THE ECONOMICAL ASPECTS OF PHOTOGRAMMETRY

Dipl. Ing. Chrzaszcz, Roman
Polish Universitary Camp of Internement
Winterthur (Switzerland)

PHOTOGRAMMETRY is the youngest branch of geodesy and has developed into an important acquisition in the service of mankind. During World War I its development was considerably fostered, theoretically as well as technically, to such an extent that the old conservative Survey Services, which were used to older and more classical methods, began to consider the advantages of this new branch of geodesy. The reception which it found was diverse; meeting mostly with aversion against something new. Others asserted it would replace all the classic methods. It was practice that brought photogrammetry into its real role and furnished the impetus to the perfecting and enlarging of its sphere of application. Despite its stormy inception, photogrammetry has entered upon its epoch of permanence.

Photogrammetry in its present state consists of the following branches: mapping, architecture, testing materials, nautical science, medicine, as well as legal matters. In our present times, no human activity could be imagined without maps. The necessity for maps has led to the examination of that method which facilitates their preparation. In photogrammetry we have won an ally with its prominent branch: aerial photogrammetry.

I

Although each individual map is for a specific need, in general the following classifications may exist:

1) Cartography-scientific—its principal aim being the obtainment of the most accurate topographic picture.
2) Military.
3) Legal, re to taxes, re demarcation of property and buildings, application.
4) Projection. The map is used as an economic state of projection and to furnish us with a knowledge of space.

When there is a demand for maps, the economical aspects of surveying must be considered. With the accelerated demands of present and future needs, the cartographic production must find the means of keeping abreast with these demands. In this case photogrammetry has proved to be of invaluable aid in the production of maps. Increasing items for aerial photogrammetry in the Surveying budgets of the different countries are eloquent proof of this fact. Consequently, there must exist good reasons for its application.

II

A large per cent of aerial photographs are being taken with cameras of vertical axis. Such a photograph is a map in itself of unknown scale and with displacement. Retaining the vertical axis is of paramount importance in measurement and this has been rendered automatic over most of Europe. The question of measurement is: to transform the central projection of the photograph into a rectangular projection. The methods of plotting are the following:

1) *Rectifying*—The results of which obtain the horizontal (plane position) of the ground. By use of this method we save photographic material (plates and film) as well as labor (see table 4, page 153). This consideration is for level terrain and does not evaluate the ratio of height.

2) *Stereoscopic Photogrammetry*—By this method we obtain position and height. It involves higher expense due to the preparation of control, larger consumption of photographic material, expensive plotting, and a lengthier process. It further necessitates trained employees who possess stereoscopic vision. The expensive plotting apparatus needs a longer period for amortization. Plotting on flat terrain is difficult and toilsome.

3) *The Picture Plane with Contour*—In order to obtain the required accuracy in elevation computation, the flying height ought to be lowered (which is economically unfavorable), so that it would be much more advantageous to draw the position of the photograph and then complete the elevations by terrestrial methods.

With the classical methods of surveying, each control point must be treated separately. Hence, the expenditure of work is dependent upon the number of control points and the cost of the map-project. Photogrammetry also bases itself on measurements of longitude and of angles, but as these are made directly on the photograph, the position as well as the height of all points (rectifying) can be determined immediately. In this way we are able to plot several points simultaneously. The determination of lines and surfaces is gathered immediately, so despite a larger number of points of little accuracy, the final result as a whole can be more accurate. Instead of considering the different points, we shall consider their composition.

Aerial photogrammetry has numerous advantages which definitely establish its sphere of application; rapid compilation, and increase in yield of figures (see tables 5 and 14 on pages 153, 156). The average time of plotting a stereoscopic pair in a large scale is five to eight hours, and the orientation of the stereogram is one to two hours. (The rectifying requires very little time.)

The plotting of one km^2 on a scale of 1:50,000 requires one to two hours, depending on the detail required. The yield on a scale of 1:20,000 amounts to: (Germany) 50 to 60 km^2/mach./day. Thus we have possibilities of yield of which we hardly dared to dream with the classical methods (see tables 5 and 15 on pages 153, 156). An aerial-photograph, when properly taken, is a map, and when used stereoscopically is of great importance for general synoptical maps, as it gives true reproduction of detail.

When taking aerial-photographs, the operator is above the ground, which makes the survey of inaccessible countries possible. On the other hand, the separation of the plotter from the ground creates an error. For this reason it is advantageous to entrust the local Survey Services with the field work and the plotting.

According to instructions, the plotter revises the whole with the same accuracy; i.e., independent from the equidistance points, and independent from the camera station and weather conditions. A well-exposed photograph gives the same accuracy of the entire area covered and does not leave the plotter at liberty, but forces him to conform with the spatial model as well as with the other requirements.

