PHOTOGRAMMETRY COMES INTO ITS OWN

George D. Whitmore, M. ASCE, Chief of Technical Staff, Topographic Division U. S. Geological Survey, Washington, D.C., and *President, American Society of Photogrammetry and Morris M. Thompson, Staff Engineer, Photogrammetry, Topographic Division, U. S. Geological Survey, Washington, D.C.*

THERE seems to be a rather widespread notion, even among some surveyors and mappers, that photogrammetry is newfangled, an infant prodigy that has yet to establish itself as a full-fledged science. It may therefore be a surprise in some quarters that this article can discuss one hundred years of photogrammetry. Yet it was in 1852, the year of the founding of the American Society of Civil Engineers, that a French army officer, Aimé Laussedat, produced the first maps ever made from photographs. As far back as 1888, Lt. Henry A. Reed, an instructor at the United States Military Academy (West Point, N. Y.) published a book entitled *Photography Applied to Surveying*, in which the first chapter was devoted to a history of photogrammetry. Since the time of Laussedat, the science of photogrammetry has developed continuously until it has now reached the status of a major engineering technique.

In looking back over a century of photogrammetry, our purpose is not so much to delve into the historical details of bygone phases of photogrammetry (in itself an interesting subject), as to gain a new perspective. Although photogrammetry is used for many purposes this article will be confined to photogrammetry as applied to surveying and mapping.

WHAT IS PHOTOGRAMMETRY?

As defined by the American Society of Photogrammetry, photogrammetry is the science or art of obtaining reliable measurements by photography. Terrestrial photogrammetry is photogrammetry using ground photographs, aerial photogrammetry is photogrammetry using aerial photographs, and stereophotogrammetry is photogrammetry using stereoscopic equipment and methods.

On reviewing a century of experience, we will find that each of these three kinds of photogrammetry has a specific set of objectives and that each is also subject to a specific set of problems or limitations. The objectives and limitations are the constant factors from which we can orient and evaluate specific developments of the past.

TERRESTRIAL PHOTOGRAMMETRY

In the first attempts at photographic surveying the plane table was replaced

Editorial Note: This was one of the excellent technical papers published in the September 1952 issue of *Civil Engineering* commemorating the one-hundredth anniversary of the founding of the American Society of Civil Engineering. Both authors are members of the American Society of Photogrammetry, and at the time of writing the paper, Mr. Whitmore was president. Permission to reprint this paper has been given. Full credit is extended to the authors, the American Society of Civil Engineering, and to the September 1952 issue of the publication *Civil Engineering* copyrighted in June 1952. Figures 1 and 3 are from Photography Applied to Surveying, by Lt. Henry A. Reed, John Wiley & Sons, New York, copyright 1888, reproduced by permission. Figures 4, 5, and 6 are from Photogrammetry by O. von Gruber, American Photographic Publishing Co., New York, 1942, also reproduced by permission. All other illustrations are U. S. Geological Survey Photographs.

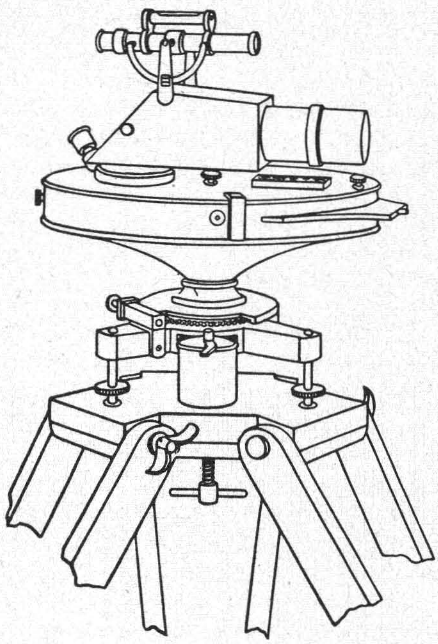

FIG. 1. Photographic plane table designed in 1858.

