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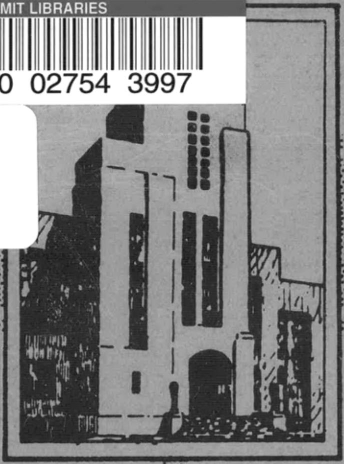
REPORT 1558



DEPARTMENT OF THE NAVY
DAVID TAYLOR MODEL BASIN

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VIBRATION AND TOWING CHARACTERISTICS OF SURFACE-SUSPENDED HYDROPHONE SYSTEMS

by

Chester O Walton and Mervin M. Merriam

HYDROMECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

AUGUST 1961

REPORT 1558

PRNC-TMB-648a (Rev. 3-58)

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ABSTRACT

An experimental investigation was conducted to determine the sources and methods of reducing cable vibrations in acoustic measuring systems, to provide information concerning full-scale towing behavior, and to accurately define the towing configuration of such systems. The results of this investigation including comparisons with theory and recommendations for improving towed acoustic systems are given in this report.

INTRODUCTION

The use of towed hydrophone systems to measure radiated noise from submarines has led to many problems which must be alleviated if such systems are to fully serve their purpose. Specifically, the vibration of the cables is believed to be one of the major sources of the high level of background noise in the low frequency bands which has been associated with such measurements. Furthermore, insufficient data concerning the resistance of these kinds of arrays have made it difficult to determine the configuration of the array and, consequently, the orientation of the hydrophones.

Accordingly, an experimental program was established under the Fundamental Hydromechanics Program at the David Taylor Model Basin to study the cause and effects of these flow-created problems as they pertain to typical surface-suspended hydrophone systems. The specific objectives of the program were: to investigate the capabilities of such systems with regard to speed, depth, and steadiness of tow; to determine how well the behavior of full-scale systems can be predicted for a range of operable conditions; and to provide information which is required to accurately define the configuration of a given system.

The facilities which are necessary to carry out tests of a complete system under highly controlled conditions and at a large enough scale required for accurate representation are not available. Consequently, the approach used was to carry out the program in the following three phases: shallow-water towing tests in the towing basins at the Taylor Model Basin to determine sources and magnitudes of low-frequency noise components in the acoustic system, open-water tests in the Chesapeake Bay to provide data on the effects of cable scope and fairing on vibrations and towing attitude of the system, and tests at sea to evaluate the characteristics of a full-scale system proposed for submarine radiated-noise measurements.

This report describes the various experimental investigations, presents the results of measurements to determine vibration characteristics, and includes pertinent observational data. The towing configuration of a proposed system is briefly described, and curves and sketches are provided to define its towing configuration. Recommendations are made on how to improve such systems as well as for future studies which are necessary for further development.

GENERAL CONSIDERATIONS

Submarine radiated-noise measurements[1, 2] are presently being obtained with a hydrophone array in which the cables are bundled, and the system is allowed to drift with the listening ship in the manner shown in Figure 1. Because of ocean currents and winds, the system is set into motion and the cables move relative to the water which results in the formation of a "Kármán Vortex Trail."[3] Above certain velocities, eddies break off alternately on either side of the cable in a periodic fashion, as indicated in Figure 2. Thus a staggered, stable arrangement or trail of vortices is formed behind the cylinder. This alternate shedding produces periodic forces normal to the undisturbed flow which act first in one direction, and then in the opposite direction. The alternating forces cause the hydrophone cables to vibrate and the cable vibrations are either received directly by the hydrophones as sound waves or cause an actual acceleration in the sensitive hydrophone elements which also results in noise. The resulting signals are of high amplitude and tend to mask out lower-level noise components present in the low frequency portion of the spectrum. Attempts to reduce the vibrations have been made by sliding loose plastic tubing over the single cable (see Figure 1) to break up the flow around the cable. This technique has been partially successful, but not to the degree necessary for accurate sound analysis.

The motion of the system through the water also causes the hydrophone array to tow in a catenary so that the hydrophones are neither at desired depths nor in a true vertical plane with respect to the noise source. Since the depth and configuration of the present type of array is difficult to predict, the assumptions made with respect to the position of the hydrophones in the analysis of data are sometimes far from accurate.

EXPERIMENTAL PROGRAM

As mentioned in the Introduction, the experimental program was restricted by limitations of test facilities at the Taylor Model Basin as to size, depth, and background noise. Therefore, this investigation was conducted in three phases:

1. Shallow-water towing tests to determine the magnitudes and sources of vibrations or low-frequency noise components in the acoustic system,

2. Open-water tests to determine the effects of cable scope and fairing in the reduction of vibrations and to obtain information relative to the towing attitude of the system, and

3. Evaluation tests at sea to determine the towing behavior and configuration of a proposed system for submarine radiated noise measurements.

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[1] References are listed on page 18.

