SOME PHOTOGRAMMETRIC PROBLEMS IN ENGINEERING PROJECTS*

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ABSTRACT

The paper deals with three specific types of engineering survey which may be referred to as "border-line cases" where the advantages of employing photogrammetric methods may at first sight appear doubtful either on practical or economic grounds. Case I deals with the provision of a large-scale contoured plan of an irrigable area in the "dry-zone" of Ceylon where the ground is completely covered in dense forest. Case II describes a method for route surveys for overhead transmission lines and outlines the particular advantages to be gained by using air survey techniques for this purpose in areas of advanced development. Case III discusses the problems of close-interval contouring by photogrammetry in areas of low-lying desert and how best to reconcile the requirement for a low flying altitude to give contour accuracy with the desired economy in ground control.

THERE can be few more exacting professions than that of the Consulting Engineer. The design of a dam, a bridge or a tunnel, the layout of an irrigation system, the routing of a new highway or rail link, the development of a port, or any other of the wide range of projects which are the concern of the constructional engineer must influence for many years to come the lives and welfare of the community he serves. It is not surprising therefore that most engineers by nature are cautious men who tend to react slowly to new methods until these have given unequivocal proof that they can produce results equal or superior to established techniques.

Despite the very rapid progress made in photogrammetry between the two world wars, and the enormous uses made of aerial photographs for purposes of intelligence and mapping during the last war, it still remained a little known science to all but the few who had been closely associated with its development and practice. I of course cannot speak for other countries but in the United Kingdom less than a decade ago it would have been difficult to find a Consulting Engineer who had ever looked at a pair of vertical photographs through a stereoscope, far less with any conception of how this new tool could be applied to engineering use.

Fortunately for the photogrammetrist and I should say also for the engineer, the surge of post-war development forced the pace to such an extent that the engineer, along with a good many other people, has had to throw some of his native caution to the winds, and cast around for new and quicker methods which enable him to meet the almost unprecedented demand for his services. I will not say that it has not taken a good deal of persuasion and "education" on the part of the photogrammetrist, but the fact is that today, after a period of ten years "courting," the marriage between engineering and photogrammetry is an assured fact, and there can be few major engineering projects anywhere in the world in which air photography does not play a vital part.

Much has already been written on the engineering uses of photogrammetry, and even if it could be done in the space of one paper, I have no desire to cover ground that has been described in detail in the many excellent papers which have appeared in recent numbers of PHOTOGRAMMETRIC ENGINEERING and other technical journals on soil surveys, highway construction, large scale railway plans, etc.

Instead I intend to confine my remarks to three specific applications with which I have been associated, and on which I believe some additional information may be of interest. Although concerned with widely different projects, all three examples must be judged border line cases where the advantages of employing photogrammetric methods may not at first seem obvious, and in fact may be said by

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some to be in doubt. It is for this very reason that I have selected them, and if certain of my statements may appear controversial, I hope at least that they will be of sufficient interest to promote discussion.

CASE I. ENGINEERING SURVEYS FOR IRRIGABLE AREAS IN CEYLON

Nearly two thirds of Ceylon is termed the "dry zone" in which the north-east monsoon during October and November accounts for practically all the rainfall that this area receives during any one year. The greater part of the dry zone is covered by dense low forest with occasional patches of savannah. Except for one great river, the Mahawali Ganga, and a few lesser streams which flow eastward into the Bay of Bengal, the only existing means of providing perennial water is by means of shallow reservoirs hemmed in by an earth dam and referred to locally as "tanks." There are literally hundreds of these tanks (Plates I and II) ranging from small village ponds of only a few hundred square yards to the largest "Wewa," such as that at Anuradapura which covers 27 square miles. The origin of some of these dates back 1,500–2,000 years during the time when the early Sinhalese kings achieved a very high standard of culture, combined with remarkable technical skill.

Most of these ancient reservoirs have long since fallen into disuse and now lie buried in the jungle unrecognizable except on an air photograph, where the unmistakable line of the bund and the perimeter of the tank are easily interpreted by differences in the vegetation cover. One of the most important tasks of the Ceylon Government is to promote re-settlement of the dry zone areas by reconstruction of the larger tanks, clearance of the forest, and provision of a system of irrigation canals.

