THE MAKING OF AN AERIAL PHOTOGRAPHIC MOSAIC

Captain William D. Wheeler, A. S., Director of Photography, Air Service Technical School, Rantoul

It will be my pleasure this evening to explain to you in detail and in the sequence of performance the steps necessary in making an aerial photographic mosaic. As pictures speak the universal and, more often, the perfect language, I have arranged my lantern slides in such an order that with a few remarks in regard to each the whole story will unfold itself in a way that I hope will be interesting and enjoyable to you.

It was the privilege of one of the officers in my department to address the Academy last year. He selected as his subject the interpretation of aerial photographs and the dissemination during warfare of the military information disclosed by them. It was for this purpose that aerial photography came into being and was developed during the World War. Very excellent maps existed of the battle fields, and the aerial photographs were used to add to these maps the various military organizations that the enemy built upon the face of the earth. Since the war the usefulness of aerial photographs in map making has been systematically studied, and while the subject is by no means thoroughly explored, commendable progress has been made, so that even now it is my personal forecast that the military map of the future will be an aerial photographic mosaic.

It is gratifying to realize that while in this work we are keeping abreast of the science involved in warfare, we are at the same time, in a greater measure, perfecting mapping and making easier and more accurate the work of our civil engineers. Even in the practice work of the Army Air Service in peace time, which, of course, is primarily intended for greater national security and the maintenance of international peace, we are producing a product useful to the map making agencies of the Government. We are turning over to them copies of these practice aerial photographs and they are using them in making better maps. It may astonish many of you to know that our own beloved country is very much un-

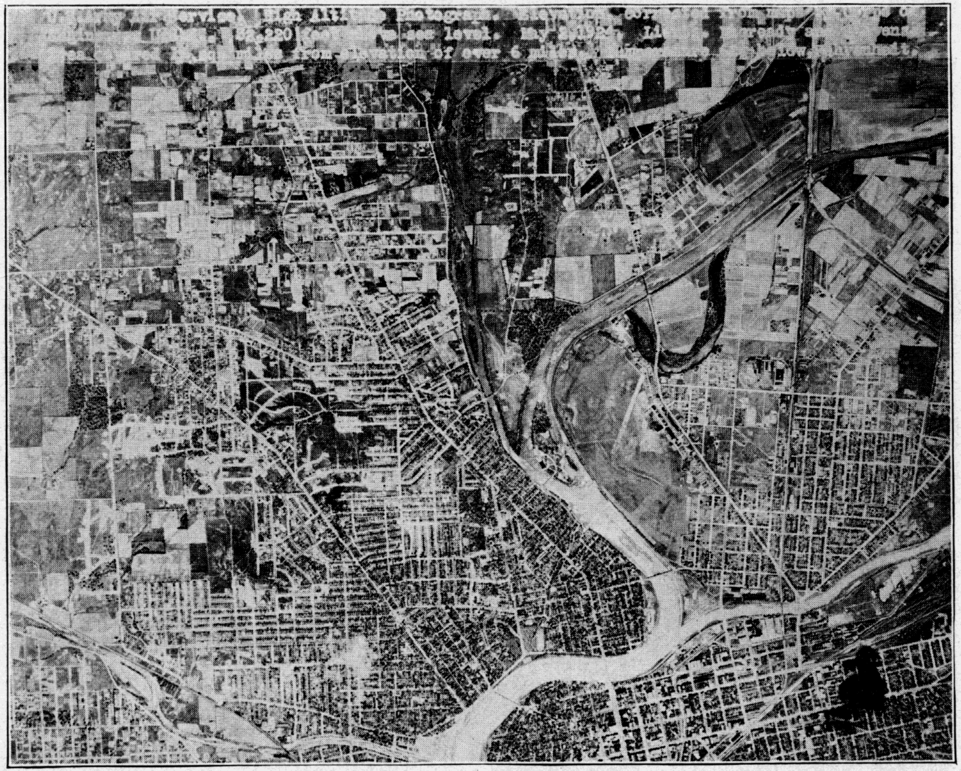

FIG. I.

mapped. At present the topographic quadrangle sheets made by the United States Geological Survey cover scarcely 40% of the United States proper. Many of the maps embraced in this percentage were made many years ago and badly need revision. Our Army Air Service while carrying out its photographic training problem has engaged in the photographing of areas of which maps were being made, and in this way it has effectively co-operated with the Corps of Engineers of the Army, the United States Geological Survey, the United States Coast and Geodetic Survey and similar federal mapping agencies, and it has been demonstrated that with the use of aerial photographs better maps can be produced more quickly and more cheaply than without these pictures.

