*Use of the Orthophotoscope**

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ABSTRACT: *The Orthophotoscope is an instrument for converting perspective photographs to the equivalent of orthographic photographs. Operational research experience with a crude experimental model showed that the system is practical and gives orthophotographs for which the scale is uniform within an acceptable tolerance. An "engineered prototype" Orthophotoscope has been constructed and is operating on a production basis. The new instrument and its operation are described and illustrated in detail. Some applications, all having the common requirement of photography on which correct distances can be measured directly, are discussed.*

SINCE the early days of photogrammetry, men have been trying to produce aerial photographs that have a uniform scale. "If we could measure distances directly on a photograph," they have reasoned, "with no significant error due to tilt, relief or lens aberrations, what a tremendous stride it would be towards simplifying the use of photography in fields like surveying, engineering, geology, and forestry!"

But a complete solution of this problem of uniform-scale photography has long remained tantalizingly out of reach. True, the application of excellent rectifier procedures has offered a solution in areas where the terrain photographed has little or no relief; as the relief is increased, however, the value of such rectification approaches the vanishing point.

It remained for a Frenchman, Robert Ferber, to establish an approach which can be translated into a practical solution of the problem. Ferber's apparatus, patented in the United States in 1936, although sound in principle, was possibly not engineered in sufficient detail to offer an economical means of accomplishing its purpose.

The Orthophotoscope, developed by the Geological Survey, is based on the same general principle as Ferber's apparatus, but is quite different in construction; besides, it works—efficiently and economically. The patent application for the Orthophotoscope, filed by Russell K. Bean for assignment to the United States Government, bases the patent claims on the unique structural arrangement of the new instrument.

WHAT IS AN ORTHOPHOTOSCOPE?

The basic properties of the Orthophotoscope are set forth in a previously published paper.[1] These properties can be restated briefly as follows:

1. PURPOSE

The purpose of the Orthophotoscope is to convert perspective photographs to the *equivalent* of orthographic photographs. A comparison of perspective and orthographic photographs of the same terrain is represented in Figure 1; as shown in this illustration, relief causes the image displacements *aa'* and *bb'* on the perspective photograph, but there is no displacement in the orthographic photograph. If the perspective photograph were tilted, additional image displacements would result.

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

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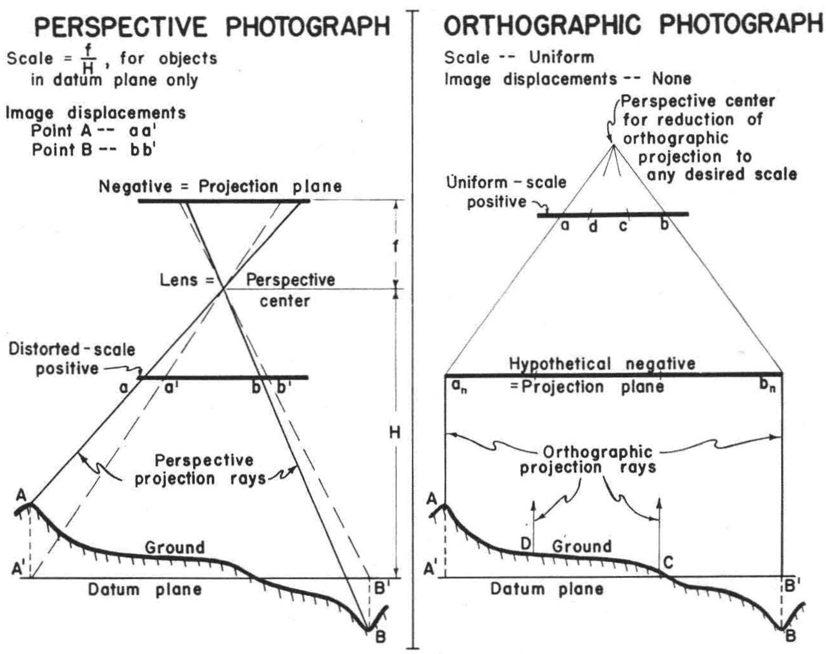


FIG. 1. Comparison of perspective and orthographic photographs, showing effect of relief.

2. MEANING OF "ORTHOPHOTOGRAPHS"

The Orthophotoscope is not a means for *direct* orthographic photography; rather, it produces the *equivalent* of orthographic photography from perspective photographs. The photographs produced are called "orthophotographs."

