SOME THOUGHTS ON AEROTRIANGULATION*

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AMIDST the confusions of moving out to California and getting more or less permanently settled, I have tried to record a few pertinent thoughts on the future for aerotriangulation. Specifically, I should like to present some ideas on stereoplotting versus analytical aerotriangulation, as a means of extending the network of ground control.

The aims of aerotriangulation can be stated as the fixing of points on the earth's surface in terms of a geometric projection on that surface. The objectives of ground survey are quite analogous to this. The differences between them are those of degree, and arise from the fact that the former is a process of indirect measurement, and the latter a process of direct measurement. The medium of indirect measurement is aerial photography. It is the ground upon which we photogrammetrists conduct our surveys.

This difference between direct and indirect measurement is quite important because it certainly limits the accuracies of the indirect measuring system to a greater degree. On the other hand the system of direct measurement may be limited in many ways by physical or economic obstacles. In any event these differences suggest circumstances under which one or the other is the better. But most often it should be a combination of both that produces a map efficiently.

As exponents of the indirect measurement approach to mapping, photogrammetrists should recognize as important those methods which make possible more direct measurement. This may seem a little ambiguous, but nevertheless it is true because indirect measurement suffers qualitatively as the number of variables in the process increases. Hence, by using a more direct method we can reduce the number of variables in our system.

Considering the indirect measurement approach I should first like to present some thoughts on the aerotriangulation problem, and second, to discuss the influence of data reduction on approach.

With respect to photogrammetric mapping systems of the present time, I hold that the ultimate objective of all is to aerotriangulate the mapping area. This is true whether one deals with one photograph or many. More specifically, one merely divides and subdivides the mapping area into smaller and smaller bits, until the graphical representation of these bits is produced in the form of a map. For the most part, this division and subdivision is a system of interpolation that is generally non-linear. Because of this non-linear interpolation, one finds in the various mapping systems a variety of ideas on the required density and distribution of geodetic control, to assume that the interpolations made will satisfy the mapping requirements. On the one hand some mapping systems require geodetic control of sufficient density to interpolate a part of one stereo model. On the other hand some may allow a reduction of geodetic density involving that interpolation of large areas covered by many stereo models. In either case I think the problem is the same, in the sense that the photographic coordinates must be transformed and projected back to the geoid.

At the present time there are two principal lines of approach to this problem, although admittedly there are many steps in the process where it is difficult to differentiate one from the other, the two main lines I refer to are generally described in the literature as the stereoplotting ap-

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proach and the analytical approach.

Stereo-Plotting systems utilize analog type instruments in attempting to project physically the optical bundles back to the geoid under conditions like those which generated there homologous counter-parts in the aerial camera cone. All measurement and adjustment is done in the outer cone, i.e., exterior orientation, assuming that the interior orientation is correct.

Analytical methods employ comparator type measuring instruments and mathematical methods to establish the relationship of these optical bundles in the inner cone using calibration data of the camera constants. Then by computation photographic coordinates are transformed to the geoid.

Practical experiences over the past twenty-five years leave little doubt as to which of the two systems has been the more efficient for the map plotting problem. The difference in efficiency has been largely in favor of the stereoplotting systems because of the simple data reduction procedures that provide the graphical representation of the terrain. In other words the virtue of the stereo plotting system is that it has been the shortest distance between photo and map.

Through all these years of stereo plotting, photogrammetrists have never been completely satisfied with one step in the process. This all-too-frequent cause of frustration has been aerotriangulation. Attempts with analog equipment to relate a series of aerial exposures so they can be treated as one photograph have failed. As a result elaborate systems of mathematical or graphical analyses are necessary to complete the relationship of these exposures for mapping use. Moreover, as attempts are made to increase analytically the accuracy of stereoplotting, the proportion of computation time to instrument time radically changes. So much so, in fact, that some of the analog stereo instruments are now being equipped with digital readouts in a form easily programmed for automatic computation. Use of automatic computation will likely put the computation time back to reasonable limits but here it it seems one gets a redundance of equipment.

