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Engineering Acceptance of Interpretation and Measurements

Imagination and initiative will expand the range and scope of application of aerial surveys.

(*Abstract on next page*)

Introduction

Acceptance is an act of recognition which is broadly received as true and significant. Information ascertained by photographic interpretation and measurements made by photogrammetric techniques are accepted, and they are given credence through their use.

The pioneers, the seekers for a better way, not only "took chances" they sought opportunities. Reports of their successes caused others to venture. Increased work loads, shortage of experienced engineers, and time-accelerated completion schedules sped acceptance of photographic interpretation and photogrammetry by the highway engineering profession.

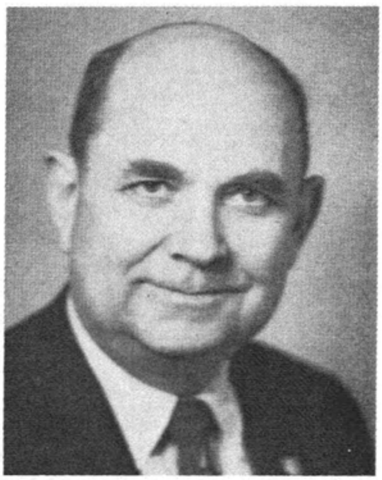
The Present

Today the acceptance of photographic interpretation and photogrammetrically determined measurements is no longer the central topic of discussion. Instead, attention is directed toward new developments and toward increasing our understanding of progressive techniques and procedures. Attention is concentrated on enlarging the scope of application and on increasing proficiency. Foresight and cooperation assure benefits from progress.

Current utilizations of aerial photographic interpretation and photogrammetry—aerial surveys—in the highway engineering field evolved through trial, adaptation, technological and scientific improvement, and research while the aerial surveys were being used.

To improve and expand the uses of aerial surveys in detail and in scope, numerous training schools have been conducted during the past 20 years. Wherever highway technicians and engineers attended, the use of such surveys soon began, and expanded use occurred earlier and more rapidly than where schools were not conducted. Within the responsibilities of highway departments and field offices of the Bureau of Public Roads, initiative for scheduling schools lies with the States, as is also true for engineering and construction work. Accordingly, requests for the schools generally indicate the foresight and initiative of chief engineers and their staffs.

Although it may not be appropriate to record in detail each particular application of aerial surveys, the significant aspects of using



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aerial surveys for highway engineering purposes can be outlined before discussing the future.

As in other professional fields, use began at an elementary level. Form-line types of instruments, such as the Stereocomparagraph and Contour Finder, were used to measure elevation differences, and to compile formline types of maps for reconnaissance surveying purposes. The Wernstedt-Mahan and KEK stereoscopic plotters were also used to a limited extent. Such uses have since been largely discontinued.

and the maps to do all of the essential engineering work.

Wherever aerial surveys are employed for compiling maps, basic control is surveyed by the usual methods on the ground, regardless of whether map scale is small (between 1:50,000 and 1:12,000) for planning and reconnaissance purposes and for route location and selection, or whether map scale is large (between 1:2,400 and 1:480) for designing the location on the selected route and preparing detailed construction plans. Unfortunately, not all basic control surveying has

ABSTRACT: *Photographic interpretation and photogrammetrically determined measurements are currently accepted and used in varying degrees of detail and scope for engineering. Aerial photography will be used even more freely in the future than at present for highway planning, location and design, construction, and completion purposes, including surveys for acquiring essential data regarding traffic, soils, geology, sources of construction materials, drainage, hydrology, land use, land ownership, archaeology, vegetation, inventory, cut-and-fill quantities, etc.*

The scope and application of aerial surveys will continue to broaden and to develop along the lines of increased utilization of **geodetic** *control; of automatic recording of field and office measurements for direct input into computers, and multiple use of the computers; of positioning slope stakes; of using aerial cameras and films, including color and infrared, and auxiliary aerial instruments such as improved altimeters (including lasers), horizon cameras, airborne profile recorders, oblique cameras, and electronic scanning and remote sensing; of using automatic coordinatographs and cartographic processes; and of obtaining optimum coordination of ground and aerial methods. Educational emphasis of surveying will strengthen engineers in their basic qualifications and professional registration laws will be applied.*

Another elementary use of vertical photographs continues and likely will not be displaced. The use is in making parallax measurements to ascertain the pertinent differences in elevation, and to compute and use incremental parallax in determining uniform gradients for locating feasible highway route alternatives.

