Increasing Productivity through Multiple Use of Basic Data

E. S. MASSIE,
U. S. Forest Service, Washington, D. C.*

ABSTRACT: *This paper gives a brief résumé of Forest Service mapping procedures which have been developed for multiple use of required basic materials thereby resulting in over-all economies of operation. In more detail it describes the methods employed to achieve increased productivity in road reconnaissance and design by utilizing the same materials when compatible with photogrammetric plotting equipment and required accuracies.*

Use of existing material decreases costs of new photography and control when procured for obtaining more rigid accuracies for engineering design.

FROM time to time papers have dealt with using photogrammetry in connection with highways. The frequency of appearance and interest in such material has increased recently. One major reason is that for the past several years the need for highways engineers has exceeded the number available by graduation from engineering schools. The shortage of professional men has been accentuated further by the Federal Aid Highway Act of 1956 (70 Stat. 387) which provides for accelerating the improvement and construction of interstate highways.

For some time the highway departments of the various states have been seeking a solution to the problem of a shortage of qualified engineers. One of the courses pursued has been to separate work formerly done by professional engineers into portions requiring professional skill and those which might be accomplished by trained technicians. One State highway department, in the laying of grades and computing earthwork quantities, made an analysis and found that engineers had been performing all of the steps but actually only approximately 30 per cent of the work required professional engineers and the balance could be performed by trained technicians. Another State found it possible to reduce the number of engineers per million dollars of construction from ten to four.

Others have employed the use of photogrammetry in connection with field work. This, coupled with the using of electronic computers, and the division of work between professional engineers and trained technicians, has done much to alleviate the manpower shortage.

The effect of the Federal Highway Act of 1956 on the manpower problem was recognized. This Act authorizes the expenditure of approximately $24.8 billion over a twelve year period, or an average of approximately $2.1 billion per year. The impact of such an increased program on an already over-strained supply of highway engineers is apparent. The Act, taking into consideration time savings effected by improved methods, provides that "in carrying out the provisions of this title the Secretary of Commerce may, wherever practicable, authorize the use of photogrammetric methods in mapping, and the utilization of commercial enterprise for such services."

The subject of highways is of general interest. Public demands require the improvement or construction of such design and character as will afford fast, comfortable and safe travel. The roadbed width, the number of traffic lanes, the profile grade, and alignment or horizontal curvature are dictated by the volume and character of present traffic and that estimated for the future. In short, highway design reflects the economic condition of the nation.

While not as readily apparent, the economic condition of the nation is coupled with the availability and use of our natural resources. One such resource is timber. Years ago vast reserves were available and the volume of timber sales from the National Forests was comparatively low. This was attributable to factors other than sup-

* The author expresses his appreciation to Mr. C. L. Arneson for his review, suggestions and assistance in the preparation of illustrations for this article. Materials used for illustrative purposes were taken from road work accomplished by photogrammetric methods under his supervision.

ply. A large percentage of National Forest timber stands is remote from centers of population, and is located in mountainous areas not accessible by road; this lack of accessibility results in high harvesting costs.

Conditions have changed. No longer is there the same extent of dependence on privately-owned timber resources, this is evidenced by continuous increases in timber sales from the National Forests. The timber cut from these forests was increased from 1.2 billion board feet just prior to World War II to 3.1 billion board feet at the close of that war. In the fiscal year 1957 the timber cut had increased to 7 billion board feet. Increases in timber sales were made possible by the construction of forest development roads. For this work appropriations available to the Forest Service in 1957 amounted to $19 million.

Acceleration of use of the forest resources poses a dual problem. Meeting the demands for timber necessitates continued procurement of data relative to the location and amount of harvestable timber. Such a timber inventory project requires maps on which to record data required for management plans. The construction of access roads for harvesting this timber requires the procurement of planimetric and topographic data. The problem is to meet both needs at minimum monetary and manpower costs.

For the most part the National Forests are located in undeveloped rugged mountainous terrain. The cost is high for procuring horizontal and vertical-control needed for map construction. It is increased when the terrain is covered with timber of varying density and height. This problem is one under constant study by the Forest Service, and its mapping methods are patterned along procedures designed to minimize expenditure of time and money.

Large-scale aerial photographs are required for timber inventory purposes. The smallest acceptable scale is approximately 1:20,000. Scales of 1:15,000 or 1:10,000 are preferred in many cases to provide greater detail for resource studies. Also new pictures are required periodically to keep resource data current.