It appears to me that as the time proportion of instrument to computation changes, a need for continual evaluation of the stereo-plotting system versus the analytical system becomes quite urgent. This is because it certainly was the complexity of tedious mathematical data reduction that influenced early photogrammetrists to adopt analog type instrumentation.

In recent years the analytical approach has received new vigor through the development of electronic computers and automatic computation systems. I think one can accept the premise that the acid test for any system will be an economic one. Thus, I think we need a real comparative evaluation of these two principal systems in terms of present day technology.

I think studies will demonstrate that analytical photogrammetry can solve the aerotriangulation problem more efficiently. I think that more efficiency can be obtained in the analytical system primarily because new computational facilities equalize the computational cost of both systems. The differences if any will likely be in the instrumentation processes.

From the present state of my knowledge, I cannot visualize any significant reduction in the cost of stereo plotting instrumentation. In fact, the tendency is to increase its cost in order to produce the quantity of superfluous data that is required for a vigorous solution by the method of least squares. The need for superflous measurement is generated by the lamentable confusion that very often exists at the end of an aerial survey when the question arises as to its accuracy. This is still a very real problem to the practical photogrammetrist, and one where an efficient solution will contribute much to the acceptance of aerial survey as an exact science on a level with geodetic survey.

I will now make mention of the analytical triangulation work being done by the ordnance survey of England. This work has been reported in the photogrammetric record during the past two years. A calibrated reseau in the focal plane of the aerial camera is being used. Reseau crosses are quite small and do not obtrude significantly in the gross photographic area. Moreover, by obtaining a precisely known coordinate system on each negative at the instant of exposure, they are able to "freeze" the relationship of images for all subsequent work. The reseau system also offers many possibilities for simplified in-

strumentation. To determine the plate coordinates of any image, it is only necessary to interpolate between the calibrated values of the nearest reseau crosses. This simplifies their measuring problem enormously.

It is likely that a simplified measurement system will enable one to provide the superfluous data for a mathematical solution in a theoretically proper way. Moreover, the ease of obtaining redundant data through the reseau will make it practical to select more numerous points for which coordinates can be established. In addition, the recording of a known coordinate system on the negative may lead more quickly to automatic comparators and automatic contouring systems. Therefore, I think it is time we look very closely to the work by the British, and consider the success they have had with their register glass and reseau cameras.

Assume for the moment, that a future photogrammetric camera will contain an optical cone with register glass and reseau. One can immediately ask about the effect on other capital equipment in use. If one looks at the cartographic camera situation today, it is apparent that the next five years will produce a changeover to the use of nominally distortion free lenses. This will require some modification of existing plotting equipment in many instances, but mostly minor in nature. Those of us who are contemplating the use of a planigon lens might well consider a reseau camera. If the plano surface of the corrector plate in this lens can be located in the focal plane, one can thereby produce a film flattening and a reseau carrying surface. This camera could be used with any of the stereo plotting systems designed for use with planigon photography and in addition would provide a simplified analytical system for aerotriangulation. Assuming that this is feasible optically, the main problems incurred would be keeping the focal plane clean and free of scratches. These, I think, would not be of enormous difficulty.

At the present time, the International Society is sponsoring a series of aerotriangulation tests. The results will be available in 1956. These tests if thoroughly examined should tell us much about the present and likely the future of aerotriangulation. I do not know whether Professor Thompson* and some of his compatriots are participating but it is unfortunate if they are not.

In the meantime, I assure my stereoplotting friends that I see no conflict between stereoplotting systems and analytical systems. But it is time for a reassessment of both in terms of their utility to the mapping problem. This reassessment I am sure, will result in more efficient aerial surveys and similarly should produce a greater reduction in the need for ground surveys.

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A new catalog which describes the six models of Kodak Contour Projectors now available, and including the Model 14–5, has been prepared by the Eastman Kodak Company and is ready for distribution. The booklet contains detailed descriptions of each model and discusses the use of optical gaging in the toolroom, in production, in receiving and in final inspection. Accessories are listed along with a full page table of specifications for all six models.

Copies of the catalog are available without charge on request from Special Products Sales Division, Eastman Kodak Company, 343 State Street, Rochester, N. Y.