SUGGESTED EQUIPMENT FOR TEACHING PHOTOGRAMMETRY

Professor Lawrence Perez, Civil Engineering Department, Pennsylvania State College

INTRODUCTION

WITH the application of aerial photographs to military problems, highway and town planning, transmission line layout, land drainage and acquisition, soil conservation and classification, geological and hydrographic shore studies, forest typing and countless other fields, it has become evident that students of civil engineering, geology, forestry and agricultural engineering should have an understanding of basic photogrammetry, in order to handle these problems properly and economically. They should know the uses and limitations of aerial photographs, the techniques of making maps and mosaics, and the methods used in measuring elevations from the photographs.

LAWRENCE PEREZ

Special equipment is needed to carry on such a program at college level. However, administrators who control the purse strings are reluctant to allocate, at one time, large sums for new special equipment, unless the student hour usage is commensurate with the disbursement, and the course does not fall into the "fly by night" category. The latter is definitely not true for photogrammetry, because as a tool in modern engineering it is long past the experimental stage. At present it is going through a rapid but conservative period of transition; new uses, new equipment and new techniques are becoming evident.

One may spend huge sums of money for special mapping equipment which when used properly will produce accurate maps. However, the more expensive the apparatus the more mechanical operations are performed by the machine, so that the student loses sight of the theory underlying the operation. Inasmuch as we are primarily concerned with acquainting the student with the "why" and "how" of photogrammetry, it is my feeling that we will best accomplish this by keeping equipment as simple as possible. The type of apparatus needed will also depend on the terminal objective of the course and the flexibility of the new equipment budget. Usually the new equipment budgets are limited, and therefore it is suggested that reputable outlets for used and war surplus material be considered, in addition to making the less complicated articles in the department shop.

The natural query of a department head is "How much do you need?" and "With how little can you get along?" In order to answer these questions,

the writer has attempted to act as a clearing house of costs and information on photogrammetric equipment needed for basic and advanced courses. The figures quoted are as of July 1950 and are subject to change with variable world and local conditions. The equipment listed, except for a few cases, will fall in the category of instructive aids which will help students understand the basic principles of photogrammetry, study photo interpretation, and practice the techniques necessary for preparing planimetric and topographic maps.

EQUIPMENT NEEDED FOR BASIC COURSES IN PHOTOGRAMMETRY

Sources of Aerial Photographs. There are three sources of aerial mapping photographs in this country: namely, (a) Government (b) Private Contractors and (c) Special Individual Contracts.

Government Sources. To avoid duplication and to act as a source of information for government agencies and the public, an inventory of areas that have been photographed, or about to be photographed in this country has been compiled by The Map Information Office, U. S. Geological Survey, Washington 25, D. C. Its index indicates the contractor who flew the area, the agency for which the work was done, the scale of photograph, the focal length of the lens used, the date of photography, and the type of photography. This information is available by direct inquiry to the Map Information Office. This office also keeps an index of the existence and availability of aerial mosaics covering areas in the United States. The cost of 9″ × 9″ aerial photographs obtained from government agencies ranges from fifty cents to one dollar, depending on the quantity ordered.

The pictures flown for some Federal Agencies are for purposes other than mapping. Therefore the general types of photography used by the principal governmental agencies in this country has been summarized from records compiled by the Map Information Office.

The Field Service Branch, the Soil Conservation Service, and the Forest Service of the Department of Agriculture, usually require an $8\frac{1}{4}$ inch nominal focal-length lens and a scale of about 1:20,000. In a few cases, scales of 1:15,840, 1:31,680 and 1:40,000 have been required. In general, the photography was obtained between 1936 and 1946. In some instances the Forest Service is obtaining infra-red aerial photography for classification studies.

Practically all the Geological Survey photography has been taken with 6 inch, 5.2 inch or 4 inch nominal focal-length lenses. In some areas the scale is as large as 1:12,000, and in others as small as 1:48,000. The major part of all photography was obtained since 1939.