3. INPUT-OUTPUT SYSTEM

The Orthophotoscope must be used in conjunction with a double-projection anaglyphic plotting instrument such as the ER-55 plotter, Kelsh plotter or Multiplex. Figure 2 illustrates the principle of the system schematically. The upper part of the figure represents the projectors of the stereoplotter, and the lower part represents the operation of the Orthophotoscope. The double-projection instrument accommodates the perspective photographs in the form of diapositives, and serves as the "input" end of the system. The Orthophotoscope converts the projected images to orthophotographs and thus serves as the "output" end of the system.

4. ORIENTATION AND VIEWING

The projectors of the double-projection instrument are oriented in the same manner for producing orthophotographs as they are for producing maps. The operator views the anaglyphic model in the same way as when plotting a map.

5. CONTROL REQUIRED

Some form of horizontal and vertical control is required for absolute orientation of each model. If the model has already been controlled for standard mapping operations, the setup is based on that control. Otherwise, enough control must be obtained from other sources to effect a sufficiently faithful absolute orientation of the model. The accuracy of vertical control is not as critical as the accuracy of horizontal control, inasmuch as it takes a considerable error in the vertical datum to produce appreciable horizontal displacement. In some applications, therefore, vertical orientation based on inspection of the terrain gives a sufficiently good vertical datum for the model.

6. SCANNING TECHNIQUE

The Orthophotoscope permits continuous variation in the height of a horizontal sensitized surface (see Figure 2.). The sensitized surface is scanned systematically by a small slit in a screen covering the sur-

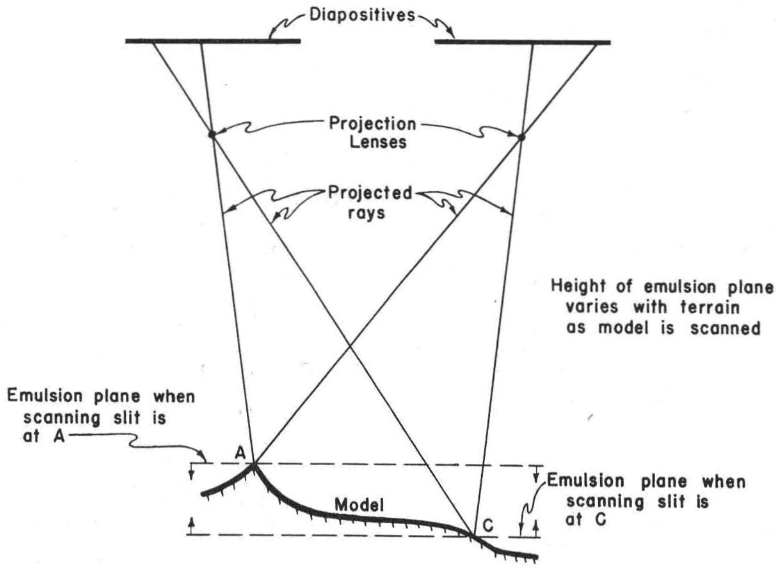


FIG. 2. Principle of the Orthophotoscope.

face. The slit permits piecemeal exposure of the surface and also serves as a floating mark. As the scanning proceeds, the slit is kept "on the ground" by the observer through operation of the height-changing mechanism. In this way, the emulsion plane is always at the correct elevation as each differential area is exposed through the slit, thus eliminating relief displacement. Tilt displacement has already been eliminated by proper orientation of the projectors, and lens distortion has been eliminated by printing the diapositives in a printer with aspheric-plate distortion correction.

7. EXPOSURE OF FILM

The slit exposes each differential area to two projected images of the same object, one in blue-green light and one in red light; but the blue-sensitive film is not affected by the red light. Thus, although both the red and blue projected rays are needed to create the stereoscopic model

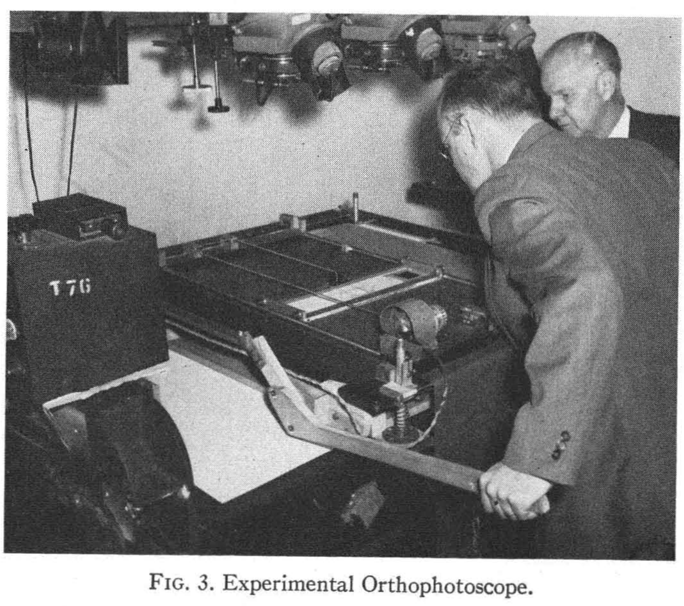


FIG. 3. Experimental Orthophotoscope.