by a measuring camera (Fig. 1). The camera was equipped with a leveling device for maintaining the photographic plate in a vertical plane and a compass for reading the bearing of the optical axis of each exposure. Its purpose was identical with that of plane-table surveying—to locate objects on a map by the intersection of conjugate lines of sight from the ends of a known base. The camera procedure had an advantage over plane-table methods in that the field work could be done quickly and that any desired point in the field of view could later be located on the map in the office, at the map maker's convenience. Laussedat, who pioneered the method in the 1850's, developed a mathematical analysis for converting overlapping perspective views into orthographic projections on any plane. This procedure permitted the determination of the elevation as well as the position of any point visible in two overlapping photographs.

There is nothing fundamentally wrong with the measuring camera procedure. Laussedat and others used it to produce useful maps a century ago, and it is still the basis of modern terrestrial photogrammetry. Today, however, the crude apparatus of the early days has given way to phototheodolites (Fig. 2) of the utmost precision. In one current application of terrestrial photogrammetry, the U. S. Geological Survey uses the phototheodolite in certain types of mountainous terrain to obtain fourth-order elevations for aerial photogrammetry.

Early plane-table photogrammetry and terrestrial photogrammetry in general also had limitations. Since the first lenses had a narrow field of view, a very large number of photographs was required, an item of great expense in those days and always a matter of inconvenience. In addition, photographic quality was poor. Pioneer efforts to solve the narrow field problem were centered chiefly on panoramic cameras, the first of which appeared as early as 1858. Their purpose was to give a continuous view by successive exposures on a strip of film. Some of these cameras were arranged to photograph only a

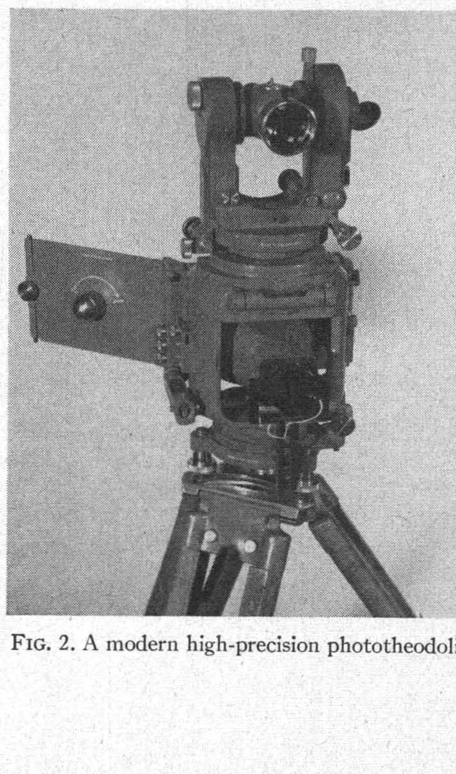

FIG. 2. A modern high-precision phototheodolite.

part of the horizon, whereas others covered the entire 360 deg. The panoramic camera is still being used, notably by the U. S. Forest Service to photograph full horizons from lookout towers, in order to detect and locate forest fires.

With modern wide-angle lenses narrowness of field is no longer a serious problem. However, terrestrial photogrammetry still has certain inherent deficiencies of major importance. For mapping purposes, the field of view commanded by a ground station is much inferior to that commanded by an air station. The conversion from a terrestrial perspective to the map plane is, at best, a cumbersome process. Every ground station must be occupied by field surveying parties, just as when plane-table methods are used, and hence the saving in cost or time is not pronounced.

SUPERIORITY OF AIR STATIONS

The superiority of the aerial camera station over the ground camera station was recognized from the very beginning of photogrammetry. In 1858, Laussedat experimented with an aerial plate camera, first supporting it from a string of kites and later attaching it to a captive balloon. The results of these experiments were not satisfactory since it was difficult to take a sufficient number of photographs from one station to cover all the area visible from that position. In addition, the slow shutters of that day made it extremely difficult to obtain sharp photographs because of the oscillation of the balloon. Laussedat eventually abandoned the aerial method and returned to terrestrial photogrammetry.

