MICROLIGHT AIRCRAFT FOR LARGE-SCALE AERIAL SURVEYING

Afremov V.G.,Nekhin S.S.,Central Scientific Research Institute of Geodesy, Air Survey and Cartography (CNIIGAiK)

Vanin A.G., Air Surveying and Geodetic Enterprise

Moscow, Russia

Mirkin V.A., Air Surveying and Geodetic Enterprise of Uzbek Republic

Tashkent, Uzbek Republic

Commission I

ABSTRACT:

Problems related to selection of microlight and efficient platform of aerial surveying camera intended for quality photography of small fields are discussed. Capabilities and specifications of manned and remotely piloted microlight carrier with and without power unit are analysed.Results of air surveys carried out by a hang glider with power unit equipped with a topographic 18x18 cm frame size aerial camera intended for large-scale mapping are given. Economic expediency and prospects of employing engine-powered hang glider for aerial surveying of small fields are stressed.

KEY WORDS: Accuracy, Camera, Cartographic, Mapping.

Implementation of civil engineering,prospecting, digging and other projects have recently caused an increase in demand for aerial surveying of selected parts of terrain and linear objects to compile large-scale topographic maps (1:500 - 1:5000) with small contour intervals. The increase in demand can be explained by the fact that currently prevailing geodetic techniques require considerable expenditure of labour and time. Employment of conventional aviation (airplanes and helicopters) for the large-scale mapping of small areas which are separated from one another by considerable distances is not profitable due to high cost and low efficiency of such surveying. Besides, in some cases aviation cannot be used at all because of limitations in speed and/or altitude of flight.

The abovementioned circustances promoted development of microlight aircraft (MLA). Employment of the aircraft for large-scale surveying makes it possible to considerably cut expenditure with the whole process of large-scale mapping owing to low cost of air camera carrier and decrease in expenses of its maintenance and operation. Low speed and altitude of MLA enables us to have images at any large-scale and of required photographic quality. An important advantage of MLA is decrease in duration of photogrammetric surveying operations owing to prompt production of surveying materials directly by field parties since any such party can employ a MLA thanks to its low cost and simplicity of maintenance.

Many types of MLA are commercially produced worldwide nowadays. All of them can be divided into two main classes: remotedly piloted and manned MLA.

The remotedly piloted planes and helicopters are small-size vehicles; they usually have a fuselage of approximatele 1.5 m long, wing span up to 2.5 m, payload equal to about 3 kg, operating height of flight up to 0.5 km, range of controlled flight up to 2 km and flying speed from 30 to 100 kmph. The specifications like these limit the weight of an air camera mounted on MLA to not more than 3 kg,hence making it necessary to use small frame-size (6 cm x 6 cm) non-metric cameras.Due to the characteristic properties of such cameras they can be used for timely aerial surveying of small areas covering approximately 1 sq. km, such as construction sites, plants, open pits, architectural monuments and other objects.

The manned MLA (airplanes and engine-powered hang gliders) are preferable when aerial surveying is performed for the purpose of large-scale mapping. A manned MLA is usually a collapsible structure with payload up to 190 kg, operating height not more than 4 km, flying range up to 180 km and cruising speed about 70 kmph. An apparatus like this is capable of carrying a camera system that weighs more than 100 kg, thus making it possible to employ conventional air cameras equipped with an autonomous vacuum system, a drive unit, a camera mount together with simple navigational equipment.

Of all the remotedly piloted MLA, engine-powered hang gliders have the most economical and simplest design; there are also developed procedures of operation and maintenance of the carriers.

The world practice demonstrates that piloted MLA are usually equipped with small frame size cameras of various design. However the technical performances of this type of carriers allow to use large frame size cameras (e.g. 18cm x 18 cm), thus making it possible to considerably improve accuracy and efficiency of photogrammetric surveying operations.

In this connection let us discuss technical-and-economic performances of air cameras with different frame sizes when they are used for large-scale photogrammetric surveys. If the largest scale (1:500) map with 0.25 m contour intervals is to be compiled, then according to the specifications currently in force, the air surveying with cartographic 18 cm x 18 cm frame size cameras should be carried out at 1:3000 scale to provide 10 cm accuracy of plane coordinates determination (this accuracy corresponds to 0.2 mm at map scale, the limited value being 0.4 mm) and accuracy of heigths determination in the order of 8 cm ($1/3\ h_c$). The figures at the image scale correspond to: $m_s = 33$ m, m_h:H=1:3800 (when f_c= 100 mm).

