VERTICAL CONTROL DETERMINATION WITH STATOMETERS AND HELICOPTER—A SUGGESTION

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AERIAL triangulation with stereoscopic or radial methods makes it possible to build photogrammetric bridges over fairly large areas where no control points are surveyed with ground methods. The stereoscopic methods allow determination of horizontal and vertical position of minor control points, the radial methods only of horizontal position. However, the so-called b_z-curve or the accumulation of temporary errors in a systematical manner, lays obstacles in the way for long stereoscopic aerial triangulations. If vertical control points are placed here and there in the strip it is possible to keep the b_z-curve under control. As it is much easier to survey vertical than horizontal controls, it is much cheaper to use vertical control points than to break down the strip in shorter strips through putting additional geodetic surveyed horizontal control points between the existing horizontal controls.

In a topographic map the tolerances in elevation are much closer than those of the horizontal position. We can compute the flying altitude on the basis of the contour interval and the plotting instrument. If a part of the allowed error must be reserved for vertical errors from the stereoscopic triangulation, the altitude must be lowered, which increases the costs. Consequently it is of advantage if there are sufficient vertical controls in every stereoscopic pair to level the model. Such points are of course of great value in photogrammetric triangulation work if done with stereoscopic methods. Consequently the frequency of vertical controls is much highly than of horizontal ones. The greatest accuracy in surveying vertical controls is obtained with spirit levelling, but such measurements are rather time-consuming, especially in those areas where no roads exist.

The barometric methods are fairly rapid and are very much used. The variation in the atmosphere causes risk of considerable errors, to which one must add the fact that the precision-barometers are rather damageable and easily can be brought out of adjustment. The first mentioned source of errors can partly be brought under control through using reference barometers all around the area in which the survey is going on. In *Mr. Davey's* paper in the March 1949 issue of this Journal he mentions that the use of three or more "bases" are under consideration. The influence of the latter source of errors is reduced to some extent through better instruments, which can stand the rather hard treatment consequent upon field conditions. The latest models of the *Wallace & Tiernan Altimeter* and the *Swedish System Paulin Aneroids* seem to be rather good.

About 1935 the Finnish scientist *Dr. Väisälä* designed a very simple and accurate instrument for determination of variations in the flying altitude during photogrammetric flights, *the statoscope.* Principally it is an ordinary liquid manometer, as shown in Figure 1. Before the measuring commences, the glass bulb B is connected with the air (1) through opening the cock C. The air-pressure in the bulb, which is kept at constant temperature with ice-water in the thermos A, is the same as in open air. Now the cock is turned so that the bulb is connected with the U-shaped glass tube D, which is partly filled with colored alcohol. The other end of the glass tube (2) is open. If the outer air-pressure gets higher, which occurs when the instrument is brought to a lower altitude, the difference in air pressure forces the liquid down in the open part of the glass

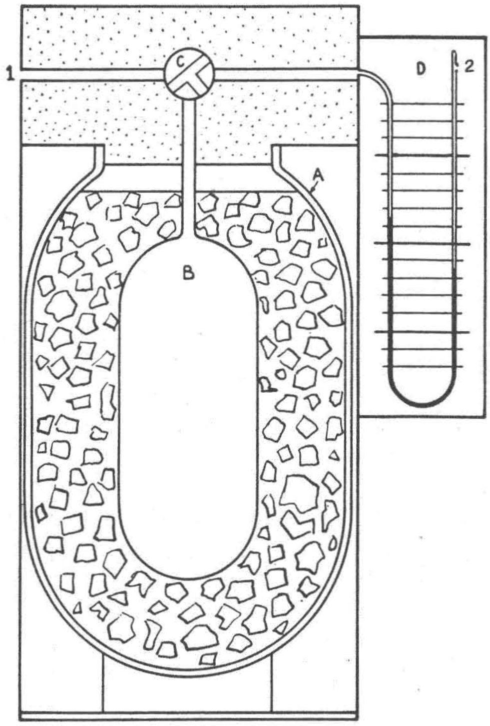

FIG. 1. Cross section of the statoscope of Dr. Väisälä.

tube. The difference in height between the two liquid surfaces gives—after some corrections—the difference of air pressure, i.e., the difference of altitude. The instrument is very simple and has no mechanical parts which can come out of adjustment or reduce the accuracy through friction. As mentioned above, the instrument was designed for measuring the b_z-values between the exposure stations during photogrammetric aerial photography work. It has been manufactured, together with recording cameras, by both *Zeiss* and *Wild*. The Finns have now modified the instrument in a very simple manner (*Kotka-statoscope*) and mounted it so that the recording is made in the margin of the negative in the main camera.

