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Investigation of photographic methods of mapping the areas visible from a fire patrol aircraft flying a predetermined route

Aubrey L. Haines
The University of Montana

AN INVESTIGATION OF PHOTOGRAPHIC METHODS OF MAPPING THE AREAS VISIBLE FROM A FIRE PATROL AIRCRAFT FLYING A PREDETERMINED ROUTE

by

Aubrey L. Haines

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Approved:

Kenneth P. Davis

Chairman of Board of Examiners

W. P. Clark

Dean, Graduate School

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CHAPTER I

PROBLEM AND SCOPE OF THE INVESTIGATION

This investigation of photographic methods of aerial seen-area mapping was undertaken to develop a technique which will provide a satisfactory map basis for planning aerial detection routes and coverages. The results indicate that seen-area maps prepared by ocular sketching from 35 mm high oblique aerial photographs meet the requirements of accuracy and low cost,

Importance of the investigation. Aircraft have been employed in the detection of forest fires since 1919, but the use during the early years was mainly opportunistic and often ineffective. However, development of the airplane, particularly the increase in reliability and performance and the decrease in operating costs, has enhanced its value in detection. This improvement in the airplane parallels the development of conditions which make aerial detection more desirable. The increased use of air transportation and smoke jumpers have made the lookout-fireman system obsolete over much of Region One, and the growing obsolescence of fire control facilities, especially lookout structures, poses the need for large expenditures if the existing system is retained.

It is thought that the integration of aerial and ground detection will lead to a type of organization better adapted to the new conditions and less costly to maintain. Such integration can best be accomplished by the use of seen-area maps, but has not been attempted because a satisfactory technique for mapping seen areas from aerial patrol routes was not available. The technique developed in this investigation provides a method which should prove satisfactory.

Limiting Conditions. A satisfactory method of aerial seen area mapping must be (1) comparable in cost and accuracy to similar work done from ground points; (2) suitable for use with planimetric maps; and (3) susceptible to routine checking.

Aerial seen-area mapping from high oblique photographs appeared to satisfy the foregoing criteria and so was selected for investigation. The working hypothesis was, that a technique employing high oblique photographs will provide a satisfactory method of aerial seen-area mapping.

Possible solutions. Four solutions differing chiefly in the manner of photograph interpretation were available. These were:

(1) Ocular sketching from individual photographs

(2) Stereoscopic sketching from pairs of photographs

(3) Graphic analysis by the principles of analytical geometry

(4) Mechanical-optical plotting with a machine such as the "Canadian Plotter for High Oblique Photographs," or the "Miller Single Eyepiece Plotter."

The first solution is simple and no equipment is required; the second allows better definition of details on the photograph but requires the use of a stereoscope; the third is difficult to use and time-consuming; and the fourth requires special equipment not readily available. Therefore, only the first and second solutions were considered worthy of investigation. They were applied to two types of photographs resulting in a test of four methods of aerial seen-area mapping, as follows:

(1) Ocular sketching from 9"x9" photographs

(2) Ocular sketching from 35mm photographs

(3) Stereoscopic sketching from 9"x9" photographs

(4) Stereoscopic sketching from 35mm photographs.

<u>Statement of the problem</u>. The problem consisted in developing and appraising photographic methods of aerial seen-area mapping by (1) comparison of the relative accuracies of the several methods; (2) determination of the costs

of those methods which appear feasible; and (3) consideration of other factors which might affect the utility of the technique.

<u>Plan of the investigation.</u> A field test was made by flying over an area on Lolo Creek, Lolo National Forest, and photographing the terrain with two cameras, a Mark Hurd II, 9"x9", and a Contax II, 35 mm, which represent extremes in precision and cost of operation. The high oblique photographs obtained were subsequently interpreted by two methods and the resulting data were analyzed to obtain comparisons of accuracy, unit cost, and suitability. The investigation is presented in three parts: the field procedure which deals with the test area, flight, and photography; the office procedure describing techniques of interpretation and analysis; and, the summary and conclusions. The volume of supporting data is too great to include with this thesis. These data are filed in the Library of the School of Forestry, Montana State University.

CHAPTER II

REVIEW OF PREVIOUS WORK AND DEFINITIONS OF TERMS USED

Previous to this investigation the only work done on the development of techniques of aerial seen-area mapping was incidental to the aerial detection study made on the Coeur d'Alene National Forest. No reference has been found of attempts to use oblique aerial photographs for the purpose and replies to inquiries indicate that it is probable the method developed in this investigation has never been used for aerial seen-area mapping.

REVIEW OF PREVIOUS WORK

The review of the pioneer work done on the Coeur d'Alene National Forest was not restricted to published literature. Manuscript reports in the files of the Northern Rocky Mountain Forest and Range Experiment Station were studied and some additional information was obtained by correspondence and conference with members of the Supervisor's staff, Coeur d'Alene National Forest. The possibility that similar work had been done by other fire control organizations was checked by letters of inquiry to those known to make extensive use of aerial fire patrols.

Coeur d'Alene aerial detection study. A trial of aerial detection based on systematic planning of routes and coverages was begun on the Coeur d'Alene National Forest in Idaho during the summer of 1945 and has been continued during succeeding fire seasons. A two million acre area of forest was selected for the trial and aircraft were used on scheduled flights over predetermined routes to give the same frequency of inspection as afforded by ground lookouts.

The planning of the flight routes led to development of a method for determining flight courses, flight altitudes and coverages.[1] The procedure consisted in the preparation of profiles from a topographic map at about one-mile intervals approximately at right angles to the proposed line of flight. These profiles were used to adjust the flight courses and altitudes in an effort to obtain 100 per cent coverage over areas considered critical on the basis of fuel type, special risk, and lack of coverage from established lookouts. Some additional profiles were subsequently added to give further coverage in certain areas. The resulting route seen-area map was later checked and supplemented by observers who sketched the blind areas from patrol airplanes. the technique used is called the Coeur d'Alene method of aerial seen-area mapping in this investigation.

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[1] R. L. Hand and H. L. Harris, "Preliminary Report on Aerial Detection Study," Fire Control Notes, 8(1):29-30, January 1947.

The method employed was not entirely satisfactory for mapping seen areas, as the following excerpt from a letter written by Acting Supervisor S. C. Sanderson indicates. He says:[2]

> . . . we were never able to satisfy ourselves that we were getting a completely accurate picture of the coverage from a plane. . . The seen area for the observer was a picture which changed every second and we found no way to measure this changing picture by mechanical means.

An examination of the Coeur d'Alene method of seen-area mapping discloses several limitations. First, it combines two distinct mapping techniques, map profiling and observer-sketching, neither of which is suited to the purpose. The use of profiles prepared from the topographic map results in a map representation which is not equivalent to the area seen by an observer flying over the route in an airplane because such transects do not reproduce the visual cone. Observer-sketching is wholly inadequate. At the relatively slow flying speed of 80 mph, the observer has only 35 minutes to sketch the same area for which from 3 to 5 hours is required by a mapper working from a fixed point. The aerial observer is further handicapped in that he cannot use an alidade or field glasses.

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[2]S. C. Sanderson, Letter (F Aerial, Cd'a, General, Coeur d'Alene National Forest, Coeur d'Alene, Idaho, Nov. 29, 1948), p. 1.

The second limitation in the Coeur d'Alene method is its dependence on the topographic map. In Region One 30 per cent of the area has never been so mapped, and for another 50 per cent only obsolete topographic maps of doubtful accuracy are available. Thus, the method is limited to use on 20 per cent of the forested area of Region One.

The third limitation in the Coeur d'Alene method is the relatively high unit cost. Where the profiled seen area is checked by only one flight over the route the cost of the mapping is as great as that for photographic mapping, but the seen-area map produced is not comparable.

As a technique for aerial seen-area mapping, the Coeur d'Alene method has the following limitations: (1) It is technically imperfect as the procedures are subject to errors for which there are no adequate checks. (2) It cannot be generally applied because of the dependence on a topographic map. (3) It is not an economical procedure.

Results of inquiries. Letters of inquiry were sent to fire control organizations to determine whether or not seen-area mapping had been done in connection with their use of aerial fire patrols. The following questions were asked:

(1) Are aerial photographs used in determining flight routes? If so, are they vertical or oblique photographs and how are they employed?

(2) Are topographic maps employed to develop seen-area maps by profiling either before or after establishment of a patrol route?

(3) Are profiles of the terrain used in any manner for determining the degree of coverage which can be obtained on a given route or at a given flight altitude?

(4) Are special conditions such as hazard, risk, access, coverage by ground lookouts and economic value taken into consideration in planning aerial detection routes?

Letters were sent to the Dominion Forest Service, Department of Mines and Resources, Ottawa, Canada; the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon; and the Superior National Forest, Ely, Minnesota. The replies indicate that aerial detection planning is done on the basis of hazard, risk, and the coverage supplied by ground stations, and that aerial seen-area mapping has not been done by the organizations contacted.

DEFINITIONS OF TERMS USED

The nature of this investigation makes necessary the use of technical terms, some of which are not adequately defined elsewhere.

The terminology used. The fire control terms used are those defined in the Glossary of Terms Used in Fire Control (1939) of the U. S. Department of Agriculture;

Forest Service. The terms and notations used in the discussion and interpretation of oblique aerial photographs is that of the Manual of Photogrammetry of the American Society of Photogrammetry.

Definitions of special terms. The special terms used in this investigation are defined as follows:

Aerial patrol route. A predetermined route followed by an aircraft for the purpose of detecting forest fires occurring on a given area.

Aerial seen-area map. A map representation of the area visible to an observer looking through a prescribed arc of view, within a limited radius from an aircraft flying a predetermined route.

Blind area. An area where the ground is more than one hundred feet below the line-of-sight from the observer.

Grazing sight. That portion of a line of sight which is within 100 feet of the terrain, measured vertically.

Intensity of coverage. A measure of the length of time a given area is visible to an aerial observer.

Seen area. An area where the ground is less than one hundred feet below the line-of-sight from the observer.

The terms "blind area" and "seen area" have been re-defined for the purposes of this investigation. Inclusion with the seen area of those areas blind by less than one hundred feet tends to generalize the seen-area mapping.

This is desirable since an aircraft provides an unstable viewing position in constant motion in three directions; the principal one forward on the line of flight, with lesser lateral and vertical motions in response to atmospheric conditions, pilotage, and instrumental errors. Thus the course is never strictly reproducible. Also, grazing sight occurs more often from the elevated view point of an aerial observer than it does from a ground point. Instead of crossing cleanly over the ridges, the line-of-sight often parallels the reverse slopes making identification of the blind areas difficult and introducing into the interpretation of the photographs an exaggeration of the blind areas, particularly the minor ones.

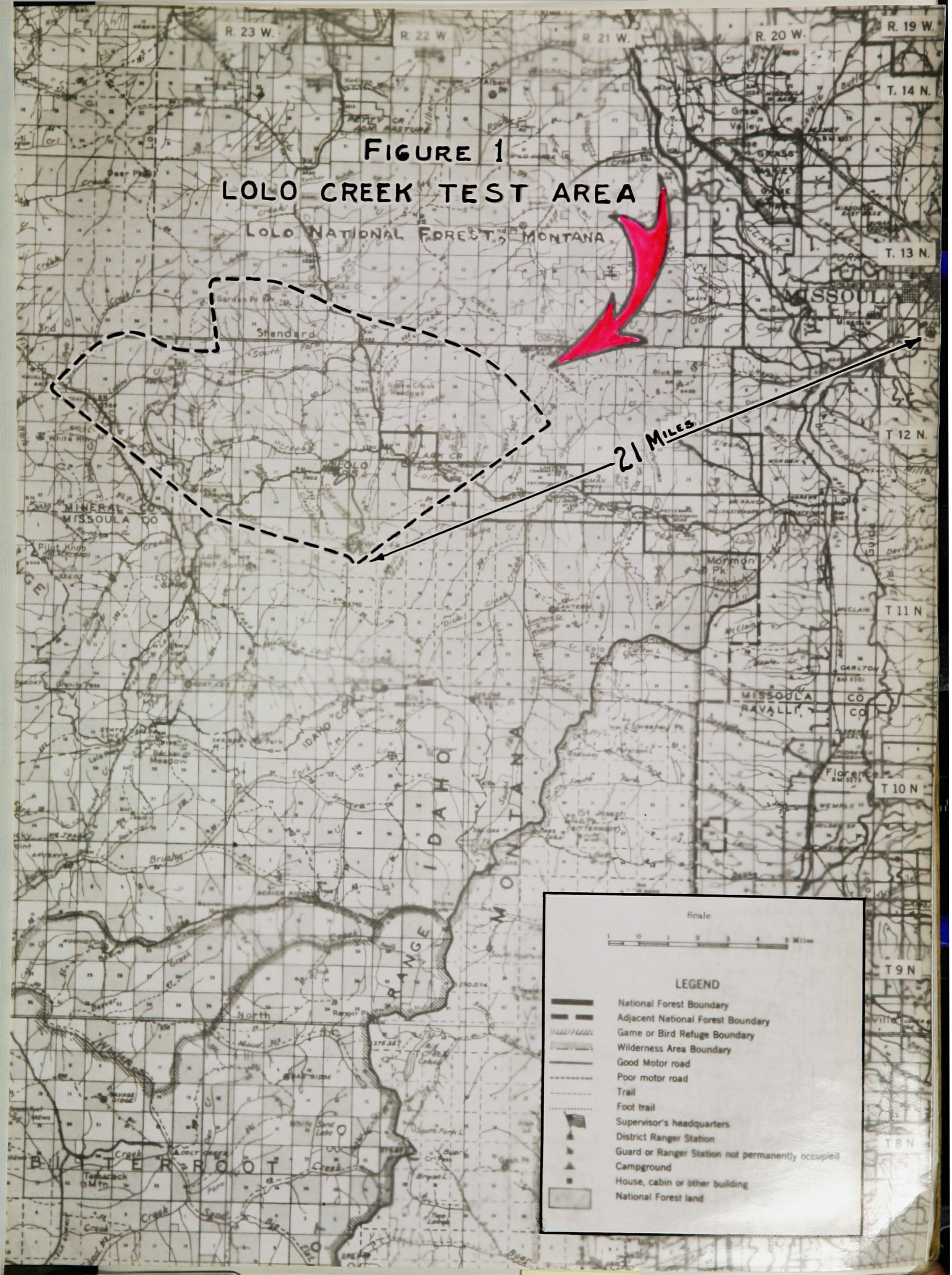


FIGURE 1
LOLO CREEK TEST AREA
LOLO NATIONAL FOREST, MONTANA
21 MILES
R. 23 W.
R. 22 W.
R. 21 W.
R. 20 W.
R. 19 W.
T. 14 N.
T. 13 N.
T 12 N.
T 11 N
T 10 N
T 9 N
T 8 N
MISSOULA
Grass Valley
Standard
MINERAL CO
MISSOULA CO
MISSOULA CO
RAVALLI CO
Pilot Knob
Lolo Hot Springs
Mormon Pk
Lolo Pk
IDAHO
MONTANA
RANGE
North
BITTERROOT
Florence
CARLTON
White Sand Lake
Scale
Miles
LEGEND
National Forest Boundary
Adjacent National Forest Boundary
Game or Bird Refuge Boundary
Wilderness Area Boundary
Good Motor road
Poor motor road
Trail
Foot trail
Supervisor's headquarters
District Ranger Station
Guard or Ranger Station not permanently occupied
Campground
House, cabin or other building
National Forest land

FIGURE 14.