An essential requirement in the initial planning of these projects is what is termed an "engineering survey" at a scale of 16 chains to the inch (1:12,672) and with contours at 10 or 20 feet vertical interval. On the results of these surveys the irrigation engineer decides (a) the most suitable location of the reservoir if this is not already known, (b) the height and length of the bund required, (c) the routing of the main canals, and (d) the extent of irrigable areas commanded and suitable for cultivation. From the study of this preliminary survey the forest cover is then cleared, so that the main layout of the scheme and subsequent construction programme can proceed.

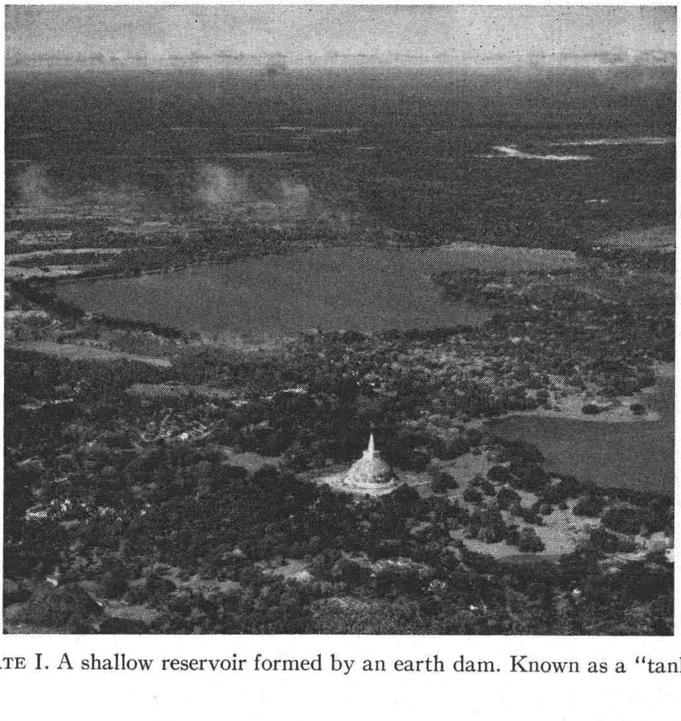

PLATE I. A shallow reservoir formed by an earth dam. Known as a "tank."

PLATE II. "Tanks" constructed for use as a water supply.

Until three years ago all such engineering surveys were carried out on the ground by the staff of the Government Survey Department. The field work involved in these ground surveys is formidable. The area is divided up into a grid of traverse lines which are cut through the jungle at regular intervals every quarter or half a mile, precisely surveyed by closed theodolite traverses, and subsequently levelled. The dense nature of the undergrowth makes the progress of cutting the lines extremely slow and laborious. On an average it takes a man one whole day to cut a hundred foot of line. In addition to the physical difficulties of preparing the route, the ground parties also have to contend with the inherent dangers of working in a forest containing an abundance of wild life including elephant, leopard, snakes, and worst of all a particularly ferocious variety of bear. An almost total lack of water adds further to the arduous nature of these expeditions.

The possibility of employing air survey methods had been considered previously by the Ceylon Government but had not been thought practicable owing to the almost complete forest cover which extends throughout the area to a height varying between fifteen and thirty feet. The requirement for the surveys was becoming so acute however that in 1952 a request was made, through the Colombo Plan, for a further examination of the problem. It so happened that I was called on to undertake this interesting task. In the course of a three months visit I had the opportunity of travelling the length and breadth of the island both in the air and on the ground, and by the end of my stay there was little doubt in my mind that even in the areas of densest jungle, photogrammetry could be employed with a large degree of success.

As a result of my recommendation, three of the most important areas for development were immediately photographed at a contact scale of 1:20,000. One of the areas, known as Padawiya, has since been mapped partly on the ground by conventional means and partly by photogrammetry, the two surveys overlapping to a considerable extent so that a direct comparison could be made between them.

Clearly the accuracy obtainable in an air survey of forest land must depend largely on the ability of the photogrammetrist to judge the height of the trees. The Ceylon jungle was particularly difficult in this respect owing to a variety of tree types and the presence of large pockets of secondary growth which merges gradually into full grown trees, and tends to give an impression of undulating ground where in fact it may be entirely flat. Nevertheless it was quite obvious from a study of the photographs that the main ridges stood out reasonably well, and the general shape of the terrain could be deduced from a study of the forest canopy. Lack of moisture on the tops of hills and ridges is likely to give rise to stunted growth compared with that in the valleys where moisture content is increased. This tends to conceal the presence of higher ground. Particular difficulty may also be experienced along rivers that have close steep banks where the vegetation is especially dense and results in the photogrammetrist assuming a milder gradient than in fact occurs. This is made clear in the sketch (Figure 1).

