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AD NUMBER: ADC002894

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C to U and Limitations removed per ONR ltr dtd 10 May 1977

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MARCH 1975 ONR R&D  
TOWED APRAY SEA TRIAL RESULTS (U)

JESSE S. DIGGS  
DAVID WALTERS  
JOHN F. WATERS

ADC002894

AUGUST 1975  
TECHNICAL REPORT NO. 147  
CONTRACT NO. N00014-72-C-0365

CLASSIFIED BY DD FORM 254  
CONTRACT N00014-72-C-0365  
DATED 1 MAY 1974, SUBJECT TO  
GDS OF EO 11652  
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⑥ MARCH 1975 ONR R&D  
and  
TOWED ARRAY SEA TRIAL RESULTS (U) ⑧

⑨ Technical rept.

⑩ Jesse S./Diggs,  
David/Walters  
John F./Waters

⑫ 94p.

⑭ TR-147

⑮ August 1975  
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-147	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MARCH 1975 ONR R&D TOWED ARRAY SEA TRIAL RESULTS (U)		5. TYPE OF REPORT & PERIOD COVERED Technical
7. AUTHOR(s) Jesse S. Diggs David Walters John F. Waters		6. PERFORMING ORG. REPORT NUMBER TR-147
9. PERFORMING ORGANIZATION NAME AND ADDRESS MAR, Incorporated 1335 Rockville Pike Rockville, Maryland 20852		8. CONTRACT OR GRANT NUMBER(s) N00014-72-C-0365
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Code 222 Arlington, Virginia 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) N/A		12. REPORT DATE August 1975
		13. NUMBER OF PAGES 98
		15. SECURITY CLASS. (of this report) CONFIDENTIAL
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE Declassify 31 December 1980
16. DISTRIBUTION STATEMENT (of this Report) In addition to the Security Requirements which apply to this report and must be met, each transmittal must be approved by the Director, ONR, Code 222.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) N/A		
18. SUPPLEMENTARY NOTES N/A		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Towed Array Self-Noise Underwater Acoustics Passive Sonar  390-477		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (U) New acoustical and vibrational data were acquired using the ONR R&D Towed Array in Sea Trial 5H4, conducted in March 1975. Limitations on valid array self-noise measurements due to towship radiated noise were investigated. The possibility of noise generation by the ribbon-faired towcable was examined. The quieting effects of a long neutrally-buoyant towcable section and of long Vibration Isolation Modules were evaluated. Effects of various hosewall materials on array module self-noise were evaluated. Acoustical scattering		

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#20. ABSTRACT (cont.)

from an intentionally inserted scattering object was investigated. Several new array acoustical and vibrational sensors were tested. Hydromechanical measurements were made to characterize the towing conditions. Good-quality analog magnetic tape recordings of sensor outputs suitable for future coherence signal processing analysis were obtained. The report documents the results and presents several recommendations for improvements needed in future sea trials involving the ONR R&D Towed Array.

*and*



**ACKNOWLEDGMENT**

The results contained herein represent the cumulative research efforts of Chesapeake Instrument Corporation, Hughes Aircraft Company, and MAR, Incorporated, performed under the direction and helpful guidance of Mr. George Boyer and LCDR George Ranes, ONR Code 222. The conclusions and recommendations presented here represent an unbiased analysis of the results and not an endorsement of the equipment of any particular manufacturer. The purpose of the ONR R&D Towed Array Program is to identify sources and reduce levels of acoustical noise which degrades towed array performance.

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## NOMENCLATURE

ASM	Array Stability Module
CGA	Control Gain Amplifier
CIC	Chesapeake Instrument Corporation
COM	Coherence Module
CTEA	Central Test and Evaluation Activity
ESM	Environmental Sensing Module
HAC	Hughes Aircraft Company
HCI	Hydrospace-Challenger, Incorporated
IRIG	Inter-Range Instrumentation Group
ITM	ITASS Module
LSM	Low-Scattering Module
MRI	Marine Resources, Incorporated
MSM	Modified STUD Module
NSRDC	Naval Ship Research and Development Center
NUSC/NLL	Naval Underwater Systems Center/New London Laboratory
NWPC	Northwest Providence Channel
ONR	Office of Naval Research
PVC	Polyvinylchloride
SEC	Seismic Engineering Company
SET	Statistical Event/Time
SLC	Singer-Librascope Company
STUD	Ship Towed Underwater Detector
TAM	Triaxial Accelerometer Module
TBL	Turbulent Boundary Layer
TFG	Triaxial Force Gauge
USRD	Underwater Sound Reference Division
VIM	Vibration Isolation Module

## Section 1

## INTRODUCTION

## 1.1 ADMINISTRATIVE INFORMATION

(U) The March 1975 ONR Sea Trial 5H4 has been one in a series of at-sea towed array tests in the Self-Noise Reduction Program of the Office of Naval Research (ONR), Code 222. The purpose of these trials is to check out new sensors and to obtain new vibrational and acoustical self-noise data.

(U) The primary array used was the ONR R&D Towed Array which has been developed during the past two years for ONR by Chesapeake Instrument Corporation (CIC) of Shadyside, MD. This is the same array which has been referred to as the ONR-CIC Baseline Towed Array when used by the Naval Ship Research and Development Center (NSRDC) during the Towed Array Hydromechanics Program. A second array, fabricated by Hughes Aircraft Company (HAC), was also evaluated during this sea trial in terms of its noise levels and potential impact on the ONR R&D Program.

(U) The March 1975 evaluations were conducted through the Central Test and Evaluation Activity (CTEA), the Ft. Lauderdale division of Naval Underwater Systems Center, New London (NUSC/NLL). The tests were performed during the period 10-17 March 1975, using the towship R/V DANIEL L. HARRIS, III, operated by Hydrospace-Challenger, Inc. (HCI). The test sites were Northwest Providence Channel (NWPC) and Exuma Sound in the Bahamas. Overall coordination of the trial was through CTEA, with at-sea personnel from CIC, HAC, and MAR, Incorporated aboard to provide trial direction and preliminary assessment of the data.

## 1.2 BACKGROUND

(U) During the past two years, the ONR R&D Towed Array has been used in several at-sea investigations of various self-noise mechanisms. Most important have been the investigation of vibrational and acoustical noise due to tow cable strumming, and the evaluation of various strum-suppression devices, performed during the NSRDC Hydromechanics Program. Other self-noise mechanisms

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(such as the production of high noise levels with increased tow speed, the gain of an array element subarray against self-noise, and the generation of noise by a flexible foam sleeve over the array) have also been investigated.

(C) In FY 75, the goal was to make the ONR R&D Towed Array as quiet as possible such that it can be used as an effective testbed for the identification of further self-noise mechanisms. Several significant changes were made to the array since it was last towed in May 1974 (Sea Trial 4H8). The three small hydrophones in the Low-Scattering Module (LSM) were replaced by 10 others with new smaller preamplifiers. Two piezoelectric accelerometers were installed in the LSM end caps. A second LSM boot, having an acoustical scattering band embedded in its hosewall, was fabricated. A new "Coherence Module" (COM), housing nine closely spaced hydrophones, was fabricated to measure the coherence of module breathingwaves and identify their frequencies and wavelengths. Tow Modified STUD (Ship Towed Underwater Detector) Modules (MSMs) with different hosewalls were integrated into the array, and various lengths and constructions of Vibration Isolation Modules (VIMs) were also available for evaluation.

## 1.3 SPECIFIC OBJECTIVES

(U) Specific objectives of the March 1975 Sea Trial as set forth in the test plan were as follows:

1. Evaluate the at-sea performance of the new CIC sensors (LSM and COM hydrophones, and LSM accelerometers) and their new preamplifier/linedrivers.
2. Evaluate long forward VIMs in comparison to short forward VIMs in terms of their effect on the array acoustical performance.
3. Investigate the acoustical scattering in the LSM by acquiring data using a boot with a scattering center, and comparing this with data obtained using a standard boot.

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4. Compare measurements made with the Triaxial Accelerometer Module (TAM) to measurements made at essentially the same point with the new LSM accelerometers; acquire array nose cone force data and array depth data.
5. Measure the coherence between adjacent hydrophones due to module breathingwaves using the newly developed COM.
6. Obtain array noise measurements from the HAC MSM and compare these to corresponding measurements from the CIC ITASS Module (ITM).
7. Compare the self-noise levels obtained with two otherwise similar HAC MSMs having polyvinylchloride (PVC) and rubber/cloth-laminate hosewalls.
8. Evaluate the NSRDC hydromechanics measurement system and the tow cable tension statistical event/time (SET) recorder, and establish the cable/array system towing characteristics.

## 1.4 SUMMARY OF RESULTS

(U) The specific objectives of the March 1975 ONR Sea Trial 5H4 were substantially attained. Conclusions which were established as a result of interpretive analysis of the data are presented in detail in Section 8 of this report.

(C) In brief, towship radiated noise significantly limited the towed array acoustical self-noise measurements throughout the sea trial. The ribbon-faired tow cable did not cause array noise. A section of neutrally buoyant tow cable had little effect on acoustical array noise. Lengthening of the forward array VIM reduced array noise slightly. A module with a PVC hosewall was significantly quieter than another similar module having a rubber/fabric laminate hosewall, but both were relatively noisy. A turbulent boundary layer (TBL) scattering band increased noise in the LSM appreciably in the vicinity of 50 Hz. The piezo-electric LSM accelerometers did not produce valid vibration noise measurements. Other array sensors performed well in general. The usefulness of the NSRDC

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hydromechanical measurement system was demonstrated. Good-quality analog magnetic tape recordings of sensor outputs suitable for coherence analysis were obtained. General experience was gained which led to several definite recommendations for improvements in equipment to be used in future sea trials.

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## Section 2

### DESCRIPTION OF SYSTEM COMPONENTS

#### 2.1 GENERAL

(U) The evaluations consisted of towing the cable/array system from the HARRIS at various cable scopes for speeds of 6, 9, 12, and 15 kt. The tow cable used consisted of two 0.84-in. diameter double-armored cables connected in series. The extreme shipboard end consisted of a 5000-ft section, whereas the extreme wet end consisted of a 3400-ft section. CIC cable termination connectors were installed back-to-back to provide the series connection and enabled lengths of up to 7000 ft to be towed. Ribbon fairings were attached to the cable to minimize strum-induced vibrations and low-frequency self-noise. The ribbons were 20 mil thick polyurethane (specific gravity = 1.1), two cable diameters wide by six diameters long, configured to give 25 percent coverage over the entire cable length. Estimated weight per unit length of the faired tow cable in seawater at 70<sup>o</sup>F was 0.807 lb/ft. The following sections describe the array modules and hydrophone spacing.

#### 2.2 ACOUSTICAL MODULE DESCRIPTIONS

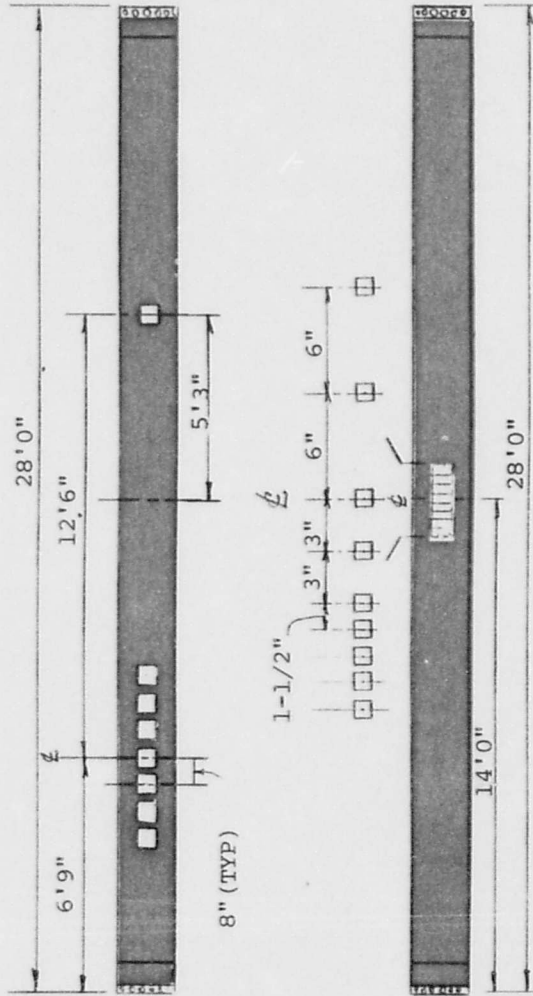
(U) Details of the hydrophone spacing and exact placement within the CIC acoustical modules are illustrated in Figure 2-1. The following sections describe the hydrophone types and mounting techniques. All hydrophones were calibrated by the Underwater Sound Reference Division (USRD), Leesburg, FL, prior to the trial. The results are presented in References 1 and 2.

##### 2.2.1 ITM - ITASS Module

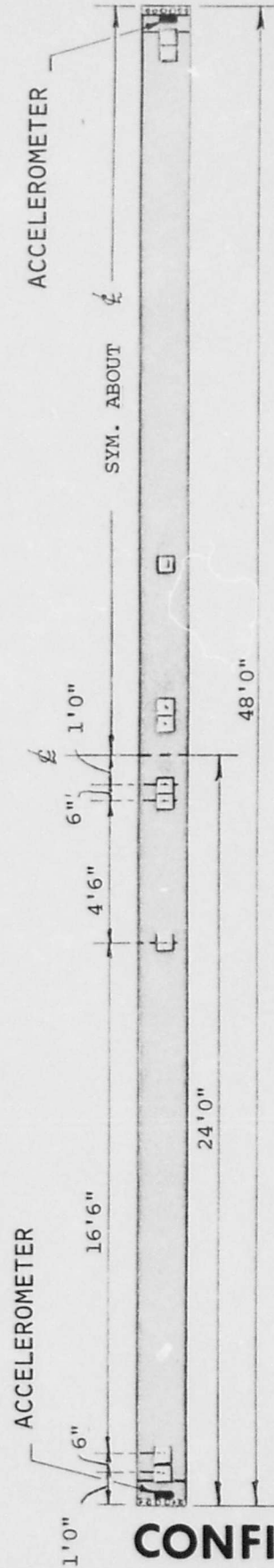
(C) Two ITMs were operated in the array to provide reference acoustical measurements. These same two modules have been towed in the array during several sea trials over the past two years without significant modifications. In each ITM, two signals were brought out through preamplifiers and line drivers onto twisted pairs for transmission up the tow cable. One signal represented the output from a group of seven hydrophones spaced 8 in. apart at the forward

AFT END

FWD END



2-2



LOW-SCATTERING MODULE (LSM)

(C) Figure 2-1. ONR R&D Acoustic Module Detail (U)

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end of the module. The other signal was from only one hydrophone (the one farthest from the end cap) in the other group of seven hydrophones at the aft end of the ITM (see Figure 2-1).

## 2.2.2 LSM — Low Scattering Module

(C) The LSM contained 10 miniature Multidyne Type MD-7 foam-mounted hydrophone elements manufactured by the Seismic Engineering Company (SEC) of Dallas, TX. The hydrophones were located in pairs near the middle and two end caps of the module, see Figure 2-1. The hydrophones were about 1/2 in. diameter by 1 in. long and weighed about 0.33 ounces in air. The units had two sensing elements wired in parallel and used a miniature preamplifier/line driver designed and built by CIC. The 10 hydrophone signals were brought up the tow cable on individual twisted pairs. Mounted on either end cap of the LSM oriented in the longitudinal direction, were two B&K Model 4338 piezoelectric accelerometers. The signals from these accelerometers were also brought up on individual twisted pairs driven by preamplifier/line drivers. Every component inside the 48-ft LSM had been purposely built as small as possible to minimize self-noise due to collimated scattering of TBL acoustical energy.

(C) A second LSM boot containing a 3-in. long circumferential metal band located at the module mid-point was fabricated by CIC. The second boot was installed over the LSM electronics at sea and was used to investigate the TBL scattering due to a hosewall discontinuity. Due to the length of the LSM and the minimal weight of the electrical components, buoyancy was controlled by using Primol<sup>®</sup> (sg = 0.87) as a relatively heavy fill fluid.

## 2.2.3 COM — Coherence Module

(C) The COM contained nine miniature foam-mounted hydrophones of similar construction to the LSM hydrophones. The hydrophones were clustered near the center of the module and had various spacings, as shown in Figure 2-1. The COM hydrophone signals were all separate and were used to study coherence between adjacent phones as a function of spacing.

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## 2.2.4 MSM — Modified STUD Module

(C) The MSM was manufactured by HAC and consisted of two 10-channel modules. The first module, MSM1, was constructed with a PVC hosewall whereas the second module, MSM2, had a standard rubber/cloth-laminate hosewall. Each module channel had a single Marine Resources, Inc. (MRI) hydrophone element. The hydrophones were equally spaced on 44-in. centers over the module length, and each pair of hydrophones (odd/even) went to a preamplifier/ linedriver electronics can for signal conditioning. The internal module construction consisted of foam hydrophone mounts, the single MRI element per channel, three-wire strength member in the vicinity of the hydrophones, and ballast as required for neutral buoyancy.

## 2.3 NON-ACOUSTICAL MODULE DESCRIPTIONS

(U) Several special purpose modules were integrated into the array to provide vibration isolation and to measure acceleration levels, array depth, and nose cone forces. The following sections give brief descriptions of each of these modules.

### 2.3.1 VIM — Vibration Isolation Module

(U) The VIMs at either end of the array served to isolate the acoustical portion of the array from tow cable and drogue vibrations, and consisted of stretchy sections of array hose. Three VIMs of different lengths and construction were evaluated during this trial. CIC provided two rubber/cloth-laminate hosewall VIMs of 20-ft and 90-ft unstretched lengths which were capable of elongating to 130 percent of their original length. The Singer-Librascope Company (SLC) provided a 100-meter PVC VIM of SEC-type construction (i.e., central strength members), capable of extending to 150 percent of its original length. The electrical through-wires inside all the VIMs were dressed with plenty of slack to accommodate the stretching.

### 2.3.2 ASM — Array Stability Module

(U) The ASMs were located forward and aft of the acoustical modules and consisted of dummy modules which are thought to reduce array self-noise. Mechanically, their construction was similar to that of the ITASS modules.

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## 2.3.3 TAM — Triaxial Accelerometer Module

(U) Each TAM contained one triaxial accelerometer sensor unit which was hard-coupled to one end cap of the 9-ft module. The sensitivity spectra of the accelerometers were essentially flat from 0 to 50 Hz and were well suited for very low frequency vibration measurements. The sensors were manufactured by Shaevitz and were of the force-balanced servo type which have been used extensively in missile vibration measurements. In the TAM, one sensor was oriented longitudinally to the module axis and the other two were oriented transversely.

(U) From each TAM, the vibration signals from the three sensors were FM-multiplexed for transmission up the tow cable on a single twisted pair of electrical conductors. A standard Inter-Range Instrumentation Group (IRIG) system was used with carrier frequencies of 16, 24, and 32 kHz, and a bandwidth of 2 kHz. There was a single set of demodulators at the shipboard receiver end.

## 2.3.4 ESM — Environmental Sensing Module

(U) The ESM contained three array environmental sensors. The first sensed internal fill fluid pressure (array depth), the second sensed overpressure of the LSM, and the third sensed internal fill fluid temperature. The three signals from the ESM sensors were multiplexed up the tow cable on a single twisted pair in the same way as the TAM signals.

## 2.3.5 TFG — Triaxial Force Gauge and Electronics

(U) The TFG consisted of two modules. The actual force gauge was located in a short 1-ft module and sensed array forces along three orthogonal axes. The electronics to support the force gauge was located in a 7-ft module adjacent to the force gauge. The TFG could have been placed anywhere within the array; however, the longitudinal loads developed at the nose cone were of most interest in Sea Trial 5H4.

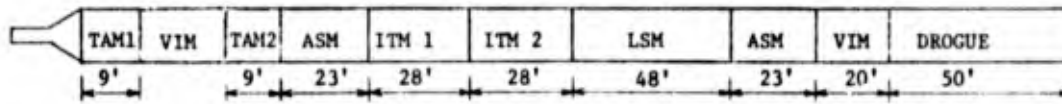
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## 2.4 ARRAY CONFIGURATIONS

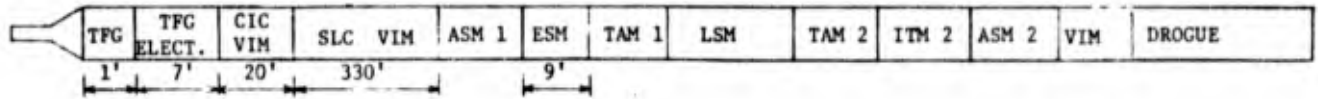
(U) Nine different ONR R&D Array configurations were evaluated, which consisted of various combinations of the previously described modules. Figure 2-2 illustrates the module placements within the array.

(U) Configuration "A" was used during the initial checkout in NWPC and as the baseline configuration for the parametric studies involving the various VIMs and NB cable effectiveness. Configuration "B" was similar to "A" with the inclusion of the ESM, TFG, and the TAMs that were placed on either side of the LSM to compare end cap acceleration levels recorded by two separate accelerometers. Configuration "C" was similar to "B," with the COM replacing the LSM. Configuration "D" was similar to "B" but utilized the LSM with the TBL scattering boot. Configuration "E" integrated the two HAC MSMs and the CIC ITM into a single array with the ITM providing reference levels. Configurations "F" and "F'" were similar to "E," only different lengths of forward VIMs were used. Configurations "G" and "G'" were special arrangements of the ONR array configured to test CIC high-speed modules (results not included in this report). Configuration "H" (not shown in Figure 2-1) consisted of simply the ESM and the CIC VIM, and was used specifically to obtain towing depth data while crossing the Gulf Stream with minimal tow cable scope.

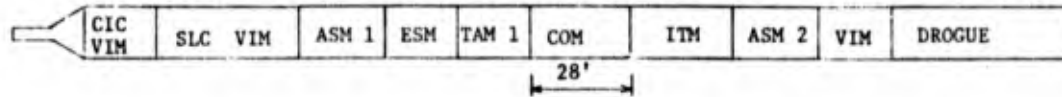
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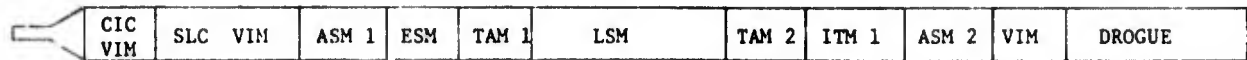
CONFIGURATION "A"



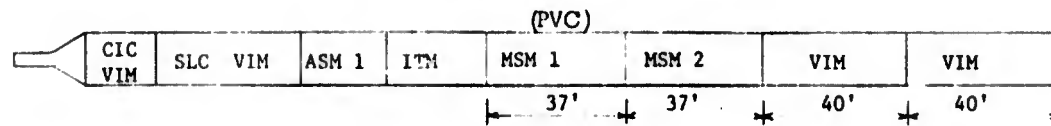
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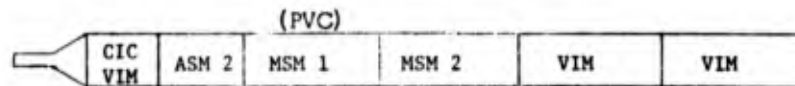
CONFIGURATION "C"



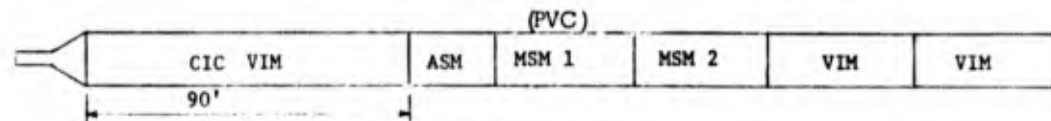
CONFIGURATION "D"



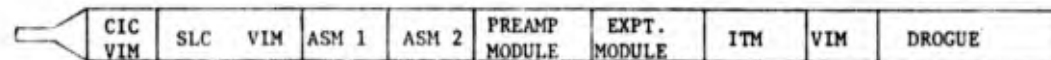
CONFIGURATION "E"



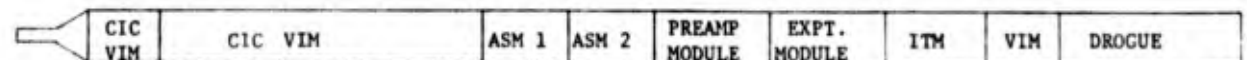
CONFIGURATION "F"



CONFIGURATION "F'"



CONFIGURATION "G"



CONFIGURATION "G'"

(U) Figure 2-2. ONR Sea Trial 5H4 Array Configurations (U)

# CONFIDENTIAL

## Section 3

### DATA ACQUISITION PROCEDURES

#### 3.1 ACOUSTICAL AND VIBRATIONAL MEASUREMENTS

(U) Processing of the acoustical and vibrational signals from the towed arrays was done on-station during each data run using the acoustical processor minicomputer which was installed in the laboratory aboard ship. The computer was operated by HCI and provided measurements of one-third octave band spectrum levels for individual array sensors, and also spectrum level averages for selected groups of sensors, as desired. Additional processing included narrow band analysis of specific signals, and coherence and phase analysis for specific pairs of sensor signals.

(U) Additional acoustical processing was available for the HAC array which included a self-contained multibeam beamformer. The preformed beamformer provided a total of 25 beams for which there existed 13 fixed outputs and two independently selectable steered beams. Analog outputs from the sum beams were also processed using the HCI minicomputer.

(U) Analog tape recordings of the acoustical and vibrational data were made during most of the sea trial using the AMPEX FR-1300 provided by CTEA. Since it was known that the analog tapes would be subjected to various post-trial data analysis techniques such as cross-correlation, auto-correlation, coherence and phase, care was taken during the recording process to put the signals from selected hydrophone pairs on the same head stack to avoid insertion of unwanted time delays upon playback on different analog magnetic tape units.

(C) Signals were acquired from the 10 LSM hydrophones, nine COM hydrophones, two ITM groups-of-seven, one ITM single hydrophone, two TAM accelerometers, and the 20 MSM single hydrophones. The on-line data sampling interval (integration time) for each signal was 30 seconds. One-third octave band analysis for most of these sensors covered frequencies from 8 to 5000 Hz.

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## 3.2 HYDROMECHANICAL MEASUREMENTS

(U) Hydromechanical measurements of shipboard towing tension, towing angle, and kite angle were obtained for various cable scopes and tow speeds. In addition, a statistical analysis of shipboard tension as a function of sea state was performed on-line to evaluate a new analyzer being developed by NSRDC. The hydromechanical data was obtained using the NSRDC towpoint gimbal, which is a specially designed instrument capable of measuring loads up to 10,000 lb, and which mounts on the HARRIS fantail. The cable/array system towing load was transferred to the gimballed towpoint, using Preformed Line Products cable grips.

## 3.3 DATA ACQUISITION RUNS

(U) The data acquisition runs which were actually performed were structured somewhat differently than the intended sequence set forth in the test plan. The intended sequence was reordered on the basis of early results, which indicated that the presence or absence of the neutrally buoyant section of tow cable ( $L = 500$  ft) was insignificant when evaluated in terms of towed array self-noise. Shipboard towing tensions measured during the initial sea state conditions indicated that a tow cable length of 5000 ft rather than 7000 ft would be better at 15 kt, in the interest of safety. As a result, all further 15 kt runs were performed at a 5000-ft scope to provide a basis for common comparison, even though the seas had subsided.

(U) Table 3-1 presents a detailed summary of all the runs which were actually performed during Sea Trial 5H4. In this table, Array Configurations "A" through "H" refer to the combinations of array modules previously presented in Figure 2-2. One-third octave band noise spectrum levels measured during each run were recorded on digital magnetic tape for Runs 1 through 85.

