c. There is as much difference in accuracy potential, among individual operators, as there is among instruments and methods of accepted varying orders of accuracy.

Equating these data in terms of an actual job, photography could be flown almost 50 per cent higher for the best, relative to the poorest, operators. This would result in a coverage of about 2.25× more terrain-per-model and result in a corresponding saving in ground-control, photographic processing, aerial triangulation effort and compilation model orientation time.

We have spent millions of dollars to develop new equipment and methods which will permit the photographic aircraft to go up about the order of 50 per cent higher and still retain the same map accuracy. We have done this because anything that will permit such an increase in photographic ceiling would certainly be a breakthrough. *On the other hand, what have we done to raise the technical level of our people?* Have we made an effort somewhat comparable to that which we have made on our hardware and methods?

The answer, of course, is that *we have sadly neglected the human field*. What we have done is pitiful by comparison with our expenditure on the inanimate components. I believe that, in order to stimulate work in this area, and to make any appreciable headway in the foreseeable future, a comprehensive program should be set up involving a group of mapping agencies, preferably on an International scale. I suggest that the International Society of Photogrammetry set up a group to conduct an International program in this field of "Photogrammetric Ophthalmology."

I hope that my presentation of these test data has helped to emphasize the magnitude of the human problem; also that, in so doing, this paper will not only encourage the dedicated few to continue their efforts, but also induce others to enter this vital, yet wide-open, field. It is a wilderness of undeveloped potential. It is photogrammetry's "depressed area."

Half-Base Convergent Photography

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To PROPERLY introduce the technique of half-base convergent photography and its attendant parameters it is appropriate to clarify the meaning of the term by describing the basic photogrammetric instrumentation and geometry. The half-base system is a modification of the "standard" convergent system presently used by the U. S. Geological Survey, uncomplicated in execution, yet showing favorable promise toward enlarging the scope of application of the convergent system in mapping operations.

The successful development of the ER-55 projector (recognized by some of you as the Balplex) with its built-in capability for the Scheimpflug accommodation gave impetus to the use of convergent photography within the Geological Survey. The "standard" convergent system, as adopted by the Survey, utilizes a twin-camera couple arranged so that each camera axis is in the plane of the flight line and is inclined 20 degrees with respect to the vertical. Two simultaneous photographic exposures at each camera station, one pointing forward, and the other to the rear, provide this system with a tremendous advantage over vertical photography in terms of total angular coverage and resultant area coverage. Each stereomodel is composed of the forward-looking exposure from one station paired with the backward-looking exposure of the succeeding station. By virtue of the larger base-height ratio inherent in this system the accuracies of vertical readings are improved relative to those derived from conventional vertical models of comparable flight-height photographs. The base-height ratio adopted for the "standard" convergent system used by the Topographic Division of the U. S. Geological Survey is 1.23.

The standard convergent system just described has proved to be efficient, economical, and practical, yet circumstances arise that force project planners to avoid its use. Areas of extreme topographic relief and/or heavy timber cover have been the most common deterrents to the universal application of the standard convergent system. In circumstances where severe relief is prevalent, the extremes of perspective viewing in stereo-

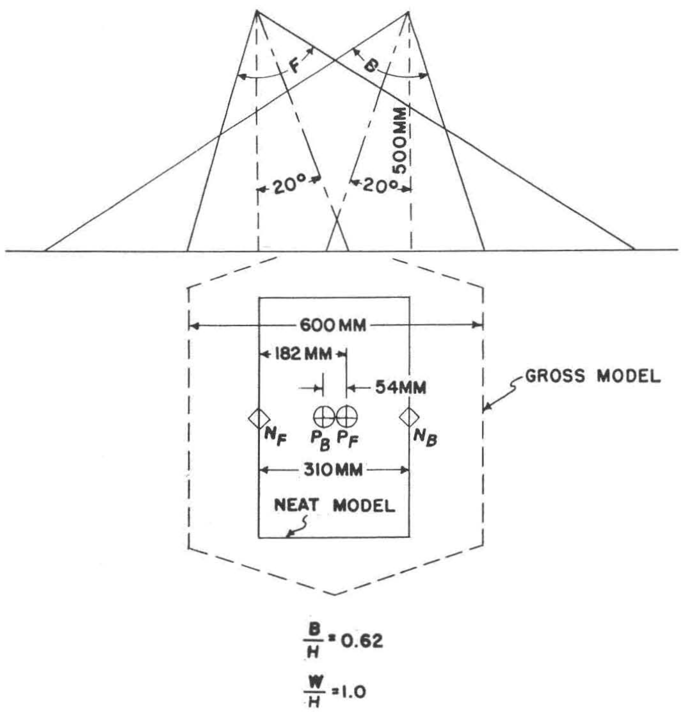

FIG. 1. The half-base convergent model (ER-55).