If a small frame size camera (e.g. 6 cm x 6 cm) is used and we want to have productivity (i.e. area coverage) compared to that of topographic 18 cm x 18 cm frame size cameras, then the former must have such parameters that would enable us to carry out surveying at a scale not larger than 1:9000 (at the same field of view angle or f_c= 33 μm). In this case m_s must not exceed 11 μm. This error depends on several factors and can be divided into three groups:
- geometric errors of surveying system (camera plus film);
- errors due to geodetic control;
- errors related to image points identification and measurement.

Assuming that errors of each group have equal influence, the errors of the first group must not exceed 11//3 = 6.4 μm. This level of accuracy is practically unachievable even if all sources of errors are allowed for, since total error due to film deformation and non-flatness alone may exceed the above value to say nothing of another error sources.

Stringent requirements must also be specified for resolution of 6 cm x 6 cm air photographs since instead of six-fold image to map ratio there must be eighteen-fold ratio, but the latter is practically unachievable.

The required accuracy of aerial photographs taken with a small frame size camera may by ensured by surveying at a scale much larger than 1:9000. At the same time, employment of such scale results in decrease of aerial techniques efficiency (the amount of horizontal/vertical control, signalling, photographic and photogrammetric processing is increased due to greater number of photographs).

Hence, the large-scale photogrammetric surveys intended for timely provision of 1:500 to 1:5000 scale map coverage of small and separeted areas are economically advisable to carry out by means of engine-powered hang gliders equipped with not less than 18 cm x 18 cm frame size aerial camera. That is why the Central Research Institute of Geodesy, Air Survey and Cartography in cooperation with Moscow Institute of Civil Aviation Engineers have developed an air surveying engine powered hang glider system (MDPA) that consists of "POISK-6" hang glider and air surveying equipment.

The "POISK-6" hang glider is a flying vehicle that consists of a flexible wing, a suspension system with pilot's seat and undercarriage, a power unit, a fuel tank and an instrument board with aneroid altimeter, rate-of-climb indicator, magnetic compass, etc. The power unit of the hang glider is designed to run on automobile fuel and lubricants. The hang glider has the following performances:
- maximum take-off weight is 360 kg; full load weight including weight of a pilot and surveying equipment is 180 kg (without the equipment the hang glider can be used as two-man flying vehicle);
- 29 kW engine, type RMZ-640M; depletion of the fuel is 15 litres per hour;
- wing area is 19.7 sq.m and wing span is 10.4 m;
- flight range at full load is 120 km; cruising speed is from 60 to 70 kmph;
- flight altitudes envelope is from 50 to 3000 m, range of flying speeds is from 40 to 130 kmph;
- take-off run is from 40 to 50 m.

Hence, as it can be seen from the above performances (full load weight, flight altitudes, flight range and speeds), the "POISK-6" hang glider meets all the requirements specified for large-scale topographic surveys and special-purpose surveys of limited areas.

The hang glider is usually equipped with AFA-TE aerial camera; the camera has 18 cm x 18 cm frame size and 70 mm, 100 mm, 140 mm or 200 mm focal length (depending on requirements specified for aerial photographs). Besides KPT-3 drive unit, an aneroid altimeter, a rate-of-climb indicator and a two-way radio communication device are mounted on the hang glider. The research and tests that had been carried out previously made it possible to introduce some improvements into the equipment thus enabling us to increase heading stability of the carrier, to decrease angle of swing, to keep an assigned orientation of air camera during surveying flight, to ensure reliable film flattening under conditions of weak air flow (due to low speed of the carrier), to replace bulky power supply system of the air camera by a lower weight and campact system, etc.

During the recent years we accumulated certain experience in aerial surveying by means of MDPA. The surveying is carried out under quite atmospheric conditions either as multistrip aerial surveys or as single-strip surveys of linear objects. Photography is made at various altitudes and at the scales from 1:6000 to 1:1500 using black-and-white film. Flying in this case is carried out along assigned routes; the routes are specified by means of a map (usually at 1:10000 scale) to ensure 40 per cent lateral overlap. Forward overlap is assigned to be equal to 90 (or 80) per cent so that the required 60 per cent overlap be always ensured in spite of any instability of forward motion of the carrier. Signals laid on the ground in the form of stripes serve as entrance and exit reference points for each route. Chemical/photographic processing of aerial films and evaluation of their photographic and photogrammetric quality are carried out in a field laboratory.

The main qualitative characteristics of aerial photographs obtained by MDPA are given in Table 1.

