ULTRA-LIGHT AIRCRAFT LOW ALTITUDE AEROPHOTOGRAPHY

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ABSTRACT:

There is a method of low altitude aerophotography for large scale mapping by photogrammetry. An aerial platform is provided by a ultra-light aircraft reformed Bee 3, Which with T-O-weight 315 Kg, cruise speed 65 Km/h, two seats in tandem. The front seat removed at this position, open a photo-window and mount the camera. It is Aero-A-17 10/18×18 (or AΦA-TЭ-10/18×18). These combined aerophotographic system operated by single pilot, who is an expert of glider. In the weather conditions of some cloud, wind < 8 m/s, illumination > 7000 lux may be flying and exposure. The photograph shall be of an image quality and geometry quality suitable for photogrammetric mapping or interpretation. Satisfy all such as following constraints:
1) Linear distortion of image < 0.03 mm; 2) Tilt: < 5°; 3) crab < 8°; 4) Altitude difference < 5% H (H: flight altitude); 5) Forward overlap 55 - 70 %; 6) Lateral overlap 15 - 30 %.

Thanks to slow speed of cruise. The micro-light aircraft can be flying safely in the low altitude, the large scale of aerophotography shall be acquired. The micro-light aircraft combined with the camera of short focal length and large format that created the fundamental and advantages condition not only provided facile, cheap cost and short period of aerophotography for the user, but also advanced the accuracy of aerophotogrammetric mapping. For instance. The inspected data from Guangzhou-Shenzhen-Zhuhai High-speed Highway field. The accuracy arrive at the level of plane error: $M_p = \pm 0.557$ M (RMS); elevation error: $M_h = \pm 0.221$ M (RMS).

This set apparatus of aerophotography is more appropriate for developing countries.

KEYWORDS: Camera, Image Quality, Mapping, Photogrammetry, Developing Country, Film, Navigation.

BACKGROUND

1. The characteristic of engineering photogrammetry: —— In the course of social economic development. We must deal with the matter of limited space, in order that to utilize the limited space efficiently, the design of construction project would be done carefully. So that all designs require the accurate and detailed large scale topographic map. Obviously that national basic map can't meets the needs of engineering design. Engineering project is always a urgent task; time limited shortly; scale of map large; detail situation would be present; mapping area small; and distribution scattered. There-fore we have to look for other way for the engineering photogrammetry. ISPRS (14th 1980 Ham-Burg) indicated that engineering surveying tendency is large scale photogrammetry, and call on researching low altitude aerophotography. According to this thinking. We put that into practice and had done following series of test and acquired some results.

2. primary exploration: —— In the early days of the eighties, our civil engineering department of Beijing Polytechnic University put forward a scientific research project "Tether balloon air photography", which was supported by the Beijing institute of survey. The shape of balloon was designed as a ship, the gall bladder made from complex plastics film, air proof sustained enough for eight hours, without any deformation. The balloon gall bladder covered with a lager of nylon fabric, its strength is greater than plastic film and provided the load of aerophotographic platform. In the beginning the balloon filling with hydrogen (H_2) but the hydrogen explode easily. In the latter, the working gas applied ammonia (NH_3). It widely produced by every fertilizer chemical plant, its price equals 0.3 of hydrogen, but its lift force equals 0.5 of hydrogen. So that the volume of balloon increase double. The platform can be turned about the perpendicular axis. The camera; video-unit; video-transmitter; radio receiver and executive devices installed on the platform. Ground video-receiver display the photo-area and direction of a frame image. The total balloon system tethered by Nylon-Rope and pulling to move every where. Proceeding of air-photography: 1) Based on the requirement of the construction project work out an air photographic plan; 2) Photo-area and flight lines noted on the 1/25000 ~ 1/50000 topographical map; 3) Put the flight lines on ground by some points, and positioning series of photo stations at the interval of longitudinal over-lap; 4) Set up projecting reflector over the station; 5) Pulling balloon system arrive at the photo-station; 6) Checking the position of platform position in the space by video-display; 7) Rectifying the bias of the platform and image by radio remote control; 8) Clutch the opportunity of balloon right over the designed station, put camera into

