also; if the source photography is poor, the quality of the orthophotographs will be correspondingly poor. Consideration should always be given to obtaining new photography—this can be economically feasible of the project is sufficiently large.

On questions of quality, it is well to remember this general rule: The orthophotograph is inherently superior in scale uniformity to the perspective photography from which it came, but its resolution is generally not as good.

COMPATIBILITY OF SOURCE PHOTOGRAPHY

Several orthophotograph projects have been executed in which source photography of a certain focal-length has been processed through a printer and projector designed for another focal-length. This can serve as an expedient in cases where no better photography is available, and when the urgency of the project is such as to preclude obtaining new photography compatible with the system. When this is done, however, the resulting product suffers in quality because of resolution loss and incorrect distortion compensation in the printer.

In the experimental project in Virginia described above, the source photography was 4-inch, Zeiss P-10 photography on a 7-inch square format. The printer and projection equipment were designed for 6-inch photography, on a 9-inch square format. Yet the work was urgently needed, and the resulting orthophotographs were exceedingly helpful in spite of the reduced quality.

The following general rule will aid the potential user in choosing source photography for orthophotographic purposes:

> Best results will be obtained if the source photography is compatible with the printer-projector combination which will be used; however, usable orthophotographs can be made from noncompatible photography.

NATURE AND COMPLEXITY OF FIELD STUDY TO BE PERFORMED

In planning a request for orthophotographs, consideration must be given to the type of project on which these orthophotographs will be used. If the area is large, encompassing several orthophotographs, the scale of orthophotographs can be small; best results are obtained when the scale is the same as the scale of the base on which the geologic detail is to be compiled. If the area contains several smaller areas of complex detail, the geologist may want coverage of these areas at a larger scale, to enable him to study and compile critical features in more detail. The potential user must realize, however, that no image will appear on the orthophotograph that was not present on the aerial negative. Within practical limits, the scale or scales desired can be obtained by a simple photographic reduction or enlargement.

Another significant point in this connection is the question of vegetation cover. With photography flown at a practical flight height at the right time of year and the right time of day, the problem is reduced to its proper size, and is certainly not confined to orthophotography.

COST

Experience at present indicates that the direct cost of producing one "neat" orthophotograph (two stereo models) is about $60. For large scales, this cost in dollars-per-acre may seem relatively high, whereas for small scales it may appear rather low.

To the potential user who has scant funds available, the cost of orthophotographic coverage for his area of study may seem so high as to be prohibitive; yet that same user may be faced with the alternative possibility of spending many more expensive days in the field to complete his study, for lack of a good base on which to plot his findings.

Topographic Applications

Although the initial interest in orthophotography within the Geological Survey was largely generated by and for geologists, it soon became evident that the potential uses of this new medium extended far beyond those proposed by the geologists. The growth of interest in using orthophotography in topographic mapping has been somewhat slower, but it has become increasingly clear that the advantages to be gained from uniform-scale photography are not to be ignored by engineers engaged in topographic mapping. As soon as the advantages of this new technique were known, the interest was quick and genuine, not only among mapmakers in government agencies but among engineering firms in private industry.

What are these topographic uses? Some of them have been implied in the foregoing discussion on geologic applications. Generally speaking, the orthophotograph is finding a place in two categories: the planimetric map and the topographic base.

PLANIMETRIC BASE

Orthophotographs can be mosaicked to form a planimetric base for several phases in the mapping cycle. The orthophotograph base can be prepared with minimum control, quickly and cheaply, without the economic necessity of leaving out planimetric detail that may be useful to the field man. Some of the phases in which such a base may be useful are as follows:

1. *Planning, reconnaissance, and execution of basic control in the field.*
2. *Supplemental control.*

   a. The planetable-traverse method of establishing vertical control can be improved if the engineer is able to plot his traverse on an orthophotograph base. In this way, every traverse point becomes a potential control point, thereby affording the utmost benefit from the field data.

   b. Photo-trig traverse can be expedited by using an orthophotograph base for measuring distances between points whose elevation difference is sought. This permits an immediate field check on observed elevations so that it is not necessary to await the photogrammetric derivation of distances in the office.

