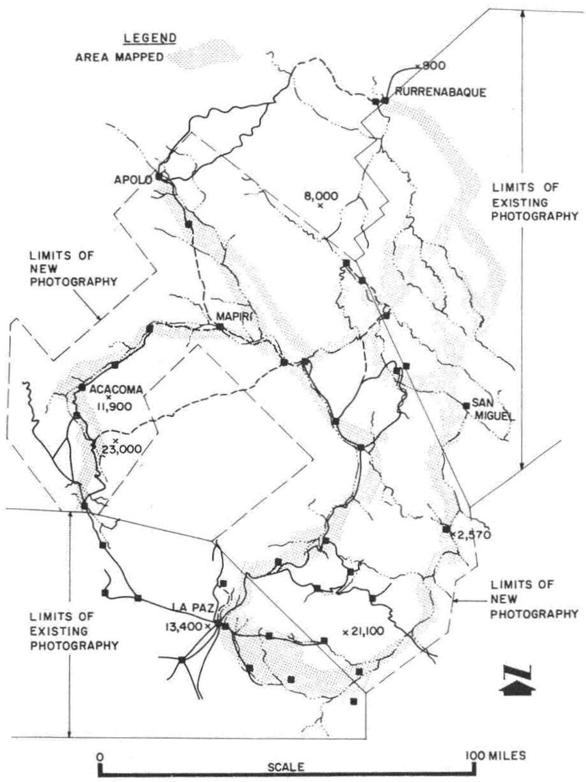
FIG. 1. Area covered by the reconnaissance study, see text page 123.



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Highway Routes in Undeveloped Areas

The selection is based on reconnaissance mapping calling for certain ingenious deviations from conventional practices used in the United States.

(*Abstract on next page*)

DESPITE THE OVERPOPULATION of some areas, vast regions of underdeveloped lands still remain, some practically devoid of human inhabitance. Governments everywhere desire to make these areas accessible and to encourage their people to develop their countries' natural resources. Organizations involved in forestry, mining, and similar activities also wish to develop these areas commercially. Therefore, it becomes a matter for the highway engineer to design and build access roads in order that development can take place. The use of photogrammetry for highway development in the United States has been well documented,[1,2] but in areas where conditions are less than ideal, its uses have not been so clearly recorded.

One of the first steps in development is the reconnaissance survey, but prior to it there is a need for map coverage upon which to base plans. More often than not, the coverage is nonexistent, or of such quality as to serve only as a general guide to the area. It is not necessary that the map meet the requirements set forth in the National Map Accuracy Standards. In general, these standards require that contours be within ½ interval of the true elevation and horizontal positions be within 1/30 inch. The extent to which these maps will approach these standards will depend upon the amount and distribution of the ground control. It is important, however, that they have good relative accuracy.

ABSTRACT: *The requirement for reconnaissance mapping in the early stages of highway engineering utilizes the advantages of aerial photogrammetry. Specifically applicable are undeveloped areas where no suitable map coverage exists. The use of existing aerial photography and ground control are necessary in developing the survey. A typical project in Bolivia extending from the Amazon Jungle near sea level to over 15,000 feet is used as an illustration. The requirements, procedures, and results, plus some of the problems encountered both in the office and in the field are important. The extent of existing control and photography, as well as newly acquired control and photography, serve to illustrate the photogrammetric problems.*

RELATIVE ACCURACY can be explained as follows: if the true ground profile were to be established and compared with that taken from the relative accuracy map, the elevations shown for two widely separated points might differ considerably from the true elevation. For example, one point might be two or three contour intervals above the correct elevation; the other point might be two or three intervals below the correct elevation. Somewhere in between these two points the elevation would be correct. The important point is that the change be gradual. Thus, for any relatively short segment of a possible route, the correct ground shape would be portrayed by the map and, therefore, the map could be used as a basis for designing highway grades and alignments. Later when more detailed surveys are made for the selected route and final plans are developed, minor adjustments in grade can be made to correct for the initial error, without changing the general alignment.

