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PROGRESS WITH AIR PHOTOGRAPHY FROM HELICOPTERS FOR HYDROGRAPHIC WORK

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ABSTRACT

Helicopters have been found to have useful applications to hydrographic tasks, especially when they can be carried on board survey ships and are thus readily available. The tasks examined in detail in this paper are the measurement of tidal streams by aerial photographic methods, surveying of the inter-tidal zone and the measurement of depths in shallow water. The problems of mounting the camera in the helicopter are also considered.

INTRODUCTION

The rapidly increasing contribution of photogrammetry to surveying and mapping, or charting, over the last decade or two has caused many people in various parts of the world to exploit the possibilities of helicopters as photographic tools. From the technical viewpoint, the ability of a helicopter to fly very low and very slowly, or even to hover in a stationary position, gives it an advantage over conventional aircraft for certain types of work. Thus it is possible to obtain very large scale photography, without image movement, from which accurate heighting may be obtained. It is also more likely to be possible to operate below cloud base. In the hydrographic world this opens up distinct possibilities in the inter-tidal and shallow water areas. From the operational and administrative standpoint the possibility of carrying a helicopter onboard ship, and the resulting greater flexibility, offers further advantages. If it is also feasible for a survey organisation to have helicopters under its exclusive control it becomes possible to co-ordinate the whole survey planning and execution to make the best use of air survey as a complementary tool to the traditional methods of ground survey.

The UK Hydrographic Department first began to explore the possibility of taking air survey photography with helicopters when HMS *Vidal* was designed to carry a helicopter in the early 1950s. In the event the helicopter installed in HMS *Vidal* proved too small to carry a survey camera. A smaller reconnaissance type camera was fitted to this helicopter, and to that carried by HMS *Protector* for surveys in the Antarctic. Both of these helicopters did produce good photography suitable for use in the simpler photogrammetric techniques, such as radial line plotting, but it was not survey quality photography.

In the early 1960s commercial survey companies, both in this country and in USA (ROBINSON and WITHEM, 1967; SCOTT, 1968) began to experiment with helicopters for obtaining air survey photographs. Mounting systems were designed to overcome the problem of vibration which, it had been thought, would make such photography impossible.

The commissioning, in the mid 1960s, of the three new H class ocean survey ships, HMS *Hecla,* HMS *Hecate* and HMS *Hydra* equipped, as they were, with Wasp helicopters, revived the possibility of obtaining survey photography.

MOUNTING THE CAMERA

The first preference for position of mounting the camera must obviously be centrally in the floor of the main cabin of the helicopter. Here the camera is afforded the best protection and can be most easily accessed and controlled when operational. This arrangement allows film magazines to be changed in flight and facilitates accurate viewfinding and monitoring of camera functioning, as well as affording protection from the elements. The Whirlwind helicopter attached to HMS *Endurance* for current surveys in the Antarctic has a Williamson F49 Mark II air survey camera so mounted. Panels were removed from the floor of the cabin and the base sealed with optically flat glass. Warm air is circulated around the camera to maintain an even temperature. This has proved an excellent system, but one major drawback has been the low flight ceiling of the aircraft, 2000 m, which gives a smallest scale of 1/12 000. In Antarctica the requirement is for photography for mapping purposes, ideally at 1/30 000 or smaller. For this purpose a camera with an 88 mm focal length lens is being investigated, which would give a photo scale of 1/20 000 — not ideal but an improvement on the present.

Unfortunately it has not been possible to fit the cameras in the Wasp helicopters on the H class survey ships in this position. An alternative mounting system has been designed to sling the camera outside and below the airframe on the starboard side, which involves the removal of the door on this side of the helicopter. As a result there is no protection from the elements for either camera or operator; control of the camera operation especially the view finding mechanism is more difficult, and it is not possible to change film magazines in flight.

When the UK Hydrographic Department began work on fitting cameras to helicopters in 1967, the problem of vibration had already been overcome by commercial operators such as Fairey Aviation Limited, who had produced some first class survey photography with helicopters. Valuable advice and assistance were received from the above company, but there were other problems to be overcome which were peculiar to the use of naval helicopters. One of these was that the helicopters used commercially had skids for landing, whilst the naval helicopters had a heavy hydraulic undercarriage. This meant that the framework to hold the camera could not be fitted from the aircraft frame to the skids, but had to be fixed to the aircraft frame alone.

