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AN EVALUATION OF THE BO'SUN MULTI-BEAM SONAR SYSTEM

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ABSTRACT

This report describes the evaluation of the BO'SUN Multi-Beam Sonar System carried out by the Hydrographic Development Section, Atlantic Region. The BO'SUN System, a product of the Harris Division of General Instrument Corporation, forms 21 adjacent narrow beams to give a cross-track coverage of 2.6 times depth. Digitized slant-range measurements along with navigation data are recorded on magnetic tape in computer-compatible format. A software package is available to process, edit, and contour the data.

A survey of Bedford Basin was carried out with sufficient line spacing to ensure 100% bottom coverage. A contoured chart was computer generated from over two million depth measurements made by the BO'SUN System. Comparison of the BO'SUN contour chart with an existing chart produced by using conventional hydrographic techniques showed the contours in general agreement. Although some differences were noted, the larger number of soundings, greater coverage, and narrower beam widths of the BO'SUN System reflected greater contour detail than would be possible to obtain from the field sheet of the conventional survey.

1. — INTRODUCTION

One hundred per cent bottom coverage is required in harbours, channels and many shipping lanes to ensure that such areas are free from navigational hazards. Using conventional techniques this can only be attained by very close spacing of sounding lines. Such a practice is both expensive and time-consuming. For example, using a sounder with a total beam-width of 25 degrees in 30 metres of water requires a line-spacing of

13.3 metres for complete coverage. It is impossible, with standard equipment, to run parallel sounding lines at this spacing with any degree of consistency.

Two devices, the side-scan sonar and the multi-beam sonar system, hold great potential for hydrographic applications by offering increased bottom coverage. Interpretation of high resolution side-scan sonar records provides information as to bottom irregularities and the existence of navigational hazards which may have been missed by a conventional survey; however, accurate depth measurements are subject to the problems of interpretation and attitude of the towed array (fish).

The General Instrument Corporation BO'SUN Multi-Beam Sonar System uses 21 adjacent narrow beams which make simultaneous slant-range measurements from the ship's transducer to the ocean bottom. These measurements sonify a strip of bottom perpendicular to the ship's track. The slant-range data is digitized and recorded along with navigation data on magnetic tape for computer processing. This technique offers greater coverage than conventional sounding systems and eliminates the interpretation problem encountered with side-scan sonar.

2. — EVALUATION

A BO'SUN system was evaluated during a three-week period by the Development Section of the Canadian Hydrographic Service, Atlantic Region. The primary objectives were threefold:

(1) to determine the over-all usefulness of the BO'SUN system as a hydrographic tool;

(2) to conduct a survey of a known area in order to gain first-hand experience in the operation of the system, and to gather data to test the contouring package;

(3) to conduct tests on the accuracy and repeatability of the measurements.

3. — SYSTEM DESCRIPTION

The components of the system evaluated were:

(1) transducer; (2) catamaran; (3) console; (4) data logger; (5) digital compass; (6) magnetic tape transport; (7) pitch and roll sensors.

A cross fan-beam technique, patented by General Instrument Corporation, is used in the BO'SUN system (fig. 1). Two identical projector-hydrophone arrays, one port and one starboard, make up the 36 kHz transducer. Each projector produces a 5 × 90 degree fan-beam with the broad axis of the beam perpendicular to the ship's head. The hydrophones receive the returned signals which are delayed and summed to form 11

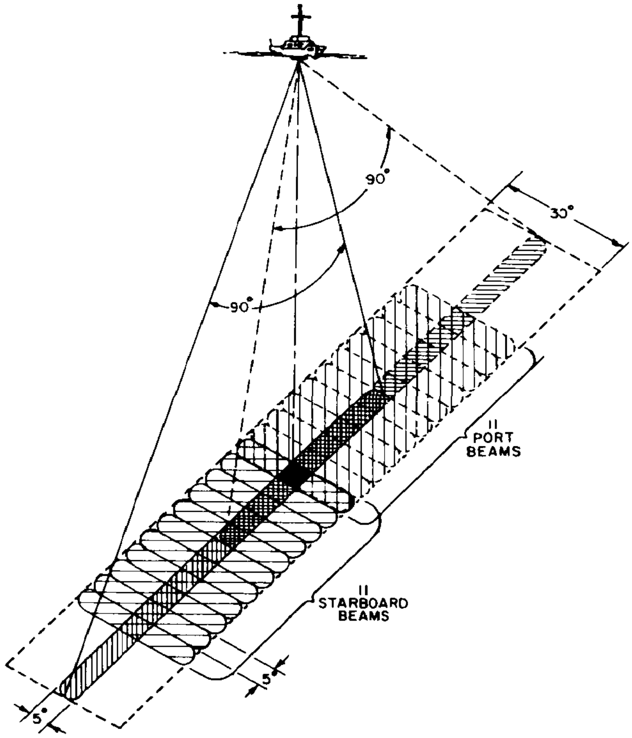

FIG. 1. — Beam formation.

