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The Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation (DOLPHIN), developed for the Canadian Hydrographic Service (CHS), was field tested in the United States by the Naval Research Laboratory, Stennis. Tests were conducted in conjunction with the National Oceanic and Atmospheric Administration (NOAA) - National Ocean Service and the CHS. Patch tests were conducted to evaluate roll, pitch, heave, and navigation errors, and survey lines were run over the Norfolk Canyon to evaluate bathymetry. Multibeam data were collected simultaneously by the NOAA ship WHITING and later by the US Navy ship LITTLEHALES. The DOLPHIN and LITTLEHALES are both equipped with the Simrad EM-100 (95 kHz) and the WHITING is equipped with the Seabeam HYDROCHART II (36 kHz). All three systems used differential GPS for positioning. The data sets were processed and evaluated and results of the evaluation of the DOLPHIN system are given for attitude, navigation, rms errors, bathymetry and handling. Recommendations are given for improving hydrographic data collection using the DOLPHIN.

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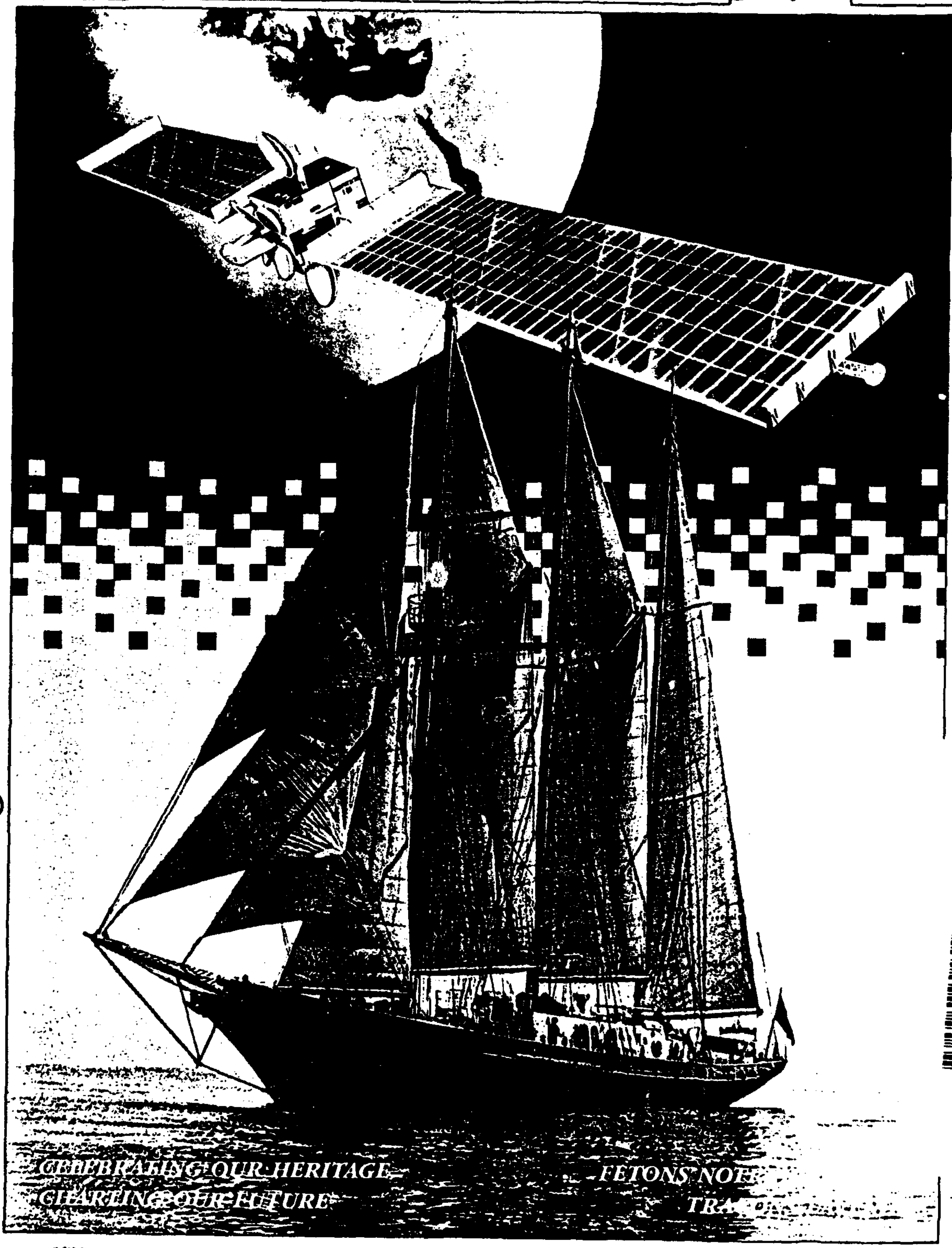

