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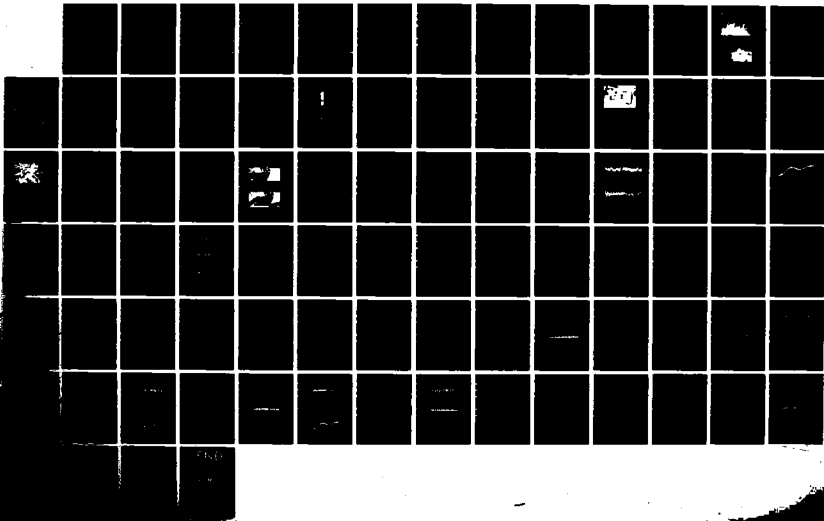

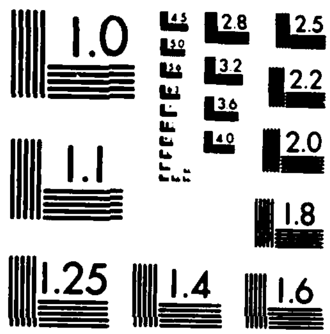
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

AD-A149 516

AN EVALUATION OF USNS HAYES AS A TOWED ARRAY TOWING PLATFORM

by

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SHIP PERFORMANCE DEPARTMENT

DEPARTMENTAL REPORT

August 1984

DTNSRDC/SPD 2001-01

AN EVALUATION OF USNS HAYES AS A TOWED ARRAY TOWING PLATFORM

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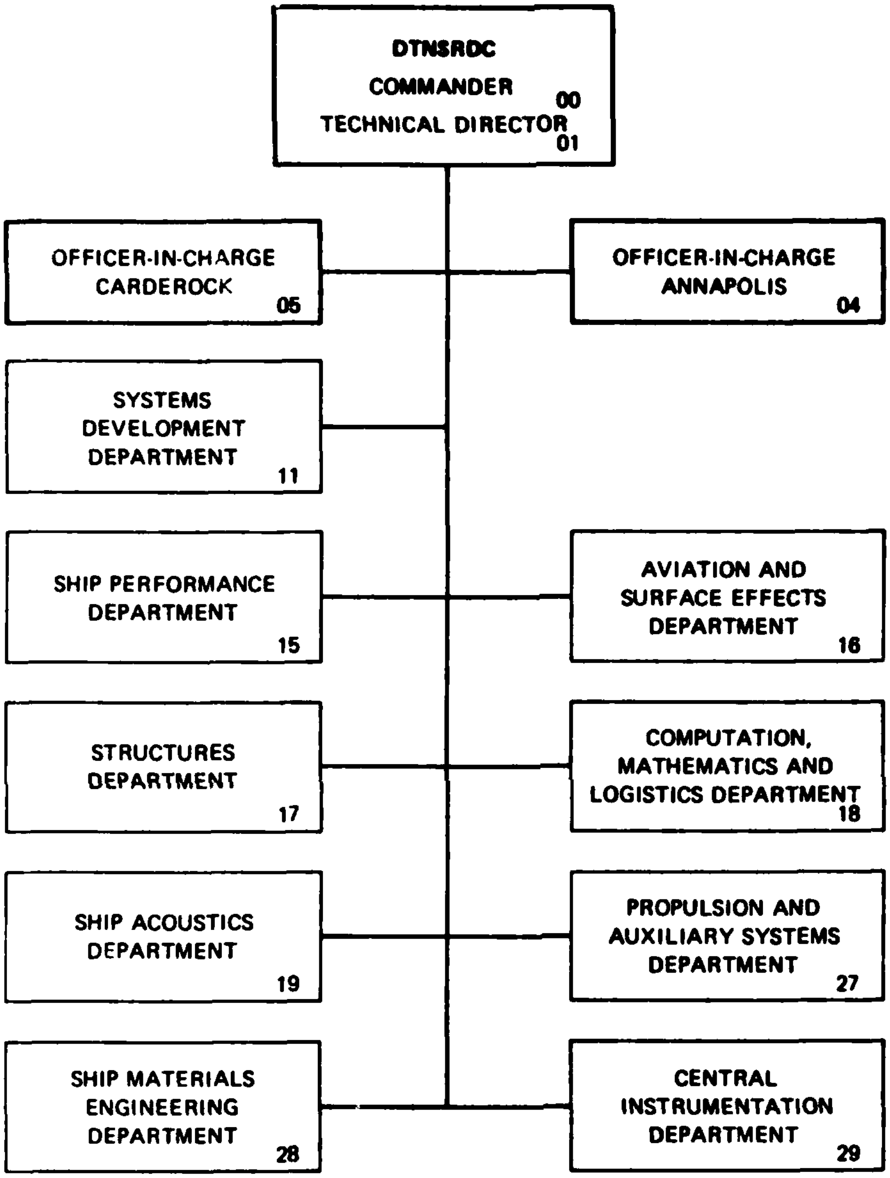

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An evaluation of the USNS HAYES as a towing platform for the TTUMS or other towed array was performed as one of three evaluations to determine HAYES' suitability as a replacement for MONOB. Of primary concern was the possibility that HAYES' motion might impart unacceptably large motions to the TTUMS array. An experiment was performed in which USNS HAYES towed the TARP array, configured to simulate TTUMS. Both TARP and the USNS HAYES were instrumented to permit track and motion measurements on the AUTEC Weapons

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Range. The array generally towed straight and horizontally with a maximum deviation of 1.5 degrees from a straight line. The typical maximum transverse velocity was 0.1 m/sec. Array handling was performed without difficulty. It was concluded that, from the aspect of a towing platform, the USNS HAYES would be capable of satisfactory performance in replacing MONOB for the TTUMS mission.

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ABSTRACT

An evaluation of the USNS HAYES as a towing platform for the TTUMS or other towed array was performed as one of three evaluations to determine HAYES' suitability as a replacement for MONOB. Of primary concern was the possibility that HAYES' motion might impart unacceptably large motions to the TTUMS array. An experiment was performed in which USNS HAYES towed the TARP array, configured to simulate TTUMS. Both TARP and the USNS HAYES were instrumented to permit track and motion measurements on the AUTEC Weapons Range. The array generally towed straight and horizontally with a maximum deviation of 1.5 degrees from a straight line. The typical maximum transverse velocity was 0.1 m/sec. Array handling was performed without difficulty. It was concluded that, from the aspect of a towing platform, the USNS HAYES would be capable of satisfactory performance in replacing MONOB for the TTUMS mission.

ADMINISTRATIVE INFORMATION

This work was funded by the Naval Sea Systems Command (NAVSEA 5042) under task area S1803555, David Taylor Naval Ship Research and Development Center Work Unit 1-1170-340 and 1-1170-441. Mr. Jesse S. Diggs is an employee of Applied Measurement Systems, Inc.

INTRODUCTION

The Ship Acoustics Department (Code 19) at the David Taylor Naval Ship R&D Center (DTNSRDC) has the responsibility to measure and document the underwater acoustical radiated noise of U.S. Navy submarines. The measurements are made by maneuvering the submarine to be measured near an array of moored or towed hydrophones and recording the acoustical noise spectrum levels. This array of moored or towed hydrophones is usually deployed from MONOB (Mobile Noise Barge), a converted yard auxiliary vessel (YAG-61) that was modified and adapted for this purpose. Although MONOB has provided this radiated noise measurement service for well over a decade, the increase in size of the U.S. Navy Fleet has placed a great demand on MONOB as a vessel.

MONOB's capabilities are limited by its speed (8-knot maximum), deck and laboratory space, age, and cost to maintain and operate. Therefore, consideration recently has been given to USNS HAYES (T-AGOR 16) as a potential candidate to perform some or all of the MONOB functions. USNS HAYES is an oceanographic research vessel built in 1971[1]. The vessel is a catamaran design as shown in Figure 1 with characteristics as described in Appendix A, Table A-1.

Even though USNS HAYES is a larger vessel and capable of greater speeds than MONOB, it must first demonstrate the capability to perform the MONOB measurement functions before further consideration can be given to it as replacement for MONOB. Specifically HAYES must be able to handle and tow the Transportable Towed Underwater Measurement System (TTUMS) in a stable manner.

The TTUMS is a towed hydrophone line array designed to measure radiated noise from submarines. In practice, TTUMS is towed from MONOB at low speeds as the subject submarine maneuvers nearby to maintain constant relative position as depicted in Figure 2. TTUMS then measures and records the submarine's radiated noise, and post-trial processing resolves the noise source.[2] The accuracy of this measurement process requires that the TTUMS array remain straight and at a near constant depth over its acoustic aperture.

TRIAL OBJECTIVE AND APPROACH

The main concern motivating this experiment was that the unusual motion associated with large catamaran vessels (i.e., snap roll, corkscrew motion, etc.) would be transmitted to the TTUMS array and result in large radiated noise localization errors. The objectives were as follows:

1. Assess USNS HAYES for speed and course maintainability and control.
2. Determine array motion (i.e., heading, depth and transverse velocity) as a function of ship's speed and course and sea state.
3. Assess HAYES in terms of array launch, retrieval and shipboard handling capabilities.

To determine the effect of HAYES motions on a towed array, full-scale in-situ trials were conducted to measure the shape and motion of the array. The basic approach was for HAYES to tow an instrumented array in a TTUMS-like configuration through the Atlantic Undersea Test and Evaluation Center (AUTEC) Weapons Tracking Range and to measure array motion as a function of ship motion. (The AUTEC Weapons Tracking Range test area is shown in Appendix B.)

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[1] References are listed on page 46.

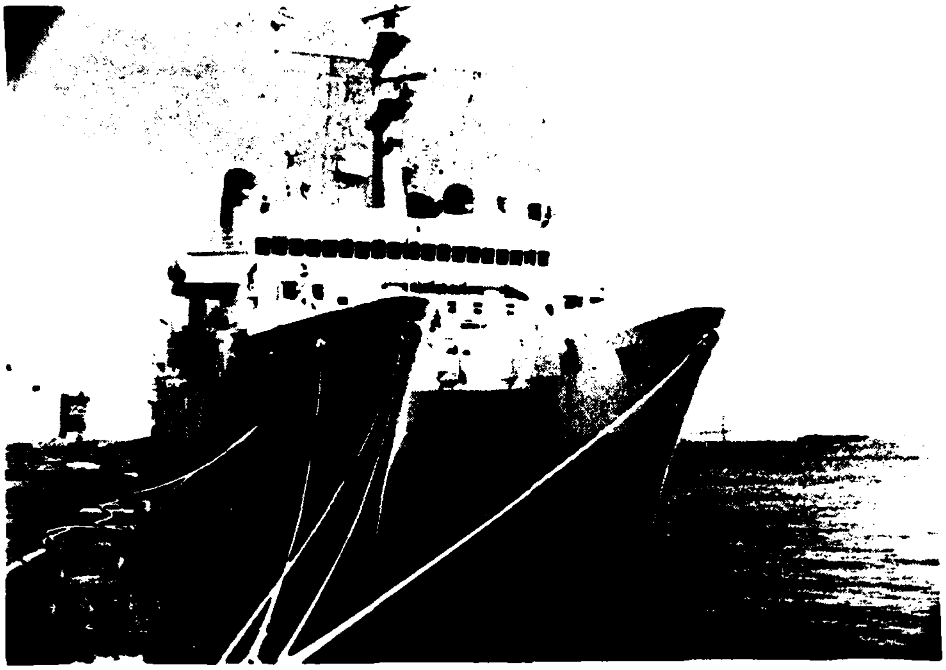

Figure 1a - Bow View

Figure 1b - Stern View

Figure 1 - USNS HAYES (T-AGOR 16)

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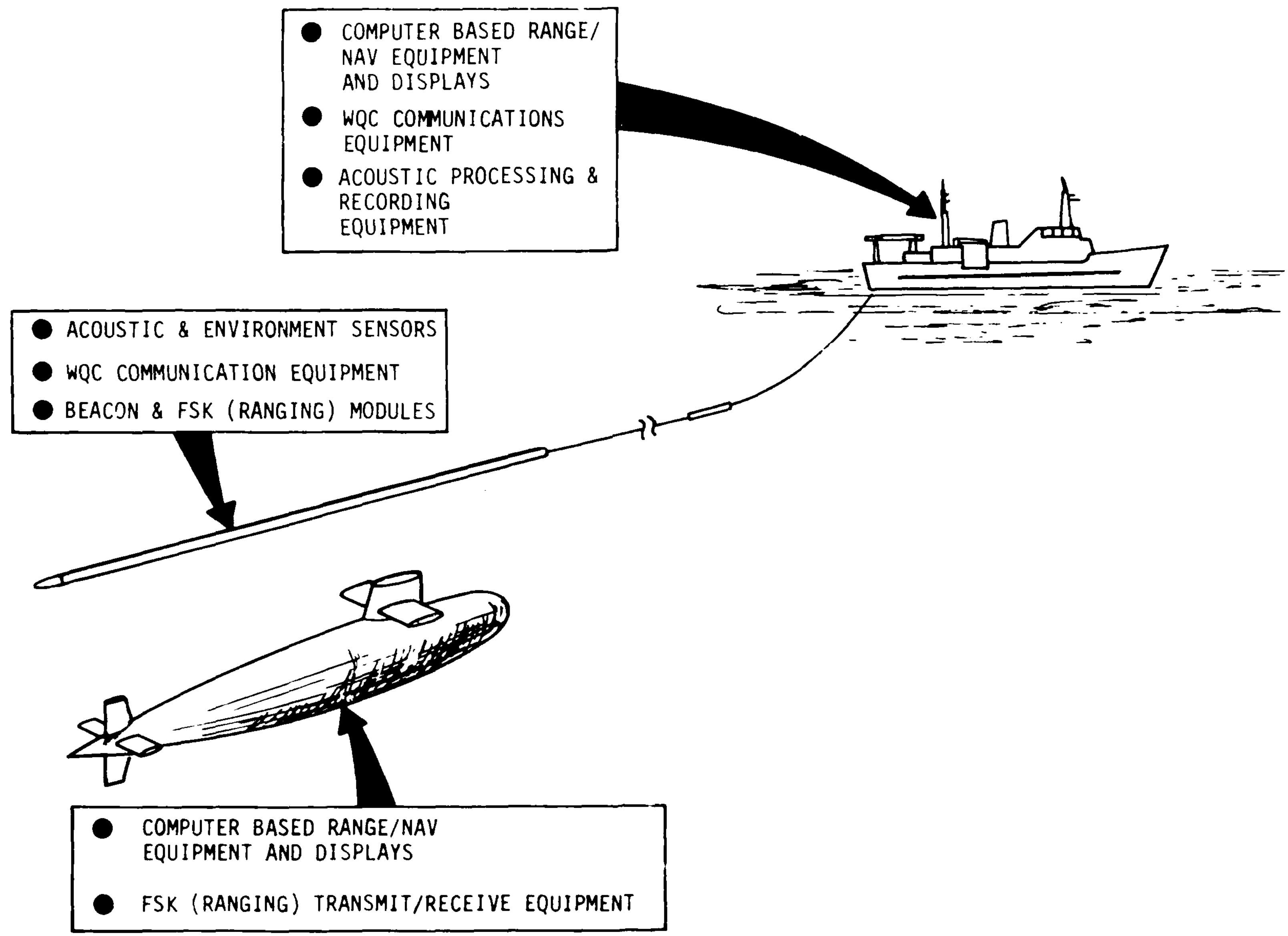


Figure 2 - TTUMS Operational Configuration

The Naval Underwater Systems Center in New London (NUSC/NLL) provided the TARP array and associated shipboard instrumentation for these experiments. The TARP array was developed specifically for a towed array motion R&D program and thus was instrumented with very accurate depth and heading sensors. The array was outfitted also with four acoustic pingers. A fifth pinger was installed aboard HAYES to facilitate acoustical tracking of its position on the AUTEC range. In addition, the array towcable forces were measured, as were the ship's motions (i.e. roll, pitch, yaw and accelerations). A compilation of such data would provide sufficient information to completely characterize the array motion and identify any coupling that may exist with HAYES motion.

The USNS HAYES Towed Array Performance Trial was one of three segments of the USNS HAYES Ship Trials which were aimed at establishing the suitability of the ship as a replacement for MONOB-1 (YAG-61), Mobile Noise Barge. The other two segments of the USNS HAYES Ship Trials were the Seakeeping and Maneuvering Ship Trials[3,4] and the Acoustic Measurement Ship Trials. Sections of the Seakeeping and Maneuvering Ship Trials were conducted simultaneously with the Towed Array Performance Trials. However, this report is concerned only with the results obtained during the Towed Array Performance Trials.

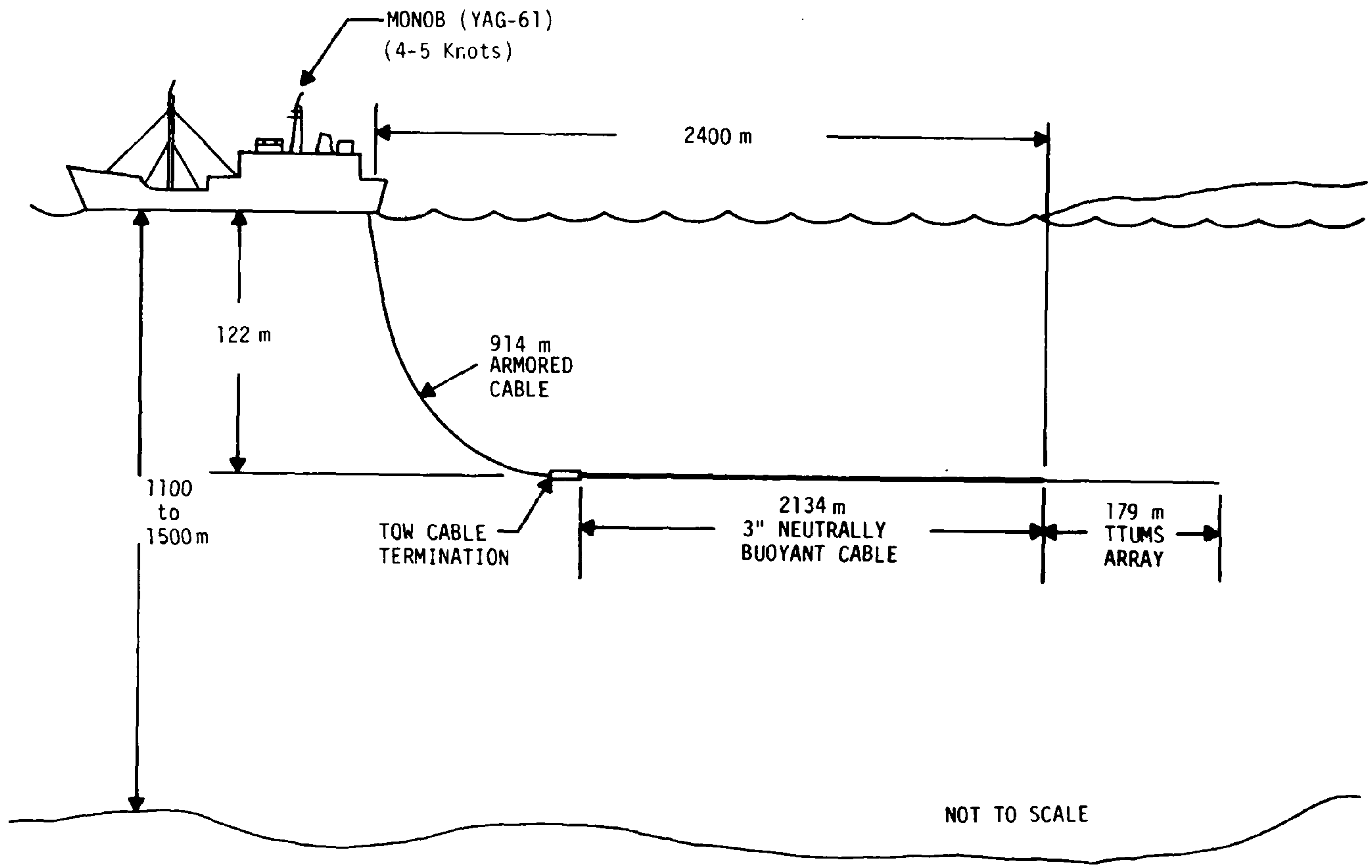
EXPERIMENTAL EQUIPMENT AND PROCEDURES

This section describes equipment and procedures used in the USNS HAYES towing evaluation. Details are presented of the towed array configuration, array and shipboard instrumentation and the arrangement of the handling system. Data acquisition and array launch and retrieval procedures also are presented.

ARRAY CONFIGURATION

The TTUMS towed array system for which the TARP array was selected as a model is shown in Figure 3. The TARP towed array system, illustrated in Figure 4, consisted of the towcable, neutrally buoyant array spacer sections and four environmental modules (EM). The towcable was a 1220-m (4000-ft) double-armored polyethelene-jacketed coax cable having the following physical characteristics:

Diameter	1.42 cm (0.560 inch)
Weight per unit length in air	0.417 kg/m (0.281 lb/ft)
Weight per unit length in water	0.245 kg/m (0.105 lb/ft)



TEST CONFIGURATION

Figure 3 - TTUMS Towing Configuration

Attached to the end of the towcable was 1000m (3280 ft) of neutrally buoyant array made up of twenty 50-m (164-ft) lengths of 2.79-cm (1.1-inch) diameter spacer modules. The function of these modules was to model the length of the TTUMS array and to provide a drogue at the end of the array. Four EMs having lengths of 3.35m (11.0 ft) each and a diameter of 8.26 cm (3.25 inch) were located along the array as shown in Figure 4. Each EM contained depth and heading sensors and an acoustic pinger. The forward EM, placed between the towcable and the first neutrally buoyant spacer module, also monitored array tension. A fifth pinger was installed on the starboard hull of HAYES, 5.8m (19 ft) off the ship's centerline. The types, ranges and accuracies of the transducers used for measuring system parameters are given in Table C-1 of Appendix C.

ARRAY INSTRUMENTATION

All in-water instrumentation was incorporated into the four environmental modules. Each EM consisted of a sensor module containing a magnetic heading sensor and a quartz oscillator depth gage, a hollow coupling section containing sensor and pinger electronics, and a pinger module housing an acoustic transponder as shown in Figure 5. The foremost EM included a tension module containing a tensiometer. Each EM was filled with DB oil which provided both neutral buoyancy for the module and acoustic impedance matching with seawater.

