COMPARISON OF AERIAL SURVEY CAMERAS WITH DIFFERENT PARAMETERS

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

ABSTRACT

In the course of aerial surveying operations as well as new aerial cameras development it may be necessary to compare the aerial survey cameras that differ in their design parameters (size and form of frame, field of view, etc) and image characteristics (geometry and resolution). Theoretical investigation of the problem of comparison is presented. The dependencies that make it possible to solve the problem are given. Criteria for the comparison are image characteristics with respect to terrain.

In the course of aerial surveying operations it may be necessary to compare aerial survey cameras that differ in their design parameters (size and form of a frame, field of view, etc) and accuracies. The problem of comparison becomes that of current concern when one has to choose the camera that meets the tasks of an aerial surveying mission.

The main indices that characterize quality and efficiency of aerial surveying and photogrammetric operations are accuracy of terrain points (heights in the first place) space coordinates determination, relation between volumes of field and office interpretation and finally productivity.

Proceeding from the indices one may conclude that aerial cameras are equivalent if they have the same accuracy of space coordinates determination, offer equal opportunities in image interpretation and at the same time ensure equal productivity. Since the opportunities in image interpretation are a function of resolution and both productivity and efficiency of surveying are proportional to projection of a stereopair's space onto terrain, then condition of equivalence can be expressed as

$$m_{ho} = m_{hi}; \quad \Delta_o = \Delta_i; \quad S_o = S_i \qquad (1)$$

where m_h is a RMS-error of terrain point height determination, Δ is element of resolution, S is a projection of stereopair's space onto terrain, index "O" belongs to a base camera and index " i " belongs to the camera which is compared with the base camera.

Reasoning analogously, it is possible to lay down a condition for comparison of cameras. Thus, of the two cameras being compared the better one is the camera that ensures advantage in one of indices (1) but without deterioration in other indices. To express this condition analytically one may use any of equalities (1)

Let us consider two cases of surveying: in the first case surveying is carried out to revise map planimetry, the aim in the second case is map compilation.

In the first case the scale of photographic mission depends on interpretation potentialities, so let us specify the following condition:

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

The condition holds true if the cameras we compare ensure the images that make it possible to distingnish terrain objects of the same dimensions. Actually it means equal volumes of office interpretation.

To find out the relation between scales of air surveys that would satisfy this condition, we shall use a well-known expression

$$\Delta = \frac{M}{2R}$$

where R is a real image resolution obtained under flight conditions, M is a denominator of photographic scale.

Taking into consideration (2) we have

$$\frac{M_i}{M_o} = \frac{R_i}{R_o} \qquad (3)$$

Now let us find relation of photographic missions productivity that corresponds to surveying at the scales that were specified in (3). Here we shall use the following expression:

$$S = (1-P_x)\cdot(1-P_y)\cdot l_{xo}\cdot l_{yo}\cdot M^2 ,$$

where P_x and P_y are, correspondingly, forward and lateral overlap coefficients, l_x and l_y are, correspondingly, lengths of a photograph's side along and across the direction of flight.

Assuming coefficients P_x and P_y are constant with the cameras we compare and taking into consideration (3), let us write down

$$\frac{S_i}{S_o} = \frac{l_{xi}\cdot l_{yi}}{l_{xo}\cdot l_{yo}}\cdot\left(\frac{R_i}{R_o}\right)^2 \qquad (4)$$

To compare the errors in terrain poins heights we shall use the following expression

$$m_h = \frac{M\cdot c}{b}\cdot m_{\Delta p} ,$$

where c is camera focal length, b is scale distance of air base, $m_{\Delta p}$ is RMS-error of forward parallaxes difference determination.

