created by the photo-electric cell is transmitted through the control box to the shutter, causing the exposure to be made. The resulting photographs are of such a quality that only people experienced in the use of aerial photographs can differentiate between photographs taken at night and those taken in the daytime.

New Single Lens Cameras Under Construction

A number of new cameras are under construction in the United States for which descriptions are not available at this time. Two of these cameras which are now under design are mentioned below.

1. Model K-15 Camera (Proposed): The Model K-15 camera will include practically all the interchangeable features of the K-3B camera. A new style magazine will be used which will accommodate longer lengths of film than have been used heretofore. In addition to greater capacity of film, the negative size will be increased from 7×9 inches (17.8×22.8 cm.) to 9×9 inches (22.8×22.8 cm.). Provision will be made for the use of lenses of 6 inch (15.2 cm.) and $8\frac{1}{4}$ inch (21 cm.) focal length. Other details regarding the design of this camera have not been released by the manufacturer, Fairchild Aerial Camera Corporation.

2. Wide Angle Camera (Fairchild Aerial Camera Corporation): Designed as a wide angle camera for photogrammetric use, it is expected that the first experimental model of this camera will be completed in June, 1938. Details regarding the design of the camera have not been disclosed as yet.

SPECIFICATIONS FOR A PRECISION MAPPING CAMERA[1]

Irvine C. Gardner

ABSTRACT: A precision mapping camera[2] is defined as a camera capable of producing photographs suitable for the making of maps of the highest accuracy that is economically feasible. Specifications for such a map are given. Details of camera construction and camera tolerances consistent with these map specifications are discussed. Two types of optical equipment are considered: the objective having a focal length of 8 inches (20.3 cm.) covering a field 9×9 inches (22.8×22.8 cm.) or 7×9 inches (17.8×22.8 cm.) and the objective that covers an extremely wide angle.

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I. INTRODUCTION

The requirements of the government agencies interested in crop control, soil conservation, large scale irrigation projects and the installation of hydro-

[1] Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[2] This paper presents the results of work done for the American Society of Photogrammetry by the Chairman of its Committee on Precision Cameras. The judgments and opinions are those of the writer and have not been considered or passed upon by the Committee.

electric plants have greatly accelerated the photographing of large areas of the United States from the air. It is desirable that these photographs be of such quality and character that they may be satisfactory, not only for present needs but also for other purposes that may develop, and thus save the expense of reflying territory that has once been photographed.

Unfortunately, difficulties arise in connection with the production of an all purpose photograph. For crop control and soil conservation purposes the user is interested in measuring areas and the measurements are planimetric rather than topographic. Consequently photographs with the minimum of relief parallax are desired in order that measurements of area may be simply made without too great error by neglecting displacements of marginal points caused by their elevation. The ideal photograph for this purpose should be made from an airplane at the highest practicable altitude with a lens of relatively long focal length in order to give the desired scale with the minimum of parallax. In such a case the area obtained on a single photograph is not unduly small although the angular extent of the field is reduced to a minimum. For large scale irrigation projects or the installation of hydro-electric plants and for future topographic mapping, such as is done by the Geological Survey, photographs, perhaps to the same or somewhat smaller scale, taken from a lesser height with a lens having a large angular field of view and a relatively short focal length are desired because this increases the relief displacement, the essential quantity by which differences of elevation are determined.

The requirements for the two purposes thus appear to be diametrically opposed, the one requiring the elimination of relief parallax so far as is possible, whereas the other demands its presence. At first this seems to preclude a satisfactory compromise. However, an amount of relief parallax considerably greater than the minimum attainable can be tolerated without introducing unduly large errors into the planimetric measurements made without stereoscopic viewing. If the camera with which the exposures are made is sufficiently accurate in its construction and if the subsequent operations performed on the negative are conducted with the requisite accuracy and precision it may also be possible to obtain measurements of the relief with sufficient accuracy for the construction of satisfactory maps. This viewpoint makes it desirable that the camera and the apparatus for operating on the finished negative be carefully studied in order that the different sources of error may be determined and steps be taken for their elimination. It is obvious that the improvement of the camera is the more urgent in order that the photographs now being made in great quantity may be of such quality as to permit the realization in the future of anticipated improvements in the mapping apparatus.