scopic pairs of convergent photographs make it difficult, and sometimes impossible, to fuse corresponding images for the stereoscopic impression so vital to photogrammetric compilation. A somewhat similar condition of poor or lost stereo-impression occurs in areas of heavy timber when viewed from widely separated perspective centers. The overall economies and efficiencies of the system, however, are justification for an attempt to resolve these difficulties and extend its use into these problem areas. The half-base convergent system retains the operational advantages of the standard convergent, and provides the means for circumventing the disadvantages. Some additional benefits unique to the half-base system will also be described in this paper.

Half-base convergent photography is defined as a relatively simple modification of standard Geological Survey 20-degree twin-low-oblique convergent photography wherein a base-height ratio of 0.62 is used, rather than the standard 1.23 ratio. Figure 1 illustrates the basic geometry of a half-base convergent model using ER-55 projectors. *F* represents the total angular photographic coverage in the plane of the air-base for one projector (forward-looking camera), and *B* represents the total coverage for the second projector (backward-looking camera at the succeeding station). The nominal 20-degree tilt for each projector is introduced by means of a mechanical step rotation of the projector prior to model orientation. The further refinement to recover the precise attitude of the taking camera results from the conventional routines for relative and absolute orientation of the stereomodel. The width-height ratio remains equivalent to that for standard convergent photography at 1.0. In the projection plane of the stereomodel the principal points have crossed, thus placing each principal-point in closer proximity to the nadir-point of the adjacent photograph rather than that of the photograph it identifies. If there can be imagined the space position of the next half-base convergent exposure station as being at a point C—to the right but not shown here—then the forward-looking exposure at *F* in Figure 1, combined stereoscopically with the backward-looking exposure at *C* would form a standard convergent model with base-height ratio of 1.23.

With the basic concept of the half-base convergent system now in mind it is possible to proceed with a presentation of the features and benefits of this system. These are based primarily on the findings of an operational research study of this method recently per-

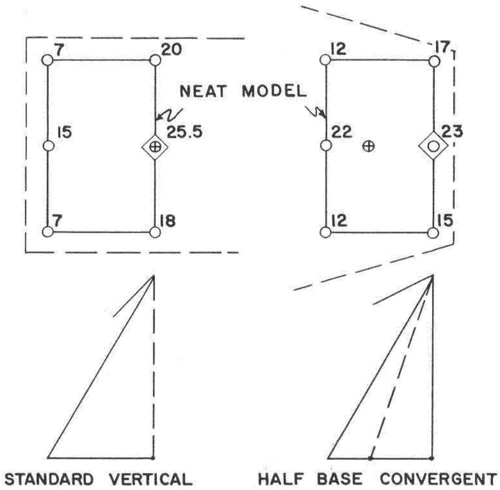

FIG. 2. Comparison of illumination, standard vertical vs half-base convergent (single projector, ER-55).

formed in the Pacific Area office of the Geological Survey. It is felt that these findings display sufficient promise to encourage those of the photogrammetric fraternity who may have overlooked this method, to consider this scheme for use in their own sphere of operations.

Figure 2 is a comparison of the illumination provided by a single ER-55 projector, setup for standard vertical photography, with that of the same projector used for half-base convergent photography. The readings shown at the six critical neat model positions are in foot-candles at 500-mm. projection distance with full lamp voltage, clear diapositive, and without a dichromatic filter. The comparison in this instance was directed between the standard vertical and the half-base convergent projector set-up since both neat models encompass equivalent areas. It will be noted that the principal-point and nadir-point are superimposed in the left-hand drawings representing standard vertical photography, and that the principal-point is properly displaced in the half-base drawings on the right. Readily apparent is the increase in illumination provided in the farthest corners of the half-base set-up and the improvement in the uniformity of intensity throughout the model. These factors not only provide a more pleasing stereomodel with which to work but also mean that fewer adjustments in light balance are required during the stereoplotting operation. The photographs made available for the previously mentioned operational research of this technique were taken at a mean flight height of 15,000 feet above terrain and included standard vertical coverage exposed simultaneously, in flight, with the low-oblique. The consensus of those who compared the stereomodels of both types was that the resolution of the half-base model was much superior to that of the vertical models. Figure 3 suggests a logical reason for this apparent improvement in resolution. Study revealed that the lenses in both cameras used for the twin-oblique photography suffered some decrease in resolution beyond the cone of 20 degrees about the lens axis. Figure 3A shows the extent of the overlap area of the 20 degree cones for the half-base model, while Figure 3B shows the similar extent of these 20 degree cones for vertical photography. The advantageous use of the more favorable part of the lens cone by the half-base technique is obvious.