However, all these thoughts are really relevant to the subject of the use of aerial photography in map making, upon which a book might profitably be written. As I am allotted only an hour this evening in which to tell you how an aerial photographic mosaic is made, I must address myself directly to my theme.

When a photograph is taken with a camera so mounted in an airplane that it points directly at the earth, the result is called a vertical aerial photograph. This is such a picture (Fig. 1). You will observe that this photographic record is really a map giving in exact and exquisite detail the objects visible on the earth's surface, such as a river and its tributaries, streets, roads, railway lines, houses, fields, woods, etc. Incidentally, this particular photograph was made by Army Air Service officers at an altitude of over six miles, the greatest height at which an aerial photograph has ever been made by man. It embraces an area of nineteen square miles, and includes practically all the city of Dayton, Ohio, and its environs. Although it was taken in May, the temperature at the height taken was 62½ degrees below zero, Fahrenheit.

The scale of this picture is small, and the altitude at which it was made was so great that it was uncomfortable for personnel. The photograph was really an altitude test rather than a sample of a common vertical photograph. It is usually our practice to fly at about one-third of this height. When this is done the scale of the ground details is much larger, but the area included in the photograph is considerably smaller. However, if it be desired to cover as large an area as that embraced in the picture I am showing you, or even a larger area, recourse must be had to the making of what is known as an aerial photographic mosaic; that is, a number of vertical photographs are so taken that they can be joined together and will form a composite picture of the entire area. In order to understand clearly the necessary steps in the making of a mosaic, we must consider the conditions under which any individual vertical picture is made.

The size of the area included in a vertical photograph depends upon:

(1) The altitude of the camera at the moment of exposure;

(2) The focal length of the lens used; and

(3) The size of the film or plate used.

From these factors each side of the ground rectangle included in the photograph can be computed, also the area of the rectangle, and the scale of the photograph. The scale of the ground objects can be regulated by selecting the height flown and the focal length of the lens used. The closer the camera is to the ground, the larger will be the images of ground objects in the photograph. At the same height the scale of a photograph taken with a longer focal length lens will be greater than that obtained with a shorter focal length lens. Thus, at the same altitude the photographic image of an object photographed with a lens of 24 inches in focal length will be exactly twice the size of the image of the same object in a photograph taken with a lens of 12 inches in focal length.

The method of making ground area and similar computations will be obvious from this diagram (Fig. II) which represents (very much out of proportion, of course) a camera suspended in the air and pointed directly at the earth, with its longitudinal axis perpendicular to the plane of the earth's surface.

"O" is the lens. "OA" and "OB", the angle of view, or inclusion, of the lens. "AB" or "L" is the distance on the ground, and "ab" or "l", the image of that distance on the plate or film in the camera. From the plan view shown by the illustration it will be seen that the

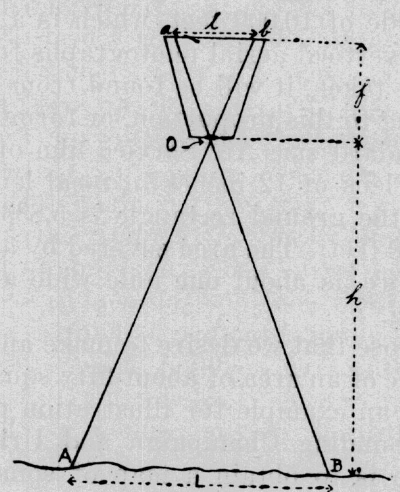

FIG. II.

distance on the ground "AB" and the sides of the angle of inclusion "OA" and "OB" form a triangle. Similarly, in the camera the image of the ground distance on the plate or film "ab" or "l", and the boundaries of the rays of light from the lens to the plate or film "Oa", "Ob", form a triangle. As these two triangles are similar, their respective sides and altitudes are proportional one to the other. It, therefore, follows, for instance, that the image of the ground distance on the plate is to the actual ground distance as the altitude of the smaller triangle (which is the focal length of the lens and indicated as "f") is to the altitude of the larger triangle (which is the height of the camera from the ground and designated as "h"). In other words:

$$l : L :: f : h$$

or

$$\frac{l}{L} = \frac{f}{h}.$$

Letting "s" represent the scale of the photograph, we find that:

$$s = \frac{l}{L} = \frac{f}{h}.$$

At an altitude of 10,000 feet, which is a common altitude at which vertical aerial photographs for the making of mosaics are taken, it will be found from computations made according to this proportion, or formula, that when using the standard size Air Service film of 18x24 centimeters and a lens of 12 inches in focal length, that the short side of the ground rectangle is 5,833 feet and the long side, 7,500 feet. The area covered by a single photograph, therefore, is about one mile wide and one and a half miles long.