This line of argument has led to a desire by the camera user and the camera manufacturer for specifications defining a "precision camera," a camera better, if possible, than those now in use and capable of producing photographs definitely superior to those that are now being obtained. As an initial step in the attainment of a precision camera the American Society of Photogrammetry has appointed a committee to prepare specifications setting forth the requirements for such a camera. This presentation sets forth information that has been obtained in connection with the work of the committee but it does not present the final approved specifications as these have not yet been formulated.

II. Definition of a Precision Camera

If a mapping camera is correctly calibrated and if the distortion is negligible, it follows that the resulting map will contain no significant errors traceable to the camera provided that it continues to perform in a manner consistent with its calibration. Unfortunately, however, many cameras now in use are not fixed and unchanging. The removal and replacement of a magazine for loading, the dismounting of the lens for cleaning, the variations in dimensions with temperature changes, and the numerous other vicissitudes that arise during use in the laboratory or field result in departures from the camera performance postulated from the calibration values. If, for the moment, we restrict our consideration to a mapping project for which a given precision is required, then a camera may be termed a "precision camera for this project" or "for this quality of mapping" provided that such variations of the camera do not exceed those permitted by the requirements of the mapping project. With this nomenclature we should have a series of precision cameras, each precise for a restricted range of usage.

This is not the classification usually adopted. The term "precision camera" is commonly used without further qualification and is properly applied to a camera so well designed and constructed that the variations in its performance, to which allusion has been made, are not inconsistent with its use on mapping projects for which the greatest practicable accuracy and precision are to be secured. Therefore, before specifications for a precision camera can be written it is necessary:

1. To arrive at an appraisal of the errors that are to be expected in photogrammetric mapping of the highest possible accuracy, and

2. To determine the allowable variations in the significant characteristics of the camera that are consistent with photogrammetric mapping of this precision.

The errors of a map arise in part from errors introduced into the photographs by the camera, from shrinkage of the film, from control points incorrectly surveyed, from incorrect fitting of the control points and the negative, from errors of the plotting machine such as lost motion, incorrect lengths for the pantograph arms, or distortion by the projection lens, and from lack of precision in making settings by the observer. The contributions from some of these sources of error, such as lens distortion or film shrinkage will be systematic to the extent that their contributions to the errors of the map will have the same sign and approximately the same magnitude over a localized region of the map. The final resultant error at any point of the map, however, arises from so many different contributions, not differing greatly in magnitude, that it will be considered sufficiently precise for our purpose to assume that the errors of the map have the characteristics of accidental errors and follow the normal error frequency curve.

A map will be assumed to be as precise as it is economically practicable to construct if the errors satisfy the following specifications:

a. Horizontal error. The probable error, measured on the map, of the location of a point shall not exceed 0.008 inch.

b. Vertical error. The probable error in the indicated elevation of a point shall not exceed 0.2 of a contour interval.

On the basis of the assumption that the errors follow the normal error frequency curve, for 90% of the points, the error will not exceed $2\frac{1}{2}$ probable errors. In accordance with this, statements a and b may be paraphrased as follows:

a′. Horizontal error. For 90% of a random selection of points, the error of the location shall not exceed 0.02 inch.

b′. Vertical error. For 90% of a random selection of points, the error in the indicated elevation of a point shall not exceed 0.5 contour interval.

This last pair of statements of the precision of a map parallels fairly closely the tentative specifications now under consideration by the Society's Committee on Specifications for Maps.[3]

III. Constructional Details of a Precision Camera

An airplane mapping camera is an elaborate and complicated mechanism that performs, in an automatic or semi-automatic manner, many functions necessary if a series of exposures, uniformly spaced at appropriate intervals, is to be made from an airplane moving at a velocity ranging from 200 to 300 miles per hour. It is not the purpose to consider, in this presentation, these many auxiliary mechanisms that contribute to the successful operation of a camera. The precision camera is a measuring instrument and consideration will be limited to the characteristics upon which precision of measurement depends. These will be briefly discussed. The metrical constancy of the camera is dependent upon the maintenance of a fixed relation between the lens, the collimation index markers and the surface that locates the film in the focal plane. To insure permanence these parts should be constructed as a unit, rarely disassembled and so designed and built that all parts return very precisely to their original positions when it is reassembled. Of this unit the largest part is the so-called cone, shaped approximately like the frustrum of a cone, which serves as a spacer between the lens and the photographic emulsion. It is not essential that the cone be made of material having a low coefficient of expansion because the expansion can be readily determined and entirely compensated by an equal change in the calibrated focal length. After first machining to remove the skin, the cone should be carefully heat-treated in order to prevent secular changes and the design should be such that the metal is uniformly disposed about the axis of the cone without large projecting lugs or abrupt changes in wall thickness. If these precautions are not observed there is danger that a change in temperature will be accompanied by a tilting of the focal plane with respect to the lens axis, a movement which will result in a significant shift of the principal point.