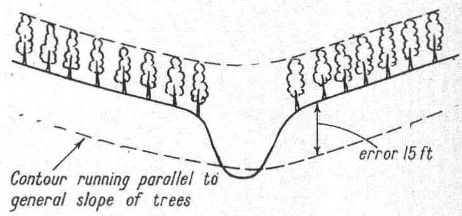

FIG. 1. The difficulty experienced along rivers that have close steep banks where the vegetation is especially dense.

GROUND CONTROL

It had been hoped to provide full control on every overlap, but due to the dearth of open spaces in the Padawiya area, it was necessary to resort to a considerable amount of aero-triangulation in which heights were "given out" on the tops of prominent trees and carried through in this way to the next model. This, unfortunately, resulted in some loss in accuracy. I believe, however, that much of this difficulty could be overcome in future surveys by employing a smaller scale of photography. This is made possible by the marked increase in resolution and freedom from distortion of the latest wide-angle objectives, in particular the Wild "Aviogon." If, for instance, it were possible to use cover at 1:40,000 scale on a 9×9 inch format, the control spacing on a single overlap would be increased to 2 miles in the direction of flight and 4 miles laterally. By this means the need for bridging between tree tops should be greatly reduced, if not entirely eliminated, and the operator with a four times increase in the field of view would be less likely to be misled by local variations in tree height when plotting contours.

Ground control for the Padawiya survey was supplied by the Ceylon Survey Department by running traverses along a regular grid pattern* in the conventional manner employed on their normal ground surveys. In this case the interval between the lines was reduced from the normal ½ mile spacing to 2 miles, with here and there a branch traverse to pick up a required spot level in a forest opening that could be located on the photograph and identified on the ground. Planimetric control was limited to that necessary for the use of slotted templets, a total of eighteen points being supplied for the whole area of 136½ square miles.

SAVING IN COST AND TIME

Some idea of the saving in cost and time to the ground parties can be gauged from the fact that for a full ground survey at ½ mile intervals, the distance involved in cutting and traversing would have totalled 400 miles as compared with only 135 miles needed for the air control. In cutting alone, therefore, the saving in labor cost would about pay for the whole of the photogrammetric mapping. Moreover, instead of taking two years to complete the task by ground methods, the air survey project, including photography, was carried through in half that time, despite some difficulties encountered through lack of experience in identification by the field parties. This introduced delays while checking the doubtful points and investigating the errors.

There is little doubt that with the experience already gained and the use of smaller scale cover, delivery of a similar area could be greatly reduced in any future survey, and the resultant cost would be

* A considerable amount of cutting might have been saved if the field parties had traversed along existing tracks or dry stream beds wherever possible, rather than adhering to the rigid system of parallel lines to which they were accustomed.

only about thirty per cent of that of a survey made entirely on the ground.

PHOTOGRAMMETRY AND COMPILATION

Bridging for height control was carried out by Multiplex so as to provide full control for each overlap. The models were then set up independently in the Wild A6 which was used for the plotting of detail and contours.

Re-plotting of the contours was carried out in duplicate by two operators who worked completely independently (Figure 2). This was done partly as a means of improving the accuracy, but mainly in order to check the extent of "wander" of the contours between the two plottings resulting from differences in interpretation of the height of the forest cover. At plotting stage no effort was made to match one overlap with another as this would have tended to exert undue influence on the operator in positioning the contours between models, whereas there was no means initially of assessing whether the contours carried out on one overlap were any more accurate than those on any other.

Final compilation of the contour trace was made by careful comparison of the two independent plottings together with all the spot heights "given out" wherever a small clearing showed in the forest. In this way an over-all picture was gained of the "flow" of the ground and the contours adjusted to give the best over-all fit. In general it was found that the shape of the contours showed remarkable consistency between the two independent plots, and the maximum discrepancy appeared to be in the region of 20 feet. When meaned it was reasonable to assume that the final result would be within the tolerance required by the specification.

