N 69 27911

N69-27911

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

NASA CR-101363

CASE FILE COPY

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

Prepared by the Geological Survey for the National Aeronautics and Space Administration

INTERAGENCY REPORT: ASTROGEOLOGY 15

PHOTOGRAMMETRIC CALIBRATION OF APOLLO FILM CAMERAS

by

W. T. Borgeson and R. M. Batson

March 1969

Prepared under NASA Contract No. T65253G

CONTENTS

Page

Abstract 1

Introduction 1

Calibration data 3

Calibration equipment 4

Detailed calibration procedures 10

ILLUSTRATIONS

Figure 1. The U.S. Geological Survey multicollimator. . . . 5

2. A pair of collimator banks and central collimator 6

3. Individual collimator target image. 7

4. The array of collimator targets which are imaged by a wide-angle aerial camera 7

5. Auto-collimator used for calibrating Apollo Hasselblads 11

6. Alining an aerial camera on the calibrator. . . . 12

PHOTOGRAMMETRIC CALIBRATION OF APOLLO FILM CAMERAS*

By

W. T. Borgeson and R. M. Batson

ABSTRACT

Pictures taken by calibrated hand-held Apollo cameras can be used to make accurate three-dimensional optical or physical models of the lunar surface. Detailed procedures have been developed for photogrammetric calibration of Apollo Hasselblad cameras and the Lunar Geologic Exploration Camera (LGEC). The processes are similar to those used to calibrate aerial mapping cameras. The camera, mounted on a specially built calibrating instrument, takes pictures on sensitized glass plates. The processed plates contain all the data required for computing (1) the location of the optimum center of perspective of the camera with respect to its film plane, (2) the location of the principal point on the film plane, and (3) the lens distortion system. The orientation and location of one stereometric camera relative to another are determined by using the camera system to take stereoscopic pictures of a precisely drafted grid.

INTRODUCTION

Stereoscopic photographs can be used to create an accurate optical reproduction, or "model," of a surface if the geometry of the camera has been carefully calibrated. The details of a stereoscopic model of the lunar surface can be studied qualitatively and quantitatively with more convenience and, from a practical standpoint, more accuracy, than can the real terrain.

The picture-taking process is a projective or "perspective point" transformation of an array of points in three-dimensional object space into an array of points in two-dimensional image space.

If two pictures of the same scene are taken from different points of perspective, the transformation can be reversed, and

---

*Prepared for the National Aeronautics and Space Administration under Contract No. T65253G.

the three-dimensional object space can be recreated by an analog process akin to triangulation.

A perfect lens would produce a picture in which each image point obeys the "collineation principle": each image point, its conjugate object point, and the center of perspective lie on a mathematically straight line. A real lens, however, bends this line slightly, resulting in a distorted picture. When a stereoscopic model of the original scene is created, its geometric fidelity depends upon the accuracy with which the original object-space rays have been regenerated. These rays can be regenerated from picture images if the following are known: (1) Orientation of the camera in object space at the time the picture was taken, (2) location of the camera in object space at the time the picture was taken, (3) location of the perspective center of the camera with respect to its image plane, and (4) magnitude and direction of the camera lens distortion. Items 1 and 2 vary with each picture taken. They are computed by various photogrammetric methods, which will not be discussed here. In single cameras acceptable for photogrammetry, however, items 3 and 4 are invariable within each camera and can therefore be determined through photogrammetric calibrations. In stereometric* systems, items 1 and 2 for one of the cameras are invariable with respect to the other, and can also be determined through calibration. The orientation of the stereoscopic model is determined by other methods not discussed here.

Original plans called for a Hasselblad camera with a 38 mm Biogon lens for use on the lunar surface on the first few Apollo landings. The calibration procedures were developed through tests made with such a camera. Although present plans call for use of a Hasselblad with a 60 mm lens, and later for use of the specially designed "Lunar Geological Exploration Camera" (LGEC), no major changes in calibration procedures are anticipated.

---

*Stereometric systems consist of two or more cameras rigidly mounted to each other with which stereoscopic pictures are taken simultaneously.

CALIBRATION DATA

The following parameters must be determined by photogrammetric calibration:

1. Fiducial or reseau mark locations--These define the camera coordinate system, and must, therefore, be so fixed to the camera body as to be absolutely immovable with respect to the lens, and located so that they are clearly imaged on each picture taken by the camera.

