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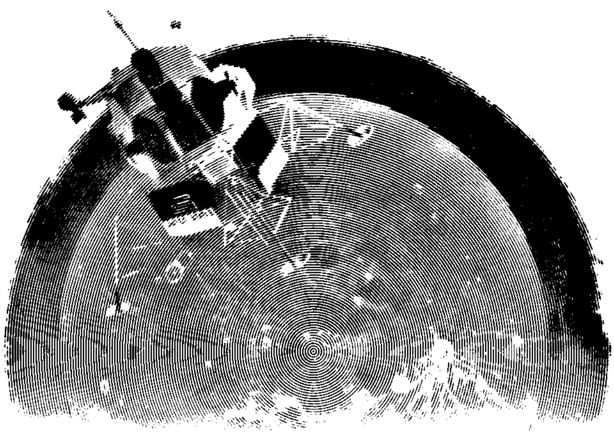

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MAPPING WITH SUPER-WIDE ANGLE PHOTOGRAPHY: SOME OBSERVATIONS ON THE COST ADVANTAGE, THE ACCURACY, AND THE PHOTOGRAPHIC PROBLEM (70-167)

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BIOGRAPHICAL SKETCH

Jean R.R. Gauthier as the Acting Head of the Research and Development Section, of the Topographical Survey, performs and co-ordinates research in photogrammetry. After graduation from the Ecole Supérieure des Géomètres et Topographes, Paris, France in 1951 he received an Engineer's Diploma in 1955. He has worked as a survey engineer for the Société française de Stéréotopographie in Paris, the Photographic Survey Corporation in Toronto, the Topographical Survey in Ottawa and for the Hydro Québec in Montréal. He also received a B.Sc. in Survey Engineering from the University of New Brunswick in 1963. He is registered as a professional engineer in the Provinces of Ontario and Québec.

ABSTRACT

For the past two years, because of the cost of high flying aircraft, photographs for topographical mapping in Canada have been mostly taken with wide angle cameras at altitudes varying between 22 and 25,000' instead of 30,000'. Considerable savings and substantial increases in efficiency could be achieved if super-wide angle photographs for very large blocks could be taken at 30,000'. The final accuracy of the manuscript would probably meet the NATO specifications for class A-1 maps. However, more experience with the use of super-wide angle cameras, especially in conjunction with jet aircraft, and additional tests to determine the optimum altitude are required before diverting much of our production to super-wide angle photography.

INTRODUCTION

Since the introduction of the Wild RC-9 camera, much literature has been published to describe the efficiency of super-wide angle photography. In particular, the late Dr. Wilfried Löscher showed conclusively that the optimum field angle of an aerial survey camera is approximately 120^{o} and that super-wide angle photography is about 1.8 times more efficient than wide angle photography (Löscher, 1963).

Despite such publicity, super-wide angle cameras are not being used extensively for topographical mapping. At the outset the lack of suitable photogrammetric instruments, for plotting and for aerotriangulation, prevented mapping agencies from diverting much of their production to super-wide angle photography. This lack of instrumentation is no longer true. Even if some older instruments which are still in use, cannot accept super-wide angle photographs, there are generally enough newer instruments to process this type of photography.

Another difficulty was probably due to some of the photographic problems associated with super-wide angle photography. These problems are discussed later in this paper and some remedies are suggested.

Parallel to this, at least in Canada, Second World War surplus aircraft capable of taking photographs at altitudes varying between 35 and 30,000' became unavailable around 1960. As a result, photogrammetric companies had to purchase modern light aircraft with operating ceilings of about 22,000' and relatively slow cruising speeds.

This altitude limitation had an adverse effect on our mapping operations that is still evident in aerotriangulation. Present semi-analytical methods permit a slight reduction in the number of control points required for mapping, but this small reduction is more than offset by the fact that photographs are taken by aircraft operating at lower altitudes. Multiplying the number of stereoscopic models, also multiplies the cost and the problems in adjusting blocks.

The purpose of this paper is to show that recent developments may change this unfavourable situation. One such change is the recent development of two super-wide angle cameras with improved lens, namely those of the Zeiss RMK A 8.5/23 and the Wild RC-10. Both these cameras have a distortion smaller than 10μ and an anticipated resolution which is superior to that of the RC-9. The other significant change is the availability of jet aircraft to take high altitude photographs at a greater rapidity.

