THE BROCK PROCESS OF TOPOGRAPHIC MAPPING*

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THE Brock process of topographic mapping is divided into separate operations for each of the required steps. It is, therefore, one of the easiest methods to teach operators as each unit is designed to do one or more of the various phases of the work separately. These steps are composed of operations, each of which will be described in order:

The camera is of the full automatic type and is provided with daylight loading magazines which hold 48 glass plates, 6.5″ by 8.5″ of 1/16″ thickness. These plates are placed on individual shelves in the magazine and moved into the focal plane and back into the magazine by septums which only act as guides and cannot cause any deviation from the optical axis.

The cone with the lens mounted and doweled therein constitutes a unit interchangeable in the camera proper. When the glass plate is in position for exposure, it is pressed firmly against the machined surface of the cone and held in place by four springs located near each corner of the cone. The camera is hand operated. Turning of a crank charges the shutter at the same time the plate moves into position. When the plate is in position, the mechanism automatically locks and is released only after the plate is exposed. After the plate is exposed and returned to the original compartment from which it came, the magazine rises and places the next plate in position to resume the operation. As the magazine rises, the light door on the magazine closes by this same amount. This operation continues until the last plate is exposed. The camera door cannot be opened unless the magazine door is closed, which prevents exposure of plates to daylight.

The next magazine is merely placed in the camera which is then ready to operate. The time required for an experienced cameraman to change magazines is about ten seconds. The number of plates that can be carried is limited only by the hours of photographic light available.

The camera is suspended in the plane by a gimbal mount, the oscillation being damped by hydraulic dash-pots. An easy means is also provided to compensate for the unequal weights of the loaded magazine.

The plates are exposed with the longer axis of the plates in the direction of the flight.

The plates must be absolutely flat glass, as any plate that is not such will only cause incorrectable trouble later on in the operations. Plates which deviate from a flatness by more than 2/1,000 inch are rejected and cannot be used. The best type of glass for this operation is of a Belgian make.

Ground Control

As the horizontalization of plates is accomplished by "parallax" differences, the only horizontal control points needed are those from which the radial triangulation is extended. These points, if properly located, can be minimized to five points per quadrangle, one located in each of the corners and the other point somewhere near the center.

Vertical control points are required near the center of each plate and at right angles to the line of flight on each side of the center, in the overlap area of the adjoining flights. A lock point is also located somewhere near the center of the

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model. With the control so located, we have a net gain of four vertical control points per model. These points with the exception of the set point and lock point are so selected to place them in the overlap area of successive plates or the adjoining flights.

At this time, it might be well to mention that good maps are very essential to produce the type of flying required for stereoscopic mapping. Although the flying is executed in strips it practically amounts to spot photography in order to have the flight lines and photographs lined up in such a manner that the ground control can be held to a minimum.

In many cases where good maps are not available, it is cheaper to fly the area for coverage to compile a photographic map for the flying of precision photography than it is to try to fly an area with poor maps.

In recent years, we have probably all heard many people say, "What a shame the country is almost completely covered by aerial photographs which are of little use for topographic mapping." This is not the case. It is merely the first step of the topographic program, since the material covering these areas is available for the compilation of a good reconnaissance map by which the flying for stereoscopic mapping and ground control programs can be carried out.

The cost of topographic mapping by any method varies in direct proportion to the number of models required and therefore the least amount of overlap both in line of flight and on adjoining strips that can be secured without gaps is the most practical. An overlap of 53% in line of flight and a side overlap of 10% are ideal for the Brock process.

Any method of securing the elevations of the selected control points may be used as long as the error in the elevation of the points does not exceed one-tenth of the contour interval.

The points selected for vertical control should always be objects on the ground such as center lines of cross roads, fence corners, field corners, railroad crossings, elevations beside prominent figures such as trees, houses, etc. Poor points are such objects as house gables, mountain peaks or any other object that is so small and pointed as to be obliterated when it is etched on the glass plate.

Enlarged Glass Positives

After the plates to be used in the mapping have been selected, the overlap and quality checked and the plates indexed, a glass positive is made on the enlarging projector to conform in size to a photograph taken with a camera having a focal distance of approximately 13.4″. These positives are made on plate glass 14″×17″ having a thickness of $\frac{1}{8}$″ and a variation from flatness throughout of less than 3/1,000 inch.

Extra fine grain emulsions and developers are used in each photographic step throughout the process. The enlarging projector is constructed with the lens and receiving plane carriers located in their 1:1 and 1:2 positions by dowel pins. A slow motion is provided to move these carriers from their positions to any other desired location. Jeweled dials reading to one-thousandth inch are provided to record such movement. The illumination is provided by Cooper-Hewitt lights.

