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Calibration of Lenses and Cameras at the USGS

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Abstract: *Calibration of photographic objectives and mapping cameras at the U. S. Geological Survey has been expanded to include services formerly provided by the National Bureau of Standards. The most frequently requested photographic and visual tests are described along with the equipment used to measure calibrated focal length, distortion, resolving power, and model flatness. Also described are the most recent modifications to the USGS camera calibrator for complete testing of super-wide-angle cameras.*

Introduction

The U. S. Geological Survey has been calibrating aerial cameras used by contractors on USGS projects for the last two decades. For tests under conditions closely approximating those of use, a camera calibrator was built.[1] An analysis of photographs taken with the camera oriented in the calibrator included a test for stereoscopic model flatness; this has proved eminently successful.

On April 1, 1973 the calibration services for aerial cameras and lenses provided by the National Bureau of Standards, U. S. Department of Commerce, were transferred to USGS. The new, combined laboratory will continue to provide calibration of both lenses and cameras used primarily in photogrammetry, enabling governmental and private users of aerial photographic services to determine compliance with specifications and applicability to specific requirements.

The test apparatus and procedures for the more commonly requested calibrations are described in the following sections, and the quantities measured are defined. A calibration report listing the tests performed and the results is supplied to the owner on payment of a scheduled fee.

Calibration of Unmounted Lenses

Accurate values are needed for all the metric characteristics of the lens that affect the accuracy of the map photograph. Federal and State agency specifications set limits on the range in magnitude of the various quantities to be measured. Lenses to be used in photogrammetry are usually evaluated by photographic methods.

A precision lens-testing camera[2] is used for measuring the following quantities: equivalent focal length *EFL*, back focal distance *BF*, distortion *D*, and resolving power *RP*. The instrument consists of 10 collimators spaced at 5° intervals, with Air Force resolution charts in the focal plane of each collimator objective. The charts are illuminated by tungsten lamps through Corning Glass 1-71 filters to approximate daylight (blackbody at 6500K).

With this instrument, the entire region of usable imagery of the lens is sampled photographically to determine the plane of best average definition[3] by examination of the resolution-chart images on the test negative. Then the separations of images are measured, and the equivalent focal length and distortion of the lens are calculated. The distance between the rear vertex of the lens and the position of the emulsion surface in the plane of best average definition is measured to obtain the back focal distance, which is of critical importance to the camera manufacturer in positioning the lens for optimum performance.

Values of resolving power are read from the images of the Air Force high-contrast resolution charts and are listed for tangential and radial lines at each test angle; in addition the area-weighted average resolution (*AWAR*) is computed and listed. Values are given in cycles per millimeter and indicate that the stated pattern and all coarser patterns are clearly resolved. Resolving power varies with target contrast and emulsion used for test exposures.[4]

The calibration described in the foregoing section is performed under USGS test RT-R(b)—Determination of back focal distance, equivalent focal length, distortion, and resolving power at 5° intervals from the center to edge of the field.

Calibration of Aerial Mapping Cameras

A camera received for calibration is given a preliminary check to determine whether its construction satisfies the requirements for that type of camera. Accessibility of the focal plane is checked. The shutter is operated to determine whether it can be held open for glass-plate exposures. Cameras submitted for adjustment of fiducial marks are examined to determine whether the adjustment is feasible. The calibration of photogrammetric cameras is based on measurements on glass and film negatives exposed in the camera magazine(s).

With the relocation of the optical calibration laboratory to the new USGS National Center in Reston, Va., several modifications were made to the camera calibrator. Four collimators were added at 50° off axis, bringing the total number of collimators to 53. The four main arrays now have complete angular coverage from 0° to 54° off axis with collimators spaced as follows:

0° to 30° —7.5° spacing
30° to 50° —5°
50° to 54.5° —4.5°.

Structural changes were made to increase stability and the accuracy of alinement of the 54° collimators. For identification, 8 minicollimators were installed to project collimator bank numbers 1 to 8 on each photographic exposure. With the installation of the 4 collimators at 50°, it is now possible to make a complete calibration for both wide-angle and super-wide-angle cameras.

The equivalent and calibrated focal lengths of the lens are determined for the actual focal plane of the camera. In addition, values of radial and tangential distortion and resolving power are measured for the 4 radii spaced at azimuths 0°, 90°, 180°, and 270°. The principal point of autocollimation is located, together with the relative positions of the fiducial marks.

