PHOTOGRAMMETRY AND ITS APPLICATION TO HYDROGRAPHIC SURVEYS*

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DESPITE the vast funds expended in the past few decades for the purpose of conducting adequate hydrographic surveys in the Americas, it can be truthfully stated that a large percentage of the charts covering the waters of the Western Hemisphere are based on reconnaissance surveys conducted by Great Britain, France, Spain, and the United States, from 50 to 100 years ago.

Although some of those surveys were adequate in the days of the clipper ships, advancements in the speed and methods of transportation make it essential that steps be taken by the American nations to re-survey all those areas not thoroughly charted. From Davis and Bering Straits to Cape Horn, both on the Atlantic and the Pacific shores of the Americas, there is a vital need for good surveys, surveys which will safeguard and expedite shipping and open new channels for commerce—surveys which are essential for the defense of our democracy.

The United States, Canada, Brazil, and Argentina have done a great deal during the past forty years to remedy this sad situation, but when the vastness of the problem is considered, it will be realized that, at the present rate of progress, it will be at least another century before we can consider the Americas adequately surveyed from a hydrographic standpoint. It may be mentioned in this respect that for the proper safety of navigation, it is essential that coastal surveys extend to the continental shelf and that the accuracy of the work be such as to permit vessels to determine their position at night or during adverse weather by soundings alone while navigating in areas where the charted submarine topography lends itself for such purpose.

A review of the present situation will indicate the urgent need of surveys in Northwestern Alaska, British Columbia, the Gulf of California, the West Coast of Colombia, Ecuador, Peru, Chile, inclusive of the Straits of Magellan, Brazil, the Guianas, the East Coasts of Nicaragua and Mexico, Honduras, and large stretches of the vast coasts of Canada. Each one of these areas presents difficult problems for the hydrographic surveyor; problems that require courage, experience, quick thinking and, above all, adequate modern equipment if they are to be executed without loss of time.

I would like to mention, at this time, the important difference that exists between a regular land survey and a hydrographic survey. The former can operate with a few men and limited equipment; the latter requires a large organization comprising a mother ship and auxiliaries, all fitted out, not only for the task of charting the ocean floor, but the adjacent coast as well. The expense of operating a hydrographic expedition is such that there should be no lost motion—it has to operate efficiently in every department involved—otherwise, thousands of dollars worth of work may be lost in only a few poorly planned days.

Planning, therefore, is of primary importance in hydrographic surveying. However, part of this planning has to be done, if practicable, months in advance of the commencement of field operations in order that the expedition may function with utmost efficiency.

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Much has been done in the last fifteen years to improve and expedite hydrographic work. To-day, the hydrographic surveyor has at his disposal instruments of high precision, sonic depth finders that have made it possible to chart the ocean floor with the same detail as was formerly possible only on topographic surveys; he has the sono radio buoy and the taut wire measuring apparatus which permits the accurate extension of control further to seaward than he ever dreamed of in former days; radio and the prismatic astrolabe have given him a quick and accurate means of determining the astronomical position of his points of origin; and last, and of as much or probably more importance than the above, he has the aerial photographic camera.

When, in 1923, the Hydrographic Office of the United States Navy utilized the airplane in conjunction with a hydrographic survey of the Island of Cuba, pioneering work was done which conclusively proved the value of the aerial photographic camera in surveying.

Cuba, with its intricate coast line, its mangrove covered cays, its treacherous reefs, as well as its rugged shores, gave the United States Navy an ideal experimental ground. In fairness to the old time surveyors who were used to the plane table, transit-stadia, or sextant methods of delineating the shore line and adjacent topography, it should be stated that they all accepted the aerial photographic method with open arms. They realized from the very start that an accurate means was at their disposal, which not only would simplify their work, but greatly enhance the value of a survey by furnishing a vivid and permanent record replete with detail.

It gave him more than that—it gave him something tangible with which to plan his work well in advance, a means which would permit the Commanding Officer and the Senior Engineer of the expedition to economize in signal construction material, safeguard personnel and equipment, and, at the same time, coordinate all survey operations to the greatest advantage.

