FIG. 1. Geocon I 6-inch, $f/5.6$, Wide Angle Lens

ROBERT A. MATOS*
*U. S. Army Engineer GIMRADA*
*Fort Belvoir, Virginia*

# Aerial Camera for Photogrammetric Research

**Those features are emphasized that are especially important for rigorously evaluating analytic methods and systems.**

(*Abstract on page 980*)

## INTRODUCTION

EARLY IN 1961 efforts were initiated by the U. S. Army Engineer Geodesy Intelligence and Mapping Research and Development Agency (USAEGIMRADA) to determine what improvements could be made to the standard KC-1 aerial mapping camera in order that it could better serve the requirements of numerical photogrammetry and specifically control extension by analytical means. Two immediate limitations were noted. First, the camera calibration reports did not include adequate information so that calibration data could be rigorously applied in the correction of photograph coordinate data. Secondly a definite need existed for in-

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1965.

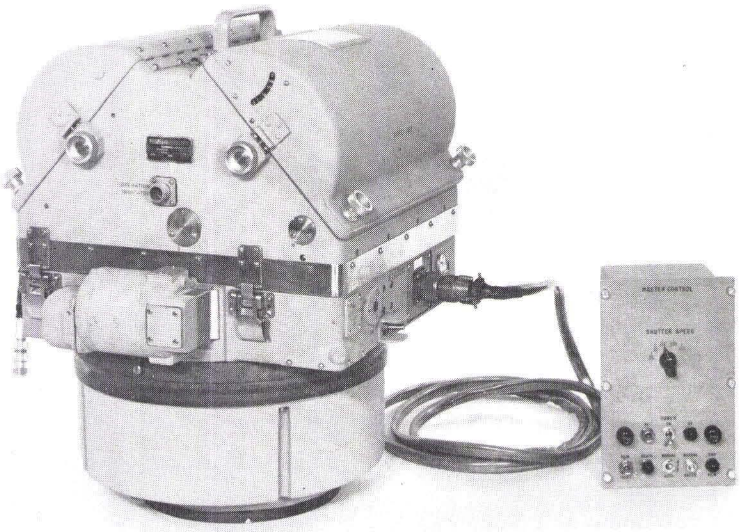

FIG. 2. KC-4 Aerial Mapping Camera

vestigation and improvement in such areas as: lens resolution; lens distortion; fiducial design, configuration, and placement; platen seating; camera environment; and data recorded on each exposure. Also, recognizing this need, the Air Force over the past few years has completed an ambitious program of updating the KC-1 aerial camera. This work has been previously well documented, so it should suffice to say it included: (a) reworking the Planigon lens to reduce radial distortion to 10 microns or less; (b) supplying more detailed calibration data better suited to modern photogrammetric needs; and (c) resurfacing the platen to achieve a plane surface over the 9- by 9-inch format area within 0.00020 inch (5 microns). However, the need for further improvement of the mapping camera system was still apparent, especially in the areas of lens resolution, image blur, and film stability.

## Background

In 1955 Dr. James Baker was commissioned by the Air Force to design a low-distortion, high resolution mapping lens. This work resulted in the development of the Geocon lens (Figure 1) which had shown in laboratory tests significant gains in resolution and image quality over the current Metrogon and Planigon lenses used in military mapping cameras. Lens distortion in the new lens proved to be less than 10 microns, and its resolution measured 52 lines/mm. on-axis and 35 lines/mm. AWAR. By 1963 a Geocon I lens was incorporated with other improvements in an aerial camera especially designed to accommodate the full $f/5.6$ speed of the lens. The new experimental camera was designated the KC-4 aerial camera (Figure 2). At about this time informal discussions between personnel of the Army and Air Force resulted in the recommendation that the KC-4 camera be modified to include the requirements of the Army for a photogrammetric research camera to be used to determine the usefulness of the high resolution Geocon lens coupled with the use of a reseau system for film distortion control and correction. This recommendation resulted in design specifications for a Photogrammetric

ROBERT A. MATOS

Research Camera and the subsequent contract for modification of the KC-4 aerial camera to meet these specifications.

## Design Development

It has been known for many years through the use of analytical triangulation techniques and in other areas where precise photogrammetric analysis is required that film distortion presents the largest single source of non-operator error in precise photograph image coordinate measurements. Adjustment for film distortion usually accomplished by adjusting the calibrated focal length is at best only an approximation of the total systematic portion of the film distortion error and provides no adjustment or correction for non-uniform or differential film distortion error in individual image locations. The system of using glass plate photography would eliminate, for the most part, the problem of correcting for film distortion, leaving for final adjustment only corrections for emulsion creep and other comparatively small magnitude errors; however, a glass plate system is uneconomical and physically unrealistic for most mapping projects of sizable proportions. The alternative has been development of stable base films which have provided a partial solution to the problem of correcting for film distortion.