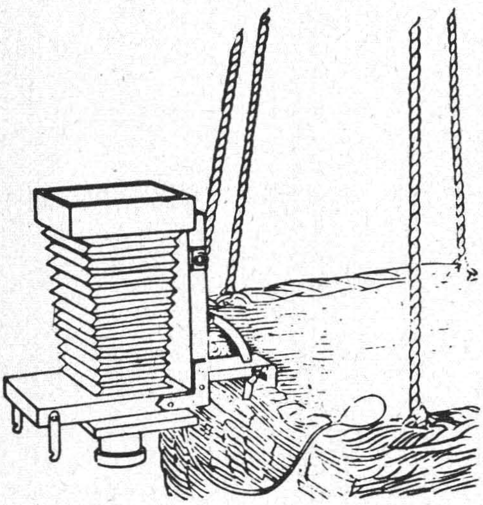

FIG. 3. Camera attached to basket of captive balloon, 1884.

Others experimented with aerial photography, using balloons (Fig. 3), kites, and even carrier pigeons, but it was not until the close of the century that Theodor Scheimpflug, a captain in the Austrian army, provided a feasible solution for the problem that had baffled Laussedat. To obtain complete coverage of the visible area from a camera station, Scheimpflug used an eight-lens camera attached to the basket of a captive balloon. This camera (Fig. 4) consisted of seven lenses taking oblique photographs grouped around a central lens taking a vertical photograph. The eight exposures were transformed into an extremely wide-angle, single, composite photograph, by a universal transforming printer. Follow Scheimpflug's work, there was a period of

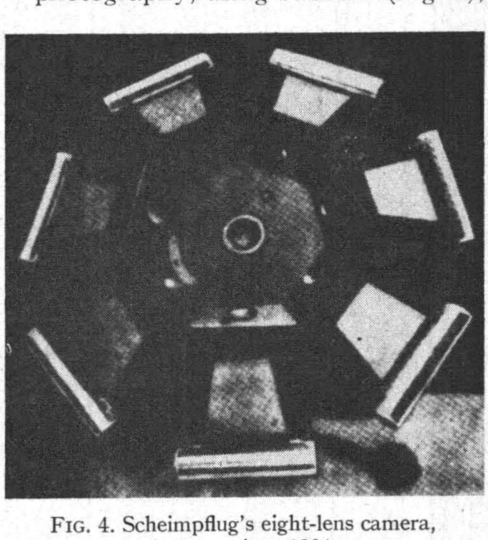

FIG. 4. Scheimpflug's eight-lens camera, bottom view, 1904.

development of multiple-lens cameras, ranging from three to nine lenses, all with the single objective of obtaining wide photographic coverage from a given air station. The wide coverage of multiple-lens cameras is still considered very advantageous in some types of mapping. A nine-lens camera is used by the U. S. Coast and Geodetic Survey in this country and by at least one commercial organization in Europe.

Even with captive balloons, ground crews were still necessary to move the cumbersome apparatus across the countryside, a slow and costly operation. Free balloons, propelled by electric motors, were in use as early as 1884, but they were not used extensively for photography. Possibly the oscillations were so great that their use was impracticable.

Aeronautical developments changed the situation completely in the early part of the twentieth century. A German zeppelin captured in France in August 1914 was found to be equipped with an aerial camera, as was an airplane shot down later in that year. This was a development of the utmost significance. The camera could now be carried to the desired aerial exposure station easily and rapidly without the necessity of placing a crew in the area to be photographed.