In several places the contouring was carried over into areas already surveyed on the ground by the Ceylon Survey Department. It was noteworthy in these areas that the machine plotted contours in practically every case agreed within 5 feet of the ground levels along the "cut lines," but did not conform very well with the shape of the contours *between* the levelled lines on the ground, although the general agreement was well within the contour interval. It was of course possible that the discrepancies in shape between ground and photogrammetric contours were due entirely to errors in assessing the varying heights of the forest canopy from the photographs. There were, however, good reasons for believing that this was not the case and that the machine contours did in fact show a better shape in general than the interpolated contours between the level lines carried out on the ground. The reasons for believing this were threefold, namely:

(1) The two independent machine plottings agreed much more closely in shape than either did with the "ground contour."
(2) It was known that due to the difficulty of movement on the ground the ground survey could have had no effective means of assessing how the contours turned in the areas between the levelled lines.
(3) The good agreement of the machine contours with the spot levels carried out on the ground wherever the former crossed the latter. It seems unlikely that the machine plotted contours could coincide well with the grid spot heights and yet go so amiss between.

As regards planimetric accuracy the agreement between the detail surveyed on the ground and that plotted from the photographs was extremely good throughout. In cases where there was any doubt about the identification of the course of a stream or track or other detail, this was shown in pencil only on the fair drawn original and later checked on the ground. The fact, however, that minor tracks and streams are often screened from the aerial view is not of importance since in any area where development is to take place, the forest will necessarily be cleared and the land must be subsequently transformed by canalization by an entirely new layout of communications.

GROUND CHECK

On completion of the photogrammetric plotting, a thorough ground check of the results over an area of sixty square miles was carried out by the Ceylon Survey Department and the following is a summary of their findings.

Out of a total number of 593 points checked by spirit levelling, 329 or $55\frac{1}{2}$ per cent showed an error of less than 10 feet, 76 per cent were within 15 feet and $87\frac{1}{2}$ per cent within 20 feet. Ignoring dif-

FIG. 2. Contouring of Forested Areas: Comparison of two machine tests of the same area made by independent operators.

ferences of ± 2 feet, 70 points showed a negative error (i.e. air survey contour less than ground height) and 442 points a positive error. The largest errors (those of ± 15 feet and above) were found to fall in groups or zones where the country (except for one zone) was shown too high. This gave the impression that in these areas the datum plane had been interpreted about 10 feet too high and tended to be distorted in waves of slight humps and hollows. It was noticeable that these "high" zones corresponded roughly in shape with the position of high ground features while the isolated "low" zone lay in a principal valley system. This indicated a tendency on the part of the photogrammetrist to "plunge" the floating mark too deeply into tree covered valleys while making insufficient allowance for tree height on the higher ground. The maximum errors were found to occur on isolations, and were possibly due to a different species of tree which, due to the nature of the soil or for some other reason, flourished on the hill tops, and were of greater height than those lower down. (In the general case it would be reasonable to expect the reverse of this to apply.) In these steeper areas, a relatively small movement of the contour lines in plan will of course make a large difference to the value of an interpolated spot height.

In general the result of the Padawiya survey may be said to have given strong evidence that even relatively flat* densely forested areas can be contoured by photogrammetric methods to a mean accuracy of ± 10 feet, and may in fact give a better over-all picture of the shape of the ground than can be obtained by traversing on a block grid. Taking into acount moreover the tremendous difference in labor, cost, and time between the two methods, there can be little doubt that the advantages are clearly on the side of photogrammetry.

Case II. Transmission Line Surveys

The method of planning the route of an overhead power line may vary enormously according to the site location, the type of terrain which the line has to cross, and the load which it has to carry. In flat open terrain, or where the route is to follow that of an existing line of communication, it is doubtful whether photogrammetry can play a very useful part. But over areas of mountainous and unmapped territory the advantages of using air survey are usually so obvious that they need no emphasis. Between these two extremes the engineer will have to weigh in each case whether on a practical or an economic basis, or both, an air survey is desirable.

In the particular case of a highly developed country, such as the United Kingdom, where accurate large-scale plans already exist, there might at first sight seem little point in going to the expense of strip air photograph, and then providing a double line of levels for the mere purpose of providing a single profile along the line of the projected route. Development, however, more often that not, brings with it social and administrative problems that are often harder to solve than the purely physical difficulties of driving a line through virgin territory. When making a comparison, therefore between the cost of ground and air methods, it should be borne in mind that far more is involved than the provision of a single profile along a route already pegged out on the ground.

