ploration of Harvard University and the Massachusetts Department of Public Works to determine how specifications for aerial contract work should be drawn so that the resulting pictures would be of maximum value for location studies.

The second paper makes evident the use of photographs for interpretation and approximate measurements in the study of highway locations and land-use relationships. We are familiar with the old Chinese Proverb that "A picture is worth a thousand words." Another old Chinese Proverb has it that—"A voyage of a thousand miles is started by taking *one step*." The first simple steps in the use of aerial survey methods in highway engineering are described by the author of the second paper.

As reported on page 34 of the Annual Report of the Public Roads Administration for the Fiscal Year 1948, the Ohio State Department of Highways organized an aerial survey section equipped to give effective assistance in highway planning and development. The author of the third paper in this Symposium gives you a picture of how the State of Ohio is integrating photogrammetric techniques into organized highway engineering procedures and practices.

In brief: in this series of three papers, each of the authors helps us to see and to understand that the main function of the aerial photograph is to supply an up-to-date surface inventory showing the relationship of obstacles, man-made or natural, to the proposed right-of-way. Much depends upon seeing the highway as a whole for a sound solution.

USE OF AERIAL PHOTOGRAPHY FOR HIGHWAY LOCATION IN MASSACHUSETTS

Elmer C. Houdlette, Director of Surveys,
Massachusetts Department of Public Works

THIS paper concerns an investigation of certain aspects of aerial photography and their applications to highway design and location work in Massachusetts. The Department of Public Works has used aerial surveys of various kinds in the past, however it was believed that full advantage had not been taken of all the potentialities of the new medium. Accordingly it was decided to try to determine, in so far as possible in the limited time available, how specifications should be drawn so that the resulting pictures would be of maximum value to the Project Division.

In order to obtain the desired information, a contract was entered into between the Massachusetts Department of Public Works and Harvard University in December 1946. Under the terms of this contract, aerial photographs were taken along designated routes where actual planning was in progress. The resulting pictures were then used by the engineers on the various projects. The advantages or disadvantages of a particular type of photograph were then determined through actual experience, so that drawbacks would be eliminated and advantages included in future work.

Particular effort was made to arrange the program in such a way as to obtain data on the following problems:

1. The most suitable scale.
   (a) Taking scale
   (b) Degree of enlargement.
2. The most suitable focal length.
3. The most suitable season.

4. The most desirable film and filter combination
   (a) Black-and-white
   (b) Color
5. Specifications for contact prints.
6. Methods of numbering and indexing.
7. Most suitable types of mosaics for various situations.
8. Methods of presenting topographical data.
9. Possible applications of oblique photography.

The aerial work consisted primarily of vertical photography at various scales with cameras of different focal lengths. A total of 525 lineal miles was flown and, in addition, approximately 110 obliques, both black-and-white and colored, were taken of selected areas and routes. Approximately 5,500 contact prints and more than 350 enlargements (varying in size from 16×20 inches to 40×40 inches) were delivered. Both controlled and uncontrolled mosaics were made to investigate the suitability of each for the work of the Department.

Analysis of Tests

Equipment Used. The following aerial cameras were used in the course of the tests:

Fairchild K3B with $8\frac{1}{4}$, 12, and 24 inch cones.
Park Precision Mapping Camera with 12-inch lens.
Fairchild F-4 fitted with 12-inch lens and focal plane shutter.
Fairchild F-8 fitted with 10-inch lens.

Most Suitable Scale

Governing Factors: The taking scale of the original negatives should

1. Be large enough so that ground objects of importance to the engineer can be easily seen under the lens stereoscope.
2. Be as small as possible since, with a smaller scale, fewer pictures are required and the cost of the work is materially reduced.
3. Be large enough to permit satisfactorily sharp blowups of critical areas for detailed delineation of property holdings, acreages, etc.

Tests Run: Route 15 from the Connecticut line to Sturbridge was flown at 800, 600 and 400 feet per inch. The contact prints were then compared under the stereoscope by various engineers. Also prints were made at 400, 200 and 100 feet from negatives with different taking scales, to study the relative sharpness with different amounts of enlargement.

The results indicated that for rural sections a taking scale of 600 feet was sufficiently large and the 5,400 feet width covered by the strip would be enough for most needs. Several proposed routes through rural areas were flown at the 600 feet scale, and planning requirements necessitated preparation of enlargements and mosaics of certain critical areas to 200 feet per inch. It was concluded that enlargements of at least three diameters were entirely feasible.