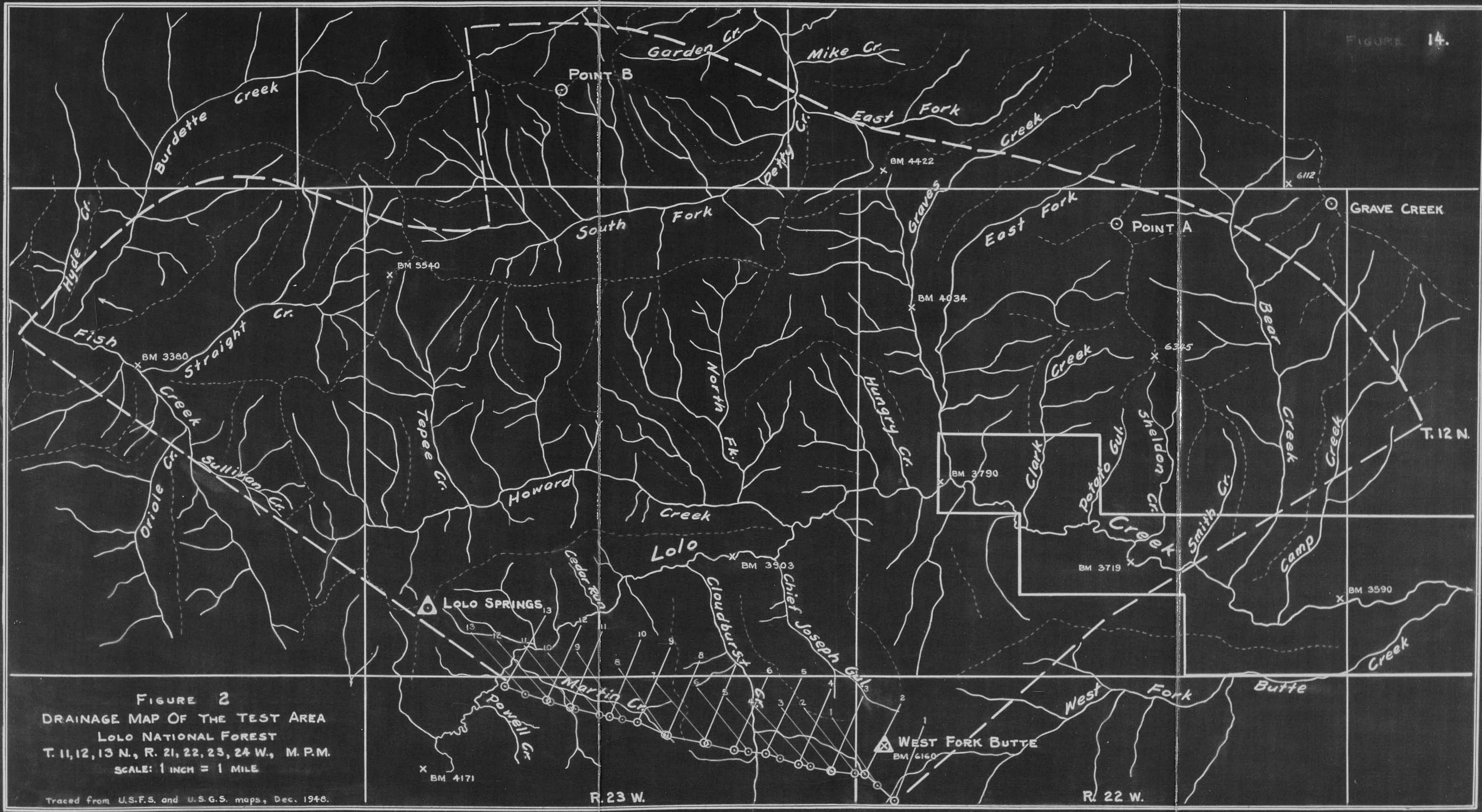


FIGURE 2
DRAINAGE MAP OF THE TEST AREA
LOLO NATIONAL FOREST
T. 11, 12, 13 N., R. 21, 22, 23, 24 W., M. P. M.
SCALE: 1 INCH = 1 MILE

CHAPTER III

THE FIELD PROCEDURE

This investigation of aerial seen-area mapping employed a field test of four photographic methods selected as representing practical extremes in equipment and technique. The field test was chosen instead of a theoretical study because it could answer more of the questions regarding practicability of the methods.

THE TEST AREA AND TEST PROCEDURE

<u>The test area</u>. An area for a field test was selected on the Lolo National Forest in the drainages of Lolo Creek, Howard Creek, Fish Creek, Graves Creek, and the South Fork of Petty Creek (Figures 1 and 2).

The topography is moderately rough with an average elevation of 5,000 feet above sea-level and a difference in elevation of slightly over 2,600 feet. Several drainages originate in the area cutting it deeply in different directions and providing a wide variety of relief forms. Mapping has been completed by the General Land Office and the Geological Survey, and a topographic map compiled by the U. S. Forest Service in 1927 is available at the scales of one-half and one inch to the mile.

A further consideration in selection of the area was its accessibility. A well developed system of fire roads facilitates entry for reconnaissance and checking. By air, the area is 21 miles on true azimuth 247° from the Missoula County Airport.

Plan of field work. The plan for the field work proposed two flights over the test area on true azimuth 270° from West Fork Butte Lookout; the first flight at an altitude of 7,500 feet and the second at 9,500 feet, with the airplane operated at its minimum air speed of 85 mph. On each flight 15 oblique photographs, spaced at 12-second intervals with a stop watch, were to be taken with each camera. Thus, the plan called for the taking of 30 high oblique aerial photographs at each altitude, or a total of 60 photographs.

The airplane available for the test flights was the U. S. Forest Service four-place Beechcraft, NC 3021V, a low wing monoplane of the "Bonanza" type. The structural characteristics of the aircraft allow photography from two positions: from the baggage door on the right side of the fuselage with the camera at an angle of approximately 100° right of the line of flight, and from the right front seat with the camera at an angle of approximately 37.5° right of the line of flight.

The photographic equipment selected for the test represented extremes in both precision and cost of operation. A Mark Hurd, MII, aerial camera with an f/4.5 Goerz lens of 8.25 inches focal length and using 9"x9" roll film was to be used through the open baggage compartment door and depressed at an angle of 25.5° from the horizon. The camera was fitted with a spot bubble mounted on a wedge in the field of the view finder to maintain the depression angle and level the horizon line.

The camera selected for use from the right front seat was a Contax II miniature with a f/2 Sonnar lens of 50 mm focal length and using 35 mm roll film. It was to be used with the lens held almost against the plexi-glass wind screen and depressed to give the best high oblique coverage.

<u>The test flight</u>. The plan for the field work was executed October 19, 1948. The weather at the Missoula County Airport at 12:45 p. m., MST, was:

Temperature, 70° F.
Barometer, 27.9" at elevation 3,186 feet.
Wind, dead calm.
Visibility, ridge lines discernible at 15 miles.
Clouds, none.

The flight started at 1:30 p.m. with Floyd Bowman as pilot, Ross Engle as photographer in the baggage compartment (aerial camera), and Aubrey Haines as photographer in the right front seat (35 mm camera). The visibility improved as the airplane gained altitude, and at 7,500 feet definition of details was good for 25 miles or better.

West Fork Butte was reached at 1:58 p.m. and the first run was started at 7,500 feet by the altimeter. The pilot found a wind of 8 mph from the southwest and estimated true speed at 80 mph with flaps down.

Photographs were made with the aerial camera on Eastman Aero film (Weston speed 100) with a K-2 filter at an aperture of f/6.8 and a shutter speed of 1/100 second. The 40-pound camera was rested on a sponge rubber cushion to absorb engine vibration.

Photographs were made with the 35 mm camera on Eastman Panatomic X film (Weston speed 24) with a G-4 filter at an aperture of f/4.5 and a shutter speed of 1/125 second.

The photography terminated at a point directly over Lolo Creek and southeast of Lolo Springs Lookout after approximately 3.5 minutes of flight on course. The airplane then climbed to an altitude of 9,500 by the altimeter, arriving again over West Fork Butte at 2:09 p.m. During the five minutes required to come into position for the second run the 35 mm camera was loaded with a fresh film magazine with some time to spare.

The photography was repeated on the second run, after which the airplane returned to Missoula. The flight ended at 2:34 p.m., with the barometer still at 27.9" at the County Airport.

DATA OBTAINED AND OBSTACLES ENCOUNTERED

Data obtained. Altogether, 14 negatives of 35 mm size and 13 of 9"x9" size were obtained on the flight at

7,500 feet and 13 negatives of 35 mm size and 6 of 9"x9" size were obtained on the flight at 9,500 feet. In addition, 8 exposures were made with the 35 mm camera to check coverage obtainable with vertical framing and the practicability of photography against the light.

The 9"x9" aerial photograph negatives are numbered 0-1-1 to 0-1-13, 10/19/48, on the 7,500 foot flight and 0-1-14 to 0-1-19, 10/19/48, on the 9,500 foot flight; they are filed at the Northern Rocky Mountain Forest and Range Experiment Station of the U. S. Forest Service, Missoula, Montana.

The 35 mm photographic negatives are numbered 1-7500 to 14-7500 on the 7,500 foot flight, and 1-9500 to 13-9500 on the 9,500 foot flight; they are retained by the experimenter.

Contact prints were prepared from the 9"x9" negatives (Figure 3), and 5.13x enlargements were prepared from the 35 mm negatives (Figure 4).

Obstacles encountered. Neither the flying nor the photography was accomplished exactly as planned. The aircraft did not enter the test course directly over West Fork Butte Lookout but at a point 0.7 miles south of it. Also, the southwest wind of 8 mph caused a drift to the north so that the track of the flight was on 284° true azimuth instead of 270°.

FIGURE 3
(½x)
A CONTACT PRINT FROM NEGATIVE 0-1-13

Taken at an altitude of 7,500 feet with a Mark Hurd II aerial camera (8.25" lens). The names of the principal drainages and control points are shown (Figure 2).

FIGURE 4

A 5.13x ENLARGEMENT FROM A NEGATIVE

Taken at an altitude of 7,500 feet with a 35 mm Contax II camera (50 mm lens). The names of the principal drainages are shown (Figure 2).

The large aerial camera proved difficult to operate. The spot bubble responded so actively to the small motions of the airplane that it could not be kept centered. The timing of the photographs was reasonably good on the flight at 7,500 feet but the camera was unsteady, resulting in inconsistencies in the leveling and depression angle of the individual photographs. An attempt to steady the camera better on the flight at 9,500 feet delayed the photography so that the series was not completed. The photographs taken on the flight at 9,500 feet could not be used in this investigation.

CHAPTER IV

THE OFFICE PROCEDURE

Only the photographs taken on the flight at 7,500 feet were used in the analysis. First the flight line and the air stations were located, then the individual photographs and stereographic pairs were sketched, and finally the map representations of the seen areas were employed in comparisons.

LOCATION OF THE FLIGHT LINE

Two techniques for locating the flight line were investigated; an approximation based on the topographic map, and a more exact photogrammetric solution suited to use with any accurate map.

Approximate location. The advantages of this procedure are simplicity and the fact that it can be used with photographs which are distorted. However, it is only approximate because of its dependence on the accuracy of the topographic map, the altimeter of the airplane, and correct map location of two points shown on the oblique photograph.

The technique was employed as follows: (1) One-half the lens angle was computed for the camera used in the photography. This was done by dividing the length of the principal line, as measured from the negative or a contact print, by twice the focal length of the lens, and then referring the quotient to a table of natural tangents to obtain the required angle. For the 9"x9" photograph 0-1-13 (Figure 3), the length of the principal line P--P', was 9.00 inches and the focal length of the lens was 8.25 inches, so that

$$\text{The angle} = \tan^{-1} \frac{9.00}{16.50} = \tan^{-1} 0.5454 = 28^{\circ}36'28''$$

Thus, 28°36'28" is the half-angle required.

(2) The half-angle was plotted on a piece of tracing paper. This was readily accomplished by drawing a base line, A--B, and erecting a perpendicular to it at B. The distance A--B was then multiplied by the natural tangent of the angle to be plotted and laid off on the perpendicular from B. A line from A through the point B' thus located became a side of the desired angle, which had for its other side the line A--B.

(3) The position of the principal point, PP, and the lower end of the principal line, P', was plotted on cross-section paper at equal horizontal and vertical scales, and a line was drawn across the sheet at the altitude of the flight.

(4) The tracing paper was placed over the cross-section paper and shifted until one leg of the plotted angle passed through the plotted position of PP, the other through the plotted position of P', and the apex of the angle rested

on the line through the flight altitude. The apex of the angle then occupied a position corresponding to that of the camera at the time the photograph was taken. It was transferred to the map by means of the scaled distance from P', on the line PP--P'. The determination of the air station from which photograph 0-1-13 was taken is diagrammed in Figure 5.

In this investigation the approximate technique is used for the location of the flight line because it can be used with the 35 mm enlargements. Any discrepancies introduced by dependence on the topographic map are assumed to affect equally the four methods of mapping tested. The flight line and the air stations for the flight at 7,500 feet are plotted on the map in Figure 1. The direction of the principal line of each photograph is shown by the arrow.

Photogrammetric location. This procedure can be used with planimetric maps and gives very good results when employed with distortion-free contact prints. However, it proved unsatisfactory with the 35 mm, 5.13x enlargements, and so was not used in this investigation.

The photogrammetric technique is described in detail in the Appendix and an example of its use with the 9"x9" photographs is presented.

