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# ANALYSES OF TOWED HYDROPHONE FLOW NOISE

J. C. Beckerle,
A. Orange and B. Wonnick

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WOODS HOLE, MASSACHUSETTS

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# ANALYSES OF TOWED HYDROPHONE FLOW NOISE

by

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November 1970

TECHNICAL REPORT

*Submitted to the Office of Naval Research under Contract N00014-70-C-0205; NR 263-103, formerly Nonr 4029(00); NR 260-101.*

APPROVED FOR DISTRIBUTION J. R. Heirtzler
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# TABLE OF CONTENTS

# ABSTRACT

Data have been obtained on the noise field observed at hydrophones being towed at speeds between 2 and 12 knots. The data were digitized and subjected to auto and cross spectral analysis. The spectra of the noise show strong peaks below approximately 100 cps and the total power and width of the peak as a strong function of ship speed. The coherency of signals at two hydrophones is low in the vicinity of the peak, indicating that this noise field is not due to water-borne true sound. At low ship speeds, the noise in the 200 - 500 cps band is shown to be coherent, but at the higher speeds, this coherence is lost. The noise power in a narrow frequency band at high ship speeds is shown to vary rapidly with time.

# INTRODUCTION

The application of noise reduction and signal detection techniques to data obtained from towed hydrophone arrays requires a knowledge of the noise field observed at the array elements. The present experiment was designed to obtain this information. Data were gathered under reasonably good sea conditions over the range of ship speed normally accessible to the survey vessel. These data were then subjected to standard digital spectral analysis and these spectra interpreted to find the characteristics of the field which effect the design of such filtering systems. This noise field is found to be dominated by a large low frequency peak which arises from a signal which is propagated at a velocity significantly less than that of sound in water. It is conjectured that this noise arises from pressure pulses in the boundary layer of the array. A much weaker component of the noise, at frequencies in excess of 200 cps is found to be water-borne sound. As ship speed is increased this true sound component of the noise field is masked by an increase in the boundary layer noise and can barely be seen at the highest ship speed.

## EXPERIMENTAL EQUIPMENT AND PROCEDURE

The block diagram of the equipment is shown in Figure 1. Photographs 1A, 1B, 1C and 1D that exhibit some details of the parts of this block diagram were provided by W. Dow who designed the array. The hydrophones were Clevite acceleration-compensated crystals installed in a castor oil-filled semi-rigid PVC housing. The housing was approximately 1/2 meter long. The hydrophone array consisted of 5 elements separated by neutrally buoyant dead sections 3 meters in length. Element diameter was 2 1/2 inches. There was a 5 inch tapered transition to the dead-section diameter of 2 inches. The output from each hydrophone element was fed to a pre-amplifier which was installed as part of the array assembly 3 meters from the first array element. As seen in Figure 1A and 1B there is a region where the diameter of the pre-amplifier case decreases over a short distance at the tow cable entry point.* The pre-amplifiers were essentially unity gain impedance transformers, designed to minimize pick-up problems in the transmission of the individual hydrophone signals from the array to the ship. An R-C high pass filter with the 3 db point at 15 cps was included in the pre-amplifier.

On board the ship, the signals were first passed through variable gain, broad-band amplifiers and then recorded on magnetic tape. A Crown 4-track high fidelity tape recorder was used. Recording speed was 7 1/2 cps. The complete system had a nominally flat frequency response from 20 cps - 15 kcps. Results of the actual calibration including the tape play-back equipment will be discussed in a later section.

The data was obtained with the array towed with the first element 600 feet behind the ship. Ship speed was varied from 0 to 12 knots in 2 kt steps. The speed was maintained to ±.25 kt during data recording. The sea was moderately calm with 1 - 3 foot swells. The data was recorded in the Atlantic Ocean on the Blake Plateau, roughly 150 miles SE of Charleston, S.C. The tow depth was close to the sea surface (5-20 meters).

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*In present seismic array designs the diameter and the places where diameter changes occur are reduced.

## DATA ANALYSIS

Selected portions of the data were digitized at the AVCO-RAD computation center, Wilmington, Mass. The analog tapes were played-back on an Ampex SP-300 tape machine. Analog signals were low pass filtered to eliminate aliasing (the folding down of signals above the Nyquist frequency into the frequency band of interest). The data conversion rate was 5 kcps per data channel. Three data channels were sampled sequentially at a total sampling rate of 15 KC. The aliasing filter was set with the corner at 2.25 kcps. The slope of rejection above this was 18 db/octave.

System calibration was performed by injecting a signal generator voltage at the input to the pre-amplifier by means of a resistor in series with the hydrophone. The results of the calibration, including the Ampex play-back electronics, is shown in Figure 2. The slight rise at the low end is attributed to a mismatch between tape recorder and tape play-back equalizations.

It should be noted that great care was taken to ensure that the calibration accuracy was maintained through the digitizing process.

The power spectra and coherency of the data samples were computed using an IBM 7090 digital computer. The power spectra were computed using standard techniques (Hannon, 1960). Smoothing was accomplished by use of the Daniell spectral window, described in the reference.

The coherency matrix of a group of signals was introduced in 1930 by N. Wiener in his classic paper on generalized harmonic analysis. The coherency coefficient of two signals is defined as the cross-power spectrum of the signals divided by the geometric mean of the two auto-power spectra. It is a complex number whose magnitude is restricted to lie between 0 and 1. Its magnitude represents the amount of linear coherency between the two signals, and its phase angle represents the phase lag of one signal with respect to the other. Since the coherency is a measure of the linear dependence of one signal on the other, it may be used to determine whether two signals arise from the same source.

## RESULTS

### Power Spectra

The results of the spectral analysis of the hydrophone flow noise obtained on R/V CHAIN Cruise 51 are presented in Figures 3 through 7. The spectra are computed with a sample length of 4500 points, representing 0.9 seconds of data. This relative signal level in db is plotted versus frequency over the range 20 - 500 cps. In Figures 3 through 5, the spectra are shown as a function of tow speed. Each of these figures pertains to a single hydrophone of the array. The principal results of examination of these spectra are the following:

1) The flow noise is strongest in the region below 100 cps. There is some evidence of a falloff below 30 cps. At 12 knots the low frequency peak is more than 30 db above the values at the high end of the spectrum.

2) The spectral peak is extremely sharp. The slope of the spectra in the range 60 - 120 cps is of the order of 20 - 25 db/octave. The slope is roughly the same at all speeds and on the three hydrophones.

3) An increase in ship speed is accompanied by an increase in noise power and broadening of the low frequency peak. The increase in flow noise over various speed changes and at various frequencies is tabulated in Table I.

# TABLE I

## Increase in Flow Noise (db) with Increase in Tow Speed

### Hydrophone 2

| Frequency | Increase in tow speed 2-12 kts | 4-12 kts | 6-12 kts | 8-12 kts | 10-12 kts |
|---|---|---|---|---|---|
| 25 cps | 17 db | 11 db | 16 db | 7 db | 0 db |
| 50 | 24 | 17 | 24 | 14 | 6 |
| 100 | 15 | 18 | 18 | 15 | 6 |
| 200 | 5 | 10 | 5 | 5 | 4 |
| 400 | 0 | 4 | 0 | 2 | 0 |

### Hydrophone 3

| Frequency | Increase in tow speed 2-12 kts | 4-12 kts | 6-12 kts | 8-12 kts | 10-12 kts |
|---|---|---|---|---|---|
| 25 cps | * | 11 db | 11 db | 7 db | 3 db |
| 50 | - | 17 | 18 | 10 | 3 |
| 100 | - | 13 | 13 | 13 | 2 |
| 200 | - | 7 | 5 | 5 | 0 |
| 400 | - | 4 | 0 | -1 | -4 |

### Hydrophone 4

| Frequency | Increase in tow speed 2-12 kts | 4-12 kts | 6-12 kts | 8-12 kts | 10-12 kts |
|---|---|---|---|---|---|
| 25 cps | 9 db | 18 db | 14 db | 6 db | 4 db |
| 50 cps | 18 | 25 | 21 | 8 | 4 |
| 100 cps | 16 | 20 | 17 | 16 | 7 |
| 200 cps | 7 | 7 | 7 | 7 | 3 |
| 400 cps | 0 | 5 | 0 | 0 | 2 |

* 2-knot data unavailable

The increase in noise power is larger at the low frequencies and is actually greatest in the region of the sharp drop in energy just above the peak. Although the three hydrophones exhibit similar behavior, there are differences and what seem to be inconsistencies in the data which illustrate the large changes in signal character with time. These changes are discussed further in a later section.

The variation in flow noise spectra among the three hydrophones analyzed at a particular speed is illustrated in Fig. 6 for 8 knots and Fig. 7 for 10 knots. For each speed, the difference between hydrophones is a function of frequency and varies in level from 0 up to about 7 db.

## Spectral Variations with Time

Flow noise variations with time were studied by means of computed running spectra, or sonograms. For this a power spectrum is computed for a short data sample. Then the spectrum is computed for the adjacent sample. This process is continued resulting in a series of power spectra which, when plotted together, form a frequency spectra vs. time plot. It is usual to overlap adjacent spectra to provide smoothing.

Frequency-time analysis was performed on the hydrophone 3 signal. Ship speed for the data section was 12 knots. The spectra were computed over the range 0 - 500 cps (in 10 cps bands) for 0.2 second samples. The overlap used was 10 percent, i.e., for each computation the data sample shifted .02 seconds.

The results are shown in Figure 8. For frequencies of 50, 100 and 200 cps the noise power is plotted in db below the peak 50 cps power as a function of time. Two observations stand out: First, the noise power varies widely, up to 20 db, over short time intervals. Second, as might be expected, the excursions are greater at the lower frequencies. In addition there does not appear to be much correlation between the power level variations at the three separate frequencies.

# COHERENCY

The coherency of the flow noise signals recorded from the three hydrophones were computed for all ship speeds. These results are shown in Figures 9 through 14. The coherency for each 2 knot speed increment is plotted as a function of frequency for three hydrophone pairs: 2-3 and 3-4, separation 3 meters; and 2-4 separation 6.5 meters.