In urban areas where land values are high and buildings close together, scales of 100 feet or larger are necessary. A portion of Boston was flown at 400 feet per inch, and a mosaic laid at 100 feet proved to be entirely satisfactory.

High shutter speed is important with large scales. Pictures taken of the same area and with the same camera were made at 200 feet per inch with shutter speeds of 1/450 and 1/200 second. These were enlarged to 30 feet per inch and the increased sharpness with short exposure was readily apparent.

Most Suitable Focal Length

Governing factors: When selecting the focal length of the lens to be used, several factors must be considered:

1. The flight altitude to give the required scale.
2. The relief displacement.
3. The tilt displacement.

Flight Altitude: In large scale flying such as undertaken for highway location studies, the problem is not to get an airplane that will go high enough, but rather to use a lens that is long enough to put the plane in smooth air so that tilts will not be excessive. Work with $8\frac{1}{4}''$ lens showed clearly that flying heights are so low that rough air is frequently encountered. With 12-inch or longer lens, flying conditions were excellent on all except two occasions.

Relief Displacement: With photographs taken at a predetermined scale, the displacement of objects caused by relief varies inversely as the focal length. Since the smaller the displacement the more satisfactory the pictures for the type of work under consideration, long focal length lenses are desirable.

Tilt Effect: The amount of tilt displacement with varying focal length lenses showed the distinct advantage of the use of the long lens.

Most Suitable Season

Governing Factors: The most suitable season for aerial photography occurs when:

1. The foliage and snow cover are such that the maximum amount of ground detail is readily apparent on the pictures.
2. There is reasonable expectancy of cloudless weather at frequent intervals.

Foliage: When trees are in full foliage, much ground detail is obscured, particularly in rural areas. To determine how much of a disadvantage this is for highway location studies, comparison strips were flown over a given area when the leaves were fully out and when the trees were bare. A representative portion of the line was studied under the stereoscope, and all visible features of significance were traced when the trees were bare and in full foliage. The main omissions caused by vegetation cover were fences, stone walls, brooks, ditches and ledge outcrops. These are important as fences and stone walls assist in locating property lines, while brooks and ledge outcrops may present engineering problems.

Snow Cover: On comparison strips made near Sturbridge, some features were visible on pictures taken when there was snow which could not be seen when the ground was bare. However, long tree shadows on the snow present a very unnatural impression that makes interpretation difficult, and in addition makes the pictures of far less value for soil identification purposes.

Most Suitable Season: The tests discussed so far indicate that air work should be limited to the period between defoliation and snow in the Fall, and between the melting of the snow and foliation in the Spring. Two maps were prepared to show the dates when snow and foliage conditions should be suitable for aerial photography. The data necessary for the preparation of these maps required adequate snow measurements throughout Massachusetts and a series of phenological records for the same area. The two maps, one for the spring period and one for the fall, show that there is a statewide period of approximately two months in the Spring and one month in the Fall when photographs may be taken under the conditions which experience has shown to be ideal.

Film and Filter Combination

Governing Factors: The film and filter combination should give maximum resolution of detail and should have sufficient exposure latitude to be practical for routine operations.

Film and Filter Combinations: One function of a filter is to increase the apparent contrast of the subject and so facilitate recognition of different objects. When using filters with panchromatic film, it is convenient to remember that an object having the same color as the filter itself will appear lighter, while an object that has the color the filter absorbs will appear dark. If red and blue objects are photographed with a red filter, the red object will be light and the blue object dark.

A second and very important function of filters in aerial photography is to decrease the effect of atmospheric haze which frequently reduces visibility and tends to cause dull and indistinct pictures. Yellow and red filters are frequently used so that the effect of haze is much less pronounced.

Infrared Photographs: In addition to an almost complete absence of detail in the shadows, infrared pictures through yellow or red filters are characterized by their tone rendering of the vegetation. The almost complete reversal of tones except for the small clumps of evergreens and the streams, makes the infrared picture difficult to interpret and so lowers the effectiveness of such pictures for highway location studies.

