TEN YEARS OF DEVELOPMENT IN PHOTOGRAMMETRIC EQUIPMENT AND TECHNIQUES

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AN EXPOSITION intended to give a complete account of the development of photogrammetric equipment and techniques through the last ten years would require months of intensive research and demand presentation in nothing less than a tome. Several approaches to the subject would be pertinent. A strict factual account chronologically exact would consider item by item in proper sequence the improvement of equipment during the past decade. Dates would abound; facts would be presented in a way which permitted no debate. Such would be the documentary approach. Or, a logical explanation would attempt to trace trends in equipment development and technique improvement. Objectives would be investigated; means and ends would be examined. Opinions would be offered and healthy debate encouraged. Such would be the rational approach.

The author prefers the latter method. Technical and mathematical discussion will be avoided. These aspects fall within the scope of the "Manual of Aerial Photogrammetry" soon to be published by the Society. No rigorous chronology will be maintained. Instead, the development of a specific type of photogrammetric equipment will be traced through the past decade to the exclusion at the moment of all other items. What were the designers seeking? Did they realize their objectives? Did the mathematician solve the problem in the most practical manner? Or would the utility of his analysis have been enhanced by introducing allowable approximations? These and other questions are answered in noting the growth of an instrument or the derivation of an analytical method. For detailed description of photogrammetric instruments, the reader is referred to technical literature and to previous issues of "Photogrammetric Engineering."

Clarity in discussing the development of photogrammetric equipment and techniques is achieved by dividing the subject into various categories based upon the principles of design or the methods of analysis involved. While not honoring the classification axiom of mutual exclusiveness, the following groupings will be considered valid for the purposes of this article; namely, analytics—graphics—mechanics, optics-mechanics, optics and auxiliary equipment and materials. The last category is in no way parallel to the first three, but it must be included to round out a treatment of the subject. Each of these phases will be considered in its pre-, present and post-decade condition. A consideration of whether a photogrammetric problem is solved analytically, graphically or mechanically, or comment on whether a particular instrument is of optical or optical-mechanical design—each will be presented by a statement of status at the time of the Society's founding, growth during the ten years past and prospects for the future as indicated by present trends.

ANALYTICS—GRAPHICS—MECHANICS

Ten years ago all the mathematical foundations of photogrammetry were laid and the edifice itself had assumed large proprtions. The vertical aerial photograph to mention the simple case is a perspective projection and as such possesses properties which are quickly reduced to formulae by the analytic attack of the mathematician. A classic problem is resection in space from known ground control points and from measurements on the photograph to determine the exposure station. Its academic solution was no mystery to the geometers who pioneered in the field of photogrammetry. However, its practical solution within the last decade is a definite achievement and the analytical method of bridging carries the computational procedure to unprecedented refinement. There are those photogrammetrists who doubt that the application of solid analytic geometry to space resection is practical and to prove their point have devised methods to compute photo tilt and flight height without recourse to strict application of geometric theorems. The principle of the scale point and equivalent elevation have been evolved during the past decade. Such concepts are the results of the efforts of what mathematicians call algorists—those individuals who discover no fundamentally new principles but who intuitively derive new solutions to old problems.

The investigation of the oblique photograph also falls within the scope of monoscopic analysis. It, too, is a perspective projection but its geometry is conditioned by the natural phenomenon of atmospheric refraction. This fact serves only to modify the computations which are solved by an adaptation of the formulae for the solution of the general case of exposure orientation. The aerial photograph in passing from the vertical, through the low oblique to the high oblique undergoes a transfer of strength in orientation from the horizontal to the vertical. The vertical photograph yields a strong determination of planimetry while the high oblique gives an accurate fix of altimetry. As in the case of the vertical photograph practical photogrammetrists avoided the laborious computations by applying a method of successive approximations to solve the space orientation of obliques.

Mathematical methods of solving the problems involved in stereoscopy were well advanced at the time of the Society's founding. The behavior of the model under various conditions of relative orientation was analyzed and the nature of the warpage surfaces were formulated. Such investigations were necessary to ascertain the accuracy of stereoscopic plotting instruments. The analytical approach was to consider the correctly oriented model an aggregate of an infinite number of homologous ray intersections. Each pair of rays must define an epipolar plane. Departure from "epipolarity" was studied to determine the resultant warp in the model. Methods of stereoscopic analysis have undergone no radical change in the last ten years.

During the last decade analysis has been used to solve problems incident to the operation of photogrammetric instruments. Thus aero-triangulation has been adjusted by least squares. The warpage of multiplex models due to lens distortion has been calculated to permit compensation in tracing. Another contribution of mathematics to the solution of instrument plotting problems is the method utilizing the properties of verticals and obliques to strengthen multiplex extensions. By using simultaneously exposed verticals and forward obliques a method of computation has been devised whereby the height determination of bridges are considerably strengthened. The properties of verticals and obliques previously discussed are thus exploited.

