invitations were sent to the more interested authorities on optics and precision measurements. Accordingly, we were fortunate to have the assistance of

Dr. F. E. Washer, National Bureau of Standards
Dr. L. E. Howlett, National Research Council, Canada
Mr. Eldon Sewell, Corps of Engineers
Mr. Paul Pryor, Air Forces, Wright Field
Dr. Constantine Pestrekov, Bausch and Lomb Optical Company

At this meeting, the general plan for the tests, equipment and procedures was determined. Dr. *L. E. Howlett* agreed to act as consultant on the project. In the course of the past year there have been frequent discussions with Dr. *Gardner*, Dr. *Washer*, and also with the other members of the original group.

Through the coöperation of the above group, there will shortly be in operation in our Jamaica, N.Y. plant, the first commercial Camera Calibration Laboratory in the United States. The equipment used and the techniques to be applied are the outgrowth of the extensive experience of the National Bureau of Standards of Washington, D.C., and of the National Research Council of Canada, both of which organizations coöperated with us generously.

In order to maintain our standards consistent with those established by the Bureau of Standards, it is our intention to submit one calibrated camera at random out of every group of cameras for verification by the Bureau of Standards. In this way we believe we will be able to carry on the high quality of testing established by Dr. *Gardner's* group at the Bureau of Standards.

The purpose of the Fairchild Camera Calibration Laboratory is three-fold:

1) To calibrate Fairchild precision cameras in the course of production.
2) To re-check and if necessary to re-calibrate Fairchild precision cameras where the demands upon the user require periodic re-certification.
3) To check, and if necessary to calibrate non-Fairchild cameras which may be submitted to us.

As soon as we gain some experience in the operation of this new Camera Calibration Laboratory, it is our intention to hold a one-day meeting at our plant for those members of this Society who may be specifically interested in the problem of camera calibration. To insure that we invite all those interested, please signify your specific interest to me or to one of our representatives.

THE FAIRCHILD PRECISION CAMERA CALIBRATOR*

Mrs. Clarice Norton, Director, Calibration Laboratory, Optical-Technical Section, Fairchild Camera and Instrument Corporation

IN PLANNING the equipment necessary for the production testing and calibrating of Photogrammetric Cameras, Fairchild was faced with the choice of either designing two separate test units, one for resolution and the other for distortion, or one all-encompassing test unit.

Since it was felt that a considerable saving of labor could be effected if one test could be made to supply all the necessary data, it was decided to build all the test requirements into a single piece of equipment. Because of the critical distortion requirements, such equipment could only result in a fixture which would be a modification of the very exacting Precision Camera Calibrator

* Paper read at Semi-Annual Meeting of the Society, Institute of Geographical Exploration, Cambridge, Mass., September 21 and 22, 1950.

designed by Dr. *Washer* and Mr. *Case* of the National Bureau of Standards and described by them in the July 1950 issue of the *Journal of Research of the National Bureau of Standards* and in the September 1950 issue of PHOTOGRAMMETRIC ENGINEERING.

The Fairchild Precision Camera Calibrator (Figure 1) was therefore built to specifications which provided a pointing accuracy comparable to that of the Precision Camera Calibrator of the Bureau of Standards, and, in addition, provided the means of testing the resolution of lenses up to 12″ in focal length and