CANADIAN HYDROGRAPHIC SERVICE
CANADIAN INSTITUTE OF GEOMATICS

SERVICE HYDROGRAPHIQUE DU CANADA
ASSOCIATION CANADIENNE DES SCIENCES GEOMATIQUES

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Field Tests of the Dolphin/EM–100 Over Norfolk Canyon

Abstract

The Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation (DOLPHIN), developed for the Canadian Hydrographic Service (CHS), was field tested in the United States by the Naval Research Laboratory, Stennis. Tests were conducted in conjunction with the National Oceanic and Atmospheric Administration (NOAA) – National Ocean Service and the CHS. Patch tests were conducted to evaluate roll, pitch, heave, and navigation errors, and survey lines were run over the Norfolk Canyon to evaluate bathymetry. Multibeam data were collected simultaneously by the NOAA ship WHITING and later by the US Navy Ship LITTLEHALES. The DOLPHIN and LITTLEHALES are both equipped with the Simrad EM–100 (95 kHz) and the WHITING is equipped with the Seabeam HYDROCHART II (36 kHz). All three systems used differential GPS for positioning. The data sets were processed and evaluated and results of the evaluation of the DOLPHIN system are given for attitude, navigation, rms errors, bathymetry and handling. Recommendations are given for improving hydrographic data collection using the DOLPHIN.

Essais in-situ du Dolphin/EM-100 au-dessus du canyon Norfolk

Résumé

La plate-forme d'enregistrement de données en mer profonde avec instrumentation d'hydrographie et de navigation [Deep Ocean Logging Platform with Hydrographic Instrumentation and Navigation (DOLPHIN)], mise au point par le Service hydrographique du Canada (SHC), a fait l'objet d'essais sur le terrain, exécutés conjointement par la National Oceanic and Atmospheric Administration (NOAA) – le National Ocean Service et le SHC. Des "Patch Tests" (routine d'étalonnage) ont été effectués pour évaluer les erreurs de roulis, de tangage, de déplacement vertical et de navigation. Des lignes de sondage ont été faites au-dessus du canyon Norfolk pour évaluer la bathymétrie. Des données multifaisceaux ont été recueillies simultanément par le navire WHITING, de la NOAA, et plus tard par le navire de la marine américaine LITTLEHALES. Le DOLPHIN et le LITTLEHALES sont tous deux équipés d'un Simrad EM-100 (95 kHz) et le WHITING est équipé du Seabeam HYDROCHART II (36 kHz). Les trois systèmes utilisaient, pour le positionnement, le Système de positionnement global (SPG) en mode différentiel. Les données ont été traités et analysées, et les résultats de l'évaluation du système DOLPHIN sont fournis en termes d'attitude, de navigation, d'erreurs quadratiques moyennes, de bathymétrie et de manipulation. Des recommandations sont faites pour l'amélioration de la collecte de données hydrographiques au moyen du DOLPHIN.

Field Tests of the Dolphin/EM-100 Over Norfolk Canyon

Maria T. Kalcic and Edit Kaminsky

Introduction

The Navy's increased requirements for data in the littoral environment have focused on the need for more efficient hydrographic data collection platforms. In addition, the downsizing of the Naval hydrographic survey fleet has necessitated a higher return on survey miles per survey ship.

The Oceanographer of the Navy, through the Tactical Oceanographic Warfare Support (TOWS) office, invested in the test and evaluation of ROV technology for shallow water surveying to address some of these requirements.

In August of 1992, NRL conducted a test and evaluation of the Canadian DOLPHIN/EM-100 system, in conjunction with the U.S. Naval Oceanographic Office (NAVOCEANO), the National Oceanic and Atmospheric Administration (NOAA)'s National Ocean Service (NOS) and the Canadian Hydrographic Service (CHS) over the Norfolk Canyon off the east coast of Virginia. These tests and evaluations were conducted with the intent of observing DOLPHIN performance, logistics, operation, manpower requirements, and EM-100 performance and data integrity. Results of this evaluation are presented here, along with some discussion on the implications of incorporating such a system into U.S. Navy's hydrographic survey fleet.