Photographic interpretation is employed in all phases and stages of aerial surveying. Interpretation is applied while determining every fact needed pertaining to the character and quality of: topography, geology, soil and ground conditions; sources of suitable construction materials; drainage; traffic (present and estimated for future); and land uses and features. Thus photographic interpretation is not only accomplished while specific measurements are being made and maps are being compiled by use of aerial photographs, it is also employed while using the measurements

been originated and closed on geodetic markers of the National network of basic control for which State plane coordinate systems have been made available. Progress is being made, however, toward correcting this omission. Since the advent in 1957 of electronic distance-measuring instruments using light waves and micro waves, basic control surveying for use of aerial surveys in highway engineering has not only increased greatly but a larger proportion has been tied to the basic network. The accuracy and utility of basic control has been improved by the combined use of the electronic distance-measuring instruments, precision angle-measuring instruments, and self-leveling levels.

Supplemental control for use of the aerial photographs in stereoscopic pairs, as needed, is established by photogrammetric bridging, and by ground surveying techniques which have an accuracy of lower order than needed

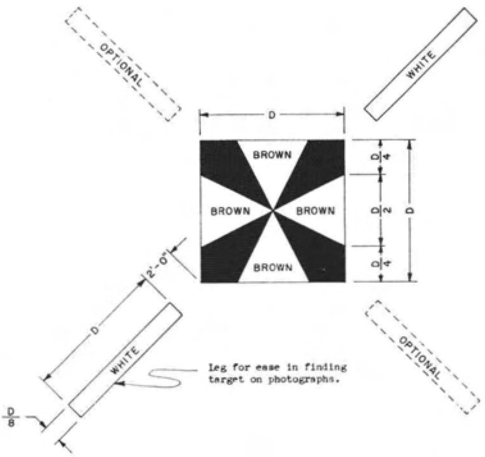

FIG. 1. Target for placement on markers of survey control.

TABLE 1. SIZE OF TARGET FOR SIX DIFFERENT SCALES OF AERIAL PHOTOGRAPHY

Smallest Scale		*Dimension* D (*feet*)	
Representative Fraction	*Feet per inch*	*Minimum*	*Recommended*
1:30,000	2,500	8	9½
1:24,000	2,000	6	8
1:18,000	1,500	4½	6½
1:12,000	1,000	3½	5
1:6,000	500	2	3½
1:3,000	250	1½	3

A target for each of the smaller photographic scales will serve well, respectively, for all larger scales, but not vice versa.

for basic control. The choice of bridging method is governed by the confidence, experience, and accuracy required, and by the purpose for which the bridging is done. For reconnaissance type work and other small-scale measuring and mapping purposes, graphical-mechanical methods using radial plot principles are employed. Contact-print size slotted templets are the most elementary, and radial templets prepared at stereoscopic model scale using double projection instruments serve well for certain types of large-scale route-location mapping, and for discerning large errors in basic control. Double projection instruments, using aerial photography taken at scales of ½ to ¼ the scale required for route mapping (for use in the design of highway locations), are used to measure both vertical and horizontal control for the large-scale measuring and mapping ranging from 1:2,400 to 1:480.

The most accurate instrumental bridging is accomplished with optical-train instruments. The X, Y, and Z coordinates of each stereoscopic model are measured and then recorded electronically in punched card, punched tape, or magnetic tape and/or typewritten, as desired. Included in the recorded data are basic control points of horizontal position and elevation. All measured points for which X, Y, and Z coordinates are needed are then correlated with, and adjusted to, the basic control by an electronic computer using a program which will provide a least squares adjustment. Recently, photographic x and y coordinates measured by use of a comparator, either monocular or stereoscopic, are also used in electronic computers to accomplish analytic aerial triangulation for obtaining essential supplemental control. Where this is done, photographs at the measuring and mapping scale are used; but where conditions and required accuracies permit, photographs of ½ to ⅓ the scale needed for the precision measuring and mapping are also used. If smaller scale photographs are used, thorough and reliable correlation is made for all measured points between the separate scales of photography.