The lens is mounted at the smaller end of the cone. The lens mounting should be so designed that the lens can be removed for cleaning or repair of shutter without the necessity for recalibrating the camera. One method of accomplishing this is by the use of flat flanges and smooth cylindrical surfaces, the flanges serving to determine the spacing and the cylindrical surfaces being utilized to maintain the common axis for the different components. Threaded cylindrical surfaces do not always present a satisfactory means for maintaining the desired axial relationships invariant with respect to assembly and disassembly.

The film, at the time of exposure, is held against a platen, either by suction or pressure. This platen should not depart from planeness more than 0.005 inch (0.01 mm.). The platen is customarily held in the proper position with respect to the lens by springs or other arrangement that holds it against bearing surfaces on the rear end of the cone. In some designs the film lies between the surface of the platen and the bearing surfaces on the cone. This has the advantage that the film is located by its film side rather than by its back surface and therefore, the emulsion will always lie in the same plane, regardless of thickness of the film base. Modern film is so uniform in thickness that this is not an advantage of major importance. Probably a more important advantage is that this design may be so developed that the marginal portions of the film are held

[3] Photogrammetric Engineering, Vol. IV, p. 87 (1938).

against the platen by mechanical pressure which supplements the suction or air pressure. A disadvantage of this arrangement is that the platen has to be equipped with a mechanism for withdrawing it from the bearing surfaces to permit the film to advance after each exposure. If the platen is made wider than the film and rests directly on the bearing surfaces of the cone beyond the edge of the film, the platen can be held against the bearing surfaces by a simple system of springs and the platen does not have to retreat after each exposure. In either design a precision camera must be so constructed that the actuating system that presses the platen against the cone will allow a retreat of the platen sufficient to permit a glass photographic plate to be inserted for test exposures. It is necessary that the exposures for the calibration tests be made on plates, rather than films in order to eliminate the camera calibration errors that would otherwise result from film shrinkage.

For determining the location of the principal point it is necessary to mount the camera on an optical bench and sight through the camera, both from the front and rear. For this purpose it must be possible to remove the magazine and platen or there must be openings on the axis, and not less than one inch in diameter, that can be made available by unscrewing caps or plugs. When the camera is mounted on the bench for location of the principal point, exposures will be made, recording on the negative an index mark forming part of the test apparatus. This recorded mark will show the exact location of the principal point. On this same negative an exposure will record the four collimation index marks so that the relation between the index marks and the principal point can be determined.

The four collimation index markers should be mounted so that one registers at the center of each edge of the photograph. Lines joining opposite index marks should intersect at the principal point and the angle between these lines should not depart more than 30 seconds from a right angle. This last requirement is made in order that all four index marks will register with the four corresponding marks used for adjusting the negative in the plotting apparatus. If these intersecting lines depart too far from a right angle when the positive is to be adjusted in the plotting machine it will be found that only three of the marks can be made to fit the corresponding marks in the plotting machine and this is a source of inaccuracy and annoyance. In order to facilitate the correct adjustment of the index markers they may be made adjustable provided arrangements are made for fixing them with dowels or some other equally secure means when the correct adjustment has been secured.

It is advisable that the index markers be designed, not only to serve as means for adjusting the positive in the plotting machine but also to carry fiducial marks that will permit the distance between opposite index marks to be precisely determined from measurements made on the glass negatives on which the principal point is recorded. Measurements of these lengths for the two pair of opposite index marks will constitute calibration constants of the camera. If similar measurements are made of the lengths between the corresponding index marks on the film it is possible to determine the longitudinal and lateral shrinkage of the film.