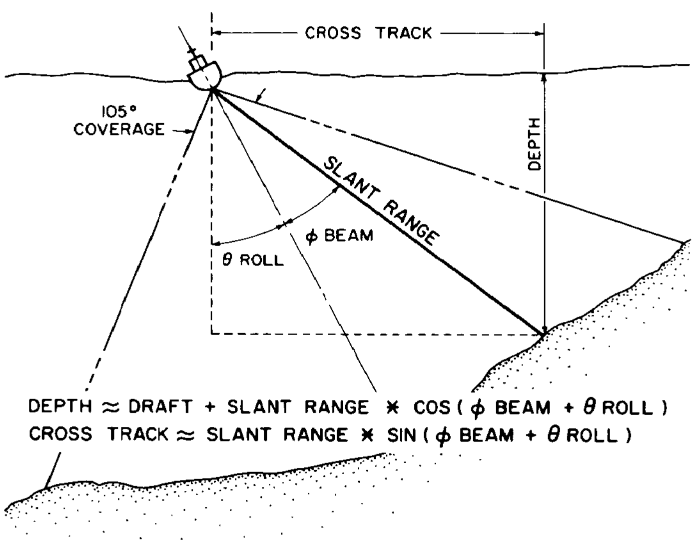

FIG. 2. — Simplified diagram of beam geometry.

adjacent 5×30 degree listening cones whose major axes lie perpendicular to that of the projector fan-beams. The receiving fan-beams intersect the projected fan-beams in 11 adjacent 5-degree squares along the insonified bottom area. On a flat bottom, in 30 metres of water, a 5-degree square is equivalent to a coverage of 2.6×2.6 metres for the vertical beam and

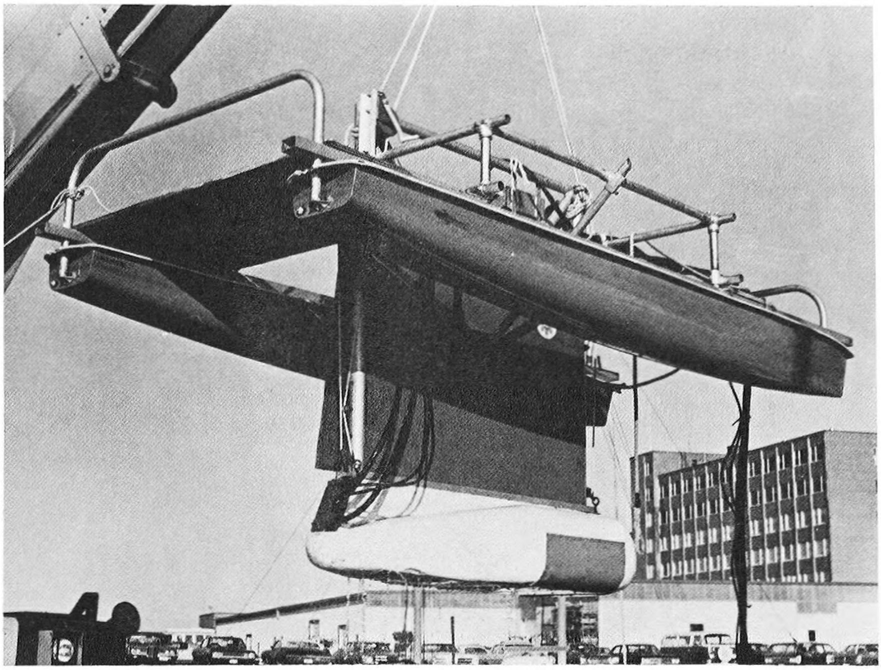

FIG. 3. — Catamaran and transducer.

2.6 × 5.3 metres for the outermost beam. The system time-shares the port and starboard arrays, alternately making 11 simultaneous slant-range measurements. A one-beam overlap of the two arrays produces a 21-beam system giving a cross-track coverage of approximately 2.6 times depth along a 5 × 105 degree strip perpendicular to the ship's track.

Pitch and roll information is required to make accurate slant-range measurements (fig. 2). Pitch errors may be minimized by a null-pitch keying mode in which the projector transmits only when the pitch is within an adjustable (± 2° to ± 5°) 'window' with respect to vertical.[1] The roll is digitized within a range of ± 20 degrees and with a specified accuracy of ± 1 degree. The pitch and roll sensors, along with the transducer, were installed on a 4-metre catamaran, as shown in figure 3, to eliminate the requirement for hull mounting. Figure 4 illustrates the towing arrangement used on the CSS *Maxwell* during the trials.

The controls for the operation of the sonar portion of the system are contained on the console as shown in figure 5. Functions such as keying (null-pitch, external or internal), gain (manual or time-varied), projector attenuation and range are selectable by the operator. A list of the system specifications is given in table 1. A video display of the 21 beams is roll-compensated and provides a monitor for the analogue output of the system. An illustration of a bottom profile on the video display as seen by the sonar system is shown in figure 6. Information from the most vertical beam, selected by the roll-compensating circuit, is available for a bathymetric recorder. The major circuits contained in the console are as

FIG. 4. — Towing arrangement.

