*Proposed Aerial Triangulation Techniques**†

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ABSTRACT: *Several novel aerial triangulation techniques utilizing stereophotogrammetric instrumentation are advanced for establishing control in areas containing insufficient geodetic control for producing topographic maps. The approaches advanced are designed to yield increased accuracies and to gain improved reliability of results. Because of the complexity and limited range of airborne devices for recording positional information and the time-consuming operations required to reduce and correlate these data with aerial triangulation processes, special attention is directed to the need for an improved system for securing and handling these data. An approach to this problem, which may alleviate some of these limitations, is presented.*

INTRODUCTION

THERE is a need for developing improved photogrammetric techniques for mapping areas where control is sparse or nonexistent, in order to offset the high costs and excessive amount of time normally required to establish control by conventional ground-survey operations. The recent introduction of electronic survey instrumentation such as the Telurometer, although capable of substantially reducing these cost and time factors, should not be considered as a final cure-all. This is so because of the need for a dense network of control in stereoplotting operations, and the inaccessibility of ground teams to certain regions due to terrain or military obstacles.

During the past few years, many different methods of securing supplemental control for photogrammetric mapping have been suggested. Basically, two avenues of approach are possible; first, securing control data coincident with the photographic mission; and second, securing control data prior to or after receipt of the aerial photography. From a logistic and time standpoint, the coincident approach is usually desirable since the required control data are procured during the photo mission and initiation of the mapping project may be expedited. Examples of this are the APR and HIRAN-SHORAN Systems which are employed in conjunction with aerial photography to secure positional data. Insufficient data have yet been secured to firmly establish the accuracy of these systems in various latitudes and terrain and under different operational conditions. Use of these systems necessitates the need for rather elaborate electronic equipment and subsequent reduction of data for correlation with aerial triangulation processes. Knowledge of meteorological conditions is also essential if proper adjustments can be made to the data obtained; otherwise serious errors in the results achieved may be introduced. However, even when these corrections are applied, appreciable errors may still be present because of the random nature of atmospheric conditions and terrain characteristics, over large areas in various portions of the globe.

Present photogrammetric aerial triangulation techniques are not wholly satisfactory for establishing control in areas which must be bridged for long distances without intermediate control or where the control must be extended into an area without recourse to any tie-in points (see Figure 1). Results obtained in cantilever tests, utilizing various types of precision stereoplotting instruments, clearly indicate that the resultant accuracy is very indefinite. Even under

* The material and opinions expressed are those "proposed" by the author on the basis of investigations to date and should not be construed as conclusions of the Chief of Engineers.

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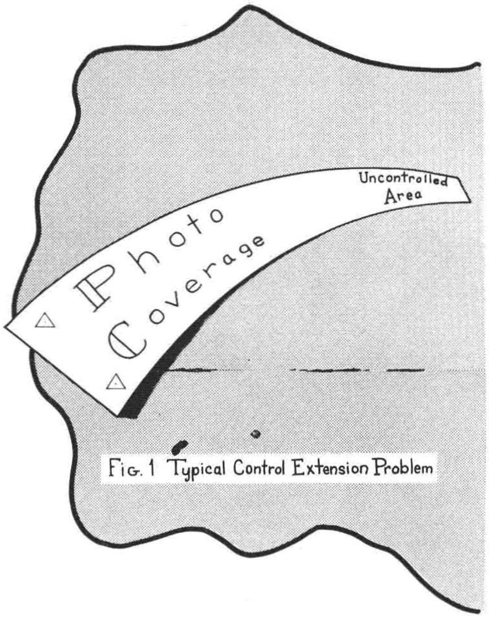


FIG. 1.

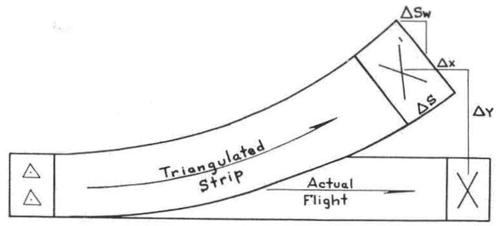


FIG. 3. Cantilever extension—positional errors.

favorable operating conditions, the results obtained have usually been discouraging because of remaining residual systematic and random errors. Figures 2 and 3 depict the cantilever errors encountered.

