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Ground Control for Aerial Photography

by

Harry Swanson

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INTRODUCTION

History of Photogrammetry

Maps or sketches existed before the time of Homer, which is generally accepted as about 900 B.C. However, such sketches were naturally quite deficient in geographic values. Since that time, the development of cartography has kept pace with other arts and sciences of civilization.

As exploration and development have taken place at an ever-increasing pace, the cartographer has been required to produce maps of greater accuracy and detail at a pace at least equal to that set by exploration and development. In order to supply demands, the cartographer has been required continually to improve his methods, technique and rate of production.

One of the most recent developments in cartography is that of photogrammetry. This relatively new scientific phase of cartography has attained a notable development in a few decades. Terrestrial photogrammetry and aerial photogrammetry was carried on by using kites and ballons and was practiced in Europe in 1900. However, it was not until the development of the airplane and the need for map information during the World War I that aerial photography developed rapidly and, in turn, effected the development of photogrammetry. During this period of development, the improvement of cameras used exclusively for aerial photography was very rapid, and that of photographic materials and other equipment no less so. Photography from the air soon assumed a place of great importance in military operations, and the interest of engineers and surveyors was focused upon its advantages as an aid to mapping. This interest has increased since the war, and cameras, materials and processes have reached a point of development equal to that which exists in the various methods of precise terrestrial mapping.

The first practical use of aerial photographs in conjunction with mapping was in the correction or amplification of existing large scale maps and in the preparation of composite pictures known as mosaics, which consist of a group of photographs pasted or stuck down together to form a rough map. It is clear that these processes satisfy only the most elementary requirements of mapping, and extensive tests and experiments have been carried out in an attempt to apply aerial photography to the solution of the most difficult problem confronting the military and civil engineer, namely: the preparation of accurate topographic maps.

The development of mapping processes involving the use of aerial photography has been rapid, and of necessity many principles have been discovered, forgotten and periodically brought to light again. It is the purpose of this report to attempt to set forth the most important of these principles, and their practical application in mapping operations, particularly with reference to the importance and types of ground control. Little space can be devoted to abstract theory, but in so far as possible, concrete examples of work actually accomplished are used to illustrate the methods and principles described.

Aerial Equipment

Cameras

The essential difference between the cameras is the number of lenses incoporated. There are two types, namely: the single lens and the multiple lens camera.

Single-lens cameras may be designated as hand-held or mounted, automatic or manual operated, suitable for vertical or oblique photography, precise mapping or general purpose cameras, roll film, cut film or glass plate, pressure or vacuum. A single camera may possess many features, but these characteristics tend to establish its position in the field of photogrammetry.

Multiple-lens aerial cameras may possess the characteristics of single-lens cameras, but are known as two-couple, tri-lens, four couple, five-lens, nine-lens, or tandem cameras (2 five-lens cameras in tandem). Multiple lens cameras are constructed specifically for the purpose of map compilation and are precise in the results obtained.

Irrespective of its type or manufacture, each camera has a lens, a shutter, a cone, a body, a focal plane, a drive mechanism, a tripping mechanism, a magazine, and a view finder which may be either attached or separate depending upon the camera. Certain types have other accessories, or adjuncts.

Definition of parts. Aerial camera objectives or lenses are usually mounted in barrels composed of a front element and a rear element, so that either element may be unscrewed separately from the mounting and which in many cameras also forms the housing for a between-the-lens shutter.

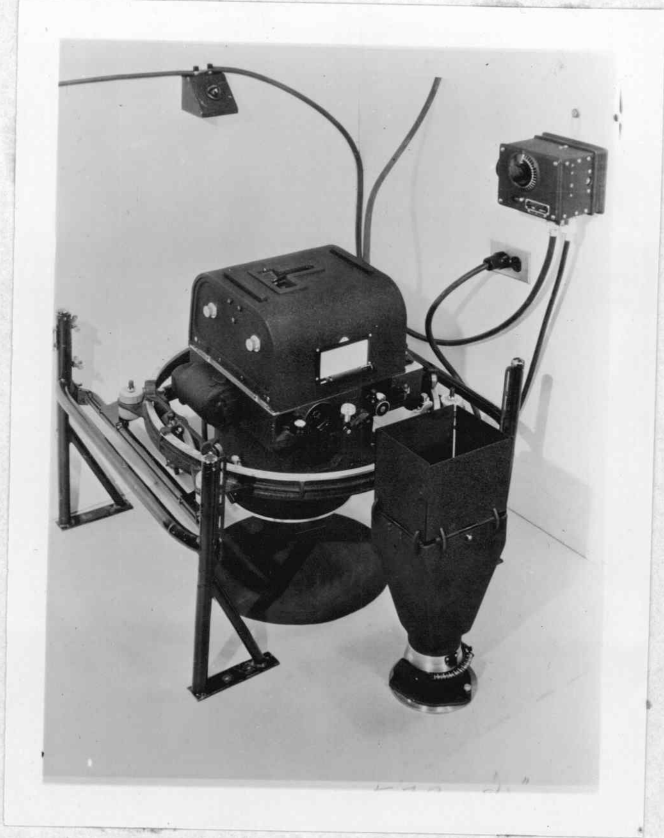


Figure 1 The K-3B, $8\frac{1}{4}$" Single Lens Mapping Camera

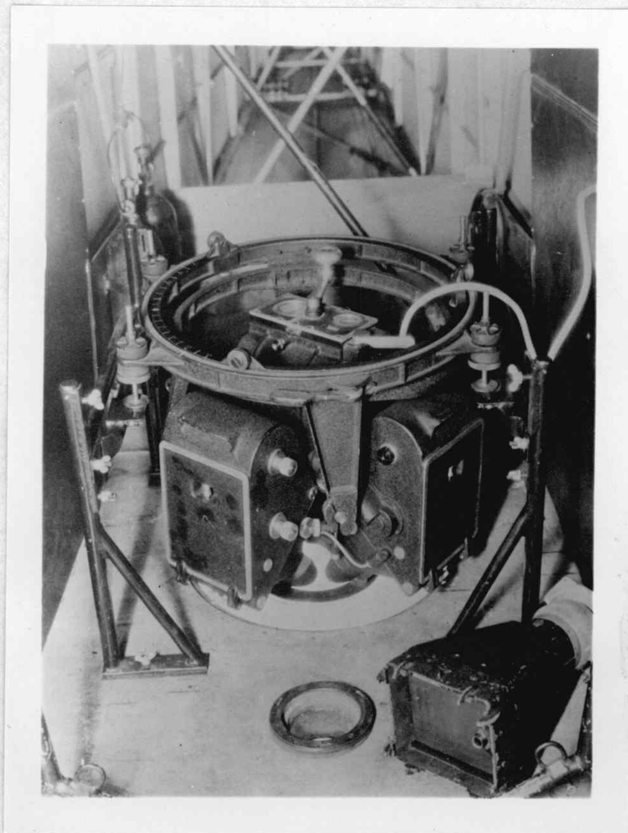


Figure 2 The T-3A, 6" (5 lens) Multiple Lens Mapping Camera

When the front and rear elements are identical the lens is symmetrical; when they are different the lens is asymmetrical. If the several elements are ground as segments of spheres, the lens is spherical. If the objective is constructed so that either the front or the rear can be used separately, the lens is a convertible lens.

There are certain errors that can creep into the lens, and it is essential that the lenses be free from spherical aberration, chromatic aberration, astigmatism, distortion, curvature of field, and have minimum vignetting at the desired speed, while retaining proper definition throughout the field of view.

Spherical Aberration. When the rays of the simple lens no longer meet at a point but intersect at different distances behind the lens to form a blurred image. This is prohibitive in an aerial camera lens which must be used at the maximum speed.

Chromatic Aberration. Natural light is composed of rays of many different wave lengths or colors, which are refracted differently as they pass through the lens and aside from spherical aberration, intersect at different distances behind the lens to cause a blurred image.

Astigmatism. The lack of definition of images seen through the portion of a reading glass near the rim are not as distinct as those seen more nearly through the central portion of the lens.

Curvature of Field. If the image points of a flat object are brought to a focus at different distances from the lens but are not formed on a flat surface, or plane, the lens is said to have curvature of field.

Distortion. When the image of an object is no longer in its original shape or form, but is unevenly magnified throughout its area, after it has been projected through a lens, it is said to be distorted.

Vignetting. When the effective size of the relative aperture diminishes for wide angles, further reducing the light admitted and thereby slowing down the lens for areas at extreme angles from the center, resulting in an uneven exposure of the film due to such loss of light; such is known as vignetting.

Shutters. Two types of aerial camera shutters are in general use in the United States: between-the-lens-shutters formed of leaves which open and close between the front and rear elements of the photographic object, and focal-plane shutters formed of a slit in a screen just in front of the focal plane of the camera, operated by being drawn rapidly across the sensitized film, thereby exposing it to the action of the light. Other types of shutters are in use in Europe, but not generally in this country.

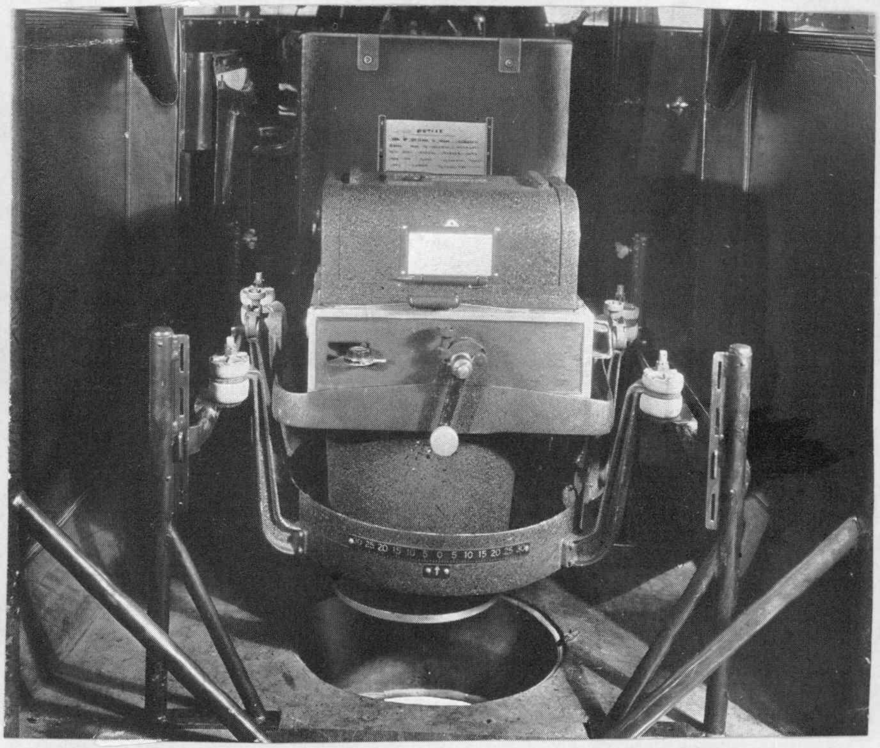
Each type of shutter has its use. Factors governing the choice of a shutter are dependability, shutter efficiency, time of exposure, and distortion of image due to shutter action.

Mounts. The camera mount is the most important accessory for fixed cameras. It should be sufficiently rugged to withstand the ordinary jars of landing, taxi-ing and in flight. It should be of a minimum of weight and should allow free motion of the camera in crab, tilt, and drift. It should be of such a shape as to fit about the camera and into the airplane with a minimum of obstruction. It should be readily attached at or near the center of gravity of the camera to eliminate rotational accelerations of the camera due to sudden changes in the altitude of the airplane. The camera should be free-moving within it, yet the mount should hold the camera in any position once established.