The principal observations are the following:

1. The signals are virtually incoherent ($\rho < .5$) in the vicinity of the low frequency flow noise peak.

2. As speed increases, the frequency range over which the signals are incoherent increases. Considering hydrophone pair 3-4, at 2 knots, the coherency is less than .5 for frequencies below 100 cps. At 8 knots the coherency is less than .5 for frequencies below 300 cps and at 12 knots, 420 cps. In all cases, the power density in the region where the signals are coherent ($\rho > .8$) is 30-40 db below the power density peak where the signals are incoherent.

3. There is no decrease in coherency with increasing hydrophone separation.

4. The coherency curves for two different hydrophone pairs at identical separations are very similar; and in turn are similar to the curve for the long separation pair.

It is felt that the shape of the coherency curve illustrates two different noise sources. The low frequency, incoherent signals, are the result of flow noise generated by turbulence in the vicinity of the individual hydrophones; this noise field is propagated with a velocity much less than that of sound. The high frequency, highly coherent noise is true sound of remote origin, in all likelihood, ship generated. As the tow speed is increased, the flow generated noise gradually swamps out more of the noise from the remote sources.

## CONCLUSIONS

The following conclusions are based on the above analysis of Woods Hole Oceanographic Institution R/V CHAIN, Cruise 51 data. We feel that they are generally applicable to towed hydrophone arrays. It should be expected that variations in the flow noise power spectrum will be encountered among different array configurations.

The power spectrum of the noise is strongly peaked and the peak occurs at a frequency below 100 cps. This peak is attributed to turbulent flow in the immediate vicinity of the hydrophone element. The power in a narrow band varies widely as a function of time, especially in the region of the flow noise peak. The amplitude of the peak and its bandwidth are strong functions of ship speed. This result is in qualitative agreement with the theory of boundary layer flow noise (Shudrzyk and Hadde, 1963).

The low frequency flow noise observed on two elements along a hydrophone array is uncorrelated at ship speeds of four knots or more. At frequencies in the band 200 to 500 cps, which is above the flow noise peak, and at tow speeds of up to 8 knots, the signals on two hydrophones are correlated, suggesting a remote source. However, the noise power in this portion of the sprectrum is quite low. At tow speeds of 10 and 12 knots the signals were uncorrelated throughout the frequency band studied.

It is plausible, although uncertain, that flow noises received on hydrophones generated at the array undergo a fluctuating destructive interference from their sea surface reflections for certain frequency ranges dependent on tow depth.* Signals in a near fade condition tend to be incoherent and are known to fluctuate greatly in amplitude. It is likely that array depth decreases with ship speed and therefore, in view of the above, the observed increase in the frequency range of incoherence between hydrophone pairs with increase in ship speed might be related to this circumstance. Further study of this possibility is warranted.

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*Conjecture advanced is offered only by one of us (Beckerle).

## ACKNOWLEDGMENTS

The authors wish to acknowledge the guidance of Dr. J. B. Hersey.

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Hannon, E. J., Time Series Analysis (Methuen and Co., London 1960).

Shrudrzyk, E. J. and G. P. Hadde, Flow Noise, Theory and Experiment in V. M. Albers (ed.), Underwater Acoustics (Plenum Press, New York 1963) Chapter 14.

