EVALUATION OF AERIAL PHOTOGRAPHS TAKEN BY FORWARD MOTION COMPENSATION CAMERAS

Nekhin S.S.,Afremov V.G.,Ilin V.B., Afanasiev I.Yu.,Babashkin N.M.,
Central Scientific Research Institute of Geodesy, Air Survey and Cartography (CNIIGAiK)

Moscow, Russia

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ABSTRACT:

Results of ground and flight tests of TK-10/18 (USSR) and LMK-15/23 (FRG) forward motion compensation cameras are presented. Standard radial distortions (average by zone) and resolving power of wide-angle lens obtained with normal-type (T-42) film and high-resolution type (T-38) film under laboratory conditions are given. Resolving power of the same surveying systems with same types of films was also determined under flight conditions by high contrast test targets. Measuring properties of the systems were estimated by test area photographs. Influence of lateral and forward motion of images upon measuring and image properties of photographs is considered.

KEY WORDS: Accuracy, Camera, Film, Image Quality, Resolution.

1. INTRODUCTION

Efficiency of air surveying techniques to no small degree depends on quality of aerial photographs taken in the process of surveying, i.e. on measuring and image properties of the photographs. The properties in their turn depend on three main components, namely: 1) aerial camera; 2) aerial film; 3) conditions under which photographing and subsequent film processing take place. At the same time, the components are not independent since they have certain effect upon one another. For instance, choice of aerial film depends on peculiarities of camera design; conditions of both photographing and chemical photographic treatment depend on the type of aerial film.

Therefore, three ways towards improvement of aerial surveying process can be singled out:
- development of aerial cameras with better performances with respect to camera lens resolution and distortion, film flattening, system of forward motion compensation (FMC), automatic exposure control (AEC), camera stabilization, etc.;
- prevision of an optimum type of aerial film with respect to its speed, resolving power, gamma, systematic and random component of deformation of film base, etc.;
- determination of optimum conditions for photographing (carrier, illumination, light filter, etc.) and for chemical photographic processing.

2. LABORATORY TESTS

Central Research Institute of Geodesy,Air Survey and Cartography together with Experimental Optomechanical Works of "Aerogeodesiya" Air Surveying and Geodetic Enterprise developed AFA-TK-10/18 forward motion compensation camera [1] . The main specifications of the camera are given in Table 1. The specifications are presented together with analogous data on LMK-15/23 camera.

Table 1

Main specifications of cameras

Parameters of camera \ Camera	TK-10/18	LMK-15/23
Frame size, cm	18x18	23x23
Focal length, mm	100	153
Angle of view,degre	103	92
Relative aperture	1:6.8	1:4.5
Distortion, μm	4	4
Minimum resolution, mm^{-1}	40	50(AWAR)
Exposure range, s	2,5	2,1
FMC and AEC systems	available	available
Film flattening method	vacuum	vacuum

When considering the resolution values given in Table 1 it should be noted that with respect to TK-10/18 camera minimum resolution at the film edge determined from high-contrast test target is given and with respect to LMK-15/23 camera area-weighted average resolution (AWAR) value is given.

Some parameters of the cameras were tested under laboratory conditions. Radial resolution values for TK-10/18 and LMK-15/23 cameras are given in Fig.1. The values were determined for T-38 (continuous line) and T-42 (dotted line) types of aerial film. The main characteristics of the two types of film are presented in Table 2.

