ciency 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.*

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RICHARD O. MAHAN

ADVANTAGES OF THE PHOTO-CONTOUR MAP

THE conventional topographic map is a well established engineering tool. Its preparation by photogrammetric methods has been the subject of considerable literature. In these maps the delineation of planimetric detail, by interpretation, selection-elimination, reduction to conventional symbols and reproduction by line engraving, is especially adapted to comparatively small-scale maps where regional coverage for general technical uses is the objective.

There remains, however, a field for a special kind of topographic map in which planimetric detail is provided by a photographic image. In such a map the full wealth of photographic detail is preserved and no draftsman's interpretation and selection is involved. There is a minimum of editing of the planimetric data.

The photographic detail must, of course, be readable and for that reason there is a visual limitation upon the smallness of scale. A scale of 1:6,000 is about the practicable minimum. In scales of this ratio or larger, however, there are real advantages in a map with photographic detail.

These advantages are especially noteworthy where the versatility of the map is important or, looked at another way, where omission of some features by selection and editing may reduce the usefulness of the map. It has also been found that the photographic-image is superior to the conventional symbolized map where the map will be used extensively in the field, and rapid and certain ground orientation is important. This is also true in office work where persons familiar with the ground are using the map. Orientation is quicker and more positive with a photographic-image.

There are other examples in point but perhaps the best proof of the special usefulness of the photographic-image is the continuing effort of cartographers to solve the problems of mosaic maps. This has proceeded with indifferent success from the inception of aerial photography to the present day. While mosaics have performed useful functions, it must be conceded that scale problems have proved to be stubbornly difficult and, especially where ground relief is significant, practically insurmountable within the limits of economics and accepted map accuracy standards. Mosaics remain essentially pictures and not maps as may be illustrated by Figure 1. Please note that the contours do not properly track the physiography.

DEFINITION

Granted the problem, it is appropriate to pose the question: What kind of map will be required to satisfactorily meet this need? Such a map may be described as an economically practicable topographic map meeting accepted standards of accuracy where planimetric detail is depicted by the photographic-image. This is an exact definition of the Photo-Contour Map as described in this paper.

The description will be started with an example of the finished product. Figure 2 shows a portion of a Photo-Contour Map. Note that, because of proper incremental rectification, contours track physiographic features as they should.

AERIAL PHOTOGRAPHY

Flight planning and control surveying do not differ in any important respect from that required for conventional topographic mapping from aerial photographs. This is also true of the photography itself. Any photogrammetrically sound photography can be used for Photo-Contour Map preparation.

However, with the risk of some digression, the particular technique used by the author will be described. This will be of some value in a better understanding of

FIG. 1. Section of Mosaic map. Note how contours fail to track the road image properly becoming progressively worse to the right of the figure. This is because the contours are correctly plotted to an orthographic projection, while the planimetric detail is from a photographic perspective. The two cannot be made to agree where there is a significant ground elevation differential in the area.

certain of the steps in the process described below, and may find further justification in the fact that this technique has proved especially well adapted to Photo-Contour Map work.

This method provides both convergent and vertical coverage. The convergent pairs are used for contour plotting as they are geometrically stronger than 60 per cent overlap verticals. The vertical coverage is used in the zone reformation process described later in this paper.

Figure 3 shows the progress of the photography and the space relationship of the exposures in a series. Only one camera is used, a specially designed mount being provided which permits rapid and accurate shifting of the camera axis during flight.

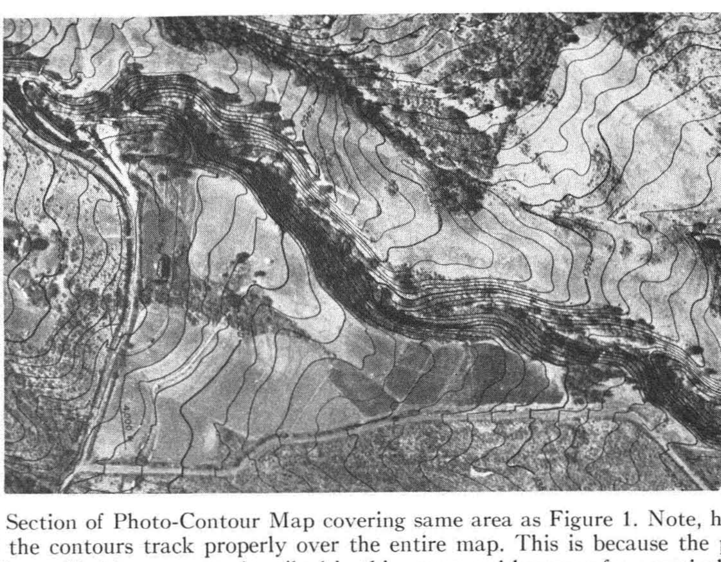

FIG. 2. Section of Photo-Contour Map covering same area as Figure 1. Note, however, that in Figure 2 the contours track properly over the entire map. This is because the photographic perspective is rectified by zones as described in this paper and becomes for practical purposes an orthographic projection at the same scale as the contour plotting.

