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 $5\frac{1}{2}\times6$ 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

control is usually more expensive than other survey operations along the coast due to difficulties of landing, and access from boats, often the only practicable means of transport.

The requirements of high accuracy of geographic position with a minimum amount of ground control led to the design of a multi-lens camera because previous experience with single lens, and four and five lens photographs had indicated that considerably higher accuracy of geographic position could be maintained with the multi-lens, given an economically restricted amount of ground control. Experience had also indicated a noticeable loss of detail from single lens photographs enlarged to cover approximately the same usable area as multi-lens photographs on the scale of 1:20,000.

Design and Construction

Having decided upon a multi-lens camera of approximately $8\frac{1}{4}$ inch (210 mm.) focal length, the first step was to test all air survey lenses of wide field and low distortion available at the time (1934). As a result of these tests the Ross Wide Angle Express lens was selected. This lens covers a field of 68° at f/4 with distortion not exceeding 0.05 millimeter. It resolves 14 lines per millimeter provided the focal plane is set somewhat short of the best definition on the axis to obtain the best average definition throughout its field. The nine lenses delivered matched each other in focal length within one-tenth millimeter after the nodal separation of one lens had been changed slightly in accordance with the instructions of the manufacturer.

The 68° field of the lenses selected made it practicable to use a single reflection for deflecting the images of the marginal lenses and to obtain a field 130×130 degrees square for the composite photograph by the use of nine lenses. A single film and a single composite photograph were decided upon as presenting marked advantages in uniformity of processing and shrinkage as well as convenience in production. Incidentally, a field of this angle and a focal length of $8\frac{1}{4}$ inches (210 mm.) give a composite photograph 35.4 inches (90 cm.) square, about the largest size that can be conveniently handled in plotting operations which require a close examination of the center of the photographs.

The use of prisms to deflect the images of the marginal lenses would have been difficult and expensive because of the large size required. Prisms of the size required would have been much slower than their mounts to take up the changes in size due to the large changes in temperature encountered in air photography and possibly difficult to hold in adjustment. In accordance with the suggestion of Mr. George E. Merritt, an experiment was made using a mirror of high chromium steel fastened to a frame of the same material. This assembly preserved its flatness within one fringe (0.00025 mm.) throughout several chillings to $-40°$C. Accordingly, the mirrors, the framework supporting them and the lenses and the lens barrels are all made from the same billet of this steel. This construction has been effective in holding the adjustment of the air camera without appreciable change through some fifteen flights, about half of which have been above 20,000 feet (6,000 meters). The mirrors are screwed solidly down on adjustable studs which are in turn locked to the supporting cone by lock nuts. It was practicable to adjust the mirrors and flatten them to a tolerance of 10 fringes. The reflectivity of the mirrors was increased from about 65 to 85% by having them coated with evaporated aluminum, a process developed by Mr. Robley C. Williams at Cornell University and used by the Evaporated Films Company. The mirrors have retained this reflectivity without deterioration for more than two years. The general design of the air camera is diagrammed in Fig. 1.

A two lens transforming printer is used for making the composite photograph from the nine image air negative (Fig. 2.). The air negative is centered in a holder between glass plates by means of adjustable sockets. At the same time the shrinkage and distortion of the film is measured. The holder is then

