AERIAL PHOTOGRAMMETRY STREAMLINES OHIO'S HIGHWAY PORGRAM*

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Introduction

The application of aerial photogrammetry in the solution of highway civil engineering problems is a formidable subject which has received considerable attention and varied treatment during the past several years. Quite naturally, the tendency of most of the established photogrammetric organizations is to unleash their learned staffs and expensive equipment in the pursuit of the more technical and tedious endeavors. Meanwhile, many of the potential passengers of this "photogrammetric express" remain somewhat perplexed concerning the origination, route, intermediate stops, type of accommodations and price for such a service—or, perhaps for a "toonerville" of their own. It shall be, therefore, the prime purpose of the greater portion of this paper to dwell upon the basic techniques and procedures of applied photogrammetry, with the thought that it may be of value to individuals or groups interested in a factual recording of investment versus achievement in this type of endeavor.

Ohio's Department of Highways has, to a degree, developed such a photogrammetric "streamliner" primarily as a result of the highway demands imposed by the construction of a huge atomic energy installation in the southern part of the State. This, coupled with the anticipated changes in traffic impacts and patterns as Ohio's Turnpike progresses, provided the required impetus to promote the photogrammetric preparation and contract sale of a complete set of construction plans for a 4.121 mile section of two-lane highway relocation adjacent to the atomic city. This photogrammetric milestone was achieved just seven years after the organization was established.

However, this "streamliner" within a civil service structure was developed on a "rail-by-rail" and "coach-by-coach" basis with each addition or modification requiring proven justification. This progressive series of expansions and achievements will be mentioned briefly in this paper.

In March 1946, Ohio's Highway Department initiated its aerial photographic program with a surplus camera and a single-engine aircraft, an engineer-pilot, the author of this paper, and Ray E. Rowe, a photographer with aerial and laboratory experience. This eager but bewildered pair was termed the Aerial Surveying and Mapping Unit—and I use the term rather loosely! It is proper at this time to pay tribute to two former Departmental Engineers, Assistant Director Edison W. Ellis, and Geometric Design Chief, Ralph J. Lehman, for their vision and strength of conviction which surmounted the opposition to such a supposedly "ridiculous" endeavor.

The embryonic organization of 1946 has continued to expand its personnel and capacities to a highly trained and specialized level. As the title implies, the existing Aerial Engineering Section enjoys complete justification as a major facet of the Bureau of Location and Design. It is composed of four basic Units which will be described in the order in which they were established.

Organization of the Aerial Engineering Section

The first, or Flight Operations Unit, under the supervision of John B. Evans, serves a twofold purpose. The primary function is providing all types of aerial photography from the plastic nose-section and oblique cabin-hatch of a converted Beechcraft T-11. Secondly, this ship's all-weather equipment and instrumentation provides executive transportation during the interim periods. Although certain types of aircraft would provide slower photographic speeds at lower altitudes, the over-all performance flexibility of this particular ship is ideal—especially in its ability to reach widely separated and highly diverse projects of high priority on the same photographic day.

* Paper read at the Semi-Annual meeting of the Society in Rochester, N. Y., September 25, 1953.

The second, or Photographic Laboratory Unit, under the supervision of John E. Rowe, serves the critical function of providing all types of high quality, photographic products upon which depend the degree of success of the ultimate photogrammetric interpretations. In addition to the more or less routine developing and printing procedures, the Unit must produce the closely controlled glass positives for use in the stereoscopic plotting apparatus. It is obviously impossible, within the scope of this paper, to develop this subject properly; but too much emphasis cannot be placed upon the critical importance of optimum photographic products produced through exacting habits of laboratory workmanship.

The third, or Photogrammetric Unit, under the supervision of Lloyd O. Herd, serves the primary function of assembling quantitative engineering information through the interpretation of the photographic products. Contact prints, indices, mosaics, controlled enlargements and medium scale (1″ to 200′) topographic maps of 5 foot contour interval have become routine production items for location analysis applications.

Large scale (1″ to 20′) topographic maps of 2 foot contour interval are produced for site maps and other detailed studies. Plans and profiles, cross-sections, drainage data and hosts of other precise information evolve from the closely controlled plotting methods.

The fourth, or Location Analysis and Plan Preparation Unit, under the supervision of James E. Guthrie, serves the singular function of locating and designing highways by aerial photogrammetric methods. It is within this Unit that constant exploration is conducted towards achieving the maximum potentials of photogrammetry in the solution of highway engineering problems.

