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NOMOGRAPHS FOR PARAMETRIC TRANSMITTING ARRAY CALCULATIONS

James C. Lockwood

Texas University

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13. ABSTRACT

Nomographs for use in evaluating the farfield source level of the parametric transmitting array are presented. The nomographs evaluate the theory given by Berktay and Leahy (H. O. Berktay and D. J. Leahy, "Farfield Performance of Parametric Transmitters," (to be published, 1973) Journal of The Acoustical Society of America). (U)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nonlinear acoustics						
Farfield parametric theory						
Source level						
Beamwidth						
Graphical solution						
Shock threshold						

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Introduction

A set of nomographs that facilitate calculations of parametric array farfield source level and beamwidth has been developed. These nomographs are an aid for applying the farfield parametric array theory as formulated by Berktay and Leahy.[1] The results obtained by use of this theory are strictly valid only in cases when finite amplitude attenuation of the primary wave is not significant. The nomographs may be used with considerable confidence for cases in which the primary source level is such that shocks will never form. A graph of the levels below which shocks will not form is provided.

A graphical aid for parametric array design has been given previously by Mellen and Moffett.[2] The Mellen-Moffett curves are more general than the present nomographs in that they include cases in which finite amplitude attenuation is important. However, for cases in which the present nomographs are applicable, their use is also much more direct. The numerical evaluation of parameters is avoided. Furthermore, for a given salinity, temperature, and pressure, a single set of nomographs may be used for a continuous range of primary and difference frequencies. The fact that saturation effects have not yet been taken into account in these nomographs is an obvious disadvantage. However, the Berktay and Leahy theory is applicable in many cases of interest, and these nomographs should prove useful for obtaining quantitative results quickly in such cases.

In the following pages a set of nomographs for sea water at 20°C is presented along with explanations of the equations they are designed to solve and detailed instructions for their use.

The Nomographs and Instructions for Their Use

The solution given by Berktay and Leahy for the farfield source level and beamwidth of a parametric array formed by the two frequency radiation from a planar piston is formulated in terms of the Westervelt[3] solution for perfectly collimated primary radiation. The solution for an array formed by piston beams involves modifications of the Westervelt results that depend on the ratio of the primary beamwidths to the difference frequency beamwidth predicted on the basis of the Westervelt model.

Figure 1 is a nomograph from which the Westervelt source level and beamwidth may be obtained. The Westervelt half beamwidth is obtained by lining up the primary center frequency and the difference frequency and reading θ_d in degrees. The nomograph is thus used to solve the equation

$$\theta_d = \sqrt{(2\alpha_T/k_-)} \quad , \tag{1}$$

where

α_T is the sum of the primary absorption factors, and

k_- is the difference frequency wave number.

The source level of a perfectly collimated array is obtained from fig. 1 by lining up the primary and difference frequencies and noting the intersection on axis X and then lining up the point on X so obtained with the value of L_s-DI and reading the difference frequency source level L_{sd} in dB re 1 μbar at 1 yd. L_s is the mean primary source level and DI is the directivity index of the source transducer

