Eleventh Congress of the
International Society for Photogrammetry

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Report of Commission III, Aerotriangulation

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The Activities of the Commission

The activities of Commission III between 1964 and 1968 were based on the resolutions and recommendations given at the end of the Tenth Congress in Lisbon in 1964, together with the directions, instructions, and suggestions received subsequently from the Offices of the President of the International Society of Photogrammetry.

Accordingly, Commission III arranged for an International Symposium on Spatial Aerotriangulation which was held February 28 to March 4 at the University of Illinois, Urbana, Ill., under the direction of Prof. H. M. Karara. More than 100 attended, 13 countries were represented, 33 papers were presented (those published to date are listed in the Bibliography at the end of this report), and a U.S.A. National Science Foundation grant enabled six foreign experts to participate in the program. Of considerable importance were the sessions devoted to the organization of the program for this Eleventh Congress, the selection of the fields of interest, and the decision to include a Working Group. Still a further session convened a week later in Washington, D. C., to specify details for the Fictitious Data for the Working Group.

The national reporters and officers of Commission III convened again in April 1966 at Bad Godesberg, Germany, together with the other Commissions, to clarify still further the program for the present Congress. Subsequently, the six themes and invited speakers (listed below) were decided on, as well as the Working Group.

The Working Group, under the Chairmanship of Mr. Charles Theurer of U. S. Coast & Geodetic Survey, obtained from Mr. Frederick J. Doyle of Raytheon/Autometric a set of fictitious, perturbed, input data for a block of 200 photographs for use in testing theories, methods, procedures, programs, etc., in analytical aerotriangulation. Seventeen organizations with international distribution were requested to participate, the data were sent to the 11 who requested the material, 8 reports on the results were received at this writing, and 2 more reports are expected. Mr. Theurer is scheduled to present a summary of the results of the work during the Commission III program at the Congress.

Although completely independent from Commission III, nevertheless significant in indicating the interest in aerotriangulation, we report the Symposium on Computational Photogrammetry of the American Society of Photogrammetry, December 4–8, 1967 at Gaithersburg, Md.

* We acknowledge the generous assistance of Messrs. Robert C. Eller, William D. Lynn, and Morris M. Thompson of the U.S. Geological Survey for translations and summaries of the Commission Reports.

List of Commission III Papers for Lausanne

Invited Papers

Theme No. 1. Analysis of Existing Aerotriangulation Systems, Prof. E. H. Thompson, England.

2. Data Acquisition Procedures, Mr. G. de Masson d'Autume, France.

3. Data Processing Procedures, Mr. G. H. Schut, Canada.
4. Techniques, Evaluation and Applications of Auxiliary Data in Aerotriangulation, Dr. H. G. Jerie, Netherlands.
5. Application of Photogrammetry in Three-Dimensional Geodesy, Dr. Hellmut H. Schmid, U.S.A.
6. Errors in Aerotriangulation, Dr. F. E. Ackermann, Germany.

Presented Papers*

Robert C. Eller, U.S.A. Computational Aerotriangulation in the Geological Survey (1)

(Author not yet named), G. B. Analytical Aerial Triangulation in the Ordnance Survey of Great Britain. (1)

Dr. Sanjib K. Ghosh, U.S.A. Global (total) Adjustment of Aerotriangulation with Analytical Plotter AP/C. (1, 3)

Dr. Ing. Vladimir Kratky, Czechoslovakia. Contribution to the Problem of Convergence of Indirect Computing Solution in Analytical Aerotriangulation. (1, 3)

Dr. Edward M. Mikhail, U.S.A. Principles and Applications of Analytical Mirror Photogrammetry. (2)

Ronald G. Davis and Maurice S. Gyer, U.S.A. Block Analytical Aerotriangulation on a Medium-Scale Computer.

Joseph Del Vecchio and Maurice S. Gyer, USA. The Analytical Aerotriangulation of a Block of 1005 Photographs on a Large-Scale Digital Computer.

