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Abstract: An investigation of structured linings employing the principle of a gradual impedance transition from water to a sound-absorbent material has been made. Prototype metal loaded butyl rubber linings have been developed which consist of a molded panel of closely-packed right circular cones and an integral backing layer. Reflection characteristics were measured for three samples having this structure but differing in the type of metal loading. In addition, measurements were made on plane samples of each type of rubber, and also on samples of Sapeir, Insulkrete, and canvas. The technique consisted of subjecting the test panel to normally incident pulse-modulated sound and measuring the reflected sound pressure with a rotating probe hydrophone. The test panel was backed by a perfectly-reflecting flat plate which also was used as a reference reflector. By this method it was possible to obtain the reflected sound intensity as a function of polar angle (reflectivity pattern) and from this the scattering and absorption were computed. An aluminum-loaded butyl rubber specimen with a multiple cone surface had the best overall acoechoic characteristics of all samples tested, over a frequency range from 50 to 250 kc. Measurements on this sample were made from 20 kc to 1 Mc. The sound reflection coefficient (ratio of total acoustic power reflected to the total incident power) was at least -20 db over the frequency range covered and at 200 kc the coefficient had a maximum value of -32 db. The maximum reflected intensity was at least -23 db from 20 kc to 1 Mc and was -38 db at 200 kc.
This report describes the results of a research program supported by Foundational Research funds under Task No. FR-5-54. It is concerned with an investigation of several types of sound absorbent panels for use as linings in underwater anechoic tanks, and describes the development of the best wide band anechoic lining reported to date in the literature of ultrasonics. This report is intended for the information of scientific personnel concerned with the problem of doing underwater ultrasonics research or development and testing work.

EDWARD L. WOODYARD
Captain, USN
Commander

D. F. BLEIL
By direction
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(c) Admiralty Research Laboratory (Teddington), "Absorption of Acoustic Energy by Rubber Loaded Heavy Particles", ARL/M/N.1/25-50D, Aug 1949 (sec)

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<tr>
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<td>$\rho$</td>
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<td>Specific density</td>
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<tr>
<td>$\psi$</td>
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<td>Radial angle of the measurement plane - The angle determined by the x axis and a line which is the intersection of the measurement plane and a plane normal to the axis</td>
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I. INTRODUCTION

1. A problem of practical interest in the field of underwater acoustics is the development of linings or coatings which reduce sound reflections. Applications of sound absorbent linings include coverings for underwater ordnance material, linings for underwater acoustic tanks, and sound baffles in underwater acoustic devices of all types.

2. The work reported here is a preliminary study of the use of an absorbent lining with a structured surface designed to reduce the reflection of underwater sound. The surface structure of this lining consists of a closely-packed lattice of uniform right circular cones (Figure 1). The basic materials from which the structures were made were metal-loaded butyl rubbers. Three specimens were measured having this structure but differing in the type of metal loading added to the basic butyl rubber. Comparative measurements were made on flat samples of each of the above materials, and on German Fafnir, British Fafnir, Insulcrete, and canvas. The frequency range covered was from 50 kc to 250 kc for all samples. However, for the most absorbent sample, measurements were made from 20 kc to 1 Mc.

II. LINING REQUIREMENTS FOR TANKS

3. Relatively small, absorbently-lined tanks may be used in underwater acoustic measurements to simulate free field conditions over certain frequency ranges. For example, a tank having dimensions 5 x 5 x 10 ft and lined with German Fafnir, is in use at this laboratory at the present time (Figure 2). The frequency range of the measurements normally made in this tank are from about 50 kilocycles to several megacycles. Pulse techniques are used to minimize the interference caused by reflections from the walls of the tank. The success of the pulse method is based on the ability to separate wall reflections from the desired signal by the difference in arrival times. Since the pulse repetition rate is chosen to allow many reflections between pulses, the absorption per reflection need not be great. Hence, absorption requirements for a tank lining in this type of service are not severe.
FIG. 1
TEST SAMPLE OF LOADED
BUTYL RUBBER LINING WITH
A CONE LATTICE SURFACE
FIG. 2
MEASUREMENT TANK LINED WITH GERMAN FIRENIR
4. Consideration of Reflection Levels. Occasionally, however, difficulty has been experienced because of inadequate absorption by the lining, particularly when the length of the desired signal is necessarily longer than the shortest path length from a wall. Consequently, no time interval of sufficient duration (5 sec) for reception of the desired reflected signal is available which is free from appreciable wall reflections. For frequencies below a lower limit of about 40 kc, reflections interfere with the desired signal, since the pulse length needed for good frequency resolution is of the same order as the tank dimensions. Measurements made below this frequency become progressively more difficult and require special precautions. To alleviate this difficulty the lining must be sufficiently absorbent to reduce the initial reflections from all walls to a negligible value relative to the desired signal.

5. It is instructive to consider a spherical, absorbently-lined enclosure with a radius equal to some multiple half wave length of the sound and a simple source located at the center. The steady-state total intensity at the center, \( I_T \), is given by

\[
I_T = I_o \left( 1 + R_e + R_e^2 + R_e^3 + \cdots + R_e^{n-1} \right)
\]

or

\[
I_T = I_o \frac{1}{\frac{1}{1 - R_e}}
\]

where \( I_o \) is the source intensity and \( R_e \) is the reflection coefficient.

The \( n \)th-order term in the series gives the contribution of the intensity \( I_n \) of the \( n \)th reflection. If only the first order term, \( R_e \), is considered as contributing to the reflected intensity, the remainder, \( \tau \), is

\[
\tau = \left( \frac{1}{1 - R_e} - (1 + R_e) \right) I_o
\]

or

\[
\tau = \left( \frac{R_e^2}{1 - R_e} \right) I_o = R_e^2 I_o \quad \text{for} \quad R_e << 1
\]

The ratio of the remainder to the first reflection is then

\[
\frac{\tau}{R_e I_o} = R_e << 1
\]
That is, the error in considering only the first reflection is negligible since it is the same order of magnitude as the fraction of sound reflected on the first reflection. Since reflections in a rectangular tank tend to be more diffuse than reflections in a spherical tank (with a source at the center), consideration of only the first reflection would normally insure satisfactory operation. It should be noted that for cases where equation (5) holds, either pulse or continuous operation may be used.

5. Consideration of Mechanism of Reflection Reduction. The requirements for an effective tank lining are first, a good impedance match to water to allow the sound to enter the material; and second, the lining must be able to absorb the sound which enters. A property which can further increase the effectiveness of a lining for some types of measurements is scattering.
7. One may consider a plane sound wave normally incident on a plane lining backed by a rigid plate, Figure 3. If one uses a theoretical approach similar to that of reference (a), the ratio of reflected to incident pressure at the surface of the lining is given by

\[ \frac{P_r}{P_i} = \frac{Z_o - Z_w}{Z_o + Z_w} \]  \hspace{1cm} (6)

where \( Z_o \) is the acoustic impedance of the lining surface, and \( Z_w \) is the acoustic impedance of the water.

Inside the lining the impedance at any point is given by the following equation which is discussed in considerable detail in reference (h):

\[ Z(x) = \frac{P}{\nabla} = \frac{(\rho C)_m}{1 + i\alpha} \coth \left[ (\alpha + i\beta)x \right] \]  \hspace{1cm} (7)

where \( \rho \) is the excess pressure at \( x \)
\( \nabla \) is the particle velocity at \( x \)
\( \alpha \) is the attenuation constant
\( \beta \) is the wave number
\( \rho \) is the density, and
\( C \) is the phase velocity.

The subscript \( m \) refers to the lining. The variation of \( \alpha \) with frequency is dependent on the nature of the loss mechanism and for loaded butyl rubbers this has not yet been determined.

8. Then for \( x = -D \), where \( D \) is the lining thickness, the acoustic impedance at the interface is

\[ Z_0 = \frac{(\rho C)_m}{i\alpha} \coth \left[ (\alpha + i\beta)D \right] \]  \hspace{1cm} (8)

If the impedance is not to vary periodically with frequency, one must have the condition

\[ e^{-2\pi D} = \frac{P}{\nabla} ; \hspace{0.5cm} \frac{P}{\nabla} < < 1 \]  \hspace{1cm} (9)

for which the \( \coth \) approaches unity.
The way of satisfying this condition is to make $D$ very large and $\alpha$ small. If at the same time one chooses

$$(PC)_m \approx (PC)_w$$

one may obtain a highly absorbent lining without appreciable mismatch. However, a lining which fulfills this condition is undesirable for the present application because of the large amount of material and space which would be required.

2. If one satisfies the condition that the product $\alpha D$ be large by making $\alpha$ very large and $D$ small, then the expression for the impedance is

$$Z' = \frac{(PC)_m}{1 + (\lambda D)^2} \left(1 + j\frac{\lambda}{(\lambda D)}\right)$$

(11)

Although this impedance is complex and the impedance of water is real, one can minimize $|\lambda D|$ by equating the absolute values of these impedances. For a constant value of $\alpha D$, one has then

$$Z' = (PC)_m e^{j\tan^{-1}(\lambda D)}$$

(12)

The minimum value of $|\lambda D|$ is, therefore,

$$\frac{\lambda D}{\alpha D} = \frac{e^{j\tan^{-1}(\lambda D)} - 1}{e^{j\tan^{-1}(\lambda D)} + 1}$$

(13)

$$= \tan \frac{1}{2} \left( \tan^{-1}(\lambda D) \right)$$

(14)

$$\lambda D < \frac{\alpha D}{\pi}$$

$$\frac{\lambda D}{\alpha D} \approx \frac{\alpha}{\pi}$$

(15)

The above equation indicates that for a good match $\lambda$ must
be small, which is contrary to the requirement that \( \rho \) be large for high attenuation in the material. This would be especially restrictive at low frequencies where \( \lambda \) is large.