Index markers are of two types, the "shadow type" which is silhouetted directly upon the film without the interposition of any optical system and the projection type for which an index mark ruled on glass is projected upon the film by an optical system. The illumination by which this projection is accomplished may be a portion of the light entering the lens or auxiliary electric lights may be used for this purpose. The shadow type of index marker gives satisfactory results and is the simpler but it is probable that the index marks can be registered with finer detail by markers of the projection type.

IV. Tolerances for a Precision Camera

1. Summary of the Equations Giving the Relations between Camera Errors and Map Errors

Equations giving the relations between the errors in the calibration constants of the camera and the corresponding errors that are consequently introduced into the maps have been derived and were discussed at the spring meeting (1938) of the Society. This material will appear in a forthcoming article in the *Journal of Research of the National Bureau of Standards.*[4]
A summary of the important equations from this article follows:

If $\pm\Delta f$ is the probable error of the calibrated focal length,

$$\Delta h_f \leqq \frac{h}{f}\Delta f \qquad 1$$

$$\Delta l_f = 0 \qquad 2$$

If Δr is the absolute value of the maximum linear distortion,

$$\Delta h_d \leqq 0.8\frac{ka}{f}\Delta r \qquad 3$$

$$\Delta l_d \leqq 0.4\Delta r \qquad 4$$

If $\pm\Delta c$ is the probable error for the location of the principal point

$$\Delta h_c \leqq 2\,\frac{k'h}{f}\Delta c \qquad 5$$

$$\Delta l_c \leqq \frac{h}{a}\Delta c \qquad 6$$

In these equations f is the calibrated focal length of the camera, a is the altitude of the camera at the time of the exposure and h is the height of the maximum elevation above the datum plane which is assumed to contain all control points. In equations 1, 3, and 5, $\pm\Delta h$ is the probable error in elevation the subscript indicating the particular error of the camera to which it owes its origin. In equations 2, 4, and 6, $\pm\Delta l$ is the probable error, measured on the map, of the location of a point, when the map has the same scale as the photograph. If the scales of the photograph and map differ the right hand members of these three equations should be divided by the scale factor of the photograph and multiplied by the scale factor of the map.

In equation 3 the constant k is a function of the focal length of the camera objective and the overlap between two successive exposures of a flight strip. For the customary overlap of 60%, k has the values 1.66, 1.95 and 2.22 for lenses of 6, 7, and 8 inch (15.2, 17.8, and 20.3 cm.) focal lengths, respectively, and a 9×9 inch (22.8×22.8 cm.) film. The constant k' of equation 5 is the

[4] Copies of this paper may be obtained by non-subscribers to the journal in the form of reprints. They will be made available to members of the American Society of Photogrammetry in a manner to be announced in PHOTOGRAMMETRIC ENGINEERING.

same as k, except that the overlap to be selected is that between two adjacent flight strips. If this overlap has the customary value of 15%, k' has the values 0.95, 1.11, and 1.27 for focal lengths of 6, 7, and 8 inches (15.2, 17.8, and 20.3 cm.) respectively.

2. Suggested Values of Tolerances and Related Constants

a. *Values of* Δf *and* Δc. In equations 1, 5, and 6, $\pm\Delta f$ is the probable error of the calibrated focal length and $\pm\Delta c$ is the probable error in the location of the principal point. The values of the calibrated focal length and the location of the principal point are determined by laboratory measurements and consequently Δf and Δc should be zero except for the errors of the laboratory determinations of these values and dimensional changes which may take place after the calibration of the camera. Errors from the determination of the calibration constants will be invariant for all photographs made with the camera. This constancy and the fact that the map errors h_f, h_c and l_c vanish for the datum plane and are proportional to h, enable the effects of the relatively small errors likely to be present in the determination of the calibration constants to be largely eliminated by the usual series of adjustments incidental to the fitting of the map to the control points. The dimensional changes of the camera remain to be considered. If the camera is properly designed for precision photography the surfaces locating the plane of the emulsion, the camera cone, and the lens form a rigid unit specially constructed to maintain the component parts in a fixed relation to each other. It has been mentioned that corrections for temperature variations of calibrated focal length can be readily applied. With a correct design the location of the principal point should not be affected by temperature changes. To allow for residual changes in f and in the location of the principal point, not otherwise compensated, values of 0.002 inch (0.05 mm.) and 0.001 inch (0.025 mm.) will be selected for Δf and Δc, the probable errors of the calibrated focal length and the location of the principal point, respectively. These values are approximately equal to the probable errors of measurement of calibrated focal length and location of the principal point as the determinations will be made for the certification of precision cameras at the National Bureau of Standards.