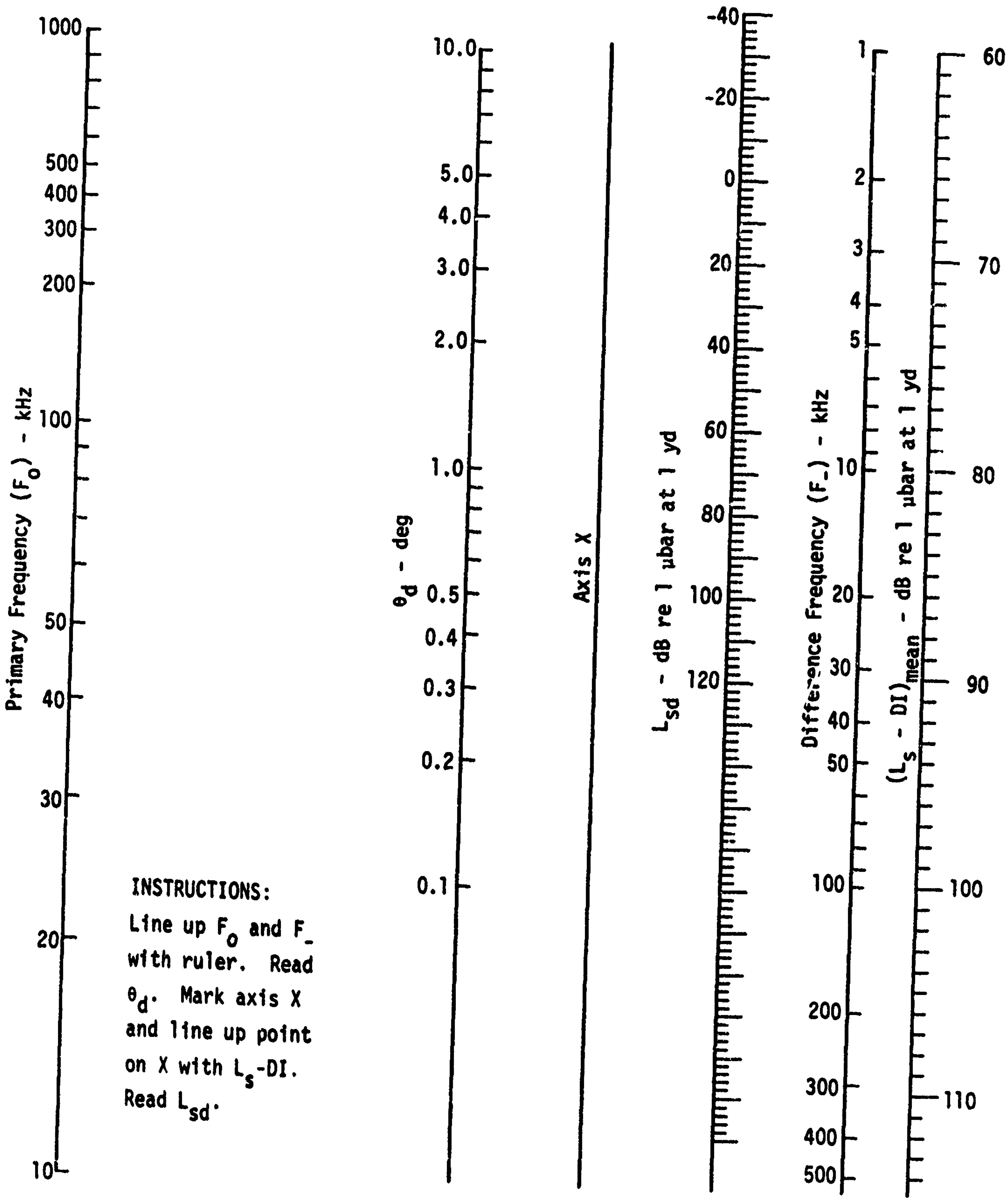

FIGURE 1

NOMOGRAPH FOR DETERMINING
DIFFERENCE FREQUENCY SOURCE LEVEL (L_{sd}) AND
HALF BEAMWIDTH OF A PARAMETRIC ENDFIRE ARRAY
IN SEA WATER (WESTERVELT)

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at the primary center frequency. The expression for difference frequency pressure upon which the solution is based is

$$p_{-} = \frac{\omega_{-}^{2}\sqrt{W_1W_2}\,\beta}{2\pi c_o^{3}R\alpha_T} \quad , \tag{2}$$

where

ω_{-} is the angular difference frequency,

W_1 and W_2 are the total radiated powers at the two primary frequencies,

β is a parameter of nonlinearity equal to approximately 3.4 for water,

c_o is the speed of sound, and

R is the range.

The source level equation is

$$L_{sd} = -141 + 20 \log F_{-} - 40 \log \theta_d + 2(L_s\text{-DI}) \text{ dB re 1 } \mu\text{bar at 1 yd} \quad . \tag{3}$$

F_{-} is expressed kiloHertz and θ_d is expressed in degrees.

The primary function of fig. 2 is the determination of the primary beamwidths normalized with respect to θ_d. For a circular transducer of radius a, the normalized beamwidth is given by

$$\psi_d = 92.5/k_o a\theta_d \quad , \tag{4}$$

and for a rectangular transducer of sides ℓ and m,

$$\psi_y = 163/k_o \ell\theta_d \quad , \tag{5}$$

and

$$\psi_z = 163/k_o m\theta_d \quad . \tag{6}$$

INSTRUCTIONS: Line up θ_d with F_o and mark axis X. Line up point so marked with piston radius or length of side and read ψ_d or $\psi_{y,z}$. DI is obtained by lining up F_o with piston radius. For a rectangular find the DI value based on the length of each side, average and subtract 4.97 dB.