![Diagram of a flat lining preceded by an impedance transition medium](image)

**FIGURE 4.**

**DIAGRAM OF A FLAT LINING PRECEDED BY AN IMPEDANCE TRANSITION MEDIUM**

10. Consider now a transition medium having an impedance which varies gradually with \( x \), inserted in front of the lining, Figure 4. The impedance is continuous and at \( x = -(D + D') \) the value of \( Z_t(x) \) is made equal to \( Z_w \), and at \( x = -D \) it is made equal to \( Z_0^* \), i.e.,

\[
Z_{t}(-D) = Z_e^{'} = \frac{(PE)_{e}}{j \tau (\sigma_{e})_{e}} \left[ 1 + \frac{j\omega}{\gamma} \right]
\]  

(26)

Since the impedance of the transition medium is a gradual continuous function of \( x \), there is practically no reflection caused by acoustic mismatch.

The use of a structured lining is an attempt to simulate...
III. SELECTION OF SAMPLES FOR MEASUREMENT

A. Selection of Material

12. Loaded Butyl Rubber Materials. Prior to the selection of a material for the structured samples, normal reflection measurements had been made on a large number of small flat samples of different types of metal-loaded rubber. The samples were approximately 1/4 in. thick, 2 1/2 in. in diameter, and were metal backed. For each frequency a single narrow-beam transducer was used to transmit a pulse-modulated wave normal to the reflecting surface and to receive the reflected signal. The method of measurement consisted essentially of comparing the magnitude of the normally-incident waves from the metal-backed samples to reflections from a bare metal disc of the same normal cross-section. The ratio of the reflected amplitude from the sample to that from the metal reference plate expressed in db constitutes a lumped loss occasioned by insertion of the sample. This quantity is denoted in this report as $A_N$, the normal reflectivity index. The measured loss does not necessarily represent the attenuation in the material, since the impedance mismatch at the water-sample interface limits the sound which can enter the material. Under these conditions, increasing the thickness of the sample does not necessarily increase the observed loss.

13. The results of these previous measurements on disc samples were used as a basis for the selection of loaded-rubber materials for the cone-lattice structured samples. Some typical results curves of $A_N$ versus frequency, are shown in Figures 5, 6 and 7. In these figures the variable parameter is the percentage of loading material. Other parameters considered in this early work were the type of metal loading, processing of samples, size of loading particles, and the method of fastening the samples.

14. The materials finally decided upon for the present measurements were: Sample A (Figure 5) which consisted of equal parts by weight of aluminum powder and butyl rubber; Sample B (Figure 6) consisted of 93 parts of lead powder, 9.25 parts of zinc, 7.5 parts of butyl rubber; and Sample C (Figure 7) consisting of 250 parts of
Fig. 5 Normal Reflectivity Index of Loaded Butyl Rubber Flat Disk Samples

Metal Loading: Aluminum Powder
Varied Parameter: Metal Proportion

<table>
<thead>
<tr>
<th>Sample</th>
<th>Proportion (by weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25 PTS/100</td>
</tr>
<tr>
<td>B</td>
<td>100 PTS/100</td>
</tr>
<tr>
<td>C</td>
<td>200 PTS/100</td>
</tr>
<tr>
<td>OA</td>
<td>Unloaded</td>
</tr>
</tbody>
</table>

![Graph showing the effect of metal loading on normal reflectivity index with frequency on the x-axis and reflectivity index on the y-axis.](image)
FIG. 6 NORMAL REFLECTIVITY INDEX OF LOADED BUTYL RUBBER FLAT DISK SAMPLES

METAL LOADING: LEAD POWDER (95 PTS/100)
VARIED PARAMETER: CUMAR AND BLOWING AGENT

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>PROPORTION (BY WEIGHT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>9.25 PTS/100 CUMAR</td>
</tr>
<tr>
<td></td>
<td>0.1 PTS/100 BLOWING AGENT</td>
</tr>
<tr>
<td>E</td>
<td>9.25 PTS/100 CUMAR</td>
</tr>
<tr>
<td></td>
<td>1.0 PTS/100 BLOWING AGENT</td>
</tr>
<tr>
<td>F</td>
<td>9.25 PTS/100 CUMAR</td>
</tr>
<tr>
<td></td>
<td>2.0 PTS/100 BLOWING AGENT</td>
</tr>
<tr>
<td>OA</td>
<td>UNLOADED</td>
</tr>
</tbody>
</table>

FREQUENCY (KC)

R(N,db)
FIG. 7 NORMAL REFLECTIVITY INDEX OF LOADED BUTYL RUBBER FLAT DISK SAMPLES

METAL LOADING: LEAD POWDER
VARIED PARAMETER: METAL PROPORTION

SAMPLE | PROPORTION (BY WEIGHT)
--------|------------------------
G       | 160 PTS/100
H       | 25 PTS/100
I       | 320 PTS/100
OA      | UNLOADED
15. **Materials other than Loaded Butyl Rubber.** The material used for the wedge elements (German Fafnir) in the existing tank lining (Figure 2) is probably buta "S" rubber. This lining was formerly used in an anechoic tank in Germany and prior to installation in our tank was stored in air for a number of years. Examination of the wedges indicates that the rubber has deteriorated and is relatively hard. Results of measurements on this lining can, therefore, be interpreted only as characteristic of existing installation and not necessarily that of Fafnir in its original condition.

16. The basic material of the wedge elements identified in this report as British Fafnir, Figure 2, is butyl rubber. Since these wedges were in good condition, the results should be representative of this material.

17. Insulkrete is a material made from coarse sand dust and cement in the proportion of 4 to 1; Figure 9. This material is being used by Underwater Sound Reference Laboratory (USRL) as a lining for a high-pressure tank. Results of measurements made at USRL Reference (b), indicate that reflection caused by surface mismatch is rather low, of the order of -20 db compared to a reference reflection plate in the frequency range considered here. This material then constitutes one of the types mentioned in the preceding section which has a relatively low absorption per unit thickness but presents a fairiy good match at the interface.

18. Canvas was included in this study because it has been used as a cheap temporary lining in small tanks. The material used for these tests was 16-ounce duck arranged in large, somewhat arbitrary pleats.

**B. Selection of Structure**

19. The proposal of a structure for simulating a medium with a transition layer, discussed briefly in Section I, was introduced by Rayleigh; Reference (c). Rayleigh mentions the possibility of transmitting sound without reflection from one medium to another when the boundary between the two is a deeply corrugated surface with a periodicity less than the wavelength of the incident sound. Under these conditions incident sound encounters a gradual change in acoustic properties in the transition region. A minimum reflection on the normal cross section of the transition medium and other to be that met in horn theory, namely, the
FIG. 8

TEST SAMPLE OF BRITISH FARNIR LINING
FIG. 9
TEST SAMPLES OF INSULKRETE TANK LININGS
FIG. 10
TYPICAL VIEWS OF FAFNIR STRUCTURE
requirement that the change of section and rate of change of section occur in a gradual continuous manner throughout the transition length, including the boundaries, reference (d). Then, also, as in horn theory, one can state that such a change of section implies a gradual continuous change of impedance.

20. German Fafnir. The principle of gradual transition has been successfully applied to the experimental development of sound-in-air absorbent linings, and more recently as reported by Meyer in reference (e) to the development of underwater sound absorbent linings. In the development of these underwater sound linings, various materials with elastic hysteresis and various shaped structures were tried. The final version of the lining, called Fafnir, was constructed of flat triangular rubber wedges with included air spaces.

21. The structure consists of rows of these elements mounted on a wood backing plus the water canals or ducts in the spaces between the rows (see Figures 2 and 10).

FIGURE 12.
DIAGRAM INDICATING TRANSITION CROSS-SECTION OF GERMAN FAFNIR LINING
The factors involved in this particular case of gradual transition may be inferred from a study of the variation of the cross section of the lining with the distance from the backing, Figure 11. If one considers only the wedges, a discontinuity in impedance exists at $x = 0$ due to a change in the cross section and at $x = -D$ due to the rate of change of cross section. The problem was to select dimensions and spacing of the wedges which would minimize these discontinuities by adjusting the acoustic properties of the water-filled canals. The final selection was made after many tests in which a single parameter was varied while the others were held constant. For a wedge cross section of 25% of the total area at $x = 0$, the structure, according to reference (e) resulted in reflection pressures of 10% of those of the incident sound wave. This reduction held between a lower cutoff frequency for which the wedge length equals a half wave length and an upper cutoff frequency for which the spacing of the canals was equal to a half wave length. It was indicated in reference (e) that the properties of the canals affect the lower and higher frequencies. Near the lower cutoff frequency, the small ratio of spacing to wave length caused the velocity of water in the canals to be decreased which, in turn, caused an impedance mismatch at the tip of the wedge. At the high-frequency cutoff the increased ratio of spacing to wave length allowed sound to enter the structure and to be reflected from the wood backing. An array consisting of a sequence of two rows of wedges 11 cm long and 1 cm thick followed by a row of wedges 21 cm long and 1 cm thick and spaced approximately 3 cm apart was found in reference (e) to increase the band width, so that the lining was effective from about 5 to 40 kc. Another factor considered in reference (e) and used for determining the parameters of our structure was that for a cross-sectional area of wedge of 50% of the total area at $x = 0$, the effect of the backing was not appreciable for wedge lengths equal to or greater than a quarter wave length. This percentage of material could not be used for the Fainir array of reference (e) without introducing an appreciable increase in the effect of the discontinuity at $x = -D$ (Figure 11) occasioned by an increase in the rate of change of cross section of the wedge structure.

