*Tidal Current Surveys by Photogrammetric Methods**

MORTON KELLER,
General Engineer,
U. S. Coast and Geodetic Survey,
Washington, D. C.

ABSTRACT: *Conventional methods of measuring current velocities generally employ current meters suspended from buoys at a limited number of selected locations and at predetermined depths. The Coast and Geodetic Survey has believed for some time that aerial photography and photogrammetric measurement would provide a synoptic view of the circulatory pattern of a fairly large area. The idea has been tested rather thoroughly in several estuaries. This paper outlines the photogrammetric methods used and the results obtained in these studies.*

INTRODUCTION

As a part of its service to maritime commerce, the Coast and Geodetic Survey has been making current surveys since 1850. The Bureau publishes annual Tidal Current Tables that predict the times of slack water and the times and velocities of the maximum flood and ebb currents, as well as special publications containing observations of data for various waterways. Current charts are also issued that show the direction and velocity of the tidal current for each hour of the tidal cycle. In recent years, the rapid population expansion and industrial growth of the nation has brought demands for more detailed circulatory current surveys in connection with water pollution, fisheries, shore erosion and engineering construction problems.

MORTON KELLER

The Bureau's first use of aerial photography specifically for the measurement of currents was at the hazardous entrance of Lituya Bay, Alaska in 1959.[1] The success of this project and the work of Canadian scientists[2,3] gave impetus to the plan of Captain L. W. Swanson, Assistant Director for Physical Sciences, to make a photogrammetric survey of a complete tidal cycle for an entire harbor area. This was first done at Charleston Harbor, S. C. in the spring of 1962, in conjunction with a conventional tidal current survey using current meters.

CURRENTS DEFINED

Current flow may be considered as tidal and non-tidal. Tidal flow is periodic and arises from astronomical causes. Nontidal flow is any current not due to the tidal movement.[4,5,6]

The tidal current is the horizontal movement of the water and is a part of the same general movement of the sea that is manifested by a vertical rise and fall of the water level known as the tides. In rivers and harbors, where the direction of flow is more or less restricted to certain channels, the tidal current flows alternately in approximately opposite directions with a period of slack water at each reversal of direction. Depending on their location, these cycles of current occur once each day (diurnally) or twice each day (semi-diurnally). On the East Coast, a complete cycle takes approximately 12½ hours

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and is an example of the semi-diurnal type of reversing current. See Figure 1.

Principle of Photogrammetric Measurement of Currents

The principal feature and advantage of the photogrammetric method is that it can provide an essentially instantaneous synoptic measurement of currents over a large area. The objective is to combine photogrammetric measurements with standard current meter surveys in order to obtain a more detailed circulatory chart.

To apply photogrammetry to current surveys, it is necessary to achieve absolute orientation on stereoscopic plotters as in normal mapping practice, and to have the water surface marked to permit the identification of specific surface points stereoscopically. This requires the seeding of suitable floating targets whose movement can be recorded on aerial photographs taken throughout the tidal cycle.

The stereoscopic models are absolutely oriented on a stereoplotter and the parallaxes at each target measured. Target movement perpendicular to the flight line results in a measurable amount of y-parallax. Target movement parallel to the line of flight manifests itself as an elevation change, due to x-parallax, relative to a zero datum present in the model. See Figure 2. By reduction of the measurements, the speed and direction of target movement, or current, can be computed. A preliminary investigation of errors inherent in the technique indicates a cumulative error of about 0.1 knot in the speed determination with the error decreasing as the interval between the exposures increases.

It is possible to interpolate current velocities between target positions and thus to fill in any gaps in the survey caused by the lack of a uniform target density. The presence of surface markings gives the water surface a texture so that if a model of moving water is examined stereoscopically, the water exhibits a relief effect depending on the velocity of the current. An approximate interpolation of current velocities is then made by comparison with the relief shown at the measured targets.