Let us suppose that we desire to make an aerial photographic mosaic of an area of about fifty square miles, and let us take as an example for illustration purposes such an area surrounding Champaign and Urbana, Illinois. Our first step is to obtain a map of some kind of the region for the use of the pilot or aviator in identifying the area and directing the flight. The quadrangle sheets issued by the United States Geological Survey are popular maps for this purpose. When they are not available we obtain any map that we can of the scale of about one inch to the mile. Here is a portion of a Geological Survey map known as the Urbana, Illinois, quadrangle sheet, including the area we have selected. We have outlined the area and drawn our proposed lines of flight. (Fig. III.) Our problem is to fly back and forth across this area taking photographs in both directions and making strips of pictures that will slightly overlap, and also make certain that the side of each strip will overlap the adjacent one. The necessary overlap is a margin of safety which insures that there will not be gaps between pictures. In the final assembly of the mosaic the individual photographs are cut so that they will exactly fit together.

The overlap used is at least one-third of the area on the ground included in each photograph. Allowing for this the net ground area included in each photograph can be calculated readily from the formula, and it can be determined how many separate exposures will be required to cover the total area to be included in the mosaic.

If the width of the area included by a single photograph has been computed and the amount of overlap has been decided, it is possible to plot on one side of the boundary of the area to be covered by the mosaic, the

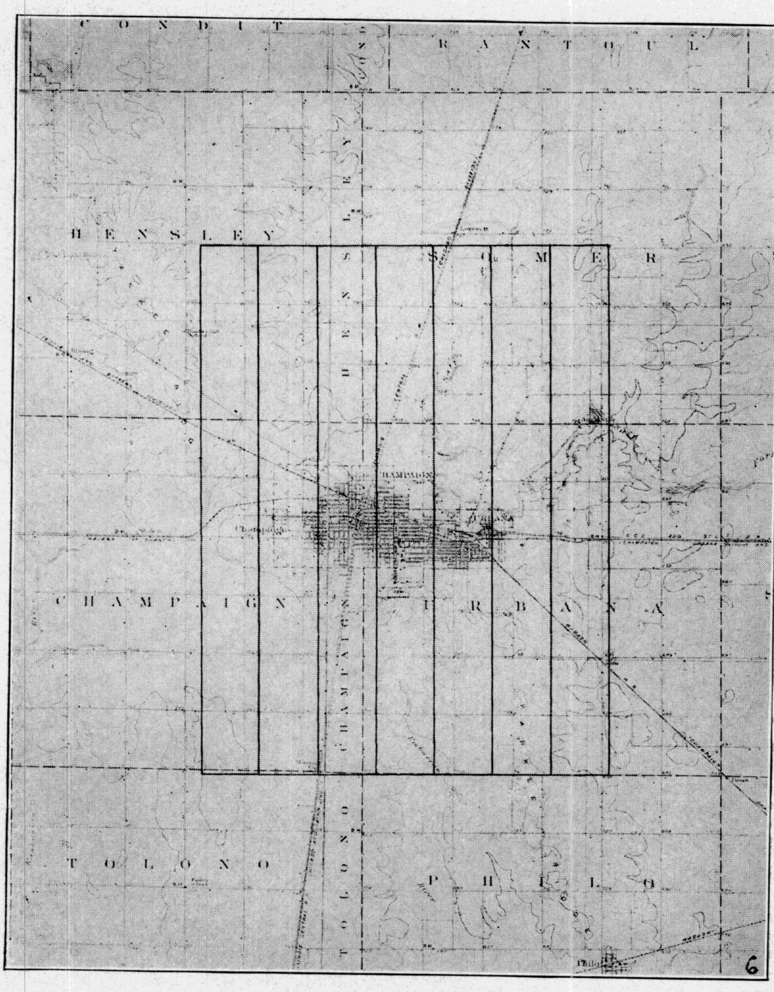
C O N D I T
R A N T O U L
H E N S L E Y
S O M E R
C H A M P A I G N
U R B A N A
T O L O N O
P H I L O
CHAMPAIGN
URBANA
6

FIG. III.

points at which the lines of flight should begin. When this has been done and the number of individual photographs necessary to cover the area has been determined, it is necessary, as an additional preparation for the mission, to know at the altitude selected how often a photograph must be taken so that the amount of overlap decided upon will be obtained. The photographs are taken with the width of the film parallel to the line of flight. If a one-third overlap be decided upon, an exposure must be made every time two-thirds of the width of the ground space is flown. The total width of the ground space can be calculated readily in the manner already explained, and as the speed of the airplane in still air is known and can be reduced, if necessary, to feet per second, it will be found that the interval in seconds between each exposure is equal to two-thirds of the width of the ground area divided by the speed of the airplane in feet per second.

