within closer tolerances, and it should be possible to adjust or modify existing commercial equipment to take care of the parallax problem.

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Discussion of Footnote on Page 788 of September 1957 Issue of PHOTOGRAMMETRIC ENGINEERING

EDITOR'S EXPLANATION

The September 1957 issue of this JOURNAL (Vol. XXIII, No. 4, p. 779) contained a paper by B. Hallert entitled "Determination and Correction of Systematic Errors in the Fundamental Operations of Aerial Triangulation." A footnote on page 788 read as follows: "According to information from Mrs. Norton,* Fairchild Camera & Instrument Corp., New York, about 500 man hours normally are required for a complete determination of the inner orientation of an aerial camera using conventional methods." On March 26, 1959 Mrs. Norton wrote to Dr. Hallert. He replied on April 29. Believing that the discussions and explanations will be helpful and appreciated by other readers of Dr. Hallert's paper, both letters are below reproduced in complete form. Also included are further comments by Mrs. Norton dated July 17.

MRS. NORTON'S LETTER OF MARCH 26 TO DR. HALLERT

A NUMBER of people have recently spoken to me about the time used at the Fairchild Camera Laboratory for calibrating mapping cameras, referring to your quotation of 500 hours as being possible. It now appears that the unusual time of 500 hours is being interpreted as the normal and it becomes necessary to correct this impression.

"When I first saw your paper I immediately thought that a typographical error had been made, making 50 become 500 (even 50 is out of line). The cost of that many labor hoors is so prohibitive for routine calibration that the error was too flagrantly obvious to be considered seriously, and I did not bother to write you.

"On the other hand, as you know, special projects of statistical nature can require hundreds of hours, and we have been involved in many such projects. I recall that at the time you visited our laboratory we had just completed one such project and it is possible our discussion of this may have led to a misunderstanding.

"Unfortunately, it is not easily possible to separate calibration from other production control tests at Fairchild, so the word calibration is loosely used. It covers (with respect to mapping cameras) incoming lens inspection, a through-focus resolution test, radial and tangential distortion, visual and dimensional inspection, a machining distance for a cone, all to government standards.

"This is followed by the tests which must be made to position the fiducials to the Point of Symmetry and the C.F.L. fiducials to the correct distance. It includes a calibration on spectroscopic plate based on a minimum of two exposures. With the cone mounted in the camera body, further checks are made on film to assure that the light metal cone is mounted free of strain and that the inner orientation features are maintained when exposed to film in the magazine. Also included are a resolution test, right angle test, film flatness and shutter synchronizing test.

"If a simple photographic calibration were

* Mrs. Clarice L. Norton, Chief, Optical Section, Quality Control.

to be made on a completed camera, much less time would be used than the present combination of testing, setting fiducials, and calibration requires.

"Calibration based on a single exposure would probably approach the 5 man-hour figure used by Carman except that our experience shows that two exposures, at different orientations of the camera in azimuth, are preferable; while the $2\frac{1}{2}°$ increments of the Calibrator angles (on opposite banks) require a little more analysis for the additional information.

"A copy of this letter is being sent to Dr. Carman and the *Photogrammetric Record* in order that this misunderstanding may be cleared up.

"I am glad to see that you are continuing your work of analyzing the accuracy and reliability of photogrammetric cameras, and I would be very interested in knowing how you are handling the positional errors due to the location of the film emulsion surface and the dimensional changes of the film. In particular, do you think we (photogrammetrists) should attempt calibration of the completed camera, including magazine, on film as a routine test? This is the direction in which we are heading on some of our special cameras and I would appreciate having your opinion on such a procedure.

"A copy of this letter is also being sent to PHOTOGRAMMETRIC ENGINEERING."

DR. HALLERT'S LETTER OF APRIL 24 TO MRS. NORTON

"I thank you very much for your letter of March 26, 1959, which arrived here yesterday, delayed nearly one month. I am very busy right now but will immediately give my points of view to those questions which you mention, in particular time consumption for camera calibration.

"When I visited you in the end of November 1954 we discussed, according to my notes, among other things, calibration and testing of cameras with different methods. I described the use of the grid method for the calibration of cameras from high towers, and the use of the same method for the determination of systematic disturbances in aerial photographs after aerial photography of special grid test fields on the ground.