H. S. Williams, South Africa. Weight-Coefficient Matrices for Unit Model Connections. (3)

Dipl.-Ing. M. Kusch, G. D. R. Analytical Block Triangulation with Medium-Speed Computers. (3)

Zeno V. Kittrell, U.S.A. An Analytical Solution to the Multi-Point Problem. (3)

Prof. H. F. Soehngen, U.S.A. Strip and Block Adjustments of the I.T.C. Block of Synthetic Aerial Triangulation Strips. (3)

J. Holsen and J. Tallhaug, Norway. A Program for Horizontal and Vertical Block Adjustment by Interpolation. (3)

Dr. J. M. Anderson, U.S.A. Coordinate Transformations for Basic Sub-Group Assembly in Simplified Systems of Analytic Aerotriangulation. (3)

S. Weissman, U.S.A. About the Incorporation of Horizon Photography in Analytical Aerotriangulation. (4)

Dr. Ing. Vladimir Kratky, Czechoslovakia. A Method of Photogrammetric Solution of the Basic Task in Satellite Geodesy. (5)

R. Kamiya, K. Kaji, and M. Nasu, Japan. Experiment on Aerotriangulation by Simulation. (6)

G. C. Tewinkel, U.S.A. The Analytical Aerotriangulation System of the Coast & Geodetic Survey. (1)

Desmond O'Connor, U.S.A. The Estimation of Y-Direction Coincidence of Floating Marks of Various Sizes. (2)

Desmond O'Connor, U.S.A. Factors Affecting the Precision of Measurements on Photographs. (2)

James S. Crabtree and John D. McLaurin, U.S.A. Photogrammetric Applications of the BAI Area Correlator. (2)

Guy Ducher, France. Direct Compensation of the Bundle of Rays and Its Application in a Long Strip of Photographs. (1)

A. Crehange, France. The Development of Analytical Aerotriangulation at the Institute Geographique National. (1)

Aerotriangulation in the Various Countries

To the extent that they have been received, summaries of the reports of the National Reporters on aerotriangulation work accomplished in the various countries are recounted.

Belgium

National Reporter—A. Verdin

Three centers in Belgium apply aerotriangulation: (1) Institut Geographique Militaire (IGM), Brussels, in the Ministry of National Defense; (2) Societe Nationale de la Petite Propriete Terrienne (SNPPT) in the Topographic and Computer Serivce; and (3) the service du Cadastre of the Ministry of Finance.

IGM Brussels uses the SOM stereocom-

* Numbers following the titles of the papers indicate the theme of the invited paper to which they apply.

parator; SNPPT uses a Wild A7 plotter and a STK 1 stereocomparator; and the Cadastral service uses the SOM stereocomparator of IGM. All these instruments have digital readout.

IGM uses a Wild RC-8 film camera at a scale of 1/22,000 to photograph strips about 35 km long containing 18 to 20 models. A Wild PUG is used to mark the points. Comparator observations are completed at the rate of 6 to 7 models per day. The computational method is that reported by I.G.N. (Paris) at the 1960 Congress. Accuracies are ± 0.75 and ± 1.00 m. horizontally and vertically, resp.

SNPPT applies two techniques: a block method and a strip method. The Anblock system of I.T.C. is employed after polynomial strip adjustments. Blocks of 40 to 50 models and 4 to 5 strips are used giving accuracies of ± 5 cm where the scale is 1/6,000. The strip method used in a less accurate manner is applied to highway surveys.

The Cadastral service is testing an analytic system, using measurements on IGM's SOM stereocomparator. The ideas are presented by J. Tersago, "Le restituteur radial Morin et le redressment numerique au moyen du redresseur Zeiss SEG V," Bulletin de la Societe Belge de Photogrammetrie, Bulletin No. 85, Sept. 1966.

Canada

During the past four years, there has been a marked increase in the number of first-order plotting instruments that can be used for single-model aerotriangulation, such as the Wild A-8. All aerotriangulation instruments have been fitted with appropriate coordinate readout to give text and punch tape or punch cards. Point transfer devices are in wide use.