This slide (Fig. IV) shows graphically the line of flight, the points, or intervals, at which the exposures must be made, and the amount of ground area and overlap covered by each successive view.

All the necessary calculations preparatory to a photographic mission of this sort have been embodied in a table of information which gives for the standard Air Service size of film, according to the focal length of the lens, the sides of the ground rectangle covered at different altitudes, the scale of the photographs and the exposure intervals for three speeds, namely eighty-five, one hundred and one hundred and ten miles an hour.

The air above us does not pass in a solid column in the direction of the prevailing surface wind, as many may think, but there are strata of currents of varying thicknesses that often move in different directions and at different velocities from one another. For instance, the surface wind from the west of a velocity of fifteen miles an hour may extend upward only 500 feet, and above that may be another stratum, of for instance 1000 feet in thickness, moving at a different velocity in an opposite direction. While it is true that we make wind-aloft readings for aeronautical and weather data which give us the direction and velocity of air currents up to the height at which the test balloon sent up for this purpose disappears, air conditions may rapidly change and the latest report may have become stale and really worthless before we actually begin photographic work at the altitude selected. Therefore, while the interval of exposure may be calculated for the speed of the plane when flying in still air, allowance must be made for the meteorological conditions, such as wind-opposition, that may be encountered at the altitude selected. As such conditions are unknown on the ground save for wind-aloft reports which may have become stale, ground calculations may be valuless at the time photographic work is begun.

In order to take into proper account these fluctuating factors, use is made of a view finder. This is a metal cone with a lens at one end and a ruled ground glass in the focal plane. The nose of the finder is rounded and fits into a socket mounted in a hole in the bottom of the plane close to the photographer's seat. The interchangeable ground glass screens are ruled for lenses of the different focal lengths used in the Air Service. The horizontal lines are designed for the common amount of overlap given, namely, 60%. The exposure interval is obtained readily with this instrument when the desired altitude is reached by the photographer's measuring the time required for the image of a ground object on the screen to pass from one horizontal line to the other.

We will suppose that we wish to make our mosaic with what is known as Type K-3 aerial camera. This employs a lens of 12 inches in focal length, which is the focal length of the lens that we decided to use when our flight map was prepared. Here is a picture (Fig. V) of this camera. This is the camera (pointing) with film magazine attached. This is an extra magazine. This is the suspension (pointing) in which the camera is mounted in the airplane. These are electrical cables which connect the storage battery with the camera. You will note that here is the motor which drives this automatic instrument. Before reaching the motor, the current passes through this device called an "intervalometer". This is an automatic switch which operates the camera at any desired frequency required by the interval of exposure. The

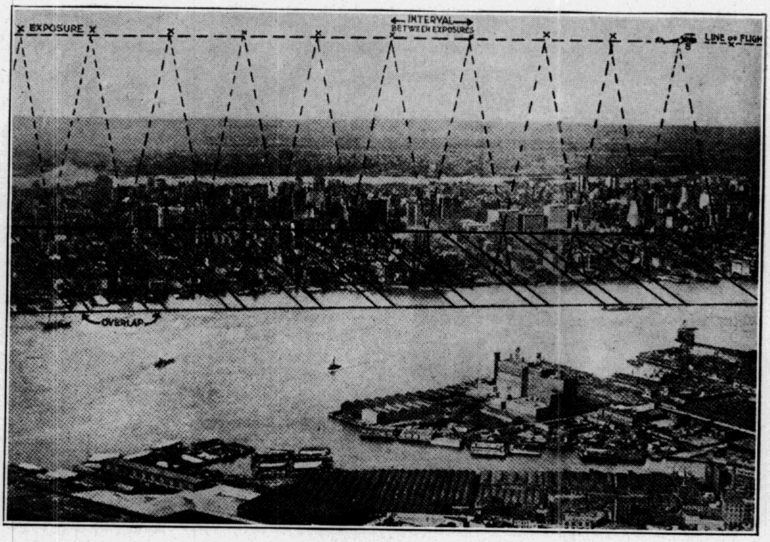
EXPOSURE
INTERVAL
BETWEEN EXPOSURES
LINE OF FLIGHT
OVERLAP

FIG. IV.