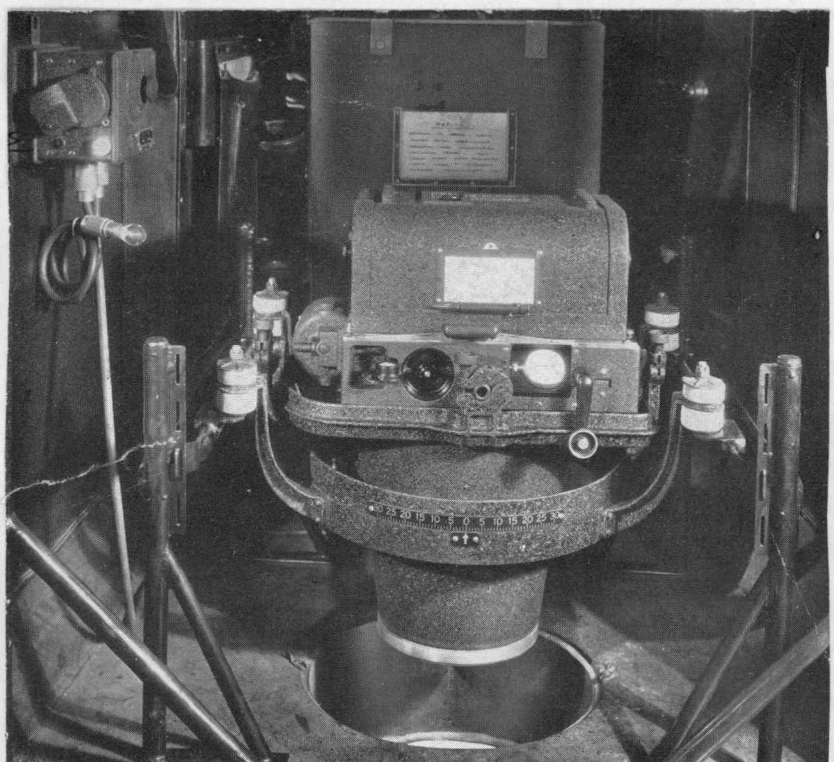
View Finder. A simple view finder consists of two leaves of sight mounted parallel to the axis of the camera lens. It is also necessary to incorporate a negative lens of the proper size and arrangement to cover the field of view of the camera. The sight then becomes a direct vision view finder through which may be seen the entire area photographed. This is usually detachable and consists of a rectangular frame which holds the negative lens and the rear sight. The lens has etched upon it a cross hair and usually one or more rectangles, and when the observer looks through the finder, he has the entire country before him and instantly knows the direction the lens is pointed and the field included by the angular coverage of the lens.

Automatic Overlap Regulators. The amount of overlap can be regulated by merely setting the knob someplace between 10% and 75%, depending upon the amount required. With the automatic interval regulator the entire attention of the observer is required in order that he may have the camera in a position of level steadiness at the instant exposure is to be made and between times to maintain synchronism between the grid and the image points of the ground.

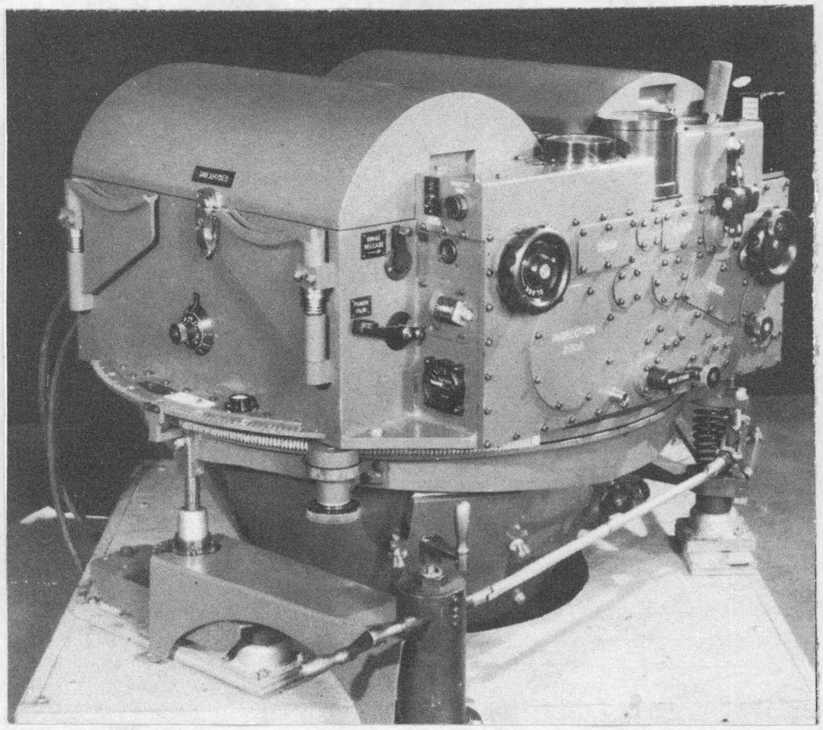
Intervalometers. The intervalometer consists of a case containing a constant speed 1 amp., 12 volt electric motor and a tripping device. The interval between exposures may be set at regular intervals between 6 and 75 seconds. Three seconds before



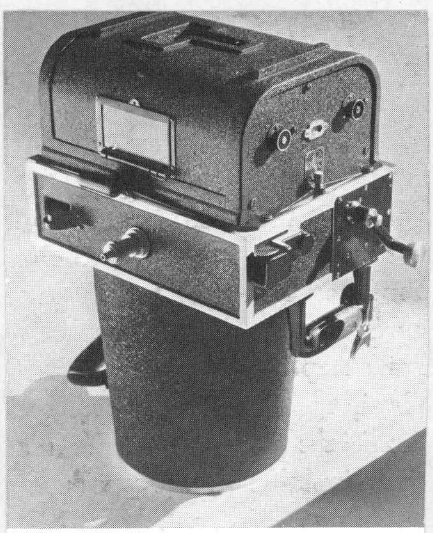
Fairchild F-4 aerial camera with vertical suspension mount installed in Fairchild 71 photographic airplane.



Fairchild K-3B camera with mount, intervalometer, cables and signal light installed in Fairchild 71 photographic airplane.



Fairchild 18 by 18 inch wide angle single lens mapping camera, a development of Fairchild Aerial Surveys, Inc., which was recently purchased by the U. S. Army Air Corps.



Fairchild F-4 aerial camera consisting of magazine, camera body and lens cone.

the exposure, electrical signal lamps are flashed as a warning to both the pilot and observer to allow time for leveling the camera before the exposure is made.

Automatic Recording Devices. This device has been developed to give certain data pertinent to the camera and mission at the instant of the exposure. The data included are usually the name of the mission, the date, names of the crew, tip, tilt and time of exposure.

Film-Flattening Devices. Aerial camera film requires some device to hold it flat against the focal plane of the camera. There are many different types in use and the essential part is that it hold the film against the focal plane during exposure and release during winding. For small focal plane areas, it can usually be held flat, but large surfaces it is extremely difficult to straighten, especially by vacuum, because of the difficulty in obtaining an air seal. For such film, air pressure is better than vacuum, but not so good as a pressure plate.

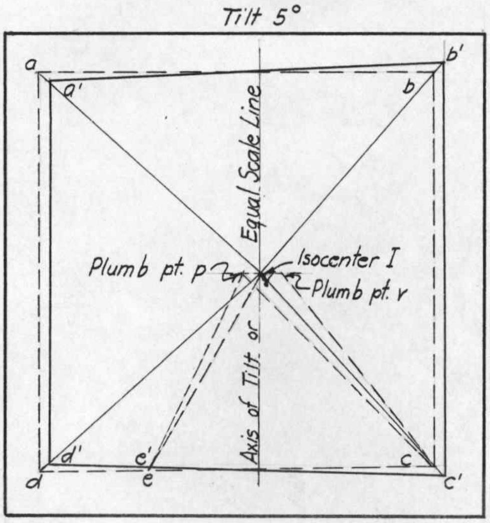
The main advantage of the pressure system over the vacuum system lies in the mechanics of its application. Aerial film is rolled on the spools with the emulsion side against the spool to prevent its being scratched in handling and during passage through the camera. During exposure the emulsion side of the film is towards the camera lens and away from the focal plane. In winding from the film spool across the focal plane with emulsion outward and onto the takeup spool, the film curls away from the focal plane in the clearance spaces along the edges of the film. When vacuum is used the seal must commence at the edges and progress, more or less, toward the center. It is not easy with large pieces of film to establish the initial vacuum seal.

When pressure is used its action commences at the center and rolls the film outward, flattening it as it goes, thereby avoiding the formation of wrens.

Orientation Devices. Whatever forms these devices take, they should provide a quick means for the determination of tip, tilt and absolute altitude of the camera above sea level or some other selected datum plane at the instant of the exposure. With such means available, it would be possible to orient and to project or observe single pictures at known scales entirely free from the effects of tip and tilt, and with resort to ground control of any sort. (See diagrams.)

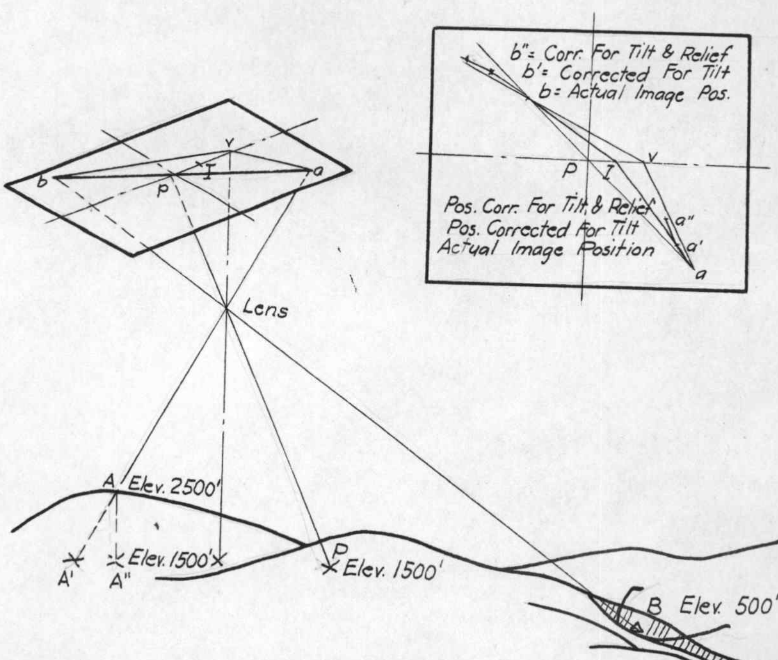
Altimeters. The present altimeters of the modern plane are of such sensitivity that they will enable the pilot to land blind, and that is all that is necessary. Thus if the reading of the altimeter is recorded at the time of the exposure, a true relative altitude is obtained between exposures which later may be further corrected or referred to some arbitrary factor from a single photograph which may permit a later and accurate determination of the picture scale.

Statoscopes. The statoscope is an air barometer, the air container of which is enclosed in a Dewar vacuum tank containing a mixture of ice and water. It has an electrically operated camera that photographs the exact reading of the altitude at the



EFFECT OF TILT

Figure 6



TILT & RELIEF COMBINED

Figure 7

time of the exposure, and is regarded by some as being extremely more accurate than the altimeter of the plane.

Films

A camera can not do more than afford a means for exposing the emulsion. It is the quality of the emulsion as much as the proper balance between the lens and the shutter that insures good photographs. Extensive work has been made on films for the ideal emulsion that accurately takes into play the action of the different colors of the spectrum and is not affected by them seriously.

The human eye is not equally sensitive to all colors, but its color sensitivity follows somewhat the curve of a in Figure V, wherein it is shown that the greatest sensitivity is to yellow and green and the least to blue and violet. It is, therefore, obvious that the best aerial photographs will be obtained by the formation onto the film of images reflected in these colors. This is accomplished by the use of emulsions sensitive to the same colors of light as the human eye and elimination by means of light filters of those to which the eye is not sensitive.