The previous description, in addition to the basic function of providing organizational information, serves two important purposes in the expansion of this paper. First, it defines a logical sequence of expansion. Second, analyzed in progressive combinations, it serves as an index to the investment in personnel and equipment required to perform certain photographic and photogrammetric accomplishments. For example: the first Unit provides transportation and exposes photography, the combination of the first two Units provides an additional abundance of reconnaissance information, the combination of the first three Units provides all types of topographic maps and precise surveying data and the combination of all four Units provides construction plans ready for contract sale.

Aerial Photogrammetric Stages of Highway Engineering

Mr. William Pryor of the Federal Bureau of Public Roads, in his excellent paper entitled "Photogrammetry as Applied to Highway Engineering"* presented in 1951 at the 17th Annual Meeting of the American Society of Photogrammetry, identified in detail the engineering stages involved in the location, design, construction and maintenance of highways, with emphasis directed towards the tremendous Mississippi River Parkway Project. Ohio's Highway Department is restricted economically and geographically to the consideration of much smaller projects; but the fundamental considerations of reconnaissance, surveying, design and construction are practically identical in nature with those outlined by Mr. Pryor. In fact, these fundamental considerations appear to be valid in the location and design of many types of transportational roadbeds, power transmission lines, fluid conduits, conveyor belts and other culture which must rest upon or in the crust of the earth.

Ohio's Aerial Engineering Section in the most fundamental analysis considers a typical project to be separated into two major Stages; first, the Location Analysis Stage with its phase components of reconnaissance and surveying; and second, the Design and Plan Preparation Stage requiring highly accurate, contributing engineering data. Of course, the know-how of design and plan composition is an absolute prerequisite to a successful conclusion and this is not extensively discussed in this paper. Conversely, emphasis is placed upon the production of the conventional engineering data derived by "unconventional" methods, allowing, of course, that photogrammetry can be termed an "unconventional" method.

The Location Analysis Stage

The problems involved in this Stage, in

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which Reconnaissance and Surveying Phases are involved, are particularly adaptable to photogrammetric solutions.

THE RECONNAISSANCE PHASE

The reconnaissance phase of a typical project is approached with a few established facts: such as the approximate terminal points, as governed by economic and phase construction restrictions, and the existing and extrapolated traffic data which define reasonable latitudes of design criteria. The singular problem of this phase is to select a route-band which is superior to any other alternate. It is extremely important to realize that this evaluation is strictly *qualitative* in character; and, despite the subsequent difficulties which may be encountered, firm conviction and proof must be established that the difficulties involved on any other alternate route-band would be greater. The resulting selection of this optimum route-band by photogrammetric methods is simple, rapid, inexpensive and defies comparison.

Two sets of small-scale aerial photographs, flown in summer or winter at a scale of 1″ to 1,600′ with a 60 per cent running overlap and at least 40 per cent sidelap, are procured for coverage of the entire pertinent area between the futuramic terminal points of the project as it might be considered scores of years in the future—not the terminal points defined by current considerations. The width of this coverage should be adequate, probably 50 per cent or more in comparison to the length. An uncontrolled mosaic is prepared from one set of glossy prints. Controlled mosaics seldom justify their cost in this qualitative comparison of route-bands. Simple stereoscopic analysis of one set of semimatte prints augmented, perhaps, by field inspection will result in the selection of all feasible route-bands of approximately 1800 foot width which would serve a highway location between the widely separated, futuramic termini. At this time, on the majority of projects, stark economic reality focuses attention to a segment of the existing route upon which physical conditions and statistical traffic data indicate a priority for initial attention. Correlation of this economic factor with the requirements for the maintenance of traffic results in the selection of satisfactory termini for a project-section which will impose a minimum penalty to the economic and geometric continuity of additional sections and will tend to allow for salvage of the project's alignments and structures in the future.

These adjusted termini will undoubtedly reduce the number of the alternate route-bands to three, or less; and, perhaps, to the final selection at this time. Existing aerials, such as the 1″ to 1,666′ U.S. Department of Agriculture photographs may be available for this study, or the services of private companies can be procured, or your own airplane, camera and small photographic laboratory will represent very little investment, amortized over many such projects.