DIAGRAM OF C & G S NINE LENS AIR CAMERA

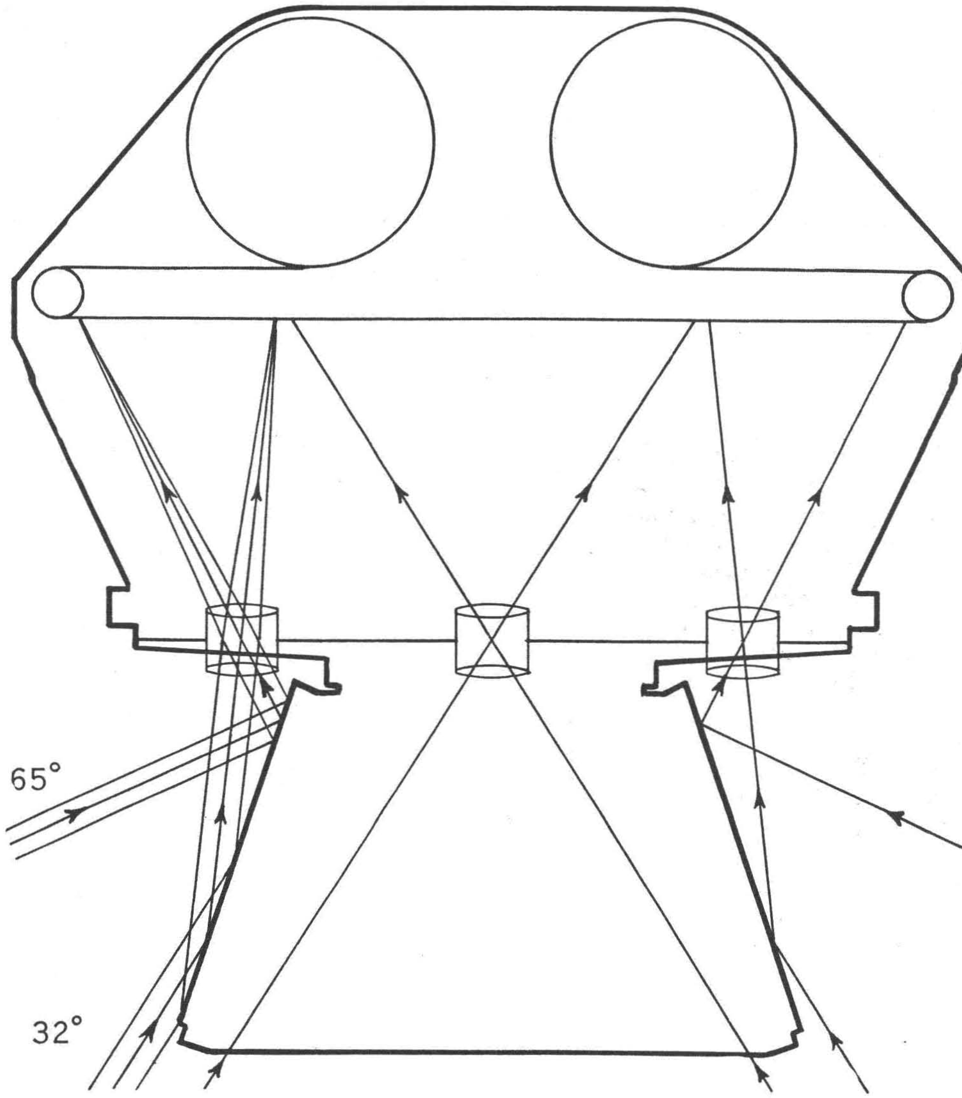

Fig. 1.

placed on dowels on a rotating carrier on the side of the printer and each marginal image is printed in turn. The vacuum plate holding the sensitized surface flat is connected by gearing to the film carrier, final setting being obtained to within 0.001 inch (0.025 mm.) by means of pins grasped in "V" jaws. After the projection of the oblique chambers the holder is placed on top of the printer and the central image is projected. Masks protect the parts of the sensitized surface not being projected. The printer is adjusted to compensate for the distortions caused by the glass of the film holder within 0.05 mm. Micrometer motions have been installed to compensate for the shrinkage and distortion of the film by which it is practicable to keep the errors of the projected composite within 0.01 inch (0.25 mm.), provided low shrinkage film and paper are used and the humidity is not allowed to decrease below 40%.

