CONTRIBUTION MADE BY AIRCRAFT AND PHOTOGRAMMETRY

TOWARDS THE SOLVING OF COMMON HYDROGRAPHIC AND CARTOGRAPHIC PROBLEMS

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FOREWORD

Hydrographers will perhaps be surprised, but certainly flattered, to learn that it was one of their own kind who invented, well in advance of his time (or rather, before photography was invented), the art of photogrammetry.

Indeed, when the young BEAUTEMPS-BEAUPRÉ first had the idea of tipping up a sextant into a horizontal position, he had just most certainly invented the "hydrographic circle", although his intention had not really been to locate the position of a boat in relation to the land, but rather to survey unexplored coasts from a boat without having to set foot on land.

Using, in the absence of photographs, panoramic sketches of a coast made from successive positions of a ship, and then measuring from these same positions horizontal and vertical angles between different landmarks located on the sketch, BEAUTEMPS-BEAUPRÉ depicted this coast by a series of fan-shaped views drawn in perspective. The chart was then compiled by plotting the above data.

Considering the means available at the time, the results thus obtained have always been, and still are, considered remarkable, but more than anything else it is the efficiency of the method which is astonishing when one considers, for example, that the chart of the west coast of New Caledonia and the adjacent barrier reef, about 240 miles of coast, was compiled in this way between 18 June and 1 July 1792.

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However, it was the development of aviation, along with the progress in optics and photography, which really launched photogrammetry and its systematic use in land mapping. The quality of the charts is irreproachable, but the earlier performance is no longer achieved, as the plotting method has changed and has now become weighed down with geodetic fieldwork.

For BEAUTEMPS-BEAUPRÉ the panoramic views were completely defined by the coordinates of their apexes and the angular values of their directions. In the case of aerial photos, it was always allowed that the position and direction of the aircraft could not be known, so that the mosaics could only be produced indirectly from a certain number of known ground control points.

The overcoming of this drawback would obviously result in restoring the effectiveness of the BEAUTEMPS-BEAUPRÉ method.

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But, curiously enough, although photogrammetry has become the basic technique employed by the land cartographer, hydrographers have not attributed much importance to this technique. Some more advanced hydrographic offices, on account of specific important requirements, have, indeed, greatly developed the techniques of photoaerial surveying, particularly for measuring shallow waters, but these are exceptions and, more often than not, if aerial photos are used by hydrographers they are very often considered as a rather secondary accessory amongst the range of tools employed in the course of a survey. And yet :
   - a photograph is a reliable, complete and accurate "record of field data";
   - the water's transparency allows "detection without any gap" of the most dangerous submerged rocks;
   - and, lastly, the aerial photos of use in hydrography are those of the coastline, which provide, vis-à-vis land photography, the immense advantage for stereoplotting of portions covered by water constituting the reference datum.

It is ironical that this particular feature alone has not been sufficiently attractive to promote the use of photogrammetry in hydrography.

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Satellite remote sensing and laser bathymetry, more and more in vogue, are in the process of superseding photogrammetry in so far as progress in techniques is concerned, and keenly interest hydrographers. These techniques are, however, still in the early stages of development and will, in any case, remain extremely expensive.

The question then is to ascertain, and that is our aim here, whether, in fact, hydrographers would not be better advised to develop the photobathymetric survey methods, and free themselves of all ground work which would result in a level of efficiency similar to that of BEAUTEMPS-BEAUPRÉ.

PART I

INTRODUCTION TO "HYDROGRAPHIC PHOTOGRAMMETRY"

I.1. Principles of the method

In photogrammetry manuals a distinction is always made between so-called "terrestrial " photogrammetry and aerial photogrammetry. As far as the former is concerned, the perspective views are defined intrinsically by their outer elements (coordinates of apexes and angular values of their directions) whereas for the latter they are defined by the coordinates of a number of reference points.

The techniques and plotting instruments used are different and are explained separately, but for the same object (a portion of land in this case), the result obtained is the same, irrespective of the method used, since it is a question of resolving the same geometrical problem.

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The "conventional plotting" of vertical aerial photos, wherein the exact position of where the shots were taken is unknown, relies upon identified points on the ground and comprises the following three operations :

    – *The making up of the plastic image* (or model) which consists of cancelling the parallax in 6 points on the overlapping pair of photos. This operation puts the planes of the photos into relative positions identical to those at the time the shots were taken. This gives a model, a 3-dimensional image geometrically similar to the photographed area, the scale and orientation of which, in relation to the reference system, are still not known.

    – *The scaling* is then carried out by comparing a distance 'd', measured on the model, with the corresponding length of the same distance on land. In practice, this operation assumes that the values of coordinates X, Y, Z of two points on the ground are known.

    – Lastly, *the absolute orientation of the model,* which will not change its shape or its scale, but which serves to bring it into a suitable position in relation to the reference system, is a process which comprises practically two operations :
        – the vertical orientation or *levelling of stereo model.* For this operation we need to know the value of the plane of an object in relation to the horizontal datum, that is to say the altitude of 3 points on the ground ;
        – *the horizontal orientation* to ensure the correct insertion of the planimetric data. This operation assumes the values of the coordinates X and Y of two points on the ground are known.

In summary, for the photogrammetric plotting of a pair of vertical photos, we need to know the coordinates X, Y, Z of at least two points and the altitude only of the third.

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In terrestrial photogrammetry, all the external elements of the perspective views are determined directly, or can easily be deduced from the measurements taken at the site. It then suffices to set each reconstituted view by inputting these values into the stereoplotter with the greatest possible accuracy.