A survey of this type requires three basis ingredients; namely, aerial photography, ground control, and office compilation. The first question then becomes. . . . What photo coverage exists? From a strictly photogrammetric engineering standpoint, it would often be desirable to ignore existing coverage and design new flights for the specific project. However, the existing coverage has two distinct advantages. First, it is immediately available. Secondly, the over-all cost of the project can probably be reduced. The first step is to examine the photography with regard to its potential. The following questions must be resolved. Where is the film stored? Can it be made available? Does the calibration report for the camera used indicate characteristics suitable for precision plotting? Last, but not least, is the matter of photography scale. If the scale is too large, the number of pictures involved would be excessive, increasing the compilation cost. Furthermore, it would make the control solution difficult, if not impossible.

THE NEXT REQUIREMENT is ground control. Without it, the photography would be of questionable value. Existing control could range from first order geodetic stations to astronomic observations. It is not necessary that the control be located within the project area as photogrammetric bridging will serve to extend the control from relatively distant locations to the project.

From beginning to end the work must be in the hands of trained and experienced photographers, surveyors, engineers, and photogrammetrists. They must be capable of providing good judgment at every turn and taking advantage of every bit of information which is available. This is especially true where existing photography and control must be utilized. Information of questionable reliability must be recognized and eliminated.

A RECENT PROJECT in Bolivia will serve to illustrate many of the problems encountered in a project of this type. In 1962, Tippetts-Abbett-McCarthy-Stratton, worldwide consulting engineers, invited Mark

Hurd Aerial Surveys to join them in a highway design project involving approximately 800 kilometers of new or realigned highways in Bolivia. Included was the requirement for approximately 7,000 square kilometers of reconnaissance surveys for new routes. The client was the Government of Bolivia. The Bolivian government contracted with Tippetts-Abbett-McCarthy-Stratton for the route study and engineering plans, and the survey work was contracted to Mark Hurd.

Figure 1 (page 121) indicates the portion of the project used for illustration. The areas under study extended from near sea level to over 23,000 feet. The purpose of the road program was to provide transportation routes in connection with the relocation of people from the relatively populated area on the barren Altiplano to the fertile lowlands. Above the 9,000-foot level, vegetation was extremely sparse and presented no problem to the ground surveyor or the photogrammetrist. Below this level the trees gradually became denser and taller until reaching the jungle area where tree heights reached approximately 300 feet. In this area the ground relief for all practical purposes was hidden by the trees. Figure 2 portrays a typical mountain road.

As shown in Figure 1, approximately one-half the area to be mapped was already covered by photography ranging from 1:40,000 to 1:60,000. A 6-inch camera had been used, and all evidence pointed to the fact that the film was suitable for contour mapping. The existing film was owned by the Government of Bolivia and stored in La Paz. This film was immediately shipped to Mark Hurd's office in Minneapolis so that the project could proceed. To comply with Bolivian law, a representative of that government served as a custodian and accompanied the film to Minneapolis, where he remained until the film was returned.

For that portion of the project not covered by photography, new flights were made with a Lockheed P-38 aircraft. Flights were made at an average altitude of 35,000 feet above sea level. However, due to the extremely high terrain elevation, the effective altitude for portions of the project was less than 20,000 feet. Based on preliminary studies, it was decided that general coverage should be obtained for an additional areas as shown in Figure 1.

The aerial photography was carefully examined and the possible highway routes were confined to the indicated corridors.

FIG. 2. Typical Mountain Road.

A SEARCH FOR GROUND CONTROL revealed a considerable amount of high order triangulation and leveling in or near the area to be mapped. There were some existing 1:20,000 scale maps which were used primarily for vertical control. The distribution of control utilized for the project is shown in Figure 3.

