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ULTRA SMALL SCALE PHOTOGRAPHY

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INTRODUCTION

At the XIV Congress of the International Society for Photogrammetry held in Hamburg, Germany, in July 1980, K. J. LESTER and P. L. MEADOWS [1)] reported on the use of ultra-small scale aerial photography at a scale of 1:150 000 for the production of 1:50 000 orthophoto maps, the plotting of 20 metre contours and the subsequent revision of the 1:50 000 national map series. The results obtained were most encouraging and further investigations which have been carried out have confirmed the feasibility of using ultra-small scale aerial photography for this purpose. The machine time for the plotting of 20 metre contours has been consistently reduced by five to six times compared with standard 1:50 000 aerial photography. When it is considered that approximately 1 000 sheets of the 1:50 000 national series still have to be metricated the increased production rate and the subsequent saving in time become particularly impressive.

AIRCRAFT

The aircraft used is a Lear Jet 24 to which various modifications have been made to enable the aircraft to fly at the extreme limit of its ceiling while carrying a maximum fuel load.

The aircraft was acquired some years ago by an Agricultural Cooperative for the purpose of weather modification during the summer season. It is seldom used during the winter months and since the majority of aerial photography is undertaken during this period it is readily available for photographic sorties. The aircraft is however not fitted with sophisticated navigational equipment and the considerable additional expenditure is not justified.

To obtain a contact scale of 1:150 000 using a Zeiss RMK A 8,5/23 aerial survey camera a minimum flying height of 12,75 kilometres above ground elevation is required and assuming an average ground height of 1,5 kilometres, the minimum flying height above sea level is 14,25 kilometres. The certified flying height of the Lear Jet is only 12,5 kilometres and the aircraft consequently operates above its certified ceiling. At this height the control of the aircraft is very sensitive and it is not particularly manoeuvreable. It always assumes a nose-high attitude until the fuel load has been reduced. The climbing speed of the aircraft above 12 kilometres must be greater than mach 0,7 (approximately 840 kilometres per hour), otherwise the approach angle is too great and it will not climb. As the fuel load reduces the speed increases to mach 0,8 (approximately 960 kilometres per hour) reaching a maximum speed of mach 0,82 (approximately 985 kilometres per hour). The aircraft has been fitted with a special modified wing to enable the height to be reached and maintained more easily.

The Lear Jet is probably the only civil aircraft capable of reaching the height and speed required for ultra-small scale aerial photography.

CAMERA INSTALLATION

A Zeiss RMK A 8,5/23 in conjunction with a standard type D yellow filter is mounted into a special camera door which fits onto the lower half of the normal door. The camera is located vertically behind an optically flat glass plate which ensures that the aircraft remains pressurized. The image quality of the camera is particularly suitable for orthophoto production and the image resolution even in the corners of the photograph is extremely high. Similarly the radial distortion of the lens is minimal and lies within 7 micrometres (microns) over the entire image field making the use of correction plates unnecessary.

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1) K. J. LESTER and P. L. MEADOWS: The Use of Ultra-Small Scale Aerial Photography in Medium Scale Mapping and Revision, XIV Congress ISP Hamburg 1980.

Formation of ice on the optical glass of the camera port at such high altitudes has caused considerable problems. The solution has been to blow warm air over the glass plate but since it is extremely difficult to distribute this air equally across the surface, cracking of the glass plate has occurred during flights causing pressure reduction in the cabin.

The intervalometer which hitherto has not been subject to icing is mounted on the squatting seat of the aircraft. A navigational telescope could be installed in the same position but serious and so far unsolved problems have also arisen with this instrument because of formation of ice on the prisms and lenses. To overcome this problem a simple alidade on which drift can be set has been constructed for use by the co-pilot who assists with the navigation. This self-constructed alidade in conjunction with the intervalometer are the only navigational aids available in the aircraft and the inability to solve the icing problem of the navigation telescope remains a serious setback for the program.