Background

The DOLPHIN/EM-100 semi-submersible is equipped with the Simrad EM-100 95-kHz multibeam and differential Global Positioning System (DGPS). The DOLPHIN was developed by International Submarine Engineering Ltd. (ISE) under the Canadian Ocean Mapping System (COMS) R&D Project of the Department of Fisheries and Oceans (DFO). The DOLPHIN was developed as a data collection vehicle that could withstand rough seas while having little adverse effect on the collection of hydrographic data [1]. Geo-Resources, Inc. (GRI) of St. John's, Newfoundland, maintains and operates the DOLPHIN/EM-100 and two other DOLPHINs for the CHS. Brooke Ocean Technology (BOT) developed the motion-compensated launch and recovery system that has been successfully tested in a sea-state 4 [2].

Dolphin

The DOLPHIN vehicle, constructed mostly of aluminum alloy, weighs approximately 7,700 lbs (dry) and measures 7.44 m in length. The DOLPHIN is diesel powered, with a Sabre 212 hp turbocharged, diesel engine and can endure up to 26 h at 12 knots, or 312 nautical miles on 90 gal of diesel fuel.

The DOLPHIN's GPS and radio link antennas are attached to a snorkel at the top of the mast [3]. In a ship/ROV situation, differential range corrections are received by the ship, and radioed to the DOLPHIN via UHF to upgrade its position. The DOLPHIN performs real-time, automatic line-keeping using these data. In the event that GPS communications are lost, the DOLPHIN surfaces and stops.

DOLPHIN operation requires one person to pilot the vehicle and one person to monitor the EM-100 operator's console. The pilot can be positioned on the bridge with the belly pack or operator console. The DOLPHIN's position is displayed along with the ship's position at all times on the bridge display. The DOLPHIN is programmed to perform automatic linekeeping and so manual control is unnecessary except to make turns or bring the DOLPHIN into position.

The person 'driving' the vehicle usually keeps the vehicle within line of sight, although the vehicle's radar reflector keeps it within the ship's radar range and visible on the radar screen at all times. The DOLPHIN is equipped with running lights and a strobe light for visibility.

The EM-100 operator monitors the Quality Assurance (Q/A) display and data logging. The EM-100 Q/A system displays the raw bathymetry from each beam in the along track and across track orientation as well as a color contour plot of the data in real time. The Q/A operator is usually in contact with the DOLPHIN operator in case the data becomes erratic or drops out.

The DOLPHIN requires a 20-ton capacity crane for launch and retrieval and about five people to handle lines and crane equipment.

Multibeam Systems

The DOLPHIN and USNS LITTLEHALES are equipped with the Simrad EM-100, a 95 kHz multibeam sounding system. From the DOLPHIN, the EM-100 data is transmitted to the EM-100 operator console at 9600 baud over a UHF radio link. These data are displayed in real time on the console and EM-100 Q/A system.

The EM-100 operates in three different modes: narrow, wide and ultrawide, covering depths from 10 to 600 meters. The EM-100 operates with a maximum of 32 receiving beams and athwartship beam apertures of 3.75, 2.5 or 2.0 degrees. The alongship beam aperture is fixed at 3.0 degrees. The maximum coverage is 100 degrees, corresponding to 2.4 times the water depth. Simrad claims accuracies better than 0.5% of the water depth across the entire swath [4]. It can acquire up to about 3 megabytes of bathymetric data per hour, more in shallow water.

The NOAA ship WHITING has General Instrument Corporation's Hydrochart II, a dual transducer multibeam sonar system that operates at 36 kHz [5]. The system uses a cross-fan transducer array to form 17 beams, 9 for port and 9 for starboard, with overlapping near-nadir beams. The swath coverage of the Hydrochart II is 2.5 times the water depth or 105 degrees.

The EM-100 and HYDROCHART II systems used sound velocity profiles measured with the Seacat conductivity, temperature, and depth (CTD) profiler. Expendable bathythermograph (XBT) casts were conducted intermittently to check for significant sound velocity fluctuations. The same tide tables were also used for both systems, using the Hampton Roads Tide Station for actual tides.

Differential GPS

The DOLPHIN's DGPS communications were connected into the WHITING's Magnavox MX4200 DGPS receivers and MX50R differential receivers. The WHITING collected the same lines as the DOLPHIN, using the same U.S. Coast Guard Beacons, at Cape Henry, Virginia (primary station) and Cape Henlopen, Delaware (check station) for the DGPS. The horizontal datum used was NAD-83. A Horizontal Dilution of Precision (HDOP) limit of 4.6 m was computed for the survey area [8].