In addition to the heavier landing gear, the naval helicopter had flotation gear and other fixtures associated with military helicopters. The weight restriction caused by the extra equipment dictated the position, type and size of the camera system. The position had to be outside the aircraft and near the centre of gravity, which is by the rear starboard door. The framework to hold the camera and its mount had to be hung from the foot of this doorway. An attempt to raise the camera up to a more suitable position would increase the amount of support required to an unacceptable weight. The requirement therefore was for a camera with an overall length not greater than 370 mm. The instruments then available in the office to process the resultant photography further dictated a camera format of

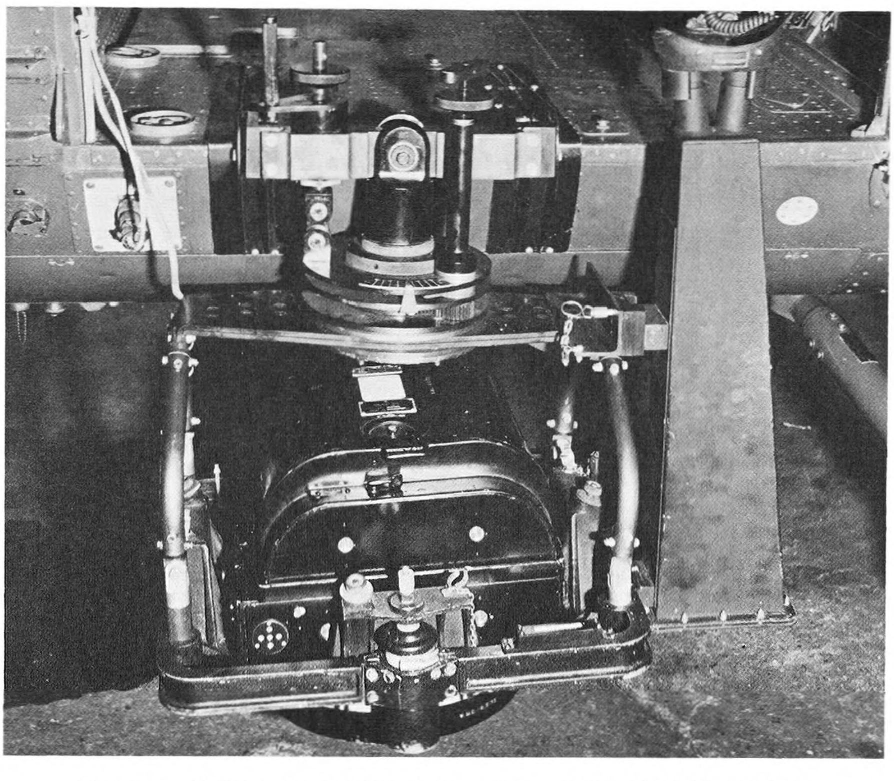

FIG. 1. — Williamson F49 Mark II camera with adjustable mount, fitted to Wasp helicopter.

230 mm × 230 mm and focal length of 152 mm. The Williamson F49 Mark II camera fulfilled all these conditions and at 36 kg was well within the weight requirement; it was also readily available. However, the camera is an old model, with a lens neither ideally suitable for survey work nor sufficiently versatile for colour photography.

The original framework for the camera and its mount was of simple design, with no correction possible for levelling or adjustment for crabbing in flight. First tests with this system were carried out in 1969 with excellent results for this type of camera. Since the mount was not adjustable for tilt, the attitude of the aircraft in flight at certain speeds had to be determined and the camera fitted so that at 60 knots it was approximately level. This speed was chosen as a speed at which the helicopter is relatively stable, in an attempt to minimise vibration and avoid sudden instability. Flight lines were planned to head the aircraft into the wind but this proved difficult as wind speed and direction are variable at different altitudes.

A second generation framework (figure 1) was then designed which would enable levelling in flight and a correction for crabbing of up to 20° to port or starboard. A prototype for this purpose was completed in 1972; modifications to this have been completed and the first production model is now in operation. A further refinement of an optical sight is in assembly stage at the moment.

WATER MOVEMENT

The traditional methods of measuring water movements, by float tracking, current meter and dye and other tracer studies, are of course well known. For many purposes these techniques are ideal and are becoming increasingly refined and sophisticated with the latest developments in electronics. Each of these techniques, however, gives data for only one point for each observation. A photogrammetric technique, which allows the nearly simultaneous tracking of an almost infinite number of targets over a certain area, has been proved very useful for such purposes as sedimentation studies, delicate ship movements, and obtaining data for hydraulic models.

The original idea of measuring water movement photogrammetrically must be credited to CAMERON (1952, 1962). The idea and techniques were further developed by FORRESTER (1960) and KELLER (1963). The basic theory was that in a stereoscopic model formed by overlapping vertical air photographs, oriented, scaled and levelled in the usual manner, there would be a false parallax between points in the water which had moved between the two exposure times. This parallax could be removed, in the X direction by a "*z*" movement and in the Y direction by a "*by*" movement. The amount of these two movements could be converted to a rate and direction of movement from a knowledge of the scale of the model and the time interval between exposures.

The UK Hydrographic Department began work in this field in 1964 (DUHAUT, 1972), drawing on the experience of the earlier work. It was soon realised, however, that a simpler method of measurement would be to set the machine in the Z direction to water level. The two positions of a moving target in the water could then be marked, one for each projector. The direction of movement was then directly indicated and the rate simply calculated by application of scale factor and exposure interval. This method was checked against the false parallax method on both the Multiplex and Wild A8 photogrammetric plotting machines and found to be of comparable accuracy. Besides being simpler, quicker and involving less calculation, the latter method has facilitated automatic recording of the two positions of moving targets via the EK22 digital read-out attached to the A8. The necessary computer software has also been developed to process this read-out for direct scribing of vectors on an automatic plotter. These vectors are proportional in length to the rate of movement and indicate the direction of movement.