Map-detail quality as procured from these photographs is excellent. But the cost of mapping is proportional to the number of stereoscopic models required to cover a $7\frac{1}{2}'$ or $15'$ quadrangle. In addition, if each of the stereoscopic models is controlled horizontally and vertically by ground methods, the cost of mapping becomes excessive.

Some 11 or 12 years ago it was decided that the practice of using small-scale aerial photographs for the purpose of controlling large-scale mapping pictures was technically sound. The use of two scales of pictures appeared, therefore, to be worthy of consideration.

Approximately 28 models of 1:40,000 and 112 models of 1:20,000 scale pictures are needed to cover a $15'$ quadrangle. The horizontal-control required for 28 models is not excessive. To control 28 models vertically for use in a Kelsh plotter would require a maximum of 140 elevations if so placed that one appears in the center and also in each corner of the model. Because of using points on more than one model, the number required averages approximately 50 points per $15'$ quadrangle. In timbered rugged mountainous terrain establishing these elevations by spirit levels is time-consuming and expensive. On the other hand, the use of vertical angles to definite photographic image points presented possibilities. Horizontal distances are needed for use in combination with vertical angles to secure differences in elevations. Those secured from templet laydowns of pictures, containing inherent inaccuracies due to tip and tilt in combination with displacement, are satisfactory only for preliminary elevations. More accurate measurements are required for correlation between small-scale control photography and large-scale mapping pictures if standard topographic mapping specifications are to be met. Accordingly, in 1947 experiments were initiated in which individual models were set up in the Kelsh plotter holding to preliminary elevations, to construct templets substantially free from errors due to tip and tilt in combination with displacement. These templets, forerunners of the present-day stereotemplets, were then laid to achieve a more exact orientation and horizontal scale for recomputing elevations needed for each stereoscopic model.

Correlation of 1:40,000 scale pictures with resource photography of larger scale permits selecting image-points common to both scales. With each small-scale picture controlled horizontally and vertically, the horizontal and vertical-control required for resource photography can be determined photogrammetrically on the Kelsh plotter. Field checks proved the adequacy of making multiple use of large-scale resource photography through coordination with small-scale control pictures. This process has been in effect in the Forest Service in construction of standard-accuracy topographic quadrangles of National Forest areas.

As indicated above, timber sales on the National Forests have been increased. This, in turn, resulted in a larger number of miles of timber access roads to be located, designed and constructed. The rate of increase in workload exceeded that of capability to accomplish the job by long-accepted standards. A search for satisfactory short cuts was needed and made.

In the mapping program small-scale control and large-scale mapping photography are available. Horizontal and vertical-control essential to the preparation of area topography has been obtained. A correlation of mapping and road needs indicated a meshing of requirements.

A decision to make a timber sale is based on many factors. Included are the amount, kind, location with respect to the prospective purchaser, and accessibility. The timber inventory provides some of the data but economic harvesting depends, among other things, on the location of the timber access road.

The standard accuracy topographic quadrangle, whether produced by the Forest Service or others, is constructed to the same specifications. These are so well known that a statement in this paper is not needed.

The construction of maps by the Forest Service to conform with these standard specifications has been based on available basic 1st and 2nd order horizontal and vertical-control, supplemented by Forest Service 3rd and 4th order horizontal and vertical-control as needed. Since the scale normally used by the Forest Service is 1:20,000, the control must meet specific requirements. Essentially horizontal-control is to be within 1/200 inch and vertical control within 1/10 the contour interval. At 1:20,000 this equates horizontally to 8′ and vertically to 2′, 4′ or 8′ depending on whether the contour interval is 20′, 40′ or 80′.

The first step in a road project is the reconnaissance of the area to determine possible routes. A standard topographic map is ideally suited for this purpose. The manner in which such a map is used in combination with aerial pictures, and the advantages accruing therefrom, are described in PHOTOGRAMMETRIC ENGINEERING, Volume XXIII, Number 5, page 923. When the topographic map is not available and work must proceed prior to its completion, alternative methods must be employed. One method is the use of stereoscope and parallax bar.

The use of two scales of photography for standard topographic mapping is advantageous in road problems. Small-scale control photography is available for use in resource photography. Horizontal and vertical-control has been secured to make use of this small-scale material. Although obtained for controlling resource or mapping photography, it can be utilized for the preparation of small-scale, large-contour-interval topography along likely road routes. Since control requirements for standard topographic mapping have been met, they are more than adequate for reconnaissance purposes.