Our surveys in Venezuela, Colombia, Panama, Costa Rica, and Ecuador have proven the value of the adoption of photogrammetry as an integral part of hydrographic surveys. The vastness of the territory covered since the adoption of this new method of surveying is a tribute to the progressive spirit of the Hydrographic Office.

During such a short period, tremendous strides have been made in the improvement of aircraft and aerial photographic cameras; photogrammetric equipment has been developed which has increased the accuracy and detail of topographic surveys a thousand fold; photographic manufacturers have developed film and paper to suit every condition of light and terrain and possessing a minimum of dimensional changes; lens manufacturers have designed and perfected aerial lenses of precision. So we can truthfully say that Photogrammetry has come into its own. Today, no major surveying program should be undertaken without its use.

Canada has used foresight in establishing a central film library where the original data are available to the entire nation not only for solving the problems of today, but more important still, the engineering and economic problems of tomorrow. In the United States, we have yet to establish a central repository for these valuable records. The American Society of Photogrammetry has made constructive recommendations to carry out such a program and is in hopes that, in a not too distant future, legislation will be enacted for the construction of a special fire proof building in which all aerial photographic film owned by the government will be suitably safeguarded and indexed and made available for general use.

However, in conjunction with such a program, it is important that specifications for aerial photographic work be standardized as, otherwise, unnecessary duplication will result. Our Society has also been active in this respect and we feel that already great economies have been effected. The aerial camera of precision, specifications for which were prepared by one of our committees, will pave the way for greater achievements in photogrammetry.

Going back to the original theme of this paper, it is my earnest hope that the charting of the waters of our two continents be given greater impetus, that all the countries concerned realize its importance and take steps to remedy the present situation.

Even if their present economic structure does not permit all of the American countries to carry out a hydrographic program, complete in every detail, there are certain phases of such a program which possibly can be undertaken with the facilities they have at hand. The main thing is to get it started. The interest which will be aroused will be so great as to insure its successful completion.

The following suggestions are, therefore, presented in the hopes that they will receive consideration by the Americas as a whole.

A cooperative program, somewhat along the following lines, if adopted and carried out by all the nations of the Western Hemisphere, could make available, at an early date, improved navigational charts of all our coastlines and, at the same time, provide a framework of control upon which future hydrographic surveys would be based.

First

That each country in the Western Hemisphere establish a commission whose duty will be to conduct precise astronomical determinations along their respective coasts at intervals of approximately thirty nautical miles, at such locations as lighthouses, capes, points or headlands as will be of value to the mariner. The observations to be conducted with the astronomical transit or the prismatic astrolabe and controlled by radio comparisons of time with the U. S. Naval Observatory in Washington, D. C. Although some of these positions will be affected by station error, due to deflection of the plumb line, they can later be adjusted. La Place azimuths should be measured whenever practicable. In addition, it will be necessary to measure the distance and azimuth between the astronomical station and at least one other easily recognizable or conspicuous object or feature along the coast within a distance of one mile. At each station, tangents should be measured and cuts taken to all conspicuous natural objects in the vicinity. (It may be mentioned that all the nations affected by the program have competent personnel and adequate equipment to carry out this work expeditiously.)

Second

That an aerial photographic survey be made of the entire coast line, utilizing, if practicable, a camera with suitable coverage and resultant facility of extending aerial triangulation over long distances. At a scale of 1:20,000 each photograph might well have a lateral coverage of approximately ten statute miles. Utilizing the slot template method, greater rigidity will be insured. The control obtained by the Astronomical party will be adequate for the preliminary adjustment of the aerial photographic survey. The resulting data can then be utilized for the preliminary correction of existing charts.

Obviously, when detailed hydrographic surveys are undertaken, additional photographs at a larger scale will be required for harbors, anchorages, etc., wherever a large scale development of hydrographic features is desired.

THIRD

After a thorough study of the photogrammetric data has been made, plans can then be formulated for the execution of the hydrographic work.