## LIST OF FIGURES

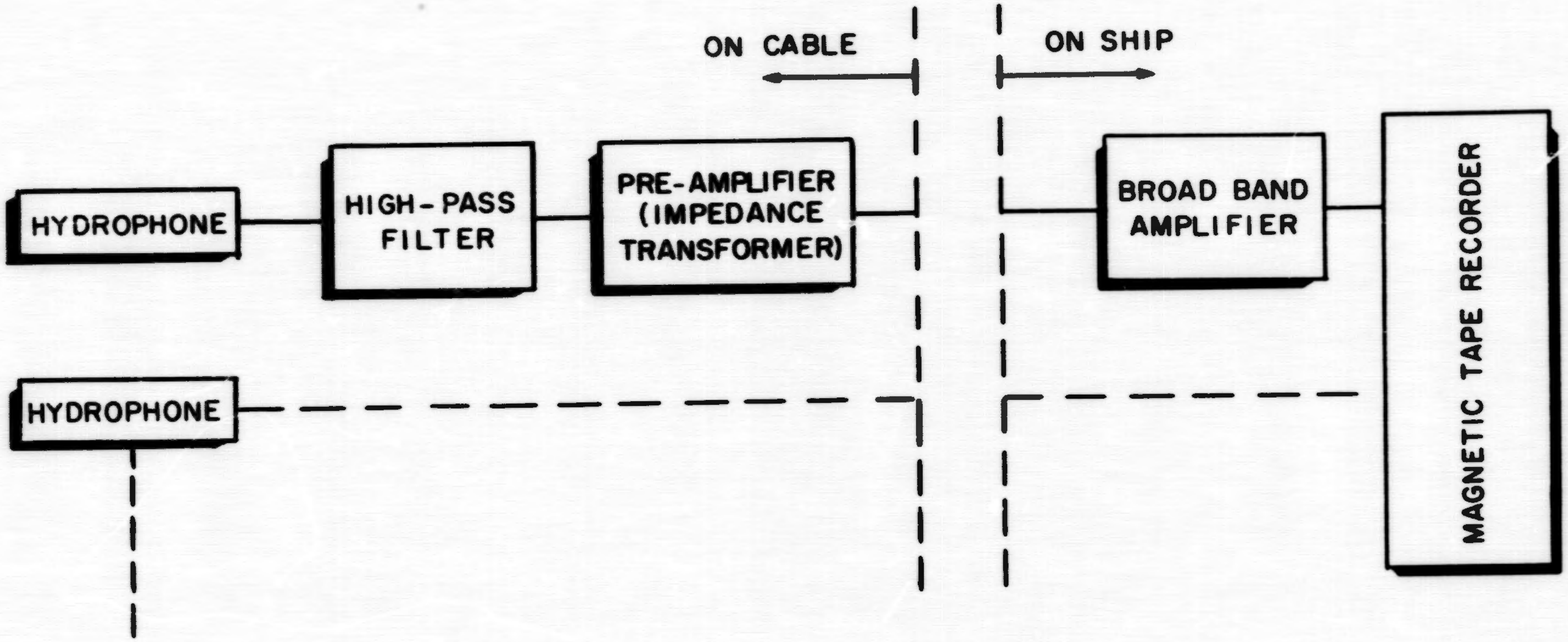

Fig. 1 System Block Diagram

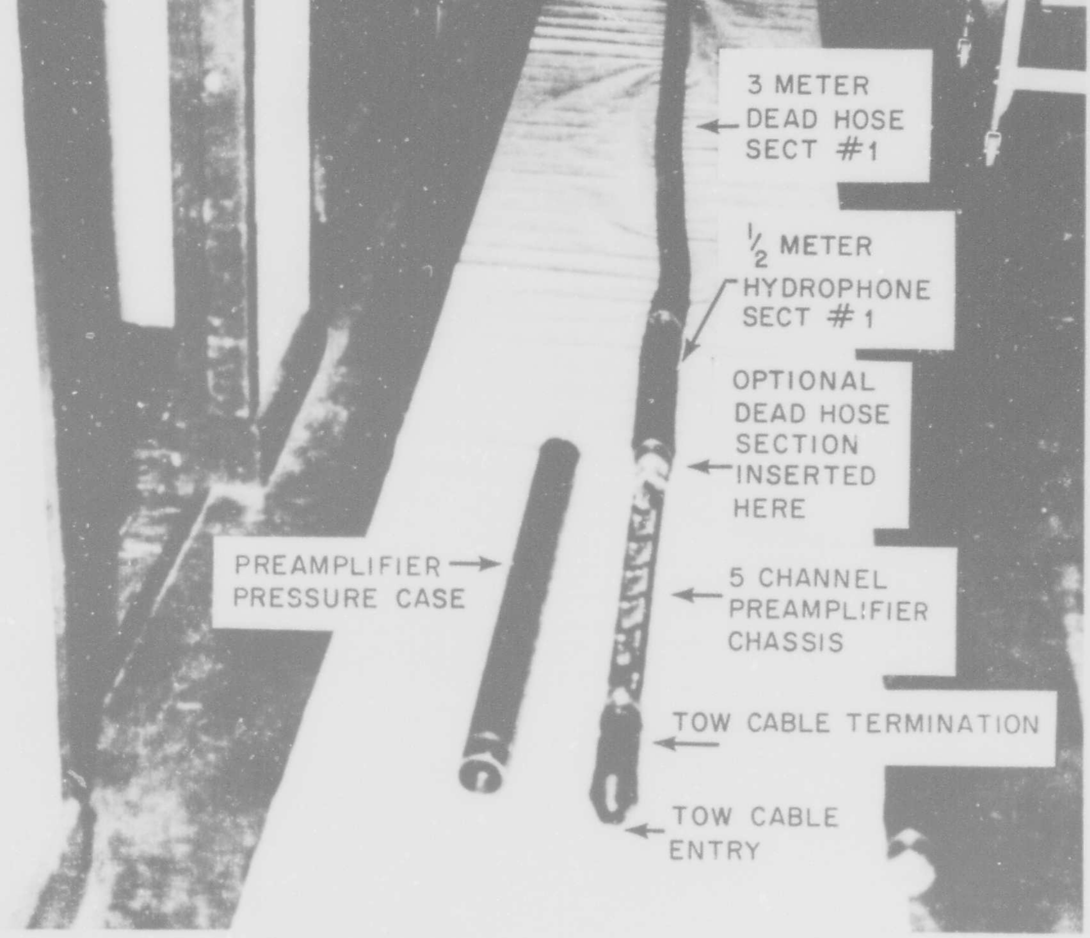

Fig. 1A Portion of Array

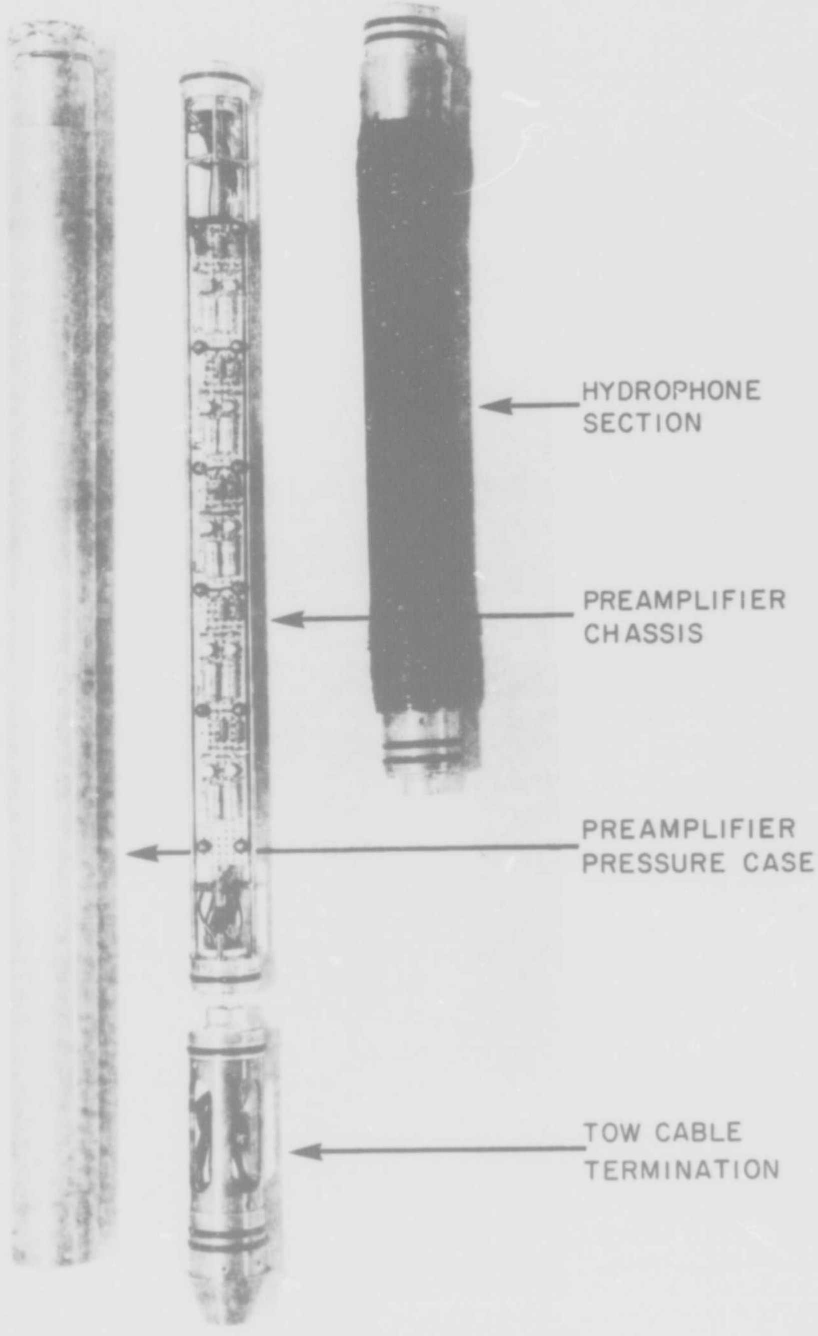

Fig. 1B Hydrophone Section and 5 Channel Preamplifier

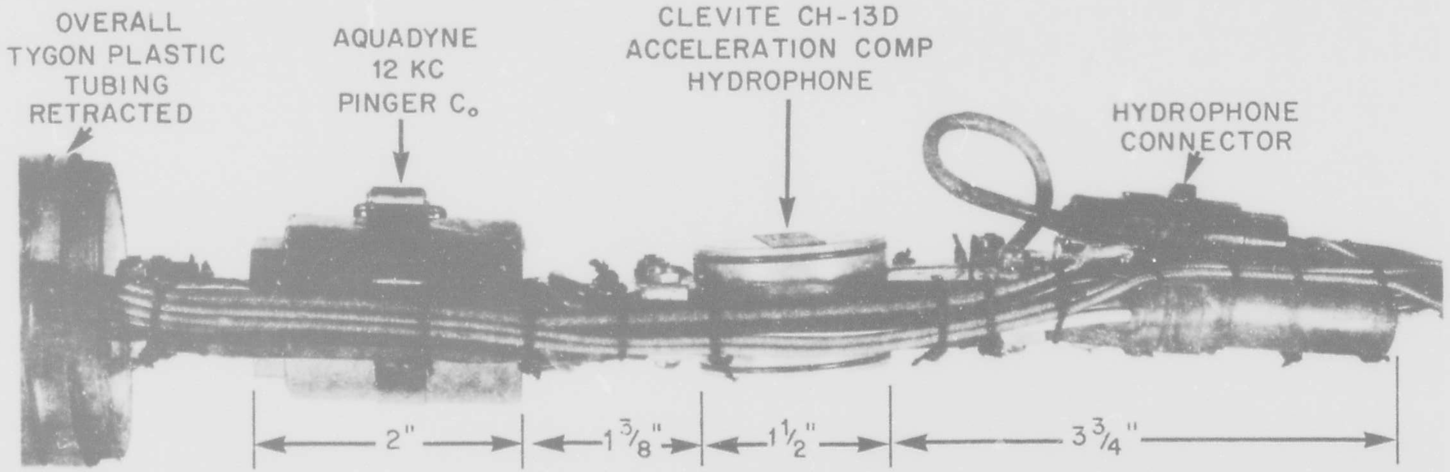

Fig. 1C Detailed Photo of Hydrophone Unit

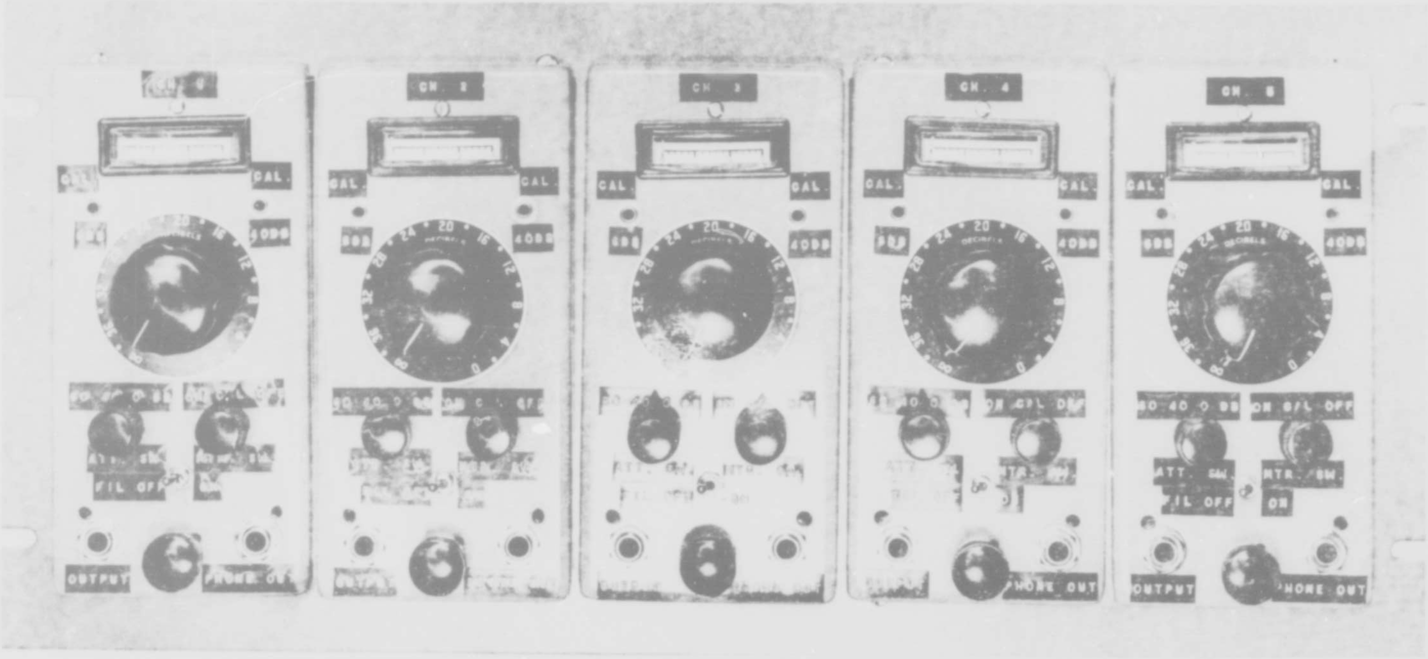

Fig. 1D Broad Band Amplifiers on Ship

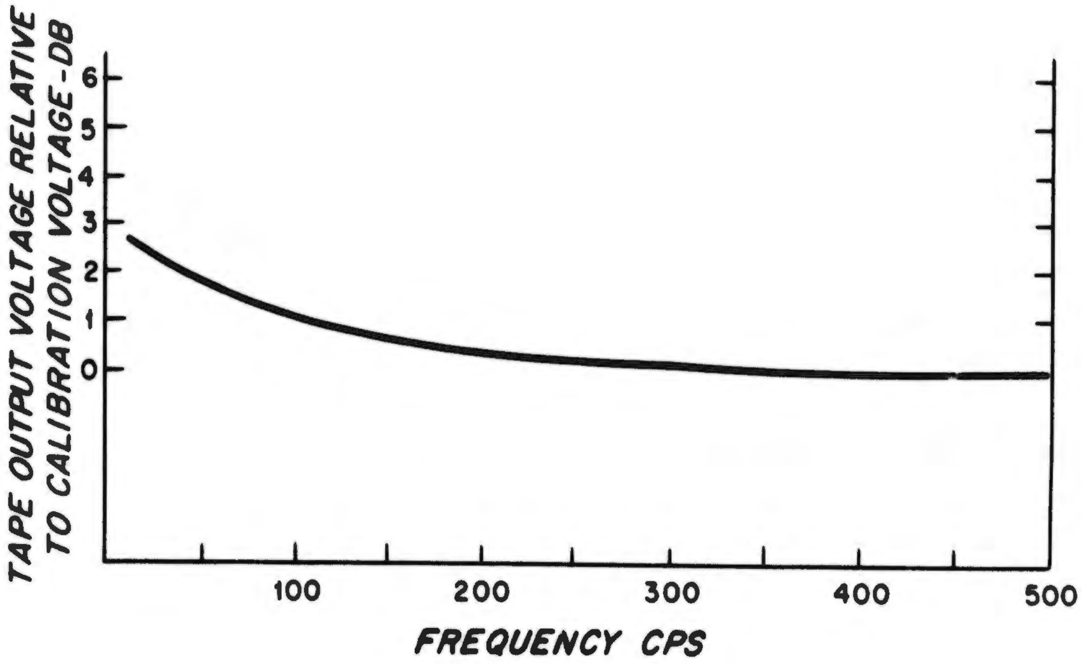