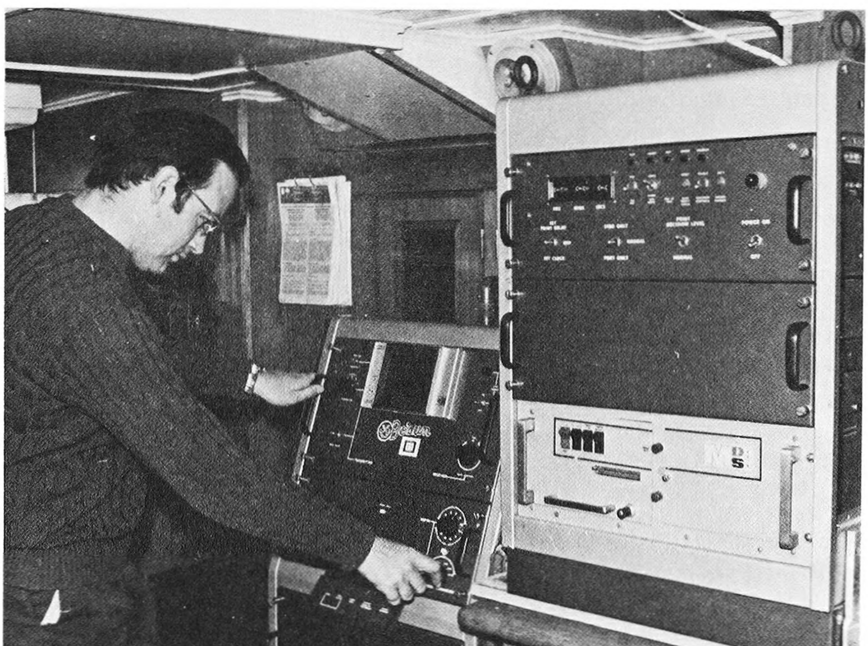

FIG. 5. — Operator's console.

TABLE 1

Systems Specifications

Depth (ft	3 to 800 ft
Range Scales (ft)	25, 50, 100, 400 and 800
Depth Range Scale Expansion	4 X
Cross Track Coverage	2.6 times depth
Pitch Null Keying	± 2° to ± 5° (adjustable)
Display Stabilization (roll)	± 20°
Beam Width (selectable)	5° x 5°, or 5° x 20°
Frequency	36 kHz
Pulse Lengths (ms)	0.5, 1, 2 and 5
Number of Beams	21
Stabilized Vertical Beams	1
Display	5-inch Cathode Ray Tube
Console Weight (lb)	300
Console Dimensions (inch)	52 x 23.5 x 26.5
Weight of Transducer (lb)	500
Size of Transducer (inch) (without fairing)	12 x 26 x 50

follows: transmitter, receiver, beam-forming matrix, roll compensator, side-lobe suppressor, and slant-range digitizers. A simple block diagram of the signal processing that takes place in this unit is shown in figure 7.

The data logger generates time of day and identification or 'mission' codes, and accepts navigation data, compass heading, roll, and slant ranges for formatting and recording on magnetic tape. Also a one-character decision level is recorded for each of the 21 beams. This is a measure of the signal strength of the return echo. Rates of recording vary with the ping rate of the sonar system with a range of 1 to 10 pings per second, depending on the depth. A ping is defined as 11 simultaneous slant-range measurements and the corresponding time, position, roll and heading data. A paper-tape printer is used to monitor the digitized slant-range measurements at rates selected by the operator. Figure 8 illustrates the format. Data are recorded using a standard Peripheral Equipment Corporation Model 2800 9-track tape transport.

During the trials a Datamarine digital compass was mounted on the CSS *Maxwell* to provide heading, and navigation data was obtained from a Motorola Range Positioning System. After the survey was completed a new and more flexible data logger was developed. New features incorporated in this logger have increased its monitoring capability and the ease with which it can be operated. The unit was designed with modular options

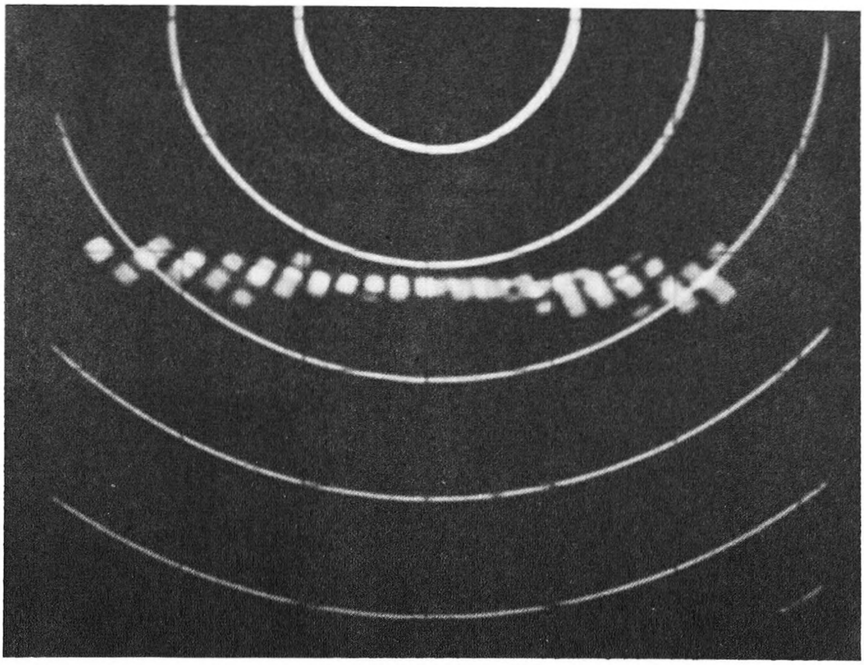

FIG. 6. — Video display of beams.

