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The Acquisition of Data in Aerotriangulation

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Introduction*

IN ALL AEROTRIANGULATION procedures there are two distinct and more or less independent phases. The first phase comprises a number of operations such as the taking of the photographs, the selecting of the aerotriangulation points, their marking, the formation of the models and the measurement of their spatial coordinates in the case of instrumental methods, or the measurement of the photographic coordinates in the case of analytical methods, etc. The numerical data thus obtained are then treated in a mathematical procedure, which is the second phase.

During the meeting of Commission III at Bad Godesberg, it was decided that each of these phases would constitute a field of interest and would be a basis for a report to be presented at the Congress at Lausanne. This decision was not made without lively discussion and the agreement was not reached without a compromise: first, the subject of auxiliary instruments would continue to be treated separately; further, a new field of interest would be created to permit discussion and comparison of different methods on the whole. But, in so doing, we evidently also risked a certain amount of overlapping, possibly accompanied by some disagreement in the conclusions reached.

The present report treats, then, the acquisition of data; but it will not be possible to make it exhaustive because the subject is too broad: hence, we will limit ourselves to points that are important, new, or controversial concerning the taking of the photographs, the instrumental procedures, and the problem of transferring control points.

The Taking of the Photographs

The taking of the photographs constitutes an essential element in all aerotriangulation projects. Too often, it is done according to the demands of the compilation, whereas, with a minimum of additional expense, it could be done in such a way as to reduce considerably the amount of field work, increase the precision, and simplify the calculations (required for aerotriangulation).

In general, cameras mounted for vertical exposures are used. Despite their theoretical advantages, multiple cameras have never had much success, doubtless because of the complications in their use, and seem to be definitely abandoned. The nonclassical continuous-strip and panoramic cameras have still less chance of being used again in present practice. One has, then, little choice but to use conventional cameras, wide-angle and super-wide-angle. The use of the latter, at as high an altitude as possible, is the most economical solution, because this reduces the number of exposures needed to cover a given area; it also gives the best altimetric accuracy, especially if the density of the control network is weak. On the other hand, if one desires to have the highest planimetric precision, wide-angle and normal-angle cameras are undoubtedly preferable.

The advantages of plates over films, and the advantages of reseau cameras, have never been incontestably proven. All that one can say for certain is that lack of flatness and dimensional stability in the sensitized surfaces are among the factors that limit the precision of aerotriangulation, and that they reduce to an illusion any effort to measure the

* This English version was translated from the French original text by Mr. Robert C. Eller and Mr. Morris M. Thompson of the U.S. Geological Survey. The paper will be published in French in the Bulletin de la Société Française de Photogrammétrie.

coordinates to better than 5 microns.

It is not a vain exercise to emphasize the importance of the plan for taking the photographs. One is usually satisfied with parallel strips with the longitudinal and lateral overlap as small as possible for reasons of economy, but this small overlap makes it necessary to select the pass points at the extreme edges of the format, in the areas where the resolution is poorest. Besides, this plan has the disadvantage of not permitting the calculation of a block *in the air*, without using any known points: the transmission of lateral strip tilt transversely from one strip to another is not really assured, since the tie points between the strips are nearly alined. The vertical control network on the ground should then necessarily include, at the extremities of each strip, the points necessary to define the lateral tilt, which would be an oppressive requirement, whereas an essentially rigid block can be supported by a small number of points distributed in random fashion. The adoption of a lateral overlap greater than 50 percent provides this rigidity; if also the camera stations were alined laterally perpendicular to the direction of the strips, one would obtain an ideal arrangement (this correspondence can be assured easily enough by adopting a longitudinal overlap of 90 percent and by choosing afterwards the photos which are suitable). But such an arrangement for the taking of the photographs has not been used very much, except for very limited tests, because of the excess of work which it imposes, notably in the instrumental phases as a consequence of the increase in the number of photographs to be treated. This increase in work can, however, be maintained at an acceptable level by the use of super-wide-angle cameras, and it would be largely compensated by the near-elimination of field work and by the gain in accuracy due to the redundancy of the system.

A less laborious solution for assuring the internal rigidity of the block is to use cross strips, long known and successfully tested in the research of the ISP on the Massif Central test area. It is truly surprising that such a simple and efficient technique is not used more often.

It may be well to note that a judiciously conceived plan for taking photographs will effectively reduce the propagation of certain systematic errors: the taking of photographs in parallel strips with alternately reversed headings minimizes the effect of horizontal curvature and the effect of progressive variation in scale; if there are transverse strips, systematic torsion can also be eliminated. But no flight scheme will eliminate the vertical curvature; this must be taken care of by elevation measurements on the ground or by the use of statoscopes.

