tion, they afford a convenient, inexpensive source of information concerning map accuracy. Highway engineers should take the lead in the development of data on map accuracy as a means of increasing the usefulness of photogrammetric mapping.

In conclusion, the author acknowledges the contributions to this study made by Rex H. Fulton, Senior Highway Engineer and George P. Katibah, Supervising Photogrammetrist, of the California Division of Highways. Over a period of several years Mr. Fulton has been responsible for many of the improvements in California mapping specifications as well as for using the stereoplotter in map checking. Mr. Katibah has supplied technical knowledge and supervision necessary for map accuracy investigation and plotter checking.

REFERENCES

1. Sharp, John V. PHOTOGRAMMETRIC ENGINEERING, June 1951, Page 358.
2. Thompson, Morris M. and Davey, C. H. *Surveying and Mapping*, January-March 1953, Page 40.
3. Thompson, Morris M. *Surveying and Mapping*, April–June 1956, Page 164.
4. A.S.T.M. Manual on Quality Control of Materials, Special Publication 15-C.
5. Harman, William E., Jr. MANUAL OF PHOTOGRAMMETRY, Page 262.
6. Altenhofen, Robert E. PHOTOGRAMMETRIC ENGINEERING, June 1951, Page 370.
7. Struck, Luis. PHOTOGRAMMETRIC ENGINEERING, March 1952, Page 84.
8. Trorey, Lyle G. PHOTOGRAMMETRIC ENGINEERING, December 1951, Page 831.
9. Pennington, John T. MANUAL OF PHOTOGRAMMETRY, Page 639.
10. Pryor, William T. *Highway Research Board Bulletin 157*, Page 23.

*Photogrammetry and Road Location in the U. S. Forest Service**

C. E. CARNAHAN,
Division of Engineering,
U. S. Forest Service, Ogden, Utah

ABSTRACT: *The author describes the photogrammetric road location and design procedures developed and used by the United States Forest Service. The processes cover all phases of road survey operations from reconnaissance through final design. A brief discussion is given to the tests conducted by the Forest Service to determine what first order photogrammetric equipment would best serve their needs. The work evolving around the Stereoplanigraph C-8 is broken down into seven distinct operations to obtain the necessary information at the required accuracy for the successful design of a road construction project.*

IN RESPONSE to the mounting demand for National Forest timber products, the Forest Service of the U. S. Department of Agriculture is engaged in a steadily expanding construction program for forest development roads. Ten years ago, the Forest Service was building less than 1,000 miles of road annually. Recent years have witnessed a considerable increase in road construction financed from appropriations

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and an even greater increase in the mileage of roads constructed yearly by purchasers of National Forest timber. Roads in both categories are located by Forest Service engineers. 3,580 miles of National Forest development roads were completed in the fiscal year ending June 30, 1957. Projects aggregating 3,500 miles or more will be commenced during the current fiscal year. Meanwhile, surveys are being made and plans prepared for 3,700 miles of construction and major reconstruction scheduled for the fiscal year commencing next July 1.

This accelerating activity together with the acute shortage of civil engineers made necessary searching for a new approach to our road survey problems. Early in 1956, after careful consideration of several alternatives, the Regional Forester for the Intermountain Region approved the establishment of a Photogrammetric Section in the Division of Engineering for that region. Its function is to locate and design roads through the use of aerial photographs and first-order photogrammetric equipment.

The heart of the Photogrammetric Section is the Stereoplanigraph C-8, manufactured by Zeiss Aerotopograph of Munich, Germany. It was installed at Ogden in February 1957. Two technicians from Germany accompanied the equipment to install, adjust and calibrate it, and to conduct a training program for section personnel.

The sequence of operations involved in photogrammetric road location varies with and is dependent upon the working data available. For illustrative purposes it is assumed that a project is located in an area for which standard U. S. Geological Survey topographic maps and 1:20,000 scale resource photography are available. The steps followed in locating, designing and determining costs of the road to be built are as follows:

Action is taken to obtain an exact-scale copy of the original topographic manuscript on which is shown all existing field control, both horizontal and vertical, thereby assuring that all basic data are made known to the Section. Using these topographic manuscripts, preliminary locations are traced, care being exercised to keep within the grade and curvature limitations of the standard of road design desired. At the conclusion of such work it may be found that five or six possible routes have been delineated for consideration.

