INFLUENCE OF CAMERA FRAME SIZE ON AIR SURVEY EFFICIENCY

Vladimir G. Afremov, Serguei S. Nekhin
Central Research Institute of Geodesy,
Air Survey and Cartography (TsNIIGAiK)
Onezhskaja 26, Moscow 125413
USSR
Commission I

ABSTRACT

Theoretical explanation for the influence of camera frame size on efficiency of air surveys is presented. Productivity of cameras with different frame sizes is estimated with respect to the same assigned accuracy of terrain heights determination or with respect to equal resolution.
An increase in camera frame size is shown to bring forth an increase in efficiency of air surveing and photographic processing or in case of equal efficiency an increase in accuracy of terrain heights determination and resolution. However this increase in camera frame size causes additional consumption of film, greater specific consumption of materials and energy, greater camera dimensions and necessity to use carriers with high ceiling.

1. INTRODUCTION

The basic size of aerial photographs intended for topographic map production and updating in the USSR at present is 18 x 18 cm size. All the technologies of map production and updating are based on this size. Development of new generation of aerial surveying cameras and photogrammetric instruments necessitates to find a good reason for choosing this or that size of aerial photograph. It is the problem of size that the report is concentrated upon.

It is known that the main features defining quality and efficiency of stereophotogrammetric survey are: 1) accuracy of space coordinates determination (heights of terrain points in the first place); 2) correlation between volumes of field and office interpretation that depends on resolution of camera; 3) productivity of air surveying that depends on projection of a stereopair's plane onto terrain. The above features can be used to formulate two criteria for comparison of two cameras with different sizes of their frame. The criteria are:
1. Out of two cameras with different frame sizes the better one is the camera which ensures better accuracy of terrain heights determination or, depending on the purpose of a survey, better resolution provided productivity of the two cameras is the same.
2. Out of two cameras with different frame sizes the better one is the camera that ensures better productivity provided accuracy of terrain heights determination (or resolution) is the same.

An increase (change) in frame size (dimensions) is an example of transformation that changes linear elements of optical system, i.e. focal length, diameters of pupils and lenses, thickness of lenses and air gaps in proportion to changes of frame size but does not change angular parameters, such as angle of view and relative aperture. This transformation with respect to basic parameters of a camera can be expressed as

$$\frac{l_1}{l_o} = \frac{c_1}{c_o} = K\ , \qquad 2\beta = \text{const}\ , \qquad \rho = \text{const}, \qquad (1)$$

where K is coefficient of increase in frame size (coefficient of proportionality), c is camera focal length, l is a side of a frame (photograph), ρ is relative aperture denominator, 2β is angle of view. Index "o" in this (1) and other formulas means basic (18x18 cm) camera frame size, index "1" referres to a camera with larger frame.

Let us compare the cameras under study from the standpoint of the second criterion. Here we shall formulate two conditions. The first one lies in the fact that elements of resolution Δ ensured by both cameras remain the same, i.e. relation between volumes of field and office interpretation do not change. This condition is characteristic of planimetry updating; the following expression holds true for the condition:

$$\Delta_1 = \Delta_o \qquad (2)$$

The second condition is characteristic of map production. It lies in the fact that equality in errors of terrain heights determination m_h holds true for both cameras:

$$m_{h1} = m_{ho} \qquad (3)$$

2. COMPARISON OF CAMERAS WITH RESPECT TO THE IMAGE QUALITY

Let us compare two cameras from the standpoint of the first condition. Here we shall use a well-known formula

$$\Delta = \frac{M}{2Rq} \qquad (4)$$

where R is practical image resolution obtained under flight condition, M is numerical photographic scale denominator, q is constant coefficient when two cameras are compared; this coefficient depends on contrast of terrain elements. Let us use the expression (4) to write down the following:

$$\frac{\Delta_1}{\Delta_o} = \frac{M_1}{M_o} \cdot \frac{R_o}{R_1} = \frac{M_1}{M_o} \cdot a_1\ ,$$

where a_1 is coefficient of relative change of quality of large-size photograph. After taking into consideration (2), we shall obtain ratio of numerical photographic scale denominators which ensure equal resolution of cameras, i.e.

$$\frac{M_o}{M_1} = a_1 \qquad (5)$$

as well as ratio of surveying altitudes H, i.e.

