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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 Lӧscher showed conclusively that the optimum field angle of an aerial survey camera is approximately 120° and that super-wide angle photography is about 1.8 times more efficient than wide angle photography (Lӧscher, 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 10 μ 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 NARO 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, 98% 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

\[
m_h = (m_{ht}^2 + m_{hc}^2 + m_{hg})^{\frac{1}{2}}
\]

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.

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.


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 taken for each model. Control points and check points may be considered as error free. The mean square error on 209 check points was

\[
m_{hs} = 0.26\% \times H
\]

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

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(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 0.384 x 50' = 15.2

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(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 Wijck, 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:

<table>
<thead>
<tr>
<th>Camera</th>
<th>m_{hs}/H %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nistri TA-3</td>
<td>0.13</td>
</tr>
<tr>
<td>Wild A9</td>
<td>0.19</td>
</tr>
</tbody>
</table>

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

\[ m_{hs} = 0.20 \% \text{H} \]

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

\[ \frac{m_{hc}}{m_{hs}} = 0.24 \% \text{H} \]

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

\[ m_{hc} = 0.24 \% \text{H} \]

and

\[ m_{hd} = 0.13 \% \text{H} \]

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

\[ \text{c.i.} = \frac{H}{C(factor)} \]

therefore

\[ C = 0.304 \frac{H}{m_{hc}} \]

which would give for the B-8

\[ C(factor) = 0.304 \frac{1000}{0.24} = 1250 \]

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 should reduce pointing errors on

(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).
5 - Natural targets.
4 - Targeted points.
3 - M.S.E. on the control used. The errors in the rest of the strips are unknown.
2 - The strips were controlled only at their extremities.
1 - All photographs were taken with super-wide angle cameras.

<table>
<thead>
<tr>
<th>Strip</th>
<th>Program</th>
<th>95 Percentile Error (in feet)</th>
<th>95 Percentile Error (in percent)</th>
<th>Strip</th>
<th>95 Percentile Error (in feet)</th>
<th>95 Percentile Error (in percent)</th>
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**Table I**

This table lists the specifications for class A target points and their error analysis. The table includes columns for the strip number, program number, 95th percentile error in height and width, and other relevant data. Each entry in the table represents a different strip with specific information about the error analysis and other parameters relevant to the target points.
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 planimeteric accuracy of block triangulation by Professor Ackermann of Staggard 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' 10u 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 45u 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 15u 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 planimeteric error of the magnitude

\[ m_p = \pm 125u \]

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 ±40u at photo scale.

IDENTIFICATION ERROR

For non-targeted control points, 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 ±40u at photo scale.
AEROTRIANGULATION ERROR

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

COMPILATION ERROR

This error can be very large: ±0.22 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

\[ m_p = \pm 125μ \]

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 (Flennig, 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 S.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 a 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 OEEPS (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 photogrammed 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>
<thead>
<tr>
<th>Case</th>
<th>f (feet)</th>
<th>H (feet)</th>
<th>Photo scale</th>
<th>Gain</th>
<th>Photos per 1000 sq.mi.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>6</td>
<td>22,000</td>
<td>1/44,000</td>
<td>2.5 mi.</td>
<td>4.4 mi.</td>
</tr>
<tr>
<td>II</td>
<td>86 mm</td>
<td>30,000</td>
<td>1/106,300</td>
<td>6.1 mi.</td>
<td>12.2 mi.</td>
</tr>
</tbody>
</table>
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 summarised in Table V.

<table>
<thead>
<tr>
<th>Case</th>
<th>Case I</th>
<th>Case II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of flight lines</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>Number of overlaps per line</td>
<td>73</td>
<td>31</td>
</tr>
<tr>
<td>Number of photos per line</td>
<td>74</td>
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</tr>
<tr>
<td>Total number of photos</td>
<td>2,368</td>
<td>384</td>
</tr>
<tr>
<td>Line miles of photography</td>
<td>5,840</td>
<td>2,270</td>
</tr>
<tr>
<td>Line miles of A.P.R. (1)</td>
<td>2,400</td>
<td>1,620</td>
</tr>
<tr>
<td>Number of horizontal control points (2)</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>Cost of diapositives @ $5.00 per plate (2)</td>
<td>11,840</td>
<td>1,920</td>
</tr>
<tr>
<td>Cost of photography / line mi. (case I: $10; case II: $30)</td>
<td>58,400</td>
<td>68,100</td>
</tr>
<tr>
<td>Cost of APR @ $12 per line mile (4)</td>
<td>28,800</td>
<td>19,500</td>
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<tr>
<td>Cost of horizontal control @ $800 per point (4)</td>
<td>29,600</td>
<td>8,000</td>
</tr>
<tr>
<td>Cost of aero triangulation @ $18 per model (4)</td>
<td>42,050</td>
<td>6,700</td>
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<tr>
<td>Total cost</td>
<td>170,690</td>
<td>104,220</td>
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<tr>
<td>Cost per map sheet</td>
<td>2,670</td>
<td>1,630</td>
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(1) Case I: one APR line every 6 O/L (15 m.i.); case II: one APR line every 4 O/L (25 m.i.). 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.
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.

### TABLE V

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of aircraft</th>
<th>Operating altitude</th>
<th>Cruising speed</th>
<th>Estimated flying hours</th>
<th>Estimated time until cloudy day</th>
<th>Time to reach photographic altitude</th>
<th>Time required to cover the area</th>
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<tbody>
<tr>
<td>I</td>
<td>Cessna Skyhawk II</td>
<td>22,000'</td>
<td>200 m.p.h.</td>
<td>45 days</td>
<td>66</td>
<td>1 h.</td>
<td>30 min.</td>
</tr>
<tr>
<td>II</td>
<td>Piper Aztec D</td>
<td>30,000'</td>
<td>200 m.p.h.</td>
<td>20 days</td>
<td>29</td>
<td>1 h.</td>
<td>25 min.</td>
</tr>
<tr>
<td>III</td>
<td>Lear Jet</td>
<td>30,000'</td>
<td>500 m.p.h.</td>
<td>12 days</td>
<td>14</td>
<td>30 min.</td>
<td>30 min.</td>
</tr>
</tbody>
</table>

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