Fig. 2 System Calibration

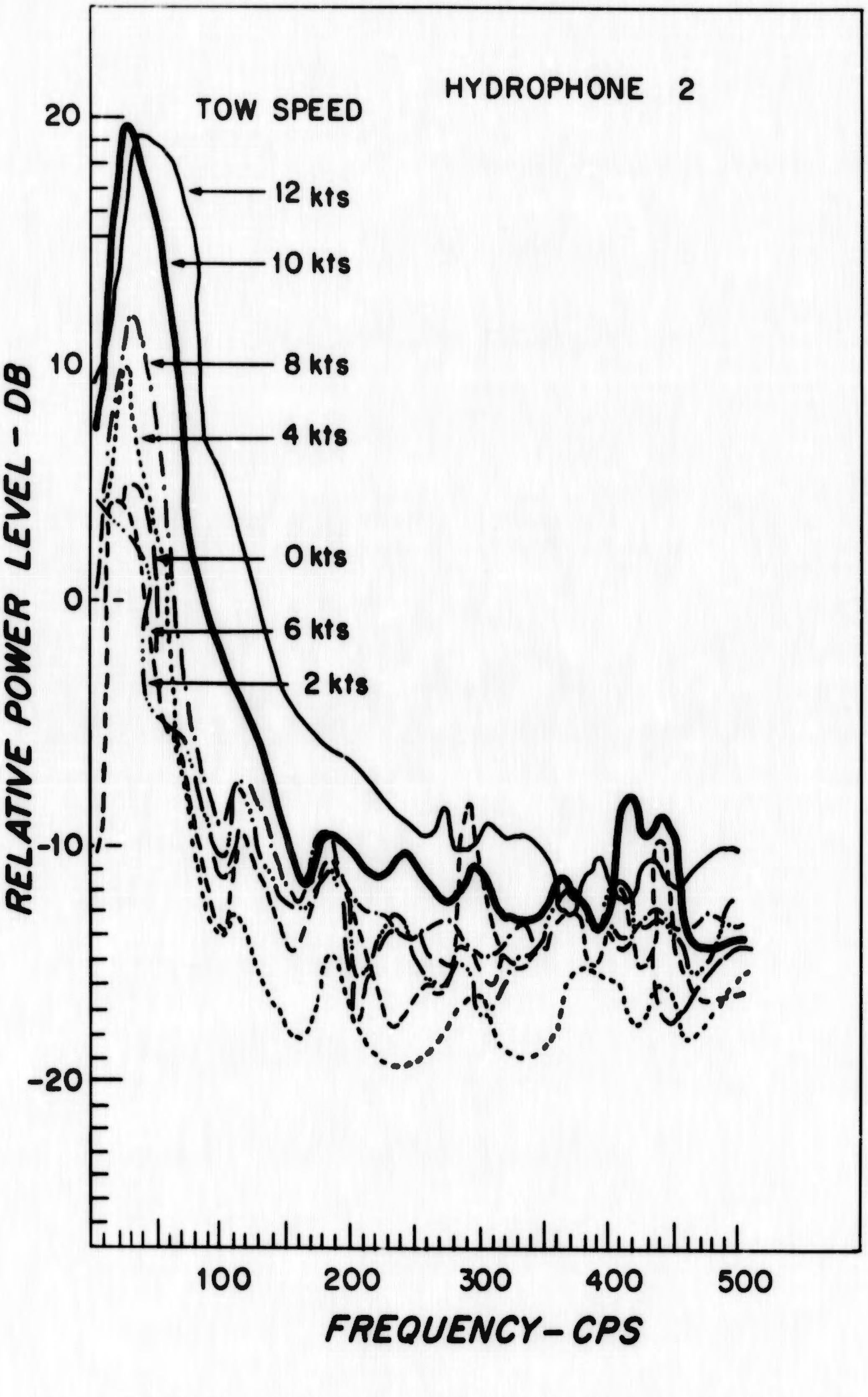

Fig. 3 Hydrophone Noise Power Spectra for Various Tow Speeds, Hydrophone No. 2

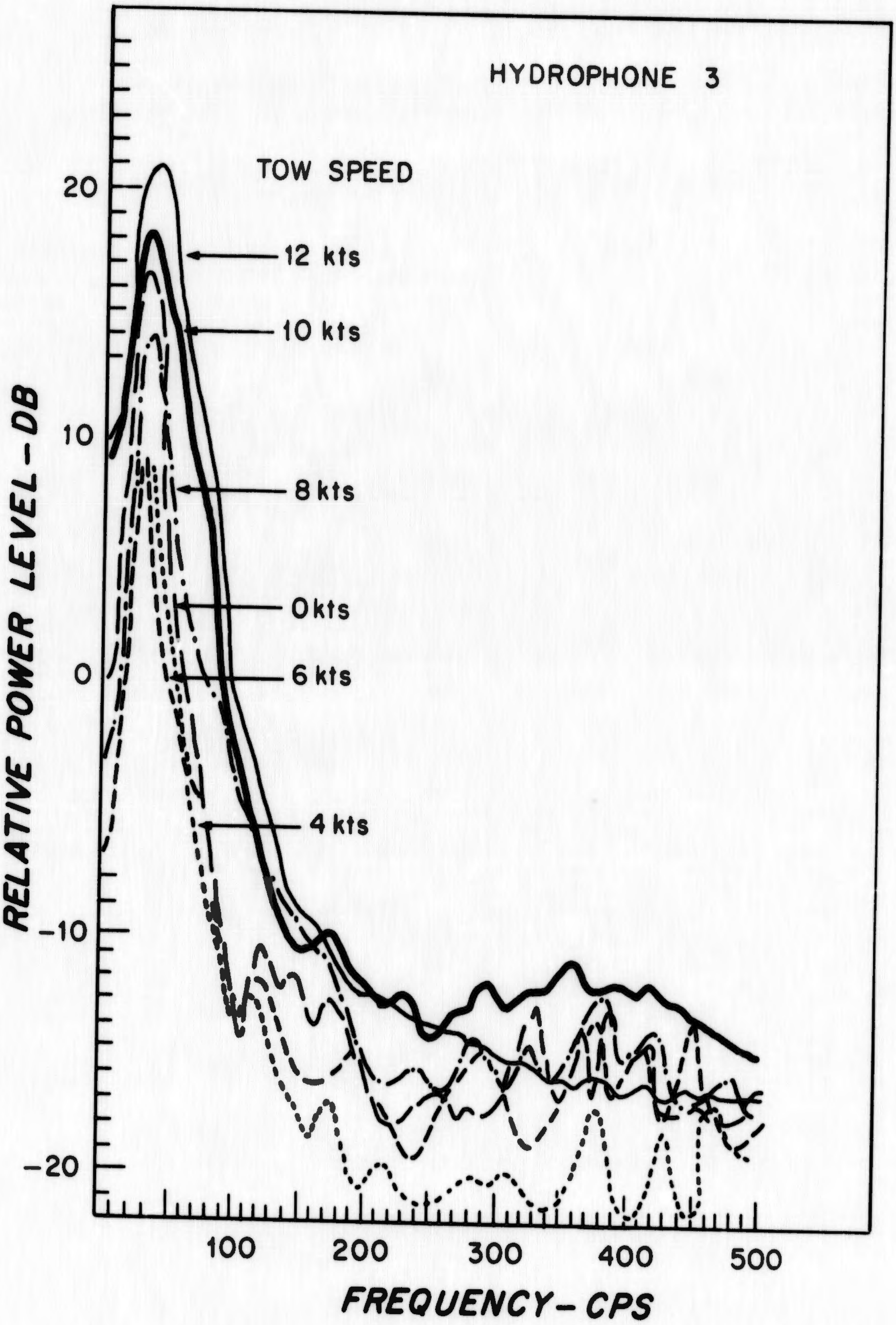

Fig. 4 Hydrophone Noise Power Spectra for Various Tow Speeds, Hydrophone No. 3

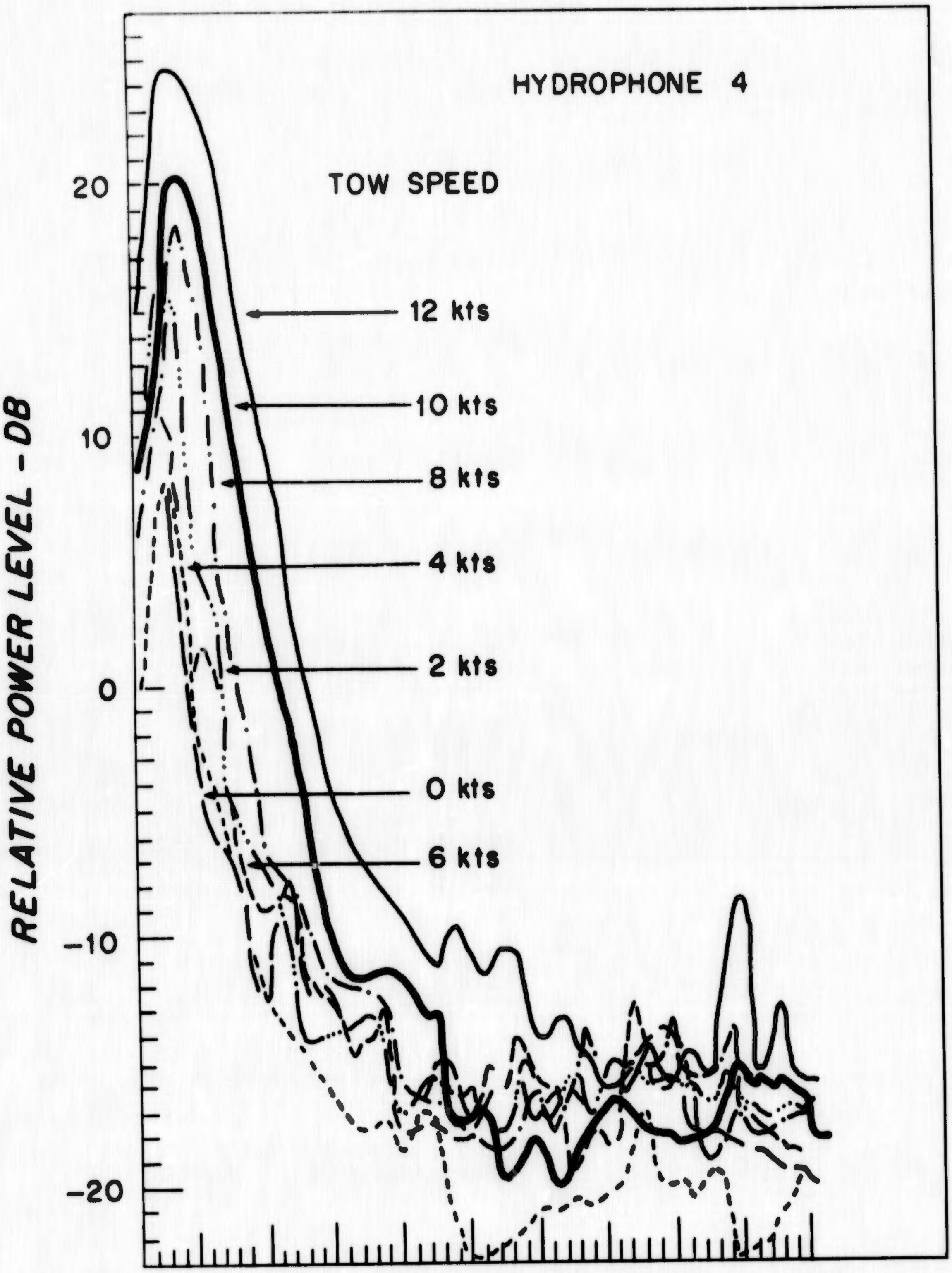

Fig. 5 Hydrophone Noise Power Spectra for Various Tow Speeds, Hydrophone No. 4

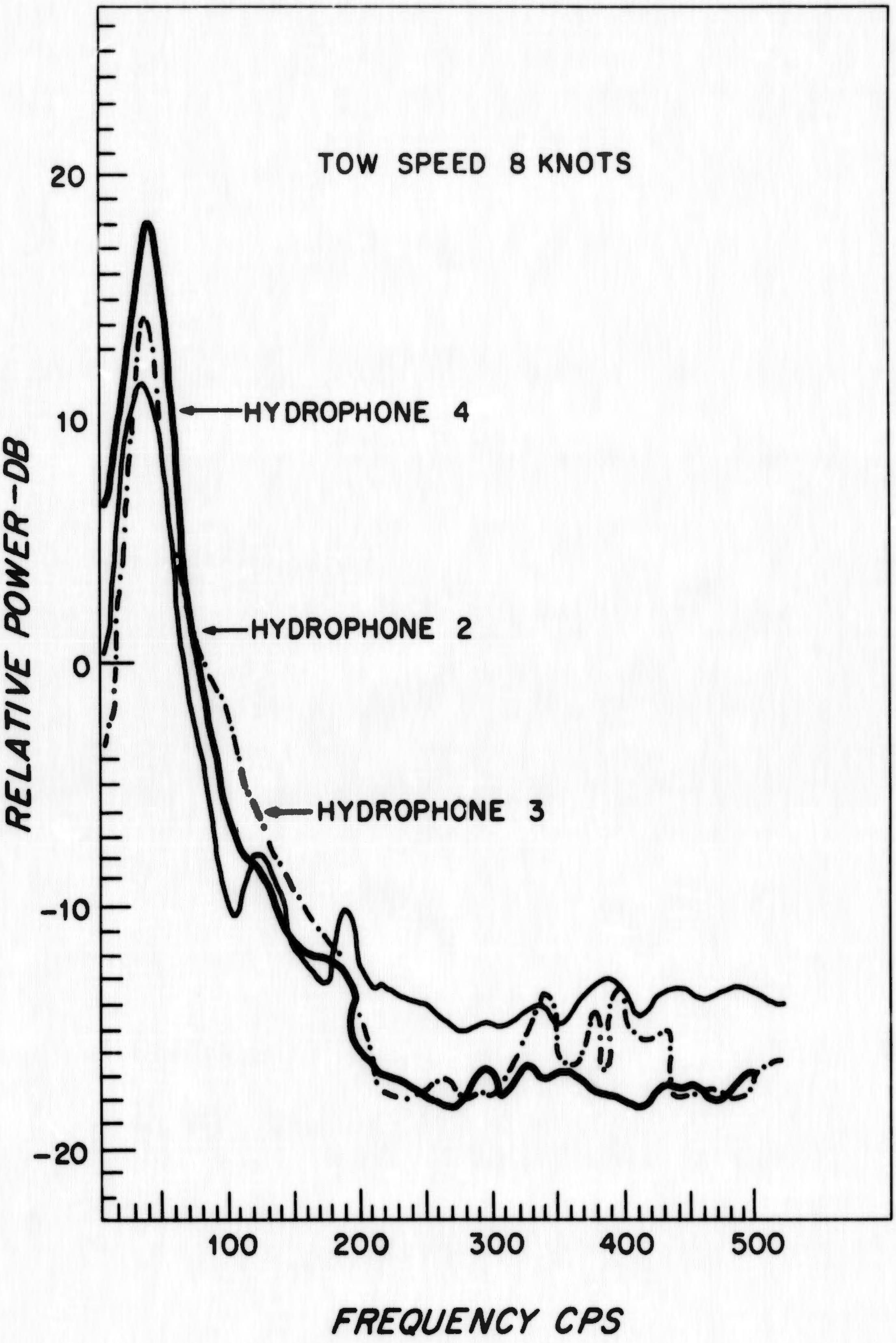

Fig. 6 Hydrophone Noise Power Spectra for Three Hydrophones, Speed 8 Knots

