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# AERIAL PHOTOGRAPHY AND THE USE OF HELICOPTERS IN HYDROGRAPHY

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Whilst the acquisition of complete and accurate detail and depths is a desirable ideal for all nautical charts, it becomes more critical in shallow waters where the consequences of omission or inaccuracy can be most serious. At the same time, classical hydrographic mapping in shoal waters with small craft is slow, hazardous and expensive. Sounding lines must be closely spaced to ensure complete topographic cover of the sea bed, and the vessel will frequently be required to break even a closely spaced grid of lines to investigate spikes, shoals or other artificial or natural obstructions. In addition the time available for working in such areas may be severely limited by tides.

Given these difficulties, any alternative method of data acquisition merits serious consideration and in the right circumstances aerial photography can be of great value.

The advantages of aerial photography for mapping on land are well established and accepted. A permanent record of the area can be acquired quickly and economically at a selected time and using a film or films which will best show the features which are to be mapped. After the addition of a certain minimum of field work to provide control in terms of dimension and for interpretation, the remainder of the mapping process can be carried out in the security and comfort of a laboratory without regard to weather, seasons and all the frustrations and delays associated with field work.

At this point, a brief introduction to the techniques and terminology used in the photogrammetric mapping from aerial photography may be of value.

A photograph taken by a precision surveying camera presents a very accurate central perspective projection of the ground, and a good aerial photograph will closely resemble a map in many aspects. However, because of camera tilts and height differences on the ground, the photograph will contain image displacements and cannot therefore be used as a plan. Whilst this might on first consideration be a bit disappointing, it should be borne in mind that image displacement due to height is the very factor which enables us to view in three dimensions when observing a stereoscopic pair of photographs. In aerial photogrammetry the area to be mapped is systematically photographed with the camera as nearly vertical as possible so that all the ground is covered by at least two photographs. The stereoscopic image available from a pair of photographs is termed a 'model', and if ground control consisting of at least two co-ordinated points for plan and 3 points for height is available, then with the aid of a suitable plotting instrument a map of the model can be plotted showing all visible detail as well as contours and spot heights. Whilst this in itself is a great convenience, even this minimum of ground control represents an appreciable amount of field surveying work and over the years the technique of "aerial triangulation" has been developed with the aim of reducing field work. In aerial triangulation photo points are observed on individual models to provide machine co-ordinates. At this stage the scale, location, orientation, tip and tilt of the model are unknown. When all the models in an aerial triangulation block have been observed in this manner they can be linked together through common points, at which stage the whole block has a common but unknown scale, location, orientation, tip and tilt. If this block is now fitted to ground surveyed plan and height control points, then it can be scaled, orientated, levelled and located in terms of the ground surveying system, and "minor control points" on each model in terms of, say, national grid and ordnance datum can be computed in lieu of the ground control previously described. After this the models are plotted and finally the machine plots are compiled into map sheets.

The difficulty with hydrographic surveying is that the mapping area is covered by water. Water absorbs and reflects light which is our data source, thus imposing limitations upon the application of aerial photography to those areas which either are exposed at low tide or where the water depth and clarity are such that the sea bed is visible through the water. The attraction of the method, as already indicated, is that these are precisely the areas where classical methods present special problems.

We have a choice of films to use, depending upon what we are trying to achieve:

(a) Panchromatic black and white photography, which is the universal tool for photogrammetric mapping, will record most onshore detail as well as having good water penetration characteristics.

(b) Modern colour aerial photography, which has remarkable clear water penetration characteristics and gives a very dramatic presentation of submerged detail, and thus facilitates interpretation of morphological, vegetation and sediment patterns. Although colour photography is more expensive than black and white it is to be preferred when water penetration and interpretation are required.

(c) Infra-red films, colour or black and white, which offer the advantage of minimal water penetration of only a few inches. They are used where the object is to establish a detailed high or low water line and either can be flown simultaneously with one of the other emulsions to provide a height control datum along the edges of the mapping area and around islands and rocks. In addition, they will show floating surface vegetation patterns and may be useful in pollution studies.