A Diesel driven vessel of from 125 to 150 feet in length, fathometer equipped, and carrying two small motor launches with portable sonic sounding equipment can, with trained personnel, accomplish a great deal, particularly if aided by an auxiliary vessel which will serve as a signal construction party. The ship-shore method of triangulation, utilizing radio, described by Captain G. S. Bryan, U. S. Navy, Hydrographer, at the 1940 annual meeting of the American Geophysical Union, would be an ideal way to expedite a hydrographic survey, specially along stretches of coast devoid of shelter and where land triangulation would be a difficult problem. By this method, the ship, while lying-to off shore, acts as an unoccupied station and angles thereto are observed simultaneously by radio equipped parties occupying the shore triangulation stations. This method which is rigidly controlled between center of expansion fifty to sixty miles apart, by accurately measured bases and azimuths, has proven successful and economical.

The above program is offered as a basis for discussion, in the earnest hope that it will stimulate some interest among our neighbors, and with the assurance that photogrammetry will be of the greatest aid in charting the American continents.

DISCUSSION OF MR. MEDINA'S PAPER

Mr. J. U. Beauchemin
Hydrographer
Dept. of Mines and Resources, Canada

Mr. Chairman and Gentlemen, two weeks ago when I accepted your invitation to lead the discussion on this paper, I had in mind to ask Mr. Medina several questions in connection with the new cameras used in the United States and the general procedure followed when a section of the coast is being photographed for hydrographic purposes. I was advised yesterday Mr. Medina could not be in Ottawa but that Mr. Wright would deliver his paper.

Mr. Wright has requested me to give you a general idea of the present organization of the Canadian Hydrographic Service and also my own experience with photogrammetry, so, Mr. Chairman, my time being limited, I shall try in a few minutes to acquaint you with our activities.

Some sixty years ago when the Canadian Hydrographic Service was being launched on its mission of public service, surveying in this country was a crude art. Evolution has since produced some radical changes in the character and extent of this service to the public and furthermore, since the last war, our nation has been more ship-minded and more thought has been given to hydrography and its new methods than ever before. New ideas and inventions have resulted in some drastic changes in the work; our Service has endeavoured to keep pace with the changes and has adopted for its own purposes a long series of scientific achievements which enable it to do more and better work at a steadily decreasing unit of cost. For the past twelve years photogrammetry has been adopted for the accurate prosecution of the work of charting our coasts.

To a land surveyor, any new theodolite or transit which falls into his hands is called a "new tripod baby," but to hydrographers any new device is called a "new baby," and during the past fifteen years our Service has adopted many of them.

We adopted the Gyro compass for determining the variation at sea and calibration of D.F. stations, etc.; we had also a "new baby" in the supersonic echo sounder, picking up echoes automatically and transferring them and registering them in feet on paper at the rate of 240 per minute; and last but not least, we have photogrammetry, which we call the "one-eye baby." When it was delivered into our hands in 1929, scientists took care to supplement its infirmities by supplying it with important interpreters, the epidiascope and the stereoscope. Mr. Chairman, this "new baby" of ours did not come from the incubator under such favourable meteorological and financial conditions as her sister from south of the border, which had its first peek-out in Cuba in 1923.

In Canada, photogrammetry and its application to hydrographic surveys began simultaneously in Hudson Bay, on the north shore of the Gulf of St. Lawrence and on the Pacific coast in 1929.

Today, due to the Inter-Departmental Committee on Civil Government Air Operations, created in 1926 by Order-in-Council and consisting of the Surveyor General of Canada, all directors of the various technical branches and Mr. R. J. Fraser, Assistant Chief Hydrographer, representing the Hydrographic Service, our Service has been supplied with sufficient air photographs to carry out a programme over a period of at least three years.

To complete the charting of the Gulf of St. Lawrence and the southeast coast of Nova Scotia including the Bay of Fundy, we have been supplied with the necessary lines of flights. We also have the necessary flight lines for the Pacific coast.

From the head of the Great Lakes to Quebec our charting is completed with the exception of Georgian Bay, and the air photographs for this portion are now available.

We have only a few hundred miles of air photography up north and in order to carry out the charting of the northern route, at least 3000 miles of air photography will have to be done in order to complete Hudson Bay and Hudson Strait.

You will realize from this, Gentlemen, that the Canadian Hydrographic Service has made good use of this new method of surveying.