However, should feasible route-bands remain for more detailed comparison, the following techniques may be used in the continuing evaluations:

1. Field inspection often resolves the decision because, after all, it is the conventional method which has enjoyed universal acceptance.
2. Enlargements of the original photographs are very useful; for example, in the comparison of right-of-way costs. However, beyond four diameters, their increased utility is doubtful.
3. Existing topographic maps, such as the U.S.G.S. sheets, are also very useful. Their utility is increased immensely if copied and enlarged photographically, on a transparent film base, to serve as an overlay at the same scale as the mosaic. A transparent overlay of this type can be used concurrently with the stereoscope. This procedure adds a quantitative factor to the study, eliminating the tedious and time consuming process of transferring information proportionately between diverse scales or from an opaque topo enlargement at the same scale as the mosaic. The inaccuracies in any map, or in its reproduction, do not penalize one route-analysis more than another; and are entirely satisfactory as an impartial tool in this reconnaissance comparison.
4. Pressure altimetry, in almost any degree of applicational accuracy, can rapidly provide comparative information between the alternates at very little cost. Barometric profiles and

cross-sections are very suitable in this phase of the work.

5. Topographic maps at a scale of 1" to 400' can be prepared from the original photography and are, of course, the acme of reconnaissance tools. Although topographic maps are seldom required in these comparative studies, their production in a well equipped organization is rather inexpensive if the accuracy specifications are compatible with their intended use for route-band comparisons. Good barometic altimetry can provide satisfactory vertical control for this work. At this point one of the chief advantages in the use of a stereoscopic plotter, directly in the location study, becomes evident. The plotter furnishes a three dimensional projection which can be used as if it were a scale model of the terrain. Required horizontal and vertical measurements can be made as the need arises. In this manner proposed locations can be investigated without additional field work; and the merit of the proposal can be proved or disproved by plotting plans, profiles and cross-sections along the suggested line. The large drainage areas are also identified and computed at this time.

In summation of the Reconnaissance Phase of the Location Analysis Stage it is important to remember that the foliage of summer photography does not detract heavily from its use, that the mechanics of this Phase are extremely simple and that the investment in time and equipment is negligible considering the tangible and tranquil assurance of knowing that continuing investigations will be directed towards the best possible engineering and economic solutions. It is the considered opinion of the author of this paper that this most basic and economical phase of aerial photogrammetry represents one of the most spectacular applications of this fruitful alliance of aviation, photography and optical physics.

THE SURVEYING PHASE

The problems involved in the Surveying Phase of the Location Analysis Stage are also readily adaptable to photogrammetric solutions. The scope of aerial surveying and mapping is a boundless subject restricted, at any one particular sitting, to a brief discussion of one of its particular facets. By necessity then this paper will confine its opinions to the surveying and mapping of a route-band approximately 1,800 feet in width, within which a modern highway is to be constructed. Of course, this 1,800 foot strip map consideration coincides with the width of a route-band so easily identified by photogrammetric reconnaissance.

It appears imperative at this time to hesitate in the progressive development of this subject and to face the reality that, if the surveying and mapping is not of purely academic nature, sufficient permanent monuments beyond the work-limits must be established at some time prior to construction for the purpose of referencing the precise location of the highway on the ground. Simple logic dictates that the best map ever produced is worthless if its specific location on the surface of the earth cannot be reestablished.

Experience has demonstrated that criticisms of most aerial surveys do not stem from photogrammetric inadequacies; but, strangely enough, have their roots in poor or incomplete ground surveys. This is especially true in highway surveys, which are often based on the unclosed traverses available from isolated sections of existing road plans. It is trite, but true, that the photogrammetric "chain" can be no stronger than the ground control "hook" upon which it hangs.

A recommended procedure for the provision of a rigid framework, into which further detail can be integrated, is as follows:

1. Initial reference to the Army Map Service Catalog of horizontal positions, in order to capitalize the benefits of existing control.
2. Closure of all important route-surveys.
3. Computation of all surveys on the State Plane Coordinate System.
4. Monumentation, on a permanent basis, of all important surveys.
5. Monumentation, for the duration of the construction stage, of a sufficient number of intermediate points which can be occupied by an instrument in providing for azimuth reference.

It should be observed that the previous five steps are necessary for any good survey, photogrammetric or otherwise.

Assuming that the previously described procedure is applied, and that photogrammetric survey methods are to be used, the additional ground control required is rather negligible if secured concurrently with the temporary and permanent monumentations.

At least three of these ground control points must be available within the overlapping portion of each pair of aerial photographs soon to be exposed. These points must be visible from the sky and marked with white sand, paint or lime, preferably in the form of crosses whose legs will appear at least 0.01 inch long on the contact image of the photography. Incidentally, these crosses assist the flight crew in the exposure of one strip of properly aligned photography at a contact scale of 1″ to 200′ along the 1,800 foot route-band. More importantly, the crosses are visible on the resulting diapositives (or glass prints) thus, enabling the stereoscopic plotter operator to produce a highly accurate route-map at a scale of 1″ to 50′ with a 2 foot contour interval. Photographic enlargements at a scale of 1″ to 50′ also result from these mapping exposures.