3. Advance field completion can be done efficiently on an orthophotograph base. If the scale is accurate (and it can be made so by correlation with mapping control) map detail can be delineated on the orthophotograph base, eliminating the necessity for any further field check. Under favorable conditions, it may not even be necessary to compile the planimetry. If the orthophotograph is on a scribe-base, the field man can scribe all detail that the photogrammetrist might be unable to see or classify, plus changes occurring since the date of the photography. From this information, with the field record of appropriate factual infor-

mation, the cartographic scriber can complete the planimetric scribing phase directly on the base. The completed planimetric base can then be furnished to the photogrammetric compiler for the addition of contours and drainage. This procedure can only be used if there is sufficient ground control initially to orient the orthophotoscope model properly. Conventional mosaics have already been used successfully in this way for mapping flat areas. Orthophotography now makes it possible in areas of considerable relief.

TOPOGRAPHIC MAP BASE

The Orthophotograph can become the base for a special-purpose map with superimposed contours and appropriate symbolization. In engineering work, the orthophotograph with frequent spot elevations in areas of interest can furnish a useful product.

Experimentation with orthophotographs for topographic use is now being conducted on two Geological Survey mapping projects. This experimentation is designed to determine the practicability of some of the above uses. These projects are:

1. Lame Deer, Montana—Orthophotographic bases were prepared from vertical photography at an approximate scale of 1:24,000 for two 7½-minute quadrangles, the Lame Deer 4, NW and SW. The bases were half-quadrangle size, water-cote halftones on Mylar scribing bases. The scale was approximate because there was *no ground-control* available. The area covered was of moderate relief. After the exact scale of the bases had been determined by field measurements, the orthophotographs were used for the primary control phase. Here the orthophotographs served as a map substitute as there was no suitable existing coverage. Next, it was proposed to use the bases for executing and recording the positions of supplemental vertical control and for accomplishing advance field completion directly on the base.

2. Arnegard 3, NW, North Dakota—Using recent convergent photography, an orthophotographic base was prepared for this 7½-minute quadrangle at a scale of 1:24,000. The terrain is of moderate relief and quite "cut up." Sufficient horizontal control, but *no* vertical-control was available. There was no map for this area. The excellent convergent photography furnished clear orthophotography and the scale of the base was carefully controlled. This project will be carried on much as the one described above, but has a better chance of succeeding because of higher quality photography and more accurate control, just as a topographic mapping project has a better chance when it is based on good photography and control, plus careful execution of all phases.

A commercial product, the *Photo Contour Map*, developed by the R. M. Towill Corporation of Honolulu, T. H. and produced in the United States by the Aero Service Corporation has aroused much interest in this application of orthographic photography.

In order for the orthophotograph to become accepted even more widely than it is, it will be necessary to overcome a condition, which is common to many engineers, known as "Mosaicphobia" or mistrust of mosaics. Many an engineer when hearing the word "mosaic," snorts disgustedly, imagining the stretching and squeezing of photographs in mosaicking operations he has seen, and the still-remaining failure of images to join across edges. Once he learns that an orthophotograph need not be stretched or squeezed to force a join, he will come to trust this product; in fact errors in orthophotography caused by operator lapse remain visible to the eye, but always unhidden and unconventionalized. The orthophotograph can be foggy if allowed to be; it can be unsharp; but it cannot be faked—it remains an honest orthographic record of the photography.

Techniques of Production

The step-by-step process of making an orthophotograph has been fully described in previous papers.[3] Essentially, there have been no changes in the fundamental process of orthophotograph production by the Geological Survey but some modifications have been made which are worthy of mention.

REDUCTION OF SCAN LINES

A source of continuing concern have been the "tracks" made by the scanning slit across the negative; these are known as scan lines. Scan lines are of a varying nature—voids (non-exposure) and overlaps (double-exposure). They are rarely in excess of 0.005 inch wide and they average

[3] See R. K. Bean-M. M. Thompson, footnotes 1, 2.