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After this brief summary, let us now look at the principles of the method outlined in this article, and which, to distinguish from the previously mentioned techniques, we will call 'hydrographic photogrammetry'. It is, in fact, a mixture of the two and it is assumed that the photos to be plotted contain both portions of water and land surfaces, i.e. a shoreline.

The line separating the water and the land is a site where the water level is known, provided we know the exact time the shot was taken and we have taken the precaution of observing the tide level at that time.

This enables the vertical orientation to be carried out, and the geometric problem of plotting a pair of photos is entirely resolved if we know the following :
   – either the planimetric coordinates X and Y of two points on the ground;
   – or the coordinates X, Y, Z of the apexes of the perspective views; that is, the exact position of the aircraft at the moment the shot was taken, which, as we will see, is now possible thanks to radiopositioning systems.

The order in which the plotting process of overlapping photos is carried out is in practice changed as follows :
   – the making up of the plastic image remains unchanged;
   – the stereo model is then directly levelled using the shoreline. At this stage, the operator is then able to plot the pair of photographs without any distortion. The scale and the planimetric orientation are not known, but can be roughly estimated from the flight parameters (altitude, heading, speed);
   – the scaling and the horizontal orientation becomes one single operation at the end, and is derived from two known points or from the nadirs of the aircraft [*]

I.2. Discussion and critique of the method

Levelling of the stereoplotter on the water plane

It is obvious that the accuracy of the levelling largely depends upon the contour of the shoreline appearing on the photograph, the ideal configuration being an archipelago of small islands well spread out. On the other hand, a strictly rectilinear

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(*) The nadir is the vertical projection of the aircraft over the ground. The level of the model is checked on the photo by the intersection of the vertical line of the plotter with the plane of the photo. One will note that in conventional plotting, the coordinates X, Y and Z of the plane are generally calculated systematically. Any abnormal variation in the apparent speed or altitude can be a sign of an error in plotting.

coastline can cause an error in the method because the model can only be "levelled" along the straight coastline.

Let us consider two concrete examples :

— The coast is rectilinear and no submerged rocks nor any underwater features appear on the photo. That indicates that the coast is steep, the chart is easy to do, and the hydrographer will not benefit from hydrographic photogrammetry. The plotting of the coastline is possible provided it is directly beneath the line of the nadirs.

— Off the rectilinear coast, a number of underwater features are visible. It is then possible on a colour coverage to make assumptions as to the depth of these submerged rocks between 0 and 12 metres. The planimetric error, resulting from the approximate levelling based on the estimated submersion of these rocks, will be minimal. An error of 10 metres along the edge of the photo at a scale of 1:30 000 would in fact produce a planimetric error of less than a metre.

Scaling using the position of the nadirs

The exact position of the aircraft will always have a random error of some metres.

On a photograph 24×24 cm at a scale of 1:30 000, the distance between two successive nadirs (2/3 overlap) is about 3.5 km. The scale error relative to a position error of 10 metres is equal to 5.10^{-3}, which might seem excessive.

In practice, the errors are minimized by compensation, for an aerial survey is composed of flight runs comprising a certain number of photos which make it possible to join them accurately by aerial triangulation. Indeed it will be recalled that aerial triangulation methods give better results with closer connecting points to the horizontal plane, which is the case for the shoreline or the submerged rocks.

The scaling and horizontal orientation are therefore done on an overall basis on the block constituted by reducing to a minimum the differences between the theoretical and observed nadirs. This point is developed in part 2 of this article in a full scale experiment.

These compensation procedures are moreover quite common and are auto-matically performed by calculators which are interfaced with stereoplotters.

Depth measurement

Our experience in this field is rather limited, and for the moment we are only restricted to a qualitative description of underwater features. The refraction and the lack of level plane of the constantly moving surface of choppy water prevents the formation of the underwater plastic image, although the more flexible human eye can discern it. It is, however, certain that the plotting of underwater features through a perfectly calm surface is possible, but in practice necessitates the use of an analytical plotter.

For information we can cite the method proposed by Messrs. S.E. MASRY and S. MacRITCHIE [3] which entails the use of two aircraft flying abreast taking synchronized shots so as to be able to fix the geometry of the choppy water surface.

I.3. Partial   conclusion

As far as the principles are concerned, it is thus quite clear that an aerial coverage of a seashore or of areas of shallow clear waters can be plotted independently of any preparation of ground control, except for the setting up of a radiopositioning chain and a tidal station.

Thus, the efficiency of BEAUTEMPS-BEAUPRÉ's "surveys under sail" is once again equalled, and even improved upon as far as the speed of the support vehicles is concerned.

The problem, then, is to check, by carrying out full scale experiments, whether the accuracy thus obtained is both acceptable and comparable to that obtained by traditional methods.

PART II

RESULTS OBTAINED FROM A FULL SCALE EXPERIMENT

II.1. General Introduction

From the tip of the Raz to the Armen Lighthouse is the Chaussée and Raz de Sein which covers a rectangle measuring about 30 km in length by 5 km in width.

The many rocks which uncover, battered by ocean swell, and the violent currents, make this a particularly unsafe and dangerous zone. The topographic survey of the area was done in 1973 by the "Mission Hydrographique de l'Atlantique" using conventional methods in, as can well be imagined, extremely severe conditions. Work on the ground was restricted to the identification and positioning of a number of rocks, which were "picked" from the colour aerial photos. Landing near the rocks was generally impossible because of the backwash, and so their position was determined from a boat at a distance which was radiopositioned by a Toran chain. The topographical sheet was then completed by plotting the colour photos.

This area, therefore, seemed to us to be an ideal testing ground to test the method proposed in Part I. The 19 perfectly located control points in this area further enabled us to determine objectively the accuracy of the method.

