Chapter 1

Cameras and Lenses

1. Cameras. There are many different types of cameras used in terrestrial photographic surveying. Those first used were simple box cameras with a pinhole instead of a lens. These were spoken of as a pinhole camera. From this early camera other types have been developed. Some follow the old box type, with the addition of a lens and shutter; others are much more complicated.

The type used by the Coast and Geodetic Survey of this country is designed somewhat along the lines of that used by the Canadian Government. Most of the photographic surveys in the United States and Canada have in the past been made in rugged mountain regions and places which are quite inaccessible. This fact has led to the development of a simple type with the least number of adjustments. It has been necessary to pack the equipment over long mountain trails, sometimes by pack horse or mule and other times by the surveyor himself. The weight, therefore, has been an important factor in the design of the camera.

The Coast and Geodetic camera consists of a metal box with a lens in the front end and plate holder in the rear. The lens is shielded from the direct rays of the sun by a hood. Directly in front of the plate holder is a rectangular frame with notches cut to indicate the horizon line and the principal line. These notches are photographed on each picture and are used to locate the principal point and the coordinate axes.

The camera fits on a tripod and is interchangeable with an ordinary transit. With the transit on the tripod both horizontal and vertical angles can be measured. The camera and transit have plate bubbles for leveling and adjusting before making the shots.

2. Phototheodolite. This instrument is a combination of the transit and camera in one compact unit. Figures 1, 2, 3, 4, 5, and 6 illustrate some of the types manufactured by the Zeiss Company. Each unit has some means of establishing a line of sight which is coincident with or parallel to the axis of the camera. Some instruments have separate telescopes which are similar to a transit telescope; others use the lens of the camera as an objective lens. Figure 6 illustrates this latter unit. The left view shows the rear of the instrument. The plate holder has been removed and an auxiliary eyepiece substituted. In sighting, the shutter of the camera is left open. The lens in combination with the eyepiece forms a telescope which can be used as any telescope on a surveying instrument.

A phototheodolite has both a horizontal and a vertical circle for measuring angles.

The lens and plates used in a terrestrial photographic camera are of a very slow-speed type. Filters are usually used and long exposures made. In fact, exposures are sometimes so slow that a moving object may pass in front of the camera without making an impression on the plate.

Plates are preferred to films as there is less distortion due to shrinkage of the film and creeping of the emulsion. The only disadvantage in the use of plates is the excessive weight when packing any great distance.

3. The Aerial Camera. Most aerial cameras are equipped to use films. One type of camera uses plates, but the necessary weight of plates limits the number of photographs that can be made in one flight. Also more trouble is experienced in making the quick change necessary. Special high-speed film or plates must be used because the exposure time varies from $\frac{1}{500}$ of a second near the ground to $\frac{1}{100}$ to $\frac{1}{50}$ of a second at higher altitudes. Film strips are usually 75 to 500 feet in length and the exposures are 7 inches by 9 inches or 9 inches by 9 inches for single-lens cameras.

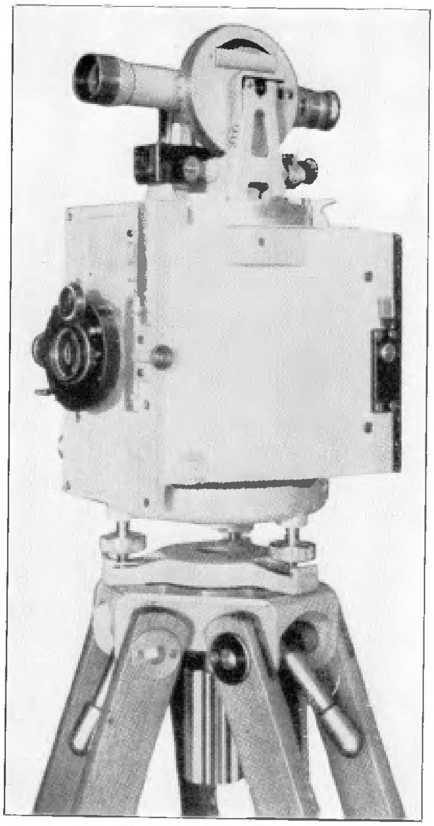


FIG. 1. Light Phototheodolite. Focal Length, $5\frac{5}{16}$ in. Plate Size, $3\frac{1}{2} \times 4\frac{3}{4}$ in.

Much surveying has been done with the single-lens camera, taking only one photograph at an exposure. After several years of experimenting in this country a five-lens camera was developed which takes five pictures simultaneously (one vertical and four obliques). This camera is the outgrowth of the three-lens camera developed in 1918 by Major

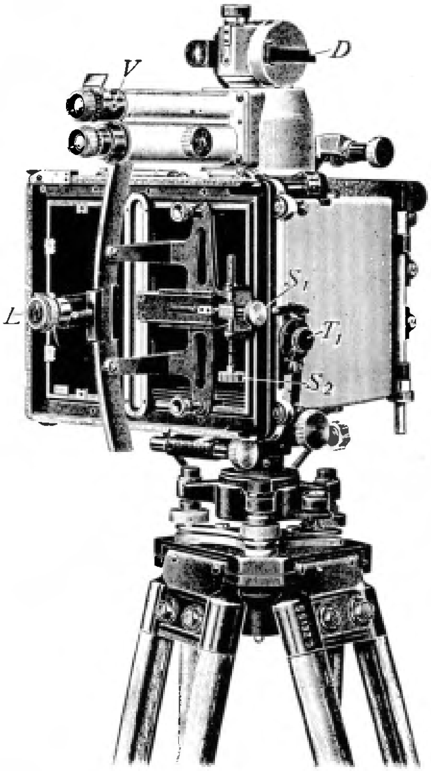


FIG. 2. Precise Phototheodolite. Focal Length, $7\frac{1}{2}$ in. Plate Size, 5×7 in.

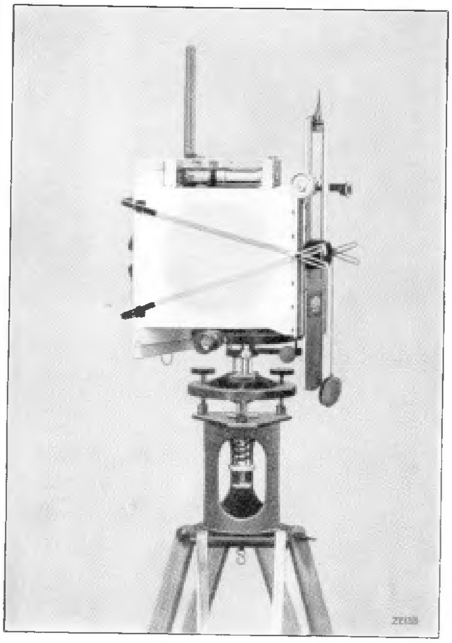


FIG. 3. Light Phototheodolite. Focal Length, $6\frac{1}{2}$ in. Plate Size, 5×7 in.

James W. Bagley of the U. S. Army Corps of Engineers. The advantages of the five-lens camera are that fewer flight strips and fewer ground control points are necessary. On the other hand a shorter focal length must be used; also the plane must be flown at higher altitudes and therefore some of the detail is lost. It is of interest to note that in the summer of 1933 the entire state of Massachusetts, with an area of 8039 square miles, was photographed with the five-lens camera in 24 hours and 40 minutes flying time. Another type of multiple-lens camera has been developed which uses nine lenses and takes nine photographs at one exposure.

As with the phototheodolite, all aerial cameras must be equipped to photograph register marks on the negative so that the coordinate axes may be plotted.

Figures 8, 9, and 10 show some Zeiss types of aerial cameras on the market today. The focal length of single-lens cameras varies from 6 inches to 28 inches and for multiple-lens cameras 6½ inches to 7½ inches.

