tected on aerial photographs, the size and complexity of these variations are such that their effect on the aerial photo appearance of crops in the research area cannot be measured. Nearly all boundaries marking major changes in landforms are coincident with boundaries between cropped and uncropped lands. The only conceivable effect which soil variations have on the photo appearance of crops is the "mottled" texture which results from tonal variations. Weather conditions are so broad in areal spread that they extend beyond the limits of the area studied. A heavy rain which flattened small grains in July, for example, damaged all small grain crops in the study area. Whereas this damage helped to differentiate small grains, it presented no variations in the photo appearance of the three small grains.

SUMMARY

In summary, farm crops can be differentiated on aerial photographs by the unique tonal and textural qualities of their photographic images, and by objects which are commonly associated with them. Variations in farm practices and in physical conditions have little effect on the photo appearance of farm crops. Optimum criteria for differentiating from crops in Northern Illinois are found on aerial photographs taken during the second half of July.

Evaluation of Several Camera Systems for Sampling Forest Insect Damage at Low Altitude

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ABSTRACT: *Large-scale color photos can be used to appraise damage caused by several forest insects. Inherent with large-scale is blurring; this negates the advantages of having a large image. Several camera systems were given limited tests to find a simple and inexpensive way to overcome image-motion. The authors feel that this can be done best by using cameras equipped with extremely fast shutters.*

INTRODUCTION

CONVENTIONAL aerial cameras are not equipped for image-motion compensation. Nevertheless, they are satisfactory for taking color photographs to be used in detecting and locating bark beetle outbreaks in mature timber (1), (7). They are also satisfactory for photographing single dead trees or groups of trees at a medium scale (1:7920) since they present off-color images that an interpreter can easily distinguish from healthy green trees. Conventional aerial cameras cannot, however, be used satisfactorily for photographing light insect defoliations, or the terminal growth of young trees killed back by weevils. Here the material to be photographed offers targets which are small and difficult to record on film; hence, large-scale photography must be used. When conventional cameras are used, the result is considerable image blurring.

A blurred image is elongated on a photo. Thereby much fine detail is obscured. Blurring occurs during each aerial exposure and is caused by image-motion due to movements of the camera or airplane in relation to the ground surface. The naked eye detects it when an image point on a photo is larger than 1/100 inch (5). When image motion from all causes is kept to less than 1/250 inch, a photograph will have acceptable sharp definition. Figure 1 illustrates the effect that blurring has on image clarity. Other factors such as poor film resolution, faulty development, and inadequate lens systems contribute to poor-quality photography, but are not related directly to blurring.

Because of the need for large-scale, sharp

FIG. 1. 70-mm. stereo pairs of a parking lot. Upper pain was blurred by excessive image motion (shutter speed, 1/200 second). Image-motion was eliminated on lower pair by using a high-speed shutter (1/1,000) Scale 1:500.

photographs in sampling many kinds of forest insect damage, several camera systems have been evaluated at the Beltsville, Maryland, Forest Insect Laboratory, for possible adaptation to single-engine planes, such as the Cessna 180 or 195. Advice, equipment, and experience were obtained from the Armed Forces since they too have been faced with image-motion problems in obtaining military intelligence through photos taken from low-flying jet planes.

This paper contains description and evaluations of several nonclassified military camera systems. Some of these have been actually tested by the Laboratory. Others, although not tested, were examined for possible application to survey programs. Selection of equipment for testing or examination was limited to those systems that produce blur-free photographs, that are adaptable to small aircraft, and are simple to operate and maintain, and that are relatively inexpensive.

IMAGE-MOTION COMPENSATING (IMC) CAMERAS AND DEVICES

This family of devices is designed to stop image-motion along the flight-line of low-flying, high-speed aircraft. Associated with low-altitude flight are turbulent air conditions that cause pitch, yaw, and roll through the three axes of the airplane; these bumpy air conditions cause camera movement away from the nadir in all directions, and can result in blurred images regardless of the corrections made along the line of flight.

SONNE CAMERA

This is a continuous-strip camera that was developed near the end of World War II, primarily to take low-altitude pictures of enemy beaches preparatory to amphibious landings. It is manufactured by Chicago Aerial Industries, Chicago, Ill.; improvement has been continuous since 1945. The Sonne is reported to have produced clear pictures at a scale of

1:250 from jet aircraft flying at 1,000 m.p.h. It is probably the only strip camera that can be used for low-altitude stereo coverage from supersonic aircraft.