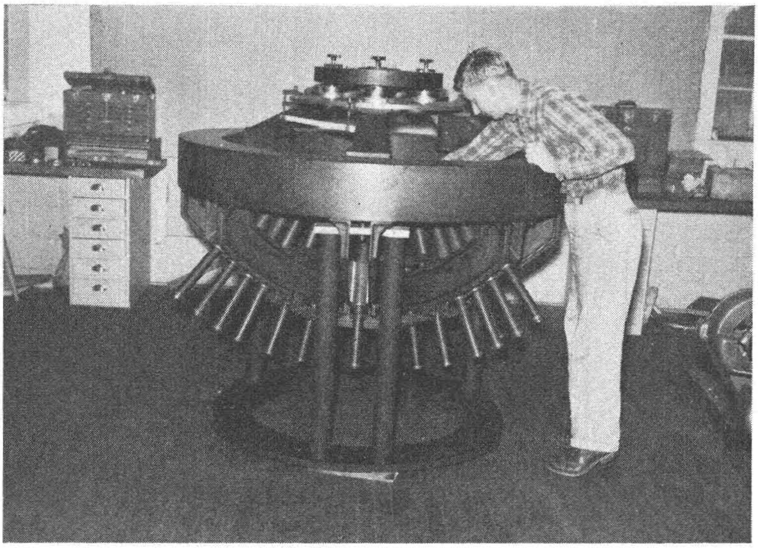

FIG. 1. Fairchild Precision Camera Calibrator. This incomplete assembly shows the general construction of the Calibrator and the means of providing the pointing accuracy. Some idea of the size can also be obtained. The base ring will fit the center ring of the vibration isolation base and will be bolted to it. A platform at a height just above the large ring (on which the mechanic's hand is resting) will be built over part of the Calibrator. At the top can be seen the leveling adapter with its three knobs. This adapter is designed to automatically position T-11 cones in cameras at the center of Collimators.

having entrance pupils equal to, or less than, 1.45″ in diameter. The inclusion of resolution test conditions in equipment designed initially for distortion testing posed problems at all stages of testing. The solution of these problems should be of interest to all photogrammetrists concerned with the Calibration of Cartographic Cameras.

As an introduction to these problems, consider first the tests which will be made on the Fairchild Precision Camera Calibrator, and then the means whereby these tests are to be maintained at an unprejudiced level. As even photogrammetric cameras vary somewhat with specifications, it may be advisable, so that no ambiguity occurs, to discuss in particular the testing and calibration of the new T-11 Cameras.

TESTS FOR CALIBRATION

In the case of the T-11 camera, a minimum of four photographic tests will be made to obtain the data required to calibrate the cone and to certify the performance of the camera. These, in the order of their performance are:

1. *A limiting resolution test of the lens-emulsion system at maximum lens aperture.* This test will evaluate the performance of the lens on Type $\overline{V}$F spectroscopic plates and will be used to determine the equivalent focal length of the lens. (The initial separation of the calibrated focal length markers will be set at the equivalent focal length distance.)
2. *A resolution and distortion test of the machined cone on Type $\overline{V}$F spectroscopic plates.* This test will confirm the optimum focus of the lens based on predetermined resolution standards and will provide data for computation of the 90° condition and the position of the principal point. It will also provide data for the plotting of the distortion curve and for the computation of the calibrated focal length. As a result of this information, all necessary adjustments of the focal plane markers can be made.
3. *Test 3 repeats Test 2 in its entirety, to confirm the accuracy of the calibration, i.e., the positioning of the fiducial markers. The results of this test supply the final calibration information of the camera which accompanies that camera at all times.*

   In order to co-ordinate resolution testing on Type $\overline{V}$F spectroscopic plates, and Aerographic Super $\overline{XX}$ films, it may be desirable to include one extra test in Test 3. By exposing Super Panchro Press plates, which closely approximate Aerographic Super $\overline{XX}$ emulsion in sensitivity range and relative sensitometric response, the gap between resolution on Type $\overline{V}$F plates and on Aerographic film can be bridged.
4. *Test 4 is a test of the final camera, complete and ready for shipment. The emulsion required is Aerographic Super $\overline{XX}$ film to be exposed at full lens aperture and a speed of 1/100 second.*

   This test will evaluate the final working camera under laboratory conditions. The resolution data of this camera test should closely approach that of the cone made on Super Panchro Press plates, significant departures from established values signaling an investigation of the discrepancies.

RESOLUTION TEST CONDITIONS

In order that the resolution values obtained from Test 1 may quantitatively represent the performance of the lens, testing conditions must be unbiased, affecting the resolution results neither favorably nor unfavorably.