Figure 11 shows a Fairchild F-4 aerial camera installed ready for use. Figures 12 and 13 show a K-3 Fairchild aerial camera with interchangeable lens cones (8½, 10, 12, and 20 inches). Figure 14 shows a K-7A Fairchild aerial camera designed for the army engineers which takes a picture 9 inches by 18 inches. Figures 15 and 15*a* show the Fairchild five-lens camera. Figure 15*b* shows an assembly of two five-lens cameras as manufactured

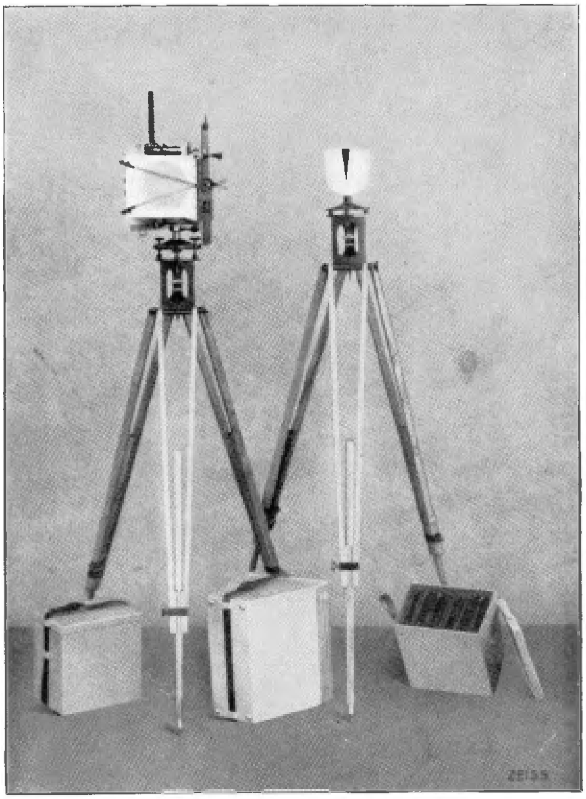


FIG. 4. Phototheodolite Outfit.

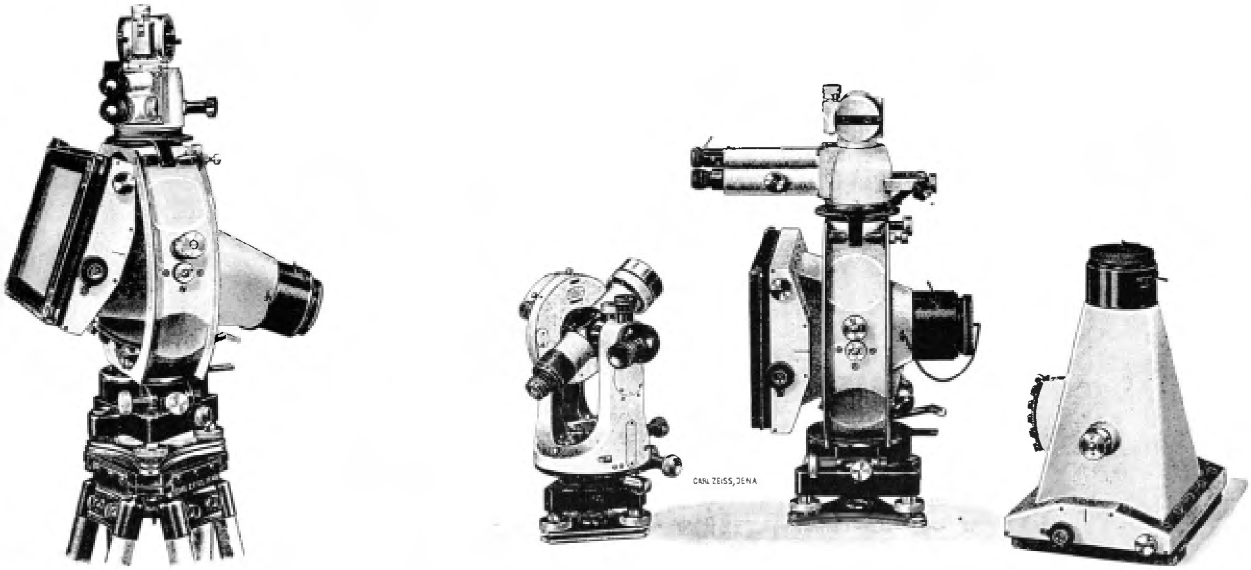


FIG. 5. Precise Phototheodolite with Two Tilting Cameras. Focal Lengths, 6½ in. and 10 in. Plate Size, 5 × 7 in.

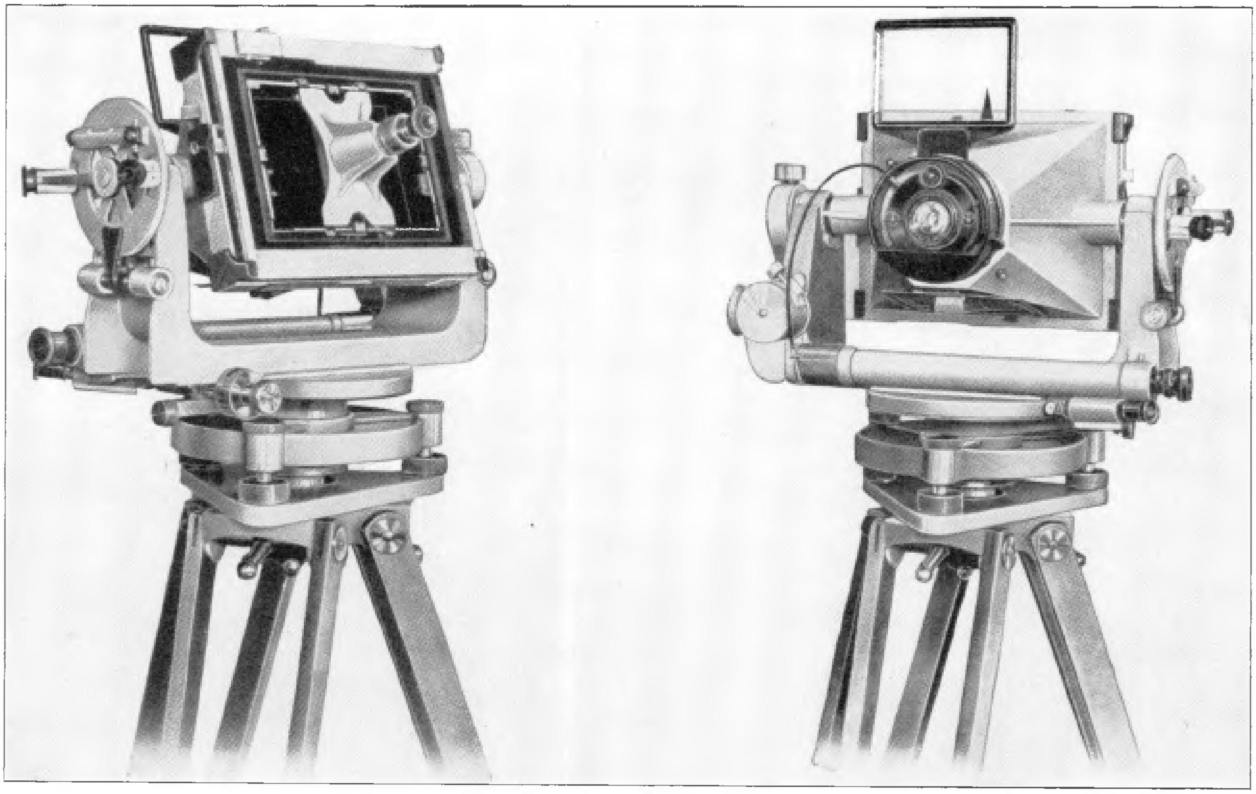


FIG. 6. Precise Phototheodolite. Focal Length, 7 in. Plate Size, 5 × 7 in.

by the Fairchild Aerial Camera Corporation which takes ten pictures simultaneously.

Some cameras are automatic. The speed of the plane is calculated, and, the desired overlap being known, a setting is made for exposures at the required interval. Some photographers object to the automatic camera because the pilot is not aware of the instant when exposures are made. They prefer to have a system of signals between the pilot and photographer so that the plane can be righted and on an even keel at the instant of exposure, the exposure being made by the photographer.