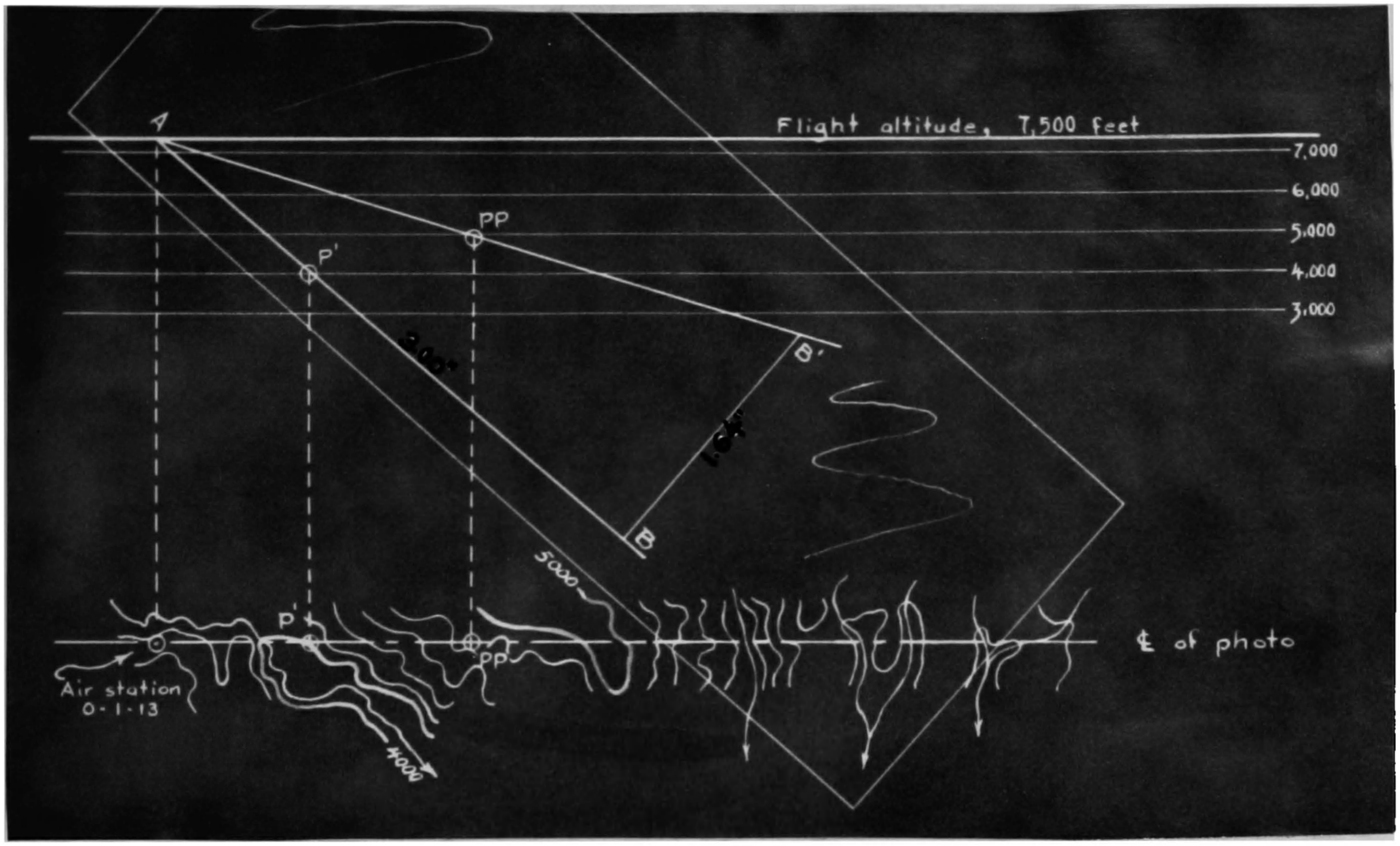


FIGURE 5

LOCATION OF AIR STATION BY THE APPROXIMATE TECHNIQUE FROM PHOTOGRAPH 0-1-13

(1) Points A, B and B' were plotted on a strip of tracing paper so that the apex angle, A, was 28° 36'.
B-B' = A-B tan 28°36' = 1.64 inches.

(2) Points P' and PP were located on the topographic map by reference to photograph 0-1-13, and plotted in profile at equal horizontal and vertical scales.

(3) The tracing paper was moved until A-B passed through P', A-B' through PP; A was on the level of the flight altitude. The projection of A on the map located the air station from which the photograph was taken.

<u>Effects of incorrect location</u>. No absolute measure of the accuracy of the flight line location obtained by the approximate technique is available. Any error resulting from location of the flight line should act equally upon the four methods tested.

At this point some generalizations can be made regarding the nature of errors introduced by variations in alignment and altitude of flight. The change is greatest in the representation of areas nearest the line of flight; the change introduced by a variation in altitude is much greater than that resulting from an equal variation in alignment; and the relative change is lessened by an increase in flight altitude. In Figure 6 the percent by which the representation of the blind area is changed is shown for altitude changes of 200 feet and lateral displacements of 0.4 miles. Curves are presented for a flight at 2,500 above the terrain, and a mask height of 500 feet at distances between one and six miles from the flight line.

An aircraft in flight is subject to conditions which will not always allow holding course within ± 100 feet vertically and right or left 0.2 mile in alignment, even with skilled pilotage. A flight line can probably be considered reproducible only within very broad limits, a concept which has an important bearing on photograph interpretation.

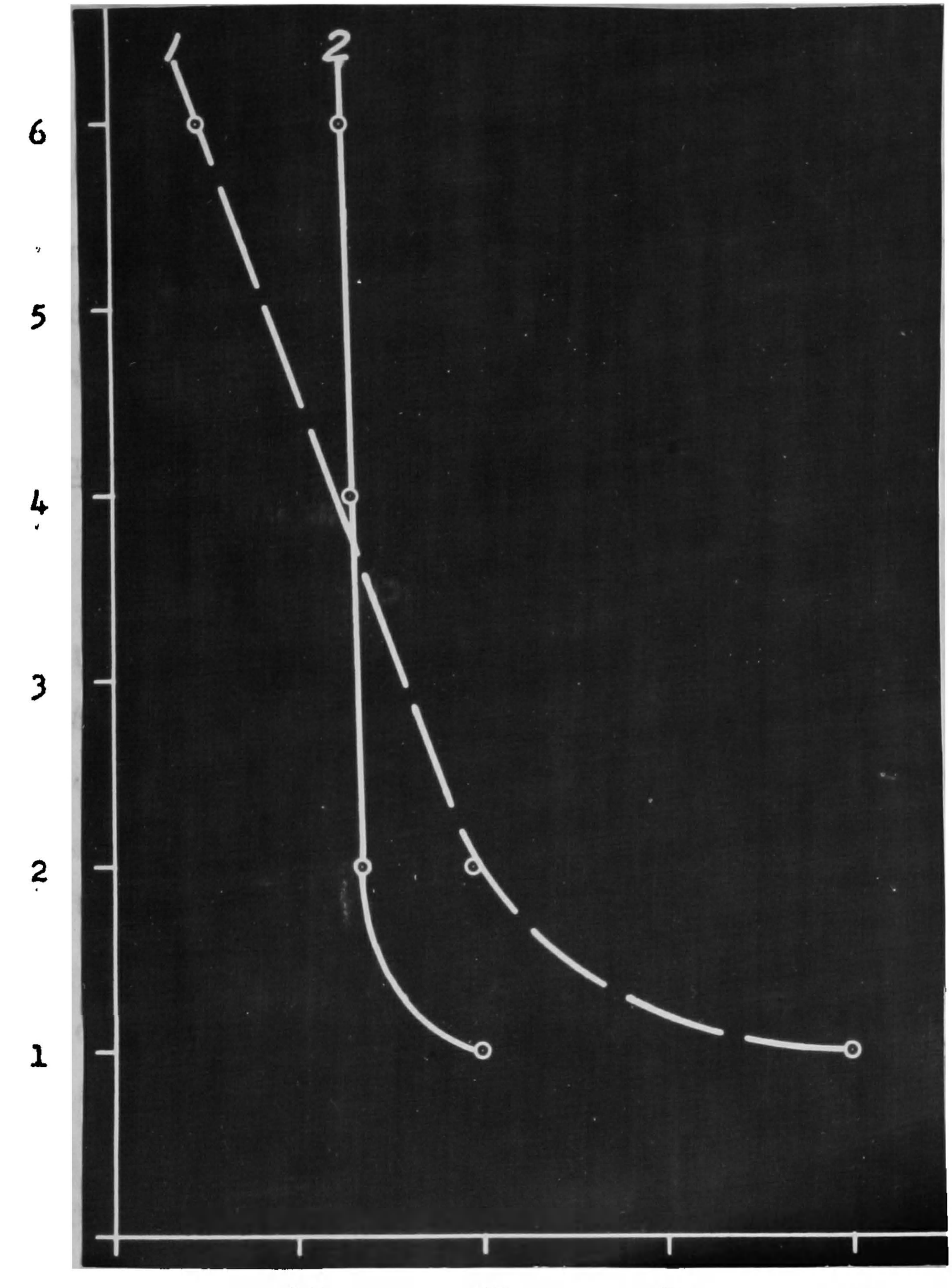


FIGURE 6

RELATIONSHIP BETWEEN DISTANCE OF MASKING TOPOGRAPHY*
AND PERCENTAGE CHANGE IN BLIND DISTANCE PRODUCED
BY VERTICAL AND LATERAL MOVEMENT OF
AN AIRCRAFT 2,500 FEET ABOVE THE TERRAIN

*Based on masking topography with a height of 500 feet and 90^o to line of flight.
1, Due to 0.4 mile change in alignment
2, Due to 200 feet change in altitude.

INTERPRETATION OF THE PHOTOGRAPHS

The photographs were interpreted in two ways: by sketching from individual photographic prints without visual aid; and by sketching from stereoscopic pairs of photographic prints viewed through a mirror stereoscope.

Individual photographs. Interpretation of the 9"x9" contact prints and the 35 mm, 5.13x enlargements was accomplished by ocular sketching with the aid of a planimetric map at the scale of one inch to the mile, or an R. F. of 1:63, 360 (Figure 2). Each photograph was sketched separately on a sheet of tracing paper (Figure 7), the seen area was shaded green, and tick marks were added to insure correct orientation in compositing. Sketching was done to a 7.5 mile radius, which is probably farther than an aerial observer can be expected to give adequate coverage.

As previously mentioned, the term seen area was redefined to include those areas lying less than one hundred feet below the line of sight. The purpose of this was twofold: to eliminate from the mapping those shallow blind areas which would, if strictly interpreted, introduce into the seen-area map a complexity altogether out of place when considered in the light of the variability of aircraft flight; and, to balance a tendency to exaggerate the blind areas in seen-area mapping. This tendency is not peculiar to aerial seen-area

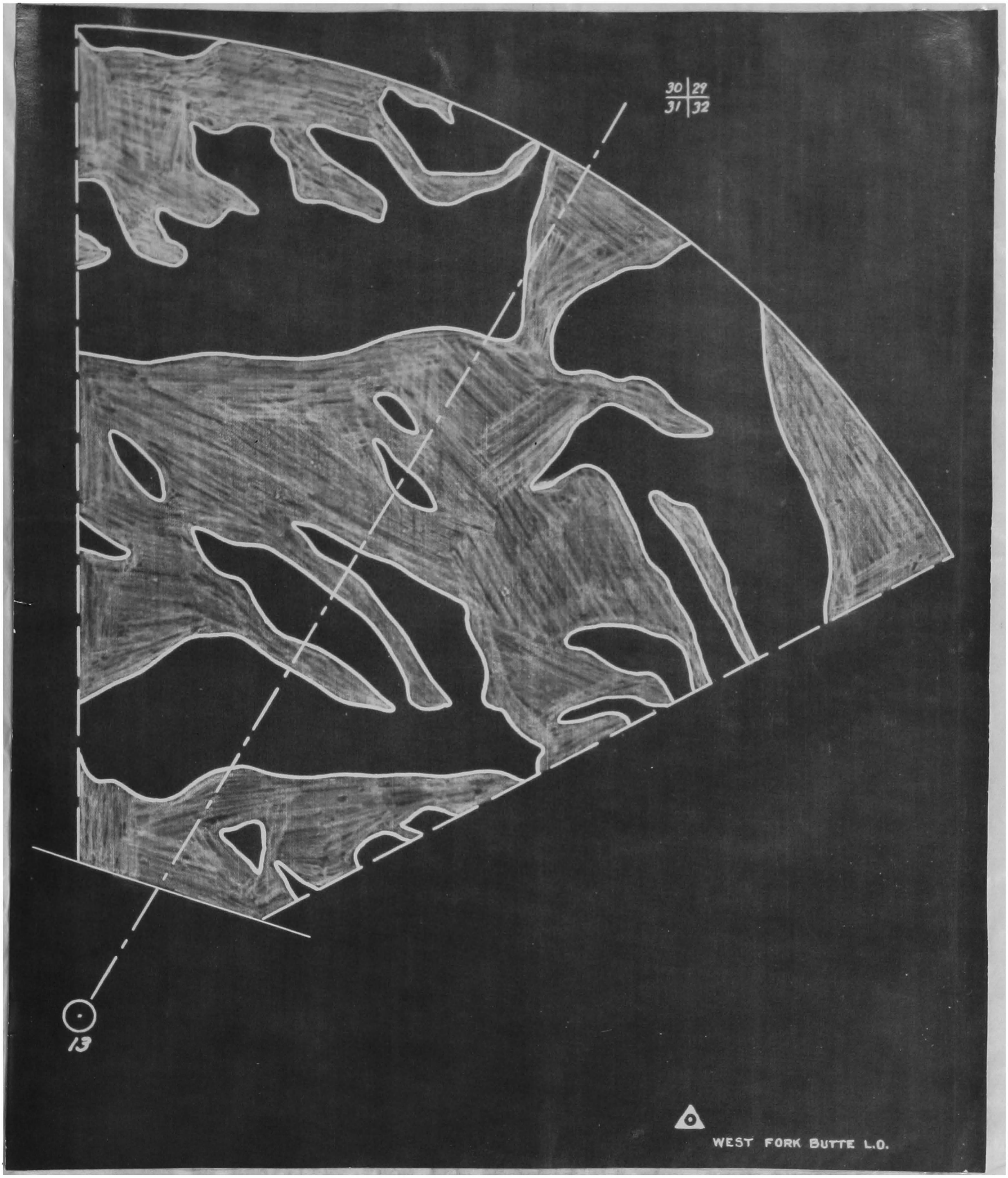


FIGURE 7

THE SEEN AREA AS REPRESENTED BY OCULAR SKETCHING

FROM PHOTOGRAPH 0-1-13

mapping but also appears in work done from ground points.