With the increasing use of analytical triangulation procedures in recent years, the need for still greater control of film stability has been recognized, and because of the impracticability of using glass plate photography, other methods of maintaining or measuring and correcting for film deformation have been sought. The British Ordnance Survey early introduced the use of a reseau for precise correction of film distortion over the format area. This system combines a calibrated glass plate located in the camera cone as a part of the lens system, etched with small dots or cross marks which are imaged on the film at the time of exposure. The calibrated marks imaged on the film are used as a very precise reference of known position to effect the correction for film distortion.

Work in this country has also been directed toward incorporation of a reseau in the military mapping camera, but the effort has been directed toward development of the reseau system as a part of the camera platen. Some advantage over the cone-mounted glass plate reseau is seen in this system provided the desired accuracies can be obtained. First attempts at a platen reseau resulted in the investigation of glass fibers or lucite rods as light pipes to carry the light and produce the dots. Use of glass fibers appeared feasible but major fabrication problems are presented which must still be worked out.

On the other hand, the use of lucite rods for lighting a platen reseau presented less of a fabrication problem and was subsequently incorporated in an aerial mapping camera. In this case, several lamp housings with the lucite pipes projecting from them were used to transmit the light to produce the dots on the film. The lucite pipes were located in the camera magazine. This system was installed in the KC-3 aerial camera, but the reseau points produced on the film have been of marginal quality. For these reasons neither fiber optics nor lucite rods was adopted for the new camera. In their place the use of a unique miniature optical projection system consisting of a lamp-reticle-lens assembly developed by Fairchild Camera and Instrument Corporation was recommended. This system, whose primary purpose is to provide optimum image quality, is shown in Figure 3.

In the photogrammetric research camera

Abstract: *Recent developments in mapping techniques, particularly analytical photogrammetric procedures, impose more stringent requirements on the accuracy of initial photographic data than can be achieved with the present design of mapping cameras. The Air Force's Aeronautical Systems Division, in cooperation with the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, has awarded a contract to Fairchild Camera and Instrument Corporation to modify the experimental KC-4 aerial mapping camera to meet specifications for a unique photogrammetric research camera. The characteristics, configuration, and engineering considerations of the proposed analytical camera include the intended application of the camera as a tool in basic and applied research operations of USAEGIMRADA and other Government agencies.*

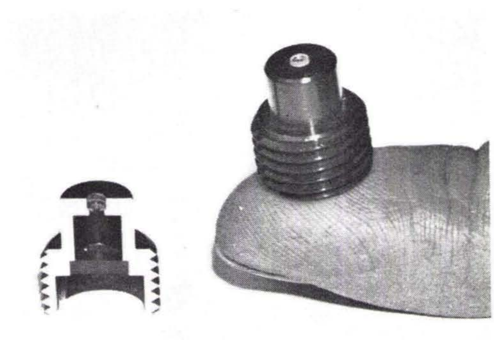

FIG. 3. Reseau Point Projector

envisioned, three distinct systems of correcting for film distortion are included for separate and combined testing to determine the usefulness of each system and, where possible, to determine the minimum design configuration required to maintain the required accuracy of results.

*Platen reseau*

A 144-point reseau, consisting of dot and cross reseau alternately spaced, will be incorporated in the platen. The reseau pattern of 12 rows of 12 points each will be centrally located in the format area with a nominal pitch of 20 millimeters between any 2 adjacent and in-line points (Figure 4). The reseau dot points will be 0.050 mm. +.020, −.000 in diameter and circular within 10 per cent of the diameter. The length of the lines of the reseau cross points will be 1.500 mm. ±.250 and the width of the lines will be .025 mm. +.010, −.005. The individual reseau points