This material is suitable for use in a variety of available stereoscopic plotting equipment such as the stereoplanigraph, Kelsh or KEK. Choice is based on desired end product. Figure 1 is illustrative of results obtained. It will be noted that instead of providing complete coverage, topographic information is available only along possible routes. The contour interval is too large to provide more than preliminary grades or distances. It can be used with aerial pictures, however, in the same manner as a topographic quadrangle to determine relative lengths, locations, grades, and conditions for various possible routes of access. No photograph or field control is required in addition to that needed for multiple-purpose use. The use of the topographic data is unilateral, however, and preparation is avoided if time requirements permit substitution of standard topography.

Through utilizing this material the selection of the most feasible route or alternate is made possible. The selected route must be studied to assure compatibility with the road standard. The Forest Service considers this to be a verification of a reconnaissance equivalent to a preliminary location survey. Its purpose is not for final location and design, but to ascertain that alignment and grade can be maintained along the tentatively selected route.

There has been some criticism for the introduction into the process of this phase, called verified reconnaissance. Some feel that data obtained from a standard topographic map is sufficient for the production of center-line and cross-section surveys. Others feel that the reconnaissance can be "walked-out," and while so doing instrumental observations can be made in critical areas.

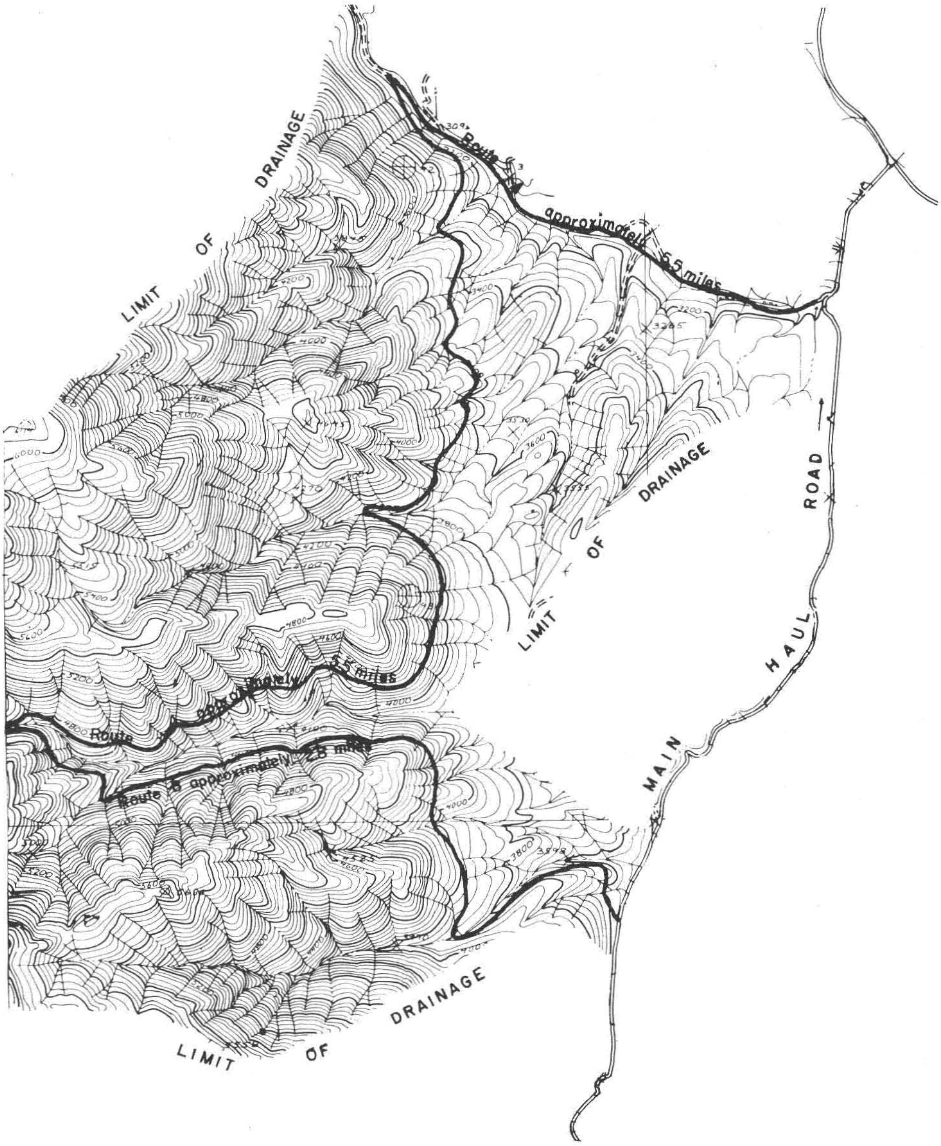


FIG. 1. Area topography showing two alternate routes with drainage area for each.