The National Research Council has developed a monocomparator which has created considerable interest in Canada because of its potential economy, speed and accuracy. However, the instrument has not yet been marketed. The bulk of coordinates in Canada are three-dimensional, obtained from instruments like the A-7.

Numerical strip and block adjustments developed by Mr. G. Schut have received national acceptance. For the most part, industry and government are using the systems designed by Schut although some universities and large government organizations have also developed procedures of their own. The IBM-1620 computer has been used considerably; some of these are now giving way to the IBM-360 systems.

Auxiliary data are sometimes used in aerotriangulation work. The APR is used within some instances simultaneous with aerial photography. Aerodist positioning photography with simultaneous APR is one of the principal methods for obtaining horizontal control for medium and small scale mapping in the national program.

Computer programs for the adjustment of single-model aerotriangulation are now in the development stage. Although it is presumptuous to predict what might happen in the next few years, one could expect that if single-model adjustment programs are available, there will be a definite reluctance to purchase first-order aerotriangulation instruments because of the large number of first-order plotting instruments already available. This will be particularly true in mapping organizations where the volume of aerotriangulation is relatively low and where first-order instruments are used for both plotting and aerotriangulation.

In summary, Canada has taken the initial step by adopting numerical procedures for adjustment of aerotriangulation. However, there is a reluctance to take the second step and go to analytical mensuration procedures, except in large government mapping organizations where the volume justifies full occupancy of the measuring equipment. There is a potential market in Canada for an economical monocomparator such as designed by the National Research Council. These or other similar instruments will set the trend for analytical procedures in this country. However, a great deal depends on the competition received from reliable computer programs that are capable of adjusting triangulation from first-order plotting instruments.

Germany (GFR)

National Reporter—Dr.-Ing. W. Brucklacher

The work in Germany (GFR) is depicted by a bibliography which is reproduced at the end of this report. Slotted templets are used to control rectified photomaps at a scale of 1/25,000. Both analog and analytic methods are used for topographic mapping for reallot-

ment and cadastral purposes at scales of 1/2,000 to 1/5,000. The Radial Secator, Stereoplanigraph C8 (with Ecomat recorder), and Stereocomparator PSK (with Ecomat) are used in data acquisition. Computers used are ZUSE Z 23, IBM, and LGP 30. Satellite triangulation will be performed through four geodetic institutes. Errors for 1/6,000 to 1/12,500 are $m_x = m_y = \pm 6$ to $\pm 20\mu$ (picture scale), and $m_z = \pm 7$ to $\pm 14\mu$. For small-scale work of 1/14,000 to 1/45,000, $m_x = m_y = \pm 23$ to $\pm 53\mu$ and $m_z = \pm 42$ to $\pm 62\mu$.

Germany (GDR)

National Reporter—Dr.-Ing. K. Regensburger

There has been a nearly complete transition from instrumental to analytical methods in practical work. Only horizontal aerotriangulation is used, however. Originally, the Schut method of aerotriangulation was used, but this has been superseded by the independent model method. Primarily strip adjustment is used.

One interesting technique: aerotriangulation for 1:10,000-scale maps is carried out with alternate strips of photographs, each absolutely oriented to control.

The Steko 1818 stereocomparator and the Stecometer of Carl Zeiss, Jena, are used for making measurements. The Zeiss Automatic Calculator ZR41 is used for computations.

In research, the main emphasis has been on developing block adjustment methods. The ITC Anblock and the Schmid methods have been programmed. Studies for the determination and elimination of photograph errors are also underway.