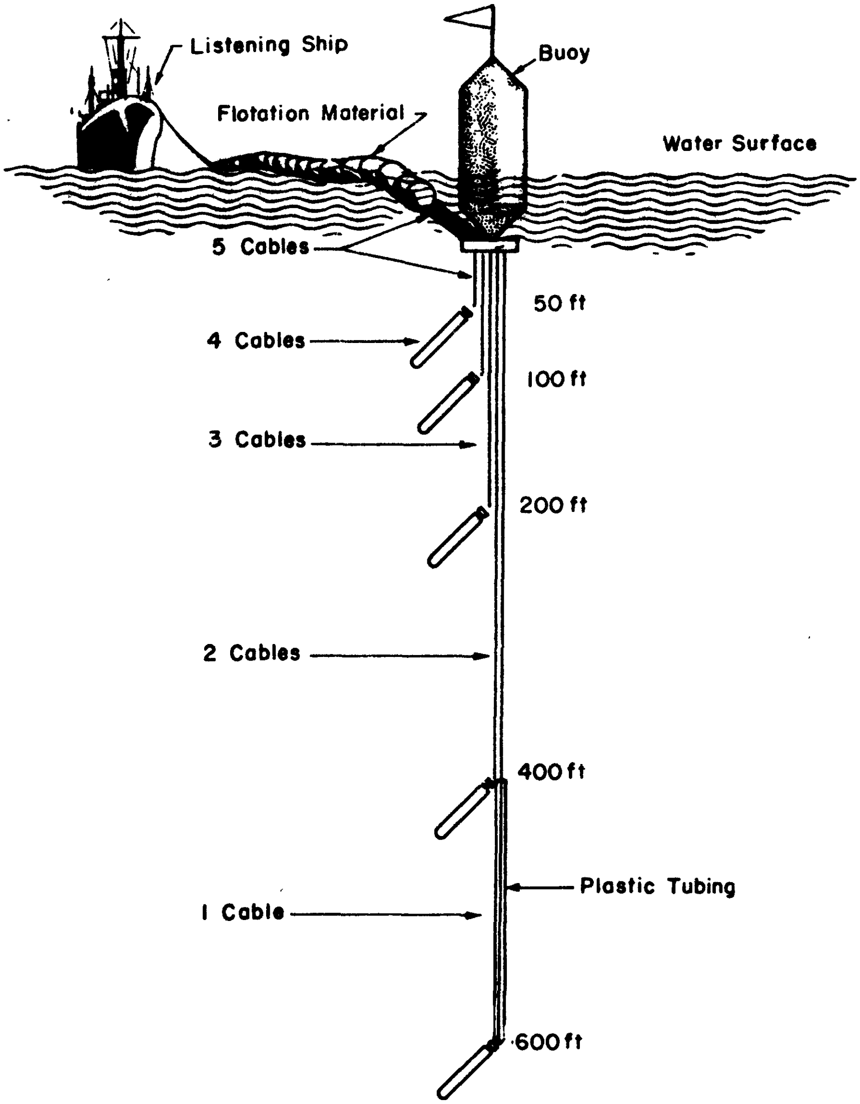

Figure 1 – Schematic Diagram of a Hydrophone Array

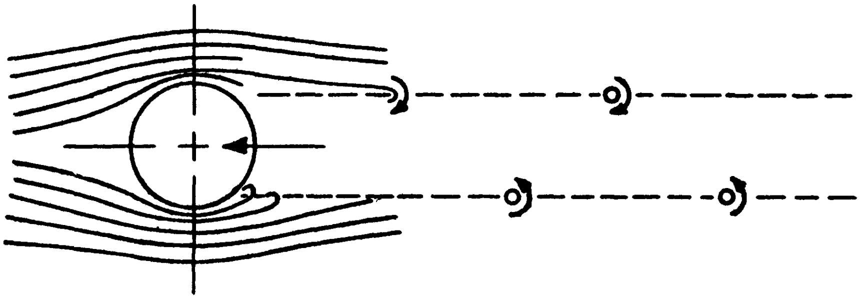

Figure 2 – Kármán Vortex Trail

SHALLOW-WATER TOWING TESTS

The shallow-water tests were conducted in the towing basins at the Taylor Model Basin primarily to ascertain whether the interference in the acoustic measurement systems was due to cable vibration or to hydrophone oscillations. This preliminary investigation was intended to set the basis for possible solutions of the problems affecting acoustic measurements.

The initial tests conducted in the basin were made using AX-58 type hydrophones, as shown in Figure 3a. A shroud-ring tail similar to that shown in Figure 3b was attached to the hydrophone to minimize oscillatory motions. Each hydrophone was towed on a 9/16-inch diameter, rubber covered, electrical cable, as shown in Figure 4. The cable had a weight of approximately 0.1 pound per foot in water and served as a conductor for the hydrophone signal. The units were towed over a speed range of 0 to 3 knots.

Standard type cable fairing was not available for the size cable being used in the basin tests. As a substitute measure, a simulated fairing made from 2-inch plastic tubing, was used for some of these tests. The tubing was placed over the cable so that it was free to align itself with the stream and was tested using the hydrophone with and without the shroud-ring tail. In an attempt to further break up the flow around the cable and thus reduce vibrations, the plastic tubing was coated with a cork mixture to roughen the surface. The system with the coated tubing was also towed over the 0-to 3-knot speed range. During each run, noise measurements were made in 1/3-octave bands using a spectrometer and a sound-level recorder.

OPEN-WATER TOWING TESTS

The shallow-water tests did not provide adequate information for determining the towing configuration of the hydrophone array as well as the effects of the use of greater cable scopes and standard cable fairing on cable vibration. Consequently, in an attempt to obtain the additional information in an environment having a minimum of background noise, tests were conducted in open water in the Chesapeake Bay. A secondary purpose of these tests was to obtain design information relative to a full-scale hydrophone array.

The tests in the Chesapeake Bay were conducted with the configuration similar to that shown in Figure 5 using a motor boat as the towing vessel. Two 50-foot sections of fairing were used as the main towline. The fairing was of an airfoil shape (TMB No. 7)[4] made of a two-durometer rubber which normally would enclose the towcable. The 50-foot sections were joined together by junction boxes, as shown in Figure 6. Both at the extreme end and at the junction of the two sections an instrument housing was attached which contained two pendulum angle indicators (one for longitudinal and the other for lateral measurements). A 100-pound faired towing weight was attached at the deepest end of the array to provide directional stability.

The initial tows were made over the stern, but satisfactory measurements could not be obtained because of propeller wake. The towing arrangement was then modified to permit over-the-side towing. It was then possible to tow the configuration and make pressure and angular measurements over a speed range