Stereoscopic pairs of photographs. The interpretation of the stereographic pairs of photographs was accomplished in the same manner as for individual photographs except that a Fairchild Tele-stereoscope was used as a visual aid. Only the area of overlap was sketched, so that the area mapped from a pair was approximately six per cent less than that from an individual photograph (Figure 8).

The 9"x9" photographs were too large for convenient handling under the stereoscope and had to be oriented separately for right and left sides. It was also necessary to re-orient to obtain stereo-vision in the near foreground as the base was too wide (0.41 miles).

The 35 mm, 5.13x enlargements are as large as can be conveniently used under the stereoscope.

NUMERICAL AND GRAPHIC COMPARISONS

The following numerical and graphic comparisons were developed as bases for quantitative measurements.

Numerical comparisons. The accuracies of the methods tested were compared by means of index numbers developed from the relationship between the sketched areas and the areas found by profiling from the topographic map. For convenience, the measurements used in the comparisons were

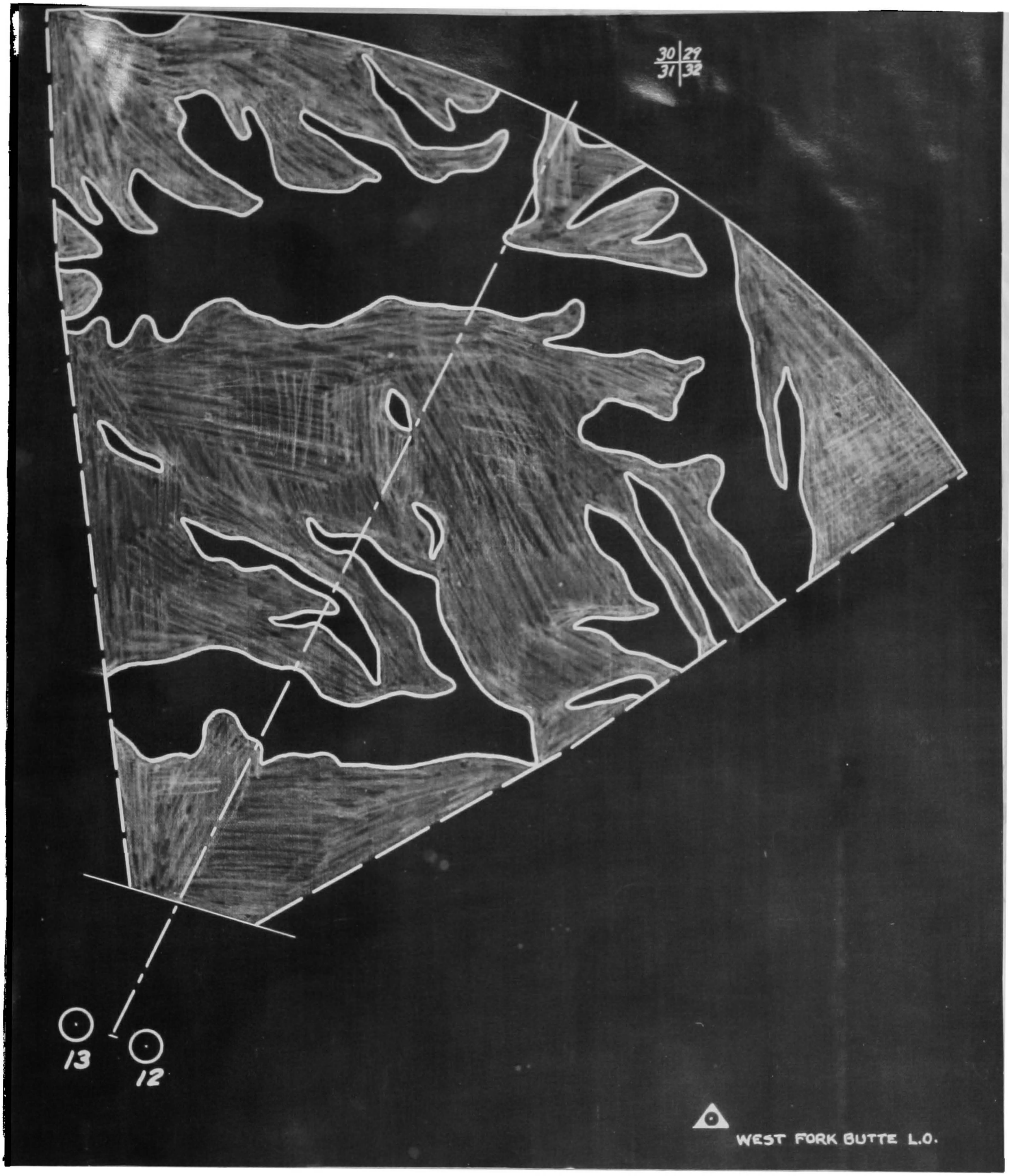


FIGURE 8

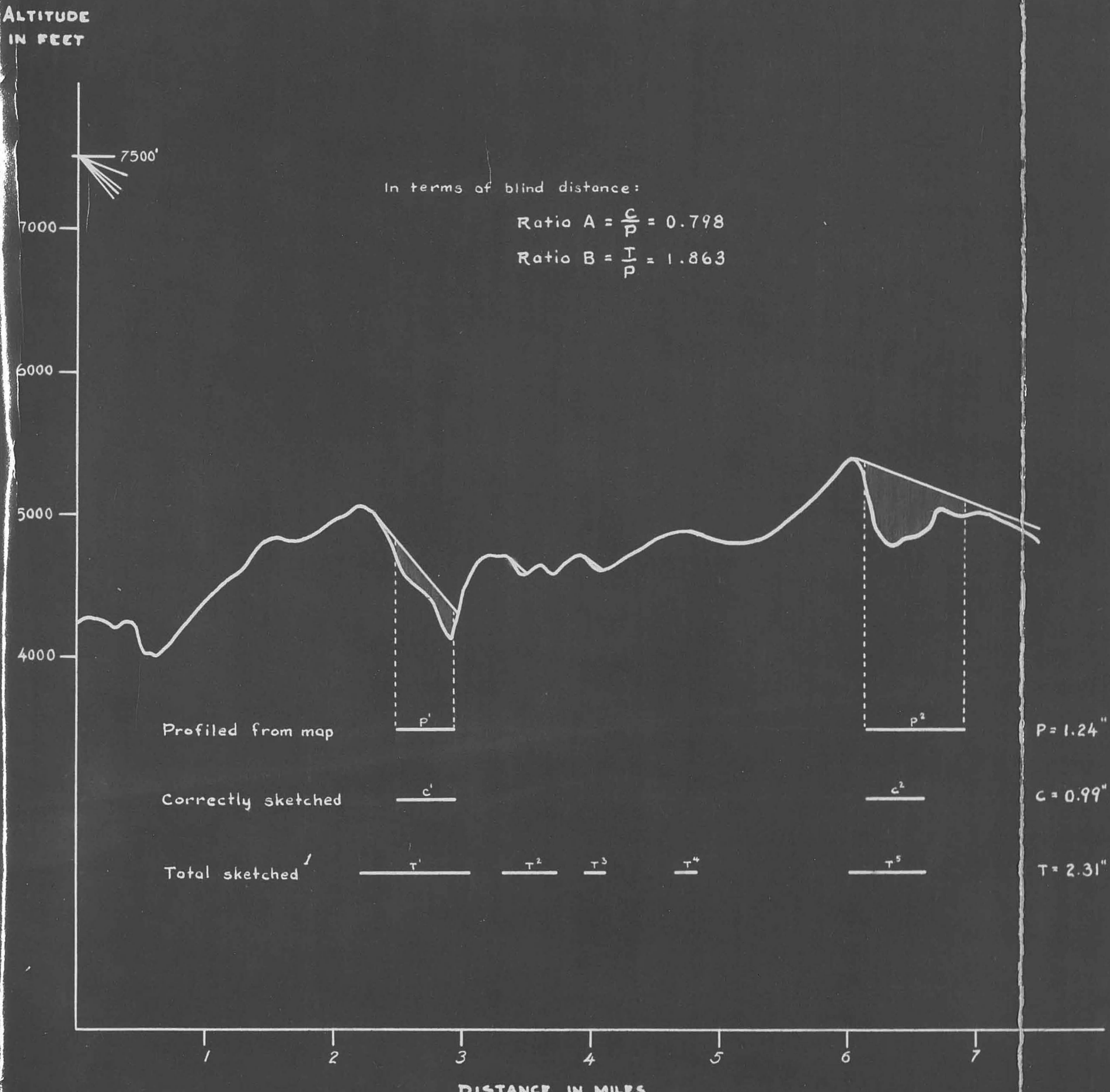
THE SEEN AREA AS REPRESENTED BY STEREOSCOPIC SKETCHING FROM PHOTOGRAPHS 0-1-12 AND 0-1-13 measurements of the blind distances. Since the blind distances are complementary to the seen distances, the accuracies of their representations are equivalent but opposite in sign.

The numerical comparisons were made as follows: a profile was prepared from the topographic map location of the center line of the individual photograph or stereoscopic pair, and the horizontal projections of the blind distances more than 100 feet below the line of sight were measured in miles and hundredths for a distance of 7.5 miles from the flight line. Then the blind distances shown on the sketch were measured on the center line to obtain the total blind distance mapped. Blind distances on the sketch which coincided with blind distances on the profile were next measured to determine the correctly sketched distances. The ratio of the correctly sketched to the total from the profile is an expression of the adequacy of the mapping and is called <u>ratio A</u>. The ratio of the total sketched to the total from the profile is an expression of the under or over mapping and is called <u>ratio B</u>, (Figure 9).

Ratio A indicates fully adequate mapping at 1.00 and entirely inadequate mapping at 0.00; ratio B is also perfect at 1.00, with any figure below that indicating under-mapping and any above, over-mapping. The necessity for two ratios

Figure 9

Computation Of Ratios A and B From A Check Profile, Photograph 0-1-13



[1] *The lines T', T² . . . T⁵ represent the blind distances as mapped by ocular sketching on the centerline of photograph 0-1-13.*

arises because neither alone expresses all the facts. For example, if the entire area of a photograph is mapped as blind, giving 7.5 miles on the center line, and the profile shows only 1.0 mile, then ratio A becomes 1.00 falsely indicating perfect mapping and ignoring the excess. Again, it is possible to have a ratio B of 1.00 where the area mapped is equal to, but not coincident with, the true blind area.

The two ratios were combined in an index number for purposes of comparison. Where B was less than 1.00, the two ratios were added and the arithmetic mean taken as the index; but when B was over 1.00, the reciprocal value was added to ratio A and the arithmetic mean taken. The index is not entirely satisfactory as a numerical comparison because it results in exaggeration in any case where the ratios are very dissimilar. The index was used only with stable means where a final comparison was required.

Graphic comparisons. The determination of the effects of multiple coverage and the optimum spacing for photographs on the line of flight was approached through two graphic comparisons.

The effects of multiple coverage on the mapping done from the 9"x9" photographs were determined by selecting an area common to all the photographs. Composites were then made showing the seen area as mapped from 2, 3, 4, 5, 7, and

13 photographs, corresponding to the spacings of 4.96, 2.48, 1.65, 0.83, and 0.41 miles, respectively, (Figure 10). The per cent of seen area shown on each composite was used in a comparison of the effects of multiple coverage.

The effects of multiple coverage on the mapping done from 35 mm, 5.13x enlargements was determined in the same manner. In this case it was necessary to use an area common to only 7 photographs as the narrow lens angle of the 35 mm camera prevented more than that number overlapping on the same area. Composites were made for 2, 3, 4, and 7 photographs, corresponding to spacings of 2.32, 1.16, 0.77, and 0.39 miles, respectively.

The relationship between photograph spacing and the unit cost of mapping was determined through the use of coverage diagrams showing the extent and character of the coverage afforded by different spacings.

Diagrams were prepared for the 9"x9" photographs for spacings of 4.96, 2.48, and 1.65 miles (Figure 11). The coverage at 1.65 miles was so complete that no closer spacings were required. A strip approximately 1.1 miles wide adjacent to the flight line was considered dead space below the angle of the camera lens. Actually the dead space varies with the separation between the camera and the terrain. Data obtained from the coverage diagrams were used

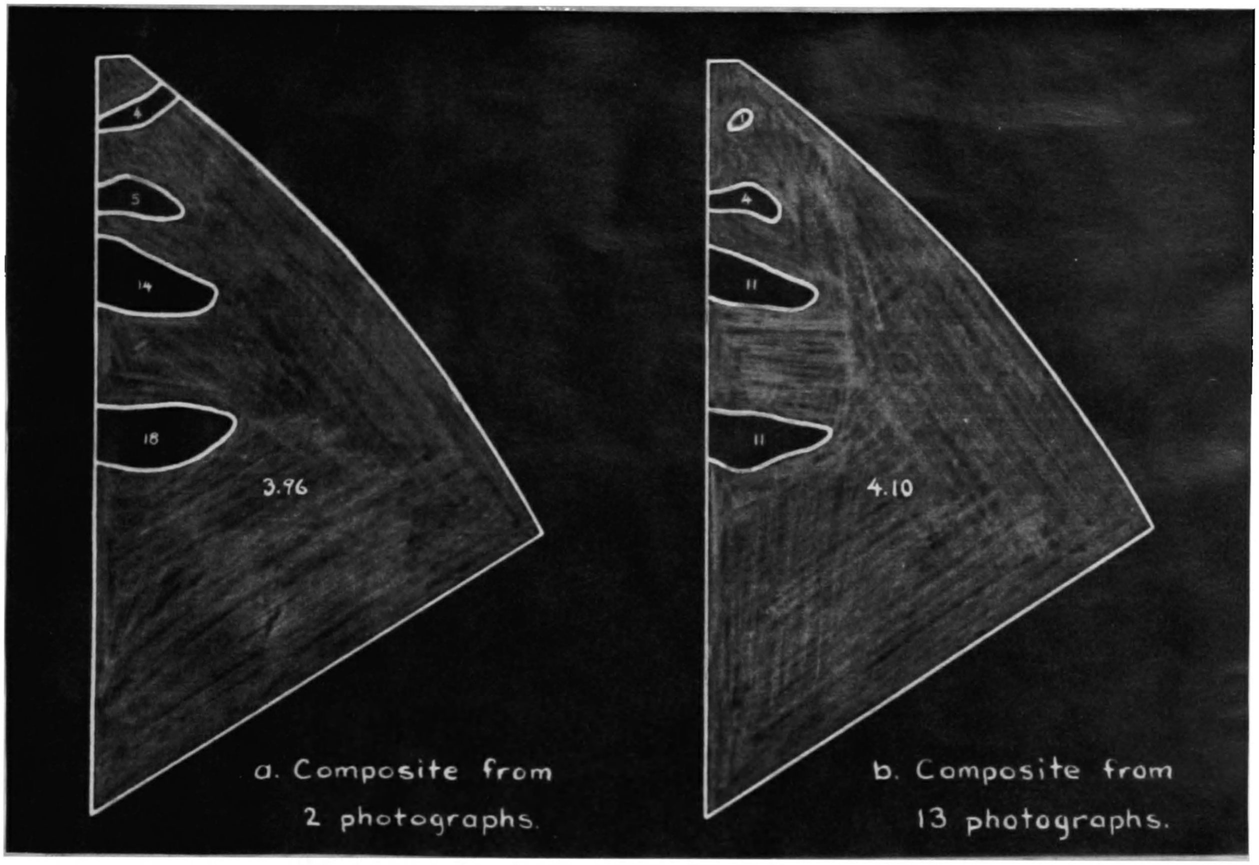


FIGURE 10

COMPOSITES USED TO COMPARE MULTIPLE COVERAGES

Note: The total common area is 4.37 square miles, thus the per cent of seen area is,

a: $\frac{3.96}{4.37} = 90.6$ b: $\frac{4.10}{4.37} = 93.7$

Composites are from ocular sketches made from 9"x9" photographs taken at 7,500 feet.

