*Hydrographic Application of Photogrammetry in the United States Coast and Geodetic Survey**

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THE publication of nautical charts of the coastline of the United States and its territories is one of the principal functions of the Coast and Geodetic Survey. The term "publication" here implies not only printing the charts, but also their construction and maintenance from the establishment of basic control surveys to the application of most recent changes. The problems encountered in providing this service differ somewhat from those of general topographic mapping inasmuch as (1) the area is usually confined to a narrow, irregular strip along the coast, (2) the scale is relatively large, and (3) intensive detail is required to serve an accurate and complete guide to the mariner. The advantages offered by photogrammetry are used to obtain basic topographic information and to aid the hydrographer.

The Photogrammetry Division is one of the six operating divisions of the Coast and Geodetic Survey, the others being Coastal Surveys, Geodesy, Geophysics, Tides and Currents, and Charts. Although the functions of the various divisions are fairly well denoted by their titles, it may be added that the Coastal Surveys Division operates the hydrographic vessels and performs the hydrographic surveys; the Photogrammetry Division provides, through the use of aerial photography, the topographic and control information required to locate inshore hydrography and to compile and maintain the nautical charts; and the Charts Division compiles, engraves, prints, and distributes the charts. The Photogrammetry Division, in turn, utilizes data provided by the Geodesy Division and the Tides and Currents Division, and supplements such data with observations of its own whenever it is advantageous.

The Photogrammetry Division comprises an unusually complete organizational unit. It owns its aerial cameras and the navigator and photographer are members of the Division. It processes its own film and reproduces its prints, enlargements and diapositives. The Division operates its own mobile field parties and compilation offices. It has a series of stereoscopic plotting instruments for nearly every appropriate application. A drafting unit is included for finishing and scribing the completed manuscripts. A small research group studies new techniques and strives to improve the old ones. The different phases of the work are united through an Operations Branch. By this complete organization, the Division is able to control and coordinate its activities including flight planning, aerial photography, control surveys, compilation, drafting, etc.

The photographic airplane is provided by another bureau, the U. S. Coast Guard, which cooperates completely in supplying the service when and where it is required. Additional airplane service is obtained through private firms by a contract arrangement whereby the Division's navigator-pilot and photographer operate the equipment.

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Two principal cameras are used in aerial photography: the nine-lens camera which was developed by Captain O. S. Reading; and a Wild RC5 film camera. The former [1, 2] is especially advantageous where the coastline is irregular and where islands lie too far offshore to be connected to land by single-lens photography at a conveniently large scale. The nine-lens camera yields large scale and high resolution, as well as having an angular field of more than 140 degrees. Irregular shoreline is frequently mapped easily with the nine-lens camera where single-lens photography results in water models which cannot be aero-triangulated, requiring more ground control. The nine-lens camera is particularly useful in areas where control surveys are difficult or expensive, and at present it is being used mostly in Alaska where its control-saving advantages are the most valuable.

The RC5 camera is used wherever single-lens aero-triangulation and compilation present no water problem and where the advantages of the nine-lens camera are not required.

An older Fairchild cartographic film camera is also used as occasion demands. As the nine-lens and RC5 cameras are carried in the same airplane, the cartographic camera is used wherever a second airplane is utilized, especially for chart revision purposes.

The Division has a photographic laboratory which develops the aerial film, furnishes prints, enlargements, diapositives and rectifications. Aerial photographers are employed in the laboratory during non-flying periods. The laboratory equipment includes two nine-lens transforming printers, a rectifier for nine-lens photographs, a Saltzman enlarger, a SEG IV rectifier, a Multiplex diapositive printer, a LogEtronics printer, a Zeiss FE-120 film developing outfit, etc. The aerial film is shipped via air from the airplane to the laboratory, wherever the airplane might be. A sample of the film from each roll is tested by the aerial photographer to assure proper operation of the camera.

It should be pointed out here that aerial photographs are usually obtained before field operations, as pre-marking or signalizing control stations has not yet become standard practice.

The Division directs its own field parties, which fluctuate in number and size, and move from project to project with the seasons of the year. These photogrammetric field survey units establish supplemental horizontal and vertical control if it is required, identify the control stations on the photographs, clarify details on the photographs to assist the compiler, and obtain special information needed for nautical charts such as bridge and cable clearances and the location of aids to navigation. These units also field-edit completed maps where necessary, although all ground information is intended to be obtained by field examination prior to map compilation. Photogrammetric field personnel also work with hydrographic survey parties to supply control and inshore data for the hydrographic surveys.