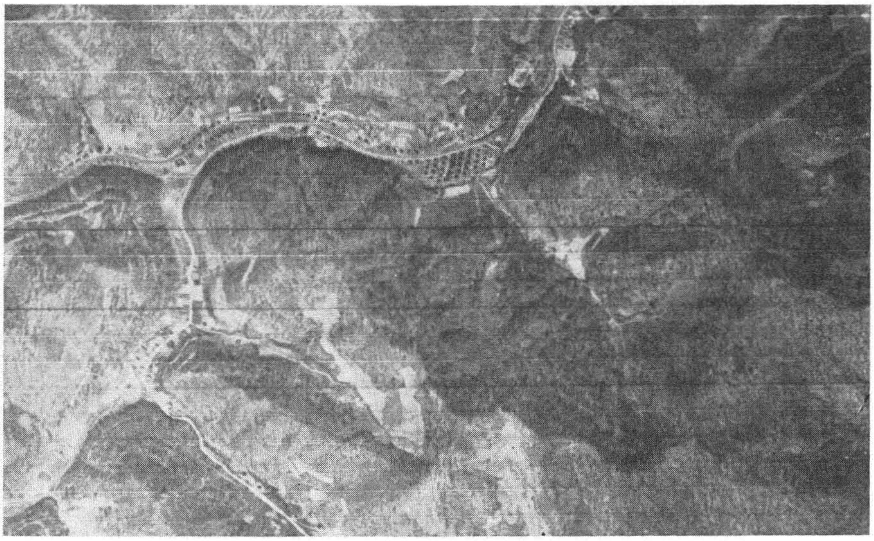


FIG. 4. Orthophotograph made on experimental instrument.

only the blue rays have an actinic effect on the film.

8. DEVELOPING AND PRINTING

When the entire model has been scanned, the film is developed by usual photographic procedures. From the resulting negative, enlargements or reductions can be made at the desired scale.

EXPERIENCE WITH EXPERIMENTAL INSTRUMENT

Up to this time, two orthophotoscopes have been built by the Geological Survey. The first instrument has been generally referred to as the "mock-up model." (See Figure 3) Actually, this was much more than a mock-up, for, even though crude in construction, it was a working instrument that produced fairly satisfactory orthophotographs. More appropriately, this original instrument will hereafter be called "the experimental orthophotoscope."

Figure 4 is a typical example of an orthophotograph made on the experimental instrument. The photographic quality is not all that could be desired, but nevertheless this print contains a world of identifiable detail, at uniform scale. The scan lines are quite prominent, and they may obscure an occasional desired image point, but they do not cause any discontinuity in the scale. If there is a discontinuity between scanning strips, this is caused by the slit not being kept properly "on the ground." The prominent scan lines resulted from excessive clearance between the screen and the film, and also from mechanical play in the x-direction setover, conditions that have been remedied in the later instrument. Despite their shortcomings, orthophotographs such as this, made on the experimental instrument, were accepted with appreciation by geologists who had an urgent need for them.

After it had been established that orthophotographs of acceptable photographic quality could be made with the experimental instrument, the Geological Survey set up an operational research project with a threefold objective:

(1) developing a detailed operational procedure,

(2) observing structural characteristics relating to possible design improvements to be incorporated in the second Orthophotoscope, the "engineered prototype" which was then on the drawing boards, and

(3) determining the accuracy of an orthophotograph mosaic.

An area comprising about half of a well-controlled $7\frac{1}{2}$-minute quadrangle that had already been mapped was chosen for the research project. Using the experimental orthophotoscope in conjunction with ER-55 projectors, uniform-scale orthophotograph negatives covering a four-model strip were prepared and mosaicked over a base sheet bearing control plotted at the model scale. Positive orthophotograph prints were then made from the mosaicked negative.