Filters. A light filter transmits light of the same color as itself; that is, a red filter transmits red light, a yellow filter transmits yellow light, etc.

Filters are used, (a) to render the sensitivity of the emulsion as nearly similar as possible to that of the human eye, (b) to increase contrast by absorbing a portion of certain colors of light which might overpower the remainder and eliminate them entirely from the final results, and (c) for the complete elimination of certain colors.

In the broadest sense, the purpose of the filter in aerial photography is to allow only those colors to which the eye is sensitive to strike the emulsion, although to a lesser extent they serve to increase the contrast. Filters are used in copy work both for the separation of colors, and to increase the contrast.

Exposing the Film. For every condition of aerial photography there is a shutter speed and a corresponding size of aperture which will give the best results. The intensity of light varies over such a wide range that it is impossible in a few simple statements to specify the correct exposure and aperture for general use. These can be best gained by experience and reference to the experience of others.

For low altitudes, either verticles or oblique, the shutter speeds should be high, more nearly 1/150 sec. or faster than the slow speeds used for high altitude work. Apertures may be correspondingly smaller.

At altitudes of 10,000 feet and above the camera should be used at the greatest aperture and the exposure regulated by the shutter speed. Shutter speeds slower than about 1/30 second for the mounted cameras are likely to show the effects of movement of the airplane due either to vibration or to linear movement of the object across the focal plane. Hand-held cameras cannot safely be used for speeds slower than about 1/20 second. Obviously such slow speeds would be considered only under conditions of very poor light and are to be avoided whenever possible.

At altitudes of 20,000 feet and higher there is need for all the light that is available and at this altitude except above areas of snow or white sand over-exposure of the film in a standard aerial camera is highly improbable.

Development of Stereoscopy in Aerial Photographs

Stereoscopy is the science of viewing objects as in three dimensions. Its application to photogrammetry is the observation of photographs for the purpose of visually discerning relative heights and distances of objects, and for the measurement of differences in such heights and distances. The ability to see stereoscopically is essential to proficiency in the use of aerial photographs.

Enclosed example shows clearly the results of one type of overlapping perspective projection may be observed by means of dichromatic prints or anaglyphs formed of over-prints of the two perspectives in complementary colors, usually blue-green and red. If the left image of such a two-color print be formed of a blue-green over the right, the left eye will see the blue-green filter over the right, and the left eye will see the blue-green image in black.

Dichromatic projection is utilized in certain stereoscopic plotting instruments, particularly the multiplex. In the utilization of dichromatic projections to form a spacial modial, which is a small scale reproduction of the original model in nature, the conditions for true stereoscopic reproduction must be observed: the cone of rays leaving the dichromatic projectors must be symmetrical with the cone of rays entering the camera at the instant of the exposure.

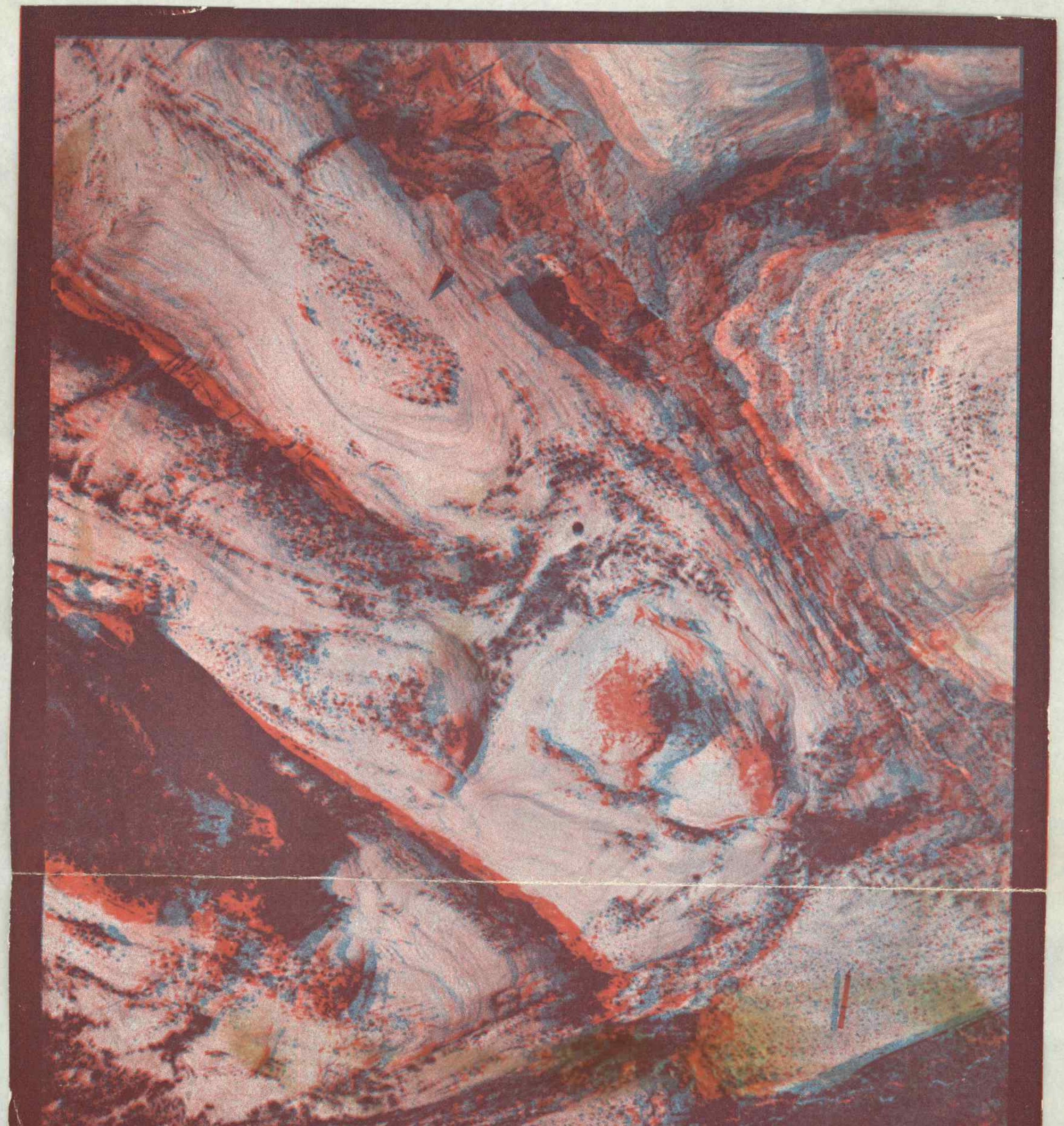


Figure 8   Anaglyph Showing Relief as used in Multiplex

The Multiplex Aero-Projector

The multiplex aero-projector is a stereoscopic plotting instrument for compiling maps by the use of simultaneous reprojection into space of several overlapping aerial photographs of a series. Such dichromatic projection consists of the projection of a series or a strip of pictures in alternate complementary colors, usually red and green, and observation through glasses of complementary colors, of the spacial model formed by the fusion of the doubly projected images of the area of overlap of the pictures considered.

To keep the size of the apparatus of reasonable dimensions, to permit working scales comparable to those desired for finished maps and to permit a ready solution of the optical, photographic and illumination problems involved, a diapositive to a greatly reduced scale is utilized in lieu of a contact print at the scale of the original aerial negatives. The multiplex consists of an adjustable supporting column, a bar containing a metric scale, a rack and electric wiring. On the bar may be mounted nine or more projectors depending upon the length of flight strip being considered.

Overlapping pairs of diapositives are placed in adjacent projectors. When the individual projectors are adjusted and illuminated a spacial model is formed in space beneath the projectors and some distance above the drawing board. This model is formed by the intersection of the bundles of red and green light rays from the projectors, and to the naked eye forms a series of blurred images on the drawing board. However, when this blurred image of the model is observed through spectacles whose glasses are equipped with filters like those in the projectors, there is formed a clear stereoscopic

Ground control; consisting of triangulation, traverses, and level lines is obtained in the field as in the past, but in a considerably lesser quantity, as under present methods a little ground control goes a long ways.

Computing Section. Projections, parallax tables, elevations of secondary control and other miscellaneous work are computed here. In addition, control is pricked on the photographs using the stereoscopes along the far wall.

Vertical control is extended on the multiplex aero projector. In the sequence of training, men progress through the various operations involved in the preparation of a topographic map. The final stage is the multiplex. The Multiplex operators came from stereo comparagraph operators. When the multiplex equipment was first received selected stereo comparagraph operators were able to do creditable work after two weeks instruction, i.e.. as soon as they became fully acquainted with the mechanics of the machine. The most skilled operators extend control and the others fill in topography.

Contouring directly from the T-3A aerial photographs by means of the Engineer sketching Stereoscope. Each pair of photographs is contoured on a separate template. The man operating this machine enlisted as a recruit two months to a day, before this picture was taken. His rate of production after three weeks on the machine was about $1\frac{1}{2}$ square miles per day, and increased to about 2 sq. miles per day at the end of three months from the time he enlisted. This is good, but not exceptional. In an emergency a large number of men could be so trained and put on actual production in less than 3 months after entering the service. It is necessary to train a man in only one operation. The course of instruction given these men is of a very high order, probably the best available anywhere in the United States.

Compiling the several contoured templates onto a single sheet of non-shrink film base.

This is the copy to be reproduced. On it are constructed the polyconic projection and the positions of all control points. The projection and field control are taken from the Master projection sheet and the secondary control from the radial line control sheet. The templates are adjusted to this control and are thereby reduced to a uniform scale.

Editing Section: This section prepares woodland over sheets, names, and road classification sheets, civil boundaries, and checks all work for possible errors. This work is later confirmed by a field check.

Figure 9 Establishment and Extension of Control model similar to the enclosed anaglyph.

Within the anaglyph are printed three "floating marks"; a diamond point, arrow and dot. All the floating marks are formed by printing duplicate images spaced at distances equal to the horizontal parallax corresponding to their own elevations. The determination of heights in the spacial model on the multiplex is accomplished by the introduction of the single floating mark. Its height in the model may be varied and measured. The floating mark may be raised and lowered by adjusting the screw on the tracing stand and this change in height is measured on the scale. By turning this adjusting screw, the floating mark may be caused to rise above the spacial model, to come in contact with it or sink below it.

In drawing the map, the floating mark is located in the exact center of the disc and a pencil is fixed directly on the stand below this point. As the tracing stand is moved over the paper, a true othographic projection of the model is transferred to the tracing sheet. The height adjustment screw on the table affords the setting of the requested contour height, and the tracing stand is merely moved around until it comes in contact with this part of the model and then it is followed around.

Each projector is free to move about a single axis and this allows the correction of crab, tilt, tip, and swing. They are in reality reduced photo projectors of the original aerial photo and are arranged along the supporting bar according to the representative fraction of the plotting scale (1/10,000, 1/20,000, etc.). This is complete for each strip flown by the plane, and finally reproduces an exact replica of the landscape as it is in three dimensions.

The best results in plotting are attained by having the unit broken into three separate three projector units in lieu of the nine projector system. The plotting rate per three projectors is three square miles per eight hours. On the basis of 22 shifts per month the output at a scale of 2" equals 1 mile would be 66 sq. mi. per month.