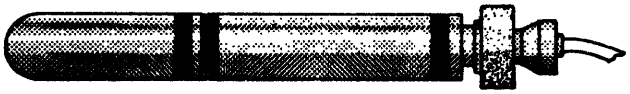

Figure 3a

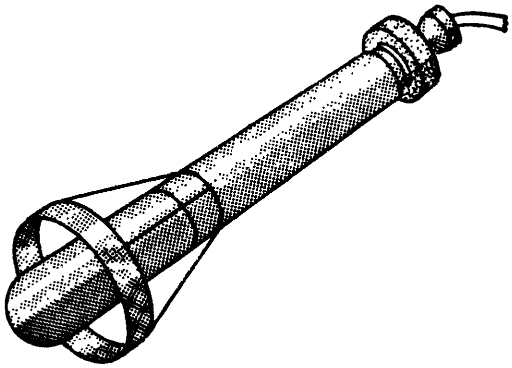

Figure 3b

Figure 3 – Sketch of Hydrophones Used in Basin Tests

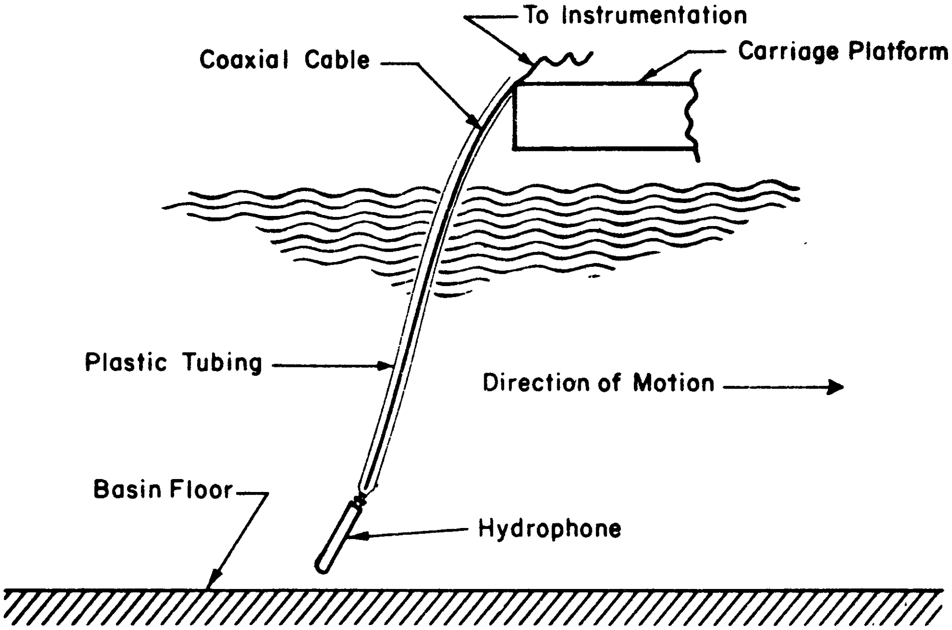

Figure 4 – Towing Configuration Used in Basin Tests

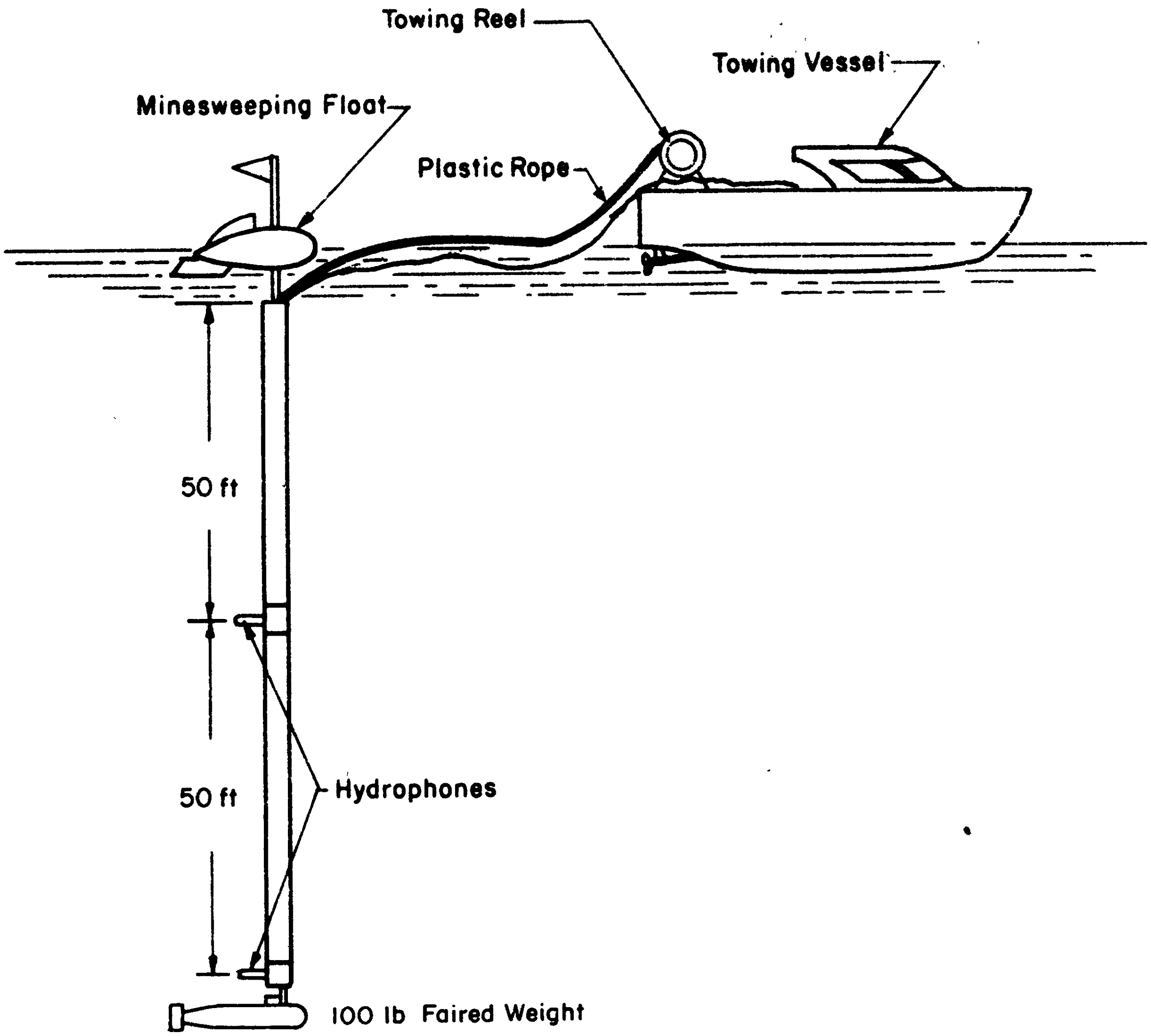

Figure 5 – Diagram of Towing Configuration Used in Open-Water Tests

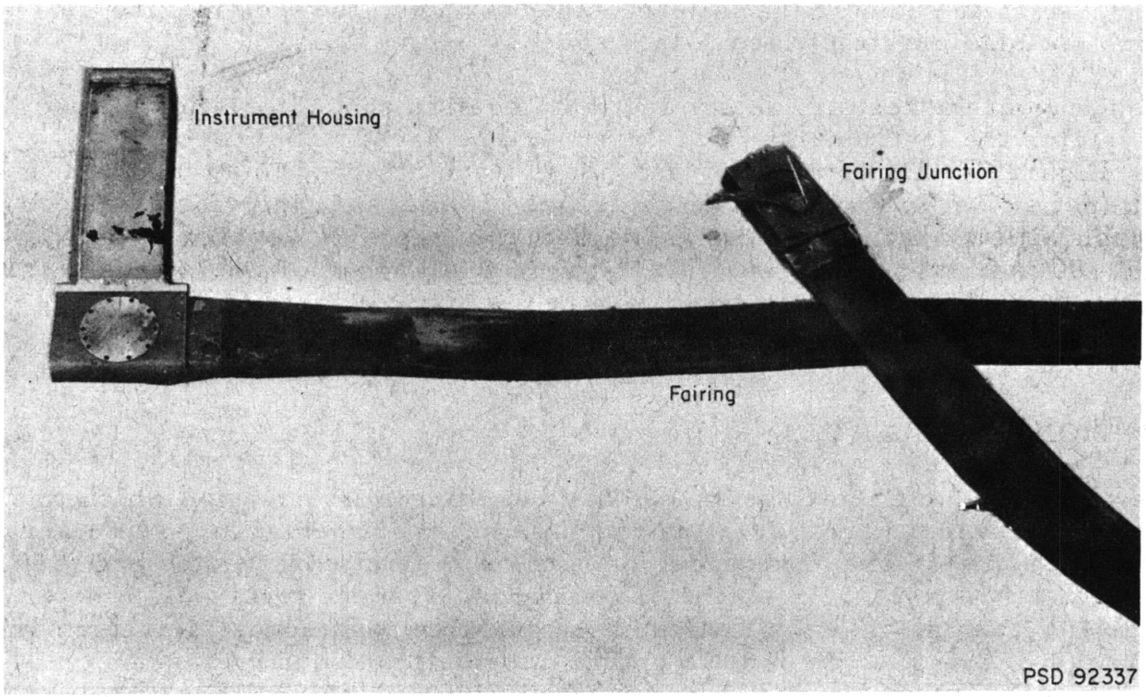

Figure 6 – Instrument Housing and Fairing Assembly

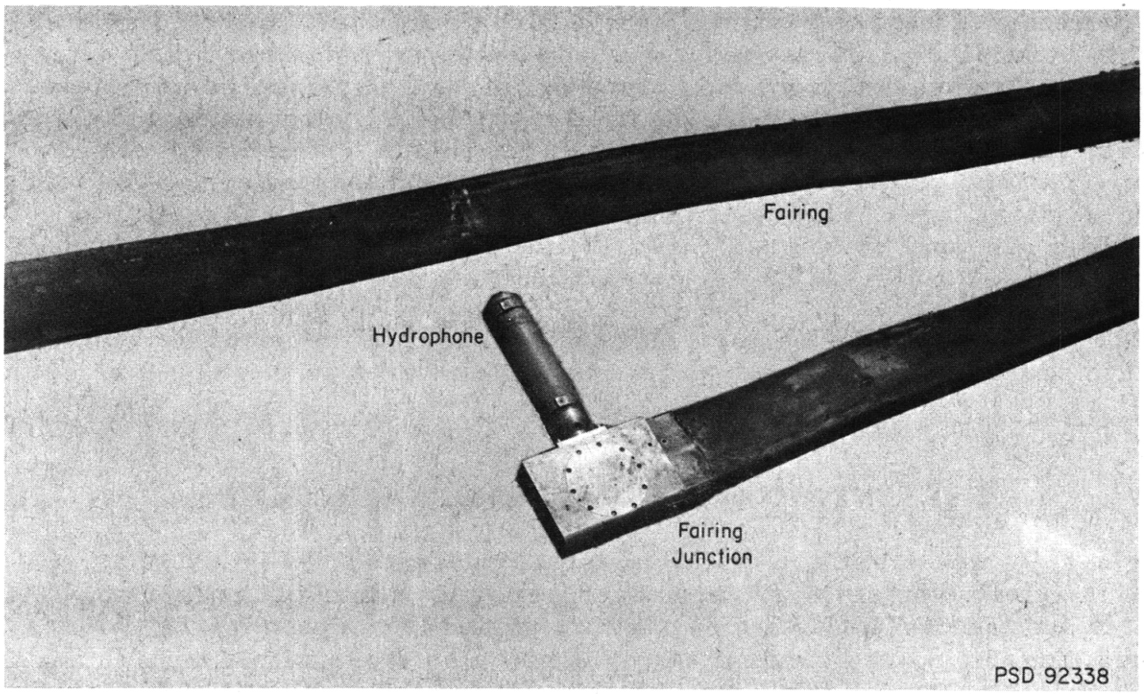

Figure 7 – Fairing and Hydrophone Assembly Used in Acoustic Tests

of 0 to 4 knots. At 4 knots, the fairing tended to tow in towards the propellers and it was not feasible to tow above this speed.

To carry out the tests to determine the vibration characteristics of the faired system, the instrumented housings were replaced with hydrophones, as shown in Figure 7. Two similar hydrophones were attached to an unfaired 5/8-inch (not shown in Figure 5) weighted line to measure the vibrations for comparison with the faired system. The hydrophones were located at depths of 50 and 100 feet in each system. Tests were made over a speed range of 0 to 4 knots and the hydrophone signals were recorded over the full speed range.

EVALUATION TESTS AT SEA

The tests conducted in Chesapeake Bay resulted in information which was applicable to full-scale arrays. Accordingly, an experimental full-scale array for studying submarine radiated-noise patterns was first constructed and then tested at sea off Key West, Florida. The purpose of these tests was to determine stability, towing characteristics, configuration, and acoustic performance of the array. It was also desired to obtain information required for design modifications for future arrays.

The array used in the first sea tests is shown by the sketch in Figure 8. It is composed of a 100-pound faired towing model, pressure gages, hydrophones, buoys, float material, and a network of cables. All three legs of the system (horizontal and two vertical legs) are composed of 0.7-inch diameter cable with 26 twisted pairs of conductors and a strength member. The intermediate cables suspended from the horizontal leg are 0.3-inch in diameter. The horizontal leg is supported by flotation material. Hydrophones and depth gages were located at the points indicated in the sketch. Junctions were provided for additional hydrophones and depth gages to be located every 100 feet along the vertical legs. The system was towed over a speed range of 0 to 3 knots while pressure measurements and hydrophone signals were recorded.

On a subsequent sea trial, the array shown by the diagram in Figure 9 was used. The added 500-pound faired towing weight in the second system was intended to provide greater depth and more vertical area in the loop formed by the array.

PRESENTATION AND DISCUSSION OF RESULTS

The results of the shallow-water tests are presented in Figure 10 as differences in relative noise level versus frequency for three of the test conditions. Since the results with the fourth condition (simulated fairing with a roughened surface) were approximately the same as those with a smooth surface they are not presented. It may be seen from Figure 10 that, for the very low speeds (0.1 to 0.25 knots), there are no significant differences in noise

