AIR PHOTOGRAPHY AND ITS APPLICATION TO FORESTRY*

H. E. Seely, Dominion Forest Service, Mines, Forests and Scientific Services Branch, Department of Mines and Resources, Ottawa, Canada

WITH the development of aircraft as a means of transportation, the air camera entered the field of practical application and challenged the surveyor and the research specialist to explore its potentialities. The result has been the growth of air photogrammetry as a new branch of engineering science, giving rise to a new group of technicians, and demanding new methods, materials and equipment in photography, surveying and mapping. This is possibly the most revolutionary development in the history of mapping, and represents a most important advance in the investigation of natural resources.

Man's enterprise has provided nothing which is more suited to a study of the surface of the earth than the air photograph, which from its elevated vantage point secures a comprehensive record, providing detailed documentary evidence of the complex appearance of the earth's surface. This wealth of information is made more intelligible by the stereoscope, which provides the semblance of a small-scale model of the land surface, wherein hills, trees, and other objects appear in their natural three-dimensional character.

Air surveys enable vast areas to be covered in the most expeditious and effective manner, thus accelerating the production of the maps which are essential for the efficient development of natural resources. Happily, the air photograph has multiple uses in providing information on resources as well as topographical features, and applies economically to the over-all development of the various resources of a region.

Of all natural resources (including soil, forests, minerals and water supply), none is better adapted to detailed study by air photography than the forest. Unless of a special or restricted nature, forest surveys should never be made without the benefit of air photography. A practically simultaneous record of the forests may be obtained over large areas, this being of special importance in the case of a growing and self-perpetuating resource in which the interplay of growth and depletion should be carefully watched.

CLASSES OF AIR PHOTOGRAPHY

Air photography may be divided into the following main classes:

1. *Vertical*—in which the photographs are taken with the camera axis pointed downward as nearly as possible in a vertical direction. Other classes may include vertical photographs in their composition.

2. *Oblique*—in which the photographs are taken with the camera axis intentionally tilted either in a high-angle or low-angle direction. High-angle obliques usually include the horizon, which acts as an important basis of control. Low-angle obliques are intermediate between high-angle obliques and vertica s. Other classes may include oblique photographs in their composition.

3. *Composite*—in which multi-lens cameras obtain two or more low angle obliques, either with or without a central vertical; the obliques are rectified so that the resultant assembly resembles a vertical photograph.

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4. *Trimetrogon*—composed of a central vertical, a port oblique and a starboard oblique. The set of three simultaneous exposures covers an area from horizon to horizon.

5. *Forestry tri-camera*—which resembles trimetrogon photography except that the side photographs are low-angle obliques instead of high-angle obliques (4). Further differences occur in matters of the focal lengths of the lenses and the camera mountings. Though this class is of comparatively recent origin it is mentioned here because it is at once economical and informative when the demand is solely for forest data. This class will be referred to again under the heading of special forest photography.

MAPPING METHODS

The compilation of a map from air photographs is usually based on the principles both of surveying as required in the establishment of ground control, and of photogrammetry as necessary in the solution of problems related to the perspective characteristics of air photographs.

The construction of a basic map showing streams, lakes and other prominent features is of prime importance to the forester and the advantages of air photographs for map-making cannot fail to attract his attention. Not only is the basic map essential as a framework on which to base the network of forest type lines, but it also serves many other forestry purposes. A basic map is a most important guide to routes of travel and accessibility of timber. When contouring or other third-dimensional information is included, the usefulness of the map in relation to the cutting and transportation of wood is greatly augmented. Furthermore, the fine detail of topographical features which is generally obtainable from air photographs may provide sufficient control for forest survey lines, thus eliminating the cutting of costly base lines.

In some cases, the forester may be content with less elaborate methods than are necessary in a comprehensive and systematic programme of mapping. In territory where limited development has taken place, he is often anxious to obtain a forest map immediately after the taking of the air photographs rather than to wait for the extension of ground control by the surveyor. In these circumstances, it has been recognized by all concerned that provisional maps may well be made from air photographs by means of simpler methods and that temporary ignorance of the exact geographical setting of the map and failure to adhere to the regular standard of accuracy, are not serious drawbacks. Paradoxically, however, the forester may ask that the map show more detail than would otherwise be demanded.