Three stationary field compilation offices, in addition to the one in the Washington Office, produce map manuscripts. The activities of all the field units, including aerial photography, are instructed and directed from an "Operations Branch" in the Washington Office.

Several overlapping categories of compilation activities may seem to be confusing to one who is unfamiliar with the procedures. In some areas topographic or contour maps are required, whereas in others only planimetric maps are needed. In some instances only a narrow fringe along the shore is required, whereas in other instances mapping is specified as complete to the nearest $7\frac{1}{2}$-minute line of latitude or longitude. If topographic mapping is wanted, the use of a stereoscopic instrument is implied; if planimetric mapping is wanted, the compilation may be accomplished by stereoscopic instrument or by graphic methods. Even if topographic maps are made from nine-lens photographs, horizontal aerial triangulation is performed by the use of transparent, vinylite, line templets; also planimetric maps are nearly always compiled graphically, although a steadily-increasing number are being compiled by instrument. Single-lens photographs are usually compiled by stereo instrument, whether for topographic or planimetric mapping, although the latter, also, are sometimes compiled graphically.

Two Stereoplanigraphs, two Reading nine-lens contour plotters, two Kelsh plotters, and one Stereotop are used in the Washington Office. In a nearby field office are two more Kelsh plotters and five Multiplex units. Two other field compilation offices each have a Kelsh plotter. Seven Focalmatic desk ratio projectors are used, some in chart revision work, and others by field units.

Prior to the extensive use of photogrammetry, shoreline data and control stations for hydrography were surveyed and located by planetable [3]. These surveys were usually made by a combined operations party as the work included geodetic triangulation, planetable surveying and hydrography. Today, photogrammetric mapping usually precedes hydrography and supplies both the shoreline data and control for the hydrography. Hydrographic signals are identified on photographs and located photogrammetrically on board the hydrographic ship. A special set of photographs is used and the method of location is by the radial line technique using a transparent copy of the photogrammetric map provided beforehand for this purpose.

Coastal mapping and inshore hydrographic surveys are nearly always coordinated and planned so that aerial photography is obtained the season before the hydrographic survey is scheduled. Geodetic control is assumed to follow aerial photography. In any event, the control is identified on the photographs, after which a map of the shoreline is compiled in an office. All possible detail which might be of assistance to the hydrographer is compiled. The high-water line is shown, with the aid of notes made here and there on the photographs during a field inspection. Contours are plotted if the topography is helpful to navigation. All landmarks are shown, such as towers, steeples, tanks and chimneys. All rocks, reefs, sand bars, and channels visible on the photographs are denoted. And, finally, of possibly greatest importance, a series of identifiable objects along the shore are located in latitude and longitude by photogrammetry with all possible accuracy. The hydrographer can then find these objects, erect signals at their sites, and use the signals for sextant sighting, or he may select other sites, identify them on the photographs and determine their positions photogrammetrically. Thus, the hydrographic operations can proceed without delay and need not wait for the progress of ground surveys.

As an interesting alternative in this connection, the geodetic work can be delayed if time is an important factor, for a planimetric map at some consistent scale can be compiled without control. The hydrography can also be performed at this unknown scale. Later, when the geodetic work is completed, a final, accurate chart can be compiled showing all planimetry, hydrography and topography in their proper relationship. In a few instances, the photography was obtained, the preliminary map compiled and sent via air to the ship, the hydrography survey was made, and geodetic work completed, all in the same season.

The Photogrammetry Division cooperates in every way in these instances. Sometimes a photogrammetrist is assigned on board the ship to help coordinate the work. Frequently, a photogrammetric shore party operates ahead of, or in conjunction with, the ship building signals and adding notes to the photographs to aid the compiler in the correct interpretation of rocks and high-water line.

Another phase of this work consists of the presence of one or more photogrammetrists assigned to the Geodesy Division when higher-order triangulation is established in a map area. The photogrammetrist identifies the stations on the photographs, and selects intersection stations to aid in subsequent photogrammetric triangulation, as well as accepting any assignment that might aid in the progress of the geodetic operation.

When the stockpile of a given chart has become exhausted and reprinting is considered, the problems of revision become important [4]. Usually, considerable data are already on hand indicating needed revisions, such as a new pier, a shipwreck, a navigation facility removed, or a reduced water depth through sedimentation. But the chart compiler cannot be certain, ordinarily, whether his data are complete. One method for determining the amount of added revisions of the land information needed on a given chart is to take aerial photographs of the coastline. A comparison of the photographs with the chart indicates the extent of revision needed. If the revisions are extensive, the chart may require reconstruction, which is equivalent essentially to making a new map. If the revisions are minor, they may be applied to the chart negative by hand to agree with the photographs. In both instances, photogrammetry is utilized.