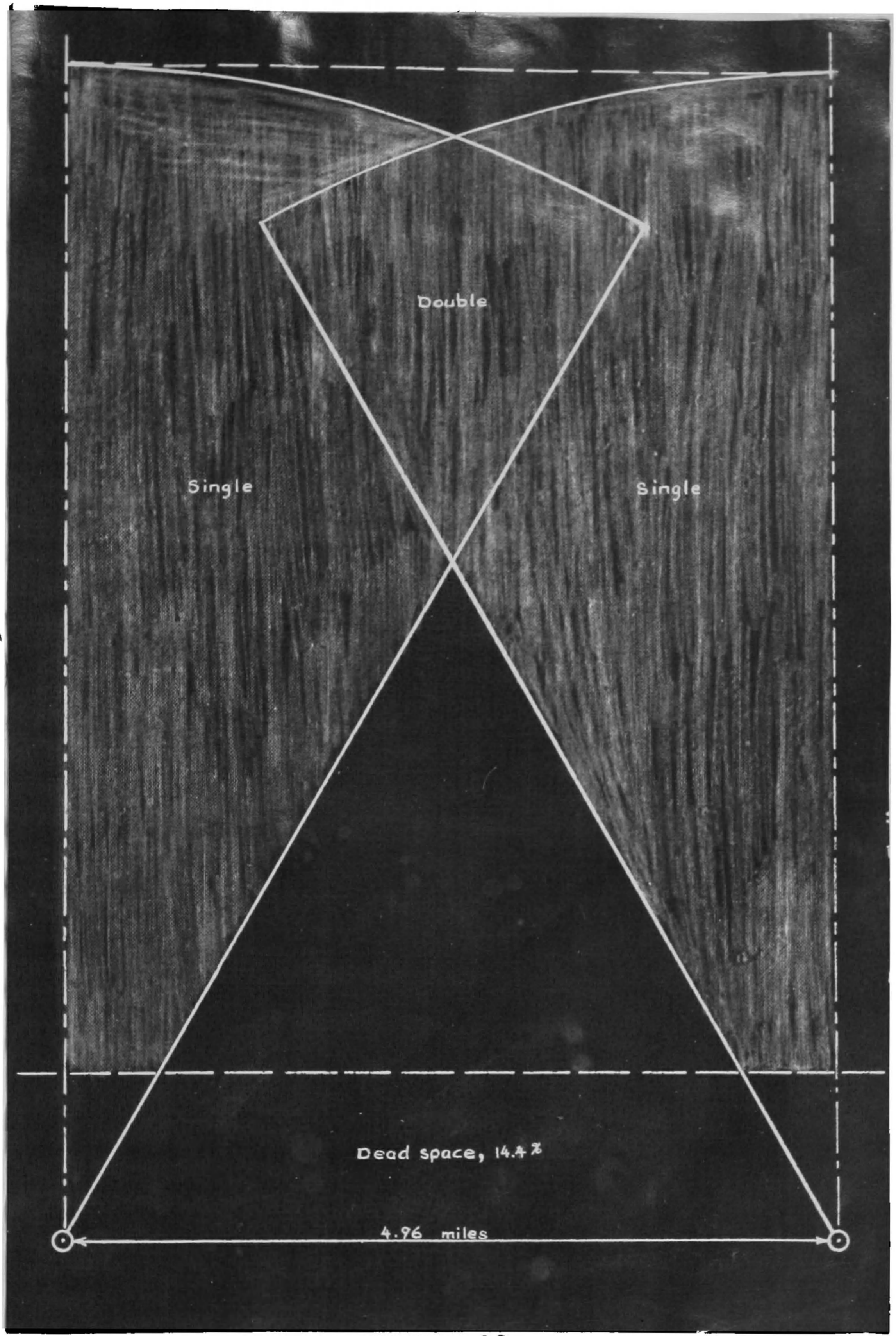


FIGURE 11

COVERAGE DIAGRAM FOR 9"x9" PHOTOGRAPHS (8.25" LENS), SPACED AT 4.96 MILES AND NORMAL TO THE LINE OF FLIGHT

Single, 58.0%   Double, 10.6%   Total, 68.6%

to plot curves of the relationship between photograph spacing and the degree of area coverage (Figure 12).

Diagrams were prepared for the 35 mm photographs for spacings of 2.24, 1.12, and 0.56 miles. The narrow lens angle of the 35 mm camera increased the dead space to 1.6 miles. The data obtained were used to plot a curve similar to the one for the 9"x9" photographs.

Composites were also used as bases for a system of rating the intensity of coverage obtained by a moving detector. A selective compilation of seen-area sketches made from 35 mm, 5.13x enlargements 1.12 miles apart was used. The coverage intensities were indicated by coloring the zones according to the length of time they were under observation. This rating system was not developed beyond the sample shown in Figure 13.

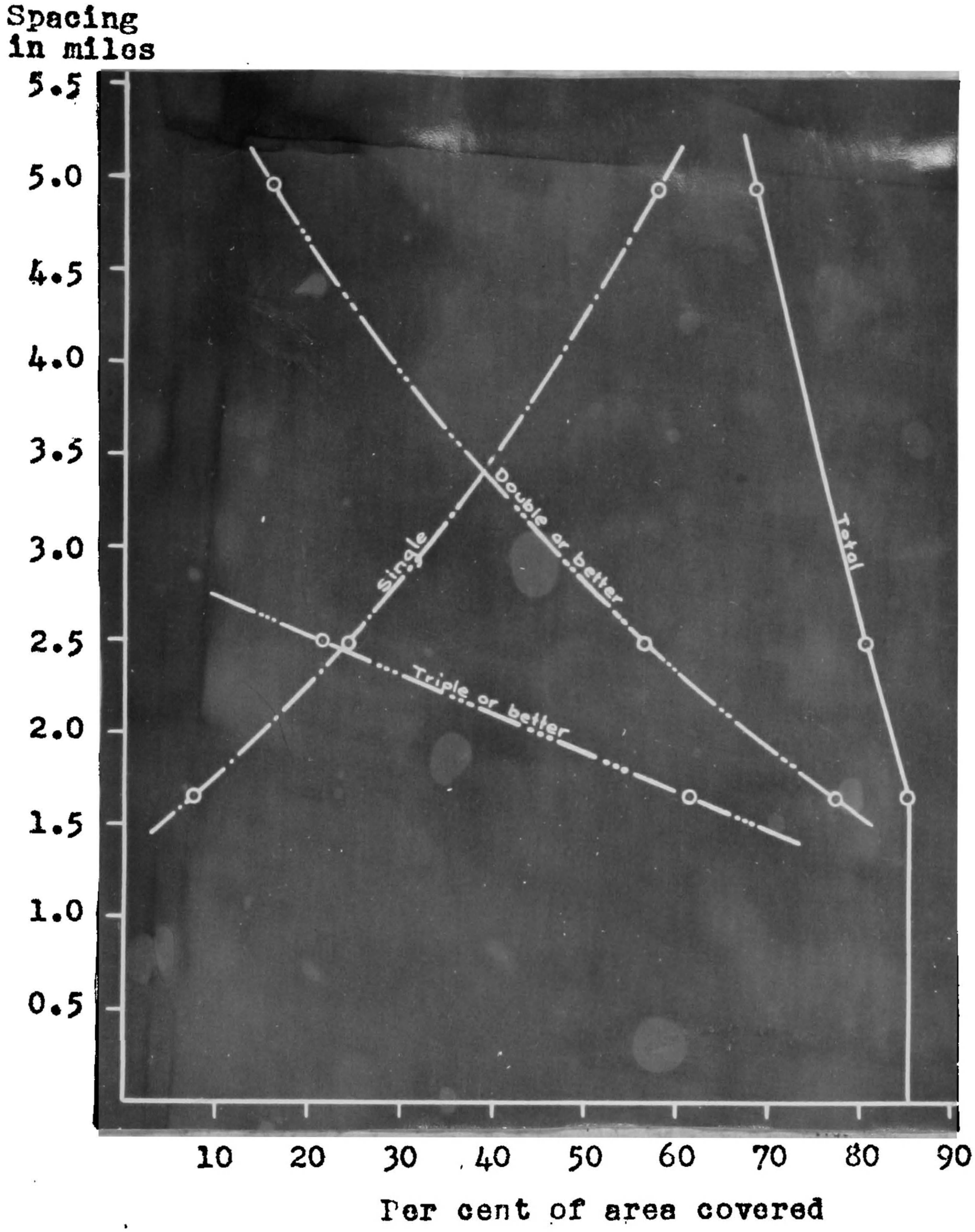


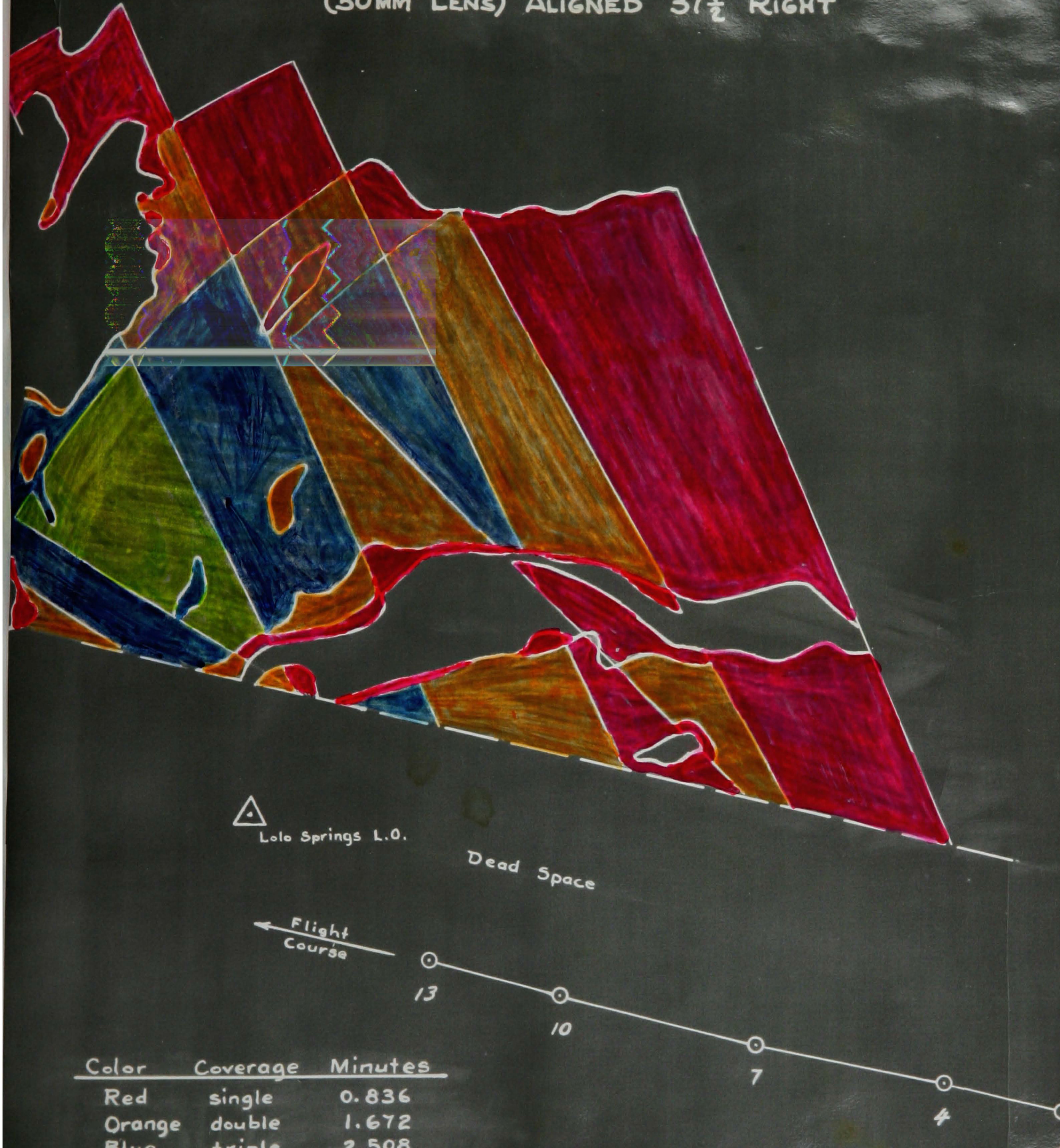
FIGURE 12

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND PER CENT OF AREA COVERED FOR FOUR DEGREES OF COVERAGE

FIGURE 13

30|29
31|32

AN AERIAL SEEN-AREA MAP SHOWING INTENSITY OF COVERAGE BY ZONES FOR 35 MM PHOTOS (50 MM LENS) ALIGNED $37\frac{1}{2}°$ RIGHT



Color	Coverage	Minutes
Red	single	0.836
Orange	double	1.672
Blue	triple	2.508
Green	quadruple	3.345

CHAPTER V

RESULTS OF THE INVESTIGATION

The results of this investigation of aerial seen-area mapping are presented in three groups; the first concerned with accuracy, the second with cost, and the third with technique. An appraisal of the data leads to the conclusion that a method of seen-area mapping by ocular sketching from high oblique aerial photographs provides a satisfactory technique. Recommendations are made regarding further studies needed.