The radial intersection method (1) is employed extensively in mapping from vertical air photographs and provides a graphical solution based on the angle-true properties of lines drawn from the photo plumb-point, with the result that a suitable map may be made regardless of the displacements which are produced in the photographs by differences of elevation in the land surface. The forester is interested in this method because of its general application but he may sometimes prefer a more serviceable procedure.

The slotted template method (1), or the comparable slotted arm method is also used for verticals, and is based mainly on the same principles as the radial intersection method, but employs a mechanical means which facilitates an overall adjustment and provides flexibility in conforming to control points. These methods are of particular value to the forester in the production of maps where there is a minimum of ground control.

In the case of oblique photography, the use of perspective grids (1) has been a very valuable method of compilation. Obliques, particularly high-angle obliques, have their best application in areas of low relief, as otherwise displacements caused by differences of elevation present a problem in mapping. Oblique photography has served the forester very well in many instances in the past, but has now been largely superseded by trimetrogon photography, with which it has much in common.

Trimetrogon mapping (1) has been employed successfully for aeronautical charts and, in many instances, for the initial mapping of a region. Slotted arm equipment, as above mentioned, and other special plotting devices have been developed for mapping from trimetrogons. They are of interest to the forester in the preliminary investigation of undeveloped territory.

The use of air photographs or portions thereof put together in the form of a mosaic (1) often appeals to the forester because it shows pictorial detail in assembled form. On the other hand, it represents uninterpreted information, and if lines and symbols are added, it begins to take on the characteristics of an ordinary forest map and loses pictorial detail because of the obscuring effect of the markings. An ordinary forest map has superior clarity and boldness, especially when colour has been added to accentuate the various forest types. Often the forester may prefer the map to the mosaic, especially when he can view the pictorial detail by examination of the loose photographs under the stereoscope. The construction of a mosaic becomes more difficult in hilly country because of displacements in the photographs, but when a mosaic can be assembled with ease it may, in certain circumstances, serve as a ready mapping method because a rough map can be traced from it directly. On the other hand, the construction of a so-called controlled mosaic is dependent upon the prior compilation of a map or at least of control data as required for map making.

The principles of the stereoscope, with its three-dimensional qualities, have been utilized in the construction of various instruments, both simple and complex, to increase the scope and accuracy of plotting from air photographs, with particular emphasis in the matter of contours. Elaborate stereo-plotting machines such as the Aerocartograph and the Stereoplanigraph are seldom of interest (5) to the forester. The multiplex is simpler and its practical application is aided by its capacity for "bridging" considerable distances where no control exists. While the stereometer or parallax bar, the parallax wedge, and similar devices are of interest to the forester in contouring and determining tree heights, he will probably find that his most commonly used instruments are the simple mirror stereoscope and the even simpler lens stereoscope. These comparatively inexpensive stereoscopes are very valuable in the interpretation of the air photographs, not only for depicting slopes and grades for logging and transportation but also for the investigation of forest sub-types and individual trees.

The most popular instruments in current use for the transferring of the forest type lines from the photograph to the map are those in which a semi-coated mirror is employed to provide superposed views of map and photo, one image being obtained by reflection and the other by direct transmission.

While the forester may, to a large extent, be interested in the same plotting equipment and stereoscopes as other users of air photographs, he will use his own special devices for the measurement of tree heights, tree crowns, and crown closure.

PHOTOGRAPHIC DETAIL

The forester is particularly anxious to secure a maximum of detail in the air photographs. The resolving power of the lens and that of the photographic emulsion are the chief limiting factors in regard to definition in the negative.

Accordingly the general practice is to increase the scale of photography when greater detail is required. Another factor is that of blurring caused by the travel of the aircraft during the instant of exposure. This blurring is not noticeable except at very large scales. In the Sonne continuous-strip camera, the film moves to keep pace with the ground speed. A compromise is being tried in which the film in an ordinary air camera will move during the instant of exposure. In the absence of such devices, fast shutter speed is beneficial.

The forester will welcome future developments in the securing of sharper detail, but in the meantime he can adopt the alternative of taking sampling photographs at large scale to supplement the general coverage photographs.

Prints on glossy paper (1) give greater detail than those made with a semi-matte surface. Transparencies on film are superior to paper prints in point of detail but are not yet widely used because of lack of facility in production and use.

Enlargements seldom provide more detail than contact prints and are bulky, expensive, and inconvenient for use with ordinary stereoscopes. On the other hand, enlargements provide more space for marking and measuring. The use of magnifying stereoscopes on contact prints is generally preferable to the employment of enlargements.