"I emphasized that the entire bundle of rays was treated simultaneously according to the grid method, and that the method entirely was founded upon the method of the least squares for the best possible determination of systematic deformations of the photographs, and for the convenient estimation of the basic accuracy of the procedure as the standard error of unit weight of the image coordinate measurements. Thereafter the accuracy of all functions of the image coordinates, for instance, the elements of the interior orientation and of the systematic disturbances as, for instance, the radial and tangential distortion, can easily be determined in a well defined way.

"We also talked about the accuracy which normally can be obtained with the grid method. I stated that according to experience the standard error of unit weight of the image coordinate measurements usually could be expected to about 0.006 mm. on the scale of the photographs for good wide-angle cameras ($c = 150$ mm.). If film is used particular attention must be paid to the affine shrinkage. The corresponding standard error of the principal distance (calibrated focal-length) of the photographs would theoretically as an average be of approximately the same magnitude. The standard error of the computed coordinates of the principal point would become somewhat larger. These standard errors could be computed from the corresponding automatically determined weight numbers. The standard error of the radial distortion curve would as an average become about the half of the standard error of unit weight of the image coordinate measurements.

"Also if the camera was tested under extreme conditions, for instance, in low or high temperatures, the calibration procedure would be easy to perform from high towers with the grid method since only the camera can be influenced by the extreme conditions, not the testing instruments.

"I asked you for your estimation of the time consumption if corresponding testing procedures with *the same accuracy conditions* were to be performed in a multi-collimator. Then your answer was about *500 man hours*. I understood your answer as follows.

"The required standard error of the basic measurements (0.006 mm.) corresponds approximately to a standard error of the directions of the individual collimators of less than 6″ (sexagesimal seconds). In order to guarantee this high precision it ought to be necessary to adjust the multi-collimator itself frequently. This may be a very difficult and time-consuming job. I think that there are organizations which have bought especially constructed theodolites for this purpose. Even such theodolites are afflicted with errors. Further, if the camera is to be

tested at temperatures of, for instance, +30°C. and −30°C., new adjustments of the multi-collimator might probably be necessary since the angles between the collimators might be considerably influenced by the temperature.

"I therefore considered the mentioned time consumption of about 500 man hours (including all necessary statistical calculations of the test measurements of the collimator itself and of the camera tests) to be acceptable. But I want to emphasize again, *this time consumption would refer to tests at the required accuracy standard of the grid method and to the tests in different temperatures.* Under other circumstances, for instance, not defined accuracy of the results or in ordinary laboratory temperature, information on the time consumption would be of very little interest.

"Concerning the accuracy which normally is obtained by camera tests in the multi-collimator there seems so far very little information to be available. Accuracy information from repeated measurements (settings) only or from repeated determinations of the elements of the interior orientation (including the radial distortion) only is of limited value since there may be considerable systematic errors which are correlated between the different tests and which consequently do not appear. It would doubtless be much more valuable to use the geometric conditions of the grid method. In other words, the center point in the image and all points which are located upon circles around this point can be used for a determination of the standard error of unit weight of the image corrdinates in accordance with the method of the least squares. In this determination of the basic accuracy the errors of the directions of the collimators would also be included. In this way the basic and real accuracy of the multi-collimator method would be determined in a well defined manner and the standard errors of the principal distance (calibrated focal-length) of the position of the principal point and of the radial distortion curve could be obtained in a theoretically correct and well defined manner for the comparison with other methods. The very simple computations are clearly demonstrated in the paper: 'A new method for the determination of the distortion and the inner orientation of cameras and projectors,' *Photogrammetria*, XI, 1954–1955: 3.

"Finally, laboratory tests of lenses and cameras are doubtless of great importance for the manufacturer's test and for the basic determination of principal distance and principal point. It is, however, quite evident, that for the *photogrammetrist* additional camera tests under real photography conditions are necessary. The systematic errors of the *photograph* must be corrected at the plotting, not only those of the lens. Sometimes it is suitable to include the influence of the earth's curvature in the correction of the radial distortion.