action; 9) So do every station one by one, until all over the total photo-area; 10) Limitation of wind speed $V_w < 4$ M/S. Examination test:— Camera: Mamiya 645; f = 50 mm; Photo-scale: M_p = 1/4000; Flight Height : H_p=200M; Mapping scale: M_m=1/500; Mapping accuracy: plane M_p=±0.07M; Height M_h=±0.06M. This advanced level of mapping accuracy is enough for all engineering project requirement. But its efficiency of production is very small. Because there are lots of obstacles on the ground, and the wind flowing in the sky always. So that balloon pulling right over the designed station is very difficult. Therefore our attention turned to the ultra-light aircraft.

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1. Selection of the ultra-light aircraft:

Ultra-light aircraft developed in the seventies in U.S.A.. In the eighties there were some institutes of aviation industry in P.R. China also produced many types of ultra light aircraft in successively. Their common characters of light small, low speed, and cheap cost are much favorable to the low altitude aerophotography. At this time, a science and technology project "Ultra light aircraft low altitude aerophotography" of communication department entrusted to us, for a year, we explored widely from institutes and libraries, and collected lots of information and specification materials compared analyzed each other. At last selected "Bee 3" from ten models of ultra light aircraft, the performance as following: (Table 1)

2. Reformation of Ultra-light Aircraft (Bee 3)

(1) Removing the fore seat. Retaining single pilot control system; (2) Under the fore seat the cabin floor opening a photo-window, beneath that attached with a sliding air proof board, above that placing camera frame and combined firmly with the aircraft structure; (3) Attaching a small wing on the main wing rear edge; (4) reforming the floor of fore cabin from head to photo-window instead of transparent material (such as polymethyl -methacrylate). So that the pilot navigated by himself.

3. Combination Design and Selection of Camera:

Low altitude aerophotography provides the aerophotography for large scale topographic mapping by aerophotogrammetry. But large scale mapping require more accurate of point position, the accuracy of altitude is more important to all engineering project. In the formula of height error $M_h = \pm 1.15 \cdot \frac{H}{b} \cdot M_q$ [H: flying height; b: photo base; M_q: parallax error (RMS)] that indicated the lower flight height and greater photo-base, the better to height accuracy. As a consequence the camera should be short focal length, and its format should be larger. Following table 2 demon-started these relations.

Table 1

name model	set	power plant	empty weight	Max. T.O. weight	Max. level speed	Max. rang	stalling speed	wing spn
Bee 3	dual train	42 HP	140 Kg	315 Kg	85 Km/h	215Km	50 Km/h	10 M

lenght overall	height overall	main wing area	T.O.and landing run	rate of climb	service ceiling	slip: fall	price (RMB)
6 M	2.6 M	15.4 M^2	50 M	1.7 M/s	3400 M	7:1	35000 yuan

Table 2

Type / Item	RMK	AΦA - TЭ	AV - A - 17	RC 10
focal lenght f_k	85 mm	100 mm	100 mm	210 mm
format	23×23 cm	18×18 cm	18×18 cm	23×23 cm
aperture	f/4	f/6.8	f/6.8	f/4.0
shutter	1/50 ~ 1/500	1/83 ~ 1/213	1/50 ~ 1/300	1/100 ~ 1/1000
photo-scale	1/5000	1/5000	1/5000	1/5000
mapping scale	1/1000	1/1000	1/1000	1/1000
flying height	425 M	500 M	500 M	1050 M
photo-base	92 mm	72 M	72 M	92 M
height error (RMS)	±0.106 M	±0.160 M	±0.160 M	±0.262 M

The view point is that the camera type RMK is best. But we took the AΦA — TЭ $\frac{10}{18\times18}$. Owing to the fact that lack of expenditure.