The first step in resolution testing in a laboratory is to provide an adequate range of targets. For aerial lenses, these targets must appear to be at an infinite distance, illuminated with light which simulates the light of day. There must be enough targets so that no doubt exists as to variations of resolution with field angle.

COLLIMATOR LENSES

The problem of providing targets at infinity is met by placing reticles having resolution patterns at the focus of collimating lenses, so that light from any one point of the reticle issues from all zones of the collimating lens parallel to the principal ray.

The lens selected for a collimator must be well corrected for spherical and longitudinal chromatic aberrations at an aperture which allows a certain decrease in the effective diameter of the collimating beam, this decrease depending on the angle subtended by the reticle at the collimating lens and the distance the collimating beam travels before it is incident on the lens being tested.

The Fairchild Precision Camera Calibrator was to be designed to test lenses up to 12″ in focal length, having entrance pupils not exceeding 1.45″ in diameter. Also the minimum angle between any two adjacent collimators was selected to be 5°. This knowledge made possible a mathematical investigation of the physical conditions involved, and obtaining a first approximation of the required aperture and focal length of the collimating lenses.

Mechanical considerations then entered the picture. Experience dictated the dimensional requirements of lens cells, collimating tubes and mounting supports; the addition of these dimensions to the tentatively selected lens aperture fixed a final implicit solution for the lens diameters, again either by geometric or mathematical means. The solution of the lens diameters in turn directed the final selection of focal length. The dimensional constants of the lenses, being now completely defined, the lens formula offering the best aberration correction for the purpose could be selected. For this Fairchild requested the assistance of Dr. *Pestrecov* of Bausch & Lomb. The 35 lenses ultimately delivered to Fairchild for use in the Calibrator were first quality achromats, carefully centered and closely matched in focal length.

COLLIMATOR RETICLES

Next to be considered were reticles (Figure 2). If the same reticle were to be used in each collimator, it would be necessary to use two conversion tables for each off-axis image on the photographic plate, because a magnification proportional to the inverse cosine of the incident angle and the inverse cosine squared is effected for the radial and tangential lines respectively when collimators are used as targets. Such a procedure would make the resolution reading of the test plates exceedingly tedious when eight different angles were involved. It therefore seemed expedient to use reticles so corrected that the resolution of any one specified pattern would be the same for all angles.

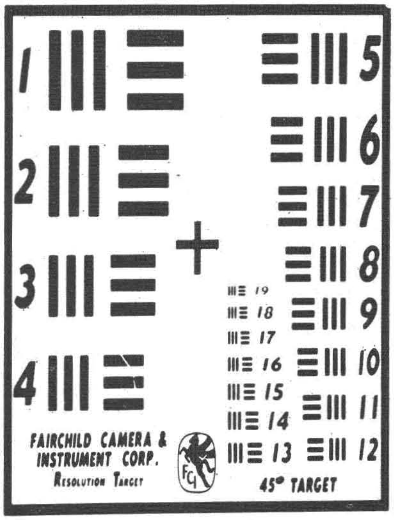

FIG. 2. Reticle for the 45° Collimators showing the cosine and cosine squared correction of pattern dimensions.

Corrections of this type are usually made in original drawings. It was difficult however to obtain resolution drawings of the required accuracy because the time element involved in making the drawings was so large as to be practically prohibitive, particularly in view of the small number of reticles needed. W. & L. E. Gurley Co. offered a photographic solution which was interesting and proved to be adequate. This is how the reticles were made:

A single master target was drawn at such a large scale that the smallest line widths and spacings could be controlled to be better than 1% accuracy. The photographing camera was then set up so that the distance between the camera and the target would effect a reduction of the image to the correct size for the reticle for the central collimator, the target being carefully made perpendicular to the axis of the photographing camera by an auto-collimation method. A highly distortion-corrected lens was used in this camera, and the total full field angle covered was at no time larger than 3°.

For each different angle at which the reticles were to be used, the distance between the photographing camera and the target was increased so that the image size was smaller than that of the central collimator by the ratio of the cosine of the incident angle at which the reticle was to be used. The target was then swung about a vertical angle through the center of the target to effect the cosine square correction of the width and spacing of the vertical lines.

