the detailed ice features had altered or vanished and only the most generalized outline of last year's pattern remained. That is why the area of the control was not too difficult to identify. Generalized configuration of the shoreline is approximately the same from year to year, while the individual crevasses and icebergs change from month to month; if they did not change, the sameness of ice features and lack of contrast in exposures of snow would make pin-pointing an ice feature extremely difficult.

At Station Elaine, the station identification was not achieved until after all phases of the survey operation were completed and then only after encircling the main station at a radius of 10 miles on foot, with photographs in hand. It is rather an empty feeling to realize after the survey is completed and it is nearly time to return, that you don't have the vaguest idea where the stations are on the photography. Four of us spent 6½ continuous hours identifying Station Elaine on the Highjump photography. And we haven't to this day located Station Edisto on the Highjump photography.

I believe I have covered the problems that gave me the greatest difficulty. In closing, I would like to say that I am indebted to the Hydrographic Office, and in particular to Mr. Medina, for the opportunity to participate in an Antarctic survey. I am also grateful to Mr. Lundahl for inviting Mr. Medina's attention to my interest in exploratory surveying. If you have enjoyed listening a fraction as much as I enjoyed participating in the operation, I am indeed happy.

TRIMETROGON PHOTOGRAMMETRY—SOME USAGES IN THE PREPARATION OF THE CANADIAN AERONAUTICAL CHART

Cecil B. C. Donnelly, D.L.S. Chief of the Aeronautical Chart Section Legal Surveys Division, Surveys and Mapping Bureau, Ottawa

EDITOR'S NOTE: The following paper is an adaptation from Mr. Donnelly's address at the Annual Meeting of the American Society of Photogrammetry, January 13–14, 1949. During his address Mr. Donnelly used numerous slides to describe procedures used in Canada. Although this paper is not illustrated, the descriptive information concerning the procedure is retained. Mr. Donnelly prefaced his address with an expression of appreciation to United States personnel for their cooperation in the early development of trimetrogon photography and its compilation.

THE flight lines for trimetrogon photography used in the preparation of Canadian Aeronautical Charts are meridians spaced 16 miles apart at the mean latitude of the operation map. Meridians are employed to simplify the operation of the solar navigator, with which trimetrogon aircraft are equipped. This obviates the necessity for time corrections made necessary when flying angularly to the meridian.

As an example of the flight accuracy attained by the use of the solar navigator in the hand of a skillful operator, several flight lines as long as 170 miles have been flown with a maximum plumb point deviation of ½ inch from a straight line joining the terminal plumb points.

Complete film reports accompany each roll of film received from the R.C.A.F. The data shown include camera number and focal length, magazine number, the type of film, emulsion and filter used, exposure time, the geographic coordinates of the beginning and end of each flight, and visibility and haze conditions during the flight. The reports also give altimeter readings reduced to elevations above mean sea level.

The fiducial marks are fixed to the camera body and are thus an integral part of the optical system. They are located precisely in the focal plane. A contact negative is exposed, film side against the fiducials. We are therefore able to measure the four fiducial distances from the principal point to each.

We use a tri camera steel mount in which are set the three cameras, so that the three principal points and all the transverse fiducials may be said to lie in one plane. Thus we have no skew, no inherent tip, and the isometric lines parallel the fore and aft fiducials. Also, the interlocks are calibrated in the laboratory to $\pm 1'$ of arc.

The calibration data are provided us by the laboratories of The National Research Council.

The depression angles to the apparent horizon are read by means of a nomographic templet calibrated for various focal lengths. A side scale on the nomograph gives the dip angles for various flying heights so that correction to the true horizon may be made. When interlock angles are required, they are read in a similar manner, taking into account the camera focal lengths.

In making the "horizon balance," print distortion is taken into account in this manner. Having measured the apparent depression angle of the oblique, say 27°, and having measured the photo distance (principal point to horizon fiducial), we find a contraction of the print for this measurement of .03″, for instance. Against these figures in a special table, we get a plus correction of 10′ to give the apparent depression angle at the instant of exposure. The right and left apparent depression angles so arrived at, plus dip angles plus calibrated interlocks spell 180°00′. If not, a misinterpretation of horizons has occurred.

To obtain correct setting for the rectoblique plotter, print distortion tables covering a wide range of possible distortion for each hundredth of an inch expansion and contraction are made for each 5′ of depression angle from 28° to 32°. The corrections are made in the following manner:

> *Y* distortion, transverse to direction of flight. We measure the distance between the photo fiducials, and against this read distance, we read the new focal length to be applied to the photo arm of the rectoblique.
>
> *X* distortion, fore and aft. We measure the full photo distance fore and aft, and opposite this distance read against the obliques depression angle, we read the new depression angle for the templet arm of the rectoblique settting.

The templet so drawn is tested on the corresponding vertical taped to a light table. If this templet fails to satisfactorily fit the vertical, we must conclude that the vertical has distorted since the instant of exposure.