OPERATIONAL PROCEDURE

In the course of executing this project, and profiting by the mistakes and false starts that naturally accompany such a pioneer effort, a detailed operational procedure was developed and is now being adapted for use with the later engineered instrument. In general, this procedure follows the broad outlines given in the previously published paper.[2] The details of the procedure will not be given here, but one major aspect merits mentioning.

As planned originally, each orthophotograph would have corresponded in coverage with the area of a given model, rather than a given exposure. It was found by experience, however, that the photographic quality deteriorated as the scanning proceeded further and further from the "blue" projector. Also, there was some confusion in correlating orthophotographs with original exposures.

The procedure finally adopted (see Figure 5) is based on the use of 3 projectors, set up simultaneously in a 3-model bridge, with the *"blue" projector* in the middle, initially. The half (BC) of one model which is adjacent to the "blue" projector is scanned, then the lights are switched to the second model and the half (CD) of that model adjacent to the blue projector is scanned. Portions AB and DE are then made, with blue and red filters exchanged from their initial positions. Thus, the resulting orthophotograph (AE) corresponds roughly with an aerial exposure rather than with a model. Not only does this technique give better results, but it has the convenience of ready correlation of aerial exposure numbers and orthophotograph numbers. One important detail of the technique is that reverted diapositives are used so that the first positive product will be direct-reading.

[2] See footnote 1.

STRUCTURAL CHARACTERISTICS

A number of structural improvements have been incorporated in the engineered Orthophotoscope as a result of the operational trials with the experimental model. The trials revealed details such as the sources of light leaks, the need for increased range of travel of the screen carriage, and the need for an improved film-loading arrangement.

ACCURACY

For an "eyeball" check of accuracy, a transparency of the topographic map was made at the same scale and superimposed on the orthophotograph mosaic. The matching of detail, while not perfect, was remarkably good; in some instances where there was a discrepancy, there was reason to believe that the detail in question was more accurately shown on the orthophotograph than on the map. A particularly gratifying aspect of this procedure was that a power line which traversed the area, up hill and down dale, showed as a matching straight line on map and orthophotograph.

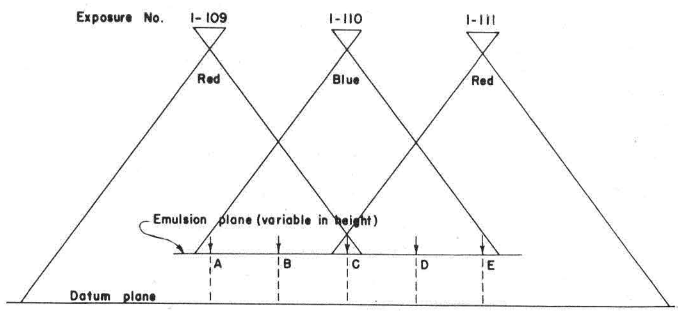


FIG. 5. Three-projector method for making orthophotographs.

For a more scientific accuracy check, we turned the mosaic over to our Control Surveys Section for computation of the distances between well-identified points of known position, and comparison of these distances with the corresponding distances measured on the orthophotograph mosaic. Based on measurements of 54 lines ranging in length from about 5,000 to 35,000 feet, the standard net error was determined to be 52 feet and the probable error 35 feet. On the basis of a 20,000-foot line, this means that the standard error would be about 1 part in 400 and the probable error

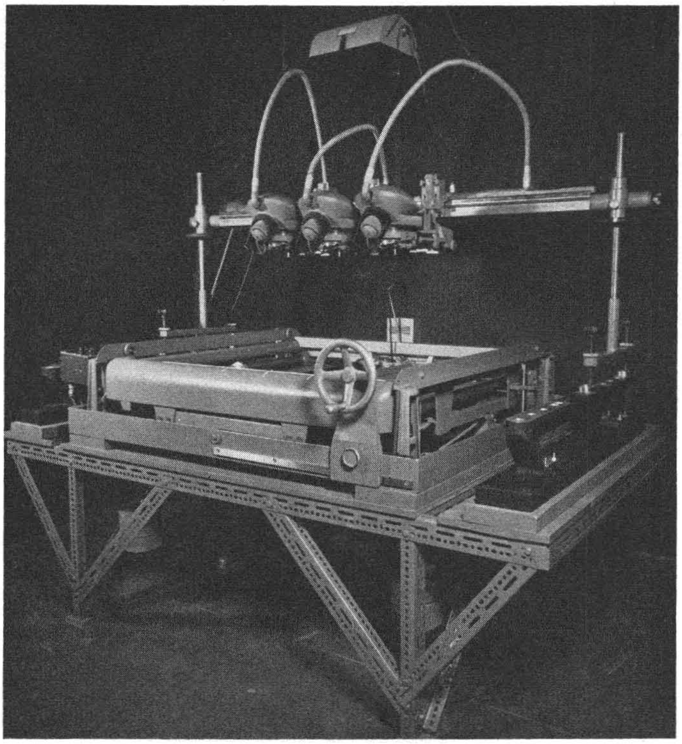


FIG. 6. Engineered prototype Orthophotoscope with ER-55 projectors.