22. British Fainir. In order to investigate the effect of increasing the cross section of approximately 100%, a structure was made from wedges of British Fainir such that adjacent rows of elements were in contact with one another (Figure 3). The structed sample is about 40 cm square overall. These wedge elements differ from those described in the preceding paragraph in that the edges are portions of large circles, 12.5" radii, terminating in a semicircle of radius of approximately 3/32 in.

The Fainir material installed in the NOL tank consisted of right triangular rubber wedges of lengths 10 and 20 cm with a spacing of 2 cm instead of the dimensions mentioned in the text for the Fainir (e). This would increase the upper cutoff frequency of the lining, as indicated in the text.
The base, thickness, and height are respectively 1 cm, 1 cm, and 10 cm corresponding to the smaller wedges discussed previously. The included air spaces are formed by slats parallel to the base, reference (c). In the present sample alternate rows of the elements are displaced one-half the width of a wedge parallel to the rows. The canals formed between the wedges are thus narrowed to the thickness of an element of about one cm, which should raise the upper cutoff frequency to approximately 70 kc. The resulting cross-sectional area versus distance from the wedge backing plate is shown in Figure 12.

The discontinuity at the base of the wedge, effective above the high-frequency cutoff, is considerably reduced by this arrangement.

21. Long-lattice Structure. From a consideration of the frequency limitation of Fabric mentioned in paragraph 21, it appeared impractical to attempt to design a lining with this type of structure which would cover the desired frequency band, namely 10 kc to several megacycles. Accordingly, a structure was designed which eliminated immediate discontinuities in the transition medium to a large extent. The structure consists of a lattice of
FIG. 13
TYPICAL VIEWS OF CONE LATTICE STRUCTURE
cones, illustrated by Figures 1 and 13, so positioned as to minimize the exposed flat area of the backing. The cones and backing consist of one molded unit of loaded butyl rubber. The dimensions of the cone elements were selected by using the results of reference (e) as a general guide. A length of 3.75 cm was chosen, which corresponds to a lower cutoff frequency of approximately 10 kc. The cone generating angle was chosen as small as practical, namely 15°. The radius of the cone base is approximately one cm. The test panels are approximately 22 cm square and 5 cm deep which includes a thickness of 1.25 cm for the base. In Figure 13 it will be observed that each cone is surrounded by six tangent cones. The exposed areas of the plane backing approximate small triangles. The percentage of area exposed is approximately 9% of the total section. Although it is possible to eliminate this flat area with the associated discontinuity, it was felt that for the purposes of this preliminary investigation it would be instructive to measure the reflection characteristics with the discontinuity present and to note the frequency at which the effect of the discontinuity becomes noticeable. From reference (e) one might expect this frequency to be around 250 kc, since at this frequency the maximum dimension of one of the "triangles" is equal to a half wave length. Also one would expect the level of the reflected sound to be of the order of 10 db below that for a flat sample of the same material. This is based on the percent of total area exposed. An additional consideration in the selection of this structure was the simple geometrical relationship between surface and volume versus distance from the cone tips which would be of value in any future theoretical study of the mechanism of gradual transition.

![Diagram](image-url)
24. Figure 14 gives the cross-sectional area versus distance from the cone tip of the multiple cone sample. Observe that there is a smooth transition at the cone tips \((x = -(D + D'))\), both the change of section and the rate of change of section approximate zero at this point. The plane area at the back of the structure \((x = -D)\) is reduced to approximately one-seventh of that shown in Figure 11 for German Faunir and can be practically eliminated by incorporating conical holes in the exposed sections of the backing (note dotted lines). The section of water included between the cones gradually tapers with distance from the wedge tips so that the discontinuity encountered with the Faunir linings due to the canals is not present.

25. It is realized that the structures studied here are proposed for use at much lower wave length-to-dimension ratios than those included in Rayleigh's work on gradual transition. The phase surfaces at these frequencies are no longer plane and the mechanism of sound transmission from water into the material is very complicated both because of the involved shape of the structure and the complex behavior of the material. Hence, this investigation has been essentially experimental.

26. The physical characteristics of the samples studied are summarized in Table I. The table also gives code numbers and figure numbers which illustrate the respective samples. The first digit of the code number refers to the sample material and the second digit denotes common physical characteristics where practical.
### PHYSICAL CHARACTERISTICS OF LINING SAMPLES

<table>
<thead>
<tr>
<th>FIG. NO.</th>
<th>SAMPLE CODE</th>
<th>STRUCTURE</th>
<th>ELEMENT</th>
<th>SAMPLE DIMENSIONS</th>
<th>MATERIAL</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SAMPLE</td>
<td>STRUCTURE</td>
<td>TYPE</td>
<td>HEIGHT</td>
<td>THICKNESS</td>
</tr>
<tr>
<td>01</td>
<td>PLANE</td>
<td>21</td>
<td>22</td>
<td>0.3</td>
<td>BRASS</td>
<td>BACED WITH 0.6 CM CORK, P = 1.25</td>
</tr>
<tr>
<td>02</td>
<td>PLANE</td>
<td>40</td>
<td>40</td>
<td>0.3</td>
<td>BRASS</td>
<td>BACED WITH 0.6 CM CORK, P = 1.25</td>
</tr>
<tr>
<td>03</td>
<td>PLANE</td>
<td>45</td>
<td>45</td>
<td>0.3</td>
<td>BRASS</td>
<td>BACED WITH 0.6 CM CORK, P = 1.25</td>
</tr>
<tr>
<td>12</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>5</td>
<td>LEAD-LOADED BUTT RIBBER</td>
<td>P = 2.61</td>
</tr>
<tr>
<td>13</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>1.25</td>
<td>LEAD-LOADED BUTT RIBBER</td>
<td>P = 2.61</td>
</tr>
<tr>
<td>21</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>5</td>
<td>ALUMINUM-LOADED BUTT RIBBER</td>
<td>P = 1.23</td>
</tr>
<tr>
<td>22</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>1.25</td>
<td>ALUMINUM-LOADED BUTT RIBBER</td>
<td>P = 1.23</td>
</tr>
<tr>
<td>21</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>5</td>
<td>LEAD-LOADED BUTT RIBBER WITH CORK AND INSULATING AGENT</td>
<td>P = 2.075</td>
</tr>
<tr>
<td>22</td>
<td>LATTICE</td>
<td>23</td>
<td>22</td>
<td>1.25</td>
<td>LEAD-LOADED BUTT RIBBER WITH CORK AND INSULATING AGENT</td>
<td>P = 2.075</td>
</tr>
<tr>
<td>21</td>
<td>(PAPER)</td>
<td>23</td>
<td>22</td>
<td>5</td>
<td>TISSUE</td>
<td>Dmfused in water</td>
</tr>
<tr>
<td>22</td>
<td>(PAPER)</td>
<td>23</td>
<td>22</td>
<td>1.25</td>
<td>TISSUE</td>
<td>Dmfused in water</td>
</tr>
<tr>
<td>21</td>
<td>(PAPER)</td>
<td>23</td>
<td>22</td>
<td>5</td>
<td>TISSUE</td>
<td>Dmfused in water</td>
</tr>
<tr>
<td>22</td>
<td>(PAPER)</td>
<td>23</td>
<td>22</td>
<td>1.25</td>
<td>TISSUE</td>
<td>Dmfused in water</td>
</tr>
<tr>
<td>61</td>
<td>IRREGULAR</td>
<td>40</td>
<td>40</td>
<td>5</td>
<td>CANVAS</td>
<td></td>
</tr>
</tbody>
</table>

**SEE NOTE PAGE 18**
IV. LABORATORY APPARATUS

27. Description of System. The apparatus for producing normally incident, pulse-modulated sound waves and for measuring the reflectivity pattern is illustrated in Figure 15.

28. A delayed trigger from a Tektronix oscilloscope, Type 512, initiates a square pulse which modulates the carrier from the signal generator. This pulse-modulated wave is amplified and then drives the projector through a matching network. The projector produces a narrow beam of pulse-modulated sound waves which are normally incident on the specimen. Reflections from the specimen are received by the rotating probe hydrophone and the voltage generated is sent through a matching network to the gated receiver which is triggered by the oscilloscope. The receiving gate can be set to correspond to the beginning of the desired reflected signal by an adjustable time delay. After amplification the signals are applied to the polar recorder which is designed to produce a continuous logarithmic plot. The angular position indicated by the recorder is made to correspond to the hydrophone orientation by the use of a selsyn system.

29. Arrangement of Apparatus. The arrangement of the apparatus is illustrated in Figures 16 and 17. Reference reflection plates were made of 1/6 inch brass plate backed by 1/4 inch copper. They were suspended vertically from the rotation framework by a 1/32 inch wire rope. The plate was held vertical by a weight which was covered with sound-absorbent material. The specimen was fastened to the reflecting plate by gum-rubber bands. The center of the sample was positioned at 50 cm below the surface of the water to allow for approximate centering of the sample between the water surface and the positioning weight (which was covered with an acoustic absorber).

V. MEASUREMENTS

A. Measurement Program

30. The measurement program consisted of the four parts outlined below. All measurements were made with sound normally incident on the reflecting surface, and unless specified otherwise were made in a single plane ($\phi = 0$). (The orientation of the $\phi$ planes are explained later.)

a. The measurement of all samples in the frequency range from 50 to 250 kc in increments of 50 kc.

b. Measurements on a cone-lattice sample and the German and British Peenir samples in the radial plane $\phi = 0$ and $\phi = 90^\circ$ to determine the effect on reflection characteristics caused by axial symmetry of the sample surface.
FIG. 15 SYSTEM FOR MEASUREMENT OF ACOUSTIC ABSORPTION

PULSE LENGTH 0.1 TO 1.0 MILLISECOND
PULSE REP. FREQ. 50 TO 200 C.P.S.
FIG. 17
ARRANGEMENT OF SAMPLE AND UNDERWATER EQUIPMENT
c. The measurement of the most promising structured sample, No. 21, the aluminum loaded one, and the corresponding flat sample, No. 22, at smaller frequency increments. This provided detailed information on the reflection characteristics versus frequency in the region between the 50 kc spot frequencies.

d. Measurement of Sample No. 21 at points 50 kc apart over a frequency range from 20 kc (the lowest practical frequency) to 1 Mc, to determine the expected useful frequency range of a tank lined with this material.