The distortion of the vertical is checked with a special scale which shows multiplication factors to apply to half the photo movement. We are thus able to picture with little practice the position of the pass points at the instant of exposure, from which we prove a satisfactory templet. At this stage, we punch the templet and photo in three places, to insure correct orientation for taking off azimuth bases later on in the process.

Special tables covering various focal lengths give the linear distances from the principal point to the nadir point for the appropriate tip and tilt values. The nadir points so plotted on the verticals should check with the nadir points of the templet from the rectoblique plotter.

The nadir points of processed verticals are transferred to the discard (intermediate) vertical, by means of a pair of Simpson Point Selectors. The adjacent photos are fused and the finely etched cross of one selector is placed over the nadir. The other is oriented on the adjacent photo and fused. A *Y* movement of the adjacent photo selector brings the arms of the fused cross into perfect contact, a swing movement horizontalizes the fused cross, and an *X* movement brings it to ground contact.

When perfectly oriented, the adjacent photo selector's optical glass is raised, and an arm, on the underside of which is a fine needle, is lowered against spring pressure, to puncture the photo in the exact point but lately occupied by the cross. This is a speedy and most accurate means of point transference.

Processed plumb points having been thus transferred to the Discard Vertical are joined by a finely etched line, which now must be transferred to the adjacent verticals.

The transfer is accomplished by means of the Air Base Line Instrument. This is a binocular instrument provided with an interocular adjusting screw. Each telescope carries a floating mark suspended in an adjustable diaphragm. When fused, they form a cross. Each telescope has focusing rings to focus sharply the eye pieces on the floating marks and the objectives for photo imagery. Parallax may thus be entirely removed, and clear definition obtained. Two platens, equipped with clamps and fine motion tangent screws, revolve freely about their vertical axes, and contain a fine punch on the surfaces at the very centres of rotation. The carriage is designed and mechanized such that the right wheel traverses the right platen very slowly, the left, both platens quickly and evenly. Thus the right wheel changes the X base very slowly, for a large movement of the wheel. Adjustable mirrors reflect the photo images to prisms, and thence to the eyes. An adjustable steel straight edge folds down to cut precisely through the platen centre punch marks.

Operation: Closing the left eye, adjust the mirror and traverse the carriage until the right floating mark coincides with the right platen centre punch. Repeat for the left eye, closing the right eye.

To the left platen clip the discard vertical so that the etched line is centred on the floating mark, at that part of the etched line near the roughly estimated position of the plumb point. On the right platen, centre the plumb point of the adjacent vertical on the floating mark, and clip on the photo. Orient the photos to give a fused model. Unless perfectly oriented, the fused cross will break into a staggered pattern. With clamp and slow motion restore its perfection. Lower the straight edge and etch the transferred line, only when, of course, the right wheel has brought the fused mark to ground contact.

The critical feature of the instrument is that however minute the lack of perfect orientation may be, the fused mark will break up, showing a jog in the horizontal lines of the cross, the jog occurring in the vertical line thereof. A rapid traverse of the carriage will show the fused cross travelling perfectly along the etched line, provided, of course, that it be kept at ground contact by means of the X changing right wheel.

The projection used is the Transverse Mercator at 1 mile lay-down scale, graticuled for 30′ quadrangles. The Canadian lune is 8° in longitude and 2° in latitude. The central meridian is one of the rectangular construction lines forming a grid of squares 2 metres to the side. Thus, the two sides of the lune are symmetrical. The book of subsidiary tables and sketches enable two operators to lay down the projection in half a day. The tables extend from 48° to 72° in latitude.

Astronomical observation points for latitude and longitude used for control, and identifiable on the high altitude mapping photos, are plotted by means of these subdivided 30′ quadrangles at 1 mile scale. One minute of longitude is divided into 10″ intervals, and a subsidiary scale is divided into 10″ intervals of latitude. These projections are drawn for each 30′ of latitude from Lat. 48° to Lat. 72°.

Having obtained the scale ratio of paper templet assembly to projection, the paper assembly is broken down into individual templets, during which process all resected points, including pass and plumb points, are punched through the assembly and circled on each templet. These punched marks are now scale factored to their one mile position, by means of two logarithmic spirals with logarithmic arcs in proper relation to the spirals, reproduced on clear film, and at the same scale, superimposed and oriented at the same point of origin. The 1.00 of one arc is set against the scale factor of the other. The paper templet's plumb point is pivoted at the origin, the punched points of each ray rotated to one spiral and an etch made on the ray at the other spiral giving 1 mile scale. In constructing metal templets, these etches are marked on their arms, but not for pass and yellows. No metal is built for these points.

