(b) *Large-scale and medium-scale mapping (including topographic mapping and photogrammetry)*

THE MODBLOCK PROGRAMME FOR PHOTOGRAMMETRIC BLOCK ADJUSTMENT*

Paper presented by Australia

As is well known, the purpose of aerial triangulation in general, and block adjustment in particular, is to economize on the amount of ground control required in mapping from photogrammetric models.

A single model has seven degrees of freedom (three displacements parallel to the axes, three rotations about the axes and a scale change) and so requires seven constraints to fix it in space so that it can be mapped. These are customarily two pairs of plan co-ordinates (*X*, *Y*) and three height co-ordinates (*Z*). If each model in a block is controlled in this way, mapping of the block is possible.

It is true that such mapping suffers inconveniences from small differences in the co-ordinates of points common to adjacent models, necessitating some manual smoothing during the plotting. One of the advantages of aerial triangulation is that it obviates this need, but this was not its prime purpose, which was to reduce the amount of ground control needed to level and scale the models for plotting.

The principle is that since successive models in a strip overlap have a common aircraft camera station, it is theoretically possible to use the constraints that common points in the overlaps and common camera stations must have the same co-ordinates. This process in effect makes up a strip like one long model with seven constraints only required to fix it in space, although mathematically in a strip of 50 models (say), at seven degrees of freedom per model, 350 equations would still need to be solved. These equations alone would occupy about 60,000 words of computer storage.

In the past, this difficulty was overcome by using a first-order plotter to observe the models. This apparatus effectively joins successive models into one long model, and the number of constraints is slightly increased to allow bending of the model when fitting it to ground control. This is the basis of the popular polynomial method of adjustment, wherein it is assumed that errors have gradually crept in while forming the strip and that it must be systematically unbent when tilting, rotating and scaling it to fit the ground control. Although less rigorous than solving 350 equations simultaneously, it is very effective and does not require a large computer.

First-order plotters are no longer used, however, and models are observed independently, to be subsequently joined up into a strip by computer in a simulation of the first-order plotter observational procedure, prior to adjustment to ground control by the polynomial method.

The whole process is most economical in that the number of co-ordinates to be supplied as ground control is only a fraction of the seven per model necessary for individual model plotting. It is of the order of 14 for a strip, depending upon the form of polynomial adopted. In practice more ground control co-ordinates are used, but by using a method of least-squares adjustment, the number of equations to be solved is not increased. The additional values allow errors to be detected and also improve accuracy.

In blocks of photography, the strips must overlap to ensure complete coverage, and it can be asked if the fact that common points to adjacent strips should receive the same co-ordinates could be used to supply constraints that could permit blocks to be built up with economies in ground control, in the same way as strips are built up from models.

The situation is not exactly parallel as there are no common camera stations in the aircraft between overlapping strips as there are between overlapping models in a strip. Nevertheless, studies have shown that as far as planimetric control points (*X*, *Y*) are concerned, none at all are required in a block except at the edges. There are fewer economies in height ground control (*Z*), but there is more latitude in positioning of control points. Moreover, whereas models must follow one another in a strip, strips in a block do not all have to be parallel and follow one another. There may be cross strips, filler strips and reflys, all of which complicate the problem.

There is no first-order-plotter type of mechanical solution, and nothing really satisfactory apart from the Jerie analogue computer was achieved until electronic computers came into use. The most common method now is the simultaneous polynomial adjustment of all strips of a block, in which the number of equations to be solved is the number of strips times the number of equations to adjust one strip. This number can quickly

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mount up, but there are iterative processes that permit the solution to be carried out on a medium-sized computer.