B. Theory of Measurements

31. The method of measuring the reflection coefficient described in paragraph 8 is practical if the reflectivity pattern of the specimen is not substantially different from the reflectivity pattern of the plate; this was the case for the flat samples previously discussed. However, a structured specimen can introduce a substantial change in the reflectivity pattern. The reflectivity pattern is critically dependent on the proper alignment of projector and sample, and this is difficult to achieve. Maximum reflection does not ordinarily occur normal to the sample. Furthermore, there is sufficient scattering so that even if we compared this maximum reflection to the maximum reflection from a plate, it would not accurately indicate the absorption characteristics of the specimen. A technique devised to take account of these difficulties consists of utilizing a separate hydrophone for measuring the reflected signals. The hydrophone is rotated in a plane which passes through the axis of symmetry of the projector and normal to the sample or reference plate, Figure 18. The reflectivity patterns thus obtained, first with a reflecting plate and then with a specimen, together with the values of maximum reflection, are used for calculating the reflection and scattering coefficients from the structured samples.

32. If sound from a projector falls on a surface, the reflected power, \( P \), through a hemisphere of radius \( r \) is given by (see Figure 15)

\[
\rho = \rho \int_{0}^{\pi} \frac{d\psi}{2} \int_{0}^{2\pi} I(\theta, \psi) \sin \theta \, d\psi \, d\theta.
\]

where

\( \theta \) is the polar angle measured from the projector axis of symmetry about an origin on the surface of the sample. \\
\( \psi \) is the radial angle measured from the \( x \) axis in the plane about the projector axis of symmetry (\( y \) axis). \\
\( I(\theta, \psi) \) is the reflected intensity, a function of both \( \theta \) and \( \psi \), \\
29
FIG. 18

GEOMETRY OF EXPERIMENT
axially symmetric about a common axis, then the reflected pattern will be axially symmetric about this axis. In this case the intensity, \( I \), is independent of \( \theta \). The reflected power from a metal reference plate, \( P_p \), is

\[
P_p = 2\pi r^2 \int_0^{\pi/2} I_p(\theta) \sin \theta \, d\theta
\]  

(18)

33. Axially Symmetric Samples. For a sample for which one can assume axially symmetric reflections, the reflected power, \( P_3 \), is similarly

\[
P_3 = 2\pi r^2 \int_0^{\pi/2} I_3(\theta) \sin \theta \, d\theta
\]  

(19)

\( I(\theta) \) in equations (18) and (19) may be measured by rotating the probe hydrophone shown in Figure 18, in the \( xy \) plane from \( \theta = 0 \) to \( \pi/2 \). According to reference (f) the reflection coefficient is defined as: "The sound reflection coefficient of a surface not a generator is the ratio of the rate of flow of sound energy reflected from the surface, on the side of incidence, to the incident rate of flow". If the metal reference plate is a perfect reflector, the reflected power \( P_p \) is equal to the incident power. The reflection coefficient, \( R_c \), may be then defined as

\[
R_c = \frac{P_3}{P_p} = \frac{\int_0^{\pi/2} I_3(\theta) \sin \theta \, d\theta}{\int_0^{\pi/2} I_p(\theta) \sin \theta \, d\theta}
\]  

(20)

\( R_c \) can be defined more generally if the single integrations in equation (20) are replaced by the double integrations appearing in equation (17).

34. Kendig and Kueber, reference (g), have devised a means of computing the power radiated from an axially symmetric source, such as given by equations (18) or (19), by a planimeter measurement of the area under a reflectivity pattern plotted on special coordinate paper (Figure 19). The angle is plotted as the abscissa expressed in degrees and scaled in terms of the function \( V = \cos \theta \). The intensity is plotted as the ordinate expressed in db down from the peak reflection, and is scaled to give a linear
FIG 19 ILLUSTRATION SHOWING USE OF POWER CHARTS FOR CALCULATING REFLECTION INDICES, R, Q, AND S

FREQUENCY 150 KC
SAMPLE NO 21 ALUMINUM LOADED BUTYL RUBBER
STRUCTURE GONE LATTICE

REFLECTIVITY PATTERN OF SAMPLE NO 21
PATTERN NO 21-41

REFLECTIVITY PATTERN OF REFERENCE PLATE NO 01
PATTERN NO 01-41

(RECORDING LEVEL 995 dB ABOVE THAT OF THE REFERENCE PLATE)

POWER REFLECTED FROM SAMPLE NO 21
(-30 DEGREES TO +30 DEGREES)

\( S = 9.3 \, \text{dB} \)
\( N = 0.05 \, \text{dB} \)
\( P = 3.8 \, \text{dB} \)

POWER REFLECTED FROM REFERENCE PLATE NO 01
(-30 DEGREES TO +30 DEGREES)

\( A_r = 521 \, \text{sq in} \)

ILLUSTRATIVE COMPUTATION

\[ \text{SHL} = 10 \log \frac{P_{\text{SHL}}}{P_{\text{REF}}} = -0.3 \, \text{dB} \]

\[ \text{CALC} = 10 \log \frac{P_{\text{CALC}}}{P_{\text{REF}}} = -0.5 \, \text{dB} \]

\[ \text{ICAL} = 10 \log \frac{P_{\text{ICAL}}}{P_{\text{REF}}} = -3.6 \, \text{dB} \]

THE 75 IN THE FIRST EQUATION IS A SCALE FACTOR BETWEEN CHARTS 4. AND 8.
Intensity plot. We can rewrite equation (4) to conform more closely to the computations as follows:

\[ R = \frac{I_{\text{m}}}{I_{\text{m}} + 10 \log_{10} \frac{A_{p}}{A_{s}}} \]  

or for brevity

\[ R = \frac{I_{\text{m}}}{I_{\text{m}} + A_{p}/A_{s}} \]  

Exposed in db,

\[ R = 10 \log_{10} \frac{I_{\text{m}}}{I_{\text{m}} + 10 \log_{10} \frac{A_{p}}{A_{s}}} \]  

\[ = A + S \]  

where \( R \) is the reflectivity index (the reflection coefficient expressed in db).

\( A \) is the peak reflectivity index, the first term in equation (23) and

\( S \) is the scattering index, the second term in equation (23).

35. It is obvious that of the three quantities, \( R, A, \) and \( S \) only two are independent. For example, any condition which would cause a strong reflection from the sample to occur without appreciably increasing \( R \) would mean an increase in \( A \) and a corresponding decrease in \( S \). The two latter parameters then indicate in a general way the distribution of sound reflection introduced by the lining. The peak reflectivity index, \( A \), indicates the maximum reflection one might expect from a sample in any direction. Since \( A_{p} \) represents specular reflection from the plate the scattering index \( S \) provides a measure of the deviation from specular reflection of sound reflected from the sample. The reflectivity index, \( R \), is an overall measure of the absorption. One may obtain the absorption loss in per cent from the equation

\[ \sigma = \left[ 1 - \frac{A_{p}}{A_{s}} \right] \times 100 \]
A structure such as that of the one-lattice sample, Figure 13, is not axially symmetric but varies with $\psi$ in a periodic manner. The power reflected from the sample as given by the exact general expression, equation (17), may be approximated in this case by making pattern measurements at small equal divisions extending over a half period. Thus, the approximate power reflected $P_\psi$ is given by

$$P_\psi = \frac{2\pi}{\eta} \int_0^{2\pi} \left[ \sum_{i=1}^N \frac{\bar{A}_i}{\bar{I}_i} \right] \sin \theta d\theta$$

(25)

where:

$N$ is the number of increments $\psi$ in a half period.

$i$ as a superscript indicates that values of the parameter are measured in the plane of $\psi$.

Through a procedure similar to that followed for the axially symmetric case the new reflectivity index $R$ is

$$R_a = 10 \log_{10} \left( \frac{P_a}{P_p} \right) = 10 \log_{10} \left[ \frac{\sum_{i=1}^N \bar{A}_i}{\bar{I}_{\text{max}} \bar{A}_p} \right]$$

(26)

The scattering index is

$$S_a = 10 \log_{10} \left[ \sum_{i=1}^N \frac{\bar{A}_i}{\bar{I}_{\text{max}}} \right]$$

(27)

The peak reflectivity indices are defined as:

$$A^* = 10 \log_{10} \frac{I_{\text{max}}}{I_{\text{peak}}}$$

(28)

and

$$A_a = R_a - S_a$$

(29)
where $\Delta \gamma$ can be thought of as the peak reflectivity index for a hypothetical axially symmetric structure with values of $k$ and $l$ equal to $n_m$ and $S_9$ respectively. The index, $\Delta \gamma$, is the maximum peak-reflectivity measured for any angle $\varphi$. For a particular sample the number of increments, $n$, necessary for a specified accuracy depends on frequency, the directional characteristics of a hydrophone, and the dimensions of the setup; this may be determined experimentally. Also, measurements may be made over the polar angle range from $\Theta = -\pi/2$ to $\Theta = \pi/2$ in the plane specified by the radial angle $\varphi_k$. The results correspond to taking an average of two measurements at equal angular phase for all samples of this experiment. The latter procedure also helps to compensate for errors due to misalignment.