Symmetrically-shaped photographic targets of effective color combinations are placed on the markers of basic control points, and on a reasonable number of the supplemental control points. Other essential supplemental control points are selected stereoscopically, comprising finite, well defined images of objects on the ground or of ground-point patterns. An example of an effective target is illustrated in Figure 1 and Table 1. Depending on the duration of time in which the target will need to remain in place before the photography, and on the use made of the land where it is placed, the target is composed of muslin cloth, or paint on cardboard, plywood, pavement, or rock. Paint is of a nondurable type which will soon wear from a paved surface. The color, shape, and dimensions make each target equally effective for all photographic scales larger than the scale for which the target size is minimum.

In analytic aerial triangulation, point transfer devices are used for marking pass points. Stereoscopic correspondence must be achieved in all pass-point marking if monocular comparators are used. Such correspondence is not necessary if the x and y measurements of singly marked pass points are made with a stereocomparator.

The usual procedures used in traverse surveying and in measuring the elevations of bench marks are also employed for supplemental control surveys. Sometimes such surveying is augmented by subtense bar and theodolite measuring to obtain distances, horizontal and vertical angles, and elevations. The remote-base-line method of traverse and remote-position-and-elevation surveying is employed for measuring both horizontal and vertical basic and supplemental control.

Precision measurements using double projection instruments with digitizing accessories, optical train instruments, and comparators to a limited extent, are also used to make measurements for cadastral surveying purposes and for the preparation of right-of-way descriptions. For such photogrammetric work, pertinent points on property corners and boundary lines, as well as the basic control points, are targeted before the aerial photographs are taken.

Other precision measurements which are made photogrammetrically are profiles and cross sections. These measurements are made for design for the purpose of computing excavation and embankment quantities for awarding contracts, for making progress payments during construction, and for making completion payments for highways which are already constructed. As in other precision work, an adequate number of photographic targets are placed on markers of basic control and supplemental control. This is done before design, and repeated during and after construction, to achieve precise correlation between the separate sets of aerial photographs used. Along routes where the ground is obscured by trees and other tall vegetation, the highway route is cleared within construction limits before the design photography is taken.

Maps compiled by photogrammetric methods are checked for accuracy and completeness using the same aerial photography with precision photogrammetric instruments; photographic transparencies printed on glass for the mapping are also used for the testing. Correlation between the basic control and the maps is achieved by measuring photogrammetrically the X, Y, and Z coordinates of other points. These are points for which ground-measured coordinates are known (but which are not used to control the mapping) and are points reserved for determining the accuracy to which the photographs are oriented for map-testing purposes. By such a procedure, each map found to be adequate in accuracy, detail, and scope is accepted. If not adequate, further tests are made by traverse and profile surveying procedures on the ground before the acceptance or rejection of the maps.

Photogrammetric testing is a sampling process by which inaccurate and/or incomplete maps are identified for testing by ground surveys before acceptance or rejection. Such a procedure has reduced the cost of map testing by as much as 80 per cent as compared to the cost of testing solely by survey methods on the ground.

Orthophotographs, with contours superposed on them, are used to a limited extent instead of topographic maps. The photographic details provided thereby are more comprehensive and informative than the usual planimetric details of maps. As techniques are improved and more use is made of orthophotographs, they will largely displace planimetry for topographic maps and for planimetric maps.

Unfortunately, research in aerial surveys for highways has been retarded. Many improvements and developments have been made, however, as alert and progressive users of aerial surveys have accomplished their engineering work. A fundamental need is identification and definition of the areas in which research should be directed. Fortunately, the Photogrammetry for Highways Committee of the American Society of Photogrammetry, and the Photogrammetry and Aerial Surveys Committee in the Department of Design of the Highway Research Board, have undertaken this task. In addition, the Research and Development Committee of the Surveying and Mapping Division of the American Society of Civil Engineers has prepared a report in which a program for research in surveying and mapping has been outlined. Completion of research, as defined in this report (which was published in Vol. 92 No. SU1 of the Journal of the Surveying and Mapping Division for January 1966) will go far toward fulfilling current research needs in aerial surveying for engineering and related purposes.

Aerial photography of every available emulsion type is now being used for photographic interpretation purposes. In addition, infrared imagery obtained by remote sensing of micro-wave radiation is also used to a limited extent. Most photogrammetric work continues to be accomplished by use of panchromatic film. Some color photography of the negative transparency type is also used.