Several novel approaches for extending control are suggested which should yield improved accuracies and, at the same time, give more reliable results. These techniques, in some instances, are not dependent upon the use of complicated electronic and optical mechanisms, or affected by type of terrain or meteorological conditions prevalent. The specific technique or combination of methods that would be adopted for a particular project would be dependent upon such factors as the problems inherent with the terrain to be mapped and equipment available. It should be stressed that these approaches are only in the embryo stage, and further study and evaluation are needed before they can be considered feasible for mapping applications. Lt. Col. K. Evinay of the Turkish Army, during his stay at the Army Map Service, graciously offered many helpful suggestions in formulating these techniques.

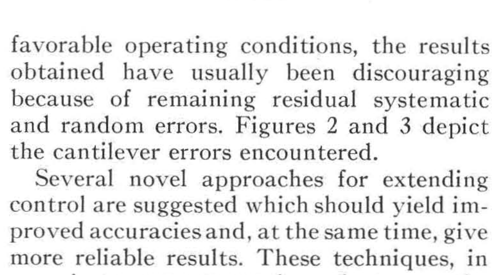


FIG. 2. Cantilever extension vertical errors.

SLAVE AIRCRAFT

It is proposed that a slave aircraft be flown simultaneously with two master aerial photographic planes, at a relatively much lower altitude and located approximately between the photo planes. The master aircrafts may either be in line of flight (Figure 4a) or in parallel flights (Figure 4b).

From economic and elapsed time considerations, the parallel-flight case would be more desirable because two flights of photography are obtained simultaneously. The slave aircraft would be rigged in a manner similar to planes towing two advertising signs (see Figure 5a). For simplicity, the distances between the towed targets would be equidistant. The distance from the targets would be dependent upon the flight altitude of the photo-mapping planes. To obtain optimum results, it would be desirable to have the total target length approximately equal to the stereo model coverage. For practical considerations, however, much smaller distances could be used. The shape, size, and color of the targets would also be designed to achieve optimum stability in flight and plotting-instrument sighting.

Ground control targets were tested[1] with Wild RC-5 Aviotar and Zeiss-Kramer MRK Topar mapping cameras at 1:5,000 and 1:10,000 scales, Yellow B Filter 480 mm. $m\mu$ (minus blue filter) 1/150–1/250 sec., $f=21$ cm., Gevaert Aerial Film Pan 30. They

[1] "Signalizing Investigation" by Engineers Hlawaty and Stickler, *Photogrammetria*, XII, 1955–56, #4, pp. 236.

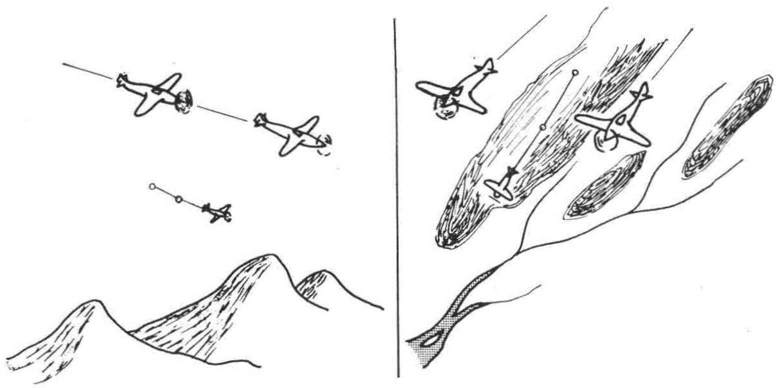


FIG. 4a. (at left) In flight; FIG. 4b. (at right) Parallel flight.

indicated that optimum results were obtained with yellow or white targets located on a purple-blue background. The same target colors were also found best against natural ground cover. The background targets were 170×180 cm. and the central targets 20×20 cm. (approximately 8 inches on a side). Aircraft or automatically guided drones could be used to tow targets of this size without much difficulty. Attached to the wing or body of the aircraft would be a camera which records the relative positions of the targets from a horizontal plane. Figure 5b illustrates an exposed print. All of the mission cameras would be set to obtain simultaneous exposures—each exposure being automatically triggered by one of the photo aircrafts. As it is radar could be used to measure the distance between the slave aircraft and the towed target.