The environmental modules, spacer modules, coax cable and shipboard array electronics used a time-division multiplexed telemetry system. This system provided two-way communication between the shipboard and array electronics. The telemetry system's purpose was to produce acoustic pulses at the four pingers in the array and to receive and decode heading and depth data from the environmental modules once every two seconds (0.5 Hz sample rate). The timing pulses that kept the system synchronous with the AUTEC shore-based tracking equipment were supplied by an AUTEC Portable Timing Unit (PTU).

TOWPOINT GIMBAL

A gimbal towpoint mounted at the stern of the ship on centerline and instrumented to measure towcable tension, cable angle and skew angle was provided by NUSC/NLL. Towcable tension was measured with a strain gage load-cell. Cable angle was measured with a pendulum potentiometer and was a measure of the angle between the towcable and the horizontal in a vertical plane. Skew angle was

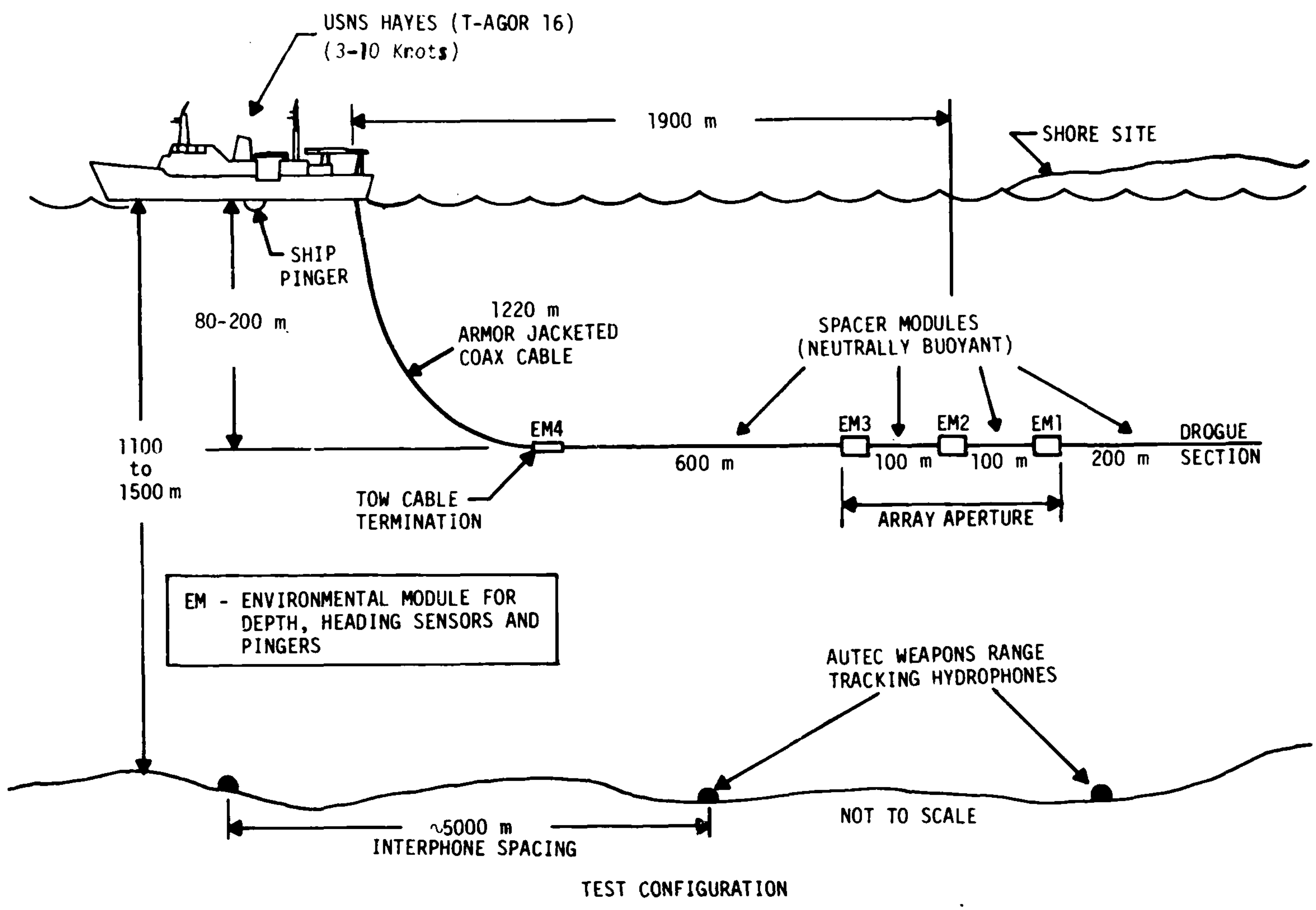


Figure 4 - TARP Array as Towed Aboard USNS HAYES

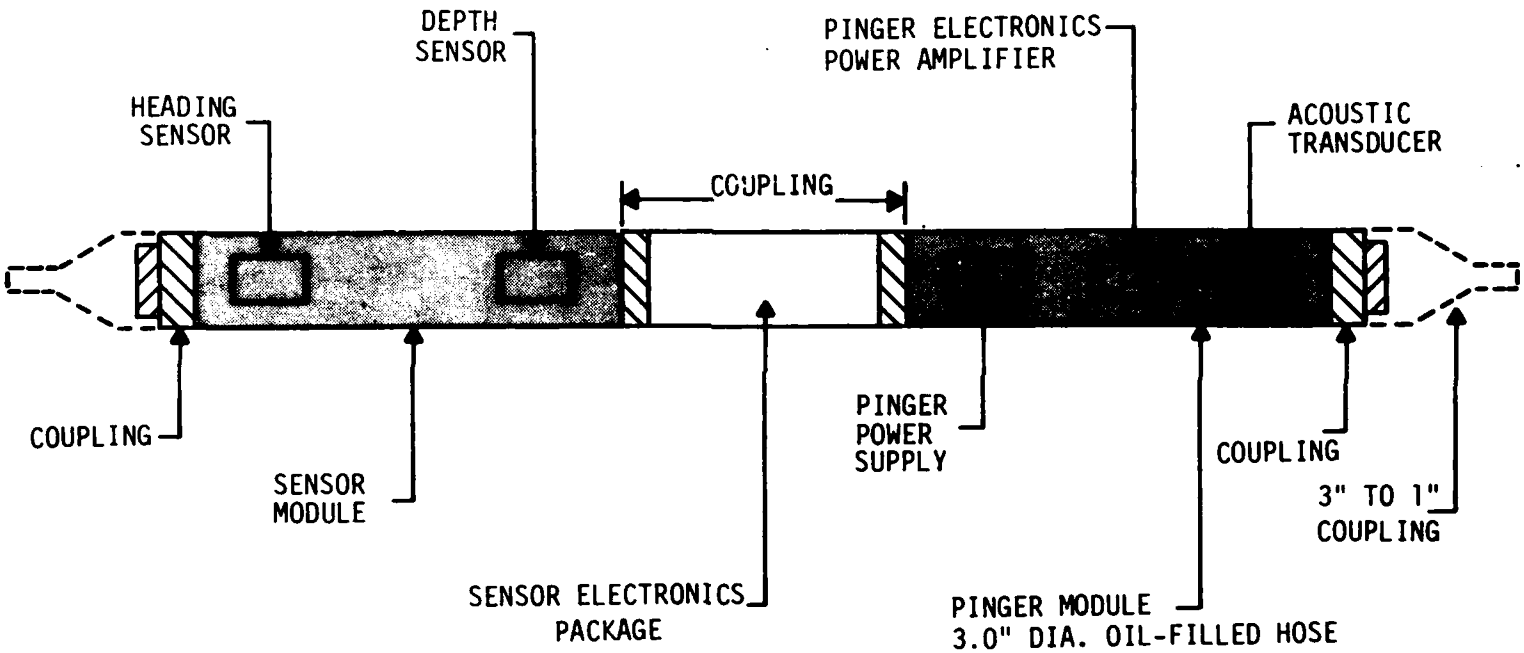


Figure 5 - Environmental Module Layout

measured with a potentiometer and is a measure of the angle between the centerline of the ship and a projection of the towcable onto a horizontal plane. The types, ranges and accuracies of these transducers are included in Table C-1 of Appendix C.

SHIPBOARD MOTION AND SHIP-OPERATING-CONDITIONS SENSORS

The shipboard motions measured were the angles and linear accelerations relative to the three major ship axes (i.e., roll, pitch, yaw, longitudinal acceleration, transverse acceleration and vertical acceleration). A stable table located near the towpoint provided ship angle information. A triaxial accelerometer box, also located near the towpoint, provided the three accelerations. These data were acquired in the event a more detailed analysis would be necessary to interpret the array EM data or AUTEC measurements. It was determined later that the array and AUTEC data acquired were sufficient to evaluate array motion aboard HAYES. These additional data will be retained, however, for future reference.

The ship speed and heading also were measured and recorded. The speed sensor used was the ship's electromagnetic log. The ship heading was acquired from the ship's gyro.

DATA COLLECTION SYSTEMS

Data were collected for this evaluation through two main systems, the shipboard data collection system and the AUTEC data collection system. Shipboard data were obtained and stored from sensors on board the ship and in the EMs in the towed array. AUTEC data were the position data obtained via ocean floormounted hydrophone arrays in the AUTEC Weapons Tracking Range using acoustic tracking techniques.

SHIPBOARD DATA COLLECTION SYSTEM

The signals from the array, the towpoint gimbal and the ship motion measurement system were collected and stored using a HP2240A Measurement and Control Processor controlled by a HP9835A Desktop Computer and an HPIB interface. The data acquisition system is shown in Figure 6. The shipboard motion and operating condition data were in the form of analog signals. The array data and towpoint gimbal data were in the form of a digital BCD ASCII string containing five data samples. Appendix C presents a block diagram of the NUSC/NLL data acquisition system. For more detailed information of the NUSC/NLL data acquisition system

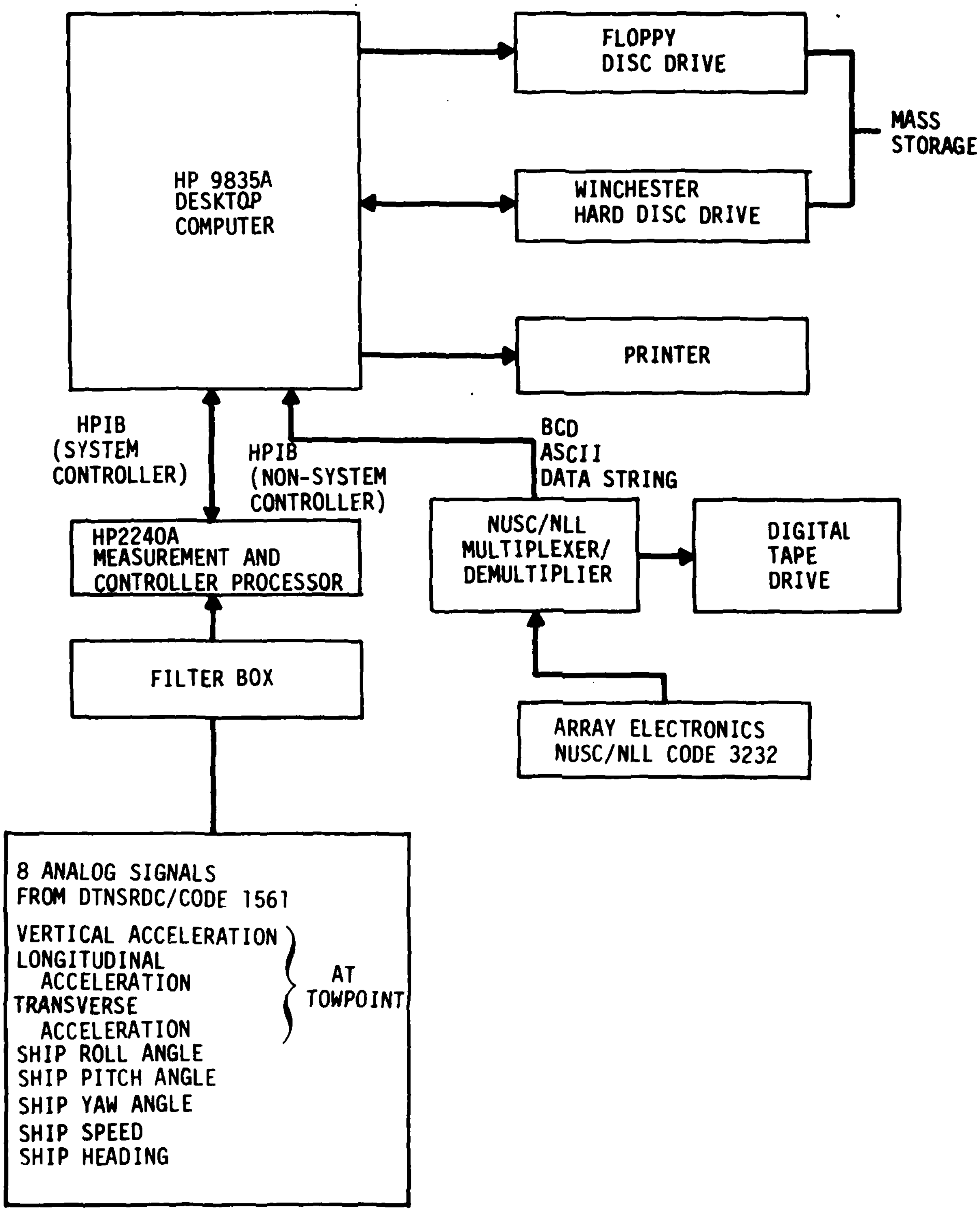


Figure 6 - Shipboard Data Acquisition and Storage System

see References 5 and 6. The sample rate for the array data was 0.5 Hz. A BCD ASCII string was sent to the HPIB interface/HP9835A every 10 seconds. During this 10-second waiting period the HP9835A/HP2240A was sampling ship motion data at a sample rate of 0.91 Hz. The difference between the ship and array sampling rate was due to the internal processing and the time required to display the data on the cathod ray tube (CRT).

The HP9835A software had a two-fold purpose. Its primary purpose was that of merging two sources of information on a single data record for post-trial analysis. Its secondary purpose was to provide a means of monitoring all ship/array parameters simultaneously. The Winchester hard disc was used as the mass storage device. At the completion of a run the run file on the Winchester was transferred to a floppy disc for post-trial analysis. The data acquisition set-up in the main deck laboratory of the USNS HAYES is shown in Figure 7.

AUTEC DATA ACQUISITION

The AUTEC Weapons Tracking Range tracked the array and towship pinger positions as functions of time. From these data, the location of each pinger could be defined in space and its rate of change calculated. AUTEC provided digital tapes of the acquired data, which were then transferred to floppy discs for additional post-trial processing and display on a HP9836/26 desktop computer. The vector formed by the COMEX and FINEX position of the HAYES in the x-y plane was chosen as the x axis in all AUTEC data as shown on Figure 8. The origin is ship position at COMEX. Therefore, all displacements to starboard are in the -y direction.

DATA ACQUISITION PROCEDURES

The data acquisition runs were of two types: straight line and sinusoidal runs. Straight line runs were performed at nominally steady speed and course for a one hour duration. The speeds were 3, 5 and 10 knots on reciprocal headings [i.e., 162°T (true magnetic north) and 342°T] with auto-pilot on and off. These runs were similar to a typical TTUMS source localization measurement. The sinusoidal runs consisted of purposely deviating from a straight line course by deflecting the rudder by plus and minus 10, 15 or 20 degrees at regular intervals, thus simulating rough seas and poor helmsmanship conditions. Table 1 shows a list of the runs completed.

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Figure 7 - Data Acquisition Set Up on USNS HAYES

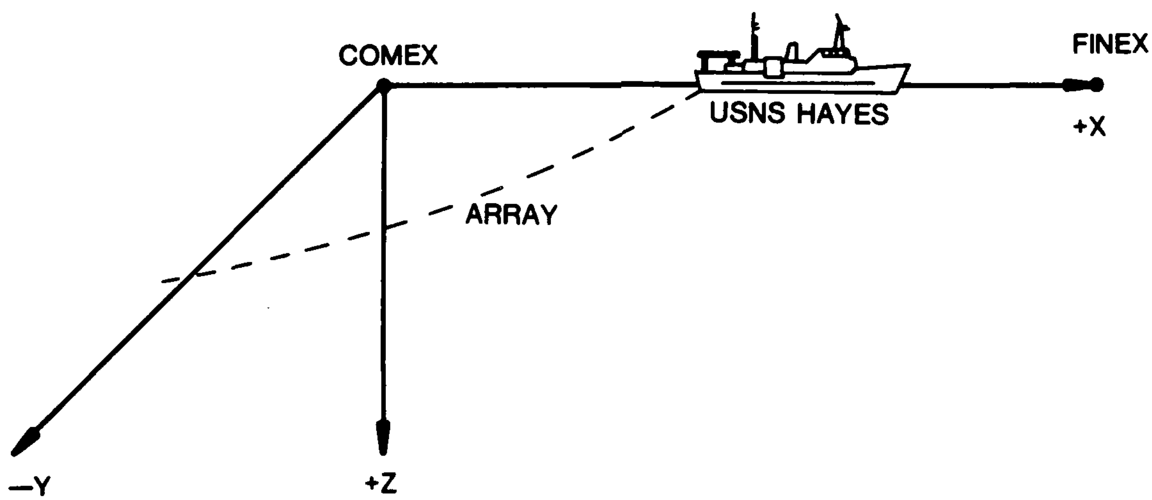

Figure 8 - Coordinate System Used for AUTEC Data

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The data acquisition procedures were as follows for a typical run. The trial director, located on the HAYES bridge, monitored ship activities and ship location via audio communications with the AUTEC shore site. When AUTEC had tracking of all five pingers (meaning the entire system was within the Weapons Range), the trial director would inquire of personnel monitoring array data whether the array appeared to be in a steady-state condition. Steady-state condition meant that the array had apparently recovered from the effects of a change in ship heading or speed at the end of a previous run. When the above conditions were met, the trial director would declare COMEX to begin a data run. Both the shipboard and AUTEC data acquisition systems then would commence acquiring data. The run time was limited to one hour because of the length of the AUTEC Weapons Range and the mass storage capability of the HP9835A.

TABLE 1 - COMPLETED DATA RUNS

Run No.	Speed knots	Heading degrees	Date, Local	COMEX GMT	FINEX GMT	Wind Speed (kt)/Direction (deg) T	Auto Pilot Status	Comments
S1010	3	162	10/28/83	0130	0230	17/75	Off	
S1030	3	342	10/28/83	0338	0431	17/78	Off	
S1040	5	162	10/28/83	0508	0608	19/55	On	
S1090	10	342	10/28/83	0704	0758	13/55	On	
S1060	5	162	10/28/83	0841	0941	20/72	Off	
S1070	5	342	10/28/83	1028	1128	18/65	Off	
S1100	10	162	10/28/83	1154	1251	20/57-92	Off	
S1080	10	162	10/28/83	1316	1416	21/82-92	On	
S1050	5	342	10/28/83	1444	1543	20/60	On	
S1110	10	342	10/28/83	0133	0233	20-25/32	Off	
S1120	5	162	10/29/83	0302	0402	16-22/57-82	Off	
Z1230	10	162	10/29/83	1800	1830	18-20/77	NA	± 10° Rudder Variations
Z1240	10	342	10/29/83	1908	1939	21-27/22	NA	± 10°
Z1211	10	162	10/29/83	2028	2058	21/87	NA	± 20°
Z1220	10	342	10/29/83	2114	2144	26/10	NA	± 2°
Z1290	8	162	10/29/83	2337	0037	19/62	NA	± 2° Long Period Variations; 10 min each change

LAUNCH AND RETRIEVAL

The towed array was stored in a fiberglass tub on the deck as seen in Figure 9. The handling system for the towed array was comprised of a towcable winch and a power sheave. The winch had a split drum to allow for the installation of a

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primary and backup cable. The winch and power sheave were installed on the starboard side of the fantail as shown in Figure 10.

Figure 9 - Towed Array Retrieval and Storage

The array was launched with the ship on a steady course and at a speed of approximately 3 knots. After the spacer modules and environmental modules were deployed over the free-wheeling power sheave from their storage tub, the towcable was deployed to the desired length of 1220m (4000 ft). At that point, the towcable load was transferred from the winch to the gimbal towpoint located at the centerline of the stern. To retrieve the system the reverse of this procedure was performed with the exception that the power sheave pulled the array in after the cable had been fully retreived as shown in Figure 11. Figure 12 shows the array being towed from the gimbal towpoint at the stern of the ship.