b. *Value of* Δr. When lenses are tested at the National Bureau of Standards the distortion that is reported is measured with respect to the paraxial or equivalent focal length and, for lenses covering a moderate field of view, the distortion for any point is approximately proportional to the cube of the tangent of its angular distance from the center of the field. The distortion is a measure of the displacement of the image of a point from its distortion-free position which, in turn, is a function of the value of the focal length. Consequently the distribution of the distortion over the field can be varied by modifying the focal length. The calibrated focal length is a value so selected that the distortion assumes positive and negative values over different portions of the field with the maximum value reduced as much as possible. The quantity Δr is the maximum value of the distortion referred to the calibrated focal length. When the distortion is referred to the equivalent focal length it has its maximum value at the edge of the field and, for lenses of moderate coverage, this will be approximately 0.004 inch (0.1 mm.) or less. This corresponds to a value of of 0.001 inch (0.025 mm.) for the value of Δr and this value will be selected for substitution in the error equations.

c. *Typical values of* a *and* h. Reference to equations 1 to 6 shows that a value for a, the altitude of the airplane, and for h, the maximum elevation above the datum plane, must also be selected if numerical values are to be assigned to all quantities in the right hand members. Fifteen thousand feet will be chosen as a typical altitude for photographic work. For this altitude, the maximum elevation above the datum plane will rarely exceed 5,000 feet (1,525 m.) This value will be selected in order to provide a particularly severe test to determine the suitability of a camera for precise mapping.

V. Suggested Tolerances for a Precision Camera

1. The 9×9 (22.8×22.8) or 7×9 Inch (17.8×22.8 Cm.) Camera Equipped with an Objective Having a Focal Length of 8 Inches (20.3 Cm.).

When f is assumed to be 8 inches (20.3 cm.) and this value, with the values for the other constants from Section IV, 2 are substituted in equations 1 to 6, one obtains for the individual contributions to the horizontal error on the map, the following values:

$$\Delta l_f = 0$$
$$\Delta l_d \leqq 0.0004 \text{ in.}$$
$$\Delta l_c \leqq 0.0003 \text{ in.}$$

and, for the individual contributions to the error of elevation, the values

$$\Delta h_f \leqq 1.25 \text{ ft.}$$
$$\Delta h_d \leqq 3.33 \text{ ft.}$$
$$\Delta h_c \leqq 1.58 \text{ ft.}$$

The total contribution of the camera to the horizontal error of the map is obtained by combining the individual contributions, 0, 0.0004 and 0.0003 inch. The allowable error is 0.008 inch (0.2 mm.). It is evident that the camera errors are insignificant when compared with the allowable error. If errors of elevation were not to be considered the suggested values of Δf, Δr, and Δc could be greatly increased without seriously impairing the accuracy of the map.

When the partial probable errors of elevation are combined in the usual manner one obtains

$$\Delta h = \sqrt{1.25^2 + 3.33^2 + 1.58^2} = 3.88 \text{ ft. } (1.18 \text{ m.})$$

where Δh represents the total contribution by the camera to the probable error of elevation. This probable error is larger than is desirable because, even with 20 foot (6.1 m.) contours, the allowable probable error is four feet and the camera absorbs nearly all of this. A consideration of the individual contributions to the probable error indicates that distortion is the most serious error of the precision camera.

There are ameliorating conditions. Contributions to the probable error from equations 1 and 5 are proportional to h. An elevation of 5,000 feet (1,525 m.) is an extreme condition and, for the usual mapping project the maximum elevation will be much less than this with a consequent reduction in the probable error. Furthermore the assumption has been made that all the control points lie in a plane. In actual practice, the ground control, over rugged territory, will be extended to include measures of the elevation of many of the peaks and saddles. Consequently instead of determining the elevation by triangulation from a datum plane the altitudes will be determined by interpolation from a system of control points with many intermediate elevations accurately determined. This should result in a great reduction of the contribution from the camera to the probable error of elevation.