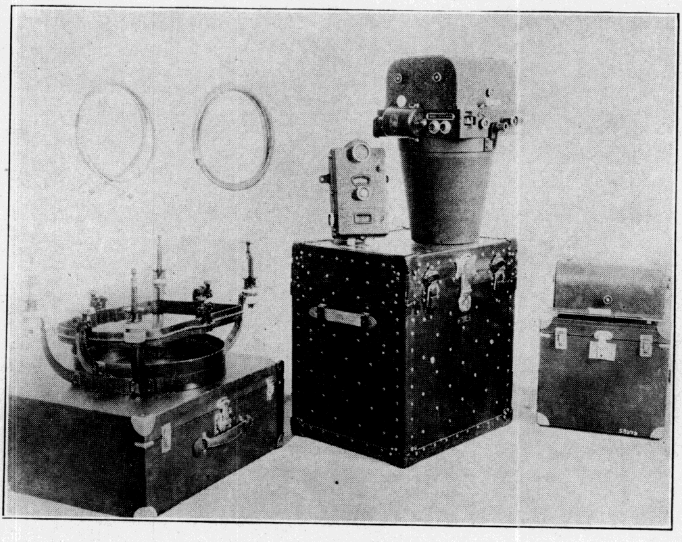

FIG. V.

camera suspension is so arranged that the points of suspension rest in soft sponge rubber so that they take up the vibration of the airplane and eliminate the blur which would otherwise be apparent in the picture. The suspension is so constructed that when the camera is mounted in it, it is virtually on a universal joint and may be moved to any angle and in any direction necessary to keep its longitudinal axis perpendicular to the surface of the earth.

Having selected our photographic apparatus we next load the magazine in much the same manner as a small camera employing film on spools. However, the size of a roll of aerial film differs greatly from that used in a hand camera. A roll of the standard aerial film is approximately 10 inches wide and 75 feet long. To both ends safety paper is attached after the fashion of spools of film for small hand cameras.

With the camera loaded, we are ready to install our photographic apparatus in the airplane. The airplane generally used in photographic mosaic work is of the De Haviland type known officially as "Type DH4BPl". It is equipped with the famous Liberty engine of 400 horse-power and is similar to the other De Haviland planes now used in the Air Service which are so popular for many common purposes. The photo ship, however, differs from the usual service type of DH in that the cowling of the rear cockpit, instead of being built up to provide for a machine gun mount, is cut away and padded. This cockpit has also been enlarged and reinforced so as to provide sufficient room for a camera and a photographer. There is an aperture in the bottom of the fuselage through which the photograph is taken; also a storage battery that supplies the motive power. The suspension is clamped to cross pieces attached to wooden uprights. The uprights in turn are fastened to the vertical ribs of the airplane body.

Success in aerial photography, aside from the necessity for suitable airplane and good photographic apparatus, depends upon the skill of the pilot and the skill of the photographer, and close teamwork between them. The pilot must keep a straight course, flying exactly down the lines of flight indicated on the map, and he must keep a constant altitude. Just before each exposure a small electric light, regulated by the camera mechanism, lights in his cockpit as a signal to hold the airplane as level as possible at the moment of exposure, which is timed to be five seconds later. If one wing of the plane is higher than the other while the photograph is being taken a distorted result is obtained. If the airplane is in a slight climb or a dive, not only would a distorted wedge-shaped picture result, but the exact ground area which that photograph should cover will be missed, as this diagram shows (Fig. VI).

