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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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FLOW NOISE ASSOCIATED WITH
MINE HUNTING SONAR, (U)

by

(10) Jerome Goodman

(11)

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ABSTRACT

(C) Current mine hunting sonar systems operating at a maximum speed of six knots do not suffer degradation of function due to flow noise. An attempt has been made to operate a riverine, mine hunting sonar system at speeds up to 15 knots. At approximately 10 knots the sonar system is unable to receive any return signal due to excessive flow noise.

(C) An investigation of the sonar system design and of the possible flow noise mechanisms indicated that turbulent boundary layer noise was secondary in magnitude to cavitation noise. Cavitation noise was excessive at about 100 kHz because of the transducer housing design and because of the stabilized bubbles in the sonar environment. Analysis of proposed transducer bodies indicated some design deficiencies in cavitation retardation.

(U) A program to study and to improve the flow noise situation in proposed mine hunting sonar systems is outlined. In addition to transducer body design a method of analyzing high frequency noise is discussed.

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ABSTRACT

(C) Current mine hunting sonar systems operating at a maximum speed of six knots do not suffer degradation of function due to flow noise. An attempt has been made to operate a riverine, mine hunting sonar system at speeds up to 15 knots. At approximately 10 knots the sonar system is unable to receive any return signal due to excessive flow noise.

(C) An investigation of the sonar system design and of the possible flow noise mechanisms indicated that turbulent boundary layer noise was secondary in magnitude to cavitation noise. Cavitation noise was excessive at about 100 kHz because of the transducer housing design and because of the stabilized bubbles in the sonar environment. Analysis of proposed transducer bodies indicated some design deficiencies in cavitation retardation.

(U) A program to study and to improve the flow noise situation in proposed mine hunting sonar systems is outlined. In addition to transducer body design a method of analyzing high frequency noise is discussed.

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INTRODUCTION (U)

(U) Mine-hunting sonar systems are used for the detection and classification of mines located in shallow coastal waters, in rivers, and in harbors. The size of the targets and the system resolution required for accurate detection and classification has necessitated the use of acoustic frequencies far above those found in conventional sonar systems. In addition, the information rate limitations of the mine-hunting sonar systems were such that the vessels carrying the sonar systems rarely exceeded a speed of 6 or 7 knots to obtain satisfactory results. Thus far the fortuitous combination of high frequency and low speed was not plagued by any of the flow-noise problems that have served to deteriorate the performance of the more numerous conventional types of shipboard sonars. However, with the advent of large scale integrated circuitry and digital signal processing, it is possible to substantially increase the information rate of mine-hunting sonars. To take advantage of the improved information rate, the mine-hunting vessel can operate at a faster speed than is now operationally feasible.

(C) The tactical advantages of mine hunting at higher speeds are obvious. Added to the increased detection and classification capability is the economy of utilizing fewer ships, fewer systems,

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and fewer men to accomplish the mine-hunting task than are now used. Unfortunately, as the speed of the vessel rises, the flow noise also rises so that the return signal is completely masked by the noise after passing about ten knots in speed. The flow noise is the critical factor that vitiates the advantages otherwise accruing from the recent advances in electronic technology.

(C) Information from the U.S. Navy operating forces in Vietnam indicates a desire to deploy mine-hunting vessels at double the present speeds, perhaps up to 15 knots, to effectively patrol rivers and harbors and to detect underwater swimmers carrying explosives. Present and contemplated mine-hunting sonars will not operate at the desired speeds.

(U) A modest study has been conducted by the Department of Acoustics and Vibration to determine the magnitude of the problem and the means of ameliorating the difficulties imposed by flow noise at high frequencies.

(U) There is a great paucity of data related to flow noise at frequencies above 20 to 30 kilohertz. The meager data that are available may not be accurate or conclusive, however, there is a vast body of theory and of experimental evidence that may be

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extrapolated from low frequencies. Also, a variety of new research techniques is available to study the major aspects of the problem that is within the capability of the Naval Ship Research and Development Center (NSRDC) to perform effective and meaningful work.

(U) This document will summarize the available information, will indicate the extent of the flow noise to be expected in mine-hunting sonar via preliminary analyses, and will indicate the research effort needed to fill in some of the more important pieces of the flow-noise puzzle.

(U) It is felt that the flow-noise difficulties in mine-hunting sonar are not insuperable and that they are amenable to the same remedies that have been used successfully to overcome the flow-noise limitations of other ship-mounted sonar systems.

FLOW NOISE MECHANISMS (U)

(C) Flow noise, in general, can be attributed to a great variety of mechanisms. The major types of flow noise that can affect mine-hunting sonar are cavitation and turbulent boundary layer noise. Other significant noise sources are pulsating bubbles, vortex shedding, and propeller noise. The seriousness of the masking caused by the various noise sources varies greatly with the

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frequency range under consideration. In addition, the stabilization of bubbles in the sonar medium presents a grave problem that is not present in other types of sonar systems. It would be instructive, therefore, to review the factors that influence high-frequency flow noise. Prime attention is directed to the frequency range from 100 to 200 kHz, since most operational mine-hunting sonars are located in this region. There are systems used at 50 kHz and also in excess of 1 mega Hz, however, these systems are not very common.