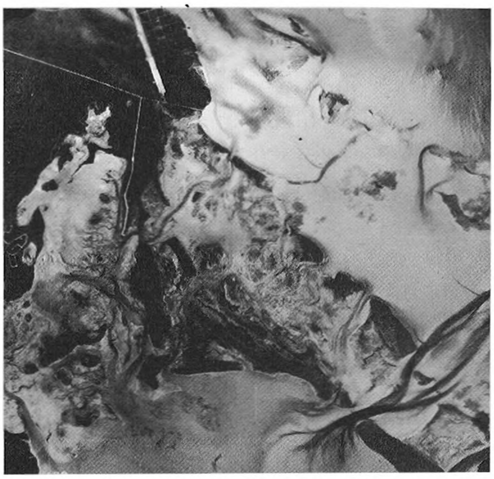

FIG. 1. — Black and white panchromatic photograph of coastal area.

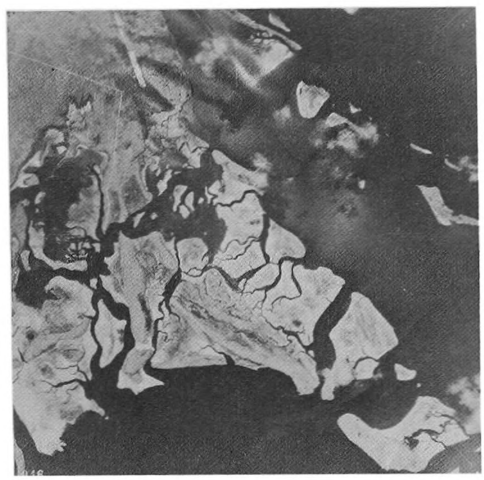

FIG. 2. — Black and white infra-red photograph of same coastal area as fig. 1.

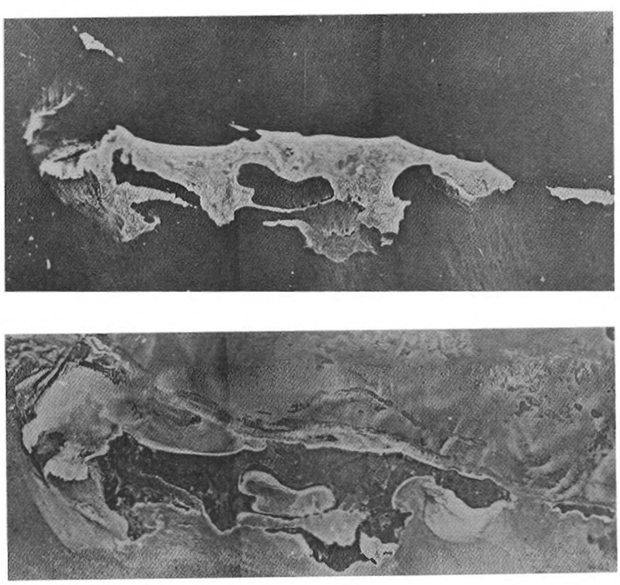

FIG. 3. — Both black and white and infra-red photograph of one area.

Having selected the correct film or combination of films, other practical limitations must be considered. Both when water penetration and when maximum tidal exposure are required, the aerial photography should be taken at low water, and where the tidal range is large, then ideally at low water spring tides. For the purposes of water penetration, a period within half an hour of low water slack is considered the best, since the depth is at its least and wave disturbance on the surface and turbidity are at a minimum. However, a very high sun angle must also be avoided, and this can pose problems in low latitudes. Obviously good illumination is of prime importance as well, so the time for taking ideal aerial photography of underwater detail can be somewhat limited. The effect of sun reflection on the water caused by too high a sun angle can be overcome by increasing both lateral and forward overlaps. If, in areas where water penetration is the main consideration, low water slack coincides with too high a sun angle, then photography should be done at high water instead, despite the reduction in underwater area covered because of increased depth. Flood and ebb tide conditions should be avoided since the presence of waves on the surface severely impairs the photogrammetric image.

In 1971 a requirement arose for a survey of the Wash in connection with a barrage scheme. Maps at 1:25,000 and in some areas at 1:10,000 were required to be prepared of the Wash Bay within the seaward boundary plus a coastal strip. All the normal detail at these scales was to be shown and in addition, boulders, shingle, sand, salt marsh, mud, ripples, sand waves and dunes were to be plotted. A 100 metre grid of spot heights accurate to ± 0.25 metres was to be supplied and in addition, contours varying between 0.5 and 10 m vertical interval were to be plotted.