37. Periodicity of Selected Samples. It may be noted that the cone-lattice structure (Figure 13) has an angular periodicity in $\varphi$ of $\pi/3$. A measurement in the plane of Section A-A corresponds then to the average of two measurements of the type $\varphi = \varphi_k = (2\pi/3)$ and a measurement in the plane of the Section B-B to the average of two measurements for $\varphi = \varphi_k = (\pi/3 + \pi + 2\pi/3)$, where $n$ is an integer. These two measurements were assumed to be sufficient to indicate approximately the variation of the reflection characteristics with $\varphi$ for the cone-lattice structure.

38. The periodicity in $\varphi$ for the Fafnir samples is $\pi$. If equal increments are desired one should take more increments for the Fafnir sample because of its larger period. However, measurements are only made in planes at 90 degrees for this preliminary investigation (corresponding to those for the cone-lattice sample).

C. Application of the Technique

39. The factors which influence the choice of measurement parameters in a practical application of the technique described above are the acoustical and geometrical characteristics of the specimen, the tank, the transducers, and the frequency range over which measurements are desired. The frequency range considered is from 20 kc to 1 Mc. Measurements at frequencies below 20 kc are of interest but could not be made satisfactorily in the existing tank.

40. Projector Parameters. There are two opposing requirements which govern the selection of the size of the projector. First, a uniform illumination over a sufficient portion of the specimen is necessary to make representative reflection measurements for the selection of a material for a tank lining. A reasonably uniform illumination is obtained with a piston-type projector. In a piston-type machine, $h$ should be small enough to allow operation
in the Fraunhofer region (reference (h)) i.e., that

\[ a \leq \sqrt{\frac{D_p}{\lambda}} \]  \hspace{1cm} (30)

where \( D_p \) is the distance from projector to sample, and \( \lambda \) is the wavelength of sound in water. For the cone structures, the minimum width of uniform illumination was selected at about 8 cm - the width of four cones. That this constitutes a sufficient portion of the lining was verified experimentally. The width of uniform illumination for a piston source was taken to be that between the half-power points, indicated by the angle \( \beta \) in Figure 20. The pressure versus the polar angle \( \theta \) from a piston source for distances for which equation (30) is valid is given in reference (h) as

\[ p = p_0 \left[ \frac{2J_1(na \sin \beta)}{na \sin \beta} \right] \]  \hspace{1cm} (31)

The pressure is a maximum for \( \beta = 0 \) and decreases with increasing polar angle and reaches the half-power point when

\[ \sin \beta' = \frac{\lambda}{4a} \]  \hspace{1cm} (32)

and passes through zero when

\[ \sin \beta_0 = \frac{0.614 \lambda}{D} \]  \hspace{1cm} (33)

Let \( D_w \) be the distance in the plane of the sample between the two half-power points, i.e.,

\[ D_w = 2D_0 \tan \beta \]  \hspace{1cm} (34)

The uniform illumination over the sample, it is advantageous to have \( D_0 \), the distance from the projector to the sample, as

\[ D_0 \]  \hspace{1cm} (35)

\[ a \]  \hspace{1cm} (35)

Since a space of 100 cm was required behind the sample in order to separate reflections from the sample and the back wall, a distance of 150 cm was
FIG. 20

DIAGRAM OF GEOMETRIC RELATIONSHIP OF PROJECTOR BEAM TO SAMPLE AND TANK
selected for \( D_p \). If \( D_w/D_p \ll 1 \), equation (34) can be written

\[
D_w = 2 D_p \sin \beta'.
\]

The requirement given by equation (30), i.e., that the sample be in the Fraunhofer region, can now be expressed in terms of \( D_w, D_p, \) and \( \lambda \) as follows:

\[
D_w = \frac{\sqrt{\lambda D_p}}{2}. \tag{36}
\]

41. The second requirement on the size of the projector is that the intensity of the sound incident on the walls of the tank or the water surface be low. This is necessary because of the relatively low-level reflections from the samples. The condition that the main beam not illuminate the sides of the tank or the water surface between the projector and the sample can be expressed as

\[
\beta_p \leq \tan^{-1} \left( \frac{D_p}{D_w} \right), \tag{37}
\]

where \( D_p \) is the working width or depth, these being approximately equal for this tank. By using the relationship between the angles \( \beta_p \) and \( \beta' \) given by equations (32) and (33) and by using equation (36), the requirement expressed by equation (37), which places a lower limit on \( D_w \), becomes

\[
D_w \leq D_p \sin \left[ \tan^{-1} \left( \frac{D_p}{D_w} \right) \right] \tag{38}
\]

It is convenient to express \( D_w \) relative to the sample width \( D_s \) as \( w = D_w/D_s \).

Thus, equations (36) and (38) can be written

\[
\frac{\sqrt{\lambda D_p}}{2} \leq w \leq \frac{D_p \sin \left[ \tan^{-1} \left( \frac{D_p}{D_w} \right) \right]}{1.22 D_s} \tag{39}
\]

This value of \( w \) was found to be satisfactory for all frequencies except for a small interference from reflector side lobes necessitating the use of 75 cm.
If \( D_p = 150 \text{ cm}, \) \( D_f = 150 \text{ cm}, \) and \( D_b = 22 \text{ cm}, \) the above equation becomes

\[
0.394 \leq \frac{1}{\alpha} \leq 1.76 .
\]  

(40)

42. In terms of the projector radius, the above condition is

\[
\sqrt{\frac{\lambda D_p}{2\alpha}} \geq a \geq \frac{0.61}{\sin \left[ \tan^{-1} \left( D_b / 2D_f \right) \right]},
\]  

(41)

since

\[
a_n = \frac{D_p - D_f}{2\alpha}.
\]  

(42)

from equations (3) and (6); and if the numerical values listed above are inserted, the restriction on the projector radius is

\[
8.67 \geq a \geq 1.93 .
\]  

(43)

Plots of equations (40) and (43) are given in Figures 21 and 22 respectively.

43. **Hydrophone Radius.** It is necessary to select a hydrophone of small radius in order that the shadow zone on the sample does not materially alter the reflection from the sample. The hydrophone shadow can be reduced by increasing the ratio \( D_f / D_b \), where \( D_f \) is the distance of the hydrophone to the sample. On the other hand \( D_b \) must not be made too small or the uniformity of illumination of the sample will be appreciably affected. For the latter condition the radius of the hydrophone case must be

\[
a_n \leq \sqrt{\frac{\lambda D_f}{2\alpha}}.
\]  

(44)

The minimum value of \( \alpha \) is 0.146 cm at the M. and the minimum value of \( D_p \) is 50 cm. Hence,

\[
a_n \leq \sqrt{\frac{0.146 \cdot 50}{2}} \times 1.91 \text{ cm
\]  

(45)

The radius of the hydrophone case selected was 0.34 cm.
LIMITING EQUATION: $0.394 \sqrt{\lambda} \leq r_w \leq 1.77$

22 CM SAMPLE

$r_w \geq 0.394 \sqrt{\lambda}$ DEFINES THE FRAUNHOFER REGION

**EFFECTIVE TANK WIDTH**

$r_w = 1.77$

**SAMPLE WIDTH**

**4 CONE BASE WIDTH**

**FIG. 21**

RESTRICTIONS ON PROJECTOR BEAM WIDTH

BEAM WIDTH vs FREQUENCY
LIMITING EQUATION: $8.65 \sqrt{\lambda} \geq a \geq 1.93 \lambda$

This indicates frequency range for given transducers.

SAMPLE: 22 cm

FIG. 22 RESTRICTIONS ON PROJECTOR BEAM WIDTH
RADIUS vs FREQUENCY
It is desirable that the directivity pattern of the hydrophone be great enough to "see" the surface of the sample illminated by the projector. The beam width is plotted as a dotted line in Figure 21 in accordance with the following equation

$$Y = \frac{Y_0}{D} = \frac{1}{1 + \frac{3}{C}}$$

It may be observed that the beam width of hydrophone XB9A exceeded the beam width of all of the projectors except the E-8 which was used at the high frequencies. For these higher frequency measurements the hydrophone beam width was approximately a third of that of the E-8. The minimum hydrophone beam width (at 1 Mc.) was such that it intercepted sound from an area having a diameter equal to the width at the base of four adjacent cones. This was tentatively accepted as the minimum width to get a representative reflection measurement.

45. **Pulse Parameters.** The pulse length in water should not exceed double the distance from the hydrophone to the specimen in order that the tail of the incident signal would not interfere with the reflection. Actually it was found to be more convenient to use about two-thirds of this value, which corresponds to a pulse duration of about 0.45 milliseconds. The repetition rate was set at about 150 pulses/sec as determined by the associated electronic equipment. The hydrophone rotation rate selected was 1/12 RPM to allow sufficient pulses per cm of hydrophone travel (approximately 50) for good pattern resolution.
VI. DISCUSSION OF RESULTS

6. The results of the present study are presented in the form of reflectivity patterns and plots of the calculated values of $R$, $A$, and $S$. In addition, plots of the normal reflectivity index, $R_p$, are shown for two of the samples, No. 21 and 22. Figure 19 shows a sample computation of $R$, $A$, and $S$. Patterns of Sample No. 21 and of a reference plate were chosen for this example. The pattern number is made up of the sample code number (see Table I) followed by a dash and a serial identification number. The special coordinate paper referred to previously is designed to cover $-30^\circ$ to $+30^\circ$ (Chart B) and $-90^\circ$ to $+90^\circ$ (Chart A). The latter was used only outside the range of Chart B. The use of the expanded scale of Chart B increased the accuracy of the power determination. After redrawing the polar plots on this special paper a planimeter is used to determine the areas under the curves, $A_p$ for the reference plate and $A_s$ for the sample as indicated in Figure 19. The peak pressures from the sample and from the reference plate are also read off the patterns and then $S$, $A$, and $R$ are calculated as shown in the figure.