The Future

Although excellent photogrammetric surveys are usually expected (but not always achieved), they will become more commonplace than heretofore. Highway engineers will no longer be frustrated for lack of essential data. The effective use of aerial surveys will provide readily the information and data needed and the mediums of use, and will enable factual illustration of the problems and their solutions. Thus, qualified engineers, with inherent inclinations for doing their best, will have the means at their disposal for achieving excellence in results.

The foregoing concepts will become a reality because the members of each engineering team of every working unit—city, county, State, federal, and consulting engineering firm—will be using aerial surveys. The aerial surveys will include the taking and use of aerial photographs by photographic interpretation and photogrammetry, including associated ground control surveys, for accomplishing the essential engineering and related work, and the factual illustration of problems and their solutions. Each use of aerial surveys will be made when and where advantageous and beneficial. This will occur in each engineering and related phase of planning for and locating, designing, constructing, using, maintaining, and improving facilities, including highways, according to need.

To get better insight into why this will be, let's first review the qualifications for and the significant phases wherein engineering use and acceptance of aerial surveys will become routine. In so doing, it will not be possible to distinguish specifically between what is and what will be, because there are no sharp and easily-defined dividing lines. Second, let's see what the acceptance and use in the future is likely to be for aerial surveys in highway engineering.

Specifically, the use of existing techniques will increase, changes in educational requirements will occur, and new technological advances will be made and accepted.

Qualifications

For attaining successful professional accomplishments, it is axiomatic that a broad background in engineering is essential—a background obtained by completing appropriate academic courses and by getting ample practical experience. Today the background must be more than the engineering education and experience that are often defined. The background should include education and experience in all phases of surveying on the ground and from the air.

Creative engineering consists in changing attributes and qualities to fulfill new requirements. Achievements can be attained by transferring attributes and qualities from one thing to another, but only after the facts regarding the things to be changed are known; hence the need for engineering surveys. Whenever engineers are coping with the consequences and the continuing work of the forces of nature (past, present, and future) the surveys can best be made, for the most part, from the air. Examples of nature's work are the ground structure, soils, topography, drainage, vegetation, and climate. Equally significant are problems confronted where existing, probable, and possible land uses of all kinds are of concern. All of the foregoing is inherent in each stage and phase of engineering, including the planning, location, design, construction, use, maintenance, and improvement of highways. Consequently, both education and experience in surveying (aerial and ground) are among the qualifying requisites for completing civil and highway engineering work.

Surveying

As soon as the foregoing qualifications become accepted practice among highway and civil engineers, many new or nearly new surveying techniques and procedures will become routine.

Accordingly, let's consider what surveying will be like in the future. It is not always possible to consider each surveying technique, procedure, and new development in chronological order within the sequential stages of engineering a new facility—such as a building or structure, a canal, a pipeline, a telephone line, and electric power transmission line, an airport, a railroad, or a highway. Nor is it feasible to attempt to classify the surveying techniques, procedures, and developments according to their significance, effectiveness, efficiency, economic advantages, and ease of use as compared with former practices. That which follows should not be construed to signify that one technique or procedure is more important, useful, or valuable than another. Each has its place, its unique and indispensable position in professionally accomplishing effective engineering.

Determining past and present land uses (and ascertaining potential and probable future land uses for planning purposes, and for estimating traffic demands including the number of vehicles by type which highway capacities should be designed and constructed to serve) will all be accomplished through appropriate use of aerial surveys to augment and to supplement other techniques and procedures. Employment of aerial surveys to determine pertinent details for evaluating the economic impact of highways on each class of land use—existing and potential—will become routine.

In conventional surveying practice, traverses and bench mark level circuits for highways, property surveys, and other engineering purposes, have had their beginnings and endings on some manmade or natural objects. Neither before the survey was undertaken nor after it was completed were the geodetic positions (horizontal and vertical) known. The horizontal and vertical dimensions between points of the survey have been obtained, and only relative positions could be determined through their use.