On account of varying conditions, it is difficult to specify the most suitable scale or scales at which the photographs will be most useful to the forester. Often a scale of 1:15,840 (1,320 feet to one inch) may be suitable for general forest inventory, while at the same time the compiler of the basic map might be satisfied with a very much smaller scale. For special forestry work, scales larger than the above will be required.

SEASONAL CONDITIONS

Related to the matter of the resolution of detail in the photographs are the effects of seasonal changes, particularly foliage, sunlight, and snow. The shedding of the foliage of deciduous species allows the trees to be seen in greater detail, and in some latitudes snow forms a bright background against which trees and tree shadows appear more clearly. On the other hand, snow obscures fine detail on the surface of the ground.

PHOTOGRAPHIC OPERATIONS

Air photography may be conducted by governmental air personnel, either military or civil, or by private air survey companies. A specially trained staff is required for flying, photography, and processing. In addition to suitable aircraft, it is necessary to employ highly specialized cameras, camera mountings, accessory instruments, and equipment. Accordingly, the forester will usually depend completely on the photographic specialist up to the stage of the delivery of the photographs.

FOREST MAPS

The construction of a basic map from the air photographs provides the foundation for the preparation of a forest map such as is usually desirable and often invaluable in forested regions. The forest map may be of a large-scale detailed nature as required to facilitate cutting operations or special forest working plans, or, alternatively, may be of medium or small scale containing only general information suitable for broad forest inventory purposes. Often it is desirable to have both types of forest maps on hand, the detailed maps being restricted to the scene of cutting operations and vicinity while the general maps would cover the whole forest. The high cost of detailed forest maps and the high probability of their becoming obsolete through cutting, fire, wind, insects, disease, and other depleting factors on the one hand, and regeneration and growth on the other hand, argue against their preparation save in cases of intensive development. The general forest inventory maps are particularly suited to remote timber lands, areas of young growth, inferior species, or poor forest sites; at the same time they provide a concise picture of all forest lands, thus facilitating general planning. The general maps also are a valuable aid in the compilation of forest inventory figures, because the data collected in intensive forest surveys may be correlated in the form of ledger entries with the subdivisions shown on the general maps. Air photography is making it more feasible economically to plan for the production of a suitable supply of these forest maps.

Where basic maps are being used for the production of a series of published map sheets, it becomes a comparatively simple matter to prepare and issue a series of forest maps produced by the photolithographic process (3). The procedure is faster than the ordinary method of preparing tracings and printing on sensitized paper, because advantage is taken of the existing plates already prepared for the purposes of the series of basic maps. Thus the draughtsman is not forced to redraw and reletter the features which appear on the basic map. A similar saving is introduced in the colouring of the maps, whereby in a single step colour plates are made which will serve for thousands of copies, whereas in hand colouring a corresponding step must be carried out for each additional copy. Furthermore, quantity production of map sheets becomes possible because of the relatively negligible cost of printing additional copies.

In the preparation of forest maps from air photographs, it will often be advantageous to classify in accordance with type, crown closure, and height, these being variables which are most readily determinable from the air photographs. Sometimes the photographs will also yield information of species, sites, subtypes, number of trees per unit area, width of crown, degree of homogeneity of the stands, and other data which, together with the aforementioned variables, may provide a basis for both quantitative and qualitative classifications.

SPECIAL FOREST PHOTOGRAPHY

The value of an economical and expeditious method of forest air photography, such as the forestry tri-camera (4), is peculiarly apparent when the necessity for rephotographing occurs. The dynamic conditions obtaining in forest stands, where cutting, growth, fire, wind, disease, and insect infestations may change the entire character of an area in a very short space of time, obviously demand a means of rapidly assessing such changed conditions, and the forestry tri-camera method has been specially designed for this purpose. It gives an optimum angle of view which facilitates accurate tree measurements and reliable identification of species. At the same time the method provides economical coverage by forgoing certain features which are essential for basic mapping purposes but which are needless for forest survey purposes. While maintaining equivalent scale, the method permits the flight lines to be spaced 2.87 times as wide as in the case of ordinary vertical photography as taken with a 6-inch (15 cm.) lens. Thus maximum forestry information is available at minimum cost.