RESULTS AND DISCUSSION

It was assumed that the TTUMS mission would normally not be attempted in conditions of sea state greater than 3, which thus would represent the worst case. Fortunately, these conditions existed throughout most of the test period and all of the data presented herein should represent the worst motion experienced by any

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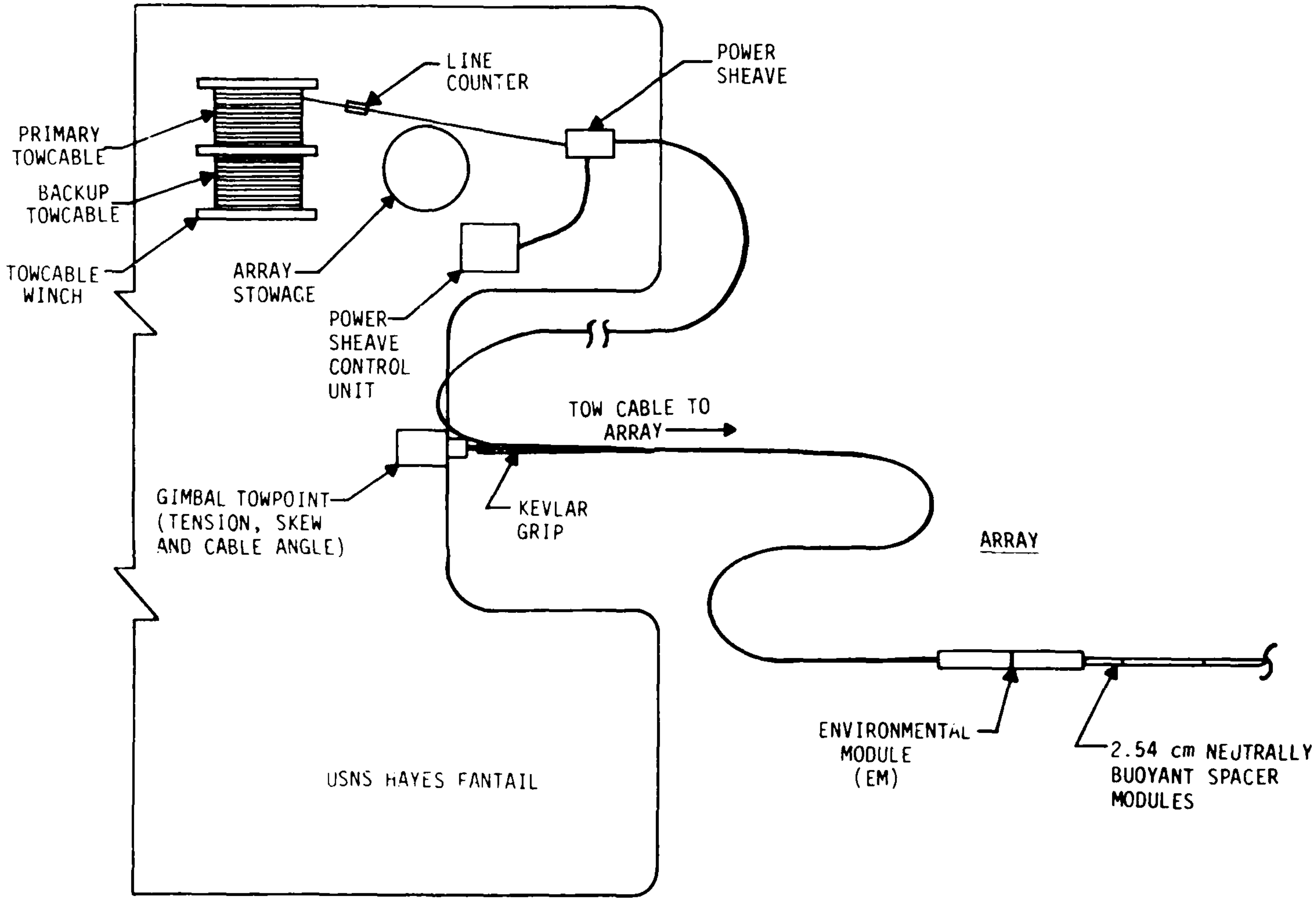

TARP VI SHIPBOARD AND ARRAY MECHANICAL SYSTEMS DIAGRAM

Figure 10 - USNS HAYES Towing Arrangement

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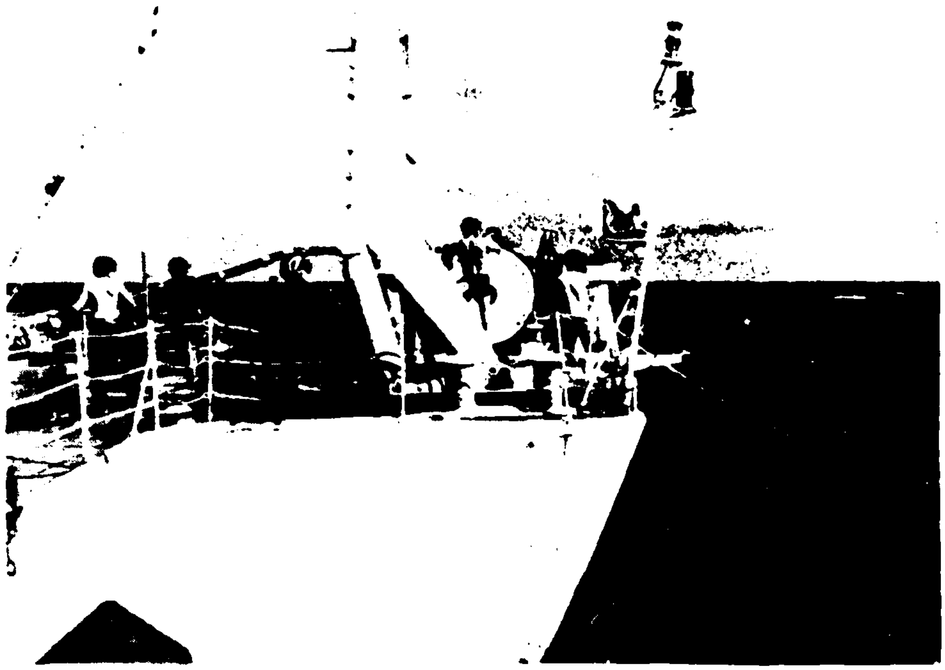

Figure 11 - Retrieval of Towed Array

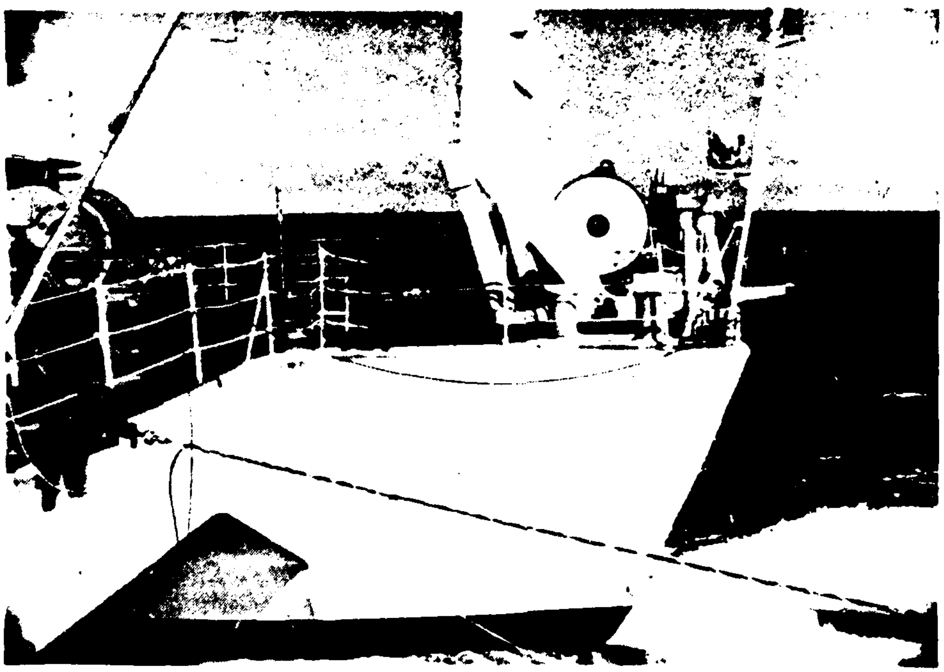

Figure 12 - Array Towed from a Gimbal Towpoint
from the Stern of USNS HAYES

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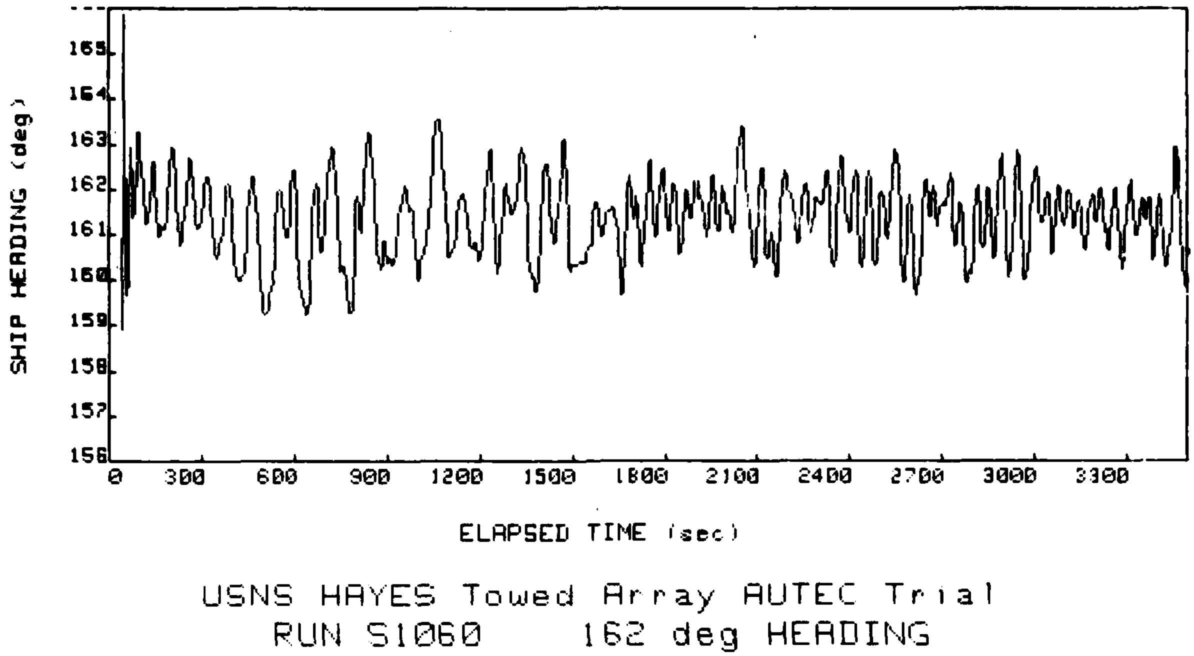
array towed from USNS HAYES. It is worthwhile to note that the motions (i.e., roll, pitch, etc.) of HAYES were quite tolerable to the trial personnel for the sea state conditions encountered and did not interfere with the trial in any way.

Due to time and cost constraints the TARP array was substituted and reconfigured to yield results approximating the TTUMS array. The center of the TTUMS aperture normally tows about 122m (400 ft) deep and 2400m (7874 ft) aft of MONOB for operational speeds of 3 to 6 knots. The TARP cable/array system was configured such that the center of the aperture towed approximately 203m (672 ft) deep at 3 knots and 87m (285 ft) deep at 10 knots and maintained a trail distance aft of about 1900m (6234 ft) for both speeds. This required deploying 1220m (4000 ft) of TARP towcable. The array motions induced by the ship were assumed to be more dependent on trail distance aft rather than array depth. Therefore, the TARP cable/array system length was modelled to approximate the TTUMS length as close as possible.

The data presented herein are confined to those of the sensor outputs from the ship (i.e., speed, heading and pitch), the TARP array (i.e., heading and depth sensors) and AUTEC (i.e., transverse displacement and velocity of each EM). Although considerably more data exist (i.e., shipboard acceleration levels, etc.), the data described above were sufficient to describe the array motion. Furthermore, of the 16 data runs completed as presented previously in Table 1, specific runs were selected as representative of the results and are presented in Appendix D. The data runs are discussed in detail below.

ARRAY CURVATURE AS A FUNCTION OF SHIP'S HEADING

The array motion trials were constrained by range geometry. Runs were made on reciprocal headings of 162°T and 342°T. The seas were driven by northeast winds at 15 to 25 knots, thus acting on the bow or stern quarter of HAYES, depending on nominal heading. During the planning of the array motion tests it was assumed that the array motion would be independent of ship heading. This assumption was based on findings from previous array motion experiments which showed that high frequency excitations at the towpoint are damped out in long towcables.[7] It can be seen from Run S1060 and S1070 in Figure 13 with autopilot off that the ship heading stability was less at a heading of 342°T than at 162°T at 5 knots. This was due to the winds and seas acting on the starboard bow causing difficulty in course maintenance, thus greater ship heading deviations.



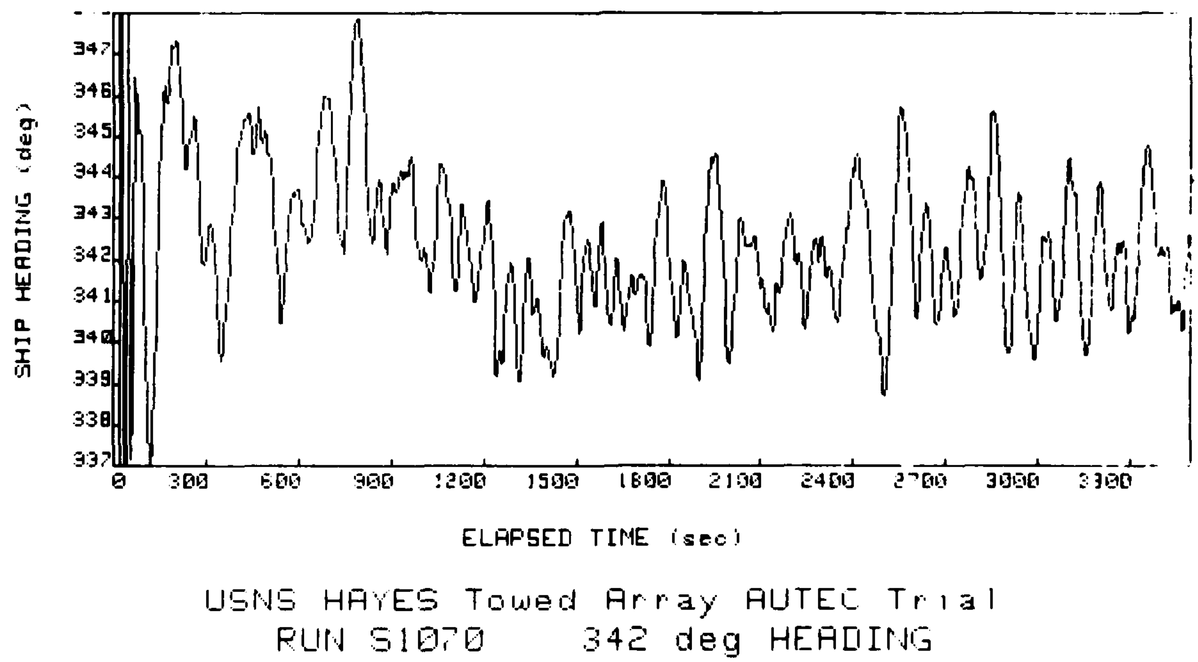


Figure 13 - Ship Heading as a Function of Time for Run S1060 and S1070 at 5 Knots for Reciprocal Headings

A definition of delta heading (H1-H3) as used in this report is shown in Figure 14. Delta heading represents the maximum heading deviation or curvature for the array aperture. This is based on the assumption that the array aperture shape will never have an inflection.

It is assumed that at lower speeds the ship motion would be most affected by sea conditions. Therefore, two 5-knot data runs at reciprocal headings are compared. Figure 15 presents delta heading (H1-H3) as a function of time during the aforementioned 5-knot runs.

It can be seen in Figure 15 that the maximum curvature of the array for both ship headings was usually between 3/4 and 1 degree. From these results, which are typical of all data runs, the effects of the ship's heading on array curvature are considered negligible.

ARRAY AND SHIP HEADING STABILITY

HAYES was equipped with a conventional autopilot for maintaining ship's heading using a standard feedback loop between the ship's gyro and the rudder. It was found that the autopilot could not be used effectively at 3 knots because of steerage and control problems associated with operating the vessel at low speed in heavy weather. However, the autopilot could be used at 5 and 10 knots. The objectives of these trials were to evaluate HAYES stability as a function of autopilot usage and to establish whether such usage affected the array stability. The 5-knot trials represented a worst case and are detailed herein.

The ship's heading variation as a function of time during the autopilot evaluations at 5 knots is presented in Figure 16. Heading variations of up to ±5 degrees about the requested course were common for the manually maintained helm. It also was observed that minimizing these heading variations required significant helmsman concentration, and thus varied with each helmsman. However, the results presented in Figure 16a were typical of a good helmsman. Figure 16b illustrates the improvement in ship's heading stability when the ship was steered with the autopilot. The heading variations were reduced to ±2 degrees although it appeared that the average measured heading was slightly offset from the requested heading. The difference between the requested course and the average course steered with the autopilot was about 1.5 degrees, and probably due to the helmsman not activating the autopilot when the ship heading was precisely on the requested heading.

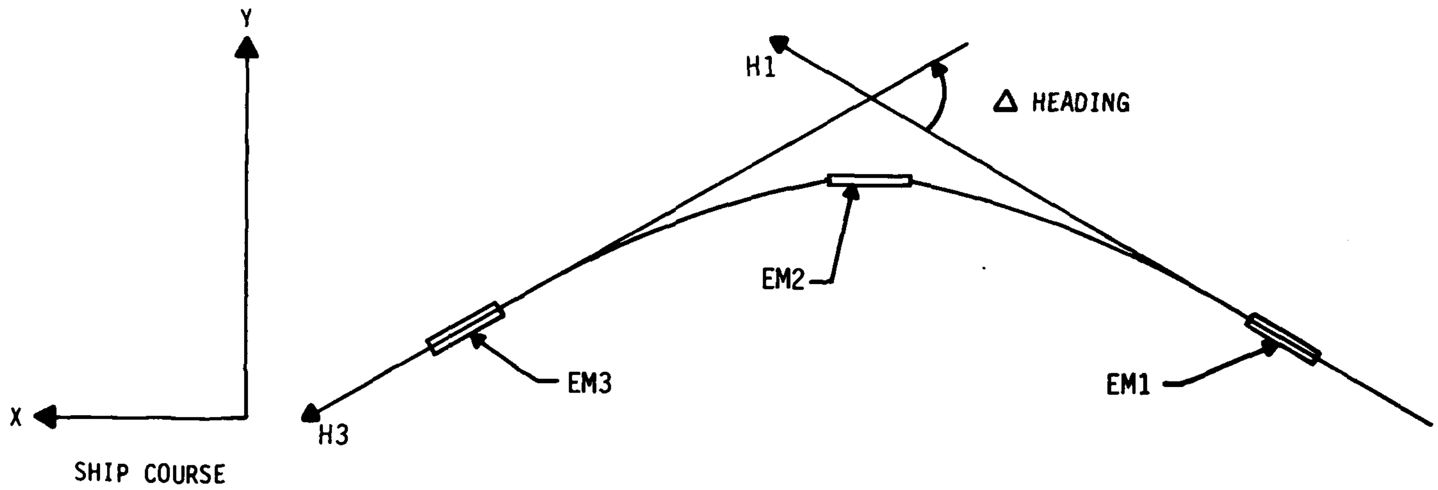
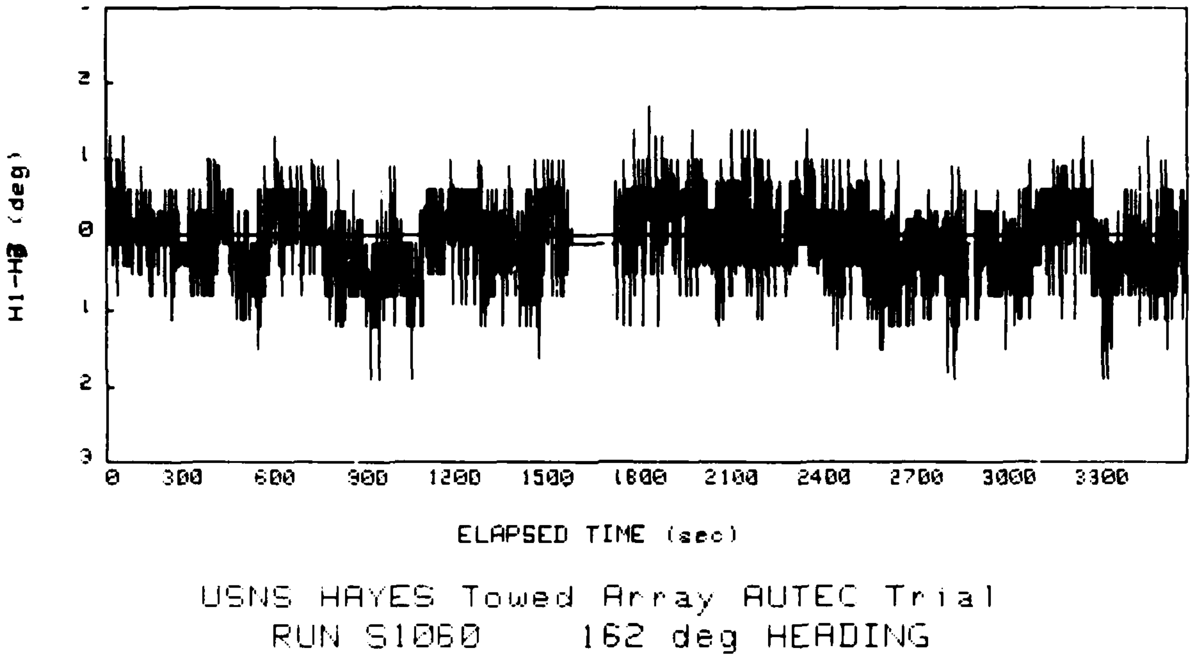


Figure 14 - Definition of Delta Heading (H1-H3)



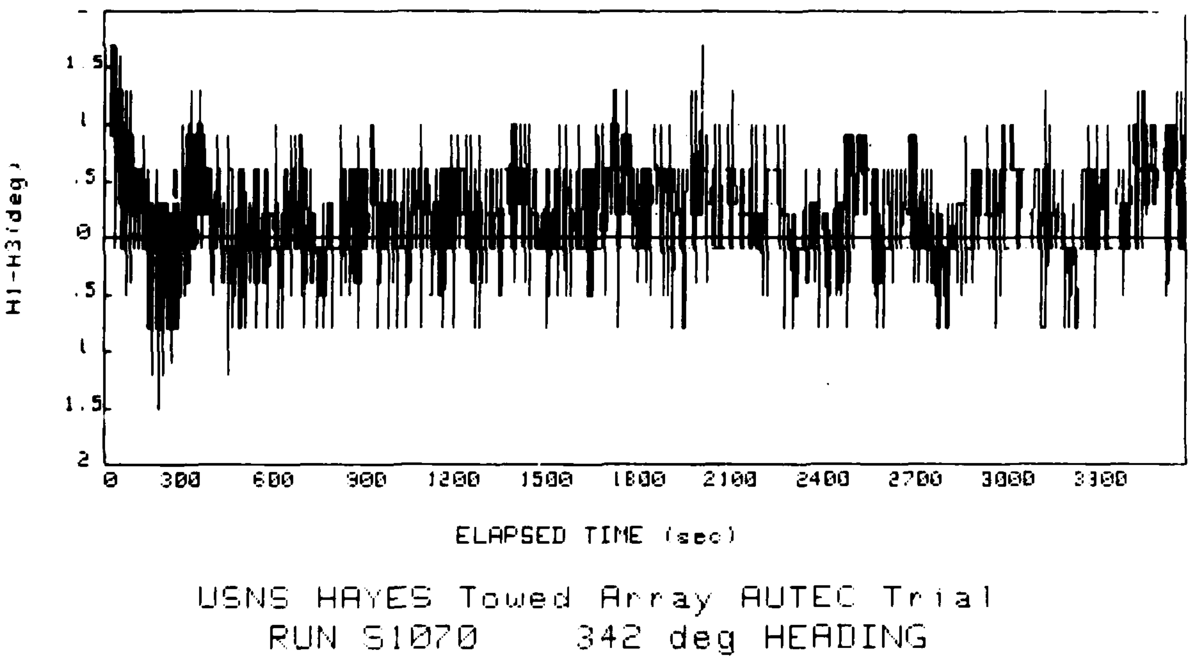


Figure 15 - Delta Heading (H1-H3) as a Function of Time for Nominal Ship Headings for Run S1060 and Run S1070 of 162°T and 342°T at 5 Knots