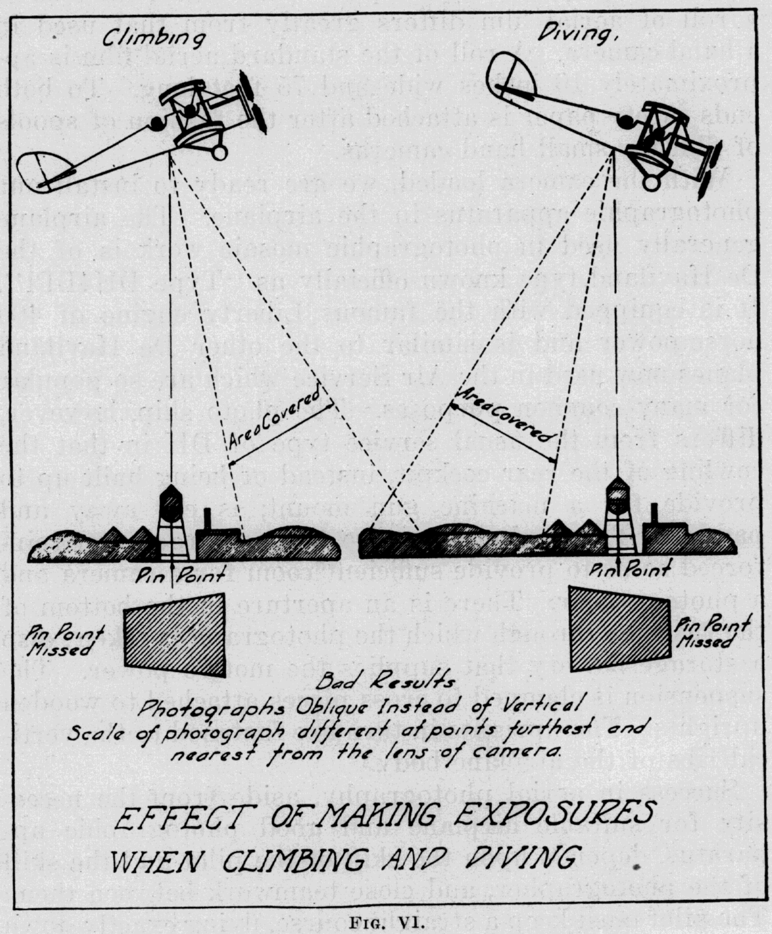

FIG. VI.

During photographic operations the photographer has much to occupy his mind. When the desired altitude is reached the pilot flies straight and level in the direction of the first strip to be made so that the photographer can find, with the use of his view finder, the correct interval of exposure and set his intervalometer accordingly. If the wind is from the side, the nose of the plane must be pointed into it, or, as we say, the ship must be "crabbed". When the wings of the airplane make other than a right angle with the line of flight, the camera must be turned in its suspension so as to overcome the saw-tooth edge which would result in the plotting of the strip of photographs if the camera were not turned to offset this yawing and thus make the photographs abut one upon the other. With the interval of exposure and the amount of crab of the plane determined, the photographer is ready to start the camera, and this he does at a signal from the pilot when over the beginning of the first strip. As the pilot, with the map in one hand, flies in a straight and level direction along the line of flight, following the course on the ground through a window in the floor of his cockpit, the camera automatically clicks off the exposures at the intervals of time regulated by the intervalometer. The photographer the while holds the camera to the vertical according to the spirit level attached thereto. At the conclusion of the strip the pilot signals to cease photographing, continues considerably beyond the area, turns and flies at the selected altitude straight and level in the direction of the second strip so that the photographer may obtain the interval of exposure and amount of crab necessary for this strip. The interval and amount of crab of a small area are considered uniform for each strip in the same direction so that when these data are obtained for the first two strips in both directions they are used for the remaining strips.

Film magazines are interchangeable in the air so that in the case of a large area a number of rolls of film, each providing over a hundred exposures, may be carried on a single flight. When photographing a large area it is the practice to carry film almost to the extent of the gasoline capacity of the plane; such capacity of course depends upon the size of the tank of the airplane and ranges from four hours and a half upward. The speed with which a mosaic is ordinarily flown is one hundred miles an hour so that a strip of one hundred photographs, each covering more than one square mile, can be made in one hour on a single roll of film.

We will assume that we have photographed the area and that we are now ready to develop the film. This is the film developing apparatus (Fig. VII). It consists of a transfer stand on which (in the darkroom of course) the film is wound from the spool around a reel and between the coils of a celluloid band called an apron. These coils are held apart by corrugated metal strips at the ends. The apron of a reel when loaded with a roll of film is secured by a retaining band. The loaded reel is then immersed into a tank of developer. This tank has a water-tight lid which can be locked on, and is also provided with a handle which permits the tank to be reversed during development in order to secure even action of the developer. The development is for a certain length of time, fixed according to the strength or degree or concentration of the developing solution, and also fixed according to the temperature thereof. At the expiration of this time the reel is rinsed in water contained in a tank similar to the developing tank, and finally transferred to a third tank of similar design, which contains the fixing bath and thence upon completion of fixation, to a fourth tank of running water. This slide (Fig. VIII) shows development in progress.