A number of conventional meter stations, operating over long periods of time at strategic locations, serve to control the photogrammetric tidal current survey. A comparison is

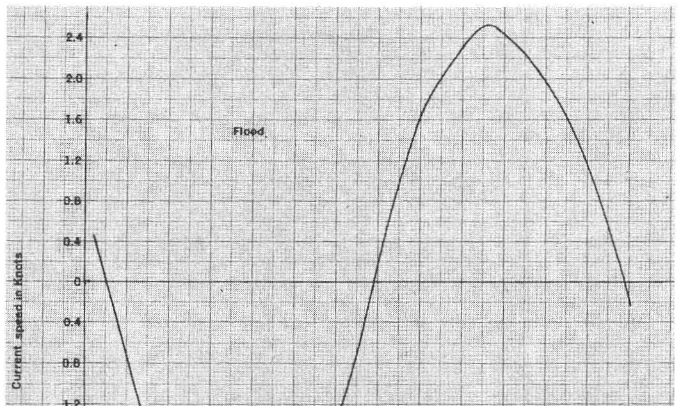

Fig. 1. Current cycle at the Charleston Harbor, S. C. reference station on April 2, 1962.

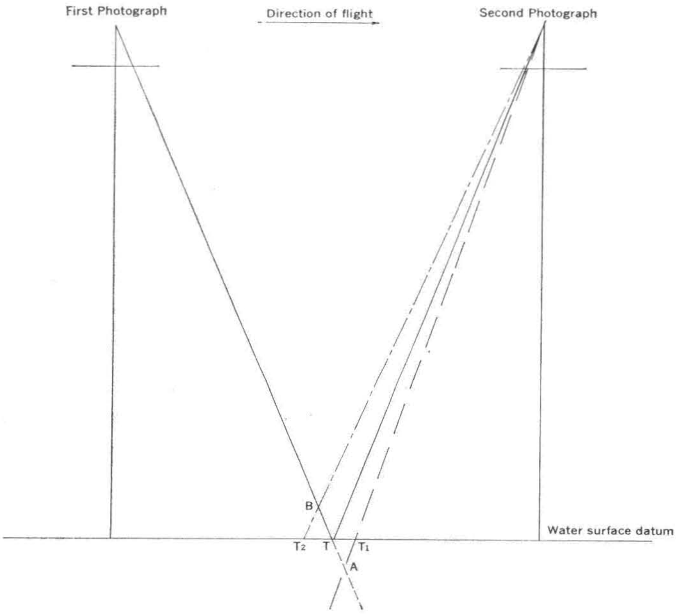

FIG. 2. Target movement parallel to the flight line manifests itself as an elevation change in the stereoscopic model. If the current direction agrees with the flight direction, the target moves from position T to T_1 between exposures and the rays intersect below the water surface datum at A. If the directions are opposed, the target moves from T to T_2 and the rays intersect above the water surface datum at B.

made of the current cycle curves generated by the meters for the different days involved in securing the photogrammetric observations. This provides sufficient information about the variation in velocities for any part of the tidal cycle from day to day to permit adequate adjustment of the observations to the equivalent of a single current cycle.

A series of charts can be produced showing the circulatory pattern for the area at differerent times of the current cycle. Current velocity relationships can be obtained from these current charts that express the velocity at numerous locations as a function of the velocity at a selected reference meter station. The relationship remains approximately without change at the same time of the current cycle on any other day. The current cycle curve generated at the reference station also provides information for use with the Tidal Current Tables that enables the prediction of current velocities at the station on future days. The application of the current velocity relationships to the predicted current at the reference station permits the prediction of expected current velocities throughout the area at any desired future time.

Preparation for a Photogrammetric Current Survey

There are many factors to be considered in preparing for a photogrammetric current survey.

Photography

In scheduling photography to obtain a complete periodic coverage of the tidal current cycle, the position of the sun relative to the photography is important. An evaluation must be made of the photograph areas that will be rendered useless for office recovery of targets because of the reflection of the sun on the water surface. This requires a plotting of the hourly trace of the sun's image at photograph scale for the survey area on the day of planned photography. See Figure 3. Depending on the time of day, different flight lines can be scheduled to preclude the appearance of sunspot in critical areas of the photography.

As the portion of the current cycle being photographed must occur during daylight hours, it may be necessary to take photography over a period of several days. In addition, the photography should be planned to correspond with the appearance of the spring tides.