The conventional method for planning the route of a line consists first of a preliminary survey carried out with the aid of the existing 6 inch to one mile Ordnance maps which are contoured at either 50 or 100 foot intervals. Taking into account both the topography and general considerations of wayleave, an initial line is chosen and this has then to be spirit levelled along its whole length before the tower positions can be selected. Not until this stage is it possible to enter into formal negotiations with local authorities and owners for permission to erect the towers, and more often than not the route will have to be changed a number of times before final agreement can be obtained. For every deviation a fresh profile has to be run on the ground with resulting delay and increase in cost. This reason, more than any other, has accounted for the interest shown by the construction engineers of the Electricity Authority in the employment of photogrammetric techniques.

Since the problem is one that is not confined merely to conditions in England but applies equally well to developed areas in any part of the world, it is perhaps of interest to record in outline the progressive stages of the method which has been successfully developed over the past four years by certain Divisions of the British Electricity Authority in co-operation with Hunting Aerosurveys Ltd.

1. Preliminary Reconnaissance

This is carried out by car and on foot with the aid of existing maps to determine the general route of the line. Reference is then made to the County Planning Authorities for their observations, and the line is amended to meet their requirements. It must be emphasized that this reconnaissance determines only the general run of the line within wide limits.

2. Air Photography

Vertical strip photography following the approximate line of the route is carried out from a mean altitude of 8,000 feet giving a width of cover just exceeding one mile, employing the Wild RC5A camera at a negative scale of approximately 1:11,600.

* The total variation in height over the Padawiya area was only 300 feet.

3. HORIZONTAL AND VERTICAL CONTROL

(a) Plan control for every overlap is provided by aerotriangulation between points of detail selected from the existing Ordnance plans at 1:2,500, and involves no ground work. It is to be noted that, provided local accuracy in fitting is sound, over-all accuracy in scale is not of major importance.

(b) Height control: Since it is relative and not absolute height that is the important requirement, it is permissible in most cases to supply levelled heights only on every third overlap. These are provided on the ground by tacheometry or spirit level from the nearest bench mark; this is seldom distant more than $\frac{1}{4}$ mile. In some cases it is necessary only to relate the actual bench mark itself to a suitable photo point. These ground heights are then supplemented by aero-triangulation employing the Wild A5 or similar high-precision instrument, to give full control for each model.

4. REVISION OF PLANS AND ADDITION OF CONTOURS

The existing Ordnance Survey 1:2,500 plans (or in some cases the 1:10,560 scale is used) are revised over a width of half a mile on either side of the initially selected route, and contoured at 10 ft. intervals, plotting being carried out on a good second-order instrument such as Wild A8 or A6.

As an example, the time taken to revise and contour a strip one mile wide and 45 miles in length including the ground work and fair drawing of the plans, required ten weeks (only one plotting machine being employed).

5. SELECTION OF ROUTE

Without further visit to the site, the construction engineer re-examines the reconnoitered line by stereoscopic examination of the photographs, taking where necessary occasional parallax readings on local features. In the words of one engineer "this method is quick and reliable, revealing both the general nature of the country and any obstacles to the proposed line."

6. PREPARATION OF PROFILE

By scaling and interpolation from the contoured plans, a profile following the accepted line of the route is prepared to a horizontal scale of 1:2,400 and vertical scale of 1:240 (20 feet to the inch). The tower positions are finally selected on the basis of this profile.

In a number of cases it has been found possible to effect economy in the number and types of towers used, by examining two or more routes in close proximity to each other, a separate profile being plotted for each; this can be done quickly and easily from the map contours. In this connection it is worth recording that the saving of a single tower would pay for the air photography and mapping of approximately 30 miles of route.

7. WAYLEAVE DEVIATIONS

During the final negotiations for wayleave it is often the case that land owners are prepared to agree to a line over their property provided alterations are made either to the route or to the positions of individual towers. Any such deviations of the line can be quickly examined with the aid of the photographs, and the contoured strip and a revised profile plotted in the office without revisiting the site. At times as many as twenty different routes may have to be examined before the final line is confirmed; the saving over ground methods is often, therefore, very great indeed.

Figure 3 shows a comparison between a profile obtained from a check level line run independently on the ground and that interpolated in the office from the photogrammetric contours. In both instances the greatest discrepancy in the height of any tower due to errors resulting from the photogrammetric method was 2 feet.