4. Camera Installation:

(1) Camera frame manufacture: ultra light aircraft cabin is small generally, camera prime frame not suited to it. We had to make a mew frame for the camera AΦA — TЭ $\frac{10}{18\times18}$ and AV-A -17$\frac{10}{18\times18}$ its function as following:

a) The frame height above the cabin floor can be adjustable;
b) The top board (focal plane) may be adjusted to level;
c) The camera on the frame will turn about the perpendicular axis so as to adjust the crab of photograph

(2) Installation of Camera Attachments:

a) Time interval control seat on the position so that the pilot operated conveniently;
b) Other attachments such as electric source; vacuum air pump distributed where ensure no displace gravity center of total aircraft.

5 Organization of Total Aerophotographical System

As above the camera assembles with the aircraft constructed an aerophotographic platform only. In addition equipping with photographic processing devices and transport vehicle. So far the total ultra light aircraft low altitude aerophotographic system is complete. In fact there are three parts consisted of series attachments illustrated as following Figure 1.

put this photo-system into action. It will behaved as the Gypsy's home truck.

6. Field Aerial Photography Test and Productive Aerial Photo:

During the course of organizing aerial-photography system, the functions and its effects of the every part or every step. We tested one by one. From testing compared with the usual aerophotographical airplane Y-5, between their results appeared some little differences. But both basically arrived at the level of national standard. As a consequence we asked the communication department to test productive aerophotography. The second highway designing institute of communication department accepted this proposition warmly and sustained the test in practice powerfully. The test combined with their Guangzhou- shen-zhen-zhuhai high speed highway designing project. In the 2-4, 1989 and 6-8, 1989 we took 971 frame aerophotographs. Two segments of that designing task. Results seeing Table 3.

7. Field Work Procedure:

The concrete steps and experiences as following.

(1) Consulting a contract:

a) The institute of Highway design (A side) put forward aerophotography task include region, area, photo-scale delivery date and other technical requirement;