BUBBLE STABILIZATION (U)

(U) Turner (Reference 1) conducted research to demonstrate that microbubbles became stabilized in a body of water and persist for long periods of time. The evidence was obtained by generating bubbles at the bottom of a water tank and measuring the decay of ultrasonic attenuation as bubbles of various sizes rose to the surface. Bubble persistence appeared to be a function of the solid particle content of the water. Also, bubbles stabilized at sizes as large as 30 microns radius in water of high particulate content.

(U) Although these studies were not conducted in salt water the data might still be applicable to those mine-hunting sonar systems that operate in fresh water rivers and harbors. Turner also

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noted that the microbubble population increased as dust fell on the water indicating that the dust may be an important vehicle for the entry of microbubbles in a body of water. These bubbles act as scattering and attenuating agents that are deleterious to sonar propagation. In addition, these bubbles are excited into pulsations by time-varying pressure fields and they also produce noise by coalescing and by collapsing. The noise produced by the bubble depends upon its size.

(U) To determine the part of the spectrum where the noise is situated, we invoke Minnaert's formula to calculate the resonant frequency of the bubble.

$$\omega = \frac{1}{R_0} \sqrt{\frac{3\gamma P_0}{\rho}}$$

where

R_0 is the bubble radius

$\gamma = 1.4$

P_0 is the static pressure

ρ is the liquid density

(C) A bubble with a stabilized radius of 30 microns near the surface of the water would have Minnaert's resonant frequency of 110 kHz. For reasons totally unrelated to bubble size many

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contemporary and some contemplated mine-hunting sonar systems operate in the general vicinity of 110 kHz. As the speed of the mine-hunting craft increases the magnitude of the time-varying pressure field increases with consequent bubble pulsations. The noise due to these phenomena is added to cavitation noise to produce a substantial masking effect at the frequencies where the noise is least desired. Further study on bubble stabilization and bubble size distribution is required so that predictive techniques related to the severity of bubble noise at high frequencies can be developed.

(C) Minnaert's formula is modified for microbubbles to include the significant effects of surface tension and of the departure of bubble stiffness from adiabatic stiffness. The Minnaert resonant frequency is multiplied by the factor

$$\frac{g}{\alpha}^{\frac{1}{2}}$$

where g is the factor that accounts for surface tension and

α is the factor describing the change in bubble stiffness.

(C) For the type of bubbles that can affect mine-hunting sonar the resonant frequency is reduced by one-third to one-half after applying the correction. Consequently, the ambient bubble spectrum

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can produce noise at the sonar's operating frequency and also in a frequency range commonly used in torpedo homing systems (Reference 13).

BUBBLE PULSATION (U)

(C) Some analytical work on bubble pulsation was published by Strasberg in 1956 (Reference 2). It is shown that volume pulsations of a bubble are excited by enforced changes in the external or internal pressure on the bubble. It is also shown that the sound generated by simple volume pulsation is quite considerable. For example, at a static pressure of 1 atmosphere and a frequency of 100 kHz, a bubble in simple volume pulsation will produce, at a distance of 1 meter, a sound pressure level of -17.2 dB re 1μ bar when oscillating with an amplitude of one thousandth of the bubble's nominal radius. This is far above return signal level used, for example, in the Buried Mine Sonar now under development at Naval Ship Research and Development Laboratory (NSRDL), Panama City

(U) Since the resonant frequency of the persistent bubbles is around the frequency of the sonar operating frequency, there exists the possibility that the sonar pings set the bubbles into oscillation. When excited by a sinusoidally fluctuating pressure a bubble will radiate sound at this pressure with the most intense sound occurring

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at the bubble's resonant frequency. A transient-pressure excitation will cause an exponentially decaying sinusoidal oscillation.

(U) Most of the energy associated with sinusoidal excitation or decay predominates at the lower frequencies, however, the nonlinear and transient effects are evident at the higher frequencies. Also, transient excitation results in a very small period during which energy is radiated, in the order of microseconds.

(U) Studies of the bubble population density are of importance in determining the severity of pulsating bubbles as a noise source. Unpublished data taken in a water tunnel at NSRDC indicates that bubbles predominated with a resonant frequency of 138 kHz and a population density of .036 bubbles/cm³. At 100 kHz, the population density was .012 bubbles/cm³. These data are very limited and inconclusive, however, they are a starting point in studies of bubble population density as related to resonant frequency. These studies obviously will have the greatest value when conducted in the actual working environment of mine-hunting sonar systems.

(U) Recent research (Reference 3) on bubble noise radiation indicates that excitation of bubbles into oscillation is initially observed at the subharmonics of the exciting frequency. This may have tactical implications in the deployment of mine-hunting vessels operating at different frequencies and also on the deployment of

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torpedoes and countermeasures.

CAVITATION SPECTRA (U)

(U) Cavitation noise, due to the collapse of cavitation voids, produces two types of spectra. Acoustic cavitation shows the random broadband spectrum that is associated with flow cavitation supplemented by line components at the excitation frequency, its harmonics, and its subharmonics (Reference 4). It would appear that the persistent stabilized microbubbles are excited and pulsate as the transient flow bubbles collapse. The magnitude of this noise is difficult to predict.