In addition to those already mentioned the following further advantages lie with the photogrammetric method:

1. Entry on the ground is not necessary until just prior to the erection of the line. This is of particular significance in the case of arable land.
2. Examination of property, entry to which cannot be obtained, is possible in the early planning of the route, thus avoiding unnecessary opposition.
3. A schedule of the towers and exten-

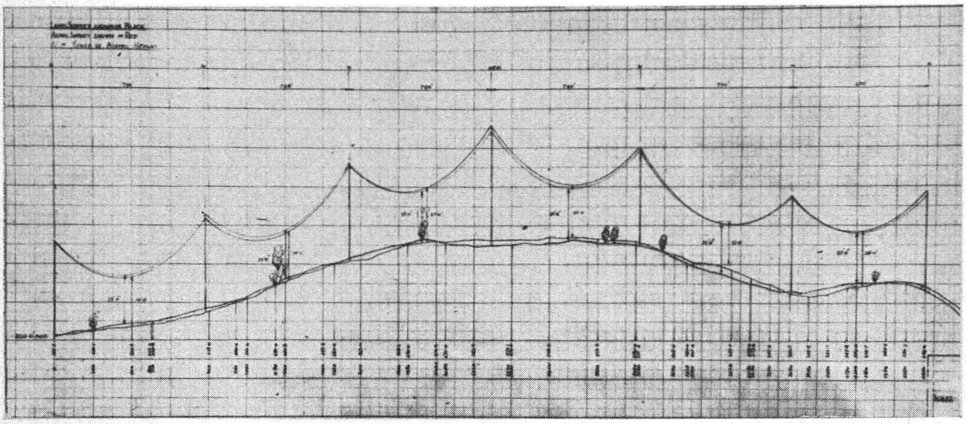

FIG. 3. Comparison between profiles obtained from Aerial Survey and final land survey for 132 K.V. D.C. Line with standard towers.

sions can be made at an early stage enabling orders for steelwork to be placed in good time.

It must, however, be emphasized that many of the advantages in employing air survey for transmission lines will be lost unless the construction engineer can plan his program well in advance. This particularly applies in countries like England where the photographic period is confined to a relatively short season. Nothing less than the highest quality of photography is acceptable, if the required accuracy is to be maintained. The cost of the ground control and photogrammetric work will also be seriously affected if short lengths of line are treated independently.

Nevertheless, with adequate planning and a proper understanding of the problems by both engineer and photogrammetrist, there is no reason why aerial techniques should not become a standard practice in the majority of power line work.

CASE III: CONTOURED MAPPING OF "FLAT" AREAS

It is probably true that the desert areas of the world are today receiving more attention than at any previous time in man's history. In addition to the vast reserves of oil which they have been found to contain, they provide an almost unlimited field for agricultural development wherever there is fertile soil and the engineer can both conserve and spread the available water resources.

These "barren" lands by their very nature have in the past remained neglected and unmapped, so that the first requirement for any kind of development is a map; for irrigation planning in particular the area must be contoured at very close intervals.

In applying photogrammetric methods for the survey of areas of slight relief, a difficulty arises in trying to reconcile the accuracy requirements of the contouring which demand a low flying height with economy in photo scale for the planimetry and ground control.

Dealing first with co-ordinate control, the solution in this respect seems relatively simple, and lies mainly in photographing the area twice at different heights, designed to meet in the one case the requirements of the contouring, and in the other that of the planimetry. Suppose for example the requirement is for a map at 1/20,000 scale with contours at 2 meter interval. If the area is semi-desert, it is probable that the only plan detail which would be shown would be dry water courses, tracks and small escarpments, all of which could be interpreted on photographs at 1:40,000 or even much smaller contact scale. In fact, the resolution obtainable with modern survey lenses is so good that the limiting factor in deciding the photo scale is governed less by difficulties of interpretation than by the ceiling of the aircraft, and also whether a precision plotting machine or slotted templet is to be used for the subsequent mapping. Plate III shows a ten times enlargement from photography taken at 1:60,000 scale