Japan

National Reporter—Dr. Kazuo Muraoka

Nearly 104,000 models were aerotriangulated during the 4 years 1964–7, with over 35,000 in 1967 of which about 29,000 were by analytical methods and 6,000 by mechanical (analog) methods. The users of the mechanical methods employed 8 C8-Stereoplanigraphs, 13 A7-Autographs, and 1 Nistri Model Beta. The analytical system is divided into *mono* and *stereo*. The two mono users employed: (1) 3 KRP pricking devices and 2 KRC monocomparators; (2) 1 PUG pricking device and 1 Mann monocomparator. The stereo users have 1 Zeiss PSK, 1 Zeiss/Jena Stecometer, and 2 PUG with 2 Wild A7. The four small to medium-size computers that are used are made in Japan: NEAC 2203, NEAC 2206, OKITA 5090, and TOSBAC 3400.

One government organization, one institute, and four private firms have adopted the analytic system. Each organization developed its own program, although they are quite similar. The methods can be divided into two classes both of which simulate the mechanical method. One system first computes relative orientation for each model independently, and then joins them together; the other simulates the steps of the mechanical methods almost exactly. Second degree conformal transformations are used for planimetric adjustments, and second degree polynomials for height adjustments. The average number of models per strip is 10 to 15. Block adjustments are not needed because of plentiful control. The principal applications of aerotriangulation are forestry, highways, rivers, and town planning.

The Netherlands

National Reporter—Ir. P. A. Roos

Analytic aerotriangulation has been practiced by several Dutch organizations during the last four years. The I.T.C. completed 2200 models using the Wild STK 1 and the Zeiss PSK at various scales. An analogue method was also applied using the Wild B8, obtaining planimetric coordinates later with a coordinatograph. Prof. R. Roelofs (21, listed in Literature from the Netherlands at end of report) developed a new block adjustment technique which contains a scheme to reduce the matrix inversion task.

K.L.M.-Aerocarto N. V. uses a Wild A-7 for independent model measurement and an I.B.M. for computing block adjustments. The survey Department of the Ministry of Transportation and Waterways completed more than 12,000 models using the Anblock

method. The Topographic Service of the Ministry of Defense used the radial triangulator method with the Wild RT for 67 blocks of about 60 models each. The Photogrammetric Service of the Cadastre has completed 73 blocks with a total of 7075 models using the Anblock method (23).

Republic of South Africa

National Reporter—P. L. Meadows

Considerable interest has been shown in analytical aerial triangulation in South Africa. A few establishments have already adopted analytical in preference to analog procedures for map production purposes at all scales, while others are actively experimenting in the application of analytical techniques. These experiments include the use of precise stereoplotting equipment as mono- or stereocomparators, methods of independent model triangulation, and the development of suitable computational methods using electronic computers. Thirteen research projects in this field are distributed among the following five organizations: Univ. of Capetown, Univ. of Witwatersrand, Univ. of Natal, Univ. of Pretoria, Durban City Engineers Dept.

Recently published articles in aerotriangulation are listed at the end of these reports.

Sweden

National Reporter—Thore Jörnstead

Up to 1966, aerotriangulation for photomaps at a scale of 1:10,000 was done using the Balplex. Beginning in 1966, the photomaps were prepared from orthophotos, so more accurate aerotriangulation was required. Aerotriangulation is now performed using the Wild A7 and a block adjustment technique involving the method of independent models. X, Y, and Z coordinates are adjusted.

Using photos at a scale of 1:30,000, the mean square errors of the discrepancies of the photogrammetric control points are about 1.5 meters in planimetry and 1 meter in eleval tion. The density of required geodetic contro- is 1 horizontal point and 8 elevation points per 100 sq km.

In the mountainous parts of Sweden, the standard topographic map is at a scale of 1:100,000. In this terrain, every model is controlled with barometric elevations so only horizontal aerotriangulation is done. One horizontal control point per 200 sq km is required.

Turkey

National Reporter—Harita Genel Mudurlugu

No aerotriangulation is done for use in production mapping; each model is absolutely oriented to four or more ground survey points.

Several experimental projects have been carried out using analog techniques and the C-8 Stereoplanigraph. The aero polygon method is used to derive X, Y, and Z strip coordinates. The strips are adjusted to control using an IBM 1130 computer and the method of Dr. Brucklacher. The mean values are used for points between adjacent strips.