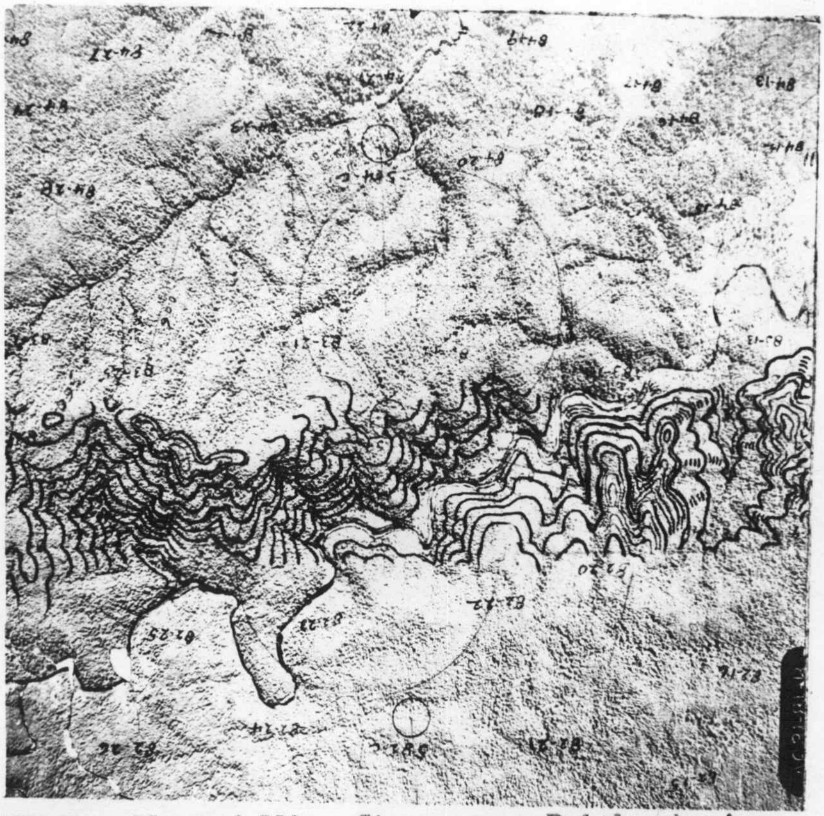
The multiplex has been developed primarily to minimize the amount of necessary ground control and has succeeded in doing this for small scale maps of large areas by reducing the ground control to as low as 25% of the amount required for ground methods.

The accuracy of the Multiplex is somewhat dependent on the types of terrain encountered; however, this usually averages about 1/1000 of the flight altitude; so for 10,000 ft. this would give a vertical accuracy of ten feet. For horizontal accuracy, the accuracy is within the limits of drafting at the plotting scale and is considerably more accurate than for radial line, or ground methods, since the location of each point image is by actual measurement and is not left to the judgment of the individual.

Stereocomparagraph

This instrument is a simple plotting machine which uses the stereoscopic principle of parallax for plotting military and other small scale contoured maps. It is one of the few steroscopic plotting instruments manufactured in this country, and is manufactured by the Fairchild Aerial Camera Corporation. It is designed to be attached to a standard type drafting machine. See enclosed illus-

Figure 10 Map Compilation with the Stereocomparagraph



Figures 11a and 11b. Stereoscope Prints showing control marking and contours

Two reduced contact prints showing control marking, contouring and numbering. These two were used in the stereocomparagraph.

tration as to description and working order. This was invented by Capt. B. B. Talley and developed by Fairchild. It has important use in the 29th Engineers in their cartograph unit.

Aerocartograph

It is sometimes known as the Universal Stereoscopic Plotter and is a combination of viewing, measuring, and drawing instrument. By means of a series of prisms and lenses, two overlapped photographs are viewed stereoscopically. A floating point is carried in each plate holder and these are fused togethers as in the Stereocomparator. This floating mark can be moved over the picture viewed in an x and y direction by the two hand wheels. The parallactic displacement, which is really a measure of the altitude, is controlled by a footplate. By operating these three controls, the floating mark can be made to trace over the portion to be mapped.

GROUND CONTROL

Up to this point I have endeavord to give the reader a definite outline of the rapid progress of aerial photography, and at the same time have endeavored to give them the simpler working principles involved. However, to a very great extent, most of this development has been done to escape one vital and expensive part of aerial mapping, that of ground control establishment. In areas that have been mapped previously by some other method it is not as bad as those that have not been mapped in the ground control expense involved; however, it is the latter that is of more importance to the Northwest. Most of the area is in this condition because of the fact that the cost of control is so high.

It has been computed that the cost of this necessary control is likely to be from two to four times the cost of the photographs and from 15% to 25% of the total cost of the map.

The old method of camera used to take much more control than the present multiple lens cameras because of the restricted range of the lense. The present 5 lens camera can have flight lines spaced from 2 to 5 times the width of the single lens camera because of the wider area of coverage of the many lenses. Being able to do this is a noticeable reduction in control.

Planes have been developed to fly higher in order to further this principle and this in turn has led to finer precession instruments because of this greater coverage, and greater chance for more error from the sources outlined previously.

Films have had to be developed to greater speed and clearity as well as the shutters. Due to the increased speed of photo taking rapid and automatic taking devices have been developed.

High altitudes call for more difficulty in recognizing the minute details of the terrain below, and thus the stereoscopic principles have been advanced very rapidly for both identification and plotting.

I have just mentioned a few of the many things that have been advanced because of the expense of the basic consideration, that of ground control. This development has not been forthcoming without a great deal of expense, but at the same time there has been very little work done to reduce the cost of the actual laying of the control.

I have mentioned one type of control that I believe could be developed to minimize the cost of the existing systems of triangulation, traverse, and plane table work, that of floating control. Of course, it is considered inaccurate because nothing has been done to further its accuracy. It is my belief that if some of the money and effort spent in research was made on this underlying factor for the solution of this problem in lieu of developing new instruments to avoid it, aerial mapping would advance faster. It is apparent that a solution of control would solve the problem to a greater extent and would curtail this advancement in the other more costly field.

It seems plausible and possible that some method of measuring distances between two distant points could be developed through sound. They have perfected this method in measuring the depth of water in soundings on the ocean, and I believe that this principle of reflected sound waves could be applied here. It seems possible that one could measure the oscillations of the sound waves between two points on the same horizontal plane, to a great degree of accuracy, perhaps a greater degree than the existing methods of stadia and chaining, and with much less expense.

Another idea in the advancement of this same theory might be via reflected light in lieu of sound and radio. The frequency of the reflected light rays from a source that was normal to the reflector should come back at a specified speed of light. I will admit that the apparent costliness of the method at the time seems to throw it out, but perfection through experiment and development could bring surprising results.

With regard to what has briefly been outlined, no such thing exists, and it is not the purpose of this paper to develop same, but it is necessary to show the methods of control used at the present time, and the methods used in extending this control in the compilation of the maps. It will not be the purpose to outline the definite field technique nor the principles involved as they are of high calibre accepted engineering principles that have been used for other types of engineering work and must be used in aerial mapping.

Types

Ground control is divided into (1) horizontal control and (2) vertical control.

In nearly all of the practical methods in use today, a certain amout of ground surveying is necessary and required. Control stations can either be chosen before or after the picture has been taken. It is best to have these stations in the form of triangulation system so that angles can be read with a transit and distances measured. Third order triangulation can be used to compute the coordinates of all the ground stations. This is known as horizontal control.

Levels are also taken to determine the elevations of all the control stations. This is known as vertical control.

Picture Point Control for Aerial Photographs

All points on a traverse line that can be easily identified from the air must be located. These points should be selected with due regard to easy identification as only such points as are clearly shown in the photographs can be used. These points should be located at well-defined road intersections, crossroads, stream crossings, railroad crossings, intersections of fence lines that are well beaten out by cattle or defined by trees or brush, large isolated single trees, and wood line junctions with roads. Nothing is superior to a road intersection in a sectionized country. Sharp angle intersections should not be selected as the points will be too indefinite. Many points commonly used are useless in controlling photographs unless they are located by reference to something that can be identified. Among these are nails in tree roots, gates, wire fences, windmills, water tanks and church steeples.

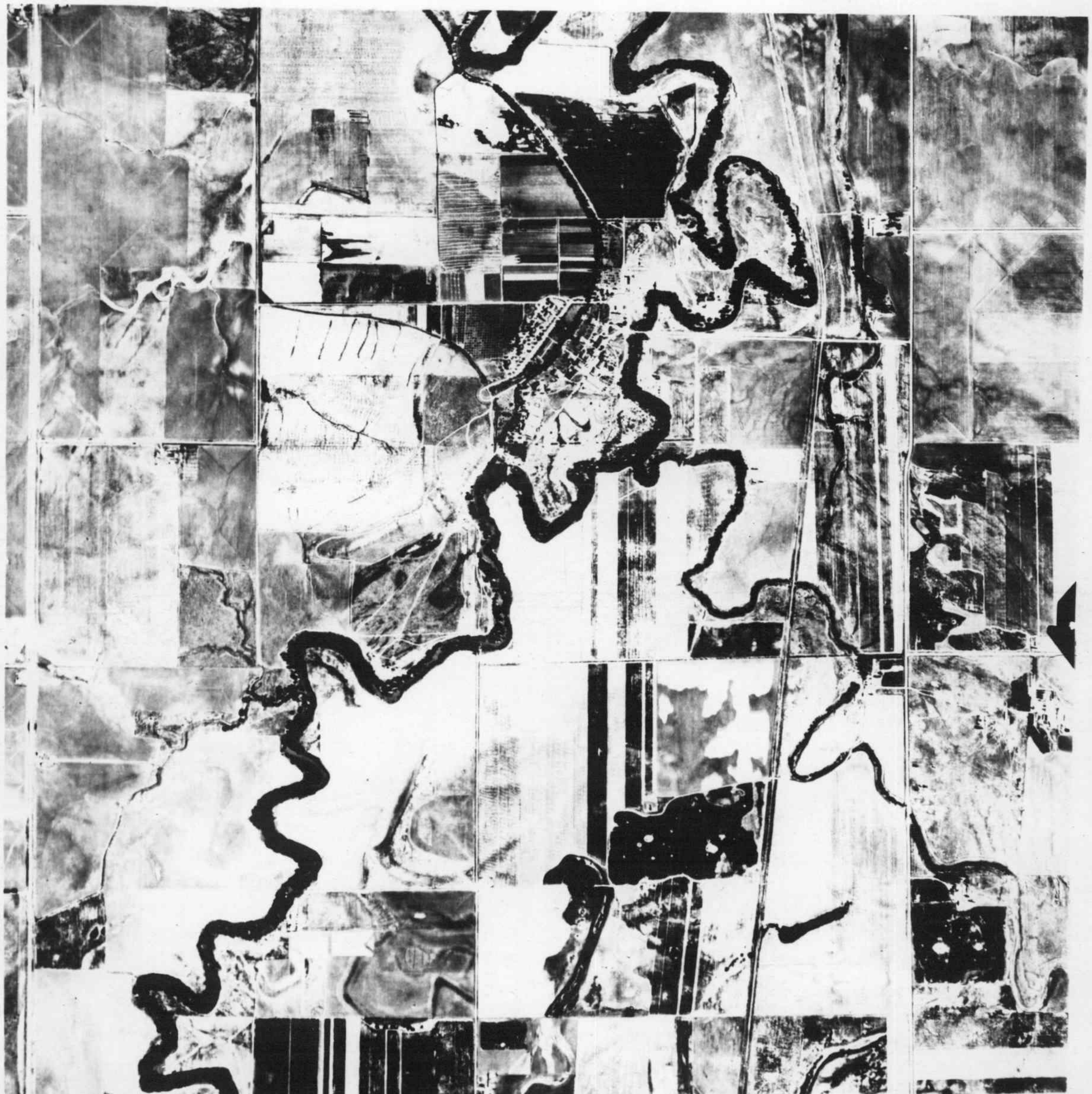


Figure 12 Contact Print Showing Drainage in Sectionized Country

Picture points should be located at one-half mile intervals wherever possible so as to allow sufficient control points on overlapping photographs. In no case will picture points be more than one mile apart.