As follows from Fig. 1, radial resolution at the edge and in the middle zone of a frame (β = 25°-30°) is practically the same with both cameras no matter whether T-38 or T-42 type of film is used. Resolution in the central part of a frame exposured by LMK-15/23 camera is 1.2 higher than in the central part of a frame expo-

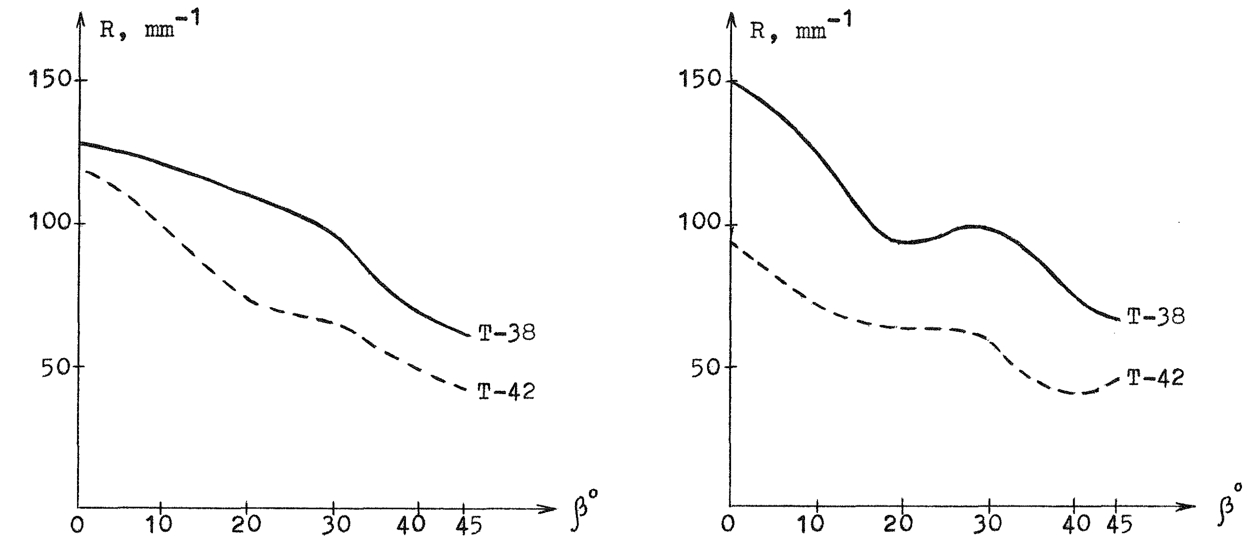

Fig. 1. Resolution of TK-10/18 and LMK-15/23 cameras

Table 2

The main characteristics of T-38 and T-42 film

Film parameters	Type of film	
	T-38	T-42
Speed:		
- GOST (All-Union State Standard) units	260	1100
- ASA units	320	1350
- DIN units	26	32
Gamma, γ	2.1	1.8 - 2.3
Foy density	0.12	0.25
Resolution R, mm^{-1}	260	110
Thickness of base, μm	80	160