Upon completion of the final washing the film is transferred to a large wooden cylindrical drum which is revolved by electric motor, thus expediting the drying of the film. When dry, the film is wound around the original wooden spool on which it was supplied and it is kept in the original metal tube or container. It is not the practice to cut negatives apart. For their identification they are numbered at present by hand. In the near future it is expected that they will be numbered by a separate numbering device in the camera that will make an impression upon the film at the moment of exposure. In numbering film the standard type of plotting table is used. This provides a window enclosing an electric light. The negative film is wound by hand

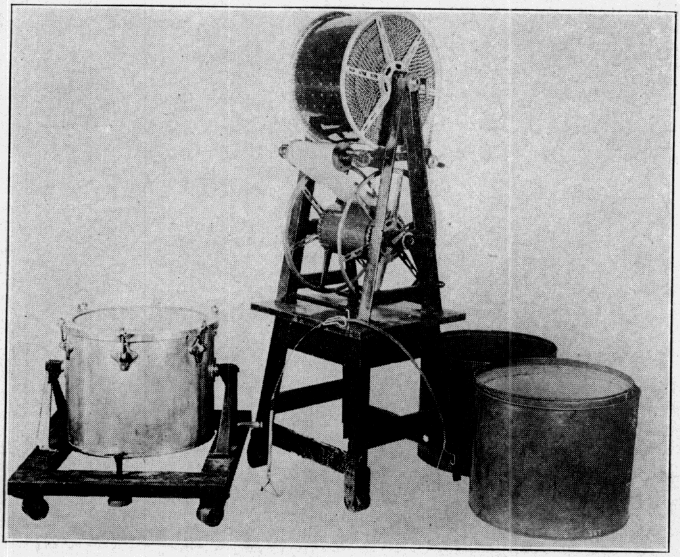

Fig. VII.

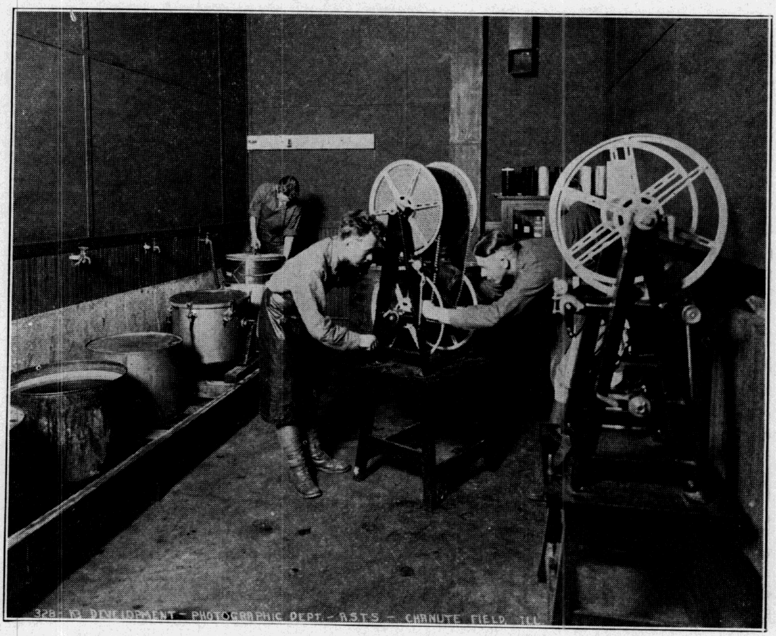

Fig. VIII.

across this window and numbered or examined at leisure. With the numbering completed, the area covered by the individual exposures are plotted on a map to scale. This is done to determine whether the area has been completely photographed. The separate plottings of the photographs are numbered, and when completed this map also serves the purpose of an index to the different exposures.

With the film numbered and plotted, the next step is the making of the positive prints, or photographs. A special form of contact printer is used, which differs from the usual type of photographic contact printer in that holders are provided for the spool of film and for a take-up spool. The film is thus rolled across the printing surface of the machine as desired. This printer has nine electric lamps controlled by separate switches so that all, or any combination of these lights, can be turned on. This permits of compensating for any uneven density in the negative by turning out a light under a too-transparent portion. As the combined candle-power of these lights is great, much heat is generated which is eliminated by a small electric blower, thus preventing the heat from cracking the ground glass diffusing screen above the lights and the plate glass top of the printer. The back of the printer has a pneumatic cushion which is found to be more satisfactory than the usual type of felt padding.

The photographic paper used in the Air Service is invariably of a glossy surface and is one of the commercial bromide or chlorobromide emulsions. The methods used in the making and finishing of the prints are essentially the same as those used by any photographer when using one of these papers. The prolonged final washing, however, is sometimes done in a special washing machine consisting of a perforated drum or holder for the prints, which is revolved by motor in a tank of running water.

