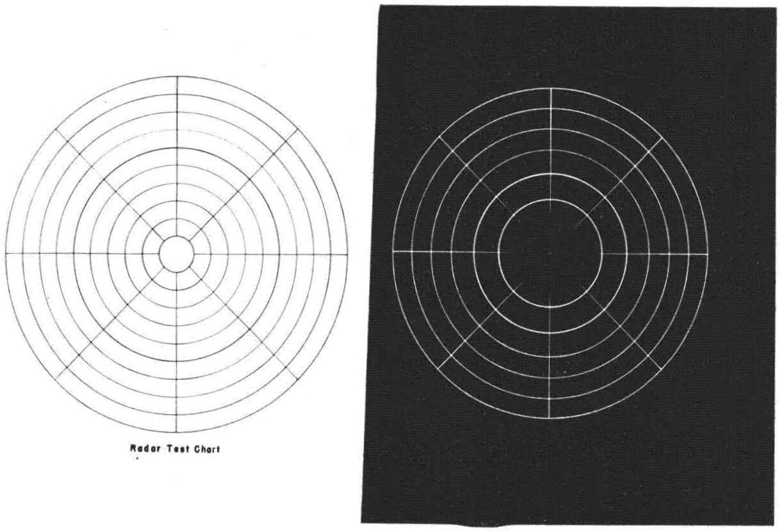

FIG. 13. Simultaneous correction for slant range, sweep delay and aircraft motion at .4, .2, and .01 of range respectively. At left—Test pattern. At right—Corrected Test pattern.

tortions and with the use of an adjustable curved mirror which is interchangeable with a plane mirror, and with the assumption that the distortions are known, the rectification can be made.

The restitutor is a promising instrument for correcting *PPI* presentations. It embodies novel and effective principles. However it should be considered as a future item of equipment until such time as suitable *PPI* radar photography for mapping is available.

*The Wild U-3 Printer**

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ABSTRACT: *The need for a photographic printer at Army Map Service, capable of processing heterogeneous photography from a variety of sources, is specified. A description of the basic approach to the problem resulting in the three printer categories, Types A, B, and C is given. The manufacturing tolerances are cited and the acceptance test procedure is outlined. Available test results and conclusions are presented.*

THE world-wide scope of the operations of an agency such as the Army Map Service necessitates the handling of photography from a variety of sources. This photography is distinguished by a wide diversity of focal lengths, format sizes and radial distortion characteristics. For satisfactory use in stereo-plotting equipment, this material often requires geometrical change and either introduction or removal of predetermined distortion.

Until recently, the printers available to Army Map Service either were designed to correct only for a fixed reduction ratio,

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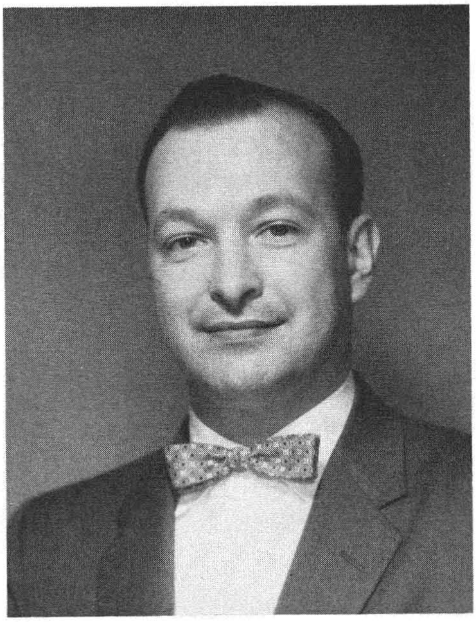

ROBERT A. PENNEY

or where several ratios were supplied, were limited in their distortion compensation ability. A universal printer was required which would be capable of enlarging or reducing images from glass or film positives or diapositives, while at the same time compensating the various lens distortions and providing the proper geometric transformation. The bulk of heterogeneous photography available necessitated a transformation range from a 1.62 enlargement to a 5.5 reduction of the original negative. To permit processing of all photography in this range, three printers were procured: the Wild U-3 Type A, Type B, and Type C.

The Type *A* printer (Figure 1) provides a transformation range from a 2.06 reduction to a 1.62 enlargement of the original negative. This accommodates photography having principal distances ranging from 97 to 210 millimeters. The optical axis is vertical, and the projection takes place from bottom to top. The Type *A* consists of three main components: base, dome, and lens head.

The base section supports the dome section and contains the film holders and light source. Illumination is provided by a 100 watt mercury fluorescent lamp. Sufficient space has been allowed in the base to permit the insertion of a multiple bank of lights in order to more efficiently dodge the negatives.