In the initial photography of a forested region, it is usual to compromise between the small scale favoured by the compiler of the basic map and the large scale desired by the forester. However, it may become desirable to have two photographic operations, one for basic mapping and the other for forest survey purposes. The two operations might, in some cases, prove more economical than a single compromise operation, because the reduced cost of each might largely compensate for the expense of separating the operations, and also the basic mapper and the forester would save much time and labour.

QUANTITATIVE ESTIMATES

There is no doubt that estimates of timber quantities can be made by measuring tree images in air photographs. The real questions, however, are what degree of accuracy is attainable, and how does the cost compare with that of equivalent ground work. The answer to the first question is that the degree of accuracy of air estimates, like that of ground estimates, is chiefly governed by the data available. The intensity of detail in the air photograph, like the intensity of a forest survey on the ground, governs the accuracy of the estimates. Factors affecting photographic detail, including seasonal changes, have been dealt with above. The answer to the second question is that under favourable conditions, suitable quantitative estimates may be made with less cost from the air than from ground work. Air estimating is more apt to show its superiority over ground work in broad forest inventory than in detailed forest surveys. However, the air method encounters considerable obstacles in very dense evergreen stands of varying height, in cases where the trees are close to the border line of merchantable size, and in regions where there is little or no occurrence of deciduous species or of snow-covered ground. In small-scale photographs, of course, estimation is handicapped by lack of good resolution of the fine detail.

Quantitative estimating from air photographs is based on measuring, and sometimes counting, the tree images. Tree heights are determined by measuring the images of the trees or their shadows. Crown widths and crown closure may also be measured or estimated as required in the quantitative technique. Use is made of data analogous to volume tables as employed in timber estimates made from ground work.

One of the strong points of the air photograph is the manner in which it facilitates the grouping and delimitation of the various forest classifications. Thus it permits a measure of correlation between air estimates and ground work whereby quantity classes may be delineated and then sampled in the field. Especially in present circumstances, the purely air method of estimating meets with difficulties, some of which are referred to above. Thus the combined use of air and ground methods is employed far more extensively than the purely air method. Though the combination applies well to the forest as a whole, it is not possible to go farther and correlate effectively in any way the air estimate and the ground estimate of an individual stand.

QUALITATIVE INFORMATION

Field sampling may generally be applied very effectively to elucidate the qualitative information which the air photograph shows in regard to species, site, height in relation to age, composition of the stand, defect, and related conditions.

Without the aid of field work, the identification of species in air photographs is generally difficult and often impossible, though the use of large-scale sampling photographs would be of great assistance. After the fall of their foliage, deciduous trees may be distinguished from evergreens. Certain desired distinctions may occasionally be obtained by a process of elimination in cases where very few species are present; by the aid of site classification from air photographs; by knowledge of the forest associations and successions; by shape, texture, and light-reflecting qualities of crown; by tone of foliage, particularly in the case of autumn colouration; and by phenological changes. A further approach to the identification of species is through the use of special films and filters, the most striking example being in the case of the employment of infra-red (6), which generally provides great contrast between the foliage of broad-leaved trees and that of needle-bearing species. While shadows are dark in infra-red photographs the foliage appears very light. The result is a great variety of tones, these being governed by the degree of shadow between and within the crowns, which does not necessarily vary in accordance with the species. However, with the aid of ground identification to establish a key for each set of photographic and forest conditions, it would appear that the pronounced contrasts of infra-red could often be employed for species identification to a greater extent than in the comparable use of the ordinary panchromatic film. On the other hand, infra-red, on account of its very dark shadows, masks a great deal of detail. A limited use may be found in the future for colour photography in special problems of species identification.

If a key to site classification is established by ground work, it will often be possible to extend the classification throughout the air photographs. The land form as visible under the stereoscope, together with other photographic detail which can be interpreted in the light of the field investigation of geological and soil conditions, is often conducive to the effective use of air photographs for site classification. Study of the nature of the existing forest by means of the photographs sometimes provides in itself a good indication of the forest site (2).

FINAL REMARKS

No attempt has been made in this paper to enter into the technical details of the subject, particularly of the technique and equipment which have been, and are being, developed. Air photogrammetry and the kindred scientific advances arising therefrom are comparatively new in origin and application. A vast field still awaits exploration, even though progress to date has been beyond our expectations. Those concerned with forests and other resources will be well advised to follow closely developments in this field.

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