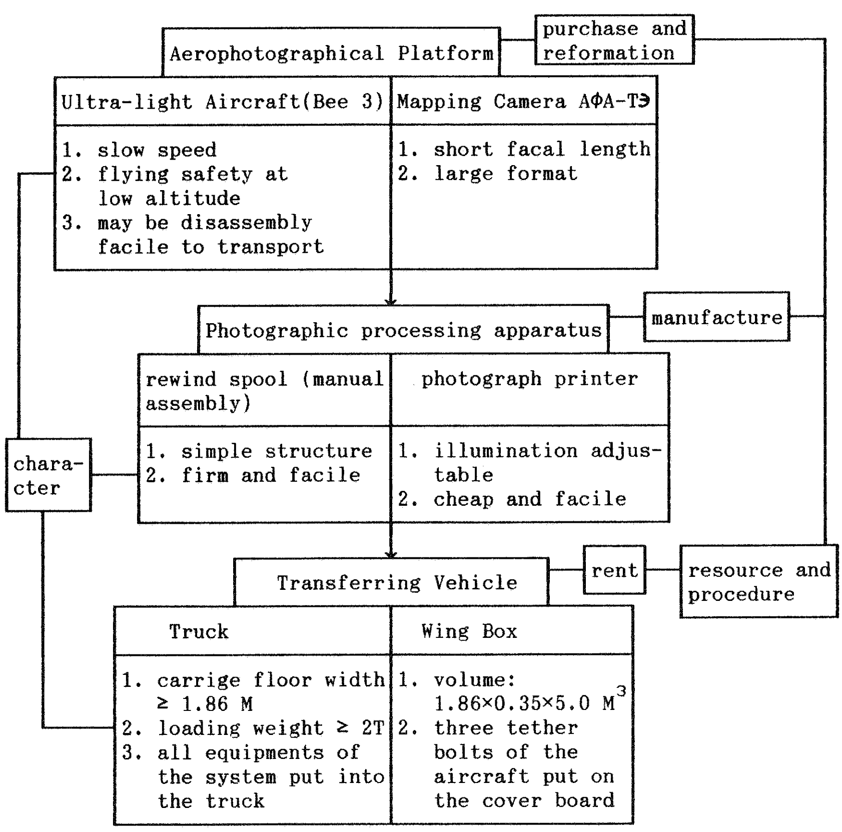

Figure 1

b) provided corresponding region 1/25000 ~ 1/50000 topographic map and highway designed map;
c) demonstrating A side must delivery to B side the amount of cost;
d) B side should be collecting the information of the photo region, such as geography, topography, meteorology, communication, price, condition of living and so on;
e) inquiring the status of the aviation governing;
f) working out a prime aerophotographic plan and its financial budget.

(2) Work of advance group:
a) organizing a group by 2~3 delegates of bath sides;
b) going to the photo-region researching the local status or special condition;
c) reporting to the government of villages and tons, and asking for their support;
d) reporting to the aviation governing department and ask for the permitting of aerophotography, determining the control station to conduct our flying, and communication method.

(3) Technical design of aerophotography:

a)parameters of aerophotography design for an example as following Table 4;

b) formation of the band flying lines:
1) at first the highway designed chart transfer to 1/25000 (or 1/50000) topographical map;
2) according to the designed route direction and the ground elevation separated some segments, every segment route curve transferred analogous straight line, namely it's the center line of the photo-band;
3) coverage width calculating:

$$D_{(N)} = [N - (N-1) \cdot \frac{25}{100}] \times L \times M_p$$

(N: number of flying line; L: image frame length);
4) the band width between the flying interval $D_i = l \times M_p \times (1-q_y)$;
5) plotting film: on the transparent paper (or film) plotting a pair of parallel straight lines, their interval $D_p = \frac{D_i}{M}$ (M_m:map scale denominator) at the center of this interval, plotting a straight line to parallel to the pair of lines. These two parallel lines denote the flight-path and the central straight line denote the band center line; plotting flying chart:— put this transparent paper on map (1/25000 ~ 1/50000). Shift the paper,when the route curve round about the band center line symmetrically and ensure the route curve turning point apart from the band boundary straight lines at a distance of 500m/Mm. Placed the paper firmly, transferring the Band center line, flying path, and a pair of photo coverage Boundary parallel lines on the map.

c). Determination of the mean level of the ground: — In the designed flying map(1/25000 ~ 1/50000), Along the Band center line and Boundary lines read elevation (Hi) of the ground points at a interval of 500m/Mm. Then, Hg=[hi]/N (N:number of points). Attention! the greatest difference of ground points greater than 1/4 designed flying height. The mean ground level of this Band would increased half of the maximum Height difference. So as to,

Table 3

statistic item / test step	aerophotogrphic region	flight lines	length of flight line	cover area	negatives (film)	positives (photograph)	remarks
aerophotograph test	G-S-Z highway section B, C	25	62.5 Km	37.5 Km^2	265	488	square stereo cross bridge
aerophotograph production testuse	G-S-Z Highway section E	18	186 Km	131.7 Km^2	706	1412	band highwy design corridor
sum		43	248.5 Km		971	1900	checked and accepted

Table 4

segement and its label	center line of a band, its azimuth	longitudinal overlap	lateral overlap	mean level of ground	flight height	flying line number
1	2	3	4	5	6	7
C section	Φ	q_x	q_y	H_m	H_f	N
E8	$81^\circ 43'$	60%	25%	176.00M	676.00M	3

flying line length	band width	band cover area	max exposure time of tolerance	exposure time interval	remark
8	9	10	11	12	13
L	$D_{(N)}$	A	t_{max}	Inter	δ: inage shift tolerance
11.0 Km	2.25 Km $D_N=[N-(N-1)\frac{25}{100}] \times L \times M$	$A=L\times D_{(N)}$ $A=24.75\ Km^2$	$t_{max}=\frac{\delta M}{W_g}$	$t_i=\frac{B_i}{W_g}$	M_p:photo-scale denominator W_g:ground speed

ensure the longitudinal overlap of photographs enough;

d.) exposure time and interval of exposure determination: The exposure time and exposure interval depended the weather and aircraft ground speed. But the ground speed always variated with the speed and direction of the wind. As a consequence, the pilot should adjusted the parameters from the advanced position in the air real time.