Comparison of Samples From 50 to 250 kc

47. Reflectivity of all samples at 100 kc. A comparison of the patterns for all samples at 100 kc is given in Figure 21. This figure is arranged to show the reflectivity patterns of the structured rubber samples on the left side and all other samples on the right. There is indicated on each pattern the identifying code number from Table I, the material, the structure, and the values of $R$, $A$, and $S$. The reference plate reflectivity pattern No. 01-136 shown in Figure 24, was used as the reference pattern for these computations.

48. The effect of sample material on the reflectivity pattern may be noted by comparing samples with the same structure, but of different material. Patterns Nos. 21-162, 11-155 and 31-152, constitute such a group for loaded butyl material with conical lattice surfaces. The pattern for Sample No. 31, the lead-loaded sample with blowing agent, in contrast with the patterns of the two other samples, indicates a concentration of energy near the axis which might be called "negative scattering". Patterns for Sample No. 21, the aluminum-loaded sample and No. 11, heavily-loaded lead sample, show scattering of the same order of magnitude as indicated by the scattering index, $S$. This is especially interesting since at 100 kc Sample No. 21 had a reflectivity index $R$ approximately 25 db below that of No. 11. Where it occurred that the system gain was adjusted to an arbitrary value to give nearly full scale at some point in all polar plots, reference patterns Nos. 21-162 should have been
FIG. 23 TYPICAL REFLECTIVITY PATTERNS

FREQUENCY 100 Kc
PROJECTOR ORC
49. A comparison of samples having a cone-lattice structure with flat samples of the same material at 100 kc is shown in the upper portion of Figure 23. The difference in scattering between the two types of surfaces (structured values minus flat pencil values) and also increased with heaviness of loading, being -3.9 db for the lead with blowing agent samples, +1.9 db for the aluminum-loaded samples, and +9.3 db for the heavily lead-loaded samples. As indicated in Table 1, the cone structure sample having lead with a blowing agent had the lowest density (1.075); the aluminum-loaded cone structure had a density of 1.28; and the heavily lead-loaded sample a density of 2.61. It should be noted that the flat lead-loaded sample with blowing agent, No. 32, had an unusual density of 1.63. These results indicate that the type of material affects the scattering index.

50. It will be noted that the British Fafnir (Pattern No. 41-113) measured in the plane of Section B-B, Figure 10, seems to show pronounced scattering off the acoustic axis than the other samples in Figure 23. This result is borne out by the fact that the British Fafnir had a high scattering index (S = 7.4 db) at 100 kc. In fact this value of S was the highest (at this frequency) for all of the samples tested.

51. The pattern for the German Fafnir, Sample No. 71 shown in Figure 23 is not necessarily typical of this structure because the narrow projector beam width illuminated too small a portion of the sample. The spacing of the elements and their dimensions were greater than in the case of the cone structure. The pattern was measured in a plane perpendicular to the wedge rows, i.e., along Section B-A, Figure 10.

52. Pattern No. 51-199, Figure 23, is for a cone-lattice array of insulators. The flat backing for this sample is thinned so that elements are only 1 cm high as compared to 10 cm for the lead-loaded cone elements. Patterns of flat
The necessity for using the present technique in evaluating the scattering and absorption characteristics of structured specimens is evident from the fact that lateral spreading occurs for most of the patterns, and that the maxima occur at angles off normal for several of the structured samples. The use of the normal reflectivity index, \( R_n \), instead of \( R \) as an indication of absorption would result in an error of 7.5 db for the British Fzfnir Sample No. 41.

55. Patterns Versus Frequency. Reflectivity patterns for Sample No. 21 are compared in Figure 24 with patterns of the reference plate at corresponding frequencies. The scattering index, shown on Pattern No. 21-161, is a maximum at 150 kc, and decreases at both ends of the frequency band. The decrease at the low-frequency end may be attributed to the increase of wavelength relative to the dimensions of the elements. The decrease at the high-frequency end is probably caused by reflection from the flat portion of the sample, as discussed in Section III, paragraph 23.

56. Reflection Parameters vs Frequency-Loaded Butyl Rubber Samples. Values for the scattering index, \( S \), peak reflectivity index, \( \Delta \), and reflectivity index, \( R \), for the various loaded-rubber samples are plotted in Figures 25 through 37. For any one sample these three parameters are plotted on the same figure. In addition, for some purposes, each parameter for all samples is plotted on a separate figure. A negative value of the scattering index indicates a concentration of sound energy by the sample relative to that produced by the reference plate.

The three core structure samples of loaded butyl rubber constitute a group which illustrates the effect of using different materials with a common type of structure. Figure 25 shows the parameters, \( S \), \( \Delta \), and \( \Gamma \), for the heavily loaded butyl
Fig 24 Reflectivity Patterns of Sample and Reference Plate

Frequency 50 to 250 KC

Projector OBG

Sample No 21: Aluminum loaded butyl rubber

Structure: Cone lattice

Sample No 21

Reference Plate No O1
Reflectivity Index (R)  
Peak Reflectivity Index (Δ)  
Scattering Index (S)

Frequency (KC)

Lead Loaded Butyl Rubber  
Cone Lattice Structure

Fig. 25

Reflection Characteristics  
vs Frequency for Sample No. 11
60. Curves for three flat samples, No. 12, 22, and 32, each made from butyl rubber but with different metal loadings illustrate the effect of these materials on the acoustic properties of flat sheets. Figure 26 shows the reflection characteristics for the heavily lead-loaded sample. The reflectivity index, \( R \), decreases from -7 db at 100 kc to -14.5 db at 250 kc. It may be noted by referring to Figure 15 that this sample is unusual in that the reflectivity index of the flat sample is less than that for the cone-lattice sample for a portion of the frequency range, namely, from 50 to 150 kc.

61. Figure 29 gives the reflection characteristics for a flat sample of aluminum-loaded butyl rubber, No. 22. The reflectivity index for this sample decreases approximately 5 db through the frequency range shown. Since the scattering index is nearly zero, the peak reflectivity index, \( \Delta \), is approximately equal to the reflectivity index, \( R \).
REFLECTIVITY INDEX \( (R) \)  
PEAK REFLECTIVITY INDEX \( (\Delta) \)  
SCATTERING INDEX \( (S) \)

FIG. 26

REFLECTION CHARACTERISTICS vS FREQUENCY FOR SAMPLE NO. 21
LEAD AND BLOWING AGENT LOADED BUTYL RUBBER CONE LATTICE STRUCTURE

FIG. 27

REFLECTION CHARACTERISTICS VS FREQUENCY FOR SAMPLE NO. 31
LEAD LOADED BUTYL RUBBER FLAT SAMPLE

FIG. 28

REFLECTION CHARACTERISTICS

vs FREQUENCY FOR SAMPLE NO. 12
Reflectivity Index \( (R) \) 
Peak Reflectivity Index \( (\Delta) \) 
Scattering Index \( (S) \)

**Fig. 29**

**Aluminum Loaded Butyl Rubber Flat Sample**

Reflection Characteristics vs Frequency for Sample No. 22
Figure 35 indicates that values of $R$ for the cone-lattice samples Nos. 21, 22, and 31 are two or more times higher than for the flat samples of the same material (Nos. 12, 17, and 18) except for Sample No. 11 at the two lowest frequencies and Sample No. 11 at the highest frequency. Since the base of the cone-lattice sample has the same thickness as the flat sample, this comparison is equivalent to noting the effect of inserting cones in front of the flat sample. The poor absorption characteristics of the cone-lattice sample of the load-loaded material at the two lowest frequencies has not been explained. All loaded butyl rubber samples showed an increase of absorption with frequency over the range from 50 to 450 kc. It may be noted that curves of $R$ for different materials are much more closely grouped for the flat samples than for the cone-lattice samples (Figure 35). Sample No. 21 was selected for a further study on the basis of a high value of absorption throughout the frequency range.

64. Samples other than Loaded Butyl Rubber. Reflection characteristics of samples other than loaded butyl rubber are shown in Figures 31 through 34. British Pafnir, Sample No. 41, shown in Figure 31, was the most absorbent of these materials except at a frequency of 100 kc. The correspondence between $A$ and $F$ may be noted. These parameters varied widely, as much as 23 dB over the frequency band used. The minimum value of $A$ was -52 dB at 100 kc, which is almost the same as the corresponding value for Sample No. 21. It may be observed that the reflectivity index is -25 dB, approximately the value claimed in reference for British Pafnir in the frequency range for which it was examined, approximately from 10 kc to 35 kc. Furthermore, it may be noted that the high value of 100 kc is above the upper cutoff frequency, indicating the absence of the closely packed British Pafnir Sample No. 41 (see paragraph 32). The scattering from S for this material is of interest because of the contrast between the usefulness of the surface structure, periodicity and

65. a) of the cone-lattice. Measurements were made parallel to the edges (see Section 4.4 of Figure 10). The periodicity index is about 0.5 higher than the maximum value for cone-lattice structures at all frequencies except one (100 kc), for which the periodicity is as approximately the same.
LEAD AND BLOWING AGENT LOADED BUTYL RUBBER FLAT SAMPLE

FIG. 30

REFLECTION CHARACTERISTICS vs FREQUENCY FOR SAMPLE NO. 32
FIG. 31
REFLECTION CHARACTERISTICS vs FREQUENCY

BRITISH FAFNIR

SAMPLE NO. 41
CONFIDENTIAL
NAVORD REPORT 2989

SAMPLE NO:
51 CONE LATTICE IMMERSED AND HEATED X
52 FLAT
53 FLAT IMMERSED
54 FLAT IMMERSED AND HEATED

MEAN FOR ALL SAMPLES

PEAK REFLECTIVITY INDEX (Δ)
SCATTERING INDEX (S)