(U) Table 3-1. March 1975 ONR Sea Trial 5H4 Data Runs (U)

Run No.	Array Configuration	Speed	RPM/Torque	Course	Analog Tape 1	On-Board Processing	Sea State	Time	Date	Purpose	Location
H1	H	6 kt	340 Port	090°	No	None	1-2	1700	3/10/75	Hydromechanical Data Only	Gulf Stream
H2	H	9	475 P	090°	No	None	1-2	1810	3/10/75	Hydromechanical Data	Gulf Stream
H3	H	12	460 Both	090°	No	None	1-2	1830	3/10/75	Hydromechanical Data	Gulf Stream
H4	H	15	600 B	090°	No	None	1-2	1900	3/10/75	Hydromechanical Data	Transit to NWPC
H5	H	6	340 P	090°	No	None	1-2	2130	3/10/75	Repeat H1	NWPC
1	A	6	360 P	115°	No	OTOB	1	0030	3/11/75	Baseline Data	NWPC
2	A	6	355 Stbd	115°	No	OTOB	1	0325	3/11/75	Engine Comparison	NWPC
3	A	9	495 S	115°	No	OTOB	1	0335	3/11/75	Baseline Data	NWPC
4	A	12	475 B	115°	No	OTOB	1	0445	3/11/75	Baseline Data	NWPC
5	A	6	335 P	300°	No	OTOB	1	1850	3/11/75	20' VIM Baseline Data	Exuma
6	A	6	330 S	300°	Yes	OTOB	1	1925	3/11/75	Engine Comparison	Exuma
7	A	9	470 S	300°	Yes	OTOB	1	1950	3/11/75	Baseline Data	Exuma
8	A	12	460 B	132°	Yes	OTOB	1	2050	3/11/75	Baseline Data	Exuma
9	A	15	605 B	132°	Yes	OTOB	1	2150	3/11/75	Baseline Data	Exuma
10	A	6	340 P	132°	Yes	OTOB	1	2200	3/11/75	Repeat 5	Exuma
11	A	6	340 S	132°	Yes	OTOB	1	2230	3/11/75	Repeat 5	Exuma
12	A	7	390 S	132°	Yes	OTOB	1	2305	3/11/75	Variations About 6 kt	Exuma
13	A	5	300 S	132°	Yes	OTOB	1	2325	3/11/75	Variations About 6 kt	Exuma
14	A	6	350 S	132°	Yes	OTOB	1	0220	3/11/75	w/o N.B. Cable	Exuma
15	A	9	465 S	132°	Yes	OTOB	1	0340	3/11/75	w/o N.B. Cable	Exuma
16	A	12	460 B	312°	Yes	OTOB	1	0520	3/12/75	w/o N.B. Cable	Exuma
17	A	15	--- B	312°	Yes	OTOB	1	0550	3/12/75	w/o N.B. Cable	Exuma
18	F	6	330 S	312°	No	OTOB	2	1250	3/12/75	Evaluate HAC Array	Exuma
19	F	6	325 P	312°	No	OTOB	2	1350	3/12/75	"Calibrate" Beamformer	Exuma
20	F	9	465 P	312°	No	OTOB	2	1500	3/12/75	"Calibrate" BF	Exuma
21	F	6	375 S	312°	No	OTOB	2	1810	3/12/75	Measure Towship Noise	Exuma
22	F	9	525 S	310°	No	OTOB	2	1850	3/12/75	Towship Noise	Exuma
23	F	6	375 S	310°	No	OTOB	2	1905	3/12/75	Repeat 21	Exuma
24	F	6	360 S	312°	No	OTOB	2	2035	3/12/75	Evaluate HAC Array	Exuma
25	F	9	515 S	312°	No	OTOB	2	2100	3/12/75	Evaluate HAC Array	Exuma
26	F	12	490 B	312°	No	OTOB	2	2140	3/12/75	Evaluate HAC Array	Exuma
27	F	15	650 B	312°	No	OTOB	2	2305	3/12/75	Evaluate HAC Array	Exuma
28	F	6	365 S	312°	No	OTOB	2	2345	3/12/75	Evaluate HAC Array	Exuma
29	A	6	340 S	312°	No	OTOB	2	0545	3/13/75	Evaluate SLC VIM	Exuma
30	A	9	475 S	312°	No	OTOB	2	0640	3/13/75	SLC VIM	Exuma
31	A	12	500 B	312°	No	OTOB	2	0840	3/13/75	SLC VIM	Exuma
32	A	15	600 B	312°	No	OTOB	2	0900	3/13/75	SLC VIM	Exuma
33	A	0	---	132°	No	OTOB	2-3	1000	3/13/75	Ambient	Exuma
34	A	0	---	132°	No	OTOB	2-3	1005	3/13/75	Repeat Ambient	Exuma
35	A	6	355 S	132°	No	OTOB	2-3	1235	3/13/75	Evaluate 90' VIM	Exuma
36	A	9	490 S	132°	No	OTOB	2-3	1325	3/13/75	90' VIM	Exuma
37	A	12	490 B	132°	No	OTOB	2-3	1405	3/13/75	90' VIM	Exuma
38	A	15	640 B	132°	No	OTOB	2-3	1430	3/13/75	90' VIM	Exuma

(U) Table 3-1. March 1975 ONR Sea Trial 5H4 Data Runs (cont.) (U)

Run No.	Array Configuration	Depth	Speed	RPM/Engine	Courses	Analog Tape 1	On-Board Processing	Sea State	Time	Date	Purpose	Location
39	B	7000 ft	6 kt	400 S	312°	Yes	NB	2-3	0210	3/14/75	LSM Data for MS1	Exuna
40	B	7000	9	585 S	312°	Yes	NB	2-3	0415	3/14/75	LSM Data	Exuna
41	B	7000	12	700 B	312°	Yes	NB	2-3	0535	3/14/75	LSM Data	Exuna
42	B	7000	12	560 B	312°	Yes	OTOB	2-3	0555	3/14/75	LSM Data	Exuna
43	B	7000	9	525 S	312°	Yes	OTOB	2-3	0630	3/14/75	LSM Data	Exuna
44	B	7000	6	405 S	312°	Yes	OTOB	2-3	0700	3/14/75	LSM Data	Exuna
45	B	7000	9	585 S	312°	No	OTOB	3	0850	3/14/75	LSM Data	Exuna
46	B	7000	6	400 S	312°	No	OTOB	3	0915	3/14/75	LSM Data	Exuna
47	B	5000	15	640 B	312°	Yes	OTOB	3	1115	3/14/75	LSM Data	Exuna
48	B	5000	15	640 B	312°	Yes	NB	3	1240	3/14/75	LSM Data	Exuna
49	C	7000	6	385 S	312°	Yes	NB	1	2010	3/14/75	COM Data	Exuna
50	C	7000	9	540 S	312°	Yes	NB	1	2040	3/14/75	COM Data	Exuna
51	C	7000	12	510 B	312°	Yes	NB	1	2200	3/14/75	COM Data	Exuna
52	C	7000	12	510 B	312°	No	OTOB	1	2220	3/14/75	COM Data	Exuna
53	C	7000	9	535 S	312°	Yes	OTOB	1	2240	3/14/75	COM Data	Exuna
54	C	7000	6	375 S	312°	Yes	OTOB	1	2320	3/14/75	COM Data	Exuna
55	C	5000	15	640 B	312°	Yes	NB	1	0050	3/15/75	COM Data	Exuna
56	C	5000	15	640 B	312°	No	OTOB	1	0120	3/15/75	COM Data	Exuna
57	D	7000	6	395 S	312°	Yes	NB	1	0635	3/15/75	LSM w/Scattering Hees	Exuna
58	D	7000	9	590 S	312°	Yes	NB	1	0720	3/15/75	LSM	Exuna
59	D	7000	12	510 B	312°	Yes	NB	1	0805	3/15/75	LSM	Exuna
60	D	7000	12	510 B	312°	Yes	OTOB	1	0845	3/15/75	LSM	Exuna
61	D	7000	9	530 S	312°	Yes	OTOB	1	0940	3/15/75	LSM	Exuna
62	D	7000	6	380 S	312°	Yes	OTOB	1	1035	3/15/75	LSM	Exuna
63	D	5000	15	640 B	312°	Yes	OTOB	1	1136	3/15/75	LSM	Exuna
64	D	5000	15	640 B	312°	Yes	NB	1	1205	3/15/75	LSM	Exuna
65	E	7000	6	385 S	312°	No	OTOB	1/2-1	1610	3/15/75	MSM1; MSM2; ITM	Exuna
66	E	7000	9	530 S	312°	No	OTOB	1/2-1	1710	3/15/75	MSM1; MSM2; ITM	Exuna
67	E	7000	12	505 B	312°	No	OTOB	1/2	1810	3/15/75	MSM1; MSM2; ITM	Exuna
68	E	5000	15	640 B	312°	No	OTOB	1/2	1910	3/15/75	MSM1; MSM2; ITM	Exuna
69	E	2000	0	---	312°	No	OTOB	1/2	2035	3/15/75	Ambient	Exuna
70	E	2000	0	---	312°	No	OTOB	1/2	2040	3/15/75	Ambient	Exuna
71	G	5000	15	640 B	312°	Yes	OTOB	1	2240	3/15/75	Experimental Module	Exuna
72	G	5000	15	640 B	312°	Yes	OTOB	1	2315	3/15/75	Repeat 71	Exuna
73	G	5000	15	640 B	312°	Yes	OTOB	1	2330	3/15/75	Repeat 71	Exuna
74	G'	5000	9	500 S	312°	Yes	OTOB	1-2	0425	3/16/75	G w/90° VIM	Exuna
75	G'	5000	15	625 B	312°	Yes	OTOB	1-2	0450	3/16/75	G w/90° VIM	Exuna
76	F	3250	15	600 B	248°	No	OTOB	1	2000	3/16/75	HAC Basaltomer Exercise	NWPC
77	F	3250	15	600 B	248°	No	OTOB	1	2030	3/16/75	Null-in	NWPC
78	F	3250	15	600 B	248°	No	OTOB	1	2200	3/16/75	Null-in	NWPC
79	F	3250	15	600 B	248°	No	OTOB	1	2230	3/16/75	Filter-in	NWPC
80	F	3250	15	600 B	248°	No	OTOB	1	2300	3/16/75	Null & Filter-in	NWPC
81	F	3250	6	350 S	248°	No	OTOB	1	2330	3/16/75	Baseline	NWPC
82	F	3250	6	350 S	248°	No	OTOB	1	2345	3/16/75	Null-in	NWPC
83	F	3250	6	350 S	248°	No	OTOB	1	0010	3/16/75	Filter-in	NWPC
84	F	3250	6	350 S	248°	No	OTOB	1	0030	3/16/75	Null & Filter-in	NWPC
85	F	3250	15	600 B	248°	No	OTOB	1	0100	3/16/75	Filter-in	NWPC

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## Section 4

### LIMITATIONS OF ACOUSTICAL MEASUREMENTS

#### 4.1 GENERAL

(U) Acoustical measurements of towed array self-noise were limited over various frequency ranges (depending upon tow speed, tow cable length, sea state and type of acoustical sensor) by three other types of noise. These were towship radiated noise, in the mid-frequency range; ambient noise associated with sea state, at high frequencies; and signal transmission system electrical noise, at low frequencies. Together, these three noise spectra formed the noise floor for measurements of towed array self-noise in Sea Trial 5H4.

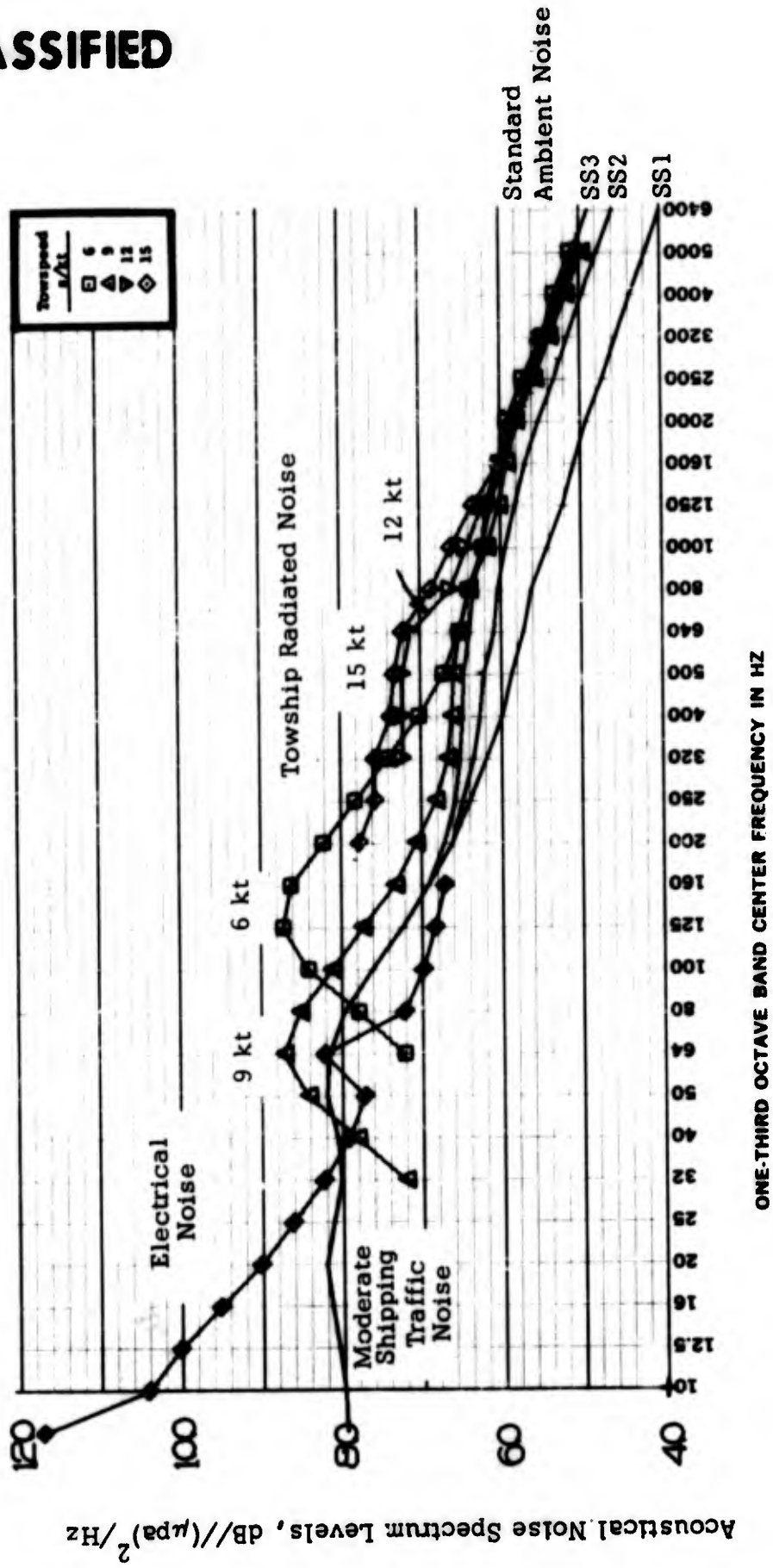
(U) Figures 4-1 through 4-3 present the composite acoustical noise floor spectra for the three general classes of test conditions involved in Sea Trial 5H4. Figure 4-1 shows the noise floors at various tow speeds for all of the runs made at  $L = 3250$  ft, in Sea States 1, 2, and 3. Figures 4-2 and 4-3 show the noise floors for the  $L = 7000$ -ft runs in Sea States 1 and 3, respectively.

(U) Selected spectra from these three figures may be used to estimate the frequency ranges over which valid measurements of towed array self-noise were obtained in any given data run in Sea Trial 5H4. To be valid at a given frequency, a measured spectrum level must be at least 6 dB greater than the level of the noise floor for that data run at that frequency.

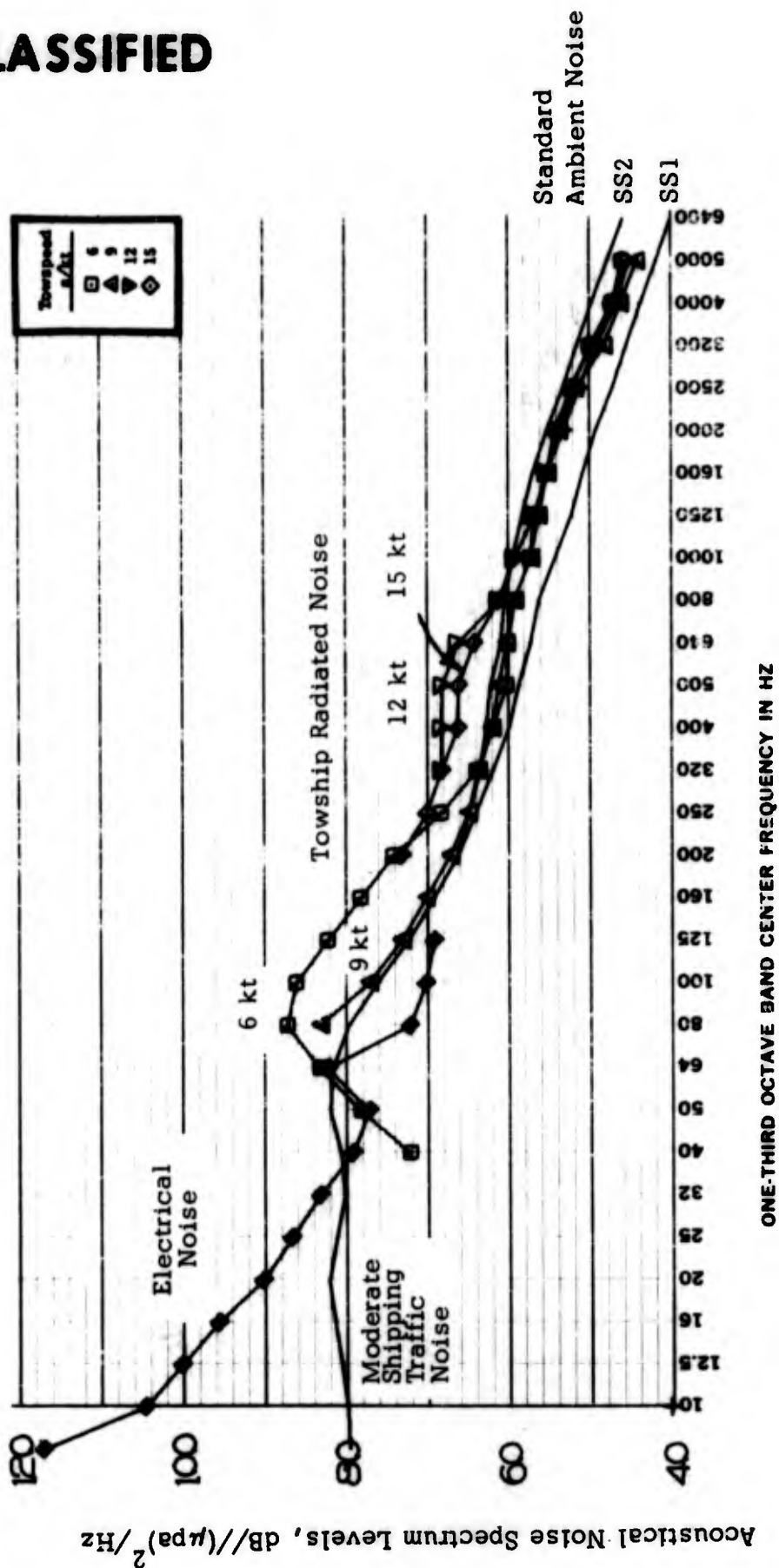
(U) The noise floor spectra shown in Figures 4-1 through 4-3 are for single hydrophones in the array. The electrical noise floor shown is for the LSM hydrophones; for the more sensitive COM and ITM single hydrophones, this electrical noise floor should be lower by 5 dB or more. Also, at the low tow speeds, starboard propulsion was used. No noise floor spectra for the noisier port propulsion system are shown.

#### 4.2 TOWSHIP RADIATED NOISE

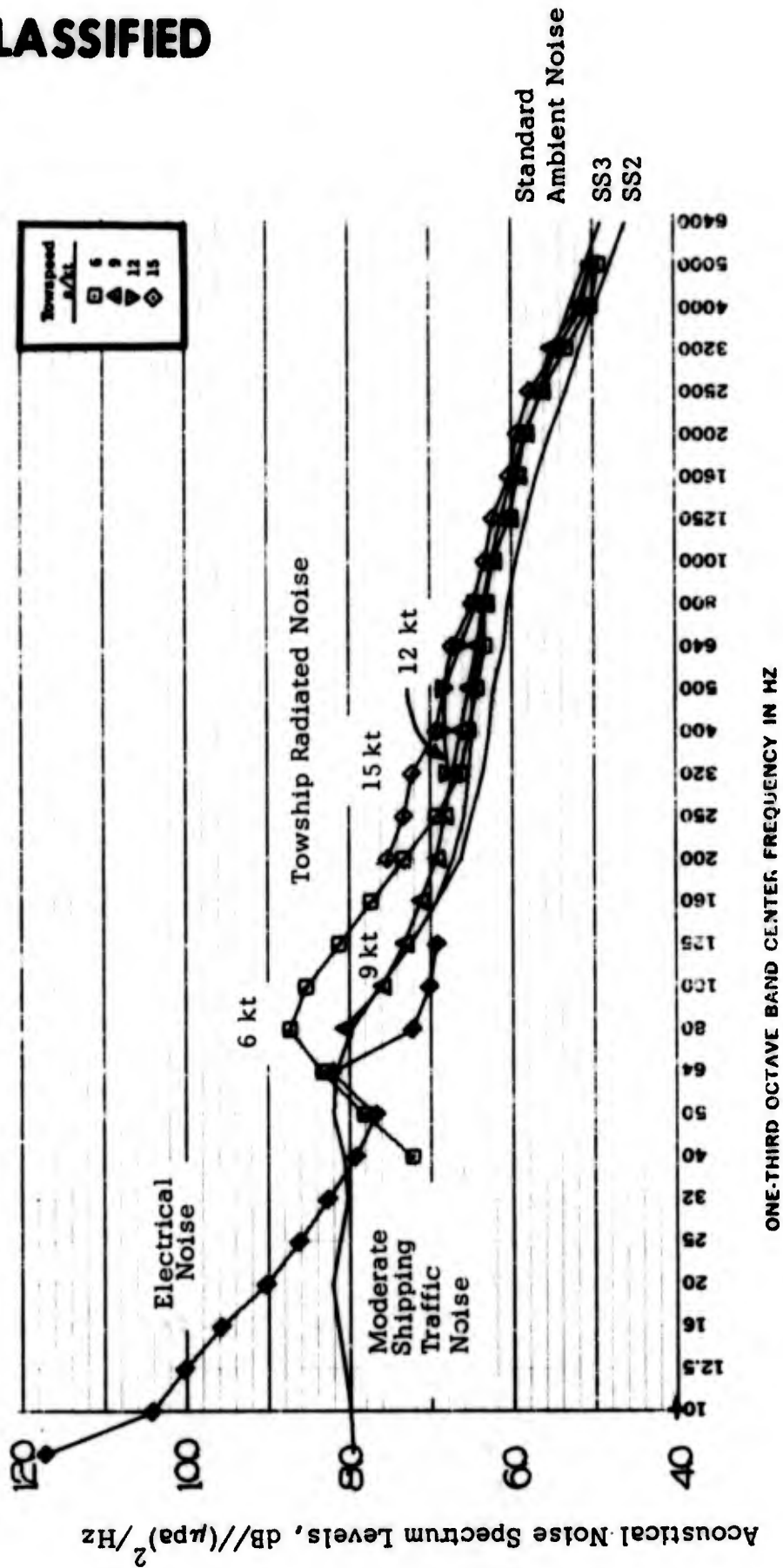
(U) Towship radiated noise was the most serious limiting factor for low-speed towed array self-noise measurements made in Sea Trial 5H4. Two separate components of towship radiated noise were evident. At all tow speeds, noise



(U) Figure 4-1. Noise Floor Spectrum Levels for Acoustical Measurements Made at 3250-ft Tow Cable Length and SS1, 2, 3 (U)



(U) Figure 4-2. Noise Floor Spectrum Levels for Acoustical Measurements Made at 7000-ft Tow Cable Length and SS1 (U)



(U) Figure 4-3. Noise Floor Spectrum Levels for Acoustical Measurements Made at 7000-ft Tow Cable Length and SS3 (U)

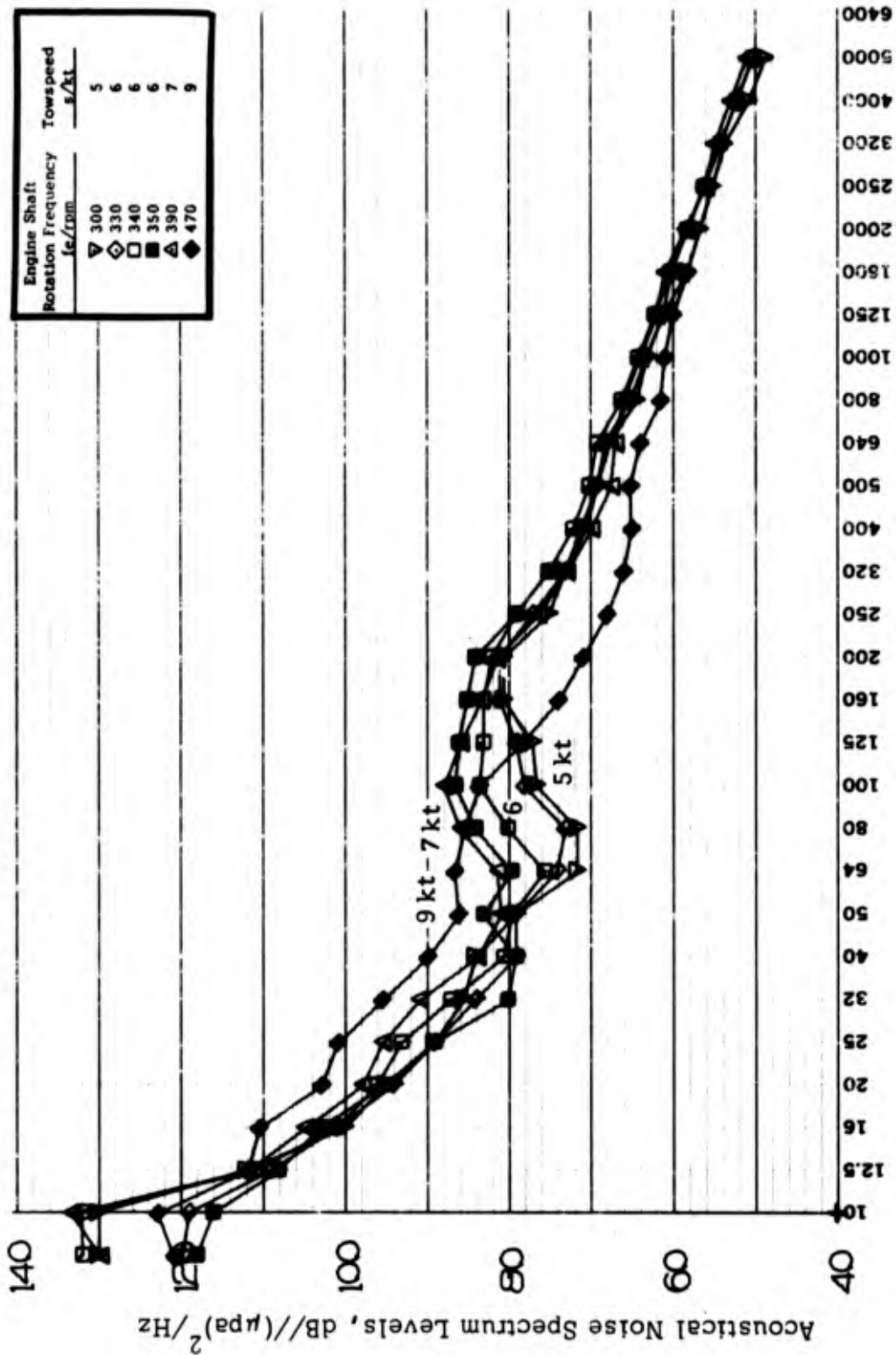
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radiated from towship propulsion machinery was significant in the high-frequency range, from 250 to 5000 Hz. At low tow speeds, propeller cavitation noise was also significant in various portions of the mid-frequency range, from 50 to 500 Hz.

(U) As may be seen from Figures 4-1 through 4-3, noise radiated from the towship propulsion machinery increased with tow speed in the 250 to 1250 Hz range, and was roughly constant with tow speed at higher frequencies, from 1600 to 5000 Hz. At the shorter tow cable length,  $L = 3250$  ft, this component of towship radiated noise dominated ambient noise for Sea State 3 and less. At the greater tow cable length,  $L = 7000$  ft, this component combined with ambient noise levels to produce composite levels which were dominated by towship radiated noise in Sea State 1, but by ambient noise in Sea State 3.

(U) Noise due to propeller cavitation at low tow speeds was strongly dependent upon propeller rotation frequency and actual tow speed. This component of towship radiated noise was characterized by a spectral peak in the 50 to 200 Hz region. As propeller rotation frequency increased, the frequency of the cavitation peak decreased and the level of the peak increased somewhat. Figure 4-4 shows this clearly. Here, propeller rotation frequency is measured in terms of engine rotation frequency, which is an available readout on the ship. As the array is towed faster, its depth decreases, which decreases the radiated noise levels received at the array because of the surface-reflection image interference effect. Thus, the trend of an increase in cavitation peak levels with increasing propeller rotation frequency is somewhat obscured in the spectra of Figure 4-4. But the trend of decreasing cavitation peak frequency with increasing propeller rotation frequency is clear. Physically, this occurs because larger cavitation bubbles which produce lower-frequency noise are generated when the propeller turns faster.

(U) The total towship radiated noise for any given run in Sea Trial 5H4 was the sum of the two components due to propulsion machinery and propeller cavitation. At a tow speed of 6 kt, the cavitation peak occurred at a frequency of about 100 Hz. At 9 kt, the peak shifted to a lower frequency of about 50 Hz. The net result of this was to lower the towship radiated noise levels in the



ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ  
 (C) Figure 4-4. ITM Noise Spectrum Levels, Showing Propeller Cavitation Peak Variation with Shaft Rotation Frequency (U)

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mid-frequency range from 100 to 500 Hz as much as 5 to 10 dB in going from 6 to 9 kt. This is why lower towed array self-noise levels were seemingly measured at 9 kt than at 6 kt in Sea Trial 5H4, in the mid-frequency range. Towship radiated noise was dominating the noise measured by the towed array in this frequency range.

(U) All of the towship radiated noise data shown here are for operation using the starboard propulsion system at 6 and 9 kt, and both port and starboard systems at 12 and 15 kt. No spectrum levels are shown for low-speed operation on the port propulsion system. The towship had a damaged port propeller at the time of Sea Trial 5H4. This caused severe cavitation noise at low tow speeds, and so the port propulsion system was not used for any towed array self-noise data acquisition runs at 6 or 9 kt. It was, however, necessary to use the port propulsion system along with the starboard system to achieve the higher tow speeds of 12 and 15 kt in Sea Trial 5H4.

## 4.3 AMBIENT NOISE

(U) Typical ambient noise spectra for moderate shipping traffic (at low frequencies) and Sea States 1, 2, and 3 (at high frequencies) have been shown in Figures 4-1 through 4-3 for reference. These are typical open-ocean ambient noise spectrum levels.

(U) Ambient noise was not a significant component establishing the noise floor for acoustical measurements at the shorter tow cable length,  $L = 3250$  ft, in Sea Trial 5H4. Towship radiated noise and signal transmission system electrical noise dominated in this case, at all tow speeds.

(U) At the greater tow cable length,  $L = 7000$  ft, Sea State 3 ambient noise dominated at high frequencies, from 500 to 5000 Hz. However, in Sea State 1 the towship radiated noise dominated at all frequencies, just as it had at the shorter tow cable length.

(U) No on-site measurements of actual ambient noise were made by a buoy or other system independent of the towed array, during Sea Trial 5H4. Thus, no information about actual low-frequency ambient noise spectrum levels in Exuma

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Sound are available to aid in the present analysis. However, acoustical measurements were made on two occasions with the towship stopped and quieted. These measurements provide an upper limit to actual low-frequency ambient noise in Exuma Sound. System electrical noise appeared to dominate from 8 to 160 Hz in these measurements.