Table 1

Characteristics of aerial photographs obtained by MDPA

Ser. No	Characteristics	Numerical value
1.	Deviation of actual axes of routes from the lines drawn on the map	2 to 4 per cent
2.	Linear image motion (at the image scale)	0.01 to 0.05 mm
3.	Deviation of flight altitude from an assigned value	10 to 15 m
4.	Deviation of longitudinal overlap of photographs from the assigned 60 per cent value	up to 10 per cent
5.	Deviation of lateral overlap of photographs from the assigned value (40 per cent)	up to 20 per cent
6.	Angles of image tilt	up to 5°-6°
7.	Lack of parallelism between photo base and side of photograph	10° to 12°
8.	Unsharpness of image at 6^x to 8^x	must be absent

In early 1990 MDPA described here was passed for operation to Air Surveying and Geodetic Enterprise of Uzbek Republic. The Enterprise used it for photogrammetric surveying at 1:2000 and 1:1000 scales. Materials of the surveys were employed for implementation of civil engineering, prospecting and other projects. The MDPA was passed together with "Service and Technical Manual" that specified surveying process according to technological diagram presented below in Fig.1.

In May 1990 the MDPA was used to survey an industrial site that occupied an area of 10 sq. km. The surveying was carried out to compile topographic maps at 1:2000 scale with 0.5 m contour intervals. The process of photography was planned to provide 90 per cent longitudinal overlap and 40 per cent lateral overlap. After selection of photographs obtained, the actual longitudinal overlap was found to vary from 58 to 78 per cent and the lateral overlap from 20 to 42 per cent. Non-linearity of flight routes varied from 1.5 to 4 per cent. Quality of aerial negatives by visual evaluation was found to be satisfactory.

Signalling of targets, determination of their vertical/horizontal coordinates and analytical phototriangulation were performed in the surveyed area. Three routes comprising 38 photographs were selected for photogrammetric processing. Values of fore-and-aft (α) and lateral (ω) angles

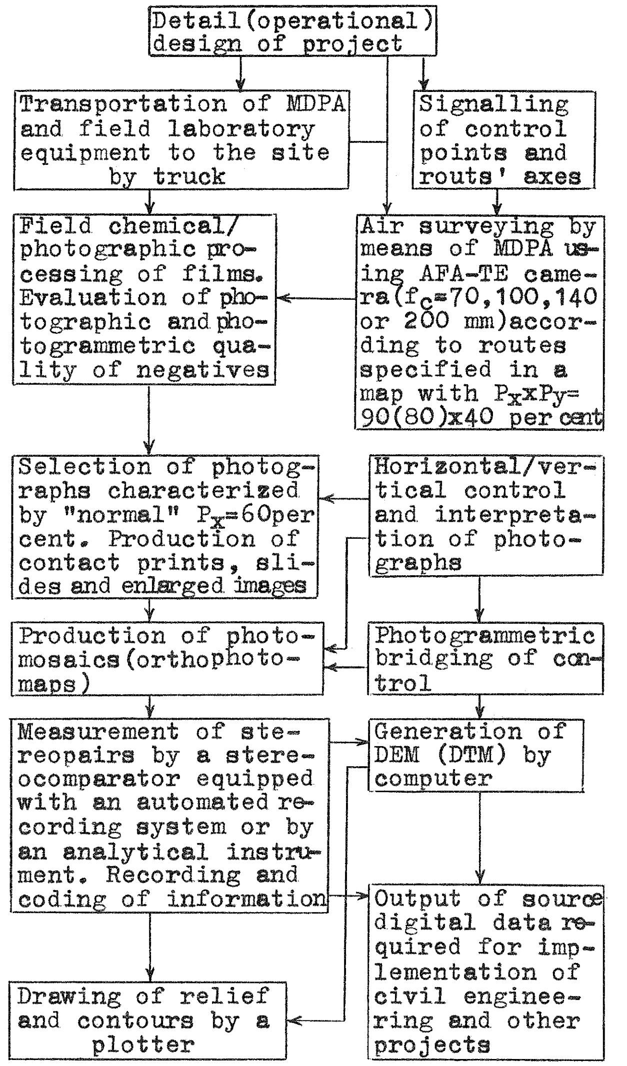

Fig.1. Technological diagram of photogrammetric surveying process by means of MDPA

of tilt obtained during photogrammetric processing of photographs by a stereocomparator and "ONEGA-2" automated recording and processing system as well as values of angles of turn ($\varkappa$) obtained in the process of mosaic assembly were determined. As can be seen from the Table 2, maximum values of fore-and-aft angles of titl amount to 5°46! Out of 38 photographs, 11 have angles of tilt more, than 4°(29 per cent) and 3 photographs have angles of tilt more than 5° (3 per cent). Besides, if we consider fore-and-aft angles of tilt, a systematic component can be singled out, e.g. all the angles in photographs belonging to the second route have a positive sign. Hence, according to the parameters described above, greater part of photographs is suitable for processing, even when widely spread analog instruments are used.