Specimen completed plots from some work at Barrow-in-Furness are reproduced here (fig. 2). This work has already been described in detail (BURTON, 1974). In this case the photographs included land on both sides of the channel, and adequate triangulated control points were available from the Ordnance Survey of Great Britain. In cases where land is available only on one side of the photographs, control buoys have been laid along the flight line and on the seaward edge of the photography. Moderate success has been achieved in an all water survey in the Thames Estuary. This is fully described in the reference already quoted, (DUHAUT 1972). In this case control buoys were laid and fixed, and refixed at frequent intervals throughout the survey, by the Hi-Fix system. An electronic fixing aid of at least this accuracy would seem to be essential for attempting this task out of sight of land.

In some areas natural markers may be present in the water, such as broken ice, driftwood, natural foam or discoloured water. Generally, however, it has been found necessary to supplement these with a seeding programme. The most satisfactory surface markers have been found to be fire fighting foam and sheets of chart paper (50 cm × 50 cm are large enough for a photo scale of the order of 1/5 000).

Sub-surface targets are 1 m × 1 m sheets of plywood with a nylon cord and metal drogue attached to the underside. By varying the length of cord observations can be made at any required depth in the water column.

Choice of flying height will be limited upwards by the likelihood of cloud cover and the minimum scale required to achieve the necessary degree of accuracy and detail in plotting. It will be limited downwards by the need to obtain a minimum area coverage including essential control points, and to keep the number of overlaps as few as possible. It is here that the helicopter proves its worth in this work in being able to fly slowly and at a low enough altitude to obtain large scale photography without image movement and to keep the interval between exposures of sufficient length to allow accurate measurements of flow rates and directions. Helicopter flying for this, and for all hydrographic survey work, has been standardised at a speed of 60 knots. This means that runs can

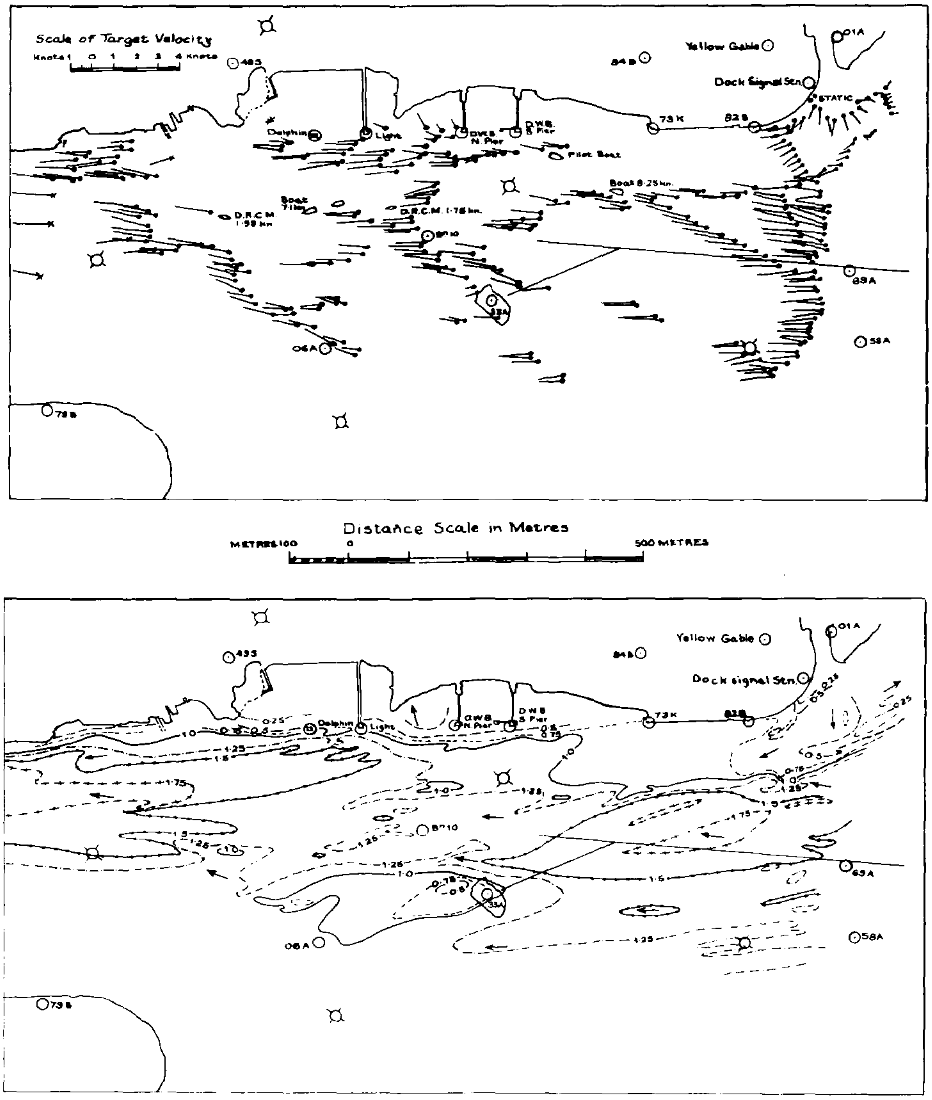

FIG. 2. — Photogrammetric water movement plot at Barrow-in-Furness, 10 March 1970 at 1409 (HW + 4 min.).

