CALIBRATION OF LENSES AND CAMERAS

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ACCORDING to definitions in dictionaries, the original specific meaning of the verb "to calibrate" is either to graduate a tube of a measuring instrument (a thermometer, for example) in appropriate units, or to check the graduation. In actual usage, however, the word "calibration" has lost its specific meaning. It is now used to denote any adjusting of the component parts of an instrument or of the whole instrument in order to obtain certain prescribed characteristics, and it is also used to denote the final measurements needed for determination of the performance of an instrument.

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With the specific boundaries removed, the meaning of calibration may be extended to cover all the designing and manufacturing efforts directed toward securing an established goal in performance. Since these efforts are usually taken for granted and are seldom discussed, an enumeration of a few salient points may be of interest to this audience.

The basic optical requirement of any photogrammetric camera is a lens, preferably of a relatively high speed, with the radial distortion reduced practically to zero, and capable of producing photographs with a satisfactory resolution of fine detail. It was an expensive and time consuming job to design a lens of these characteristics. But the task was at least partially accomplished with the introduction in this country of the now well known Metrogon lenses.

The precision-minded photogrammetrists will be interested to note that the maintenance of the nominally established characteristics in the actual production lots of Metrogon and of similar lenses involves manufacturing calibration procedures in which the thicknesses of the individual elements are matched within a few microns, and the air spacings are critically adjusted in each lens to secure the optimum performance.

The basic limitation of the Metrogon formula is that its linear distortion, although not exceeding in any part of the field the astonishingly small value of 0.1%, is still high enough to require a further compensation in mapping instruments.

Major efforts have been expended within the last few years to eliminate this shortcoming. The result of these efforts is represented by a new formula, the samples of which have been already made by Bausch & Lomb for the Photographic Laboratory at Wright Field and for the Geological Survey, and which will become commercially available under the name of Cartogon as soon as some manufacturing problems are solved. A conservative estimate of the maximum residual distortion in this formula is of the order of 0.02%. There are also expectations that the photographic resolution with this new formula may attain somewhat higher values than those obtainable with Metrogons in the region of 35°–45°.

One of the most interesting developments in the calibration of lenses at the time of manufacture was brought about by the excellent analysis by *J. T. Pennington*[1] of some obscure errors in photogrammetric extension of control. These errors were traced to residual eccentricities of mechanical and optical components. It was established that the combined effect of these eccentricities manifests itself as a peculiar distortion, now known under the name of tangential. It was thought originally that attempts to eliminate this distortion would impose an impossible task on manufacturing processes. Later, however, mainly through the efforts of *J. V. Sharp*, *H. Gruner*, and *H. H. Hayes* of Bausch & Lomb, calibration procedures were established which permit the reduction of tangential distortion to a value not exceeding a few microns, thus restricting displacements of image points to a maximum of 10 seconds from their undistorted positions.

The calibration procedures at the factory involve all the adjustments and measurements which will assure the manufacturer and the customer that the lens meets a given set of performance specifications.

When the lens arrives at its ultimate destination and is mounted in a camera, the camera manufacturer employs his own calibration procedures in order to secure the proper performance of the lens-camera combination. In the extended sense of the word, these calibration procedures also begin in the design stages, in the course of which the inherent performance characteristics of the camera are established. The calibration procedures used during the manufacturing process provide safeguards against major deviation from the goals established by the designer and from the limits defined by applicable specifications, whose severity is well illustrated by the data given in an article by *G. J. Podeyn*[2] on Fairchild equipment.

The purpose of calibration of a lens-camera combination is to obtain the final assurance that the performance characteristics are within the specified values, and to establish a numerical record of these characteristics. While this final calibration could be performed at the camera plant as the last step in the series of manufacturing calibrations, it has become customary to vest this responsibility in the National Bureau of Standards. The formal reason for this is that government agencies have delegated to the Bureau of Standards the task of final inspection of all the cameras procured by them or used on their projects by private contractors. The other reason is that the Bureau of Standards was the first to build equipment specifically designed for determination of all the important characteristics of aerial cameras, and it is still the only organization in this country possessing the most modern equipment for calibration of cameras. It is expected, however, that in the near future similar equipment will be in operation at the Fairchild plant in New York.

The equipment and procedures used for the final calibration of precision aerial cameras are thoroughly described in a recent paper by *F. E. Washer* and *F. A. Case*[3] of the Bureau of Standards. Therefore, it should be sufficient to recapitulate here only the quantities customarily determined in the process of final calibration. These are: the angle between the lines joining the opposite

[1] Pennington, J. T., "Tangential Distortion and Its Effects on Photogrammetric Extension of Control," PHOTOGRAMMETRIC ENGINEERING, Vol. XIII, No. 1, March 1947, pp. 135–142.

[2] Podeyn, G. J., "New Fairchild Mapping Equipment," PHOTOGRAMMETRIC ENGINEERING, Vol. XV, No. 3, September 1949, pp. 374–385.

[3] Washer, F. E., and Case, F. A., "Calibration of Precision Airplane Mapping Cameras," PHOTOGRAMMETRIC ENGINEERING, Vol. XVI, No. 4, September 1950, pp. 502–524.

pairs of fiducial marks; the location of the point of intersection of these lines (this is the center of collimation); the coordinates of the center cross (which is the point where an infinitely distant object point lying on a line perpendicular to the focal plane is imaged by the camera lens); the coordinates of the principal point; the calibrated focal length; the calibrated distortion; and the resolution of the lens-emulsion combination.

While the determination of all these quantities is sufficient to assure that the camera meets some generally acceptable standards, suggestions have been recently made that determination of some additional quantities may be helpful to securing still higher standards and to a better utilization of photogrammetric equipment. Thus proposals have been made that the determination of tangential distortion and of the direction of its maximum be included in the final calibration, and the question has been raised by *E. D. Sewell*[4] whether the determination of point of symmetry of radial distortion should not supplant or supplement the determination of the principal point, which, according to the current definition, is the point where a perpendicular from the rear nodal point of the lens to the camera plane intersects the focal plane. Still another proposal, as made by *R. Roelofs*[5] is to entirely divorce the concept of the principal point from such hazy and elusive optical concepts as "principal or nodal point," "center of perspective in the image space," or "optical axis," and to define the principal point and the photogrammetric center of perspective on the basis of a thorough analysis of the metric data on the photographs and of fundamental principles of geometrical restitution.

The photogrammetric significance of tangential distortion and of tilt pattern in distortion and of differentiation between the center cross, the various concepts of the principal point, and the point of symmetry may be interesting topics for discussion before this panel.

Chairman Howlett: Before we pass to our next prepared paper, I should like to record, on behalf of all of you as well as the members of the panel, how extremely grateful we are to our European colleagues who took this panel discussion as seriously as we had asked them to do in preparation for the work planned by the International Society at its next general meeting; namely, the preparation of some specifications which will receive international agreement. Our colleagues went to a great deal of trouble and held a meeting in Paris which lasted several days over the Christmas season.

Mr. Corten, who is well known for his work in the photogrammetric field in Europe, has been kind enough to travel all the way to our meeting. He will give us some idea of the way they are thinking in Europe.

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[4] Sewell, E. D., "Field Calibration of Aerial Mapping Cameras," PHOTOGRAMMETRIC ENGINEERING, Vol. XIV, No. 3, September 1948, pp. 363–398.

[5] Roelofs, R., "Distortion, Principal Point, Point of Symmetry and Calibrated Principal Point," *Photogrammetria*, No. 2, 1950–1951.