$$\frac{H_1}{H_o} = \frac{K}{a_1} \qquad (6)$$

As is known, projection of stereopair's plane onto terrain is expressed by

$$S = (1-P_x)\cdot(1-P_y)\cdot l^2 \cdot M^2 \qquad (7)$$

where P_x and P_y are constant coefficients of photographs' lateral and longitudinal overlaps. An increase in productivity can be written as a relation which, after allowing for (1), (5) takes the following form:

$$\frac{S_1}{S_o} = \left(\frac{K}{a_1}\right)^2 \qquad (8)$$

The expressions (6) and (8) show that if $a_1 = K$, i.e. resolution of a large-size aerial photograph decreased by a factor of K and, consequently, angular resolution did not change, then under the conditions given in (2) the altitude of air surveying carried out with a large frame size camera cannot be increased, hence there will be no increase in productivity. On the contrary, if $a_1 = 1$, i.e. resolution of a large-size photograph did not change and angular resolution increased by a factor of K, then altitude of aerial surveying would increase as K^2. The latter case corresponds, according to (5), to aerial surveying at the same scales made with two cameras under comparison i.e. $M_o = M_1$. It appears from the above that numerical value for an improvement in productivity can be found by determining the factors that raise angular resolution as camera frame size is increased.

The resolution of an aerial photograph as is known, is mainly due to the following components:

1. Resolution of lens R_o, which depends on quality of aberration correction only. It is known from the theory of optics that proportional changes of all parameters of a lens do not bring changes in angular resolution. By expressing coefficient a_{1_o} in terms of angular resolution γ_i, namely

$a_{1_o} = \frac{\gamma_1}{\gamma_o} K$, we can find out that in this case

$$a_{1_o} = K \qquad (9)$$

2. Resolution that depends on image motion R_w. Let us use a well-known expression for a resolution element in an image δ_w which is caused by image motion $\delta_w = \frac{W\cdot t}{M}$,

and accept that values of W (speed of a carrier) and t (time of exposure) are constant. So we can write down the following relation: $a_{1w} = \frac{\delta_{1w}}{\delta_{ow}} = K\cdot\frac{H_o}{H_1}$;

if altitudes of surveying are the same, then

$$a_{1w} = K \tag{10}$$

3. Resolution of aerial film R_f. Since the same film is used for both cameras we may accept that

$$a_{1f} = \frac{R_{of}}{R_{1f}} = 1 \tag{11}$$

4. Resolution that depends on lens pupil diffraction, R_d. The value of resolution element due to diffraction phenomena δ_d is calculated from

$$\delta_d = 0.00034 \cdot \rho \cdot (1 + tg^2 \beta)$$

since ρ and β are constant for both cameras, then

$$a_{1d} = \frac{\delta_{1d}}{\delta_{od}} = 1 \tag{12}$$

One can see from (9-12) that had quality of large-size aerial photographs depended on the first two components an increase in frame size (according to (8)) would not bring to an increase in productivity. At the same time if only the last two components have an effect, productivity increases as K^2. Since a_1 coefficient depends on combined influence of all components, the coefficient values cannot be equal neither to one nor to K. Hence if we take $a_1 = K$ we shall not use an opportunity to raise productivity at the cost of increase in frame size. Moreover, if we accept that $a_1 = 1$ (this will be equivalent to surveying at the same scale with two cameras with different frame size) we shall violate the condition (2) and thus increase volume of field interpretation.

To determine quantitative value of the coefficient a_1 we can use an empirical formula that correlates resolution of a photographic image with its components

$$\frac{1}{R} = \frac{1}{R_o} + \frac{1}{R_w} + \frac{1}{R_f} + \frac{1}{R_d}$$

Since $R = \frac{1}{2\delta}$, we shall obtain the folloving:

$$\delta = \delta_o + \delta_w + \delta_f + \delta_d$$

Thus, with respect to two cameras under comparison one may write down the following expressions for resolution elements taking into account expressions (9-12):

$$\Delta_1 = (\delta_o K + \delta_f + \delta_d) \cdot M_1 + \delta_w M_1 , \tag{13}$$

$$\Delta_o = (\delta_o + \delta_f + \delta_d) \cdot M_o + \delta_w M_o \tag{14}$$

Having taken into consideration (2) and (5) and bearing in mind that

$$\delta_{w1} \cdot M_1 = \delta_{wo} \cdot M_o = W \cdot t = const,$$

we shall obtain the following:

$$a_1 = \frac{\delta_o K + \delta_f + \delta_d}{\delta_o + \delta_f + \delta_d} \qquad (15)$$

In addition to the above expressions, let us present formulas (omitting their derivation) that determine relation between general number of aerial photographs n and flight strips n_s which are necessary to survey an assigned terrain area

$$\frac{n_1}{n_o} = \frac{S_o}{S_1} \qquad (16)$$

$$\frac{n_{s1}}{n_{so}} = \sqrt{\frac{S_o}{S_1}} \qquad (17)$$

Besides, we can use the expression (from [1]) which describes relative consumption of film

$$\frac{E_1}{E_o} = a_1^2 \qquad (18)$$

where E is a total area of film required to survey an assigned area of terrain.

