The WILD B8 Aviograph—
A Simple Photogrammetric Plotter

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THREE main types of stereoplotting instruments are used in photogrammetric practice:

1. The various types of large plotters based on rigorous geometrical principles. The rigorous geometrical solution provides a geometrically correct conversion of a stereoscopic pair of pictures from central perspectives into a spatial orthogonal projection;
2. projection instruments such as the Kelsh Plotter, Balplex and Multiplex; and
3. various small plotters with approximate and makeshift solutions.

Instruments from the first group are the most accurate and most suitable for the interpretation of the photographic record. Certainly, they are mostly comparatively complicated in construction, but on the other hand they are fairly versatile in many respects; also, their purchase prices are considerably higher than those of plotters in the other groups.

The instruments in the second group are less expensive, but have the disadvantage that the projected parts of the pictures are seen on a surface which gives a diffused reflection, and where they must be fused into a spatial model by means of the anaglyph method, polarization, or blinkers. In no case are the pictures viewed orthogonally, but only obliquely. The diffused projection and the indirect viewing of the image shown on a screen render it impossible to make full use of the resolving power of the camera lens; details in the pictures cannot be recognized and interpreted as well as with instruments of the first group. Further, the range of sharp focussing is limited.

Most instruments of the third group are used for plotting only, with a considerable reduction of the original photographic scale. They are suitable only for studies of the terrain and approximate plotting, for which exact model fits and undeformed models are not essential. For plotting large areas, various tricks and methods of compensation must be used in order to get results which are comparable—at least approximately—with those of the large plotters. These problems call for highly qualified operators who are able to assess correctly what model deformations are present. It is seldom that a small plotter is not put away in a corner, to lie there unused, as soon as intensive work is required, and large instruments have been put into service.

Nevertheless, the large instruments are not always economical for all tasks, and for this reason the photogrammetrist would like to have a smaller and less expensive plotter, based on the principle of the rigorous geometrical solution, for plotting from vertical photography with nadir distances limited to 5°. Of course it is impossible to fulfill all of these wishes with one instrument. It is hardly possible to construct a plotter with the size and price of a third-order auxiliary instrument, with the rigorous geometry of a second-order plotter, and satisfying first-order accuracy requirements, and in addition, with sufficient magnification in the operating system and enlargement of the plotting scale.

But the ideal solution of the problem of a precise smaller plotter can be approached very closely. It is necessary to analyze the photogrammetrist's wishes, to reduce them to the basic essentials and to investigate the plotting potential obtainable with the simplest means. All of the disadvantages of existing large plotters should be avoided while preserving as many of the advantages as possible. The interests of the practicing photogrammetrist must be considered in the simplest terms, various concessions must be made, sensible limits drawn, unnecessary comfort put aside—but the rigorous geometrical solution must be maintained at all costs.

What are the advantages which cannot be given up in a photogrammetric plotter?

1. *Direct frontal observation* of the unreduced original aerial negatives or their diapositives.
2. *Optimum magnification* for observation by means of an optical system with

a field of view as large as possible, large exit pupils, adjustable eyebase, and squint correction.

3. *Free-hand control of the floating mark*, so as to increase the usefulness of the plotter in all fields of application.
4. *Rigorous geometrical solution*, not only with respect to the intersection of the rays, but also with the several degrees of freedom for swing, tip and tilt of the separate pictures, with the possibility of scale change within a certain range, tip of the base and tilt of the model for the complete relative and absolute orientation, by the same method as with instruments of the first and second order.
5. *Direct reading* of terrain heights in meters or feet.
6. *Correction of residual lens distortion*, and if necessary also the earth curvature.
7. *Plotting from vertical photography* (with nadir distances up to 5°) for the usual focal-lengths and formats, which include today the 120° super wide-angle camera.
8. *Direct enlargement of the model scale* in the plotter to twice that of the negative scale with an extra tolerance of at least 5% of the flight-height above ground. (This computation of the direct enlargement range corresponds to the limit placed upon free-hand movement of the floating mark—i.e. the plotting pencil—by the length of the operator's arm.)
9. *A pantograph* should be provided for enlargement of the plotting scale.
10. *A compact instrument* is required, nevertheless of high stability and accuracy and with the simplest adjustments.

