was measured three times, using a Mann Comparator previously calibrated to an accuracy of ±3 microns. The accepted taut wire procedure of checking the tangential distortion on one plate exposed at zero and 180 degree positions was used. Two plates were exposed at ratios of 1:1 and 1.53:1. Measurements of relative position were made at 20 millimeter intervals along the image of the wire. The resolution was checked using a standard Air Force resolution-target at the ratios of 1:1.53, 1:1, and 1.53:1. The determinations were made at the scale of the exposed plate.

The Type *A* printers met the contract specifications pertaining to general requirements, tangential-distortion, resolution, reduction-ratios, compensating-plates and distortion-free quality of the projection-lens. At 1:1 ratio, the root mean square errors of the distortion-free exposures for the two printers were 6 microns and 3 microns, respectively. The root mean square errors of residual radial-distortion using the various compensating plates ranged between 4.4 and 7.3 microns.

This paper concerns solely AMS procurement and testing of the Wild U-3 Printer. It should not be considered as an endorsement of the Wild Company approach as superior to that of other photogrammetric instrument manufacturing concerns.

Although only a limited amount of production has thus far been completed using the Type *A* printer, the availability of universal type transformation printers is expected to be of distinct advantage to Army Map Service and any other agency responsible for processing a wide variety of aerial photography for the purpose of using it in the plotting instrument that is best suited to obtain maximum efficiency for a specific task.

*Calibration of Airplane Cameras**

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A THOROUGHGOING analysis of random errors that affect the accurate calibration of airplane cameras has just been completed[1] Experiments conducted in the course of the investigation showed that various methods may be employed to eliminate the errors when they become apparent. The work, sponsored in part by the U. S. Air Force, should improve the procedures for testing camera-lens combinations used in aerial photography. One conclusion drawn from the study is that cameras showing an excessive amount of prism effect should not be used for precise photogrammetric mapping.

The purpose of airplane camera calibration is to obtain accurate values of the scale factor used in map interpretation. As airplanes and cameras have improved, requirements placed on lenses have become more stringent. To achieve the required accuracy of camera calibration, testing laboratories have steadily advanced in their techniques. With this advancement, two principal methods of calibration, the visual and the photographic, have evolved; and the latter method is principally employed at the Bureau.

Shortly after World War I, Government agencies started to submit cameras to the Bureau for calibration. At first, visual optical benches, were used with good results. Later, a precision lens testing cam-

[1] For further technical information, see the following papers: Effect of camera tipping on the location of the principal point, *J. Research NBS*, 57, 31 (1956) RP 2691; Sources of error in various methods of airplane camera calibration, PHOTOGRAMMETRIC ENGINEERING, 22, 727 (1956); A simplified method of locating the point of symmetry, *ibid.*, 23, 75 (1957); The effect of prism on the location of the principal point, *ibid.*, 23, 520 (1957); Prism effect, camera tipping, and tangential distortion, *ibid.*, 23, 721 (1957).

* Summary Technical Report 2161, National Bureau of Standards, U. S. Department of Commerce.

era[2] was developed and employed. But as exacting requirements and work volume grew, more precise, easier-to-operate equipment was needed; and in 1949 a camera calibrator was designed which met these demands.[3]

Heart of the instrument is a bank of 25 collimators arranged in the form of a cross and suspended from a table with a central circular opening. The collimators provide distant targets for the camera, which is mounted above the circular opening of the table to undergo test. With the increase in knowledge derived from calibrations made with the new equipment, various factors were recognized which affected the accuracy of the results obtained. The present study was proposed to pinpoint these factors, show their relationship to each other, and develop methods, where possible to overcome them.

Investigations disclosed that among the principal sources of error are those inherent in measuring techniques. These include errors in angle measurement and errors in linear scale on the test negative. In addition, errors were found to result from curvature of the plates used in making the test negative.

Asymmetric distortion is introduced into a lens-camera combination when the camera is incorrectly aligned for calibration—in other words, when the camera is "tipped." Experiments were conducted to determine the effect of camera tipping on the displacement of the central image of a distant object from the original position of the principal point of autocollimation (also known as the "center cross"). Methods were found for accurately determining the magnitude of the angle of camera tipping for both equal and unequal opposite angles. Thus, the principal point of autocollimation can be computed from the measured values of distortion. It was shown that in the absence of prism effect, the "point of symmetry" is identical with the principal point of autocollimation.

[2] Specifications for a precision-mapping camera, NBS *Tech. News Bul.* No. 256, 71 (1938); Precision camera for testing lenses by Irvine C. Gardner and Frank A. Case, *J. Research NBS*, 449 (1937) RP 984.

[3] New precision camera calibrator, *NBS Tech. News Bul.*, 33, 8 (January 1949); Calibration of precision airplane mapping cameras, by Francis E. Washer and Frank A. Case, *J. Research NBS*, 45, 1 (1950) RP 2108, and PHOTOGRAMMETRIC ENGINEERING, 16, 502 (1950).

A detailed study was made of prism effect. In the cameras calibrated at the Bureau during the past 20 years, no instance occurred in which the asymmetric part of the observed distortion pattern could not in large measure be attributed to a simple thin prism. Usually a small residual distortion remained which was not fully accounted for; such distortion, though, is negligibly small when compared to the initial values of the asymmetric distortion. The effect of a thin prism in the optical path can be produced by placing a filter with non-parallel surfaces in front of the lens. This effect can also be produced by small lens decentrations. The results are similar to those produced by camera tipping.

Prism effect as related to the principal point was investigated. The term "principal point" in photogrammetry refers to the point of intersection of a perpendicular dropped from the interior perspective center of the camera to the plane of the photograph. When a camera under calibration is so aligned that the focal plane of the camera is normal to the line which joins the front nodal point of the lens to a distant object, the central image of the distant object is located at the principal point of autocollimation. If asymmetric values of distortion are then found, the principal point does not coincide with the principal point of autocollimation and, in addition, prism effect is present.

It is generally accepted that both radial asymmetric distortion and tangential distortion may be caused by prism effect although some questions persist regarding the relative magnitudes. In an experiment with a 5.00 diopter prism placed in front of the lens, it was found that radial asymmetric distortion is the larger of the two.

An analysis was made of the errors resulting from curvature of the plates used in making the test negative. A striking reduction in the errors was noted with increasing thickness of the photographic plates. It was shown that the thicker plates are less likely to warp or depart from their initial state of planeness.

Recognition of the factors outlined above is the first step in eliminating sources of error inherent in airplane camera calibration. The methods developed by the Bureau for overcoming these factors should prove of considerable benefit to testing laboratories charged with certifying the accuracy of camera-lees combinations.