To quantify coefficient a_1 we shall take parameters of AFA-TEA-10 stock-produced camera as basic parameters. The camera has 18x18 cm frame size, 100 mm focal length, 100° field of view and 1:6,8 relative aperture. The data of photographic image resolution tests using Type 28 aerial film were employed to derive the following values of resolution elements which are members of expression (15): δ_o = 0,00227; δ_f = 0,00217; δ_d = 0,00556. This base camera was compared with 23x23 cm and 30x30 cm frame size cameras. The resulting coefficients of proportionality K were correspondingly the following: K_{23}= 1,28; K_{30}= 1,67. Thus we obtain from (15) that a_1=1,063 and a_1=1,152.

The changes in initial economic parameters with respect to 18x18 cm frame size base camera are given in Table 1. The parameters were calculated from formulas (8,16-18).

Table 1: Relative changes in initial economic parameters in the process of map revision when frame size is changed

Frame size, cm	$\frac{M_1}{M_o}$	$\frac{H_1}{H_o}$	$\frac{S_1}{S_o}$	$\frac{n_1}{n_o}$	$\frac{n_{s1}}{n_{so}}$	$\frac{E_1}{E_o}$
23x23	0,94	1,20	1,44	0,69	0,83	1,13
30x30	0,87	1,45	2,10	0,48	0,69	1,33

As follows from Table 1, the transition from 18x18 cm to

23x23 cm frame size has the following effects on the process of planimetry revision: when surveying the same area of terrain (resolution of the two cameras is the same) the scale of aerial photograph will be larger by 6% and altitude of surveying can be increased by 20%. The latter raises productivity by approximately 40% hence the number of aerial photographs decreases by 30% and number of flight strips as well as fuel and lubricants consumption decreases by 17%. However consumption of aerial film increases by 13%. In case of transition to 30x30 cm frame size the above mentioned showings increase, correspondingly,by 13, 45, 110, 52 and 31%. Consumption of aerial film increases by 33%.

3. COMPARISON OF CAMERAS WITH RESPECT TO THEIR MEASURING QUALITY

Let us compare two cameras from the standpoint of the second condition. Here we shall use the following formula:

$$m_h = \frac{c \cdot M}{(1-P_x) \cdot l} \cdot m_{\Delta p} \quad , \tag{19}$$

where $m_{\Delta p}$ is error of horizontal parallaxes difference determination. Just like in the previous section let us write the relation;

$$\frac{m_{h1}}{m_{ho}} = \frac{M_1}{M_o} \cdot \frac{m_{\Delta p1}}{m_{\Delta po}} = \frac{M_1}{M_o} \cdot a_2$$

After taking into account (3) we obtain that

$$\frac{M_o}{M_1} = a_2 \tag{20}$$

$$\frac{S_1}{S_o} = \left(\frac{K}{a_2}\right)^2 \tag{21}$$

and by analogy with the previous section

$$\frac{H_1}{H_o} = \frac{K}{a_2} , \qquad \frac{E_1}{E_o} = a_2^2 \tag{22}$$

The expression (21) is similar to the formula (8), but in the first case coefficient a_1 depends on resolution and in the second case it depends on both resolution and metric accuracy of photographic image. That is why just like in the previous case, if $a_2 = K$, i.e. if all linear errors increase proportionally with increase in frame size or if their angular errors remained unchanged, then increase in frame size does not bring forth raise in productivity. However if $a_2 = 1$, i.e. all linear errors of a photographic image remain unchanged,or their angular error decreases by a factor of K , then productivity raises as K^2 .

It is known that the main components that influence accuracy of $m_{\Delta p}$ value determination are: error due to lens distortion ($m_{\Delta pr}$), error due to non-flatness of filter surface ($m_{\Delta pf}$), error due to atmospheric refraction ($m_{\Delta pa}$), error due to non-flatness of film surface ($m_{\Delta pn}$), error due to casual deformation of aerial film ($m_{\Delta pd}$), error of measuring images with a photogrammetric instrument ($m_{\Delta pi}$), error of pointing and image points identification ($m_{\Delta pv}$).

The first three factors are function of angular deviation of light beam. One may assume to a sufficient degree of accuracy that in the case of proportional transformation the total angular value of their errors is constant, hence

$$m_{\Delta pA1} = K\cdot m_{\Delta pAo} \qquad (23)$$

where $m_{\Delta pA}$ is error of horizontal parallaxes difference determination due to angular parameters

$$m_{\Delta pA} = \sqrt{m^2_{\Delta pr} + m^2_{\Delta pf} + m^2_{\Delta pa}} \qquad (24)$$

Linear parameters of the three folloving factors do not change when camera frame size is increased thus their angular values decrease proportionally with K. Thus, for example,casual deformation of aerial film does not depend on the size of the latter and systematic deformation is allowed for within sufficient degree of accuracy. Experience gained in the course of developing cameras with large frame size shows that to achieve flatness of aerial film surface it is necessary to make additional efforts to ensure that residual errors do not exceed those of cameras with 18x18 cm frame size. As for the accuracy of measurements made with photogrammetric instruments, it depends on the accuracy rating of the instruments, not on the size of a frame. Hence we may put down that

$$m_{\Delta pC} = \sqrt{m^2_{\Delta pn} + m^2_{\Delta pd} + m^2_{\Delta pi}} \qquad (25)$$

where $m_{\Delta pC}$ is error of horizontal parallaxes difference determination due to the factors linear values of which remain constant when frame size is changed.