Field parties should also remember that an accurate sketch of the fences, roads, and woodland around a located point is more valuable in identifying the point than any description can be.

Methods of Control

In general it is necessary to use polyconic projections for map compilation. It is necessary to place it on the same plane as existing surveys have been made in order that they might work together. In so far as possible the North American 1927 Datum plane should be used, although an occasion might arise while working in a section of the country where the existing records are of an older unconverted system to use this system. It would be practically impossible to set the entire system of control for aerial maps without the cooperation with other agencies. Every effort should be expended to use all existing reliable control, and in the event it is not extensive enough it will be necessary to establish more for the type of map being compiled.

It will be beyond the scope of this paper to endeavor to outline the various methods for control for actual topographic mapping as outlined by the Board of Surveys and Maps.

Triangulation

The establishment of extensive triangulation nets should not be necessary in connection with the Forest Service. This is true in a large degree for the Eastern part of the U.S., but not so true for the Northwest. However, should the amount of existing control of first and second order be insufficient to meet the requirement of the Board of Surveys and Maps, arrangements should be made with the U.S.C. & G.S. for the establishment of such additional positions. Any third order stations needed for the project could be established by the Forest Service or a cooperation of the two agencies together.

In general there should be at least three third order positions available in each fifteen minute quadrangle. In the event that there is a need for supplemental control, third order may be used in which case the triangles should close with a maximum error of 10 seconds and an average error of 5 seconds. Closures in length of lines should not exceed 1/5000.

Traverse

The principle traverse lines on which the aerial survey map depends for accuracy in horizontal position shall conform to the standards of third order control as established by the Board of Surveys and Maps. It is essential that this permissable error not allow for compensating errors of closure, but require that each and every line must be within that degree of accuracy, if this order is sufficient for the accuracy of the map being compiled.

Plane Table Control

Plane table control shall be considered as fourth order accuracy. In graphic compilation by aerial methods, the plane table is valuable in preventing accumulation of error for position in as much as the error will spread or distributed over the entire area.

Plane table could be used to supplement traverse control where the country is so rugged that the cost of the other might be prohibitive for the scope of the map.

In extending control by this method it is recommended that it not be extended further than four figures from the base.

General Land Office Control Land Lines

Maps could be prepared from the existing control of the G.L.O. land net system. A map made from this type of control could be considered as conforming to the standards of the Board of Maps and Surveys.

In planning a control system of a project it would be more profitable to tie in two or three points of the existing grid and combine it either in traverse or triangulation form, which in turn would have the results of spreading the control over a wider area.

Floating Control

In the event that the existing control is not sufficient and there is not the possibility of tying in with any existing control, you could establish this type of control. It consists of making a straight controlline of known length and location and can be used on the photographs in the same manner as before. Control of this type will be more inaccurate than third order control and should be considered as such.

Other Control

Cadastral surveys and other surveys should not be used to such an extent as to affect the accuracy of the map, but can be used in many instances to a great advantage in locating drainage and culture, providing the reliability of the survey has been established.

Field Activity Prior to Photographic Work

It is very important that the key control stations are easily identified on the photographs after they have been taken. In order to do this, it would be necessary to cover the control points before photographing in such a manner that they could be definitely descernable. However, it should be remembered that many of the corners so marked may not be so located as to be economically tied to the control. These positions may be located by radial control.

Satisfactory results have been obtained by taking the center as the point and constructing a circle of lime 50' in diameter and five feet wide around the point. In the event that the points are highly inaccessible, crosses of cheese cloth have been constructed. In some instances, it has been found that such markings have been hard to discern because of the ability of the surrounding terrain to absorb them at high altitudes. This should be considered from the economic standpoint in marking the control before the photographs have been taken.

In the case of the traverse, the control points should be selected to form an approximate equilateral triangle, and it should be within the stereoscopic overlap of the two pictures and as far apart as this area will permit.

Sometimes the photographs are available at the same time the control is to be placed in the field. "hen such an occasion arises it has been found to be greatly advantageous to study the area stereoscopically, outline the traverse routes and carefully select in the office the approximate location of the desirable ground control points and designate the approximate location on the photographs by means of a small circle in red. Along this line, it should be held in mind the idea of trying to form the triangles mentioned before, and that the outside points on each photograph will fall in the adjacent flight. It is highly desirable to have the three points show in three photographs in question and that points are not selected in close proximity to the azimuth line of the flight in question and that points are not selected in the close proximity to the azimuth line of the flight.

After the points have been outlined in the office, a person trained in interpretation of aerial photographs should follow this control route on the ground, and within the limits of each circle having been marked on the photograph, distinguish some type of control point on the ground. This point should be pricked through on the photo, and a distinguishing number recorded on the back. It is definitely tied in with existing control accompanied by a description.

The true identification of the point method is very difficult and is one of the most important steps in aerial mapping. For the most part, the features present that actually show up on the photographs, such as railroads, highways, roads, trails, large streams and shore lines are easily discerned on the print. Buildings, swamps, and other points which are partially hidden by timber, are not so good, and it has been proven that such points have to be identified with the photograph in the field. It is imperative that one have a clear and unmistakable identification of the point, and in many instances the use of the stereoscope should be employed, except in the case of railroad crossings and highway intersection. However, the angle of intersection for these points should not be too sharp as it will entale a wider range of interpretation for the exact control point.

As an alternate method, the control engineer may be furnished with the photographs with the instructions to go into the field and mark and measure the control as the transverse is extended. It has been proven that this method retards the extension of the control and the results are not exactly those wanted when the instrument man has to make the selection and identification of the points.

It should be remembered that it is not the purpose of this paper to outline the field methods of actually outlining the engineering principles to be used in the field, but they should be of the same high calibre and the approved methods used by competent engineers of today.

Flight Reconnoissance for Control

It has been generally accepted that one of the most convenient and in many instances the most economical way of collecting this information is the formation of an uncontrolled flight mosaic.

From this map it would be advantageous to go out and establish such control as the finished map would require. This is essential in extremely rough terrain as in the Olympic quadrangle. It is many times advisable not only to take vertical photographs, but to make use of oblique photographs for better and easier recognition of land marks, drainage, and elevation points.

An operation of this nature would far surpass the time element of ground reconnoissance, and actually having all the area beneath you would enable you to study it all at once, and thus would have a more efficient analysis of the entire project. In the case of an abundance of established control, it is recommended to go out and mark these points without a flight reconnoissance.

EXTENSION OF CONTROL

Graphical Methods

In using the graphical methods of control, the attempt is made of matching photographs by intersection in much the same way as ordinary plane table intersection. The different methods are listed as follows:

1. Straight line method
2. Section line method
3. Three point method
4. Radial method
5. Template method
6. Slotted template method

From past operations it has been found that 85% of the photographs taken with modern equipment have been tilted less than one degree, and about 12% between one and two degrees. It has been the general practice to use photographs that are not tilted more than three degrees without correction. The maximum difference in radial direction of objects on a photograph tilted three degrees is four minutes 36 seconds at 45 degrees from the axis of tilt.

Past experience has shown that it is easy to have a variation of one hundred feet in altitude due to rough air currents. This has not been regarded as serious, and in compiling a map a variation of 2% in any one series of photographs is not considered excessive. If greater precision is desired, they may be rectified as described previously in this paper.

Straight line method

The principle point of each photograph is marked, and by means of a straight edge an attempt is made to match the prints so that the principle points fall on this straight line. Natural features are also matched such as roads, rivers, etc.; at least two points are selected in the first print which fall on this straight line. These same points are then located on print number two which overlaps print number one by approximately 65% in line of flight and 20% between flight lines. The straight line joins the two points on each of the two prints and then these lines are matched and the prints held in place. This is repeated throughout the strip for all the succeeding photographs.

Section line method

This method is similar to the straight line method except that the section lines of the Public Lands Division are used for matching.

Three point method

The same principle is involved as the graphical solution involved in the orientation of a plane table. Three well defined points are located and then lines are drawn to them from the principle point. These points are located on the base map by triangulation and plotted. Then you place the tracing over the photograph and mark the number and the relative position of the photograph on the tracing. This is repeated for each of the photographs, and as far as possible, the overlapping points of the photographs are synchronized, and this is continued until the flight line is completed.

Radial line method

In this method the principle points may be considered as the origin of the radial direction of the different objects shown on the map. For example let us consider the principle point as an instrument station and lines radiating from it may be drawn on the photograph through the objects which are too plotted on the map. The photograph may be plotted on a tracing of the map by causing the radial lines which pass through the control points as located on the photogrphas to pass through their corresponding plotted positions on the map.

After the photograph has been oriented and plotted on the map, a second overlapped photograph may also be plotted by its radial through the control and its radial through new objects of secondary control. This is continued till completion.

Template method

The template method is more or less an outgrowth of the radial line method. This method is faster, easier, permits a division of work, and is of equal accuracy. The extra cost of the celluloid for the templates is small and is overbalanced by the saving in time.

The prints are marked in much the same manner as in the radial method, for both the ground control and secondary control with the principle point usually being the center of the picture having been marked on the print by a mark on the camera lens. This is known as the principal point and is marked with a red circle, all others are marked with blue. Great care should be exercised in chosing and pricking of all points.

The templates are made of transparent celluloid and have a low shrinkage value. For the single lens camera they are 8" x 10" in size. They are held in place over the photograph and the radial line from the principle point to the secondary point is drawn. It is not necessary to draw the lines in solid as only an inch on each side of the radial point is sufficient.

It is essential that you have a projection sheet prepared for the operation according to the scale of the photographs. The latitude and longitude lines are laid out at the desired scale. After this has been done, it is necessary to plot very accurately the ground control stations.

In starting the operation it is practically essential that there be three definite ground control points at the start of each flight line. Now you take each of the templates and lay them in order. For instance, take the first template. The ground control stations are located on the base map and on the template. These are matched. Then the second template is laid so the principle point of the second template is over the same point on the first template. The radial lines from both templates will intersect at the secondary control points as the lines have been radiating to the same points from the photos. These intersections are pricked and marked on the base map. This is continued for one flight line and then the templates are usually held together by scotch tape. In the event that the intersections do not close in a perfect fix, the error is distributed within the triangle of error and spread out over the entire assembly. Corresponding/flight strips are matched together in the same manner.

After this work has been completed it is ready for tracing the map from the prints. In placing the prints under this control sheet it has been found that seldom if ever all three points of the print will coincide identically with the same on the control sheet. This is corrected by proportioning the error between the points, placing more weight on the principle point and proportional weight according to the distance of the point from the principle point. After this has been done, it is okey to trace the area off the photo within this restricted area. Due to the overlap of the prints, there will be sufficient duplication that the tracings will match. This is continued until completed.

Slotted template method

This method is an outgrowth of the template method outlined above. It was developed and is patented by the Fairchild Camera Corporation. It substitutes a slotted template for the celluloid template and the templates are held rigidly together by small collar-button-like studs in lieu of the scotch tape. It is easier and faster than the template method, but it is quite expensive at the present time due to the cutting of the templates and the preparation of the yokes that ratio the error within the triangles of error as outlined above. See enclosed sample of template made of cardboard and drawing of stud. I will not explain this method further, as it is a similar operation in principle, but different only in mechanical operation as the template method. It is accepted that this method is more accurate than the ordinary template method.

Findings of the American Society of Photogrammetry

Beltsville Demonstration Area
Showing Results of Radial Triangulation
by the Slotted Template Method

In 1937, the American Society of Photogrammetry sponsored a test in collaboration with several of the Government bureaus on three systems of graphical control, namely: the straight line, the radial line template, and the slotted template system. The Committee selected an area of 150 square miles in the vicinity of Beltsville, Maryland. This is a gentle rolling country, with maximum elevation difference of about 200 feet. The area had been photographed with a 9" x 9" camera on a scale of 1:12,000.