And so, on 25 September 1980, between 1215 and 1250, at the low water equinoctial springs, a photoaerial survey of the Chaussée de Sein was carried out using a radiopositioned aircraft. This survey was done in 2 East-West runs of 20 photos each at a scale of about 1:20 000. Poor weather conditions, together with the presence of cloud, rendered some photos unusable, thus causing a certain amount of discontinuity in the aerial triangulation, which was made up of 6 rather disjointed blocks.

II.2. Equipment onboard the aircraft

The aircraft was equipped with :
- a WILD RC9 camera with a wide angle 88.5 mm lens;
- a Trident III linked to 4 transponder beacons on the ground;
- an automatic data acquisition microprocessing unit interfaced also with a printer.

The acquisition of positioning data is triggered by the camera's shutter release working automatically (every 16.8 seconds, in this particular case). The position of the aircraft is obtained from the intersection of 4 ranges of the transponder beacons.

The Trident III system [*] is, in fact, a range-range system with 4 independent position lines. Its accuracy is in the order of a few metres. This system is adapted for taking measurements during flight; the drag effect is nullified due to the speed of the aircraft. The range is the geographical range, limited, however, by the manufacturers to 262 km.

Remarks

— The time of the aerial survey was decided upon by the time of low tide, and the choice of a wide angle camera proved to be a bad one because of the disturbing sun reflection.

— the equipment was installed in the aircraft rather hastily and without much thought. In particular, no verification (or calibration) could be made on the simultaneous reception of Trident data with the opening of the shutter of the camera.

II.3. Determination of aircraft position

The processing of the Trident "ranges" to obtain the fix was carried out in two phases :
- calculation of the altitude of the plane : Z;
- calculation of the X and Y coordinates of the 'nadirs' [**] of the aircraft.

Adoption of the altitude : since the two passes were made on identical altimeter readings, we can assume that, in view of their short duration (7 minutes), they were made at a constant altitude.

We can thus calculate the fix for different altitudes projected over the earth's surface, relate it to the centre of the Earth by 'least squares', and determine the differences between the observed and calculated distances. The sum of the residues thus obtained for a beacon and for a run is a function of the assumed altitude. The flight altitude corresponds to the minimum of this function. We thus found that our flight altitude was 1 650 metres for both the runs.

(*) French system built by Thomson-CSF.
(**) The nadir is the vertical projection of the aircraft position above the water area.

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Fig. 1. – Extract from chart 5316.

The following table gives the averages of the absolute values of the residues and their standard deviations for this altitude.

Table 1

Number of beacon	First run			Second run		
	No of fixes	Mean	σ	No of fixes	Mean	σ
1	28	1.5 m	1.4 m	24	1.4 m	0.9 m
2	28	1.3 m	1.4 m	24	1.4 m	1.0 m
3	28	0.8 m	0.8 m	24	0.8 m	0.5 m
4	5	3.3 m	0.9 m	5	3.2 m	3.1 m

This table enables us to assess the accuracy of the Trident fix which is of the order of ± 2 metres.

Calculation of the coordinates of the nadirs : having determined the flight altitude, the observed distances are reduced to the datum of the Clarke 1880 ellipsoid which is also used for the calculation of the fix by least squares.

II.4 Determining the accuracy of the method

The photogrammetric plotting of the survey of the Chaussée de Sein [*] was, above all, aimed at determining the level of accuracy obtained by "hydrographic photogrammetry". The stereoplotter was a Wild A10 Autographe equipped with compensating plates to allow for the distortion of the camera lens. We then proceeded as follows :

— Due to the presence of cloud on certain photographs, or the total absence of any sea details, the North and South runs were cut into 'strips' which were then joined by aerial triangulation. Six strips were made.

— The photogrammetric aerial triangulation was carried out in the conventional way by taking measurements on the photographs backed by the Trident position fixes.

— Simultaneously, the known control points identified on the photos were treated as connecting points of the aerial triangulation.

— The transformation of the instrument coordinates into Lambert coordinates, together with the application of the compensating processes, enabled us to determine the geographical coordinates of the control points. The comparison between these and their true geodetic coordinates represents the overall accuracy of the method.

— The observed differences, being large, and initially attributed to a poor synchronisation between the reception of the Trident fix and the taking of the shot,

(*) Subcontracted to SOFRATOP (Société Française de Travaux Topographiques et Photogrammétriques).

were referred to a system of "axes" associated with the flight direction and its perpendicular. Thus :
   − the lateral differences represent the accuracy;
   − the average of the differences in the flight direction represents the time lag between the taking of the shot and the reception of the fix, their range of errors encompassing not only the uncertainties of the method, but also any possible variations in the time lag.

The results are borne out by the table and the diagram (Fig. 2).