Graphics is a logical outgrowth of analytics. Frequently, the two methods are combined to devise a more practical technique. Graphical methods usually spring from the need for rapid solutions of repeating problems. Frequently, calculations are tedious and needlessly time-consuming. Simplification is achieved by drawing lines instead of writing their equations. For example, radial triangulation can be computed by utilizing comparator measurements from aerial photographs, but a far more practical procedure is to assemble hand templets.

Graphical sketching of map detail from high obliques by use of the Canadian perspective grid and the graphical method of the Survey of India for surveying by means of oblique photograph are instances of the geometrical procedure. Other constructional methods have been applied to determine the tilt of vertical exposures by working with "upright planes" or developing the pyramid formed by the perspective center and three or four well distributed control points.

In the analytical method lines are defined by equations; in the graphical procedure, by their geometric representations on paper; and finally in the mechanical process, by a lineal, a metal arm or a slot cut in a templet. The mechanical method of solving photogrammetric problems is usually occasioned by the need to eliminate much of the human factor from the graphical techniques. Radial triangulation by means of slotted templets as developed during the last ten years is cited as clearly demonstrating the transition from graphics to mechanics. Greater rigidity is assured in an assembly of slotted templets since it is the substitution of an aerial for a linear solution, if a strip of hand templets is assumed to be linear. The U. S. Geological Survey spider templets are laid in a similar fashion. These devices demonstrate the characteristics of the mechanical method—elimination of the human error, rigidity, speed and ease of adjustment. The Rectoblique Plotter developed for use in the trimetrogon system of compilation is a mechanical solution of a trigonometric equation. Other devices may apply geometric theorems. The development of mechanical methods for the solution of photogrammetric problems during the past ten years can be attributed primarily to the need for speed in processing the immense volume of photography produced during this period. The mass production of maps and mosaics could be accomplished in no other way.

Future developments in analytics, graphics, and mechanics as applied to aerial photogrammetry are rather difficult to suggest particularly with reference to the first two techniques. No doubt the algorists will direct their talents toward the discovery of new computational methods. Such contributions would involve no new concepts. As suggested by an advocate of analytical methods, the efforts of mathematicians new to the field of photogrammetry might demonstrate the application of a new branch of the science. For example, rays from the perspective center to control points have direction and magnitude and are therefore vectors. This fact suggests the possible use of the methods of vector analysis. Mechanical devices will no doubt be designed to solve hitherto neglected trigonometric equations by ingenious use of lineals and linkages. Such devices will also be improved structurally by increasing use of plastics which materials will mean added utility because of transparency and lack of weight.

Mechanics—Optics

Combinations of mechanical and optical elements are considered to be the basis of all photogrammetric plotting devices from simple monoscopic viewers to complicated universal stereoscopic plotters. It might be surmized that the stereo-plotting instruments in use at the time of the Society's organization were generally of foreign make. With one outstanding exception, the Brock Process, all plotters of the universal or near-universal type were manufactured outside the United States. This is reasonable. No instruments, no practitioners, no American Society of Photogrammetry. Therefore, an awakening to the value of photogrammetric methods, the founding of the Society and the beginning of instrument development in this country were contemporaneous events. It is true that terrestrial photographs were used for survey purposes for some time prior to 1934, but precise phototheodolites were not American made.

Ten years ago the fundamental designs of the following foreign instruments were already established: German Stereoplanigraph, Aerocartograph and Multiplex; English "Big Bertha" and Stereogoniometer; French Stereotopograph and Galtus-Ferber scintillating plotter; Swiss Stereo-Autograph; Italian Photocartograph. These masterpieces of instrumental design were the ingenious assemblies of optical and mechanical systems. All had as their objective the complete exploitation of a stereoscopic pair to plot an accurate map. Some were more theoretically sound than others. Generally, improved design demands the substitution of rays for lineals. The instrument which applies this principle, the stereoplanigraph is found to be the most accurate and versatile. Another example of the substitution of rays for lineal is the method of anaglyphic or double projection demonstrated by the Multiplex Aero Projector. This is a photogrammetric instrument which clearly demonstrates the principles of stereoscopic reconstruction.

The present day Multiplex is a modification of the originally imported model. Its improvement is the outstanding example of American activity in the field of photogrammetric equipment design. In fact, the modified Multiplex is typical of the accomplishments of American designers in the field of universal plotting machine construction, namely, the improvement of an existing instrument. Sturdier construction, closer tolerances, compensation in the printer for camera lens distortion were some of the improvements to this instrument which has become standard equipment for all stereomapping units in the Corps of Engineers. Further modification has made possible the plotting of maps from trimetrogon oblique exposures.

