ELEMENTS
OF
PHOTOGRAMMETRY

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PREFACE

The elements of photogrammetry are presented in this book, with particular emphasis on the physical and mathematical principles involved. Photogrammetry is followed logically through the successive stages of planning an aerial survey, the flight, the production of photographs, ground control, and the use of the photographs, beginning with the simpler devices and progressing to the more complex stereoplotting equipment.

The book has developed from many years of teaching an elementary course in the subject to civil engineering classes. Fundamental principles have been emphasized, especially with respect to the vertical photograph and the theory and use of the stereoscope, an instrument upon which all photogrammetrists are so dependent in one way or another. Although intensive training in the use of complex plotting instruments is more appropriate to advanced courses, this and other topics are introduced to stimulate student interest in further reading and research.

Varied numerical problems are provided, which are suitable either as home assignments or as supplements to the laboratory work. Ample laboratory work is suggested for either two or three semester hours, depending upon the availability of photographs and equipment.

The author wishes to express his grateful appreciation to all those individuals, companies, and government agencies that have so kindly supplied photographs and other material. The statements of interest and good wishes were most encouraging. Finally, he expresses thanks to his wife, who not only typed the manuscript but suggested changes for its improvement.

WILFRED H. BAKER

Morgantown, West Virginia
October, 1960

CONTENTS

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1

INTRODUCTION

1–1. Definition of Photogrammetry. Derived as it is from three Greek roots meaning "light–writing–measurement," the word *photogrammetry* refers to the art and science of making measurements on photographs. It is also usually extended to include the use of these measurements in bringing forth a resulting product and sometimes the production of the photographs themselves. It may readily be appreciated that photogrammetry can be used in many fields, such as geology, forestry, agriculture, and even medicine and archaeology, to mention but a few, but the principal applications that will be considered throughout this text are in the field of surveying and mapping.

1–2. Development. The development of photogrammetry has been intimately connected with that of the camera and photographic materials and processes. Since photography from the air has advantages over that taken on the ground for mapping purposes, the growth of aerial photogrammetry was quite rapid following the inception and manufacture of suitable aircraft. In its own right, the history of photogrammetry consists largely of the development of instruments possessing various ranges of complexity for the transformation of photographs into maps or survey information. Also may be included the development of graphical and analytical methods of accomplishing all or part of these same ends.

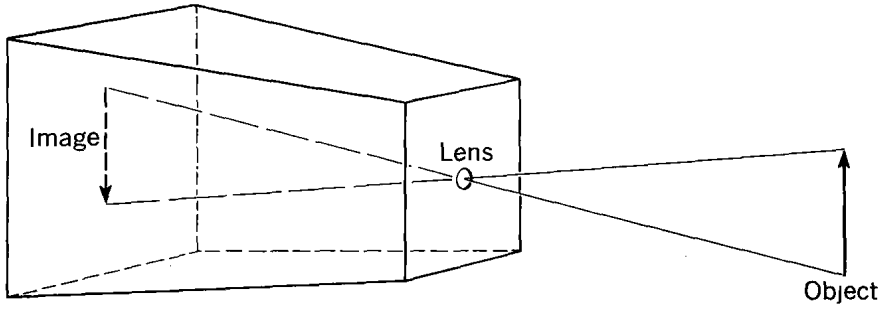


FIG. 1–1. Sketch of a camera obscura.

1–3. The Camera. The modern camera had its origin in the camera obscura (Fig. 1–1), credit for the invention of which is sometimes given to Giovanni della Porta in 1553, although it seems certain that the principle was known and used much earlier. Subsequent developments included the

use of lenses, diaphragms, and portable boxes, so that early in the eighteenth century the camera obscura had become a regular article of commerce. These devices merely caught the image of the landscape or subject without retaining it; another hundred years elapsed before images were successfully fixed on plates. In 1822 the first permanent photograph was made by J. N. Niopce. Plates of metal or glass were used at first, but as the result of a search for something lighter and more flexible, the roll film was developed in 1884 by George Eastman and W. H. Walker.

1–4. Aircraft. The earliest work in photogrammetry was done with pictures made at ground stations. Aerial photographs were first taken from kites and captive balloons beginning about 1860, but the greatest advances resulted from the development of the dirigible and the airplane, especially during World War I. While the camera's position could not be directed with a high degree of accuracy in these types of aircraft, they were yet far superior to the balloon, which was at the complete mercy of air currents. It was about 1913 that the first photograph for mapping purposes was taken from an airplane.