The statoscope was designed for measuring small differences of altitude, but soon it was realized that the instrument, somewhat modified, could be used for terrestrial measurements of elevation. Several modified models of such statometers were built in Sweden and elsewhere, but as far as I know most of them were not of good design; the designers may have had too little field experience. But there are no special difficulties and there is no doubt that a good and accurate field instrument can be manufactured. Such an instrument is very suitable for photographic recording as there is no coinciding to be done. As soon as the movements of the liquid have stopped, which may take 20 seconds, the instrument can be read or recorded.

It is possible to build a self-recording instrument which can be used as a reference instrument or an airborne instrument. I propose that such an instrument should contain the following parts:

1. Two statometers well insulated against heat.
2. Simple control instruments showing if the inner temperature of the thermos flasks deviates from 0°C. (melting ice).
3. Thermometer showing the temperature in open air.
4. Simple aneroid barometer (pocket size).
5. Two small chronometers.
6. Dose-spirit-level.
7. Data card.
8. A simple recording camera (16 mm.) recording directly or through mirrors the above mentioned instruments and card. (Figure 2.)
9. A pedulum arrangement which closes a warning circuit if the instrument is more inclined than, e.g., 5°.

If the instrument is to be used as an automatic reference instrument, a special power supply- and timing unit (accumulator and timing clock) must be coupled to the instrument unit.

Helicopters have been used successfully in geodetic survey for transportation and reconnaissance. Now I suggest that helicopters should be used in vertical control survey with self-recording statometers in the following way. The instrument is mounted in a shock-reducing mounting consisting of a simple self-horizontalizing part (Figure 3) and resilient steel ribs placed in a ring, every rib with a bulb of plastic on the outer end. The helicopter is stopped a couple of meters over the predetermined place, marked in advance on the photo; this is a vertical control point. These points are selected stereoscopically in the laboratory and always in a little flat area without too many bushes, if possible a water surface. The instrument is lowered with a cable which contains an electric circuit until it stands on the ground or floats on the water. While giving out more cable, the helicopter is flown so far away from the instrument that the air currents caused by the helicopter rotor can have no influence on the air pressure in the vicinity of the instrument. By means of an electric switch on

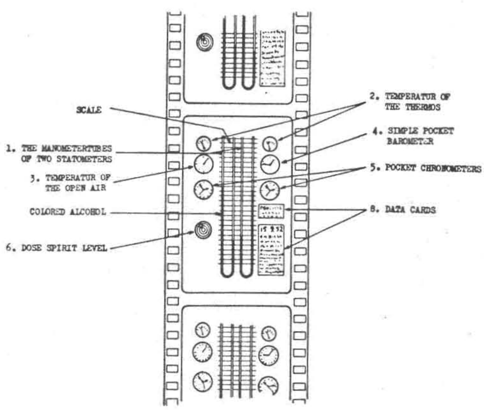

FIG. 2. Photographic record of instruments and data on 16 mm. film.