By utilizing the available 1:20,000 photography and third-order photogrammetric plotting instruments, these preliminary lines are transferred very carefully to the photographs, thus producing a "bird's-eye" view of the several possible routes for the proposed road. The photogrammetrist has now made available to the design engineer a delineation of preliminary locations from which a vast amount of information can be obtained. A report is prepared describing each line in detail with regard to grade, per cent of sidehill slopes needed to hold the road, type and density of cover, and all unusual topographic features which might be encountered.

At this point the soils analyst begins to study the survey material. The Intermountain Region is exceptionally fortunate in that the staff has a soils specialist who has made an intensive study of photo interpretation as it pertains to soils, and who is capable of determining probable soil structure from the appearance of topographic features and of cover types with correlation with soil classification maps. He prepares a report on each traced line in which he points out the advantages and disadvantages expected to be encountered. His report also indicates areas in which heavy rock work is apparent, those in which unstable soils are likely to be encountered, the intensity of drainage dissection, probable subsoil conditions, etc. All of these can be predicted to a certain degree of accuracy. The importance of such preliminary data cannot be overstated.

If timber survey maps are available, the routes are also delineated on them, thus further completing the picture for consideration by personnel involved in Timber Management. It quickly tells the story of the type, age and density of timber which will be reached by adding the road to the Transportation System.

Following the preparation of maps, photos and analyses, the material is submitted to the Forest Supervisor under whose jurisdiction the proposed project falls. He, with his Forest Engineer and other members of his staff, select the most appropriate route. By this means there is a feeling of certainty that the road will be located where it will best serve multiple use of the forest. Without question this is the most important service that this part of the Engineering Division can provide.

It is mandatory at this point in the operations for the Forest Engineer or other competent person to traverse the selected route by foot or horseback to gain first-hand information, to verify the grades and interpretations, and to set reflector signals for use as reference points which will register on the large-scale photography which must still be obtained for survey purposes. This step is called "verification of route reconnaissance," since, up to this time, route study has been conducted without putting a survey crew in the field.

The reflector signals set during ground reconnaissance serve an extremely important function in photogrammetric surveys. First, as a positive and unquestionable tie between the paper and ground locations. The signals are normally located at convenient intervals along the route where they will serve as reference points and also on all section, quarter section, H.E.S. and other land monuments which determine the location of private land holdings. Signals are set on any field established elevation, traverse PI or triangulation station which may be encountered along the route. By marking these points prior to acquisition of the survey photography, the accuracy of all operations is considerably increased, and the data are more easily utilized.

Before proceeding with a discussion of the actual processes involved in determining the road location and design, there will be briefly considered the background that motivated the Forest Service to invest in high-order photogrammetric equipment.

The original efforts of the Forest Service were developed around Kelsh plotter-type equipment since this was available and the personnel were well versed in its operation and capabilities. Several projects were undertaken—each with a variation in the procedural approach and with varying degrees of success. The procedure was essentially one of drawing a large-scale topographic strip map using the the Kelsh plotter and designing the road on this base. Regardless of the technique employed, there were continual limitations characteristic of the machine, such as the graphical analysis or radial plot which is required to tie stereo-models together and to ground-control, its inability to extend costly field-control, and the human tendency to commit errors.

In 1955, Zeiss-Aerotopograph of Munich, Germany, offered the Forest Service the use of its RMK 21/18 camera and a C-8 Stereoplanigraph for test purposes, to determine the capability of this equipment to perform precise photogrammetric surveys. The Forest Service accepted the offer and selected an area on the Tahoe National Forest in California for use as a proving ground. The tests conducted there were to study advanced photogrammetry as applied to cadastral surveys and engineering surveys of bridge sites, dam sites, administrative building sites, and road location. The Tahoe Project was photographed at varying scales with the RMK 21/18 camera during the summer of 1955. Field-control operations were executed in the same season by U. S. Forest Service engineers. Subsequently, during the winter, Mr. J. E. King went to Munich, Germany to present the problems and to observe the work in progress. At this point acknowledgement is made of the exceptionally fine work and cooperation by both the Forest Service personnel in California and the Zeiss-Aerotopograph organization; largely because of their combined efforts the recent advances were made possible.

For the benefit of those interested in the cadastral survey application of these tests, attention is invited to Mr. King's report, "Photogrammetry in Cadastral Surveying" which was given before the combined meetings of the American Society of Photogrammetry and the American Congress of Surveying and Mapping in Denver, Colorado, October 2, 1956.[1]

An analysis of the data obtained through these tests (with emphasis on accuracy) formed the basis for purchasing one RMK 21/18 camera and two Stereoplanigraph C-8 instruments. One instrument is located at the Eastern Photogrammetric Section, Alexandria, Viginia, and the other at the Intermountain Regional headquarters of the U. S. Forest Service in Ogden, Utah. The latter instrument is devoted entirely to road location operations, and is the equipment which is the subject of today's discussion.