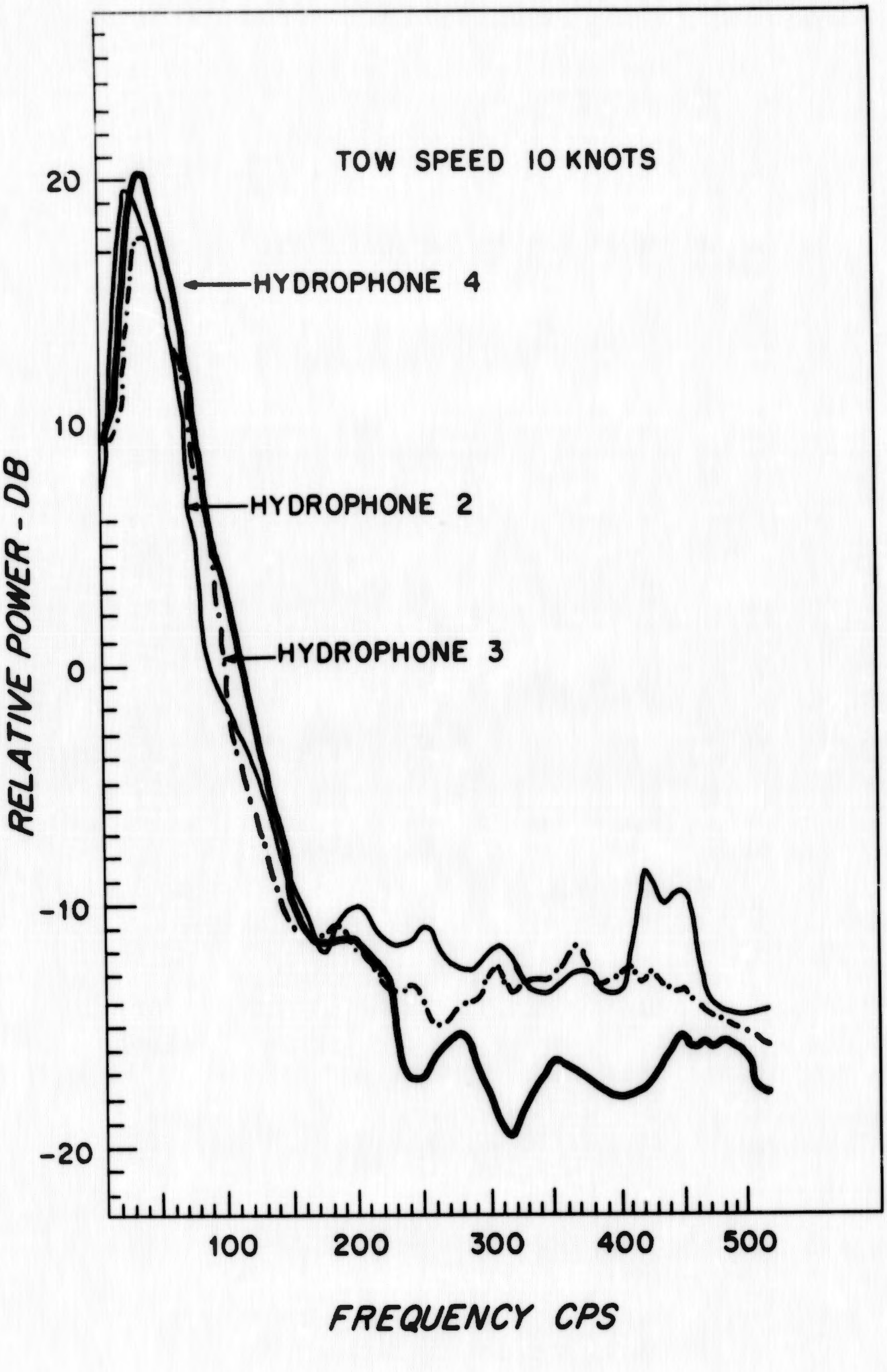

Fig. 7 Hydrophone Noise Power Spectra for Three Hydrophones, Speed 10 Knots

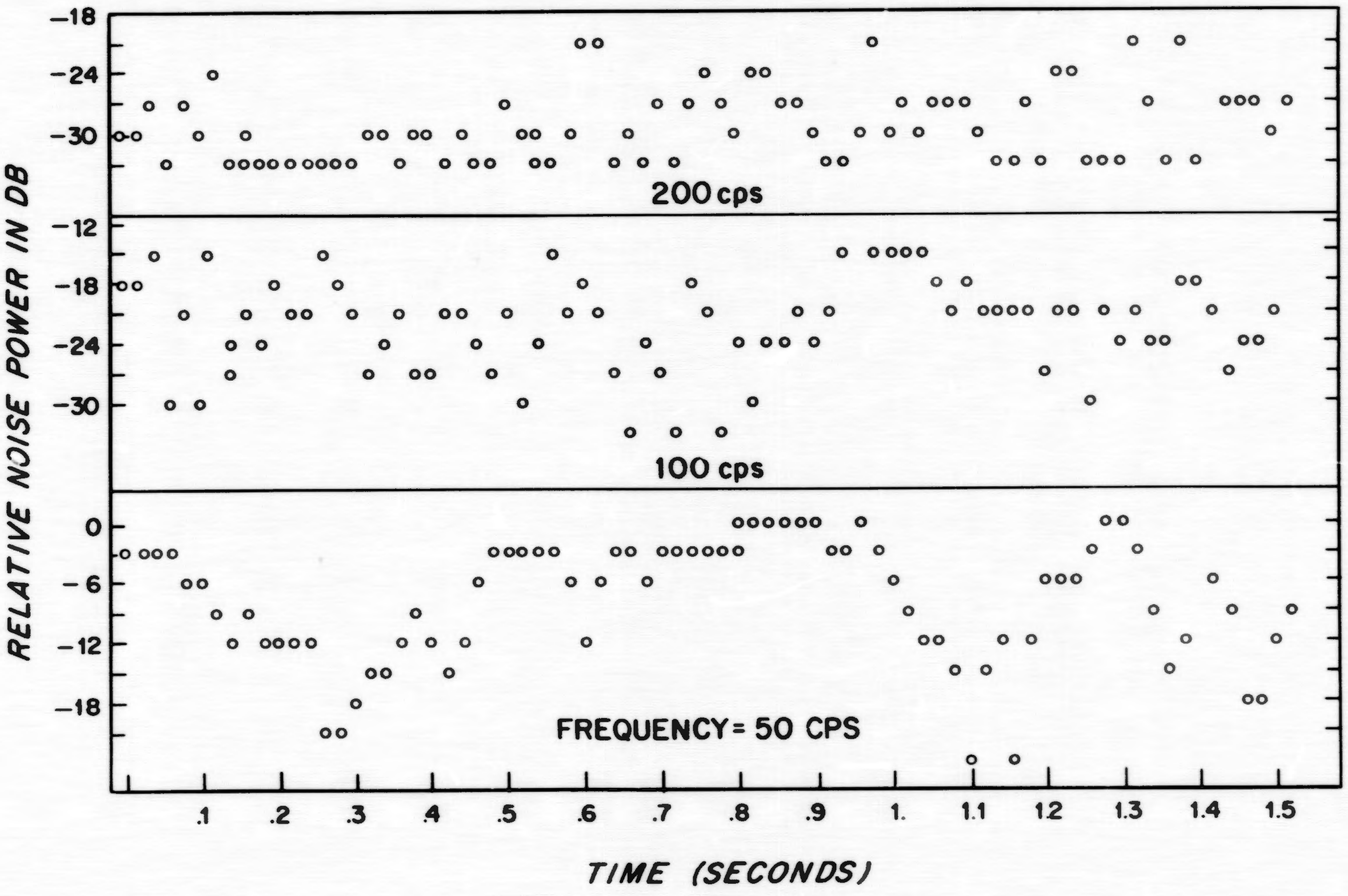

Fig. 8 Variation of Flow Noise Power vs Time for Three Frequencies

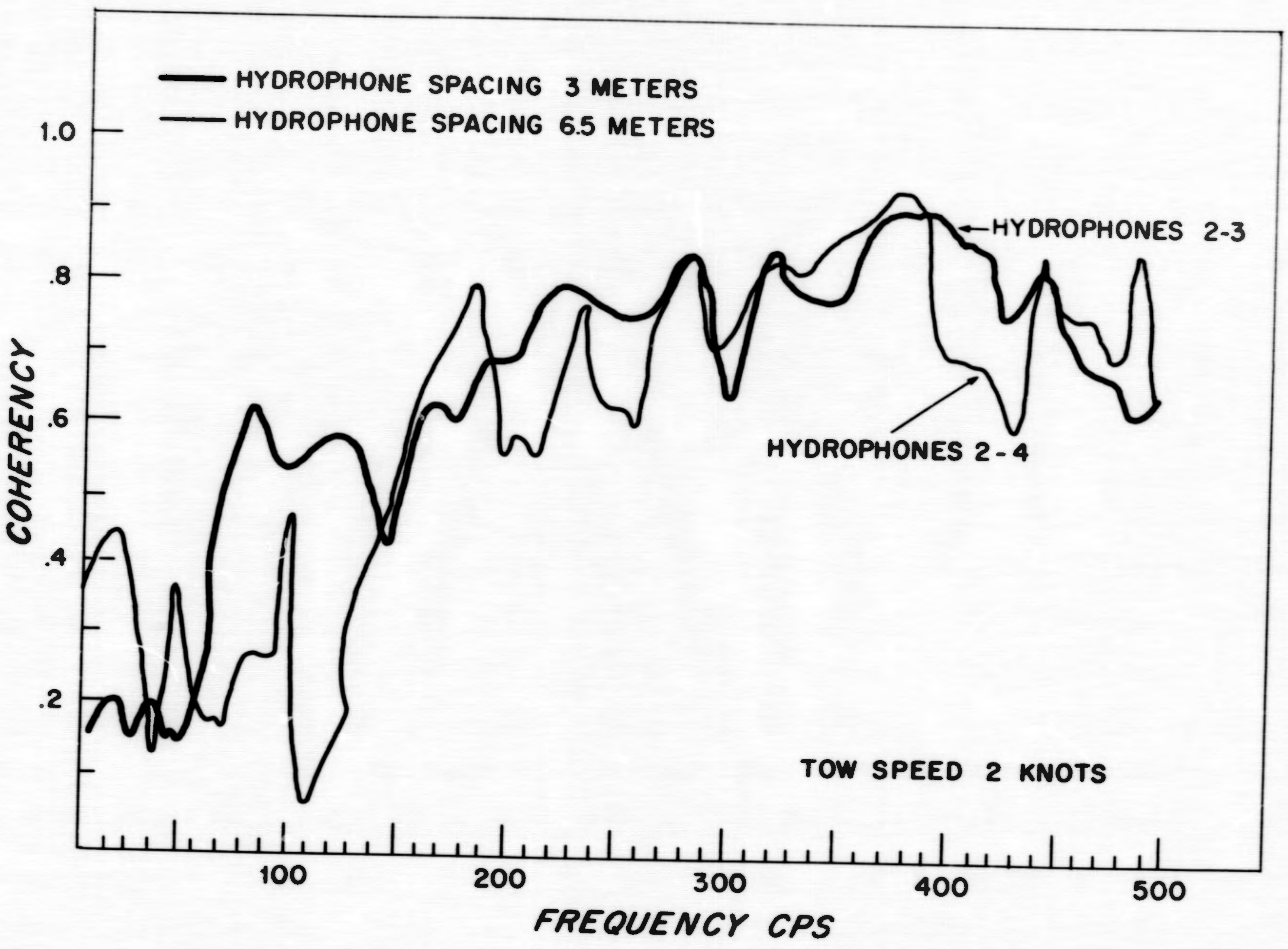

Fig. 9 Coherency between Hydrophone Pairs. Tow Speed - 2 Knots

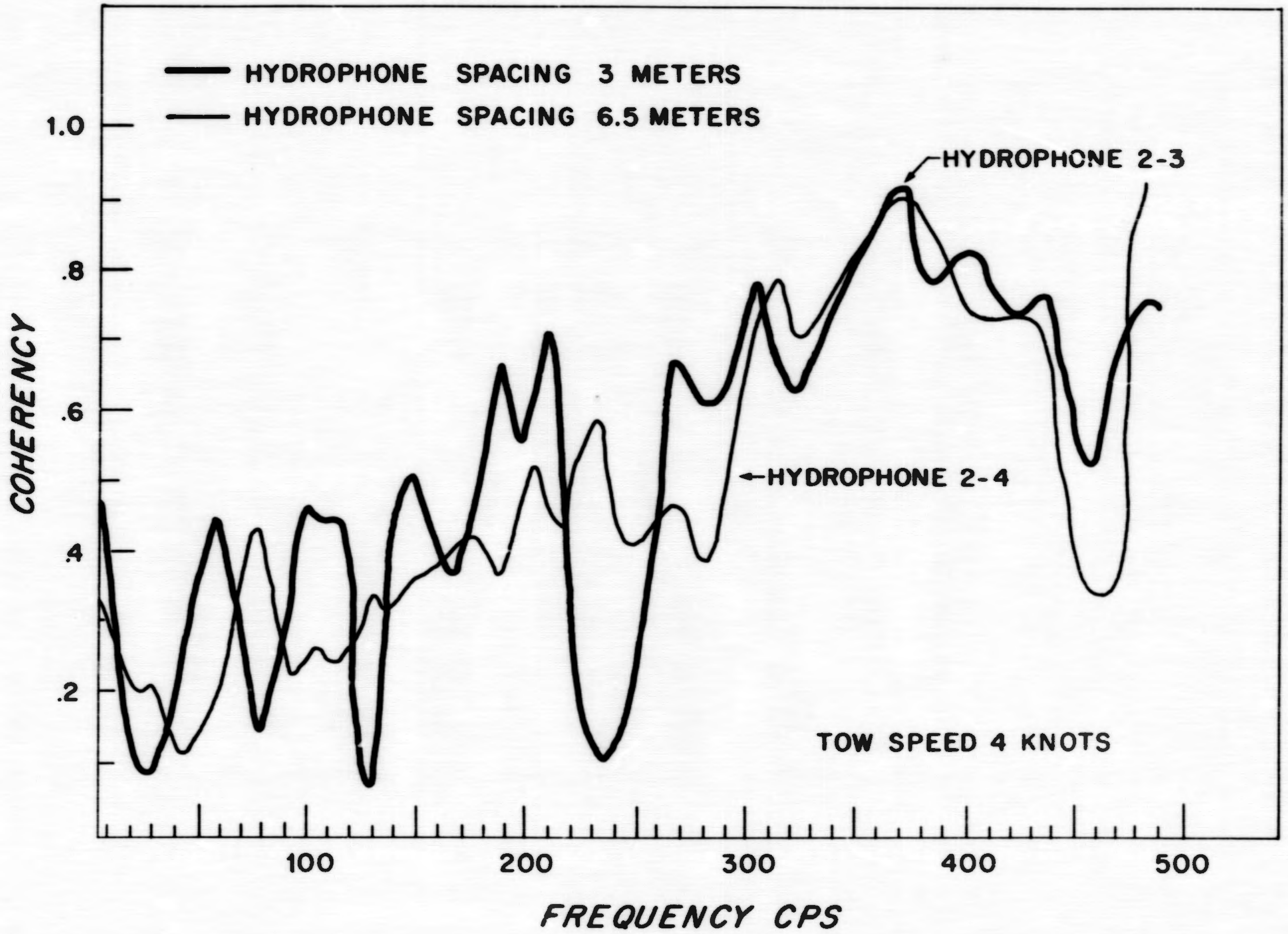

Fig. 10 Coherency between Hydrophone Pairs. Tow Speed - 4 Knots