(U) At the higher frequencies, from 500 to 5000 Hz, actual acoustical ambient noise levels measured in Sea Trial 5H4 were about 3 dB lower than those which would be expected on the basis of estimates of sea state. This was true at Sea State 1, at Sea State 2 to 3, and at Sea State 3. The estimates of sea state are made by the ship's crew on watch in the wheelhouse of the towship. These estimates may be regarded as consistently reliable. It is therefore useful in the analysis of other acoustical data acquired using the same towship, to establish the relationship between estimated sea state and the corresponding actual acoustical ambient noise spectrum levels.

## 4.4 SYSTEM ELECTRICAL NOISE

(U) Estimates of the signal transmission system electrical noise floor for the LSM hydrophones have been presented in Figures 4-1 through 4-3. These estimates were made on the basis of the spectra measured with the towship stopped and quieted. As shown in the figures, system electrical noise dominated the total noise floor at low frequencies, from 8 to about 100 Hz.

(U) At present, it has not been established whether the system noise floor originates in the preamplifier/linedriver electronics in the towed array, or in the postamplifier electronics aboard the ship. It is believed that the electrical noise floor for a COM hydrophone is about 5 dB lower than that shown, since these hydrophones are 5 dB more sensitive than the LSM hydrophones. The electrical noise floors for the ITM sensors are thought to be even lower.

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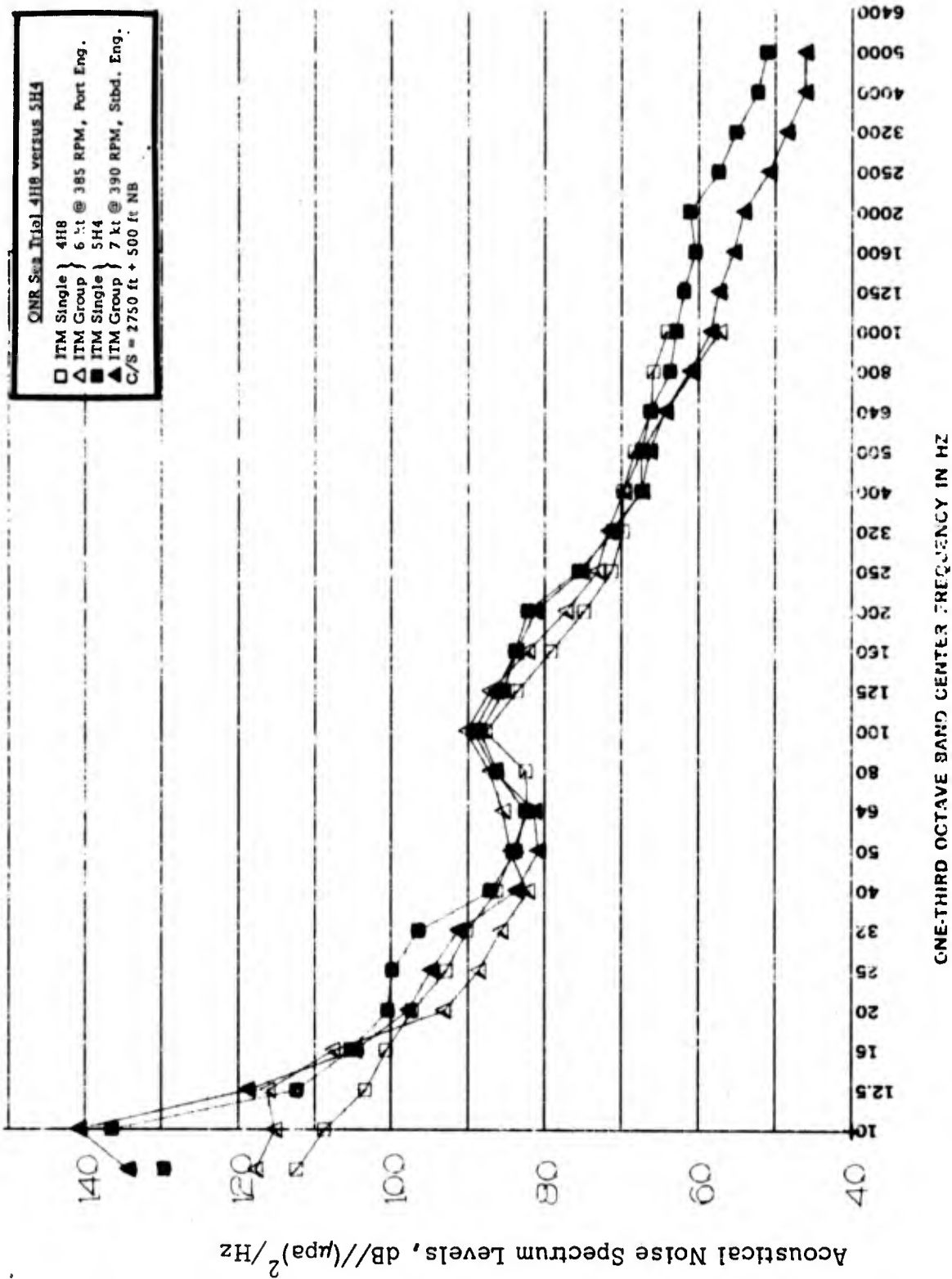
## Section 5

### ARRAY MODULE PERFORMANCE

#### 5.1 GENERAL ASSESSMENT OF DATA

(U) The general quality of the acoustical data obtained during the trial was assessed on-line during acquisition to determine its validity. The common barometer from which to make this judgment was the performance of the ITMs, as those modules were not altered since the last ONR sea trial of May 1974, Sea Trial 4H8. It was assumed that if the ITM results appeared reasonable, then the acoustical levels obtained from the other modules were also true and valid indications of their performance.

(U) Figure 5-1 illustrates the ITM results obtained during Sea Trial 5H4, compared to those from the previous ONR Sea Trial 4H8. For both trials, the test site, sea state, and array configuration were similar. However, there were differences in the type of cable fairing, engine line-up, ship's heading, and tow speed. Trial 4H8 used a fairing which consisted of 30 mil thick polyurethane ribbons with 50 percent coverage, whereas Trial 5H4 used 20 mil thick ribbons with 25 percent coverage. The widths and lengths of the ribbons in both configurations were identical. At a tow speed of 6 kt, the towing load<sup>3</sup> for 4H8 was 4061 lb and the engine speed was 385 rpm on the port engine for a ship's heading of 319 degrees. For this trial at the same engine speed on the starboard engine, the towing load was about 2250 lb for a ship's heading of 132 degrees and resulted in a through water speed of 7 kt. Oceanographic conditions at the test site for Winter (January-March) indicate the prevailing surface current velocity is 1 kt at 030 degrees.<sup>4</sup> For Spring (April-June), this current shifts to 350 degrees with the same magnitude. This would indicate that the Trial 4H8 6-kt run data was obtained while traveling with a 1-kt surface current, resulting in a true course of 323 degrees and an array speed of 6.88 kt, whereas the Trial 5H4 6-kt run had a true course of 076 degrees with an array speed of 7.96 kt. Knowledge of the subsurface current profile was not available.



(C) Figure 5-1. ITASS Module Noise Spectrum Level Comparison for Trials 4H8 and 5H4 at Equal Engine Speeds and Cable Scope

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(C) Even though the tow speeds differ by about 1 kt, comparison of the plots shown in Figure 5-1 illustrate several significant points. At 10 Hz, the 5H4 ITMs measured very high noise levels which were as much as 25 dB above the 4H8 results. Although both tow cables were faired, their percent coverage differed and strumming could have occurred, especially if the cross-current at the surface extended to a significant depth. Generally, cable strumming generates narrow band energy and usually causes several harmonics to appear in the acoustical data. This extreme low-frequency concentration of energy could be due to towing instabilities of the array itself, or array or neutrally buoyant cable strumming due to local variations from neutral buoyancy. However, this phenomenon was observed only during certain 6-kt runs and diminished as tow speed or cable scope increased. At frequencies above 320 Hz, the two ITMs measured remarkably similar acoustical levels, which would indicate that the flow noise generated at 7 to 8 kt is less than the towship radiated noise at 390 rpm.

(U) Despite the slightly different test conditions, the similarity of the two ITM acoustical spectrums indicates that the results obtained by the other modules should be true and valid measurements of their acoustical performance, and that the data are comparable to previous data obtained in Exuma Sound with the towship HARRIS.

## 5.2 INDIVIDUAL MODULE RESULTS

### 5.2.1 ITM (Reference Module)

(C) Two ITMs were integrated into the array during most of the trial, as previously shown in Figure 2-2. Signals obtained included those from the single and group-of-seven hydrophones, designated S1 and G1 for ITM1, and that from the group-of-seven hydrophones from ITM2, designated G2. The single element hydrophone from ITM2 was sacrificed in the interest of obtaining more data from other modules (this was a physical wiring limitation, since only 20 signals could be transmitted by the tow cable).

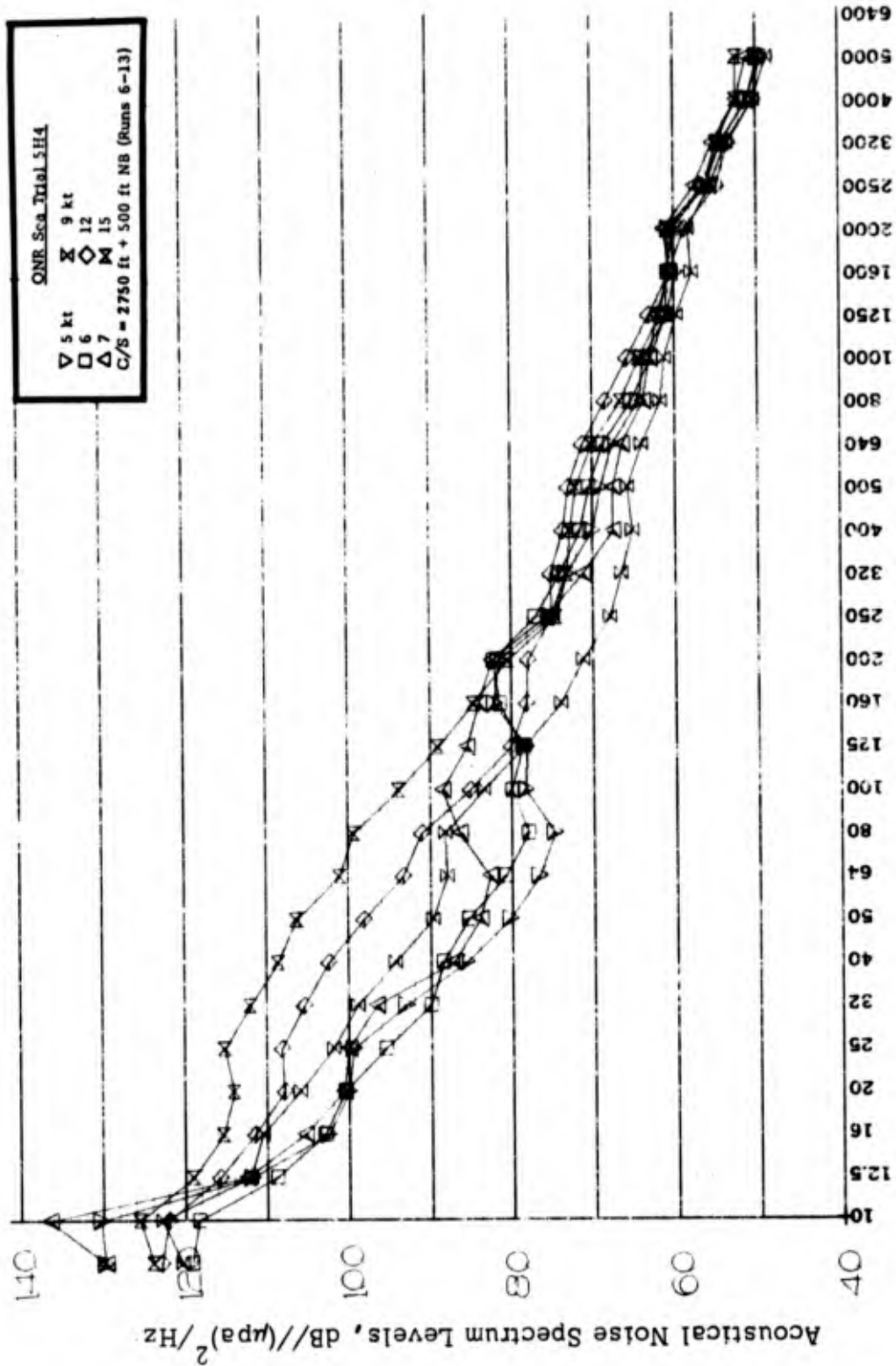
(C) Generally, the ITM groups measured acoustical noise spectrum levels which were 2 to 8 dB lower than those of the single ITM hydrophone, as would be

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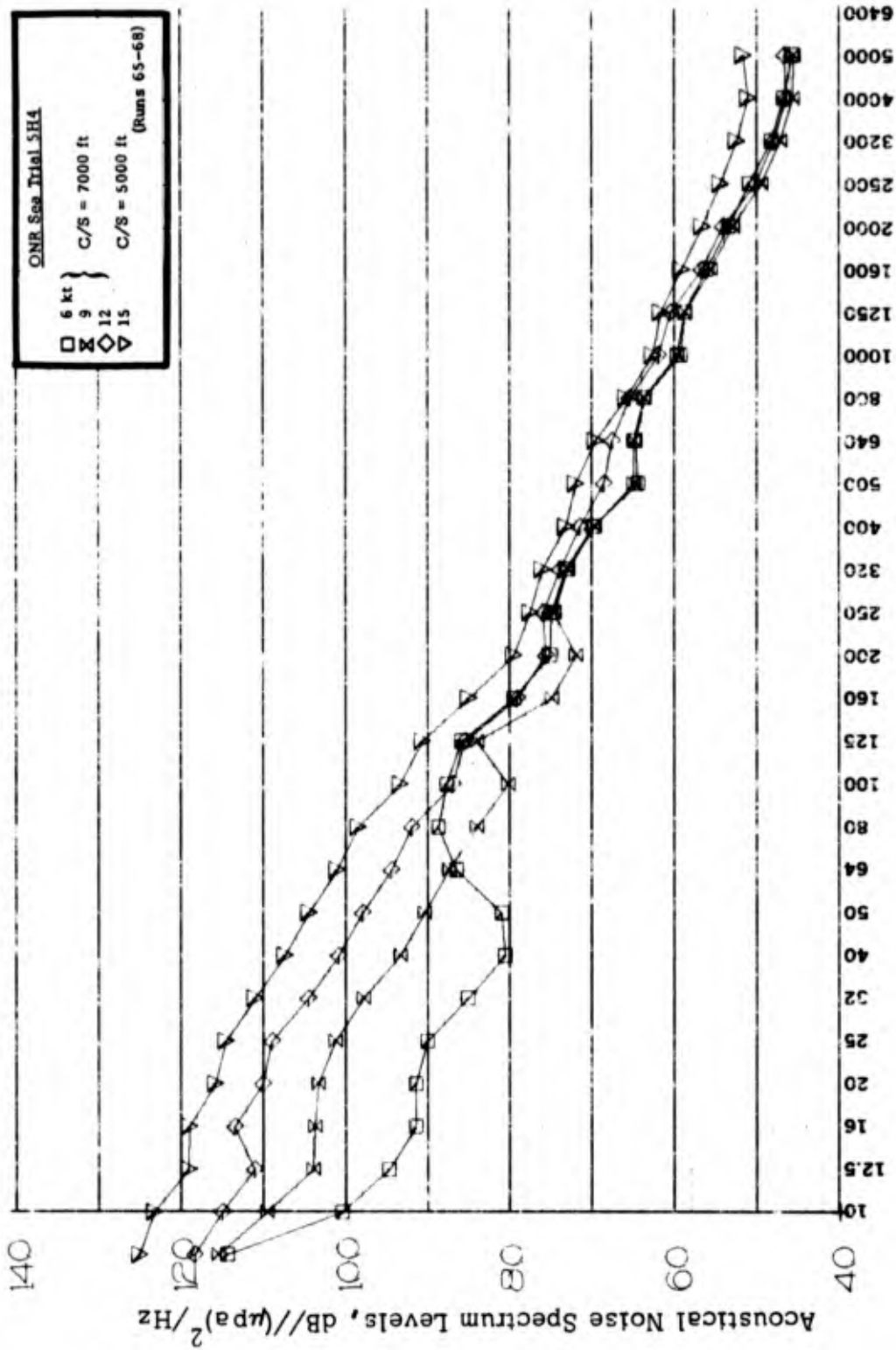
expected due to grouping gain against flow noise at low frequencies, and against towship radiated noise at high frequencies. This was true for all combinations of tow speed and cable scope, and for all frequencies except for a band from 80 to 320 Hz. In this region, both the ITM groups and single hydrophone spectrum levels were dominated by towship radiated noise, and the ITM groups as well as the single hydrophones had omnidirectional response. At frequencies greater than 320 Hz, the endfire responses of the ITM groups to towship radiated noise were typically 2 to 6 dB less than the response of the ITM single hydrophone.

(C) Figure 5-2 presents the acoustic noise spectrum levels measured by a single element ITM hydrophone for Array Configuration "A," located at a slant range of approximately 3320 ft (2750-ft tow cable, 500-ft NB cable, and 70-ft array length to hydrophone) from the towship. At 10 Hz, high acoustical levels were measured at 5 and 7 kt; however, the 6-kt run did not indicate such levels. Since all the data were acquired within a two-hour period while on constant heading, there should not have been any anomalies present due to variations in ocean currents. It therefore appears that the high 10-Hz levels were due to local instabilities in the array towing characteristics rather than the traditional strumming associated with bare tow cables. At frequencies between 20 and 80 Hz, the acoustic noise spectrum levels increased with tow speed by about 2.5 dB/kt. For frequencies between 80 and 250 Hz, the hydrophone noise spectrum levels were dominated by towship propeller cavitation radiated noise. The 9-kt noise levels were consistently 4 to 10 dB below the 6-kt levels in the frequency range from 125 to 320 Hz for all data runs. This illustrates the shift to lower frequencies of the propeller cavitation spectral peak, resulting in a lower level of mid-frequency radiated noise.

(C) Figure 5-3 presents the noise spectrum levels for the same ITM single hydrophone at greater slant ranges of 7392 ft for speeds up to 12 kt, and 5392 ft for the 15-kt runs. Tension fluctuations due to sea state limited the 15-kt runs to a maximum cable scope of 5000 ft in the interest of safety. The Array Configuration was "E," which included the 330-ft SLC VIM. At 6 kt, the noise spectrum levels were 4 to 15 dB lower than at the 3320-ft scope levels, in a frequency range



(C) Figure 5-2. ITM Single Hydrophone Noise Levels versus Tow Speed at 2750-ft Cable Scope (U)



ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

(C) Figure 5-3. ITM Single Hydrophone Noise Levels versus Tow Speed at 7000-ft Cable Scope (U)

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from 8 to 50 Hz. Between 64 and 160 Hz, the spectrum levels measured at the long scopes were actually greater than at the 3320-ft scope, by as much as 10 dB. This was probably due to the increased engine speed required to maintain 6 kt with the long cable scope. From 320 to 5000 Hz, the 7392-ft levels were approximately 6 to 8 dB less than the 3320-ft levels, due to the spherical spreading losses associated with sound propagation from a point source such as the towship.

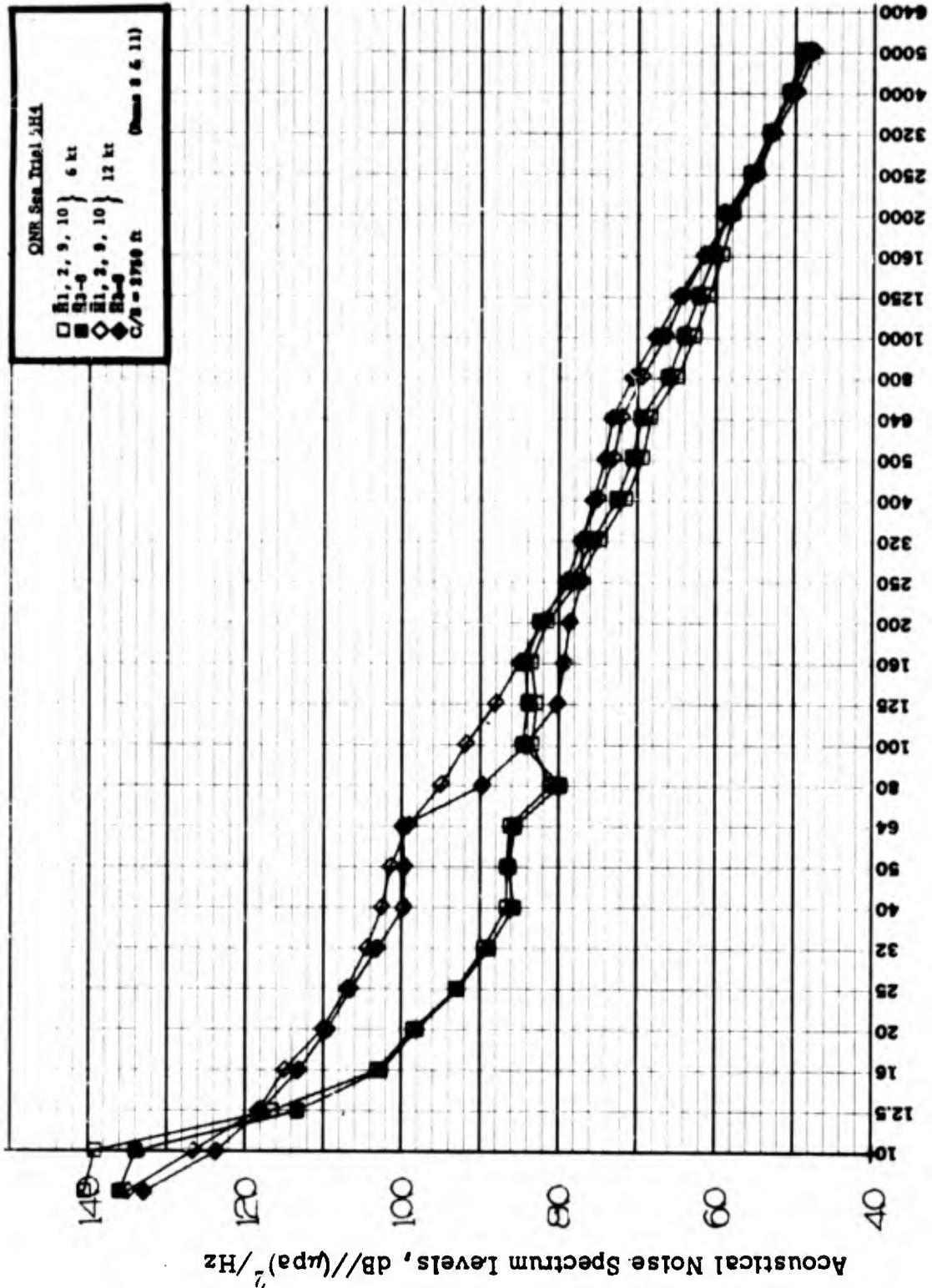
(C) At 9, 12, and 15 kt, and for frequencies below 16 Hz, the spectrum levels obtained at the longer scopes were 8 to 12 dB less than those for the short scope. Between 20 and 125 Hz, the noise spectrum levels for both long and short scopes were similar, indicating that a local phenomenon such as TBL flow-noise or module breathingwaves may have limited the acoustical performance of the array. For frequencies from 320 to 5000 Hz, the noise spectrum levels obtained using the long cable scope were below the levels measured with the short scope by an amount equivalent to the spherical spreading losses based on the different cable lengths, again confirming the influence of towship radiated noise.

(U) Figures 5-2 and 5-3 provide baseline reference data from which to assess the performance of the single hydrophones of the various other array modules. However, the data is intended to provide a guideline for interpretive analysis only. The hydrophones that were mounted in the various array modules are of a more sophisticated design and specifically intended for R&I use.

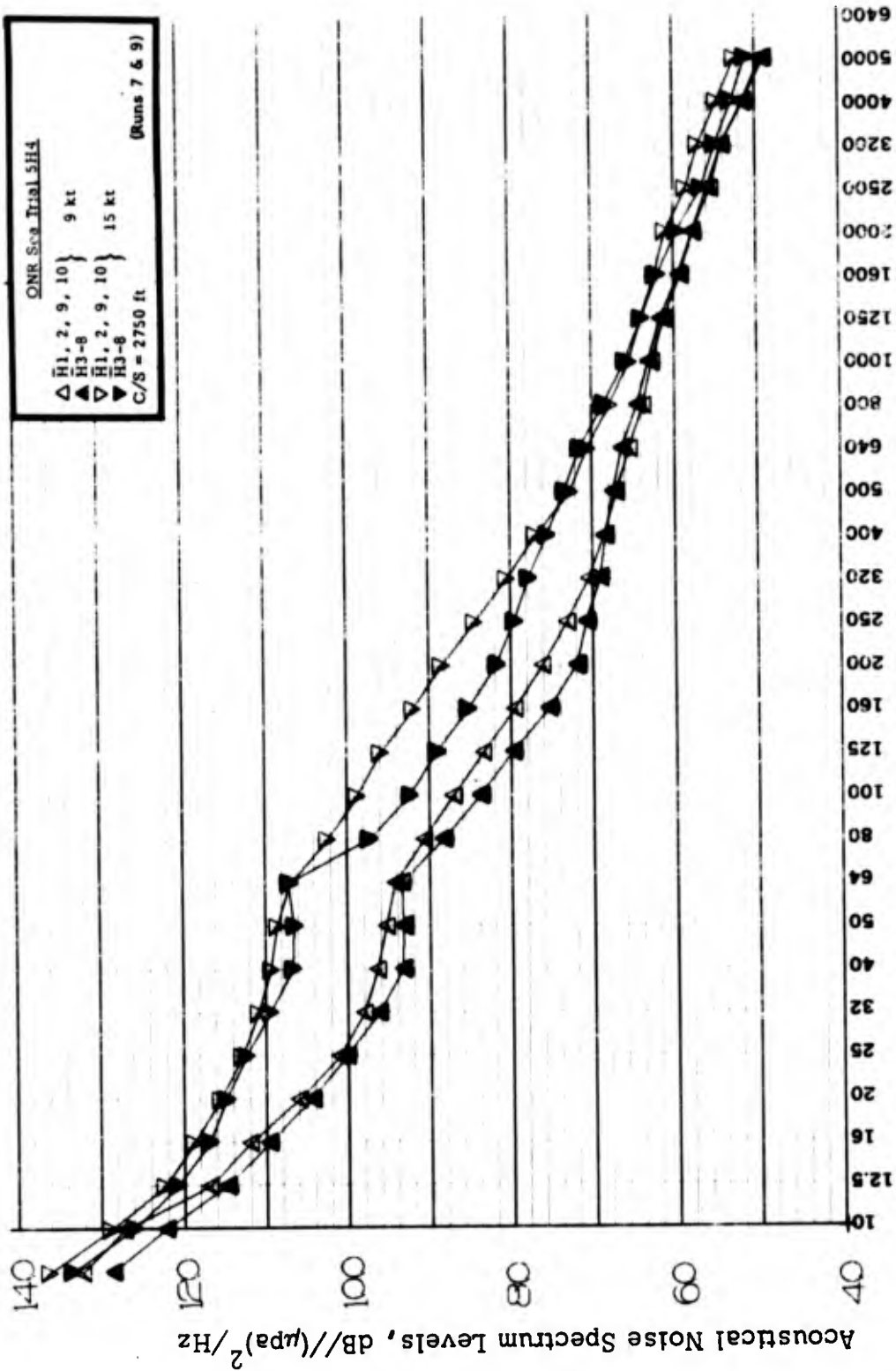
## 5.2.2 LSM

(C) The LSM was integrated into the ONR R&D Array for Configurations "A," "B," and "D" and provided baseline measurements for the 10 new hydrophones, comparative measurements of the three VIMs, and the two LSM boots. The signals obtained included the 10 single hydrophones, designated H1-H10 (numbered from the forward end), and the two accelerometers mounted in the module end caps, designated A1 and A2.