1–5. Early Beginnings. The science of photogrammetry dates from about 1850 when Colonel Aimé Laussedat, often called the father of photogrammetry, first utilized measurements from photographs for the compilation of map data for the French army. Development of the new science was slow because of the limitation of photography and the usual resistance to new methods, but the ideas and principles had been founded. In 1888 Captain Edouard Deville of Canada developed a practical method of using stereoscopic photographs in a single instrument for drawing a map.

1–6. European Workers. From Canada, the interest and progressive efforts were transferred to Europe, where many became active in the development of automatic plotting instruments. Workers there included Dr. A. Meydenbauer in Germany, M. Chevallier of France, and Captain Theodor Scheimpflug of Austria, the last of whom in 1904 developed an eight-lens camera which was attached to the basket of a balloon. Thus a forerunner of the most modern of composite cameras (Art. 1–9) was constructed almost as soon as the single-lens mapping camera itself.

1–7. Instruments. The use of photographs for mapping purposes was greatly enhanced by the invention and development of various instruments, especially the stereoscopic ones, which make possible the simultaneous viewing of two photographs of the same area taken from different stations. An important feature of many of these is the floating mark, the principle of which was discovered in 1892 by F. Stolze and adapted to measuring instruments by Dr. C. Pulfrich. All the modern stereoscopic plotting or measuring instruments described in later chapters utilize this principle. The discovery of the stereoscopic effect itself and the construction of the first stereoscope is credited to a noted British physicist, Sir Charles Wheatstone, about 1835.

1–8. Early Use in the United States. Mapping agencies of the United States government did not take readily to the innovation and were somewhat behind Canada in this respect. The method of radial plotting (Chapter 6) was developed by C. B. Adams of the United States Army in 1893, and terrestrial photogrammetry (Chapter 12) was used in 1894 by the Coast and Geodetic Survey for topographic mapping on the Alaska-Canada boundary survey. Here, as in other countries, aerial photogrammetry was little known or used until the development of the airplane in World War I.

1–9. Coast and Geodetic Survey. In 1920 the Coast and Geodetic Survey revised the topography of the charts along the New Jersey coast from aerial photographs taken by the Army Air Corps, and photogrammetric surveys have been used continuously by the Survey since 1928. A nine-lens camera

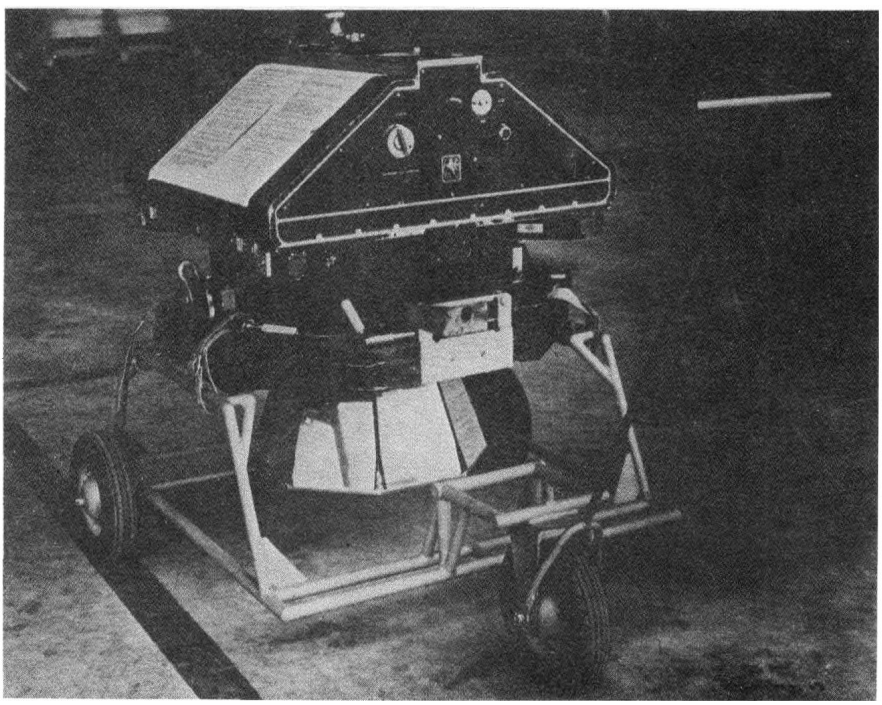


FIG. 1–2. Nine-lens aerial camera. Although all the lenses are parallel, eight of them take oblique views by means of mirrors, which can be seen at the lower part of the camera. (Courtesy of Coast and Geodetic Survey.)