(4) preparation before aerophotograph practice:

a.)Repairing Take off landing field;
b.)Assembly aircraft;
c.) Aircraft function inspect: — Engine Running Normal; hermetization of Oil box; control system efficient and its stability; components connecting firm
d.) aviation apparatus inspect: — Flying compass bias(A)calibration; local magnet bias calibration

$\Delta\Phi = \Phi_{mag} - \Phi_N$

(Φ_{mag}:local Azimuth; Φ_N: true north Azimuth); convergence angle(r) correct

$\Phi_N = \Phi_M + r$

(Φ_M: map Azimuth); calculation of aircraft compass Azimuth.

$\Phi_f = \Phi_N + \Delta\Phi + \Delta A$

(Φ_f:aircraft compass azimuth);

e.) Camera inspect: — motor running normal; interval control efficient; cleaning dust from lens; Magazine light tight; film without tearing or scar during the winding;
f.)photograph processing devices and materials preparation:— dark room light tight inspect: water quality test; photosensitive material storage safety; medicinal liquid preparation

(5) Navigation:

a.) visual flight (navigated by morphological distinguishing feature)and assistance from the ground artificial label;
b.) pilot must get familiar with aerophotographic plan. And understand aerophotographic Band geography position; selected some identifiable points along the flying line from map; plotting Multiply flying chart;
c.) Going to photo area put the exploration on the ground. The aerophotographic plan designer should accompany pilot to go; comparing and identifying the ground between the map. Look for the difference. And repairing the map. To conform with the ground:along the flight-path. Look out some special points as a label of flight path on the ground. And note a signal at the homologous points on the map;
d.) As to the some smooth area. there are lack of relief or construction spot. In this case put the orange color cloth strip on the homologous ground flight path. The ground navigator must arrive at that place before aircraft, and communication with pilot by radio. As such, the right coverage may be acquired certainly;
e.) suspension wind tunnel on the T.O-landing field, displaying the direction and speed of the wind over the field;
f.) installing an air meter observing the variation of the direction and speed of wind;
g.) placing a label of T-cloth indicating the take-off-landing position and direction.

(6). Flying photograph:

a.) 24hr before the take off reporting flight plan to the aviation control station;
b.) Asking for the permit of flying before two hours Take-off;
c.) Inspect before take off: — (a). Mechanist examine the total aircraft by eyesight and power test. (b). photographer examine the camera kinematic status. Shutter exposure test, time interval control test, special cheek the condition of weather: visibility S > 3km; illumination > 7000 Lux; wind speed < 8m/s; cloud height>flight height; (c.) pilot inspect: examine important parts of the aircraft by eyesight; kinematic test engine running to full scale range; (d.)flying photograph procedure: take off; climb altitude; put heading into flight path bearing. While measure the heading bias and ground speed; drawing the Board of the photographic window; report to flying control station; cruise flying; Arrive at photo region; At the first, don't photo, but flying round the ground targets, and comparing with the map. Identify the photo area and label clear. Without any suspect; heading should parallel to the sun light make photos; There are many lines in a band should flying in same direction take photographs, so that pilot will avoid multiple revision for flight parameter. On order to sustain the stability of flying posture pilot must always scan the navigation meters and ground targets in a firm proceeding. Careful to make the flight height, heading, speed and level uniform. At the beginning and the end of flying line turn on (and turn off) the camera must ensure the margin of 2--3 frame photographs; if meet with the disturbing air flow correct the deviation in the exposure interval as far as possible if the deviation great should correct many times. every time correct a bit of deviation. to restore the prime posture at last. (e.) Return to Base: shut off electric power; report to control station of aviation; shut off the photo window; landing;Report the status of the aircraft and camera to mechanist and photographer; write report table of flying and aerophotograph; Remove the camera send to dark room processing

(7).Photograph processing:

a.) A piece of exposed film test
b.) Film development;
c.) Film dry by airing;
d.) Arrange the number of image frames;
e.) Print photographs;
f.) According to the two (Forward lateral) overlaps compile into flight path and area;
g.) Exhibiting the quality of flying and photograph;
h.) Analyzing the problem;
i.) deciding to duplicate aerophotograph or otherwise.