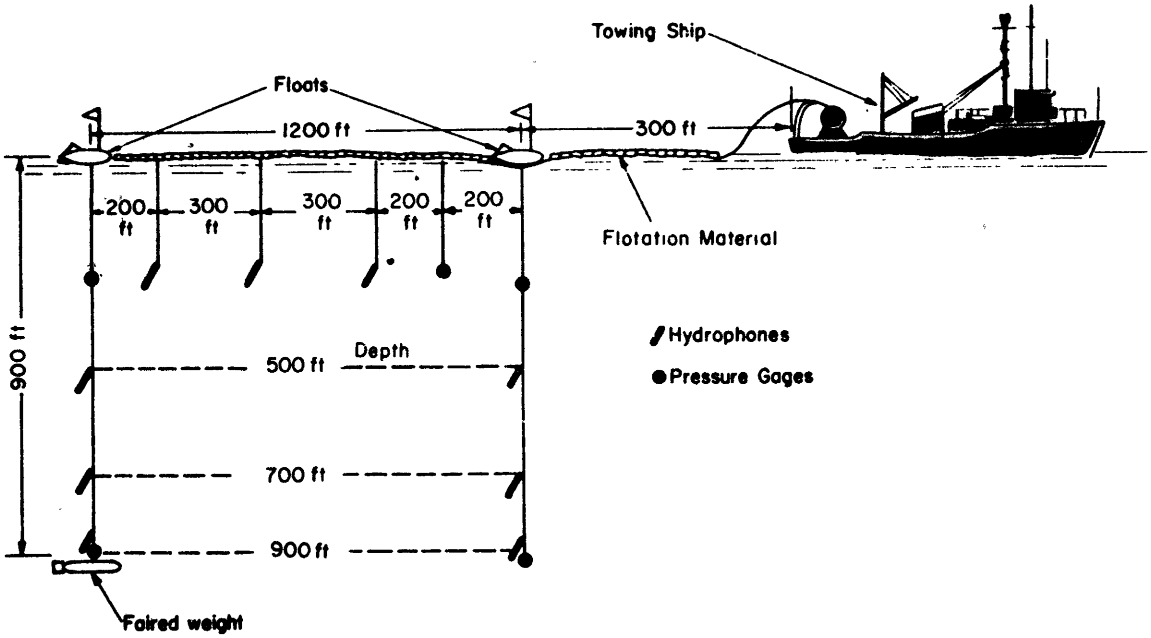

Figure 8 – Diagram of an Experimental Directivity Hydrophone System

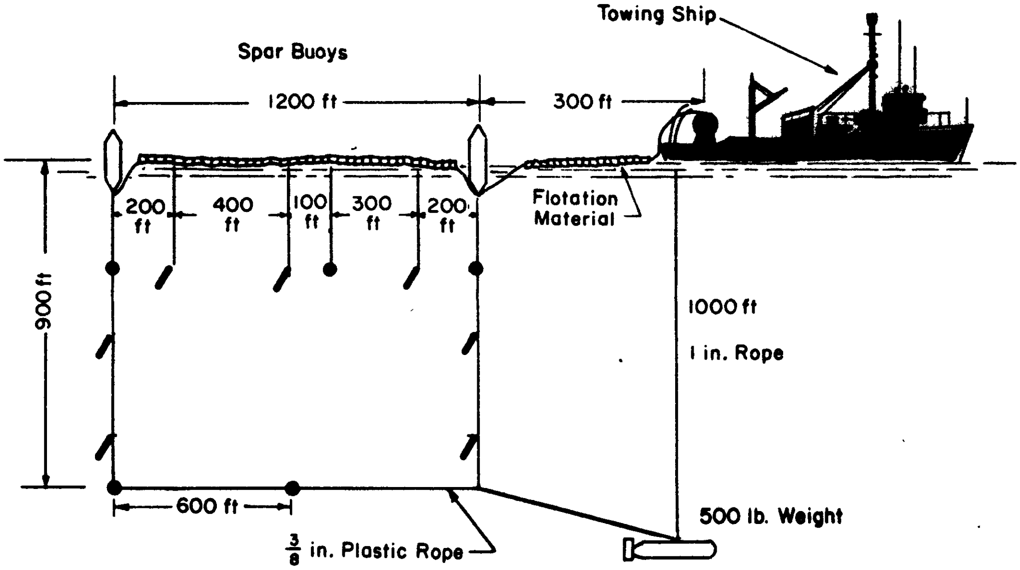

Figure 9 – Diagram of the Modified Experimental Directivity Hydrophone System

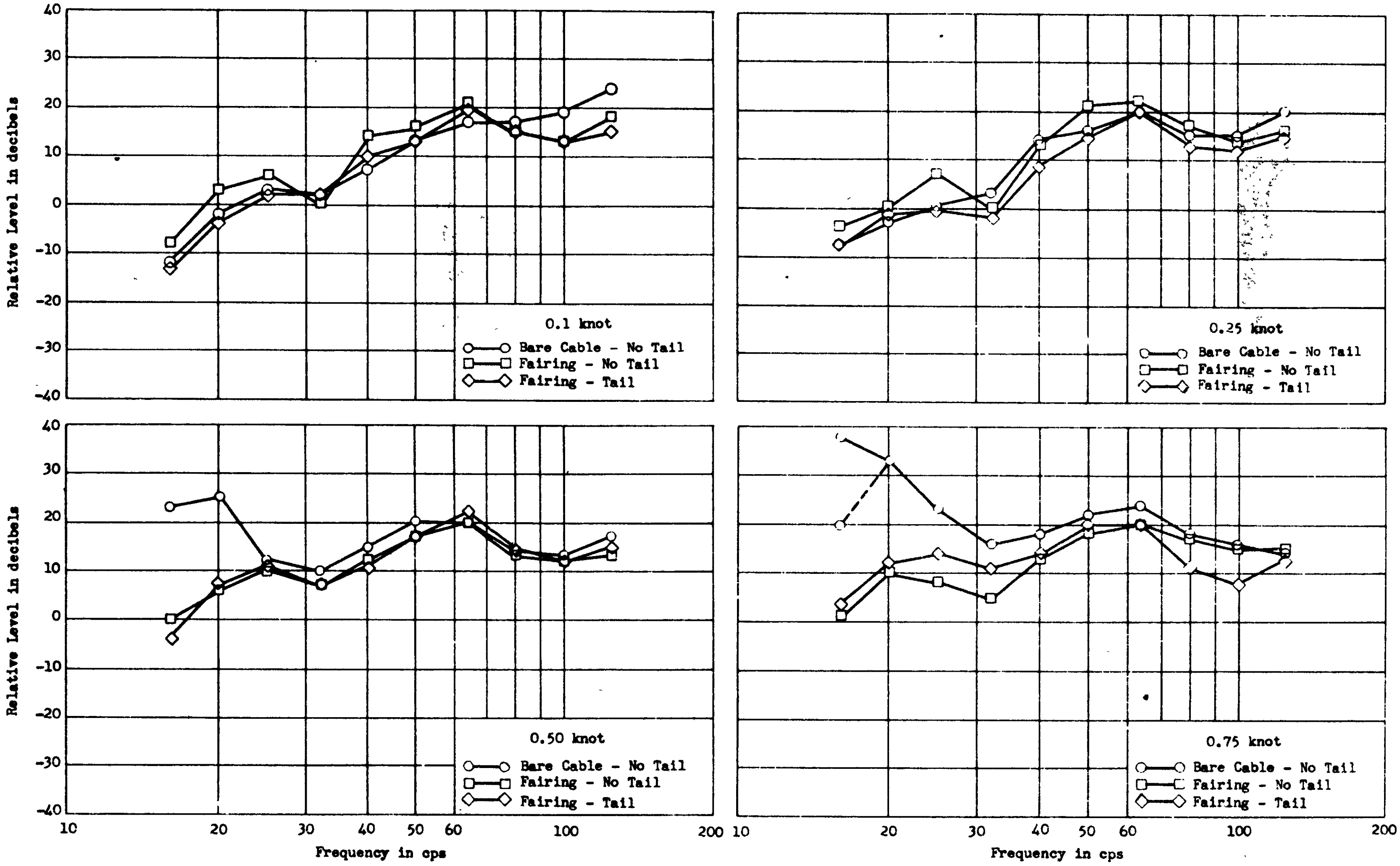

Figure 10 – A Comparison of the Relative Noise Levels Received from an AX-58 Hydrophone Tested in the Basin under Various Conditions