OPERATIONAL PROCEDURES

The specification requires strips of photography to be flown along predetermined flight lines in an east-west/west-east or north-south/south-north direction with a minimum fore and aft overlap of 90 %, the strips normally following the centre lines of the 1:50 000 standard sheets that are to be revised. At least 10 % coverage is required beyond the boundaries of the task and the maximum deviation in metres in the flight line position must not exceed:-
0,046 S - 0,20 dx where
S = photo scale denominator and
dx = maximum sheet side in metres at map scale.
In South African latitudes this deviation is normally of the order of 1,5 kilometres when flying east-west/west-east at a scale of 1:150 000. A north-south/south-north direction of flight gives a greater tolerance in navigation and the allowable deviation from the predetermined flight line is approximately 2,3 kilometres. Experience has however shown that the jet streams encountered at this flight altitude tend to flow in an easterly direction and this makes navigation in the north-south/south-north direction more difficult. The flying height has generally been between 12 and 13,75 kilometres above mean ground elevation. At this latter height the tolerance increases to approximately 2 kilometres along an east-west/west-east flight line. Notwithstanding the fact that the aircraft is being flown above its certified ceiling and that no sophisticated navigational aids are available it has been found that the average deviation of the flight line is of the order of 500 metres.

Initially significant omega tilts were encountered during photography. These were caused by the inability of the aircraft which is provided with a yaw-damper to undertake flat turns. This meant that any change in direction had to be effected by banking and the problem has been overcome by ensuring that turns are only made during the time interval between two successive exposures. A study of the tilts encountered on randomly-selected tasks over the past four years indicates that this procedure has resulted in a noticeable improvement.

The proposed flight lines are drawn on the best available maps of the area, normally at a scale of 1:250 000. In areas of sparse detail such as bush areas and in the featureless desert where navigation has proved extremely difficult, use has been made of enhanced Landsat imagery at a scale of 1:250 000.

The pilot follows the flight lines on a compass bearing and course corrections are determined by the co-pilot who identifies detail ahead using the navigational alidade described previously. The camera operator using the intervalometer and the co-pilot report continuously as to whether the aircraft is maintaining the required line of flight by identification of detail on the map. The aircraft is also not capable of executing sharp turns and if this is attempted it loses considerable height. It has therefore been found desirable to fly strips alternately rather than adjacently.

Since the flying of short flight lines with the Lear Jet is not economical because of the time lost while turning, the majority of tasks have extended across at least three degrees of longitude (approximately 330 kilometres). The specification requires each flight line to be continuous and unbroken for its entire length over the area being photographed, but breaks in strip continuity have been allowed where these have been necessitated by unfavourable weather.

In spite of the many problems that have been encountered it has been possible to meet the stringent specification for aerial photography without much difficulty. It has only been necessary to refly approximately 5 - 10 % of strips since the experimental work was first commenced during 1977. The main reasons for rephotography have been icing on the camera port, deviations from the predetermined flight lines and excessive omega tilts. The nose-high attitude of the aircraft has not produced any significant problems and where heights of camera stations have been determined the flight paths have appeared to remain constant with average deviations of the order of 0,4 % of the flying height.

To minimise the effect of shadows photography is normally only undertaken when the solar altitude is at least 30 degrees. In South African latitudes this can be achieved if the photography is flown from 1 to 3 hours before or after local noon.

Generally the photographic quality of all tasks has been excellent and eminently suited for orthophoto production at enlargement factors of three to four times. Enlargements of up to six times have also been successfully produced.

AERIAL FILM

The exposure of the film should produce a negative having a minimum image density of between 0,10 and 0,30 above base fog. The film is processed in a Kodak Versamat automatic processor. In view of the nature of the terrain and especially since large differences in contrast occur, development tests are always carried out to ensure that the best possible results can be achieved for a particular area. The optimum negative has an average gradient within the range 0,75 to 1,15. In extreme cases where the photography is of terrain of a low brightness range processing to reach a value as high as 1,5 has been found desirable. The lower values (shadow reading) apply to areas with a high brightness range such as in mountainous area where deep shadows occur while the higher values (highlight reading) apply to areas such as the sand often encountered in the featureless desert. Care is taken to avoid "catchlights" caused either by the reflection of the sun off water resulting in very high readings or dense black shadows where the readings equal base fog.

The following table indicates the average range recorded on tasks covering various terrains photographed during the past four years:-

Task	Minimum above Base Fog	Maximum above Base Fog	Average Gradient
1977	0,51	1,35	0,84
1978	0,27	1,43	1,16
1979	0,16	1,17	1,01
1980	0,24	0,94	0,70

It will be noted that in the 1977 task the average gradient was satisfactory although the minimum image density above base fog (0,51) was higher than desirable while in the 1980 task the average gradient was rather low (0,70).