2. "Principal point" location on the image plane with reference to the fiducial marks--The principal point is defined as the intersection with the film plane of a line perpendicular to that plane which passes through the perspective center of the camera.

3. Camera "principal distance"--This is the distance between the center of perspective of the camera and the principal point. In the special case of a camera focused on infinity, the principal distance is equivalent to the "calibrated focal length."

4. The magnitudes and directions of lens distortions--Radial distortion is the radial distance between the theoretical, undistorted position and the actual position of an image point. This kind of distortion is present in all lenses to a greater or lesser degree. It can be reduced only by increasing the complexity of the optical design. The locus of points of equal distortion on the image plane is circular about the principal point. If this locus is not circular, asymmetric radial distortion exists. Tangential distortion is the difference between a theoretical and an actual image location in a direction on the image plane that is perpendicular to the line between the principal point and the theoretical image location. Tangential and asymmetric radial distortion are caused by manufacturing errors in assembly of the lens elements and have only second- or third-order effects on overall distortion in modern high-quality lenses.

5. Stereometric camera relative orientation--This includes determining the orientation of one camera system with respect to

the other, and measuring the separation between the perspective centers of the cameras.

The perspective center of a camera is a mathematical rather than physical property. For a real lens, the image is an approximation of a perspective projection. The real picture can be considered to be a rigorous perspective projection with respect to an assigned perspective center modified by a field of displacements (optical distortions) in the picture plane. The distortions are definitive and determinate only when the position of the perspective center is specified. The perspective center in any camera can be so defined that distortion is zero at a given point in the picture. The calibrations specified in this document are sufficient to collect data from which the location of the perspective center of a camera can be selected so that distortion in the plane defined by the fiducial marks is at a minimum.

CALIBRATION EQUIPMENT

A photographic procedure is used for photogrammetric calibration. The calibration elements are derived from a mathematical comparison of (1) the measured coordinates of an array of image points on one or more glass plate negatives, and (2) the theoretical coordinates which would be imaged by a perfect camera. The U.S. Geological Survey multicollimator camera calibrator (fig. 1) provides an array of points of suitable for photography. It was designed for calibrating and checking precision cartographic cameras. Similar systems are used by the National Bureau of Standards and by Fairchild Camera and Instrument Corp.

The camera calibrator (figs. 1 and 2) consists of 41 collimators, a camera platform, and post-mounted, auto-collimating telescope with movable cross hairs. Each collimator has a 0.6 m focal length lens with a resolution target and center cross (fig. 3) set in its focal plane and focused at infinity. The collimators are arranged in four minor banks of three collimators each, four major banks (semidiagonals) of seven each, and one central collimator, the axis of which defines the system axis. Figure 2 shows

