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TOPOGRAPHIC AND THEMATIC MAPPING FROM SPACELAB PHOTOGRAPHS

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Introduction

This year of 1979, when we have seen Skylab fall out of the sky and marked the tenth anniversary of man landing on the moon, is a milestone in space exploration, yet it has become fashionable to criticise the U.S. National Aeronautical and Space Administration (NASA) and the space programme and to suggest that not only is the programme unproductive but that NASA is incompetent as well. If we pause to consider the advances which have been made in the field of remote sensing over the last ten years we can realise that in that field such criticism is unfounded. Crop assessments on a global basis can now be made using satellite data and much useful work has been done in the fields of land use mapping, forestry, geology and many allied fields. Ten years ago people were saying that topographic mapping was not possible from space imagery and that remote sensing was a band wagon with nowhere to go, but a vast amount of money is now being invested in this type of project and there is a confident expectation that the investment will pay dividends.

The subject of this paper is the European Space Agency (ESA) Spacelab project which will contain an experiment using a Zeiss RMK 30/32 metric camera. This first experiment is a step towards a full evaluation of the potential of space imagery and perhaps towards an operational mapping satellite.

EXISTING DATA: LANDSAT AND SKYLAB

Let us first put Spacelab into perspective. So far no standard mapping camera has been used in space although Itek cameras have been used to map part of the surface of the moon and have provided useful photography from Skylab. The main source of imagery from space has been the Landsat series of satellites which have now been operational for seven years. The Multispectral Scanners (MSS) on board Landsat 1, 2 and 3 have provided imagery in digital form in four or five spectral bands and this has been much used by photo interpreters. Many organisations have tested the data from Landsat and Skylab for use for topographic mapping, a summary of results is given in Table 1.

Experience has shown that Landsat MSS imagery allows identification of some features, particularly linear features which are less than the expected resolution of $2\sqrt{2}$ times the pixel size of 80 m. MOTT and CHISMON (1975) identified railways and rivers of 40 m width. Better interpretation is expected in dry latitudes (20° - 40°) than in temperate and tropical areas. Mathematical Transformations have given fits between Landsat images and ground control to the order of 50 m - 100 m.

	Principal distance (mm)	*Format (mm)*	*Flying height† (km)*	*Photoscale*	*B : H ratio†*	*Ground resolution (m)*	*σxy (m)*	*σz (m)*
Landsat 1 and 2 MSS	—	185×185	920	1 : 1000 000	0·14	220	±50–100§	±400‖
Skylab S–190A	150	57×57	435	1 : 2850 000	0·26	99	max. 325¶	±148‖
Skylab S–190B	460	114×114	435	1 : 950 000	0·10	38	max. 140¶	500–675‖
Spacelab RMK 30/23††	300	230×230	250	1 : 820 000	0·3	20–40	?	20–30
NASA/ITEK large format camera††	300	460×230	250	1 : 820 000	0·6	20–40	?	10–20
Long focal length camera††	600	230×230	250	1 : 410 000	0·15	5–10	?	20–30

† Values for flying height are mean values.

§ Various sources; for example Wong (1975), Mott and Chismon (1975) and Mohamed (1977).
‖ Welch and Lo (1977).
¶ Mott and Chismon (1975).
†† Values given are examples theoretical accuracies.

Table 1. Table giving comparison of different satellite-borne sensors.

Heighting is virtually impossible with Landsat imagery. Similar results as obtained from the MSS are possible from the Landsat 1 and 2 return beam vidicon (RBV) cameras. A RBV camera is included in Landsat 3, launched in March 1978. The resolution of this camera is twice that of the RBV in Landsat 1 and 2.

The Skylab photography was of much better quality than Landsat but was much more limited in extent. The S-190A multispectral photographic facility had the better quality for mapping since it used a between the lens shutter and forward motion compensation (FMC). The S-190B Earth Terrain Camera used a focal plane shutter with a long focal length lens which gave a poor base to height ratio; results were less satisfactory for mapping purposes.

Experience has shown that imagery of the type provided by Landsat or Skylab is inadequate for mapping but that better results are obtained with the S-190A where a film camera with a between the lens shutter FMC and recoverable film is used. The small photoscale gives poor planimetric accuracy but, even at this small scale, heighting accuracy is much better. Table 1 shows that much better results are expected from metric cameras.

Landsat and Skylab were both high altitude, long mission flights. In order to use a metric camera efficiently, the mission must be at a low altitude and therefore of short duration. There is therefore a conflict of requirements between large scale imagery and the opportunity to obtain cloud free coverage on a long flight.