COMPARISON OF ACCURACIES

The accuracies of photographic methods of aerial seen-area mapping were determined by (1) comparison of numerical ratings computed for the four methods under consideration, (2) gross comparison of the representation obtained by photographic methods with that obtained by profiling from the topographic map, and (3) comparison of the accuracies of photographic methods with the accuracy of mapping done from ground points in the same area.

Photographic methods. Numerical ratings are given for individual photograph interpretations in Tables I, II, III, and IV. Table V summarizes the ratings for the four methods on the basis of the arithmetic means of the ratios

TABLE I

ANALYSIS OF ACCURACY OF PHOTOGRAPH INTERPRETATION BY OCULAR SKETCHING FROM 9"x9" CONTACT PRINTS

Photographs	Miles blind on centerline			Ratio A[1]	Ratio B[2]
	Map Profile	Correctly Sketched	Total Sketched		
0-1-1	0.82	0.37	1.03	0.452	1.255
0-1-2	0.39	0.08	0.71	0.205	1.820
0-1-3	1.14	0.29	1.08	0.254	0.947
0-1-4	0.60	0.47	1.34	0.783	2.230
0-1-5	0.78	0.58	1.60	0.744	2.050
0-1-6	0.75	0.43	0.64	0.573	0.853
0-1-7	0.64	0.63	2.01	0.984	3.140
0-1-8	1.09	0.96	2.37	0.881	2.175
0-1-9	1.98	1.75	2.90	0.883	1.465
0-1-10	1.84	1.18	2.48	0.641	1.348
0-1-11	1.06	0.65	1.82	0.613	1.717
0-1-12	1.88	1.21	2.31	0.644	1.229
0-1-13	1.24	0.99	2.31	0.798	1.863
Total				8.455	22.092
Mean				0.650	1.699

[1]This ratio is computed by dividing the miles of blind distance correctly sketched by the true miles of blind distance obtained from the map profile.

[2]This ratio is computed by dividing the total miles of blind distance sketched by the true miles of blind distance obtained from the map profile.

TABLE II

ANALYSIS OF ACCURACY OF PHOTOGRAPH INTERPRETATION
BY STEREOSCOPIC SKETCHING FROM 9"x9" CONTACT PRINTS

Photographs	Miles blind on centerline			Ratio A	Ratio B
	Map Profile	Correctly Sketched	Total Sketched		
0-1-1,2	0.30	0.16	0.78	0.533	2.600
0-1-2,3	0.57	0.42	0.74	0.737	1.299
0-1-3,4	0.61	0.38	0.57	0.622	0.934
0-1-4,5	0.99	0.61	0.68	0.616	0.687
0-1-5,6	0.73	0.52	0.82	0.712	1.122
0-1-6,7	0.96	0.84	0.93	0.875	0.968
0-1-7,8	1.43	0.98	1.51	0.685	1.055
0-1-8,9	1.66	0.91	1.38	0.548	0.831
0-1-9,10	1.93	1.25	1.98	0.647	0.994
0-1-10,11	1.42	0.95	1.51	0.669	1.062
0-1-11,12	1.36	0.99	1.62	0.727	1.191
0-1-12,13	1.81	1.31	1.82	0.724	1.010
Total				8.095	13.753
Mean				0.675	1.146

TABLE III

ANALYSIS OF ACCURACY OF PHOTOGRAPH INTERPRETATION BY OCULAR SKETCHING FROM 35 MM, 5.13X ENLARGEMENTS

Photograph	Miles blind on centerline			Ratio A	Ratio B
	Map Profile	Correctly Sketched	Total Sketched		
1-7500	1.26	0.67	0.70	0.532	0.556
2-7500	0.92	0.22	0.95	0.239	1.033
3-7500	0.54	0.15	0.90	0.278	1.667
4-7500	1.44	0.73	1.08	0.507	0.750
5-7500	1.83	0.73	1.11	0.398	0.606
6-7500	1.45	0.92	1.18	0.634	0.813
7-7500	2.34	1.55	1.88	0.662	0.803
8-7500	2.58	1.82	2.37	0.705	0.918
9-7500	2.04	1.82	2.24	0.892	1.098
10-7500	1.97	1.72	2.28	0.872	1.157
11-7500	2.66	1.91	2.32	0.718	0.872
12-7500	2.74	2.01	2.09	0.734	0.762
13-7500	2.74	2.13	2.28	0.777	0.832
Total				7.948	11.817
Mean				0.611	0.909

TABLE IV

ANALYSIS OF ACCURACY OF PHOTOGRAPH INTERPRETATION

BY STEREOSCOPIC SKETCHING FROM 35 MM, 5.13X ENLARGEMENTS

Photographs	Miles blind on centerline			Ratio A	Ratio B
	Map Profile	Correctly Sketched	Total Sketched		
1,2 -7500	0.97	0.73	1.23	0.752	1.268
2,3 -7500	1.04	0.42	1.30	0.404	1.250
3,4 -7500	0.79	0.62	1.60	0.785	2.025
4,5 -7500	1.77	1.04	1.87	0.587	1.056
5,6 -7500	2.17	1.34	1.77	0.617	0.815
6,7 -7500	2.10	1.46	2.15	0.695	1.023
7,8 -7500	2.61	1.84	2.06	0.704	0.789
8,9 -7500	2.29	1.89	2.25	0.825	0.982
9,10-7500	2.08	1.90	2.21	0.913	1.062
10,11-7500	2.42	1.85	2.37	0.764	0.979
11,12-7500	2.51	2.11	2.86	0.840	1.139
12,13-7500	2.94	2.78	3.02	0.945	1.027
Total				8.779	13.415
Mean				0.732	1.118

TABLE V

COMPARISON OF ACCURACY OF PHOTOGRAPH INTERPRETATIONS
BY FOUR METHODS

(Summary data from Tables I, II, III, and IV)

Method	Ratio A	Ratio B	Index
Ocular sketching:			
9"x9" contact prints	0.650	1.699	0.619
35 mm enlargements	0.611	0.909	0.760
Stereoscopic sketching:			
9"x9" contact prints	0.675	1.146	0.776
35 mm enlargements	0.732	1.118	0.813

and the index numbers obtained from them. The work of interpretation was accomplished in the same order in which the methods are listed.

The index numbers indicate that a bias may have been introduced by the increase in sketching proficiency as the work progressed, despite precautions taken to eliminate such an effect. In particular, there was considerable over-mapping in the first group, as shown by the B ratios in Table I. It is probable that the rating for ocular sketching from 9"x9" photographs would have been higher on the basis of equal sketching proficiency.

Better results were obtained by stereoscopic sketching, but not enough better to justify the increase in cost of interpretation. In general, it appears that personal skill in interpreting the photographs is a more important factor in the results obtained than is the type of photograph or the method of interpretation. Any photograph with good definition can probably be used satisfactorily. There appears to be no singular difference in the methods on the basis of accuracy.

Profiling from topographic map. The only comparison possible between the photographic methods of aerial seen-area mapping and profiling from the topographic map was a gross comparison of the representation of a common area.

An area of 4.37 square miles is common to the 13 photographs of 9"x9" size. A seen-area map prepared from profiles spaced and directed in the same manner as the photographs, showed a seen area of 3.81 square miles, or 87.2 per cent. In Table VI the seen area mapped by ocular sketching increases from 90.6 per cent where two photographs are used, to 93.8 per cent where 13 are used.

For the 35 mm photographs an area of 4.26 square miles is common to 7 photographs. In this case the profiled seen area is 2.63 square miles or 61.7 per cent. Table VII shows that the seen area mapped by ocular sketching increases from 68.7 per cent where two photographs are used, to 70.6 per cent where 7 are used.

In both examples, mapping from photographs represented the seen area as larger than found by profiling. This is to be expected as the camera view, like human vision, is a cone which allows some marginal sight behind any object not exactly on the centerline. The close agreement of the representations of the seen areas mapped by photographic methods with those determined by profiling indicates that the reliability of seen-area maps produced by sketching from photographs may be higher than the numerical ratings suppose.

Mapping from ground points. A comparison of the numerical ratings for the four methods of aerial seen-area mapping with similar ratings for seen-area mapping done

TABLE VI

EFFECT OF MULTIPLE COVERAGE ON THE REPRESENTATION OF THE SEEN AREA BY OCULAR SKETCHING FROM 9"X9" PHOTOGRAPHS

Number of separate photographs covering the same area	Total area	Seen area	Percent of total seen
13	4.37	4.10	93.8
7	4.37	4.04	92.4
5	4.37	4.03	92.2
4	4.37	4.03	92.2
3	4.37	3.96	90.6
2	4.37	3.96	90.6

TABLE VII

EFFECT OF MULTIPLE COVERAGE ON THE REPRESENTATION OF THE SEEN AREA BY OCULAR SKETCHING FROM 35 MM PHOTOGRAPHS

Number of separate photographs covering same area	Total area in sq. miles	Seen area in sq. miles	Percent of total seen
7	4.26	3.01	70.6
4	4.26	2.95	69.2
3	4.26	2.97	69.7
2	4.26	2.93	68.7

from ground points gives a basis for further appraisal of the accuracy of photographic methods. The seen-area maps for two lookouts situated in the test area were obtained and profiles prepared at 20° intervals as the basis for numerical rating.

The lookouts used were Lolo Springs and West Fork Butte. The mapping was done in 1934 by R. E. Hoffland using the technique developed by Lloyd Hornby in Fire Control Planning in the Northern Rocky Mountain Region. Table VIII shows the ratings for 12 check lines, 6 from each lookout, in the test area. The ratings for Lolo Springs lookout (check lines A through F), where the mapper worked from an established station, give an index number of 0.942. The ratings for West Fork Butte (check lines G through L), which was not a lookout at the time the mapping was done, give an index number of 0.794. West Fork Butte presented no particular mapping problem as the point is a rocky ridge free of masking timber; hence, it is reasonable to suppose that work done under more difficult circumstances, as from a tree top, would show an even lower rating.

The results of this investigation indicate that the accuracy of photographic methods of aerial seen-area mapping is from 5 to 25 per cent less than the accuracy obtained by an experienced mapper working under good conditions from a ground point.

TABLE VIII

ANALYSIS OF ACCURACY OF SEEN-AREA MAPPING FROM TWO GROUND POINTS*

Check line[1]	Miles blind on check line			Ratio A	Ratio B
	Map profile	Correctly sketched	Total sketched		
A	5.45	4.83	5.43	0.886	0.996
B	6.72	6.46	6.76	0.962	1.005
C	5.55	5.33	6.07	0.960	1.092
D	6.49	6.15	6.32	0.947	0.973
E	4.84	4.05	4.72	0.837	0.975
F	4.75	4.22	5.12	0.[illegible]	1.078
G	4.98	4.94	5.38	0.989	1.080
H	4.99	4.49	6.21	0.899	1.242
I	2.42	2.33	5.09	0.962	2.102
J	4.48	4.16	5.00	0.928	1.130
K	2.75	1.79	3.42	0.651	1.243
L	2.70	2.55	4.98	0.944	1.850
Total				10.853	14.846
Mean				0.904	1.220

*Based on work done by R. E. Hoffland, using the technique developed by Lloyd Hornby.

[1]Check lines A to F, incl., are from Lolo Springs Lookout (seen-area study 110, Lolo National Forest), and check lines G to L, incl., are from West Fork Butte Lookout (seen-area Study 117, Lolo National Forest).

COMPARISON OF UNIT COSTS

The unit costs of photographic methods of aerial seen-area mapping were determined by (1) comparison of the unit costs for the four methods under consideration, (2) comparison of the unit costs of photographic methods with probable costs for the Coeur d'Alene method, and (3) comparison of the unit costs of photographic methods with those for mapping done from ground points.

Photographic methods. The comparison of accuracy did not show a significant increase in accuracy with stereoscopic interpretation of the photographs. However, Table IX shows that the cost of interpreting the photographs is materially increased by the use of the stereoscope. The increase amounts to 41 per cent for the 9"x9" photographs and 111 per cent for the 35 mm enlargements. The two methods of mapping employing stereoscopic interpretation were not considered further since it was apparent that they cost too much in relation to any increase in accuracy gained from their use.

The problem remaining was the determination of the cost per square mile for aerial seen-area mapping by the two methods employing ocular sketching. The cost contains two elements: fixed costs represented by aircraft and camera rentals, salary of the photographer and project expenses; and, variable costs represented by film and processing costs, interpretation and compilation.

TABLE IX

COMPARISON OF COST OF PHOTOGRAPH INTERPRETATIONS

BY FOUR METHODS

Method	Time in Minutes	Cost*	Area in sq. miles	Cost per sq. mile
Ocular sketching from:				
9"x9" contact prints	30	$0.750	27.91	$0.027
35 mm enlargements	15	0.375	14.32	0.026
Stereoscopic sketching from:				
9"x9" contact prints	40	1.000	26.45	0.038
35 mm enlargements	30	0.750	13.62	0.055

*Computed at the rate of $1.50 per hour.

The costs for the 9"x9" camera, not including interpretation, are:

(1) Fixed costs, per minute,

Beechcraft, 4-place "Bonanza" with pilot and fuel, $12.50 per hr.,	$0.208
Mark Hurd II, 9"x9" aerial camera, $14.00 per day,	0.029
Aerial photographer, $2.22 per hr.0	0.037
Total,	0.274

(2) Variable costs, per photograph,

9"x9" aerial film, $27.36 per roll,	0.274
Developing, $4.00 per roll,	0.080
Printing,	0.450
Total,	0.804

The costs for the 35 mm camera, not including interpretation are:

(1) Fixed costs, per minute,

Beechcraft, 4-place "Bonanza" with pilot and fuel, $12.50 per hr.,	$0.208
Contax, 35 mm (f/2, 50 mm, or f/8, 28 mm), camera at 1 per cent,	0.001
Aerial photographer, $1.50 per hr.,	0.025
Total,	0.234

(2) Variable costs, per photograph,

Panatomic X, 35 mm film, $0.90 per 36 exp. roll,	0.025
Developing, $1.50 per roll	0.042
Enlarging to 5.13x,	0.250
Total,	0.317

Table X converts fixed and variable costs to costs per square mile of mapping. Addition of the cost of photograph interpretation from Table IX gives the total cost per square mile. The total costs for several methods and photograph spacings are given in Tables XI and XII.

The costs for the 9"x9" camera are given for only one side of the flight line because it is impractical to photograph two sides with such heavy equipment. However, the cost per square mile compares favorably with the cost of mapping done with the 35 mm camera. Table XIII gives the unit costs computed for the 35 mm camera with a 28 mm lens. The data were based entirely upon the broader coverages possible with the 28 mm lens; no test photographs were taken with it in this investigation.