Above : Movements of the markers
surface (foam) ——●
5 metres below surface ——×

Below : Continuous velocity contour profiles, here marked from 0.25 to 1.75 knots.

be repeated at something like 10-20 minute intervals, for the size of work area attempted so far, throughout the part of the tidal cycle which is of interest. Exposure intervals are usually of the order of 10-20 seconds, depending of course on flying height.

The sample plots in fig. 2 differentiate the various kinds of marker by the use of different symbols. The lines from the symbols indicate the direction of movement, and the length of the line is proportional to velocity which can be read off from the scale of target velocity. The data given, which is only a selection of the total available, indicates the spread of observations obtained. This is judged sufficient, in this case, to draw continuous velocity contour profiles, one example of which is given here (fig. 2).

SURVEYING THE INTER-TIDAL ZONE

The inter-tidal zone can be very extensive in some estuaries and port approaches and be difficult, dangerous and time consuming to survey by ordinary hydrographic survey methods. Considerable success has been achieved in measuring drying heights photogrammetrically from photographs taken at low water when the banks are uncovered. Here again the advance has been partly due to helicopters obtaining large scale photography on which accurate and detailed heighting is possible. Monochrome film has been used in this work.

It is highly desirable that the available triangulation points and bench marks in the area are inspected, and the levels checked, and a selection marked to ensure identification on the photographs, before flying begins. It is also necessary to have accurate tide gauge records in the area during the time of flying, so that the relationship of water level to chart datum can be calculated. Flying is then scheduled as near as possible to a low water spring tide, at the smallest scale which will give the required accuracy in height determination. This is usually of the order of 1/5 000 - 1/10 000.

Given adequate pre-flight planning in this way, each stereoscopic model will have adequate height control from triangulation points, bench marks and an established water level. As many heights as required may then be added by machine measurement. If the operator is also a trained

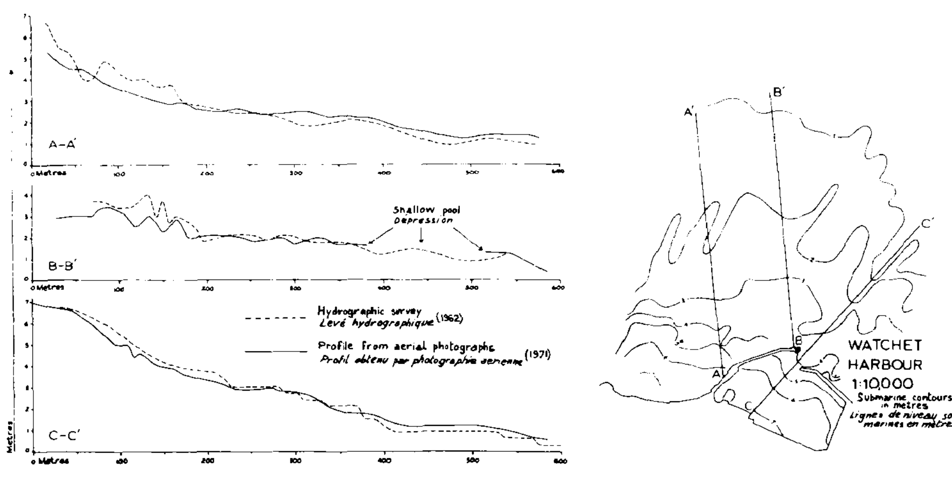

FIG. 3. — Beach profiles from aerial photographs and hydrographic survey.

chart compiler, he can ensure that all the high spots, obstructions and rocks are found and also the deepest parts of channels. This must of necessity give better results than the regularly spaced lines of a traditional hydrographic survey as well as saving an enormous amount of time and effort. Figure 3 shows some profiles of beach survey work of this nature at Watchet in the Bristol Channel compared with the latest hydrographic survey. The photogrammetric plotting agrees generally with the hydrographic survey to within 0.25 metre or less. This technique is being extended to drying sand banks in estuaries and would seem to have interesting possibilities wherever a survey is required in an area where the inter-tidal zone is at all extensive.