about 1 part in 600. This of course is not good enough when a high order of ac curacy is required. But for many uses such as in geology, forestry, and some phases of surveying, orthophotographs of this accuracy would meet the requirements. With the later improved instrument, still better results are to be expected.

The experimental Orthophotoscope, having served its purpose usefully and honorably, was retired from service upon the completion of the engineered prototype.

THE ENGINEERED PROTOTYPE

The fabrication of the engineered prototype Orthophotoscope (Figure 6) was completed early in 1956 at the Geological Survey's Research and Development facilities in Arlington, Va., and was exhibited at the ASP-ACSM Annual Meeting in March. After a period of shakedown and adjustment by the Research and Development Group, the instrument was moved to the quarters of the Special Maps Branch in Washington, where it is now operating on a full-time production basis. Along with the production operations, the Special Maps Branch maintains continual liaison with the research group regarding difficulties, "bugs," suggested improvements,—and even successes in operation. After a reasonable period of operating experience, a final design revision will be completed and it is expected that the Geological Survey will seek to obtain Orthophotoscopes commercially.

MAJOR CHANGES

Figure 6 reveals some changes from the original concept of the Orthophotoscope as embodied in the experimental model. The engineered instrument is larger and heavier than originally evisioned. No longer is it practicable to transport it from one stereoplotting unit to another with relative ease. Thus, portability has given way to the more important quality of stability; and experience showed that this is just as well, for a permanent setup of the equipment permits use of a specially designed table and working in a room particularly adapted to the purpose. (Incidentally, if the background of figure 6 appears to be rather dark, this is because the walls and ceiling of the room are painted dull black to minimize reflection of stray light rays. The switching arrangement is such that when

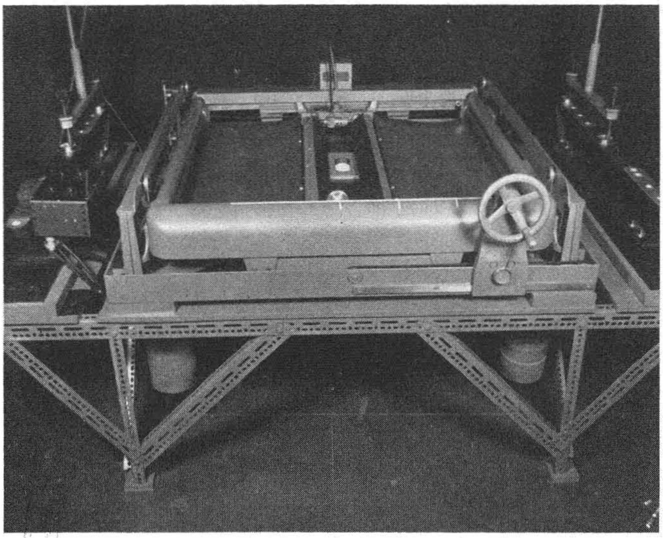


FIG. 7. General view of Orthophotoscope.

the projector lights are turned off, the safelight shown at the top of the illustration goes on so that the operator is never in complete darkness.)

Another change that is readily apparent in Figure 6 is the use of a handwheel to replace the lever of the experimental model for height control.

The three ER-55 projectors shown and the supporting frame on which they are mounted are standard stereoscopic plotting equipment, with the usual hose connections for cooling. The only change required in each projector is the black collar placed around the lamp assembly to intercept stray light. The particular orientation shown is for vertical photography, but the system also accepts low-oblique or high-oblique photography.

RELATION OF HEIGHT-CONTROL TO SCANNING SYSTEM

Figure 7 is a general view of the Orthophotoscope itself. The inner frame, bearing the film support and scanning system, is moved vertically in relation to the outer frame by manipulating the hand wheel. The film rests on the film support and is covered by the curtain at either side of the scanning ways, the telescoping black metal sheets within the scanning ways, the platen carriage, and the platen itself. Only the slit in the platen permits exposure of the film. Thus as the slit scans the model in the y-direction, the operator keeps the slit "on the ground," by means of the height-control hand wheel so that each differential element of the film is exposed at the proper elevation.