(8).Quality inspect and results acceptance:

a.) Image quality examination: (a.) image clear; (b.) contrast moderate (c.) indicator of frame distinct; (d.) without cloud shadow. scar or blemish;
b.) Flight quality inspect: — (a.) According

to national standard to examine all photograhhs by every item (b.) Check results recording into table and sum; (c.) Acceptance: — (a.) B side delivery the all aerophotographs and their checked results; (b.) A side delegates examine the results and the table. Deciding acceptance. Then, the delegates of both sides take signature. So far the acceptance procedure completed. And the aerophotographic contract to the end.

(9). Aerophotogrammetric mapping accuracy:

on order to research the mapping accuracy from ultra-light aircraft aerophotography on the field aerophotograph days. Surveyed a lot of ground control points. And increase the control point density in room. Plotting 1/1000 topographic map by A 10 and BC1. Examined by field measuring. Plane points 52; elevation points 225. Acquired the accuracy of plane error $M_p = \pm 0.557$ M (RMS), Height error $M_h = \pm 0.221$ M (RMS).

CONCLUSION

The exploration and series of practical tests had fully proved the superiority of ultra-light aircraft low altitude aerophotography, the main advantages as followings:

1. Aerophotographic proceeding cycle short:

the group of aerophotograph may be executing a single aerophotographic mission. The group as far as possible live to near the photo-region, the non-productive flying rang reduced. In the non-standard photo weather, the ultra-light aircraft can be to take photograph also and make use of the transient good weather. So that increasing the aerophotographic opportunity. Under the same condition, the practice proved that Aerophotographic Cycle Ultra-light shorter than the common airplane two times at least.

2. Mapping accuracy advanced:

Due to the ultra light aircraft aerophotographic flight height low, photo-scale great; camera focal length short ; large format derived photo scale great. Provide the superior condition for aerophotogrammetric mapping. There-for the accuracy of map advanced, specially in height such as above mentioned height error $M_h = \pm 0.221$ M (RMS). Comparing with that accuracy of height $M_h = \pm 0.870$ M (RMS) which acquired from much multiply aerophotogrammetric mapping, height error descended 2.9 times. More than the height error $M_h = \pm 0.160$ M (RMS) theoretical calculating result only ± 0.06M. This level of height accuracy had met with the needs of productive practice.

3. Flying safety:

Ultra light aircraft speed small glide performance superior. Operation nimble and reliable and the pilot was full of the experience of glider. So that the safety sure. For a instance, one day during the proceeding of aerophotograph, the oil box was broken, engine running stopped suddenly in the air, the pilot deal with the problem calmly, urgent forced landing success. Man and aircraft all safe.

4. Cost cheap:

Ultra-light aircraft price less than 1/10 of common aerophotographic airplane, because of the ultra-light aircraft fly slow, even though fly in the low altitude, apply general mapping camera. Shutter at 1/100 second, the image shift is still less than the national standard, thus avoiding to buy expensive forward motion compensation camera. In summary, the weight, volume, and speed of the ultra-light aircraft are small; and a few of flight apparatus; only the area of wing is large. These characters combined with the aerophotographic system produced some new properties, which provide the aerophotography with a sort of rapid, accurate, safety, and cheap method. But in the otherwise these characters derived some defects, lack of navigation apparatus and weakness of resisting wind. Beside these, the single pilot not only operating the aircraft, scanning the flight meter, but also seeing the out side ground navigation label, his attention sense is very tense, some time there are phenomenon of attend to one thing and lose sight of another, these problems expect to overcome in the future.

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