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Technical Report No. 26
Scattering of Sound by a Prolate Spheroid

by
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SCATTERING OF SOUND BY A PROLATE SPHEROID

By H. L. Poss

ABSTRACT

Some experimental information has been obtained on target strength to be expected for scattering of sound by a submarine in the frequency range of 40 to 150 cps. Measurements using pulsed sound were carried out in the NOL anechoic chamber using a lucite spheroid model of axes ratio 10. Sound was incident broadside to the model. Back-scattered sound was measured in the plane containing the long axis and incident beam at angles of 0°, 30°, and 60° with respect to the incident beam. Too high a background was present to permit measurements to be made with sound incident in the direction of the long axis. For 0°, the results, when scaled to the case of a submarine, indicate a target strength of 26 db. This figure is comparable to values obtained at ultra-sonic frequencies. For angles of observation of 30° and 60° with respect to the incident beam, the target strength is 10 to 20 db lower than the above figure. These figures should furnish a basis in considering the feasibility of low frequency explosive or mechanical type sources for echo ranging purposes.

SCATTERING OF SOUND BY A PROLATE SPHEROID

I Introduction

The amount of sound scattered by a target is important in considering the feasibility of active sonar systems using the low audio frequencies. Although the sound that would be scattered by a submarine can be calculated if it is represented by an appropriate geometrical shape, such as a prolate spheroid, the calculations for the frequency range of interest involve as yet untabulated functions and have not been carried out*.

In the absence of the calculations, an experimental approach was adopted in order to obtain some information about the problem in a short time. Experiments, using models, were carried out during July 1954 in the anechoic chamber of the Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland. The models used were two prolate spheroids, one having a ratio of long axis to short axis of 2 and the other of 10. Some measurements were also made using a sphere in order to have a comparison with theory. In this report, only the results obtained with the more eccentric spheroid will be mentioned. Its shape approximates that of a fleet type submarine. The equivalent water frequencies covered by the measurements are in the range of 40 to 150 cps. The incident sound was perpendicular to the long axis of the model, analagous to beam aspect. Back-scattered sound was measured in the plane containing the long axis and incident beam at angles of 0°, 30°, and 60° with respect to the incident beam. With the sound incident in the direction of the long axis, analagous to bow or stern aspect, the scattered sound was too low in level to be distinguished from the background present.

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*Calculations by R. D. Spence and S. Granger, JASA 23, 701 (1951) are applicable to sound scattered by a submarine at frequencies up to 15 cps. D. Sternberg of this laboratory has noted errors in their work and is making calculations applicable to higher frequencies.

A report including the results obtained with the other models and the status of theoretical studies of the scattering problem is planned for the future.

II Method and apparatus

Pulsed sound was used in order to separate the scattered wave from the incident one. Measurements were made in air at frequencies in the range of 1500 to 6000 cps. Pulse lengths varied between 5 and 10 milliseconds.

The prolate spheroid model was accurately machined out of a solid piece of lucite. Its major and minor axes are 20 inches and 2 inches in length respectively.

The source to model and model to detector distance used in the measurements was 15 feet. This distance is sufficiently large compared to the dimensions of the model and wavelength of sound used so that measurements of the scattered wave can be considered to apply to the far field. It is also large enough so that sound waves from the source can be treated as plane in the region occupied by the model, within the accuracy of the measurements.

The sound source consisted of an Atlas driver unit, model PD-8VL, coupled to an exponential horn 2 feet in length and 1 foot in diameter at the mouth. It was powered by a McIntosh amplifier, type M-150a. The frequency of the oscillator driving the amplifier was monitored with a Berkeley model 554 EPUT meter. This device contains a decade scaling unit which counts the cycles of the frequency in question for an interval of one second, displays the result, and automatically repeats the procedure. The one second interval is derived from a built-in crystal oscillator. The audio oscillator could be easily set to within 0.1% of the desired frequency and was sufficiently stable so that it maintained its frequency to within 2 cps during the several minutes required for a measurement of echo amplitude. A gate circuit was interposed between the oscillator and power amplifier to permit pulsed operation of the sound source.

An Altec 21C condenser microphone was used as a detector. It was followed by a tuned amplifier of adjustable selectivity*, the output of which was displayed on a Tektronix model 512 oscilloscope. A synchronizing pulse from the gate circuit served to trigger the oscilloscope trace. The tuned amplifier was used with low selectivity, a Q of about 5, to preserve the shape of the pulses.