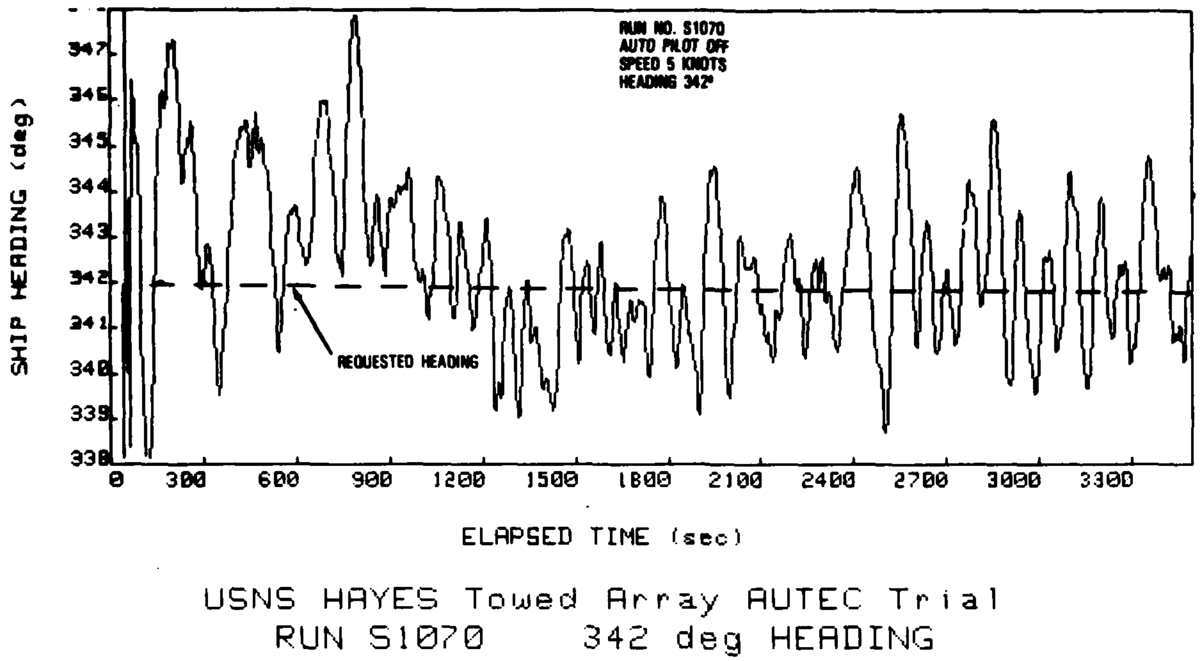


Figure 16a - Autopilot Off

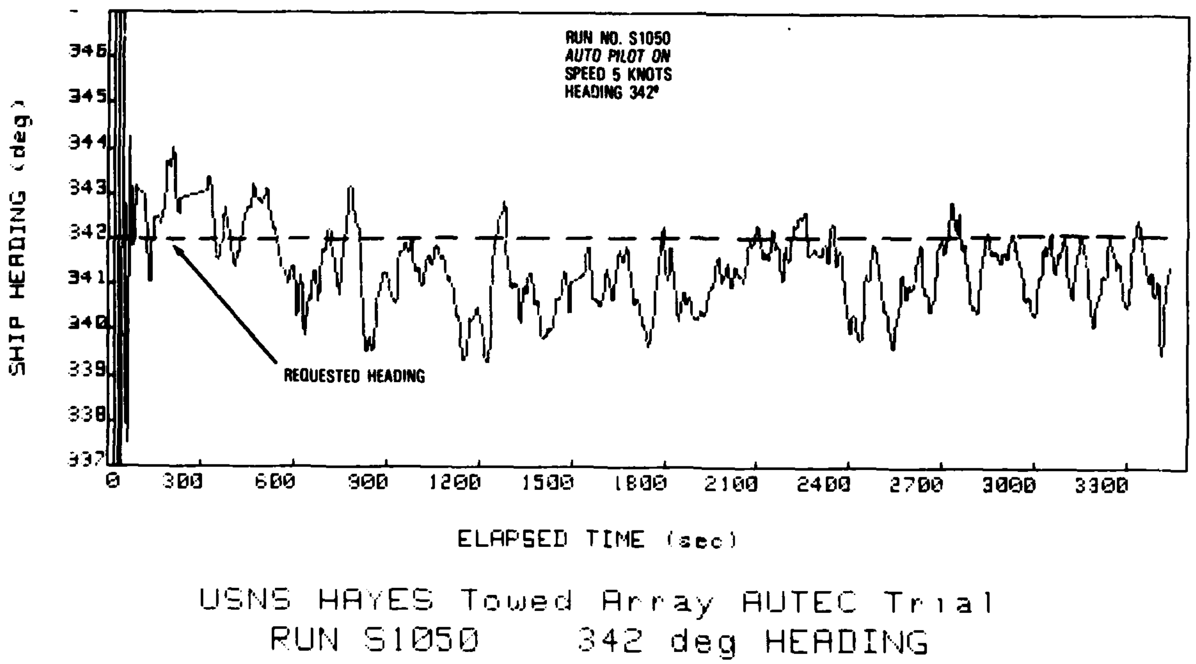


Figure 16b - Autopilot On

Figure 16 - Ship Heading Variation as a Function of Time for Autopilot On and Off

The resulting array heading variations as a function of time during the aforementioned autopilot evaluations are presented in Figure 17. Note the difference in the data traces in the two figures. Most shipboard data presented in this report are filtered using a six-pole Butterworth low-pass digital filter to improve readability. In addition, both AUTEC and shipboard data are processed with a data dropout removal routine which removes any data that exceed prescribed bounds. The output shown in Figure 17a results from deleting dropouts and not filtering the data. The data trace for each module has a width of about 0.3 degree, which is the resolution of the module heading sensors. Figure 17b illustrates filtered data for a run with data dropout. For this run each data trace has been filtered with a cutoff frequency of 0.05 Hz to reduce noise resulting from the heading resolution. However, as seen in Figure 17b, whenever data with dropouts were filtered, decaying noise spikes were added to the data traces at the data dropout. Thus, only shipboard data with few data dropouts were filtered.

As shown by Figure 17a, for tests without the autopilot, the array heading tended to meander about the average requested heading, with a maximum variation of about 3.5 degrees. For the trial using the autopilot, Figure 17b, the array heading also meandered about the average heading with a variation of 3 degrees. The difference between the array headings that occurred during these test was insignificant and the autopilot had no measureable effect on array stability. Furthermore, examination of the headings measured within the aperture section reveals the aperture section was straight to within approximately 1.5 degrees regardless of autopilot usage. The autopilot did decrease the ship's heading variation, but it had no measureable effect on array stability.

ARRAY MOTION AS A FUNCTION OF TOWSPEED

After it was determined that neither ship's heading nor autopilot usage affected array stability for these tests, the motion of the array itself could be characterized as a function of speed. The delta heading as a function of time for speeds of 3, 5 and 10 knots is shown in Figure 18. Figure 18c shows a mean offset of about 0.5 degree. The reason for this offset is not known at this time. Taking this offset into account, the maximum delta heading was slightly dependent on speed; however, it never exceeded approximately 1.5 degrees. In fact, if a smooth line is drawn through the data, neglecting the spikes, a maximum delta heading of less than 1 degree is seen.

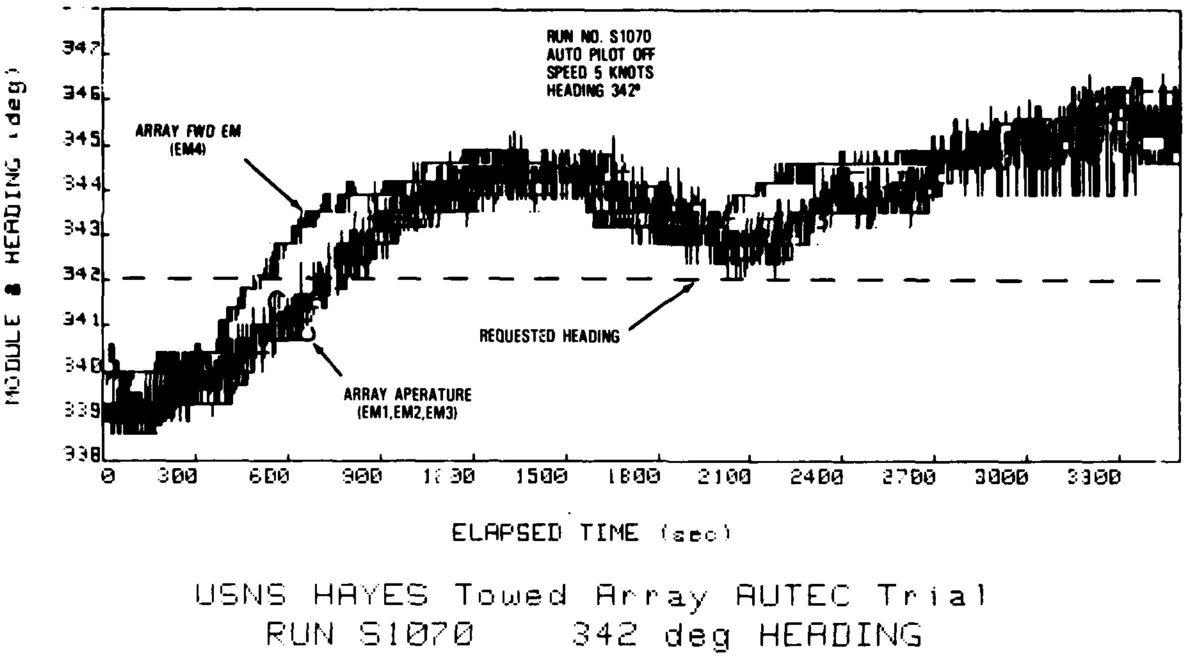


Figure 17a - Autopilot Off

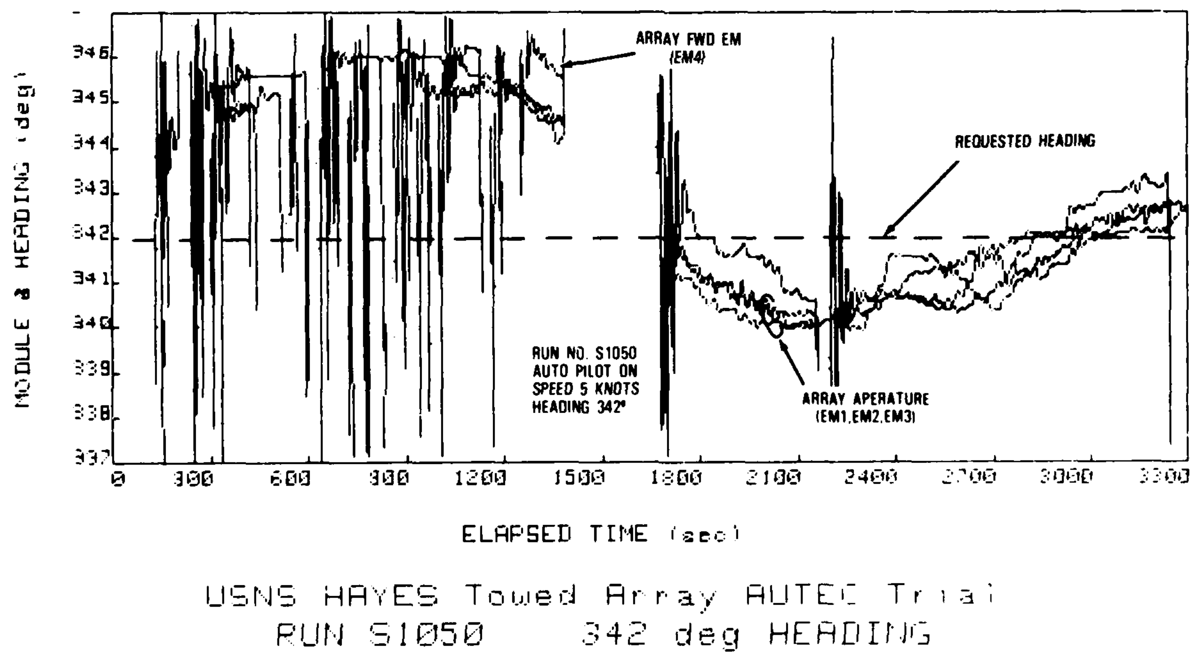


Figure 17b - Autopilot On

Figure 17 - Array Heading Variation as a Function of Time for Autopilot On and Off

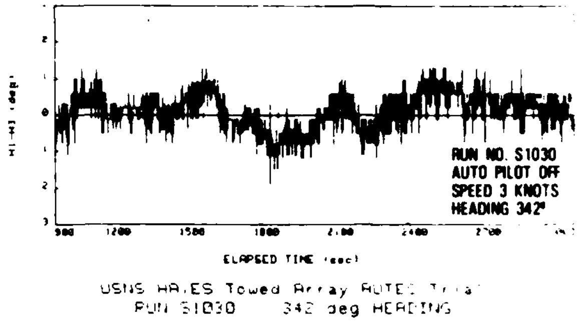


Figure 18a

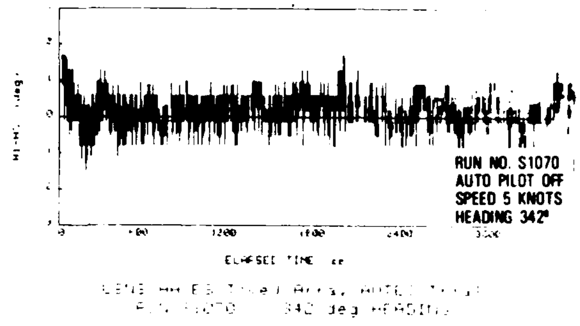


Figure 18b

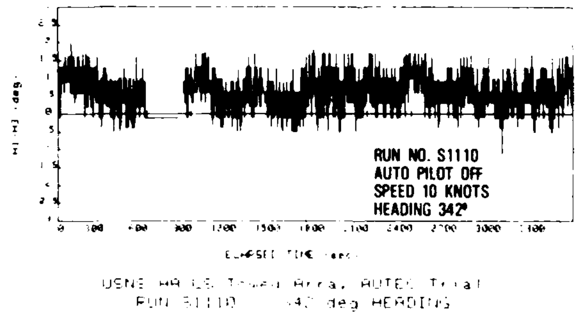


Figure 18c

Figure 18 - Delta Heading (H1-H3) as a Function of Time for 3, 5, and 10 Knots

Generally, as speed increases, the lift on the towcable increases. This increase of lift decreases the depth at which the array section tows as can be seen in Figure 19. Each time series graph shows the depth of all array modules. The three data lines shown grouped at the same depth are the data from the array aperture modules. The data line shown well below these on each graph is the time series for the nosecone module. These data show the effects of a slight neutral buoyancy imbalance in the array. The separation between the nosecone module and the array aperture modules decreases as speed increases and the array becomes more horizontal. The spikes in Figure 19b are due to data transmission failures in the array.

The rate of array depth excursion with time for the three trial speeds is shown in Figure 20. The spikes, particularly in Figure 20a (Run S1030), should be ignored for they represent AUTEC tracking losses. The trend in this data is that the depth excursion rate increases as speed increases. However, the approximate maximum rate is only 0.05 m/sec.

A trend similar to the depth rate data occurs in the transverse displacement rate data. As speed increases, transverse displacement rates show a slight increase as shown in Figure 21. The first half hour of the data in Figure 21b (Run S1070) shows an aberration from this trend. This aberration can be attributed to the transient response of the array after the towship performed a Williamson turn. For most runs, enough time was allowed after the towship turn for the array to reach a pseudo steady-state condition. For Run S1110, as shown in Figure 21c, at 10 knots the maximum transverse displacement rate was 0.1 m/sec. It appears that, in general, the transverse displacement rate is twice the depth excursion rate. These results (i.e., array becomes more straight and horizontal as speed increases and transverse displacement rate increases as speed increases) are completely consistent with the results of other towed array hydromechanical studies.[7] The local motion of a towed array generally is driven by the turbulent boundary layer wall pressure spectra, which are functions of towspeed. It has been observed that array transverse acceleration levels are significantly greater than longitudinal acceleration levels and tend to increase with increasing towspeed, with an attendant decrease in amplitude. This would result in an increase in transverse velocity, as measured and reported herein.

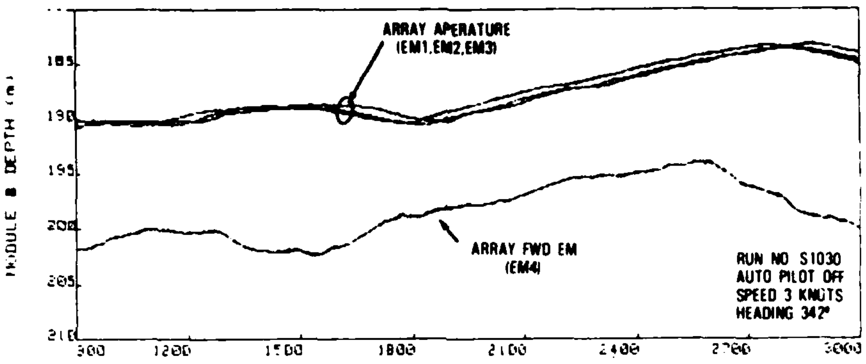


Figure 19a

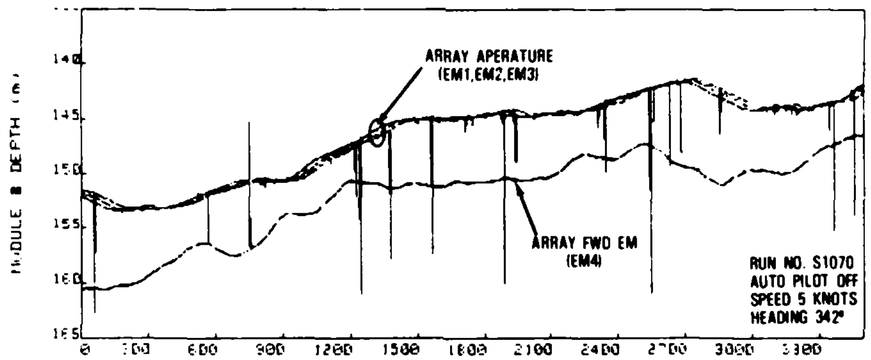


Figure 19b

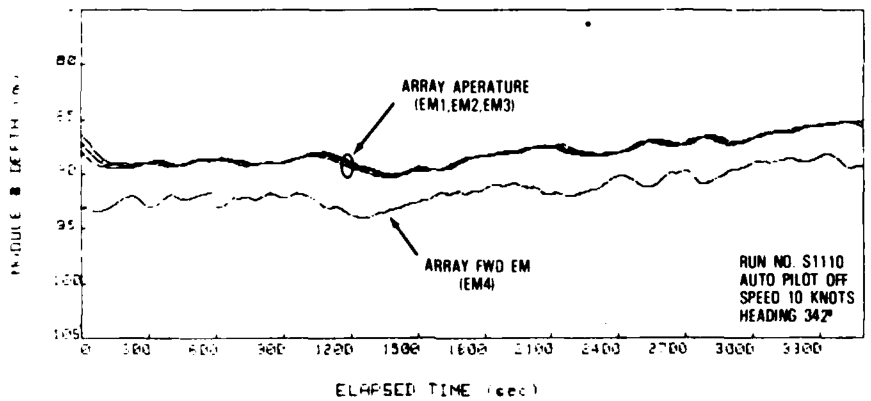


Figure 19c

Figure 19 - Array Depth as a Function of Time for 3, 5, and 10 Knots

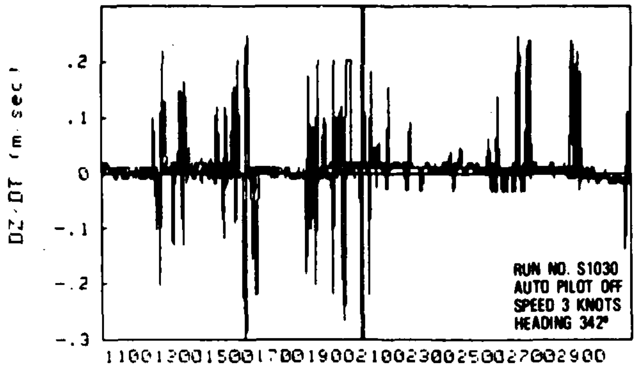


Figure 20a

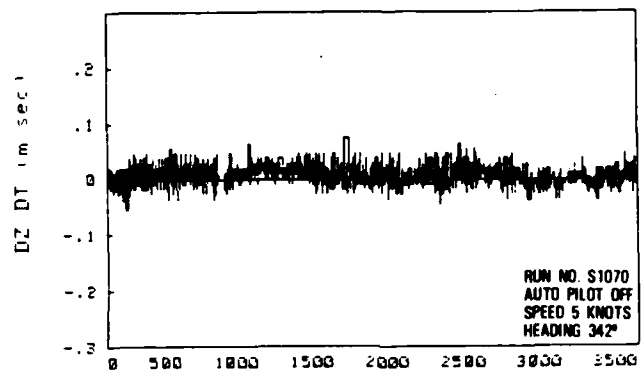


Figure 20b

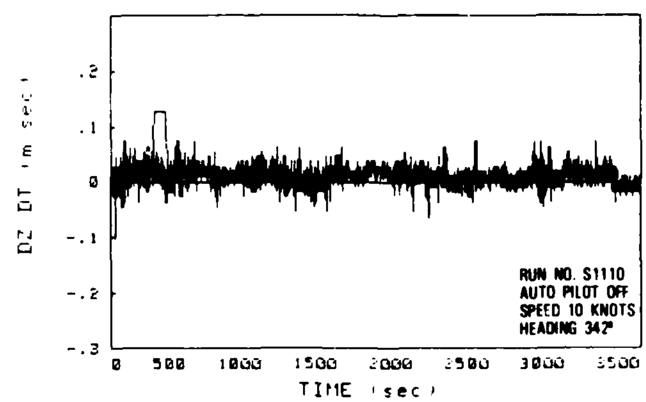


Figure 20c

Figure 20 - Rate of Depth Excursions (DZ/DT) as a Function of Time for 3, 5, and 10 Knots

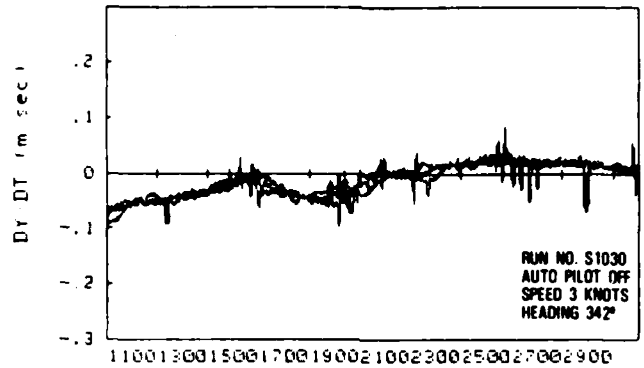


Figure 21a

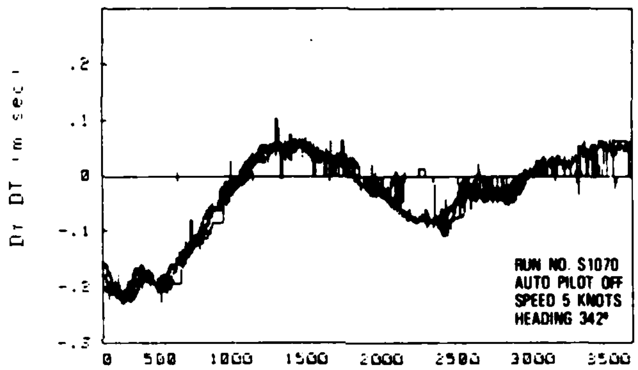


Figure 21b

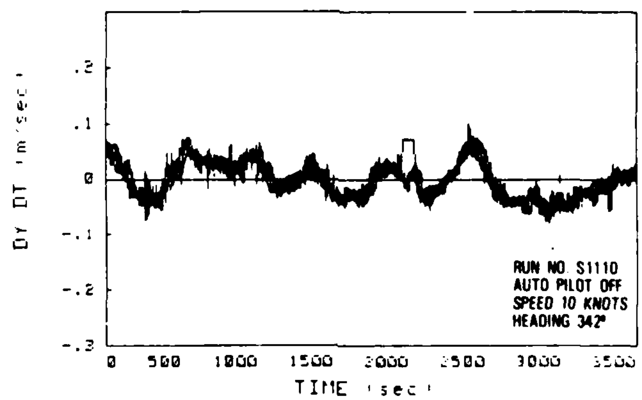


Figure 21c

Figure 21 - Rate of Transverse Displacements (DY/DT) for 3, 5, and 10 Knots

ARRAY RESPONSE TO SINUSOIDAL STEERING

For straight line runs the array motion is primarily dependent on towspeed. In order to investigate the transmission of ship motion to array motion more thoroughly, the HAYES' motion was purposely increased in an attempt to force the array to respond. This was done by performing a series of runs in which the helm was purposely varied about a base course with a regular period. This approximated a sinusoidal ship's course, the amplitude and period of which became the independent variables. As shown previously in Table 1, the sinusoidal runs occurred at 8 and 10 knots using rudder angles of ±2, ±10, and ±20 degrees. Examination of results revealed that the high-frequency, short period sinusoidal runs using ±10 and ±20-degree rudder had no measurable effect on array motion or configuration. However, the low frequency, longer period sinusoidal run using ±2 degrees rudder did result in some array motion.