The photography of the Tennessee Valley Authority may be divided into two general classifications. For mapping, practically all of the area was photographed with a 4 inch lens, the resulting exposure being 7 × 7 inches. In addition considerable special purpose photography at scales larger than 1:20,000 was taken with $8\frac{1}{4}$ inch or larger focal-length lenses.

The photography of the Bureau of Reclamation was usually taken with an $8\frac{1}{4}$ inch lens at a scale of 1:20,000.

The photography of the Coast and Geodetic Survey is generally at either 1:10,000 or 1:20,000 scale. The special nine-lens camera was used for part, while the remainder was taken with a single-lens camera of 6 inch or 12 inch nominal focal-length.

The aerial photography of the Corps of Engineers and of the Army Air Force varies so widely as to scales and types that no reasonably accurate generalized description can be given.

In this summary it is evident that where maps are required, the photography

is made with the 4 inch, 5.2 inch or the 6 inch nominal focal-length lenses so as to fit the special mapping equipment. If general land use studies, acreage measurements, preparation of aerial mosaics and other non-stereoscopic uses are to be made of the photograph, the longer focal-length lenses are much more desirable. Therefore it may be seen that one will have some difficulty fitting government pictures into a general basic course.

Commercial Sources. The photography obtained by private contractors or commercial firms also varies considerably as to scale, focal-length of the lens and type, but in general will be better for student use. The cost per print will be much higher than if obtained from the Federal Agencies. The unit cost per 9″×9″ print on double-weight, aero paper will range between $1.00 and $2.00, if for education purposes. Naturally the price would be higher if the photographs were to be used for professional purposes, as most contractors or commercial agencies give an educational discount.

The prospective user should first ascertain from the Map Information Office which contractor has the photography he desires. After this detailed information may be obtained directly from that contractor.

Special Individual Contract. The ideal method of obtaining prints for classroom work is to arrange for an experienced contractor to photograph an area of 30 square miles or more in a region accessible to the student. The surveying and photogrammetric problems may be thus related in such a way as to maintain high student interest. By having the negatives it is possible for the instructor to start the work in the dark room, and to carry it through to the finished map. In this way a student will gain the confidence necessary for using a new tool, and also develop a better understanding of the problems of the private contractor. Although the initial cost of obtaining the negatives is high, the great advantage of having current pictures and being able to make a variety of prints for various purposes cannot be overlooked.

There are a large number of factors which influence the cost of aerial photography, such as

1—Size and location of area
2—The required scale
3—The required accuracy
4—The type of terrain
5—The time of year for proposed flying
6—The type of photography

Accordingly it is impossible to give a specific figure until the actual conditions are known. At The Pennsylvania State College, in 1949, we had an area of 76 square miles covered with "leafless" flying, at a scale of 1:9600 with a 6 inch lens. One set of prints, index mosaic and negatives were supplied for $900, which is approximately $12 a square mile. We have just had 160 square miles flown with infra-red at a scale of 1:12,000. Three sets of prints, an index mosaic and negatives were supplied for $1700. It might be well to add that the first contractor was located 75 miles from the area, while the second company was located 210 miles from the photographed section.

We are amortizing the cost of the negatives by selling sets of 8 prints and 4 prints to our students in photogrammetry and route surveying respectively.

In order to obtain a reasonable cost for flying small areas, such as 30 square miles, it would be wise to have the area flown at a time when the contractor would have a plane and crew in the immediate area; otherwise the charge for traveling to the site may make the total cost prohibitive.

The figures in the following table indicate current costs of flying small areas, as quoted by some of the leading contractors in this country.

Contractor	*Area Square miles*	*Cost per Square mile*	*Remarks*
A	76	$12	"Leafless" flying April 1949
B	30	33	Within 100 miles of base
C	160	11	July 1950
D	30	14	Does not include cost for travel
E	30	30	
F	30	10 to 15	Plane in immediate area

The above cooperating contractors supplied the quotations on very meager specifications, and therefore the figures are approximate, except for Contractors A and C. For a firmer estimate, more detailed information would have to be submitted to the individual contractor.