Test Survey of Norfolk Canyon

The joint NAVY/NOAA/CHS survey was conducted with the WHITING and DOLPHIN over the Norfolk Canyon, off the east U.S. coast, from August 3 to 7, 1992. The survey originated at NOAA's Atlantic Marine Center (AMC) in Norfolk and was based at the Little Creek Naval Amphibious Base (NAB). The USNS LITTLEHALES was sent to survey the area on August 23, 1993, due to earlier delays while undergoing final contract trials.

Survey operations were planned for two areas, Fig. 1, by GRI, NRL and NOS's Hydrographic Surveys Branch. A shallow water area, site A, was selected to test the system on the first day of surveying for system 'shakeout'. The Norfolk Canyon, site B, was selected for the deeper survey area. Site B is located approximately 62 nm east of Cape Charles, Virginia. The transit line, C, was also a data collection line. Several lines were run along contours with cross tracks across contours (Fig. 2). In addition, patch tests were run to evaluate pitch, roll, heave, and time delay errors. These tests are standard for system calibration and involve running the system over the same line from different directions, different speeds, etc. Patch tests are outlined in [6,7].

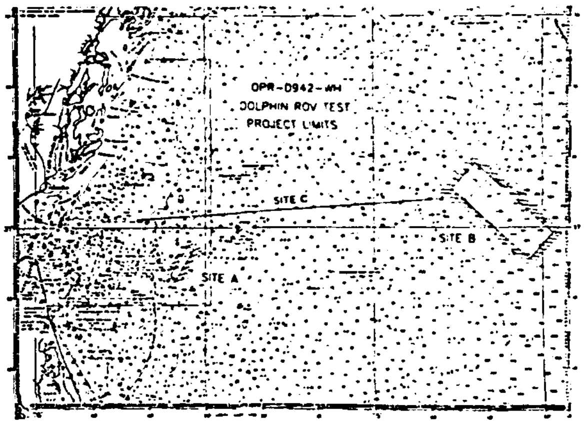

Figure 1. DOLPHIN test sites (all depths are in fathoms)

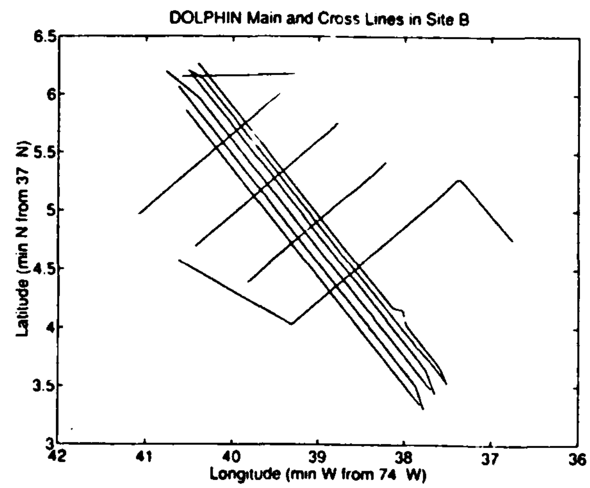

Figure 2. Track lines surveyed by DOLPHIN, WHITING and USNS LITTLEHALES

Survey Results

The DOLPHIN was launched from the dock at the Little Creek NAB and traveled to the Norfolk Canyon on its own power. Data were collected over the Norfolk Canyon, over the same survey lines, on two different days. These tests were to evaluate the DOLPHIN in somewhat different environmental conditions, and to get better estimates of sea state, system errors, and noise. A total of approximately 30 linear nautical miles were collected. Six mainscheme lines (lines B03 through B08) were run parallel to the Norfolk Canyon's contours, with three upslope crosslines (B21, B22 and B24), and three downslope crosslines (same lines) perpendicular to the mainscheme line. These lines are shown in Fig. 2. One mainscheme line, run during calm seas, was also run during rougher seas (light chop with 3-ft swells) to evaluate the affects of sea state on the data. No significant differences were found due to sea state.

At one point in the Norfolk Canyon survey, the DGPS position jumped to a location 100 m off the programmed track, making the DOLPHIN respond with an abrupt turn in an effort to correct its course. The abrupt turn caused the DOLPHIN's sensors to detect an excessive acceleration and to therefore shutdown and surface. The DOLPHIN was immediately restarted and brought back on track, with only a few minutes of lost survey time. Filtering algorithms could be implemented to remove navigation spikes like DGPS dropouts.