Point Marking

After the glass positives have been made the "C" point or center of the glass plate is recovered by etching a cross on the glass, using the indices which were photographed on the plate by the taking camera for its recovery.

The plates are now placed on the large stereometer which is a precision measuring instrument and is used later in the process for the contouring. This stereometer is provided with two plate holders, each rotating about centers on the same horizontal axis, a means being provided to optically correct any deviation of the center of rotation of either of the plates from this axis. The plates can be moved together as a unit on both the horizontal and vertical axis or the left plate can be moved independently in the horizontal axis. A dial indicator is provided for the measuring of this movement. The dial is calibrated to 1/1,000 inch but .0003 inch can be read easily. All the optics of the stereometer are stationary. The measurements of the desired images are made bymoving the plates under the optical system until the images appear under the cross-hairs of the eyepieces. The cross-hairs are etched on optically flat glass and can be independently moved up and down until they appear to be in focus on the same plane as that of the objective without any apparent measurable parallax. The power of the lens in the eyepiece is approximately 2½ diameters.

In order that the plates may be centered as fast as possible, a rule is provided which has a long etched line and center cross on glass. This rule is detachable and fits over the rotating plate holders, the cross being fixed in the axis of the rotation of the plate holder.

The left plate is now moved under the corresponding eyepiece until the cross on the rule is directly under the cross-hair of the left eyepiece. The rule having served its purpose is then removed. The plate is now moved by two thumb screws on independent X and Y axes, (which are built inside of the circular plate holder) until the center of the etched cross is directly under the cross-hairs of the eyepiece. The plate is then locked. The same operation is repeated for the right-hand plate. A sheet of English vellum placed over one of the glass plates will later serve as a template in the extension of the radial triangulation.

The markers are now swung into position under the eyepiece and the etchers removed, leaving a hole of about an inch to peer through and examine the vertical and horizontal control points which are to be reconstructed on the plates. As the plates are now on the center of rotation of the horizontal axis, one or both of the plate holders is rotated the amount necessary to bring the images of the selected point into stereoscopic fusion without throwing the plates out of their proper alignment. When the conjugate images selected are in such agreement the etchers are placed back in their holders and twisted. This operation breaks through the vellum template and the emulsion of the plate and records the control point by leaving a tiny clear hole.

At the time the selected point was in stereoscopic fusion and before the marking was made, the dial indicator was read. Now the cross-hairs are independently checked by "blinking," that is, one eye is closed and the plates are independently examined to see if the etched marking is directly under the cross-hair. If either of the points is not under the cross-hairs, they are moved in coincidence and the dials reread. These differences which have the effect of shortening or lengthening the base are recorded as high or low by the amount of the discrepancy. As the stereoscopic image of the point is sought, these errors in the markings are applied to all further calculations or readings throughout the process.

After all the points have been marked, the plates are rotated back to the original lineup so that the plate centers and conjugate centers all lie on the same horizontal axis.

One of the elevation points near the center of either plate is selected as the set point. This set point is assumed to have no parallax and is used as the base distance for the comparison of all bases measured on the model. The plates are now separated until the etched markings of the set points lie under the cross-hairs of the corresponding eyepieces and the dial gauge is set on zero and locked.

The plates are now moved under the eyepieces until another control point is visible in the right eyepiece. This etched marking is made to coincide with the vertical cross-hair of the right eyepiece. Holding the right plate in this position, the left plate holder is now moved independently on the horizontal axis until the image of the control point on this plate comes into coincidence with the left cross-hair.

The gauge now records the distance of spread or separation from the base distance of the set point. This difference, which is called the original parallax, is recorded and will be used later in the preliminary tilt analysis. While this difference is called the original parallax, it must be remembered that it is a combination of three factors, error due to tilt, scale differences due to variation of altitude in the exposure stations of the two plates, and parallax.

The original parallaxes are measured in the same manner for all vertical control points on the model.

Throughout the Brock process, the difference in distance between two pairs of conjugate image points measured parallel to the horizontal axis, due to the difference in elevation of the two corresponding ground points, is called "parallax." The distances from the horizontal axis of the two conjugate images, measured parallel to the vertical axis are referred to as "ordinates." The differences in the ordinates of the four vertical control points which are located in the corners of the model are also measured and recorded. These ordinate differences are also used in the tilt analysis as well as the parallaxes.

Radial Control

The English vellum overlays which were over the glass positives now have the control points marked thereon by a very fine needle-like point. The templates are placed over a light table and a very fine radial line is constructed from the "C" point through all the vertical and horizontal control points. These points are sufficient to extend the radial triangulation without the addition of other points.