At spring low tides, which in this area have a range of some 7 m, approximately 50 % of the Wash Bay is exposed, and it follows that at least 25 % of the area would be very difficult to survey by sounding. It was also quite clear that a detailed survey of the shoal areas made by classical ground survey methods was not a practical proposition due to the dangers

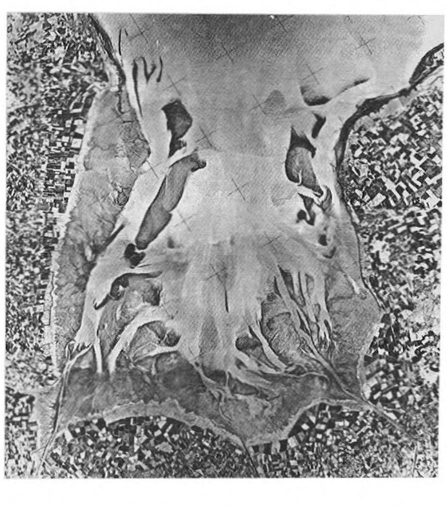

FIG. 4. — Black and white panchromatic mosaic of the Wash.

of working in such an extensive inter-tidal zone which included areas of quicksand and soft mud and numerous channels that impeded progress and which on the flood threatened to cut off surveyors from the shore.

The solution adopted was to survey the inter-tidal zone by aerial photography and the deeper areas by hydrographical methods. Fairey Surveys undertook the aerial survey and Wimpey Central Laboratories the hydrographic work.

1:50,000 contact scale panchromatic black and white photography of the whole area and 1:10,000 contact scale true colour photography of the inter-tidal zone was flown at spring low tides between September 5th and September 8th 1971. The 1:50,000 photography was used for planimetric aerial triangulation and plotting of planimetry, and the 1:10,000 colour photography for height and aerial triangulation, spot height and interpretation of contours and inter-tidal detail. Plan and height control around the shoreline of the Wash was readily available from Ordnance Survey maps. Hydrographic survey was to be carried out in the deeper waters and height control of the offshore banks could be provided at high water by this method. Thus the need for infra-red photography to provide a height datum did not arise.

Before the 1:10,000 photography could be used for contouring, a framework of ground-surveyed and photo-identified height control points had to be established at 3 overlap intervals, approximating to cross sections at 3-kilometre intervals across the inter-tidal zone. Unlike a normal photo control exercise, there were several constraints placed on the field work. Obviously levelling could only take place a few hours each day when the tide was out. In addition, there were areas which could only be reached at spring low tides. There were large areas of soft mud and quicksands over which it was dangerous to level and indeed, accurate results would have been difficult to achieve. In addition to these natural hazards, the area included bombing ranges within which the time available for survey work was strictly limited by the Royal Air Force.

After an initial reconnaissance by the project surveyor, it was decided that in the interests of progress and safety a helicopter would be required. A helicopter reconnaissance confirmed that the areas of most difficult access were located on the inland coast and the estuaries of the Ouse and Welland. These were also areas where, due to the lack of firm detail, photo identification was most difficult. It was decided to concentrate the use of the helicopter in these areas and, if time permitted, on the Boston to Skegness coast where in places the low water line was more than 5 kilometres from the sea wall. In the event this target was achieved during the six days of spring tides from 4th–9th October 1971.

The Bell 47 helicopter available dictated the use of a two surveyor team, instrument man and staffman, who were in radio contact with each other. Readings were taken onto a movable target on the levelling staff and sights were of the order of 500 metres. The readings were booked by both the staff holder and the instrument man and were check-sighted after booking. Precision of sighting was found to be within 3 cm. The two sets of readings were compared at the end of each day, and no booking error was revealed throughout the operation. Photo-identification was difficult in places, but was greatly assisted by the "camera eye view" available from the helicopter. It was quite evident that even after just one month changes in the sand banks had taken place.

Apart from changes, identification and indeed navigation was made difficult, particularly near the low water line, by overall changes in the sea/land pattern which resulted from quite small differences in water level between the time of photography and time of levelling.

In order to avoid possible height control errors, the pattern of levelling followed as far as possible the areas of positive identification even though this at times resulted in control falling at intervals other than the 3 overlaps standard. When, despite these precautions identification was still not positive, care had to be taken to select photo points in very flat areas so that height error due to plan shift would be minimised.

The lines of helicopter levelling were carried out in "U" loops starting from and closing onto bench marks established on the sea walls. These loops averaged between 10 and 15 km in length and all closed within 15 cm which is commensurate with the sighting accuracy.