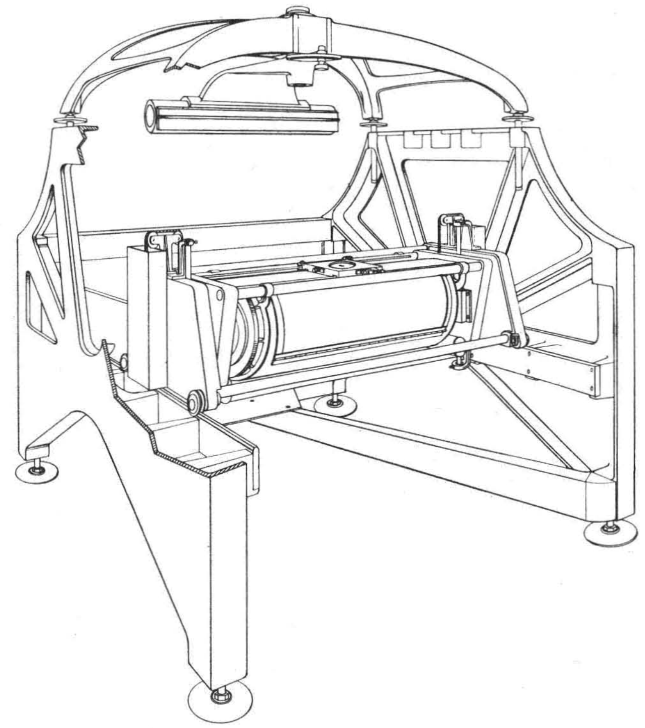

FIG. 5. Proposed New Orthophotoscope.

about 0.003 inch. They do not affect image position; the undesirable effect they have is one of nuisance factor. The lines are largely caused by the failure of this machine to cover exactly contiguous areas as adjoining strips are scanned. That they are mechanically caused is indicated by the fact that one orthophotograph after another made on the same machine have the same pattern of voids, overlaps and joins.

Milling of fine saw-teeth in the edges of the scanning aperture has improved the condition considerably, but at present the scan-lines can still be detected.

VARIATION IN TONE

Another valid criticism of orthophotographs has been that there is a variation in density from one scan to another and from one piece of mosaicked orthophotograph to the next. The scan-to-scan variations are caused by differential speeds of the scanning mechanism. This problem is mechanical and can be solved.

The differing density from one mosaic-piece to another is photographic in nature—these pieces are made from different projectors and different diapositives. To alleviate this condition, careful balancing of diapositive density is required. In addition, prior to scanning, the operator should carefully check the light balance with a sensitive light meter so that proper differential light settings for consecutive projectors can be made.

Experience has shown that extreme care is needed in all phases of orthophotograph production—failure in any phase results in reduced quality. The task of the orthophotoscope operator is, therefore, particularly demanding in nature. Photographic laboratory techniques are also extremely critical and must be carefully supervised.

THE NEW ORTHOPHOTOSCOPE

A major step is presently being taken toward improving instrumentation in orthographic photography. A new Orthophotoscope is being designed, which, it is believed, will be far superior to the 1956 model (Figure 5). This new machine embraces sweeping changes in design which should result in increased operator efficiency and comfort, and in an improved photographic product.

The heart of the new design is a large cylinder aligned parallel to the projector bar. Blue-sensitive film is wrapped tightly around this cylinder and the direction of scanning will now be in the x-direction. The cylinder is designed to be rotated and translated automatically so as to accomplish continuous scanning paths across the film.

The new machine will be of sufficient size to accommodate the stereoscopic model of any double-projection plotter now in use. The operator will conduct scanning from a comfortable seated position; and by moving his chair forward at intervals as required, he can retain the same position relative to the scanning platen at all times.

The superior mechanical design of this new instrument should lead to a better product. Increase of operator comfort may not directly improve the product but it should result in increased production.

Conclusion

On the basis of accomplishments it can be concluded that already available are the means for producing acceptable orthophotographs and that they have already been used successfully on some projects. In these times of great scientific advancement, it is difficult to predict the changes in the next few years. The future promises continued improvements in orthophotograph instrumentation and techniques and to an ever-widening range of applications. One thing seems sure—if orthophotography is now a baby just learning to walk, his rate of progress is such that in another five years he should be moving on the dead run.

*The Photo-Contour Map: A Topographic Map at Accepted Accuracy Standards Where Planimetric Detail Is Provided by the Aerial Photographic Image**

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ABSTRACT: *A Photo-Contour Map is a topographic map whereon the elevations are shown by contours in the conventional manner, and planimetric detail is photographic as projected from the aerial perspective. This type of map has unique advantages, the most important being its versatility. Scale problems are, however, difficult. Mosaics have in general been unsatisfactory when terrain relief is significant. A method of overcoming these problems is presented. A theoretical discussion is included. The method of zone reformation whereby the projection of the aerial perspective meets topographic map accuracy standards for scale and for orthographic characteristics is described. Zone masking and exposing techniques made possible by advances in masking and low-shrink materials are discussed.*

* Presented at the Society's 24th Annual Meeting, Hotel Shoreham, Washington, D. C., March 27, 1958.