REFLECTIVITY INDEX (R)

INSULKRETE

FIG. 32
REFLECTION CHARACTERISTICS vs FREQUENCY

56
surface, Sample No. 51; a flat surface which was measured without being previously immersed. Sample No. 52; a flat sample which
was kept submerged for three days at room temperature before making measurements. Sample No. 53; and another flat sample which was
kept submerged at 183°F for three days before measurement. Sample
No. 54. As mentioned previously, the cones of the cone-lattice
structure had the same base dimensions as the butyl sponge lattice
but could be made only one centimeter high because of the fragile
nature of the material. Reference to Figure 32 indicates that
the Insulkrete a submerged surface provides very little benefit
for is in contrast to samples made from loaded butyl rubber.
Immersing and heating the samples likewise appears to have little
effect. The deviation of the reflectivity index from the mean for
all samples except No. 51 was only a few db. If the reflectivity
index of Sample No. 51 is adjusted for the difference in the
volume of material, its deviation is also a few db. Since the
reflectivity index decreased about 6 db and the scattering index
increased about 6 db, the peak reflectivity index decreased
approximately 12 db over the frequency range used. The value of
the reflectivity index measured at 50 kc (approximately 5 db) on
samples 5 cm thick agrees with measurements made by Trout and
Darnier, reference (b), on samples 12 in thick which indicated
a reflection coefficient of about one percent or a reflectivity
index of -20 db. It is evident from this agreement and also from
the insignificant effect of a cone-lattice surface structure
that for flat samples of Insulkrete the absorption is not limited
by surface mismatch. This was not the case for flat samples of
loaded butyl rubber.

66. Figure 33 shows the reflection characteristics of the pleated
canvas, Sample No. 61. Before measurements were made the sample
was immersed in water at 183°F for three days to remove as much
untrapped air as possible. The reflectivity index is between -3
and -5 db over the frequency range. This lining had essentially
no effect as a sound scatterer, the scattering index varying
between small negative and positive values. This sample was
included in the measurements since it has been tried as a cheap
substitute for an absorbent lining in a small, high-pressure tank,
the purpose being only to reduce the reverberation time. Even
though the reflectivity index is only about -4 db it is of some
value for the desired purpose.

67. Figure 34 illustrates the reflection characteristics of the
German Fefnir lining used in the open tank at NOL. The material
at one end of the tank is designated as Sample No. 71 and the
material at the other end as Sample No. 72. It should be noted
that these measurements were made above the frequency band for
which this lining was designed. Measurements were made perpendi-
cular to the plane of the ridges (see Figure 10). The reflectivity
PLEATED CANVAS

FIG. 33

REFLECTION CHARACTERISTICS

vs FREQUENCY FOR SAMPLE NO. 61
MEAN OF TWO SAMPLES

SAMPLE NO. 71  X
SAMPLE NO. 72  ○

REFLECTIVITY INDEX (R)
PEAK REFLECTIVITY INDEX (Δ)
SCATTERING INDEX (S)

GERMAN FAFNIR SAMPLES (ENDS OF TANK)

FIG. 34

REFLECTION CHARACTERISTICS VS FREQUENCY
index for Samples No. 71 and 72. These indexes are due to factors which vary over the frequency range. In general, the periodic variation in reflection characteristics (\( R \) and \( \Delta \)) is to be expected because of the highly banded nature of the projectors relative to the dimensions of the elements. This is especially true at the upper end of the frequency band. The faraday index increased with frequency from 50 kc to about 400 at 250 kc. In addition to Sample Nos. 71 and 72, measurements were made on a German Faunir panel identified as Sample No. 71. The reflection characteristics of this sample will be discussed later in the following section on sample orientation.

Measurements Considering Periodicity in \( \psi \)

68. The results presented here have been for a single orientation, \( \psi = \psi_0 \) which will be called the first orientation. Since in general these samples are periodic in the radial angle \( \psi \), the measurements reported in this section were made to obtain a comparison between results based on a single orientation and results based on two orientations. For the second orientation the samples were measured in the plane \( \psi = \psi' = \pi/2 \). The theory of these measurements is more fully described in Section III A, paragraphs 32 thru 36.

6. As usual, the symbols \( R, \Delta \), and \( S \) are used to denote the reflection characteristics in the plane \( \psi = \psi_0 = 0 \); the symbols \( R_\perp, \Delta_\perp \), and \( S_\perp \) are used to denote reflection characteristics in the plane \( \psi = \psi_0 = \pi/2 \); and \( R_\parallel, \Delta_\parallel \), and \( S_\parallel \) are used to denote the average of the above values. These average quantities are defined by equations 27 through 29. Measurements were made on the cone-lattice sample, No. 21, and the German Faunir sample, No. 71, through the frequency range from 50 kc to 250 kc and also on the British Faunir samples, No. 41 at 250 kc. The \( \psi_0 \) orientations chosen were for the cone-lattice sample a plane through Section A-A (Figure 13); for the German Faunir sample a plane perpendicular to the parallel surfaces of the wedge elements (Section A-A of Figure 13) and for the British Faunir samples it was in a plane parallel to the parallel surface of the wedge elements (Section B-B of Figure 13).

70. Figure 13, Sample No. 21 at 150 kc, illustrates Pattern No. 11 of for \( \psi_0 \) and No. 23-16) for \( \psi_0 \), respectively. The general shape of the patterns is similar; however, the pattern of \( R_\perp \) is slightly more scattering than the \( R_\parallel \) pattern. The shaded and two orientations are plotted from 50 to 250 kc in Figure 13. The values of \( R \) and \( R_\perp \) show deviations from \( R_\parallel \) of approximately one \( \Delta \). The deviation of \( R \) and \( \Delta_\parallel \) from \( R_\parallel \)
FIG. 35 REFLECTIVITY INDEX, R, FOR ALL SAMPLES vs FREQUENCY
FIG. 36

PEAK REFLECTIVITY INDEX (Δ), FOR ALL SAMPLES VS FREQUENCY

SAMPLES OTHER THAN METAL LOADED RUBBER

INSULKRETE AV

11

22 12 32

31 21

(OR) LEVEL

0 10 20 30 40 50

-50 -100 -150 -200 -250

-50 -100 -150 -200 -250

METAL LOADED RUBBER SAMPLES

100 FREQUENCY (KC)

200 300
FIG. 38 REFLECTIVITY PATTERNS FOR PLANES $\psi_r$ AND $\psi_s$

SAMPLE NO. 21: ALUMINUM LOADED BUTYL MATERIAL
STRUCTURE: CONE LATTICE
FREQUENCY: 150 KC
PROJECTOR: QBG

PLANET $\psi_r$
SECTION B-B, FIG. 13
PATTERN NO. 21-156
$S = 102$ dB
$\Delta = 42$ dB
$R = 32.1$ dB

PLANET $\psi_s$
SECTION A-A, FIG. 13
PATTERN NO. 21-161
$S = 87$ dB
$\Delta = 405$ dB
$R = 318$ dB
ALUMINUM LOADED BUTYL RUBBER CONE LATTICE

REFLECTION CHARACTERISTICS FROM MEASUREMENTS IN THE PLANES $\psi_o$ AND $\psi_r$ FOR SAMPLE NO. 21

FIG. 39
and $S$ and $S_r$, i.e., $S_r$, are approximately one db with the exception of the values at 120 kc. At this frequency the maximum deviations are 3 db for $S$ and 4 db for $S_r$. A comparison of the $S_r$ and $S$ curves indicates that the scatering increased slightly at the lower frequencies in the plane $\psi_r$ which corresponds to a wider spacing of the elements.

71. Figure 40 compares reflection characteristics for Sample No. 73, German Fafnir, from 50 to 250 kc. These curves illustrate the effect of averaging results for a sample which has a different geometry in the planes $\psi'$ and $\psi''$. The maximum deviation of $S_r$ and $R$ from $R_r$ is about 2 db; $S$ and $S_r$ differ from $S_r$ about 2 db and finally $\Delta$ and $\Delta_r$ differ from $\Delta_r$ about 3 db.

72. Table 11 gives the average values of the reflection parameters for measurements on British Fafnir at 250 kc.

**TABLE II**

**Effect of Orientation on the Reflection Characteristics of British Fafnir**

<table>
<thead>
<tr>
<th>(db)</th>
<th>(db)</th>
<th>Average (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>$S_r$</td>
<td>8.0</td>
<td>$S_r = 9.6$ (see eq. (27))</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>-25.0</td>
<td>$\Delta_r = -26.5$ (see eq. (29))</td>
</tr>
<tr>
<td>$R$</td>
<td>-16.9</td>
<td>$R_r = -16.9$ (see eq. (28))</td>
</tr>
</tbody>
</table>

It may be observed that the scattering is 3.4 db greater in the plane of $\psi_r$ than in the $\psi_r$ plane. The larger spacing of elements occurs in the $\psi_r$ plane. Results shown in Figure 31 were made subsequent to those of Table II and since improvements had been made in the technique in the meantime, the reported values differ somewhat. The values in the table are presented to show only the effect of changing the plane of rotation of the probe elements and are considered to be sufficiently accurate for this purpose.