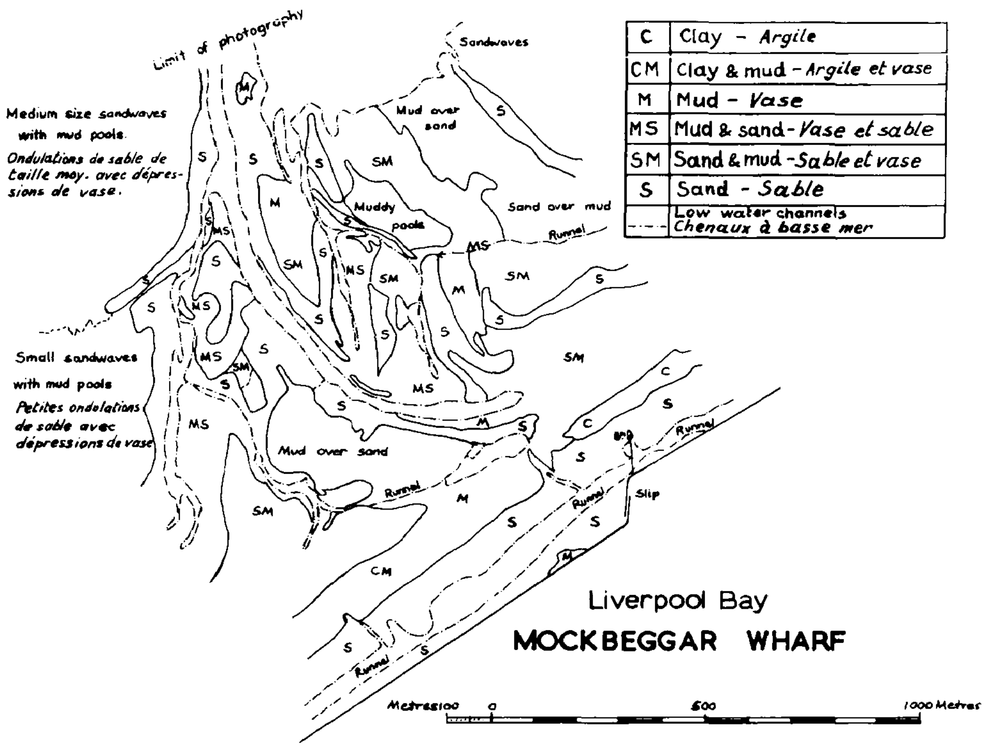

FIG. 4. — Mapping of surface sediments in the inter-tidal zone from aerial photographs.

Coral infested waters are a rather special case of this work. Very rarely have inshore waters in coral areas been surveyed in sufficient detail to ensure that all dangers are charted. Large scale helicopter photography is capable of picking up all drying and shallow water coral patches. It is therefore often used for a safety check to update existing information before a ship begins survey work in such an area. From this it has been a logical development actually to chart the coral reefs from photography, leaving the ship to do suitable checks and concentrate on sounding. However, photogrammetric measurement is now extending its range of application below the water surface, and this subject will be dealt with further in the section on shallow water depth measurement.

A further aspect of the study of the inter-tidal zone is the determination and delineation of sediment types, but the UK Hydrographic Department has only examined the problem briefly. Figure 4 shows an attempt to map the sediments in a part of Liverpool Bay from ordinary panchromatic black and white photography at a scale of 1/10 000. The results were considered to be very satisfactory but the actual sediment types could only be certainly identified with the help of sediment samples taken from the beach. Further, the results only reflect surface distribution and, without sampling in depth on the beach itself, the results of the study are rather superficial. It is probable that colour photography could assist considerably in this task. However, should a requirement arise for this type of work, it seems that photogrammetric techniques are available to deal with it.

SHALLOW WATER DEPTH MEASUREMENT

During the last decade or so increasing attention has been given to measuring depths below the surface of the water, by photogrammetric methods. This has met with considerable success and has been described by TEWINKEL (1963), GROENEVELD MEIJER (1964) and UMBACH and HARRIS (1973), who have established methods of dealing with the refraction of light rays at the air-sea interface. The UK Hydrographic Department, drawing on this earlier work, has developed a computer program to process the digital output of the Wild A8, applying the appropriate refraction correction and producing a data tape for the automatic plotting of the location and depth of every point chosen. In the calculation of the refraction correction for each point the refractive index at the air/sea interface is taken as constant at 1.34. The variable parameters considered are flying height, base length, apparent water depth and the x, y co-ordinates of the particular point in the model. The effect on refraction of the variations in temperature and salinity within the waters around the British Isles has been found to be so slight that a constant mean value is used for these parameters. The greatest extremes encountered would affect depths by less than one per cent.

Apart from limited experiments, where colour film has been tried, work on this subject so far has been on panchromatic black and white photography. It is obvious that colour film would be a great help in this work and there is now a colour film being developed specially for water penetration (SPECHT *et al.*, 1973). However, the UK Hydrographic Department does not have, at present, the camera capability to use colour film. Some very useful results have been obtained from black and white film, one example of which will be discussed below to illustrate the technique.

Depth penetration will obviously be easiest in clear, calm and sunlit waters such as the coral reefs of the tropics. Penetration to 18-20 metres or even 30-40 metres has been claimed in such areas. In the shallow waters of the British continental shelf, penetration is often down to zero, but in more favourable locations it has been possible to work down to 10 metres. Sunspot and the breaking of the sea surface by wave action are obviously other hindrances in this work.