Omission of the step would be desirable. It may be dispensed with in flatter, more open terrain where grades and alignment are not as critical as in the Berthoud Pass in Colorado, Donner Pass in California, along the Locksa River in Idaho, and innumerable other areas in the National Forests. It took the Forest Service more than two field seasons to force through a 20 mile line along the Deadwood River in Idaho for what might be considered as one possible route for a highway through the Sawtooth Mountains.

The Forest Service is not constructing highways where the amount of traffic, high speeds, and comfort of travel justify comparatively high standards and big monetary expenditures. Instead it is locating, designing and constructing timber access roads which, as the name implies, provide access to bodies of timber ready for harvest and for hauling logs or lumber to mill or market. Roadbed widths may be as little as 10 feet, with unfavorable grades as high as 8 per cent, and with the radius of curve as small as 100 feet. Again photography and control procured for meeting other requirements are utilized to satisfy the verified reconnaissance needs. Aerial photographs of a sufficiently large scale for the dual purpose of resource inventory and standard topographic mapping can be used in combination with the same horizontal and vertical mapping-control. This photography is taken with an $8\frac{1}{4}''$ lens on scales of 1:15,000 to 1:20,000. Flight height for this lens scale combination varies from 10,300 to 13,750 feet above datum. Reported *C*-factors for contouring with a Kelsh plotter vary from 850 to 1,200 and for spot elevations as high as 4,250.[1]

Depending on the *C*-factor used, contour intervals of from 8′ to 16′ can be drawn with this photography with the expectation of meeting standard topographic specifications. Spot elevations in critical areas can be determined within much closer tolerances. Therefore, topography drawn for verified reconnaissance purposes can also

[1] MANUAL OF PHOTOGRAMMETRY and PHOTOGRAMMETRIC ENGINEERING, Vol. XVII, No. 3, pp. 370–375.