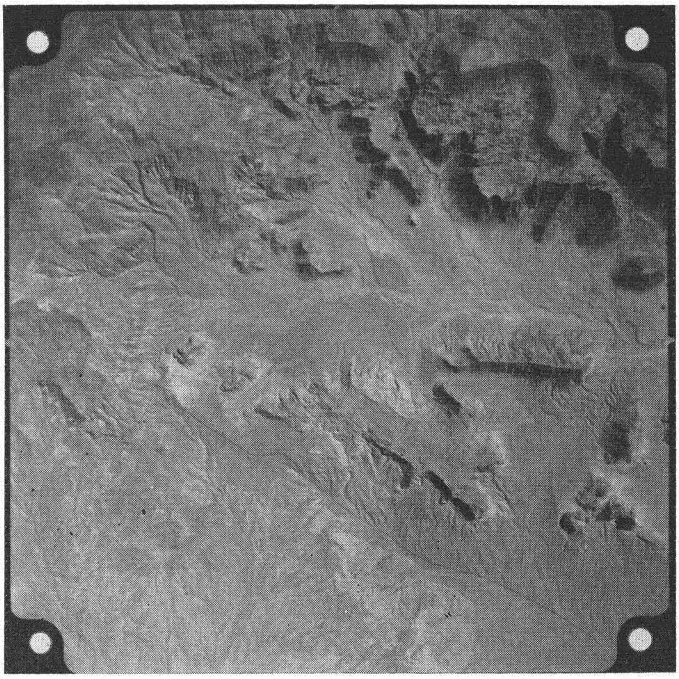

PLATE III. 1.60,000 Contact Scale Photograph. (Wild Aviogon lens, 11.5 cm. focal length on 18 cm.×18 cm. format.) (Hunting Aerosurveys Limited.)

which is now being employed for aero-triangulation and mapping by Wild A5. In this particular survey the requirement for coordinate control is limited to an average of one point every 10–20 miles. This illustrates the tremendous economy in ground work to be gained in re-flying at a small scale and by employing a first-order plotting instrument for mapping.

The real problem lies, however, in how to overcome the excessive amount of control needed for close interval contouring where the range of height relief is small and there are few recognizable points on the ground. It seems unlikely that any form of aero-triangulation, when it comes to contouring at intervals of say less than 3 meters, can be expected to maintain the accuracy required and therefore should be ruled out, except in the rare case where the area is inaccessible on the ground due to swamp, quicksand or other reasons.

An alternative, and in my opinion the far sounder method of minimizing control, is to increase the flying height to say twice that which would normally be specified for contouring, and to use the plotting machine for giving out a close grid of spot heights at intervals of not more than 5 cms apart at the plotted scale of the plan. Since each machine height will be the mean of several direct pointings, it is reasonable to expect that the accuracy will be at least double that of normal contouring, and can therefore be relied on to say 1:3,000 or 1:4,000 of the flying altitude. The machine will still be required to trace the contours, but these will be used merely as an indication of the general land-form, and will be adjusted wherever necessary to agree with the spot heights. This method should be entirely reliable provided (a) photography is undertaken with a lens of maximum distortion of no more than .01 mm. and is of course of first-class quality, (b) level control is provided to a density of five points per model, and (c) only a first order type of plotting instrument is employed in the photogrammetry.

It can be worked out that the resultant saving in ground points by this method would be approximately 16:5 (assuming only four points per model for the lower flying height). The time taken at photogrammetric stage in the provision of the grid of machine heights will be to some extent offset by quartering the number of settings. Any additional machine time will in any event be far out-weighed by the economies introduced in ground levelling as well as in flying.

Aneroid Control

Although this paper is intended to deal with photogrammetric methods rather than those of field survey, the approach to both techniques is so closely related in the type of survey under discussion that this seems to be a suitable opportunity for mentioning some recent experiments that have been carried out with aneroid barometers of a particular type, and which give good grounds for believing that with careful use very satisfactory results can be achieved by this means, at a tremendous saving in cost and time.

In May 1954 by arrangment with the Survey Department of the Sudan Government, four Wallace and Tiernan aneroids were flown out by air to Khartoum. Initially they were subjected by the Department to a week's test in temperatures ranging between 92 and 104 degrees F, and a close watch of their performance was made in order to study the range of diurnal variation for each instrument, for purposes of comparison. The results obtained are summarized in Table 1.

The last column giving the range of maximum disagreement shows that during the initial period of the test, the instruments were affected by the sudden change in environment, and then gradually settled to their new atmospheric conditions. By the end of the week the range of disagreement was almost negligible.