The Sonne has no shutter. The exposure is made as the film moves continuously, in synchronization with the ground speed, past a slit at the focal plane; thus, image-motion caused by the aircraft moving forward is effectively eliminated. Film movement varies from 0.2 feet to 50 feet per second. Because of the difficulty in installing this complex system in a small plane, only an examination of its component parts and an inspection of photographic results were made. The equipment consists of: (1) a camera with magazine and stereo lens assembly; (2) a photo-electric cell scanner; (3) an amplifier with servo unit; (4) a generator assembly; and (5) a control assembly.

Disadvantages:

1. The Sonne is too bulky—16 cu. ft. of cabin space is needed—for installation in commercial, single-engine photographic planes, and requires too great a power demand. Most small planes have 12 volt, low-amperage (25–35 ampere) electrical systems (300–400 watts).
2. Image-motion is stopped only in the direction of flight; thus, images are frequently distorted—straight roads have waves and curves, houses appear as parallelograms, etc. —because of roll through the aircraft's longitudinal axis.
3. Scale is frequently difficult to determine accurately along the line of flight. Gross measurement errors can result because slight variations in the film transport speed can lengthen or shorten an image at the focal-plane.
4. This equipment is expensive to buy (approximately $12,000), to maintain, and to install in a small plane.
5. A special viewer is required to obtain a 3-dimensional image.

IMAGE-MOTION COMPENSATION MAGAZINE

This system, which operates in a manner comparable to the Sonne camera, was developed so that image-motion compensation could be adapted to conventional cameras. Here the film is moved in a direction opposite to the line of flight, at just the right speed, during the instant the shutter is opened. When operating properly, this camera system produces sharp photographs.

An entire unit embodying this principle was borrowed from the Air Force in January 1956 for a period of 9 months. The equipment (Figure 2), except for the camera and power supply, was built by Chicago Aerial Industries, Inc., and consisted of the following units:

Description	*Weight*
K-17C aerial camera—rapid recycling ($1\frac{1}{4}$ sec.) 12 inch focal-length	20
IMC magazine (A-18 model)	57
Amplifier	
Control box	40
Inverter	
Extra 12-volt battery	
	117

Advantages:

1. Excellent, sharp pictures can be taken at 500 feet above ground when flying at 150 m.p.h.;
2. Conventional steroscopic viewing is possible.

Disadvantages:

1. The power supply available in small aircraft is inadequate to handle the 500 watts necessary for this equipment. A small twin-engine plane with two 24-volt generators would be more suitable.
2. The large bulky magazine and accessory equipment occupies about 16 cubic feet of cabin space. It is also heavy and difficult to balance in a conventional camera mount.
3. No fiducial marks are available; this makes it difficult to locate principle and conjugate photo-points which are essential for making measurements on prints.
4. It is a piece of complex electronic equipment that requires elaborate test equipment and an electronic technician in the event repairs are needed.
5. On all four corners of the print, distortion is quite pronounced at scales of 1:1,000 or larger when the 12-inch focal-length camera is used. A longer focal-length (24 inches) would relieve this distortion.
6. Stereo overlap cannot be obtained because of the slow ($1\frac{1}{4}$ sec.) recycling time of the K-17C camera if combinations of low altitude and high airspeeds are used. For example, to obtain 60-per cent overlap at this altitude the plane must be slowed to 80 m.p.h. to permit the camera to recycle.
7. Image-motion compensation is available only along the line of flight (x axis).
8. Estimated cost of magazine and necessary components is $3,460.

PANNING CAMERAS

One of the simplest methods for stopping image-motion is to move the camera along