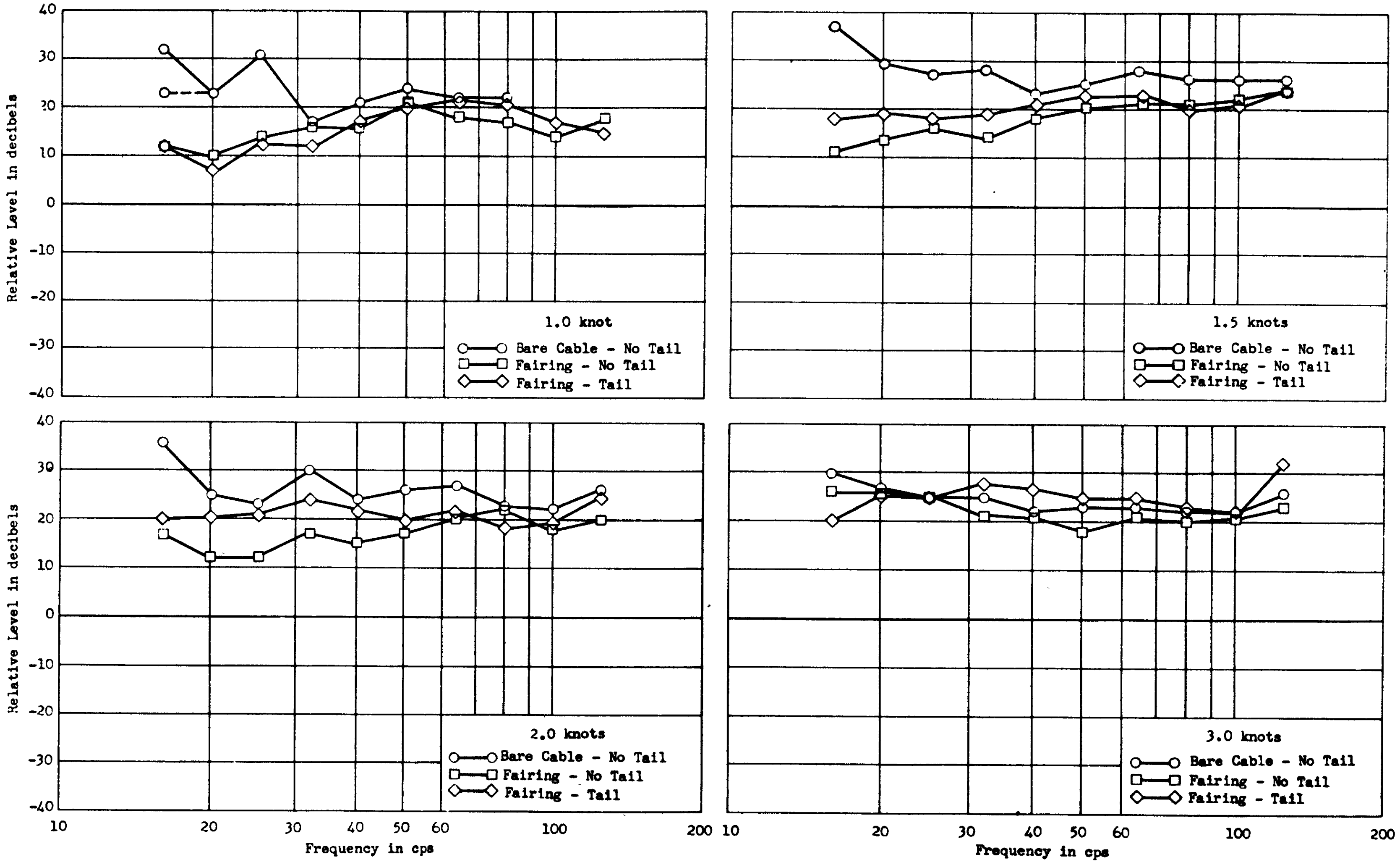

Figure 10 (continued)

levels among the conditions tested. However, observations made during the tests indicated that the bare cable vibrated at these speeds and that these vibrations appeared to influence the motion of the hydrophone as well as its signal as seen on an oscilloscope. The vibrations at these speeds are of such low frequency that they do not appear in the analysis, since the lowest 1/3-octave band on the spectrometer is centered at 16 cycles per second.

At speeds between 0.5 and 2.0 knots, the noise levels for the bare cable condition are from 5 to 20 decibels higher in the low frequency bands (16 to 125 cycles per second) than for the faired cable condition. All test conditions produced high-noise levels for speeds above 2.0 knots.

The addition of plastic tubing (fairing) reduced cable vibration at all speeds and seemed to completely eliminate the vibrations at the low speeds. The shroud-ring tail on the hydrophone greatly reduced the very low-frequency oscillation of the hydrophone at all speeds. The effect of the reduction does not appear in the analysis because the frequency of the oscillations is below the frequency range of the instrumentation. The addition of the shroud-ring tail to the hydrophone had no effect in reducing the higher frequency cable vibrations.

It should be noted, however, that the results shown in Figure 10 may be influenced by background noise in the basin, and noise and vibration of the tow carriage. Nevertheless, the data indicate that further investigation into the effects of more refined fairing, greater cable scopes, and other towing configurations is warranted.

The experimental results obtained from the open-water tests conducted in Chesapeake Bay are presented in Figure 11. The results of theoretical calculations, using the method outlined in Reference 5, are superimposed for comparison. It may be seen that the computed position of the array does not agree very well with the measured portion. Lack of agreement is attributed mainly to the fact the system towed to one side. Using a constrained, flexible, faired section that is not free to swivel, the tow member will cause the towline to develop side forces which deflects the system to one side. This occurrence is indicated in this system by lateral angular measurements which approached 45 degrees at 4 knots. The angular records and observations showed that although the array towed to one side, it remained reasonably steady over the speed range.

A qualitative narrow-band frequency analysis was performed on the hydrophone signals recorded during the open-water tests. It was found that for the condition with the hydrophone at 100-foot depth suspended on the faired cable, the interference which might be attributed to cable or fairing vibration in the 0-to 50-cps frequency range was negligible. Thus, the broad-band signal could be amplified so that other noise components such as the firing rate of the boat's engine, signals from a passing tanker, random background noise, etc., could be identified. However, the records from the two hydrophones secured to the unfaired weighted rope were quite different. In particular, the record for the 100-foot depth hydrophone in the latter system showed many interfering high-level noise components in the very low frequency range. The hydrophone was taped directly to the rope which was the vibrating member in this case.