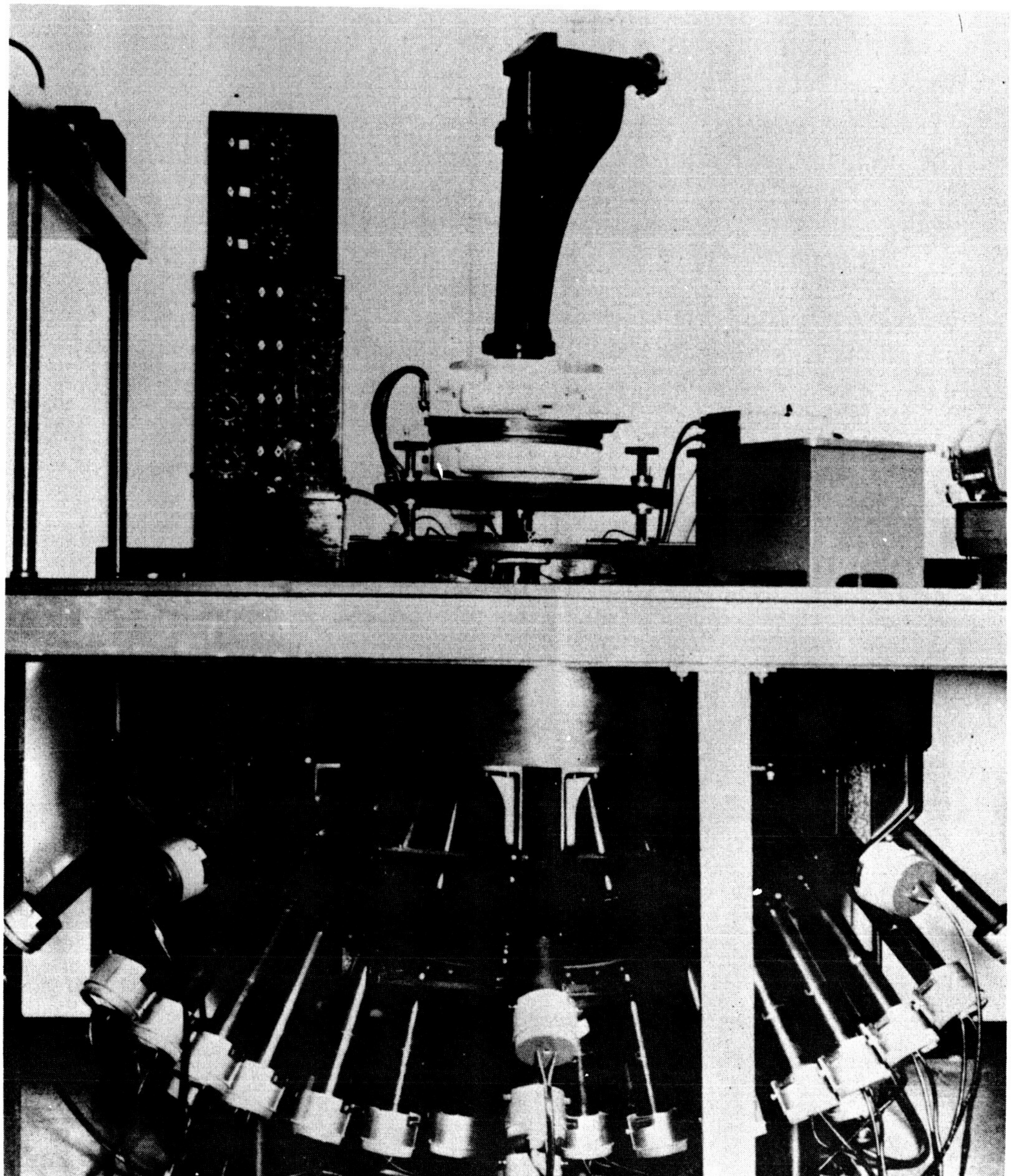

Figure 1.--The U.S. Geological Survey multicollimator (Topographic Div., McLean, Va.).

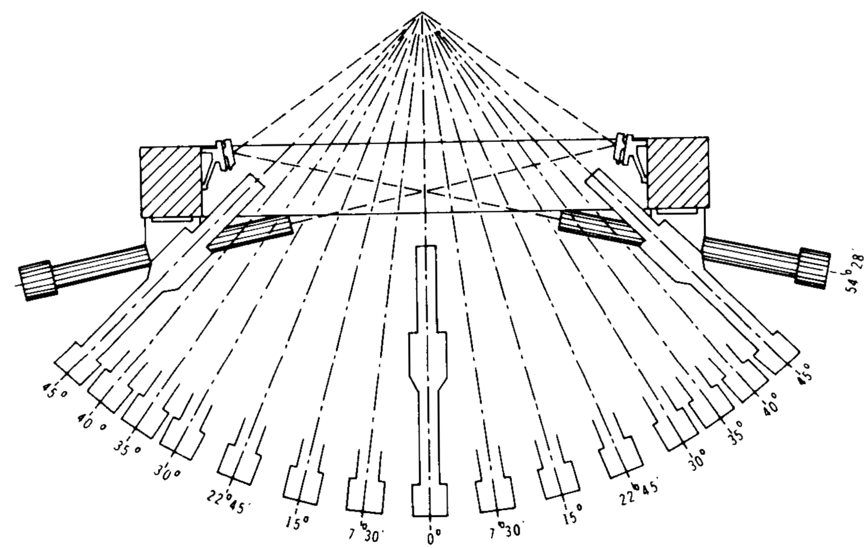

Figure 2.--A pair of major collimator banks and central collimator.

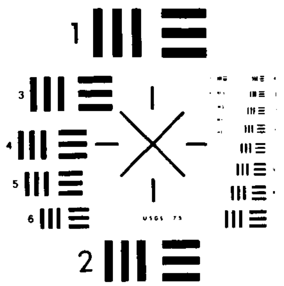

Figure 3.--Individual collimator target image.