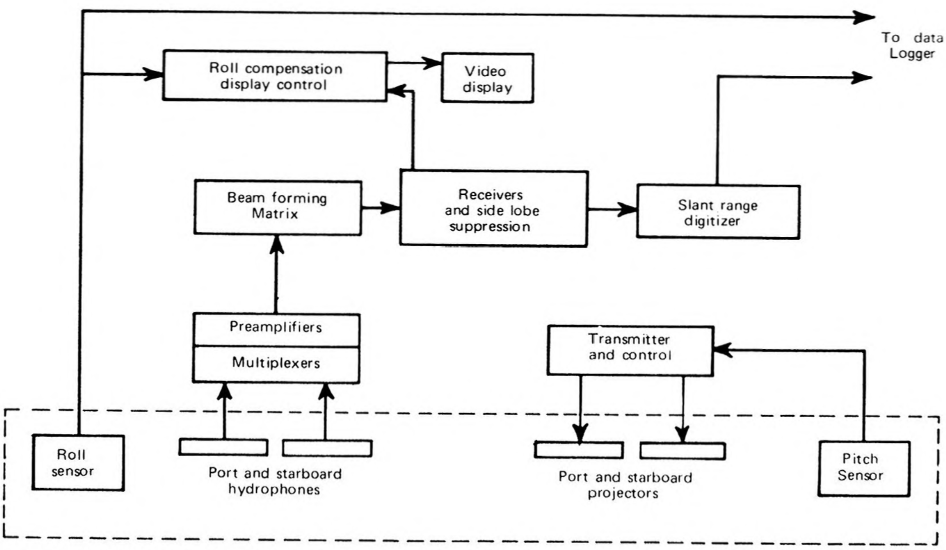

FIG. 7. — Simplified block diagram of BOS'UN multibeam signal processing.

for a paper tape printer interface, magnetic tape interface, and navigation interface. The paper tape printer permits all recorded data to be monitored. A five-digit LED display can be controlled to monitor a string of data being recorded by the magnetic tape unit.

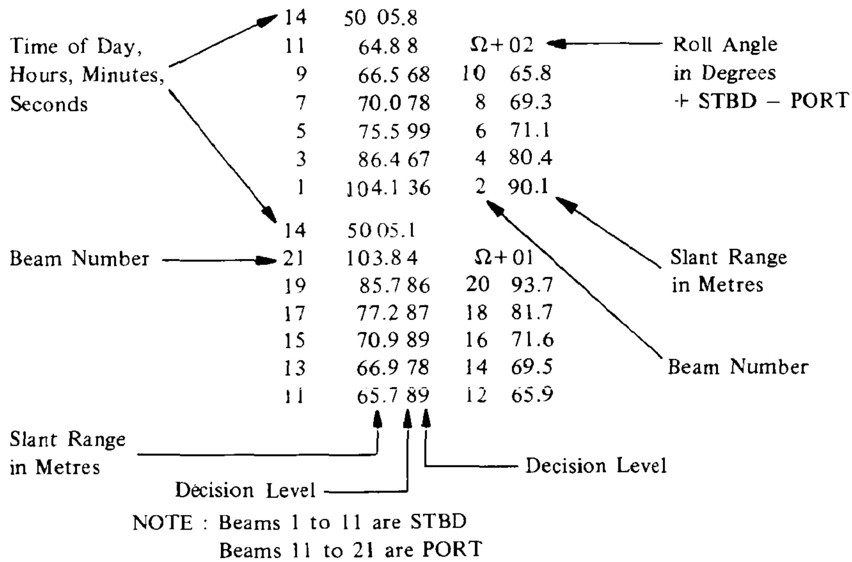

FIG. 8. — Paper tape format.

4. — SOFTWARE DESCRIPTION

A contract was let to General Instrument Corporation to contour the Bedford Basin survey data which were collected at the time of the evaluation. The general processing procedures and options are described below.

The raw data on 9-track magnetic tape contains an identification number, the slant-range measurements, roll data, time, position information, ship's heading, and signal strength information. Records contain 64 pings of information and an identification label (2565 characters). A reduction program, SODR, reduces this data, producing a data tape containing time, the corrected ship's position in rectangular coordinates, and the corrected cross-track position and depth for each beam. The depth data are corrected for roll, tide, draught, and propagation velocity. Options exist to set bad data to zero depending on the signal strength information which characterizes each beam. If desired, a slope-checking program, BOSEDIT, can be used to edit the corrected data. This involves setting a maximum change permitted between a candidate depth and its surrounding values, within a ping and between adjacent pings. Candidate points failing this test are set to zero.

Since more than one data tape may exist, and since long lines are run by the ship, the data is scanned and sorted into large blocks or sites. This program, SITEGEN, decreases the searching time for GRDGEN. Before the data is contoured, depths are obtained for a matrix of grid points. In GRDGEN, a series of 5-inch square blocks are set up using a 51 × 51 grid matrix containing 2601 points. The 0.1-inch grid spacing that is used represents 60 feet at a scale of 1/7200. The depth for each grid point is the average of all the soundings in a 0.1 inch square box centered on that grid point. The density of averaged depths ranged from zero to over 200 per grid point, with an over-all average of 35. A margin is added to the perimeter of the 5-inch squares to make certain that grid values on the boundaries agree with those of adjacent squares. After grid points are generated, options exist to perform further slope checks on the grid data and to manually insert points or set them to zero. The final program, CHART, linearly interpolates through all voids in the grid data before contouring. The contours contain no annotations but have tick marks which point up the slope. Data may be listed any time during processing. Sounding density and rejected data points may also be listed. Options exist to smooth navigation data (NAVPROC) and plot a ship's track chart (SHIPTRK).