The National Bureau of Standards was freely consulted when writing specifications for the camera and each optical part was tested there before accept-

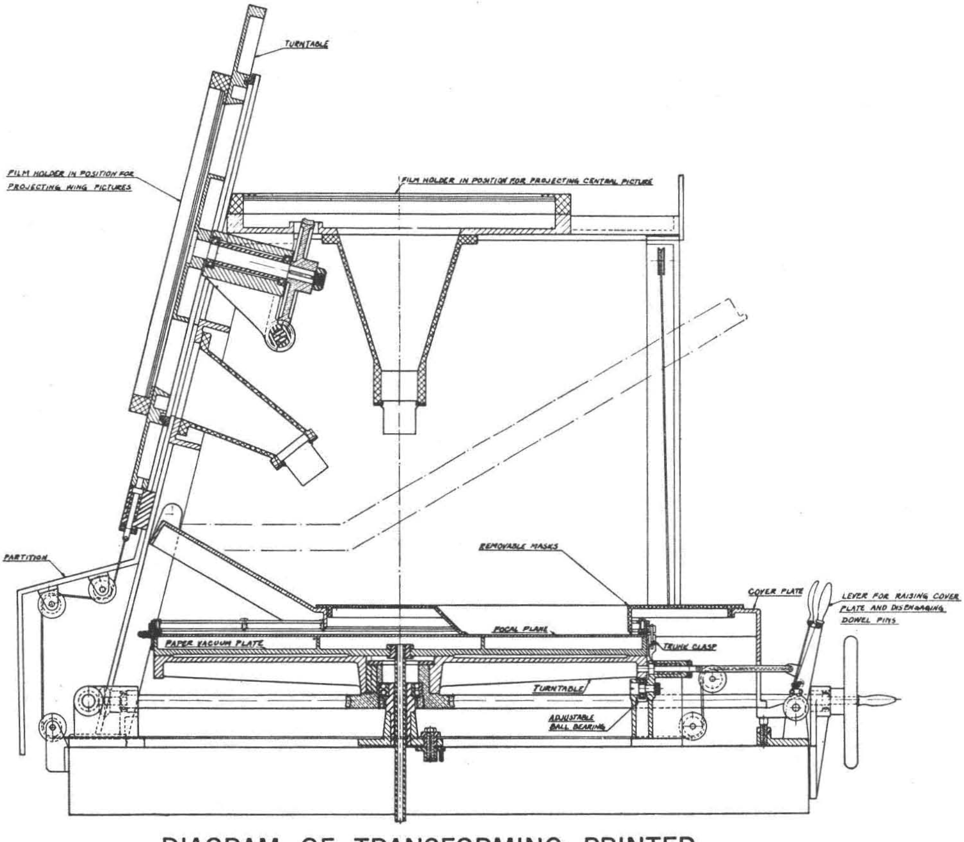

DIAGRAM OF TRANSFORMING PRINTER

Fig. 2.

ance. The final assembly and adjustment of the optical parts of the camera, and assembly and adjustment of the transforming printer were done by the Coast and Godetic Survey.

The camera was constructed by the Fairchild Aerial Camera Corporation in accordance with design specifications of the Coast and Geodetic Survey. The Fairchild Corporation designed and assumed full responsibility for the mechanical operation of the camera, and is to be congratulated for building a first model of so large and complicated an automatic apparatus to function satisfactorily from the start with only minor corrections. Each lens of the camera is equipped with an electric shutter with speeds of 1/80 and 1/50 second developed by the Fairchild Corporation from specifications of the U. S. Army

Air Corps. The nine shutters are opened, not merely tripped, by solenoids in series so designed that they must open simultaneously if they open at all. The camera is also equipped with lights and lenses to photograph simultaneously on the film the collimating marks, watch, counter, levels, and data card. A sight and intervalometer is provided which exposes the film automatically at the desired overlap when the operator adjusts the speed of the traveling wires in the sight to coincide with the motion of the image of the ground, at the same time compensating for crab or drift. A signal light glows five seconds before exposure and a telltale light blinks as the exposure is made to show that the shutter circuit is functioning satisfactorily. No attachments for photographing the sun, the horizon or a statoscope are included, although such devices could be included in the operating circuit of the camera without much difficulty. Since a displacement of 0.01 inch (0.25 mm.) indicates a relative tilt between photographs of three minutes of arc, it is practicable to span considerable distances between control without recourse to indirect methods.