The dome section contains a 200 millimeter focal-length, optically distortion-free lens, aspheric corrector-plate, two film pressure-plates, electrical timer, diffusion glass plate, and lens-positioning scale. When using glass plate and cut film negatives, the lower pressure-plate may be removed and the material held in position by clamps on the upper pressure-plate. For use with various types of photography, four separate pressure-plates are provided. These contain fiducial marks for orienting photographs having 9×9 inch, 18×18 centimeter, 14×14 centimeter and 11.5 ×16.5 centimeter format sizes. Timing can be handled in intervals of 1 second or 0.1 second.

The lens head contains the glass image stage plate, a folding mirror, ground glass viewing-plate, and magnifying glass arrangement to aid in the alignment of the fiducial marks, and the image stage positioning scale.

Concerning the photography to be transformed in the Type *A* printer, Table I shows each type of photography introduced into the system and the material obtained as a result of processing. Those in Group I require a change from a specific distortion pattern to distortion-free. Those

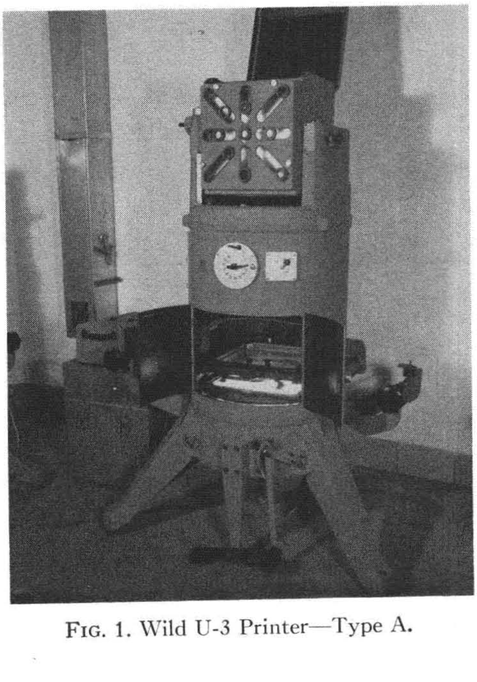

FIG. 1. Wild U-3 Printer—Type A.

TABLE I

PHOTOGRAPHY ACCOMMODATED BY AMS WILD U-3 PRINTER—TYPE A

Original			Transformed		
Photography	*Focal Length (mm.)*	*Image Size (CM)*	*Focal Length (mm.)*	*Image Size (CM)*	*Distortion*
		Group I			
Topogon, film	100	14×14	153	21×21	Zero
Aquilor, plate of film	125	18×18	153	22×22	Zero
Aquilor, plate or film	150	18×18	153	18×18	Zero
Metrogon, film	153	23×23	153	23×23	Zero
Planigon, film	153	23×23	153	23×23	Zero
		Group II			
Aviogon, plate	100	14×14	153	21×21	Zero
Aviogon, film	115	18×18	153	24×24	Zero
Aquilor, plate or film	125	11.5×16.5	153	14×20	Zero
Avigon, film	153	23×23	153	23×23	Zero
Aviotar, plate	170	14×14	153	13×13	Zero
Aviotar, film	210	18×18	153	13×13	Zero
Topar, film	210	18×18	153	13×13	Zero
		Group III			
Metrogon, film	153	23×23	100	15×15	Topogon
Planigon, film	153	23×23	100	15×15	Topogon
Metrogon, film	153	23×23	125	19×19	Aquilor
Planigon, film	153	23×23	125	19×19	Aquilor

in Group II are considered to be distortion-free and require only a change in the focal-length. Those in Group III are changed from one radial distortion-pattern and focal-length to any other specified distortion-pattern and focal-length.

In all cases, a nominal distortion-curve is selected as the basis for the compensation. Additional adjustment to better fit the nominal curve to the specific camera may be accomplished by changing the calibrated focal-length of the camera. If more ideal compensation is desired, additional compensating-plates may be obtained.

The varied focal-lengths of individual cameras are converted to a fixed focal-length by use of nomographs. This feature allows all stereo projectors to be laboratory calibrated to a fixed principal distance. The flexibility of the calibrated focal-lengths of individual cameras becomes entirely a function of the printer rather than of the plotting cameras. It is much easier to calibrate one series of printer settings than the variable settings of numerous stereo plotter projectors.