For engineering and construction purposes, and for establishing or delineating property boundaries, future surveys will originate and close on *geodetic survey points* monumented in the ground, the exact positions of which are known and permanently preserved. For the origin and closure of all horizontal measurements, the monumented geodetic points will be identified, and their positions defined and used in a plane coordinate system. Each system of plane coordinates used in precision mapping for engineering design and for cadastral purposes will be on a datum where the differences between distances measured on the ground and distances determined from plane coordinates on the maps will not be larger than the differences (called "errors") acceptable in basic control surveys. For vertical measurements, the monumented geodetic bench marks will be identified by their elevation with respect to the established sea level datum. For making the exacting ties of each survey to such control, the geodetic markers and bench marks will be close to and accessible from each survey project because of the density of monumented points in the network of basic control surveys. In actuality, this practice will result in each appropriately monumented engineering and cadastral survey becoming an extension and integral part of the national network of control surveys.

The entire nation will be topographically mapped at the scale of 1:24,000. Succeeding mapping programs will be concerned primarily with updating maps in areas of continuing and rapid change, and with compiling larger scale topographic and other essential maps. Each urbanized area will be mapped in detail both photographically and topographically, and extensive planning and transportation system maps will be kept up-to-date in a program of successive revision. Photographic details converted from perspective to orthographic position will be retained and used in lieu of line-planimetry for both planimetric and topographic maps. Such will be more feasible, both technically and economically, because of advances in automation.

All engineering surveys will encompass the combined use of both ground and aerial methods. The ground survey will include, to varying degrees, the usual methods employed in the past, although the use of electronic distance measuring instruments and precision angle measuring instruments will become more commonplace. All measurements will be recorded automatically in a form suitable for acceptance by electronic computers which will make the essential computations and adjustments. Each type of the numerous precision photogrammetric instruments will have an effective and efficient place, according to the type of measurements being made and mapping done—just as a pickup truck, a dump truck, a carryall scraper, a power shovel, and so forth, has its separate and effective use on construction projects. Added to the use of aerial photography of the usual black-and-white and color types will be infrared photography of the black-and-white and color types, infrared imagery of the thermal sensing measurements of heat radiation, and radar photography. All of these techniques will be employed in obtaining essential qualitative information and quantitative data.

As the engineering work is done, photographic interpretation will be accomplished routinely for all phases and stages of the work. For improving results and facilitating the interpretation, photographs from various emulsions (taken with appropriate filters, depending on needs, to obtain better contrast and more detail) will be readily available. Such photography will be supplemented as necessary by infrared imagery and radar photography.

The classes of survey for which all of such techniques will be employed are numerous. Among the survey classes are: traffic; soil; position identification, and quality and quantity classification, of sources of suitable construction materials; hydrology; compila- of essential maps of drainage, geology, archaeology, vegetation, land use, and ownership; precision compilation of basic photographic, planimetric, and topographic maps; measurement of profile and cross sections; and measurement of X, Y, and Z dimensions at scales as large as from 1:1,200 to 1:240 for engineering and cadastral uses. The availability of large-capacity electronic computers also makes the digital terrain model methods (supplemented by photographic interpretation) effective for these purposes. Included will be measurement of excavation, embankment, and other quantities—during construction and after completion—for the determination of payments to construction contractors.

Before and during construction the positions for slope stakes, and other construction stakes on the ground, will be established using aerial surveying techniques. The position for right-of-way lines and structures will be similarly established. Each establishment will be based on positions determined during design through the use of data obtained by aerial surveys.

Inventory and condition surveys will be made routinely by photographic interpretation using aerial black-and-white photographs, color infrared photos of black-and-white and color types, and infrared imagery, and employing a combination of photogrammetric and electronic measuring techniques. Programs for maintenance and improvement will be geared to the results of such surveys.

Increased use will be made of auxiliary devices to improve the accuracy and utility of aerial triangulation, and of measuring and mapping. Such devices will consist of improved radio altimeters, horizon cameras, airborne profile recorders, airborne position measuring instruments, auxiliary oblique photography for measuring tilt and height, etc. Lasers will also have their place in surveying on the ground and from the air.

TESTING AND CHECKING

Photogrammetric techniques will be used routinely to measure the sag and/or other bending-moment deflections while materials, structural members, and structures are being tested in the processes of stressing them to failure. Photogrammetric techniques will be applied in testing pavements and all other structures to analyze their stresses and performance while in use, and to determine when failure is impending.

Photogrammetric methods will be employed routinely as the best technique for determining whether or not maps, photogrammetrically made measurements, and ground-survey measurements will require further testing for acceptance or rejection because of either failure to comply with stipulations for accuracy, or failure to be adequate in detail and scope.