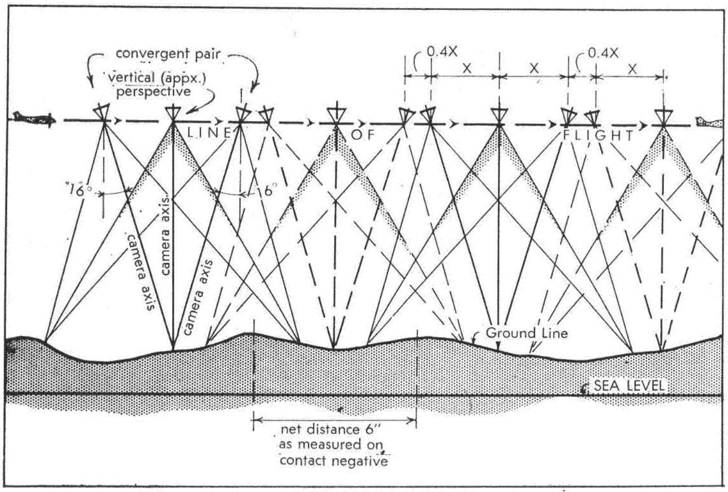

FIG. 3. Diagram of progression of aerial photography and relationship of exposures in the series. Note that for a given ground area both vertical and convergent coverage is accomplished.

It is apparent that success in this scheme of photography is dependent upon sound planning, accurate timing of exposures and careful drift determination and control.

PREPARATION OF MANUSCRIPT SHEET

Contours are plotted on the manuscript sheet by conventional methods using the convergent perspectives. The material used for the manuscript is scribe coated film base. A pattern of pass-points for each photographic pair is selected, marked on the sheet, and the elevation determined and marked. There should be not less than nine pass-points for each model. These will be used to rectify the near vertical perspective, and must therefore be selected for qualities of accurate visual identification. The contours, contour numbers, control points, and grid are then scribed on. The result is a negative of the contour pattern.

ZONE REFORMATION THEORY

Before proceeding with the rest of the process description, it will be well to consider the theory upon which the next stage of the project is founded.

Consideration should be given to the negative of the near-vertical perspective. This negative can be placed in a projector having the same geometry as the taking camera. This projector can then be oriented to the spatial position and tilt (relative to the sea-level datum-plane) which the taking camera had when the exposure was made. A rectified-image can then be projected onto the projection plane.

Since the ground is not level, the projected-image will have an infinite number of scales. But the projected-image is a rectified-image; hence the images of all points at the same ground elevation will be at a single and consistent scale relative to one another. That is to say: the projected-image along any contour will be at a consistent scale, but the image scale along each contour will be different from that along all other contours.

This is illustrated in Figure 4. All projected points along the contour represented by ground elevation *A-A* will be at a uniform scale. Likewise, this quality of uniformity applies to contour elevations *B-B* or *C-C*. But the scale at contour *A-A* is larger than the scale at the other two contours, since ground points at elevations *A-A* were closer to the taking camera.

It will now be supposed that the projection plane is raised above the position of sea-level datum. If it is raised a distance (at map scale) representing the elevation of contour *A-A*, then the image projected on the plane will be at map scale at all points along that contour. If the plane is then lowered to the elevation of contour *B-B* the projected-image will be at map scale at all points along that contour. This can be repeated for each contour on the map.