The DOLPHIN operated without further problems on both trips to the Norfolk Canyon, operating for 24 h the first trip, and slightly over 26 h on the second trip. On the second leg, the DOLPHIN left Little Creek, surveyed the Norfolk Canyon, and returned to AMC the next morning. Operation of the DOLPHIN was done in shifts, and the DOLPHIN remained visible on the operator console and radar screen at all times.

Data Processing

The Hydrographic Information Processing System (HIPS) software was used to process the DOLPHIN and LITTLEHALES data. HIPS was developed for the CHS by Universal Systems Limited (USL) in conjunction with the University of New Brunswick (UNB), both in Fredericton.

The WHITING used the Hydrochart "Phase II" Intermediate Depth Swath Survey System (IDSSS) to process data. IDSSS was developed for NOAA by the University of Rhode Island (URI), in conjunction with the Office of NOAA Corps Operations (ONCO) and Seabeam Instruments, Inc.

Attitude Data Results

Figure 3 shows a comparison of pitch records for the DOLPHIN and WHITING over the same time interval. The DOLPHIN showed considerably less pitch for line B03 than the ship, which agrees with results obtained by Preston [9]. However, results for line B04 showed that the DOLPHIN pitched considerably more when traveling in the opposite direction. Table 1 shows results for each line in opposite directions. This result implies that the direction of the prevailing seas and winds has a noticeable effect on the dynamics of the DOLPHIN vehicle. Based on observations by GRI, DOLPHIN performance and stability is marginally superior when running into the seas and waves as opposed to running with the seas [10].

These results are attributed to the response of the stabilizing planes as the DOLPHIN runs into the seas, producing a more rapid vehicle response. Running with the seas, the DOLPHIN's relative speed is reduced, some surfing occurs and there is less water passing over the stabilizer planes.

Table 1. Pitch Data (in degrees)

Platform	Line	Course	Max	s
DOLPHIN	B03	139	1.8	0.25
WHITING			3.1	0.65
DOLPHIN	B04	319	2.8	0.70
WHITING			2.6	0.49
DOLPHIN	B05	139	1.8	0.31
WHITING			3.6	0.72
DOLPHIN	B06	319	2.6	0.66
WHITING			2.3	0.47
DOLPHIN	B07	139	1.8	0.31
WHITING			3.0	0.80
DOLPHIN	B08	319	3.6	0.72
WHITING			2.4	0.43
DOLPHIN	B21	231	2.8	0.83
WHITING			2.6	0.56
DOLPHIN	B24	051	1.8	0.28
WHITING			2.6	0.67

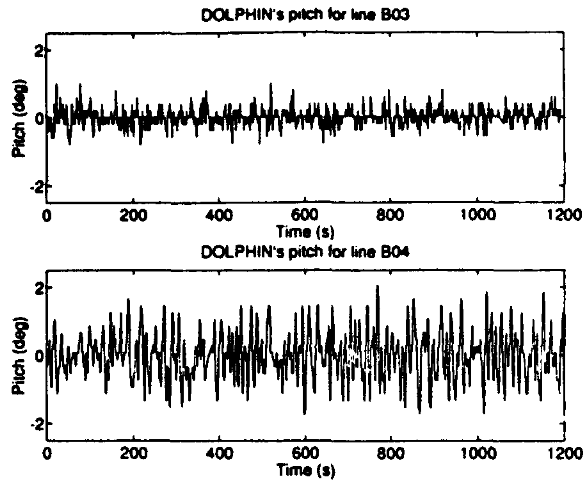

Figure 3 (a) DOLPHIN pitch record for lines B03 and B04

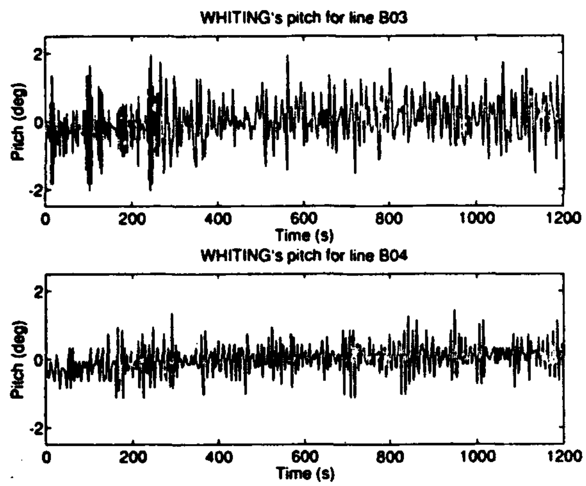

Figure 3 (b) WHITING pitch record for lines B03 and B04

With a conventional monohull vessel, the converse is true as running into the seas produces thrusts on the bow at different intensities resulting in pitching. A ship running with the seas results in less thrust and less pitch with a longer period.