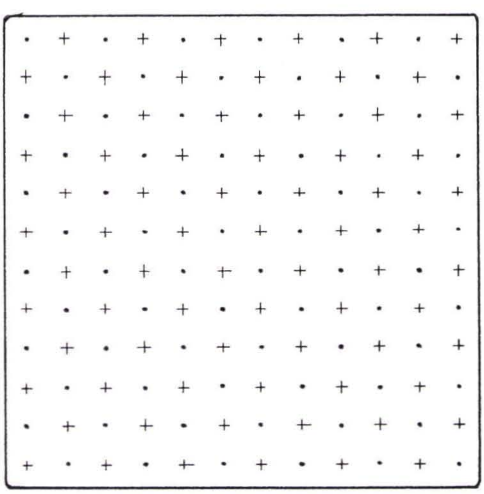

FIG. 4. Platen Reseau (144 Points)

will be generated through the miniature optical projection system previously described to permit optimized image recording on the sensitized material. The reseau points will be illuminated by individual lamps affixed to each reseau projector. The intensity of illumination of all points will be uniform within 10 per cent. The intensity of all lamps as a unit will be variable by operator control to obtain point densities between 1 and 2 on the negative. The intensity of illumination and the point density is critical for later point identification, especially if automatic point locating and measuring instruments are to be used. A switch and indicator light will be provided so that the platen reseau can be switched off and the indicator light turned on to indicate the off condition of the reseau. The registering face of the platen will be made flat within ±0.0019 mm. over the entire format area. Although the reseau will be calibrated separately from the camera system, it can be related to the interior orientation of the camera system by translating the reseau coordinate system into the fiducial coordinate system.

Recent laboratory tests conducted by GIMRADA have indicated that current films used for aerial mapping, including the relatively new Estar thin base films, are extremely stable under ideal laboratory conditions. Comparative studies have resulted in only minor nonuniform distortion errors remaining after linear cross interpolation between reseau intersections spaced 1.0, 1.5, 2.0, and 2.5 inch, as indicated by the root-mean-square-error values shown in Table 1. From the results of these and other laboratory tests, the 144-point reseau is felt to represent the maximum number of points necessary for researching the effect of film distortion over a 9- by 9-inch format. The field tests of the camera will be directed toward verifying the laboratory test results and to determine the utility of various point configurations and spacing for optimum correction.

FIDUCIAL RESEAU SYSTEM.

The format plate will house an array of eight artificially illuminated fiducial dots located within the 9- by 9-inch format area (Figure 5). The fiducials will be illuminated by incandescent lamps operated through a suitably designed lamp driver to control pulse duration and voltage levels. Each fiducial dot point, like the reseau points, will be generated through the miniature optical projection system consisting of a lamp-reticle-lens assembly to permit precision adjustment of fiducial position and optimized image recording on

TABLE 1

RESEAU SPACING

| *Reseau Spacing* | *Maximum Deviation μ* | *Max RMS Error μ* | *Max CPE μ* |
|---|---|---|---|
| 1.0 | 4 | 1.64 | 1.40 |
| 1.5 | 4 | 1.84 | 1.77 |
| 2.0 | 5 | 2.36 | 2.58 |
| 2.5 | 6 | 2.56 | 2.30 |

the sensitized material. The diameter of the fiducial dots will be nominally 0.050 mm. +.020, −.000 on the film under conditions of proper exposure and processing. The eight fiducial reseau marks will be calibrated as a part of the interior orientation of the camera system. The rectangular coordinate system of the fiducial reseau will allow certain values to be determined concerning the film distortion of each plate. This 8-point format reseau system has a decided advantage over the present 4-point fiducial configuration of either side or corner fiducials for the correction of film distortion. Mr. Tewinkel of the Coast and Geodetic Survey, in his studies of film distortion at the Massachusetts Institute of Technology in May 1960, concluded that in using nine fiducials to reduce the distance between any two calibrated marks from 9 to $4\frac{1}{2}$ inches, the residual error will be quartered and if the center format point is omitted, the value will lie between $\frac{1}{4}$ and 1.

PERIPHERAL RESEAU

A system of illuminated points will be placed on the periphery of the format plate. These points will be located as close to the format edge as practicable in a configuration which places five equally spaced points adjacent between fiducial marks (Figure 6). The resulting pattern will form a box peripheral reseau about the picture format, with point spacing approximately equal to the platen reseau spacing and with each point in close alignment with its opposite matching point. As in the case of the fiducials and platen reseau, each peripheral reseau dot will be generated through a miniature optical projection system. The diameter of the reseau points will have a nominal value of 0.050 mm. +.020, −.000 on the film when properly exposed and processed. As this peripheral reseau, like the fiducial markers, forms a part of the inner lens cone, a fixed relationship will exist between it and the principal point of autocollimation. This exact relationship will be determined and recorded. The utility of this system as a basis for film distortion correction will be determined and compared to the results using the platen reseau system and the eight-fiducial system. Some advantage is seen in the box-reseau system especially if color photography is used.