The ship and array transverse displacements as a function of time for the short period and long period runs are presented in Figure 22 and are compared with a baseline straight line run. As indicated for the straight line run, the array followed nearly directly in the ship's path with a minimal displacement to port of only about 10m. The ship's transverse displacement during the ±10 degree rudder sinusoidal trials (Figure 22b) had a period of 96 seconds, yet the array track indicated virtually no response to the ship motion. (Note that the array displacement at the beginning of this run indicates that the array was still recovering from the Williamson turn after the previous run.) However, the array did respond to the low frequency ±2 degrees sinusoidal tests having a 1200-second period (Figure 22c). In general, the ship's sinusoidal amplitude was greater than the array's response amplitude, had the same period, and had a time lag approximately equal to the spatial separation between pingers divided by the towing speed (i.e., time required for each pinger to advance to the ship's location). Clearly, the array motion was effectively isolated from the ship motion except at the lowest frequency. These results were consistent with conventional "water pulley" effects that describe array motion relative to the towship.[8]

The array heading measurements for these same straight line and sinusoidal runs are presented in Figure 23. As shown, the array was only responsive to ship motions for the low frequency sinusoidal run (Figure 23c). The response amplitude was about ±3 degrees, and the period was about the same as the ship excitation

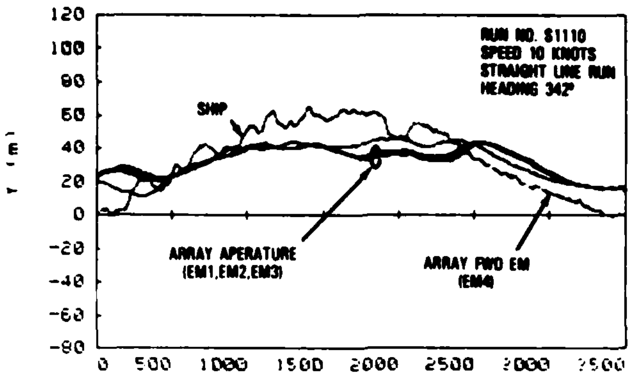


Figure 22a

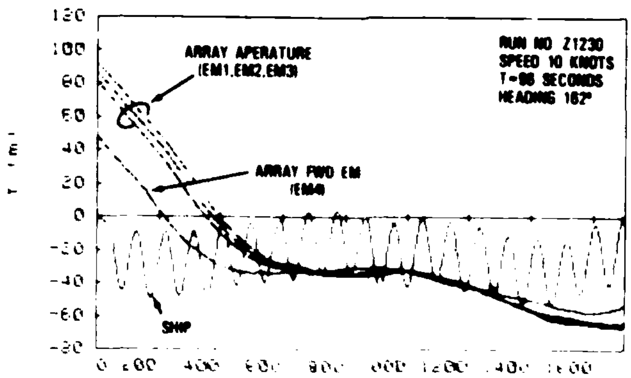


Figure 22b

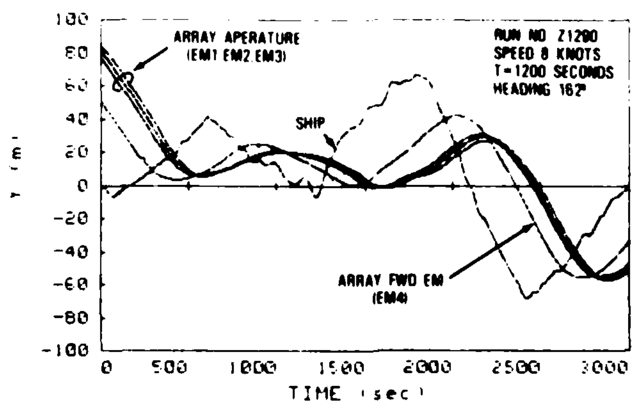


Figure 22c

Figure 22 - Ship and Array Transverse Displacements as a Function of Time for a Straight Line Run and Two Dimensional Runs

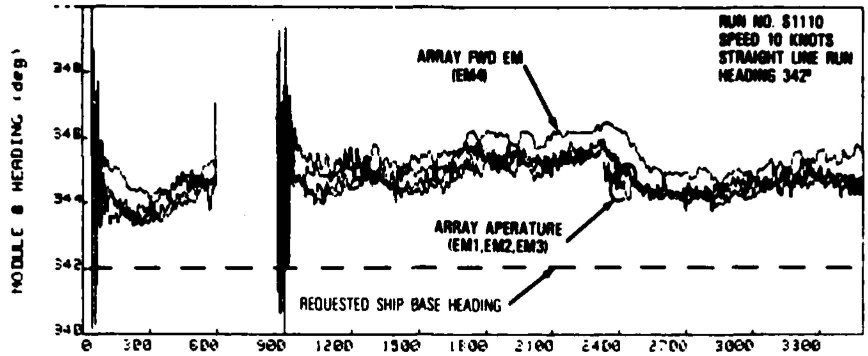


Figure 23a

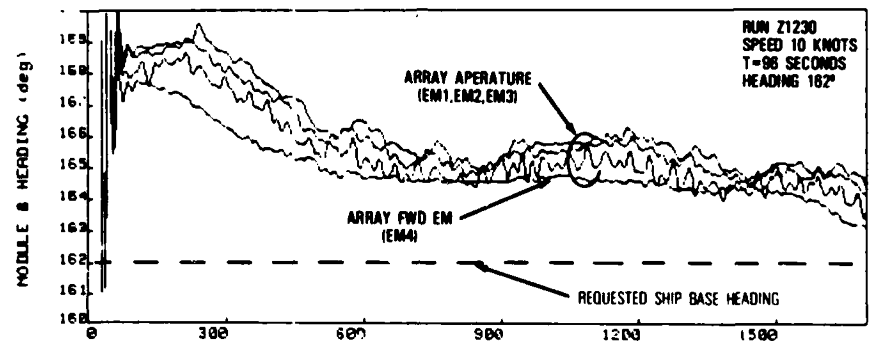


Figure 23b

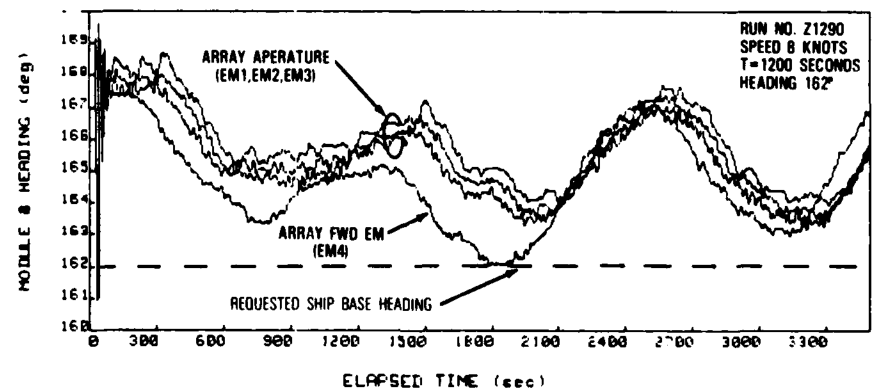


Figure 23c

Figure 23 - Array Heading Variation as a Function of Time for a Straight Line Run and Two Sinusoidal Runs

period. Note that the array operative heading measurements (i.e., H1, H2, and H3) were still within 1.5 degrees of each other, indicating that the array was still very straight, even though it followed the ship's sinusoidal displacement.

The array depth measurements as a function of time for these straight line and sinusoidal runs are presented in Figure 24. As shown, array depth across the 200-m (656-ft) aperture was essentially constant to within 0.5m, (1.64 ft) and independent of the ship's sinusoidal displacement. These results were consistent with cable/array hydromechanics wherein depth is primarily a function of towspeed, which remained constant during these sinusoidal tests. The array motion was nearly independent of HAYES motion for all but the lowest frequency sinusoidal runs. The array 200-m (656-ft) aperture still remained straight to within 1.5 degrees.

DISCUSSION OF LAUNCH AND RETRIEVAL

The array was retrieved twice during the sea trial, the first event occurred after the transit to the AUTEC range and the second occurred at the completion of the trials. Two spacer modules were damaged during each of these retrieval sequences. The damage to the array consisted of the hosewall separating from the coupling and was a result of the high freeboard putting excessive weight and drag on the section of the array between the power sheave and the water. This problem is unique to arrays using the internal strength members where the hosewall lacks sufficient strength for supporting the entire towing load. The problem also may be unique to this particular array. The attachment of the hosewall to the coupling is still undergoing design work.

Besides the aforementioned problem, the launch and retrieval of the towed array system from the stern of HAYES was accomplished with little difficulty. The deck space for the winch, winch power supply, power sheave, power sheave power supply, the array, its tub and personnel was more than adequate.

TOWING LOAD AS A FUNCTION OF TOWSPEED

Towcable tension at the ship and nosecone tension as functions of ship speed over the ground are shown in Figure 25. The curves drawn through the data points are an empirical least squares power fit. It should be noted that these tensions may not be indicative of tensions for the TTUMS array.

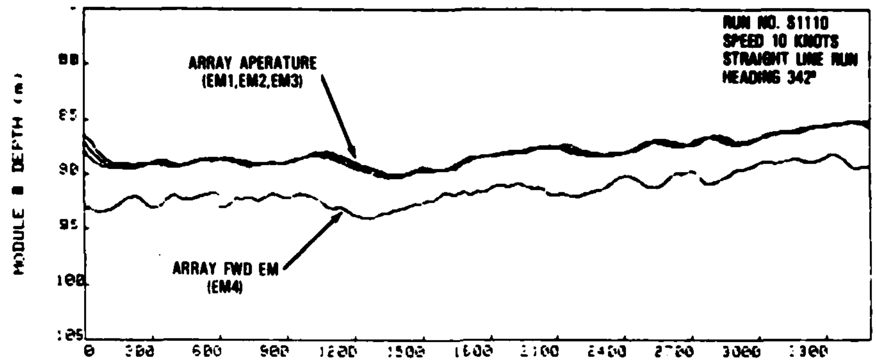


Figure 24a

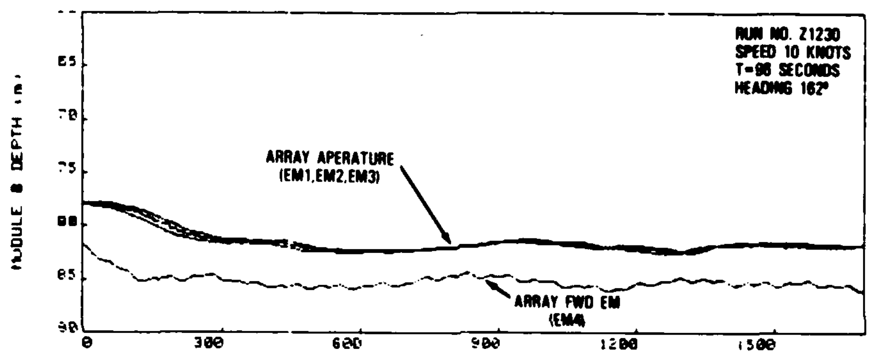


Figure 24b

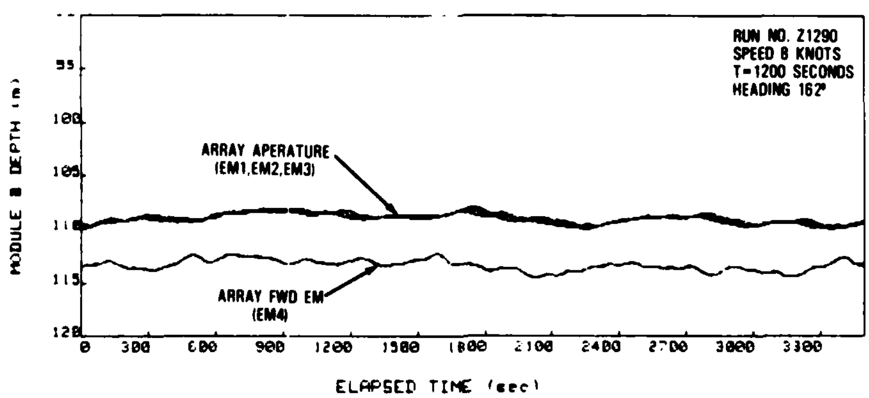


Figure 24c

Figure 24 - Array Depth as a Function of Time for a Straight Line Run and Two Sinusoidal Runs

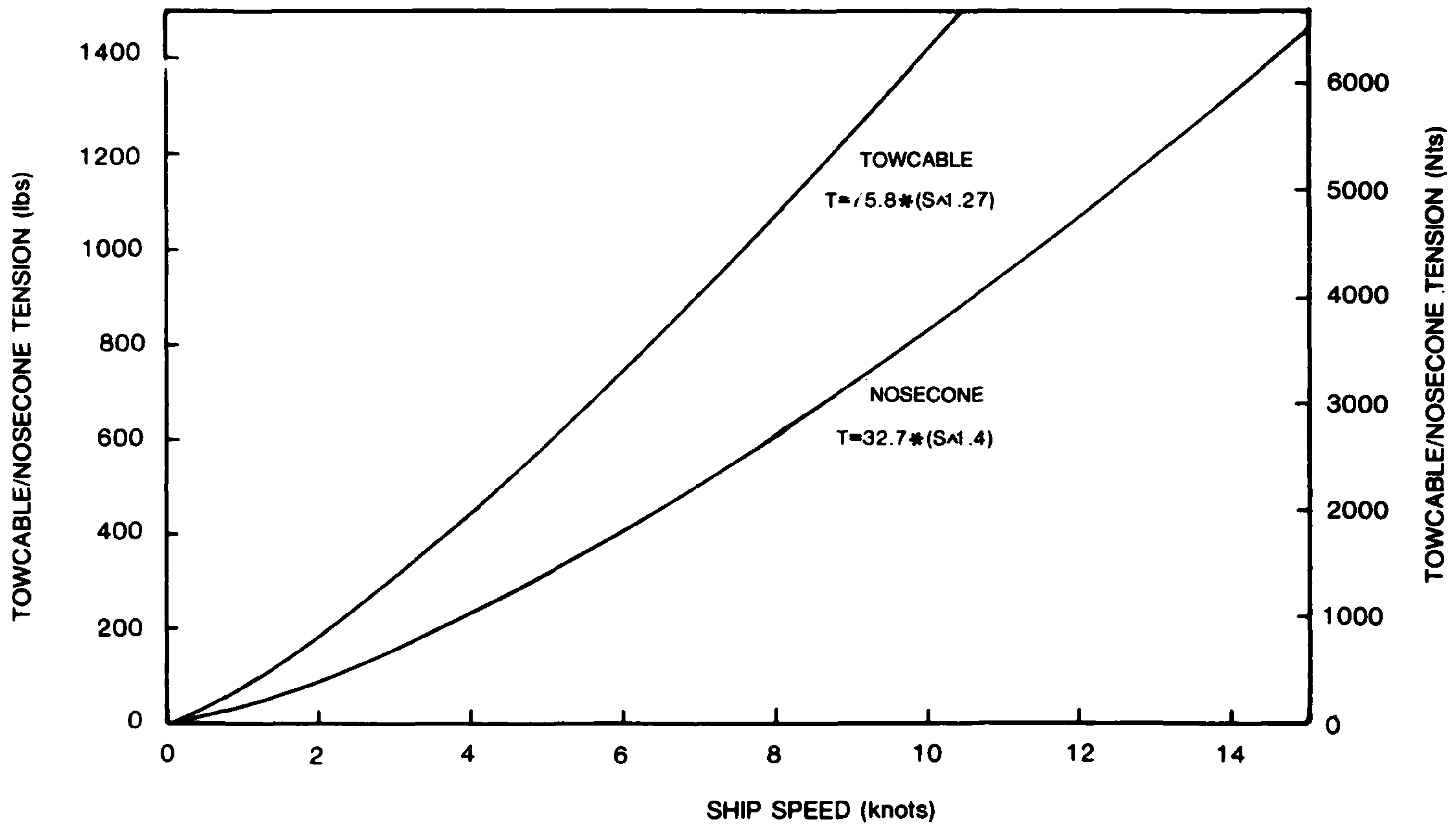


Figure 25 - Towcable and Nosecone Tension as a Function of Speed

CONCLUSIONS

The purpose of these experiments was to obtain sufficient data to determine if the USNS HAYES' motion introduced unacceptably large motions into a TTUMS-like towed array. Because HAYES had a reputation as a rough riding ship with a unique corkscrew motion, there was concern for its usefulness as a TTUMS towing platform. For serious consideration, the ship needed sufficient stability with minimal motion to facilitate array stability, on-deck handling operations, and crew comfort. The results of these tests indicate that the HAYES' motion was not adverse but completely tolerable. The experiments were very successful and resulted in the acquisition of a significant bank of towed array motion data. The towcable acted as a low-pass mechanical filter and effectively isolated the array from high-frequency motion transmitted by HAYES.

Sea Conditions were:

1. Sea states from 2.5 to 4;
2. Wind speeds from 13 to 27 knots;
3. Wind directions from 10 to 87 degrees T.

The following is a summary of key observations drawn from the experimental results:

a. For nominally straight-ahead ship trajectories the array remained straight to within about 1.5 degrees over the entire 200-m (656 ft) aperture at all times and to within approximately 1.0 degree on average.

b. The array aperture towed nearly horizontal with maximum depth variations of less than 1m (3.3 ft).

c. The array motion was primarily speed dependent, but independent of high-frequency ship motion.

d. Array curvature was independent of ship's heading.

e. The array motion was generally independent of most helmsman errors or course meandering that would normally occur during straight-line TTUMS-like towing tests. In addition, array motion was independent of autopilot usage.

f. The long period sinusoidal runs had a noticeable effect on the array configuration. The towcable acted as a low-pass mechanical filter and isolated the array from all but the lowest frequency ship motions.

The TTUMS classified requirements dictate a maximum allowable deviation for depth and heading over the aperture length and a maximum transverse velocity.

Based on the data presented here, the resulting motion of the TARP array in a TTUMS like towing configuration over the towspeed range of 3 to 10 knots was:

Maximum Heading Deviation = 1.5 degrees

Typical Maximum Heading Deviation = 1.0 degree

Average Depth Deviation = 0.5m (1.64 ft)

Average Transverse Velocity = 0.1 m/sec (0.33 ft/sec)

The exact TTUMS requirements have not been totally defined. However, these motions should be adequate for the TTUMS mission. The ship is stable in the sea conditions of the experiment and does not adversely affect array motion or stability. It has ample space for electronic laboratories, technical conference rooms, and data analysts' offices. Furthermore, there was sufficient room for all aft gear installations. And lastly, the personnel accomodations are extremely spacious and comfortable for both on and off watch activities. Based on these results HAYES should be a suitable TTUMS towing platform.

ACKNOWLEDGEMENTS

The authors would like to recognize Don Abraham, Joe Mingrone, Gabriel de la Cruz, Jim Archer and Lambert Burton of the Naval Underwater Systems Center, New London, CT for supplying the TARP array and associated instrumentation and for providing substantial assistance in many areas of the experiment.

The authors also would like to thank Denny Woolaver, Rich Bishop, Gordon Minard and their associates of the David Taylor Naval Ship R&D Center for providing ship data input.

REFERENCES

1. McClinton, A.T., "USNS HAYES (T-AGOR 16) U.S. Navy Oceanographic Research Ship," NRL Report 7370 (Apr 1972).

2. "Student Handbook: TTUMS" Gould/Defense Electronics Division, Glen Burnie, MD.

3. Woo, E., et al. "Performance and Manuevering of USNS HAYES (T-AGOR 16) with and without a Towed Array," DTNSRDC SPD 2001-02 (1984).

4. Woolaver, D., et al. "Results of Seakeeping Trials Conducted Aboard USNS HAYES (T-AGOR 16)," DTNSRDC SPD 2001-03 (1984).

5. Abraham, D.D., "Engineering Design and Development for TARP VII AUTEC Sea Trial," NUSC TM No. 811025 (Jan 1981).

6. Abraham, D.D., "Results of TARP VI Shakedown Sea Trial," NUSC TM No. 801208 (Dec 1980).

7. Kennedy, R.M., "Cable Dynamics Experiment, Final Report," NUS Technical Report 6467 (22 Oct 1981).

8. Journal of Underwater Acoustics, Theme Issue: Towed Arrays, Vol 27, Issue 2, (Apr 1977).

APPENDIX A

USNS HAYES CHARACTERISTICS

TABLE A-1 - USNS HAYES DESIGN CHARACTERISTICS

Hull	
Length (LOA)	246 ft
Beam (Max)	75 ft
Freeboard (Amidships)	34 ft
Draft (Max)	19 ft
Displacement (Full load)	3,180 tons
Potable Water (Full load)	31 tons (7,451 gal)
Diesel Fuel (Full load)	368 tons (100,753 gal)
Machinery	
Main Propulsion	
Propulsion shafts	2 (i.e., one per hull)
Design full power	5,400 BHP
Endurance @ 13.5 knots	600 nm
Maximum sustained speed	15 knots
Personnel Requirements	
Officers and Crew (req'd)	45
Scientists (available)	25
Deck Gear	
Significant complement of deep sea winches, A-Frames, overhead cranes, etc.	
Laboratory Space	
Over 3000 square feet of electronics laboratory plus mechanical and electrical shops, wet laboratories, data analysis and conference rooms, etc.	