METRIC CAMERAS

In 1982, the first European Space Agency Spacelab will be launched in the American space shuttle. A Zeiss (Oberkochen) RMK A 30/23 aerial camera, modified for use in space, will be on board. The specification for the camera is given in Table 2. During take-off and landing the camera will be mounted in racks and after take-off it has to be mounted, by the payload specialist on board, over an optical window. The time during which the camera will be pointing towards the earth is limited by the demands of other experiments in Spacelab. The number of films which are carried will depend on the weight limit put on the experiment but it is expected to be three films, each allowing for 550 photographs and giving a total of 1650 exposures. With 80 per cent overlap, the interval between exposures is 5 s, with 60 per cent overlap it is 10 s. As a result, about 5 hours has been allowed for camera operation.

Camera system	
Zeiss (Oberkochen) RMK A 30/23 camera	
Lens	Topar A1 with f = 305 mm Distortion 4μm at r = 150 mm Resolution $40\ell mm^{-1}$ at r = 100 m
Format	230 x 230 mm
Shutter	Aerotop rotating disc, between lens Speeds: 1/100s, 1/250s, 1/500s, 1/1000s
Aperture	f/5.6, f/8, f/11
Experiment parameters	
Altitude	250 km approximately Inclination 570 Time for one orbit 1·5 h
Relative velocity	7.55 km s^{-1}
Photograph scale	1:820 000
Ground coverage	188 x 188 km per photograph

Table 2. Parameters of the Spacelab metric camera experiment.

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The actual target areas for photography have not yet been decided upon and will depend on the demands of the other experiments on the flight. The Metric Camera Working Group set up by ESA has set priority areas which will be input into the flight planning program. These areas have been decided on after study of the proposals for the use of the imagery sent to ESA from all over the world.

Experiments have been carried out to choose the best films for the flight but a decision has not yet been made on which one to use. DUCHER (1979) has described the experiments and indicated that black and white film will have priority but that colour or colour infra red film could also give good results. Again, there is a conflict between good definition black and white film for topographic mapping and other emulsions for interpretation.

APPLICATIONS OF SPACELAB PHOTOGRAPHY

ESA has circulated very widely an invitation to submit proposals for experiments using the metric camera photography. The emphasis is on application involving topographic mapping or aerial triangulation but proposals for thematic mapping were also asked for. About 100 replies have been received from 33 different countries with proposals in roughly equal numbers for aerial triangulation, map revision and orthophotography and rather more for topographic mapping. There are only slightly fewer proposals for thematic mapping than for topographic mapping.

Most of the experiments envisage mapping at a scale of 1:100 000 and ask for photography of specific areas where ground control exists or which are of particular interest to the experiments. Let us examine the chances of the aims of the experiments being achieved under the headings technical and operational.

Technical considerations

The specifications for the Spacelab mission with the RMK camera will ensure, providing there is no equipment malfunction, that photographs at a scale of 1:820 000 are produced with 80 % overlap. The resolution of detail should be in the region of 20 m, 7 m of which results from image movement, but from experience with Landsat it is to be expected the accuracy of point co-ordinates will be better than this and that the resolution should be good enough for most roads to appear. On a Wild A10 plotting instrument an enlargement to 1:100 000 should be possible and most detail usually plotted at that scale should be visible. The contour interval is likely to be no less than 50 m. A principal distance of 305 mm can be accommodated in some plotting instruments but the analytical plotter is the ideal restitution instrument.

The prospects for aerial triangulation are also good in that the models will have large coverage and should be undeformed (although allowance must be made for earth curvature) and accuracies of ±10 m on a continental scale should be possible. For thematic mapping the resolution will be superior to Landsat which has proved to be very useful for interpretation of land use, soils, geology etc. so better results should be expected from Spacelab. There are restrictions in that the basic data are photographic whereas many people are now using digital data in several spectral bands from Landsat. Many people are quite used to using panchromatic photographs for interpretation and the photographs can be converted to digital form.

Operational considerations

It is operational features which are most likely to reduce the chance of attaining experimental aims. There will be some flexibility in the flight plan, that is in the times when photography is possible, but some areas where photography was requested will not be photographed and other areas will not be imaged because of cloud cover.

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The Metric Camera Working Group are doing all they can to ensure that areas of maximum interest will be included in the programme; the priority areas are Africa, Europe, Canada and S.E. Asia. The main problem is likely to be cloud. In Europe and similar mid latitude areas the chances of finding a particular area with less than 2/8 cloud cover on a particular day are between 10 and 20 percent, whilst in tropical areas it is likely to be nearer 5 %. Since Spacelab is only in orbit for seven days, there is a good chance of obtaining cloud free cover only in arid and semi arid areas.

THE NEED FOR IMAGERY FROM SPACE

One of the most hotly debated issues surrounding topographic mapping from space imagery is whether or not it is necessary. If Spacelab shows that 1:100 000 mapping is possible, it is still necessary to show that 1:100 000 mapping is needed. Figures published by the United Nations indicate that large areas of the earth are unmapped or only have out of date maps at 1:100 000 or 1:200 000 scale. These figures were confirmed by a report commission by ESA on the mapping needs of African Nations, although the report noted that the greatest need is for revision and production of 1:200 000 maps first and secondly for 1:50 000 mapping. It was also felt that there are problems of personnel and management in operating and maintaining sophisticated equipment in developing areas, especially where international arrangements exist. The report also concludes that the high resolution of the metric camera photography is a great advantage for thematic mapping but that the lack of repetivity and multispectral bands is a disadvantage.