The principal dimensions, coverage, and other items of interest regarding the camera are given in the following table:

U. S. COAST AND GEODETIC SURVEY NINE LENS AERIAL CAMERA

Focal length 8.24 inches (209.7 mm.), field 130×130 degrees square.
Net weight 306 pounds (140 kg.), gross weight with all equipment for photography 750 pounds (340 kg.).
Size of camera 29 inches (74 mm.) wide, 27 inches (67 mm.) fore and aft, 31 inches (79 mm.) high.
Size of film 23 inches (58 mm.) by 200 feet (61 meters) (100 exposures plus leader).
Size of composite photographs 35.4 inches (90 cm.) square.
Cost of film, including development, approximately $2.00 per exposure.
Cost of ordinary paper, including development, approximately $1.00 per print.
Labor in making composite print approximately 1½ man hours.
Camera can be reloaded in air if desired.

COVERAGE DATA

Scale	1:10,000	1:15,840	1:20,000	1:31,680
Width of strip				
Statute miles	5.6	8.8	11.2	17.7
(Kilometers)	(9.0)	(14.2)	(18.0)	(28.5)
Altitude above ground				
Feet	6,875	10,890	13,750	21,780
(Meters)	(2,095)	(3,319)	(4,191)	(6,639)
Area covered whole photo				
Sq. statute miles	31.2	78.3	124	313
(Sq. kilometers)	(80.8)	(202.8)	(321.1)	(810.7)
Per photo overlapped				
80%×60% Sq. stat. miles	2.5	6.3	10	25
(Sq. kilometers)	(6.5)	(16.3)	(25.9)	(64.8)
80%×30% Sq. stat. miles	4.4	10.9	17.5	44
(Sq. kilometers)	(11.4)	(28.2)	(45.3)	(113.9)
60%×60% Sq. stat. miles	5.0	12.5	20	50
(Sq. kilometers)	(12.9)	(32.4)	(51.8)	(129.5)
60%×30% Sq. stat. miles	8.7	21.9	35	88
(Sq. kilometers)	(22.5)	(56.7)	(90.6)	(227.9)
66%×33% Sq. stat. miles	7.0	17.8	28.5	71
(Sq. kilometers)	(18.1)	(46.1)	(73.8)	(183.9)
Statute miles (kilometers) of strip per loading				
80% overlap	112	177	223	354
	(180.2)	(284.8)	(358.9)	(569.7)
66% overlap	190	300	380	602
	(305.8)	(482.8)	(611.6)	(968.8)
60% overlap	223	354	447	708
	(358.9)	(569.7)	(719.4)	(1139.4)

It will be noted from the foregoing table that the camera is capable of photographing in a single flight in a modern airplane more than 8,000 square miles (20,000 sq. kilometers) with 60×30% overlap on a scale of two inches to the mile (1/31,680). A single one of its composite photographs includes the same area as sixteen to twenty normal angle and six to eight wide angle single