Depth measurement is difficult or impossible over large areas of flat and featureless sandy sea bed, because of the lack of reference points for heighting purposes. The technique is best used in areas of uneven and rocky seabed which are, of course, the more difficult to survey by conventional methods. The work described here is a small section of the Isles of Scilly, one of the innumerable shallow sea passages between the islets, where the water is calm and clear under suitable weather conditions. The bottom is a mixture of rock and sand. Accurate tidal records were obtained during the period of photographic survey so that the water level on the photographs could be correctly related to both chart datum and Ordnance Datum and the depths corrected accordingly, see figure 5. Figure 6 shows the control available from Ordnance Survey triangulation points in the area. These were supplemented by the fixing of a number of other reference marks and bench marks by an AIM (Aero-triangulation by Independent Models) process in the Wild A8. All control and reference points were checked, and where necessary marked in the field, and their height above Ordnance Datum accurately established by ground survey before the photography was taken.

Overlapping pairs of photographs were set up in the Wild A8 plotter and orientated, scaled and levelled in the usual way. Plentiful and accurate reference points in the vertical plane are an essential part of this task. The standard reference parameters were then fed into the EK 22 digitiser attached to the A8 plotter. The position and apparent value of each

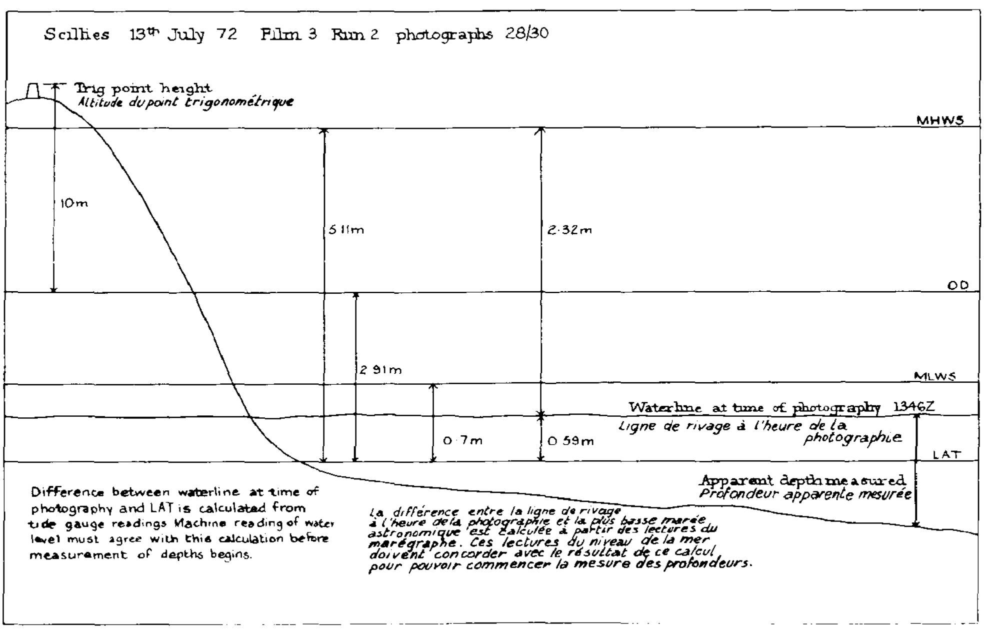

FIG. 5. — Diagram to show the relationship between various datums involved in shallow water depth measurement.

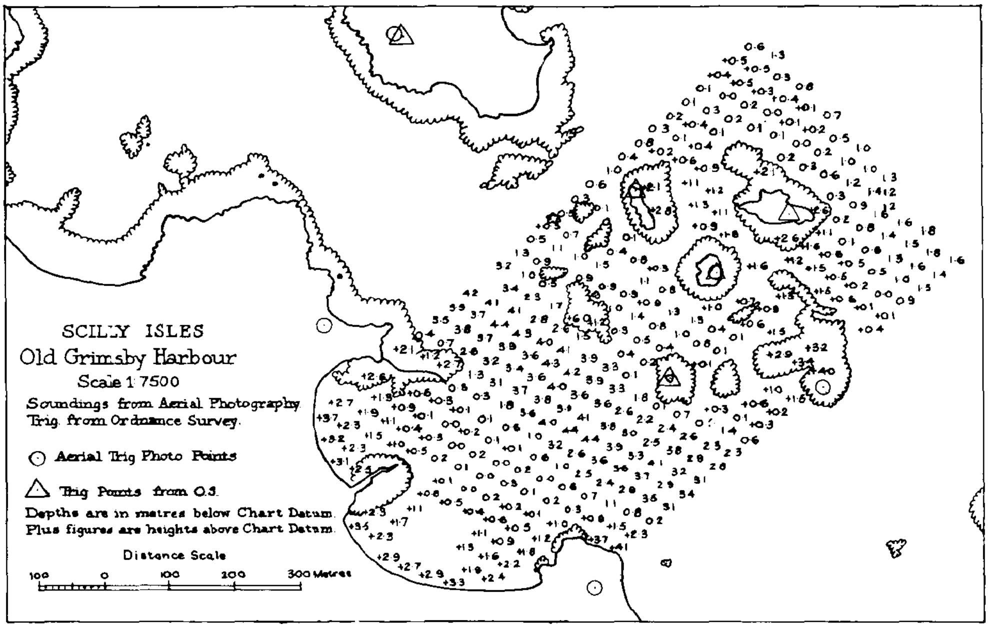

FIG. 6. — Triangulation control and selection of photogrammetric depths.