APPENDIX B

AUTEC WEAPONS RANGE TEST AREA

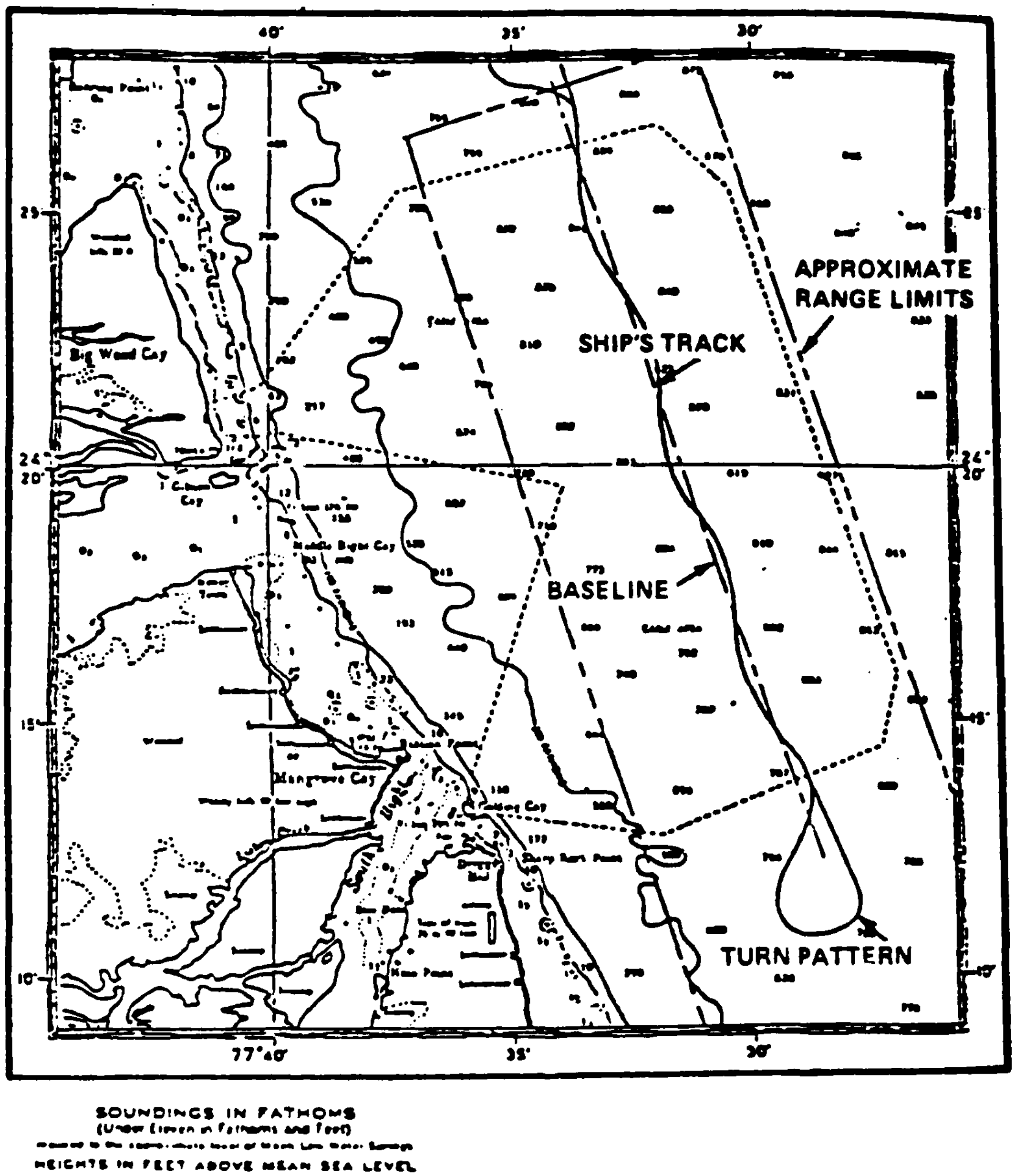


Figure B-1 - AUTEC Weapons Range Test Area

APPENDIX C

SHIPBOARD/ARRAY INSTRUMENTATION

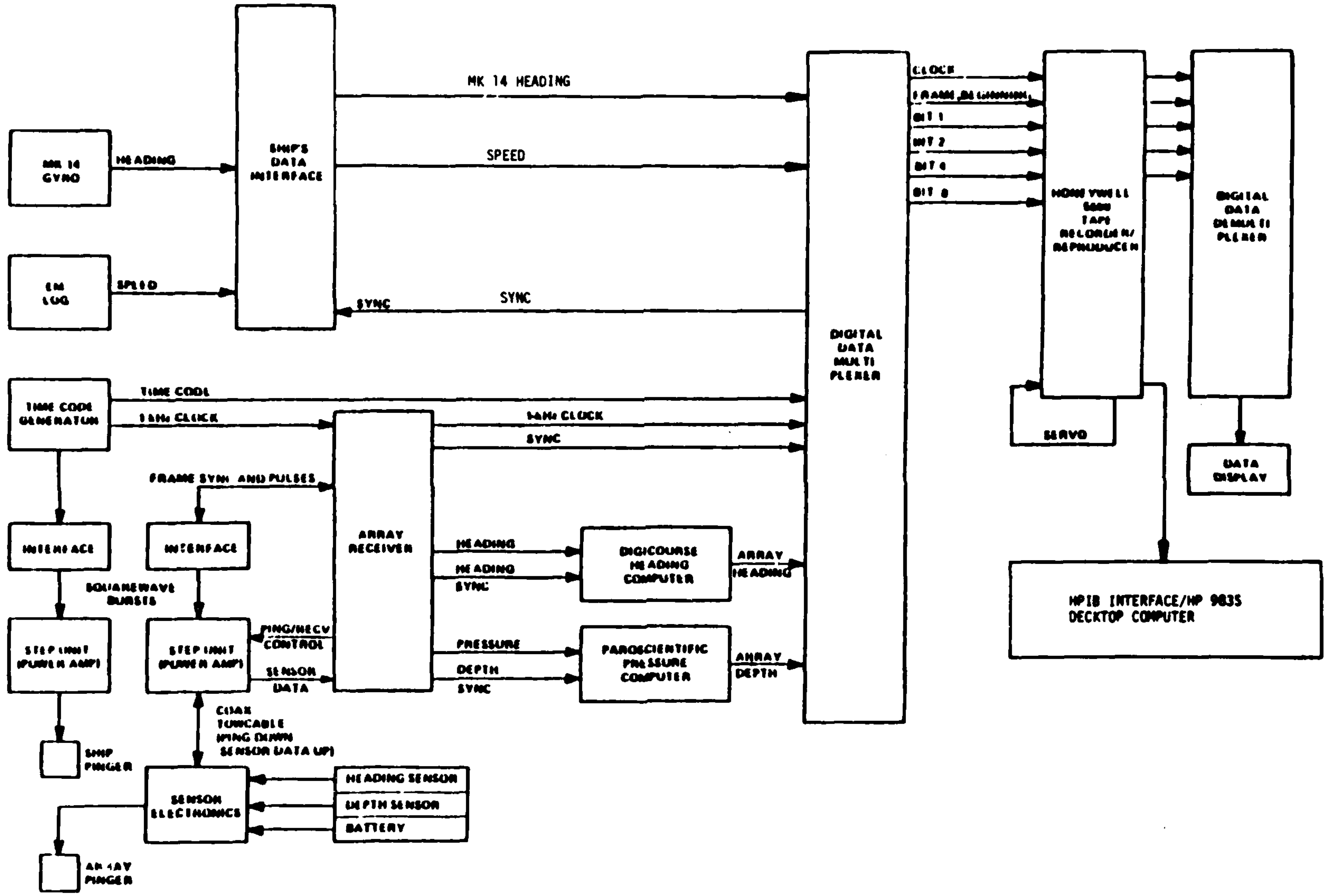


Figure C-1 - Primary Instrumentation Schematic for TARP Array

TABLE C-1 - PRIMARY SHIPBOARD INSTRUMENTATION

Sensor	Manufacturer	Model No.	Location	Range	Accuracy
Array Headings	Digicourse	318	Environmental modules	0 -359.9°	± 1/3°
Array Depths	Paroscientific	8270	Environmental modules	0 -270.0000m	± .0675m
Array Tensiometer	Oceanic Industries	2000	Environmental module 4	0 -2000 lb	± 10 lb
Towpoint Tensiometer	*	*	Gimbal towpoint	0 -5000 lb	± 50 lb
Towpoint Cable Angle	*	*	Gimbal towpoint	0 -90	± 1/2°
Towpoint Skew Angle	*	*	Gimbal towpoint	+45°-45°	± 1/2°
Ship Speed (EM log)	*	*	*	*	*
Ship Heading (Gyrocompass)	Sperry	*	*	*	*

* Not Available

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APPENDIX D
SELECTED MEASURED DATA

Figure D-1 - Run S1030 with Autopilot Off, at a Speed of 3 Knots and a Ship Heading of 342 Degrees

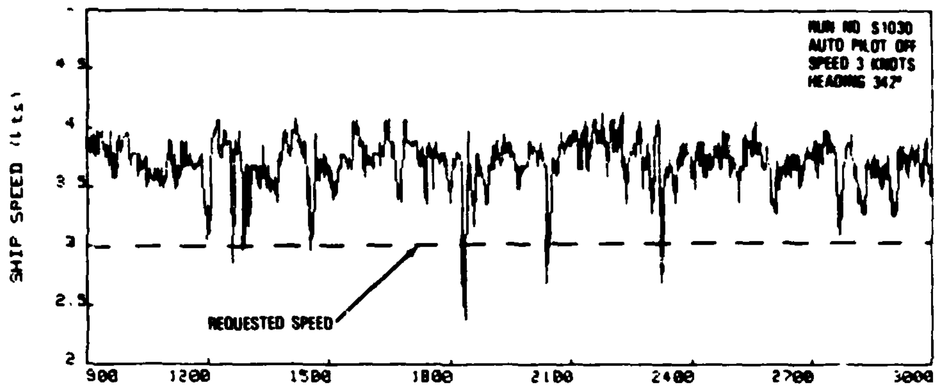

Figure D-1a

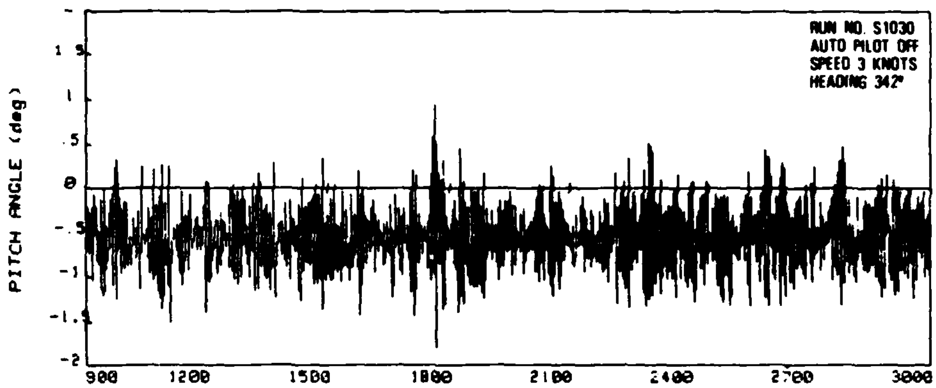

Figure D-1b

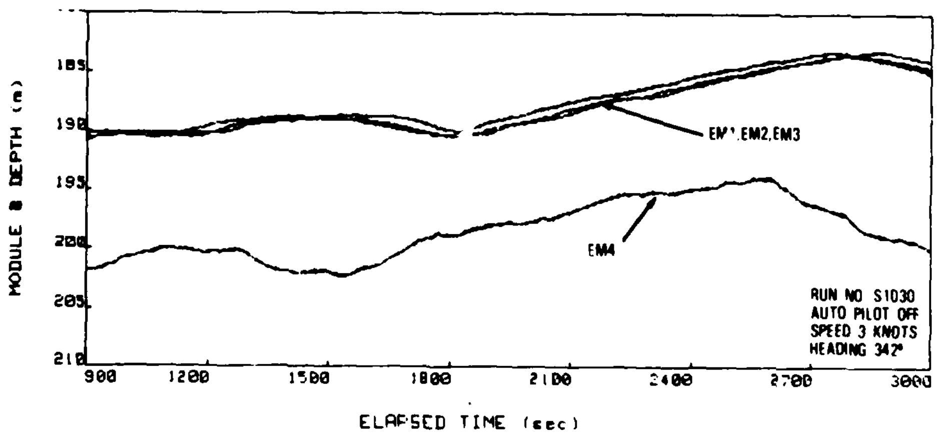

Figure D-1c

Figure D-1 (Continued)

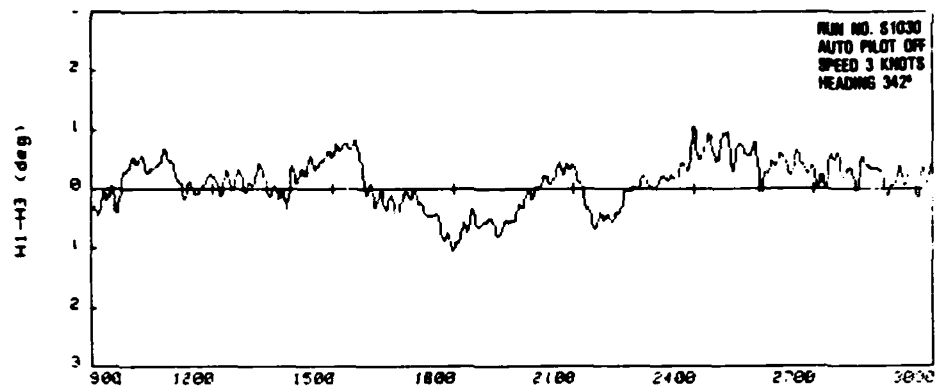

Figure D-1d

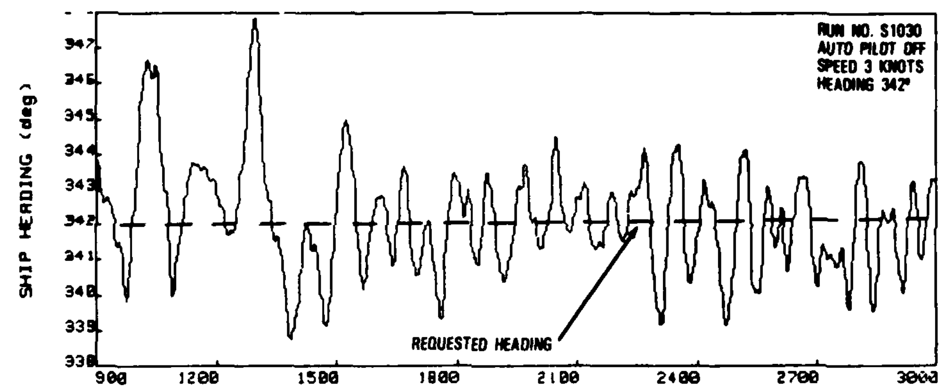

Figure D-1e

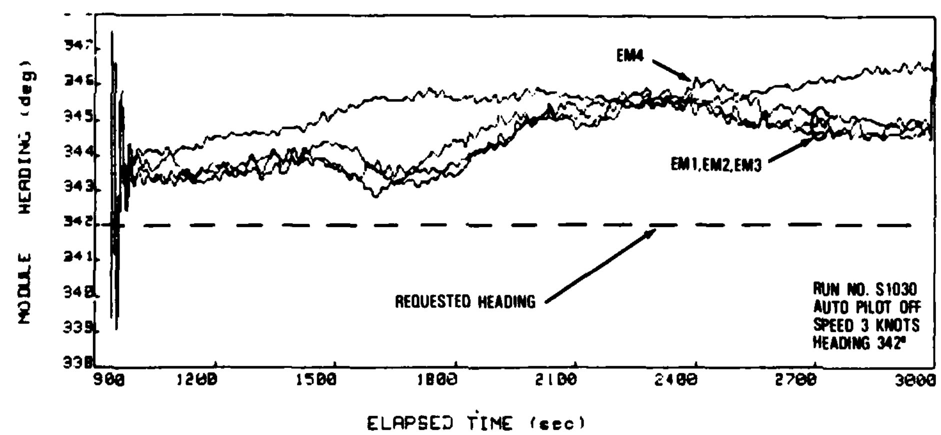

Figure D-1f

Figure D-1 (Continued)

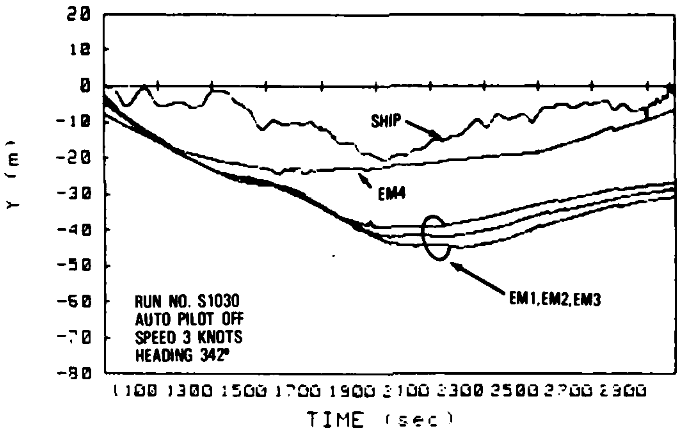

Figure D-1g

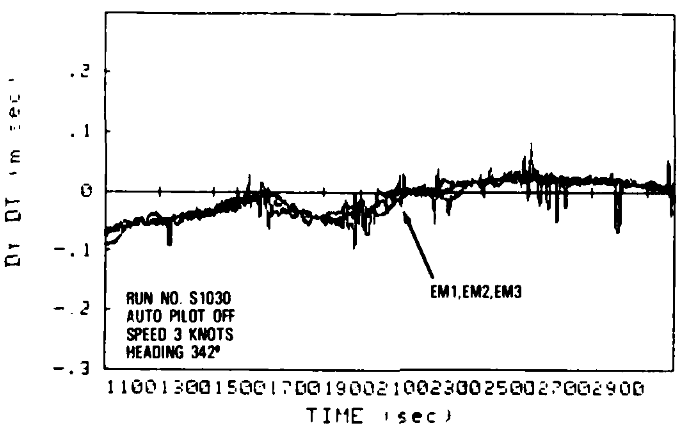

Figure D-1h

Figure D-2 - Run S1050 with Autopilot On, at a Speed of 5 Knots and a Ship Heading of 342 Degrees

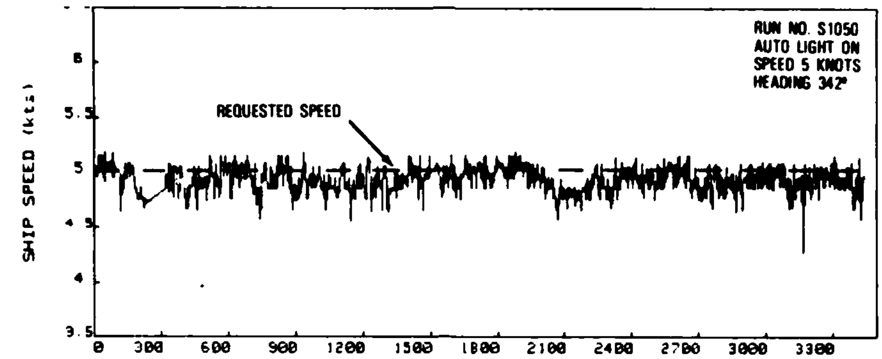

Figure D-2a

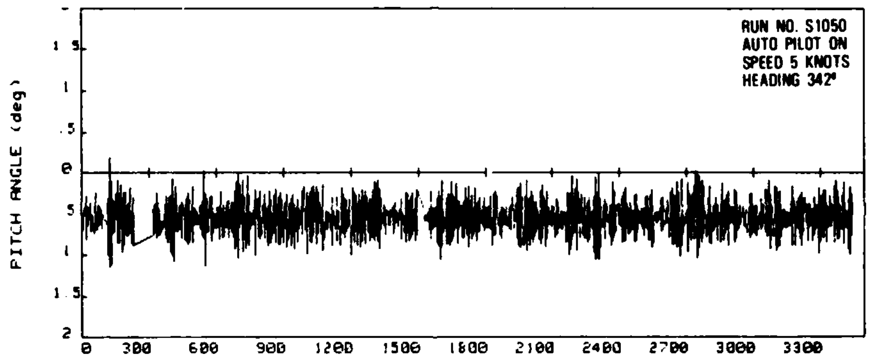

Figure D-2b

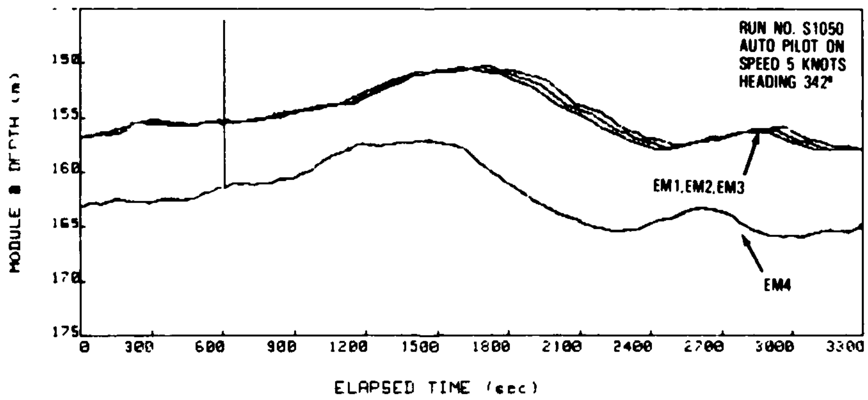

Figure D-2c

Figure D-2 (Continued)

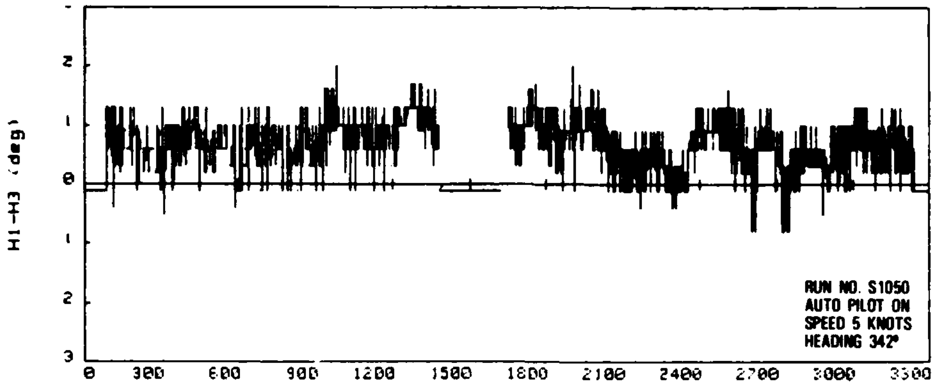

Figure D-2d

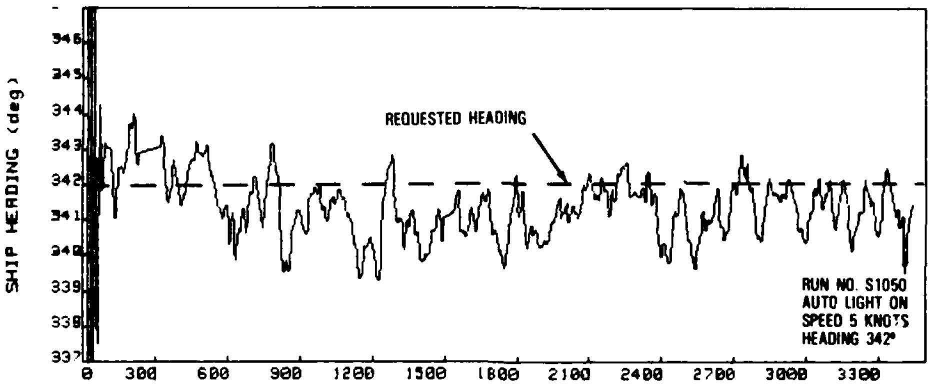

Figure D-2e

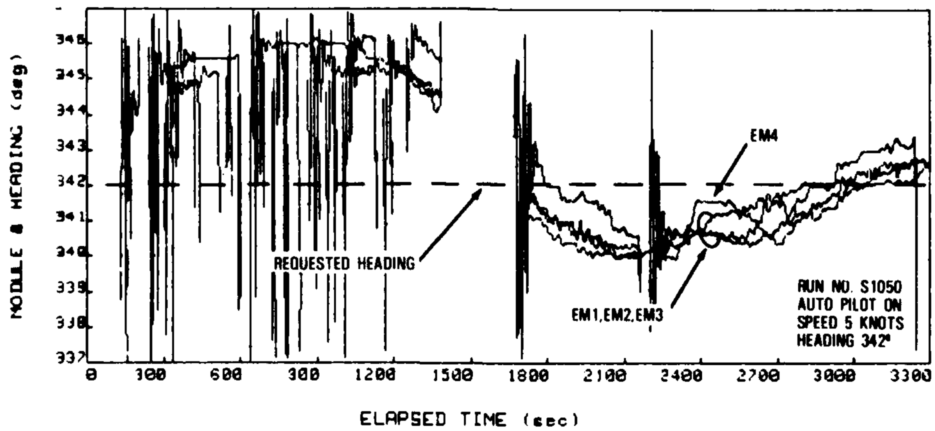

Figure D-2f

Figure D-2 (Continued)