The extension of radial triangulation by the Brock method has been used by many mapping organizations and is probably well enough known that it will not be necessary to go into this phase of the process.

Lens Altitude Computations

The lens height for each vertical control point is computed thus: measure the distance from the "C" point to the control point on both the plate and its corresponding position on the radial plot; obtain the ratio of these bases by dividing the distance on the plate into the distance on the plot; obtain the theoretical lens height by multiplying the scale of the plot in feet per inch by the focal length of the taking camera in inches and multiply this product by the enlargement factor of the plate being used. Then multiply the ratio of the bases by the theoretical lens height to secure the preliminary lens altitude for this particular point. To the preliminary lens altitude the elevation for the vertical control point is added. If the plates were exposed while the camera was truly vertical each of these preliminary lens altitudes would be the correct lens altitude for the particular point, but as the ratios from which we started the computations were calculated using distances scaled from a tilted plate, each of the computations is in error.

Since the control points are so distributed that they lie approximately opposite or 180° from each other, the tilted bases are compensated and a mean of the preliminary lens altitudes is taken as the lens altitude for the plate.

From this lens altitude, the elevation of the set point is subtracted to secure the lens height above the set point.

Computations of Parallax for Tilt Analysis

In order to simplify the computations for parallax, tables have been compiled giving the parallax value resulting from any elevation difference from the set point up to 1,000′. These tables are computed for a lens height of 10,000′ and a base distance between picture centers of 10″. In the preliminary analysis, the distance between the center of the plate and the conjugate center of the adjoining plate is used as the base distance.

To find the parallax of any elevation change of ground for any lens height above the "set point" or datum, divide the table lens height by the lens height in question and the result will be a constant in reference to the pair of plates involved. Multiply the elevation change by this factor and in the tables opposite the apparent ground change will be found the correct parallax. Since the table base is 10″, the final result must be the product of the table parallax and the real base.

Now that the parallax for the vertical control points has been computed and the original parallax for the same points has been read on the stereometer, the difference between these results is the amount of error caused by tilt in the plates and the difference in scale caused by the variation in altitude of the two exposure stations.

Tilt Analysis

A set of transparent celluloid tilt charts, each having a range of ten minutes and running up to $2\frac{1}{2}$°, is available. These charts show the movement of any point in the area in both the parallax and ordinate directions if this amount of tilt is applied. A vellum template is traced from one of the plates showing the location of vertical control points in reference to a line projected from the center of the plate to the conjugate center of the adjoining plate.

Since all of the error in the plates is not caused by tilt, a study is made of the lens heights of the two plates and an enlargement factor applied to bring both plates of the model to a uniform scale.

The result of this scale change as it effects the individual control points is deducted from the difference between the original parallax readings and the computed parallax. This difference is assumed to be the error caused entirely by tilt.

The tilt charts are laid over the vellum overlay, orienting the charts on the X and Y axes of the plate in reference to the center and conjugate center and the movements of the various points are tabulated for the top tilts and side tilts which are required to bring the errors to an apparent zero. When the computations show the points to all be within 2/1,000 inch of their computed base distance, the pair is ready to place in the correcting projectors.

Now that the top tilts and side tilts for each plate have been computed, these results are referred to a set of resultant tilt tables which show the azimuth of the axis of tilt and degree of tilt for such a condition.

It will be noted that each model is handled separately for the tilt analysis and that the entire plate cannot be considered as corrected. This condition results from the tilts of each model being referenced to its own axis which is the base between the centers of the plate on the model, and also that a scale change has in most cases been applied to bring the exposure stations to a uniform datum.*

Correcting Projector

The plates are now placed in a pair of duplicate projectors. The plate holder of the projector is mounted in a rotator having a horizontal axis and means are provided to bring the center of the plate into this axis. Behind each plate is a lamp house fitted with Cooper-Hewitt lights by which the image of the plate is projected its exact size onto a matte finished precision grid with $\frac{1}{2}''$ spacings in both directions intersecting at right angles.

The intersection of the two main grid lines is adjusted to lie in the horizontal axis of the image plane rotator and in the axis of the lens when the focal planes are not tilted. Means are provided to move the grid screen on both the X and Y axes a sufficient distance to measure the distance from any image point to the closest grid line. The grid is provided with dial indicators to record these measurements. The plates are placed in the projectors with the center point of the plate and the conjugate center of the adjoining plate both lying on the horizontal axis of the grid.