Assuming $P_x =$ const as well and taking into consideration (3) we have

$$\frac{m_{hi}}{m_{ho}} = \frac{l_{xo}}{l_{xi}} \cdot \frac{c_i}{c_o} \cdot \frac{R_i}{R_o} \cdot \frac{m_{\Delta pi}}{m_{\Delta po}} \qquad (5)$$

When comparing aerial cameras with different parameters, the problem of relative consumption of air film should be considered as well. Let us suppose that we must take **n** number of photographs to survey $A_x \times A_y$ size area. Here

$$n = \frac{A_x \cdot A_y}{S} .$$

Thus the total consumption of film E required to survey $A_x A_y$ size area is

$$E = \frac{A_x \cdot A_y}{S} \cdot l_x \cdot l_y .$$

So, taking into account (4) we have

$$\frac{E_i}{E_o} = \left(\frac{R_o}{R_i}\right)^2 . \qquad (6)$$

As for the second case, here we deal with map compilation; the scale of a flight depends on an admissible RMS-error of terrain heights determination, so let us specify the following condition:

$$m_{hi} = m_{ho} .$$

Let us use this condition to find for one thing a relation of surveying scales that provides equal accuracy of terrain points' heights determination and secondly the dependencies that define the relations between accuracy characteristics given in (1). Reasoning in the same way as in the first case we shall have

$$\frac{M_i}{M_o} = \frac{c_o}{c_i} \cdot \frac{l_{xi}}{l_{xo}} \cdot \frac{m_{\Delta po}}{m_{\Delta pi}} \; ; \qquad (7)$$

$$\frac{S_i}{S_o} = \left(\frac{l_{xi}}{l_{xo}}\right)^3 \left(\frac{c_o}{c_i}\right)^2 \cdot \frac{l_{yi}}{l_{yo}} \cdot \left(\frac{m_{\Delta po}}{m_{\Delta pi}}\right)^2 \; ; \qquad (8)$$

$$\frac{\Delta_i}{\Delta_o} = \frac{R_o}{R_i} \cdot \frac{c_o}{c_i} \cdot \frac{l_{xi}}{l_{xo}} \cdot \frac{m_{\Delta po}}{m_{\Delta pi}} \; ; \qquad (9)$$

$$\frac{E_i}{E_o} = \left(\frac{l_{xo} \cdot c_i}{l_{xi} \cdot c_o}\right)^2 \cdot \left(\frac{m_{\Delta pi}}{m_{\Delta po}}\right)^2 . \qquad (10)$$

Employing expressions (3-10) it becomes possible to compare cameras with different parameters and to establish interrelation between productivity of aerial survey operations and main scale-forming factors. All the formulas contain both geometric parameters (camera focal length and frame sizes) and accuracy characteristics (resolution and errors of determination of forward parallaxes difference). The geometric parameters of aerial cameras are known, as for the accuracy characteristics they can be obtained either from results of studies (if the existing cameras are compared) or precomputed (if we have to compare the cameras being designed).

As for specific cases, the relations we derived here will be simpler. Let us consider some of them.

1. Cameras with the same square frames but different focal lengths and fields of view are compared. In this case we can write down with respect to geometric parameters

$$l_{xi} = l_{yi} = l_{xo} = l_{yo} \quad \text{and} \quad \frac{c_i}{c_o} = K_1 ,$$

and with respect to accuracy characteristics

$$\frac{R_i}{R_o} = a_1 \quad \text{and} \quad \frac{m_{\Delta po}}{m_{\Delta pi}} = a_2 .$$

It is known that if $c_i > c_o$ then $a_1 > 1$ and $a_2 > 1$. Hence formulas (3-6) will take the form

$$\left.\begin{aligned} &\frac{M_i}{M_o} = a_1 > 1; && \frac{S_i}{S_o} = a_1^2 > 1 \\ &\frac{m_{hi}}{m_{ho}} = \frac{K_1 \cdot a_1}{a_2}; && \frac{E_i}{E_o} = \frac{1}{a_1^2} < 1 \end{aligned}\right\} \qquad (11)$$

Analysis of the formulas (11) shows the following. If surveying is carried out with the purpose of map planimetry revision then employment of long focal length cameras is economically advisable since in this case productivity is increased and film consumption is decreased. The upper limit of increase in depends on possible altitude of photography. The accuracy of terrain points height determination, which in this case is not this much important, depends on coefficients K_1, a_1, and a_2. If $K_1 \cdot a_1 < a_2$, then the accuracy of heights determination (in case long focal length camera is employed) improves, and vice versa, if $K_1 \cdot a_1 > a_2$ then the accuracy deteriorates.