AREA COVERED AT EQUAL SCALE

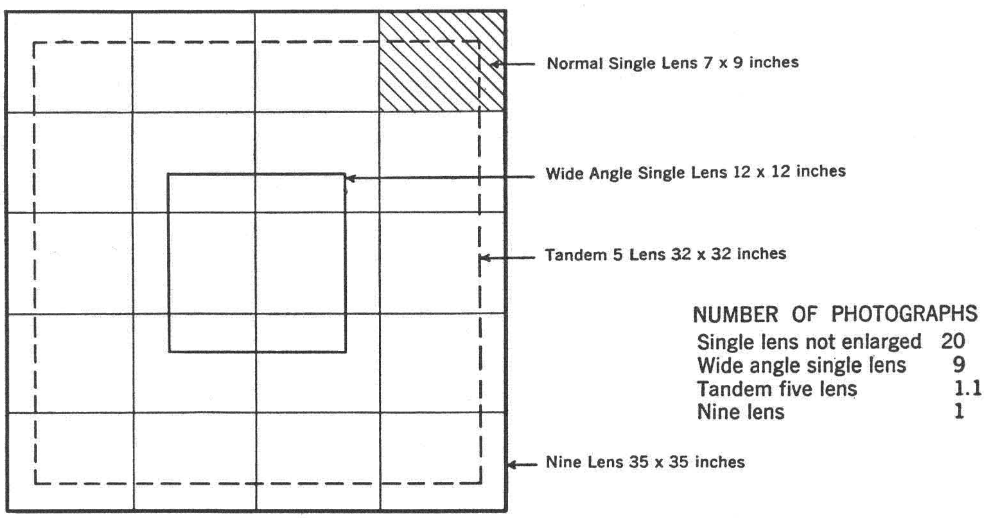

Fig. 3.

STEREOSCOPIC PARALLAX

(Relative displacement available for measuring differences in elevation)

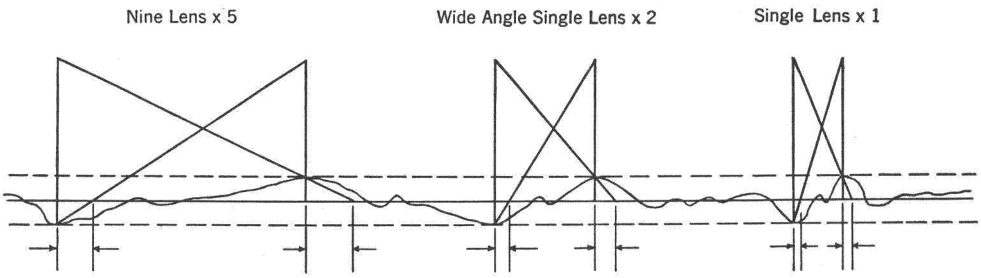

Fig. 4.

lens photographs (Fig. 3). Three to four times as much area can be covered in the same flying time as with single lens cameras.

The stereoscopic base can be lengthened to more than four times that of normal angle and more than twice that of wide angle single lens photographs (See Fig. 4.) This extremely long base exaggerates relief too much for easy examination of terrain of much relief but is very valuable for measuring the relief of relatively flat lands. It is, of course, easy to regulate the length of the stereoscopic base as desired during photography. No steresocopic mapping has been done with the photographs as yet. A rectifying camera to accommodate the large photographs is now being made. On completion of this it is hoped that a very efficient and simplified stereoscopic plotter can be constructed.

The camera is shown on the cart used to transport it when not in the airplane in Fig. 5 and separately in Fig. 6.

After the completion and tests of a first model of a new instrument one always considers what improvements could be made in a second. The develop-