(U) Several varieties of cavitation spectra have been obtained experimentally by Jorgensen (Reference 5) and by Mellen (Reference 6). Jorgensen's data were confined to low frequencies, however, Mellen's data cover the frequency range of interest in mine-hunting sonar; Mellen computed the source levels of a series of stirring rods. This provides information on the type of propeller noise that affects mine-hunting sonar and for which baffles must be provided.

(U) The source levels at one meter in a band one Hz wide, with dB referred to 1μ bar are:

<u>f-kHz</u>	<u>dB</u>
100	-21
200	-28

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(C) Since these noise levels are above the return signal level in both the Applied Research Laboratory (ARL) and Naval Ship Research and Development Laboratory, Panama City riverine sonar systems, it is obvious why acoustic baffling was applied behind the transducers for operation at low speeds. At high speeds, the return signal was masked by additional flow noise.

TURBULENT BOUNDARY LAYER (U)

(U) High-frequency noise resulting from pressure fluctuations in the turbulent boundary layer is a phenomenon that is still relatively unexplored. The state of the art has only recently reached the point where instrumentation is available that has the low internal noise characteristics required for obtaining data up to 200 kHz. Finely resolved spectrum analysis is now possible at 200 kHz through the use of data applied to high-speed analog to digital converters and then processed by a Fast Fourier Transform. The turbulent boundary-layer noise data that are currently available for high frequencies can only be interpreted to be an indication of order of magnitude.

(U) Skudrzyk and Haddle (Reference 7) conducted studies in a water tunnel up to about 175 kHz using the criterion that, lacking the presence of visually observable bubbles which are indicative of flow

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cavitation, the prime disturbance recorded by their instrumentation is that due to the turbulent boundary layer. Since the analyzing filter was comprised of one-half octave bands, it is difficult to determine the influence of line components such as those producible by pulsating microbubbles.

(C) The spectrum levels in the range of 100 to 175 kHz at speeds up to 50 feet per second are about -50 dB, re: 1μ bar. This is about 20 dB above the level of thermal omnidirectional noise in the ocean and it is about 15 dB below the riverine sonar return signal level. So that turbulent boundary-layer noise is probably not a significant contributor to received signal obliteration at high frequencies.

(U) Further confirmation of the minimal influence of turbulent boundary-layer noise on a properly designed body comes from Project HYSURCH which was conducted at NSRDC. HYSURCH was concerned with a bottom-mapping oceanographic application at 100 kHz and flow-noise data were gathered as high as 200 kHz. A non-cavitating body was designed which contained flush-mounted hydrophones. The data, found in Reference 14, were analyzed in one-third octave bands and thus contain the same broadband lack of fine resolution that affect the data of Skudrzyk and Haddle. However, the spectrum level up to 10 knots, at 100 to 200 kHz, is about -50 dB which is the same as that obtained by Skudrzyk and Haddle.

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(U) A comparison of the turbulent boundary-layer noise obtained by Skudrzyk and Haddle and by the HYSURCH project with the cavitation noise levels published by Mellen shows that the cavitation noise has great significance in the overall flow noise level. If the two types of noise are added to obtain an overall noise level, the turbulent boundary-layer disturbance comprises less than one-half decibel of the total.

MINE-HUNTING SONAR FLOW NOISE (U)

(C) Ambient noise is not of any great significance in high-frequency sonars. Thermal noise is usually the only environmental noise source present at high frequencies. Experience has shown that the thermal noise in sea water is usually much lower than that found in the electronic components of the sonar hydrophones and receivers. Flow noise at high speeds limits sonar operation; also, at high speeds, cavitation noise in the vicinity of propellers. All of these sources are known to be broadband and to contain appreciable energy at mine-hunting sonar frequencies. Since the noise sources are somewhat dependent on the characteristics of each boat's sonar system, the extent to which this type of noise will limit operation cannot be predicted accurately. Only limited data have been collected, and these data are valid for only the particular sonar soundhead and boat

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configuration tested. More of this type of data must be collected and analyzed before there can be a high confidence in the prediction of limitation of sonar performance due to flow noise (Reference 8).

(U) The specific flow noise problems encountered in two systems now under development will be examined to show the magnitude of the problem and the practical measures that must be taken to obtain relief.

APPLIED RESEARCH LABORATORY RIVERINE SONAR (U)

NSRDL-Panama City and the University of Texas, Applied Research Laboratory (ARL), Austin, Texas, are each developing a riverine sonar system. These systems have differing end uses and each employs its own design philosophy to attain specific operating goals.

(C) The ARL sonar transducer is a line array of elements housed in a free-flooded winglike shape. A polypropylene window comprised the housing which was mounted to the hull of a vessel. Evaluation of the system was conducted on a Higgins boat with a corrugated-type hull. At the initial operating trial the high-frequency noise emanating from propeller tip cavitation completely masked the return signal. Baffling was applied behind the transducer array to cut down the propeller noise to a tolerable level. In order to determine operating effectiveness without the polluting influence of propulsion system

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noise, the boat was towed by a helicopter and a plot of noise signal against speed was generated. At a speed of ten knots the helicopter towed noise signal equalled the propeller driven noise signal--both with the baffles installed. It would seem that cavitation had started much before ten knots but had reached its masking value when ten knots was attained. This masking of receive signal was not a problem when the vessel operated at its normal speed of six knots.