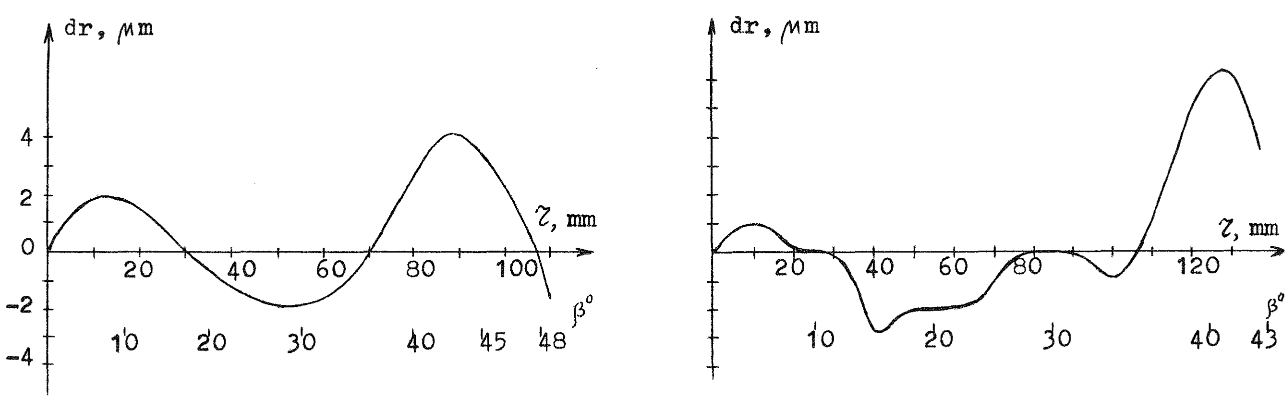

Fig. 2. Distortion (average by zone) of TK-10/18 and LMK-15/23 cameras

sured by TK-10/18 camera when T-38 type film is used; however when T-42 type film is used the resolution is approximately 1.3 times higher with TK-10/18 camera.

Plots representing laboratory determinations of TK-10/18 and LMK-15/23 normal radial distortion (average by zone) within angles of view β 48° and 43° are presented in Fig. 2. Maximum distortion value for TK-10/18 and LMK-15/23 cameras is, correspondingly, 4 μm and 6 μm.

Unlike laboratory conditions, quality of photography under field conditions is influenced by several additional factors, including speed of aircraft, vibration, meteorological conditions etc. Hence evaluation of aerial cameras measuring and image quality under flight conditions are of special interest.

3. DETERMINATION OF AERIAL PHOTOGRAPHS IMAGE QUALITY

Evaluation of aerial photographs and camera image quality was performed by photographing test targets using T-38 and T-42 type panchromatic films. The photography was made at 1:3000, 1:5000, 1:10000, 1:15000 scales and at exposures from 1/50 to 1/400 s. Besides, the aerial cameras were operated in two modes: forward motion compensation and forward motion non-compensation mode. AN-30 aircraft was used as the cameras carrier. The aircraft was passing over the test targets at the speeds varying from 300 to 360 kmph to achieve different degree of image motion. The flight paths were laid out in such a manner that images of test targets fall to different parts of images and bars of the test target are aligned both along and across the direction of flight.

The films obtained in the course of aerial surveys were being developed until satisfactory images of terrain objects appeared. Resolution of the aerial films was determined from images of test targets by viewing them through a microscope at 10^x magnification. In the course of viewing we singled out the last group of stripes in which each bar could be seen separately. Depending on the number of the group, we estimated resolution of images within the range of 10 mm^{-1} to 70 mm^{-1} in 5 mm^{-1} steps. Accuracy of resolution estimation was 10%. Average value of resolution at the edges and in the central part of images was calculated for each exposure time. Results of image resolution determinations averaged for exposure ranges are presented in Tables 3 and 4. Data in the tables are given in the form of fractions; numerator and denominator of the fractions mean resolution values (mm^{-1}) determined correspondingly from longitudinal and lateral stripes of test targets.

Analysis of data from Tables 3 and 4 as well data of tests made it possible for

Table 3

Resolution of TK-10/18 camera with different types of aerial films

Type of film	Exposure, s	Availability of FMC	Resolution (mm^{-1}) when bars are oriented along (numerator) and across (denominator) the direction of flight at scales			
			1:3000	1:5000	1:10000	1:15000
T-38	1/50 - - 1/90	-	21-35 / 10-15	15-37 / 10-18	30-50 / 20-30	45-62 / 30-45
		+	14-35 / 25-35	22-63 / 27-63	30-62 / 20-56	45-75 / 35-45
	1/170 - - 1/200	-	30-42 / 15-28	15-60 / 15-25	35-50 / 20-40	45-68 / 40-60
		+	30-42 / 25-35	15-63 / 15-60	35-65 / 20-60	46-77 / 46-62
T-42	1/50 - - 1/90	-	21-35 / 6-20	15-30 / 10-15	30-35 / 20-30	
		+	10-35 / 10-27	10-40 / 15-35	30-35 / 20-35	
	1/120 - - 1/160	-	18-36 / 10-21	28-35 / 10-17	35-45 / 30-45	
		+	30-42 / 24-42	35-50 / 35-50	35-52 / 30-45	
	1/300 - - 1/400	-	30-42 / 30-42	27-50 / 22-40	30-50 / 30-40	
		+	30-42 / 30-42	31-55 / 25-42	30-62 / 30-50	

us to draw the following conclusions.