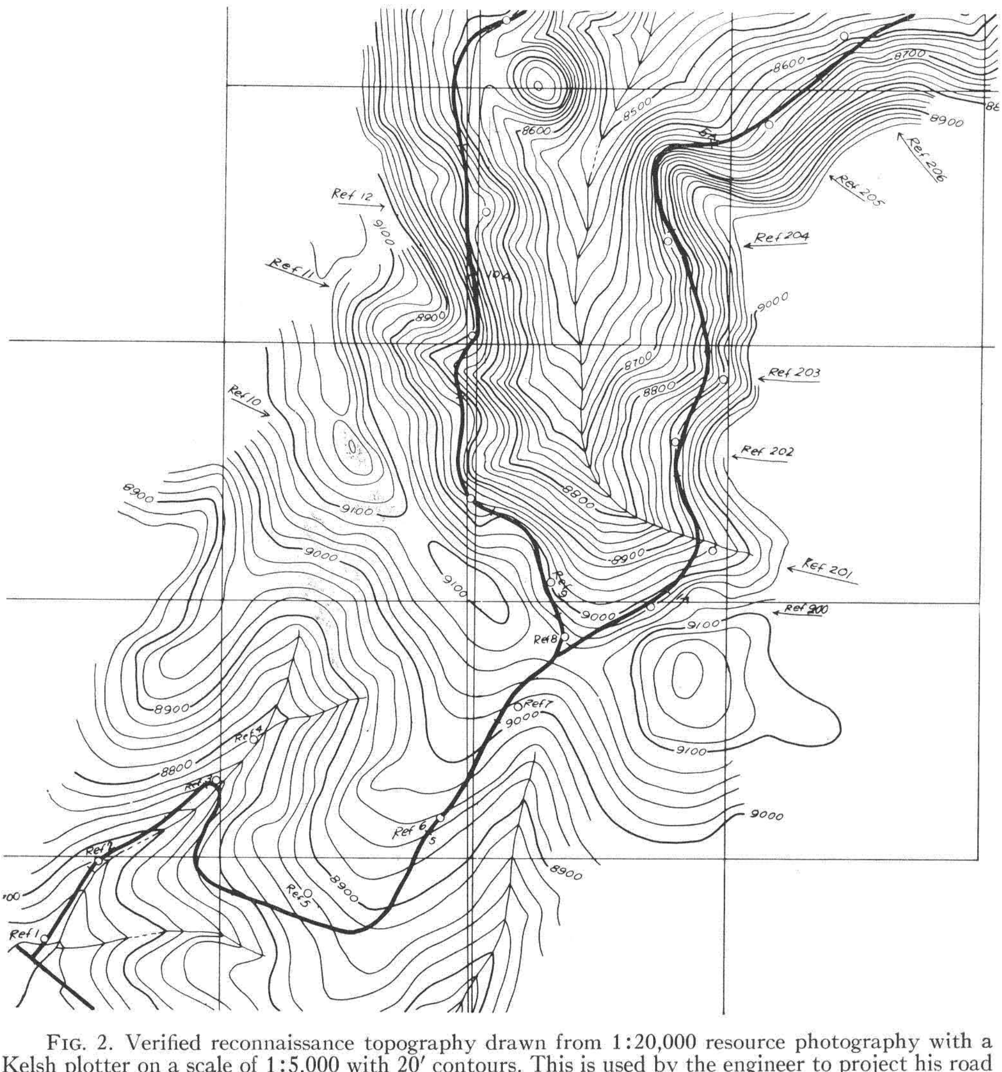


FIG. 2. Verified reconnaissance topography drawn from 1:20,000 resource photography with a Kelsh plotter on a scale of 1:5,000 with 20′ contours. This is used by the engineer to project his road and walk out the proposed route, and in this instance one alternate. Reference points are shown which aid the engineer in locating himself on the ground.

serve as a contribution to area topography.

While based on horizontal and vertical control established for the purpose of complying with the above accuracy specifications, the work on verified reconnaissance is somewhat different from that used in preparing standard topographic maps. Greater care is exercised in delineating contours inasmuch as the Kelsh operator is studying the proposed routes to ascertain any information which will be helpful in connection with road construction. Any evidence of rock outcrops, slide rock, swamp areas and other characteristics visible on aerial photographs is noted. Grades compatible with road specifications are uppermost in the mind of the operator. Accordingly, except for areas where the ground is obscured by vegetative cover, the contours may be expected to be plotted with more care than for standard topographic mapping activities.

The horizontal scale of the verified reconnaissance varies from approximately 1:3,750 to 1:5,000 depending on the flight height. At these scales it is possible to make a preliminary layout of the road with expectancy of reasonable accuracy in grade, alignment and comparative quantities.

By combining horizontal and vertical data procured from this step, it is possible to select a tentative location of the road center-line. Photographic images are selected as close to the tentative center-line as is possible. These are shown on the pictures and the verified reconnaissance strip map. A list of the selected reference points is made and a description of each prepared. Figure 2 shows a section of verified reconnaissance and numbered reference points. Figure 3 shows the routes delineated on the 1:20,000 resource photographs; the areas where targets are to be built are marked. Using resource photographs; with the areas where targets are to be built are marked. Using this information the line can be walked out and a visual inspection made of actual ground conditions. No instrumental observations are required since quantitative information of sufficient accuracy is available by use of the verified reconnaissance.

If no adverse conditions are found which require rejection or modification of this route, work can proceed with procuring material of sufficient accuracy for road design. The accuracy of information discussed up to this point is measurable in terms of standard topographic mapping specifications. Assuming the use of 1:15,000 photographs, the expected accuracy of horizontal data would be 1/30 of approximately 310′, or 10′. The expected accuracy of vertical data would be 1/2 of 10′, or 5′. While not of great magnitude, and entirely adequate for standard topographic mapping, the possible error is excessive for engineering surveys.

The above might be rephrased. Up to this point, Forest Service procedures have made possible making multiple use of basic data to determine road location to within narrow limits. Greater accuracy requirements for further road work make these data inadequate. Therefore, it becomes necessary to procure single-purpose data to complete the job. The cost of procuring this additional information is kept to a minimum through using materials available for multiple uses.

The term "strip mapping" has been adopted as the name for this single-purpose material. In terms of engineering requirements the desired scale is 1 inch equals 100′ or 200′ with a contour interval (depending on conditions) of 1′, 2′ or 5′. Several factors require special attention in connection with processing the strip map.