Conceding that there are a number of ways of utilizing aerial photography, the writers will confine themselves to problems connected with map making from single-lens vertical photographs using a plotting instrument. A vertical photograph is one taken with the optical axis of the camera nearly vertical or, in other words, with the plane of the photograph nearly parallel to the earth's surface. If the plane of the photograph were exactly parallel to the earth's surface at the time of exposure and if the surface of the earth were perfectly flat, the photograph would represent a true map. However, the airplane noses and rolls as it flies its course, so that the photograph is invariably tilted to some degree. As a result, the image of the earth's surface on the negative does not have a uniform scale. Furthermore, the relief of the terrain causes local displacements of the image. These are fundamental geometrical properties of the photograph arising from the orientation of the camera and the nature of the terrain. In addition, the image is distorted by the physical imperfections of the photography, such as lens aberrations, camera movement during exposure, film curvature, and film shrinkage. Because of these three factors—tilt, relief, and photographic imperfections—the task of converting aerial photographs into accurate topographic maps presents a formidable, but by no means insurmountable, problem. Some methods of solving this problem will now be examined.

APPLICATION OF STEREOSCOPY

When the problems of aerial photogrammetry or terrestrial photogrammetry are solved by the use of stereoscopic instruments, the procedure is referred to as stereophotogrammetry. It should be understood that stereoscopic plotting instruments do not offer the only solution to these problems. For example, the radial-line method of plotting, known as early as 1893, with its corollary, the slotted templet method, has a wide and useful application in photogrammetry. The positions of points in the radial-line method are plotted in their correct relative position to one another by a system of intersection and resection, using the radial center of each photograph as the origin of radials through the images of the points. There are also strong, although somewhat tedious, analytical methods of solution based on parallax measurements.

By far the greater part of photogrammetric mapping, however, is done with stereoscopic plotting instruments. The parlor stereoscope was a familiar instrument of the late nineteenth century, and photogrammetrists were quick to recognize the possibilities of three-dimensional viewing of photographs for surveying purposes. A stereoscopic plotting instrument (Fig. 5) for use with terrestrial photographs was devised about 1890 by E. Deville, Surveyor-General of Canada. This was probably the first such instrument to prove of practical value. At about the same time, the Italian Professor Porro and the German Professor Koppe developed the important Porro-Koppe principle of overcoming the effect of camera lens distortion by observing the photograph through a lens identical to the camera lens.

A fundamental problem in the utilization of stereoscopic principles was the necessity of devising a method of horizontal and vertical measurement in the stereoscopic model. In 1892, Stolze, of Germany, discovered the principle of the floating mark, and soon thereafter his compatriot Pulfrich developed a practicable method of measuring with floating marks. These advances opened the way for the development of modern stereoscopic plotting instruments.

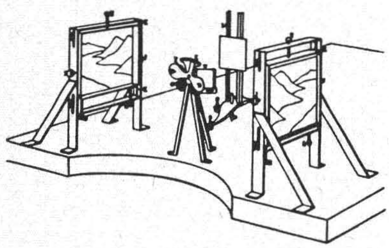

FIG. 5. Deville plotter, 1890.

The catalog of stereoplotting instruments is long and varied. They range from simple and inexpensive instruments of low accuracy to intricate and costly machines of the highest precision. Most of these instruments have a useful function for some specific purpose. If only form lines are required, there is no need to have a precision instrument. If high precision is required, it cannot be obtained with a low-cost instrument.

The problem of tilt and relief displacements is solved in the same general manner in most stereoplotting instruments, although there are wide differences in the mechanical details and in the degree of accuracy attained. A pair of overlapping photographs is oriented in the instrument to recover the relative orienta-