Table 2

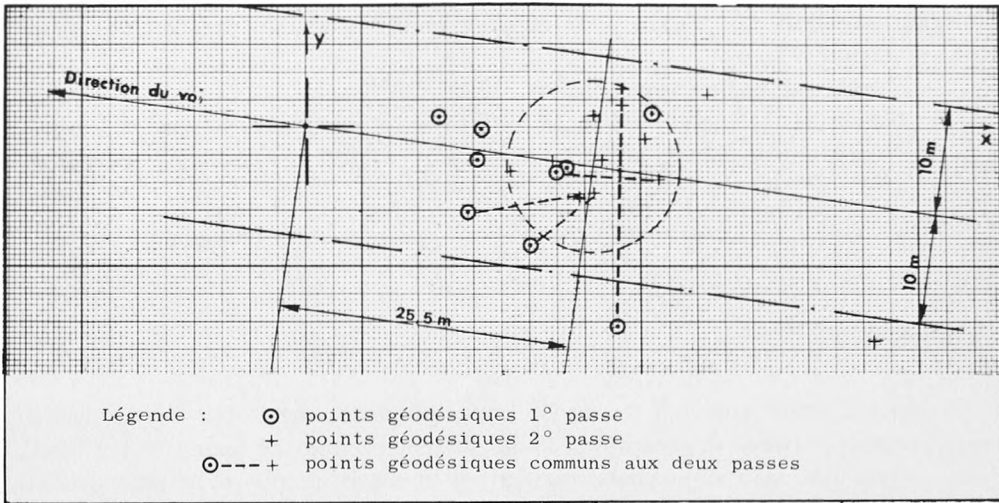| Number of control point	1st run		2nd run	
	Δx metres	Δy metres	Δx metres	Δy metres
203	30.83	5.53		
202	21.66	− 7.68	25.36	− 2.27
201	15.93	− 5.65	26.56	− 2.27
415	15.55	1.93		
353	12.19	2.65		
362	15.59	− 0.89		
202			18.76	− 1.50
316			30.21	3.12
177			26.92	6.31
394	30.52	− 13.99	27.82	7.56
382	22.86	− 0.91		
384	23.66	− 0.65	31.78	− 0.33
139			35.19	7.90
380			22.05	0.02
385			25.60	4.78
394			27.72	6.29
377			26.84	0.65
178			48.13	− 12.65

It appears that the differences corresponding to the first run are not the same as those for the second; thus the second run appears more homogeneous and less scattered. The number of individual differences is, however, too small to draw a positive conclusion.

In order to analyse these differences more closely, the problem was considered again, in reverse. Basing the aerotriangulation on the known control points, the theoretical coordinates of the nadirs were recalculated.

Their comparison with the observed coordinates is illustrated by the following diagram (Fig. 3).

Four fixes can be considered aberrant. They create anomalies[*] in respect of the speed of the aircraft, which can be calculated between two successive positions from the Trident fixes, and from the time of the position signals provided by the data

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(*) The anomalies associated with the collection of Trident data or data from the beacons have not been elucidated.

Légende : ⊙ points géodésiques 1° passe
            + points géodésiques 2° passe
        ⊙---+ points géodésiques communs aux deux passes

Cible des écarts entre coordonnées réelles des points géodésiques et coordonnées calculées lors de la restitution

Nombre de points : 22

Moyenne des écarts par rapport à la ligne de vol

- latéraux   : 0,01 m   —   écart type : 6,19 m

- longitudinaux : 25,50 m   —   écart type : 7,83 m

FIG. 2. — Read from top to bottom : Control points, 1st run ; Control points, 2nd run ; Control points common to both runs. Diagram showing differences between control points true coordinates and those obtained by stereoplotter. Number of fixes : 22 ; Average difference in relation to flight run : lateral : 0.01 m — standard deviation : 6.19 m ; longitudinal : 25.50 m — standard deviation : 7.83 m.

Légende :
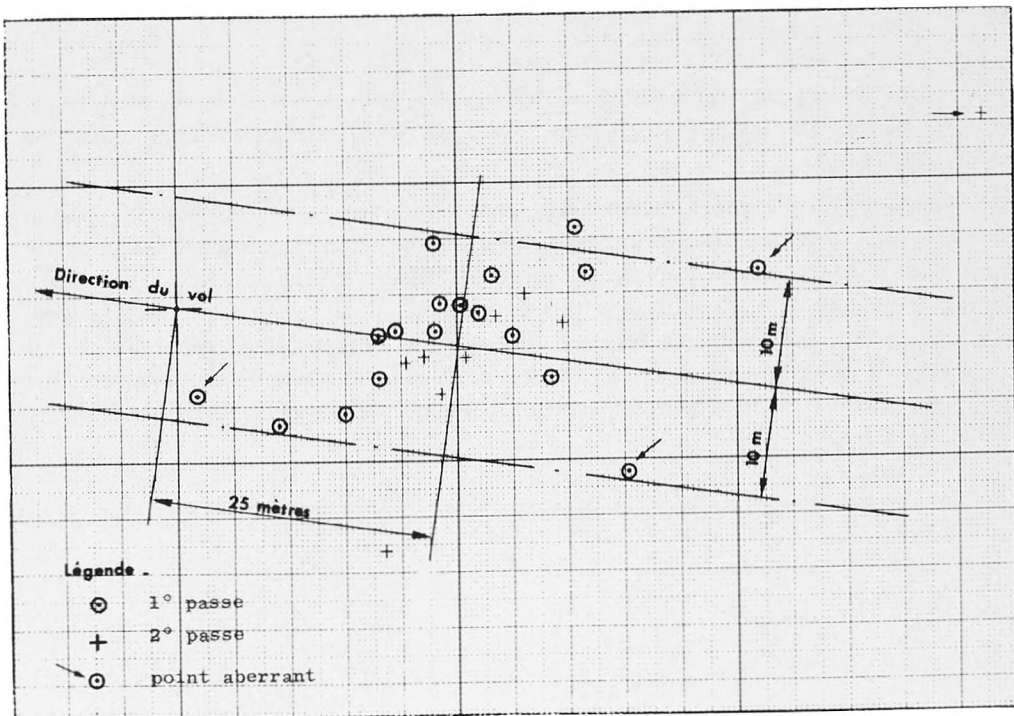
⊙ 1° passe

+ 2° passe

↗⊙ point aberrant

FIG. 3. — Diagram showing differences between the positions of nadirs obtained during plotting and the positions of nadirs fixed by Trident.

acquisition microprocessing unit. After elimination of these fixes, we can obtain the following digitized results :

- number of points/fixes observed : 22 ;
- average of the lateral differences : + 0.13 m − standard deviation : 6.71 m ;
- average of the longitudinal differences : + 24.95 − standard deviation : 6.52 m.