(C) Figures 5-4 and 5-5 present the average noise spectrum levels measured by various hydrophones in two distinct locations within the module, for tow speeds of 6, 9, 12, and 15 kt. Hydrophones H1, H2, H9, and H10 are pairs that were



(C) Figure 5-4. LSM Noise Level Comparisons for End Cap versus Centrally Mounted Hydrophones at 6 and 12 kt (U)



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(C) Figure 5-5. LSM Noise Level Comparisons for End Cap versus Centrally Mounted Hydrophones at 9 and 15 kt (U)

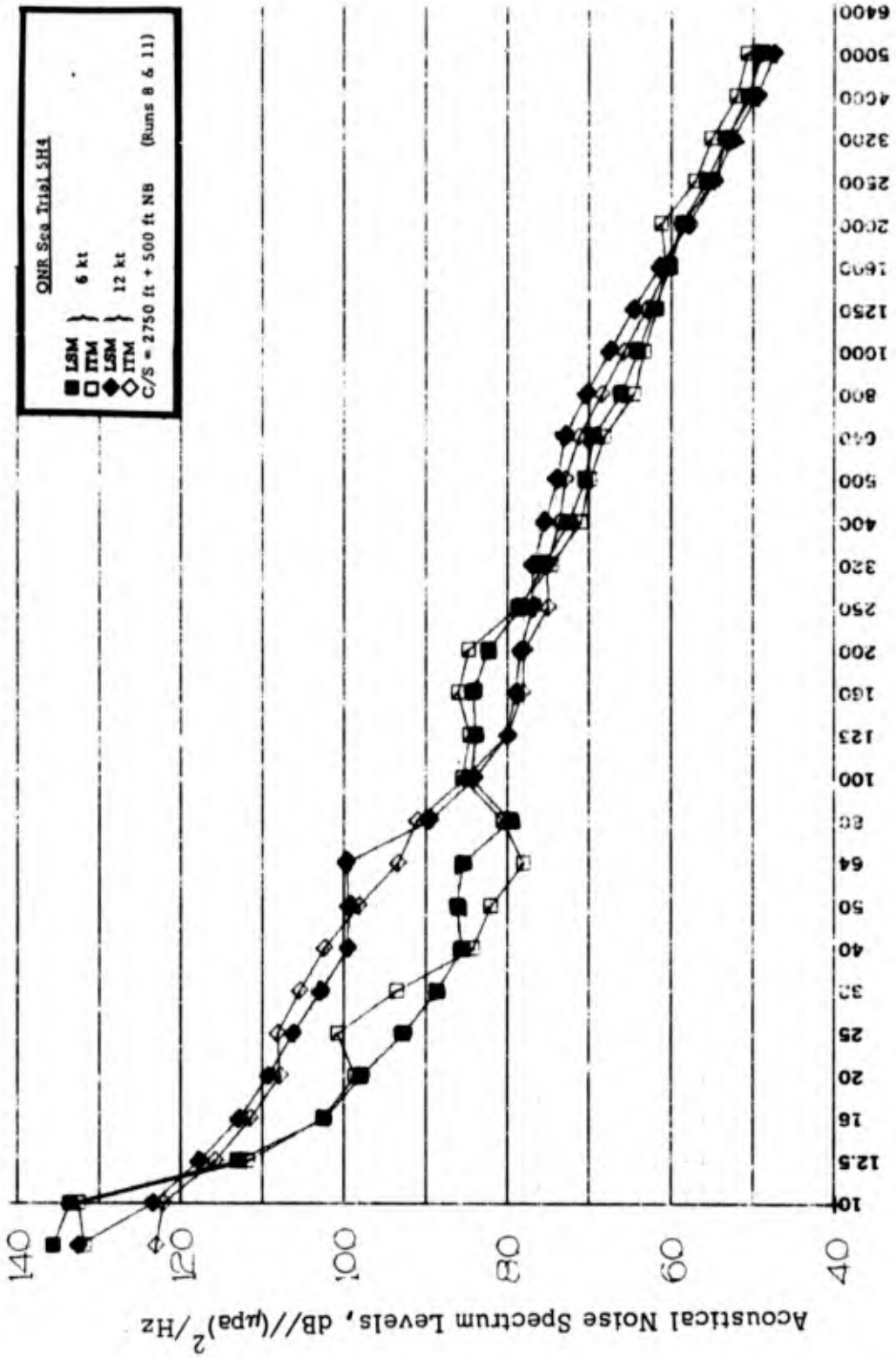
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located within 1.5 ft from the module end caps, whereas H3-H8 were centrally located and at least 18.0 ft from either end cap (see Figure 2-1). As shown in the figures, the centrally located hydrophones consistently measured lower noise levels than the hydrophones located near the end caps, at frequencies less than about 320 Hz. The largest differences occurred for speeds of 9, 12, and 15 kt in the frequency range from 64 to 320 Hz, where the centrally located hydrophones measured noise levels as much as 6 to 8 dB below those measured by the end cap hydrophones. This indicates that the end cap hydrophones are affected by some local phenomena such as towing instabilities due to mass discontinuities at the module coupling, TBL scattering due to hosewall surface discontinuities, or high module energy breathingwaves originating at the module end caps. This implies that the long separation distance from the end caps to the central hydrophones allows the module to provide sufficient damping of module breathingwaves such that the energy is dissipated.

(C) Since the noise levels measured by the LSM central hydrophones were consistently lower than those measured by the hydrophones mounted near the end caps, the central hydrophones are hereafter considered the baseline hydrophones for comparative noise level measurements for frequencies up to 320 Hz. At higher frequencies, both the central hydrophones and the end cap hydrophones measured equivalent noise levels, because their noise spectra were dominated by towship radiated noise and ambient noise.

(C) Figures 5-6 and 5-7 present plots of the average of the spectrum levels measured by the LSM central hydrophones, H3-H8, compared to those measured by the ITM single hydrophone for tow speeds of 6, 9, 12, and 15 kt, and for a cable scope of 2750 ft plus 500 ft of NB cable. The noise levels measured by the LSM hydrophones were 2 to 8 dB below those measured by the ITM single hydrophone at frequencies below 40 Hz for all tow speeds. Between 40 and 80 Hz, the LSM hydrophone noise spectrum levels increased to as much as 6 dB above the ITM hydrophone levels. At higher frequencies, the LSM and ITM noise levels were very similar except in a frequency band from 200 to 1600 Hz. Here the LSM hydrophones measured higher noise levels by as much as 4 dB above the

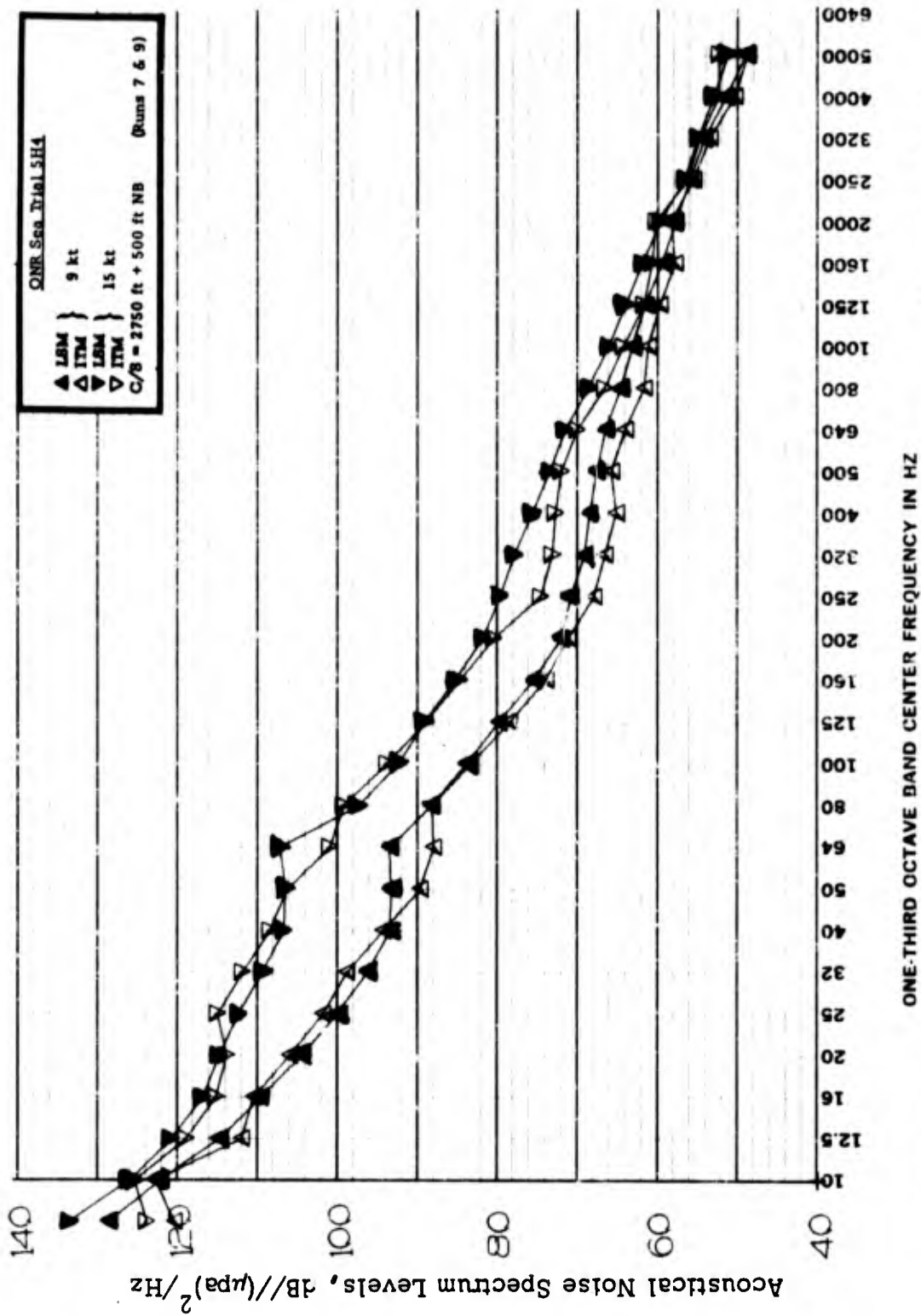
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(C) Figure 5-6. LSM versus ITM Single Hydrophone Noise Levels at 6 and 12 kt for 2750-ft Cable Scope (U)

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(C) Figure 5-7. LSM versus ITM Single Hydrophone Noise Levels at 9 and 15 kt for 2750-ft Cable Scope (U)

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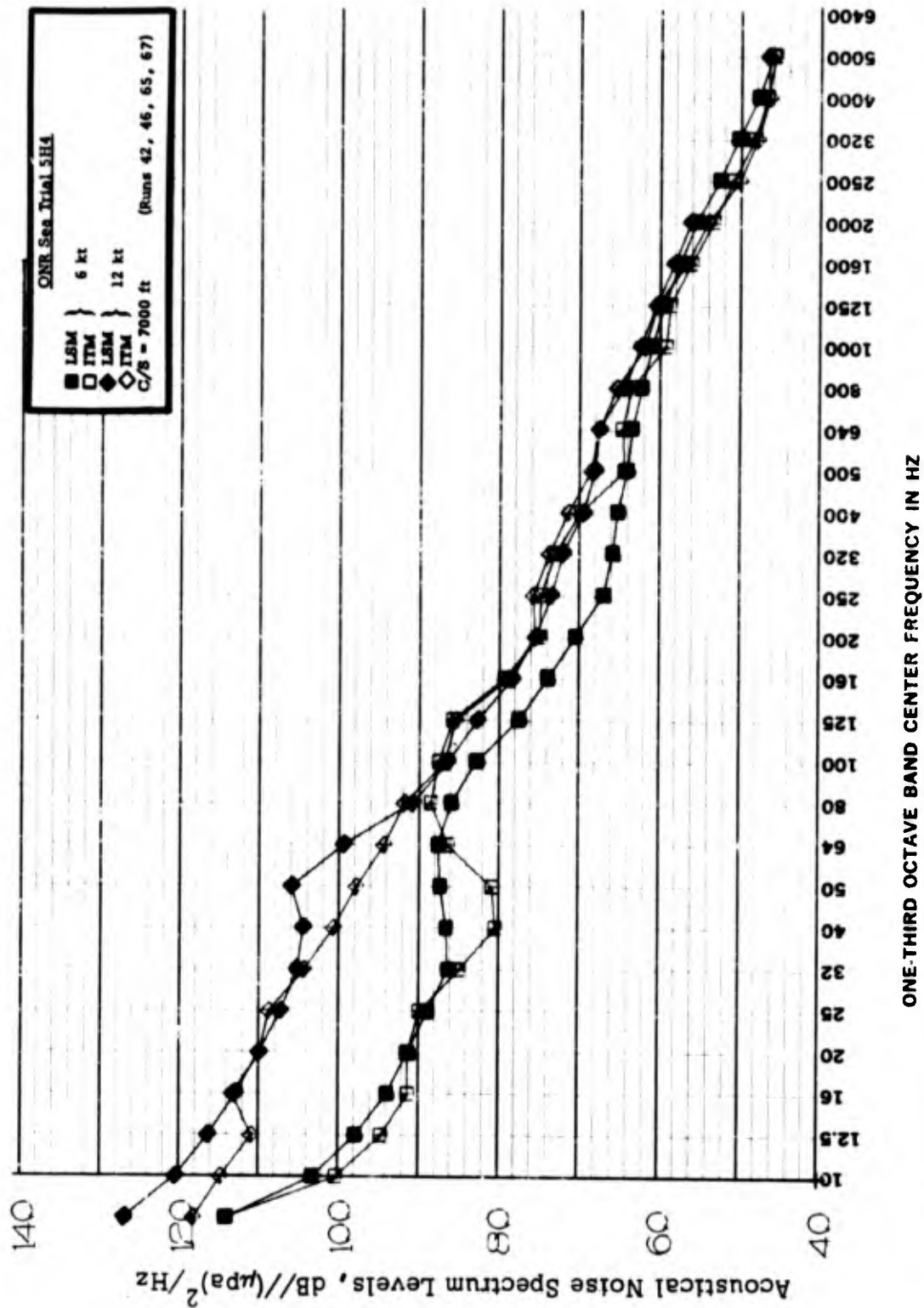
ITM hydrophone noise levels. This was especially pronounced at speeds of 9 and 15 kt. Since this was a region where towship radiated noise should dominate all hydrophones, there must have been additional noise sources affecting the LSM hydrophones, such as an increased TBL thickness or array vibrations propagating from the tail drogue.

(C) Figures 5-8 and 5-9 present a comparison of the LSM and the ITM noise spectrum levels for the longest cable scope tested. However, these data were obtained during different portions of the sea trial, rather than simultaneously, as previously presented. At 6 kt and at frequencies below 25 Hz, the LSM hydrophone noise levels were limited by the electrical noise floor of the system. Between 32 and 64 Hz, the ITM hydrophone measured lower noise levels than the LSM hydrophones, by as much as 6 dB. For tow speeds of 9 and 12 kt, the ITM hydrophone measured lower noise levels in two distinct frequency bands — less than 20 Hz and between 32 and 64 Hz. At 15 kt, the LSM hydrophone levels were 2 to 4 dB below the ITM hydrophone levels up to 50 Hz. At frequencies above 80 Hz, and for speeds of 6 and 9 kt, the LSM hydrophones measured lower noise levels than the ITM hydrophone by as much as 8 dB. However, the ITM hydrophone signals at these speeds were contaminated by even-numbered harmonics of 60-Hz noise. For tow speeds of 12 and 15 kt, the two modules measured essentially the same noise levels.

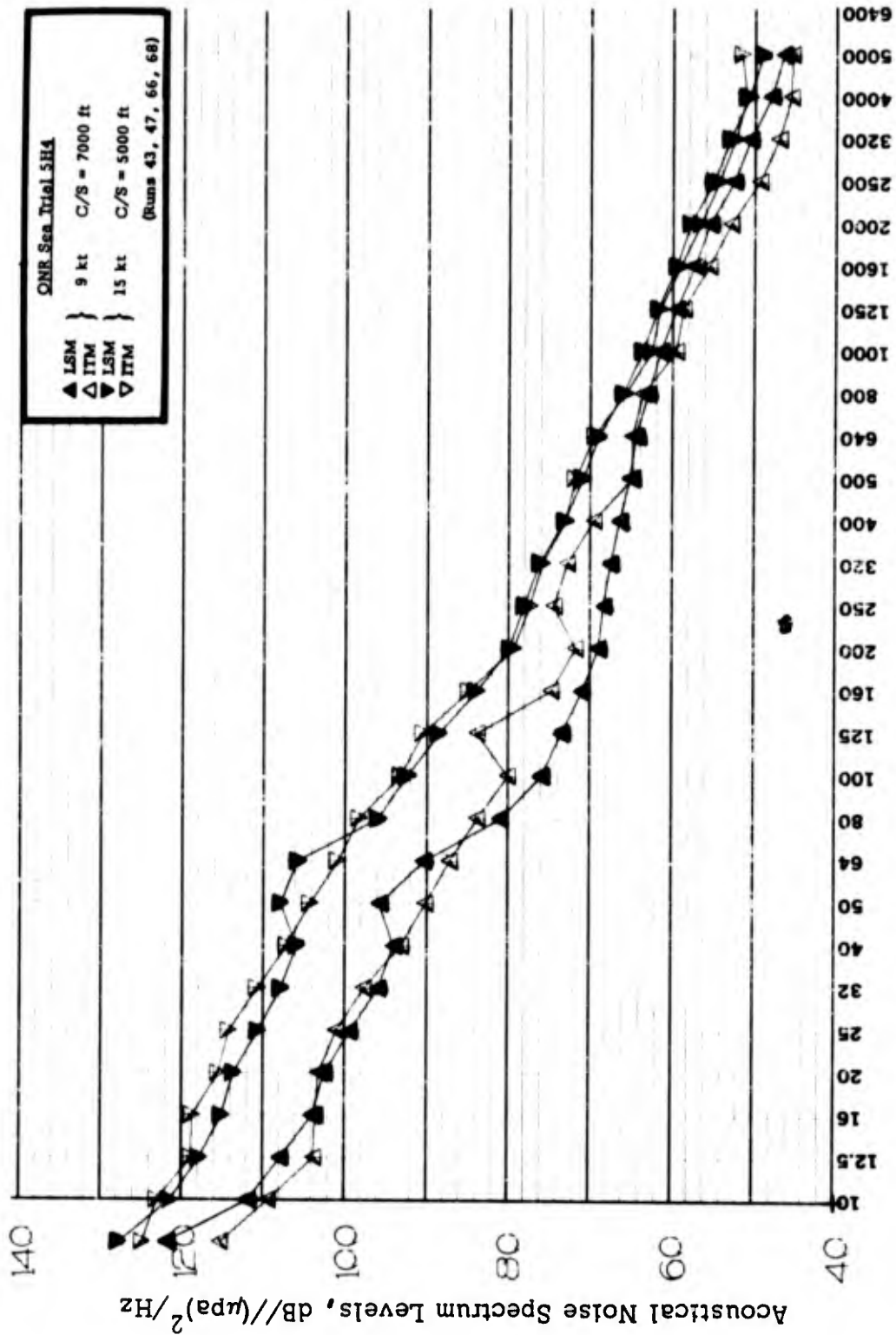
(C) It can thus be concluded from the above comparison plots that the central LSM hydrophones, H3-H8, measured lower noise levels than the end cap hydrophones, H1-H2 and H9-H10, and that these levels were comparable to the levels measured by the ITM single hydrophone. Also, towship radiated noise dominated the LSM hydrophone noise spectrum levels in the frequency range from 80 to 1600 Hz, for tow speeds of 12 and 15 kt, even at the greatest slant ranges used in the trial.

### 5.2.3 COM

(C) The newly constructed COM was integrated into Array Configuration "C" during only one set of data acquisition runs involving the longest cable scope available. The signals obtained included the nine individual hydrophone outputs, numbered C1-C9 from the module forward end (see Figure 2-1).



(C) Figure 5-8. LSM versus ITM Single Hydrophone Noise Levels at 6 and 12 kt for 7000-ft Cable Scope (U)



(C) Figure 5-9. LSM versus ITM Single Hydrophone Noise Levels at 9 and 15 kt for 700C-ft Cable Scopes (U)

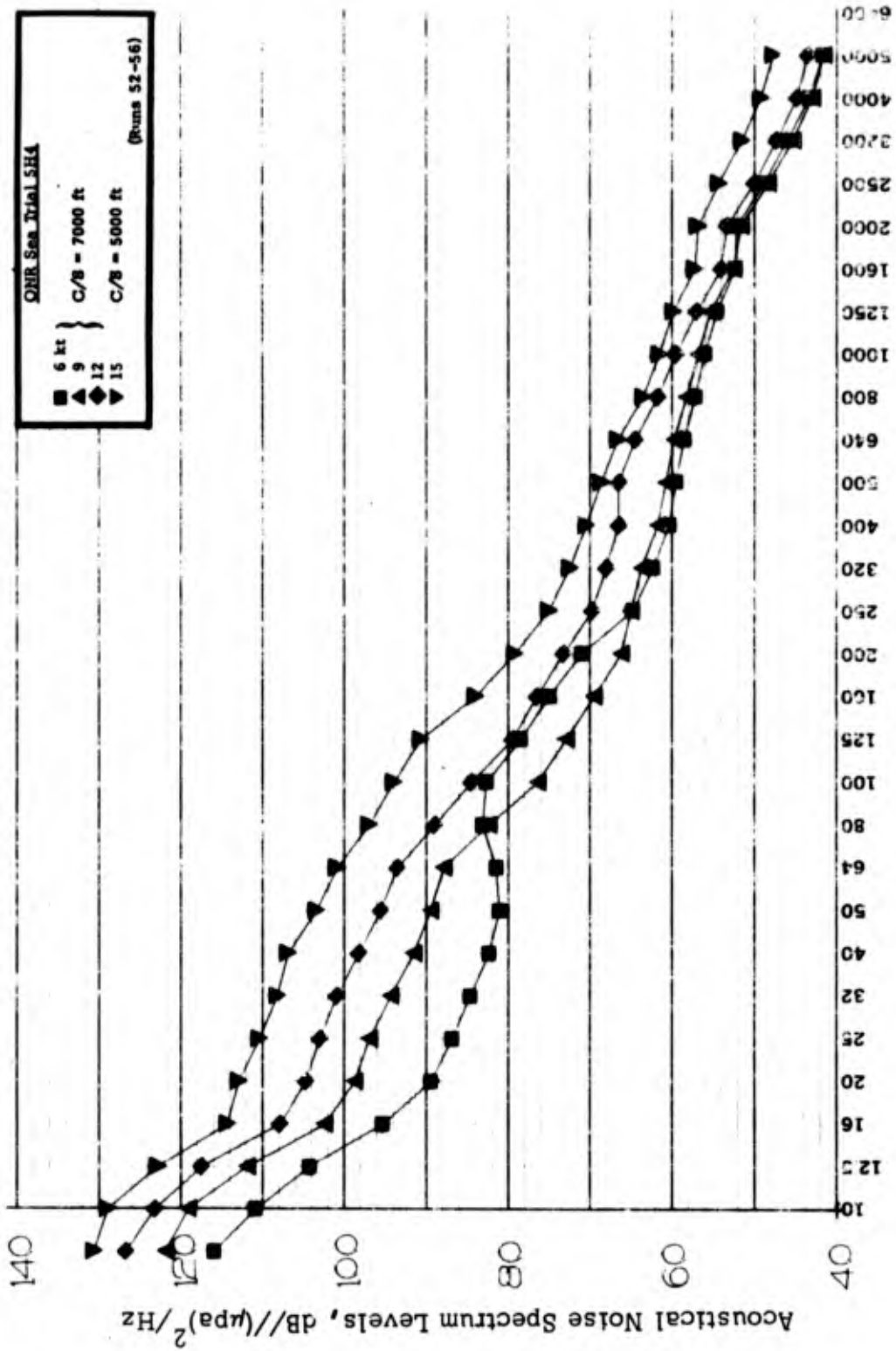
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(C) Figure 5-10 presents the average noise spectrum levels as measured by the COM hydrophones for tow speeds of 6, 9, and 12 kt for 7000 ft of cable, and 15 kt for 5000 ft of cable. As illustrated in the figure, at frequencies between 16 and 80 Hz, the COM noise spectrum levels increased by about 2.5 dB/kt from 6 to 12 kt. From 12 to 15 kt, the COM noise spectrum levels increased by about 2.0 dB/kt.

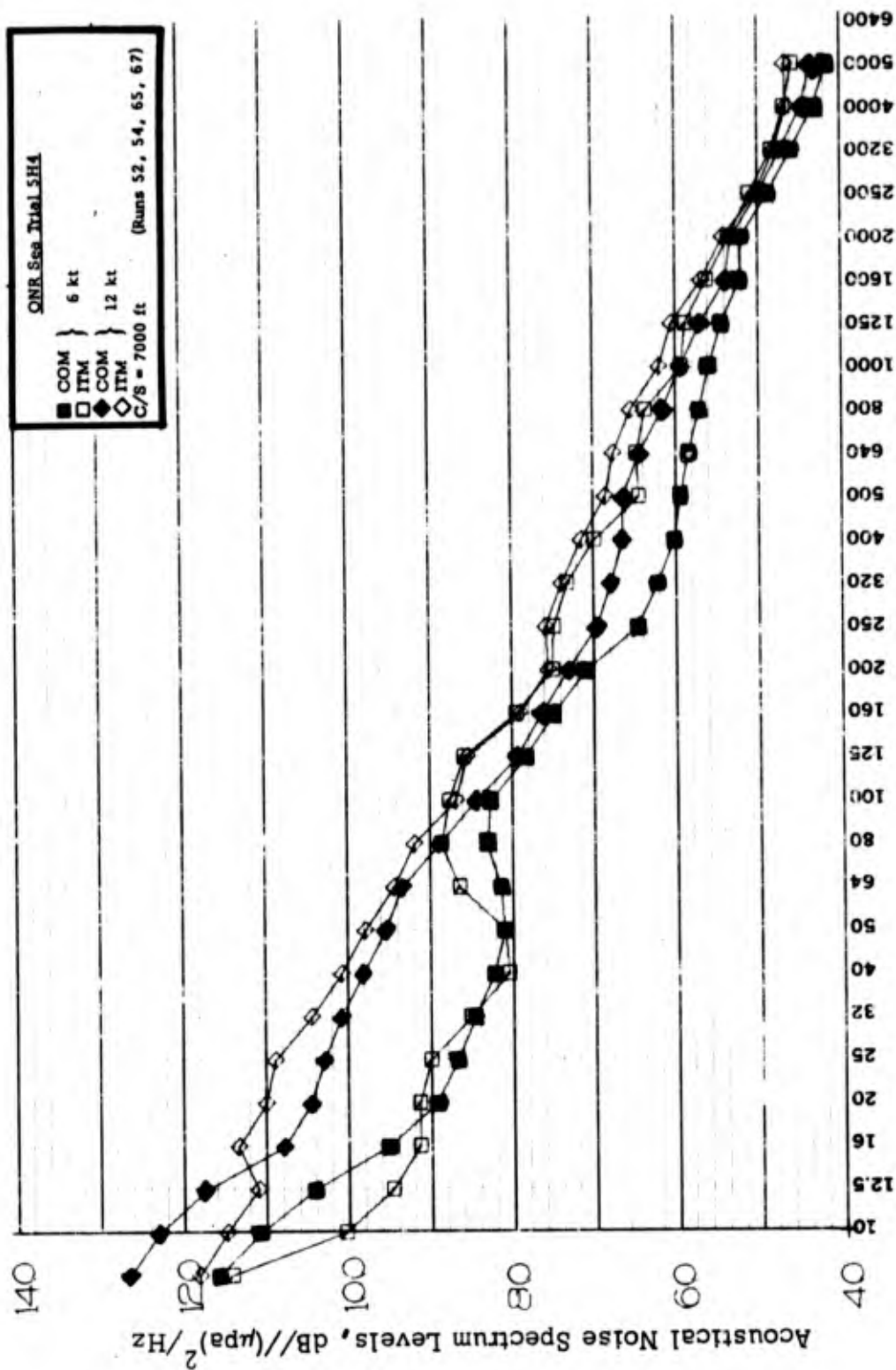
(C) At 6 kt and for frequencies below 25 Hz, the COM noise spectrum levels were limited by the electrical noise floor of the system. Comparison of the 6- and 9-kt noise spectrum levels in the frequency range of 80 to 250 Hz indicates that at 9 kt the hydrophones actually recorded lower levels, by as much as 6 dB below the 6-kt case. This once again illustrates the effect of propeller cavitation noise on the acoustical noise spectrum levels and the shift of the spectral peak to lower frequencies at higher engine speeds. At 12 kt, the noise spectrum levels at frequencies above 250 Hz were 4 to 6 dB above either the 6- or 9-kt case. This was due to increased flow noise and the addition of the port engine to the lineup. At 15 kt, the high noise spectrum levels measured were due to the dual engine lineup, flow noise, and the shortened cable scope (5000 ft compared to 7000 ft) required to obtain the higher tow speeds.

(C) Comparison of the COM noise spectrum levels with the ITM single hydrophone levels are presented in Figures 5-11 and 5-12. Generally, at frequencies below 16 Hz, the COM noise levels were as much as 8 dB above the ITM single hydrophone levels for all tow speeds. Between 25 and 64 Hz, the COM noise levels were below the ITM levels by as much as 6 dB. At the higher frequencies, this trend continued and the COM noise levels were as much as 12 dB below the ITM single hydrophone noise levels, again for all tow speeds. Note that at tow speeds of 6 and 9 kt and for frequencies above 100 Hz, the ITM hydrophone signals were significantly contaminated with even-numbered harmonics of 60-Hz noise. In general, the COM hydrophones exhibited a slightly lower self-noise level than the ITM over the frequency range of 25 to 2000 Hz for all tow speeds.

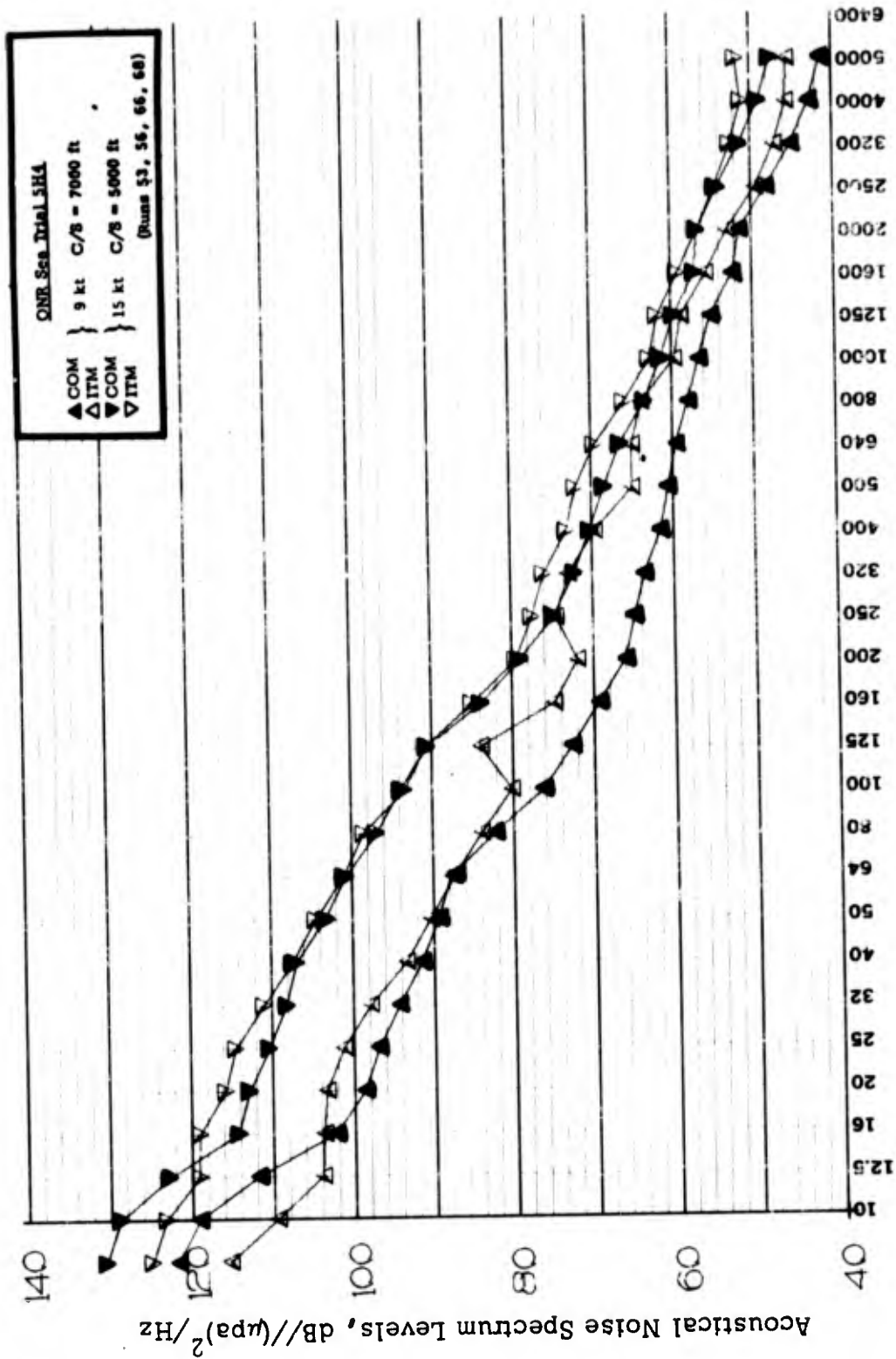
(U) The results of extensive analysis of the COM individual hydrophone spectrum levels and coherence and phase analysis of specific hydrophone pairs is presented in Reference 5.