The tolerances that have been selected

$$\Delta f \leqq 0.002 \text{ inch } (0.05 \text{ mm.})$$
$$\Delta r \leqq 0.001 \text{ inch } (0.025 \text{ mm.})$$
$$\Delta c \leqq 0.001 \text{ inch } (0.025 \text{ mm.})$$

can be satisfied by cameras equipped with lenses of 8 inch (20.3 cm.) focal length. Such a lens can be used to cover a 9×9 inch (22.8×22.8 cm.) film (half-angle of field for the extreme corner equals 38.5°) or to cover a 7×9 inch (17.8×22.8 cm.) film (half-angle for the extreme corner equals 35.4°). In either instance, with the lenses now available, the extreme corners will not be sufficiently well defined to permit their use for mapping and the useful field will rarely extend farther than 32° from the axis. If the portion of the field more than 30° from the axis is not used it is possible to secure lenses by more careful selection, for which $\Delta r = 0.0005$ inch. This corresponds to a distortion of 0.002 inch or 0.05 mm. when measured with respect to the equivalent focal length. So far as the errors of the camera are concerned this would be an undoubted advantage because, as has been shown, distortion is the great obstacle to the satisfactory determination of elevation. Whether or not this more restrictive tolerance is to be recommended will depend, to some extent, on whether or not the subsequent errors in the process of making the map will be sufficiently free from error to make this refinement justifiable.

2. Wide Angle Lenses

In equations 1 to 6 the angle of view of the lens enters only in connection with the determination of the values of k and k'. For purposes of illustration consider a camera equipped with an objective having a focal length of 6 inches (15.2 cm.) and making photographs 9×9 inches (22.8×22.8 cm.). For the extreme corner of the field the half-angle is 46.7°. The extreme wide angle lenses cover such a field with satisfactory definition except at the corners. Equation 3 which gives the elevation error as a function of distortion is the equation that expresses the limiting condition for the precision of the map so far as the errors introduced by the camera are concerned. For the 8 inch (20.3 cm.) focal length, with a 9×9 inch (22.8×22.8 cm.) film, $k=2.22$, whereas with the 6 inch (15.2 cm.) focal length, $k=1.66$. This variation of k is favorable to the 6 inch (15.2 cm.) focal length and indicates the advantage in precision that arises from the increased relief parallax resulting from the greater angular field of view and the consequent more oblique viewing of the elevations. The chief practical advantage derived from the use of the wide angle lens is the inclusion of more territory in a single photograph with a reduction in the number of photographs required to cover a given mapping project. If the size of the film is not increased the photograph taken with the wide angle lens will not include more territory unless the scale factor is decreased. In equation 3 the reciprocal of the scale factor appears in the right hand member and this tends to neutralize the advantage of the shorter focal length as indicated by the diminished k. If the lens having a focal length of 8 inches (20.3 cm.) is used at an altitude of 15,000 feet (4,570 m.) substitution in equation 3 shows that

$$\Delta h_d = 40000\ \Delta r.$$

When values corresponding to the use at the same altitude of a lens having a focal length of 6 inches (15.2 cm.) are substituted, one again obtains the result

$$\Delta h_d = 40000\ \Delta r.$$

Therefore, when flown at the same height, the lenses will give equal precision in the measurement of elevation so far as the error arising from distortion is concerned. It appears that the 6 inch (15.2 cm.) focal length is the more desirable because fewer pictures will be required for a given area. This is postulated upon the assumption that Δr, the maximum value of the distortion in the field utilized, has the same value for the two focal lengths. The National Bureau of Standards has not had the opportunity to test all makes of lenses or a large number of lenses of any one make covering a field having a half-angle of 45° but, for the few lenses that have been tested, the maximum distortion for the 6 inch (15.2 cm.) focal length has been 4 or 5 times as great as the maximum distortion for the 8 inch (20.3 cm.) focal length covering a field of 30°. Consequently, so far as this evidence extends, the error in elevation resulting from distortion will be far more serious with the wide angle short focus lenses now available than with the lenses of longer focal length covering a field of the same linear dimensions. So far as the horizontal errors of the map are concerned the lens of either 6 or 8 inch (15.2 or 20.3 cm.) focal length is entirely adequate and the contributions to the vertical error arising from error of focal length or location of principal point will not be greatly different for the two lenses.