(Figs. 1–2, 1–3) was constructed in 1936 under the direction of O. S. Reading, with the cooperation of the Bureau of Standards and the Fairchild Camera Corporation. A Division of Photogrammetry was organized in the Survey in 1945.

1–10. Geological Survey. The United States Geological Survey used a panoramic terrestrial camera for topographic surveys in Alaska as early as

FIG. 1–3. Photograph taken with the nine-lens camera. (Courtesy of Coast and Geodetic Survey.)

1904. In 1920 the planimetry of the Schoolcraft, Michigan, quadrangle was mapped with single-lens aerial photographs, the contours being added by topographic methods in the field (Art. 6–27). A section of Photographic Mapping was established in 1921, and in 1927 the Survey imported a Hugershoff Aerocartograph from Germany, the first automatic stereoscopic plotting instrument utilizing aerial photographs to be owned by an agency of this government.

1–11. Recent Developments. A tremendous need for maps arose with various new or expanded programs of the government about 1933, and photogrammetry had developed sufficiently to assume a major part of the huge task which was thus thrust upon the map-makers of the nation. An

expanded land acquisition program for National Forests, the development of the Tennessee Valley, and a vast program of farm crop control by the Agricultural Adjustment Administration all required maps or area surveys. The latter agency alone was eventually to be responsible for aerial photography covering some 2,500,000 square miles. These demands were instrumental in the organization of many air-surveying companies, the development of cameras and related equipment, and the training of an increased number of photogrammetrists and technicians in this field (Fig. 1–4).

FIG. 1–4. Expert cartographers adding place names and reviewing previous compilations from aerial photographs. (Courtesy of Bausch & Lomb Optical Co.)

1–12. Writers. The development of methods and instruments has been accompanied by a literature on these subjects by workers in photogrammetry and related fields. A list of the more prominent early writers would include Aimé Laussedat of France, Reinhard Hugershoff and Otto von Gruber of Germany, Martin Hotine of England, Edouard Deville of Canada, and Earl Church of the United States.

1–13. Education. Photogrammetry, as it developed in theory and applications to the field of surveying and mapping, began to be introduced into college curricula and, like surveying itself, has usually been placed in civil engineering departments. It may have been inserted as a part of the regular courses in surveying or made a distinct course, either as a requirement or as an elective. In a few instances, photogrammetry has been offered under a separate department or as an option in the civil engineering curriculum.

The first major course in photogrammetry in the United States was established at Syracuse University in 1929 under the direction of Professor Earl Church. This was made possible by grants from the Daniel Guggenheim Fund for Aeronautics to be used for the purchase of instruments and equipment. Syracuse was selected because of its pioneer work in this field, a course in terrestrial photographic surveying having been required in the civil engineering curriculum since the founding of the engineering college in 1902. The new program established by these grants included eight courses, ranging from map-making and aerial navigation to the economics of aerial mapping. Soon afterward a graduate program was established, which attracted many students both from the United States and from foreign countries.

1–14. American Society of Civil Engineers. One of the technical divisions of the American Society of Civil Engineers, founded in 1852, is devoted to the fields of surveying and mapping. The development of photogrammetry has been increasingly noted in the work of this division, and for the past several years a large proportion of its papers has been directly or indirectly concerned with photogrammetry and its applications to surveying and mapping problems. These papers are published in the *Proceedings* of the Society and many of them are also included in the annual *Transactions*.

1–15. International Society for Photogrammetry. The International Society for Photogrammetry was founded in Austria on July 4, 1910, and serves to facilitate the exchange of ideas and information among the photogrammetrists of the world. It organizes the International Congresses and Exhibitions for Photogrammetry which, since 1926, have been held regularly at four-year intervals except during World War II. The 7th Congress was held at Washington, D. C., in 1952, the 8th at Stockholm in 1956, and the 9th was set for London in 1960. Publication of the quarterly journal, *Photogrammetria*, which was started in 1939 and interrupted shortly thereafter because of the international situation, was resumed in 1949. Technical

commissions of the society include Photography and Aerial Navigation; Plotting Instruments and Techniques; Aerial Triangulation and Geometric Computations; Mapping and Commercial Applications; Miscellaneous Applications; Education, Terminology, and Bibliography; and Photo-Interpretation.

1–16. American Society of Photogrammetry. The American Society of Photogrammetry was founded in 1934 with 217 charter members. Its first president was Colonel C. H. Birdseye, and some of the other prominent men in photogrammetry who have been honored with this office include O. S. Reading, Virgil Kauffman, Marshall S. Wright, and George D. Whitmore. Membership is open to those who are directly or indirectly working in the field of photogrammetry and to students engaged in undergraduate or graduate work in any university or school recognized by the Society. The student members are entitled to all the privileges of the Society except the right to vote.