When surveying is carried out with the purpose of map compilation, the abovementioned formulas (7-10) are transformed as follows:

$$\left.\begin{aligned} \frac{M_i}{M_o} &= \frac{a_2}{K_1}; & \frac{S_i}{S_o} &= \left(\frac{a_2}{K_1}\right)^2 \\ \frac{\Delta_i}{\Delta_o} &= \frac{a_2}{a_1 K_1}; & \frac{E_i}{E_o} &= \left(\frac{K_1}{a_2}\right)^2 \end{aligned}\right\} \qquad (12)$$

An analysis of the factors that bring forth geometric errors in an aerial photograph gives us a good reason to believe, that if frame size is constant and camera focal length is increased within $K_1 \leqslant 2$ limits then a_2 value is rather close to K_1 value. Thus it follows from (12) that equal errors of terrain points heights measurements can be obtained for close photographic scales under practically the same productivity and consumption of aerial film. However employment of long focal length cameras provides in this case greater resolution. Nevertheless these conclusions are subject to further refinement since the problem of relation between a_2 and K_1 values requires an experimental check.

2. Aerial cameras with the same fields of view but different focal length and dimensions of square frame. The geometric parameters of aerial cameras in this case obey the following dependencies:

$$l_{xi} = l_{yi} = K_2 \cdot l_{xo} = K_2 \cdot l_{yo}; \qquad \frac{c_i}{c_o} = K_2;$$

As for the accuracy characteristics, let us assume that

$$\frac{R_o}{R_i} = a_3 \quad \text{and} \quad \frac{m_{\Delta pi}}{m_{\Delta po}} = a_4 .$$

According to theoretical studies, if $c_i > c_o$, then $1 < a_3 < K_2$ and $1 < a_4 < K_2$.

Formulas (3-6) acquired for the case of map revision will take on the following form:

$$\left.\begin{aligned} \frac{M_i}{M_o} &= \frac{1}{a_3} < 1; & \frac{S_i}{S_o} &= \left(\frac{K_2}{a_3}\right)^2 > 1 \\ \frac{m_{hi}}{m_{ho}} &= \frac{a_4}{a_3}; & \frac{E_i}{E_o} &= a_3^2 > 1 \end{aligned}\right\} \qquad (13)$$

Besides, when aerial cameras with different frame sizes are compared it is expedient to give ratios of altitudes of photography **H**

$$\frac{H_i}{H_o} = \frac{K_2}{a_3} > 1 \tag{14}$$

In case surveying is carried out with the purpose of map compilation, the formulas (7-10) are transformed as follows

$$\left.\begin{aligned} &\frac{M_i}{M_o} = \frac{1}{a_4} < 1 \; ; \qquad && \frac{S_i}{S_o} = \left(\frac{K_2}{a_4}\right)^2 > 1 \\ &\frac{\Delta i}{\Delta o} = \frac{a_3}{a_4} \; ; && \frac{E_i}{EE_o} = a_4^2 \quad > 1 \end{aligned}\right\} \tag{15}$$

Besides

$$\frac{H_i}{H_o} = \frac{K_2}{a_4} > 1 \tag{16}$$

An analysis of the expressions (13-16) shows that an increase in frame size brings forth an increase in altitude of photography and scale of surveying. As a result productivity is improved, but simultaneously aerial film consumption grows. However the increase in altitude of photography with respect to the case of map compilation may be advantageous according to (16) if $a_3 \leqslant a_4$. Otherwise an improvement in productivity may cause an increase in volume of field interpretation since it will be found that $\Delta_i > \Delta_o$.

Let us conclude that this report comprises the main principles for comparison of aerial cameras used for topographic surveys. Whenever a particular case is considered, the numerical relation between K and **a** values must be established which is subject to an independent investigation.