Control monuments, both horizontal and vertical, were photo-identified and used to their fullest extent. However, as expected, the existing control was not sufficient to produce a map suitable for the intended purpose. Con-

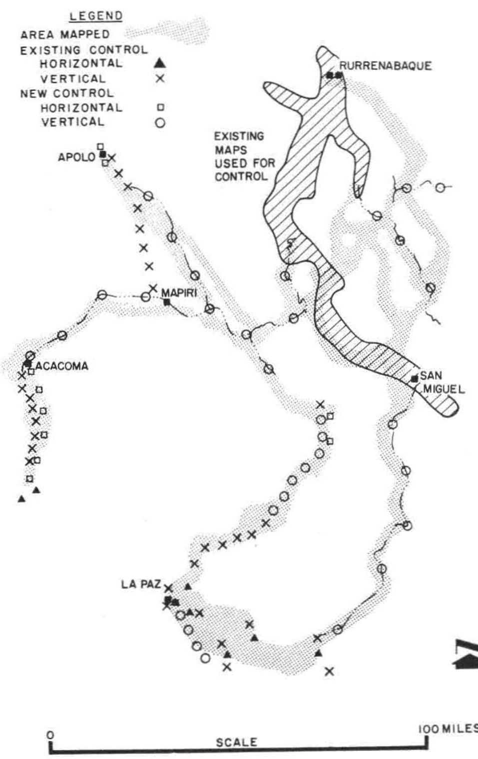

FIG. 3. Distribution of control used for mapping.

FIG. 4. Tellurometer crew at high altitude.

sequently, a survey crew equipped with Tellurometers, T-2 theodolites, and precise survey altimeters proceeded to establish a minimum of new control. Figure 4 pictures a Tellurometer crew operating at high altitude in autumn.

Many of the points were reached using pack animals over rugged mountain trails. Helicopters were considered, but were not available. Furthermore, they could not have been used over much of the area due to the extremely high altitude. During one of the trips, the animal carrying one of the Tellurometer units lost his footing, plunging 150 feet to his death. Upon reaching the spot where he had landed, the crew expected to find a complete loss of animal and equipment. Instead, they found that the animal had hit the ground first and cushioned the fall of the equipment, minimizing the damage. They were able to repair the equipment and complete the survey.

The new control was obtained by running Tellurometer traverses, and, where practical, establishing elevations by precise altimeters. In extremely inaccessible areas, it was necessary to utilize the rivers for supplemental vertical control. This was done by making a careful analysis of each river and estimating relative gradients. The vertical points shown at intervals along the rivers in Figure 2 represent this supplemental control.

FIGURE 5 INDICATES the pattern of flights and exposures used in the compilation procedure. The most difficult and critical process of the survey was the bridging; that is, the task of obtaining a homogeneous horizontal and vertical solution of the models required for compilation. Approximately one half of the models involved in the bridging were required for final completion.

The bridging was accomplished using ER-55 Balplex plotters and was executed in two steps. The first step consisted of setting each model independently and plotting the neces-

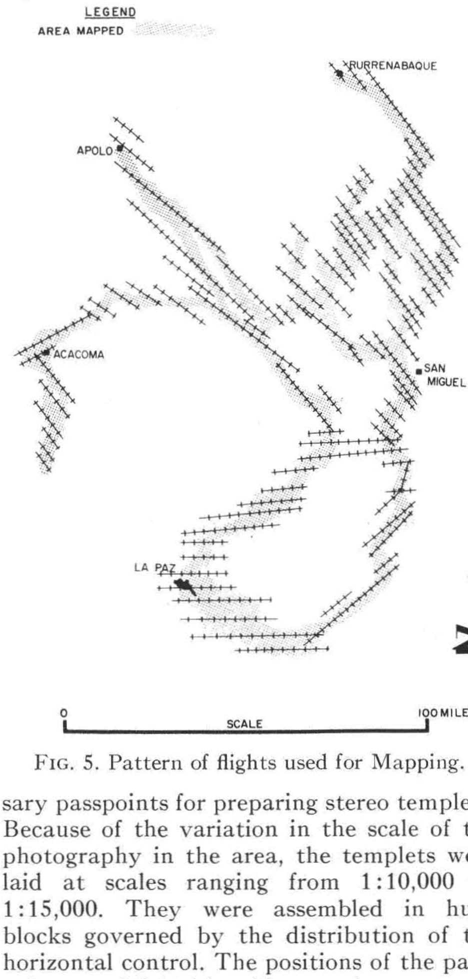

FIG. 5. Pattern of flights used for Mapping.