Short focal-length wide-angle lens photography is more conducive to accuracy than longer focal-length normal-angle pho-

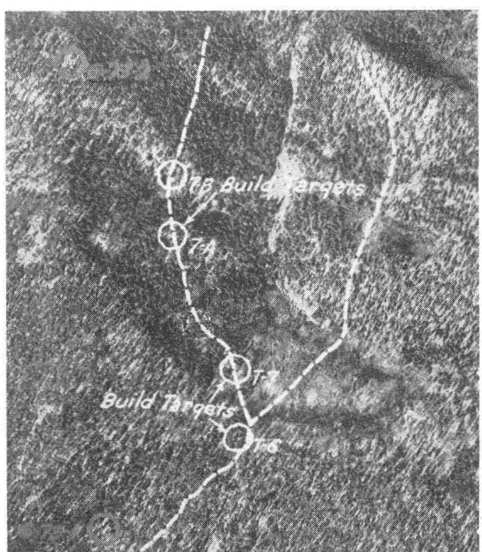


FIG. 3. A portion of a resource photograph used in the preparation of Figure 2. The proposed routes and location of points for construction of ground targets have been delineated on the picture.

tography taken from the same flying height. If a 6″ Kelsh plotter is to be used for plotting at a scale of 1 inch equals 100′ the flying height would be approximately 3,000′. The empirical *C*-factor for 5′ contours with this combination would be 600. Expected accuracy should be greater than $2\frac{1}{2}'$, or $\frac{1}{2}$ the contour interval.

Many timber access roads are built in canyons with timber-covered sidehills. An example is shown in Figure 4. Low flying presents a hazard. If accomplished the photographic image of trees is an oblique instead of a vertical view. Openings in tree canopy which permit stereoscopic viewing of the ground are closed.

If an $8\frac{1}{4}''$ instead of a 6″ Kelsh plotter is used, the flying height is increased to 4,100. This 1,100′ decreases the flying hazards and is needed particularly in country where the

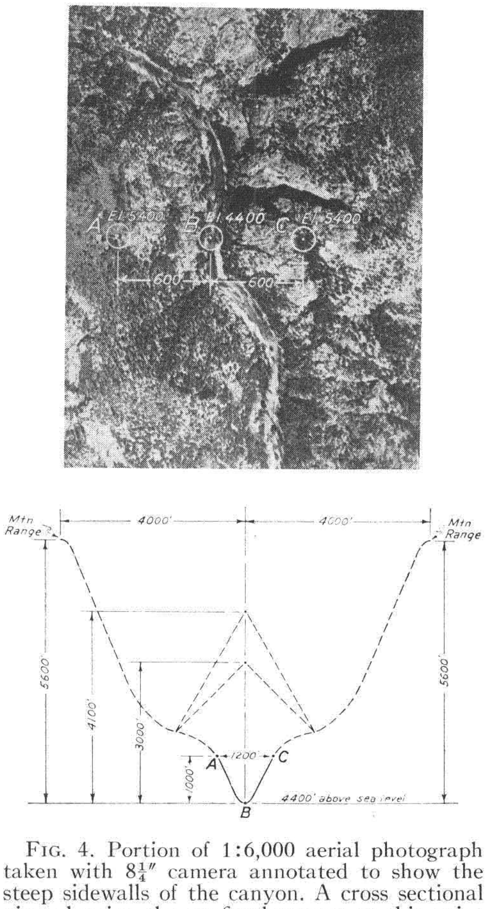


FIG. 4. Portion of 1:6,000 aerial photograph taken with $8\frac{1}{4}''$ camera annotated to show the steep sidewalls of the canyon. A cross sectional view showing the confined canyon at this point has been extended beyond photographic coverage to show relative positions of the plane with respect to adjacent mountains.

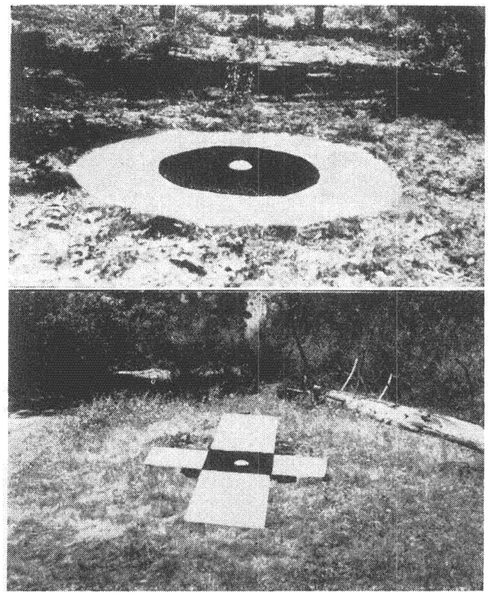


FIG. 5

mountain peaks on either side of the flight line are higher than plane elevation. The normal-angle lens decreases obliquity and tends to preserve openings in the tree canopy. While the empirical *C*-factor is increased to 820, the Kelsh plotter still qualifies for use with expected accuracy exceeding $2\frac{1}{2}'$ or $\frac{1}{2}$ the contour interval. Therefore, the $8\frac{1}{4}''$ lens has been adopted as offering the better possibilities of securing desired results.