Quality and dimensional control during construction, and determination of settlement and deformation of embankments and land slides will be accomplished by photogrammetric methods. Need for repeated surveying of control for successive use of stereoscopic models will be eliminated by use of targets on semi-permanent markers of horizontal and vertical control points outside the limits of construction. Nothing will be overlooked, because correlation and repeatability are assured.

AERIAL PHOTOGRAPHY

The quality of aerial photographic film will be greatly improved with respect to durability and scale stability. Photographic emulsions will be faster and finer in grain, and will force a need for improving the resolving power of lenses in all aerial cameras. To improve contrast and to achieve the best possible photographic recording of details for interpretation and measurement, spectral reflectivity measurements will be made for choosing filter-emulsion combinations. Faster shutter speeds will be possible and the problems of image motion will be greatly reduced. The taking of successive, stereoscopic, aerial photographs of fixed format at scales as large as 1:1,200 for precision work will be easy to accomplish by use of synchronized aerial cameras in one aircraft. Maximum scales of aerial photography for precision measuring and mapping by photogrammetric methods will be limited only by the controlling relief-height to flight-height ratios.

INSTRUMENTATION

The images of aerial photographs, by tone or hue and by contrast and texture, will be translated from their inclusive photographic patterns into an appropriate form for use in electronic computers. Such translation will be done, as desired, whether the photographs are of uniform size (format) or are continuous strip, and whether the photographic emulsion is panchromatic or infrared for producing black-and-white images, or is the usual color or infrared color. By this translation and use through electronic techniques photographic images will be transformed automatically from their perspective positions to orthographic positions, and image contrast will be changed and enhanced as desired. The X, Y, and Z dimensions of the ground, and the objects on the ground, will be measured precisely for electronic computer use of the transformed photographic images.

Electronically, maps and other accurately compiled graphical representations and photographic images will be scanned and data pertaining thereto will be numerically recorded in appropriate form for storage and use in electronic computers. Computer programs will correlate and selectively use the data to solve engineering problems. Among the digital outputs will be cross sections, profiles, volumes of excavation and embankment, inventories, rights-of-way boundary coordinates and areas, traffic information, and so forth.

Precision coordinatographs will automatically respond to digital data from an electronic computer and will accurately delineate all map details, plot profile or cross sections, and accurately portray other dimensional data as desired. The digital data for the delineation of maps and for the plotting of points will come to the electronic computer directly from a photogrammetric instrument. Once in the computer, and before transmission to the coordinatograph, the photogrammetrically-measured digital data will be corrected automatically for lens distortions, for dimensional changes in the exposed photographic film, and for atmospheric refraction; and adjusted as necessary for earth curvature. Photographs of almost any format, focal length, and image contrast will be usable. Stereoscopic models in the photogrammetric instruments may be examined at the instrument or in any remote location by any number of persons situated together or separately. Projection lenses will disappear from newly-developed photogrammetric instruments of the future.

Use of targets on markers of geodetic and other basic control will be commonplace for certainty in originating photogrammetric measurements, and for precision transfer of designed facilities from maps and plans to the ground for construction. Increasingly, more of the supplemental control required for most photogrammetric uses of photography will be ascertained by electronic computer use of photographic coordinates measured with stereocomparators rather than using stereoscopic model coordinates measured with double projection, optical train, and other types of photogrammetric instruments.

Used at will, all new techniques and procedures will not displace the conventional uses of aerial photographs. Instead, these uses will be augmented and supplemented by all subsequent increases in utility of aerial photographs, especially for engineering purposes.

REGISTRATION LAWS

Registration laws for engineers and surveyors will be changed. Both photographic interpretation and photogrammetric uses of photography will be recognized and accepted as surveying for both engineering and cadastral purposes. Surveying will be acknowledged and accomplished as a professional service. Cadastral surveying and the preparation of property plats, as well as the reconciliation of differences, will be done photogrammetrically.

CONCLUSION

Aerial photographs and photogrammetric instruments will not become obsolete. Refinements and increases in variety and uses will continue. The range in scope of their uses will be limited only by the imagination and initiative of all specialists who will benefit from using aerial photographs and photogrammetric instruments in their work. Improvements in photographic emulsions, film bases, aerial cameras, and photogrammetric and ground surveying instruments are essential for increasing the detail, accuracy, and scope-of-use of aerial surveys for engineering purposes.