Finally, the time of surveying has an influence upon the office work as consideration must be given to the best light for photography. The quality of the aerial-photograph is highly dependent on the time of survey, for shadows will spoil the stereo-effect, and plotting is more difficult if there is new snow cover on the ground. Leafy woods should be surveyed in Spring or Autumn.

Photogrammetry is sometimes reproached with being in arrear of the classical methods. However, accuracy and cost are two differentials which always contrast, and between which we constantly strive for a medium. It is often necessary to forego cartographic accuracy in order to complete a mapping project. This follows the principle of obtaining photogrammetric compilation results which are equal to the classical methods. For such comparison we can apply aerial photogrammetry on larger scales. The scales 1:500, 1:1000, 1:2,000 are not unfamiliar to photogrammetry. Work at these scales has been done satisfactorily all over Italy, France, Portugal, etc., for cadastral and city-plan projects. This is direct refutation to the claim that photogrammetry can only be used successfully for small scale maps. The accuracy of photogrammetric compilation is dependent on the photographic material (film, emulsion, etc.), aerial-camera, proper flight lines, plotting, and plotting apparatus.

As a further advantage, photographic material represents incontestable evidence of the actual condition of the landscape; it can be preserved for many year and can be plotted again at any time.

III

The aerial-photogrammetric method as a whole consists of the following parts:

1) Photographic flight
2) Survey and preparation of geodetic control
3) Plotting
4) Ev. field completion, and
5) Printing of the map.

As this work is done in general by several groups, it is highly important to organize the work in such a manner as to assure the full utilization of the employees. This has a direct bearing on the firm's budget as well as its ability to secure and handle a larger number of projects.

Photographic flight is to furnish us with the complete survey material at the accuracy required; namely, the fixed scale of survey and base ratio. The flight is executed according to a pre-arranged plan which gives the direction of the flight lines, speed of the plane, height above sea level, time intervals for duration of exposure, and base-ratio (usually 1:3). Photographic strips must be in a straight line and parallel. Curved strips with overlapping photographs multiply the prints, prolong the time of survey, and increase the cost of plotting and control. It may occur that in some place it is not possible to obtain sufficient forward or lateral overlap. In such cases it is advisable to execute the flight at a lower altitude. The crew of the airplane have maps at their disposal, as well as the compass, solar-navigator, and other apparatus which are of great aid in properly executing the flight plan.

The Meteorological Service contributes invaluable aid by advising as to the most advantageous weather conditions. The crew should be constantly ready to benefit by the service.

Because of the expense involved, aerial surveys are more practical for large areas. For small areas the flying cost would be too high. The photographs represent a considerable portion of the total expense (see pages 153, 156, for tables 10 and 11), and we should always endeavor to reduce the quantity of material needed. This influences the general cost of the aerial survey (secondary control points, plotting, rectifying). This reduction may be obtained by increasing the flying height as well as using a wider angle lens. Higher flying, however, causes a smaller map-scale and is less accurate.

This introduces another problem, the enlargement of the picture angle of the camera. The surface of the reproduced ground on the photograph increases with the square of height and the tangents of the half angle of field of view.

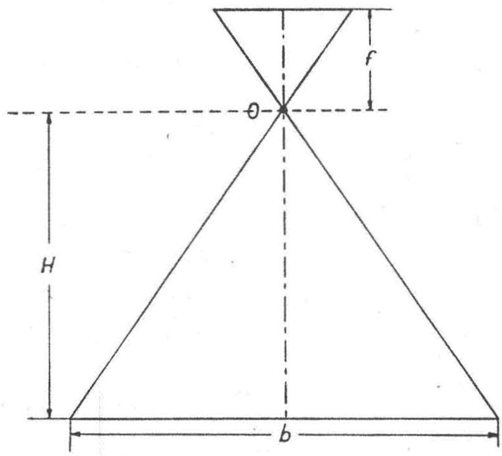
(the photograph $b \times b$)

$P = b^2$ — H = flying height over the ground $= \dfrac{f}{S}$

$b = 2H \text{ tg } \dfrac{\alpha}{2}$ — α = angle of view

$P = 4H^2 \text{ tg}^2 \dfrac{\alpha}{2}$ — f = width of picture

$P = 4 \dfrac{f^2}{S^2} \text{ tg}^2 \dfrac{\alpha}{2}$ — S = picture scale



This is also in ratio with the square of the focal length and conversely with the square of the scale of the photograph.

The question of picture angle has been solved in the following manner.