The need for land detail to achieve absolute orientation of stereoscopic models, together with the desirability of reducing the volume of photogrammetric measurement, emphasizes the necessity of securing small-scale

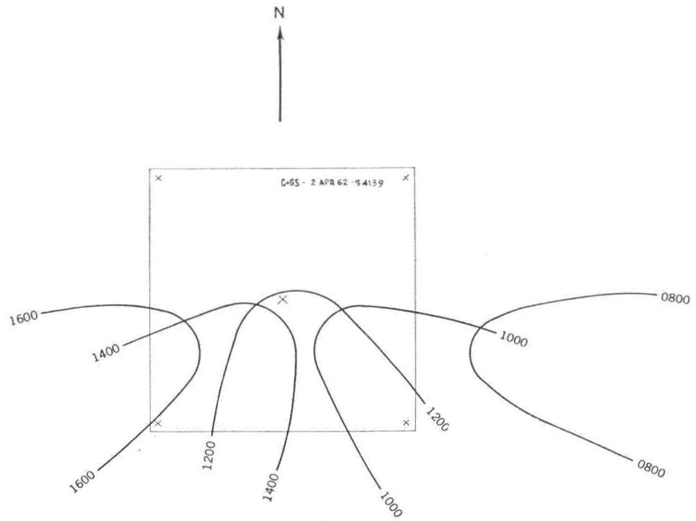

FIG. 3. Sunspot study for Charleston Harbor, S. C., April 1962, showing the trace of the reflected image of the sun on the water surface during the day of photography.

photography, Where the body of water is too wide to be spanned, large floats must be anchored at strategic locations prior to the photography.

CAMERA AND FILM EMULSION

High resolution, low distortion, wide-angle cameras are required for the photography. A super-wide-angle camera, such as the Wild RC-9 (3.5 inch focal-length) has the advantage of being able to secure a desired photographic scale from a much lower altitude than is possible with a 6 inch focal-length aerial camera.

The Coast and Geodetic Survey employs panchromatic, infrared, and color emulsions in its photography missions. Though each has certain advantages, panchromatic emulsion used with a minus-blue filter is often the best choice for current surveys. Infrared emulsion yields a reduced sunspot size while providing for excellent definition of artificial surface targets, but the resulting dark to black tone of the water hinders the recording of minor surface markings. Color emulsion permits the use of a color coding system to denote different types of targets. Its ability to penetrate water enables the recording of some of the harbor bottom details. This same ability, however, makes it difficult to distinguish surface details caused by minor discolorations. Furthermore, color photography has the disadvantage of a larger sunspot size. Simultaneous photography with several emulsions is, of course, highly desirable whenever possible.

TARGET DESIGN AND SEEDING

Drift-type current measuring target devices can be classified as surface, trans-surface, and sub-surface floats.[7] The surface class consists of those which remain essentially at the surface, such as an oil slick, plywood, dye, foam, or confetti. The trans-surface group comprises devices that measure the current in the upper layers of the water such as current poles. The sub-surface class includes submerged floats such as drogues attached to a surface target. The seeding of the targets in the survey area by small boats and/or helicopter must be performed so as to provide for their uniform distribution.

WEATHER

The possible presence of clouds and high winds must be considered, as time limitations may not permit waiting for perfect weather. In the event of a cloud ceiling at altitudes that preclude the use of a 6 inch focal-length camera, the availability of a shorter focal-length camera, such as the Wild RC-9, may provide a solution.

Difficulties arise in photogrammetric surface current surveys whenever strong winds prevail over the survey site. The winds may produce a mass surface movement of the water that is somewhat similar to normal current flow. Wind effect can be detected through a careful stereoscopic examination of the photographs as the wind induced movement extends right up to the shore where currents do not usually exist. A study is under way of means to correct photogrammetric measurements in the presence of wind action. A promising method is the use of current meters shielded from direct wind forces by being suspended at various depths.

Current Survey Projects Completed and in Progress

CHARLESTON HARBOR, S. C.

Field operations for the photogrammetric surface current survey of Charleston Harbor were completed in April, 1962. 1:20,000 scale panchromatic photography, with a 60% endlap, was secured at hourly intervals using a 6 inch focal-length Wild RC-8 camera and a 3.5 inch focal-length Wild RC-9 camera. Photography of the complete current cycle required two days. Approximately 500 painted plywood targets, weighing 3,000 pounds and occupying 80 cubic feet, were seeded in the harbor by skiff and helicopter at half mile intervals. Reseeding was performed by helicopter during the photography to maintain the target density. This did not prove entirely satisfactory as the helicopter could not locate the previously seeded targets too well while flying at the low altitude needed for proper seeding. Coordination of activities was accomplished by the use of "walkie-talkie" radio units.