Color Film: Both obliques and verticals were taken with Kodacolor Film which were easy to interpret because of the sense of reality that comes when objects are reproduced in their correct color. Comparison of the Kodacolor pictures and black-and-whites of the same area indicated that while recognition of objects was quicker and easier on the colored pictures, they showed no difference in color pattern that did not have a corresponding difference in tone on the black-and-whites taken on panchromatic film.

Specifications for Prints

General: Photographic paper is available in various colored stocks, weights, surfaces and contrasts. Each of these variables must be correctly chosen if the prints are to be of the maximum usefulness.

Color of Paper Stock: The paper stock ranges from white through cream and old ivory to buff. We have found that the white stock is best for highway location studies.

Weight of Paper Stock: All work done on this project so far indicates that the greater stiffness, durability and dimensional stability of double weight paper makes it preferable to single weight.

Paper Surface: A print made on a glossy surface will show a little more very fine detail and have a slightly greater contrast than if a lustre surface had been used. The glossy paper prevents the use of pencils when annotating the pictures. Accordingly, it was found that the best surface to meet the particular needs was semi-matte.

Contrast: Papers are made in varying grades of contrast. Experience in working on the various jobs indicated that prints having a full range of tones from white to black and exhibiting what might be called "average contrast" gave the best results.

Methods of Numbering and Indexing Negatives

Numbering: The most satisfactory system for our use is to have each negative carry the date and the project number and in addition the serial number

indicating its position in the sequence of pictures. In addition the time, scale, and focal length is marked on the first and last picture of each flight strip.

Index Maps: Some method of indexing is essential if the prints covering a specific area are to be found easily and quickly.

After trying several methods, we came to the conclusion that the best results were obtained when the centers of every other photograph are plotted on a Geological Survey map and the centers are then connected by a line indicating the general course of the airplane, and the area covered by a single picture is outlined at intervals to show the width of the strip.

Mosaics

General: Mosaics are used to present cultural information about larger areas than can be included in one picture.

Ground Control: Ground control is the term applied to those points which can be identified readily on an aerial photograph and whose horizontal positions are known. The accuracy of a mosaic is dependent on this ground control and increases as the amount of control increases. Massachusetts is in a particularly favorable situation in regards to ground control since the coordinates of more than 5,500 points are on file. There are few places where highway surveys are run that are not tied to horizontal control.

Uncontrolled Mosaics: When the photographs are oriented on their flight lines and no ground control is used, there will be errors in both scale and azimuth so that, if a grid is superimposed from map coordinates of a few prominent features, errors in position of 150 feet or more are to be expected at a few random points. However, such an uncontrolled mosaic may be assembled quickly and cheaply and proved very useful in conferences to study the properties affected by various suggested locations.

Semi-controlled Mosaics: A semi-controlled mosaic was laid showing Route 15 from the Connecticut line to Sturbridge. Variations in elevation throughout the job did not exceed 400 feet, nor 200 feet in the area covered by one picture. A Massachusetts grid was constructed at a scale of 400 feet per inch, and six traverse stations along the present highway were plotted by their coordinates on the grid and picked on the contact prints from the descriptions. As the taking scale was 800 feet per inch, it was necessary to enlarge the pictures. The average amount of this enlargement for each portion of the strip between control points was determined from a comparison of the distance between control points as measured on the grid and as measured on the contact prints. Each print used for the compilation was enlarged by a ratio that would yield good image match with adjacent prints and yet maintain the average ratio for the particular section of the strip. Twenty-one negatives were used and the final mosaic was about nine feet long. To check the accuracy of this compilation, grid coordinates of twenty-one points as determined from the mosaic were compared with those obtained from the Geological Survey map. The maximum error was 125 feet and the average error 62.3 feet, while 90 per cent of the points had an error of 100 feet or less.

Controlled Mosaics: A mosaic was compiled of the General Edward Lawrence Logan Airport at East Boston where positions and directions were important. Here a radial line plot was required to give positions of nine points on each print, the radial line plot being adjusted to ground control established by triangulation. The mosaic consisted of 64 pictures compiled by ratioing each individual print to its appropriate size. A check on 30 random points indicated an average error of 26.9 feet and a maximum error of 50 feet.

Methods of Presenting Topographical Detail

General: Mosaics show the culture and its relationship to the proposed location, but they convey very little information about the topography, which is generally an important factor. It is true that pairs of individual pictures examined under a stereoscope show the relief, but actual elevations cannot be determined, and there is the great disadvantage of being able to see only short sections of the line at one time with the consequent difficulty of obtaining an over-all knowledge of the terrain.