No practitioner is likely to argue that any of the conditions given above is unnecessary; nor is the photogrammetrist likely to give up any of these points easily. If a relatively inexpensive instrument with the above mentioned properties could be constructed, it would be a unique photogrammetric plotter for many tasks. When the ten requirements are stripped of complications and are examined technically, the principles of the simplified plotter can be brought into existence step by step.

Let us set ourselves the problem of developing this instrument. In the first instance, there are several numerical decisions to be made. We want the instrument to be usable for plotting from wide-angle photography by the survey cameras most used nowadays—i.e. with negative format of 9″×9″ (23 cm. × 23 cm.) and focal-length $f=6''=152$ mm. with a tolerance of ±3 mm., as well as for working with super wide-angle photography with the same format and a focal-length of 88 mm. ±3 mm.

Figure 1 shows the geometrical photographic relationships: Two camera stations separated by the base *B*; a ground point *P* is imaged at *P1* and *P2*, by the rays through *I* and *II*. The reverse process, shown in Figure 2, with the same positions of the cameras, demonstrates by the reconstruction of the ground point *P* how the model is formed through simple intersection of rays, and reduced in the ratio of air-base *B* to model-base *b*. The diagram is arranged to show that

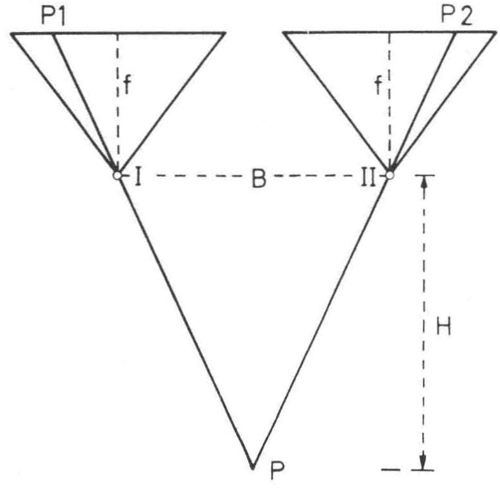

FIG. 1

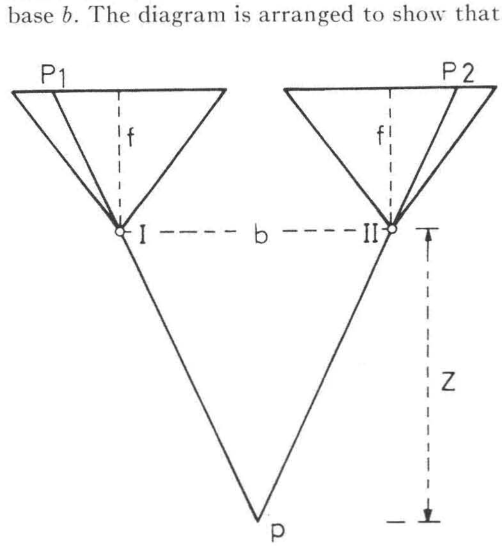

FIG. 2

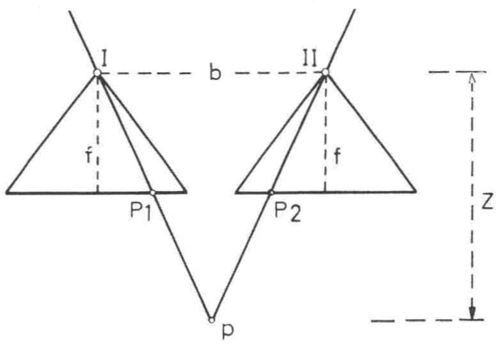

FIG. 3

the ground point is represented by the model point in the reconstruction at a distance of about twice the focal-length. If, as Figure 3 shows, the reconstruction is made using diapositives instead of negatives, it can be seen that if this arrangement can be realized as a construction, the influence on the size of the plotter will be favorable.