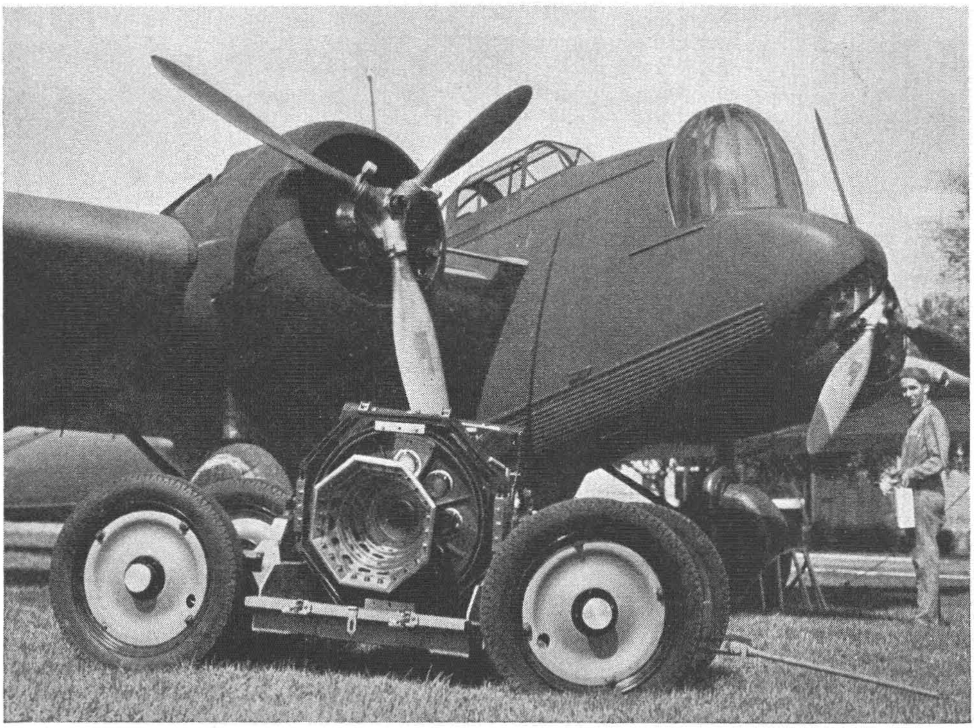

Fig. 5.

ment of the wide angle low distortion lenses such as the Zeiss "Topogon", the Russian "Liar 6" and the Bausch and Lomb "Metrogon" would make it practicable to use a wider field for the central lens in a second camera. This in turn would make possible considerably smaller mirrors with attendant ease in adjustment and saving in weight. More highly corrected lenses of somewhat narrower field could then be used for the wing lenses with probably an appreciable improvement in definition along the margins of the composite print. Experiments also indicate that an improvement in definition along these margins when photographing in hazy weather may be obtained by using the new high speed red sensitive emulsions with red filters. A set of such filters has been ordered for the present camera.

Conclusions

The construction and tests of the nine lens camera of the U. S. Coast and Geodetic Survey have shown:

1. The design adopted is successful in holding its adjustment through the wide temperature range and vibrations encountered in air photography.

2. The handling of the large size apparatus and photographic materials presents no excessive difficulties with correctly designed auxiliary apparatus and modern airplanes.

3. The increased displacement due to relief and wide angle of view make the photographs much less satisfactory for approximate mapping, scaling of