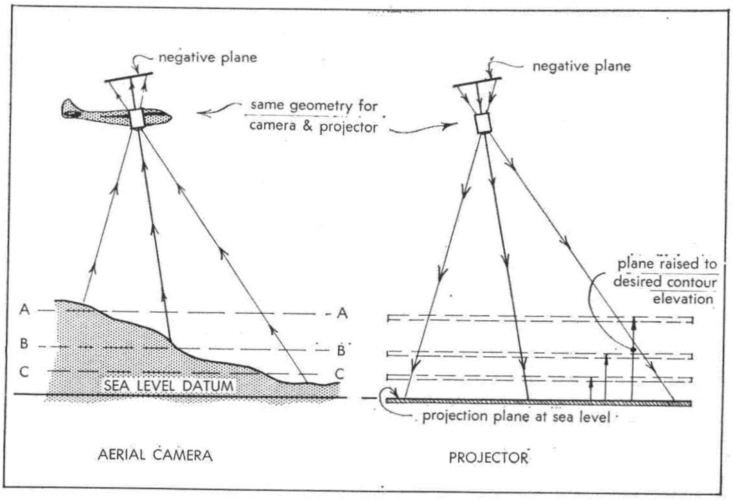

FIG. 4. Diagram of aerial camera and of projector after rectification showing contour-scale relationships.

With the projection plane at contour *A-A*, the images of points at any other contour are misplaced due to the scale difference. If the elevation of contour *B-B*, for example, is substantially below *A-A*, then the map error is great. If, on the other hand, the contour interval were relatively small, then the error would be small.

The inherent accuracy of the final map is the extent of feature displacement which may be tolerated. Planimetrically, this can be expressed as a distance, such as, for example, 0.04 inch.

Figure 5 diagrams the projection of the near vertical photograph. For simplicity the rectifying tilt has been omitted. The extreme edge of the useful image projection is at angle *A* with the vertical axis. If the projection plane is at *Y-Y*, all projected ground points at the elevation of the plane will be to scale and in accurate horizontal position. But all points at the elevation of plane *Z-Z* will be displaced. The maximum displacement will occur at the extremity of the useful image or at angle *A*. This displacement may be determined

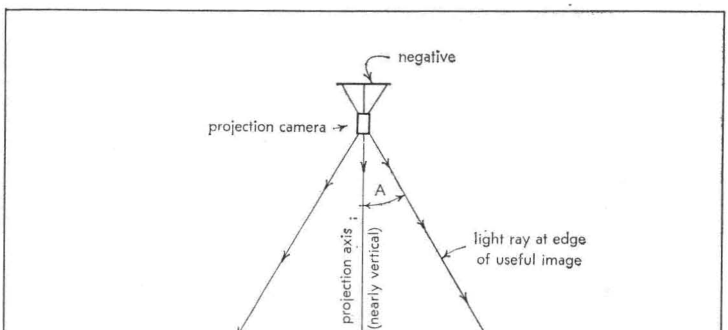

FIG. 5. Diagram of projection of nearly vertical negative showing elements for determining contour interval to be used in zoning process.

by multiplying the contour interval by the sine of angle A. This equality may be transposed and expressed as follows, (using the letters shown in the figure):

$$I = \frac{d}{\sin A}.$$

By use of this relationship a contour interval can be computed which represents a "zone" within which the projected image will be planimetrically correct within map error specifications.

To illustrate: Suppose that A is 30 degrees and d is 0.04 inch. For a map scale of, say, 1:6,000 the maximum map error represents a ground distance of 20 feet.

Solving for I it is found that in such a case the "zone" or contour interval of allowable error is 40 feet. If the projection plane were set at elevation 500 feet, for example, then all portions of the projected image lying between elevations 480 feet and 520 feet would satisfy the map accuracy position requirements.

Zoning and Preparation of Mask

The map is now ready for zoning. After computing the acceptable interval, a central elevation and an upper and lower limit contour is selected for each zone throughout the entire map.

A contact film-positive is made from the manuscript sheet, and from the positive a zone reformation mask sheet is made by contact, using silk-screen material. This latter consists of an opaque and relatively thick photo-sensitive emulsion on a stable film base. After exposure and processing, the unexposed lines (the contours, etc.) which are soluble in hot water have been washed away entirely down to the film base. On all exposed areas the opaque material has become insoluble and is left. This produces a negative image. The adherence of the emulsion with the base is not absolute, and with skill can be peeled away (stripped) from the base. When this stripping is done the emulsion will break off sharply at the contours since the contour lines have been photographically etched as described. The zone reformation mask is thus strippable.

The draftsman now strips away the opaque material from a number of noncontiguous zones. Figure 6 shows this process in simplified form. The zones which are opened are marked A.

The negative is now ready for use in zone reformation by use of the zone printer.