Original design of mechanical-optical plotting instruments in the United States has been generally confined to monoscopic or the simpler stereoscopic devices. Examples of the former are the photo-alidade employing telescopic examination of a single photograph, the single eyepiece high oblique plotter applying the pinhole principle and the sketchmaster posing as the modern version of the camera-lucida. Simple stereoscopic plotting instruments designed in America include the stereocomparagraph, KEK and Soil Conservation Service plotters and the Rectoblique Plotter. Simplicity, compactness and low cost are characteristics of these devices. With simplicity goes lack of theoretical correctness. Thus, the stereocomparagraph gives only a perspective drawing. The KEK and SCS plotters give an accurate orthographic drawing only for the case of a vertical stereopair. When tilt is present these instruments demonstrate the shortcomings of all devices which are an attempt to circumvent the conditions which must be met in designing a universal machine. There is a semblance of relative orientation but internal perspective is not recovered. Such deficiencies, however, do not detract from the utility of this type of equipment given excellent photography and a multiplicity of ground control. Perhaps their most useful application will be to supplement an instrument such as the Multiplex which can accomplish control extension and provide a frame work upon which to fix the model by model production of the simple plotters. Truly representative of American inclinations in the field of photogrammetric equipment design is the stereo-plotter being built by the U. S. Coast and Geodetic Survey and designed to utilize the composite photographs produced by this agency's nine-lens camera. This device is a Brobdignagian version of the stereocomparagraph modified to permit orthographic drawing from rectified prints. Thus, this instrument is the application of an old principle on a grand scale. Another example of American genius for improving upon existing equipment is the modified Multiplex which outperforms its European predecessor. The purely native plotting procedure, the

Brock Process, is the systematic solution in specific steps of the sequence of fundamental problems encountered in passing from the photographs to the orthographic map. As such, it employs equipment basically simple, but designed to gain full utility from its simplicity and production line characteristics. American designers have, therefore, usually directed their efforts to the improvement of existing equipment or the construction of simple instruments. No elegant combinations of interminable optical trains, involved linkages and complicated drawing mechanisms are found in their devices.

Perhaps this avoidance of the universality of foreign instruments is indicative of future trends in the design of optical-mechanical equipment, that is, toward simplicity of design. The military need for compact stereoplotters which will withstand rough usage in the field and permit the use of contact prints may well result in the production of simple devices utilizing new combinations of mirrors, lens and prisms. Efforts to stabilize cameras gyroscopically to produce essentially vertical photographs, if successful, would result in the simplification of stereo plotting machines. Photographs possessing tilts less than 15 minutes would probably lend themselves to horizontal extensions of accuracy approaching 1 to 3,000 without the use of elaborate plotters. A revolutionary improvement in stereoscopic instrument design might result from the application of electronic scanning of models to eliminate the human factor. It might be possible, and this is pure conjecture, to devise a densitometric system whereby the identity of conjugate images in a stereopair is verified photo-electrically to be recorded with a minimum of operator effort. Other improvements in instrument construction will no doubt be realized by using new materials such as lighter metals, plastics and improved optical parts. Furthermore, it is not impossible that entirely new principles might be demonstrated by unique combinations of optical and mechanical parts.

Optical

The lens is the heart of photogrammetric equipment. Without a sound heart the body is unhealthy. Without a well designed lens, the exact negative could not be exposed and the measurements taken therefrom would be useless for mathematical analysis. If lens design had not kept pace with technique development photogrammetry would not have attained the status of an exact science. Other precision optical elements which play an important part in the design of photogrammetric equipment are prisms and mirrors. All of these elements whose designs are governed by optical laws have undergone improvement by the use of more versatile materials. Specific fixing of optical constants in the manufacture of glass and grinding techniques permitting the shaping of aspheric surfaces are factors which have combined to give the lens designer increased control over the passage of light through his product.

Investigation reveals that the photographic objectives in use ten years ago possessed angular fields not exceeding 70°. Distortions in precise cameras were negligible. Photogrammetrists were aware of the advantages of wide angle lenses for stereoscopic plotting. But the lens designer was confronted with having to solve the problem of increasing the field while holding distortion to a minimum. Furthermore, he was hampered with falling off in illumination at the edges of the field, in accordance with the "fourth power of the cosine" law. Therefore, until the advent of new glasses and grinding techniques the photogrammetrist had to be satisfied with normal angle objectives. To eliminate the effect of distortion in the aerial camera lens he applied the Porro principle in his plotting instruments. This restriction required the viewing the "aerogram" through the taking lens or one of similar characteristics and increased the intricacy of design. To increase field a multiple lens was employed. Scheimpflug's 8 lens camera of 1904 and Aschenbrenner's of 1926 are examples.