The source, model, and detector were suspended by strings from overhead supports. They were positioned in the lower half of the chamber because of echoes from the overhead supports which would mask the echo from the model unless it was separated from them in time. The echo arising from the model was identified from the others by swinging the model and noting the back and forth motion of its echo along the oscilloscope trace.

The quantity measured in these experiments is the ratio of the amplitude of the scattered wave to the amplitude of the incident wave at the model. The amplitude of the echo corresponding to the scattered wave was measured directly on the oscilloscope, by substituting an oscillator for the microphone signal. The output voltage of the oscillator, read with a vacuum tube voltmeter, and the calibrated amplifier attenuator were then adjusted so that the resulting deflection on the oscilloscope matched that of the echo. The voltage pulse across the voice coil of the driver was also measured by displaying it on the oscilloscope and matching its deflection to that of a measured CW signal. The echo amplitude was thus known for a given voice coil voltage. To measure the amplitude of the incident wave in the region occupied by the model, the model was replaced by the microphone and the microphone output voltage measured for a given voice coil voltage for each of the frequencies used in the measurements.

* The amplifier was designed by M. Lomask of this laboratory.

The peak power applied to the voice coil did not exceed one watt, well below the 30 watt rating of the driver and amplifier. The overall linearity of the system was checked by noting that the microphone output voltage was proportional to voltage across the voice coil of the driver for the values used in the measurements.

The ratio of the amplitude of the scattered wave to that of the incident wave is then simply the ratio of the corresponding microphone output voltages. Such factors as the absolute calibration of the microphone, the frequency response of the source plus microphone system, or the distortion of the sound field caused by the presence of the microphone are common to the two measurements making up the ratio and so need not be considered.

A slight distortion was noted in the waveform of the CW signal with which the voltage pulse across the voice coil was compared on the oscilloscope in order to determine its magnitude. Because of this distortion, the peak value of the voice coil voltage could not be assumed to be $\sqrt{2}\ V_{rms}$, where V_{rms} is the rms value of the CW signal. Using the oscilloscope to compare the peak value of the distorted signal with that of a pure sine wave voltage of the same rms value, the peak value of the distorted signal was determined to vary from $1.07\ \sqrt{2}\ V_{rms}$ at the highest frequencies used down to $1.00\ \sqrt{2}\ V_{rms}$ at the lower end. This factor has been taken into account. Any uncertainty in it is small compared to the estimated uncertainties in the measurements themselves.

The accuracy of the measurement of the echo from the model was limited by its being superimposed on a distribution of low level echoes visible on the oscilloscope trace. The origin of these echoes was not determined. They could not be explained as due to low level sound from the source during the interval between pulses. They might have resulted from small reflections from the wedge-shaped members making up the floor of the chamber. The source, model, and detector were lowered to 5 feet from the floor in order to avoid troublesome echoes from overhead crane supports, as has been previously mentioned.

Figure 1 illustrates the appearance of the oscilloscope trace with a relatively slow sweep of 10 ms/cm. The sound frequency was 3500 cps. The microphone was at an angle of 30° to the incident beam in the back direction. The large pulse at the left is the direct arrival from the sound source. The next largest pulse in the left half is the echo from the model. The echoes attributed to the overhead supports can be observed further along on the trace. Figure 2 shows just the region of the echo with a faster sweep of 2 ms/cm and illustrates the continuous background referred to above.

III Results

Figure 3 indicates the geometrical arrangement of the experiment. Measurements over the widest frequency range were made for the 0° position of the microphone. At the other angles, the smaller size of the echoes together with a more pronounced background at some frequencies restricted the region in which reliable data could be obtained. The frequencies for which the echoes were measured were selected to be integral multiples of the parameter $k(d/2)$, where k is $2\pi/\lambda$ and d is the inter-focal distance of the spheroid, in order to facilitate comparison with calculations being carried out for some of these values.

A summary of the measurements is given in Table I. The uncertainty in the values is estimated to be about 30%, mostly attributable to the presence of the background. $(p/p_0)_\Theta$ is the ratio of the amplitude of the back-scattered wave, r yards from the center of the model at an angle Θ with respect to the incident beam, to the amplitude of the incident wave for the case of broadside incidence. It appears to be insensitive to frequency over the measured range. In Table II, calculated values are given for the sound scattered by a submarine. They are derived from the values of Table I on the basis of the 20" spheroid representing a 300 ft. submarine.