Some 20 models from different crucial periods of the current cycle were chosen for immediate measurement on the Zeiss C-8 Stereoplanigraph and the Wild B-8 Aviograph, with the remainder to follow. Several current charts were constructed, two of which are shown here. See Figures 4 and 5.

Figure 4 depicts the surface circulatory pattern at one hour before maximum ebb current at the Charleston Harbor reference station on April 2, 1962. It is an example of the very complete type of current survey that can be made by photogrammetric methods. In some models the number of observations approaches a density of 125 current measurements per square mile. These observations result from measurements made on plywood targets, distinctive configurations of natural foam, and current velocities interpolated by a stereoscopic study of the photographs.

The presence of so many foam configurations suitable for use as targets would appear to indicate that numerous artificial targets are not essential for a photogrammetric survey. However, the availability of foam will be unknown unless a preliminary photographic survey is made of the area. Also, the number of such targets tends to be proportional to the magnitude of the current speed. As we are equally interested in measuring small current velocities, we cannot depend only on the presence of natural foam targets.

Figure 5 illustrates the surface current flow just prior to maximum flood current at the reference station. The chart is interesting because of the complex current patterns revealed by the large eddy formations around Ft. Sumter and around the bend of Hog Island. Obviously, a very large number of meter stations would be required to duplicate all of the information derived photogrammetrically.

The conventional tidal current survey of the harbor required the occupation of nearly 50 meter stations and extended from January to June of 1962. Most of the stations consisted of three Roberts Radio Current Meters suspended at various depths from a buoy.

The photogrammetric surface current velocities were compared with the approximation of the surface currents found by a linear extrapolation of current readings from the three meters at stations in operation during photography. In all cases, save two, wherever the photogrammetric and the extrapolated values were in close proximity to each other, the velocities agreed within 0.3 knots. The two instances of disagreement were caused by wind action, as discovered through a stereoscopic study of the photographs, and by an unsatisfactory linear extrapolation of the surface speed due to a marked lack of alignment of the plotted meter readings.

A comparison of photogrammetric surface current speeds with those derived by extrapolation of meter readings predicted for the time of photography from meters operating on other days, revealed a similar close correlation.

OCRACOKE INLET, N. C.

A photogrammetric surface current survey was undertaken in the fall of 1962 at Ocracoke Inlet on the Outer Banks of North Carolina. This was a cooperative survey made by the Coast and Geodetic Survey for the Corps of Engineers. The movement of 4'×8' plywood targets was recorded on 1:30,000 scale photography. The survey required the construction of several plywood platforms on the Pamlico Sound side of the inlet, and of the anchoring of launches on the ocean side to serve as stations for absolute orientation of the models. Twenty-three models were measured to produce a series of current charts for