The more pertinent specifications for the Type *A* printer will be cited here. The specification concerning radial distortion requires that all points when measured radially from the center of the diapositive for all magnifications and all format sizes, shall not deviate by more than 0.02 millimeter. The tangential distortion at the printer's maximum magnification within the circular area of the 9×9 inch format shall have no point displaced greater than 0.007 millimeter when measured, in the plane of the diapositive, from its distortion-free position. The resolving power of the optical system at any ratio of reduction or enlargement shall not be less than 30 lines per millimeter when measured in the plane of the diapositive.

The Type *B* printer (Figure 2) is designed to a variable ratio reduction of 1:1.8 to 1:3.2. The primary purpose of this type at Army Map Service is to transform existing photography between the principal distance range of 97 and 156 millimeters for distortion-free use in the Balplex projector with its 55 millimeter focal-length. The functions of the individual components will not be detailed since all are identical to those given under Type *A* printer. The

TABLE II

PHOTOGRAPHY ACCOMMODATED BY AMS WILD U-3 PRINTER—TYPES B & C

Photography	*Focal Length* (*mm*)	*Image Size* (*CM*)
Group I		
Topogon, film	100	14×14
Aquilor, plate or film	125	18×18
Aquilor, plate or film	150	18×18
Metrogon, film	153	23×23
Planigon, film	153	23×23
Group II		
Aviogon, plate	100	14×14
Aviogon, film	153	23×23

nominal focal-length of the lens is 120 millimeters. The photography to be processed is shown in Table II.

The specifications covering the resultant photography, written in a manner similar to those of the Type *A* printer call for a maximum residual radial distortion of 5 microns, a maximum tangential distortion of 3 microns, and a resolution of 50 lines per millimeter, when measured in the plane of the diapositive.

The Type *C* printer contains a variable ratio reduction of 1:3.0 to 1:5.5. All of the photography shown in Table II, covering processing for Type *B*, may also be processed in the Type *C* for distortion-free multiplex use at the focal-length of 28.182 millimeters.

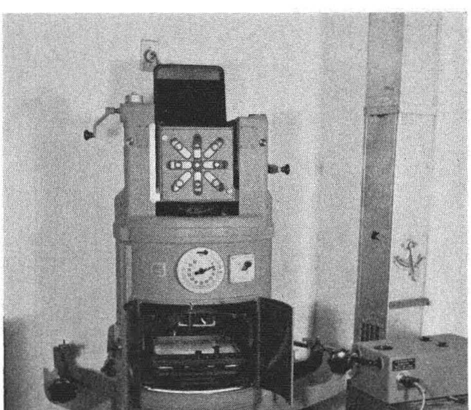

FIG. 2. Wild U-3 Printer—Type B.

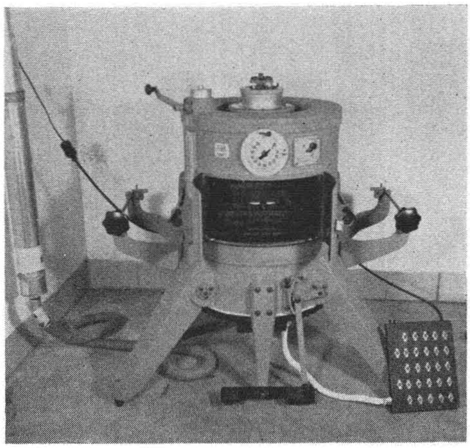

FIG. 3. Wild U-3 Printer—Type C.

In the Type *C* printer (Figure 3) only two main components are provided: base and lens head.

As in the previous cases, the base section contains the light source and film holders. In contrast to the projection lens and the image plane in the other two printers moving independently, here they move as a unit. The printer settings are made by use of a ring which adjusts the position of the stage plate. The nominal focal-length of the transforming lens is 60 millimeters.

The Type *C* specifications require a maximum residual radial-distortion of 3 microns, a maximum tangential-distortion also of 3 microns, and a resolution of 50 lines per millimeter.

Testing for conformance to contract specifications has been completed only for the two Type *A* printers. A brief summary of the test procedures is included here in order to provide a better understanding of the meaning of Army Map Service conformance to specifications in this case.

A calibrated grid containing 41 measured points along two diagonals was used in the check of the residual radial-distortion. Using the distortion-free plate, the grid was exposed at each of the six printer ratios indicated previously in Table I at zero and 180 degree positions, the purpose of the rotation being to separate the basic causes of errors, i.e., errors inherent in the printer elements from errors in the grid itself or in alignment of the grid. Next, a grid exposure was made at each ratio using the appropriate compensating plates. A total of 49 exposures was made. Taking each plate in turn, each grid intersection 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.