Actually this is a much simplified version of the methods employed because at every step extreme care was taken to control distortion and to obtain the precise angular orientations of the target to the camera axis. Some small distortion in the rectangular form of the patterns was, of course, inevitable, but the final results showed a maximum deviation from the nominal values of less than 2% in all patterns measured. This means that, for a system rated at 50 lines/mm. on the axis, the maximum error in evaluation of the system due to the target would be less than 1 line/mm.—a very acceptable value.

COLLIMATOR LIGHT SOURCE

The next optical component required for the individual collimators was the light source; a light source "white" in composition, of a prescribed color temperature; one having an intensity adequate for testing a finished camera at specified aperture and speed; a light source which could be varied in intensity so that optimum resolution values would be available; and finally, one whose developed heat could be controlled below the point where it could cause differential expansion of the Calibrator—thus subjecting the accuracy of the pointing angles to question.

A series of tests established light intensity requirements at approximately 60 watts tungsten, to meet the speed specifications of the final camera test. All the spectral requirements were met by the tungsten source, but the heat developed during a period of operation equivalent to a production scheduled run, indicated the necessity of providing an extremely efficient heat evacuation system. Consideration of space and design emphasized the complex problems such a system would introduce.

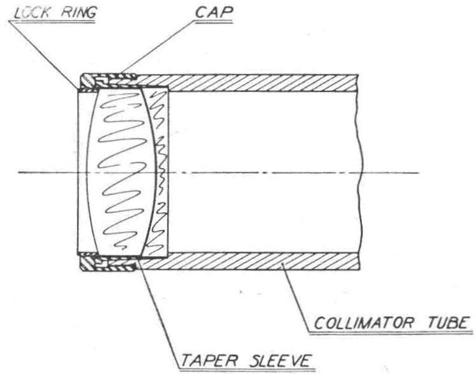

FIG. 3. Taper Sleeve Design for positioning the collimator lens securely, but without stress.

A white, cold cathode fluorescent lamp wound in various forms was therefore tested as a collimator light source. As a result of these tests and of consultation with the Bureau of Standards regarding the spectral quality of the lamp, Fairchild has decided to use a cold cathode, spiral-wound fluorescent, rated at 3,500° K. With this lamp operating at rated voltage, adequate intensity is obtained for optimum density on the film for the camera test. Furthermore, a wide range of intensities for a small change in Kelvin temperature is obtainable with variation in voltage. Only a few air vents suffice to render the heat problem virtually non-existent, while the mounting of the lamps as compared with tungsten lamps is greatly simplified. The 3,000 hour life of the lamp and the controlled output guaranteed by the manufacturer assure a long, trouble-free performance, no mean advantage to production equipment.

The three optical components, lens, reticle and light source, supply the basic requirements of first quality collimators for the resolution testing of a specified range of lenses (Figure 3). The selected components have been carefully handled by Mr. *David Mann* so that their excellent qualities have been retained unimpaired.

DISTORTION TESTING

The assembly of the individual collimators into a rigid bank in the form of cross, with all collimators pointing toward a single center provides the means of testing for distortion (Figure 4). The axis of these collimators has still to be set to angles known to a high degree of accuracy. This will be done using the method of biprisms established by Dr. *Washer*. The accuracy of the pointing, once set, must be dependable, and toward this end infinite care has been expended. The design and the machining have been such that forces have been balanced, and stresses which might ultimately warp any part have been eliminated (Figure 5). Lenses have been mounted free of stress but rigidly, by specially designed retaining rings. The assembly of the unit has been time consuming, as attention has been given to every slightest detail which would affect the ultimate accuracy and stability of the equipment.

MISCELLANEOUS PROBLEMS

But even with adequate collimators at known angles, a few more problems remained.