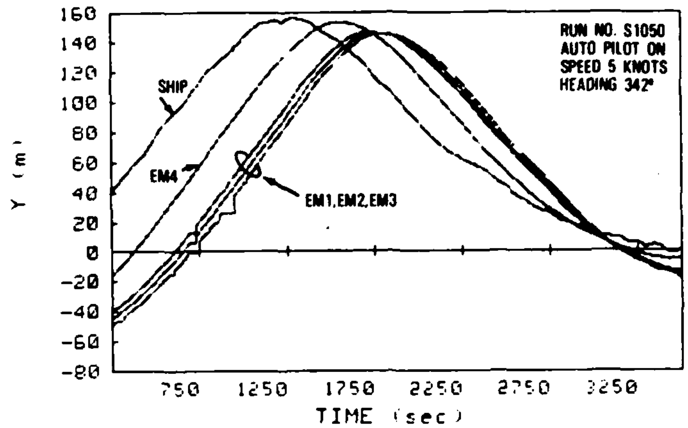

Figure D-2g

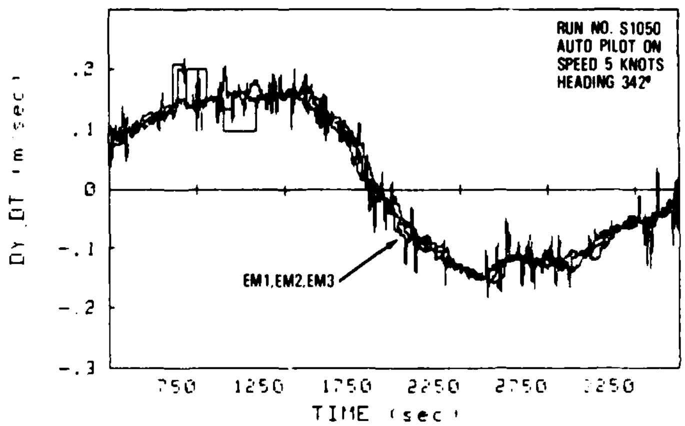

Figure D-2h

Figure D-3 - Run S1060 with Autopilot Off, at a Speed of 5 Knots and a Ship Heading of 162 Degrees

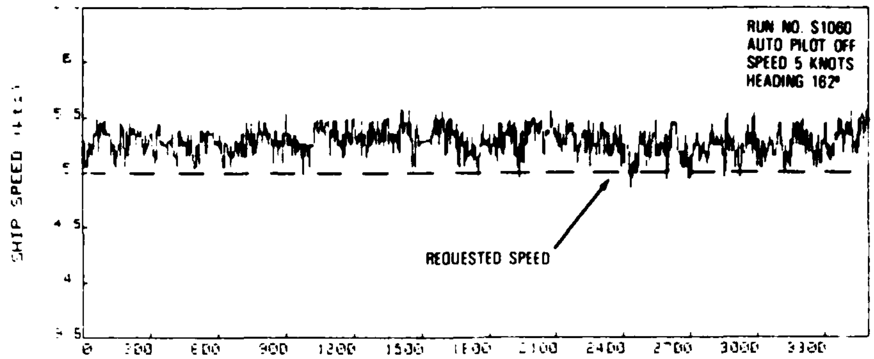

Figure D-3a

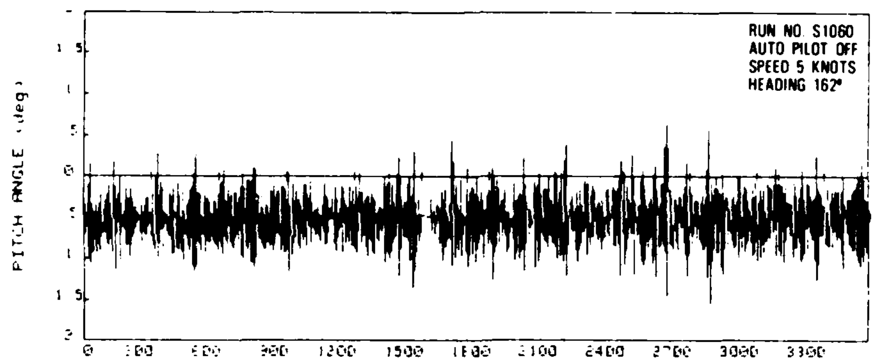

Figure D-3b

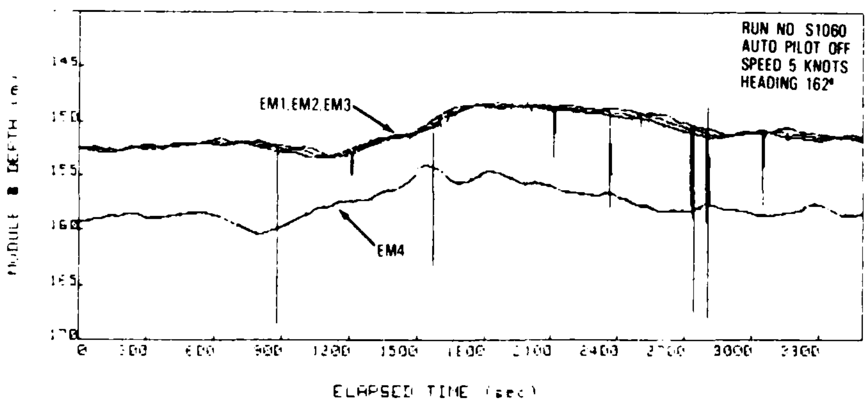

Figure D-3c

Figure D-3 (Continued)

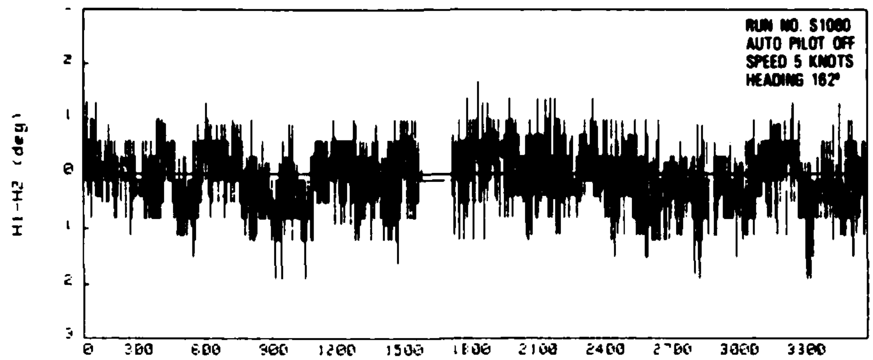

Figure D-3d

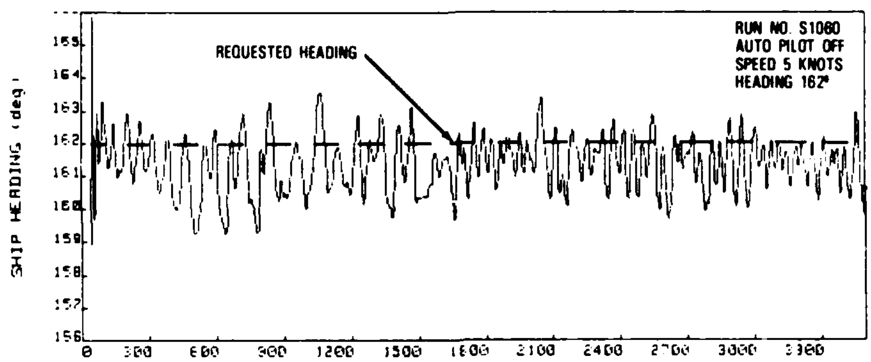

Figure D-3e

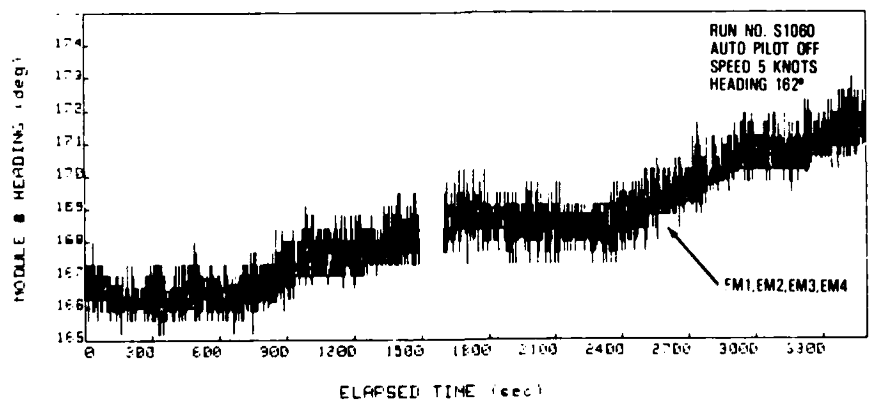

Figure D-3f

Figure D-3 (Continued)

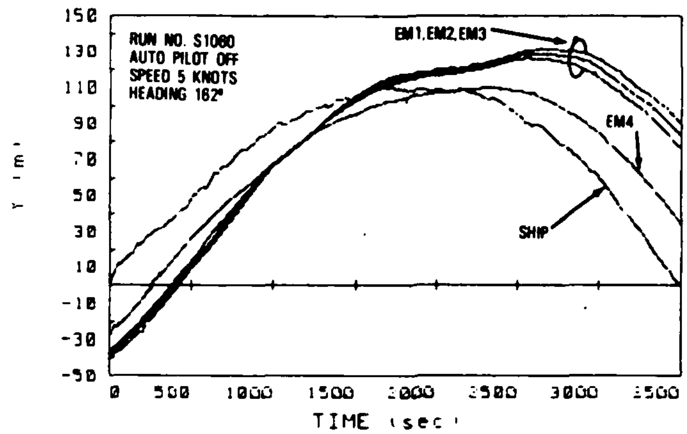

Figure D-3g

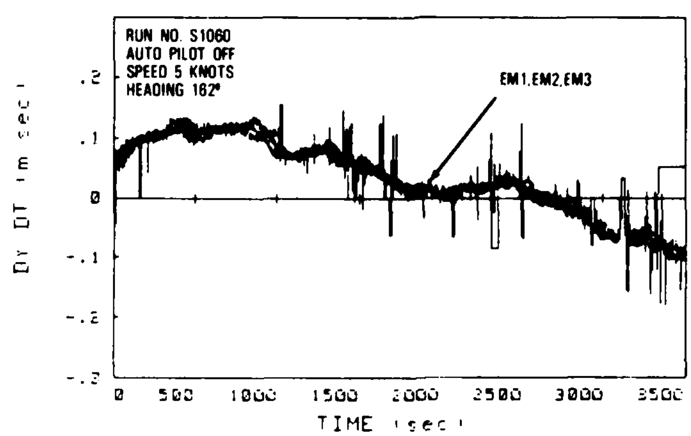

Figure D-3h

Figure D-4 - Run S1070 with Autopilot Off, at a Speed of 5 Knots and a Ship Heading of 342 Degrees

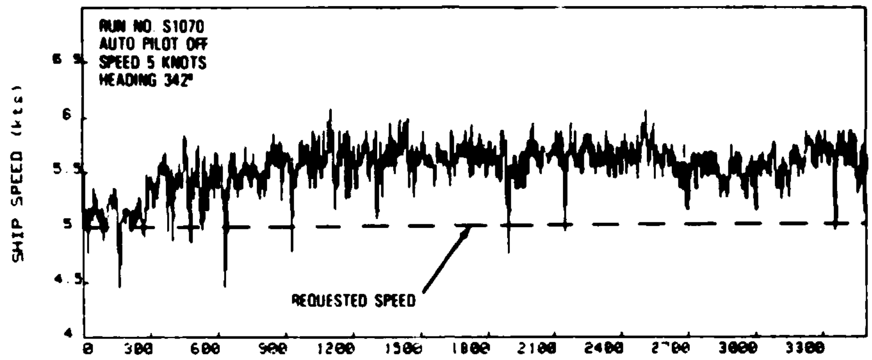

Figure D-4a

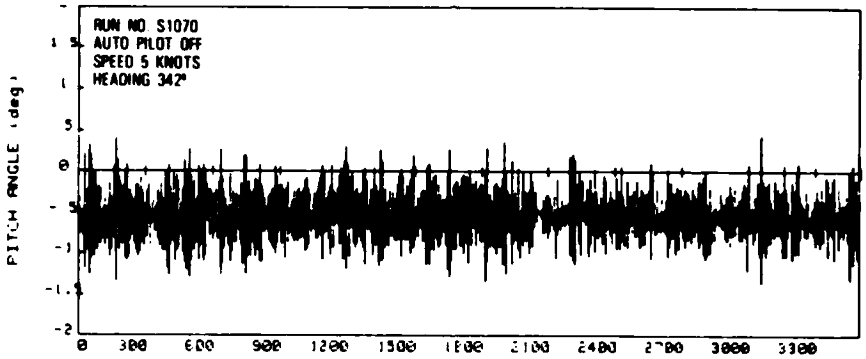

Figure D-4b

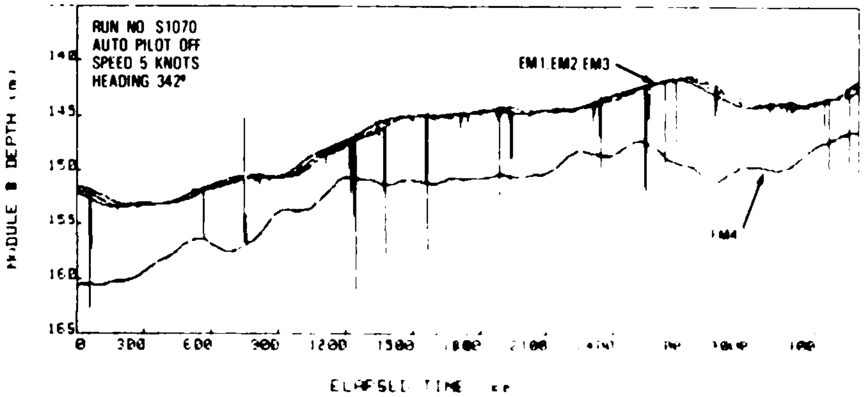

Figure D-4c

Figure D-4 (Continued)

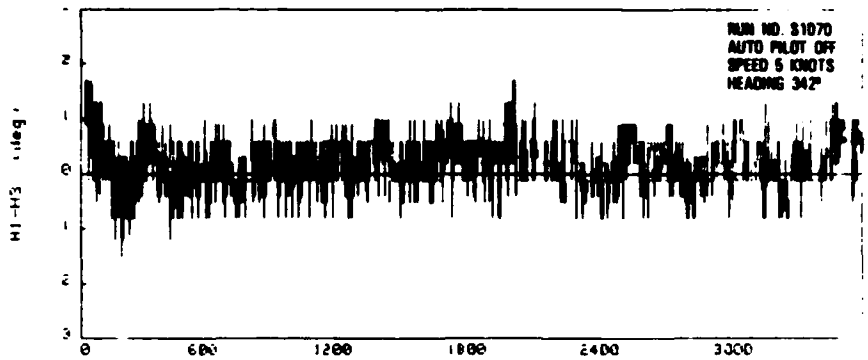

Figure D-4d

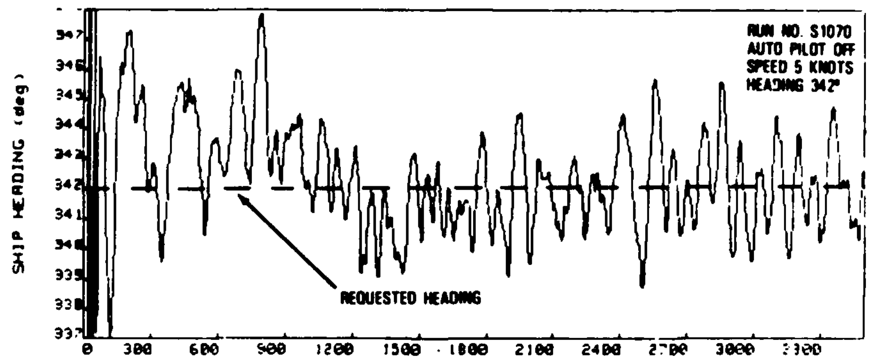

Figure D-4e

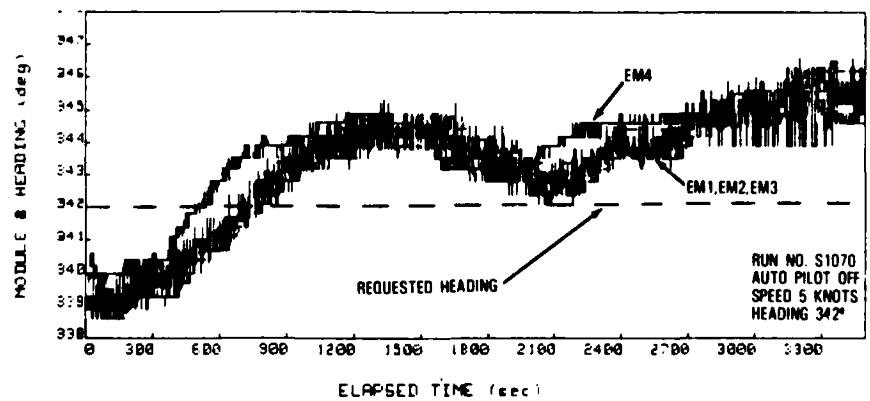

Figure D-4f

Figure D-4 (Continued)

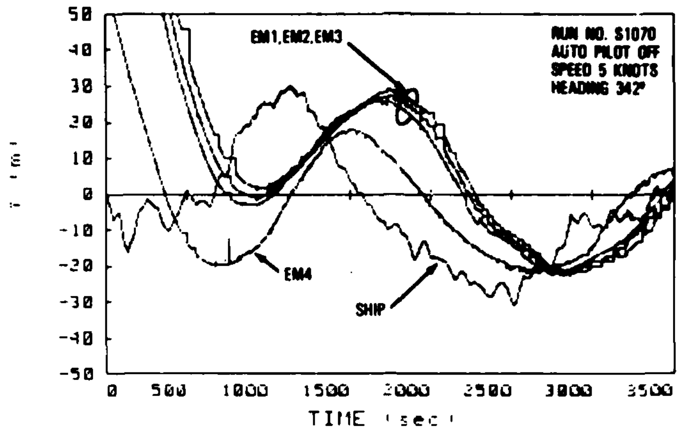

Figure D-4g

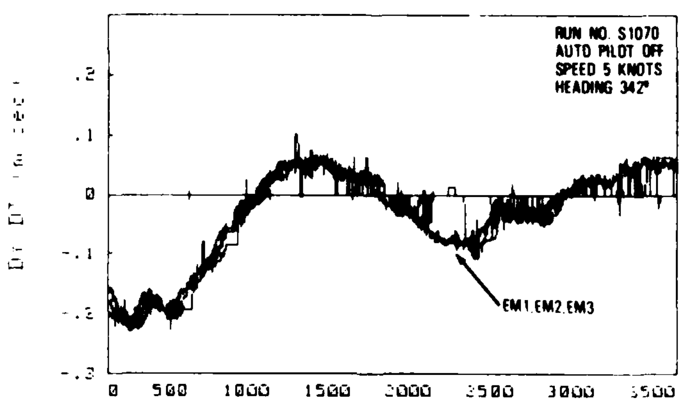

Figure D-4h

Figure D-5 - Run S1110 with Autopilot Off, at a Speed of 10 Knots and a Ship Heading of 342 Degrees

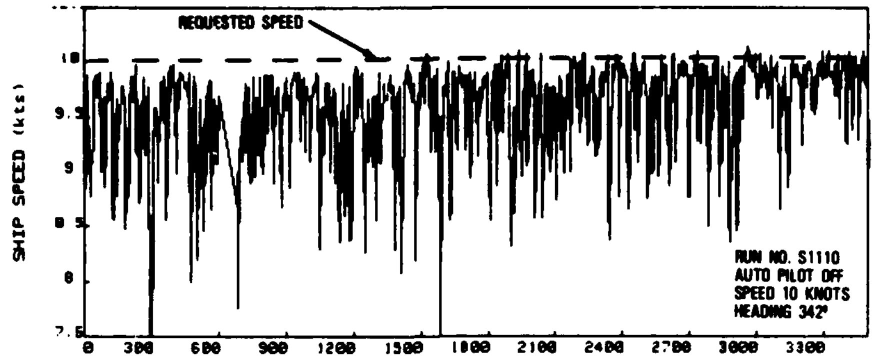

Figure D-5a

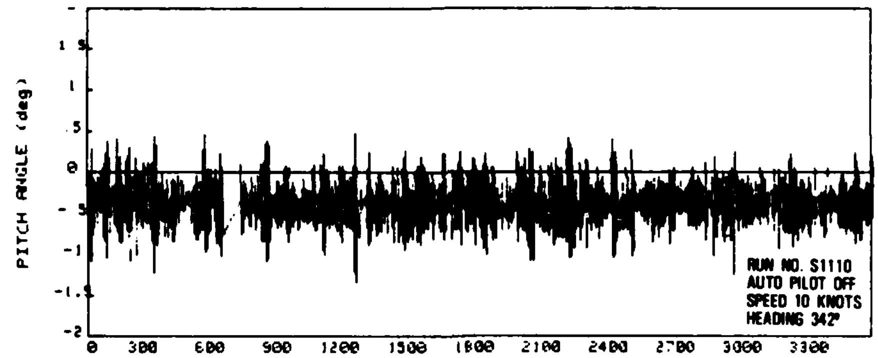

Figure D-5b

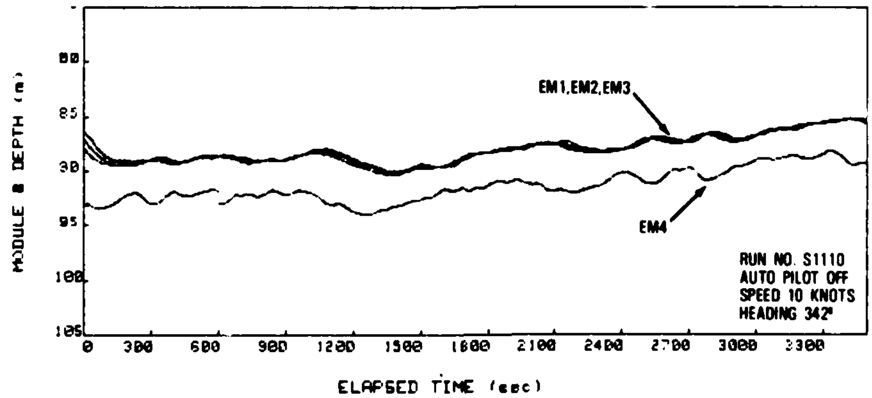

Figure D-5c

Figure D-5 (Continued)