The U.S.G.S. laid out an intensive traverse net, and with the assistance of the SCS, which furnished additional needed survey personnel, 273 ground control points were obtained with a position accuracy of 1:10,000.

The photographs covered the area in 12 flights, averaging 19 photographs to the flight with approximately 60% overlap in the line of flight and 30% side overlap.

The test included four different laydowns of control and the results were as follows:

Laydown No. 1

Control

Four picture points, one located in each corner of the area.

Results

Maximum error recorded as 125 feet.

Maximum error between adjacent control points was 55 feet.

The average error between adjacent control points was 25 feet.

Average error for 237 points was 43 feet.

Laydown No. 2

Control

Additional control point in the middle of the area.

Results

Maximum error was 125 feet.

Average error for 236 points was 36 feet.

Maximum error between adjacent control points was 50 feet.

The average error between adjacent points was 20 feet.

Laydown No. 3

Control

One point added at mid point of each side and the point in the center of the plot removed.

Results

Maximum error was 90 feet.

Average area of 232 points was 18 feet.

Maximum error between adjacent control was 55 feet.

Average error between adjacent points was 10 feet.

Laydown No. 4

Control

Thirty-one picture points, 1 in each corner, 1 in each common overlap of each flight.

Results

Maximum error was 50 feet.

Average error of 206 points was 15 feet.

Maximum error between adjacent control points was 50 feet.

Average error between adjacent control points was 10 feet.

PLANNING A PHOTOGRAPHIC MISSION

Considerations

The first consideration in planning a photographic mission is the choice of the type of photographs to be obtained; whether they are to be oblique or vertical from single or multiple lens cameras.

It is becoming more and more the practice of the user to require that the photographs be made under a definite set of specifications, to meet the requirements for said map.

Vertical photography

Vertical photographs are made for the purpose of obtaining some form of measurement of land areas. The first requirement is that they possess the required amount of accuracy for the project. The amount of distortion of the photographs will depend to a large extent on the type of camera used and the extent to which the plates will be used.

Secondary in importance to the camera is the selection of proper focal length. There is a limit of choice in this matter. Accuracy and the greatest economy can be obtained by use of the camera with the largest plate, providing it can be flown at an altitude which will give the desired scale. This permits a saving of flying time for the photographic crew and a saving in labor and materials for the user, who in this way has the minimum number of photographs to handle.

Estimates

This should include the amount of flying time, the scope of the project, the location of the flight lines, the amount of time to get from the base of operation to the actual flight line, the length of the flight line, and the number of prints to be taken; considering the overlap and then adding 25% for the amount of retake that will more than likely be necessary because of improper prints.

Selection of a Base of Operation

The ideal location for a base of operation is in the center of the area to be photographed, although this is rarely possible. The distance from the actual operation is somewhat dependent upon the rate of climb and flight altitude of the project without a loss in time or additional expense due to travel back and forth.

If there is a choice, it is well to select a base to the west of the area to be photographed, inasmuch as weather cycles usually travel from west to east and advantage can be taken of suitable weather much more rapidly if it passes over the base of operation before it reaches the area to be photographed.

It is preferred to have the plane housed at an airport in order that it will be possible to keep it in perfect repair and to move instantly. Housing facilities in many instances are merely auto trailer for the personnel in order that they will be available to move at any time.

Preparation of Flight Maps

Some sort of map must be prepared from which to fly the area, and this may vary from a sketch to a highly accurate map. The type preferred is a colored type map with a scale of one inch equals one mile, providing the area to be mapped is not too large.

The present advancement of equipment has made the flight of strips more or less automatic with the Fairchild Solar Navigator. With this new rig, flight strips may be flown absolutely straight and parallel regardless of wind changes or magnetic variations. This is a great improvement due to the fact that the control points on the edge of the strip will be able to be utilized. See enclosed picture.

Prevailing winds or landmarks may make it appear desirable to lay down the flight lines in some particular direction, and in the past it has been considered best to fly either east and west or north and south.

The limitation in the length of the strips should only be the li itation in the number of exposures it is possible to take with one loading of the camera. The distance of the strips from the base of operation might be a cause for cutting them short. Whenever possible, the minimum length should be between ten and fifteen miles. Anything less than this requires too much turning and loss of valuable photographic time.

Index maps

The index map is prepared for the purpose of recording the approximate location of each of the photographs taken over the area being mapped. This indexing is usually done on a copy of the old flight map, or one could be drawn in a simplified manner just to show the number of the photograph and the numbers of the flight line.

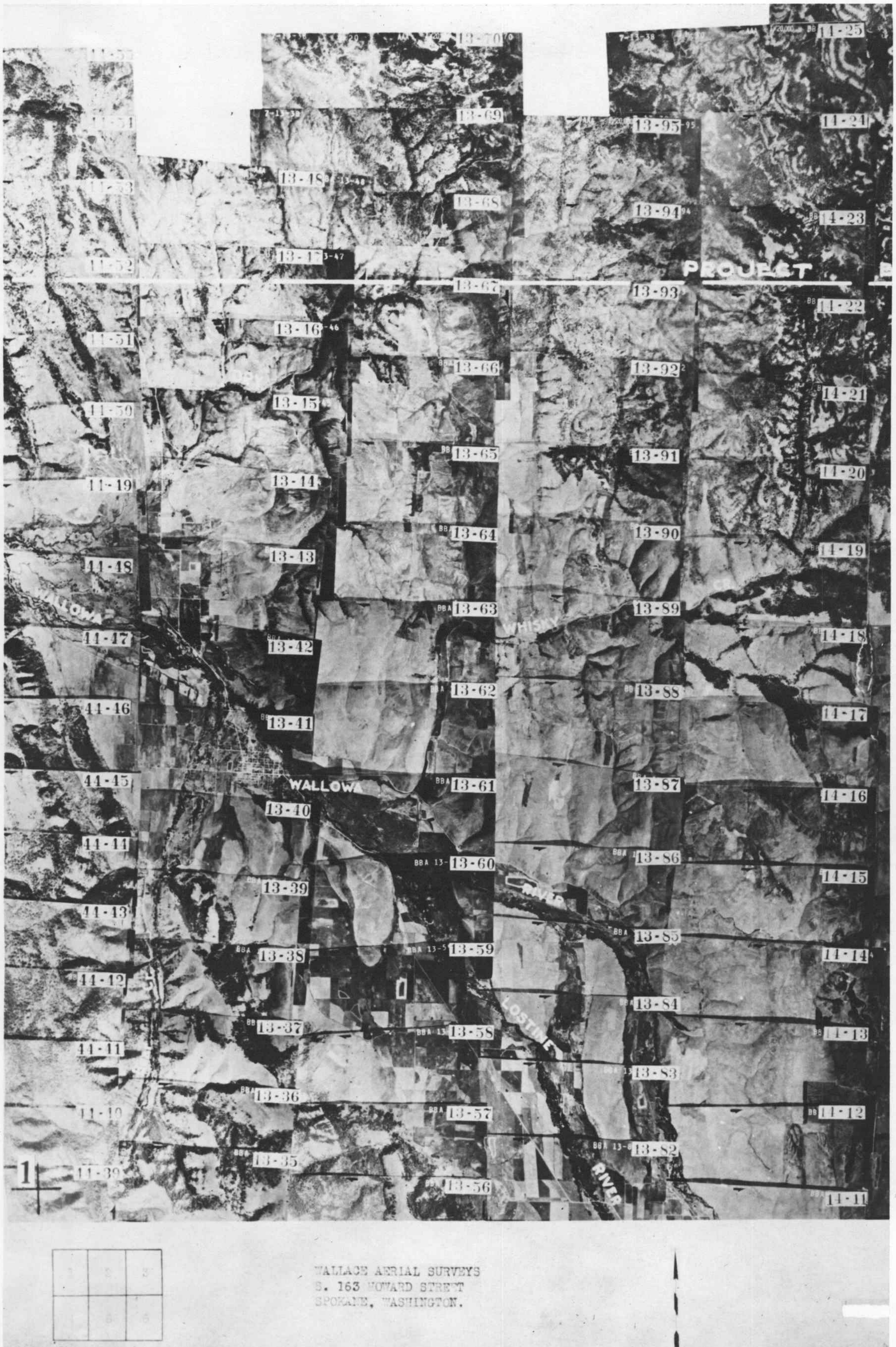
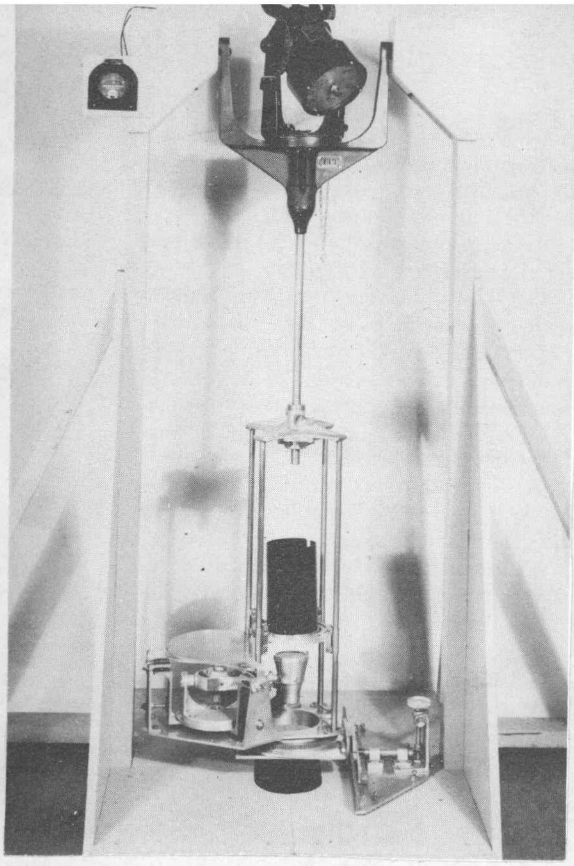


Figure 13 Section of Flight Index Map



The Fairchild Solar Navigator which enables photographic pilot to fly an absolutely true ground course regardless of wind conditions or magnetic variations is shown here. Above is the complete instrument set up for demonstration purposes. Below is an actual installation in a photographic airplane. Only the lower portion of drift sight and gyro are shown in this view.

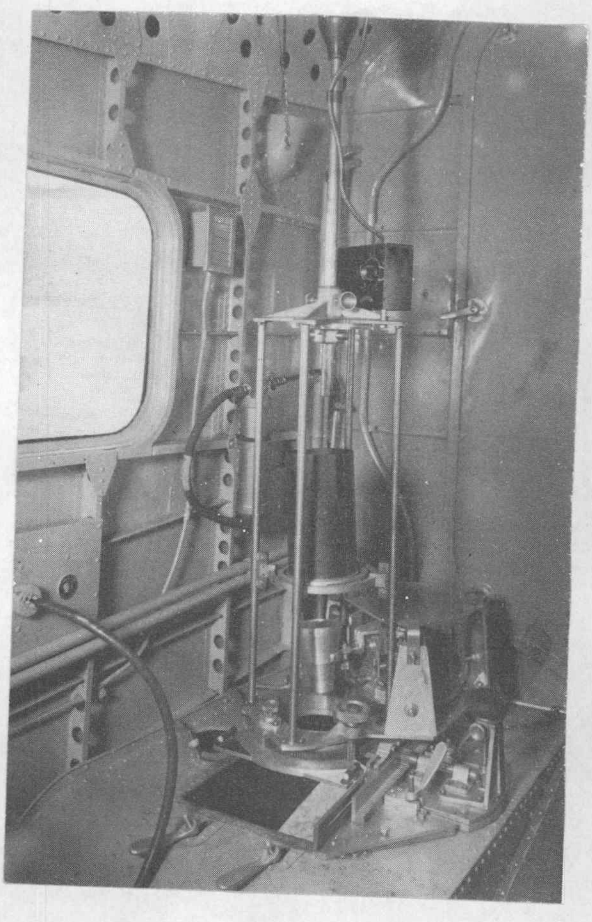


Figure 14 Fairchild Solar Navigator

Airplanes

Any plane which may be flown hands-off at the desired photographic altitude and possesses room and lift sufficient to carry the necessary personnel and equipment may be considered satisfactory.