The present software package is operational on a CDC 6600 computer system and has a minimum requirement of a disc, two magnetic tape drives, and 32K of core. Figure 9 is a reduced copy of the contour chart

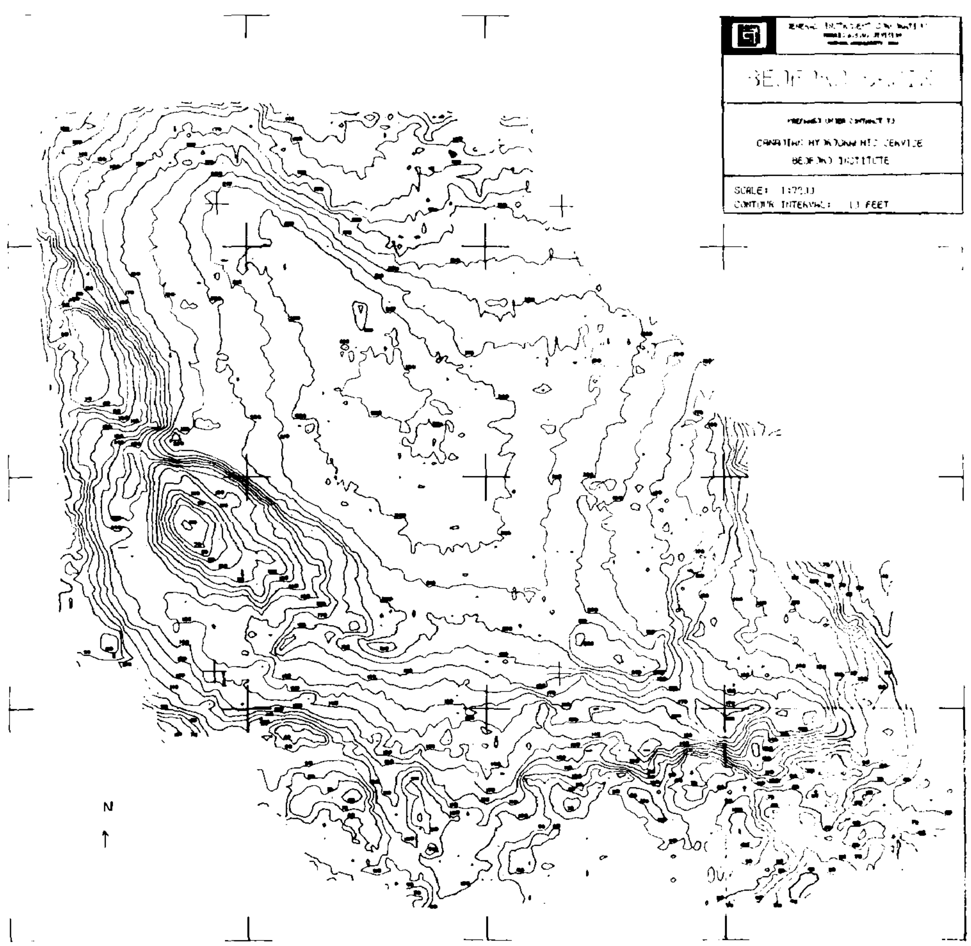

FIG. 9. — Bedford Basin chart produced from Bo'SUN survey data. Blocked area selected for comparison.

of the Bedford Basin produced by General Instrument Corporation. It was plotted off-line on a 30-inch Calcomp drum plotter. To produce the contour chart required about two hours central processor time, eight hours peripheral processor time, and five hours plotting time. These times include all phases of checking, reducing, editing and chart production. A computer time breakdown is given in table 2. If all data were recorded without error and were reliable, the computer times would be about 1.4 hours for the central processor, 2.6 hours for the peripheral processor, and 4.9 hours for plotting.

TABLE 2

Computer Time Breakdown

	Central Processor Times (s)	Peripheral Processor Times (s)	Plotting Time (min)
DUMPR	877.619	3 497.646	–
SODR	1 346.716	1 375.631	34.9
BOSEDIT	1 966.438	871.397	–
NAVPROC	253.104	967.608	–
SHIPTRK	462.433	1 849.918	276.3
REDLETE	46.339	966.682	–
SITEGEN	380.306	2 477.902	–
GRDGEN	487.788	3 458.853	–
CHART	996.307	1 377.264	291.6
OVERHEAD	713.779	13 292.721	–
TOTAL	7 332.829 (122 min)	30 135.622 (502 min)	602.8 min

A major requirement in hydrography is the precise depth determination and delineation of shoals, deeps and navigation hazards. At present, peaks and deeps are not marked on the chart, but they can be manually obtained from the grid point listings. It should be noted that the peak values listed are the average depth over a 60-foot square. Although the sonar system has the capability of measuring the peak values, the software often averages out the peak and therefore does not take advantage of the system's resolution.

5. — REPEATABILITY AND ACCURACY TESTS

Various trials were conducted to evaluate the measurement properties of the 21 individual beams. They consisted of target tests, repeatability tests, and roll tests. The slant-range data were analysed to measure the accuracies of the system. To check the accuracy of the roll data, port and starboard roll-biases of up to 10 degrees were forced on the catamaran while measurements were made over a relatively flat bottom. The catamaran was also rocked at different rates. The slant-range measurements at 70-metre depth were compared. An attempt was made to minimize drift and changes in heading by conducting the tests during favourable weather conditions. Table 3 illustrates the standard deviations of a particular test. These are representative of the results calculated from other such measurements taken in different depths of water.