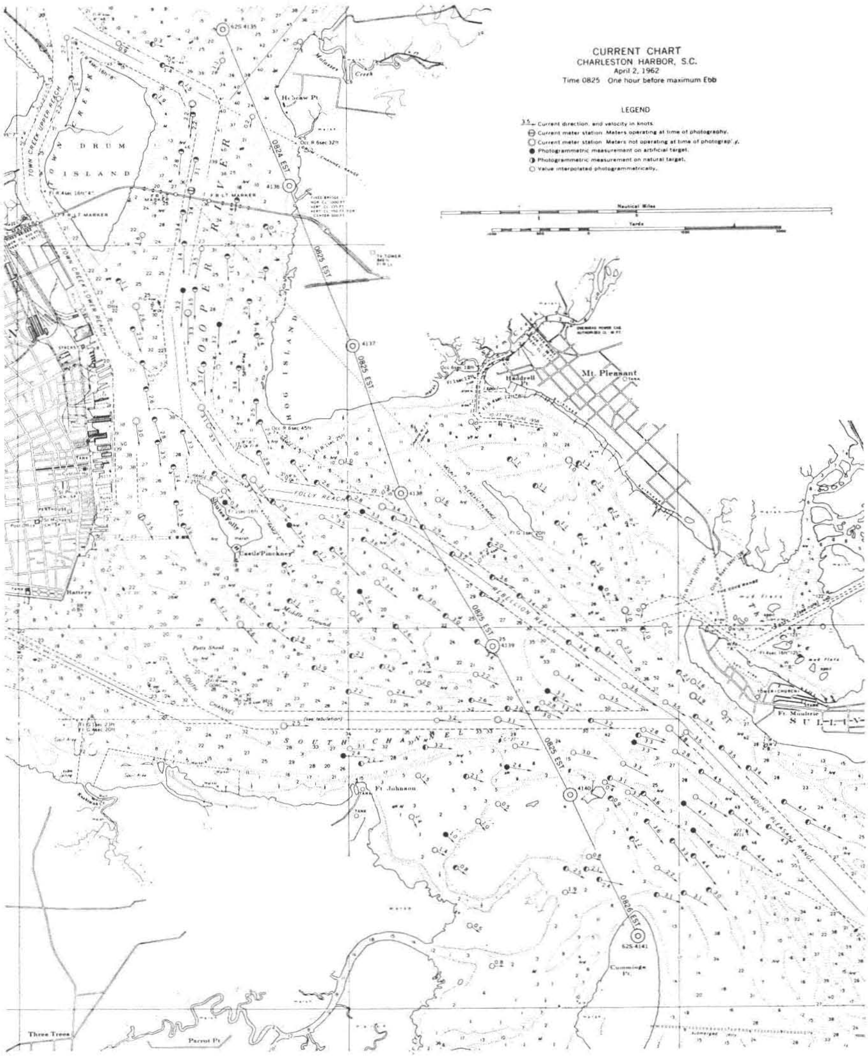

FIG. 4. Surface current chart for Charleston Harbor, S. C. at one hour before maximum ebb current at the reference station on April 2, 1962.

the area. Figure 6 depicts the surface current flow in the inlet at maximum flood current.

TAMPA BAY, FLORIDA

In April, 1963 photography was taken at 1:80,000 scale of Tampa Bay, Florida to cover 240 square miles of water. The large plywood targets required for the small photography scale were not used as they are relatively expensive and are difficult to handle in volume because of their weight and bulk. Based on the successful use of natural foam targets at Charleston Harbor, a mechanically produced firefoam was distributed on the water surface in short streaks by skiffs to provide the needed targets. See Figure 7. A small plane was employed as an observation post throughout the operation. The office measurement of the artificial foam target movement and data reduction will be commenced in the near future.

To extend the application of photogrammetry to the measurement of current velocities below the water surface, studies were initiated at Tampa Bay of various sub-surface current measuring target designs and of materials suitable for use in their construction. Investigation is proceeding to optimize the designs so that future photogrammetric surveys can incorporate these additional observations.

Conclusions

On the basis of results obtained to date, the application of photogrammetry to tidal current surveys is warranted in many instances, especially where detailed circulatory information is desired. Consideration of the manpower and equipment requirements, the time and cost of the operations, and the final product obtained, serves to point out the advantages of the photogrammetric approach.

The conclusions to be drawn from the results are:

1. Photogrammetric methods provide accurate measurements of large as well as small current velocities.
2. Photogrammetry provides synoptic

FIG. 5. Surface current chart for Charleston Harbor just prior to maximum flood current at the reference station on April 2, 1962.