(C) Examination of the transducer housing indicated that too little attention has been devoted to roughness, waviness, discontinuities, or streamlining. No pressure distributions around the body has been computed to determine the location on the body and the speed at which one would observe the inception of cavitation. In short, no significant attention had been applied to the hydrodynamic aspects of the transducer design. It is contemplated that future models of the transducer housing will have an improved design since this is really the first time that flow noise has appeared as a problem in a high-frequency sonar system.

(U) The experience of ARL has been replicated, to a great extent, by NSRDL-Panama City, who is developing a different type of riverine sonar system.

NSRDL RIVERINE SONAR (U)

(C) The transducer system utilized in the NSRDL Riverine Sonar

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operates via an acoustic lens. An array of piezoceramic elements is mounted at the rear of a thin-shelled sphere made of acrylic butadiene styrene. In the sphere is a liquid whose acoustic index of refraction causes the formation of a narrow beam pattern, without the need for complex electronic systems, to perform shading and beam steering. At the time ARL Riverine Sonar was evaluated, the NSRDL lens was mounted on the Higgins boat and both systems simultaneously experienced the same degradation in operation due to propeller noise and to excessive flow noise at 10 knots.

(C) Some rough acoustic data were taken. The levels of received signal and noise at 125 kHz, corrected for directivity and expressed as spectrum level, are:

Table I

	<u>dB re: 1μ bar/Hz</u>
Thermal noise	-73
Transducers baffled-Helicopter towed	-51 @ 7 knots
Transducers baffled-Propeller driven	-42 @ 7 knots
Return Signal	-35

(C) At 12 knots the noise level for both the propeller driven and the helicopter towed configurations was -33 dB which exceeded the signal level by 2 dB. It is interesting to note that the helicopter towed levels at 7 knots are at the value that was obtained from the

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Skudrzyk and HYSURCH studies of turbulent boundary-layer noise.

(C) Due to the lack of attention to hydrodynamic factors both of the riverine sonar systems have exhibited excessive cavitation noise above 10 knots. More study will have to be devoted to this problem as some uncertainty exists regarding the magnitude of the corrective actions to be applied or even to the ultimate efficacy of the corrections.

NSRDL BURIED MINE SONAR (U)

(U) The onset of cavitation and its locations can be predicted, for specific bodies, from a knowledge of the pressure distributions around the body. When the maximum negative value of the pressure coefficient is equal to or smaller than the cavitation index then cavitation will start and its magnitude will increase as the speed of the body increases. Since mine-hunting sonar is ordinarily used at the surface or in a towed body about twenty feet in depth we can easily compute the onset of cavitation for certain simple shapes. The idealized shape of the buried mine sonar developed at NSRDL-Panama City is a hemisphere attached to a cylinder; the hemisphere containing an acoustic lens. Another proposed shape is a towed spheroid. These are blunt shapes and possess many interesting properties. An analysis of these bodies in relation to cavitation inception would be instructive in outlining the practical hydroacoustic problems that arise in this type of sonar system.

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CAVITATION INCEPTION (U)

(U) The pressure distribution around an idealized hemisphere-cylinder combination has been calculated and is presented as Figure 1 (Reference 9). It can be noted that the maximum negative value of the pressure coefficient is 0.77 and it occurs at the surface of the hemisphere on a circle that is a 80% of the hemisphere's axis. The cavitation will start on this circle when a critical speed is passed, and it will further increase in magnitude as the speed is increased. A calculation of cavitation index at speeds of 0 to 20 knots allows the determination of the speed at which the body experiences cavitation inception and the results are presented in Table II. The location of the cavitation approximately coincides with the opening that is the active portion of the acoustic lens.

Table II

<u>Depth (feet)</u>	<u>Speed for Cavitation Inception (knots)</u>
0	31.5
5	33.6
10	35.5
15	37.8
20	39.5

(U) Since the proposed body of the buried mine sonar is not quite the idealized shape that is analyzed above and it contains many sharp

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appendages, it is contemplated that cavitation will start at a considerably lower speed and that it will possibly be more widespread.

(U) It is also interesting to note the variation in the resonant frequency of stabilized microbubbles as depth is increased. These bubbles form some of the nuclei that are excited into cavitation and that also pulsate in a time-varying pressure field. The variation in resonant frequency is shown in Table III.

Table III

<u>Depth (feet)</u>	<u>Resonant Frequency of Bubble (.003 cm Radius) kHz</u>
0	58
5	63
10	67
15	70
20	74
25	76

(U) The implications of this information in regard to choice of an optimum sonar operating frequency are best considered in light of other information pertinent to scattering, resolution, and reverberation.

THE TOWED SPHERE (U)

(U) The towed sphere is a configuration that has been proposed for a future mine-hunting sonar system. The sphere would contain an acoustic lens and some processing electronics which would probably

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be in the form of integrated circuits. Analysis of this shape shows that it is not suited for high speed use.

(U) Pressure distributions around a sphere have been obtained experimentally and selection of the pertinent distribution is a function of the Reynolds number that characterizes the flow. At speeds of five knots and above, the Reynolds number of a sphere suitable for an acoustic lens falls in the supercritical region so that the empirically determined pressure distribution can be obtained from Reference 10. The pressure distribution is shown in Figure 2, and from it the calculation showing cavitation inception is presented as Table IV.