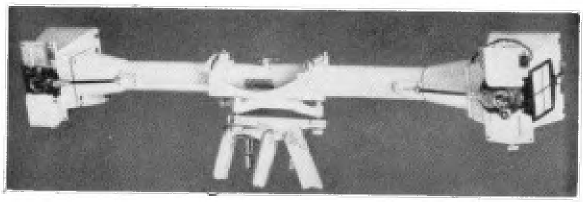


FIG. 7. Stereometric Twin Camera Used in Research Photography and Photography of Criminal Evidence.

The Multiple-Lens Camera. A great practical advantage in the use of a multiple-lens camera is the much larger area covered in a single exposure. However a shorter focal length is necessary, and this, along with the necessary higher altitude of flight, reduces the detail of the photograph. In the past few years this has been partially overcome with the improvements of camera lens and film. The first multiple-lens camera was of the three-lens type, and the resulting photographs were of the type shown in Fig. 15*c*.

The center picture is a vertical and the two wing pictures obliques. These obliques are rectified into flats or verticals.

Later developments introduced an extra oblique in the direction of flight, which takes the form shown in Fig. 15*d*.

A third form developed by the Fairchild Aerial Survey Corporation in conjunction with the army engineers is the five-lens camera, a photograph from which is shown in Fig. 15*e*.

Figure 15*f* shows the five untransformed pictures

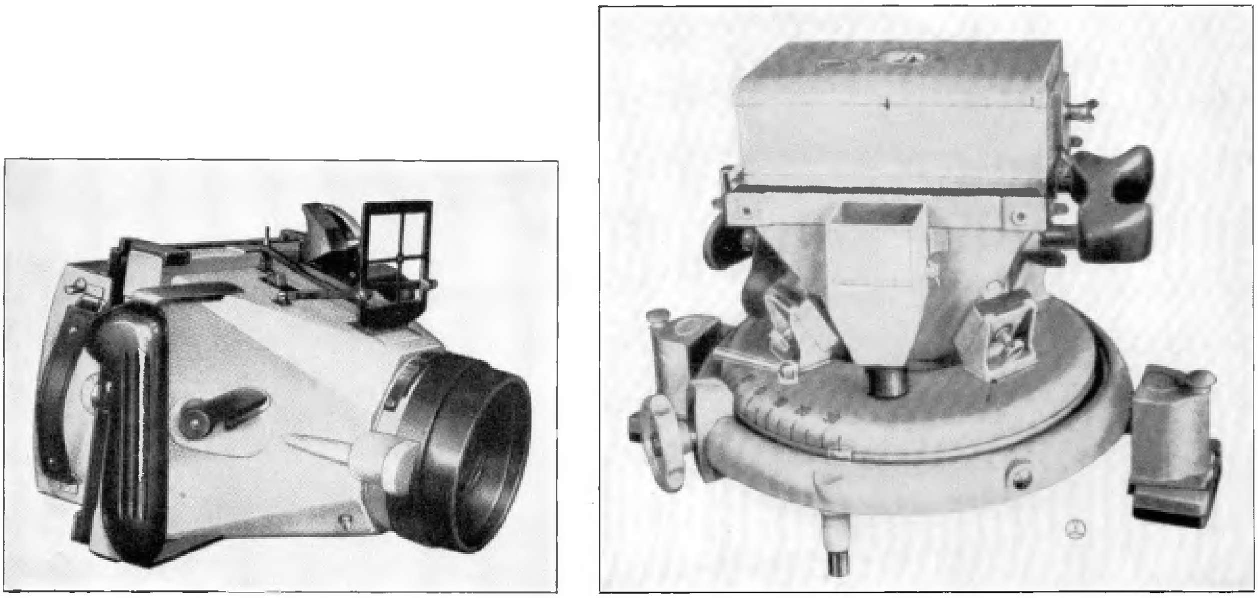


Fig. 8.

Hand Surveying Camera. Focal Length, 7 in. Film or Plate Size, 5 × 7 in.

Hand Surveying Camera in Suspension Mount for Aerial Photography.

of the T-3A Fairchild aerial camera and Figure 15*g* the correctly transformed.

In operating a multiple-lens camera the photographs are taken in flight strips and are overlapped like the single photographs. Much of the detail is lost in the outer portion of the wing pictures but they serve a valuable purpose in orienting by the "radial line method."

Another multiple-lens type of camera, developed by German engineers, uses nine lenses. This was designed with the purpose of filling in the blank spaces between the wing pictures of the five-lens camera. Special rectifying apparatus and a short focal length are required. It has the distinct advantage of covering a large area and thus reduces the number of exposures and the flying time. A description of this

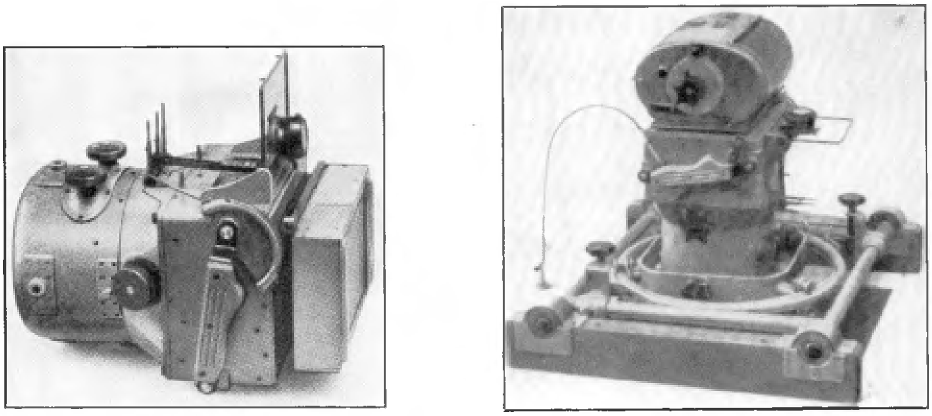


Fig. 9.

Hand Surveying Camera. Focal Length, 8½ in. Film or Plate Size, 5 × 7 in.

Hand Surveying Camera in Suspension Mount.

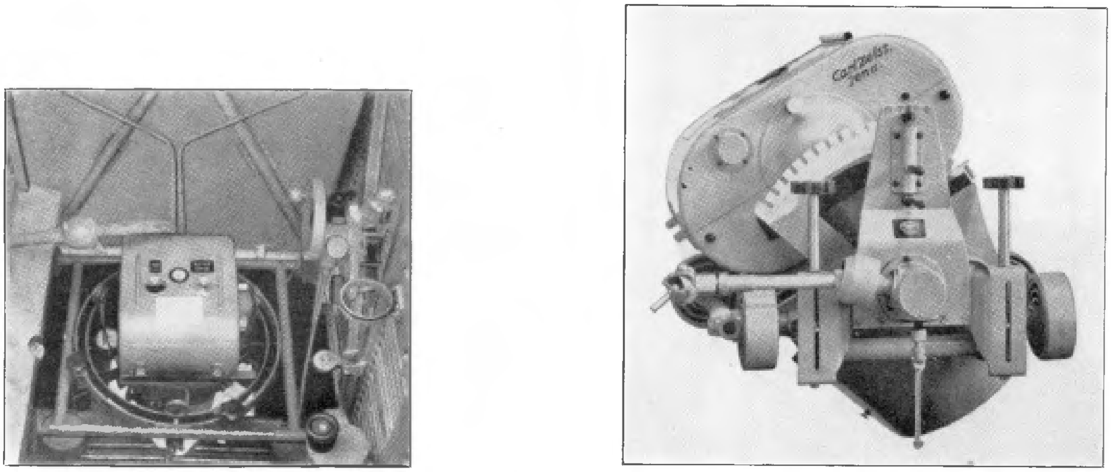


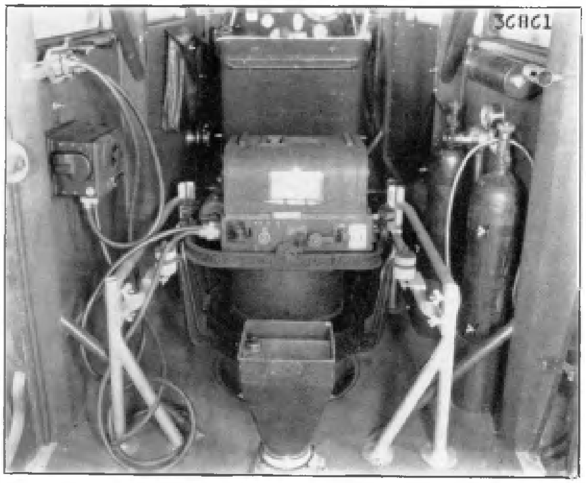
FIG. 10.