An estimate of submarine target strength at the listed water frequencies can be made from these results. We take for the definition of target strength*, T = 10 log K. K is the constant in the expression

$$I_r = K\,(I_o/r^2)$$

where I_o is the intensity of the incident sound striking the target and I_r is the intensity of the scattered sound at the distance r in some specified direction. The units of K are taken to be square yards. Since the intensities are proportional to the square of the pressures,

$$K = r^2(p/p_o)^2$$

For the O° case, from Table II, the value $p/p_o = 20/r$ is representative for the frequency range measured. K then equals 400 giving for the target strength

$$T = 26 \text{ db}$$

This figure is about the same as those reported for ultra-sonic frequencies at beam aspect**. For sound incident at beam aspect, but with the angle of observation 30° or 60° with respect to the beam, the figures in Table II indicate a target strength of from 10 to 20 db lower than the above value.

It thus appears from these results that the submarine target strengths which would be encountered using low frequency sources, explosives or mechanical types, would be about the same at beam aspect as those obtained in the ultra-sonic region. It should be mentioned, however, that in planning field experiments, departures from free space transmission should be considered if the transducer and target are only a small number of wavelengths below the surface, or if sound channel effects are present.

Acknowledgement is due M. Lomask for his assistance in carrying out these measurements. We are also greatly indebted to G.S. Cook and T.F. Johnston of the Naval Ordnance Laboratory for placing the anechoic chamber at our disposal and for rendering very valuable advice and assistance in its use.

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* Chapter 19, Part III, Physics of Sound in the Sea, Vol. 8, NDRC Summary Technical Reports, Div. 6

** Ibid. Chapter 23

TABLE I : Scattering of sound from a prolate spheroid model. Ratio of long to short axis: 10. (see Figure 3 for the geometrical arrangement)

$$(p/p_o)_\Theta = A_\Theta / r \text{ yd}$$

Sound Frequency in air	k(d/2)	$A_{0°}$	$A_{30°}$	$A_{60°}$
1520 cps	7	0.13		
2180	10	0.14		
2830	13	0.12		0.012
3260	15	0.11		
3480	16	0.11	0.045	0.011
3690	17	0.12	0.029	0.018
4350	20	0.13		
4560	21	0.12	0.022	
6080	28	0.14	0.025	

TABLE II : Scattering of sound from a submarine based on the model values of Table I.

$$(p/p_o)_\Theta = A_\Theta / r \text{ yd}$$

Sound Frequency in water	k(d/2)	$A_{0°}$	$A_{30°}$	$A_{60°}$
37 cps	7	24		
52	10	25		
68	13	22		2.2
79	15	21		
84	16	20	8.1	2.0
89	17	22	5.2	3.2
105	20	23		
110	21	22	4.0	
147	28	25	4.5	

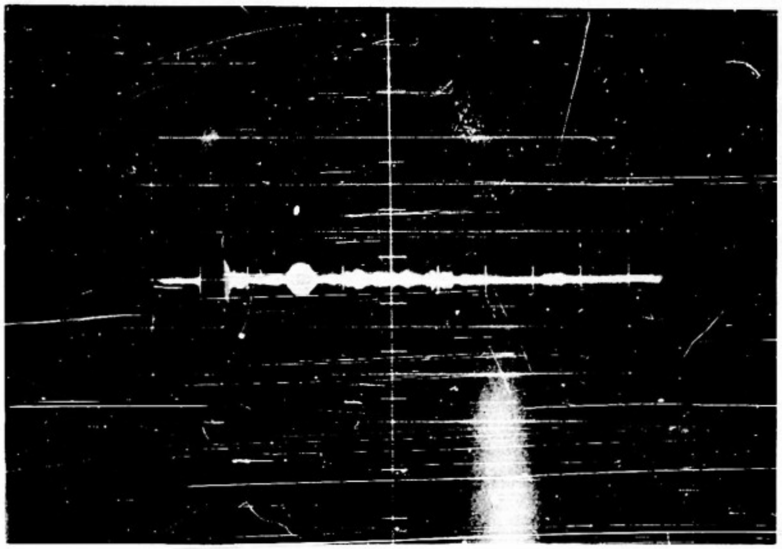


FIGURE 1

Incident beam broadside to spheroid. Microphone at 30° with respect to beam in the back direction 15 feet from spheroid. Large direct arrival followed by echo from model in left half of picture.