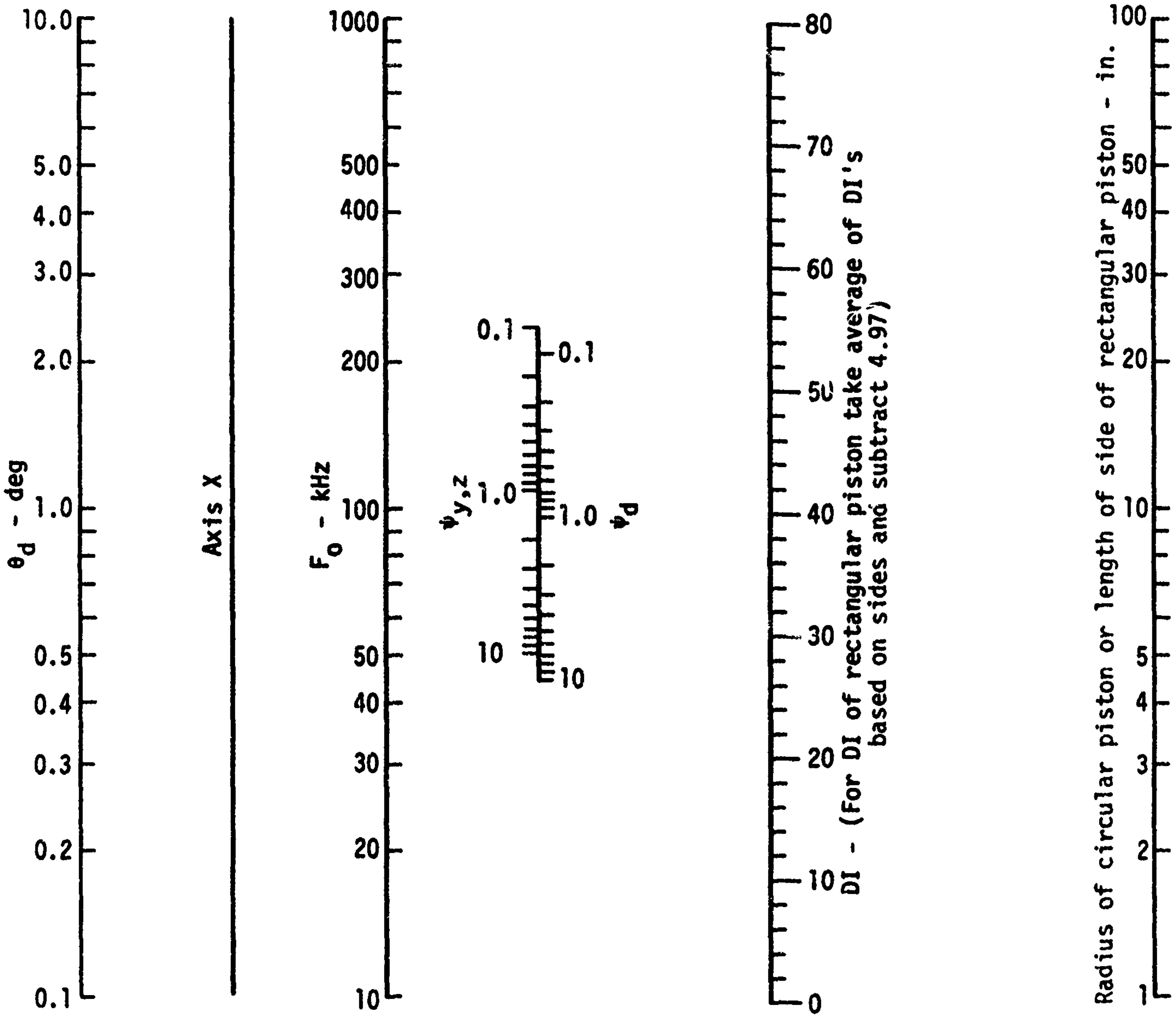

FIGURE 2

NOMOGRAPH FOR DETERMINING NORMALIZED PRIMARY BEAMWIDTHS

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The normalized beamwidths are obtained from fig. 2 by lining up θ_d and F_o to determine the intersection on axis X and then lining up that point with the radius of a circular transducer or the length of a side of a rectangular transducer and reading ψ_d or $\psi_{y,z}$. The DI scale on fig. 2 is provided as a convenience for obtaining the directivity index.

Once the normalized primary beamwidths have been obtained, the source level obtained from fig. 1 may be reduced by the "relative pressure ratio" determined from fig. 3 to give the corrected difference frequency source level. The ratio of the actual difference frequency half beamwidth to θ_d may be obtained from figs. 4 and 5. Figures 3 through 5 are reproduced from Berktay and Leahy.

Shock Threshold

The Berktay-Leahy theory does not take finite amplitude attenuation into account; hence, it seems reasonable to use the threshold for eventual shock formation as a least upper bound for validity of the results predicted by use of the present nomographs. An approximate model is used to estimate the shock threshold. The piston radiation field is assumed to approximate plane waves out to the Rayleigh distance $R_o=S/\lambda$, the piston area divided by wavelength, and spherical waves beyond R_o. Some unpublished results of Lockwood indicate that shocks will eventually form if

$$\frac{\beta\epsilon k}{\alpha}\left[1-\exp(-\alpha R_o)\right] + \beta\epsilon k R_o \int_{R_o}^{\infty} \exp(-\alpha R)(dR/R) \geq 1 \quad . \tag{7}$$

Figure 6 gives the shock threshold as a function of frequency for several values of R_o.