Single Serial Automatic Camera.

Tilting Serial Automatic Camera.

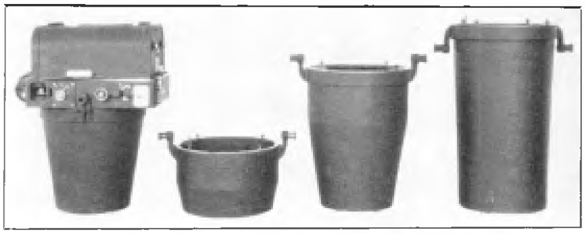
Courtesy Fairchild Aviation Corporation.

FIG. 11. Fairchild Aerial Camera with View Finder Mounted in a Plane.



Courtesy Fairchild Aviation Corporation.

FIG. 12. Fairchild K-3 Aerial Camera.

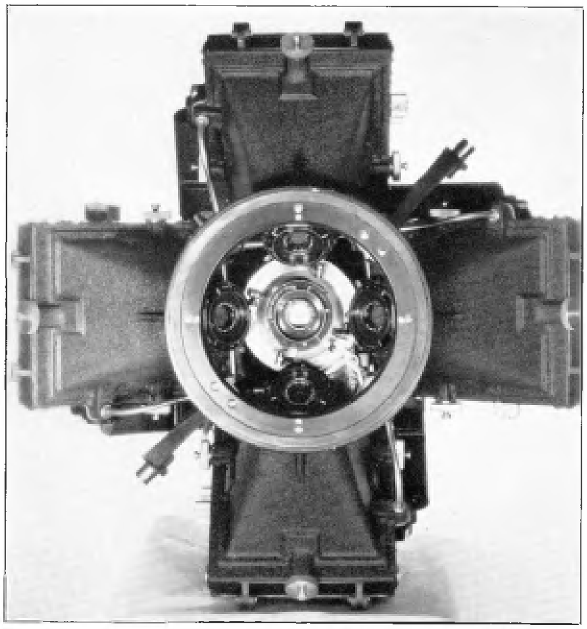


Courtesy Fairchild Aviation Corporation.

FIG. 13. The Fairchild K-3 Aerial Camera with Interchangeable Lens Cones.

Courtesy Fairchild Aviation Corporation.

FIG. 15. Five-Lens Camera.

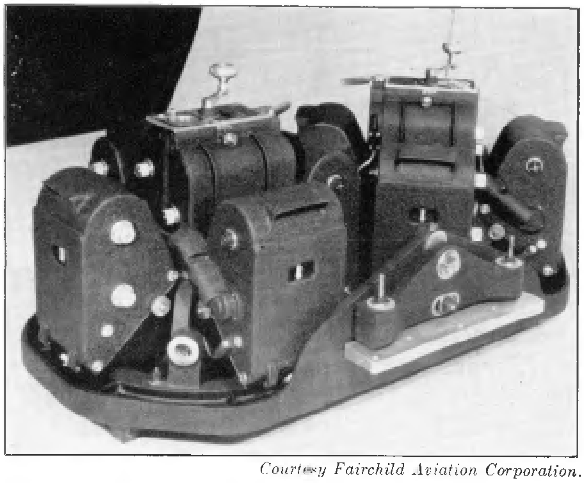


Courtesy Fairchild Aviation Corporation.

FIG. 15*a*. Five-Lens Camera.

Courtesy Fairchild Aviation Corporation.

FIG. 14. The Fairchild K-7A Aerial Camera.



Courtesy Fairchild Aviation Corporation.

FIG. 15*b*. Fairchild Tandem T-3A Camera.

camera may be found in the Proceedings of the American Society of Civil Engineers of September, 1932, page 1226.

The Coast and Geodetic Survey has constructed a nine-lens camera and transformer. The nine pictures taken at one exposure are transformed onto a single negative, forming a single picture, with a coverage equal to that of two five-lens camera assemblies set at 45 degrees to each other and mosaicked.

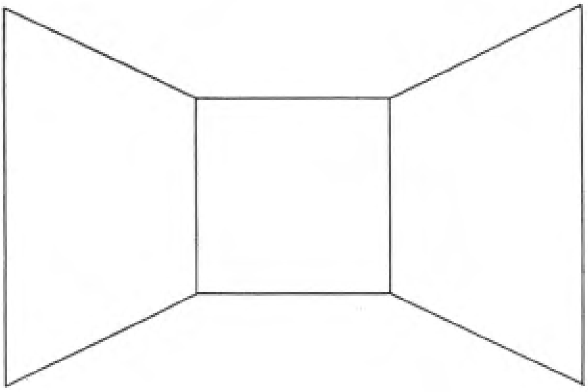


Fig. 15*c*. Three-Lens Type Aerial Photograph.

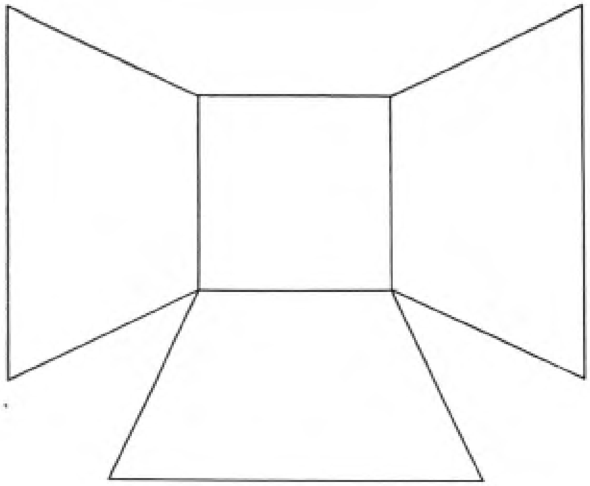


Fig. 15*d*. Four-Lens Type Aerial Photograph.

4. Precision Cameras. Plotting methods and plotting instruments have developed to such an extent that a demand has developed for a camera of high precision. It is quite useless to make refined measurements on a photograph if that photograph is full of distortions due to imperfect camera equipment. Two new precision cameras are now on the market: the Fairchild F-51 and the Abrams' explorer aerial topographic camera. Figure 16 illustrates the Fairchild camera F-51 and Fig. 17 illustrates the Abrams explorer.

The F-51 differs from the usual Fairchild cameras in that it is a single-purpose camera designed to supply precise photographs for use in conjunction with most accurate planimetric and topographic mapping.