We have asked for a frontal (orthogonal) observation system: this is provided as a matter of course when the mechanical space-rod system is chosen. The diapositive position is also convenient as far as the length of the space-rods is concerned. These pass through the base terminals and intersect at the model point observed. So as to allow the space-rods to be moved freely, the diapositive plates must be laterally displaced outwards. With a displacement "a" to left and right, as shown in Figure 4, then provision for scanning can be achieved by providing each space-rod with a moving tie-rod for connecting the observing optics to the space-rod, which must always move parallel to the direction of displacement of the corresponding picture. Further, in order to place observing microscopes at the ends of the tie-rods, the pictures must be moved upwards and into the focal-plane of the observing lenses. This is illustrated in Figure 5. It will be practical to build the measuring marks directly into the observing microscopes so that they will always move at a constant distance from the picture plane, and thus reduce to a minimum the possibilities of error in combining picture and mark. The tie-rods of constant length must move in a plane at a perpendicular distance f, as plotting focal-distance, from the projection centers, i.e. the base terminals *I* and *II*. The parallel guidance of the tie-rod is to be provided by a system of parallel rails. The diapositive carriers are illuminated from above by lamps with reflectors, as shown in Figure 6.

The images of the two picture parts are formed by the observing microscopes in the planes of the measuring marks. These images

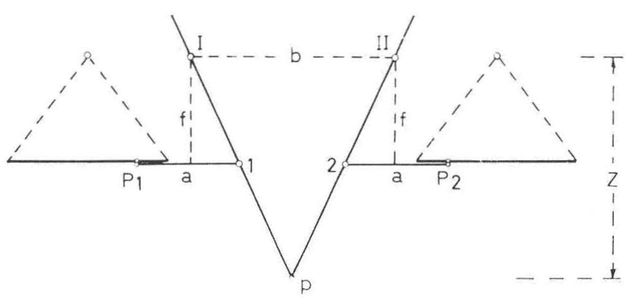

FIG. 4

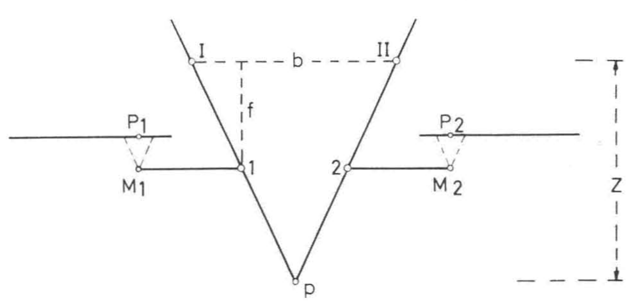

FIG. 5

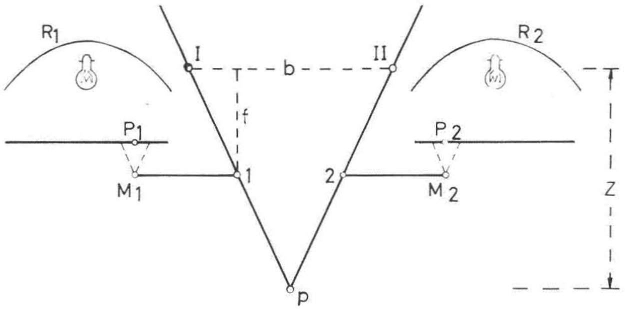

FIG. 6

must be transferred, by two optical cardans and through an optical system with adjustable dove prisms (in consideration of removable tilt differences), to the viewing optics. Here tests have shown that a six-times magnification is generally most useful.

The picture carriers must have centering marks and made as either plane parallel glass-plates or as correction-plates, and must be provided with movements for swing, tip and tilt. These can be limited to $\kappa = \pm 10°$ and ψ, $\omega = \pm 5°$. The base must be adjustable between 60 and 260 mm. for plotting from wide-angle and super wide-angle photography with 50% to 80% overlaps. For simple absolute orientation by empirical means, it is desirable to make the base tip about its mid point, with a range of $\pm 5°$. The tilt in the model will be removed during absolute orientation by changing the tilt of each picture separately by the same amount.

The space-rods meet at the tracer in such a way that heights are adjustable.

It is, however, desirable that the space-rods are not brought to intersect at the tracer, so that as much use as possible can be made of the height range even when the base-ratio reaches a minimum with 80% overlaps. To eliminate this intersection, a short auxiliary base of a few millimeters can be introduced at the top of the tracer's height column, and each space rod rests in a common hinge on the tracer: of course, with the introduction of the short auxiliary base Δb, it is essential to keep this base parallel to the main base, and provision must therefore be made to tip the hinge (i.e. the base Δb) on the tracer by means of a micrometer screw.

The main base b must be extended by the length of the auxiliary base Δb, as shown in Figure 7.

The tracer should stand on three polished spherical agates, resting on a flat surface on which they can slide easily. For the flat reference plane we choose a slab of polished granite, the base-plate.