Some of the advantages of the system are:

1. Control is established coincident with the photographic mission.
2. It offers the possibility of setting up models independently or in sets to obtain a best fit. This would be ideally suited for use on highway, dam, bridge, meteorological and power plant projects.
3. Since each model offers an independent solution, there is less likelihood of propagating errors that are normally encountered in triangulated strips. The adjustment process may be accomplished during or after the aerial triangulation.
4. An area can be mapped prior to receipt of ground-control to obtain a relative orientation. This makes possible immediate plotting of maps. Absolute orientation can be accomplished upon receipt of known ground-control at some later date.
5. It can be used with any type of photography, i.e., short or long focal-lengths, vertical, convergent, or terrestrial views.

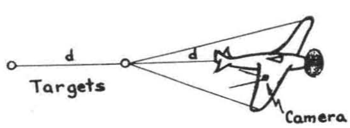
Some of the apparent disadvantages of the proposed system are:

1. Need for additional aircraft and gear if simultaneous exposure is required of the slave aircraft.
2. Need for placing towed targets in correct position prior to exposure. This, however, is not as critical as the means for performing this operation, since the the targets need only be located somewhere in the area of stereo coverage.

CAMERA REVERSAL PHOTOGRAPHY

In this system aerial photography is exposed with the intervalometer of camera set for 80 per cent forward lap photography.

However, instead of the camera being positioned in the same direction throughout the entire mission, every other exposure is



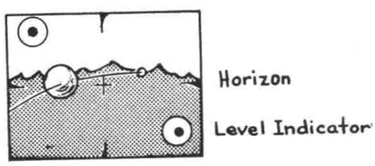


FIG. 5a. (at left) Slave aircraft; FIG. 5b. (at right) Recording camera.

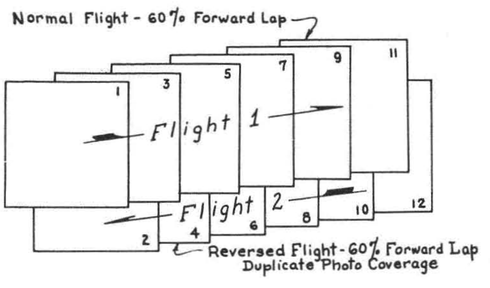


FIG. 6. Camera reversal photography.

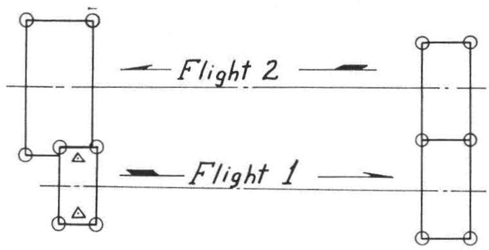


FIG. 7. Aerial triangulation—normal side lap.

taken with the camera rotated 180 degrees. Thus, two sets of 60 per cent photography will be obtained, one set being taken in the reversed direction (see Figure 6). Rotation of the camera is made by electrical or mechanical means. A stop will indicate the 180 degree camera-rotation position. Approximately one-half a minute will normally be available to rotate the camera before an exposure is taken.

The photography obtained would be the same as if two separate flights were flown, one towards and the other away from an uncontrolled area. Thus, procurement of almost identical duplicate coverage, exposed at the same altitude is obtained to provide for a more rigid triangulation solution. It would be exceedingly difficult and perhaps impossible to secure duplicate or even parallel strip coverage over very large distances by conventional methods. Different weather conditions may also be present in the return flight to introduce excessive random errors in the final adjusted positions.

The adjustment of control is based upon the assumption that the geometry of the initial oriented model is extended throughout all successive models in the same and adjacent strips by means of common tie-in pass-points. The coordinates of the plotted instrument points may then be adjusted by determining the rate of change of the various x, y, and z component errors. This is accomplished by analyzing the common pass-point discrepancies and obtaining a mean fit of the adjusted positions. Figure 7 illustrates an aerial triangulation with present photo strips and Figure 8 utilizes the camera reversal technique.