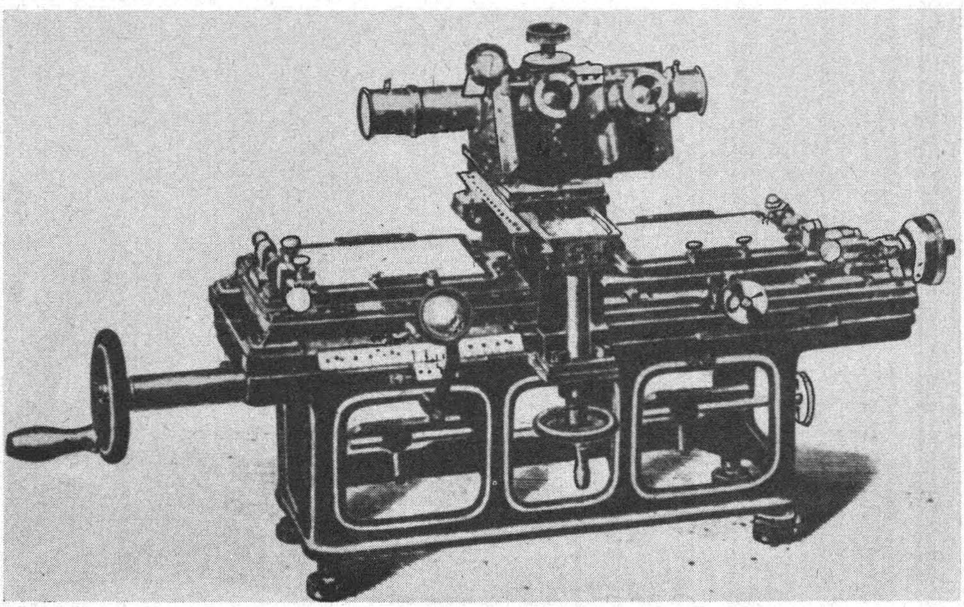

FIG. 6. Stereocomparator, 1901.

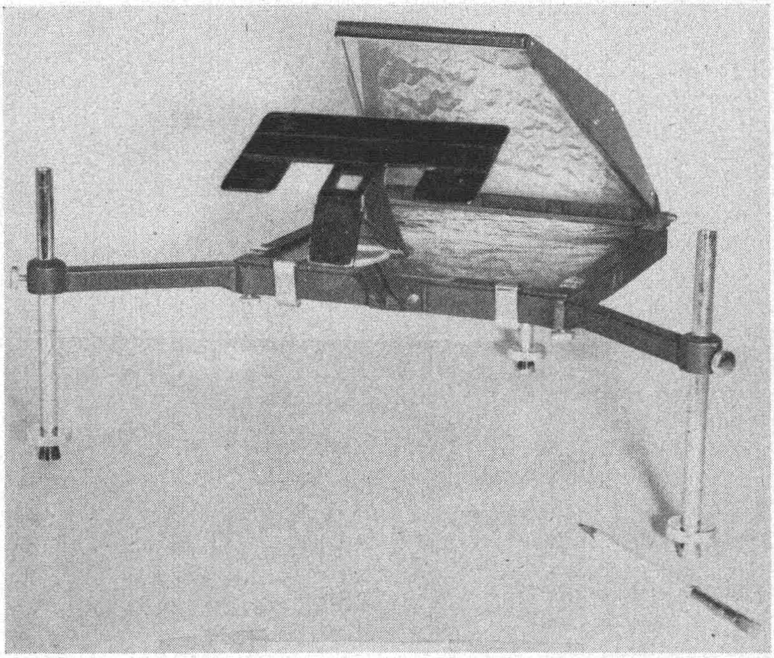

FIG. 7. Sketchmaster.

tion of the negatives at the instant of exposure. A stereoscopic viewing system is provided so that a miniature model of the terrain appears to be created. The model can be brought to the desired scale and oriented with respect to a datum, as represented by ground-survey control points. Measurements are made, and map detail is transferred to the manuscript sheet, by a floating mark. Since the space model is similar in every respect to the terrain in nature, the tilt and relief displacements are automatically solved. As the clarity and geometrical accuracy of the model and the precision of transferring detail to the map in-