Various sources of errors are being investigated in an effort to improve the results.

The data for five test strips is included in the report. The photo scales range from 1:8,000 to 1:40,000. Strip lengths are from 10 to 14 models. The mean errors on the test points are between 0.60 and 1.34 meters in the vertical and between 0.32 and 1.82 meters in the horizontal.

United Kingdom

National Reporter—A. D. N. Smith

Methods ranging from fully analytical to stereotemplets are used in production. The main methods are listed below together with the data acquisition device.

A. Fully analytical method.
Data from Hilger & Watts stereocomparators.
Simultaneous X, Y, Z block adjustments.
Largest reported block was 118 models.
Used iterative method by Proctor.
Confined to 1:10,560 maps.
No auxiliary data.

B. Semianalytical methods.
1. Independent model (AIM).
Data from A8.
Auxilliary data limited to APR.
2. Strip aerotriangulation.
Data from A5 and A7's in strip form.
Various block adjustments used.
APR data used on occasion.

C. Analogue method.
Plan adjustment by slotted template assembly.
Some height bridging with PG-2 and Multiplex.

Research: No significant research results reported

Trends: Trends seem to be mostly toward independent model methods with limited increase in fully analytical methods.

United States

National Reporter—Carl J. Born

A great variety of methods are used, ranging from analogue and graphical techniques to highly sophisticated fully analytical procedures. The various methods are classified as follows:

A. Analogue
1. Instrumental bridging in plan and height
2. Combination of instrumental and graphical methods such as stereotemplets.

B. Semianalytical
1. Strip and block adjustment from instrumental strips
2. Independent model methods.

C. Fully analytical methods
1. Sequential strip and block adjustments
2. Simultaneous block adjustments.

Increasing use is being made of fully analytical block methods, particularly the sequential methods, which are preferred because of the availability of programs and their adaptability to smaller computers. The consensus indicates that fully analytical methods are twice as accurate as semianalytical methods. Blocks having as many as 180 photographs have been successfully solved.

Monocomparators in conjunction with point marking devices are more commonly used than stereocomparators. Some new comparators have been developed, such as the Mann Stellar Comparator and the D. Brown & Assoc. self-calibrating monocomparator.

Some experimental work has been done with a LASER terrain profile recorder as an auxiliary sensor. This system has a higher precision of distance measuring than other systems now available.

Some successful aerotriangulation has been accomplished with lunar orbiter photography reconstituted from signals derived by scanning film that has been exposed and processed in the orbiter. A program, combining the techniques of analytical photogrammetry and orbital mechanics into a statistically rigorous least-squares solution, has been developed. It is capable of solving a strip of 20 photographs and yielding relative errors at the one sigma level of 36 meters horizontal and 114 meters vertical from 1:575,000-scale photographs.

Passive satellites are photographed with BC-4 observational cameras on a world-wide program to derive improved parameters for the spheroid and provide a uniform geodetic network. Several field units are in continuous operation; the photographs from these observations are measured with Mann monocomparators, and large computers are employed in the reduction of the data. Observations have been completed over half the earth using the Pageos satellite, and 21 stations in North America have been established using the Echo satellites.

The Baker–Nunn optical observation system consists of 12 basic permanent stations widely distributed throughout the world. The results of this system to date have yielded: (1) a new gravity model consisting of 128 coefficients including 13 zonal and 54 tesseral harmonics; (2) an ellipsoid of revolution for the earth with $a=6.378165$ and $1/f=298.25$; and (3) positions for the twelve ground stations with an internal consistency in position of 10 to 15 meters.

The PC-1000 camera system operates in a geometric mode similar to the BC-4 system. Its purpose is for densification of the BC-4 net and for developing arcs of triangulation between widely spaced stations where conventional methods are impossible. Such

stations are spaced 500 to 1000 miles apart. The rate of error propagation through a typical triangulation net was computed to be 15 feet per thousand miles.

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