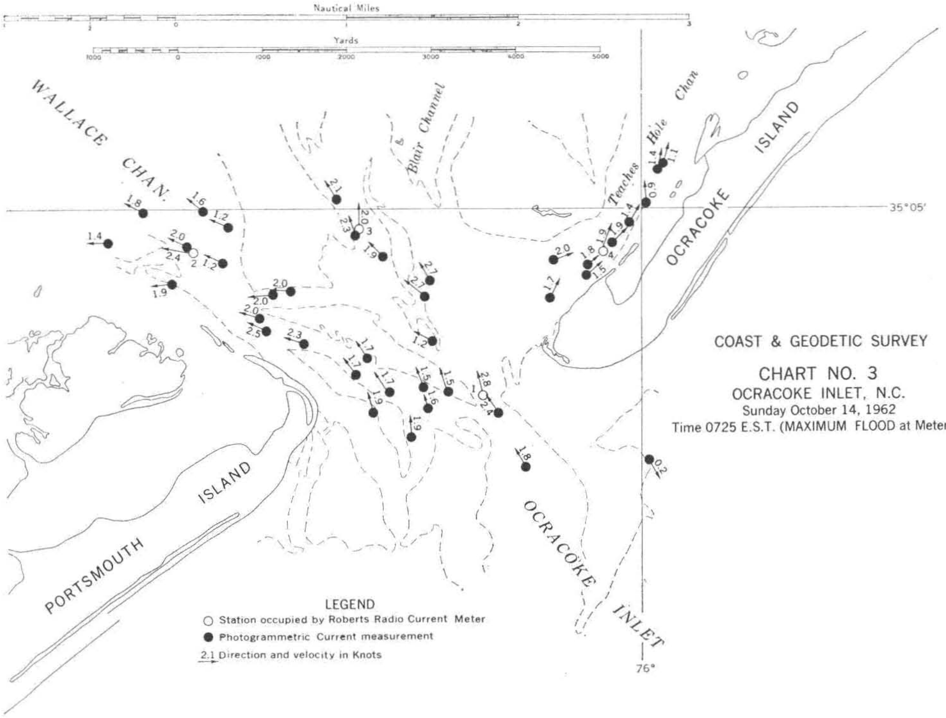

FIG. 6. Surface current chart for Ocracoke Inlet, N. C. at the time of maximum flood at meter station 1.

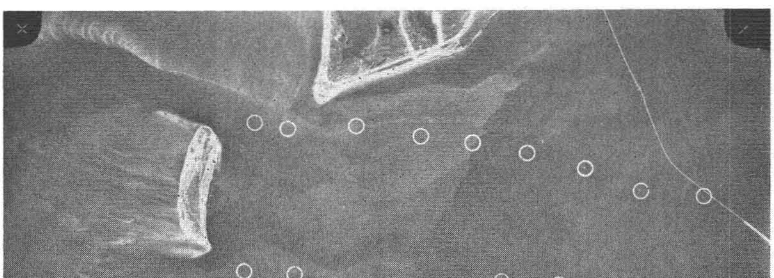

FIG. 7. 1:80,000 scale photograph of Tampa Bay, Florida showing a sample distribution of artificial foam targets.

measurements of a large area, thus obtaining more detailed information than is otherwise feasible.
3. Photogrammetric measurements must be made in conjunction with current meter readings for proper reduction of data. The long periods of meter observation allows the removal of eccentricity introduced into the instantaneous photogrammetric observations by meteorological disturbances.
4. Data are provided by the photogrammetric technique for future predictions when referenced to basic data obtained by conventional methods.

The Coast and Geodetic Survey plans to apply photogrammetry to current surveys as a production operation whenever more detailed information is needed than can be readily obtained by conventional methods. The extension of photogrammetry to this phase of oceanography illustrates again the increasing ability of photogrammetry to aid in the solution of many scientific and engineering problems. It is essential that members of the scientific community make the best possible use of this relatively new tool of photogrammetry and remain alert to the broader applications which can be made in the future.

A detailed technical bulletin is now in preparation and will be available shortly. A copy can be secured by writing to the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C.

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*Forest Road Survey Practice—Northern Region**

JOHN G. COLLINS,
U. S. Forest Service,
Missoula, Mont.

ABSTRACT: *The techniques which are discussed are those adopted by the Northern Region, U. S. Forest Service, in providing all types of road survey data, ranging from area reconnaissance through route reconnaissance and rights-of-way determination to the production of basic road design surveys. The equipment utilized is noted. These techniques and equipment are used in various combinations depending on the exact nature of the basic problem.*

THE preparation of map and photogrammetric engineering data of all kinds for the 16 National Forests which comprise the Northern Region, U. S. Forest Service, is the responsibility of the Surveys and Maps Branch, Division of Engineering. One of the major portions of this task is the preparation by photogrammetric methods of road reconnaissance, location, and design maps. In addition, rights-of-way maps, bridge site surveys, cadastral plats, recreation, and administrative site maps are prepared. The Northern Region, when things go according to the basic plan, uses a three-tiered attack to

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