SCANNING SYSTEM

Figure 8 represents the scanning system with the hinged masks flipped back to show the actuating parts. The 18-volt direct-current motor at the rear of the scanning way drives the bicycle chain in the y-direction at a constant rate of speed. The platen carriage travels with the chain, to which it is connected. When the desired amount of y-motion towards the rear has been covered, a properly placed dog in the chain trips an escapement which, in combination with a spacer control, steps the entire scanning system over, in the x-direction, by an amount equal to the slit width. The direction of travel reverses automatically and the next strip is scanned towards the front. The scanning proceeds in this manner until the desired area is covered.

HEIGHT-CONTROL SYSTEM

Some details of the height-control system are represented in Figure 9. The jack-screw shown is one of four which control the height of the inner frame in relation to the outer frame. These screws are actuated by a continuous bicycle-chain drive geared in to the handwheel. A small portion of this drive chain is barely visible just above the lower left-hand member of the outer frame. (The other chain, which is plainly shown passing over a sprocket, is part of the curtain control.)

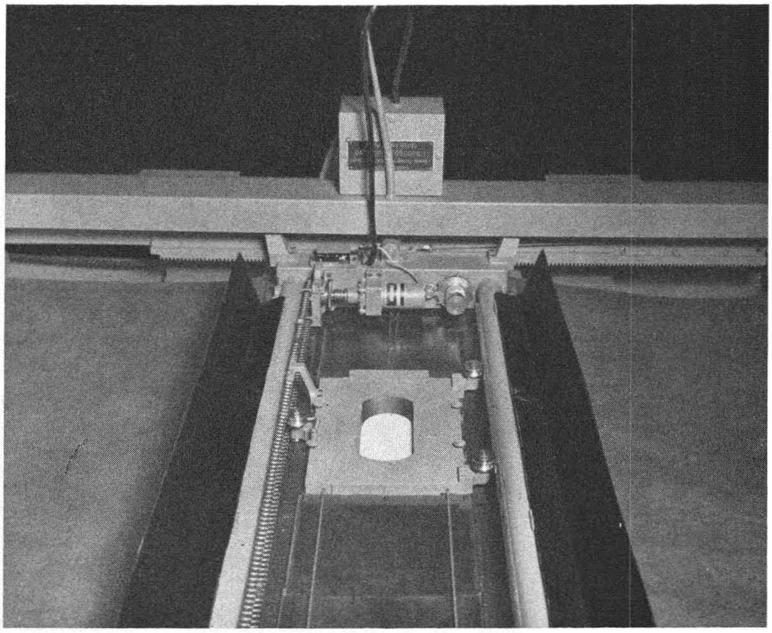


FIG. 8. Scanning system.

The height-indicating device can be seen in Figure 9, adjacent to the jack screw. This is an adaptation of the wall-projecting height indicator devised by Robert Boisseau of the Geological Survey, for use with standard tracing tables. The device includes a flexible but dimensionally stable transparent scale which is fixed to the outer frame and passes through a small projecting device, in such a manner that the height reading is projected on the wall of the room, where the operator can easily read it from his operating position. The projecting device, consisting of a lamp, an index mark, and a lens is fixed to the inner frame and rides up and down with it as the height changes. Height readings are needed only for setting up the projectors; once the setup is made, height control is maintained by keeping the slit "on the ground."

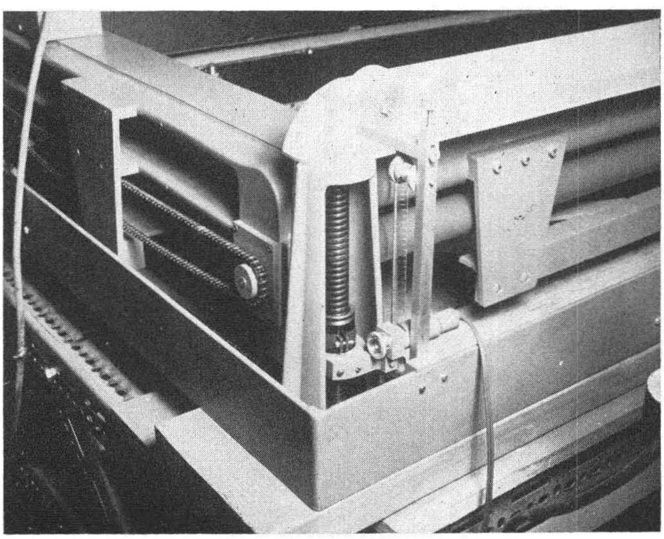


FIG. 9. Portion of height-control system.