Orienting Zone Printer

The zone printer is a projector in which the projecting camera is fixed in vertical position but can be tilted in any direction. It is provided with an iris diaphragm capable of stopping down so as to become "fixed focus." The projection-plane is a board which can be levelled and raised or lowered with precision. The position of the plane relative to sea-level (at the mapping scale) is always known by means of a calibrated lead screw, gear train and counter arrangement. The plane is provided with four removable registration pins, and all material placed on the plane is punched for these pins thus assuring accurate register, a most important matter in this process.

The near-vertical perspective negative is placed in the projector, and the manuscript sheet positioned on the plane. Using the pass-points on the manuscript and identifiable on the projected image, the projector is spatially oriented so as to eliminate the effect of tilt in the perspective negative.

The manuscript sheet having been punched using a template, the registration pins are affixed to the table so as to fit the punched holes.

Zone Reformation Printing

The manuscript sheet is removed and is replaced by unexposed film and the zone reformation mask with a number of opened zones is overlayed. All opened zones but one are covered with cardboard or other convenient material; the plane is elevated to the central contour of the uncovered zone; and an exposure is made. The exposed zone is covered, another zone is uncovered, the plane adjusted to its proper elevation and the next exposure made. This is repeated for each stripped zone.

The mask is removed to a light table, all exposed zones opaqued (marked B on Figure 6) and a new series of zones stripped open. The mask is returned to the printer, re-registered and the exposure process repeated for this new series. This process is repeated until the entire map has been exposed, zone by zone, each zone having been exposed with a rectified-image corrected

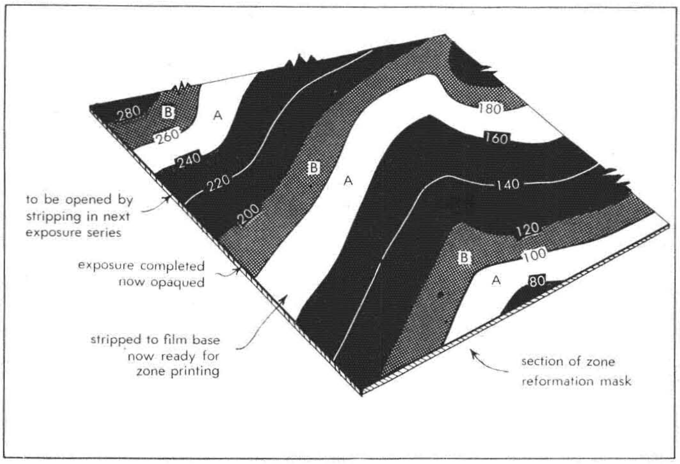

FIG. 6. Sketch of portion of zone reformation mask showing stripping and opaquing routine which permits printing by zone reformation. For the sake of simplicity it is assumed that each contour is a zone boundary.

for ground elevation. A constant scale for the map results.

COMPLETING MAP, EDITING

At this point there is at hand a film exposed for a continuous-tone positive photographic-image, zone reformed and planimetrically correct. By using the manuscript as a negative all contours and other line information can be exposed so as to print black; or, if it had been desirable, a positive overlay could have been introduced to hold back the line information during zone reformation, so that it would show up white on the positive. An edit sheet with border information, lettering and any other notes required is made up, and negatives or positives of the complete map at various feasible scales can be projected by double printing. A half-tone screen is often introduced so that the map may be reproduced by photolithography or by blue-print shop methods and materials.

Editing for accuracy is relatively simple and certain. The contours must track. That is, they must accurately fit road and railroad cuts and fills, houses and other topographic breaks which appear on the photographic-image. In addition the "break" in the photographic-image at the zone junctions must meet map accuracy standards since the maximum error will occur at zone junctions. This ease of visual checking of the map is a desirable feature of the Photo-Contour Map.

CONCLUSION

A word about materials is now in order. It is evident that all drafting and photographic base materials used in the process must have excellent qualities of scale stability. Without these the process will fail. Fortunately, such materials have become available in recent years and are used in each of the drafting and printing steps described.

The evolution of the Photo-Contour Map has not been without its difficulties. It is a demanding process in the sense that great care must be observed at each step. Failure to strictly adhere to high standards of precision will surely result in a disappointment in the map. Given the necessary care of execution, however, the process described in this paper works well. Indeed, excellent topographic maps at practicable costs result and are today in daily use by the U. S. Navy, the Hawaii Territorial Highway Department, large agricultural interests, the Honolulu City Planning Commission and others.