Table IV

<u>Depth (feet)</u>	<u>Speed for Cavitation Inception (knots)</u>
0	27.2
5	28.6
10	30.8
15	32.4
20	33.8

(U) The location of the cavitation on the sphere's surface covers a much greater area than the hemisphere-cylinder configuration previously analyzed. It can be concluded from this study that the optimum type of body for use in high-speed mine-hunting sonar is

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yet to be developed.

(U) This glimpse of the flow-noise problems that serve to impair the ultimate efficacy of mine-hunting sonar has revealed that very little solid information is available about the exact nature of the phenomenon and the environment in which it occurs. From this study it now becomes possible to outline a program of research and development that would serve to illuminate the situation and to ameliorate the difficulties that have been encountered.

RESEARCH PROGRAM (U)

(U) The research and development program to be outlined herein is a combination of analytical and experimental activities utilizing the tools of classical physics and modern electronics. The very broad frequency range that is handled in mine-hunting sonar limits some of the studies because the state of the electronic art places severe restrictions on the bandwidth of the hardware. For example, mine-hunting sonars use frequencies ranging from 50 kHz up to 1.5 megahertz; but the preamplifiers used with broadband hydrophones can be commercially obtained only up to 200 kHz. This is not as bad as it seems since most of the high-frequency sonars now in use do not exceed 200 kHz in operating frequency. Individual frequencies above 200 kHz can be handled with filters and with limited bandwidth amplifiers.

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INSTRUMENTATION (U)

(U) If the broadband noise investigations are limited to 200 kHz it is possible to obtain virtually all of the required instrumentation. For the HYSURCH project, the Department of Acoustics and Vibration obtained hydrophones with built-in preamplifiers to cover the range of 40 to 200 kHz. Most preamplifiers for use with hydrophones do not go beyond 100 kHz, however, a development effort to extend the frequency range was successfully undertaken. A similarly successful development produced a post-amplifier that reached 200 kHz. Several of these sensors and their associated amplifiers are now available for future investigations.*

(U) A multi-channel Ampex tape recorder is available at NSRDC that records up to 200 kHz at 60 inches per second. NSRDL-Panama City has a CEC tape recorder with a 300 kHz capability so that little difficulty will be encountered in recording broadband flow noise. Analyzing equipment should be available at NSRDL-Panama City by December 1970 for obtaining finely resolved spectra of flow noise. A high-speed analog-to-digital converter has been ordered which will prepare tapes for a large digital computer at Panama City. The computer is programmed with a Fast Fourier Transform to produce a power spectrum up to 1 megahertz.

* Ostrow Hydrophone-Preamplifier available from Enviresearch Corporation, Bethesda, Maryland.

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(U) One great difficulty experienced in the HYSURCH project was the lack of adequate filters for fine frequency analysis and a variety of stratagems were employed to overcome this deficiency. For example, data were recorded at 60 inches per second and played back at half speed to use one-third octave band filters that went to 100 kHz. As a one-third octave band at 200 kHz is 46 kHz wide the resolution of the spectrum does not allow one to determine the effects of line components. The Fast Fourier Transform is a relatively expensive means of obtaining a power spectrum at high frequencies. After a digital tape is produced the computer time to process a spectrum from 20 kHz to 200 kHz comes to 30 minutes. At the current computer usage charges this amounts to \$100 per spectrum. Advances in computer technology and in programming techniques might reduce the cost.

(U) The availability of water tunnels and towing facilities at NSRDC with electronic equipment and boats at NSRDL-Panama City presents the opportunity to approach the research and development program as an in-house venture. The practical hydrodynamic and acoustic problems being faced by NSRDL-Panama City in its current mine-hunting sonar developments are amenable to solution by the personnel and facilities at NSRDC.

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(U) Various aspects of the research and development will now be explicated.

ACOUSTIC LENS SYSTEMS (U)

(U) Analysis of transducer and array configurations to obtain the optimum acoustic properties for mine hunting point to the use of acoustic lenses in the future. NSRDL-Panama City is developing acoustic lenses and their ancillary systems for use in riverine and buried mine sonars. It has been demonstrated in the technical note that the spherical and cylindrical configurations which these lenses assume have the undesirable property of cavitation inception at fairly low speeds. To make the acoustic lens feasible for use at speeds that can effectively utilize the unique qualities of these lenses it is necessary to start a program to investigate the manner in which the shape of the lens can be modified for streamlining purposes. As a part of this investigation one must find materials with properties that will satisfy acoustic, mechanical, and cavitation erosion criteria.

(U) The use of mine-hunting sonars at higher speeds than is now customary will evoke noise problems caused by vibration. High-frequency piezoceramics are sensitive to vibration at low excitation frequencies through cross coupling of modes that produce high frequency output. This was vividly demonstrated on the HYSURCH

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project in which vibration excitation at about 2 kHz evoked a signal of 100 kHz in an acoustic transducer. Vibration isolation of the transducer eliminated the noise signal on a vessel that was operated at a speed in excess of 30 knots. The configurations of the high-frequency acoustic arrays should be evaluated in terms of this acceleration noise.

(U) A research and development program to minimize the flow-noise problems that serve to inhibit proper operation of an acoustic lens would consequently be devoted to the study of optimum shapes that would delay the inception of cavitation and that would move the transition between turbulent and laminar flow behind the transducer array.