When the metal is lifted every other paper templet is oriented on the projection by means of the red points which were punched and circled thereon when lifting the metal. The positions of all resected points punched on the paper assembly are transferred to the projection and marked by squares. The scale factored positions of pass and yellows as given by the spirals, are punched and circled on the projection to complete the net of minor control points.

About every 24 miles we make a blue point lateral tie between adjacent flights. Upon laying adjacent flights between their respective terminal control points, we may find that opposing blue points do not coincide. We do not strain or move any metal to make them agree. We let them fall where they will, and then adjust all reds and yellows to a balanced position of the non-coincident blues. We do not adjust pass points; we believe we have done our best in azimuth and pass point scale.

To adjust reds we use two transparencies. Different colors are used to draw the parallel lines 0.2″ apart on the sloping one, and black to draw the parallel lines 0.2″ apart on the vertical one, which has also transversals placed 5″ apart. One of these 5″ lubber lines is laid on the projection joining the coincident blues to the balanced position of the non-coincident blues. The first transparency is laid so that one of its colored lines contains the two non-coincident blues. The travel of the broken line constructs a parallelogram starting at the plotted position of the red and terminating in its adjusted position.

The yellow points are now adjusted using their contemporary reds. An etch is made on the pass point line joining the unadjusted red and yellow produced. Thence a section of the line to the adjusted red is drawn. The intersection of this section, and a line drawn through the unadjusted yellow, parallel to that joining the two reds, is the point sought. Sketchmaster projection on the net of points so adjusted is satisfactory.

Detail points on verticals of mountainous and hilly terrain are fixed in this manner. A resected pass point is transferred from an adjacent vertical to the Discard Vertical, and a ray drawn on the Discard to the Transferred point from the estimated position of its nadir. The Discard is slipped under the projection with its etched azimuth coincident with the projection plumb point line, and the pass point ray cutting its corresponding projection pass point. Then rays may be drawn to the added detail points. The adjacent vertical is oriented under the acetate and rays to corresponding detail points fix a bisection on the projection.

It sometimes happens that misinterpretation of the horizons gives rise to tilted templets and assemblies thereof. We make it a rule to adhere strictly to the same interpretation of the horizons throughout the flight, as any departure from that interpretation anywhere in the flight means a sudden change in the azimuth. While this may be apparent in triangles at the resections, they may not be big enough to cause alarm and promote search for the cause. To correct the positions of resected points, necessitated by small residual tilts in the constructed templets, recourse is had to perspectometers. Used in conjunction with a squared grid for 1 mile scale, the paper templet is placed on the perspectometer and the tilted resected points thereon rectified on a transparency placed on the squared grid.

The acetate is finally cut into quadrangles of 30′ of latitude and 1°00′ of longitude for photographic reductions for compilation and final draughting at 5.33 miles to 1 inch. This size suits the convenience of our camera copy board, and filing of acetate for record.

EUROPEAN FIRST ORDER TRIANGULATION AND ITS ADJUSTMENT*

Floyd W. Hough, Chief, Geodetic Division,
Army Map Service, Corps of Engineers

THE measurement of distances between points on the surface of the earth through the method of triangulation is not of recent origin. Nearly four centuries ago, in the year 1579, the Danish Astronomer, Tycho Brahe established an observatory on an island near Copenhagen. There he determined an azimuth and an astronomic position in latitude and longitude from observations on the stars. A base line was measured on the ground to furnish his initial distance. The angles to a new station were then measured at the ends of the base line. The distances to the new point and its latitude and longitude were computed, and the azimuth carried forward, through the application of the well known elementary principles of trigonometry. The geographic positions of additional stations were likewise determined from succeeding angular measurements. A check base line was even measured on the ice during the winter months. This procedure is recognized as the familiar one still employed by geodetic engineers when surveys are initiated in new areas. The old Danish triangulation arc is all the more remarkable when we consider that it antedated by half a century the invention of the telescope by the Hollander, Hans Lippershey, in 1608. Brahe observed his angles by sighting distant church spires or similar targets on clear days with the unaided eye.

2. Following this initial arc in Denmark, and particularly during the past century and a half, the Europeans have extended their basic triangulation over the entire continent. The lower order control, fitted within the basic first-order triangulation, is likewise very extensive in Europe, much more so than in the United States. This minor control with its dense coverage is primarily for mapping and cadastral purposes. It is not uncommon, especially in Germany, to find a horizontal control density of one or two points for each square mile. The standard German requirement, which we consider excessive, was not less than 22 horizontal control points per map sheet of 1:25,000 scale.

3. This paper deals with the adjustment only of basic European triangulation of first-order accuracy. This accuracy has been defined by the International Association of Geodesy as that represented by an agreement between the value of a baseline measured with a probable error of 1:1,000,000 and the computed value of the same line carried through the triangulation of not more than one part in 25,000 of the length of the base, after the angle and side equations have

* Paper read at Annual Meeting, American Society of Photogrammetry, Washington, D. C., January 13, 1949.