In bridging or extending control over very large distances, it is desirable to provide for additional photography beyond the project limits, to aid in the bz curve solution and, where possible, to utilize any additional control to strengthen the adjustment. The proposed system may then be used to considerable advantage, since the trend of the triangulated strip to and from the uncontrolled area may be more readily established.

The results obtained for bridging control over very large distances by conventional methods have indicated the presence of excessive random and systematic errors remaining in the final adjusted instrument positions. Use of the proposed system would provide a convenient tool for averaging-out these errors. Where no control is available, a map may be constructed wherein the data presented are relatively correct. An approximate scale may be determined from barometric altimeter recordings. Availability of control at a later date would provide means for establishing absolute orientation.

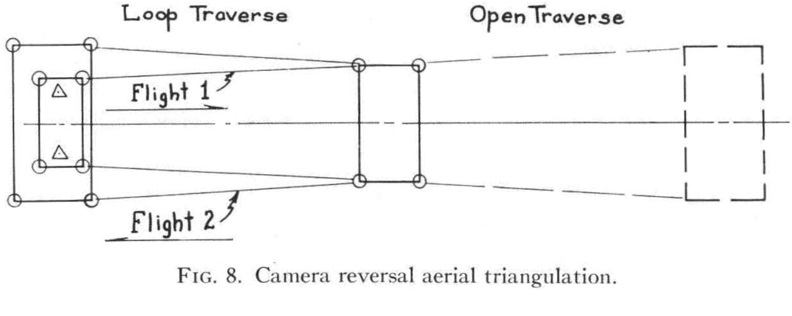


FIG. 8. Camera reversal aerial triangulation.

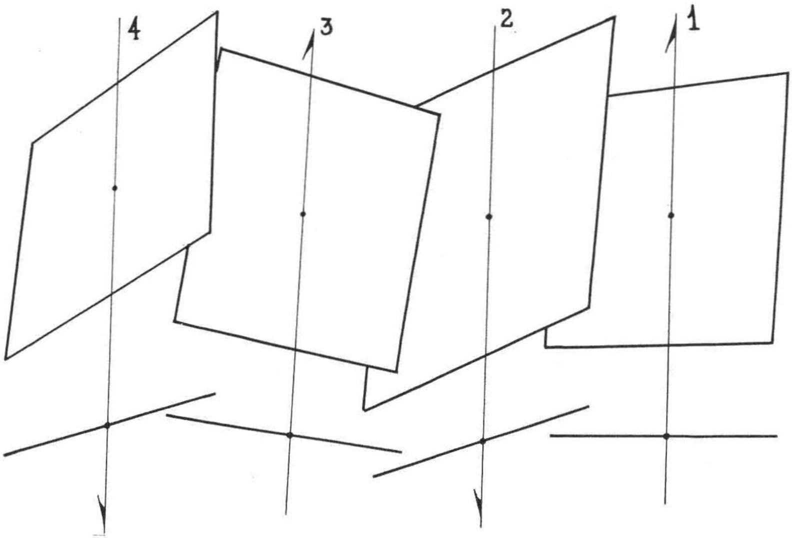


FIG. 9. Strips triangulated with 15% side lap.

The proposed system is not limited to use of vertical photography; convergent photography may also be employed. The aerial triangulation solution may be further enhanced if simultaneous aerial photography, and if APR and HIRAN data were obtained in conjunction with atmospheric data. The proposed system is also ideally suited for high altitude, long distance aerial triangulation by either stereophotogrammetric or analytical methods.

60 PER CENT SIDE LAP PHOTOGRAPHY

Experience has indicated that the pass-point control established along the center-line of a strip of triangulated aerial photography is usually the most accurate. Evidently this is so because resolution is best in this area, relief and tilt effects are minimized, and the triangulation process employs center pass-points for establishing scale. It follows that the common side-lap areas, usually about 15 per cent (see Figure 9), are normally the weakest because of such factors as poor resolution, greater distortion effects, detrimental effects or relief and tilt, and model warpage. The results obtained are usually unreliable even when common pass-point values in the area of sidelap are in close agreement prior to adjustment because of the minimum side coverage available.