Coeur d'Alene method. Actual cost data for the aerial seen-area mapping done on the Coeur d'Alene National Forest were not available but an estimate based on the techniques employed was made.

Profiling from a topographic map can be done at the rate of 1.1 miles of profile per minute. Thus, the cost per mile of profile is $0.023, with labor at $1.50 per hour. With profiles spaced one mile apart, the cost of profiling becomes $0.023 per square mile. To this must be added the cost of the check by observer-sketching.

TABLE X

FLYING TIME AND NUMBER OF PHOTOGRAPHS REQUIRED AT 80 MPH,*
BY TYPE AND SPACING OF PHOTOGRAPHS

Camera and photograph spacing	Photographs per square mile	Flying time per sq. mile	
		One side minutes	Two sides minutes
9"x9", 8.25" lens:[1]			
4.96 miles	0.0383	0.1445	---
2.48 miles	0.0662	0.1231	---
1.68 miles	0.1262	0.1175	---
35 mm, 50 mm lens:[2]			
2.24 miles	0.1071	0.1977	0.0988
1.12 miles	0.1980	0.1830	0.0914
0.56 miles	0.3392	0.1780	0.0889
35 mm, 28 mm lens:[2]			
2.24 miles	0.0780	0.1337	0.0678
1.12 miles	0.1210	0.1277	0.0638

*For a speed of 150 mph, multiply values by 0.533.

[1]Camera axis aligned 90° from the line of flight.

[2]Camera axis aligned 37.5° from the line of flight.

TABLE XI

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND COST*
OF MAPPING WITH A 9" x 9" CAMERA WITH 8.25" LENS
ALIGNED 90° FROM THE FLIGHT LINE

Spacing in miles	Cost per square mile at 80 mph		Cost per square mile at 150 mph	
	One side	Two sides	One side	Two sides
4.96	$0.098	---	$0.052	---
2.48	0.114	---	0.061	---
1.65	0.161	---	0.086	---

TABLE XII

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND COST*

OF MAPPING WITH A 35 MM CAMERA WITH 50 MM

LENS ALIGNED 37.5° FROM THE FLIGHT LINE

Spacing in miles	Cost per square mile at 80 mph		Cost per square mile at 150 mph	
	One side	Two sides	One side	Two sides
2.24	$0.107	$0.084	$0.057	$0.045
1.12	0.137	0.115	0.073	0.061
0.56	0.176	0.155	0.094	0.083

TABLE XIII

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND COST*
OF MAPPING WITH A 35 MM CAMERA WITH 28 MM
LENS ALIGNED 37.5° FROM THE FLIGHT LINE

Spacing in miles	Cost per square mile at 80 mph		Cost per square mile at 150 mph	
	One side	Two sides	One side	Two sides
2.24	$0.082	$0.066	$0.044	$0.035
1.12	0.094	0.079	0.050	0.042

If flying is based on the rental of the Beechcraft, 4-place "Bonanza" used in this investigation, the rate for the aircraft is $0.208 per minute. However, rentals on the aircraft actually used varied from $20.00 to $40.00 per hour or $0.333 to $0.666 per minute. The rate for the observer is $0.025 on the basis of $1.50 per hour. At a speed of 80 mph, the cost per square mile for the observer-sketching is $0.012 where the Beechcraft is used, and $0.018 and $0.034, respectively for the two aircraft with higher rentals. The Coeur d'Alene method, on the basis of the lowest aircraft rental, costs $0.035 per square mile with the observer checking a strip 15 miles wide. A comparison of this minimum cost with the figures in Tables XI, XII, and XIII shows that the minimum cost of photographic mapping varies from $0.035 to $0.052, depending on the technique employed.

Mapping from ground points. The cost of photographic methods of aerial seen-area mapping can best be judged by comparison with the cost of seen-area mapping done from ground points. The North Idaho Fire Survey[3] provides data on the costs of such mapping for similar terrain conditions.

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[3] Mass, Fred H., "Plan Summarization, North Idaho Fire Survey, 1934-35," (AS(o)FC and TP, Region I, U. S. Forest Service, Missoula, Montana), unnumbered summary sheet.

The project consisted in the mapping of 423 points covering 3,416 square miles. The cost was $25.47 per point which is equal to $0.103 per square mile on the basis of 40 per cent seen area (282 square miles) per point. That figure is for 1934 and must be doubled to make it comparable with the cost determined in this investigation. Thus, $0.206 per square mile is the probable cost of equivalent seen-area mapping at the present time.

The cost per square mile for the North Idaho Fire Survey contains three elements: mapping, 38.8%; travel time, 43.4%; and supervision, 17.7%. Since the costs computed for the photographic methods do not include travel time and supervision, a fair comparison can only be made on the basis of mapping costs. The mapping cost for seen-area mapping from ground points should be considered as $0.053. This is a severe criterion but one which photographic seen-area mapping can meet as Tables XI and XII show.

COMPARISON OF COVERAGES

The coverages obtained by the several methods of aerial seen-area mapping were determined by (1) comparison of the effect of spacing on the intensity of coverage obtained, and (2) comparison of the coverage distribution as affected by the photograph angle.

Effect of spacing. The intensity of the coverage obtained is important in two ways: it affects the reliability of the map representation of the seen areas, and it provides a means for rating the effectiveness of aerial detection. The relationships between photograph spacing and the intensity of coverage obtained by the photographic methods of mapping are shown in Tables XIV, XV, and XVI. The coverage cannot reach 100 per cent because of the dead space below the lens angle. The allowance for dead space is 14.4 per cent for the 8.25" and 28 mm lenses, and 26.7 per cent for the 50 mm lens. The allowance is probably in excess of the actual dead space in most instances. The spacings used in Table XIV are convenient multiples of the average distance between the 9"x9" photographs (0.413 miles). The spacings used in Tables XV and XVI are multiples of 0.28 miles.

The most economical spacing for the photographs on the line of flight was determined by means of an arbitrary decision regarding the intensity of coverage necessary. The coverage decided upon was nine-tenths of double or better over the mapped area. In Table XIV, only the spacing of 1.65 miles gave such coverage (77.5 ÷ 85.5 = 0.906), but in Table XI, the minimum cost for that spacing was $0.086 per square mile; a figure considerably above the amount for ground mapping ($0.053). Thus, the use of ocular sketching from 9"x9" photographs was eliminated as too costly.

TABLE XIV

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND CHARACTER OF COVERAGE OF A 9"x9" CAMERA WITH 8.25" LENS ALIGNED 90° FROM THE LINE OF FLIGHT

Spacing	Per cent of area covered[1]				
in miles	Single	Double	Triple	Quadruple	Total*
4.96	58.0	10.6	---	---	68.6
2.48	24.3	35.2	21.4	---	80.9
1.65	8.0	15.8	16.4	45.3	85.5

*Coverage cannot exceed 85.6 per cent

[1]Based on a strip 7.5 miles wide, of which 14.4 per cent is considered dead space.

TABLE XV

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND CHARACTER OF COVERAGE OF A 35 MM CAMERA WITH 50 MM LENS ALIGNED 37.5° FROM THE LINE OF FLIGHT

Spacing in miles	Per cent of area covered[1] Single	Double	Triple	Quadruple +	Total*
2.24	29.9	33.0	0.8	---	63.7
1.12	10.2	13.2	23.2	22.2	68.8
0.56	4.5	4.9	5.3	56.4	71.1

*Coverage cannot exceed 73.3 per cent.

[1]Based on a strip 6.0 miles wide, of which 26.7 per cent is considered dead space.

TABLE XVI

RELATIONSHIP BETWEEN PHOTOGRAPH SPACING AND CHARACTER OF COVERAGE OF A 35 MM CAMERA WITH 28 MM LENS ALIGNED 37.5° FROM THE LINE OF FLIGHT

Spacing in miles	Per cent of area covered[1]				
	Single	Double	Triple	Quadruple +	Total*
2.25	18.4	28.3	31.7	0.1	78.8
1.12	7.0	9.2	11.5	54.9	82.6

*Coverage cannot exceed 85.6 per cent

[1]Based on a strip 6.0 miles wide, of which 14.4 per cent is considered dead space.

Continuing with Table XV, only the spacing of 0.56 miles gave the desired coverage (66.6 ÷ 71.1 = 0.936), but again the cost for the spacing was too high. ($0.083 per square mile in Table XII). The use of the 35 mm camera with the 50 mm lens was also eliminated.

In Table XVI, the spacing of 1.12 miles gave the desired coverage (75.6 ÷ 82.6 = 0.915), and in Table XIII the cost of the spacing was found to be $0.042 per square mile. Thus, the use of ocular sketching from 35 mm photographs taken with a 28 mm lens and spaced 1.12 miles apart along the flight line appeared to be within the allowable limits of cost.

The use of a technique which insures double or better coverage over nine-tenths of the mapped area makes the mapped representation of the seen areas more reliable. In addition, it provides a means for rating the intensity of coverage in terms of the length of time any portion of the area is under observation by the aerial observer. An example of intensity of coverage rating is shown in Figure 13. It was developed from the ocular sketches made from 35 mm photographs taken with the 50 mm lens, and is based on a spacing of 1.12 miles. The use of an adequate spacing (0.56 miles for the 50 mm lens) would have materially increased the intensity of coverage shown.

The value of rating the intensity of coverage lies in the comparison which it makes possible between aerial detection and ground detection. On the basis of 150 square miles of seen area for a ground station of average coverage, and a time of 20 minutes for a complete sweep of the terrain, the coverage per minute is 7.5 square miles. The length of time required by an aerial observer to give equal coverage at a speed of 80 mph, is $29.5 \div 7.5 = 3.93$ minutes; where 29.5 is the approximate number of square miles within a visual angle of 60^{o} to a radius of 7.5 miles.

The rating of intensity of coverage cannot be given adequate treatment in this investigation, and must remain for future study.

Coverage distribution. Another important consideration was the distribution of the coverage obtained by methods of aerial seen-area mapping. The two camera angles employed yielded coverage patterns which were entirely different. Photographs taken with the lens aligned 110^{o} from the flight line yielded coverages which were most intense near the outer edges of the flight strip. Photographs taken with the lens aligned 37.5^{o} from the flight line yielded coverages which were most intense midway between the flight line and the outer edge of the strip.

Reference to Figure 6 shows that the effect of flight errors is greatest near the flight line. Thus the camera angle which gives the best coverage near the flight line appears preferable. The multiple coverage then strengthens the map representation at the point where most needed.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

__Summary.__ This investigation of photographic methods of aerial seen-area mapping was undertaken to develop a technique which will provide a satisfactory map basis for planning aerial detection routes and coverages. The problem consisted in developing and appraising photographic methods of aerial seen-area mapping by (1) comparison of the relative accuracies of the several methods; (2) determination of the costs of those methods which appeared feasible; and (3) consideration of other factors which might affect the utility of the technique.

A practical solution appeared to be sketch mapping from oblique aerial photographs taken at intervals along the proposed flight route. The apparent advantages of such a solution were that it could be used with any reasonably accurate map, would provide a permanent record of the observers' view, and would allow the sketching to be done in the office under good working conditions.

The investigation consisted of a field test followed by an office analysis of the results. The field test was made by flying over an area on Lolo Creek, Lolo National Forest, and photographing the terrain with two cameras, a 9"x9" Mark Hurd and a 35 mm Contax, representing extremes

in precision and cost of operation. Photographs were taken at approximately 0.4 mile intervals along a predetermined route five miles in length. The large aerial camera was used from the open baggage compartment door at an angle of 100° right of the flight line and depressed 25.5° from the horizon. The small 35 mm camera was used from the right front seat of the airplane with its axis at an angle of 37.5° right of the flight line.

The two types of photographs obtained on the test flight were interpreted by two methods, ocular sketching and stereoscopic sketching, both based on a drainage map of the area. The interpretations of the seen-areas were then compared with profiles from the topographic map to determine the relative accuracies of the four combinations. Unit costs were computed for those that appeared feasible, and other factors, such as the optimum spacing of the photographs, effect of the camera angle, and flight speed were considered. A comparison was also made between aerial seen-area mapping and seen-area mapping done from ground points.

The results of the investigation led to the following conclusions:

(1) Aerial seen-area maps of sufficient accuracy for planning detection routes and coverages can be made from high oblique aerial photographs. The type of photograph is not important as long as details can be readily defined.

(2) Ocular sketching from a drainage map provides a satisfactory technique for interpreting high oblique aerial photographs. Stereoscopic sketching provides a more accurate representation of the seen areas but the gain in accuracy is not commensurate with the increase in cost.

(3) The cost of aerial seen-area mapping is comparable to the cost of seen-area mapping done from ground points. The cost of satisfactory procedures varied from 4.2 to 8.6 cents per square mile, depending on the degree of coverage. This compares well with the average cost of 5.3 cents per square mile for the mapping done on the North Idaho Fire Survey, a project involving 423 ground points.

(4) Adequate coverage for aerial seen-area mapping is provided by photographs spaced so that nine-tenths of the area is overlapped. A camera angle of 37.5° from the line of flight gives better coverage than a 90° angle.

(5) Photographic aerial seen-area mapping provides a basis for rating the intensity of coverage obtained from a patrol airplane. The route seen-area map can be zoned to show the length of time any part of the area is under observation.

<u>Recommendations</u>. Satisfactory aerial seen-area mapping can be accomplished by means of the following techniques:

(1) Photography. Photographs should be taken at one-mile

intervals on each side of the line of flight from an airplane traveling at least 150 mph, and at least 2,500 feet above the terrain. The camera should be directed at an angle between 37.5° and 45° from the line of flight and depressed so that the horizon line is just retained. If it is necessary to photograph through a windscreen, the camera should be held as close to it as possible. Any convenient small camera can be used if it has the proper characteristics. These are: a roll film capacity of at least 36 exposures; shutter speeds up to 1/250 second; a lens of f/4.5 or better, with an angle of acceptance between 45° and 70°, and, an eye-level viewfinder. Actually few amateur cameras other than 35 mm models can qualify as most do not have the necessary film capacity. There is also a possibility that the Fairchild K-10 or K-20 hand-held aerial cameras would be satisfactory.

Good photographic results are dependent on a suitable airplane. An ideal ship would be one similar to an attack-bomber, where the photographer could have unrestricted view forward, downward, and to right and left. However, any four-place, high-wing monoplane should do. In such a ship the photographer could occupy the rear seat and alternately photograph the two sides of the flight route.