Significant savings and a substantial increase in the efficiency of some photogrammetric operations associated with our mapping program could be achieved if high altitude, super-wide angle photographs are taken for very large blocks over the undeveloped and extensive land areas of Canada.

THE FLYING HEIGHT

The acceptable height error will be the determining factor in selecting the flying height H. According to NATO specifications, the mean square error in height m_h must be smaller than 15' for a class 1 map with a contour interval of 50'. Or, stated in another way, 90% of the heights checked are to be within half the contour interval.(1) We can disregard the effect of the planimetric error on the contours because the specifications state the height discrepancies beyond the acceptable limits "may be decreased by assuming the unavoidable horizontal displacement of planimetric features". The mean square error in height is equal to

$$m_h = (m_{ht}^2 + m_{hc}^2 + m_{hg}^2)^{\frac{1}{2}} \qquad \text{Eq. 1}$$

where,

m_{ht} = height error resulting from aerotriangulation

m_{hc} = height error on the contour due to plotting inaccuracies

m_{hg} = height error of the vertical ground control.

(1) If e_h is the error in height of any point and it is normally distributed with mean zero, then the two statements,

$$Pr\{-0.5 \text{ c.i.} < e_h < 0.5 \text{ c.i.}\} = 0.9$$

and $Pr\{-0.304 \text{ c.i.} < e_h < 0.304 \text{ c.i.}\} = 0.6827$ are equivalent. And 0.304 x 50' = 15.2

In Canada, vertical control for 1/50,000 mapping with 50' contours is frequently established by APR with a mean square error approximately equal to

$$m_{hg} = \pm 10'$$

The other two height errors m_{ht} and m_{hc} are functions of H and more difficult to estimate.

Let us first consider m_{hc}, the plotting error on contours. This error is given by

$$m_{hc} = (m_{hs}^2 + m_{hd}^2)^{\frac{1}{2}}$$

where, m_{hs} = mean square error on spot heights

m_{hd} = additional uncertainty caused by continuous drawing.

We can get a reasonable estimate of m_{hs} for super-wide angle photographs from two independent tests:

Test 1. The Swiss block test (Neumaier, 1966).

Photography for the Swiss block was flown at 6.9 km (23,000') with a Wild RC-9 camera. The photo scale was therefore 1/75,000. Six models were compiled on the Wild B-8 by two agencies(2). Six vertical and horizontal control points were given for each model. Control points and check points may be considered as error free. The mean square error on 209 check points was

$$m_{hs} = 0.26‰ \text{ H}$$

Six points with very large height errors (±7m or more) were eliminated.

(2) The Institute of Applied Geodesy, Frankfurt, and the Department of Photogrammetry, Topography and Cartography of the Technical University of Munich.

Test 2. The NRC Renfrew test (van Wijk, 1964).

The photographs used for this study were taken from an altitude of 13.0 km (42,500') using an RC-9 camera. The photo scale was therefore 1/148,000. The test model with 60% overlap contained 45 check points. This test model was measured twice on the Nistri TA3 Stereocomparator and three times on the Wild A-9. Since the height deformation in the model was adjusted by second-degree polynomials, the results of this test will be better than what can normally be expected. These results were:

Nistri TA-3	$m_{hs} = 0.13‰ H$
Wild A9	$m_{hs} = 0.19‰ H$

From the results of these two tests we can reasonably estimate that, with improved cameras, the mean square error on spot heights will be in the neighborhood of

$$m_{hs} = 0.20‰ H$$

The contour accuracy in the case of super-wide angle photography is even more difficult to evaluate. James R. Skidmore (Skidmore, 1965) found that the ratio between the m.s.e. on contours and the m.s.e. on spot heights is

$$\frac{m_{hc}}{m_{hs}} = 1.2$$

for wide angle photographs and for both the Wild A-7 and A-9. If we apply this ratio to our case, we find that

$$m_{hc} = 0.24‰ H$$

and $$m_{hd} = 0.13‰ H$$

The requirement that 90% of the heights checked be within half the contour interval may be expressed by

$$m_{hc} = 0.304 \text{ c.i.}$$

but $$\text{c.i.} = \frac{H}{C(\text{factor})}$$

therefore $$C = 0.304 \frac{H}{m_{hc}}$$

which would give for the B-8

$$C(\text{factor}) = 0.304 \frac{1000}{0.24} = 1250$$

This is not unreasonable and may be used as a basis for speculating at what height super-wide angle photography could be taken. It should be evident, however, from the manner in which these figures were derived, that real tests with photographs obtained with the new S.W.A. cameras must be performed for planning purposes.