Instrumental Procedures

From the earliest days, there has been a general tendency toward simplification of instrumental procedures, achieved at the cost of an increase in the volume of calculations. The earliest methods required the use of universal plotting instruments, with which the models of each strip were formed successively, the scale and the absolute orientation being effectively transmitted from model to model. But as early as 1948 there appeared at IGN the method called *constant altitude* in which no attempt was made to transmit longitudinal tilt, the Bz component being maintained equal to zero. Very soon the models were formed with the By component equal to zero and with a constant Bx component in order to maintain as constant as possible the effect of the instrumental errors. Still later, the transmission of transverse tilt was also abandoned, ending in the method called *independent models*.

The transmission of absolute orientation from model $n-1$, n to model n, $n+1$ can be done in two ways:

(1). By measuring the parameters defining the orientation of the camera n in each of the two models. These parameters can, for example, be the angles of inclination of the principal rays, referred to the reference system of the instrument. If the instrument does not have graduated circles or levels for making this measurement, the orientation can be defined by the parameters governing two particular perspective rays, corresponding, for example, to two marks on the edge of the camera frame or to points marked on the photographs. It is sufficient to align these points monocularly, at an arbitrary distance z and to record the x and y instrumental coordinates as if they were ordinary control points.

(2). The second procedure does not require any special measurements: the transmission of the orientation can, in effect, be calculated from the spatial coordinates x, y, z of at least two points in the two models, referred to the common perspective center.

The two methods are not in all respects equally rigorous. The first involves only *directions*, and is not affected by errors of identification: the transmission of orientation is, in effect, based entirely on the reduction of the transverse parallax. The second, on the contrary, is concerned with *points*, intersections of two corresponding rays; but these rays will not intersect exactly because there is always some residual parallax, so that the rotation thus calculated would be slightly different from that which would be obtained from the first method—besides, it would be directly affected by the errors in identification of the points common to the two models, and must therefore be considered as less reliable.

The basic concept of the method of independent models is that it is always better to make a measurement and derive a correction for it mathematically than to apply the correction manually. One is then justified in asking if it is really necessary to obtain a perfect orientation, and if it is not preferable to simply measure the residual parallaxes, the relative orientation being then refined by the calculations in the course of treatment of the data. To this concept, proposed by Inghilleri, one can object that the currently available instruments, even if they do permit measurement of the parallax, are not generally equipped for automatic recording of this parameter so that it must be done manually, with consequent risk of error and waste of time.

Pursuing this direction still further, one can eliminate relative orientation completely, and reduce the parallaxes, by means, for example, of By ,which can be recorded at the same time as the coordinates x, y, and z. These quantities define the directions of the two corresponding perspective rays and are equivalent to measurements made on the stereocomparator: it is by this method (mentioned as a matter of interest) that the first trials of a so-called *analytical* method were carried out by *I.G.N.* in 1957.

The Problem of Transferring Points in Analytical Methods

The logical end result of this evolution is the measurement of photographic coordinates x,y for each control point on all the photographs upon wihch it appears, with the aid of a comparator. But it is not enough to make these measurements with the greatest possible precision; it is also necessary to be certain that exactly the same point is observed on all the photographs, because any error in identification will have exactly the same effect as a measurement error. It appears, then, that the transferring of control points is a critical problem in all instrumental procedures and that this transferring should be done with a precision equal to that of the measurements.

When they were first introduced, analytical methods were designed to duplicate mathematically the operations that were normally done by plotting instruments, that is to say, the formation of the spatial model; this idea led to the use of stereocomparators which, by stereoscopic fusion, assured correct identification of corresponding points in the stereopair. But it is also necessary to be certain of the identification of points common to neighboring stereopairs in the strip; stereocomparators having three plateholders have been designed for this purpose. But there is a less expensive solution, applicable to instruments having only two plateholders. In certain of these instruments, the movements of the plateholders are independent and the coordinates x, y, and x_2, y_2 are recorded directly. In passing to the next stereopair, it is easy to recover the previous coordinates on the common plateholder to assure identification, the stereoscopic setting then being accomplished by adjusting the other plateholder. However, experience shows that the execution of a setting with four independent movements is not very convenient. Other stereocomparators are provided with an xy-movement acting on both plateholders together and a differential movement dx, dy between them; it permits convenient setting but does not allow recovery of a point already observed in the preceding stereopair by simple resetting of the coordinates. The IGN uses a stereocomparator designed especially to solve this problem; the recorded coordinates are indeed x, y, and x_2, y_2, but there is a differential control capable of adjusting the left or the right plateholder at will.

There remains still the problem of identification of points on different strips, a problem which has taken on greater importance with the generalization of treatment in blocks by purely analytical methods.