(C) Figure 5-10. Average COM Hydrophone Noise Levels versus Tow Speed (U)



(C) Figure 5-11. COM versus ITM Single Hydrophone Noise Levels at 6 and 12 kt (U)



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(C) Figure 5-12. COM versus ITM Single Hydrophone Noise Levels at 9 and 15 kt (U)

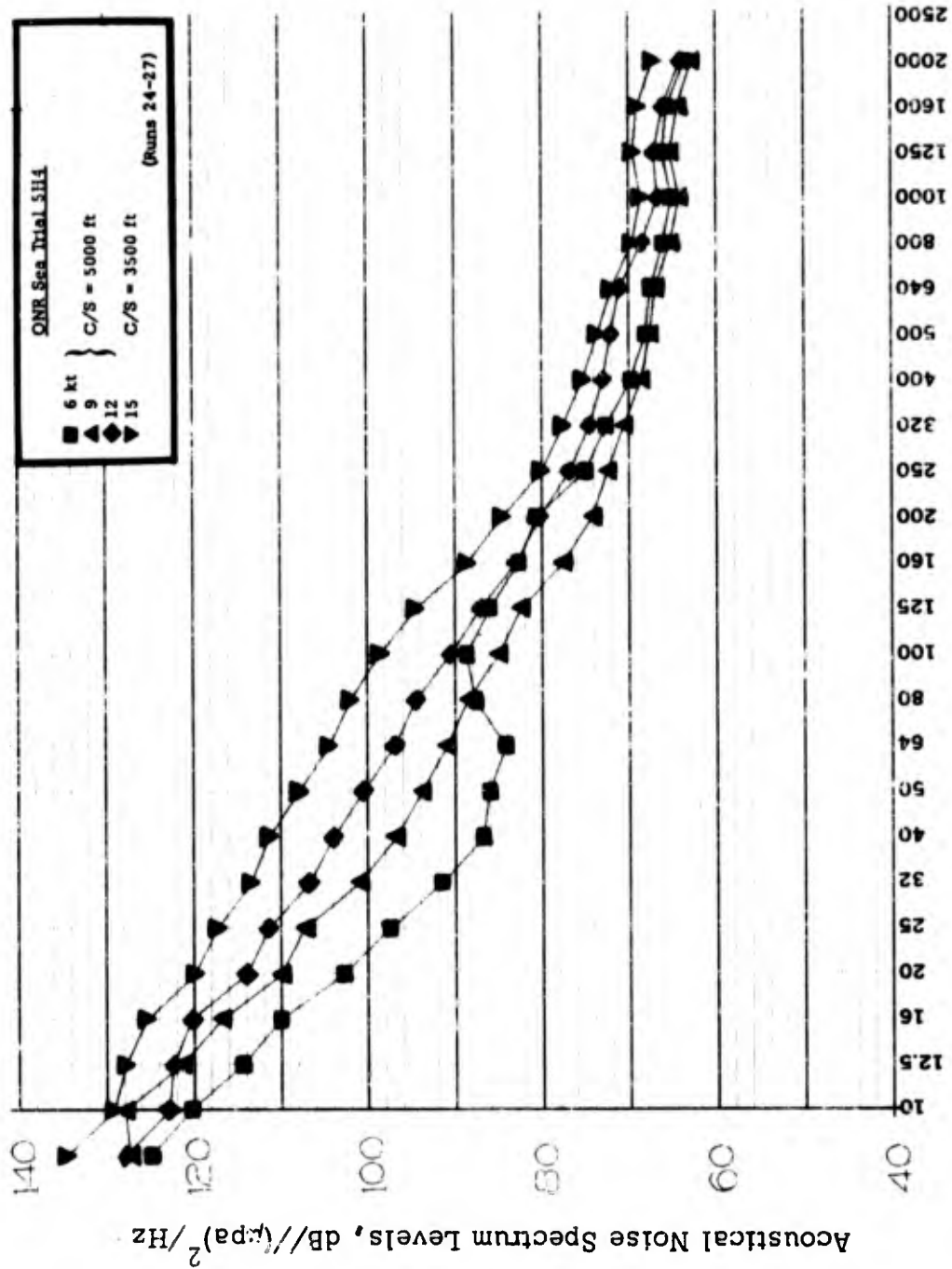
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## 5.2.4 MSM

(C) Two MSMs were integrated into Array Configurations "E" and "F." The first module, MSM1, consisted of a PVC hosewall enclosing 10 equally spaced hydrophones designated M1-M10. The second module, MSM2, was of the standard rubber/fabric laminated hosewall construction, and also housed 10 equally spaced hydrophones, designated M11-M20. Acoustic signals received for Array Configuration "E" consisted of the odd-numbered MSM hydrophone channels and the single ITM hydrophone. Configuration "F" signals included all 20 MSM hydrophone signals, with the ITM signal sacrificed.

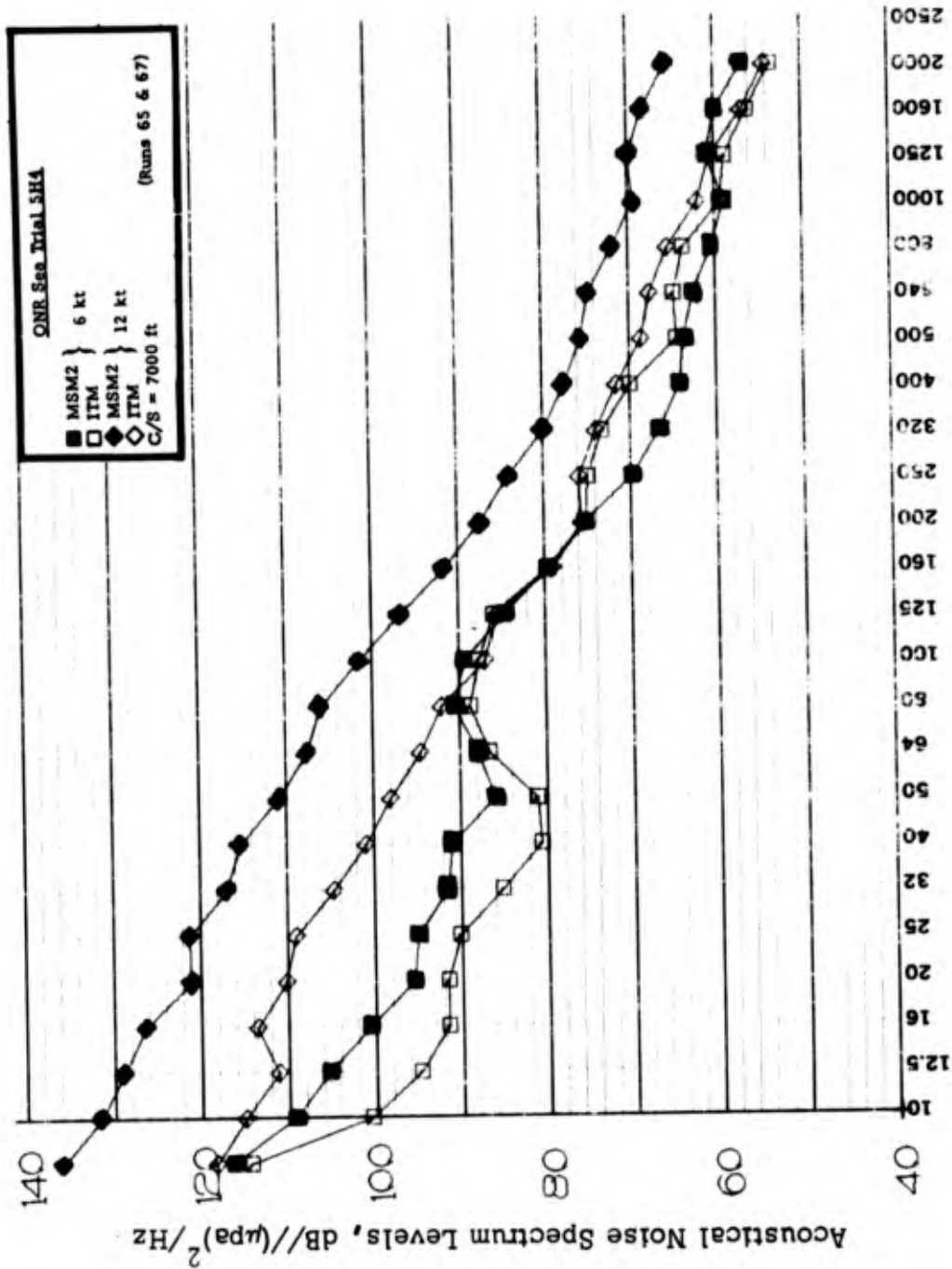
(C) Figure 5-13 presents the average MSM hydrophone noise spectrum levels as a function of tow speed for a short cable scope condition. Since there was a significant difference in the noise levels measured by MSM1 (PVC hosewall) and MSM2 (rubber/fabric hosewall), the average levels shown in Figure 5-13 are presented to illustrate the general trend of the data only, and not for purposes of absolute comparisons (see Section 6). As shown, for frequencies below 80 Hz, the noise spectrum levels increased by about 2.3 dB/kt, from 6 to 12 kt. Also, the 9-kt noise levels were again well below the 6-kt levels at frequencies between 80 and 500 Hz, due to the propeller cavitation component of towship radiated noise.

(C) Figures 5-14 and 5-15 present the averages of the MSM2 hydrophone noise spectrum levels compared to the ITM single hydrophone noise levels. Direct comparisons between noise levels measured by these two modules were reasonable, since their hosewalls were of similar construction. As shown in the figures, the MSM2 noise levels were generally higher than the ITM single hydrophone levels by as much as 5 to 10 dB over the entire frequency range and for all tow speeds. The only exceptions occurred at 6 kt and 9 kt, in the frequency range from 200 to 1000 Hz, where the MSM2 levels were 6 to 8 dB below the ITM levels. As previously observed, the ITM hydrophone noise levels at 6 and 9 kt for frequencies above 100 Hz were contaminated due to even-numbered harmonics of 60-Hz electrical noise. Therefore, the higher frequency results obtained with MSM2 were compared with the COM results shown in Figure 5-10.

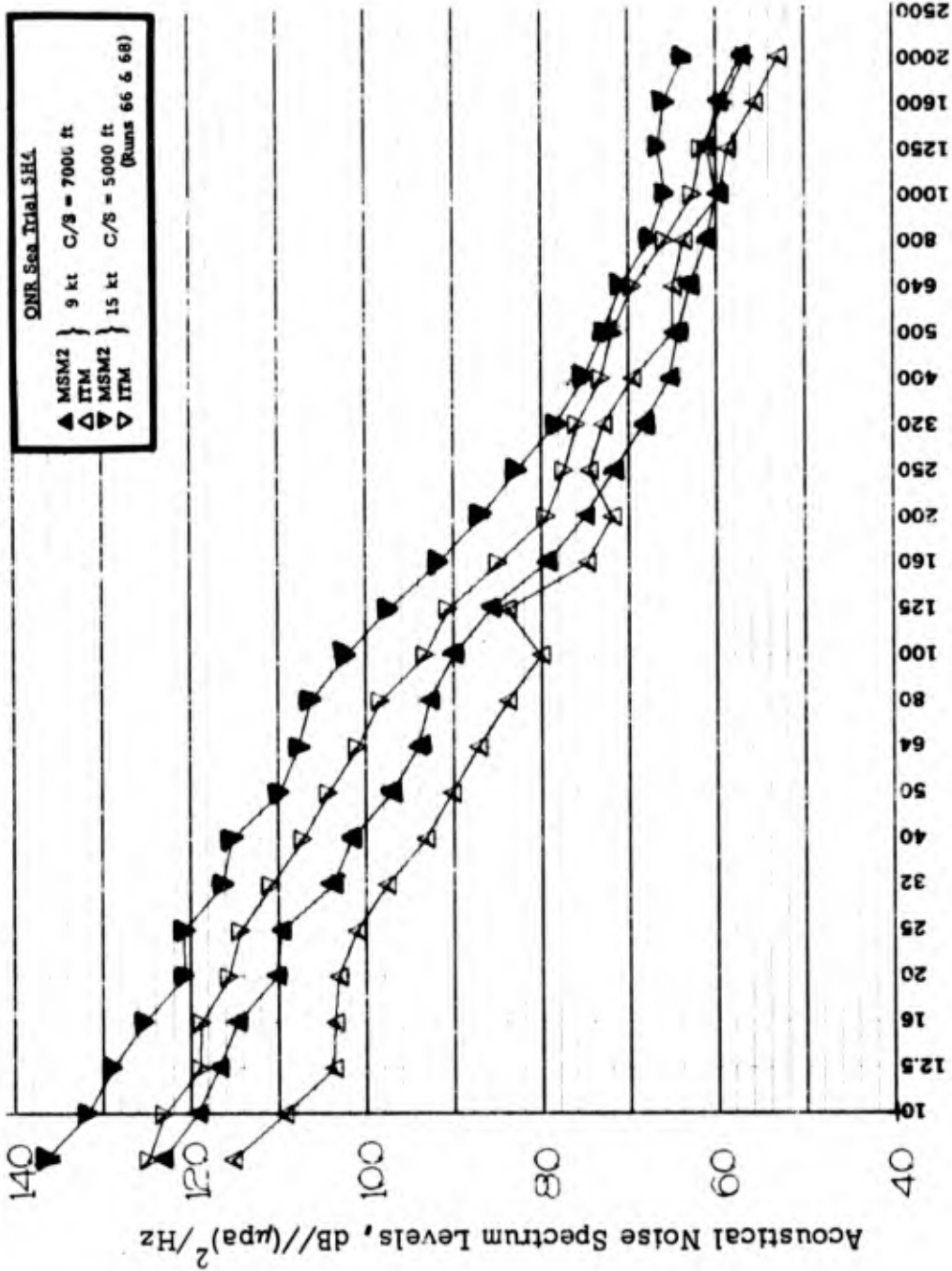


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(C) Figure 5-13. Average of MSM1 and MSM2 Hydrophone Noise Levels versus Tow Speed (U)



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(C) Figure 5-14. MSM2 versus ITM Single Hydrophone Noise Levels for 6 and 12 kt (U)



(C) Figure 5-15. MSM2 versus ITM Single Hydrophone Noise Levels for 9 and 15 kt (U)

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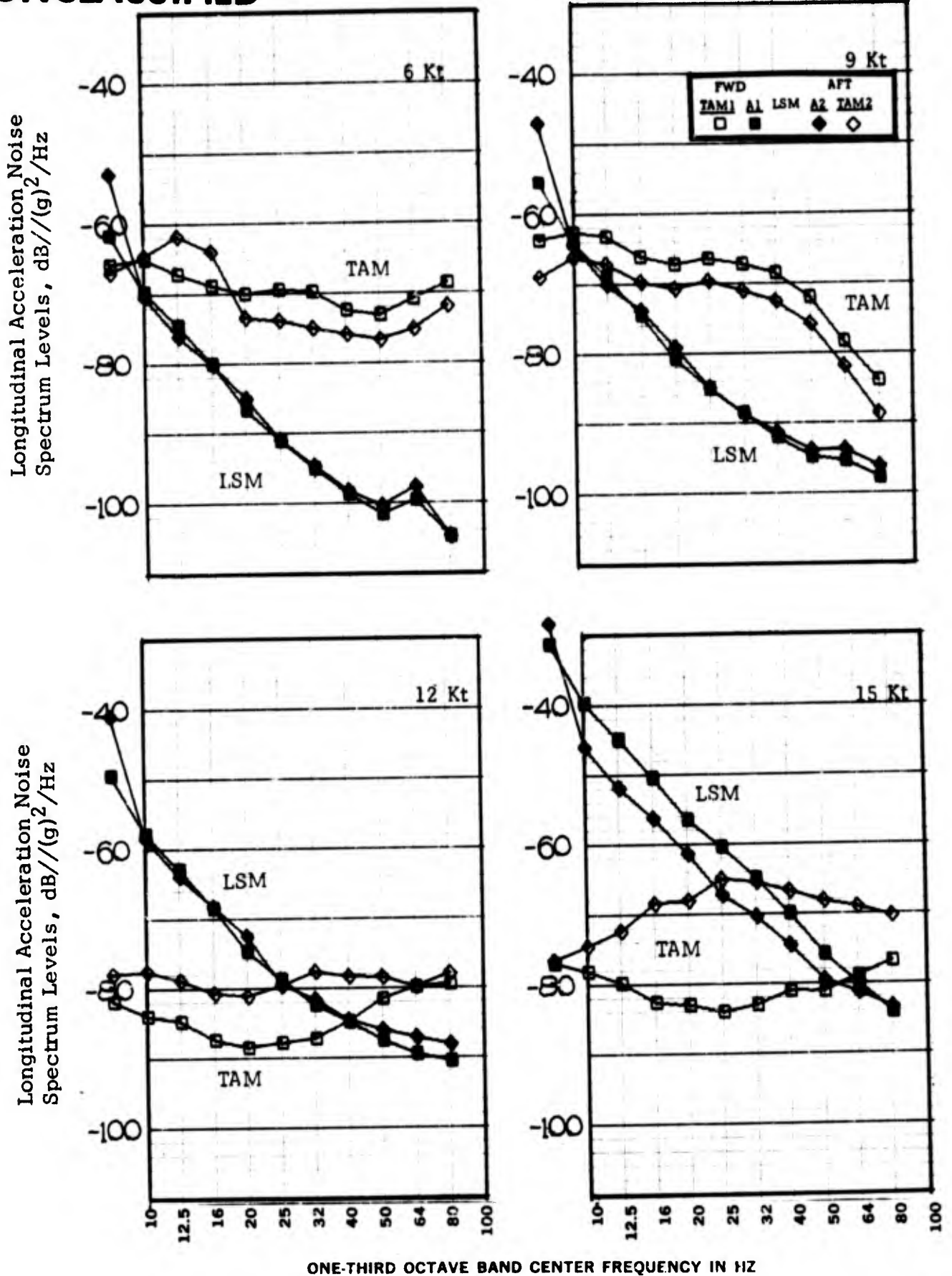
Generally, the COM hydrophone signal levels were 4 to 6 dB below the MSM2 signal levels for all tow speeds. This indicates that the MSM2 hydrophones are being affected by some localized internal self-noise source.

## 5.2.5 TAM and LSM Accelerometers

(U) Vibration measurements have been made in the ONR R&D Array since March 1973 by use of the TAMs, which can be moved around to measure vibrations in various parts of the array. Since the sensors are force-balanced servo type units, they are limited to low frequency measurements. There is a resonance in their sensitivity spectrum at about 90 Hz. The TAM data obtained in the past is believed to be valid for frequencies from 0 to about 50 Hz, for the following reasons: (1) the spectra often show tow cable strumming peaks (when employing bare cable) similar to those observed in the acoustical sensor spectra, (2) those TAM spectrum levels not associated with cable strum increase with tow speed, and (3) the amplitudes of the TAM-measured vibrations at the tow cable strumming frequencies (8 and 16 Hz) are in good general agreement with the vibration amplitudes predicted theoretically from the measured acoustical pressure amplitudes at nearby hydrophones.

(U) Despite what is believed to be good past performance of the TAMs, there is a continuing desire to improve vibration measurements in the ONR R&D Array. The most important considerations are to increase the frequency ranges of the vibrational measurements to match those of the acoustical measurements, and to keep the vibrational sensors small and locate them exactly rather than approximately where the measurements are needed in the array.

(U) Therefore, two TAMs were integrated into the array during Trial 5H4 for Array Configurations "A," "B" and "D" to provide measurements of the vibration transmissibility of the various VIMs and the vibration levels near the LSM end shells. To meet the needs of increased frequency response with minimal mass, piezoelectric crystal accelerometers were mounted in the LSM end shells and were compared to the TAM measurements made at essentially the same location. These results are shown in Figure 5-16 and illustrate a severe discrepancy between the TAM vibration spectra and that measured by the LSM accelerometers.

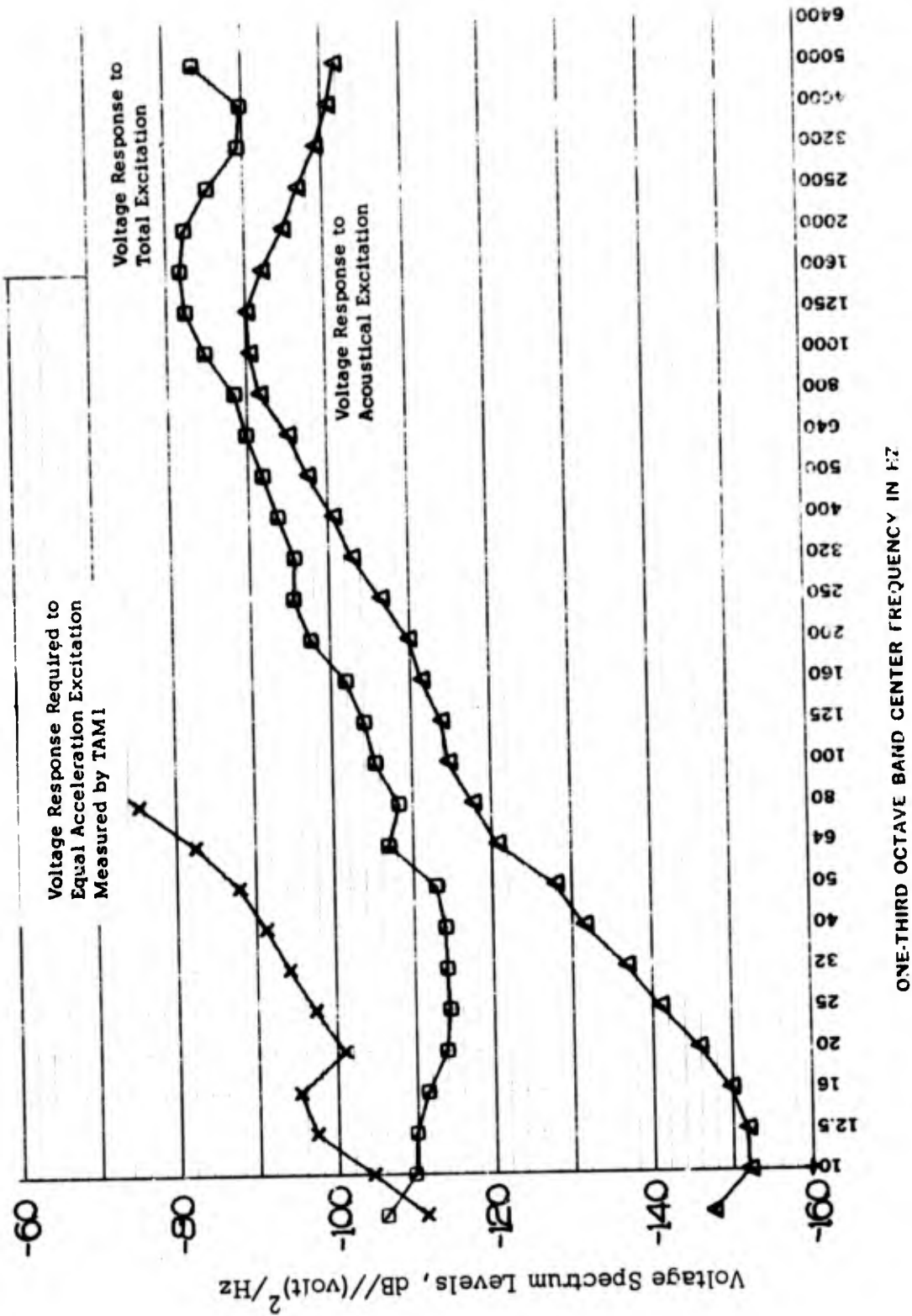


(U) Figure 5-16. Comparison Between Piezoelectric and Force-Balanced Servo Accelerometer Measurements at LSM End Caps (U)

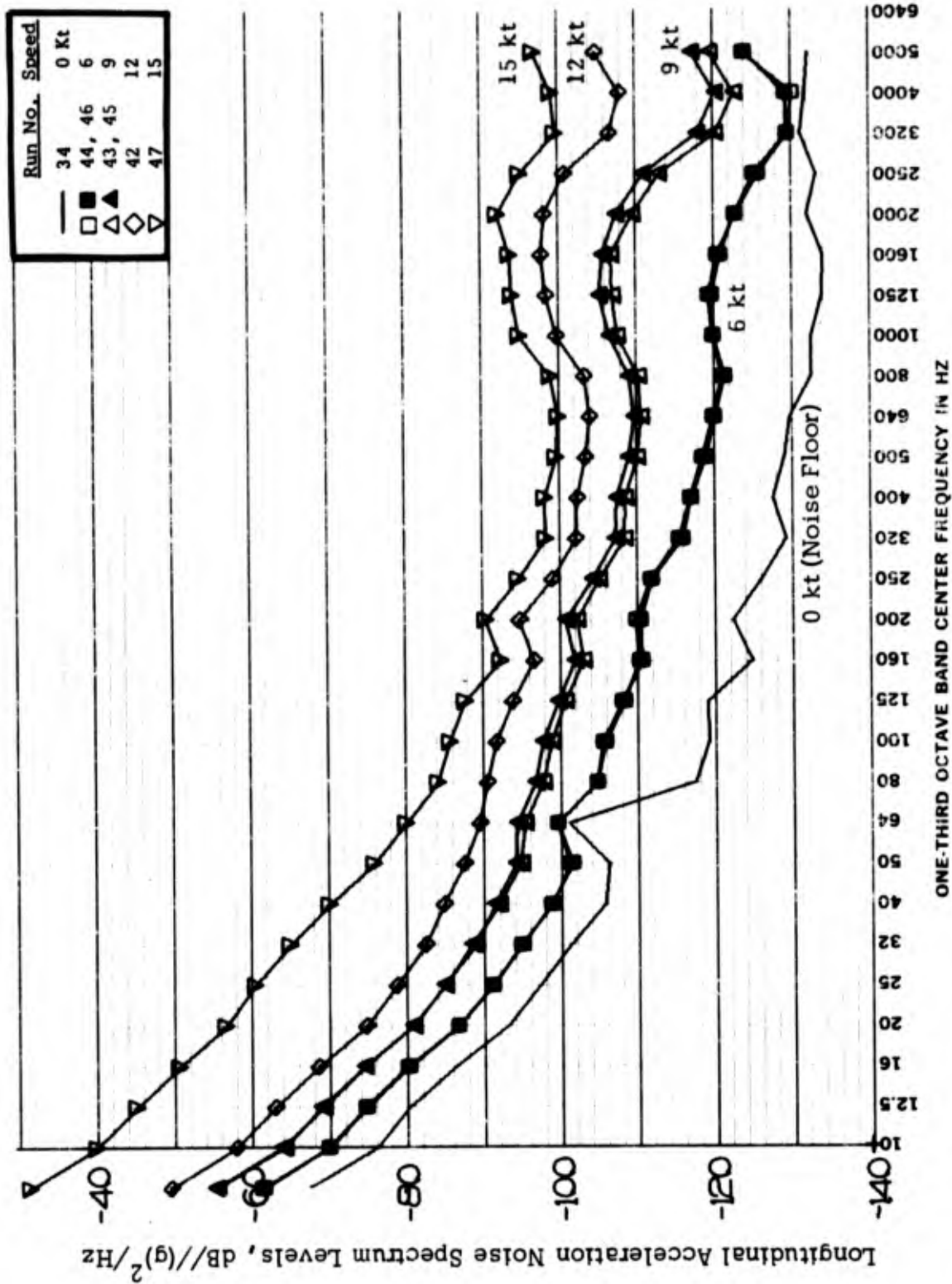
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There was a recognized problem with the acoustical sensitivities of the LSM piezoelectric accelerometers, which were measured in calibration prior to the trial.<sup>1</sup> If the absolute vibration levels measured by the TAMs (which were acoustically insensitive) may be assumed to be valid, then the corresponding voltage spectrum levels required for the LSM accelerometers to produce the same vibration levels can be determined by multiplying by their vibrational sensitivities. Additionally, the contributions due to acoustical excitation can be determined by multiplying the absolute sound pressure levels as measured by an adjacent hydrophone by the accelerometer acoustical sensitivity values. The results are presented in Figure 5-17. These clearly show that the voltage spectrum levels measured by the LSM accelerometer were 10 to 30 dB below the expected levels, and that acoustical excitation may have been the dominant signal. If fluid leaked into the piezoelectric accelerometers due to ambient pressures of the order of 1000 psi, this may have caused the sensor vibration sensitivities to decrease and the acoustical sensitivities to increase.