These results are consistent with those of the preceding paragraph.

II.5. Conclusion

From the above analysis, the result leaves no doubt that there is an offset of some 25 metres between the reception of the Trident fix and the taking of the 'shot', which corresponds to a non-synchronisation of about a quarter of a second. This offset is probably quite constant since the lateral and longitudinal differences are practically identical.

The accuracy obtained is irrespective of the source of the planimetric data used (control points or positions of nadirs).

An aerial survey conducted by an aircraft radiopositioned by Trident, without any control stations on the ground, can thus be ranked amongst the topographical near-shore surveys. It will be seen, however, that such categorization is based essentially and exclusively upon the performance of the Trident III system, which is remarkable.

But we cannot conclude this study without dealing with the financial aspects of this experiment. To conduct it, the following is needed :

- 4 man/days to establish the 4 transponder beacons on known control points ;
- about an hour's flying time ;
- 1 film with 50 (24 × 24 cm) frames ;
- the setting up and plotting of 40 pairs of photos. The fees for this work, paid to SOFRATOP, to whom this work was subcontracted, amounted to 85,000 Fr.

The area of the zone covered was about 210 km^2, and the cost of such a survey, without taking into account the amortization of the equipment, amounts to about 500 F per square kilometre. It is very difficult to evaluate the cost of the plotting sheet done in 1973, but as at this time the aerial survey and the plotting were both carried out, the difference between the two can be considered generally similar to the cost of the entire work at sea, which is considerable when one considers that the daily cost of a hydrographic vessel, carrying 2 launches, is approximately 30,000 Fr.

PART III

SOME EXAMPLES OF SPECIFIC APPLICATIONS IN THE SOLUTION OF HYDROGRAPHIC AND MARINE CARTOGRAPHIC PROBLEMS

In view of the above, the hydrographer has already had an indication of the advantage of using hydrographic photogrammetry. However, it would be useful to look at some specific examples of problems of coastal hydrography or marine cartography, where the use of aerial methods is, from now on, essential. This third part is indeed intended to give food for thought to hydrographers on the advisability of equipping themselves with aerial means.

III.1. Survey of practically unexplored coral regions

The areas are extremely extensive, and their surveying although not inexistent, remains rather fragmentary. Riddled with reefs, which are, for the most part, just awash or slightly submerged, and quite often very far from any land, their survey by conventional methods is tedious, costly and sometimes dangerous. Their survey requires the use of ships carrying sounding launches which can work independently. Navigating such ships in the unexplored coral zones is delicate and hazardous, and cannot be undertaken without first carefully consulting aerial photos of the area, upon which depths, up to about a dozen metres, are clearly visible.

As it would be difficult to do without such an aerial survey, it is better for it to be carried out by an aircraft positioned by Trident III, because, from that, a detailed large scale field sheet (1:10 000) can be prepared. In certain cases this chart (or plotting sheet) will completely fill the hydrographic requirement; in other cases, field work by a hydrographic party will be necessary to complete the survey.

New Caledonia and the Loyalty Islands present two such cases. The chart attached herewith shows how, from Trident beacons sited on control points on the mainland, it is possible to survey the Loyalty Islands and the scattered neighbouring reefs, such as the Astrolabe reefs or the Beautemps-Beaupré reef, within a geodetic system consistent with the one used for New Caledonia. The isolated reefs cited constitute the only navigational dangers, and the compilation from the aerial survey is more than sufficient to meet the hydrographic needs. As for the Uvea lagoon, for example, the hydrographic requirement is adequately met by the aerial survey, except for the approach channel leading to the port and the adjacent anchorages. The photogrammetric stereoplotting of the aerial survey enables the best choice to be made for this channel or the anchorages, and to identify the areas to be surveyed by conventional methods. By thus reducing the area to be surveyed by conventional methods, the overall efficiency of the survey is greatly increased.
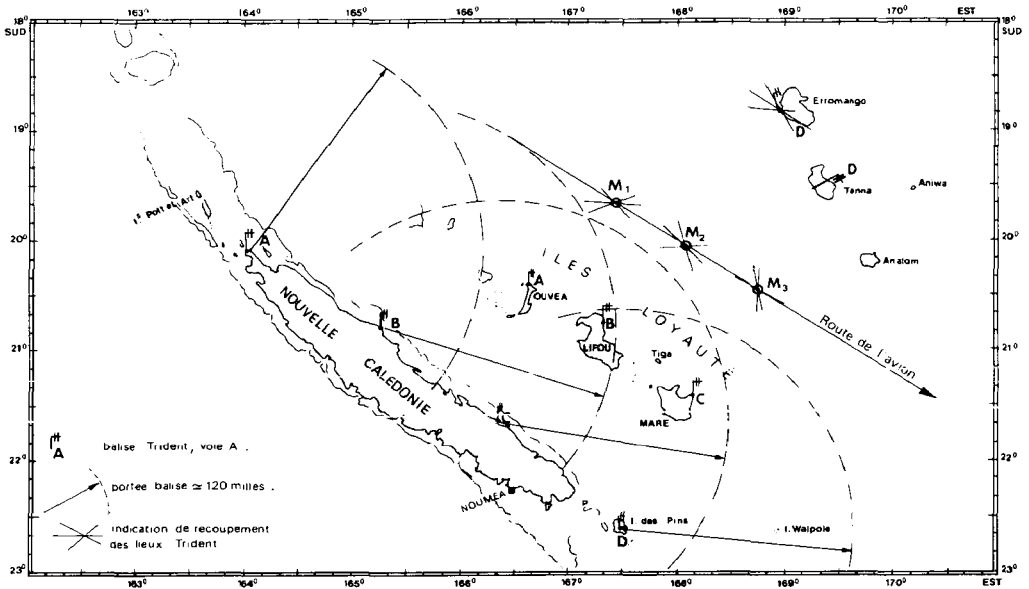
FIG. 4. – Read from top to bottom : Trident beacon, lane A: Range of Beacon ≈120 miles; Intersection of Trident position lines; Aircraft track.