From the description of the half-base technique as presented here so far, one can fairly well predict the findings with regard to map-

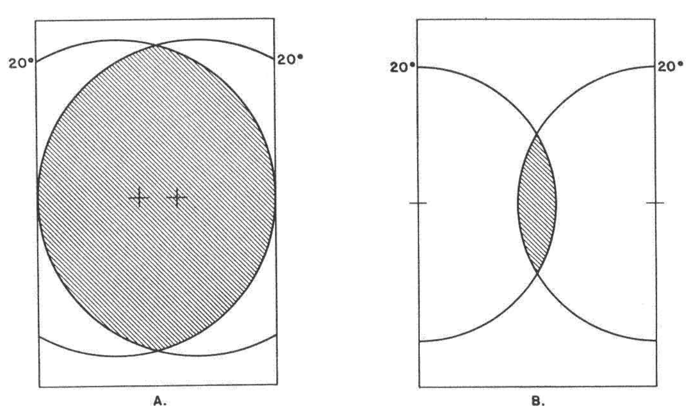

FIG. 3. Neat stereomodels of half-base convergent photographs (A), and standard vertical photographs (B), showing extent of overlap area within 20° of optical axes.

ping in timbered areas. Since the half-base stereomodel furnishes the same perspective view as the equivalent vertical model, the ability to penetrate heavy timber for map compilation is likewise equivalent. Therefore, by providing half-base convergent photographs throughout a forested area, the zones of sparse timber cover can be compiled by utilizing the standard 1.23 base-height ratio convergent photographs (alternate exposure stations); the voids in compilation resulting from heavy timber cover, can be filled by the supplemental use of the half-base stereomodels (consecutive exposure stations).

To ascertain that the half-base convergent photographs would in fact contribute to the capability of mapping forested areas and serve as a supplementary aid to the standard convergent photographs, a selected area was compiled with both sets of photographs. The results were then compared. The findings indicate that with the standard convergent photographs contouring can be completed with confidence if the tree crown-cover does not exceed 25 per cent, while some additional contouring can be done in areas approaching 50 per cent crown-cover. If the density of cover approaches 75 per cent, however, the stereo-impression of the ground is lost.

With a half-base model, on the other hand, areas containing up to 50 per cent crown-cover were contoured with confidence, and the contouring was extended successfully into many areas with 75 per cent crown-density.

The benefits of the half-base system in mapping mountainous terrain parallel the pattern for mapping of forested areas. The half-base system was found to furnish insurance against voids in compilation where loss of stereo-imagery was brought about by extremes of perspective viewing of steep slopes. In this type of area the standard convergent model was first compiled to its fullest extent. Then, to fill in any voids in compilation caused by the previously described condition, the intervening projector for the half-base model was set up on the compilation instrument supporting frame, without disturbing the original standard base set-up. The forward- or backward-looking photographic exposure, whichever was needed, was then introduced to form the stereomodel by conventional methods. Any area suitable for mapping with standard vertical photographs can thus be mapped using half-base convergent photographs. Economies result in the use of the latter system, however, since supplemental field control to determine the vertical datum of the stereomodel need only be established for the models of 1.23 base-height ratio.

The reduced requirement in the number of supplemental vertical control points and the increased latitude permitted in its placement is illustrated in Figure 4.

In this hypothetical control plan the circled points are those for which elevations would need to be determined by field methods. Note that these points are selected so as to control the standard base convergent models, that is, those of 1.23 base-height ratio. These points are opposite the alternate photo centers. Photogrammetric elevations (shown by squares) can then be established within these standard base stereomodels for use in controlling two corners of each half-base model. Thus, approximately half as many elevations need to be determined by field methods as would be needed for standard vertical photo operations. There is also available an increased latitude with regard to selection of the alternate combinations forming the 1.23 base-height ratio models to be controlled by field-established elevations.

Areas difficult of access can be more easily worked into the plan for compilation by rearrangement of the plan for using photogrammetric elevations. For example, if circled points *A* and *B* opposite the third photo-center are difficult to obtain in the field, proceeding downward from the upper right-hand corner along the photo-centers in Figure 4, the option exists of establishing field elevations opposite the second and fourth photo-centers and resorting to photogrammetric elevations for the original *A* and *B* points.