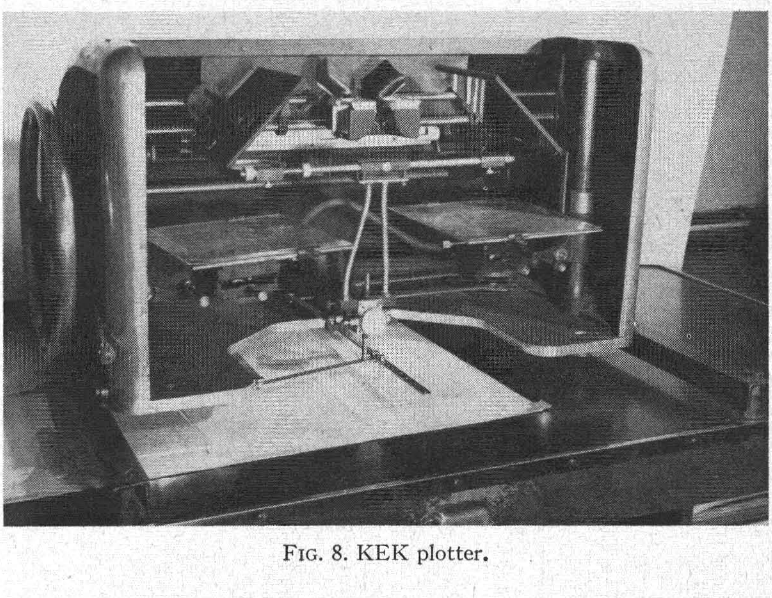

FIG. 8. KEK plotter.

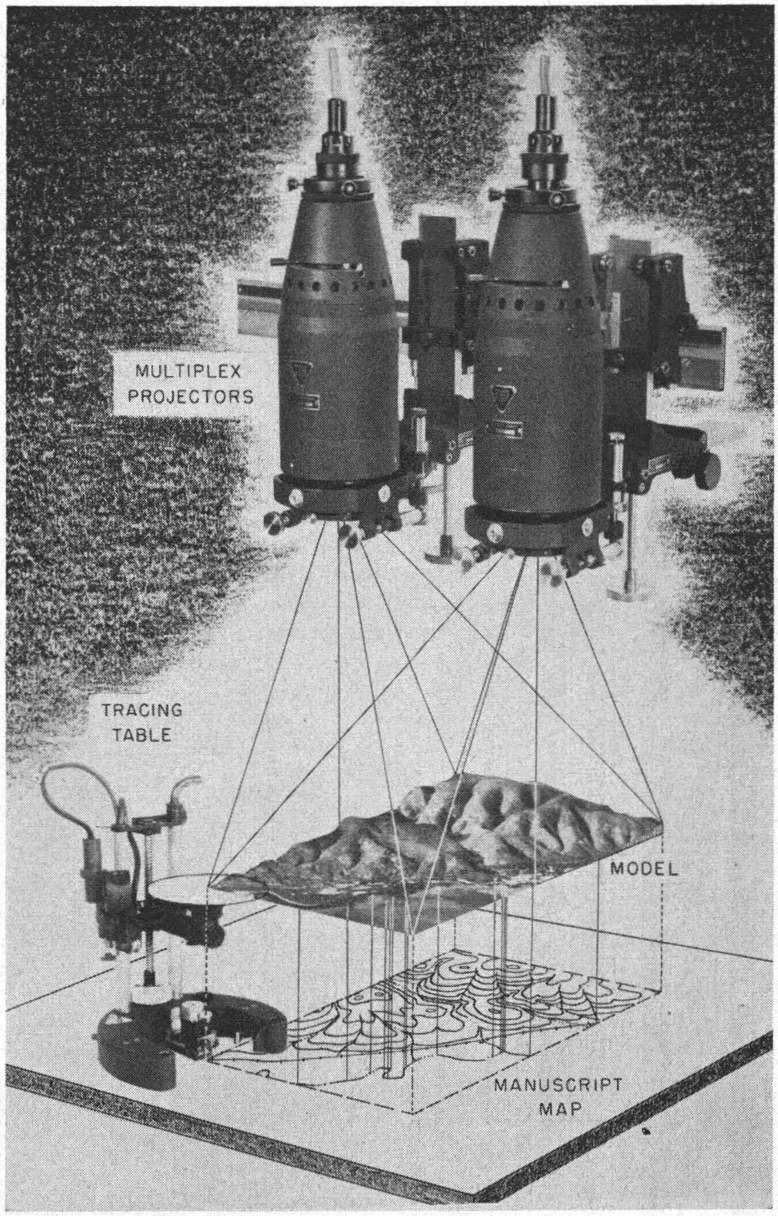

FIG. 9. Principle of the Multiplex.

crease, the accuracy of the map produced increases and so, very likely, does the cost of the instrument.