In a block adjustment, the disadvantages of the polynomial method of adjustment become apparent. It assumes that the distortion in a strip is regular, which is not really so. This disadvantage is of little import in a single strip where there is insufficient information to discover the true distortions. In a block adjustment, the many common points in the side laps of parallel strips give a great deal of information as to the progress of distortion, which information is not fully utilized in a polynomial adjustment imposing regularity

The answer is a rigorous adjustment where all models, each with seven degrees of freedom, are adjusted simultaneously; or all photographs, each with six degrees of freedom, are adjusted simultaneously as in a bundle adjustment from comparator observations. This procedure involves the solution of many thousands of equations and would exceed the capacity of even large computers. Thus, a block of 300 independent models requires the solution of 2,100 equations.

Special methods have been devised to bring the labour within the capacity of a modern large computer; even so the programming effort is great. Three successful solutions can be mentioned.

The firm of DBA in the United States of America appears to have an excellent programme. It is understood that this firm carries out adjustments commercially for a fee.

The other two, the Programme Package for Aerial Triangulation with Independent Models (PAT-M43) of Stuttgart University and the Model Block Adjustment (MODBLOCK) programme of the Division of National Mapping are similar in concept, but differ in detail and in the all-important solution of the equations. Both are independent model adjustments. The Stuttgart programme is available commercially.

The MODBLOCK programme was written in Iran 10 years ago by C. W. B. King, who is now with the Division of National Mapping. At that time, it ran on a medium-size computer, an IBM 7040, and utilized five tape drives. It was subsequently expanded and improved to run on the UNIVAC 1108, and the current version runs on the Control Data Corporation (CDC) CYBER 76.

The principle upon which the programme operates is that the seven unknowns of each independently observed model are solved simultaneously for all models of a block in a full least-squares solution. The constraints are that all transformed values of observations of ground control points should as nearly as possible fit their true ground values, and that all transformed values of observed points in a model must as nearly as possible fit their transformed values in every adjacent model (if any) in which they also fall. This means that each model is made to fit all its neighbours at once, irrespective of the way strips have been flown; and it is clearly better than the polynomial method of forming up strips as a first step, without considering overlapping strips, and then holding the model connexions fixed in the subsequent adjustment.

The number of equations to be formed and solved is great, but the process is broken down into stages that do not affect the rigour of the solution.

It will be clear that strips may be at varying scales, may overlap in any fashion and need not necessarily be parallel. In Australia, the mapping photography is flown east-west to cover a map at 1:250,000 scale and three north-south tie strips are flown across each map area. The simultaneous adjustment of this pattern of photography permits the amount of height control to be reduced.

The dimensions of the programme are large: there may be up to 90 strips of 50 models each. There may not be more than 1,000 points in any one strip, but longer strips may be treated as two strips. Up to 2,100 control points are permitted. Control points may be genuine usable points or check points, or a mixture with usable plan co-ordinates and a check height co-ordinate. Check points are not used in the adjustment but their residual errors are obtained and printed. Their use provides a convenient means of testing doubtful control values. A control point does not necessarily have to have all three co-ordinates supplied.

Since independent models are usually observed with a mixed base, the programme accepts the first pair of projection centre co-ordinates supplied as applying to all models until there is a change of base, as can occur when a reobserved model is inserted or when more than one plotter has been used for the observations. However, the base can change at every model, as is the case with the Planimats or PG2s as used by the Division; and to facilitate their use the space rod constant can be automatically applied by the programme. Earth curvature corrections may also be applied by the programme.

A feature that makes the programme easy to use is that sorting routines have been incorporated. The user has only to take the two principal points and the two projection centres as the first four points of every model. He does not have to specify that a point is a control point, a check point, a connexion point between models of a strip, a tie point between strips or a single point. The discrimination is done for him automatically. The final transformed co-ordinates are set out model by model for ease of plotting, with all common points correctly meaned over all the models in which they appear. Within each model, points are sorted in order of ascending point name. This is valuable for dense models as in cadastral work.

Subsidiary programmes plot the vectors of residuals at control points and/or check points for visual interpretation of the validity of the adjustment and also plot all transformed co-ordinates on base sheets for mapping.

The Division of National Mapping will be happy to make the MODBLOCK programme available to any prospective user at this meeting who has access to a sufficiently large computer.