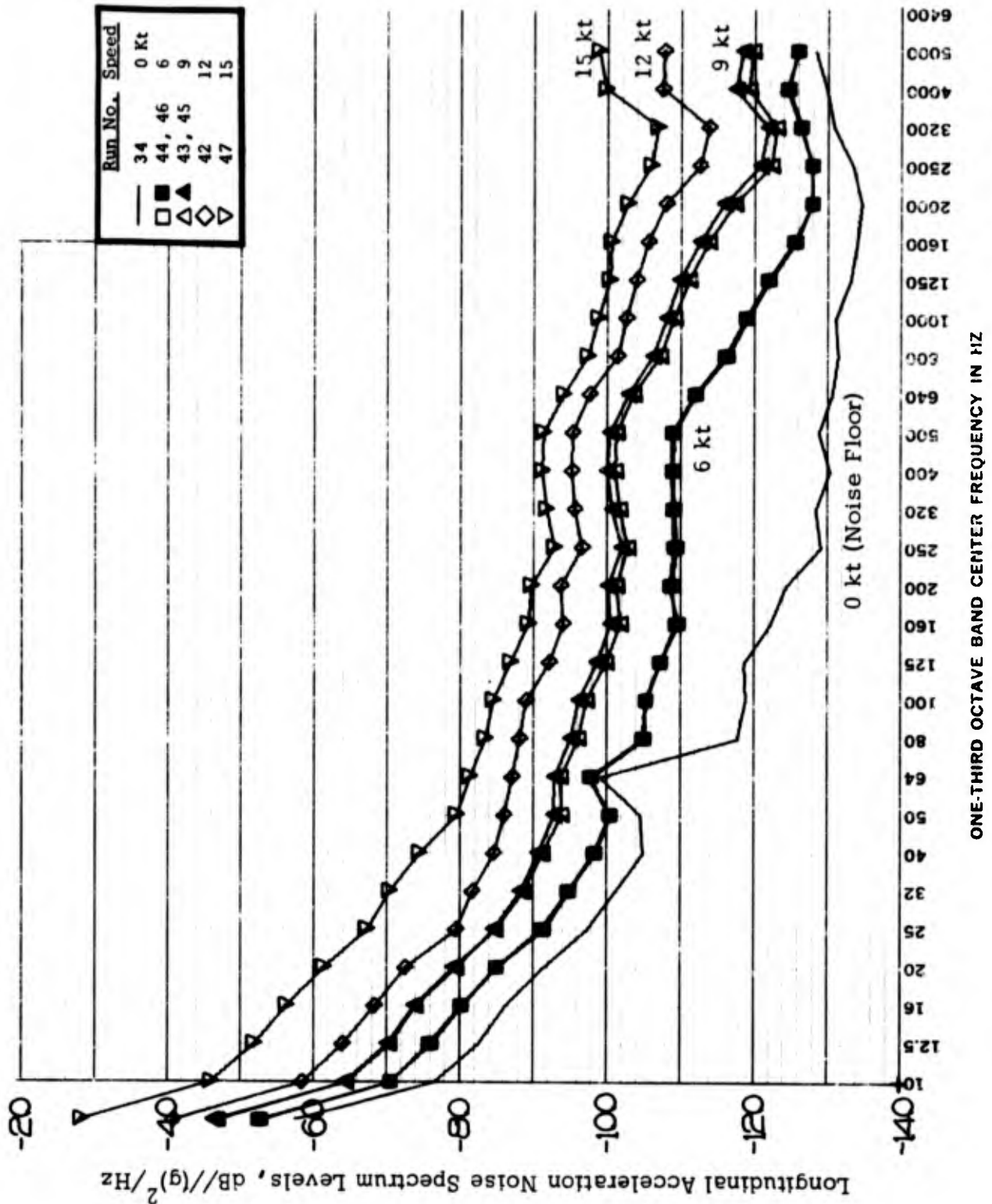
(U) LSM accelerometer noise spectrum levels at various tow speeds at frequencies up to 5000 Hz are presented in Figure 5-18 (forward LSM end cap) and Figure 5-19 (aft LSM end cap). The results are quite similar to previously presented acoustical noise spectrum levels, exhibiting a uniform increase in levels as speed increases. Also, note that the forward accelerometer spectrum levels shown in Figure 5-18 exhibit a broadband peak between 800 and 3200 Hz that increases with tow speed, whereas the aft accelerometer spectrum levels shown in Figure 5-19 have a lower-frequency peak in the 250 to 800 Hz range. Additional measurements and extensive calibrations of TAM and LSM accelerometers will be required before their spectra can be further interpreted with any confidence.



(U) Figure 5-17. LSM Accelerometer Voltage Responses to Various Excitations (U)



(U) Figure 5-18. LSM Accelerometer Noise Spectra Measured at Forward End Cap (U)



(U) Figure 5-19. LSM Accelerometer Noise Spectra Measured at Aft End Cap (U)

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## Section 6

### PARAMETRIC EVALUATIONS

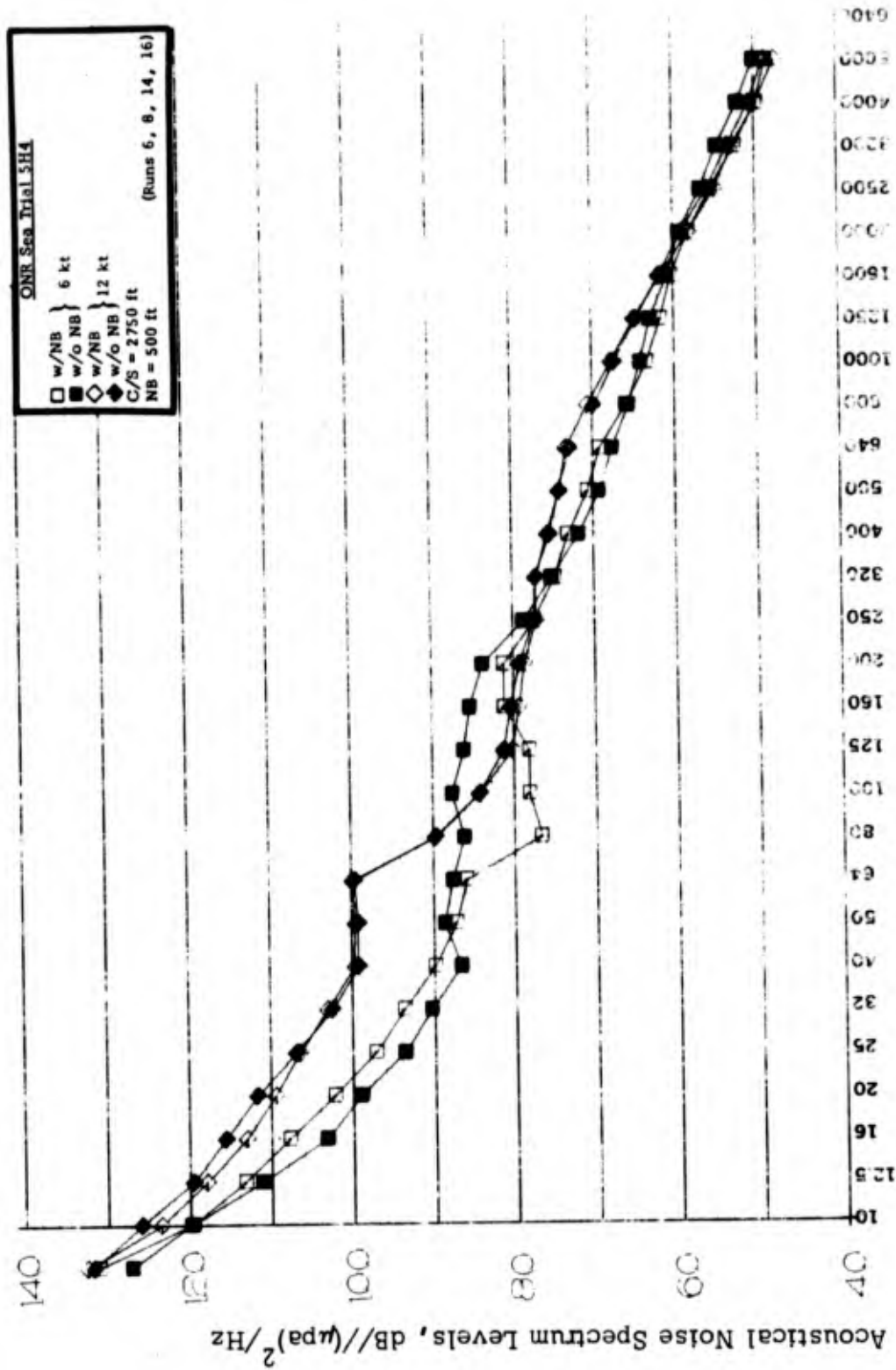
#### 6.1 GENERAL

(U) One of the objectives of the sea trial was to investigate the relative noise spectrum levels associated with various mechanical components of the array design. These included the relative merits of NB cable, the effect of long VIMs of various constructions, the effects of hosewall materials, and the effects of a TBL scattering boot. The following sections describe each of these parametric evaluations and the ensuing results.

#### 6.2 NB CABLE EVALUATION

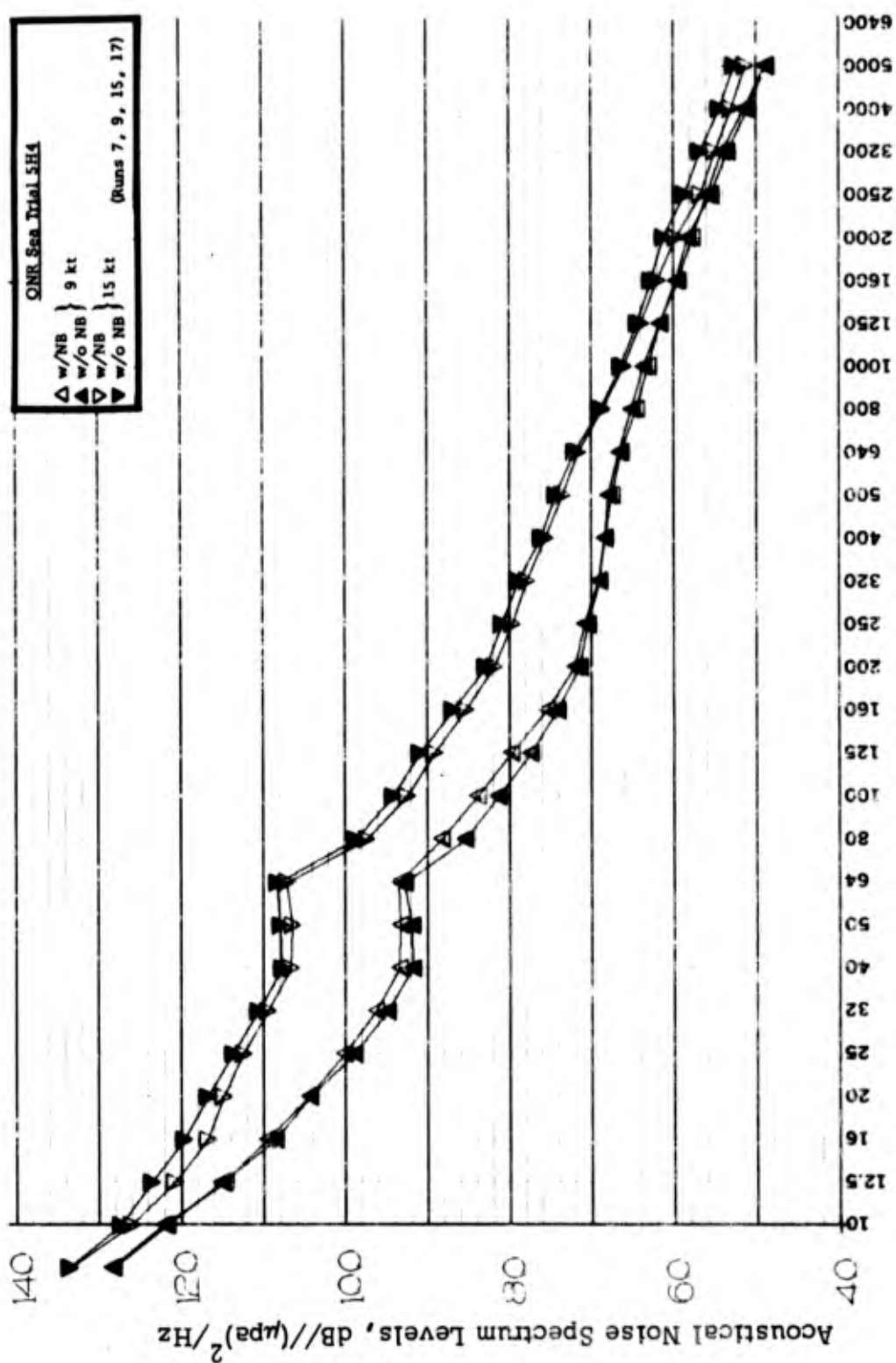
(U) The relative merits of employing a neutrally buoyant intermediary cable to isolate the array from the tow cable was investigated using Array Configuration "A." The neutrally buoyant cable was approximately 500 ft long, 1.5 inches in diameter, and had a smooth polyethylene jacket. The array was towed at 6, 9, 12 and 15 kt, both with and without the NB cable. Tow cable scope was increased by 500 ft when the NB cable was removed, in an effort to maintain approximately the same slant range from the hydrophones to the towship. This caused the array to tow approximately 100 ft deeper at 6 kt, and 40 ft deeper at 15 kt, without the NB cable.

(C) Figures 6-1 and 6-2 present the LSM central hydrophone (H3-H8) noise spectrum levels both with and without the NB cable at tow speeds of 6, 9, 12 and 15 kt. A noticeable reduction in noise levels occurred for the 6-kt case without the NB cable at frequencies below 50 Hz and were limited to the electrical noise floor. Spectrum levels measured at higher frequencies were dominated by towship radiated noise and were highly dependent upon engine shaft rotation frequency. The higher levels shown in the frequency range of 80 to 250 Hz without the NB cable were caused by the higher engine speed (350 rpm) required to maintain 6 kt, as compared to the 330 rpm required when employing the NB cable. At tow speeds of 9, 12 and 15 kt, the noise spectrum level differences between "with" and "without" NB cable were small and may be considered negligible.



(C) Figure 6-1. LSM Hydrophone Noise Levels With and Without NB Cable for 6 and 12 kt (U)

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(C) Figure 6-2. LSM Hydrophone Noise Levels With and Without NB Cable for 9 and 15 kt (U)

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(U) The acceleration levels measured by the TAMs during the NB cable evaluations are presented in Figure 6-3. These illustrate the vibration noise spectrum levels occurring near the array nose cone and in the interior of the array. At all tow speeds, the longitudinal acceleration levels occurring at the array nose cone when employing the NB cable are lower than without. Also, the attenuation across the VIM is greater at 6 and 9 kt than at 12 and 15 kt. This indicates that the hydrophone self-noise levels should be higher in the low frequency region without the NB cable, which is the case as shown in Figures 6-1 and 6-2. For speeds of 12 and 15 kt, the acceleration levels measured by the aft TAM are similar and result in similar self-noise levels. It is therefore concluded that there is no significant array self-noise reduction benefit derived from employing a 500-ft section of NB cable to isolate the array from the tow cable, at least when a strum-suppressed tow cable is used to tow the array.

## 6.3 VIM COMPARISONS

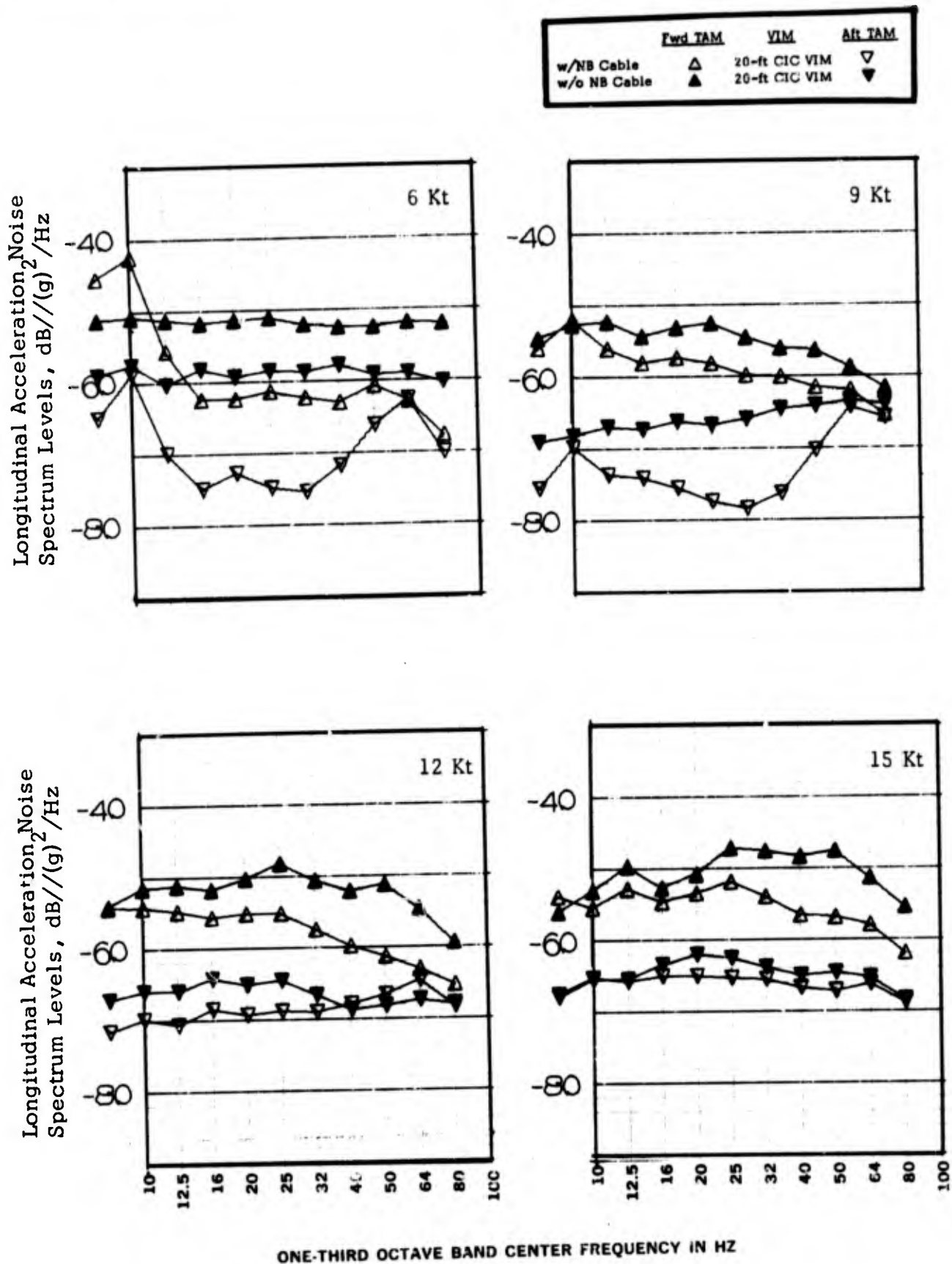
(U) Long compliant forward VIMs have the potential to isolate the array from low frequency vibrations originating at the tow cable. The degree to which their effectiveness is a function of length was investigated using the three available VIMs which were the following:

1. A 20-ft long CIC rubber/fabric laminate VIM;
2. A 90-ft long CIC VIM of similar construction; and
3. A 330-ft long SLC PVC VIM with internal stretch members.

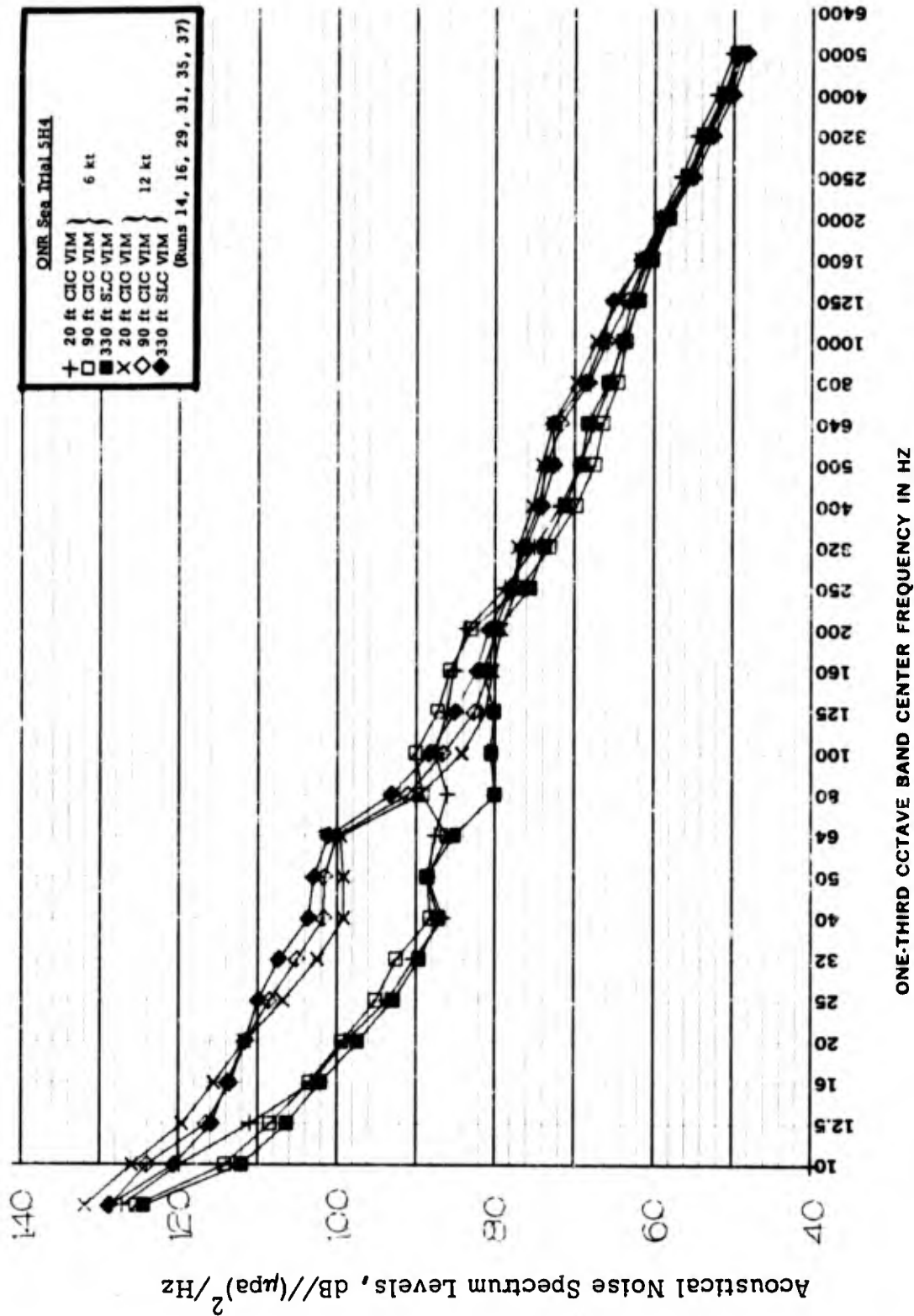
The relative performances of the VIMs were assessed in terms of the LSM central hydrophone noise spectrum levels measured in Array Configuration "A," at a cable scope of 3250 ft (without NB cable), at tow speeds of 6, 9, 12 and 15 kt.

(C) Figures 6-4 and 6-5 present the LSM hydrophone noise spectrum levels as a function of VIM type and tow speed. Comparisons between the two CIC VIMs, which were of similar construction but different lengths, indicate that at frequencies below 16 Hz, the 20-ft VIM was 2 to 4 dB noisier than the 90-ft VIM at all tow speeds. From 20 to 64 Hz, the short VIM produced lower noise levels, by 2 to 5 dB, than the 90-ft VIM at corresponding tow speeds. This indicates that the

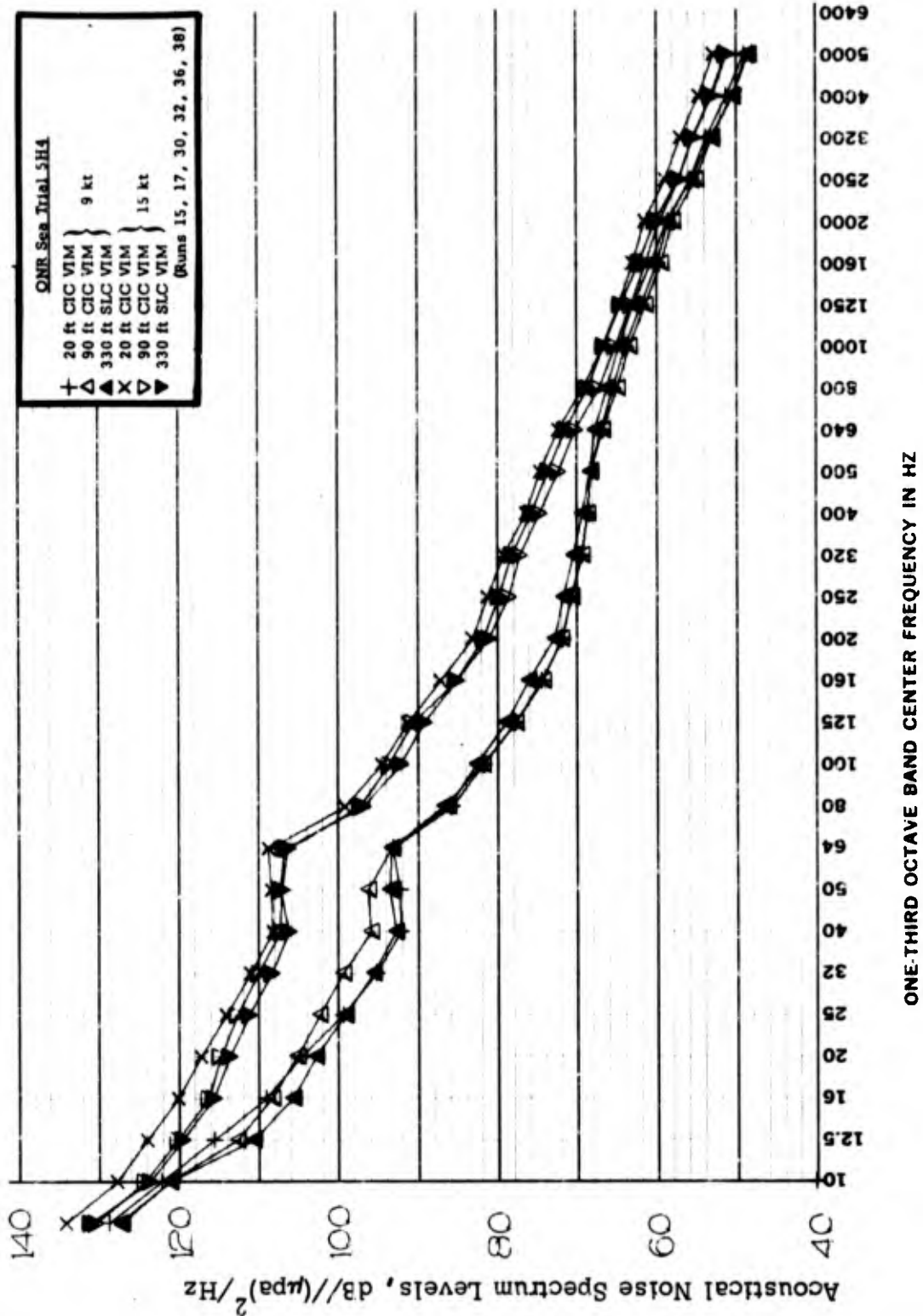
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(C) Figure 6-3. Longitudinal Acceleration Levels During NB Cable Evaluations (U)



(C) Figure 6-4. LSM Hydrophone Noise Levels versus VIM Type for 6 and 12 kt (U)



(C) Figure 6-5. LSM Hydrophone Noise Levels versus VIM Type for 9 and 15 kt (U)

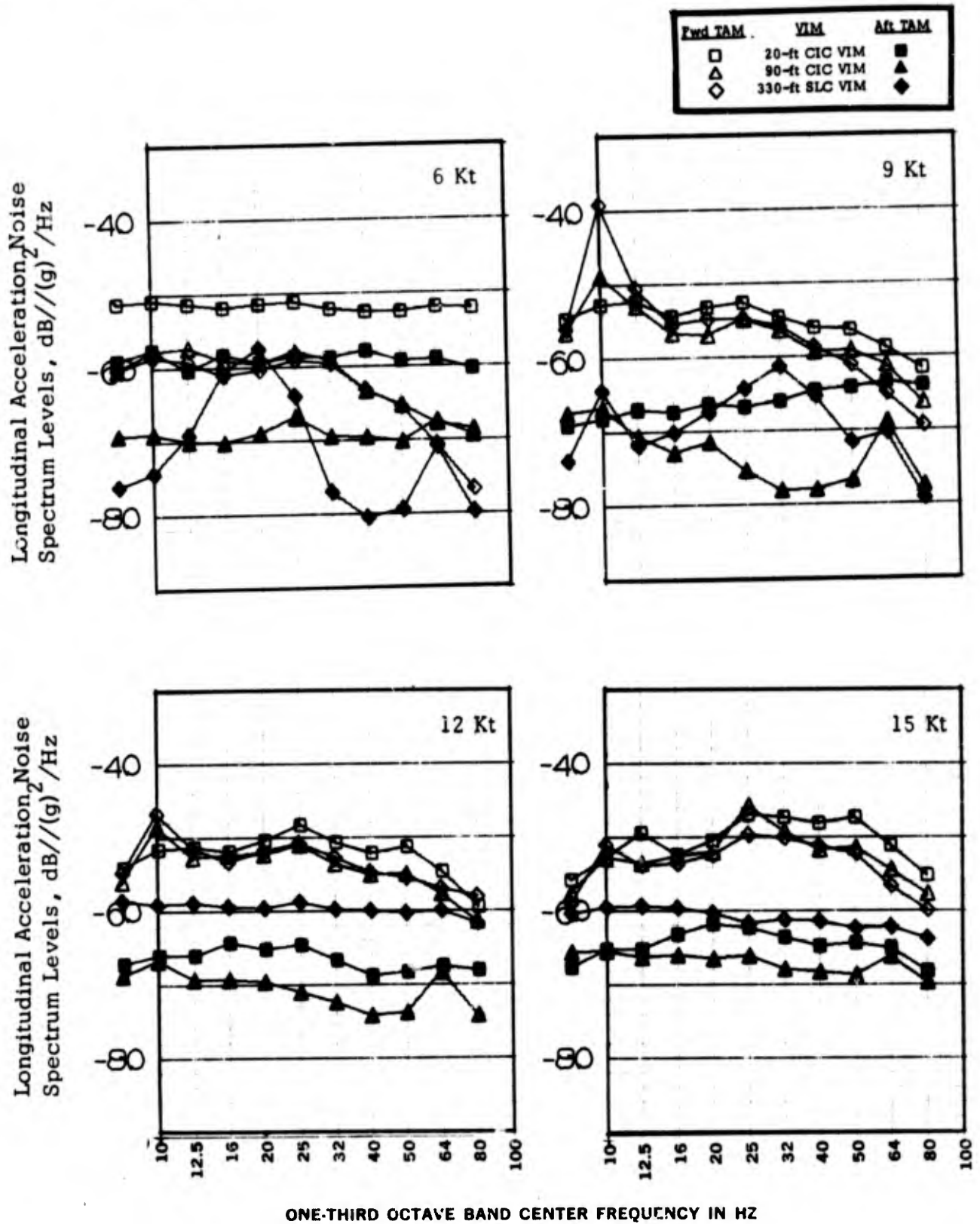
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longer VIM attenuates low frequency vibrations better than the short VIM, but causes higher self-noise levels in the 20 to 64 Hz region, possibly due to boundary layer growth over the increased length.