The mechanical and optical problems involved in the design of stereoplotting instruments are multitudinous, and often very complex. Beginning with the development of the Stereocomparator (Fig. 6) by Pulfrich in 1901, there has been a steady stream of plotting devices with many variations in mechanical and optical details. But practically all have the fundamental objective of recovering the original relative orientation of the photographs as a step toward creating a space model. These devices may be roughly classified as follows, in ascending order of accuracy and cost:

1. Simple non-stereoscopic instruments for limited purposes, such as the Sketchmaster (Fig. 7), which do not provide a three-dimensional model.
2. Topographic mapping instruments utilizing paper contact prints, such as the KEK plotter (Fig. 8).
3. Topographic mapping instruments utilizing anaglyphic projection, such as the Multiplex (Fig. 9).
4. Topographic mapping instruments utilizing optical or mechanical-optical trains, such as the Autograph A-5 (Fig. 10).

The problem of imperfections in the original photography, common to all plotting methods, has never been wholly solved. There are various methods for compensating the effects of camera lens distortion and film shrinkage, but the real solution is the elimination of these effects at the source. There has been some progress in this direction recently. New photogrammetric lenses, virtually distortion free, have become available and plans have been made for the installation of some of these in aerial cameras. One solution of the film shrinkage problem is the use of glass plate negatives, but this is expensive and inconvenient. A new plastic-base film of very high dimensional stability has been announced, and may aid in eliminating the shrinkage problem.

Only in the last decade or so has photogrammetry had a really profound influence on the economics of surveying and mapping. Until about 1935, photogrammetry had operated, relatively speaking, solely on the fringes of the broad field. However, when the full impact of a century of development was brought suddenly to bear, under the urgent necessities of World War II, the effect was revolutionary and permanent. Within the last ten years photogrammetry instead of field work with the plane table has become the basic procedure for the making of topographic maps and for many other activities in the surveying field. This does not mean that field work is a thing of the past. Field engineers are still needed in considerable numbers for control surveys, for completion surveys, and for contouring flat terrain. But the undeniable fact is that, in major mapping

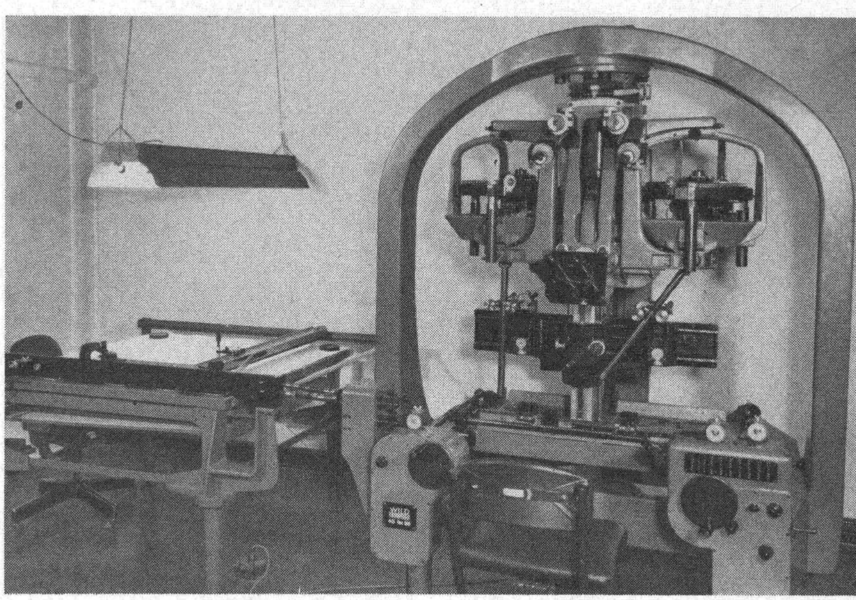

FIG. 10. Autograph A-5.

enterprises, field operations are now supplementary to photogrammetric operations and must be tailored to fit the photogrammetric program.