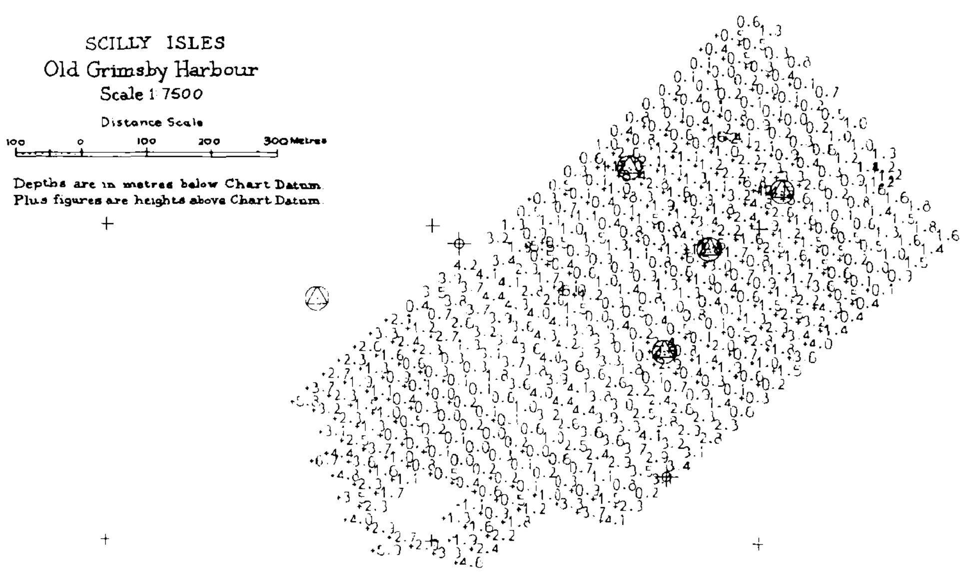

FIG. 7. — Printout of photogrammetric depths directly from the automatic plotter.

required depth was then plotted and output onto paper tape. This tape was processed with the computer program for correction for refraction and tidal reduction, and input tapes produced for the Kingmatic automatic plotter. Figure 7 shows the finished result directly from the plotter. A selection of these depths was added to the plot of coastline and low water rock (figure 6) to produce a complete survey.

CHECKING OF THE PHOTOGRAMMETRIC DEPTHS AGAINST HYDROGRAPHIC SURVEYS

Absolute comparison between any two methods of obtaining soundings in the nearshore zone, whether it be echo sounding, lead lining or aerial photographs, is impossible. All methods can be expected to have slight inherent inaccuracies. Horizontal positioning will always be responsible for some inconsistencies and the actual beach profile may change, either marginally over a single tide or very considerably over a period of weeks or months.

Several different checks have been applied to the depths determined by photogrammetric methods. The first was to take an identifiable transit line into Hugh Town, Isles of Scilly. The line was about 300 m long, of which 250 m was seawards of the low water line. Profiles were plotted from both an echo sounding survey and the aerial photographs. In this case horizontal positioning should have been very close but there was a time interval of three months between the boat survey and photography. The profiles agree very well above the low water line and at the offshore end of the line where the depths were 1-2 m. The worst discrepancies were 0.5 m in the area immediately seawards of the low water line, and some of this was almost certainly due to the movement of beach material.

A second type of check was to photograph the same area from two different altitudes. Since all the calculations and refraction corrections were quite different for the two scales there was no possibility of any correlation between the two sets of photography until the final results had been converted to the same scale. The agreement between the two was excellent, which seems to indicate that the plotting technique is sound and the procedure for dealing with refraction is correct.

The third check was made of an area about 1 km by 1.5 km in Charlestown Bay, Canouan Island, in the West Indies. In this case the hydrographic survey was dated fifteen months later than the photography. On both the survey and the photo plot a series of vertical cross sections was drawn in two directions at right angles, spaced at about 150 m intervals. Both surveys were also contoured at 0.5 m intervals and the differences between them contoured. There were widespread differences of up to 0.5 m, with the photogrammetric depths generally deeper than those from the hydrographic survey. The worst discrepancies were slightly more than 1 m but these were only in very limited areas. This check was unfortunately not ideal, since the hydrographic survey was not a rigorous one, the scale of photography was smaller than the optimum, and the time interval between the two was considerable.

The fourth, and most positive, check has been to fly a small area at both high and low water on the same day. Figure 8 shows cross section profiles taken from the two sets of photography, thus comparing drying heights at low water with depths at high water. Generally the agreement was very close, either exact or within 0.2 m. This test was limited in extent, covering only relatively shallow water, and further tests of this nature are planned.