A photographic plane must be able to perform the task expected of it. It must carry the necessary load at the desired altitude; it must be capable of stable operation at high altitudes. An altitude of 15,000 feet is no longer considered a high altitude for photography for mapping.

The airplane should permit visibility both straight ahead, to the left and right, and straight down. For the latter, a glass window should be provided in the floor to enable the pilot to plumb himself over a point or over the flight line. If the plane is multi-engined, the engines should not obstruct the view of the adjacent flight lines. The pilot may wish to study his map while flying the strips in order to identify and select well-defined landmarks over which he must fly in succeeding strips.

Use of Oxygen

Continuous flying at altitudes above 15,000 feet requires an artificial supply of oxygen to insure the proper mental and physical functioning of the human body. It is possible to live at altitudes of 18,000, 20,000, or higher without artificial supply of oxygen, but for the accomplishment of an aerial mission in these altitudes, oxygen is not only desirable, but necessary.

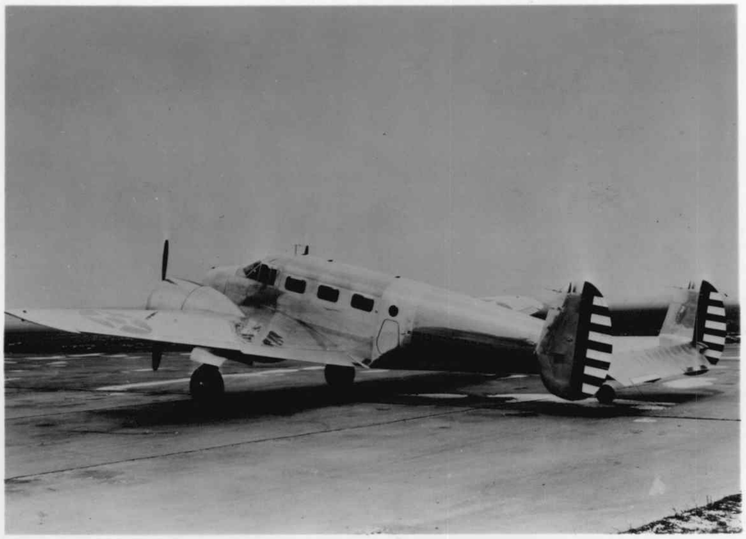


Figure 15   The U. S. Army's Latest Photographic Plane


The Abrams Explorer, High-Altitude Mapping Plane
Abrams Aerial Survey Corp.

Figure 16   Commercial Mapping Plane

The quantity of oxygen required varies over a wide range for different individuals depending upon the exertion they undergo, their inherent consumption rate, their nervous state, and their inclinations toward conservancy. It has been found that oxygen is consumed at approximately the rates given in the following table.

Altitude (Ft. above sea level)	Oxygen Consumption (Cu. Ft. per minute)	
	Pilot	Observer
10,000	0.6	1.3
15,000	1.1	2.2
20,000	1.5	3.1
25,000	2.1	4.3
30,000	2.9	5.7
35,000	3.7	7.4

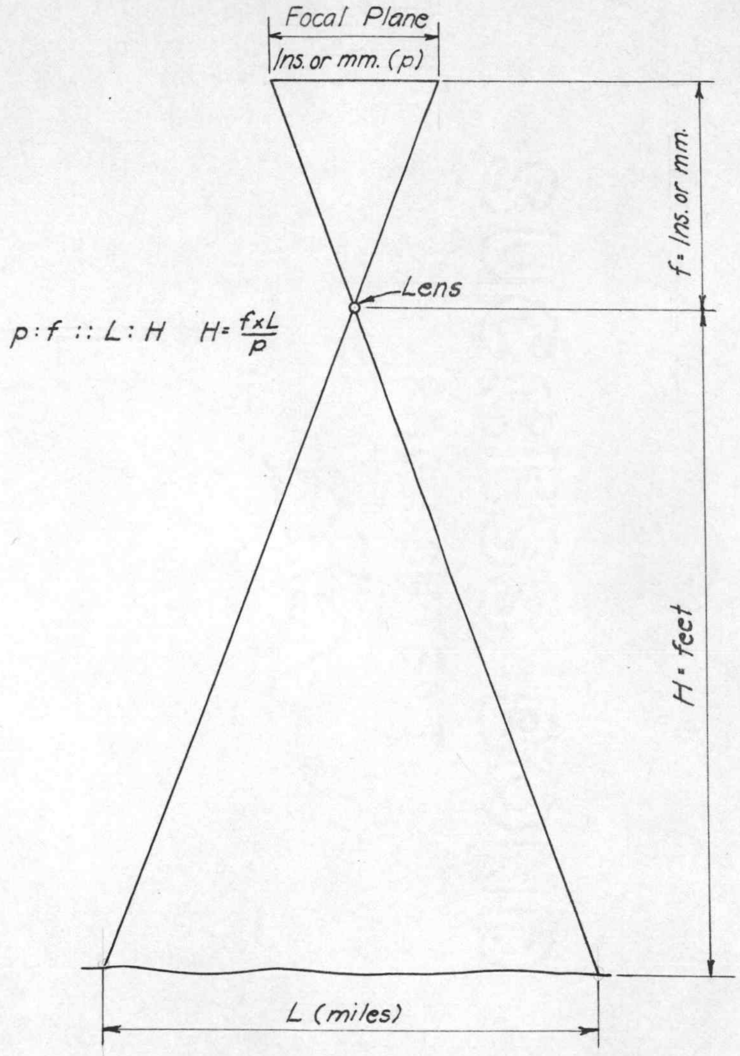
It seems to be the general consensus of opinion that a person working in high altitudes for any length of time even though the supply of oxygen might be adequate, the morale of such an individual hits a remarkably low ebb and does not give much as to whether the job to be done keeps or not. It has a decided effect on one's morale, and this is a very limiting factor. At the same time one's efficiency drops with surprising rapidity.

Scale of Photographs

It should be remembered that in selecting the control stations, points on the tops of hills as a rule do not make the best control points for aerial control, but rather points at average elevation of the terrain to be mapped. The reason for not using the top of hills is the fact that too much change of scale may be introduced because of the value of H being reduced and therefore the scale H/f is reduced. See Figure 17 for the computation of scale.

The most common scale fraction is 1:63,360. This can be computed if the focal length of the camera in inches and the ground length in feet are known, the scale fraction becomes a direct proportion. In other words, it is the ratio of the altitude of the lens to the focal length of the lens, and this is usually known as the scale fraction.

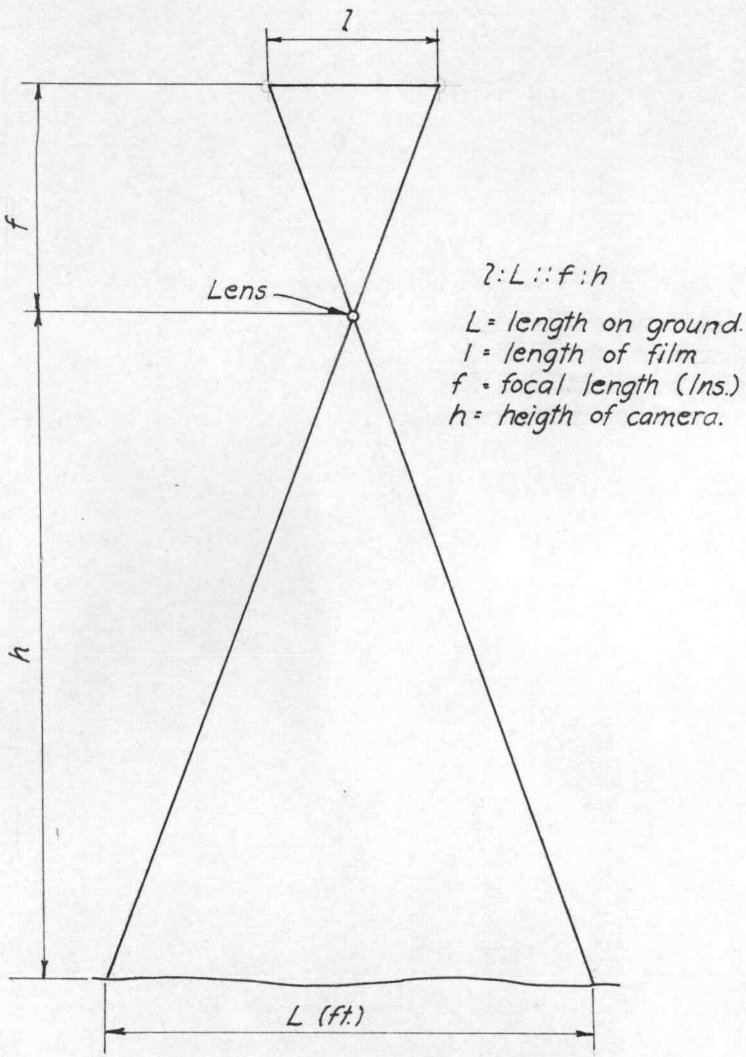
Likewise the altitude of the photograph may be computed when the scaled ground distance is known and the focal length and focal plane of the camera. This computation is illustrated in the accompanying illustration.



COMPILATION OF ALTITUDE FROM SCALE OF VERTICAL PHOTO

Figure 17

All terms of the equations are in same unit.



DETERIMATION OF GROUND AREA

Figure 18

CLASSIFICATION OF MAPS AND USES

There are many different types of maps that can be made from photographs. These include both the single lens and multiple lens camera, since the latter type can be rectified into verticals before being used.

Col. C. H. Birdseye of the U. S. Geological Survey and past President of the American Society of Photogrammetry has made the following classification:

1. Aerial photographic survey. The operation of taking aerial photographs.

2. Uncontrolled aerial mosaic. A representation of the ground made by matching aerial photographs without reference to ground control points.

3. Controlled aerial mosaic. A representation of the ground made from aerial photographs by bringing them to a uniform scale and fitting them to ground control stations.

4. Aerial line map. A map made from data derived from aerial photographs but which does not show contour lines.

5. Aerial topographic map. A map made from data derived from aerial photographs and which shows contour lines.

6. Aerial-Stereotopographic Map. A topographic map made from aerial photographs in which the contour lines have been determined by the use of the stereoscopic instruments.