The simplest solution is evidently to mark all control points on the ground before taking the photographs, with targets visible on the photos. But this solution is not always possible; besides, it entails considerable work which is scarcely justified except for large-scale surveys, and it eliminates, at least partially, the principal advantage of aerotriangulation which is that it reduces the amount of field work. Another inconvenience, not negligible, is that it imposes difficult requirements of precision on the taking of the photographs if it is desired to have the points fall exactly at preplanned locations. Finally, experience indicates that pretargeted points are sometimes difficult to recover.

On the other hand, pretargeting permits the use of a simple monocomparator, a comparatively low-cost instrument which gives perfectly independent measurements.

In the absence of pretargeting, one can use natural images, such as the corner of a building, the centerlines of crossroads, etc., but such details are rarely distinct and sharp, and they may have different appearances on different photos, making the measurements uncertain. Recourse to stereoscopic vision, and consequently to a stereocomparator, is quite indispensable, but this alone is not enough to assure the transfer of a control point from one strip to another.

An attractive-appearing solution is the marking of the points on the plates, using an instrument like the Wild PUG or the Zeiss Snap Marker. There are two ways in which they can be used:

1. Each point can be marked on only one plate of each strip, the pointing being done stereoscopically in a stereocomparator. But it is not very practical to make a precise stereoscopic pointing if one of the points is already marked, unless, as pointed out by Prof. E. H. Thompson, the shape and dimensions of the stereoscopic index are exactly adapted to those of the mark; in fact, it is well known that pointing by superposition of identical images is far less precise than pointing by bisection or by framing.

2. The second manner of operating consists in marking all the points on all the plates. To carry out this operation, it is necessary to associate one plate, on which the point has been chosen, successively with all the other plates upon which the point appears, and to make a very precise stereoscopic pointing on each, the first plate being marked last. This amounts to the same thing as in the case of pretargeted points, and the measurements can be made very rapidly on the stereocomparator. Prof. Thompson has criticized this method on accuracy and economic grounds. It is certain that the fact that there are in reality two pointings, one stereoscopic and the other monocular, reduces the precision to some extent, to say nothing of the errors introduced in marking the points or of the greater or lesser suitability of the mark made in the emulsion. On the other hand, regarding the economic considerations, one can hardly dispute the fact that the marker-monocomparator combination is appreciably less costly than most of the monocomparators now on the market, especially since a considerable number of markers can be associated with a single monocomparator. Prof. Thompson has justly stated that the slowest and most demanding operation is the association of the plates, two at a time, and their arrangement for stereoscopic examination: once this has been done, it is not much more difficult to measure the coordinates on the stereocomparator than to do the marking. But the difficulty is that if one adopts this method, the measurements must be made point by point rather than plate by plate; consequently, each plate must be put in place for measuring as many times as the number of points it contains, and, each time, it is necessary to point and to measure the coordinates of at least two fiducial marks, so that the measurements can be related to the same system of axes. One can perhaps avoid these repeated measurements if the positioning of each plate on the plateholder can in some way be recaptured with a precision on the order of a micron. But one cannot escape the manipulations necessary to associate the plates two at a time, which is a source of time loss incompatible with the efficient utilization of so expensive an instrument.

The method of photographic recording appears capable of solving the irritating problem of how to transfer points in aerotriangulation. It is on the Nistri TA3 stereocomparator that one finds the principal application of this technique; this instrument allows one to photograph on 35-millimeter film the image seen through the oculars—that is, the point with the reticle superimposed. This idea has been adopted in the SOM stereocomparator, with the difference that a reversed positive made from the film can be introduced in the instrument, examined in one or the other of the oculars, and fused stereoscopically with the corresponding area on the plates being measured. This resolved, at least theoretically, the problem of transferring from one strip to another. But, as a matter of fact, this possibility has never been utilized in practice at the IGN because of the complications introduced in the operational procedure, the insufficient capacity of the 35-millimeter film magazine, the difficulty of obtaining a correct exposure, and the additional burden imposed on the photographic laboratories. The differences in scale between strips, entailing inequalities in the apparent diameters of the photographic mark and the instrumental mark, would probably have revealed difficulties that appear more serious, although not insurmountable. However, abandoned by the IGN, the idea was momentarily picked up by the U.S. Geological Survey. According to information submitted by Marvin B. Scher, consideration was given to applying the idea to an instrument of the monocomparator type; but this project, unfortunately, does not seem to have been brought to fruition.