If extensive revisions are necessary, the procedure is not much different from that for constructing a new chart in an unknown territory, such as Alaska. However, sufficient horizontal control may often be identified so that none may need to be established. If contours are required, levelling may be needed to establish vertical control in areas required by the stereoscopic instruments. On the other hand, a very complete field inspection may be needed before compilation. Such areas are often well developed, whence the inspection is more difficult than for a new chart.

If the revisions are expected to be minor, a small airplane and crew may be assigned to photograph the shoreline from a relatively low altitude, such as 5,000 feet, where the nautical chart scale is 1:40,000. The navigator, who is well versed in the over-all chart requirements, may pilot the airplane with a connoted nautical chart in his lap, marking the places that appear different than shown; and then reflying the place to take at least three photographs with stereoscopic overlap. This was done for the entire eastern coast of the United States in two seasons, using only three or four days per month when both the sun and tide were in correct relationship for photography at low-water stage.

Contact prints of the aerial photographs are ideal for graphic compilation of revisions, as small areas near the centers of the photographs are used almost entirely. Sufficient sharp detail, common to the chart and to the photograph, exists so that the areas need only to be matched and then applied directly to an appropriate copy of the chart.

The present method consists of delineating a change on a contact print in a bright ink, using a stereoscope, and transferring the photographic detail (1:10,000) onto an appropriate copy of the chart (1:40,000) using a Focalmatic desk projector. Larger revision areas are compiled on a stereoscopic instrument and then applied to the chart. A Stereotop has been purchased recently to facilitate this work. Other phases and variations of this operation, and the use of plastic scribing, are included in [4].

Aero-triangulation is applied in four different ways: (1) nine-lens, graphic, radial plotting, (2) Multiplex bridging, (3) model templet bridging with the Kelsh plotter, and (4) stereoplanigraph bridging.

For the nine-lens mapping, the photographs have 70 per cent forward lap and 60 per cent side lap which establishes a geometrically strong triangulation solution. The transforming technique has now been perfected to the place where junction errors are normally no greater than 0.1 mm near the center and 0.2 at the outer edge; thus, the junction errors are smaller than graphic errors. Seldom is any new horizontal control established for nine-lens plotting: existing control is sufficient, particularly as the method is very tolerant as to the relative location of the control. Vertical bridging is not attempted except for preliminary or reconnaissance maps.

Multiplex bridging is done in a normal manner for as many as 10 models. Vertical bridging is not attempted as elevations are furnished in each of the four corners of every model, either by field methods or by means of stereoplanigraph.

Ordinarily, all control, horizontal as well as vertical, is furnished to the Kelsh plotter, either by field methods or by stereoplanigraph. Where neither of the auxiliary methods is convenient, model templet bridging is performed. The model templets consist of etched lines on transparent stable plastic. Inasmuch as the mapping areas between control are not very large, the number of templets is small enough so that they can be manipulated by hand without undue difficulty, and the slotted type of templets is not required. The Kelsh pantograph is not used in making model templets because of the possibility of added systematic errors. If the templet scale is too large, it is reduced by drawing the radial lines nearer the radial center.

Stereoplanigraph triangulation is being done continually, both vertically and horizontally, at various scales. In fact, the stereoplanigraphs are being used almost exclusively to furnish control by aero-triangulation for Multiplex and Kelsh compilation. The general method is the same as that of the Army Map Service, the principal difference being the use of International Business Machines for a linear transformation [5] of instrument coordinates prior to the graphic analysis of systematic errors.

The Coast and Geodetic Survey looks forward to even more useful and valuable applications of aerial photography in its hydrographic service. Interest is expressed concerning the application of 120 degree photography in addition to, or in place of its nine-lens camera. As the Bureau uses International Business Machines in its geodetic work, the application of computational analytical aero-triangulation appears to be both possible and practical. Studies of analytical methods are in progress. Infrared photography has been tested in swamp areas and found to be a valuable auxiliary water delineation source. Plans are being followed steadily to replace as rapidly as practical all graphic compilation with stereoscopic instrument compilation. The report of Mr. Harry [6] indicates very high accuracies that are possible by means of photogrammetry. Accuracies of this relative dimension would be useful for the hydrographic control work of the Coast and Geodetic Survey. Although the use of signalized points has not been seriously employed in the United States, it is considered that it may present one method for greatly improving the accuracy of photogrammetric control surveys for nautical chart compilation.

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