Heave and roll data were not available from the HYDROCHART II merged files that NRL received, so comparisons between the WHITING and DOLPHIN could not be made for those parameters. Since sea conditions were different for the LITTLEHALES survey, comparisons could not be made there either.

Bathymetry Data Results

Bathymetry was compared for DOLPHIN noise and accuracy relative to each of the ship platforms, and the ship's data were compared to each other. Raw data profiles were used to compute noise, and gridded data were used to compare bathymetry. Raw data were subtracted from fitted data to compute noise [11]. All data were gridded with the same software to a common, evenly-spaced, georeferenced grid.

Figure 4 shows raw bathymetry data collected by the WHITING and DOLPHIN in the same area. The data shown are from the center beams of each system. The HYDROCHART II data appears considerably noisier than the EM-100. Analysis showed the HYDROCHART's root-mean-square (rms) noise levels, about 0.28% of depth, to be about 40% above the DOLPHIN's EM-100 noise levels, about 0.2% of depth.

Note that the Hydrochart II is typically used to survey in 150 m to 1,000 m depths. NOS quantizes all the HYDROCHART II data to 1 m resolution. The IHO standard [12] in 150 m water requires 0.9 m accuracy in depth soundings, however since most of the HYDROCHART II surveys are in deeper water, NOAA/NOS quantizes all the data to 1 m. Comparisons of DOLPHIN and WHITING data are based on the quantized HYDROCHART II data, with quantization errors being minimal (.08 m^2).

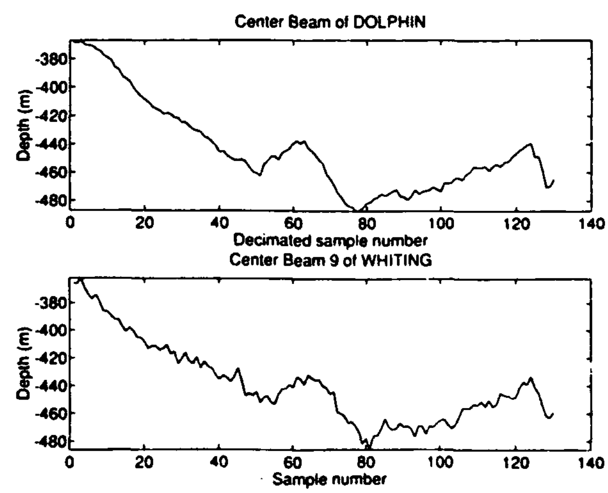

Figure 4. Profiles of DOLPHIN and WHITING data

Figure 5 shows data over a steep slope of the canyon for DOLPHIN and LITTLEHALES. The LITTLEHALES data along this track shows a considerable amount of dropout (zero values). The two data sets show relatively good agreement. Some offsets exist between samples due to lack of georeferencing, sampling rate differences or positioning errors.

Other results show the noise in the DOLPHIN's EM-100 data to be about 0.2% of depth, and that of LITTLEHALES's EM-100 data to be about 0.17% of depth. The rms difference, .03% of depth, is negligible.

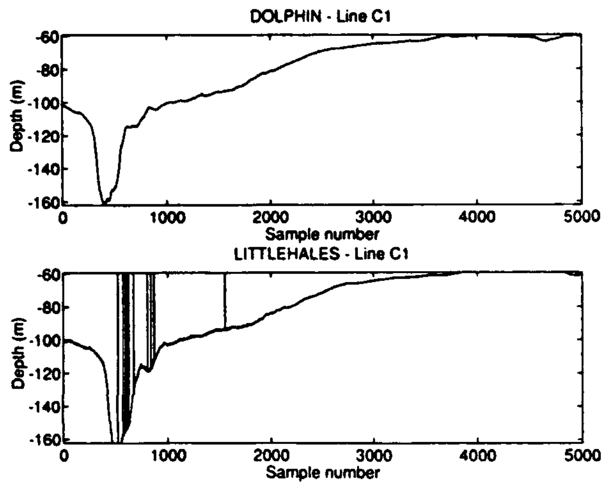

Figure 5. Profiles of DOLPHIN and LITTLEHALES data

Figure 6 shows georeferenced 50 m contours from the three platforms over an area of site B. The three different contour lines are generally in agreement with each other, varying from 0 m to 85 m (worst case) of each other.