It should be noted that in comparison with test flights made in 1988 and 1989, the flight described here yielded higher quality materials. Thus, 30 per cent of all the photographs taken during a 1989 flight had angles of tilt greather than 5°

Table 2

Values of tilt and image turn angles

Indicators	Values of tilt and image turn angles								
	Route 1 (15 images)			Route 2 (14 images)			Route 3 (9 images)		
	α	ω	κ	α	ω	κ	α	ω	κ
Minimum	-0°04'	+0°30'	+1°30'	+0°08'	-0°06'	0°00'	+0°38'	+0°01'	0°00'
Maximum	-3°06'	+6°18'	+7°50'	+5°46'	+5°50'	-12°00'	-2°46'	-3°19'	-10°00'
Average	1°19'	2°48'	3°23'	2°43'	2°38'	4°36'	2°03'	1°10'	4°05'

After completion of photogrammetric bridging, stereoplotting of relief and outlines was made using STs-1 analog instrument. The stereoplotting was performed to produce topographic map at 1:2000 scale and 0.5 m contour intervals (aerial photographs with angles of tilt greater, than 4° - 4°5 were processed by a stereocomparator equipped with a device to automatically record measuring data). We selected a site within the surveyed area to carry out check on the ground. The site occupied 33 hectares and was typical of irrigated agriculture zone of Uzbekistan. Within the site there was a rural populated place with sporadic one-storey development, ramified irrigation system and availability of orchards and vineyards. The relief of the site was hilly with a number of artificial features.

The check on the ground consisted in determination of errors in planimetric position of map features and in estimation of accuracy of relief stereoplotting using geodetic techniques.

Planimetric position was checked by measuring distances from check points to clearly-defined outlines as well as by measuring distances between elements of situation (clearly-defined outlines) all over the site. Data on checks of planimetric position of outlines are given in Tables 3 and 4. The average error of planimetric position with respect to geodetic control was 0.9 m or 0.45 mm at the map scale, with tolerance equal to 0.5 mm; the maximum error was 2.0 m.

Table 3

Position with respect to geodetic control

Distribution of differences measured on the ground and on the map	
Interval, mm	Quantity, per cent
0 - 0.25	12.5
0.26 - 0.50	62.5
0.51 - 0.75	6.2
0.76 - 1.00	18.8

The average error of relative position of outlines was 0.72 m or 0.36 mm at the

Table 4

Relative position of elements of situation

Distribution of differences measured on the ground and on the map	
Interval, mm	Quantity, per cent
0 - 0.20	32.7
0.21 - 0.40	49.0
> 0.41	18.3

map scale, with the tolerance equal to 0.6 mm. All the measurements of buildings and distances between them (by buildings we mean solid structures) yielded data that differed from those derived from the map by not more than 0.8 m, i.e. they did not exceed 0.4 mm tolerance at the map scale.

Checking of relief stereoplotting was performed by geodetic techniques, i.e. by determination of points' heights with respect to heights of check points. Six to twelve test points were determined with respect to each check points (all in all 67 test points). The results are presented in Table 5.

Table 5

Checking of points'height determination

Differences between test points as defined from the map and on the ground	Quantity,per cent
0 - 0.20	47.8
0.21 - 0.40	28.4
0.41 - 0.60	19.4
> 0.61	4.5

The average difference between points on the map and on the ground was 0.14 m with tolerance equal to 0.17 m (1/3 h_c); the maximum difference was 0.38 m.

As can be seen from the results of the check on the ground, the stereophotogrammetric surveying of relief and outlines carried out by engine-powered hang glider meets all the requirements of normative documents now in force. Estimation of technical-economic efficiency of aerial surveying by the engine-povered hang glider demonstrates that the surveying at 1:1000 and 1:2000 scales and h_c= 0.5 m as compared to ground surveying makes it possible to increase productivity two times and to decrease labour expenditure by ~33 persons/year. The hang glider and surveying equipment pay back after the first year of their service.

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