1) Multiple lens cameras in which the total picture angle attains 130°, and
2) Wide angle cameras.

In the case of the multiple lens camera a wide common angle of view is obtained by combining several normal angle cameras obliquely around a center vertical camera. However, the oblique or wing pictures and the plotting apparatus will need transformation and this process will cause a new source of errors. Again the reciprocal orientation of the multiple-lens camera did not remain unchanged as had been supposed, and finally the oblique rays are strongly influenced by atmospheric refraction, so that the avoidance of distortion was replaced by other errors. With the ancillary system camera (Nenon) the image of the horizontal rays may be obtained. In Europe the adoption of the wide angle camera has replaced to a great extent the manufacture of the ancillary type camera. The introduction of a correction device in plotting (the same lens, mechanical or optical correction WILD A-5), has diminished the error of lens distortion to a point where it may be considered negligible.

In general it may be stated that wide angle cameras are best suited for small scale mapping and for large scale mapping a camera with a long focal length is preferred. In the use of the wide-angle camera, for a flying-height $H=4000$

m., for 20 km², 3 points of secondary control are needed. In this case for desired accuracy the flight should not be executed too low.

Note the great advantage of the wide-angle camera when the terrain has varying elevations. When plotting the Bernese Oberland (Switzerland) with 3500 m. difference in elevations, the wide-angle camera permitted execution of flight lines without regard to the direction of the valleys. Full possibility of stereoscopic plotting was given, without sight, due to dead fields.

Map and Photograph Scale

From the scale of the desired map we may determine an average or approximate photograph scale.

The image-scale is limited by the photographic emulsion, atmospheric conditions, and accuracy of the plotting equipment. The scale should be used which will give accurate detail with a minimum number of photographs.

The photograph scale is a function of focal length of camera and flying height.

$$S = \frac{f}{H} \cdot$$

We can choose these two ratios in such a manner as to obtain the most economical scale. By this determination we can economize on photographic material, plotting-time, and ground-surveying. The use of the altimeter enables the pilot to fly at a desired height.

The production cost of a map 1:5,000 for 1 km² amounted to:

TABLE 1

Picture scale	1:5500	597 RM	Germany
	1:7500	374 RM	
Similar	1:38000	$1.00	U.S.A.
	1:24000	$1.58	

and the plotting possibilities were the same.

The photographic scale for a small scale map is in converse ratio to that for a large scale map. The ratio is approximately as follows.

TABLE 2. DENOMINATOR OF PHOTO-SCALE

Photo	Map	Scale
5.0–3.5	1.0	1:1,000
7.5	5.0	1:5,000
2.0	2.5	1:25,000
3.0	5.0	1:50,000
4.0	10.0	1:100,000

A ratio of 1:1 will be attainable for a scale 1:15,000–1:20,000. Accuracy of position and flying height decide these ratios. For small scale maps we are, in general, interested in the position and delineation of the planimetry and for large scale maps we are not always interested in all the topographic data visible and a smaller scale could be used. Plotting the photographs on a larger scale than the map scale proved to be a practical manner in which to reduce machine errors.

TABLE 3

(Switzerland)	Photograph	1:15,000
	Plotting	1:10,000
	Map	1:25,000

This increases the cost of the finished map but gives a commensurate increase in accuracy.

The *secondary control* points are an important part of photogrammetry. Their purpose is the orientation of the ground within the established co-ordinates. The frame-work of fixed points is to be condensed for determination of position of at least four points for rectifying, or 3–4 points of known co-ordinates and height for a stereogram.

In small scale mapping the main problem is the condensation of the known elevations, which can be obtained by barometric height measurement of the fixed points. These points are defined astronomically and located before the photographic flight. Between these astronomic points we trace in, on about 100 km. of distance, an aero-triangulation net (I order) through aerolevelling and aerotriangulation, etc. We then plot the areas between the longitudinal and horizontal stripes as usual. We can then fill in the triangulation (I) with the autograph (WILD A-5) and (WILD A-6).

Systematic errors and lens distortion have a direct bearing on the accuracy desired. We can reduce the caused curvature of the model by application of the statascope and reproduction of the horizon.

Previous methods of radial triangulation which are less precise and without height determination have lost their importance.

For a scale of 1:5000 and larger, the position as well as the height of secondary control points are important. The position can be determined by triangulation or traverse. In cases where distance-meters are available, traverse is more advantageous, as it can be done independent of visibility and atmospheric conditions. For a traverse of about 300 m. we can measure about 6 km. of the polygonal course per day. The heights are measured trigonometrically.