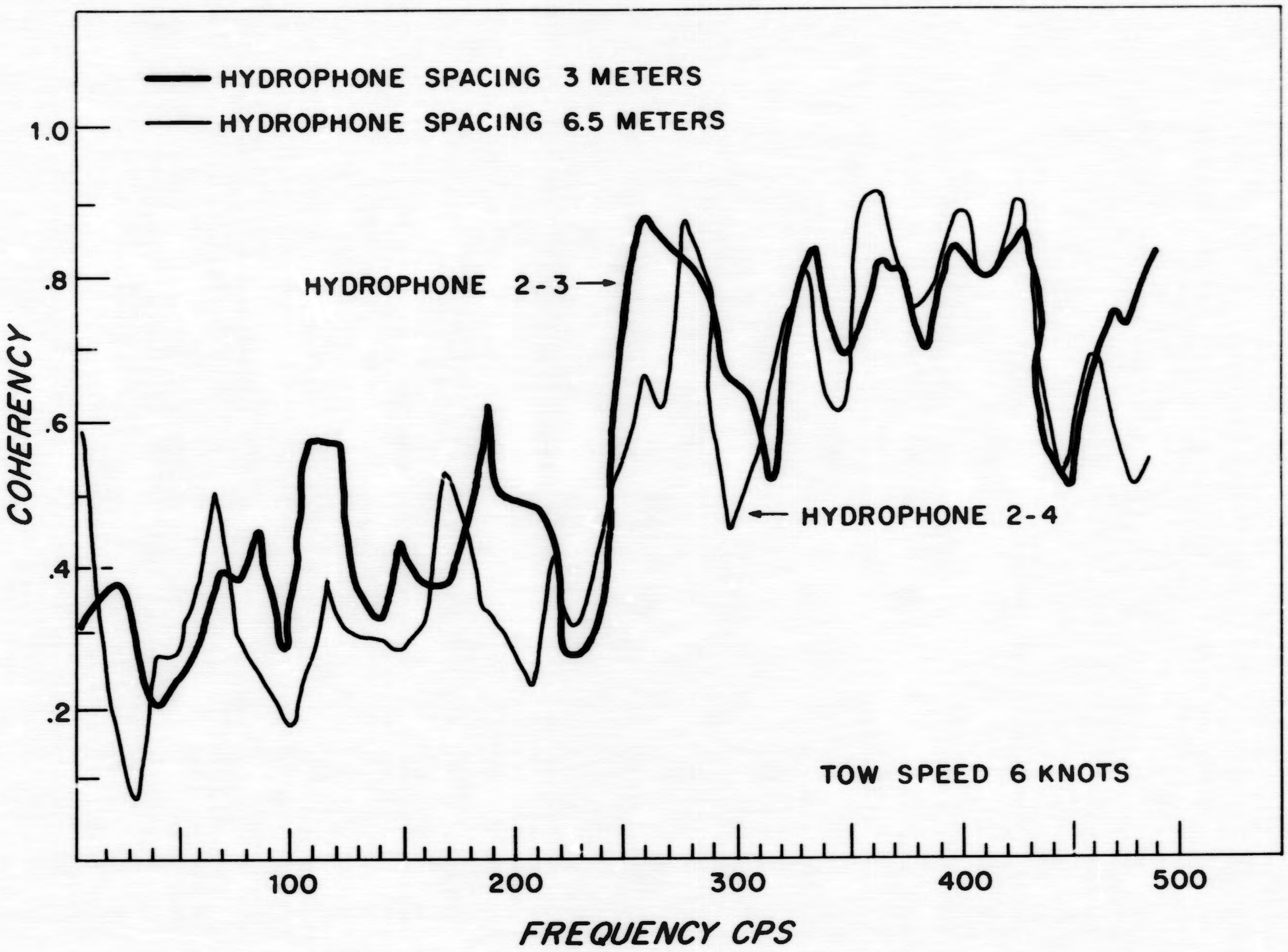

Fig. 11 Coherency between Hydrophone Pairs. Tow Speed - 6 Knots

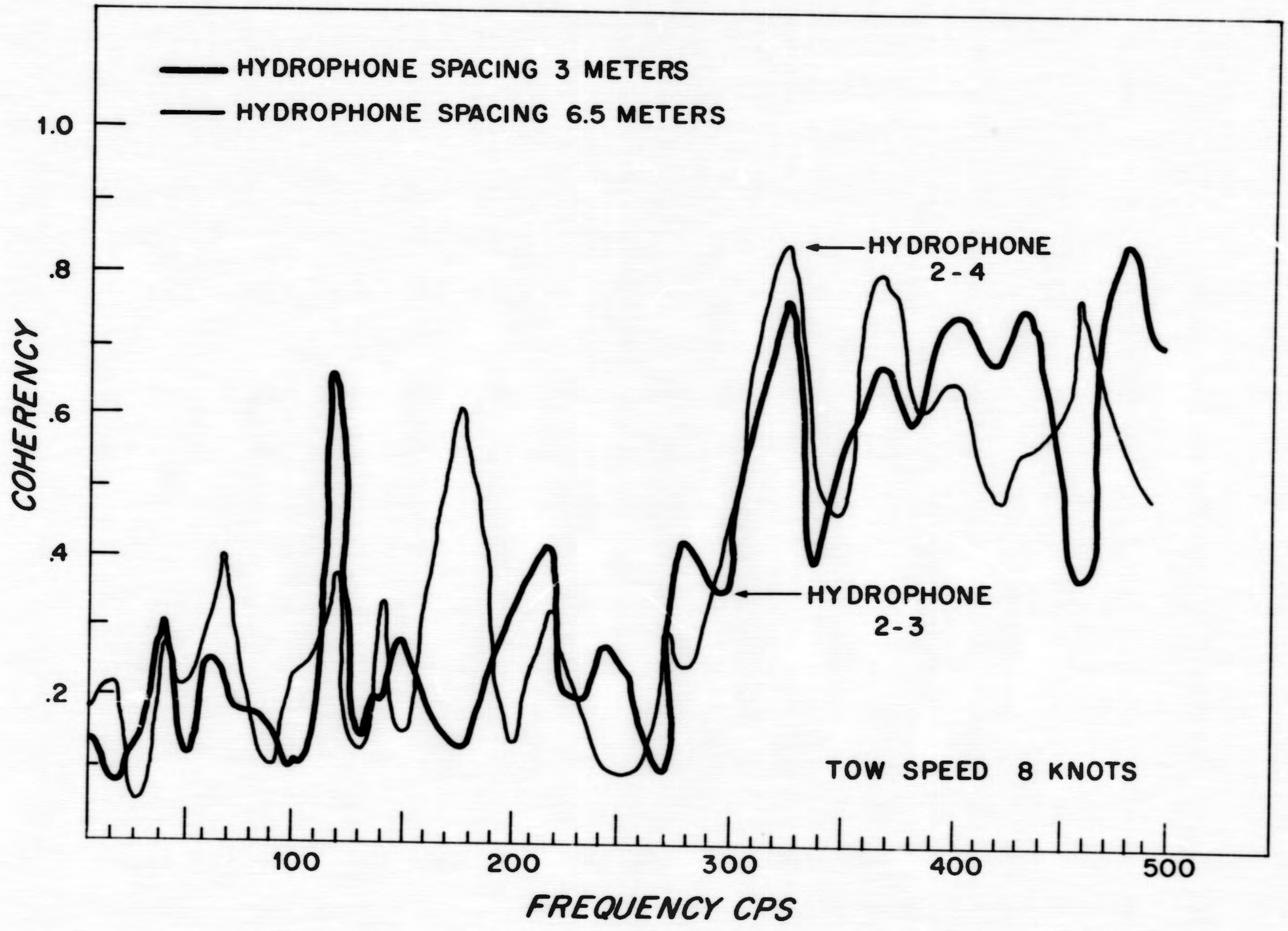

Fig. 12 Coherency between Hydrophone Pairs. Tow Speed - 8 Knots

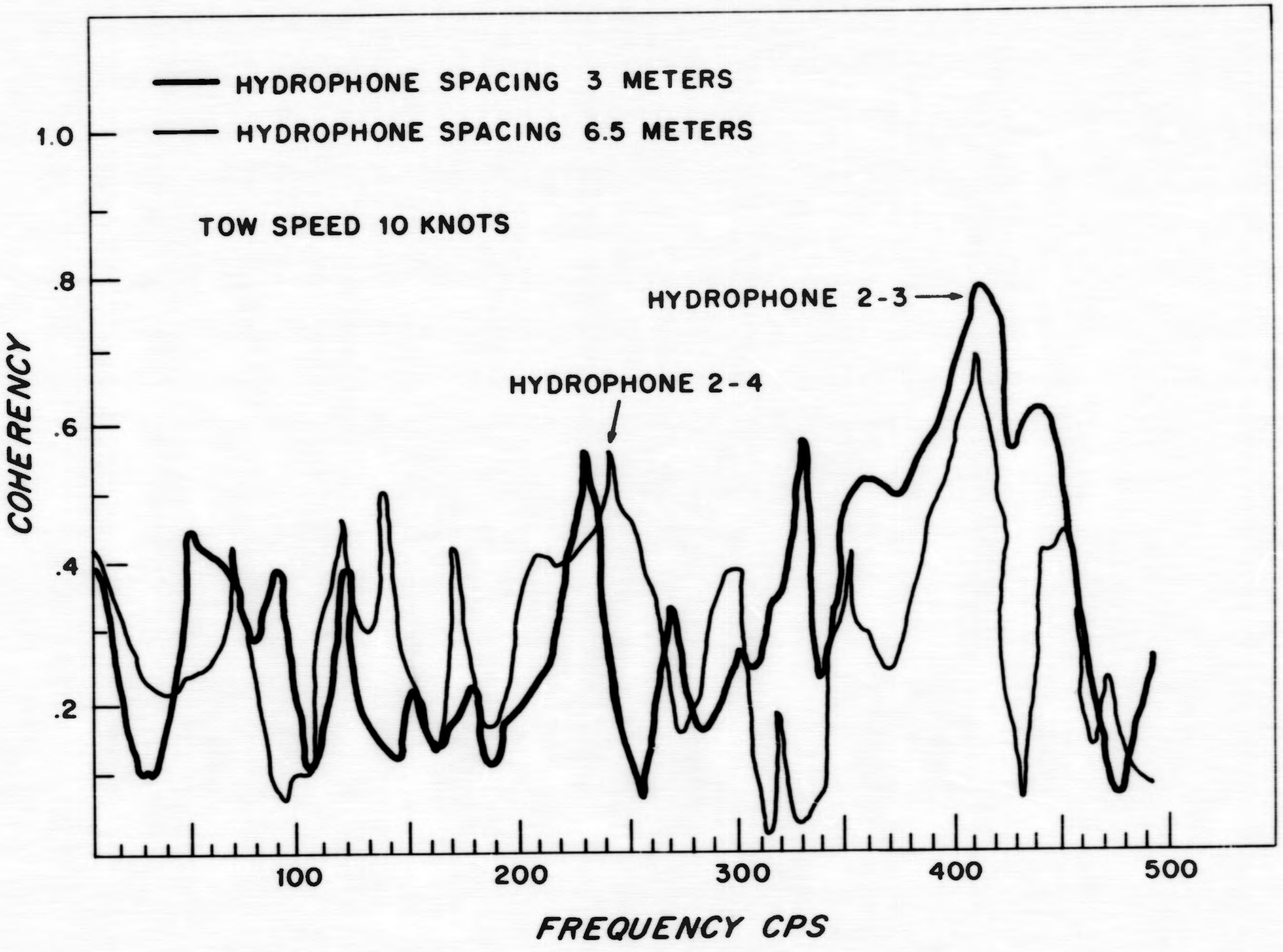

Fig. 13 Coherency between Hydrophone Pairs. Tow Speed - 10 Knots

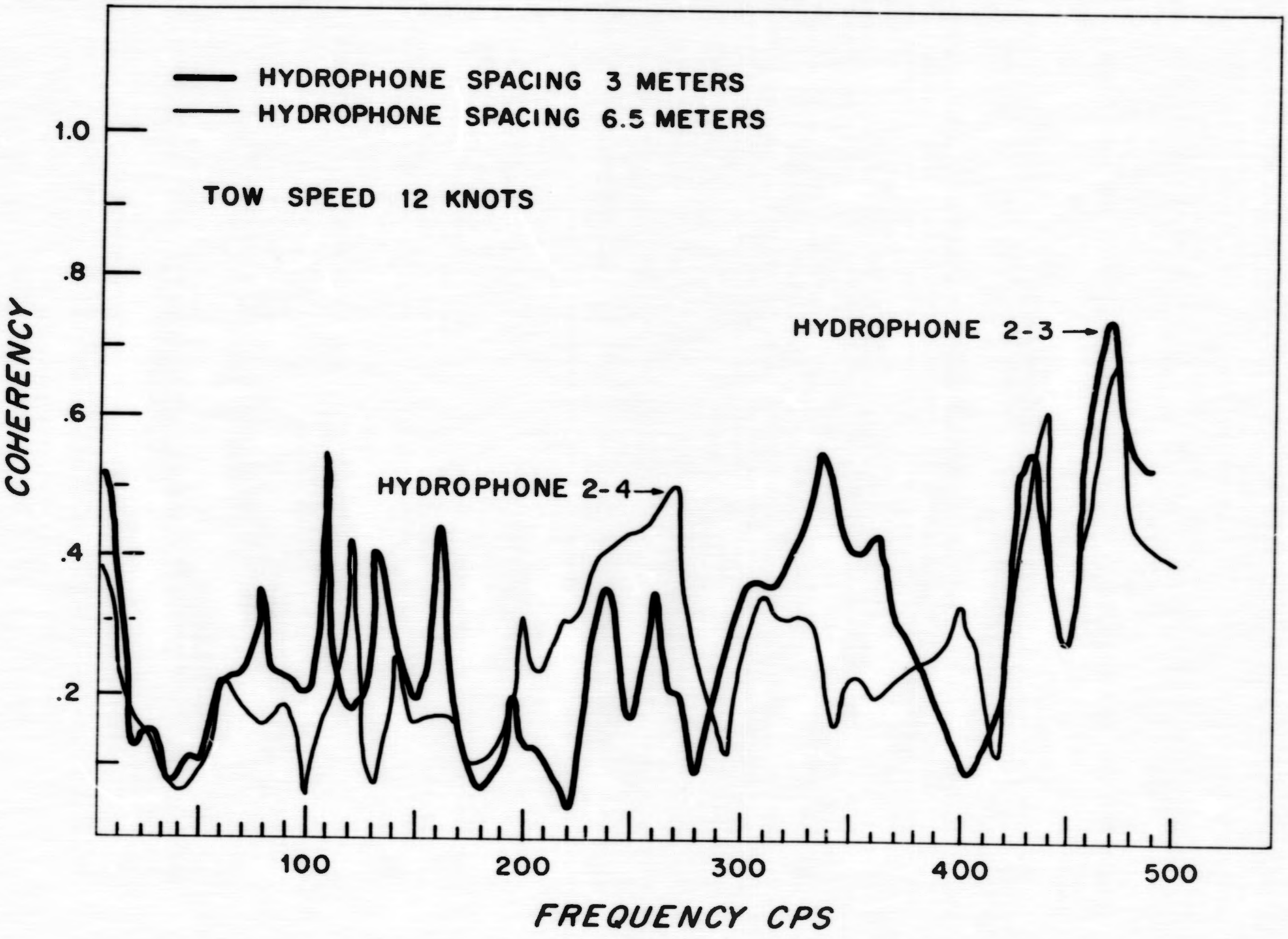

Fig. 14 Coherency between Hydrophone Pairs. Tow Speed - 12 Knots

Unclassified

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## DOCUMENT CONTROL DATA - R&D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

1 ORIGINATING ACTIVITY (Corporate author)

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

2a REPORT SECURITY CLASSIFICATION

Unclassified

2b GROUP

3 REPORT TITLE

ANALYSES OF TOWED HYDROPHONE FLOW NOISE

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5 AUTHOR(S) (Last name, first name, initial)

Beckerle, J. C., Orange, A., and Woznick, B.

6 REPORT DATE

November 1970

7a TOTAL NO. OF PAGES

10 pp.,14 figures

7b NO. OF REFS

8a CONTRACT OR GRANT NO.

ONR N00014-70-C0205; NR 263-103

b PROJECT NO.

c

d

9a ORIGINATOR'S REPORT NUMBER(S)

WHOI REF. NO. 70-56

9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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|---|---|---|---|---|---|---|
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| 2. Towed Array |  |  |  |  |  |  |
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