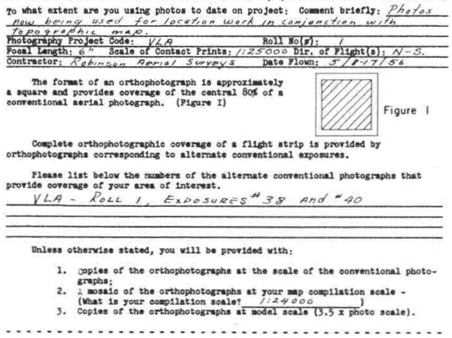
There are, of course, many features in this instrument which required detailed engineering design, but which cannot be covered in a paper of this type.

Applications of the Orthophotoscope

To date the principal application of the Orthophotoscope has been in the field of geology. Actually it was the demand of Geological Survey geologists for some sort of uniform-scale photography that spurred the development of the instrument. With the realization of successful orthophotographs, it has been necessary for the Geological Survey to set up a committee to screen and monitor the multitude of requests for orthophotographs from its own geologists. To aid this screening process, an "Orthophotograph Request Form" has been instituted, as illustrated in Figure 10.

To illustrate the interest outside the Geological Survey, it can be reported that a single news item concerning the instrument, printed in a mining journal, brought a flood of requests for futher information from private geologists who envisioned important applications in their own particular activities.

To the geologist, the orthophotograph offers a combination of the wealth of detail supplied by photography (and only partially shown on conventional maps) with the accuracy of measurement supplied by a map (and lacking in conventional photography). The orthophotograph can be made in a fraction of the time required for a map, thus eliminating months, or even years of waiting for a reliable base on which to plot strikes, dips, fault lines, lithologic contacts and other features shown on geologic maps.


Prepare in Trip. Retain one copy. Forward two.

Form No. Ortho. - 2
Committee Approval:
By

REQUEST FOR ORTHOPHOTOGRAPHS

Date Sept. 10, 1956

Project Name: Connecticut Valley Quad Name: Hanover, S.E. State: Vt-N.H.
Branch & Name of Requester MINERAL DEPOSITS - Joseph X. Smith
Date Field Work Commences: Oct. 1 Topo Base Map Avail.? Yes Scale of Map: 1:62,500
Planned Scale for (a) Reg. Mapping: 1:24000 (b) Special-Purpose Mapping: —
Total Relief in Area: 900 ft. Average Local Relief: 900 ft.

Character and density of vegetation: Describe briefly:
Rather dense mixture of coniferous and deciduous growth.

Are contacts visible on photographs? Are photos to be used for location purposes only? Comment briefly:
- Only occasional contact visibility.
- Mostly for location purposes!

To what extent are you using photos to date on project: Comment briefly: Photos now being used for location work in conjunction with topographic map.
Photography Project Code: VLA Roll No(s): 1
Focal Length: 6" Scale of Contact Prints: 1:25000 Dir. of Flight(s): N-S.
Contractor: Robinson Aerial Surveys Date Flown: 5/8-17/56

The format of an orthophotograph is approximately a square and provides coverage of the central 80% of a conventional aerial photograph. (Figure I)

Figure I

Complete orthophotographic coverage of a flight strip is provided by orthophotographs corresponding to alternate conventional exposures.

Please list below the numbers of the alternate conventional photographs that provide coverage of your area of interest.
VLA - Roll 1, Exposures #38 and #40

Unless otherwise stated, you will be provided with:

1. copies of the orthophotographs at the scale of the conventional photographs;
2. A mosaic of the orthophotographs at your map compilation scale - (What is your compilation scale? 1:24000)
3. Copies of the orthophotographs at model scale (3.5 x photo scale).

Please use reverse side of this form for additional comments, remarks, or sketches.

FIG. 10. Orthophotograph request form.

One might attempt to catalog the possible specific applications of orthophotographs in fields such as forestry, crop inventory, soil classification, base maps for topographic mapping, and property surveys; but the catalog would be endless. The whole range of applications can be covered by saying simply this: *whenever there is an advantage in being able to determine accurately on an aerial photograph the positions of points, the lengths or directions of lines, the courses of curved lines, or the shapes or areas of given tracts, the orthophotograph offers a potential means of accomplishing the desired end.* As a simple illustration, Figure 11 (left) shows a perspective photograph in which a straight power line appears crooked because of relief displacement. Figure 11 (right) shows an orthophotograph made from the perspective photographs on the engineered prototype; it will be observed that the power line shows correctly as a straight line.