In smaller scale mapping, the identification of the control (fixed) points is done by means of special aluminum plates or with chalkmilk before the photographic flight. Identification of secondary control points when aerotriangulating without control is only being done in the autograph. For large scale mapping the location of secondary control points is done either prior to the flight (in which case they are previously marked), or after the flight by location of the intersecting points when surveying. In this manner we avoid the possibility that the secondary control point located by ground survey does not appear on the photograph which would necessitate the location of another secondary control point. Property-surveys, where the limits must be clearly defined, form a special case. If old maps are available, we can take the secondary control points from them, and calculate evaluated graphic co-ordinates.

The purpose of *map-drawing* is of paramount importance. Depending upon the object of the map we can rectify or plot the space and choose a corresponding scale. Compilation will be different in each case for the topographic, cadastral, economic, military, or data planning map. The objects will be considered according to the purpose and accuracy desired. The time for mapping as well as the cost will vary accordingly.

The *map scale* is an important factor. The larger the scale, the greater the cost. As large scale mapping requires a low flight altitude, more photographs are needed, and many more secondary control points must be located and identified. Large scale mapping should be used in countries where triangulation of low order and levelling already exist. On the other hand, where the condensation of primary control is limited, small scale mapping should be used. This is where European photogrammetry has a decided advantage as it has an established system of triangulation and levelling at its disposal. With few exceptions the other areas of the world do not possess such a frame-work of control. This emphasizes the great importance of aerotriangulation of areas deficient in control, as this deficiency makes outer orientation of the photogram difficult.

Table 4, in the form of an extract of reports, gives some indications regarding cost; unfortunately these are not complete:

TABLE 4

Country	Scale	Picture Map	Picture Plan	Pro ha
Germany	25,000	1.52	1.02	
	5,000	26.00–31.00	5.00	
Portugal	1,000		225.00	
	5,000		45.00	
	10,000		22.50	
	25,000		4.00	
	100,000			
Switzerland	1:10,000	27.00	6.1	with amortization of equipment
	25,000	15.25	3.25	
U.S.A.	1:12,000	3.80	2.56	
	1:24,000	2.85	1.69	

The plotting or rectifying should not be done with too much precision and should be done in such a manner as to secure the largest possible use for the mapping. This applies especially to the large and average scale maps. These are more costly but their possibilities of application are greater. This helps make an equitable distribution of cost, and avoids repeated survey of the same territory. This can best be accomplished by a central planning service responsible for the execution of the mapping project. (See table 4, comparison of cost.)

In table 5 are found ratios of stereoscopic plotting:

TABLE 5

1:2,000	5–6 ha./hour/Aut.
1:5,000	0.5 ha./16 h./Aut.
1:25,000	5 km²/day/Aut.
1:100,000	100,000 km² per year, 16 hours working time with one autograph.

The Terrain

The *topography* of an area has an influence on the mapping cost, namely:

1) Differences in height force us when rectifying for a mosaic, to use only the central parts of the photographs (as displacement increases toward the edge of the print). We must have photographs of large overlap, or proceed to space-plotting.
2) Stereoscopic plotting demands long and careful treatment. Flat countries are not suitable for stereoscopic observation (compare page 148). The characteristic points which facilitate the orientation of the model are moderate differences in height, the slopes, the conduct of the measuring (floating) mark on the apparent model.

In Italy the cost of a cadastral map at 1:2000 amounts to (per ha.):

TABLE 6

	ratios:—
Flat ground	1.0
Undulating ground	4.0
Mountainous ground	8.3

In Italy the cost of a topographic map 1:2000 with 2.0 contours is:

TABLE 7

Medium ground	1.0
Difficult ground	2.6
Average	1.8

Table 8 shows us the yield per day, dependent on plotting:

TABLE 8

(Italy)	Equidistance (contour interval)	Ground map	Cadastral map
1:1,000	1 m.	10	20 ha. per day
1:2,000	2 m.	40–50	30–40
1:4,000–5,000	4–5 m.	80–120	

The culture of the terrain must be considered, i.e., in forestry maps, especially in heavy pine areas, delineation of the contours is difficult because of heavy foliage throughout the year. In this case we can compute the average height of the trees or check from point to point and after adjusting can draw the contours above the trees. This handicaps plotting and introduces another source of error.

The plotting of an accumulation of detail (houses, property-limits) also tends to make delineation of the contours difficult. (Compare page 156, table 13 for France.)

The surfaces of seas, lakes, large rivers, and other bodies of water materially aid in the outer orientation of photographs and they are valuable as a plotting check. This has been proven in work performed in China, U.S.A., Greenland, and the Netherlands Indies.