WAVE VECTOR FILTER (U)

(U) One interesting technique for studying the wave number structure of the flow noise in mine hunting sonar involves the use of a wave vector filter. The theory of the wave vector filter has been described in the literature (Reference 11).

(U) It is possible to design a wave vector filter that will be sensitive to near field fluctuations such as bubbles and turbulent boundary layer at the high frequencies used in mine hunting sonar. If we are interested only in sonic wave numbers the task of designing and manufacturing a wave vector filter is not formidable. A frequency

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of 100 kHz would have a sonic wave number of 10.47 per inch. The array of elements needed to discern this wave number would be composed of .20 inch wide ceramic slabs with an interelement spacing of .10 inches. An acceptable beam width would require six elements. The dimensions of a 100 kHz and two other wave vector filters usable for mine hunting sonar are found in Table V.

Table V

<u>Frequency</u> (kHz)	<u>Wave Number</u> (in. ⁻¹)	<u>Width</u> (in.)	<u>Interelement</u> <u>Spacing (in.)</u>
100	10.47	.20	.10
500	52.33	.04	.02
1,000	104.67	.02	.01

(U) A computer program to process the data from a wave vector filter is available at NSRDC with which it is possible to perform beam shifting and other operations on the flow noise signal. It is then possible to make estimates of the wave number structure of the flow disturbances and to ascertain the relative contributions of bubbles and turbulent boundary-layer noise to the overall noise. There is a fly in the ointment, however; each particular frequency or small range of wave numbers requires a separate wave vector filter with its own data processing. If it is desired to explore a very broad frequency range the cost and time requirements are

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quite prodigious. A limited study, though, could be a very worthwhile effort.

PIPE FLOW STUDIES (U)

(U) One means of studying the acoustic properties of flow at high frequencies is the use of a pipe instrumented with hydrophones or with a wave vector filter. Primarily, one is able to study turbulent flow and wall pressure fluctuations. The Department of Acoustics and Vibration at NSRDC has a three-inch diameter pipe flow facility that can accommodate gravity flow or flow under pressure without the polluting effect of pumps or propulsion systems noise. It is possible to generate flow up to a speed of 15 knots for a period of five minutes.

(U) If the pipe diameter was increased to 12 inches to be more representative of the turbulence that an actual mine hunting sonar would encounter, then the test time would be reduced to about 20 seconds which may be insufficient for high-frequency noise determinations. In addition, the cost of conversion would be about \$15,000 to install the larger pipe. One substantial problem involved in using any flush-mounted transducer in a flow facility is the applicability of a transducer free field calibration. One should calibrate a transducer in a large baffle to negate edge effects and to obtain a calibration

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that can be used in the near field with appropriate corrections.

(U) In spite of its many limitations the pipe flow facility affords a means of studying high-frequency flow noise to fill in the missing part of the picture related to turbulent boundary-layer fluctuations.

KAMLOOPS STUDIES (U)

(U) The KAMLOOPS vehicle operated by the Department of Acoustics and Vibration at Bayview, Idaho, offers a means of studying high-frequency flow noise in a manner that adds the effects of bubbles and other environmental factors to the type of data obtained in a pipe flow facility. KAMLOOPS, as a buoyantly propelled vehicle that does not suffer the effects of propulsion system noise, is able to act as a platform for sensors that can pick up the flow noise in its pristine form.

(U) Adaptation of the electronics to handle the broad frequency range of mine hunting sonar would be required. However, this would be a minor consideration since the KAMLOOPS vehicle is instrumented with more than 50 hydrophones and the modification of two or three channels might supply sufficient information on the initial attempt to determine if more detailed studies would be of value in succeeding years.

(U) Availability of the KAMLOOPS vehicle would make a substantial capital investment unnecessary. Also, any data gathering

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activities could be conducted in conjunction with other studies so that the KAMLOOPS vehicle might provide the most economical means of obtaining legitimate high-frequency flow noise data. The availability of high-frequency data reduction facilities at NSRDL-Panama City is another attractive consideration.

BUBBLE DISTRIBUTION STUDIES (U)

(U) Some of the fundamental information related to high-frequency flow noise is contained in studies of bubble size distribution. These studies aid in the prediction of cavitation or bubble noise and in the evaluation of reverberation limits in sonar system design. Two techniques have been explored at NSRDC that need more development. These are an acoustic technique and a laser holographic technique (Reference 12).

(U) The acoustic technique is based upon the measurement of acoustic attenuation. A computer program has been prepared so that one merely inserts the frequency, acoustic attenuation due to bubbles, and the transducer separation to obtain a bubble size distribution. Many assumptions about the properties of the dissolved gases are contained in the computer program, such as the thermal conductivity and the adiabatic expansion constant for the gas for example. Although these figures are known for dissolved air in fresh water, they are not known for dissolved gases in sea water

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such as carbon dioxide. The acoustic technique, then, is very limited in application.

(U) Laser holography, though, is a more general technique. Holograms have been obtained in a water tunnel at NSRDC from which bubble distributions have been plotted. The hologram when placed under a microscope provides a three-dimensional view of the bubble field. Bubbles are counted to obtain distribution density and their size is measured with a caliper. This process is admittedly very time consuming and tedious, however, it produces worthwhile information. To obtain "in-situ" data the construction of a sea chest to house the laser and its associated equipment would be necessary. Boats are available at NSRDL-Panama City at a moderate rental upon which the holograms can be generated at sea.