III.2. Geodesy by aircraft and trilateration

To use a similar example, the geodetic link of the Loyalty Islands with New Caledonia can be considered as an application and a by-product of the aerial survey. On each of these islands, it is, in fact, possible to determine the coordinates X, Y and Z of a perfectly identifiable ground control station, which could afterwards be used for geodetic control, if the need arises. This method enables the correction of errors which generally affect the positions of such sparse islands.

The possibility of obtaining 4 distances offered by the Trident III system enables, during a flight, the correlative determination of the position of a fourth beacon by exploiting to the maximum the range performances of the system, since the aircraft is flying at a high altitude. Thus, for example, the Tanna and Erromango Islands could be connected within an accuracy of ±10 metres with transmitting beacons sited on the Loyalty Islands, which are more than 140 miles away.

III.3. Britanny's cadastral maps

The granting of concessions to meet the growing demand for new plantation beds of oyster or shellfish, also bearing in mind the interest of tourism and yachting, is currently facing great difficulties in Britanny because of the old age of the existing charts, most of them dating back to the last century. A fresh cadastral survey of the foreshore is thus badly needed, and the need becomes even more evident each time the problem of pollution is raised or ecological inventories are to be carried out.

Considering the area to be surveyed and the constraints imposed by the tide for carrying out the survey, it is obvious that only the aerial method can enable the cadastral survey to be completed in a reasonable period of time and at a reasonable cost, as illustrated by the survey of the Chaussée de Sein described in Part 2.

III.4. Marine   Cartography

The decision to update national charts by way of large corrections is primarily due to important changes such as construction of a port, a local port survey, a change in the buoyage system... or simply to implement a programme of systematic updating of the set of charts. It is quite rare that such updating is carried out in a complete and detailed fashion by a field hydrographic team.

A fresh aerial coverage fills this need adequately as illustrated by the chart of the Sables d'Olonne (Fig. 5). The considerable revision of this chart, still in the process of being carried out, was necessary due to the change in the buoyage system and the construction of a port for pleasure boats.

The 1979 aerial survey, carried out by the Institut Géographique National, not only enabled preparation of a more accurate layout of the port than could be done from a construction design, but also permitted updating of the most important landmarks and topography in general. We can thus, on the one hand, check that the landmarks shown on the chart or cited in Sailing Directions are still in existence, and have not been obscured by new constructions, and on the other, note that a certain number of very important new landmarks warrant being charted.

It can be readily seen, from the three stereograms shown on figure 6, that eight large corrections are essential to be included in the revision of the chart.
— Stereogram No. 1 : the existence of a prominent tower (about 50 m) on the dune
                     to the N.W. of the port and a holiday village to be
                     represented as a built-up mass.
— Stereogram No. 2 : the presence of two large dolphins in the old port; the
                     prominent tower on the sea front is no longer noticeable
                     and is obscured in the alignment of the new large building
                     along the beach; the presence of two prominent towers, one
                     near the station, and the other on the old port.
— Stereogram No. 3 : the existence of one single water tower instead of three as
                     indicated on the chart; three prominent towers near the
                     hospital.

The determination of the coordinates X, Y of these landmarks by stereoplotter levelled along the water line and scaled according to the existing control points (lighthouses, church towers, etc.) is not difficult, and obtaining their altitude in relation to the surrounding topography enables us to check their values.