Adoption of this particular combination of lens, scale of photography, scale of strip map, and contour-interval has presented other factors at variance with those normally encountered in standard topographic mapping. The reference points indicated in Figure 3 may have been a small tree or bush. With 1:4,800 scale photographs viewed on a scale of 1″ = 100′ smaller reference points are required for positive identification and positioning. Diameters of one and two feet are discernible. Natural objects of this size which will photograph are difficult to find. Therefore, ground targets such as shown in Figure 5 are constructed prior to photographic operations. These serve more than one purpose. Horizontal or vertical control for road construction purposes include these targets, thereby providing positive coordination of field work with photogrammetric operations. They serve as navigational aids in procuring special large-scale photography facilitating placement of photographic flights. They are easily recoverable at the time of road construction and provide the needed reference points for use in construction.

The strip map may be procured by contract or force account. For either method, the verified reconnaissance is available for use in the execution of the work. It is an excellent flight map on which flight-lines and ground-targets may be shown. It also serves as a guide to the extent of contouring needed. Figure 6 is the same as Figure 2 with the exception that photographic reference-points have been replaced with the location of ground-targets, and flight-lines with desired flight-heights have been added. It should be noted that individual flight-lines are required, rather than several parallel strips to secure adequate width of topography which is restricted to short distances on each side of the center-line.

The Forest Service is equipped with first-order stereoscopic plotting instruments. This equipment has made possible executing a modified photogrammetric bridge, holding to within one and two feet to horizontal positions established for construction phases of road work. When the bridge coordinates have been employed as the means of setting up models on a Kelsh plotter, little if any adjustment has been necessary. Scale is established and the model horizontalized on three vertical points. With using the vertical elevation in the fourth corner of the model, it has checked to within such close tolerance that little, if any, adjustment has been necessary. Readings on ground targets agree with constructional elevations.