When a number of light beams of known cross-sectional area are directed from different angles toward a single point, there is a limited and well-defined space from which all beams are available. Any lens being tested for resolution must be so positioned with respect to this space, called the center of collimators, that the light rays which pass through its entrance pupil are a maximum. It is therefore necessary to know the extent of this space and to be able to locate it physically. It is also necessary to have enough design information from the lens manufacturer so that a physical reference point on the lens mount can be used for positioning the lens at optimum location. This information must be known for every lens tested.

In the case of the 6″ Metrogon lens, both the lens-focusing test fixture and all the camera cones were designed with locating slots which positioned the lens laterally with respect to the axis of the central collimator. The movement of the cones and focusing cone, parallel to the axis of the central collimator, was then controlled by stops on the leveling adaptor, making it necessary to accomplish all leveling within a full range of 1/16″ movement parallel to the central lens axis. The nominal position of the cone on the leveling adaptor then automatically located the entrance pupil of the lens with respect to the center of collimators within the above limits. This was sufficient for the cones and cameras whose flange focal distances are machined, but not the focusing cone which must accommodate a specified range of focal lengths. This range was made available by moving the focal plane while the lens was maintained at its initial position, parallelism of focal plane and rear lens flange seating surface being held to .0005″ in 14″ for any position of the focal plane.

In the final analysis of the designing and building of this unit, no smallest detail was neglected. There were many too dull to be mentioned here; others deserve brief mention. Among the latter were: the location of the diaphragms in the collimator tubes; the method of moving the reticles and holding them fixed; the first aligning of the collimators as mechanical units; the design of the auto collimating telescope and its reticle; the mounting of this telescope, and the necessity for swiveling it.

The Calibrator will be mounted on a huge five ton base which will isolate the equipment to a natural frequency not exceeding 80 cycles/min. [This base which was specially designed by Jayburn Engineering.] In addition to its isolation requirement, it meets one special requirement which Fairchild must impose on all equipment; it must be movable. For this reason the base was made in two parts, symmetrical with respect to the line which joins these parts. The photo taken before the cement was poured shows the supporting members, and gives an idea of the construction.

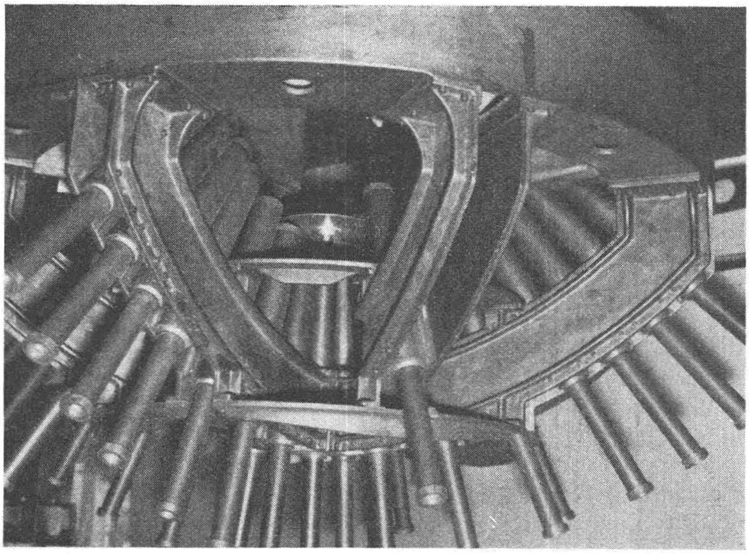

FIG. 4. Large Ring with Collimators, Inverted: The basic design of the Calibrator can clearly be seen. The center Collimator casting acts as the bearing surface for the four arms and is therefore perfectly square. All Collimators have been scraped so their bearing surfaces and the distance between these surfaces is the same. The holes for the bolts which position the collimators were set up with a jig, the jig positions being calculated and then physically set with a tangent arrangement.