The *value of the land* is the decisive factor, as an important amount of work will not be profitable in economically poor countries, unexplored or economically weak countries, as for these small scale maps will suffice. In the case of valuable lands such as cities, important political areas, or land rich in minerals such as the Netherlands Indies, larger scale maps of greater accuracy should be used.

A few of the most notable achievements which aerial surveys have attained are:

1. Economy in mapping
2. The ability to map large areas rapidly
3. The ability to map areas where land-survey is almost impossible.

The reconnaissance work although playing a minor photogrammetric role is of definite bearing on the map cost, and the work of a day of *field reconnaissance* group on a scale of 1:5000 ranges as high as 1.5 km^2.

The Printing of the Map

As an additional note in air mapping we might mention a very practical method of printing which is especially applicable for large scale mapping. This is of aid in avoiding the problem of maps becoming out of date, immediately after printing. We can design on tracing paper the situation (property limits, utilization of ground) and trace all changes. On another tracing paper we can design the contours and relief. We can then print the sheet desired. This method has given good results in Germany and has reduced printing expenses. As printing represents a considerable part of mapping expense such a method is of definite aid in reducing the over-all project cost.

TABLE 9

	scale	% of total expense of photogrammetry
Latvia	1: 5000	13.2%
Sweden	1:10000	19.7%

IV

After discussing the various factors which influence photogrammetry, it would be of interest to examine the following common items of expense.

TABLE 10. PHOTOGRAPHIC MATERIAL AS A PERCENTAGE OF THE TOTAL EXPENSE

a) 1:5,000 Latvia	Photographic survey	12%
	Delimitation on the field	31%
	Rectifying	19%
	Mapping	25%
	Other work and material	13%
b) 1:10,000 Sweden	Photographic survey	34.8%
	Signalling	7.6%
	Radial triangulation	21.3%
	Rectifying	12.1%
	Mapping	24.1%
c) 1:25,000 Latvia	Photographic survey	11.9%
	Field work	30.6%
	Rectifying	18.1%
	Various work	14.6%
d) 1:25,000 Finland	Photographic flying and material	30%
	Fixed-angle measurement	37%
	Rectifying and mapping	21%
	Amortization	22%

TABLE 11. THE PICTURE MAP

a) 1:20,000–40,000 France	Photographic survey	9–12%
	Net for plotting	25–26%
	Plotting	31–34%
	Completion	35–28%
b) 1:10,000 Switzerland	Preliminary cad. work	2.3%
	Photographic and flying-service	12.0%
	Point-signalling	2.7%
	Identification of air-pictures	13.1%
	Determination of points of minor control	10.1%
	Stereoscopic machine setting	8.1%
	Plotting	36.2%
	Completion on the field	2.7%
	Elaboration of the general plan	12.8%

c) 1:2,000 Cad. Italy

Firm	Photographic Flying	Signal. Reconnaissance Triangul.	Demarcation Completion	Plotting	Drawing Elaboration of Records	Control Verifying	Reproduction
SARA	12.5%	22.5%	25%	30%	10%		
EIRA	5.0%	45%		15%	30%	5%	
IRTA	17%	38%		38%			7%

In comparison with the cost it will be interesting to compare the percentage of work terms on the same scale and under the same conditions of labor.

TABLE 12

Belgium:		Rectifying	Plotting
	Photographic flying	7%	10%
	Field work	16%	29%
	Rectifying, Plotting	33%	34%
	Drawing	44%	27%

Statement covering saving of expense for photographic plans:

TABLE 13

Country	Scale and kind	Percentage of Expense
Bulgaria	1:25,000 (Surveyor's table)	30%
Finland	1:25,000 (plane table survey)	20%
France	1:1,000–2,000 (Cad.)	(Inhabited land 50%) (Undulating land 30%) (Flat land 15%)
Italy	average	33%
Latvia	1:5,000	38%
Hungary	1:5,000	50%

TABLE 14. RATIO OF COST

Country	Scale	Picture Plan Class. (old)	Photo-grammetry	Photographic Map (old)	Photo-grammetry
Latvia	1:25,000	2.1	1		
Poland	1:5,000	3.0	1		
Portugal	large			2.5	1
	average			1.7	1
	small			3.0	1

TABLE 15

Gives us the ratios re time in Portugal:	
large scales	1:3
average scales	1:2
small scales	1:4

In Sweden it was estimated that the mapping of an area of 270,000 km^2 by standard methods required about thirty years while the same area can be mapped by photogrammetry in less than five years.

Considering the large areas of the world which have not been surveyed, we must admit that photogrammetry is the solution to correct and economical mapping.

Revised on the basis of photogrammetric journals (Switzerland, Germany, France, Italy, United States of America) as well as of reports of the 5th Int. Congress of Photogrammetry.