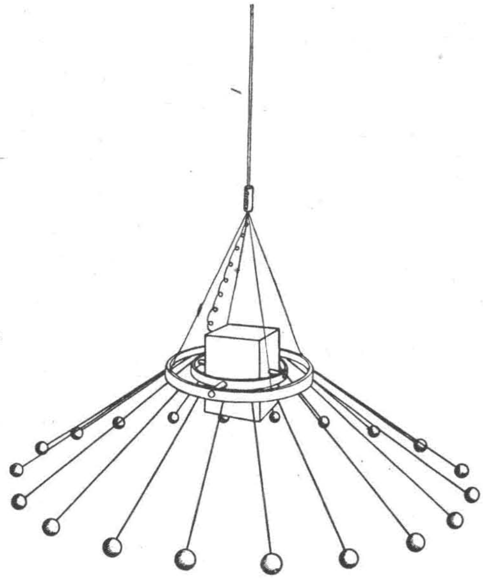

FIG. 3. Recording statometer (barometric altimeter) in shock-reducing, self-horizontalizing mount for lowering onto ground from a helicopter.

board the helicopter, the self-recording statometer is brought to function long enough to make two or three recordings. After that, the helicopter is moved back again to a position just above the statometer which is hoisted up to a bar on the side of the helicopter.

It is possible to transport reference statometers by means of helicopters to the edges of the operation area, and it might be possible, if such station instruments are designed as the above mentioned air-borne instrument, to put them in place without landing and to pick them up by "fishing." In such a case all the operations can be done in a very short time even if the terrain is very difficult to pass. As the accuracy of elevation measurements based on air-pressure usually is a function dependent on time, it is easy to understand that the elimination of perhaps 95% of the time needed for transport purposes is an essential consideration.

The operation program will be about the following. As soon as weather is stable (overclouded if possible, no wind or light breeze) the statometers are furnished with melting ice and water and placed together on the ground. Some ten simultaneous recordings are made with the five instruments after which they are suspended from the bars on the sides of the helicopter. The helicopter is flown to the corners of the intended operation area for the day and the reference instruments are placed there, if possible on bench marks. Thereafter the air-borne instrument is flown to the predetermined vertical control points which are to be surveyed. These points are easily located in the air photos. Every time the helicopter is near a reference instrument the air-borne instrument is placed beside it and recordings are made. When the area of the day is ready, the reference instruments are picked up, but before picking up such an instrument, the point is measured with the air-borne instrument. After having returned to the base, all the instruments are placed on the ground and some ten recordings are made.

When the film has been developed, the negatives are studied under great magnification, and the data obtained give material for calculating air-pressure variations and differences which form the data for the height differences.

If the method is to be economic, it is essential that the work be well organized so that every minute of the rather expensive flight time of the helicopter is used. The proposed method will be suitable for rough or wet terrain where transportation is difficult and tedious. In Sweden, we have a fairly close net of points or lakes with the elevation surveyed, so we are perhaps not so prone to use the method here and to spend money for building the instruments in question; but in non-European countries, where the first survey is just going on, the method may well be used. The above description has been made in view of localities of this latter category, and in spite of the fact that no tests have as yet been made.

USE OF ALTIMETER AND HELICOPTER FOR ESTABLISHING VERTICAL CONTROL FOR PHOTOGRAMMETRIC MAPPING*

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DURING the 1949 field season the Topographic Division of the U. S. Geological Survey successfully established vertical control on an area of 5,750 square miles in central Alaska by means of helicopter and altimeter. For that reason we are very much interested in Mr. Fagerholm's article on establishing vertical control in remote areas through use of a helicopter and a self-recording statometer. It will, therefore, be the purpose of this paper to describe the Geological Survey's altimeter-helicopter method as used in central Alaska, and to compare it with Mr. Fagerholm's proposed statometer-helicopter method.

The field work on the central Alaskan project consisted of executing horizontal and vertical control for multiplex mapping of 21 quadrangles, each quadrangle being 15 minutes of latitude by 30 minutes of longitude. Final maps are to be published at 1:63,360 scale with 50 and 100 foot contour intervals, that is, 50 foot supplemental contours in the flat areas and 100 foot contours in the predominantly mountainous areas.

The area in general was about one-half rugged mountains, and the other half low gentle slopes or muskeg area, with numerous lakes and swamps. Elevations ranged from 1,000 to 7,800 feet above sea level. No point on any of the quadrangles was located more than 30 miles from an automobile road, spirit level line or a first-order triangulation station.

The whole area was covered with east-west flown vertical photography with

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