The requirement for high accuracy in planimetric mapping is due mainly to special mapping projects for which funds are limited yet for which precision is essential. Such special projects include careful land subdivision, area determination for checking the effectiveness of crop control, area measurement for tax assessment, measurements for soil conservation, and erosion studies. Certain methods are in current use in conjunction with planimetric mapping for the above projects which enable area measurements to be kept within the remarkably small maximum error of 1½ per cent. With ground control in every photograph, the problem would be relatively simple and any high-grade camera similar to the Fairchild K-3B, K-3C, or F-14 could be used. Yet the cost of ground control in every photograph is too costly for these special projects and the method of "bridging" six or seven photographs between control must be resorted to

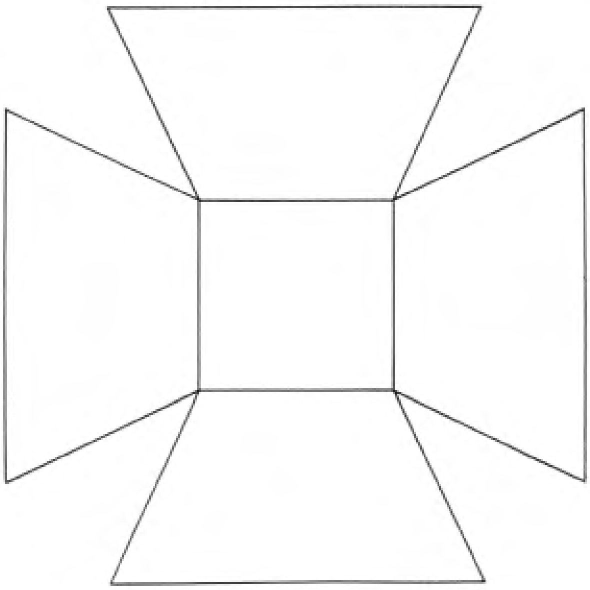
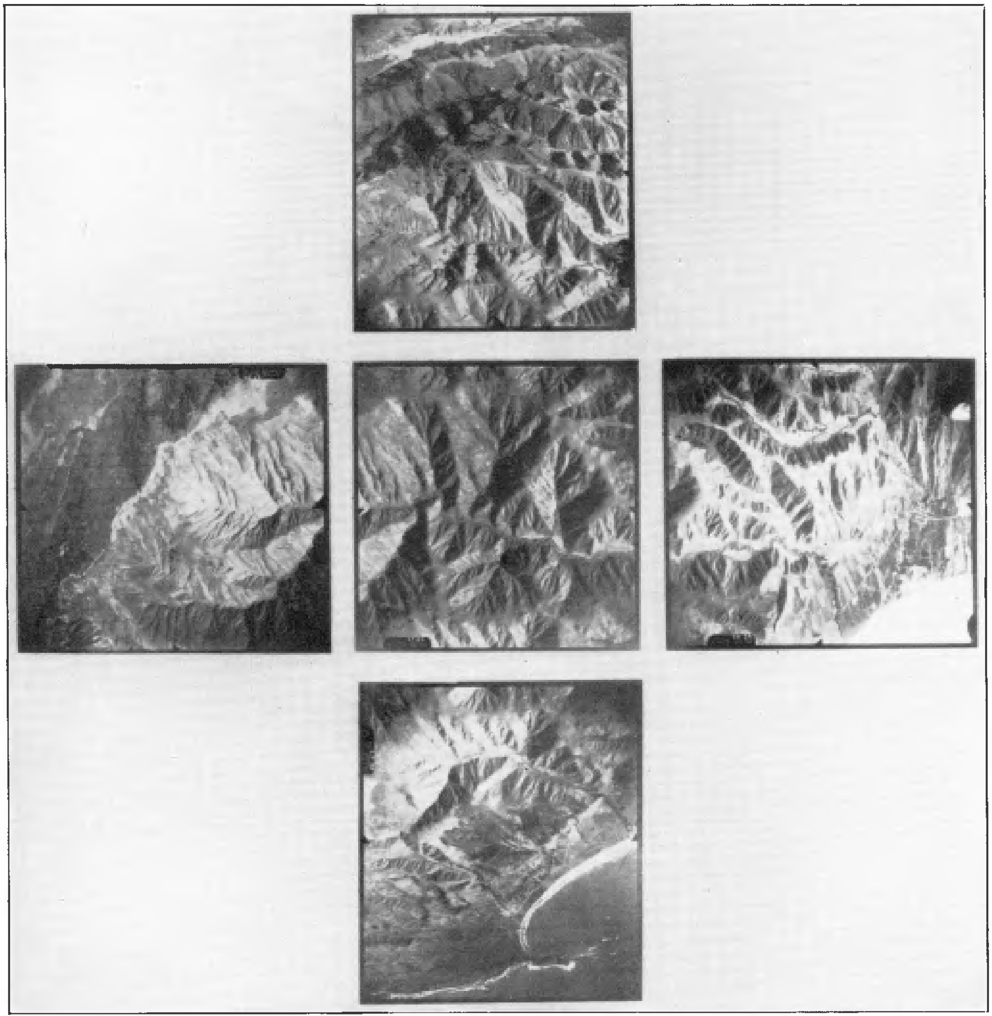


Fig. 15*e*. Five-Lens Type Aerial Photograph.



Courtesy Fairchild Aviation Corporation.

Fig. 15*f*. Contact Prints (Five-Lens Camera).

for the sake of economy. In the "bridging" process it is only through the use of a highly precise camera that the many inherent errors can be reduced to a minimum and the desired results obtained.

The most desirable, although expensive, form of map is one which shows relief by means of contours as well as planimetric positions, known as a topographic map. Such maps are almost entirely plotted through the medium of such stereoscopic plotting instruments as the stereocomparagraph, multiplex, autograph, aerocartograph, and stereoplanigraph. The principle upon which these instruments depend for the determination of horizontal and vertical distances, and subsequent plotting, is parallax difference. Even in mountainous areas, parallax difference is a small quantity. Thus, a small absolute error in a parallax measurement can introduce a high percentage of error in an elevation determination. Such parallax errors are not necessarily due to the plotting instrument but are often attributable to the aerial camera used. Only with a specially designed camera of unquestioned precision can these parallax errors be minimized and topographic maps of high quality and accuracy be obtained.

In order that the F-51 may be perfectly adapted to all types of precise mapping photography, it has been designed to utilize lenses ranging in focal length from 8¼ inches (21 cm.) to 5.21 inches (131 mm.). When the 131-mm. lens is used the camera

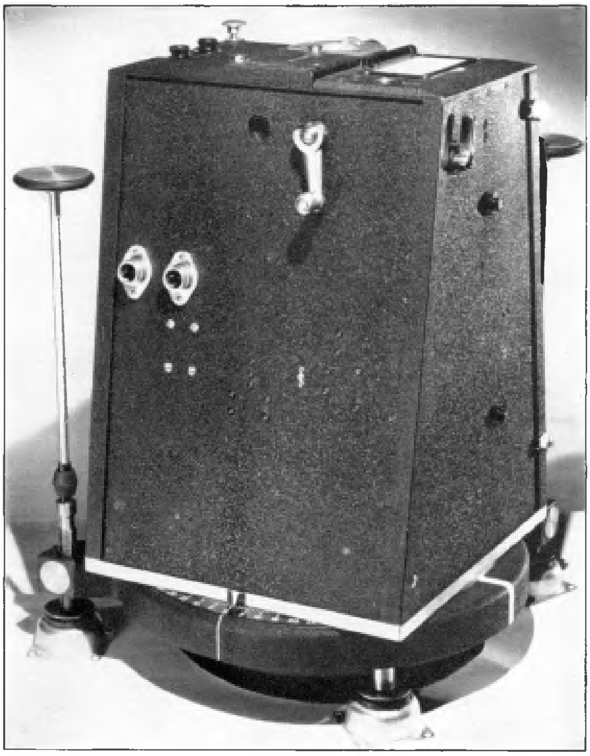
Courtesy Fairchild Aviation Corporation.

FIG. 15*g*. Rectified Prints (Five-Lens Camera).

coverage angles amount to 90 degrees, making the F-51 one of the widest angle cameras available today. The necessity for a range of focal lengths lies in the fact that the F-51 is intended for use in conjunction with both planimetric and topographic mapping. The former depends for its accuracy upon the reduction of relief displacements to approach the condition of rendering the photograph an orthographic projection. Naturally, the longer the focal length of the camera, the more nearly will this condition be approached. However, economy of photographic mapping depends upon reduction in ground control and flying, and this reduction can be achieved only through the use of short focal-length wide-angle lenses. American photogrammetrists after two years of investigation have decided upon a focal length of 21 cm. as the economical compromise for planimetric mapping photography.

Topographic mapping, through the use of stereoscopic plotting instruments, requires the use of short focal-length wide-angle lenses both for accuracy and economy. As pointed out previously, it is the principle of "parallax difference" which makes it possible to determine differences in elevation from photographs. As the angular coverage of a mapping camera is increased, the stereoscopic parallax likewise increases proportionately. Naturally, the greater the amount of parallax the more accurately can elevations be determined. At present, the 131-mm. lens is the shortest focal-length lens which can attempt to cover a negative 9 inches by 9 inches. Thus, this 131-mm. lens has been selected as the other limit of the range of focal lengths available in the F-51. With the interchangeability of lenses possible, it is significant to note that no loss in accuracy whatever results.