Our last parameter must be estimated in formula (1), namely the height error m_{ht} resulting from aerotriangulation. Because so many factors influence the accuracy of points established by aerotriangulation, the results of any test can be considered only as a rough guide, and a local experience and critical knowledge of the operating procedures currently in use in the mapping organization concerned must be applied. The results of three completely independent tests are summarized in Table I.

The superior results of the American experiment is due to the use of 60% side overlap and to the rigorous nature of the adjustment employed at the USCGS. It is regrettable that a few of the vertical control points available for the NRC test were not used as check points. However, at the time, the experiment was designed to compare the precision of the Wild A-9 with a more precise instrument and not to determine the accuracy attainable with super-wide angle photography. Consequently, all the models of these 3 strips were well controlled, and all possible precautions and corrections were applied; two ideal conditions which would never occur in practice. The results derived from this investigation are therefore better than would normally be expected and must be interpreted with caution. As for the results of the DOS test, their significance is limited by the absence of control points and of check points in the middle of the strips.

In our case, a small but significant improvement of the height accuracy could be expected by the use of better cameras. In particular, the improved lens resolution near the edges of the field(3) should reduce pointing errors on

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(3) 7 L/mm at 60° for the Super-Aviogon (Löscher, 1963) versus not less than 20 L/mm for the Super-Aviogon II (Bormann, 1969).

TABLE I

Agency	Photo-scale	No. of Photos	Instrument	No. of Points used: control	No. of Points used: check	Type of Adjustment	M_h in ‰ H	Reference
NRC	1/150,000	3 individual strips of 7 or 8 photos	Nistri TA3	63	none	Strip 2nd degree	0.19	van Wijk, 1964
			Wild A9	63	none		0.31	
DOS	1/36,000	4 strips of 10 or 11 photos	Zeiss Jena 3030	unknown[2]	none	Strip	0.30[3]	Eden, 1966
USCGS & USGS	1/60,000	150 photos 9 strips 60% side lap	Stereocomparator	22 (targeted)	9[4]	USCGS adjustment program	0.10	Eichert, 1969
					9[5]		0.14	

1 - All photographs were taken with super-wide angle cameras.

2 - The strips were controlled only at their extremities.

3 - m.s.e. on the control used. The errors in the rest of the strips are unknown.

4 - Targeted points.

5 - Natural targets.

the pass points. Also, the use of infrared films, as suggested later in this paper, may also reduce pointing errors on these points. Finally a new block adjustment programme now under preparation in Topographical Survey will permit the inclusion of multiple readings on lake surfaces of unknown elevation. Since many parts of Canada are literally peppered with lakes of various sizes this new block adjustment feature should reduce the mean square error in height after adjustment by a significant amount. The use of lake information is not unlike the use of the horizon camera except that it can be much more powerful because when lakes overlap strips and models, the models will be levelled and the error propagation in height will be controlled.

Considering all these results we may reasonably expect a mean square error in height on the pass points of about 0.30‰ H in day-to-day operations using semi-analytical methods of aerotriangulation. This magnitude also corresponds well within the range of usual aerotriangulation precision (between 0.30‰ H and 0.40‰ H) given by Jerie for wide angle photography (Jerie, 1965).

As we now possess all the elements of formula Equation 1, the m.s.e. in height for different altitudes can be computed. The results are shown in Table II.

TABLE II

H	22,000'	24,000'	26,000'	28,000'	30,000'	32,000'	34,000'	36,000'	38,000'	40,000'
m_h in ft	13.1	13.6	14.1	14.7	15.3	15.8	16.5	17.1	17.7	18.3

This analysis leads to the probability of meeting NATO specifications for class 1 maps (scale: 1/50,000; contour interval 50') using super-wide angle photography taken at 30,000'. However, further tests to determine the height error after aerotriangulation and after compilation are necessary to determine the optimum flying height.