Partial Listing of Flying Contractors in the United States

Aero Service Corp.,
236 East Courtland Street,
Philadelphia 20, Pa.

Aero Graphic Surveys Corp., &
Harry Tubis, Inc.,
47 Clinton Street,
Newark 2, N. J.

Air Survey Corporation,
3203 O. Street, N. W.,
Washington, D. C.

Pennsylvania Aerial Surveys,
P. O. Box 184,
New Cumberland, Penn.

Robinson-Standard Aerial Surveys,
418–426 Central Avenue,
Newark, N. J.

Park Aerial Surveys, Inc.,
Standiford Field,
Louisville, Ky.

Abram Aerial Survey Corp.,
606 E. Shiawassee Street,
Lansing 1, Michigan.

Chicago Aerial Survey Co.,
332 South Michigan Avenue,
Chicago 4, Illinois.

Mark Hurd Mapping Co.,
230 Oak Grove Street,
Minneapolis, Minn.

Jack Ammann Photogrammetric Engineers,
829–31 N. St. Mary's Street,
San Antonio 2, Texas.

Fairchild Aerial Surveys,
224 E. 11th Street,
Los Angeles 15, California.

Edgar Tobin Aerial Surveys,
502 W. Mistletoe,
San Antonio, Texas.

Geophoto Services, Inc.,
305 E. & C. Building,
Denver 2, Colorado.

Southwestern Aerial Surveys,
111 E. 10th Street,
Austin, Texas.

Kargl Aerial Surveys, Inc.,
212 N. Colorado Street,
Midland, Texas.

Wallace Aerial Surveys,
P. O. Box 2205, Felts Field,
Spokane, Washington.

STEREOSCOPES

A student should be supplied with some type of stereoscope, so that he may appreciate the three-dimensional effect obtained from properly oriented aerial photographs. The stereoscope is useful in locating picture and conjugate points on photographs, and in studying photo interpretation either in the office or in the field. The *lens* type of stereoscope is the most reasonable in cost and may be obtained from equipment manufacturers. (Sources are indicated later in this paper.)

If one's budget is limited, satisfactory lens stereoscopes for photo interpretation may be made from eye-glasses with 5 diopter lenses bought in the "Five and Dime" stores for $1.50, or from 5 diopter meniscus lenses bought from optical supply houses and inserted in special holders to suit the need of the

user. Although the lens stereoscope gives a magnification of between $2\frac{1}{2}\times$ and $4\times$, it has the disadvantage that the entire overlapped portions of the adjacent photographs may not be seen at one time, and the stereoscope rests on the pictures so that it interferes with the orientation.

The *mirror* stereoscope corrects the faults of the lens type but it is much more expensive; therefore it is suggested that one be made available for each five students. It is also possible to make this type in the school shop in order to stretch the budget. To obtain satisfactory results, it is necessary to use front surface mirrors which may be obtained from the Evaporated Metals Co., 436 W. State Street, Ithaca, New York. The cost of mirrors for a normal size stereoscope will be approximately $6.

The mirror stereoscope and the lens stereoscope may also be obtained from reputable dispensers of war surplus material at greatly reduced prices.

The *prism* stereoscope developed by the Geological Survey is ideal for field use in that it is compact and convenient to handle. The model is not magnified as it is viewed with the unaided eye. Insofar as known, this device is not manufactured commercially, but it can be made in a department shop for the nominal cost of $8 for materials. The prism is right angled; of good quality, crown optical glass; free of bubbles and imperfections; 7″ wide having acute angles of 30 and 60 degrees. The prism may be obtained for $6 if ordered in pairs from J. Unertl Optical Co., 3551–3555 East Street, North Side, Pittsburgh 14, Pa. The following list includes some of the manufacturers of stereoscopes in this country.