A Z column must be built into the tracer such that it can be moved in height by turning a control drum. The tracer must carry a drawing point which stands clear of the feet and the Z column, i.e., towards the operator, so that he has a clear view of his plotting and can make additions, etc., even in the immediate vicinity of the drawing pencil. A simple lever is to be provided on the tracer for raising or lowering the pencil. In order both to keep the space-rod base parallel to the main base, and to keep movement of the pencil parallel to the center of the tracer, the latter is attached to a parallel guide which is fixed to the back of the instrument.

All controls for setting the orientation elements must be accessible to the operator comfortably from the seated position and while he is viewing the model through the eyepieces.

One of the items laid down in the principles of construction of the instrument was that it should be small enough to stand on a normal office desk. It is hardly possible further to

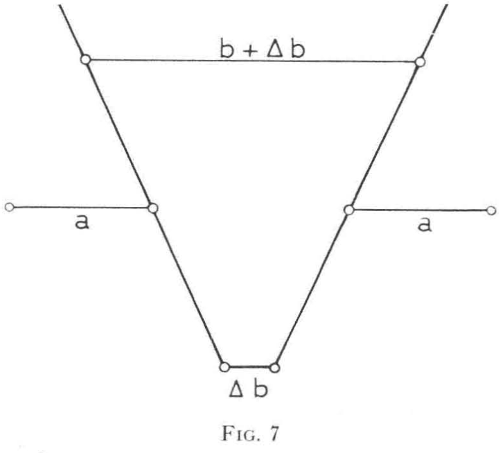

FIG. 7

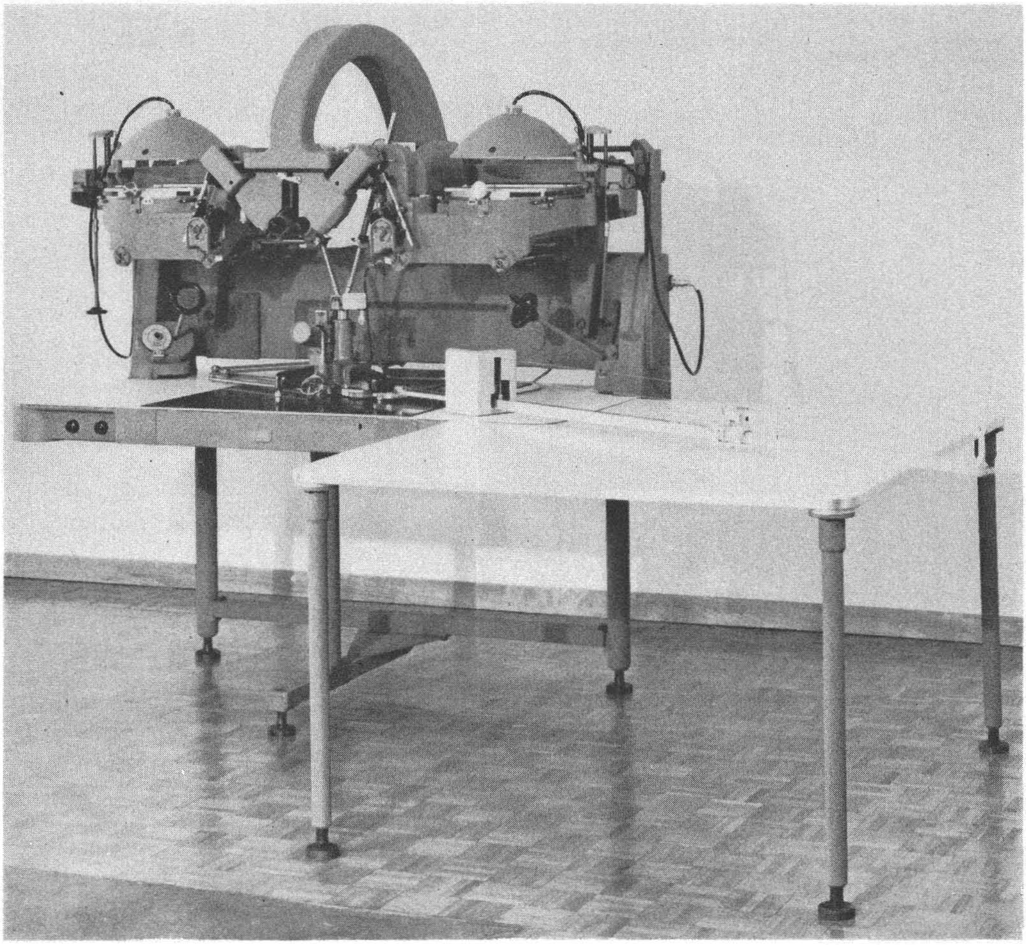

FIG. 8. B8 Plotter.

reduce the dimensions with a rigorous spatial solution, since the minimum distances are determined by the picture format and the direct 2× model enlargement.