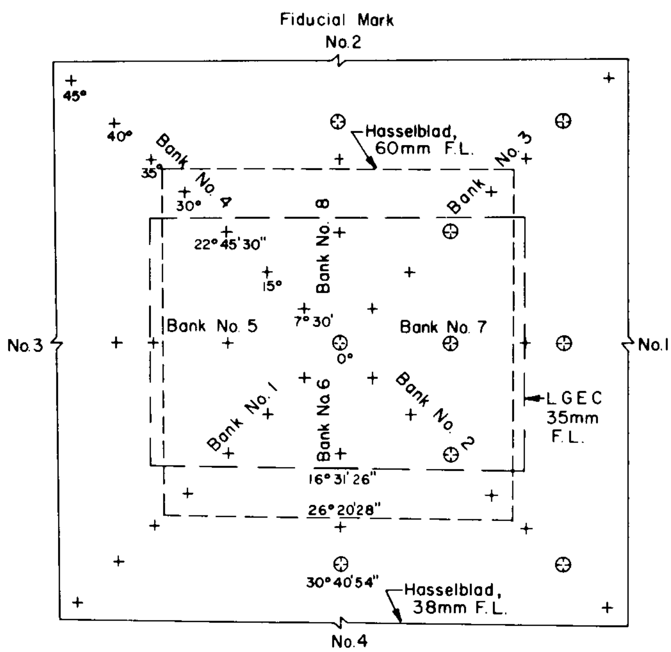

Figure 4.--The array of collimator targets which are imaged by a wide-angle aerial camera. The collimator bank and fiducial mark numbering conventions shown here are the ones used in calibration data reduction programs. The configuration shown is that viewed on the film plane from above. The dashed lines show the collimator format that would appear on plates taken by a Hasselblad with a 60-mm focal length lens, and by the wide angle LGEC lenses. The Hasselblad with the 38-mm focal length lens would cover the same field as a conventional aerial camera.

two major banks and the central collimator. The two end collimators employing mirrors are used with a 120° field of view camera. The number of collimator images appearing on calibration plates depends on the field of view of the camera being calibrated.

The collimator targets are imaged by a wide-angle camera as shown in figure 4. The numbers refer to the nominal collimator pointing angles with respect to the central collimator. The actual angles differ from the nominal values by a few seconds of arc. Fiducial marks are numbered as shown in figure 4. With the camera hand held and pointed horizontally, fiducial mark 1 is at the right, and 2 is at the top. Similar numbering conventions are used for reseau grids.

Special equipment must be used with the standard equipment discussed above to accommodate Apollo cameras. The Hasselblad and the Lunar Geological Exploration Camera (LGEC) are smaller and are configured differently than aerial cameras, so a special mount must be used to hold the camera rigidly in position on the camera platform. Such a mount was built and tested with an Apollo Hasselblad with a 38-mm Biogon lens, which was to have been used on the first few landings, to allow manipulation of all controls while the camera is in the mount. It is fastened to a heavy mounting ring which can be rotated about a vertical axis.

A different mount must be used to accommodate the LGEC, which is really three cameras rigidly mounted to each other, each of which must be calibrated separately. The two wide-angle stereometric cameras are calibrated on the camera calibrator, necessitating design of a mount which will hold the LGEC firmly on the camera platform with either of the wide-angle lenses in place over the collimator array. The third lens of the LGEC is a narrow-angle lens, the internal geometry of which is calibrated by mathematical comparison of images in a natural scene appearing both on the telephoto pictures and on the previously calibrated stereometric pictures. Thus, no special equipment or procedures are necessary for calibrating the telephoto camera.

The Hasselblad magazine blocks the view of the focal plane when the camera is on the calibrator; thus, camera and magazine must be calibrated as a unit. A special auto-collimating system was devised for this purpose. It consists of a carrier which is clamped firmly to the lower stage of the calibrator and has openings to allow a moderate amount of adjustment of the upper stage carrying the camera and a broken-axis auto-collimator to mount on the carrier (fig. 5). One end of the auto-collimator holds a prism which deflects the sight line downward; at the other end is an improvised Gauss eyepiece consisting of a 60X microscope with a polished metal illuminating mirror, a small 3 volt light bulb, and a machined holder to screw onto the back end of the auto-collimator telescope. When the carrier is clamped in position, the prism end of the auto-collimator is inside the magazine of the Hasselblad and looks down on the plane-parallel plate on the camera film plane.