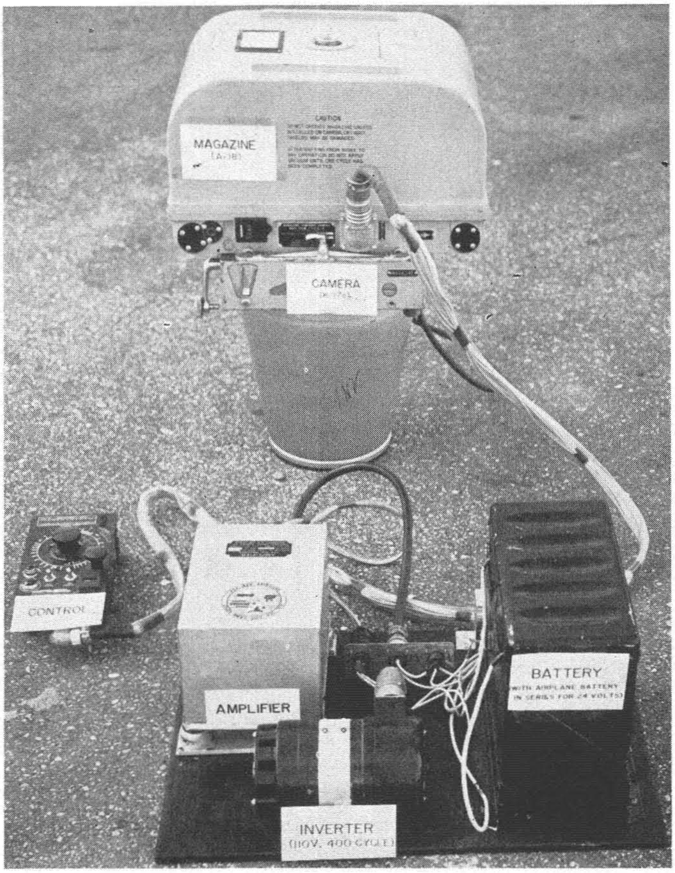

FIG. 2. A-18, image-motion compensation magazine mounted on K-17C camera with control box and amplifier. Auxiliary battery is hooked in series with airplane battery and furnishes 24 volts. An inverter provides 110 volts a.c., 400-cycle current to amplifier.

with the moving object and snap the picture when the two appear to be traveling at the same speed. It is called panning. This method was tried by Losee (4) when taking vertical photographs of timber in Canada for inventory purposes. In his tests the cameraman panned a 24-inch focal-length camera from an altitude of 2,400 feet. Losee claims that 66 per cent of the blur due to image-motion was eliminated and that the resulting photography was excellent.

How consistent the results would be for such a manual operation over many photo impulses is not known. Much would depend upon the ability of the photographer to consistently move the camera at the proper speed and snap the shutter when the camera crosses the nadir. Large-scale photography would impose a heavier load on the overworked photographer.

A mechanized panning system was developed by U. S. Navy personnel of the Experimental Project Branch, Overhaul and Repair, North Island, Calif., as an interim answer to the need for an operational IMC device (6). This device, called the "Wiggler" (Figure 3), is for use with conventional aerial cameras that are flown in jet aircraft. It accomplishes image-motion compensation through camera oscillation, as was done manually in Losee's test. The pilot has complete control of this device for varying altitudes and ground speeds.

In operation an electrical impulse energizes a drive motor in the "Wiggler." This accelerates to full r.p.m. within 180 degrees of rotation, and oscillates the camera. The angular velocity attained by the camera is determined by fulcrum displacement, the latter being controlled from the cockpit. As the camera swings aft through the vertical, a micro switch trips the shutter. A second micro switch stops the drive motor after one complete revolution and returns the camera to

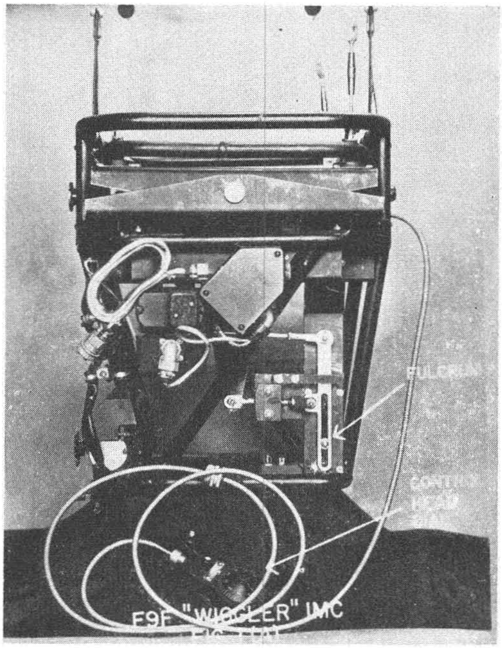

FIG. 3. Navy "Wiggler" device developed to overcome image-motion compensation for conventional aerial cameras.

the starting position for the next pluse. The minimum interval between pulses is 1 second, which is faster than the recycling time of most cameras.