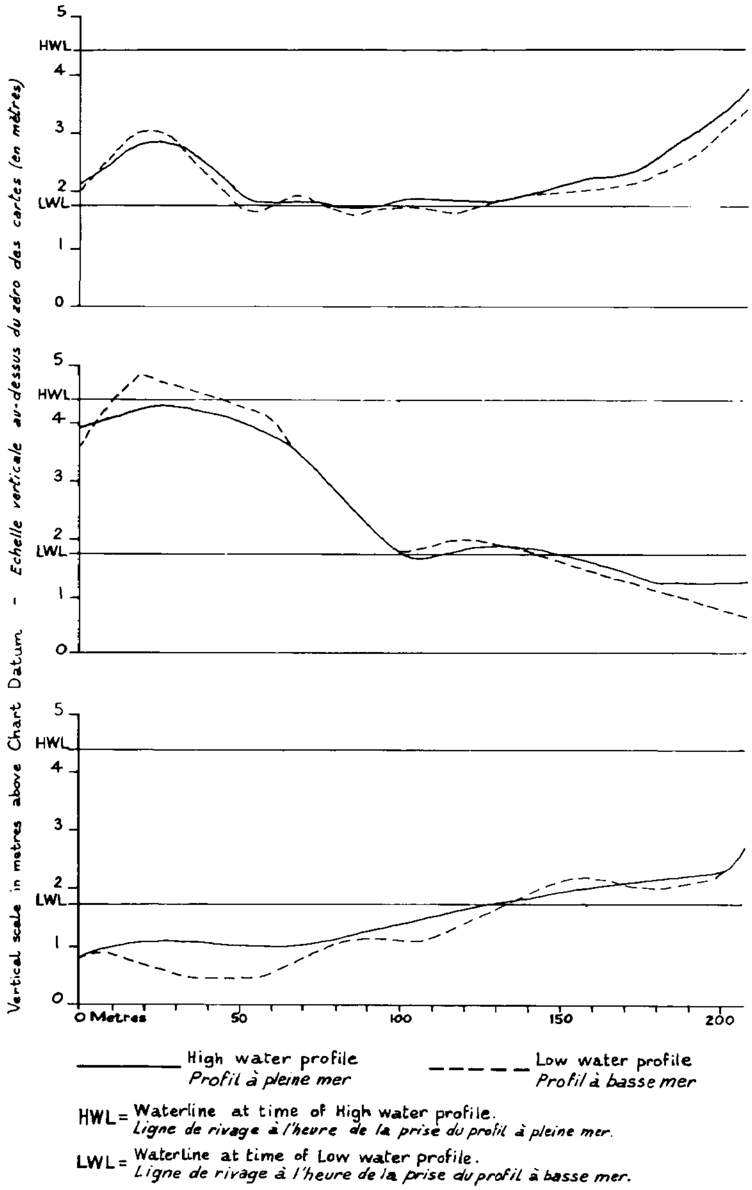

FIG. 8. — Profiles at High Water and Low Water at Old Grimsby Harbour, Isles of Scilly.

The technique of shallow water depth measurement can be used over large parts of the world's shallow seas. It has, however, a very special application to coral atoll areas. According to the degree of detail required and the depth of penetration obtainable, photography at a suitable scale will enable all dangers to surface navigation to be accurately plotted.

Monochrome photography can be used for this purpose, although colour film would be a decided advantage. Having plotted the dangers it is possible to complete the survey by conventional boat sounding with greater ease and safety. With adequate vertical control, it may be possible to complete the survey in its entirety by photogrammetric techniques, at least to the depths of interest to normal surface shipping.

THE ROLE OF THE HELICOPTER IN AN INTEGRATED SURVEY PLAN

When it is possible to deploy helicopters equipped to take survey class photography onboard survey ships, considerable advances are possible in the execution of hydrographic surveys. This work can be undertaken, of course, in addition to the other uses of the helicopter in the efficient movement of personnel, supplies and equipment, especially in areas of difficult terrain.

Ideally when an area is proposed for hydrographic survey, it should be visited the previous season, the trigonometric control inspected and marked as necessary, and survey photography taken. This can then be worked on in the office during the winter and a controlled plot produced for the ship showing coastline and topography, horizontal control, drying heights, reefs, dangers and shallow water depths. The ship can then limit work to field checks of the photogrammetric plotting and completion of the deeper water sounding. Of course in some cases time, manpower, or other considerations, may require that less is done in the office and more by the ship.

Where advance visits are not possible, the survey ship, with capability on board to process survey film, may still use the helicopter to good advantage. Photographic cover can assist in planning the survey and in locating dangerous shoals and reefs. It will usually also be possible to use the simpler techniques, such as radial line plotting, on board to insert coastline, islands, mangroves, drying rock and so on. The photography will also of course be used as raw material, along with the survey, in the processes of chart compilation.

Another small task for which helicopters are now being used is the taking of oblique photographs with hand held cameras for use in the compilation of sailing direction volumes and to assist in the identification of stranded wrecks.

CONCLUSIONS

The last decade has seen great progress in the use of the helicopter as an air survey tool. The applications to hydrographic tasks are increasing, both in number and in usefulness. Further progress can be expected, both in the developments of cameras and suitable films and in the plotting techniques, where automation is playing an increasing part. In the intertidal and shallow water zones particularly, the helicopter, with its ability to fly at slow speeds and low altitudes, has opened up very interesting possibilities. There are also other non-photographic fields of advance such as aerial float tracking and depth sensing from helicopters, but these are outside the scope of this paper.

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