In considering the subject of equipment and why it was selected for the Region's road location operations, first to be con-

[1] Published in PHOTOGRAMMETRIC ENGINEERING, Vol. XXIII, No. 3.

sidered is the aerial camera, the RMK 21/18; this has a focal-length of $8\frac{1}{4}''$ and a $7\times7''$ format. The accuracy tests to which this camera has been subjected rate the resolving power of the lens at roughly twice that normally found in $8\frac{1}{4}''$ lens; its measured distortion is 3 microns as compared to 25 microns frequently encountered in conventional cameras. It has a new, extremely fast shutter which will operate up to 1/1,000 of a second, thus making it capable of practically stopping image motion at the instant of exposure. The intervalometer which actuates the shutter has automatic features incorporated within it which make virtually impossible the photographer losing the desired overlap in line of flight. All of these features add up in the long chain of items affecting accuracy. But of all these precision characteristics, the most important is that the camera is matched to the Stereoplanigraph C-8 and becomes a companion instrument in every sense of the word.

Perhaps the question most frequently asked is, "what makes a first-order instrument so much better than those of lower order?" This will be answered briefly:

1. The resolving power of the optics incorporated in the instrument.
2. The accuracy of its tracks, ball-bearings, spindles, and motion trains.
3. The accuracy of the camera lens-distortion compensating device.
4. The magnification ratio of its viewing system.

Some of you may think of the accuracy of photogrammetric equipment in terms of *C*-factor, which is defined as the ratio of the photographic flight height to the smallest contour interval which can be drawn. Those in the Forest Service involved in applying photogrammetry to road location do not use this concept; instead the thought is in terms of point measurement, and it is recognized that many things enter into the picture when determining *C*-factors which do not apply to the Section's work.

The drawing of contours causes a loss in accuracy since the operator does not have the opportunity to make repeated measurements. Further, the ability of operators to move a floating mark over the surface of the ground varies radically between individuals.

The *C*-factor was originally conceived for use as a tool in planning a photogrammetric topographic mapping job, and values were assigned to various plotting instruments for this purpose. However, it is felt that it fails to represent the true accuracy of the instrument.

The preference is the determination of the root mean-square error of the measured values made on precision grid plates. These must be oriented in the machine and multiple readings made on each grid intersection by the operator so as to minimize the human element of error. The recorded values of these measurements are then analyzed for the accuracy obtained. Using this means that by checking the C-8 Stereoplanigraph in Ogden on a projection distance of 418 mm., its accuracy was determined to be 1:17,800 of this distance. This means that measurements can be made to 0.0235 mm. on $8\frac{1}{4}''$ photography; this value in terms of feet-on-the-ground will vary with the scale of the photography. As an example, assume it is decided to obtain photography for a survey job with the RMK 21/18 camera flying at an elevation of 3,500 feet. By simple ratio it is determined that *under ideal conditions* the machine is capable of measuring to 0.2 ft. in vertical displacement. This figure, as has been stated, applies strictly to the machine capabilities.

The actual field tests of the equipment reflect the accumulated errors of all the equipment, materials and processes utilized to produce the diapositives being used. The test therefore becomes realistic and true and not one of comparison.

The photography obtained on the Tahoe National Forest Project, for use in the Munich test for profiling and cross sectioning, was 1:2,400 (200 ft. per inch). The control was established photogrammetrically from 1:27,000 scale photography, also flown at this time.

The area of the test is described by the field crew as follows: "Topographic features consist of ridges, gulches, and slopes of varying steepness with dense coverage of manzanita 8 to 12 feet in height. There are many madrone, oak, pine and fir trees scattered throughout the area. Poison oak, bitter brush and severe erosion in some of the gulches combine to make this a difficult test for the plotter." A ground check traverse was run over 31 centerline stations and 6 cross sections selected at random from the centerline and cross-sections established and measured by the plotter. The extent of the field check was reduced due to the heavy line clearing which was found necessary. Thirteen man-days of work were required to check this limited area, which gives an indication of the cover density. The average error of the 100 points tested was ±0.51 ft.; however, 50 per cent of the points that were checked showed an error of 0.3 ft. or less, and 65 per cent were with 0.5 ft.