The increase in resolution of aerial images on T-38 type film as compared to T-42 type film under real surveying conditions was not always as considerable as it was under laboratory conditions due to vibrational movements of image.

As it was expected, forward motion compensation to improved resolution of images, especially in case of long exposures (the improvement can be clearly seen on the images of test targets with lateral stripes). If 1/350 - 1/400 s exposures were set, the influance of forward motion upon image resolution was weak and efficiency of FMC decreased considerably; besides the influance of lateral (vibrational) image motions was also decreased. However,

Table 4

Comparison of TK-10/18 and LMK-15/23 cameras resolution when T-42 type film is used

Camera	Exposure, s	Availability of FMC	Resolution (mm^{-1}) when bars are oriented along (numerator) and across (denominator) the direction of flight at scales	
			1:3000	1:5000
TK-10/18	1/50 - 1/60	+	10-35 / 10-27	10-40 / 10-35
	1/120 - 1/175	+	30-42 / 24-42	25-50 / 25-50
	1/350	+	30-42 / 30-42	35-50 / 25-41
LMK-15/23	1/50 - 1/60	+	17-30 / 10-25	15-35 / 10-35
	1/120 - 1/175	+	30-41 / 25-35	30-50 / 20-40
	1/350	+	30-50 / 30-40	30-50 / 25-45

when 1/50 s to 1/60 s exposures were set, image motions took place, although FMC system was employed. When FMC system was not used, images of test targets with lateral stripes were blurred practically in all cases.

Maximum resolution value of TK-10/18 camera with respect to longitudinal stripes of the test target is 77 mm^{-1} when surveying is performed with forward motion compensation at 1:15000 scale and 1/200 s exposure; minimum of the camera resolution with respect to lateral stripes is 10 mm^{-1} when surveying is performed both with and without image motion compensation at 1/50 s to 1/60 s exposures, thus demonstrating considerable influence of vibrational motions. Therefore, to increase resolution of aerial images we must employ not only forward motion compensation systems but high-effective platforms as well, capable of damping both high- and low-periodic oscillations and vibrations of camera carrier.

If we consider all the variants of scales and exposures then, as follows from Table 4, resolution of both TK-10/18 and LMK-15/23 cameras is practically the same when T-42 type film is used.

4. DETERMINATION OF MEASURING PROPERTIES OF AERIAL PHOTOGRAPHS

Measuring properties of aerial photographs taken by TK-10/18 and LMK-15/23 cameras were determined by surveying a test area at 1:3000, 1:5000 and 1:10000 scales. To take the images T-38 and T-42 types of film were used; the test area was photographed at different exposures with and without forward motion compensation. The test area was a 2.0 km x 2.4 km parcel of even terrain. There were 340 points in the test area, their coordinates were determined geodetically to a high degree of accuracy (2.5 cm horizontal and 0.5 cm vertical accuracy). The points were marked in the form of Maltese cross, each ray of the cross formed an isosceles triangle; the base and height of such triangle were equal correspondingly to 0.5 m and 1.0 m.

Point coordinates in the images (negatives or positives) were measured by high-accuracy instruments, namely by Stecometer stereocomparator together with Onega-2 automated recording and processing system and by Stereoanagraph analytical instrument. About 40 points evenly dispersed over a stereopair area were measured every 2 cm. Relative orientation in the course of mathematic processing was performed using all the measured points, the absolute orientation was made using four points located in the corners of the stereopair. Error of geometrical distortions determination was equal to 10-12 percent. Characteristics of the materials used and results of photogrammetric processing of aerial photographs taken by TK-10/18 and LMK-15/23 cameras are presented in Table 5.