"As an example we will here demonstrate the radial distortion curve of the *aviogon lens* which was used for the photography of the aerial test photographs of Commission IV: 3 (Canada) (flying altitude about 7,500 meters, $c = 152.38$). See Diagram 1. This radial distortion was probably determined with a laboratory method. With the *y* parallax method the radial distortion curve of the *photographs* (diapositives) has been determined in a Wild Autograph A7 nr 310. See Diagram 2. In the same diagram the influence of the earth's curvature and the atmospheric refraction according to Leijonhufvud has been indicated and added to the radial distortion curve of the lens. The distortion correction should preferably be made with respect to this total distortion curve. In Diagram 3 the elevation *errors* of the model due to the total radial distortion curve are demonstrated. Evidently there will remain considerable systematic errors in the elevations of the model if the radial distortion curve of the lens is corrected only. The position and the number of control points will of

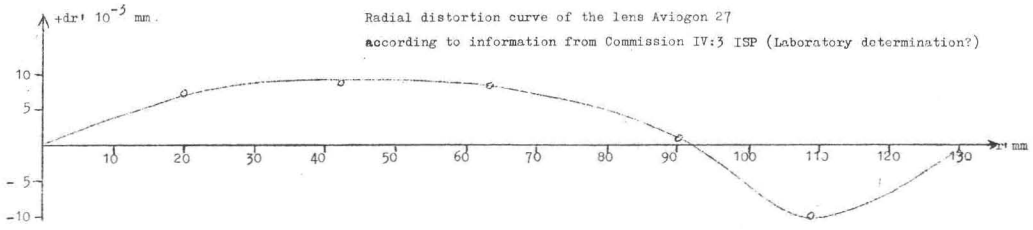

DIAGRAM 1

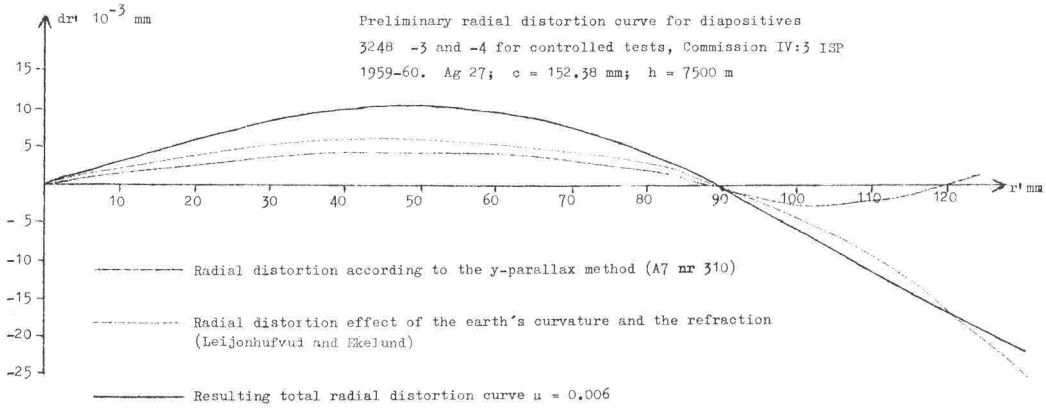

DIAGRAM 2

Elevation errors in meters of the model due to the total radial distortion curve diagram

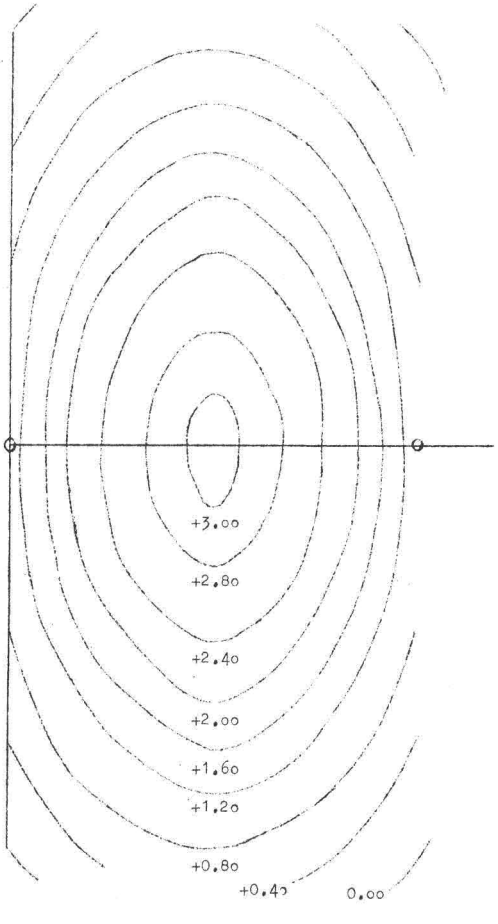

DIAGRAM 3

course have a great influence upon the final distribution of the elevation errors. Therefore different elevation errors will be found from model to model.