If a wide angle lens can not be obtained with the required freedom from distortion there is another alternative. It is possible to do precise mapping with a camera containing excessive distortion provided that the photographs are interpreted on a plotting machine constructed to correct for the distortion of the camera lens. This can be done by applying the Porro principal in which the negative, when adjusted in the plotting machine, is viewed through an objective having its distortion identical with that of the camera objective, that is with the maximum discrepancy not exceeding 0.001 inch (0.025 mm.). On the multiplex type of instrument the distortion of the projection lens should have the value requisite to compensate for the distortion of the diapositive constructed from the negative made in the camera. This is a feasible method of correcting for distortion. It has not been mentioned previously because it is desirable to avoid this method of compensation if it is possible. The question of tolerances for a precision camera will, in all probability, ultimately be connected with the certification of cameras and cameras that do not comply with the established tolerances will be denied certification. If a camera with excessive distortion is to be designated a precision camera, subject to its use with a given plotting machine, a restricted form of certification will be required and it will be necessary to have precise information regarding the distortion of the lenses on the plotting machine before such restricted certification can be made. The resulting photographs must be interpreted on a particular plotting machine and it is evident that this introduces difficulties when a contract for making photographs is let on the basis of competitive bidding and the map is to be constructed by a second contractor or by a government agency. This method is more nearly free from disadvantages when all processes incidental to the making of a map are performed by a single contractor. In such a case the acceptance of his work depends upon the precision of the finished map and the precision of the intermediate steps is chiefly of interest to the contractor.

Multiple Lens Cameras

T-3A (Five Lens) Camera, Fairchild Corporation

This camera was designed to furnish maximum coverage on a single photograph so as to reduce the amount of ground control required for map compilation.

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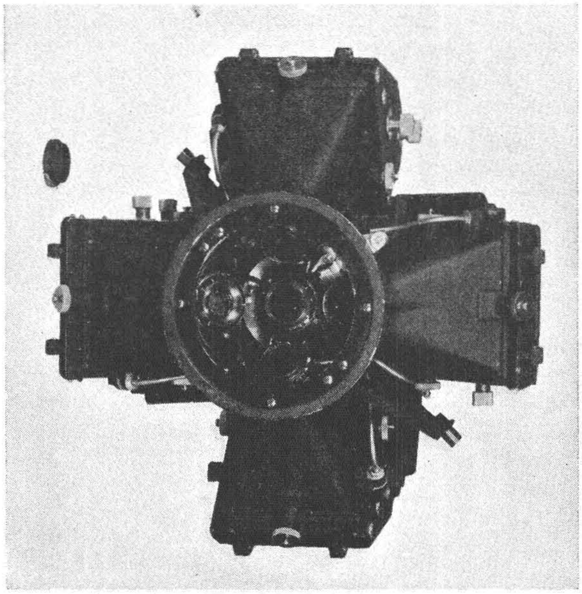
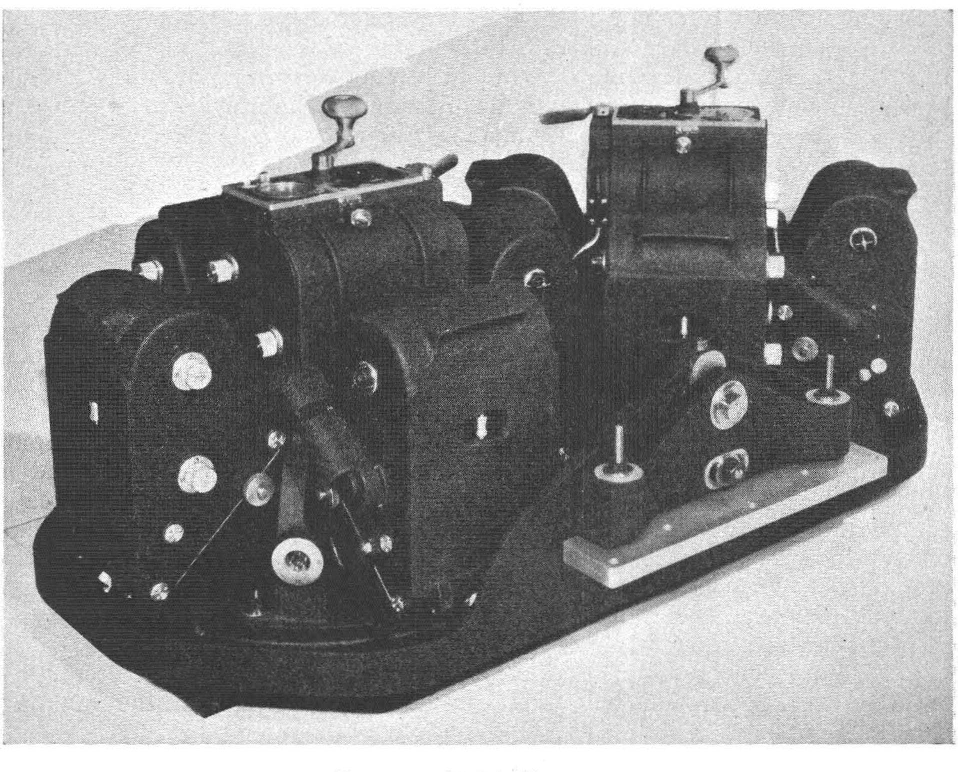