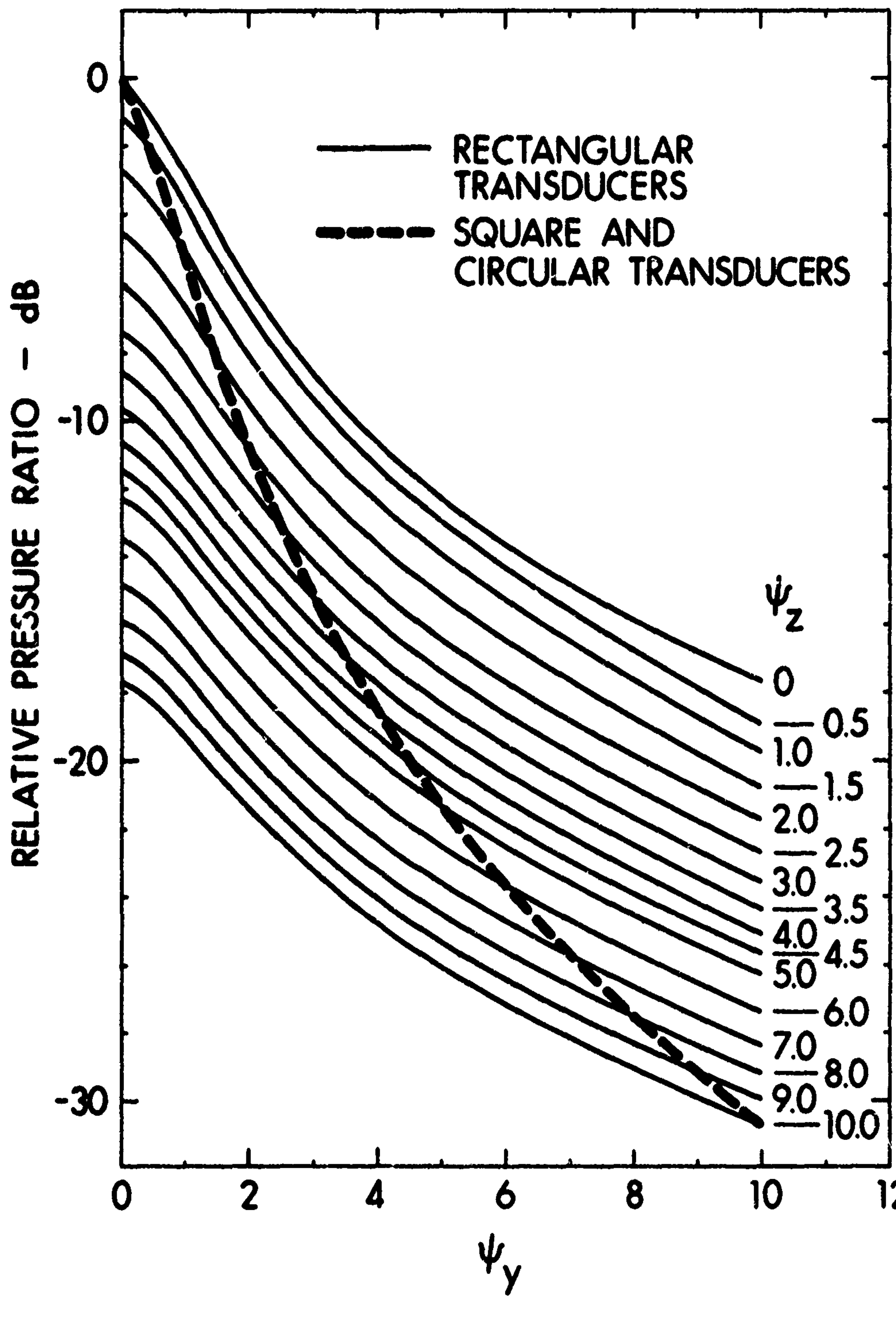

FIGURE 3
PRESSURE REDUCTION FACTOR, |v|, FOR RECTANGULAR AND CIRCULAR TRANSDUCERS