CONTOURING

As mentioned in the introduction comprehensive investigations were previously conducted to ascertain the contour accuracy obtainable under production conditions using 1:150 000 ultra-small scale aerial photography to plot 20 metre contours at a scale of 1:50 000. The photogrammetric plotting was undertaken on both a Kern PG2 and Wild A10 Stereoplotter, with mechanical compensation for the effects of earth curvature. The vertical accuracy specification of the South African 1:50 000 series with a 20 metre contour requires that 90 % of elevations tested must be within one-half a contour interval and the remaining 10 % within one-half and one contour interval. The slopes of the terrain tested earlier with these stereoplotters, varied from 1°45' to 38°40' with a mean of 6°15' and bearing in mind that more than 90 % of the sheets that still require to be metricated fall in the flatter areas of the country the results obtained were most encouraging.

The standard error of the final contour on the published map was expressed as

$m_{elevation} = \pm (B + A\,\mathrm{Tan}\mu)$ where

μ is the slope of the terrain.

For the Kern PG2 fitted with a standard table and L type pantograph it was found that for an average slope of 5° the standard error was 6,1 metres (0,043 % H). Assuming a normal distribution it could be expected that 90 % of points tested would fall within the 10 metres required by the specification. Similarly for the Wild A10 fitted with an external table it was found that areas with average slopes of up to 9° could be contoured and the resulting map would comply with the specification.

During the latter half of 1980 correction plates to compensate for earth curvature were obtained for the Zeiss Planicart E2 Stereoplotter and data acquisition systems were fitted to this machine as well as to the Zeiss Planimat D2 Stereoplotter. The latter is connected to an external tracing table while on the Planicart all plotting is done directly at model scale on the integral plotting table. A Wild Aviotab TA1 digital plotting table was connected to the Kern PG2 Stereoplotter at much the same time and it was decided to use these three Stereoplotters to plot the 20 metre contours of different terrains, the most rugged being where the slope varied from 2°55' to 63°00' with an average of 13°20'.

The results below followed from the investigation:-

Terrain Slope			INSTRUMENT	Standard Error		Allowable Slope
Max	Min	Average		metres	%H	
33°	0°	2°26'	Zeiss Planimat D2 Zeiss Planicart E2	3,4 3,4	0,023 0,023	9°30' 9°30'
78°	1°30'	9°39'	Zeiss Planimat D2 Zeiss Planicart E2	5,4 5,5	0,036 0,036	9°00' 9°00'
63°	3°	13°21'	Zeiss Planimat D2 Zeiss Planicart E2 Kern PG2 and Wild Aviotab	9,5 9,9 8,9	0,063 0,066 0,059	8°00' 7°30' 8°30'

The standard errors in elevation were as expected and all three stereoplotting machines gave a result similar to that previously achieved on the Wild A10. In all cases average slopes of up to 9° could be tolerated whereafter the specified accuracy could not be achieved. It was interesting to note that the Zeiss Planimat D2 did not achieve better results than the Zeiss Planicart E2 while the Kern PG2 fitted with the digital plotting table gave results substantially better than previously obtained with the pantograph-tilting table combination.

Machine times for two areas of approximately 650 square kilometres each were as follows:-

Average Terrain Slope	INSTRUMENT	Models	Machine Time
2°26'	Zeiss Planimat D2 Zeiss Planicart E2	2 2	3,25 hours 3,50 hours
9°39'	Zeiss Planimat D2 Zeiss Planicart E2	2 2	7,5 hours 6,75 hours

Although there was no direct standard against which to compare these times the machine times for similar areas where 1:50 000 super-wide angle photography had been used were at least six times longer.

It should be borne in mind that the contours serve a dual purpose in that they also provide the digital terrain data required to produce orthophotos on the Wild OR1 system.

THE 1:50 000 ORTHOPHOTO

The production of orthophotos at a scale of 1:50 000 is undertaken on the Wild OR1 System. The digital terrain data is normally acquired during the process of contouring and three Kern PG2 Stereoplotters which have been connected to Wild Aviotab TA1 digital plotting tables, together with a Wild A10, Zeiss Planicart E2 and Zeiss Planimat D2 can be used for this purpose.