A recent test made on the Ogden machine in which 1:15,000 scale photographs were used resulted in an average error of 0.4 ft. for 15 points tested. Interfering ground cover in this instance was sparse; this eliminated the problems presented by the dense brush cover encountered in the Tahoe test.

Accuracy, although of prime importance in the Forest Service concept of photogrammetric surveying, is not the only consideration. It is well known that the areas in which the Forest Service has to operate are remote, rugged and often difficult to reach. All field surveys and operations are difficult and costly. With the Stereoplanigraph, control can be extended through inaccessible areas by a process known as Stereotriangulation or "Bridging," thus making possible establishing field control where the least cost and effort are required. This is a point of major importance.

Still another extremely valuable characteristic of the Stereoplanigraph is the plane-coordinate grid system incorporated within it, and an attendant tabulating device which records the x, y and z coordinates at any point measured with the floating mark. The existence of these features point immediately to the possibilities of the mathematical treatment of data and its transformation to the State Plane Coordinate System for ground application.

The techniques used to arrive at final design may vary to a certain extent from project to project depending upon the basic information available; however, they have now reached the point where there is confidence in proceeding in a positive manner.

The Section's concept of photographic needs for road location operation is identical to that of the Ohio Department of Highways. Two scales of photography are used—one for reconnaissance and control purposes and the other for design. The small-scale or control-photography is normally about 1:20,000 scale. Design photography may vary from 1:2,500 to 1:10,000 depending upon the class of road desired, ruggedness of terrain, and density of cover. The very nature of National Forest areas, rugged terrain, relative low land values, inaccessibility, etc. permit the use of smaller scales of photography; and concurrently a lower order of accuracy than would be required in heavily populated and industrialized areas.

Assuming that a given project has been authorized for survey and that the reconnaissance has been completed, and the route selected, the procedure to be followed in actually completing a survey will now be discussed.

First—Field control (both horizontal and vertical) is established to meet the requirements of the Stereoplanigraph *and* the small-scale photography. Full use is made of all existing 3rd-order or better control which has been established and published by the various responsible government agencies. This may necessitate a little search and a bit of correspondence; however, the effort is usually well rewarded. It may be found that level lines and triangulation stations already established will serve the needs and that actually these already have been photo identified, thus entirely eliminating field operations. Usually, however, some additional field work will be required, and this is accomplished by using the T-2 theodolite for horizontal and vertical-angle measurement and self-leveling level for vertical control.

At this point acknowledgement is made of the exceptionally fine cooperation received from the Geological Survey through making its field control data available. The cooperation between these two agencies is an excellent example for all Government agencies.

Second—If the reflector signals previously mentioned were not set during verification of the reconnaissance, they must now be established. The importance of this operation cannot be overestimated; upon it much of the accuracy of the survey is dependent.

Third—Both control photography and large-scale aerial photographs for design use are obtained with the RMK 21/18 camera. The ratio of these scales should not exceed 3 to 1 due to differences in image, size and concurrent reading acuity. The camera is owned by the Forest Service. National Forest aerial photography is ordinarily contracted but owing to difficulty attending advance scheduling of road survey photography, only the plane and pilot are contracted. The photographer is a Forest Service employee who is well informed on the requirements of the photogrammetric equipment and in addition is acquainted with the forest areas in which the work is being done. His all-around knowledge is exceptionally helpful.

Fourth—With the small-scale photography and the field-control which has been obtained, the photogrammetrist using the Stereoplanigraph establishes and extends supplementary control by the Stereotriangulation or "Bridging" technique. Roughly, this may be described as the precise orientation of the initial model to established field control, to which is added a succession of 3-dimension models to form a network of control similar in appearance to a field triangulation scheme. As this network is extended it intercepts other field established control. Because the machine bridges along a flat plane which does not correspond with the earth's surface, and because of minute systematic errors in even this precision equipment, it is reasonable to expect deviations from the true values of field established control at a *systematic rate*. It is apparent then that because these deviations are systematic, this elimination or correction can be accomplished mathematically. The differences in the recorded and ground-coordinates form the basis for this mathematical adjustment. This adjustment applies not only to the limited field-control points but to all machine measured points as well. It is obvious that this is a tremendous undertaking in mathematics.

At the time this paper is written, the Section is cooperating with various computor companies, Zeiss Corporation and the Coast & Geodetic Survey in the establishment of a fully electronic computer adjustment. It is believed that its successful conclusion will surely be realized quickly. In making this spacial bridge, in the same operation, there is established supplementary control for the large-scale design photography. This is merely a matter of selection and measurement of points common to the two scales of photography.