As for the error of pointing and identification, it remains proportional to image resolution and contrast of the image points under observation

$$m_{\Delta pv} = \frac{1}{qR} \qquad (26)$$

If we assume the value of q constant, just like in the previous case, we may write down

$$\frac{m_{\Delta pv1}}{m_{\Delta pvo}} = \frac{R_o}{R_1} = a_1 \qquad (27)$$

Thus the relation between a_2 values for base camera with smaller frame size and a camera with larger frame size can be presented as

$$a_2 = \frac{m_{\Delta p1}}{m_{\Delta po}} = \sqrt{\frac{K\, m^2_{\Delta pA} + m^2_{\Delta pC} + a_1 m^2_{\Delta pvo}}{m^2_{\Delta pA} + m^2_{\Delta pC} + m^2_{\Delta pvo}}} \qquad (28)$$

Let us calculate the values of coefficient a_2. For this purpose, just like in the previous case, we shall use basic parameters of AFA-TEA-10 camera. The values of $m_{\Delta p}$ (in micremeters) presented in Table 2 were calculated according to the technique described in [2]; the values of errors were taken from [3-5].

Table 2

$m_{\Delta pr}$	$m_{\Delta pf}$	$m_{\Delta pa}$	$m_{\Delta pn}$	$m_{\Delta pd}$	$m_{\Delta pi}$	$m_{\Delta pv}$
10	3	5	5	12	4	6

Using the data one can get from (28) that

$$a_{2(23)}=1{,}120 \quad \text{and} \quad a_{2(30)}=1{,}307.$$

Changes in initial economic parameters with respect to base 18x18 cm frame size camera which were calculated from formulas (16,17,20-22), are presented in Table 3.

Table 3: Relative changes in initial economic parameters in the process of map production when frame size is changed

Frame size, cm	$\frac{M_1}{M_o}$	$\frac{H_1}{H_o}$	$\frac{S_1}{S_o}$	$\frac{n_1}{n_o}$	$\frac{n_{s1}}{n_{so}}$	$\frac{E_1}{E_o}$
23x23	0,89	1,14	1,31	0,76	0,87	1,25
30x30	0,76	1,28	1,63	0,61	0,78	1,71

As follows from Table 3, employment of 23x23 cm frame size camera for map production makes it possible to decrease the total number of aerial photographs by 23%, number of flight strips and fuel consumption by 13%. At the same time film consumption increases by 25%. If 30x30 cm frame size camera is employed the above showings increase by, correspondingly, 39 and 22%. Consumption of aerial film increases by 70%.

Theoretical investigation on influence of camera frame size on productivity of air surveying can be used to validate a choice of aerial photograph size.

4. CONCLUSION

Thus it follows from the data presented here that an increase in frame size provides for increase in productivity of surveying, photographic processing and, partially, photogrammetric operations. In the case when productivity is the same, this increase in frame size ensures improvement in accuracy of terrain height determination and resolution. Hence one may say that employment of cameras with larger frame size for photogrammetric surveys is economically justified. At the same time increase in frame size results in additional consumption of film, greater specific consumption of materials (weight) and energy, greater camera dimensions as well as necessity to use carriers with high ceiling.

REFERENCES

I. АФРЕМОВ В.Г.,ИЛЬИН В.Б. Сравнение топографических аэрофотоаппаратов с разными параметрами. Геодезия и картография. № 2, I987, с. 45-47.

2. АФРЕМОВ В.Г.,НЕХИН С.С. Влияние формата кадра аэрофотоаппарата на технико-экономические показатели аэрофотосъёмочного процесса. Геодезия и картография. № 6, I987, с. 34-39.

3. ЛОБАНОВ А.Н. Аэрофототопография. Изд. 2 доп. М.,"Недра", I978, 575 с.

4. Аэрофотоаппараты топографические электронные. ТУ 68-II0-84.

5. КОНШИН М.Д. Ошибки аэроснимков и способы их учета при фотограмметрической обработке одиночных стереопар. Труды ЦНИИГАиК, вып.2I7, М.,I977, с. 78-I0I.