The new version of the SORA-OP program (Edition B) developed by Professor Dr.-Ing. Karl KRAUS at the Institute of Photogrammetry, Technical University of Vienna,was recently acquired and has been installed in a Univac 1100/61 computer configuration. The input from and output to magnetic tape is in ASC II code. This powerful program which can assemble digital terrain data covering up to 100 models makes it possible to handle large blocks of 1:50 000 sheets. It is anticipated that the 32 1:50 000 sheets that form a standard 1:250 000 sheet (2° x 1°) will be computed as a single grid comprising the digital terrain data for 64 models. The elevation data will thus be stored in regular grids and eventually it is hoped that a grid will be available for each of the 70 1:250 000 sheets covering the Republic of South Africa. This high density elevation data base will provide information concerning the landscape which will be of great importance to planners and other scientists.

The orthophoto is primarily used for the detail revision of standing material of the 1:50 000 series. The positional accuracy specification for the South African 1:50 000 series requires that 95 % of all well defined points of detail be within 0,75 mm of their true position on the ground. Tests carried out earlier indicated that a standard error of 0,40 mm between the orthophoto and the existing standing material could be expected. It is therefore possible to update and improve where necessary the existing standing material by direct tracing from the orthophoto.

It has been found that changes of detail such as realignments of roads and railways, new roads, extensions to townships and areas of cultivation are generally easy to recognise and amend. At the same time the depiction of the drainage pattern and other natural features can be considerably improved with the aid of the orthophoto while inaccurate compilation can also be amended by direct tracing.

There can be no doubt that the 1:50 000 orthophoto has revolutionised the techniques of revising the national series. The method offers the map-maker a means of producing up-to-date and superior maps in a considerably shorter time than has hitherto been possible.

Although it is not the intention to produce an orthophoto series at a scale of 1:50 000 there has been a demand from specialists and skilled users for these to be made available. Serious consideration has been given to producing the orthophoto in monochrome on the reverse side of the published map but it is unlikely that this will be done in the near future.

CONCLUDING REMARKS

Quite clearly the challenge which the Surveys and Mapping Branch of the Republic of South Africa now faces is its ability to apply this technique as well as other advanced technology available in the most effective manner.

Although the revision of maps will dominate the activities of the branch during the next decade it has become apparent that while basic topographic mapping remains the fundamental tool for planning the conventional line map and orthophoto map no longer provide all the information required by the specialist user.

Like other mapping organisations throughout the world the applications of automation,especially digital map compilation and cartographic data banks,are being investigated. There are no reasons why the present methods cannot be adapted to the needs of the future.

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Abstract

This paper describes the procedures currently being used in the Republic of South Africa to obtain high-flown super-wide angle aerial photography at a scale of 1:150 000 and the subsequent applications thereof to the plotting of 20 metre contours, the production of 1:50 000 orthophotos and the revision of the 1:50 000 national map series.

Ultra-kleinmaßstäbige Luftaufnahmen

Zusammenfassung

Der Vortrag beschreibt die gegenwärtig in der Republik Südafrika angewendeten Hochbefliegungen für Überweitwinkel-Luftaufnahmen im Maßstab 1:150 000 und deren Auswertung zur Kartierung von 20 m - Höhenschichtlinien, zur Produktion von 1:50 000 Orthophotos und zur Revision des nationalen Kartenwerks 1:50 000.

Photographies aériennes à micro-échelle

Résumé

L'exposé décrit les vols à tres grande altitude de la République de l'Afrique du Sud qui permettent d'obtenir des prises de vues aériennes super-grand-angulaires à l'échelle de 1:150 000 et leur restitution pour la réalisation de courbes de niveau de 20 m, pour la production d'orthophotographies à l'échelle de 1:50 000 et pour la révision des cartes nationales à l'échelle de 1:50 000.

Fotografía a escala ultra-pequeña

Resumen

En la conferencia se describen los vuelos a grandes alturas que actualmente se llevan a cabo en la República de Sudafrica para obtener fotografías super-granangulares a la escala 1:150 000 y la restitución de las mismas para trazar curvas de nivel cada 20 m, producir ortofotos 1:50 000 y para revisar las series de mapas nacionales 1:50 000.

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