Of all the devices to overcome blurring due to image motion, this one seems the simplest and cheapest to build and maintain. The Navy has used it successfully, and it should have application in civil photography taken at low altitudes. As with the Sonne camera and IMC magazine, however, blurring is arrested only along the line of flight.

HIGH-SPEED SHUTTER CAMERAS

Until very recently, aerial color photography was restricted to shutter speeds not in excess of 1/225 second, because of low film sensitivity. In 1955, however, the Ansco Division of General Aniline and Film Corporation developed a means of increasing the sensitivity of their color films, and these are now comparable to the faster black and white films. By underexposing to an ASA (American Standards Association) of 125 and then over-developing according to Ansco recommendations, very acceptable color pictures can be taken with Anscochrome film having normal ASA rating of 32. Transparencies with still better color balance result when using Super Anscochrome, ASA 100, with normal development. These improvements in color film permit the use of high-speed shutters to stop image-motion along all axes in place of the more complicated devices described earlier.

ZEISS AEROTOPOGRAPH RMK 21/18

Only brief mention will be made of this aerial camera because it embodies a high shutter-speed (1/1,000 second), and a fast f 4.0 lens to take advantage of the new type color film. There seems to be little doubt that the electrically-driven, continuously-rotating shutter designed for this camera can be surpassed in efficiency. The Engineering Division of the Forest Service, U. S. Department of Agriculture, has purchased one of these cameras ($8\frac{1}{4}$-inch focal-length and 7-inch format) and a C-8 stereoplanigraph for conducting road and cadastral surveys (3). Samples of large-scale photography (1:1,000) taken with the camera are extremely sharp and distortion free, which speaks well for the advanced design lens and fast shutter. The primary drawback to this equipment is its cost—$14,800. Secondly, the camera mount, camera, and intervalometer make up a large bulky unit (183 pounds) that would be difficult to install in most single-engine planes.

70-MM. CAMERAS

Because of the need for highly developed miniature camera systems in photo intelligence work, several 70-mm. cameras with high shutter-speeds have been produced. Small-format photography fits well into a sampling survey program. Most insect outbreaks are randomly located. Therefore, detection of damage by color photography lends itself to a sampling procedure that can be subjected to statistical treatment. Strip sampling of outbreaks is advantageous for two reasons: (1) records of population changes and fluctuations in extent of timber damage can be obtained without having to resort to 100 per cent photographic coverage and (2) costs are much less for sample photographic coverage and are not too high for use with relatively low-value crops.

On the basis of sample strip photography being adequate for conducting forest insect surveys, the 70-mm. system, which has been developed for use in photo intelligence work, was examined. There are three main advantages to this system: (1) the cost for equipment and materials (cameras, film, developing tanks, chemicals, viewers, etc.) is lower than for large-format photography. (2) The size of the equipment simplifies installation, use, and storage. (3) 70-mm. photos with 60

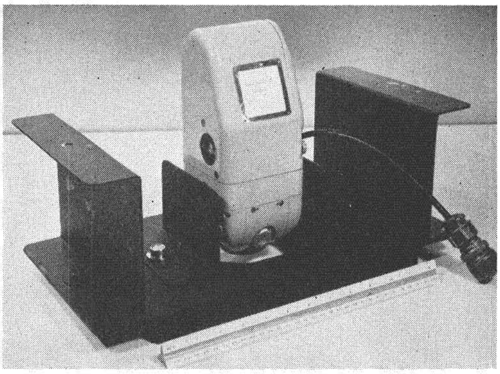

FIG. 4. J. A. Mauer, Model P-2, 70-mm. camera and magazine mounted on adapter to fit NR1A camera mount.

per cent or more overlap have a parallax base that varies from 1.6 to 1.7 inches; thus permitting easy viewing of roll film with a pocket stereoscope. (Because of the ease in interpreting rolls of film in this manner, costs for obtaining photo intelligence should be reduced markedly for color strip photography.)