Of course, there is no question of doing an exhaustive revision of the landmarks on these aerial photos, an operation which will always require evaluation by the navigator. At least we can fill in the most obvious gaps in the chart by this process.
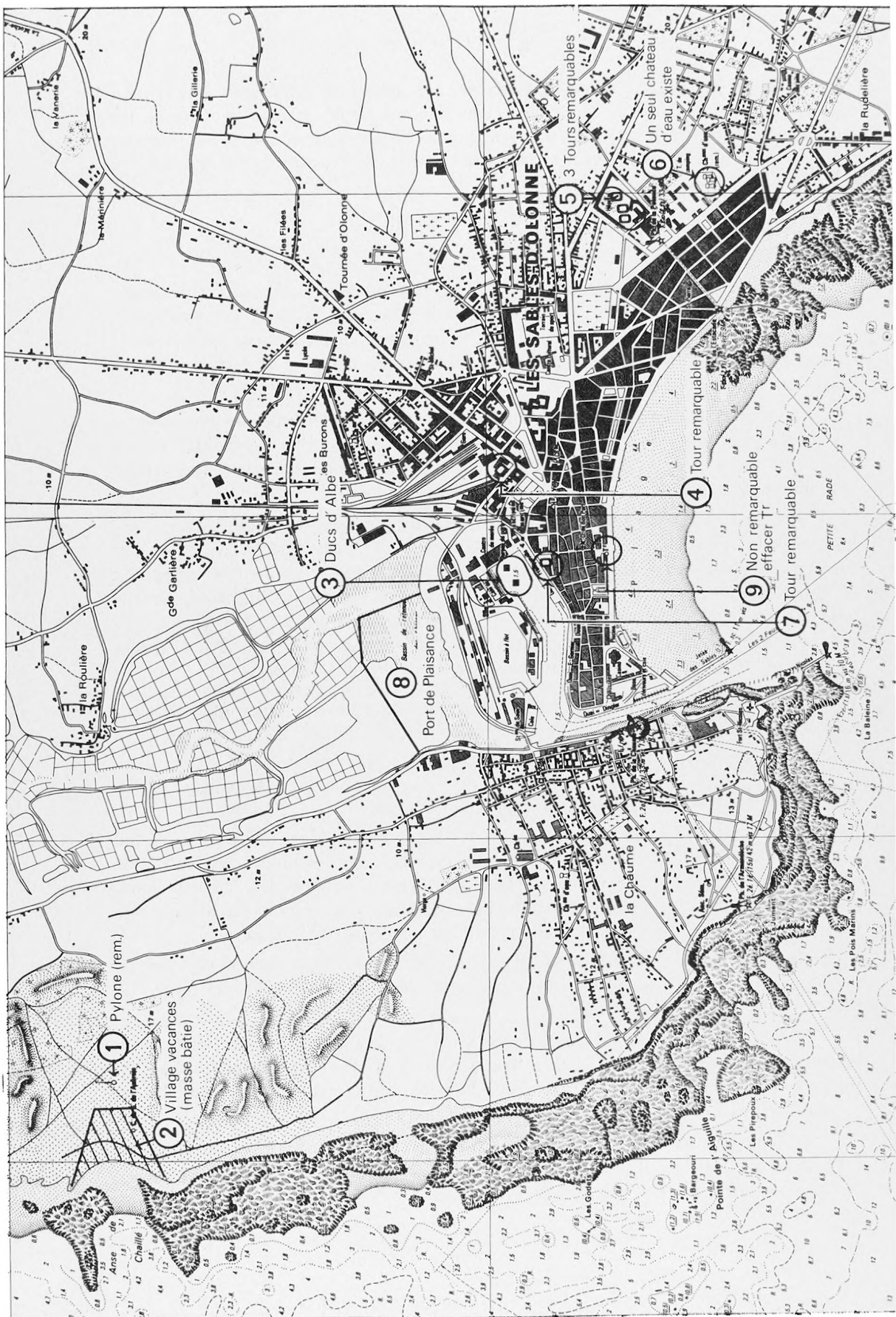
FIG. 5. — Extract from chart 6551.