As can be seen from the results, the type of photographic material (negative, positive) does not produce a significant influence on the accuracy of photogrammetric processing. One can see higher accuracy of photogrammetric models when aerial photographs at 1:10000 scale were used in comparison to that at 1:3000 and 1:5000 scales (provided image motion value is the same); this can be explained by better conditions of stereoscopic viewing to images of marked points in the test area and by smaller effect of errors of geodetic points coordinates determination.

As follows from Table 5, compensation of forward image motion makes possible to improve the accuracy of photogrammetric determinations of coordinates 1.1 to 1.5 ti-

Table 5

Results of photogrammetric processing of test area photographs

Camera	Type of film	Scale of image	Variant	Exposure 1/t, s	Amount of motion, mm	Use of FMC	Accuracy		
							$m_{x,y}$, μm	m_h, cm	m_h : H
TK-10/18	T-38	1:3000	1	1/60	0.19	-	12.4	3.4	1:8900
			2	1/60	0.21	+	10.5	3.2	1:9500
		1:5000	3	1/60	0.17	-	10.8	4.3	1:11600
			4	1/60	0.17	+	9.9	4.0	1:12800
		1:10000	5	1/60	0.13	-	11.1	7.7	1:11000
			6	1/60	0.13	+	7.3	5.6	1:17800
			7	1/300	0.03	-	7.5	6.8	1:14700
			8	1/300	0.03	+	7.0	5.1	1:19500
	T-42	1:3000	9	1/100	0.16	-	13.8	4.2	1:7200
			10	1/100	0.16	+	13.2	3.6	1:8400
		1:5000	11	1/100	0.07	-	13.9	6.2	1:8100
			12	1/100	0.07	+	10.6	5.3	1:9500
		1:10000	13	1/70	0.13	-	12.5	12.1	1:8700
			14	1/70	0.13	+	9.7	9.7	1:10500
			15	1/300	0.03	-	9.4	9.9	1:10100
			16	1/300	0.03	+	7.8	8.3	1:12100
LMK-15/23	T-38	1:3000	17	1/100	0.20	-	15.6	4.1	1:9800
			18	1/100	0.20	+	13.4	3.4	1:13200
		1:5000	19	1/200	0.10	-	12.8	5.4	1:13900
			20	1/200	0.10	+	10.1	5.0	1:15000
		1:10000	21	1/200	0.04	-	10.5	9.2	1:16300
			22	1/200	0.04	+	8.3	8.0	1:18700
	T-42	1:3000	23	1/200	0.10	-	16.8	5.1	1:8800
			24	1/200	0.10	+	15.2	3.2	1:14200
		1:5000	25	1/300	0.07	-	14.9	7.1	1:10600
			26	1/300	0.07	+	13.1	6.2	1:12100
		1:10000	27	1/300	0.03	-	12.4	12.2	1:12300
			28	1/300	0.03	+	11.2	12.3	1:12200

mes (depending on the value compensated and type of aerial film). The amount of image motion determines not only the degree of errors of photogrammetric model coordinates (see variants 5 and 7, 13 and 15) but efficiency of compensation (expressed as residual errors, see variants 14 and 16) as well. The residual errors also point at the presence of vibrational or lateral motion in addition to forward motion (variants 6 and 7, 14 and 15).

As for the results of camparison of films, higher resolution of T-38 type film, as was expected, provided higher accuracy of photogrammetric models. At the same time, in case of long exposures, hence greater image motion, this type of film has no advantage since forward motion compensation system neutralizes negative effect of lateral and vibrational movements.

When accuracies of photogrammetric determinations in the images taken by TK-10/18 and LMK-15/23 cameras compared then the accuracies of heights occur almost the same if we take into account different frame sizes of the cameras [2] (in some cases relative values of m_h : H with LMK-15/23 camera is somewhat higher due to greater f_c). Accuracy of plane coordinates is slightly higher with TK-10/18 camera (variants 2 and 18, 8 and 22, 12 and 26, 16 and 28) though LMK-15/23 frame size is more effective.

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