Unlike conventional mapping cameras, which are set at infinity focus, the Apollo cameras will be used at several discrete, detented focus settings. The Hasselblad can be calibrated at the infinity focus setting, and then the change in lens-to-image plane distance in switching from an infinity setting to a finite distance setting can be measured. The principal distance for infinite focus settings would be determined by adding the measured changes to the photographically determined calibrated focal length. It is unlikely, however, that these principal distance values will be consistent with optimum radial distortion curves. Therefore, even though the targets are not sharply imaged, a set of calibration plates is made for each focus setting. Poor image quality caused by incorrect focus settings does not materially affect the accuracy with which the calibration plates can be measured. It is nearly as easy to find the intersection of the arms of a blurred cross as a sharp one. In any case, any problem of this sort that may arise can be alleviated by using small aperture settings and long exposures to increase the depth of field of the camera.

DETAILED CALIBRATION PROCEDURES

1. Determination of optimum plate exposure--Determination of plate exposure values for optimum image clarity is done with engineering model cameras to avoid unnecessary handling of the flight cameras. Individual transformer settings on the collimators, and optimum iris settings and exposure times, are determined by experimentation with sensitized plates. Any special illumination requirements, such as auxiliary lighting of fiducial marks or reseau marks, are determined during this phase.

2. Auto-collimating telescope alinement--If the film plane on the camera to be calibrated is accessible, the cross hairs of the broken-axis auto-collimating telescope (fig. 1) are brought into alinement with the target cross hairs of the central collimator.

In the case of the Hasselblad, the special auto-collimating device described previously (fig. 5) must be used. The carrier is clamped in place on the lower stage, the auto-collimator is positioned on the carrier, the power to the light bulb is turned on, and the footscrews are manipulated to center the cross hairs on the center collimator cross. The friction screws are then tightened. If necessary, the prism holder may be rotated by loosening one and tightening the other of two small hex-drive set screws near the front end of the prism-holder housing.

3. Camera alinement--If the film plane on the camera to be calibrated is accessible, as is the case with the LGEC, the camera, without its magazine, is placed on its mount. The film plane of the Hasselblad, on the other hand, is inside the magazine. This camera must therefore be placed on its mount with a magazine in place, but with the film transport removed.

The iris is set at the value determined during optimum plate exposure calibration, the focus set at infinity, and the shutter either removed or set on "bulb." The camera, on its mount, is then bolted to the heavy mounting disk, and the entire assembly is