The drying can be expedited by the use of a special drying machine, which consists essentially of an electrically heated drum around which an endless belt is revolved. Prints are placed upon this belt, and by the time they have been slowly conducted by the belt around the drum they are dropped dry into a receiving receptacle.

With prints completed, we are ready to join the separate, individual photographs in order to make the composite photograph or mosaic. In this assembly the photographs are cut or torn so as to fit together, and as each is cut it is pasted to a suitable mount. In order that the composite photograph may be accurate as to scale it is necessary that the work of assembling and affixing the prints to the mount be controlled by measurements between the photographic representation of objects which will be in proportion to the distances between the actual objects on the ground. The ground distances are obtained in the form of surveyor's notes. If the area is large enough to make the curvature of the earth material, a polyconic projection is made upon the mount, and on this the stations appearing in the surveyor's notes are accurately plotted to the same scale as the photographs.

A photograph showing one or more of these stations is then pasted to the mount so that the point or station in the photograph will be exactly superposed over the station as plotted on the mount from the surveyor's notes.

The adjoining photograph is then found and is cut so that it will not only fit the first photograph but so that any stations in that picture will exactly fit over the stations plotted on the mount. The fitting together of the pictures, aside from the superposition required by control points, is not only a test of manual dexterity in cutting the pictures, but also of skill in photographic printing, because great pains must be taken that the tone of all prints match so that the completed assemblage will be of uniform color. In laying down or assembling the mosaic the exact superposition of a control point in a photograph over that plotted on the mount is effected by an ingenious device known as a mosaic control point indicator. A steel phonograph needle is suspended from an arm which may be raised and lowered. This needle is fixed on the control point plotted on the mount, and the arm of the device is then raised so that the print with adhesive applied can be placed on the mount. The control point in question, as shown on the photograph, is placed as nearly as possible over that on the mount as indicated by the needle point of the indicator, which, after the print is placed in position, is lowered. If necessary the print is moved about until the needle point rests upon the control point, as shown in the photograph.

Adverse meteorological conditions, or lack of skillfulness of the pilot, or a combination of both, may result in differences in scale of the photographs covering an area and may require that some of the prints, in order to fit together, be of a greater or a smaller scale. This change in the scale of a print can be easily effected by a certain type of enlarging or reducing camera. This apparatus consists of a camera on a movable arm. In this camera the negative to be projected at a different scale is inserted in the focal plane of the camera and in front of a suitable light source surrounded by a reflector. The sensitive photographic paper is placed on the horizontal easel. By raising or lowering the arm holding the camera a projection to the exact scale desired may be instantly made. A variable cam in the camera arm mechanism regulates the focusing of the lens as the arm is raised or lowered so that any size projection effected by the moving of the camera in the manner stated is always in focus. In all other respects the operation of the apparatus is similar to that of any enlarging camera.

At the moment of exposure the airplane may not have been level, thus causing what is known as "tilt" in the photograph, shown by the fact that the print is not uniformly to scale over its entire surface. This tilt may be removed by use of a "restitutional printer" by projecting the negative image on an easel which may be swung at any angle. Three or more points are selected in the negative to be restituted, and the ground distances between those points are plotted to the desired scale on a sheet of drawing paper attached to the easel. In projecting the negative images of these points the easel is moved until each plotted point on the paper coincides with each corresponding negative image of it. A sheet of photographic paper is then substituted for the drawing paper. The exposure and subsequent operations with respect to photographic paper are the same as those employed in enlarging.

The pasting together of the individual aerial photographs, with or without correction, as explained, completes our mosaic.

As the reduction required in lantern slide making prevents me from giving you an adequate close-up picture of our mosaic, it here seems opportune to extend a cordial invitation, on behalf of the Commandant of the Air Service Technical School, to those within the reach of my voice to visit Chanute Field, especially the Department of Photography, where I will take great pleasure in showing you the original copies of photographic mosaics. I regret that limitations in lantern slide making prevent me from bringing you adequate pictures of them.

This naturally gives rise to the question as to how we circulate mosaics. The original mosaics are too large and cumbersome for this purpose and we, therefore, reproduce them photographically in sections. To do this we employ a large copying camera which takes a photograph twenty-four inches square. The mosaic is attached to an easel which permits the picture to be raised to any height and moved back and forth. The process of copying is complementary to that of mosaic making. In this case, the camera remains stationary, and in the form of a mosaic we "move the earth" so to speak back and forth, at the same time so photographing it in sections that they may be joined together easily and accurately by anyone. The large size picture made by this camera permits us to cover a large mosaic in a few sections.