Manufacturer	*Type*	*Cost**	*Remarks*
Abrams Instrument Corp.,	Lens	$ 10.30	Model CF-8—with case
Lansing 1,	Lens	18.80	Model B-3 Folding portable
Michigan	Mirror	75.00	Model SF-1
Aero Service Corp.,	Mirror	125	Model 1000 S for 9×9 Prints
236 E. Courtland St.,	Mirror	135	Model 1000 L for 18×18 Prints
Philadelphia 20, Pa.			
Fairchild Camera & In-	Lens	9.75	F-271 Folding pocket type
strument Corp.,	Mirror	150	F-71
88–06 Van Wyck Blvd.,			
Jamaica 1, N. Y.			
Harrison C. Ryker, Inc.,	Lens	9	Model D 12
843 Thirty-fifth Ave.,	Mirror	137.50	Model M-11
Oakland 1, Calif.	Lens	?	Field Stereoscope
Stratex Instrument Co.,	Lens	10	Folding pocket type
1861 Hillcrest Ave.,			
Los Angeles, Calif.			

* These prices are only approximate inasmuch as current prices are not now available.—*Ed.*

PHOTOGRAMMETRIC TRIANGULATION

Radial Line. The radial line technique for triangulating or bridging is preferred over the analytical method for instruction in basic photogrammetry, because it is less cumbersome and time consuming. Although the analytical method is more exact, the calculations are so lengthy that the student is put in a position where he cannot "see the woods for the trees."

The most reasonable method for demonstrating the radial line technique is to use acetate sheets 0.21 mm. thick and cut to print size. The rays from the principal point to each of the picture points are scribed on the smooth side of

the acetate. This permits the removal of crayon which is rubbed into the scribe lines to make them more legible. The acetate may be obtained from Eastman Kodak Company, Rochester, New York under the name Topographic Sheeting.

Slotted Template. The slotted template method for using the radial line plot requires the construction of a special punch and slot cutter because commercial models are not available. Cardboard of the quality used for the template material may be purchased in 20×26 inch sheets for ten cents. The plugs for holding the slotted templates in place may be obtained from the Abrams Instrument Corporation, or may be made locally from flat-head machined rivets. The material for the punch and slot cutter used at The Pennsylvania State College costs approximately $4.

Mechanical Triangulators. The mechanical triangulators or "Lazy Daisy" metal templates may be obtained from the Abrams Instrument Corp., for $375 for parts to cover 100 vertical photographs, or from the Fairchild Aerial Surveys, Inc., Los Angeles, Cal., at approximately $200 for parts to cover 75 photographs. The metal templates have the advantage over the other methods in that they may be used repeatedly without material loss. However, the radial line or the slotted template method is preferred for student use in basic photogrammetry, inasmuch as the acetate sheets or cardboard templates may be included in their notes for future reference. The metal templates are ideal where maps are incidental to the consideration of the final problem.

RECTIFYING AND PLOTTING PLANIMETRIC DETAILS

Planimetric detail may be *traced* or *sketched* on the map sheet from aerial photographs if scale changes and distortions are negligible. This method requires no special equipment, but the tedious delineation of detail by this crude technique tends to deflate the student's interest.

The sketchmaster type of rectifier is a reasonable and desirable piece of equipment for transferring detail to the map sheet, from either oblique or vertical photographs. After a few visual adjustments are made it is possible to trace in detail, with moderate accuracy. The sketchmaster is based on the camera lucida principle, and is made so as to enlarge up to 2.6 times and reduce to 0.4 times the picture scale. There are three types sold commercially; the Vertical Sketchmaster for reasonably vertical photographs, the Oblique Sketchmaster for oblique pictures, and the Universal Sketchmaster which may be used for either vertical or oblique prints.