J. A. MAUER, MODEL P-2

The Air Force has several thousand units of Model P-2 (Figure 4) for use as aerial-strike cameras in fighter aircraft. The main advantages over the 16-mm., gun camera used formerly are (1) a larger format ($2\frac{1}{4}$ by $2\frac{1}{4}$ inches as compared to 0.3 by 0.4 inches) which makes inspection easier, and (2) very sharp pictures that are suitable for enlargement.

The specifications are as follows:

Size—Magazine 4 1/32 by 4 1/32 by 9 7/16 inches equipped with 3-inch focal-length lens.
Weight—9 pounds loaded with 50 feet of film.
Electrical requirements—24 to 29 volts d.c., 4.0 amperes.
Shutter speeds—1/500, 1/1,000, and 1/2,000 second; focal-plane type.
Lens—f 2.8—3 inch focal-length.
Frames per second—5.5
Magazine loading

In February 1957, a borrowed P-2 camera with color film was flown over a test target at Beltsville, Md.* under conditions that were rigid enough to provide a thorough evaluation of the camera. A Cessna 195 was flown at 100 m.p.h. at 4 altitudes—125, 250, 500 and 1,000 feet. This gave scales of 1:500, 1:1,000, 1:2,000, and 1:4,000. Only the 1/500- and 1/1,000-second shutter-speeds could be used with the color film then available. Intervals between impulses were $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 seconds for each increase of flying height. This gave 60-per cent overlap. A specially designed electronic intervalometer (2) was used to produce timed intervals (0.125 to 30 seconds).

Advantages:

No loss in image sharpness on photos taken at the lowest altitude (125 feet) and at a shutter-speed of 1/1,000 second was found. The camera was light in weight and easy to work within small aircraft. Its small magazine was simple to load and unload in the close confines of a changing bag. No mechanical malfunction of the camera could be found in this limited test. It was very positive-acting and seemed to be excellently designed and well made.

Disadvantages:

1. The 24-volt d.c. electrical demand requires either the installation of an additional battery or a dynamotor to furnish the proper voltage in a small plane.
2. The short focal-length (3-inch) lens exaggerates parallax, which makes stereo viewing of tall objects taken at a large scale difficult. A longer focal-length lens is now available.
3. Only 3 shutter-speeds, 1/500, 1/1,000, and 1/2,000 second, are available. A wider selection of speeds would be desirable to permit color photography under more varied light conditions.
4. The cost of camera and magazine equipped with 150-mm lens is $3,200.

HULCHER 70, MODEL 102

This camera (Figure 5) was developed for sequence photography in tracking missile firings, because both 16- and 35-mm. movie cameras lacked ability to produce sharp images on which precise engineering measurements could be made. In addition to its use in the ordnance field, the Hulcher 70 is likewise used by press and sports photographers because of its ability to get action shots with no blur; also because of its large $2\frac{1}{4}$-by $2\frac{1}{2}$-inch format, and its portability and ease of operation.

The specifications are as follows:

Size—$6\frac{3}{4}$ by 8 by 18 inches with 150-mm. (5.9-inch) lens.
Weight—18.5 pounds when loaded with 100 feet of film.

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* J. A. Mauer, Inc., N. Y., loaned the P-2 to the Beltsville Forest Insect Laboratory for a 2-week period.

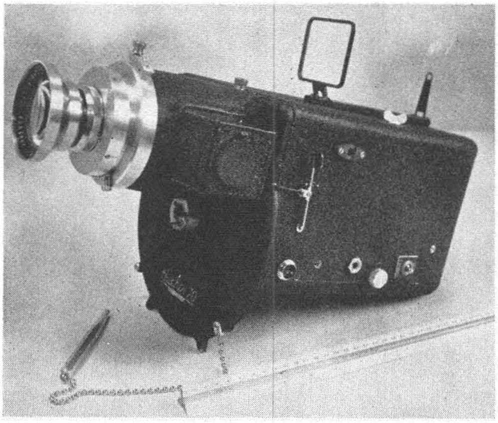

FIG. 5. Hulcher 70-mm. camera equipped with 150-mm. Schneider lens.

Electrical requirements—12 volts d.c., 7 amperes.

Shutter-speeds—1/25 to 1/7,200 second with any intermediate combinations; rotary focal-plane type shutter.

Frames per second—(1) 5 to 20 when the camera is used in sequence as a movie camera; (2) Up to 8 when used by pulse operation from an intervalometer as a conventional aerial camera.

Film is loaded directly into camera body—not magazine loaded.