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HOB - RFO
7- 18 - 72

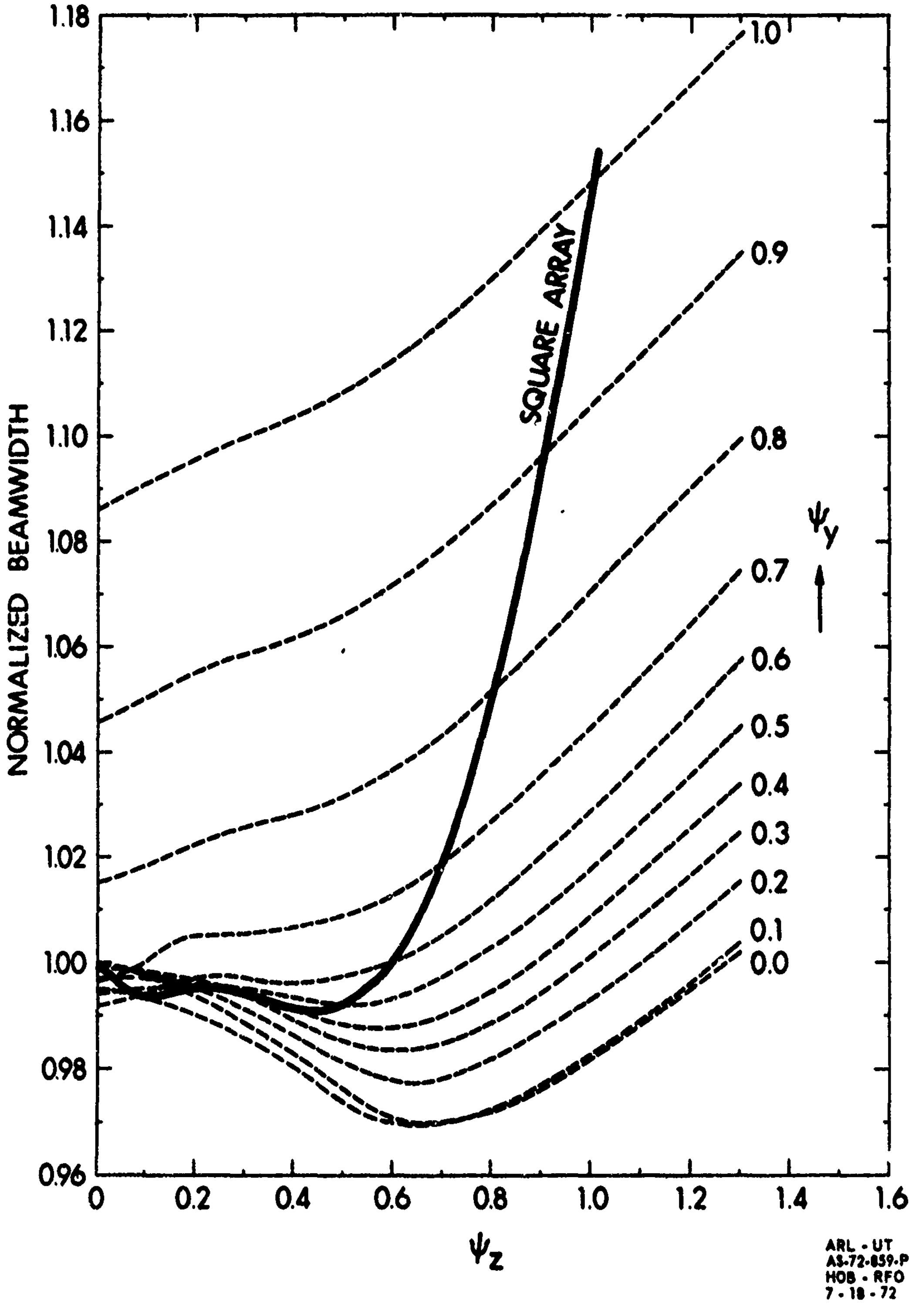
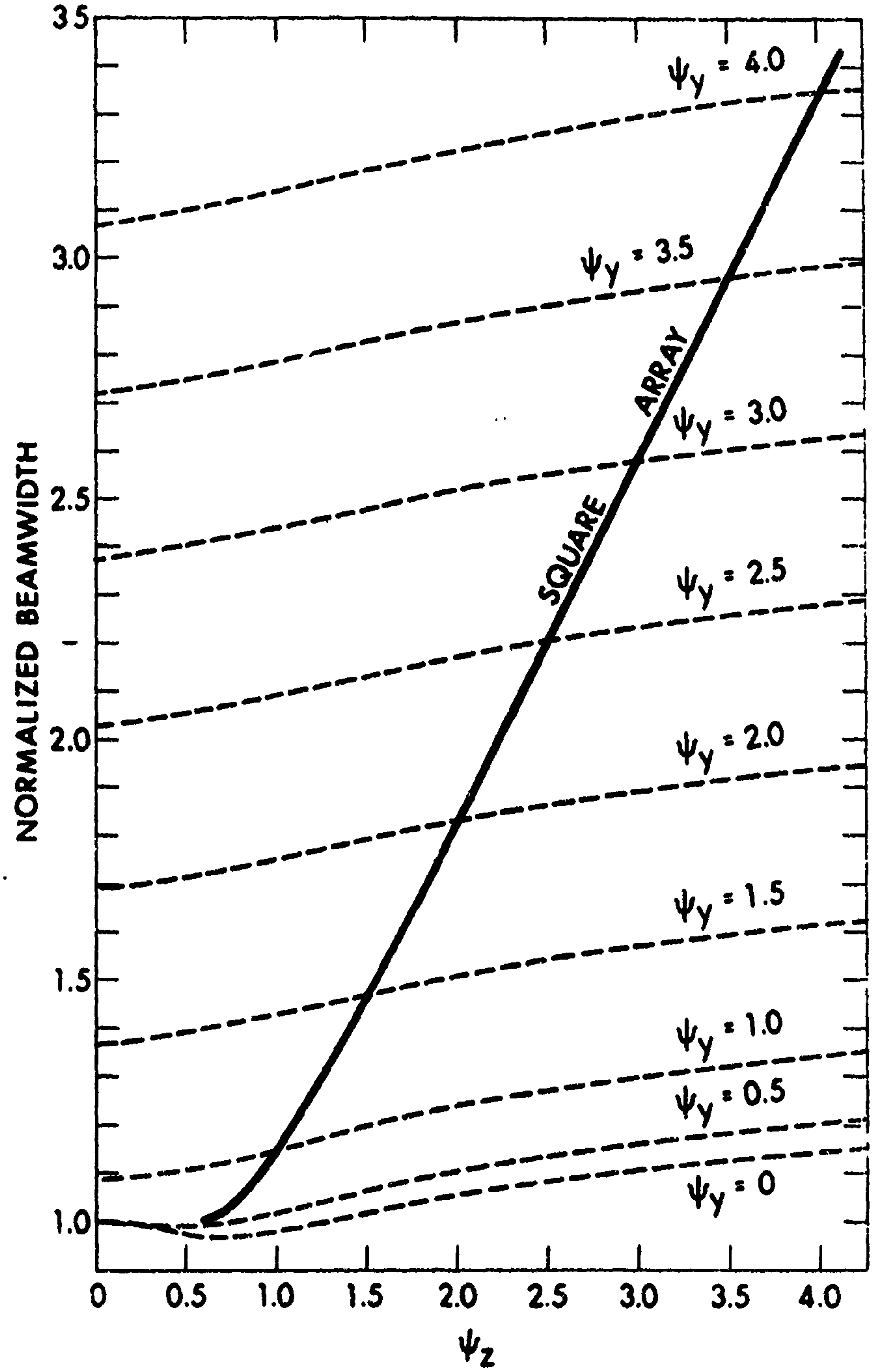