In the final analysis, whether the photography is being carried out for planimetric or topographic mapping, the ease and speed of use of the photographs depend upon the care taken in the aerial photography and in the photographic flying. The model F-51 photogrammetric camera is fully automatic, thus reducing the photographer's duties to a minimum. In addition, all the controls are grouped on or near the top of the camera within easy sight and reach of the photographer.



Courtesy Fairchild Aviation Corporation.

FIG. 16. The Fairchild Precision Aerial Camera F-51.

Special Conditions. The accuracy of any map made from aerial photographs can be adversely affected by any one or all of the possible errors in aerial cameras listed below.

1. A change in the calibrated focal length may occur between the time of calibration and the time of use of a mapping camera.
2. A difference may occur between the adjusted position of the principal point and the actual position at the time of use of the camera.
3. The film may not be held exactly in the focal plane.
4. The type and manner of operation of the shutter may cause unwanted distortion.
5. A poorly made and mounted filter can cause distortion.
6. A glass focal plane pressure plate also introduces distortion.
7. Excessive lens distortion is serious in a mapping camera.

With a full knowledge of the cause and relative seriousness of the above errors, the model F-51 has been designed to eliminate them or to reduce them to an absolute minimum. The means by which this reduction or elimination of fundamental errors has been accomplished is described in detail below.

Courtesy Abrams Instrument Company.

FIG. 17. Abrams Explorer Precision Aerial Camera.

Permanence of the Calibrated Focal Length. The calibrated focal length is the figure used to determine photographic scale, and it also forms the basis of positioning a negative in a stereoscopic plotting machine. Any appreciable change in the calibrated focal length will cause an error in an elevation determination equal to

$$\frac{h}{f} \cdot \Delta f$$

where h = elevation.
f = calibrated (E.F.L.) focal length.
Δf = change in calibrated focal length.

Therefore, the camera must be so designed that once the calibrated focal length has been determined, the value will remain unchanged throughout the life of the camera. The calibrated focal length is determined only after the lens has been mounted in a camera. Therefore, to preserve the calibrated focal length it is essential to preserve the metrical conditions which existed at the time of calibration. To do this, the optically and mechanically centered lens elements are permanently and rigidly mounted in heat-treated alloy housings. The lens cone is a cylinder of revolution which has been machined both inside and out to remove all strains and to give uniform wall thicknesses. Since the cone is a cylinder it is possible to machine all surfaces which link the lens with the focal plane, at the same time insuring perfect alignment in one case and parallelism in another. In the operation, tolerances of ±0.0005 are rigidly adhered to. The focal-plane plate is carefully machined so that its top and bottom surfaces are flat within 0.002 and consequently parallel within one minute of arc. Immediately after the camera is calibrated, the focal-plane plate is permanently doweled to the camera cone. Thus, for the duration of the life of the camera, the focal-plane plate and the lens cone act as one integral unit.

In order to make it possible to clean the lens element and to repair the shutter when necessary, a provision has been included which makes it possible to remove the lens without affecting the calibrated focal length. The opening in the camera cone has been machined to fit the shoulder of the lens mount with a clearance not exceeding 0.0002 inch on the diameter. The lens mount is held in place by four machine screws which are unsymmetrically placed to make it impossible to rotate the lens mount when replacing it after a cleaning or a shutter repair. Thus, removal and replacement of the lens have no effect upon the calibrated focal length.

A temperature change will cause the camera cone to expand or contract to a certain degree. A 50° C. temperature change will cause a corresponding change in focal length of a 6-inch lens cone of 0.007 inch. When this change is analyzed, using the formula $\frac{h}{f} \cdot \Delta f$, the insignificance of this temperature error will be realized. However, temperature change error is only insignificant in the F-51 because of the symmetrical design which causes all parts to change uniformly and prevents warping of the focal plane or cocking of the lens.

Permanent Location of Principal Point. The principal point of a camera is defined as "the point at the foot of the perpendicular dropped from the (rear) nodal point of the lens." All planimetric and topographic mapping assumes a correctly located principal point and depends upon this assumption for accuracy. Any deviation from the correct position will cause errors both in elevation and horizontal position of points of a magnitude expressed by

$$\Delta h_c \leqq 2\frac{Kh_N}{f} \quad \text{and} \quad \Delta l_c \leqq \frac{h}{a}\Delta_c$$

where Δh_c = error in elevation due to error in principal point.
K = constant dependent upon per cent overlap, between strips (approximately one for usual overlap).
h = elevation of point.
f = focal length.
Δ_c = change in position of principal point.
Δl_c = error in horizontal position of point.
a = altitude of flight.

In the model F-51, the principal point is located by the intersection of lines drawn through the fiducial marks which are located at the center of each edge of the negative opening. These fiducial marks are first adjusted so that the intersection will lie at the center of the focal plane opening within ±0.005. Furthermore, the fiducial marks are so adjusted that the projected lines intersect at an angle of 90° ±1′. When once adjusted, the fiducial marks are permanently doweled to the focal-plane plate and from then on act integrally with it. When the camera is calibrated at the National Bureau of Standards, the focal-plane plate is adjusted so that the intersection coincides with the principal point within ±0.003 inch. It has been mentioned previously that the focal-plane plate is doweled to the cone after calibration, thus precluding the possibility of any subsequent change in the position of the principal point.

Focal-Plane Flatness. Errors caused by failure of the emulsion surface to be maintained flat in the focal plane can be large, non-uniform, and consequently serious. Not only does failure of the film to lie flat in the focal plane cause metrical errors, but it also may impair the photographic quality. To eliminate possible error from this source, the film-flattening system of the F-51 has been carefully designed. A locating film back is provided with vacuum holes by means of which the film is held tightly and flatly to the plate. To insure flatness, the surface of this plate is so finished that it does not depart from flatness at any point more than ±0.0005. To insure proper operation of the vacuum system, the locating back is made to lift clear of the film during the time the film is moving in the camera. At the end of the winding cycle the plate clamps the film in the focal plane on all four edges, thus sealing the vacuum. Not only does this system require less vacuum for proper operation but it insures that the emulsion surface will be located exactly in the focal plane.

Type and Operation of Shutter. Focal-plane shutters under normal conditions of use can cause a distortion of the metrical characteristics of a negative approximately four times greater than the combined distortions from other sources. Therefore, the model F-51 is equipped with a between-the-lens type of shutter which, by virtue of its simultaneous exposure over the entire negative, eliminates metrical distortion in the negatives. However, to be of maximum value in aerial photography, the efficiency of the shutter should approach 100 per cent as closely as possible. The Fairchild shutter is outstanding in this respect owing to its exceptionally high efficiency, which is 88 to 94 per cent at $\frac{1}{50}$ second.

Filter. The effect of a gelatin filter with respect to a distortion of light rays passing through is unpredictable and non-uniform and hence has no place in a precise mapping camera. Glass filters of low grade are likely to give a weak prism effect owing to non-parallelism of the faces, which can be a serious defect. Likewise, a lack of flatness of the filter surfaces may cause the filter to act as a lens and affect the sharpness of the image and introduce unwanted distortion. Therefore, the F-51 is equipped with filters made from solid colored optical glass, the faces of which are held flat within six fringes and plano-parallel within very close limits. Since it is conceivable that strain due to improper mounting may be detrimental, a special filter mount is provided in the F-51 which precludes any possibility of strain.

Pressure-Plate Distortion. In many cameras the emulsion surface is located in the focal plane by a device which pressed the film against a glass plate. Light rays must therefore pass through this glass pressure plate before reaching the emulsion. As light passes through a glass plate, it is displaced owing to refraction by an amount which increases as the angle of incidence increases. In the effort to reduce or eliminate all sources of error in the F-51, no focal-plane plate is used. The film is held flat in the focal plane by the vacuum systems explained previously. Thus, there is nothing between the lens and the emulsion surface.