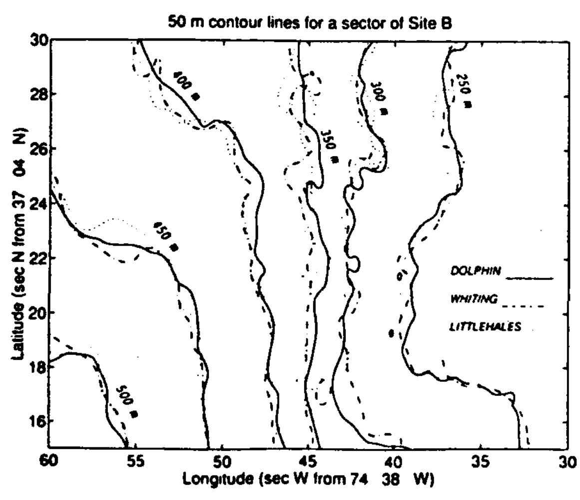

Figure 6. Contour intervals for area of site B for WHITING, LITTLEHALES and DOLPHIN surveys

Table 2 shows bathymetry results for a small area of site B. The mean difference between platforms is expressed as μ. The rms depth differences between DOLPHIN and WHITING data were 1.9% of depth, and between DOLPHIN and LITTLEHALES, the rms was 2.0% of depth. The rms depth difference between the two ships was 2.3% of depth. These figures indicate that differences in depth measured by the two ships varied more than differences between the DOLPHIN and either ship for this particular area of site B. (The rms is used interchangeably with the standard deviation, s, when the mean difference of the samples is zero. Since the mean difference is not zero in this example, the rms is slightly higher than s.)

Table 2.
System Comparisons for Section of Site B

System Comparison	Percentage of Depth μ	s	rms
DOLPHIN vs LITTLEHALES	0.58	1.90	1.99
DOLPHIN vs WHITING	0.28	1.88	1.90
LITTLEHALES vs. WHITING	-0.32	2.23	2.25

Although differences between the two ships varied more than between either ship and the ROV, the mean difference between the two ships was almost a meter smaller than for the DOLPHIN and the ships. Kaminsky [11] shows that the mean difference between the ships was 0.48 m and was -1.7 m and -1.3 m, respectively, between the DOLPHIN and LITTLEHALES and DOLPHIN and WHITING. As a percentage of depth, the DOLPHIN and WHITING are closest, and have the smallest rms error. This result shows that the DOLPHIN was sounding shallower than the two ships in this area. Figure 6 shows some of the DOLPHIN contours (solid lines) to be shifted slightly to the right of the ship contours (towards the shallow side). The fact that the rms differences were smaller between the DOLPHIN and the ships than between the ships, indicates that there might have been a calibration problem either in the depth measurement or in the navigation rather than spurious noise.

Table 3 shows computed beam noise for the center and outer beams of the EM-100 and a center beam of the WHITING. DOLPHIN data were slightly noisier than the LITTLEHALES, but less noisy than the WHITING data. All computed noise was less than 1% of depth.

Table 3. Beam Noise (meters)

Line/Course	Beam	DO	LH	WH	Depth
B03/139	01	1.0	1.0		
	16(9*)	1.5	1.1	3.9	450
	32	1.6	0.9		
B04/319	01	2.6	2.1		
	16(9*)	1.9	1.6	3.2	410
	32	2.0	1.8		
B07/139	01	1.5	1.3		
	16(9*)	2.0	1.3	2.8	290
	32	1.9	1.6		

* The center beam of the HYDROCHART II used for comparison is beam no. 9.

Tests performed over a relatively flat area (99 to 102 m) showed that the DOLPHIN EM-100 noise for beams close to nadir was 0.1% of depth and less than 0.25% for all beams.

Conclusions

The DOLPHIN is a stable and efficient data collection platform. The savings in ship-years and manpower could potentially give the Navy a very economical data collection platform. DOLPHIN can operate in many sea conditions where a hydrographic survey launch can't operate and DOLPHIN can operate for longer periods of time.

The shallow water site, site A, scheduled for the first day of operations, was abandoned due to a malfunction in the DOLPHIN's hydraulic system. The problem was due to the loss of a retainer nut on the hydraulic ram. The DOLPHIN had to be towed into Little Creek NAB. The hydraulic problem was identified and corrected in under two hours. The towing of the DOLPHIN was slow and emphasized the need for a ship-based handling system. A launch and recovery system allows DOLPHIN operations from any point whereas a shore-based launch and recovery limits the area of operation and does not provide for retrieval of a disabled DOLPHIN.