(U) Although most of the equipment for laser holography is available at NSRDC the extreme and sophisticated application contemplated requires personnel with an intensity of experience that is not readily available. This type of expertise might be available outside of NSRDC.

BODY DESIGN (U)

(U) A research and development effort that will prove of immediate value in aiding NSRDL-Panama City in its buried mine

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sonar development would be the design of a body to house the sonar transducer array. The body performs many of the functions of a sonar dome, and in addition forms the case of an acoustic lens. It has been demonstrated in this technical note that a substantial improvement in shape is required to increase the speed of cavitation inception so that the sonar system can be utilized above current operating speeds. Techniques used by the Department of Acoustics and Vibration in the design of sonar domes are good starting points in the design of a low cavitation body. Computer programs are available through which the pressure distribution around an arbitrary body can be computed. In addition, it is possible to compute and to move the location of the transition point between laminar and turbulent flow so that turbulence will have a minimal effect on noise production.

(U) After several iterations of the computer program to select a desirable body shape it is good practice to evaluate the model in a water tunnel to verify the low cavitation properties. Further evaluation of a full-scale model or of the operational body can be performed in the towing basins at NSRDC where the actual high-frequency flow noise levels can be measured. Full-scale sea trials of the complete sonar system will provide the ultimate verification

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of the design procedures effectiveness since this is not the current practice used in developing mine hunting sonar.

CONCLUSIONS (U)

(C) Sea trial experience has indicated that current designs of mine hunting sonar are not operable above 10 knots because of excessive flow noise. The flow-noise data exist for a few discrete frequencies and it is not available in the form of finely resolved spectra. Consequently, the area of high-frequency flow noise is a vast unknown. Practical considerations related to increasing the tactical scope of mine-hunting sonar operations thus depends upon a greater knowledge of the nature of high-frequency flow noise and the means of controlling it.

(U) The most pressing areas of research and development, as described in this technical note, are related to bubble distributions, to design of a low pressure coefficient body, and to generation of broadband acoustic spectra. Bubble distribution studies might be deferred temporarily due to the unavailability of specialized personnel. However, the other activities should proceed.

(U) A low-pressure coefficient body is an immediate need to support current design and development activities at NSRDL-

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Panama City. Generation of a broadband acoustic spectrum can be modestly approached through analysis of the existing HYSURCH tapes and through analysis of data generated with a low-pressure coefficient body to indicate the lower flow noise limit possible at the present state of the art.

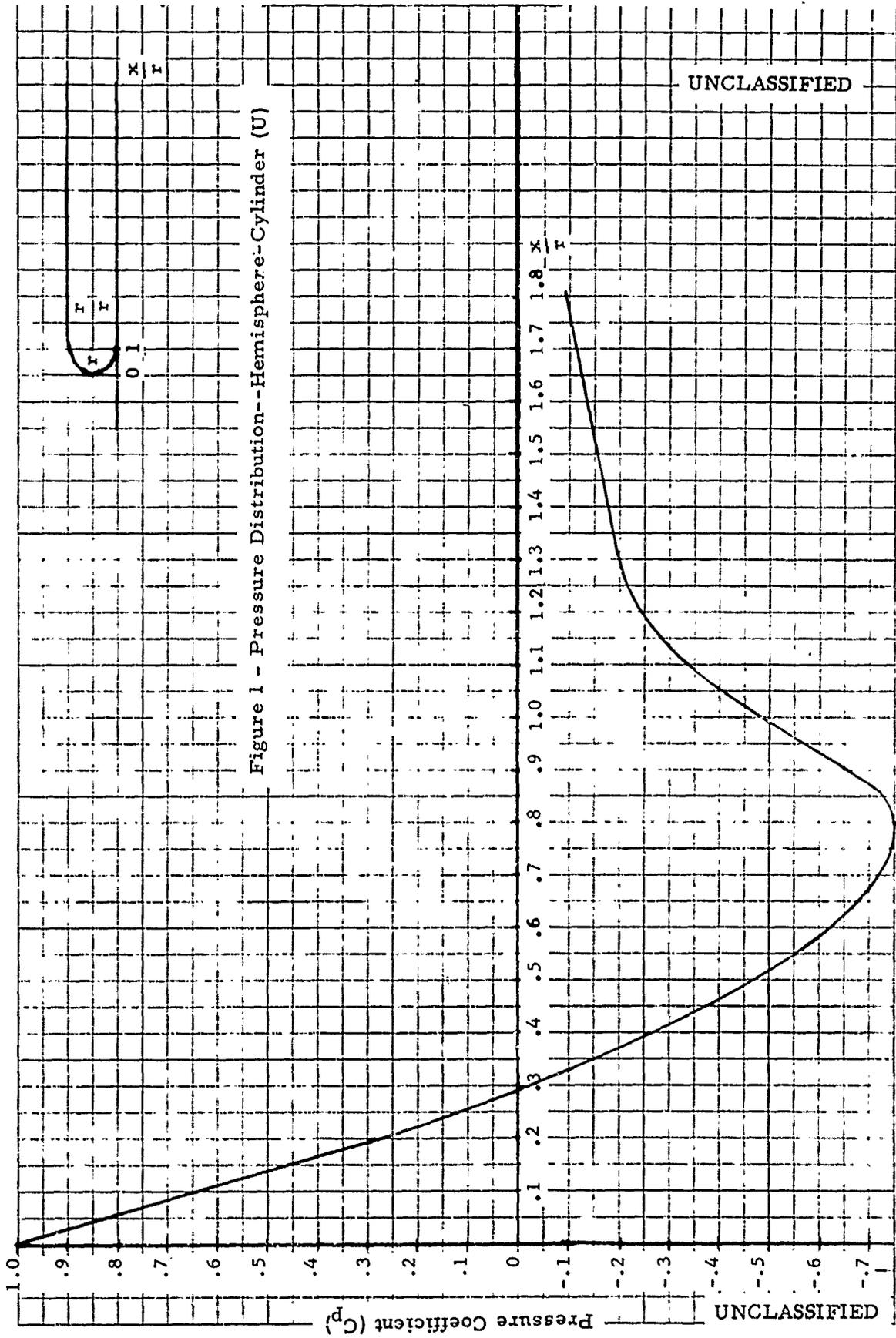
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Figure 1 - Pressure Distribution--Hemisphere-Cylinder (U)