TABLE 3

Summary of Beam Test

Water Depth 70 metres Drift 1 metre Measurement Interval 10 s
Heading Change 1° Roll ± 2° Measurements 20 per beam
Rejected Measurements
2 on Beam # 21

Location	Centre			Outermost Port		
Beam Number	11	13	15	17	19	21
Standard Deviation*	0.19	0.36**	0.35	0.55	0.78	0.91 edited 2.50 unedited

* All values in metres
** High due to incorrect signal processing and digitization

The slant-range data were reduced to depth and offset so that a least squares fit of a second-order equation could be applied. Standard deviations with respect to the second-order equation were calculated for each beam. Two general trends emerged; one being the gradual degradation of the accuracy towards the outermost port and starboard beams, and the second, a tendency towards occasional, erratic, slant-range measurements on the outermost portion of the array.

During the analysis of the data, it was observed that the roll data applied to the slant-range measurements caused a misrepresentation of the bottom. The problem was traced to the inability of the roll sensors to handle sudden surges in the catamaran's motion during the survey. Gross errors were caused by the lateral and roll acceleration of the catamaran as it was towed through waves of less than 1 metre. The roll data were analysed and filtered on the computer in an attempt to smooth out erratic data.

Targets, consisting of three 16-inch air-filled glass spheres, were suspended at various depths and positions relative to the catamaran. In most cases, it was easy to spot the target on the video display and analogue recorder; however, under normal operating conditions the bottom slant-range distance was the value most frequently digitized. It was difficult to obtain consistent digitized measurements of target distances by manipulating the gain controls. The situation can be explained by the fact that the slant-range digitizers, in effect, look for the peak signal strength of the reflected energy and that the bottom return was stronger than that of the target.

Ray bending, due to changes in sound velocity and thermal layering did not present a problem during the evaluation. If the sound velocity profiles are known it is relatively simple to make approximate corrections.

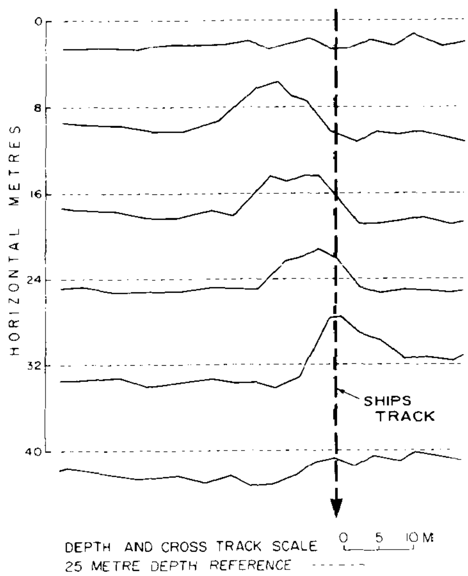

FIG. 10. — Depth profiles of submerged wreck obtained from BO'SUN data.

A submerged wreck, located at a depth of 25 metres in the approaches to Halifax Harbour, was used to investigate the search capability and resolution of the system. The wreck was picked up by both the video display and the analogue recorder. Some of the cross-sectional profiles calculated from the digitized data on magnetic tape are shown in figure 10. Estimates on the size and orientation of the wreck made from this data were in agreement with information gathered by divers and from a previous survey carried out using a 200 kHz sounder.

6. — CONTOUR CHART COMPARISONS

Figure 11 is a manually contoured chart of sounding data collected in 1960 and 1972 by different hydrographic surveys. Before comparing this manually contoured chart with the BO'SUN contoured chart a few words of caution are in order. The hydrographic sounding lines were run with a 25-degree beam sounder at a line spacing of 300 feet using sextants for positioning. Selected representative soundings were manually plotted on a field sheet and were contoured at 10-foot intervals. The contour lines were drawn so as not to go through the numbers representing soundings, causing distortion of the true bottom. This tended to smooth contour lines, especially in the east-west direction of the sounding lines.