Air photographs, provided they are of recent date, are of considerable assistance for coasting details, but from the hydrographer's point of view there are generally difficulties in making full and effective use of them for coastline purposes, for the following reasons:—

(a) Each photograph shows only the water's edge at the moment of its exposure; on shelving beaches this may be some distance from the high water line, and it may not be possible to identify the position of the latter.
(b) The photographs give little indication of the character of the fore-shore and have therefore to be supplemented by inspection on the ground.
(c) Air photographs taken early in the spring when the rivers are discharging all sediments of the inland areas, are of very little assistance in detecting the underwater features, such as shoals, sunken rocks or obstruction, etc.

I am convinced that if air photography could be done in clear weather and when the water is smooth and free from sediment, under-water features such as shoals and banks could be studied in relation to the soundings to make sure that no dangers have been overlooked.

All the air photographs used by our Service are required to be vertical and are properly controlled by triangulation and fixes.

On major surveys, the ordinary field stereoscope is used in the field of opera-

tion and for office work at headquarters the epidiascope (Barr and Stroud) is used, and as mentioned above, our photographs being all verticals, these two instruments are used in reducing to scale, examining and obtaining the control lines.

In conclusion, I may add that the air photographs used by the Hydrographic Service were taken by the Royal Canadian Air Force from specifications prepared by our Bureau as to the number and direction of the flight lines to be carried out, also the altitude which, in most cases, varies from 10,000 to 15,000 feet.

DISCUSSION OF MR. MEDINA'S PAPER

Mr. R. J. Fraser
Hydrographic Service, Canada

Mr. President and Gentlemen, I did not come prepared to enter into the discussion on this paper. I had hoped, however, to gain from Mr. Medina's paper some idea of the practical results which the Hydrographic Office, U. S. Navy, might have obtained in their serial photography of waters and whether they have obtained any real practical results in the interpretation of under-water features from the photographs. We have not had the same opportunities of carrying out photographic operations ourselves, though we have been admirably served by the Air Force with photographs of sections of our coast line which we have had to chart, but we have not had the opportunity of experimenting in that particular branch of the science ourselves.

My own experience of trying to interpret under-water features from the air has not been very successful. I had an opportunity of flying over some English coastal waters, which I myself, had been charting, about twenty-five years ago and the result was that what I interpreted as shoals and shoal water turned out to be the deeps.

It would be very instructive to learn if real success has attended experiments or efforts to read the depths, within reasonable limits of course, and the nature of the bottom and shapes of rocks or sand bars, either by direct observation from a plane, or from the photographs taken at certain heights.

We hear statements occasionally made by ardent exponents of aerial photography on the capability of accurate interpretation of depths and contours from air photographs. We know where this has failed to work out in our practice, and it would be very informative to learn of actual instances of reliable results, dependable enough for incorporation in a mariner's chart.

I would appreciate it very much if Mr. Medina could tell us something of the actual results they have obtained, and I would like to take this opportunity to thank him for the preparation of this paper and also Mr. Wright for its presentation.

FURTHER DISCUSSION OF MR. MEDINA'S PAPER

Mr. J. L. Rannie
Geodetic Service of Canada

In connection with Mr. Medina's interesting paper, there are a couple of points which I would like to discuss: neither is in connection with the application of aerial photography to hydrography; my remarks only apply to Mr. Medina's suggested control throughout the Americas.

Mr. Medina suggests establishing precise astronomical stations every thirty miles or so as control for plotting the photographs. Since these determinations

contain "station errors," he suggests that these errors may be adjusted and, presumably, eliminated.

Astronomical stations are very valuable as control where nothing else exists, but they must be used with a knowledge of their probable deficiencies and should only be applied to the class of reconnaissance maps or charts. Also they must not be spaced too closely, as exemplified later. I believe that thirty-mile spacing is much too close even in the average case. One hundred miles is nearer the mark.

In Canada the average error of astronomical stations due to the deflection of the vertical is about 600 feet, as obtained from a comparison of astronomic and geodetic positions. In very hilly country these errors may be as great as half a mile. Granting an average deflection of 600 feet in opposite directions at adjacent astronomical stations it is quite possible to have an error of 1 in 130. Even stadia traversing can be kept within an error of about 1 in 400, and in certain sixty-mile intervals we have in Canada instances of errors of 1 in 200 between astronomical stations.