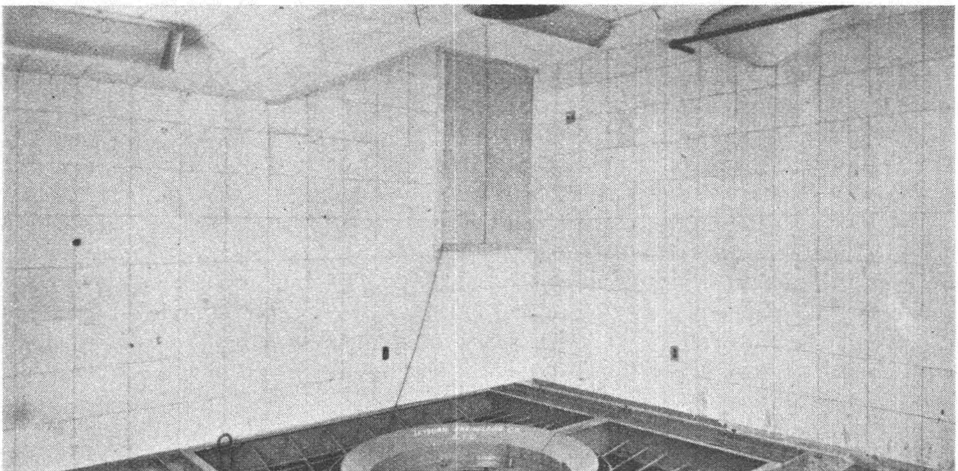

FIG. 5. Vibration Isolation Base, 9′×11′ showing the welded construction (prior to pouring cement). The Calibrator base bolts to the center ring. Six 10″×23″ vibro isolators, each having 16 heavy off-set springs, will float the six-ton assembly of Calibrator and base.

With the Calibrator mounted on this base, it is believed that tests can be conducted at all times and that resolution testing even for research purposes (if such need should arise) should be practically unlimited, even using high resolution spectroscopic plates.

A specially built air-conditioned room, with temperature controlled from that room, will house all the calibration equipment. Cameras and cones coming into the room for testing will be brought in a full day prior to testing or calibrating. The setting, pinning and doweling of the fiducials will all be done in the same temperature controlled section.

Although this equipment was built for production work Fairchild believes that the quality is such that if at any time the need arises, it can be used as a reliable research tool.

The success which we are now in position to predict for the Fairchild Calibration project will be largely due to collaboration between men prominent in the field of photogrammetry and the Fairchild personnel. There are many who have contributed generously of their time and knowledge, but in particular the authors would like to express their appreciation of the constant interest and encouragement in addition to substantial aid offered by Drs. *Irvine C. Gardner* and *Francis E. Washer* of the National Bureau of Standards and Dr. *L. E. Howlett* of the Canadian Research Council.

At Fairchilds, Mr. *Irving Doyle*, Engineer in Charge, has guided the project, making available his many long years of experience in the field of aerial cameras.

THE STUDY OF SIZE AND SHAPE BY MEANS OF STEREOSCOPIC ELECTRON MICROGRAPHY*

Chester J. Calbick, Member of Technical Staff, Bell Telephone Laboratories, Murray Hill, N.J.

IT IS with some trepidation that a microscopist presumes to address a Society such as yours which is concerned basically with the *measurement* of photographic records; he realizes, and a very brief perusal of a few articles in the current magazines quickly confirms, the fact that a microscopist usually is concerned with qualitative aspects of the pictures he takes. True, he wants to know as accurately as possible the magnification or scale of his microgram, and there are a few cases such as measurement of particle size histograms where detailed measurements are the principal purpose. But in the great majority of cases, he is interested in observing characteristic features of the material depicted in the micrographs. For example, a biologist observes in electron micrographs that certain fibers in connective tissue exhibit a periodic substructure; or a metallurgist observes in optical or electron micrographs certain tree-like markings which he calls dendrites. These observations are analogous to and may be compared with such common observations as that a freshly plowed field exhibits furrows, or that a river system consists of a river with large numbers of branching tributaries. Usually, what the microscopist would like to find out is the cause of these characteristic features, and he is only secondarily concerned with detailed measurement.

* Paper read at Semi-Annual Meeting of the Society, Institute of Geographical Exploration, Cambridge, Mass., September 21 and 22, 1950.