Each grid is rotated to its azimuth of tilt and clamped. The plate holder is rotated until the center and conjugate center coincide with the horizontal axis of the central grid line. By turning a hand wheel both plates of the projector are tilted through equal angles and the rotators of the plate holder and the grid screen are both equally displaced towards the intersection of the two prolonged tilted planes. This displacement is accomplished by a linkage which is based on the function of a taking camera having a focal distance of 13.4″ and the $9\frac{1}{2}''$ focal distance of the projector lens. Therefore, as the planes are tilted, the true scale line moves into the tilt axis of the focal plane.

As the machines were tilted, the intersections of the main grid lines simultaneously moved onto the points where the plumb lines through the lens pierced the pictures. The rotators of each projector are rotated until the main grid line is in coincidence with the conjugate images of the respective "V" points or nadir points of each plate. While in this position, the bases to all the control points are measured and compared with the base of the set point. If the results are not the same as the preliminary analysis showed, a touch up is made from these readings and the same procedure carried out until the results are satisfactory.

The markers of the machines are set on the main X and Y grid lines of the machine, which will photograph on the plate glass negative which is about to be made. The grids are removed from the machines, plate holders inserted and the plates exposed.

Final Glass Positives

From these corrected negatives, the final glass positives are made, the scale change, if any is required, being taken care of at this time.

Computations of Contour Parallax

The computation for the contour parallax is essentially the same as that for the preliminary parallax except the new base distance between the "V" points of the model is substituted for the distance between the center of the plate and the conjugate center of the adjoining plate. The difference of elevation from the set point and contour datum is used in each case.

Contouring

After the plates have been horizontalized and corrected for scale, they are placed on the stereometer with the "V" points being used for the alignment of the plates. The plates are set at a separation with the images of the set point under the cross-hairs of the eyepieces. The parallax slide is fastened and the dial set to read zero.

A transparent sheet is superimposed on the right-hand plate on which the contours and detail are to be drawn. The "V" point and control points are marked on the transparent sheet. The plates are separated and set at a proper separation corresponding to the parallax of the particular contour. By means of hand wheels all parts of the plate are brought into the field of the optics.

Now the reticule lines which are perpendicular to the horizontal axis of the plates have blended into one pair of intersecting lines. These lines appear to float in space over any terrain that is below the elevation of the parallax setting and when the elevation of the ground is higher than the parallax setting, the reticules appear to split. Where the point in the line appears to touch the ground, the contour is drawn on the transparent paper. This operation is repeated until the whole meandering contour is drawn.

The parallax setting for the next contour is made and the operation continued until the entire plate is contoured. The culture which is to appear on the final map is delineated while being viewed stereoscopically. This detail is also drawn on the transparent paper which is over the right-hand plate.

Scale Equalization

The sheet containing the contours, cultural detail and drainage is now placed over the radial control plot and oriented by radial lines originating from the "V" point. When all the radials pass through the control points on the plot, the "V" point is transferred to the radial plot. The final lens altitude computations are now made in the same manner as those of the preliminary lens altitude computations except the distances for the ratios are measured from the "V" point to the control points instead of from the old picture centers.

These new results from the lens altitudes usually check the preliminary results by 10′ or 15′. This average lens altitude which we have now determined, minus the theoretical lens altitude, gives us the ground elevation at which the sheet is the same scale as the plot. Since the contoured sheet is now in a conic projection, each contour, as represented, has a different lens altitude equal to the amount of the contour interval. So, in order to bring this sheet to an equal scale drawing on an orthographic projection it is necessary to change the scale setting for each of the contours before they are retraced.

This is accomplished by drawing a tenth-inch line on the contoured sheet and computing the length to which this line will be required to be reduced or enlarged to bring each contour individually to the scale of the plot. The lens height above the contour divided by the theoretical lens height and multiplied by ten will give us the result. The contoured sheet is now placed between two glass plates in the frame at the rear of another projector called the T. I. machine.

The image of this sheet is projected to another transparent paper placed over the image plane of the machine. This machine is so constructed that the scale of the drawing can be changed by turning the hand wheel to the left which also operates the automatic focus.

By means of vertical horizontal controls near the rear of the glass top table, the "V" point on the drawing is brought into register with an etched intersection on the glass top of the table which marks the optical center of the machine.

By means of the scale change control wheel, the scale of the drawing is changed so that the 10″ line on the drawing measures the required length for the highest contour. This highest contour and all adjoining detail are now traced on the new sheet. The machine is set so that the original 10″ line now measures the new required length for the next lowest contour and this contour and adjoining detail are traced. This operation is continued until the entire conic projection has been reconstructed as a true scale drawing to the scale of the final map compilation.