PLANIMETRIC ACCURACY

What kind of planimetric accuracy can we expect from super-wide angle photography flown at 30,000'? The planimetric accuracy of the manuscript depends on:

- errors on the control points
- identification errors if the points are not targeted
- errors on the pass points after adjustment
- plotting errors

Of the four types of errors listed, the accuracy after block adjustment is the most difficult to estimate. It is almost impossible to base accuracy investigations on practical examples of aerotriangulation. This difficulty arises because most areas triangulated do not have adequate ground control and check points to permit general conclusions concerning accuracy. This is particularly true for large blocks of several hundred photographs.

Alternatively the accuracy of pass points can be determined theoretically using hypothetical data and several configurations of control.

In the preparation of this paper, two theoretical investigations were used:

- an excellent study of planimetric accuracy of block triangulation by Professor Ackermann of Stuggard University (Ackermann, 1966)
- several tests by Professor Soehngen at the University of Illinois (Soehngen, 1967)

The planimetric accuracy of block triangulation may be expressed as a mean square error in microns at photo scale. Expressed in these terms, the error is independent of the flying height and of the type of photography, that is wide angle or super-wide angle photography. In our case with S.W.A. photography taken at 30,000' 10μ on the photo is about equal to 1 m on the ground.

Based on the investigations of Ackermann and Soehngen mentioned previously, the planimetric mean square error for a block of 12 strips of 30 overlaps (to be considered in our cost analysis later in this paper) will be approximately 45μ at photo scale or 4.5m on the ground with 10 horizontal control points on the perimeter of the block.

It is useful to know the accuracy of the pass points relative to one another, for it establishes a factor of the internal accuracy. This relative accuracy can be loosely defined as the distance accuracy in a local range. This is virtually independent of the block size, control density, and distribution since it is a measure of the accuracy of the photogrammetric work. This relative accuracy amounts to about 15μ at plate scale or 1.5 m at ground scale.

Using the law of propagation of errors, we can now combine the survey error, the identification error, the aerotriangulation error, and the compilation error to derive a resultant planimetric error of the magnitude

$$m_p = \pm 125\mu$$

or ±0.25 mm at the scale of the manuscript.

The terms and parameters of the four cases of error used in the combination are now defined.

SURVEY ERROR

This error can be assumed to be of the order of ±4 m in a rectangle of 140 x 180 miles. That is an error of ±40μ at photo scale.

IDENTIFICATION ERROR

For non-targeted control point, in parts of the country where there are no man-made details this error can be considerable. We now use a photographic identification of the point made at the time of the survey with a reconnaissance camera. This identification is transferred on the diapositive using a succession of photographic operations. It is reasonable to assume that under these circumstances the identification error is of the order of ±40μ at photo scale.

AEROTRIANGULATION ERROR

This error is estimated to be of the order of ±45μ.

COMPILATION ERROR

This error can be very large: ±0.2 mm at manuscript scale. With a manuscript scale of 1/50,000 and a photo scale of 1/106,000, this is about ±100μ on the photo.

As mentioned earlier the resulting planimetric error at photo scale will be

$$m_p = \pm 125\mu$$

or ±0.25 mm at the scale of the manuscript.

This result when converted to the NATO Circular Map Accuracy Standard with a percentage probability of 90%, becomes CMAS = 2.146 x 0.25 mm = 0.54 mm or 27 m at ground scale. Thus our derived planimetric error is just slightly more than the permissible error of 25 m for a class A map.

THE PHOTOGRAPHIC PROBLEM

Fewer than one hundred rolls of S.W.A. photography have been exposed for Topographical Survey over several regions of Canada during the past six years. This limited experience was sufficient to establish the fact that any quality-deteriorating factor which affects wide angle photography also affects super-wide angle photography to a greater extent (Fleming, 1968). Thus, while the photographic quality of S.W.A. photography taken under optimum conditions can be equal to good wide angle photography, the average quality of S.W.A. photography is lower than the average quality of wide-angle photography. These quality deteriorating factors and possible remedies will now be discussed.