The training of personnel to operate and maintain the DOLPHIN is especially important, and NAVOCEANO personnel could be trained to perform these functions.

In any survey with an ROV, a notice to mariners would be appropriate. A study of international law concerning the operation of ROVs needs to be done. The DOLPHIN's strobe and running lights would have to conform to regulations for maritime shipping.

Summary

The DOLPHIN/EM-100 system was tested and evaluated over the Norfolk Canyon, 60 miles east of Cape Henry, Virginia in August of 1992. The operation of the DOLPHIN indicated that the system was capable of 24 h data collection and that no major problems existed in its operation. The breakdown of the DOLPHIN on its initial shakeout survey demonstrated its ease of repair and stressed the need for a ship-based launch and recovery system. The system requires about five people to launch, retrieve, operate and maintain it. Normal surveying with DOLPHIN/EM-100 requires only two people. The system operated for a full 24 to 26 hours on each of two surveys without any problems. Noise levels seem to be within 0.03% of the LITTLEHALES depth data.

From an operational survey standpoint, the use of survey launches would still be required for 0 m to 10 m, for taking bottom samples, shore-based operations and transportation to the ship. The use of a DOLPHIN with high resolution imaging capability would free the survey launches to perform more of the these operations, would double the ship's survey capability in deeper water, and thus curtail the length of the survey operation and optimize the number of survey miles per ship.

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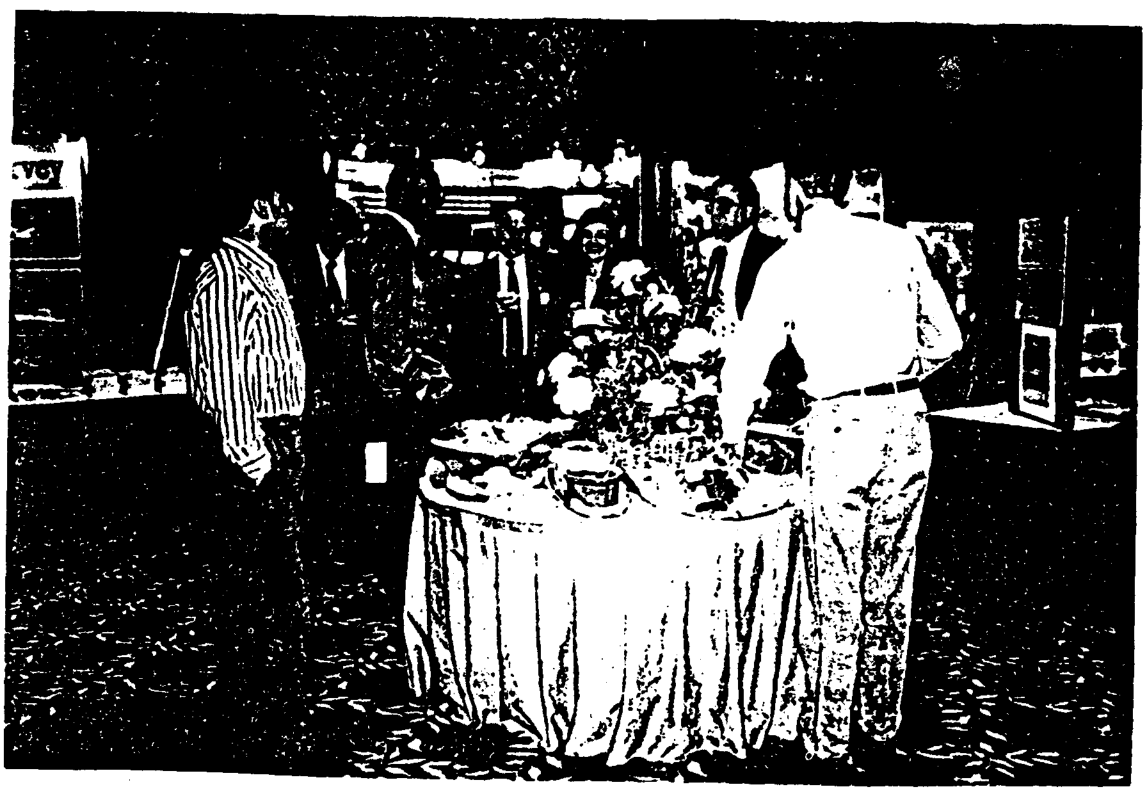

Exhibitors' Luncheon