The instruments were then taken by truck over a distance of 260 miles, care being taken to avoid violent shocks to them during the journey over rough country. On arrival at site the aneroids were divided into two batteries of two instruments each, and a series of recordings made along a stretch of railway line between spirit levelled bench marks employing both the "leap-frog" and the stationary base methods. Both manual and mechanical means of transport were also tried alternately. In computing the results, the mean of each battery was taken as the station reading and the mean of two instruments for the air temperature.

The results are of particular interest since they show that (a) careful road transport had no harmful affect on the readings and (b) the stationary base method, which is faster and easier, is not inferior to the "leap-frog" method.

The average discrepancy over a circuit of 20 miles long was only $1\frac{1}{2}$ feet and the maximum error of any reading was 3.2 feet.

There is, of course, nothing new in the idea of using barometric methods for controlling a photogrammetric survey, but the Sudan test does. I think, provide sufficiently convincing evidence to lead one into believing that much greater use can be made of this method in irrigation surveys of the kind referred to above. If, therefore, it is possible by this means to confine the spirit levelled lines to every fifth or even tenth flight line and to rely on aneroid traverses in between, we shall have gone a long way towards providing a practical and economic solution for the close contouring of large areas of low lying land.

Conclusion

In attempting to cover three rather diverse problems in the course of one paper,

Table 1

Date 9 to 14 hrs.	Difference in feet between readings recorded at 9 and 14 hrs.				Range of disagreement
	6–1,506	6–1,807	6–1,839	6–1,886	
12.5.54	92	95	89	93	6
13/5	96	96	91	96	5
15/5	104	104	103	110	7
16/5	103	103	100	105	5
17/5	98	98	95	98	3
18/5	71	71	72	69	3
19/5	99	99	98	98	1

it is evident that the omission of many details was necessary. I hope that some of these may be brought out in subsequent discussion.

While experience has shown that in each of the particular examples discussed, aerial photogrammetry has effected a considerable saving in both time and cost, one must be cautious in assuming that this will always be true. Local factors such as climate, extent of area, shortage of staff, political considerations and the nature of the terrain, all play their share in influencing the manner in which the work can be most efficiently carried out. It should be borne in mind that photogrammetry is still a comparatively new tool to the engineering profession, and any attempt by the photogrammetrist to oversell the employment of this method can only result in a loss of confidence by those who do not always appreciate that like all other tools, the aerial camera and the plotting machine have their limitations.

Finally, I express my indebtedness to the Surveyor-General of Ceylon, The Transmission Engineer of the Eastern Division of the British Electricity Authority, and the Director of Surveys of the Sudan Government for permission to publish the results of projects initiated by them, and to which reference has been made in this account.

GLOBAL MAPPING*

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Abstract

From the extremely localized activities of the earliest cartographers, the scope of the mapping industry has expanded until today its operations have assumed a global aspect. Previewed in World War II, confirmed by the Korean War, and emphasized by the recent efforts toward international cooperation, the need for an over-all mapping preparedness program on a world-wide basis has become imperative. As the primary military mapping agency of the United States, the Army Map Service is endeavoring to accomplish such a program by increased productive capacity, an intensified research and development program, participation at national and international conferences, increased collaboration with foreign mapping agencies, and actual operations in far-flung parts of the world.

IN PRESENTING to you a résumé of the Corps of Engineers world-wide mapping efforts, one portion of my remarks will be confined to the current progress in this direction. The other portion will be restricted to those problems incidental to global mapping, which still need resolving, and for which your aid is solicited.

Global mapping is influenced by two requirements—economic and military. United States participation in world-wide mapping efforts coincides with: first, its search for economic resources and world markets; second, the necessity for protecting its citizens, property and interests; third, a need to maintain military security of its mainland and outlying possessions; fourth, a need to service actual or anticipated expeditionary forces; and finally, a duty to implement those official collective actions of the United Nations.

Fulfillment of this complex mapping requirement has been extremely difficult, time consuming and expensive. Many reasons can be cited for the inability of the United States to obtain optimum mapping coverage of those portions of the world which are vital to its interests. A few of these reasons are: The limited season and adverse weather conditions in certain areas of the world (such as the Arctic) for ground surveys and photography; inadequate logistic support because of the lack of communication facilities (as in certain desert or mountainous regions); the difficult terrain characteristics (such as dense forest growths in the tropics or

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