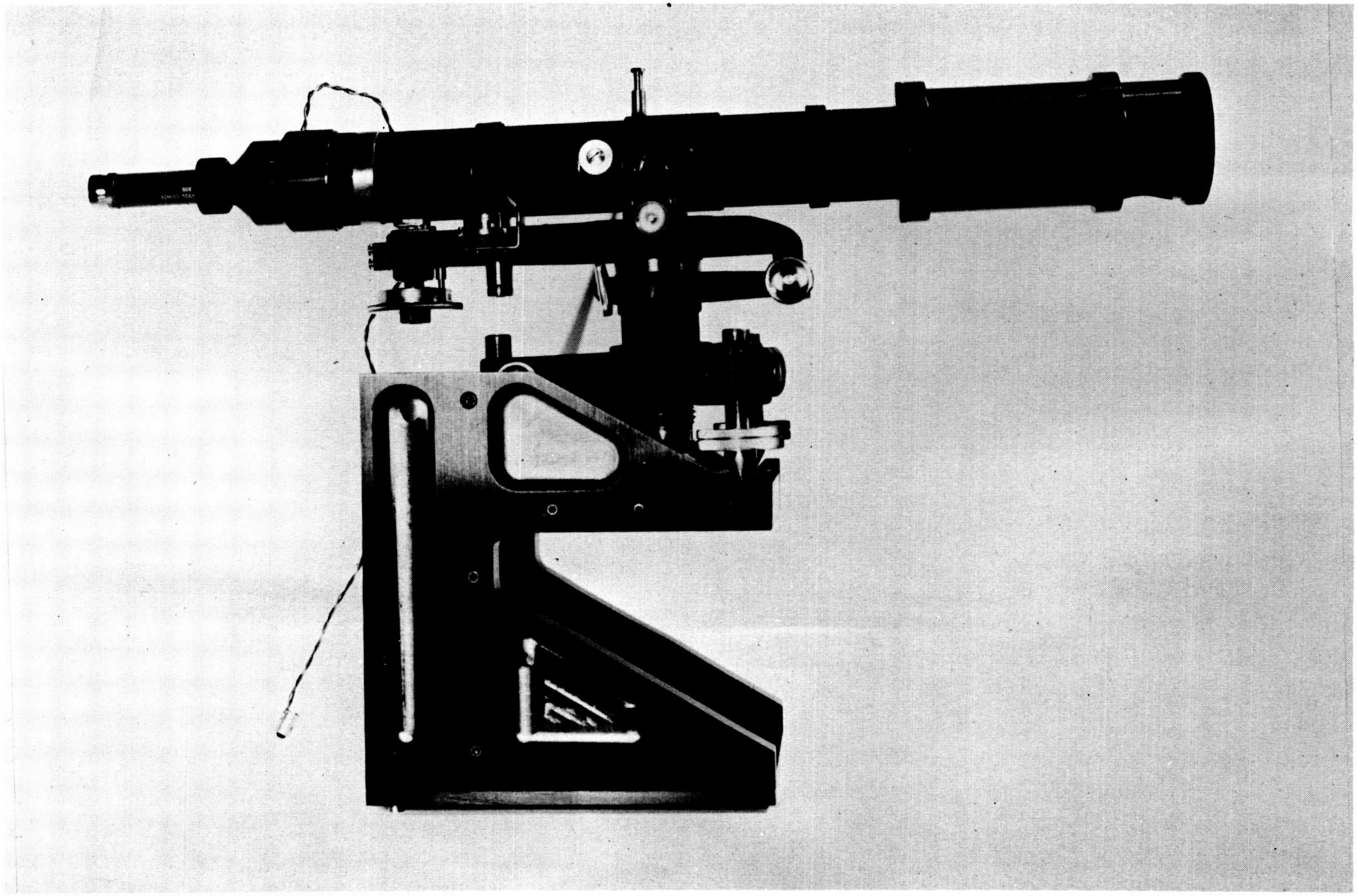

Figure 5.--Auto-collimator used for calibrating Apollo Hasselblads. This device must be used because the Hasselblad film plane cannot be viewed from above when the camera is in place on the calibrator. The larger end of the auto-collimator contains a prism, which permits a vertical view of the film plane when inserted in the side of the magazine.