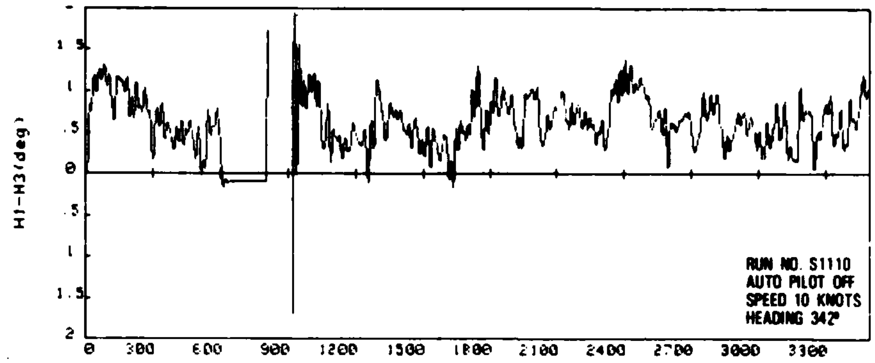

Figure D-5d

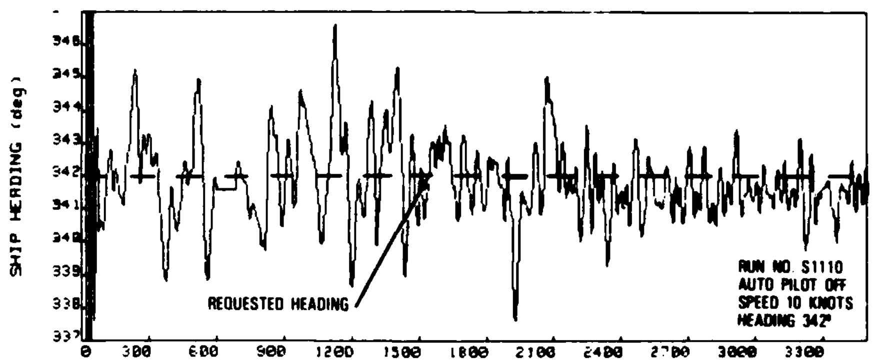

Figure D-5e

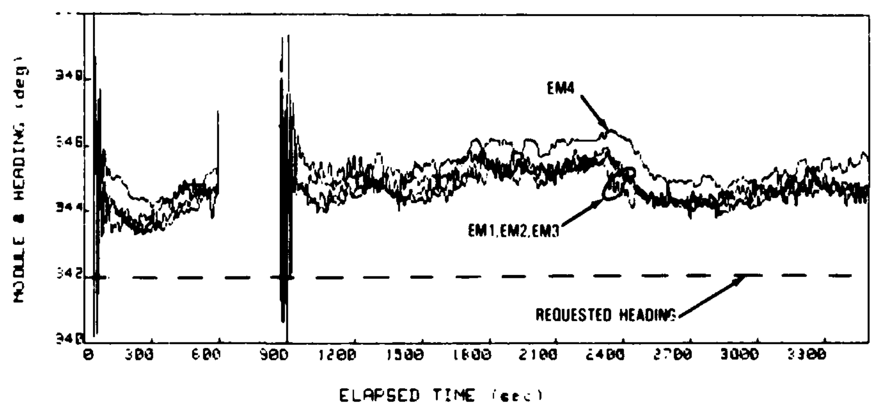

Figure D-5f

Figure D-5 (Continued)

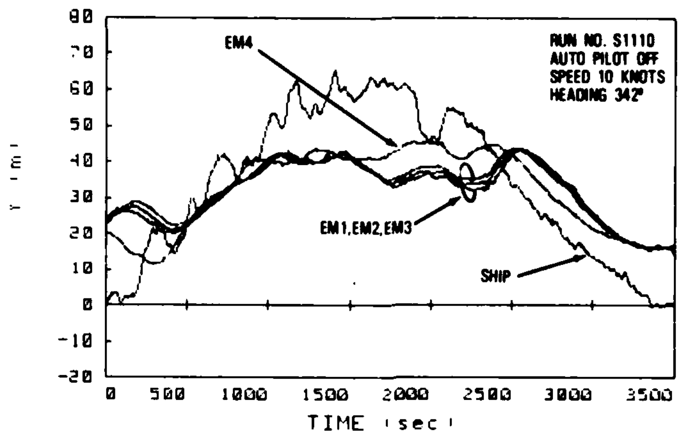

Figure D-5g

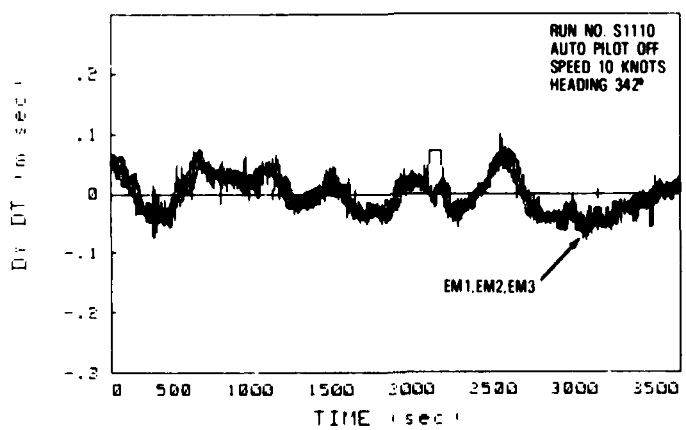

Figure D-5h

Figure D-6 - Run Z1230 with Speed of 10 Knots and 90 Second Period Sinusoidal Course

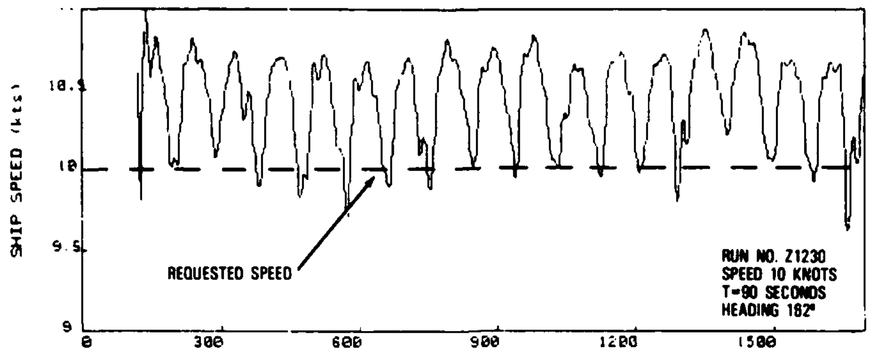

Figure D-6a

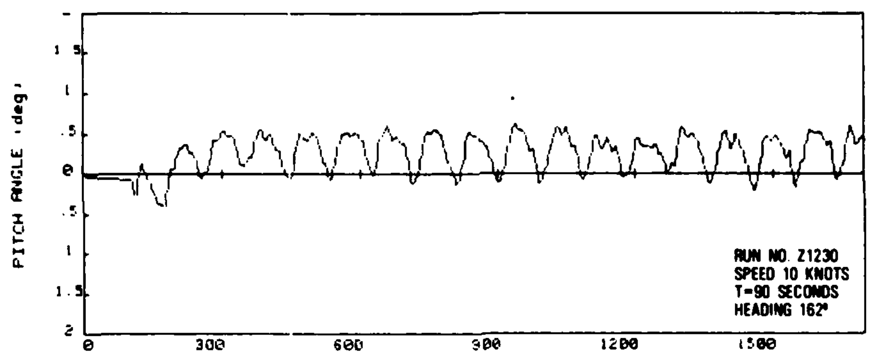

Figure D-6b

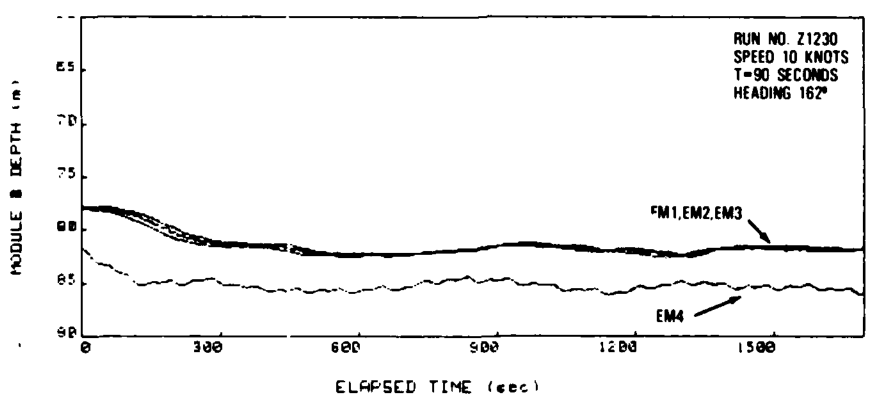

Figure D-6c

Figure D-6 (Continued)

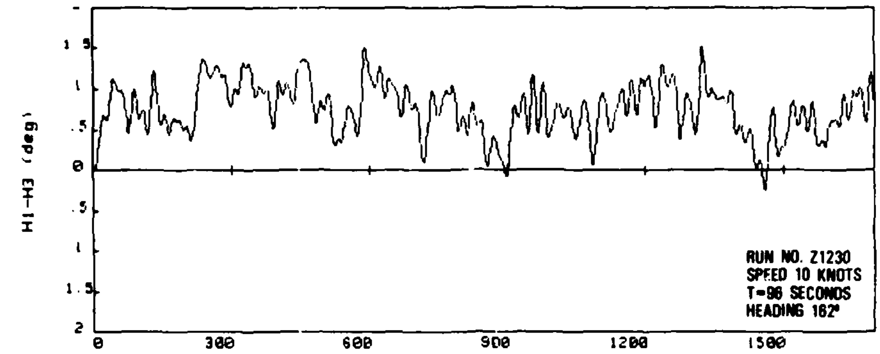

Figure D-6d

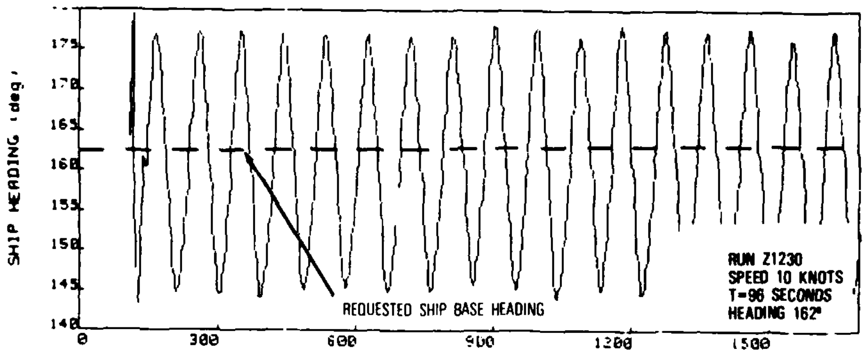

Figure D-6e

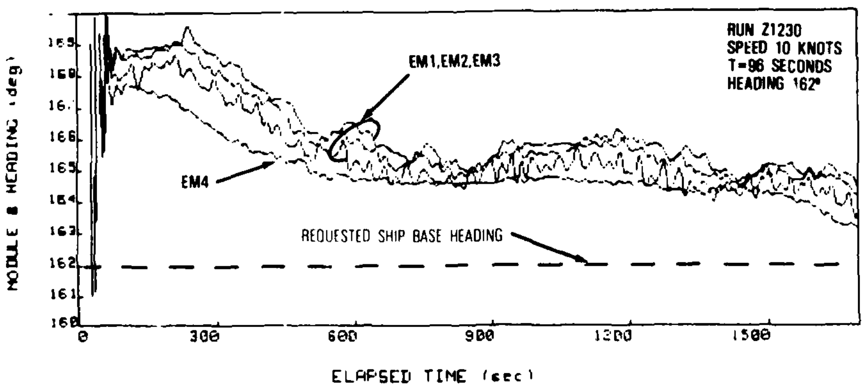

Figure D-6f

Figure D-6 (Continued)

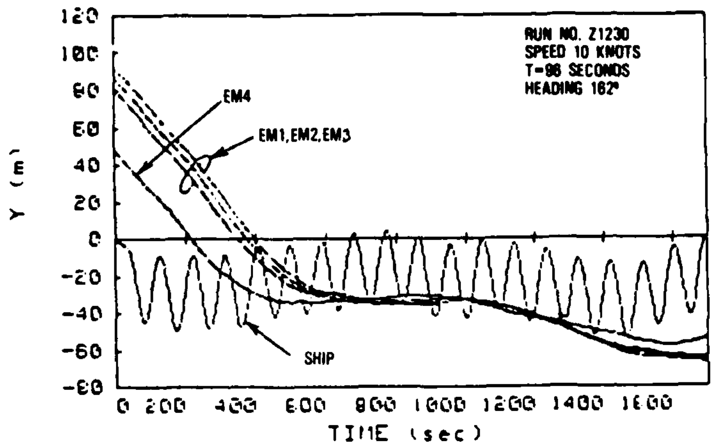

Figure D-6g

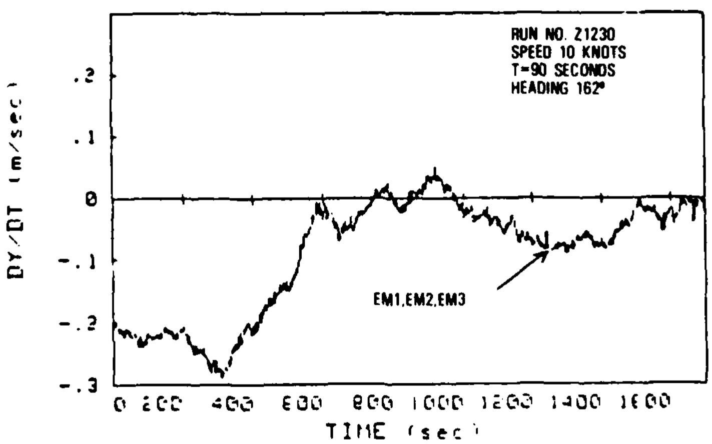

Figure D-6h

Figure D-7 - Run Z1290 with Speed of 8 Knots and 1200 Second Period Sinusoidal Course

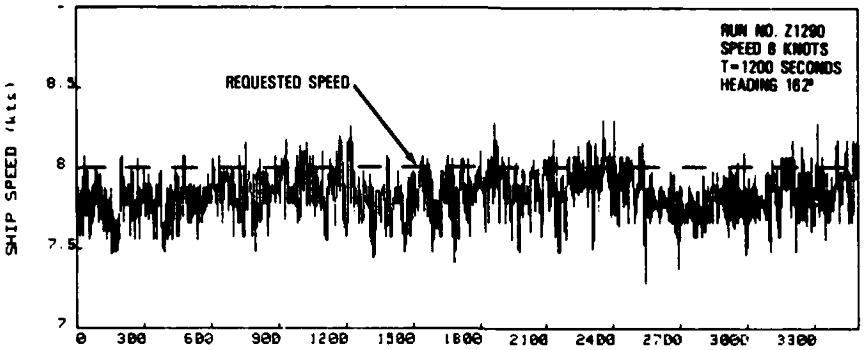

Figure D-7a

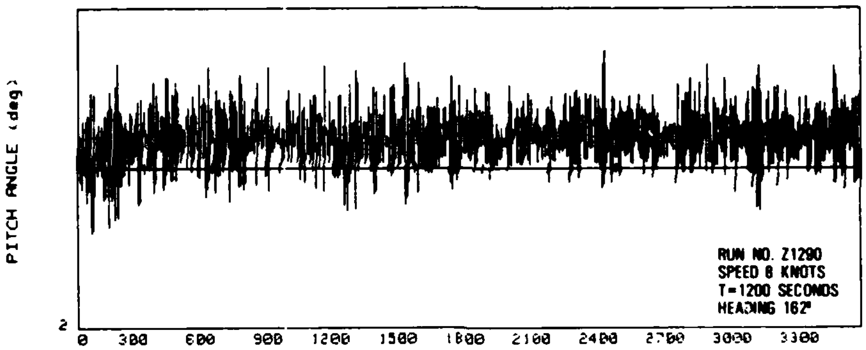

Figure D-7b

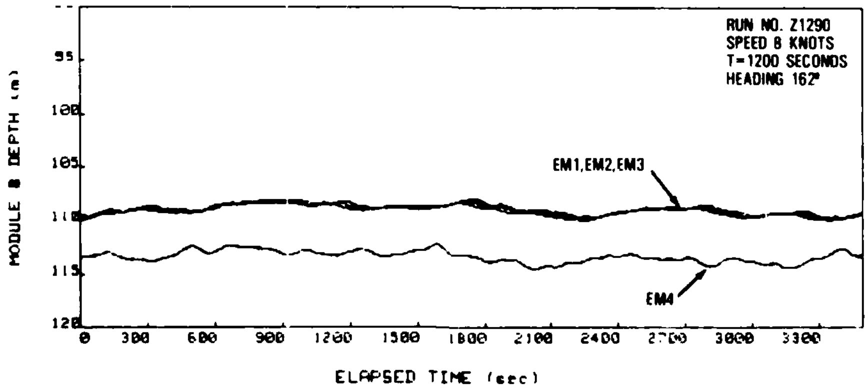

Figure D-7c

Figure D-7 (Continued)

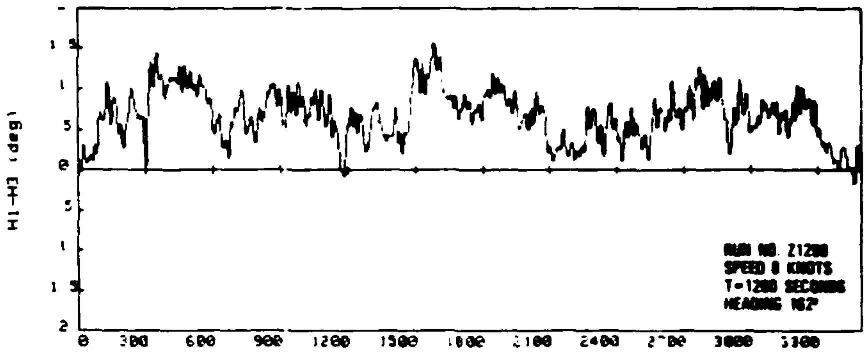

Figure D-7d

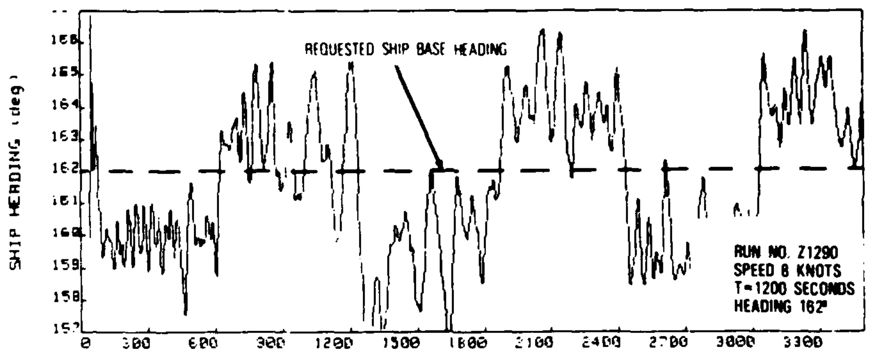

Figure D-7e

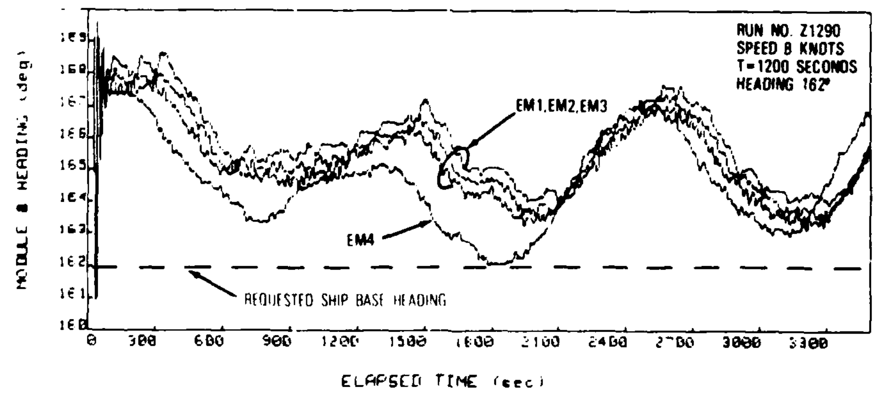

Figure D-7f

Figure D-7 (Continued)

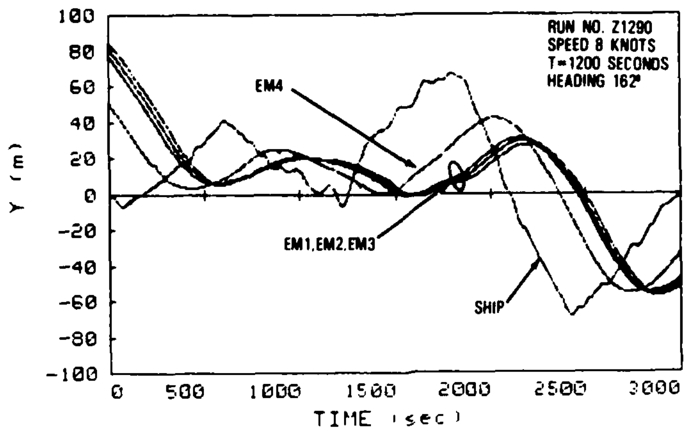

Figure D-7g

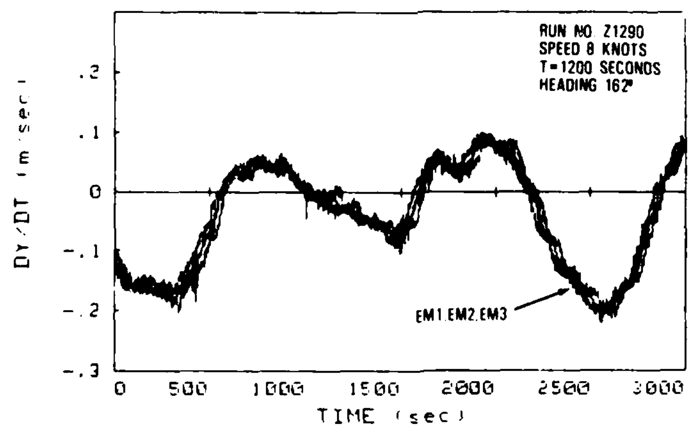

Figure D-7h

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

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