Before progressing from this Surveying Phase to the Design and Plan Preparation Stage it is opportune to mention that site maps have been in quantity production by Ohio's Aerial Engineering Section for several years. These site maps for bridges, intersections and other detailed studies result from one pair of photographs, one-half day's work of a two-man field crew and one day's work of a Kelsh plotter. These 800 foot 1,200 foot maps, at a scale of 1″ to 20′ with a 2 foot contour interval are produced for less than the cost of placing a five-man survey crew in the field for one day.

It was in fact the quantity production of these highly accurate and amazingly cheap site maps that sponsored the successful investigations and procedures which have allowed Ohio's photogrammetric organization to enter the realm of design and plan preparation which has been confined to the more conventional techniques for so many, many years.

Design and Plan Preparation Stage

Despite the fact that the production of precise maps had formerly been considered the ultimate of photogrammetric potentials by the majority of the industry, Ohio's Highway Department has recently proved that this is not true. The production in early 1953 of a complete set of construction plans for a 4.121 mile section of a completely relocated highway was followed immediately by the competitive award to a private contractor for the construction which is now in progress. This fact demonstrates that the horizons of aerial photogrammetry have not yet been fixed.

This progressive step is primarily the result of one simple, plotting fundamental which is that static interpretation of point-elevations is at least twice as accurate as the moving interpretation of contour lines. Furthermore, successive photogrammetric point-elevation determinations are entirely individual in character; thereby eliminating cumulative errors so common to field survey methods.

This point-evaluation procedure leads to the production of profiles, cross-sections, determination of earthwork quantities detailed drainage designs, intersection designs and the immediate quantitative availability of miscellaneous field conditions. For example, in the determination of profiles and cross-sections, the center line is first drafted on the stabilized plotting board and perpendiculars are erected at predetermined intervals, such as those at the centerline stations. The steroscopic plotter operator then determines the point-elevations along these cross-section lines at any break in the ground form; not, necessarily, at specific lateral distances. All breaks in ground-form along the profile are also recorded. Furthermore, the operator plots cross-sections at any intermediate station which he deems necessary for the contribution of additional, pertinent information. Incidentally, great savings in time and in the elimination of conversion errors have been accomplished by the use of a mechanism which translates the Kelsh plotter parallax readings directly into decimal portions of a foot. This was the contribution of Mr. Stuart Bolin, a Section Photogrammetrist.

Summation of the accuracy potentials indicates that, under conditions of minimum ground cover in mapping photography, point-elevations can be consistently established at 0.001 of the contact scale. In this example, readings of 0.20 of a foot are available from the 1″ to 200′ photography exposed with an old K-3B, 8.25 inch focal length camera. The relatively high speed of the twin-engine Beechcraft for low altitude mapping does not enhance the accuracy potentials in this type work. Possibilities for improvements in precision will be discussed in the ensuing portion of this paper, but it bears repetition to observe that commensurate horizontal accuracies must be available in the transfer of this information to the ground, or from the ground to the map.

Recommendations for Future Progress

Ohio's Aerial Engineering Section, guided by the progressive leadership of the Location and Design Bureau's K. L. Rothermund and E. S. Preston, intends to exploit the following areas for the continuing improvement of photogrammetric interpretations and plan preparations:

1. Development of a mechanism which would automatically record tape-readings of the location and elevation of Kelsh point-determinations.
2. Reduction of flight speeds at lower altitudes; or perhaps, stationary camera platforms in the sky.
3. Optimum photography available from improved cameras with increased cycling and shutter speeds; or from convergent axis exposures.
4. Crystallization and standardization of techniques and products.
5. Standardization of the consumer's procedures, especially in the twelve decentralized highway engineering offices of the State.
6. Application of grade-contours, so easily available from stereoscopic work.
7. Continuing reduction of the cost of plan preparation from the existing 2.5 per cent to a figure of approximately 1.0 per cent of the contract construction cost.
8. Increased application, in public relations, of oblique aerial photographs with artists' conceptions of the proposed highway improvement integrated into the image area.

Conclusion

Obviously the ties, rails, coaches and locomotion of the current "Photogrammetric Express" could never have been assembled without the scientific studies and academic efforts of the photogrammetric scholars; neither can future progress be accomplished without their efforts. However, accommodations are afforded to everyone in the remarkable technical assistance available from photogrammetry's most simple and basic applications.

Do not be awestricken by the relatively complicated mechanisms of this "streamliner." Buy your ticket to increased efficiency with the confidence derived from a familiarity with, and the use of, the operational capacities of applied aerial photogrammetry.

ANNUAL MEETING

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