Some 120 kilometres of levelling was achieved during the six day period in 18 hours and 20 minutes of flying time, and we considered the operation to be a great success.

It is in the context of ground control in difficult areas such as the Wash that the helicopter is of greatest value. In general the helicopter is not a good platform for the acquisition of photography; fixed wing aircraft are faster, more stable and less subject to vibration which can induce camera shake and consequent loss of definition.

The Hunstanton coast and other areas of easy access were height controlled by normal field levelling methods, and thereafter the preparation of the maps should have been able to proceed at our laboratories in Maidenhead. Unfortunately, the Wash still had an unpleasant lesson to teach us. Our ground control requirements had been based upon the criteria established in terrestrial mapping. In the event we found, due to the nature of the ground, particularly in estuaries where at low water, a fine film of water remained on the surface of the mud, that the photographic image lacked definition and that the accuracy of our height aerial triangulation was therefore degraded. This necessitated the addition of extra ground control at a later stage in order to meet the specified accuracies. In the final analysis however, a complete, detailed and accurate survey of short time datum was produced which it would have been difficult to equal by any other method and then only at far greater cost.

Provided that the water is calm and clear and underwater detail is reasonably photogenic, for example, rocks, coral or other textural features, then aerial photography can be used to penetrate depths up to about 10 metres. The effect of refraction at the air/water interface is to displace all points away from the Nadir. The amount of displacement is related to depth of water and distance from the Nadir and when control in plan and height is to be extended by aerial triangulation, then corrections to the photogrammetrically observed co-ordinates must be applied in an iterative manner for the triangulation solutions. When a stereoscopic overlap has been height controlled either by aerial triangulation or by hydrographical means, then the observed depths will all appear to be too shallow. The correction factor will vary from approximately 1.36 at the centre of a normal overlap to 1.50 in the corners. In the expected maximum depth of 10 metres therefore, the correction of the observed depth at the centre of the overlap would be 2.65 metres and in the corners 3.33 metres.

Thus errors arising from the use of an average correction factor of say 1.43 would be of the order of 0.5 metre, and the decision whether to use a differential correction factor or a mean factor would depend upon the depth of water to be surveyed and the accuracies required. The information quoted is based on published results, controlled experiments carried out by us in Maidenhead, and empirical data which we have acquired in the course of carrying out such work.

One such project arose in 1975 when we were surveying an area on the Red Sea which called for 1:1,000 scale mapping with 1 metre contours of a coastal strip and extension offshore for 500 metres or to the edge of the coral reef whichever was less. It was required for the planning and execution of civil engineering works. It was our intention to provide the offshore survey by classical methods consisting of frequent cross sections surveyed by combination of wading and dip-stick and echo sounding from shallow draft boats. The terrestrial work was being carried out by aerial survey and in the event we found that 1:10,000 and 1:5,000 panchromatic black and white aerial photography had achieved good penetration of the water to the edge of the coral reef, and we were thus able to extend the aerial triangulation offshore and provide the underwater detail and contours by photogrammetry. The conventional offshore work was reduced to the provision of far fewer cross sections as checks on the aerial triangulation and plotting and to the survey of restricted areas where pollution and turbidity had reduced penetration. Thus we were able to produce a very detailed and complete survey whilst at the same time achieving economies.

Both in the case of the Wash and the Red Sea coast, photogrammetry provided the best solution for hydrographic surveys, but I should like to emphasise that aerial survey is no panacea for hydrographic problems. In the case of the Wash, we were extremely fortunate that the spring tide period in September 1971 coincided with perfect photographic weather. Had we missed the September and October windows, then the aerial survey would have been set back by at least six months.

On the other hand, we were not so lucky with the accuracies achieved, and the need to provide extra ground control did in fact delay the mapping and increase costs. On the Red Sea, we were lucky to achieve the water penetration, but nevertheless, there were areas, as already indicated, where pollution and turbidity necessitated reversion to conventional methods. Thus, over-optimism is not be recommended.

Areas of the world where sea and weather states are predictable offer the best conditions for aerial survey and I understand the United States National Ocean Survey, as a result of trials carried out in the Puerto Rico area in the early seventies, has advanced underwater contouring by photogrammetric methods to an operational level. At the very least, at the planning stage of a project, it should be ascertained whether suitable aerial cover already exists or whether it is feasible to acquire suitable new photography, and engineers, hydrographers and photogrammetrists should pool their knowledge and resources to devise the optimum solution to each survey case by case.