For a calibration, the camera is placed on the calibrator so that the front nodal point of the lens is approximately at the point of intersection of the axes of the 53 collimators and the focal-plane frame is normal to the axis of the central collimator. There the camera is adjusted in azimuth so that the images of the collimator targets lie in the diagonals of the focal-plane frame. A plane-parallel plate is placed on the focal plane of the camera, and by viewing through an autocollimating telescope, the camera is adjusted by tipping until the plane-parallel plate is perpendicular to the axis of the autocollimating telescope.

A photographic plate is placed on the focal-plane frame, and the plane-parallel plate is placed on top of it to insure that the emulsion surface is in the focal plane of the camera. After making each test exposure, the position of the camera is checked to make sure that no change has occurred since the initial adjustment.

Although a single negative contains all the information necessary for metric calibration, in practice two glass-plate and four film exposures are made, with the camera rotated 180° in azimuth between exposures, and the measurements from individual exposures are averaged.

From the film exposures, a pair of diapositives are made for the stereomodel deformation test. The base-height ratio used is 0.6 for cameras having a 90° field and 1.0 for cameras having a 120° field.

Each camera is calibrated with the filter in place in front of the lens. Filters are measured for nonparallelism of the surfaces. In addition the film-platen is checked for flatness with a dial-indicating instrument which measures departures from flatness with an accuracy of ±0.002 mm. The effective speed and efficiency of the shutter, at an indicated aperture, are also measured for a full range of speeds.

These calibration steps are performed under one or more of the following USGS tests:

RT-R(c). Determination of compliance of camera film platen with flatness requirements; requested if a magazine is submitted separately.

RT-R(d). Determination of calibrated focal length, radial and tangential distortion, and resolving power from center to edge of field.

RT-R(e). Location of the principal point of autocollimation; check of 90° condition for either 4 or 8 fiducial marks; distance between fiducial marks; stereomodel values for cameras of 153 mm and 88 mm (6 inch and 3.5 inch) focal length; shutter speed and efficiency; compliance of camera filter surfaces;

and film-platen flatness requirements. This test together with test *RT-R(d)* constitutes a complete aerial mapping camera calibration for determining compliance with any Federal or State mapping agency specifications.

RT-R(f). Setting the principal point of autocollimation and 90° condition. If the principal point can be positioned properly with respect to the center of collimation by a ready adjustment of the lens in a transverse direction or by a ready adjustment of the fiducial marks, pins are fixed to preserve the setting after adjustment. Normally this calibration is made on cameras that have been modified, with or without installation of a new lens.

Calibration of Copy-Camera Lenses

The lenses used in copy cameras, at finite distances, come in such a wide range of sizes and focal lengths that it is impractical to calibrate them by photographic methods because of space limitations. It is therefore necessary to use a visual optical bench for these lenses. Measurements commonly made on the visual optical bench include equivalent focal length, back and front focal distance, lens thickness, nodal-point separation, and distortion.

The optical bench currently in use at the Geological Survey consists of a set of bench ways on which are mounted slides carrying a viewing microscope and a nodal-slide assembly. A collimated beam of light is provided by a parabolic mirror mounted at one end of the bench.

Length measurements are made with respect to a scale mounted on the bench ways or, in the measurement of distortion, with respect to a transverse scale that indicates sideways displacement of the viewing microscope. The nodal slide on which the lens is mounted is provided with adjustments for positioning the lens in the vertical axis of rotation over either nodal point.

The distance between the image formed by the lens and its rear nodal point is the equivalent focal length *EFL*. The distance between the image and the vertex of the back surface of the lens is the back focal distance *BF*.

For lenses used at finite distances, the front equivalent focal length, front focal distance *FF*, nodal-point separation *NPS*, and lens thickness *T* are measured. The front and back equivalent focal lengths can usually be re-