(C) Comparison of the PVC construction SLC VIM with the CIC VIMs indicates that for frequencies below 80 Hz, the SLC VIM noise spectrum levels were consistently 2 to 5 dB below those for either CIC VIM, at speeds of 6, 9 and 15 kt. At 12 kt, the SLC VIM produced good attenuation of noise relative to the CIC VIMs, typically 4 dB at frequencies below 20 Hz, but for frequencies from 25 to 250 Hz, the SLC VIM produced LSM hydrophone noise levels which were higher by as much as 6 dB than those for the shortest CIC VIM.

(U) The acceleration levels measured by the TAMs during the VIM evaluations are presented in Figure 6-6. These illustrate the vibration noise levels forward and aft of each VIM at the various tow speeds. At 6 kt, the attenuation across the 330-ft VIM is greater than that across any of the others, and results in a very low acceleration level in the interior of the array. This is true except near 20 Hz, where it appears that the long compliant VIM may be resonating. At speeds of 9, 12 and 15 kt, the vibration attenuation across the long VIM is not nearly so pronounced, and there is a considerable spread in the aft TAM vibration levels. These trends observed in the vibration noise spectrum levels do not appear in the corresponding acoustical noise levels, however, so vibrations in the array interior must not be the dominant source of array noise in the present case.

(C) Therefore, it can generally be concluded that VIM performance is influenced by VIM characteristics such as length, surface roughness, and material compliance. For VIMs constructed of rubber/fabric laminates, long lengths are beneficial at frequencies below 20 Hz, but detrimental between 25 and 80 Hz. For smooth PVC jacketed VIMs, long lengths are beneficial over the entire frequency range up to 80 Hz, in terms of vibration attenuation. A better evaluation of VIM performance could, in the future, be obtained using a bare tow cable rather than a strum-suppressed tow cable.



(C) Figure 6-6. Longitudinal Acceleration Levels During VIM Evaluations (U)

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## 6.4 HOSEWALL COMPARISONS

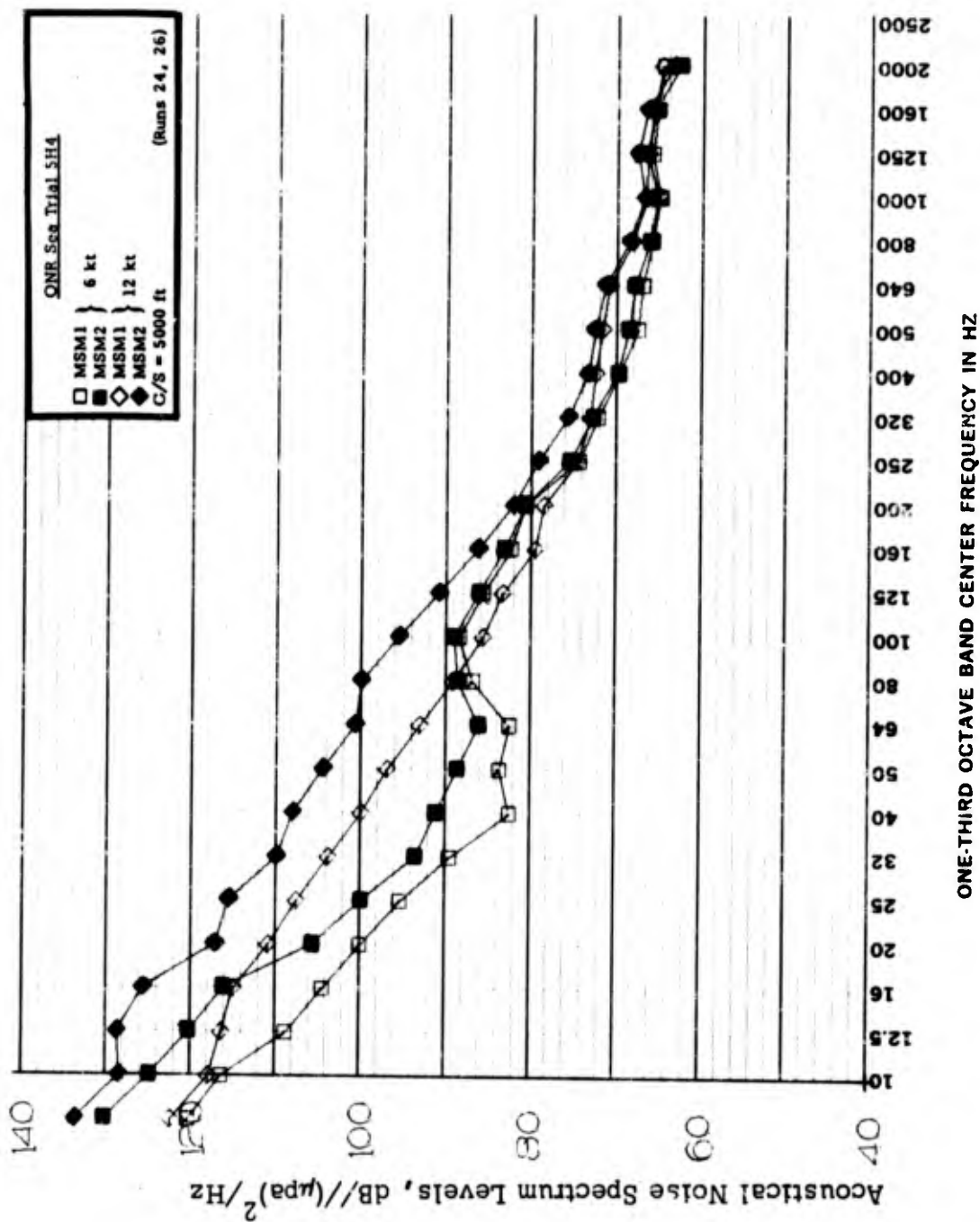
(U) The potential benefits of PVC over rubber/fabric laminate array module hosewalls were investigated using the HAC MSMs in Array Configuration "F" at tow speeds of 6, 9, 12 and 15 kt, with cable scopes of 5000 ft and 3500 ft (15-kt case only). The two MSM modules were of the same length and hydrophone spacing.

(C) Figures 6-7 and 6-8 present the average MSM1 (PVC hosewall) hydrophone noise spectrum levels compared to the average MSM2 (rubber/fabric laminate hosewall) noise levels for corresponding tow speeds and cable scopes. At 6 kt, for frequencies below 100 Hz, the PVC hosewall noise levels were consistently lower than the rubber/fabric hosewall levels by as much as 10 to 12 dB. At frequencies above 100 Hz, towship noise dominated at 6 kt. At 9 kt, the PVC levels were lower than the rubber/fabric levels by 10 to 12 dB for frequencies up to 320 Hz; for 12 kt, 10 to 12 dB lower up to 400 Hz; and for 15 kt, 10 to 12 dB lower up to 800 Hz. This indicates that the MSM noise levels (both modules) were of sufficient amplitude as to be greater than the towship noise below these frequencies. Despite these excessive levels, the relative differences between PVC and rubber/fabric hosewalls are a significant local phenomena that affect the array self-noise. It is therefore concluded that substantial reductions in some forms of low frequency array self-noise can be obtained by utilizing PVC rather than rubber/fabric hosewalls.

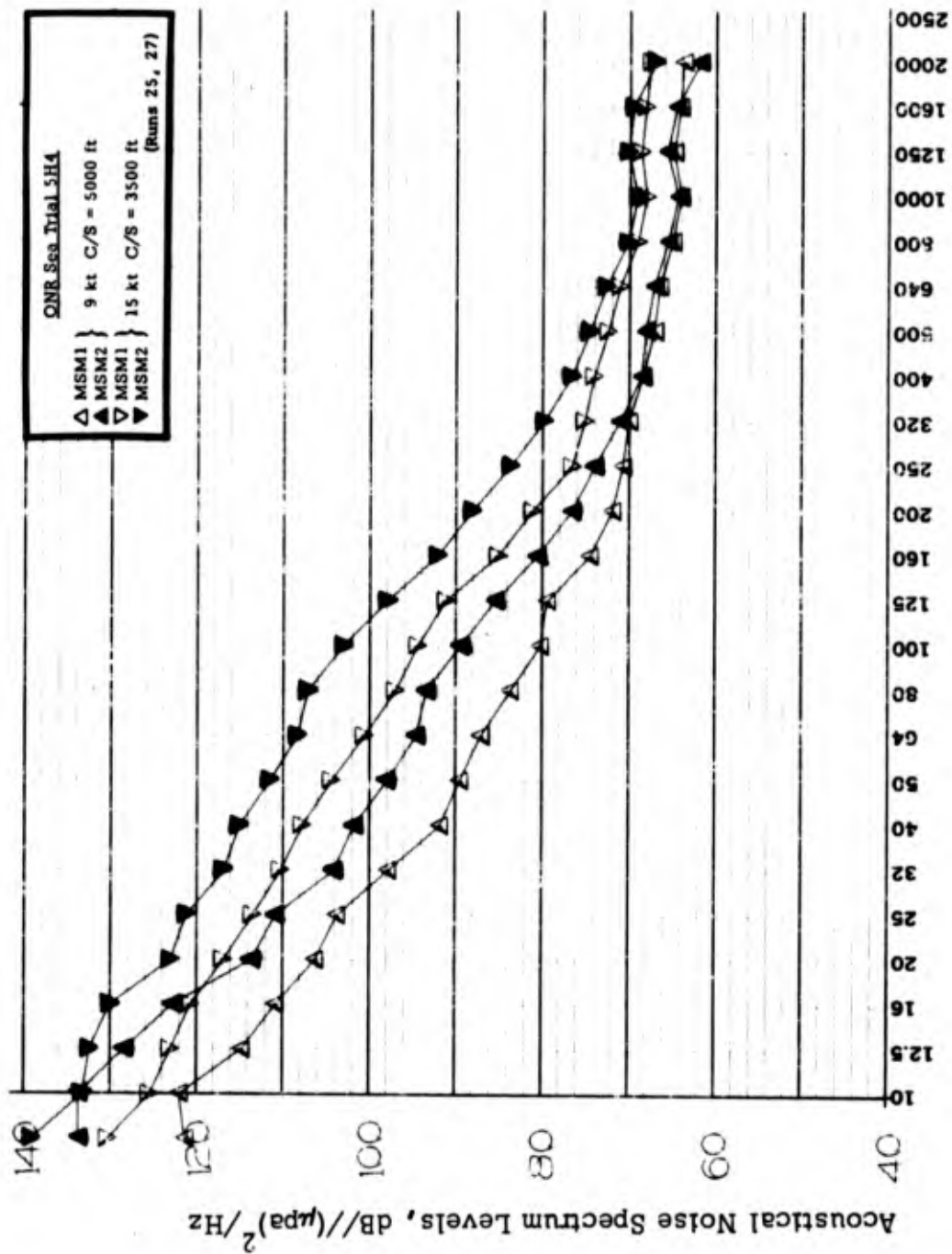
## 6.5 TBL SCATTERING BOOT COMPARISONS

(C) The relative effects of impregnating a rubber/fabric laminate hosewall with a mechanical discontinuity in an effort to scatter TBL energy were evaluated using Array Configuration "D." The LSM boot from Array Configuration "B" was removed and replaced by another which had a 3-in. long steel band impregnated in the hosewall at the module mid-point. The acoustic aperture was identical for the two configurations.

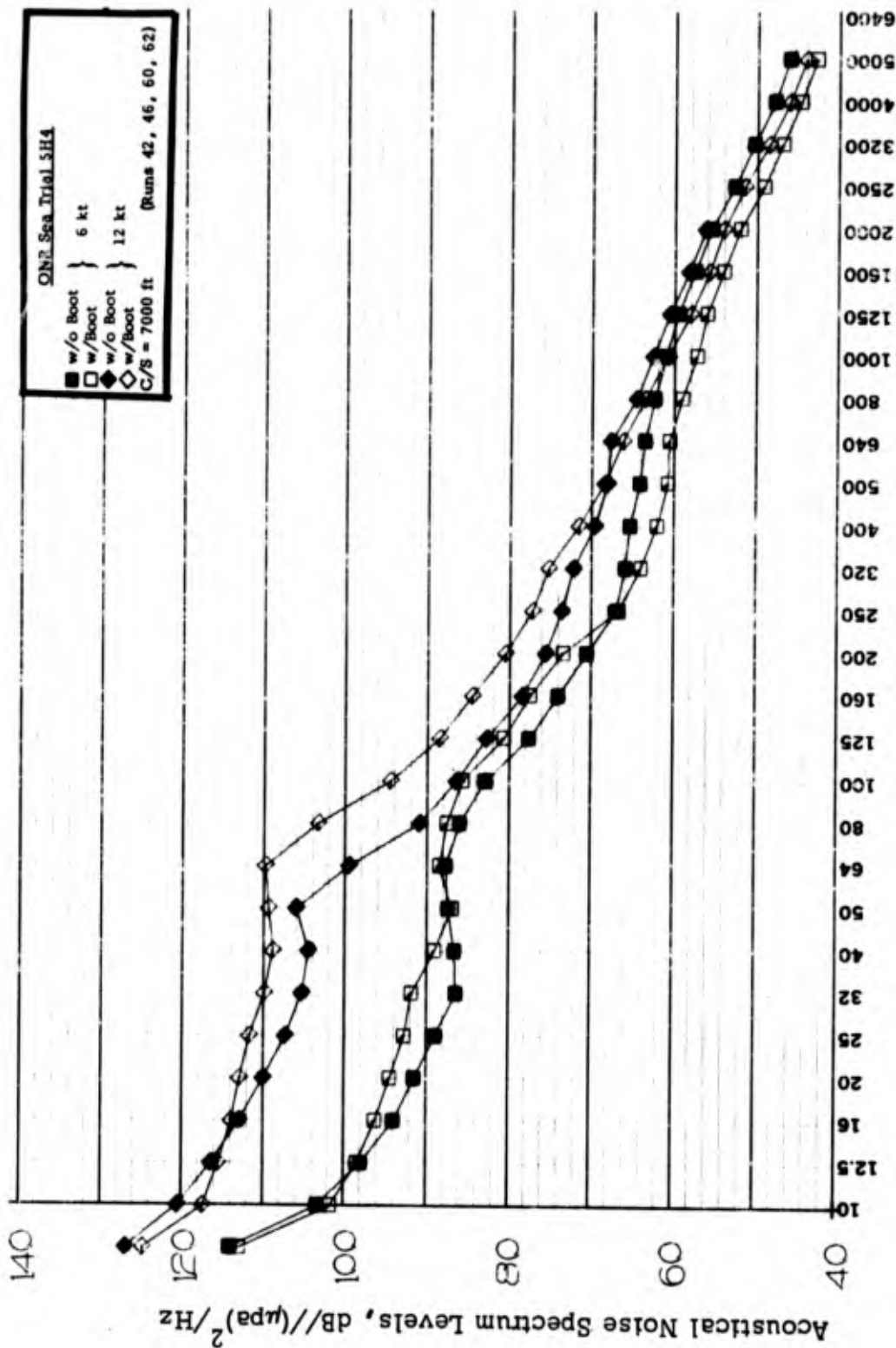
(C) Figures 6-9 and 6-10 present comparisons between LSM central hydrophone noise spectrum levels measured with and without the scattering boot. At 6 kt, the noise spectrum levels with the boot exceeded those without the boot by



(C) Figure 6-7. MSM1 (PVC) versus MSM2 (Rubber/Fabric) for 6 and 12 kt (U)



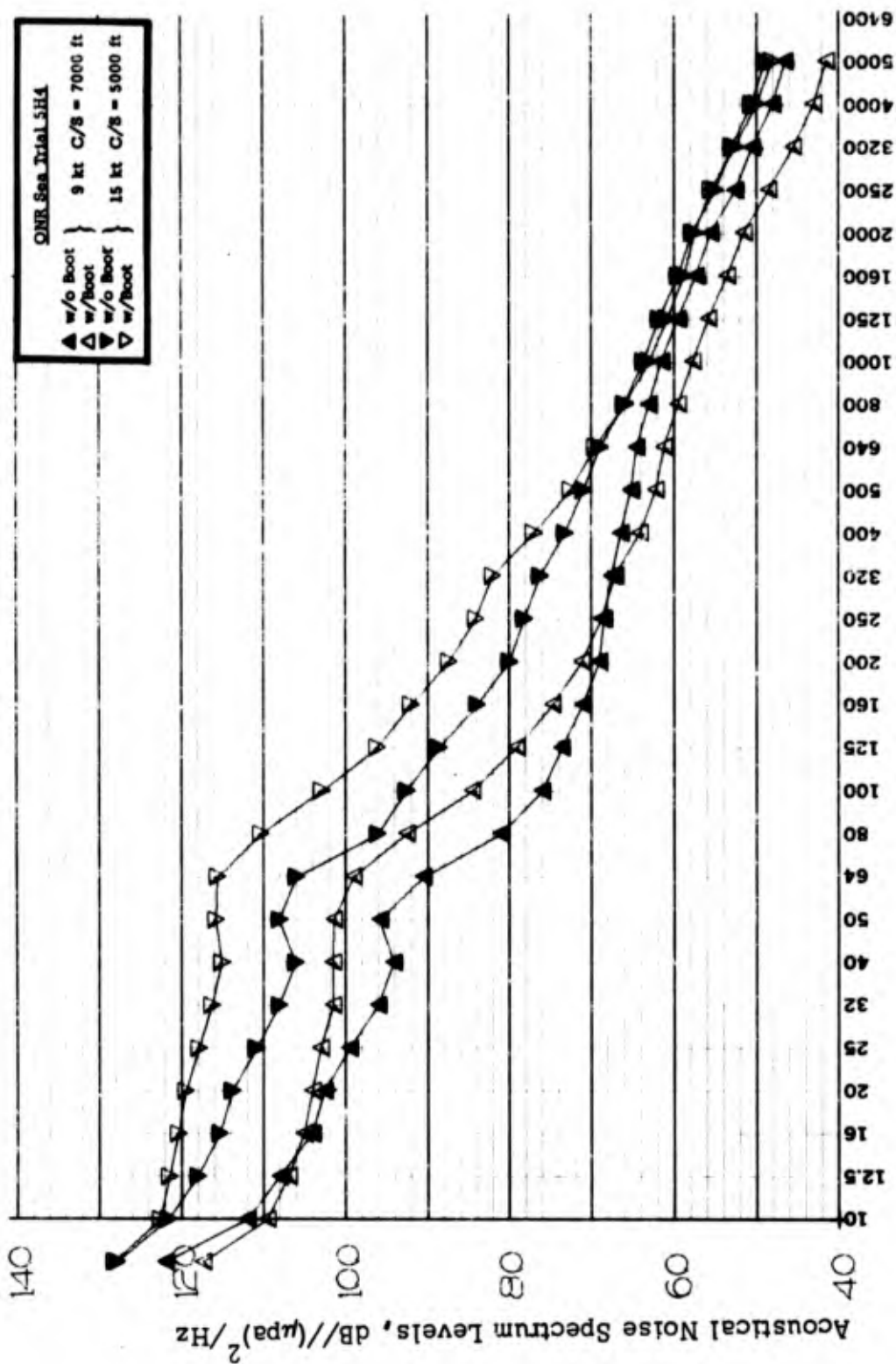
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ  
 (C) Figure 6-8. MSM1 (PVC) versus MSM2 (Rubber/Fabric) for 9 and 15 kt (U)



ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

(C) Figure 6-9. LSM Hydrophone Noise Levels With and Without the Scattering Boot for 6 and 12 kt (U)

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(C) Figure 6-10. LSM Hydrophone Noise Levels With and Without the Scattering Boot for 9 and 15 kt (U)

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as much as 4 dB in the frequency range from 12 to 50 Hz, where measurements made without the boot were electrical noise floor limited. At frequencies above 250 Hz, the scattering boot appeared to have no effect and the difference in noise levels was due to ambient noise difference in the different sea states encountered. Between 80 and 250 Hz, propeller cavitation radiated noise again dominated the spectrum levels at 6 kt. At 9 kt, for frequencies from 80 to 5000 Hz, the LSM hydrophone levels without the boot were towship noise limited. However, the LSM with the scattering boot measured higher levels, by 10 to 12 dB, which must be due to a localized noise source. At 9 kt, for frequencies above 320 Hz, the LSM with the scattering boot actually measured lower noise levels than those measured in the corresponding run without the scattering boot. This was due to the lower sea state encountered during the TBL scattering boot evaluations (see Table 3-1). At 12 and 15 kt, the LSM with the scattering boot measured higher noise levels than without the boot, by as much as 12 dB for frequencies from 16 to 500 Hz. For frequencies above 500 Hz, both LSMs measured essentially the same noise spectra.

(C) It can be concluded that the 3-in. long steel TBL scattering band located at the center of the LSM module produced higher noise spectrum levels over the frequency range of 16 to 500 Hz at all tow speeds. For frequencies above 500 Hz, the effects of the TBL scattering band were not significant relative to towship radiated noise and ambient noise levels.

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## Section 7

### HYDROMECHANICAL RESULTS

#### 7.1 GENERAL

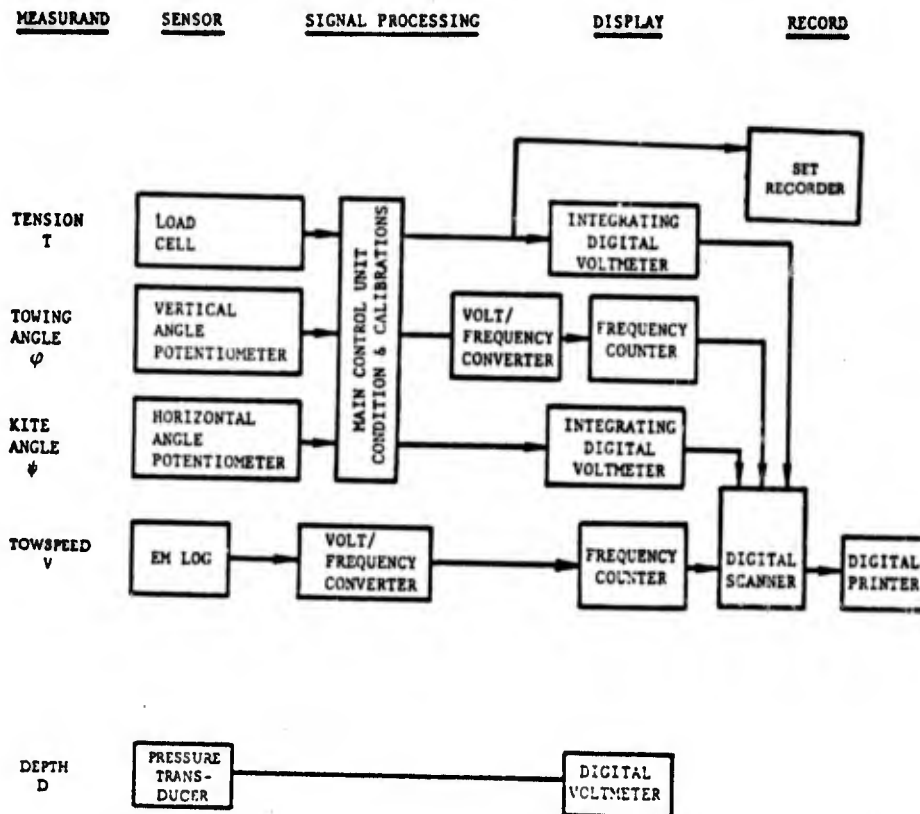
(U) Cable/array system design from the viewpoint of hydromechanical integrity is largely dependent on the anticipated static and dynamic tensions developed in the towline and array nose cone, and the array depth as a function of tow speed. Excessive safety margins can be avoided with a priori knowledge of the expected loads. Also, the cost, size and weight of shipboard handling equipment and cable terminations can be minimized.

(U) During this sea trial, operational data were acquired using the NSRDC tow point gimbal to measure both the static towing tensions and angles, and the amplitudes of dynamic tension surges during a Sea State of 1 to 2. Additionally, array depth was measured using the ESM, and array nose cone tension was measured using the TFG, both supplied by CIC. SLC provided a 330-ft PVC VIM, which was used to approximate a PVC array and whose drag characteristics were evaluated.

#### 7.2 TEST DESCRIPTION

(U) During transit through the Gulf Stream enroute to NWPC, an abbreviated form of the ONR-CIC array was towed using 2000 ft of the ribbon-faired tow cable. The array consisted of a short 20-ft CIC VIM and the ESM. Data obtained included steady-state and dynamic tension, towing angle, kite angle, tow speed and depth, using the instrumentation arrangement shown in Figure 7-1. Data acquired in transit through the Gulf Stream were used for dynamic tension surge analysis, whereas steady-state data were obtained during various portions of the trial. Hydromechanical data were taken for four scopes at tow speeds from 6 to 15 kt.

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(U) Figure 7-1. Instrumentation Block Diagram (U)

## 7.3 STEADY-STATE RESULTS

(U) The steady-state data were analyzed by use of the technique developed during the FY 74 NSRDC Hydromechanics of Towed Arrays Program. Briefly, this technique consisted of correcting the measured steady-state values to account for electronic drift, correcting for the change in slope of the tow cable portion which is above the water surface, and linear regression curve fitting to the resulting data. This gave values for the tension variations per unit cable length  $dT/dS$ , cable angle  $\phi$ , and kite angle  $\psi$  for each tow speed for use in the following equations:<sup>3</sup>

$$C_N = \frac{W \cos \phi \cos \psi}{\rho/2 D V_\infty^2 \sin^2 \phi (1 + \cot^2 \phi \sin^2 \psi)^{3/2}}$$

$$C_t = \frac{dT/dS - W \sin \phi}{\rho/2 \pi D V_\infty^2 \cos^2 \phi \cos^2 \psi}$$

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$$C_L = \frac{W \cos \varphi \sin \psi}{\rho/2 D V_\infty^2 (1 + \cot^2 \varphi \sin^2 \psi)^{1/2}}$$

where:

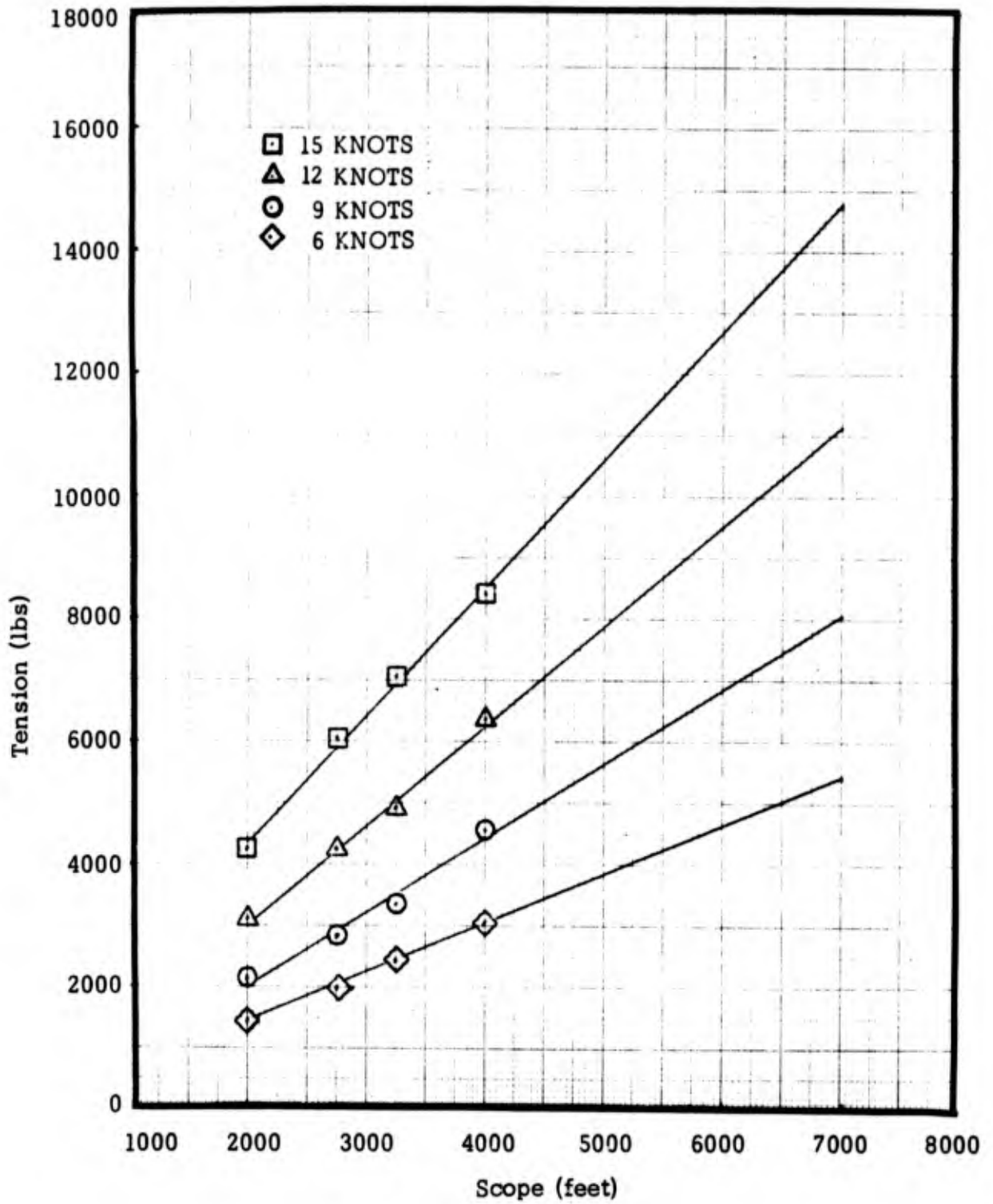
W	=	cable density in sea water, lb/ft
$\rho$	=	density of sea water, slug/ft <sup>3</sup>
$\varphi$	=	cable angle, deg
$\psi$	=	kite angle, deg
D	=	cable diameter, ft
$V_\infty$	=	tow speed, ft/sec

(U) Figure 7-2 presents the shipboard tension as a function of cable scope for 6, 9, 12 and 15 kt. The curves have been extended to project the tensions that probably occurred at the longer scopes of 5000 to 7000 ft, which exceeded the capabilities of the instrumentation and could not be measured. In accordance with the analysis of Pode,<sup>6</sup> tension varies linearly with scope for a constant speed, once the cable/array system is towing at its critical angle.