**Instrumental Measurements on Samples No. 31 and No. 22**

Figure 41 shows the reflection characteristics of Sample No. 31 in the frequency range from 150 to 260 kc taken in 5 kc steps. It may be observed that the scattering index $S$ is low and hence the values for $\Delta$ and $R$ are approximately...
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AVERAGE

\( \psi_r \)

\( \psi_o \)

PEAK REFLECTIVITY INDEX (\( \Delta \))

LEVEL (db)

REFLECTIVITY INDEX (R)

REFLECTIVITY INDEX (S)

FREQUENCY (KC)

GERMAN FAFNIR SAMPLE

REFLECTION CHARACTERISTICS FROM MEASUREMENTS IN THE PLANES \( \psi_o \) AND \( \psi_r \) FOR SAMPLE NO. 73

FIG. 40

67

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Fig. 4.1

REFLECTION CHARACTERISTICS VS FREQUENCY FOR SAMPLE NO 22

ALUMINUM LOADED BUTYL RUBBER FLAT SAMPLE
the same, but vary as much as 5 db in a frequency interval of 5 kc. This variation places a limitation on the interpolation of $A$ and $R$ between values measured at intervals of 50 kc.

74. The curve for $R$ shows a roughly periodic variation with frequency from 150 to 200 kc, but from 200 to 245 kc $R$ shows little variation except at 250 kc where there is a pronounced minimum.

75. Figure 42 shows the reflection characteristics of Sample No. 21, the cone-lattice sample corresponding to the plane-surface sample No. 22, measured at 5 kc increments over the frequency range from 140 to 260 kc. The scattering index for this cone sample is approximately 8 db at 140 kc and decreases to a value of about 4 db at 250 kc. As has been mentioned previously this decrease in scattering is believed to be caused by the increase of reflection with frequency from the flat surfaces between the cone bases. The peak reflectivity index, $A$, is a minimum, -41 db, at around 170 kc; it is about -37 db at 140 kc and increases to -34 db at 260 kc. The reflectivity index, $R$, is approximately -30 db at both ends of the frequency band (140 kc and 260 kc) and is a minimum (-37 db) at 250 kc.

Comparison of $R$ and $R_n$. Figures 43 and 44 show the normal reflectivity index, $R_n$, for the flat sample and the cone-lattice sample, respectively. The corresponding curve for the reflectivity index $R$ is plotted on each curve for comparison. It may be observed that $R_n$ is more nearly equal to $R$ for the flat sample than for the structured sample. The necessity for using the present technique for measuring structured samples may be noted by observing that the difference between the two curves shown in Figure 44 is about 28 db at the low-frequency end.

Broad Frequency Range Measurements - Sample No. 21

77. Measurements were made on Sample No. 21, the aluminum-loaded butyl rubber sample with a cone-lattice structure over the frequency range from 20 kc to 1 Mc, in 50 kc increments. Four projectors (QE, KE41A, P8, and Q3) were used in order to cover the wide frequency range. Figure 21 shows the beam widths versus frequency of these four transducers.

78. Typical Reflectivity Patterns. Figure 45 shows reflectivity patterns for Sample No. 21 as well as for the reference plate at five representative frequencies. The reflection indices $R$, $A$, and $\Delta$, the pattern number, the frequency, and the projector used are indicated on each pattern. Since the values of $R$, $A$, and $\Delta$ obtained with the KE41A transducer do not agree with the averages from 150 kc to 200 kc, the measurements made with this transducer may not be as reliable as the other measurements.
ALUMINUM LOADED BUTYL RUBBER CONE LATTICE SAMPLE

REFLECTION CHARACTERISTICS vs FREQUENCY FOR SAMPLE NO. 21

FIG. 42
ALUMINUM LOADED BUTYL RUBBER FLAT SAMPLE
COMPARISON OF NORMAL REFLECTIVITY INDEX, $R_N$, AND THE REFLECTIVITY INDEX, $R$, OF SAMPLE NO. 22

FIG. 43
ALUMINUM LOADED BUTYL RUBBER GONE LATTICE SAMPLE
COMPARISON OF NORMAL REDUCTIVITY INDEX, R_N AND
THE REFLECTIVITY INDEX, R OF SAMPLE NO. 21
FIG. 44
FIG 45 REFLECTIVITY PATTERNS OF SAMPLE AND REFERENCE PLATE

FREQUENCY 35 KC TO 1 MC
SAMPLE NO 21: ALUMINUM LOADED BUTYL RUBBER STRUCTURE CONE LATTICE

SAMPLE NO 21

REFERENCE PLATE NO. 01

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79. A comparison of the patterns for the "Ferr transducers at
overlap frequency points is shown in figure 45. The values of
S for the patterns at 250 kc differ by 0.0 db. However, the
differences in B are only about 1.5 db for the sets of patterns
at 50 and 250 kc. A differs by 1.4 db at 250 kc but falls
within 1 or 2 db at the other two frequencies.

80. Reflection Characteristics. Figure 47 is a plot of the
reflection characteristics of Sample 21 throughout the frequency
range from 20 kc to 1 kc. Measurements made with the different
projectors are indicated by different symbols. The plotted
curves represent an average of all available points except the
points marked X. The latter are for the rotated plane $\psi = \pi/2$.
The curves thus represent measurements made in the plane $\psi = 0$.
It is considered probable that the decrease in S and the increase
in A and R over the range from 200 kc to 300 kc are caused by
the plane portions of the structure between the cones. The
average value of R is below -20 db for the entire range and the
average value of A is below -25 db for all but the two lowest
frequencies. The increase in scattering from 25 kc to 150 kc is
in agreement with the theory given by Rayleigh concerning
corrugated surfaces, reference (c). Values of R, A, and S at the
two highest frequencies are somewhat doubtful because of the
narrow hydrophone pattern.

Interpretation and Reliability of Results

81. The overall system was checked for linearity and drift as
part of the procedure for each run. The drift was checked by
retracing an initial low-level portion of the reflectivity pattern
and the maximum deviation allowed without discarding a run was
approximately 1/2 db. Usually, the retrace did not deviate a
measurable amount. The linearity was checked by noting recorder
deflection versus oscillator output (see figure 15 for a block-
diagram of the equipment). Acceptable values of recorder de-

deflection were $-20 \pm 1$ db for a 20 db decrease of oscillator
output. The deviation was usually about 0.5 db. It was
established that this deviation usually occurred in the range
from $-15$ to $-20$ db, corresponding to low-level portions of the
patterns.

82. The ability to duplicate measurements was checked as
thoroughly as the limited time available allowed. However, this
did not permit very many repeat runs to be made. Repeat runs
were made only under similar conditions on Sample No. 21 in the
frequency range from 50 to 250 kc. The results showed an
average deviation for values of R, A, and S of $\pm 1$ db. Compar-
ison runs were made at intervals of several days. The sample
was removed and then replaced for these comparisons.
FIG 46 REFLECTIVITY PATTERNS OF SAMPLE NO 21
VS
PROJECTOR BEAM WIDTH
SAMPLE NO 21 ALUMINUM LOADED BUTYL RUBBER MATERIAL
STRUCTURE CONE LATTICE
### Aluminum Loaded Cone Lattice

**Reflection Characteristics vs Frequency for Sample No. 21**

**FIG. 47**

#### Frequency (KG)
```
<table>
<thead>
<tr>
<th>FREQUENCY (KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
</tr>
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<td>50</td>
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<tr>
<td>100</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>1000</td>
</tr>
</tbody>
</table>
```

#### Level (db)
```
<table>
<thead>
<tr>
<th>LEVEL (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15</td>
</tr>
<tr>
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<tr>
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</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>
```

**Symbols**
- QBG
- X84IA
- E8
- QBE
- QBG

**AVERAGE OF ALL POINTS FOR \( \psi_0 \) PLANE
VII. CONCLUSIONS AND RECOMMENDATIONS

64. The results of the present study indicate that Sample No. 21, the cone lattice structure of aluminum-loaded butyl rubber, shows outstanding promise as a tank lining over the frequency range from 20 kc to 1 Mc. It would probably be useful at both higher and lower frequencies also.

65. It appears that this lining could be improved for high frequencies by eliminating the discontinuity caused by the plane portion of the lining. Results indicate that reflections from these small plane surfaces are significant at frequencies for which the width of this flat surface is greater than a half-wave length of the sound. For Sample No. 21 this frequency was about 200 kc. These plane surfaces could be replaced by properly shaped depressions.

66. Further improvement of the lining at low frequencies will probably be more difficult than at high frequencies. One possibility is to use included air spaces to permit more deformation of the material and in turn increase the loss. This method was used effectively for Fafnir.

67. Another possible means for improving the absorption of the material at low frequencies is to increase the length of the cones. This would probably have the additional advantage of increasing the scattering at the lower frequencies. The disadvantages are that such a lining would occupy more space, and require more material.

68. It is probable that absorption can be increased somewhat at all frequencies by the selection of better materials. The material consisting of 100 parts of aluminum to 100 parts (by weight) of butyl rubber was selected for cone-lattice structure panels on the basis of reflection measurements made on flat samples. This proportion may not be optimum for a cone-lattice sample. It could be determined by an experimental investigation of a series of cone-lattice samples in which the proportion of metal was varied. There is some indication that the heat treatment during the molding process has considerable effect on the characteristics of the material. Measurements on samples having the same formula indicate differences in reflection characteristics. For example, the flat samples consisting of 120 parts aluminum to 100 parts of butyl rubber, No. 24, indicate approximately 3 db lower reflective loss than Sample No. 22, Figure 20, although the flat samples are only approximately 50% thicker than the former.
Experimental investigation of the acoustic properties of
core-lattice samples subjected to a variation of heat treatment
during the molding process should be made and the processing
techniques standardized as far as practical.

69. In order to extend and refine the knowledge of the
applicability of this lining to acoustic tanks, the following
additional measurements are recommended:

a. The measurement of reflection characteristics versus
the angle of incidence.

b. The measurement of normal reflection reduction versus
pressure. These measurements would indicate the applicability
of linings for use in acoustic pressure tanks.

c. The measurement of reflection characteristics below
20 kc. Results of these measurements would indicate the lower
frequency limit of a tank lined with a core-lattice structure
of aluminum-loaded rubber.

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