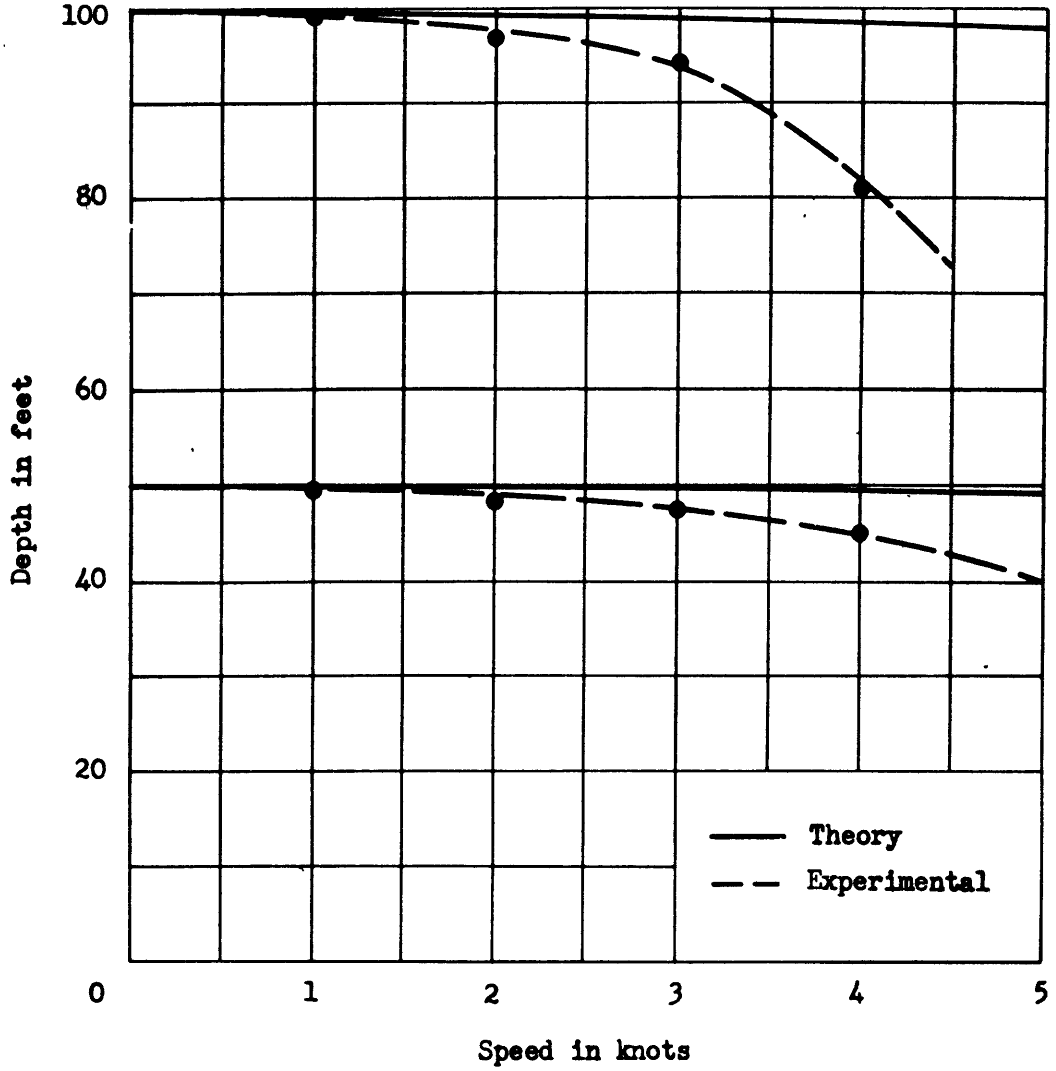

Figure 11 – Comparison of Computed and Actual Configuration of the Experimental Array Used in Open-Water Tests

The frequency of vibration for arrays of this type can be approximated by using the equation

$$f = \frac{NV}{d}$$

where

f is frequency of vibration,

N is Strouhal Number,

V is velocity of fluid, and

d is diameter of cable.

Figure 12 shows the relationship of Strouhal Number and Reynolds Number and can be used to compute the frequency for a series of speeds and cable diameters. It should be noted that these data refer to rigid cylindrical sections and should be applied with caution to cables. Once an elastic body has been excited, the motion of the body modifies the frequency.

Figure 13 compares the frequencies measured on the system used in the open-water tests with values computed by the foregoing method. It may be seen that, in spite of the fact that the computed value is based on rigid cylinders, it compares reasonably well with the low frequency components that were measured. The interfering components seemed to be composed of fundamental frequencies and a number of related harmonics. These frequencies changed with towing speed. The noise components were not present for the portion of the record taken when the boat was not moving. When these components were present on the record, they were of such a high level that the broad-band signal could not be amplified to allow the identification of other signals without overloading the analysis instrumentation.

The results of the evaluation tests at sea are shown in Figures 14a and 14b, the corresponding theoretical computations are superimposed for comparison. It may be seen that, in these two cases, the theory and experiment are in very good agreement. The system without the weight (Figure 14a) was observed to tow in a reasonably steady manner.

A qualitative frequency analysis of samples of hydrophone signals for three towing speed conditions was made. The records showed that there was considerable interference due to cable vibration in the low frequency region at all speeds. The frequency of vibration in these cases is proportional to the flow velocity divided by the diameter of the cable. This was substantiated by the records which showed that the frequencies received by the same hydrophone became higher both with increased towing speeds for fixed diameter, and with decreased cable diameter for fixed speed. The signals from hydrophones on the weighted leg were higher in amplitude than those from the non-weighted leg. This was attributed to the fact that the weighted leg was a better carrier for the flow-induced vibrations than was the non-weighted leg.