Concerning the pantograph for further enlargement of the plotting scale, it will be sensible to fix a side table to the base-plate of the instrument rather than to increase the size of the base-plate itself.

What will the adjustments be for a plotter of this design? With base plate and picture carriers levelled, and the space-rods each placed (one after the other) exactly vertical, then the image of the measuring mark must appear in each case exactly at the central adjustment cross of the diapositive carrier plate.

An important factor for the instrumental accuracy has not been mentioned so far: it can be recognized in Figures 4 and 5. Consider the case where the two diapositive planes are exactly horizontal and parallel to the plane of the base-plate. When, under these conditions, the tracer is moved, the measuring marks will describe exactly a contour line during scanning of the model surface. Figure 7 shows that for all positions of the tracer for equal terrain elevations, the distance between the measuring marks must be constant, their separation is related to the horizontal parallax present, the constant value of which defines the contour. The mechanical solution with tie-rods of constant length which are guided parallel to the base, therefore guarantees maintenance of constant horizontal parallaxes with the highest possible accuracy. This is even the case should the parallel guides of the tie-rods show some play, since an angular error in the parallel guidance has the influence only of its cosine, i.e. it is negligibly small in practice. This fact ensures, from the outset, the maximum height accuracy using the most simple construction that can be imagined.

If we now evaluate the instrument critically, we might ask whether an approximation or expediency linkage, remote control or some sort of indirect solution could be chosen instead of the orientation system or the space and tie-rod system as described. One reaches the conclusion, however, that the simplest, geometrically correct solution is also the most economical and most reliable. Any deviation from these ideas would lead to complications and sources of error.

In order that the instrument be usable for both focal-lengths mentioned above, it must have exchangeable mechanical adaptors to regulate the focal distance from the base terminals, and the reflectors must be correspondingly adjustable in height.

A plotter complying with the requirements given here has been developed and is in production in Heerbrugg. It is called the *WILD B8 Aviograph* (Figure 8). Even the first work with this instrument showed that all the requirements are fulfilled and that the accuracy obtained in plotting from wide and super wide-angle photographs, complies fully with the standards set. The correct basic principle of the rigid distance between the measuring mark from the space-rod, in combination with well-made mechanical cardans and parallel guides and a close tolerance for the flatness of the granite plate, all produce good relative height accuracy which approaches that of a first-order plotter. Similarly, the positional accuracy in the mechanical model is well within the plotting accuracy, while the mechanical stability of the pantograph is responsible for making full use of this planimetric accuracy in the transfer to the enlarged plotting.

A special pantograph has been developed for the *B8*. It is a linear pantograph supported at one point only on a robust vertical axis, thus reducing inertia to a minimum. Movement of the bearing-mounted pencil carriage is controlled through a gearbox with interchangeable gear ratios and a cable drive. The mapping accuracy is within 0.3 mm. when the plotting carriage is at the end for the pantograph, i.e. at the extreme and least favorable position.

It can be concluded that the *WILD B8 Aviograph* is indeed a desirable plotter which the photogrammetrist has had in mind for simple and inexpensive, but nevertheless reliable and accurate, instruments.

Variations in Aerial Photo Image Recovery Resulting from Differences in Film and Printing Technique[1]

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(*Abstract is on next page*)

Introduction

In the aerial photographic industry, electronic printers are supplementing or replacing conventional contact printers for more efficient and automatic production of prints and diapositives. Quality improvement and material savings in certain types of mapping photography have been noted, but

[1] Based on a portion of a research problem submitted in June 1958 to the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Forestry; authorized for publication on August 1, 1959, as *Sci. Jour.* Ser. Paper No. 4203 of the Univ. of Minn. Agr. Expt. Sta.

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