Stéréogramme n°3

Stéréogramme n°2

FIG. 6. – Stereogram of Sables d'Olonne area made up from aerial photographs from the French "Institut Géographique National" (I.G.N.) for the reproduction of which the author has obtained authorization No. 99.1015.
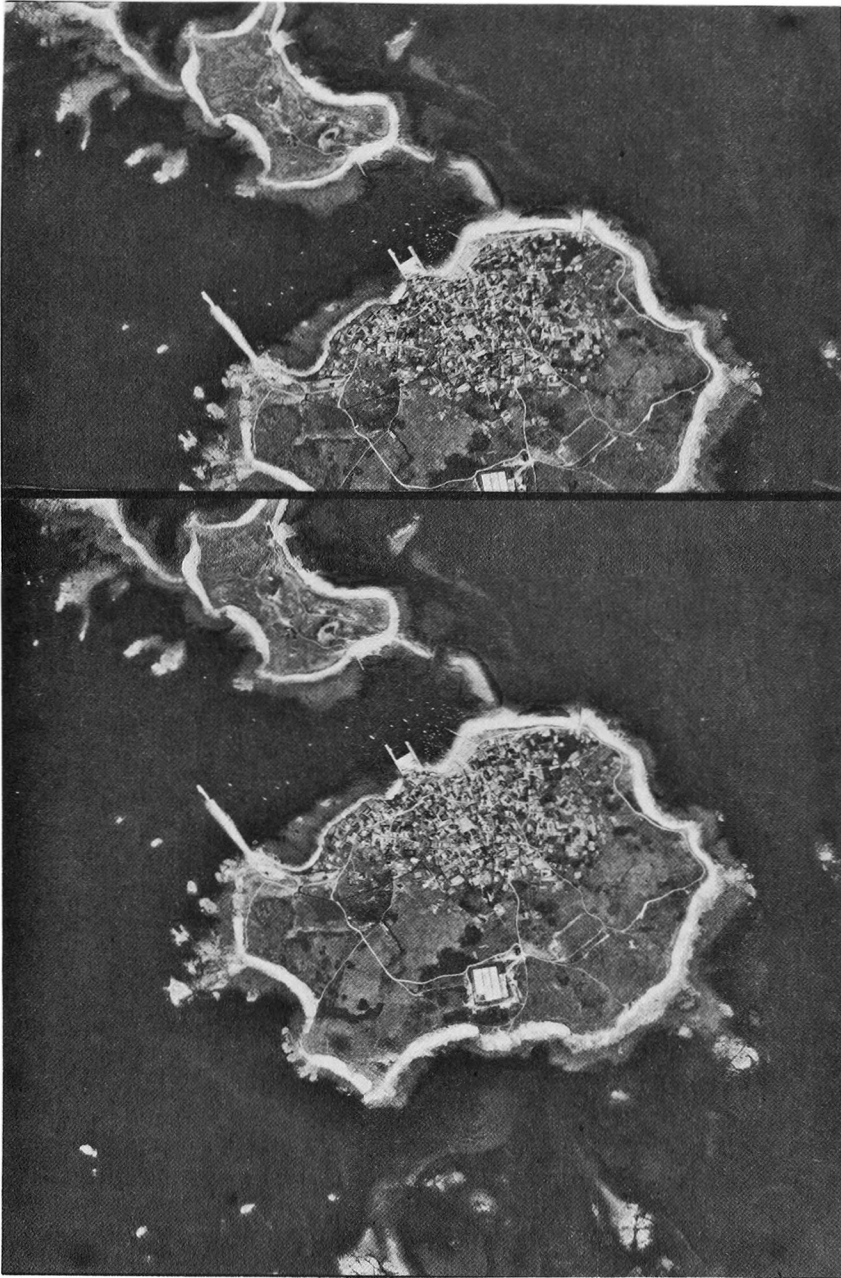
FIG. 7a. – Isle of Molene : stereogram made up from aerial photographs
from the I.G.N for the reproduction of which the author has obtained
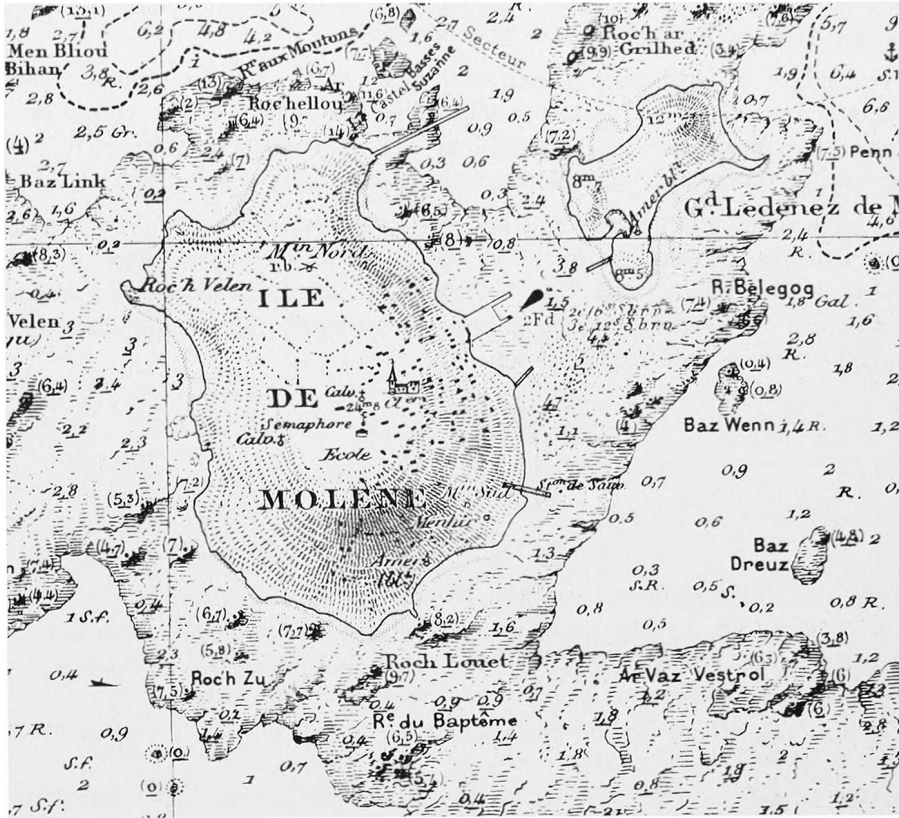authorization No. 99.1015.

FIG. 7b. – Extract from chart 5567.

Another striking example is provided by the stereogram in figure 7a where the small port of Molene off the Northern tip of Brittany is represented in relief. The chart (Fig. 7b) represents an area of rocks uncovered at low tide and thus shows a particularly unsafe port, which differs from the aerial photo. On the one hand, the port is sheltered on the S.E. by a rocky bay divided by a narrow channel, and on the other, the sea bed is free of rocks, and grounding at low tide can thus be considered relatively safe, except possibly in a north-easterly wind. It can also be seen that the breakwaters of the Grand Ledenes are not charted, nor is a prominent tower on the elevation to the east of the pier.

IV. GENERAL CONCLUSION

We have intentionally adopted an analytical, almost pedagogical, method of presenting the specific possibilities offered to the hydrographer by photoaerial methods.

This report is not really addressed to those already familiar with photogrammetrical methods. Those hydrographers need only retain the details on the capability of the Trident III system of positioning an aircraft to within a few metres, but may also

note the advantages of this system over the inertial systems currently employed and the development of the photoaerial techniques.

This article is particularly intended for those responsible for recently established hydrographic services with limited resources in the Third World countries. Their task remains immense, for the surveying of their national waters is yet to be done, and is now an important requirement for any economic development.

Because of its effectiveness and low cost, photoaerial surveying by a radioposi-tioned aircraft, by its very nature, gives these countries renewed hope of decisively developing, in due course, their own hydrographic surveying capabilities, although it remains limited to shallow waters, and needs to be backed by a traditional survey for the regions to be opened to navigation.

BIBLIOGRAPHY

[1] BONNEVAL : Photogrammétrie générale. Editions Eyrolles.

[2] DANIEL, R. (1952) : La photogrammétrie appliquée à la topographie. Editions Eyrolles.

[3] MASRY, S.E. & MacRITCHIE, S. (1980) : Different considerations in coastal mapping. *Photogrammetric Engineering and Remote Sensing*. Vol. 46, No. 4, April.

[4] WENYON, B.Sc. (Hons) (1978) : Photogrammetry in hydrographic surveying. *The Hydro-graphic Journal*, No. 11, April.

[5] TEWINKEL, G.C. (1963) : Water depths from aerial photographs. *Photogrammetric Engineering*, Vol. XXIV, No. 6.