PHOTO WEATHER

Because of the wide field of view, large areas must be cloud-free for photography to take place. Given patchy weather, wide-angle photography can often be carried out

successfully in the cloud gaps, whereas the super-wide angle camera would not be productive in such conditions.

However, given good weather, the super-wide angle camera has a tremendous advantage over the wide angle since the area can be covered more rapidly. To further increase this advantage, jet aircraft, instead of propeller driven aircraft, could be used as camera platforms. The rate of climb and the speed of the jet can be exploited to full advantage in optimum weather conditions. With speedy jet aircraft, good weather can be "searched for" instead of having to wait for it.

HAZE

Most of the haze forming particles in the atmosphere are below the aircraft when small scale photography is taken. This is equally true for W.A. and S.W.A. photography. However the light path through the haze near the edges of the field of view of a super-wide angle lens is much longer. As a result there is greater reduction of contrast at the edges and corners of super-wide angle photos than there is on wide angle photos taken under the same conditions.

Aerial infrared films, now available on stable base, would likely reduce this haze effect on super-wide angle photographs. Furthermore, a picture on an infrared emulsion will have more contrast than on a panchromatic emulsion. On small scale photographs this may increase the stereoscopic perception in the parts of the model with low contrast (grey areas) and thus improve the height accuracy. Bodies of water would be sharply defined on infrared film. This factor will be of increasing value as water resource studies become more important.

SPECULAR REFLECTION

Water surfaces such as lakes, rivers, and swamps are common in many regions of Canada. At certain solar altitudes their surfaces will reflect the sun's image directly into the camera lens. The water surface then appears white on one photograph and black on the other, thus making it extremely difficult to read shoreline heights. This effect is further aggravated by the intense exposure of the emulsion at the point of reflection which exhausts the developer in that local region so that adjacent detail is not properly developed.

The larger angular field of view of super-wide angle cameras results in specular reflection occurring at lower sun altitudes and therefore more often on S.W.A. than on W.A. photographs.

HOT SPOT

For reasons similar to those just mentioned the hot spot (the point at which the aircraft's shadow would occur on an aerial photo) will be present more often on S.W.A. photographs than on W.A. ones.

HIGH OVERCAST

Small scale photographs are dependent on shadows for accentuation of ground detail. With decreasing scale, stronger shadows are desirable for accurate height determination. Consequently S.W.A. photographs taken under a high overcast will lack contrast in comparison to the contrast on W.A. photographs taken at the same altitude. The use of infrared may partly remedy this.

We can therefore conclude that periods of good photographic conditions will be fewer and shorter when using an S.W.A. camera as compared to the situation when using an W.A. camera. This drawback associated with the S.W.A. camera may be overcome by the use of higher coverage jet aircraft and infrared films. However, these problems indicate clearly that more experience is needed before making extensive use of S.W.A. photography for small scale mapping.

COMPLETENESS

When using very small scale photography the question of loss of image detail must be considered.

The conclusions of both the OEEPE (Neumaier, 1966) and the NRC (van Wijk, 1964) are that only point-like details such as buildings are lost or incorrectly interpreted. Linear details such as roads, railways, limits of trees retain their definitive detail. As this method of small scale photography is advocated primarily for remote areas of Canada, which at present are unmapped at the 1/50,000 scale, the loss of topographical detail should not present a problem. If small areas with many planimetric details exist, they could be photographed at a more suitable lower altitude by the same aircraft, using the same camera and under the terms of the same contract.

COST COMPARISON

To compare costs we studied two well defined cases limited to mapping at the scale of 1/50,000 with 50' contours. Case 1 corresponds to the present practice, that is, photography taken with a light aircraft at 22,000' with 6" wide angle cameras. Case 2 is that proposed in this paper, that of a flying height of 30,000' and photographs taken with modern super-wide angle cameras. Provided terrain slopes are less than 30°, the lateral overlap in Case 2 could be only 10% instead of the usual 15% as in Case 1. This should not create a problem in navigation because the lateral overlap, at ground scale, in Case 2, would be more than 8,000', whereas it would be only 5,000' in Case 1.