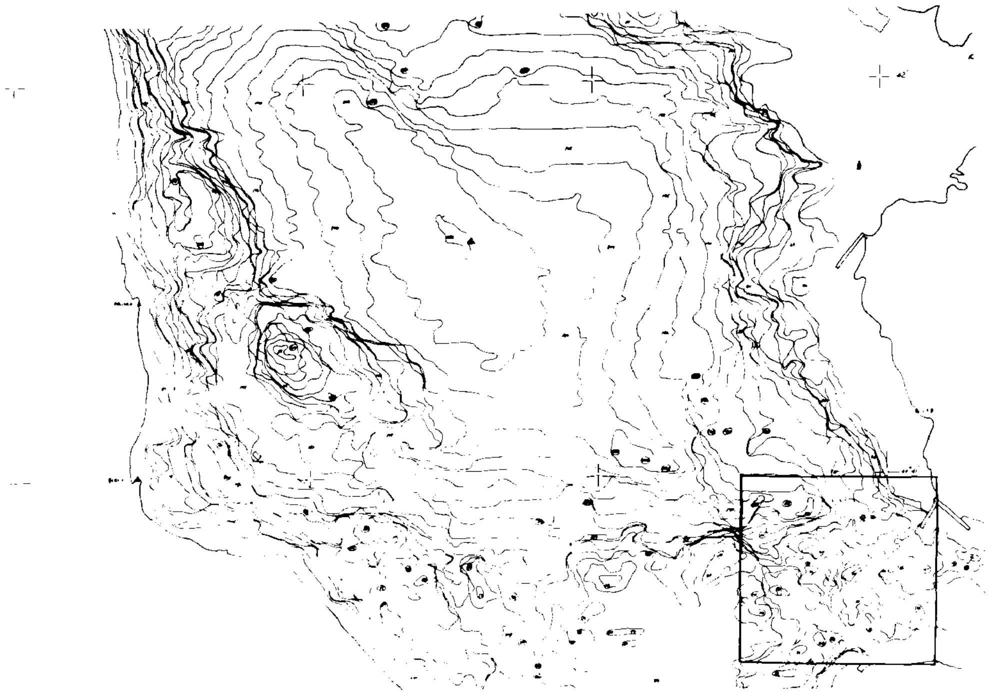

FIG. 11. — Bedford Basin contour chart produced from Field Sheet 2878 H-8 and revisory survey carried out in 1972. Blocked area selected for comparison.

A comparison of the BO'SUN chart and the manually contoured chart reveals that all the major features of the relief occur in both and that they correspond well in general shape and location. The higher density of points which were contoured in the BO'SUN chart resulted in much more detailed contoured lines and also many extra, small (but unlabelled) contour lines. From over two million depth measurements made by the BO'SUN system, approximately 26 000 interpolated values were used for the computer generation of the contoured chart. In contrast, 4500 soundings, selected from an estimated 300 000 acoustical measurements made during the conventional survey, were used to generate the manually contoured chart.

Over 40 sample depths of shoals and deeps from both charts were compared. The 0.1-inch grid values are printed by the computer for the BO'SUN chart enabling this comparison. The large number of depths (26 000) made it impractical to do a detailed comparison for all of the field sheet. The majority of the shoals and deeps selected were obtained from the contoured blocks in figures 12 and 13. This area was conventionally surveyed in 1972 with dense line spacing to check for shoals. On the average the BO'SUN shoals were three feet deeper than the shoals measured during the hydrographic survey. The deeps selected from the BO'SUN chart were, on the average, two feet deeper than the hydrographic chart indicated. The majority of the shoals compared were about 50 feet deep.

Part of the three-foot depth difference between shoals can be attributed to the strict editing and the averaging of the shallowest depth with its surrounding values. Depth differences between deeps may be the result of

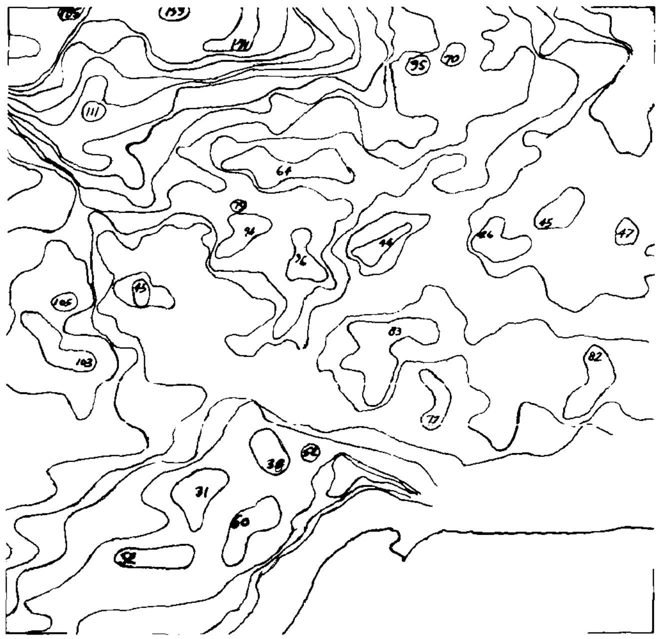

FIG. 12. — Enlargement of comparison site (from conventional chart).

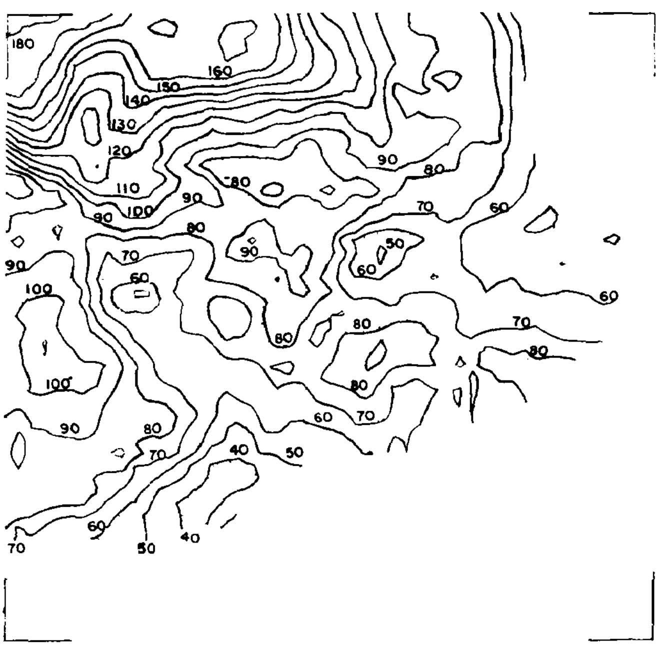

FIG. 13. — Enlargement of comparison site (from BOS'UN chart).

several factors. The BO'SUN system, with narrower beams and greater coverage, is more likely to pick out isolated deeps than a conventional wide-beam sounder. Null-pitch keying was not used due to the limited repetition rates of the graphic recorder. Since the depth measurements were not all made when the catamaran's pitch was at a minimum, there was a tendency towards longer slant-range measurements.