It is recommended that when arranging a budget one sketchmaster for every five students be considered. This type of equipment may be obtained from the following manufacturers—

Manufacturer	*Type*	*Cost**
Abrams Instrument Corp., Lansing 1, Michigan	Vertical	$185
	Oblique	192
Aero Service Corp., 275 E. Courtland St., Philadelphia 20, Pa.	Vertical	135
	Universal	175
Fairchild Camera & Instrument Corp., 88–06 Van Wyck Blvd., Jamaica 1, N. Y.	F 248 Rectoplanigraph (universal)	425
Harrison C. Ryker, Inc. 843 Thirty-fifth Ave., Oakland 1, Calif.	Vertical	125

* These prices should be considered as approximate only inasmuch as current prices are not now available.—*Editor.*

MEASURING HEIGHTS OR ELEVATIONS OF OBJECTS

For accurate determination of elevations or heights from aerial photographs, either special expensive stereoscopic equipment or an abundance of ground control is essential. There are a number of excellent but expensive stereoscopic instruments available, and they will be mentioned in the section on "Equipment for an Advanced Course in Photogrammetry." However, with adequate ground control, a scale accurately divided to hundredths of an inch will suffice for making measurements for the purpose of determining height or elevation. This technique allows the student to concentrate on the problem rather than becoming involved with instrumental technique.

After the scale method of measurement, the student should be exposed to those parallax measuring devices which are used with the lens stereoscope. Such devices are the Harvard Wedge, or the Variable Elevation Wedge which permits more precise parallax measurements than obtainable with the scale. These wedges range in price from $1.10 to $5 per unit; quantity orders will reduce the unit cost by as much as 20%. The Abrams Instrument Corporation also makes an attachment to its lens stereoscope which may be used for measuring parallax.

These items are reasonable in cost and it is recommended that at least one per student be made available.

The parallax bar which measures parallax to 0.01 mm. is used with the mirror stereoscope. It is a combination plotting and height finder which may be considered as a compromise for the more expensive simple stereo-plotting apparatus. One bar per mirror stereoscope may be considered at a cost of approximately $95.

One simple stereo-plotting device such as the Fairchild unit 210 Stereo Comparagraph or the Abrams Contour Finder should be available so that its operation may be demonstrated in a basic course. These are ideal and relatively inexpensive devices for training students in stereoscopic plotting. Although they are not as precise as more expensive and complex stereoscopic instruments, they provide a reasonable degree of accuracy.

The above mentioned equipment may be purchased from the following manufacturers—

Manufacturer	*Type*	*Cost**	*Remarks*
Abrams Instrument Corp., Lansing 1, Michigan	Lens	$ 35	Model H F 2 Height Finder
	Lens	355	Model F C 3 Contour Finder
Fairchild Camera & Instrument Corp., 88–06 Van Wyck Blvd., Jamaica 1, N. Y.	Mirror	395	Unit 210 Stereo Comparagraph
	Parallax Bar	95 approx.	Type F 163 parallax bar
Park Aerial Surveys, Louisville, Kentucky	Variable Elevation Wedge	5	
Chief, U.S. Forest Service, Washington, D. C.	Parallax Wedge	1.10	

* These prices should be considered as approximate only inasmuch as current prices are not now available.—*Ed.*

SPECIAL EQUIPMENT FOR ADVANCED PHOTOGRAMMETRY

All the equipment previously mentioned is simple in design and easily manipulated, so that it can be used advantageously in a basic, 3 credit college course in photogrammetry. Naturally if the funds are available and more advanced work is desired, it is possible to purchase equipment which satisfies the needs of graduate work. This equipment should be purchased with idea of doing research and development.

There are many types of stereoscopic plotting instruments ranging from $600 to $50,000, so one must choose that instrument which is both functional and economical.

Four of the stereoscopic plotting instruments which might be called economical and functional in their respective groups are the Multiscope, the Multiplex, the Kelsh Plotter and the Wernstedt-Mahan Type Plotter. There are many other styles and models and for a more comprehensive description of stereoscopic plotting, one is referred to the excellent article "A Functional Comparison of Stereoscopic Plotting Instruments" by R. J. Sparling and J. V. Sharp in PHOTOGRAMMETRIC ENGINEERING, Vol. XIV, No. 3, 1948.

The Multiscope is a combination of the mirror stereoscope and the camera lucida in a highly flexible form. Plotting is done directly from the photographs. It is made by the Northeastern Engineering Co., Manchester, New Hampshire, and sells for $650 net f.o.b. Manchester, New Hampshire. Further technical discussions on this equipment may be obtained by referring to PHOTOGRAMMETRIC ENGINEERING, Vol. XII, 1946, pp. 269–271, Vol. XII, 1946, pp. 309–312, Vol. XI, 1945, pp. 171–178.