Test Run: Two methods of presenting topographic information in conjunction with the mosaic were tried.

A semi-controlled mosaic was laid at a scale of 600 feet per inch so that images of prominent features would fit their position as determined from a Geological Survey map. The map was then enlarged to the scale of the mosaic, and the two were mounted one above the other so that the elevation of any point on the mosaic could be determined by projection.

The second method consisted of laying a mosaic to match a Geological Survey sheet. Contour lines and a few prominent features were traced from an enlargement of the map. These contours were then copied, and positives made on process film using a dye coupler developer to give the contours sufficient color to afford contrast. The contoured overlay was then fixed to the edge of the mosaic so that it could be turned back out of the way when not needed, or dropped into position to study the topography.

Obliques

General: Obliques are easier for the layman to understand than are verticals. Therefore, they have a definite value at hearings where it is desirable to explain to the public exactly why a certain location was selected and to show which properties are affected.

Test Run: Obliques with a 12-inch lens at altitudes from between 400 and 500 feet were taken at about 1,000 feet intervals along the route of the proposed Expressway in East Boston to show the types of buildings that would be affected. The resulting pictures, when used in conjunction with verticals of the same area having the takings delineated, proved eminently satisfactory for presentation at the hearings where, in addition to having the prints available for individual study, lantern slides were projected on a screen so that the entire group could be "briefed" simultaneously.

Conclusions

Our experience with the different types of pictures and mosaics indicated the following conclusions:

(1a) The most suitable taking scale for urban work is 400 feet per inch. For rural work a taking scale of 600 feet is sufficiently large.

(1b) Under normal conditions, negatives should not be enlarged more than three diameters; however, enlargements of four or six diameters of critical areas are entirely usable if the original pictures were taken with a high speed shutter.

(2) The aerial camera should have a focal length of 12 inches or more.

(3) The most suitable season for the aerial photography is when the leaves are off the trees and there is no snow on the ground. Every effort should be made to plan the projects sufficiently in advance to permit photography under these conditions.

(4a) Panchromatic film should be used for the black and white photography,

and in rural areas, the choice of filter should be left to the contractor so that he may use the one that will best meet the haze conditions existing on each flight. In urban areas where high buildings will cast long shadows, the contractor should be limited to the use of yellow filters, and these should be permitted only when the resulting photographs contain sufficient shadow detail to satisfy the engineer.

Infrared film should not be used.

(4b) Color photography should be confined to pictures needed for use in public hearings where the added sense of reality inherent in color would justify the added expense.

(5) Contact prints should be on double weight paper for durability and dimensional stability, and the surface should be semi-matte to permit easy marking and to reduce objectionable reflections.

(6) Each negative should be marked clearly with the Project Number followed by the serial number of the particular negative within the project. The date of photography should appear on each negative, and the first and last negatives of each strip should also show the time of exposure, the scale, and the focal length of the camera used.

For the index map, the appropriate Geological Survey sheet should be used as a base, and the centers of every other photograph plotted, numbered, and connected by a straight line to indicate the general path of the airplane. In addition, the area covered by the first and last picture on each strip should be outlined on the map. Photographic reproductions should then be made on Ad-Type (or equal) paper to permit the prints to be folded without cracking.

(7) The requirements of a particular project will determine whether an uncontrolled, semi-controlled or controlled mosaic will be needed.

(8) Topographical information in regards to a proposed location may be presented by reproducing the Geological Survey map above or below the mosaic, or the contours may be reproduced on a transparent overlay kept in register with the mosaic.

(9) Oblique photographs serve a useful purpose in planning interchanges and illustrating proposed takings at public hearings. Such obliques should be taken with a camera having a focal length of 12 inches or more. The flight altitude for 12-inch lenses should be 1,000 feet in rural areas and 500 feet in urban areas where property values are high, and may be increased proportionally with longer lenses.

(10) Our greatest difficulty in Massachusetts is to find engineers in the Department that can interpret aerial photographs accurately and extract all the information they contain. I believe that a selected personnel should be given elementary practical instruction in photo interpretation, the use of the stereoscope, radial line plotting, and assembly of mosaics. They will then be in a position to use aerial photographs with assurance and precision.

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