Astronomical stations provide valuable points of departure for local surveys, but they should not be employed as control for surveys which have any high pretensions of accuracy. I am certain that neither the Hydrographic Office, U. S. Navy, nor the Canadian Hydrographic Service would consider adequate any methods which might give errors as great as 1 in 130 between control points.

Unfortunately also, it is impossible to predict or compute the station error under such conditions of absence of good surveys as Mr. Medina's method might be applicable. It is possible to approximate what is called the topographic deflection where the topography is known, but here we ignore the unknown effect of sub-surface conditions of density which may be predominant. Indeed the topographic deflection, though it generally reduces the station error, may in some cases increase it. One case in southern Quebec comes to mind. The combined station error between two points twenty miles apart was 1150 feet before the topographic deflection was applied and 853 feet after its application, an error of 1 in 125.

One concludes that in many cases the aerial photography could control the astronomical stations and that the possibility of other methods of control should be sought before employing astronomical stations at the intervals suggested by Mr. Medina.

MR. MEDINA'S REPLY TO ABOVE DISCUSSION

Referring to Mr. Beauchemin's interesting remarks, I am glad to find out that photogrammetry has been playing an integral part in all Canadian hydrographic surveys since 1929.

It is true that photographs, in order to be of value, should be well controlled and be obtained during clear weather. The practice of the Hydrographic Office is to furnish one copy of each photograph to the field parties so that notations regarding the culture of the terrain, high water line, heights of adjacent reefs and rocks may be noted on the photographs.

The fact that aerial photographs are available does not relinquish the responsibility of the hydrographic surveyor to details which must appear on the resulting charts.

Referring to Mr. Fraser's remarks, the Hydrographic Office has had several opportunities of making good use of aerial photographs covering sunken reefs. Although no practicable method has been devised as yet to determine the depth of the water over such reef areas, the fact that the aerial camera, under good

conditions of light and sea, can record the limits of such areas is of great value to the hydrographic surveyor as it can permit him to plan sounding operations to greater advantage. A person familiar with such photographs, and who has had experience in hydrographic work, can determine whether or not the reefs are close to the surface or at depths ranging anywhere from 10 to 30 feet.

Referring to Mr. Rannie's discussion, it is regretted that there is a certain amount of misconception regarding the program outlined for expediting the completion of the hydrographic surveys of the Americas. Due to the fact that existing charts are based on very old surveys anti-dating the use of radio for the determination of longitude, it is known that the position of some of the most important "land falls" are considerably in error. To map this vast coast line in detail would be a very costly and lengthy undertaking. Therefore, the plan outlines a scheme by which *preliminary* corrections could be made to existing charts and at the same time make available data, from which to *plan* detail hydrographic operations of the most important areas.

It is realized that astronomical determinations are affected by mass attraction. However, when positions are suspected to be out as much as five miles, and when it is realized that the average celestial determination for a ship at sea has an error of approximately one mile, it is believed that the corrections which will be derived from this survey will be an improvement.

It may be noted that the plan required the determination of check bases 30 miles apart for use in adjusting the scale of the aerial photographs. As a fair determination of latitude and longitude can be obtained with the astrolabe in a few hours' time, provided suitable weather is present, it is believed that, despite any errors in those positions due to mass attraction, they would be of considerable value.

It must be remembered that the plan proposed is not the one in practice by the Hydrographic Office in its regular surveys. Our surveys are geodetically controlled, with suitable check bases and astronomical azimuths, and the position selected as astronomic origin is always one least affected by mass attraction.

MR. V. RALPH SOBIERALSKI has relinquished his duties as Secretary-Treasurer of the Society of Photogrammetry due to the fact that he has recently transferred from the Soil Conservation Service to the field service of the Coast and Geodetic Survey. The Society wishes him success in his new assignment as Deck Officer.

MR. DON I. DUNN, a charter member of the Society, has assumed the duties of Secretary-Treasurer.