To take advantage of the more favorable properties present in a stereo model, it is proposed that the photography be flown to obtain 60 per cent side-lap coverage (see Figure 10). Adoption of this photo pattern for aerial triangulation has the following indicated advantages:

1. Improvement of the accuracy re-

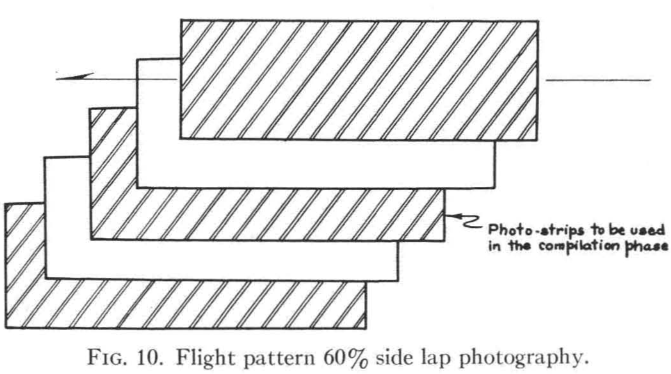


FIG. 10. Flight pattern 60% side lap photography.

quired to map large uncontrolled areas would be considerably aided.

2. Cross-flights could be eliminated or minimized considerably.
3. The need for using wing-points in the stereo compilation operations would be eliminated.
4. The random and systematic errors presently remaining in triangulated strips after block adjustment procedures have been performed would be reduced.
5. Stronger radial line and slotted templet plots would be permitted.
6. Photo mosaics would be superior in quality since extreme edges of photos would not have to be used.
7. Flight gaps would be minimized, thus eliminating costly red lights.

Although the proposed system has the disadvantage of requiring that twice as many strips be flown, it is felt that the advantages far outweigh this aspect. In the compilation phase, it would be necessary to use only every other strip of photography as presently practiced. The additional time needed to triangulate the extra strips probably would not be significant, since only center pass-points need be precisely triangulated. Experience has shown that, in achieving orientation of a stereo model, the greatest amount of time is consumed in the removal of minute parallaxes and cross-tilts which exist in the corners of the model. These time-consuming operations would be minimized by use of the proposed method since only the centerline of the strips need be used for control purposes. Also it would not be necessary to critically remove minute parallaxes and maintain elevations in the corners of each model as is presently done.

Convergent Aerial Triangulation

A technique for triangulating convergent photography with projection type instruments, such as the Multiplex, is presented which does not require use of a Stereopontometer (see Figure 11). Photos 1F, 2R, and 3R are oriented relative to each other and to ground-control to achieve absolute orientation. Pass-point control is established in the area of common overlap. Photo 2R is then replaced with 2F, which is oriented in turn to 1F and 3R. It should be noted here that, since 2R and 2F were exposed simultaneously, there is no air base and 2F need be oriented only in Φ, Ω, and K. The *bx*, *by*, and *bz* components are not disturbed because of common exposure stations. 4R is then oriented to 2F and 3R, and pass-points are dropped in the area of common overlap. Photo 3R is replaced with 3F and the aerial triangulation procedure carried forward. Because of the use of triplicate coverage and the large B/H ratio employed, it appears that the proposed technique offers a solution which is simpler than, and may be superior in accuracy to the present stereopontometer method of convergent aerial triangulation. This technique affords an excellent means for identifying imagery in the area of triplicate overlap to achieve optimum accuracy and reliability of the pass-point connection in a triangulation network.

Optimization of Airborne Profile Data Recording

It is known that the isobaric surface is normally more stable and definitive in areas where the earth's surface is relatively flat. Tests have also indicated that APR soundings are weakest in rugged areas. Therefore, it appears logical that advantage be taken of these phenomena and that consideration be given to flying APR or radio altimeter soundings over relatively flat terrain, or where the terrain characteristics do not change abruptly in shape and texture. For example, flights could be designed to hug

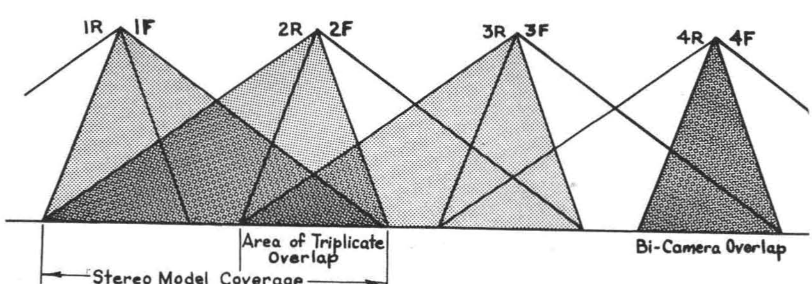


Fig. 11. Convergent Aerial Triangulation.