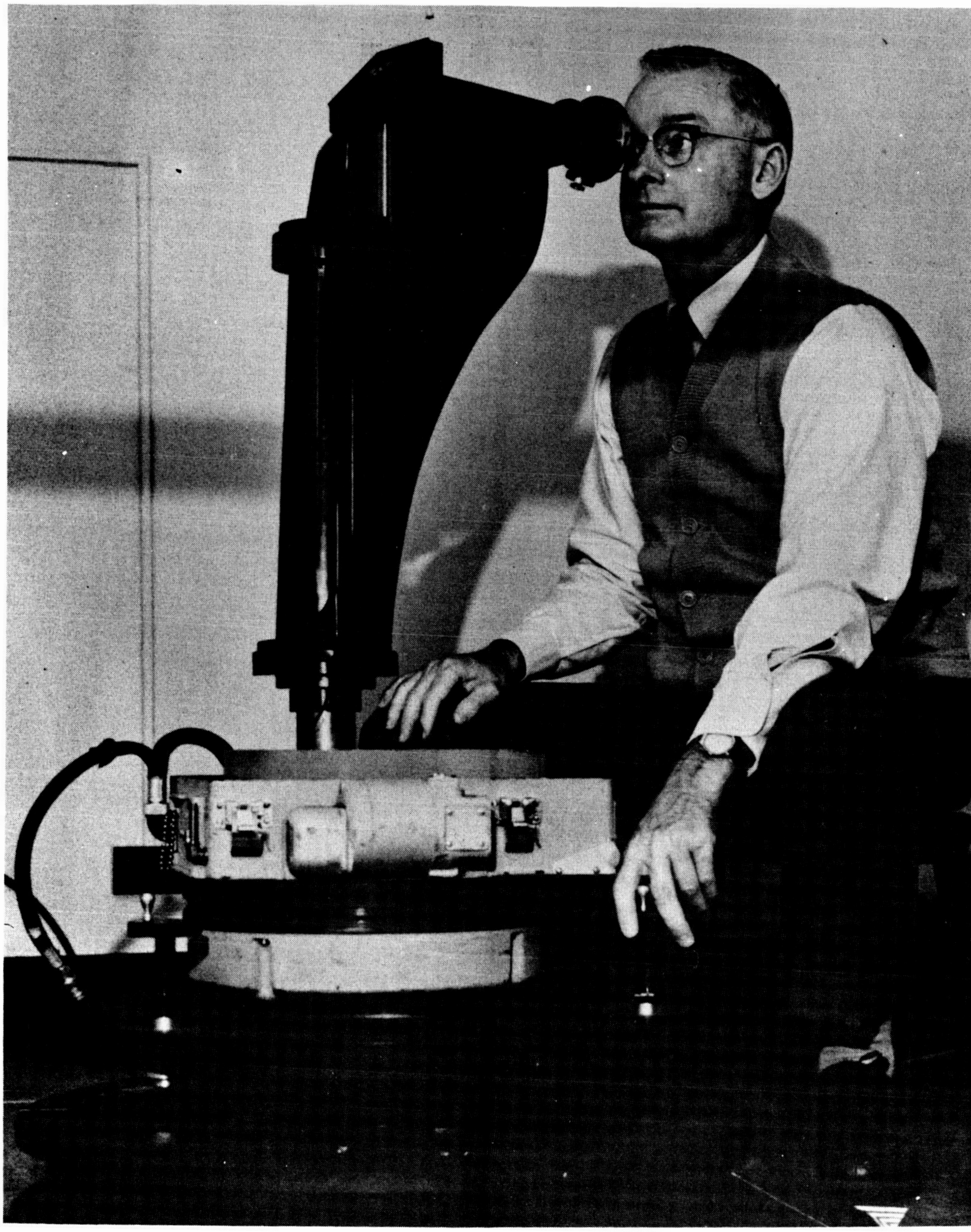

Figure 6.--Alining an aerial camera on the calibrator. The hand screws on either side of the camera platform are used for orientation. Apollo film cameras are mounted in special mounts, but are oriented on the calibrator in a similar manner.

slipped into place on the calibrator, taking care not to disturb the previously adjusted auto-collimator.

A silvered plane-parallel glass plate, with mirror surface up, is placed on the film plane. Again, caution must be used to avoid disturbing the auto-collimator. The three camera stage footscrews are then manipulated, while observing the illuminated auto-collimator reticle by means of the eyepiece microscope, until auto-collimation is achieved (fig. 6).

4. Plate exposure--The camera shutter is closed, or a capping shutter is put in place, and the room lights are turned off. The plane parallel plate is removed from the film plane and replaced by a sensitized glass plate. The plate is exposed, either by operating the camera shutter or by removing the capping shutter, according to the optimum plate exposure determined in step 1.

The plate is then removed from the film plane and processed by standard photographic techniques.

5. Data Reduction--The x-y coordinates of the collimator images and the images of reseau or fiducial marks on the photographic plates are measured with a precision comparator with a 1 micron least count. Data are punched on cards and computer processed to determine principal distance, principal point, and distortion parameters. The details of the data reduction are beyond the scope of this report.

Glass plates acquired through the above procedure contain all the data needed for computing the required internal photogrammetric calibration parameters for a given focus setting. The entire procedure must be repeated for each focus step to be used. Small systematic errors are statistically reduced by repeating the calibration after rotating the camera around its optical axis approximately 45°. This is done eight times, resulting in the collection of eight calibration plates for each focus setting with the image of the collimator array in eight different orientations with respect to the reseau or fiducial mark pattern on the camera.

6. Relative Orientation of Stereometric Cameras--The camera system is mounted firmly with its optical axes roughly perpendicular to a precisely drawn rectangular grid, and approximately 1.5 meters from the grid. The grid itself is 1.1 m wide and 1.6 m long, with rulings every 0.1 m. The camera aperture is set at f/22, the focus on its near-field setting, and glass plates are exposed simultaneously on each camera. The camera system is rotated 45° and another set of plates is exposed. The process is repeated until eight sets of plates have been made.

The process is repeated for each available focus setting. This procedure is designed specifically for the LGEC.

The relative orientation of other stereometric cameras is calibrated by the same procedure, but different numerical values are used depending on the camera system.