A novel and somewhat surprising solution has been experimented with in the last few years by the Directorate of Overseas Surveys; it consists of using as control points natural details in the photographic image, the novelty lying in the fact that these details have very small dimensions (a few tens of microns). They are selected according to a somewhat complex procedure in which, after stereoscopic examination under moderate enlargement, the final choice is made under very great enlargement, but without precise stereoscopic fusion. The points are then marked by a system whose sole aim is to facilitate their recovery, and they are then measured in a simple monocomparator, preferably one which is provided with a reticle which permits pointing by framing. It is certain that this procedure is particularly economical; it is also quite fast since point selection and point measuring are not separated. It does not eliminate the need to choose and mark the images that will be used, but this preparation is common to all the methods; at the most, one can say that the points should be particularly minute.

According to the articles published by the D.O.S., the results of preliminary trials are very satisfactory: if they are verified, they will have made a serious and almost sacrilegious attack on the fundamental principle of stereophotogrammetry which says that only by stereoscopic fusion is it possible to assure the correct identification of corresponding points that are not targeted on the ground, with a precision that is considered axiomatically to be higher than that of monocular pointing. There is room for apprehension, however, that the points whose coordinates will be measured in the vicinity of the *center* of more or less ill-defined spots, and which can appear very different on different photographs, may not be exactly homologous; but it is possible that, because of the small dimensions of the spots, the error thus committed will be on the order of a few microns and can be considered negligible.

Great hope has been placed on automation of procedures for selecting the points, and for stereoscopic pointing, by use of diapositive image correlators. But these image correlators make only a relatively gross simulation of stereoscopic fusion, and one cannot hope for very much saving of time, since the coarse matching would, without doubt, have to be done manually. Besides the fact that the equipment used in this work would be very costly, the use of this equipment would not eliminate the tedious work of preparation, with the many manipulations of the plates that would be required.

An entirely automatic solution, sometime in the future, can nevertheless be envisioned; it would consist of reducing all the photographs to digital form, using a technique that has already been tested: each photograph is broken down into very small elements and their photographic densities are recorded according to a scale composed of a number of gradations, the analysis of density being made, of course, automatically, by scanning, with the aid of, e.g., an IBM analogue scanner. Starting with these data, recorded on magnetic tapes, disks, or some other medium, it would be theoretically possible to resolve all the problems of aerotriangulation. Perhaps we will be set free from the idea of discreet points, the calculations being henceforth concerned with finite areas, and ending in the definition of complete topographic surfaces, broken down into elements dx, dy, by knowing the elevation and the photographic density of each element, from which one could obtain orthophotomaps with contours directly. Thus, there would be realized, at the same time as complete automation, the synthesis of aerotriangulation and of plotting; but it is hardly necessary to state that this will not take place tomorrow, nor before the next Congress of the ISP.

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The Eleventh Congress of ISP

ONCE EVERY FOUR YEARS the International Society for Photogrammetry (ISP) meets for two full weeks of papers and exhibits at its Congress. This year, July 8 to 20, it convenes at Lausanne, on Lake Geneva, in Switzerland. The purpose of each Congress is to report, review and discuss the new applications of photogrammetry that have occurred since the previous meeting. Between congresses each of the seven technical commissions often holds a symposium where its subject is treated in a depth and candor which may be difficult to accomplish otherwise.

The founding of ISP in 1907 is credited to Prof. Dr. Dolezal of Austria. ISP is an association of national societies of photogrammetry—46 of them to date. The organization of ISP consists of a Council of seven members supported by the technical commissions. ISP is financed through a levy on the national societies of one Swiss franc per year for each of their individual members.

At the close of each Congress, the delegates (one per member country) select the site of the next Congress and the new members to the Council. Also the seven commissions are redistributed among the member nations; each host nation appoints the president and secretary of its commission. The president and secretary are responsible for the technical program in their field during the following four years and at the next Congress. The proceedings of each Congress is published under the title *Archives* which is released during the following year.

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nomogram which is applicable to all scales of photography. The nomogram is used directly on the photographic print on which one can also draw pencil lines orthogonal to the wave fronts to aid in orienting the nomogram (Figure 1).

The left-hand scale of the nomogram (Figure 2) represents H/f which is the inverse of the conventional photo scale fraction. The center scale is $\log \lambda$ expressed in units of feet; this is the scale on which one reads the answer. The right hand scale consists of a slot cut out of the transparent nomogram where the opening of the slot is the actual orthogonal distance λ between the photo images of two successive sea waves on the photographs. As with most nomographs, the two scales and the slot width are logarithmic.

The nomogram is moved about until a wave length image, orthogonal to the wave front, just fits into the slot. A straight-edge connecting this point on the slot with the appropriate point on the H/f-scale gives the actual wave length in feet on the middle scale. The value can be recorded directly on the photograph.

The nomogram is only useful for measuring waves which are very clearly defined; where this is not true one would need to resort to alternative more sophisticated methods for finding λ, such as microdensitometer traces.