The Kelsh Plotter is a two-projector single-model instrument which forms an anaglyphic model on a movable tracing platen. In operation it uses diapositives the size of the original 9×9 negative. It is made by the Instruments Corporation, 4 N. Central Avenue, Baltimore 2, Maryland. The latest prices quoted are as follows—

Kelsh Photogrammetric Plotter	
Complete for standard angle photography	$4,075
Complete for wide angle photography	4,775
Complete for both standard and wide angle photography (wide angle instrument plus extra cones, plate holders and accessories for standard angle work)	5,225

The Multiplex equipment, made by Bausch and Lomb Optical Company, Rochester, 2, New York, is now in a price range where it might be considered for instructional purposes.

The Auxiliary unit is priced at $4,710. This includes three standard multiplex projectors, supporting stand and tracing table, and two pairs of filter spectacles. If only two projectors are desired the price of the equipment would be $3,710. All prices are quoted f.o.b. Rochester, New York.

In order to use this equipment, diapositives can be obtained from cooperating government or commercial organizations, or it is possible to purchase diapositive printing service from commercial concerns.

The Wernstedt-Mahan type plotter based on the floating mark principle is made by Harrison C. Ryker, Inc., Oakland 1, California; unfortunately the writer was unable to obtain a quotation up to the time of this meeting.

A reflecting projector of the Saltzman Type is a desirable instrument if production methods are to be studied. It provides a rapid means of rectifying.

When large-scale mapping is desired the graphical processes are generally

replaced by mathematical, mechanical or optical methods. The comparator method for triangulating should be mentioned because it is unquestionably the most accurate; however the calculations are too lengthy and involved to be attempted in a basic course. The comparator is a custom-built piece of equipment, and while expensive, it is an indispensable piece of equipment for graduate instruction. Quotations, if desired, must be obtained from instrument makers.

INCIDENTAL EQUIPMENT

In addition to the special equipment already mentioned, beam compasses for projection layouts, two pairs of large scissors, five scribers, and three metal straight edges should be made available for use. A delineascope and lantern slide projector plus slide and prints will prove very helpful in presenting the basic material. A glue known as Hydratite and made by the National Starch Products, 1305 Germantown Avenue, Philadelphia 22, Pa. is very satisfactory in making mosaics. One 5 gallon drum sells for $8.75.

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SUMMARY

To help interested individuals prepare a tentative budget, the types and approximate costs of equipment necessary to service a class of twenty students in basic photogrammetry are suggested as follows—

Stereoscope	*No. Required*	*Cost*†
Lens	20	$195
Mirror	4	500
*Prism	4	100
Surplus		
Improvised (lens)	20	50

	No. Required	*Cost*
Sketchmaster		
Vertical	4	640
Oblique	1	175
*Universal	1	425
*Multiscope	1	605
Triangulators		
Type		
*Abrams	1	375 (100 units)
*Fairchild	1	200 (75 units)
Height and Elevation Measuring Devices		
Type		
Wedge	20	22
*Height Finder	4	104
*Parallax Bar	4	380
Stereocomparagraph	1	395

* Optional equipment.

† These prices may have been changed since the preparation of this paper.—*Editor.*

Chairman McNair: All of the preceding papers were written by college professors. We will now hear from the people who are really doing the job and get their opinion as to the kind of training they think the student should receive at these schools.

First, we will hear from Mr. Moravetz, Assistant to the Chief Topographic Engineer of the U. S. Geological Survey. He has had considerable training in surveys. Considerable is certainly not an exaggeration; I think he started when he was nine or ten years old. He has worked with TVA, the Army Map Service, and the Geological Survey. He has had experience with inter-agency problems; that is, Geological Survey versus Public Roads or versus Coast and Geodetic Survey. He is currently very much involved in the matter of the Civil Service classification of photogrammetric personnel and in the recruitment of personnel for photogrammetric work.