sary passpoints for preparing stereo templets. Because of the variation in the scale of the photography in the area, the templets were laid at scales ranging from 1:10,000 to 1:15,000. They were assembled in huge blocks governed by the distribution of the horizontal control. The positions of the passpoints established by this procedure were adjusted as necessary from block to block.

Using horizontal positions established by the templets, the majority of the models were set a second time and bridged on Balplex long bars to obtain a vertical solution. The results were analyzed and adjusted, using all possible vertical control.

Using the adjusted horizontal and vertical passpoints, the compilation models were set a third time to draw map detail. The compilation was performed in pencil on Cronaflex material, and all compilation sheets were reproduced and brought to a common scale of 1:10,000. The contour interval was five meters. Delivery consisted of reproducible positives of the penciled manuscripts. A portion of a typical sheet is shown in Figure 6.

Based on observations during the stereo triangulation procedure, it is estimated that in those areas where some type of vertical control was used the contours are generally within one interval. In those areas where stream

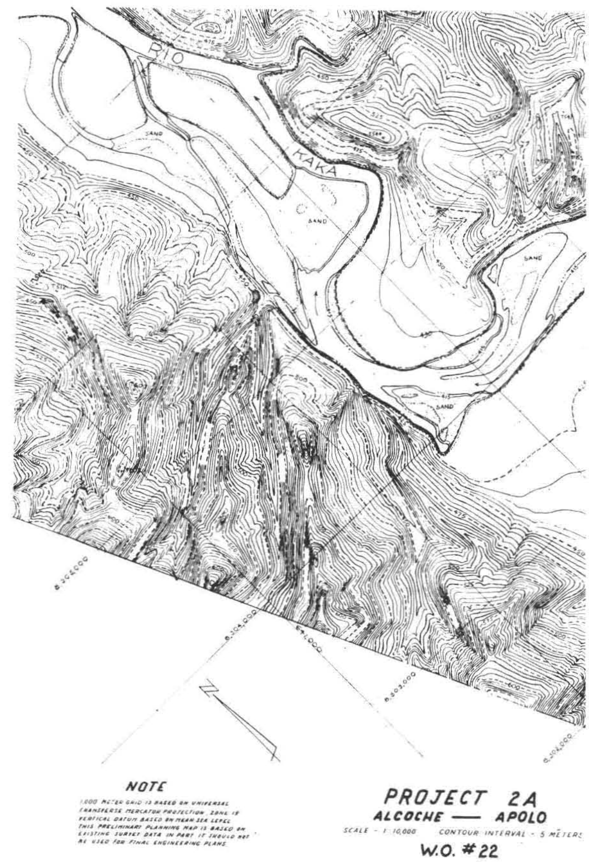

FIG. 6. Portion of a completed reconnaissance map sheet.

beds were utilized as supplemental control, it is obviously rather difficult to estimate the absolute accuracy. However, the maps have served their purpose for route selection, and the roads are now under construction. Horizontally, there is no doubt that they have exceeded the requirements of the intended purpose.

REFERENCES

1. Pryor, W. T., "Evaluation of Aerial Photography and Mapping in HighwayDevelopment," PHOTOGRAMMETRIC ENGINEERING, v. XXX, n. 1, p. 111, 1964.
2. "Panel on Photogrammetry in the new Federal Highway Program," PHOTOGRAMMETRIC ENGINEERING, v. XXIII, n. 4, p. 733, 1957.

(See page 154)