FIGURE 4
NORMALIZED HALF-POWER BEAMWIDTHS,
θ_{HP}/θ_d, FOR RECTANGULAR TRANSDUCERS.
(THE BEAMWIDTH IN THE x-y PLANE IS SHOWN)



ARL - UT
AS-72-860-P
HOB - EJW
7 - 18 - 72

FIGURE 5
NORMALIZED HALF-POWER BEAMWIDTHS,
θ_{HP}/θ_d, FOR RECTANGULAR TRANSDUCERS.
(THE BEAMWIDTH IN THE x-y PLANE IS SHOWN)

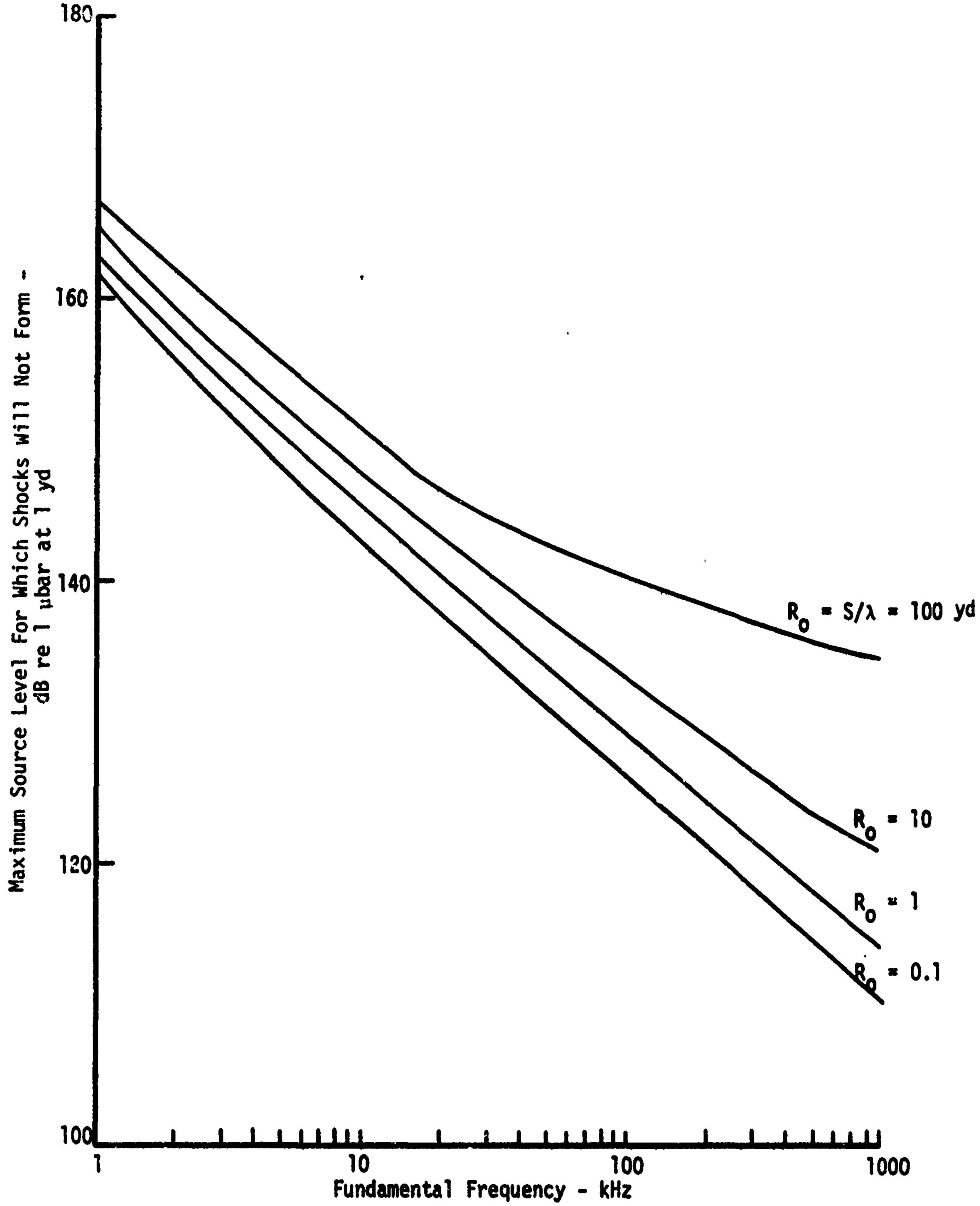


FIGURE 6

GRAPH OF LEVELS BELOW WHICH SHOCKS WILL NOT FORM
IN RADIATION FROM A PLANAR PISTON
IN SEA WATER

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APPENDIX A