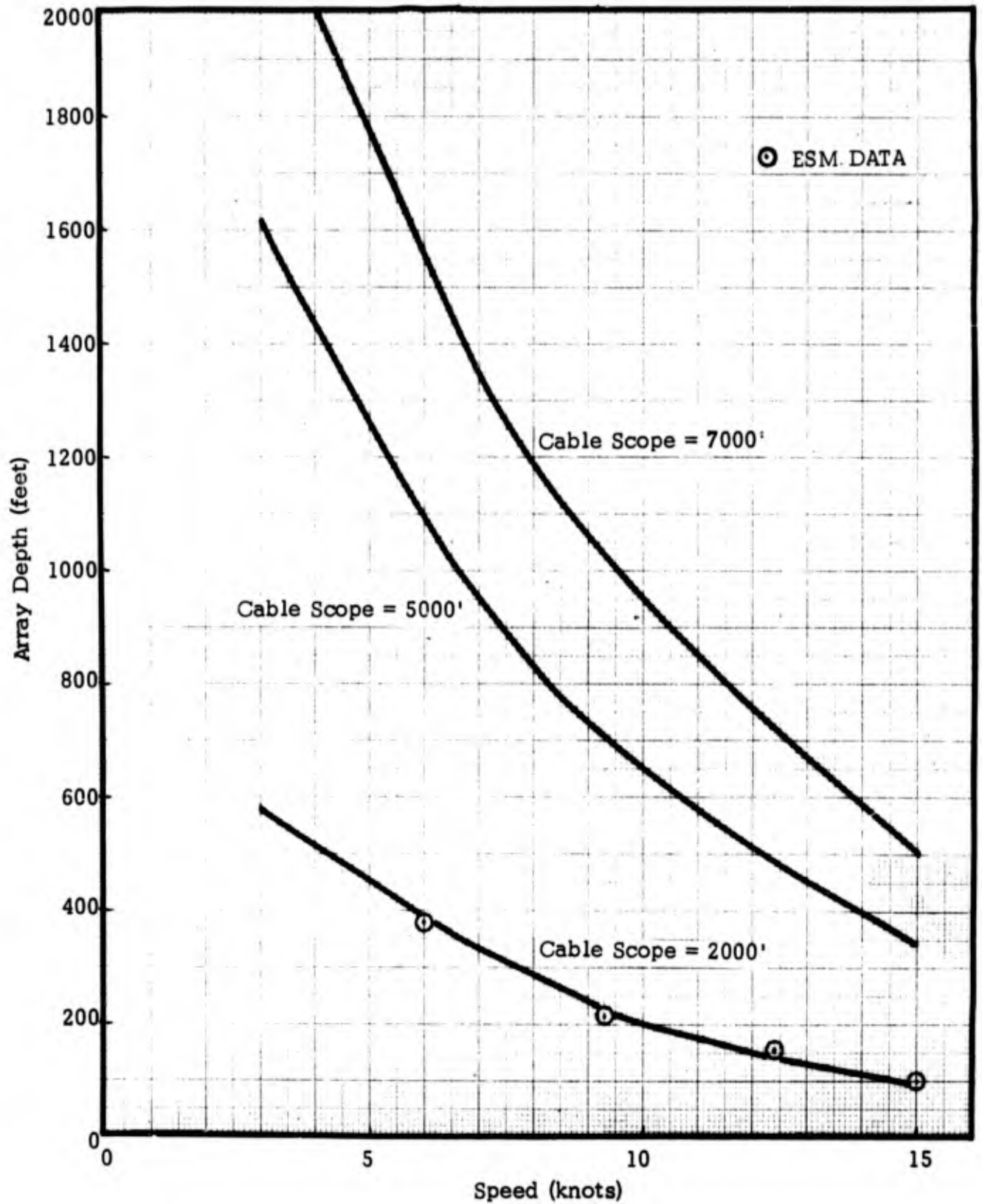
(U) Array depth as a function of tow speed for the cable scopes evaluated is presented in Figure 7-3. Note that data was used for only the 2000-ft case. Subsequent data taken at 5000 and 7000-ft scopes was discounted since the ESM was subjected to extremely high pressures during the 7000-ft run. Depth data for the other cable scopes was extrapolated using the linearity concepts of Pode.

(U) The resulting tow cable drag coefficients as a function of Reynolds number based on cable diameter and free stream velocity are presented in Figure 7-4, shown cross-plotted with results of previous trials.<sup>3</sup> As would be expected, the tangential drag coefficient of the 20 mil, 25 percent coverage tow cable closely approximates that of the 15 mil, 50 percent coverage and the various ribbon-stub configurations. The normal drag coefficient of the 20 mil, 25 percent coverage tow cable is lower than that for all other ribbon-faired tow cables except the 15 mil, 50 percent case. The steady-state lift coefficient for this

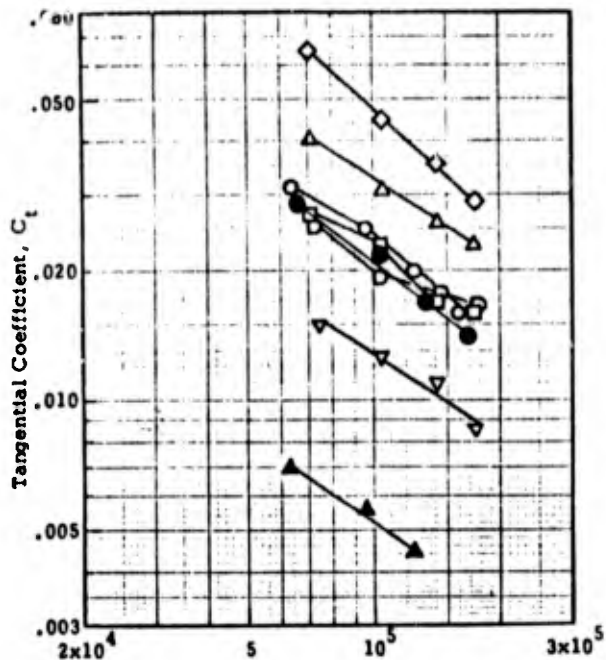
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(U) Figure 7-2. Shipboard Tension versus Cable Scope for Discrete Speeds (U)

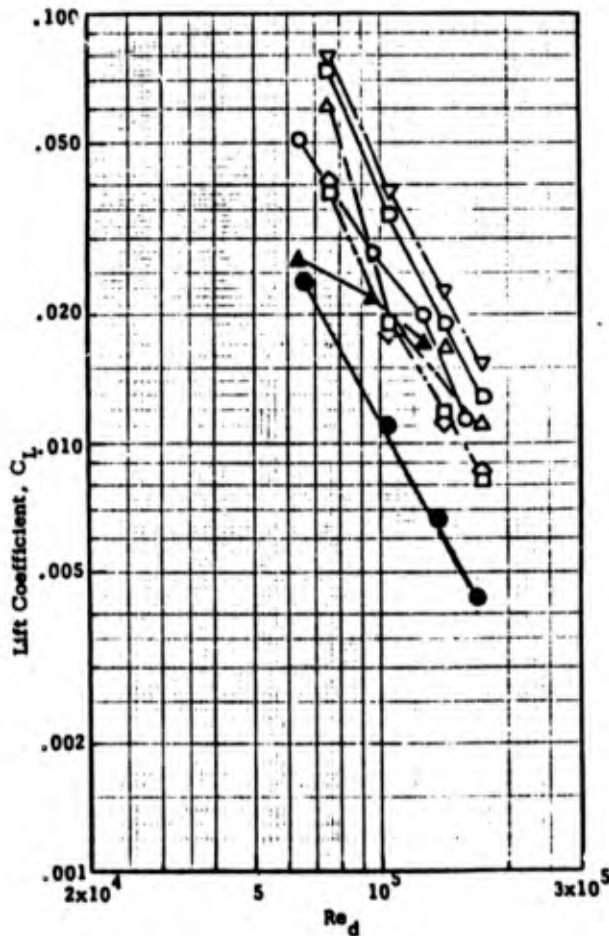
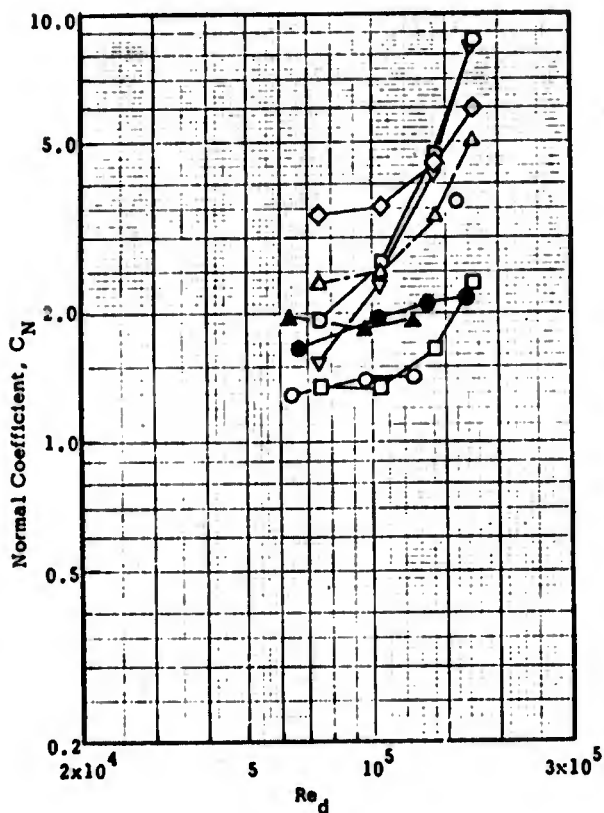


(U) Figure 7-3. Array Depth versus Speed for Discrete Cable Scopes (U)



Ribboned Cable Sea Data

- 50% Ribbons, 15 mil (3H25)
- 50% Ribbons, 15 mil (4H1)
- ◇ 50% Ribbons, 30 mil (4H8)
- △ 25% Ribbons x 25% Stubs (4H8)
- ◻ 12-1/2% Ribbons x 37-1/2% Stubs (4H8)
- ▽ 0% Ribbons x 50% Stubs (4H8)
- ▲ 0.84-inch Bare Cable (3H25)
- 25% Ribbons, 20 mil (5H4)



(U) Figure 7-4. Drag Coefficients for 20 mil, 25% Ribboned Tow Cable Compared to Other Configurations (Ref. 3) (U)

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fairing is lower than all other cables evaluated, indicating minimal kiting effects. In summary, the fairing evaluated during 5H4 offers the same strum suppressive qualities as previous ribbon fairings, yet had essentially the same or lower tangential drag coefficient, and lower normal and lift drag coefficients.

## 7.4 DYNAMIC TENSION RESULTS

(U) Enroute to NWPC and while on station in Exuma Sound, the NSRDC SET recorder was evaluated. The recorder essentially samples the voltage output of the load cell and records the total time of occurrence in one of 10 preset voltage windows. For example, a constant tension of 2000 lb for 60 seconds would record as 60 seconds in the voltage window corresponding to 2000 lb. Each of the windows can be interrogated, and a tension histogram can thus be obtained. The SET recorder performed well; however, the voltage windows for this trial were set too wide to obtain a good cross section of the tension distribution.

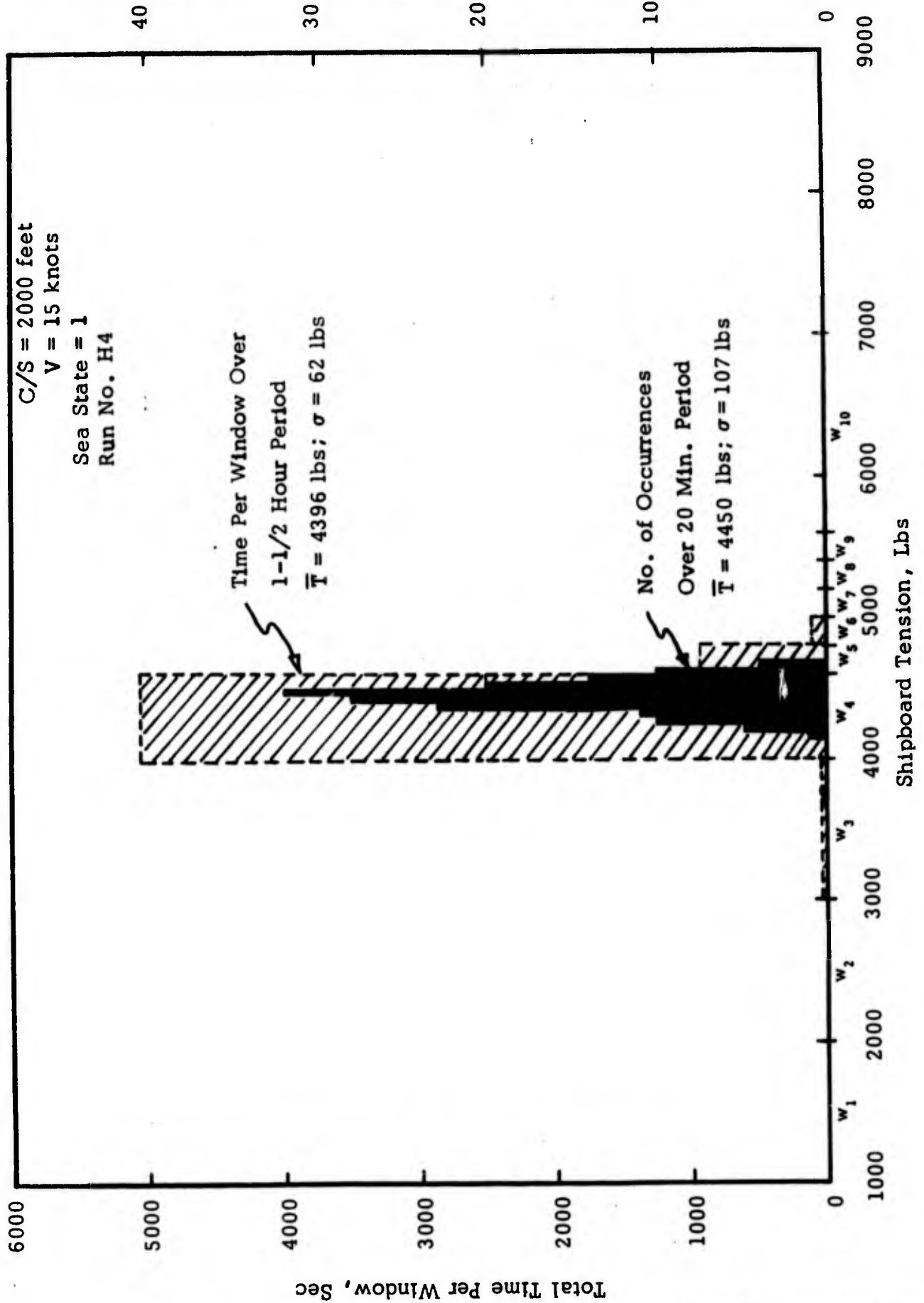
(U) Figure 7-5 presents the results of measurements made during a 15-kt transit through the Gulf Stream in a Sea State 1 to 2. Also shown are the results of a manual sampling of tension at 6.5-second intervals, divided into 11 windows of 50 lb each. As illustrated by the figure, the tension variations were minimal and had a standard deviation of only about 100 lb.

## 7.5 COMPARISON OF PVC AND FABRIC HOSE

(U) Also during this sea trial, a 330-ft SLC PVC VIM was made available and was mated with the CIC-ONR array in an attempt, from the hydromechanical viewpoint, to look at the differences in drag brought about by the use of the PVC hose. During the data runs using this configuration, the tension at the nose cone was measured and corresponded to the array drag at a particular speed. Knowing the drag, speed, and the length of the array,  $dT/dS$  and subsequently  $C_t$  was found as a function of Reynolds number. This represents the drag of the CIC-ONR array with the SLC VIM. The drag of the CIC-ONR array alone was found from the data taken on previous sea trials<sup>3</sup> near the same Reynolds number. When this drag was subtracted from the composite system drag, the result was merely the drag of the SLC VIM. This drag divided by the length of the VIM gives

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Frequency of Occurrence Per 6 Sec Sampling Rate  
(Based on 50 Lb Range)



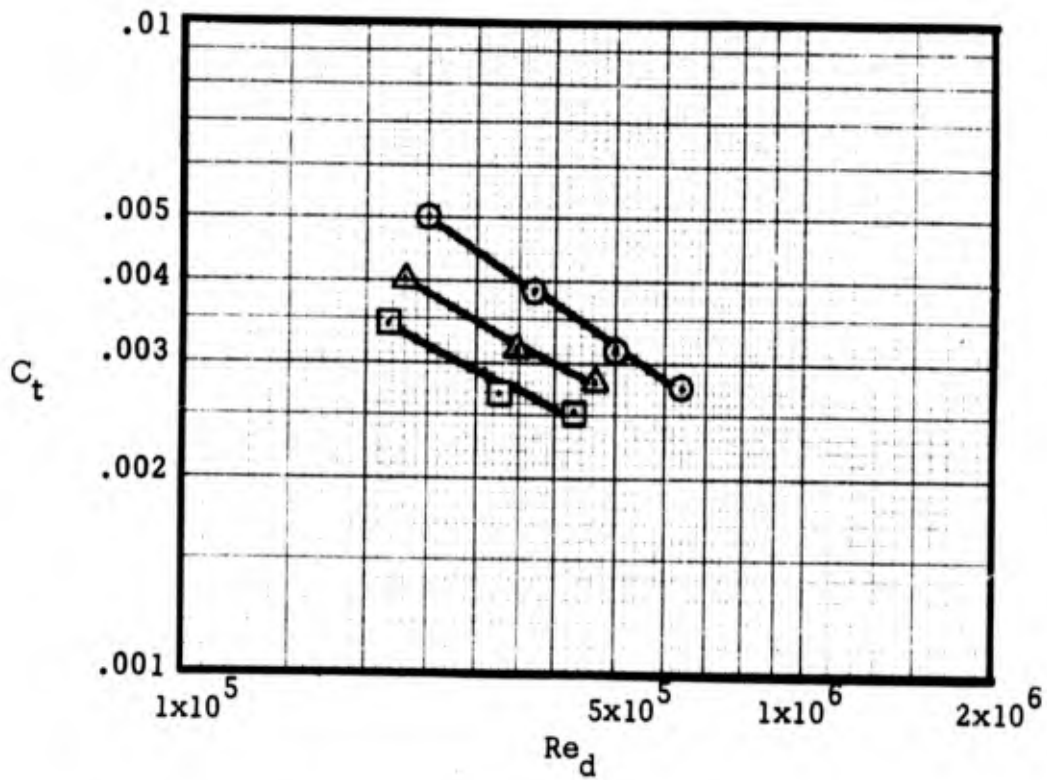
(U) Figure 7-5. Statistical Distribution of Tension Measured During Trial 5H4 (U)

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$dT/dS$  and leads to the tangential drag coefficient for the SLC VIM. This was done for different speeds and a plot of tangential drag coefficient versus Reynolds number was obtained, as shown in Figure 7-6.

- ⊙ CIC Rubber/Fabric Laminate Array (4H8)
- △ Rubber/Fabric & PVC Integral Array (5H4)
- SLC PVC VIM (5H4)



(U) Figure 7-6. Tangential Drag Coefficients as a Function of Reynolds Number for Various Array Construction Materials (U)

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## Section 8

### CONCLUSIONS

#### 8.1 GENERAL

(U) The objectives of the March 1975 ONR Sea Trial 5H4 were substantially attained. Good quality data were acquired using modules from both the CIC Baseline Array and the HAC Modified STUD Array. These modules performed well, both individually and when integrated together into a composite array. Reliability of the CIC Baseline modules was good. The ITM continued to provide useful reference noise spectrum level measurements against which other module noise levels could be compared. The LSM and COM produced a considerable amount of good-quality data. The HAC MSM array also performed well. It produced useful noise level measurements for PVC versus rubber/fabric hosewall comparisons. The HAC array and signal processor also successfully formed array beams steered in various directions, in their initial sea trial as a part of the ONR program.

#### 8.2 SPECIFIC CONCLUSIONS

(C) Interpretive analysis of the acoustical and vibrational noise spectrum levels measured in Sea Trial 5H4 establishes the following specific conclusions:

1. Towship radiated noise was a significant limiting factor in the measurement of acoustical self-noise spectrum levels. Propulsion machinery noise levels at frequencies greater than 250 Hz exceeded Sea State 1 ambient noise levels at all tow speeds, even with a 7000-ft tow cable length. At 6 kt, propeller cavitation noise further dominated total towed array noise at mid-frequencies, from 80 to 250 Hz, in operations using the starboard propulsion system. The port propulsion system generated even more noise than the starboard system, probably due to a damaged propeller blade. It was not usable for low-speed runs. For the 12- and 15-kt runs, it was necessary to use both the port and starboard

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propulsion systems, which probably caused the high-speed towship radiated noise spectrum levels at frequencies greater than 250 Hz to be unusually high.

2. The ribbon fairing on the ONR tow cable did not cause the excessive mid-frequency noise which was measured at 6 kt. This "100-Hz hump" was generated by propeller cavitation, probably caused by one slightly bent blade on the starboard propeller.
3. A 500-ft section of neutrally buoyant tow cable immediately forward of the array reduced the low-frequency vibrational noise levels measured both forward and aft of the forward array VIM, but had no significant effect on array self-noise levels. This result was obtained using a strum-suppressed tow cable.
4. Lengthening a rubber/fabric laminated construction VIM from 20 to 90 ft reduced low-frequency noise levels slightly, but increased mid-frequency noise levels somewhat. Changing to a 330-ft VIM with PVC hosewall and internal stretch members further reduced acoustical noise levels slightly, at all tow speeds. These results were obtained using a strum-suppressed tow cable.
5. In the presence of one particular dominant form of array self-noise, a PVC module hosewall significantly reduced array self-noise levels relative to those obtained under the same towing conditions using a rubber/fabric laminate hosewall. The PVC hosewall also produced less tangential drag.
6. The use of a TBL scattering band embedded in the hosewall at the middle of the LSM produced significantly higher acoustical noise levels in the vicinity of 50 Hz, at all tow speeds, compared to results obtained without the scattering band.

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7. Vibration noise levels measured by the piezoelectric LSM accelerometers were significantly lower than those measured simultaneously by adjacent TAM accelerometers. It is believed that leakage of fluid into the LSM accelerometers under high static pressures severely degraded the vibrational sensitivities, while somewhat enhancing the acoustical responses of these sensors.
8. The new LSM and COM hydrophones and associated preamplifier/line drivers performed well in general, and provided good data for parametric evaluation purposes and for coherence data processing. Those sensors were, however, degraded by exposure to high static pressures at typical low-speed array operating depths.
9. The ITMs continue to be reliable modules which measure relatively low self-noise levels. It is necessary to pay careful attention to intermodule wiring connections to make sure that the ITM signals are successfully brought out of every array configuration.
10. The integration of various acoustical modules from different manufacturers into a single R&D array can be successfully accomplished without significantly sacrificing the performance of either. The benefits include a direct comparison of various manufacturing techniques and recent developments.
11. The NSRDC hydromechanical measurement system is useful in determining the towing characteristics of a cable/array system, and in measuring a statistical distribution of the dynamic tension variations as a function of sea state.
12. At the longest cable scope (7000 ft) and the slowest tow speed (6 kt), the COM and LSM self-noise levels that can be measured were limited by the system electrical noise floor (10 to 64 Hz), the towship radiated noise (80 to 320 Hz), and by Sea State 3 ambient noise (above 500 Hz).

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## 8.3 RECOMMENDATIONS

(U) Based on the results and conclusions from this sea trial, the following recommendations have been developed:

1. Hydrophone and accelerometer calibrations continue to be sources of uncertainty and should be conducted prior to each at-sea evaluation. Hydrophones should be of the pressure compensating type; this should be experimentally verified prior to array assembly. Accelerometers should have minimal acoustic sensitivity.
2. Future arrays should be of PVC hosewall construction, with a long forward VIM. No NB cable is required.
3. In conjunction with knowledge of oceanographic conditions at the test site, the R&D array should be instrumented with a reliable and accurate depth sensor and a water speed sensor.
4. A pre-trial knowledge of the total array system electrical noise floor is essential, as is knowledge of the ambient noise levels.
5. The post-amplifier filters (6 dB/octave) in the shipboard electronics should be deleted from the system, in order to lower the low-frequency electrical noise floor when a strum-suppressed tow cable is used.

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6. Pode, L., "Table for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream," Report No. 687, DTMB, U.S. Navy, 1951
7. McDaris, J., "Coherence Module Acoustic Sensitivity as a Function of Temperature and Pressure," Chesapeake Instrument Corporation, TN 203-JCM-001, May 1975
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## Appendix A

### DEFICIENCIES

#### A.1 GENERAL

(U) Throughout the trial, several deficiencies occurred which caused various degrees of degradation to array performance. Most were insignificant and could be discounted; however, several proved to be vital to the system and in some ways compromised the trial objectives.

(U) Table A-1 presents a summary of the various module hydrophones that were omitted during averaging, since their measured noise spectrum levels deviated from the levels measured by the majority of hydrophones by  $\pm 5$  dB (high or low). Since some of these hydrophones have been found to be pressure sensitive,<sup>7</sup> the depths at which the failures occurred is also indicated in the table. The following sections describe the failures on a module-by-module basis.

#### A.2 ITM

(U) As seen in Table A-1, the ITM hydrophones consistently measured reliable acoustical noise levels and did not appear to be pressure sensitive. The failure that occurred during Run 17 did not affect the trial objectives.

#### A.3 LSM

(C) Serious deficiencies occurred with several LSM hydrophones, which appeared to be directly related to towing depth. Sporadic deficiencies occurred with Hydrophones H1, H3 and H10 prior to the noise floor measurements made in Runs 33 and 34. However, the ambient run allowed the array to attain a depth of approximately 3250 ft and resulted in permanent damage to Hydrophones H2, H5 and H10. Since the central LSM hydrophones, H3 - H8, were used for most of the parametric studies reported here, these failures were of minor consequence to the overall trial objective.

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(U) Table A-1. ONR Sea Trial 5H4 Deficient Hydrophone (U)

Run No.	Hydrophone Levels High	Hydrophone Levels Low	Depth (ft)
14	H2,6		700
17	S1		200
24	M5	M6,9,10,11,14,16,17	1100
25	M5	M6,9,10,11,16,17	700
26	M5	M6,11,16,17	500
27	M5	M6,11,16,17	225
28	M3,5	M6,7,8,9,10,11,16,17	1100
29		H3	700
30		H3	450
31		H1,3,10	300
32		H1,3	200
33	H8	H3,10	3250
34	H6	H1,3,10	3250
35	H5,6	H10	700
36	H3,4	H10	450
37		H10	300
38		H10	200
42	H2	H5,10	700
43	H2	H5,10	1000
44	H2	H5,10	1600
45	H2	H5,10	1000
46	H2	H5,10	1600
47	H2	H5,10	350
52		C3,7,9	700
53		C3,7,9	1000
54		C3,7,9	1000
56		C3,7,9	350
60	H2	H5,10	700
61	H2	H5,10	1000
62	H2	H5,10	1600
63	H2	H5,10	350
65		M3,9,11,17	1600
66		M3,9,11	1000
67		M3,9,11	700
68	M5	M11	350
70		M3,9,11	2000

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## A.4 COM

(C) COM Hydrophones C3, C7 and C9 were found to be highly pressure sensitive<sup>7</sup> and their spectrum levels should be discounted during future analysis of the COM data.

## A.5 MSMs

(C) Both MSMs developed deficiencies with respect to specific hydrophones which degraded the parametric evaluations to a minor degree, and the beamforming capabilities to a much greater extent. Hydrophones M3, 6, 9, 10, 11, 14, 16 and 17 measured unusually low spectrum levels that were attributed to either problems in the shipboard electronics or decreased hydrophone sensitivities caused by array depth. Hydrophone M5 measured unusually high levels for undetermined reasons.

(U) The HAC shipboard electronics included a multi-beam beamformer requiring the signals received from the 20 hydrophones in both modules. Upon assembly of the system at sea it became apparent that the Control Gain Amplifier (CGA) gains were not properly set. An attempt was made to reset all CGA gains to obtain a constant output for beamforming purposes by subjecting the hydrophones to the excessive radiated noise of the port propulsion system in a 6-kt run at a 1000-ft tow cable length. This resulted in a pseudo-calibration, and made the beamformer useful for minimal quantitative observations, as reported in Reference 8.