(2) Interpretation. Photographs should be interpreted by ocular sketching from contact prints or enlargements of at

least 5"x7" size. This can best be done on a sheet of thin tracing paper placed over the approximate area on a topographic or planimetric map. A separate sheet of tracing paper should be used for each photograph. The location of the flight line is not essential as the sketching is done entirely by reference to points which can be identified on the photographs. A patrol route seen-area map is prepared from the individual sketches by compositing them.

Where a topographic map is available it should be used in preference to a planimetric map. The contours will aid the sketcher in identifying terrain features, particularly ridge lines, and should result in superior mapping.

Some suggestions for further study of aerial seen-area mapping are offered.

A comparison is needed of the results of ocular sketching based on topographic and planimetric maps. Photographs taken from suitable ground lookouts could be used for this work and would make the experiment less costly. This would also make possible a direct comparison with seen-area mapping as done from ground points.

An investigation of the relationship between mapping accuracy and the separation between the aircraft and the terrain is needed. There were indications in this investigation that the accuracy increases with increase in the separation. Such a study might lead to a solution of the problem of how high aerial fire patrols should fly, particularly if photograph-scanning is analogous to observer-scanning. Photographs taken along the same course on flights at a number of altitudes would be necessary for this experiment. Provision should be made for locating the flight line more accurately; probably by tracking the airplane with a transit located at a ground point on or near the flight line.

The possibilities inherent in the rating of intensity of coverage should be investigated further.

Two pieces of equipment which might be adapted to aerial seen-area mapping are the Sonne Continuous Strip Camera and the Abrams Oblique Sketchmaster. The continuous strip camera is a development of World War II and many of its details are still military secrets. The camera photographs on a continuous strip of film, either color or black and white, and the resulting print looks like a long narrow painting. It was the opinion of a former U. S. Navy photographer, who used a Sonne Camera during World War II, that it could be used for oblique aerial photography.

The Oblique Sketchmaster is a device manufactured by the Abrams Aerial Survey Corporation, of Lansing, Michigan. It works on the principle of the camera-lucida and makes the transferring of detail from oblique photographs to a base sheet or map a relatively simple procedure. The use of this instrument would probably lower the cost of photograph interpretation materially and increase the accuracy of the work.

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APPENDIX

APPENDIX

Photogrammetric method. Wilson[4] in his treatise on the use of oblique photographs says, "In practice the graphical method requires only the ordinary drafting equipment already available to any engineer." On page 598 he sums up the problem as follows:

> The general problem, therefore, involves finding the horizon line on the photograph, and then determining the position, elevation and orientation of the camera, entirely through information that appears in the photograph itself. Usually the solution is possible if at least three ground points of known position and elevation can be identified in the photograph. These control points on the ground compose the base upon which the solution rests. . . Obviously they should form a triangle as large and wide as is feasible within the field of view.

At the time the test procedure was planned the intention was to simplify the solution outlined above by placing a spot bubble on the Mark Lurd aerial camera. The spot bubble was arranged to indicate a level horizon and a depression angle of 25.5° when centered. However, the control proved inadequate, probably due in part to minor motions of the aircraft which were too rapid for the relatively insensitive bubble, and in part to parallax

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[4] R. M. Wilson, "Oblique Photographs for the Surveyor," Manual of Photogrammetry, Preliminary edition, (New York: Pitman Publishing Company, 1944), p. 597.

resulting from the position of the photographer's eye. Inspection of the contact prints showed considerable variation in the relative positions of the apparent horizons.

This difficulty necessitated a tedious computation based on the apparent horizon as indicated by the bottom of the haze lines in the photographs. The computation was made for only three photographs; 0-1-1, 0-1-7, and 0-1-13. The computation was begun with the formula given by Wilson[5] where the distance of the true horizon above the apparent horizon, H-H', is $(f' \sqrt{z} \div 3500 \cos^2 i)$. f', the effective focal length of the camera, is equivalent to the designated focal length of 8.25 inches because the camera was focused at infinity; z is the camera elevation, which was 7,500 feet; and i is the inclination of the camera axis which was assumed to be 25.5° for the trial solution. Figure 14).

Substituting into the formula,

$$
\begin{aligned}
H\text{-}H' &= (8.25 \sqrt{7500} \div 3500 \cos^2 25°30') \\
&= 8.25\ (86.06) \div 3500\ (0.90259^2) \\
&= 709.9950 \div 2851.3380 \\
H\text{-}H' &= 0.249 \text{ inches}
\end{aligned}
$$

The distance H-H' was then used to plot a tentative true horizon, and d, the distance of the true horizon

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[5] Wilson, op. cit., p. 600.

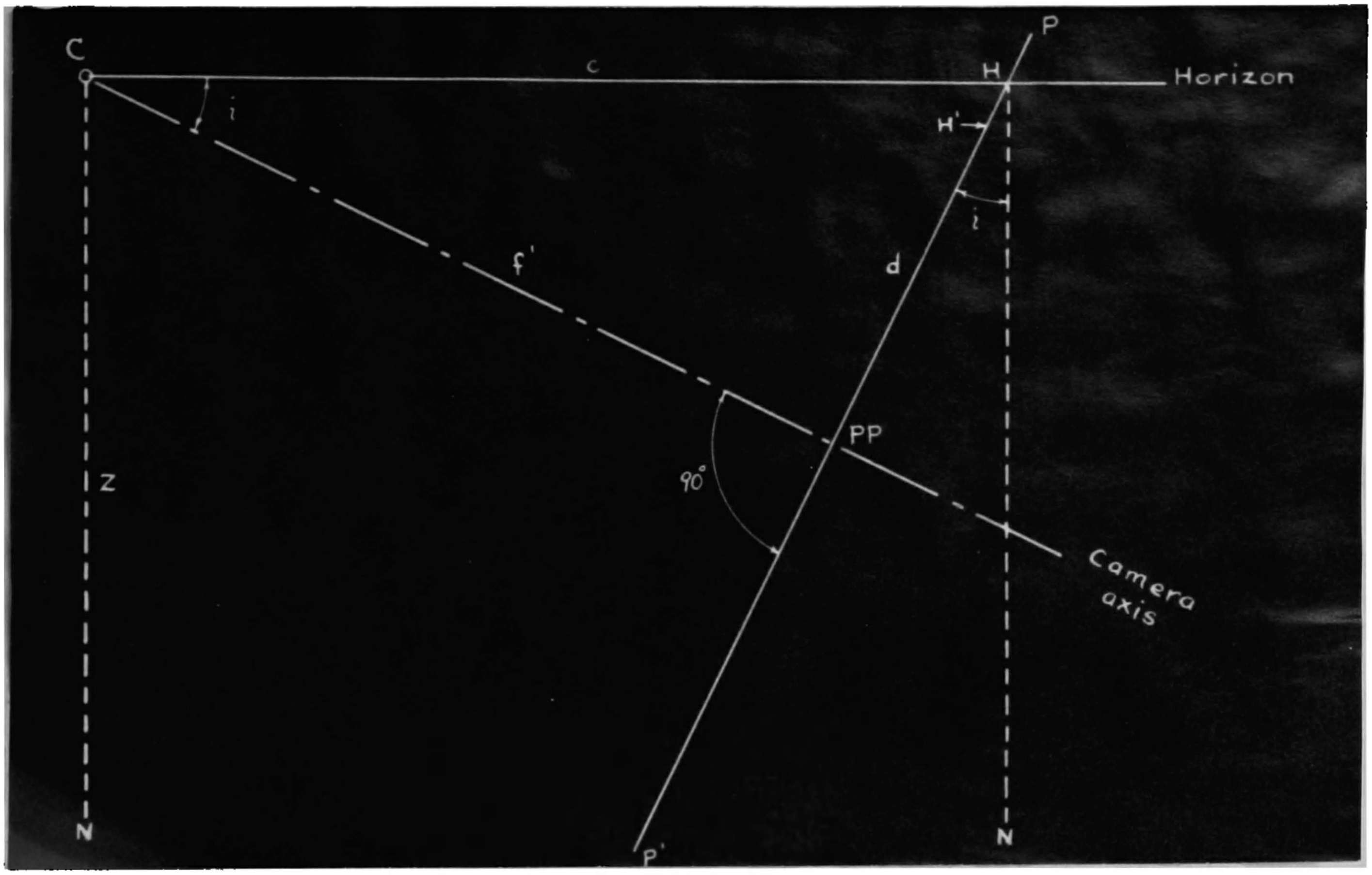

FIGURE 14

DETERMINATION OF THE TRUE HORIZON AND OTHER ELEMENTS IN WILSON'S SOLUTION FOR HORIZONTAL ANGLES FROM OBLIQUE PHOTOGRAPHS

PP,	the principal point of the photograph.
P-P',	the principal line of the photograph.
H,	the true horizon on the principal line (also V).
H',	the apparent horizon on the principal line.
N,	the nadir, or plumb point.
C,	the air station, or camera point.
c,	the distance C-H.
d,	the distance PP-H.

above the principal point, PP, was measured from the photograph. The tangent of the angle of inclination was then found by dividing d by f'. For photograph 0-1-13

$$\tan i = 3.38 \div 8.25$$

$$= 0.40969, \text{ or } \quad i = 22^\circ\, 16'\, 18''$$

With the new value of i, 22°16', a recomputation of H-H' was made, giving a value of 0.240 inches for the distance of the true horizon above the apparent one. The distance d was remeasured and tan i solved for again, giving 0.40848, or an angle of 22°13'09".

A third computation of H-H' made with i as 22°13' gave a value which did not vary appreciably from the second; the true horizon was considered established.

The next step consisted in finding c, the hypotenuse of the right triangle formed by f' and d.

$$c = \sqrt{f'^2 + d^2}$$

$$= 8.92 \text{ inches}$$

A piece of tracing paper was laid over the photograph, and the horizon line V^2-V^4 drawn on it (Figure 15). From V a perpendicular was constructed to pass through PP, and the distance c scaled off to locate the point C. From each control point, g^2, g^3 and g^4, lines were drawn perpendicular to the horizon at V^2, V^3 and V^4. The distances measured on the photograph for g^2v^2, g^3v^3 and g^4v^4 were then divided into parts in the same ratio as c was

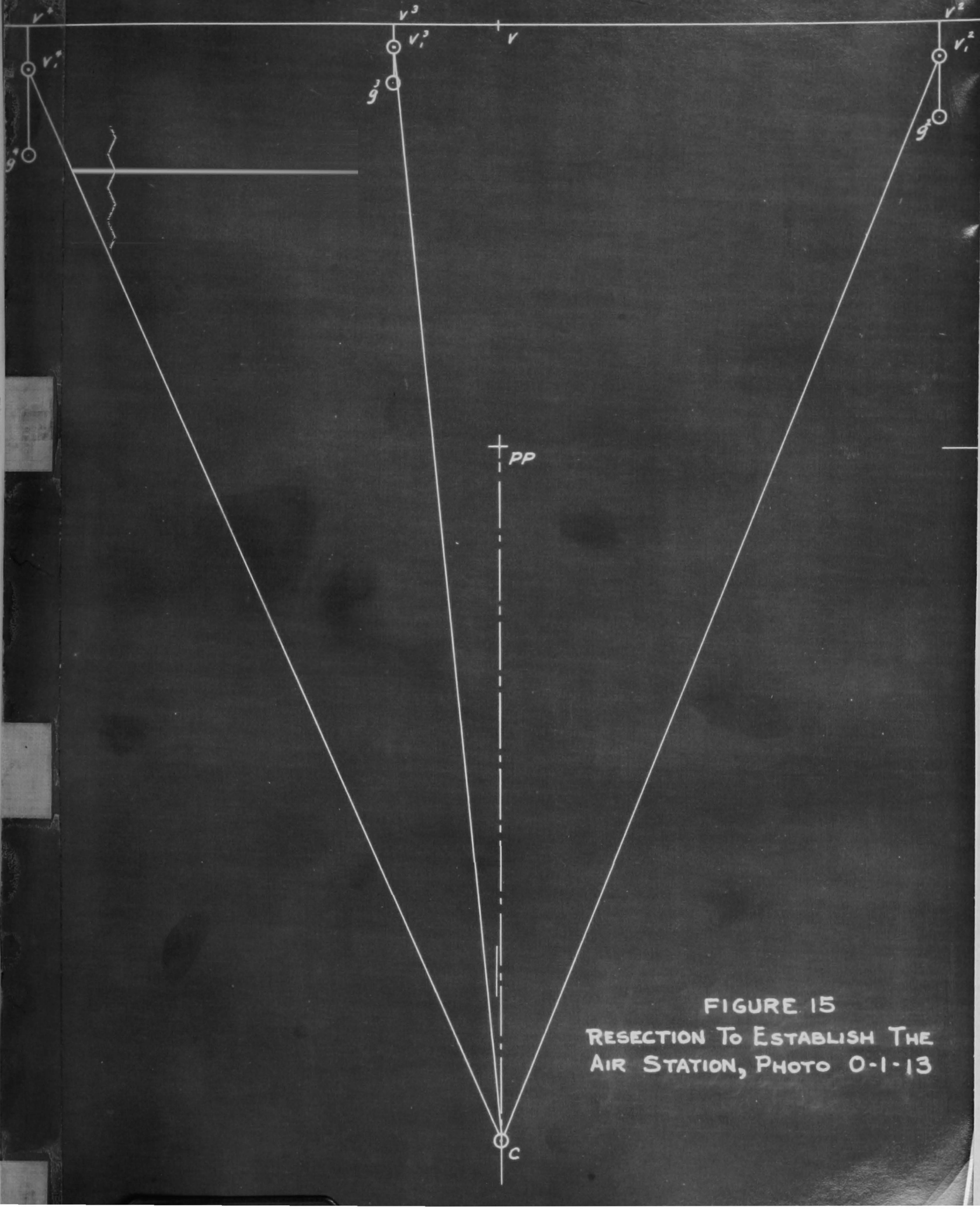

FIGURE 15
RESECTION TO ESTABLISH THE AIR STATION, PHOTO 0-1-13

divided by p. Thus, the points V_1^2, V_1^3 and V_1^4 were established and from them lines were drawn to C. The lines so drawn subtend true angles at C, and the tracing paper provides a means for resecting the position of C on any map on which the control points are shown.

In the following tabulation the computations for locating the air station of photograph 0-1-13 are given:

	Initial values	First Computation	Second Computation
f'	8.25"	8.25"	8.25"
H-H'	---	0.25"	0.24"
d	---	3.38"	3.37"
i	25°30'	22°16"	22°13"
c	---	---	8.92"
d:c			0.378
$v^2 - v_1^2$			0.29"
$v^3 - v_1^3$			0.18"
$v^4 - v_1^4$			0.35"