Nomograph for Fresh Water

Figure A-1 is a nomograph for determining the Westervelt source level and beamwidth for fresh water at 20°C. For fresh water calculations it replaces fig. 1.

Figure A-2 is the shock threshold graph for fresh water at 20°C to replace fig. 6.

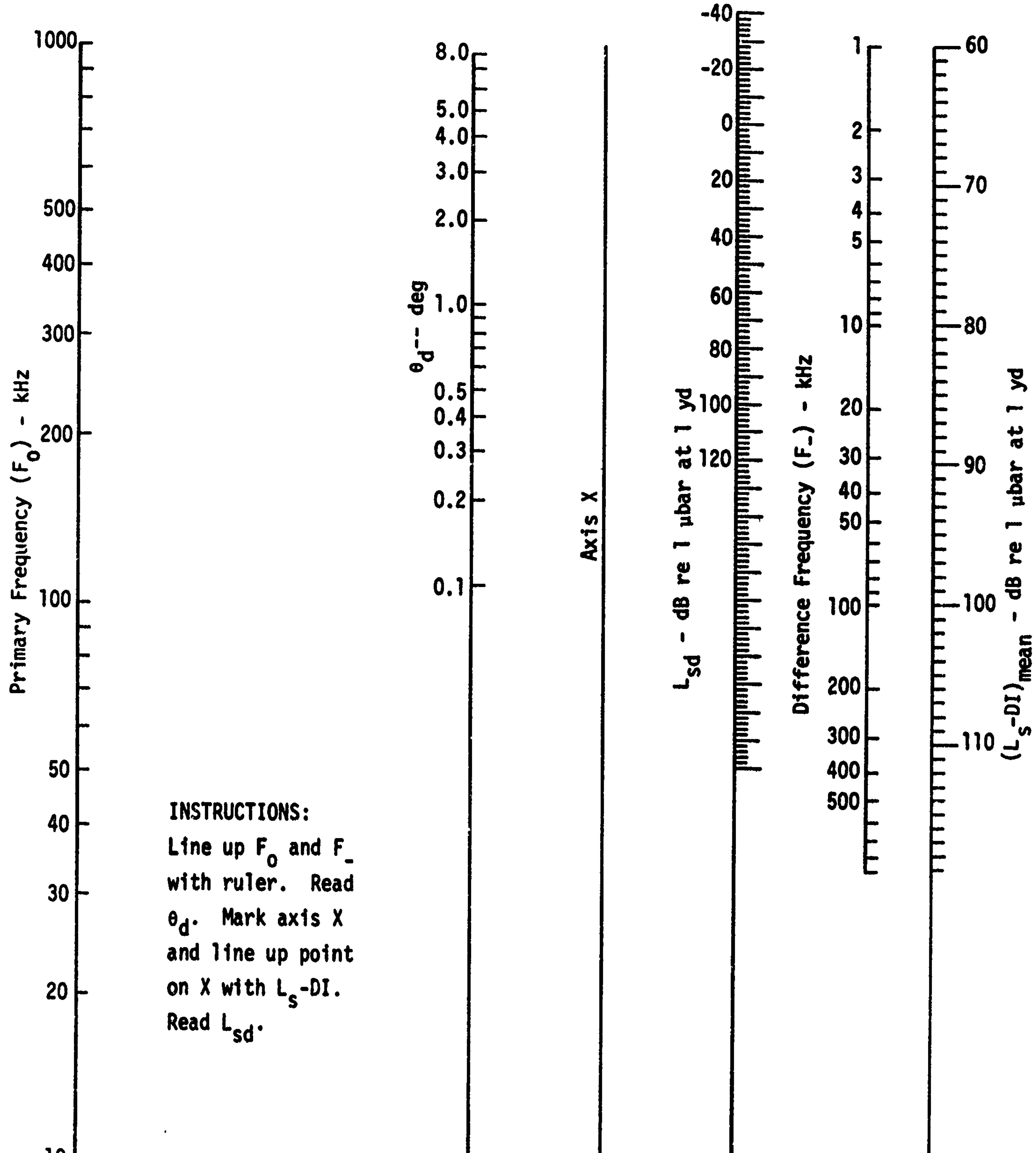

FIGURE A-1

NOMOGRAPH FOR DETERMINING
DIFFERENCE FREQUENCY SOURCE LEVEL (L_S) AND
HALF BEAMWIDTH OF A PARAMETRIC ENDFIRE ARRAY
IN FRESH WATER (WESTERVELT)