The annual meeting, usually held in Washington, D. C., brings together those who are interested in photogrammetry, for the presentation and discussion of papers and an interchange of ideas and problems. The Society publishes *Photogrammetric Engineering*, a quarterly journal containing news, papers, and articles of benefit to those engaged in or interested in this field. It has also published the *Manual of Photogrammetry*, first in 1944 and a revision in 1952, a comprehensive volume covering the major divisions of the subject written by active workers in the field.

Aside from these publications, other major achievements of the Society include the development of standard specifications for aerial photography (largely through the efforts of Colonel H. H. Blee, the Society's second president), precision camera specifications, and specifications for map accuracy.

1–17. American Congress on Surveying and Mapping. The first meeting of the American Congress on Surveying and Mapping was held in Washington, D. C., in 1941 and was sponsored by the following five groups: the Committee on Surveying and Geodesy of the (now) American Society for Engineering Education, the Surveying and Mapping Division of the American Society of Civil Engineers, the American Society of Photogrammetry, the Federal Board of Surveys and Maps, and the National Geographic Society. Its first president was Robert H. Randall.

The first listing of the technical divisions of this organization included one for Photogrammetric Mapping, with Virgil Kauffman as chairman, and a second entitled Surveying and Photogrammetric Instruments, with H. M. Dibert as chairman. However, in 1956 neither of these divisions existed as such, the field of photogrammetry evidently having been absorbed in the other divisions, which were Cartography, Control Surveys, Education, Instruments, Property Surveys, and Topography.

2

AERIAL PHOTOGRAPHY

2–1. Aerial Surveys. Aerial photography for surveying and mapping purposes has been increasingly used in this and other countries by various governmental agencies. A large part of the United States is covered by aerial photography, most of it having been done by private companies under contract with the U. S. Geological Survey, the U. S. Coast and Geodetic Survey, and agencies of the U. S. Department of Agriculture. Some of this photography has been utilized for accurate mapping, while some has been used for rough mapping and the calculation of farm areas. Other uses* for aerial surveying may be listed: highway surveys, pipe line location, and route surveys in general; geological surveying and exploration; and the preparation of cadastral and administrative maps. Aerial photography is especially suitable for reconnaissance surveys for routes, where some measure of secrecy is desirable to avoid an inordinate raising of land prices.

It is to be appreciated that the economy of using aerial photography depends upon the size of the area to be covered. An aerial survey would probably not be justified for a single farm of 100 acres, while it undoubtedly would be justified for an entire state or even a county. It would be impossible to set a definite size of area marking the division between a profitable and an unprofitable aerial survey, for there are too many factors which would vary in different instances. It would seem that the burden of the photography must be assumed by large companies and government organizations, but once the photographs are available, the private surveyor or engineer may find many ways of using them for making location studies and reconnaissance, and even an accurate survey or map of a relatively small area.

2–2. Cameras. The cameras used in aerial photography (Figs. 2–1, 2–2, 2–3) are manufactured with a high degree of precision. Negatives on glass plates are preferred for accuracy because of their low differential expansion and small distortion from a plane surface at the time of exposure. However, films are not so expensive or bulky, each roll containing from 100 to 200 exposures in a relatively small space.

The aerial camera is of fixed focus, since it is always used at an altitude sufficiently high to be considered infinite. As indicated in Fig. 2–4, it consists of a light-tight chamber at one end of which is a lens and shutter assembly

* Further descriptions and examples of applications are given in Chapter 13.