Camera Calibration. To be used on a mapping project for the U. S. Government, a camera must be calibrated at the National Bureau of Standards and must have a certificate attesting to its suitability for this work. The certificate number can then be marked on a plate provided for that purpose in the F-51 which will cause the number to photograph on every negative. Thus, when any mapping organization receives negatives or prints they need only to note the number and send for the certificate to learn the exact characteristics of the camera used on the photography.

Summary of Specifications

Lens. This camera may be equipped with any of the following lenses:

Bausch and Lomb f6.5 lens of $5\frac{1}{8}$ in. (13 cm.) focal length.
Bausch and Lomb f6.3 lens of 6 in. (15 cm.) focal length.
Ross f5.5 lens of 6 in. (15 cm.) focal length.
Goerz Aerotar f6.8 lens of $8\frac{1}{4}$ in. (21 cm.) focal length.

A focal length of $5\frac{1}{8}$ in. (13 cm.) will give an angle of coverage of 93 degrees.

A focal length of $8\frac{1}{4}$ in. (21 cm.) will give an angle of coverage of 76 degrees.

Shutter. Speeds from $\frac{1}{50}$ to $\frac{1}{300}$ of a second.

Fiducial marks: A very accurately machined fiducial-mark plate sits on the top surface of the lens cone. This plate is held to the cone by means of screws for which oversize holes are provided in the fiducial-mark plate. These oversize holes are provided so that the fiducial-mark plate may be shifted around during collimation in order to have the intersection of the fiducial marks coincide as exactly as possible with the axis of the lens. When this condition is found, the fiducial-mark plate is doweled to the cone, after which it cannot possibly move.

Focal Plane. The negatives produced by this camera are 9 in. × 9 in. The film is held flat during exposure by suction created by a venturi tube. Because of the design of the vacuum type of focal plane, only one to two inches of mercury vacuum are needed. The focal-plane plate actually rises to permit the film to pass through and is then forced down against the fiducial-mark plate, thereby sealing the vacuum, after which the film is drawn perfectly flat. The focal plane is actually flat within three ten-thousandths of an inch.

Film. The F-51 accommodates roll film in lengths up to 500 ft. (152 meters). This amount of film is sufficient for approximately 700 exposures. Investigations have proved that with modern high-speed photographic airplanes and most efficient operation, between 600 and 700 photographs can be made in a single flying day.

Shorter-length film can be used, if desired, and the magazine can be loaded by daylight. A special feature of the magazine is that, while a picture is being taken on one section of the film, a full 9-in. section of film is standing free within the camera to become adjusted to the conditions of temperature which exist at the altitude at which the airplane is working.

Controls. All controls, such as the winding handle, trip lever, and electrical connections, are at or near the top of the magazine within easy reach of the photographer. On top of the magazine also are knobs by which the shutter speed and diaphragm adjustments are controlled. Next to these is another knob by which the film can be punched so that it may be cut in the darkroom in order to develop the film in shorter lengths than 500 ft. (152 meters). On top of the magazine also are a pair of bubble tubes at 90 degrees to each other. These level bubble tubes are provided with a means whereby they can be adjusted or checked against a master level bubble placed on the focal plane.

Camera Mount. A new type of camera mount has been designed which is extremely compact and permits the camera to be lowered to any depth necessary, depending upon the depth of the floor of the airplane. This is essentially important where wide-angle lenses are used as in this type of camera. The design of the mount is also such that the camera hole will be practically sealed so that there will be no strong drafts of air or blinding rays of light coming up to annoy the photographer. The mount is attached to the floor by means of three supports. The level of the camera is controlled by two handwheels at the ends of flexible shafts. Although the support is a three-point type, the supports are so arranged that turning one handwheel alters the level of the camera in only one direction. This greatly simplifies the operator's work in connection with three-point support mounts. This condition is achieved by having the lines joining the three points of support form a right angle at the non-adjustable point.

This does not result in a truly symmetrical arrangement of the supports, but the deviation from symmetry is so slight that there are no harmful effects.

THE ABRAMS EXPLORER

The explorer is a camera developed by the Abrams Instrument Company. The chassis is constructed of aluminum castings and the top and bottom chassis covers are made of aluminum spinnings. The heart of the camera is made of invar steel because of its low coefficient of expansion. An aerial camera is frequently subjected to severe changes of temperature, and this camera is designed for a change of 300° F., with no dimensional change in the lens supports.

The focal plane is permanently sealed in position and does not move up and down between exposures. The heart of the camera floats on rubber, free from all dimensional changes of the aluminum casting used in the chassis.

The explorer has a film capacity of 500 feet, which is enough for approximately 650 pictures of size 9½ inches by 9 inches.

The following special features are offered in the explorer.

1. Stopwatch with sweep second-hand returning to zero after each exposure.
2. Level bubble on trigger.
3. Veeder counters for number of strip exposures and for total camera exposures.
4. Film gage showing number of exposures remaining in camera.
5. Punch for marking film.
6. Inspection door with lock.
7. Optional vacuum or air pressure or combination of both to keep film flat at instant of exposure.

8. Choice of 5-, 6-, 8-, or 10-inch lens without changing exterior of camera.
9. Special adapters for different lenses.
10. Shutters—Abrams', Compur, or Ilex.
11. Trunnion for camera mounting—optional.
12. Automatic valve for maintaining constant and correct film pressure or suction.

5. Lens Tests and Camera Calibrations. With an ever-increasing use of stereoscopic plotting instruments, it is important that a camera of high precision be used and that it be tested and calibrated by an organization fully equipped to do this work. The Bureau of Standards is best equipped with instruments and personnel to handle these tests.

Photogrammetrists should appreciate the importance of precise camera equipment. In the following paragraphs an attempt is made to give some of the fundamental requirements necessary for a good camera.

Elementary Optical Principles. Chromatic aberrations are produced by the different wave lengths of various colors as projected through the lens. To illustrate, assume that two colors A and B enter a lens where they are deflected and come to focus at different points, such as A' and B' (Fig. 18). Under normal conditions, there may be many colors entering a lens and all of them coming to focus at different points. This distortion is known as chromatic aberrations.

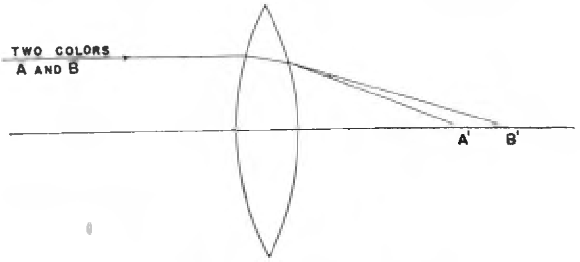


Fig. 18. Chromatic Aberrations.

Spherical aberrations are produced by slight imperfections in the grinding of a lens. The rays of light entering a lens may not come to focus in the same plane. To illustrate, assume that four rays of light enter a lens such as A, B, C, D. They are deflected and come to focus at A', B', C', D'. (See Fig. 19.)

If the lenses shown are used in a camera, it can be seen that not all the images will come to focus in the plane of the negative. The distortions are greater at the outer edges of a lens. Nearly every one has taken pictures at some time and realizes that better results are obtainable by using a relatively small aperture opening. In higher-priced cameras, most of the distortions have been removed, which is one reason they cost more.

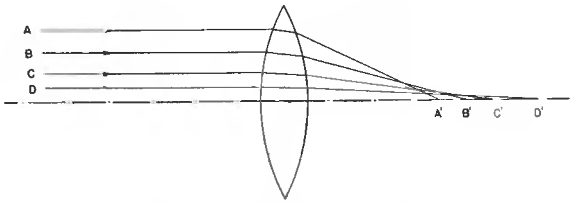


Fig. 19. Spherical Aberrations.

The F value, such as F-8, F-11, etc., is the ratio of the focal length of the lens to the diameter of aperture. Since a larger aperture opening admits a greater amount of light, there must be a corresponding reduction in the time of exposure. F-1.9 is a relatively fast lens because the size of opening (aperture) is larger with respect to the focal length and therefore admits a large amount of light.