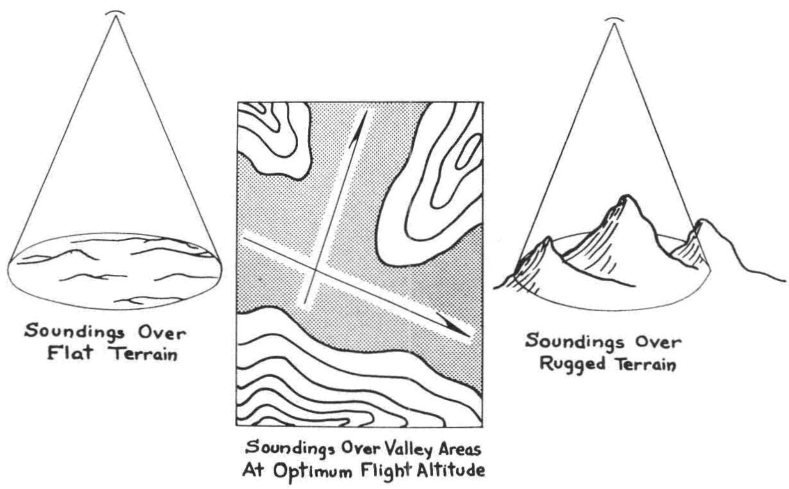


FIG. 12. Optimumization of radar soundings.

valley lines and flown at optimum radar flying height (see Figure 12). Results to date indicate best results at approximately 5,000 to 10,000 feet. The control established would serve as a basis for setting up a primary network from which intermediate pass-point data can be established.

One of the most troublesome areas in aerial triangulation is azimuth determination. The Canadian National Research Council has successfully used Infrared 60° oblique photography in conjunction with APR to control the transversal bend of a triangulated strip.[2] A standard accuracy of ± 9 m. over 240 kilometers has been achieved. It is assumed that a collinear relationship exists between photographic and terrain datum planes. The horizon is used to compensate for cross-tilt and a straight line is used to align points common to the oblique photography. Adherence to a straight flight is highly desirable in order to maintain an accurate systematic adjustment. Because of the potential of the Canadian system, the Army Map Service plans to exploit this technique in a forthcoming APR test.

FUTURE PROSPECTS

Many other solutions to this problem area have recently been advanced to excite the imagination of those interested in triangulation processes. Such innovations as the introduction of the super wide-angle camera, precision automatic coordinate readout systems, and high-speed computers for analytical aerial triangulation operations hold considerable promise. World War I and II concepts of relatively immobile type warfare have been outmoded with the introduction of high-speed aircraft, missiles, and pentomic armies. It is anticipated that photography and supplemental data will frequently have to be secured from unmanned, unrecoverable vehicles travelling at high altitudes and speeds, thus suggesting the need for nonjammable feed-back systems. We have all recently read in our newspapers of the successes in missile recovery. This should open up a vast new area for the attention of map makers.

SUMMARY

The techniques proposed herein, if proven feasible, may serve to alleviate one of the most pressing problems confronting map-producing agencies—that of securing positional data over sparsely controlled regions. In view of anticipated military demands for rapidly producing maps over these areas, accelerated research and development efforts should be made to search out and to resolve new and improved map data recording and processing systems. The coincident approach, whereby positional data can be obtained concurrently with the procurement of aerial photographic coverage, appears particularly worthy of additional attention. With such a capability, speed-up of map preparation phases would be realized. Aerial triangulation techniques would also be simplified, since they conceivably could concern only single-model adjustments, thereby reducing present complex and time-consuming transformation procedures.

[2] U. V. Helava, *Photogrammetria*, XII, 1955–56, #4, pp. 230–235.