Sound Frequency: 3500 cps Sweep Speed: 10 ms/cm

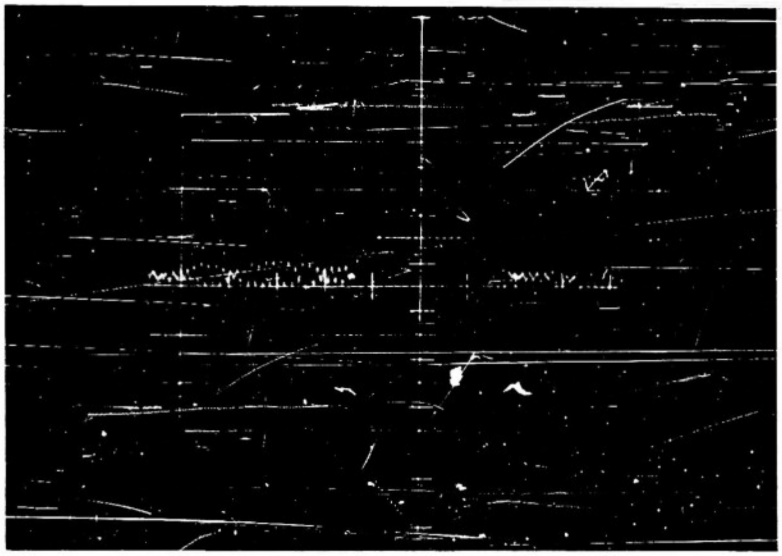
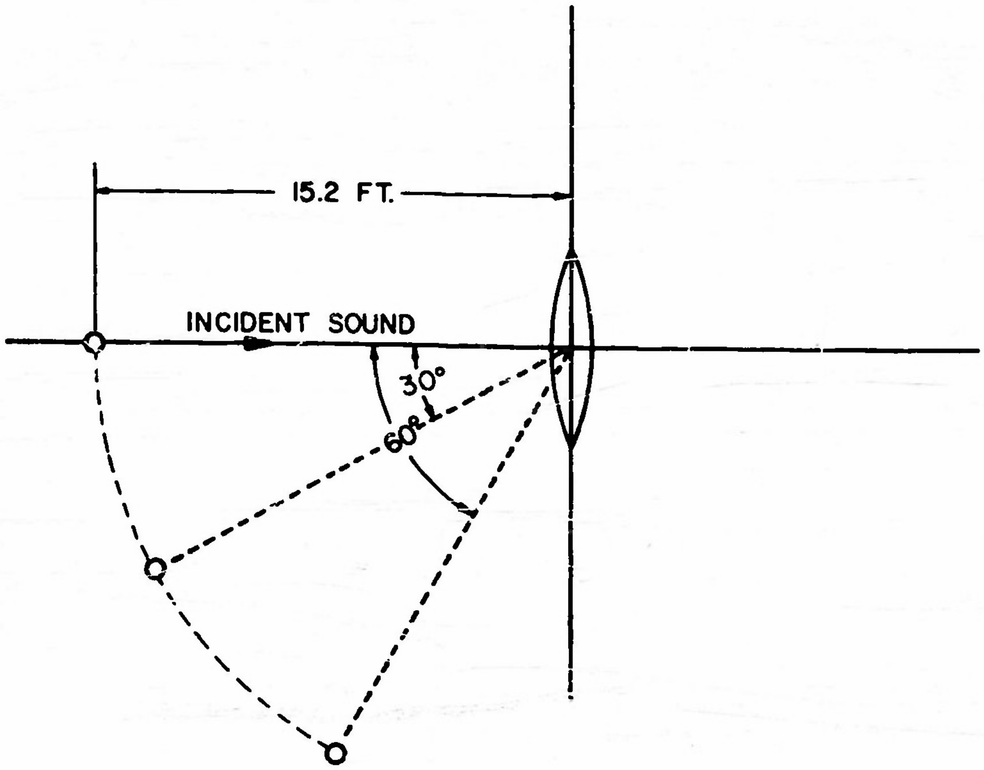


FIGURE 2

Echo region of Figure I Sweep speed: 2 ms/cm

GEOMETRICAL ARRANGEMENT OF THE EXPERIMENT



O:- DETECTOR POSITION

FIG. 3

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