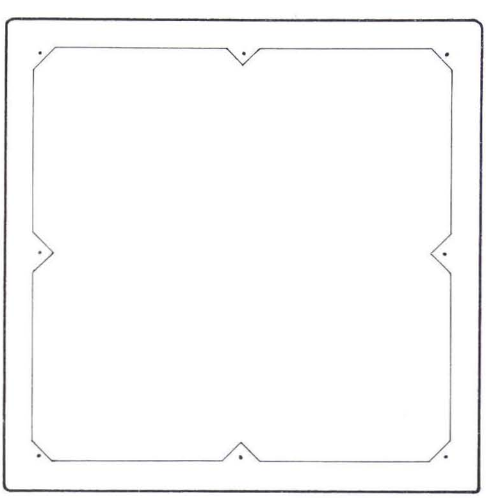

FIG. 5. Fiducial Reseau (8 Points)

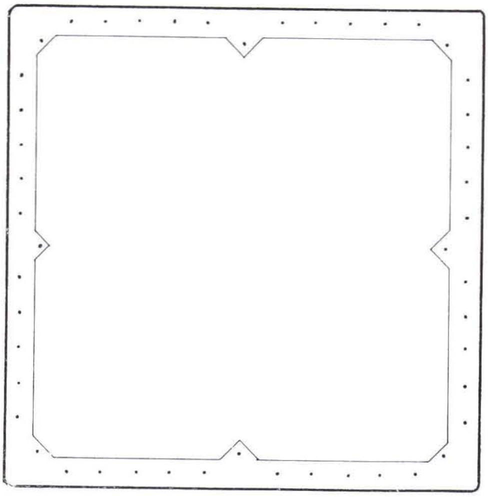

FIG. 6. Peripheral Reseau (48 Points)

## PROBLEMS

Some questions as to dot and cross size, density, and configuration exist. The design specifications used here were the result of combining information available on previous successful and unsuccessful reseau systems and requirements of point marking and automatic point reading instruments. The experimental photography to be obtained with this camera will form a basis for recommendations of future reseau instrument systems.

The modification of the KC-4 camera as a photogrammetric research camera, although representing a major step in the design of an analytical camera, will still leave many questions yet to be answered in determining an optimum camera configuration for data collection for use in analytical aerial triangulation systems. Many authors have recognized the need in this area. Several years ago Mr. D. W. G. Arthur suggested in a paper entitled "A Camera for Aerial Triangulation" a completely new camera designed specifically for conducting analytical triangulation, which he stated would be ideally suited for mapping vast territories. Whether we design completely new cameras or try to update present cameras, some mechanical optical problems which limit the collection of optimum data will usually remain; therefore, it is believed that all new systems must include adequate devices for correcting the error model. The devices used on which to base the corrections must be designed and tested in the same critical way as the basic instrument itself.

The unique design for the modified KC-4 Photogrammetric Research Camera resulted from GIMRADA's investigation into the requirements for correcting some of the major error sources occurring in the application of analytical aerial triangulation in field and base plant operation. The camera will be used to provide special test photography for evaluating the photogrammetric potential of employing any or all of these modifications on standard mapping cameras and will be used to provide actual data on which to base specifications for design of future mapping cameras. The camera will also be used in specific research studies requiring high geometric fidelity and precise engineering data, using either black and white or color film to produce the required data.

It is believed that the modifications to be made to the KC-4 camera will enhance its use for metric data reduction of both black and white and color photography.

It is expected that the modifications will be completed this year and that use of the camera to obtain photography for research and other special test purposes over various test areas and conditions throughout the world would soon follow.

## Conclusion

Mr. A. J. Van der Weele in his paper, "Numerical and Analytical Photogrammetry at Large Scales," presented at the Lisbon International Congress of Photogrammetry, September 1964, states:

"The use of a reseau camera has special advantages in combination with analytical resitution. Most of the film distortion and unflatness are automatically taken into account so that results, in particular those of aerial triangulation, may be of a higher quality." He goes on to say that: "It is strongly recommended that the reseau camera be used in tests to find out whether the expected improvements can be fully realized. These tests would also give a possibility to check the film deformation under varying circumstances."

It is expected that through the use of this photogrammetric research camera, we will be able to provide not only the test data for determining utility of reseau photography, but also a means for field evaluation of the high density reseau configuration and of the utility of employing the platen reseau.

## Bibliography

Livingston, R. G., "A History of Military Mapping Camera Development," USAEGIMRADA, 1 May 1963.

Norton, Clarice L., "American Mapping Cameras," Fairchild Camera and Instrument Corporation, 1964.

Tewinkel, G. C., "Film Distortion Compensation for Photogrammetric Use," MIT, May 1960.