At present the Forest Service is engaged

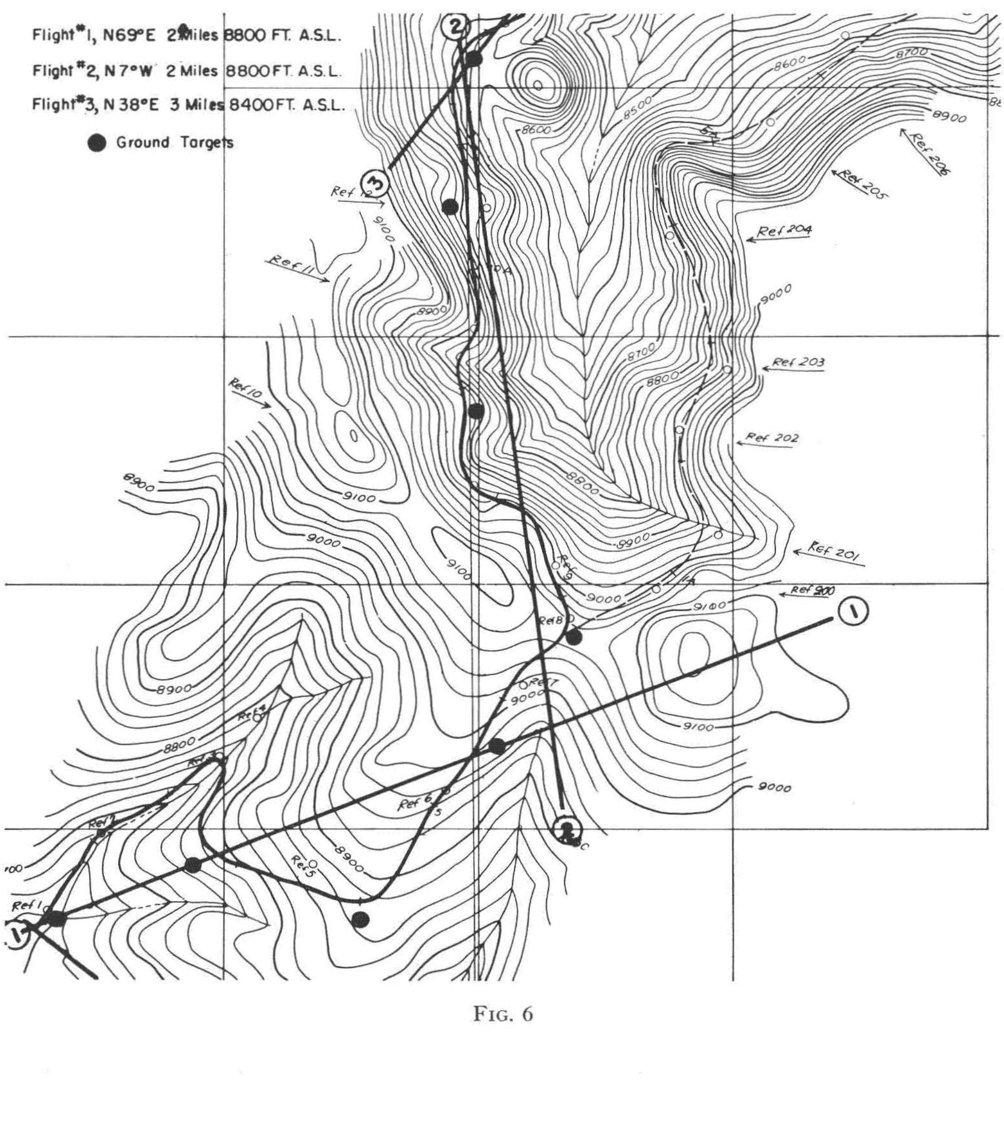


FIG. 6

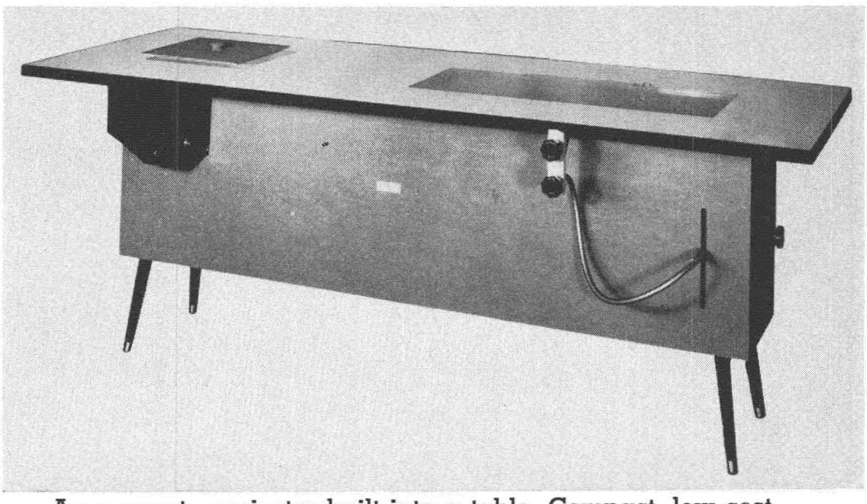
in taking the equivalent of cross-section survey notes by photogrammetric processes utilizing the Kelsh plotter. Elevations are read directly. Since the plotter in use is not equipped with a coordinatograph, the distances are scaled. These notes are so prepared that they can be employed in electronic computers for the calculation of earth work quantities.

Another project underway consists of the execution of a stereoplanigraph bridge for an area of approximately 300 square miles. Five flight-lines of photography are needed to cover the area. Horizontal and vertical-control has been executed in the area specifically for this project, with vertical-control established on ground-targets to assure vertical accuracy required for engineering surveys. The horizontal adjustment[2] for the first strip has been completed withholding horizontal positions, as a means of checking the accuracy of the bridge work. After the elimination of mis-identification of ground-control, errors in the bridge are of such small magnitude that use of the method is assured. The vertical adjustment has not been completed but a direct tie exists between bridge-control and engineering elevations to provide for any needed correlation.

Extensive timber operations are planned in the area. Additional timber access roads will be needed as these operations proceed. This knowledge led to the use of the stereoplanigraph bridge for the entire area. As the need for these additional roads arises, basic data will be available for use in location, design and construction.

[2] The assistance of the U. S. Coast and Geodetic Survey, utilizing its own methods, in adjustment of the bridge and checking Forest Service work, is gratefully acknowledged.

KAIL REFLECTING PROJECTOR—MODEL K-5



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