T-3A CAMERA



TANDEM T-3A CAMERA

The T-3A camera has been in use for about seven years and has been used for the larger part of the multiple lens photography in the United States.

The instrument consists of five cameras rigidly connected to form a single unit. Four oblique chambers are arranged around the vertical chamber, the optical axes of the oblique lens being inclined 43° from the vertical. The shutters operate synchronously and are tripped electrically by a single motion of a handle at the top of the camera. The film supply, consisting of five rolls of film, is wound simultaneously in all five chambers by operation of a single winding handle.

Camera data: negative size $5\frac{1}{2}\times 6$ inches (14×15 cm.), roll film, capacity of each magazine 200 exposures, vacuum flattening by means of Venturi tube, each lens of 6 inch (15 cm.) focus with aperture of f/6.8, oblique lenses matched to 0.1 mm. in focal length, between the lens shutters, hand operation.

The vertical negative is contact printed and the oblique negatives are transformed and printed into the plane of the vertical negative by means of a fixed type transforming printer. The five separate prints are then mounted to form a single composite vertical photograph in the form of a Maltese cross, 32 inches (72 cm.) wide.

Tandem T-3A Camera

The tandem T-3A aerial camera consists of two standard five lens cameras oriented at 45° with respect to each other and installed in a special mount. This arrangement of two T-3A cameras in a single mount permits the photographer to obtain all the advantages of the single T-3A camera and to eliminate the objection to the Maltese cross type photograph. The resulting photographs are octagonal in shape. Because of this octagonal shape no provision is made for adjusting the Tandem camera for the "crab" of the airplane. Furthermore, provision is made for leveling the camera in only a fore and aft direction, depending upon the pilot to maintain his airplane level in a transverse direction. The transforming printing is accomplished in the same manner as with the regular five lens camera.

THE NINE LENS AIR CAMERA OF THE U. S. COAST AND GEODETIC SURVEY

O. S. Reading

There are three main requirements of air photographic surveys of the coast which the nine lens camera of the U. S. Coast and Geodetic Survey was designed to meet:

1. Scales of 1:10,000 and 1:20,000, the same as the inshore hydrographic surveys, to facilitate the transfer of geographic positions of objects used in locating the soundings, the shore line, and details of the foreshore for ready compilation and comparison with the hydrography. This requirement indicated a focal length of about $8\frac{1}{4}$ inches (210 mm.) entailing flights at altitudes of about 7,000 feet (2,100 meters) and 14,000 feet (4,200 meters), high enough to avoid the roughest air and low enough to avoid the need for special oxygen, respectively.

2. High accuracy of geographic position throughout the air photographic survey to avoid discrepancies difficult and expensive to correct in the combined survey.

3. The maintenance of such high accuracy of geographic position with the minimum amount of ground control measurements. A close network of ground