Slightly different sound velocities (about 1%) were used between the two charts causing the BO'SUN soundings to be about two feet deeper in 200 feet of water. This is especially noticeable when comparing the 230-foot contours in the flat center area of the basin.

Correlation of the grid values with the corresponding points on the conventional field sheet revealed a few isolated depths that were in conspicuous disagreement; however, the bulk conformed with the conventional survey. The major discrepancies appear as small dots (closed contours) on the chart shown in figure 11. It is impossible to sort out these differences. Some may be attributed to a combination of erratic outer beam measurements, positioning problems, and roll sensing problems encountered during the survey. On the other hand, many of these small closed contours reflect the additional detail obtained with the BO'SUN system because of the increased coverage and narrower beam widths. Subsequent checks of a few unrealistic grid depth values, using conventional side-scan sonar, did not reveal any such pinnacles.

7. — CONCLUSIONS

Conclusions based on the experience gained during the trials, the results of the tests, the processing algorithms, and chart comparisons are as follows:

(1) The catamaran, limited to a speed of five knots and operation in waves of one metre or less, proved very unsatisfactory as a platform for the transducer, but it was required to eliminate the necessity for hull-mounting. The quality of the data and system performance would have increased considerably if the transducer had been hull-mounted. However, an externally-mounted transducer would be susceptible to ice damage, and the size of the unit (see table 1) may present difficulties for flush mounting on a small vessel.

(2) Operation of the system is straightforward. The video display and printer output are very useful for the monitoring of data.

(3) Close inspection of the slant-range data and the test data at first revealed, and later it was confirmed, that the electronic signal processing on a few of the beams was marginal or incorrect. Also, the system was not correctly calibrated, resulting in a bias on the roll data. (The roll bias was compensated for in the data processing). A thorough calibration and check-out would eliminate these problems.

(4) To conform to hydrographic requirement, considerable changes would be required regarding software. At present, a large shore-based computer is required for processing the BO'SUN data. If the system is used in remote areas a shipboard computer is essential

for on-site checking and partial processing. Software is available to produce a ship's track plot and a contoured bathymetric chart; however, actual shoals or selected soundings cannot be plotted on the contoured chart using existing programs. This is a definite shortcoming in hydrographic applications. Also, with the existing software package, equal weights are given to depths derived from the most vertical beam and the outermost beams. Based on the results obtained from the standard deviation tests, it may be best to give weighting factors whereby the most vertical beams are favoured (see table 2).

Figure 10 illustrates the resolution that can be obtained with the system; however, the current processing program would average out most of this detail. With hydrographic application in mind, the resolution and the shallow and deep depths are prime considerations, hence the software should be modified to take advantage of the system's capability. Although the slope-check feature which can be applied at various processing points is variable, it was too strict, causing good data in rough terrain to be set to zero.

(5) The results of the various tests (see table 2 and figure 9) suggest that the BO'SUN sonar system is capable of providing the accuracy, with increased coverage, required for regular hydrographic work. Also the contoured chart output displays much more detail, because of the increased number of soundings, when compared to a contoured chart of a conventional hydrographic survey.

(6) The capabilities, accuracies, and limitations of system operation in deep water were not thoroughly investigated as the maximum depth encountered during the survey was 72 metres.

(7) The significance of the 'decision level' or signal strength description for each beam should be investigated. Producing a definite relationship between it and sounding reliability would ease the editing of data and increase confidence that the processed data are valid.

(8) The BO'SUN Multi-Beam system shows potential for sounding in ice-covered areas. An 11-beam transducer could be lowered through a hole in the ice and rotated. The angle of rotation could be recorded on magnetic tape. Such an approach is both economically and operationally advantageous when compared with using an unmanned submersible.

(9) Maintenance is one consideration that must be kept in mind, as the BO'SUN system is relatively large and complex. High level sparing and a trained technician would be advisable when working in remote areas. Once the initial 'bugs' were worked out of the system there was no down time during the three-week evaluation.

(10) It would probably be more advantageous for a system like BO'SUN to be leased, with operational personnel, rather than purchased out-right. This would eliminate a large capital outlay and the need to train a staff of operators and technicians.

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Before the BO'SUN system could be used by the Canadian Hydrographic Service, a few hardware modifications and considerable software changes would be required; however, it is the feeling of the authors that this type of system offers great potential for the future.

The BO'SUN system is a prime candidate for route surveys of shipping corridors and navigable channels. With the supertanker has come the sudden requirement to survey vast expanses of water to greater depths and accuracies than ever before. Multi-beam systems hold great promise in meeting this requirement.

THINGS DON'T CHANGE!

Instructions on how to manage a telescope as supplied with the instrument made by James SHORT in 1763.

"After opening the Box, you carefully observe how every Part of the Instrument lies, so as to be able to pack it up again, if required".