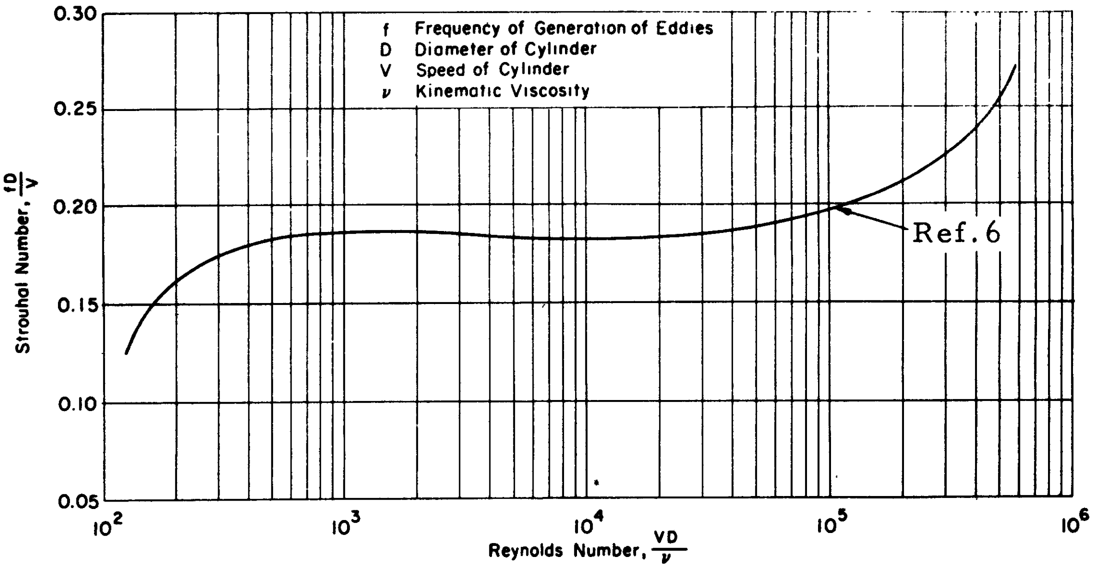

Figure 12 – Strouhal Number as a Function of Reynolds Number

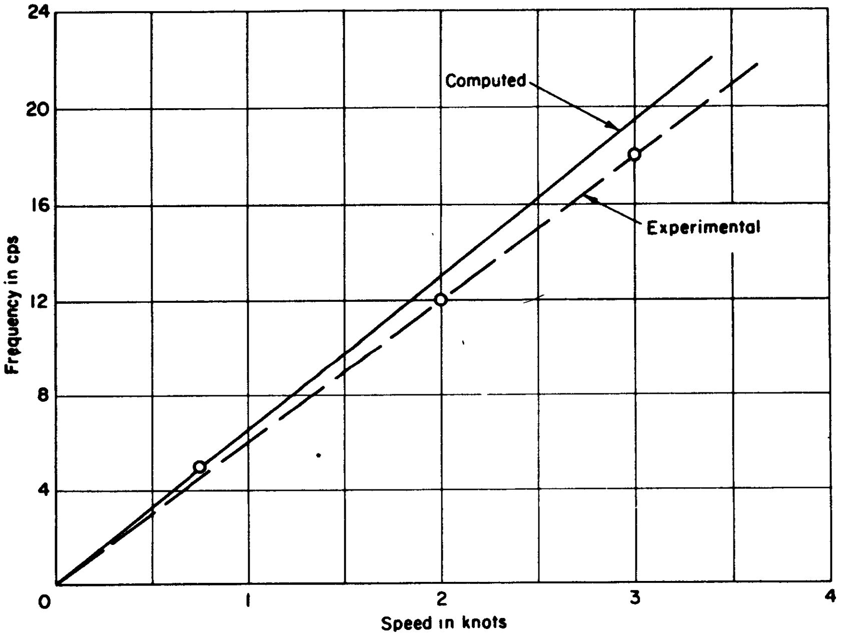

Figure 13 – Comparison of Computed and Experimental Frequencies for System Used in Open-Water Tests

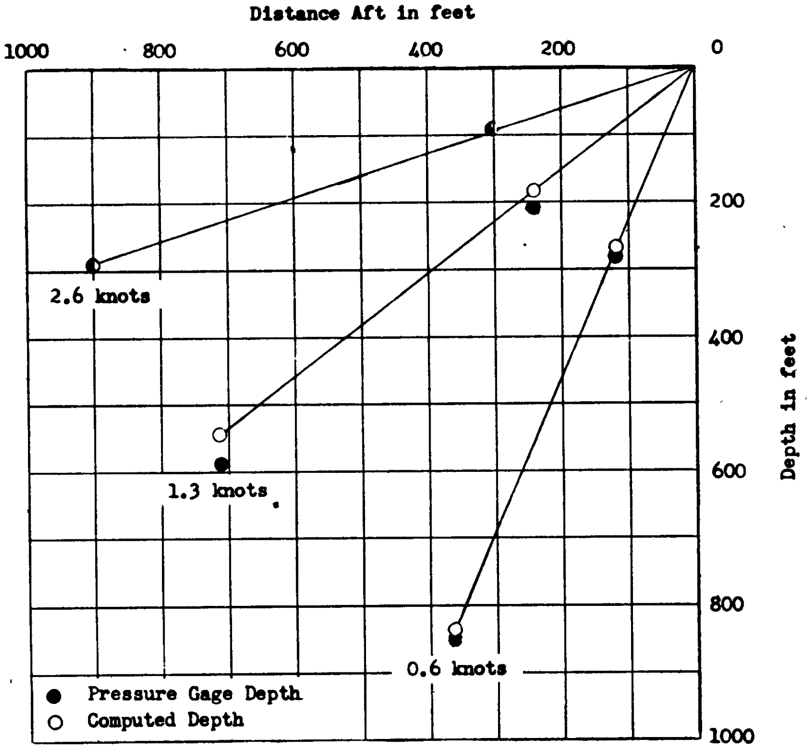

Figure 14a — Without Weight

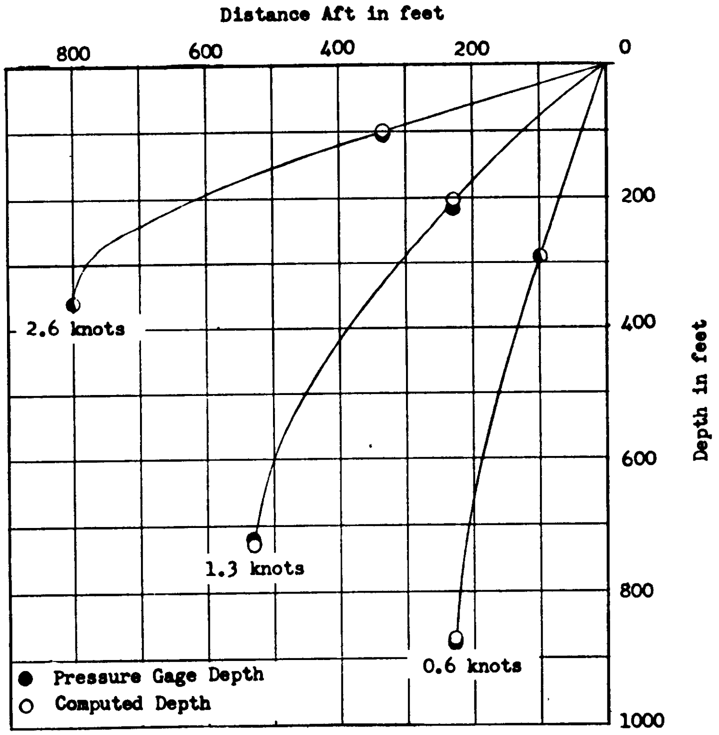

Figure 14b — With 100-Pound Weight

Figure 14 - Comparison of Measured and Computed Cable Configurations for the Experimental Directivity Array

CONCLUSIONS AND RECOMMENDATIONS

On the basis of experimental and theoretical investigations of typical surface-suspended hydrophone systems, it is concluded that:

1. Any movement of sensitive non-acceleration cancelling hydrophones such as the AX-58, whether due to cable vibrations or to hydrophone oscillations, affects the acoustic signal in the low frequency range.

2. By stabilizing the hydrophone with the addition of a shroud-ring tail the very low frequency oscillations are substantially reduced for the range of towing speeds which are usually encountered during submarine radiated-noise measurements.

3. Single hydrophone cables in a flow environment tend to vibrate due to vortex shedding of the Von Karman vortex street type. The vibrations of the single cables interfere with acoustic measurements in the lower end of the frequency range of interest. In general, bundling a number of cables, thereby increasing the effective size of the cylinder, decreases the frequency of vibration below the range of interest.

4. Fairing hydrophone cables reduces cable vibration, aids in obtaining greater operating depth and speed, and improves the stability of the system.

5. The configurations of arrays similar to the ones investigated can be predicted with reasonable accuracy.

6. To obtain maximum depth at speeds above one knot, vertical cables in array systems must be weighted. However, this may increase the acoustic interference.

7. The overall towing attitude of the full-scale array is satisfactory.

Based on the foregoing conclusions, it is recommended that:

1. Hydrophones in surface-suspended array systems be stabilized to reduce the oscillations and vibrations.

2. The vibratory motions of the array lines be reduced by fairing methods.

3. Further tests be made to determine the type of cable fairing most suitable for these kinds of arrays.

4. The amount of fairing required to eliminate or reduce cable vibration should be determined either experimentally or theoretically.

5. Techniques for improved fabrication, launching, and storage of complete array systems should be investigated.

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