One last item dealing with vertical bridging is considered worthy of being brought to attention. The experience in bridging with half-base photographs has been limited but shows promise. The technique developed for this is referred to as the "splint" method. In this, half-base convergent photography with the 0.62 base-height ratio is used. However, the vertical bridge extensions utilize *only* the 1.23 base-height ratio models, bridging in succession *all* such models in the flight. To illustrate, if the successive exposure stations in the flight of half-base convergent photography are numbered in consecutive order 1, 2, 3, 4, etc., then the models used for bridging (base-height ratio 1.23 only) would be 1–3, 2–4, 3–5, and so on. This bridging can be performed on a single model compilation-type instrument by setting-up and taking down the successive models after recording the readings required for bridging. In this method each 1.23 base-height ratio model overlaps the preceding model *and* the succeeding model by a full 50 per cent or an amount equivalent to a

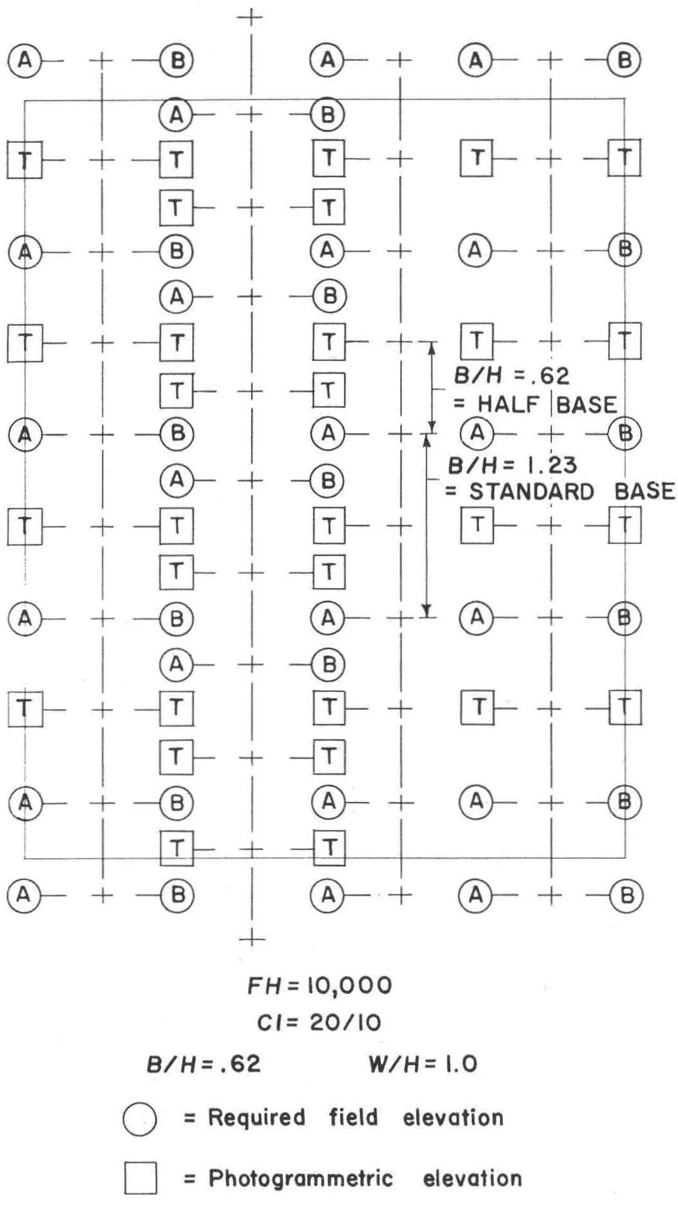

FIG. 4. A supplemental control plan for half-base convergent photography.

complete vertical model. Limited tests so far have shown that photogrammetric elevations established by this method are less accurate than those established by the Twinplex (a 4-model bridge had a mean square error of 5.5 feet compared with 4.7 feet for the same photography bridged in the Twinplex). Since the splint method uses less complex equipment, will tolerate less exact camera-couple orientation, and is not adversely influenced by shutter nonsynchronization, it is worthy of further investigation.

As is generally realized, there are numerous advances in the field of new instrumentation and sophisticated systems of mapping. These advances come so quickly that newer systems at times overwhelm an existing system before it can be exploited to its fullest capability. Certainly the half-base convergent concept will serve to extend the usefulness of the proven convergent system.