IN SUMMARY:

"For a multi-collimator determination of the elements of the interior orientation (including the radial distortion and other non-projective systematic errors) of aerial cameras with the same precision as usually is obtained with the grid method, I got the impression from you that special attention must be paid to the adjustment of the multi-collimator. If the camera also is to be tested under extreme temperature conditions according to practice the mentioned adjustment would probably become very difficult and time-consuming if a high and well defined precision in the results is to be obtained. The time 500 man hours for a complete calibration refers to this condition. If the precision of the calibration procedure is not determined or not well defined any information on the time consumption is of very little interest.

"It seems self-evident that the systematic errors which are to be corrected at the plotting procedure must refer to the *photographs* and that they must be determined under *real working conditions*. For such purpose there are the grid method (tower method and the Oland test area method) the elevation model deformation method (x-parallax method) according to Lemaire and the y-parallax method available. The parallax methods, however, have to be regarded as approximative methods in comparison with the grid method since

the correlation between the photographs may conceal such systematic errors, which have the same influence upon corresponding rays of the two bundles. In particular the *y*-parallax method is a very convenient aid for the determination under normal conditions of residual systematic errors in arbitrary photogrammetric models in arbitrary stereoscopic instruments without any control points. Simultaneously valuable information on the basic accuracy of the entire photogrammetric procedure is obtained automatically as a standard error of the basic parallax measurements. The limitations of the method which earlier have been published and emphasized have always to be remembered, however. No parallax methods can be used for *complete calibration* of cameras.

"I fully agree with you that tests of the completed camera, as it is used during practical work, must be preferred by the photogrammetrists. In particular for the construction and application of specifications for the photogrammetric procedure the fundamental operations must be tested separately.

"Using suitable mathematical conditions at the testing (for instance the well-known projective conditons for single bundles of rays and for pairs of such bundles) the basic accuracy can be determined and expressed according to the method of the least squares, which is a very convenient and unique manner. Then all possible errors, also those due to the location of the film emulsion surface and the dimensional changes of the film, will be included in the basic accuracy determination. In analytical photogrammetry the systematic dimensional changes of the film can easily be corrected for. In graphical plotting it seems possible to correct at least the affine deformations of the film with the aid of special adjustment of the gimbal axes of the instruments.

"Finally, recent construction of very high television towers (more than 300 meters or 900 feet) may be of considerable interest for the tower calibration and different tests of aerial cameras. Slightly oblique photographs from such towers can be used for the tests, also under extreme conditions.

"I thank you for this exchange of ideas and thoughts, which I hope will continue. In this way the development of photogrammetry doubtless can become favourably influenced."

Closure by Mrs. Norton*

"Professor Hallert's foregoing letter certainly explains the misunderstanding of the time it takes to calibrate a camera. It was fortunate that his notes were so complete. I am in complete agreement with him that a laboratory calibration, particularly where it involves only the cone, is inadequate for the values which the camera contributes to the total mapping system.

"The Government agencies using mapping photography have long recognized this inadequacy. One agency uses additional laboratory tests and another requires aerial testing over controlled ranges with every mapping camera. The function of these tests is two-fold. It proves the quality of the camera and it selects the final values contributing to the total mapping system. 500 hours are easily expended in the latter test.

"Professor Hallert's suggestion of using the Tower method is one that is attracting the interest of photogrammetrists who recognize the need for controls. I believe we will shortly be entering into a much expanded testing phase in evaluation of cameras, call it by the name of calibration or any other.

"This phase should include a test on film in the calibration laboratory, the results of which should be compared with those obtained on spectroscopic plates. Further, it is my belief and hope that many of the refinements of the various calibration laboratories, as for instance the plate flattener developed at the Canadian Research Council, will become a requirement for all laboratories during the most critical work.

"It is only by a constant refinement of present day techniques, and a close relationship between the different laboratories that progress will be maintained."

* Included in her letter of July 17—Editor.

NEW DISTANCE-DETERMINATION SYSTEMS DESCRIBED

A whole new family of electronic surveying systems, now in the final development stage, will soon be made available to surveyors and photogrammetrists. Their description was the major feature of a paper delivered by Floyd W. Hough, internationally known geodesist, at the annual convention of the American Society of Civil Engineers last month. Mr. Hough reported that development of two new distance-measuring instruments will solve some heretofore very difficult surveying problems.