TABLE III

Case	f	H (feet)	Photo scale	Gain forward (mi.)	Gain lateral (mi.)	Gain per exposure (sq. mi.)	Photos per 1000 sq.mi.
I	6"	22,000	1/44,000	2.5 mi.	4.4 mi.	10.9	92
II	86 mm	30,000	1/106,300	6.1 mi.	12.2 mi.	74	13.5

Table III gives some significant flight planning data for the two above cases. For instance, the number of photos required in the second case is only 0.15% of that required in the first case. This factor alone, explained the significant difference of costs between Cases 1 and 2 as shown on Table IV. The savings per map sheet is in the order of $1,000 in favour of Case 2, a saving of almost 40%.

The only debatable point is the cost of horizontal control. It could be argued that the cost of establishing 40 points in a particular area will not be four times that of establishing 10 points or, as it is often the case, that some control is already available in the area. There is no doubt that some saving will be made on the horizontal control, but should we choose to disregard it, the savings per map sheet of about $700 or more than 30%, would still be realized.

SUMMARY

During recent years the annual production of new 1/50,000 map sheets by the Topographical Survey has varied between 250 and 350 with a tendency to increase. Most of the settled parts of Canada are already mapped at that scale, therefore most future new mapping will be of unsettled areas. If we assume that super-wide angle photography is used for 250 map sheets per year, annual savings would accrue of between $200,000 and $250,000.

Another factor of some significance is that the elapsed time necessary to complete a photographic mission over a certain area with a jet aircraft will be much shorter than that with a propeller driven aircraft. Considering the short season suitable for aerial photography in Northern Canada, this speed factor may make the difference between getting photographs completed in one year or having to wait for next year. To illustrate this point a comparison was made of the estimated flying hours and elapsed time to cover the same block of 64 map sheets used in Cases 1 and 2 mentioned previously, with the additional assumption that the area to be photographed is located in Northern Ontario between Lake Superior and James Bay. This comparison is summarized in Table V.

TABLE IV

STATISTICS FOR A BLOCK 178 mi. x 138 mi.
(64 map sheets at the scale of 1/50,000 at 50° Lat.)

	Case I	Case II
Number of flight lines	32	12
Number of overlaps per line	73	31
Number of photos per line	74	32
Total number of photos	2,368	384
Line miles of photography	5,840	2,270
Line miles of A.P.R.(1)	2,400	1,620
Number of horizontal control points	≃ 37	≃ 10
Cost of diapositives @ $5.00 per plate(2)	11,840	1,920
Cost of photography [case I: $10/line mi. ; case II: $30/line mi.]	58,400	68,100
Cost of APR @ $12 per line mile	28,800	19,500
Cost of horizontal control @ $800/point	29,600	8,000
Cost of aerotriangulation @ $18/model	42,050	6,700
Total cost	170,690	104,220
Cost per map sheet	2,670	1,630

(1) Case I: one APR line every 6 O/L(15 mi.); case II: one APR line every 4 O/L(25 mi.). Plus 30% in both cases to close the APR lines on points of known elevation.

(2) The costs shown in this table are used only for the purpose of comparison and are based on a limited sample.

TABLE V

Case	Type of aircraft	Operating altitude	Time to reach photographic altitude	Cruising speed	Estimated flying hours	Estimated elapsed time (1)
I	Cessna Skyknight or Piper Aztec D	22,000'	1 h.	200 mi/h.	66	45 days
II	Piper Navajo (turbo super charged)	30,000'	1 h.	200 mi/h.	29	20 days
II	Lear jet	30,000'	25 min. to 30 min.	500 mi/h.	14	12 days

(1) Estimated using average weather conditions in the area compiled over a 10 year period.

Another advantage in using high altitude super-wide angle photography is that bodies of water, so numerous in Canada, must be more than 6 miles wide before creating a break in a strip. With wide angle photography taken at 22,000' any lakes, inlets or bays wider than 2.5 miles may necessitate additional horizontal control. Similarly, off-shore islands may not have to be positioned by ground methods when using super-wide angle photography.

A final advantage may occur in photomapping. Although height displacement is magnified by a factor of 1.7 on super-wide angle photographs, this magnification is probably compensated by the fact that 85% less photos are necessary in covering the same area. Accumulated errors made in joining photos are therefore reduced and considerable savings of time and money result.

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