Fifth—A second bridge is made, this time utilizing the large-scale (or design) photography and the supplementary control established by the first "bridge." The technique is identical to the first, and its purpose is to further refine the machine-established control, minimizing any reading errors which may have been committed.

Sixth—Following the second adjustment the diapositives are re-oriented in their corrected positions and work may proceed with design and cross-sectioning and the establishment of coordinate values on reference points which had been marked during the verification of the reconnaissance. It should be pointed out that at this point the work may be "farmed-out" to second-order plotting equipment for drawing strip topography.

It is believed that the characteristics of the C-8 can best be used in point measurement whether it be control extension, profiling, or cross sectioning. If contours are to be drawn in any amount the work should be delegated to less expensive equipment. Whatever the innovations introduced at this point—the final step is to actually profile and cross-section the designed road with the Stereoplanigraph in order that the most accurate measurements possible may be recorded for traverse and earthwork quantity determinations. In this way, the errors inherent in contour lines and the attendant errors of interpolating and scaling data from them are avoided. Currently attempt is being made to design a section of road without strip topography; its possibilities cause enthusiasm.

Seventh—The final step is drawing plans and profiled and completing the calculations necessary prior to issuing construction contracts. The possibilities of using electronic computing equipment to achieve final results from data furnished via the Stereoplanigraph was at the outset exciting, but not considered particularly necessary. As the work has progressed and methods have developed, this combination of Stereoplanigraph and electronic computer has become more and more important. Although the actual computation work has not yet been completed by electronics—the plans are made and the procedure established except for minor details. In a few short weeks this phase of the operation should be well established and in good operating order.

What is gained by turning to photogrammetry for road location surveys? (1)

a location acceptable to the majority of interested people; (2) a twelve-month survey season instead of the usual six; (3) a saving of engineering manpower for preparing contract specifications and supervision of construction; (4) the survey dollar stretched over many more miles than it previously covered; (5) already a saving of many miles of high-cost construction and avoidance of difficult areas by being able to "look ahead" through photogrammetry.

Although the equipment represents a considerable monetary investment, there is every reason to believe that in two to four years it will pay for itself in actual cash savings to the U. S. Forest Service. This estimate is based on a double-shift capacity of 150 miles of road design per year at a savings of approximately $300.00 per mile or $45,000 per year. Each operation is directed toward saving time and money and the elimination of interference from adverse weather conditions, limited field season and personnel shortages.

The efforts are only just beginning to materialize into production. The operation has been shifted into second gear—so to speak—with 16 hours of operation per day; there is hope of having seven road surveys completed within the next 6 or 8 months. A standing invitation is given to visit the laboratory to observe the work, discuss procedures and exchange a few ideas. Like topographic mapping, engineering surveys have taken to the air and tedious computations are being comfortably consumed by the electronic computer.

The Forest Service engineers have accepted these new tools and are enthusiastic about their possibilities. It is hoped that they will help others to accept and use these tools successfully.

The operations and procedures described in this paper are in use by the Forest Service, U. S. Department of Agriculture at the Region 4 headquarters of the Forest Service at Ogden, Utah. Dr. Richard E. McArdle is Chief of the Forest Service and Mr. Floyd Iverson is Regional Forester for Region 4. Mr. Arval Anderson is the Assistant Regional Forester in charge of the Division of Engineering and the author is Chief of the Cartographic Section of that Division.

*Mapping of the Ungava Peninsula**

S. G. GAMBLE, *Chief Topographical Engineer, Dept. of Mines and Technical Surveys, Ottawa, Canada*

ABSTRACT: *The mapping of the mineral wealthy Ungava Peninsula of northern Quebec has provided the Topographical Survey of Canada to assess new survey and photogrammetrical techniques on a large practical test. The environment is described with particular emphasis on mapping conditions and the initial planning and surveys are outlined. In the Ungava operation the application of electronic instruments was impressive and included the use of Shoran for geodetic control, radar altimeters for vertical control and horizontal scale, tellurometers for secondary survey control and for establishing scale on selected flights. Experience gained from the Ungava project should reduce the cost of mapping in the northern areas of Canada.*

THE mapping of the Ungava Peninsula of northern Quebec has proved to be one of the most important mapping projects ever undertaken by the Topographical Survey of Canada. The reason is not that the potential mineral wealth of the Penin-

* By permission of the Director, Surveys and Mapping Branch, Department of Mines & Technical Surveys, Ottawa, Can., presented at 24th Annual Meeting of the Society, Hotel Shoreham, Washington, D. C., March 26, 1958.