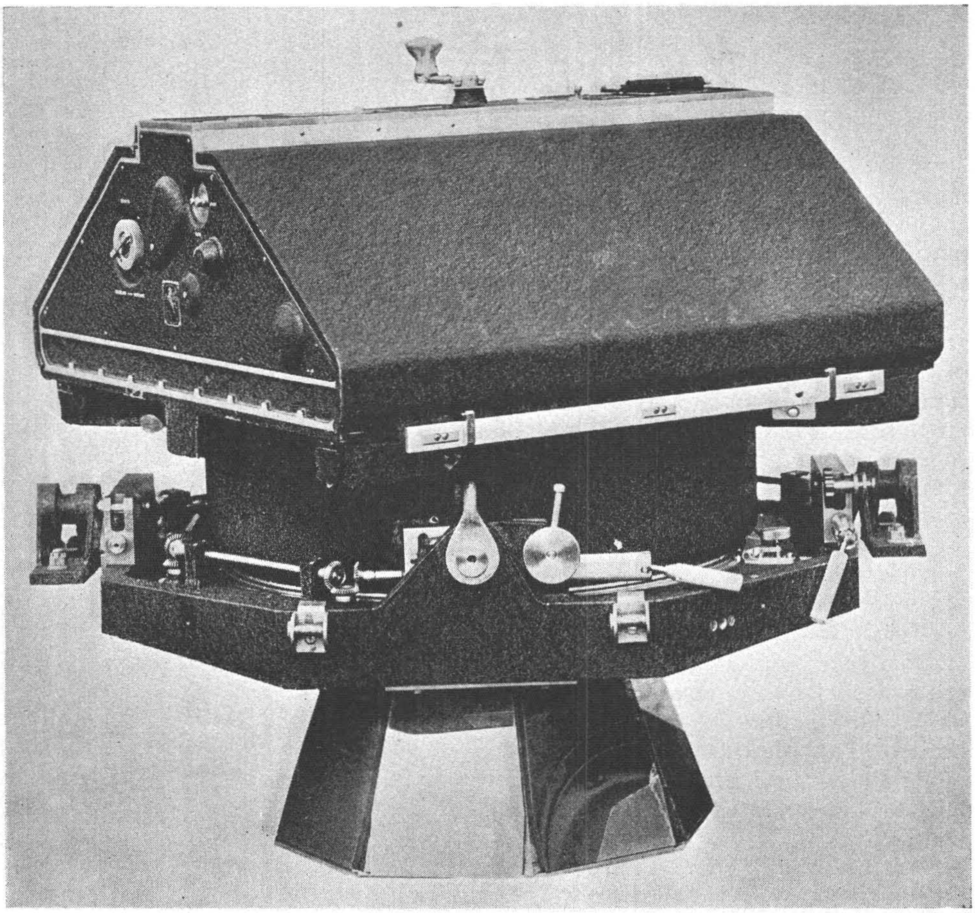

Fig. 6.

acreages without plotting apparatus or processes, than normal angle single lens photographs, except for flat lands. When suitable plotting apparatus becomes available, this limitation will be removed.

4. The large area covered at relatively large scales by the photographs permits of maintaining the highest graphic accuracy of plotting with one-half to one-fourth the amount of ground control required by single lens photographs and without sacrifice of fine detail.

5. It is practicable to photograph from three to five times as much area in a given interval of suitable photographic weather as with single lens cameras. This ordinarily more than compensates for the increased cost of airplane, apparatus and materials.

6. It is practicable with controlled temperature and humidity, modern low shrinkage film and paper, and micrometer adjustments to compensate for shrinkage and distortion observed, to produce composite prints correct within 0.01 inch (0.25 mm.).

7. It is practicable to exaggerate the stereoscopic relief to five times that of normal angle single lens photographs with attendant advantage in completely mapping relatively flat lands.

Film and Paper

Films and paper in current use for air photography are described in the following paragraphs from information furnished by the respective manufacturers.

Agfa Films and Paper for Air Photography

1. Super Sensitive Panchromatic Aero Film: This is an all purpose panchromatic film of high color sensitivity for general air photography under normal weather conditions.

2. Supreme Aero Film: The Supreme Aero is a high speed film of brilliant gradation and extremely fine grain. The film has approximately twice the speed of regular Agfa S. S. Panchromatic film and a somewhat more brilliant gradation. It is coated on special gray base which offers anti-halation protection similar to that common to practically all 35 mm. motion picture film. The fine grain together with anti-halation protection give extremely high resolution. The film is useful for wide angle photography and for areas having little contrast as in desert regions.

3. Triple S Panchromatic Aero Film: This film has a speed of approximately four times, or two full stops, greater than the regular Agfa S. S. Panchromatic film. Color sensitivity quite similar to the S. S. Panchromatic film although it is slightly lower in relative red sensitivity. Its gradation and developing characteristics are practically identical to the regular S. S. Panchromatic and the grain size is slightly smaller.

While this film has not yet been announced to the market it is available in limited quantities.

It should be useful in northern latitudes for photography with wide angle lens of small apertures with filters, and for photography of terrains lacking in contrast.

4. "Mapping Special" Paper: This is a new type paper which has just been put on the market. It is of clear white stock with very low shrinkage characteristics for unlaminated or unlacquered paper. The differential shrinkage averages as little as 0.04% and may frequently be less. At the present time, the paper is being supplied only with Brovira enlarging emulsion in three degrees of contrast, soft, medium, and hard.

Eastman Films for Air Photography

The Eastman Super Sensitive Panchromatic Aero Film has been used for general air photography for many years. Used with the Wratten Aero No. 1, Aero No. 2, No. 12, No. 25 filters, it has proved very satisfactory for vertical and oblique photography of most types of terrain.

As the result of the increasing use of aerial photography during the past few years, special conditions have been encountered in which the most desirable results could not be obtained by the use of the standard film. Three new types