The whole range of possibilities might be exemplified by one application contemplated by the Geological Survey in the field of topographic mapping. In obtaining supplemental control for stereoscopic mapping of certain areas, the Survey uses the system known as "photo-trig." In this system a field engineer, at a point of known elevation, reads a vertical angle to another point for which the elevation is desired. If the distance between the two points is known, elevation difference can be readily calculated as a function of the distance and the vertical angle. In the conventional photo-trig method, however, the distance is not known until it is determined later in the office by photogrammetric plotting. Given an orthophotograph, the field engineer can measure the distance and calculate the elevation difference on the spot; if there are any errors or inconsistencies, he can make the necessary checks at once, without requiring a later trip to the field. Even the experimental Orthophotoscope gave line lengths accurate to one part in 400 (standard error) in the operational research problem cited

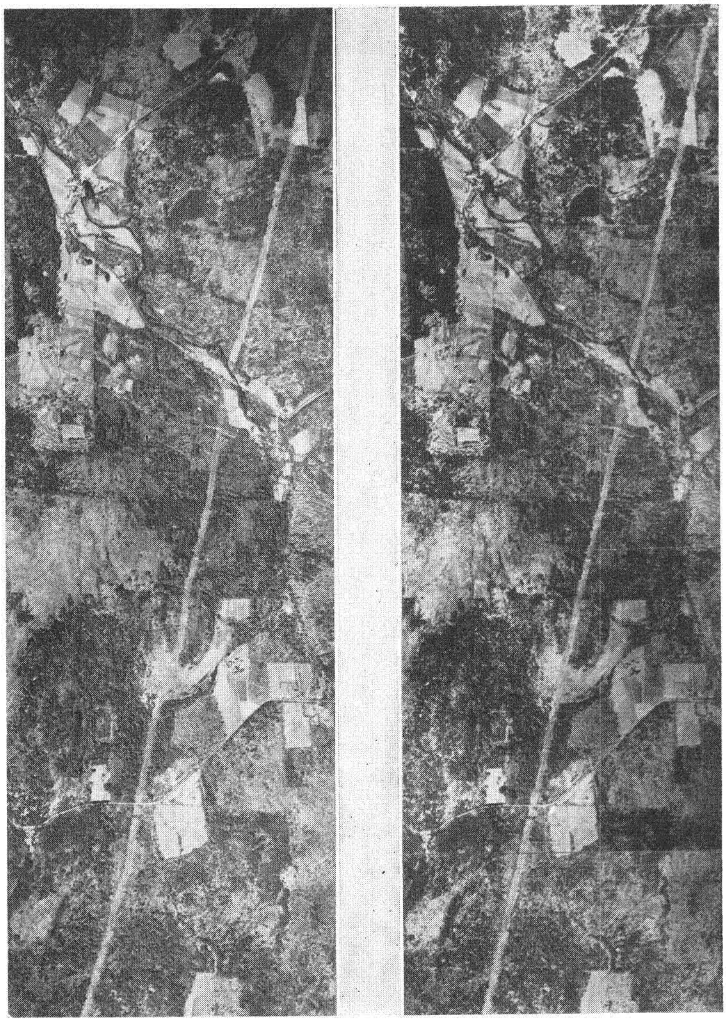


FIG. 11. Corresponding portions of a perspective photograph (left) and an orthophotograph (right). In the perspective photograph the power line appears to be crooked, while in the orthophotograph it is shown in its true straight alinement.

above. This assures the required accuracy being met for supplemental control obtained by photo-trig, if the vertical angles are not excessive.

A word of caution about the range of application of the Orthophotoscope is in order. As already indicated, rectified photographs and controlled mosaics give excellent results when there is low relief in the area of interest. When the range of relief is less than, say, 50 feet, the conventional controlled mosaic is still the undisputed leader in the field from the standpoint of quality and cost. The two systems together cover the entire range of relief—the controlled mosaic at the lower end, the orthophotograph mosaic at the upper end. The limitations of each should be well understood.

CONCLUSION

Judging by past experience, there is every reason to believe that the Orthophotoscope described in this paper as the "engineered prototype" is just a step along the way, albeit a big step. We can expect to see improvements in instrumentation, improvements in techniques, and improvements in results. But one thing seems certain—the day of the uniform-scale photograph has dawned.