Lens—f 2.8 Schneider Xenotar, 150-mm. focal length.

The Hulcher Company loaned a camera to the laboratory in April 1957, to conduct a series of tests similar to those made with the Mauer P-2 camera. Only the lowest scale (1:500) photography was tested, mainly because it would constitute the severest test of the camera's ability to overcome image-motion and to recycle fast enough for a 60-per cent overlap. The photographic results obtained were equally as good as those obtained with the Mauer. All pictures were exceedingly sharp despite bumpy flying conditions at 250 feet above the ground.

Advantages:

1. The infinite combination of shutter speeds permits the use of color film under many light conditions.
2. Because of the simple design, repairs can be made by nontechnical personnel.
3. The rapid recycling feature permits a wide range of flight speeds and altitudes.
4. For recycling speeds in excess of 8 frames per second, the camera can be used on sequence operation up to 20 frames per second.
5. Cost—$2,000 for all lens and accessory equipment needed to convert it to aerial operation.

Disadvantages:

1. The Hulcher 70 is more bulky than the Mauer and is twice as heavy; however, it is still quite small when compared with most aerial cameras. It is roughly the same size as the K-20 hand-operated aerial camera.
2. If the Hulcher is loaded or unloaded in daylight, about 6 feet of leader and 2 to 3 feet of trailer film are lightstruck. Therefore, some care must be exercised to avoid making exposures on these parts of the film. An indicator light to show when the film supply spool is exhausted should be installed for aerial work.

Ten 100-foot rolls of color film were exposed in July and August of 1957 with the Hulcher 70 and no malfunction was experienced in any of the 4,500 exposures. Images on the transparencies were extremely sharp and permitted accurate evaluation.

CONCLUSIONS

Of the camera systems evaluated in the limited tests at Beltsville, image-motion was overcome most effectively by cameras employing high-speed shutters. Cameras with shutter-speeds of 1/1,000 second or faster produce blur-free photos without resorting to complex electronic systems that are both expensive and bulky. The Zeiss Aerotopograph camera seems best suited for large-format photography. Of the smaller 70-mm. cameras, the Hulcher 70 seems most adaptable to all photographic conditions.

Because of recent advances made in the developing process for the more sensitive color film (Anscochrome and Super Anscochrome), full advantage can be taken of high-speed shutters. This combination of factors offers many potentialities for improving assessment of forest insect damage. It is also probable that tree measurements and timber typing can be made more accurately with this superior kind of color photography.

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Differential Elevation by Adaptation of the Parallax-Correction Graph to Parallax Measurements on Aerial Photographs

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ABSTRACT: *This paper describes a method which will assist the photogrammetrist in attaining greater accuracy in determining elevations from aerial photographs. Through the use of simple and inexpensive equipment and the application of correction factors, the effects of distortion and mis-orientation on parallax measurement are reduced to a considerable degree, thereby improving the accuracy of the values used in the determination of elevation.*

DISTORTION in aerial photographs has long been appreciated as an active source of error in parallax measurements taken on aerial photographs for the purpose of determining elevation. Likewise, systematic errors may be introduced by tilt and mis-orientation of the photographs in mounting them for stereoscopic viewing. The purpose of this paper is to describe a method of applying corrections to observed parallax measurements which will substantially improve the quality of the measurements.

This method contemplates the use of a lens or mirror stereoscope with a parallax ladder (for description and use see Figure 6).* These, when skillfully employed, enable the photogrammetrist who is limited in experience and equipment to improve his accuracy in determining elevations from aerial photographs.

A stereo-pair of photographs is carefully oriented and mounted securely so that the flight line of each photograph is superimposed in extension with that of the other, and separated from each other the correct amount for the creation of a clear stereoscopic model when viewed with a stereoscope.

Parallax measurement between points of corresponding imagery is accomplished by means of the parallax ladder.

The formula used to convert parallax measurement into difference in elevation varies somewhat from the conventional form in that the photo-base, employing the average measurement between the principal and conjugate principal-points of each photograph, is dispensed with and the total separation distance between the principal points of the stereo-pair is employed.

Referring to Figure 1 it is shown that

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* With the lens stereoscope the author employs a simple mirror accessory which permits the mounting of a stereo-pair without overlapping, and simplifies the application of the parallax-correction graph.