Such a revolution, which has affected governmental and commercial mapping organizations alike all over the world, would not have come about unless it paid in dollars and cents. Relative costs of field mapping versus photogrammetric mapping are not easy to evaluate for there is always the debatable question of how to amortize expensive plotting equipment and the additional service operations that are an inescapable part of photogrammetric procedures. However, photogrammetric procedures, if not always cheaper than field procedures, at least give better maps for the same money. Over and above the measurable cost per square mile of mapping, photogrammetry permits the completion of vast mapping projects within a time interval beyond the range of practicability for field methods. Considering that in many instances time is money, the economics of the situation consistently dictates the use of photogrammetric methods for extensive mapping projects.

The economics of photogrammetry has also brought a perennial mapping problem—the cost of ground-survey control—into sharper focus than ever. When topography was done by plane table, field parties had to be on the ground anyway, and it seemed quite natural that they devote part of their efforts to control surveys. But now that the topography is determined from aerial photographs, the continuing need for even larger amounts of control to be done by surveying parties in the field makes everyone control-cost conscious. Indeed, the cost of control sometimes exceeds the cost of photogrammetric compilation. It is therefore only natural that intensive efforts are being made to eliminate, or at least reduce, the requirements for ground-survey control. Some progress has already been made in this direction for some classes of mapping, using airborne radar and shoran techniques.

Mapping by photogrammetric methods has broadened the scope of skills and knowledge required. So many skills and varied scientific backgrounds are necessary that few can hope to master all of them. Thus, although the field of surveying and mapping has broadened immeasurably and has created a need for high-level scientific knowledge, paradoxically the participation of the individual in the construction of the map has narrowed. He now tends to become a specialist, participating in only one phase of the operations, whereas the old-time topographer knew the satisfaction of creating an entire map from beginning to end.

PHOTOGRAMMETRY INFLUENCES SOCIETY

Some might say, rather glibly, that the impact of photogrammetry on society is a rather far-fetched conception, that photogrammetrists can scarcely make their weight felt. But consider this conception further. What about the impact on society of aviation, of well-constructed highways, of the development of natural resources, of the conduct of wars? None would deny that all these have a far-reaching influence. Yet each depends on maps, maps now made largely from photographs. Take away the pilot's aeronautical chart, the detailed strip map of the turnpike planner, the conservationist, topographic or resource map, the general's military map—and society has been deprived of vital tools indeed.

Without the speed of photogrammetry, the lack of maps would constitute a bottleneck in the development of other fields whose importance is more obvious. In this way, photogrammetry constitutes a very real, if indirect, force in the pattern of our civilization.

THE CRYSTAL BALL

It is good engineering practice to predict future developments by extrapolating the trends of the past. The trend, as we have seen it in reviewing a century of experience, is toward the ever-increasing self-sufficiency of photogrammetric methods. We can look forward then to new and improved instruments and techniques, to new methods of obtaining control without recourse to ground surveys, and to an ever-increasing demand for more and better maps. At the same time, since every new development has raised its new quota of problems, we can expect that the photogrammetrist of the future, having solved the most baffling problems of today, will be vexed by questions beyond our conception.

Even if distortion-free lenses, mechanically perfect cameras, absolutely stable film, faultless developing techniques, and sharp-sighted, trouble-free plotting instruments could be produced, photogrammetry would still be confronted with difficult and interesting problems. In areas of heavy timber cover, the ground would still be invisible to the camera. Adequate ground control would still be difficult to obtain in remote or inaccessible areas. Personnel sufficiently skilled in both the science of photogrammetry and the art of topography to utilize the procedures to the best advantage would still be relatively rare.

Although photogrammetry has come a long way technically since 1852, it has still a long way to go.