During the past decade the outstanding achievement in optical design is the production of the wide angle lens sufficiently distortion free to obviate application of the Porro principle. The Metrogon lens and its forerunner the Topogon both covering fields in excess of 90° are triumphs of lens calculation. Furthermore, the variation in illumination from the center to the edges of the field of these objectives is kept within the latitude of the film. Development of the compensating lens in the Multiplex reduction printer is an important contribution to photogrammetry. It makes possible the distortion free diapositive which has increased the accuracy and efficiency of the double projection method of stereoplotting. Another step forward is the design of shorter focal length objectives with a resultant increase in resolving power. Since the resolution of film exceeds that of the lens a subsequent enlargement would cause no appreciable deterioration of the image.

Discussion of short focal length lenses leads to a consideration of future accomplishments in optical design. Undoubtedly, even shorter focal lengths will be achieved with an attendant reduction in camera size and an increase in speed and economy. Color photography will place greater emphasis upon the elimination of chromatic aberrations. This new type of photography will require application of polarized light to permit the viewing of a colored model. The future may witness further increase in lens field angles. However, the limit seems to have been approached in the Metrogon unless possible masking within the camera is used to effect an equalization of illumination between center and edge of field. Of course the wider the field of view the more the peripheral parts of the photograph take on the characteristics of an oblique exposure. The disparity between conjugate images in a stereopair may be enough to prevent stereoscopic fusion. Whatever future progress is made in lens design it is certain that the controlling factors will be as always angular field, definition, distortion, character of emulsion, altitude, ground speed, vibration and character of illumination.

Auxiliary Equipment and Materials

The design of all auxiliary photogrammetric equipment should be directed toward the economical production of accurate aerograms for use in any of the devices previously discussed. This necessary precision is primarily dependent upon the construction of the aerial camera which device is essentially a lens properly separated by a cone from its focal plane. The dimensional stability of this cone fixes the calibration constancy of the instrument during its use through extreme ranges of temperature. Camera development during the years prior to 1934 kept pace with lens improvement. The need for precision manufacture was realized and construction did justice to the normal angle lenses then available. As previously noted several multiple lens cameras were produced. Sound engineering was applied in the design of equipment auxiliary to the cameras,—mounts, view finders, intervalometers, orientation devices, auxiliary horizon cameras, film magazines, film flattening devices and shutters. The need for stabilization was recognized with the result that pendulum mounts and gyroscopic control were proposed to achieve automatic leveling.

Auxiliary equipment and materials have undergone remarkable development during the last ten years. Wide angle cameras to accommodate the Topogon and Metrogon lenses deserve first mention. Multiple lens cameras built during this period include the T3A both single and tandem and the U. S. Coast and Geodetic

Survey 9 lens. The Tri-Metrogon installation is the novel employment of 3 wide angle lenses to permit simultaneous photography of both side horizons. An oscillating camera of foreign design has been produced to increase the field without recourse to multiple lenses. In time it will be revealed that the military need for reconnaissance photography has produced unique camera combinations.

Vital to the taking of high quality aerial photographs is stable flight. The Solar Navigator is a recently developed device to improve the quality of flying. A step toward orientation of the aeroplane in space is the design of more accurate altimeters. Precise height determination by use of ultra-short radio waves as in the Terrain Clearance Indicator has been achieved under certain conditions. Automatic pilots based upon gyroscopic control have made possible virtually untilted photography.

Photographic materials have benefited from the intensive research activity of the last ten years. Aerial film, the principal material, has improved in speed, latitude, color sensitivity, resolving power and dimensional stability. The last property is a characteristic of topographic film which is now prepared on an acetate instead of a nitrate base. Speed has been achieved without sacrificing fineness of grain. Increased latitude permits the use of wider angle lenses since it accommodates for excessive variation in illumination. Increased resolving power makes possible the use of shorter focal length lenses with their higher resolution. The development of color film is an outstanding achievement of the last decade. Full benefit of its application to civilian photogrammetry will not be realized until after the war.

A discussion of future trends in the development of appurtenant photogrammetric equipment and materials makes a fitting conclusion to this discourse. Contemplation of this phase of the subject suggests yet another category, electronics, in addition to those established at the outset. A hint as to possible application of the phenomena embraced by electronics was given under the treatment plotting instruments. Further exploitation might be possible in the camera. If there is an electron microscope, why not an electron aerial camera which would produce a record without visible light or through hitherto impenetrable clouds? Progress of such revolutionary character is not impossible. In fact the next ten years will witness a broadening of the science of photogrammetry largely attributable to the impetus given research by the military needs of World War II.