Recent experience in South East Asia has revealed a great interest in Spacelab for thematic mapping and map revision but a lack of enthusiasm for the photography as a tool for topographic mapping, because 1:50 000 maps already exist for many areas, in Thailand and Malaysia for example, and because of problems of cloud cover. There is also a lack of computer assisted mapping equipment in this area and examples of problems where it has been used. We can thus see that there is a need for new maps at scales of 1:50 000 and 1:100 000, for map revision and to give higher resolution for thematic mapping.

The question then is how to satisfy these needs. The first possibility is normal photogrammetric methods - these have not been able to solve the problem in the past mainly because they are too slow or too costly to have a high priority. A second alternative is ultra high altitude photography - this does offer a possible answer and is as yet untried in production but it would be expensive and suffer from much the same problems of cloud cover as space photography. Either of these alternatives could work if money from space program diverted. The other possibilities are cameras in space and other forms of space imagery.

THE ROLE OF SPACELAB

How then does Spacelab fit into a scheme to satisfy the needs for topographic mapping?

The first Spacelab mission will show whether or not our assumptions about metric cameras in space are correct and whether 1:100 000 mapping and 1:50 000 revision is possible. It will also give some idea of how great is the problem of cloud cover.

A future Spacelab mission could contain a camera with a longer principal distance to give greater resolution and larger scale and a means to produce convergent photographs to improve the base to height ratio. A long focal length camera, with a principal distance of 610 mm is one of the options being considered by the Metric Camera Working Group for ESA. A vertical photograph could have a scale of 1:410 000 from 250 km. It would be necessary to have a forward motion compensation device (FMC) to give suitable resolution. A pair of vertical photographs would have a base to height ratio of half that of the RMK 30/23 so it is necessary to improve the heighting accuracy by using convergent photography; this could be done by fore and aft tilt or by lateral tilt of either the camera or a mirror. Lateral tilt using a mirror is probably the most useful solution because three strips of photography could be imaged in one pass thus restoring the coverage lost by using a narrow angle and helping to reduce image loss due to cloud cover. Stereoscopic coverage would be available from adjacent passes and it would be possible with close enough orbit to obtain complete vertical coverage for orthophoto production if required. A practical limit to tilt on Spacelab may be 15° giving heighting accuracy of about ±14 m. One problem with lateral overlap is that weather or lighting conditions may have changed between passes making stereoscopic viewing difficult.

An analytical plotter would be essential for plotting convergent photography with principal distance of 610 mm. The cost of such a development would be high although the cost could be reduced if an existing camera could be modified.

FURTHER DEVELOPMENTS

The first Spacelab mission and subsequent missions not yet planned in detail will provide invaluable information which will be used to develop a policy for topographic mapping. The results for Spacelab will have to be compared with other methods being developed. At present there are two main alternatives:

1. A large format camera.
2. A linear array sensor.

These systems could be supplemented by radar imagery to give all weather capability and a laser altimeter system to supplement height information.

A large format camera will be flown in an American Space Shuttle in 1981. Its main advantage is a format of 460 mm in the direction of flight and a consequently improved base to height ratio giving the same scale as the RMK 30/23 but with twice the height accuracy. The disadvantage is its great size and weight.

The linear array or push broom scanner is being developed by several agencies at present. It is to be used in the French SPOT satellite to be launched in about 1984. The French system will give 10 m resolution from 800 km and offers the best possibility for long flights giving repetitive cover. The push broom scanner is not photographic and presents a different set of problems to the film cameras which would be flown on low altitude platforms.

Radar systems such as the Synthetic Aperture Radar carried on Seasat and to be carried in Spacelab offer all weather capability with high resolution, but until the Seasat data are processed and available a full evaluation is not possible. A great deal of data processing is required to obtain a distortion free, high resolution image.

CONCLUSION

Developments planned at the moment are aimed at evaluating systems which may be suitable for producing topographic maps from space imagery. The photographic systems have the immense advantage that they give geometrically correct photographs and many organisations could make use of them, also that the photograph is a very efficient data storage medium; they have the disadvantages that low orbits are required giving less opportunity for obtaining cloud free cover and a basic difficulty in improving heighting accuracy to the presently expected standards.

The linear array sensors, which could be carried in high altitude platforms for long periods, are at present not proven and would involve a much greater development in associated computer technology than photographic systems. In the long term these sensors, together with radar, may offer the best solution but metric cameras may give the short term answer and Spacelab is the first step in evaluating the potential.

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