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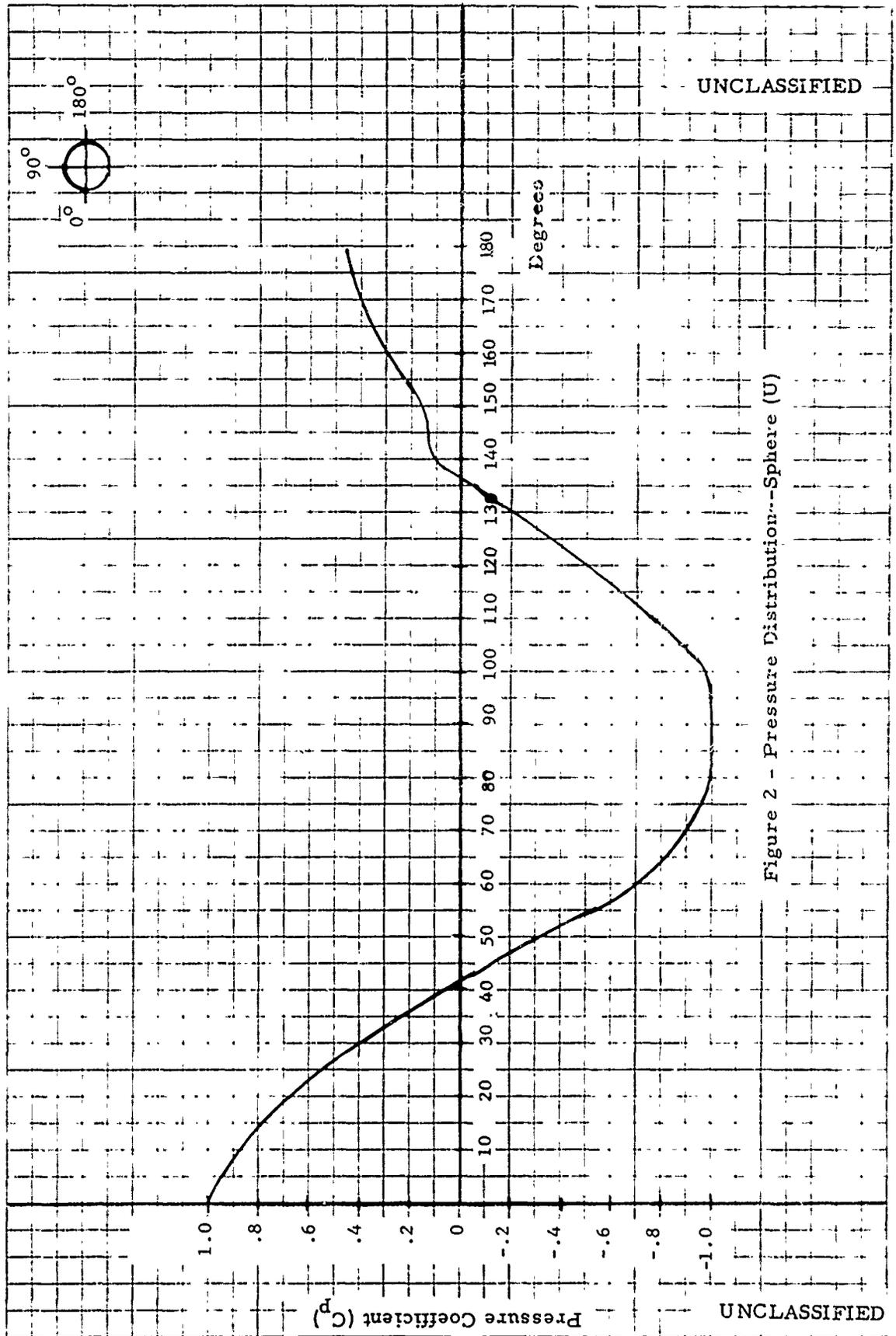


Figure 2 - Pressure Distribution--Sphere (U)

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