Uses

Some of the possible uses for these maps could include the

Figure 19 Contact Print with partial contouring

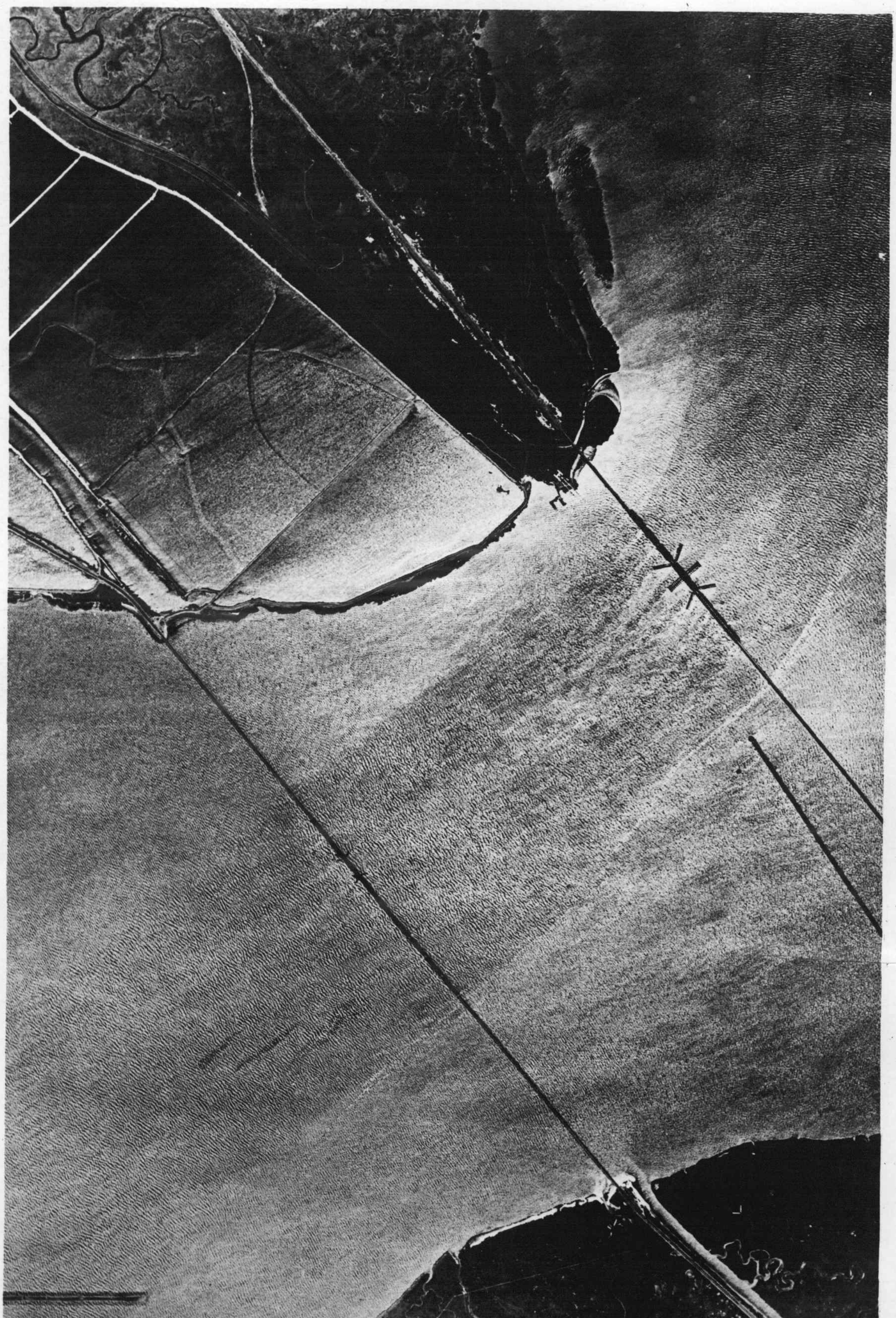


Figure 20 Contact Print showing bridge, trestle and coast line

following; however, there are many individual uses that could not begin to be ennumerated.

1. For studying stream and river embankments for the location of bridges.

2. For measuring water sheds and timber stands to determine the amount and species of the stand.

3. For highway and railroad location.

4. Assistance in planning the location of a pipe line or a transmission line.

5. To plot land to be purchased for right of way, and could be done at a saving of cost and at the same time the owner would never know such a project was going through.

6. Use in city zoning and planning.

7. Flood control as shown in the Willamette Valley.

8. Water supply and hydrolic development

The U. S. government specifies in most cases that all maps to be used on large projects shall be made with the aid of photographic surveys. The largest single agency in the Federal Government has been the Department of Agriculture. In the past ten years approximately $6,840,000 has been spent to photograph about 1,953,000 square miles of area of which 90% has been performed since 1934.

At the present time there is a mapping plan for the Board of Surveys and Maps stating that 1,500,000 square miles or 50% of the entire area of the United States is unmapped, and they are going to map this area with aerial photography. They predict that such an undertaking will entail $5,540,000 for aerial photography,

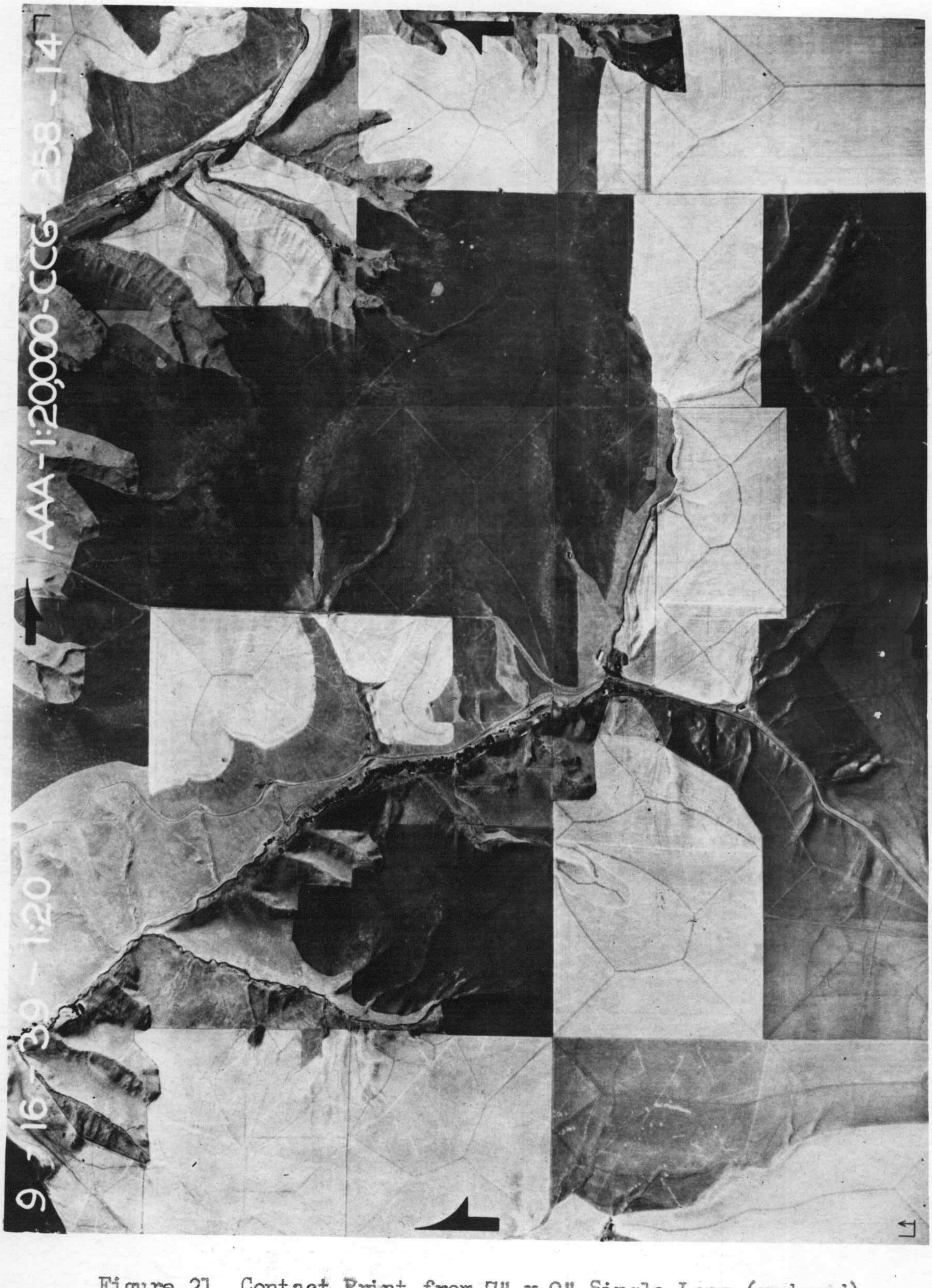


Figure 21 Contact Print from 7" x 9" Single Lens (reduced)

$20,200,000 for control surveys, $21,486,000 for planimetric mapping, $60,722,000 for contour mapping, and $9,583,000 for reproduction. This will give a total of $117,531,000 for the entire area and bring up to date the lands that have already been surveyed by some other means, but are considered inadequate. They consider completing this over a ten year period, and financing it through the government with state and civic cooperation where larger scaled maps would be required for their special uses.

COMPARATIVE COSTS

It has been shown in the State of Rhode Island that the aerial mapping of the state took less than one-hundredth of the time that it would have taken to prepare the maps from some other means, and at a cost of less than one-fiftieth of the cost of a ground survey.

In the Northwest it was shown that it would cost over $1000 per square mile to get an accurate contour map of the Olympic Peninsula and the Army did it for less than $75 per square mile completed, and with no chance of human error.

The Soil Conservation Service found that it cost 1/3 ¢ per acre for a completed planimetric map by aerial methods, whereas a ground survey cost 2¢ per acre.

The costs will vary according to the type of map desired.

SUMMARY

Future Predictions for Uses of Aerial Maps and Photographs

Timber Typing

The use of aerial photographs for timber typing is at the threshold of acceptance and a complete expedient practice. The difference in color of the different types is quite noticeable to the eye, and this can be carried even further by the use of filters and super-sensitive film. This is extremely true among the different species of conifers, i.e. the difference in color between hemlock and fir. It may be used very readily in typing the conifers from hardwoods and has been used quite extensively in Rhode Island. Of course, the photographs taken at 20,000 ft. will have to be enlarged considerably and then studied under magnifying stereoscopes, but it is possible and very practicable and time saving.

I believe that the use of polarized glass in the lens and in the stereoscopes will enable the men in the office to blot out the different types as they desire, and this would be a great expedient in mapping the types. Of course, it will be necessary to run sample plots on the ground, but the percentage of sampling will not be as extensive as it is at the present time.

Cruising

There is an extensive use of aerial photographs in cruising inaccessible timber tracts. The use of parallax in determining the height of the trees, and mild sampling gives the accurate cruise of the area. Accurate disease factors and species can be obtained as outlined above. Capt. B. B. Talley listed 37 samples of trees measured on the ground and those measured by parallax and the total average error was a minus four feet in the case of photographs over the actual ground measurements.

Fire Suppression

Each ranger district should have a complete set of stereoscopic prints of the area within the district for the use of fire suppression. By having them indexed according to number from a base map and the number on the photo index map, the P. A. would be able to see in three dimension an actual condition of the terrain in which the fire has been reported and would lead to more accurate detection and better equipped suppression crews. The township and range lines would be superimposed on the card, giving an accurate tie-in with the other existing maps and plotting board.

Logging Operations

The use of aerial maps and photographs will enable the logger to make extensive road reconnoissance in his office, and will be able to accurately visualize the tracts to be logged in respect to their surrounding terrain. He could carry on a selective logging show from this layout, and this has been done to a large extent by the West Fir Logging Company of Washington with success. They have actually located and plotted the trees on the map and then gone to the field and marked them for cutting. Most of this has been in cutting the fir and leaving the hemlock.

Flying

Mr. Abrams of the Aerial Survey Company has advocated that airplanes are going to be developed that will be able to fly at 40,000 feet and higher and be controlled by robot and radio with no personnel aboard. All pictures will be taken by the use of automatic instruments, and the precision of the photographs will rest in the automatic accuracy of the instruments which will be much greater than the present method. By flying at this extremely high altitude, more area will be covered by one photograph, even with the present 7" x 9" camera and with the new Fairchild 18" x 18" camera, this will be much greater, and all in all will require much less ground control.

In connection with this flying, it might not be too far distant to have the photographs relayed to the ground station of plane operation by television and to take pictures of these relayed photographs as they come in by radio at the ground station.

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