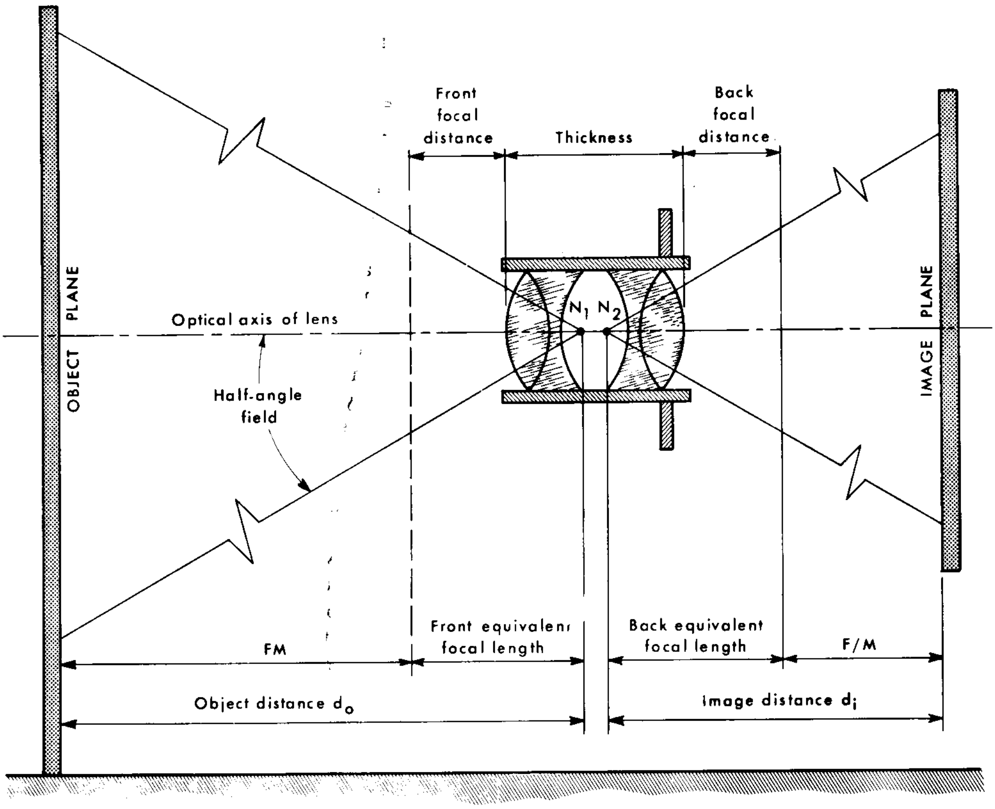

Fig. 1. A photographic objective showing the optical constants and the relation between the object and image distances.

garded as equal. These quantities are related as follows:

$$2EFL + NPS = BF + FF + T.$$

It is necessary to have reliable values of these quantities for proper positioning of object plane, lens, and image plane in a copy camera at specified values of the reduction ratio (I/M) where M is the ratio of object-to-image size, shown in the schematic drawing of a photographic objective (Figure 1).

The object distance d_o and image distance d_i are given by the formula

$$d_o = f(M+I)$$
$$d_i = f(I+I/M)$$

and the distance D separating the object and image planes is

$$D = d_o + d_i + NPS$$
$$= (f/M)(M + I)^2 + NPS.$$

The calibration described in the foregoing section is performed under USGS test *RT-R(a)*—Determination of equivalent focal length, back focal distance, separation of nodal points, and lens thickness.

Fees for Calibration

The calibrations described are performed on a fee schedule, with the fees determined by the actual cost of labor and materials used in the work. Current fees were set in a USGS announcement of July 1973.

The calibrations are performed as promptly as possible after receipt of the camera, lens, or accessory. To minimize the time a camera or lens is out of service, a contractor should not ship it to USGS until a tentative schedule has been agreed on.

A formal purchase order or letter of request for the calibration or test should be sent before or at the time the camera or lens is shipped. The document must clearly identify the camera, magazine, filters, lenses, etc. USGS reserves the right to decline any request for special calibration services if the work would interfere with the normal work of the optical calibration laboratory.

Further information or inquiries for calibration and testing services should be addressed to U.S. Geological Survey, Topographic Division RT-R (#526), National Center, Reston, Virginia 22092.

References

1. Bean, R. K., U. S. Geological Survey Camera Calibrator, paper presented at ACSM-ASP Annual Meeting, 1962.
2. Washer, F. E., Tayman, W. P., and Darling, W. R., Evaluation of Lens Distortion by Visual and Photographic Methods, J. Research NBS 61, 509 (1958).
3. Washer, F. E., and Tayman, W. P., Location of the Plane of Best Average Definition for Airplane Camera Lenses, *Photogrammetric Engineering* 26:3 June (1960).
4. ——, Variation of Resolving Power and Type of Test Pattern, *J. Research NBS* 64C-3, (1960).

Notice to Contributors

1. Manuscripts should be typed, double-spaced on 8½ × 11 or 8 × 10½ white bond, on *one* side only. References, footnotes, captions—everything should be double-spaced. Margins should be 1½ inches.
2. Ordinarily *two* copies of the manuscript and two sets of illustrations should be submitted where the second set of illustrations need not be prime quality; EXCEPT that *five* copies of papers on Remote Sensing and Photointerpretation are needed, all with prime quality illustrations to facilitate the review process.
3. Each article should include an abstract, which is a *digest* of the article. An abstract should be 100 to 150 words in length.
4. Tables should be designed to fit into a width no more than five inches.
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