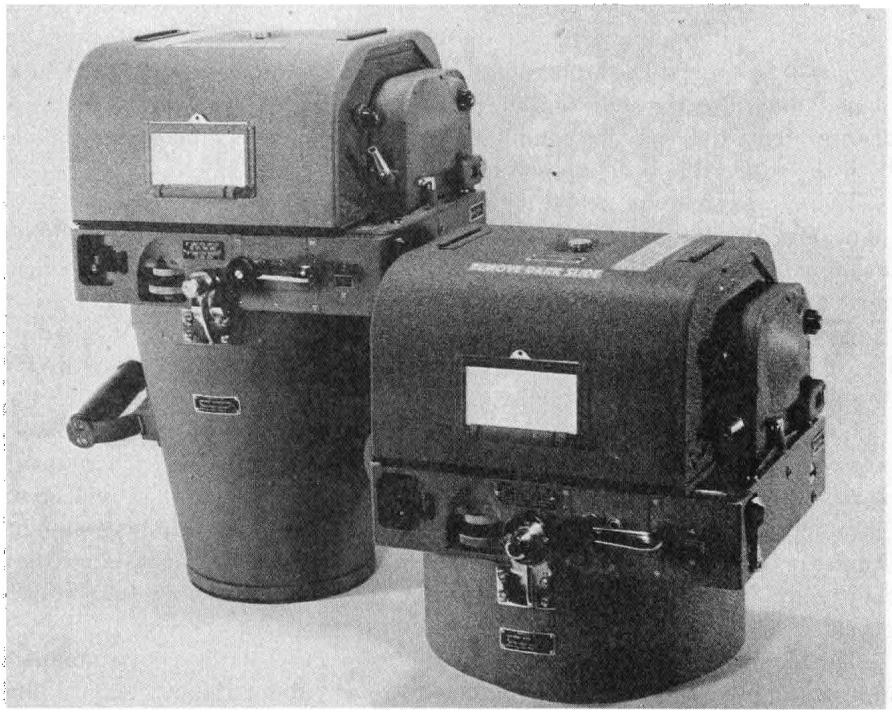


FIG. 2–1. Type K-17 mapping and reconnaissance cameras, 9-in. by 9-in. photographs, 12-in. and 6-in. focal lengths. (Photo from files of Gordon Enterprises.)

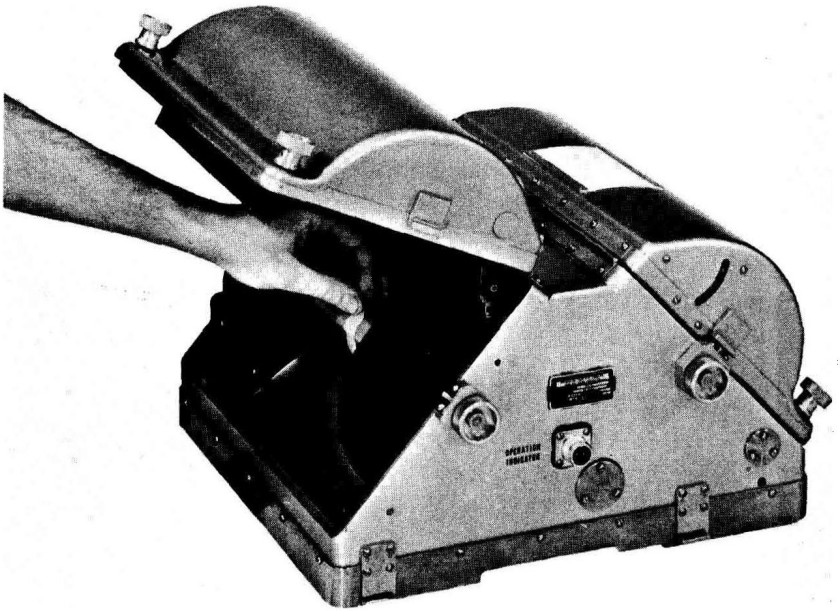
FIG. 2–2. Type CA-6a camera, 4-in. by 5-in. photographs, 15-in. focal length, used for hand-held oblique photography. (Photo from files of Gordon Enterprises.)

(Fig. 2–5) to control the admission of light. At the opposite end is the focal plane, which, for the infinite object distance, is placed at exactly the focal distance from the lens. To complete the camera, there is a magazine to hold both the exposed and unexposed plates or films.

There are three principal types of shutters: between-the-lens, focal plane, and louver. The first is most commonly used because of its durability and freedom of obstruction in the opening. Lying between the component parts of the lens itself, it consists of a series of curved, thin blades hinged on the periphery of a circular ring and is activated by a suitable mechanism for opening and closing. Speeds may range from 1/100th to 1/500th of a second.

In the focal plane shutter (Fig. 2–6) an opaque curtain lies immediately below the camera's focal plane. Upon release, the curtain moves across this plane, carrying a narrow slit from one side to the other, thus providing an extremely small time exposure for any portion but a relatively long time for the entire photograph. While images are sharp as a result of the fast exposure, they may be relatively displaced from one side of the picture to the other.

The louver shutter consists of a number of parallel slatlike parts mounted in a rectangular frame, each being free to rotate about its own longitudinal



(a)

FIG. 2–3. Type T-11 mapping camera, disassembled. (a) Magazine holding 390 feet assembly in camera body. (Courtesy of