Do not confuse the F values just mentioned with the focal length of a lens, which is usually designated by f.

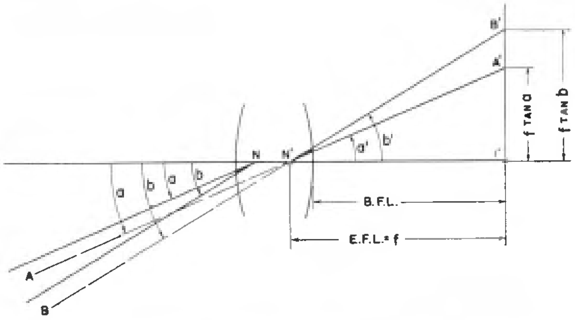


Fig. 20. Metrical Characteristics (Infinite Distance).

The metrical characteristics of an image formed by an ideal lens, free from distortions, are determined by the equivalent focal length and the location of the two nodal points. The nodal points of a camera lens are the points of unit angular magnification. To illustrate, assume a ray entering a lens from a near point at the left and making an angle a with the horizontal axis at N. It will leave the lens with the angle a at N'. N and N' are the nodal points (Fig. 20).

When the points A and B are at infinite distance, the rays pass through the rear nodal point and the images formed in the focal plane are at A' and B'. The dotted lines are parallel to the heavy lines. When a lens is tested for infinite focus, the point N need not be considered. When a camera is used in an airplane, the surface to be photographed is at a great, but finite, distance from the lens. The conditions shown in Fig. 20 can, however, be used as the distance is so great that we may assume that a sharp image will be formed in the focal plane.

The plane of the film can fail to coincide with the focal plane by 0.05 mm. without harmful results. It can be shown that satisfactory results may be obtained when this condition is satisfied:

$$\frac{D}{f} \geqq \frac{f}{0.05}$$

where D = distance to object photographed.
f = E.F.L. (Equivalent Focal Length).

Example. When $f = 150$ mm. (6 in.) D must equal or exceed 450 meters (1500 ft.) to satisfy this condition.

If the distance between nodal points is 3 mm., the angle between the lines drawn from the two nodal points to an object 30 degrees from the axis will not exceed one-half second. These values are typical and indicate the distance to the object. They may be considered as infinite for practically all aerial photography.

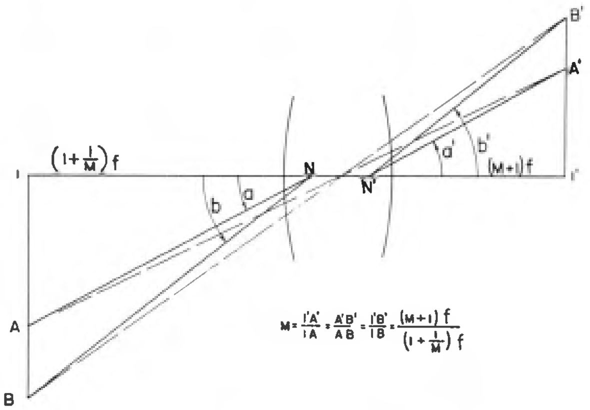


FIG. 21. Metrical Characteristics (Finite Distance).

If f is known, the angle a corresponding to any object point may be found by measuring the length $I'A'$ on the negative and using the equation, $\tan a = I'A'/f$.

Object at Finite Distance. If the object and image are at a finite distance, the metrical relations are as shown in Fig. 21.

This corresponds to a lens used for copying or rectification.

The magnification M is the ratio of a length in the image plane to its conjugate length in the object plane.

If points A and A', B and B', or any other pair of conjugate points are joined by straight lines, these lines will intersect at a point lying between N and N' and divide the distance II' into segments, one of which is M times the other. This relation is shown by the dotted lines in the figure.

N and N' do not necessarily lie in the order shown in Fig. 21. It sometimes happens that N' precedes N, that is, the vertices of the projections systems overlap instead of being separated.

DETERMINATION OF FOCAL LENGTH AND LOCATION OF NODAL POINTS

We may write the following relation

$$f = \frac{I'A'}{\tan a} \quad \text{(from Fig. 20)}$$

and this suggests a method for the determination of the focal length of a lens.

1. Two distant targets are provided, one on the optical axis and the other at a known angle a from it.
2. These targets are photographed by the lens to be tested and the distance $I'A'$ in Fig. 20 measured on the resulting negative.
3. Substitute these values in the above equations and obtain f.
4. The back focal length (B.F.L.) is measured from the rear vertex of the lens to the position occupied by the photographic plate.

All lenses having the same equivalent focal length are equivalent in that they will produce equal images.

Lenses of the same equivalent focal length may have back focal lengths that differ greatly.

A telephoto lens may have a back focal length one-half or one-fourth that of a lens of the more usual type of the same equivalent focal length.

From Fig. 20, it may be seen that the distance from the vertex of the lens to the back nodal point = E.F.L. − B.F.L.

The front focal length (F.F.L.) may be determined by reversing the lens and repeating the process to determine the distance from the front surface of the lens to the plane $I'B'$. The distance from the front of the lens to the front nodal point may now be determined.

Distortions Due to Aberrations. The statements and equations mentioned in the preceding paragraphs are all based upon the assumption that a lens is free from aberrations. Unfortunately, most lenses have these characteristics and therefore give a distorted image. It is impossible to eliminate aberrations entirely, but it is the function of the lens designer to so choose the glasses to be used and to so arrange the surfaces as to give an image substantially free from harmful aberrations when the lens is properly used. Each lens, therefore, is a compromise, and the preferred compromise is determined by the purpose of the lens. This compromise gives rise to the different types of lenses.

Most military cameras require a fast lens as many pictures must be taken under adverse conditions. In this case, it is necessary to limit the angle of view to avoid distortions at the edges of the photographs.

On the other hand, for ordinary photographic surveying, it is economical to use a lens of wider angle and less speed. In this case, the photographer may wait for favorable weather and lighting conditions.

Aberrations which interest the photogrammetrist are of two kinds:

(*a*) Those which introduce systematic errors of distortion in the metrical characteristics.
(*b*) Those producing lack of definition.

If a lens is accurately constructed so that all points are symmetrical about the axis, the distortions will also be symmetrical about the same axis. Thus, an image will be displaced radially toward or from the center of the field.

If two determinations of the focal length are made by measuring angles a and b and distances $I'A'$ and $I'B'$ of Fig. 20 and the focal lengths are determined by

$$f_1 = I'A' \tan a$$

$$f_2 = I'B' \tan b$$

it will be found generally that the two values of f are different. In cases like this, it is usual to define the equivalent focal length f as the limiting value f that is obtained as the angle a approaches zero as a limit.

With this definition of f and distortion present, we may write

$$I'A' = f \tan a + d_A$$

$$I'B' = f \tan b + d_B$$

where d is the distortion and will have different values for points at different distances from the axis.

The distortion will be zero for points near the center of the field of view and will increase directly with the distance from the center outward.

The National Bureau of Standards is equipped with a precision camera and with it the distortion may be measured at five-degree intervals from 0 to 30 degrees.

The displacement is designated as + if away from the center; therefore the correction will be negative.

Since the photogrammetrist is interested in f for use in the scale fraction, arbitrary corrections may be used where distortions exist. By arbitrarily choosing a slightly larger value of f, the corrections may be so distributed that those near the center of the field are negative and those away from the center are positive. To do this, it is necessary to have a list of the distortions at five-degree intervals. The distortion of modern cameras is usually less than 0.1 mm. even near the edge of the plate.

The focal length furnished by the Bureau of Standards is the limiting value of f at the center of the field and has not been altered to distribute the errors from the presence of distortion.

From the preceding discussion, it will be seen that the distortion of a lens used for infinite distance will be different from one used at finite distance. Therefore, when a lens is to be tested, this fact should be remembered and stated in the request for testing. A more complete description of camera calibrations may be found in *Photogrammetric Engineering*, Vol. III, Number 1.*

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* The title of the article is "The Interpretation of Lens Tests and Camera Calibrations," by Irvine C. Gardner.