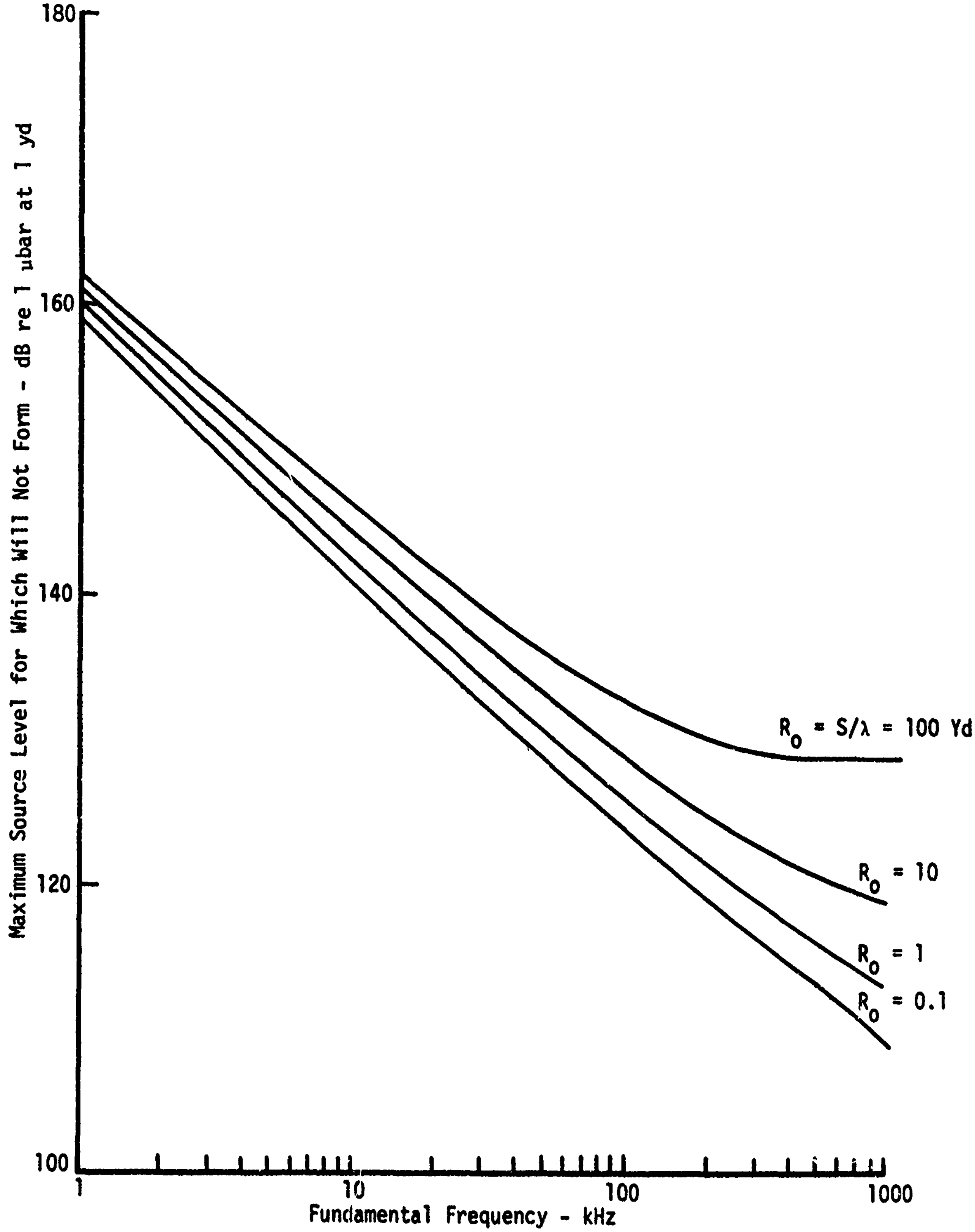

FIGURE A-2
GRAPH OF LEVELS BELOW WHICH SHOCKS WILL NOT FORM
IN RADIATION FROM A PLANAR PISTON
IN FRESH WATER

REFERENCES

1. H. O. Berktay and D. J. Leahy, "Farfield Performance of Parametric Transmitters" (to be published, 1973, Journal of The Acoustical Society of America).

2. R. H. Mellen and M. B. Moffett, "A Model for Parametric Sonar Radiator Design," Naval Underwater Systems Center Technical Memorandum No. PA41-229-71 (1971).

3. P. J. Westervelt, "Parametric Acoustic Array," J. Acoust. Soc. Amer. 35, 535-537 (1963).